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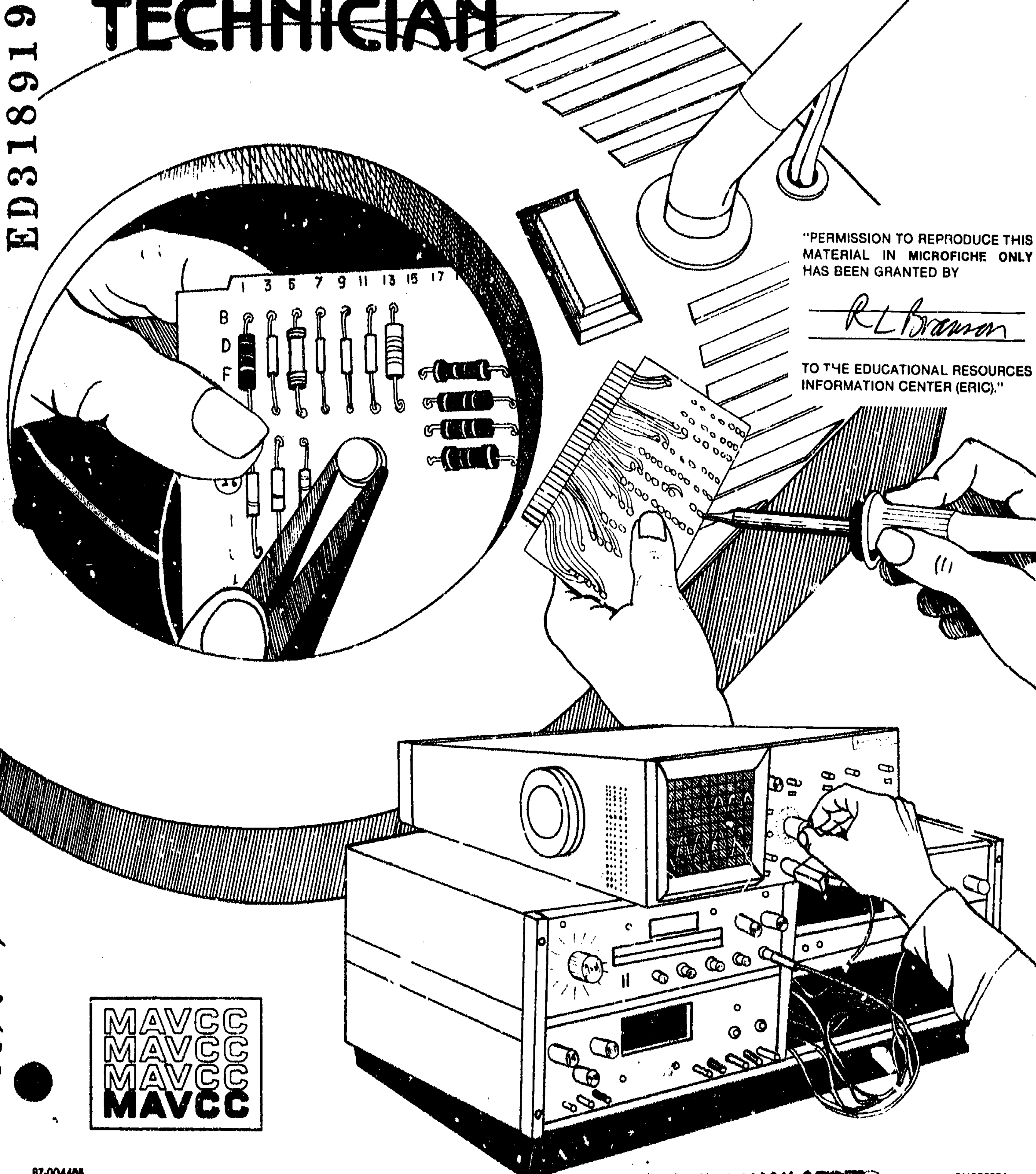
ABSTRACT

This module follows the "Basic Electronics" module as a guide for a course preparing students for job entry or further education. It includes those additional tasks required above Basic Electronics for job entry in the electronics field. The module contains eight instructional units that cover the following topics: (1) test equipment; (2) fundamentals of DC; (3) fundamentals of AC; (4) discrete semiconductor devices and circuits; (5) linear integrated amplifier circuits; (6) circuit applications; (7) power supplies; and (8) logic devices. Each instructional unit follows a standard format that includes some or all of these eight basic components: performance objectives, suggested activities for teachers and students, information sheets, assignment sheets, job sheets, visual aids, tests, and answers to tests and assignment sheets. All of the unit components focus on measurable and observable learning outcomes and are designed for use for more than one lesson or class period. Instructional task analyses, a glossary, and 21 references are also included. (KC)

GENERAL ELECTRONICS TECHNICIAN



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GENERAL ELECTRONICS TECHNICIAN

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FOREWORD

The Mid-America Vocational Curriculum Consortium has developed a total concept for electronics. This approach is designed to provide a practical and realistic approach to competency-based training materials in electronics and to provide basic electronics competencies for many other vocational programs.

Identified are those tasks that are common not only to the entry-level electronic technician but also to other vocational occupational programs such as appliance repair, heating and air conditioning, auto mechanics, diesel mechanics, and farm machinery mechanics, etc. *Basic Electronics* therefore covers the tasks not only required of the electronic technician but also those tasks required in many other occupations. *Basic Electronics* provides the foundation and serves as a building block for progressing to a higher level of competency in many occupations.

General Electronics Technician includes those additional tasks required above *Basic Electronics* for job entry in the electronics field.

Upon completion of the *Basic Electronics* and *General Electronics Technician* competencies, students are ready for job entry or may continue their education by specializing in one of many electronics areas such as communication electronics.

Every effort has been made to make these publications basic, readable, and by all means, usable. Three vital parts of instruction have been intentionally omitted from the publications: motivation, personalization, and localization. These areas are left to the individual instructors and the instructors should capitalize on them. Only then will these publications really become a vital part of the teaching-learning process.

Bob Patton, Chairman
Board of Directors
Mid-America Vocational
Curriculum Consortium

Greg Pierce
Executive Director
Mid-America Vocational
Curriculum Consortium

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USE OF THIS PUBLICATION

Instructional Units

General Electronics Technician contains eight units. Each instructional unit includes some or all of the basic components of a unit of instruction; performance objectives, suggested activities for teachers and students, information sheets, assignment sheets, job sheets, visual aids, tests, and answers to the tests. Units are planned for more than one lesson or class period of instruction.

Careful study of each instructional unit by the teacher will help to determine:

A. The amount of material that can be covered in each class period
B. The skills which must be demonstrated

    1. Supplies needed
    2. Equipment needed
    3. Amount of practice needed
    4. Amount of class time needed for demonstrations

C. Supplementary materials such as pamphlets or filmstrips that must be ordered
D. Resource people who must be contacted

Objectives

Each unit of instruction is based on performance objectives. These objectives state the goals of the course, thus providing a sense of direction and accomplishment for the student.

Performance objectives are stated in two forms: unit objectives, stating the subject matter to be covered in a unit of instruction; and specific objectives, stating the student performance necessary to reach the unit objective.

Since the objectives of the unit provide direction for the teaching-learning process, it is important for the teacher and students to have a common understanding of the intent of the objectives. A limited number of performance terms have been used in the objectives for this curriculum to assist in promoting the effectiveness of the communication among all individuals using the materials.

Reading of the objectives by the student should be followed by a class discussion to answer any questions concerning performance requirements for each instructional unit.

Teachers should feel free to add objectives which will fit the material to the needs of the students and community. When teachers add objectives, they should remember to supply the needed information, assignment and/or job sheets, and criterion tests.

Suggested Activities for the Instructor

Each unit of instruction has a suggested activities sheet outlining steps to follow in accomplishing specific objectives. Duties of instructors will vary according to the particular unit; however, for best use of the material they should include the following: provide students with objective sheet, information sheet, assignment sheets, and job sheets; preview filmstrips, make transparencies, and arrange for resource materials and people; discuss unit and specific objectives and information sheet; give test. Teachers are encouraged to use any additional instructional activities and teaching methods to aid students in accomplishing the objectives.

Information Sheets

Information sheets provide content essential for meeting the cognitive (knowledge) objectives in the unit. The teacher will find that the information sheets serve as an excellent guide for presenting the background knowledge necessary to develop the skill specified in the unit objective.

Students should read the information sheets before the information is discussed in class. Students may take additional notes on the information sheets.

Transparency Masters

Transparency masters provide information in a special way. The students may see as well as hear the material being presented, thus reinforcing the learning process. Transparencies may present new information or they may reinforce information presented in the information sheets. They are particularly effective when identification is necessary.

Transparencies should be made and placed in the notebook where they will be immediately available for use. Transparencies direct the class's attention to the topic of discussion. They should be left on the screen only when topics shown are under discussion.

Assignment Sheets

Assignment sheets give direction to study and furnish practice for paper and pencil activities to develop the knowledge which is a necessary prerequisite to skill development. These may be given to the student for completion in class or used for homework assignments. Answer sheets are provided which may be used by the student and/or teacher for checking student progress.

Job Sheets

Job sheets are an important segment of each unit. The instructor should be able to demonstrate the skills outlined in the job sheets. Procedures outlined in the job sheets give direction to the skill being taught and allow both student and teacher to check student progress toward the accomplishment of the skill. Job sheets provide a ready outline for students to follow if they have missed a demonstration. Job sheets also furnish potential employers with a picture of the skills being taught and the performances which might reasonably be expected from a person who has had this training.

Test and Evaluation

Paper-pencil and performance tests have been constructed to measure student achievement of each objective listed in the unit of instruction. Individual test items may be pulled out and used as a short test to determine student achievement of a particular objective. This kind of testing may be used as a daily quiz and will help the teacher spot difficulties being encountered by students in their efforts to accomplish the unit objective. Test items for objectives added by the teacher should be constructed and added to the test.

Answers to Assignment Sheets/Test

Answers to assignment sheets and the test are provided for each unit. These may be used by the teacher and/or student for checking student achievement of the objectives.

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INSTRUCTIONAL/TASK ANALYSIS

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)	RELATED INFORMATION: What the Worker Should Know (Cognitive)

UNIT I: TEST EQUIPMENT

1. Terms and definitions
2. Types of test equipment
3. Types of meters
4. Types of analog meter movements
5. Characteristics of an ammeter
6. Characteristics of a voltmeter
7. Characteristics of an ohmmeter
8. Characteristics of a digital meter
9. Oscilloscope controls and functions
10. Oscilloscope construction
11. Measurements that may be taken with an oscilloscope
12. Calculate effective or root-mean-square voltage from sine wave dimensions
13. Calculate time and frequency from waveform dimensions
14. Determine phase relationships of AC signals
15. Determine the resistance of a meter movement
16. Construct and analyze a voltmeter

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)	RELATED INFORMATION: What the Worker Should Know (Cognitive)

17. Construct and analyze a simple ohmmeter

18. Construct and analyze an ammeter

19. Adjust oscilloscope controls for a stable waveform display

20. Measure frequency using an oscilloscope

21. Measure AC voltage using an oscilloscope

22. Measure DC voltage using an oscilloscope

23. Calibrate an oscilloscope probe

UNIT II: FUNDAMENTALS OF DC

1. Terms and definitions

2. Relationships of matter, energy, and electronics

3. Composition of matter

4. Structure of the atom

5. Characteristics of the electron

6. Sources of electricity

7. Characteristics of electron movement

8. Characteristics of conductors, insulators, and semiconductors

9. Characteristics of electrical charges

10. Electromotive force, potential difference, and voltage

11. Measure of electrical current

12. Resistance, ohm, and conductance

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)

RELATED INFORMATION: What the Worker Should Know (Cognitive)

13. Basic types of resistors

14. Basic circuit requirements

15. Basic circuit configurations

16. Fundamental Ohm's law formulas

17. Fundamental Watt's law formulas

18. Characteristics of current, voltage, power, and resistance in series circuits

19. Characteristics of current in a parallel circuit

20. Characteristics of resistance in a parallel circuit

21. Characteristics of voltage and power in a parallel circuit

22. Characteristics of series-parallel circuits

23. Voltage divider characteristics

24. General troubleshooting considerations

25. Types of bridge circuits

26. Maximum power transfer

27. Steps for the application of the super position theorem

28. Steps for the application of Thevenin's theorem

29. Solve problems for an unknown voltage

30. Solve problems for an unknown amperage

31. Solve problems for an unknown resistance

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)	RELATED INFORMATION: What the Worker Should Know (Cognitive)
32. Determine the total resistance in a series circuit	
33. Determine total voltage in a series circuit	
34. Determine voltage drops across resistances in a series circuit	
35. Determine current in a series circuit	
36. Compute power from the power formula	
37. Determine unknown circuit values in a series circuit	
38. Calculate resistance in parallel circuits	
39. Calculate current and voltage in parallel circuits	
40. Calculate power in parallel circuits	
41. Calculate various values in parallel circuits	
42. Trace current flow in series-parallel circuits	
43. Solve for total resistance in a series-parallel circuit	
44. Solve for total current in series-parallel circuits	
45. Solve for total voltage in series-parallel circuits	
46. Solve for total power in series-parallel circuits	
47. Identify resistor values using a standard color code	
48. Measure voltage drops in a series circuit	

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)	RELATED INFORMATION: What the Worker Should Know (Cognitive)

49. Analyze current values in a series circuit

50. Measure voltage, current, and resistance in a parallel circuit

51. Troubleshoot series-parallel circuits

52. Measure voltages in a balanced bridge circuit

53. Measure voltages in an unbalanced bridge circuit

54. Determine the maximum power transfer point on a resistor circuit

UNIT III: FUNDAMENTALS OF AC

1. Terms and definitions
2. Ways magnets are classified
3. Characteristics of magnetic materials
4. Characteristics of magnetic flux lines
5. Terms related to magnetic quantities
6. Relationships of magnetism to electricity
7. Fundamentals of electromagnetism
8. Principles of induction
9. Generating voltage by elctromagnetic induction
10. Values of the AC waveform
11. In-phase and out-of-phase relationships
12. Characteristics of AC resistive circuits
13. Characteristics of self-induction

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)	RELATED INFORMATION: What the Worker Should Know (Cognitive)

14. Characteristics of inductance
15. Factors affecting inductors
16. Equation for determining time constants of inductive circuits
17. Current and voltage relationships in an inductive AC circuit
18. Characteristics of inductive reactance
19. Process of mutual inductance
20. Connecting inductors in series and parallel
21. Quality of inductors
22. Power characteristics in an inductive circuit
23. Characteristics of voltage and current in RL circuits
24. Characteristics of impedance in RL circuits
25. Trigonometric based formulas for finding the angle of phase shift in RL circuits
26. Characteristics of capacitance
27. Types, ratings, and common defects of capacitors
28. Equations for combining capacitors in series and parallel
29. Equation for determining time constants in an RC circuit
30. Voltage and current relationships in a capacitive AC circuit
31. Equation for determining capacitive reactance

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)	RELATED INFORMATION: What the Worker Should Know (Cognitive)
	32. Characteristics of series RC circuits
	33. Characteristics of impedance in RC circuits
	34. Equation for finding the phase angle in an RC circuit
	35. Characteristics of power in an AC resistive-capacitive circuit
	36. Equations related to the characteristics of parallel RC circuits
	37. Applications of capacitive circuits
	38. Characteristics of series RCL circuits
	39. Resonant characteristics of series RCL circuits
	40. Characteristics of parallel RCL circuits
	41. Resonant characteristics of a parallel RCL circuit
	42. Applications of resonant circuits
	43. Fundamentals of rectangular and polar notation
44. Determine sine wave conversions	
45. Compute period	
46. Determine current flow direction	
47. Answer questions regarding induction and inductors	
48. Solve for total inductance	
49. Compute inductive reactance	
50. Compute applied voltage and impedance of RL circuits	
51. Compute the Q of inductors	

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)	RELATED INFORMATION: What the Worker Should Know (Cognitive)

52. Solve time constant problems
53. Compute capacitance values
54. Compute RC time constants
55. Compute capacitive reactance
56. Determine phase relationships in RC circuits
57. Compute values of RC circuits
58. Solve for reactance
59. Solve for impedance
60. Solve for parameters of resonant circuits
61. Solve problems related to parallel RCL circuits
62. Analyze a parallel resonant circuit
63. Show the effect of inductance in AC circuits
64. Solve for values of an operating RL circuit
65. Test capacitors with an ohmmeter
66. Determine the effect of AC and DC on capacitors
67. Determine time constants of RC circuits
68. Construct a neon bulb flasher
69. Show the effect of capacitive reactance in AC circuits
70. Determine capacitive reactance and impedance in RC circuits
71. Determine resonance in a series RCL circuit
72. Determine the resonant frequency of an RCL parallel circuit

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)

RELATED INFORMATION: What the Worker Should Know (Cognitive)

UNIT IV: DISCRETE SEMICONDUCTOR DEVICES AND CIRCUITS

1. Terms and definitions
2. Characteristics of semiconductors
3. Characteristics of N-type and P-type semiconductors
4. Characteristics of the P-N junction
5. Forward and reverse biasing of diodes
6. Diode characteristics
7. Characteristics of special semiconductor diodes
8. Bipolar transistor characteristics
9. Characteristics of bipolar transistor operation
10. Characteristics of the common-base circuit
11. Characteristics of the common-collector circuit
12. Characteristics of the common-emitter circuit
13. Classes of operation
14. Transistor biasing techniques
15. Methods of coupling
16. Special semiconductor devices
17. Construction of the field effect transistor
18. Characteristics of the junction field effect transistor
19. Characteristics of the insulated gate field effect transistor

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)	RELATED INFORMATION: What the Worker Should Know (Cognitive)
	20. Safety precautions in handling FET's
	21. Decibel
22. Label the parts of a transistor circuit	
23. Construct a load line for a common-emitter amplifier circuit	
24. Calculate the overall gain of multi-stage amplifier circuits	
25. Compute voltage, current, and power stage gain in decibels	
26. Perform a static test of semiconductor diodes	
27. Test semiconductor diodes and plot the characteristic curves	
28. Test transistors	
29. Construct and test a common-emitter circuit	
30. Construct and test a common-base circuit	
31. Construct and test a common collector circuit	
32. Plot a transistor output characteristic curve	
33. Construct and test a single-ended amplifier	
34. Construct and test a field effect transistor amplifier	

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JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)

RELATED INFORMATION: What the Worker Should Know (Cognitive)

UNIT V: LINEAR INTEGRATED AMPLIFIER CIRCUITS

1. Terms and definitions
2. Fundamentals of differential amplifier circuits
3. Integrated circuit construction
4. Maximum ratings of an operational amplifier
5. Input and output parameters of the op-amp
6. Dynamic parameters of the op-amp
7. Desirable operational characteristics of the op-amp
8. Characteristics of the inverting amplifier
9. Characteristics of the noninverting amplifier
10. Relationship between gain, bandwidth, and feedback in an op-amp
11. Schematic diagram of DC summing and difference amplifiers
12. Calculate the closed-loop gain for an inverting and noninverting amplifier
13. Calculate the output voltage of a DC summing amplifier
14. Construct and test an inverting amplifier
15. Construct and test a noninverting amplifier
16. Construct and test a differential amplifier
17. Construct and test a DC summing amplifier

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)	RELATED INFORMATION: What the Worker Should Know (Cognitive)

UNIT VI: CIRCUIT APPLICATIONS

1. Terms and definitions
2. Basic power amplifier characteristics
3. Power amplifier circuit configurations
4. Steps in troubleshooting multistage amplifiers
5. Basic oscillator requirements
6. Basic types of oscillator circuits
7. Characteristics of active filters
8. Characteristics of optocouplers
9. Construct and test a push-pull amplifier
10. Construct and test a two-stage direct coupled amplifier
11. Construct and test a basic Darlington pair amplifier
12. Construct and test a Hartley oscillator
13. Construct and test a low-pass active filter
14. Construct and test a 555 timer circuit

UNIT VII: POWER SUPPLIES

1. Terms and definitions
2. Uses for transformers in power supplies
3. Schematic diagram of a half-wave rectifier circuit
4. Schematic diagram of a full-wave rectifier circuit

JOB TRAINING: What the Worker Should Be Able to Do
(Psychomotor)

RELATED INFORMATION: What the Worker Should Know
(Cognitive)

5. Schematic diagram of a bridge rectifier circuit

6. Schematic diagrams of combination power supplies

7. Basic types of filter configurations

8. Equation for calculating ripple factor

9. Basic voltage multiplier circuits

10. Regulation of power supply output

11. Regulator configurations as series or shunt regulators

12. Block diagram of a feedback regulator

13. Characteristics of switching regulators

14. Schematic diagram of a "crowbar" protection circuit

15. Calculate average DC voltage for half-wave and full-wave rectifier circuits

16. Calculate ripple factors and percent regulation

17. Construct and test a half-wave rectifier circuit

18. Construct and test a full-wave bridge rectifier circuit

19. Construct and test a voltage doubler circuit

20. Construct and test a capacitor filter circuit

21. Construct and test a Pi-section filter circuit

22. Construct and test a zener regulator

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)	RELATED INFORMATION: What the Worker Should Know (Cognitive)

UNIT VIII: LOGIC DEVICES

1. Terms and definitions
2. Fundamentals of number systems
3. Fundamentals of basic logic gates
4. Types and characteristics of multivibrator circuits
5. Types of counters
6. Characteristics of shift registers
7. Types of combinational logic circuits
8. Types of digital integrated devices
9. Types of displays
10. Convert binary numbers to decimal and octal numbers
11. Convert binary numbers to hexadecimal and BCD (8421) numbers
12. Construct and test an "AND" gate circuit
13. Construct and test an "OR" gate circuit
14. Construct and test a "NAND" gate circuit
15. Construct and test a "NOR" gate circuit
16. Construct and test an "exclusive-OR" gate circuit
17. Construct and test a four-bit shift register
18. Construct and test a flip-flop circuit
19. Construct and test J-K counter circuits
20. Construct and test an A/D converter
21. Construct and test a D/A converter
22. Construct and test a BCD-to-7-segment decoder

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GLOSSARY

Accuracy — How near the instrument reading is to the actual value

Active device — A component in a circuit which has gain or which directs the flow of current

Alternation — Moving from zero to a maximum (or minimum) and back to zero

Amplitude — The extreme range of varying quantity such as the maximum height of a waveform

Analog signal — A DC or AC current or voltage that varies smoothly or continuously

Aquadag — A colloidal suspension of graphite deposited on the inner side walls of cathode-ray tubes to serve as an electrostatic shield or an accelerating anode

Attenuate — To decrease in amplitude or intensity

Bandwidth — The band of frequencies over which the response in a circuit falls within a specified fraction of the maximum value

Base — A region which lies between an emitter and collector of a transistor into which minority carriers are injected

Battery — Consists of a number of cells connected together so as to produce more electrical capacity than a single cell

Bias — External electrical potential (voltage) applied to a P-N junction

Binary coded decimal (8421) — A digital code where a four bit binary character is used to represent each single digit decimal character

Binary number system — Number system which has digits zero (0) and one (1) only

Bit — A single binary digit, 0 or 1

Bleeder resistor — A resistor which is used to draw off fixed current and as a safety measure to discharge filter capacitors after the circuit is de-energized

Bonding — The holding together of atoms to form a molecule

Calibration — Techniques of adjusting an instrument by referencing it to another instrument or standard of known accuracy and precision

Cascaded — A series of electronic circuits or devices connected so that the output of one is the input of the next

Cell — A receptacle containing electrodes and an electrolyte for producing electricity from chemical action

Chassis ground — A common return circuit in electronic equipment that may be at a potential above or below ground

Clear (CLR) — To reset, as in the case of a flip-flop, counter, or register

Closed circuit — Circuit in which there is a complete and unbroken path for current to flow

Closed-loop operation — An application of an operational amplifier circuit that uses external feedback

Collector — The region in a transistor through which a primary flow of carriers leaves the transistor

Combinational logic — A combination of gate circuits used to combine or generate specified functions

Common-mode signal — Signal voltages that are in phase, of equal amplitude and frequency, applied to both inputs of a differential amplifier

Comparator — A circuit which compares two inputs and produces an output that is a function of the result of the comparison

Complementary symmetry — An arrangement of PNP and NPN type transistors that provides push-pull type operation from a single input signal

Coulomb — Quantity of electrons representing approximately 6.25×10^{18} electrons

Covalent bonding — Two or more atoms sharing electrons in their outer shell to form a stable molecule

Crossover distortion — Distortion in push-pull amplifiers at the zero center line of the AC signal due to nonlinearity of the transistor characteristics

Crosstalk — Interference due to cross coupling between adjacent circuits or due to intermodulation of two or more carrier channels

CRT — Cathode ray tube used in oscilloscope

Cycle — Events occurring in sequence; i.e. one complete reversal of an alternating current from negative to positive and back to the starting point

Darlington pair — A circuit consisting of two bipolar transistors with the collectors connected together and the emitter of one connected to the base of the other acting together as a single unit like a very high gain transistor

DC offset voltage — The small output voltage in practical op-amp circuits that is a resultant of bias currents in the circuits

Depletion region — The junction area that has no free charges

Dielectric — An insulating material capable of accumulating an electrical charge

Differential amplifier — A circuit that amplifies the difference between two inputs; the input stage of an op-amp

Digital circuit — A circuit that acts like a switch, either on or off

Diode — A two-terminal semiconductor device consisting of a P-N junction which allows majority carriers to flow in one direction

Doping -- The process of adding impurities to an intrinsic material

Electromagnet — A soft iron core surrounded by a coil of wire that temporarily becomes a magnet when an electric current flows through the coil of wire

Emitter — The region in a bipolar junction transistor from which carriers flow through the emitter junction into the base

EPROM — Erasable programable read-only memory

Extrinsic material — A material to which an impurity has been added

Feedback — The transferring of voltage from output of a circuit back to its input

Filter — A circuit or device used to minimize or eliminate ripple

Flip-flop — A bistable multivibrator circuit

Flourescence — Emission of light during electron bombardment

Frequency — Number of cycles per second measured in hertz (Hz)

Gain bandwidth product — Equal to the unity-gain frequency of an op-amp and determined by multiplying the gain and bandwidth of a specific circuit

Galvanometer — Meter which indicates very small amounts of current and voltage

Graticule — Grid lines on the screen of a CRT

Ground — A common return circuit in electronic equipment whose potential is zero

Hertz (Hz) — Basic unit of frequency

Holes — The absence of electrons in a covalent bond

Impedance — Total opposition to flow of an alternating current as a result of reactance and resistance

Induction — The process of magnetizing an object by bringing it into the magnetic field of an electromagnet or permanent magnet

Integrated circuit — A complete electronic circuit that is fabricated on a single chip of silicon

Internal resistance — The resistance which is within a voltage source

Intrinsic material — A pure crystal of material

Ion — An atom which has lost or gained an electron

IRED — Infrared emitting diode

JFET — A junction field-effect transistor in which the gate electrode is formed by a PN junction

Joule — Unit of energy equal to one watt-second

LC network — One of the classifications of oscillator circuits in which the frequency is determined by the inductor (L) and the capacitor (C) in the tank (resonant) circuit

Light-emitting diode (LED) — A diode specially doped to emit light when forward biased

Linear IC — A classification of integrated circuits used for analog amplification purposes

Load — A device to which electrical energy is being supplied and expended

Logic high — High voltage (usually five volts or more) representing binary 1

Logic low — Low voltage (usually 0 or near 0) representing binary 0

Magnet — Device or material that has the property of magnetism

Magnetism — Property possessed by certain materials which exerts a mechanical force on other magnetic materials, and which can cause induced voltage in conductors when relative movement is present

Majority carriers — Electrons in N-type materials and holes in P-type materials

Minority carriers — Electrons in P-type materials and holes in N-type materials

Monolithic IC — An integrated circuit fabricated from a single chip of semi-conductor material, usually silicon

MOSFET — A field-effect transistor containing a metal gate over thermal oxide on silicon

Open circuit — Circuit in which the path for current has been broken

Open-loop operation — An application of an operational amplifier circuit that uses no external feedback

Operational amplifier (Op-Amp) — A solid-state integrated circuit amplifier with very high gain, differential inputs, and uses external feedback to control its gain

Optocoupler — A device which provides for electrical isolation between circuits using optoelectronic components

Oscillator — An electronic circuit which converts electrical energy from a DC source into AC energy

Overload — A load on a circuit or system greater than the load for which it was designed

Passive device — A component in a circuit which has no gain characteristics such as a resistor, capacitor, or inductor

Peak inverse voltage (PIV or PRV) — The maximum reverse-bias voltage which can be applied to a P-N junction without damage to the junction

Percent regulation — Comparison of the no-load voltage to the full-load voltage expressed as a percentage of the full-load voltage

Period — Time for one complete cycle to occur

Permeability (μ) — A measure of the effectiveness of a material as a path for magnetic lines of force as compared to the effectiveness of air

Permeance — The reciprocal of reluctance

Persistence — Length of time the phosphor on a CRT continues to glow after electron bombardment ceases

Phase — Time relationship of one waveform to another

Phosphorescence — Emission of light after bombardment of electrons has stopped

Photo-diode — A diode made from photo-sensitive material whose resistance decreases with increased light

Photo-sensitive — Reactive to light

P-N junction — The region where N-type and P-type semiconductor materials join together

Preset (PR) — To initialize a digital circuit to a predetermined state

Push-pull amplifier — An amplifier which uses two transistors connected so that each transistor contributes current to the output signal on alternate half cycles of the input signal

RAM — Random access memory

RC network — One of the classifications of oscillator circuits in which the frequency is determined by the resistance and the capacitance in the circuit

Rectifier circuit — A circuit that converts AC voltages to pulsating DC voltages

Reluctance (R) — Magnetic resistance

Resistor — Device which opposes the flow of electrical energy

Retentivity — Ability of a material to retain magnetism

Ripple — Variations in the DC voltage output of rectifier circuits

Ripple counter — A digital counter in which each flip-flop is clocked with the output of the previous stage

ROM — Read only memory

Schematic — A graphic representation of an electrical circuit using standard symbols for parts

Screen — The term commonly used to refer to the face of a CRT

Semiconductor — A material which has a resistivity between conductors and insulators whose conductivity increases with temperature

Sensitivity — How well an instrument or circuit responds to small values of voltage

Sequential logic — A broad category of digital circuits whose logic gates are dependent on a specified time sequence

Shift register — A digital circuit that is capable of storing and shifting data

Shunt — A circuit that is in parallel with another and typically used to extend the range of an ammeter

Single-ended amplifier — Denotes the method of supplying an input signal or obtaining an output signal from an amplifier in which one side of the input or output is connected to ground

Trace — The visible form on the screen of a CRT

Truth table — Summarizes the various combinations of input and corresponding output signals for logic gates

Vector — Straight line drawn to scale, showing direction and magnitude of a force

Voltage drop — An energy loss in a component made evident by a difference in voltage measured across a component

Waveform — The shape of a wave as a function of time, distance, and amplitude

Word — A group of bits representing a complete piece of digital information

Work — Force moved through a distance, measured in foot-pounds

GENERAL ELECTRONICS TECHNICIAN

REFERENCES

(NOTE: The following is an alphabetical list of references used in completing this text.)

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TEST EQUIPMENT
UNIT I

UNIT OBJECTIVE

After completion of this unit, the student should be able to apply theoretical knowledge related to test equipment, construct and analyze types of test equipment, and use an oscilloscope to measure frequency, AC voltage, and DC voltage. Competencies will be demonstrated by correctly performing the procedures outlined in the assignment and job sheets and by scoring a minimum of 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to test equipment with their correct definitions.
2. Match types of test equipment with their functions.
3. Complete statements related to the types of meters and their characteristics.
4. Name six types of analog meter movements.
5. Complete statements related to the characteristics of an ammeter.
6. Select true statements related to the characteristics of a voltmeter.
7. Complete statements related to the characteristics of an ohmmeter.
8. Select true statements related to the characteristics of a digital meter.
9. Match the oscilloscope controls with their functions.
10. Complete statements related to oscilloscope construction.
11. Name measurements that may be taken with an oscilloscope.

OBJECTIVE SHEET

12. Calculate effective or root-mean-square voltage from sine wave dimensions. (Assignment Sheet #1)

13. Calculate time and frequency from waveform dimensions. (Assignment Sheet #2)

14. Determine phase relationships of AC signals. (Assignment Sheet #3)

15. Demonstrate the ability to:

    a. Determine the resistance of a meter movement. (Job Sheet #1)

    b. Construct and analyze a voltmeter. (Job Sheet #2)

    c. Construct and analyze a simple ohmmeter. (Job Sheet #3)

    d. Construct and analyze an ammeter. (Job Sheet #4)

    e. Adjust oscilloscope controls for a stable waveform display. (Job Sheet #5)

    f. Measure frequency using an oscilloscope. (Job Sheet #6)

    g. Measure AC voltage using an oscilloscope. (Job Sheet #7)

    h. Measure DC voltage using an oscilloscope. (Job Sheet #8)

    i. Calibrate an oscilloscope probe. (Job Sheet #9)

TEST EQUIPMENT
UNIT I

SUGGESTED ACTIVITIES

A. Obtain additional materials and/or invite resource people to class to supplement/reinforce information provided in this unit of instruction.

B. Make transparencies from the transparency masters included with this unit.

(NOTE: Activities A and B should be completed prior to the teaching of this unit.)

C. Provide students with objective sheet.

D. Discuss unit and specific objectives.

E. Provide students with information and assignment sheets.

F. Discuss information and assignment sheets.

(NOTE: Use the transparencies to enhance the information as needed.)

G. Provide students with job sheets.

H. Discuss and demonstrate the procedures outlined in the job sheets.

I. Integrate the following activities throughout the teaching of this unit:

1. Locate local suppliers of test equipment.
2. Demonstrate and use a variety of brand names and models of test equipment.
3. Review catalogs and test equipment specifications.
4. Review the proper storage procedures and locations of test equipment in your shop area.
5. Demonstrate the correct use of an ammeter, a voltmeter, and an ohmmeter.
6. Meet individually with students to evaluate their progress through this unit of instruction, and indicate to them possible areas for improvement.

J. Give test.

K. Evaluate test.

L. Reteach if necessary.

INSTRUCTIONAL MATERIALS INCLUDED IN THIS UNIT

A. Objective sheet

B. Suggested activities

C. Information sheet

D. Transparency masters

1. TM 1 — VOM (Simpson 260)
2. TM 2 — DVOM
3. TM 3 — Moving Coil Meter (D'Arsonval Movement)
4. TM 4 — Taut Band DC Meter
5. TM 5 — Electrodynamometer
6. TM 6 — Iron Vane Meter
7. TM 7 — Thermocouple Meter
8. TM 8 — Correct Amperage Measurements
9. TM 9 — DC Ammeter
10. TM 10 — Correct Voltage Measurements
11. TM 11 — DC Voltmeter
12. TM 12 — CRT
13. TM 13 — CRT Signal Trace
14. TM 14 — Simplified Block-Diagram Oscilloscope
15. TM 15 — Peak-to-Peak and Peak Voltages of an AC Waveform
16. TM 16 — Pulse Width, Rise and Fall Time and Amplitude of Rectangular Waveforms
17. TM 17 — Phase Relationships of AC Signals
18. TM 18 — Lissajous Phase Patterns
19. TM 19 — Lissajous Phase Patterns (Continued)

INSTRUCTIONAL MATERIALS INCLUDED IN THIS UNIT

E. Assignment sheets

1. Assignment Sheet #1 — Calculate Effective or Root-Mean-Square Voltage From Sine Wave Dimensions
2. Assignment Sheet #2 — Calculate Time and Frequency from Waveform Dimensions
3. Assignment Sheet #3 — Determine Phase Relationships of AC Signals

F. Answers to assignment sheets

G. Job sheets

1. Job Sheet #1 — Determine the Resistance of a Meter Movement
2. Job Sheet #2 — Construct and Analyze a Voltmeter
3. Job Sheet #3 — Construct and Analyze a Simple Ohmmeter
4. Job Sheet #4 — Construct and Analyze an Ammeter
5. Job Sheet #5 — Adjust Oscilloscope Controls for a Stable Waveform Display
6. Job Sheet #6 — Measure Frequency Using an Oscilloscope
7. Job Sheet #7 — Measure AC Voltage Using an Oscilloscope
8. Job Sheet #8 -- Measure DC Voltage Using an Oscillscope
9. Job Sheet #9 — Calibrate an Oscilloscope Probe

H. Test

I. Answers to test

REFERENCES USED IN DEVELOPING THIS UNIT

(NOTE: The following is a list of references used in completing this unit.)

A. Bruce, David. *Modern Electronics.* Reston, VA: Reston Publishing Co., Inc., 1984.

B. *Electronic Test Equipment,* Heathkit/Zenith Educational Systems. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1983.

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E. Siebert, Leo N. *Introduction to Industrial Electricity — Electronics.* Stillwater, OK: Oklahoma Curriculum and Instructional Materials Center, 1981.

TEST EQUIPMENT
UNIT I

INFORMATION SHEET

I. **Terms and definitions**

A. Accuracy — How near the instrument reading is to the actual value

B. Aquadag — A colloidal suspension of graphite deposited on the inner side walls of cathode-ray tubes to serve as an electrostatic shield or an accelerating anode

C. Calibration — Techniques of adjusting an instrument by referencing it to another instrument or standard of known accuracy and precision

D. CRT — Cathode ray tube used in oscilloscope

E. Cycle — Events occurring in sequence; i.e. one complete reversal of an alternating current from negative to positive and back to the starting point

F. Flourescence — Emission of light during electron bombardment

G. Frequency — Number of cycles per second measured in hertz (Hz).

H. Graticule — Grid lines on the screen of a CRT

I. Hertz (Hz) — Basic unit of frequency

J. Period — Time for one complete cycle to occur

K. Persistence — Length of time the phosphor on a CRT continues to glow after electron bombardment ceases

L. Phosphorescence — Emission of light after bombardment of electrons has stopped

M. Screen — The term commonly used to refer to the face of a CRT

N. Sensitivity — How well an instrument or circuit responds to small values of voltage

O. Shunt — A circuit that is in parallel with another and typically used to extend the range of an ammeter

P. Trace — The visible form on the screen of a CRT

II. **Types of test equipment and their functions**

A. Multimeters are available in analog (VOM's) and digital (DVOM's) types and are used to measure voltage, current, and resistance.

INFORMATION SHEET

B. Function generators provide a voltage source with multiple outputs, typically sine wave, square wave, and sawtooth waveforms.

C. Audio signal generators provide a sine wave voltage output within the audio signal spectrum (approximately 20 Hz to 20 KHz).

D. Power supplies provide a controlled source of AC and/or DC power for use on the test bench for equipment or test and experimental circuits.

E. Logic probes are used to identify logic levels in digital circuits.

F. Logic pulsers provide short pulses for injecting signals into digital circuits.

G. A logic clip is a device that fits over an IC chip and identifies logic levels at each pin of the IC.

H. A resistance bridge is used to measure precision values of resistance.

I. An inductance bridge is an instrument to measure values of inductance.

J. A capacitance bridge is used to measure values of capacitance.

K. An impedance bridge is a combination bridge used to measure resistance, capacitance, and inductance.

L. Transistor testers are used to determine the condition of transistors and diodes.

M. An isolation transformer provides a source of AC through transformer action which has no direct physical connection to the power line and therefore provides an "isolated" source of electrical energy (a safety factor for equipment and personnel).

III. **Types of meters and their characteristics**

A. A VOM (volt-ohm-milliammeter) is a relatively inexpensive portable, multifunction analog meter used to measure voltage, resistance, and current. (Transparency #1)

B. Analog Electronic Voltmeters (EVM) are meters which use electronic components within the meter circuitry, use a calibrated analog scale as the readout, and need a power supply to operate, and are multifunction instruments like the VOM.

1. A VTVM (vacuum tube voltmeter) uses vacuum tubes within the meter circuitry, absorbs very little energy from the circuit being tested, needs a power supply or batteries to operate (usually internally mounted) and has a high degree of accuracy.

INFORMATION SHEET

2. A TVM or TRVM (Transistorized-volt-meter) uses transistors in the meter circuitry, requires a power supply (internal power supply or batteries), absorbs little energy from the circuit being tested, uses an analog scale, and has a high degree of accuracy.

C. Digital meters are multifunction instruments, have a digital display as the readout device, have electronic circuitry like the EVM's, are useful for making precise measurements, and are usually the meter of preference for use in testing modern electronic circuits. (Transparency #2)

D. AC meters are constructed so as to give an up-scale reading regardless of polarity of the voltage or current applied and are of primarily three different types.

1. The thermal type AC meter uses the heating effect of current, which is independent of polarity, to provide deflection on a meter scale (such as a hot-wire or thermocouple activated meter).

2. The electromagnetic type of AC meter maintains a constant relative magnetic polarity although the current may reverse (such as in the iron-vane meter, the dynamometer, and wattmeter).

3. The rectifier type AC meter converts an AC input to a DC output to the meter movement — usually a D'Arsonval movement.

(NOTE: The rectifier type is generally used in multifunction meters that are used to read both AC and DC voltage and current.)

IV. **Types of analog meter movements**

A. The moving coil (or D'Arsonval) DC meter movement consists of a horseshoe magnet with semicircular pole pieces, a soft-iron core positioned within the field of the magnet, and a movable coil to which a pointer is attached and is polarity sensitive. (Transparency #3)

B. Taut-band DC meter movements are constructed similar to the moving coil meter except that the moving core of the meter is supported by two tightly stretched metal ribbons to decrease the amount of friction in the movement of the coil and are used where highly sensitive movements are required. (Transparency #4)

C. The electrodynamometer is similar to the moving coil meter except that the permanent magnet is replaced by two stationary coils, are generally rather insensitive, will measure DC and low frequency AC, and are used where power drain from the circuit under test can be tolerated. (Transparency #5)

D. An iron vane meter movement primarily is used to read rms current, is not real sensitive, and is used mostly in low frequency (60 Hz) power circuits where their heavy current drain may be tolerated. (Transparency #[illegible]

INFORMATION SHEET

E. The thermocouple meter is basically a moving coil meter with a thermocouple input and is used to provide an accurate measurement of AC over a wide range of frequencies. (Transparency #7)

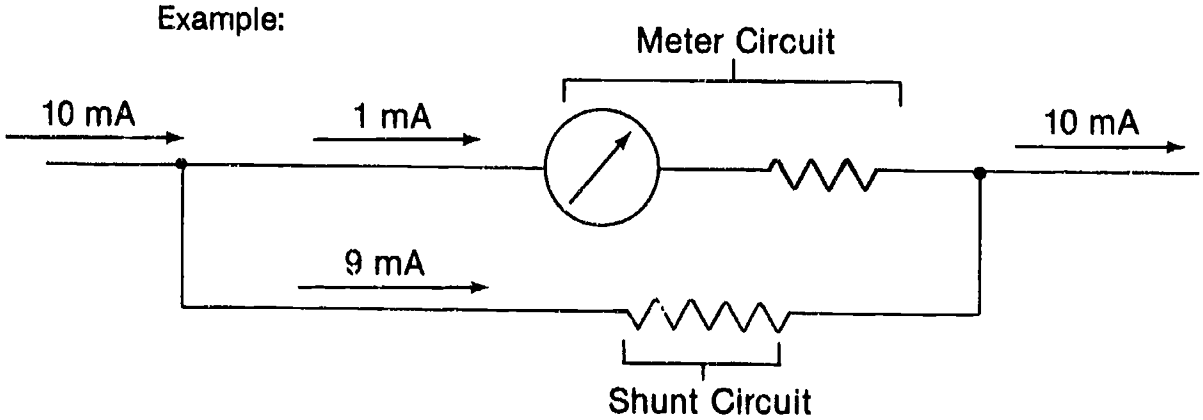
F. The electrostatic meter movement is the most sensitive and accurate of all movements, is constructed on the same principle as a variable capacitor (fixed plates and movable plates), and draws current from the circuit only for initial charging.

V. **Characteristics of an ammeter** (Transparency #8)

A. Ammeters are connected in series with the circuit under test when making current measurements.

B. The full-scale range of the ammeter may be extended using a shunt resistor which is a resistor connected in parallel with the meter movement. (Transparency #9)

Example:



C. The shunt resistance may be calculated using Ohm's law.

1. Multiply the meter full-scale current by the meter resistance (E = IR) to determine the voltage across the meter at full-scale.

2. Subtract the meter current from the total current to be measured to get the current of the shunt.

3. Divide the meter voltage by the shunt current (R = E/I) to get the necessary shunt resistance.

(NOTE: The meter shunt may also be calculated using the formula Rs=Rm/(N-1) ohms where Rs is the shunt resistance, Rm is the meter resistance, and N is the range multiplier.)

D. The sensitivity of the ammeter is the amount of current required to cause full-scale deflection of the pointer

INFORMATION SHEET

VI. **Characteristics of a voltmeter** (Transparency #10)

A. Measurements using a voltmeter are obtained by placing the voltmeter leads in parallel with the circuit component or source across which the voltage is to be determined.

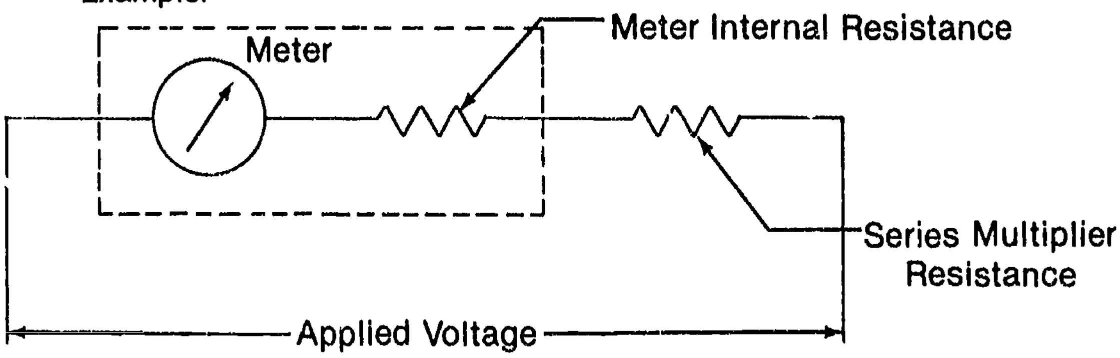
B. Polarity must be observed when making voltage measurements.

C. Basic meter movements may be used to measure both voltage and current and each has its basic full-scale voltage rating as well as full-scale current rating

Example: A 1 mA meter movement which has a resistance of 1000 ohms deflects full scale when connected across a voltage of 1 volt.

D. The voltage range of the basic meter movement may be increased by adding a multiplier resistor which is a resistor in series with the meter movement. (Transparency #11)

Example:



E. The resistance of the multiplier may be calculated by using Ohm's law as follows:

1. Divide the meter full-scale voltage by the meter internal resistance to determine the meter full-scale current.

2. Find the total resistance of the high voltage range by dividing the new full-scale voltage by the meter full-scale current.

3. Subtract the meter resistance from the total resistance to determine the value of the series multiplier resistor.

F. A typical voltmeter has a number of multipliers hooked to a switch giving the capability of a number of voltage ranges.

G. The sensitivity of a voltmeter is the reciprocal of the full-scale current rating of the meter and is expressed in ohms-per-volt.

Example: A voltmeter with a full-scale current rating of one milliamp has a sensitivity equal to 1/.001 or 1000-ohms-per-volt.

INFORMATION SHEET

H. Since a voltmeter is placed in parallel to take measurements, the resistance of the meter changes the total resistance of the test circuit and therefore the meter resistance should be very high to minimize the circuit loading effect of the parallel connection.

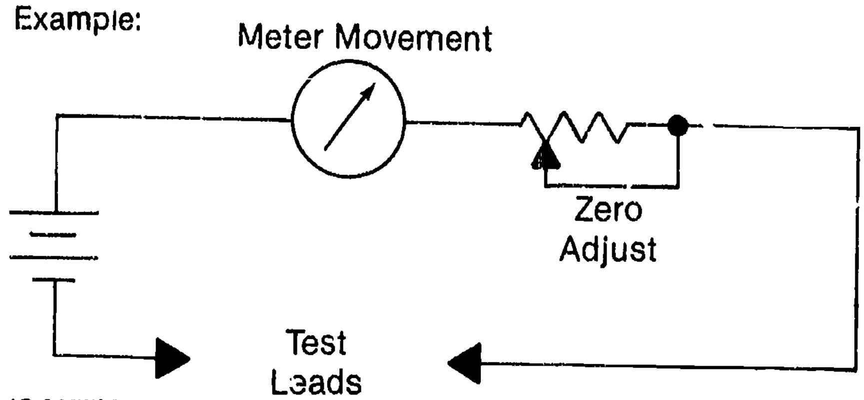
VII. **Characteristics of an ohmmeter**

A. An ohmmeter utilizes a basic meter movement, a series resistance, and a battery.

1. The purpose of the battery in an ohmmeter is to force a current through an unknown resistance.

2. The meter movement is used to measure the resulting current to give an indication on a scale calibrated in ohms.

Example:



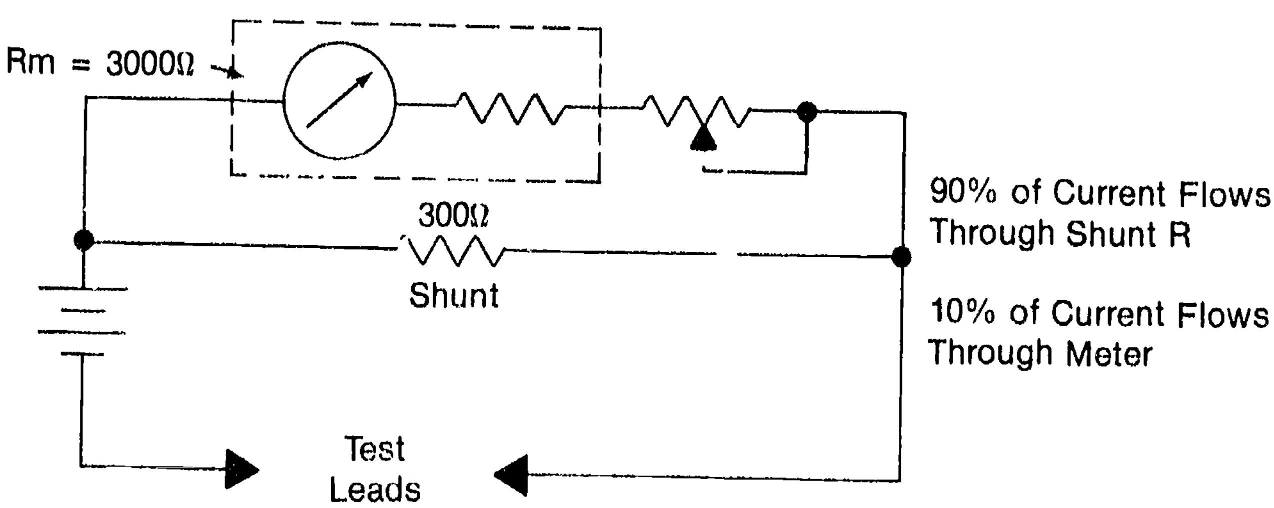
(CAUTION: An ohmmeter should never be connected to a circuit where power is applied.)

B. A multi-range ohmmeter uses a combination of series multiplier resistors and parallel shunt resistors to obtain different resistance ranges.

1. Multiplier resistors are used when the basic meter movement is in series with the unknown resistor.

2. Shunt resistors are used when the meter movement is acting as a voltmeter connected in parallel with a precision standard resistor (used to measure lower values of R).

Example:

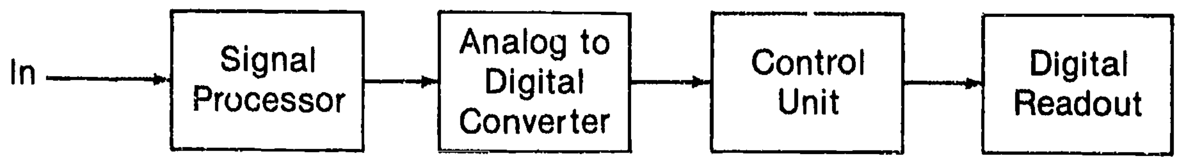


INFORMATION SHEET

VIII. **Characteristics of a digital meter**

A. The digital meter performs the same functions as an analog meter but displays the values in a digital readout rather than on an analog scale.

B. The digital meter consists of four basic blocks of electronic circuitry, a signal processor, an A/D converter, a control section, and a digital readout device.



1. The signal processor converts the input to a form that is usable by the analog to digital converter.

2. The A/D converter takes the output from the processor and converts it to a digital number.

3. The control block determines the flow of information within the meter circuitry and transfers the information to the digital readout.

4. The digital readout may be any one of the many available types that provide the visible result of the meters action.

C. Most digital meters are auto-ranging and have automatic polarity selection.

IX. **Oscilloscope controls and their functions**

(NOTE: Most of the controls are labeled on an oscilloscope with abbreviations for each of the controls. The names of some controls vary slightly. It is best that you consult the operation manual for the oscilloscope you are using to familiarize yourself with the control names, their abbreviations, and the function of each.)

A. Power switch — Turns oscilloscope on and off

B. Scale illumination — Illuminates the graticule on the CRT display

C. Focus — Adjusts image clarity and sharpness of the waveform presentation on the CRT display

D. Calibration — Provides a calibration signal to adjust the oscilloscope for accurate measurements

E. Intensity — Adjusts image brightness of the displayed waveform

F. Sweep mode — Selects which channel will be displayed on the CRT display

INFORMATION SHEET

G. Horizontal position — Moves image to the right or left on the CRT display

H. Sweep time/cm — Selects horizontal sweep rate which compresses or expands the displayed waveform

I. External horizontal input — Provides for an external input to allow control of the horizontal sweep by an external signal

J. Trigger source — Selects the signal to initiate or trigger the sweep

K. Trigger level — Selects voltage level of the triggering waveform that initiates the sweep

L. External trigger — Provides for the input of an external voltage to be used as the trigger to initiate the sweep

M. Vertical position — Provides for positioning of the image up or down on the CRT display

N. Coupling — Selects between DC or AC inputs

O. Channel A and Channel B input — Provides for the connection of input voltages to each of two channels

X. **Oscilloscope construction**

A. An oscilloscope display consists of three primary parts: the CRT, the electron gun, and the deflection plates.

1. The cathode ray tube (CRT) is the heart of the oscilloscope and provides the visual display of electronic signals. (Transparency #12)

2. The electron gun provides a fine beam of high velocity electrons that bombard the phosphor screen of the CRT causing the phosphor to glow giving the visual presentation on the CRT.

3. The electrostatic deflection plates control both the horizontal and vertical movement of the electron beam. (Transparency #13)

B. Electronic circuits within the oscilloscope allow operator control and automatic control of the electron beam to provide a useful presentation on the screen of the CRT. (Transparency 14)

C. The deflection plates are driven by amplifiers which generally increase the input to cause a specific deflection of the electron beam.

D. The horizontal amplifier has two inputs: one allows an external input to be displayed on the horizontal axis, the other is from the sweep generator to produce the horizontal trace across the screen.

INFORMATION SHEET

XI. **Measurements that may be taken with an oscilloscope**

A. The oscilloscope is capable of measuring voltage and time.

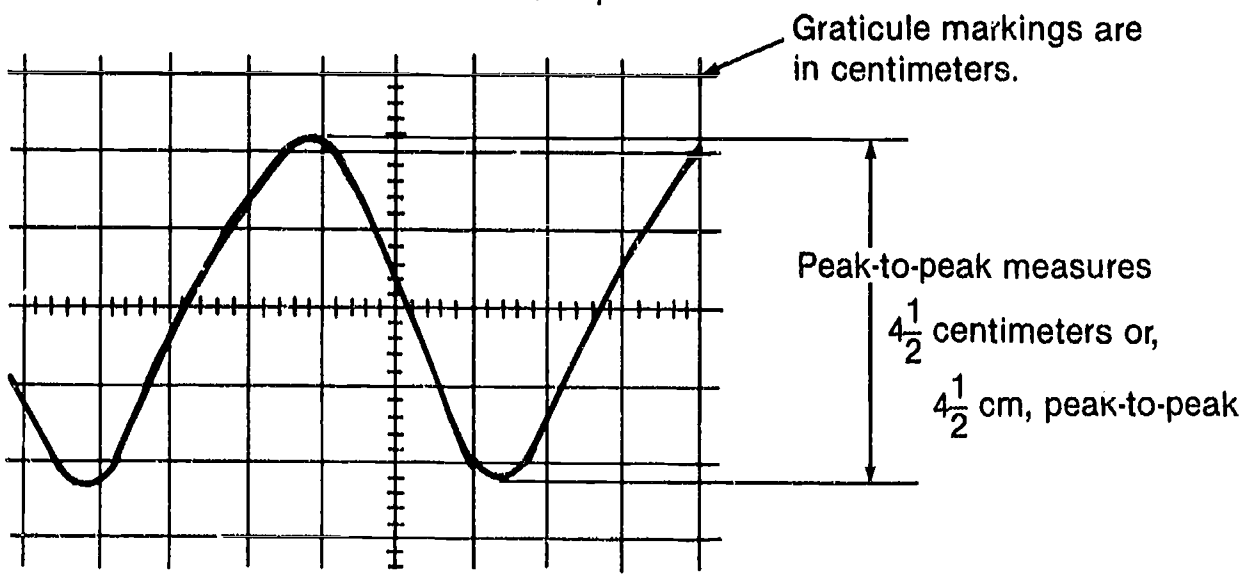
B. All measurements are made with the graticule on the oscilloscope screen.

C. The shape, phase, and frequency of the voltage waveform may be viewed while measurements are being made.

D. An oscilloscope may be used to measure DC voltage by counting the number of divisions on the graticule that the trace moves up or down when the voltage is applied to the input and then multiplying the number of divisions by the volts/cm setting.

E. The peak-to-peak and peak voltages of an AC waveform may be measured by counting the number of vertical divisions on the graticule that the waveform displaces. (Transparency #15)

Example: Measure the sine wave peak-to-peak distance with the graticule on the oscilloscope.



Check the volts/cm selector position; multiply that value by peak-to-peak graticule measurement to get peak-to-peak voltage.

4 1/2 cm times 2 volts/cm = 9 volts peak-to-peak.

Peak voltage equals 1/2 of peak-to-peak or 4.5 volts.

To convert to rms value, multiply peak by .707 = 3.18 volts rms.

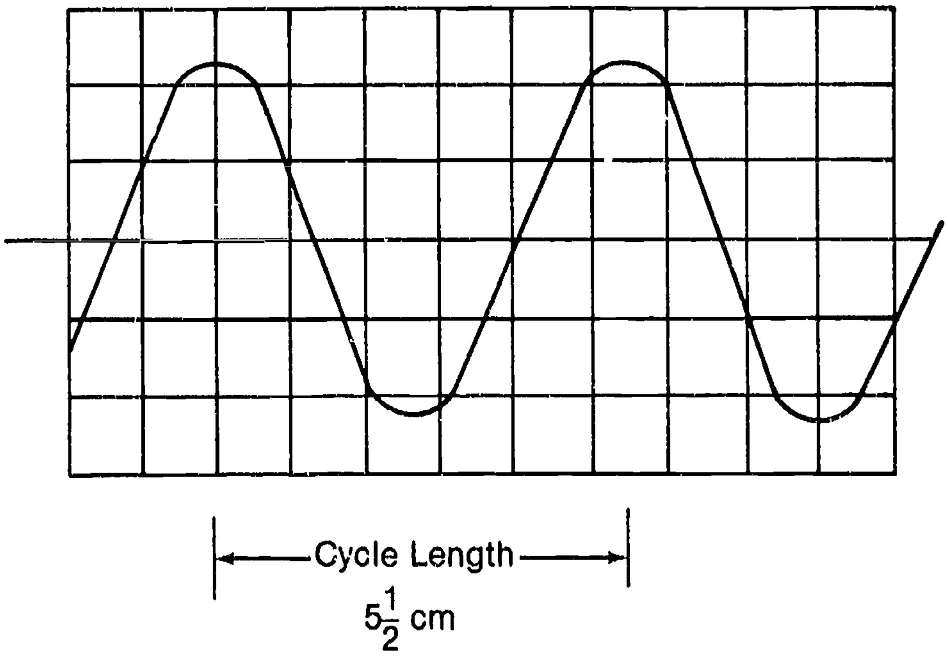
INFORMATION SHEET

F. The frequency of a sine wave may be determined by counting the number of divisions that one cycle displaces and multiplying that number by the sweep time/cm setting on the oscilloscope.

Examples: Measure the length of one cycle with the oscilloscope graticule, multiply that value by the sweep time/cm setting on your oscilloscope to get the time of one cycle; then using the formula f = 1/t, substitute values into the formula to find frequency.

$5\ ^1/_2$ cm x 5 ms/cm = .02755

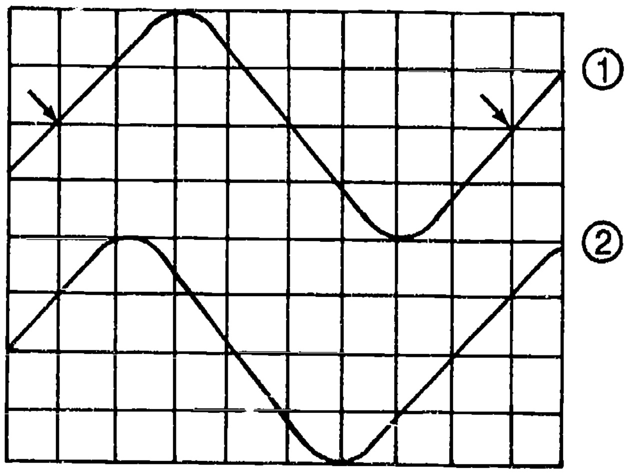
$$f = \frac{1}{t} = \frac{1}{.0275} = 36.36\ \text{Hz}$$



G. Pulse width, rise and fall time, and amplitude of rectangular waveforms may be measured with the oscilloscope. (Transparency #16)

INFORMATION SHEET

H. Phase relationships may be determined by comparing waveforms while simultaneously displaying them on a dual trace oscilloscope. (Transparency #17)

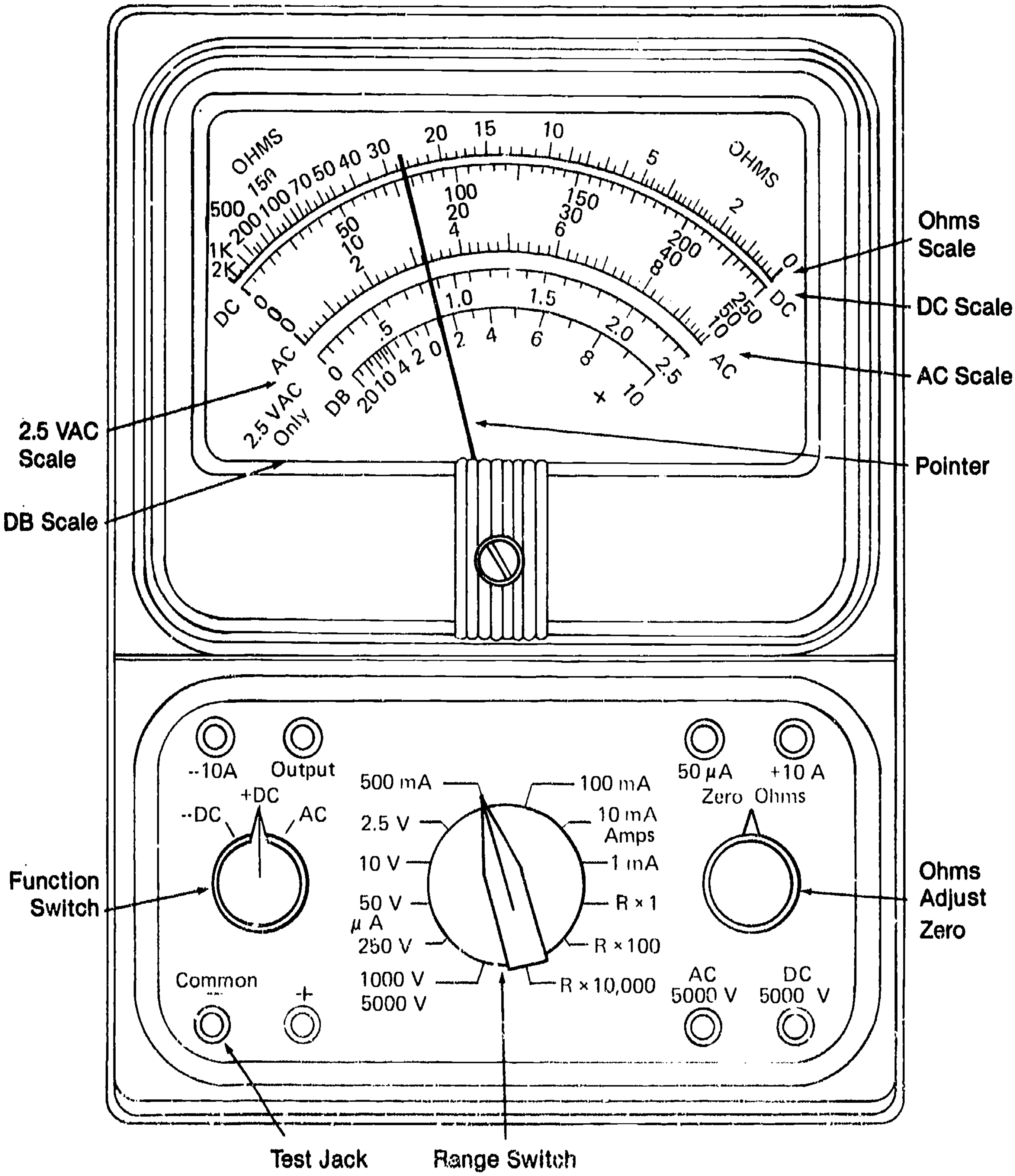


One cycle = 8 cm
1 cm = 45°

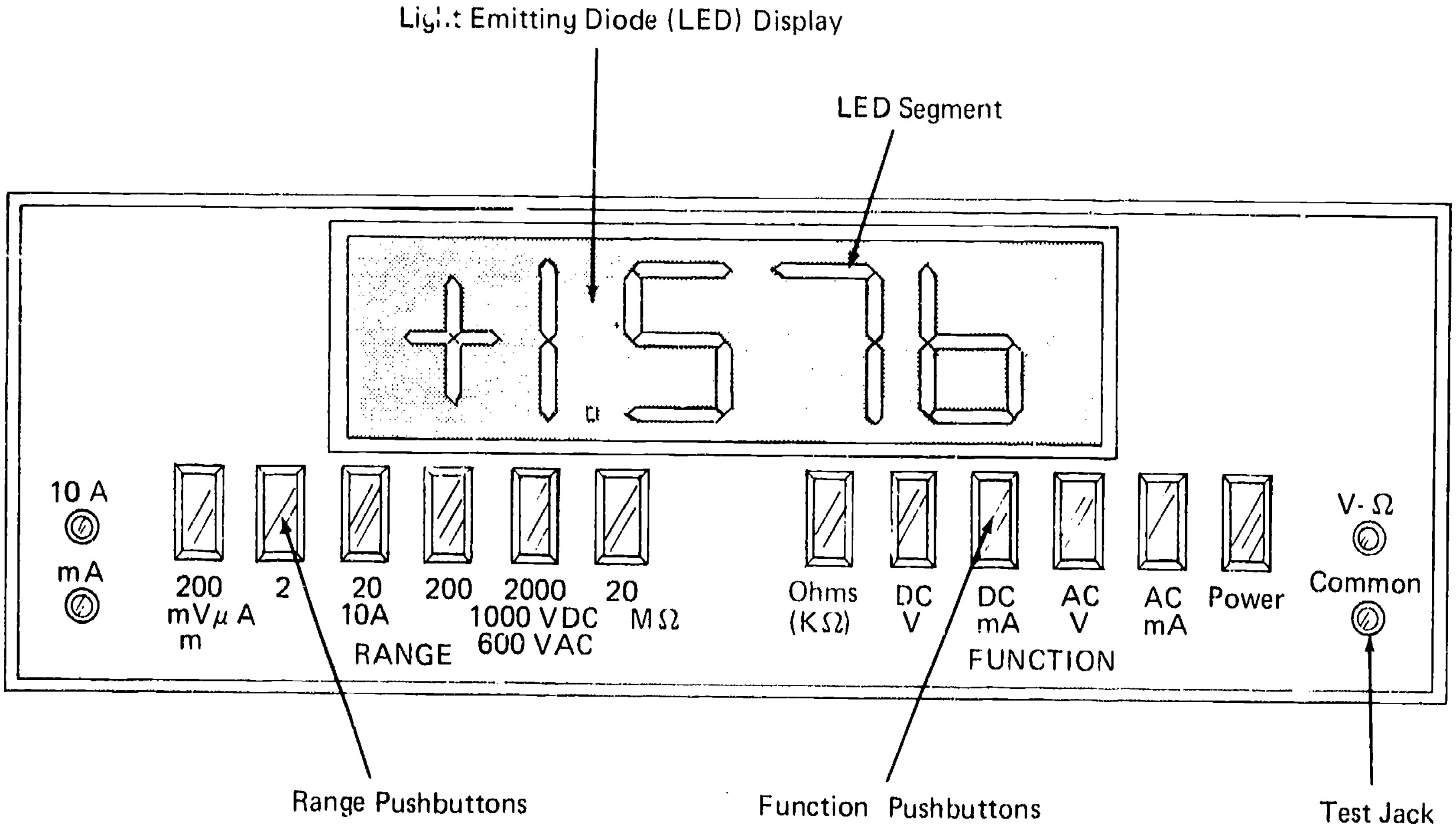
Phase difference = #cm × 45°
1 cm × 45° = 45°

I. Phase relationships may also be determined from lissajous patterns displayed on an oscilloscope. (Transparencies #18 and #19)

VOM
(Simpson 260)

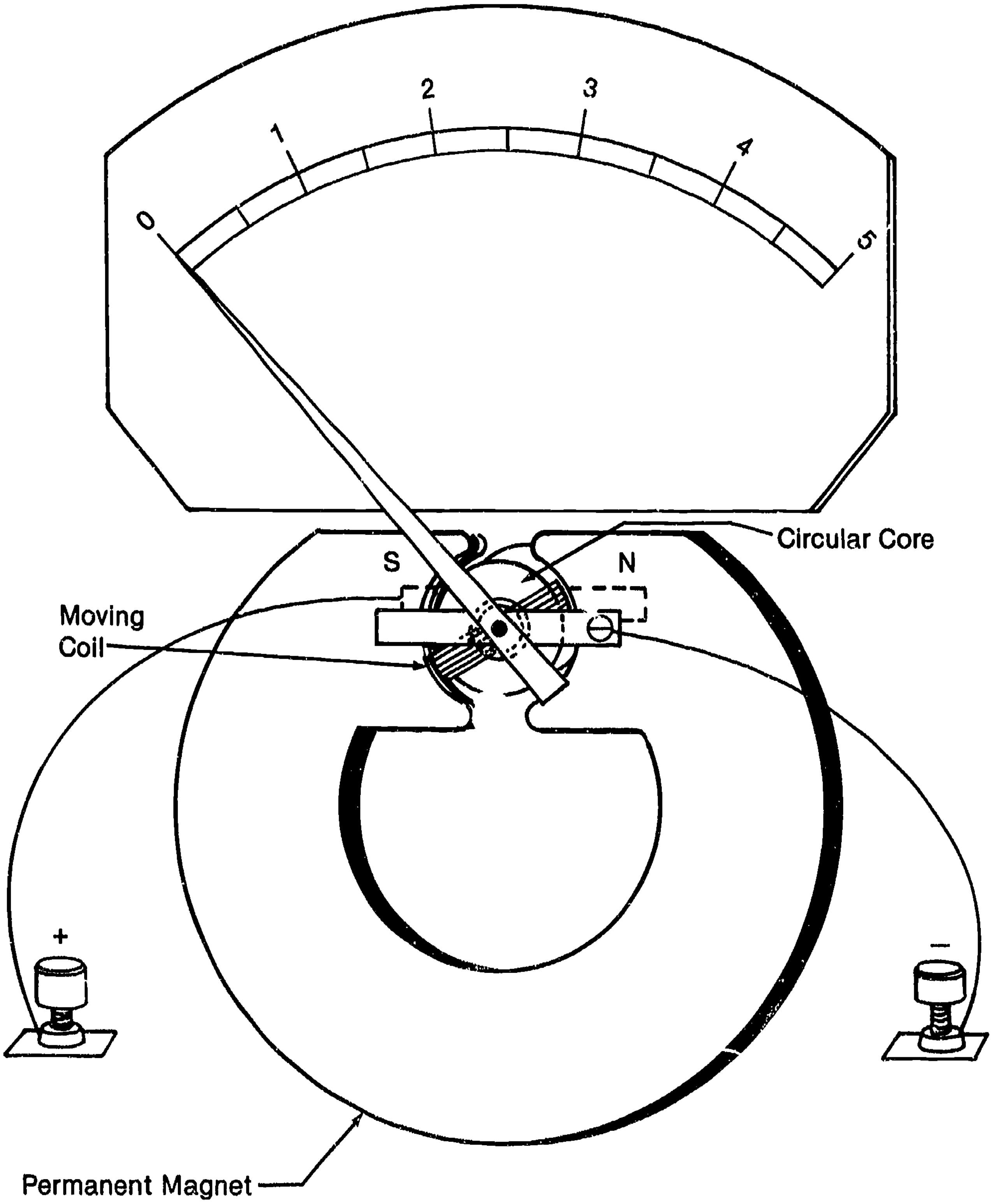


DVOM

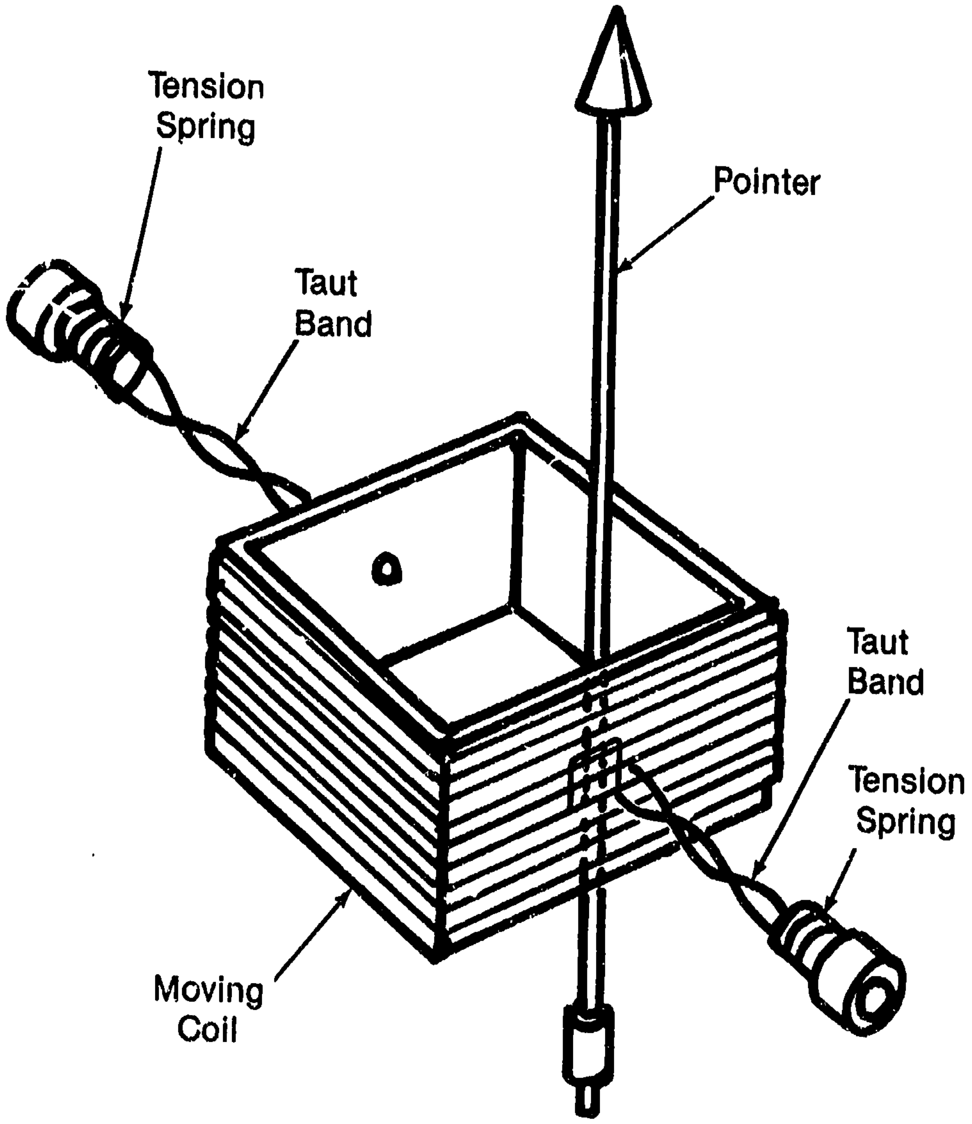

Light Emitting Diode (LED) Display
LED Segment
+1.576
10 A
mA
200
mVμA
m
2
20
10A
200
2000
1000 VDC
600 VAC
20
MΩ
RANGE
Ohms
(KΩ)
DC
V
DC
mA
AC
V
AC
mA
Power
FUNCTION
V-Ω
Common
Range Pushbuttons
Function Pushbuttons
Test Jack

Moving Coil Meter

(D'Arsonval Movement)



Taut Band DC Meter



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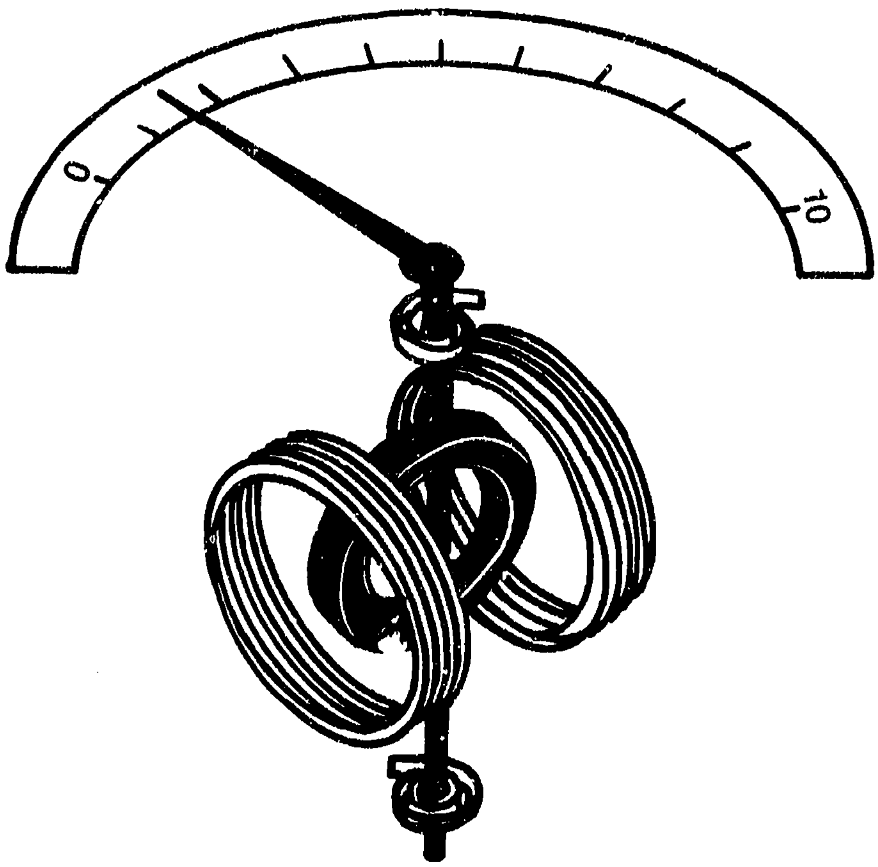
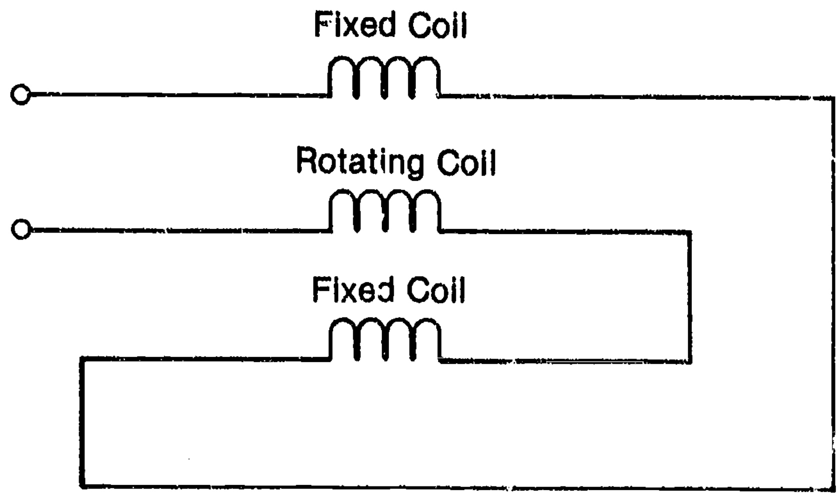
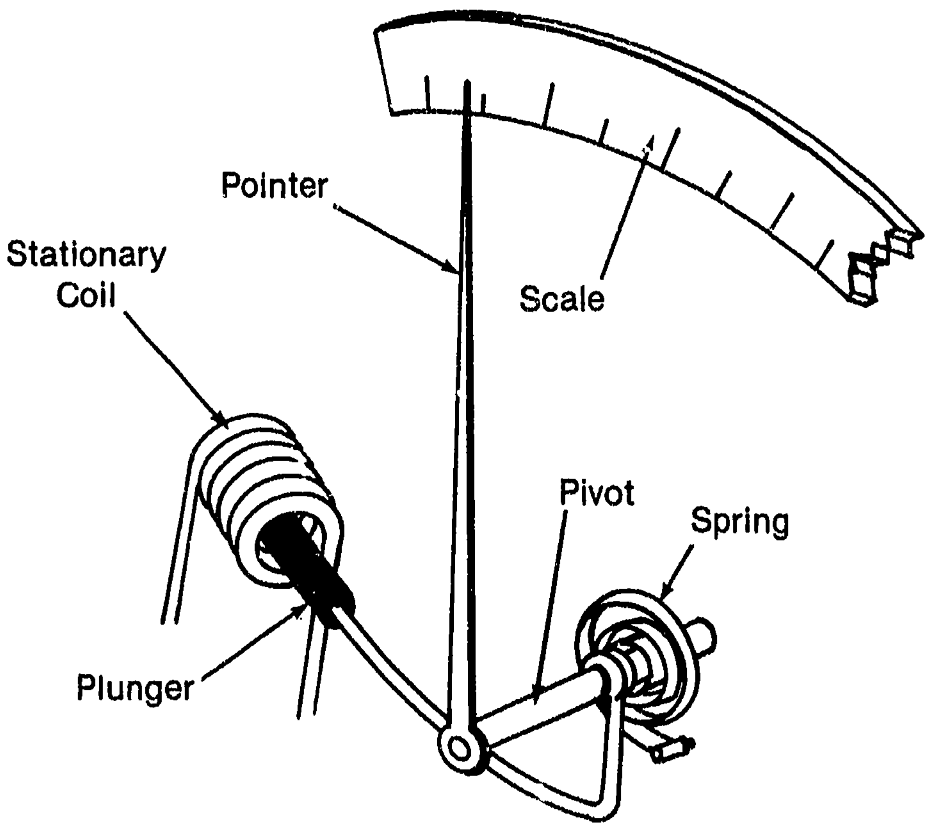
Electrodynamometer





Iron Vane Meter



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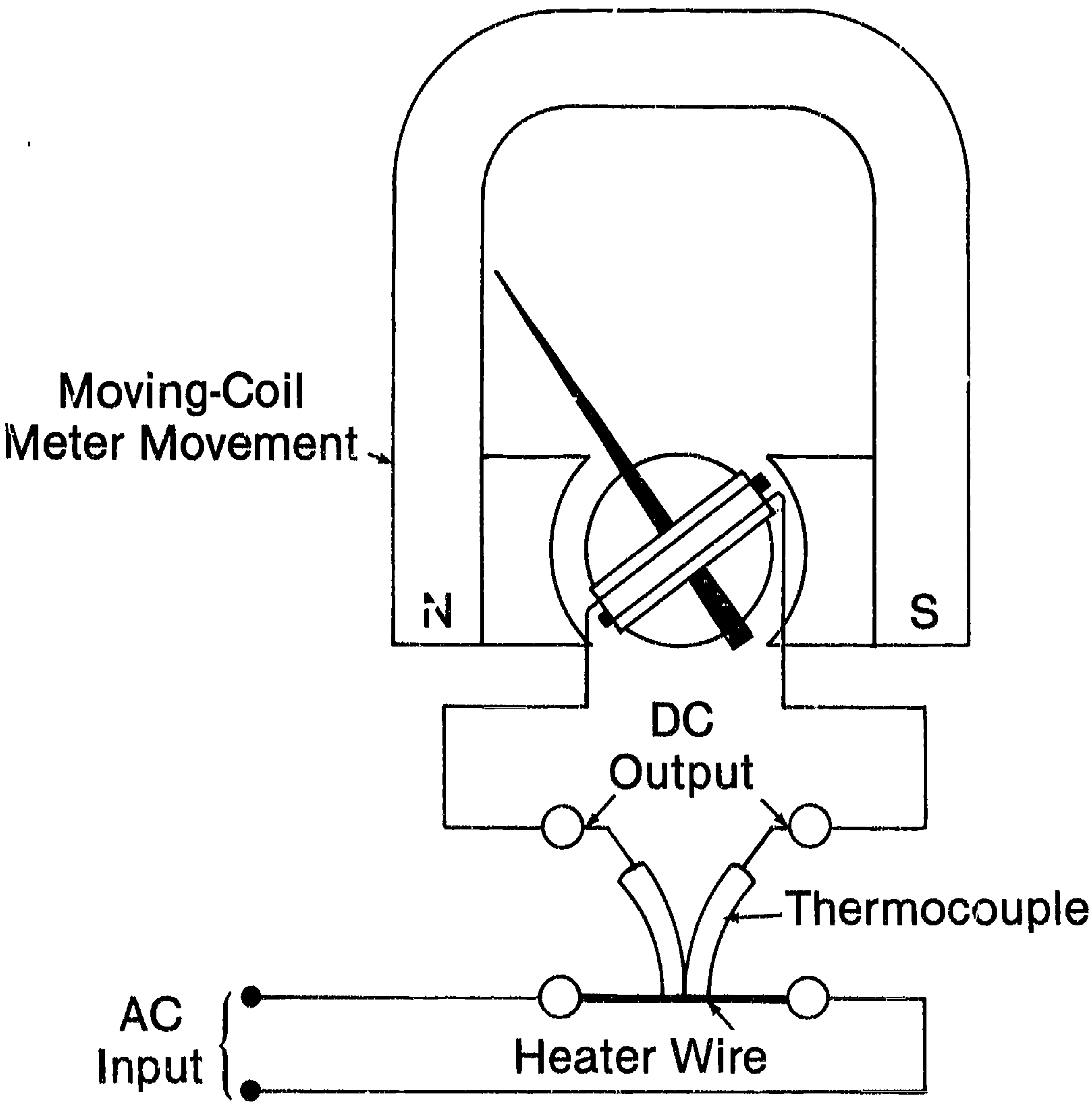
Thermocouple Meter



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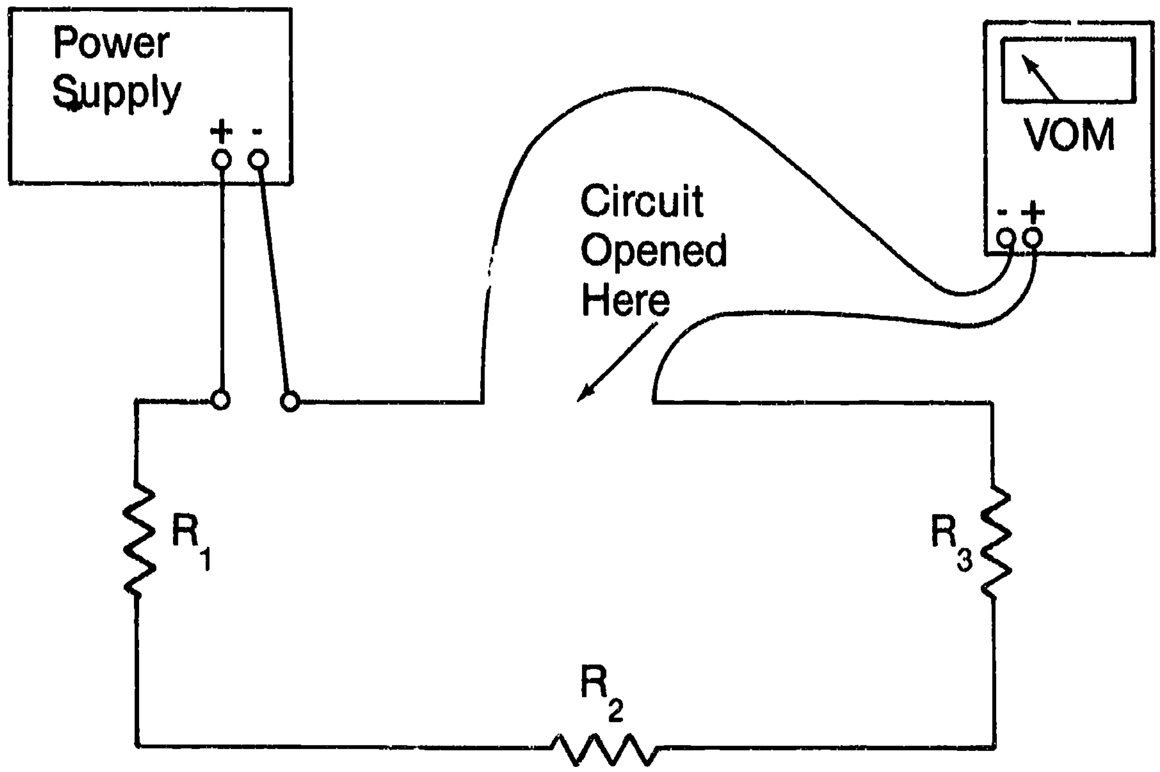
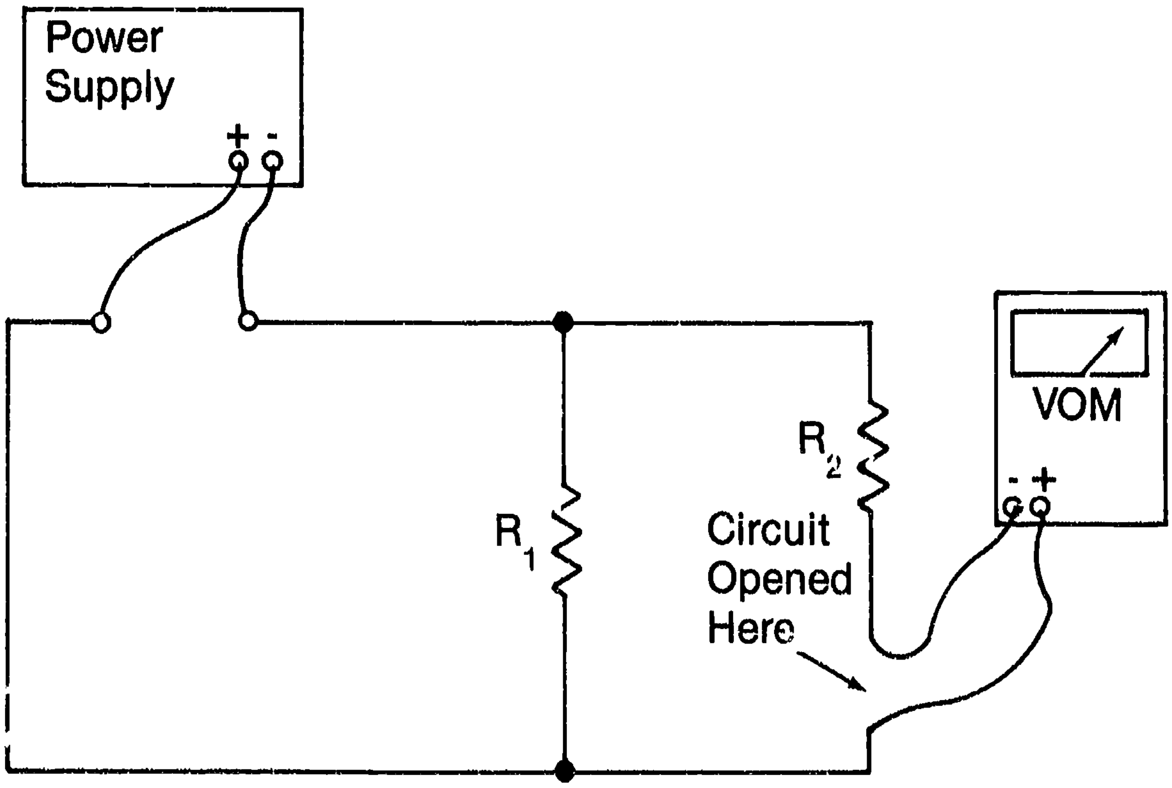
Correct Amperage Measurements

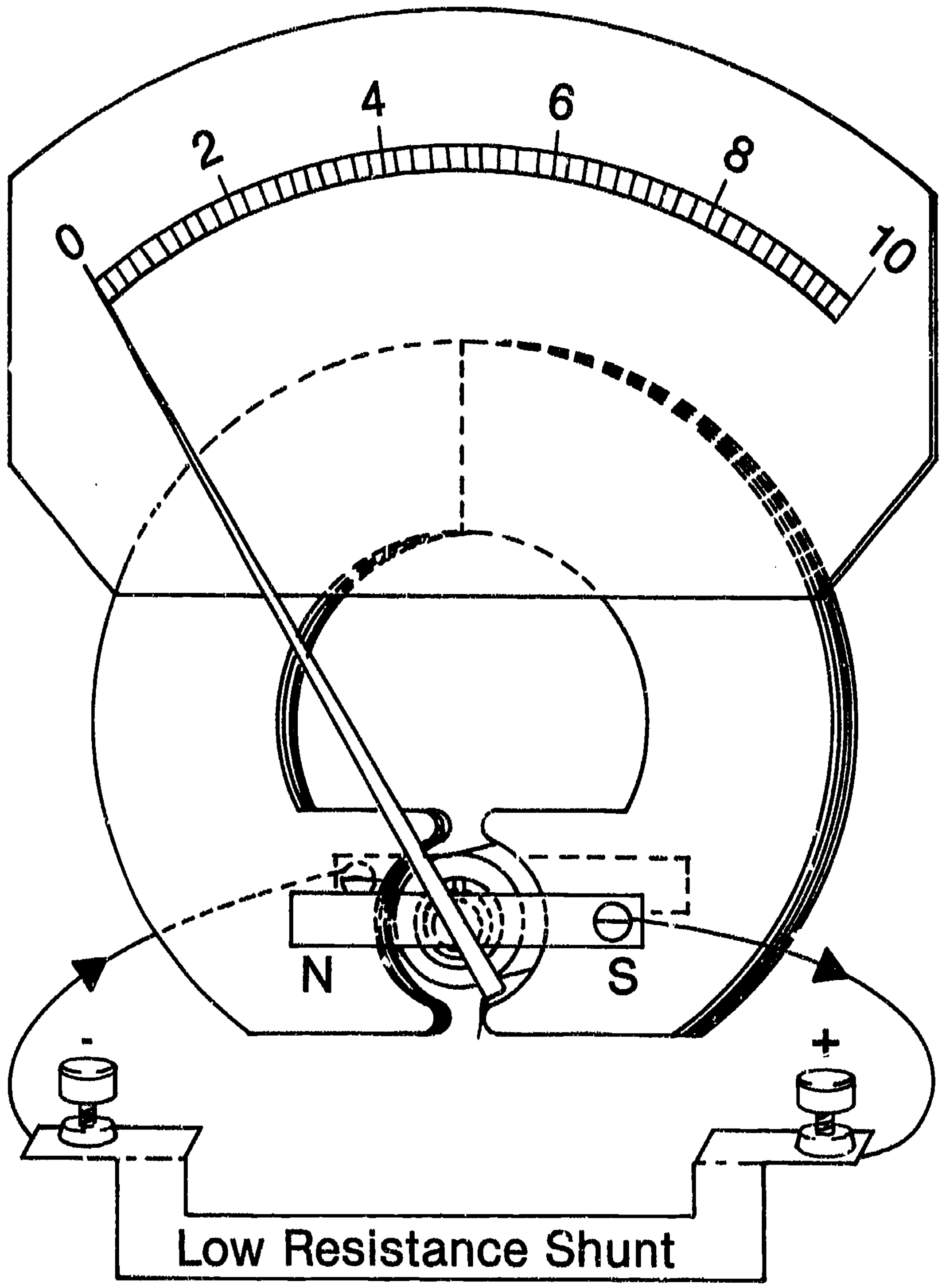


Measuring Amperage in Series Circuits

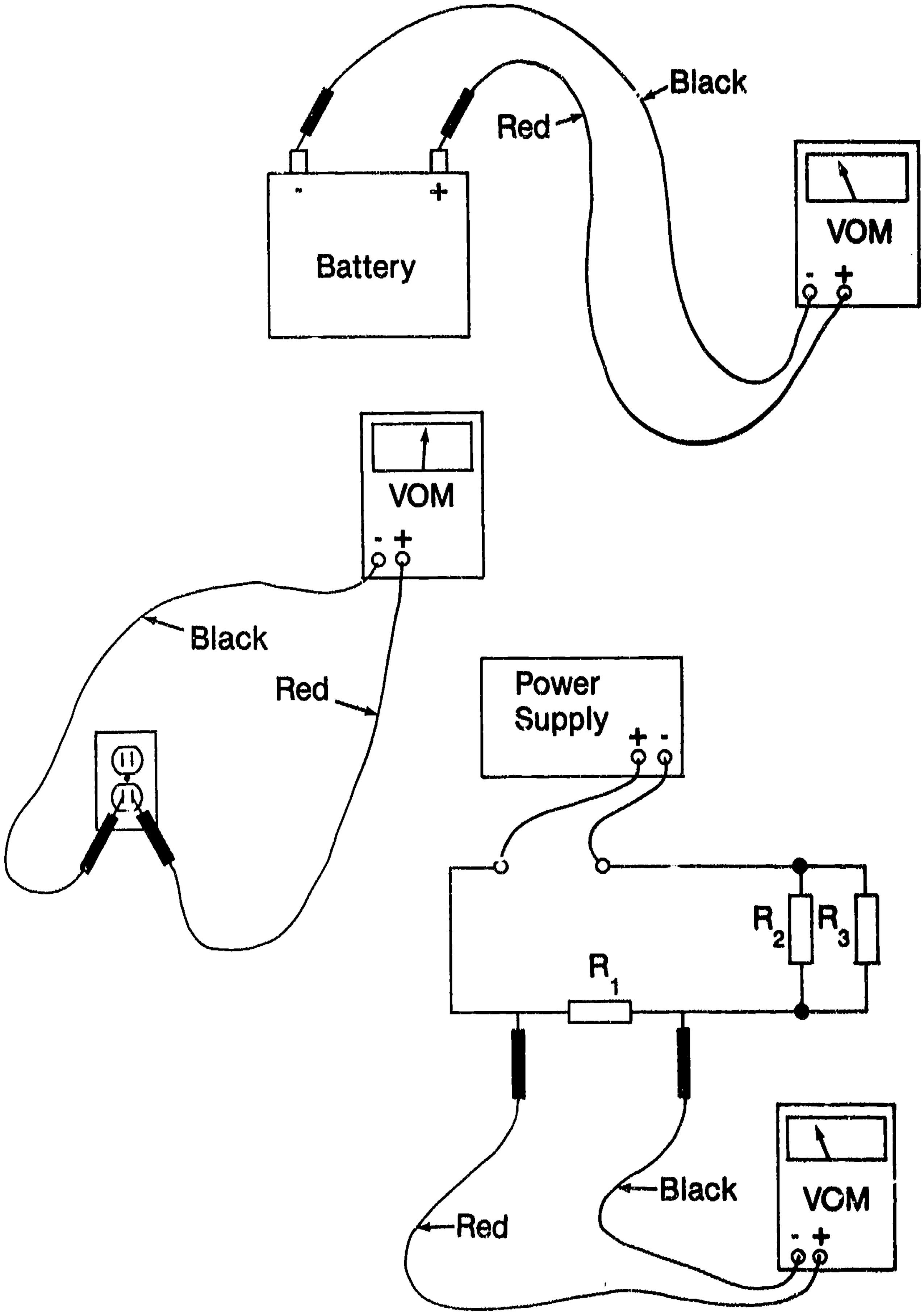


Measuring Amperage in Parallel Circuits

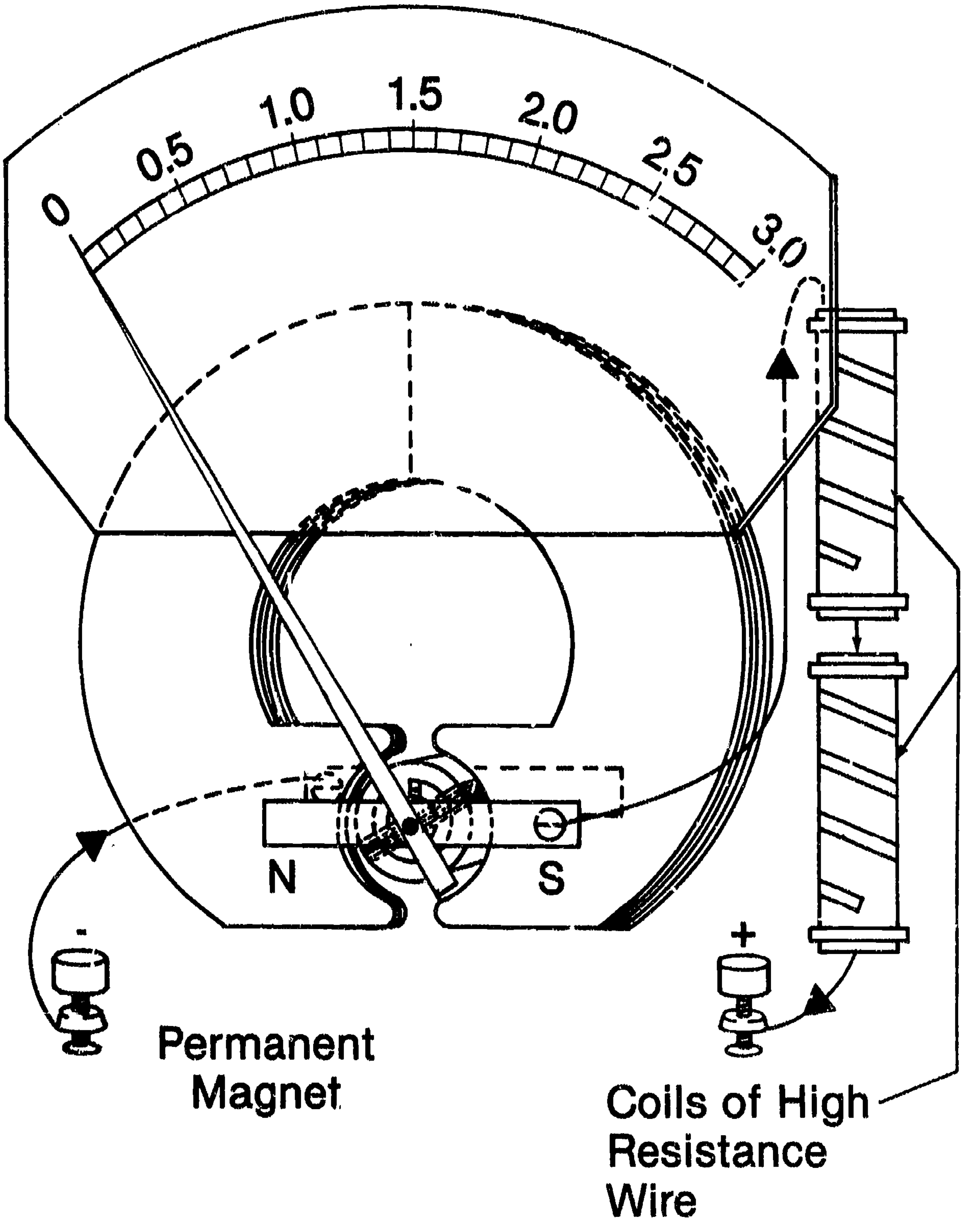
DC Ammeter



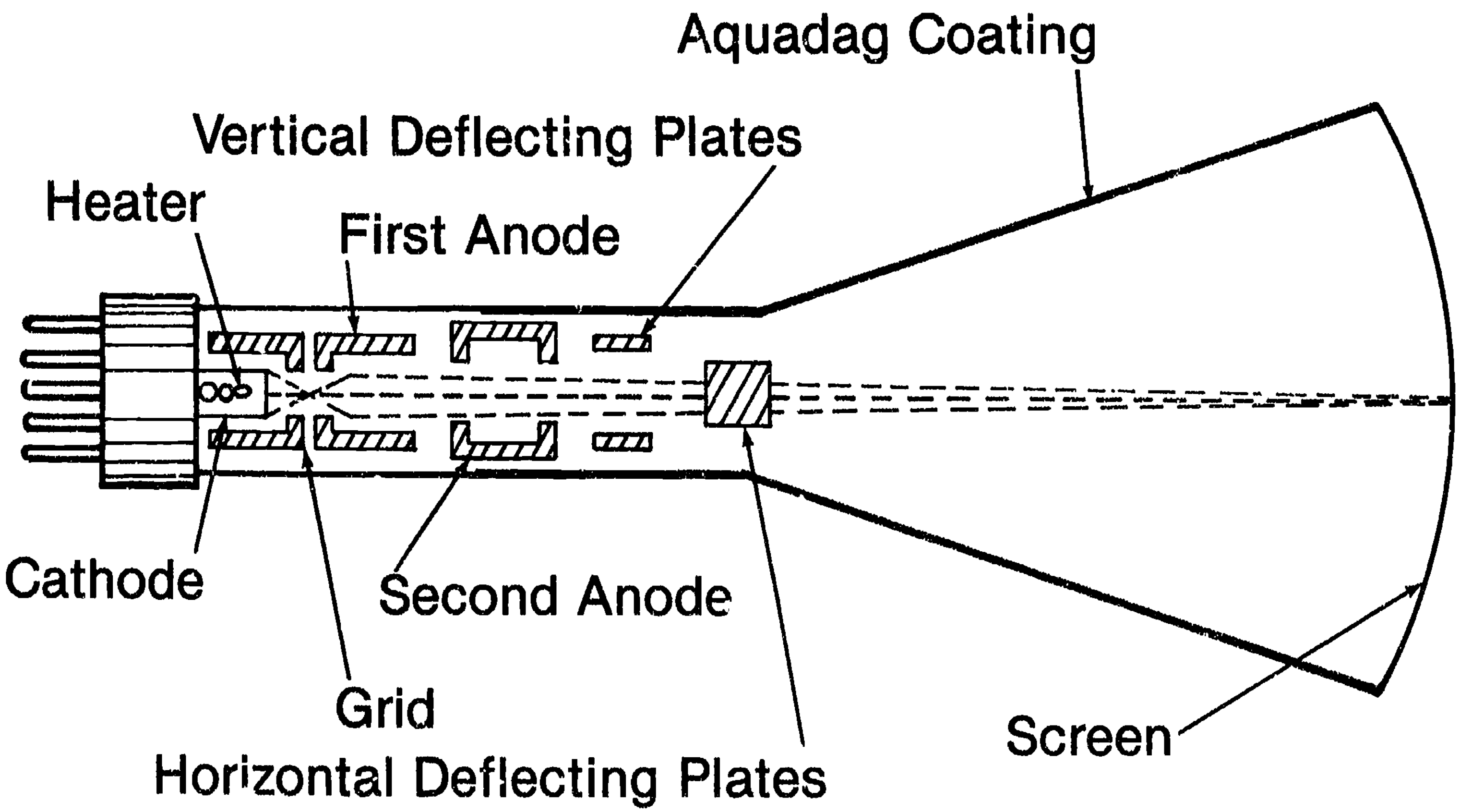
Correct Voltage Measurements



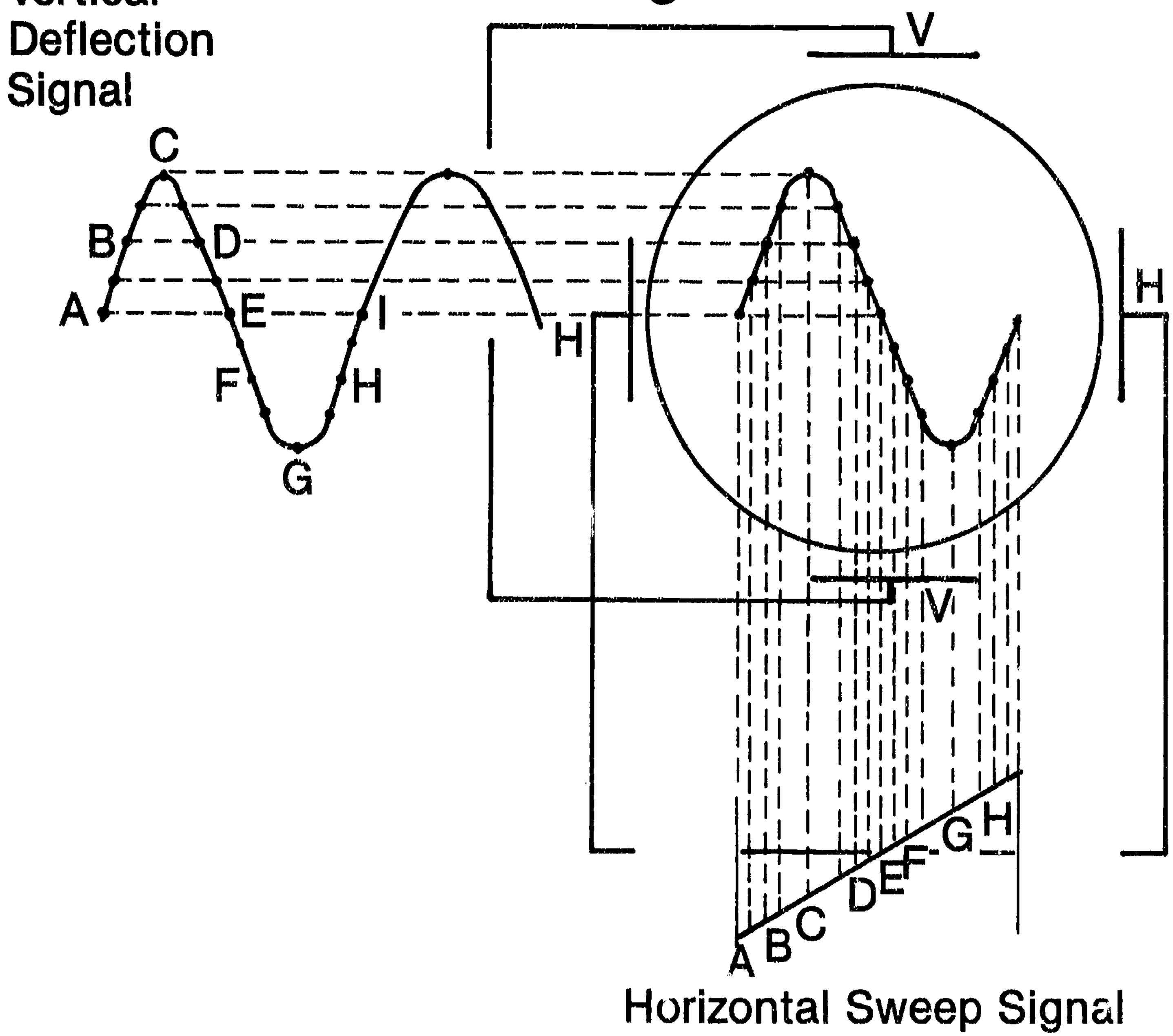
DC Voltmeter



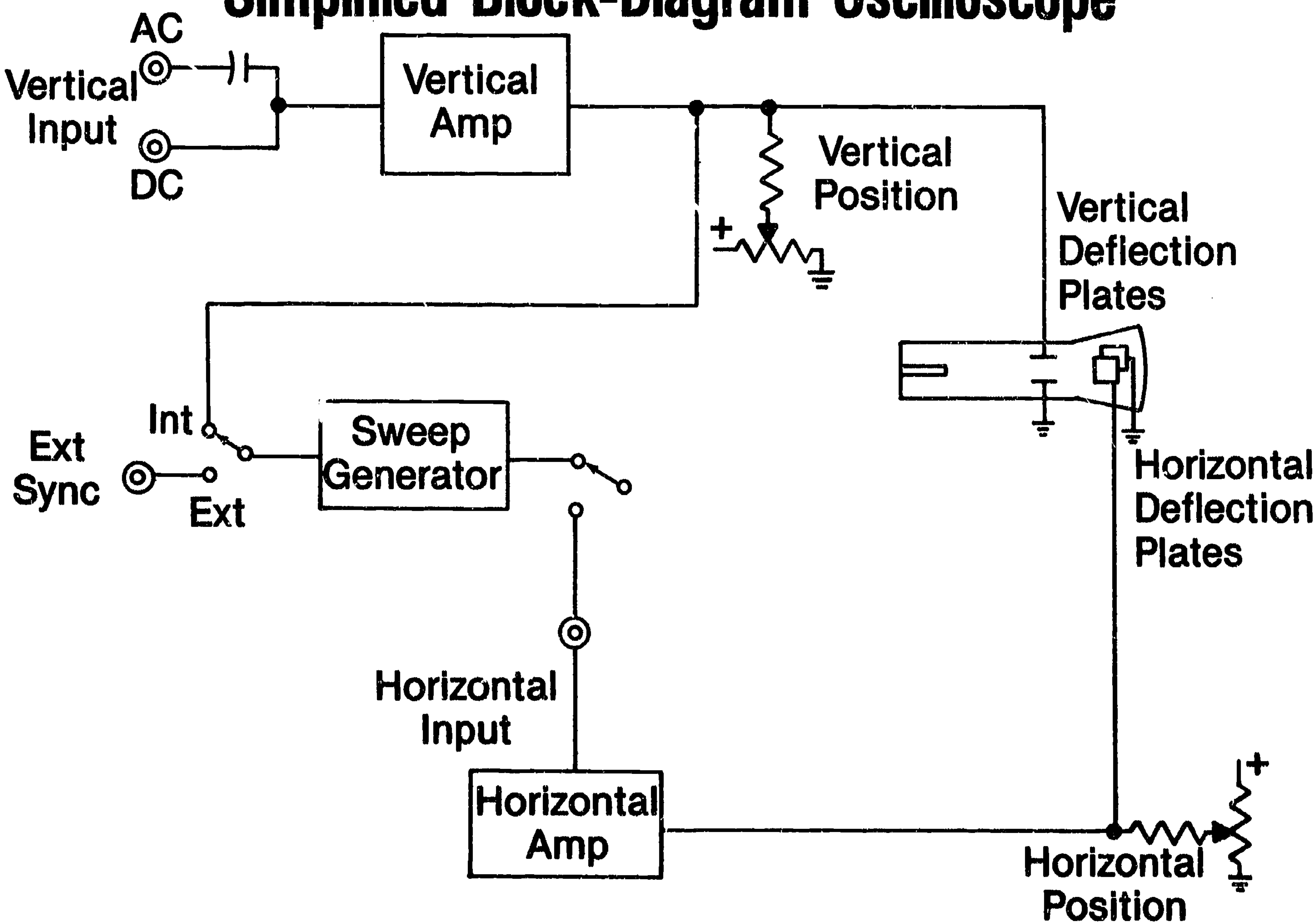
CRT
(With Electrostatic Deflection/Focusing)



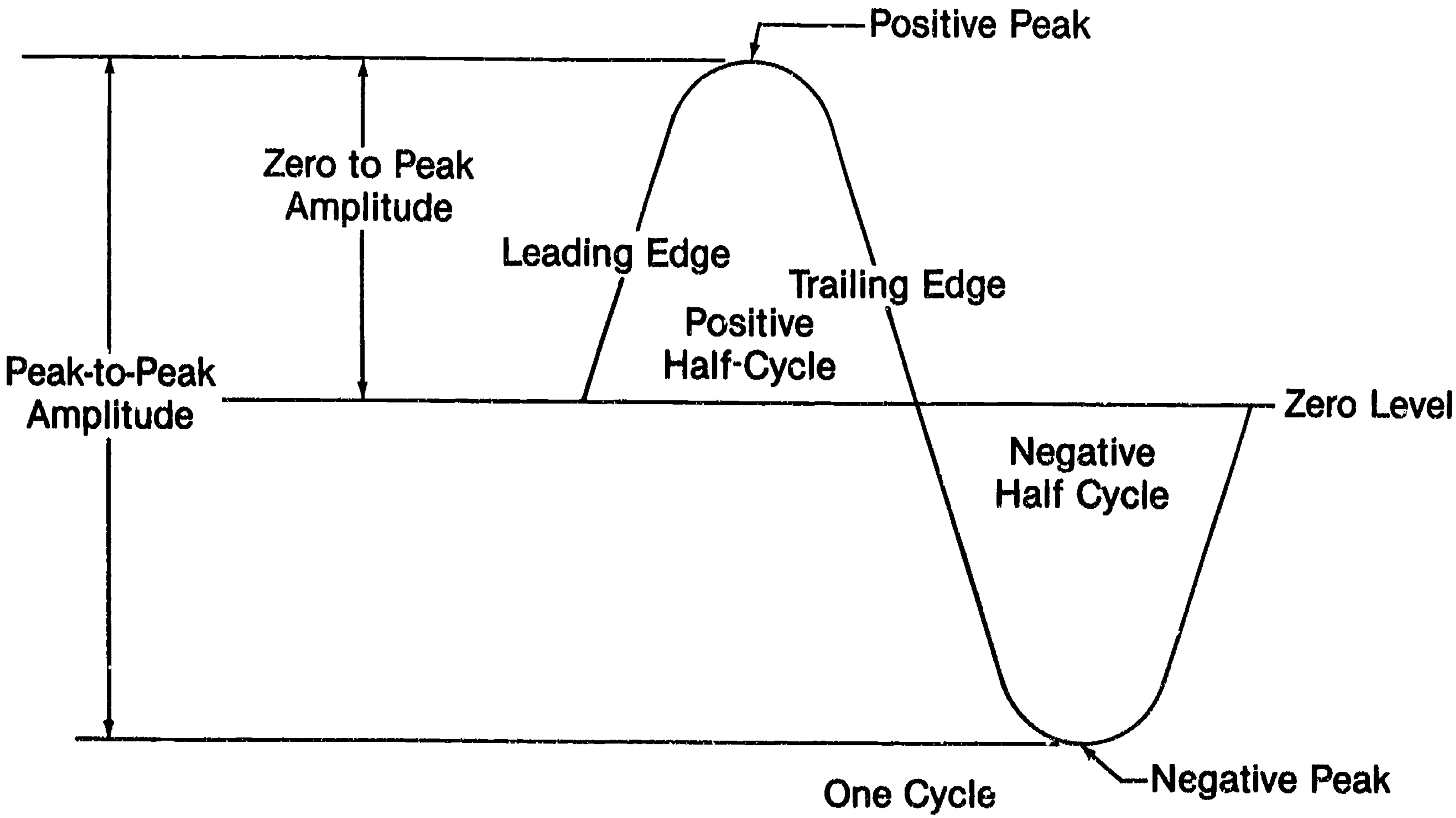
CRT Signal Trace



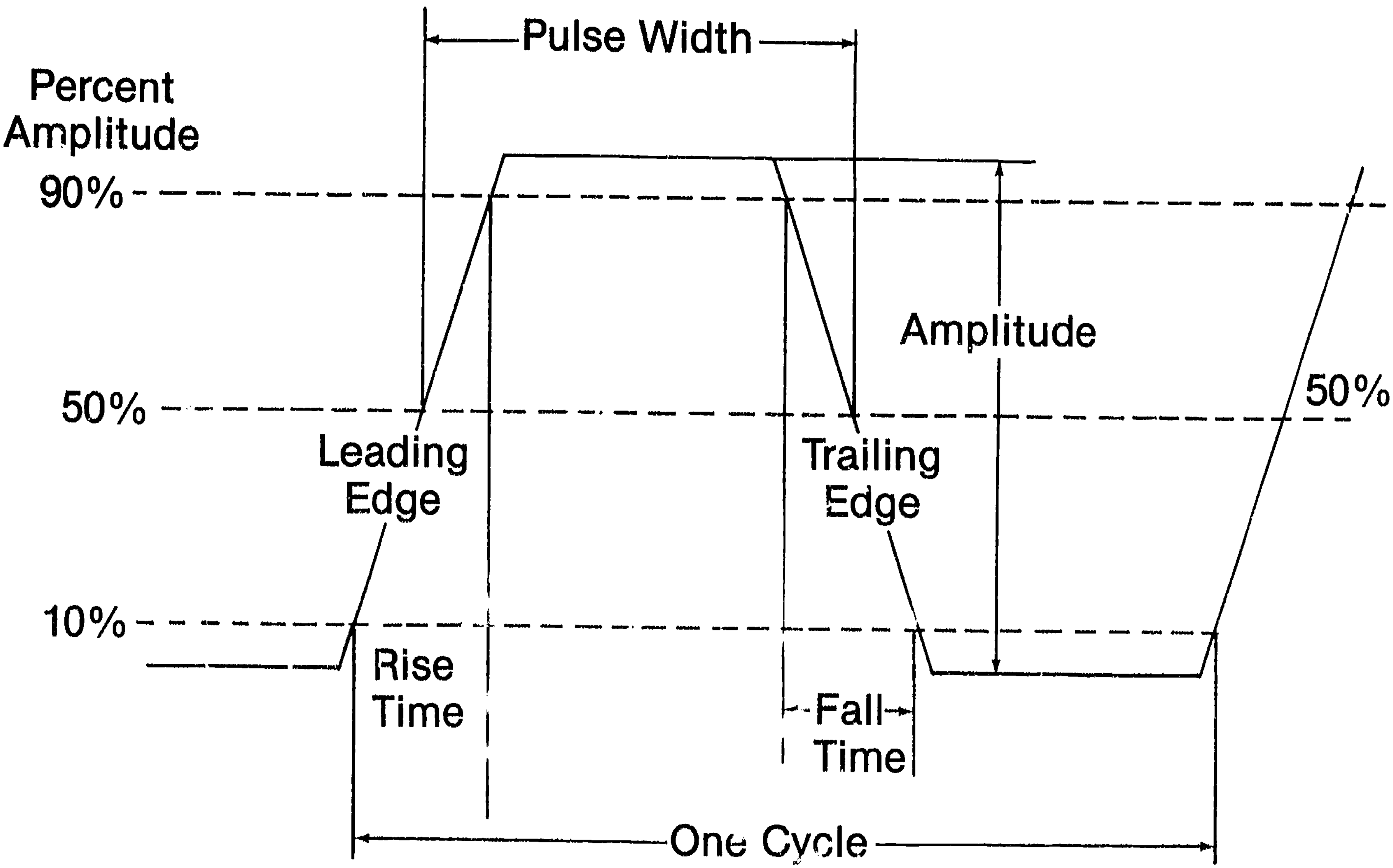
Simplified Block-Diagram Oscilloscope



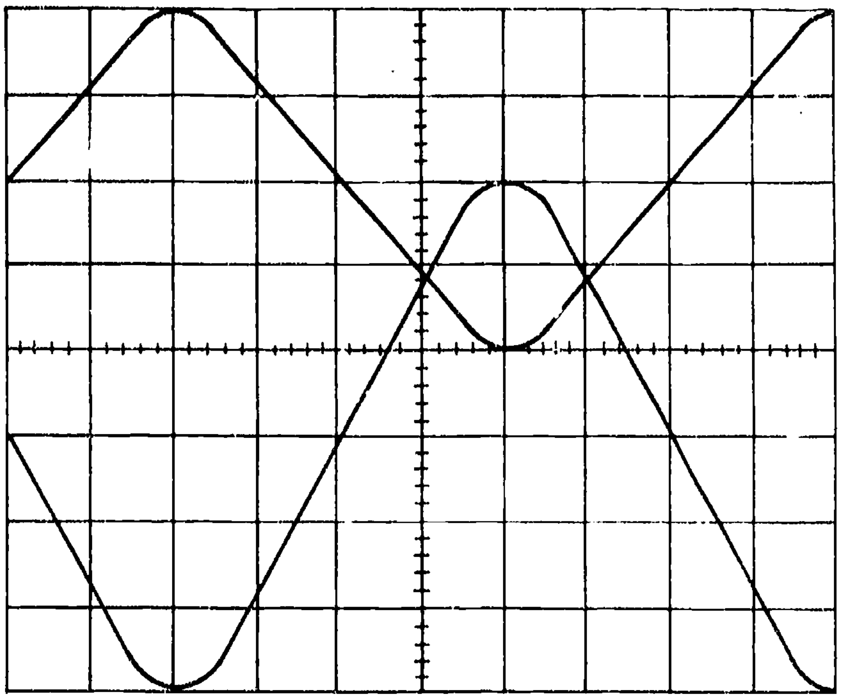
Peak-to-Peak and Peak Voltages of an AC Waveform



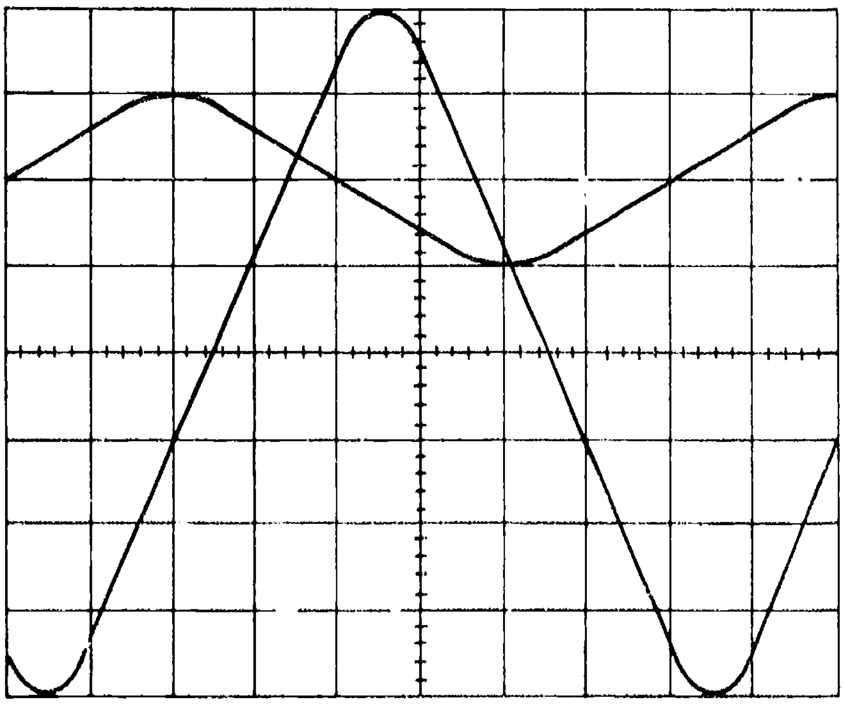
Pulse Width, Rise and Fall Time and Amplitude of Rectangular Waveforms



Phase Relationships of AC Signals

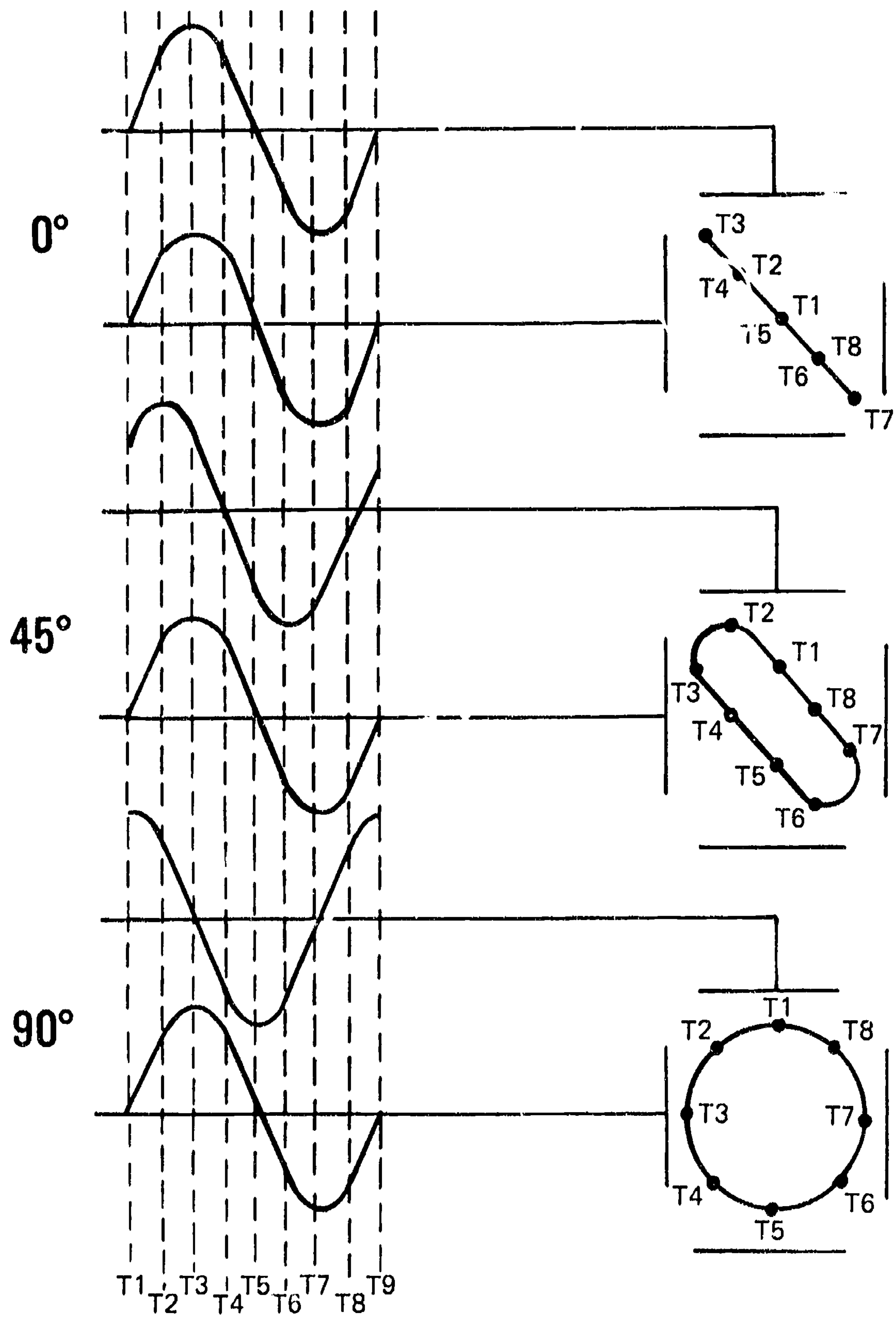


1 Cycle = 8 cm
1 cm = 45°
4 cm between Peaks
4 cm x 45° = 180°
or 180° Out of Phase

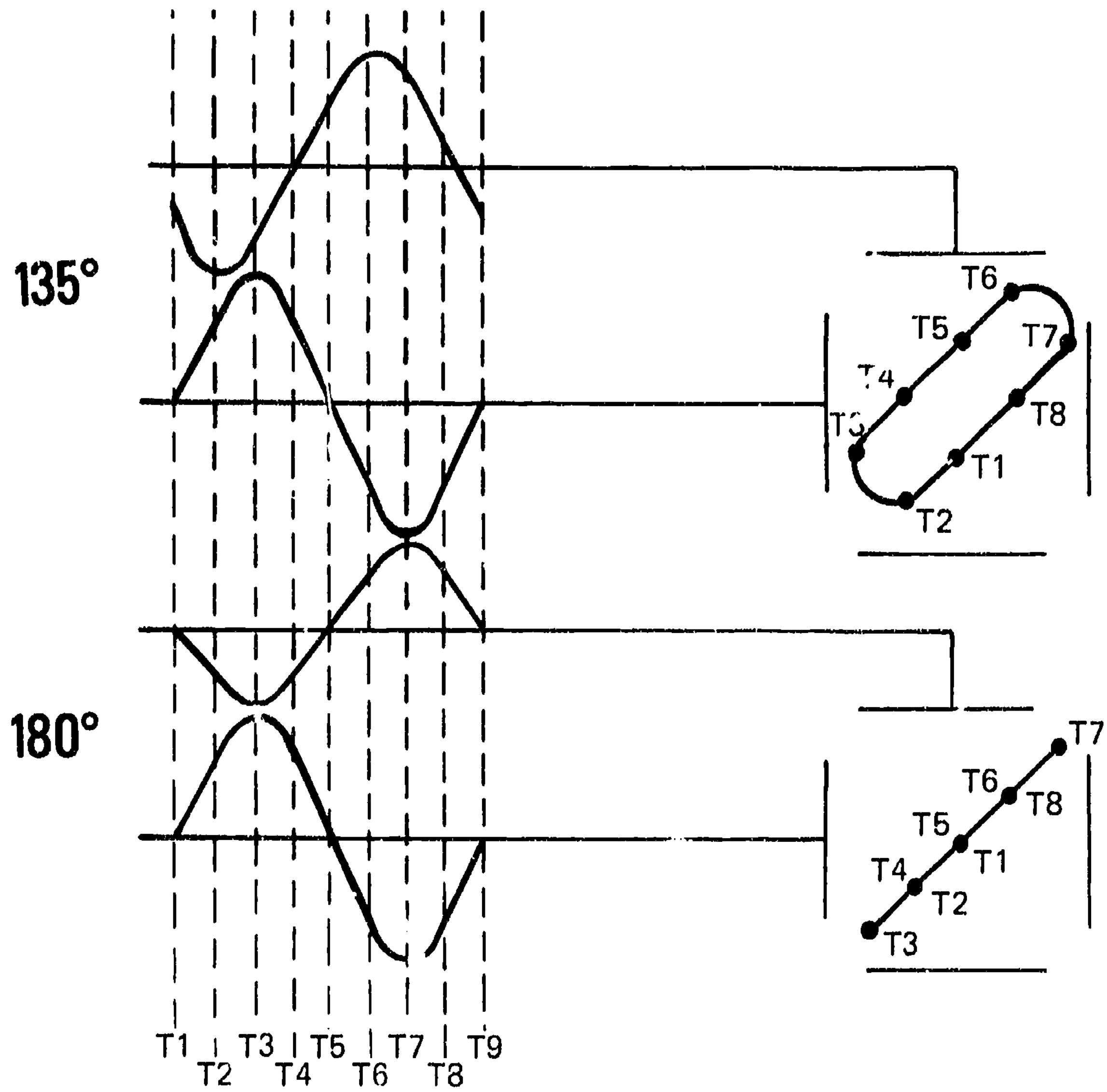


2.6 cm x 45° = 117°
or 117° Out of Phase

Lissajous Phase Patterns



Lissajous Phase Patterns
(Continued)



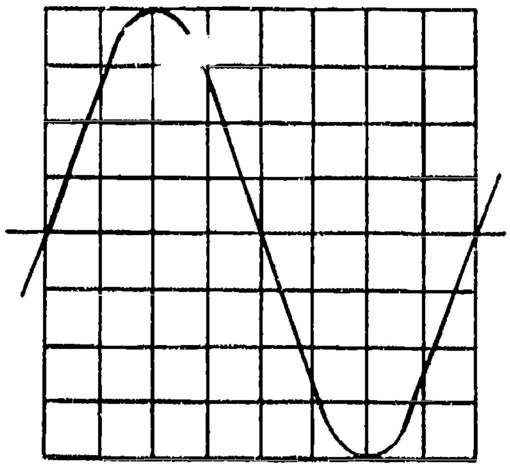
TEST EQUIPMENT
UNIT I

ASSIGNMENT SHEET #1 — CALCULATE EFFECTIVE OR ROOT-MEAN-SQUARE VOLTAGE FROM SINE WAVE DIMENSIONS

Calculate the effective or root-mean-square (rms) voltage for each waveform in the problems below. Write the correct answers in the blanks.

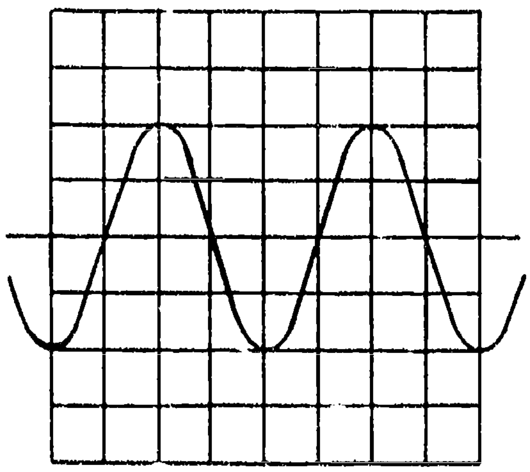
1. Volts/cm set a 2

   Probe is 10x = ______________________ volts, rms



2. Volts/cm set at .05

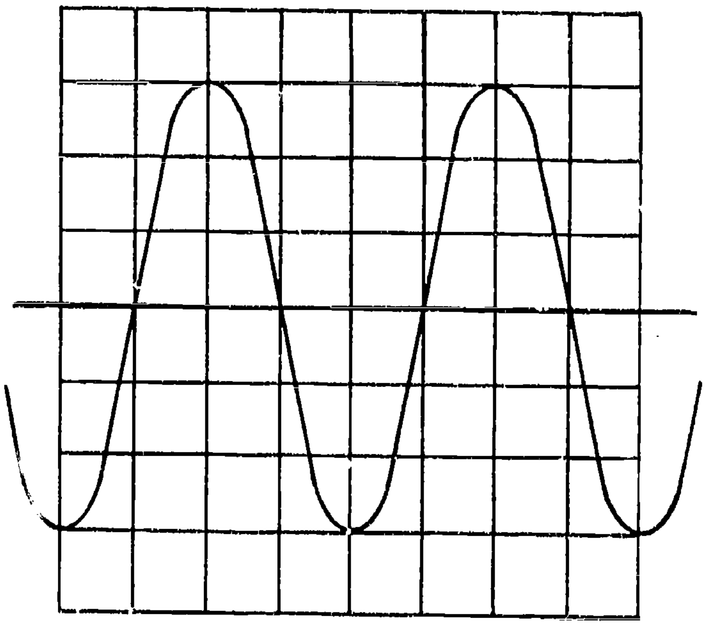
   Probe is 1x = ______________________ volts, rms



ASSIGNMENT SHEET #1

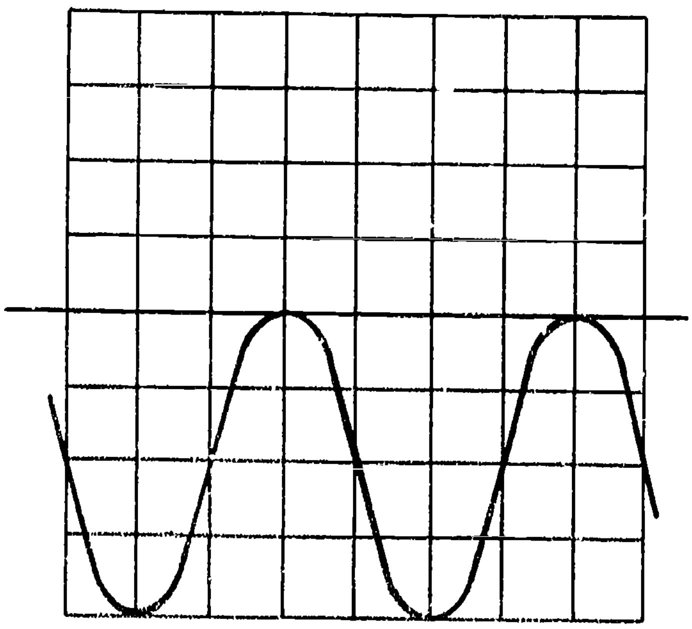
3. Volts/cm set at .5

Probe is 10x = ____________________ volts, rms



4. Volts/cm set at 20

Probe is 1x = ____________________ volts, rms



TEST EQUIPMENT
UNIT I

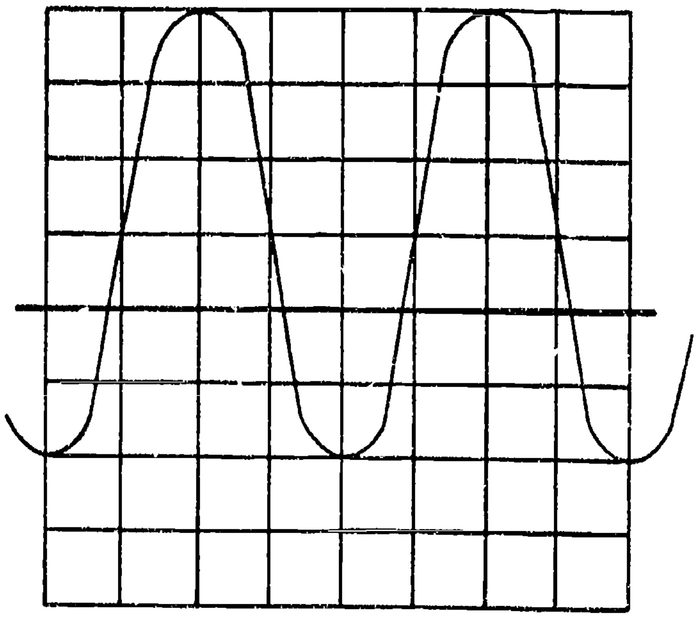
ASSIGNMENT SHEET #2 — CALCULATE TIME AND FREQUENCY FROM WAVEFORM DIMENSIONS

Calculate the time and frequency for each waveform in the problems below. Write the correct answers in the blanks.

1. Time/cm set at 2 μs/cm

   ______________________ s

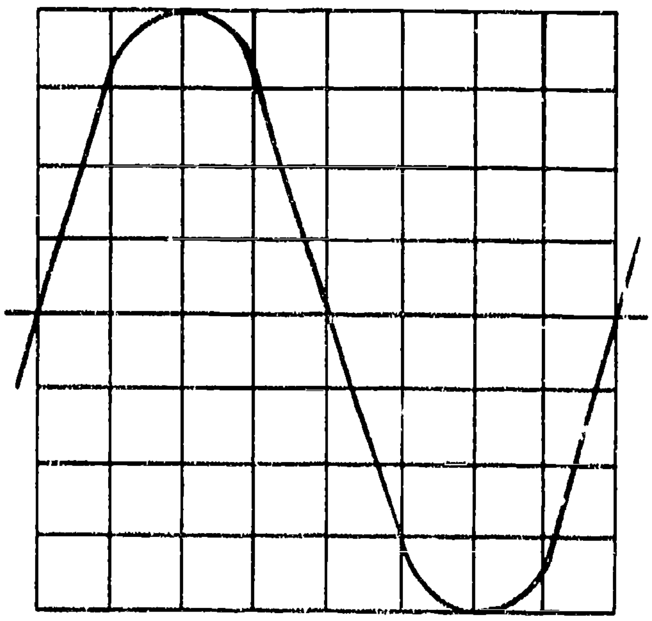
   ______________________ MHz



2. Time/cm set at 1 ms/cm

   ______________________ s

   ______________________ kHz

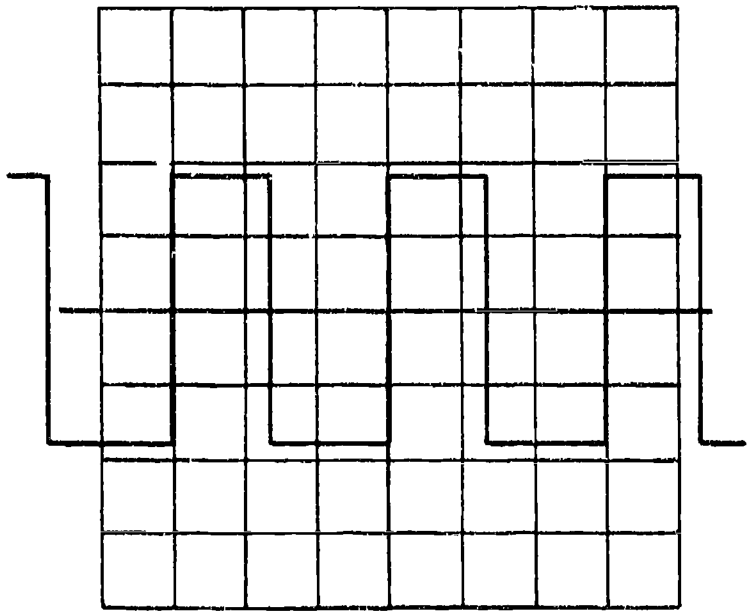


ASSIGNMENT SHEET #2

3. Time/cm set at 1 s/cm

____________________ s

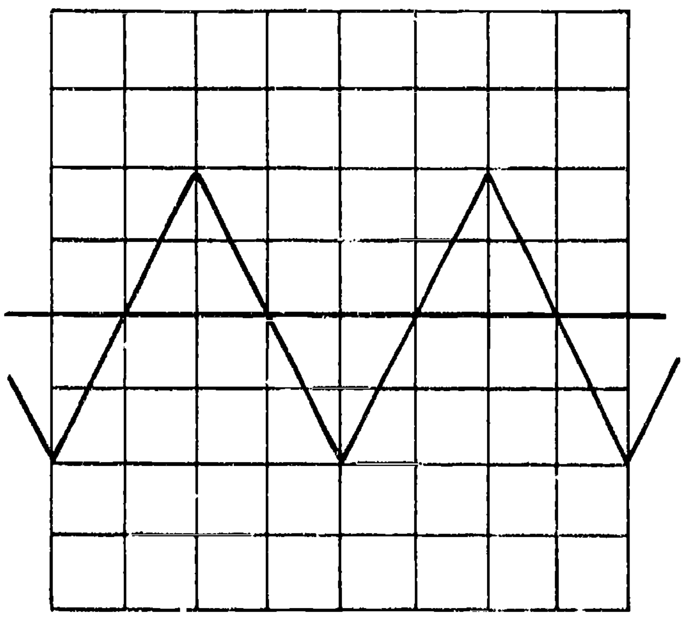
____________________ Hz



4. Time/cm set at .2 ms/cm

____________________ s

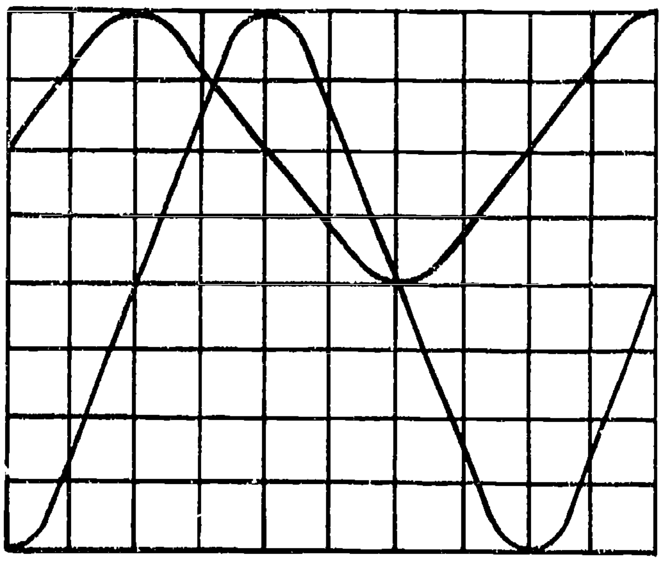
____________________ kHz



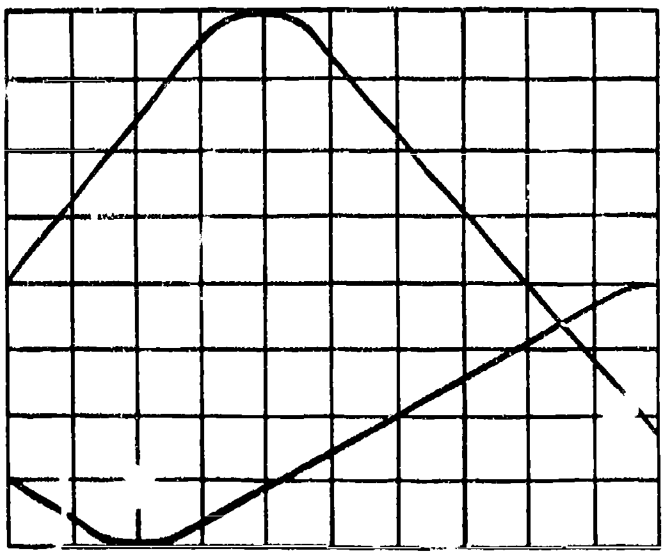
TEST EQUIPMENT
UNIT I

ASSIGNMENT SHEET #3 — DETERMINE PHASE RELATIONSHIPS OF AC SIGNALS

Calculate the phase relationships of the oscilloscope displays below. Write the correct answers in the blanks below each display.

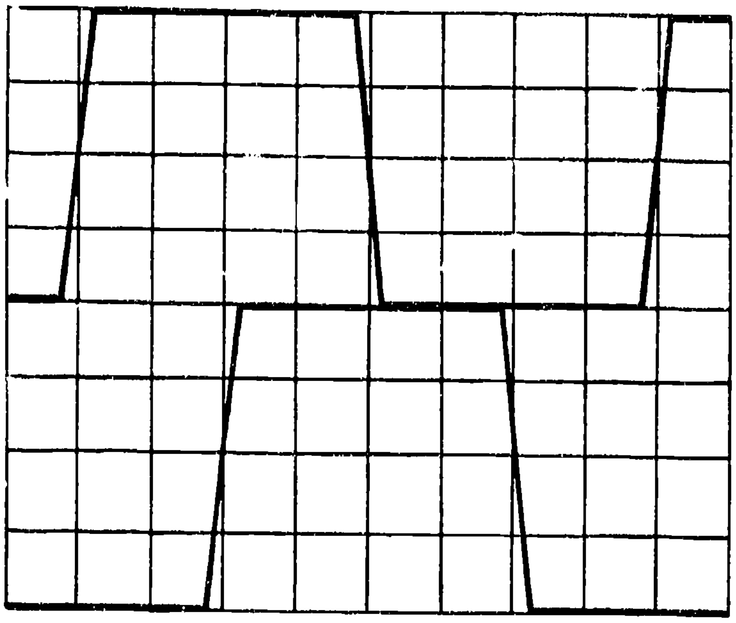


1. ________________________ degrees out of phase

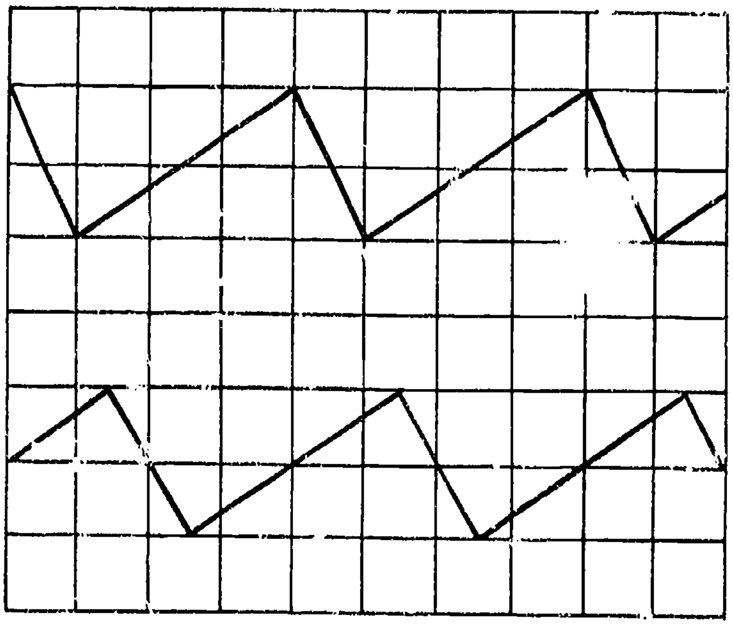


2. ________________________ degrees out of phase

ASSIGNMENT SHEET #3

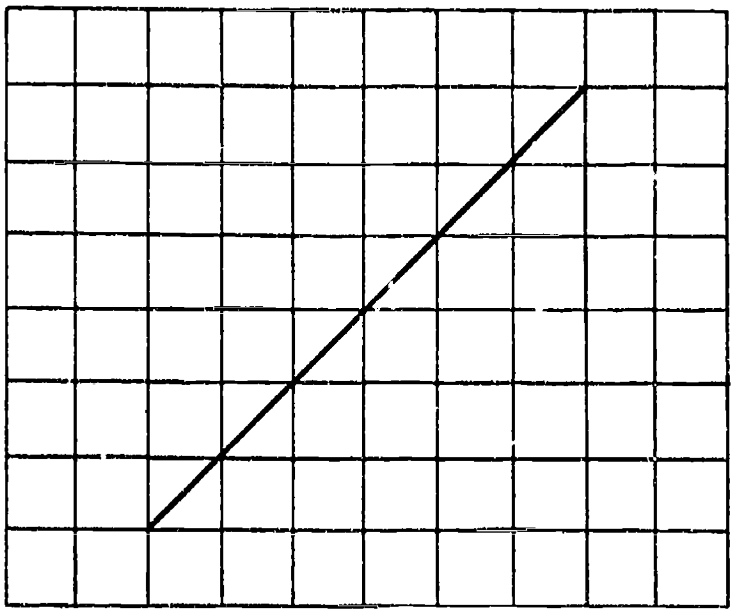


3. ________________________ degrees out of phase

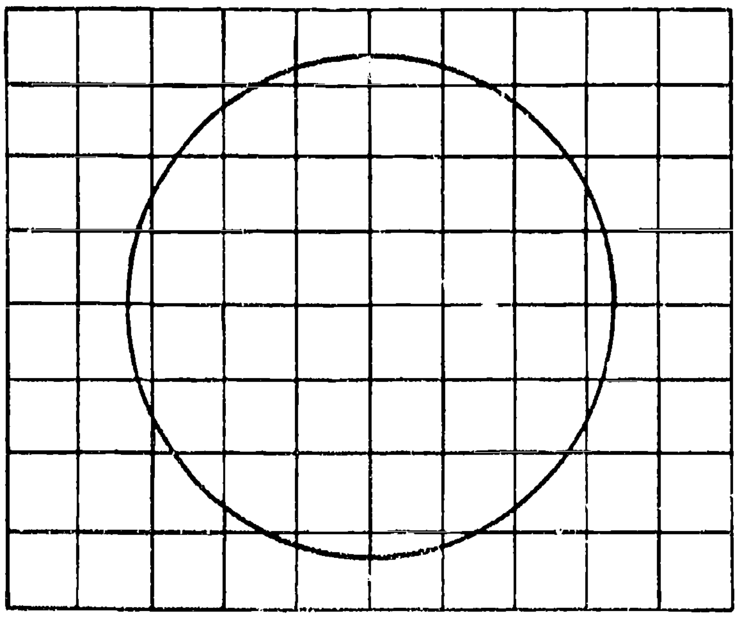


4. ________________________ degrees out of phase

ASSIGNMENT SHEET #3



5. ______________________ degrees out of phase



6. ______________________ degrees out of phase

TEST EQUIPMENT
UNIT I

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #1

1. 56.56 volts rms
2. .0707 volts rms
3. 10.605 volts rms
4. 28.28 volts rms

Assignment Sheet #2

1. 8μs; .125 MHz
2. 8ms; .125 KHz
3. 3s; .33 Hz
4. .8ms; 1.25 KHz

Assignment Sheet #3

1. 90°
2. 135°
3. 90°
4. 135°
5. 180°
6. 90°

TEST EQUIPMENT
UNIT I

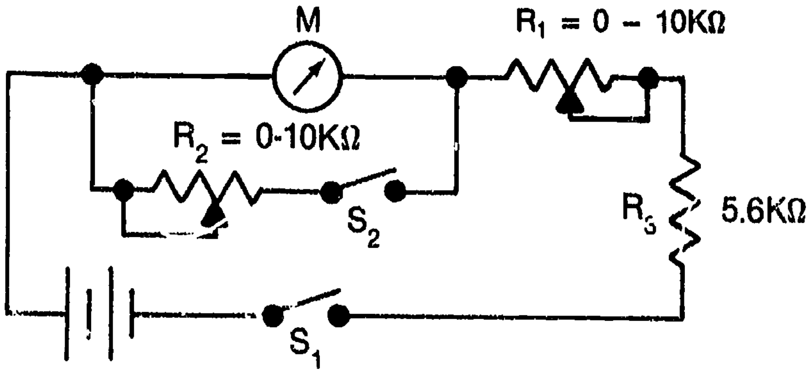
JOB SHEET #1 — DETERMINE THE RESISTANCE OF A METER MOVEMENT

A. Equipment and materials needed

1. Battery, 1.5 volt
2. 0-1 milliameter movement
3. 2-10 kilohm potentiometer
4. Ohmmeter
5. Resistance decade box

B. Procedure

1. Connect the meter circuit below.



2. With switches open, set V at 10 volts and R_1 at maximum resistance.
3. Close S_1 and decrease R_1 until the meter reads full-scale.
4. Close S_2 and adjust R_2 until the meter reads half-scale deflection.
5. Turn off the power supply and measure the value of R_2 (this is equal to the resistance of the meter).
6. Record meter resistance. Rm = ____________
7. Dismantle the circuit and return equipment and materials to their proper storage location.

TEST EQUIPMENT
UNIT I

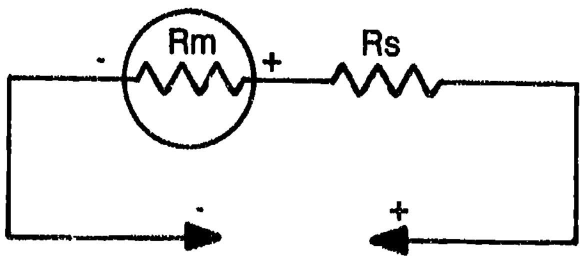
JOB SHEET #2 — CONSTRUCT AND ANALYZE A VOLTMETER

A. Equipment and materials needed

1. 0-1 milliameter movement
2. Voltmeter
3. Resistance decade box (or potentiometer)
4. Two 100 K Ω resistors

B. Procedure

1. Using the formula $Rs = \frac{Vrange}{Im} - Rm$, calculate the multiplier required to convert your meter movement into a 10-volt meter (Rs equals the multiplier, Im = full-scale current, and Rm = resistance of meter movement).
2. Using your calculated value for Rs, construct the voltmeter circuit below (use decade box for Rs).

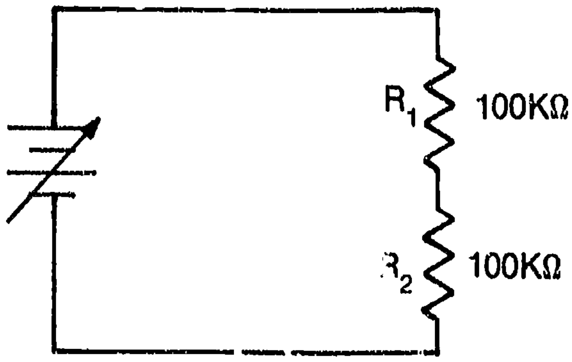


3. Adjust your power supply to 10 volts and apply to your meter circuit (this should cause full-scale deflection of your meter movement).
4. Repeat the preceding steps to convert your meter circuit to read thirty volts full scale.

   What is the value of your multiplier resistor? ____________

JOB SHEET #2

5. Retain your voltmeter circuit and construct an additional circuit like the one below.



6. Apply twenty volts to the circuit.

7. Use an electronic voltmeter to measure and record the voltage across R_1 ______________

8. Now use your experimental voltmeter circuit to measure and record the voltage across R_1 ______________

   Was there any difference in the value of voltage across R_1 when measured with the EVM and your experimental voltmeter circuit?

   ____

   ____

   ____

   Explain what caused this difference to occur.

   ____

   ____

   ____

   ____

9. Dismantle the circuit and return equipment and material to their proper storage location.

TEST EQUIPMENT
UNIT I

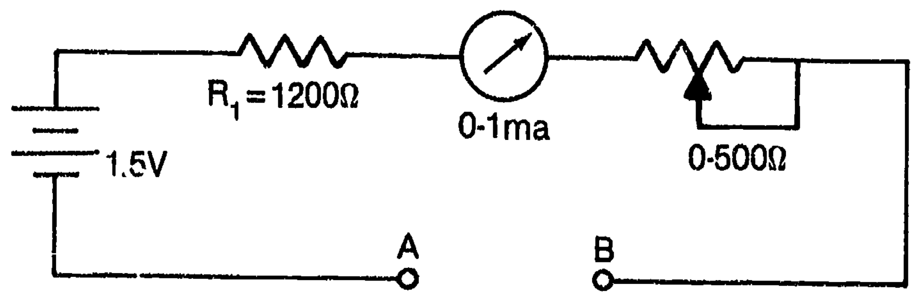
JOB SHEET #3 — CONSTRUCT AND ANALYZE A SIMPLE OHMMETER

A. Equipment and materials needed

1. Battery 1.5 volt
2. 0-1 milliameter movement
3. 500 ohm potentiometer
4. Electronic voltmeter
5. Resistance decade box

B. Procedure

1. Connect the series ohmmeter circuit.



2. Short terminal A to B and adjust the potentiometer R1 for full-scale deflection of the meter pointer (zero adjust).

   (NOTE: This procedure is equivalent to that of the zero ohms adjustment on a commercial ohmmeter. The adjustment compensates for battery voltage deterioration.)

3. Label this position on the meter scale at zero ohms.

4. Measure and record the battery voltage while terminal A and B are shorted.

   Battery voltage ____________

5. Remove the short from between terminals A and B

   (NOTE: If the terminals are left shorted, you will deplete the energy of the battery.)

6. Label this position as infinity on the meter scale.

JOB SHEET #3

7. Calculate the total resistance of the meter circuit which gives full-scale deflection.

   $Rt = \frac{V}{Im}$

   V = Your measured battery voltage

   Im = 1ma (the full-scale I rating of the meter movement)

8. Connect a decade resistance box between terminals A and B and adjust for 50 percent deflection on the meter scale.

9. Determine and record the resistance of the decade box, and label the scale with this value at the 50 percent deflection point

   Resistance A to B at 50% deflection ____________

10. Repeat steps eight and nine for 25 percent and 75 percent deflection of the meter

    (NOTE: You may wish to repeat this procedure a number of times for additional scale readings.)

    Resistance A to B at 75% deflection ____________

    Resistance A to B at 25% deflection ____________

    How could you modify the meter circuit to obtain a center scale reading of fifty ohms?

    ____

    ____

11. Dismantle the circuit and return parts and equipment and materials to their proper storage location.

TEST EQUIPMENT
UNIT I

JOB SHEET #4 — CONSTRUCT AND ANALYZE AN AMMETER

A. Equipment and materials needed

1. 0-1 milliameter movement
2. Electronic voltmeter
3. Resistance decade box (or potentiometer)
4. Two 100 K Ω resistors

B. Procedure

(NOTE: To increase the range of an ammeter, the shunt resistance must carry the additional current that is beyond the basic meter movement's capability.)

1. Using the formula $Rsh = Rm \times \frac{Im}{It - Im}$ calculate the shunt resistance required to convert your meter movement into a 0-10 ma meter.

   (Rsh equals the shunt, It = total current, m = meter current and Rm = resistance of meter movement)

2. Draw a 0-10 ma meter circuit using your experimental meter and calculated value for the shunt resistance.

3. Apply power to your circuit.

   Does your ammeter circuit perform as expected? Describe its performance.

   ___

   ___

   Explain how you could add an additional range to the meter circuit to read current in the 0-50 ma range.

   ___

   ___

4. Return equipment and materials to their proper storage location.

TEST EQUIPMENT
UNIT I

JOB SHEET #5 — ADJUST OSCILLOSCOPE CONTROLS FOR A STABLE WAVEFORM DISPLAY

A. Equipment and materials needed

1. Oscilloscope
2. Signal generator
3. Test leads

B. Procedure

1. Set up oscilloscope for operation.

   (NOTE: Consult the operating manual.)

2. Turn on signal generator.
3. Connect signal generator to oscilloscope.
4. Adjust the volts/cm so that the peak-to-peak amplitude is visible on screen.
5. Set trigger control to internal position; select channel that has the signal generator as an input.
6. Adjust trigger level and slope controls until waveform is stable.
7. Set sweep time/cm so that waveform is only a few cycles in length.
8. Readjust all controls to obtain the clearest and most stable trace possible.

   (NOTE: Ask instructor to check your resulting waveform.)

9. Turn off oscilloscope and signal generator.
10. Return equipment and materials to their proper storage location.

TEST EQUIPMENT
UNIT I

JOB SHEET #6 — MEASURE FREQUENCY USING AN OSCILLOSCOPE

A. Equipment and materials needed

1. Oscilloscope

2. Signal generator

3. Test leads

B. Procedure

1. Set up the oscilloscope and signal generator for operation.

2. Connect signal generator to oscilloscope.

3. Adjust oscilloscope for a stable waveform.

4. Determine the time of the sine wave.

5. Record your reading.

   Sine wave time = ______________

6. Calculate frequency of sine wave.

7. Record the frequency.

   Frequency = ______________

   (NOTE: Check your answer with the instructor.)

8. Turn off oscilloscope and signal generator.

9. Return equipment and materials to their proper storage location.

TEST EQUIPMENT
UNIT I

JOB SHEET #7 — MEASURE AC VOLTAGE USING AN OSCILLOSCOPE

A. Equipment and materials needed

1. Oscilloscope
2. Signal generator
3. Test leads

B. Procedure

1. Set up oscilloscope and signal generator for operation.
2. Connect signal generator to oscilloscope.
3. Adjust oscilloscope for a stable waveform.
4. Measure voltages.
5. Record the voltages.

   Voltage = ______________________________ peak-to-peak

   Voltage = ______________________________ rms

   (NOTE: Check your answers with the instructor.)

6. Turn off oscilloscope and signal generator.
7. Return equipment and materials to their proper storage location.

TEST EQUIPMENT
UNIT I

JOB SHEET #8 — MEASURE DC VOLTAGE USING AN OSCILLOSCOPE

A. Equipment and materials needed

1. Dual-trace oscilloscope
2. DC power supply
3. Test leads

B. Procedure

1. Set up oscilloscope and power supply for operation.
2. Connect power supply to oscilloscope.
3. Adjust oscilloscope to measure DC voltage.
4. Measure voltage.
5. Record your results.

   Voltage = ______________________________

   (NOTE: Check your answer with the instructor.)
6. Turn off oscilloscope and power supply.
7. Return equipment and materials to their proper storage location.

TEST EQUIPMENT
UNIT I

JOB SHEET #9 — CALIBRATE AN OSCILLOSCOPE PROBE

A. Equipment and materials needed

1. Oscilloscope

2. Oscilloscope probe

B. Procedure

1. Set up oscilloscope for operation.

2. Connect oscilloscope probe to oscilloscope input.

3. Connect probe to calibration jack on oscilloscope.

4. Adjust oscilloscope for stable square wave display on cathode-ray tube.

5. Check square wave signal for distortion in signal.

6. Adjust oscilloscope probe for no distortion in displayed signal.

   (NOTE: If the square wave signal has no distortion, vary adjustment watching for distortion. If distortion cannot be eliminated, notify instructor. Have instructor check you work.)

7. Return equipment and materials to their proper storage location.

TEST EQUIPMENT
UNIT I

NAME ____________________

TEST

1. Match the terms on the right with their correct definitions.

_____a.	How near the instrument reading is to the actual value	1.	Frequency
_____b.	How well an instrument or circuit responds to small values of voltage	2.	Flourescence
_____c.	Techniques of adjusting an instrument by referencing it to another instrument or standard of known accuracy and precision	3.	Persistence
_____d.	A circuit that is in parallel with another and typically used to extend the range of an ammeter	4.	Phosphorescence
_____e.	Cathode ray tube used in oscilloscope	5.	Cycle
_____f.	The term commonly used to refer to the face of a CRT	6.	Accuracy
_____g.	The visible form on the screen of a CRT	7.	Screen
_____h.	Grid lines on the screen of a CRT	8.	Aquadag
_____i.	Emission of light during electron bombardment	9.	Sensitivity
_____j.	Emission of light after bombardment of electrons has stopped	10.	Calibration
_____k.	Length of time the phosphor on a CRT continues to glow after electron bombardment ceases	11.	Shunt
_____l.	Basic unit of frequency	12.	CRT
_____m.	Time for one complete cycle to occur	13.	Trace
_____n.	A colloidal suspension of graphite deposited on the inner side walls of cathode-ray tubes to serve as an electrostatic shield or an accelerating anode	14.	Period
_____o.	Number of cycles per second measured in hertz (Hz)	15.	Hertz
_____p.	Events occurring in sequence, i.e. one complete reversal of an alternating current from negative to positive and back to the starting point	16.	Graticule

TEST

2. Match the types of test equipment on the right with their correct functions.

_____a.	Are available in analog (VOM's) and digital (DVOM's) types and are used to measure voltage, current, and resistance	1. Multimeters
_____b.	Provide a voltage source with multiple outputs, typically sine wave, square wave, and sawtooth waveforms	2. Power supplies
_____c.	Provide a sine wave voltage output within the audio signal spectrum	3. Audio signal generators
_____d.	Provide a controlled source of AC and/or DC power for use on the test bench for equipment or test and experimental circuits	4. Inductance bridge
_____e.	Are used to identify logic levels in digital circuits	5. Capacitance bridge
_____f.	Provides short pulses for injecting signals into digital circuits	6. Isolation transformer
_____g.	A device that fits over an IC chip and identifies logic levels at each pin of the IC	7. Transistor tester
_____h.	Is used to measure precision values of resistance	8. Logic clip
_____i.	An instrument to measure values of inductance	9. Logic probes
_____j.	Used to measure values of capacitance	10. Function generators
_____k.	A combination bridge used to measure resistance, capacitance, and inductance	11. Resistance bridge
_____l.	Used to determine the condition of transistors and diodes	12. Impedance bridge
_____m.	Provides a source of AC through transformer action which has no direct physical connection to the power line and therefore provides an "isolated" source of electrical energy	13. Logic pulsers

TEST

3. Complete the following statements related to the types of meters and their characteristics by inserting the word(s) that best completes each statement.

   a. A __________ is a relatively inexpensive portable, multifunction analog meter used to measure voltage, resistance, and current.

   b. Analog __________ voltmeters (EVM) are meters which use electronic components within the meter circuitry, use a calibrated analog scale as the readout, and need a power supply to operate, and are multifunction instruments like the VOM.

   c. A __________ uses vacuum tubes within the meter circuitry, absorbs very little energy from the circuit being tested, needs a power supply or batteries to operate and has a high degree of accuracy.

   d. A __________ uses transistors in the meter circuitry, requires a power supply, absorbs little energy from the circuit being tested, uses an analog scale, and has a high degree of accuracy.

   e. __________ meters are multifunction instruments, have a digital display as the readout device, have electronic circuitry like the EVM's, are useful for making precise measurements, and are usually the meter of preference for use in testing modern electronic circuits.

   f. AC meters are constructed so as to give an up-scale reading regardless of __________ of the voltage or current applied and are of primarily three different types.

   g. The thermal type AC meter uses the __________ effect of current, which is independent of polarity, to provide deflection on a meter scale.

   h. The __________ type of AC meter maintains a constant relative magnetic polarity although the current may reverse.

   i. The __________ type AC meter converts the AC to a DC output to the meter movement — usually a D'Arsonval movement.

4. Name six types of analog meter movements.

   a. ______________________________

   b. ______________________________

   c. ______________________________

   d. ______________________________

   e. ______________________________

   f. ______________________________

TEST

5. Complete the following statements related to the characteristics of an ammeter by inserting the word(s) that best completes each statement.

   a. Ammeters are connected in __________ with the circuit under test when making current measurements.

   b. The full-scale range of the ammeter may be extended using a __________ resistor which is a resistor connected in parallel with the meter movement.

   c. The __________ of the ammeter is the amount of current required to cause full-scale deflection of the pointer.

6. Select true statements related to the characteristics of a voltmeter by placing an "X" in the blanks preceding the true statements.

   _____a. Measurements using a voltmeter are obtained by placing the voltmeter leads vertical with the circuit component or source across which the voltage is to be determined.

   _____b. Polarity must be observed when making voltage measurements.

   _____c. Basic meter movements may be used to measure both voltage and current and each has its full-scale voltage rating as well as full-scale current rating.

   _____d. The voltage range of the basic meter movement may be decreased by adding a multiplier resistor which is a resistor in series with the meter movement.

   _____e. A typical voltmeter has a number of multipliers hooked to a switch giving the capability of a number of voltage ranges.

   _____f. The multiplier of a voltmeter is the reciprocal of the full-scale current rating of the meter and is expressed in ohms-per-volt.

   _____g. Since a voltmeter is placed in parallel to take measurements, the resistance of the meter changes the total resistance of the test circuit and therefore the meter resistance should be very low to minimize the circuit loading effect of the parallel connection.

7. Complete the following statements related to the characteristics of an ohmmeter by inserting the word(s) that best completes each statement.

   a. An __________ utilizes a basic meter movement, a series resistance, and a battery.

   b. The purpose of the __________ in an ohmmeter is to force a current through an unknown resistance.

   c. A multi-range ohmmeter uses a combination of series multiplier resistors and parallel shunt resistors to obtain different resistance __________.

   d. __________ resistors are used when the meter movement is acting as a voltmeter connected in parallel with a precision standard resistor.

TEST

8. Select true statements related to the characteristics of a digital meter by placing an "X" in the blanks preceding the true statements.

_____a. The A/D converter converts the input to a form that is usable by the analog to digital converter.

_____b. The signal processor takes the output from the processor and converts it to a digital number.

_____c. The control block determines the flow of information within the meter circuitry and transfers the information to the digital readout.

_____d. The digital readout may be any one of the many available types that provide the visible result of the meter's action.

_____e. Most digital meters are auto-ranging and have automatic polarity selection.

9. Match the oscilloscope controls on the right with their correct functions.

(NOTE: Answers to questions a.-j. appear on this page.)

_____a. Turns oscilloscope on and off

_____b. Illuminates the graticule on the CRT display

_____c. Adjusts image clarity and sharpness of the waveform presentation on the CRT display

_____d. Provides a calibration signal to adjust the oscilloscope for accurate measurements

_____e. Adjusts image brightness of the displayed waveform

_____f. Selects which channel will be displayed on the CRT display

_____g. Moves image to the right or left on the CRT display

_____h. Selects horizontal sweep rate which compresses or expands the displayed waveform

_____i. Provides for an external input to allow control of the horizontal sweep by an external signal

_____j. Selects the signal to initiate or trigger the sweep

1. Trigger source
2. Sweep time/cm
3. External horizontal input
4. Power switch
5. Scale illumination
6. Sweep mode
7. Focus
8. Intensity
9. Calibration
10. Horizontal position

TEST

(NOTE: Answers to questions k.-o. appear on this page.)

_____k.	Selects voltage level of the triggering waveform that initiates the sweep	11. External trigger
_____l.	Provides for the input of an external voltage to be used as the trigger to initiate the sweep	12. Channel A and Channel B input
_____m.	Provides for positioning of the image up or down on the CRT display	13. Vertical position
_____n.	Selects between DC or AC inputs	14. Coupling
_____o.	Provides for the connection of input voltages to each of two channels	15. Trigger level

10. Complete the following statements related to oscilloscope construction by inserting the word(s) that best completes each statement.

    a. The _____________ is the heart of the oscilloscope and provides the visual display of electronic signals.

    b. The _____________ provides a fine beam of high velocity electrons that bombard the phosphor screen of the CRT causing the phosphor to glow giving the visual presentation on the CRT.

    c. The electrostatic deflection plates control both the horizontal and vertical movement of the _____________ beam.

    d. The _____________ plates are driven by amplifiers which generally increase the input to cause a specific deflection of the electron beam.

    e. The horizontal amplifier has two inputs; one allows an external input to be displayed on the horizontal axis, the other is from the _____________ generator to produce the horizontal trace across the screen.

11. Name four measurements that may be taken with an oscilloscope.

    a. ____

    b. ____

    c. ____

    d. ____

TEST

(NOTE: If the following activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

12. Calculate effective or root-mean-square voltage from sine wave dimensions. (Assignment Sheet #1)

13. Calculate time and frequency from waveform dimensions. (Assignment Sheet #2)

14. Determine phase relationships of AC signals. (Assignment Sheet #3)

15. Demonstrate the ability to:

    a. Determine the resistance of a meter movement. (Job Sheet #1)

    b. Construct and analyze a voltmeter. (Job Sheet #2)

    c. Construct and analyze a single ohmmeter. (Job Sheet #3)

    d. Construct and analyze an ammeter. (Job Sheet #4)

    e. Adjust oscilloscope controls for a stable waveform display. (Job Sheet #5)

    f. Measure frequency using an oscilloscope. (Job Sheet #6)

    g. Measure AC voltage using an oscilloscope. (Job Sheet #7)

    h. Measure DC voltage using an oscilloscope. (Job Sheet #8)

    i. Calibrate an oscilloscope probe. (Job Sheet #9)

TEST EQUIPMENT
UNIT I

ANSWERS TO TEST

1. a. 6
   b. 9
   c. 10
   d. 11
   e. 12
   f. 7
   g. 13
   h. 16
   i. 2
   j. 4
   k. 3
   l. 15
   m. 14
   n. 8
   o. 1
   p. 5

2. a. 1
   b. 10
   c. 3
   d. 2
   e. 9
   f. 13
   g. 8
   h. 11
   i. 4
   j. 5
   k. 12
   l. 7
   m. 6

3. a. VOM
   b. Electronic
   c. VTVM
   d. TVM (or TRVM)
   e. Digital
   f. Polarity
   g. Heating
   h. Electromagnetic
   i. Rectifier

4. a. Moving coil or D'Arsonval
   b. Taut-band
   c. Electrodynamometer
   d. Iron vane
   e. Thermocouple
   f. Electrostatic

5. a. Series
   b. Shunt
   c. Sensitivity

6. b, c, e

7. a. Ohmmeter
   b. Battery
   c. Ranges
   d. Shunt

8. c, d, e

ANSWERS TO TEST

9.
- a. 4
- b. 5
- c. 7
- d. 9
- e. 8
- f. 6
- g. 10
- h. 2
- i. 3
- j. 1
- k. 15
- l. 11
- m. 13
- n. 14
- o. 12

10.
- a. Cathode-ray-tube (CRT)
- b. Electron gun
- c. Electron
- d. Deflection
- e. Sweep

11. Any four of the following:
- a. Time
- b. Phase
- c. Voltage
- d. Shape
- e. DC
- f. Pulse width
- g. Rise time
- h. Full time

12.-14. Evaluated to the satisfaction of the instructor

15. Performance skills evaluated to the satisfaction of the instructor

FUNDAMENTALS OF DC
UNIT II

UNIT OBJECTIVE

After completion of this unit, the student should be able to apply theoretical knowledge of direct current circuit fundamentals, use Ohm's and Kirchoff's laws in circuit analysis, and troubleshoot basic electrical circuits. Competencies will be demonstrated by correctly performing the procedures outlined in the assignment and job sheets and by scoring a minimum of 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to fundamentals of DC with their correct definitions.
2. Complete statements concerning the relationship of matter, energy, and electronics.
3. Match terms related to the composition of matter with their correct definitions.
4. Complete statements concerning the structure of the atom.
5. Select true statements concerning the characteristics of the electron.
6. Complete statements concerning the sources of electricity.
7. Complete statements concerning the characteristics of electron movement.
8. Select true statements concerning characteristics of conductors, insulators, and semiconductors.
9. Complete statements concerning characteristics of electrical charges.
10. Define electromotive force, potential difference, and voltage.

OBJECTIVE SHEET

11. Select true statements concerning the measure of electrical current.
12. Define resistance, ohm, and conductance.
13. Match terms related to basic types of resistors with their descriptions.
14. List the three basic circuit requirements.
15. List the three basic circuit configurations.
16. State the three fundamental Ohm's law formulas.
17. State the three fundamental Watt's law formulas for finding electrical power.
18. Complete statements related to the characteristics of current, voltage, power, and resistance in series circuits.
19. Complete statements concerning the characteristics of current in a parallel circuit.
20. Select true statements concerning the characteristics of resistance in a parallel circuit.
21. Complete statements concerning the characteristics of voltage and power in a parallel circuit.
22. Select true statements concerning the characteristics of series-parallel circuits.
23. Select true statements concerning voltage divider characteristics.
24. Complete statements concerning general troubleshooting considerations.
25. Identify types of bridge circuits.
26. Select true statements concerning maximum power transfer.
27. Arrange in order the steps for the application of the superposition theorem.
28. Arrange in order the steps for the application of Thevenin's theorem.
29. Solve problems for an unknown voltage. (Assignment Sheet #1)
30. Solve problems for an unknown amperage. (Assignment Sheet #2)
31. Solve problems for an unknown resistance. (Assignment Sheet #3)
32. Determine the total resistance in a series circuit. (Assignment Sheet #4)
33. Determine total voltage in a series circuit. (Assignment Sheet #5)

OBJECTIVE SHEET

34. Determine voltage drops across resistances in a series circuit. (Assignment Sheet #6)

35. Determine current in a series circuit. (Assignment Sheet #7)

36. Compute power from the power formula. (Assignment Sheet #8)

37. Determine unknown circuit values in a series circuit. (Assignment Sheet #9)

38. Calculate resistance in parallel circuits. (Assignment Sheet #10)

39. Calculate current and voltage in parallel circuits. (Assignment Sheet #11)

40. Calculate power in parallel circuits. (Assignment Sheet #12)

41. Calculate various values in parallel circuits. (Assignment Sheet #13)

42. Trace current flow in series-parallel circuits. (Assignment Sheet #14)

43. Solve for total resistance in a series-parallel circuit. (Assignment Sheet #15)

44. Solve for total current in series-parallel circuits. (Assignment Sheet #16)

45. Solve for total voltage in series-parallel circuits. (Assignment Sheet #17)

46. Solve for total power in series-parallel circuits. (Assignment Sheet #18)

47. Identify resistor values using a standard color code. (Assignment Sheet #19)

48. Demonstrate the ability to:

    a. Measure voltage drops in a series circuit. (Job Sheet #1)

    b. Analyze current values in a series circuit. (Job Sheet #2)

    c. Measure voltage, current, and resistance in a parallel circuit. (Job Sheet #3)

    d. Troubleshoot series-parallel circuits. (Job Sheet #4)

    e. Measure voltages in a balanced bridge circuit. (Job Sheet #5)

    f. Measure voltages in an unbalanced bridge circuit. (Job Sheet #6)

    g. Determine the maximum power transfer point on a resistor circuit. (Job Sheet #7)

FUNDAMENTALS OF DC
UNIT II

SUGGESTED ACTIVITIES

A. Obtain additional materials and/or invite resource people to class to supplement/reinforce information provided in this unit of instruction.

B. Make transparencies from the transparency masters included with this unit.

(NOTE: Activities A and B should be completed prior to the teaching of this unit.)

C. Provide students with objective sheet.

D. Discuss unit and specific objectives.

E. Provide students with information and assignment sheets.

F. Discuss information and assignment sheets.

(NOTE: Use the transparencies to enhance the information as needed.)

G. Provide students with job sheets.

H. Discuss and demonstrate the procedures outlined in the job sheets.

I. Integrate the following activities throughout the teaching of this unit:

1. Obtain or construct a model showing the structure of the atom.
2. Show examples of sources of electricity.
3. Explain the difference between E_a and E_T to the class.
4. Show examples of conductors, insulators, and semiconductors.
5. Construct a circuit board which can be used to demonstrate the flow of electricity and can be used to measure electrical current.
6. Display basic types of resistors and discuss their functions.
7. Take students on a tour of an electronics firm to observe technicians at work. Ask a technician to give a brief talk on technician duties and career opportunities.
8. Provide an assortment of resistors (20) for students to identify in Assignment Sheet #19.
9. Meet individually with students to evaluate their progress through this unit of instruction, and indicate to them possible areas for improvement.

J. Give test.

(NOTE: Due to the length of this unit, it is suggested that the information be tested in two parts.)

SUGGESTED ACTIVITIES

K. Evaluate test.

L. Reteach if necessary.

INSTRUCTIONAL MATERIALS INCLUDED IN THIS UNIT

A. Objective sheet

B. Suggested activities

C. Information sheet

D. Transparency masters

1. TM 1 — The Atom and Its Particles
2. TM 2 — Friction Produces Electricity
3. TM 3 — Chemical Action Produces Electricity
4. TM 4 — Magnetism Produces Electricity
5. TM 5 — Light Produces Electricity
6. TM 6 — Heat Produces Electricity
7. TM 7 — Pressure Produces Electricity
8. TM 8 — Conductors and Regulators
9. TM 9 — Standard Copper Wire Gauge Sizes
10. TM 10 — Types of Wire Conductors
11. TM 11 — Dielectric Strength of Common Insulators
12. TM 12 — Voltage
13. TM 13 — Current
14. TM 14 — Prefixes
15. TM 15 — Resistance
16. TM 16 — Symbols Used for Resistance and Resistors
17. TM 17 — Types of Resistors
18. TM 18 — Basic Circuit Elements (Power Sources)
19. TM 19 — Basic Circuit Elements (Resistance and Load)
20. TM 20 — Schematic Showing Current Flow

SUGGESTED ACTIVITIES

21. TM 21 — Series Circuit
22. TM 22 — Parallel Circuit
23. TM 23 — Resistance Circuits
24. TM 24 — Ohm's Law Memory Wheel
25. TM 25 — Ohm's Law Computing Voltage
26. TM 26 — Ohm's Law Computing Current
27. TM 27 — Ohm's Law Computing Resistance
28. TM 28 — Power
29. TM 29 — Kirchhoff's Law of Voltage
30. TM 30 — Voltage Drops in a Resistive Circuit
31. TM 31 — Current in a Series Circuit
32. TM 32 — Parallel Circuit
33. TM 33 — Current Flow in a Parallel Circuit
34. TM 34 — Finding Current in a Parallel Circuit
35. TM 35 — Resistance in Parallel Circuits
36. TM 36 — The Reciprocal Resistance Method
37. TM 37 — Finding the Total Resistance in Parallel Circuits
38. TM 38 — Voltage in a Parallel Circuit
39. TM 39 — Series-Parallel Circuit
40. TM 40 — Series-Parallel Circuit and Equivalent Circuit
41. TM 41 — Circuit Reduction
42. TM 42 — Circuit Reduction (Continued)
43. TM 43 — Steps to Simplify a Series-Parallel Circuit
44. TM 44 — Voltage Divider
45. TM 45 — Unloaded Voltage Divider
46. TM 46 — Loaded Voltage Divider
47. TM 47 — Series Circuit with Open

SUGGESTED ACTIVITIES

48. TM 48 — Series Circuit with Short
49. TM 49 — Balanced Bridge
50. TM 50 — Impedance Matching to Attain Maximum Power Transfer
51. TM 51 — Superposition Method for Solving a Two-Source Network
52. TM 52 — Thevenin's Theorem

E. Assignment sheets

1. Assignment Sheet #1 — Solve Problems for an Unknown Voltage
2. Assignment Sheet #2 — Solve Problems for an Unknown Amperage
3. Assignment Sheet #3 — Solve Problems for an Unknown Resistance
4. Assignment Sheet #4 — Determine the Total Resistance in a Series Circuit
5. Assignment Sheet #5 — Determine Total Voltage in a Series Circuit
6. Assignment Sheet #6 — Determine Voltage Drops Across Resistances in a Series Circuit
7. Assignment Sheet #7 — Determine Current in a Series Circuit
8. Assignment Sheet #8 — Compute Power from the Power Formula
9. Assignment Sheet #9 — Determine Unknown Circuit Values in a Series Circuit
10. Assignment Sheet #10 — Calculate Resistance in Parallel Circuits
11. Assignment Sheet #11 — Calculate Current and Voltage in Parallel Circuits
12. Assignment Sheet #12 — Calculate Power in Parallel Circuits
13. Assignment Sheet #13 — Calculate Various Values in Parallel Circuits
14. Assignment Sheet #14 — Trace Current Flow in Series-Parallel Circuits
15. Assignment Sheet #15 — Solve for Total Resistance in a Series-Parallel Circuit
16. Assignment Sheet #16 — Solve for Total Current in Series-Parallel Circuits
17. Assignment Sheet #17 — Solve for Total Voltage in Series-Parallel Circuits
18. Assignment Sheet #18 — Solve for Total Power in Series-Parallel Circuits
19. Assignment Sheet #19 — Identify Resistor Values Using a Standard Color Code

F. Answers to assignment sheets

SUGGESTED ACTIVITIES

G. Job sheets

1. Job Sheet #1 — Measure Voltage Drops in a Series Circuit
2. Job Sheet #2 — Analyze Current Values in a Series Circuit
3. Job Sheet #3 — Measure Voltage, Current, and Resistance in a Parallel Circuit
4. Job Sheet #4 — Troubleshoot Series-Parallel Circuits
5. Job Sheet #5 — Measure Voltages in a Balanced Bridge Circuit
6. Job Sheet #6 — Measure Voltages in an Unbalanced Bridge Circuit
7. Job Sheet #7 — Determine the Maximum Power Transfer Point on a Resistor Circuit

H. Test

I. Answers to test

REFERENCES USED IN DEVELOPING THIS UNIT

(NOTE: The following is a list of references used in completing this unit.)

A. Bruce, David, *Modern Electronics.* Reston, VA: Reston Publishing Company, Inc., 1984.

B. *DC Electronics.* Heath/Zenith Education System. Englewood Cliffs, NJ: Prentice-Hall Inc.

C. Gerrish, Howard H. and William E. Dugger. *Electricity and Electronics.* South Holland, IL: Goodheart-Willcox Co. Inc., 1980.

D. Grob, Bernard. *Basic Electronics.* New York: McGraw-Hill Book Co., 1977.

E. Robertson, L. Paul. *Basic Electronics I (Revised Edition).* Stillwater, OK: Mid-America Vocational Curriculum Consortium, 1982.

F. Rutkowski, George B. *Basic Electricity for Electronics.* Indianapolis, IN: Bobbs-Merrill Educational Publishing Co., 1984.

G. Siebert, Leo N. *Introduction to Industrial Electricity — Electronics.* Stillwater, OK: Oklahoma Curriculum and Instructional Materials Center, 1981.

FUNDAMENTALS OF DC
UNIT II

INFORMATION SHEET

I. **Terms and definitions**

A. Battery — Consists of a number of cells connected together so as to produce more electrical capacity than a single cell

B. Cell — A receptacle containing electrodes and an electrolyte for producing electricity from chemical action

C. Chassis ground — A common return circuit in electronic equipment that may be at a potential above or below ground

D. Closed circuit — Circuit in which there is a complete and unbroken path for current to flow

E. Coulomb — Quantity of electrons representing approximately 6.25×10^{18} electrons

F. Dielectric — An insulating material capable of accumulating an electrical charge

G. Galvanometer — Meter which indicates very small amounts of current and voltage

H. Ground — A common return circuit in electronic equipment whose potential is zero

I. Impedance — Total opposition to flow of an alternating current as a result of reactance and resistance

J. Internal resistance — The resistance which is within a voltage source

K. Ion — An atom which has lost or gained an electron

L. Joule — Unit of energy equal to one watt-second

M. Load — A device to which electrical energy is being supplied and expended

N. Open circuit — Circuit in which the path for current has been broken

O. Overload — A load on a circuit or system greater than the load for which it was designed

P. Photo-sensitive — Reactive to light

Q. Resistor — Device which opposes the flow of electrical energy

R. Schematic — A graphic representation of an electrical circuit using standard symbols for parts

INFORMATION SHEET

S. Voltage drop — An energy loss in a component made evident by a difference in voltage measured across a component

T. Work — Force moved through a distance, measured in foot-pounds

II. The relationship of matter, energy, and electronics

A. Matter and energy are regarded as equivalents in modern physics, and are mutually convertible by Einstein's formula (i.e., energy equals mass multiplied by the square of the velocity of light, $E = mc^2$.)

B. Electrical energy is a property of certain fundamental particles of all matter, as electrons (negative charges) and protons or positrons (positive charges) that have a force field associated with them and can be separated by the expenditure of energy.

C. To control the behavior of the electron is essentially the basic purpose of electricity and electronics; therefore, to understand these areas, we need to study the basic make-up of matter, the structure of the atom, and the basic behavior of the electron.

III. Composition of matter

A. Matter is commonly described as anything which has weight and occupies space.

(NOTE: Matter exists in three different states — solid, liquid, and gas.)

B. The basic particles of which all matter is composed are called elements.

C. A substance composed of two or more elements is called a compound.

D. A molecule is the smallest particle of a compound that can exist and still retain its identity.

E. An atom is the smallest particle to which an element can be reduced and retain its identity.

IV. Structure of the atom (Transparency #1)

(NOTE: Scientists have identified numerous sub-particles on the atom. The particles of interest to electronics are the electron, proton, and neutron.)

A. The nucleus of an atom contains protons and neutrons.

B. A neutron is the heaviest of the three fundamental particles of an atom, and is electrically neutral.

C. A proton is one of the three primary particles within an atom and has a positive charge with a weight nearly the same as a neutron.

D. Electrons are the lightest of the three primary particles of an atom, and have a negative charge and revolve in orbits around the nucleus.

INFORMATION SHEET

V. **Characteristics of the electron**

A. The number of electrons equals the number of protons in a normal, neutral state atom.

B. Electrons rotate in various orbits or shells around the nucleus with the outermost shell being of particular importance to electronics.

C. The outermost electron shell is called the valence shell.

(NOTE: The terms orbit, shell, and ring are commonly used interchangeably to refer to the paths electrons follow within the individual atoms.)

D. The electrons contained in the valence shell are called valence electrons.

VI. **Sources of electricity**

A. Electrical energy may be produced from friction by rubbing two non-conducting materials together (triboelectric effect). (Transparency #2)

Example: When you slide your feet across a nylon or wool carpet your shoes develop a charge which is transferred to the body

B. Electrical energy may be produced from chemical reaction in batteries and cells (electrochemistry). (Transparency #3)

Example: Automobile and flashlight batteries produce electricity from a chemical reaction

C. Electrical energy from magnetism is the most common method of producing electricity and is obtained by moving a conductor through a magnetic field (magnetoelectricity). (Transparency #4)

Example: Generator in a power plant or automobile

D. Electrical energy is produced when light strikes the surface of special photo-sensitive materials (photoelectric effect). (Transparency #5)

Example: Solar cell frequently used on spacecraft

E. Electrical energy may be produced when heat is applied to the junction of two unlike metals (thermoelectric effect). (Transparency #6)

Example: Thermocouple used in a water heater

F. Electrical energy may be produced when mechanical pressure is applied to crystalline substances, such as quartz or tourmaline (piezoelectric effect). (Transparency #7)

Example: A crystal microphone or in a phono cartridge on the pickup arm of a record player

INFORMATION SHEET

VII. Characteristics of electron movement

A. When loosely attached electrons in conductors are dislodged from their orbit, they tend to drift at random, unless controlled, and are called free electrons.

(NOTE: Only the valence electrons in the outermost orbit move freely.)

B. When electrical charges are applied to the ends of a conductor (negative to one end, positive to the other end), the random shift of electrons is changed to a directed drift with electrons moving from negative to positive.

C. The directed or controlled drift of free electrons, or charge in motion, is called electron flow.

(NOTE: Electron flow, electrical current, current flow, and current are terms commonly used interchangeably to describe the movement of electrons from negative to positive potential.)

VIII. Characteristics of conductors, insulators, and semiconductors (Transparency #8)

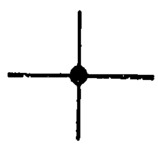
A. Conductors have valence electrons which are loosely attached to the atom and are easily separated from the atom and provide an easy path for electrons to flow from point to point.

Example: Silver, copper, and aluminum wire

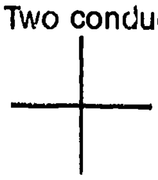
1. Conductors possess very little opposition (resistance) to electron flow; the amount of resistance is affected by the size (circular-mil area), the length, and the temperature. (Transparency #9)

2. Conductors may be represented on a schematic with a straight line

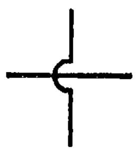
   a. Two conductors connected

   b. Two conductors not connected

   or

3. Conductors are of various types and sizes (Transparency #10)

B. Insulators have valence electrons which are tightly attached to the atom and can only be separated by applying extreme force and therefore are used to prevent electrons from flowing from point to point. (Transparency #11)

(NOTE: A good insulator has the ability to store a charge, in which case it is called a dielectric.)

INFORMATION SHEET

C. Semiconductors have four valence electrons (half-filled valence shell) which are attached only moderately to the atom and have characteristics of special value in the construction of transistors and other semiconductor devices.

Example: Germanium, silicon

IX. Characteristics of electrical charges

A. The unit of electrical charge is called the coulomb.

B. A coulomb is equal to the charge of 6.25×10^{18} electrons.

C. The natural law which describes the interaction of charges is called Coulomb's law.

(NOTE: Electrons and negative ions are examples of negative charges, and protons and positive ions are positive charges.)

D. Coulomb's law states that charged bodies attract or repel each other with a force that is directly proportional to the product of their charges, and is inversely proportional to the square of the distance between the charges.

E. Coulomb's law can be expressed in the formula

$$F = \frac{q_1 \times q_2}{d^2}$$

F = force of attraction or repulsion

q_1 = the charge of one body

q_2 = the charge on the second body

d = the distance between the two bodies

(NOTE: Actual problems to determine force between charges need not be completed However, by examining the equation, relationships may be determined. Notice that if either charge doubles (q_1 or q_2) the force (F) also doubles. Also note that if the distance (d) between charges is doubled, the squaring of d in the formula causes the force to be reduced to one fourth its former value.)

F. Coulomb's law establishes the important relationship that

1. Like charges repel
2. Unlike charges attract

INFORMATION SHEET

X. **Characteristics of electromotive force, potential difference, and voltage** (Transparency #12)

A. The force or pressure that causes electrons to flow is called electromotive force (emf).

B. When a difference exists in the amount of charge accumulated at two different points, a force or potential for moving electrons exists and is called potential difference.

C. Voltage is the unit of measure for emf and potential difference.

1. One volt is the amount of emf that will cause one joule of electrical energy to be expended in moving one coulomb of charge between two points.

   (NOTE: The volt may be more simply defined when the concept of resistance is used, i.e. one volt is the electrical force required to move one ampere of current through a resistance of one ohm.)

2. The volt is symbolically represented by the letter E or V.

(NOTE: Potential difference, emf, and voltage are terms which are often used interchangeably.)

XI. **Measure of electrical current** (Transparency #13)

A. Current is the flow of electrons from negative to positive.

B. The unit of measure for current is the ampere (amp).

1. The ampere is the rate at which electrons flow past a given point.

2. One ampere equals the flow of one coulomb of electrons past a given point in one second.

3. The letter I is used to indicate current (for intensity of electron flow) or as A (for amperes).

C. In modern circuits, current is commonly indicated in units less than an ampere. (Transparency #14)

1. Milliamp indicates a thousandths of an amp.

2. Microamp indicates a millionths of an amp.

3. Picoamp indicates a trillionth of an amp.

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XII. **Characteristics of resistance** (Transparency #15)

A. An opposition to electron flow which limits the amount of current in a material is called resistance.

1. Conductors have a small resistance to electron flow.

2. Insulators have a large resistance to electron flow.

B. The unit of measure for resistance is the ohm. (Transparency #16)

1. One ohm is the value of resistance when a potential of one volt causes one ampere of current to flow in a closed loop. The ohm is represented by the greek letter omega (Ω)

2. Resistance is represented symbolically by the letter R.

C. The reciprocal of resistance (1/R) is called conductance (G) and is the ability to conduct an electrical current.

XIII. **Basic types of resistors** (Transparency #17)

A. Wire-wound resistors are generally made of a nickel-chromium alloy wire wound on a ceramic tube and covered with a protective coating.

B. Carbon-composition resistors are made by mixing carbon granules with a powdered insulating material, solidified into a rod shape with a binding agent, and coated with a non-conductive material.

(NOTE: Carbon composition resistors are generally inexpensive and very common in electronic equipment.)

C. Deposited-film resistors are made by depositing a resistive film on a rod, such as glass or ceramic, and then covered with a protective coating.

D. Sliding contact resistors are constructed of resistance wire with a moveable contact that may be placed at different positions on the bare resistance wire to achieve the desired resistance.

E. A potentiometer is a three terminal variable resistor constructed of circular carbon composition ribbons (or resistance wire) with an arm attached to a moveable shaft so that when the shaft is turned, resistance is varied between a moveable center contact and the terminals on both ends of the resistor.

F. The rheostat is a two terminal resistor that is a slight variation of the potentiometer with one terminal attached to an end and one to a moveable shaft so that when the shaft is turned the resistance between the two terminals varies.

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XIV. **Basic circuit requirements**

A. A source of potential difference (applied voltage), such as a cell or battery, is required to cause a flow of electrons. (Transparency #18)

B. A load (such as a lamp, a manufactured resistor, or other device) is required within the external circuit for it to perform practical, useful functions. (Transparency #19)

C. A complete path (conductor) must be provided for electrons to flow from one side of the applied voltage, through the external circuit path, back to the other side of the applied voltage. Current flows from the negative terminal of the applied voltage source, through the load, and returns to the positive terminal of the source. (Transparency #20)

(NOTE: Practical circuits also may have two other elements, one being a control device such as a switch, the other a safety device such as a fuse or circuit breaker.)

XV. **Basic circuit configurations**

A. A circuit which is arranged so that all of the current flowing in the circuit will pass through all the components in the circuit is called a series circuit. (Transparency #21)

B. When a number of components are connected to the same voltage source in a parallel or side-by-side manner so a division of current occurs, it is known as a parallel circuit. (Transparency #22)

C. When a circuit is arranged with a combination of both series and parallel connected components such that the same current flows through some components (series connection), while other components have different currents with a common voltage (parallel components), the total circuit arrangement is called a combination circuit or series-parallel circuit. (Transparency #23)

XVI. **Fundamentals of Ohm's law**

A. One of the fundamental laws for electrical circuits, Ohm's law, states that the current (amperes) in a circuit is equal to the electromotive force or potential difference (volts) divided by the resistance in ohms. (Transparency #24)

B. Ohm's law may be expressed by formula in three ways to determine current, voltage, or resistance in a circuit or component:

1. To determine voltage (Transparency #25) (Assignment Sheet #1)

$$E \text{ (in volts)} = I \text{ (in amperes)} \times R \text{ (in ohms)}$$

2. To determine current (Transparency #26) (Assignment Sheet #2)

$$I \text{ (in amperes)} = \frac{E \text{ (in volts)}}{R \text{ (in ohms)}}$$

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3. To determine resistance (Transparency #27) (Assignment Sheet #3)

$$R \text{ (in ohms)} = \frac{E \text{ (in volts)}}{I \text{ (in amperes)}}$$

XVII. **Characteristics of electrical power** (Transparency #28)

A. The fundamental unit of measure for electrical power is the watt (W) and may be measured with an instrument called a wattmeter

1. Electrical power is the time rate at which a charge is moved by voltage.

2. One watt equals the work accomplished in one second by one volt of potential difference in moving one coulomb of charge.

(NOTE: 746 watts = 1 horsepower.)

B. Power (P) in an electrical circuit may be calculated by using Watt's law, expressed by three basic formulas:

$P \text{ (in watts)} = E \text{ (volts)} \times I \text{ (amperes)}$

$P \text{ (in watts)} = I^2 \text{ (amperes)} \times R \text{ (ohms)}$

$$P \text{ (in watts)} = \frac{E^2 \text{ (volts)}}{R \text{ (ohms)}}$$

C. Power is dissipated in resistance in the form of heat and is made evident by a voltage drop across the resistance.

XVIII. **Characteristics of current, voltage, power, and resistance in series circuits**

A. In a series circuit, the sum of the resistance equals the total resistance (R) of the circuit.

(NOTE: This may be expressed as $R_t = R_1 + R_2 + R_3 \ldots$)

B. Kirchoff's voltage law states that the algebraic sum of all the voltage drops and voltage rises in a closed loop (series circuit) is equal to zero or, stated simply, the sum of the voltage drops is equal to the applied voltage. (Transparency #29)

(NOTE: This may be expressed as $V_t = V_1 + V_2 + V_3 + \ldots$)

1. The voltage drop across each individual resistor may be found by multiplying the resistance by the current through it ($E = I \times R$). (Transparency #30)

(NOTE: The voltage drop will be directly proportional to the value of the resistance. [The larger the R, the larger the E.])

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2. For multiple source circuits, voltages connected in series-aiding (polarities the same) may be added for a total equivalent voltage while those in a series-opposing configuration (polarities opposite) may be subtracted for an equivalent voltage.

C. Current (I) is the same at all points in a series circuit. (Transparency #31)

D. Total power dissipated in a series resistive circuit is the same as the total power supplied by the source and may be found by totaling the power's dissipated by the resistors.

(NOTE: This may be expressed as $P_t = P_1 + P_2 + P_3 + \ldots$)

XIX. **Characteristics of current in a parallel circuit** (Transparency #32)

A. Current in a parallel circuit follows Kirchoff's current law which states that the algebraic sum of currents into any point equals the algebraic sum of the currents out of that point. (Transparency #33)

(NOTE: This also means that the sum of the individual branch currents may be added to obtain the value of total current in a parallel circuit, $I_T = I_1 + I_2 + I_3 + \ldots$)

B. Only a portion of the total circuit current R_t flows through an individual branch. (Transparency #34)

C. The current of each branch is equal to the voltage divided by the resistance of that branch, $I = E/R$.

D. Total circuit current equals the sum of the individual branch currents ($I_T = I_1 + I_2 + I_3 + \ldots$).

E. Total current may also be found by dividing the applied voltage by the total resistance, $I = E/R$.

F. When branch resistance decreases, current in the branch increases; when resistance increases, current decreases.

XX. **Characteristics of resistance in a parallel circuit**

A. Total resistance of a parallel circuit is always less than the resistance of any individual branch.

B. The reciprocal of the total resistance equals the sum of the reciprocals of the parallel resistances. (Transparencies #35 and #36)

$$R_t = \frac{1}{1/R_1 + 1/R_2 = 1/R_3 \ldots} \text{ or } R_t = 1/R_1 + 1/R_2 + 1/R_3 \ldots$$

INFORMATION SHEET

C. When the resistances of the individual branches are all equal, the total resistance is equal to the value of one branch resistor divided by the number of the branches.

$$R_t = \frac{R \text{ (of individual branch)}}{N \text{ (number of branches)}}$$

D. The total of two unequal resistances in parallel may be found by the formula

$$R_t \times \frac{R_1 \times R_2}{R_1 + R_2}$$

E. When total current is known, total resistance may be found by dividing the applied voltage by the total current (R = E/I). (Transparency #37)

XXI. **Characteristics of voltage and power in a parallel circuit**

A. Voltage across each branch of a parallel circuit is the same (Transparency #38)

Example: Christmas tree lights: the whole string of lights does not go out when one bulb burns out

B. The voltage across each branch of a parallel circuit is equal to the source voltage.

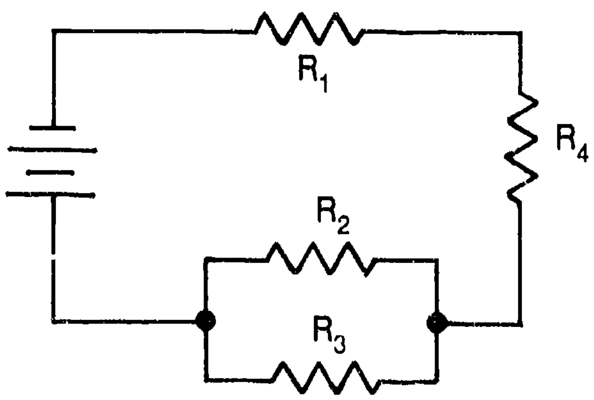
C. Total power in a parallel circuit is the total power generated by the source and may be found by adding the individual values of power dissipated in the branches, i.e., $P_t = P_1 + P_2 + P_3 + \ldots$

(NOTE: Power in both series and parallel circuits is equal to the power delivered by the source.)

XXII. **Characteristics of series-parallel circuits**

A. A series-parallel circuit is one in which some components are connected in series to have the same current, while others are connected in parallel and have the same voltage. (Transparency #39)

Example:



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B. The characteristics or "rules" for current, voltage, resistance, and power in series and parallel circuits are as follows.

	Rules for Parallel Circuits	*Rules for Series Circuits*
Current	Total current is the sum of the currents in the branches and the current in a branch varies inversely with the resistance of the branch. $I_T = I_1 + I_2 + I_3 \ldots$	Current is the same through all components in a series circuit. $I_T = I_1 = I_2 = I_3 = \ldots$
Voltage	Total voltage (applied voltage) is the same across all branches. $E_a = E_1 = E_2 = E_3 \ldots$	Sum of the voltage drops in a series circuit equals the applied voltage. The voltage drop varies directly with the resistance. $E_a = E_1 + E_2 + E_3 \ldots$
Resistance	Total resistance of a parallel circuit is always less than the resistance of any branch. The reciprocal of the total resistance equals the sum of the reciprocals of the parallel resistances.	Total resistance in a series circuit equals the sum of the individual resistances.
Power	The total power consumed in a parallel circuit equals the sum of the power consumed in each branch.	The total power consumed in a series circuit equals the sum of the power consumed in each component.

C. To determine values of E, *I*, and R in series-parallel circuits, simplify the circuit to an equivalent series circuit. (Transparencies #40, #41, #42, and #43)

1. Identify which are series components and which are parallel components (or groups or components).

2. Reduce each parallel group of components to an equivalent resistance (R_{eq}).

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3. Redraw the circuit using single equivalent resistors to represent each parallel group as determined in step 2.

   (NOTE: This new circuit is now a series circuit.)

4. Combine all resistances in the new circuit to find total resistance (R).

5. Determine total current by dividing the applied voltage by the total resistance.

XXIII. Voltage divider characteristics

A. A voltage divider is a circuit that may be used to provide, from a single DC source, different voltage values to different loads each of which may draw a different value of current. (Transparency #44)

   1. A voltage divider circuit consists of two or more resistors connected in series across a single power source.

   2. The fraction of voltage required by a load or loads may be tapped off as the voltage is dropped through successive steps of the series resistors.

   3. The values of the series resistors is determined by the voltage drops required.

   4. If a chassis ground is used, both negative and positive voltages may be obtained from a single source.

B. There are two types of voltage dividers: unloaded and loaded.

   1. An unloaded divider is the series string of resistors without a current drawing load attached. (Transparency #45)

   2. When a load is attached (in parallel) to the divider network, the circuit becomes a loaded voltage divider. (Transparency #46)

   3. The network is usually designed so that about 90 percent of the total current supplied by the source goes through the load.

   4. Ten percent of the current flows through the series divider network.

      (NOTE: The current that does not flow through the load is called the Bleeder Current.)

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XXIV. General troubleshooting considerations

A. Basic troubleshooting axioms and assumptions are usually followed in successful repair of defective circuits and equipment.

1. In a normally operating resistive circuit, the voltage across the individual resistors and the current in every part of the circuit is distributed according to Ohm's law and Kirchoff's law.

2. In a defective circuit the voltage across individual resistors and the current in every part of the circuit is not distributed according to Ohm's and Kirchoff's laws.

3. It may be assumed that in a circuit which is not operating properly, the trouble is caused by one and only one component.

   (NOTE: If a circuit still operates improperly after one problem has been found and corrected, we proceed and again look for a single defective component.)

B. The natural human senses of sight, hearing, and smell are called upon often in troubleshooting and can become excellent troubleshooting "tools" with practice.

1. Look to see if any parts are broken, missing, or loose.

2. Smell the equipment for the obvious odors given off by overheated or burned components.

3. Listen for unusual sounds from the equipment such as buzzing, clicking, sizzling, or whirring sounds.

4. Touch components to detect temperature.

C. Two common problems which occur in electronic equipment are open circuits and short circuits and can be located with voltmeter and ohmmeter checks.

1. An open circuit is one in which burned-out components, broken conductor paths, corroded contact, or other similar problems cause the current path to be broken preventing electron flow. (Transparency #47)

2. A short circuit is one in which an unwanted low (or zero) resistance current path is created by a defective component, solder or wire chips left in the equipment, defective conductor insulation, or other like defect occurs. (Transparency #48)

D. Changes in circuit operation, from the normal operating condition, can be caused by changes in the characteristics of the individual circuit components, shorted circuits, open circuit, or trouble in the power source or circuit protection device.

1. When a resistor opens, or its resistance value increases, it will cause a resultant decrease in total circuit current and a proportionate increase in the voltage drop across the increased resistance.

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2. Switches may develop mechanical troubles.

3. Interconnecting conductors may become open or shorted.

4. The safety device, fuse, or circuit breaker may be open due to an overload condition.

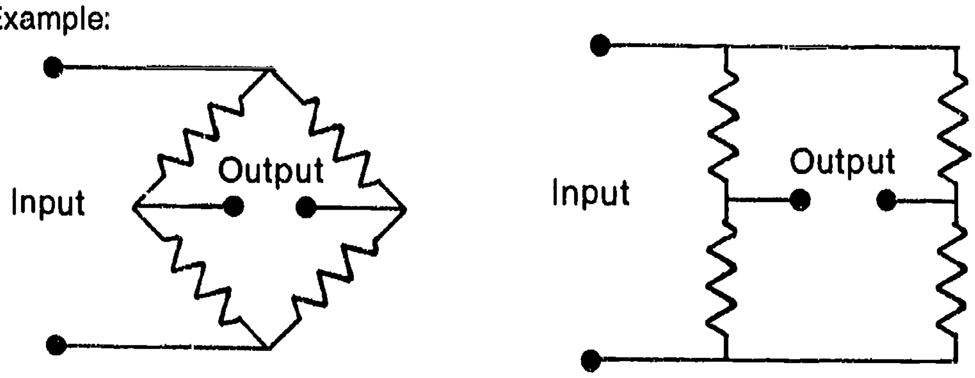
5. The power source may be defective due to an internal malfunction.

   (NOTE: A battery may develop a high internal resistance. When the terminal voltage is checked under a no-load condition, it may appear to be acceptable. However, when a battery with high internal resistance is placed under load, the output may decrease to a great extent and cause the circuit to be inoperative. Therefore, a battery should be checked under a loaded condition.)

XXV. **Types of bridge circuits**

A. A simple bridge circuit is a series-parallel circuit which has two input terminals and two output terminals. (Transparency #49)

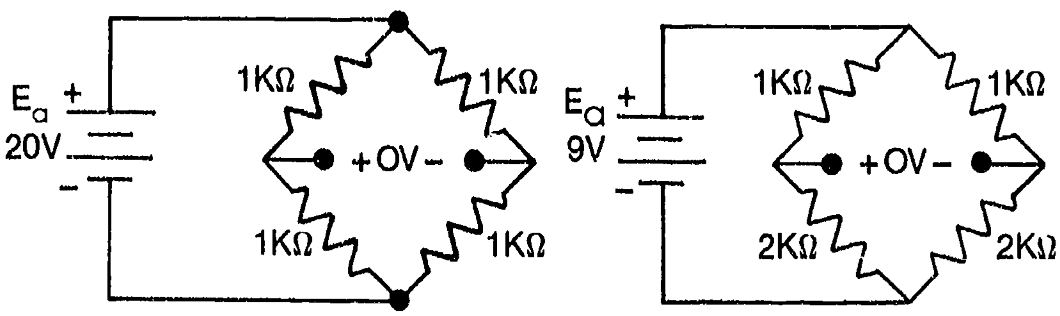
Example:



(NOTE: The "bridge" is the component or device which is connected across the output terminal, frequently a meter.)

B. A balanced bridge circuit is one in which the voltage division is such that the potential difference across the output terminals is zero.

Example:



(NOTE: In the figure on the left, the resistors have the same value and the voltage across the output terminals is zero. The circuit on the right has unequal resistors and the voltage across the output terminals is also zero because the voltage division within each branch is in equal proportion.)

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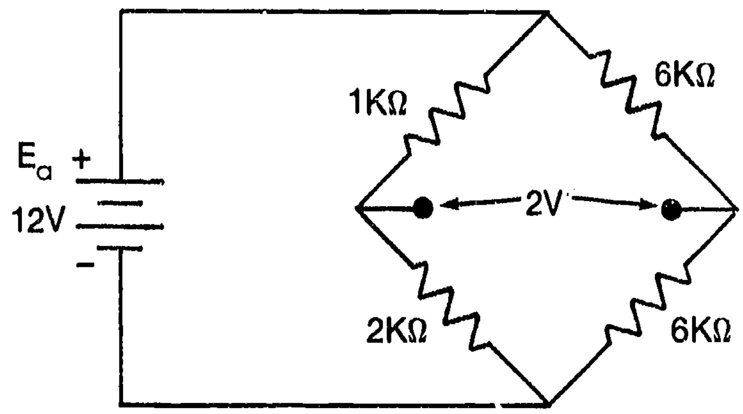
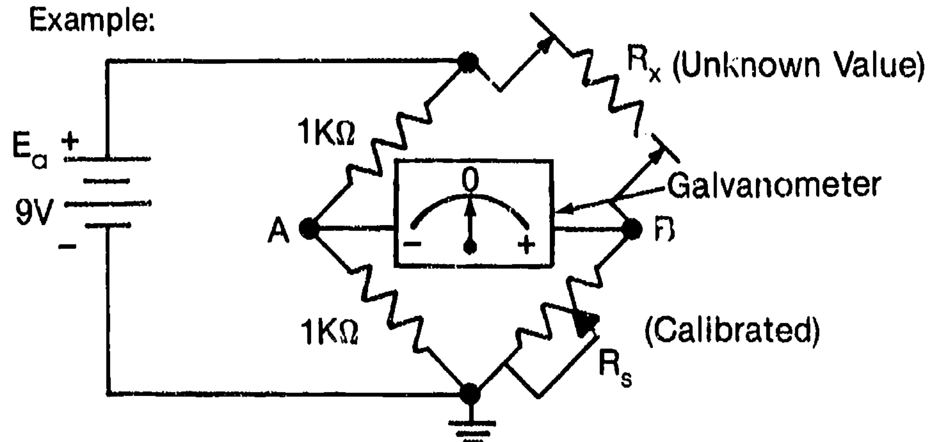
C. An unbalanced bridge circuit is one in which a potential difference exists across the output terminals of the circuit.

Example:



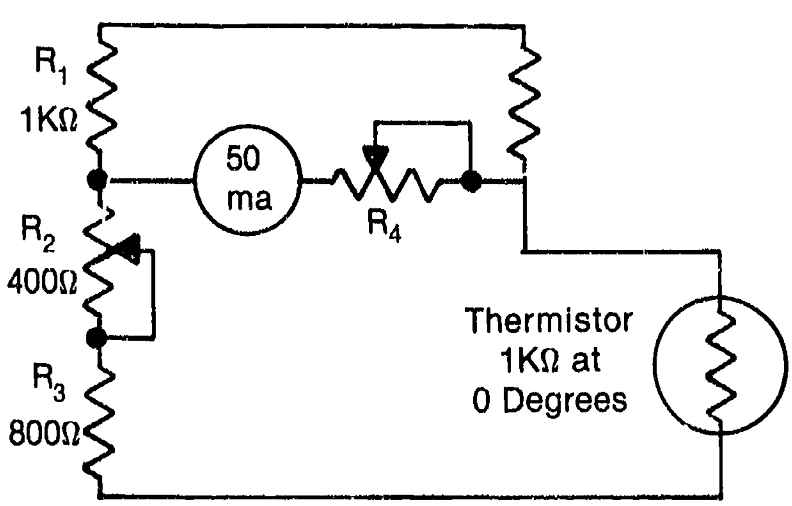
D. The wheatstone bridge is a practical application of a bridge circuit and is used for measuring resistance.

Example:



E. Bridge circuits have many applications in control and instrumentation circuits and devices.

Example:



INFORMATION SHEET

XXVI. **Maximum power transfer** (Transparency #50)

A. The maximum power transfer theorem says in effect that maximum power is transferred from the source to the load when a resistance of the load is equal to the internal resistance of the source.

B. The efficiency of power transfer (ratio of output to input power) from the source to the load increases as the load resistance is increased. (Job Sheet #3)

1. Efficiency approaches 100 percent as the load resistance approaches a relatively large value compared with that of the source, since less power is lost in the source.

2. At the point of maximum power transfer, efficiency is only fifty percent.

3. As the resistance of the load approaches relatively low values compared with the resistance of the source, the efficiency becomes very low and approaches zero efficiency.

4. Maximum power transfer and 100 percent efficiency cannot be achieved at the same time; therefore, a compromise between the two is made depending upon the overall needs of the circuit or equipment attached to the source.

(NOTE: This concept is also of importance when using test instruments, such as a voltmeter. When a voltmeter is attached across a circuit component, it effectively lowers the circuit resistance, thus changing the efficiency of the circuit. It is therefore necessary, when measuring voltages in modern, high-efficiency circuits, to use a voltmeter with an impedance of a very high value — millions of ohms.)

XXVII. **Application of the superposition theorem** (Transparency #51)

A. The superposition theorem states that in a network with two or more sources, the current or voltage for any component is the algebraic sum of the effects produced by each source acting separately.

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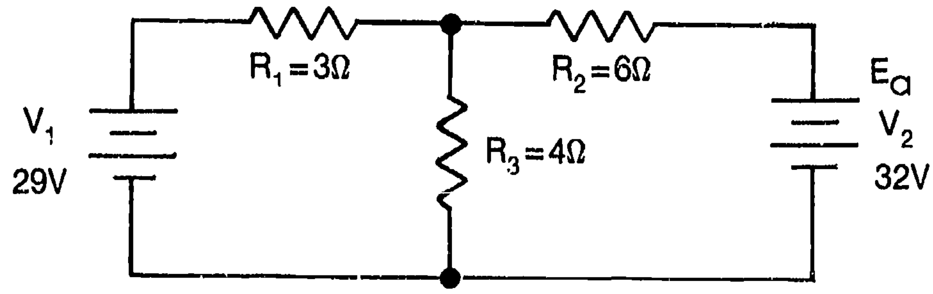
B. To use the superposition method on multi-source circuits we must short out (assuming zero internal resistance) first one source, peiform the necessary calculations, then short the other source and again perform circuit calculations, and finally consolidate the results obtained from the two single source circuits.

Example: Find th^ cunent IR_3 and voltage ER_3.

Given: R_1 = 3 ohms, R_2 = 6 ohms, R_3 = 4 ohms, V_1 = 29 volts, V_2 = 32 volts



Step 1: Short out V_2

Step 2: Calculate $R_{t1} = R_1 + \frac{R_2 \times R_3}{R_2 + R_3} = 5.4$ ohms

Step 3: Short out V_1

Step 4: Calculate $R_{t2} = R_2 + \frac{R_1 \times R_3}{R_3 + R_3} = 7.71$ ohms

Step 5: Calculate $It_1 = \frac{V_1}{Rt_1} = 5.37$ ohms

Step 6: Calculate $It_2 = \frac{V_2}{Rt_2} = 4.15$ amps

Step 7: Calculate $ER_4 = I_{t1} \times R_4 = 12.89$ volts

Step 8: Calculate $ER_3 = I_{t2} \times R_3 = 7.10$ volts

Step 9: Calculate $IR_3 = \frac{ER_4}{R_3} + \frac{ER_5}{R_3} = \frac{ER_4 + ER_5}{R_3} = 5$ amps

Step 10: Calculate $ER_3 = IR_3 \times R_3 = 20$ volts

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XXVIII. **Application of Thevenin's theorem** (Transparency #52)

A. Thevenin's theorem states that any network of linear components (resistors) and voltage sources, if viewed from any two terminals in the network, can be replaced with an equivalent voltage source (E_{th}) and an equivalent series resistance (R_{th}).

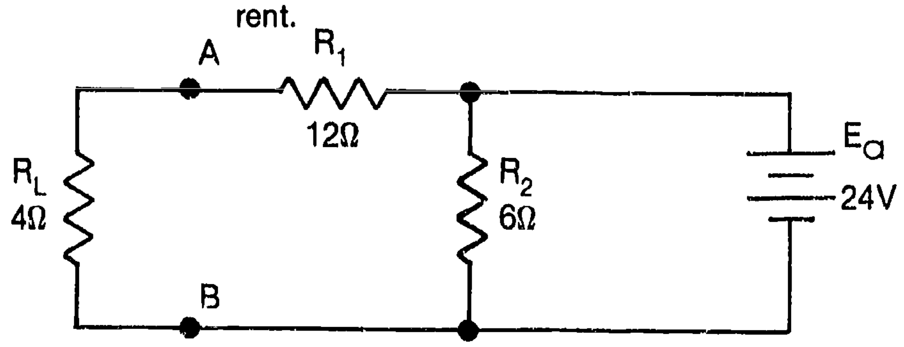
B. A circuit may be converted through a series of steps following two basic rules: one to find E_{th}, the other to find R_{th}

1. The voltage E_{th} is the voltage "seen" across the load terminals in the original network, with the load resistance removed (open circuit voltage).

2. The resistance R_{th} is the resistance seen from the terminals of the open load, looking into the original network when the voltage sources in the circuit are replaced by their internal resistance.

(NOTE: To this point we have become accustomed to looking at an electronic circuit essentially from the viewpoint of the voltage source. Thevenin's theorem allows us to look at the circuit from the viewpoint of the load — what the load "sees". In doing this we can greatly enhance our understanding of the interrelationships that exist in electronic circuits which we often fail to see when we do not practice use of the theorem.)

Example: Find the voltage across the load resistor R and its current.



Step 1: Disconnect the load resistor R_2.

Step 2: With the load terminals open, calculate the open circuit voltage by any convenient method to find E_{th}.

$$E_{th} = \frac{R_2}{R_1 + R_2} \times Ea = 8 \text{ volts}$$

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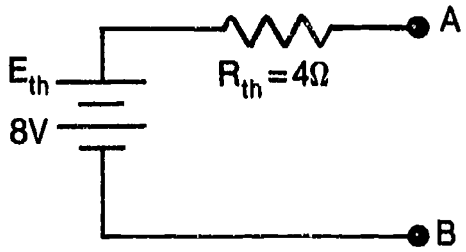
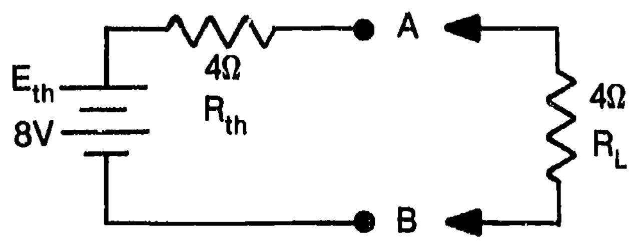
Step 3: Short the power source and calculate the Thevenin resistance (R_{th}) as seen at the open load terminals.

$$R_{th} = \frac{R_1 \times R_2}{R_1 + R_2} = 4 \text{ ohms}$$

Step 4: Draw the equivalent Thevenin circuit.



Step 5: Replace the load resistance in the Thevenized series circuit.



Step 6: Calculate the equivalent Thevenin circuit current (I_{th}).

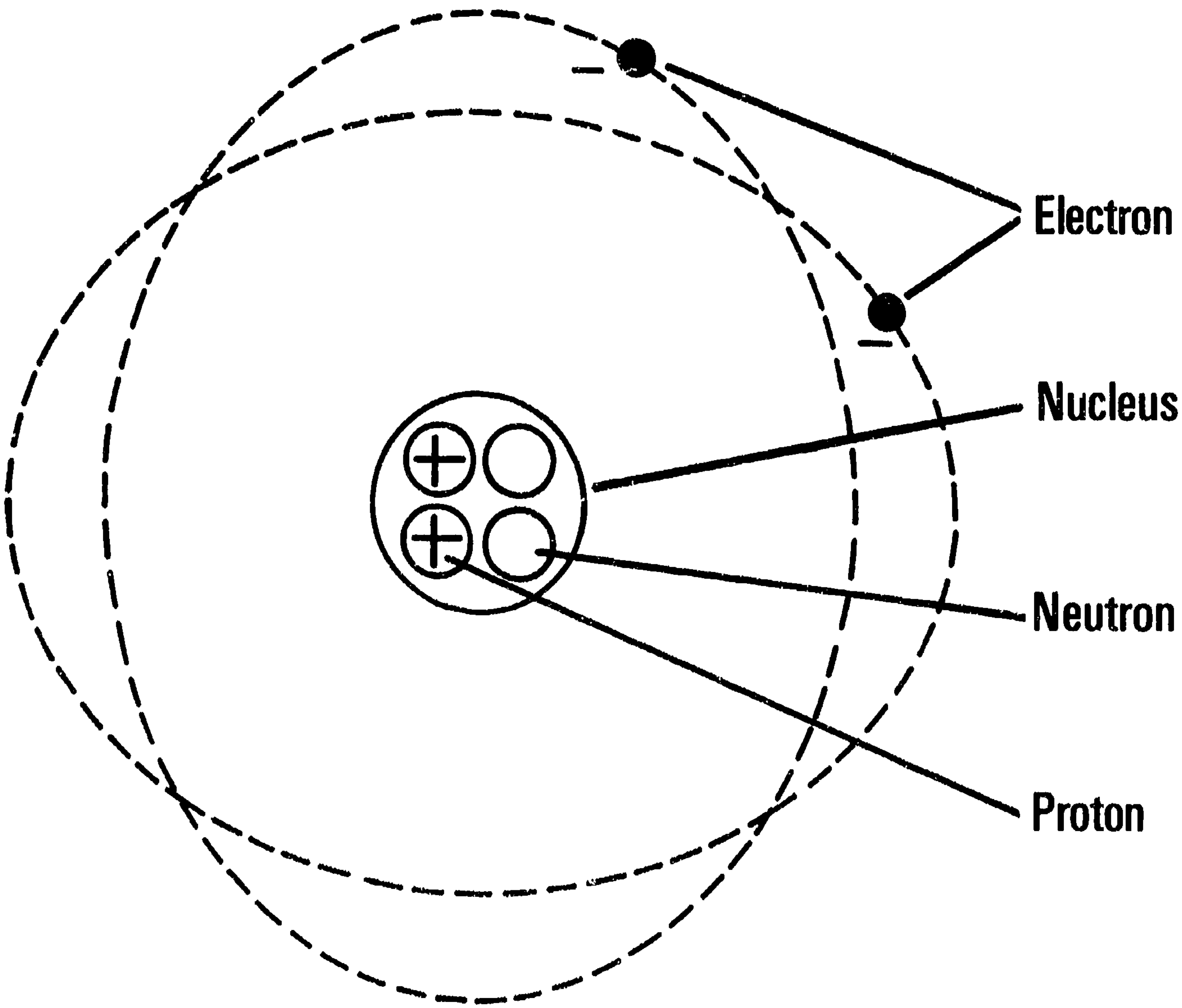
$$I_{th} = \frac{E_{th}}{R_{th} + R_L} = 0.4 \text{ amp}$$

Step 7: Calculate load voltage using Ohm's law.

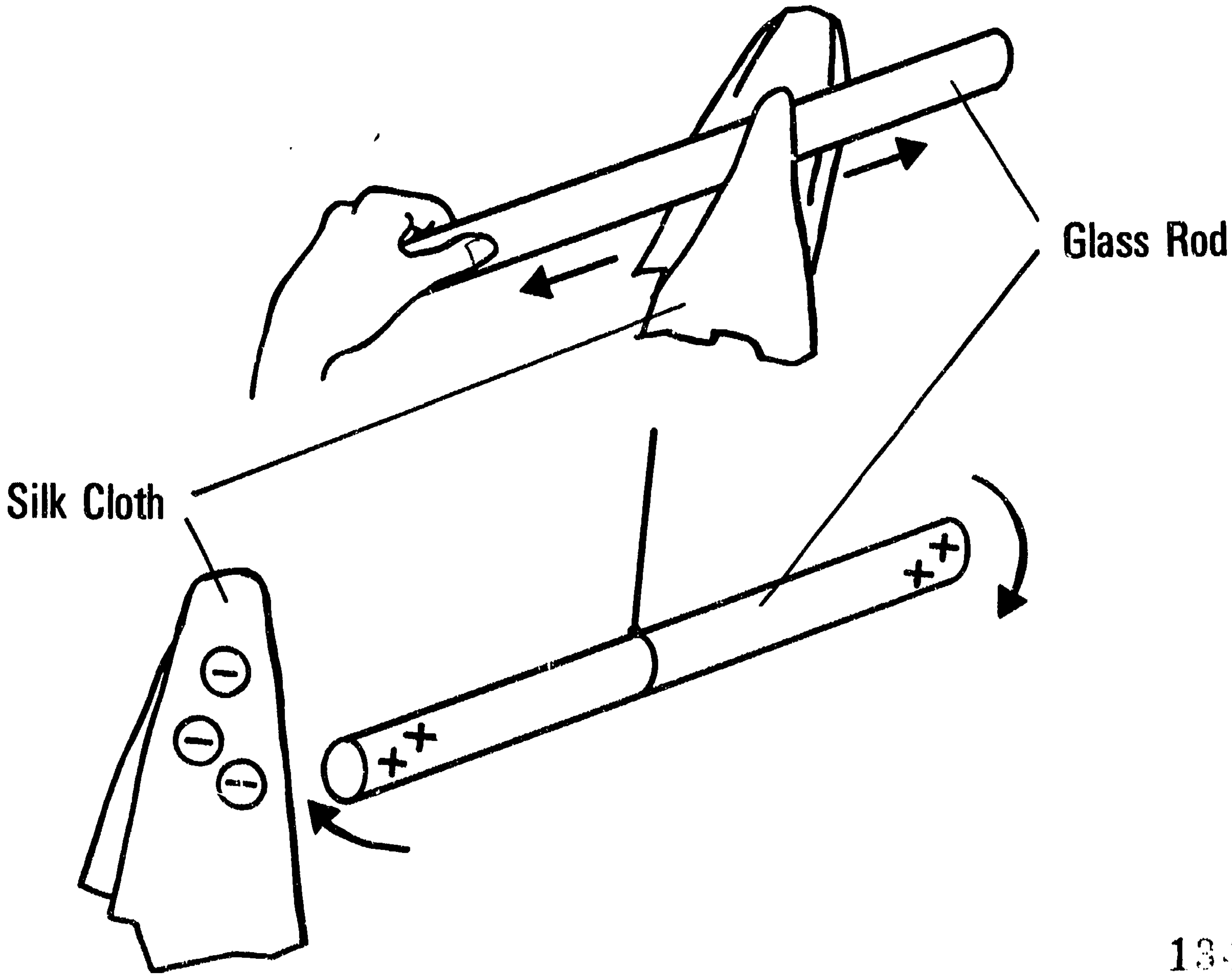
$E_{RL} = E_{th} \times RL = 6.4$ volts

(NOTE: You may insert the calculated values into the original to prove that they are correct.)

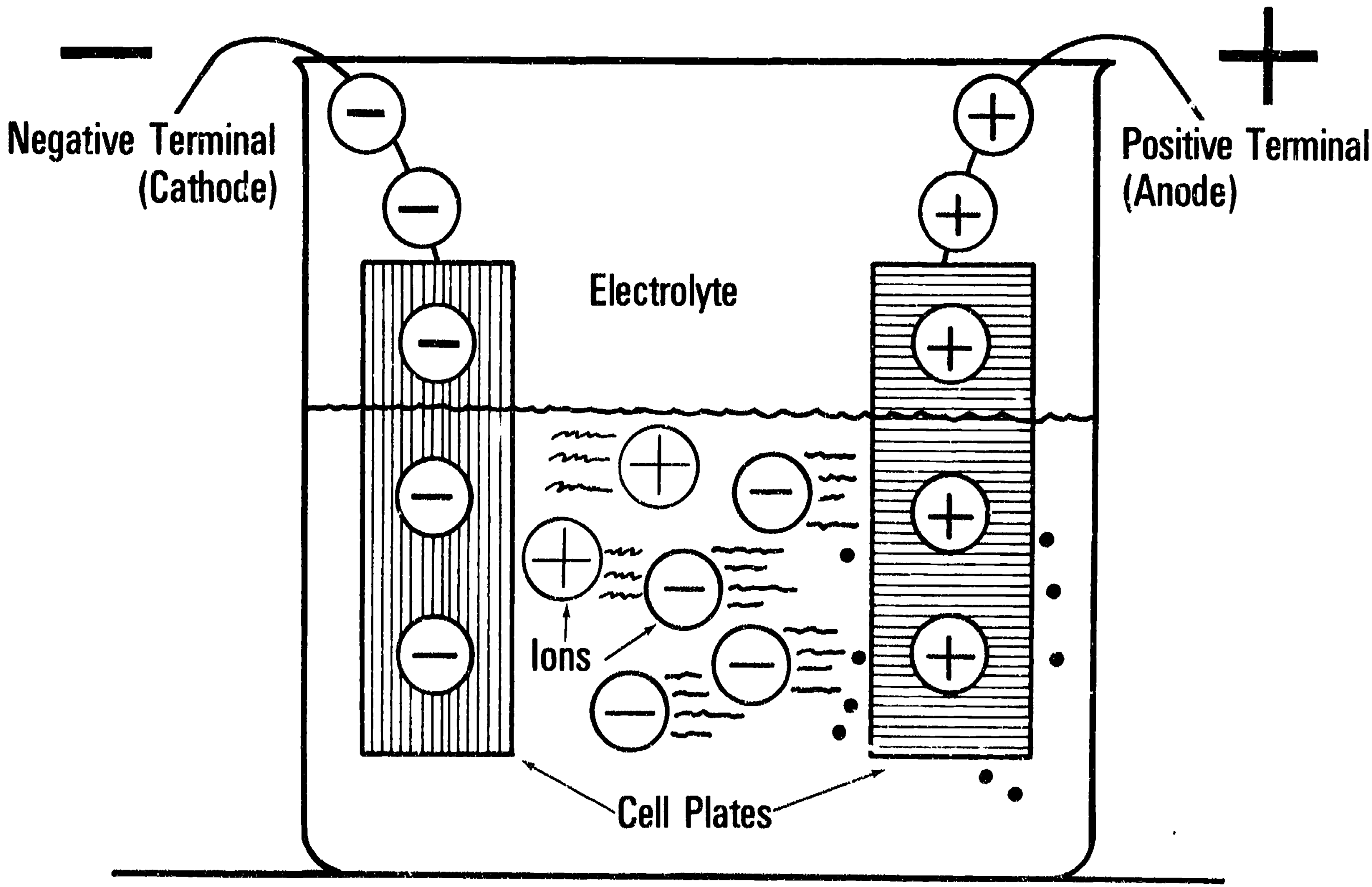
The Atom and Its Particles



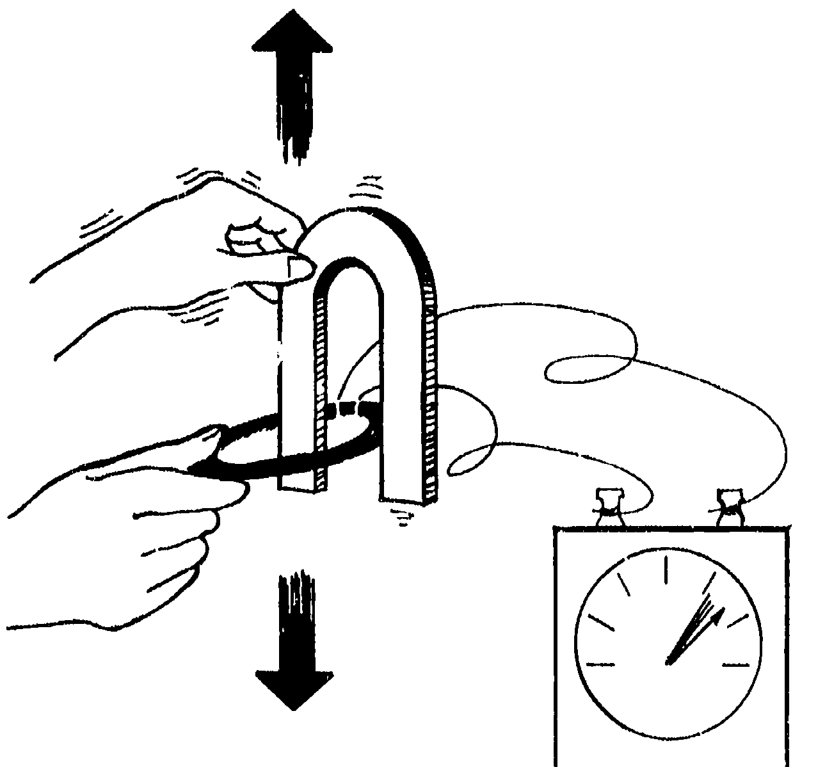
Friction Produces Electricity



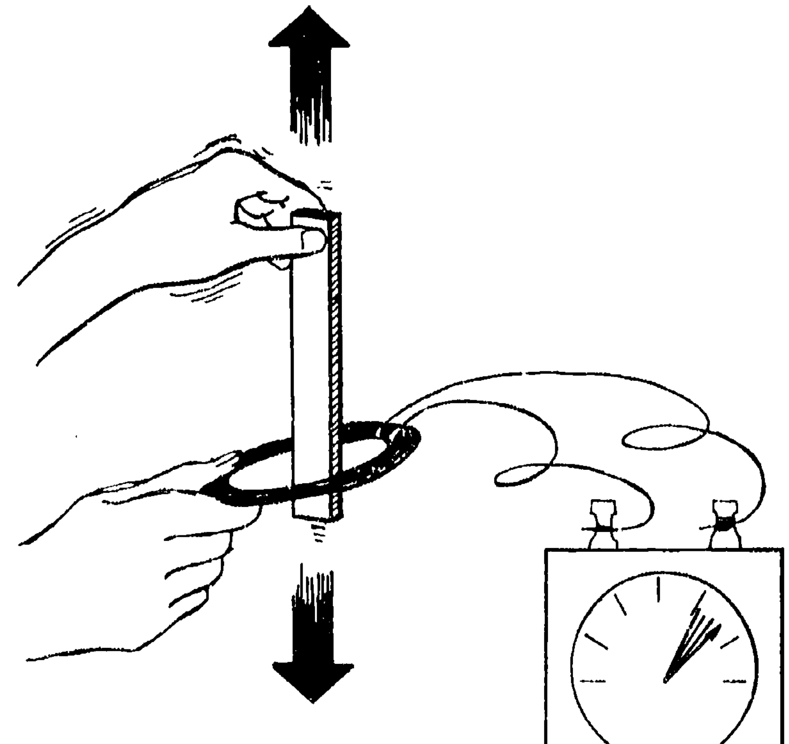
Chemical Action Produces Electricity



Magnetism Produces Electricity



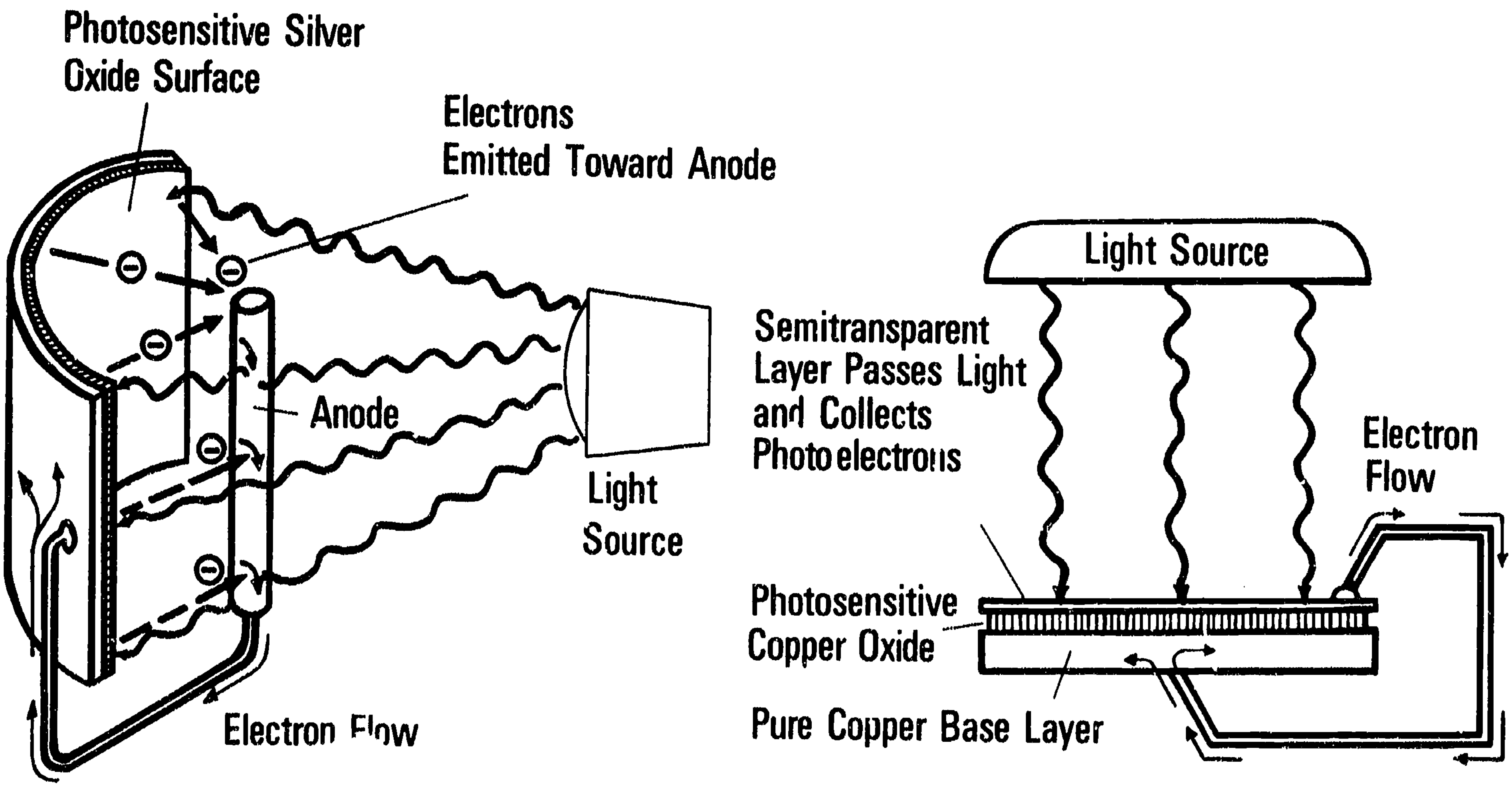
Producing Electricity by Moving a Horseshoe Magnet Through a Coil of Wire



Producing Electricity by Moving a Bar Magnet Through a Coil of Wire

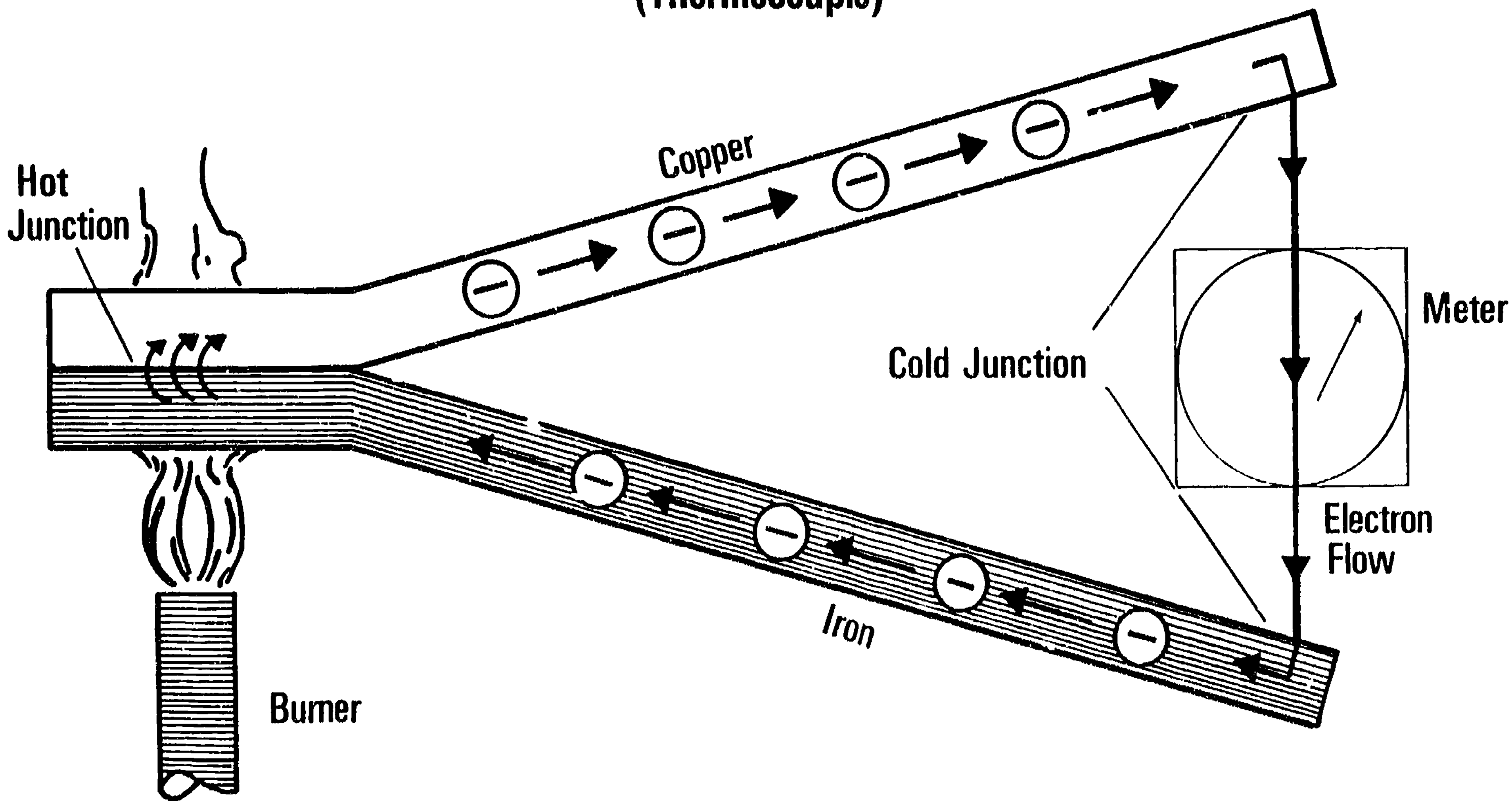
This principle is used in generators.

Light Produces Electricity



Heat Produces Electricity

(Thermocouple)



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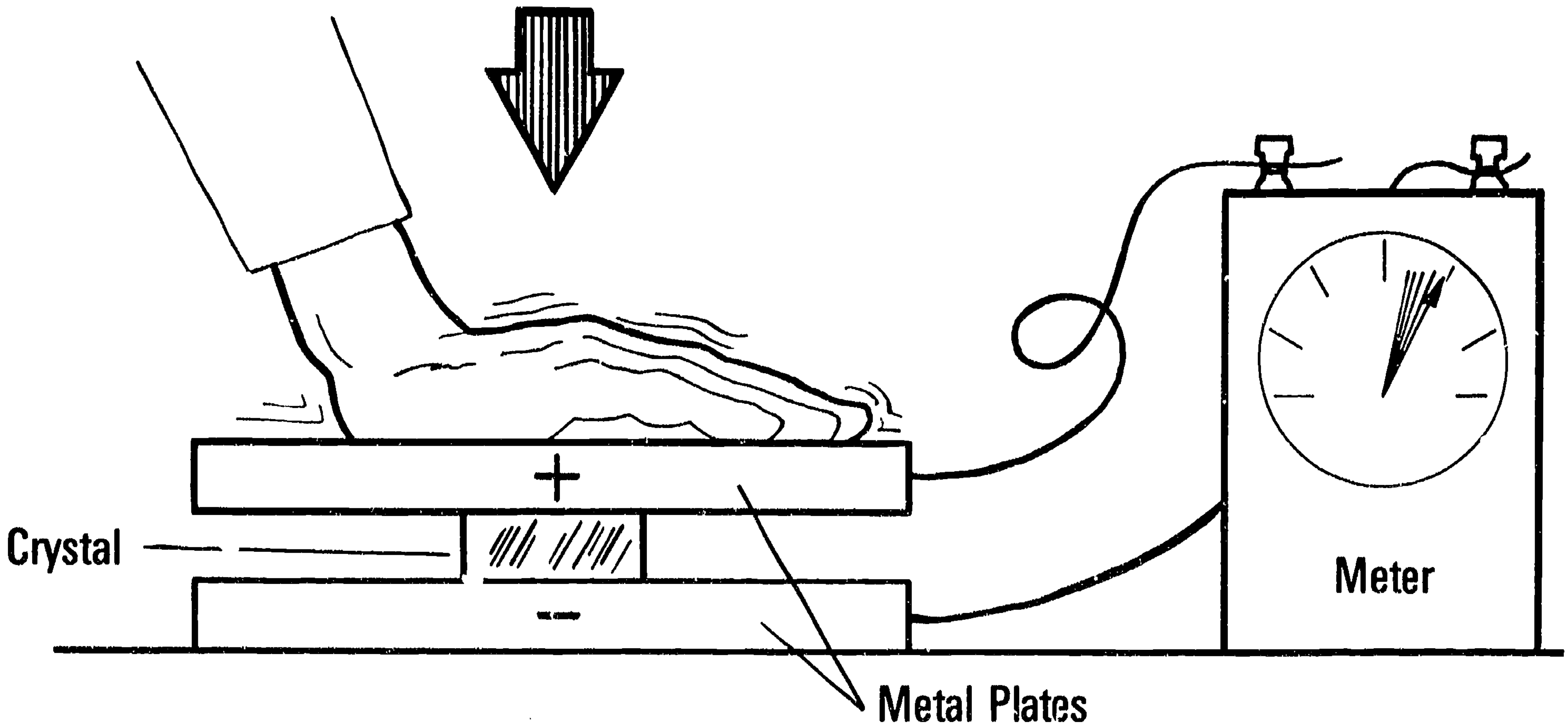
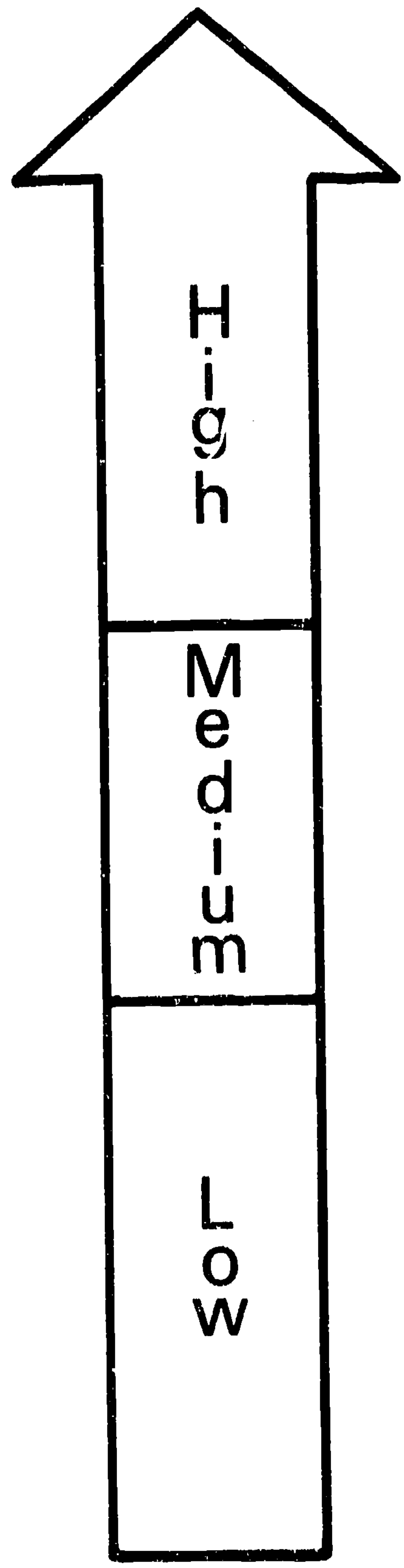
Pressure Produces Electricity

(Piezoelectric Effect)



Conductors and Insulators

Increasing Resistance



Insulators

- Mica
- Glass
- Shellac
- Paper
- Rubber
- Bakelite
- Fiber
- Air or Vacuum

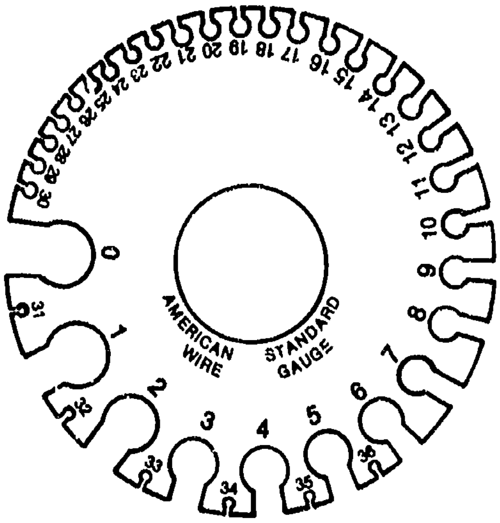
Semiconductors

- Germanium
- Silicon

Conductors

- Iron
- Nickel
- Tungsten
- Aluminum
- Gold
- Copper
- Silver

Standard Copper Wire Gauge Sizes

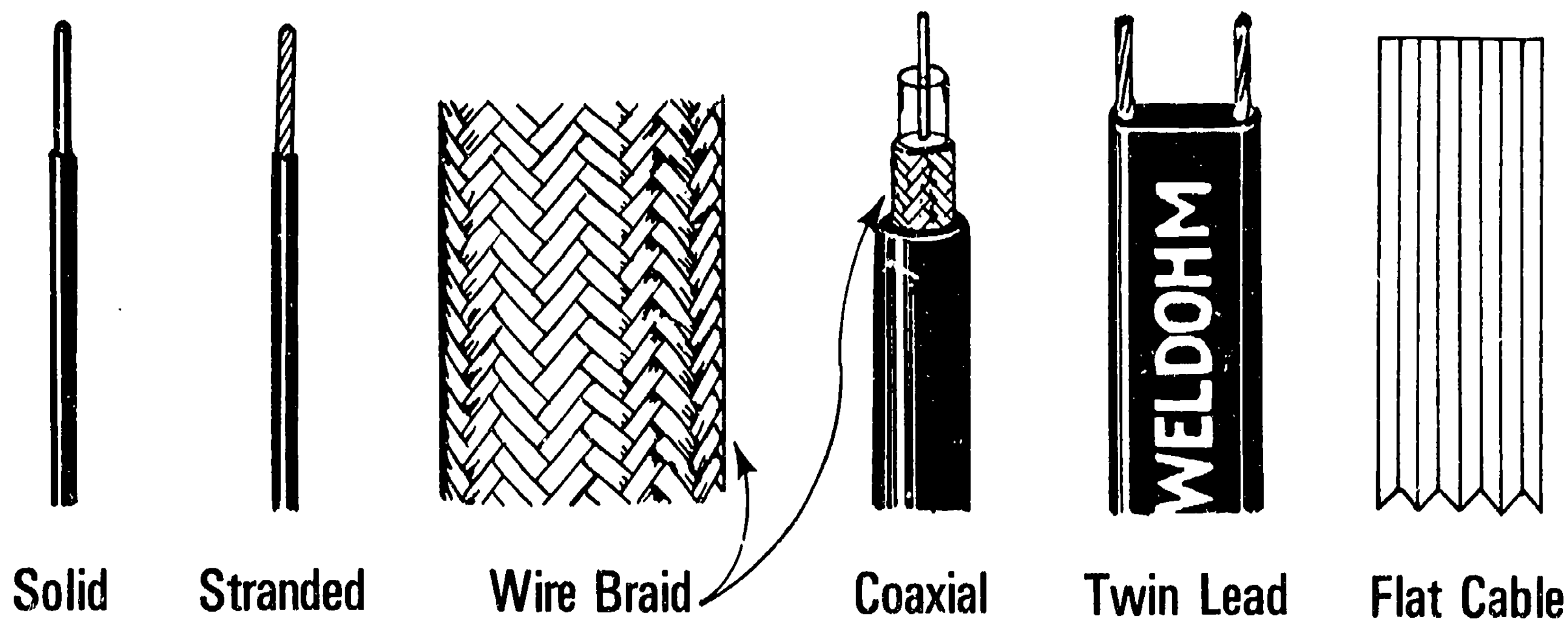


AMERICAN STANDARD WIRE GAUGE

GAUGE NO.	DIAMETER, MILS	CIRCULAR-MIL AREA	OHMS PER 1,000 FT OF COPPER WIRE AT 25°C*	GAUGE NO.	DIAMETER, MILS	CIRCULAR-MIL AREA	OHMS PER 1,000 FT OF COPPER WIRE AT 25°C*
1	289.3	83,690	0.1264	21	28.46	810.1	13.05
2	257.6	66,370	0.1593	22	25.35	642.4	16.46
3	229.4	52,640	0.2009	23	22.57	509.5	20.76
4	204.3	41,740	0.2533	24	20.10	404.0	26.17
5	181.9	33,100	0.3195	25	17.90	320.4	33.00
6	162.0	26,250	0.4028	26	15.94	254.1	41.62
7	144.3	20,820	0.5080	27	14.20	201.5	52.48
8	128.5	16,510	0.6405	28	12.64	159.8	66.17
9	114.4	13,090	0.8077	29	11.26	126.7	83.44
10	101.9	10,380	1.018	30	10.03	100.5	105.2
11	90.74	8,234	1.284	31	8.928	79.70	132.7
12	80.81	6,530	1.619	32	7.950	63.21	167.3
13	71.96	5,178	2.042	33	7.080	50.13	211.0
14	64.08	4,107	2.575	34	6.305	39.75	266.0
15	57.07	3,257	3.247	35	5.615	31.52	335.0
16	50.82	2,583	4.094	36	5.000	25.00	423.0
17	45.26	2,048	5.163	37	4.453	19.83	533.4
18	40.30	1,624	6.510	38	3.965	15.72	672.6
19	35.89	1,288	8.210	39	3.531	12.47	848.1
20	31.96	1,022	10.35	40	3.145	9.88	1,069

*20 to 25°C or 68 to 77°F is considered average room temperature.

Types of Wire Conductors



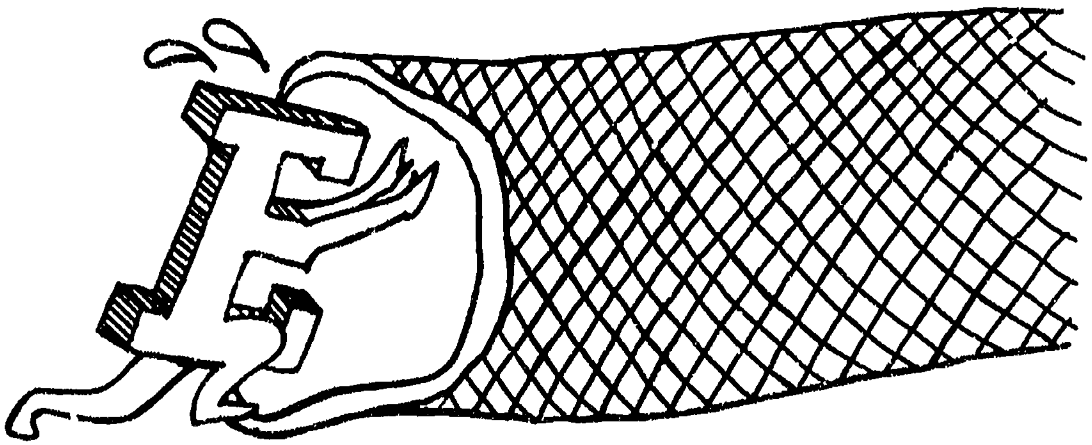
TM 10

GET-143

Dielectric Strength of Common Insulators

MATERIAL	DIELECTRIC STRENGTH, V/MIL	MATERIAL	DIELECTRIC STRENGTH, V/MIL
Air or vacuum	20	Paraffin wax	200-300
Bakelite	300-550	Phenol, molded	300-700
Fiber	150-180	Polystyrene	500-760
Glass	335-2,000	Porcelain	40-150
Mica	600-1,500	Rubber, hard	450
Paper	1,250	Shellac	900
Paraffin oil	380		

Voltage



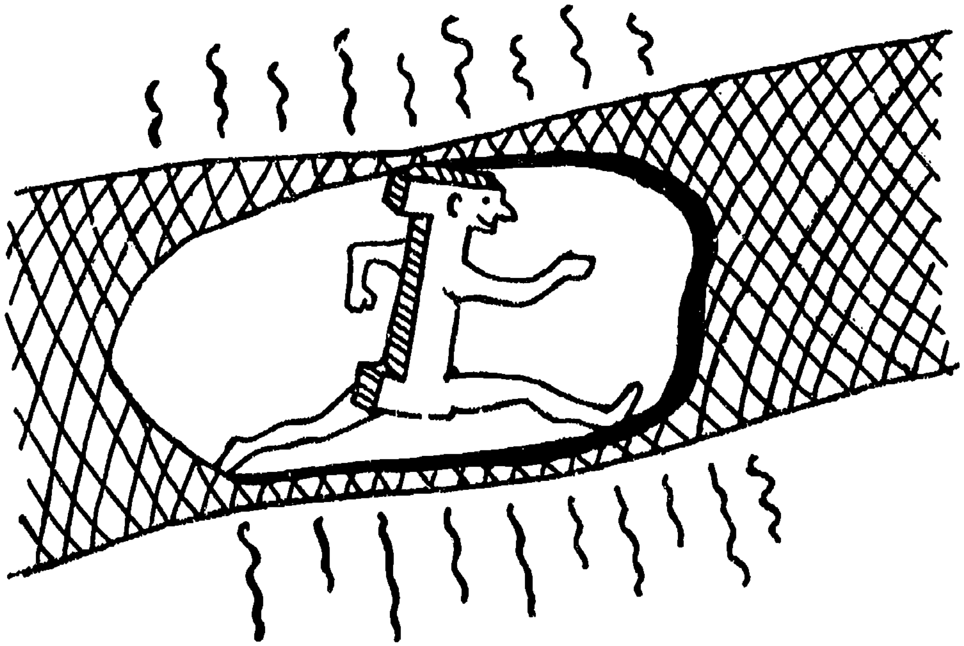
Voltage is pressure, or electromotive force

Voltage makes electrons "want to move" — Symbol: E or V

Measured in: Volts — Symbol: V

Instrument used to measure: Voltmeter. Symbol -(V)-

Current



Current is the rate of flow of electrons

Definition: The rate of electron flow through a conductor is called current flow. A flow of 6.28×10^{18} electrons per second is called an ampere.

Symbol: I

Measured in: Amperes (1 ampere = one coulomb/second)
Instrument used to measure: Ammeter.

Symbol -ⓐ- or -Ⓘ- or -Ⓐ-

Prefixes

Milli = .001 = 1/1000 = $1X10^{-3}$

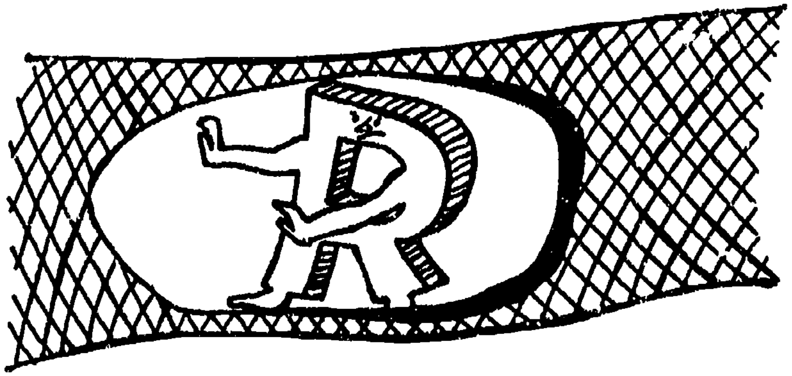
Micro = .000001 = $1X10^{-6}$ or 1/1,000,000

Pico = .000000000001 = $1X10^{-12}$ or 1/1,000,000,000,000

Kilo = 1000 = $1X10^{3}$

Mega = 1,000,000 = $1X10^{6}$

Resistance



Resistance is opposition to current flow

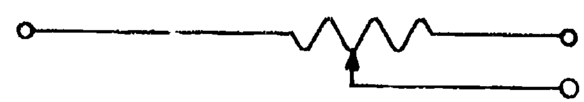
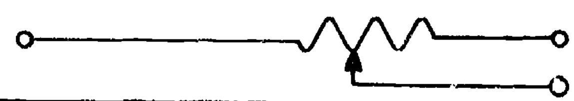
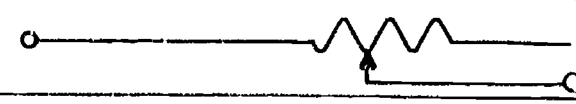
Definition: Resistance can be said to be the internal friction involved in the passing of electrons through a wire.

Symbol: R

Measured in: Ohms

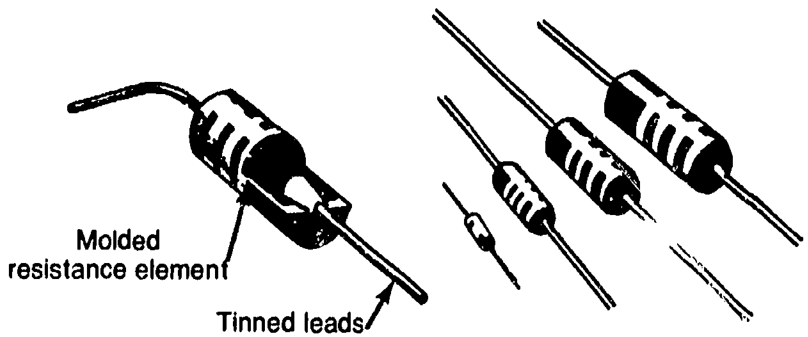
Instrument used to measure: Ohmmeter

Symbols Used For Resistance And Resistors

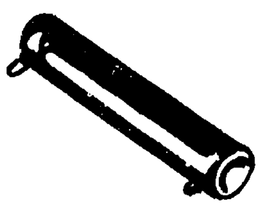
ITEM	LETTER SYMBOL	GRAPHIC (SCHEMATIC) SYMBOL
OHM	(GREEK CAPITAL LETTER "OMEGA") Ω	
KILOHM	K or KΩ	
MEGOHM	M or MΩ	
RESISTOR	R	
FIRST, SECOND, THIRD, ETC. RESISTOR	R 1, R 2, R 3, etc.	
VARIABLE (TAPPED WIRE) RESISTOR	R	
POTENTIOMETER	R	
RHEOSTAT	R	

Types Of Resistors

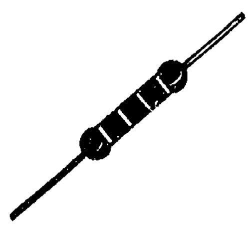
FIXED



Carbon-Composition Resistors

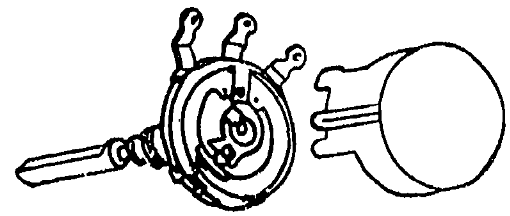


Wire-Wound Resistor

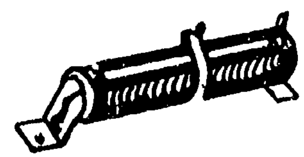


Film Resistor

ADJUSTABLE



Carbon-Composition Potentiometer



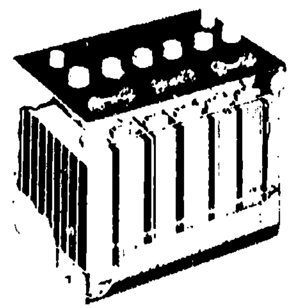
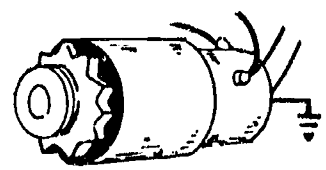
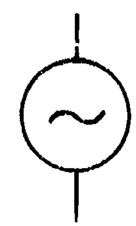
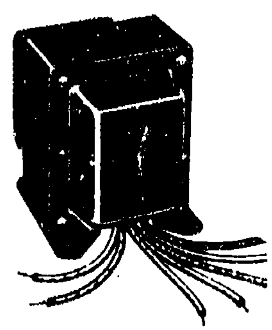
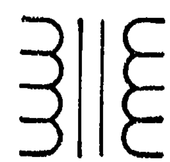
Wire-Wound
Variable Resistor

Wire-Wound
Potentiometer

Wire-Wound Rheostat

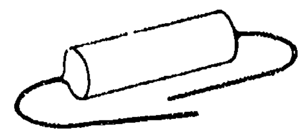
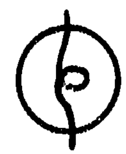
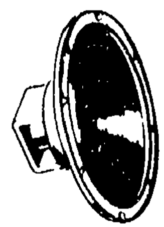
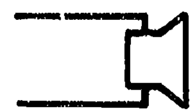
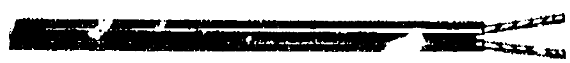
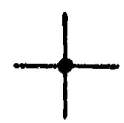
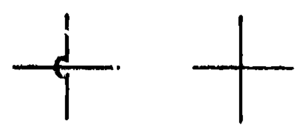
Basic Circuit Elements

(Power Sources)

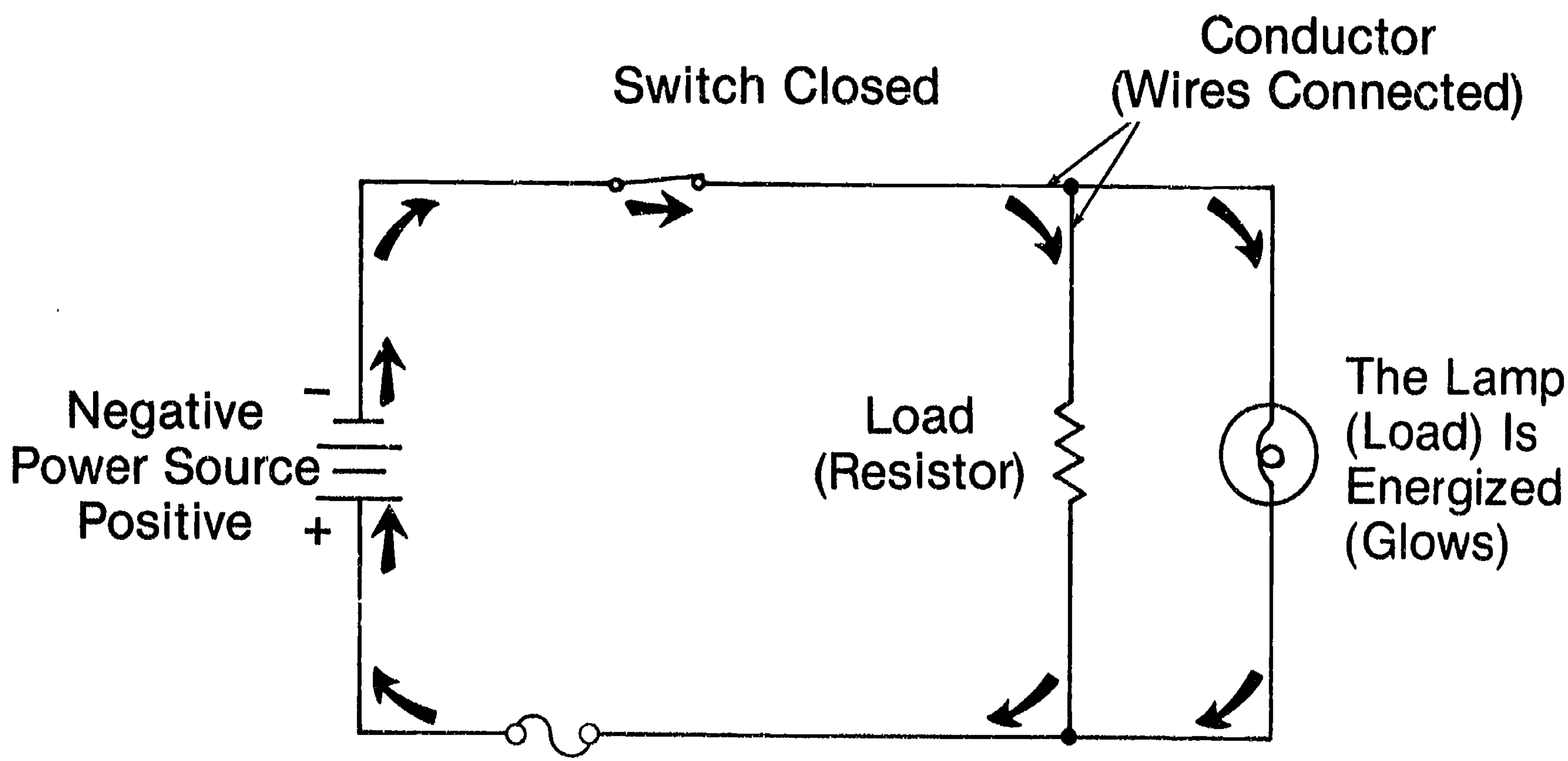
Element	Picture	Schematic Symbol
Battery		
Generator		 A.C.
Transformer		

Basic Circuit Elements

(Resistance and Load)

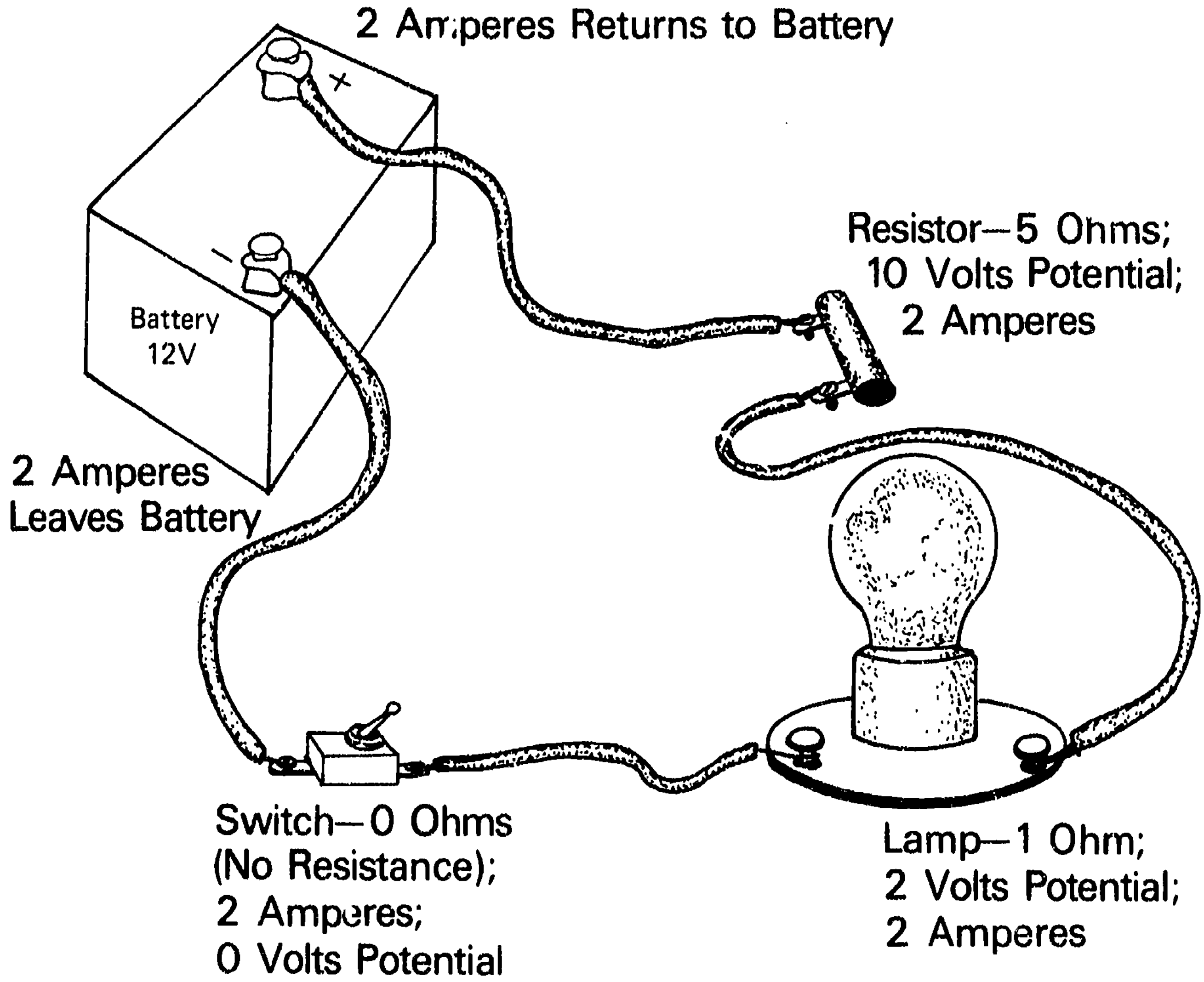
Element	Picture	Schematic Symbol
Resistor		
Lamp		
Loudspeaker		
Electrical Wires		 Connected  Not Connected

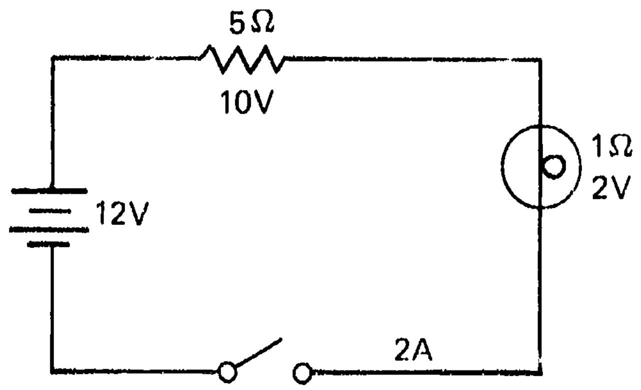
Schematic Showing Current Flow



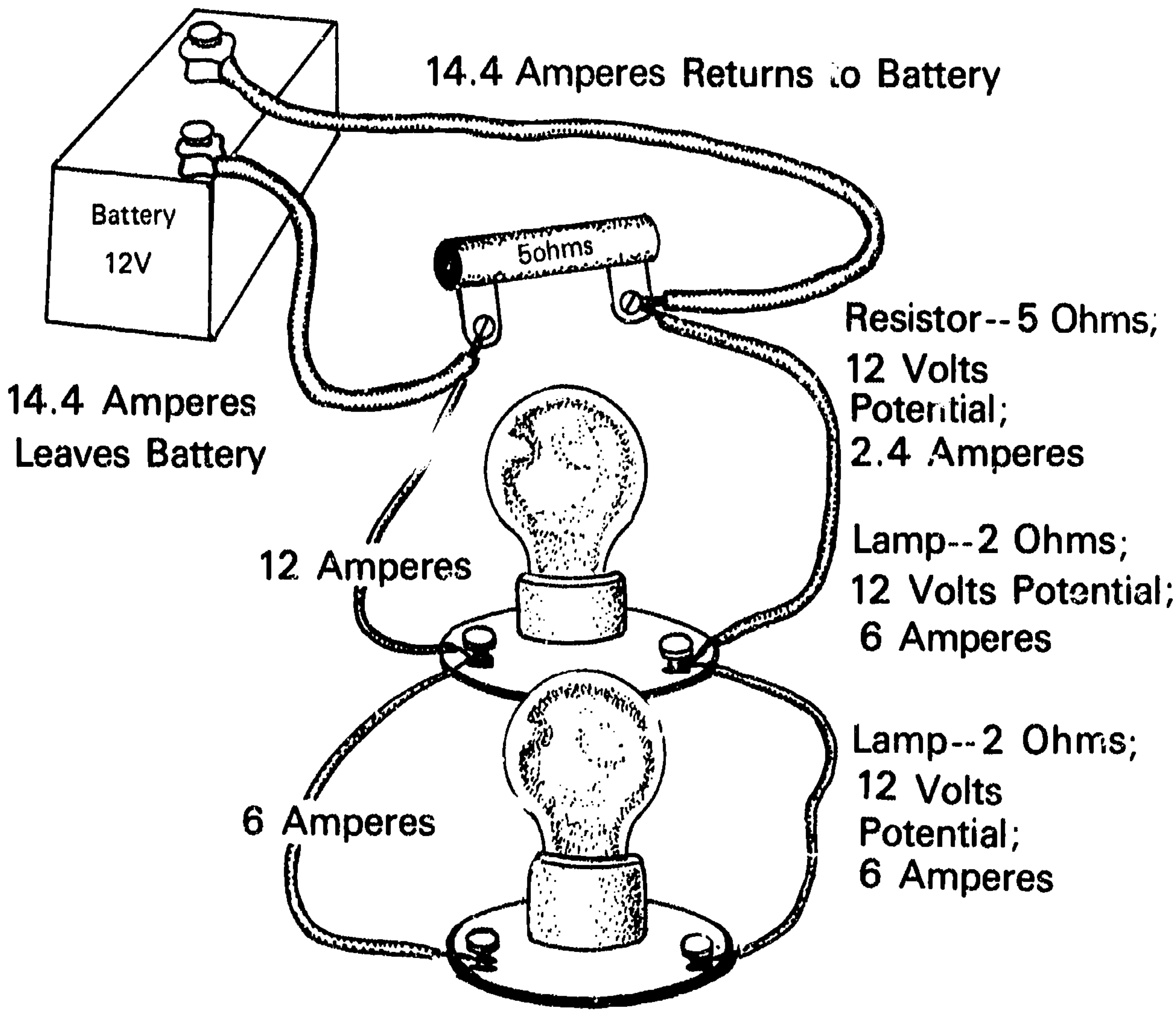
Electricity flows from the Negative (-) side of the battery, through the closed circuit, back to the Positive (+) side of the battery.

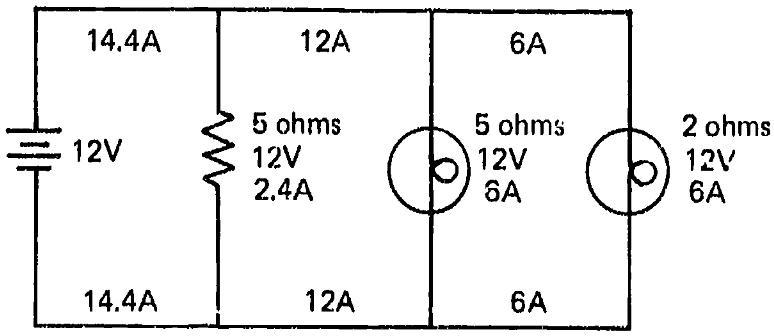
Series Circuit



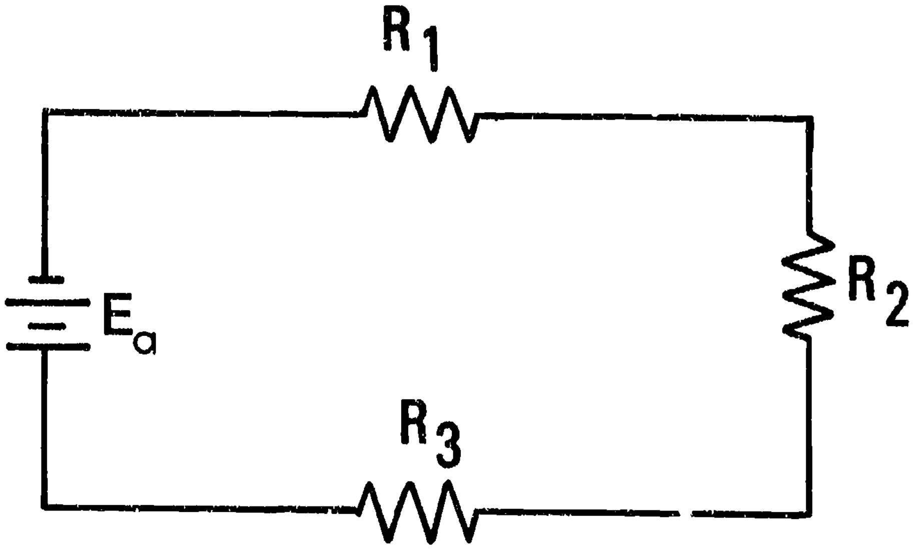


Parallel Circuit

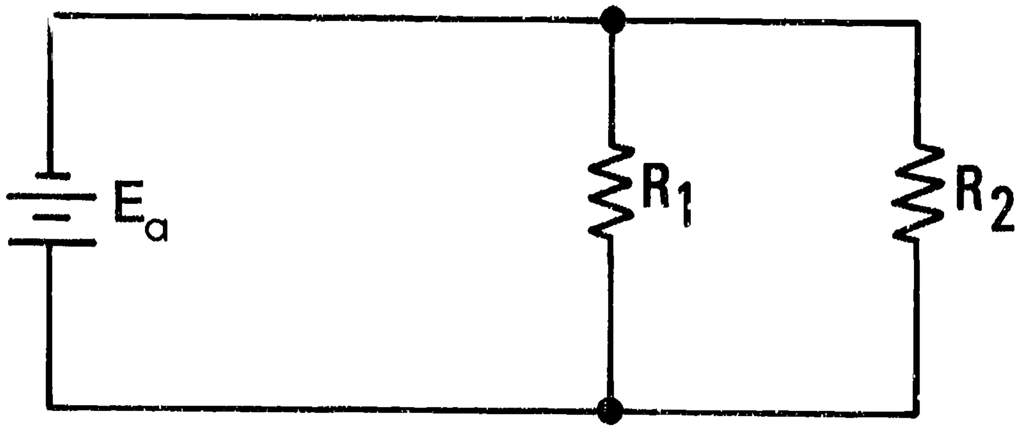




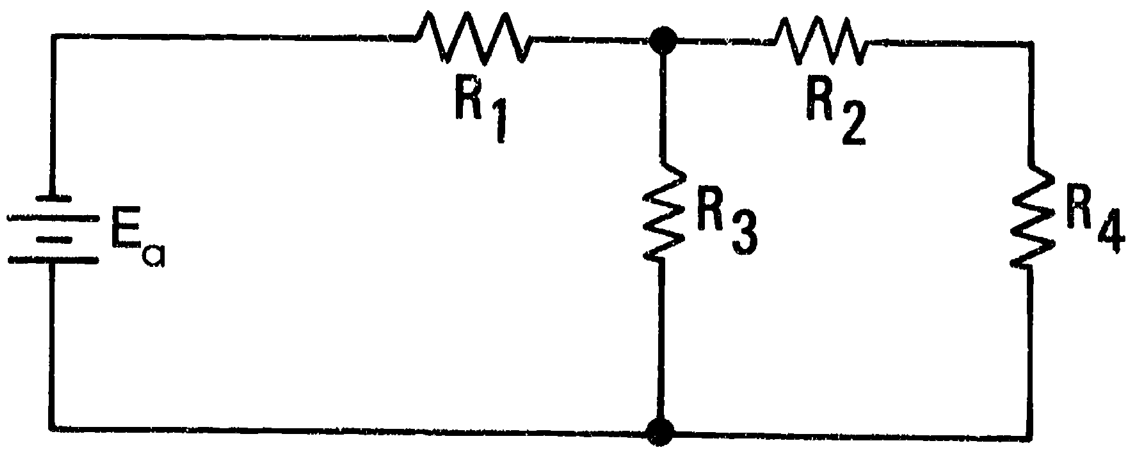
Resistive Circuits



Series Circuit

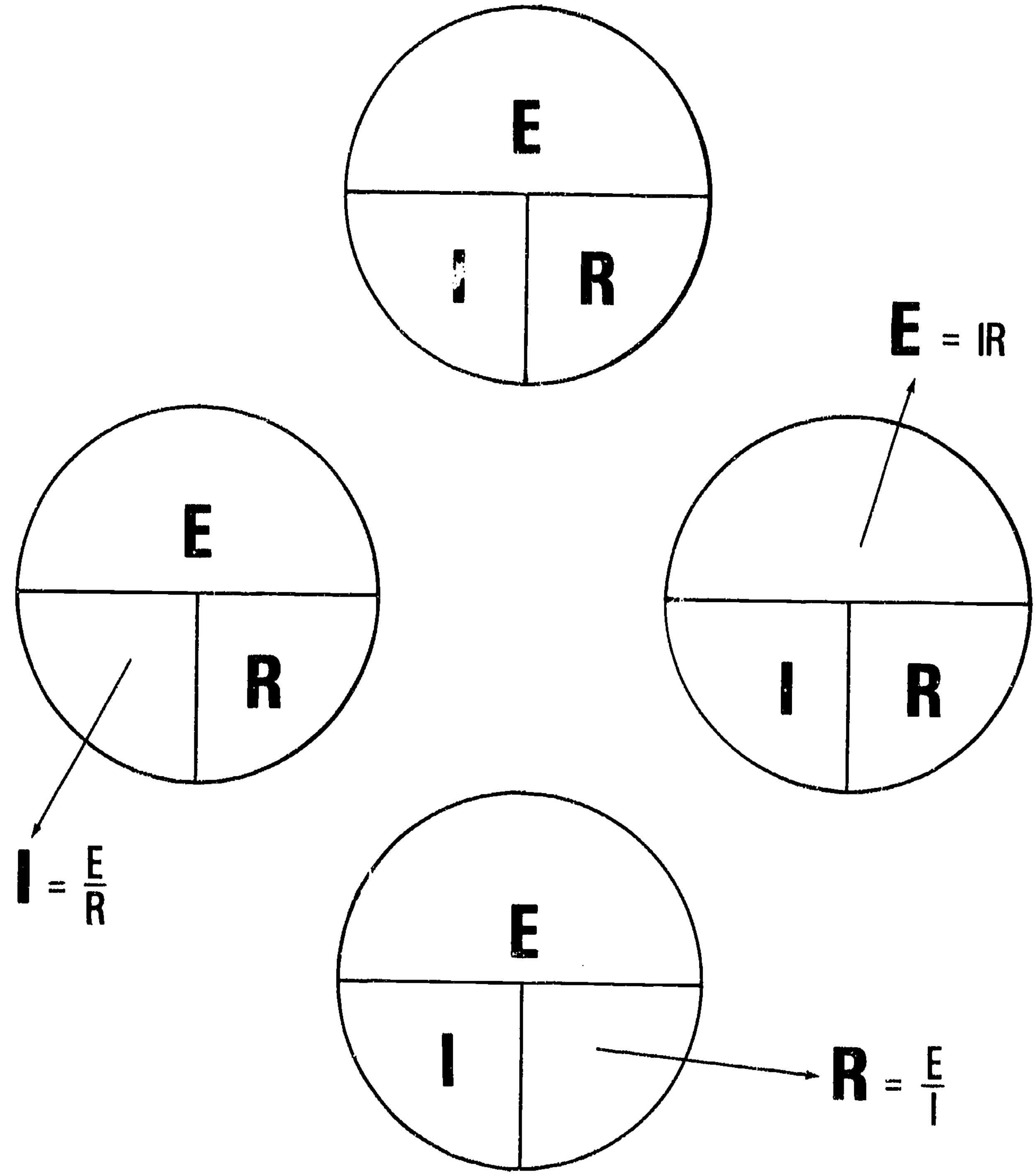


Parallel Circuit

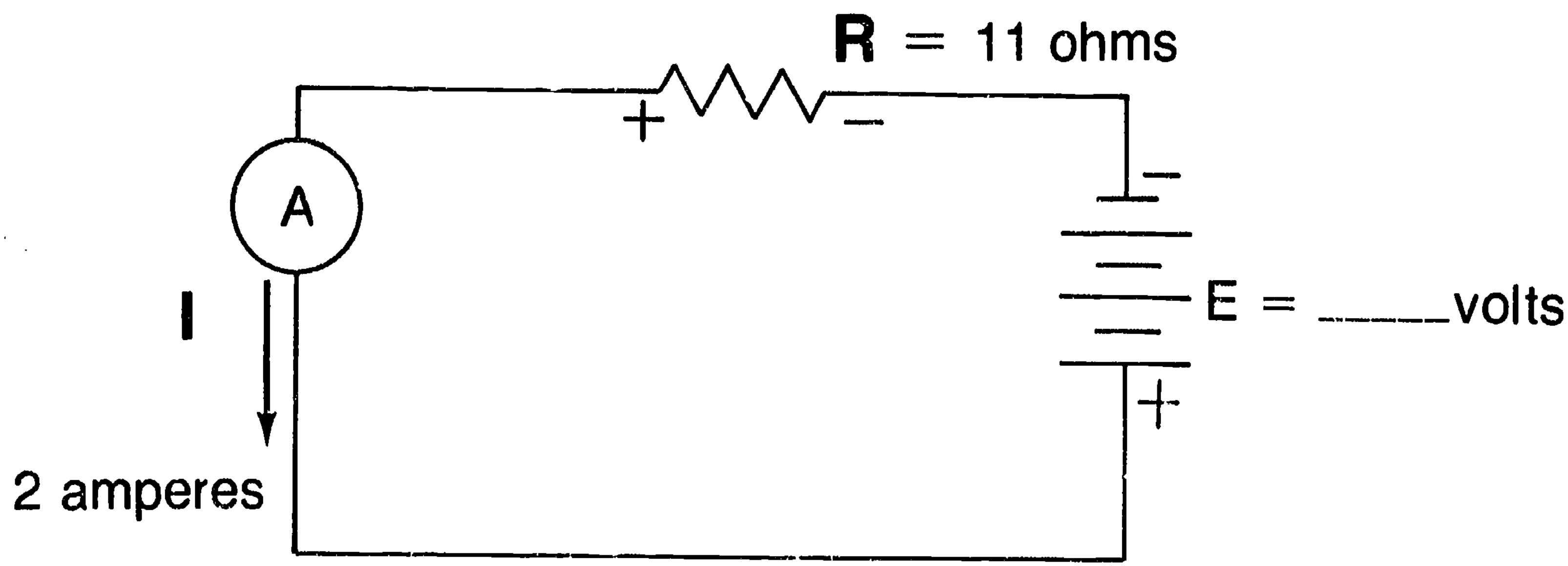


Series-Parallel Circuit

Ohm's Law — Memory Wheel



Ohm's Law — Computing Voltage

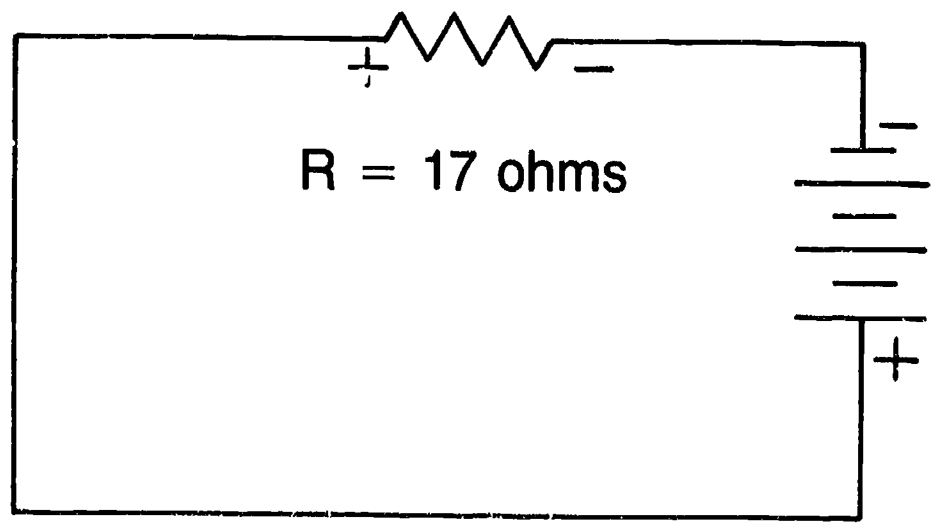


What voltage is being supplied by the battery?

E = IR   E = 2 amperes x 11 ohms, E = 22 volts

The value of the voltage being supplied by the battery is 22.

Ohm's Law — Computing Current



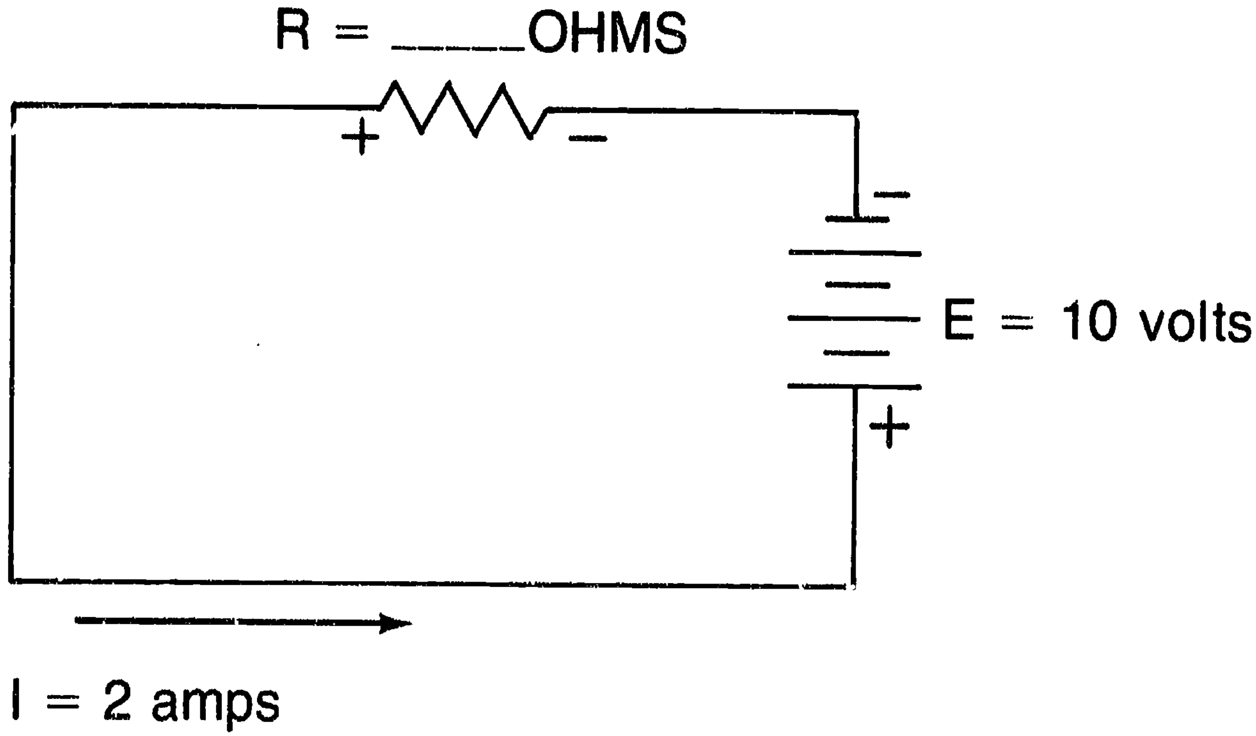
E= 68 Volts

I = _____ amps

How many amperes of current are flowing in this circuit?

$E = IR$ $\qquad I = \frac{E}{R}$ $\qquad I = \frac{68 \text{ volts}}{17 \text{ ohms}} = 4 \text{ amperes}$

Ohm's Law — Computing Resistance



What is the resistance value of the resistor in this circuit?

$E = IR \qquad R = \frac{E}{I} \qquad R = \frac{10 \text{ volts}}{2 \text{ amperes}} = 5 \text{ ohms}$

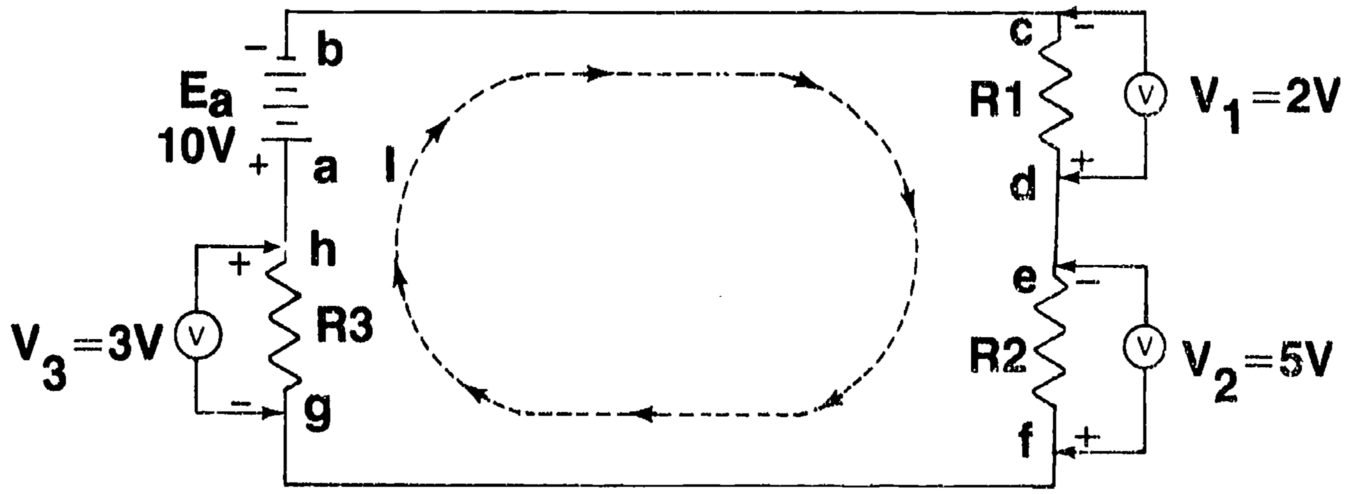
Power

- Is defined as the rate of doing work (w/t)
- Has the symbol "P"
- Can be calculated with formulas $P = IE$, $P = I^2 R$, $P = E^2/R$ Watt's Law
- Is measured in watts 1 watt = 1 ampere x 1 volt
- Is measured by a wattmeter

Kirchhoff's Law of Voltage

The algebraic sum of the voltages around a closed loop must equal the applied voltage.

Voltage Drops in a Resistive Circuit



Applied Voltage (E) = 10V

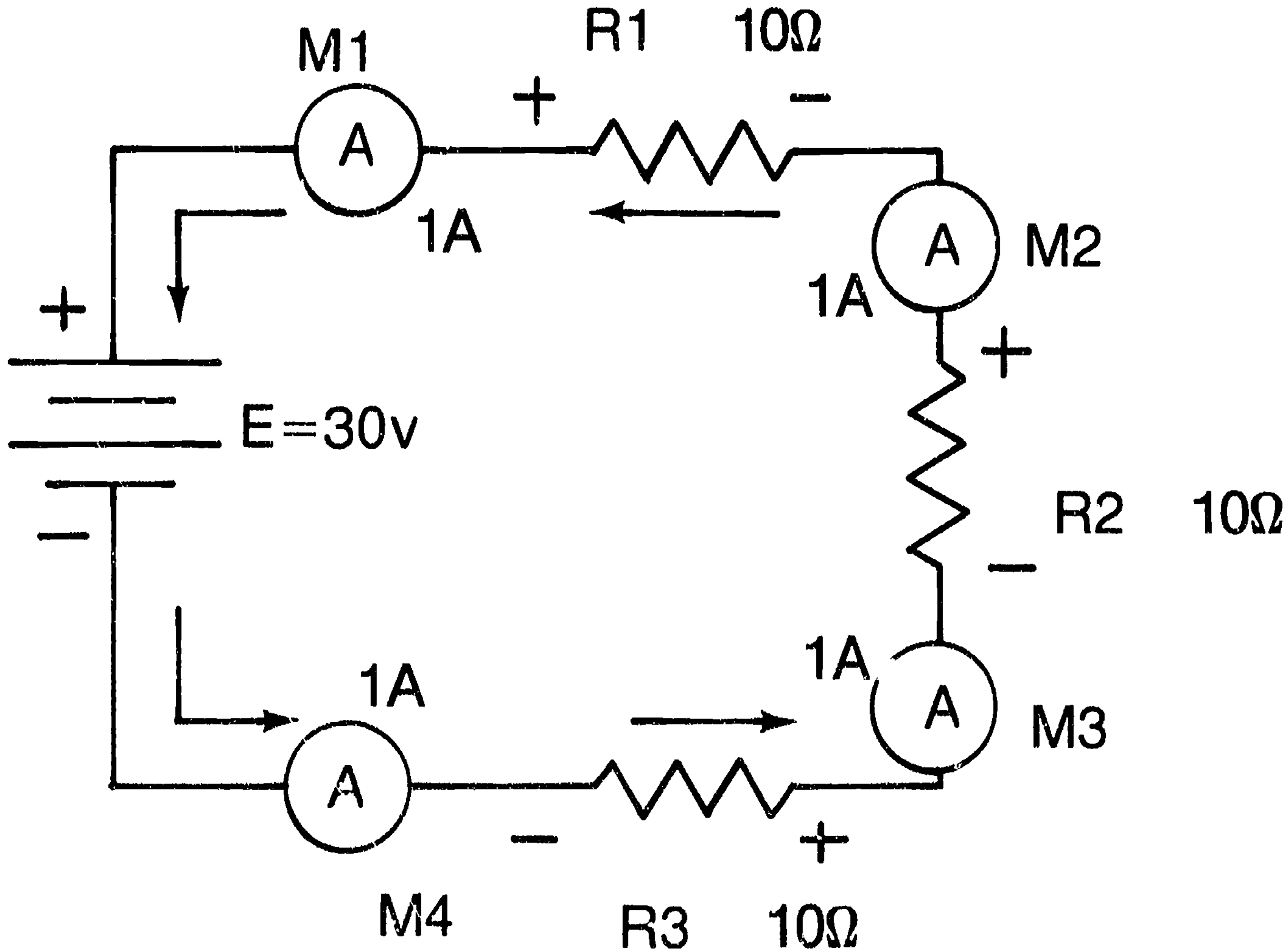
Direction of Electron Flow: Negative (b) to Positive (a)

Application of Kirchhoff's Law of Voltage:

$$V_1 + V_2 + V_3 = E_a$$

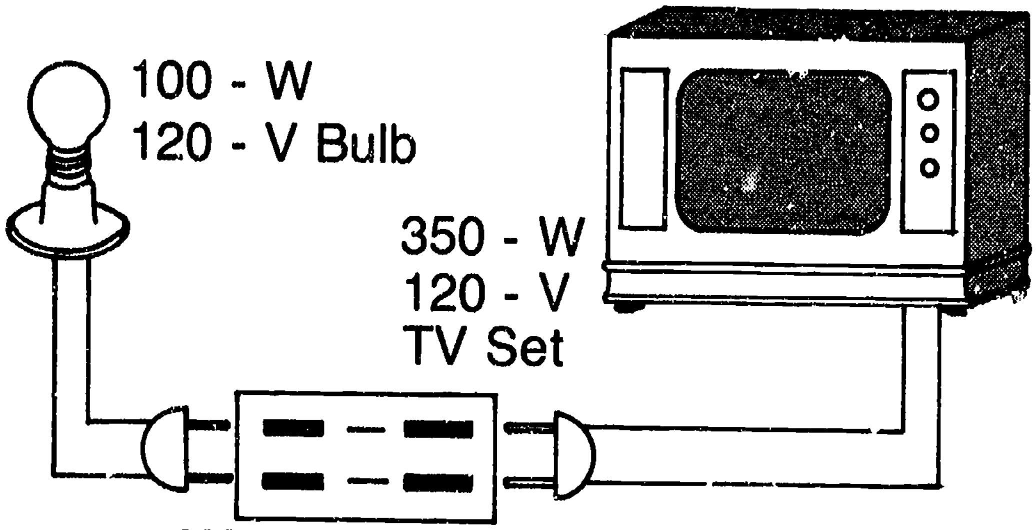
$$2V + 5V + 3V = 10V$$

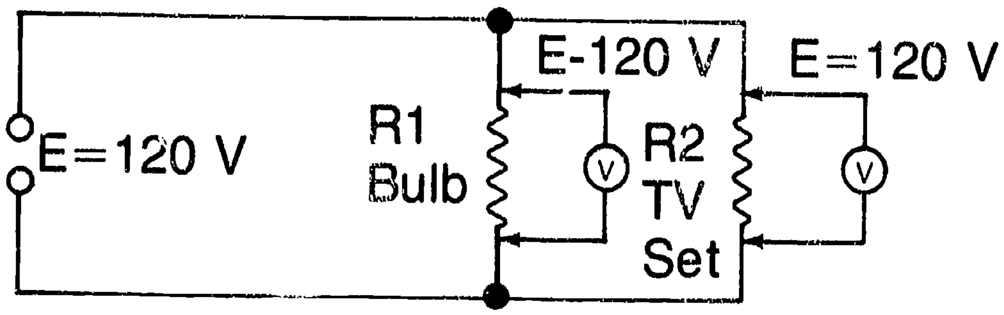
Current in a Series Circuit



Current measured by M1 will equal that of M2, M3 or M4.

Parallel Circuit



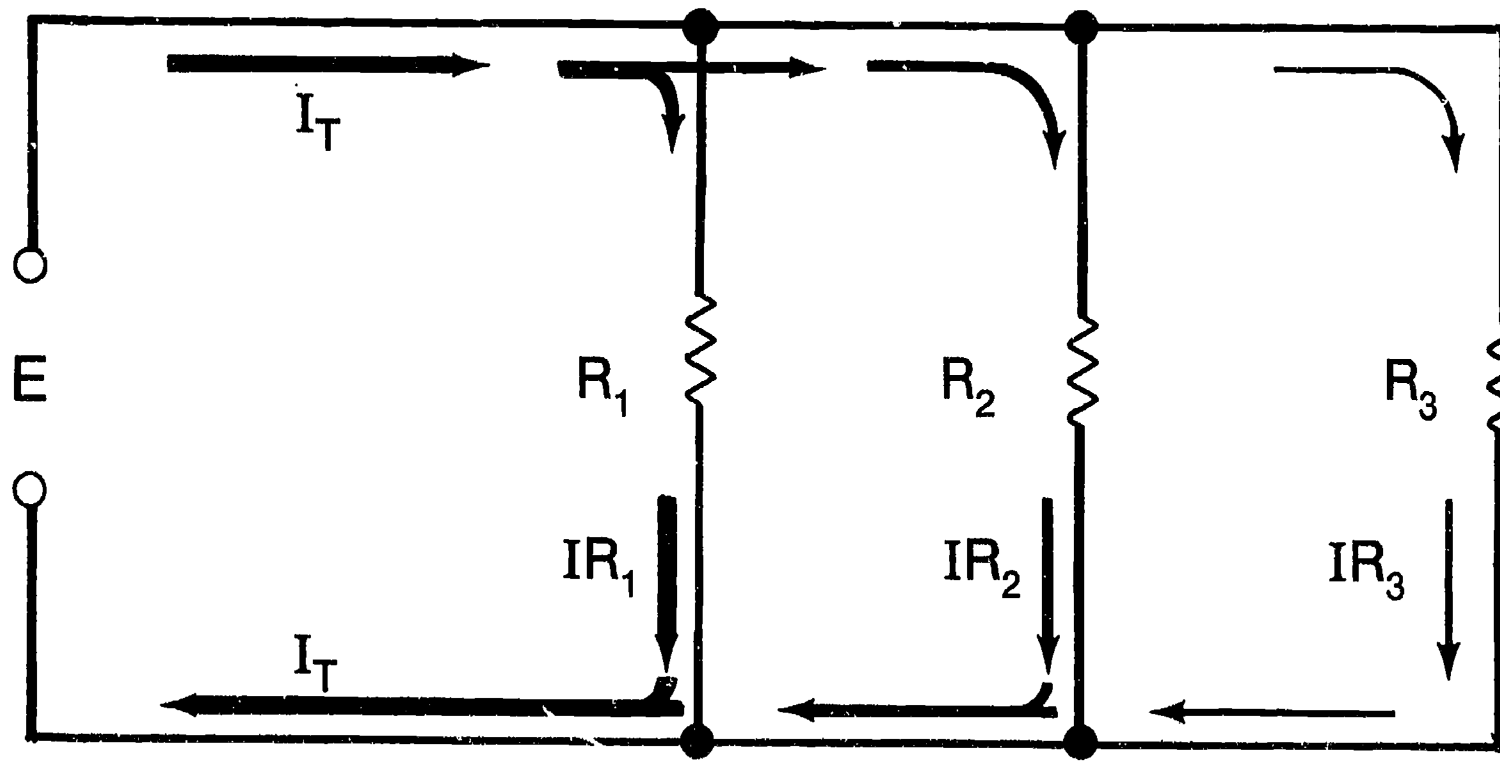


This circuit provides two paths for current flow: Through R1 (Bulb) and through R2 (TV Set).

Note that the voltage across both the bulb and the TV set is the same as the applied voltage (120 v).

Current Flow in a Parallel Circuit

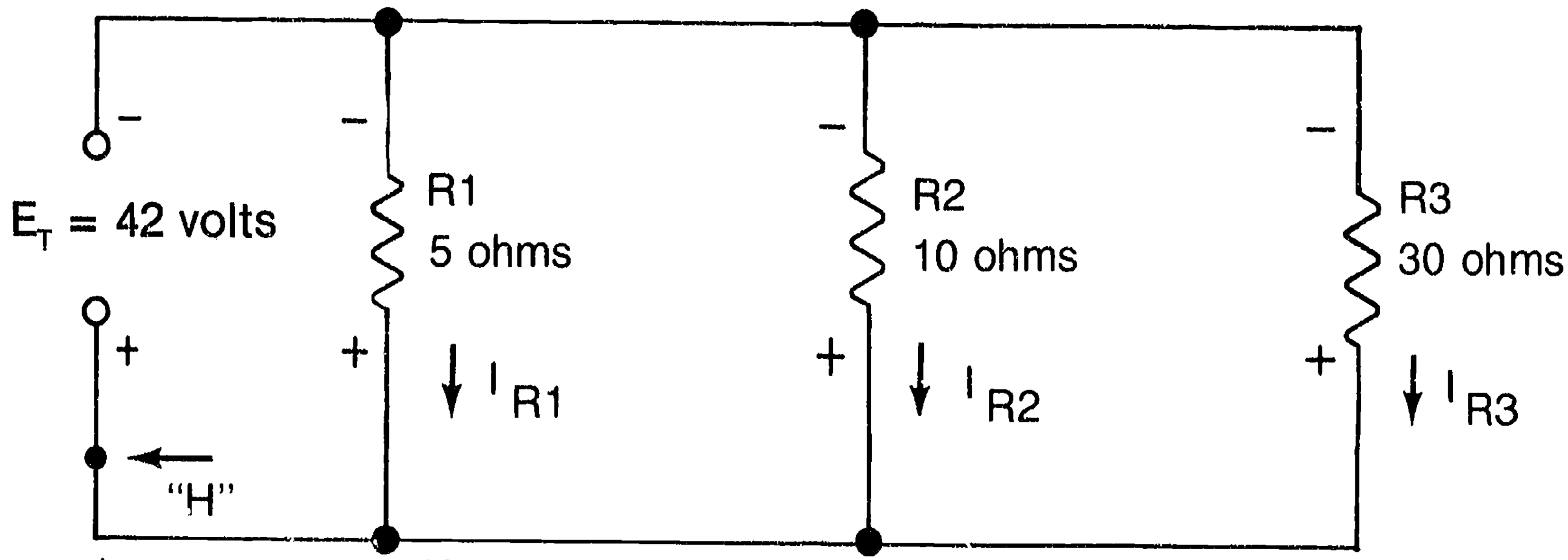
(Kirchhoff's Current Law)



The total current flowing through a parallel circuit is the sum of the currents flowing through each branch.

In the above circuit: $I_T = I_{R1} + I_{R2} + I_{R3}$

Finding Current in a Parallel Circuit



I_T =________(Amperes)

How much current is passing through point "H" in this circuit? There are two methods for determining total current in this circuit:

1. Find the current flowing through each branch (ex.: I_{R1} $\frac{E}{R1}$), then add all 3 branch currents ($I_T = I_{R1} + I_{R2} + I_{R3}$).
2. Find the total resistance using the reciprocal resistance formula, then calculate total current ($I_T = \frac{E}{R_T}$).

Resistance in Parallel Circuits

The reciprocal of the total resistance of a parallel circuit is equal to the sum of the reciprocals of the individual resistances

or

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5} + \cdots$$

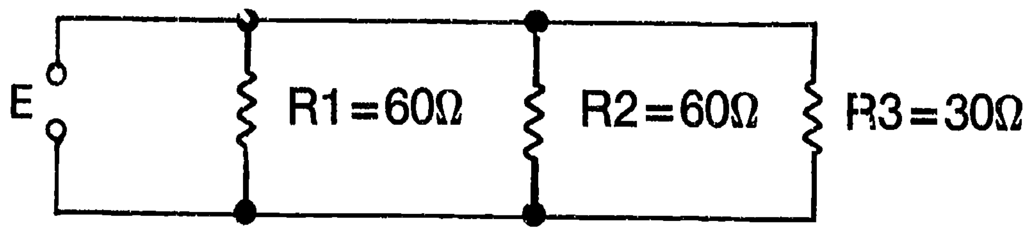
or

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5} + \ldots}$$

The Reciprocal Resistance Method

For Calculating Total Resistance

in a Parallel Circuit: $1/R_T = 1/R1 + 1/R2 + 1/R3$



Step 1: Find Least Common Denominator and Add the Reciprocals:

Common Denominator = 60

Reciprocal of $R_1 = \frac{1}{60}$

Reciprocal of $R_2 = \frac{1}{60}$

Reciprocal of $R_3 = \frac{2}{60}$

$\frac{1}{60} + \frac{1}{60} + \frac{2}{60} = \frac{4}{60}$ = Total of Reciprocals

Step 2: Invert the Reciprocals:

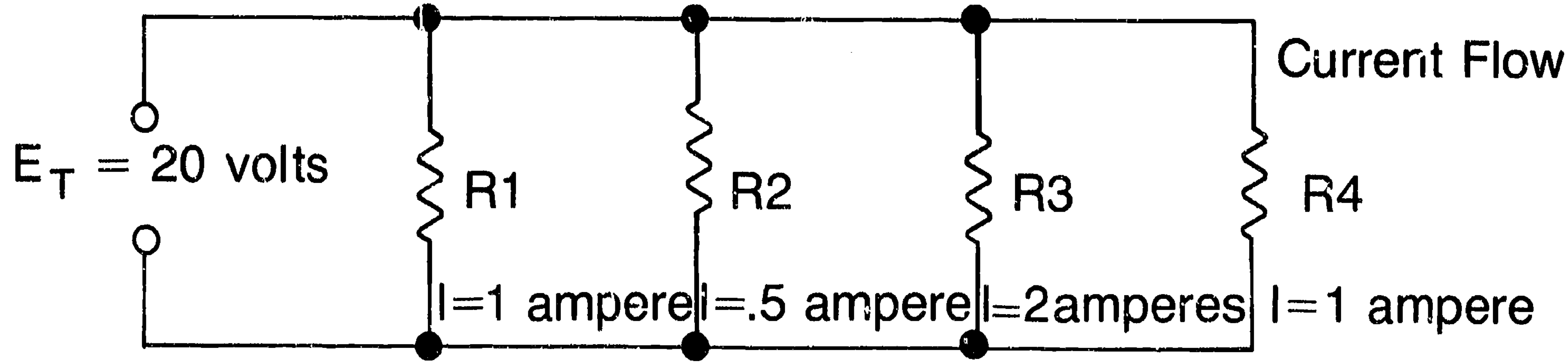
$$\frac{1}{R_T} = \frac{4}{60}$$

$$R_T = \frac{60}{4}$$

Step 3: Solve For R_T: $R_T = 15\Omega$

(Less Than Any of the Individual Resistors)

Finding the Total Resistance in Parallel Circuits



$$R_T = \frac{E_T}{I_T} = \frac{E_T}{I_T} = 4.4 \text{ ohms}$$

$$R1 = \frac{20 \text{ volts}}{1 \text{ ampere}} = 20 \text{ ohms}$$

$$R2 = \frac{20 \text{ volts}}{.5 \text{ ampere}} = 40 \text{ ohms}$$

$$R3 = \frac{20 \text{ volts}}{2 \text{ amperes}} = 10 \text{ ohms}$$

$$R4 = \frac{20 \text{ volts}}{1 \text{ ampere}} = 20 \text{ ohms}$$

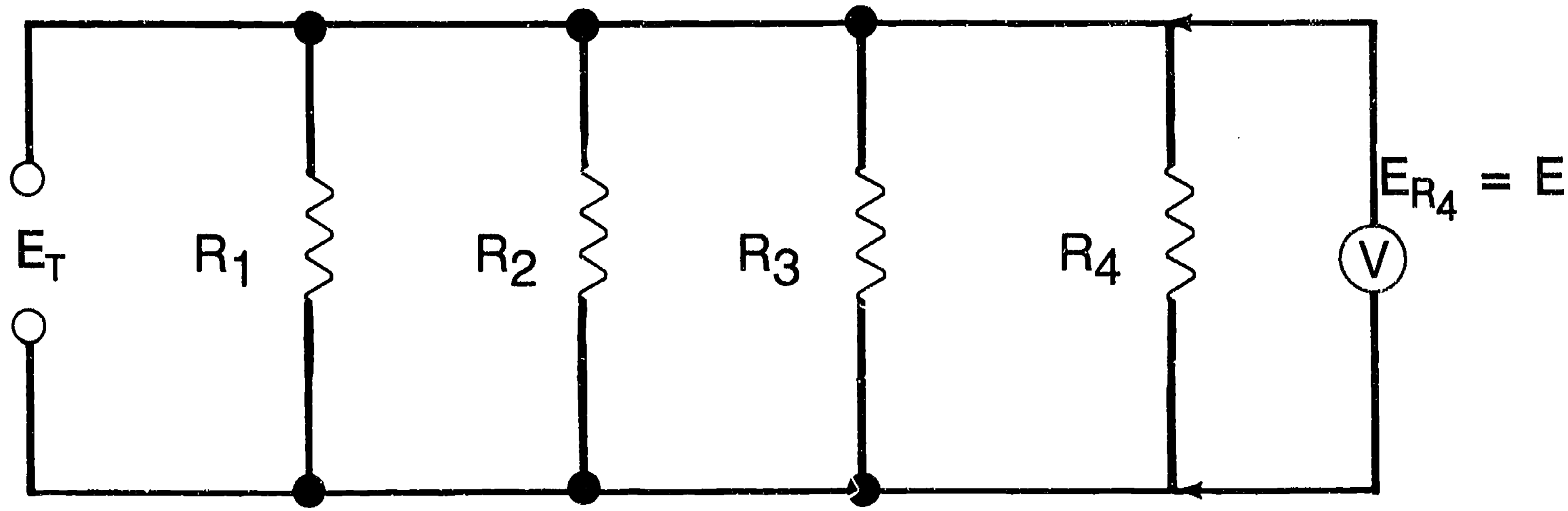
$$\frac{1}{R_T} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \frac{1}{R4}$$

$$\frac{1}{R_T} = \frac{1}{20} + \frac{1}{40} + \frac{1}{10} + \frac{1}{20}$$

$$\frac{1}{R_T} = \frac{2 + 1 + 4 + 2}{40} = \frac{9}{40}$$

$$R_T = \frac{40}{9} = 4.4 \text{ ohms}$$

Voltage in a Parallel Circuit



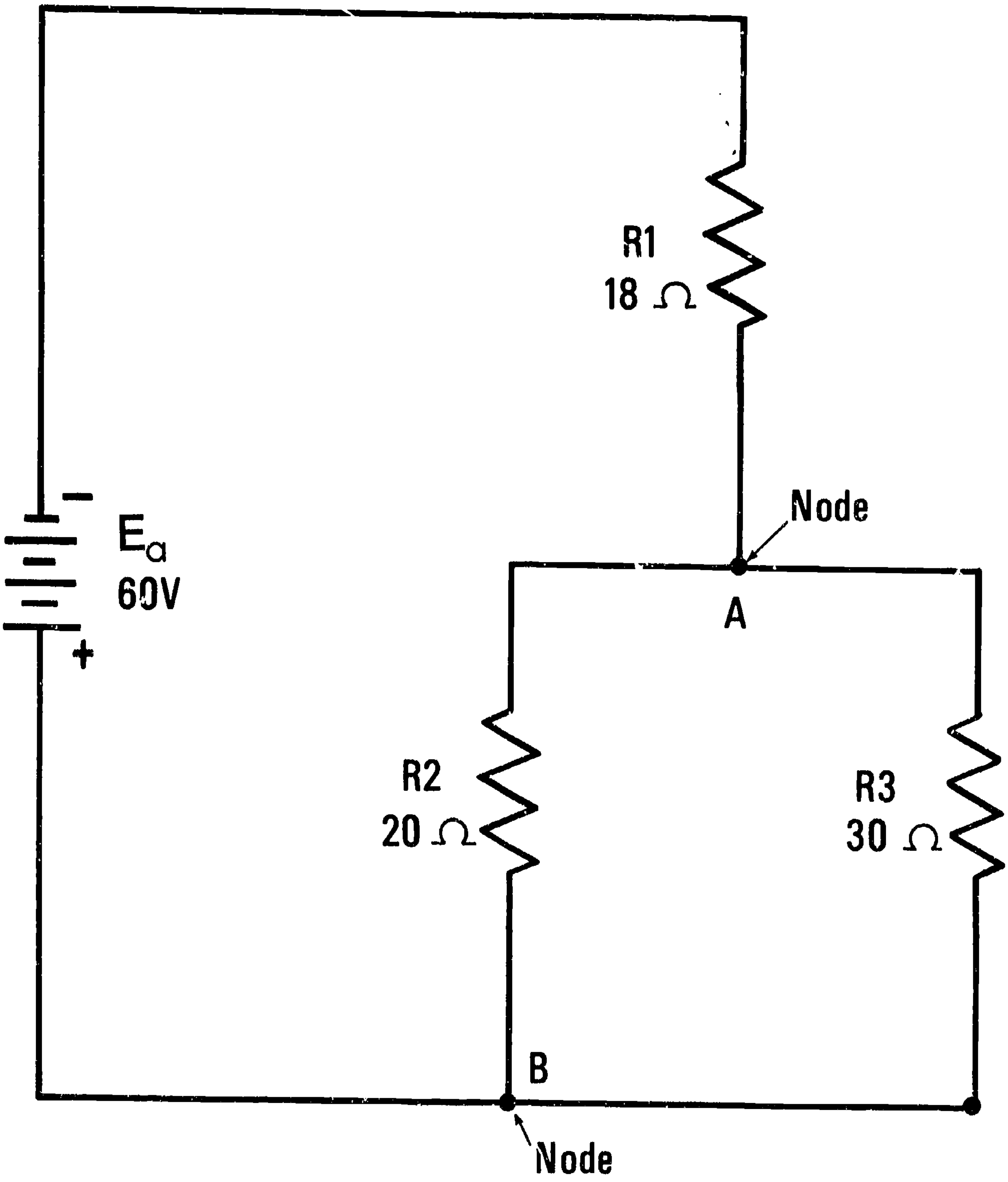
The voltage across each branch of a parallel circuit is the same value.

or

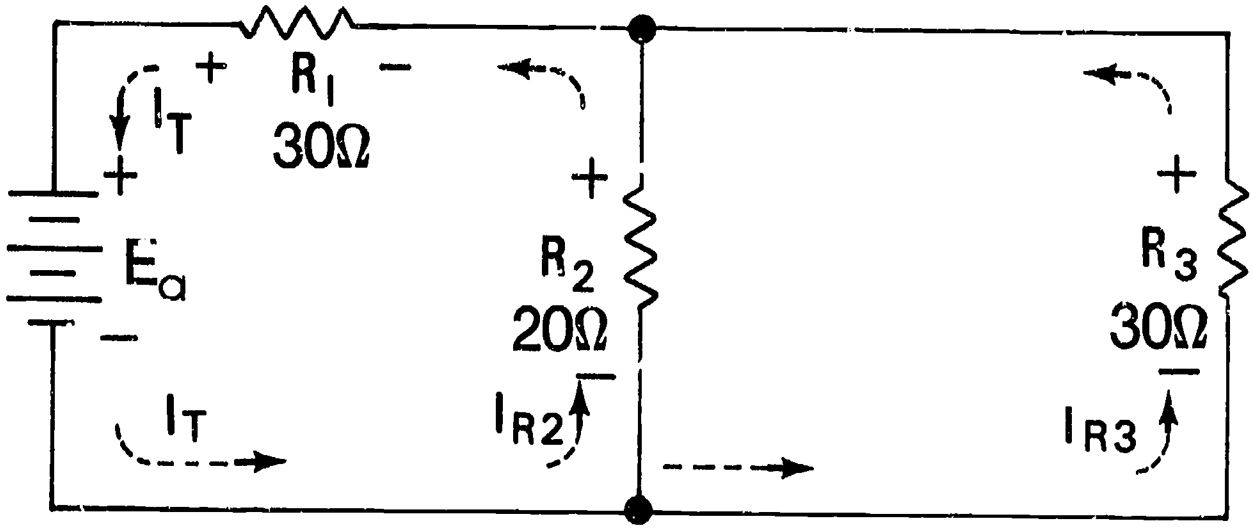
$$E_T = E_{R_1} = E_{R_2} = E_{R_3} = \ldots$$

Series-Parallel Circuit

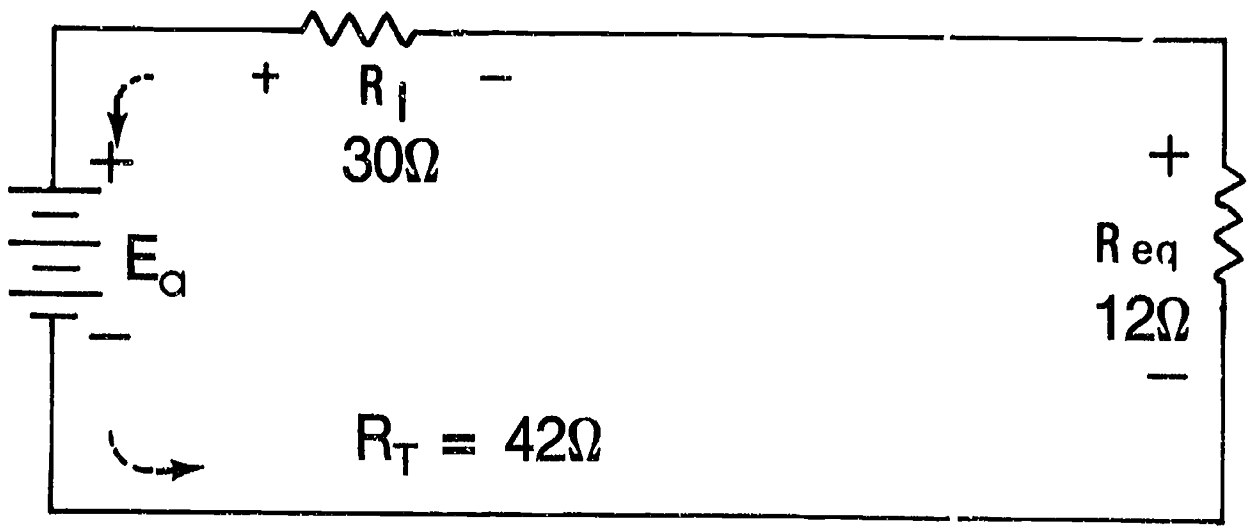
R1 is in Series with the Parallel Branches R2–R3



Series-Parallel Circuit and Equivalent Circuit

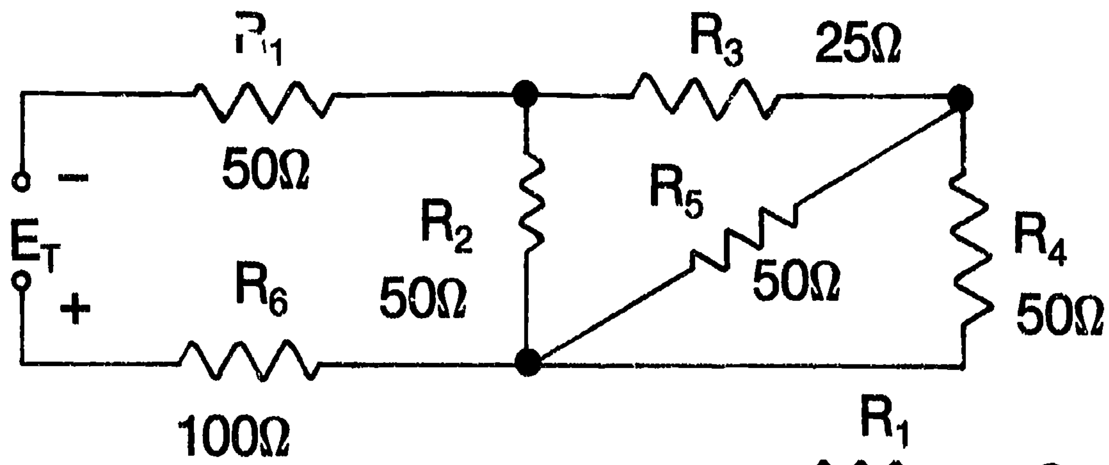


Circuit

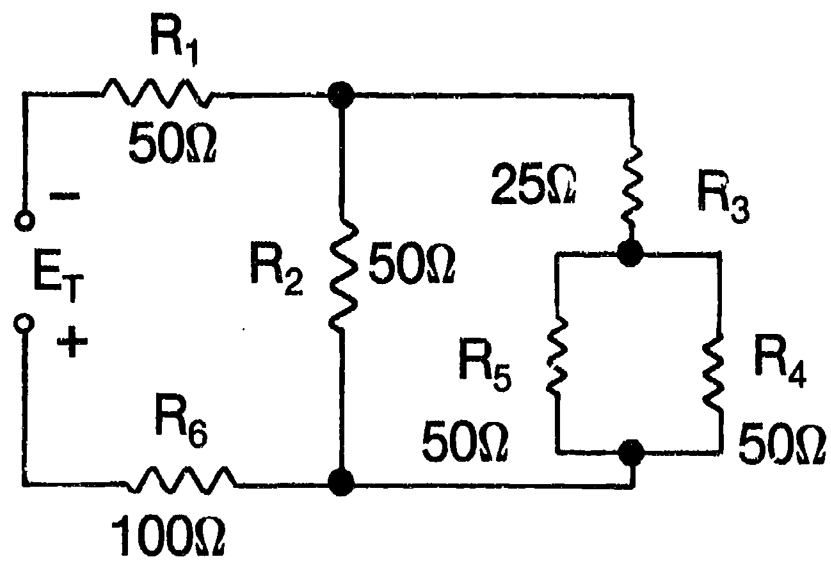


Equivalent Circuit

Circuit Reduction



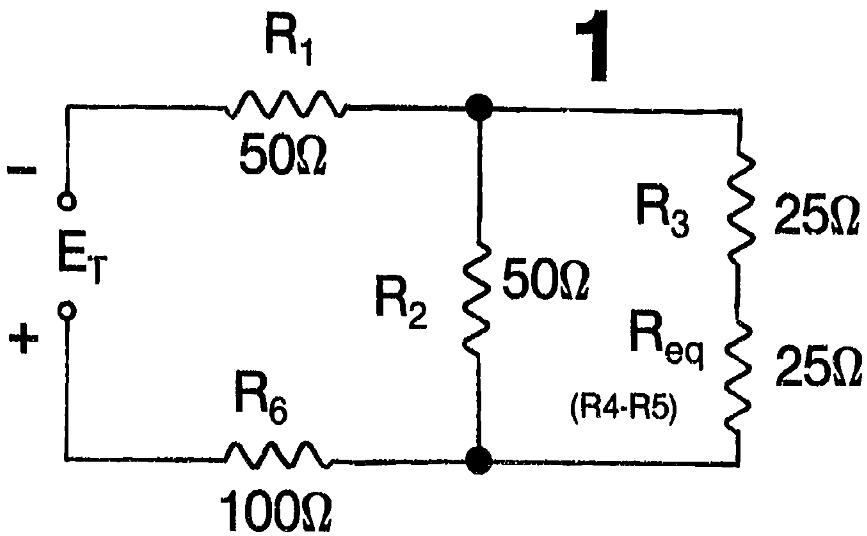
Step A: Trace Current Flow and Re-Draw Circuit

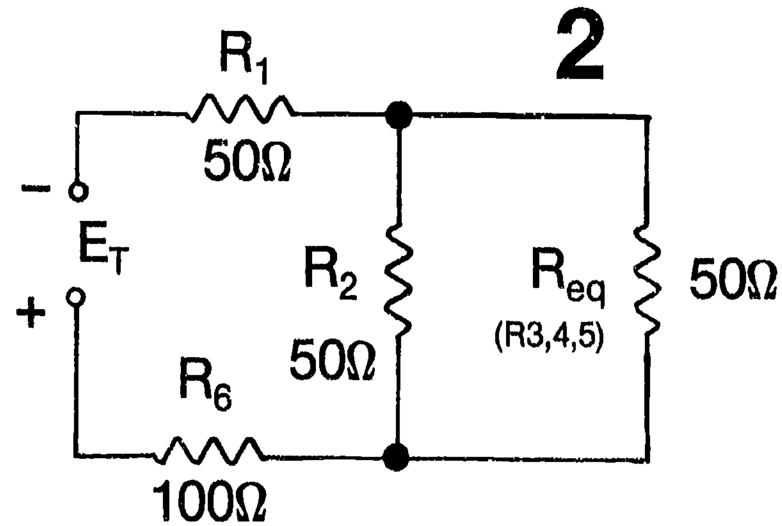


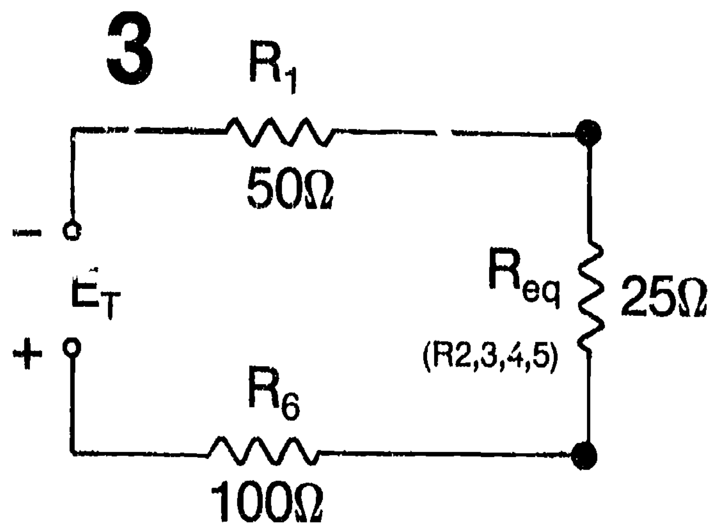
Circuit Reduction

(Continued)

Step B: Reduce Circuit

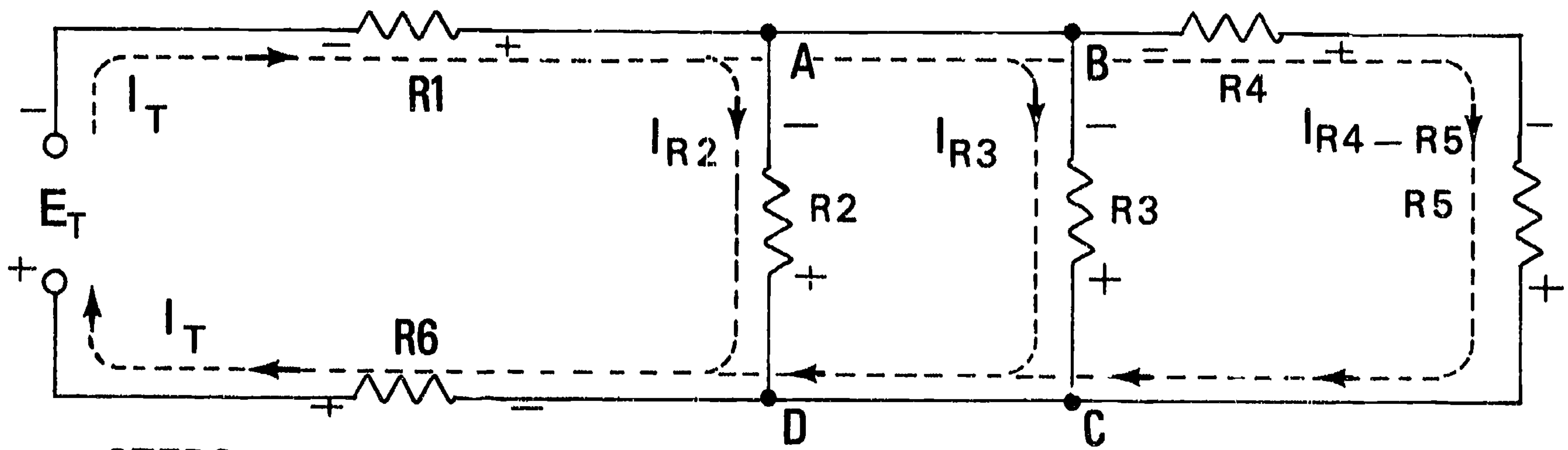






$R_T = R_1 + R_{eq} + R_6 = 175\Omega$

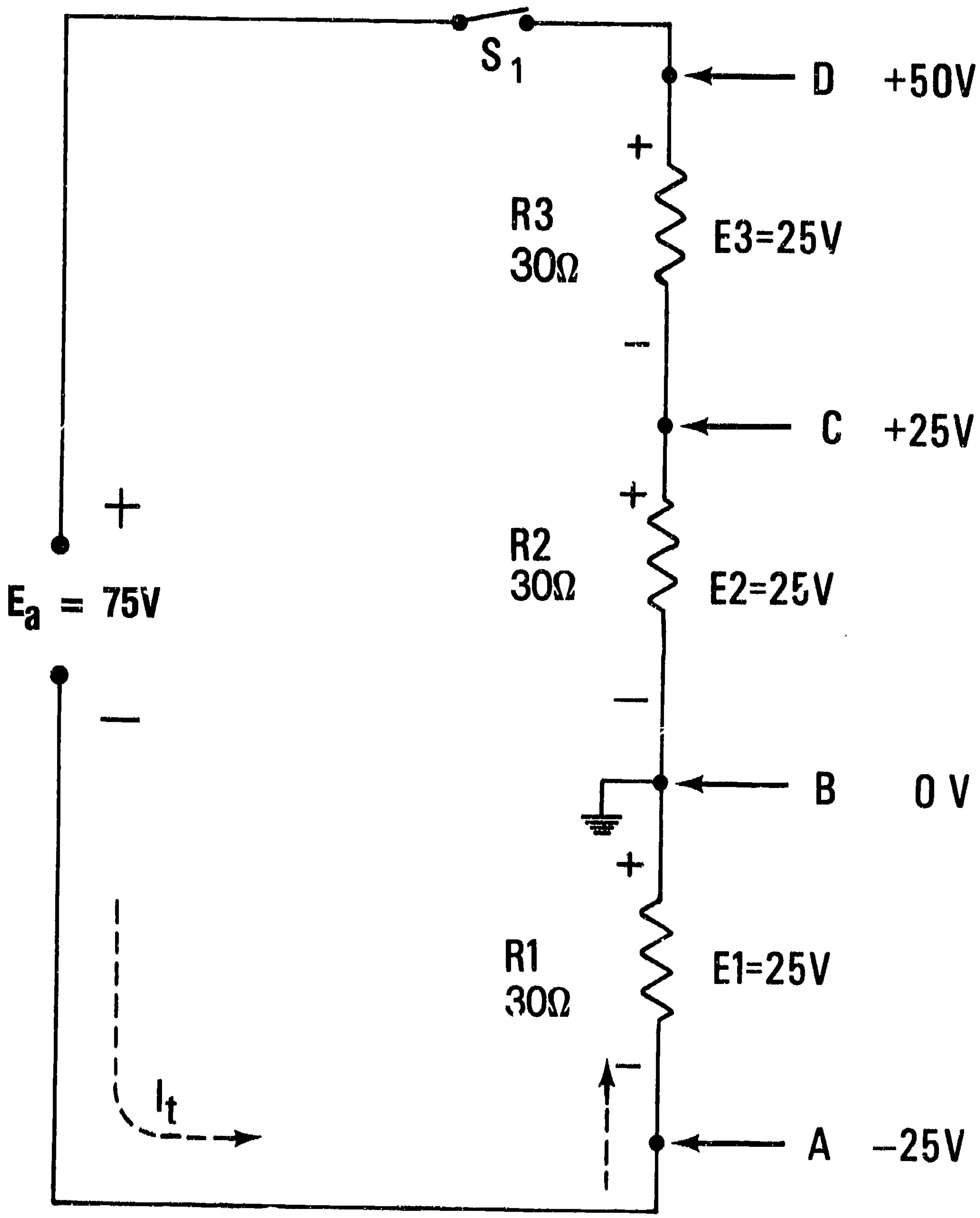
Steps to Simplify a Series-Parallel Circuit



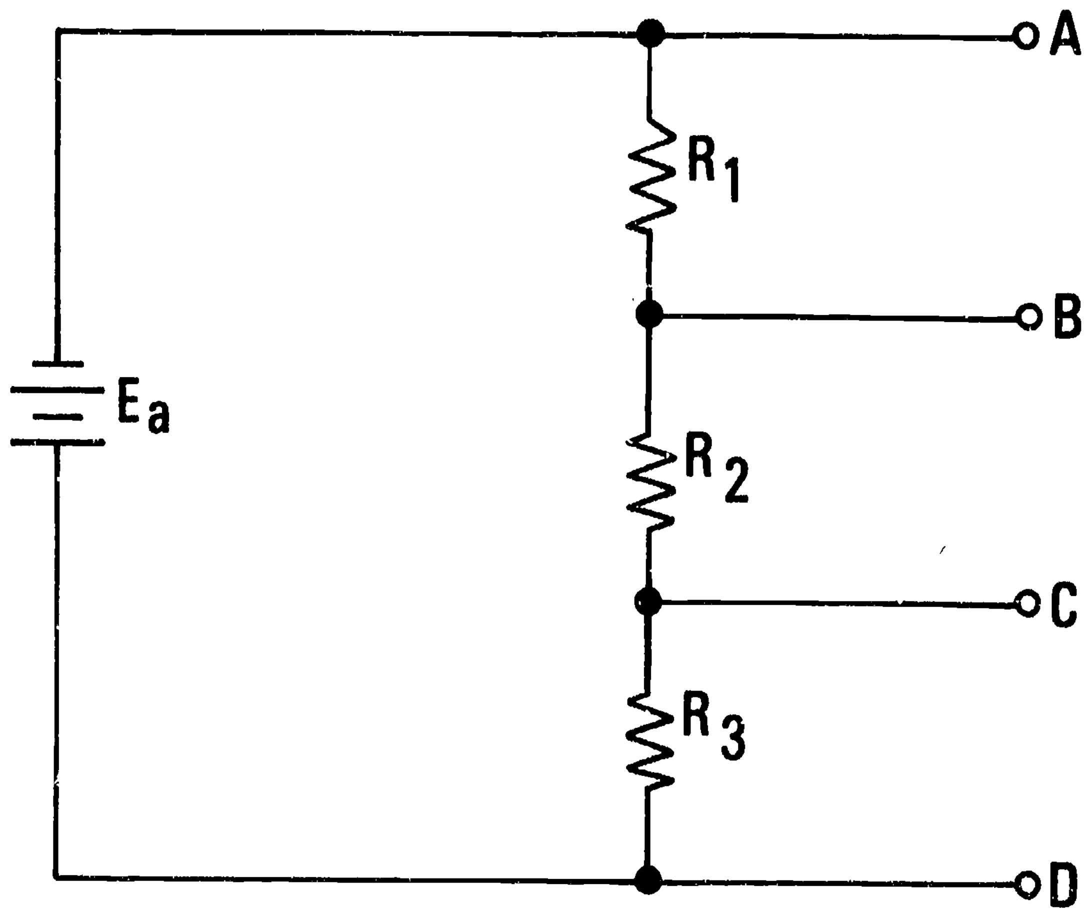
STEPS:

1. Trace Current Flow and Identify Voltage Drop Polarity (See Above)
2. Identify Nodes
   a. Current Division — A & B
   b. Current Return — C & D
3. Identify Resistors in Series With E_T: R1 & R6
4. Identify Resistors in Parallel: R2, R3, & (R4 + R5)
5. Identify Series-Parallel Resistors:
   a. R2, R3, & (R4 + R5) Become R_{eq} When the Reciprocal Resistance Formula is Applied
   b. R1 & R6 are in Series with R_{eq}
6. Determine Total Resistance: $RT = R1 + R_{eq} + R6$

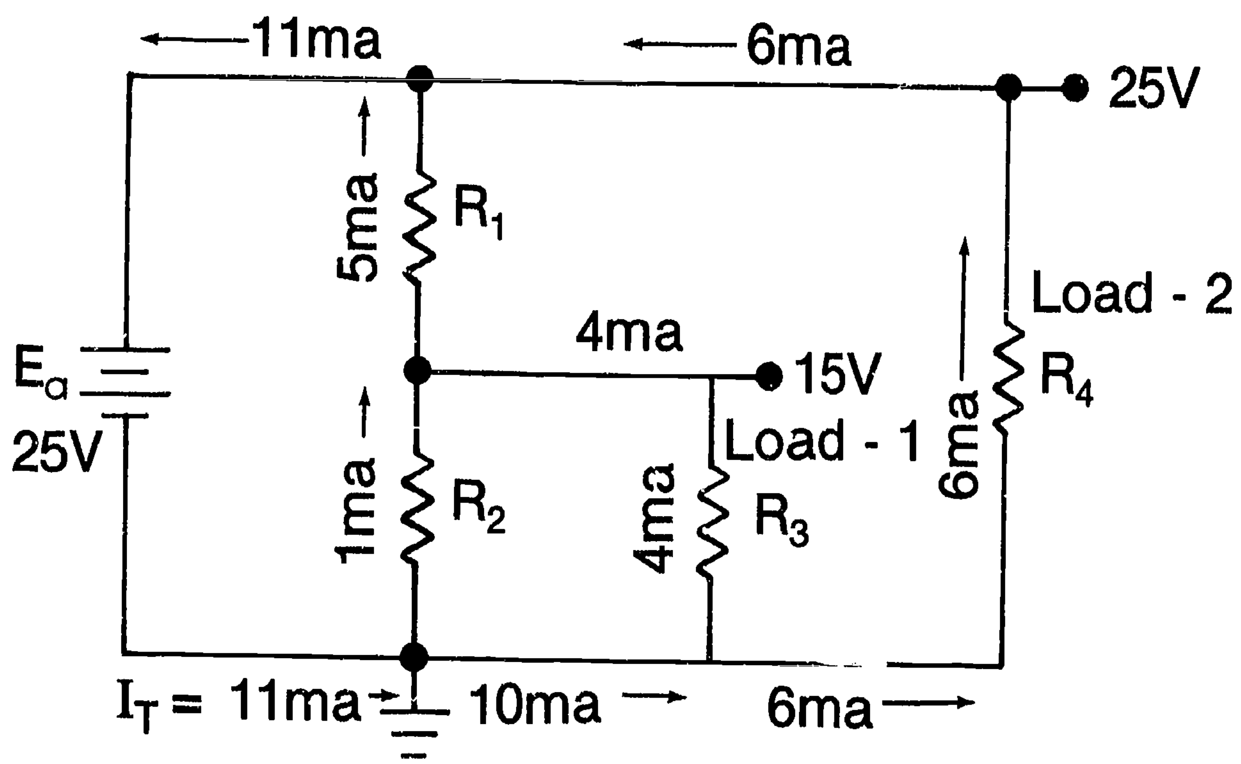
Voltage Divider



Unloaded Voltage Divider



Loaded Voltage Divider



Resistances may be calculated with Ohm's Law

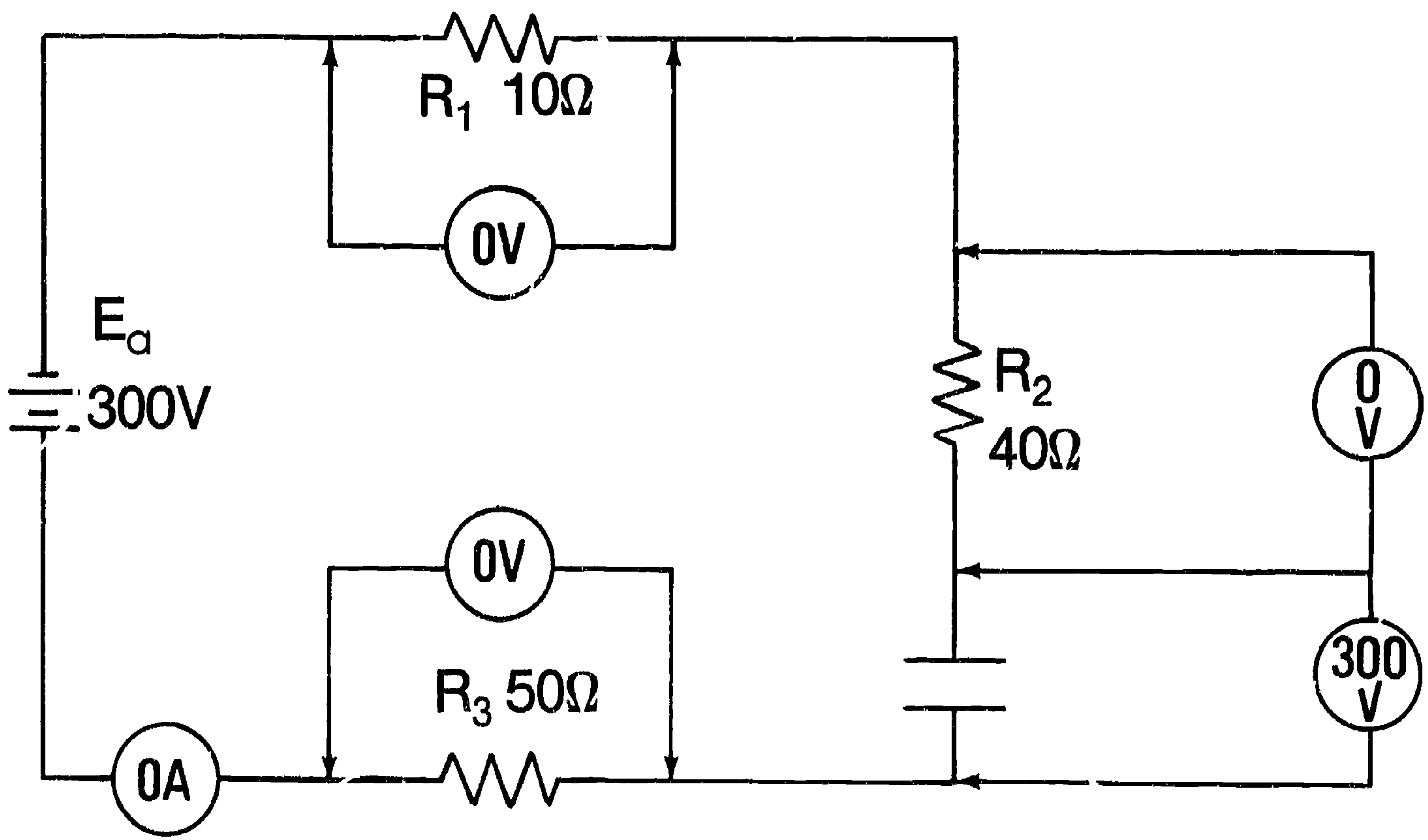
$$R_1 = \frac{E_{R1}}{I_{R1}} = \frac{10V}{.005A} = 2000\Omega\ (2K\Omega)$$

$$R_2 = \frac{E_{R2}}{I_{R2}} = \frac{15V}{.001A} = 15000\Omega\ (15K\Omega)$$

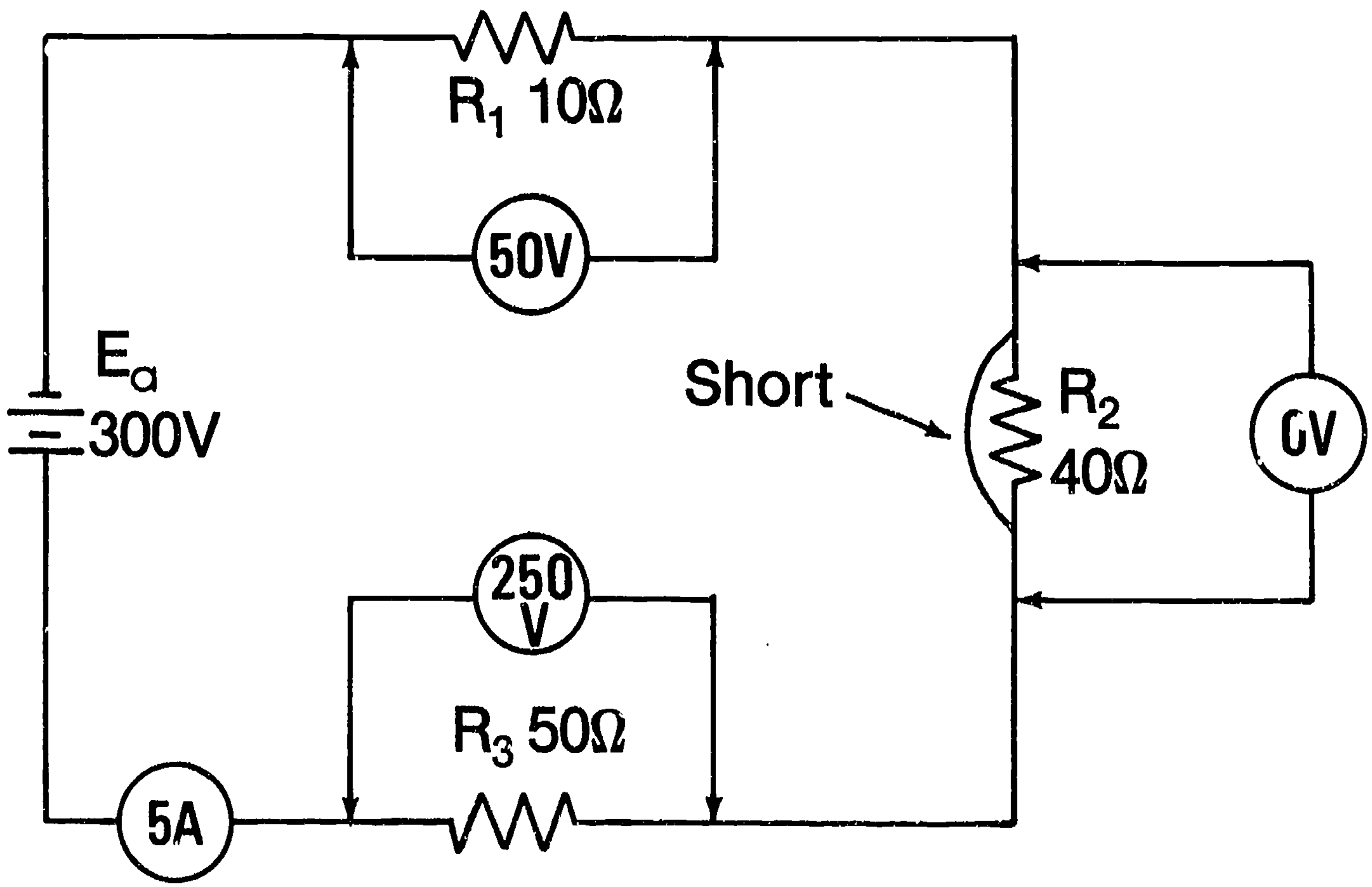
$$R_3 = \frac{E_{R3}}{I_{R3}} = \frac{15V}{.004} = 3750\Omega\ (3.75K\Omega)$$

$$R_4 = \frac{E_{R4}}{I_{R4}} = \frac{25V}{.006A} = 4164\Omega\ (4.16K\Omega)$$

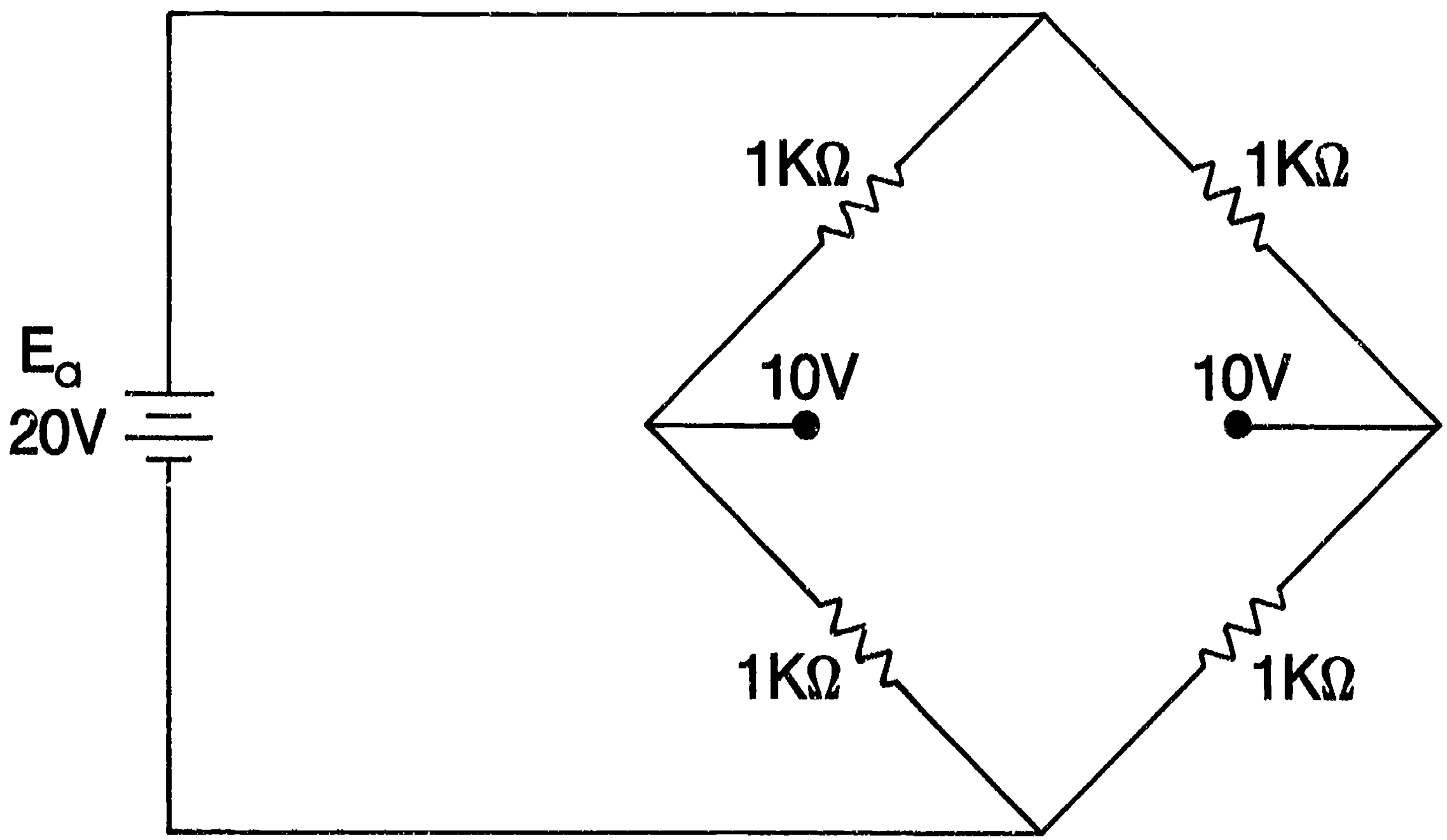
Series Circuit with Open



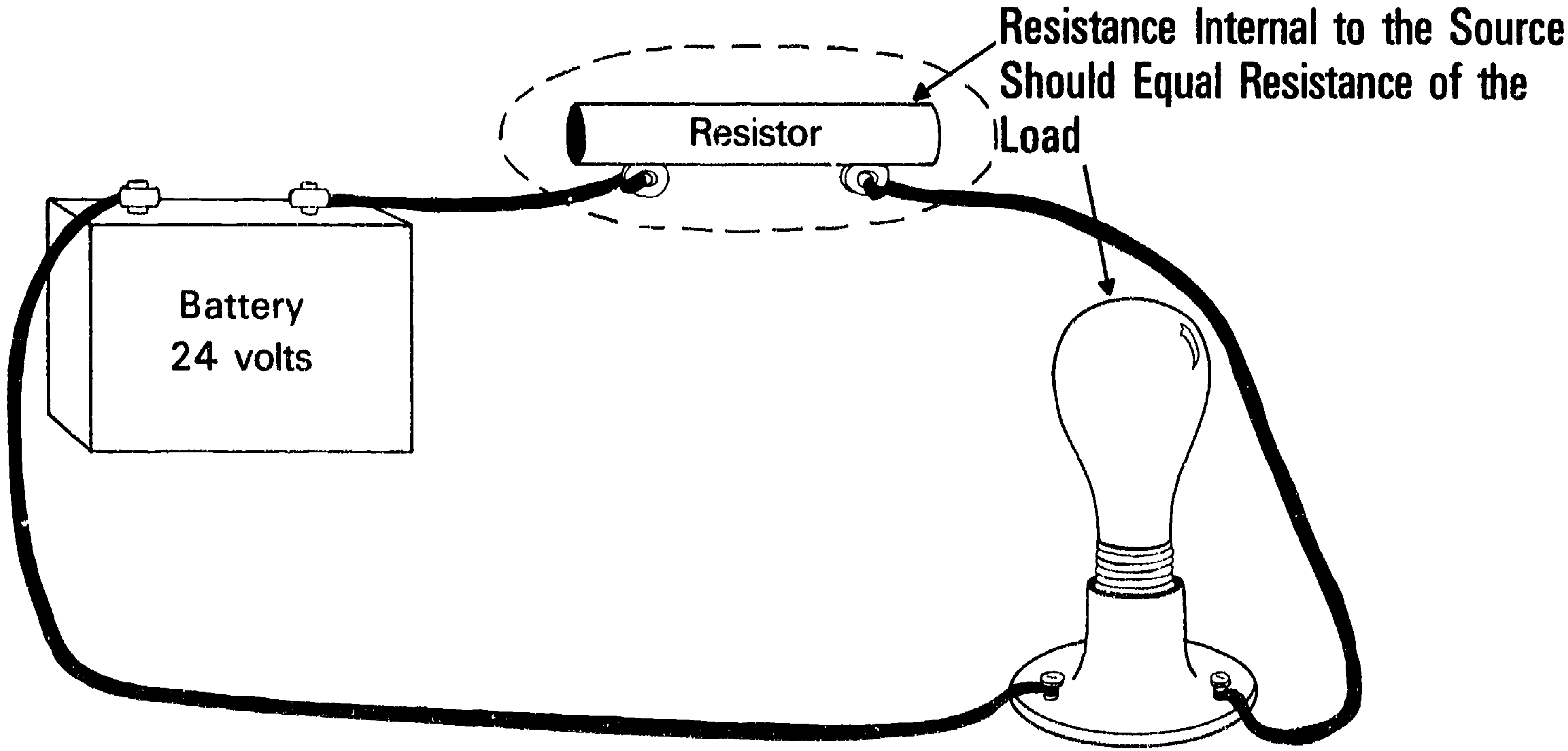
Series Circuit with Short



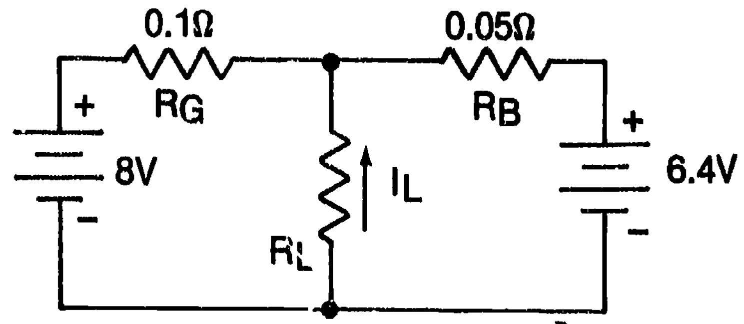
Balanced Bridge



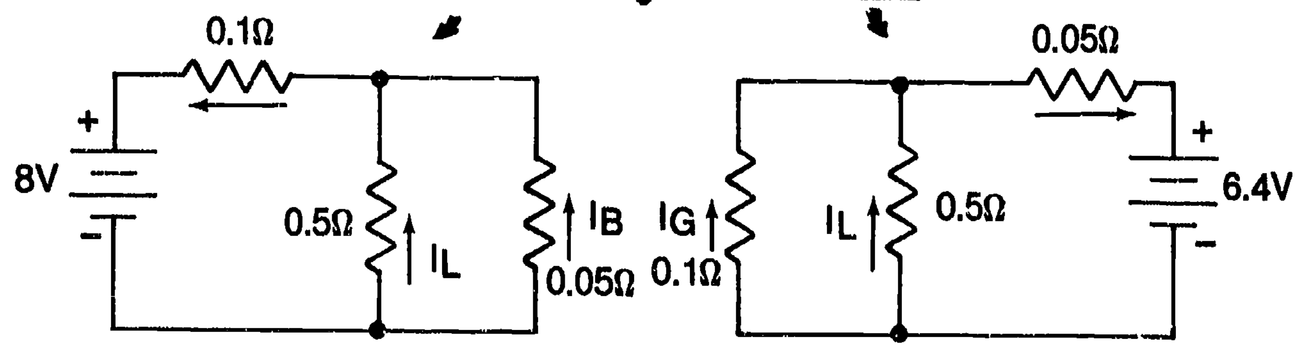
Impedance Matching to Attain Maximum Power Transfer

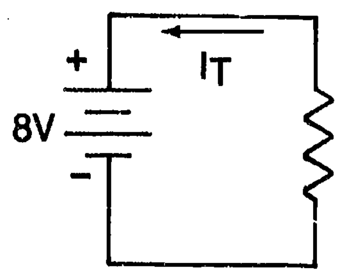


Superposition Method for Solving A Two-Source Network

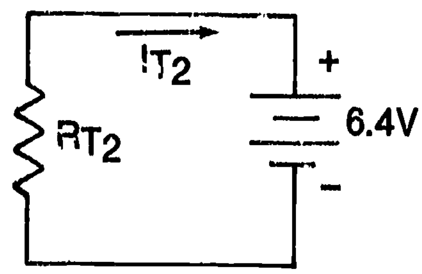


FIND: I_L





$$R_{T1} = 0.1\Omega + \frac{(0.5)\ (0.05)}{0.5 + 0.05}\ \Omega$$



$$I_{T1} = \frac{8V}{0.145} = 55\ \text{AMP}$$

$$R_{T2} = 0.05\Omega + \frac{(0.1)\ (0.5)}{0.1 + 0.5}\ \Omega$$

$I_{T1} = I_B + I_L$

AND $I_B = 10 I_L$

$\therefore I_{T1} = 11 I_L + I_L$

$55 = 11 I_L$, $I_L = 5$ AMP

$R_{T2} = 0.133\Omega$

$$I_{T2} = \frac{6.4V}{0.133\Omega} = 48\ \text{AMP}$$

$I_{T2} = I_G + I_L$

$I_G = 5 I_L$

$\therefore I_{T2} = 5 I_L + I_L$

$48 = 6 I_L$

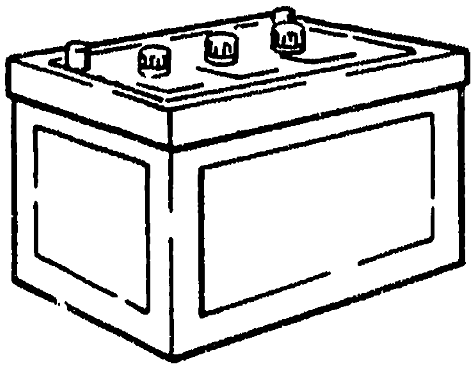
$I_L = 8$ AMP

CONCLUSION:

SINCE THESE TWO CURRENTS PASS THROUGH R_L IN THE SAME DIRECTION

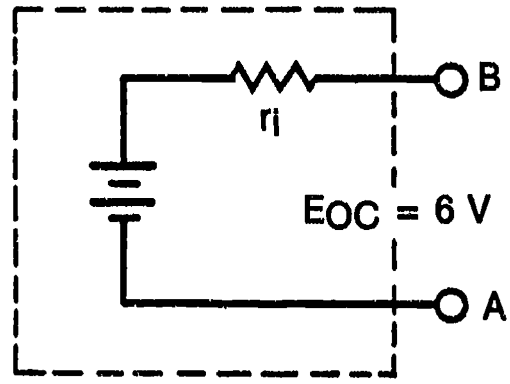
I_L TOTAL = 5+8 = <u>13 AMP</u>

Thevenin's Theorem

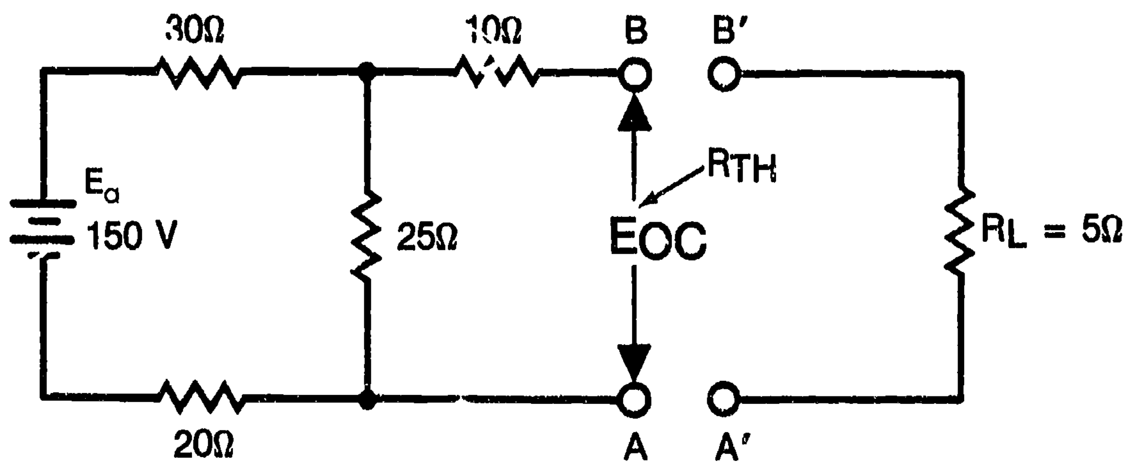


Six Volt Battery

=



Constant Voltage Source

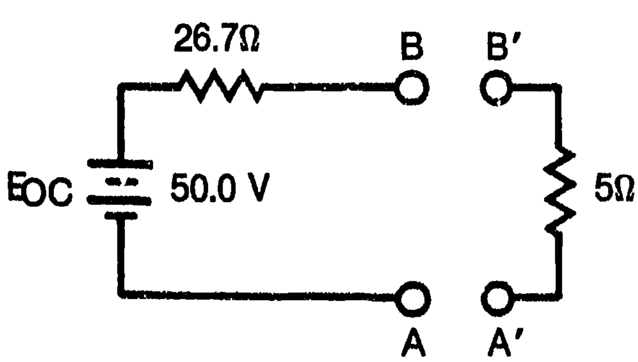


$$E_{OC} = 150 \left(\frac{25}{30 + 20 + 25} \right) = 50.0\text{V}$$

$$R_{TH} = 10 + \frac{(25)\,(30 + 20)}{25 + 30 + 20}$$

$$R_L = 10 + 16.7$$

$$R_L = 26.7\Omega$$



$$I_{5\Omega} = \frac{50}{26.7 + 5} = 1.575 \text{ AMP}$$

FUNDAMENTALS OF DC
UNIT II

ASSIGNMENT SHEET #1 — SOLVE PROBLEMS FOR AN UNKNOWN VOLTAGE

Directions: Apply the appropriate formula from Ohm's law to find the voltage in the following problems.

Example: 2 amps, 60 ohms = ____________ volts

Answer: E = IR = 2 × 60 = 120 volts

Problems:

	Amps	*Ohms*	*Volts*
1.	20	6	________
2.	4	60	________
3.	9.6	2.5	________
4.	5	3	________
5.	75	0.16	________
6.	2×10^{-3}	5×10^{3}	________
7.	1×10^{-6}	10×10^{3}	________
8.	8μ	1M	________
9.	2m	2K	________
10.	1	1	________

FUNDAMENTALS OF DC
UNIT II

ASSIGNMENT SHEET #2 — SOLVE PROBLEMS FOR AN UNKNOWN AMPERAGE

Directions: Apply the appropriate formula to find the amperage in the following problems.

Example: 120 volts, 40 ohms = ____________ amps

Answer: I = E/R = 120/40 = 3 amps

Problems:

	Volts	*Ohms*	*Amps*
1.	240	12	________
2.	110	11	________
3.	440	20	________
4.	120	30	________
5.	24	3	________
6.	12	1	________
7.	5×10^{-6}	1	________
8.	2×10^{-3}	4×10^{-3}	________
9.	20 KV	5×10^{-6}	________
10.	1 KV	0.5×10^{6}	________

FUNDAMENTALS OF DC
UNIT II

ASSIGNMENT SHEET #3 — SOLVE PROBLEMS FOR AN UNKNOWN RESISTANCE

Directions: Apply the appropriate formula to find resistance.

Example: 440 volts, 10 amps = ____________ ohms

Answer: R = E/I = 440/10 = 44 ohms

Problems:

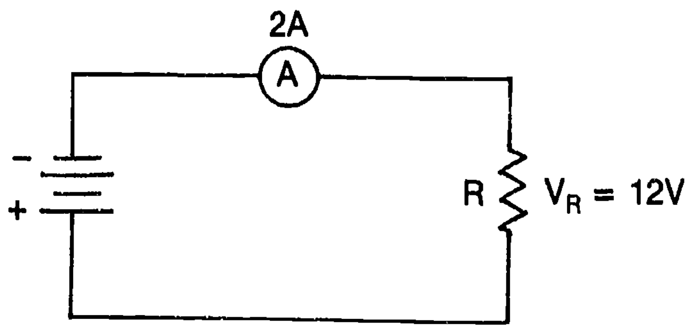
	Volts	*Amps*	*Ohms*
1.	240	4	________
2.	24	9.6	________
3.	12	5	________
4.	230	5	________
5.	24	8	________
6.	24	2mA	________
7.	12	3μA	________
8.	1 KV	5mA	________
9.	1×10^3	0.5×10^{-3}	________
10.	2.5×10^3	5×10^{-3}	________

FUNDAMENTALS OF DC
UNIT II

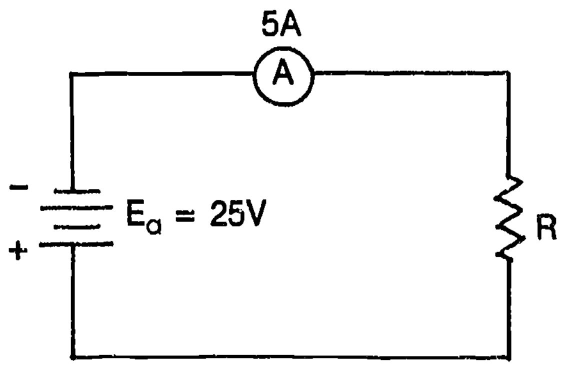
ASSIGNMENT SHEET #4 — DETERMINE THE TOTAL RESISTANCE IN A SERIES CIRCUIT

Directions: Determine the total resistance in the following series circuits.

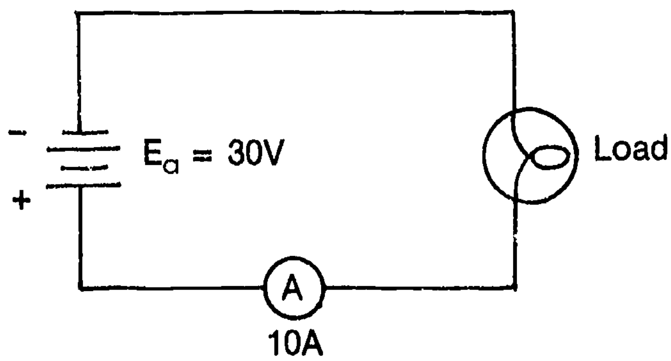
1. R_T = ______________



2. R_T = ______________



3. R_T = ______________

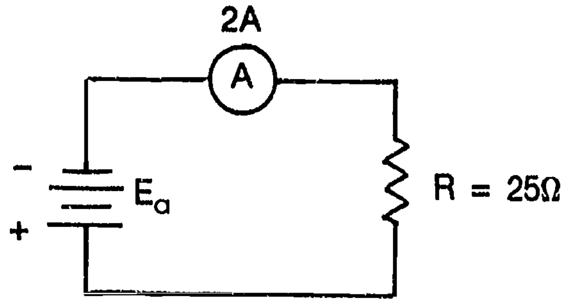


FUNDAMENTALS OF DC
UNIT II

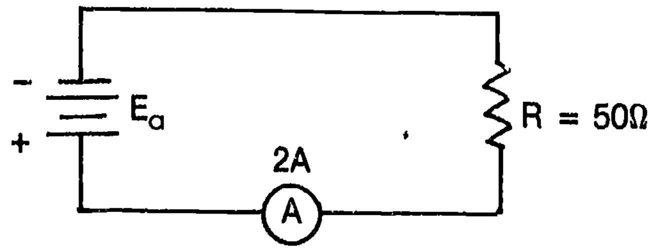
ASSIGNMENT SHEET #5 — DETERMINE TOTAL VOLTAGE IN A SERIES CIRCUIT

Directions: Determine the total voltage in the following series circuits.

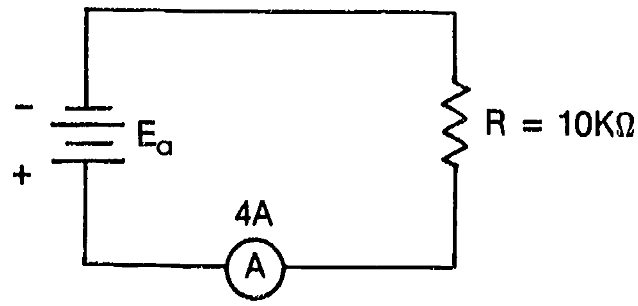
1. E_a = ______________



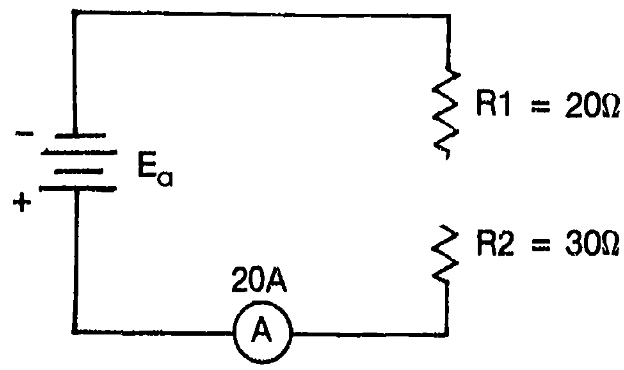
2. E_a = ______________



3. E_a = ______________

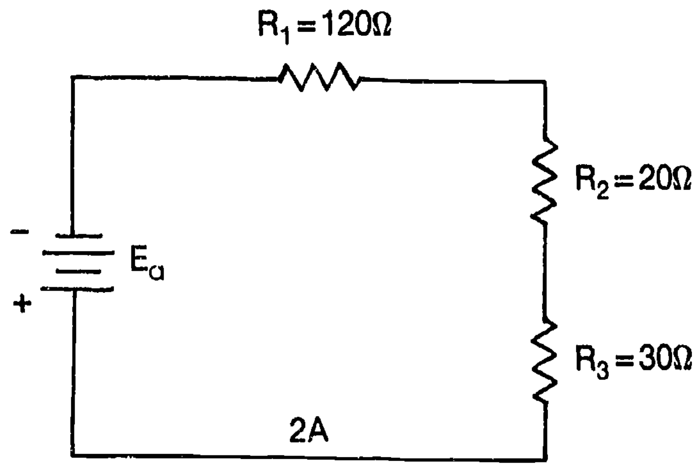


4. E_a = ______________

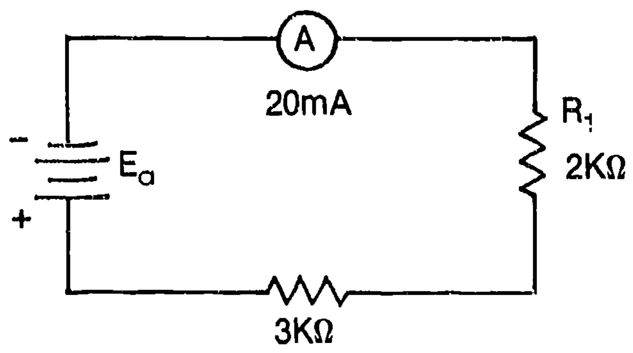


ASSIGNMENT SHEET #5

5. E_a = ____________



6. E_a = ____________



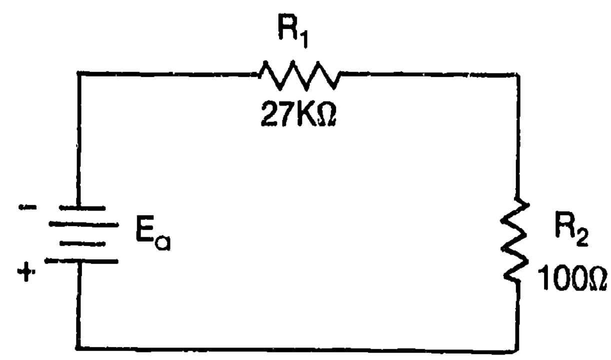
FUNDAMENTALS OF DC
UNIT II

ASSIGNMENT SHEET #6 — DETERMINE VOLTAGE DROPS ACROSS RESISTANCES IN A SERIES CIRCUIT

Directions: Determine voltage drops across resistances in the following series circuits.

1. True or False?

   ______ V_{R1} is greater than V_{R2}

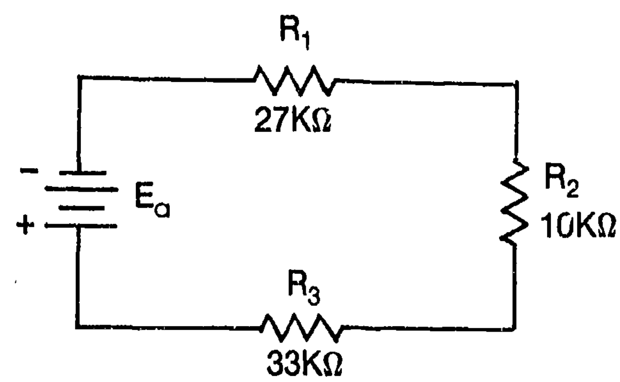


2. The largest voltage drop is

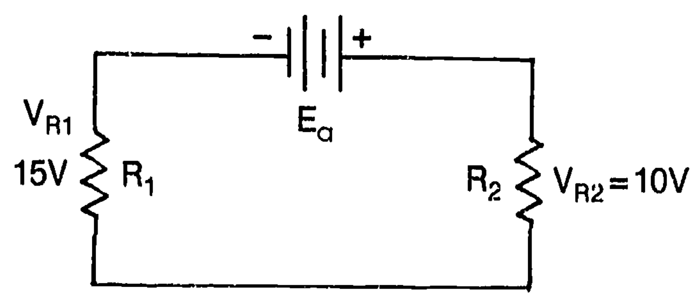
   ______a. V_{R1}

   ______b. V_{R2}

   ______c. V_{R3}

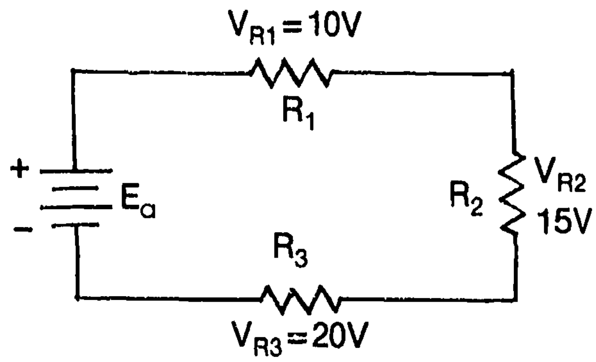


3. E_a = ______

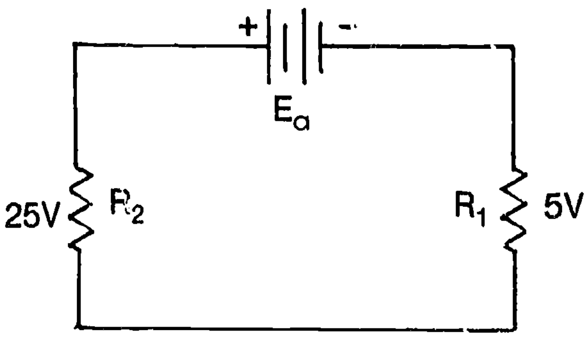


ASSIGNMENT SHEET #6

4. E_a = ______



5. E_a = ______

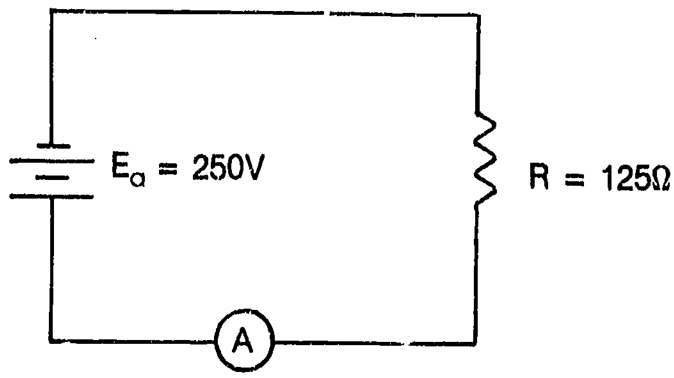


FUNDAMENTALS OF DC
UNIT II

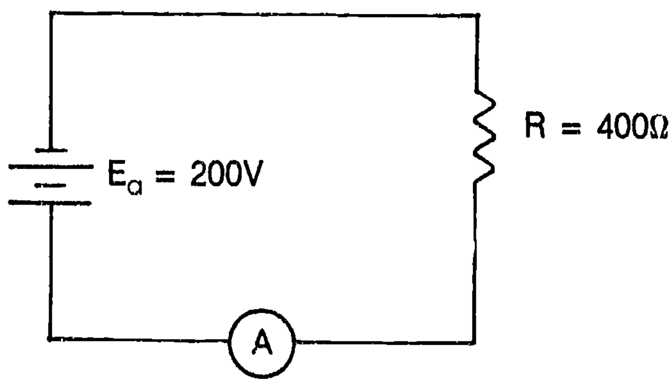
ASSIGNMENT SHEET #7 — DETERMINE CURRENT IN A SERIES CIRCUIT

Directions: Determine the current in the following series circuits. Be sure to indicate units.

1. I = ______

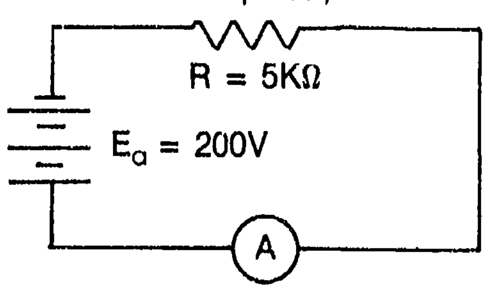


2. I = ______



3. I = ______

(NOTE: Give answer in milliamperes.)

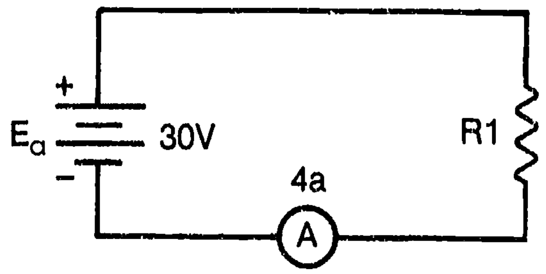


FUNDAMENTALS OF DC
UNIT II

ASSIGNMENT SHEET #8 — COMPUTE POWER FROM THE POWER FORMULA

Directions: Given the formulas for power, $P = EI$ when current and voltage are known, $P = I^2R$ when current and resistance are known, and $P = E^2/R$ when voltage and resistance are known, study the following schematics and answer the questions below them.

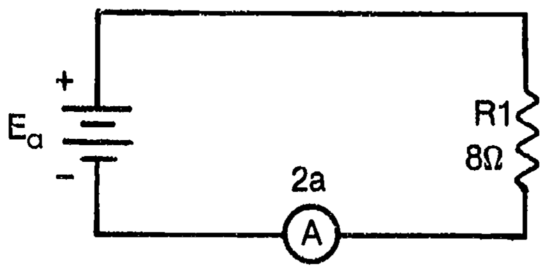
1.



a. State the power formula needed to solve for power.

b. Solve for P.

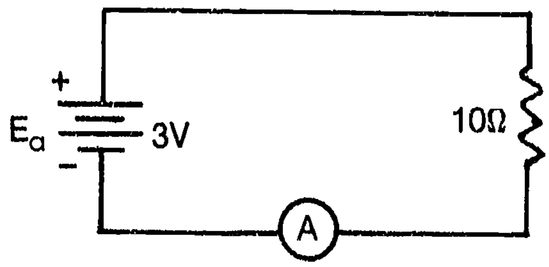
2.



a. State the power formula needed to solve for power.

b. Solve for P.

3.



a. State the power formula needed to solve for power.

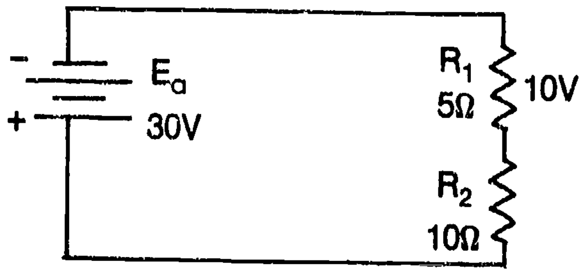
b. Solve for P.

FUNDAMENTALS OF DC
UNIT II

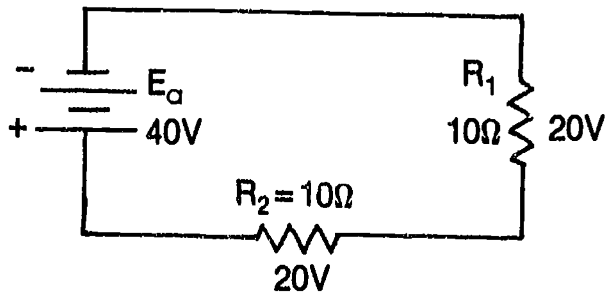
ASSIGNMENT SHEET #9 — DETERMINE UNKNOWN CIRCUIT VALUES IN A SERIES CIRCUIT

Directions: Study the following schematics and determine the unknown circuit values.

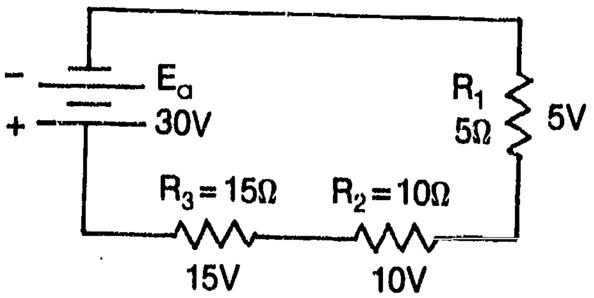
1. I_{R1} = ______



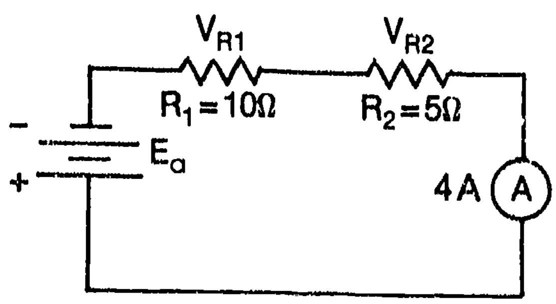
2. I_{R2} = ______



3. I_{R3} = ______



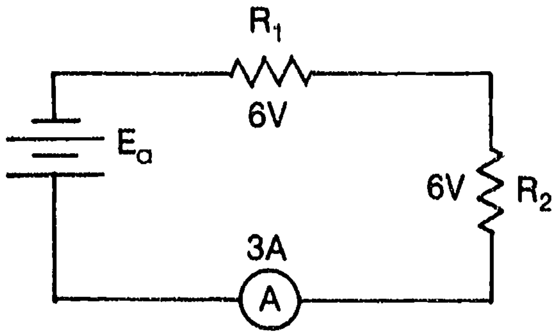
4. V_{R2} = ______



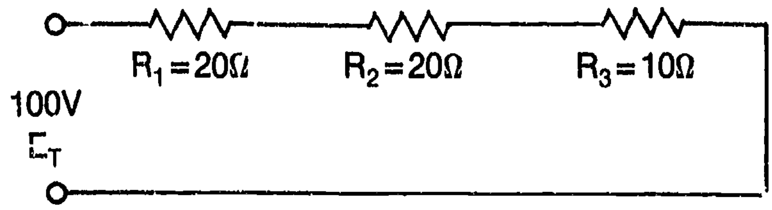
(NOTE: The Ohm's law formula applies to all parts of a circuit.)

ASSIGNMENT SHEET #9

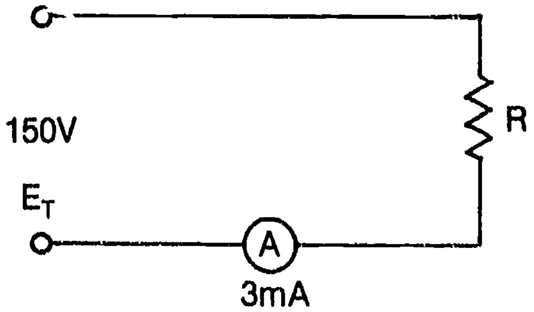
5. R2 = ____



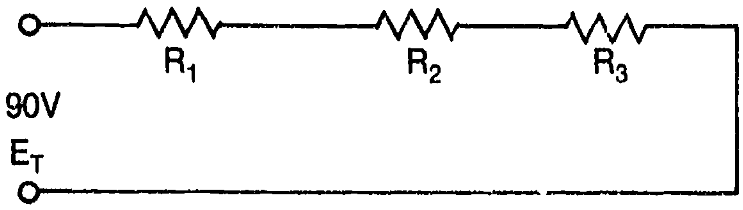
6. V_3 = ____



7. R = ____



8. V_1 = ____



(NOTE: All resistors are equal in value. E_a represents the battery voltage. E_T is the total voltage from a source.)

FUNDAMENTALS OF DC
UNIT II

ASSIGNMENT SHEET #10 — CALCULATE RESISTANCE IN PARALLEL CIRCUITS

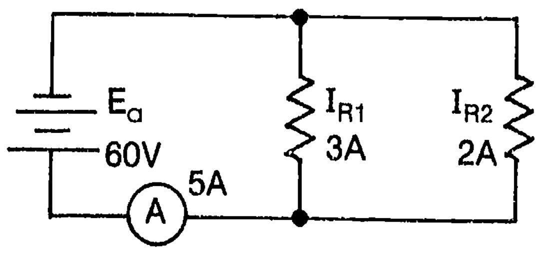
1. Calculate quantities indicated.

   a. R_1 ______

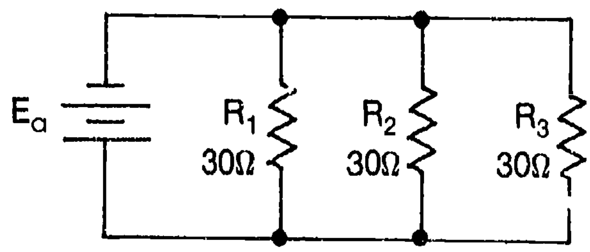
   b. R_2 ______

   c. R_T ______

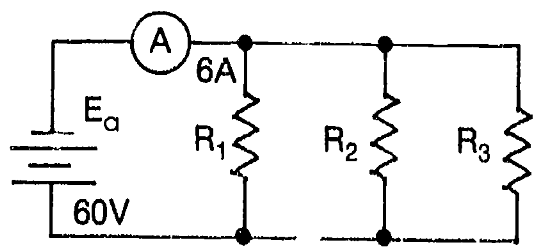
   d. $\frac{E_T}{I_T}$ = ______



2. Calculate R_T ______



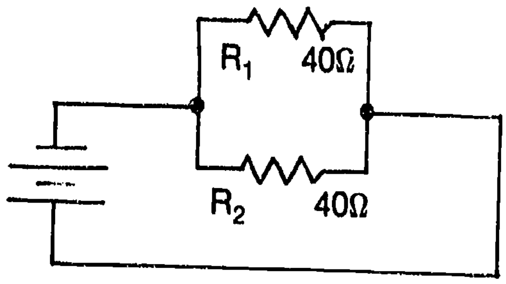
3. a. Calculate R_T ______



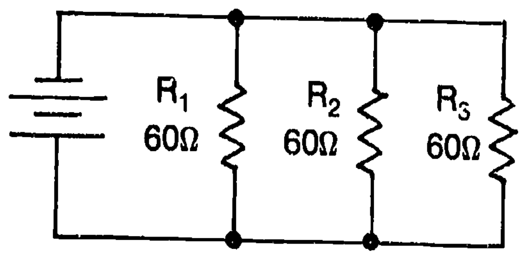
   b. If the three resistors are equal in value, R1 = ______ ohms.

ASSIGNMENT SHEET #10

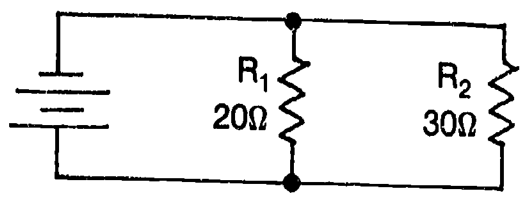
4. Calculate R_T ______



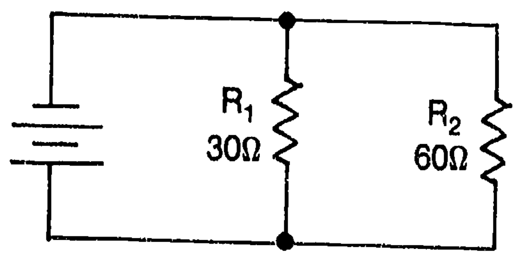
5. Calculate R_T ______



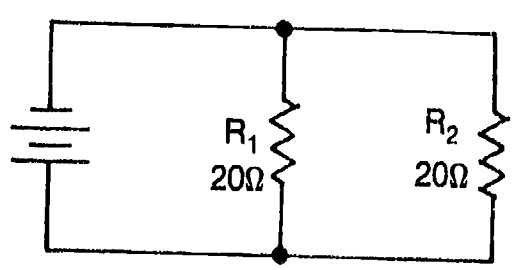
6. Calculate R_T ______



7. Calculate R_T ______



8. Calculate R_T ______



FUNDAMENTALS OF DC
UNIT II

ASSIGNMENT SHEET #11 — CALCULATE CURRENT AND VOLTAGE IN PARALLEL CIRCUITS

1. Calculate quantities indicated.

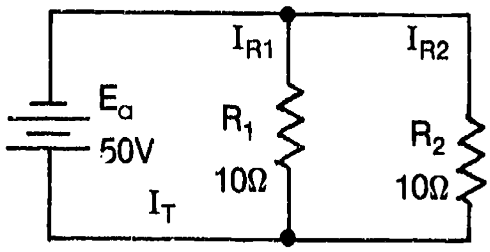
   a. E_{R1} ______

   b. I_{R1} ______

   c. E_{R2} ______

   d. I_{R2} ______

   e. I_T ______



2. Calculate quantities indicated.

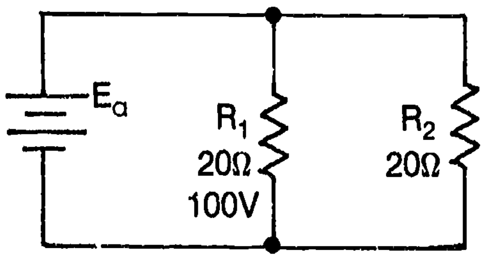
   a. I_{R1} ______

   b. E_{R2} ______

   c. I_{R2} ______

   d. I_T ______

   e. E_a ______



3. Calculate quantities indicated.

   a. I_{R1} ______

   b. I_{R2} ______

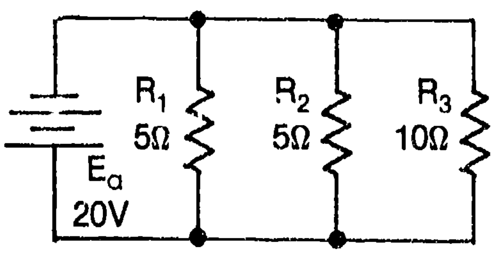
   c. I_{R3} ______

   d. I_T ______

   e. E_{R1} ______

   f. E_{R2} ______

   g. E_{R3} ______



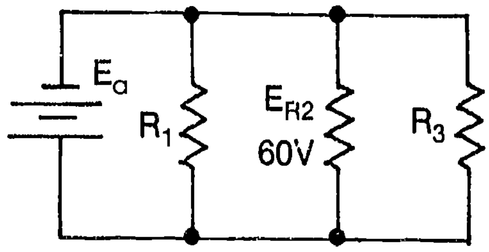
ASSIGNMENT SHEET #11

4. Calculate quantities indicated.

   a. E_{R1} ______

   b. E_{R3} ______

   c. E_a ______



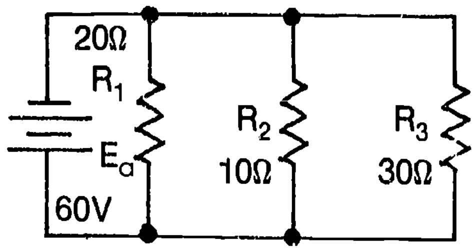
5. Calculate quantities indicated.

   a. I_1 ______

   b. I_2 ______

   c. I_3 ______

   d. I_T ______



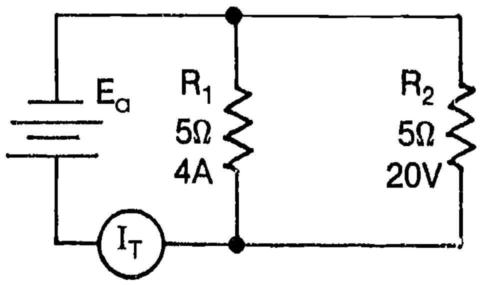
6. Calculate quantities indicated.

   a. I_2 ______

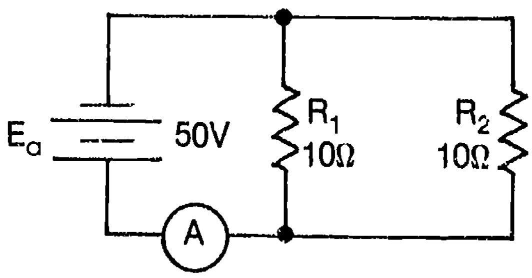
   b. I_T ______

   c. E_{R1} ______

   d. E_a ______



7. If you measured current where the ammeter is located, what should it indicate? ______



8. Calculate quantities indicated.

   a. I_1 ______

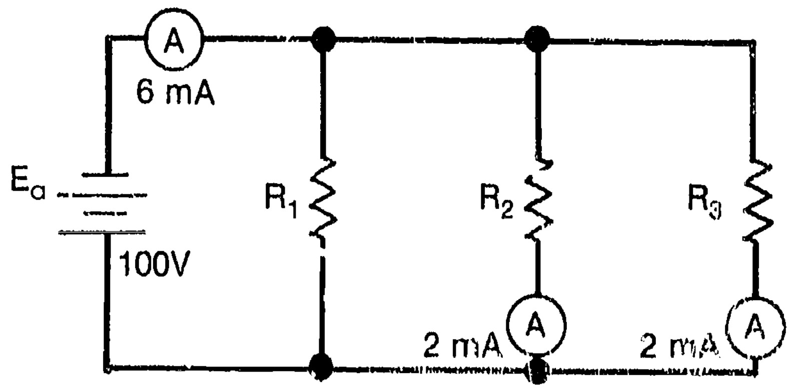
   b. E_{R1} ______

   c. E_a ______

   d. I_T ______

   e. E_{R2} ______

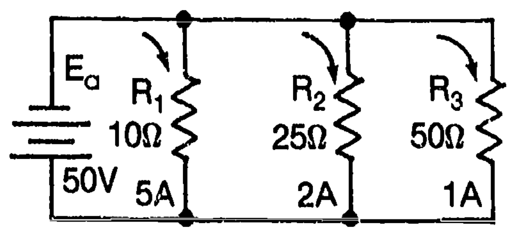
   f. E_{R3} ______



FUNDAMENTALS OF DC
UNIT II

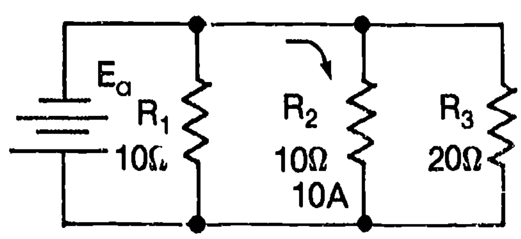
ASSIGNMENT SHEET #12 — CALCULATE POWER IN PARALLEL CIRCUITS

1. Calculate P_T



_____Watts

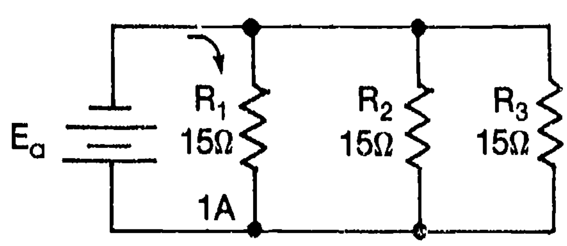
2. Calculate P_T



_____Watts

(NOTE: I_{R2} = 10A.)

3. Calculate P_T



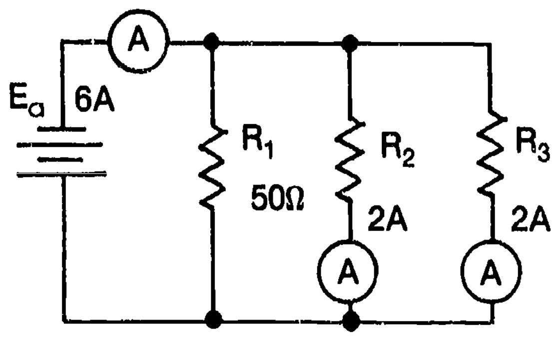
_____Watts

(NOTE: I_{R1} - 1A.)

FUNDAMENTALS OF DC
UNIT II

ASSIGNMENT SHEET #13 — CALCULATE VARIOUS VALUES IN PARALLEL CIRCUITS

1. Calculate quantities indicated.



a. E_{R1}____________

b. E_a____________

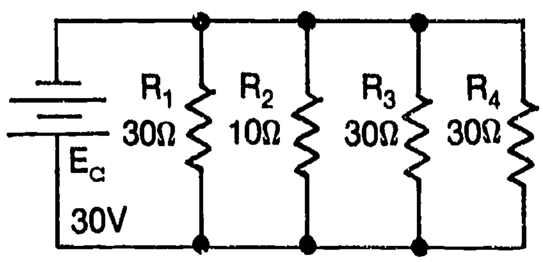
c. R_T____________

d. R_2____________

e. R_3____________

f. P_T____________

2. Calculate quantities indicated.



a. R_T____________

b. I_1____________

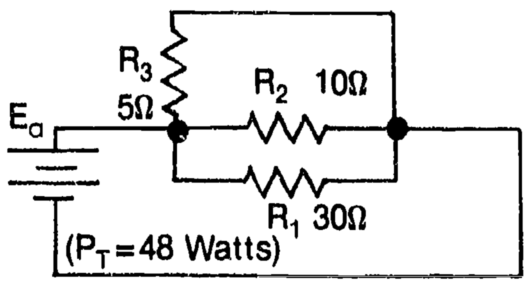
c. I_2____________

d. I_3____________

e. I_4____________

f. I_T____________

3. Calculate quantities indicated.



a. R_T____________

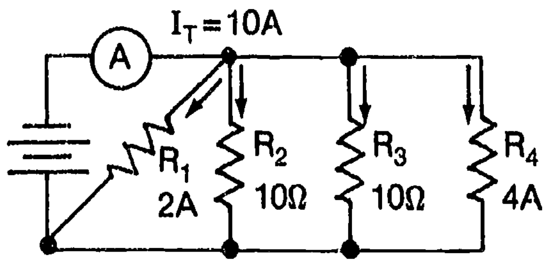
b. I_T____________

c. E_a____________

d. I_{R1}____________

ASSIGNMENT SHEET #13

4. Calculate quantities indicated.



a. E_a ______________

b. R_4 ______________

c. I_{R2} ______________

d. I_{R3} ______________

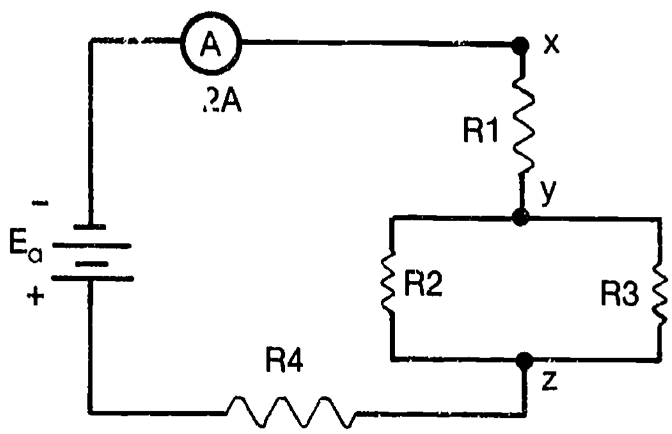
e. R_T ______________

f. P_T ______________

FUNDAMENTALS OF DC
UNIT II

ASSIGNMENT SHEET #14 — TRACE CURRENT FLOW IN SERIES—PARALLEL CIRCUITS

1. Study the schematic and complete the statement below it.



Current will divide at Point _____, and come back together at Point _____.

2. From the circuit above, list the resistors:

   in series ____________.

   in parallel ____________.

3. In the circuit above, Resistors 2 and 3, (check the correct statement)

   _____a. will carry a combined two amps of current

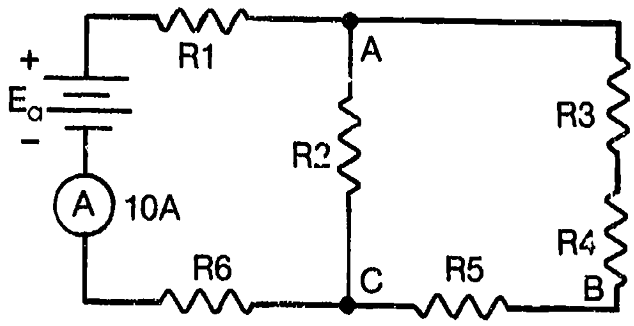
   _____b. will each carry two amps of current

   _____c. will carry a combined one amp of current

   _____d. will *each* carry less than two amps of current

ASSIGNMENT SHEET #14

4. Study the schematic below and complete the questions below it.



a. At what point does current divide? ______________________

b. At what point does it come back together? ______________________

c. Does current divide more than once? ______________________

5. List the three resistors in the circuit above that form a series string.

a. ______________________

b. ______________________

c. ______________________

6. List the resistors in the circuit above in series with the source.

____

7. In the circuit (4), which statements below are correct?

_____a. R2 is in parallel with R3, R4, and R5

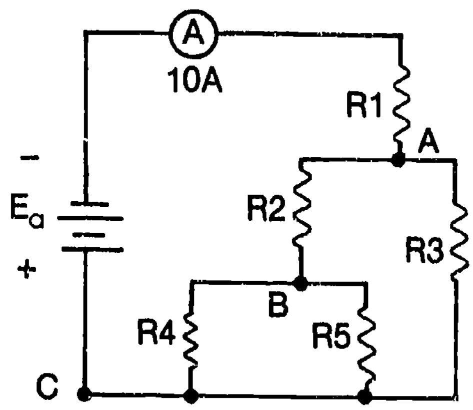
_____b. Less than 10 amps will flow through R2

_____c. 10 amps will flow through R6

_____d. Less than 10 amps will flow through R3, R4, R5

ASSIGNMENT SHEET #14

8. Study the following schematic and answer the questions below it.



a. At what point does current first divide?____________________

b. At what point does current next divide?____________________

c. At what point does current all come back together?________________

9. In the circuit (8) check the pairs of resistors that are in parallel with each other.

______a. R1 and R3

______b. R2 and R4

______c. R2 and R5

______d. R4 and R5

10. Answer these questions (Circuit 8)

a. How many resistors are directly in series with the rest of the circuit?________

b. Is the R_{EQ} of R4 and R5 in series with R2?____________________

11. Check the statements that are correct. (Circuit 8)

______a. $I_{R2} + I_{R3} = 10$ amps

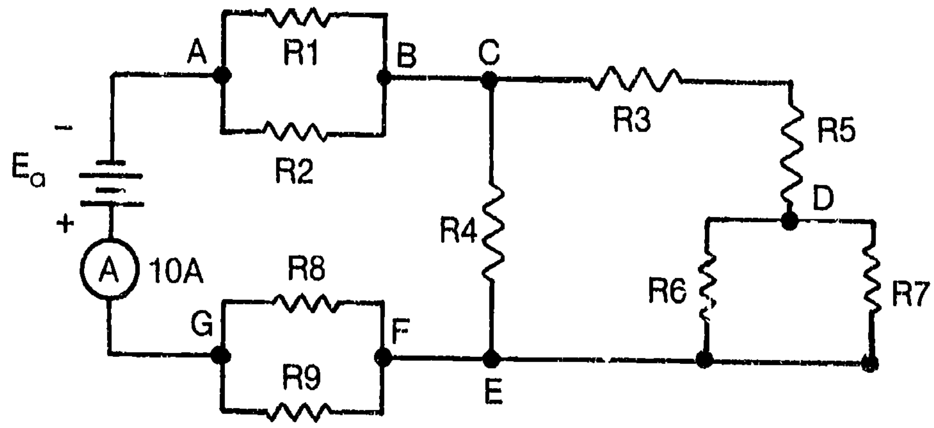
______b. An ammeter at Point C will measure 10 amps

______c. Current through R5 will be more than through R1

______d. $I_{R4} + I_{R5} = I_{R2}$

ASSIGNMENT SHEET #14

12. Study the following schematic and answer the questions below it.



a. Current first divides at which point?____________________

b. Current next divides at which point?____________________

c. Does current also divide at Point D? Point F?____________________

d. How many resistors are in series with the source?____________________

e. Will there be a full 10 amps of current through R7?____________________

f. Will there be a full 10 amps of current through R4?____________________

g. Will there be a full 10 amps of current at Point G?____________________

h. Does total current go through R2?____________________

i. Does a full 10 amps enter R9?____________________

j. Will current be common through R3 and R5?____________________

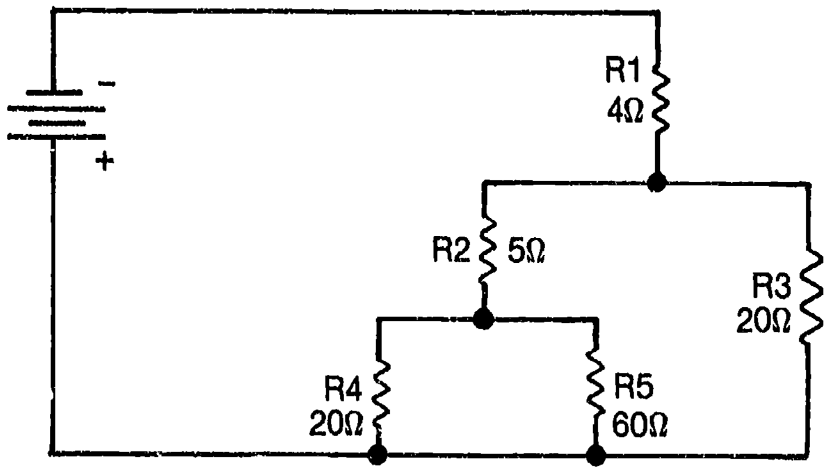
k. Does the full 10 amps of current enter Point D?____________________

l. Name the two resistors in string.____________________

FUNDAMENTALS OF DC
UNIT II

ASSIGNMENT SHEET #15 — SOLVE FOR TOTAL RESISTANCE IN A SERIES—PARALLEL CIRCUIT

1. This assignment will combine circuit reductions and solve for total circuit resistance in more complex circuits. Use the steps cited in the Information Sheet and refer to it if necessary. Study the circuit below. Trace current flow and determine which resistors are in parallel.



a. First, find R_{eq} for R4 and R5 = ____________

b. Redraw circuit, showing R4 and R5 combined into one equivalent resistor. Show values.

c. Note that R2 and R_{eq} are not in series and are additive. Combine R2 and R_{eq} into one equivalent resistor, R_{eq}. Redraw the circuit and show values.

ASSIGNMENT SHEET #15

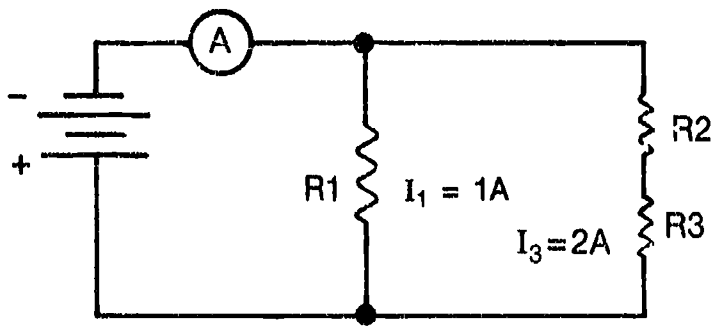
3. Notice now that the R_{eq} is in parallel with R3. Find the next R_{eq} and redraw the circuit with appropriate values shown.

4. Redraw the final circuit showing one equivalent resistor, R_T.

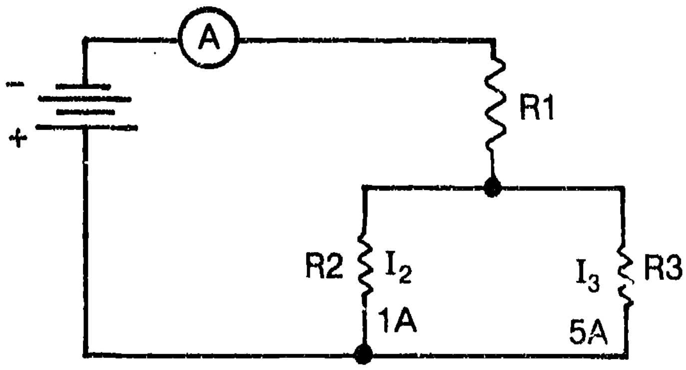
FUNDAMENTALS OF DC
UNIT II

ASSIGNMENT SHEET #16 — SOLVE FOR TOTAL CURRENT IN SERIES—PARALLEL CIRCUITS

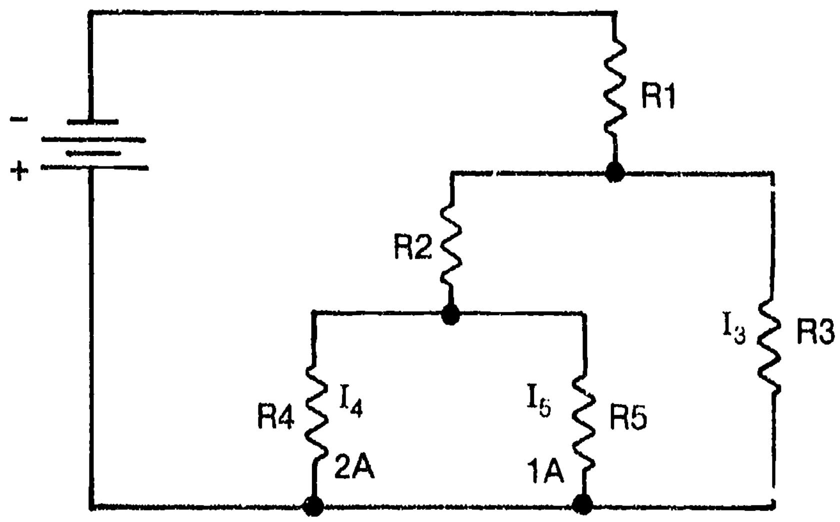
1. Study the circuit below. I_T = ____________.



2. Find I_T = ____________.



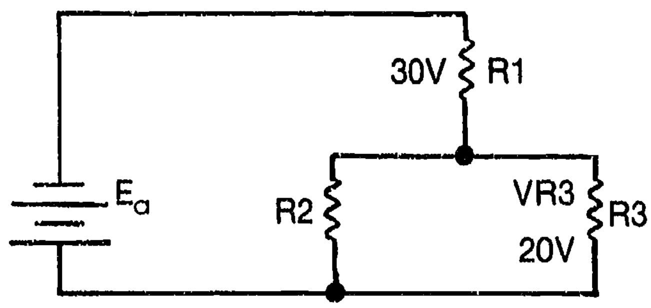
3. Find I_T = ____________.



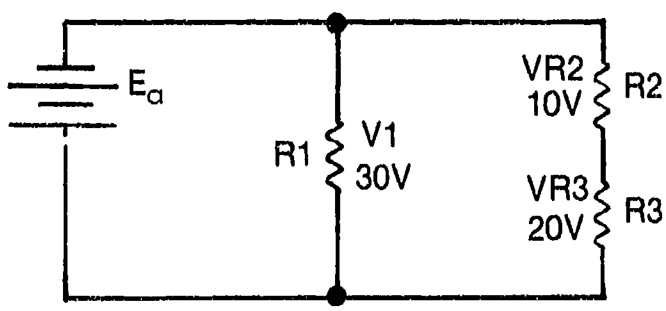
FUNDAMENTALS OF DC
UNIT II

ASSIGNMENT SHEET #17 — SOLVE FOR TOTAL VOLTAGE IN SERIES—PARALLEL CIRCUITS

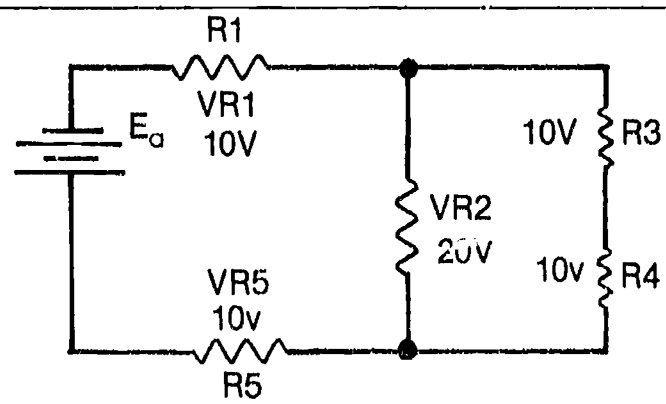
1. Find E_a. E_a = ____________________



2. Find E_a. E_a = ____________________



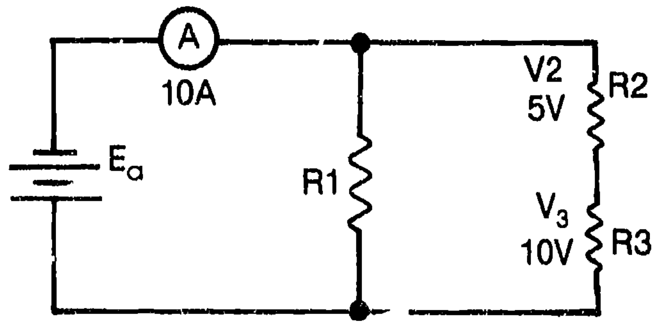
3. Find E_a. E_a = ____________________



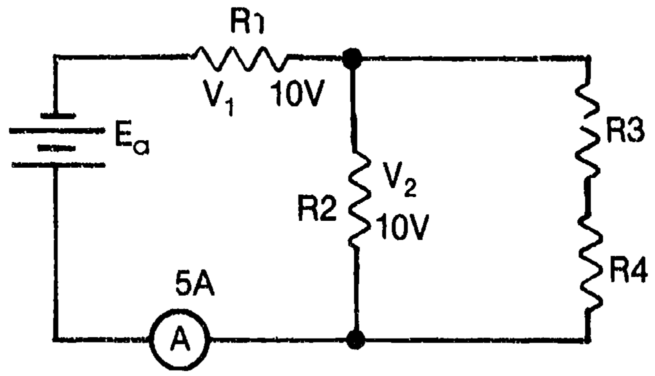
FUNDAMENTALS OF DC
UNIT II

ASSIGNMENT SHEET #18 — SOLVE FOR TOTAL POWER IN SERIES—PARALLEL CIRCUITS

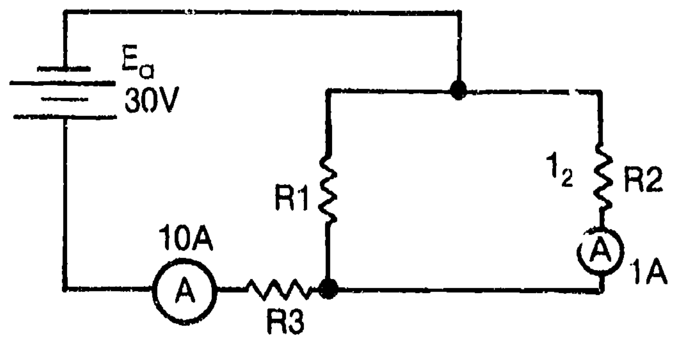
1. Find P_T. P_T = ______________________



2. Find P_T. P_T = ______________________



3. Find P_T. P_T = ______________________



FUNDAMENTALS OF DC
UNIT II

ASSIGNMENT SHEET #19 — IDENTIFY RESISTOR VALUES USING A STANDARD COLOR CODE

Directions: Using the color code chart provided in this assignment sheet, identify the value of each resistor provided by your instructor.

RESISTOR COLOR CODE CHART

Color	Band 1	Band 2	Band 3		Band 4	Band 5
	1st Digit (Number)	2nd Digit (Number)	Multiplier		Tolerance (percent)	Reliability (percent)
Black	0	0	10^0	1		
Brown	1	1	10^1	10	1	1.0
Red	2	2	10^2	100	2	0.1
Orange	3	3	10^3	1,000	3	0.01
Yellow	4	4	10^4	10,000	4	0.001
Green	5	5	10^5	100,000		
Blue	6	6	10^6	1,000,000		
Violet	7	7	10^7	10,000,000		
Gray	8	8	10^8	100,000,000		
White	9	9	10^9	1,000,000,000		
Gold			10^{-1}	0.1	5	
Silver			10^{-2}	0.01	10	
none					20	Not tested

ASSIGNMENT SHEET #19

1. __________	6. __________	11. __________	16. __________
2. __________	7. __________	12. __________	17. __________
3. __________	8. __________	13. __________	18. __________
4. __________	9. __________	14. __________	19. __________
5. __________	10. __________	15. __________	20. __________

FUNDAMENTALS OF DC
UNIT II

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #1

1. 120V
2. 240V
3. 24V
4. 15V
5. 12V
6. 10V
7. 10×10^{-3}V or .01V
8. 8V
9. 4V
10. 1V

Assignment Sheet #2

1. 20A
2. 10A
3. 22A
4. 4A
5. 8A
6. 12A
7. 5×10^{-6} or .000005 or 5μA
8. .5A
9. 4mA
10. 2mA

Assignment Sheet #3

1. 60 Ω
2. 2.5 Ω
3. 2.4 Ω
4. 46 Ω
5. 3 Ω
6. 12K or 12,000 Ω
7. 4M or 4,000,000 Ω
8. 200K or 200,000 Ω
9. 2×10^6 or 2,000,000 Ω or 2MΩ
10. 500K or 500,000 Ω

Assignment Sheet #4

1. 6 Ω
2. 5 Ω
3. 3 Ω

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #5

1. 50V
2. 100V
3. 40,000V or 40KV
4. 1,000V or 1KV
5. 340V
6. 100V

Assignment Sheet #6

1. True
2. C
3. 25V
4. 45V
5. 30V

Assignment Sheet #7

1. 2A
2. 500mA or 0.5A
3. 40mA

Assignment Sheet #8

1. a. $P = EI$
   b. 120 watts
2. a. $P = I^2R$
   b. 32 watts
3. a. $P = E^2/R$
   b. $P = .9$ watts

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #9

1. 2A
2. 2A
3. 1A
4. 60V
5. 2 Ω
6. 20V
7. 50K Ω or 50,000 Ω
8. 30V

Assignment Sheet #10

1. a. 20 Ω
   b. 30 Ω
   c. 12 Ω
   d. 12 Ω
2. 10 Ω
3. a. 10 Ω
   b. 30 Ω
4. 20 Ω
5. 20 Ω
6. 12 Ω
7. 20 Ω
8. 10 Ω

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #11

1. a. 50V
   b. 5A
   c. 50V
   d. 5A
   e. 10A
2. a. 5A
   b. 100V
   c. 5A
   d. 10A
   e. 100V
3. a. 4A
   b. 4A
   c. 2A
   d. 10A
   e. 20V
   f. 20V
   g. 20V
4. a. 60V
   b. 60V
   c. 60V
5. a. 3A
   b. 6A
   c. 2A
   d. 11A
6. a. 4A
   b. 8A
   c. 20V
   d. 20V
7. 10A
8. a. 2ma
   b. 100V
   c. 100V
   d. 6mA
   e. 100V
   f. 100V

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #12

1. 400 watts
2. 2500 watts
3. 45 watts

Assignment Sheet #13

1. a. 100V
   b. 100V
   c. 16.7Ω
   d. 50Ω
   e. 50Ω
   f. 600W
2. a. 5Ω
   b. 1A
   c. 3A
   d. 1A
   e. 1A
   f. 6A
3. a 3Ω
   b. 4A
   c. 12V
   d. 0.4A or 400mA
4. a. 20V
   b. 5Ω
   c. 2A
   d. 2A
   e. 2Ω
   f. 200W

Assignment Sheet #14

1. Point Y, Point Z
2. In series — R_1 and R_4
   In parallel — R_2 and R_3
3. a and d
4. a. Point C
   b. Point A
   c. No

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #14 — continued

5. R_3, R_4, R_5

6. R_1, R_6

7. All are correct

8. a. Point A

   b. Point B

   c. Point C

9. d

10. a. One (R_1)

    b. Yes

11. a, b, c

12. a. Point A

    b. Point C

    c. Yes, yes

    d. None

    e. No

    f. No

    g. Yes

    h. No

    i. No

    j. Yes

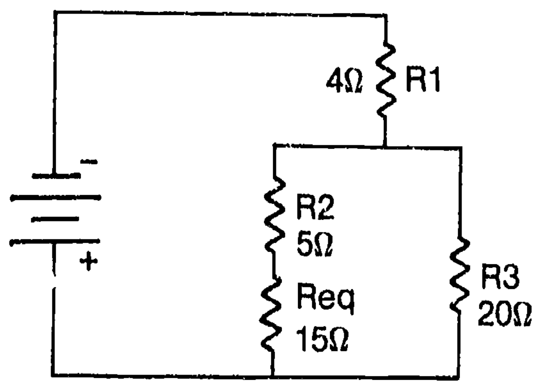
    k. No

    l. R_3 and R_5

Assignment Sheet #15

1. a. 15 ohms

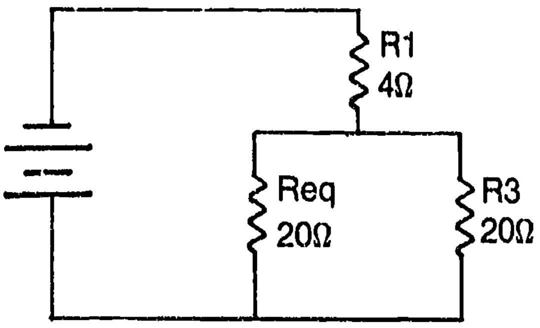
   b.



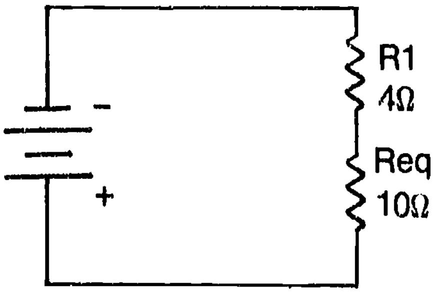
ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #15 — continued

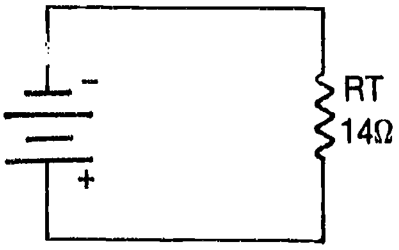
2.



3.



4.



Assignment Sheet #16

1. 3A
2. 6A
3. 4A

Assignment Sheet #17

1. 50V
2. 30V
3. 40V

ANSWERS TO ASSIGNMENT SHE S

Assignment Sheet #18

1. 150 watts

2. 100 watts

3. 300 watts

Assignment Sheet #19 — Evaluated to the satisfaction of the instructor

FUNDAMENTALS OF DC
UNIT II

JOB SHEET #1 — MEASURE VOLTAGE DROPS IN A SERIES CIRCUIT

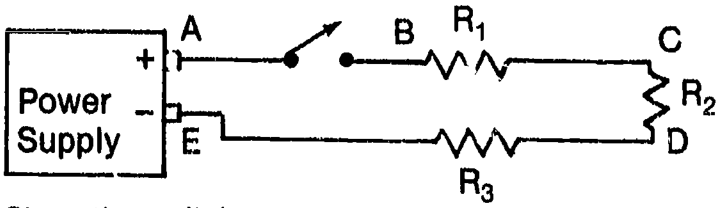
A. Equipment and materials needed

1. Power supply
2. Switch (SPST)
3. Two resistors of the same value
4. One resistor of a different value
5. Voltmeter (or multimeter)

(NOTE: Your instructor will give you the value of voltage and the value of resistors to use.)

B. Procedure

1. Connect the circuit according to the following schematic.



2. Close the switch.
3. Use the voltmeter to read and record the following:

E_a = ______________

V_{R1} = ______________

V_{R2} = ______________

V_{R3} = ______________

4. Add the voltage drops across the three resistors and compare the sum with the amount of applied voltage.

(NOTE: Discuss if Kirchhoff's law is confirmed by your results.)

JOB SHEET #1

5. Compare the voltage drops across R_1, R_2, and R_3 having the same value of ohms and with the voltage drop across the other resistor.

   (NOTE: Discuss how applied voltage distributes itself across resistances of unequal or of equal value.)

6. Identify the most negative point in the circuit.

7. Return equipment and materials to their proper storage location.

FUNDAMENTALS OF DC
UNIT II

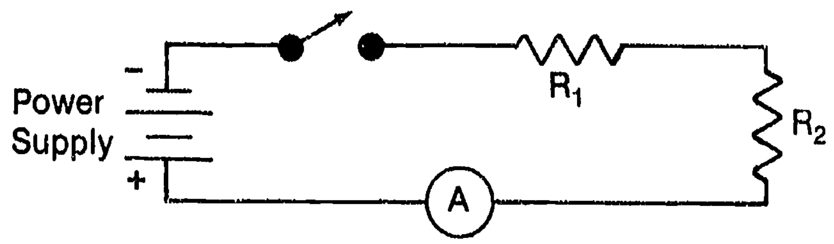
JOB SHEET #2 — ANALYZE CURRENT VALUES IN A SERIES CIRCUIT

A. Equipment and materials needed

1. Power supply
2. Switch (SPST)
3. Two resistors: R_1 = 4.7K, 1 watt; R_2 = 1K, 1W.
4. Ammeter (or multimeter)
5. Voltmeter
6. Ohmmeter

B. Procedure

1. Measure and record the ohms value of the two resistors.
2. Connect a circuit as shown in the following schematic.



3. Close the switch and adjust the power supply output to 24 volts.
4. Use the voltmeter to measure the following voltages:

   V_{R1} = ______ V_{R2} = ______ E_a = ______

5. Read and record the ammeter indication I = ______
6. Disconnect the circuit by opening the switch.
7. Use Ohm's law and compute:

   I_{R1} = ______ I_{R2} = ______ I_T = ______

JOB SHEET #2

8. Compare the values of the various current computations, and explain the differences, if any, in these values.

9. Return equipment and materials to their proper storage area.

FUNDAMENTALS OF DC
UNIT II

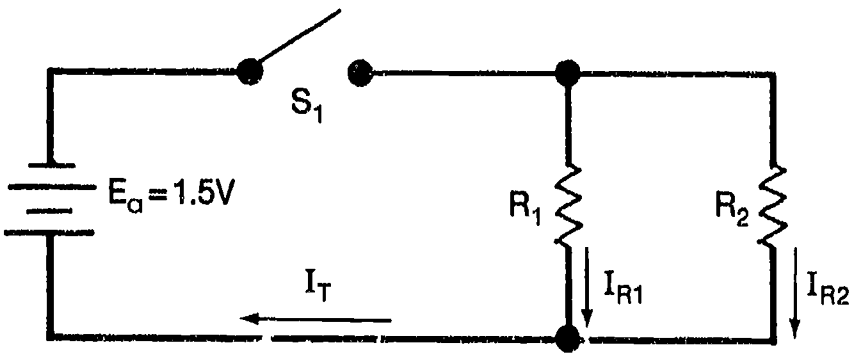
JOB SHEET #3 — MEASURE VOLTAGE, CURRENT, AND RESISTANCE IN A PARALLEL CIRCUIT

A. Equipment and materials needed

1. 1.5 battery or equivalent
2. Two small resistors of equal value or two small lamps
3. VOM or voltmeter
4. VOM or ammeter
5. Switch
6. Wire to complete circuit

B. Procedure

1. Construct a parallel resistive circuit according to the schematic below.



2. Close switch S_1.
3. Measure and record applied voltage (E_a).
4. Measure and record voltage across R_1. and across R_2.
5. Compare recorded voltages. Are they all equal? Explain why.
6. Open switch S_1.
7. Connect ammeter in series with R_1.
8. Close switch S_1 and read and record current (I_{R1}).

JOB SHEET #3

9. Open switch S_1.

10. Disconnect ammeter from R_1 branch and connect it in series with R_2.

11. Close switch S_1, and read and record current (I_{R2}).

12. Open switch S_1.

13. Disconnect ammeter from R_1 branch, and connect it in series with the voltage source (E_a) and switch S_1.

14. Close switch S_1 and read and record main current (I_T).

15. Open switch S_1.

16. Are recorded currents I_{R1} and I_{R2} equal? (NOTE: Explain why or why not.)

17. Add I_{R1} and I_{R2}. Does the sum equal I_T? (NOTE: Explain why or why not.)

18. Close switch; if lamps were used for R_1 and R_2, note that both lamps are glowing.

19. Disconnect R_2 from circuit.

20. Record ammeter indication, and, if R_1 and R_2 are lamps, note any changes in R_1 operation when R_2 (lamp) was removed.

21. Replace R_2, and remove R_1 from circuit.

22. Record ammeter indication, and note any changes in R_2 operation, if applicable.

23. Reconnect R_1.

24. Using voltmeter read and record applied voltage (E_a), E_{R1}, and E_{R2}.

25. Using measured E_a and I_T, compute total resistance of the circuit (R_T).

26. Using measured voltage and current values, compute R1 and R2, and from these figures compute R_T.

27. If R_1 and R_2 are lamps, explain changes in lamp operation when one lamp was removed from the circuit.

28. Return equipment and materials to proper storage area.

FUNDAMENTALS OF DC
UNIT II

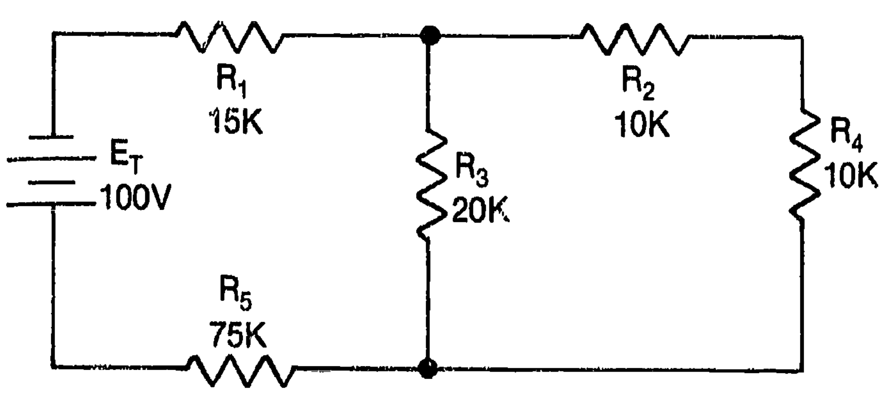
JOB SHEET #4 — TROUBLESHOOT SERIES-PARALLEL CIRCUITS

A. Equipment and materials needed

1. Multimeter
2. Circuit board
3. Resistors — Two, 10 Kohms
4. Resistor — 20 Kohms
5. Resistor — 15 Kohms
6. Resistor — 75 Kohms
7. DC power supply — Capable of 120 VDC

B. Procedure

1. Connect the series-parallel circuit as shown below.



(NOTE: Have instructor check the circuit.)

2. Look back over Job Sheets #1, #2, and #3 to familiarize yourself with the voltages, current, and resistance values of the circuit above.
3. Ask the instructor to insert a "trouble" in the figure above.
4. Troubleshoot the circuit using correct troubleshooting procedures.

JOB SHEET #4

5. Indicate the problem and explain the procedures used to locate the "trouble."

(NOTE: At this point, the instructor should check student work and discuss troubleshooting procedures used.)

6. Repeat steps 3 through 5 for each additional "trouble" the instructor adds.

7. Indicate the problems and explain procedures used to locate them.

8. Return equipment and materials to their proper storage location.

FUNDAMENTALS OF DC
UNIT II

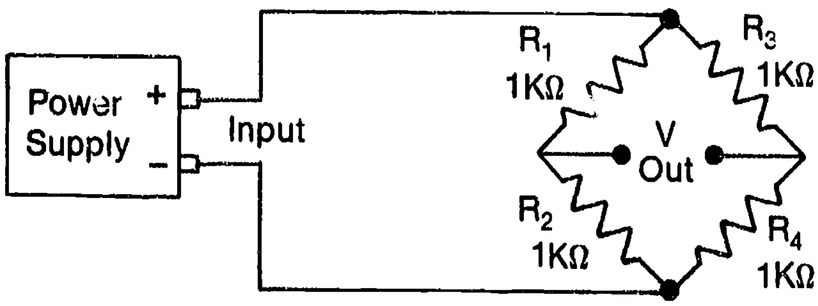
JOB SHEET #5 — MEASURE VOLTAGES IN A BALANCED BRIDGE CIRCUIT

A. Equipment and materials needed

1. Power supply
2. Voltmeter (or multimeter)
3. 4 — 1000 ohm resistors

B. Procedure

1. Connect the circuit according to the following schematic:



2. Apply 10 volts DC to circuit input.
3. Use a voltmeter to read and record the voltage drop across each resistor and the output terminals.

   E_{R1} = ______ E_{R3} = ______ E_{out} = ______

   E_{R2} = ______ E_{R4} = ______

   (NOTE: Notice how the voltages drops are equal across the resistors.)
4. Return equipment and materials to proper storage area.

   (NOTE: You may want to continue with the next job sheet at this time.)

FUNDAMENTALS OF DC
UNIT II

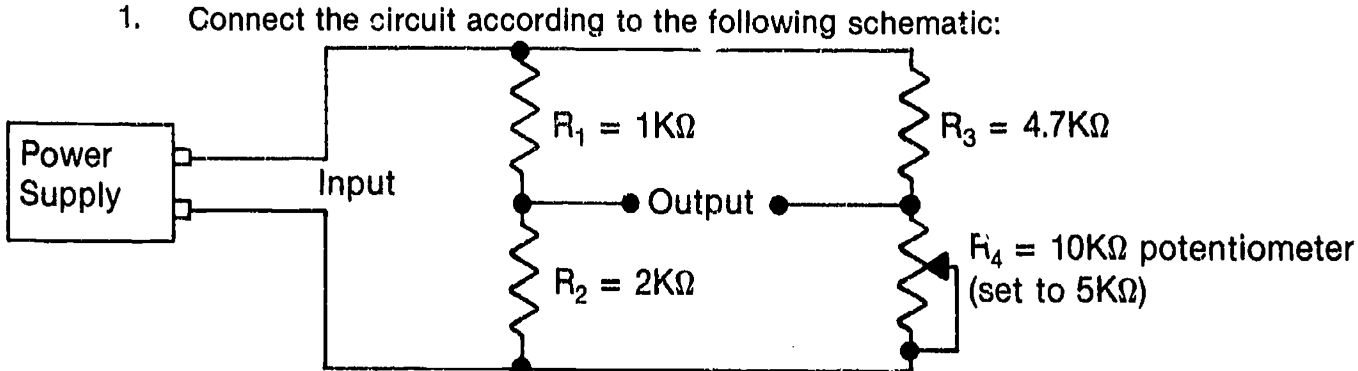
JOB SHEET #6 — MEASURE VOLTAGES IN AN UNBALANCED BRIDGE CIRCUIT

A. Equipment and materials needed

1. Power supply
2. Voltmeter (or multimeter)
3. Decade box or 10 KΩ potentiometer

B. Procedure

1. Connect the circuit according to the following schematic:



2. Apply 12 volts DC to the circuit.

3. Use a voltmeter to measure the voltage drops across each of the resistors and the voltage between the output terminals.

   E_{R1} = ______ E_{R3} = ______ E_{out} = ______

   E_{R2} = ______ E_{R4} = ______

   (NOTE: In this unbalanced bridge, the voltage drops are not all equal and there is voltage across the output terminals.)

4. Vary the potentiometer. Measure the output voltage.

   What happened when R_4 was varied? ______________________________

   ____

5. Return equipment and materials to their proper storage area.

FUNDAMENTALS OF DC
UNIT II

JOB SHEET #7 — DETERMINE THE MAXIMUM POWER TRANSFER POINT ON A RESISTOR CIRCUIT

A. Equipment and materials needed

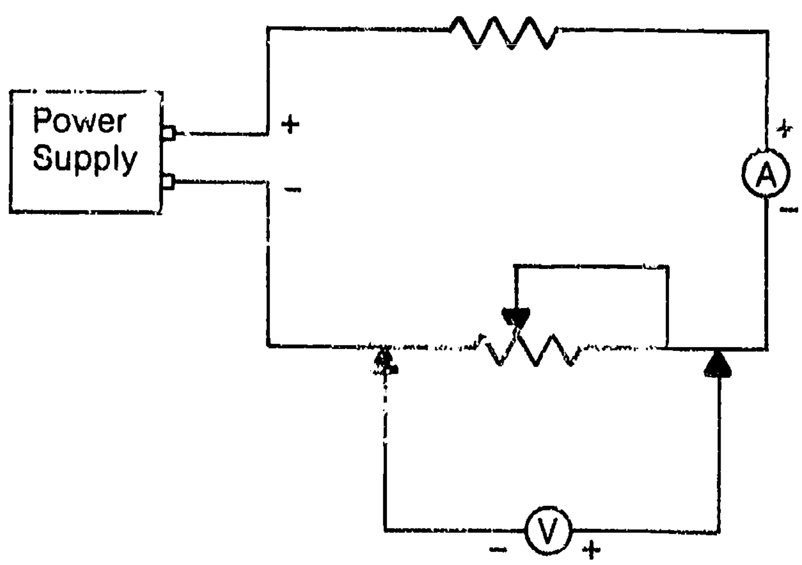
1. DC power supply
2. Fixed resistor — 200 ohms, 1/2 watt or more
3. Variable resistor (potentiometer) — 0 to 400 ohms, or as high as 0 to 1000 ohms, 1/2 watt or more

   (NOTE: A potentiometer is often referred to as a *pot.*)
4. Multimeter
5. Ammeter
6. Test leads

B. Procedure

1. Connect the two meters, fixed resistor, and potentiometer as shown below.

   (NOTE: Do not connect to the power supply at this time.)



JOB SHEET #7

2. Turn on the disconnected power supply and adjust the output for 10 volts.

3. Turn power supply off.

4. Set the ammeter to measure 0.05 amperes DC, somewhere near the limit of the scale.

5. Set the multimeter to measure from zero to 10 volts DC.

   (NOTE: Have instructor check your circuit, both multimeter settings, and the power supply settings.)

6. Connect the circuit.

7. Turn on the power supply.

8. Vary the potentiometer from zero ohms (where the voltage of the parallel meter will be zero) increasing by 1-volt increments until the table below is completed.

9. Record the indication of the series meter at each increment.

   (NOTE: Do not allow meters to go beyond a full scale indication.)

DATA TABLE

ADJUST	READ	CALCULATE
Parallel Meter Readings (Volts)	Series Meter Readings (Amps)	Power to the Potentiometer P=IE (Watts)
0		
1		
2		
3		
4		
5		
6		
7		

JOB SHEET #7

10. Find the reading in the last column of the table where the wattage value was the greatest.

    (NOTE: This is the maximum power transfer to the potentiometer.)

11. Turn power supply off.

    (NOTE: Show your results to the instructor.)

12. Return equipment and materials to their proper storage area.

FUNDAMENTALS OF DC
UNIT II

NAME ____________________

TEST

1. Match terms on the right with their correct definitions.

(NOTE: Answers to questions a.-o. appear on this page.)

_____a.	Quantity of electrons representing approximately 6.25×10^{18} electrons	1. Load
_____b.	Circuit in which there is a complete and unbroken path for current to flow	2. Dielectric
_____c.	Circuit in which the path for current has been broken	3. Ground
_____d.	An atom which has lost or gained an electron	4. Overload
_____e.	A receptacle containing electrodes and an electrolyte for producing electricity from chemical action	5. Schematic
_____f.	Consists of a number of cells connected together so as to produce more electrical capacity than a single cell	6. Chassis ground
_____g.	Reactive to light	7. Ion
_____h.	Device which opposes the flow of electrical current	8. Open circuit
_____i.	A common return circuit in electronic equipment whose potential is zero	9. Closed circuit
_____j.	A common return circuit in electronic equipment that may be at a potential above or below ground	10. Coulomb
_____k.	A device to which electrical energy is being supplied and expended	11. Resistor
_____l.	A load on a circuit or system greater than the load for which it was designed	12. Photo-sensitive
_____m.	A graphic representation of an electrical circuit using standard symbols for parts	13. Battery
_____n.	An insulating material capable of accumulating an electrical charge	14. Cell
_____o.	An energy loss in a component made evident by a difference in voltage measured across a component	15. Voltage drop

TEST

(NOTE: Answers to questions p.-t. appear on this page.)

_____p.	Unit of energy equal to one watt-second	16. Internal resistance
_____q.	Meter which indicates very small amounts of current and voltage	17. Work
		18. Impedance
_____r.	Total opposition to flow of an alternating current as a result of reactance and resistance	19. Galvanometer
		20. Joule
_____s.	Force moved through a distance, measured in foot pounds	
_____t.	The resistance which is within a voltage source	

2. Complete the following statements concerning the relationship of matter, energy, and electronics by inserting the word(s) that best completes each statement.

   a. ___________ and ___________ are regarded as equivalents in modern physics, and are mutually convertible by Einstein's formula.

   b. Electrical ___________ is a property of certain fundamental particles of all matter, as electrons (negative charges) and protons or positrons (positive charges) that have a force field associated with them and can be separated by the expenditure of energy.

   c. To control the behavior of the ___________ is essentially the basic purpose of electricity and electronics; therefore, to understand these areas we need to study the basic make-up of matter, the structure of the atom, and the basic behavior of the electron.

3. Match terms related to the composition of matter on the right with their correct definitions.

_____a.	Is commonly described as anything which has weight and occupies space	1. Molecule
		2. Matter
_____b.	The basic particles of which all matter is composed	3. Compound
_____c.	A substance composed of two or more elements	4. Element
		5. Atom
_____d.	The smallest particle of a compound that can exist and still retain its identity	
_____e.	The smallest particle to which an element can be reduced and retain its identity	

TEST

4. Complete the following statements concerning the structure of the atom by inserting the word(s) that best completes each statement.

   a. The ____________ of an atom contains protons and neutrons.

   b. A ____________ is the heaviest of the three fundamental particles of an atom, and is electrically neutral.

   c. A ____________ is one of the three primary particles within an atom, and has a positive charge with a weight nearly the same as a neutron.

   d. ____________ are the lightest of the three primary particles of an atom, and have a negative charge and revolve in orbits around the nucleus.

5. Select true statements concerning the characteristics of the electron by placing an "X" in the blanks preceding the true statements.

   _____a. The number of electrons equals the number of protons in a normal, neutral state atom.

   _____b. Electrons rotate in various orbits or shells around the nucleus with the outermost shell being of particular importance to electronics.

   _____c. The electrons contained in the valence shell are called valence electrons.

6. Complete the following statements concerning the sources of electricity by inserting the word(s) that best completes each statement.

   a. Electrical energy may be produced from ____________ by rubbing two non-conducting materials together (triboelectric effect).

   b. Electrical energy may be produced from ____________ ____________ in batteries and cells (electrochemistry).

   c. Electrical energy from ____________ is the most common method of producing electricity and is obtained by moving a conductor through a magnetic field (magnetoelectricity).

   d. Electrical energy is produced when ____________ strikes the surface of special photosensitive materials (photoelectric effect).

   e. Electrical energy may be produced when ____________ is applied to the junction of two unlike metals (thermoelectric effect).

   f. Electrical energy may be produced when ____________ ________ ____ is applied to crystalline substances, such as quartz or tourmaline (piezoelectric effect).

TEST

7. Complete the following statements concerning the characteristics of electron movement by inserting the word(s) that best completes each statement.

   a. When loosely attached electrons in conductors are dislodged from their orbit they tend to drift at random, unless controlled, and are called ____________ electrons.

   b. When electrical charges are applied to the ends of a conductor (negative to one end, positive to the other end), the random drift of electrons is changed to a directed drift with electrons moving from ____________ to ____________.

   c. The directed or controlled drift of free electrons, or charge in motion, is called __________ ___ ____________.

8. Select true statements concerning characteristics of conductors, insulators, and semiconductors by placing an "X" in the blanks preceding the true statements.

   ______a. Insulators have valence electrons which are loosely attached to the atom and are easily separated from the atom and provide an easy path for electrons to flow from point to point.

   ______b. Conductors have valence electrons which are tightly attached to the atom and can only be separated by applying extreme force and therefore are used to prevent electrons from flowing from point to point.

   ______c. Conductors may be represented on a schematic with a straight line.

   ______d. Semiconductors have four valence electrons (half-filled valence shell) which are attached only moderately to the atom and having characteristics of special value in the construction of transistors and other semiconductor devices.

9. Complete the following statements concerning the characteristics of electrical charges by inserting the correct word(s) that best completes each statement.

   a. The unit of electrical charge is called the ____________.

   b. A ____________ is equal to the charge of 6.25×10^{18} electrons.

   c. The natural law which describes the interaction of ____________ is called Coulomb's law.

   d. Coulomb's law states that charged bodies attract or repel each other with a force that is ____________ proportional to the product of their charges, and is ____________ proportional to the square of the distance between the charges.

   e. Coulomb's law establishes the important relationship that

      1) Like charges ____________.

      2) Unlike charges ____________.

TEST

10. Define electromotive force, potential difference, and voltage.

    a. Electromotive force — ______________________________

    ____

    ____

    b. Potential difference — ______________________________

    ____

    ____

    c. Voltage — ______________________________

    ____

    ____

11. Select true statements concerning the measure of electrical current by placing an "X" in the blanks preceding the true statements.

    _____a. Current is the flow of electrons from positive to negative.

    _____b. The unit of measure for current is the ampere (amp).

    _____c. The ampere is the rate at which electrons flow past a given point.

    _____d. One ampere equals the flow of one coulomb of electrons past a given point in one second.

    _____e. The letter I is used to indicate current (for intensity of electron flow) or as A (for amperes).

    _____f. Milliamp indicates a millionths of an amp.

    _____g. Microamp indicates a thousandths of an amp.

    _____h. Picoamp indicates a trillionth of an amp.

12. Define resistance, ohm, and conductance.

    a. Resistance — ______________________________

    ____

    ____

TEST

b. Ohm — ______________________________

____

____

c. Conductance — ______________________________

____

____

13. Match terms related to basic types of resistors on the right with their correct descriptions.

_____a. Resistors which are generally made of a nickel-chromium alloy wire wound on a ceramic tube and covered with a protective coating

_____b. Resistors which are made by mixing carbon granules with a powdered insulating material, solidified into a rod shape with a binding agent, and coated with a non-conductive material

_____c. Resistors which are made by depositing a resistive film on a rod, such as glass or ceramic, and then covered with a protective coating

_____d. Resistors which are constructed of resistance wire with a moveable contact that may be placed at different positions on the bare resistance wire to achieve the desired resistance

_____e. A three terminal variable resistor constructed of circular carbon composition ribbons (or resistance wire) with an arm attached to a moveable shaft so that when the shaft is turned, resistance is varied between a moveable center contact and the terminals on both ends of the resistor

_____f. A two terminal resistor that is a slight variation of the potentiometer with one terminal attached to an end and one to a moveable shaft so that when the shaft is turned the resistance between the two terminals varies

1. Potentiometer
2. Sliding contact
3. Deposited-film
4. Carbon-composition
5. Wire-wound
6. Rheostat

TEST

14. List the three basic circuit requirements.

    a. ______________________________

    b. ______________________________

    c. ______________________________

15. List the three basic circuit configurations.

    a. ______________________________

    b. ______________________________

    c. ______________________________

16. State the three fundamental Ohm's law formulas for finding current, voltage, and resistance.

    a. I = ____________

    b. E = ____________

    c. R = ____________

17. State the three fundamental Watt's law formulas for finding electrical power.

    a. P = ____________

    b. P = ____________

    c. P = ____________

TEST

18. Complete the following statements related to the characteristics of current, voltage, power, and resistance in series circuits by inserting the word(s) that best completes each statement.

    a. In a series circuit the sum of the resistances ____________ the ____________ resistance of the circuit.

    b. Kirchhoff's ____________ law states that the algebraic sum of all the voltage drops and voltage rises in a closed loop (series circuit) is equal to zero or, stated simply, the sum of the voltage drops is equal to the applied voltage.

    c. The voltage drop across each individual series resistor may be found by multiplying the resistance by the ____________ through it.

    d. For multiple source circuits, voltages connected in ____________-____________ (polarities the same) may be added for a total equivalent voltage while those in a ____________-____________ configuration (polarities opposite) may be subtracted for an equivalent voltage.

    e. Current (I) is the ____________ at all points in a series circuit.

    f. Total power dissipated in a series resistive circuit is the same as the total power supplied by the ____________ and may be found by totaling the powers dissipated by the resistors.

19. Complete the following statements concerning current in a parallel circuit by inserting the correct word(s) that best completes each statement.

    a. Current in a parallel circuit follows Kirchoff's current law which states that the algebraic sum of currents into any point ____________ the algebraic sum of the currents out of that point.

    b. Only a portion of the ____________ ____________ ______ ______ flows through an individual branch.

    c. The current of each branch is equal to the ____________ divided by the ____________ of that branch.

    d. ____________ circuit current equals the sum of the individual branch currents.

    e. When branch resistance decreases, current in the branch ____________; when resistance increases, current ____________.

20. Select true statements concerning the characteristics of resistance in a parallel circuit by placing an "X" in the blanks preceding the true statements.

    ______a. Total resistance of a parallel circuit is always less than the resistance of any individual branch.

    ______b. The reciprocal of the total resistance equals the sum of the reciprocals of the parallel resistances.

TEST

_____c. When the resistances of the individual branches are all equal, the total resistance is equal to the value of one branch resistor multiplied by the number of the branches.

_____d. When total current is known, total resistance may be found by dividing the applied voltage by the total current.

21. Complete the following statements concerning the characteristics of voltage and power in a parallel circuit by circling the correct words.

    a. (**Voltage, Power**) across each branch of a parallel circuit is the same.

    b. The (**voltage, power**) across each branch of a parallel circuit is equal to the source (**voltage, power**).

    c. Total (**voltage, power**) in a parallel circuit is the total (**voltage, power**) generated by the source and may be found by adding the individual values of (**voltage, power**) dissipated in the branches.

22. Select true statements concerning the characteristics of series-parallel circuits by placing an "X" in the blanks preceding the true statements.

_____a. A series-parallel circuit is one in which some components are connected in series to have the same current, while others are connected in parallel and have the same voltage.

_____b. The characteristics or "rules" for current, voltage, and resistance in series and parallel circuits are followed for their respective part(s) of the series-parallel circuit.

_____c. To determine values of E, I, and K in series-parallel circuits, simplify the circuit to an equivalent series circuit.

23. Select true statements concerning voltage divider characteristics by placing an "X" in the blanks preceding the true statements.

_____a. A voltage divider is a circuit that may be used to provide, from a single DC source, different voltage values to different loads each of which may draw a different value of current.

_____b. A voltage divider circuit consists of two or more resistors connected in series across a single primary power source.

_____c. The fraction of voltage required by a load or loads may be tapped off as the voltage is dropped through successive steps of the series resistors.

_____d. The values of the series resistors is determined by the voltage drops required.

TEST

_____e. If a chassis ground is used, both negative and positive voltages may be obtained from a single source.

_____f. An unloaded divider is the series string of resistors without a current drawing load attached.

_____g. When a load is attached (in parallel) to the divider network, the circuit becomes a loaded voltage divider.

_____h. The network is usually designed so that about 60 percent of the total current supplied by the source goes through the load.

_____i. Forty percent of the current flows through the series divider network.

24. Complete the following statements concerning general troubleshooting considerations by inserting the correct word(s) that best completes each statement.

a. In a normally operating resistive circuit, the voltage across the individual resistors and the current in every part of the circuit is distributed according to __________ law and __________ law.

b. It may be assumed that in a circuit which is not operating properly, the trouble is caused by __________ and only __________ component.

c. The natural human senses of __________, __________, and __________ are called upon often in troubleshooting and can become excellent troubleshooting "tools" with practice.

d. An __________ circuit is one in which burned-out components, broken conductor paths, corroded contact, or other similar problems cause the current path to be broken preventing electron flow.

e. A __________ circuit is one in which an unwanted low (or zero) resistance current path is created by a defective component, solder or wire chips left in the equipment, defective conductor insulation, or other like defect occurs.

f. When a resistor opens, or its resistance value increases, it will cause a resultant decrease in total circuit current and a proportionate __________ in the voltage drop across the increased resistance.

g. __________ may develop mechanical troubles.

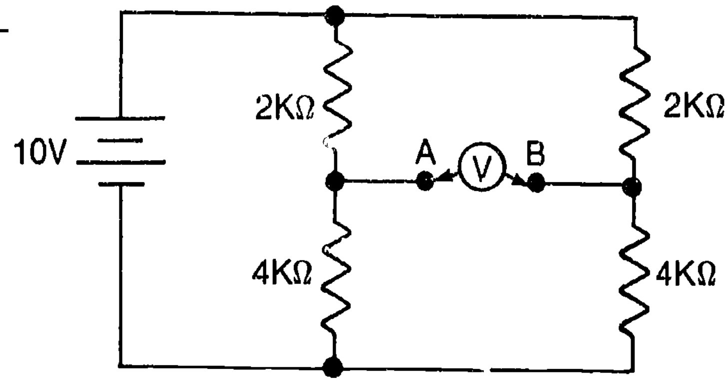
h. Interconnecting conductors may become __________ or __________.

i. The safety device, fuse, or circuit breaker may be __________ due to an overload condition.

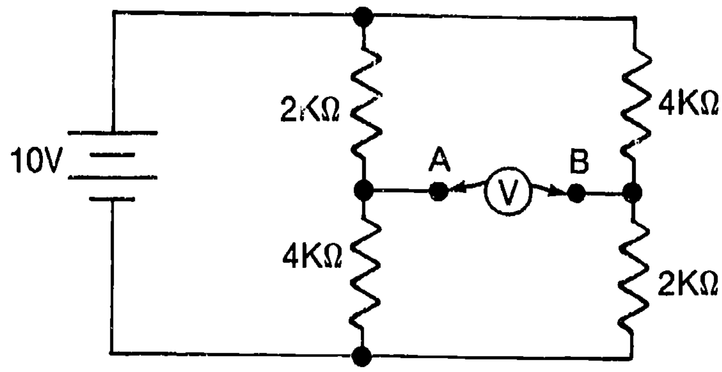
TEST

25. Identify types of bridge circuits in the schematic diagrams below.

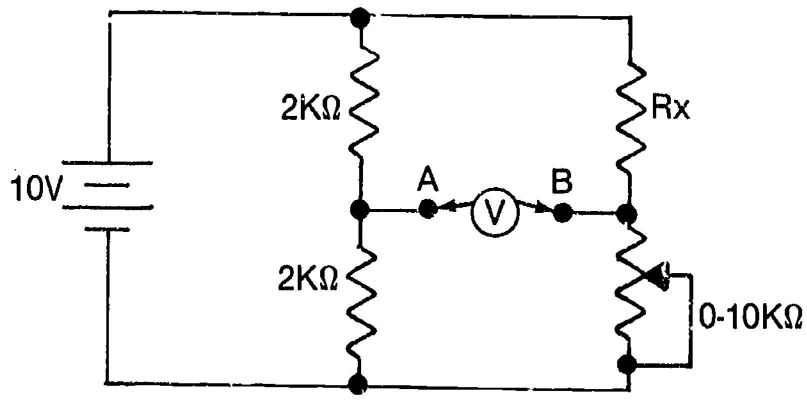
a. ____________



b. ____________



c. ____________



1. Unbalanced bridge 2. Balanced bridge 3. Wheatstone bridge

26. Select true statements concerning maximum power transfer by placing an "X" in the blanks preceding the true statements.

_____a. The maximum power transfer theorem says in effect that maximum power is transferred from the source to the load when a resistance of the load is equal to the internal resistance of the source.

_____b. The efficiency of power transfer (ratio of output to input power) from the source to the load increases as the load resistance is increased.

_____c. Efficiency approaches 80 percent as the load resistance approaches a relatively large value compared with that of the source, since less power is lost in the source.

TEST

_____d. At the point of maximum power transfer, efficiency is only fifty percent.

_____e. As the resistance of the load approaches relatively low values compared with the resistance of the source, the efficiency becomes very low and approaches zero efficiency.

_____f. Maximum power transfer and 100 percent efficiency may be achieved at the same time.

27. Arrange in order the steps for the application of the superposition theorem by indicating the first step as 1, the second step as 2, and so on for each procedure.

_____a. Calculate $It_1 = \frac{V_1}{Rt_1} = 5.37$ ohms

_____b. Calculate $Rt_1 = R_1 + \frac{R_2 \times R_3}{R_2 + R_3} = 5.4$ ohms

_____c. Calculate $ER_3 = IR_3 \times R_3 = 20$ volts

_____d. Calculate $ER_4 = I_{T1} \times R_4 = 12.89$ volts

_____e. Calculate $R_{t2} = R_2 + \frac{R_1 \times R_3}{R_3 + R_3} = 7.71$ ohms

_____f. Short out V_2

_____g. Short out V_1

_____h. Calculate $= t_2 = \frac{V_2}{Rt_2} = 4.15$ amps

_____i. Calculate $ER_3 = I_{T2} \times R_3 = 7.10$ volts

_____j. Calculate $IR_3 = \frac{ER_4}{R_3} + \frac{ER_5}{R_3} = \frac{ER_4 + ER_5}{R_3} = 5$ amps

28. Arrange in order the steps for the application of Thevenin's theorem by indicating the first step as 1, the second step as 2, and so on for each procedure.

_____a. Calculate load voltage using Ohm's law.

_____b. Replace the load resistance in the Thevenized series circuit.

_____c. Draw the equivalent Thevenin circuit.

_____d. Short the power source and calculate the Thevenin resistance (R_{th} as seen at the open load terminals.

TEST

_____e. Disconnect the load resistor R_2.

_____f. Calculate the equivalent Thevenin circuit current (I_{th}).

_____g. With the load terminals open, calculate the open circuit voltage by any convenient method to find E_{th}.

(NOTE: If the following activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

29. Solve problems for an unknown voltage. (Assignment Sheet #1)
30. Solve problems for an unknown amperage. (Assignment Sheet #2)
31. Solve problems for an unknown resistance. (Assignment Sheet #3)
32. Determine the total resistance in a series circuit. (Assignment Sheet #4)
33. Determine total voltage is a series circuit. (Assignment Sheet #5)
34. Determine voltage drops across resistances in a series circuit. (Assignment Sheet #6)
35. Determine current in a series circuit. (Assignment Sheet #7)
36. Compute power from the power formula. (Assignment Sheet #8)
37. Determine unknown circuit values in a series circuit. (Assignment Sheet #9)
38. Calculate resistance in parallel circuits. (Assignment Sheet #10)
39. Calculate current and voltage in parallel circuits. (Assignment Sheet #11)
40. Calculate power in parallel circuits. (Assignment Sheet #12)
41. Calculate various unknown values in parallel circuits. (Assignment Sheet #13)
42. Trace current flow in series-parallel circuits. (Assignment Sheet #14)
43. Solve for total resistance in a series-parallel circuit. (Assignment Sheet #15)
44. Solve for total current in series-parallel circuits. (Assignment Sheet #16)
45. Solve for total voltage in series-parallel circuits. (Assignment Sheet #17)
46. Solve for total power in series-parallel circuits. (Assignment Sheet #18)
47. Identify resistor values using a standard color code. (Assignment Sheet #19)

TEST

48. Demonstrate the ability to:

    a. Measure voltage drops in a series circuit. (Job Sheet #1)

    b. Analyze current values in a series circuit. (Job Sheet #2)

    c. Measure voltage, current, and resistance in a parallel circuit. (Job Sheet #3)

    d. Troubleshoot series-parallel circuits. (Job Sheet #4)

    e. Measure voltages in a balanced bridge circuit. (Job Sheet #5)

    f. Measure voltages in an unbalanced bridge circuit. (Job Sheet #6)

    g. Determine the maximum power transfer point on a resistor circuit. (Job Sheet #7)

FUNDAMENTALS OF DC
UNIT II

ANSWERS TO TEST

1.
a.	10	i.	3	q.	19
b.	9	j.	6	r.	18
c.	8	k.	1	s.	17
d.	7	l.	4	t.	16
e.	14	m.	5		
f.	13	n.	2		
g.	12	o.	15		
h.	11	p.	20		

2. a. Matter, energy
   b. Energy
   c. Electron

3. a. 2
   b. 4
   c. 3
   d. 1
   e. 5

4. a. Nucleus
   b. Neutron
   c. Proton
   d. Electrons

5. a, b, c

6. a. Friction
   b. Chemical action
   c. Magnetism
   d. Light
   e. Heat
   f. Mechanical pressure

7. a. Free
   b. Negative, positive
   c. Electron flow

8. c, d

9. a. Coulomb
   b. Coulomb
   c. Charges
   d. Directly, inversely
   e 1) Repel
     2) Attract

ANSWERS TO TEST

10. a. Electromotive force — The force or pressure that causes electrons to flow
    b. Potential difference — Existence of a difference in voltage between two electrical charges
    c. Voltage — Unit of measure for emf and potential difference

11. b, c, d, e, h

12. a. Resistance — Opposition to electron flow
    b. Ohm — Unit of measure for resistance
    c. Conductance — Reciprocal of resistance or the ability of a material to carry electrical current

13. a. 5
    b. 4
    c. 3
    d. 2
    e. 1
    f. 6

14. a. Source of potential difference
    b. A load
    c. Path for current to flow

15. a. Series
    b. Parallel
    c. Series-parallel or combination

16. a. $I = E/R$
    b. $E = I/R$
    c. $R = E/I$

17. a. $P = E \times I$
    b. $P = I^2 \times R$
    c. $P = E^2/R$

18. a. Equals, total
    b. Voltage
    c. Current
    d. Series-aiding, series-opposing
    e. Same
    f. Source

19. a. Equals
    b. Total circuit current
    c. Voltage, resistance
    d. Total
    e. Increases, decreases

20 a, b, d

ANSWERS TO TEST

21. a. Voltage
    b. Voltage, voltage
    c. Power, power, power

22. a, b, c

23. a, b, c, d, e, f, g

24. a. Ohm's, Kirchhoff's
    b. One, one
    c. Sight, hearing, smell
    d. Open
    e. Short
    f. Increase
    g. Switches
    h. Open, shorted
    i. Open

25. a. Balanced bridge
    b. Unbalanced bridge
    c. Wheatstone bridge

26. a, b, d, e

27.

a.	5	f.	1
b.	2	g.	3
c.	10	h.	6
d.	7	i.	8
e.	4	j.	9

28.

a.	7	e.	1
b.	5	f.	6
c.	4	g.	2
d.	3		

29.-47. Evaluated to the satisfaction of the instructor

48. Performance skills evaluated to the satisfaction of the instructor

FUNDAMENTALS OF AC
UNIT III

UNIT OBJECTIVE

After completion of this unit, the student should be able to apply theoretical knowledge of alternating current circuit fundamentals, solve for values of an operating RL circuit, and determine the effect of AC and DC on capacitors. Competencies will be demonstrated by correctly performing the procedures outlined in the assignment and job sheets and by scoring a minimum of 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to fundamentals of AC with their correct definitions.
2. List five ways magnets are classified.
3. Complete statements related to the characteristics of magnetic materials.
4. Complete statements related to characteristics of magnetic flux lines.
5. Match terms related to magnetic quantities with their correct descriptions.
6. Complete statements concerning the relationships of magnetism to electricity.
7. Complete statements related to the fundamentals of electromagnetism.
8. Complete statements related to the principles of induction.
9. Complete statements related to generating voltage by electromagnetic induction.
10. Complete statements related to values of the AC waveform.
11. Describe in-phase and out-of-phase relationships.

OBJECTIVE SHEET

12. Select true statements related to characteristics of AC resistive circuits.

13. Select true statements related to characteristics of self-induction.

14. Complete statements related to the characteristics of inductance.

15. Select true statements concerning factors affecting inductors.

16. Give the equation for determining time constants of inductive circuits.

17. Complete statements concerning current and voltage relationships in an inductive AC circuit.

18. Select true statements related to characteristics of inductive reactance.

19. Complete statements related to the process of mutual inductance.

20. Complete statements related to connecting inductors in series and parallel.

21. Select true statements related to the quality of inductors.

22. Select true statements related to power characteristics in an inductive circuit.

23. Complete statements related to the characteristics of voltage and current in RL circuits.

24. Complete statements related to characteristics of impedance in RL circuits.

25. Give the trigonometric based formulas for finding the angle of phase shift in RL circuits.

26. Complete statements related to the characteristics of capacitance.

27. Select true statements concerning types, ratings, and common defects of capacitors.

28. Give the equations for combining capacitors in series and parallel.

29. Give the equation for determining time constants in an RC circuit.

30. Complete statements related to voltage and current relationships in a capacitive AC circuit.

31. Give the equation for determining capacitive reactance.

32. Complete statements related to the characteristics of series RC circuits.

33. Complete the equations related to the characteristics of impedance in RC circuits.

OBJECTIVE SHEET

34. Give the equation for finding the phase angle in an RC circuit.

35. Select true statements related to characteristics of power in an AC resistive-capacitive circuit.

36. Complete equations related to the characteristics of parallel RC circuits.

37. Name four applications of capacitive circuits.

38. Complete statements related to the characteristics of series RCL circuits.

39. Complete statements related to resonant characteristics of series RCL circuits.

40. Complete statements related to characteristics of parallel RCL circuits.

41. Complete statements related to resonant characteristics of a parallel RCL circuit.

42. Select true statements concerning applications of resonant circuits.

43. Complete statements related to fundamentals of rectangular and polar notation.

44. Determine sine wave conversions. (Assignment Sheet #1)

45. Compute period. (Assignment Sheet #2)

46. Determine current flow direction. (Assignment Sheet #3)

47. Answer questions regarding induction and inductors. (Assignment Sheet #4)

48. Solve for total inductance. (Assignment Sheet #5)

49. Compute inductive reactance. (Assignment Sheet #6)

50. Compute applied voltage and impedance of RL circuits. (Assignment Sheet #7)

51. Compute the Q of inductors. (Assignment Sheet #8)

52. Solve time constant problems. (Assignment Sheet #9)

53. Compute capacitance values. (Assignment Sheet #10)

54. Compute RC time constants. (Assignment Sheet #11)

55. Compute capacitive reactance. (Assignment Sheet #12)

56. Determine phase relationships in RC circuits. (Assignment Sheet #13)

57. Compute values of RC circuits. (Assignment Sheet #14)

OBJECTIVE SHEET

58. Solve for reactance. (Assignment Sheet #15)

59. Solve for impedance. (Assignment Sheet #16)

60. Solve for parameters of resonant circuits. (Assignment Sheet #17)

61. Solve problems related to parallel RCL circuits. (Assignment Sheet #18)

62. Analyze a parallel resonant circuit. (Assignment Sheet #19)

63. Demonstrate the ability to:

    a. Show the effect of inductance in AC circuits. (Job Sheet #1)

    b. Solve for values of an operating RL circuit. (Job Sheet #2)

    c. Test capacitors with an ohmmeter. (Job Sheet #3)

    d. Determine the effect of AC and DC on capacitors. (Job Sheet #4)

    e. Determine time constants of RC circuits. (Job Sheet #5)

    f. Construct a neon bulb flasher. (Job Sheet #6)

    g. Show the effect of capacitive reactance in AC circuits. (Job Sheet #7)

    h. Determine capacitive reactance and impedance in RC circuits. (Job Sheet #8)

    i. Determine resonance in a series RCL circuit. (Job Sheet #9)

    j. Determine the resonant frequency of an RCL parallel circuit. (Job Sheet #10)

FUNDAMENTALS OF AC
UNIT III

SUGGESTED ACTIVITIES

A. Obtain additional materials and/or invite resource people to class to supplement/reinforce information provided in this unit of instruction.

B. Make transparencies from the transparency masters included with this unit.

(NOTE: Activities A and B should be completed prior to the teaching of this unit.)

C. Provide students with objective sheet.

D. Discuss unit and specific objectives.

E. Provide students with information and assignment sheets.

F. Discuss information and assignment sheets.

(NOTE: Use the transparencies to enhance the information as needed.)

G. Provide students with job sheets.

H. Discuss and demonstrate the procedures outlined in the job sheets.

I. Integrate the following activities throughout the teaching of this unit:

1. Show and identify different types of magnets.
2. Show the internal parts of a piece of equipment and identify the capacitors, inductors, and transformers used in the equipment.
3. Show various types of capacitors (as available) and explain their differences.
4. Have students view an AC waveform on an oscilloscope.
5. Demonstrate the effect of a magnetic field using iron filings and a magnet.
6. Meet individually with students to evaluate their progress through this unit of instruction, and indicate to them possible areas for improvement.

J. Give test.

(NOTE: Due to the length of this unit, it is suggested that the information be tested in three parts.)

K. Evaluate test.

L. Reteach if necessary.

INSTRUCTIONAL MATERIALS INCLUDED IN THIS UNIT

A. Objective sheet

B. Suggested activities

C. Information sheet

CONTENTS OF THIS UNIT

CONTENTS OF THIS UNIT

CONTENTS OF THIS UNIT

REFERENCES USED IN DEVELOPING THIS UNIT

(NOTE: The following is a list of references used in completing this unit.)

A. *AC Electronics*. Benton Harbor, MI, Heathkit Educational Systems, 1978.

B. Bruce, David. *Modern Electronics*. Reston, VA: Reston Publishing Co., Inc., 1984.

C. Cook and Adams. *Basic Mathematics for Electronics*. New York: McGraw-Hill Book Co.

D. Gerrish, Howard and William E. Dugger. *Electricity and Electronics*. South Holland, IL: Goodheart-Willcox Co., Inc., 1980.

E. Robertson, L. Paul. *Basic Electronics I. (Revised Edition)*. Stillwater, OK: Mid-America Vocational Curriculum Consortium, 1982.

F. Rutkowski, George B. *Basic Electricity for Electronics*. Indianapolis, IN: Bobbs-Merrill Educational Publishing Co., 1984.

FUNDAMENTALS OF AC
UNIT III

INFORMATION SHEET

I. **Terms and definitions**

A. Alternation — Moving from zero to a maximum (or minimum) and back to zero

B. Amplitude — The extreme range of varying quantity such as the maximum height of a waveform

C. Attenuate — To decrease in amplitude or intensity

D. Bandwidth — The band of frequencies over which the response in a circuit falls within a specified fraction of the maximum value

E. Cascaded — A series of electronic circuits or devices connected so that the output of one is the input of the next

F. Cycle — The series of events occurring in sequence as the complete reversal of an alternating current from positive to negative and back to the starting point (two alternations)

G. Electromagnet — A soft iron core surrounded by a coil of wire that temporarily becomes a magnet when an electric current flows through the coil of wire

H. Filter — Frequency discriminating network

I. Induction — The process of magnetizing an object by bringing it into the magnetic field of an electromagnet or permanent magnet

J. Magnet — Device or material that has the property of magnetism

K. Magnetism — Property possessed by certain materials which exerts a mechanical force on other magnetic materials, and which can cause induced voltages in conductors when relative movement is present

L. Permeability (μ) — A measure of the effectiveness of a material as a path for magnetic lines of force as compared to the effectiveness of air

M. Permeance — The reciprocal of reluctance

N. Phase — Time relationship of one waveform to another

O. Reluctance (R) — Magnetic resistance

P. Retentivity — Ability of a material to retain magnetism

Q. Vector — Straight line drawn to scale, showing direction and magnitude of a force

R. Waveform — The shape of a wave as a function of time, distance, and amplitude

INFORMATION SHEET

II. **Classification of magnets** (Transparency #1)

A. Magnets may be classified as **natural** magnets such as the earth or lodestones. (Transparency #2)

B. Magnets may be classified as **artificial** magnets formed by stroking a material with a natural magnet or by subjecting the material to a strong magnetic field. (Transparency #3)

C. Magnets may be classified as **temporary** or **permanent** depending upon the retentivity of the material of which they are made.

D. Magnets may be classified by their **shape** such as horseshoe, bar, or ring.

E. Magnets may be classified by the **type of material used** such as ceramic or metallic (Alnico-aluminum, nickel, cobalt alloy; Cunife-copper, nickel, iron alloy).

III. **Characteristics of magnetic materials**

A. The three natural elements of iron, cobalt, and nickel respond to magnetic fields.

B. Substances which readily respond to magnetism or magnetic fields are called ferromagnetic.

C. Substances which are attracted only slightly by a strong magnetic field are called paramagnetic.

D. Diamagnetic materials are substances which are slightly repelled by magnetic fields.

E. The relative permeability of diamagnetic materials is less than unity; paramagnetic is slightly greater than unity; and ferromagnetic is much larger than unity.

(NOTE: Permeability may be compared to conductance in a circuit.)

IV. **Characteristics of magnetic flux lines** (Transparency #4)

A. Magnets are surrounded by a force field made up of flux lines.

B. Flux lines have both direction and polarity.

C. Magnetic lines of force are assumed to exit from the north pole of a magnet and return through the surrounding space to enter the south pole of the magnet.

D. The magnetic lines of force surrounding a magnet form complete loops.

E. Flux lines do not cross each other.

(NOTE: Like poles repel each other.)

F. Flux lines will tend to restrict themselves to the smallest possible loops.

(NOTE: Unlike poles attract each other.)

INFORMATION SHEET

V. **Magnetic quantities** (Transparency #5)

A. Flux is the complete magnetic field surrounding a magnet and is represented by the Greek letter phi (Φ).

B. Flux density refers to the number of lines of flux per unit area and is represented by the letter B.

C. Magnetomotive force (mmf) is the force which produces flux in an electromagnet or coil and is measured in ampere-turns.

D. Field intensity or magnetizing force refers to both mmf and the length of the coil, expressed as ampere-turns per inch, and is represented by the letter H.

E. Permeability is the ease with which a material can accept lines of force and is represented by the Greek letter mu (μ).

(NOTE: Permeability may also be thought of as the ability of a material to concentrate lines of force.)

F. Reluctance is the opposition to flux and the reciprocal of permeability and is represented by the letter R.

G. The relationship of magnetic quantities is expressed in the "Ohm's law for magnetism" which states that the magnetic flux developed in a core material is directly proportional to the magnetomotive force and inversely proportional to the reluctance and may be expressed in the equation

$$\text{phi } (\Phi) = \frac{\text{mmf}}{R}$$

VI. **Relationship of magnetism to electricity**

A. When current flows through a wire, a magnetic field is produced around the wire. (Transparency #6)

1. The direction of the field is determined by the direction of electron flow.

2. The left-hand rule for conductors may be used to determine the direction of the lines of flux. (Transparency #7)

a. Grasp the conductor with the left hand with the thumb pointing in the direction of electron flow.

b. The direction of the magnetic field is in the direction which the four fingers are pointing.

B. The field surrounding a conductor may be strengthened by forming the conductor into a coil.

INFORMATION SHEET

VII. **Fundamentals of electromagnetism**

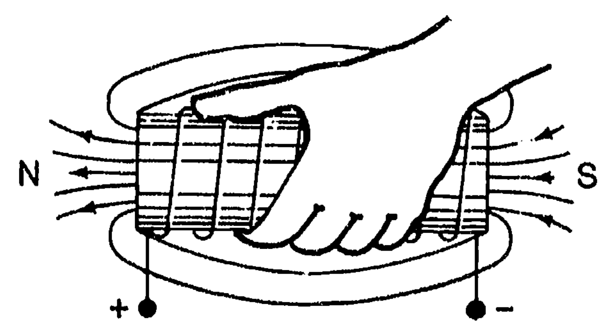
A. The strength of the magnetic field around a coil is directly proportional to both the number of turns in the coil and the amount of current through the coil.

B. The strength of the electromagnetic field may be dramatically strengthened by placing a core of ferromagnetic material inside the coil.

C. The polarity of the electromagnetic field may be determined by the left-hand rule for electromagnets. (Transparency #8)

1. Grasp the coil with your left hand in such a way that your fingers encircle the coil in the same direction that the current is flowing. (See figure below.)

2. Your thumb will point in the direction of the north pole of the electromagnet.



VIII. **Principles of induction** (Transparency #9)

A. Magnetic induction occurs when a magnet is placed in close proximity to a ferromagnetic material causing the material to also become magnetized.

B. Electromagnetic induction is the action which causes electrons to flow in a conductor when the conductor cuts the lines of force in a magnetic field. (Transparency #10)

C. The amount of current induced into the conductor is determined by four factors (Faraday's law):

1. **Strength** of the magnetic field

2. **Speed** of the conductor with respect to the field

3. **Angle** at which the conductor cuts the field

4. **Length** of the conductor in the field.

INFORMATION SHEET

D. Lenz' law states simply that the direction of the induced current must be such that its own magnetic field will oppose the action that produced the induced current.

IX. **Generating voltage by electromagnetic induction** (Transparency #11)

A. There are three basic requirements for generating voltage electromagnetically:

1. A magnetic field

2. A conductor in the magnetic field

3. Relative motion between the conductor and the magnetic field

B. Direction of the voltage generated by electromagnetic induction is determined by the direction of motion and the direction of magnetic flux.

C. When a conductor, shaped in a loop, is rotated in a magnetic field, a sinusoidal alternating voltage waveform is produced. (Transparency #12)

D. The left-hand generator rule may be used to determine the direction of emf and the resulting electron flow. (Transparency #13)

E. The magnitude of the induced voltage is proportional to the number of flux lines cut per second by the conductor.

F. The number of flux lines cut per second by the conductor is determined by four factors:

1. The **velocity** of the conductor

2. The **strength** of the magnetic field

3. The **length** of the conductor

4. The **angle** at which the conductor cuts the field

(NOTE: When the conductor moves parallel to the lines of force, no voltage is generated; when the conductor moves at right angles to the lines, maximum voltage is generated.)

X. **Values of the AC waveform** (Transparency #14)

A. The sine wave have an infinite number of instantaneous values in each alternation.

B. The sine wave has two alternations; one positive and one negative.

INFORMATION SHEET

C. Peak value of a sine wave is the point at which the waveform is at its maximum amplitude in the positive (90 degrees) or negative (270 degrees) alternation (1.414 × rms).

D. Peak-to-peak value of the sine wave's amplitude is the value from positive peak to negative peak (two times peak).

E. The average voltage of one alternation is 0.636 times the peak value.

F. The rms (root-mean-square) or effective value of the sine wave is 0.707 times peak value.

(NOTE: Effective value is the value of alternating current that will produce the same amount of heat in a resistance as the corresponding direct-current value.)

G. The time (T) required for one cycle of AC to occur is called a period.

H. The number of cycles that occur in one second of time is called the frequency (F) of the waveform and is expressed in Hertz (Hz).

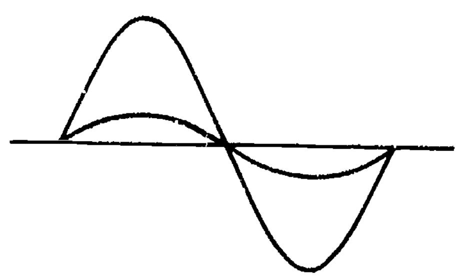
I. The formula for expressing the relationship between frequency and period is

$$f = \frac{1}{T} \text{ and } T = \frac{1}{f}$$

XI. **Phase relationships**

A. When two waveforms coincide so that their maximum instantaneous values both occur at the same time they are said to be in phase.

Example:

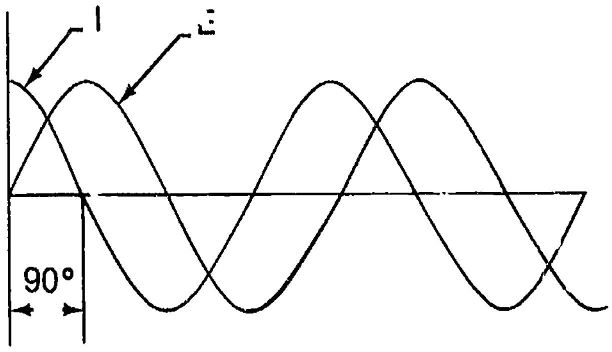


In-Phase Relationship

INFORMATION SHEET

B. When two waveforms do not occur at the same time they are said to be out of phase.

Example:



90° Out-of-Phase

C. The amount of phase displacement is usually measured in degrees.

XII. Characteristics of AC resistive circuits

A. Ohm's law may be used to calculate voltage, current, and resistance in resistive AC circuits just as in DC circuits.

1. The rules for calculating resistance in series and parallel AC circuits are the same as those used for DC circuits.

2. The effctive value of AC voltage and current is used when performing calculations in AC circuits that contain only resistance.

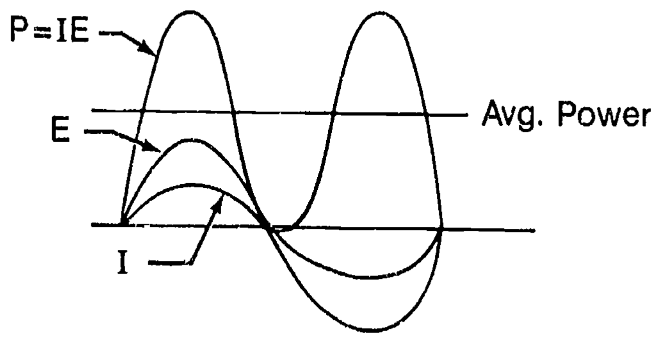
B. Power is consumed in a resistive AC circuit in the form of heat dissipated by the resistor.

1. The rules used for power in DC circuits may be applied to AC circuits.

INFORMATION SHEET

2. Effective values of voltage and current are used to determine average power.

Example:



XIII. **Characteristics of self-induction** (Transparencies #15 and #16)

A. When current begins to flow in a wire or coil, a sequence of events occur and produces self-induction.

1. The switch is closed.

2. Current starts to flow in the wire.

3. A magnetic field begins to form around the wire.

4. The moving magnetic field being formed induces a voltage back into the wire.

B. The induced current caused by self-induction is counter to the original current.

(NOTE: The induced current is called counter EMF (CEMF).

C. Self-induction occurs both when current is increasing in a circuit and when current is decreasing in a circuit.

D. The effect of self-induction or counter EMF is to oppose changes in current flow.

XIV. **Characteristic of inductance**

A. Inductance is the physical property of a circuit or device which indicates an ability to oppose a change in current.

B. Inductance may also be defined as the ability to induce an EMF into a conductor when there is a change in current flow.

INFORMATION SHEET

C. The symbol for inductance is the letter L.

D. The unit of measurement for inductance is the Henry.

1. A Henry is the amount of inductance the induces an EMF of one volt into a conductor when the current changes at the rate of one ampere per second

2. The Henry is expressed symbolically with the letter "H".

(NOTE: The Henry is a relatively large unit, therefore the millihenry (mH) and the microhenry (uH) are the units generally used in practice.)

XV. **Factors affecting inductors** (Transparency #17)

A. An inductor is a physical device consisting of a coil of wire usually wound on a core.

(NOTE: An inductor may also be called a coil or choke.)

B. The inductance of a coil varies as the square of the number of turns.

C. Inductance of a coil may be increased dramatically by winding the coil on a core of material that has a high permeability.

D. Inductance varies inversely with the length of the coil.

XVI. **Time constants of inductive circuits** (Transparency #18)

A. The time required for current to fall or rise in a circuit is called the time constant.

B. A time constant of an inductor is the time required for the current to rise to 63.2% of its maximum possible value or decrease by 63.2% of its maximum value. (Transparency #19)

C. The inductive time constant in a circuit is a function of both inductance and resistance.

1. The time constant is directly proportional to the inductance and inversely proportional to the resistance.

2. The relationship of time constant, resistance, and inductance is expressed by the formula $T = L/R$.

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XVII. **Current and voltage relationships in an inductive AC circuit** (Transparency #20)

A. When an AC voltage is applied to an inductor, the AC current which flows produces a varying magnetic field that induces a voltage into the inductor.

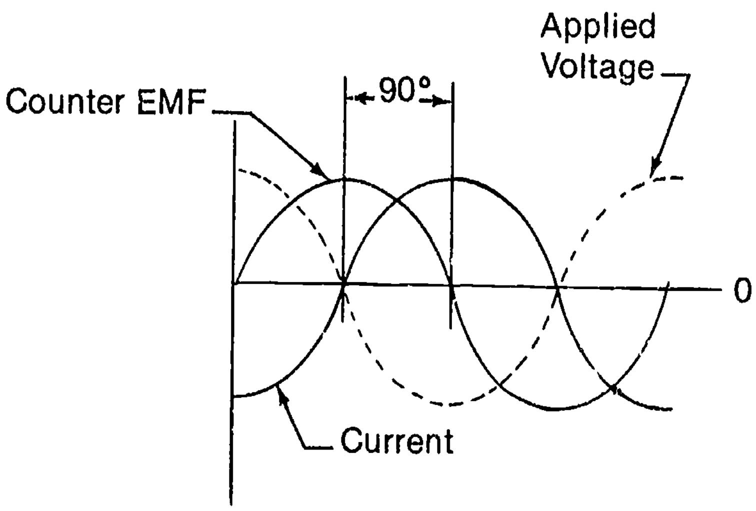
1. The induced voltage is 180 degrees out of phase with the applied voltage.

2. If the circuit current is a sine wave, the induced voltage will be a sine wave.

3. The rate of change of current determines the amplitude of the induced voltage.

B. Counter EMF is 90 degrees out of phase with the circuit current.

Example:



C. The current flowing in an inductive circuit is directly proportional to the voltage applied and inversely proportional to the inductive reactance and may be represented by the formula $I = E/X_L$.

XVIII. **Characteristics of inductive reactance**

A. Inductive reactance is the opposition to AC.

B. Inductive reactance is directly proportional to the inductance and frequency of the applied voltage.

1. As frequency increases, the rate of change in current increases and inductive reactance becomes greater.

2. As frequency decreases, the rate of change in current decreases and causes inductive reactance to decrease.

INFORMATION SHEET

C. Inductive reactance is represented by the symbol X_L.

D. The unit for inductive reactance is the ohm.

E. Inductive reactance may be calculated by using the formula $X_L = 2\pi fL$.

XIX. **The process of mutual inductance**

A. Mutual induction is the process by which one conductor causes a voltage to be induced into another.

1. Mutual inductance is represented by the symbol Lm.

2. The unit of mutual inductance is in the henry (H).

B. The amount of mutual inductance between adjacent coils primarily depends upon the degree of coupling between them.

1. The degree of coupling between coils is called the coefficient of coupling (k).

2. A coefficient of coupling of one (k=1) represents a coupling of 100 percent.

C. Mutual inductance between two coils is the function of the coefficient of coupling (k) and the values of inductance of the two coils (L_1 and L_2).

(NOTE: Mutual induction is expressed by the formula

$$Lm = K\sqrt{L_1 \times L_2}$$

D. Mutual inductance of one henry is the condition when a current change of one ampere per second in an inductor induces a voltage of one volt into another.

(NOTE: Iron cores may be used to concentrate lines of force in a coil. When two coils are located close to one another iron cores may be used to concentrate the field in the core and allow nearly no mutual induction to take place between them. Conversely, mutual inductance may be increased by winding two coils on a common iron core to increase mutual inductance between the coils (as in transformers).

XX. **Connecting inductors in series and parallel**

A. The rules for connecting inductors in series and parallel are similar to those used with resistors.

B. For two or more inductors connected in series the total inductance is the sum of the inductances when no mutual inductance exists ($L_T = L_1 + L_2 + L_3 + \ldots$).

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C. When mutual inductance is present, and the magnetic fields are aiding, the total inductance of two or more inductors in series may be expressed by the formula $L_T = L_1 + L_2 + 2Lm$.

D. When two inductors are connected in series, the magnetic fields opposing the total inductance of the combination may be found with the formula Lt = L1 + L2 - 2Lm.

E. When two inductors are connected in parallel the total inductance may be found with the formula

$$L_T = \frac{L_1 \times L_2}{L_1 + L_2}$$

(NOTE: The reciprocal formula used to find resistors in parallel may also be applied to inductors in parallel.)

XXI. **Quality of inductors**

A. A manufactured inductor is not pure inductance because the wire of which the coil is made has resistance.

B. Power is dissipated in inductors within the resistance in the wire of the coil.

C. Inductors are compared in quality by a figure of merit called Q.

D. The Q of a coil is the ratio of energy stored in the coil in the form of a magnetic field to the energy dissipated in the resistance of the coil.

E. The Q of a coil may also be expressed as a ratio of inductive reactance to the resistance

$$Q = \frac{X_L}{R}.$$

F. Since Q is directly proportional to the inductive reactance, the Q increases with frequency.

XXII. **Power characteristics in an inductive circuit** (Transparency #21)

A. No power is dissipated in a pure inductance.

(NOTE: We are unable to make totally pure inductors and therefore all inductors have some resistance within the wire of which they are made.)

B. Power dissipation in an RL circuit occurs in the resistance within the circuit.

C. Since power is dissipated only in the resistance, it may be calculated using the standard power formulas

$$P = EI \qquad P = I^2R \qquad P = \frac{E^2}{R}.$$

INFORMATION SHEET

XXIII. Characteristics of voltage and current in RL circuits

A. AC current flow in an RL circuit causes voltage drops across the resistor and the inductor.

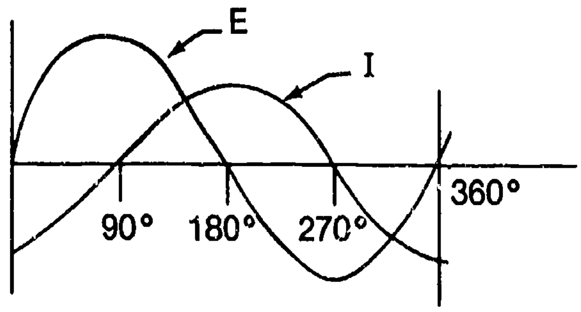
B. The voltage drop across the resistance may be found using Ohm's law $E_R = IR$.

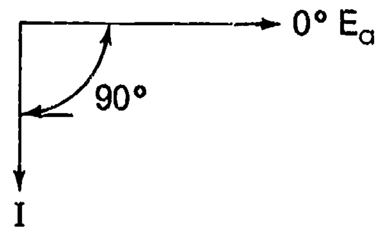
C. The voltage drop across the inductor may also be found using Ohm's law $E = IX_L$.

D. The circuit current in an RL circuit lags the applied voltage by 90 degrees.

(NOTE: This also may be stated that the voltage across the inductor leads the current by 90 degrees.)

E. The voltage and current phase relationships in a series RL circuit may be illustrated by a vector diagram. (Transparency #22)





F. The applied voltage is the vector sum of the resistor and inductor voltages

$$E_a = \sqrt{E_R^2 + E_L^2}$$

(NOTE: Pythagorean's theorem is used to find vector sums. The basic formula for Ea may be rearranged to also find the resistor or inductor voltages as shown below.)

$$Ea = \sqrt{(E_R^2) + (E_L^2)} \quad E_R = \sqrt{(E_a^2) - (E_L^2)} \quad E_L = \sqrt{(E_a^2) - (E_R^2)}$$

XXIV. Characteristics of impedance in RL circuits

A. The total opposition to current flow offered by both the resistor and inductor in an RL circuit is called impedance.

B. Impedance is expressed in ohms.

INFORMATION SHEET

C. The applied voltage and the circuit current may be used to determine the impedance according to Ohm's law.

$$\text{Impedance } Z = \frac{E_a}{I_T}$$

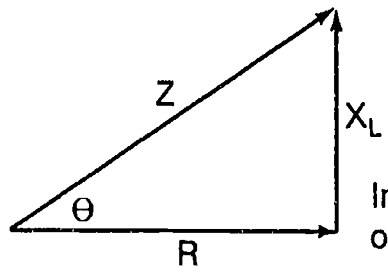
D. The impedance of a series RL circuit also may be determined by vector summation of resistance and the inductive reactance.

$$Z = \sqrt{R^2 + X_L^2}$$

(NOTE: Resistance and inductive reactance may also be found using Pythagorean theorem and noted below with the impedance triangle of a series RL circuits.)

$$R = \sqrt{Z^2 - X_L^2}$$

$$X_L = \sqrt{Z^2 - R^2}$$



Impedance Triangle of Series RL Circuit

XXV. Phase shift in RL circuits

A. Phase shift in an RL circuit is a function of the resistance and inductive reactance.

B. The phase angle theta (Θ) of an RL circuit may be found mathematically by the use of trigonometric based formulas

$$\tan\Theta = \frac{X_L}{R},\ \Theta = \arctan\frac{X_L}{R},\ \Theta = \arctan\frac{E_L}{E_R}.$$

XXVI. Characteristics of capacitance

A. The property of a circuit or device which enables it to store electrical energy with an electrostatic field is called capacitance. (Transparency #23)

B. A device that is made to have a specific value of capacitance is called a capacitor.

1. The number of electrons that a capacitor can store for a given applied voltage is a measure of its capacitance.

2. A capacitor has the ability to store electrons and discharge them at a later time.

INFORMATION SHEET

C. A capacitor is a device constructed of two metal plates separated by a dielectric. (Transparency #24)

D. Capacitance of a capacitor is determined by three factors:

1. The **area** of the metal plates (Transparency #25)
2. The **spacing** between the plates (Transparency #26)
3. The **type** or **nature** of the dielectric (Transparency #27)

E. The unit of capacitance is the farad (F).

F. One farad is the amount of capacitance which will store a charge of one coulomb when one volt of EMF is applied.

(NOTE: The farad is a very large unit and therefore is commonly expressed in terms of micro-farads or pico-farads.)

G. Capacitance may be expressed in terms of charge and voltage by the formula $C = Q/E$ (C is the capacitance, Q is the quantity of electrical charge in coulombs, and E is the applied voltage).

XXVII. **Types, ratings, and common defects of capacitors**

A. Capacitors are classified according to a number of factors.

1. There are two basic types: fixed value capacitors and variable capacitors.
2. Capacitors are classified by the type of dielectric used such as mica, ceramic, paper, and mylar.
3. Capacitors may be an electrolytic type.

   (NOTE: Polarity must be observed.)

B. Capacitors are rated according to value of capacitance.

C. Defects in capacitors are related to four common failures:

1. Shorts occur when the dielectric is punctured or otherwise fails.
2. A capacitor may open when one or both leads become disconnected from the plates.
3. Excessive leakage may develop when a resistive path forms between the two plates (partial failure of dielectric).
4. The capacitor may change in value due to a manufacturing defect or improper use (excessive temperature or applied voltage may cause a change in value).

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XXVIII. **Combining capacitors in series and parallel**

A. When two or more capacitors are connected in parallel the total capacitance is the sum of the individual capacitors
$C_T = C_1 + C_2 + C_3 + \ldots$

(NOTE: This is in contrast to that of inductors or resistors in parallel.)

B. The total capacitance of a parallel combination is always greater than any single value in the combination.

C. The formula for finding total capacitance of a series network is

$$C_T = \frac{C_1 \times C_2}{C_1 + C_2}.$$

(NOTE: The reciprocal formula may be used for multiple capacitors in series.)

D. When two or more capacitors are connected in series the total capacitance of the combination is less than the capacitance of the smallest capacitor.

XXIX. **Determining time constants in an RC circuit** (Transparency #28)

A. Two factors determine charge and discharge time of an RC circuit:

1. The value of the capacitor

2. The value of the resistance in the charge/discharge path

B. One time constant is the time required for a capacitor to charge to 63.2 percent of the applied voltage or the time required for the voltage across the capacitor to discharge by 63.2 percent.

C. The time constant is expressed in the equation $T = R \times C$ where t is time in seconds required to reach 63.2 % of full charge (R is the resistance in ohms, and C is the capacitance in farads).

XXX. **Voltage and current relationships in a capacitive AC circuit** (Transparency #29)

A. When a sine wave is applied to a pure capacitive circuit, a sine wave voltage will be developed across the capacitor that is equal to and in phase with the applied voltage.

B. The sine wave current developed in the circuit leads the applied voltage (Ea) and capacitor voltage (Ec) by 90°.

C. When Ea and Ec are at the maximum value of their positive and negative alternations, current in the circuit is zero.

INFORMATION SHEET

D. When Ea and Ec are at zero, current in the circuit is maximum.

XXXI. **Determining capacitive reactance**

A. The opposition to AC current flow offered by a capacitor is capacitive reactance.

B. The capacitive reactance of a capacitor is determined by the capacitance and the frequency of the applied voltage.

C. Capacitive reactance is inversely proportional to the capacitance and the frequency.

D. Capacitive reactance may be calculated by the formula

$$X_C = \frac{1}{2\pi fC}$$

(NOTE: This formula may be rearranged to also calculate for frequency or capacitance.)

E. Capacitive reactances in series are combined like resistances ($Xct = Xc_1 + Xc_2 + Xc_3 \ldots$).

F. Capacitive reactances in parallel are combined like resistances in parallel using the reciprocal formula ($1/C_T = 1/C_1 + 1/C_2 + 1/C_3 \ldots$).

XXXII. **Characteristics of series RC circuits** (Transparency #30)

A. Series RC circuits contain resistors and capacitors connected in series.

B. The voltage drop across the resistor in the series RC circuit is in phase with the current in the circuit.

C. The voltage across the capacitor lags the current flowing in the circuit by ninety degrees.

D. Voltages in the series RC circuit may be found through vector summation (Pythagorean theorem) using the following formulas:

$$E_a = \sqrt{(E_R)^2 + (Ec)^2}$$

$$E_R = \sqrt{(E_a)^2 - (Ec)^2}$$

$$Ec = \sqrt{(E_a)^2 - (E_R)^2}$$

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XXXIII. **Characteristics of impedance in RC circuits** (Transparency #31)

A. The total opposition to current flow in a resistive-capacitive AC circuit offered by the resistance and capacitance is called impedance.

B. Impedance is expressed in ohms.

C. The impedance of an RC circuit may be calculated by dividing the applied voltage by the total circuit current.

$$\text{Impedance } Z = \frac{E_a}{I_T}$$

D. The impedance of an RC circuit may also be determined by using Phythagorean's theorem using the resistance and capacitive reactance in the circuit.

$$Z = \sqrt{R^2 + X_C^2}$$

(NOTE: Resistance and inductive reactance may also be found by using the Phythagorean theorem as noted below.)

$$R = \sqrt{Z^2 - X_C^2} \qquad X_C = \sqrt{Z^2 - R^2}$$

XXXIV. **Finding the phase angle in an RC circuit**

A. The phase angle in an RC circuit may be found by using the basic trigonometric expression

$$\text{phase angle } (\Theta) = \arctan \frac{X_C}{R}$$

B. If the capacitor and resistor voltage in a series RC circuit are known, the phase may be found with the trigonometric expression

$$\text{phase angle } (\Theta) = \arctan \frac{E_C}{E_R}$$

XXXV. **Characteristics of power in an AC resistive-capacitive circuit** (Transparency #32)

A. True power is dissipated only in the resistance in an RC circuit.

B. Apparent power is the term used to describe the power which "appears" to be consumed in an RC circuit when the power formula $P = IE$ is applied to the circuit.

INFORMATION SHEET

C. The ratio of true power to apparent power in an AC circuit is referred to as power factor expressed as a formula

$$\text{Power factor (PF)} = \frac{\text{true power}}{\text{apparent power}}$$

D. The ratio of the resistance to the impedance is also equal to the cosine of the phase angle of the circuit expressed in the formula (Transparency #33)

$$\text{Cosine } \Theta = \frac{R}{Z} = \text{power factor (PF)}$$

XXXVI. **Characteristics of parallel RC circuits** (Transparency #33)

A. The current in the resistive branch of a parallel circuit is determined by dividing the applied voltage by the resistance ($I = E/R$).

B. The current in the capacitive branch of a parallel circuit is determined by dividing the applied voltage by the capacitive reactance ($I = E/Xc$).

C. Due to the phase difference between the resistance branch current and the capacitive branch current, the total current must be found by vector summation using the Pythagorean theorem

$$I_T = \sqrt{(I_R)^2 + (I_C)^2}$$

D. The impedance of a parallel RC circuit is found by dividing the applied voltage by the total current.

$$Z = \frac{E_a}{I_T}$$

E. When the resistance and capacitive reactance are known, the impedance may be calculated with the formula

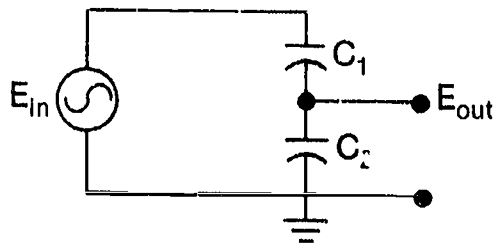
$$Z = \frac{RXc}{\sqrt{R^2 + X_C{}^2}}$$

INFORMATION SHEET

XXXVII. Applications of capacitive circuits

A. A capacitive voltage divider consists of capacitors connected in series.

$$E_O = \frac{E_{in} \times C_2}{X_{c1} + X_{c2}}$$



1. The amount of voltage developed across each capacitor is a function of the circuit current and the reactance of the capacitor with the output voltage in the circuit above being a function of Ohm's law.

$$E_O = E_{c2} = IX_{c2}$$

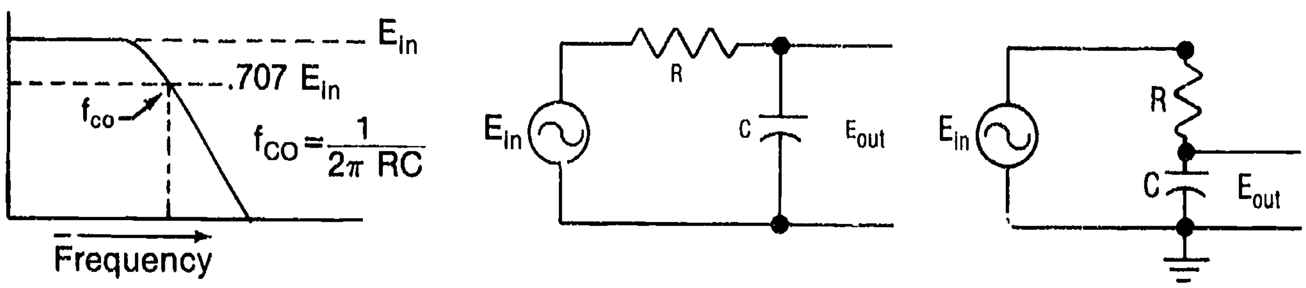
2. The output voltage may also be found with the voltage divider formula.

$$E_O = \frac{X_{c2}}{X_{c1} + X_{c2}} \times (E_i)$$

3. The output voltage may also be found by a voltage division ratio proportional to the capacitance as given in the formula.

$$E_O = \frac{C_1}{C_1 + C_2} (E_i)$$

B. An RC circuit may be used as a low pass filter circuit.



1. At low frequencies the capacitive reactance will be very high resulting in most of the voltage appearing across the capacitor effectively passing the low frequency from input to output.

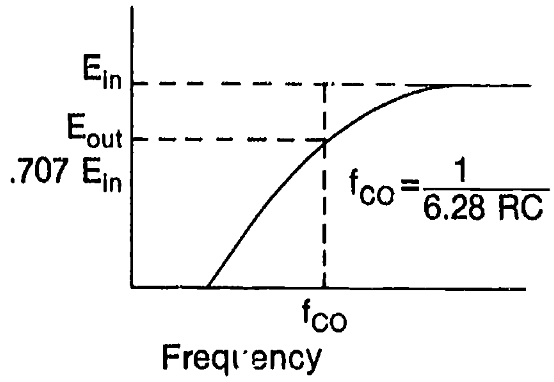
2. At high frequencies the capacitive reactance will be lowered resulting in a major portion of the voltage to appear across the resistance, and little across the output capacitor, therefore essentially blocking the high frequencies from passing from input to output.

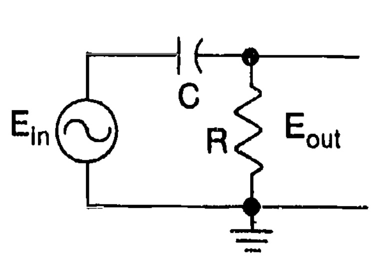
INFORMATION SHEET

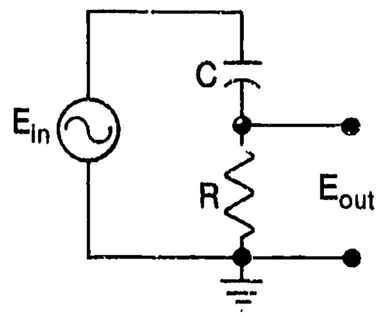
3. Cut-off frequency is the point at which the output drops to .707 of the input frequency and may be calculated by the formula

$$\text{Cut-off frequency } f_{co} = \frac{1}{6.28\ RC}$$

C. An RC circuit may be used as a high-pass filter circuit.





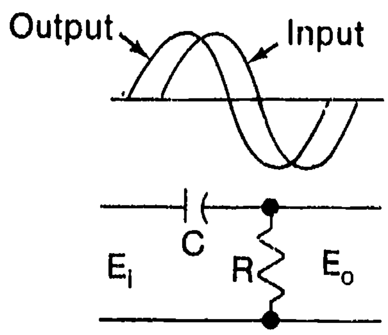


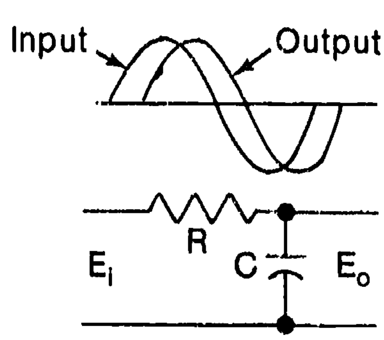
1. At very high frequencies the capacitive reactance will be very low compared to the resistance therefore allowing most of the input voltage to be developed across the output resistor effectively passing the major portı n of the high-frequency input to the output.

2. At low frequencies the capacitive reactance is high therefore developing most of the input voltage across the capacitor effectively blocking the voltage from being developed across the output resistor.

3. Cut-off frequency may be calculated with the same formula used for low-pass filters.

D. RC circuit may be used to obtain a phase shift.



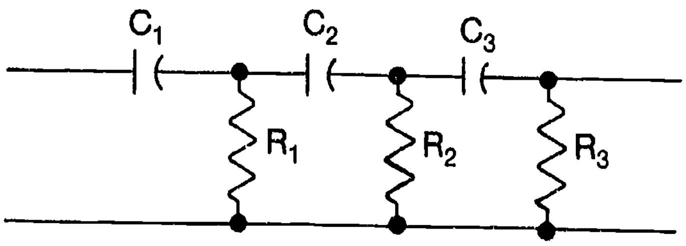


1. The amount of phase shift may be determined by finding the phase angle with the formula, $\tan \phi = E_R/E_C$

INFORMATION SHEET

2. When a phase shift of more than 60 degrees is required, networks may be cascaded.

   Example:



3. Phase shift networks are designed for specific frequencies and the phase shift for another frequency will be different.

XXXVIII. Characteristics of series RCL circuits

A. Series RCL circuits contain resistance (R), capacitance (C), and inductance (L) connected in series.

B. Total reactance in a series RCL circuit is a combination of X_L and X_C.

   1. Net reactance X_T equals the difference between X_L and X_C.

   2. When the inductive reactance is greater than the capacitive reactance the circuit appears inductive.

   3. When the capacitive reactance is greater than the inductive reactance, the circuit appears capacitive.

   4. When inductive and capacitive reactance are equal the circuit appears resistive (resonant).

C. Impedance in an RCL circuit may be found by using the formula (Transparency #35)

$$Z = \sqrt{R^2 + X_T^2}$$

D. Current is common to all components in a series RCL circuit and the phase of voltages within the circuit may be referenced to the common current. (Transparency #35)

   1. Voltage across the resistance (V_R) is in phase with the current.

   2. Voltage across the inductor (V_L) leads the current by ninety degrees.

   3. Voltage across the capacitor (V_C) lags the current by ninety degrees.

INFORMATION SHEET

4. Reactive voltage (V_T) is the vector sum of the inductive voltage (V_L) and capacit've (V_C) voltages.

5. The vector sum of the resistive voltage and the reactive voltage equals the applied voltage

$$E_a = \sqrt{V_R^2 + V_X^2}$$

XXXIX. **Resonant characteristics of series RCL circuits** (Transparency #36)

A. Resonance in a series RCL circuit occurs when the inductive effect equals the capacitive effect.

(NOTE: Resonance is also commonly stated as that point at which inductive reactance equals capacitive reactance.)

1. Impedance of the circuit is at minimum value at resonance.

2. Circuit current is at its maximum level at resonance.

3. The phase angle between v tage and current is zero at resonance.

4. The inductive voltage (V_L) and the capacitive voltage (V_C) are equal at resonance and larger in value than the applied voltage.

B. The resonant frequency (f_r) of a series RCL circuit may be calculated using the formula

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

1. Increasing inductance or capacitance decreases the resonant frequency.

2. Decreasing inductance or capacitance increases the resonant frequency.

C. Circuit Q is a figure of quality for a series resonant circuit and is the ratio of the reactance at resonance to the series AC resistance. (Transparency #38)

$$Q = \frac{X}{R}$$

(NOTE: Since $X_L = X_C$ at resonance, either value may be used for X in the formula.)

INFORMATION SHEET

D. Bandwidth (BW) of a series resonant circuit is measured between the half-power points of the circuit and may be calculated by dividing the resonant frequency by the circuit Q.

$$BW = \frac{f_r}{Q}$$

XL. Characteristics of parallel RCL circuits (Transparency #38)

A. A parallel RCL circuit is a circuit in which resistance (R), capacitance (C), and inductance (L) are connected in parallel.

B. Voltage is the same across all branches of a parallel RCL circuit and the phase of the individual branch currents may be referenced to it.

1. Current through the resistive branch is in phase with the voltage and may be found using the formula $I = E_a/R$.

2. Current through the inductive branch of the parallel RCL circuit lags the voltage by 90° and may be found using the formula $I = E_a/X_L$.

3. Current through the capacitive branch of the parallel RCL circuit leads the voltage by 90° and may be found using the formula $I = E_a/X_C$.

C. The reactive current (I_X) is the difference between the current in the inductive branch (I_L) and the capacitive branch (I_C).

D. Total current in a parallel RCL circuit is the vector sum of the resistive current (I_R) and the reactive current (I_R).

$$I_T = \sqrt{I_R^2 + I_X^2}$$

E. Impedance in a parallel RCL circuit may be found by dividing the applied voltage by the total current.

$$Z = \frac{E_a}{I_T}$$

XLI. Resonant characteristics of a parallel RCL circuit (Transparency #39)

A. Resonance in a parallel RCL circuit occurs when the inductive effects equal the capacitive effects (tank circuit).

1. Impedance of the parallel RCL circuit is maximum at resonance and may be calculated using the formula $Z = E_a/I_Z$.

INFORMATION SHEET

2. Current is at minimum value at resonance and equals the resistive current.

3. The phase between the applied voltage and the total current is zero.

B. The resonant frequency (f_r) of a parallel RCL circuit may be calculated using the formula

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

C. The Q of a parallel resonant circuit may be calculated by dividing the inductive reactance by the total AC resistance.

$$Q = \frac{X_L}{R}$$

D. The bandwidth (BW) of a parallel resonant circuit may be calculated by dividing the resonant frequency by the Q. (Transparency #40)

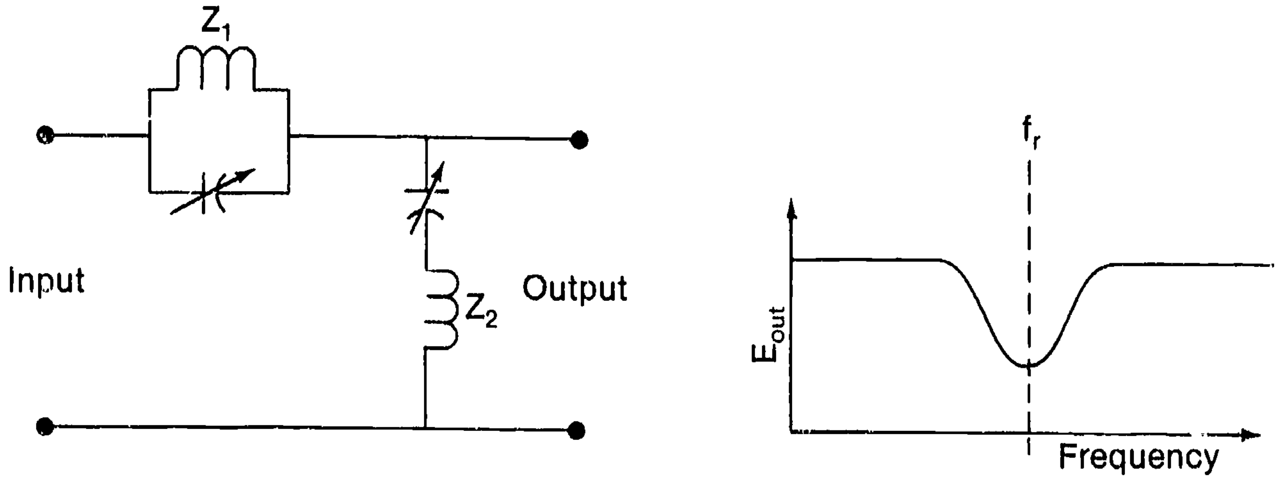
$$BW = \frac{f_r}{Q}$$

XLII. **Applications of resonant circuits**

A. Resonant circuits may be used as filters to accept or reject a specified band of frequencies.

B. A band stop filter is designed to stop a band of frequencies while allowing all other frequencies to pass to the output.

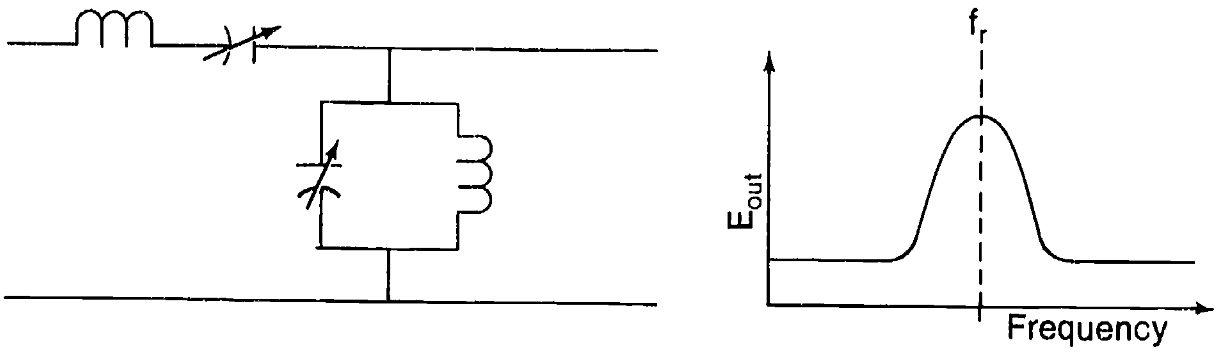
Example:



INFORMATION SHEET

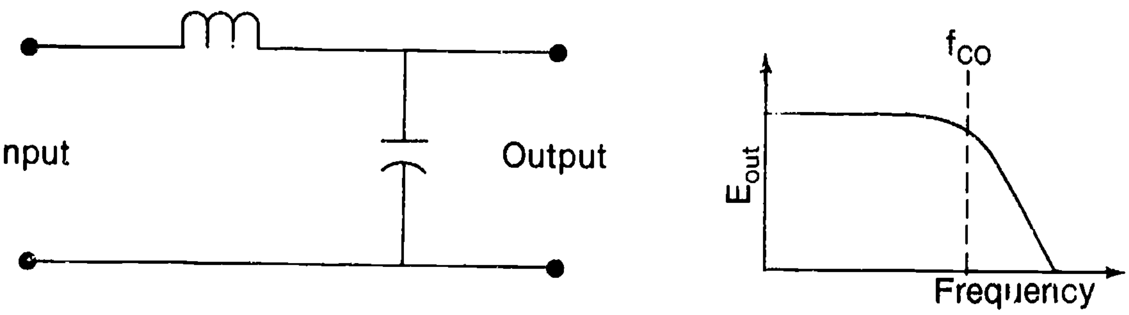
C. A band pass filter may be designed to pass a certain band of frequencies and stop all other frequencies.

Example:



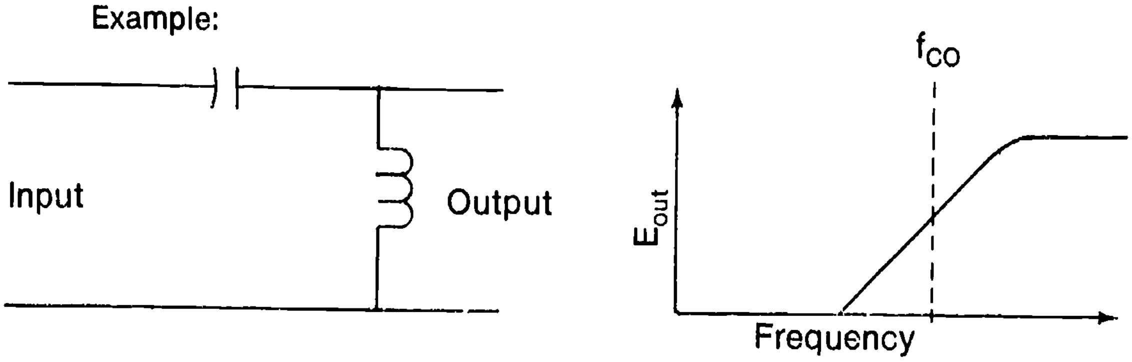
D. A low pass filter is designed to pass all frequencies below the cutoff frequency (f) and attenuate all frequencies above the cutoff frequency.

Example:



E. A high pass filter may be designed to pass all frequencies above the cutoff frequency and attenuate all frequencies below the cutoff frequency.

Example:



XLIII. Fundamentals of rectangular and polar notation

A. Rectangular and polar forms of notation are not methods of solving circuits but convenient forms of notation that describe circuit conditions from both the electrical and the mathematical viewpoints.

INFORMATION SHEET

B. In rectangular notation the letter j is used as a symbol of operation indicating direction of rotation (clockwise or counterclockwise) of a vector.

1. A +j indicates the rotation of a vector in a counterclockwise direction through an angle of 90° (indicating inductive characteristics in a circuit).

   Example: +j75 indicates an inductive reactance of 75 ohms

2. A −j indicates the rotation of a vector in a clockwise direction through an angle of 90° (indicating capacitive characteristics in a circuit.

   Example: −j85 indicates a capacitive reactance of 85 ohms

C. The impedance of a series RL circuit of 6 ohms resistance and 8 ohms of inductive reactance may be notated in rectangular form as $Z = R + jX = 6 + j8$.

D. The impedance of a series RL circuit of 6 ohms resistance and an inductive reactance of 8 ohms (phase angle of 53.1 degrees) may be written in polar form as $Z = 10\angle 53.1^\circ$ ohms.

E. Converting from rectangular form to polar form is completed by vector summation of rectangular components.

Example: Given the rectangular form $Z = 250 - j100$

$$Z = 250 - j100$$

$$\tan \Theta = X/R = 100/250 = 0.400$$

$$\Theta = -21.8^\circ$$

$$Z = X/\sin \Theta = 100 \sin 21.8^\circ = 269$$

therefore $Z = 269 -\angle 21.8^\circ$ (polar form)

F. Converting from polar notation to rectangular notation may be completed by using trigonometric functions and the formula $Z = Z \cos \pm jZ \sin$.

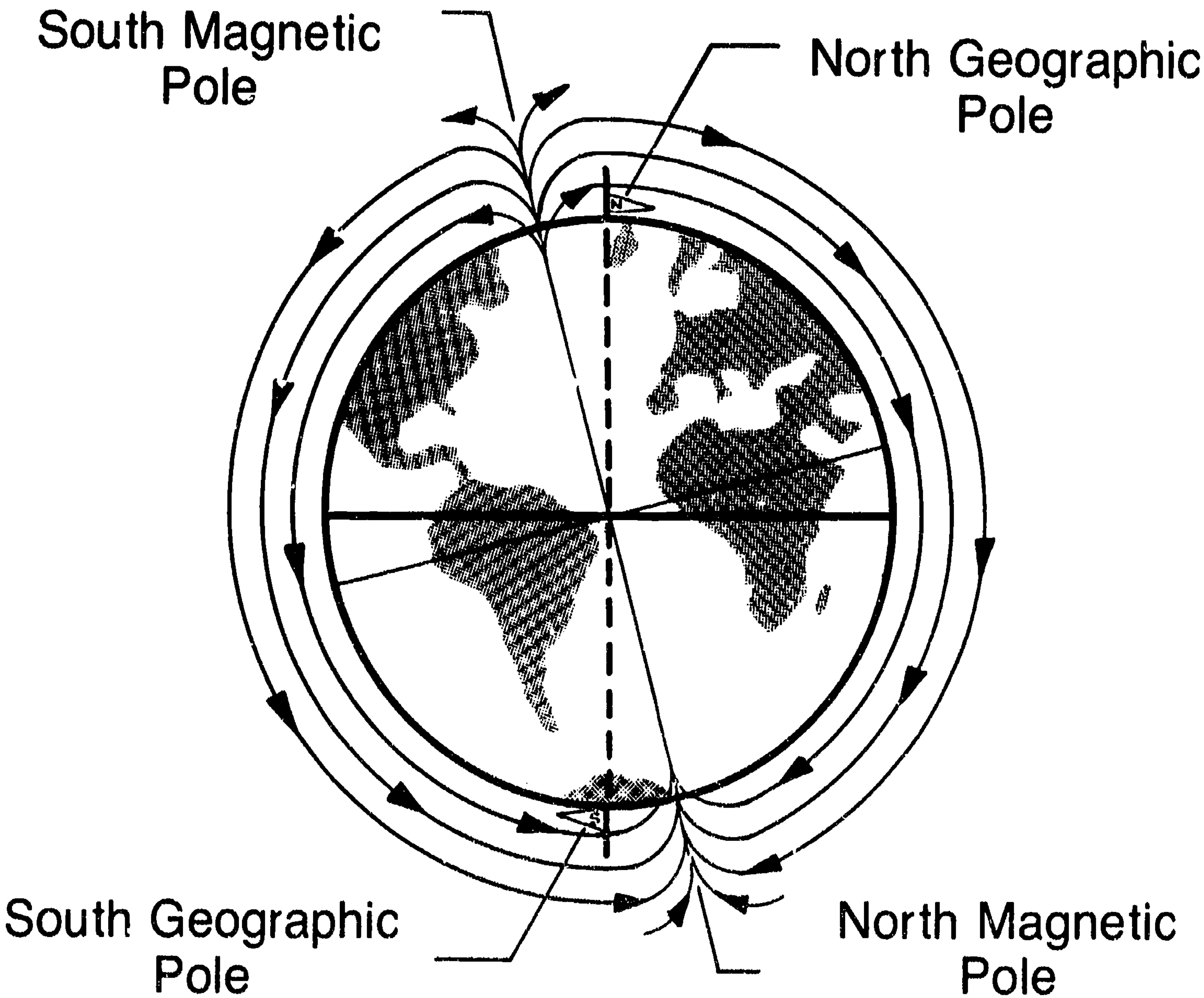
Example: Given the polar form $Z = 269 -\angle 21.8^\circ$

$$Z = Z \cos - jZ \sin$$

$$Z = 269 \cos 21.8^\circ - j269 \sin 21.8^\circ$$

$Z = 250 - j100$ ohms (rectangular form)

Magnetic Poles



TM 1

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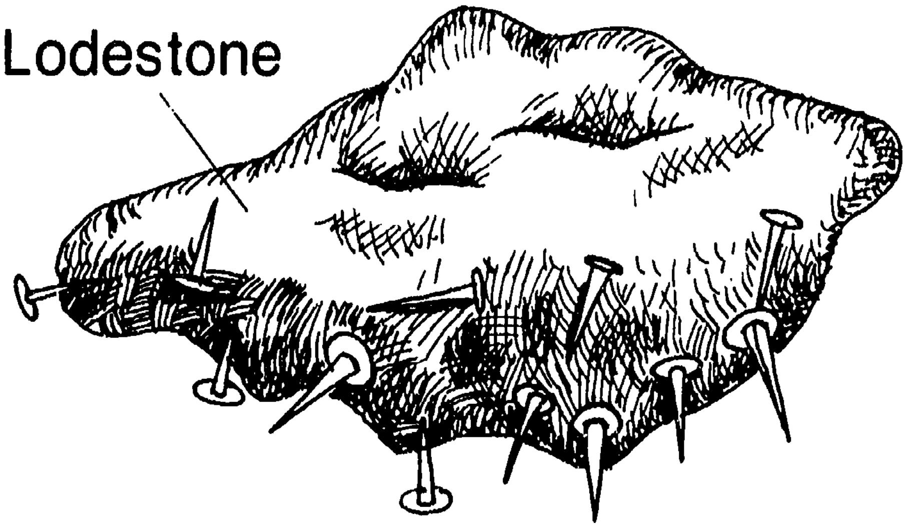
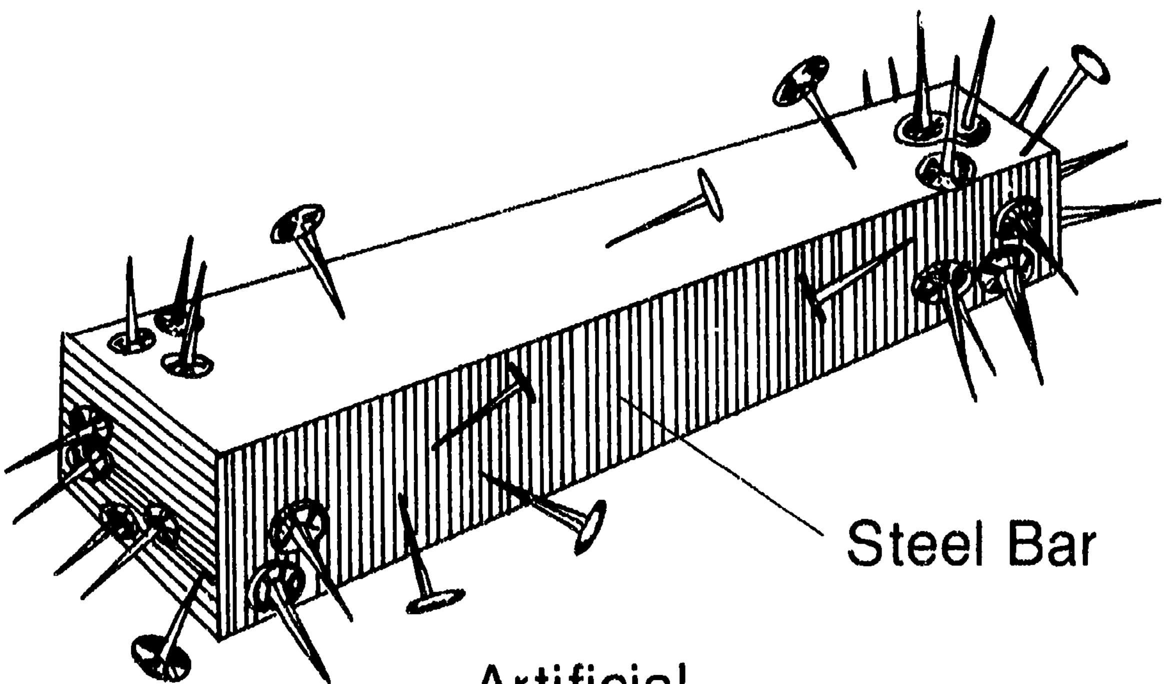
Types of Magnets

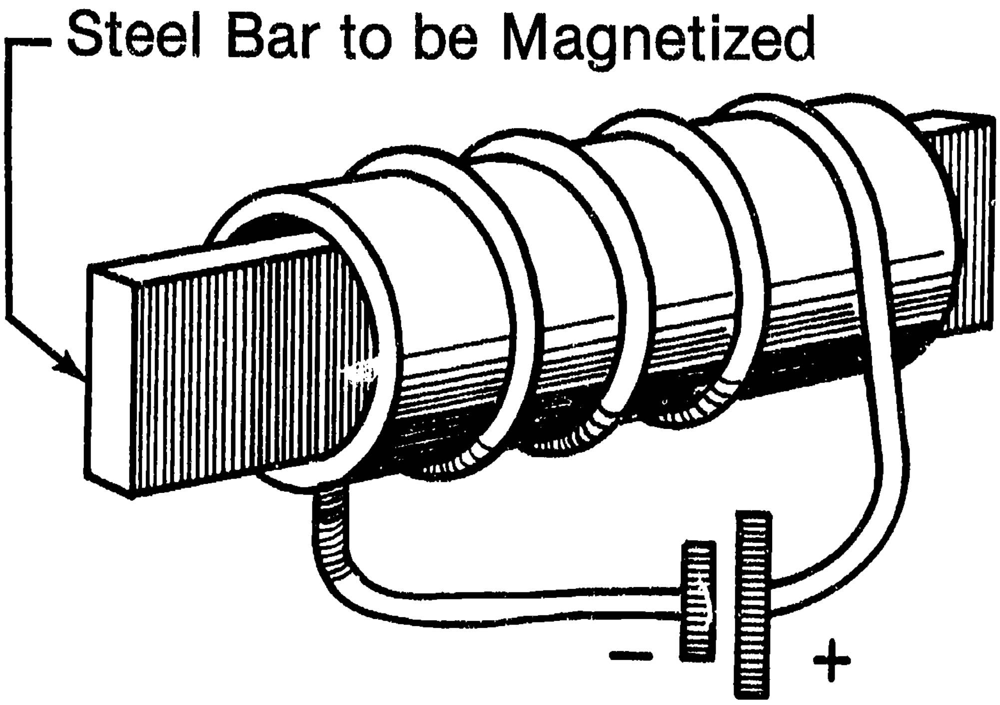


Natural

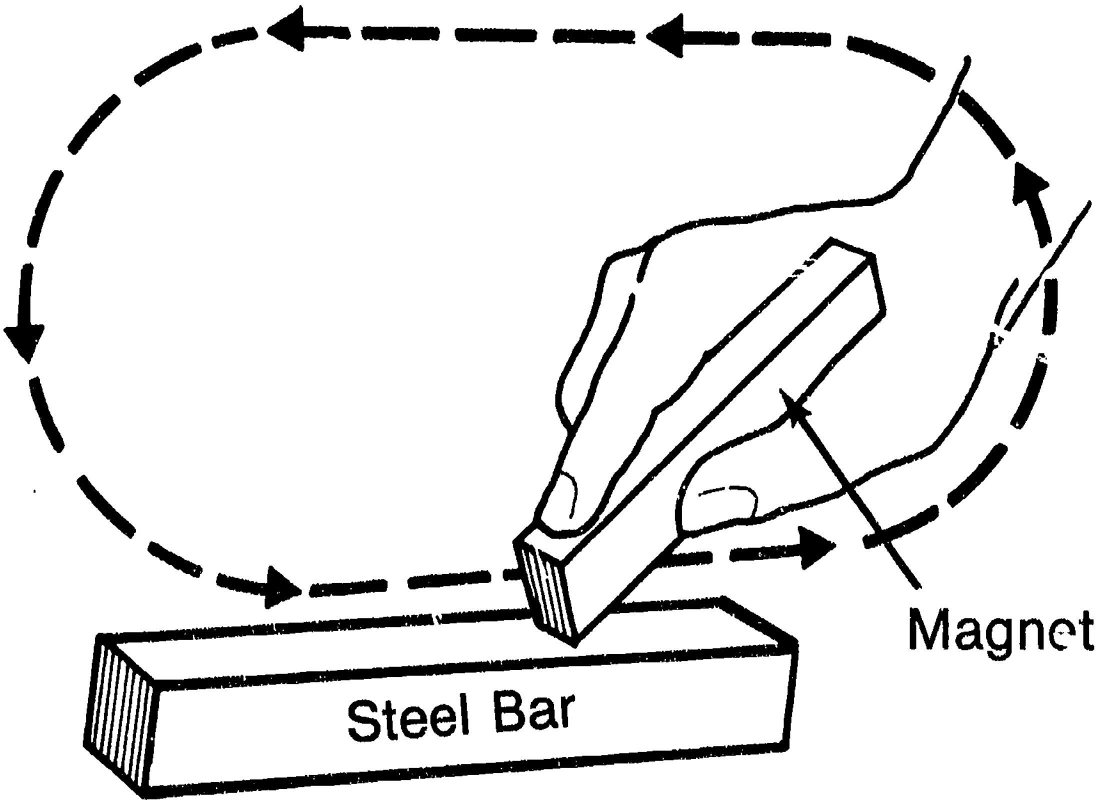


Artificial

Producing Artificial Magnets

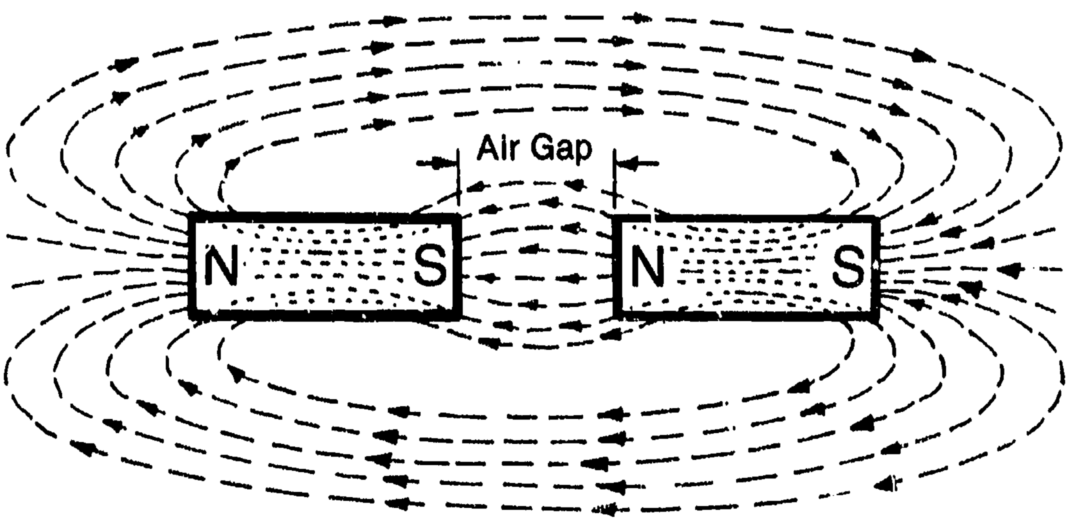


Coil Method

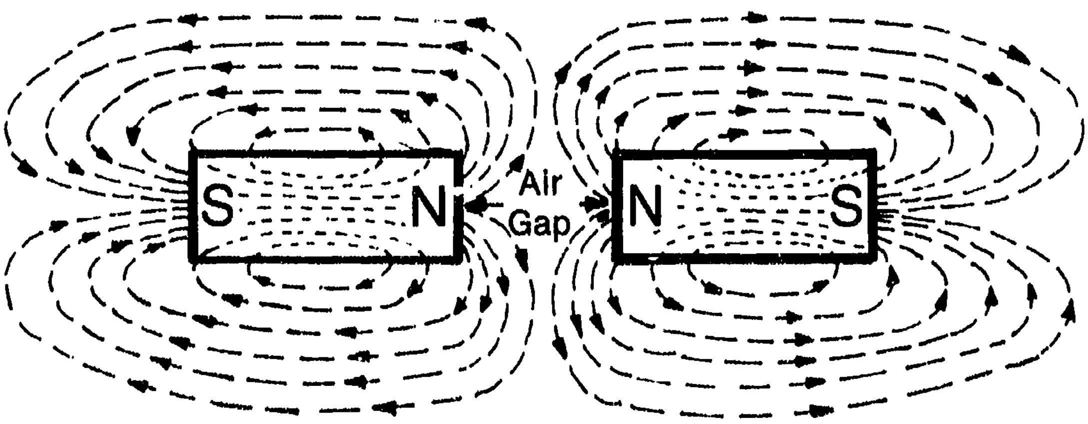


Stroking Method

Magnetic Lines of Force



Unlike Poles Attract



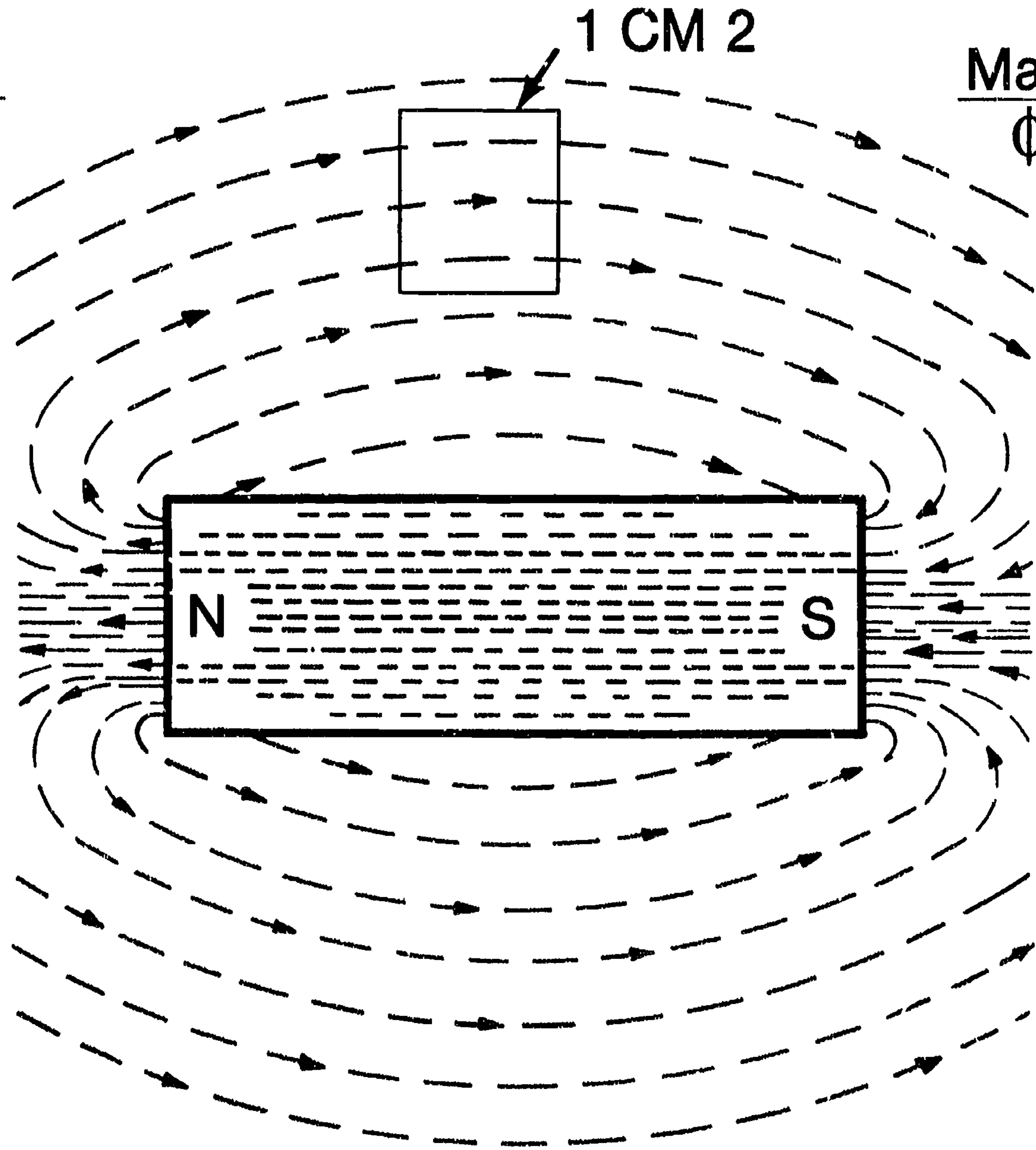
Lines of Force

Like Poles Repel

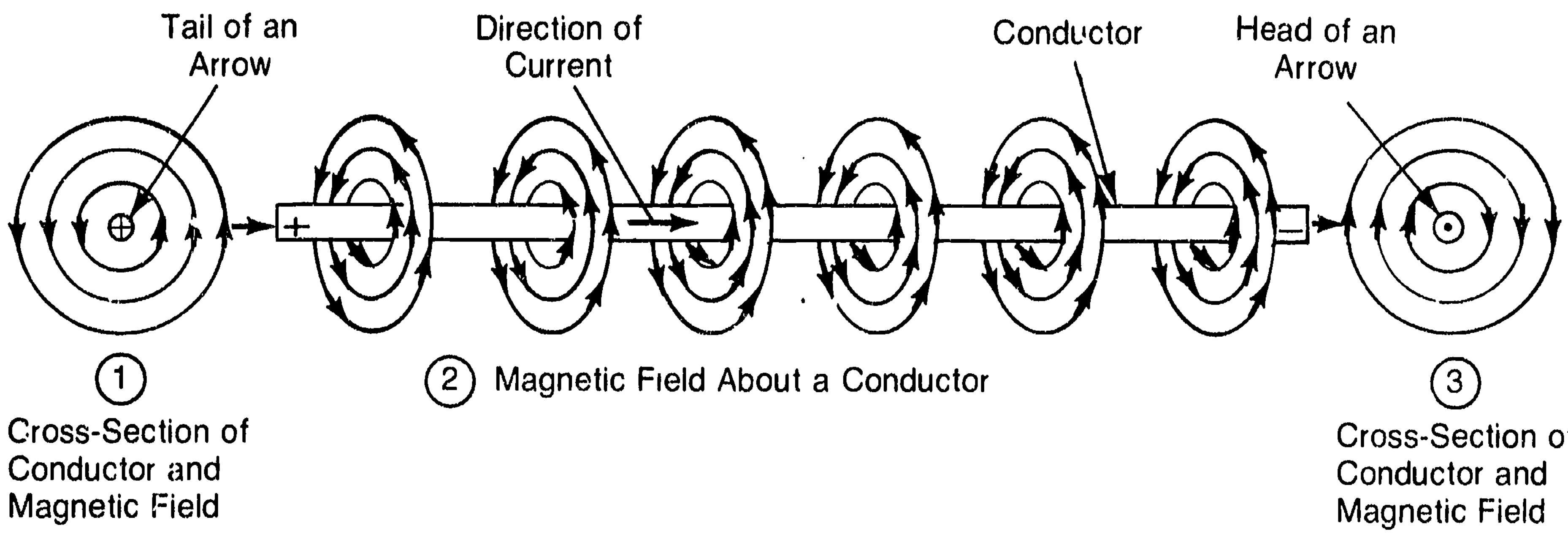
Magnetic Flux and Flux Density

Flux Density
$B = 4\ G$

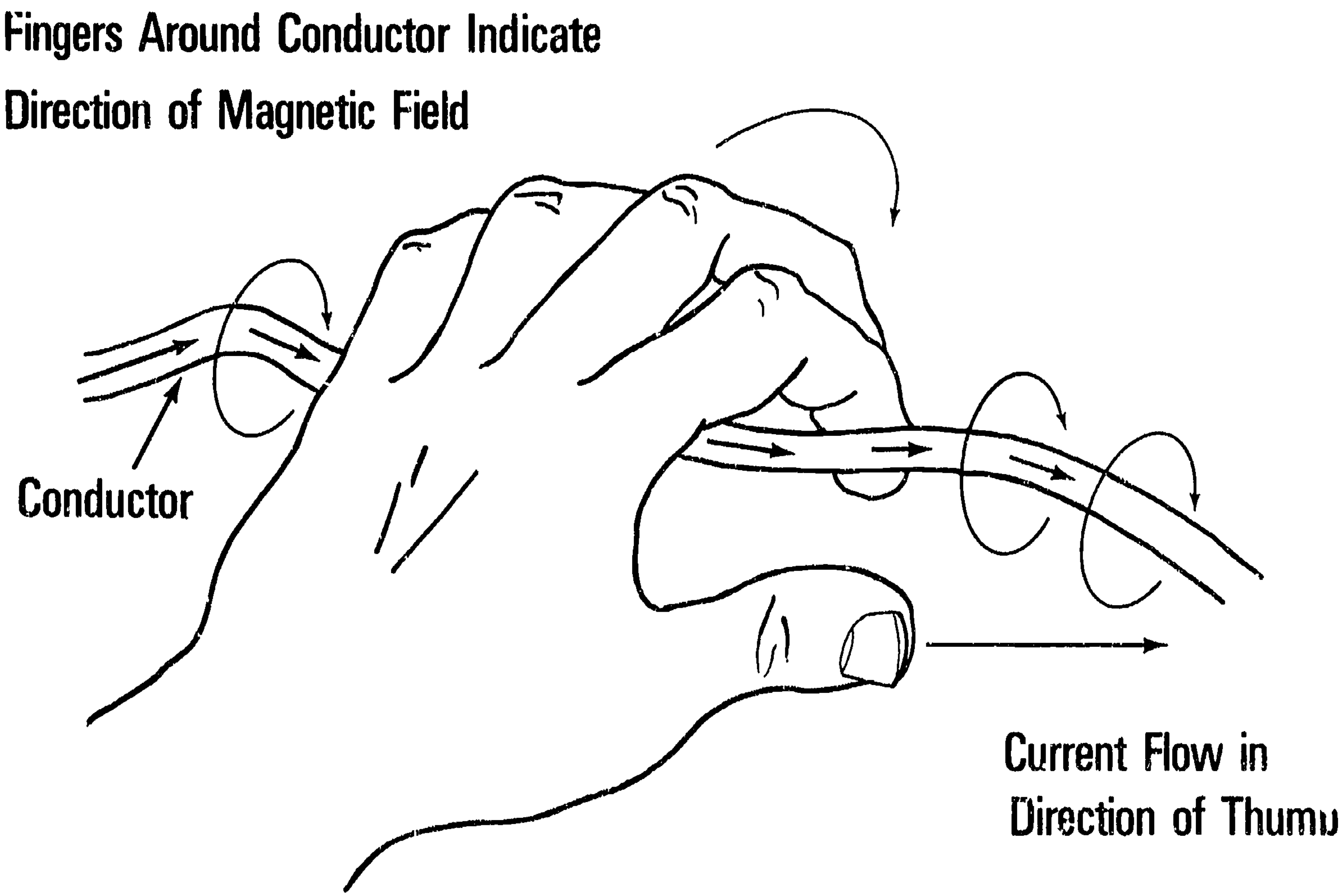
Magnetic Flux
$\phi = 14\ Mx$



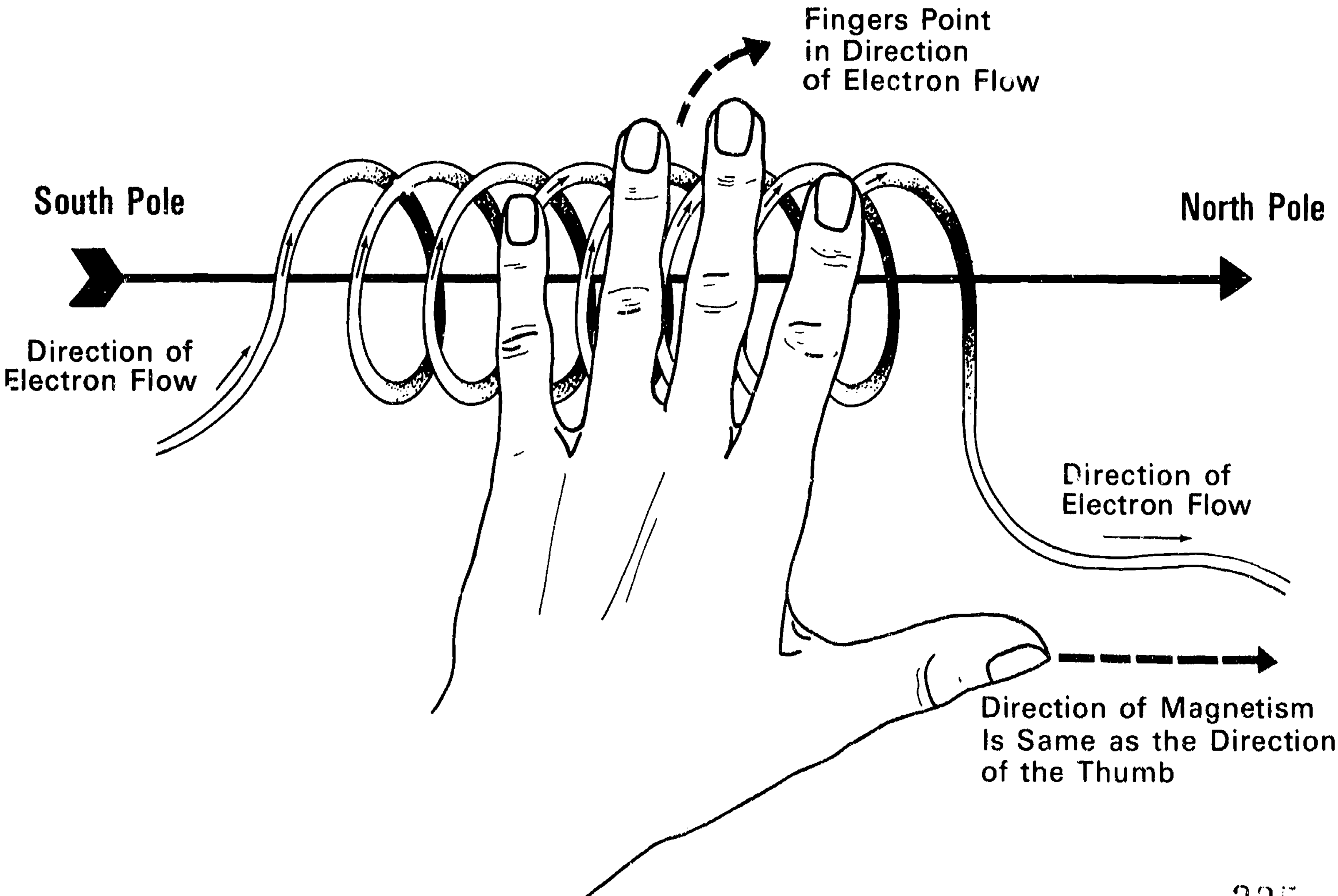
Magnetic Field Around A Current-Carrying Conductor



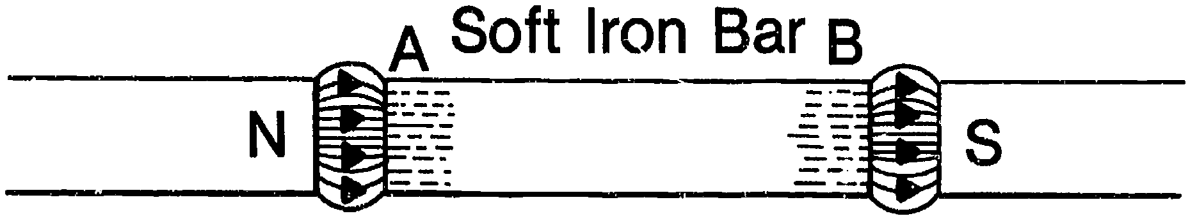
Left-Hand Rule for Magnetic Lines of Flux



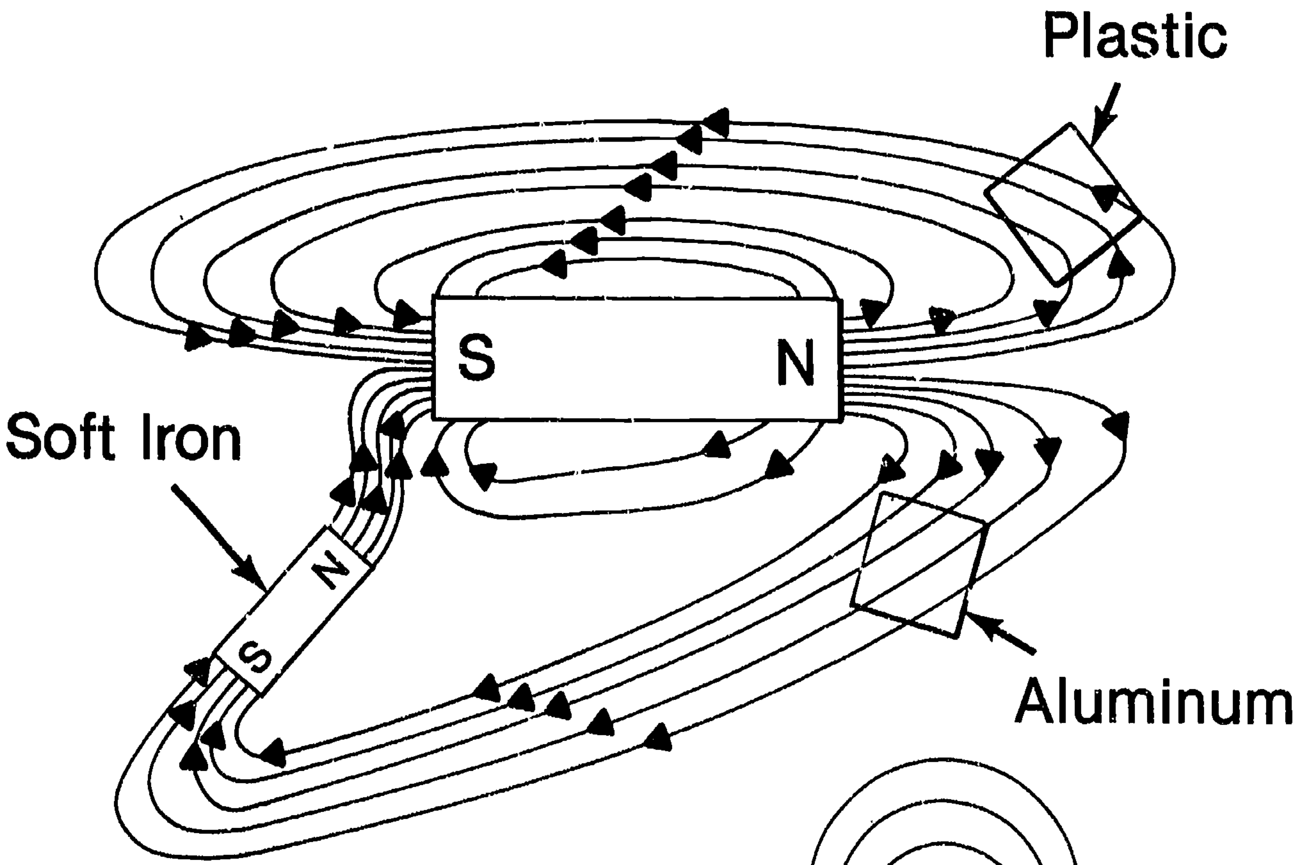
Left-Hand Rule for Electromagnets

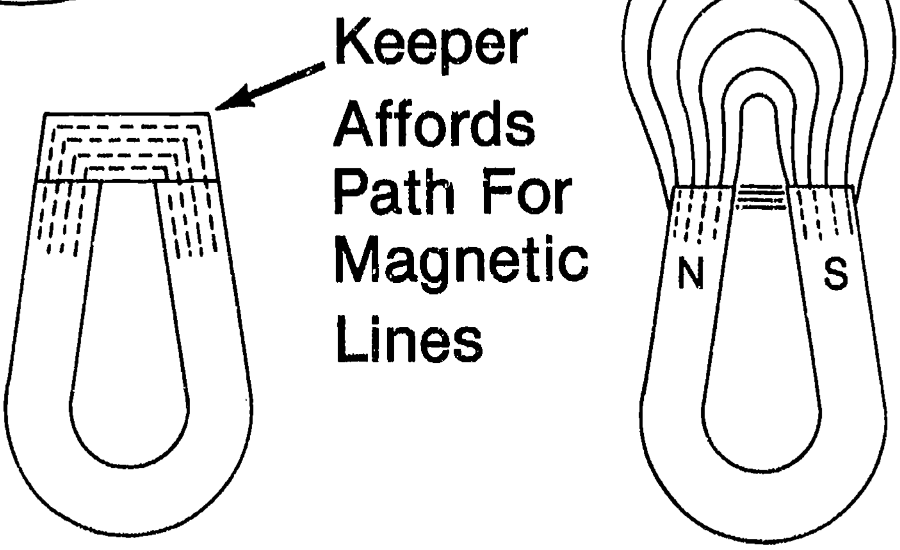


Concentration of Lines of Flux

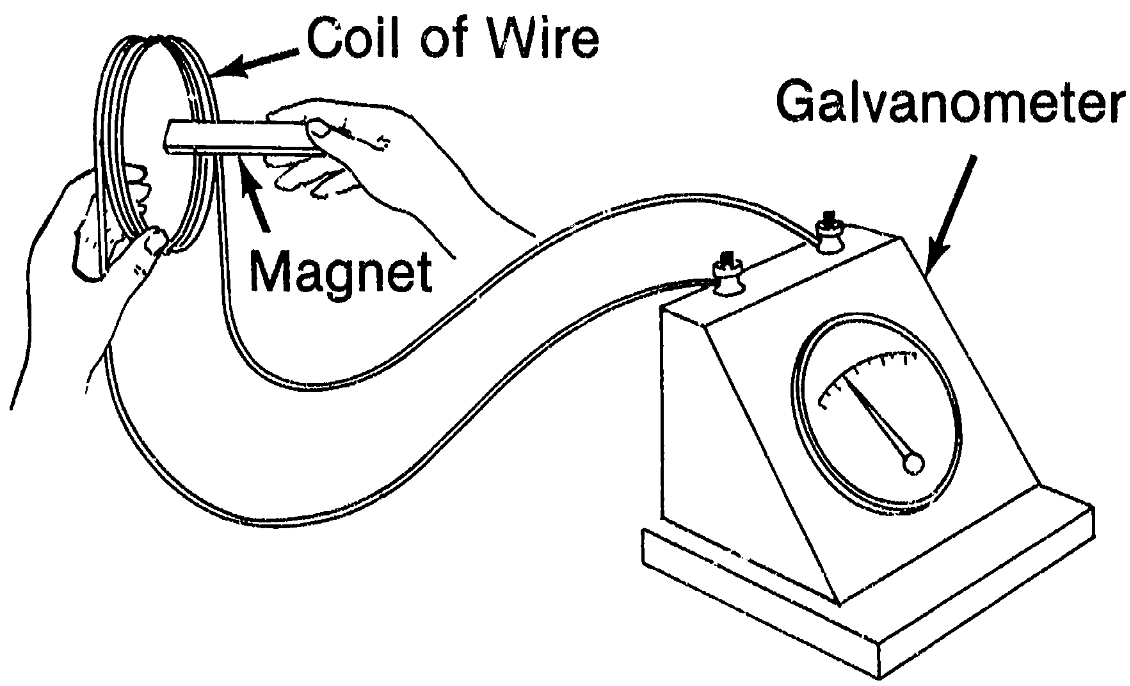


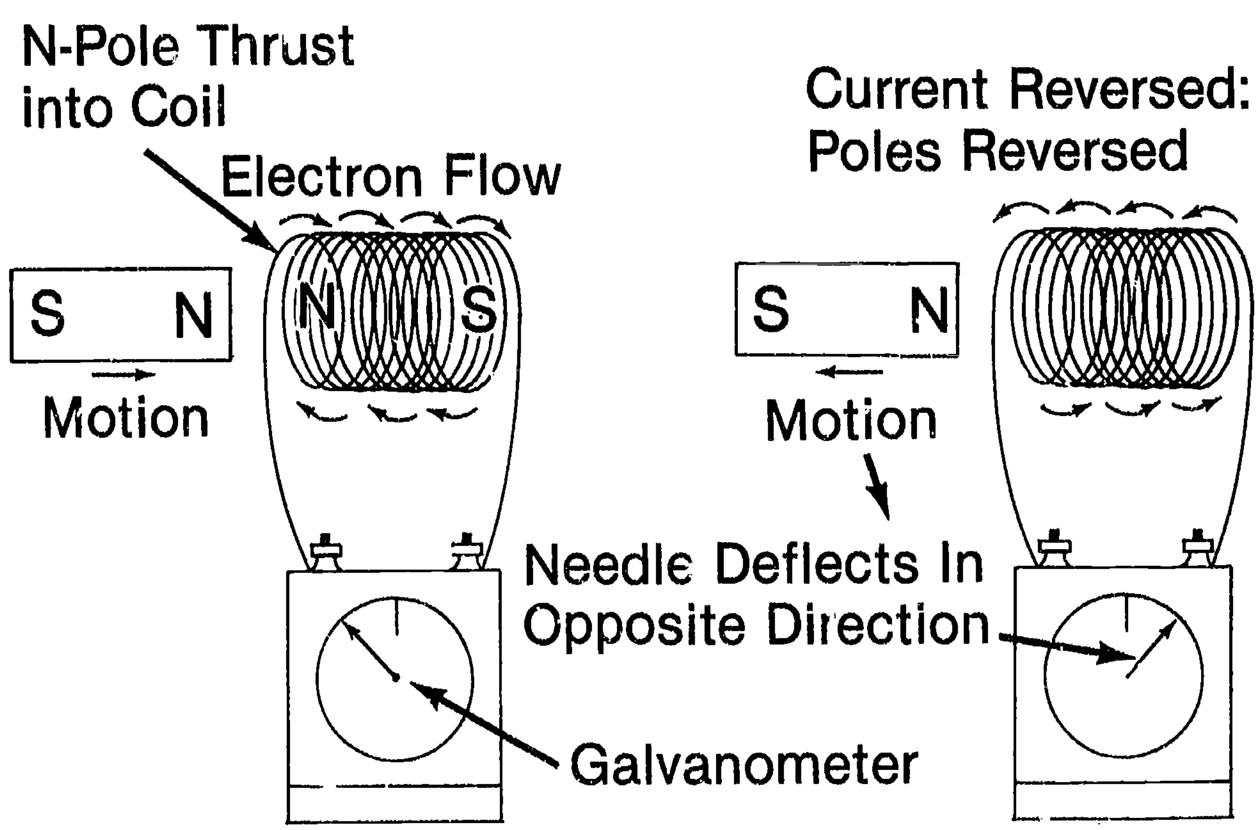
Magnetizing an Iron Bar by Induction



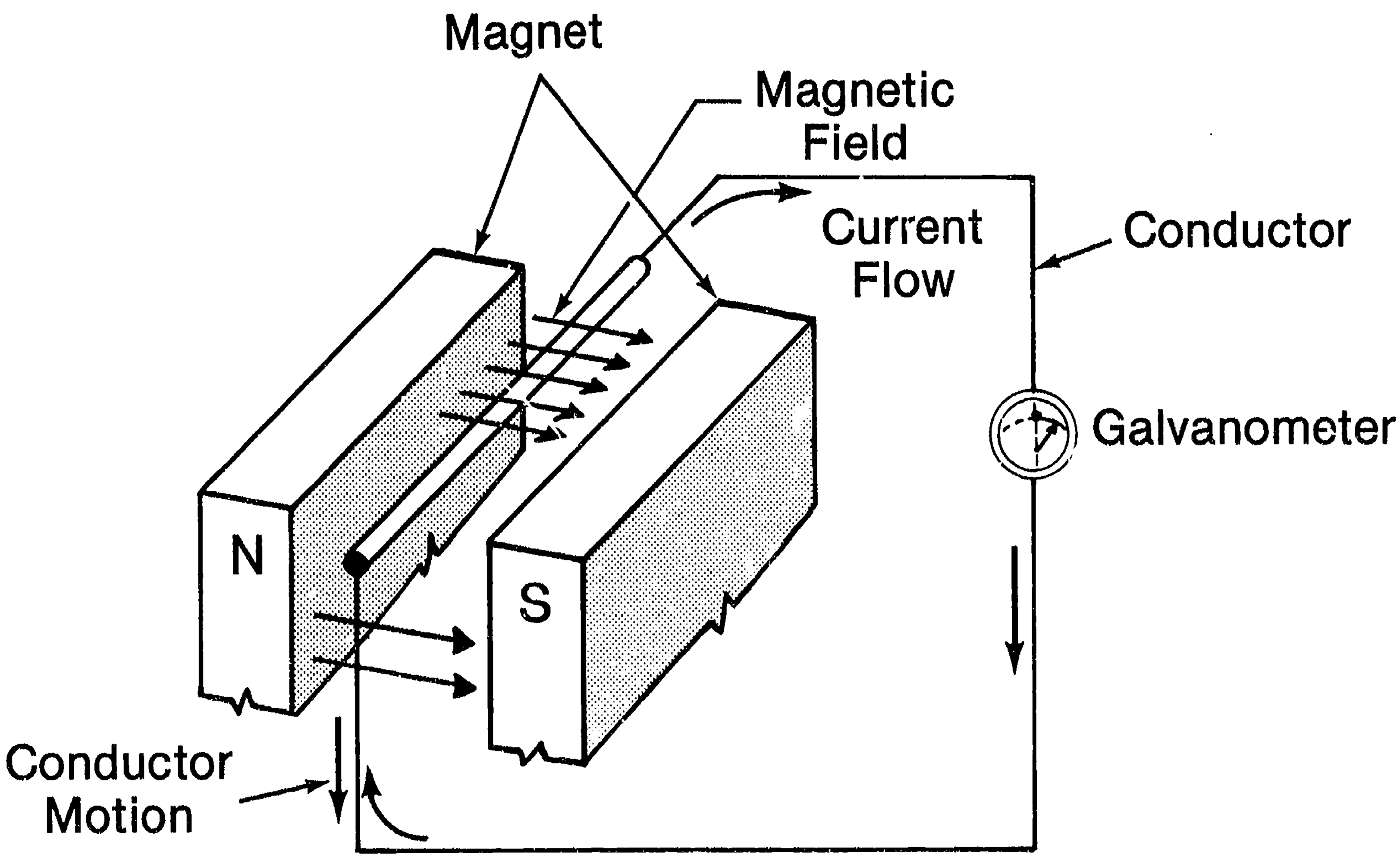


Induced Current

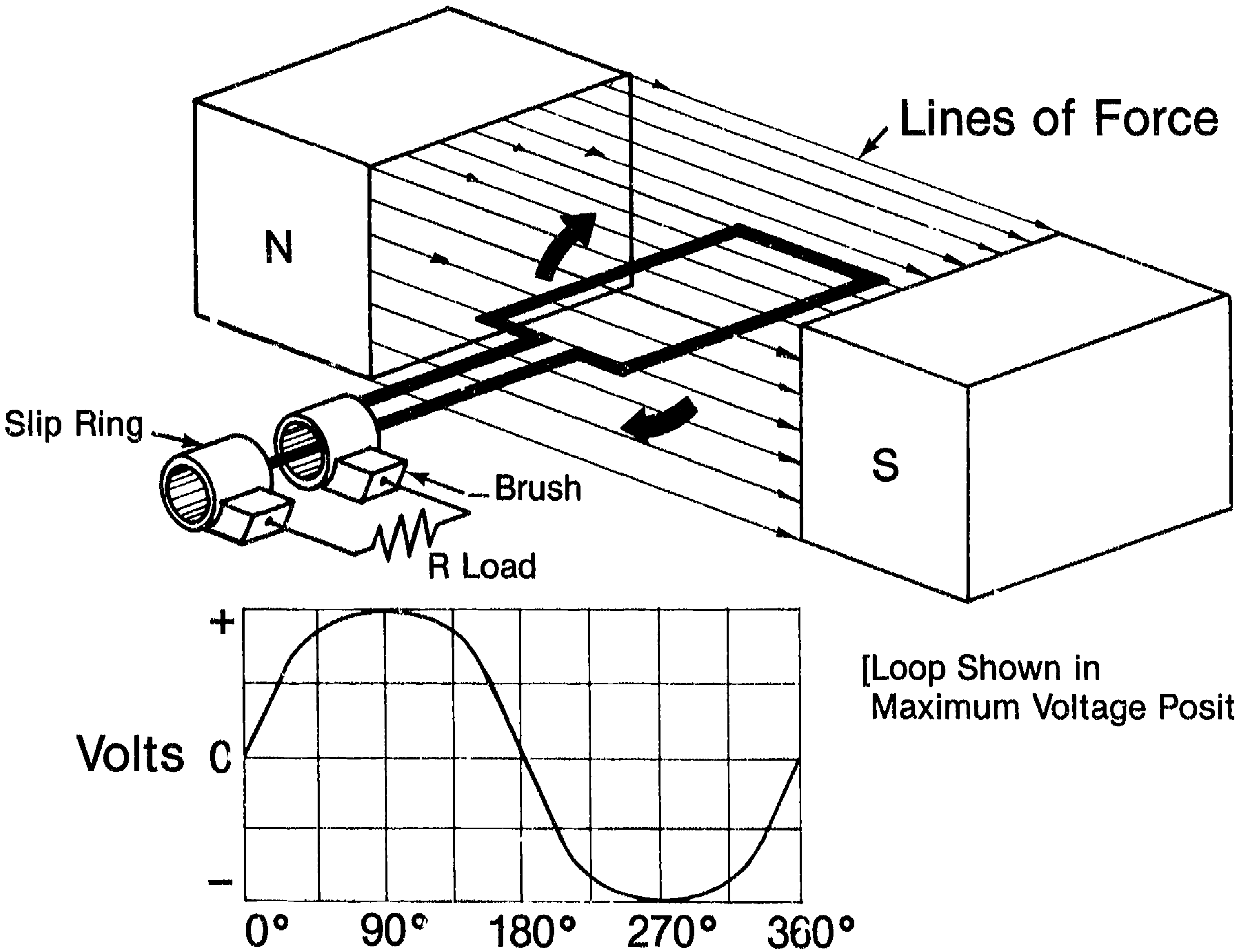




Electromagnetic Induction

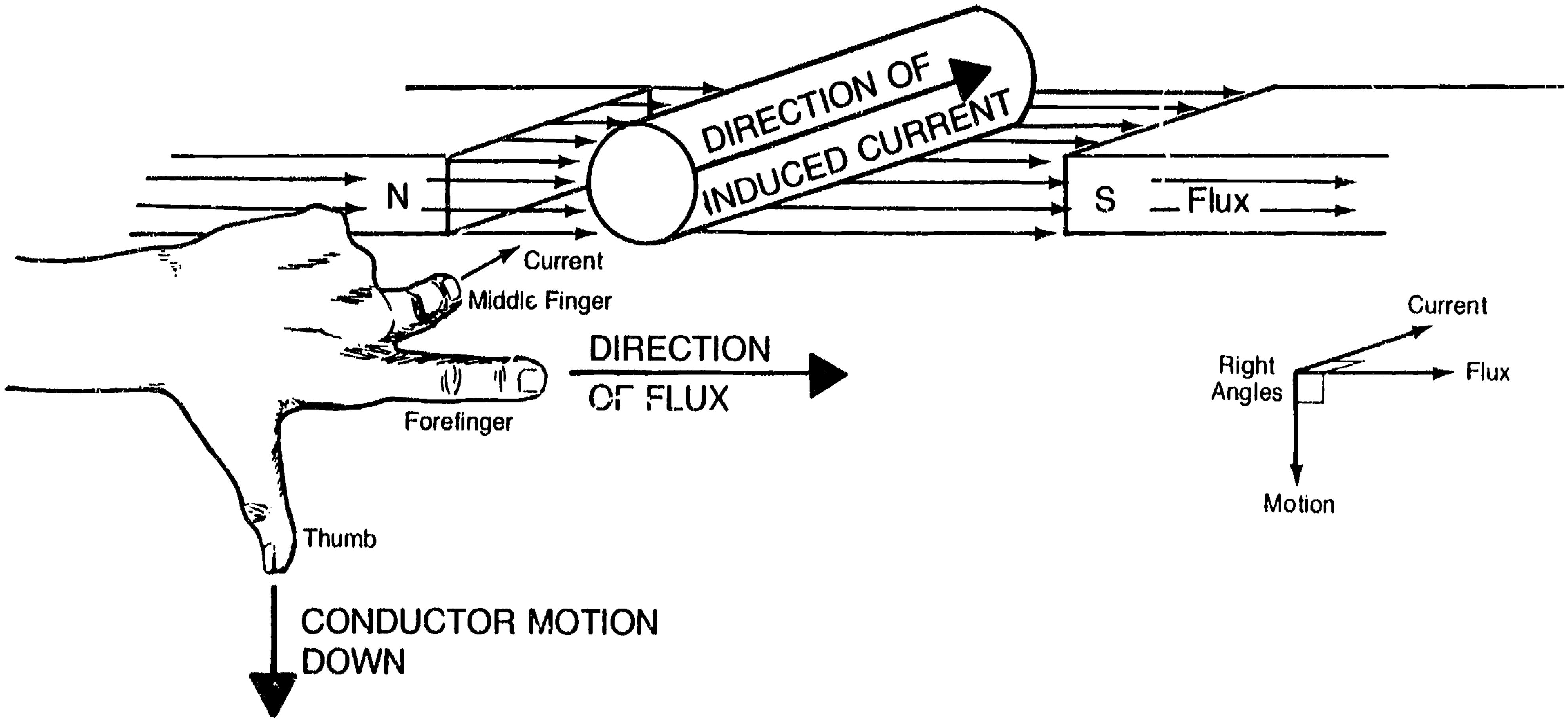


Simple AC Generator

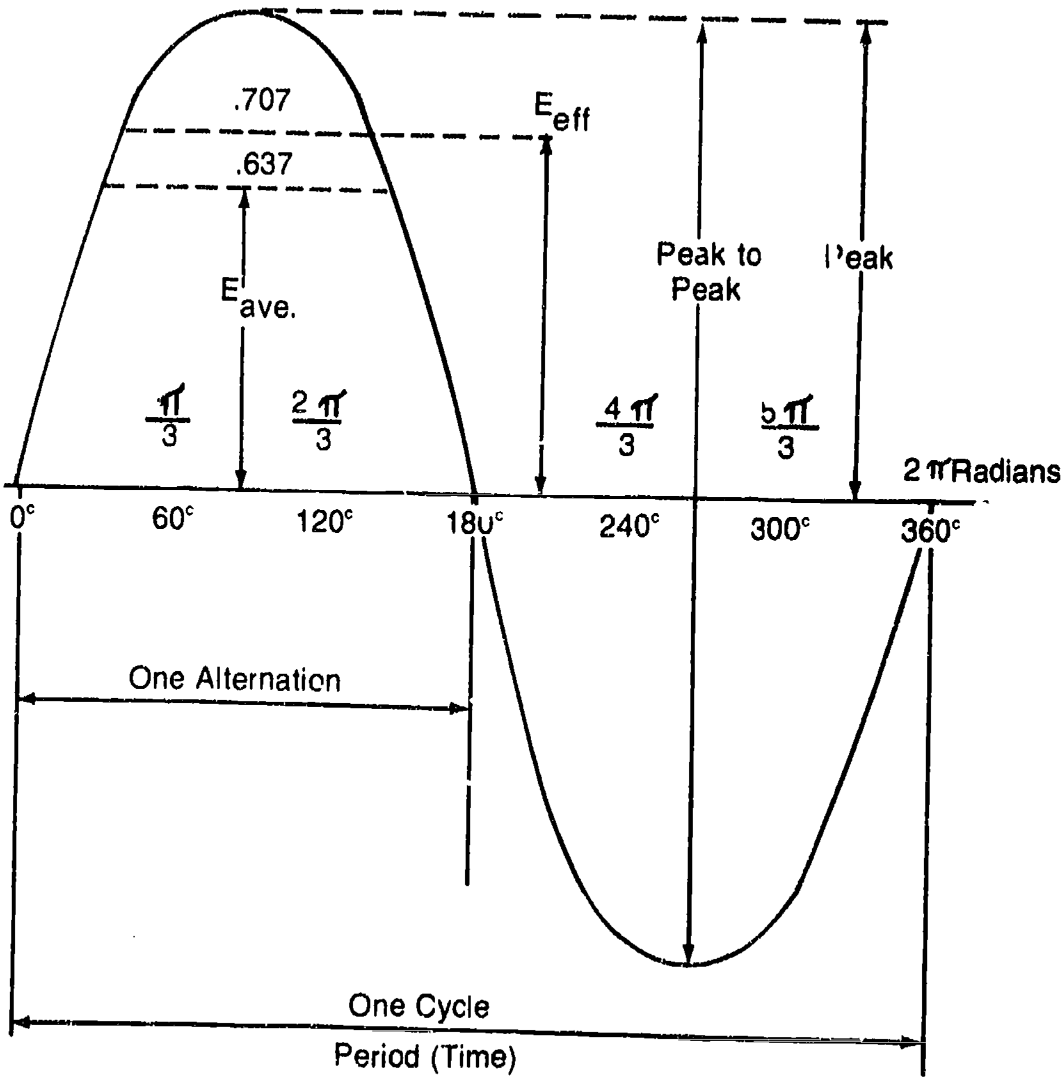


[Loop Shown in Maximum Voltage Position]

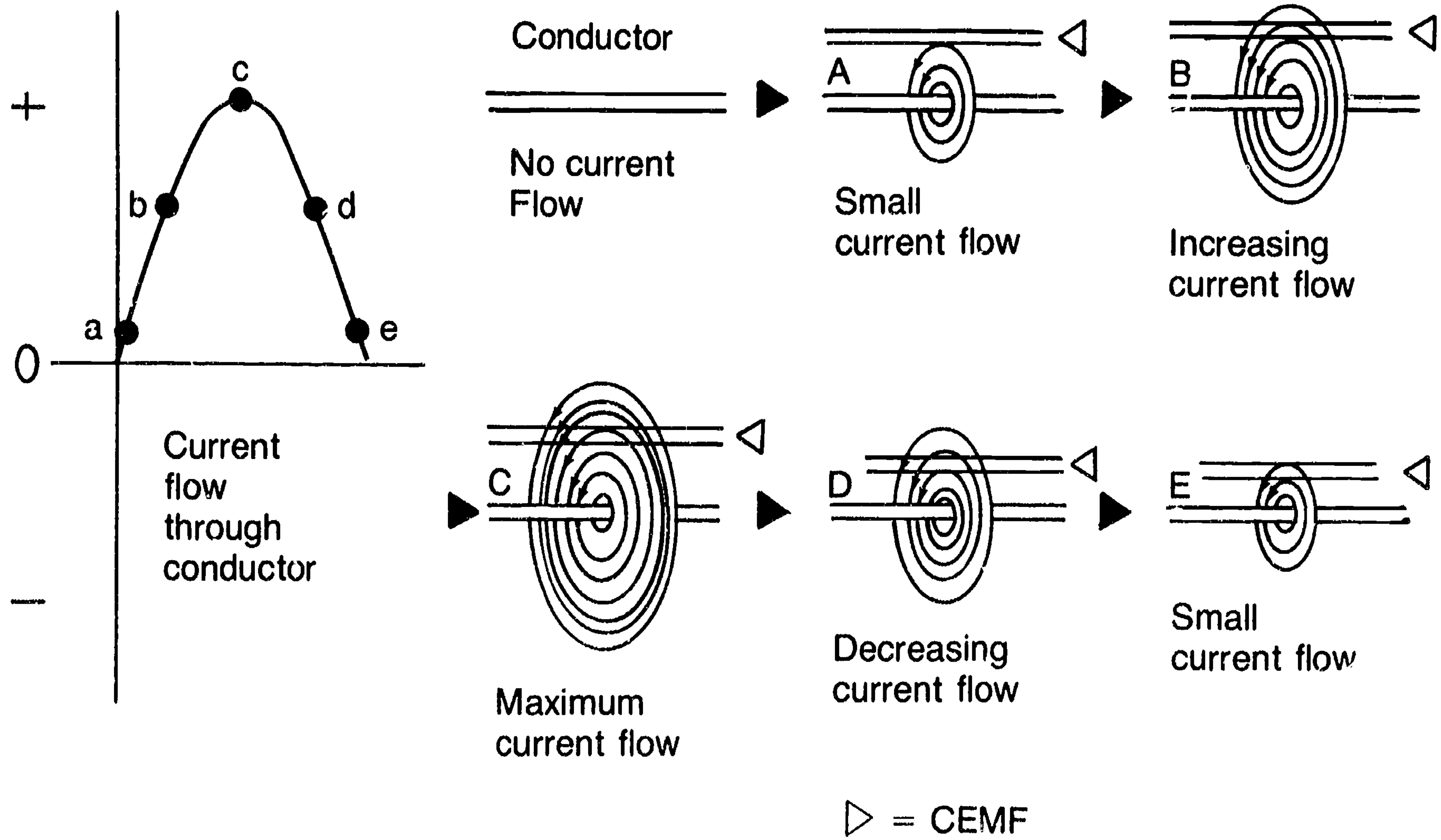
The Left-Hand Generator Rule



Sine Wave Relationships

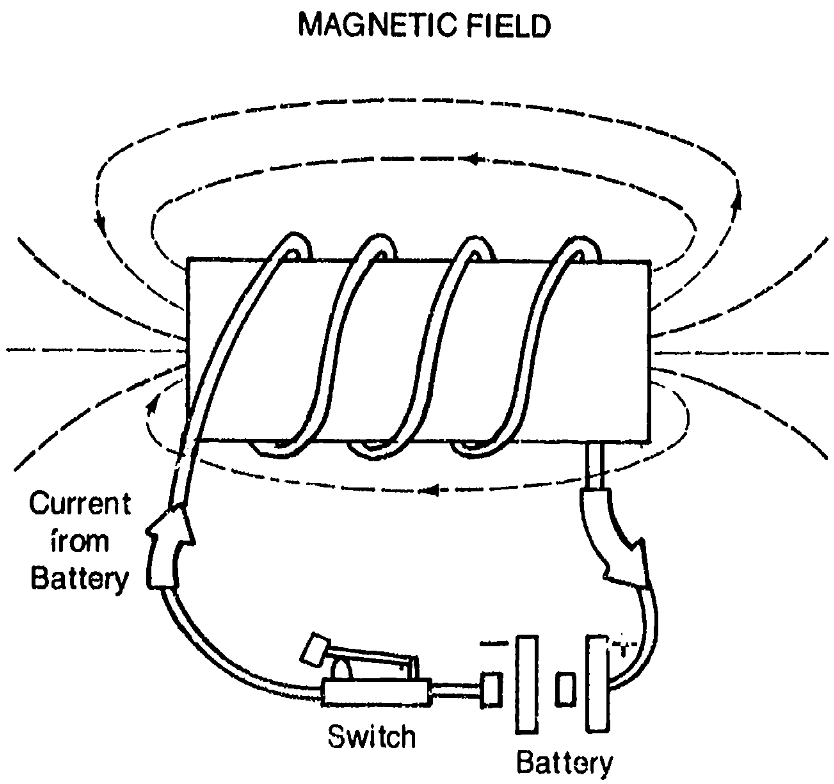


Induction

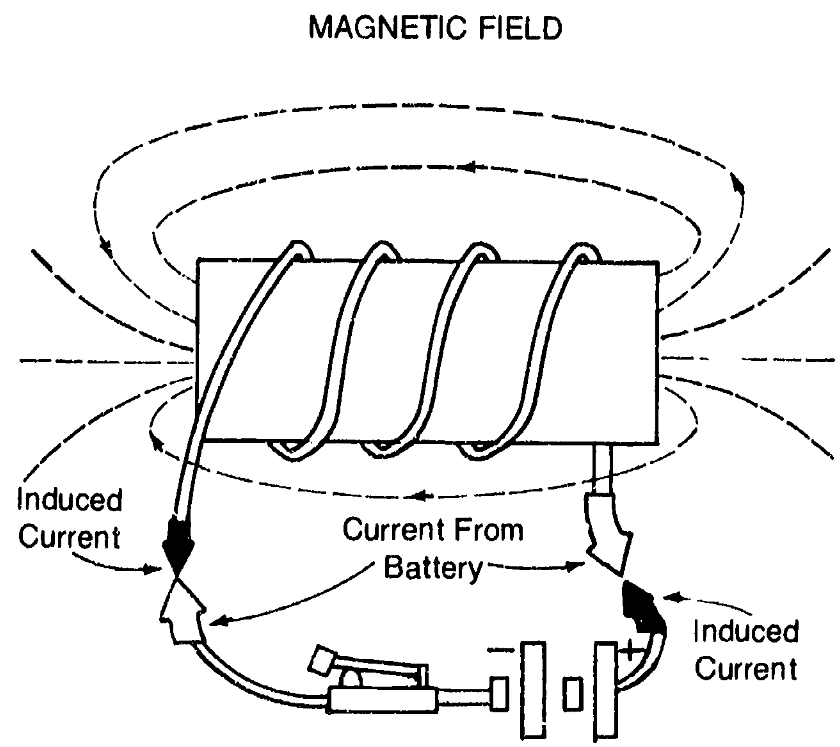


Relationship of magnetic field around a wire to current flowing through the wire.

Self-Inductance in a Coil



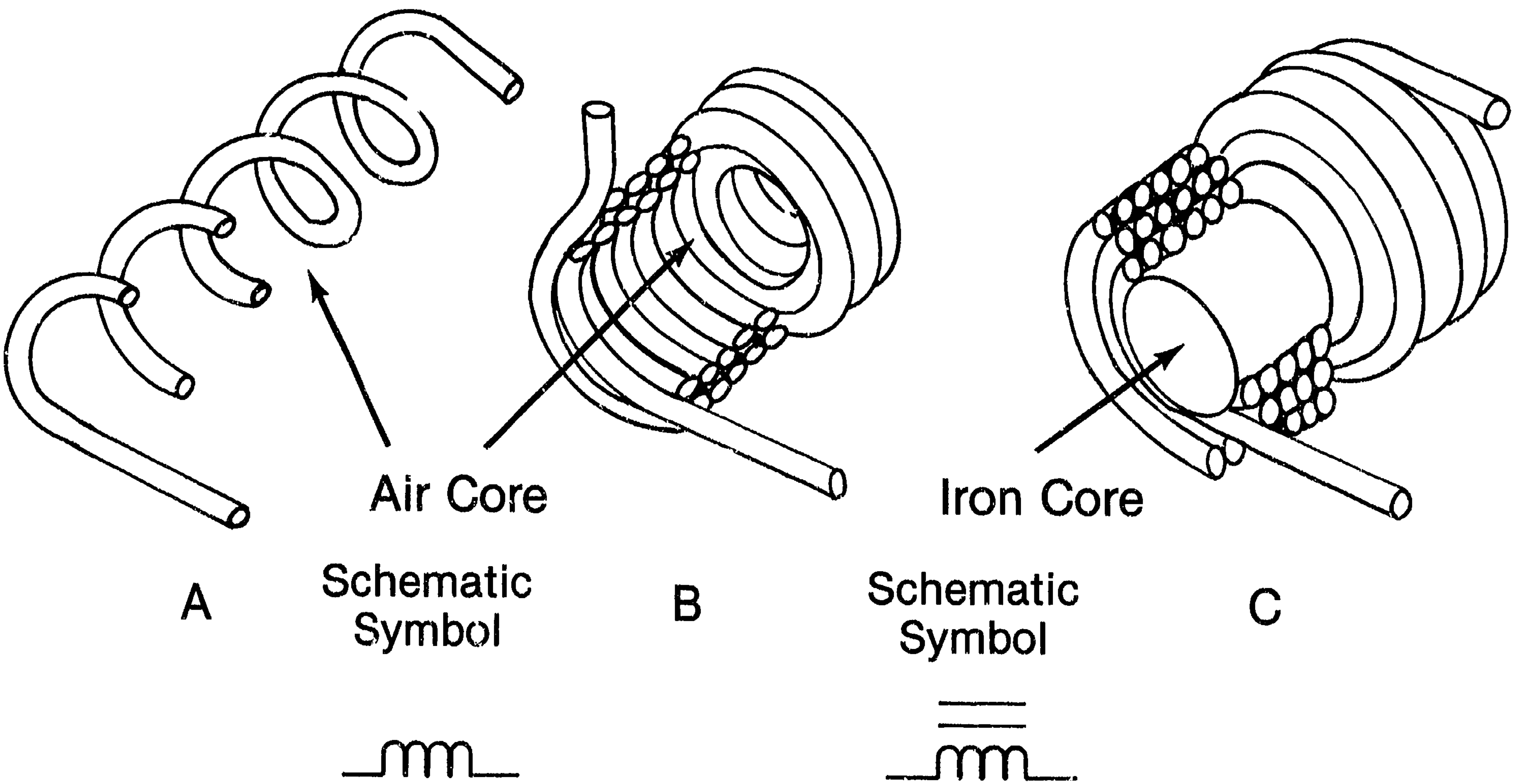
A. Current Creates Magnetic Field



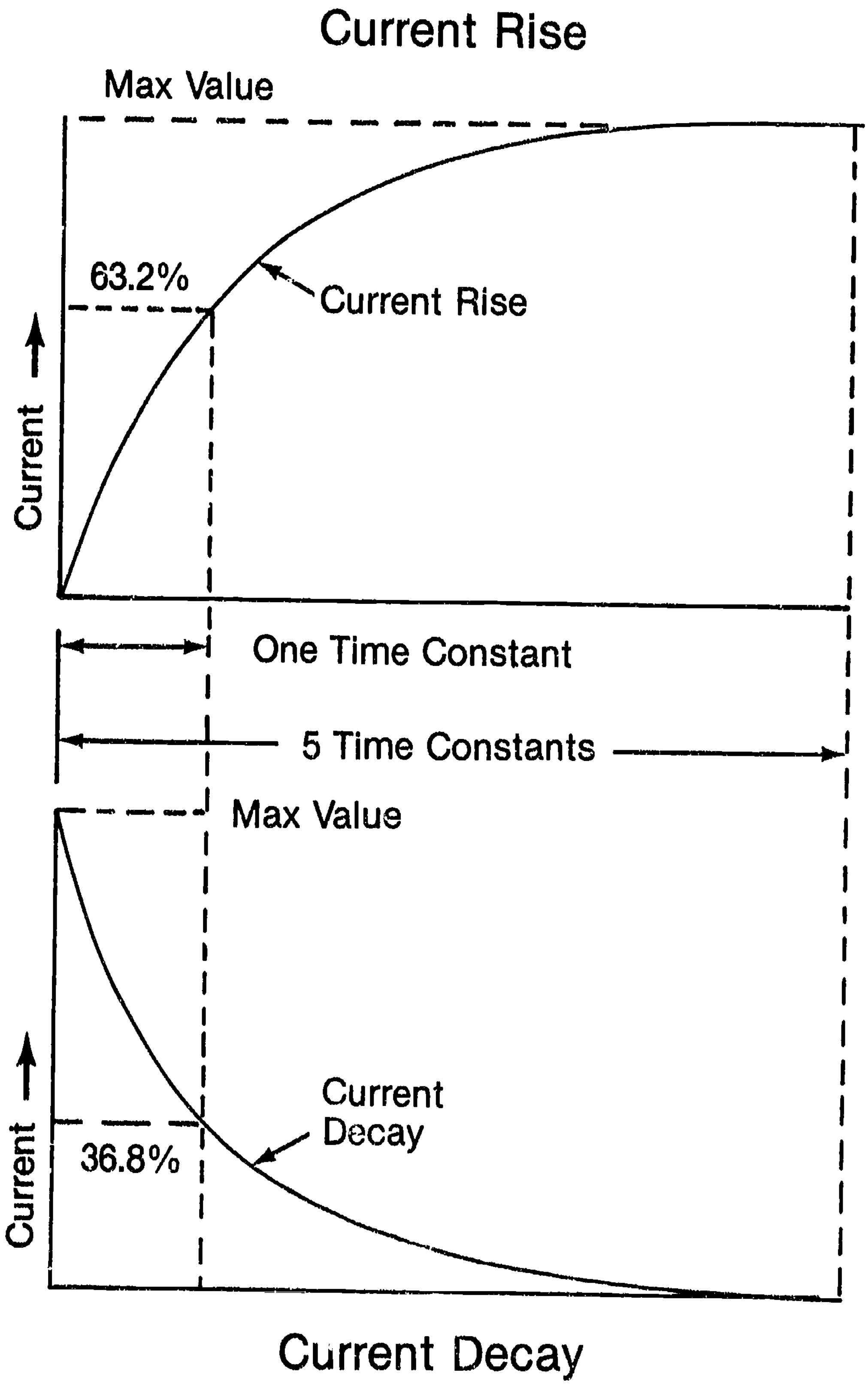
B. Magnetic Field Induces Opposing Current

Coils of Various Inductances

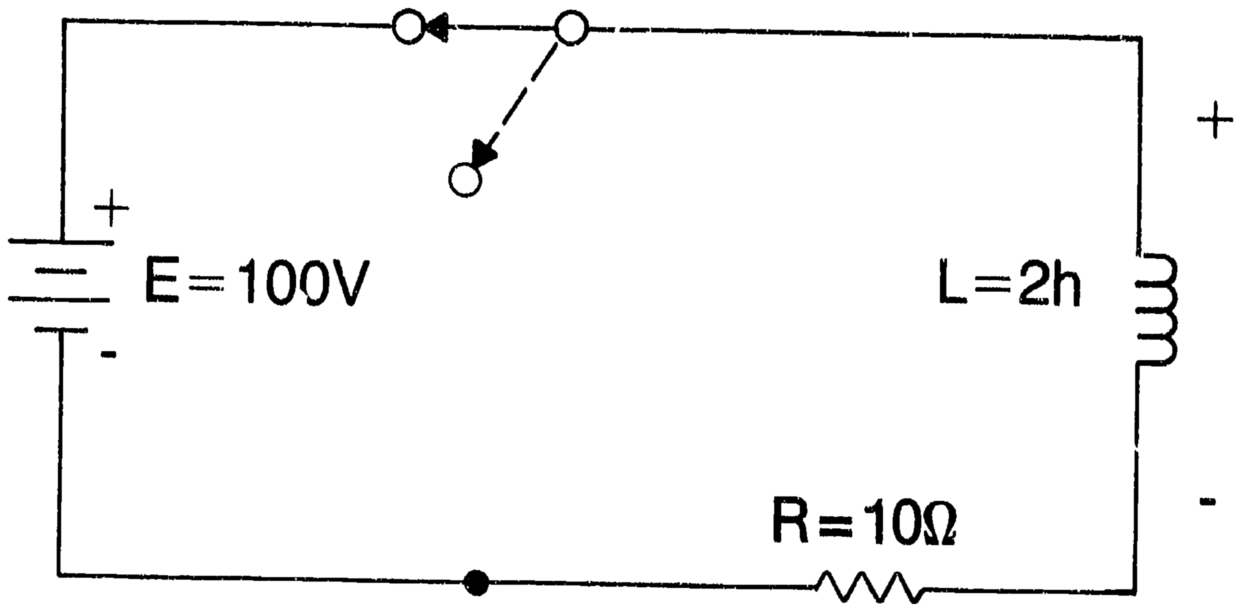
(NOTE: Inductances use many different materials in the cores.)

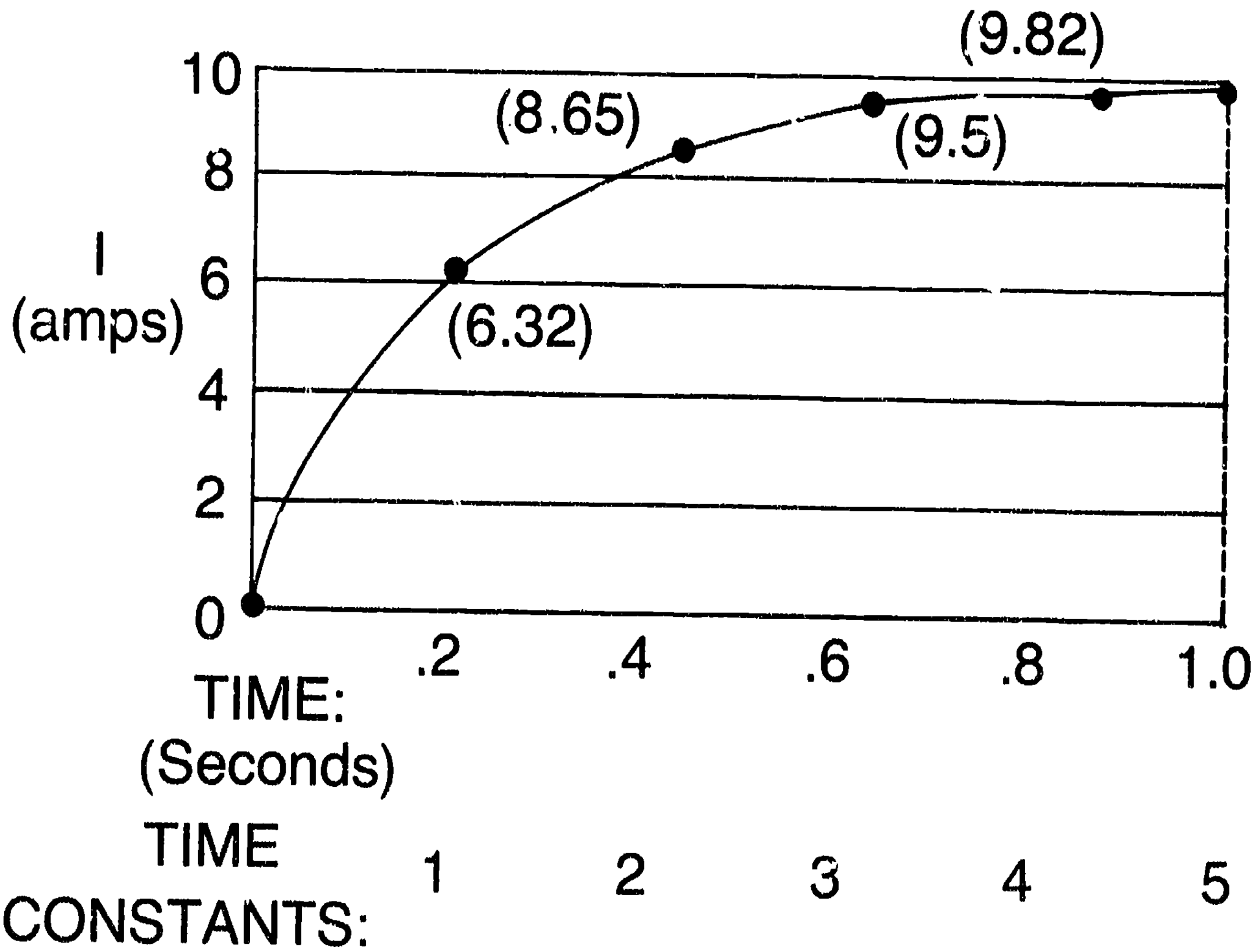


Current Rise and Decay in an Inductcr

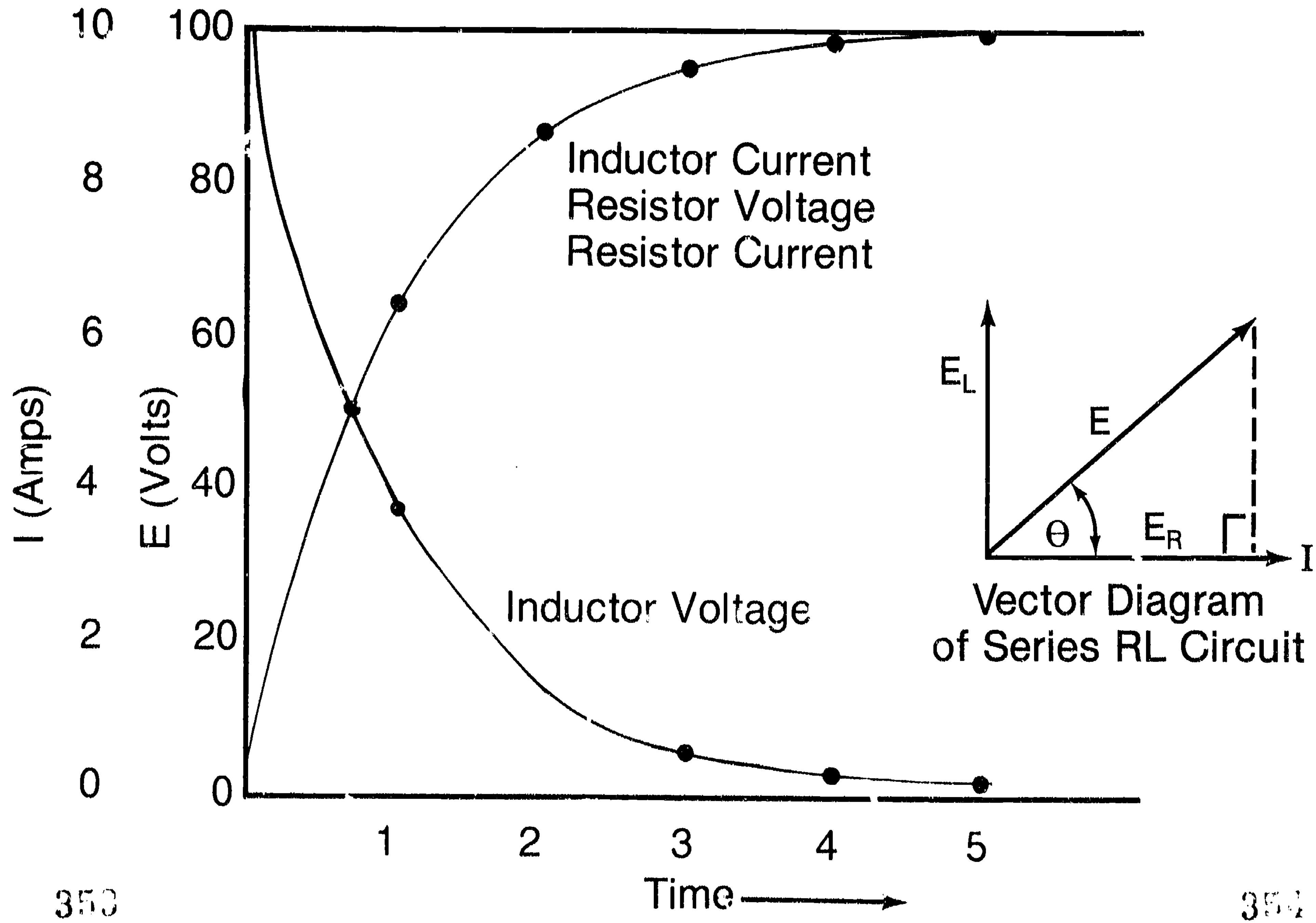


RL Circuit and Current Rise

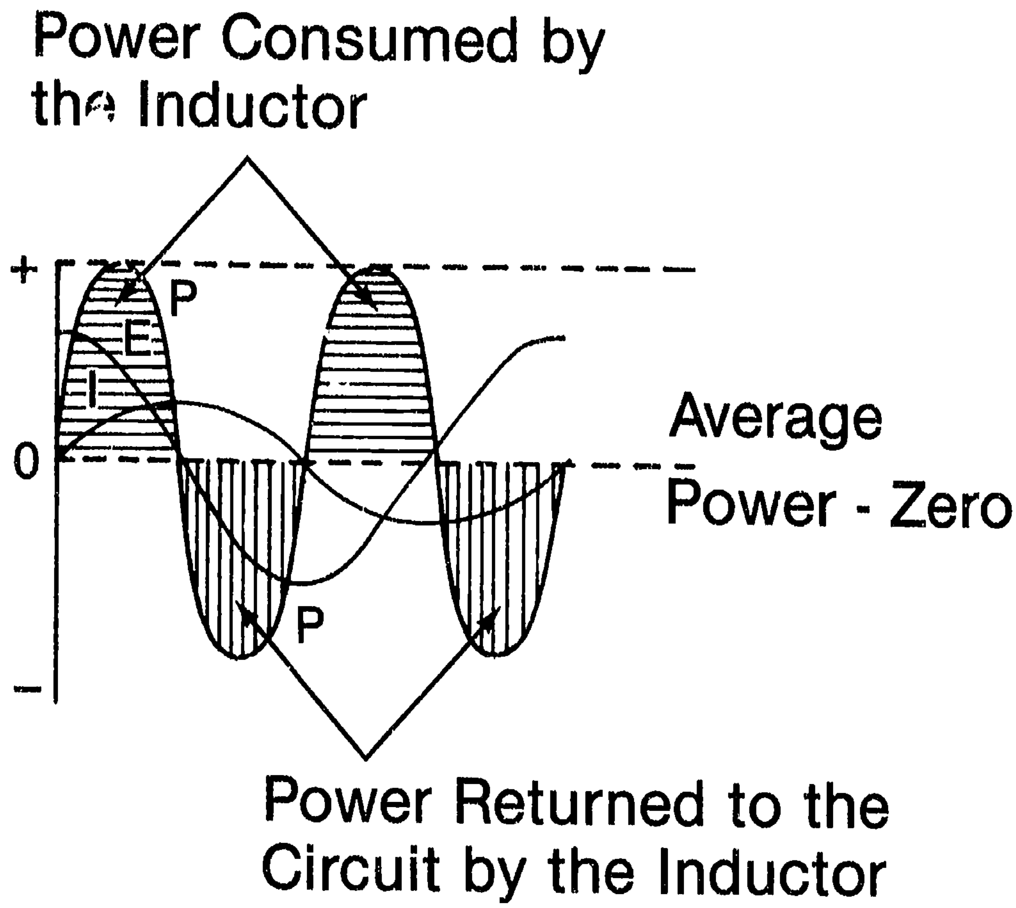


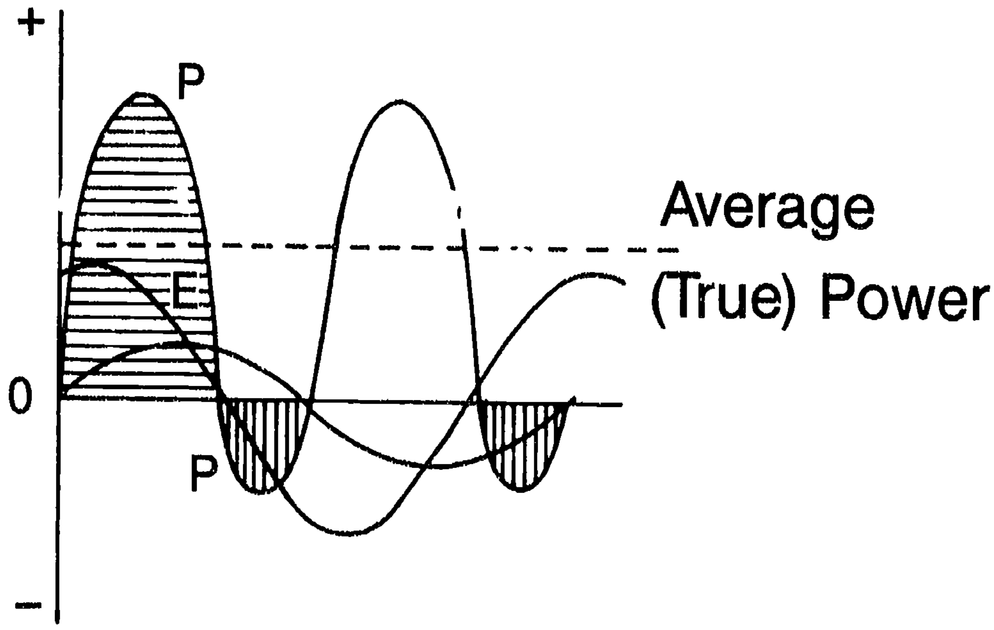


Current and Voltage Relationships in an AC Circuit

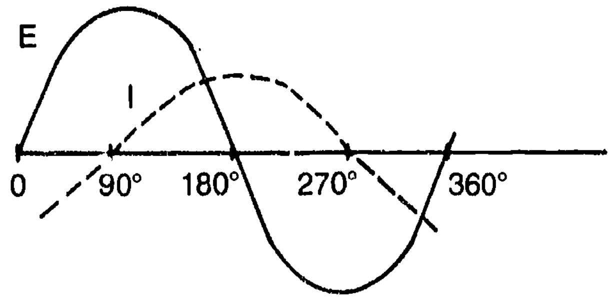


Power in RL Circuits

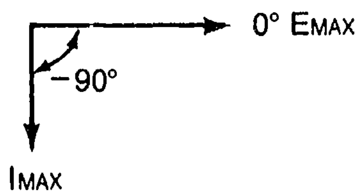




Comparison Sinusoidal and Phasor (Vector) Diagrams

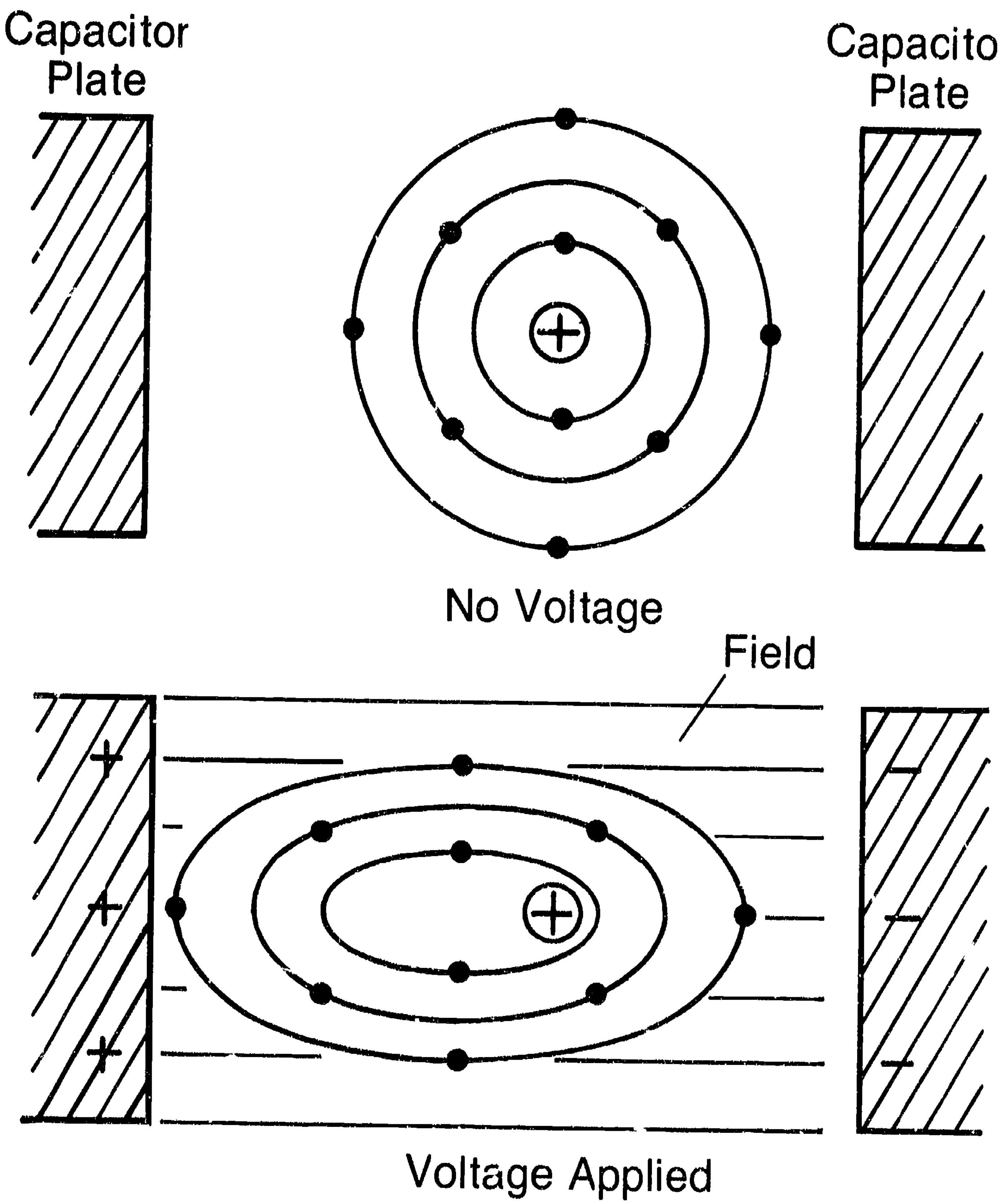


SINUSOIDAL GRAPH



PHASOR DIAGRAM
(VECTOR DIAGRAM)

Electric Field Effect on Dielectrics



Capacitor Construction

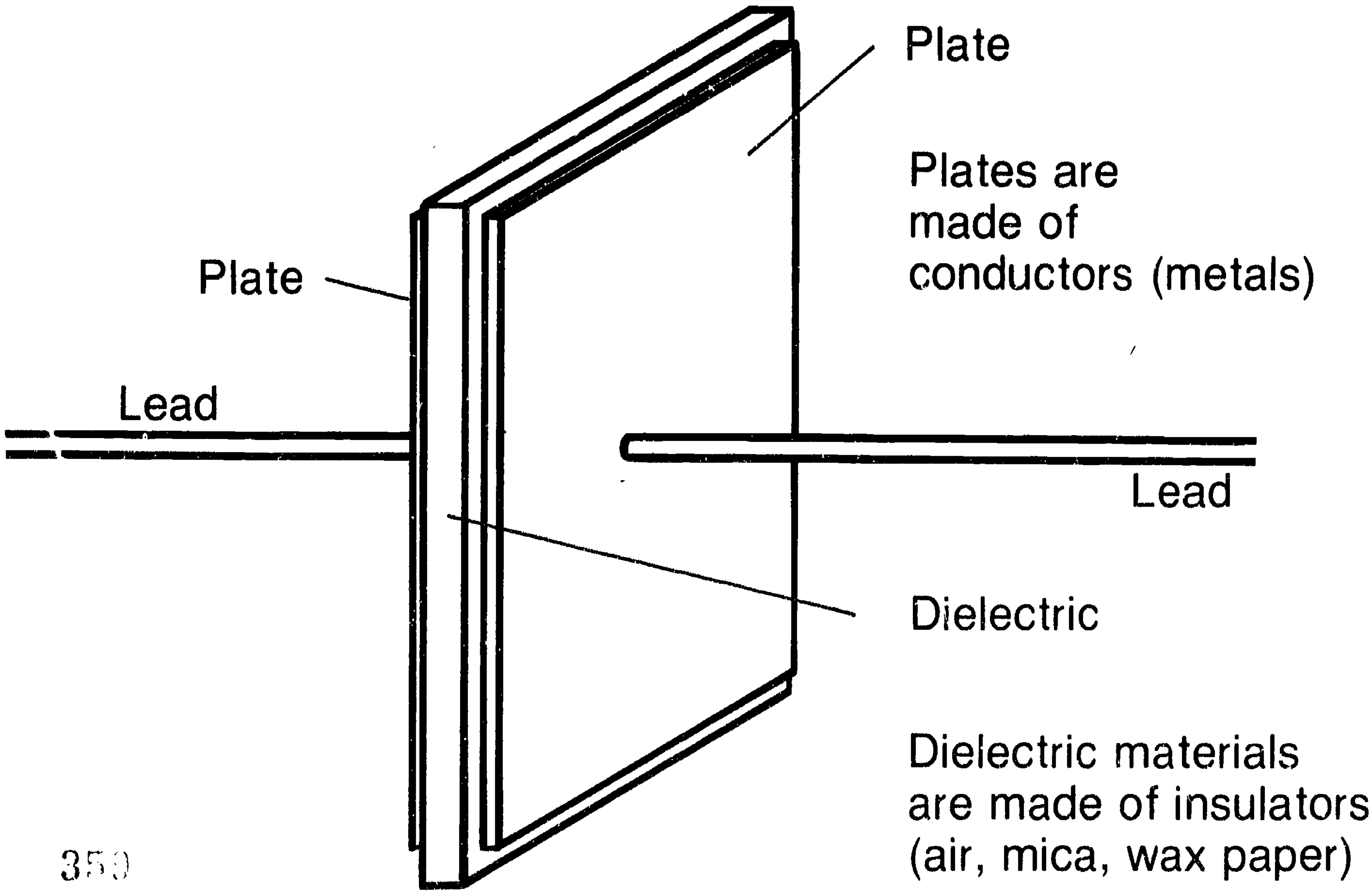
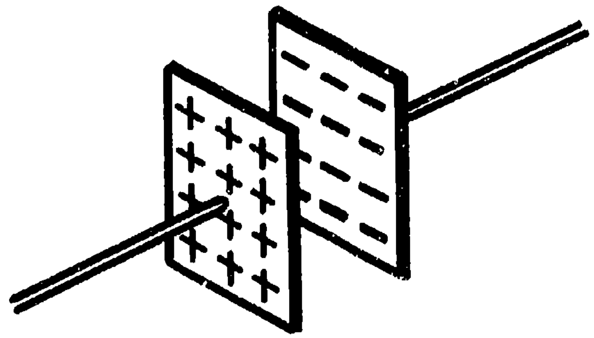
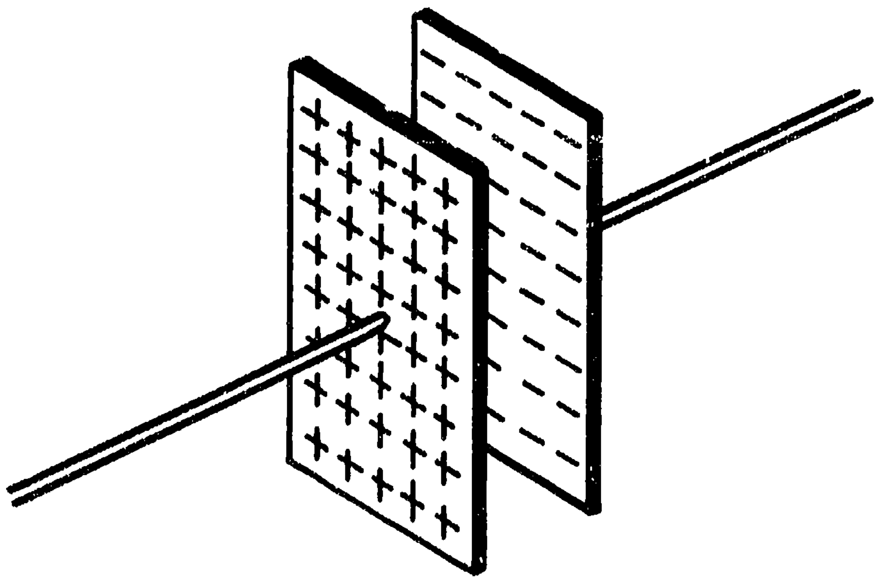


Plate Area

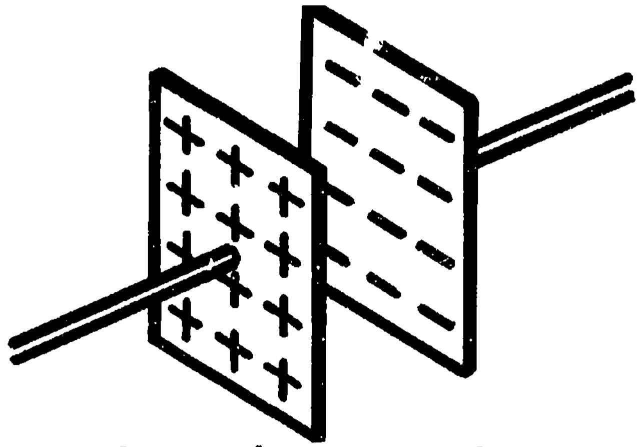


Larger plates hold more electrons.

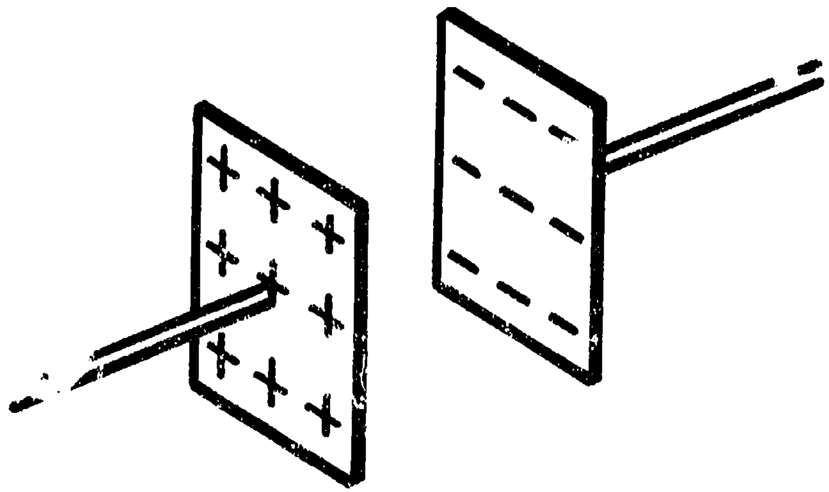


Increased plate area increases capacitance.

Plate Distance



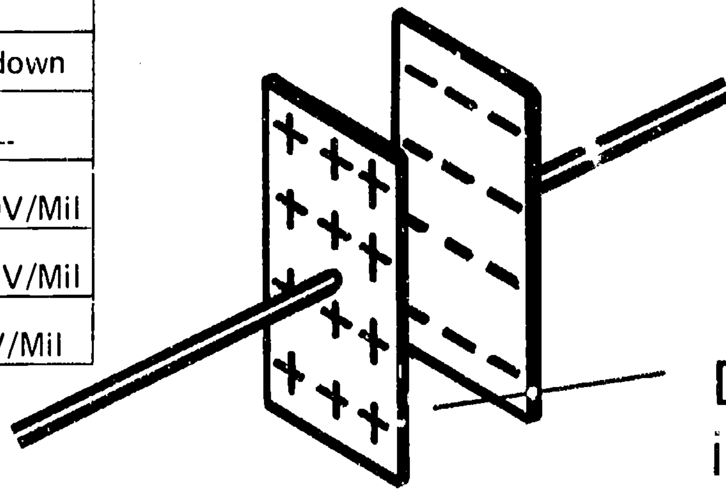
The distance between two charges determines their effect on one another.



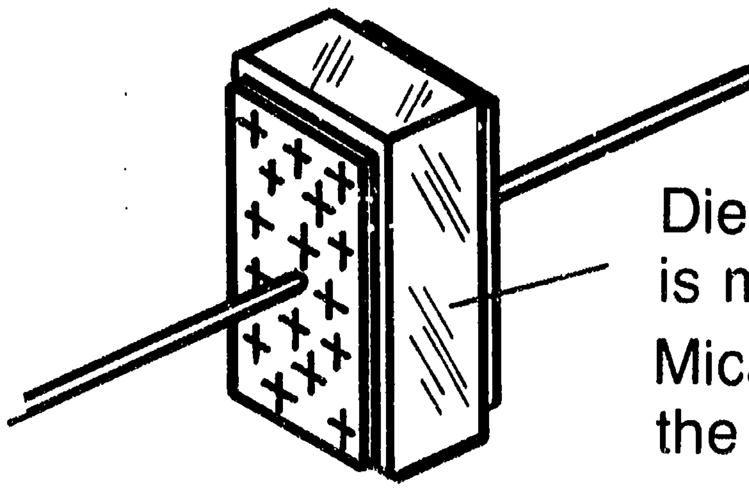
Increasing the distance between the plates decreases capacitance.

Effect of the Dielectric

Typical Dielectrics		
Type	Constant	Breakdown
Air	1.0	-----
Mica	5.4	5000V/Mil
Teflon	2.1	1500V/Mil
Paper	3.0	200V/Mil



Dielectrical material is air.



Dielectrical material is mica.

Mica dielectric increases the capacitance.

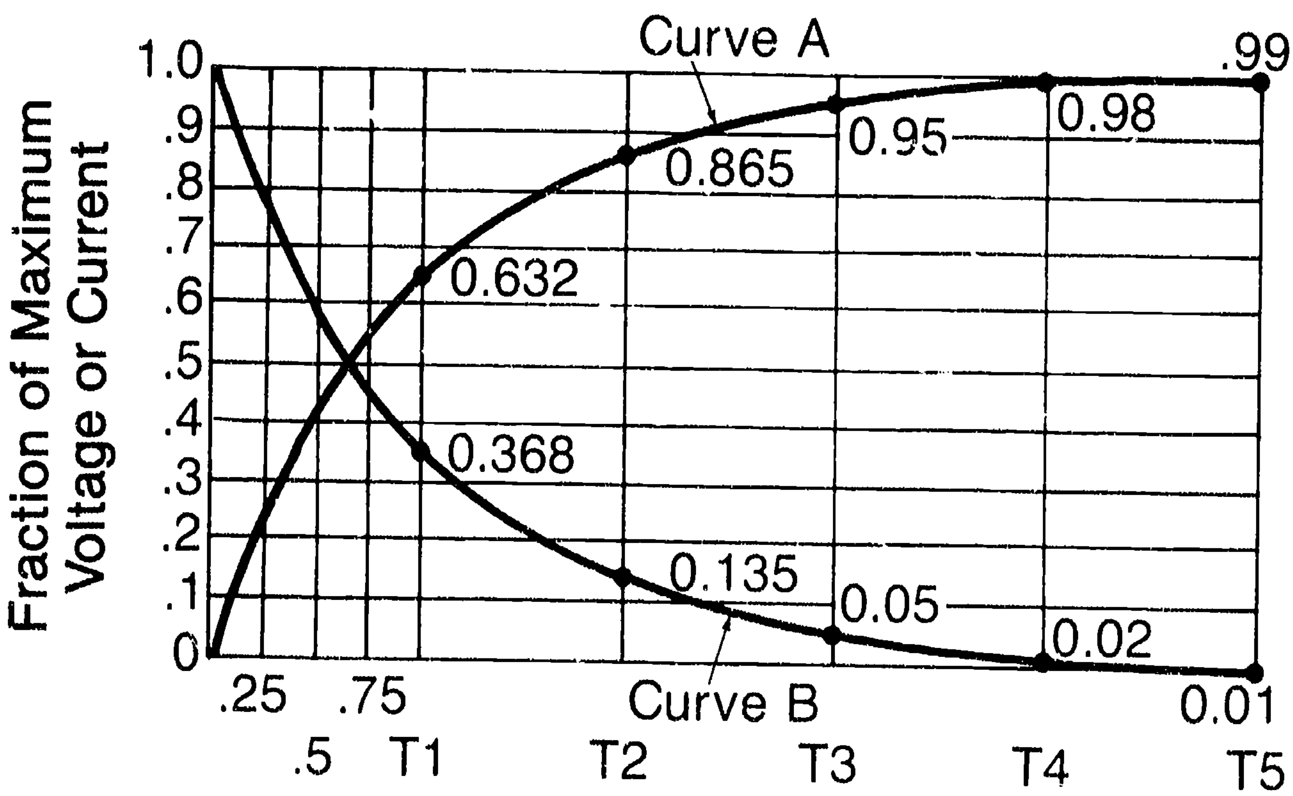
Changing the dielectric material changes the capacitance.

Universal Time Constant Chart for RC and RL Circuits

Capacitor voltage on charge.

Inductor current on growth.

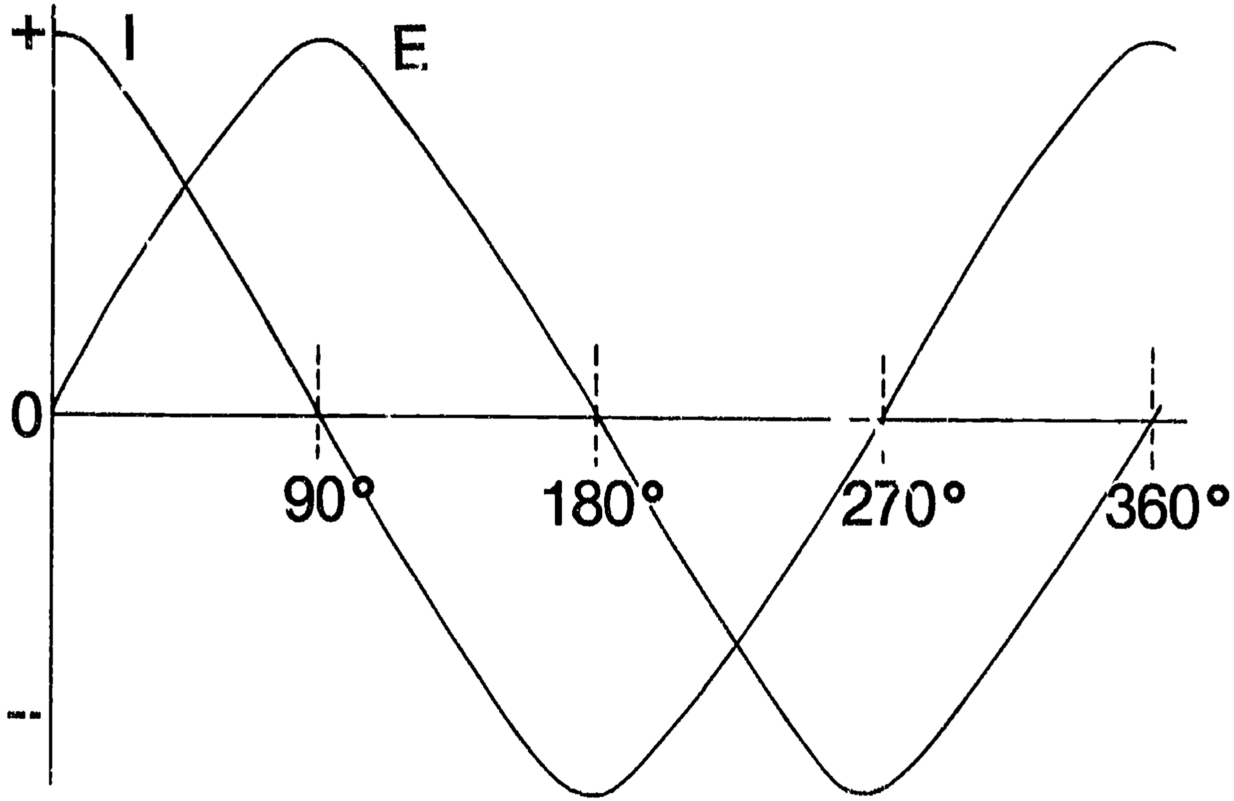
Resistor voltage on growth of inductor current.

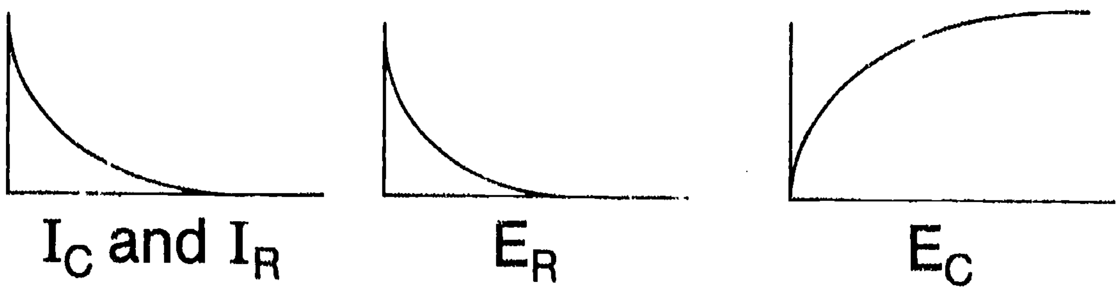


Time Constant: RC or $\frac{L}{R}$

Capacitor voltage on discharge. Capacitor current on charge. Inductor voltage on growth of current. Inductor current on decay. Resistor voltage on charge.

Current and Voltage Relationships in a Purely Capacitive Circuit





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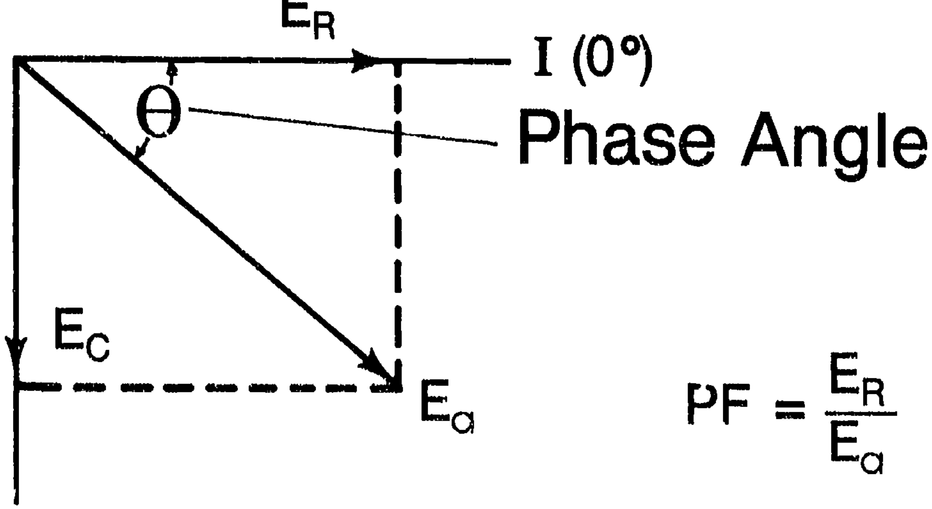
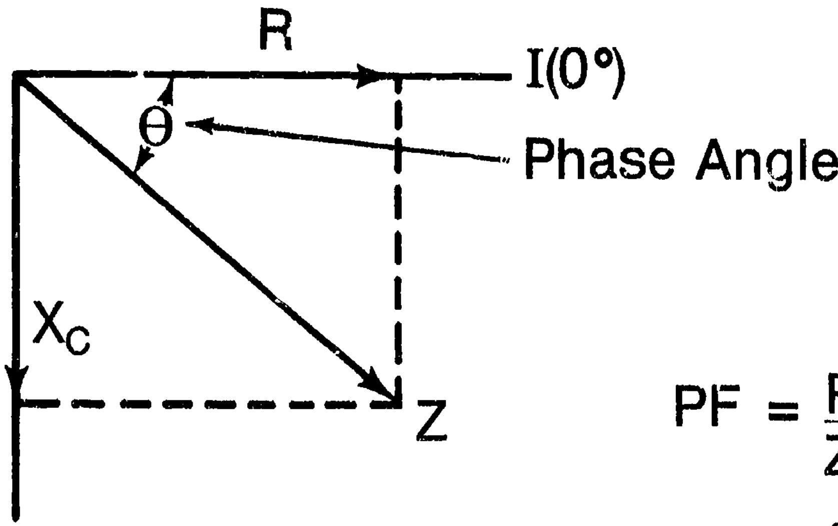
Voltage Relationships in an RC Circuit



$$PF = \frac{E_R}{E_a}$$

$$E_a = I \times Z = \sqrt{(E_a)^2 + (E_{[illegible]})^8}$$

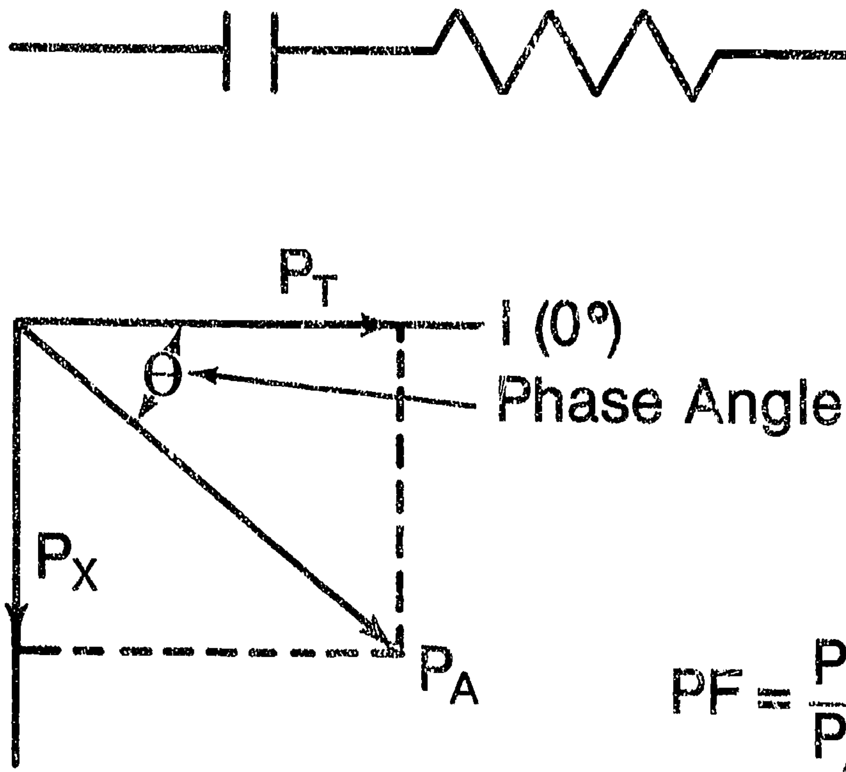
Impedance Relationships in an RC Circuit



$$PF = \frac{R}{Z}$$

$$Z = R^2 + X_C^2$$

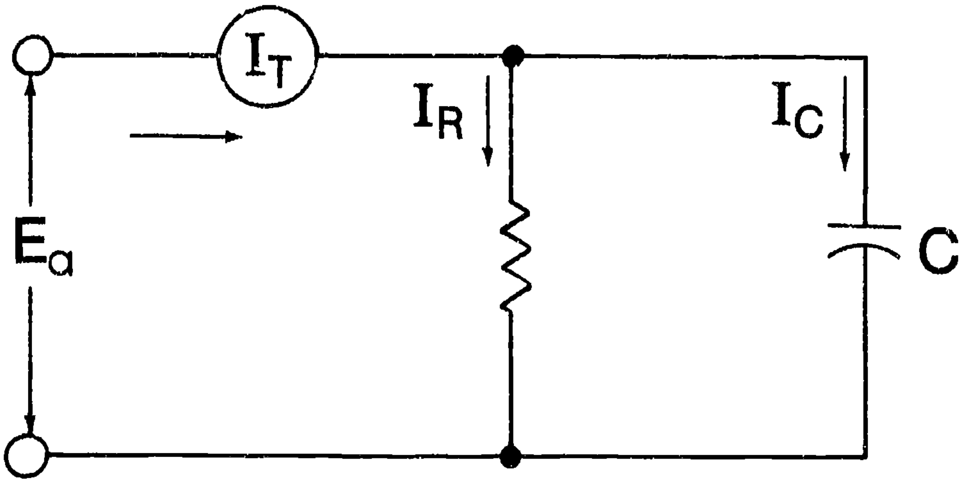
Power Relationships in an RC Circuit



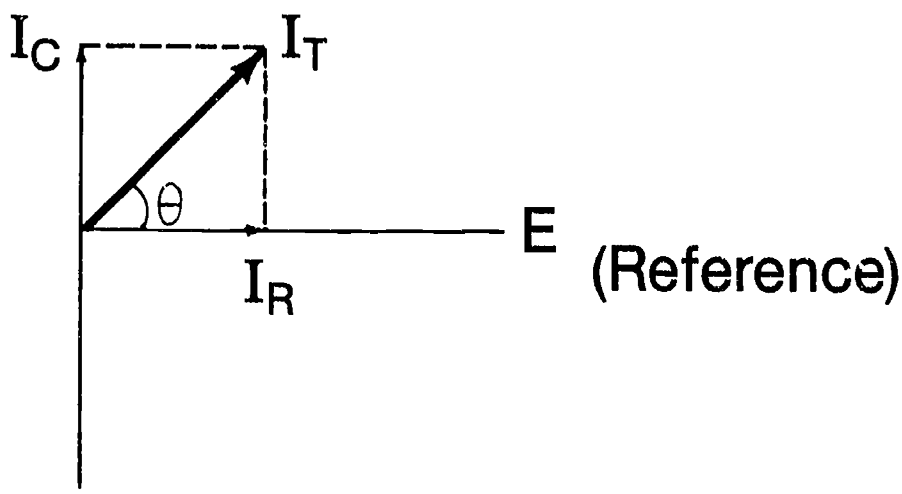
$$PF = \frac{P_T}{P_A}$$

$$P_A = E_A \times I$$

Current Relationships In A Parallel RC Circuit



$$E_a = E_R = E_C$$

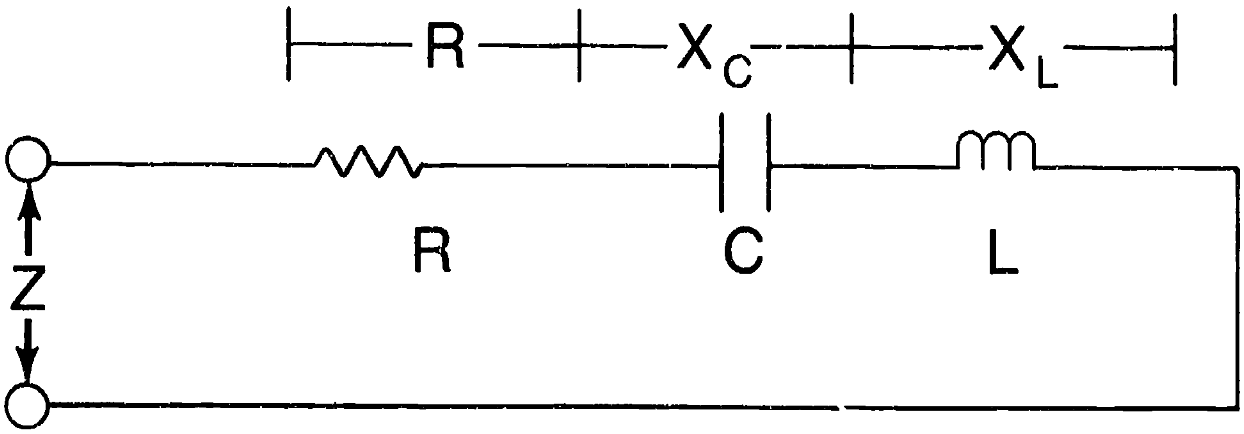


$$I_T = \sqrt{I_R^2 + I_C^2}$$

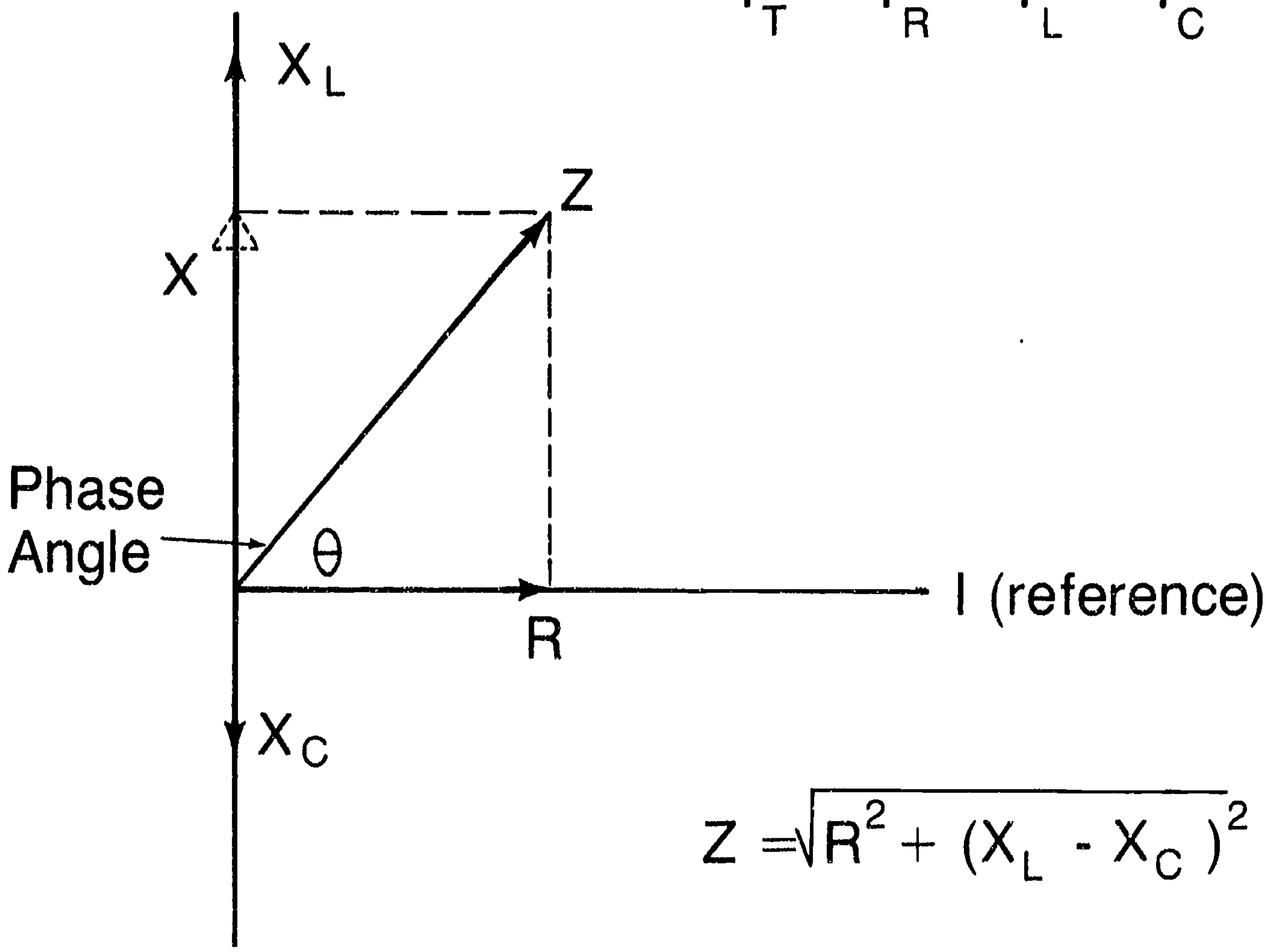
$$Z = E_a / I_T$$

$$\theta = \text{ARC COS } (I_R / I_T)$$

Impedance Relationship in a Series RCL Circuit

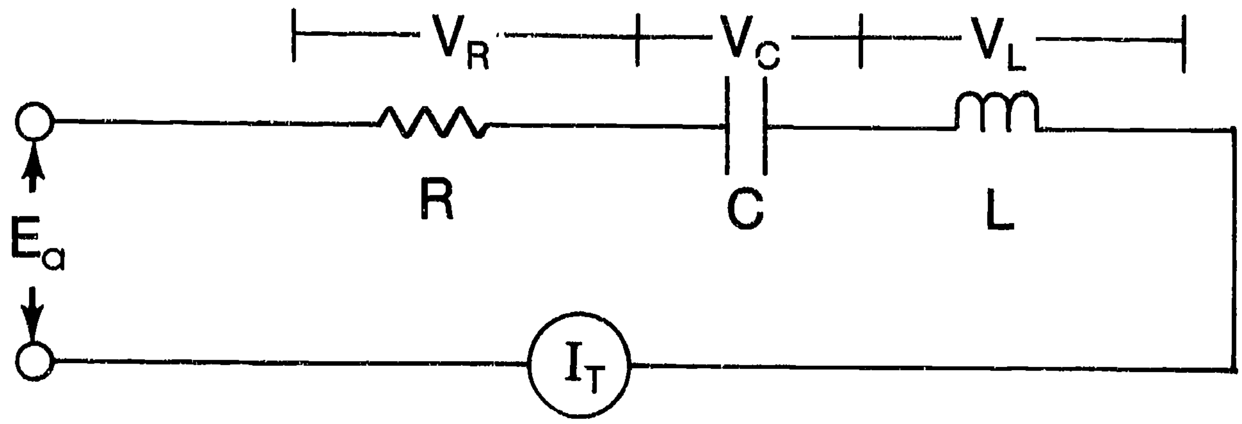


$I_T = I_R = I_L = I_C$

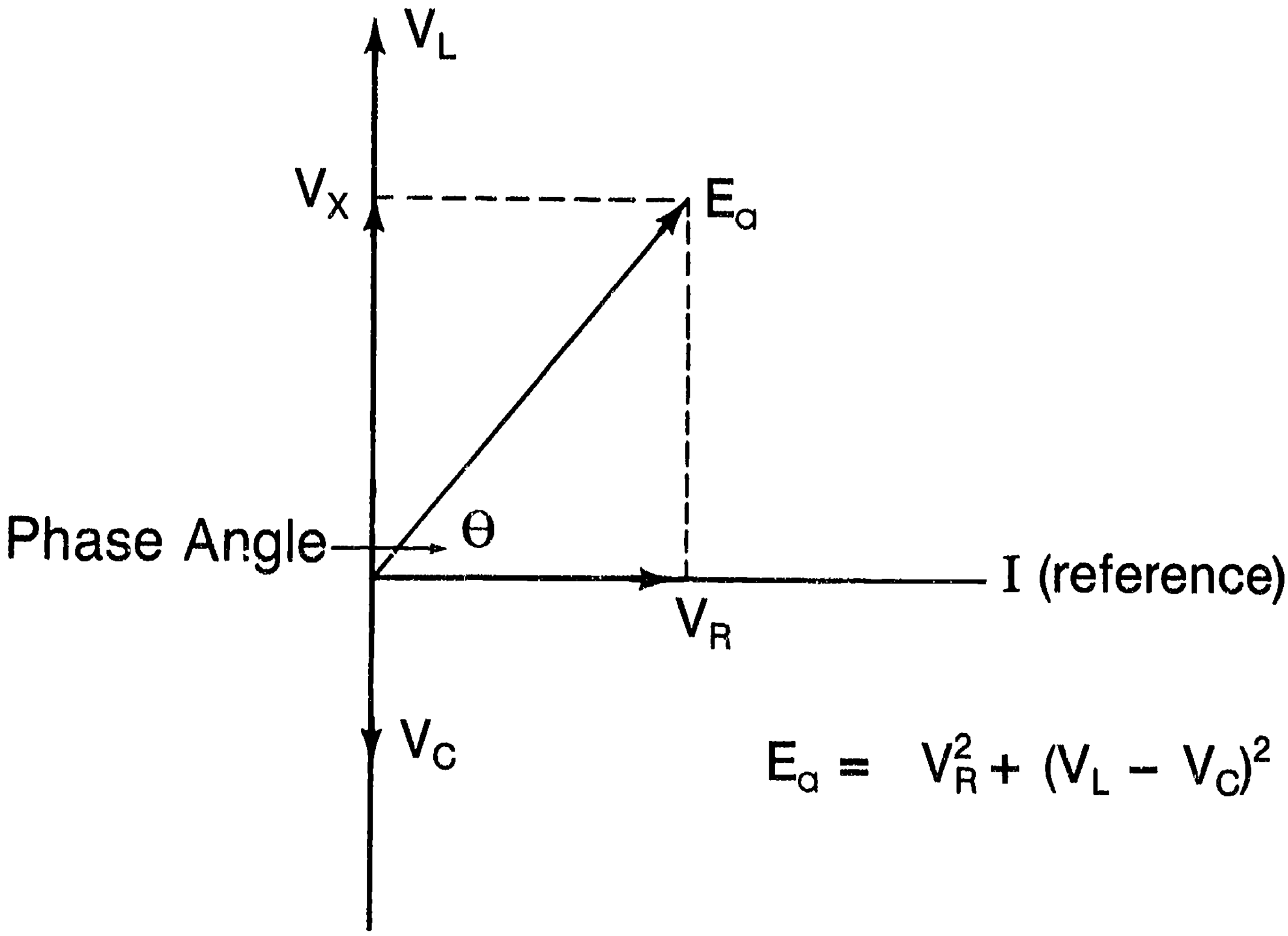


$Z = \sqrt{R^2 + (X_L - X_C)^2}$

Voltage Relationship in a Series RCL Circuit

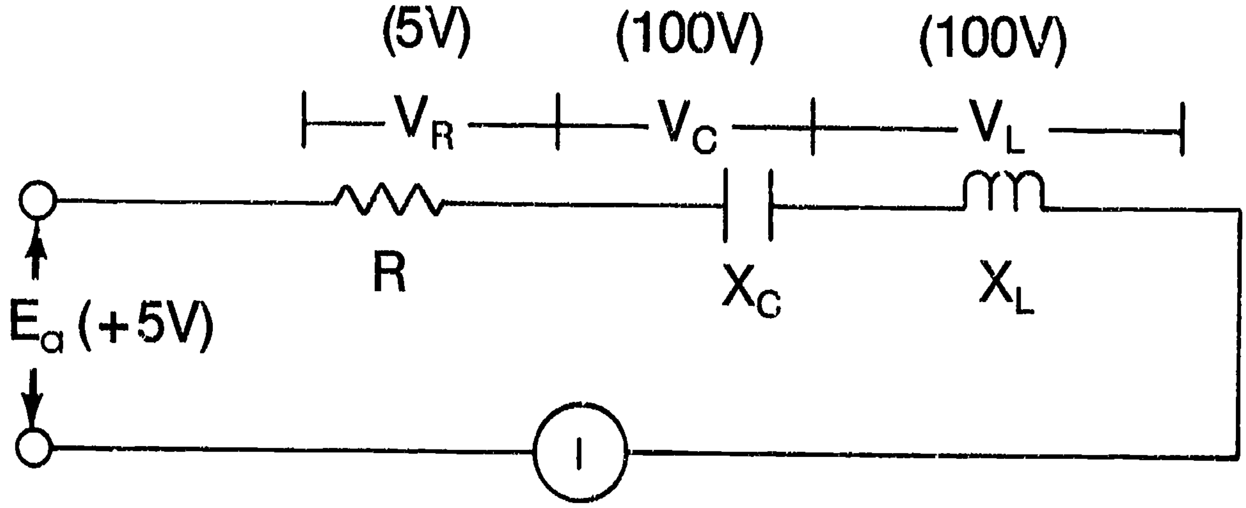


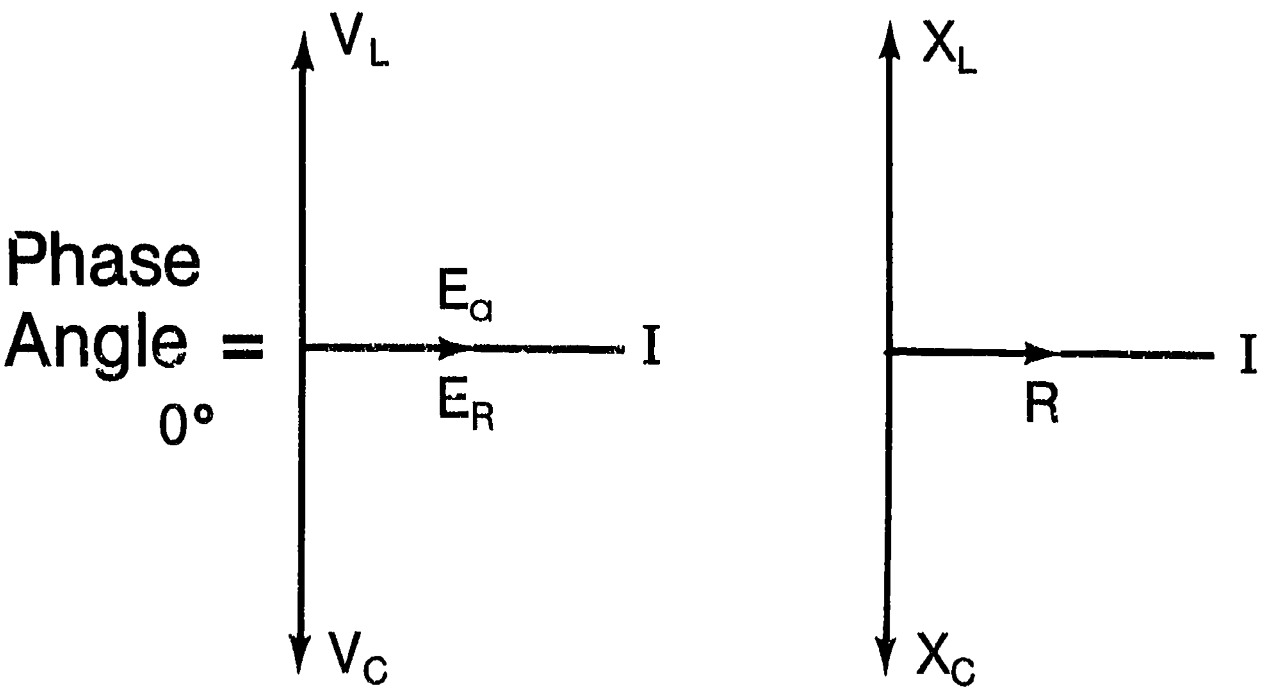
$I_T \quad I_T = I_R = I_C = I_L$



$$E_a = \quad V_R^2 + (V_L - V_C)^2$$

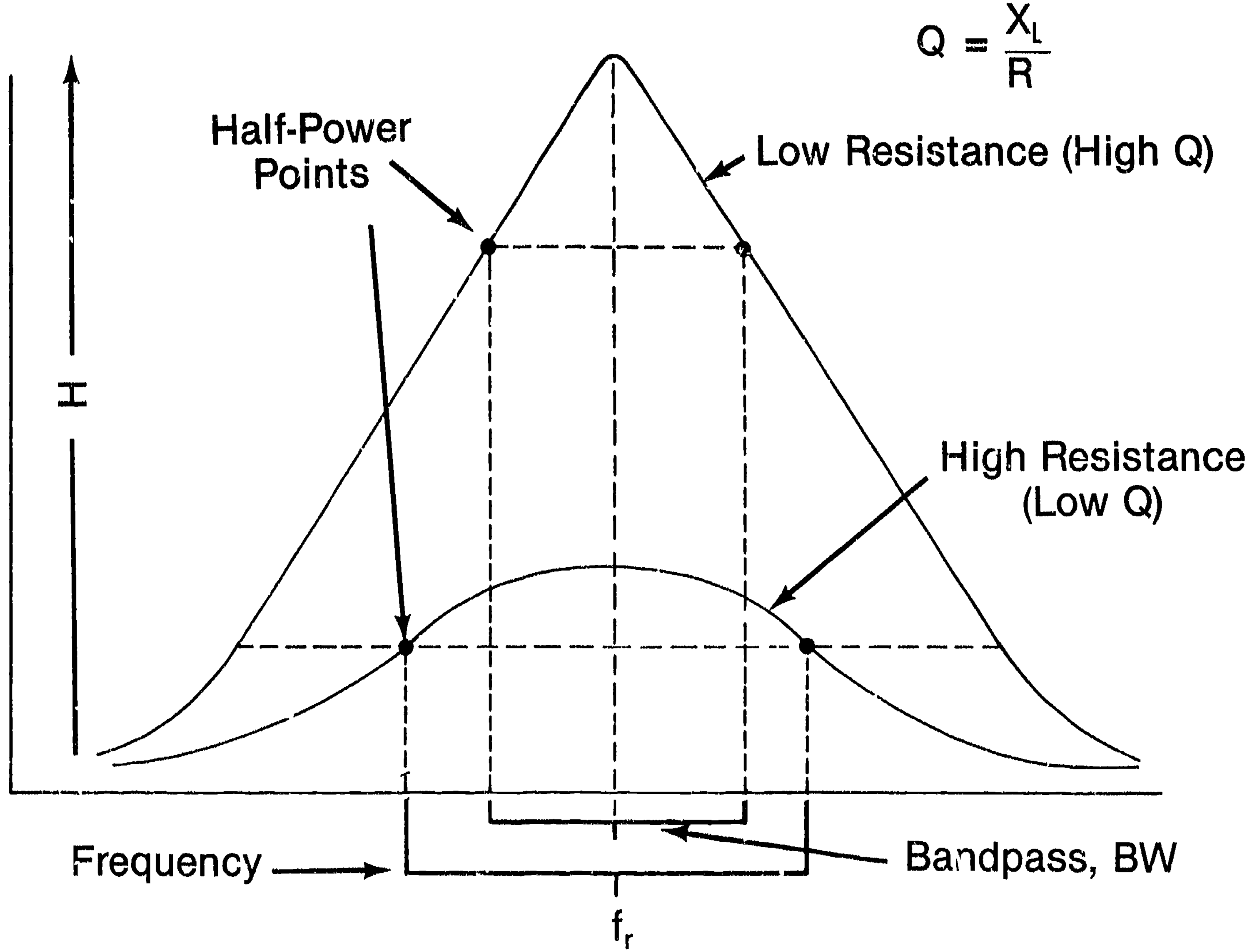
Resonance Relationship in a Series RCL Circuit



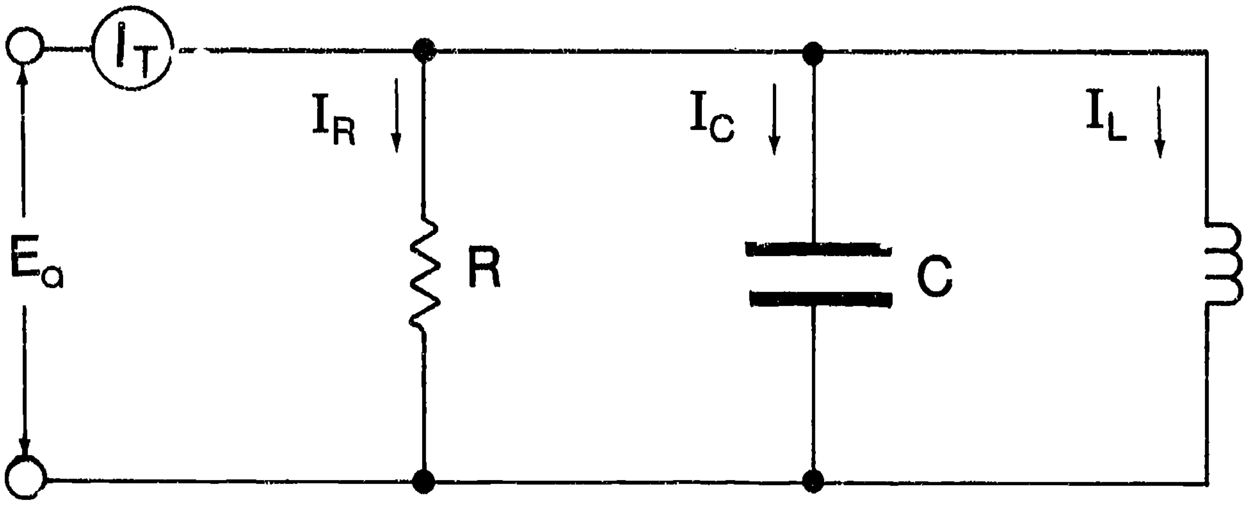


$E_L = E_C$; $E_a = E_R$ $X_C = X_L$; $Z = R$

Typical Resonant Curves

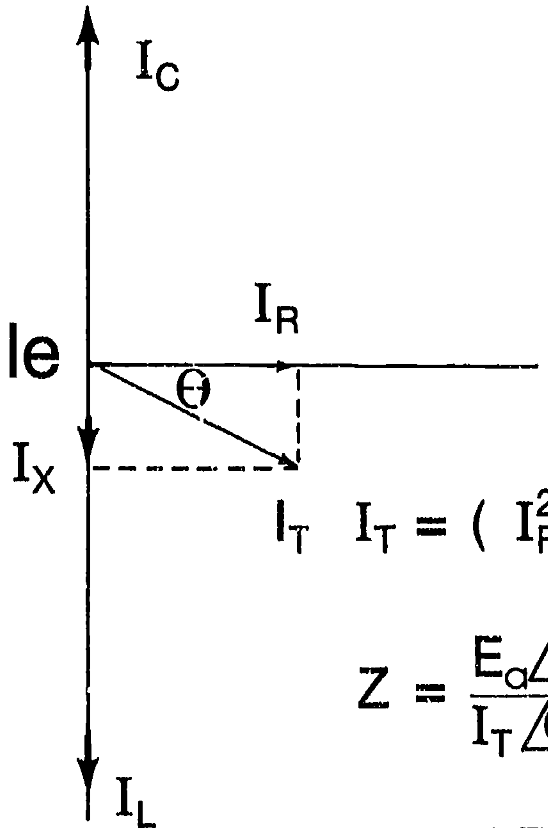


Current Relationship in a Parallel RCL Circuit



$$E_a = V_R = V_C = V_L$$

Phase Angle



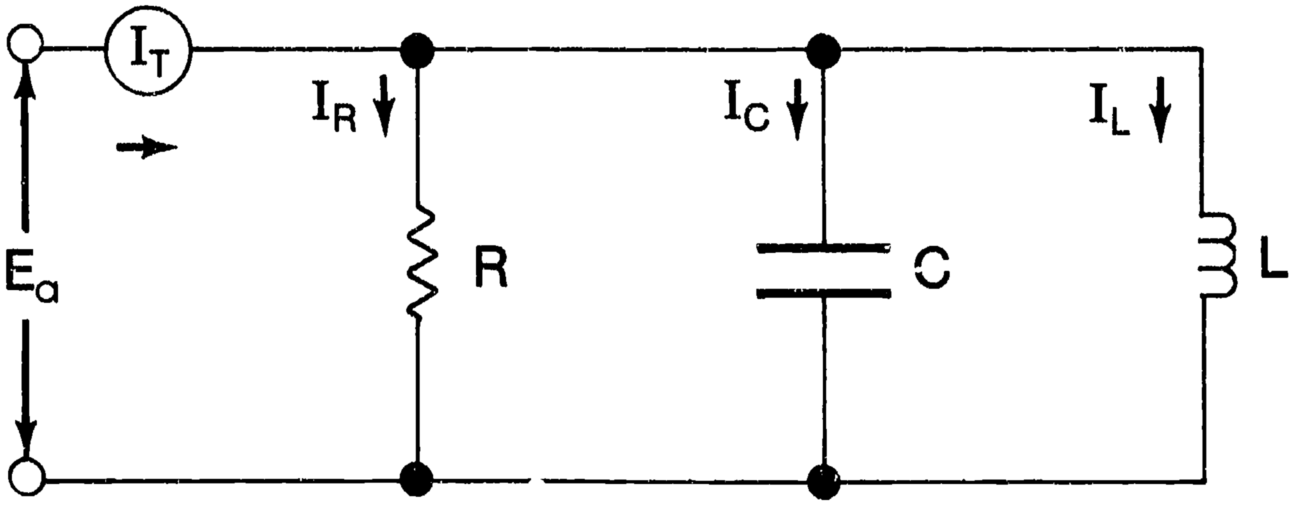
$$I_T = (\ I_R^2 + (I_C - I_L)^2)\ \angle\theta$$

$$Z = \frac{E_a \angle 0^\circ}{I_T \angle \theta}$$

$$\theta = \text{ARC TAN}\ \frac{I_X}{I_R}$$

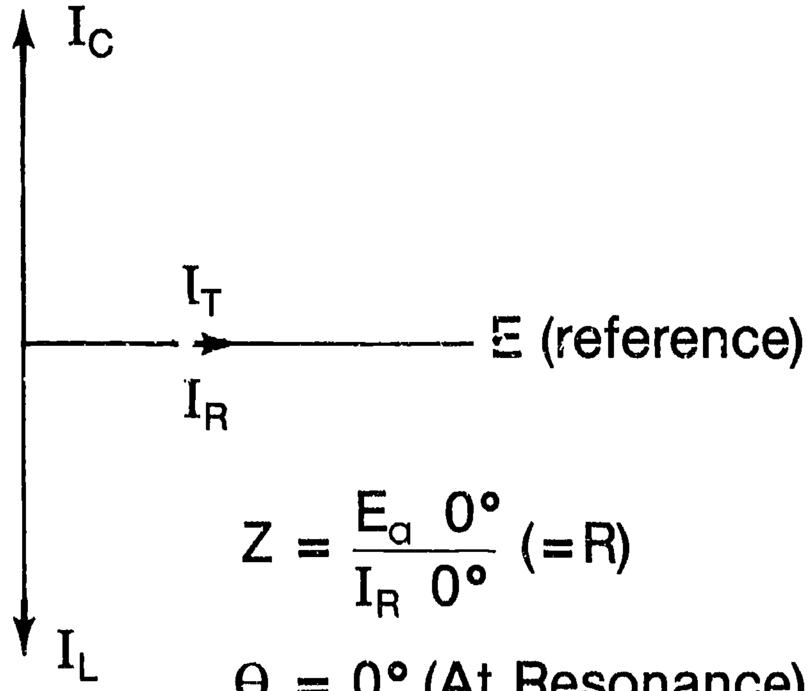
$$\theta = \text{ARC COS}\ \frac{I_R}{I_T}$$

Resonance Relationship in a Parallel RCL Circuit



$E_a = V_R = V_C = V_L$

Phase Angle = 0°



$Z = \frac{E_a \; 0°}{I_R \; 0°} \; (= R)$

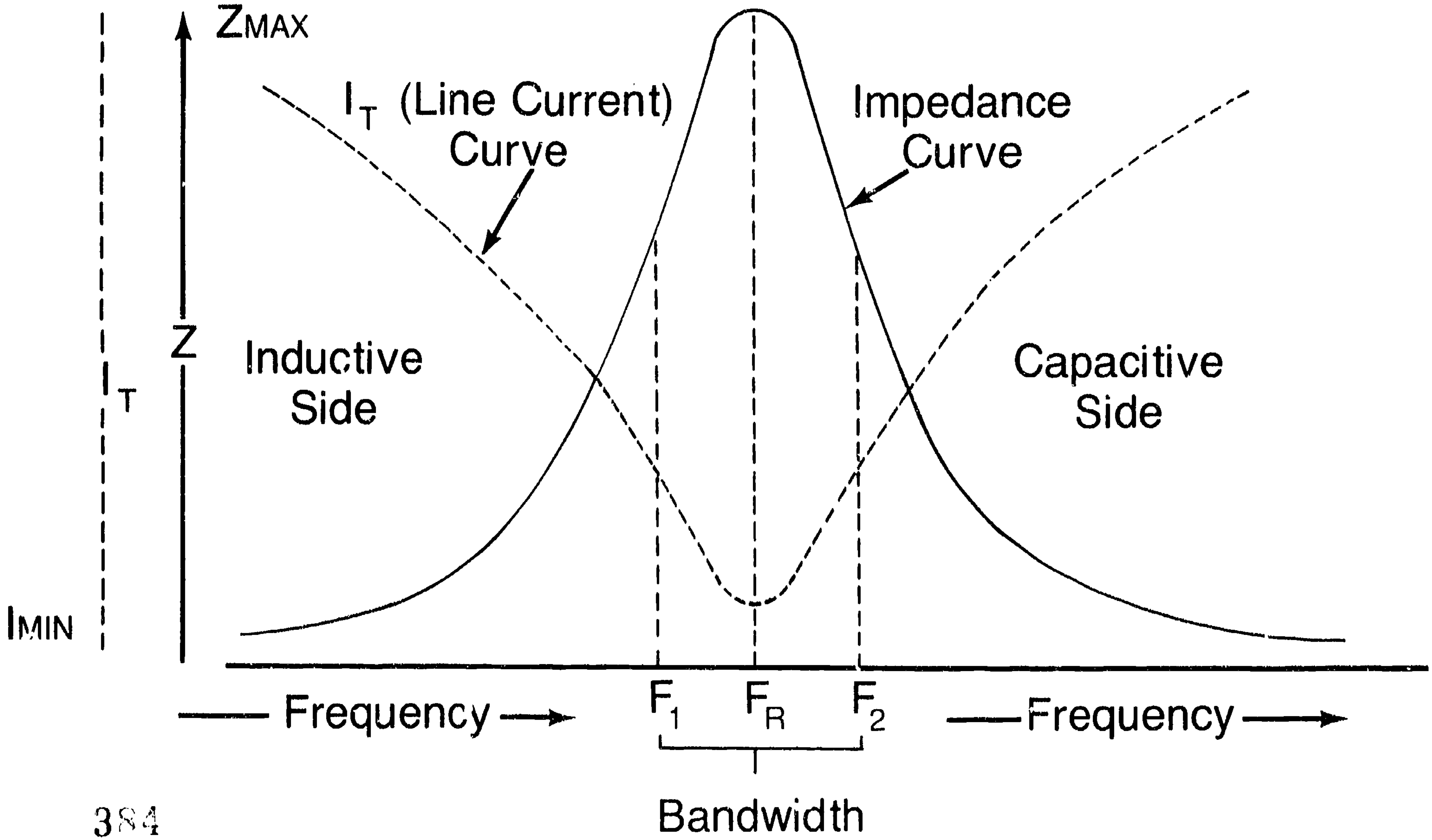
$\theta = 0°$ (At Resonance)

$I_C = I_L$

$I_T = I_R$

$Z = R$

Tuned Parallel Circuit Curves



FUNDAMENTALS OF AC
UNIT III

ASSIGNMENT SHEET #1 — DETERMINE SINE WAVE CONVERSIONS

1. An oscilloscope shows that the peak voltage value of an AC wave is 155.6 volts. What is the voltage that would be read on the AC scale of a multimeter (i.e., RMS voltage value)?

   Answer:____________

2. If your voltmeter reads 25 volts (effective value), what would be the peak voltage shown on an oscilloscope (peak value)?

   Answer:____________

3. In problem 2, what would the peak-to-peak voltage be?____________

4. If the peak value of a sine wave is 100, the average value of one alternation is ____________.

FROM	TO			
	EFFECTIVE	AVERAGE	PEAK	PEAK-TO-PEAK
EFFECTIVE (RMS)	1.0	0.900	1.414	2.828
AVERAGE	1.110	1.0	1.571	3.142
PEAK	0.707	0.637	1.0	2.000
PEAK-TO-PEAK	0.354	0.318	0.500	1.0

FUNDAMENTALS OF AC
UNIT III

ASSIGNMENT SHEET #2 — COMPUTE PERIOD

Directions: Compute period using the following formulas:

$$T = \frac{1}{f}$$

$$f = \frac{1}{T}$$

(NOTE: Radio waves have a velocity of 3×10^{10} cm/s or 186,000 mile/s.)

1. How much time is required for a 60 cycle per second (60 Hz) voltage to complete one cycle? ____________ seconds

2. If one cycle requires 1/400th of a second, the frequency is ____________ Hz.

3. If you increase frequency, the time required for one cycle will **(increase, decrease)**.

FUNDAMENTALS OF AC
UNIT III

ASSIGNMENT SHEET #3 — DETERMINE CURRENT FLOW DIRECTION

1. Mark these statements True (T) or False (F).

   _____a. Moving a conductor which cuts the lines of a magnetic field induces a voltage in the conductor

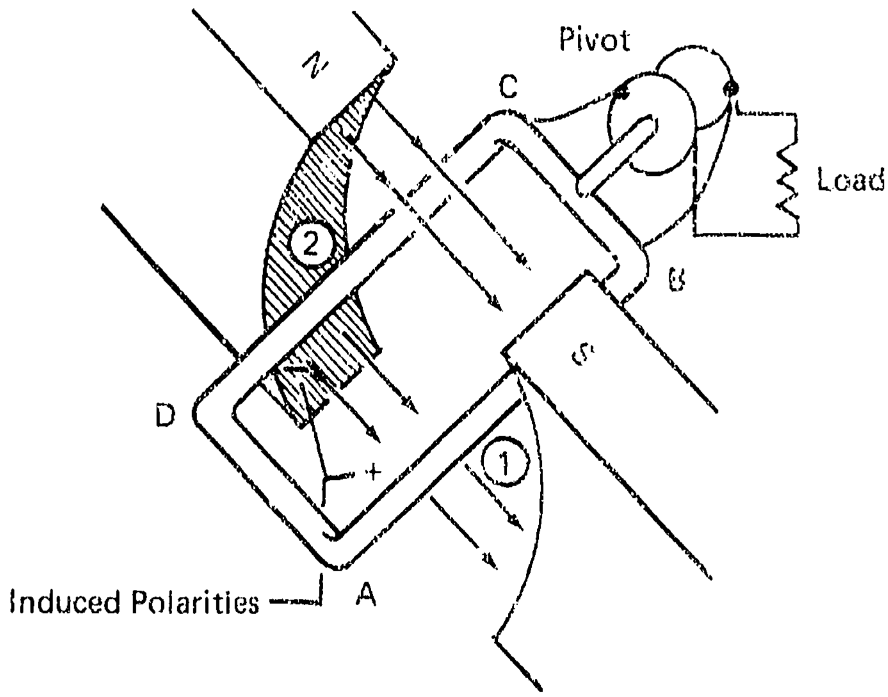
   _____b. EMF is generated when the magnetic field is moved and the conductor is stationary (assuming that lines of flux are being cut)

   _____c. The left-hand generator rule can be used to determine electron displacement

2. Match the following concerning the left hand generator rule.

_____a.	Thumb	1. Direction of current flow
_____b.	Forefinger	2. Direction of conductor motion
_____c.	Middle finger	3. Direction of magnetic flux lines

3. Study the illustration and answer the following questions:



ASSIGNMENT SHEET #3

a. When leg (1) is moving downward, from which letter position will current move out of the loop into the circuit? (A or B) ________

b. When leg (1) moves downward, current will flow from (A or B) ________ to (A or B) ________ in leg (1)

c. When leg (2) moves upward, current will flow from (C or D) ________ to ________ (C or D) in leg (2)

d. When leg (2) gets to the shown position of leg (1), what happens to the current? ________

FUNDAMENTALS OF AC
UNIT III

ASSIGNMENT SHEET #4 — ANSWER QUESTIONS REGARDING INDUCTION AND INDUCTORS

1. Match the statement on the right with their effects.

_____a. Source current increased

_____b. Source current decreased

1. Inductance and induced EMF **source** current
2. Inductance and induced EMF **sustain** source current

2. Match the phrases on the right with their effects.

(NOTE: Answers may be used more than once.)

_____a. Decrease core permeability

_____b. Add turns to a coil

_____c. Increase cross-sectional area of core

_____d. Decrease length of core

1. Inductance increases
2. Inductance decreases

3. Place an "X" next to statements which correctly finish this phrase: In an inductive circuit when the switch is suddenly opened,

_____a. the magnetic field around the coil begins to collapse

_____b. current tries to continue to flow due to induced voltage

_____c. current decays rather than abruptly going to zero

_____d. all of the above are correct

4. What is another name for induced voltage?

____

5. True or false:

_____a. The induced voltage caused by inductance opposes any change in circuit current

_____b. The induced voltage is called CEMF

ASSIGNMENT SHEET #4

6. Name three different core materials used in inductor construction.

   a. ______________________________

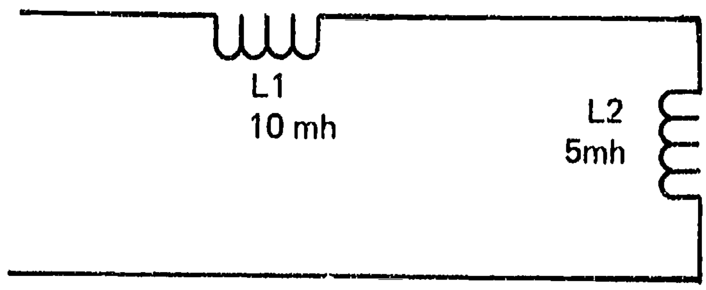
   b. ______________________________

   c. ______________________________

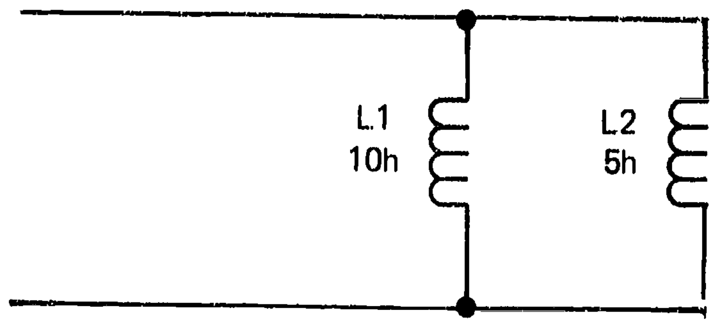
FUNDAMENTALS OF AC
UNIT III

ASSIGNMENT SHEET #5 — SOLVE FOR TOTAL INDUCTANCE

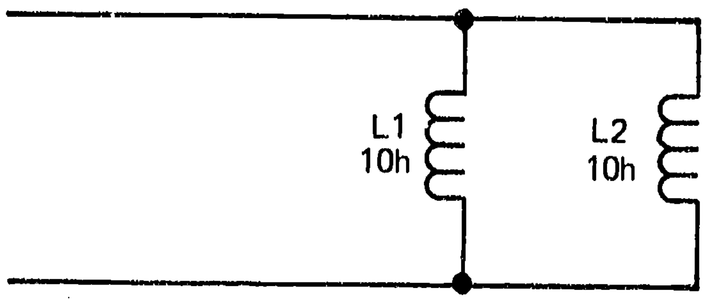
1. Find L_T in this circuit (assume no mutual inductance.)



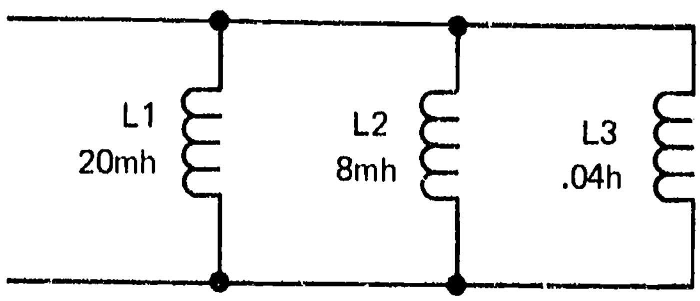
2. Solve for L_T.



3. Solve for L_T.

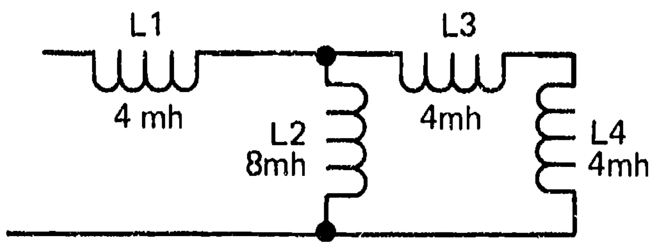


4. Solve for L_T.



ASSIGNMENT SHEET #5

5. Solve for L_T.



FUNDAMENTALS OF AC
UNIT III

ASSIGNMENT SHEET #6 — COMPUTE INDUCTIVE REACTANCE

1. Write the formula for computing inductive reactance.

2. Select the unit of measure inductive reactance is expressed in.

   a. Henrys

   b. Ohms

   c. Farads

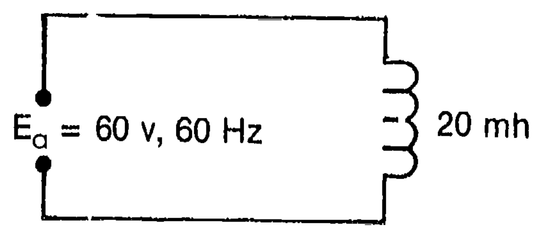
   d. Radians

3. If the frequency of the applied voltage of an RL circuit is increased, the inductive reactance (**increases, decreases**).

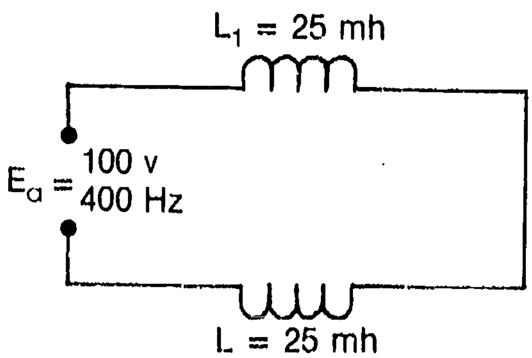
4. If the inductance is increased in a given circuit, the inductive reactance (**increases, decreases**).

5. In the following circuits, solve for X_L.

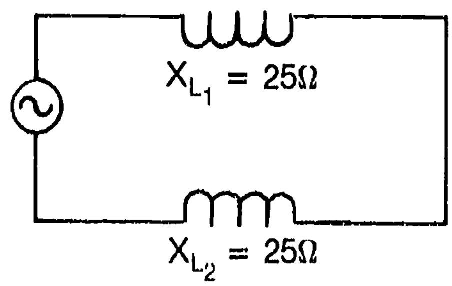
   a. X_L = ____________



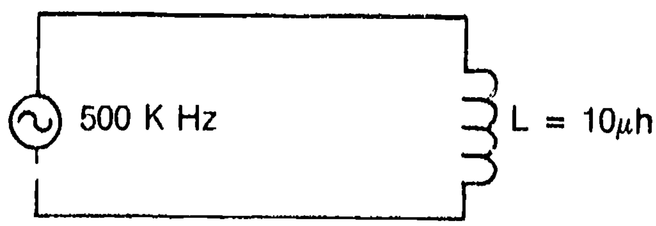
   b. X_L = ____________



   c. X_{LT} = ____________



   d. X_L = ____________



FUNDAMENTALS OF AC
UNIT III

ASSIGNMENT SHEET #7 — COMPUTE APPLIED VOLTAGE AND IMPEDANCE OF RL CIRCUITS

1. Select true statements relating to RL series circuits by placing an "X" in the appropriate blanks.

   _____a. The current in a series RL circuit is the same in the inductor as in the resistor (at all times).

   _____b. In a purely inductive circuit, the current lags the applied voltage by 90 degrees.

   _____c. In a practical circuit containing inductance and resistance, the current will lag the voltage by an angle somewhere between almost zero and almost 90 degrees.

   _____d. The voltage across the inductor is always in phase with the applied voltage.

   _____e. The voltage across the resistor is always in phase with the applied voltage.

   _____f. The voltage across the resistor is always in phase with the current flowing through the resistor.

   _____g. The applied voltage is the vector sum of the voltage drops across the resistor and the inductor.

   _____h. If 100 volts is applied to a circuit having 50 ohms of resistance and 50 ohms of inductive reactance, there will be 50 volts across the resistor and 50 volts across the inductor.

2. If there are 10 ohms of resistance in series with 10 ohms of inductive reactance, the circuit impedance will be __________ ohms.

3. If there is a 30 volt drop across the resistor and a 40 volt drop across the inductor in a series RL circuit, the applied voltage is __________ volts, and the cosine of the phase angles is __________. (Remember, the cosine of the phase angle equals E_R/E_a.)

ASSIGNMENT SHEET #7

4. Solve as indicated.

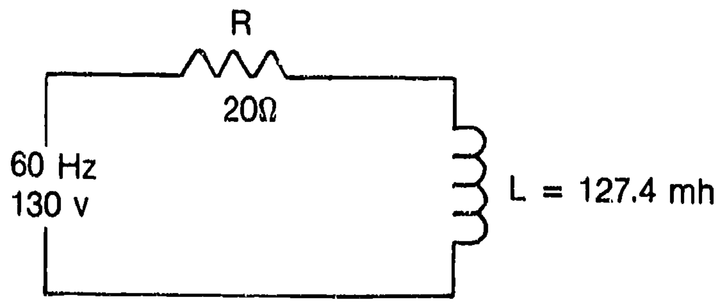
   a. X_L = ____________

   b. Z = ____________

   c. I = ____________

   d. E_R = ____________

   e. E_L = ____________



FUNDAMENTALS OF AC
UNIT III

ASSIGNMENT SHEET #8 — COMPUTE THE Q OF INDUCTORS

1. State the formula for computing Q.

   Q = ____________________

2. Two inductors have the same value of L but one has more resistance in its windings than the other. The one with the most resistance has the (**higher, lower**) Q.

3. Select true statements regarding the Q of inductors by placing an "X" in the appropriate blanks.

   _____a. All inductors have some resistance.

   _____b. High Q coils usually have relatively little resistance.

   _____c. In general, high Q coils have greater energy storage ability than do low Q coils.

   _____d. Since Q equals X_L divided by R_S, an inductor having a Q of "100" means that it has 100 ohms.

4. A coil is measured with a DC ohmmeter as having 0.5 ohms resistance. If the coil has an X_L of 300 ohms, the Q is ____________.

5. Increasing the angular velocity slightly (**increases, decreases**) the Q of the coil.

6. An inductor has an internal resistance of 0.5 ohm and is rated at 500 mh. If 10 volts at 60 Hertz is applied, the Q of the inductor is ____________.

FUNDAMENTALS OF AC
UNIT III

ASSIGNMENT SHEET #9 — SOLVE TIME CONSTANT PROBLEMS

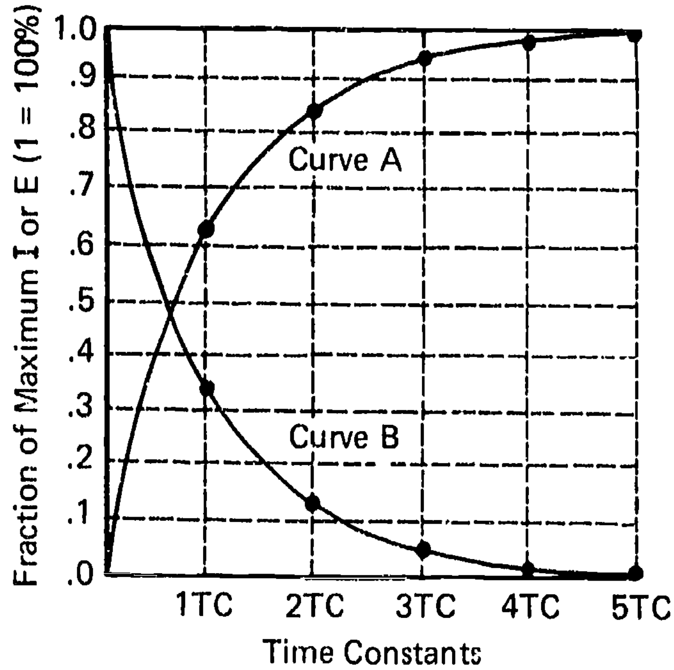
1. The percentages in the universal time constant chart show in a series RL circuit as (check the correct statements).

_____a. Current increase on Curve B

_____b. Current increase on Curve A

_____c. Current decrease on Curve B

_____d. Current decrease on Curve A



2. Refer to the chart. How many time constants are required for

_____a. Current rise to maximum value?

_____b. Current decay from maximum to zero?

3. Refer to Curve A only in the chart. At 1TC, what is the percentage of current increase? __________

4. What is the percentage of current increase at 2TC? __________

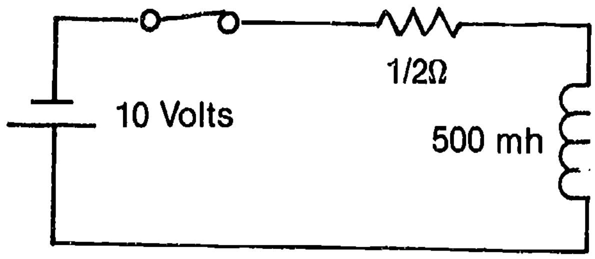
5. What is the percentage of rise at 3TC? __________ 4TC? __________

6. In effect, when the switch is turned off and current starts to decay, it will have dropped to what percentage of its maximum value at 1TC? (the first percentage on the B curve). __________

7. What is the percentage decay at 2TC? __________ 3TC? __________

ASSIGNMENT SHEET #9

8. Using the following circuit and the universal time constant chart, answer the questions below the circuit.



a. The maximum current that will flow in the circuit is ____________ amps.

b. The time for one time constant is ____________.

c. The time required to reach the maximum current after switch closure is ____________.

d. The time required to reach 19 amperes is ____________ seconds after switch closure.

FUNDAMENTALS OF AC
UNIT III

ASSIGNMENT SHEET #10 — COMPUTE CAPACITANCE VALUES

1. Write the formula showing the relationship between farads, volts, and electric charge (or quantity).

   ____

2. If 50 volts is applied to the following capacitors, compute the amount of charge that will appear on the plates.

   a. 2 F = ____________ coulombs

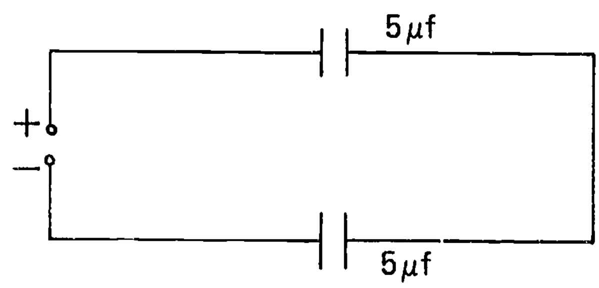
   b. 2μF = ____________ coulombs

   c. 2pF = ____________ coulombs

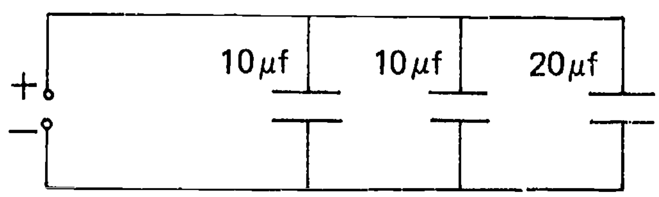
   d. 100μF = ____________ coulombs

3. In the following circuits solve for the total capacitance, C_T.

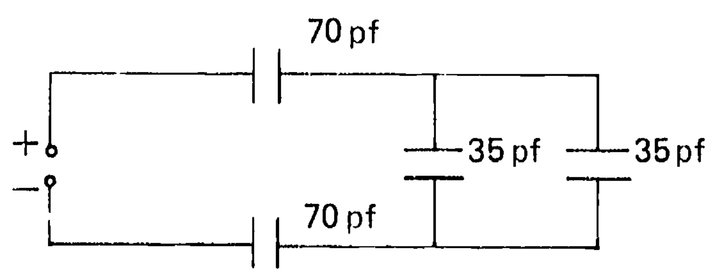
   a. C_T = ____________



   b. C_T = ____________



   c. C_T = ____________



FUNDAMENTALS OF AC
UNIT III

ASSIGNMENT SHEET #11 — COMPUTE RC TIME CONSTANTS

1. Write the formula for computing one time constant in an RC circuit.

____

2. Match the curves on the right to the correct descriptions.

_____a. Voltage of capacitor during charge

_____b. Voltage of capacitor during discharge

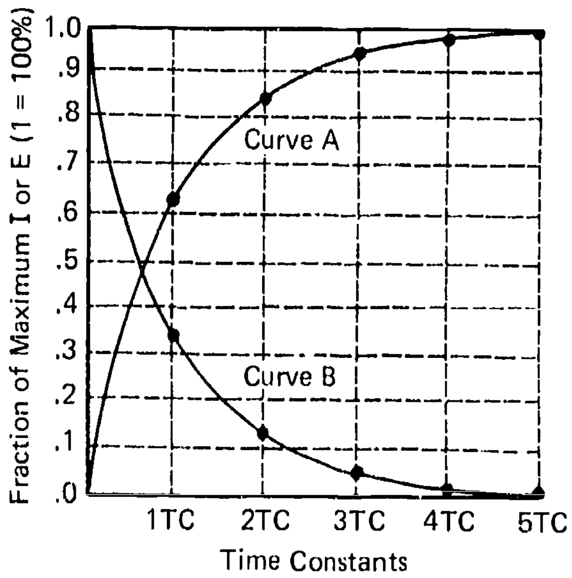
_____c. Current during charge

_____d. Current during discharge

_____e. Voltage of resistor during charge

_____f. Voltage of resistor during discharge

1. Universal chart rising curve
2. Universal chart falling curve



3. If E_A = 200 volts and R = 50 ohms, compute (use the universal chart) the following for an RC circuit during charge.

a. Maximum current ______________________

b. Current after two time constants ______________________

c. e_C after three time constants ______________________

d. e_R after three time constants ______________________

ASSIGNMENT SHEET #11

4. Using the same values for E_A and for R as in problem 3, compute the following for an RC circuit during **discharge.**

   (NOTE: Use universal chart.)

   a. Current after four time constants ____________________

   b. e_C after two time constants ____________________

   c. e_R after two time constants ____________________

5. A circuit has the following values of R and C; compute one time constant.

   a. R = 1 Megohm, C = 1μf TC = ______

   b. R = 1 kilohm, C = 20000μf TC = ______

   c. R = 1500 ohms, C = 200 pf TC = ______

   d. R = 47 kilohm, C = 30μf TC = ______

FUNDAMENTALS OF AC
UNIT III

ASSIGNMENT SHEET #12 — COMPUTE CAPACITIVE REACTANCE

Directions: Review the formula for computing capacitive reactance and compute X_C from the C and f values given below:

1. Write the formula for computing capacitive reactance.

   X_C =

2. Select the units of measure capacitive reactance is expressed in

   _____a. Farads

   _____b. Henrys

   _____c. Ohms

   _____d. Radians

3. If the frequency of the applied voltage to an RC circuit is increased, the capacitive reactance will **(increase, decrease)**.

4. If the capacitance is increased in a given RC circuit, the capacitive reactance will **(increase, decrease)**.

5. The angular velocity is decreased by decreasing:

   _____a. Frequency

   _____b. Phase angle

   _____c. Power factor

   _____d. Capacitance

6. Compute X_c for the following values of C and f:

   _____a. C = 10,000 μF, f = 10 Hz

   _____b. C = 10 μF, f = 60 Hz

7. At what frequency would a 0.05 microfarad capacitor have 40 ohms of capacitive reactance?

FUNDAMENTALS OF AC
UNIT III

ASSIGNMENT SHEET #13 — DETERMINE PHASE RELATIONSHIPS IN RC CIRCUITS

Directions: Using the chart and diagrams below, determine the following:

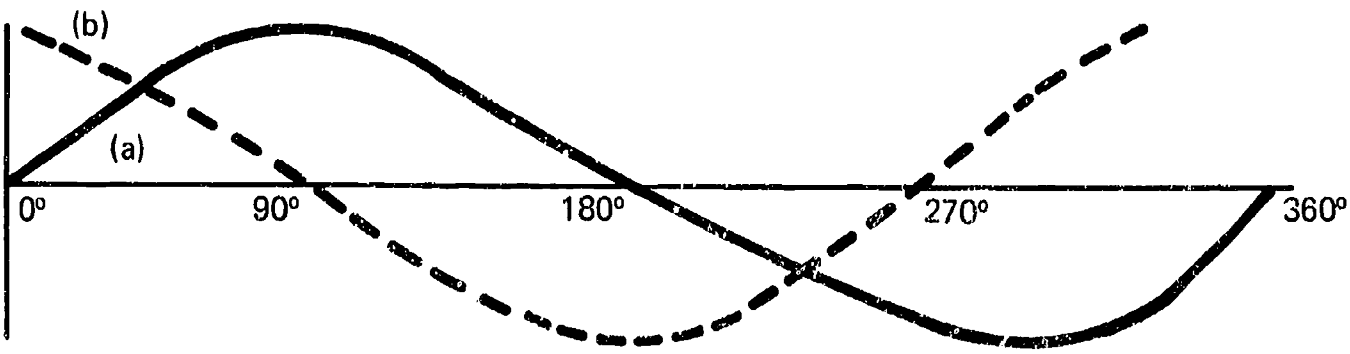
1. Which curve from the chart in Figure 1 represents AC current in a capacitive circuit?

   ____

2. Which curve from the chart in Figure 1 represents AC voltage in a capacitive circuit?

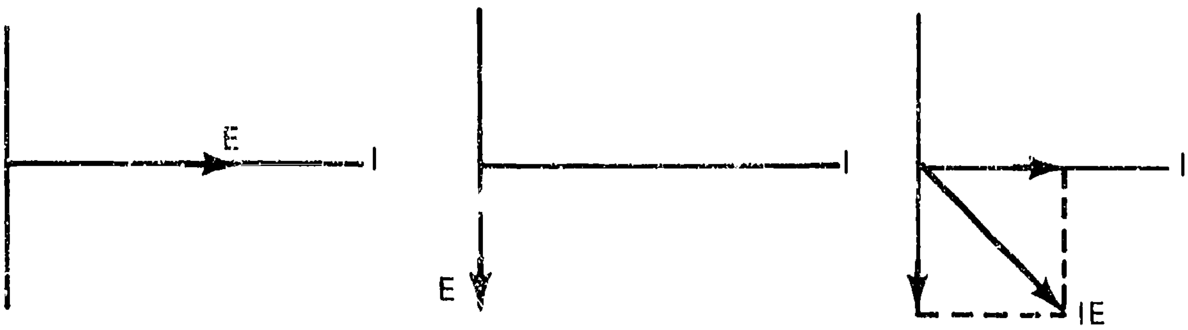
   ____

FIGURE 1



3. Which diagram in Figure 2 represents a purely capacitive AC circuit?____________
4. Which diagram in Figure 2 represents a purely resistive AC circuit?____________
5. Which diagram in Figure 2 represents a circuit with R and C?____________

FIGURE 2



6. Explain what is meant when a circuit has a power factor of 1.

   ____

   ____

FUNDAMENTALS OF AC
UNIT III

ASSIGNMENT SHEET #14 — COMPUTE VALUES OF RC CIRCUITS

1. Select true statements concerning RC circuits by placing an "X" in the appropriate blanks.

_____a. The current in a series RC circuit is the same in the resistor as in the capacitor at all times when AC voltage is applied.

_____b. The voltage in a series RC circuit is the same across the resistor as across the capacitor at all times when AC is applied.

_____c. Current leads the voltage by 90 degrees in a purely capacitive circuit.

_____d. Current lags the voltage by 90 degrees in a purely capacitive circuit.

_____e. Current is in phase with voltage in a purely resistive circuit.

_____f. Voltage lags the current by 90 degrees in a purely capacitive circuit.

_____g. Voltage across the resistor is always in phase with the applied voltage in an RC circuit.

_____h. If 100 volts is applied to a circuit having 50 ohms of resistance and 50 ohms of capacitive reactance, there will be 50 volts drop across the resistor and 50 volts drop across the capacitor.

2. If there are 40 ohms of resistance in series with 40 ohms of capacitive reactance, the circuit impedance, Z, equals ____________ ohms.

3. If there is a 40 volt drop across the resistor and a 30 volt drop across the capacitor in an RC circuit, the applied voltage is ____________ volts and the phase angle is ____________ degrees.

4. Solve the following circuit for the indicated values.

a. X_C = ______

b. Z = ______

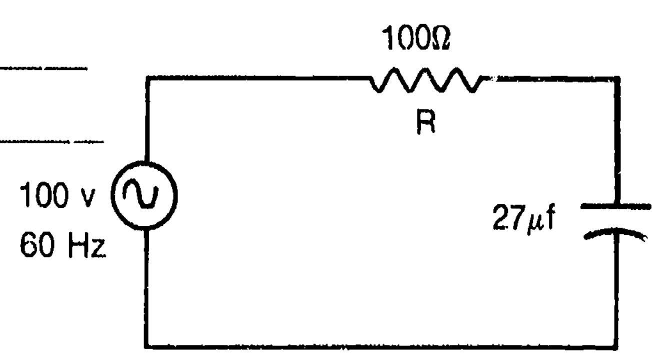
c. I = ______

d. E_R = ______

e. E_C = ______

f. θ = ______

g. PF = ______



FUNDAMENTALS OF AC
UNIT III

ASSIGNMENT SHEET #15 — SOLVE FOR REACTANCE

1. The formula for computing total reactance, X_T is ______________________________.

2. If X_L is 10 ohms and X_C is 5 ohms, X_T equals ____________ ohms and the circuit is **(capacitive, inductive)**.

3. If X_L is 5 ohms and X_C is 10 ohms, X_T equals ____________ ohms and the circuit is **(capacitive, inductive)**.

4. The formula used to compute inductive reactance, X_L, is ______________________.

5. The formula used to compute capacitive reactance, X_C, is ______________________.

6. Capacitance is measured in ____________ (units) and capacitive reactance is measured in ____________.

7. Inductance is measured in ____________ and inductive reactance in ____________.

8. If a 1mH coil is in series with a 5F capacitor, the circuit will be **(inductive, capacitive)** at 3 Hertz but will be **(inductive, capacitive)** at 1KHz.

9. Inductive reactance varies **(directly, inversely)** with frequency.

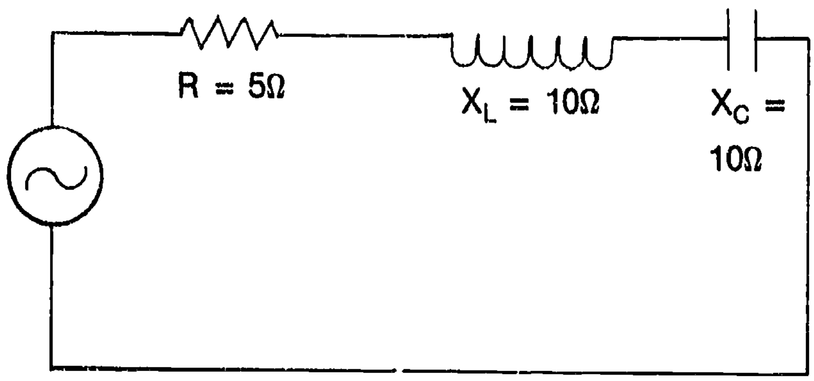
10. Capacitive reactance varies **(directly, inversely)** with frequency.

FUNDAMENTALS OF AC
UNIT III

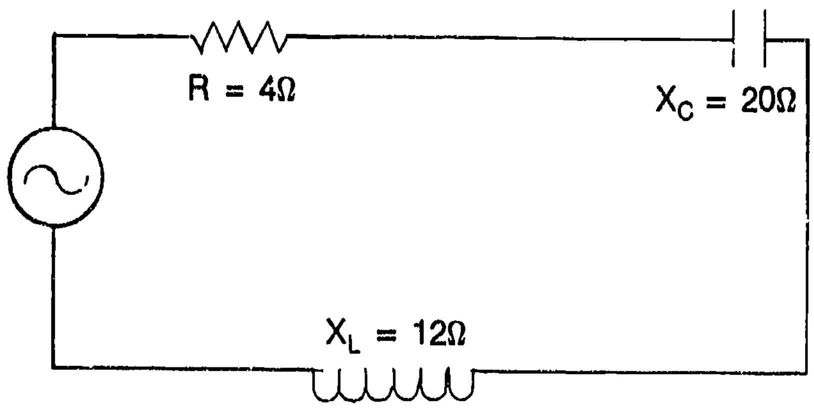
ASSIGNMENT SHEET #16 — SOLVE FOR IMPEDANCE

(NOTE: In each circuit, make a sketch of the impedance triangle.)

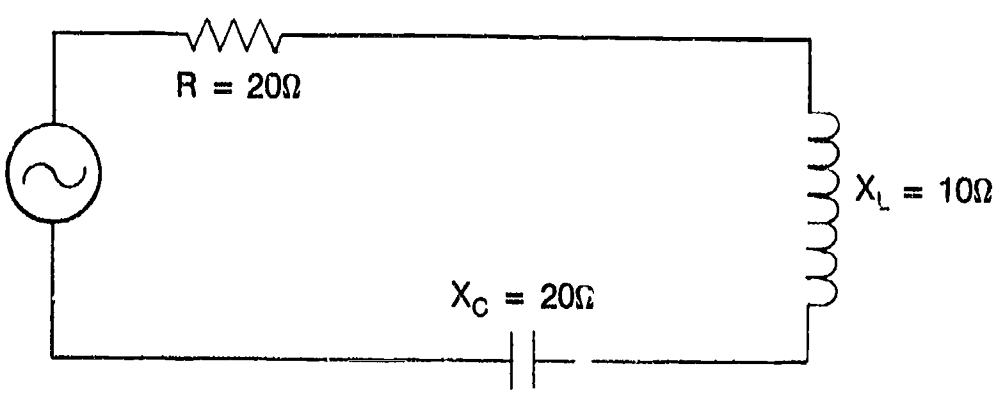
1. Compute impedance in the following circuit. Z = ____________



2. The impedance of the circuit below is ____________ ohms.



3. The impedance in the following circuit is ____________.



ASSIGNMENT SHEET #16

4. The effective reactance of the circuit in problem A is ____________.

5. The effective reactance of the circuit in problem B is ____________.

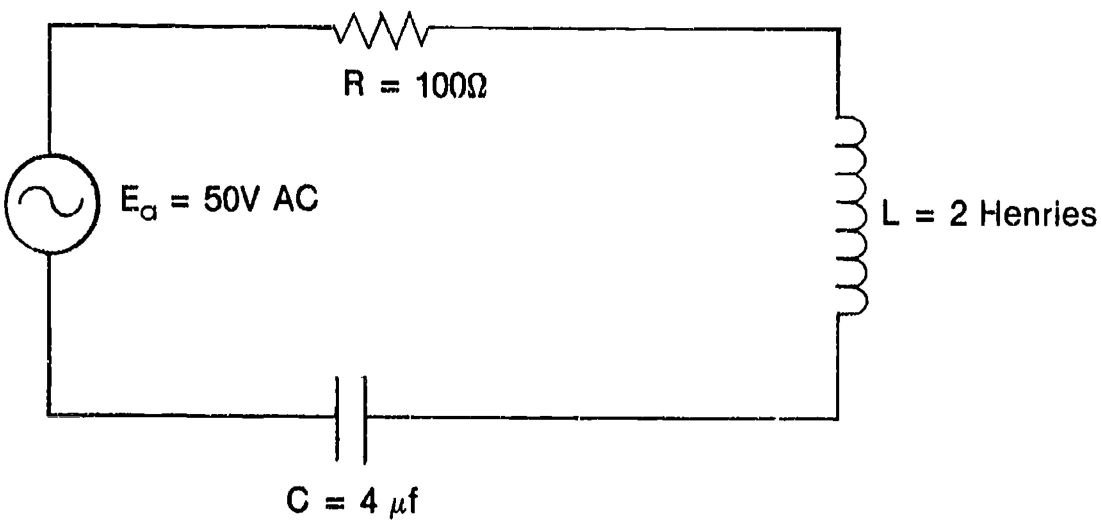
6. The effective reactance of the circuit in problem C is ____________.

FUNDAMENTALS OF AC
UNIT III

ASSIGNMENT SHEET #17 — SOLVE FOR PARAMETERS OF RESONANT CIRCUITS

Directions: Use the following circuit to solve all problems on this assignment sheet.

(NOTE: Be sure to include your units of measurement.)

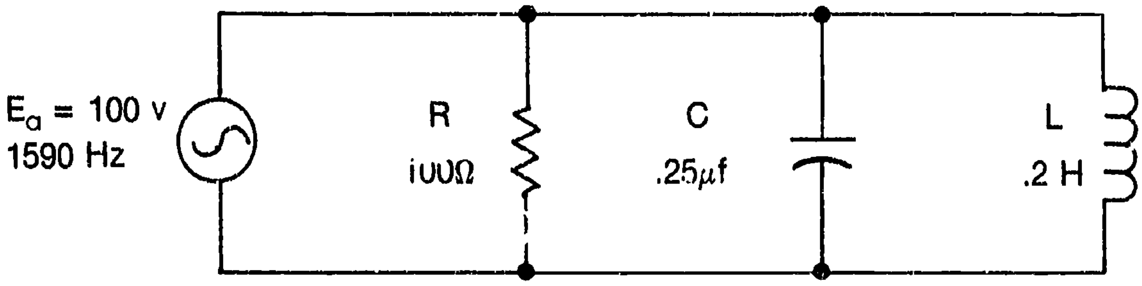


1. The resonant frequency, f_r, equals ____________________.
2. The total current at resonance equals ____________________.
3. The inductive reactance, X_L, equals ____________________.
4. The capacitive reactance, X_C, equals ____________________.
5. The inductive voltage drop, V_L, equals ____________________.
6. The capacitive voltage drop, V_C, equals ____________________.
7. The resistive voltage drop, V_R, equals ____________________.
8. The power dissipated in the circuit, P, equals ____________________.
9. The Q of the circuit is ____________________.
10. The bandwidth, BW, of the circuit is ____________________.

FUNDAMENTALS OF AC
UNIT III

ASSIGNMENT SHEET #18 — SOLVE PROBLEMS RELATED TO PARALLEL RCL CIRCUITS

1. In the circuit below, a 100 ohm resistor, a .2 henry inductor, and a .25 μf capacitor are connected in parallel across a source voltage of 100 volts at 1590 hertz; solve for the indicated parameters.



a. X_L = ____________

b. X_C = ____________

c. I_R = ____________

d. I_C = ____________

e. I_L = ____________

f. I_T = ____________

g. Z = ____________

h. P_T = ____________

i. P_A = ____________

j. Power Factor, PF, = ____________

k. Phase Angle, θ = ____________

2. Make a sketch of the phasor (vector) diagram of the above circuit.

FUNDAMENTALS OF AC
UNIT III

ASSIGNMENT SHEET #19 — ANALYZE A PARALLEL RESONANT CIRCUIT

1. In a parallel circuit, impedance is a function of the ____________ of the voltage applied.

2. At parallel resonance,

   _____a. impedance is minimum.

   _____b. impedance is maximum.

   _____c. current is minimum.

   _____d. current is maximum.

3. Frequencies higher than the resonant frequency of a parallel RCL circuit causes more current to be in the

   _____a. capacitive branch.

   _____b. inductive branch.

4. Frequencies lower than the resonant frequency of a parallel RCL circuit cause more current to be in the

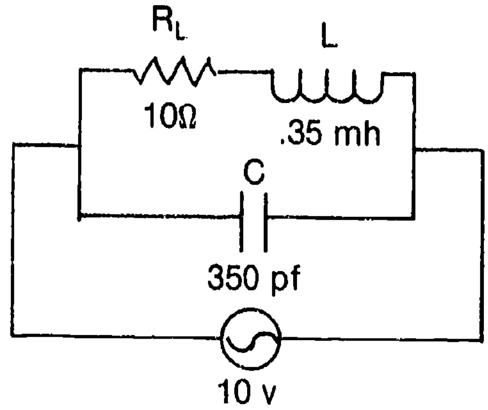
   _____a. capacitive branch.

   _____b. inductive branch.

5. The formula for computing resonant frequency is ______________________________.

ASSIGNMENT SHEET #19

6. An inductor and capacitor are connected as shown in the schematic below and ten volts are applied; solve for the indicated parameters



a. Resonant Frequency, F_R, = ______________________

b. The Q of the circuit = ______________________

c. I_C (also called tank current) = ______________________

d. I_T (use Q and I_C) = ______________________

e. Impedance, Z, = ______________________

f. Power consumed, P_T, = ______________________

g. Band width, BW, = ______________________

FUNDAMENTALS OF AC
UNIT III

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #1

1. 110 volts
2. 35.35 volts
3. 70.7 volts
4. 63.7 volts

Assignment Sheet #2

1. $^1/_{60}$ second
2. 400 Hz
3. Decrease

Assignment Sheet #3

1. a. T
   b. T
   c. T
2. a. 2
   b. 3
   c. 1
3. a. B
   b. B to A
   c. D to C
   d. The current reverses direction

Assignment Sheet #4

1. a. 1
   b. 2

ANSWERS TO ASSIGNMENT SHEETS

2. a. 2

   b. 1

   c. 1

   d. 1

3. d

4. CEMF

5. a. True

   b. True

6. Air, iron, ferrite, powdered, iron

Assignment Sheet #5

1. 15 mh
2. 3.33 mh
3. 5 h
4. 5 mh
5. 8 mh
6. 20 mh

Assignment Sheet #6

1. $X_L = 2\pi fL$
2. b
3. Increases
4. Increases
5. a. 7.54 Ω

   b. 125.7 Ω

   c. 50 Ω

   d. 31.4 Ω

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #7

1. a. True
   b. True
   c. True
   d. False
   e. False
   f. True
   g. True
   h. False
2. 14.1 ohms
3. 50 volts; $^{30}/_{50}$ or .6
4. a. 48 ohms
   b. 52 ohms
   c. 2.5 ohms
   d. 50 volts
   e. 120 volts

Assignment Sheet #8

1. $Q = X_L/R$
2. Lower
3. a. True
   b. True
   c. True
   d. False
4. 600
5. Increases
6. 377

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #9

1. b, c
2. a. 5

   b. 5
3. 63.2%
4. 86.5%
5. 95%, 98%
6. 36.8%
7. 13.5%, 5%
8. a. 20 amperes

   b. 1 second

   c. 5 seconds

   d. 3 seconds

Assignment Sheet #10

1. Q = CE
2. a. 100

   b. 100×10^{-6}

   c. 100×10^{-12}

   d. 5000×10^{-6}
3. a. 2.5 μf

   b. 40 μf

   c. 23.3 pf

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #11

1. T = RC
2. a. 1
   b. 2
   c. 2
   d. 1
   e. 2
   f. 1
3. a. 4A
   b. 54A
   c. 190V
   d. 10V
4. a. .08A
   b. 27V
   c. 27V
5. a. 1 second
   b. 20 seconds
   c. .3 μ sec
   d. 1.41 seconds

Assignment Sheet #12

1. $X_C = 1/2\pi fc$
2. C
3. Decrease
4. Decrease
5. a
6. a. 1.59 ohms
   b. 265 ohms
   c. 79,500 Hz

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #13

1. a
2. b
3. b
4. a
5. C
6. A power factor of 1 means that the circuit is a resistive circuit

Assignment Sheet #14

1. a, c, e, f
2. 56.6 ohms
3. 50 volts; 36.9° (arc cos 40/50)
4. a. 98.1 ohms
   b. 140 ohms
   c. 714 ohms
   d. 71.4V
   e. 70V
   f. 45.6 degrees
   g. .699

Assignment Sheet #15

1. $X_L - X_C$
2. +5, inductive
3. −5, capacitive
4. $2\pi FL$
5. $\frac{1}{2\pi fC}$
6. farad, ohms

ANSWERS TO ASSIGNMENT SHEETS

7. Henries, ohms
8. capacitive, inductive
9. directly
10. inversely

Assignment Sheet #16

1. 5 ohms
2. 8.94 ohms
3. 22.36 ohms
4. O ohms
5. 8 ohms (capacitive)
6. 10 ohms (capacitive)

Assignment Sheet #17

1. 57 Hz
2. 0.5 amps
3. 713 ohms
4. 713 ohms
5. 356.5 volts
6. 356.5 volts
7. 50 volts
8. 25 watts
9. 7.13
10. 7.96 or 8 Hz

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #18

1. a. 1,997 ohms
   b. 400 ohms
   c. 1 amp
   d. 0.25 amp
   e. 0.05 amp
   f. 1.02 amp
   g. 98 ohms
   h. 100 watts
   i. 102 VA
   j. 0.98
   k. 11.3 degrees leading

Assignment Sheet #19

1. Frequency
2. C
3. A
4. b
5. $f_r = \frac{1}{2\pi\sqrt{LC}}$
6. a. 455 KHz
   b. Q = 100
   c. 10 mu
   d. 0.1 mu
   e. 10 KΩ
   f. 0.001 watt
   g. 4.55 KHz

FUNDAMENTALS OF AC
UNIT III

JOB SHEET #1 — SHOW THE EFFECT OF INDUCTANCE IN AC CIRCUITS

A. Equipment and materials needed

1. Filter choke approximately 2H or larger
2. 75 ohm, 1 watt resistor
3. DC and AC milliammeters
4. Multimeter
5. AC and DC power supplies

B. Procedure

1. Connect the 75 ohm resistor and DC ammeter in series with the DC power supply.
2. Adjust the voltage until there are 5 volts across the resistor.
3. Record the ammeter indication; then compute R_{DC}.

   (NOTE: $R_{DC} = E/I$.)
4. Connect the 75 ohm resistor and AC ammeter in series with the AC power supply.
5. Adjust the voltage until there are 5 volts across the resistor; then record the current from the ammeter and compute R_{AC}.

   (NOTE: $R_{AC} = E/I$.)
6. Compare R_{DC} and R_{AC} and explain differences noted, if any.
7. Connect the filter choke (inductor) and DC ammeter in series with the DC power supply.
8. Adjust the DC power supply until there are 5 volts across the choke; read the current indication on the ammeter and compute $Z_{L(DC)}$.

   (NOTE: $Z_{L(DC)} = E_L/I_L$.)
9. Repeat Step 8 using the AC ammeter and AC power supply and compute $Z_{L(AC)}$.

   (NOTE: $Z_{L(AC)} = E_L/I_L$.)

JOB SHEET #1

10. Compare the current recorded in Step 8 with that recorded in Step 9 and explain any differences noted.

11. Use the filter choke value (Henries) and the voltage frequency to compute X_L.

12. Compare the computed X_L (Step 11) with the DC impedance (Step 8) and with the AC impedance (Step 9).

13. Explain any differences noted.

14. Return equipment and materials to their proper storage area.

FUNDAMENTALS OF AC
UNIT III

JOB SHEET #2 — SOLVE FOR VALUES OF AN OPERATING RL CIRCUIT

A. Equipment and materials needed

1. Filter choke approximately 2H or larger
2. Resistor, 750 ohms, 5 watts
3. AC power supply
4. AC ammeter
5. Multimeter
6. Switch

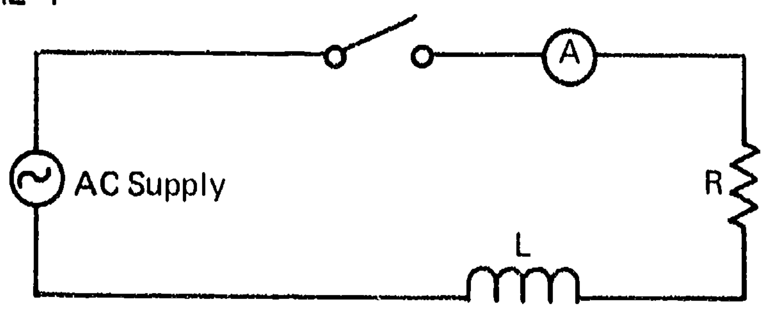
B. Procedure

1. Measure and record the resistance of the inductor (filter choke) with your ohmmeter

   (NOTE: This is the DC resistance (R_{DC}) of the coil.)

2. Measure and record the value of the 750-ohm resistor.
3. Connect the circuit as shown in the following schematic. (Figure 1)

   FIGURE 1



4. Connect an AC voltmeter across the AC supply, close the switch and adjust the AC input until the meter indicates 30 volts.
5. Read and record the voltage across $R(E_R)$.
6. Read and record the voltage across $L(E_L)$.

JOB SHEET #2

7. Read and record the applied voltage (across both R and L).

8. Read and record the current flowing in the circuit (I).

9. Compute the value of X_L.

10. Add the coil's DC resistance (Step 1) and the resistor value (Step 2); then multiply this value by the circuit current and compare the result with the applied voltage (E_a) observed in step 7.

11. Arithmetically add E_R (Step 5) and E_L (Step 6) and compare with E_a (Step 7).

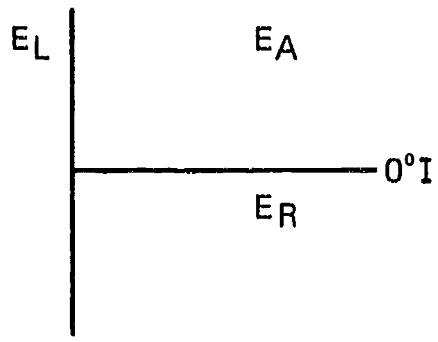
12. Repeat Step 11 but use the formula.

$$E_a = \sqrt{E_R^2 + E_L^2}$$

13. Multiply the current (Step 8) and the computed value of X_L (Step 9) and compare the result with E_L (Step 7).

14. Make a vector diagram to scale (Figure 2) showing the values of of E_R, E_L, and E_a, letting E_a be the hypotenuse of the right triangle formed by sides E_R and E_L; explain any differences noted.

FIGURE 2



15. Discuss and explain differences observed with your instructor.

16. Return equipment and materials to their proper storage area.

FUNDAMENTALS OF AC
UNIT III

JOB SHEET #3 — TEST CAPACITORS WITH AN OHMMETER

A. Equipment and materials needed

1. Ohmmeter
2. 3 capacitors (large, medium, small e.g. less than 0.1 μf)
3. 1 shorted capacitor
4. 1 open capacitor
5. 1 leaky capacitor

B. Procedure

(CAUTION: Always discharge capacitor before and after use.)

1. Place the ohmmeter leads across the large (good) capacitor.
2. Note the swing of the needle across the scale to zero and its return to infinity as the capacitor is charged by the ohmmeter battery.
3. Repeat Steps 1 and 2 with the medium and with the small (good) capacitors.
4. Note the smaller deflection of the needle during charge.
5. Place the ohmmeter leads across the open capacitor.
6. Note the lack of any deflection of the ohmmeter needle, indicating no current path.
7. Place the ohmmeter leads across the shorted capacitor.
8. Note that the needle indicates zero ohms resistance (no return toward infinity and thus no charging of the capacitor plates).
9. Place the ohmmeter leads across the leaky capacitor.
10. Note the return of the needle to some specific resistance indication rather than a return to infinity.
11. Place the ohmmeter leads across the medium sized (good) capacitor and permit the indication to return to infinity.
12. Reverse the ohmmeter leads and observe the difference in initial ohmmeter needle indication.

JOB SHEET #3

13. Repeat Steps 11 and 12 using the small (good) capacitor.
14. Discuss your findings with your instructor.
15. Return equipment and materials to proper storage area.

FUNDAMENTALS OF AC
UNIT III

JOB SHEET #4 — DETERMINE THE EFFECT OF AC AND DC ON CAPACITORS

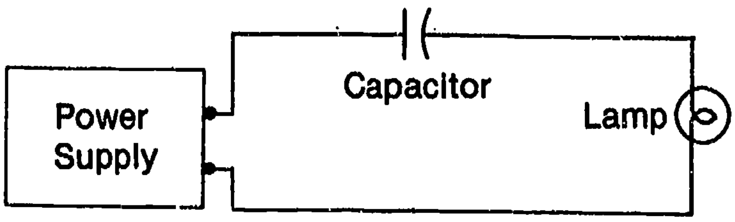
A. Equipment and materials needed

1. DC power supply, 0-40v
2. AC power supply, 0-40v
3. Electrolytic capacitor, approximately 10 μf, 100WVDC

   (NOTE: Two 5 μf capacitors may be used.)
4. Miniature lamp and holder

B. Procedure

1. Use the DC power supply, capacitor, and lamp, and connect the circuit as shown below.



2. Turn on the power supply and adjust to 20 volts DC.
3. Observe whether or not the lamp lights.
4. Return the voltage to zero.
5. Turn off the power supply.
6. Disconnect the circuit from the DC power supply.
7. Connect the circuit to the AC power supply.
8. Turn on the AC power supply and adjust to 20 volts AC.
9. Observe whether or not the lamp lights and compare with results obtained in Step 2.
10. Return the voltage to zero.
11. Disconnect the circuit.
12. Return equipment and materials to proper storage area.

FUNDAMENTALS OF AC
UNIT III

JOB SHEET #5 — DETERMINE TIME CONSTANTS OF RC CIRCUITS

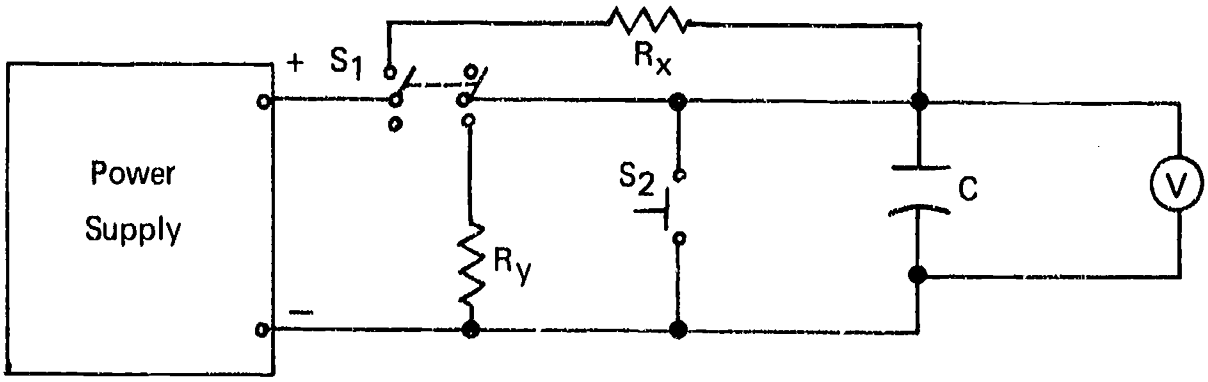
A. Equipment and materials needed

1. DC power supply, 0-20V
2. Voltmeter
3. R_1 — Resistor, 100 k-ohm, 1 watt
4. R_2 — Resistor, 470 k-ohm, 1 watt
5. R_3 — Resistor, 1 M-ohm, 1 watt
6. R_4 — Resistor, 2.2 M-ohm, 1 watt
7. C_1 and C_2 — Electrolytic capacitor, 10 μf, over 20VDC
8. S_1 Switch, double pole/double throw
9. S_2 Switch, normally open push button
10. Stopwatch (or watch with second hand)

B. Procedure

1. Connect the DC power supply, electronic voltmeter, switches, resistors R_1 and R_2, and Capacitor C_1 as shown below; let R_1 and R_2 be R_Y, R_X, and C_1 be C.

   (CAUTION: Do not turn on the power supply at this time.)



2. Calculate the time constant for the charging circuit above and enter in Table.

   (NOTE: Switch S_1 will be in the up position.)

JOB SHEET #5

3. Calculate the total time (5 time constants) for the capacitor to be fully charged and enter in Table.

TABLE

R-C VALUES			CHARGE		DISCHARGE	
			CALCULATED	MEASURED	CALCULATED	MEASURED
Rx	Ry	C	1-TC 5-TC	Total Time	1-TC5-TC	Total Time
1. R_1	R_2	C_1				
2. R_3	R_4	C_1				
3. R_4	R_2	C_1 C_2 Series				
4. R_3	R_1	C_1 C_2 Parallel				

4. Calculate the time constant for the discharge circuit (S_1 will be in the down position) and enter in Table.

5. Calculate the total time (5 time constants) for the capacitor to be fully discharged and enter in Table.

6. Turn the power supply on and with S_1 in the up position, adjust for 15 volts as indicated by the voltmeter when the capacitor is fully charged.

7. Flip S_1 to the down position to isolate the charging source.

8. Close S_2 to discharge the capacitor, then release it.

9. Start the stopwatch at the same time S_1 is placed in the up position to measure the time required for capacitor C_1 to charge to 15 volts, and record in Table.

10. Start the stopwatch at the same time S_1 is placed in the down position to measure the time required for capacitor C_1 to completely discharge, and enter in Table.

11. Rewire the circuit and repeat Steps 2 through 10 for R-C values 2, 3, and 4 as shown in Table.

12. Discuss with your instructor differences observed in calculated and measured value.

13. Return equipment and materials to proper storage area.

FUNDAMENTALS OF AC
UNIT III

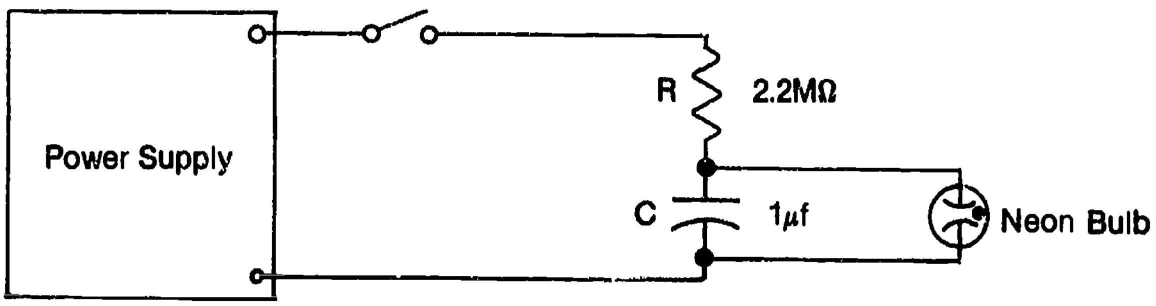
JOB SHEET #6 — CONSTRUCT A NEON BULB FLASHER

A. Equipment and materials needed

1. DC power supply, 0-100V
2. Two 2.2 M-ohm resistors
3. Two 1 μf capacitors (at least 100v)
4. Neon bulb

B. Procedure

1. Connect the circuit as shown below.



2. Adjust the power supply to 100 volts.
3. Close the switch and observe the neon bulb.
4. Open the circuit and add a 2.2 M-ohm resistor in series to make a total of 4.4 M-ohms resistance.
5. Close the switch and observe the neon bulb.
6. Open the switch and remove one of the 2.2 megohm resistors.
7. Add a 1 μf capacitor in parallel with C in the circuit making 2 μf of capacitance.
8. Close the switch and observe the neon bulb.
9. Draw a sketch of the neon bulb lighting and going out using time as the horizontal axis and voltage as the vertical axis.

   (NOTE: Assume 70 volts will cause the neon bulb to light and it will remain lit until the voltage drops to 40 volts.)

10. Discuss the effect of increasing R and of increasing C.
11. Return equipment and materials to proper storage area.

FUNDAMENTALS OF AC
UNIT III

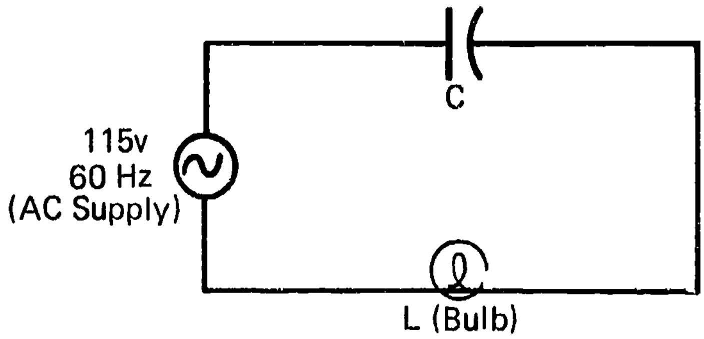
JOB SHEET #7 — SHOW THE EFFECT OF CAPACITIVE REACTANCE IN AC CIRCUITS

A. Equipment and materials needed

1. Two capacitors — 8 μf and 1 μf, 450 WVDC
2. One 15W, 120V light bulb and holder
3. Multimeter
4. AC power supply

B. Procedure

1. Connect the circuit as shown below using the 8 μf capacitor



2. Turn on the AC and observe the brightness of the bulb.
3. Measure and record E_a, E_C, and E_L (voltage across bulb or load).
4. Compute $(E_C)^2$ plus $(E_L)^2$, obtain square root, then compare with measured value of E_a.
5. Substitute the 1 μf capacitor for the 8 μf capacitor, then repeat Steps B, C, and D.
6. Discuss the relative amounts of capacitive reactance of the 8 μf and 1 μf capacitor; that is, which has the most opposition to the flow of current.
7. Discuss the differences observed between measured and calculated values of E_a.
8. Return equipment and materials to proper storage area.

FUNDAMENTALS OF AC
UNIT III

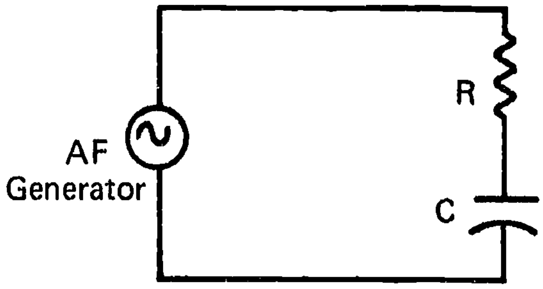
JOB SHEET #8 — DETERMINE CAPACITIVE REACTANCE AND IMPEDANCE IN RC CIRCUITS

A. Tools and materials needed

1. One A.F. generator
2. One capacitor — .3 μf
3. One resistor, 1000 ohm, 1-watt
4. Multimeter
5. Graph paper and protractor

B. Procedure

1. Connect the circuit shown in the following schematic.



2. Set the af generator to a frequency of 150 Hz and adjust the output to one volt, then measure E_R and E_C and record in the data table.
3. Set the af generator to the next frequency listed in the data table; adjust the output to one volt, then measure and record E_R and E_C.
4. Repeat Step 3 for each listed frequency.

Data Table

			I	Z	X_C	X_C	Z	θ	θ	PF
Frequency	E_R	E_C	E_R/R	$E_A I$	$1/2\pi fC$	$E_C/1$	Graph	Graph	Arc cos E_R/E_A	Cos θ
150 Hz										
250 Hz										
450 Hz										
900 Hz										
1100 Hz										

JOB SHEET #8

5. Compute I (E_R/10,000) for each frequency and enter into table.

6. Compute Z (E_a/I) for each frequency and enter.

7. Compute X_C by using the formula 1/C for each frequency.

8. Compute X_C (E_C/I), enter into table, and compare results with Step 7.

9. Using X_C of Step 8, and 1000Ω for R, draw a graph showing the vector relationships, then measure the value of Z on the graph.

10. Compare the results of Step 9 with Step 6.

11. Measure the phase angle, Θ, on the graph and enter.

12. Compute the phase angle, Θ, by obtaining the angle whose cosine is E_R/E_a.

13. Compute and enter the power factor.

14. Calculate the frequency necessary to have X_C equal to 1000 ohms.

15. Set the af generator to this frequency and enter all information called for into the data table.

16. Analyze and discuss your results with your instructor.

17. Return equipment and materials to proper storage area.

FUNDAMENTALS OF AC
UNIT III

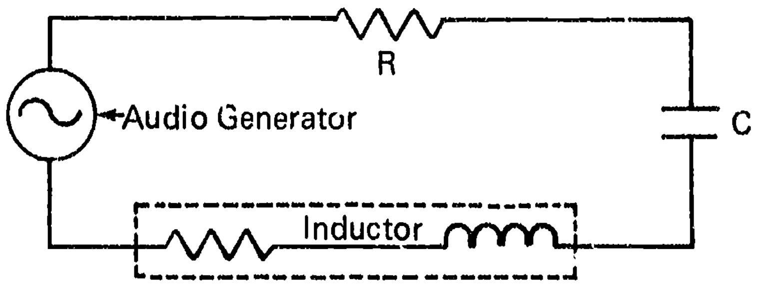
JOB SHEET #9 — DETERMINE RESONANCE IN A SERIES RCL CIRCUIT

A. Equipment and materials needed

1. Audio generator
2. Oscilloscope
3. Multimeter
4. 1 μf capacitor
5. 1H inductor
6. 100-ohm resistor
7. Linear graph paper

B. Procedure

1. Use your ohmmeter and measure the resistance of the 100-ohm resistor and the resistance of the inductor; record these measurements in the data table provided in this job sheet.
2. Connect the resistor, inductor, and capacitor in series to the audio generator as follows:



3. Use the values of your capacitor and inductor to compute the expected resonant frequency of this circuit.
4. Connect the multimeter across the generator output terminals and set the generator for maximum voltage at 100 Hz; vary the generator frequency around the value computed in Step 3 until the voltage output is at a minimum and make a mental note of the voltage output.

JOB SHEET #9

5. Choose a generator voltage slightly less than the minimum noted above and set the generator to this value; this will be the applied voltage, E_a, for the following steps and must be maintained at all times.

6. Remove the multimeter and connect the oscilloscope across the generator output termnals; observe carefully the indication on the oscilloscope because you must maintain a constant E_a (as indicated on the oscilloscope) for the remaining steps.

7. Connect the multimeter across the 100-ohm resistor; read and record in the data table the voltage across the resistor, V_R, for generator frequencies of 80, 100, 120, 140, 160, 180, 200, 220, 240, and 260 Hz and be sure that your applied voltage E_A is the same for all of these frequencies.

8. Adjust the generator to the frequency that gives the maximum V_R reading and be sure that E_a is at its correct value; record this resonant frequency of the circuit, F_O, in the data table along with its corresponding V_R.

9. With the generator at F_O and E_a at its proper value, connect the oscilloscope across the resistor and observe the wave form.

10. Move both leads in sequence and connect them across the capacitor and observe the wave form.

    (NOTE: Equipment grounds can cause improper indications.)

11. Repeat for the inductor; be sure to watch for shifts in both amplitude and in horizontal movement.

12. Set the generator to 100Hz, and E_a to its correct value; using your oscilloscope, observe the voltage wave forms across the resistor, capacitor, and inductor.

13. Turn the generator off.

14. Use Ohm's law and compute the circuit current I_T, for each frequency; record each computed value in the data table $I_T = V_R/R$.

15. Use Ohm's law and compute the circuit impedance, Z, for each frequency; record each computed value in the data table $Z = E_a/I_T$.

16. Prepare a graph by letting the horizontal scale be the various frequency settings listed in your data table. Plot the corresponding values of I_T on the vertical axis. Draw a smooth curve between these points (include F_r).

17. Plot the values of Z on the same graph and draw a smooth curve between these points.

18. Return equipment and materials to proper storage area.

JOB SHEET #9

C. Discuss the following:

1. Does the computed resonant frequency, f_r of Step 3 equal the observed resonant frequency, F_O, of Step 8? Explain any difference.

2. Why is the generator output voltage in Step 4 at a minimum at the resonant frequency? (HINT: Is there any resistance inside the generator?)

3. On your graph compare the maximum value of I_T and the minimum value of Z. Do these occur at the same frequency?

4. Compare the minimum value of Z with the circuit's total resistance found in Step 1; explain the difference.

5. Why was there such a large difference between the capacitor voltage and the resistor voltage observed in Step 9? Were the capacitor voltage and the inductor voltage observed in Step 9 equal but opposite in phase?

6. Explain why the inductor voltage was smaller than the capacitor voltage in Step 12; how do these voltages differ from those observed in Steps 9, 10, and 11?

7. If this circuit was connected between a generator and a load, what frequency would be passed most easily? What impedance would be presented? How much greater would be the impedance if the frequency were 80 Hz lower? How much impedance for a frequency 80 Hz higher? (Use your graph for these answers.)

8. Does your graph confirm that impedance and current vary inversely with each other?

Data Table

E_a = ______ volts Measured Resistance: R = ______ R_L = ______

Frequency:	80 Hz	100	120	140	160	180	200	220	240	F_r = ______
V_R										
I_T										
Z										

FUNDAMENTALS OF AC
UNIT III

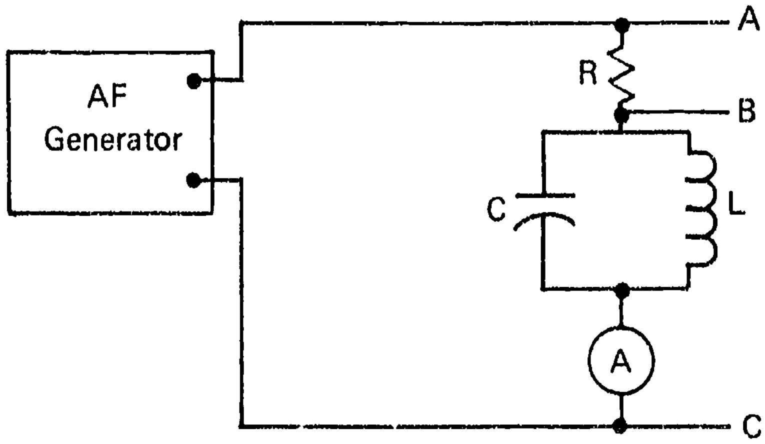
JOB SHEET #10 — DETERMINE THE RESONANT FREQUENCY OF AN RCL PARALLEL CIRCUIT

A. Equipmentand materials needed

1. Audio frequency generator
2. Multimeter (electronic type)
3. Ammeter, 0-150μA
4. One capacitor, .001 microfarad
5. One resistor, 10 Kohms, 1 watt
6. One inductor, 10 millihenry
7. Graph paper

B. Procedure

1. Connect the circuit as shown in the following schematic.



2. Calculate the resonant frequency, F_R = ____________ Hz.
3. Adjust the audio frequency generator to the frequency calculated in Step 2.
4. Adjust the generator for maximum output.
5. Connect your voltmeter which is set to the 5V AC range across the tank circuit (points B and C) making sure that the common leads of the generator and the voltmeter are both connected to point C.

JOB SHEET #10

6. Adjust the generator above and below the calculated frequency (Step 2) until there is a maximum voltage reading and a minimum reading on the ammeter.

7. Record the frequency determined in Step 2 in the data table; this is the true F_R.

8. Adjust the generator for an output of one volt (points B to C).

9. Measure the voltage, V_C obtained in Step 6 in the data table.

10. Enter V_C obtained in Step 7 in the data table.

11. Measure and enter the total current, I_T, as indicated by the ammeter.

12. Calculate the inductive reactance, X_L, at the resonant frequency, and enter in the data table.

13. Compute and enter the capacitive reactance, X_C.

14. Calculate I_L and I_C and enter into the data table.

15. Calculate the parallel tank circuit impedance, Z, and enter into the data table.

16. Repeat Steps 8 through 15 at 10 kilohertz steps above and below the resonant frequency; be sure to adjust the generator for one volt output with each change of frequency.

17. Plot the tank circuit impedance (vertical axis) versus frequency points (horizontal axis) as calculated and enter in the data table.

18. Connect the points to obtain a response curve.

19. Discuss the following:

    a. Explain the difference between the true resonant frequency and the calculated resonant frequency.

    b. Why is the current a minimum at the resonant frequency?

    c. Does the tank circuit pass or block currents near the resonant frequency?

    d. Is this a low Q or a high Q circuit? Explain ______________________________

    e. Is the total impedance larger than the series resistor or approximately equal to it? Why?

JOB SHEET #10

f. What is the band width shown on your graph? does this correspond with the band width formula?

DATA TABLE

FREQUENCY	V_C (tank)	I_T	X_L	X_C	I_L	I_C	Z (tank)
(F_R – 30KHz)							
(F_R – 20KHz)							
(F_R – 10KHz)							
F_R = ______							
(F_R + 10KHz)							
(F_R + 20KHz)							
(F_R + 30KHz)							

20. Return equipment and materials to storage area.

FUNDAMENTALS OF AC
UNIT III

NAME ____________________

TEST

1. Match the terms on the right with their correct definitions.

   (NOTE: Answers to questions a.-k. appear on this page.)

_____a.	Property possessed by certain materials which exerts a mechanical force on other magnetic materials, and which can cause induced voltages in conductors when relative movement is present	1.	Alternation
_____b.	Device or material that has the property of magnetism	2.	Electromagnet
_____c.	Ability of a material to retain magnetism	3.	Amplitude
_____d.	A soft iron core surrounded by a coil of wire that temporarily becomes a magnet when an electric current flows through the coil of wire	4.	Retentivity
_____e.	The process of magnetizing an object by bringing it into the magnetic field of an electromagnet or permanent magnet	5.	Magnet
_____f.	A measure of the effectiveness of a material as a path for magnetic lines of force as compared to the effectiveness of air	6.	Cycle
_____g.	The series of events occurring in sequence as the complete reversal of an alternating current from positive to negative and back to the starting point (two alternations)	7.	Waveform
_____h.	Moving from zero to a maximum (or minimum) and back to zero	8.	Phase
_____i.	The extreme range of varying quantity such as the maximum height of a waveform	9.	Induction
_____j.	The shape of a wave as a function of time, distance, and amplitude	10.	Magnetism
_____k.	Time relationship of one waveform to another	11.	Permeability

TEST

(NOTE: Answers to questions l.-r. appear on this page.)

_____l.	Frequency discriminating network	12. Attenuate
_____m.	To decrease in amplitude or intensity	13. Reluctance
_____n.	Straight line drawn to scale, showing direction and magnitude of a force	14. Filter
_____o.	Magnetic resistance	15. Vector
_____p.	The reciprocal of reluctance	16. Permeance
_____q.	A series of electronic circuits or devices connected so that the output of one is the input of the next	17. Bandwidth
_____r.	The band of frequencies over which the response in a circuit falls within a specified fraction of the maximum value	18. Cascaded

2. List five ways magnets are classified.

   a. ______________________________

   b. ______________________________

   c. ______________________________

   d. ______________________________

   e. ______________________________

3. Complete the following statements related to the characteristics of magnetic materials by inserting the word(s) that best completes each statement.

   a. The three natural elements of ____________, ____________, and ____________ respond to magnetic fields.

   b. Substances which readily respond to magnetism or magnetic fields are called ____________ materials.

   c. Substances which are attracted only slightly by a strong magnetic field are called ____________ materials.

   d. ____________ materials are substances which are slightly repelled by magnetic fields.

   e. The relative permeability of ____________ materials is less than unity; the ____________ is slightly greater than unity; and ____________ is much larger than unity.

TEST

4. Complete the following statements related to characteristics of magnetic flux lines by inserting the word(s) that best completes each statement.

   a. ____________ are surrounded by a force field made up of flux lines.

   b. Flux lines have both ____________ and ____________.

   c. Magnetic lines of force are assumed to exit from the ____________ pole of the magnet and return through the surrounding space to enter the ____________ pole.

   d. Flux lines will tend to restrict themselves to the ____________ possible loops.

5. Match the terms related to magnetic quantities on the right with their correct descriptions.

_____a.	The complete magnetic field surrounding a magnet and represented by the Greek letter Phi (Φ)	1. Reluctance
_____b.	Refers to the number of lines of flux per square inch and is represented by the letter B	2. Flux
_____c.	The force which produces flux in an electromagnet or coil and is measured in ampere-turns	3. Permeability
_____d.	Refers to both mmf and the length of the coil, expressed as ampere-turns per inch and is represented by the letter H	4. Flux density
_____e.	The ease with which a material can accept lines of force and is represented by the Greek letter mu (μ)	5. Field intensity
_____f.	The opposition a material offers to flux (reciprocal of permeability) represented by the letter R	6. Magnetomotive force

6. Complete the following statements concerning the relationships of magnetism to electricity by inserting the word(s) that best completes each statement.

   a. When current flows through a wire, a magnetic ____________ is produced around the wire.

   b. The direction of the field is determined by the direction of ____________________.

   c. The ____________ rule for conductors may be used to determine the direction of the lines of flux.

   d. The field surrounding a conductor may be strengthened by forming the conductor into a ____________.

TEST

7. Complete the following statements related to the fundamentals of electromagnetism by inserting the word(s) that best completes each statement.

   a. The strength of the magnetic field around a coil is directly proportional to both the number of ____________ in the coil and the amount of ____________ through the coil.

   b. The strength of the electromagnetic field may be dramatically ____________ by placing a core of ferromagnetic material inside the coil.

   c. The polarity of the electromagnetic field may be determined by the ____________ rule for coils.

8. Complete the following statements related to the principles of induction by inserting the word(s) that best completes each statement.

   a. ____________ induction occurs when a magnet is placed in close proximity to a ferromagnetic material causing the material to also become magnetized.

   b. ____________ induction is the action which causes electrons to flow in a conductor when the conductor cuts the lines of force in a magnetic field.

   c. The amount of current induced into the conductor is determined by four factors (Faraday's law):

      1) ____________ of the magnetic field

      2) ____________ of the conductor with respect to the field

      3) ____________ at which the conductor cuts the field

      4) ____________ of the conductor in the field

   d. Lenz' law states that the direction of the induced current must be such that its own magnetic field will ____________ the action that produced the induced current.

9. Complete the following statements related to generating voltage by electromagnetic induction by inserting the word(s) that best completes each statement.

   a. There are three basic requirements for generating voltage electromagnetically:

      1) A ____________ field

      2) A ____________ in the magnetic field

      3) Relative ____________ between the conductor and the magnetic field

TEST

b. Direction of the voltage generated by electromagnetic induction is determined by the direction of ____________ and the direction of magnetic flux.

c. The ____________ of the induced voltage is proportional to the number of flux lines cut per second by the conductor.

d. The number of flux lines cut per second by the conductor is determined by four factors:

1) The ____________ of the conductor

2) The ____________ of the magnetic field

3) The ____________ of the conductor

4) The ____________ the conductor cuts the field

10. Complete statements related to values of the AC waveform by inserting the word(s) that best completes each statement.

a. The ____________ ____________ has an infinite number of instantaneous values in each alternation.

b. The sine wave has two alternations; one ____________ and one ____________.

c. ____________ value of a sine wave is the point at which the waveform is at its maximum amplitude in the positive (90 degrees) or negative (270 degrees) alternation (1.414 × rms).

d. ____________ value of a sine wave's amplitude is the value from positive peak to negative peak.

e. The ____________ voltage f one alternation is 0.636 times the peak value.

f. The ____________ or effective value of the sine wave is 0.707 times peak value.

g. The time required for one cycle of AC to occur is called a ____________.

h. The number of cycles that occur in one second of time is called the ____________ of the waveform and is expressed in Hertz.

11. Describe in-phase and out-of-phase relationships.

a. An in-phase relationship exists when ____

____

____

TEST

b. An out-of-phase relationship exists when ______________________ ______

____

____

12. Select true statements related to the characteristics of AC resistive circuits by placing an "X" in the blanks preceding the true statements.

_____a. Ohm's law may be used to calculate voltage, current, and resistance in resistive AC circuits just as in DC circuits.

_____b. The rules for calculating resistances in series and parallel AC circuits are the same as those used for DC circuits.

_____c. The effective value of AC voltage and current is used when performing calculations in AC circuits that contain only resistance.

_____d. Power is consumed in a resistive AC circuit in the form of heat dissipated by the resistor.

_____e. The rules used for power in DC circuits may be applied to AC circuits.

_____f. Effective values of voltage and current are used to determine maximum power.

13. Select true statements related to characteristics of self-induction by placing an "X" in the blanks preceding the true statements.

_____a. The induced current caused by self-induction is counter to the original current.

_____b. Self-induction occurs both when current is increasing in a circuit and when current is decreasing in a circuit.

_____c. The effect of self-induction or counter EMF is to oppose changes in current flow.

14. Complete the following statements related to the characteristics of inductance by inserting the word(s) or letter that best completes each statement.

a. ____________ is the physical property of a circuit or device which indicates an ability to oppose a change in current.

b. Inductance may be defined as the ability to induce an EMF into a conductor when there is a change in ____________ ____________.

c. The symbol for inductance is the letter ____________.

d. The unit for measurement for inductance is the ____________.

e. A Henry is the amount of inductance that induces an EMF of one volt into a conductor when the ____________ changes at the rate of one ampere per second.

f. The henry is expressed symbolically with the letter ____________.

TEST

15. Select true statements concerning factors affecting inductors by placing an "X" in the blanks preceding the true statements.

    _____a. An inductor is a physical device consisting of a coil of wire usually wound on a core.

    _____b. The inductance of a coil varies as the square of the number of turns.

    _____c. Inductance of a coil may be decreased dramatically by winding the coil on a core of material that has a high permeability.

    _____d. Inductance varies inversely with the winding of the coil.

16. Give the equation for determining time constants of inductive circuits.

    T = ____________.

17. Complete the following statements concerning current and voltage relationships in an inductive AC circuit by circling the correct words or numbers.

    a. When an AC voltage is applied to an inductor, the AC current which flows produces a varying magnetic field that induces a **(voltage, current)** into the inductor.

    b. The induced voltage is **(180, 90)** degrees out of phase with the applied voltage.

    c. If the circuit current is a sine wave, the induced voltage will be a **(sine, square)** wave.

    d. The rate of change of current determines the **(amplitude, shape)** of the induced voltage.

    e. Counter EMF is **(180, 90)** degrees out of phase with the circuit current.

    f. The current flowing in an inductive circuit is **(directly, inversely)** proportional to the voltage applied and **(directly, inversely)** proportional to the inductive reactance and may be represented by the formula $I = E/X$.

18. Select true statements related to characteristics of inductive reactance by placing an "X" in the blanks preceding the true statements.

    _____a. Inductive reactance is the opposition to AC.

    _____b. Inductive reactance is indirectly proportional to the inductance and frequency of the applied voltage.

    _____c. As frequency increases, the rate of change in current increases and inductive reactance becomes greater.

    _____d. As frequency decreases, the rate of change in current decreases and causes inductive reactance to decrease.

    _____e. Inductive reactance is represented by the symbol X_L.

    _____f. The unit for inductive reactance is the henry.

    _____g. Inductive reactance may be calculated by using the formula $X_L = 2 L$.

TEST

19. Complete the following statements related to the process of mutual inductance by inserting the word(s) that best completes each statement.

    a. Mutual inductance is the process by which one conductor causes a voltage to be ____________ into another.

    b. Mutual inductance is represented by the symbol ____________.

    c. The unit of mutual inductance is the ____________.

    d. The amount of mutual inductance between adjacent coils depends upon the degree of ____________ between them.

    e. The degree of coupling between coils is called the ____________ of ____________.

    f. A coefficient of coupling of ____________ represents a coupling of 100 percent.

    g. Mutual inductance between two coils is the function of the coefficient of coupling (k) and the values of ____________ of the two coils (L1 and L2)

    h. Mutual inductance of one ____________ is the condition when a current change of one ampere per second in an inductor induces a voltage of one volt into another.

20. Complete the following statements related to connecting inductors in series and parallel by inserting the word(s) that best completes each statement.

    a. The rules for connecting inductors in series and parallel are similar to those used with ____________.

    b. For two or more inductors connected in series the total inductance is the ____________ of the inductance when no mutual inductance exists.

    c. When mutual inductance is present, and the magnetic fields are aiding, the total inductance of two or more inductors in series may be expressed by the formula L_T = ____________.

    d. When two inductors are connected in series with their magnetic fields opposing the total inductance of the combination may be found with the formula Lt = ____________.

21. Select true statements related to the quality of inductors by placing an "X" in the blanks preceding the true statements.

    ______a. A manufactured inductor is not pure inductance because the wire of which the coil is made has no resistance.

    ______b. Power is dissipated in inductors within the resistance in the wire of the coil.

    ______c. Inductors are compared in quality by a figure of merit called Q.

    ______d. The Q of a coil is the ratio of energy stored in the coil in the form of a magnetic field to the energy dissipated in the resistance of the coil.

TEST

______e. The Q of a coil may also be expressed as a ratio of inductive reactance to the resistance

$$Q = \frac{X_L}{R}$$

______f. Since Q is indirectly proportional to the inductive reactance, the Q increases with frequency.

22. Select true statements related to power characteristics in an inductive circuit by placing an "X" in the blanks preceding the true statements.

______a. No power is dissipated in a pure inductance.

______b. Power dissipation in an RL circuit occurs in the resistance within the circuit.

______c. Since power is dissipated only in the resistance, it may be calculated using the standard power formulas.

23. Complete the following statements related to the characteristics of voltage and current in RL circuits by inserting the word(s) that best completes each statement.

a. The voltage drop across the ______ ______ may be found using Ohm's law $E_R = IR$.

b. The voltage drop across the __________ may also be found using Ohm's law $E = IX_L$.

c. The circuit current in an RL circuit __________ the applied voltage by 90 degrees.

d. The __________ voltage is the vector sum of the resistor and inductor voltages $E_a = \sqrt{(E) + (E)}$.

24. Complete the following statements related to characteristics of impedance in RL circuits by inserting the word(s) that best completes each statement.

a. The total opposition to current flow offered by both the resistor and inductor in an RL circuit is called __________.

b. Impedance is expressed in __________.

c. The applied __________ and the circuit __________ may be used to determine the impedance according to Ohm's law.

d. The impedance of a series RL circuit also may be determined by vector summation of __________ and the __________ reactance.

25. Give the trigonometric based formulas for finding the angle of phase shift in RL circuits.

$\tan \Theta =$ __________ $\Theta = \arctan$ __________ $\Theta = \arctan$ __________

TEST

26. Complete the following statements related to the characteristics of capacitance by inserting the word(s) that best completes each statement.

    a. The property of a circuit or device which enables it to store electrical energy with an electrostatic field is called ____________.

    b. A device that is made to have a specific value of capacitance is called a ____________.

    c. A capacitor is a device constructed of two metal plates separated by a ____________.

    d. Capacitance of a capacitor is determined by three factors:

        1) The ____________ of the metal plates.

        2) The ____________ between the plates.

        3) The type or nature of the ____________.

    e. The unit of capacitance is the ____________.

    f. One ____________ is the amount of capacitance which will store a charge of one coulomb when one volt of EMF is applied.

27. Select true statements concerning types, ratings, and common defects of capacitors by placing an "X" in the blanks preceding the true statements.

    _____a. There are two basic types of capacitors: fixed value capacitors and variable capacitors.

    _____b. Capacitors are classified by the type of dielectric used such as mica, ceramic, paper, and Mylar.

    _____c. Capacitors may be an electrolytic type.

    _____d. Capacitors are rated according to value of capacitance.

    _____e. Defects in capacitors are related to four common failures.

28. Give the equations for combining capacitors in series and parallel.

    a. Series ____________

    b. Parallel ____________

29. Give the equation for determining time constants in an RC circuit.

    T = ____________

TEST

30. Complete the following statements related to voltage and current relationships in a capacitive AC circuit by inserting the word(s) that best completes each statement.

    a. When a sine wave is applied to a pure capacitive circuit, a sine wave voltage will be developed across the capacitor that is equal to and in phase with the ____________ ____________.

    b. The sine wave current developed in the circuit ____________ the applied voltage (Ea) and capacitor voltage (Ec) by ninety degrees

    c. When Ea and Ec are at the maximum value of their positive and negative alternations, current in the circuit is ____________.

    d. When Ea and Ec are at zero, current in the circuit is ____________.

31. Give the equation for determining capacitive reactance.

    X_C = ____________

32. Complete the following statements related to the characteristics of series RC circuits by inserting the word(s) that best completes each statement.

    a. Series RC circuits contain ____________ and ____________ connected in series.

    b. The voltage drop across the resistor in the series RC circuit is in phase with the ____________ in the circuit.

    c. The voltage across the capacitor ____________ the current flowing in the circuit by ninety degrees.

33. Complete the equations related to the characteristics of impedance in RC circuits by placing the correct symbols in the blanks.

    a. Impedance Z = ____________

    b. Z =

    c. R =

    d. X_C =

34. Give the equation for finding the phase angle in an RC circuit.

    Phase angle = ____________

TEST

35. Select true statements related to characteristics of power in an AC resistive-capacitive circuit by placing an "X" in the blanks preceding the true statements.

_____a. True power is dissipated only in the resistance in an RC circuit.

_____b. Apparent power is the term used to describe the power which "appears" to be consumed in an RC circuit when the power formula P = IE is applied to the circuit.

_____c. The ratio of true power to apparent power in an AC circuit is referred to as power factor expressed as a formula

$$\text{Power factor (PF)} = \frac{\text{true power}}{\text{apparent power}}$$

_____d. The ratio of the resistance to the impedance is also equal to the cosine of the phase angle of the circuit expressed in the formula

$$\text{cosine } \Theta = \frac{R}{Z} = \text{power factor (PF)}$$

36. Complete equations related to the characteristics of parallel RC circuits by placing the correct symbols in the blanks provided.

    a. The current in the resistive branch I = _____________.

    b. The current in the capacitive branch I = _____________.

    c. Total current It = _____________.

    d. Total impedance Z = _____________.

37. Name four applications of capacitive circuits.

    a. ____

    b. ____

    c. ____

    d. ____

38. Complete the following statements related to the characteristics of series RCL circuits by inserting the word(s) that best completes each statement.

    a. Net reactance X_T equals the _____________ between X_L and X_C.

    b. When the inductive reactance is greater than the capacitive reactance, the circuit appears _____________.

    c. When the capacitive reactance is greater than the inductive reactance, the circuit appears _____________.

TEST

d. When inductive and capacitive reactance are equal, the circuit appears ____________.

e. Voltage across the resistance is in phase with the ____________.

f. Voltage across the inductor ____________ the current by ninety degrees.

g. Voltage across the capacitor ____________ the current by ninety degrees.

h. The vector sum of the ____________ voltage and the ____________ voltage equals the applied voltage.

39. Complete the following statements related to resonant characteri... f series RCL circuits by inserting the word(s) that best completes each statement.

a. ____________ in a series RCL circuit occurs when the inductive effect equals the capacitive effect.

b. Impedance of the circuit is at ____________ value at resonance.

c. Circuit current is at its ____________ level at resonance.

d. The phase angle between voltage and current is ____________ at resonance.

e. Increasing inductance or capacitance ____________ the resonant frequency.

f. ____________ inductance or capacitance increases the resonant frequency.

g. Circuit Q is a figure of quality for a series resonant circuit and is the ratio of the ____________ at resonance to the series AC resistance.

h. ____________ of a series resonant circuit is measured between the half-power points of the circuit and may be calculated by dividing the resonant frequency by the circuit Q.

40. Complete the following statements related to characteristics of parallel RCL circuits by inserting the word(s) that best completes each statement.

a. Current through the ____________ branch is in phase with the voltage and may be found using the formula $I = E/R$.

b. Current through the inductive branch of the parallel RCL circuit ____________ the voltage by 90° and may be found using the formula $I = E_a/X$.

c. Current through the capacitive branch of the parallel RCL circuit ____________ the voltage by 90° and may be found using the formula $I = E_a/X$.

d. The ____________ current is the difference between the current in the inductive branch and the capacitive branch.

e. ____________ current in a parallel RCL circuit is the vector sum of the resistive current and the reactive current.

f. ____________ in a parallel RCL circuit may be found by dividing the applied voltage by the total current.

TEST

41. Complete the following statements related to resonant characteristics of a parallel RCL circuit by inserting the word(s) that best completes each statement.

    a. Impedance of the parallel RCL circuit is ___________ at resonance and may be calculated using the formula $Z = E_a/I$.

    b. Current is at ___________ value at resonance and equals the resistive current.

    c. The phase between the applied voltage and the total current is ___________.

    d. The Q of a parallel resonant circuit may be calculated by dividing the inductive reactance by the total AC ___________.

    e. As in a series resonant circuit the ___________ of a parallel resonant circuit may be calculated by dividing the resonant frequency by the Q.

42. Select true statements concerning applications of resonant circuits by placing an "X" in the blanks preceding the true statements.

    _____a. Resonant circuits may be used as filters to accept or reject a specified band of frequencies.

    _____b. A band stop filter is designed to stop a band of frequencies while allowing all other frequencies to pass to the output.

    _____c. A band pass filter may be designed to pass a certain band of frequencies and stop all other frequencies.

    _____d. A high pass filter is designed to pass all frequencies below the cutoff frequency (f) and attenuate all frequencies above the cutoff frequency.

    _____e. A low pass filter may be designed to pass all frequencies above the cutoff frequency and attenuate all frequencies below the cutoff frequency.

43. Complete the following statements related to fundamentals of rectangular and polar notation by circling the correct words.

    a. $Z = 10 + j75$ indicates (**inductive, capacitive**) reactance of 75 ohms.

    b. $Z = 10 + j75$ is (**polar, rectangular**) notation.

    c. $Z = 10 + j75$ indicates (**impedance, resistance**) of 10 ohms.

    d. $Z = 269\underline{/-21.8°}$ is (**polar, rectangular**) notation.

(NOTE: If the following activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

44. Determine sine wave conversions. (Assignment Sheet #1)

45. Compute period. (Assignment Sheet #2)

46. Determine current flow direction. (Assignment Sheet #3)

TEST

47. Answer questions regarding induction and inductors. (Assignment Sheet #4)
48. Solve for total inductance. (Assignment Sheet #5)
49. Compute inductive reactance. (Assignment Sheet #6)
50. Compute applied voltage and impedance of RL circuits. (Assignment Sheet #7)
51. Compute the Q of inductors. (Assignment Sheet #8)
52. Solve time constant problems. (Assignment Sheet #9)
53. Compute capacitance values. (Assignment Sheet #10)
54. Compute RC time constants. (Assignment Sheet #11)
55. Compute capacitive reactance. (Assignment Sheet #12)
56. Determine phase relationships in RC circuits. (Assignment Sheet #13)
57. Compute values of RC circuits. (Assignment Sheet #14)
58. Solve for reactance. (Assignment Sheet #15)
59. Solve for impedance. (Assignment Sheet #16)
60. Solve for parameters of resonant circuits. (Assignment Sheet #17)
61. Solve problems related to parallel circuits. (Assignment Sheet #18)
62. Analyze a parallel resonant circuit. (Assignment Sheet #19)
63. Demonstrate the ability to:
    a. Show the effect of inductance in AC circuit. (Job Sheet #1)
    b. Solve for values of an operating RL circuit. (Job Sheet #2)
    c. Test capacitors with an ohmmeter. (Job Sheet #3)
    d. Determine the effect of AC and DC on capacitors. (Job Sheet #4)
    e. Determine time constants of RC circuits. (Job Sheet #5)
    f. Construct a neon bulb flasher. (Job Sheet #6)
    g. Show the effect of capacitive reactance in AC circuits. (Job Sheet #7)
    h. Determine capacitive reactance and impedance in RC circuits. (Job Sheet #8)
    i. Determine resonance in a series RCL circuit. (Job Sheet #9)
    j. Determine the resonant frequency of an RCL parallel circuit. (Job Sheet #10)

FUNDAMENTALS OF AC
UNIT III

ANSWERS TO TEST

1.
a.	10	f.	11	k.	8	p.	16
b.	5	g.	6	l.	14	q.	18
c.	4	h.	1	m.	12	r.	17
d.	2	i.	3	n.	15		
e.	9	j.	7	o.	13		

2. a. Natural
   b. Artificial
   c. Temporary or permanent
   d. Shape
   e. Type of material used

3. a. Iron, cobalt, nickel
   b. Ferromagnetic
   c. Paramagnetic
   d. Diamagnetic
   e. Diamagnetic, paramagnetic, ferromagnetic

4. a. Magnets
   b. Direction, polarity
   c. North, south
   d. Smallest

5. a. 2
   b. 4
   c. 6
   d. 5
   e. 3
   f. 1

6. a. Field
   b. Electron flow
   c. Left hand
   d. Coil

7. a. Turns, current
   b. Strengthened
   c. Left hand

8. a. Magnetic
   b. Electromagnetic
   c. 1) Strength
      2) Speed
      3) Angle
      4) Length
   d. Oppose

ANSWERS TO TEST

9. a. 1) Magnetic
      2) Conductor
      3) Motion
   b. Motion
   c. Magnitude
   d. 1) Velocity
      2) Strength
      3) Length
      4) Angle

10. a. Sine wave
    b. Positive, negative
    c. Peak
    d. Peak-to-peak
    e. Average
    f. rms
    g. Period
    h. Frequency

11. a. Two waveforms coincide so that their maximum instantaneous values both occur at the same time
    b. Two waveforms do not occur at the same time

12. a, b, c, d, e

13. a, b, c

14. a. Inductance
    b. Current flow
    c. L
    d. Henry (H)
    e. Current
    f. H

15. a, b

16. L/R

17. a. Voltage
    b. 180
    c. Sine
    d. Amplitude
    e. 90
    f. Directly

18. a, c, d, e, g

19. a. Induced
    b. Lm
    c. Henry
    d. Coupling
    e. Coefficient, coupling
    f. One
    g. Inductance
    h. Henry

20. a. Resistors
    b. Sum
    c. L1 + L2 + 2Lm
    d. L1 + L2 − 2Lm

ANSWERS TO TEST

21. b, c, d, e

22. a, b, c

23. a. Resistance
    b. Inductor
    c. Lags
    d. Applied

24. a. Impedance
    b. Ohms
    c. Voltage, current
    d. Resistance, inductive

25. $\frac{X_L}{R}$, $\frac{X_2}{R}$, $\frac{E_L}{E_R}$

26. a. Capacitance
    b. Capacitor
    c. Dielectric
    d. 1) Area
       2) Spacing
       3) Type, nature
    e. Farad
    f. Farad

27. a, b, c, e

28. a. $Ct = \frac{C_1 \times C_2}{C_1 + C_2}$

    b. $Ct = C1 + C2 + C3 + \ldots$

29. $t = R \times C$

30. a. Applied voltage
    b. Leads
    c. Zero
    d. Maximum

31. $X = \frac{1}{2\Omega fc}$

32. a. Resistors, capacitors
    b. Current
    c. Lags

33. a. $\frac{E_a}{It}$
    b. $\sqrt{R^2 + X_C^2}$
    c. $\sqrt{Z^2 - X_C^2}$
    d. $\sqrt{Z^2 - R^2}$

34. Arctan $\frac{Xc}{R}$

ANSWERS TO TEST

35. a, b, c, d

36. a. E/R
    b. E/Xc
    c. $\sqrt{(I_R^2) + (I_C^2)}$
    d. $Z = \frac{E_a}{I_T}$

37.

38. a. Difference
    b. Inductive
    c. Capacitive
    d. Resistive
    e. Current
    f. Leads
    g. Lags
    h. Resistive, reactive

39. a. Resonance
    b. Minimum
    c. Maximum
    d. Zero
    e. Decreases
    f. Decreasing
    g. Reactance
    h. Band width

40. a. Resistive
    b. Lags
    c. Leads
    d. Reactive
    e. Total
    f. Impedance

41. a. Maximum
    b. Minimum
    c. Zero
    d. Resistance
    e. Band width

42. a, b, c

43. a.
    b.
    c.
    d.

44.-62. Evaluated to the satisfaction of the instructor

63. Performance skills evaluated to the satisfaction of the instructor

DISCRETE SEMICONDUCTOR DEVICES AND CIRCUITS
UNIT IV

UNIT OBJECTIVE

After completion of this unit, the student should be able to apply theoretical knowledge related to discrete semiconductor devices and circuits, and construct and test common circuits and amplifiers. Competencies will be demonstrated by correctly performing the procedures outlined in the assignment and job sheets and by scoring a minimum of 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to discrete semiconductor devices and circuits with their correct definitions.
2. Complete statements related to the characteristics of semiconductors.
3. Complete statements concerning the characteristics of N-type and P-type semiconductors.
4. Select true statements concerning the characteristics of the P-N junction.
5. Describe forward and reverse biasing of diodes.
6. Complete statements concerning diode characteristics.
7. Select true statements concerning the characteristics of special semiconductor diodes.
8. Select true statements concerning bipolar transistor characteristics.
9. Complete statements concerning characteristics of bipolar transistor operation.
10. Select true statements concerning the characteristics of the common-base circuit.
11. Select true statements concerning the characteristics of the common-collector circuit.

OBJECTIVE SHEET

12. Select true statements concerning the characteristics of the common-emitter circuit.

13. Match the classes of operation with their descriptions.

14. Describe transistor biasing techniques.

15. Identify four methods of coupling.

16. Match special semiconductor devices with their descriptions.

17. Complete statements concerning the construction of the field effect transistor.

18. Select true statements concerning the characteristics of the junction field effect transistor.

19. Complete statements concerning the characteristics of the insulated gate field effect transistor.

20. Describe four safety precautions in handling FET's.

21. Explain the term decibel.

22. Label the parts of a transistor circuit. (Assignment Sheet #1)

23. Construct a load line for a common-emitter amplifier circuit. (Assignment Sheet #2)

24. Calculate the overall gain of multi-stage amplifier circuits. (Assignment Sheet #3)

25. Compute voltage, current, and power stage gain in decibels. (Assignment Sheet #4)

26. Demonstrate the ability to:

    a. Perform a static test of semiconductor diodes. (Job Sheet #1)

    b. Test semiconductor diodes and plot the characteristic curves. (Job Sheet #2)

    c. Test transistors. (Job Sheet #3)

    d. Construct and test a common-emitter circuit. (Job Sheet #4)

    e. Construct and test a common-base circuit. (Job Sheet #5)

    f. Construct and test a common collector circuit. (Job Sheet #6)

    g. Plot a transistor output characteristic curve. (Job Sheet #7)

    h. Construct and test a single-ended amplifier. (Job Sheet #8)

    i. Construct and test a field effect transistor amplifier. (Job Sheet #9)

DISCRETE SEMICONDUCTOR DEVICES AND CIRCUITS
UNIT IV

SUGGESTED ACTIVITIES

A. Obtain additional materials and/or invite resource people to class to supplement/reinforce information provided in this unit of instruction.

(NOTE: This activity should be completed prior to the teaching of this unit.)

B. Make transparencies from the transparency masters included with this unit.

C. Provide students with objective sheet.

D. Discuss unit and specific objectives.

E. Provide students with information and assignment sheets.

F. Discuss information and assignment sheets.

(NOTE: Use the transparencies to enhance the information as needed.)

G. Provide students with job sheets.

H. Discuss and demonstrate the procedures outlined in the job sheets.

I. Integrate the following activities throughout the teaching of this unit:

1. Identify various semiconductor devices used in the shop area.
2. Identify various types of packaging used for semiconductor devices and show actual components when available.
3. Identify types of circuits used in equipment by viewing the schematic for actual equipment present in the school shop.
4. Show films that demonstrate how semiconductor devices are made.
5. Visit an industrial installation where devices are manufactured.
6. Meet individually with students to evaluate their progress through this unit of instruction, and indicate to them possible areas for improvement.

J. Give test.

(NOTE: Due to the length of this unit, it is suggested that the information be tested in three parts.)

K. Evaluate test.

L. Reteach if necessary.

INSTRUCTIONAL MATERIALS INCLUDED IN THIS UNIT

A. Objective sheet

B. Suggested activities

C. Information sheet

INSTRUCTIONAL MATERIALS INCLUDED IN THIS UNIT

D. Transparency masters

1. TM 1 — Semiconductor Crystal Structures
2. TM 2 — P-N Junction
3. TM 3 — Forward and Reverse Bias
4. TM 4 — P-N Junction Diode Characteristic Curves
5. TM 5 — Zener Diode Characteristics and Schematic Symbol
6. TM 6 — Tunnel Diode Characteristics and Schematic Symbol
7. TM 7 — Transistor Block Diagrams and Schematics
8. TM 8 — Typical Transistor Types
9. TM 9 — Correctly Biased Transistors
10. TM 10 — Electron Flow in NPN and PNP Transistor Circuits
11. TM 11 — Comparison of Transistor Circuit Combinations
12. TM 12 — Common Base Amplifier (PNP) Circuit
13. TM 13 — Common Collector Amplifier (NPN) Circuit
14. TM 14 — Common Emitter Amplifier (NPN) Circuit
15. TM 15 — Transistor Load Line
16. TM 16 — Junction Field Effect Transistor
17. TM 17 — Insulated Gate Field Effect Transistor (IGFET) or Metal Oxide Semiconductor Field Effect Transistor (MOSFET)

E. Assignment sheets

1. Assignment Sheet #1 — Label the Parts of a Transistor Circuit
2. Assignment Sheet #2 — Construct a Load Line for a Common-Emitter Amplifier Circuit
3. Assignment Sheet #3 — Calculate the Overall Gain of Multistage Amplifier Circuits
4. Assignment Sheet #4 — Compute Voltage, Current, and Power Stage Gain in Decibels

F. Answers to assignment sheets

G. Job sheets

1. Job Sheet #1 — Perform a Static Test of Semiconductor Diodes
2. Job Sheet #2 — Test a Semiconductor Diode and Plot the Characteristic Curves
3. Job Sheet #3 — Test Transistors

INSTRUCTIONAL MATERIALS INCLUDED IN THIS UNIT

4. Job Sheet #4 — Construct and Test a Common-Emitter Circuit
5. Job Sheet #5 — Construct and Test a Common-Base Circuit
6. Job Sheet #6 — Construct and Test a Common Collector Circuit
7. Job Sheet #7 — Plot a Transistor Output Characteristic Curve
8. Job Sheet #8 — Construct and Test a Single-Ended Amplifier
9. Job Sheet #9 — Construct and Test a Field Effect Transistor Amplifier

H. Test

I. Answers to test

REFERENCES USED IN DEVELOPING THIS UNIT

(NOTE: The following is a list of references used in completing this unit.)

A. Boylestad and Nashelsky. *Electronics Devices and Circuit Theory.* Englewood Cliffs, NJ: Prentice-Hall, Inc., 1982.

B. Bruce, David. *Modern Electronics.* Reston, VA: Reston Publishing Co., Inc., 1984.

C. *Electronic Circuits.* Heath Learning Publications. Benton Harbor, MI: Heath Company, 1978.

D. Robertson, L. Paul. *Basic Electronics I. (Revised Edition).* Stillwater, OK: Mid-America Vocational Curriculum Consortium, 1982.

E. *Semiconductor Devices.* Heath/Zenith Educational Systems. Benton Harbor, MI: Heath Company, 1980.

F. Siebert, Leo N. *Introduction to Industrial Electricity — Electronics.* Stillwater, OK: Oklahoma Curriculum and Instructional Materials Center, 1981.

DISCRETE SEMICONDUCTOR DEVICES AND CIRCUITS UNIT IV

INFORMATION SHEET

I. **Terms and definitions**

A. Base — A region which lies between an emitter and collector of a transistor into which minority carriers are injected

(NOTE: This may also be stated as the section used to control the flow of majority carriers from emitter to collector.)

B. Bias — External electric potential (voltage) applied to a P-N junction

C. Bonding — The holding together of atoms to form a molecule

D. Collector — The region in a transistor through which a primary flow of carriers leaves the transistor

(NOTE: This may also be stated as the section which collects majority carriers.)

E. Covalent bonding — Two or more atoms sharing electrons in their outer shell to form a stable molecule

F. Depletion region — The junction area that has no free charges

G. Diode — A two-terminal semiconductor device consisting of a P-N junction which allows majority carriers to flow in one direction

H. Doping — The process of adding impurities to an intrinsic material

I. Emitter — The region in a bipolar junction transistor from which carriers flow through the emitter junction into the base

(NOTE: This may also be stated as the section which supplies majority carriers.)

J. Extrinsic material — A material to which an impurity has been added

K. Holes — The absence of electrons in a covalent bond

L. Intrinsic material — A pure crystal of material

M. Light-emitting diode (LED) — A diode specially doped to emit light when forward biased

N. Majority carriers — Electrons in N-type materials and holes in P-type materials

O. Minority carriers — Electrons in P-type materials and holes in N-type materials

P. Peak inverse voltage (PIV or PRV) — The maximum reverse-bias voltage which can be applied to a P-N junction without damage to the junction

Q. Photo-diode — A diode made from photo-sensitive material whose resistance decreases with increased light

INFORMATION SHEET

R. P-N junction — The region where N-type and P-type semiconductor materials join together

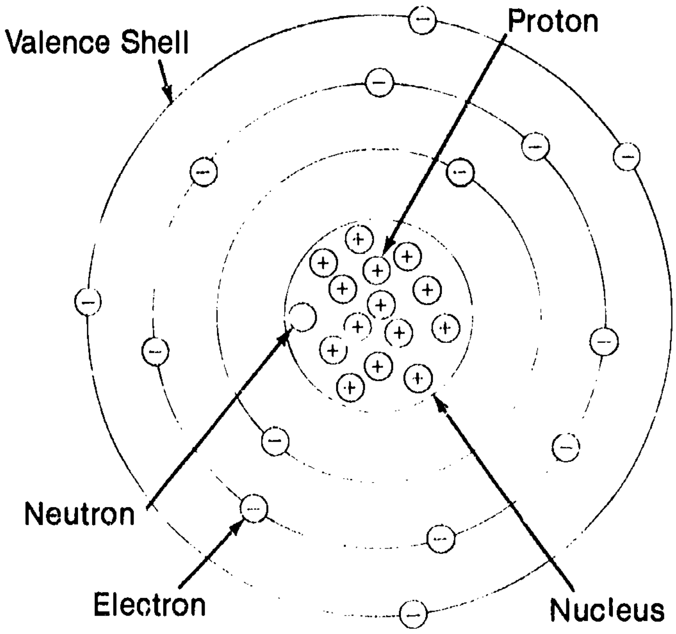
S. Semiconductor — A material which has a resistivity between conductors and insulators whose conductivity increases with temperature

T. Single-ended amplifier — Denotes the method of supplying an input signal or obtaining an output signal from an amplifier in which one side of the input or output is connected to ground

II. **Characteristics of semiconductors**

A. Two important semiconductor materials of which solid-state devices are made are silicon (Si) and germanium (Ge).

B. An atom of semiconductor material has four valence electrons and does not easily give up or accept electrons.



C. Semiconductor atoms are bonded together in a crystalline structure through covalent bonding.

D. When a difference of potential is applied across a semiconductor material, current flows in the form of both electrons and holes.

1. Holes function as positively charged particles.

2. Electrons are negatively charged particles.

INFORMATION SHEET

III. **Characteristics of N-type and P-type semiconductors** (Transparency #1)

A. The conductivity of semiconductor materials can be increased significantly through a process called doping.

B. When pure intrinsic semiconductor materials such as germanium or silicon are doped with a pentavalent material such as arsenic, they become extrinsic N-type semiconductor materials.

1. N-type semiconductor materials have electrons as the majority carriers.

2. Holes are the minority carriers in N-type material.

3. Atoms of N-type materials are referred to as donor atoms.

C. When semiconductor materials are doped with a trivalent material such as gallium (Ga), they become P-type semiconductors.

1. P-type semiconductor materials have holes as majority carriers.

2. Electrons are the minority carriers in P-type materials.

3. Atoms of P-type materials are referred to as acceptor atoms.

IV. **Characteristics of the P-N junction** (Transparency #2)

A. P-type and N-type material may be joined together by several manufacturing methods to form a P-N junction.

B. When formation of the P-N junction is completed, a device known as a junction diode is the result.

C. The schematic symbol for the diode is .

D. A depletion region extends for a very short distance on each side of a P-N junction.

E. The action within the depletion region causes a barrier potential to be developed.

1. Silicon diode barrier potential is typically 0.7 volts.

2. Germanium diode barrier potential is typically 0.3 volts.

V. **Biasing of diodes** (Transparency #3)

A. The conductivity across the P-N junction of a junction diode may be varied by applying an external voltage across the diode.

INFORMATION SHEET

B. Bias a plied to a semiconductor junction with polarity so that relatively high current flows through the junction is called forward bias.

C. Bias applied to a semiconductor junction with polarity so that little or no current flows through the junction is called reverse bias.

VI. **Diode characteristics** (Transparency #4)

A. Forward current through a semiconductor diode is very small and almost insignificant until forward bias across the diode is increased beyond the barrier potential (0.3 volts for germanium, .7 volts for silicon).

B. When a forward bias is increased beyond the barrier potential, the forward current increases rapidly at a relatively linear rate.

C. When a reverse bias is applied to a semiconductor junction, majority current essentially ceases to flow.

D. Reverse bias at low potential will not cause a significant increase in minority current (reverse current).

E. At a higher value of reverse voltage minority carriers increase and support a rapid increase in reverse current.

F. The value of reverse voltage that causes a rapid increase in reverse current is known as the breakdown voltage.

G. Manufacturers of diodes specify important characteristics of each diode.

1. Maximum for current (I_f) the diode can handle without damage

2. The maximum reverse voltage that can be applied safely to a diode is commonly specified as peak inverse voltage (PIV) rating.

VII. **Characteristics of special semiconductor diodes**

A. The zener diode is a diode designed to operate at a specific value of reverse breakdown voltage and current. (Transparency #5)

1. The specific voltage at which a zener diode operates is called the zener voltage.

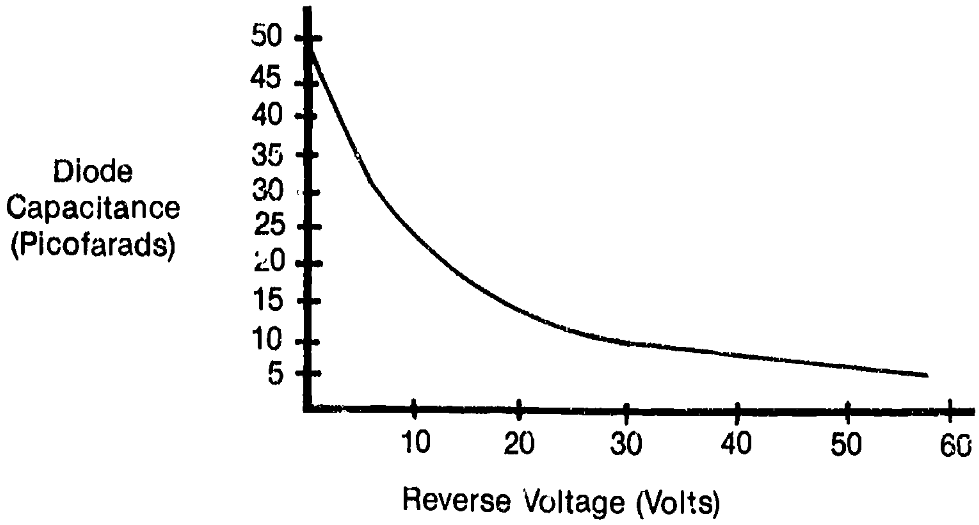
2. The operating point of a zener diode is just beyond the zener voltage point known as the zener region.

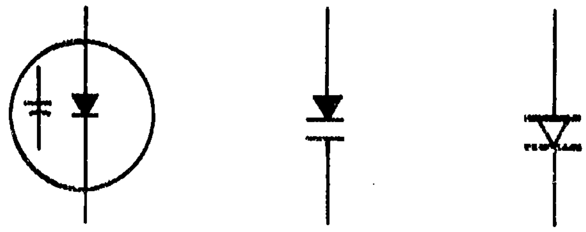
3. The current that flows when a zener diode is operating in the zener region is known as zener current.

INFORMATION SHEET

B. The tunnel diode is a heavily doped semiconductor device with a narrow depletion region and a high barrier voltage. (Transparency #6)

C. The varactor diode is a special purpose diode that makes use of the variable width of the depletion region to act as a variable capacitance.





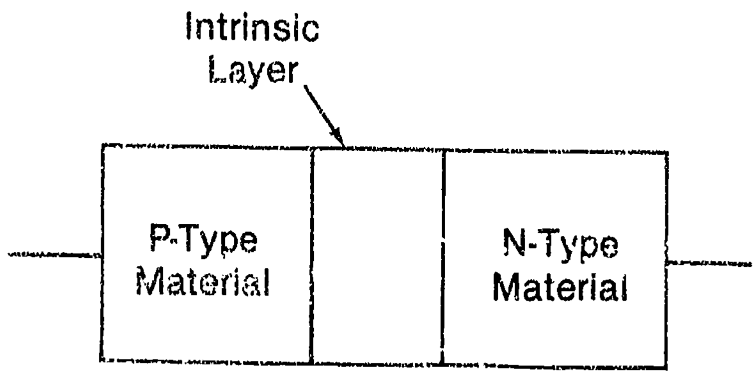
Schematic Symbols

1. The larger the reverse bias on a varactor diode, the smaller the barrier capacitance.

2. The larger the forward bias on the varactor diode, the larger the capacitance.

INFORMATION SHEET

D. A PIN diode is a three layer diode which is capable of changing from one operating state to another at an extremely fast rate and therefore used in high frequency applications.



1. The characteristics of operation of a PIN diode make it useful as a current controlled variable resistor.

2. The internal resistance of the PIN diode changes linearly with forward voltage.

3. Low bias voltages and currents are capable of controlling the operation of the PIN diode.

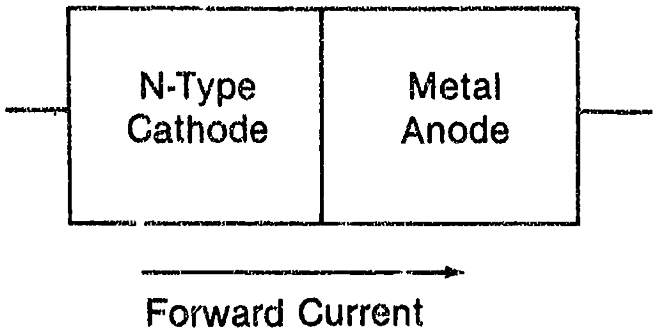
E. The IMPATT (impact avalanche transit time) diode operates within its reverse breakdown region.

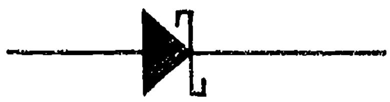
1. The characteristics of the IMPATT diode permit it to be used to generate rf power.

2. IMPATT diodes are used in high frequency microwave applications.

INFORMATION SHEET

F. Hot carrier diodes (HCD) are formed by placing an N-type material in contact with a metal such as gold, silver, or aluminum to form a metal to semiconductor junction.





Schematic Symbol

1. The barrier voltage in a hot carrier diode is approximately one half as great as the barrier voltage within a silicon diode.

2. The barrier voltage is often referred to as the Schottky-barrier.

3. The HCD operates with electrons as majority carriers and almost no minority carriers are involved.

4. The HCD is able to turn on and off at a very fast rate.

G. The Gunn-effect diode is not a true diode in that it does not have a P-N junction but is able to produce a negative resistance characteristic within bulk semiconductor materials.

1. The Gunn-effect diode is capable of generating rf signals when used with a resonant circuit.

2. Although the Gunn-effect diode is not a P-N junction, it is usually designed for a biasing in one specific direction.

VIII. **Bipolar transistor characteristics** (Transparency #7)

A. A bipolar transistor is a three-terminal current-controlled semiconductor device containing two P-N junctions.

1. The bipolar transistor consists of three sections called the emitter, base, and collector.

2. The three sections of the transistor are separated by two P-N junctions.

INFORMATION SHEET

B. Bipolar transistors are of two major types, the NPN and the PNP

1. The PNP transistor consists of P-type material for the emitter, N-type material for the base, and P-type material for the collector.

2. The NPN transistor consists of N-type material for the emitter, P-type material for the base, and N-type material for the collector.

C. Bipolar transistors are used primarily to increase the amplitude or strength of electronic signals and for switching.

D. Bipolar transistors are packaged in a specially designed container to improve temperature stability, to protect the device, and to support the transistor and its interconnecting leads. (Transparency #8)

IX. **Characteristics of bipolar transistor operation** (Transparency #9)

A. The collector-base junction of a bipolar transistor is normally reverse biased.

B. The emitter-base junction of a bipolar transistor is normally forward biased.

C. The relationship between emitter current (I_E), base current (I_B), and collector current (I_C) is established in the following equations: (Transparency #10)

1. $I_E = I_B + I_C$

2. $I_C = I_E - I_B$

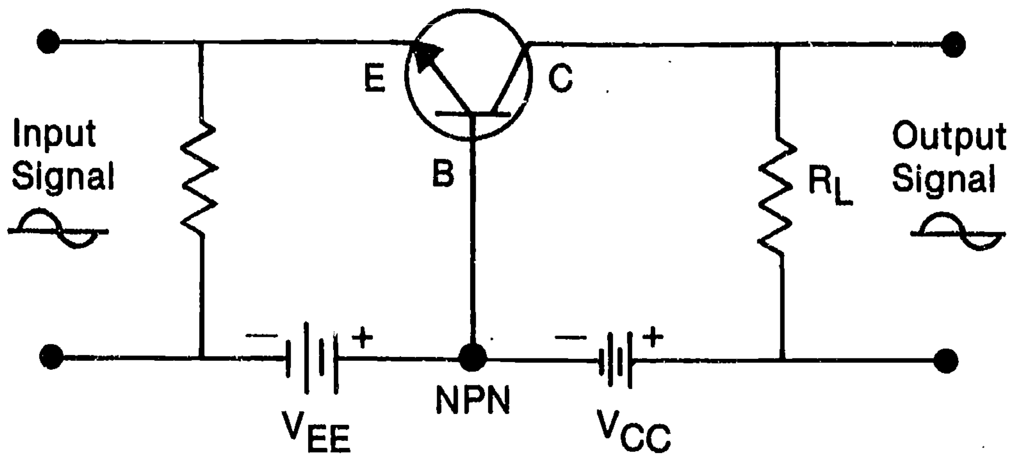
3. $I_B = I_E - I_C$

D. Transistor circuits are commonly arranged in three basic configurations as common-base (CB), common emitter (CE) and common collector (CC) (Transparency #11)

INFORMATION SHEET

X. **Characteristics of the common-base circuit** (Transparency #12)

A. The common-base (CB) circuit configuration uses the base as the common reference point and the emitter and collector regions of the transistor serve as input and output connections.



B. The CB circuit has a relatively high voltage gain.

C. The CB has a low current gain (gain less than 1, typically .95 to .99).

(NOTE: The current gain of a common-base circuit is identified by the greek letter alpha (α) and is equal to the change in collector current divided by the change in emitter current.)

D. The CB has a medium power gain.

E. The CB has a low input impedance.

F. The CB has a high ouput impedance.

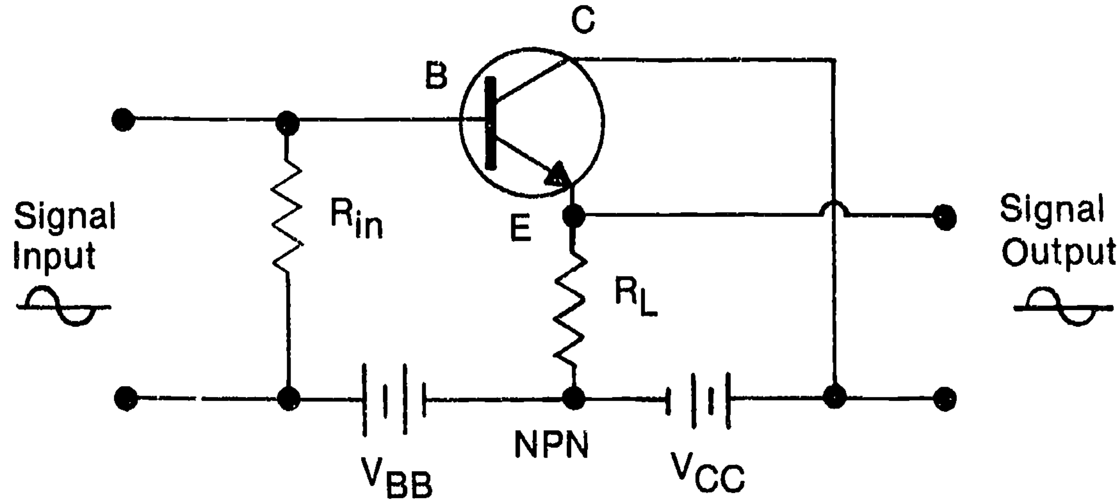
G. The input signal is in-phase with the output signal.

INFORMATION SHEET

XI. **Characteristic of the common-collector circuit** (Transparency #13)

A. The common-collector (CC) configuration uses the collector as the common reference point and the base and emitter as the input and output connections.

(NOTE: The common-collector is also known as an emitter follower.)



B. The CC has a low voltage gain.

C. The CC has a high current gain.

(NOTE: The current gain of a CC is 1 + β.)

D. The CC has a low power gain.

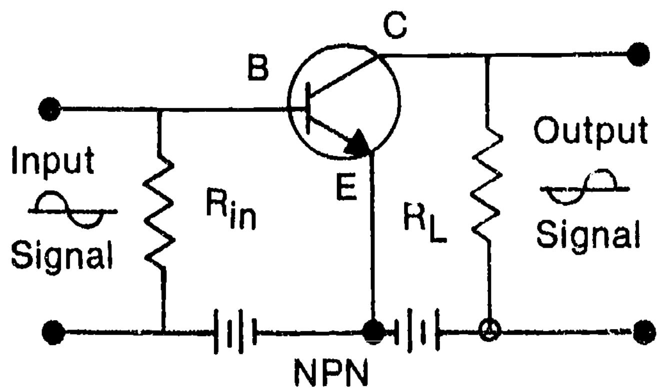
E. The CC has a high input impedance.

F. The CC has a low output impedance.

G. The input signal is in-phase with the output signal.

XII. **Characteristics of the common-emitter circuit** (Transparency #14)

A. The common-emitter (CE) configuration uses the emitter as the common reference point and the base and collector as input and output connections.



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INFORMATION SHEET

B. The CE has a relatively high voltage gain.

C. The CE has a high current gain.

(NOTE: The current gain a common emitter circuit is commonly identified by the greek letter beta (β) and is calculated by dividing the change in collector current by the change in base current.)

D. The CE has a very high power gain.

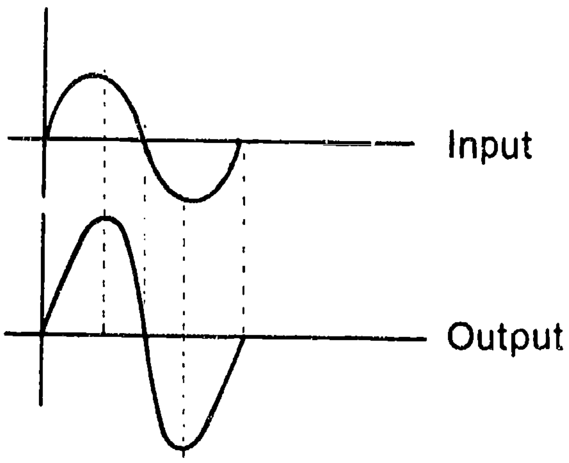
E. The CE has a medium value of input impedance.

F. The CE has a medium value of output impedance.

G. The input signal is out-of-phase with the output signal.

XIII. Classes of operation

A. A class A operation is an amplifier circuit biased so that the collector current flows during the entire input-signal cycle.

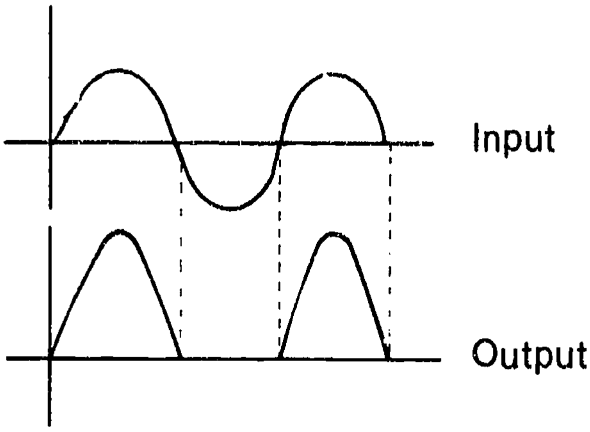


1. A transistor load line may be constructed to determine the operating or Q point of a circuit. (Transparency #15)

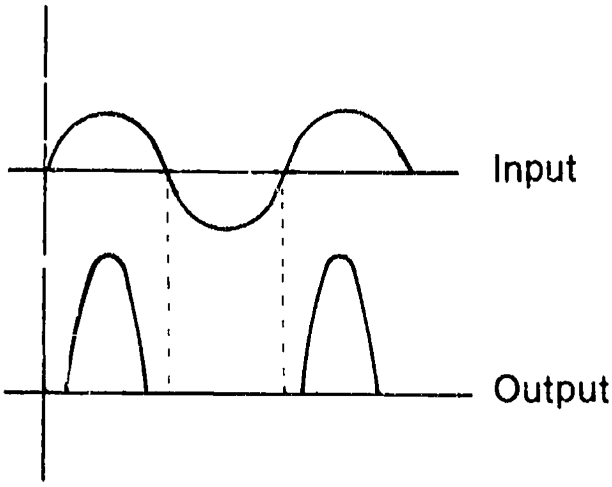
2. The cut-off and saturation points may be determined using a load line and transistor characteristic curves.

INFORMATION SHEET

B. A class B operation is an amplifier circuit biased so that the collector current flows during half of the input-signal cycle.



C. A class C operation is an amplifier circuit biased so that the collector current flows for less than half of the input-signal cycle.

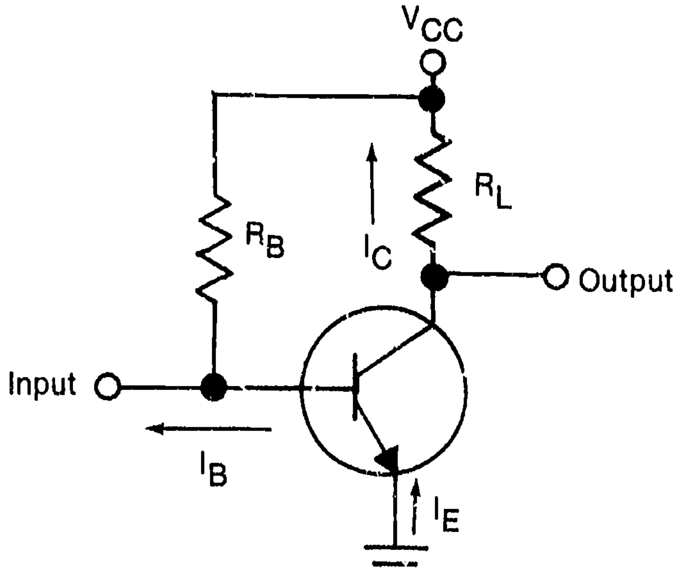


INFORMATION SHEET

XIV. Transistor biasing techniques

A. Practical transistor circuits are biased using a single voltage source.

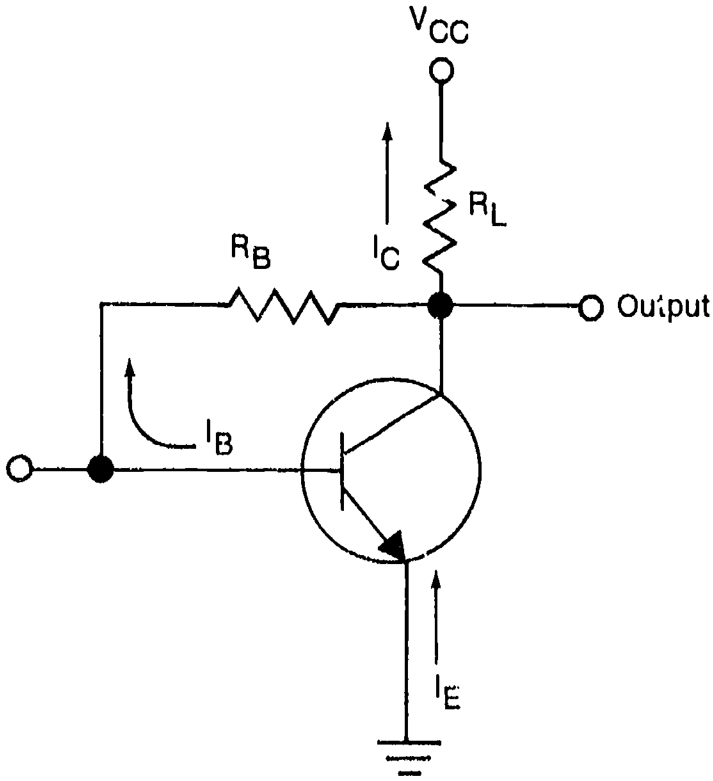
B. Base-biasing is the most simple form of transistor biasing but is not used extensively because of its thermal instability.



C. Feedback bias may be used to improve thermal stability of a circuit.

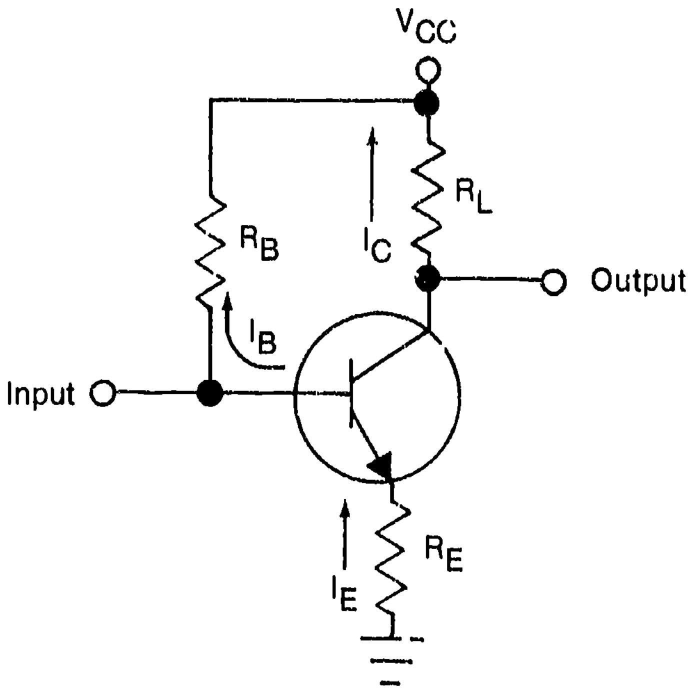
1. Degenerative or negative feedback may be used to counteract changes due to thermal instability.

2. Collector feedback provides degenerative feedback.

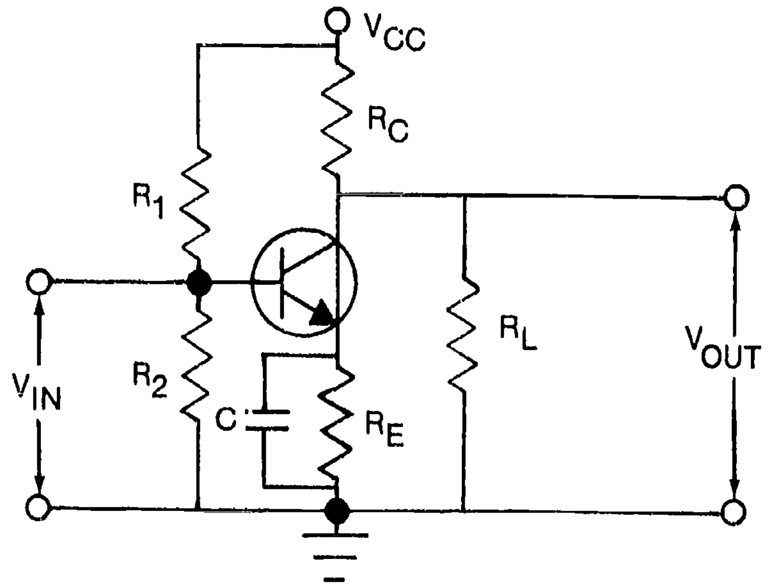


INFORMATION SHEET

3. Emitter feedback may be used to provide degenerative feedback.



D. Voltage divider bias is a widely used type in electronic circuits and provides a great degree of circuit stability.



"Rule-of-thumb" characteristics

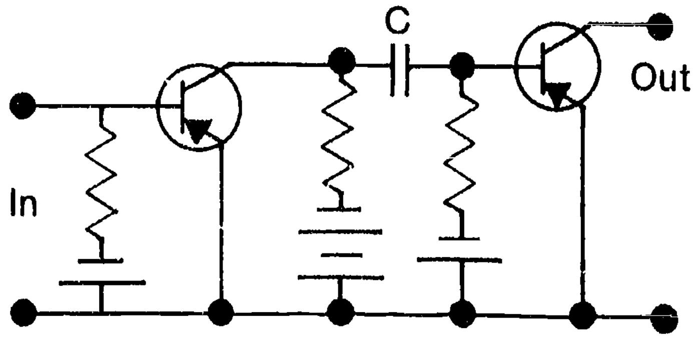
1. R_E will drop about one-tenth V_{CC}
2. R_2 value is approximately 10 times R_E
3. R_1 value is approximately 9 times R_2
4. R_L value chosen to drop 45% of V_{CC}
5. C will have an X_C about one-tenth R_E at lowest operating frequency

INFORMATION SHEET

XV. **Methods of coupling**

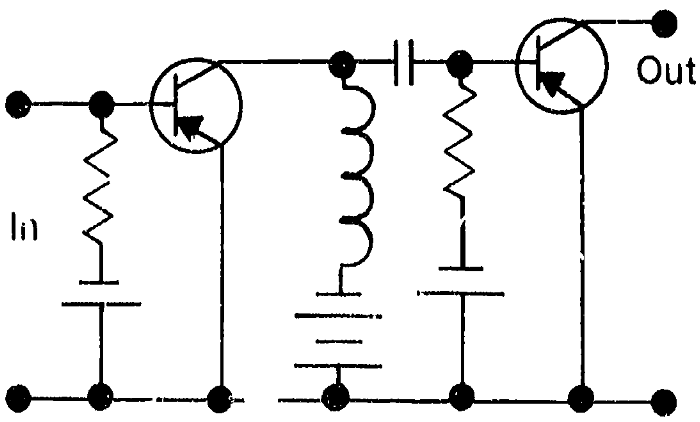
A. To obtain higher overall gain, two or more amplifier stages may be coupled together.

B. Resistance-capacitance (RC) coupling is one of the most widely used methods of coupling.



(NOTE: This method has broad frequency response, is economical to construct, has a small physical size, provides DC isolation, and limits low frequency response.)

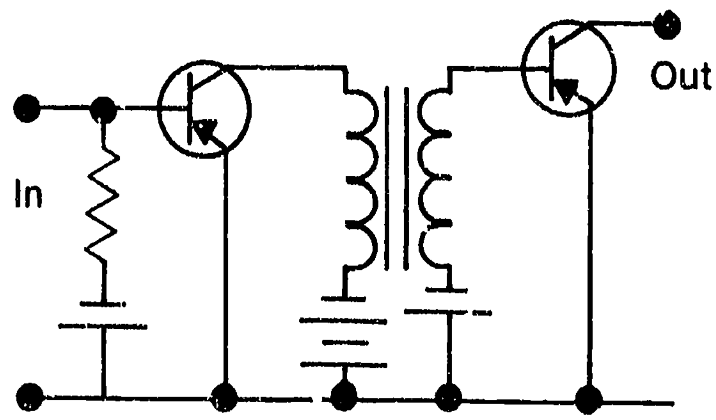
C. Impedance coupling is similar to RC coupling except that an inductor is used in place of a load resistor.



(NOTE: Amplifier output is larger at high frequencies than at low frequencies. This method is used primarily when a small band of frequencies or a single frequency is to be amplified.)

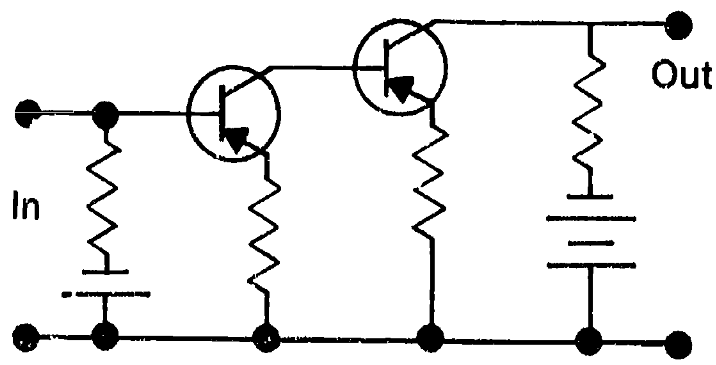
INFORMATION SHEET

D. Transformer coupling is used primarily for impedance matching purposes.



(NOTE: This method is used in power amplifier stages, is more costly than RC coupling, requires more space and is heavier, provides DC isolation between stages, and frequency range is somewhat limited.)

E. Direct coupling is used primarily when very low signal frequencies must be amplified.



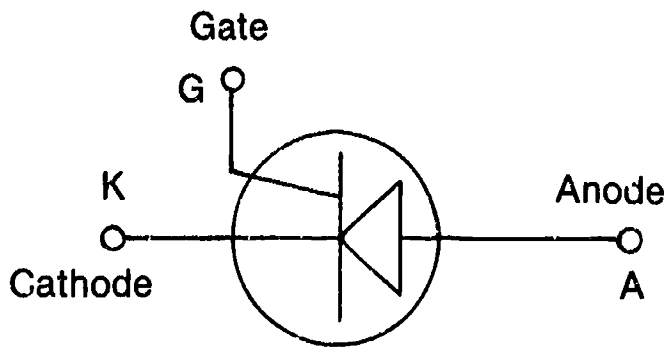
(NOTE: This method is used to couple only a few stages because of noise and signal amplification, and is used in Darlington pair amplifiers.)

INFORMATION SHEET

XVI. **Special semiconductor devices and their descriptions**

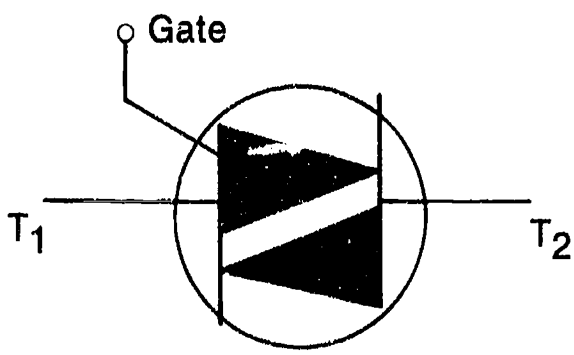
A. Thyristors are a family of multilayered semiconductor devices which are used primarily for switching current.

B. Silicon controlled rectifier (SCR) is a three-terminal device similar to an ordinary rectifier except its rectifying characteristics can be controlled (a member of the thyristor family).



C. **A diac is a bidirectional trigger diode.**

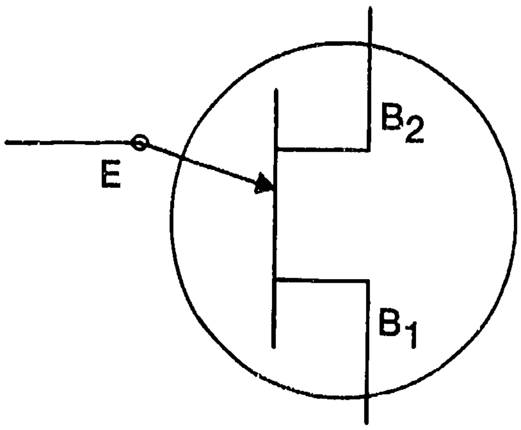
D. A triac is a three terminal device which is a member of the thyristor family and generally applied as an AC switching device.



INFORMATION SHEET

E. A thermistor is a temperature sensitive resistor.

F. A unijunction transistor (UJT) is a specialized type of junction transistor which is normally used as a switching device.



G. A field effect transistor (FET) is a transistor which is voltage controlled and has a very high input impedance.

XVII. **Construction of the field effect transistor** (Transparency #16)

A. The source terminal corresponds to the emitter of a transistor and is where charge carriers enter the channel to provide current through the channel.

B. The drain corresponds to the collector of a transistor and is the terminal where current leaves the channel.

C. The gate corresponds to the base of a transistor and is the electrode that controls the conductance of the channel between the source and the drain.

D. The substrate serves as a platform on which the other elements of the device are formed.

INFORMATION SHEET

XVIII. **Characteristics of the junction field effect transistor**

A. The JFET is a voltage sensitive device which uses an electrostatic field to control conduction.

B. The JFET has a very high input impedance.

C. The control of current through the channel of a JFET is accomplished by varying the reverse bias voltage between the gate and the source.

D. The gate-to-source voltage required to reduce the drain current to zero is called the gate-to-source cutoff voltage.

E. The value of drain-to-source voltage which limits the drain current (due to depletion of majority carriers) is called the pinch-off voltage.

XIX. **Characteristics of the insulated gate field effect transistor** (Transparency #17)

A. The IGFET uses a metal gate that is electrically insulated from the semiconductor channel by a thin oxide layer and is therefore called an insulated gate FET.

(NOTE: Because of the metal oxide layer, this device is also commonly referred to as a metal-oxide semiconductor or MOSFET.)

B. The IGFET has a very high input impedance because of the insulation layer.

C. The IGFET may be operated either as a depletion-mode device or as an enhancement-mode device.

1. The enhancement type is normally "off" and has no deposited channel region.

2. The depletion type is normally "on" and has a deposited channel region.

XX. **Safety precautions in handling MOSFET's (IGFET's)**

A. Device leads should be kept shorted together while handling.

B. Persons handling devices should be grounded such as with a grounded metallic wristband.

C. Soldering iron tips should be grounded.

D. The device should never be inserted or removed from the circuit with the power on.

INFORMATION SHEET

XXI. Decibel measurements and calculations

A. The decibel (dB) is not an absolute quantity but it is a measurement of the ratio of one power to another.

Example: If an amplifier increases an input of 2 watts to an output of 20 watts, it has increased the signal power 10 times or 10 dB.

(NOTE: The decibel is one-tenth Bel. The Bel, as a unit, is not used in favor of the preferred unit, the decibel.)

B. Decibel gain may be calculated using the formula

$$dB = 10 \log \frac{P_1}{P_2}$$

C. Decibels is the ratio of two powers, and since power is proportional to voltage (E/R) and current (I/R), decibel ratios between output current and voltage may also be computed as follows:

1. $dB = 10 \log \frac{E^2/R_o}{E^2/R_i}$

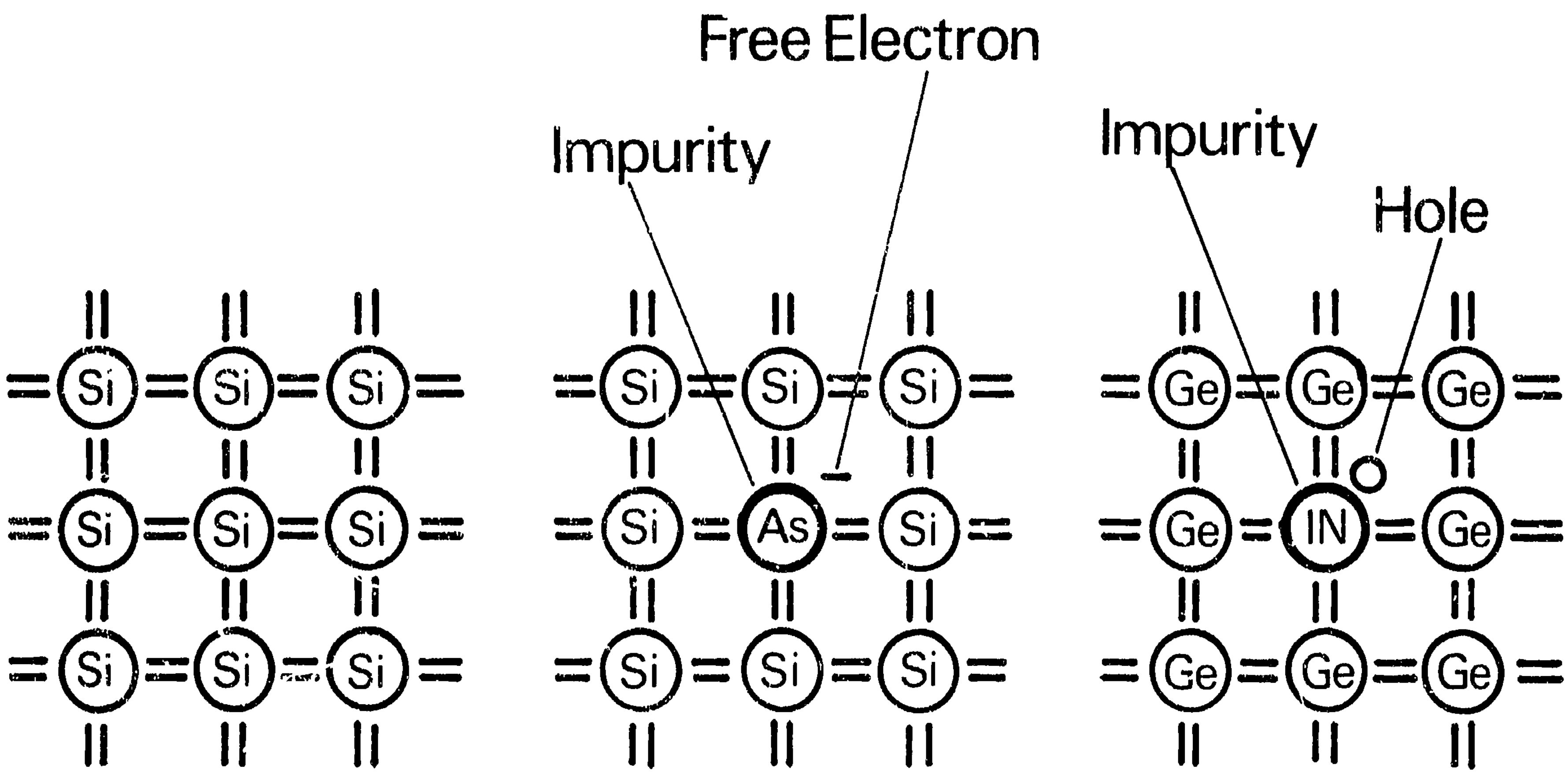
2. $dB = 10 \log \frac{I^2R_o}{I\ R_i}$

D. When input and output and output resistances and impedances are equal, the equations may be simplified as follows:

1. $dB = 20 \log \frac{E_o}{E_i}$

2. $dB = 20 \log \frac{I_o}{I_i}$

Semiconductor Crystal Structures



Pure Silicon Crystal
Intrinsic

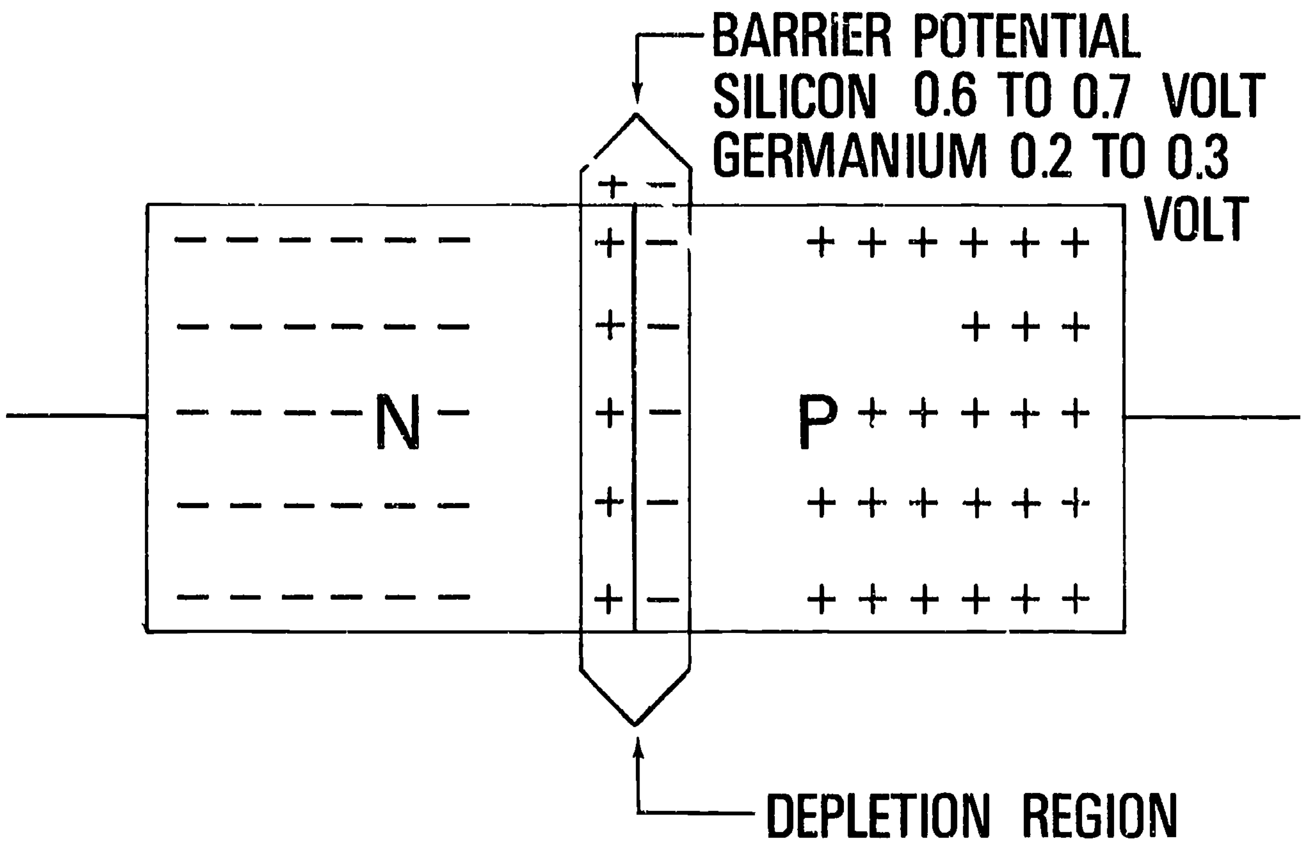
N-Type Silicon
Crystal
Extrinsic

P-Type Germanium
Crystal
Extrinsic

TM 1

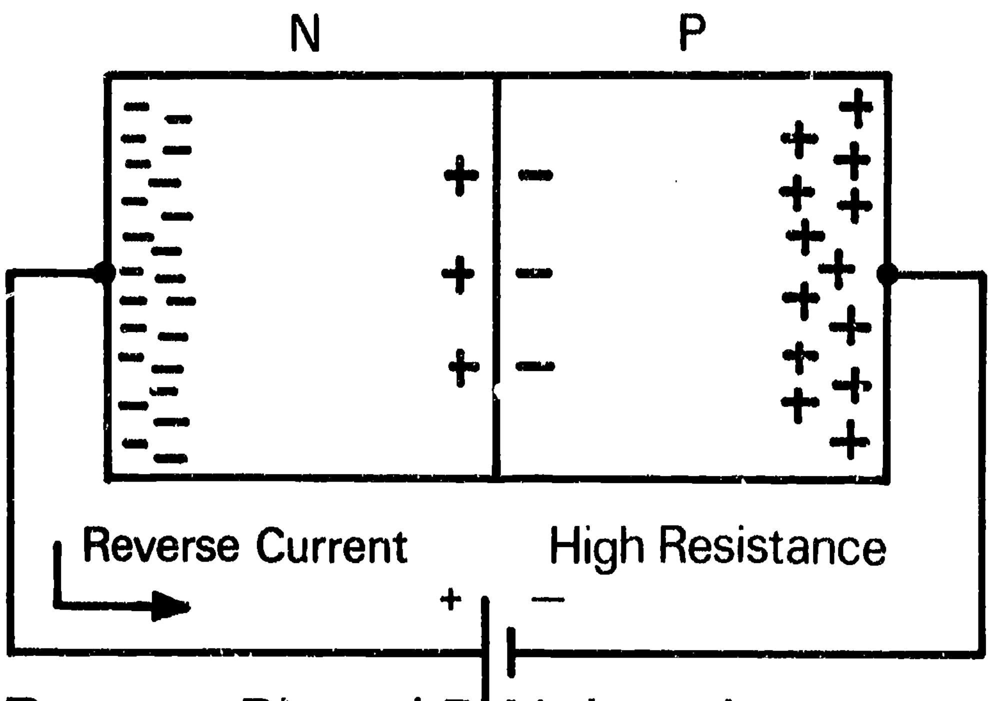
GET-543

P-N Junction

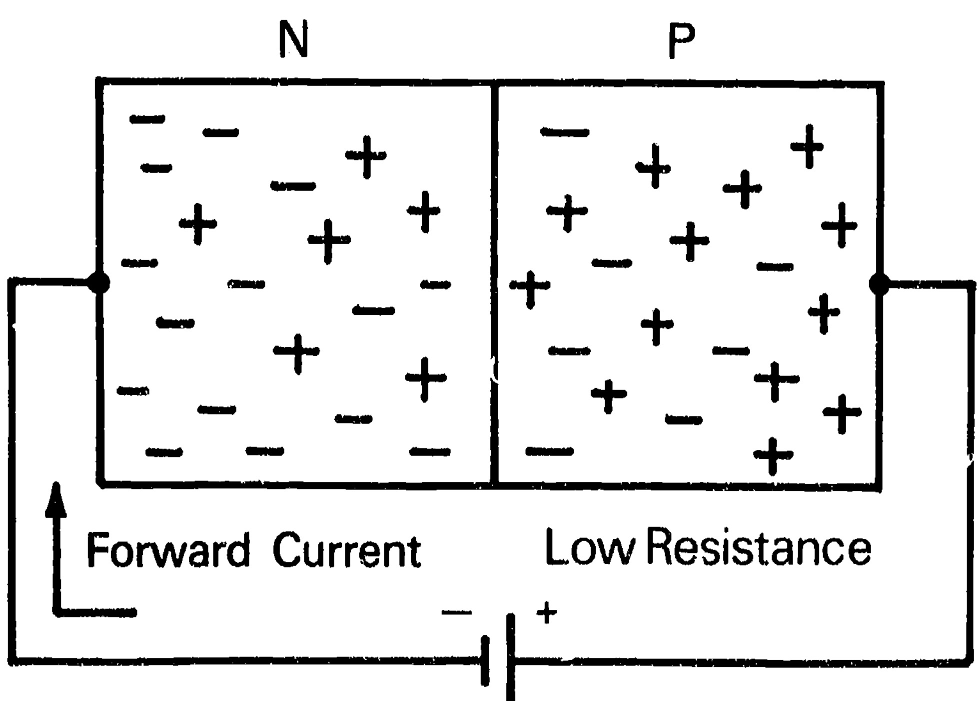


P-N JUNCTION
Showing Barrier Potential
And
Depletion Region

Forward and Reverse Bias



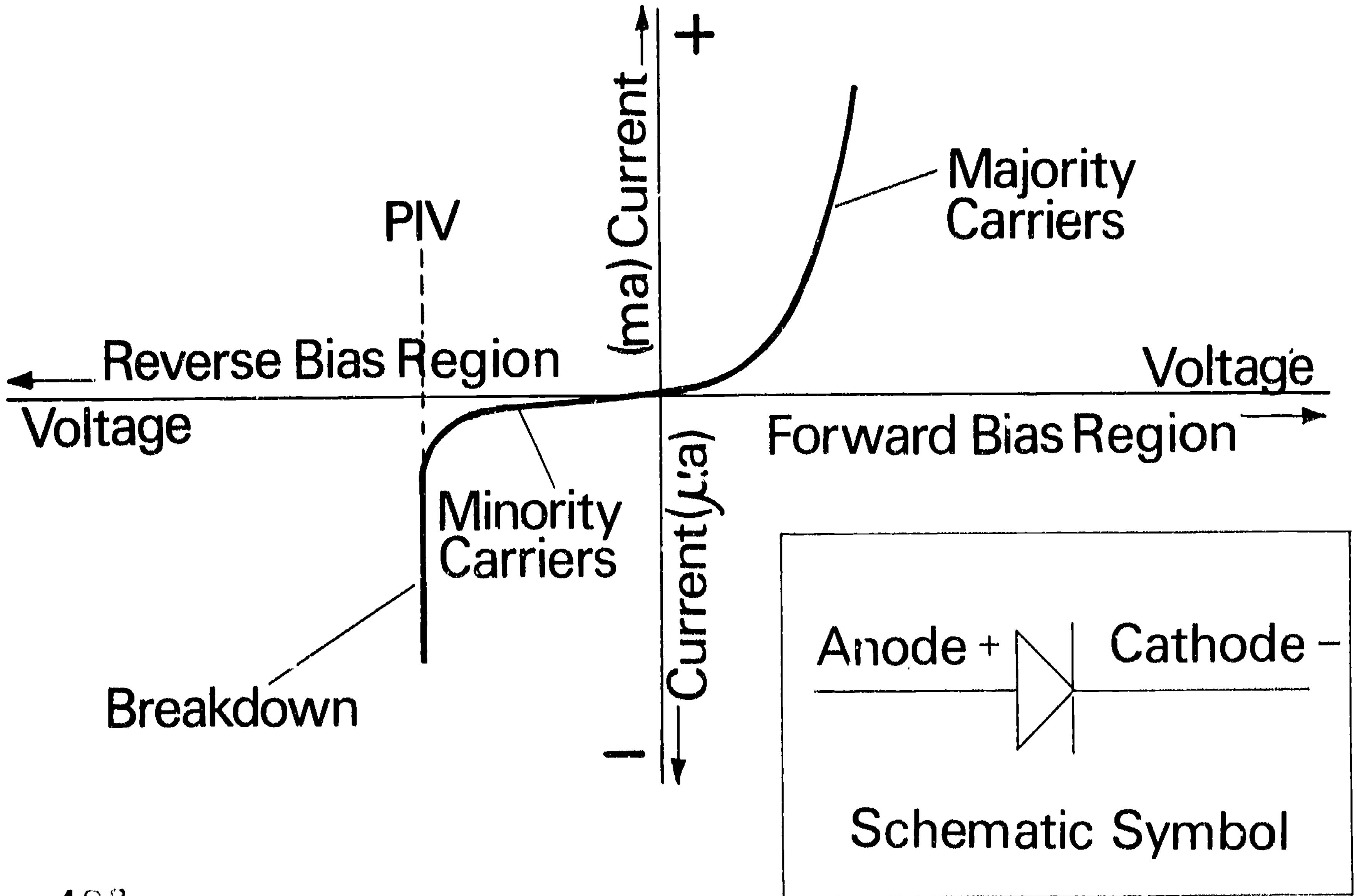
Reverse Biased P-N Junction



Forward Biased P-N Junction

(Note— Barrier potential increases and depletion region widens as reverse bias is increased.)

P-N Junction Diode Characteristic Curves



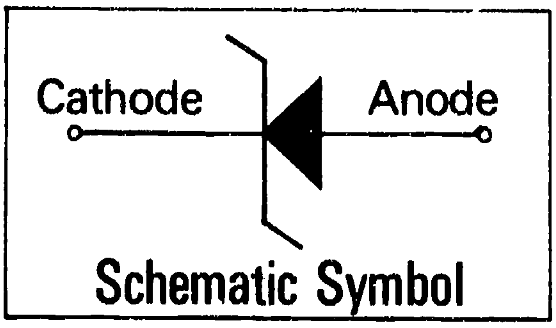
486

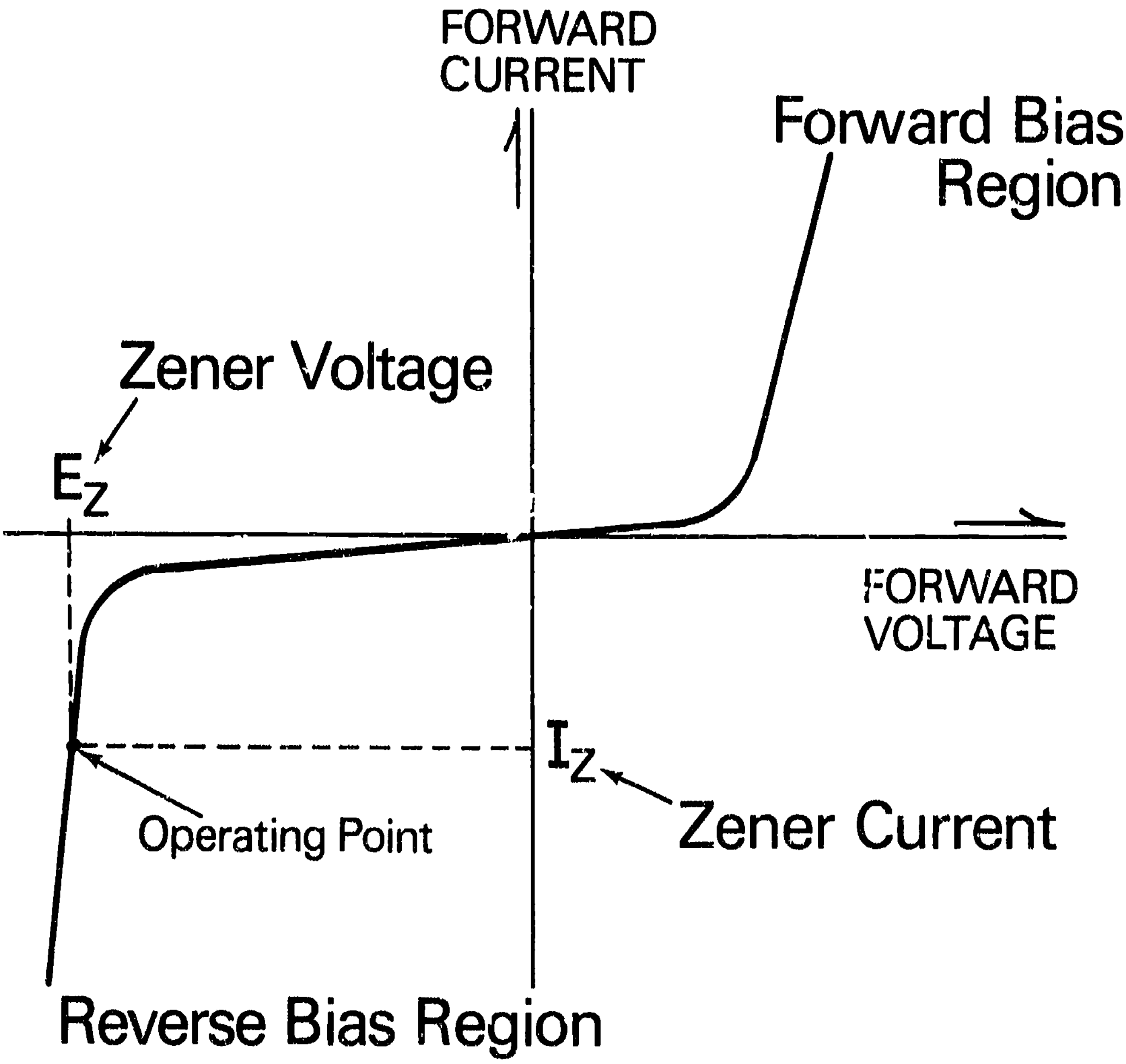
TM 4

487

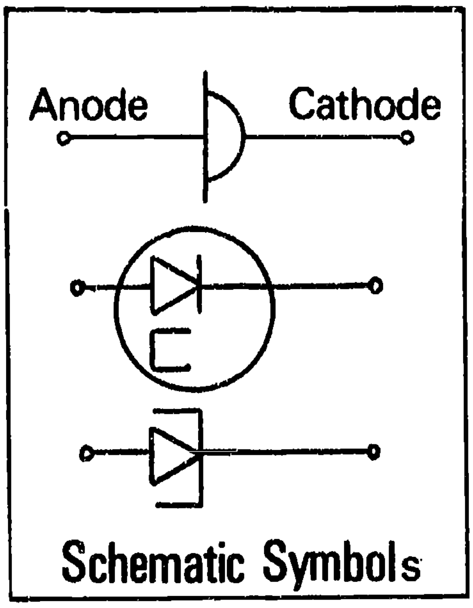
GET-549

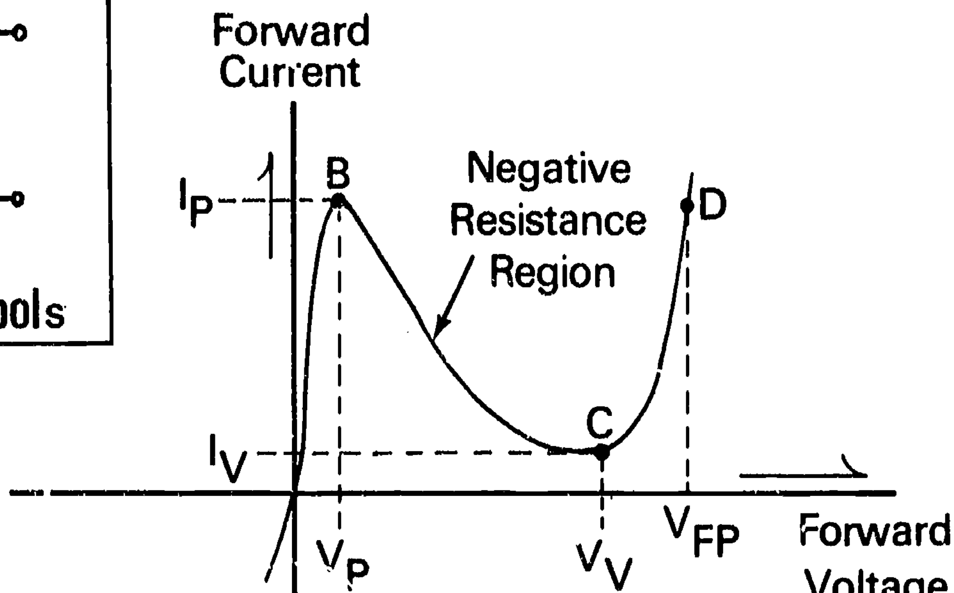
Zener Diode Characteristics and Schematic Symbol





Tunnel Diode Characteristics and Schematic Symbol





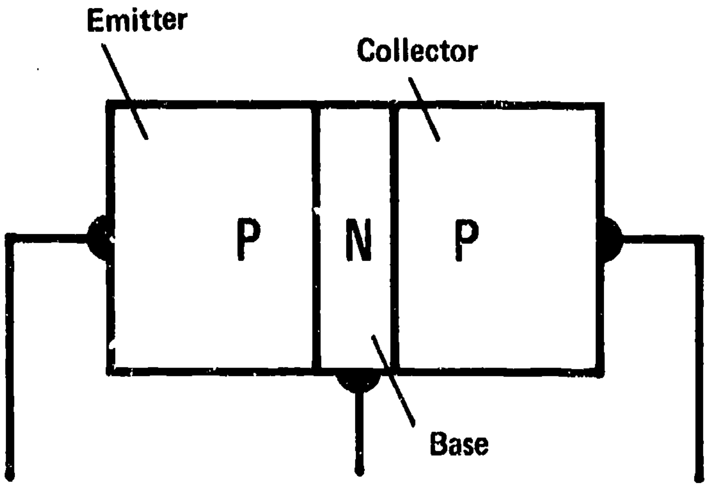
B — I_P - Peak-Point Current
B — V_P - Peak-Point Voltage

C — I_V - Valley- Point Current
C — V_V - Valley-Point Voltage

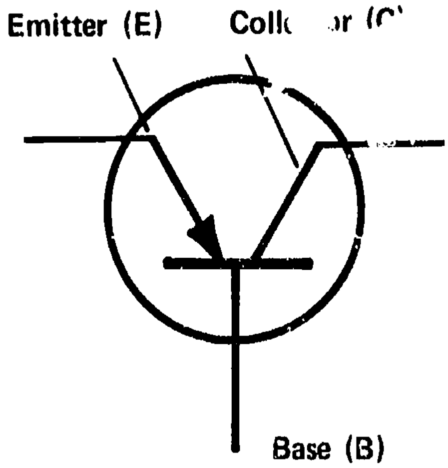
D — V_{FP} - Forward-Point Voltage

Note:
Negative Resistance Region Exists Between Points B and C

Transistor Block Diagrams and Schematics

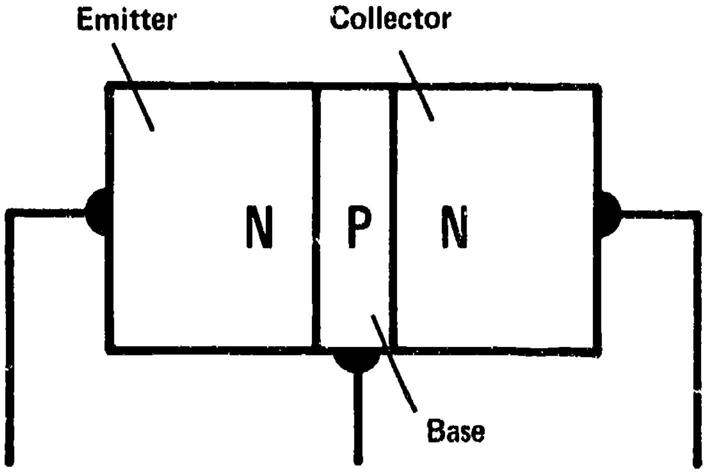


Block Diagram

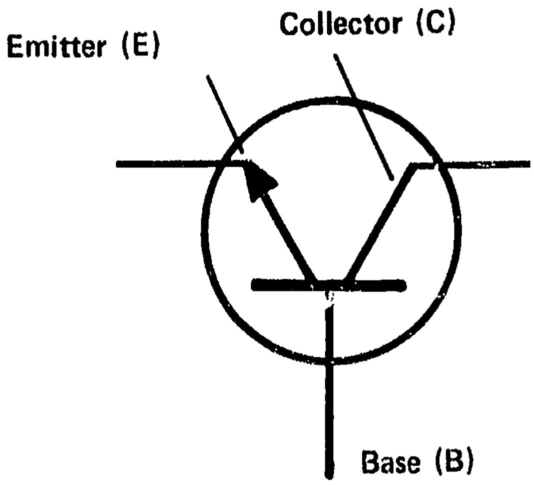


Schematic

PNP Transistor



Block Diagram



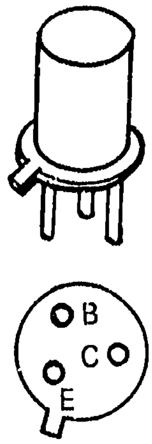
Schematic

NPN Transistor

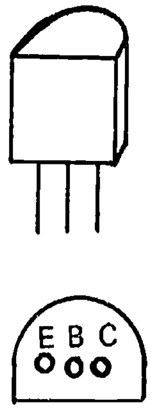
(NOTE: In both PNP and NPN transistors, the arrow on the emitter lead points toward the N-type material.)

Typical Transistor Types

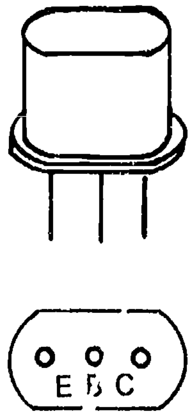
Small Signal Transistors



(Bottom View)

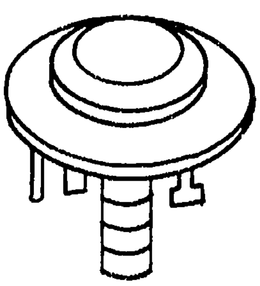


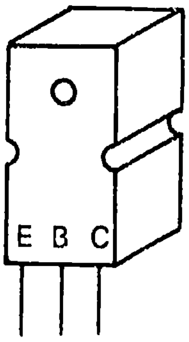
(Bottom View)

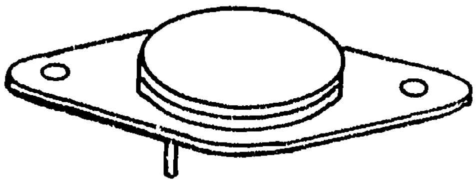


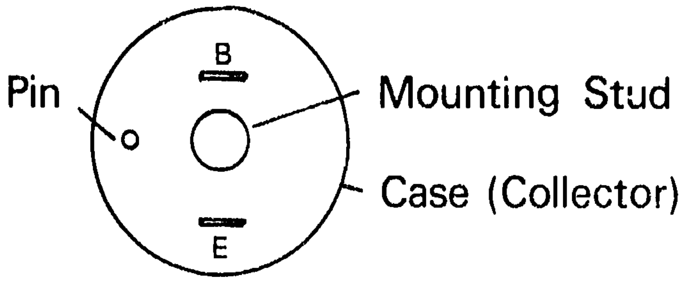
(Bottom View)

Power Transistors

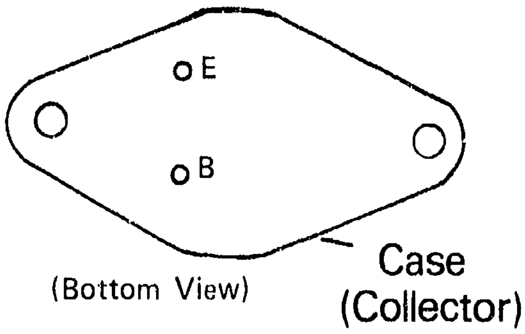








(Bottom View)



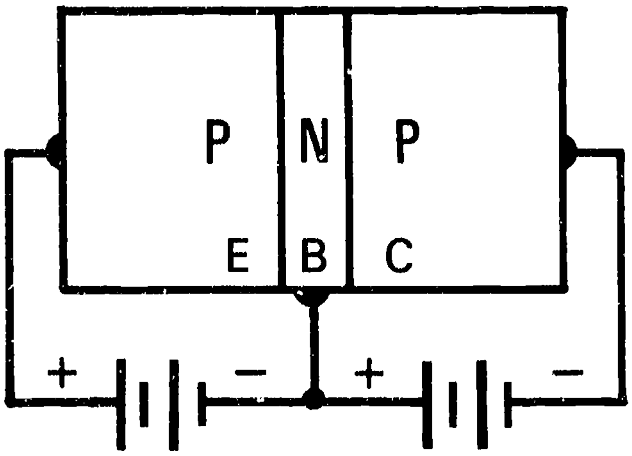
(Bottom View)

(NOTE: There are other base diagrams. See manufacturer's catalog for others.)

490 a

Correctly Biased Transistors

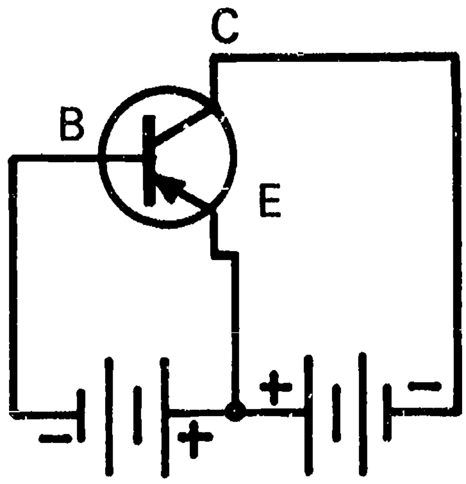
Common Base



Forward Bias　　Reverse Bias

Block

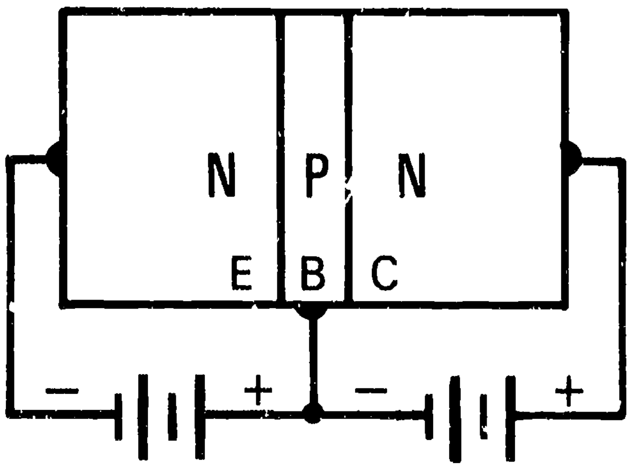
Common Emitter



Schematic

PNP Transistor Bias

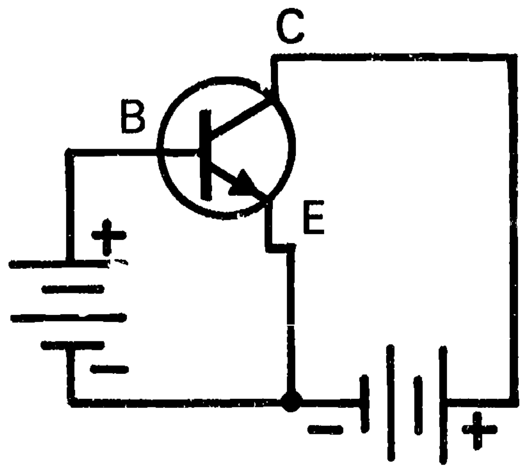
Common Base



Forward Bias　　Reverse Bias

Block

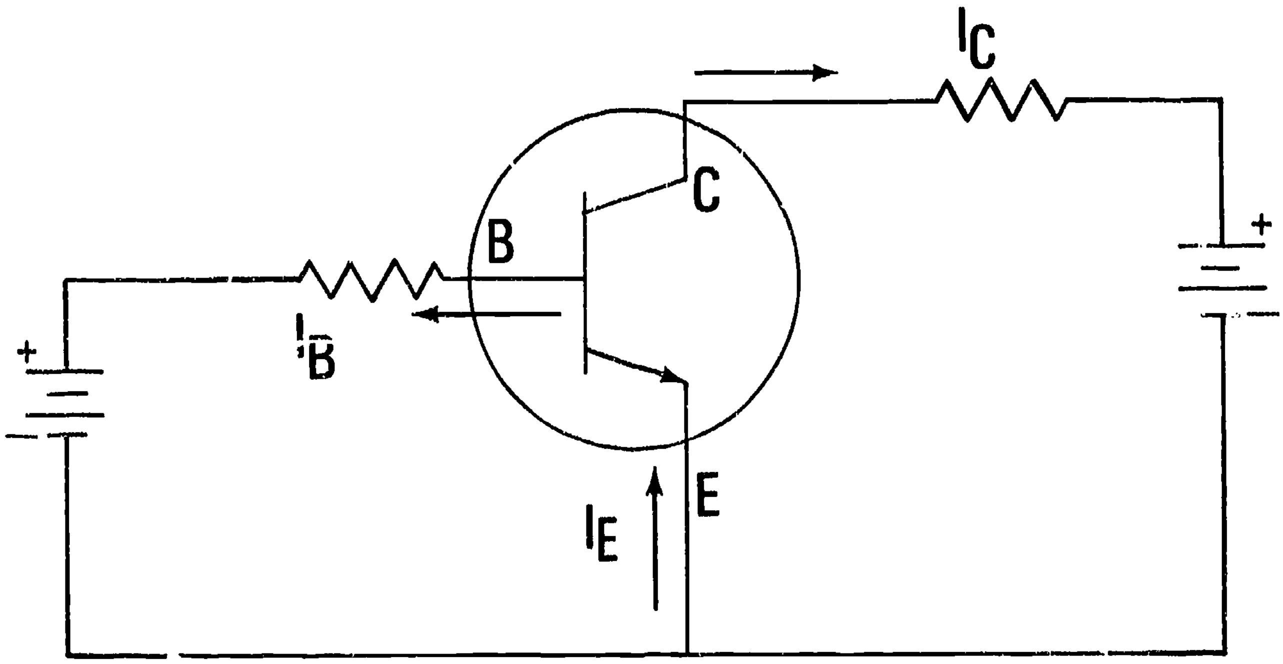
Common Emitter



Schematic

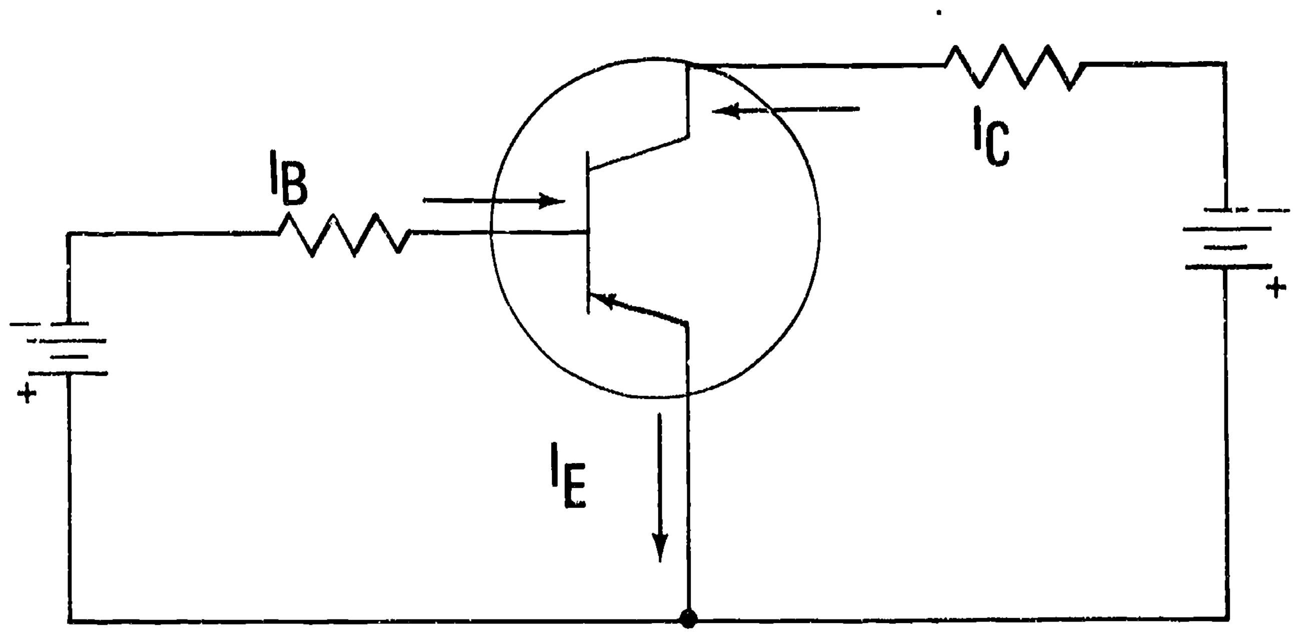
NPN Transistor Bias

Electron Flow in NPN and PNP Transistor Circuits



$I_E = I_B + I_C$

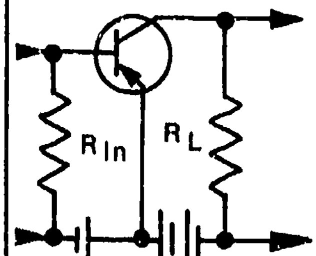
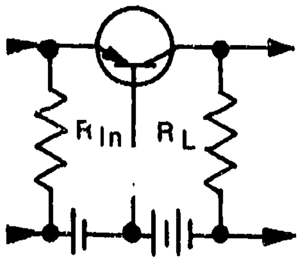
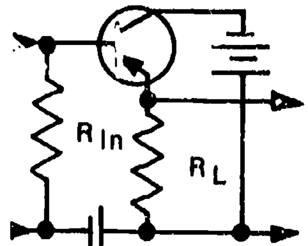
NPN Circuit



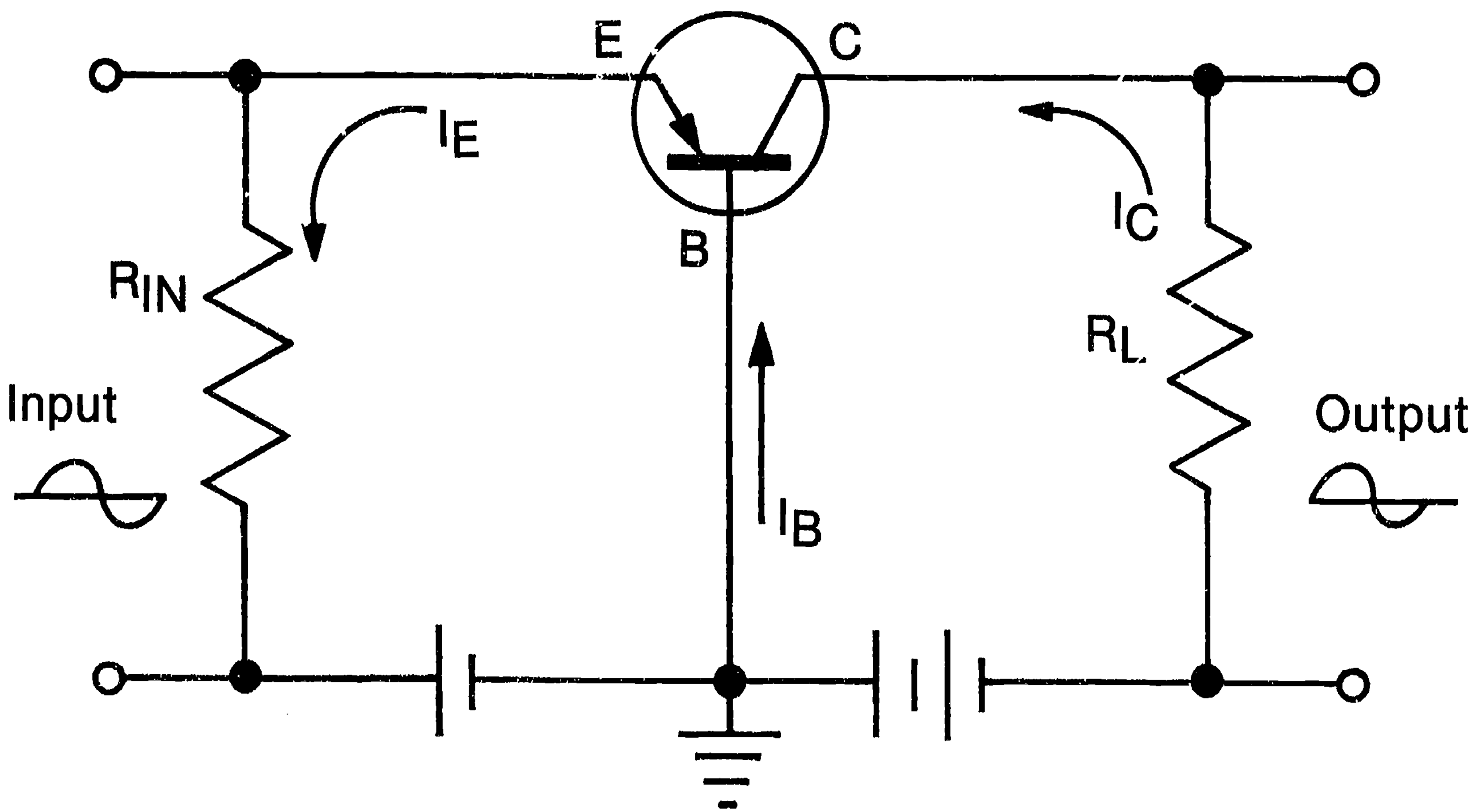
$I_E = I_B + I_C$

PNP Circuit

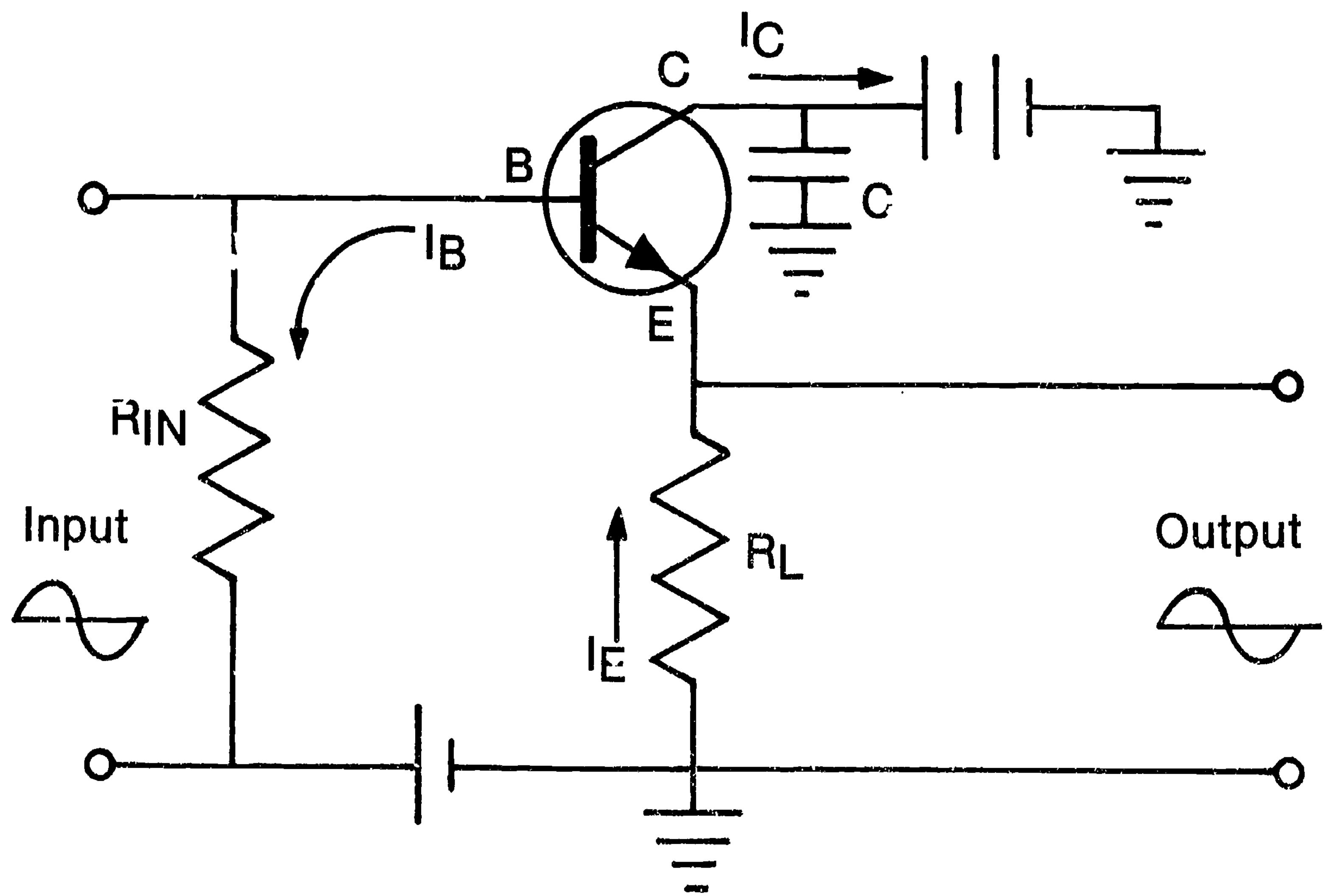
Comparison of Transistor Circuit Combinations

Characteristics	 Common Emitter	 Common Base	 Common Collector
Voltage Gain $A_e = \frac{E\ out}{E\ in}$	High (300)	High (500)	Low Less Than One
Current Gain $A_i = \frac{I\ in}{I\ out}$	High (50)	Low (0.97)	High (50)
Power Gain $A_p = \frac{P\ out}{P\ in}$	Very High (12,000)	Medium (400)	Low (30)
Input Impedance	Medium (1,000)	Low (60)	High (400,000)
Output Impedance	Medium (50,000)	High (1 M)	Low (100)
Phase Reversal	Yes	No	No

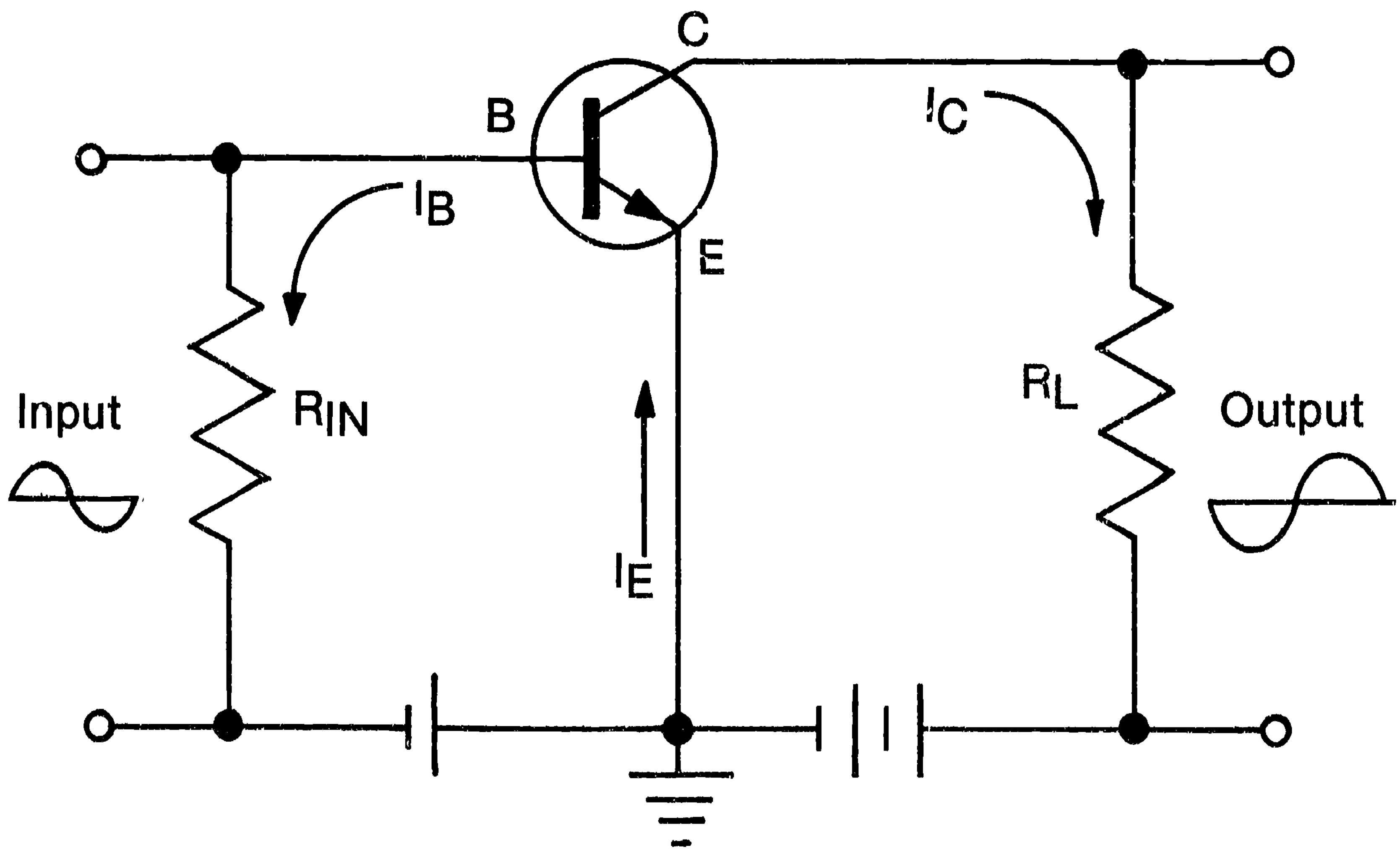
Common Base Amplifier (PNP) Circuit



Common Collector Amplifier (NPN) Circuit

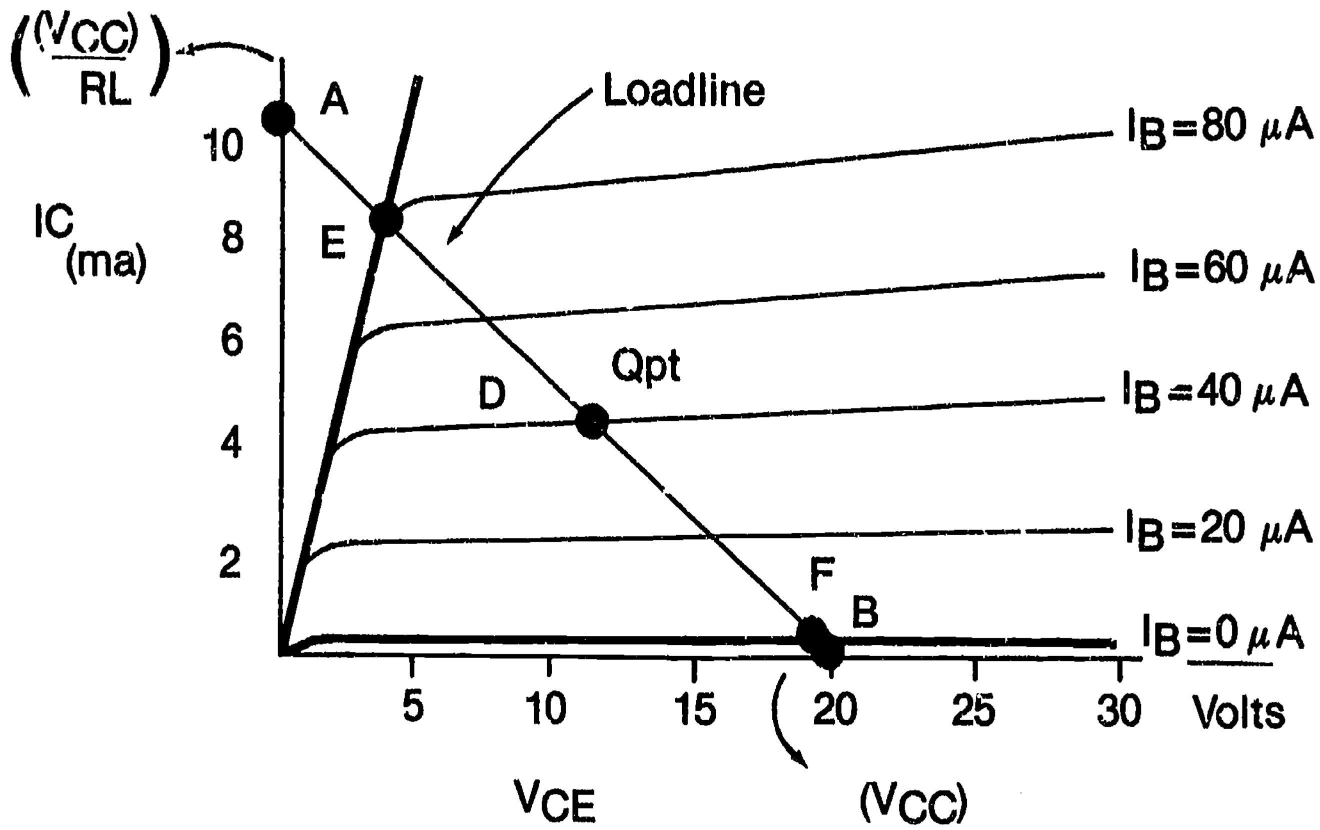


Common Emitter Amplifier (NPN) Circuit



Transistor Load Line

(Class A Operation)



Procedure

A. Locate maximum current point

$$\frac{V_{CC}}{RL} = I_{max}$$

B. Locate maximum voltage point

$$V_{CE} = V_{CC}$$

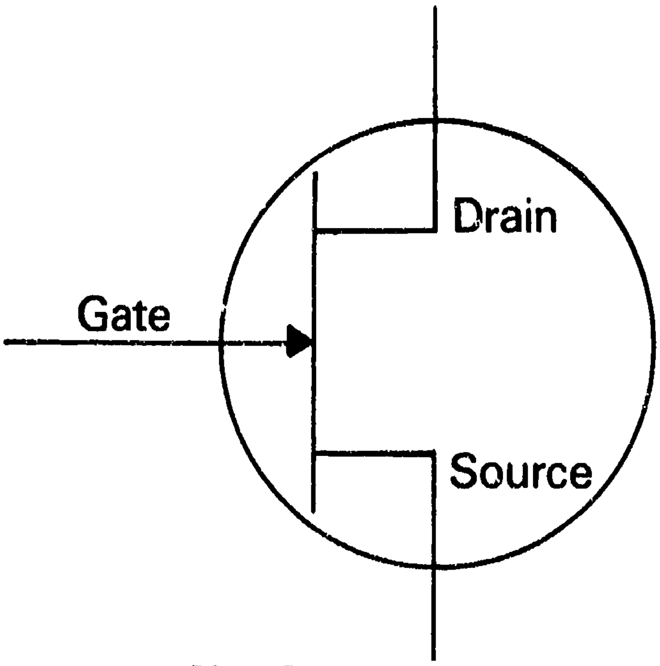
C. Connect these two point with a straight line

D. Locate operating point, Q point, by the intersection of the I B line with the load line

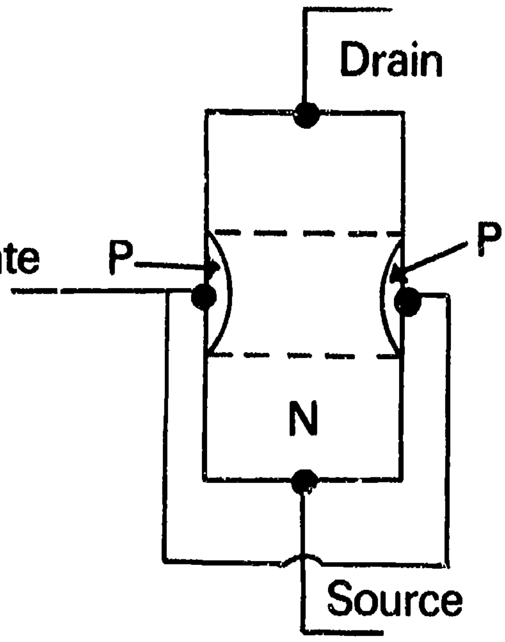
E. Saturation point

F. Cut off point

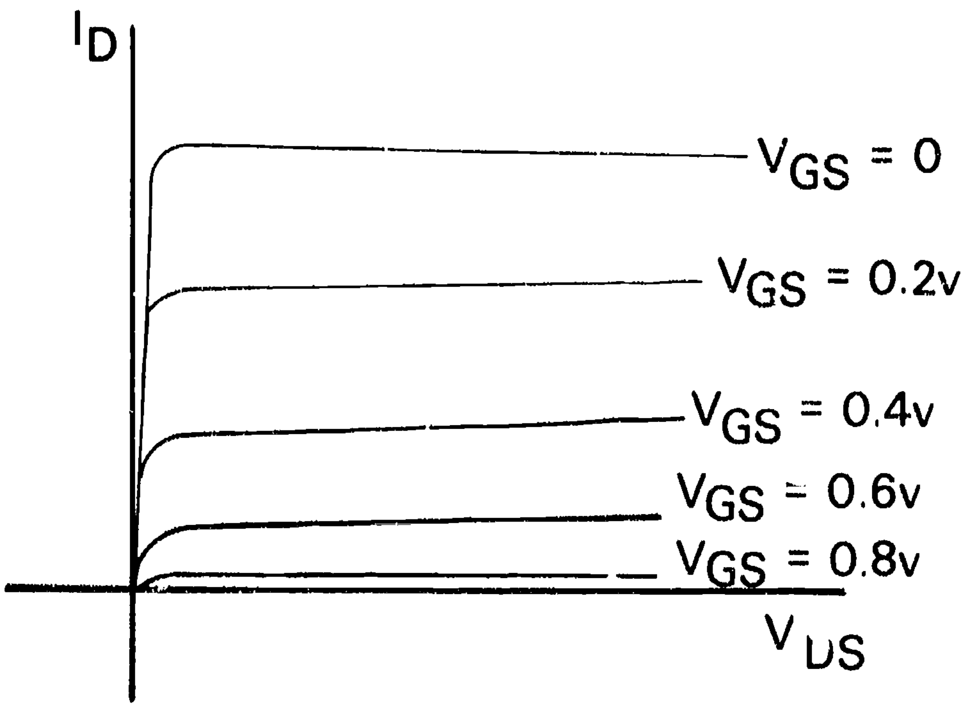
Junction Field Effect Transistor
JFET



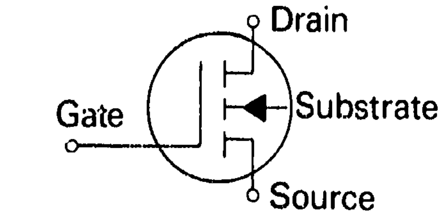
N - Channel Junction
Field Effect Transistor



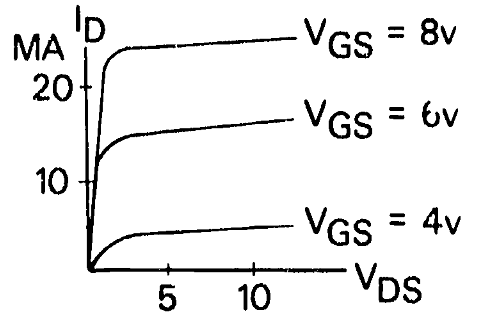
JFET Construction



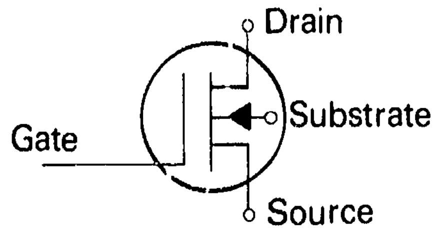
Insulated Gate Field Effect Transistor (IGFET) or Metal Oxide Semiconductor Field Effect Transistor (MOSFET)



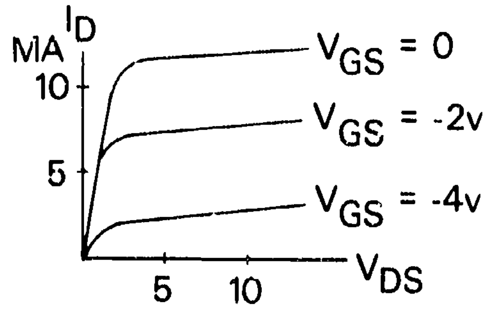
Enhancement Mode
(Type N-Channel)
Schematic Symbol



Output Characteristic Curves

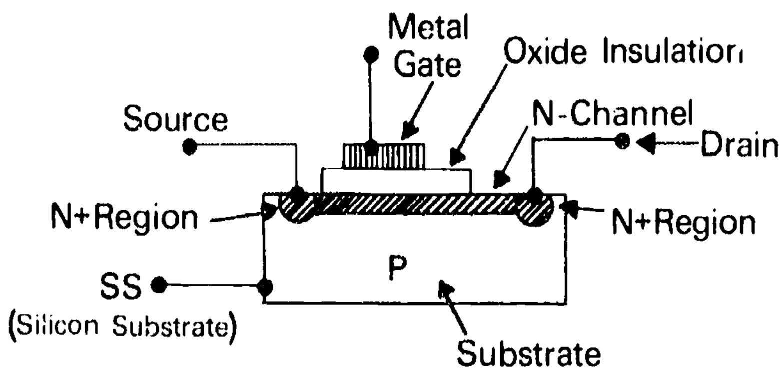


Depletion Mode
(Type N-Channel)
Schematic Symbol



Output Characteristic Curves

Arrow always points toward the N-type material.



MOSFET Construction – Depletion-Type

DISCRETE SEMICONDUCTOR DEVICES AND CIRCUITS
UNIT IV

ASSIGNMENT SHEET #1 — LABEL THE PARTS OF A TRANSISTOR CIRCUIT

Directions: On the transistor circuit below, label or draw the following:

A. Category of transistor

1. NPN

2. PNP

B. Leads

1. Emitter

2. Base

3. Collector

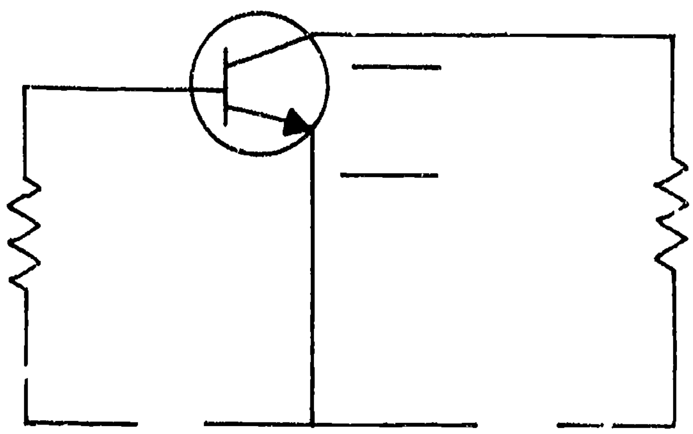
C. Correct battery-bias supplies

D. Electron circuit flow

1. I_E

2. I_B

3. I_C



DISCRETE SEMICONDUCTOR DEVICES AND CIRCUITS UNIT IV

ASSIGNMENT SHEET #2 — CONSTRUCT A LOAD LINE FOR A COMMON-EMITTER AMPLIFIER CIRCUIT

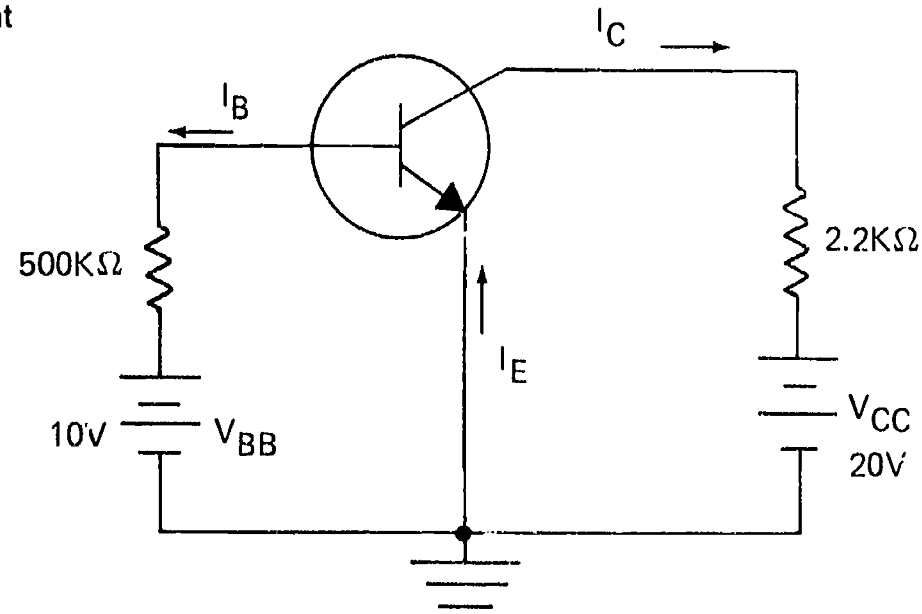
Directions: Construct a load-line for the transistor circuit shown below and locate the following points:

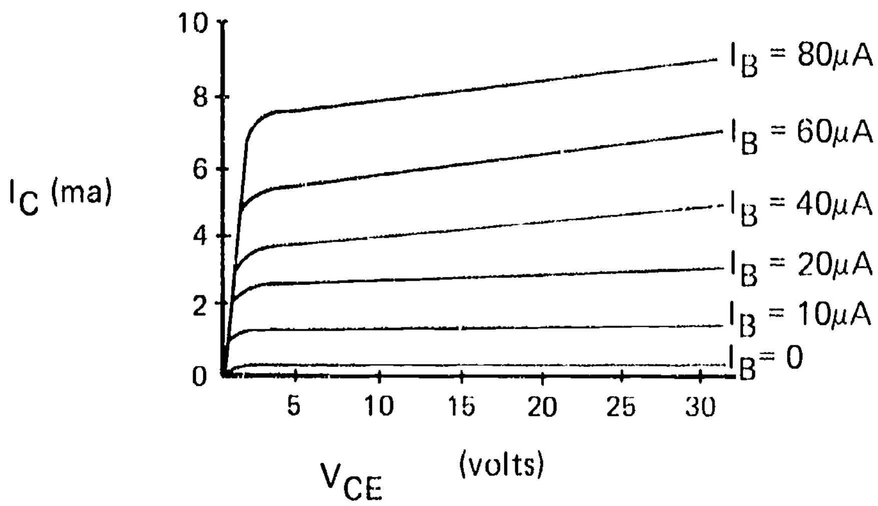
(NOTE: The ▷ symbol indicates an amplifier circuit.)

A. Q point (operating point)

B. Saturation point

C. Cutoff point

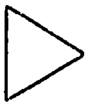




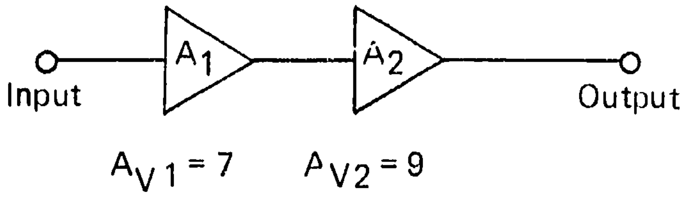
DISCRETE SEMICONDUCTOR DEVICES AND CIRCUITS
UNIT IV

ASSIGNMENT SHEET #3 — CALCULATE THE OVERALL GAIN OF MULTISTAGE AMPLIFIER CIRCUITS

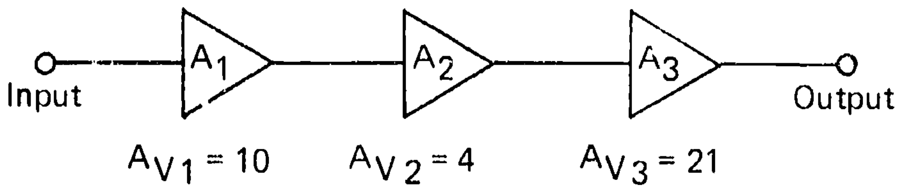
Directions: Given the amplifier block diagrams below, calculate the overall gain and express in dB.

NOTE:  is a symbol for an amplifier.

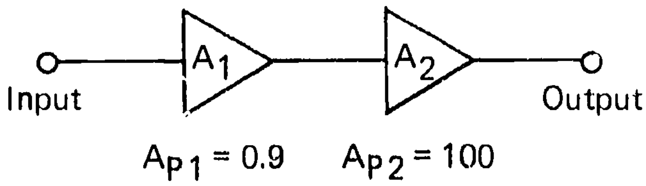
A.



B.



C.



DISCRETE SEMICONDUCTOR DEVICES AND CIRCUITS UNIT IV

ASSIGNMENT SHEET #4 — COMPUTE VOLTAGE, CURRENT, AND POWER STAGE GAIN IN DECIBELS

Directions: Using the formulas given below, convert the gain values to their equivalent db value.

A. Formulas

1. Voltage gain — 20 log Av = gain in dB
2. Current gain — 20 log Ai = gain in dB
3. Power gain — 10 log Ap = gain in dB

Example: If voltage gain is 100, then the gain in dB would be 20 times the log of 100 which is equal to 20 × 2 or a dB gain of 40

B. Problems

1. Voltage gain
   a. $A_v = 100$ dB gain = ____________
   b. $A_v = 75$ dB gain = ____________
2. Current gain
   a. $A_i = 1$ dB gain = ____________
   b. $A_i = .96$ dB gain = ____________
3. Power gain
   a. $A_p = 25$ dB gain = ____________
   b. $A_p = 2$ dB gain = ____________

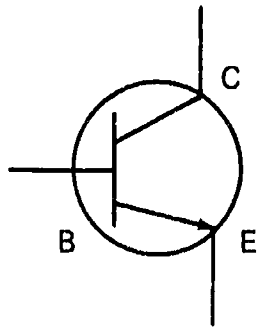
DISCRETE SEMICONDUCTOR DEVICES AND CIRCUITS
UNIT IV

ANSWERS TO ASSIGNMENT SHEETS

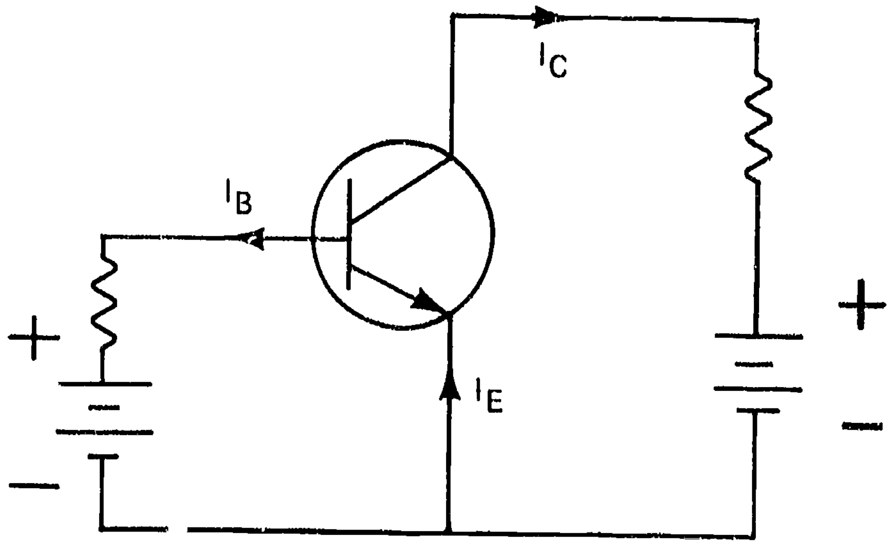
Assignment Sheet #1

A. NPN

B.

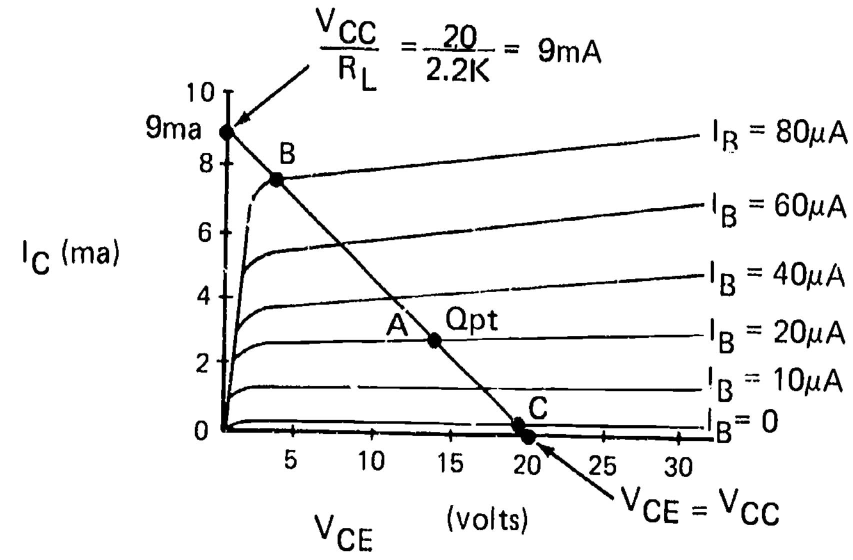


C.



ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #2



A. Qpt = $I_B = \frac{10V}{500K} = 20\mu A$

B. Saturation point

C. Cut off point

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #3

A. Av Total = 35.99 db

A_{V1} (7) × A_{v2} (9) = 63

A_vdB = 20 log 63

B. A_{v1} = 10 A_{v2} = 4 A_{v3} = 21

A_v Total = 10 × 4 × 21 = 840

A_v Total db = 20 log 840 = 58.49

C. A_{p1} = 0.9 Ap_2 = 100 = 90

A_{p1}dB = .46 Ap_2 = 20dB = 19.54

A_v Total = (0.9) (100) = 90

A_v Total dB = (10 log .9) = 10 log 100

-.46 + 20 = 19.54

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #4

A. 1. 40 db

2. 37.5 db

B. 1. 0 db

2. -0.35 db

C. 1. 13.98 db

2. 3.01 db

DISCRETE SEMICONDUCTOR DEVICES AND CIRCUITS UNIT IV

JOB SHEET #1 — PERFORM A STATIC TEST OF SEMICONDUCTOR DIODES

A. Equipment and materials needed

1. Two multimeters
2. Three different types of diodes from your instructor

B. Procedure

1. Determine the polarity of your ohmmeter leads by connecting them to a voltmeter.
2. Mark the polarity of the ohmmeter leads.
3. Connect the positive lead of the ohmmeter to the anode of the diode and the negative lead of the ohmmeter to the cathode of the diode.
4. Read and record the ohmmeter reading in the data table below.

   (NOTE: The ohmmeter should be on a R × 100 scale to avoid possible damage to the diode.)
5. Reverse the ohmmeter connection to the diode, read and record the ohmmeter reading.
6. Determine from the ohmmeter reading whether the diode is good or bad.

   (NOTE: A good diode will have a low ohmic reading in the forward-biased direction and a high ohmic reading when reverse biased.)
7. Repeat the above procedure for each of your diodes.

DATA TABLE 1 — STATIC TEST

DIODE	FORWARD RESISTANCE	REVERSE RESISTANCE	GOOD OR BAD
D_1			
D_2			
D_3			
D_4			

8. Return equipment and materials to proper storage area.

DISCRETE SEMICONDUCTOR DEVICES AND CIRCUITS
UNIT IV

JOB SHEET #2 — TEST A SEMICONDUCTOR DIODE AND PLOT THE CHARACTERISTIC CURVES

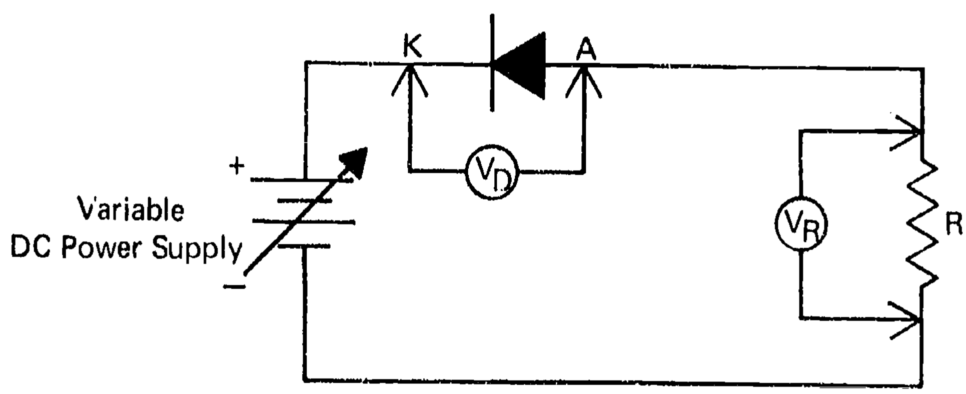
A. Equipment and materials needed

1. Variable DC power supply (0-30 volts)
2. 220 ohm, 5 watt resistor
3. Silicon diode (1N4004 or equivalent) optional germanium diode
4. Two multimeters
5. Graph paper

B. Procedure

1. Connect the following circuit for a reverse-biased diode but do not apply power.

   (NOTE: Connect the multimeters as voltmeters and observe the proper polarity.)



2. Apply power.
3. Read and record V_D (voltage across the diode) and V_R (voltage across the resistor) when the power supply is set a 0, 1, 2, 3, 4, 5, 10, 15, 20, and 25 volts.

   (NOTE: The peak inverse voltage rating of the diode must be equal to or greater than 25 volts.)

4. Turn the power supply off.
5. Reverse the diode connection in the circuit so it will be forward biased.

JOB SHEET #2

6. Read and record V_D and V_R for power supply settings of 0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0 9, 1.0, 2, 4, volts.

7. Compute the current flowing in the circuit for each reading taken in Steps 2 and 5.

8. Draw a graph of the diode forward and reverse characteristic curve.

   (NOTE: The horizontal axis should be V_D and the vertical axis should be I_D.)

9. Check your calculations and your graph with your instructor.

10. Return equipment and materials to proper storage area.

JOB SHEET #2

DATA TABLES

TABLE I - REVERSE BIAS

V Supply	0_V	1_V	2_V	3_V	4_V	5_V	10_V	15_V	20_V	25_V
V_O										
V_R										

TABLE II - FORWARD BIAS

V Supply	0.0	$.1_V$	$.2_V$	$.3_V$	$.4_V$	$.5_V$	$.6_V$	$.7_V$	$.8_V$	$.9_V$	1.0_V	2.0_V	4.0_V
V_D													
V_R													

JOB SHEET #2

DISCRETE SEMICONDUCTOR DEVICES AND CIRCUITS
UNIT IV

JOB SHEET #3 — TEST TRANSISTORS

A. Equipment and materials needed

1. Assortment of transistors (both signal and power types)

2. Ohmmeter

3. Transistor tester (if available)

B. Procedure

1. Carefully examine the assortment of transistors and note the differences in size, shape, and lead arrangements.

2. Choose two signal transistors and one power transistor.

3. Determine which ohmmeter lead is positive and which is negative.

   (NOTE: Either get this from the manufacturer's instruction book or by measuring the voltage with a voltmeter.)

4. Identify the emitter, base, and collector leads.

5. Place the ohmmeter on R × 100 range.

   (NOTE: This is necessary because there may be too much voltage if the ohmmeter is placed in a high range.)

6. Determine the forward-biased emitter base junction.

   a. Place the positive ohmmeter lead on the emitter lead and the negative ohmmeter lead on the base lead.

   b. Note the resistance reading.

   c. Place the negative ohmmeter lead on the emitter and the positive ohmmeter lead on the base.

   d. Note the resistance reading.

   e. Compare the two resistance readings.

   f. Repeat Steps 1 through 5 for the collector-base junction.

JOB SHEET #3

g. From above reading, determine whether the transistor is good or bad.

h. If the transistor tested was good, state whether it is PNP or NPN.

i. If the transistor tested was bad, state where it was open or shorted.

7. If your lab has a transistor tester, following the instructions given in operations manual, check the transistor.

8. Check your findings with your instructor.

DATA CHART

EMITTER-BASE JUNCTION

R_{EB} ____________

R_{BE} ____________

COLLECTOR-BASE JUNCTION

R_{CB} ____________

R_{BC} ____________

TYPE OF TRANSISTOR ____________

9. Return equipment and materials to proper storage area.

DISCRETE SEMICONDUCTOR DEVICES AND CIRCUITS
UNIT IV

JOB SHEET #4 -- CONSTRUCT AND TEST A COMMON-EMITTER CIRCUIT

A. Equipment and materials needed

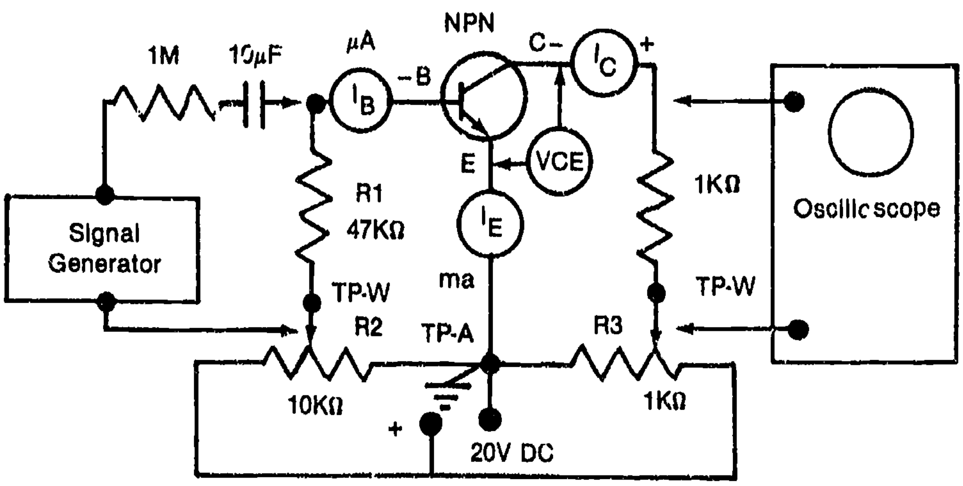
1. NPN transistor
2. Ammeters (zero to 50 mA range)
3. Voltmeter
4. Oscilloscope
5. Audio signal generator
6. Resistors, one-1M Ω, one-47K Ω, one-1K Ω, one-10K Ω and one-1K Ω potentiometer (use 1/2 watt resistor)

   (NOTE: Resistor values may vary for your particular transistor.)

7. 10μF capacitor
8. Power supply 0-20VDC

B. Procedure

1. Do not turn on power supply at this time.
2. Connect the circuit as shown below.



(NOTE: If you do not have a microammeter for I_B, insert a 100 Ω resistor in series and use your voltmeter to read the voltage drop. Then, compute the current from the voltmeter reading and the value of the resistor.)

JOB SHEET #4

3. Have your instructor approve your circuit wiring.

4. Set the potentiometer to zero ohms between test points A and W.

5. Set the power supply for 20V DC.

6. Adjust the collector potentiometer R_3 until V_{ce} is 6.0 volts.

7. Adjust the base resistor R_2 until the base current, I_B, is 20 microamperes.

8. Recheck V_{ce} to see that it has remained at 6.0 volts.

   (NOTE: It may be necessary to readjust R_3 to maintain V_{ce} = 6 volts and I_a = 20μA.)

9. Read and record I_c when V_{ce} = 6.0v and I_B = 20μA.

10. Using your voltmeter, read and record the base-emitter DC voltage.

11. Increase the base resistor, R_2, until I_B is 40 microamperes.

12. Recheck V_{ce} = 6.0 volts, adjust R_3 as needed.

13. Read and record I_c when V_{ce} = 6.0v and I_B = 40μA.

14. Connect the signal generator across the 47K Ω input resistor, and set the output frequency to 1 KHz.

15 Turn the signal generator on and adjust the input signal, e_{in}, across the input resistor R_1 to 10 mV rms value.

16. Use the oscilloscope to view this waveshape and make a sketch of the waveshape showing frequency and amplitude.

17. Move the oscilloscope to observe the output voltage across the 1K Ω output resistor.

18. Make a sketch of the output waveform, showing amplitude and frequency.

19. Compute and record the output voltage, e_0, in rms.

20. Compute the output current, i_{out}, by dividing the output voltage, e_o, by the load resistance, 1KΩ.

21. Measure the rms voltage across the 1 M Ω series resistor.

22. Compute and record the input current i_{in}.

23. Calculate the current gain by dividing I_{out} by i_{in}, and express your answer in dB.

24. Have your instructor check your calculations.

25. Return equipment and materials to proper storage area.

JOB SHEET #4

Data Table

DC Measurements

	I_E	I_B	I_C	V_{BE}
V_{CE} = 6v		20μA		
V_{CE} =		40μA		
A_I =				

AC Measurements

	P-P	rms
V_{in}		
i_{in} calculated		
V_{out}		
i_{out}		
A dB= Cal.		
A_IdB cal.		
A_pdB cal.		

DISCRETE SEMICONDUCTOR DEVICES AND CIRCUITS
UNIT IV

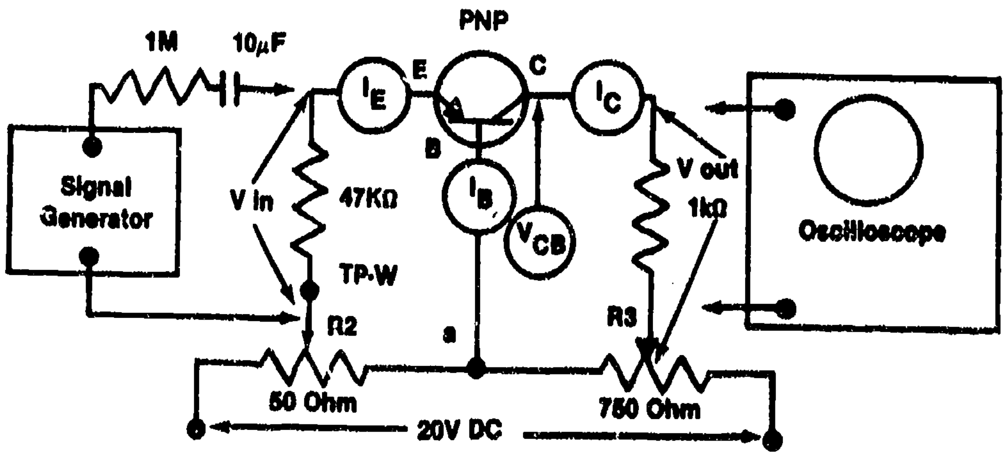
JOB SHEET #5 — CONSTRUCT AND TEST A COMMON-BASE CIRCUIT

A. Equipment and materials needed

1. PNP transistor
2. Variable power supply (0-20V DC)
3. Oscilloscope
4. Audio signal generator
5. Voltmeter
6. Microammeter (or multimeter)
7. Two milliameters (or multimeter)
8. Resistors, one-1KΩ, one-47KΩ, one-1MΩ (use 1/2 watt resistor)
9. Capacitor — 10μF
10. Potentiometers — 50 Ω, 1W & 750 Ω, 1W

B. Procedure

1. Do not turn on power supply at this time.
2. Connect the circuit as shown below.



3. Have your instructor check your circuit wiring.

JOB SHEET #5

4. Adjust potentiometer R_2 until the resistance between test point A and test point W reads zero ohms.

5. Turn on power supply and set for 20 volts.

6. Adjust potentiometer R_3 until V_{CB} reads 5.8 volts.

7. Adjust potentiometer R_2 until the collector current reads 25 mA.

8. Read and record I_C, I_B, and I_E.

9. Adjust potentiometer R_2 to obtain a 20 microamp increase in I_B.

10. Measure and record I_C, I_B, and I_E.

11. Measure V_{EB} with the voltmeter.

12. State whether your transistor is germanium or silicon.

13. Connect the signal generator across to 47KΩ input resistor.

14. Set the signal generator for 1 KHz.

15. Adjust the signal generator until the voltage across the 47KΩ input resistor reads 10mV rms.

16. Using the oscilloscope, observe the waveshape of the voltage e_{in} across the 47KΩ input resistor.

17. Sketch the waveshape of e_{in} showing frequency and amplitude.

18. Measure the rms voltage across the 1MΩ resistor and compute the rms input current, i_{in}.

19. Using the oscilloscope, observe the waveshape of the voltage e_o across the 1KΩ load resistor.

20. Sketch the waveshape of e_o showing amplitude and frequency.

21. Calculate the rms value of e_o.

22. Calculate the rms value of the output current, i_o.

23. Calculate the voltage gain of the circuit.

24. Express the voltage gain of the circuit in db.

25. Have your instructor check your calculations.

    (NOTE: Remember to convert peak-to-peak voltage readings from scope to rms value.)

26. Return equipment and materials to proper storage area.

JOB SHEET #5

Data Table

DC Measurements

(NOTE: △ indicates "change in.")

	VCE	I_C	I_B	I_E	$\frac{\Delta I_C}{\Delta I_B}$
Test 1 (Step H)	25μA				
Test 2 (Step J)					

AC Measurements

	P-P	RMS
e_{in}		
V_{in}		
i_{in}		
$e_{o(VIx)}$		
i_o		
A_v		
A_vdB		

DISCRETE SEMICONDUCTOR DEVICES AND CIRCUITS
UNIT IV

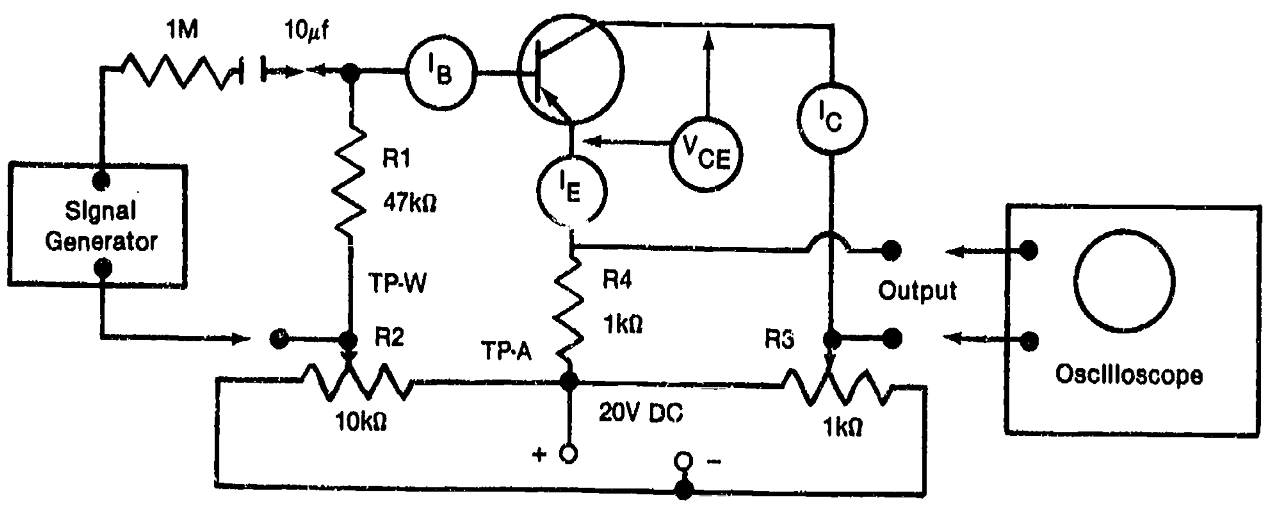
JOB SHEET #6 — CONSTRUCT AND TEST A COMMON-COLLECTOR CIRCUIT

A. Equipment and materials needed

1. Variable power supply (0-20V)
2. PNP transistor
3. Oscilloscope
4. Signal generator
5. Voltmeter
6. 10μf capacitor
7. Resistors, one-47KΩ, one-1KΩ, one-1MΩ (use 1/2 watt resistor)
8. Microammeter (multimeter)
9. Two milliameters (multimeters)
10. Potentiometers, one-10KΩ, one-1KΩ (use 1 watt potentiometer)

B. Procedure

1. Do not turn on power supply at this time.
2. Connect recircuit as shown below.



JOB SHEET #6

3. Have your instructor approve your circuit wiring.
4. Set potentiometer R_2 to zero ohms between test points A and W.
5. Set the power supply to 20 volts.
6. Adjust potentiometer R_2 until I_B reads $20\mu A$.
7. Adjust potentiometer R_3 until V_{ce} as measured by the voltmeter reads 6 volts.
8. Measure and record I_E, I_B, and I_C.
9. Adjust potentiometer R_2 until I_B reads $40\mu A$.
10. Measure and record I_E, I_B, I_C.
11. Measure V_{BE} with the voltmeter and determine if the transistor is germanium or silicon.
12. Connect the signal generator across the input resistor (47ΩK).
13. Connect the voltmeter across the 47KΩ resistor and adjust the signal generator at 1KHz until the voltmeter reads 10mV, rms.
14. Read the rms voltage across the 1 megohm resistor.
15. Calculate the input current.
16. Sketch the waveshape of the input voltage showing both amplitude and frequency, as displayed on the oscilloscope.
17. Sketch the observed output waveshape across the 1KΩ load resistor and calculate the rms output voltage.
18. Calculate the rms value of the output current, i_o.
19. Calculate the circuit's power gain and express the value in db.
20. Have your instructor check your calculations.
21. Return equipment and materials to proper storage area.

JOB SHEET #6

Data Table

DC Measurements

V_{CE}	I_C	I_B	I_E	$\frac{\triangle I_C}{\triangle I_B}$
6.0V		20μA		
6.0V		40μA		

AC Measurements

	P-P	RMS
I_{in}		
I_{out}		
V_{ik}		
I_{out}		
V_{1m}		
I_{in}		
A_I		
A_idB		

DISCRETE SEMICONDUCTOR DEVICES AND CIRCUITS
UNIT IV

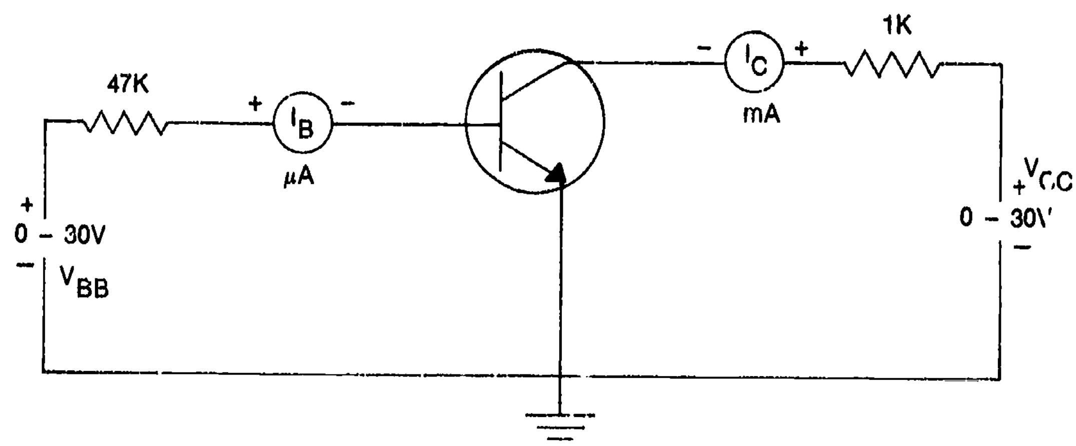
JOB SHEET #7 — PLOT A TRANSISTOR OUTPUT CHARACTERISTIC CURVE

A. Tools and equipment needed

1. NPN transistor
2. One-microammeter and two-milliameters (or three multimeters)
3. Voltmeter
4. Two power supplies (0-20V DC)
5. Graph paper
6. 1KΩ and 47 KΩ resistors

B. Procedure

1. Do not turn on power supply at this time.
2. Connect the circuit as shown below.



3. Set the V_{BB} power supply until I_B reads 20μA.
4. Record this value.
5. Adjust the V_{CC} power supply for voltages from 0 to 15 volts and record the value of I_C for each voltage reading.

   (NOTE: It will be necessary to use small voltage clamps for V_{CC} between 0 and 5 volts. This will allow more measurements for I_C at the points where I_C rises rapidly.)

6. Set V_{CC} back to 0 volts.

JOB SHEET #7

7. Readjust V_{BB} for I_B equal to 40μA.

8. Record this value.

9. Readjust V_{CC} from 0 to 15 volts, recording the value of I_C at each value of V_{CC}.

10. Set V_{CC} equal to 0 volts.

11. Readjust V_{BB} for I_B equal to 60μA.

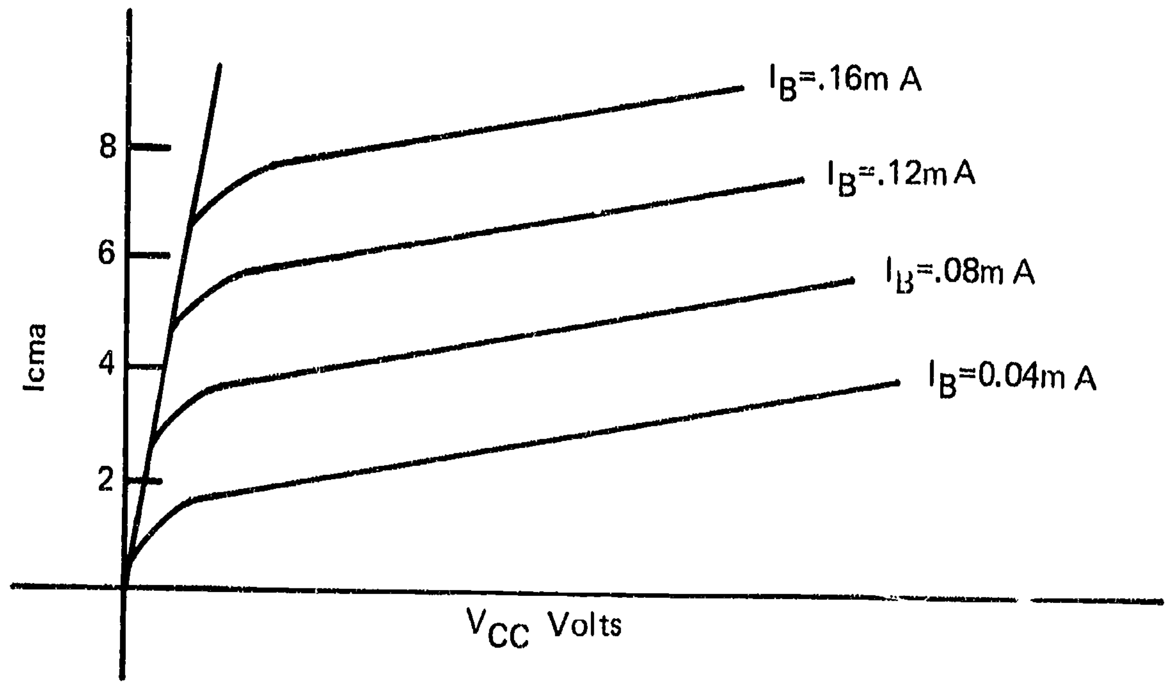
12. Record this value.

13. Readjust V_{CC} from 0 to 15 volts, recording the values of I_C at each value of V_{CC}.

14. Ask your instructor how many settings of I_B you should use.

15. Plot a graph showing the relationship between I_B, I_C, and V_{CC}.

    (NOTE: The following is a sample of what your graph should look like.)



16. Return equipment and materials to proper storage area.

DATA TABLE

$I_B = 20\ \mu A$

V_{CC}	0.2	0.4	0.6	0.8	1.0	1.5	2.0	2.5	3.0	5.0	7.5	10.0	15.0
I_C													

$I_B = 40\ \mu A$

V_{CC}	0.2	0.4	0.6	0.8	1.0	1.5	2.0	2.5	3.0	5.0	7.5	10.0	15.0
I_C													

$I_B = 60\ \mu A$

V_{CC}	0.2	0.4	0.6	0.8	1.0	1.5	2.0	2.5	3.0	5.0	7.5	10.0	15.0
I_C													

DISCRETE SEMICONDUCTOR DEVICES AND CIRCUITS
UNIT IV

JOB SHEET #8 — CONSTRUCT AND TEST A SINGLE-ENDED AMPLIFIER

A. Tools and equipment needed

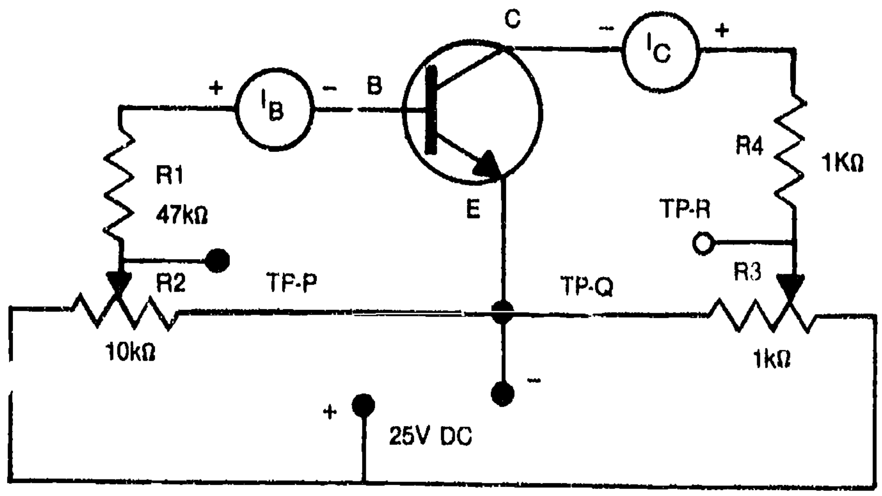
1. NPN transistor
2. 47kΩ resistor
3. 1kΩ resistor
4. One microammeter and one milliameter (or two multimeters)
5. 22kΩ resistor
6. 220kΩ resistor
7. 1.5kΩ resistor
8. 4.7kΩ resistor
9. DC power supply (0-25V)
10. Soldering iron or soldering gun

    (NOTE: All resistors are 1/2 watt.)

11. 1kΩ potentiometer
12. 10kΩ potentiometer

B. Procedure

1. Wire the circuit shown below.



JOB SHEET #8

2. Adjust potentiometer R_2 so that the voltage between test points Q and P is zero.

3. Plug in soldering iron or gun.

4. After instructor approves wiring, turn on the power; then adjust R3 for 18 volts between test points Q and R.

5. Adjust R2 to 50 microamps of base current, I_B.

6. Record the value of collector current, I_C.

7. Hold hot soldering gun or iron near the transistor case for three seconds.

8. Record the maximum value of the collector current.

9. Remove iron and wait until the collector current is approximately the same value as that recorded in Step 4.

10. Remove power and insert a 1.5kΩ resistor (R_e) between the emitter and ground.

11. Apply power and readjust R2 to 50 microamps base current.

    (NOTE: It may be necessary to readjust R_3 for 18 volts.)

12. Read and record the collector current.

13. Repeat Steps 7 and 9.

14. Remove power and replace 1.5kΩ with a 4.7kΩ resistor.

15. Repeat Steps 7 and 9.

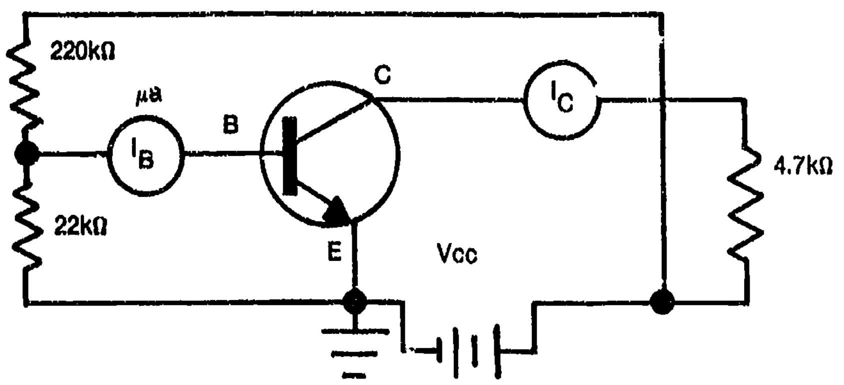
16. Calculate the changes in collector current, I_C, for each of the three conditions as shown in the table below.

TABLE

R_E	I_B	I_C (Cool)	I_C (Hot)	$\triangle I_C$
0				
1.5kΩ				
4.7kΩ				

JOB SHEET #8

17. Turn off the power supplies and rewire circuit as shown below.



18. After instructor has checked the wiring, turn on the power supply and set it for an output of 15 volts.

19. Read and record I_B and I_C.

20. Hold the soldering gun or iron close to the transistor and heat it for 3 seconds.

21. Read and record the maximum value of I_C.

22. Remove power and leave one end of the 220kΩ resistor connected to the base.

23. Remove the other end from the power supply and connect it to the collector of the transistor.

24. Apply power and read and record I_B and I_C.

25. Hold the soldering gun close to the transistor and heat it for 3 seconds.

26. Read and record the maximum value of I_C.

27. Compute the change observed in I_C in these two circuits and record in the table below.

	I_B	I_C (Cool)	I_C (Hot)	$\triangle I_C$
Voltage Divider across V_{CC}				
Collector Feedback				

28. Check completed tables with your instructor.

29. Return equipment and materials to proper storage area.

DISCRETE SEMICONDUCTOR DEVICES AND CIRCUITS
UNIT IV

JOB SHEET #9 — CONSTRUCT AND TEST A FIELD EFFECT TRANSISTOR AMPLIFIER

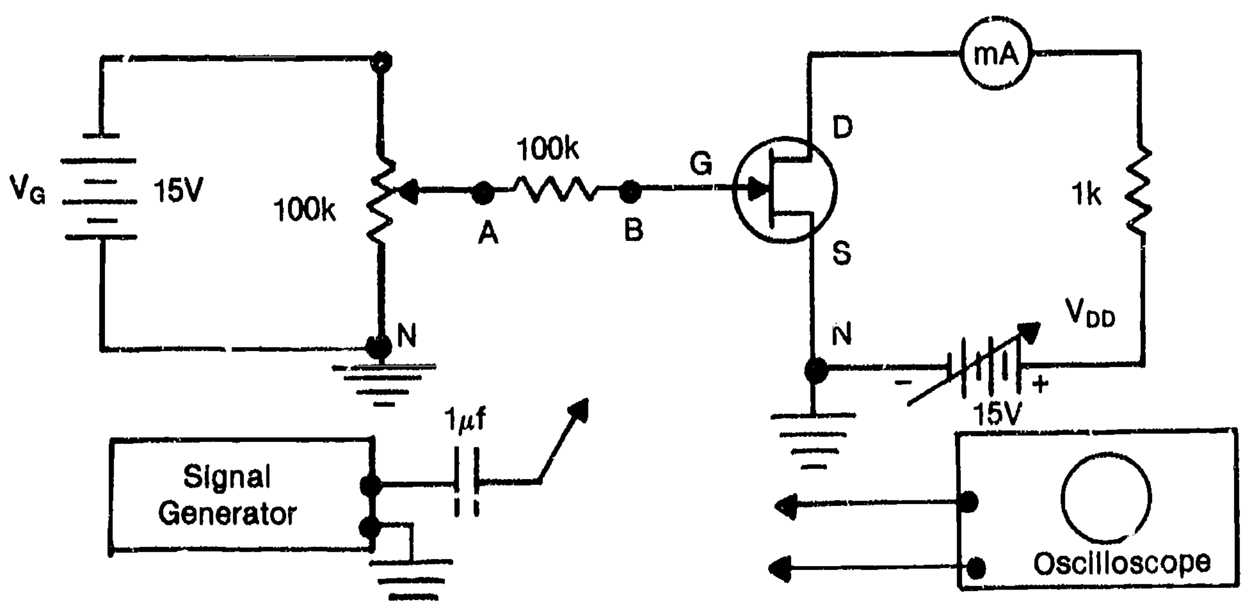
A. Equipment and materials needed

1. 2N5555 JFET or equivalent
2. 2-15 volt power supplies
3. 100kΩ resistor
4. 1kΩ resistor
5. 100kΩ potentiometer
6. 1μF capacitor
7. Signal generator
8. Oscilloscope
9. Multimeter
10. Milliammeter
11. Graph paper

B. Procedure

1. Wire the following circuit.

   (CAUTION: Do not turn on the power at this time.)



JOB SHEET #9

2. Turn on the drain power supply (V_{DD}) and observe the drain current on the milliammeter meter.

3. Turn on the gate power supply (V_G and observe any change in drain current.

4. Adjust the potentiometer until the drain current is barely measurable, then record the voltage at Point A to ground.

5. Recheck to see that both power supplies are set to 15 volts (with polarities as shown in the schematic).

6. Adjust the potentiometer until the drain current is at 4 mA, then record the voltage at Point A to ground.

7. Adjust the potentiometer until the drain current is at 5 mA, then record the voltage at Point A to ground.

8. Short out the milliammeter.

9. While reading the drain to source voltage with a multimeter, adjust the potentiometer until the voltage equals +10 volts.

10. Connect the signal generator through a 1 μF capacitor to Point B.

11. Adjust the signal generator for a signal of 1 kHz, and an amplitude of 0.1 volt peak-to-peak.

12. Connect the oscilloscope across the 1kΩ load resistor.

13. Record the amplitude of the signal voltage across the load resistor.

14. Make a scale drawing of both input and output voltage waveshapes.

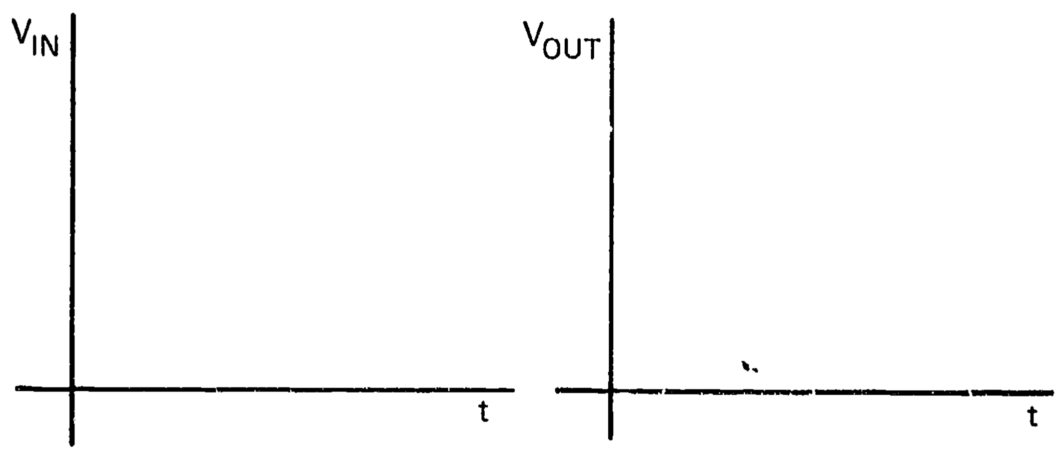
15. Check your results and your drawing with your instructor.

16. Return equipment and materials to proper storage area.

JOB SHEET #9

Data Table

I_D	V_{AN}	
Initial		
4mA		
5mA		



DISCRETE SEMICONDUCTOR DEVICES AND CIRCUITS UNIT IV

NAME ____________________

TEST

1. Match the terms on the right with their correct definitions.

(NOTE: Answers to questions a.-o. appear on this page.)

_____a.	Two or more atoms sharing electrons in their outer shell to form a stable molecule	1. Bonding
_____b.	A pure crystal of material	2. Covalent bonding
_____c.	A material to which an impurity has been added	3. Diode
_____d.	A material which has a resistivity between conductors and insulators whose conductivity increases with temperature	4. Majority carriers
_____e.	The process of adding impurities to an intrinsic material	5. Doping
_____f.	The region where N-type and P-type semiconductor materials join together	6. Intrinsic material
_____g.	External electric potential applied to a P-N junction	7. P-N junction
_____h.	A two-terminal semiconductor device consisting of a P-N junction which allows majority carriers to flow in one direction	8. Bias
_____i.	The holding together of atoms to form a molecule	9. Depletion region
_____j.	Electrons in N-type materials and holes in P-type materials	10. Peak inverse voltage
_____k.	Electrons in P-type materials and holes in N-type materials	11. Light emitting diode
_____l.	The absence of electrons in a covalent bond	12. Holes
_____m.	The maximum reverse-bias voltage which can be applied to a P-N junction without damage to the junction	13. Extrinsic material
_____n.	The junction area that has no free charges	14. Semiconductor
_____o.	A diode specially doped to emit light when forward biased	15. Minority carriers

TEST

(NOTE: Answers to questions p.-t. appear on this page.)

_____p.	A diode made from photo-sensitive material whose resistance decreases with increased light	16. Photo-diode
		17. Base
_____q.	The region in a transistor from which charge carriers that are minority carriers in the base are injected into the base	18. Collector
		19. Emitter
_____r.	Denotes the method of supplying an input signal or obtaining an output signal from an amplifier in which one side of the input or output is connected to ground	20. Single-ended amplifier
_____s.	The region in a bipolar junction transistor from which carriers flow through the emitter junction into the base	
_____t.	A region which lies between an emitter and collector of a transistor into which minority carriers are injected	

2. Complete the following statements related to the characteristics of semiconductors by inserting the word(s) which best complete(s) each statement.

   a. Two important semiconductor materials of which solid-state devices are made are ____________ and ____________.

   b. An atom of semiconductor material has four ____________ electrons and does not easily give up or accept electrons.

   c. Semiconductor atoms are bonded together in a crystalline structure through ____________ bonding.

   d. When a difference of potential is applied across a semiconductor material, current flows in the form of both ____________ and ____________.

3. Complete the following statements concerning characteristics of N-type and P-type semiconductors by inserting the word which best completes each statement.

   a. The conductivity of semiconductor materials can be increased significantly through a process called ____________.

   b. When pure intrinsic semiconductor materials such as germanium or silicon are doped with a pentavalent such as arsenic, they become ____________ N-type semiconductor materials.

   c. N-type semiconductor materials have ____________ as the majority carriers.

   d. ____________ are the minority carriers in N-type material.

   e. Atoms of N-type materials are referred to as ____________ atoms.

   f. P-type semiconductor materials have ____________ as majority carriers.

   g. ____________ are the minority carriers in P-type materials.

   h. Atoms of P-type materials are referred to as ____________ atoms.

TEST

4. Select true statements concerning the characteristics of the P-N junction by placing an "X" in the blank preceding each true statement.

   _____a. P-type and N-type material may be joined together by several manufacturing methods to form a P-N junction.

   _____b. When formation of the P-N junction is completed, a device known as a junction diode is the result.

   _____c. The schematic symbol for the diode is

   _____d. A depletion region extends for a very long distance on only one side of a P-N junction.

   _____e. The action within the depletion region causes a barrier potential to be developed.

   _____f. Silicon diode barrier potential is typically 0.3 volts.

   _____g. Germanium diode barrier potential is typically 0.7 volts.

5. Describe forward and reverse biasing of diodes.

   a. Forward bias ____

   ____

   b. Reverse bias ____

   ____

6. Complete the following statements concerning diode characteristics by circling the word that best completes each statement.

   a. When a (**forward, reverse**) bias is applied to a semiconductor junction, majority current essentially ceases to flow.

   b. When a (**forward/reverse**) bias applied is increased beyond the barrier potential, the forward current increases rapidly at a relatively linear rate.

   c. Forward current through a semiconductor diode is very small and almost insignificant until (**reverse, forward**) bias across the diode is increased beyond the barrier potential.

   d. (**Forward, Reverse**) bias at low potential will not cause a significant increase in minority current (reverse current).

   e. At a higher value of (**forward, reverse**) voltage, minority carriers increase and support a rapid increase in reverse current.

   f. The value of reverse voltage that causes a rapid increase in reverse current is known as the (**rapid, breakdown**) voltage

TEST

7. Select true statements concerning the characteristics of special semiconductor diodes by placing an "X" in the blank preceding each true statement.

_____a. The bipolar transistor is a diode designed to operate at a specific value of reverse breakdown voltage and current.

_____b. The tunnel diode is a heavily doped semiconductor device with a narrow depletion region and a high barrier voltage.

_____c. The varactor diode is a special purpose diode that makes use of the variable width of the depletion region to act as a variable capacitance.

_____d. A PIN diode is a three layer diode which is capable of changing from one operating state to another at an extremely slow rate and therefore used in low frequency applications.

_____e. The IMPATT (impact avalanche transit time) diode operates within its reverse breakdown region.

_____f. Hot carrier diodes (HCD) are formed by placing an N-type material in contact with a metal such as gold, silver or aluminum to form a metal to semiconductor junction.

_____g. The Gunn-effect diode is a true diode with a P-N junction and is able to produce a negative resistance characteristic within bulk semiconductor materials.

8. Select true statements concerning bipolar transistor characteristics by placing an "X" in the blank preceding each true statement.

_____a. A bipolar transistor is a three-terminal current-controlled semiconductor device containing two P-N junctions.

_____b. The bipolar transistor consists of three sections called the emitter, base, and collector.

_____c. Bipolar transistors are of two major types, the "X" and the "Y".

_____d. The PNP transistor consists of P-type material for the emitter, N-type material for the base, and P-type material for the collector.

_____e. Bipolar transistors are used primarily to increase the amplitude or strength of electronic signals and for switching.

_____f. Bipolar transistors are packaged in a specially designed container to primarily improve its appearance.

TEST

9. Complete the following statements concerning characteristics of bipolar transistor operation by inserting the word(s) or equations that best complete(s) each statement.

   a. The collector-base junction of a bipolar transistor is normally ____________ biased.

   b. The emitter-base junction of a bipolar transistor is normally ____________ biased.

   c. The relation between emitter current (I_E), base current (I_B), and collector current (I_C) is established in the following equations:

      1) I_E = ____________

      2) I_C = ____________

      3) I_B = ____________

   d. Transistor circuits are commonly arranged in three basic configurations as common-____________, common ____________, and common ____________.

10. Select true statements concerning the characteristics of the common-base circuit by placing an "X" in the blank preceding each true statement.

   ______a. The common-base (CB) circuit configuration uses the base as the common reference point and the emitter and collector regions of the transistor serve as input and output connections.

   ______b. The CB circuit has a relatively high voltage gain.

   ______c. The CB has a low current gain (gain less than 1, typically .95 to 99).

   ______d. The CB has a medium power gain.

   ______e. The CB has a high input impedance.

   ______f. The CB has a low output impedance.

   ______g. The input signal is out-of-phase with the output signal.

11. Select true statements concerning the characteristics of the common-collector circuit by placing an "X" in the blank preceding each true statement.

   ______a. The common-collector (CC) configuration uses the collector as the common reference point and the base and emitter as the input and output connections.

   ______b. The CC has a low voltage gain.

   ______c. The CC has a high current gain.

TEST

______d. The CC has a low power gain.

______e. The CC has a high input impedance.

______f. The CC has a low output impedance.

______g. The input signal is out-of-phase with the output signal.

12. Select true statements concerning the characteristics of the common-emitter circuit by placing an "X" in the blank preceding each true statement.

    ______a. The common-emitter (CE) configuration uses the collector as the common reference point and the base and emitter as the input and output connections.

    ______b. The CE has a relatively high voltage gain.

    ______c. The CE has a high current gain.

    ______d. The CE has a very low power gain.

    ______e. The CE has a medium value of input impedance.

    ______f. The CE has a medium value of output impedance.

    ______g. The input signal is in-phase with the output signal.

13. Match the classes of operation on the right with their descriptions.

______	a.	An amplifier circuit biased so that the collector current flows during half of the input-signal cycle	1. Class A 2. Class B
______	b.	An amplifier circuit biased so that the collector current flows for less than half of the input-signal cycle	3. Class C
______	c.	An amplifier circuit biased so that the collector current flows during the entire input-signal cycle	

14. Describe three transistor biasing techniques.

    (NOTE: You may use a drawing to illustrate your answer if needed.)

    a. Base biasing is ____

    ____

TEST

b. Feedback bias is ____

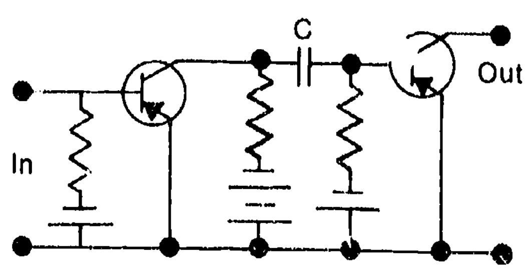
____

c. Voltage divider bias is ____

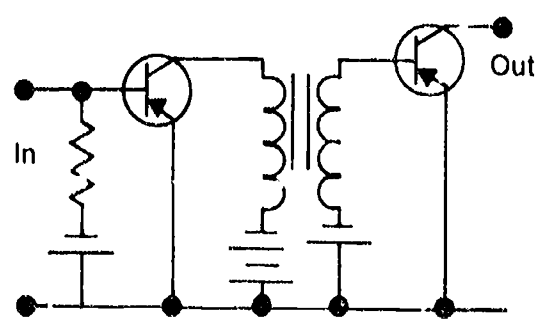
____

15. Identify four methods of coupling.

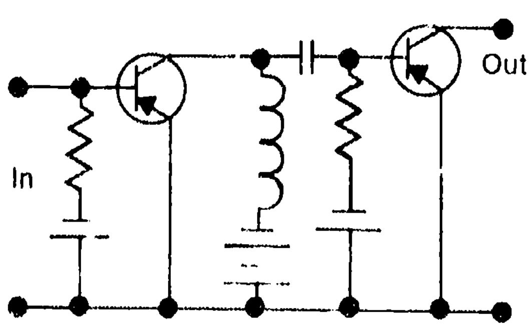
a. ______________________________



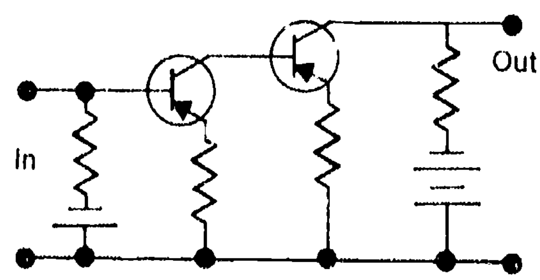
b. ______________________________



c. ______________________________



d. ______________________________



TEST

16. Match special semiconductor devices on the right with their descriptions.

_____a.	Family of mulitlayered semiconductor devices which are used primarily for switching current	1. Diac
		2. Triac
_____b.	Three-terminal device similar to an ordinary rectifier except its rectifying characteristics can be controlled (a member of the thyristor family)	3. Thermistor
		4. Thyristor
		5. Silicon controlled rectifier
_____c.	Bidirectional trigger diode	
_____d.	Three terminal device which is a member of the thyristor family and generally applied as an AC switching device	6. Field-effect transistor
		7. Unijunction transistor
_____e.	Temperature sensitive resistor	
_____f.	Specialized type of junction transistor which is normally used as a switching device	
_____g.	Transistor which is voltage controlled and has a very high input impedance	

17. Complete the following statements concerning the construction of the field effect transistor by inserting the word that best completes each statement.

    a. The _____________ terminal corresponds to the emitter of a transistor and is where charge carriers enter the channel to provide current through the channel.

    b. The _____________ corresponds to the collector of a transistor and is the terminal where current leaves the channel.

    c. The _____________ corresponds to the base of a transistor and is the electrode that controls the conductance of the channel between the source and the drain.

    d. The _____________ serves as a platform on which the other elements of the device are formed.

18. Select true statements concerning the characteristics of the junction field effect transistor by placing an "X" in the blank preceding each true statement.

    _____a. The JFET is a current operated device rather than a voltage operated device as are transistors.

    _____b. The JFET has a very high input impedance.

TEST

______c. The control of current through the channel of JFET is accomplished by varying the reverse bias voltage between the gate and the drain.

______d. The gate-to-source voltage required to reduce the drain current to zero is called the gate-to-source pinch-off voltage.

______e. The value of drain-to-source voltage which limits the drain current (due to depletion of majority carriers) is called the pinch-off voltage.

19. Complete the following statements concerning the characteristics of the [illegible]ted gate field effect transistor by circling the word that best completes each st[illegible].

    a. The IGFET uses a (**fiber, metal**) gate that is electrically insulated from the semiconductor channel by a thin oxide layer and is therefore called an insulated gate FET.

    b. The IGFET has a very high input (**current, impedance**) because of the insulation layer.

    c. The enhancement type IGFET is normally (**on, off**) and has no deposited channel region.

    d. The depletion type IGFET is normally (**on, off**) and has a deposited channel region.

20. Describe four safety precautions in handling IGFET's (MOSFET's).

    a. ____
    ____

    b. ____
    ____

    c. ____
    ____

    d. ____
    ____

21. Explain the term decibel.

    ____
    ____

TEST

(NOTE: If the following activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

22. Label the parts of a transistor circuit. (Assignment Sheet #1)

23. Construct a load line for a common-emitter amplifier circuit. (Assignment Sheet #2)

24. Calculate the overall gain of multi-stage amplifier circuits. (Assignment Sheet #3)

25. Compute voltage, current, and power stage gain in decibels. (Assignment Sheet #4)

26. Demonstrate the ability to:

    a. Perform a static test of semiconductor diodes. (Job Sheet #1)

    b. Test semiconductor diodes and plot the characteristic curves. (Job Sheet #2)

    c. Test transistors. (Job Sheet #3)

    d. Construct and test a common-emitter circuit. (Job Sheet #4)

    e. Construct and test a common-base circuit. (Job Sheet #5)

    f. Construct and test a common-collector circuit. (Job Sheet #6)

    g. Plot a transistor output characteristic curve. (Job Sheet #7)

    h. Construct and test a single-ended amplifier. (Job Sheet #8)

    i. Construct and test a field effect transistor amplifier. (Job Sheet #9)

DISCRETE SEMICONDUCTOR DEVICES AND CIRCUITS
UNIT [illegible]

ANSWERS TO TEST

1.

a.	2	g.	8	m.	10	r.	20
b.	6	h.	3	n.	9	s.	18
c.	13	i.	1	o.	11	t.	17
d.	14	j.	4	p.	16		
e.	5	k.	15	q.	19		
f.	7	l.	12				

2. a. Silicon, germanium
   b. Valence
   c. Covalent
   d. Electrons, holes

3. a. Doping
   b. Extrinsic
   c. Electrons
   d. Holes
   e. Donor
   f. Holes
   g. Electrons
   h. Acceptor

4. a, b, c, e

5. a. Forward bias is present when the polarity across the junction is such that it causes current to flow
   b. Reverse bias is present when the polarity across the junction is such that little or no current flows through the junction

6. a. Reverse
   b. Forward
   c. Forward
   d. Reverse
   e. Reverse
   f. Breakdown

7. b, c, e, f

8. a, b, d, e

9. a. Reverse
   b. Forward
   c. 1) $I_E = I_B + I_C$
      2) $I_C = I_E - I_B$
      3) $I_B = I_E - I_C$
   d. Base, emitter, collector

ANSWERS TO TEST

10. a, b, c, d

11. a, b, c, d, e, f

12. b, c, e, f

13. a. 2
    b. 3
    c. 1

14. a. Base-biasing is a simple form of providing bias for the base through a resistor connected to Vcc. It has very poor temperature stability and is not used extensively.
    b. Feedback bias is a circuit which provides bias through a resistive feedback circuit from collector or emitter. It has increased temperature stability but other factors cause it to not always be used as the preferred bias network.
    c. Voltage divider bias is the most used form of bias and is provided by a voltage divider network employing feedback for stability.

15. a. R-C coupling
    b. Transformer coupling
    c. Impedance coupling
    d. Direct coupling

16. a. 4
    b. 5
    c. 1
    d. 2
    e. 3
    f. 7
    g. 6

17. a. Source
    b. Drain
    c. Gate
    d. Substrate

18. b, e

19. a. Metal
    b. Impedance
    c. Off
    d. On

20. a. Device leads should be kept shorted together while handling.
    b. Persons handling devices should be grounded such as with a grounded metallic wristband.
    c. Soldering iron tips should be grounded.
    d. The device should never be inserted or removed from the circuit with the power on.

ANSWERS TO TEST

21. The decibel is a measurement of the ratio of one power level to another.

22.-25. Evaluated to the satisfaction of the instructor.

26. Performance skills evaluated to the satisfaction of the instructor.

LINEAR INTEGRATED AMPLIFIER CIRCUITS
UNIT V

UNIT OBJECTIVE

After completion of this unit, the student should be able to apply theoretical knowledge related to linear integrated amplifier circuits, and construct and test various types of amplifiers. Competencies will be demonstrated by correctly performing the procedures outlined in the assignment and job sheets and by scoring a minimum of 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to linear integrated amplifier circuits with their correct definitions.
2. Select true statements concerning the fundamentals of differential amplifier circuits.
3. Complete statements concerning integrated circuit construction.
4. Complete statements concerning the maximum ratings of an operational amplifier.
5. Complete statements concerning the input and output parameters of the op-amp.
6. Select true statements concerning the dynamic parameters of the op-amp.
7. List desirable operational characteristics of the op-amp.
8. Complete statements concerning the characteristics of the inverting amplifier.
9. Select true statements concerning the characteristics of the noninverting amplifier.

OBJECTIVE SHEET

10. State the relationship between gain, bandwidth, and feedback in an op-amp.

11. Draw the schematic diagram of DC summing and difference amplifiers.

12. Calculate the closed-loop gain for an inverting and a noninverting amplifier. (Assignment Sheet #1)

13. Calculate the output voltage of a DC summing amplifier. (Assignment Sheet #2)

14. Demonstrate the ability to:

    a. Construct and test an inverting amplifier. (Job Sheet #1)

    b. Construct and test a noninverting amplifier. (Job Sheet #2)

    c. Construct and test a differential amplifier. (Job Sheet #3)

    d. Construct and test a DC summing amplifier. (Job Sheet #4)

LINEAR INTEGRATED AMPLIFIER CIRCUITS
UNIT V

SUGGESTED ACTIVITIES

A. Obtain additional materials and/or invite resource people to class to supplement/reinforce information provided in this unit of instruction.

(NOTE: This activity should be completed prior to the teaching of this unit.)

B. Make transparencies from the transparency masters included with this unit.

C. Provide students with objective sheet.

D. Discuss unit and specific objectives.

E. Provide students with information and assignment sheets.

F. Discuss information and assignment sheets.

(NOTE: Use the transparencies to enhance the information as needed.)

G. Provide students with job sheets.

H. Discuss and demonstrate the procedures outlined in the job sheets

I. Integrate the following activities throughout teaching of this unit:

1. Show films related to linear integrated circuit construction.
2. Give examples of applications, using linear integrated circuits.
3. Provide catalogs from electronic device suppliers, show examples of specific devices listed in the catalogs, and have students look up their listed prices.
4. Review manufacturers' specifications for specific devices and circuit applications.
5. Meet individually with students to evaluate their progress through this unit of instruction, and indicate to them possible areas for improvement.

J. Give test.

(NOTE: Due to the length of this unit, it is suggested that the information be tested in three parts.)

K. Evaluate test.

L. Reteach if necessary.

INSTRUCTIONAL MATERIALS INCLUDED IN THIS UNIT

A. Objective sheet

B. Suggested activities

C. Information sheet

D. Transparency masters

1. TM 1 — Basic Differential Amplifier
2. TM 2 — Differential Amplifier (Single-Input, Single-Output)
3. TM 3 — Differential Amplifier (Single-Input, Differential-Output)
4. TM 4 — Differential Amplifier (Differential-Input, Differential-Output)
5. TM 5 — Categories of Integrated Circuits
6. TM 6 — Monolithic Integrated Circuit
7. TM 7 — Hybrid Thick Film Circuit
8. TM 8 — Operational Amplifier
9. TM 9 — Simplified Comparator Circuit
10. TM 10 — Inverting Amplifier
11. TM 11 — Noninverting Amplifier
12. TM 12 — Gain Vs. Bandwidth
13. TM 13 — Summing Amplifier (Two-Input)
14. TM 14 — Summing Amplifier (Four-Input)
15. TM 15 — Differential DC Amplifier

E. Assignment sheets

1. Assignment Sheet #1 — Calculate the Closed-Loop Gain for an Inverting and a Noninverting Amplifier
2. Assignment Sheet #2 — Calculate the Output Voltage of a DC Summing Amplifier

F. Answers to assignment sheets

INSTRUCTIONAL MATERIALS INCLUDED IN THIS UNIT

G. Job sheets

1. Job Sheet #1 — Construct and Test an Inverting Amplifier
2. Job Sheet #2 — Construct and Test a Noninverting Amplifier
3. Job Sheet #3 — Construct and Test a Differential Amplifier
4. Job Sheet #4 — Construct and Test a DC Summing Amplifier

H. Test

I. Answers to test

REFERENCES USED IN DEVELOPING THIS UNIT

(NOTE: The following is a list of references used in completing this unit.)

A. Boylestad and Nashelsky. *Electronic Devices and Circuit Theory.* Third Edition. Englewood Cliffs, NJ: Prentice-Hall Media, Inc., 1982.

B. Dugan, Frank R. *Linear Integrated Circuits for Technicians.* North Scituate, MA: Breton Publishers, 1984.

C. *Operational Amplifiers.* Heath/Zenith Educational Systems. Benton Harbor, MI. 1980.

D. Robertson, L. Paul. *Basic Electronics I. (Revised Edition).* Stillwater, OK: Mid-America Vocational Curriculum Consortium, 1982.

E. Siebert, Leo N. *Introduction to Industrial Electricity — Electronics.* Stillwater, OK: Oklahoma Curriculum and Instructional Materials Center, 1981.

LINEAR INTEGRATED AMPLIFIER CIRCUITS
UNIT V

INFORMATION SHEET

I. **Terms and definitions**

A. Active device — A component in a circuit which has gain or which directs the flow of current

B. Analog signal — A DC or AC current or voltage that varies smoothly or continuously

C. Closed-loop operation — An application of an operational amplifier circuit that uses external feedback

D. Common-mode signal — Signal voltages that are in phase, of equal amplitude and frequency, applied to both inputs of a differential amplifier

E. Comparator — A circuit which compares two inputs and produces an output that is a function of the result of the comparison

F. Crosstalk — Interference due to cross coupling between adjacent circuits or due to intermodulation of two or more carrier channels

G. DC offset voltage — The small output voltage in practical op-amp circuits that is a resultant of bias currents in the circuits

H. Differential amplifier — A circuit that amplifies the difference between two inputs; the input stage of an op-amp

I. Feedback — The transferring of voltage from output of a circuit back to its input

J. Gain bandwidth product — Equal to the unity-gain frequency of an op-amp and determined by muliplying the gain and bandwidth of a specific circuit

K. Integrated circuit — A complete electronic circuit that is fabricated on a single chip of silicon

L. JFET — A junction field-effect transistor in which the gate electrode is formed by a PN junction

M. Linear IC — A classification of integrated circuits used for analog amplification purposes

N. Monolithic IC — An integrated circuit fabricated from a single chip of semiconductor material, usually silicon

O. MOSFET — A field-effect transistor containing a metal gate over thermal oxide on silicon

P. Open-loop operation — An application of an operational amplifier circuit that uses no external feedback

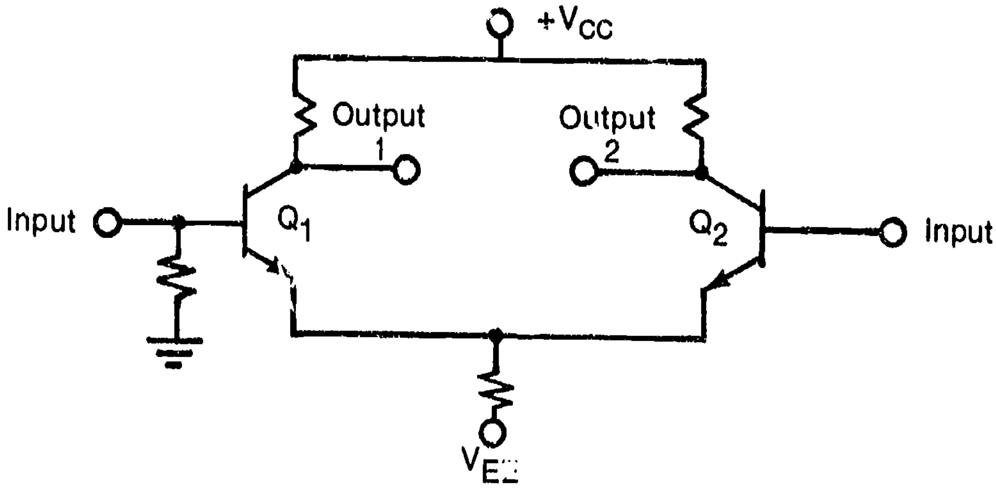
INFORMATION SHEET

Q. Operational amplifier (Op-Amp) — A solid-state integrated circuit amplifier with very high gain, differential inputs, and uses external feedback to control its gain

R. Passive device — A component in a circuit which has no gain characteristics such as a resistor, capacitor, or inductor

II. **Fundamentals of differential amplifier circuits**

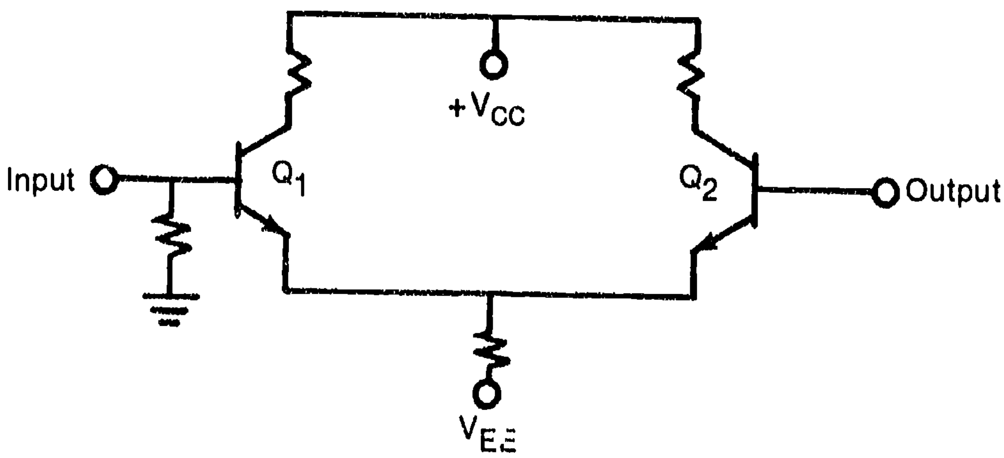
A. A basic differential amplifier circuit has two input terminals and two output terminals. (Transparency #1)



1. An input can be applied to either or both bases.

2. An output can be taken from either collector with respect to ground or between the two collectors.

B. The simplest connection is the single-input, single-output connection. (Transparency #2)



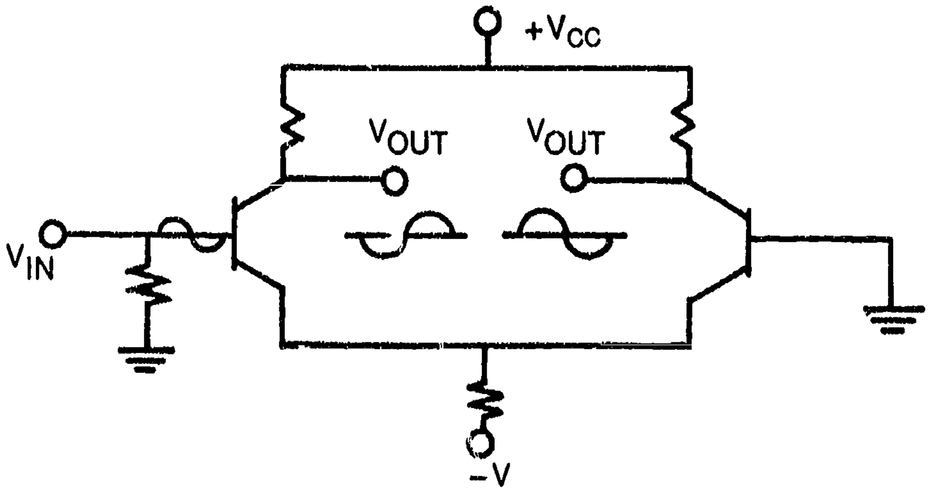
1. The output signal is in phase with the input.

2. The overall voltage gain is approximately the same as that of a common-base amplifier.

3. The amplifier works for both AC and DC signals.

INFORMATION SHEET

C. The single-input, differential-output has one input terminal and two output terminals. (Transparency #3)



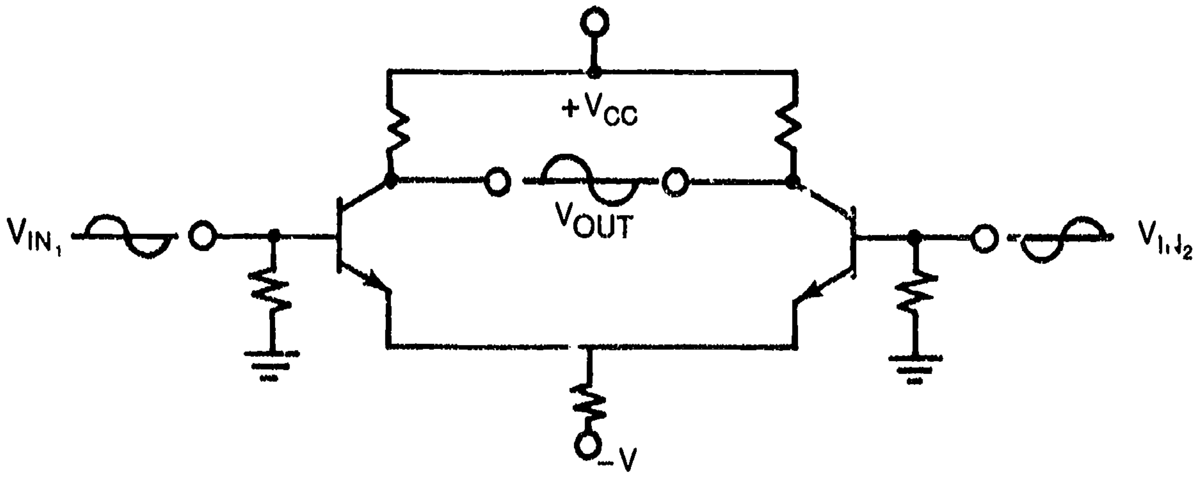
1. One output is in phase with the input; the other is 180 degrees out of phase with the input.

2. A load can be connected between either of the output terminals and ground.

3. The outputs are of equal amplitude but of opposite phase.

4. The gain of the stage can be effectively doubled by connecting the load between the two output terminals.

D. The differential-input, differential-output circuit has two input terminals and two output terminals. (Transparency #4)



1. The two input signals are normally the same except 180 degrees out of phase.

2. The circuit amplifies the difference between the two input signals.

3. V-out is equal to V1 minus V2 times the gain of the amplifier or V-out = A(V1 − V2).

INFORMATION SHEET

E. The differential amplifier will reject common-mode signals (noise and unwanted frequencies of the same phase as the inputs) and amplify differential signals.

F. The ability of the differential amplifier is expressed as a ratio of the difference gain to common-mode gain and called the common-mode rejection ratio (CMRR).

G. The differential amplifier is easily adaptable for application in integrated circuits and is used as a basic concept in a great number of linear integrated circuits.

III. **Integrated circuit construction** (Transparency #5)

A. Integrated circuits (IC's) are classified as monolithic, thin-film, thick-film, and hybrid integrated devices.

B. The monolithic IC is a complete circuit including active and passive devices and all interconnections fabricated through a diffusion process on a single piece of semiconductor material. (Transparency #6)

C. A thin-film IC is a circuit consisting of patterns of miscellaneous materials which have been laid down in very thin ribbons on a single substrate of insulating material such as glass or ceramic.

1. Components such as resistors, capacitors, and interconnecting conductors are formed with extremely thin layers of metals and oxides on the insulating substrate.

2. Active devices such as diodes and transistors are formed separately and then permanently attached in the proper locations.

D. A thick-film IC is a circuit in which resistors, capacitors, and conductors are deposited on a substrate usually through a silk-screen printing process.

1. Thick-film components are larger and thicker than thin-film components.

2. Active devices such as diodes and transistors are formed separately and added to the substrate to make the complete circuit.

E. Hybrid IC's are constructed with a combination of thin-film, thick-film, and monolithic processes to form a complete circuit. (Transparency #7)

IV. **Maximum range of an operational amplifier**

A. The operating temperature is the ambient (room temperature) range for which the operational amplifier (op-amp) will operate within the manufacturer's specifications.

B. The supply voltage is the maximum positive and negative voltage that can be used to power the op-amp.

INFORMATION SHEET

C. The internal power or dissipation is the maximum power that an op-amp is capable of dissipating in a specified ambient temperature.

D. The input voltage is the maximum input voltage that can be simultaneously applied between both inputs and ground (often referred to as common-mode voltage).

E. The output short circuit duration is the time that the output of the op-amp can be short-circuited to ground or to either supply voltage.

F. The differential input voltage is the maximum voltage that can be applied across the + and − inputs.

V. **Input and output parameters of the op-amp**

A. The input resistance is the resistance at either input to the op-amp with the remaining input grounded.

B. The input offset voltage is the voltage that must be applied to one of the input terminals to give a zero output voltage.

C. The input bias current is the average of the currents flowing into both inputs and ideally both bias currents are equal.

D. The input offset current is the difference of the two input bias currents when the output is zero.

E. The input voltage range is the range of the voltage common to both inputs and ground (range of common-mode input voltage).

F. The output resistance is the resistance seen looking inward from the op-amp output.

G. The output short-circuit current is the maximum output current that the op-amp can deliver to a load

H. The output voltage swing is the maximum peak output voltage that the op-amp can supply without saturation or clipping.

VI. **Dynamic parameters of the op-amp**

A. The open-loop voltage gain is the ratio of the output to input voltage of the op-amp without external feedback.

B. The rise time is the ten to ninety percent closed-loop, step-function response time of an amplifier under small-signal conditions.

C. The large-signal voltage gain is the ratio of the maximum voltage swing to the change in the input voltage required to drive the output from zero to a specified voltage.

D. The slew rate is the maximum rate of change of output voltage under large-signal conditions.

INFORMATION SHEET

E. The common-mode rejection ratio is a measure of the ability of the op-amp to reject signals that are simultaneously present at both inputs and usually expressed in decibels.

F. The channel separation is the amount of "crosstalk" between op-amps when more than one op-amp is present in a single package.

VII. **Basic operational characteristics of the op-amp**

A. The op-amp is a high gain amplifier consisting of several stages cascaded together. (Transparency #8)

B. The cascading of several different types of amplifier stages gives the op-amp desirable characteristics such as

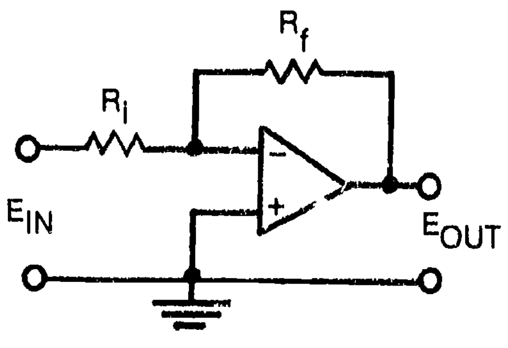
1. Very high gain
2. Very high input impedance
3. Very low output impedance
4. High common-mode rejection
5. Frequency response down to DC

C. The op-amp may be operated in an open-loop mode but there are no practical open-loop circuits except for a comparator. (Transparency #9)

D. The op-amp may be operated in a closed-loop mode with two basic configurations being that of the inverting configuration and the noninverting configuration.

VIII. **Characteristics of the inverting amplifier**

A. The inverting configuration is the most popular of the op-amp configurations. (Transparency #10)



R_f = Feedback resistor

R_i = Input resistor

B. The output of the op-amp in the inverting configuration is 180 degrees out-of-phase with the input.

INFORMATION SHEET

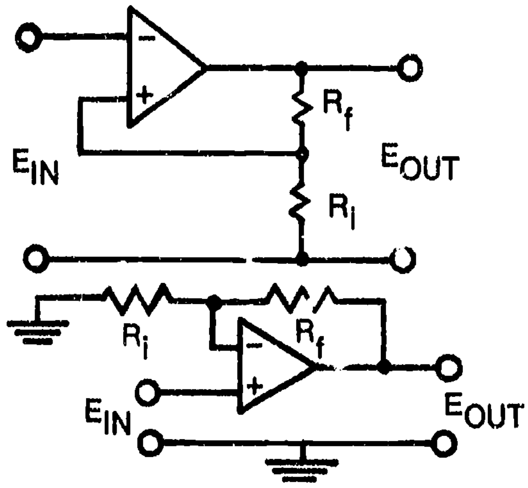
C. The voltage gain of the op-amp stage is equal to the ratio of R_f to R_i ($A = R_f/R_i$).

D. The input impedance is equal to the value of R_i.

IX. **Characteristics of the non-inverting amplifier** (Transparency #11)

A. The non-inverting amplifier is used to provide an output that is in-phase with the input.

(NOTE: Schematics are equivalent.)



R_f and R_i form a voltage divider network for feedback.

B. The output signal is the difference between the input signal applied to the noninverting input and the feedback signal applied to the inverting input.

C. The stage gain may be obtained by using the equation

$$A_v = 1 + \frac{R_f}{R_i}$$

D. The input impedance is very high (greater than the input impedance of the op-amp).

X. **Relationship between gain, bandwidth, and feedback** (Transparency #12)

A. Degenerative feedback applied to an op-amp decreases the gain.

B. Degenerative feedback applied to an op-amp increases the bandwidth.

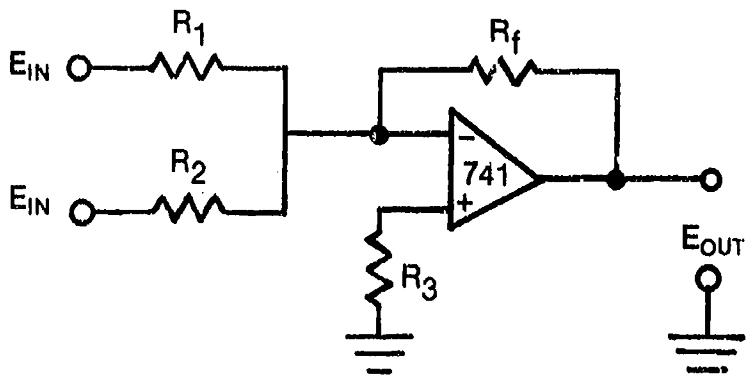
C. The gain-bandwidth product is constant for a given op-amp.

INFORMATION SHEET

XI. Characteristics of the DC summing and difference amplifiers

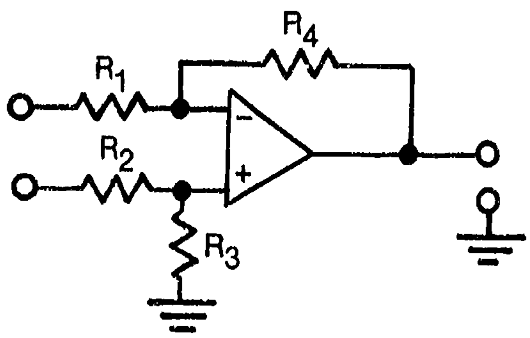
A. The DC summing amplifier has two or more inputs with one output. (Transparency #13 and #14)

(NOTE: This is also known as an analog adder.)



B. The common point at which the input resistors are connected is known as the summing point.

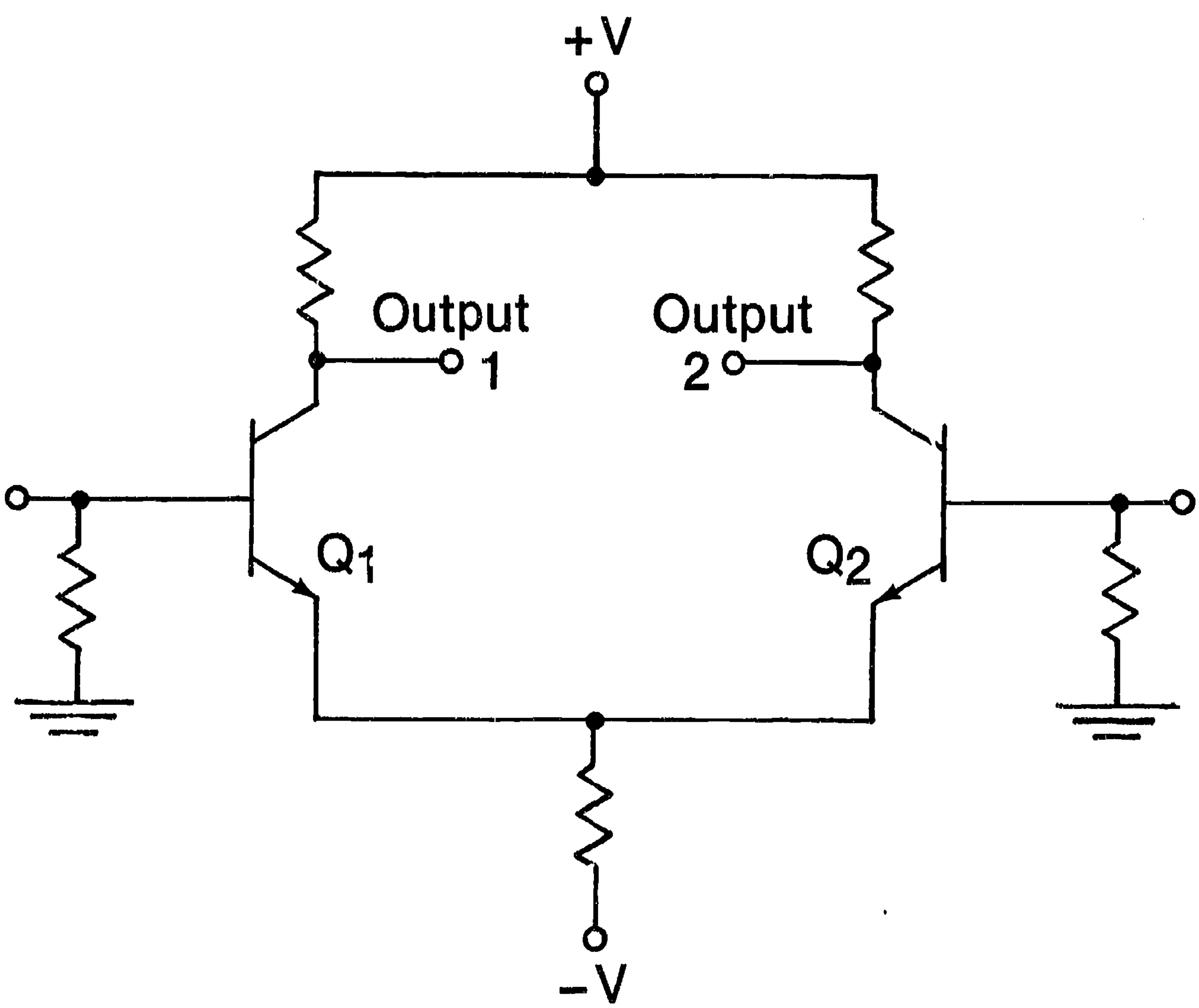
C. The op-amp may be connected as a difference amplifier. (Transparency #15)



D. The gain of the difference amplifier is determined by the value of the resistors.

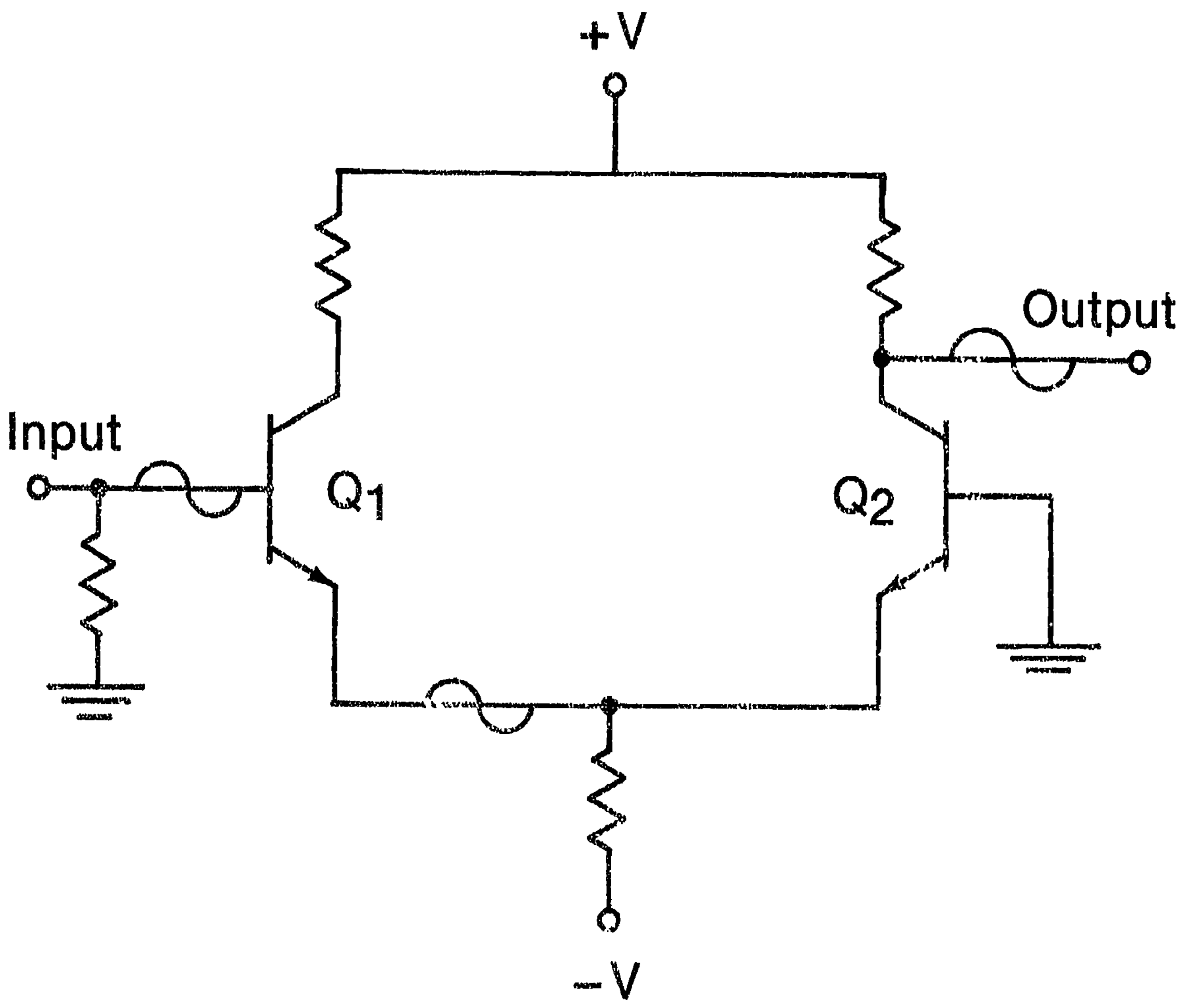
Example: When all four resistors are equal, E-out equals $E_1 - E_2$. Normally, when unequal resistors are used, the ratio of R_1 to R_2 is made equal to the ratio of R_3 to R_4 in which case E-out is equal to $R_1/R_2\ (E_1 - E_2)$

Basic Differential Amplifier



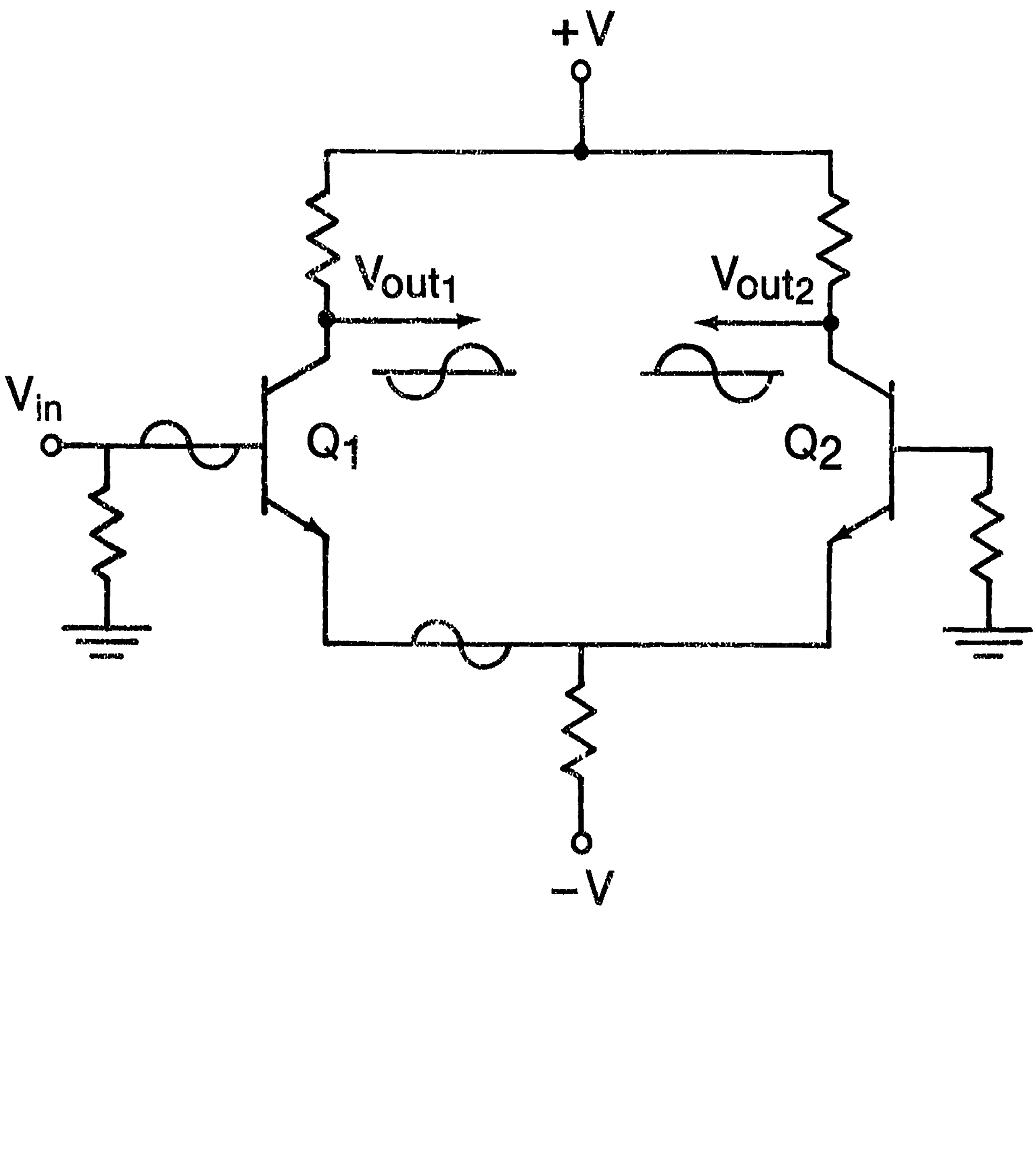
Differential Amplifier

(Single-Input, Single-Output)



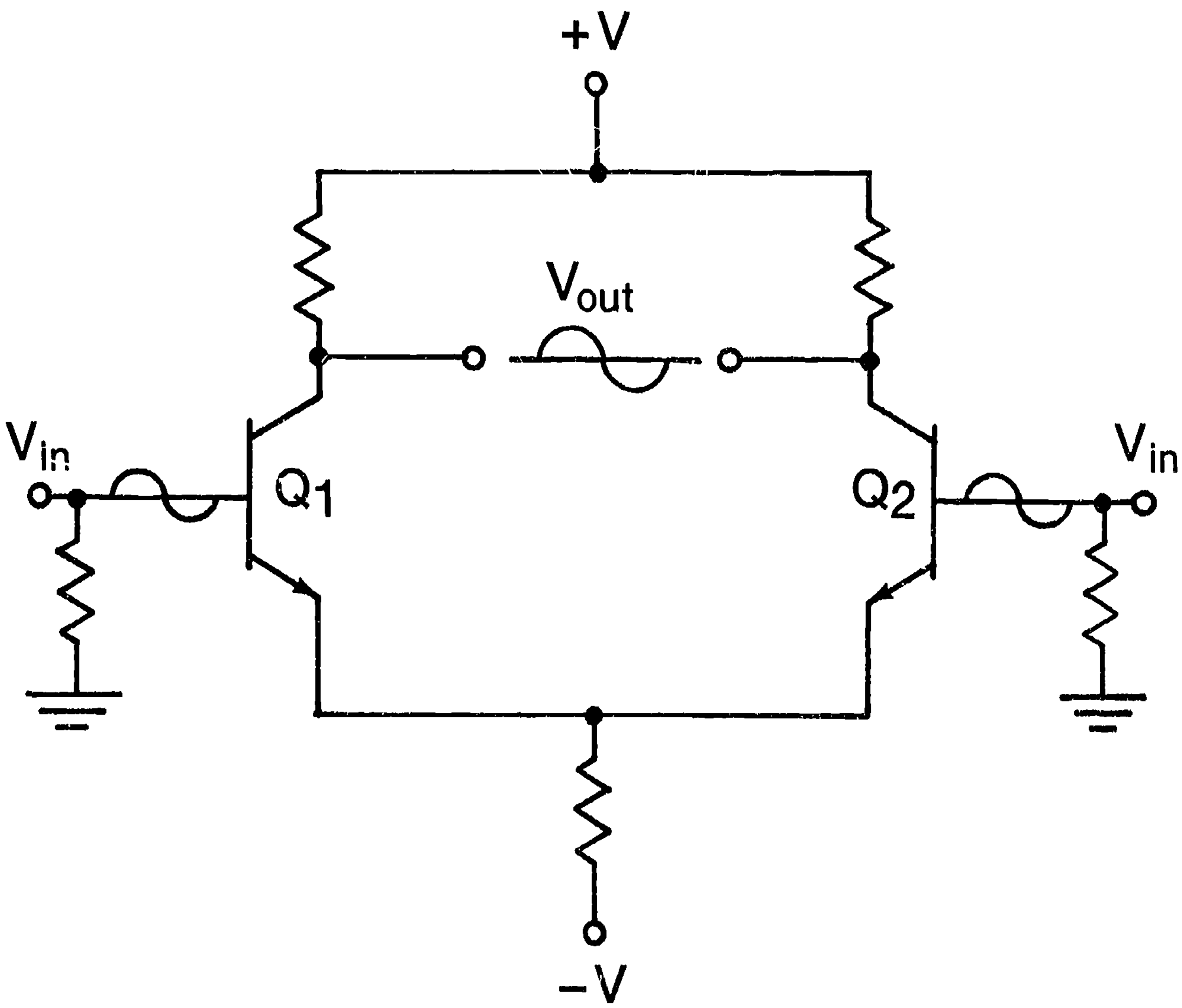
Differential Amplifier

(Single-Input, Differential-Output)

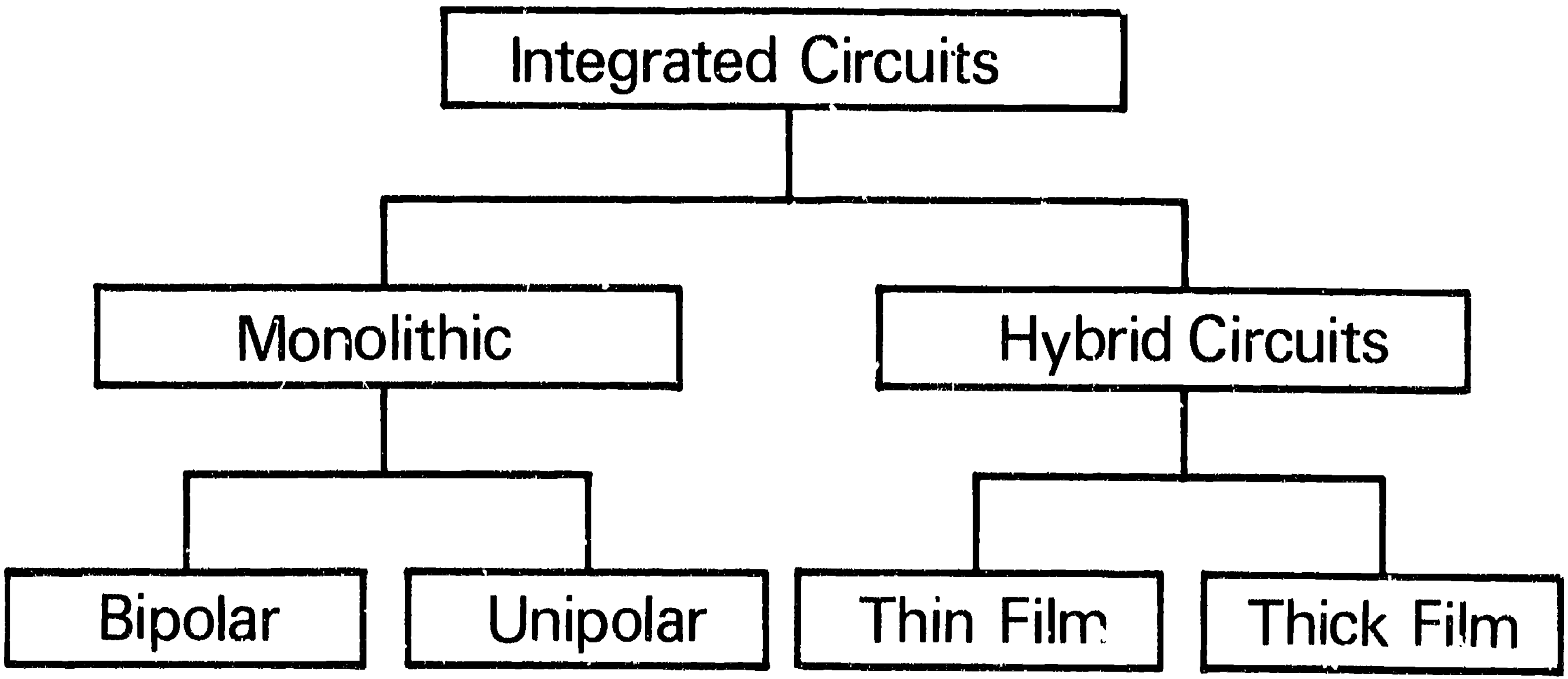


Differential Amplifier

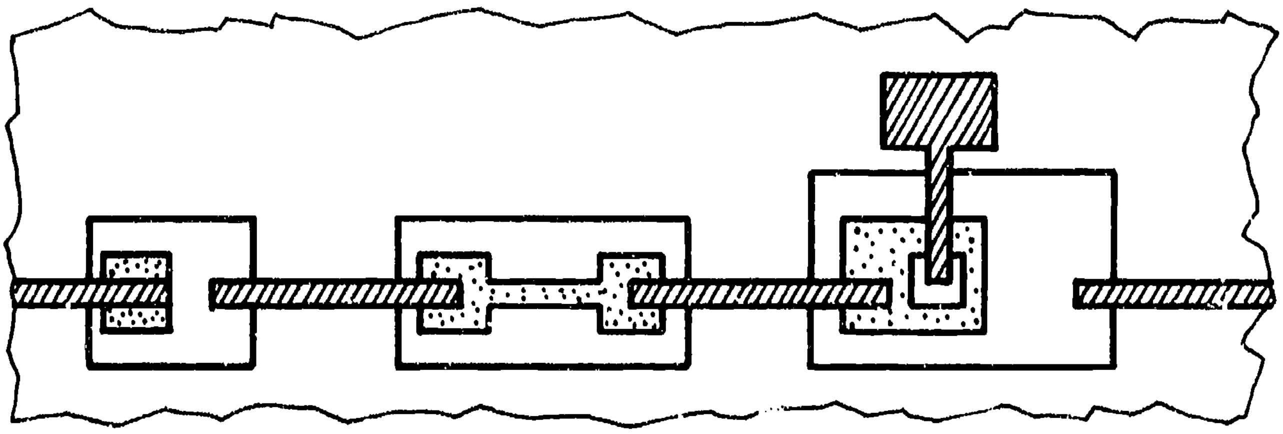
(Differential-Input, Differential-Output)



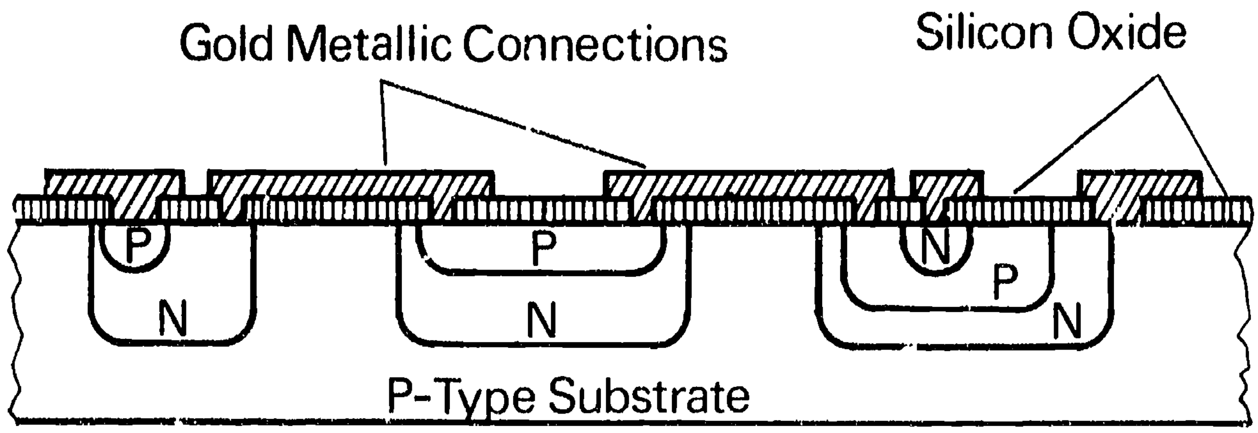
Categories of Integrated Circuits



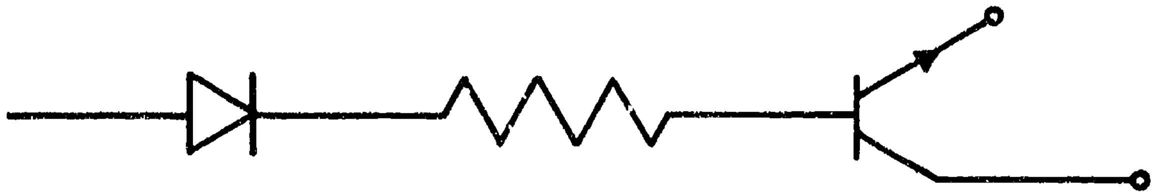
Monolithic Integrated Circuit



Top View (oxide omitted)

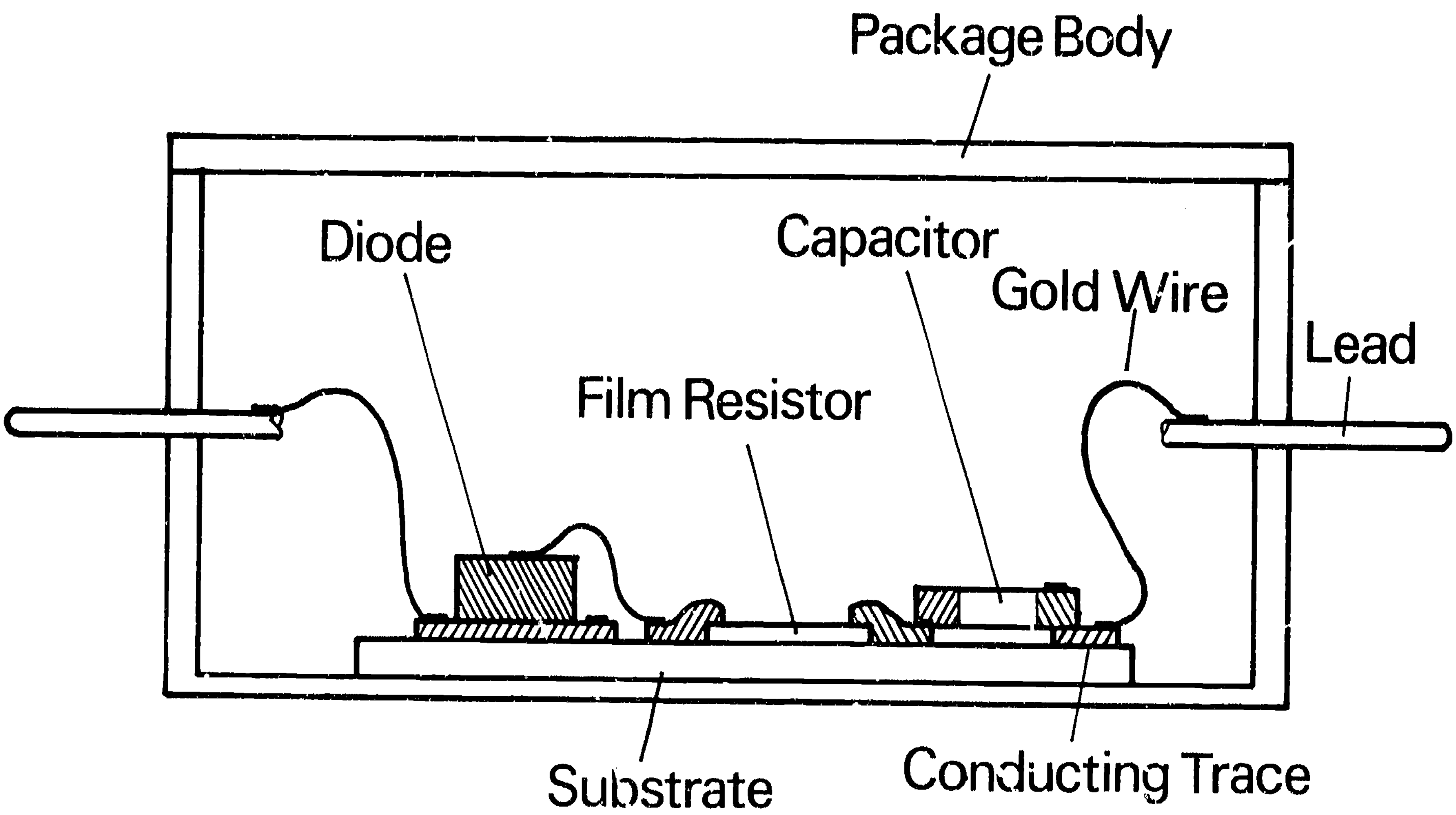


Cross Section



Schematic

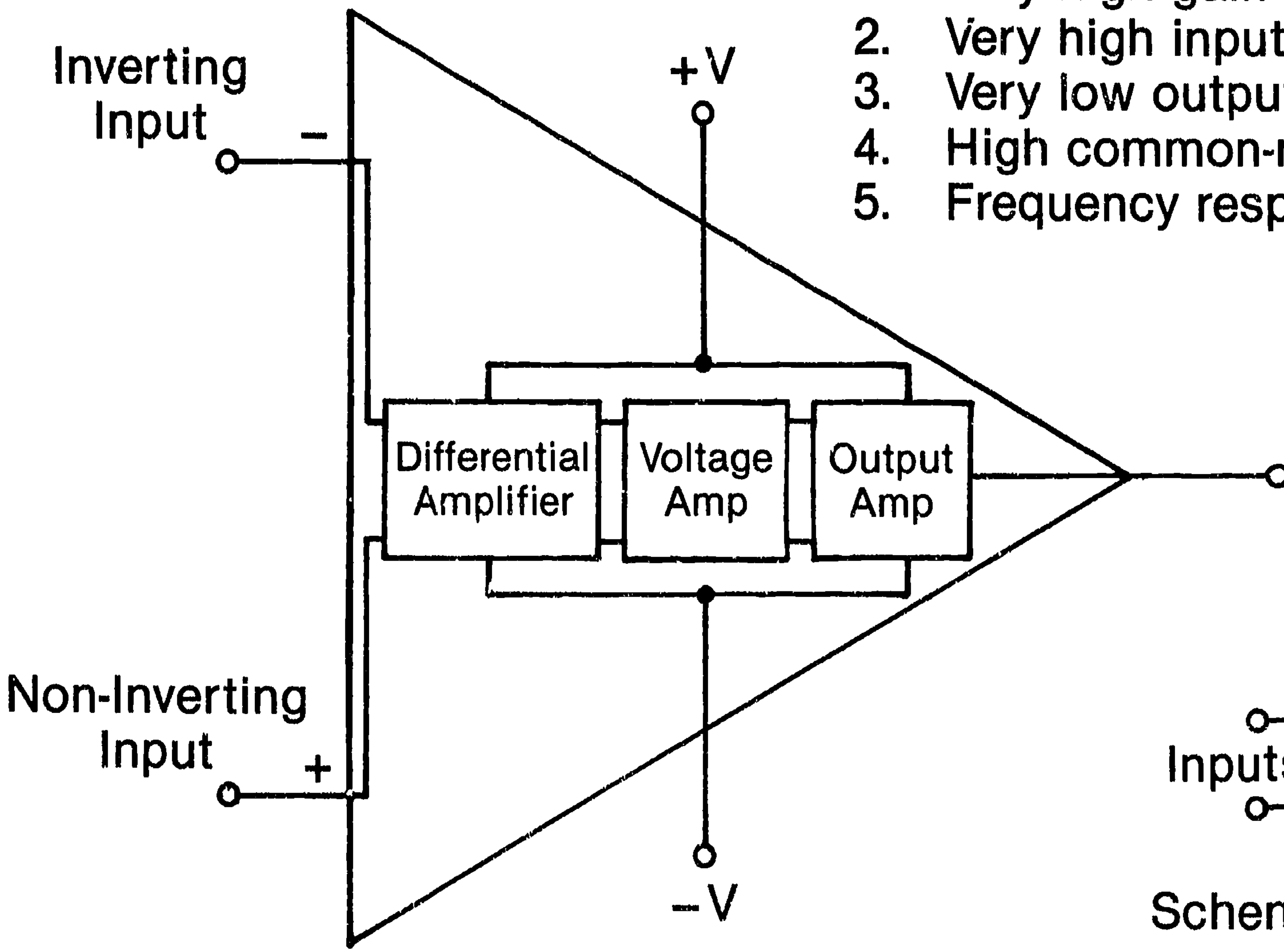
Hybrid Thick Film Circuit

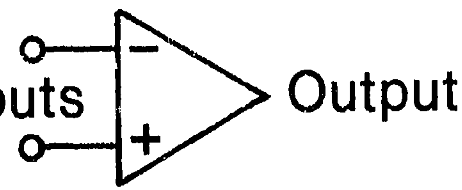


Operational Amplifier

Desirable Characteristics

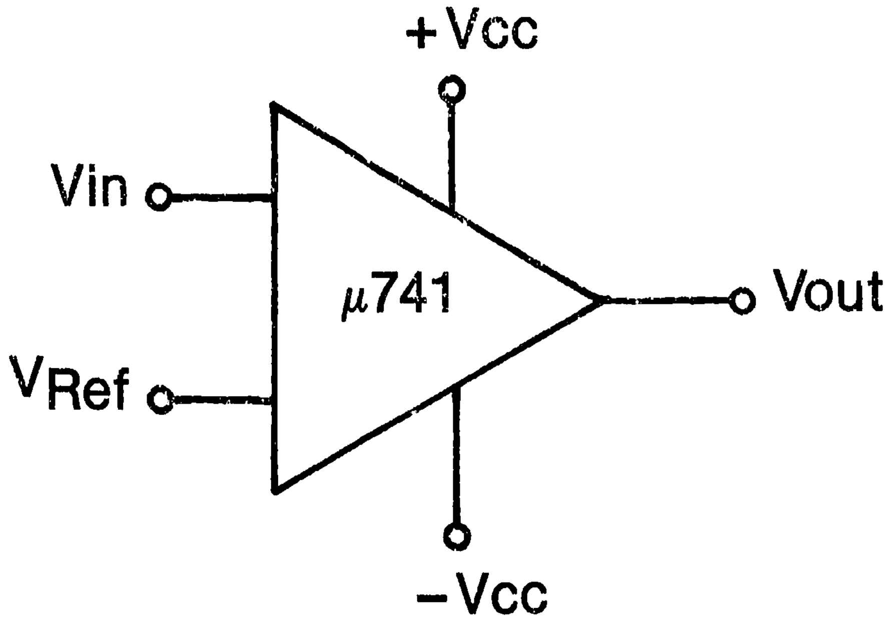
1. Very high gain
2. Very high input impedance
3. Very low output impedance
4. High common-mode rejection
5. Frequency response down to DC

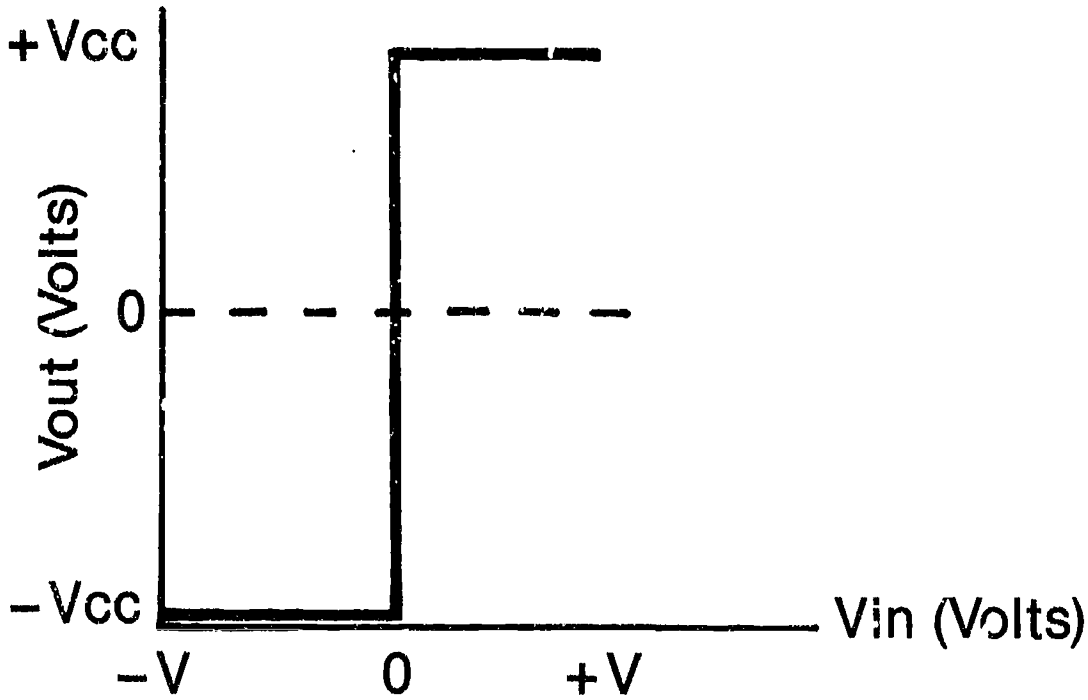




Schematic Symbol

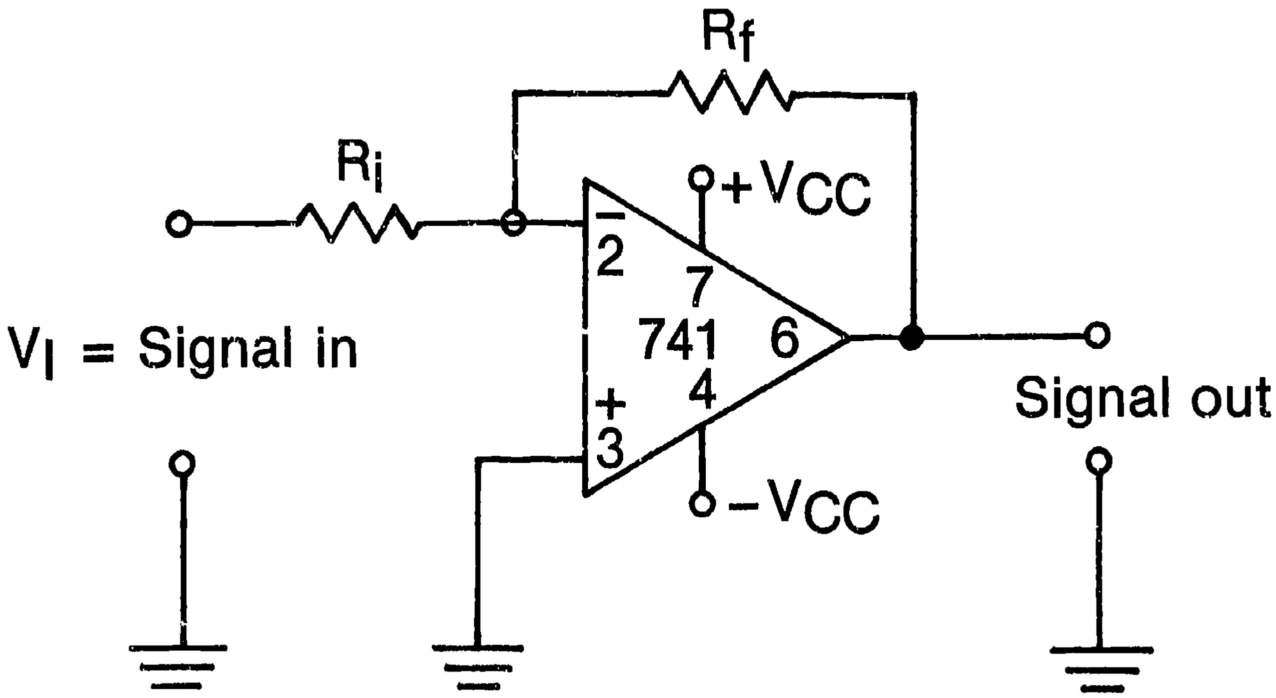
Simplified Comparator Circuit





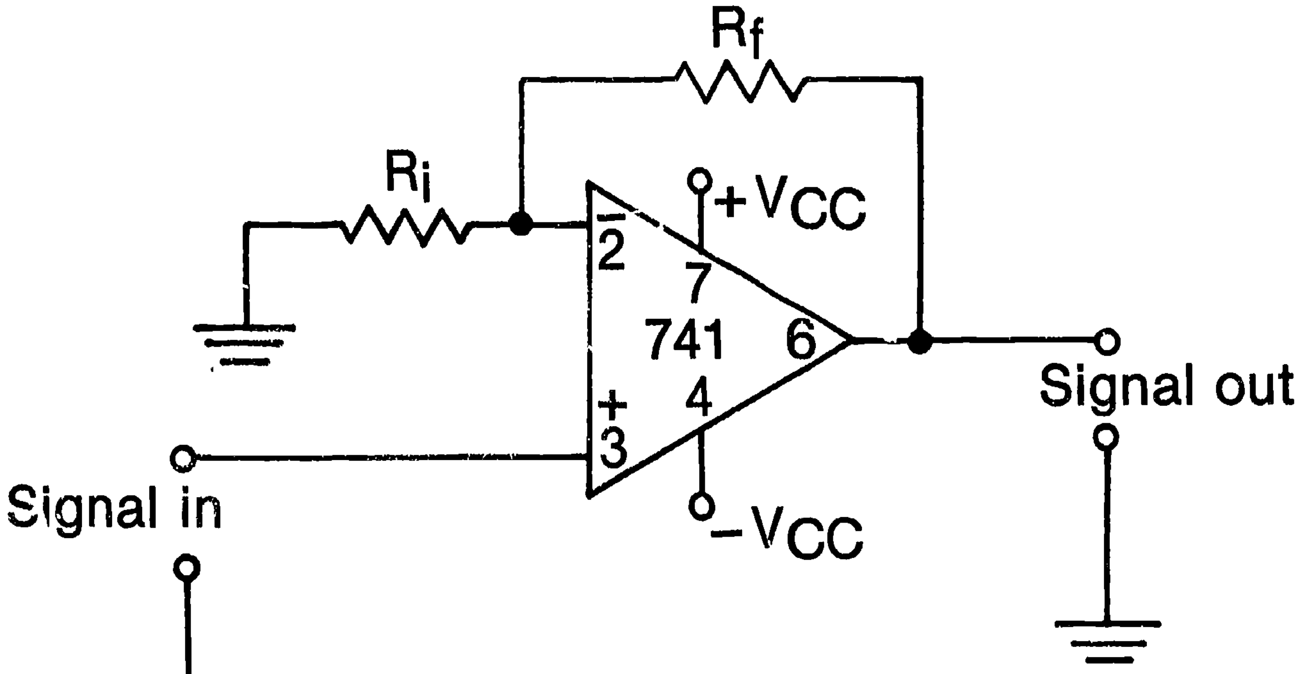
Ideal Comparator Output

Inverting Amplifier



$$A_V = \frac{-R_f}{R_i}$$

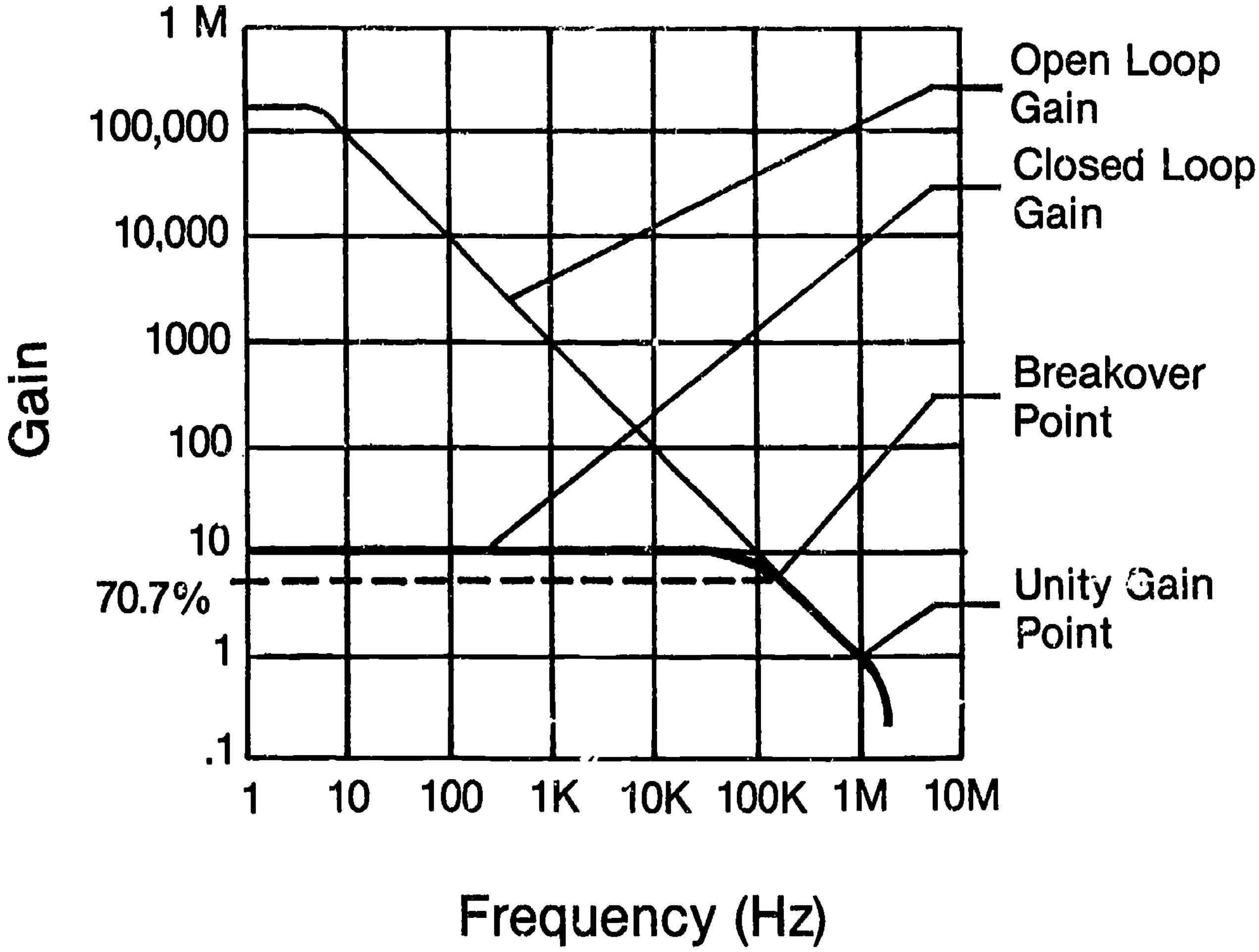
Noninverting Amplifier



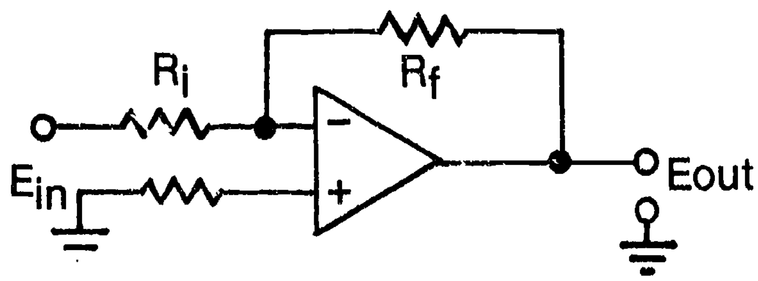
$$V_O = V_i A_V$$

$$A_v = \frac{R_i + R_f}{R_i} = 1 + \frac{R_f}{R_i}$$

Gain Vs. Bandwidth

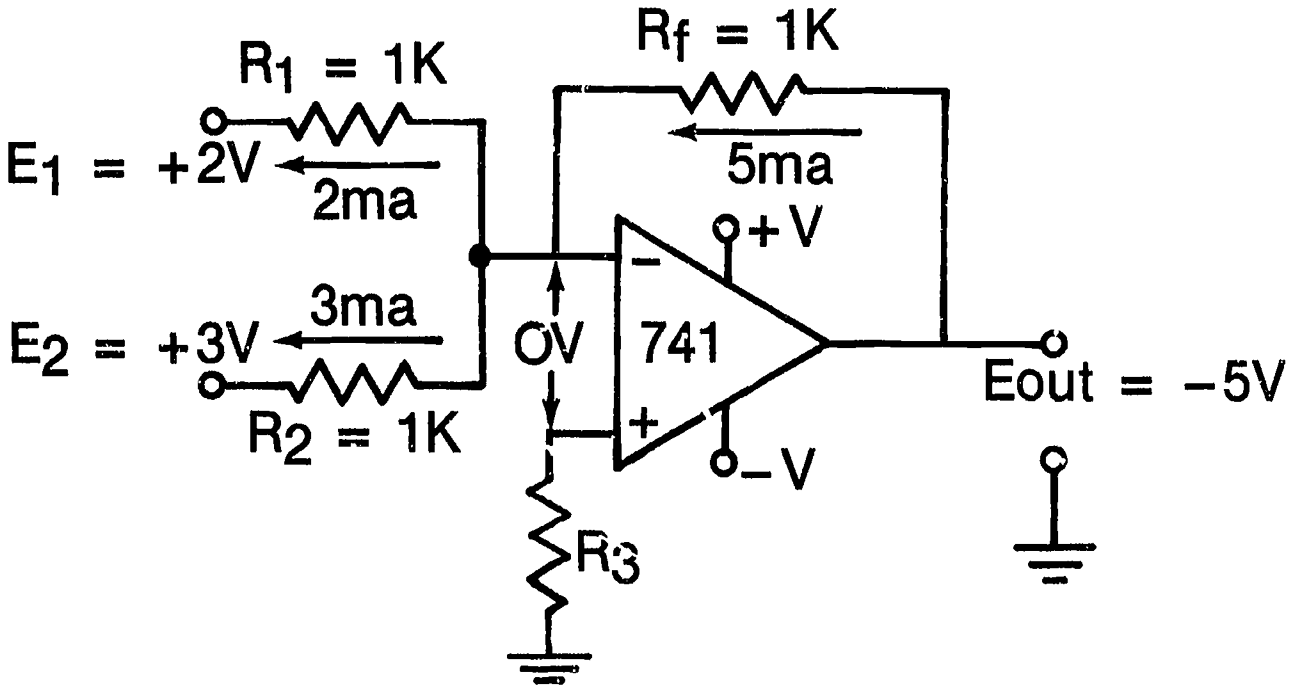


R_i	R_f	Gain	Bandwidth	R_{in}
10K	10K	1	1MHZ	10K
10K	1K	10	100KHZ	1K
100K	1K	100	10KHZ	1K
100K	100K	1000	1KHZ	100K



Summing Amplifier

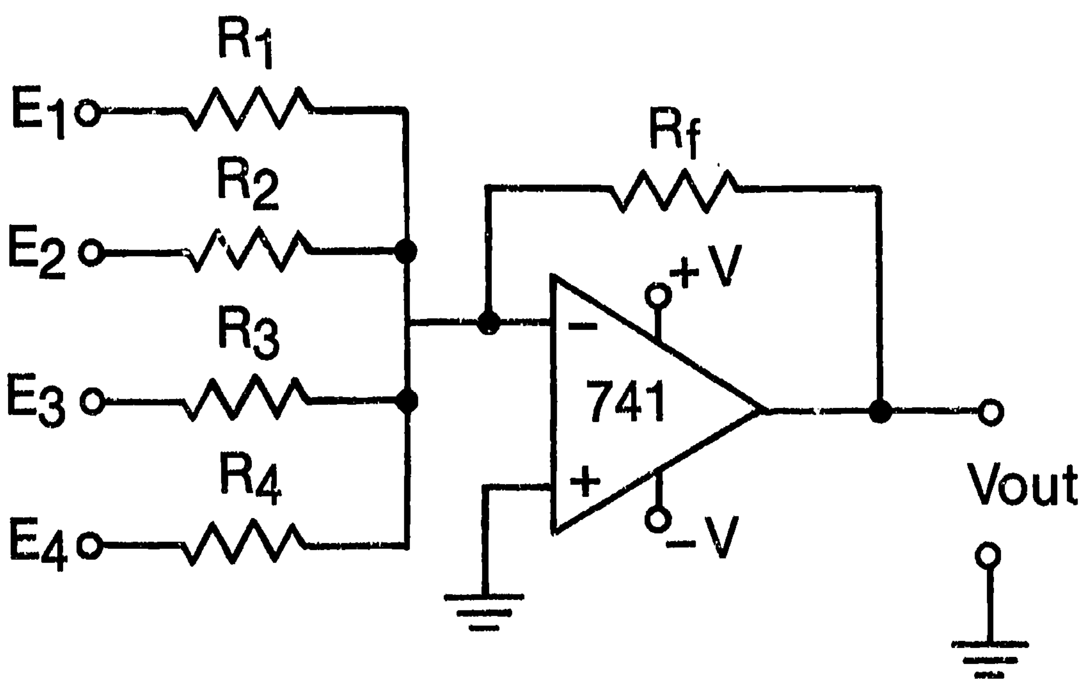
(Two-Input)



$$E_{out} = -(E_1 + E_2)$$

(for equal resistors)

Summing Amplifier
(Four-Input)

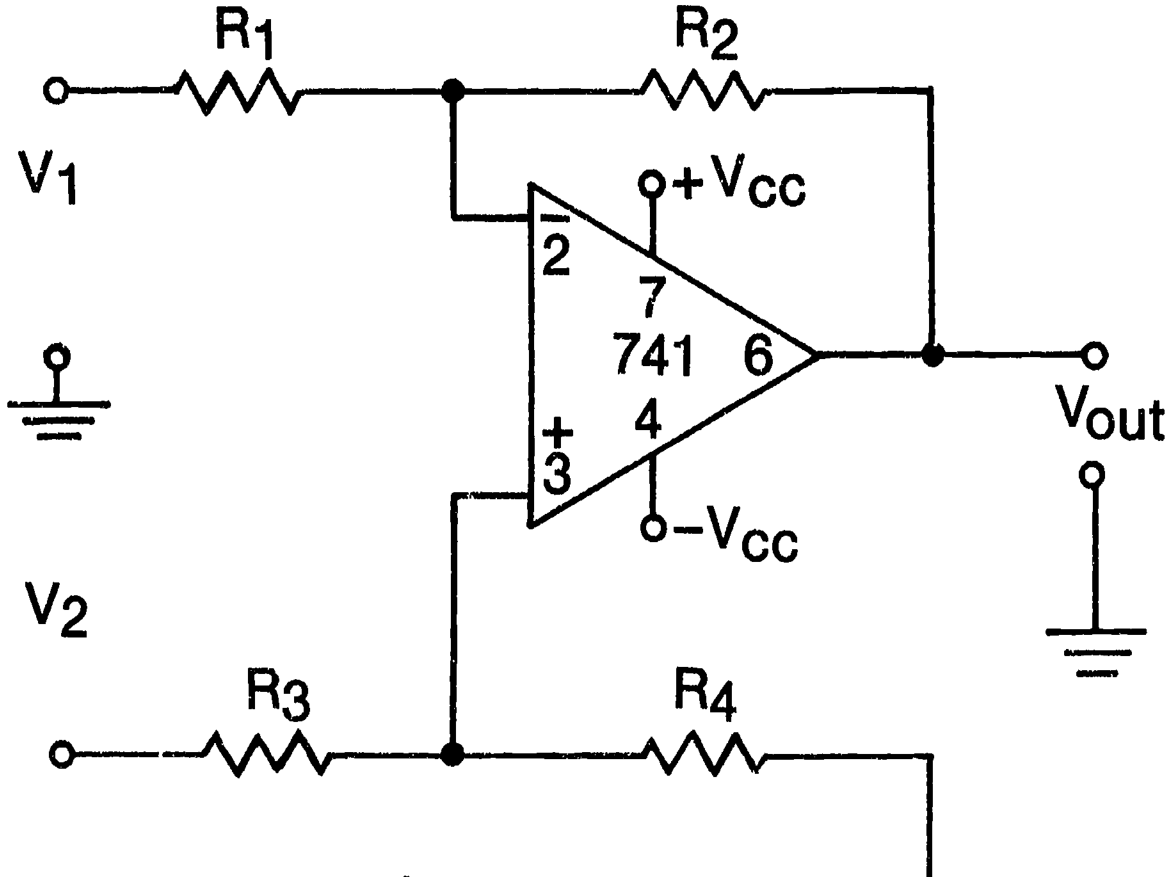


$R_1 = 8K,\ R_2 = 4K,\ R_3 = 2K,\ R_4 = 1K,\ R_f = 8K$

$$E_{out} = -\left(\frac{R_f}{R_1}E_1 + \frac{R_f}{R_2}E_2 + \frac{R_f}{R_3}E_3 + \frac{R_f}{R_4}E_4\right)$$

(for unequal resistors)

Differential DC Amplifier



$$A_V = \frac{R_2}{R_1} \quad \Big| \quad R_4 = R_2 \;\; R_1 = R_3$$

$$V_{out} = \frac{R_2}{R_1}(V_2 - V_1)$$

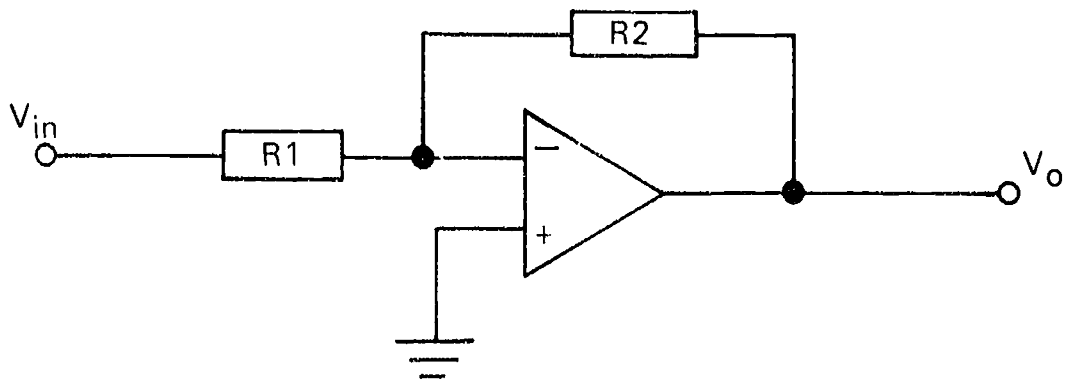
LINEAR INTEGRATED AMPLIFIER CIRCUITS
UNIT V

ASSIGNMENT SHEET #1 — CALCULATE THE CLOSED-LOOP GAIN FOR AN INVERTING AND A NONINVERTING AMPLIFIER

A. Inverting amplifier

1. For the schematic shown below, calculate the closed-loop gain given $R_1 = 10K\Omega$ and $R_2 = 100K\Omega$

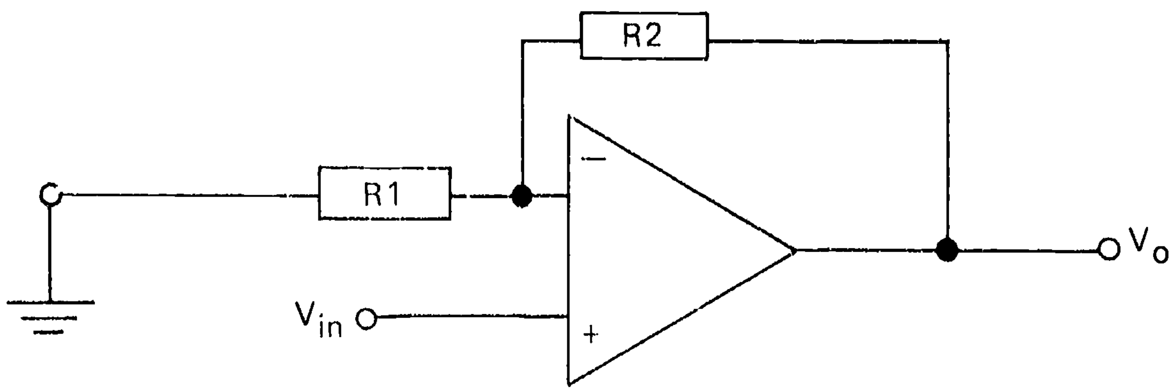
2. Calculate V_o for part 1 above given $V_{in} = +5$ volts.



B. Noninverting amplifier

1. For the schematic shown below, calculate the closed-loop gain given $R_1 = 5K\Omega$ and $R_2 = 10K\Omega$

2. Calculate V_{in} for part 1 above given $V_o = +10$ volts.



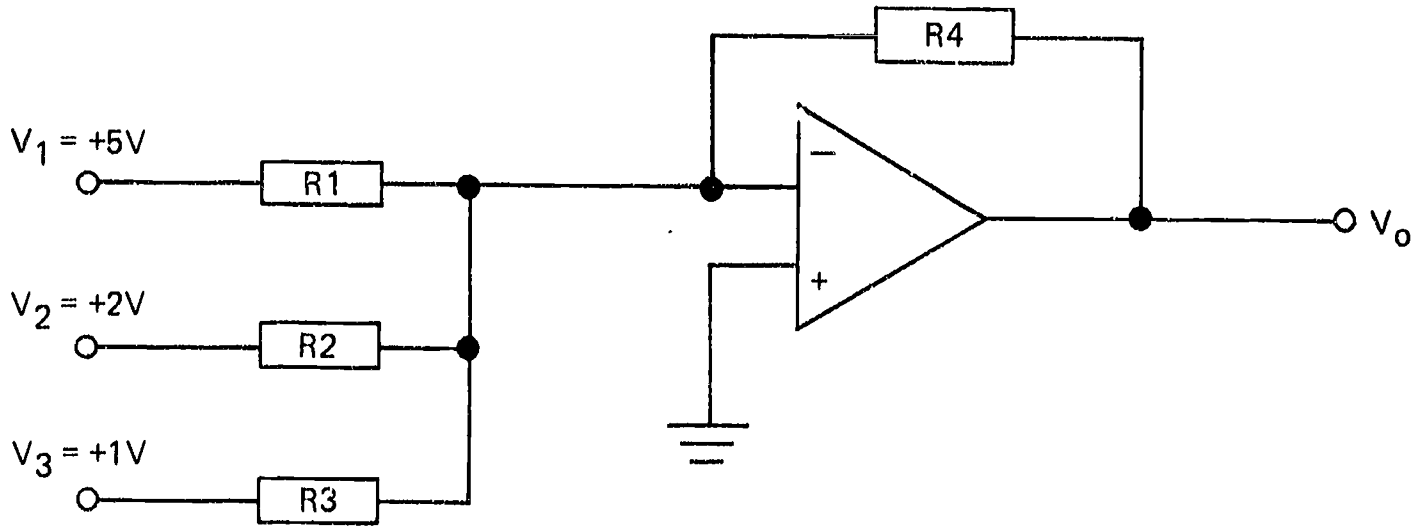
LINEAR INTEGRATED AMPLIFIER CIRCUITS
UNIT V

ASSIGNMENT SHEET #2 — CALCULATE THE OUTPUT VOLTAGE OF A DC SUMMING AMPLIFIER

A. For the schematic shown below, R_1 = 10KΩ, R_2 = 5KΩ, R_3 = 10KΩ, R_4 = 10KΩ

Calculate V_o

B. Repeat part A changing R_4 to 100KΩ.



LINEAR INTEGRATED AMPLIFIER CIRCUITS
UNIT V

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #1

A. Inverting amplifier

1. $A_v = \frac{-R_2}{R_1} = \frac{-100K\Omega}{10K\Omega} = -10$

2. $A_v = \frac{V_o}{V_{in}}$

$V_o = (A_v)(V_{in}) = (-10)(5) = -50$ Volts.

B. Noninverting amplifier

1. $A_v = \frac{R_1 + R_2}{R_2} = 1 + \frac{R_2}{R_1}$

$= 1 + \frac{10K\Omega}{5K\Omega} = 1 + 2 = 3$

2. $A_v = \frac{V_o}{V_{in}}$

$V_{in} = \frac{V_o}{A_v} = \frac{10}{3} = 3.33$ Volts

Assignment Sheet #2

A. $V_o = (V_1)\frac{R_4}{R_1} + (V_2)\frac{R_4}{R_2} + (V_3)\frac{R_4}{R_3}$

$V_o = (5)\frac{10K\Omega}{10K\Omega} + (2)\frac{10K\Omega}{5K\Omega} + (1)\frac{10K\Omega}{10K\Omega}$

$V_o = (5 + 4 + 1) = -10$ Volts.

B. $V_o = (5)\frac{100K\Omega}{10K\Omega} + (2)\frac{100K\Omega}{5K\Omega} + (1)\frac{100K\Omega}{10K\Omega}$

$= -(50 + 40 + 10)$

$= -100$ Volts

LINEAR INTEGRATED AMPLIFIER CIRCUITS
UNIT V

JOB SHEET #1 — CONSTRUCT AND TEST AN INVERTING AMPLIFIER

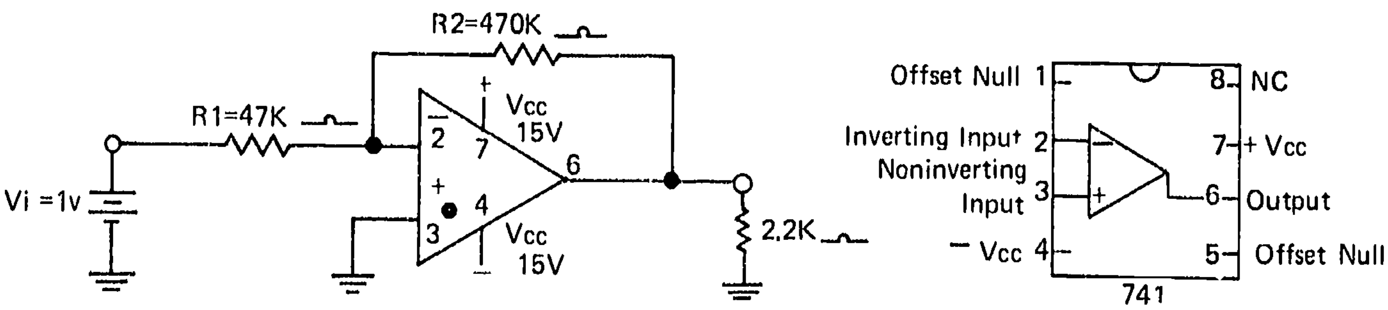
A. Equipment and materials needed

1. Op amp type LM741 or equivalent
2. 470KΩ resistor 1/4 watt
3. 47KΩ resistor 1/4 watt
4. 2.2KΩ resistor 1/4 watt
5. ±15 volt DC power supply or dual tracking DC supply
6. Variable DC power supply (regulated)
7. Proto-board or equipment to connect an integrated circuit
8. Multimeter
9. Dual trace oscilloscope
10. Sine wave generator

B. Procedure

1. Connect the following circuit.

   (NOTE: Review the data sheet for pin connection for the operational amplifier.)



2. Calculate the voltage gain.
3. Calculate the output voltage across the 2.2KΩ load resistor.
4. Turn on the power supply (15V) to the operational amplifier.

   (NOTE: Most operational amplifiers require a power supply that has a positive (+) and a minus (−) voltage with reference to a common point [ground].)

5. Apply a 1 volt DC to the input resistor R_1.

JOB SHEET #1

6. Measure and record the output voltage and the input voltage.

   (NOTE: Be sure to observe the polarity of the output voltage as compared to the input voltage.)

7. Using the measured values, calculate the voltage gain; $A_v = V_{out}/V_{in}$.

8. Compare the measured gain value (step 7) with the calculated gain value (step 2).

9. Check your calculations with your instructor.

Data Table

Av Calculated	V_{out} Calculated	V_{in} Measured	V_{out} Measured	Av Measured	% Diff

10. Apply a sine wave (1.5V p-p) to the input in place of the one-volt DC.

11. Observe the input and output of the circuit with the dual trace oscilloscope.

12. Compare the input and output signal. How does the gain compare to the measured DC gain?

13. Return equipment and materials to their proper storage area.

LINEAR INTEGRATED AMPLIFIER CIRCUITS
UNIT V

JOB SHEET #2 — CONSTRUCT AND TEST A NONINVERTING AMPLIFIER

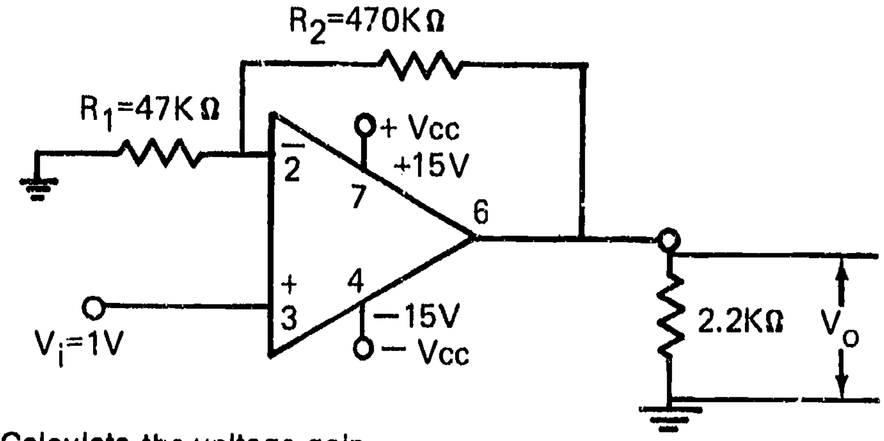
A. Equipment and materials needed

1. Op amp type LM741 or equivalent
2. 470KΩ resistor ¼ watt
3. 47KΩ resistor ¼ watt
4. 2.2KΩ resistor ¼ watt
5. ±15 volt DC power supply or dual tracking DC supply
6. Variable DC power supply
7. Proto-board or equipment to connect an integrated circuit
8. Multimeter
9. Dual-trace oscilloscope
10. Sine wave generator

B. Procedure

1. Connect the following circuit for a noninverting DC amplifier.

   (CAUTION: Do not turn on power at this time.)



2. Calculate the voltage gain.
3. Calculate the output voltage.
4. Turn on the ±15 volt power supply.
5. Apply a 1 volt DC to the noninverting input (pin 3).

LINEAR INTEGRATED AMPLIFIER CIRCUITS
UNIT V

JOB SHEET #3 — CONSTRUCT AND TEST A DIFFERENTIAL AMPLIFIER

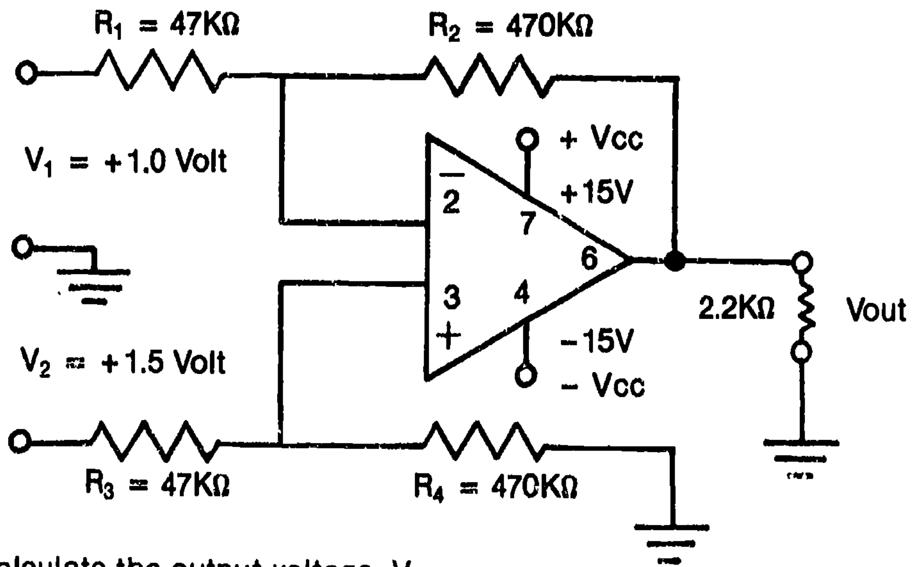
A. Equipment and materials needed

1. Op amp type LM741 or equivalent
2. 2-470KΩ resistor 1/4 watt
3. 2-47KΩ resistor 1/4 watt
4. 1-2.2KΩ resistor 1/4 watt
5. ±15 volt power supply or dual tracking
6. 2-DC power supplies (variable)
7. Proto-board or equipment to connect an integrated circuit

B. Procedure

1. Connect the following circuit for a differential DC amplifier.

   (CAUTION: Do not apply power at this time.)



2. Calculate the output voltage, V_{out}.
3. Turn on the ±15 volt power supply.
4. Apply 1.0 volt at V_1 and 1.5 volts at V_2.

   (NOTE: You may use two separate power supplies to obtain these inputs.)

JOB SHEET #3

5. Measure and record the output voltage and the input voltages.

6. Compare the output voltage measured to the output voltage calculated.

7. Adjust V_2 to 1 volt and measure the output voltage.

   (NOTE: The output voltage should be very small.)

8. Calculate the common mode gain by the following formula:

$$A_C = \frac{V_{out}}{V_{in}} \text{ or } \frac{V_{out}}{V_2}$$

   (NOTE: Use values from part 7 for the above calculation.)

9. Calculate the difference mode gain by the following formula:

$$A_D = \frac{V_{out}}{V_2 - V_1}$$

   (NOTE: Use values from part 5 for the above calculation.)

10. Check your calculations with your instructor.

Data Table

V_{out} Measured $V_1 = 1.0V$ $V_2 = 1.5V$	V_1 Measured	V_2 Measured	V_{out} Calculated	V_{out} Measured $V_1 = V_2 = 1.0V$	A_C	A_D

11. Return equipment and materials to their proper storage area.

LINEAR INTEGRATED AMPLIFIER CIRCUITS
UNIT V

JOB SHEET #4 — CONSTRUCT AND TEST A DC SUMMING AMPLIFIER

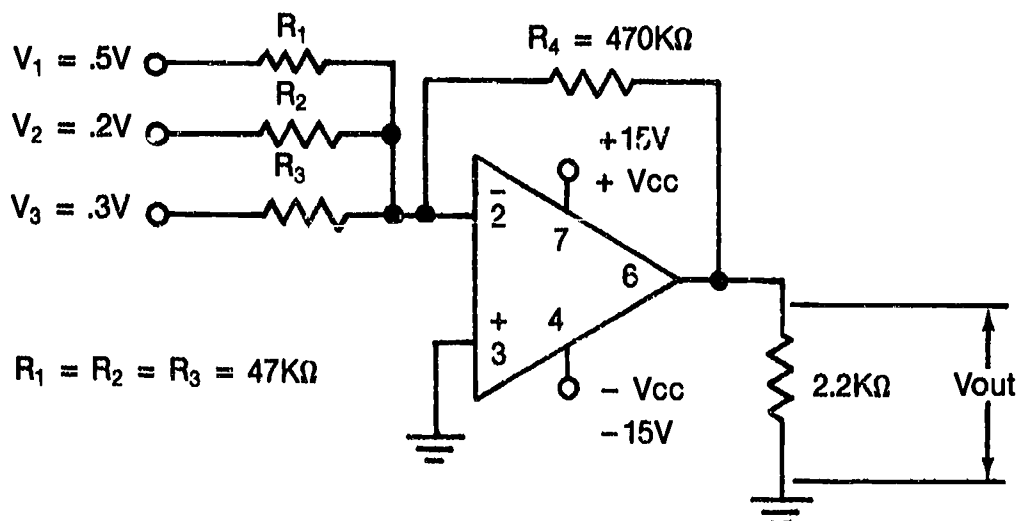
A. Equipment and materials needed

1. Op amp type LM741 or equivalent
2. 470KΩ resistor 1/4 watt
3. 3-47KΩ resistor 1/4 watt
4. 2.2KΩ resistor 1/4 watt
5. ±15 volt power supply or dual tracking
6. Variable DC power supply
7. Proto-board or equipment to connect an integrated circuit
8. Multimeter

B. Procedure

1. Connect the following circuit for a DC summing inverting amplifier.

   (CAUTION: Do not turn on the power at this time.)



2. Calculate the output voltage.
3. Apply 0.5V to input V_1, 0.2V to input V_2, 0.3V to input V_3.

   (NOTE: It may be necessary to build a voltage divider to achieve these input voltages.)

JOB SHEET #4

4. Turn on the ±15 volt power supply.

5. Measure and record the output voltage and the input voltage.

   (NOTE: Observe the polarity of the output voltage as compared to the input voltage.)

6. Compare the output voltage measured to the output voltage calculated.

7. Compute the output voltage if $R_1 = R_2 = R_3 = 470K\Omega$ resistance.

8. Compute the output voltage if $R_1 = 4.7K\Omega$, $R_2 = 3.3K\Omega$, and $R_3 = 6.8K\Omega$.

9. Check your calculations with your instructor.

Data Table

V_{out} Calculated	V_{in} Measured	V_{out} Measured	% Diff	V_{out} 470KΩ Calculated	V_{out} 4.7KΩ Calculated

10. Return equipment and materials to their proper storage area.

LINEAR INTEGRATED AMPLIFIER CIRCUITS
UNIT V

NAME ____________________

TEST

(NOTE: Answers to questions a.-l. appear on this page.)

1. Match the terms on the right with their correct definitions.

_____a. A complete electronic circuit that is fabricated on a single chip of silicon		1. Monolithic IC
_____b. A solid-state integrated circuit amplifier with very high gain, differential inputs, and uses external feedback to control its gain		2. JFET
_____c. An application of an operational amplifier circuit that uses no external feedback		3. Passive device
_____d. An application of an operational amplifier circuit that uses external feedback		4. Active device
_____e. A classification of integrated circuits used for analog amplification purposes		5. MOSFET
_____f. A DC or AC current or voltage that varies smoothly or continuously		6. Comparator
_____g. A component in a circuit which has gain or which directs the flow of current		7. Linear IC
_____h. A component in a circuit which has no gain characteristics such as a resistor, capacitor, or inductor		8. Integrated circuit
_____i. An integrated circuit fabricated from a single chip of semiconductor material, usually silicon		9. Operational amplifier
_____j. A junction field-effect transistor in which the gate electrode is formed by a PN junction		10. Open-loop operation
_____k. A field-effect transistor containing a metal gate over thermal oxide on silicon		11. Closed-loop operation
_____l. A circuit which compares two inputs and produces an output that is a function of the result of the comparison		12. Analog signal

TEST

(NOTE: Answers to questions m.-s. appear on this page.)

_____m.	A circuit that amplifies the difference between two inputs; the input stage of an op-amp	13. Differential amplifier
_____n.	Signal voltages that are in phase, of equal amplitude and frequency, applied to both inputs of a differential amplifier	14. Feedback
_____o.	Leakage from one signal path to another producting objectionable signal interfere	15. Crosstalk
_____p.	The transferring of voltage from output of a circuit back to its input	16. Common-mode signal
_____q.	Equal to the unity-gain frequency of an op-amp and determined by multiplying the gain and bandwidth of a specific circuit	17. Gain-bandwidth product
_____r.	The cancelling of DC offset voltage in an op-amp	18. DC offset voltage
_____s.	The small output voltage in practical op-amp circuits that is the resultant of bias currents in the circuit	19. Offset-null

2. Select true statements concerning fundamentals of differential amplifier circuits by placing an "X" in the blank preceding each true statement.

_____a. A basic differential amplifier circuit has two input terminals and two output terminals.

_____b. The simplest connection is the single-input, single-output connection.

_____c. The single-input, differential-output has one input terminal and two output terminals.

_____d. The differential-input, differential-output circuit has two input terminals and two output terminals.

_____e. The differential amplifier will reject common-mode signals (noise and unwanted frequencies of the same phase at the inputs) and amplify differential signals.

_____f. The ability of the differential amplifier is expressed as a ratio of the difference gain to common-mode gain and called the common-mode rejection ratio (CMRR).

_____g. The differential amplifier is not easily adaptable for application in integrated circuits.

TEST

3. Complete the following statements concerning integrated circuit construction by inserting the word that best completes each statement.

   a. Integrated circuits are classified as ____________, thin-film, thick-film, and hybrid integrated devices.

   b. The ____________ IC is a complete circuit including active and passive devices and all interconnections fabricated through a diffusion process on a single piece of semiconductor material.

   c. A ____________ IC is a circuit consisting of patterns of miscellaneous materials which have been laid down in very thin ribbons on a single substrate of insulating material such as glass or ceramic.

   d. A ____________ IC is a circuit in which resistors, capacitors, and conductors are deposited on a substrate usually through a silk-screen printing process.

   e. ____________ IC's are constructed with a combination of thin-film, thick-film, and monolithic processes to form a complete circuit.

4. Complete the following statements concerning the maximum ratings of an operational amplifier by inserting the word that best completes each statement.

   a. The operating temperature is the ____________ (room temperature) range for which the operational amplifier (op-amp) will operate within the manufacturer's specifications.

   b. The ____________ voltage is the maximum positive and negative voltage that can be used to power the op-amp.

   c. The internal power dissipation is the maximum ____________ that an op-amp is capable of dissipating in a specified ambient temperature.

   d. The input voltage is the maximum input voltage that can be simultaneously applied between both inputs and ____________ (often referred to as common-mode voltage).

   e. The output short circuit duration is the time that the output of the op-amp can be short-circuited to ____________ or to either supply voltage.

   f. The ____________ input voltage is the maximum voltage that can be applied across the + and − inputs.

5. Complete the following statements concerning the input and output parameters of the op-amp by circling the word that best completes each statement.

   a. The (**output, input**) resistance is the resistance at either input to the op-amp with the remaining input grounded.

   b. The (**output, input**) offset voltage is the voltage that must be applied to one of the input terminals to give a zero output voltage.

TEST

c. The (**output, input**) bias current is the average of the currents flowing into both inputs and ideally both bias currents are equal.

d. The (**output, input**) resistance is the resistance seen looking inward from the op-amp output.

e. The (**output, input**) short-circuit current is the maximum output current that the op-amp can deliver to a load.

f. The (**output, input**) offset current is the difference of the two input bias currents when the output is zero.

g. The (**output, input**) voltage range is the range of the voltage common to both inputs and ground (range of common-mode input voltage.

h. The (**output, input**) voltage swing is the maximum peak output voltage that the op-amp can supply without saturation or clipping.

6. Select true statements concerning the dynamic parameters of the op-amp by placing an "X" in the blank preceding each true statement.

______a. The open loop voltage gain is the ratio of the output to input voltage of the op-amp with external feedback.

______b. The rise time is the ten to ninety percent closed-loop, step-function response time of an amplifier under small-signal conditions.

______c. The large-signal voltage gain is the ratio of the minimum voltage swing to the change in the input voltage required to drive the output from ten to a specified voltage.

______d. The slew rate is the maximum rate of change of output voltage under large-signal conditions.

______e. The common-mode rejection ratio is a measure of the ability of the op-amp to reject signals that are simultaneously present at both inputs and usually expressed in decibels.

______f. The channel separation is the amount of "crosstalk" between op-amps when more than one op-amp is present in a single package.

7. List three basic operational characteristics of the op-amp that give the op-amp desirable characteristics.

a. ______________________________

b. ______________________________

c. ______________________________

TEST

8. Complete the following statements concerning the characteristics of the inverting amplifier by inserting the word(s) that best completes each statement.

   a. The ____________ configuration is the most popular of the op-amp configurations.

   b. The output of the op-amp in the ____________ configuration is 180 degrees out-of-phase with the input.

   c. The ____________ ____________ of the op-amp stage is equal to the ratio of feedback to input resistors.

   d. The input ____________ is equal to the value of the input resisto:.

9. Select true statements concerning the characteristics of the noninverting amplifier by placing an "X" in the blank preceding each true statement.

   _____a. The noninverting amplifier is used to provide an output that is out of phase with the input.

   _____b. The output signal is the difference between the input signal applied to the noninverting input and the feedback signal applied to the inverting input.

   _____ c. The stage gain may be obtained by using the equation

$$A_v = 1 + \frac{R_i}{R_f}$$

   _____d. The input impedance of an op-amp is very low.

10. State the relationship between gain and bandwidth when degenerative feedback is employed in an op-amp circuit.

____

____

____

11. Draw the schematic diagrams of a DC summing and a difference amplifier. Label each diagram with its proper name.

TEST

(NOTE: If the following activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

12. Calculate the closed-loop gain for an inverting and a noninverting amplifier. (Assignment Sheet #1)

13. Calculate the output voltage of a DC summing amplifier. (Assignment Sheet #2)

14. Demonstrate the ability to:

    a. Construct and test an inverting amplifier. (Job Sheet #1)

    b. Construct and test a noninverting amplifier. (Job Sheet #2)

    c. Construct and test a differential amplifier. (Job Sheet #3)

    d. Construct and test a DC summing amplifier. (Job Sheet #4)

LINEAR INTEGRATED AMPLIFIER CIRCUITS
UNIT V

ANSWERS TO TEST

1. a. 8
   b. 9
   c. 10
   d. 11
   e. 7
   f. 12
   g. 4
   h. 3
   i. 1
   j. 2
   k. 5
   l. 6
   m. 13
   n. 16
   o. 15
   p. 14
   q. 17
   r. 19
   s. 18

2. a, b, c, d, e, f

3. a. Monolithic
   b. Monolithic
   c. Thin-film
   d. Thick-film
   e. Hybrid

4. a. Ambient
   b. Supply
   c. Power
   d. Ground
   e. Ground
   f. Differential

5. a. Input
   b. Input
   c. Input
   d. Output
   e. Output
   f. Input
   g. Input
   h. Output

6. b, d, e, f

7. Any three of the following:
   a. Very high gain
   b. Very high input impedance
   c. Very low output impedance
   d. High common-mode rejection
   e. Frequency response down to DC

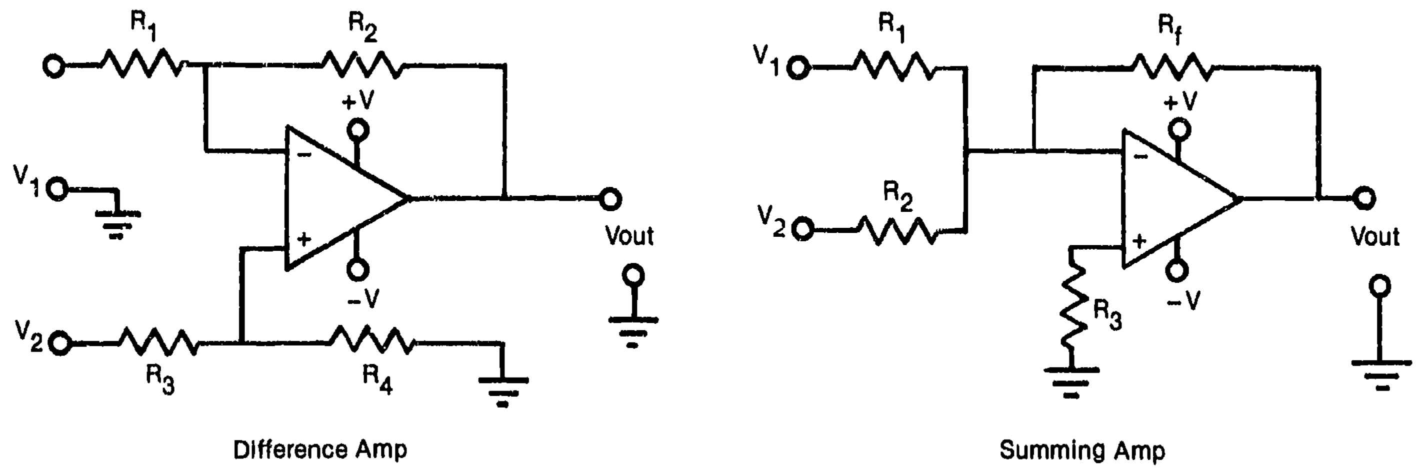
8. a. Inverting
   b. Inverting
   c. Voltage gain
   d. Impedance

ANSWERS TO TEST

9. b

10. An increase in degenerative feedback decreases gain and increases bandwidth

11. (Schematic configurations may vary)



12.-13. Evaluated to the satisfaction of the instructor

14. Performance skills evaluated to the satisfaction of the instructor

CIRCUIT APPLICATIONS
UNIT VI

UNIT OBJECTIVE

After completion of this unit, the student should be able to apply theoretical knowledge related to circuit applications, and construct and test various amplifiers, a Hartley oscillator, and a 555 timer. Competencies will be demonstrated by correctly performing the procedures outlined in the job sheets and by scoring a minimum of 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to circuit applications with their correct definitions.
2. Complete statements concerning basic power amplifier characteristics.
3. Identify basic power amplifier circuit configurations.
4. Arrange in order the steps in troubleshooting multistage amplifiers.
5. List basic oscillator requirements.
6. Identify basic types of oscillator circuits.
7. Complete statements concerning the characteristics of active filters.
8. Complete statements concerning the characteristics of optocouplers.
9. Demonstrate the ability to:
   a. Construct and test a push-pull amplifier. (Job Sheet #1)
   b. Construct and test a two-stage direct coupled amplifier. (Job Sheet #2)

OBJECTIVE SHEET

c. Construct and test a basic Darlington pair amplifier. (Job Sheet #3)

d. Construct and test a Hartley oscillator. (Job Sheet #4)

e. Construct and test a low-pass active filter. (Job Sheet #5)

f. Construct and test a 555 timer circuit. (Job Sheet #6)

CIRCUIT APPLICATIONS
UNIT VI

SUGGESTED ACTIVITIES

A. Obtain additional materials and/or invite resource people to class to supplement/reinforce information provided in this unit of instruction.

   (NOTE: This activity should be completed prior to the teaching of this unit.)

B. Make transparencies from the transparency masters included with this unit.

C. Provide students with objective sheet.

D. Discuss unit and specific objectives.

E. Provide students with information sheet.

F. Discuss information sheet.

   (NOTE: Use the transparencies to enhance the information as needed.)

G. Provide students with job sheets.

H. Discuss and demonstrate the procedures outlined in the job sheets.

I. Integrate the following activities throughout the teaching of this unit:

   1. View films and filmstrips related to circuit applications.

   2. Demonstrate the troubleshooting procedures in an audio amplifier system.

   3. Identify specific circuits using the schematic to equipment available in the laboratory.

   4. Discuss trouble analysis and typical component failures.

   5. Meet individually with students to evaluate their progress through this unit of instruction, and indicate to them possible areas for improvement.

J. Give test.

K. Evaluate test.

L. Reteach if necessary.

INSTRUCTIONAL MATERIALS INCLUDED IN THIS UNIT

A. Objective sheet

B. Suggested activities

C. Information sheet

D. Transparency masters

1. TM 1 — Single-Ended Power Amp
2. TM 2 — Darlington Pair
3. TM 3 — Push-Pull Amplifier
4. TM 4 — Complementary Power Amplifier
5. TM 5 — Frequency Compensation Networks
6. TM 6 — Simplified Troubleshooting Flow Chart
7. TM 7 — Armstrong Oscillator
8. TM 8 — Hartley Oscillators
9. TM 9 — Colpitts Oscillators
10. TM 10 — Wein-Bridge Oscillator
11. TM 11 — Crystal Controlled Oscillator
12. TM 12 — Active Filters

E. Job sheets

1. Job Sheet #1 — Construct and Test a Push-Pull Amplifier
2. Job Sheet #2 — Construct and Test a Two Stage Direct Coupled Amplifier
3. Job Sheet #3 — Construct and Test a Basic Darlington-Pair Amplifier
4. Job Sheet #4 — Construct and Test a Hartley Oscillator
5. Job Sheet #5 — Construct and Test a Low-Pass Active Filter
6. Job Sheet #6 — Construct and Test a 555 Timer Circuit

INSTRUCTIONAL MATERIALS INCLUDED IN THIS UNIT

F. Test

G. Answers to test

REFERENCES USED IN DEVELOPING THIS UNIT

(NOTE: The following is a list of references used in completing this unit.)

A. Boylestad and Nashelsky. *Electronic Devices and Circuit Theory,* Third Edition. Prentice-Hall, Inc.: Englewood Cliffs, NJ, 1982.

B. Dugan, Frank R. *Linear Integrated Circuits for Technicians.* North Scituate, MA: Breton Publishers, 1984.

C. Heath/Zenith Educational Systems. *Operational Amplifiers.* Benton Harbor, MI: Heath Company, 1980.

D. Sahm, W.H. *General Electric Optoelectronic Manual.* Syracuse, NY: General Electric Company, 1979.

CIRCUIT APPLICATIONS
UNIT VI

INFORMATION SHEET

I. **Terms and definitions**

A. Complementary symmetry — An arrangement of PNP and NPN type transistors that provides push-pull type operation from a single input signal

B. Crossover distortion — Distortion in push-pull amplifiers at the zero center line of the AC signal due to nonlinearity of the transistor characteristics

C. Darlington pair — A circuit consisting of two bipolar transistors with the collectors connected together and the emitter of one connected to the base of the other acting together as a single unit like a very high gain transistor

D. Feedback — The coupling of energy from the output back to the input of a circuit

E. IRED — Infrared emitting diode

F. LC network — One of the classifications of oscillator circuits in which the frequency is determined by the inductor (L) and the capacitor (C) in the tank (resonant) circuit

G. Optocoupler — A device which provides for electrical isolation between circuits using optoelectronic components

H. Oscillator — An electronic circuit which converts electrical energy from a DC source into AC energy

I. Push-pull amplifier — An amplifier which uses two transistors connected so that each transistor contributes current to the output signal on alternate half cycles of the input signal

J. RC network — One of the classifications of oscillator circuits in which the frequency is determined by the resistance and the capacitance in the circuit

K. Single-ended amplifier — An amplifier in which only one transistor is used in the amplifier stage

II. **Basic power amplifier characteristics**

A. An amplifier is considered a power amplifier when it is connected to a low-resistance load (such as a speaker) or when it is required to deliver more than a few milliwatts to a load.

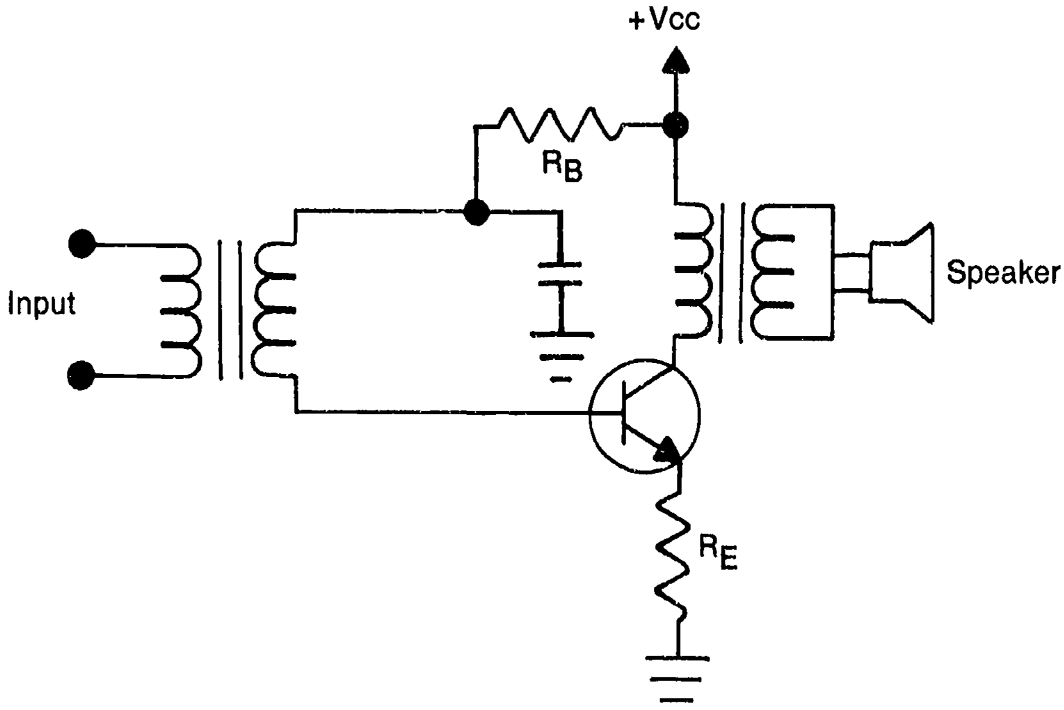
B. The power amplifier is typically the last stage of amplification in a system.

C. The power amplifier should have a very low characteristic output impedance.

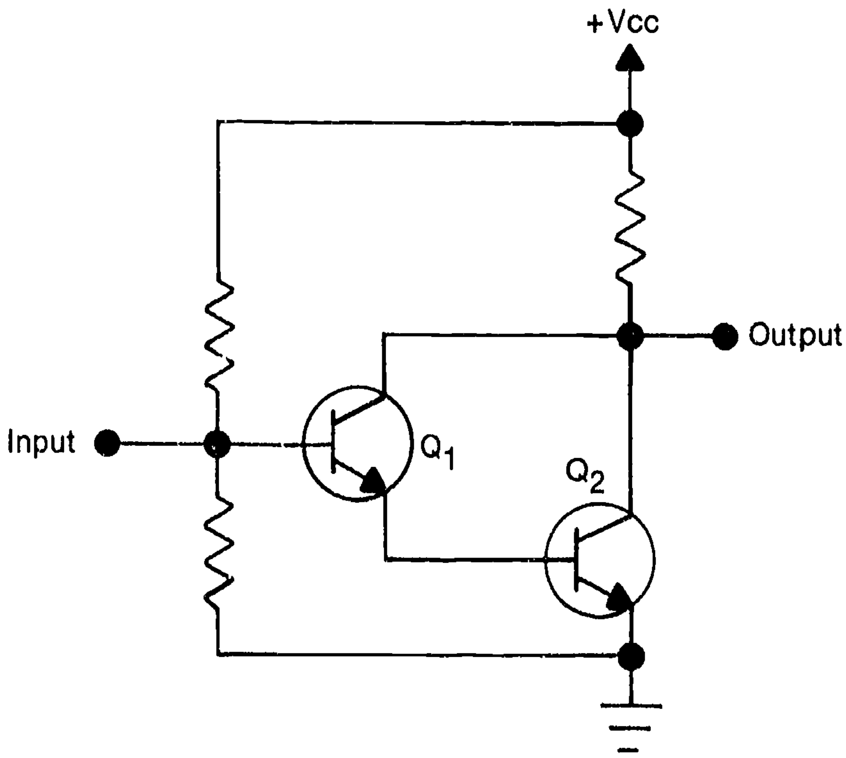
INFORMATION SHEET

III. Basic power amplifier circuit configurations

A. A single-ended power amplifier uses a single transistor biased to operate class A. (Transparency #1)



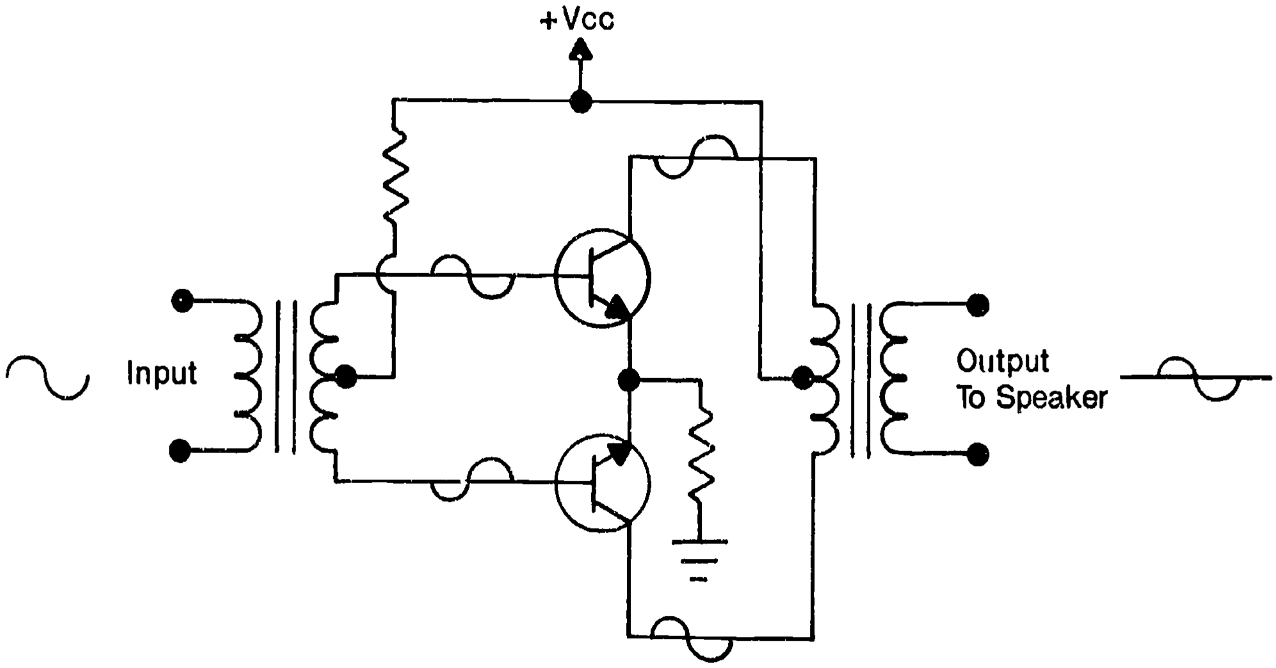
B. The Darlington pair arrangement may be used to increase the voltage gain in a power amplifier. (Transparency #2)



INFORMATION SHEET

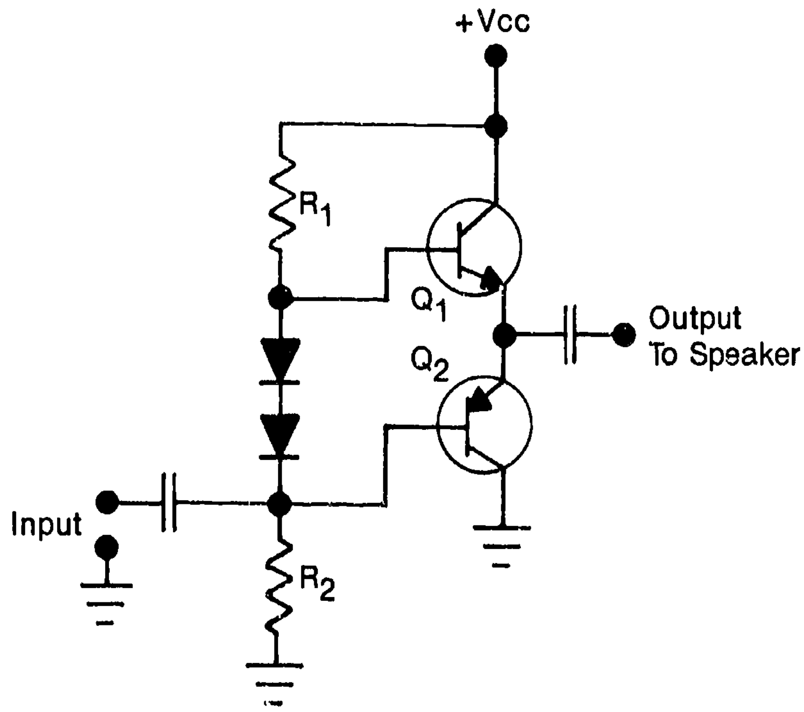
C. The push-pull power amplifier requires two transistors to operate class B. (Transparency #3)

(NOTE: Push-pull amplifiers are normally operated class AB to reduce crossover distortion.)



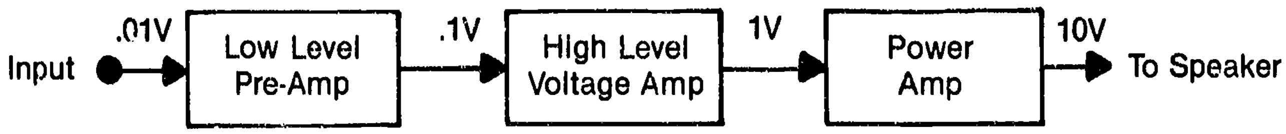
D. The complementary amplifier makes use of the complementary characteristics of one NPN and one PNP transistor. (Transparency #4)

(NOTE: The characteristics of the two transistors should be identical; therefore, matched-pairs of transistors are typically used.)



INFORMATION SHEET

E. Multistage amplifiers are used in a typical amplifier system when more amplification is required than can be obtained from a single stage.



F. Since any distortion introduced within a circuit is amplified by the following stages, negative feedback and frequency compensation networks are used extensively to prevent and reduce distortion. (Transparency #5)

IV. **Troubleshooting multistage amplifiers** (Transparency #6)

(NOTE: The most common failure in power amplifiers is the transistor.)

A. Inspect the equipment for obvious symptoms such as burned, overheated, or broken components.

B. Check the power supply for normal operation.

C. Isolate the defective stage by making waveform checks beginning at the output and working back toward the input.

D. Make DC voltage checks with a voltmeter to find any biasing problems.

(NOTE: Check high-power components first.)

E. Test individual suspect components.

(NOTE: Intermittent troubles may sometimes be isolated with a hair dryer and a can of coolant spray.)

V. **Basic oscillator requirements**

A. A frequency determining network (typically a tank circuit or crystal) to set the oscillation frequency

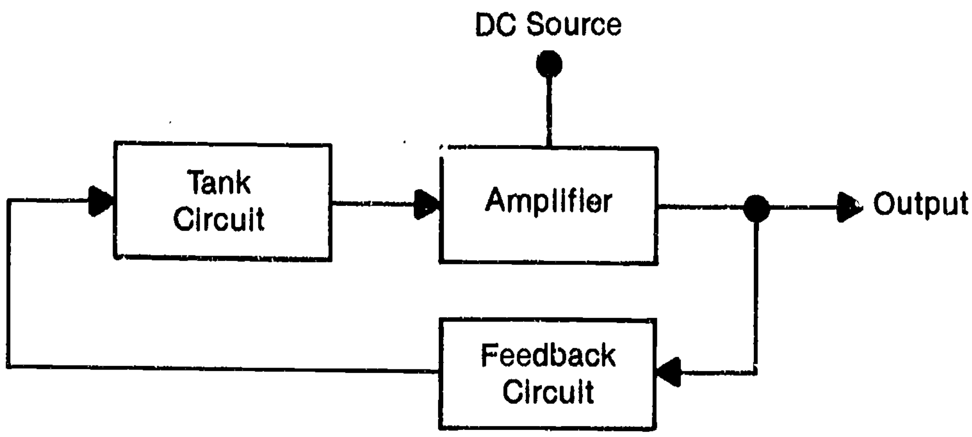
B. An amplifier stage for replacement of circuit losses

C. A positive feedback circuit to supply a regenerative signal back to the frequency determining components to maintain oscillations

D. A DC power source to supply the frequency determining network and amplifier with electrical energy

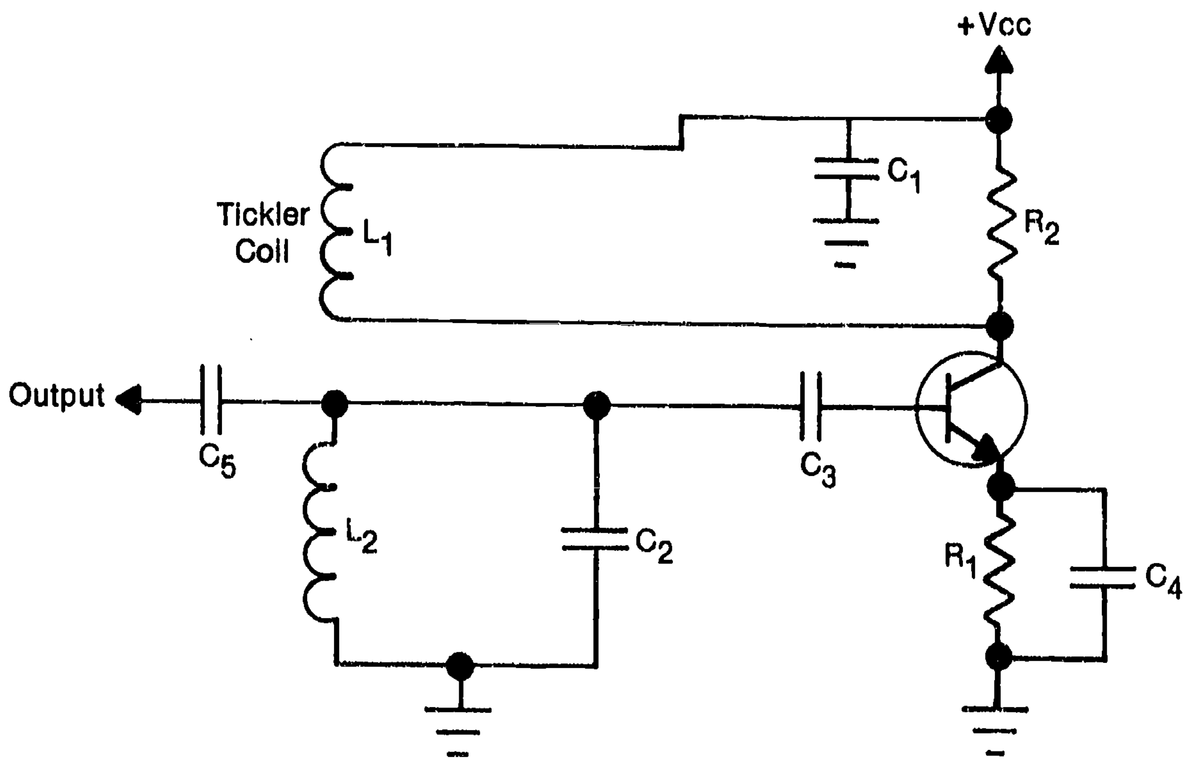
INFORMATION SHEET

E. Oscillator must be self-starting



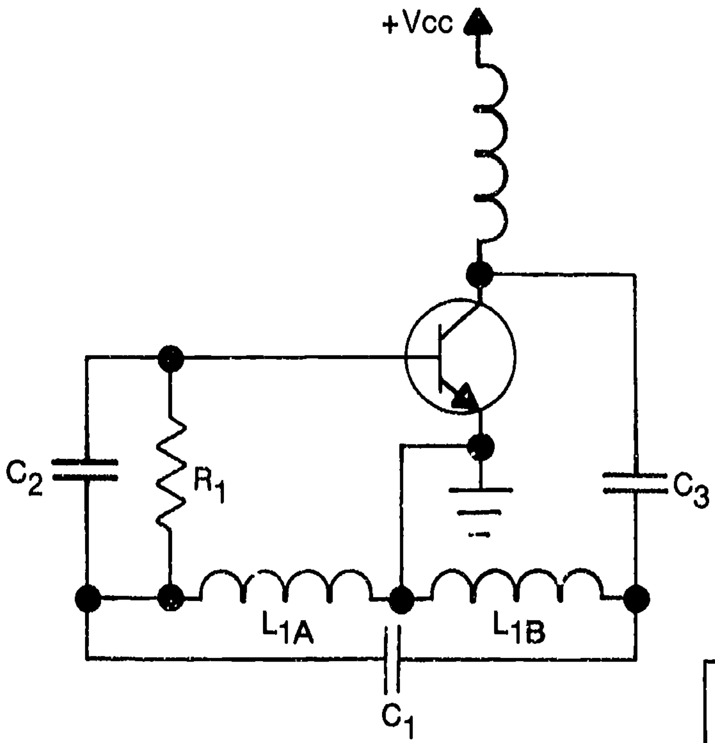
VI. **Types of oscillator circuits**

A. The Armstrong oscillator utilizes the tickler-coil principle for operation and may be series-fed or shunt fed types. (Transparency #7)

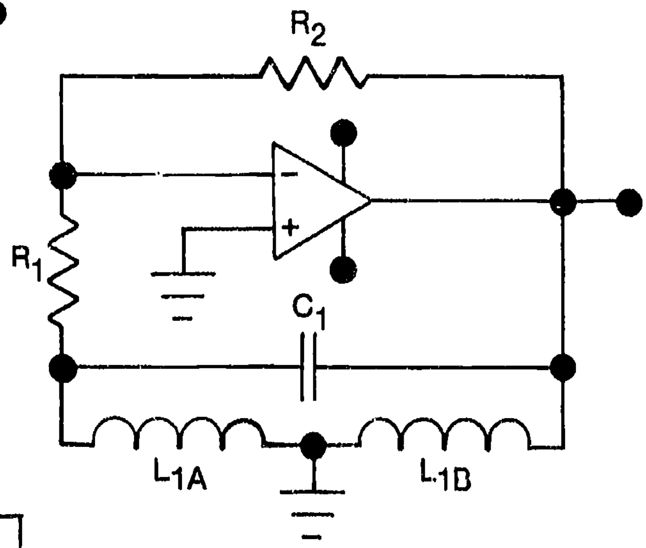


INFORMATION SHEET

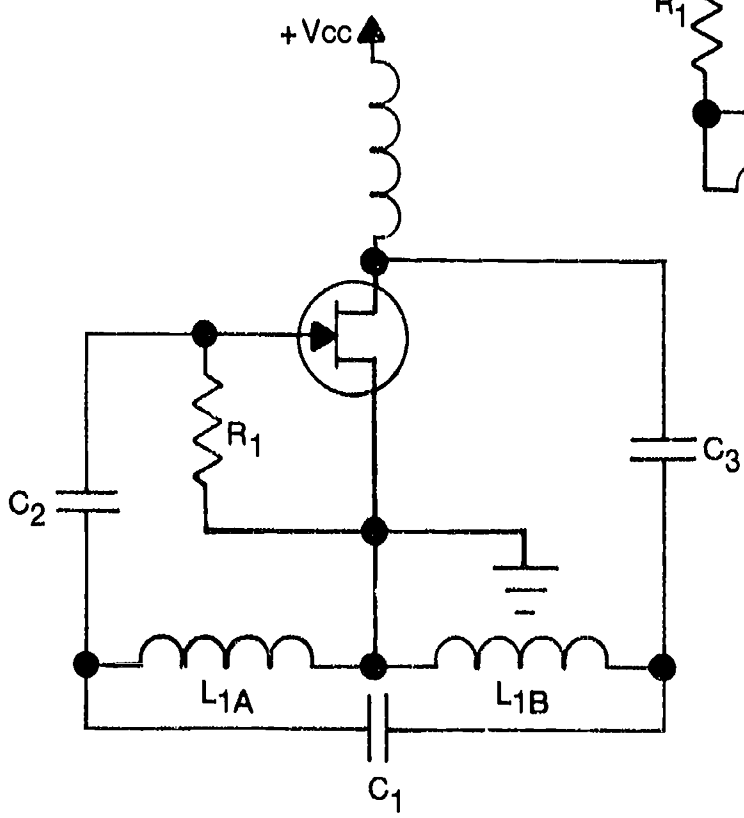
B. The Hartley oscillator (shunt type) utilizes a tapped coil for in-phase feedback, an LC frequency determining network, and may be configured using either a transistor, FET, or op-amp. (Transparency #8)



Transistor Type



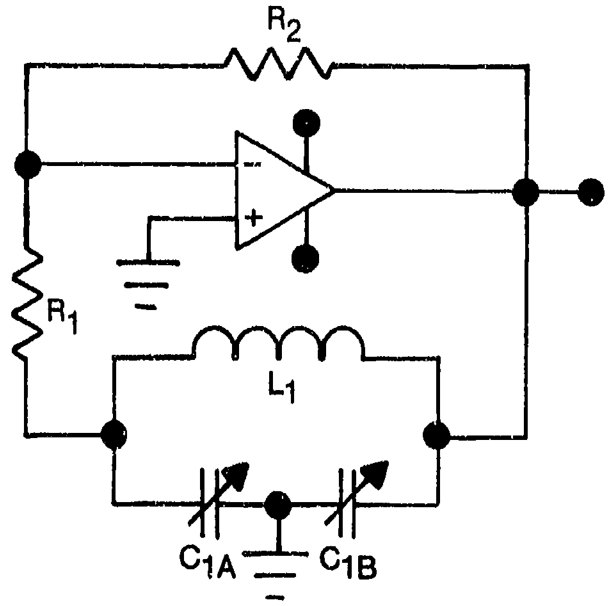
OP-Amp Type



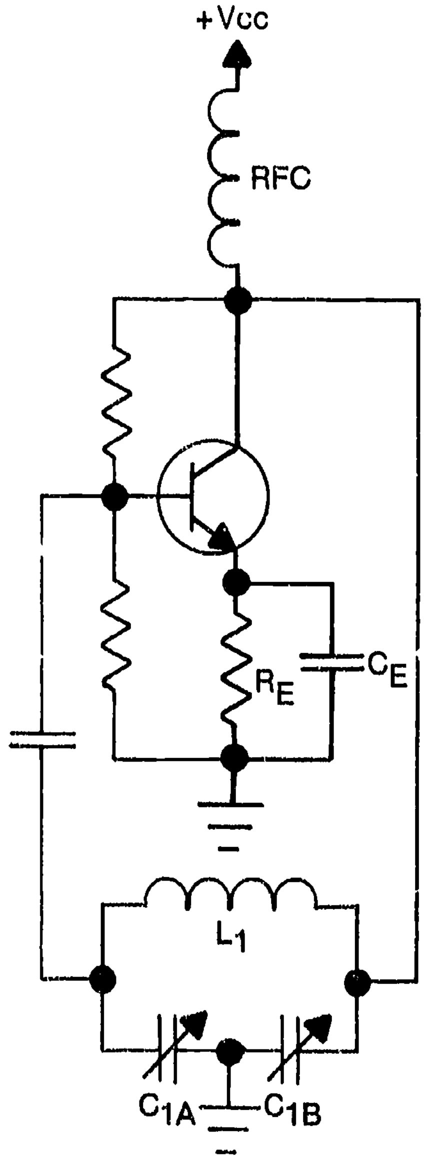
FET Type

INFORMATION SHEET

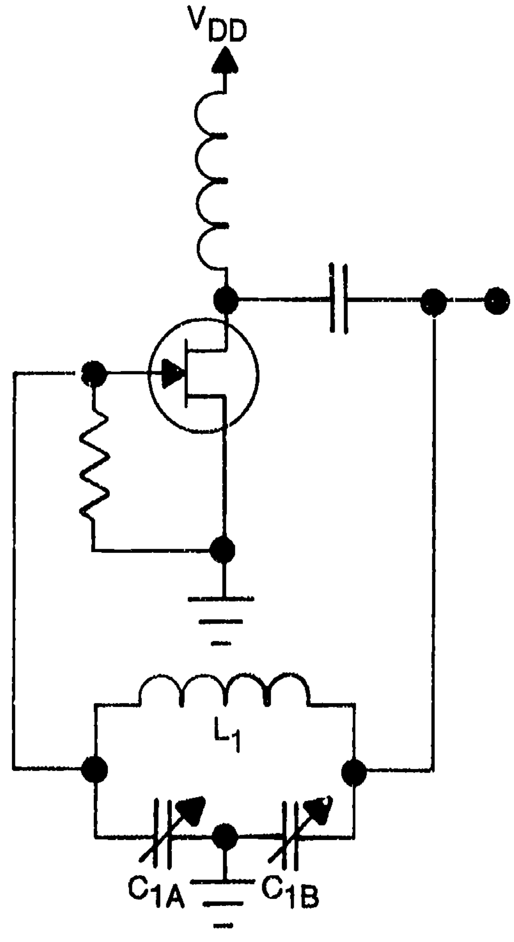
C. The Colpitts oscillator uses a tapped capacitor arrangement for feedback, an LC frequency determining network, and a transistor, FET, or op-amp may be used as the amplifier. (Transparency #9)



OP-Amp Type



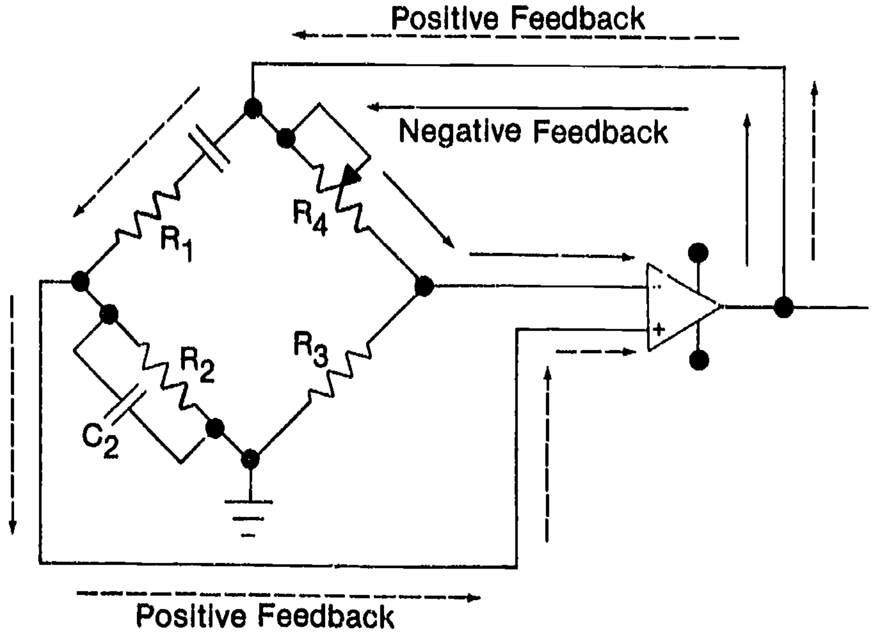
Transistor Type



FET Type

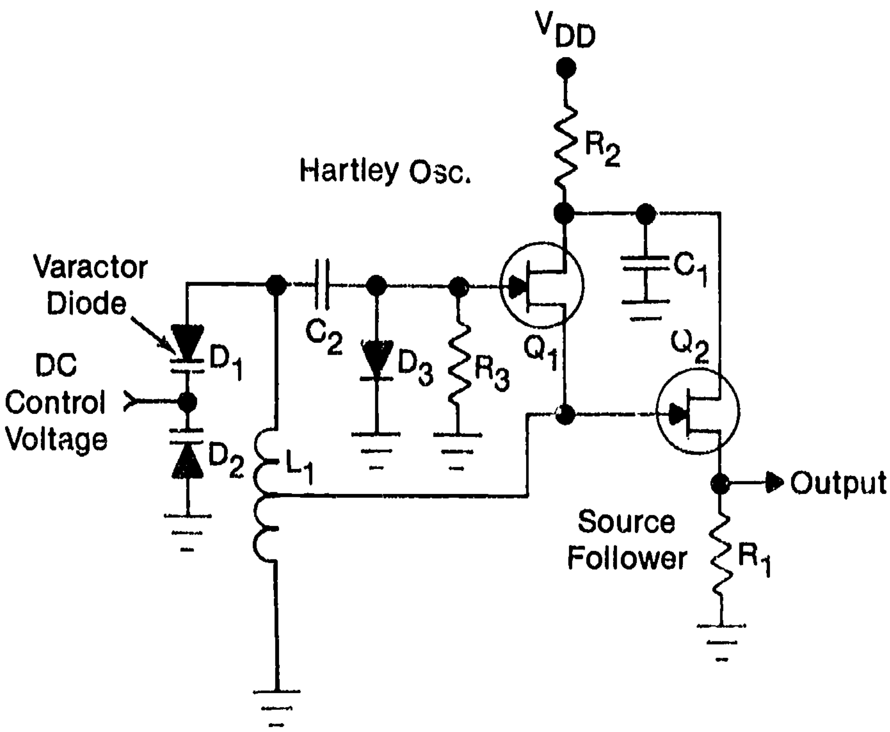
INFORMATION SHEET

D. The Wein-bridge oscillator uses an RC network to determine its frequency, and provides regenerative feedback to the inverting input of an op-amp and degenerative feedback to the noninverting input of the op-amp to determine and maintain the oscillator output. (Transparency #10)



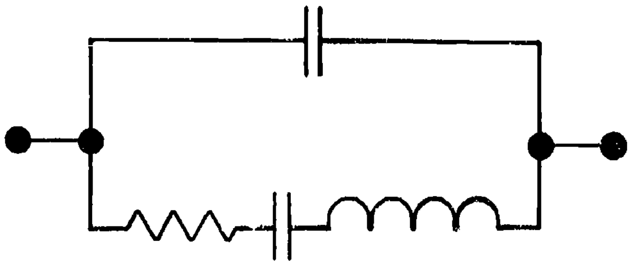
E. The voltage-controlled-oscillator (VCO) is an oscillator circuit whose frequency is automatically controlled by a DC voltage.

(NOTE: Traditional oscillator circuits such as the Hartley oscillator may be modified by replacing the capacitors in the frequency determining network with varactors. The frequency of the oscillator is then varied by controlling the DC voltage across the diode.)

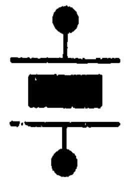


INFORMATION SHEET

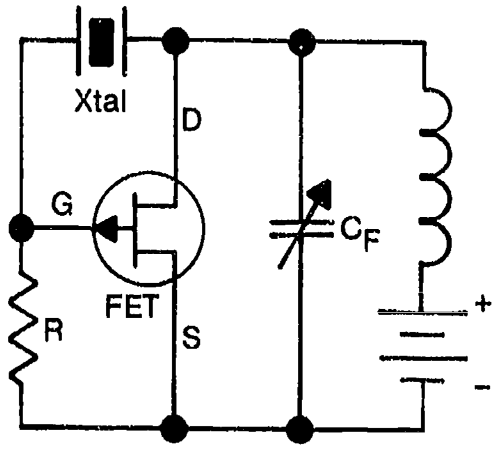
F. The crystal controlled oscillator used in oscillator circuits to replace LC frequency determining networks to achieve improved accuracy and stability. (Transparency #11)



Crystal Equivalent Circuit



Crystal

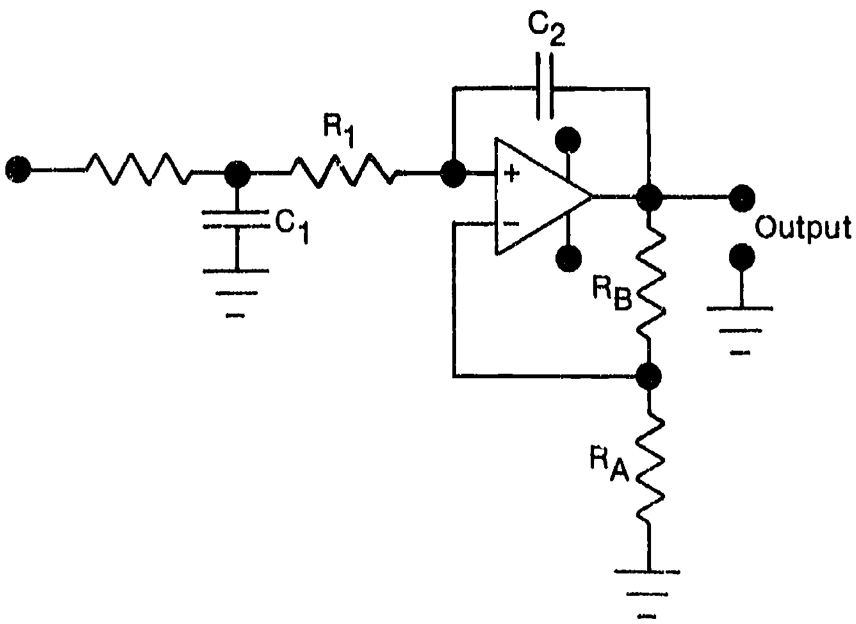


Pierce Oscillator

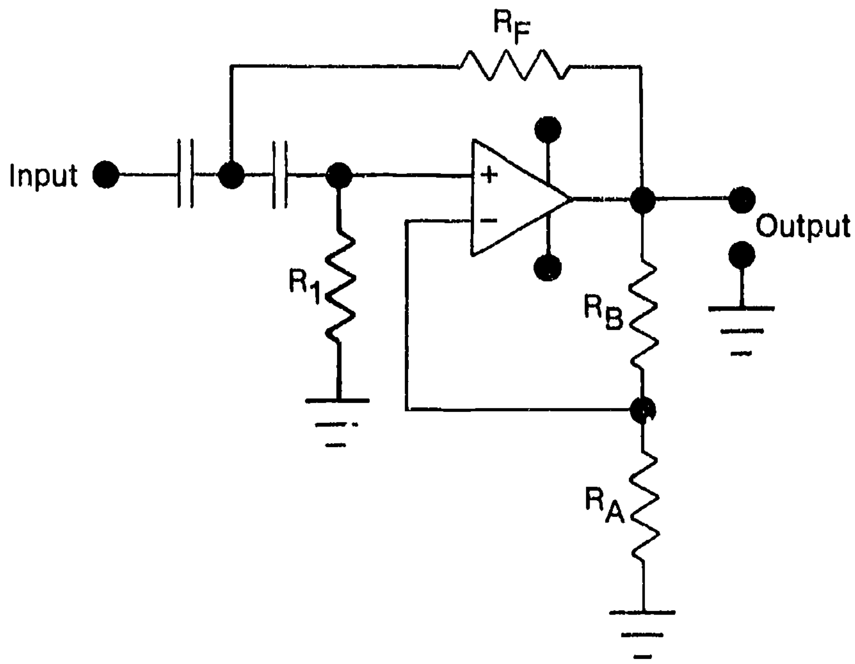
VII. **Characteristics of active filters** (Transparency #12)

A. Active filters are operational amplifier circuits which have been made frequency sensitive with RC feedback circuits.

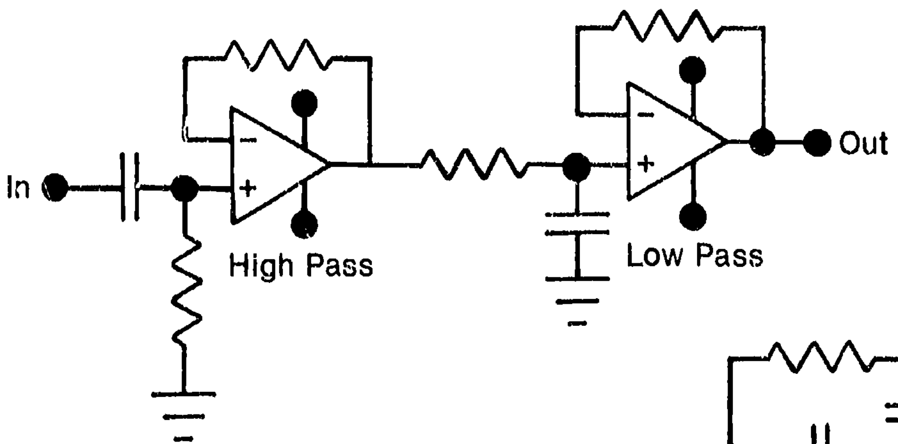
B. A low pass active filter may be constructed using an RC filter to pass low frequencies and shunt high frequencies to ground.

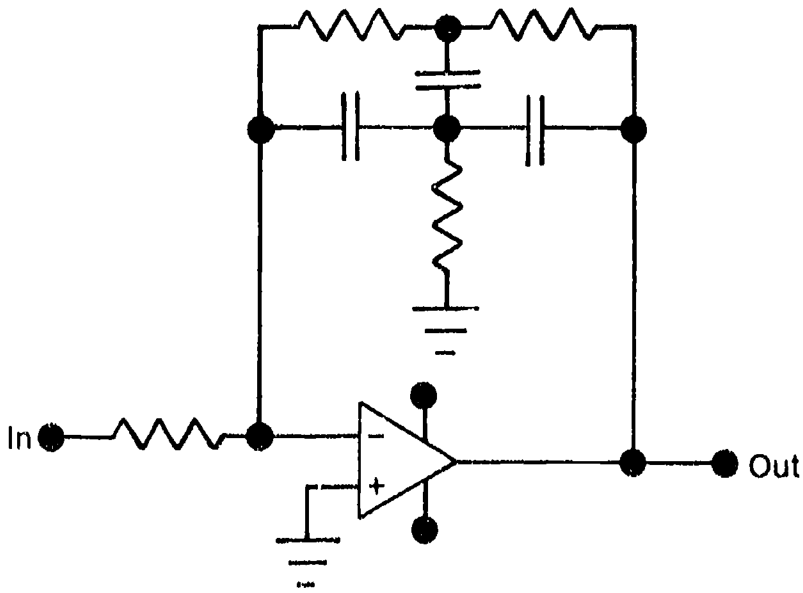


C. A high pass active filter may be constructed using an RC filter network to attenuate the low frequencies and pass the high frequencies.



D. The bandpass filter passes a narrow band of frequencies while blocking lower and higher frequencies.





VIII. Characteristics of optocouplers

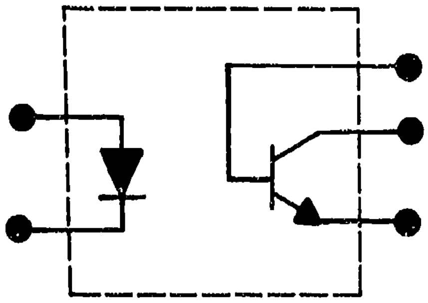
A. Optocouplers, also known as optoisolators, are purely electronic components.

B. An optocoupler consists of an infrared emitting diode (IRED), an enclosed light path, and a photodetector.

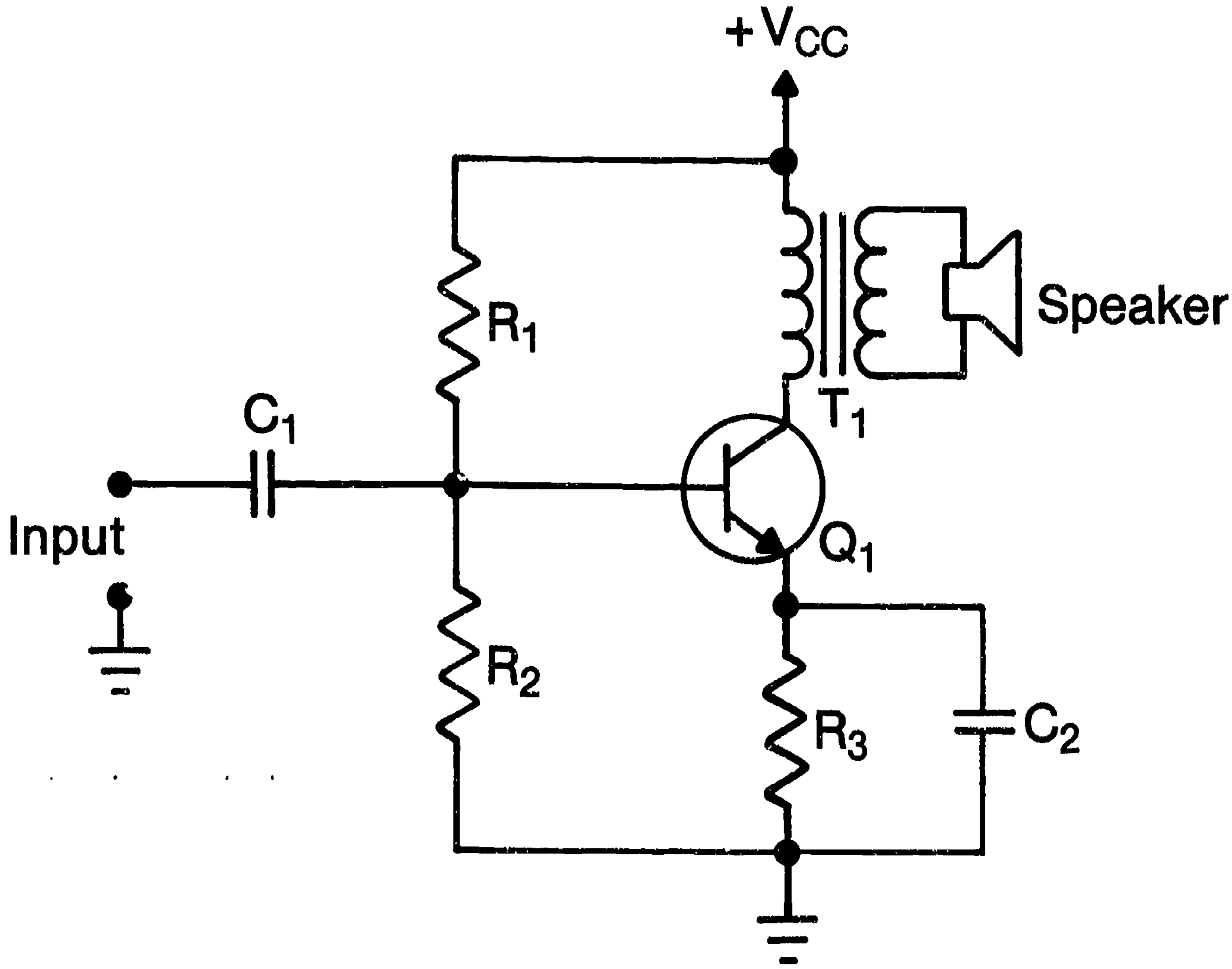
C. Optocouplers provide a way to transfer electrical signals from one circuit to another without any electrical connection between them.

D. The amount of electrical isolation between the devices is controlled by the material (typically glass) in the light path and the physical distance between the IRED and the photodetector.

Optocoupler

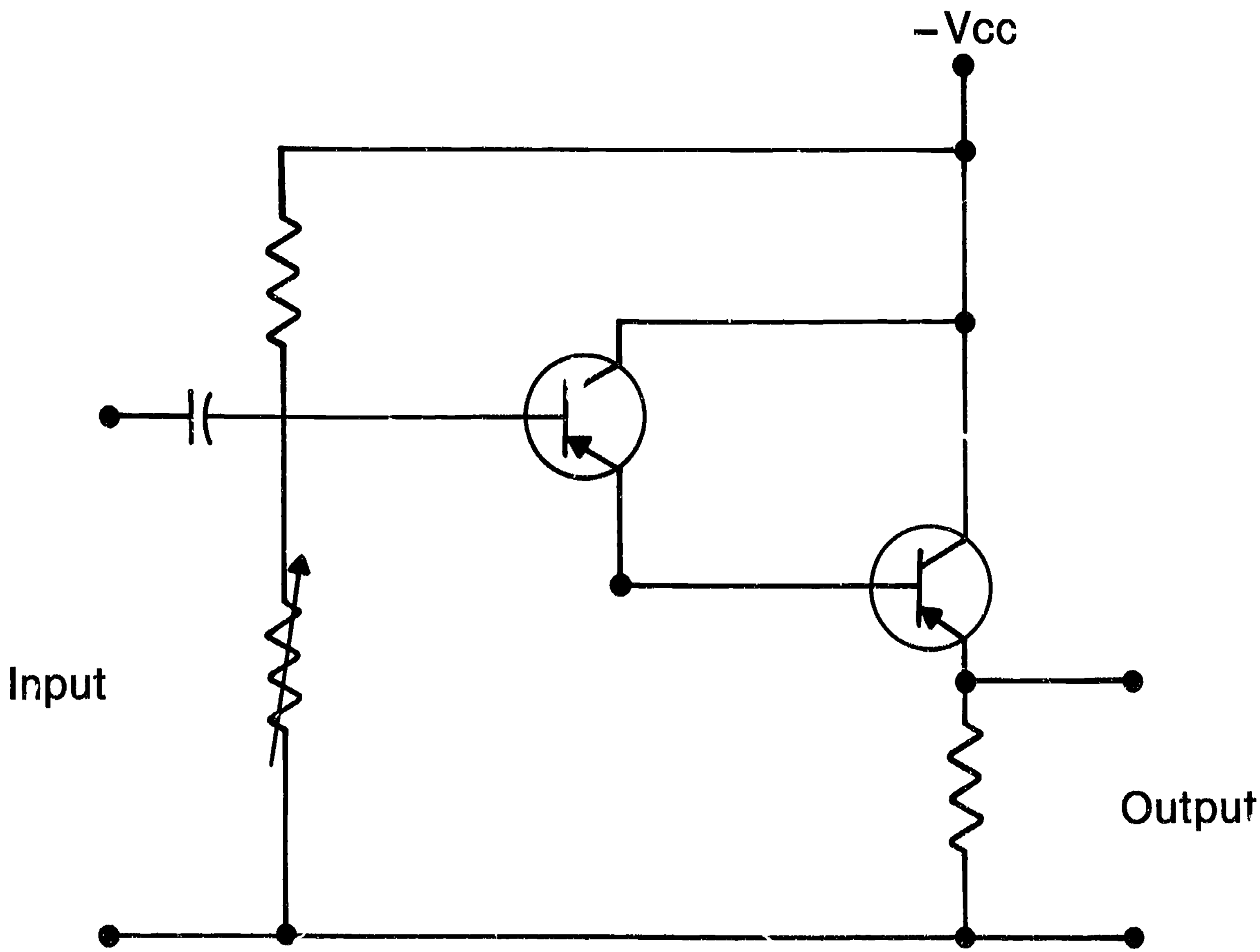


Single-Ended Power Amp

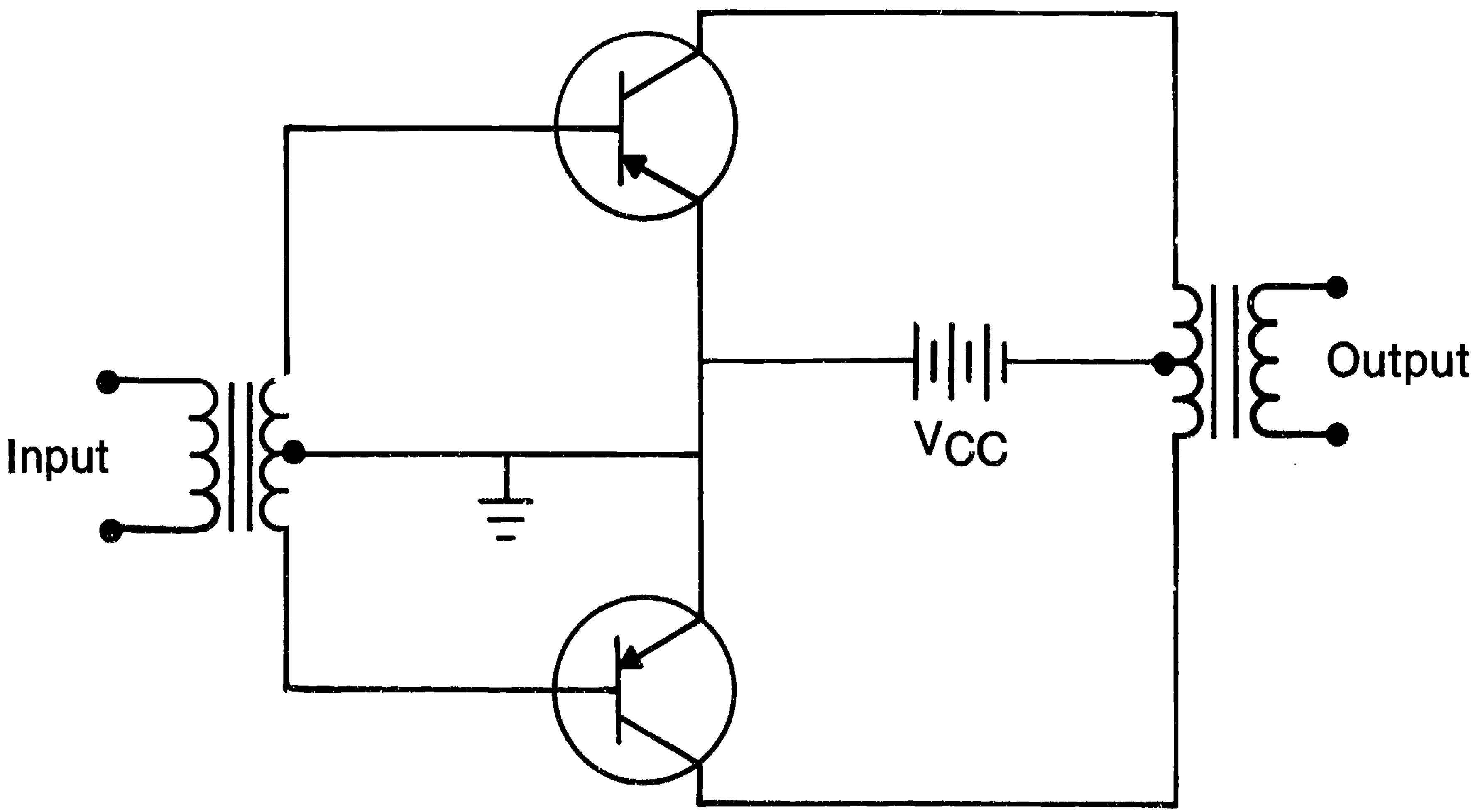


Class "A" Operation

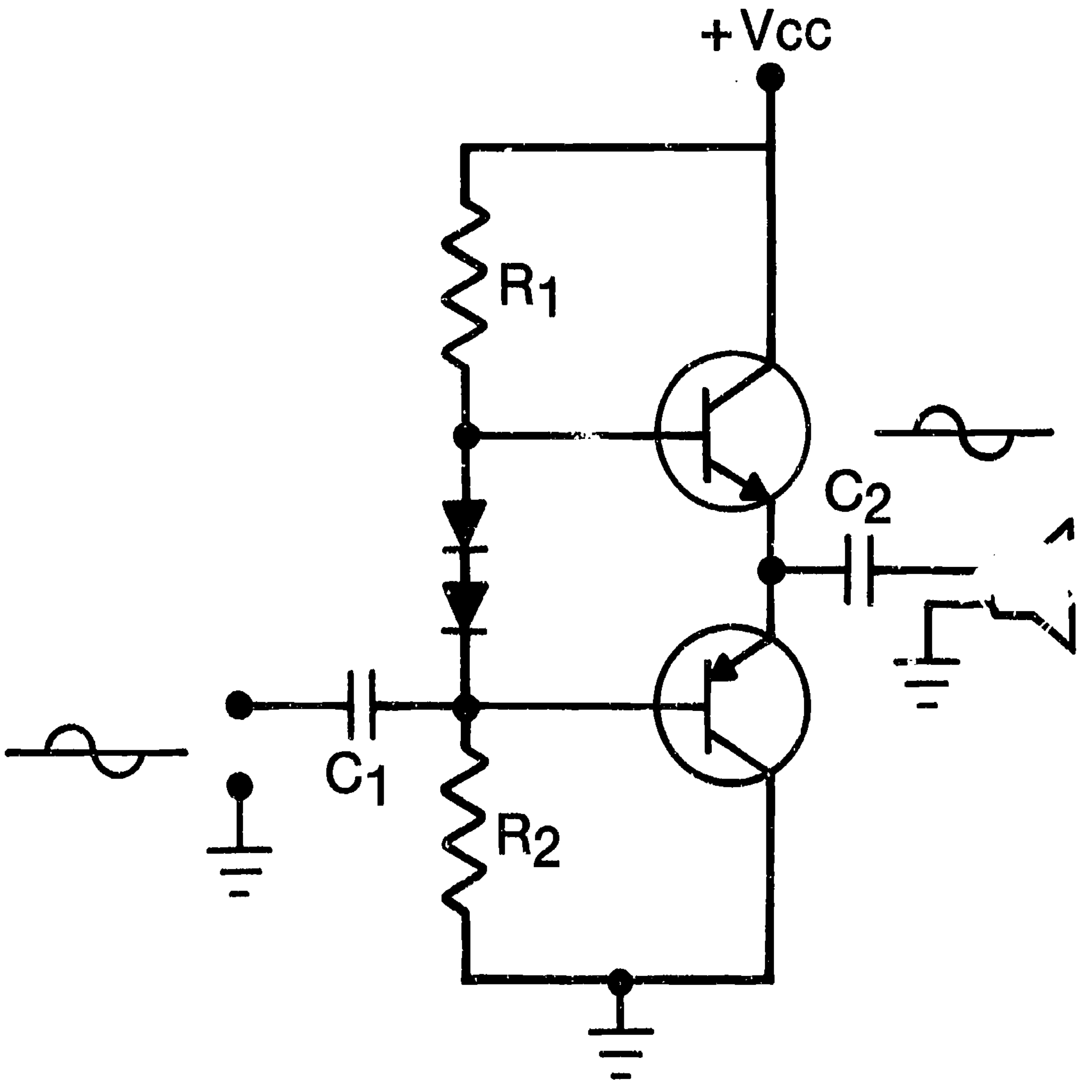
Darlington Pair



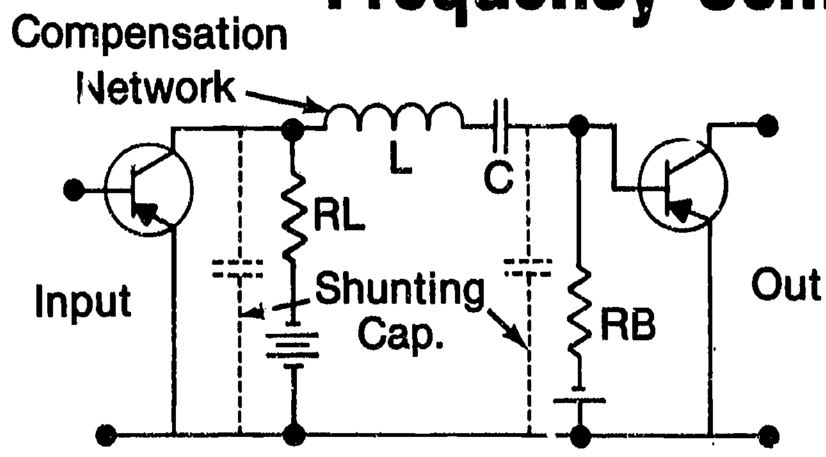
Push-Pull Amplifier



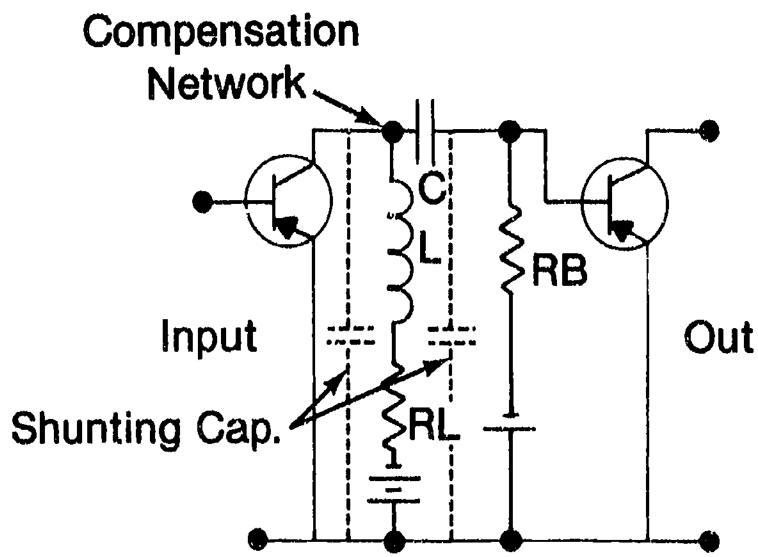
Complementary Power Amplifier



Frequency Compensation Networks

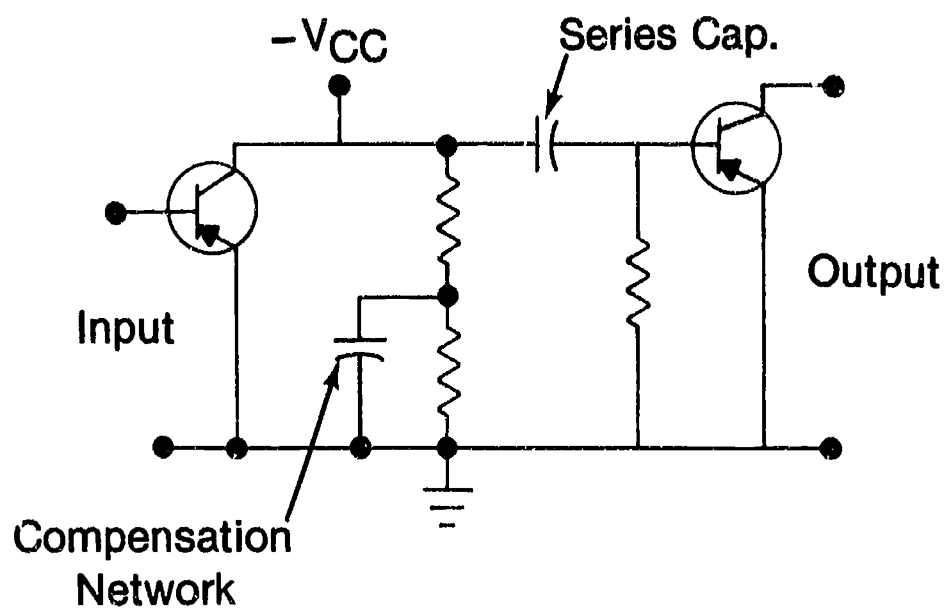


Series Compensation



Shunt Compensation

High Frequency Compensation

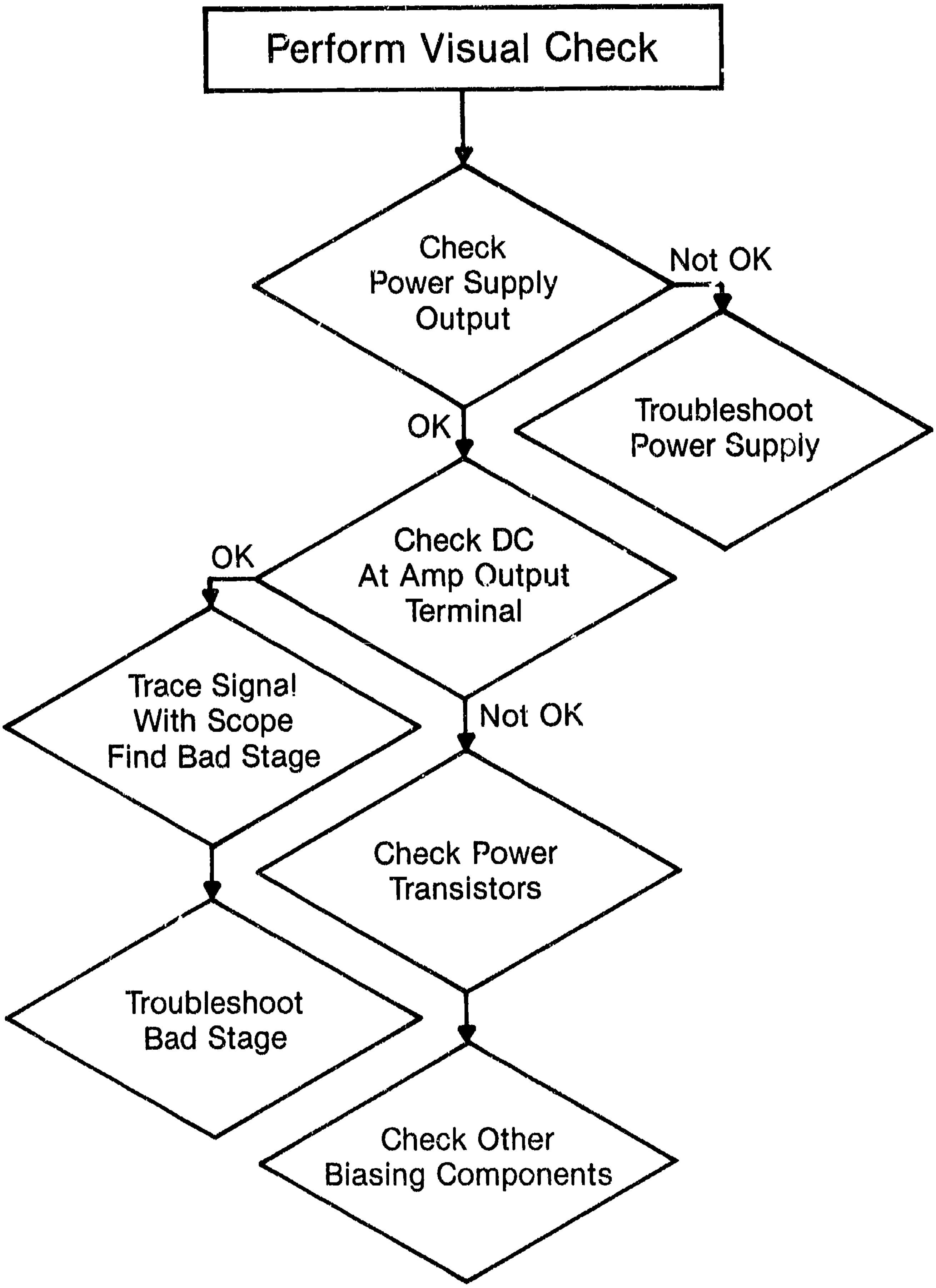


Low Frequency Compensation

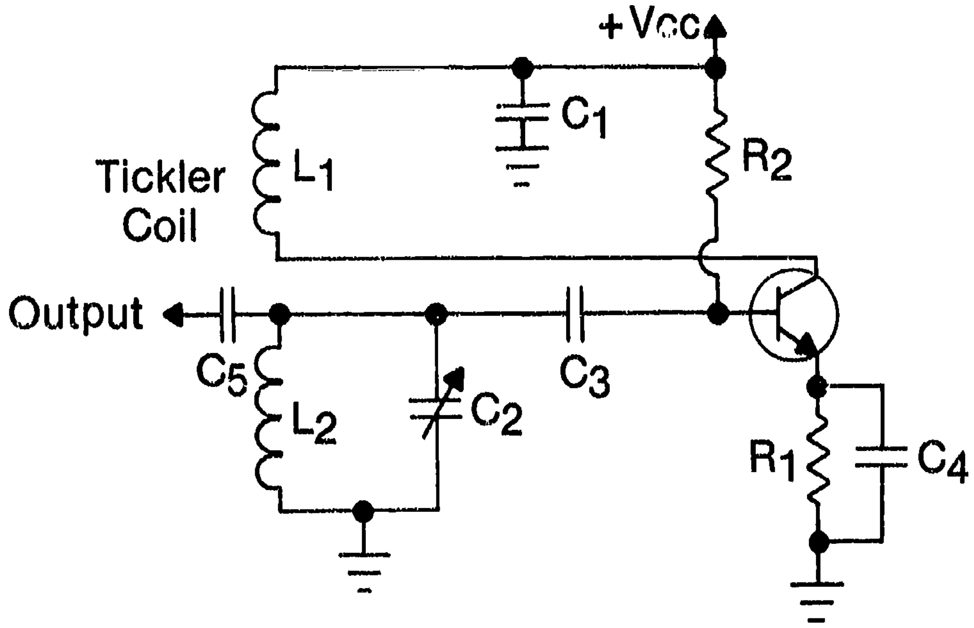
TM 5

GET-727

Simplified Troubleshooting Flowchart

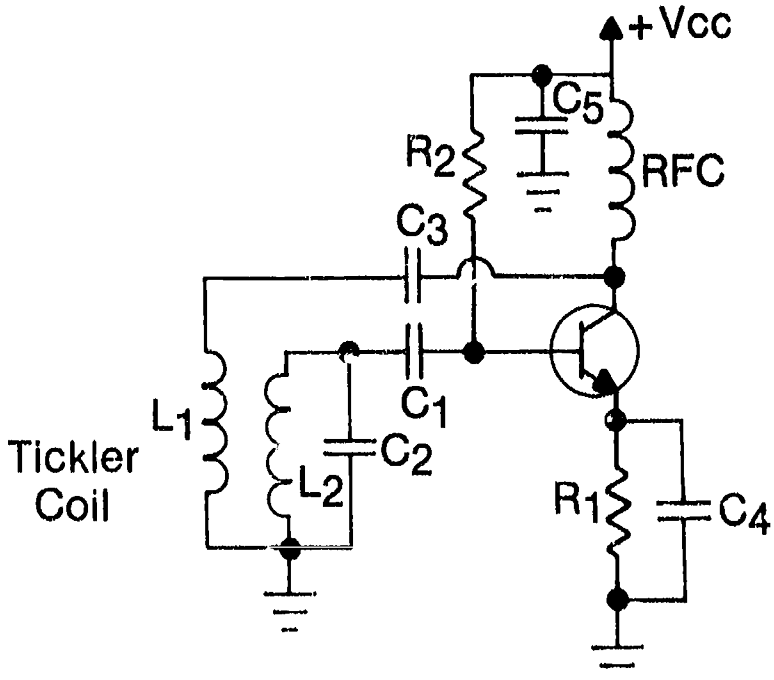


Armstrong Oscillator



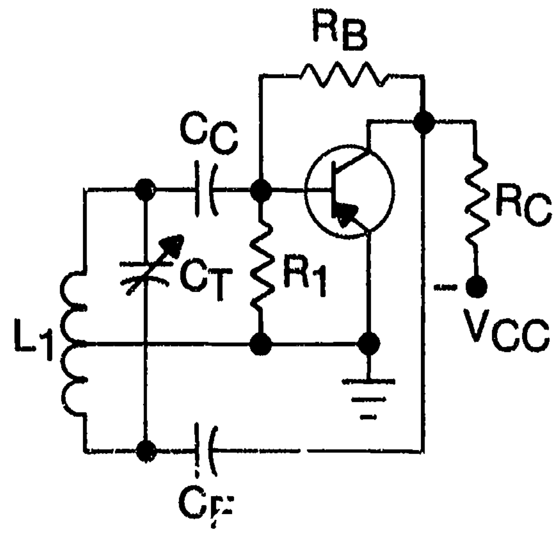
Series-Fed Armstrong

- Inductive Feedback (Tickler Coil)
- In-Phase Feedback
  (Phase Determined By Direction Of Turns In Tickler Coil)
- Amplitude Of Feedback Determined By Degree Of Coupling Between Coils
- Frequency Determined By LC Product Of Tank
- Forward Biasing Of Amp Required For Self-Starting
- Capacitive Coupled Output Employed

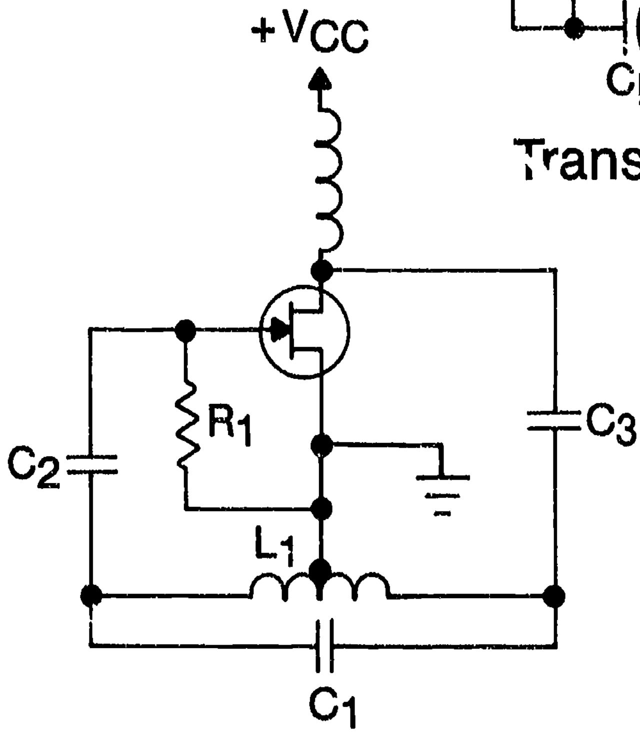


Shunt-Fed Armstrong

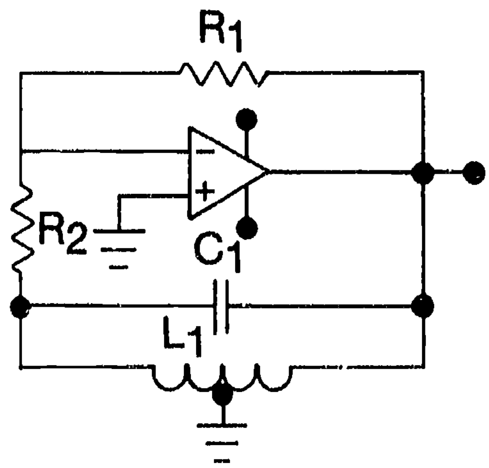
Hartley Oscillators



Transistor Type



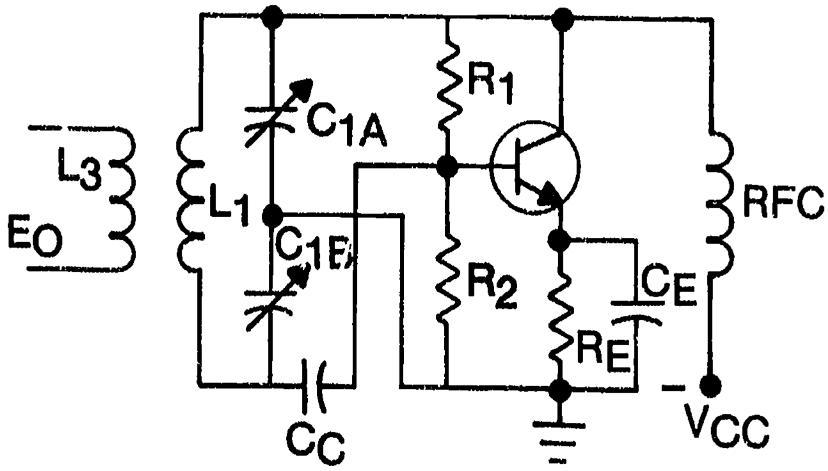
Fet-Type



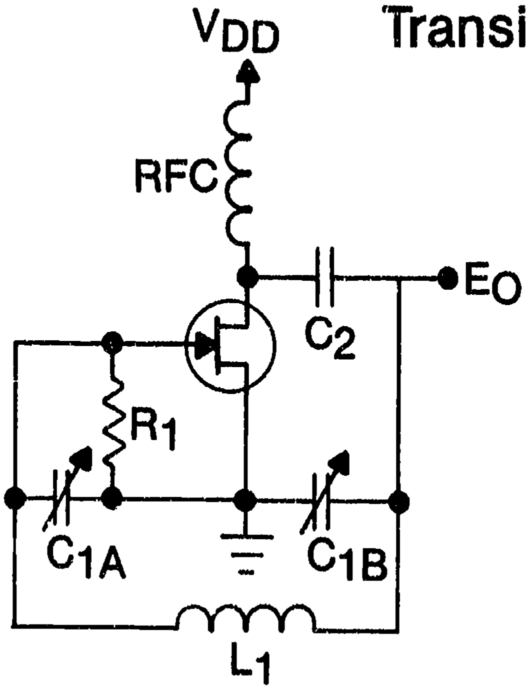
Op-Amp Type

- Inductive Feedback Is Utilized
- Amplitude Of Feedback Determined By Ratio Of Turns Between L_{IA} And L_{IB}
- Phase Of Feedback Determined By Direction Of Windings In Coils
- LC Type Frequency Determining Network

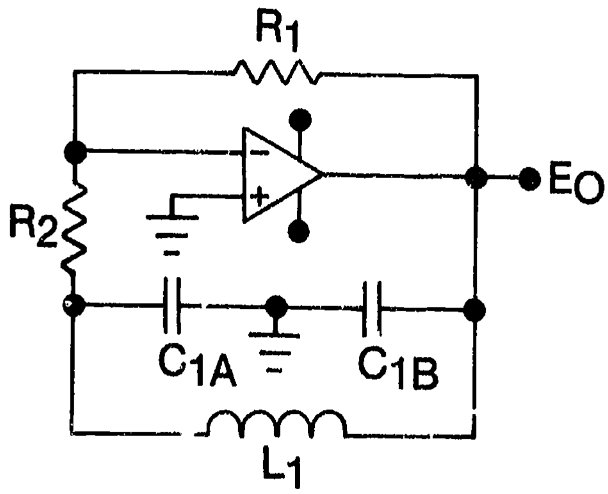
Colpitts Oscillators



Transistor Type



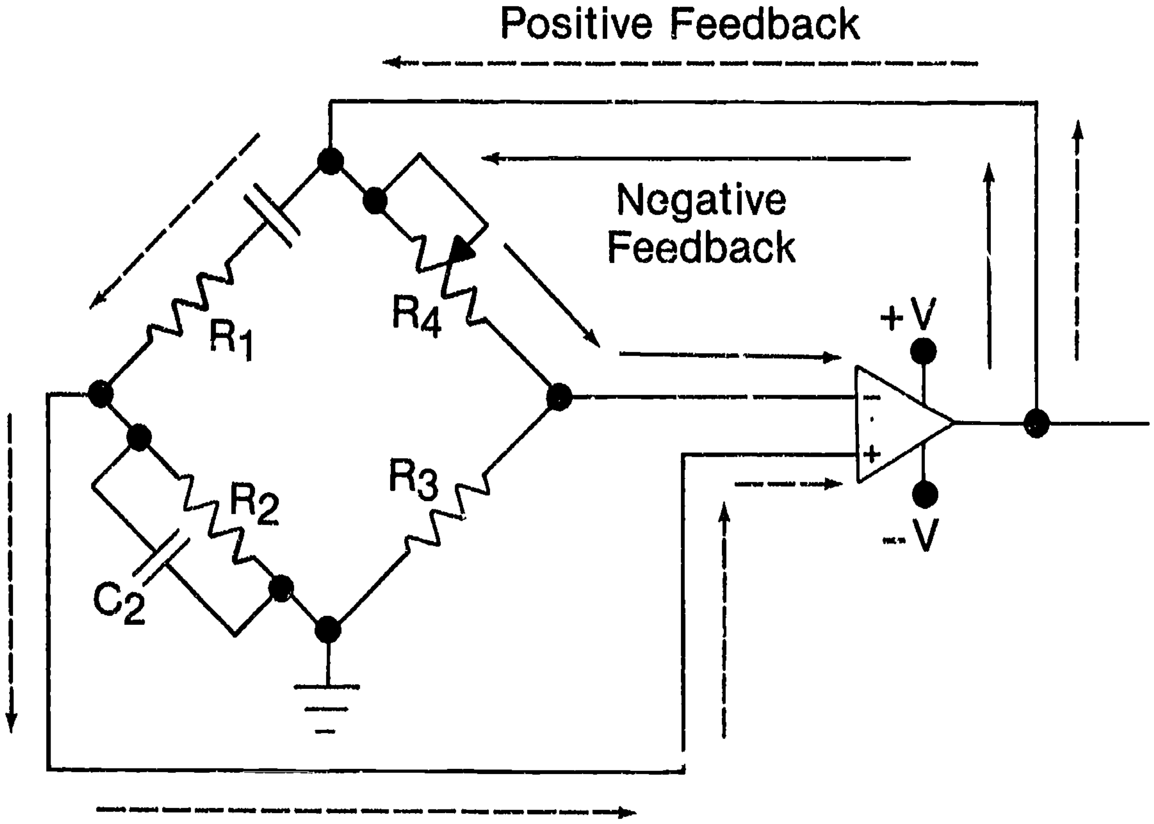
Fet Type



Op-Amp Type

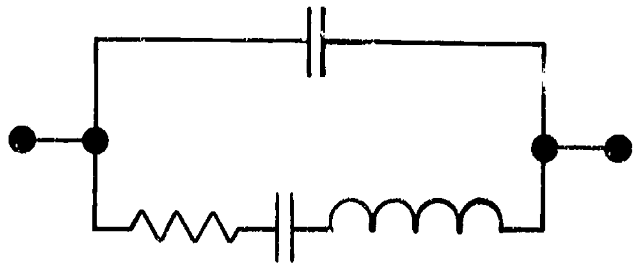
- Capacitive Feedback
- Ratio Between C_{1A} And C_{1B} Determines Amplitude Of Feedback
- Frequency Determined By LC Tank Circuit

Wein-Bridge Oscillator

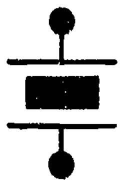


- C_1, R_1, and C_2, R_2 Form The Frequency Determining Network
- R_3 and R_4 Develop The Degenerative Feedback

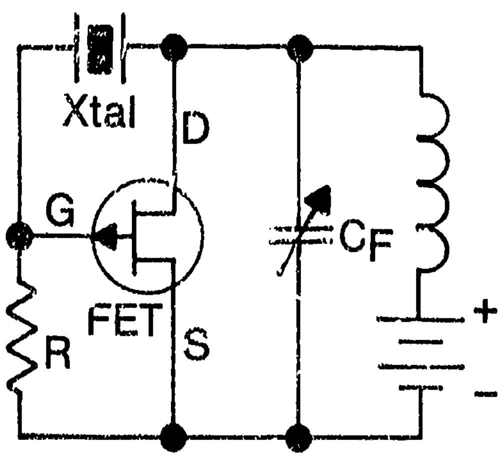
Crystal Controlled Oscillator



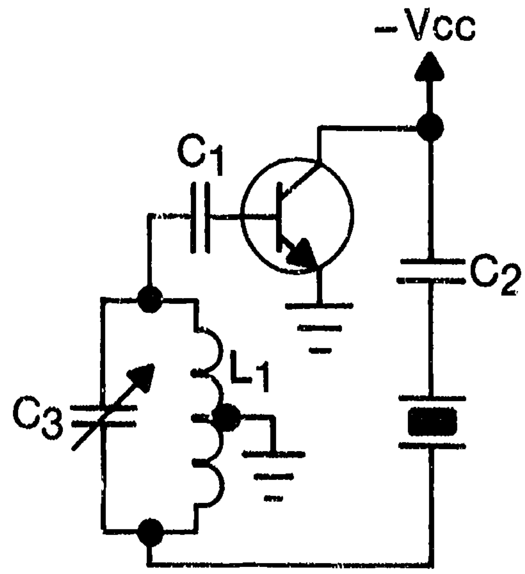
Crystal Equivalent Circuit



Crystal

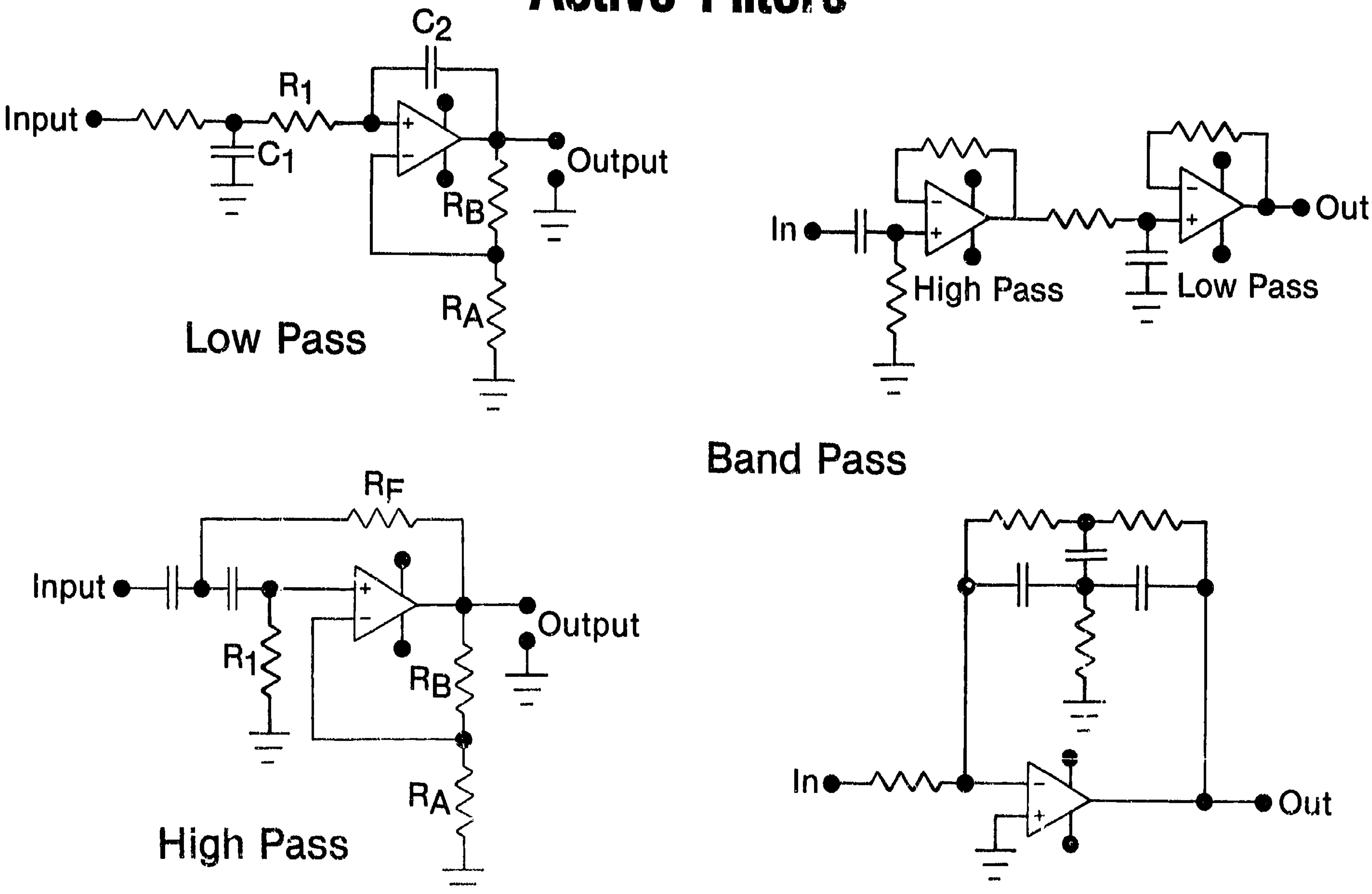


Pierce Oscillator



Crystal Controlled Hartley

Active Filters



CIRCUIT APPLICATIONS
UNIT VI

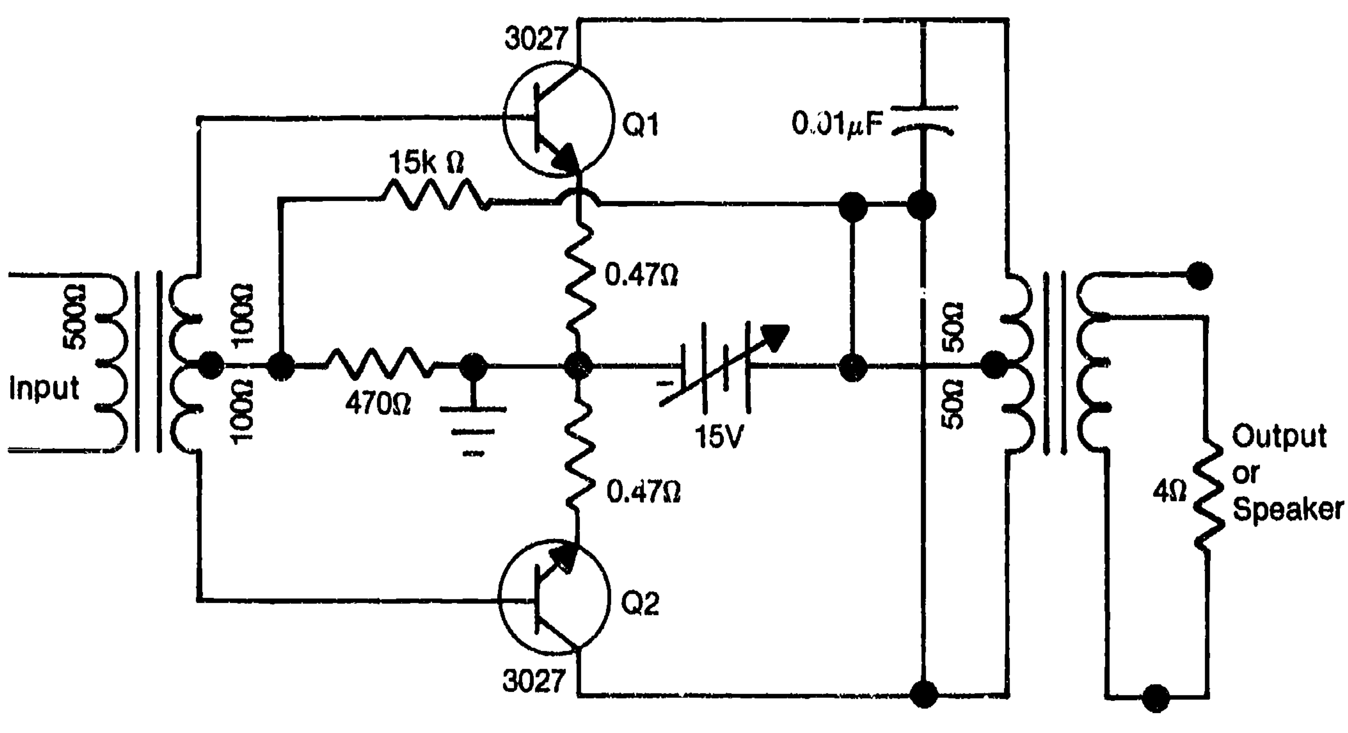
JOB SHEET #1 — CONSTRUCT AND TEST A PUSH-PULL AMPLIFIER

A. Equipment and materials needed

1. Two power transistors
2. Input transformer (500 ohm primary — 200 ohm center-trapped secondary)
3. Output transformer (100 ohm CT — 4 ohm)
4. 15 ohm resistor, 1/2 watt
5. 470 ohm resistor, 1/2 watt
6. 4 ohm resistor, 2 W
7. 0.47 ohm resistor, 2 W
8. AF signal generator
9. Oscilloscope
10. Graph paper
11. 0.01 μF capacitor
12. Regulated power supply
13. Multimeter

B. Procedure

1. Connect the circuit shown in the following schematic with power off.



JOB SHEET #1

2. Have instructor approve wiring, then turn on the power supply and adjust for 15 volts.

3. Measure and record the base-emitter bias voltages V_{BE} of Q1 and Q2.

4. Compute the DC-emitter currents using Ohm's Law by measuring the voltage drops across the 0.47 ohm resistors.

5. Connect the audio generator to the input transformer and set the output of the generator to 1000 Hz.

6. Connect the oscilloscope across the 4-ohm load on the secondary of the output transformer and adjust the signal generator for maximum undistorted output as read on the oscilloscope and sketch the waveshape.

7. Connect the oscilloscope across the input and make a scale drawing of the scope display.

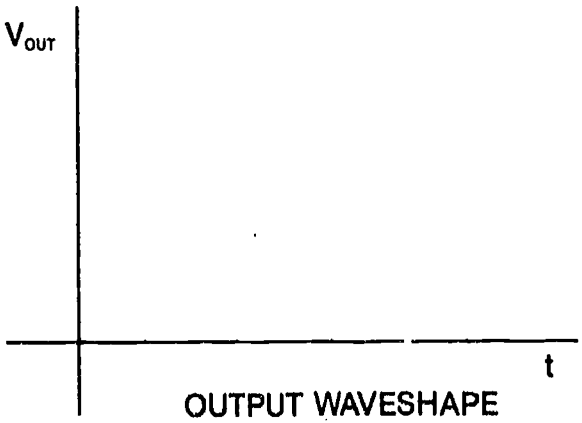
8. Connect the oscilloscope across the base-emitter junction of Q1 and sketch the waveshape.

9. Repeat for Q2.

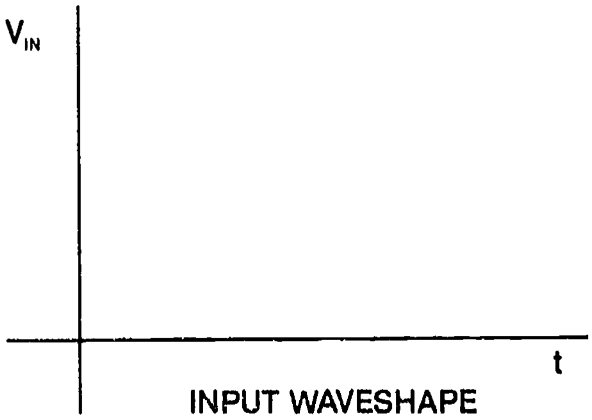
10. Check calculations and drawings with your instructor.

Data Table

	V_{BE}	I_E	$V_{OUTP\text{-}P}$	$V_{INP\text{-}P}$	
Q_1					
Q_2					



OUTPUT WAVESHAPE



INPUT WAVESHAPE

11. Return equipment and materials to their proper storage area.

CIRCUIT APPLICATIONS
UNIT VI

JOB SHEET #2 — CONSTRUCT AND TEST A TWO STAGE DIRECT COUPLED AMPLIFIER

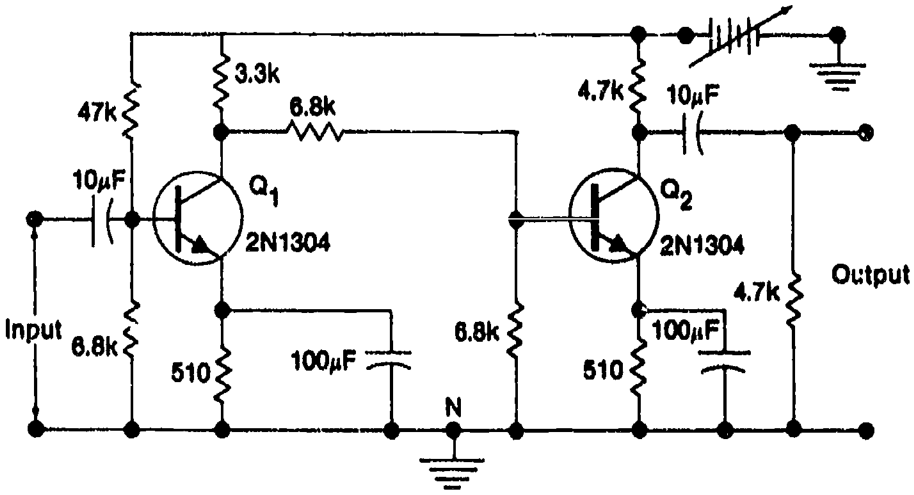
A. Equipment and materials needed

1. Two transistors or equivalent
2. Two 10 μF capacitors (20V)
3. Two 100 μF capacitors (20V)
4. 47kΩ resistor (1/2 watt)
5. Three 6.8kΩ resistors, 1/2W
6. Two 4.7kΩ resistors, 1/2W
7. 3.3kΩ resistor, 1/2W
8. Two 510 ohm resistors, 1/2W
9. Variable DC power supply (0-20V) regulated
10. Oscilloscope
11. Signal generator
12. Graph paper
13. D.C. voltmeter

B. Procedure

1. Connect the following circuit with power off.

   (NOTE: A voltage divider is used between the two stages to provide the necessary bias for the second stage.)



JOB SHEET #2

2. Connect the oscilloscope across the 4.7kΩ output resistor.

3. Connect the signal generator to the input terminals and adjust the frequency for 1000Hz; leave the voltage level at zero.

4. Adjust the power supply for 15 volts and measure and record the voltages with respect to ground on the emitter, base, and collector of the two transistors.

5. Adjust the signal generator until an undistorted waveshape appears on the oscilloscope.

   (NOTE: All voltage measurements should be referenced to ground.)

6. Measure and record the peak-to-peak output voltage using the oscilloscope and sketch the waveshape.

7. Measure and record the peak-to-peak input voltage at the base of the second transistor.

8. Measure and record the peak-to-peak output voltage at the collector of the first stage.

9. Measure and record the peak-to-peak input voltage at the base of the first stage.

10. Determine the voltage gain of the first stage and convert the voltage gain to a dB gain.

11. Determine the voltage gain of the second stage and convert the voltage gain to dB gain.

12. Determine the overall voltage gain and convert the voltage gain to dB gain.

13. Connect the oscilloscope on the input (base) to the first stage and adjust the signal generator for the maximum undistorted signal at 10KHz.

    (NOTE: The input signal voltage must be maintained at a constant level.)

14. Measure and sketch the voltage across the output resistor.

15. Adjust the signal generator for the following frequencies and record the input and output voltage for each frequency: 10,000, 8000, 6000, 4000, 2000, 1000, 800, 600, 400, and 200 Hz.

16. Plot a graph of the output voltage versus the frequency; the frequency should be plotted on the horizontal axis and the voltage on the vertical axis.

17. Check calculations and sketches with your instructor.

18. Return equipment and materials to their proper storage area.

JOB SHEET #2

Data Table

	V_{BE}	V_{CE}	V_{EN}	$V_{OUTP\text{-}P}$	$V_{OUTP\text{-}P}$	$V_{OUTP\text{-}P}$	$V_{INP\text{-}P}$	A_V	A_{VdB}
Q1									
Q2									

A_V TOTAL = __________ dB

	10KHz	8KHz	6KHz	4KHz	2KHz	1KHz	800Hz	600Hz	400Hz	200Hz
$V_{INP\text{-}P}$										
$V_{OUTP\text{-}P}$										

CIRCUIT APPLIC/‴ ɔNS
UNIT VI

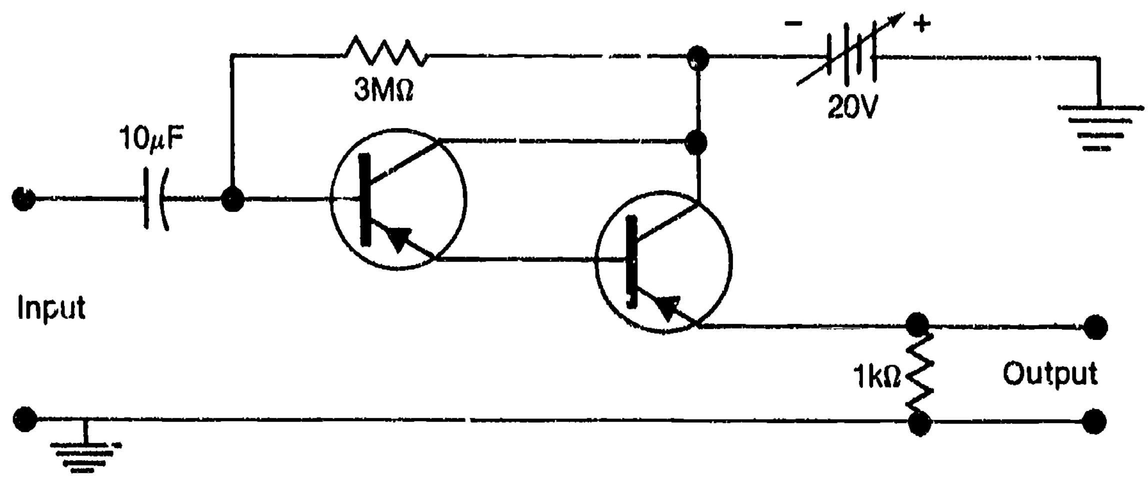
JOB SHEET #3 — CONSTRUCT AND TESΓ A BASIC DARLINGTON PAIR AMPLIFIER

A. Equipment and materials needed

1. Two PNP transistors (or equivalent)
2. 10μF capacitor (25V)
3. 3MΩ resistor, ½W
4. 1kΩ resistor, 1W
5. Oscilloscope
6. Signal generator
7. Regulated power supply (0-40V, DC)

B. Procedure

1. Connect the following circuit with power off.



2. Connect the oscilloscope to the output of the signal generator and the signal generator to the circuit input.
3. Set the generator for 1000 Hertz and adjust until 4 volts peak-to-peak is on the oscilloscope screen.
4. Place the generator leads to the Darlington circuit input leads, and leave the oscilloscope still connected to th‧ ‧jenerator output.

JOB SHEET #3

5. Move the oscilloscope leads from the input to the output and measure the output voltage (peak-to-peak).

6. Compute the overall voltage gain in dB.

7. Check your calculations with your instructor.

Data Table

V_{INP-P}	V_{OUTP-P}

A_{VdB} = ____________

8. Return equipment and materials to their proper storage area.

CIRCUIT APPLICATIONS
UNIT VI

JOB SHEET #4 — CONSTRUCT AND TEST A HARTLEY OSCILLATOR

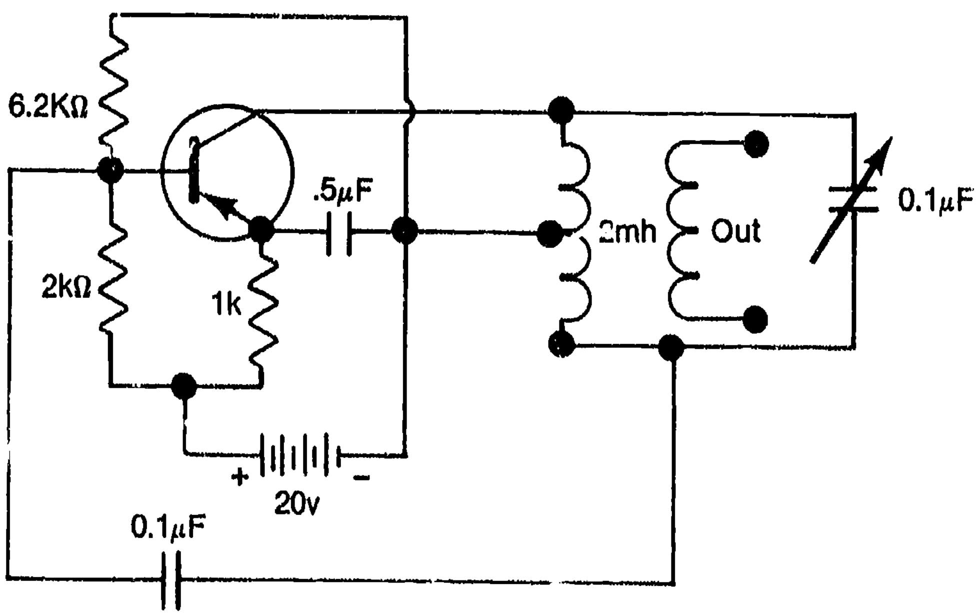
A. Equipment and materials needed

1. PNP transistor or equivalent
2. 2mH RF transformer
3. 0.1μF variable capacitor
4. 0.1μF capacitor
5. 0.5μF capacitor
6. 1KΩ resistor
7. 2KΩ resistor
8. 6.2KΩ resistor
9. Oscilloscope
10. Regulated DC power supply (0-25V)
11. Frequency counter (optional)

B. Procedure

1. Connect the following circuit.

   (CAUTION: Do not turn on power supply at this time.)



JOB SHEET #4

2. Connect the oscilloscope to the output winding of the RF transformer.

3. Turn on the power supply and observe the waveshape.

4. Adjust the variable capacitor and observe the change in frequency.

5. Measure the lowest frequency obtainable by adjusting the variable capacitor and the peak-to-peak voltage output.

6. Measure (using the oscilloscope) the highest frequency obtainable and the peak-to-peak output voltage.

7. With the oscillator operating at its highest frequency, place your finger on the transistor until your observe a change in frequency caused by the slight heating of the transistor.

8. Turn off the power supply and replace the transistor with another 2N3638 PNP transistor.

9. Turn on the power supply and notice the changes that occur in the output frequency or the output voltage level.

10. Check your findings with your instructor.

11. Return equipment and materials to their proper storage area.

CIRCUIT APPLICATIONS
UNIT VI

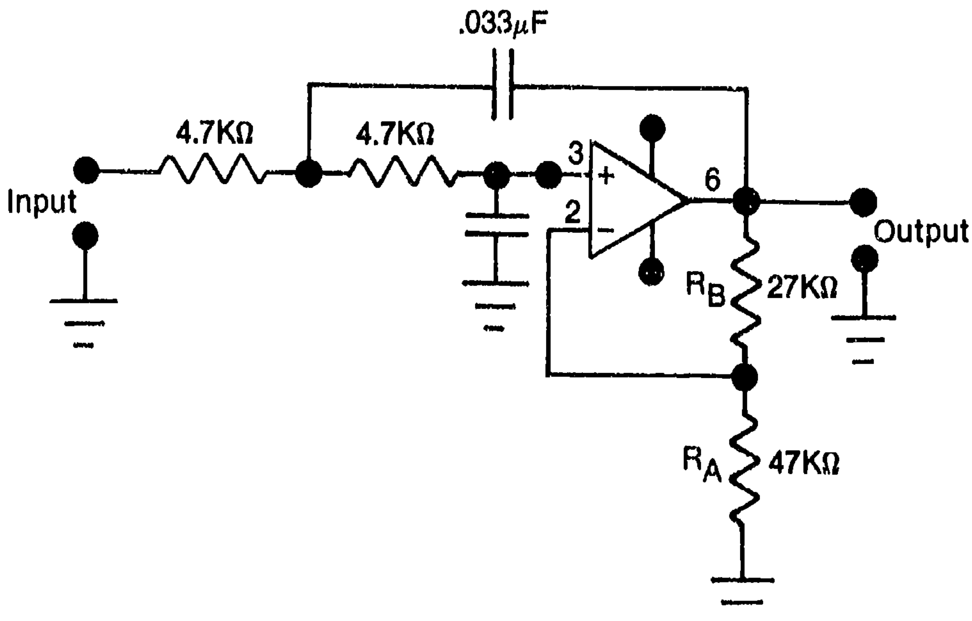
JOB SHEET #5 — CONSTRUCT AND TEST A LOW-PASS ACTIVE FILTER

A. Equipment and materials needed

1. 741 op-amp
2. Two 4.7kΩ, 1/4 watt resistors
3. 27kΩ, 1/4 watt resistor
4. 47kΩ, 1/4 watt resistor
5. Two 0.033 μF capacitors
6. Oscilloscope, dual trace
7. Sine wave generator
8. Power supply, dual voltage (—12v)

B. Procedure

1. Connect the following circuit.



2. Apply power to the circuit.
3. Apply a 100 Hz, two-volt peak-to-peak sine wave to the input terminals.
4. Measure the peak-to-peak amplitude of the output and record in Table 1.

JOB SHEET #5

5. Repeat Step 4 for each of the input frequencies listed in Table 1.

   (NOTE: Be careful to maintain the two volt peak-to-peak input for each frequency.)

6. Using the values for V_{OUT} recorded in the Table, calculate the gain for each frequency. Use the formula: Voltage gain = V_{OUT}/V_{IN}. Record your answers in the volage gain column of Table 1.

7. Calculate the dB gain for each frequency listed in the Table. Use the formula: Gain (dB) = 20 $\log_{10}$ (voltage gain). Record your answers in Table 1.

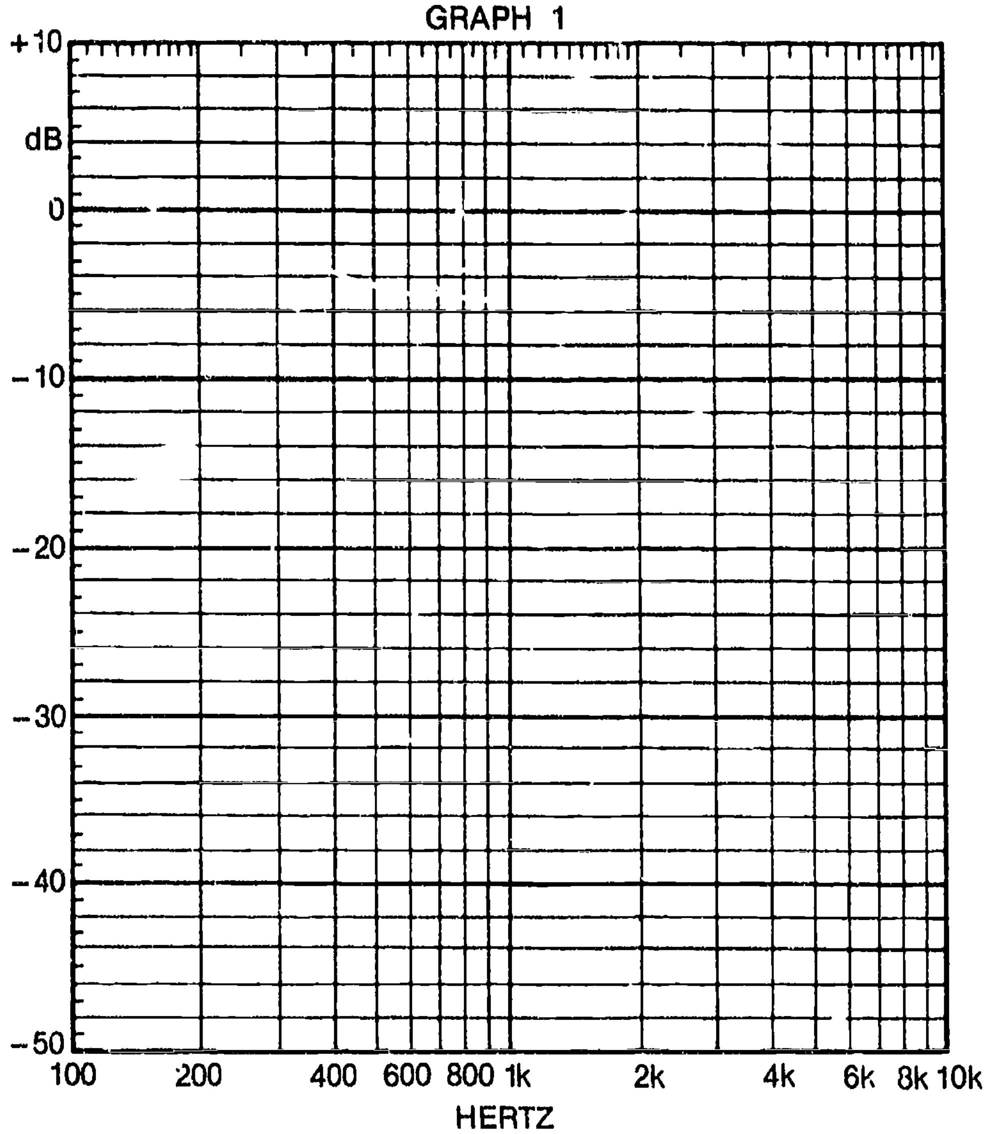
TABLE 1

Input (F) Frequency	V_i	V_O	Voltage Gain $\frac{V_O}{V_1}$	Gain (DB) 20 Log$\left(\frac{V_O}{V_1}\right)$
100Hz	2v			
200Hz	"			
400Hz	"			
600Hz	"			
800Hz	"			
1,000Hz	"			
2,000Hz	"			
4,000Hz	"			
6,000Hz	"			
8,000Hz	"			
10,000Hz	"			

JOB SHEET #5

8. Using your dB values as recorded in Table 1, plot a response curve on Graph 1.

GRAPH 1



9. From your graph, determine your filters and cut-off frequency. Cut-off frequency is ______________.

10. Return equipment and materials to their proper storage area.

CIRCUIT APPLICATIONS
UNIT VI

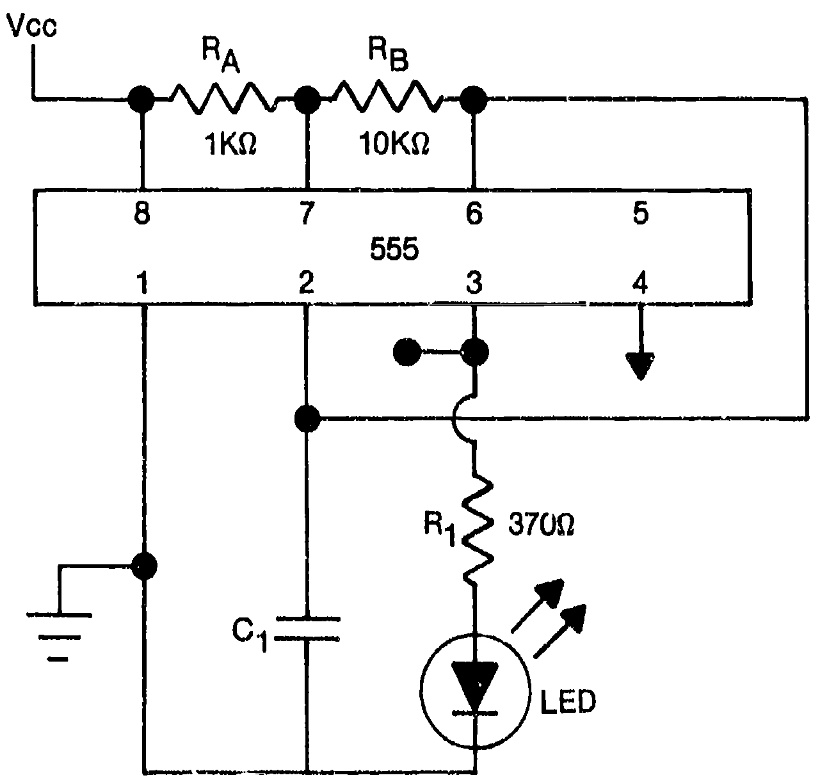
JOB SHEET #6 — CONSTRUCT AND TEST A 555 TIMER CIRCUIT

A. Equipment and materials needed

1. 555 IC timer
2. 10 mF, 15 VDC electrolytic capacitor
3. 1kΩ, 1/4 watt resistor
4. 10kΩ, 1/4 watt resistor
5. 100kΩ, trim potentiometer
6. 270Ω, 1/4 watt resistor
7. Light emitting diode (LED)
8. Oscilloscope
9. Power supply (+5vDC)

B. Procedure

1. Connect the circuit below.



JOB SHEET #6

2. Calculate the frequency to be expected from the test circuit.

   Frequency = ______________________________

   (NOTE: Use equation $F = 1.46/(R_A + 2R_B) C_1$)

3. Calculate the duty cycle using the equation: Duty cycle = $R_B/(R_A + 2R_B)$

   Duty cycle = ______________________________

4. Apply power.

   (NOTE: LED should go on and off.)

5. Observe the output pin 3 with an oscilloscope.)

   a. Sketch the output waveform.

   b. What is the frequency of the output waveform? ______________

   c. The ratio of logic-high time to overall time is the duty cycle. What do you estimate the duty cycle of the circuit to be? ______________

6. Remove power.

7. Replace R_B (10kΩ) with a 100kΩ potentiometer.

   (NOTE: Connect potentiometer as a variable resistor.)

8. Apply power.

9. Observe the output at pin 3 with an oscilloscope.

10. Vary the potentiometer through its range of resistance. Note the change in frequency and duty cycle.

11. What is the lowest frequency you can obtain from this circuit? ____________

12. What is the highest frequency you can obtain from this circuit? ____________

13. At what frequency, as seen on the oscilloscope, is the duty cycle at 50 percent?

    ____

14. Turn off power.

15. Return equipment and materials to their proper storage area.

CIRCUIT APPLICATIONS
UNIT VI

NAME ____________________

TEST

1. Match the terms on the right with their correct definitions.

_____a.	An amplifier in which only one transistor is used in the amplifier stage	1. Single-ended amplifier
_____b.	An amplifier which uses two transistors connected so that each transistor contributes current to the output signal on alternate half cycles of the input signal	2. IRED
_____c.	A circuit consisting of two bipolar transistors with the collectors connected together and the emitter of one connected to the base of the other acting together as a single unit like a very high gain transistor	3. Optocoupler
_____d.	Distortion in push-pull amplifiers at the zero center line of the AC signal due to nonlinearity of the transistor characteristics	4. Complementary symmetry
_____e.	An arrangement of PNP and NPN type transistors that provides push-pull type operation from a single input signal	5. Crossover distortion
_____f.	An electronic circuit which converts electrical energy from a DC source into AC energy	6. RC network
_____g.	The coupling of energy from the output back to the input of a circuit	7. LC network
_____h.	One of the classifications of oscillator circuits in which the frequency is determined by the inductor (L) and the capacitor (C) in the tank (resonant) circuit	8. Push-pull amplifier
_____i.	One of the classifications of oscillator circuits in which the frequency is determined by the resistance and the capacitance in the circuit	9. Feedback
_____j.	Infrared emitting diode	10. Oscillator
_____k.	A device which provides for electrical isolation between circuits using optoelectronic components	11. Darlington pair

TEST

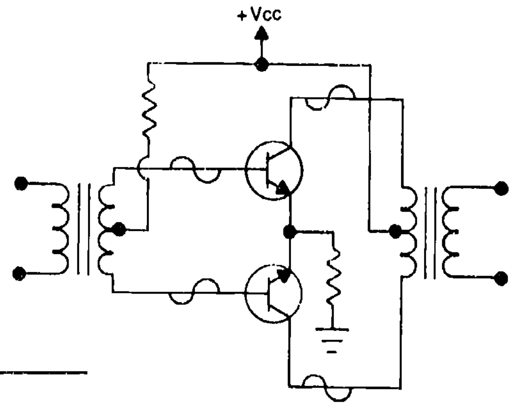
2. Complete the following statements concerning basic power amplifier characteristics by circling the words which best complete each statement.

   a. An amplifier is considered a power amplifier when it is connected to a low-resistance load (such as a speaker) or when it is required to deliver more than a few **(watts, milliwatts)** to a load.

   b. The power amplifier is typically the **(first, last)** stage of amplification in a system.

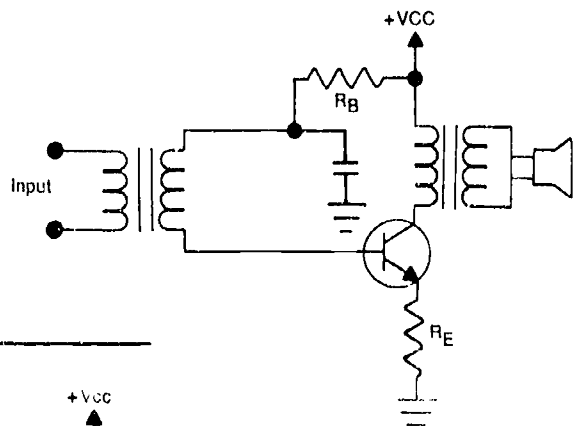
   c. The power amplifier should have a very **(low, high)** characteristic output impedance.

3. Identify basic power amplifier configurations by placing the correct number in the appropriate blanks.

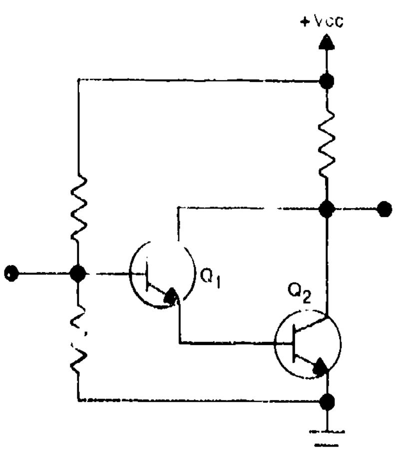


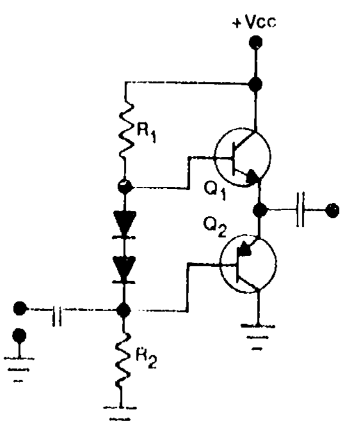
1. Single-ended power amp
2. Push-pull amplifier
3. Darlington pair
4. Complementary amplifier

a. ____________________



b. ____________________





c. ____________________

d. ____________________

TEST

4. Arrange in order the steps in troubleshooting multistage amplifiers by indicating the first step as 1, the second step as 2, and so on for each procedure.

_____a. Make DC voltage checks with a voltmeter to find any biasing problems.

_____b. Isolate the defective stage by making waveform checks beginning at the output and working back toward the input.

_____c. Inspect the equipment for obvious symptoms such as burned, overheated, or broken components.

_____d. Test individual suspect components.

_____e. Check the power supply for normal operation.

5. List four basic oscillator requirements.

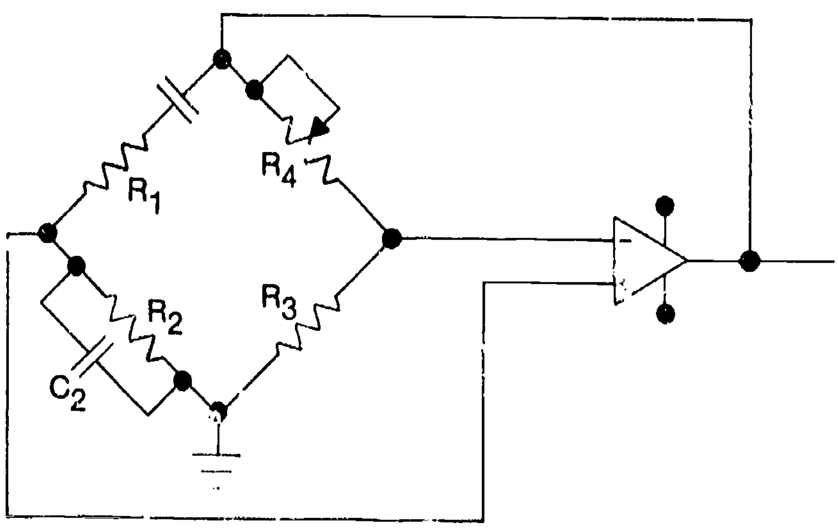
a. ______________________________

b. ______________________________

c. ______________________________

d. ______________________________

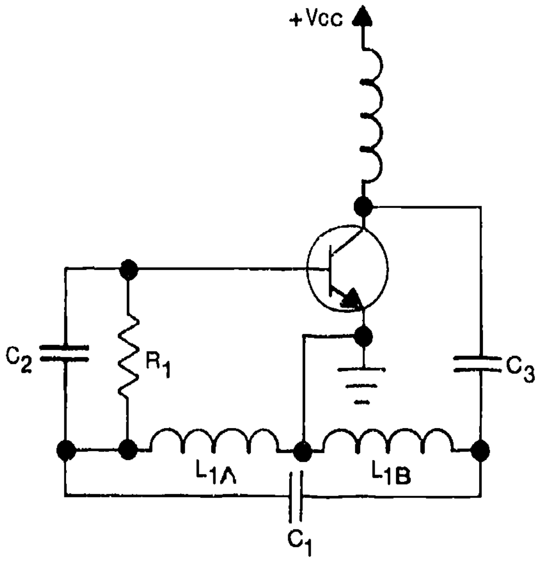
6. Identify basic types of oscillator circu[illegible] placing the correct number in the appropriate blank.



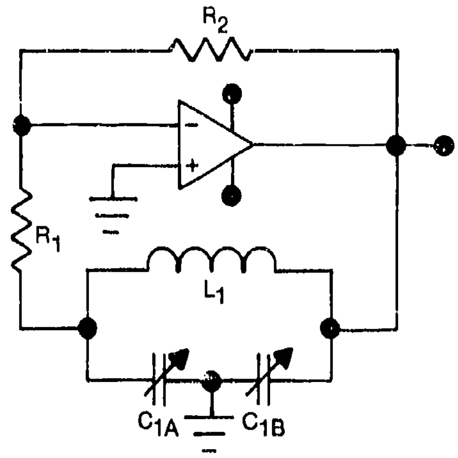
1. Armstrong
2. Hartley
3. Colpitts
4. Wein-bridge

a. ______________

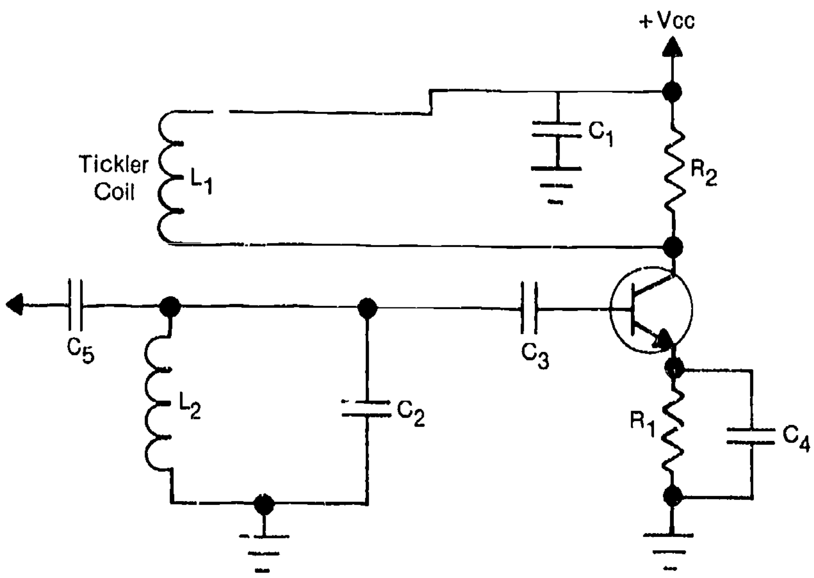
TEST



b. ____________



c. ____________



d. ____________

7. Complete the following statements concerning characteristics of active filters by inserting the word(s) that best completes each statement.

   a. Active filters are operational amplifier circuits which have been made ____________ sensitive with RC feedback circuits.

   b. A low pass active filter may be constructed using an ____________ to pass low frequencies and shunt high frequencies to ground.

TEST

c. A high pass active filter may be constructed using an RC filter network to attenuate the ____________ frequencies and pass the ____________ frequencies.

d. The ____________ filter passes a narrow band of frequencies while blocking lower and higher frequencies.

8. Complete the following statements concerning the characteristics of optocouplers by inserting the word(s) that best completes each statement.

   a. Optocouplers, also known as ____________, are purely electronic components.

   b. An optocoupler consists of an ____________ emitting diodes, an enclosed ____________ path, and a ____________.

   c. Optocouplers provide a way to transfer ____________ signals from one circuit to another without any electrical connection between them.

   d. The amount of electrical isolation between the devices is controlled by the ____________ in the light path and the physical distance between the IRED and the photodetector.

(NOTE: If the following activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

9. Demonstrate the ability to:

   a. Construct and test a push-pull amplifier. (Job Sheet #1)

   b. Construct and test a two stage direct coupled amplifier. (Job Sheet #2)

   c. Construct and test a basic Darlington pair amplifier. (Job Sheet #3)

   d. Construct and test a Hartley oscillator. (Job Sheet #4)

   e. Construct and test a low-pass active filter. (Job Sheet #5)

   f. Construct and test a 555 timer circuit. (Job Sheet #6)

CIRCUIT APPLICATIONS
UNIT VI

ANSWERS TO TEST

1.
   a. 1
   b. 8
   c. 11
   d. 5
   e. 4
   f. 10
   g. 9
   h. 7
   i. 6
   j. 2
   k. 3

2.
   a. Milliwatts
   b. Last
   c. Low

3.
   a. 2
   b. 1
   c. 3
   d. 4

4.
   a. 4
   b. 3
   c. 1
   d. 5
   e. 2

5. Any four of the following:
   a. Frequency determining network
   b. Amplifier
   c. Feedback circuit
   d. DC power source
   e. Self-starting

6.
   a. 4
   b. 2
   c. 3
   d. 1

7.
   a. Frequency
   b. RC filter
   c. Low, high
   d. Bandpass

8.
   a. Optoisolators
   b. Infrared, light, photodetector
   c. Electrical
   d. Material

9. Performance skills evaluated to the satisfaction of the instructor

POWER SUPPLIES
UNIT VII

UNIT OBJECTIVE

After completion of this unit, the student should be able to apply theoretical knowledge related to power supplies, and construct and analyze power supply circuits. Competencies will be demonstrated by correctly performing the procedures outlined in the assignment and job sheets and by scoring a minimum of 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to power supplies with their correct definitions.
2. Select true statements related to the uses for transformers in power supplies.
3. Draw the schematic diagram of a half-wave rectifier circuit.
4. Draw the schematic diagram of a full-wave rectifier circuit.
5. Draw the schematic diagram of a bridge rectifier circuit.
6. Draw schematic diagrams of combination power supplies.
7. Identify three basic types of filter configurations.
8. State the equation for calculating ripple factor.
9. Identify three basic voltage multiplier circuits.
10. Select true statements concerning the regulation of power supply output.
11. Identify regulator configurations as series or shunt regulators.

OBJECTIVE SHEET

12. Draw the block diagram of a feedback regulator.

13. Complete statements related to the characteristics of switching regulators.

14. Draw the schematic diagram of a "crowbar" protection circuit.

15. Calculate average DC voltage for half-wave and full-wave rectifier circuits. (Assignment Sheet #1)

16. Calculate ripple factors and percent regulation. (Assignment Sheet #2)

17. Demonstrate the ability to:

    a. Construct and test a half-wave rectifier circuit. (Job Sheet #1)

    b. Construct and test a full-wave bridge rectifier circuit. (Job Sheet #2)

    c. Construct and test a voltage doubler circuit. (Job Sheet #3)

    d. Construct and test a capacitor filter circuit. (Job Sheet #4)

    e. Construct and test a Pi-section filter circuit. (Job Sheet #5)

    f. Construct and test a zener regulator. (Job Sheet #6)

POWER SUPPLIES
UNIT VII

SUGGESTED ACTIVITIES

A. Obtain additional materials and/or invite resource people to class to supplement/reinforce information provided in this unit of instruction.

(NOTE: This activity should be completed prior to the teaching of this unit.)

B. Make transparencies from the transparency masters included with this unit.

C. Provide students with objective sheet.

D. Discuss unit and specific objectives.

E. Provide students with information and assignment sheets.

F. Discuss information and assignment sheets.

(NOTE: Use the transparencies to enhance the information as needed.)

G. Provide students with job sheets.

H. Discuss and demonstrate the procedures outlined in the job sheets.

I. Integrate the following activities throughout the teaching of this unit:

1. Obtain a schematic to laboratory power supplies and identify the circuitry used.
2. Review the specifications for the laboratory power supplies.
3. Obtain a schematic for electronic equipment such as an audio amp or TV, and trace the diagram of the power supply.
4. Explain that 1000 μf per amp = rule of thumb for filter caps.
5. Meet individually with students to evaluate their progress through this unit of instruction, and indicate to them possible areas for improvement.

J. Give test.

K. Evaluate test.

L. Reteach if necessary.

INSTRUCTIONAL MATERIALS INCLUDED IN THIS UNIT

A. Objective sheet

B. Suggested activities

C. Information sheet

D. Transparency masters

1. TM 1 — The Transformer
2. TM 2 — Half-Wave Rectifier Circuits
3. TM 3 — Conventional Full-Wave Rectifier
4. TM 4 — Bridge Rectifier
5. TM 5 — Combination Power Supplies
6. TM 6 — Basic Filter Configurations
7. TM 7 — Half-Wave Voltage Doubler Circuit
8. TM 8 — Full-Wave Voltage Doubler Circuit
9. TM 9 — Voltage Tripler
10. TM 10 — Voltage Regulation
11. TM 11 — Series Regulators
12. TM 12 — Zener Regulators
13. TM 13 — Feedback Regulator
14. TM 14 — Switching Regulator
15. TM 15 — Load Protection

E. Assignment sheets

1. Assignment Sheet #1 — Calculate Average DC Voltage For Half-Wave Rectifier and Full-Wave Rectifier Circuits
2. Assignment Sheet #2 — Calculate Ripple Factors and Percent Regulation

F. Answers to assignment sheets

INSTRUCTIONAL MATERIALS INCLUDED IN THIS UNIT

G. Job sheets

1. Job Sheet #1 — Construct and Test a Half-Wave Rectifier Circuit
2. Job Sheet #2 — Construct and Test a Full-Wave Bridge Rectifier Circuit
3. Job Sheet #3 — Construct and Test a Voltage Doubler Circuit
4. Job Sheet #4 — Construct and Test a Capacitor Filter Circuit
5. Job Sheet #5 — Construct and Test a Pi-Section Filter Circuit
6. Job Sheet #6 — Construct and Test a Zener Regulator

H. Test

I. Answers to test

REFERENCES USED IN DEVELOPING THIS UNIT

(NOTE: The following is a list of references used in completing this unit.)

A. Boylestad and Nashelsky. *Electronic Devices and Circuit Theory,* Third Edition. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1982.

B. Bruce David. *Modern Electronics.* Reston, VA: Reston Publishing Co., Inc., 1984.

C. Rutkowski, George B. *Basic Electricity for Electronics.* Indianapolis, IN: Bobbs-Merrill Educational Publishing Co., 1984.

D. Schrader, Robert E. *Electronic Communications,* Fifth Edition. New York: McGraw-Hill, Inc., 1985.

E. Willison, Neal and James Shelton. *Basic Electronics II.* Stillwater, OK: Mid-America Vocational Curriculum Consortium, 1981.

POWER SUPPLIES
UNIT VII

INFORMATION SHEET

I. **Terms and definitions**

A. Bleeder resistor — A resistor which is used to draw off fixed current and as a safety measure to discharge filter capacitors after the circuit is de-energized

B. Filter — A circuit or device used to minimize or eliminate ripple

C. Percent regulation — Comparison of the no-load voltage to the full-load voltage expressed as a percentage of the full-load voltage

D. Rectifier circuit — A circuit that converts AC voltages to pulsating DC voltages

E. Ripple — Variations in the DC voltage output of rectifier circuits

II. **Uses for transformers in power supplies** (Transparency #1)

A. The transformer is a device used to either step-up (increase in amplitude) or step-down the AC voltage input to a rec ier circuit.

1. The relationship between transformer input voltage and its output voltage is dependent upon the ratio between the number of turns in the primary and secondary expressed by the equation

$$\frac{E\ primary}{E\ secondary} = \frac{N\ primary}{N\ secondary}$$

2. When voltage is stepped-up from primary to secondary, the current is stepped-down at the same ratio.

3. The phase relationship between primary and secondary voltage is dependent upon the method of construction and the direction of the windings.

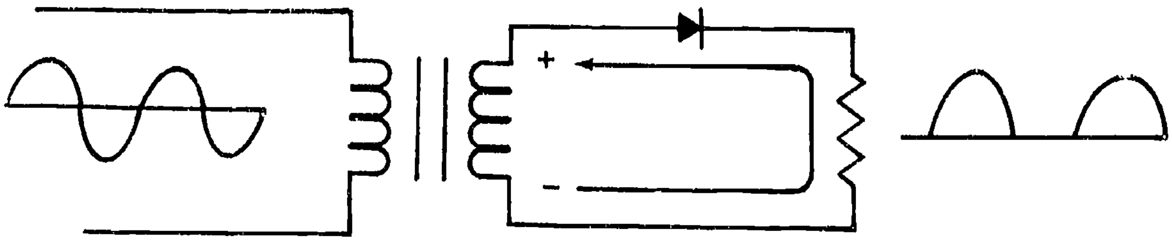
B. The transformer is used to provide isolation of the equipment and circuit from the power line.

C. A transformer may be used to provide multiple voltages to a number of rectifier circuits.

INFORMATION SHEET

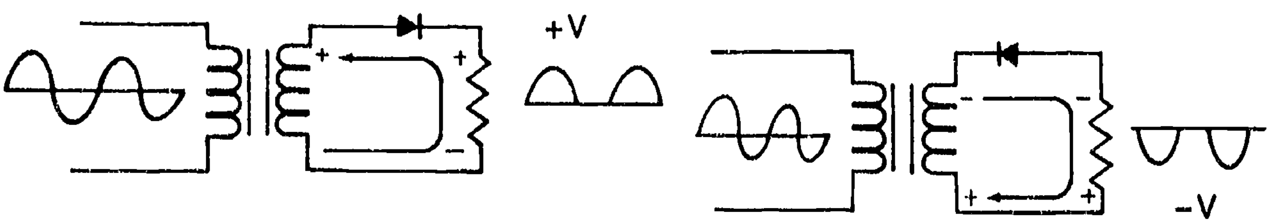
III. **Characteristics of a half-wave rectifier circuit** (Transparency #2)

A. A half-wave rectifier circuit converts AC voltage to pulsating DC voltage and allows DC current to flow only through the load during one-half of each AC input cycle.



B. The frequency of the output pulses is equal to the frequency of the AC input.

C. A half-wave rectifier may produce either a positive or a negative voltage with respect to ground.



D. The average, peak, and effective (rms) voltage output of a half-wave rectifier circuit may be determined by the following equations:

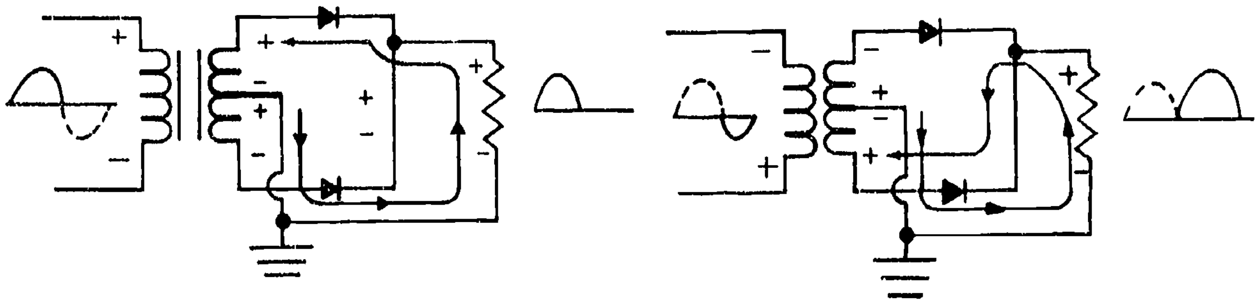
1. $E_{rms} = E_{peak} \times 0.707$
2. $E_{peak} = E_{rms} \times 1.414$
3. $E_{avg} = E_{peak} \times 0.318$

(NOTE: 0.707 equals the $\frac{\sqrt{2}}{2}$; 1.414 equals $\sqrt{2}$.)

INFORMATION SHEET

IV. **Characteristics of a full-wave rectifier circuit** (Transparency #3)

A. A full-wave rectifier converts AC voltage to pulsating DC voltage and allows current to flow through the load in the same direction during both alternations of the AC input cycle.



B. The frequency of the pulsating DC output (ripple frequency) is twice that of the AC input frequency.

C. The polarity of the output voltage may be reversed by reversing the direction of the diodes.

D. The output voltage of the full-wave rectifier may be calculated using the following equations:

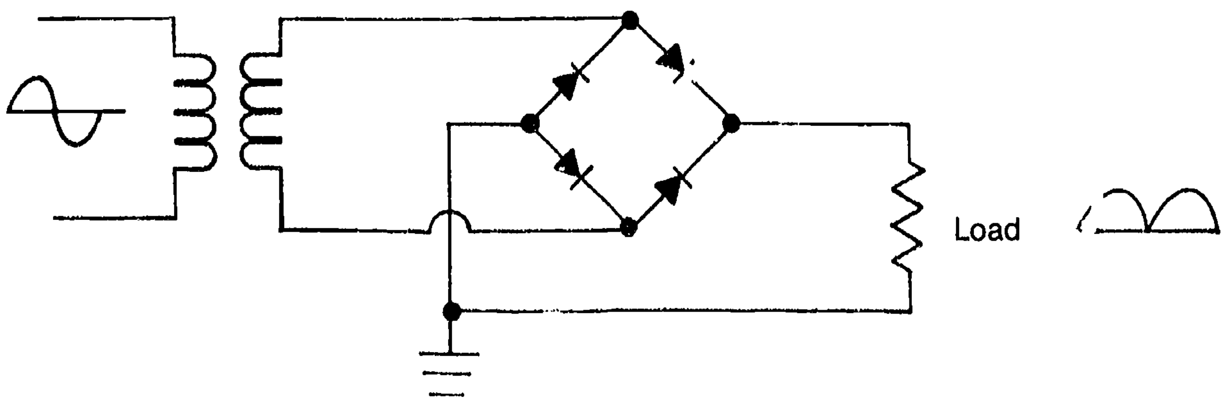
$$E_{peak} = E_{rms} \times 1.414$$

$$E_{avg} = 2 \times \frac{E_{peak}}{\pi}$$

$$E_{rms} = E_{peak} \times 0.707$$

V. **Characteristics of a bridge rectifier circuit** (Transparency #4)

A. The bridge rectifier converts AC voltages into pulsating DC voltage by using four diodes arranged in a "bridge" type configuration.



B. The frequency of the pulsating DC output (ripple frequency) is twice that of the AC input frequency.

INFORMATION SHEET

C. The polarity of the output voltage may be either positive or negative and is determined by the arrangement of the diodes.

D. The output voltages may be determined by the following equations:

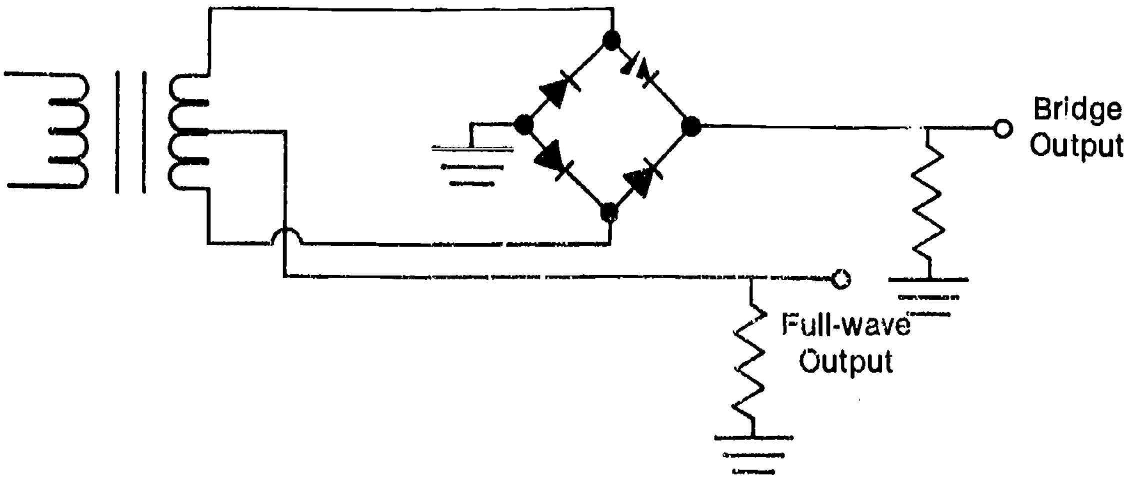
1. E peak = E rms × 1.414

2. E rms = E peak/1.414

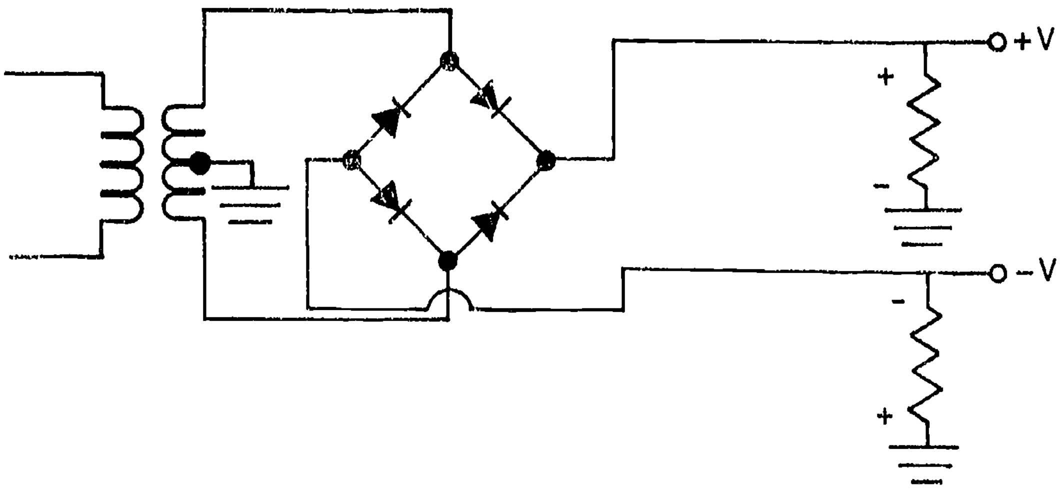
3. E avg = E peak × 0.636 1

VI. **Characteristics of combination power supplies** (Transparency #5)

A. A full-wave/bridge combination power supply may be used to provide two DC voltage sources.



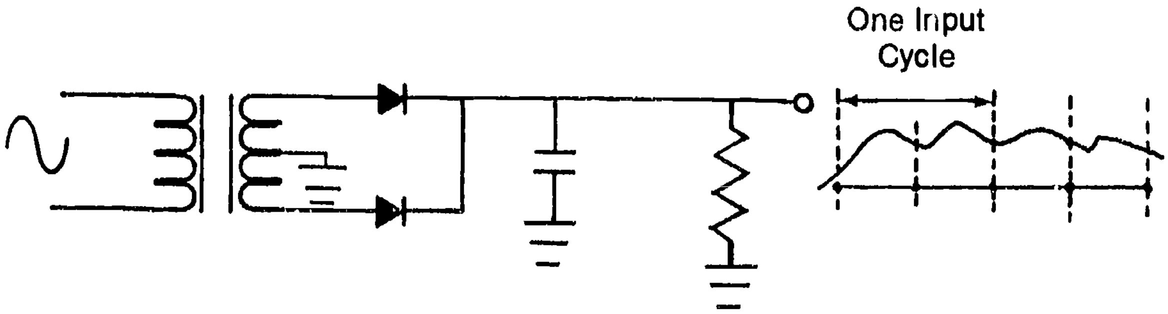
B. A full-wave/full-wave combination power supply may be used to provide two outputs of opposite polarity.



INFORMATION SHEET

VII. Basic types of filter configurations (Transparency #6)

A. The capacitor filter is the simplest form of filter.

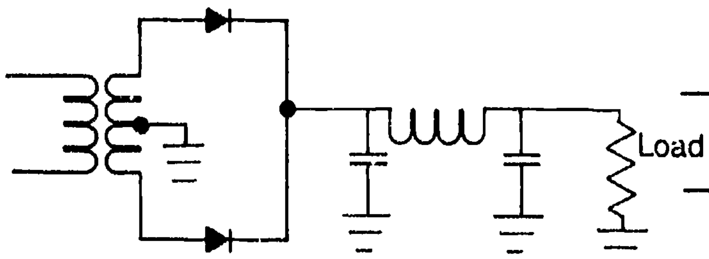


1. It is the most economical.

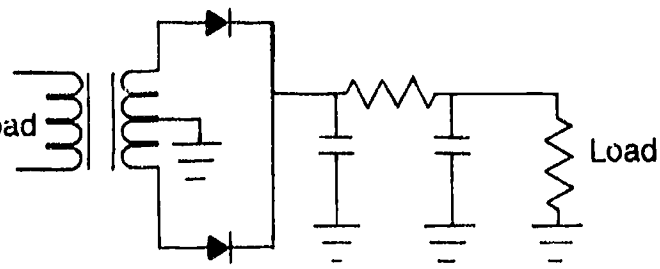
2. It is used where load does not require an extrem-'; -mooth DC voltage.

B. The PI-section filter works on the low-pass filter principle and uses two capacitors and a resistor or inductor as components.

(NOTE: This is also called a capacitance-input filter.)



LC Filter

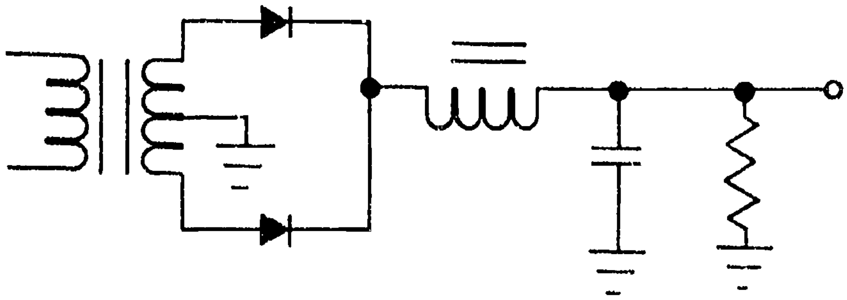


RC Filter

1. It is used when a smooth DC voltage is required at relatively low current.

2. The PI-section, RC type filter is less expensive but filter action is slightly less than the LC type.

C. The L-section filter ("choke-input") uses an inductor and capacitor in an inverted L-type of an arrangement to provide filtering in higher current applications.

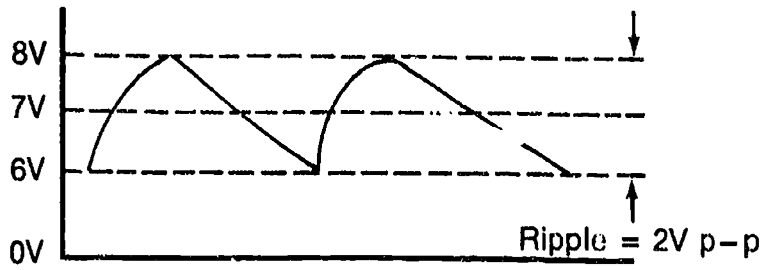


INFORMATION SHEET

VIII. Ripple factor — The figure of merit which tells how good a filter does its job; it may be calculated by the equation

$$\% \text{ ripple} = \frac{\text{E rms of ripple}}{\text{E avg}} \times 100$$

Example:

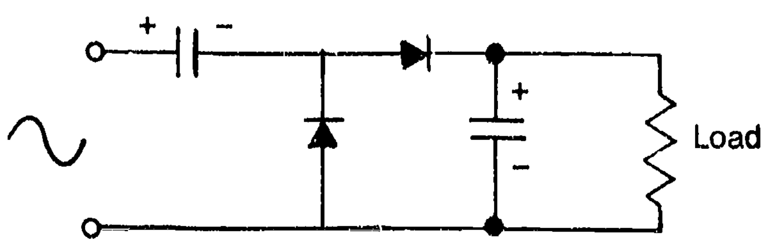


$$\% \text{ ripple} = \frac{0.707 \text{ Vrms}}{7 \text{ Vrms}} \times 100 = 10.1 \%$$

IX. Basic voltage multiplier circuits

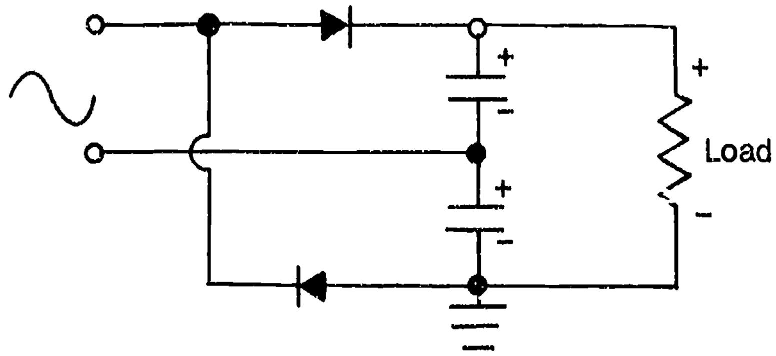
A. The half-wave voltage doubler produces a DC output voltage which is approximately twice the peak value of the input AC sine wave. (Transparency #7)

(NOTE: Two disadvantages of this type circuit is that the ripple voltage is hard to filter and the output capacitor must have a voltage rating at least twice the peak value of the AC input.)

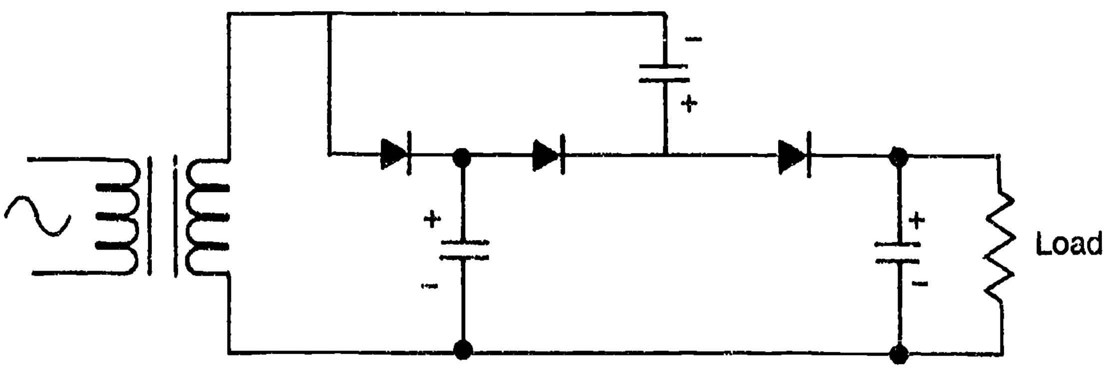


INFORMATION SHEET

B. The full-wave voltage doubler produces a DC output voltage of about twice the peak input AC voltage and overcomes the two primary disadvantages of the half-wave doubler. (Transparency #8)



C. The voltage tripler produces a DC output voltage approximately three times the peak value of the AC input. (Transparency #9)

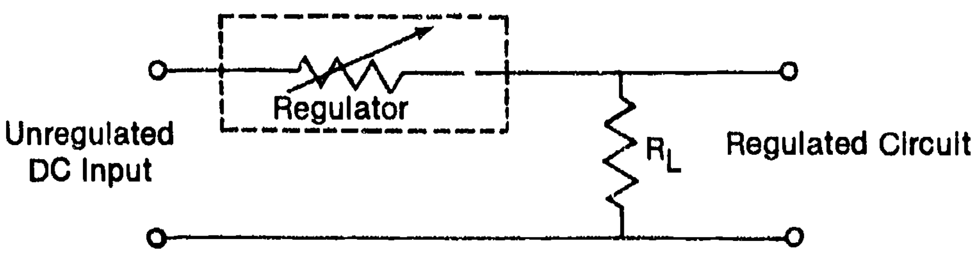


X. **Regulation of power supply output** (Transparency #10)

A. The figure of merit for a power supply is its percent regulation and may be determined by the equation

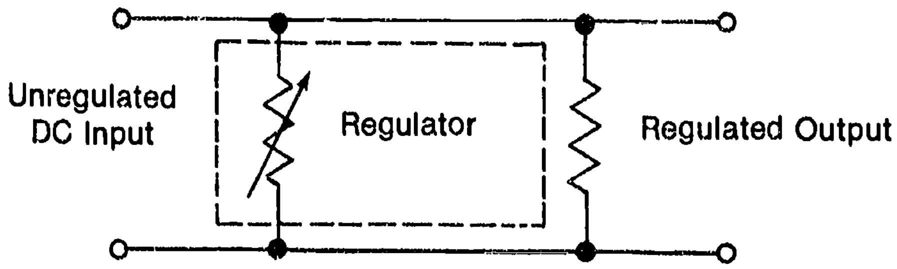
$$\% \text{ Regulation} = \frac{\text{E no-load} - \text{full-load}}{\text{E full-load}} \times 100$$

B. A series regulator is one in which a control device is placed in series with the load to act as an automatically variable resistor in a voltage divider to maintain a constant voltage to the load.



INFORMATION SHEET

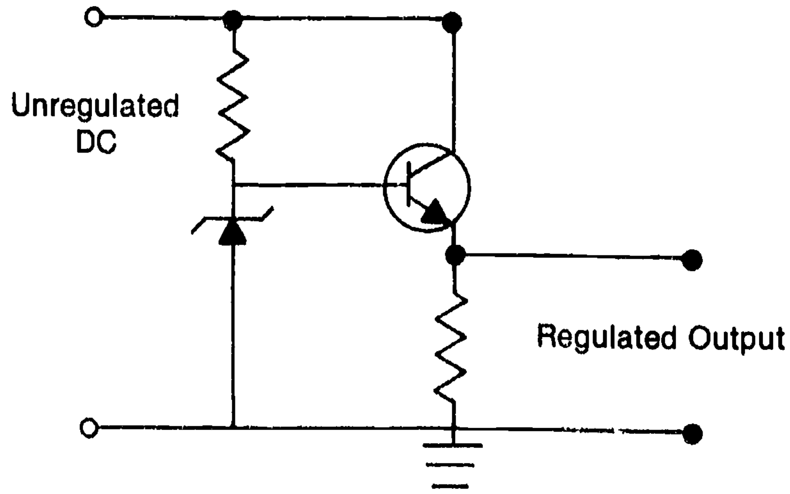
C. A shunt regulator is one in which a control device is placed in parallel with the load to act as an automatically variable resistor to provide voltage division and a constant voltage to the load.



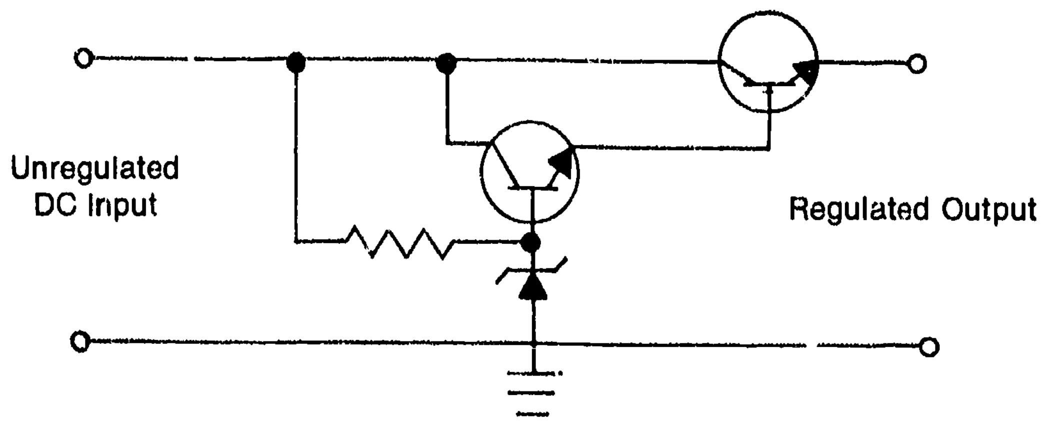
D. The bleeder resistor connected to a power supply provides a minimum load for the power supply and decreases the no-load voltage improving the supply's regulation.

XI. **Series and shunt regulator configurations** (Transparency #11)

A. The simplest series regulator is the emitter follower type.

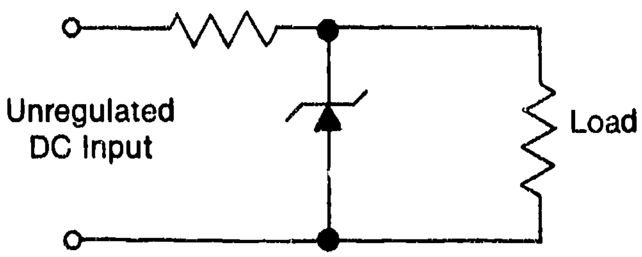


B. The Darlington configuration is an improved series regulator.

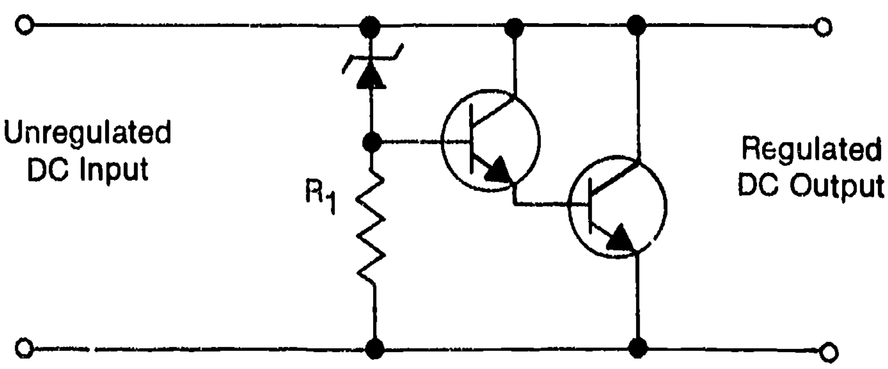


INFORMATION SHEET

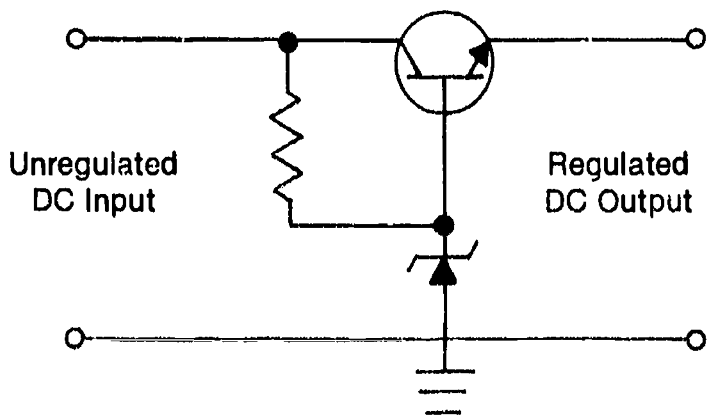
C. The basic zener regulator is a simple but effective shunt type voltage regulator (Transparency #12)



D. The basic zener regulator may be improved by adding transistors to the regulator circuit and controlling the voltage between the base and collector (and forward bias in conjunction with R1) of the transistor.



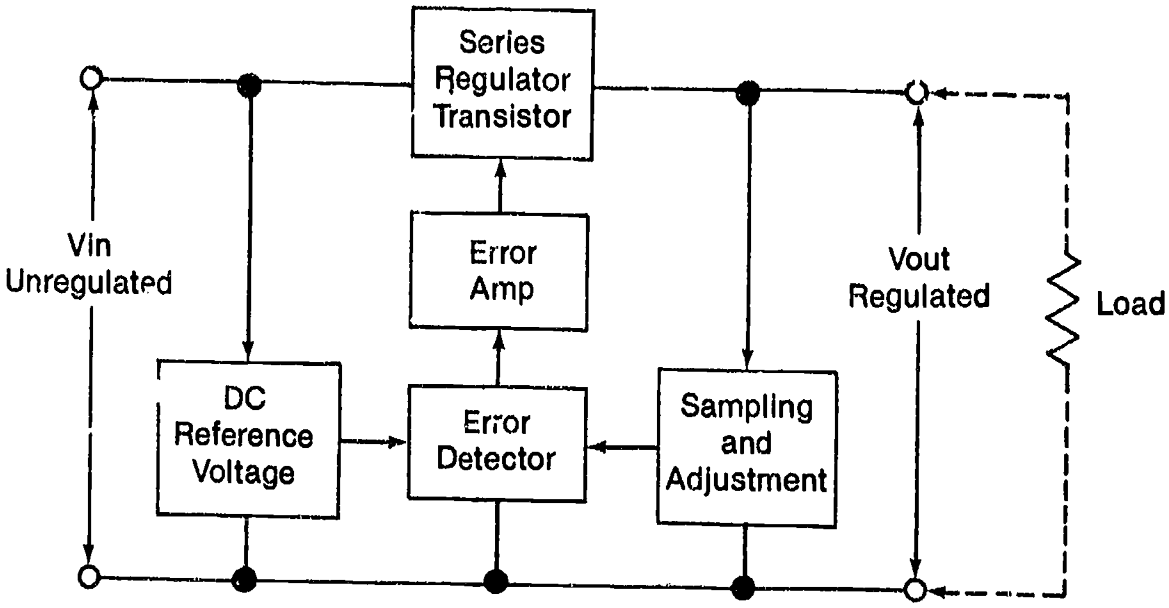
E. A zener diode may be used in a series regulator configuration.



INFORMATION SHEET

XII. Feedback regulator configurations (Transparency #13)

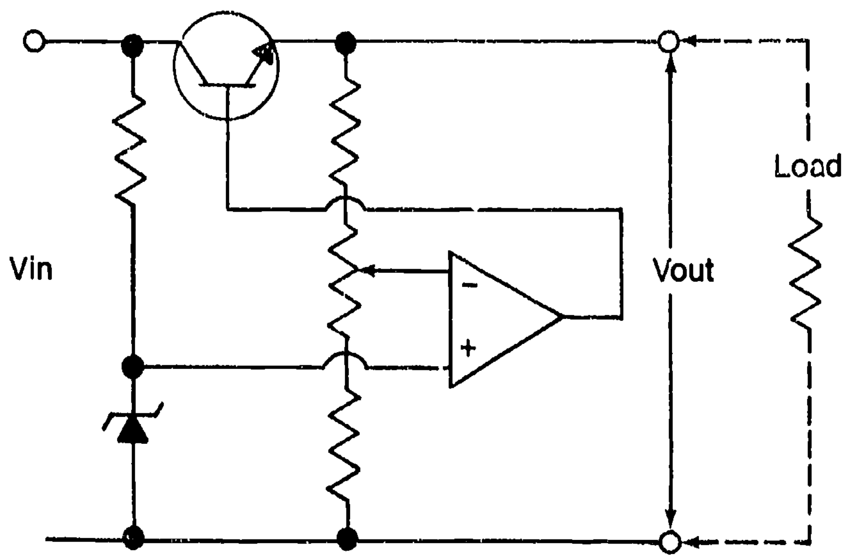
A. A feedback regulator consists of five basic circuits —



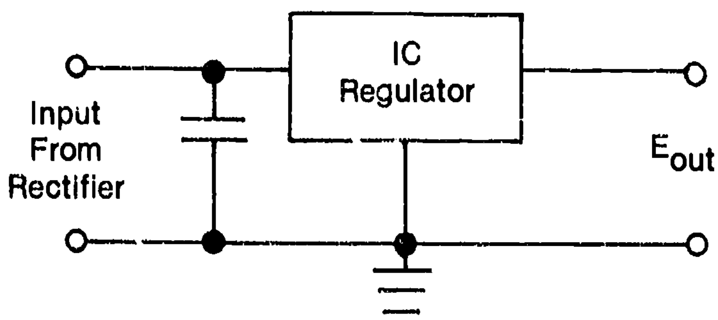
1. A sampling circuit which is usually a voltage divider network connected across the output
2. A DC reference voltage usually provided by a zener diode
3. An error detector which compares the sampled voltage to the reference voltage
4. An error voltage amplifier which amplifies the difference between the sampled voltage and the reference voltage
5. A series regulator transistor whose conduction is controlled by the amplified error voltage to compensate for the original change in output voltage

INFORMATION SHEET

B. An op-amp may be used as the error detector and amplifier in a feedback regulator circuit.



C. Complete regulators are constructed as three terminal IC packages including protective circuits which make them virtually blow-out-proof



XIII. **Characteristics of switching regulators** (Transparency 14)

A. Switching regulators are used to improve the efficiency of the regulator circuit by using a pulsing technique.

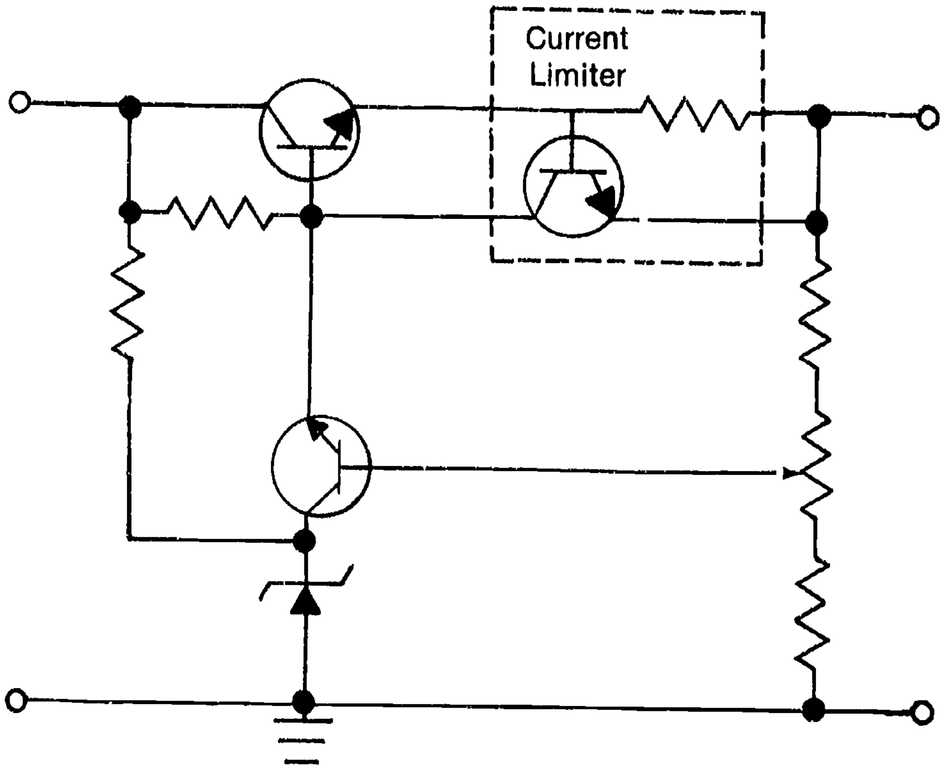
B. Switching regulators may be operated in step-up, step-down or inverting modes.

XIV. **Types of overload protection circuits**

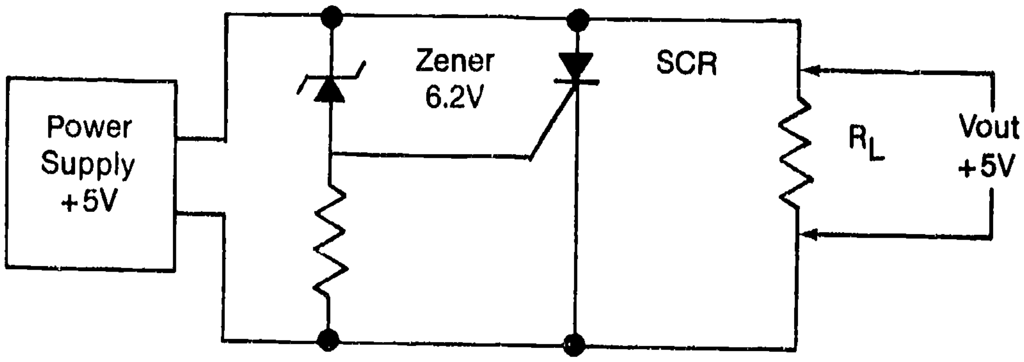
A. The fuse and circuit breaker are the simplest form of overload protection.

INFORMATION SHEET

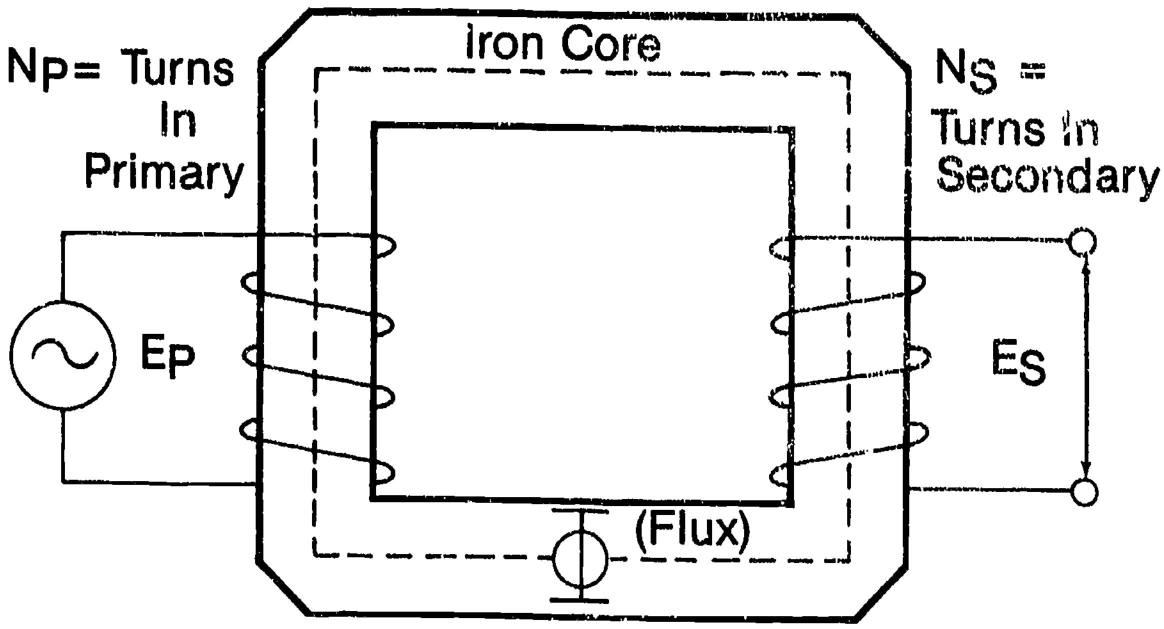
B. A current limiting circuit may be added to a regulator to protect the series regulator transistor from short circuits in the load.



C. The "crowbar" circuit is used to protect the load from an overvoltage condition. (Transparency 15)

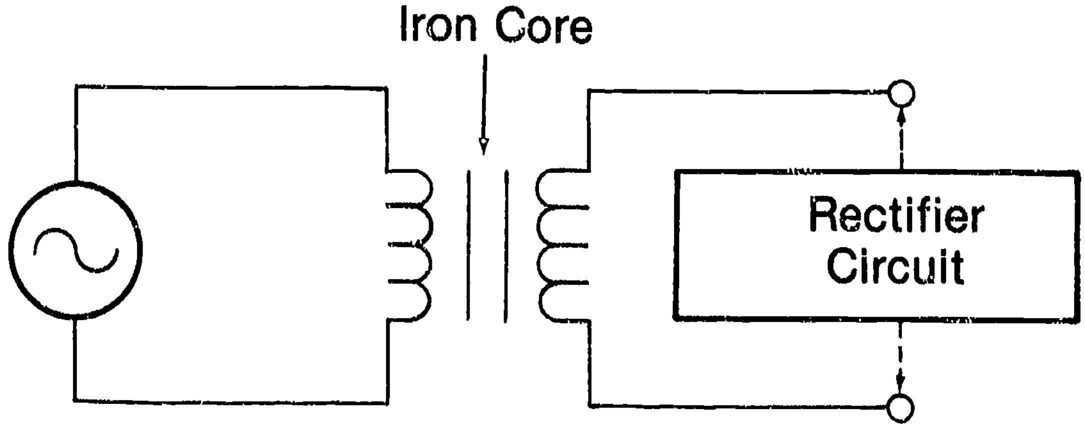


The Transformer



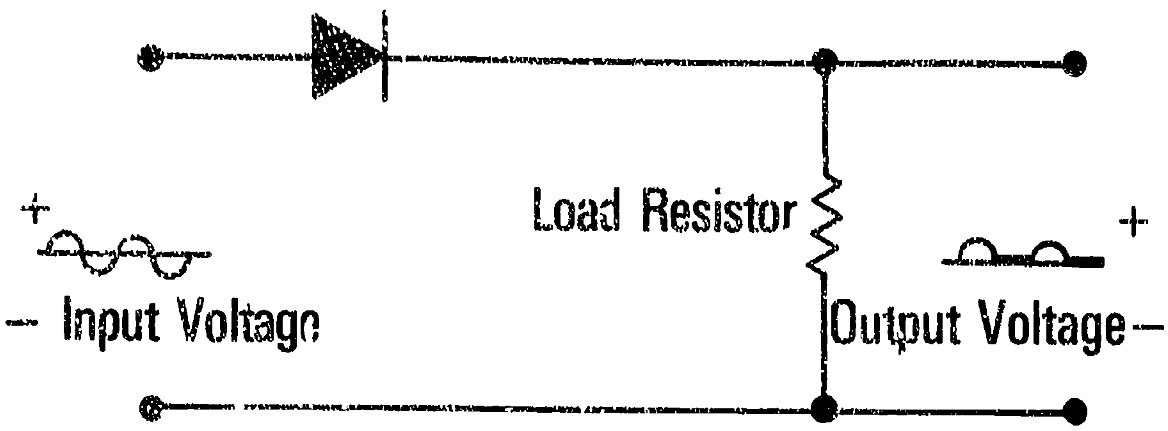
Pictorial Representation

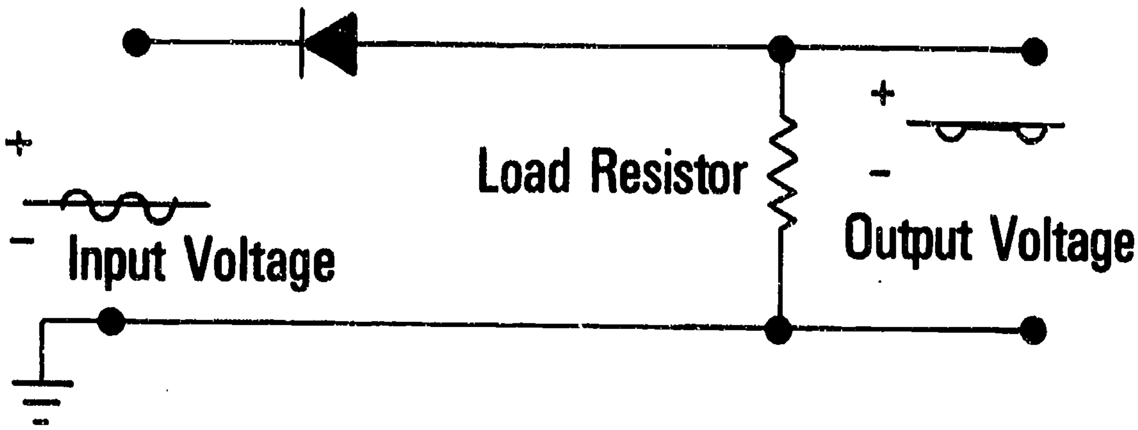
$$\frac{E_S}{E_P} = \frac{N_S}{N_P} \qquad E_S = E_P \frac{N_S}{N_P}$$



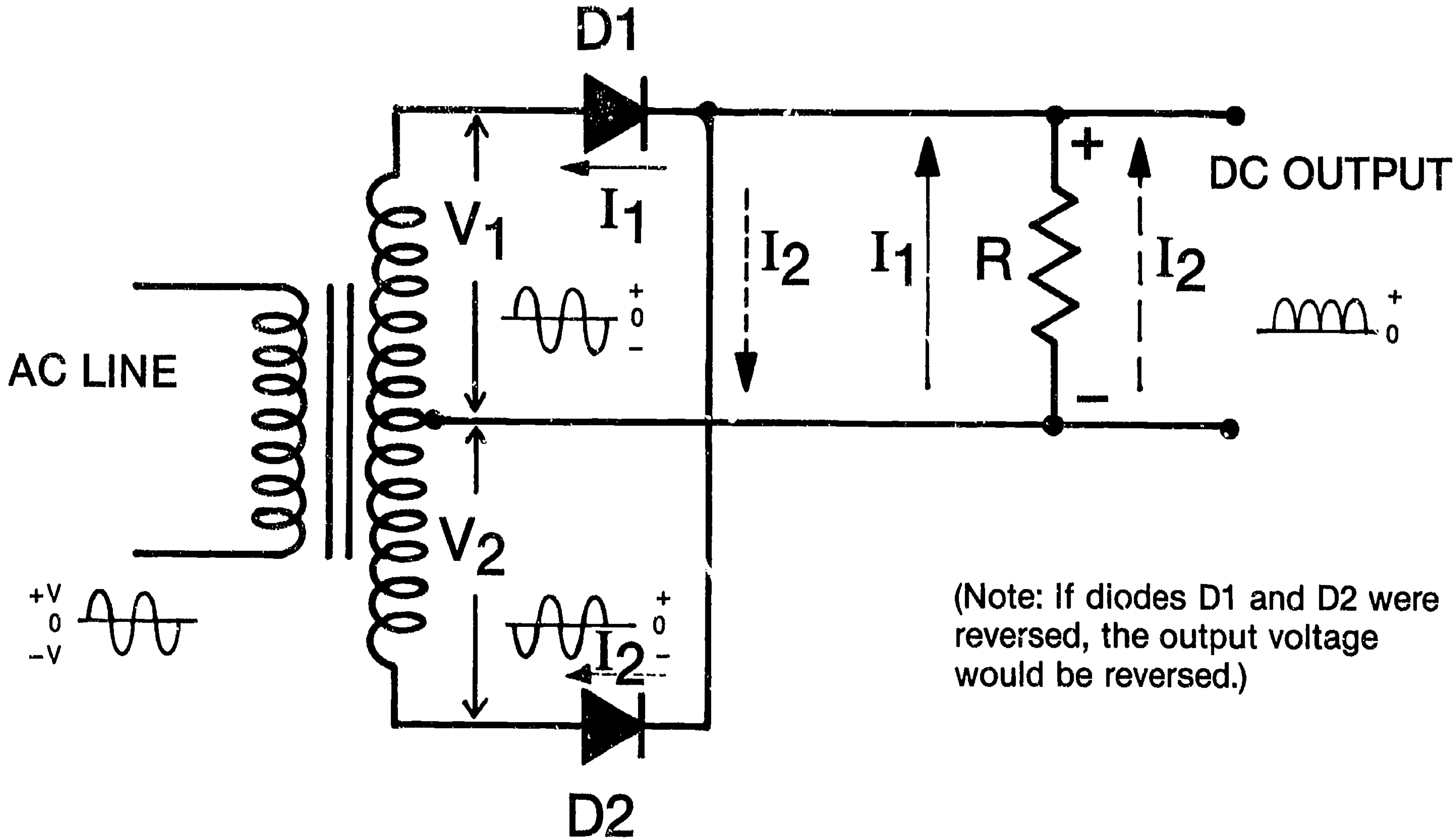
Schematic

Half-Wave Rectifier Circuits



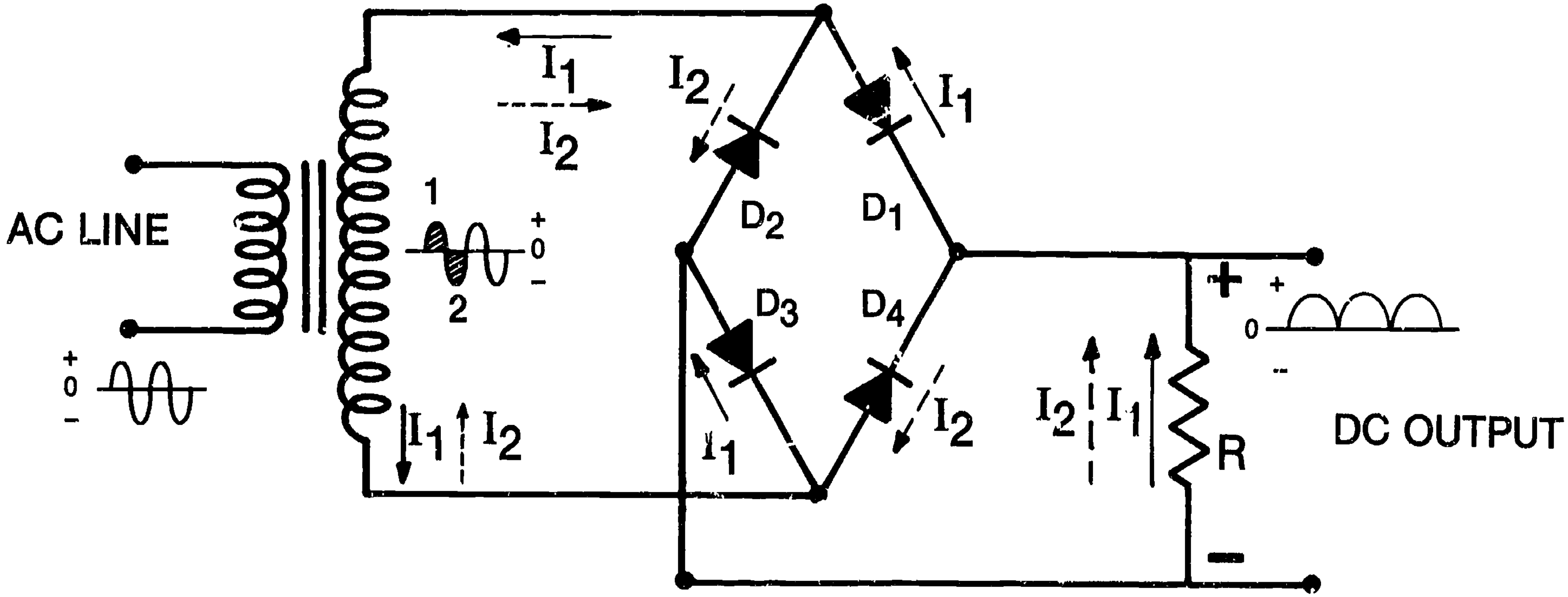


Conventional Full-Wave Rectifier



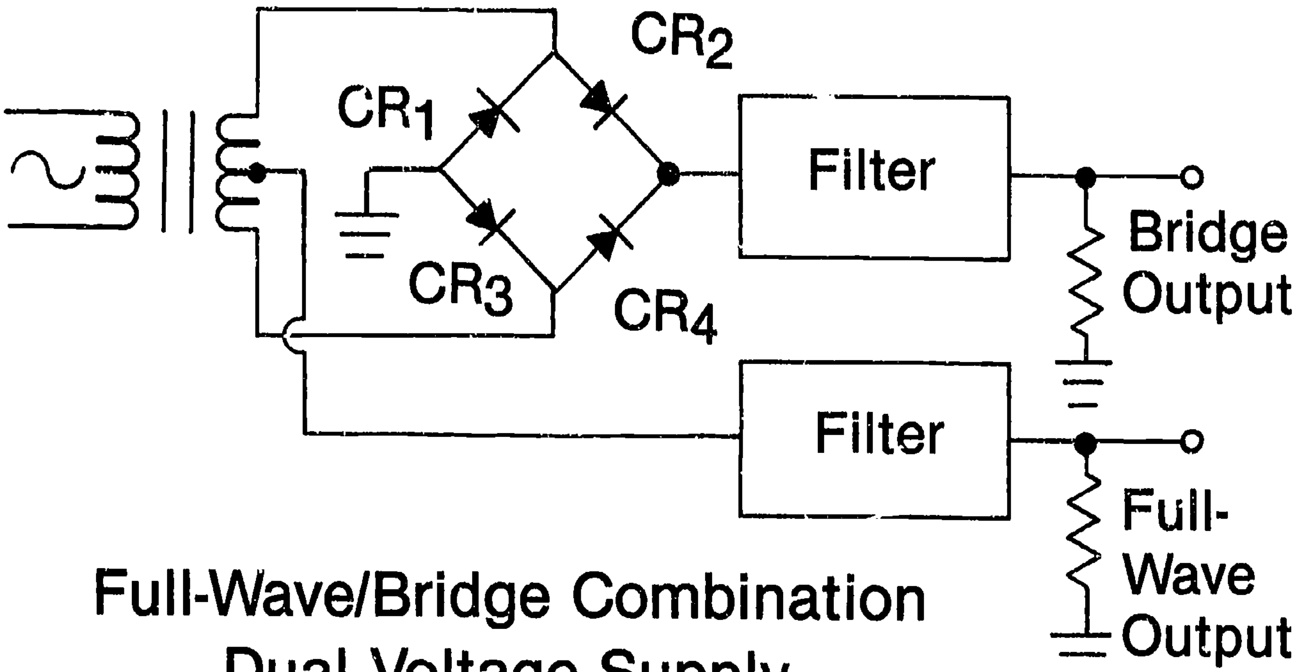
(Note: If diodes D1 and D2 were reversed, the output voltage would be reversed.)

Bridge Rectifier

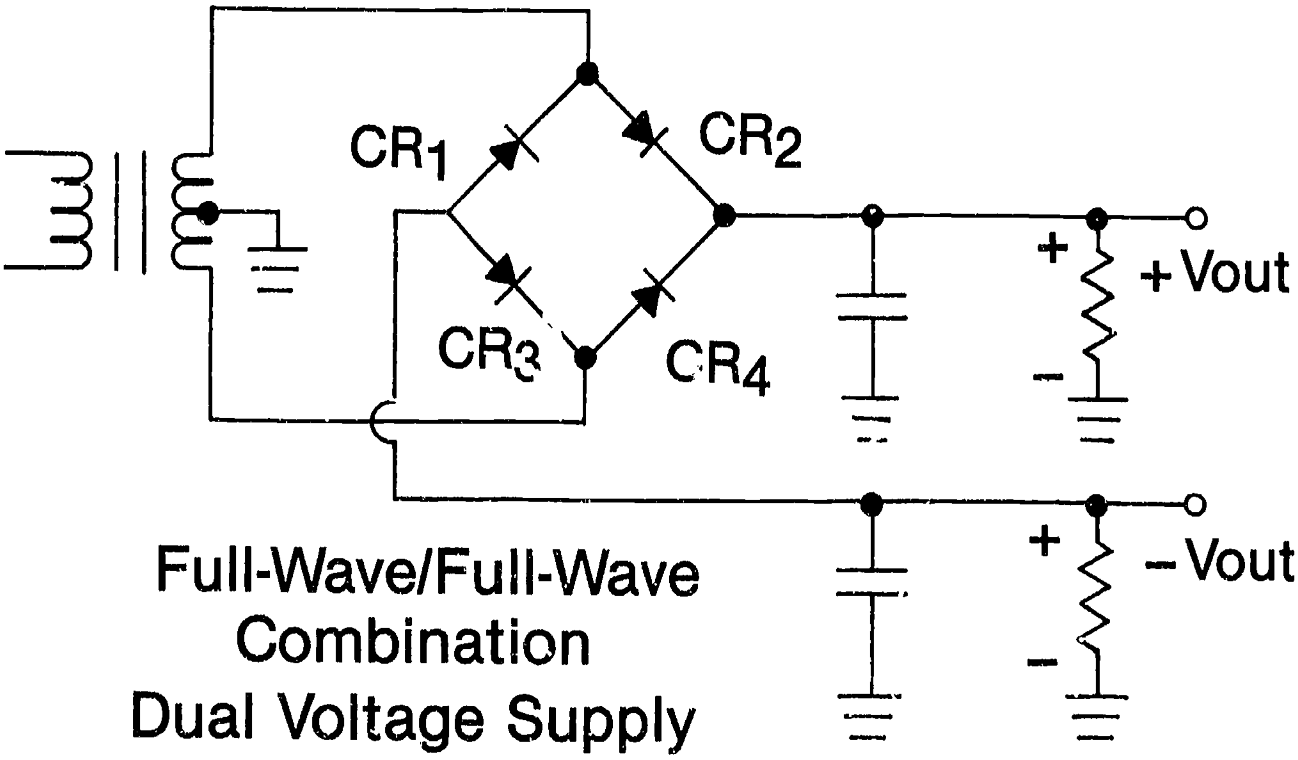


(Note: If each of the diodes were reversed the output would be reversed.)

Combination Power Supplies

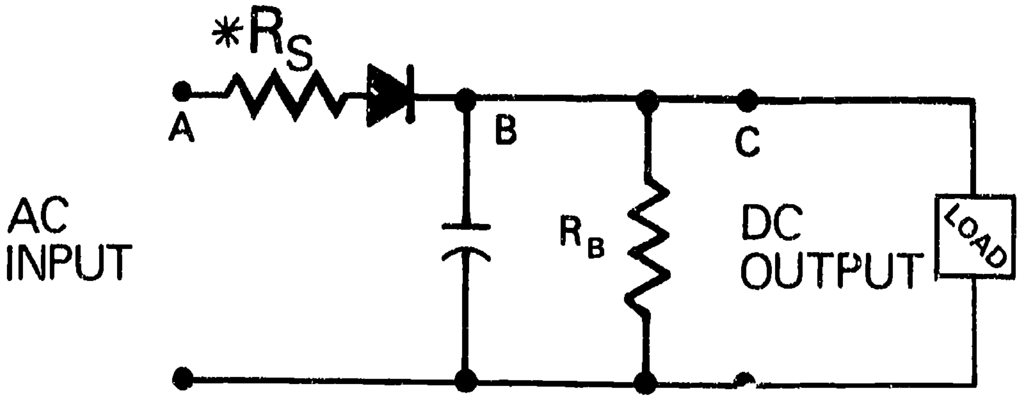


Full-Wave/Bridge Combination
Dual Voltage Supply

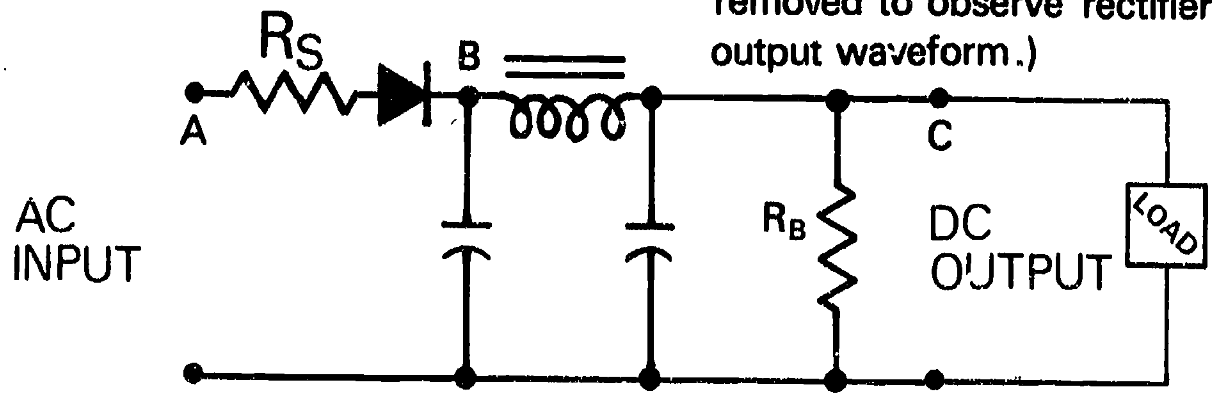


Full-Wave/Full-Wave
Combination
Dual Voltage Supply

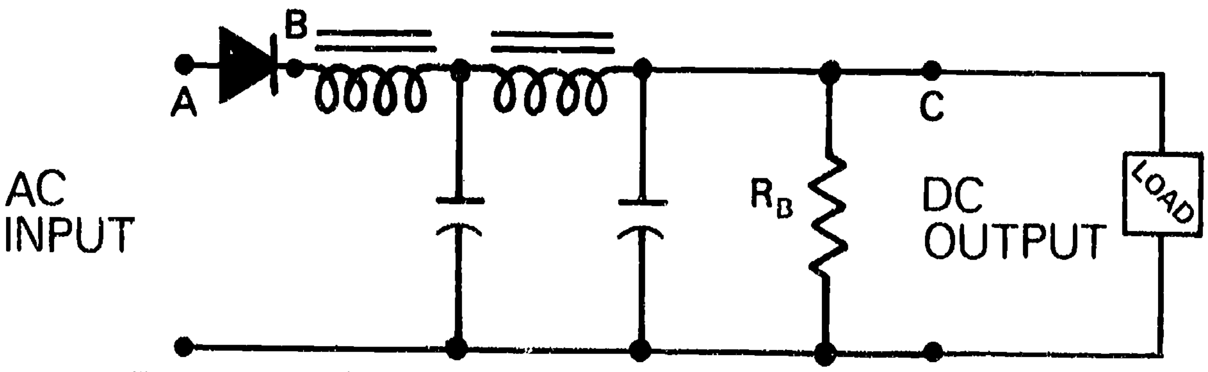
Basic Filter Configurations



Capacitor Filter (NOTE- Capacitor must be removed to observe rectifier output waveform.)



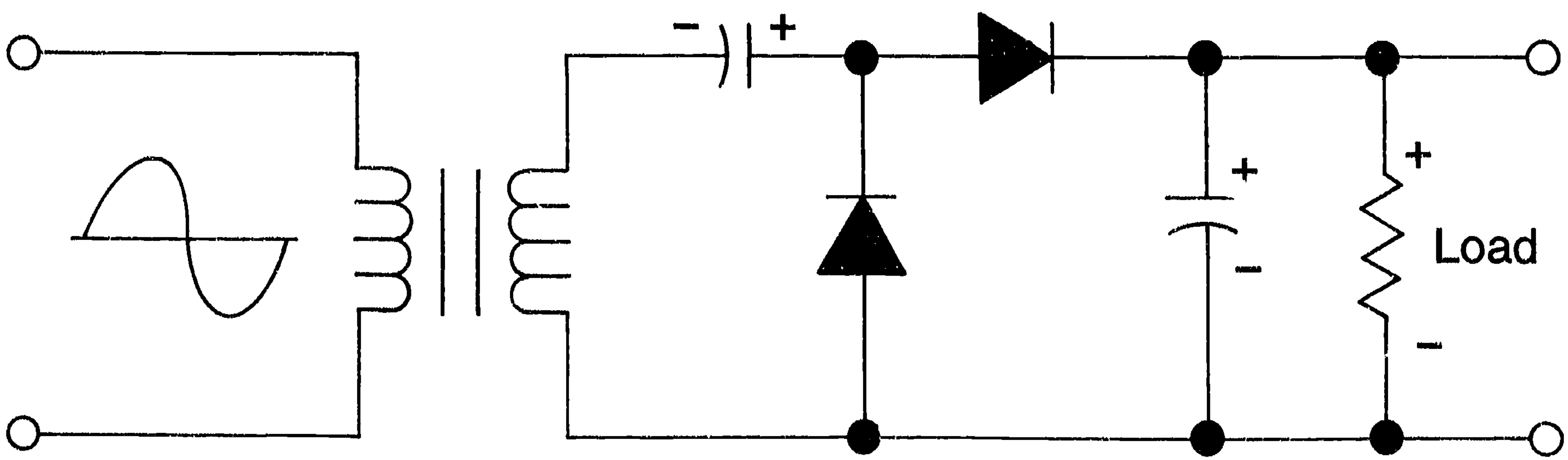
PI-Section Filter



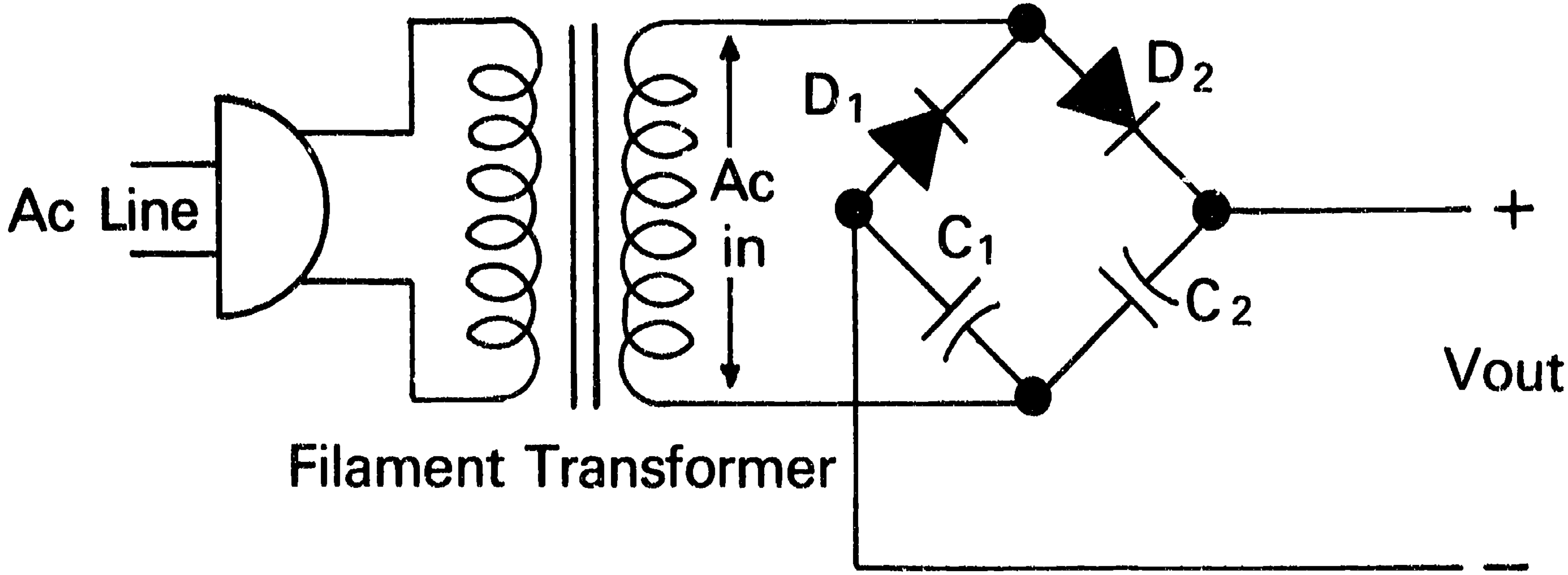
Two L-Section Filter

* (NOTE- R_S in series with diode limits initial surge of current due to capacitor and is called a surge resistor.)

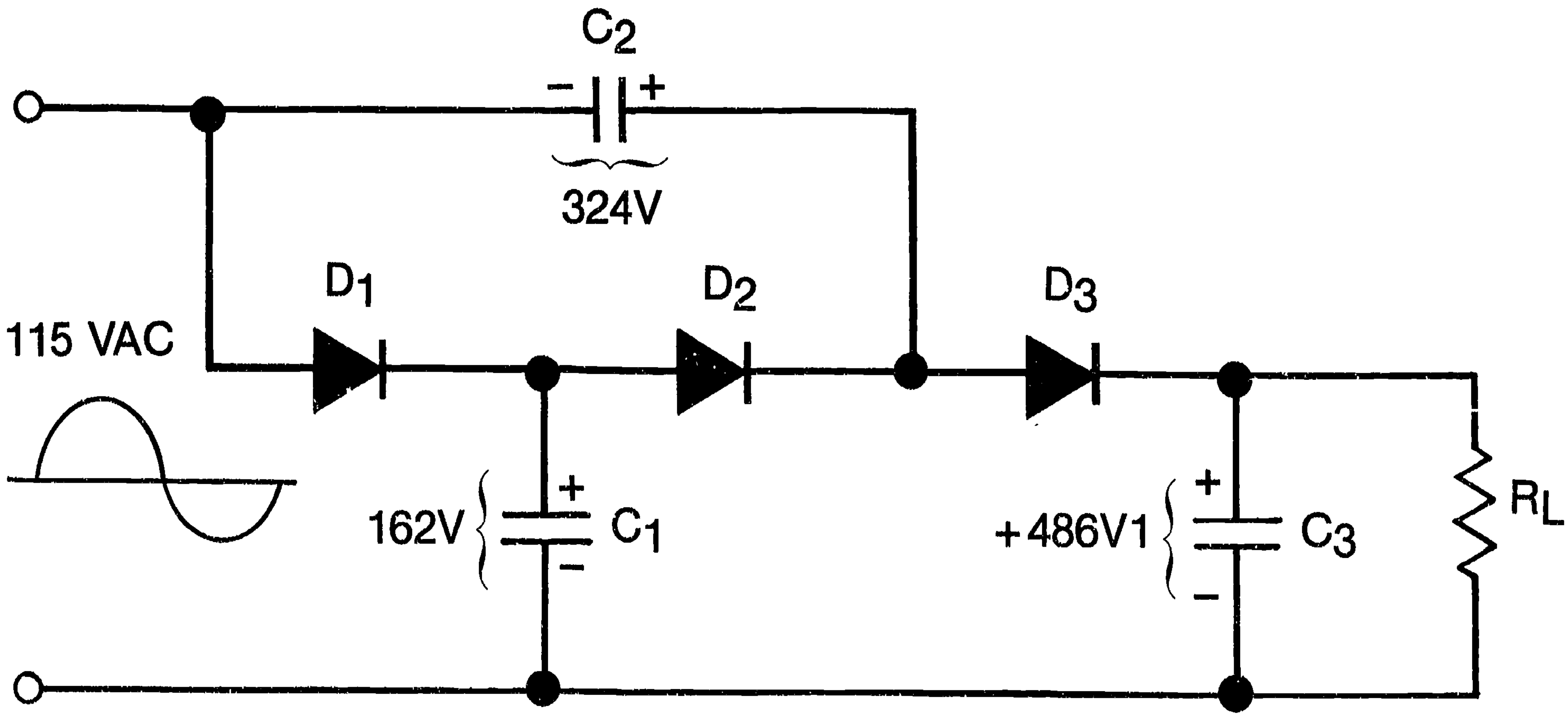
Half-Wave Voltage Doubler Circuit



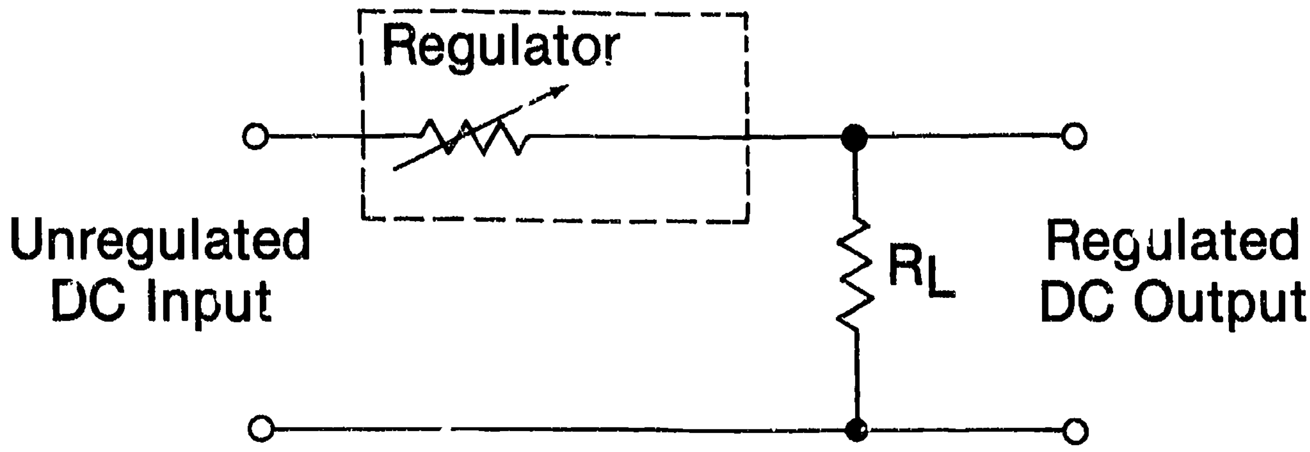
Full-Wave Voltage Doubler Circuit



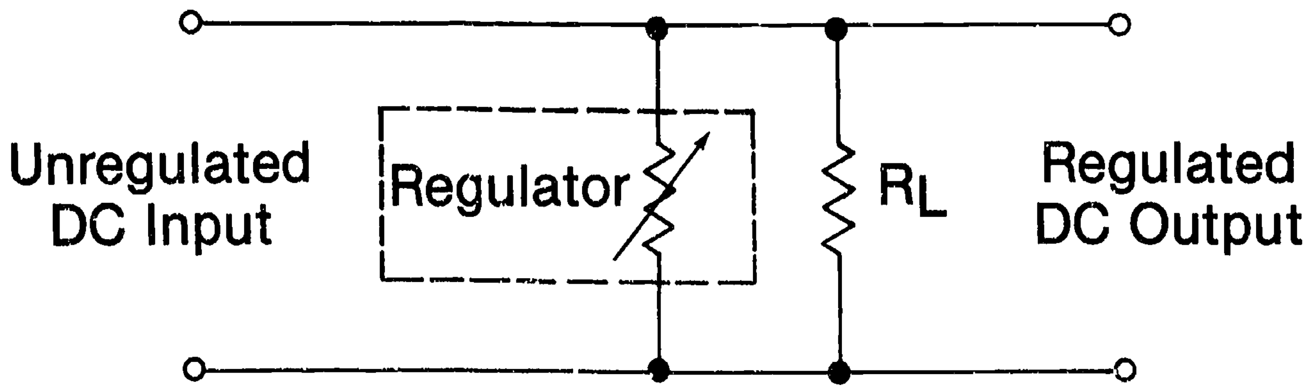
Voltage Tripler



Voltage Regulation



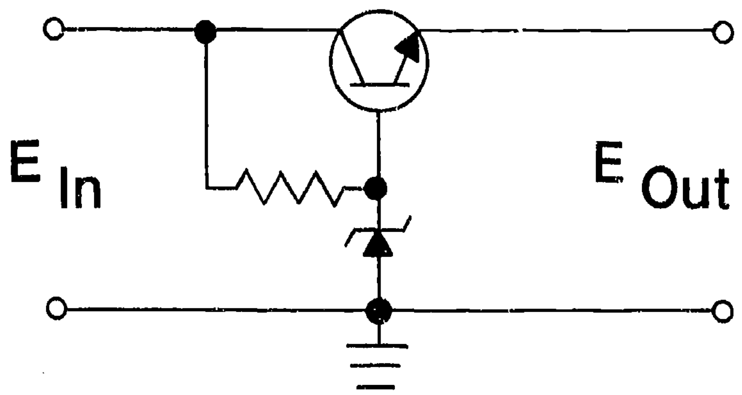
Series Regulation



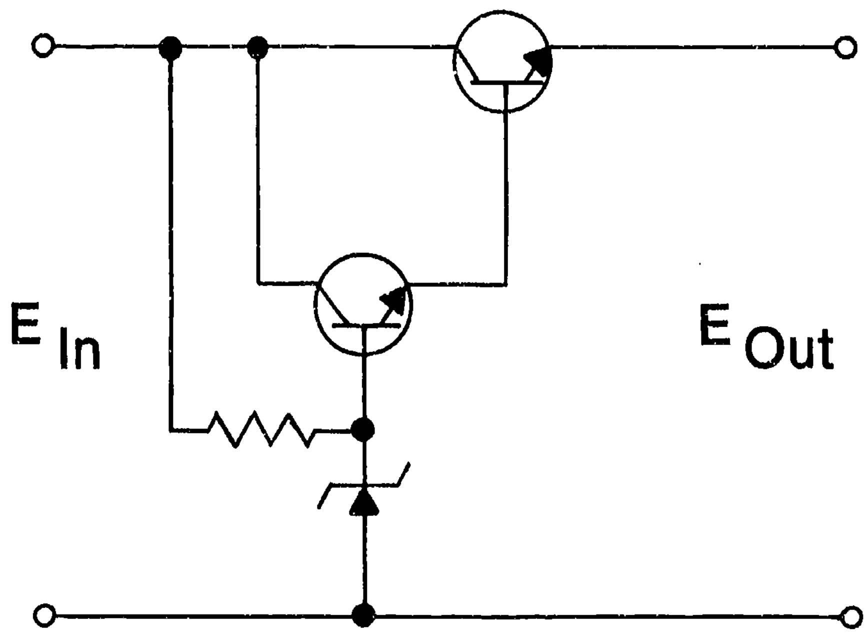
Shunt Regulator

$$\% \text{ Regulation} = \frac{E_{\text{No-Load}} - E_{\text{Full-Load}}}{E_{\text{Full-Load}}} \times 100$$

Series Regulators

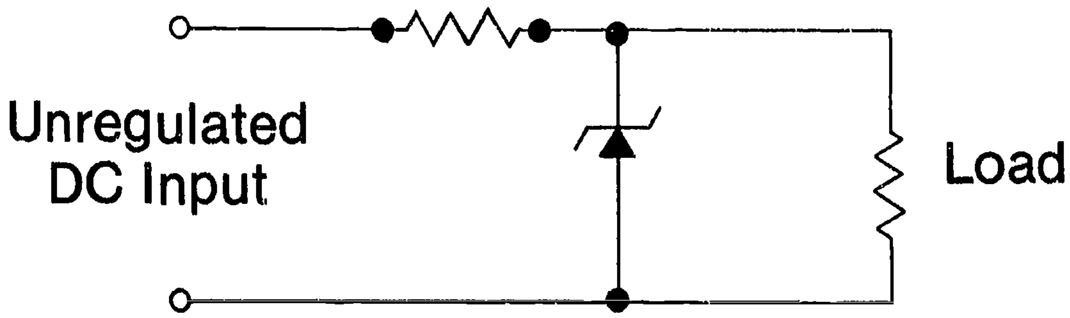


Emitter Follower Regulator

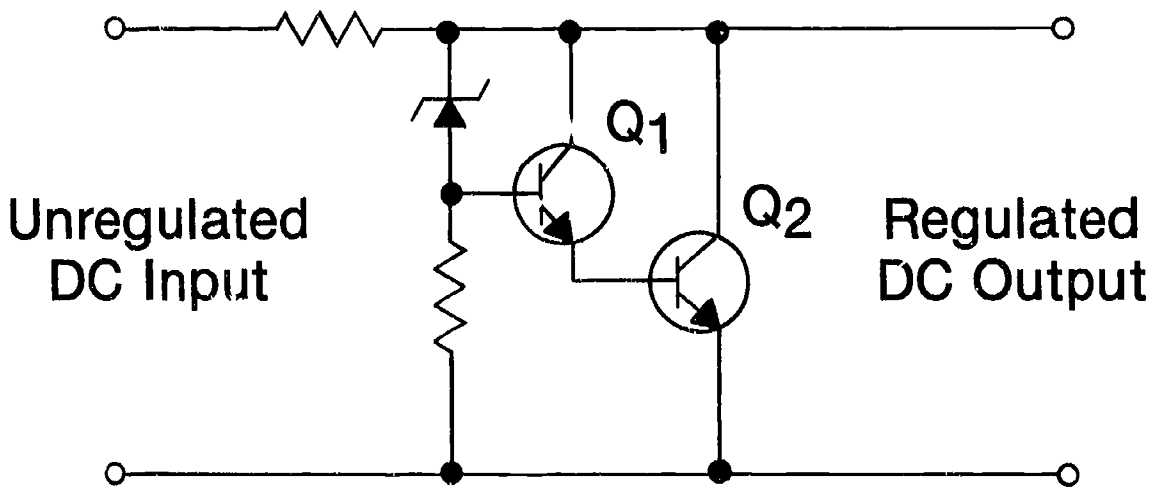


Darlington Configuration

Zener Regulators

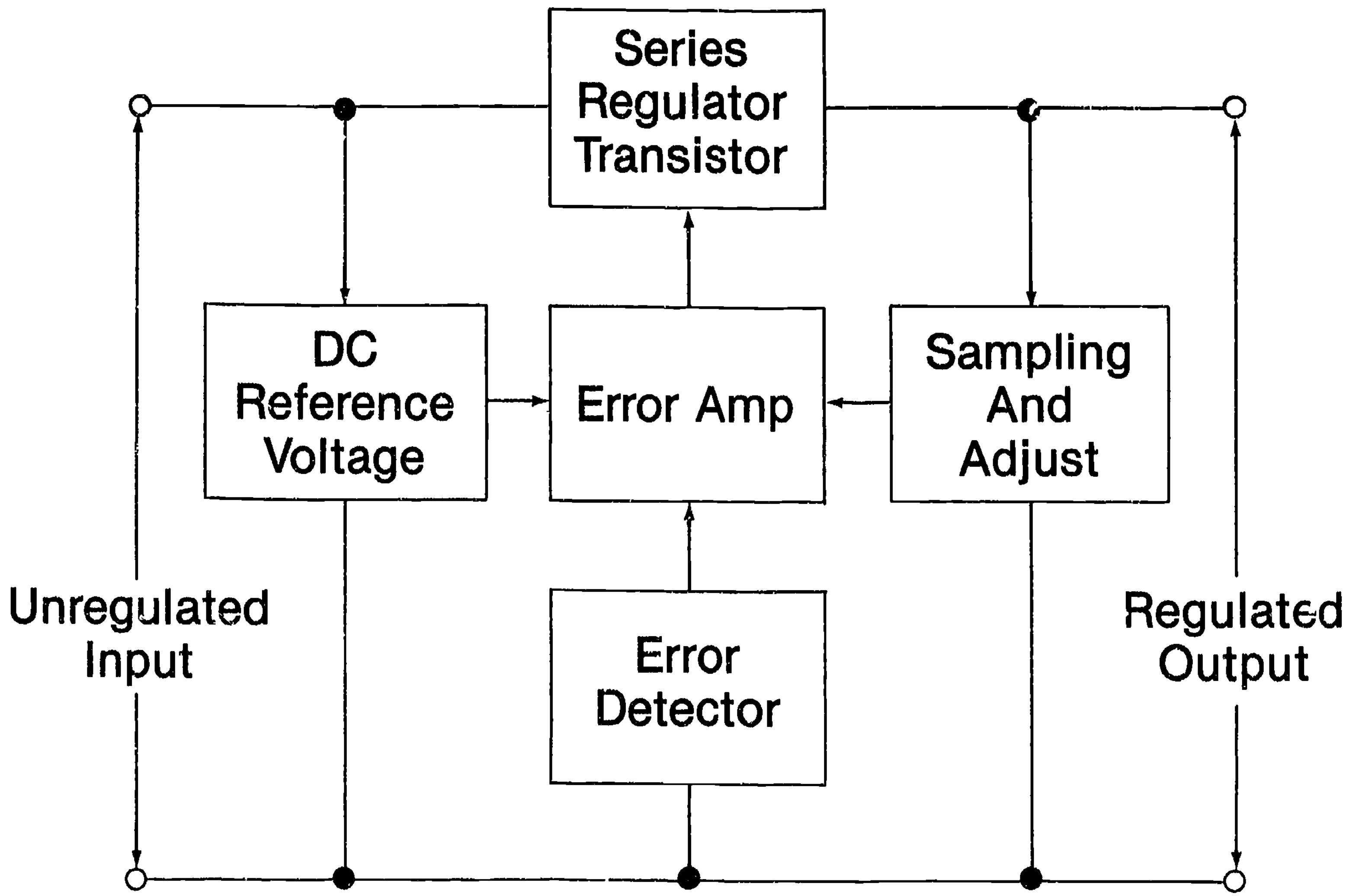


Zener Type Shunt Regulator



Improved Zener Diode Shunt Type Regulator

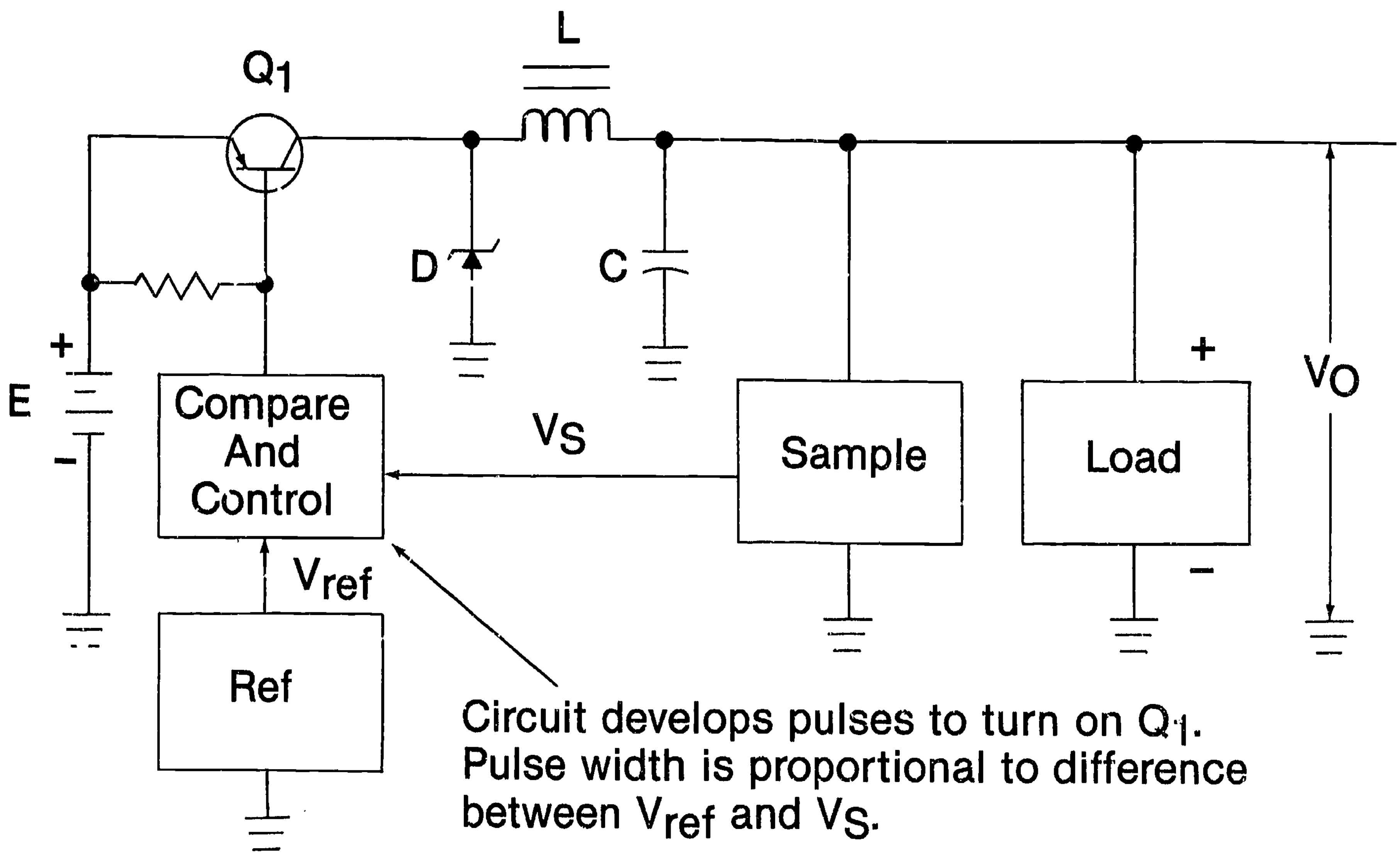
Feedback Regulator



TM 1[illegible]

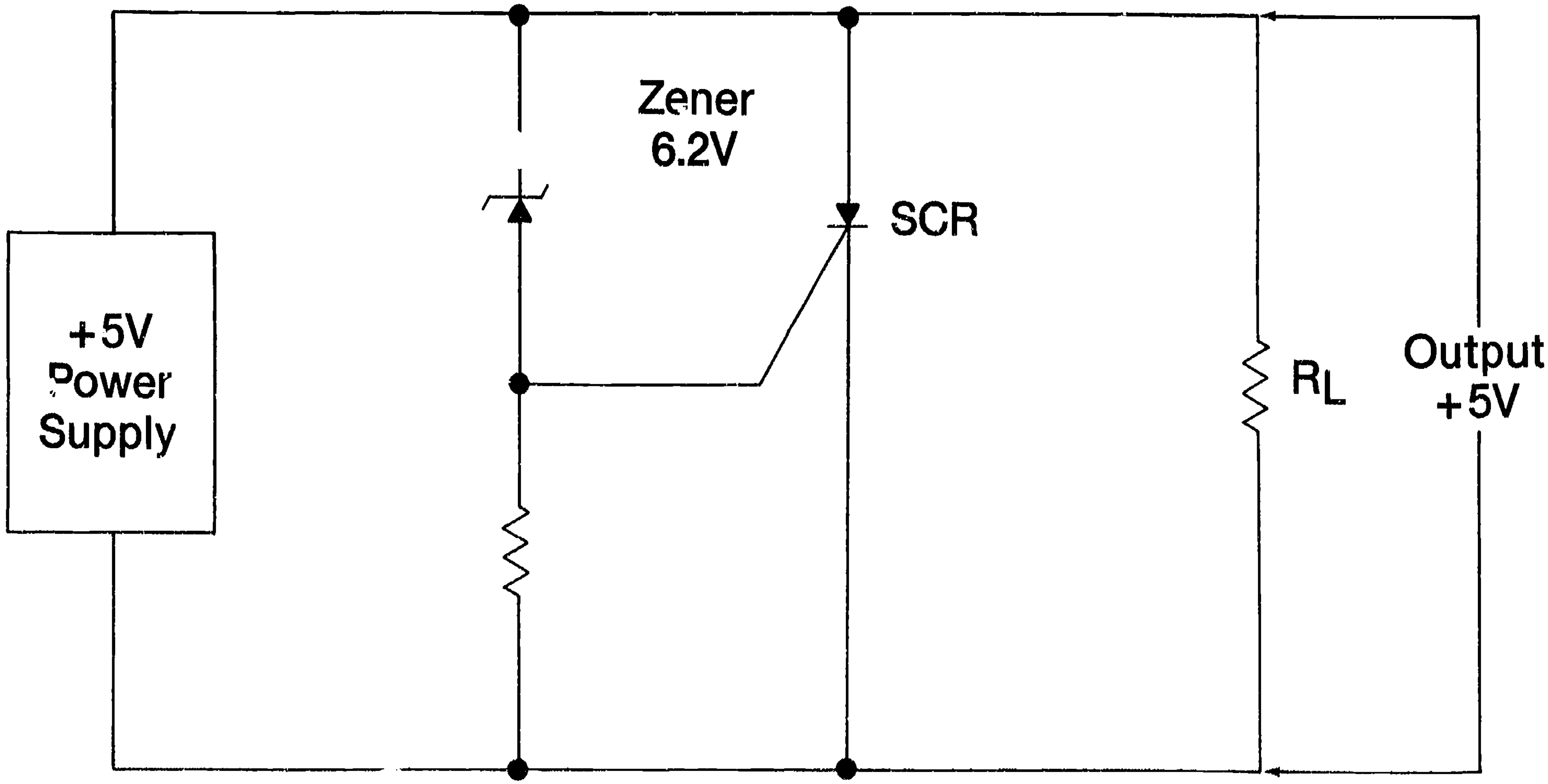
GET-809

Switching Regulator



Circuit develops pulses to turn on Q_1. Pulse width is proportional to difference between V_{ref} and V_S.

Load Protection

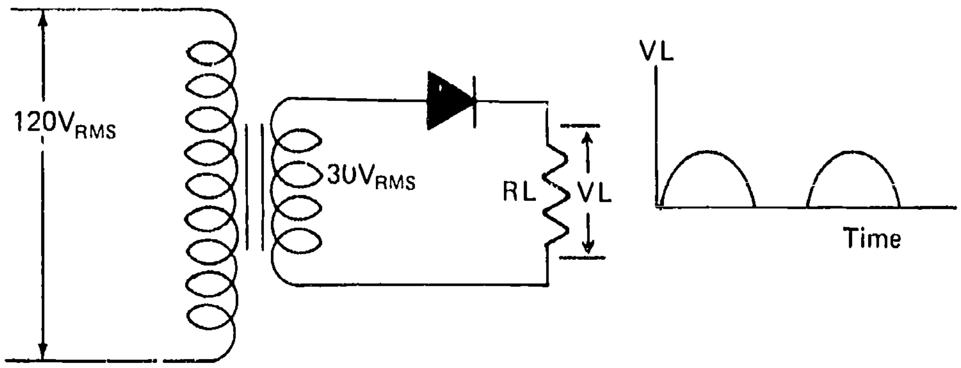


"Crowbar" Protection Circuit

POWER SUPPLIES
UNIT VII

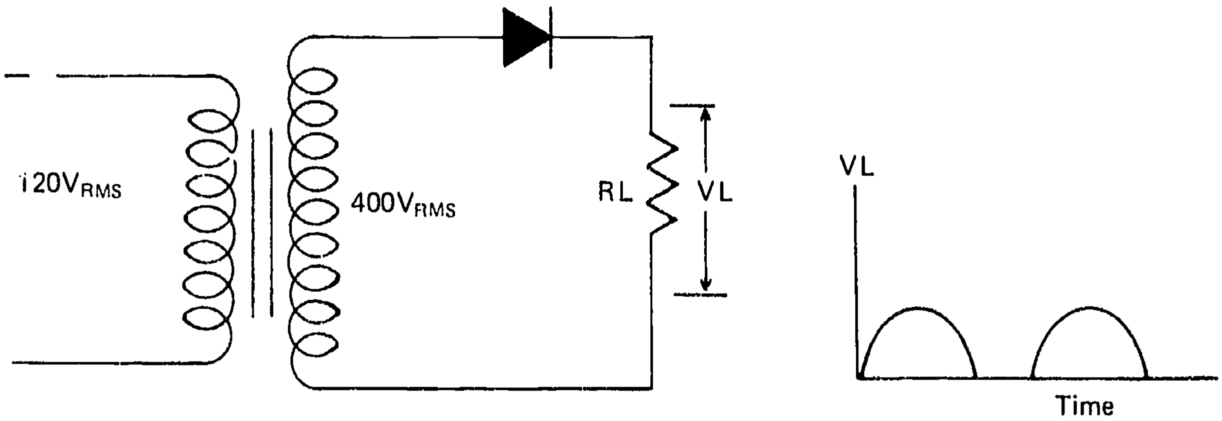
ASSIGNMENT SHEET #1 — CALCULATE AVERAGE DC VOLTAGE FOR HALF-WAVE RECTIFIER AND FULL-WAVE RECTIFIER CIRCUITS

1. Calculate the average DC voltage for the following circuit.



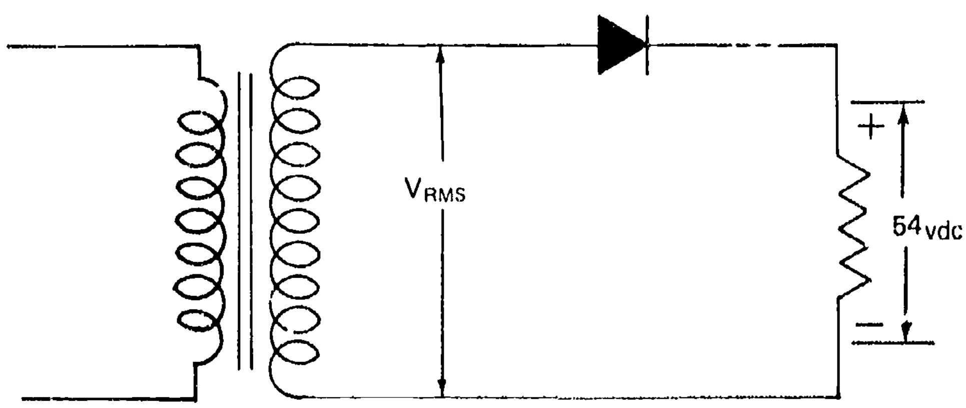
Vdc =

2. Calculate the average DC voltage for the following circuit.



Vdc =

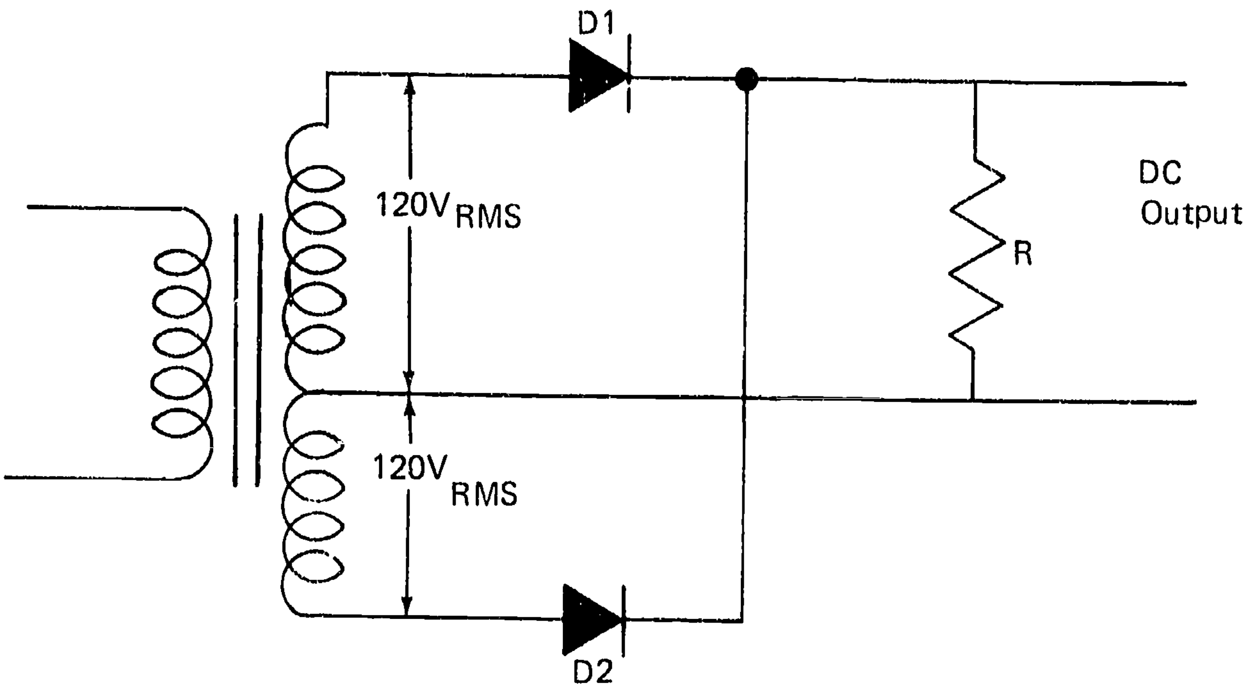
3. Calculate the transformer's secondary rms voltage.



Vrms =

ASSIGNMENT SHEET #1

4. Calculate the average DC voltage for the following circuit.



Vdc =

POWER SUPPLIES
UNIT VII

ASSIGNMENT SHEET #2 — CALCULATE RIPPLE FACTORS AND PERCENT REGULATION

1. A power supply has DC output voltage of 30 volts and a ripple of 10 Vrms. The ripple factor is ____

2. A power supply has DC output voltage of 15 volts and a ripple of .050 volts rms. The ripple factor is ____

3. Which one of the above power supplies has the most effective filtering and why?

4. A power supply has an output voltage at no-load of $24V_{DC}$ and an output voltage of $22V_{DC}$ at full-load. The percent regulation is ____________________________

POWER SUPPLIES
UNIT VII

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #1

1. V_{dc} = 13.5V
2. V_{dc} = 180V
3. Vrms = 120V
4. V_{dc} = 108V

Assignment Sheet #2

1. r = 0.33
2. r = 0.0033
3. #2, smaller ripple factor
4. 8.3%

POWER SUPPLIES
UNIT VII

JOB SHEET #1 — CONSTRUCT AND TEST A HALF-WAVE RECTIFIER CIRCUIT

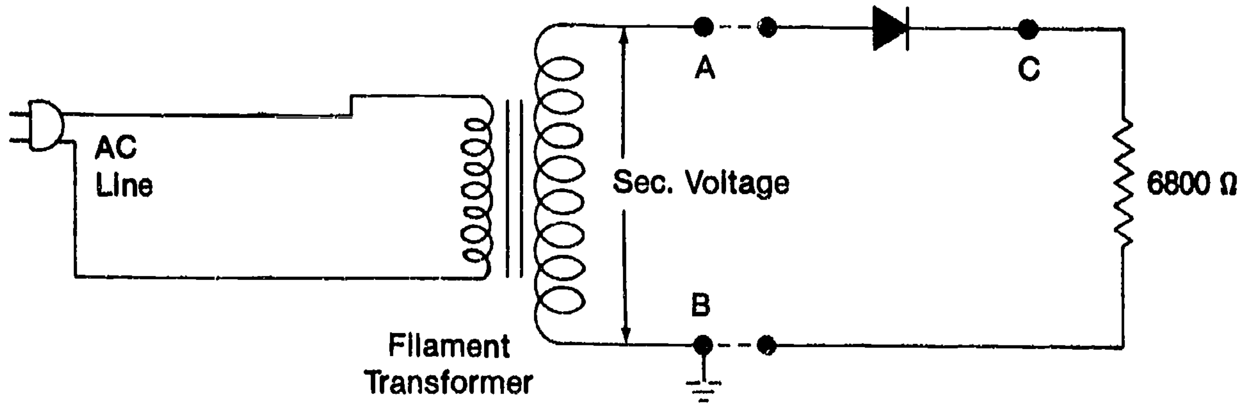
A. Equipment and materials needed

1. Low power filament transformer (120V Primary)
2. Silicon diode, 1N4004 or equivalent
3. Two 6800 ohm, 1/2 watt resistors
4. Multimeter
5. Oscilloscope
6. Graph paper

B. Procedure

(CAUTION: Dangerous voltage levels are present during this procedure. Check with your instructor regarding safety procedures.)

1. Connect the multimeter (set for AC) to secondary of the filament transformer.
2. Plug the filament transformer into the line voltage and measure the secondary voltage at points A and B.
3. Turn off the power.
4. Connect the following circuit to the secondary of the filament transformer.



JOB SHEET #1

5. Turn the power on.

6. Measure the voltage between points A and B and record this below as the AC input voltage.

7. Measure and record the DC output voltage with the multimeter.

8. Observe and make a scale drawing below of the AC input voltage (A to B) and the DC output voltage (C to B).

9. Calculate the average DC output voltage and compare it to the measured DC output voltage.

10. Check your calculations and your drawing with your instructor.

DATA:

Measured voltage A to B ______ V_{rms}

Measured voltage B to C ______ V_{rms}

Calculated output voltage ______ V_{dc}

11. Return equipment and materials to their proper storage area.

POWER SUPPLIES
UNIT VII

JOB SHEET #2 — CONSTRUCT AND TEST A FULL-WAVE BRIDGE RECTIFIER CIRCUIT

A. Equipment and materials needed

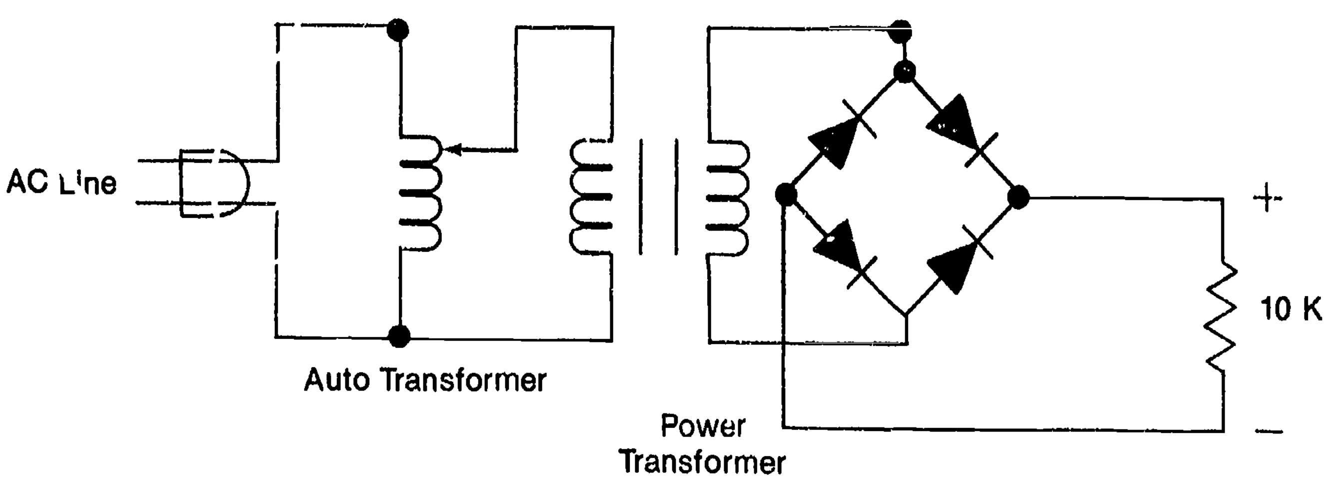
1. Auto transformer (0-130V)
2. Power transformer (110-220V CT)

   (NOTE: You may use a low power filament transformer. See Job Sheet #1.)
3. Four silicon diodes IN4004 or equivalent
4. One 10KΩ, 1W resistor
5. Multimeter
6. Oscilloscope
7. Graph paper

B. Procedure

(CAUTION: Dangerous voltage levels are present during this procedure. Avoid shock hazards.)

1. Construct the circuit shown below but do not connect power at this time.



2. Have your instructor check your circuit.
3. Connect the multimeter across the secondary of the power transformer.

JOB SHEET #2

4. Connect the auto transformer to the AC line and adjust for a reading of 10V on the multimeter.

5. Read and record the DC voltage across the 10KΩ load resistor.

6. Connect an oscilloscope across the filament transformer secondary and observe and sketch the waveform.

7. Connect an oscilloscope across the 10KΩ load resistor and observe and sketch the waveform.

8. Calculate the average DC output voltage and compare with the measured DC output voltage.

9. Check your calculations and your sketch with your instructor.

DATA:

Measured voltage A to B ______ V_{rms}

Measured voltage B to C ______ V_{dc}

Calculated output voltage ______ V_{dc}

10. Return equipment and materials to their proper storage area.

POWER SUPPLIES
UNIT VII

JOB SHEET #3 — CONSTRUCT AND TEST A VOLTAGE DOUBLER CIRCUIT

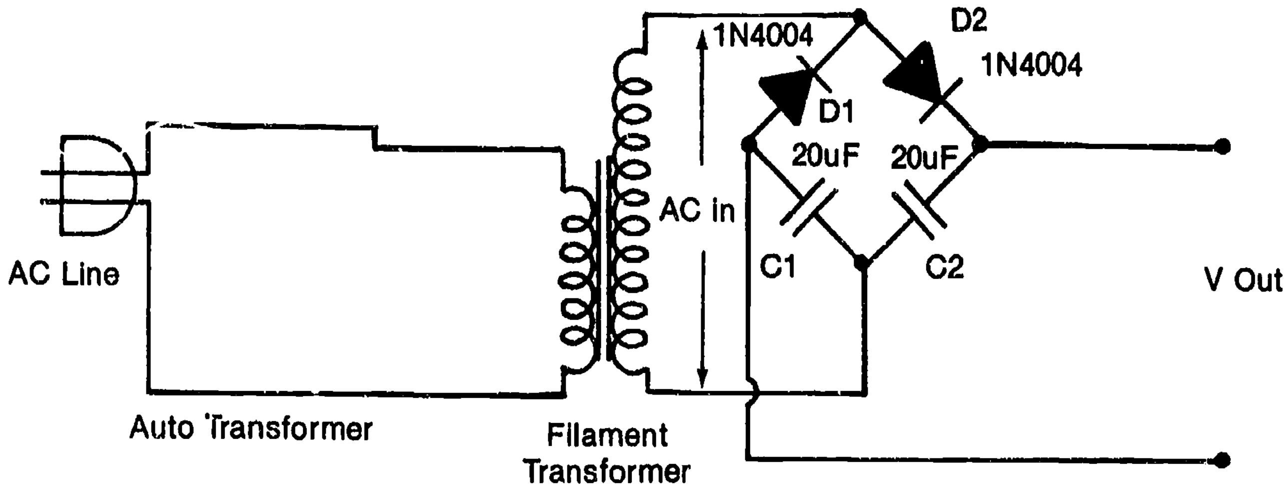
A. Equipment and materials needed

1. Low power filament transformer (120V Primary)
2. 2-silicon diodes, 1N4004 or equivalent
3. Two 20 μF capacitors, 450v
4. Multimeter
5. Oscilloscope

B. Procedure

(CAUTION: Dangerous voltage levels are present during this procedure. Avoid shock hazards.)

1. Connect the following circuit but do not connect the filament transformer to the AC line.



2. Have your instructor check your wiring, then plug in the filament transformer.
3. Measure and record the voltage across C_1, C_2, the output, and the secondary winding of the filament transformer.
4. Using an oscilloscope, observe and measure the input and output voltages of the rectifier circuit and sketch the waveforms.

JOB SHEET #3

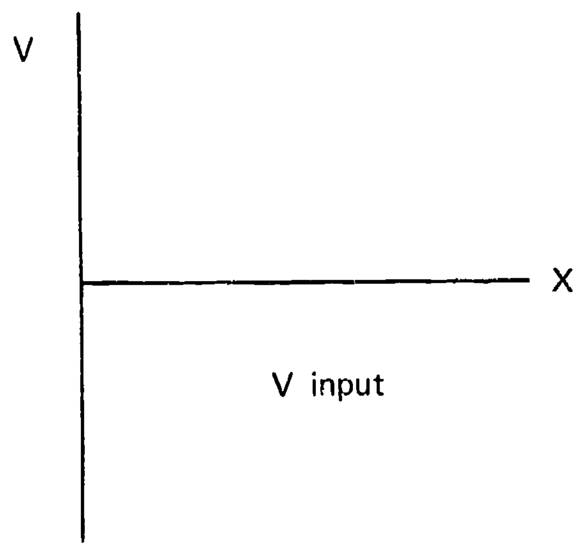
5. Check your findings with your instructor.

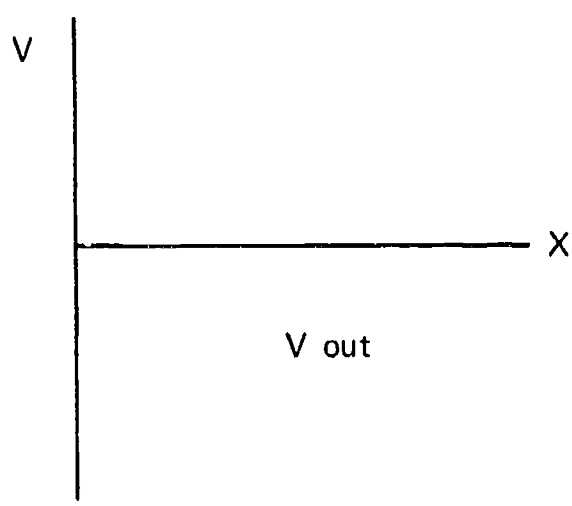
DATA:

V_{c1} = ______

V_{c2} = ______

$V_{secondary}$ = ______





6 Return equipment and materials to their proper storage area.

POWER SUPPLIES
UNIT VII

JOB SHEET #4 — CONSTRUCT AND TEST A CAPACITOR FILTER CIRCUIT

A. Equipment and materials needed

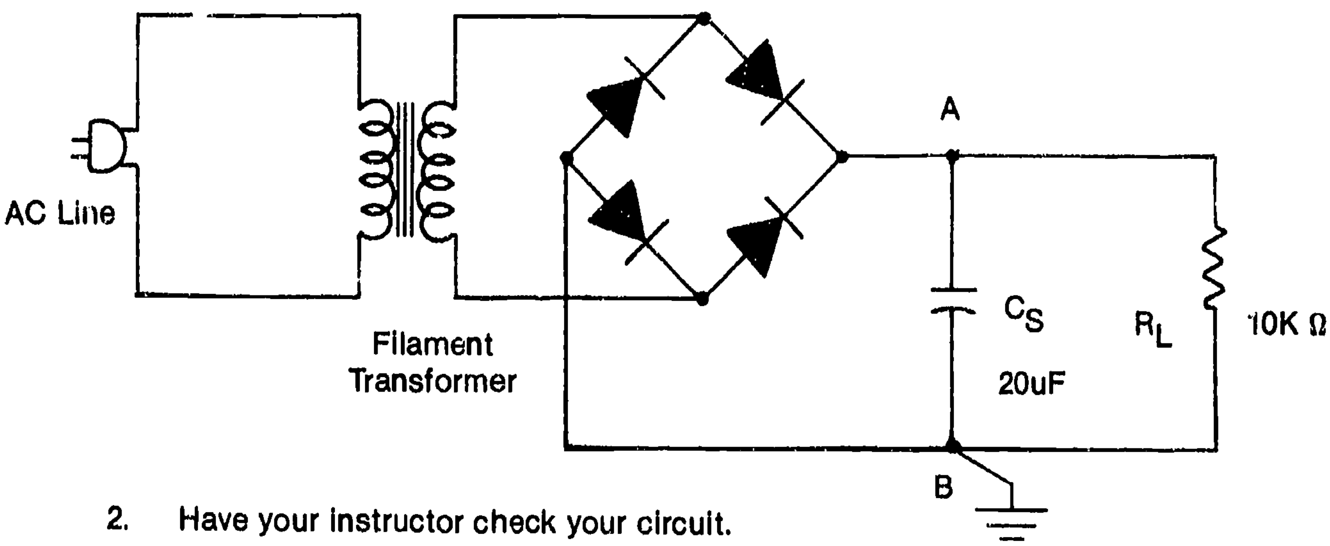
1. Low power filament transformer (120V primary)
2. 4-silicon diodes 1N4004 or equivalent
3. 1-10KΩ, ½ watt resistor, 1-1KΩ, ½ watt resistor, 2-20 μF capacitor, 25 WVDC or greater
4. Multimeter
5. Oscilloscope
6. Graph paper

B. Procedure

(CAUTION: Dangerous voltage levels are present during this procedure. Avoid shock hazards.)

1. Construct the circuit shown below but do not connect power at this time.

   (NOTE: Do not connect the capacitor at point A & B at this time.)



2. Have your instructor check your circuit.
3. Connect the multimeter across the secondary of the filament transformer and record the voltage.
4. Read and record the DC voltage across the load resistor.

JOB SHEET #4

5. Connect an oscilloscope across the load resistor, observe and sketch the wave form.

6. Turn off the power.

7. Connect the 20 μF capacitor at points A and B.

8. Turn the power on.

9. Repeat Steps 4 through 6.

10. Replace the 10KΩ load resistor with the 1KΩ load resistor and repeat Steps 4 through 9.

11. Compare the wave shapes and DC voltage levels of the filter and a 10K load resistor with the filter and a 1KΩ load resistor.

12. Using the output voltage measured with the 10KΩ load resistor as no-load voltage and the output voltage regulation on the table below.

DATA	$V_{sec.}$	$V_{10K\Omega}$	$V_{1K\Omega}$	% Reg
No filter				
With filter				

13. Check your calculations and sketches with your instructor.

14. Return equipment and materials to their proper storage area.

POWER SUPPLIES
UNIT VII

JOB SHEET #5 — CONSTRUCT AND TEST A PI-SECTION FILTER CIRCUIT

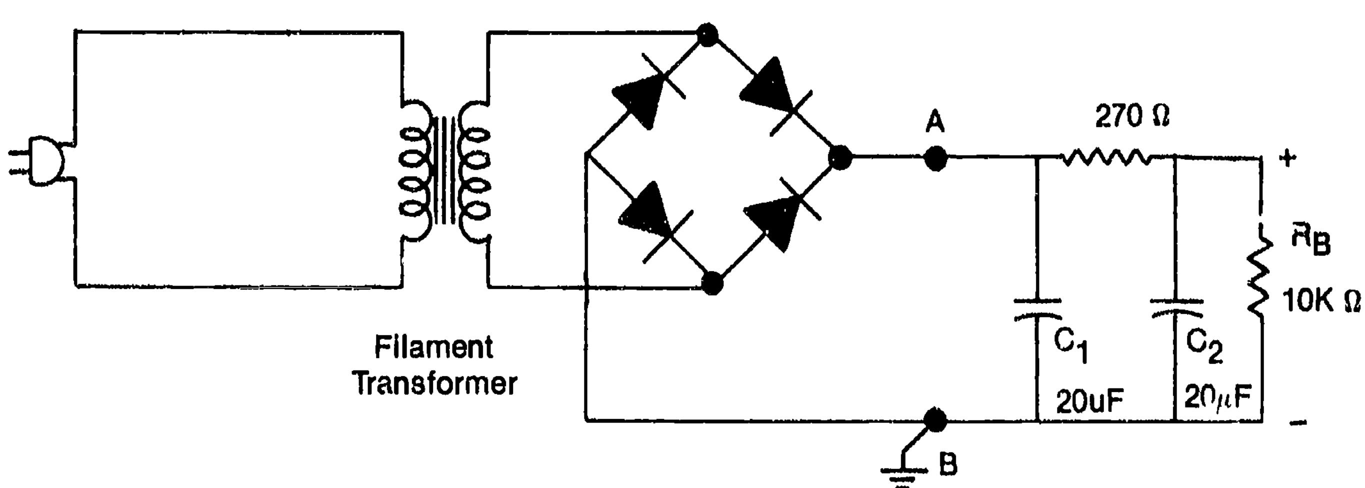
A. Equipment and materials needed

1. Low power filament transformer (120V primary)
2. 4-silicon diodes 1N4004 or equivalent
3. 10K, 1/2 watt resistor
4. 1KΩ, 1/2 watt resistor
5. Two 20 μF capacitors 25WVDC or greater
6. Multimeter
7. Oscilloscope
8. Graph paper
9. 270 ohm resistor

B. Procedure

1. Connect the circuit shown below but do not apply power at this time.

   (NOTE: Do not connect the Pi-section filter network at point A and B at this time.)



2. Have your instructor check your circuit.

JOB SHEET #5

3. Connect the multimeter across the secondary of the filament transformer.

4. Read and record the DC voltage across the load resistor.

5. Connect an oscilloscope across the load resistor, observe, and sketch the wave form.

6. Turn off the power.

7. Connect the Pi-section at points A and B.

8. Turn on the power.

9. Repeat Steps 4 through 6.

10. Replace the 10KΩ load resistor with a 1KΩ load resistor and repeat Steps 4 through 9.

11. Compare the wave shapes and DC voltage levels of the Pi-section filter and the 10K load resistor with the Pi-section filter and the 1KΩ resistor.

12. Using the output voltage measured with the 10KΩ load resistor as no-load voltage and the output voltage measured with the 1KΩ resistor as full-load, compute percent voltage regulation on the table below.

DATA	$V_{10K\Omega}$	$V_{1K\Omega}$	% Reg.
No filter			
With filter			

13. Check your calculations and your sketches with your instructor.

14. Return equipment and materials to their proper storage area.

POWER SUPPLIES
UNIT VII

JOB SHEET #6 — CONSTRUCT AND TEST A ZENER REGULATOR

A. Equipment and materials needed

1. DC power supply (0-10 volts)

2. VOM

3. 5.1 volt zener diode, 1-watt

4. 62 ohm, 1-watt resistor

B. Procedure

1. Measure the resistance from the anode to the cathode of the zener diode.

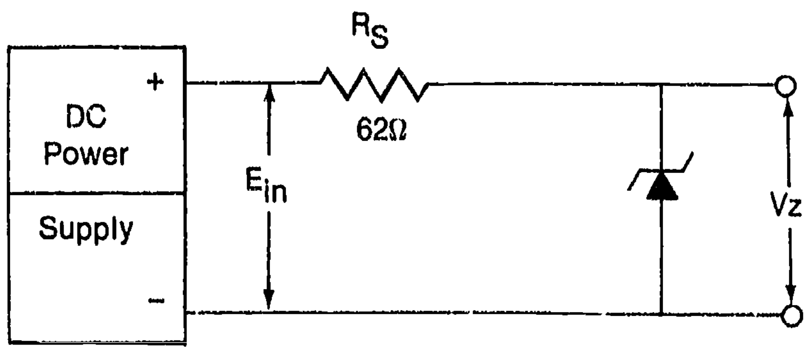
   Anode to cathode R = ____________

2. Reverse the leads of the ohmmeter and read the resistance of the zener diode in the reverse direction.

   Cathode to anode R = ____________

   (NOTE: The front to back resistance should be a large ratio if the zener diode is a good one.)

3. Connect the circuit in the figure below.



4. Set the power supply to 0-volts out.

5. Turn on the power supply.

JOB SHEET #6

6. Set values as listed in the table and record the value of V_z for each E_{in} listed in the chart below.

V_{in}	0	1	2	3	4	5	6	7	8	9
V_z										

At what voltage did regulation begin to occur? ____________

7. Return equipment and materials to their proper storage area.

POWER SUPPLIES
UNIT VII

NAME ____________________

TEST

1. Match the terms on the right with their correct definitions.

_____a. A circuit that converts AC voltages to pulsating DC voltages

_____b. Variations in the DC voltage output of rectifier circuits

_____c. A circuit or device used to minimize or eliminate ripple

_____d. A resistor which is used to draw a fixed current and a safety measure to discharge filter capacitors after the circuit is de-energized

_____e. Comparison of the no-load voltage to the full-load voltage expressed as a percentage of the full-load voltage

1. Ripple
2. Percent regulation
3. Filter
4. Rectifier circuit
5. Bleeder resistor

2. Select true statements related to the uses for transformers in power supplies by placing an "X" in the blanks preceding the true statements.

_____a. The transformer is a device used to either step-up (increase in amplitude) or step-down the AC voltage input to a rectifier circuit.

_____b. When voltage is stepped-up from primary to secondary, the current is stepped-up at the same ratio.

_____c. The phase relationship between primary and secondary voltage is dependent upon the method of construction and the direction of the windings.

_____d. The transformer is used to provide isolation of the equipment and circuit from the power line.

_____e. A transformer may be used to provide multiple voltages to a number of rectifier circuits.

3. Draw the schematic diagram of a half-wave rectifier circuit.

TEST

4. Draw the schematic diagram of a full-wave rectifier circuit.

5. Draw the schematic diagram of a bridge rectifier circuit.

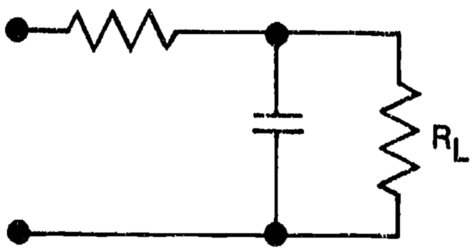
6. Draw the schematic diagram of combination power supplies as indicated below.

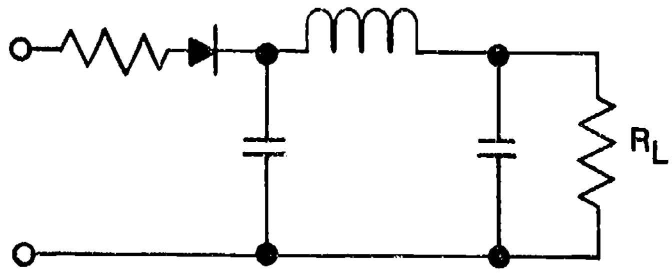
   a. Full-wave/bridge combination power supply.

   b. Full-wave/full-wave combination power supply.

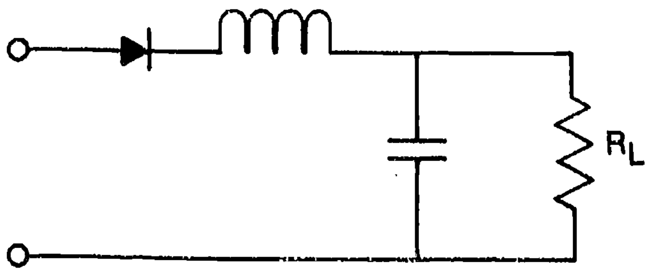
TEST

7. Identify three basic types of filter configurations.





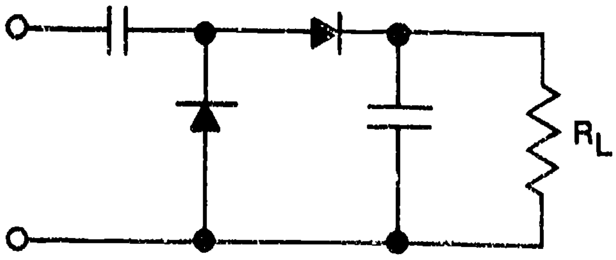
a. ______________________ b. ______________________

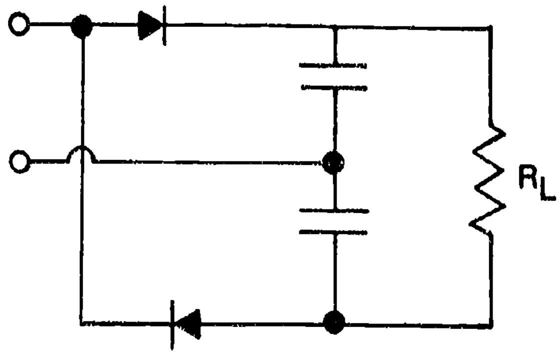


c. ______________________

8. State the equation for calculating ripple factor.

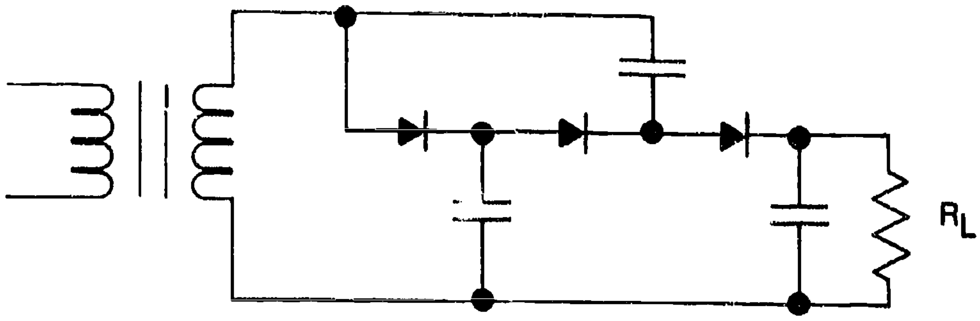
9. Identify three basic voltage multiplier circuits.





a. ______________________ b. ______________________

TEST



c. ______________________________

10. Select true statements concerning the regulation of power supply output by placing an "X" in the blanks preceding the true statements.

_____a. The figure of merit for a power supply is its percent regulation and may be determined by the equation

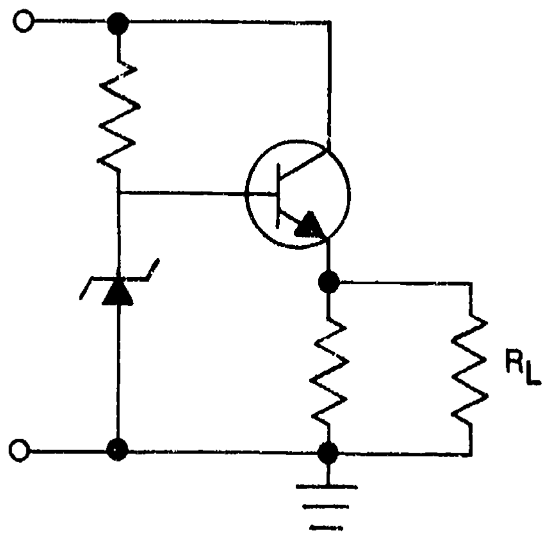
$$\% \text{ Regulation} = \frac{E \text{ no-load} - E \text{ full-load}}{E \text{ full-load}} \times 100$$

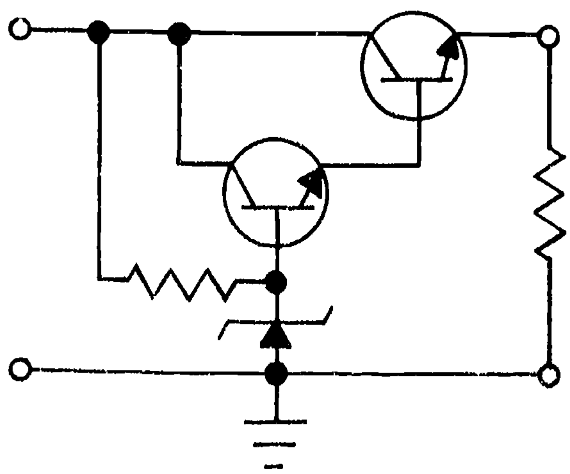
_____b. A series regulator is one in which a control device is placed in series with the load to act as an automatically variable resistor in a voltage divider to maintain a constant voltage to the load.

_____c. A shunt regulator is one in which a control device is placed in parallel with the load to act as an automatically variable resistor to provide voltage division and a constant voltage to the load.

_____d. The bleeder resistor connected to a power supply provides a maximum load for the power supply and increases the no-load voltage improving the supply's regulation.

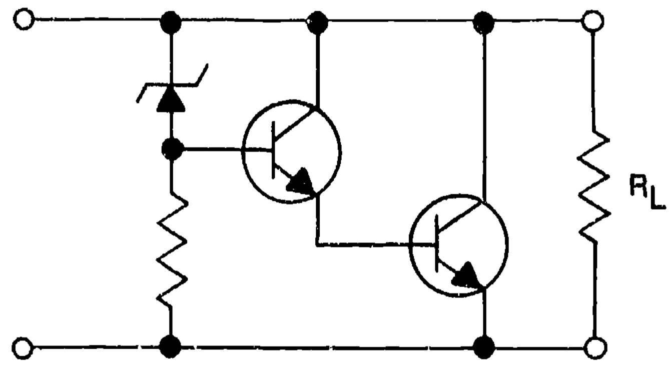
11. Identify the following regulator configurations as series or shunt type.

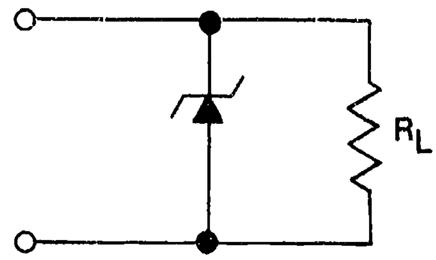




a. ______________________________ b. ______________________________

TEST





c. ______________________ d. ______________________.

12. Draw the block diagram of a feedback regulator.

13. Complete the following statements related to the characteristics of switching regulators by inserting the word(s) that best completes each statement.

    a. Switching regulators are used to improve the efficiency of the regulator circuit by using a ____________ technique.

    b. Switching regulators may be operated in ____________, ____________, or ____________ modes.

14. Draw the schematic diagram of a "crowbar" protection circuit.

TEST

(NOTE: If the following activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

15. Calculate average DC voltage for half-wave and full-wave rectifier circuits. (Assignment Sheet #1)

16. Calculate ripple factors and percent regulation. (Assignment Sheet #2)

17. Demonstrate the ability to:

    a. Construct and test a half-wave rectifier circuit. (Job Sheet #1)

    b. Construct and test a full-wave bridge rectifier circuit (Job Sheet #2)

    c. Construct and test a voltage doubler circuit. (Job Sheet #3)

    d. Construct and test a capacitor filter circuit. (Job Sheet #4)

    e. Construct and test a Pi-section filter circuit. (Job Sheet #5)

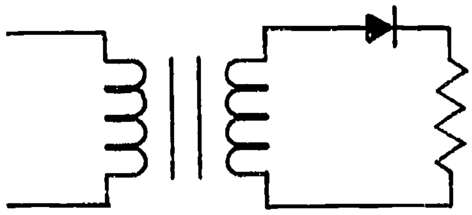
    f. Construct and test a zener regulator. (Job Sheet #6)

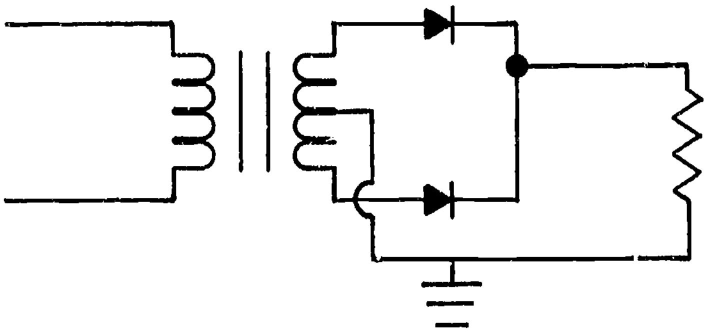
POWER SUPPLIES
UNIT VII

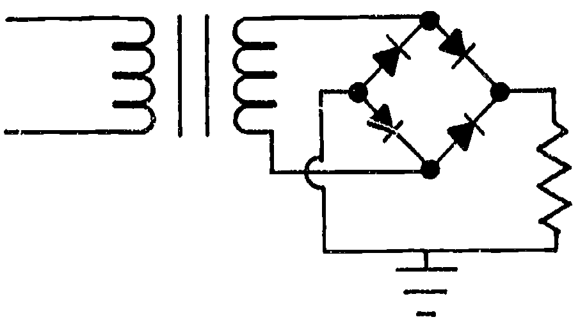
ANSWERS TO TEST

1. a. 4
   b. 1
   c. 3
   d. 5
   e. 2

2. a, c, d, e

3.


4.


5.


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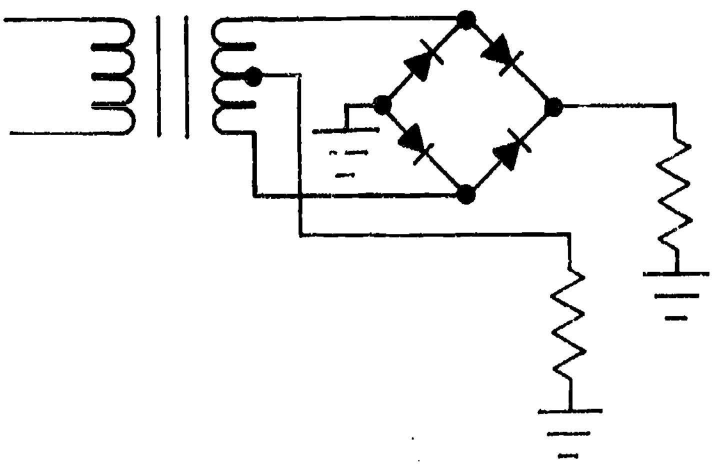
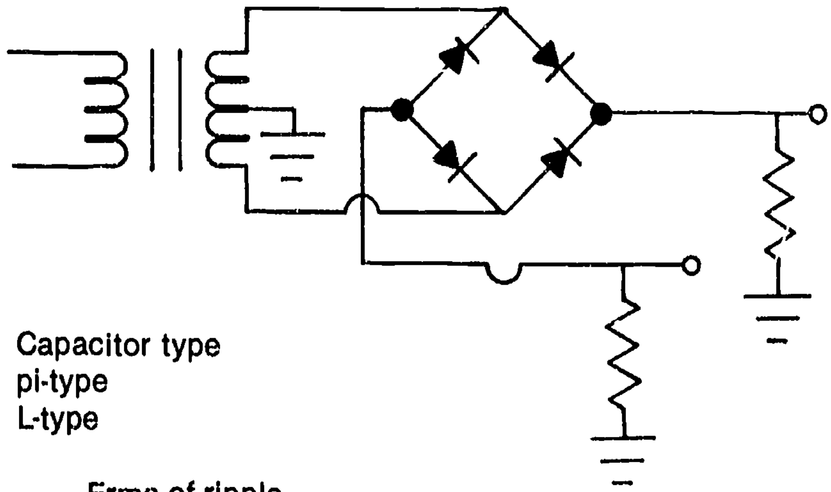


ANSWERS TO TEST

b.



7. a. Capacitor type
   b. pi-type
   c. L-type

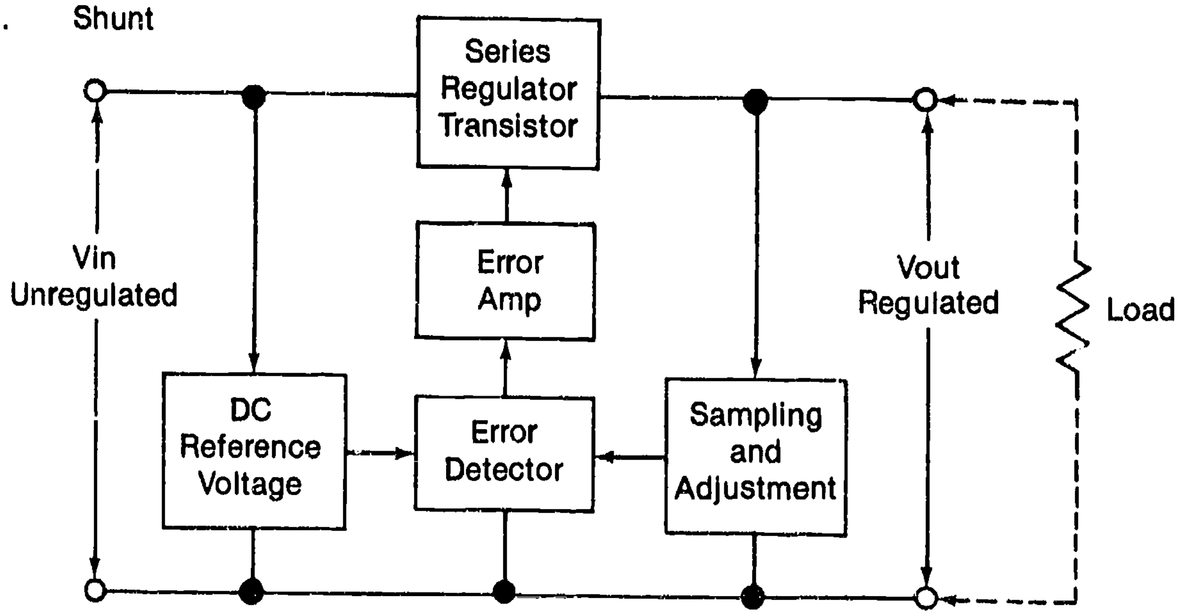
8. $\% \text{ ripple} = \dfrac{\text{Erms of ripple}}{\text{E avg}} \times 100$

9. a. Half-wave doubler
   b. Full-wave doubler
   c. Tripler

10. a, b, c

11. a. Series
    b. Series
    c. Shunt
    d. Shunt

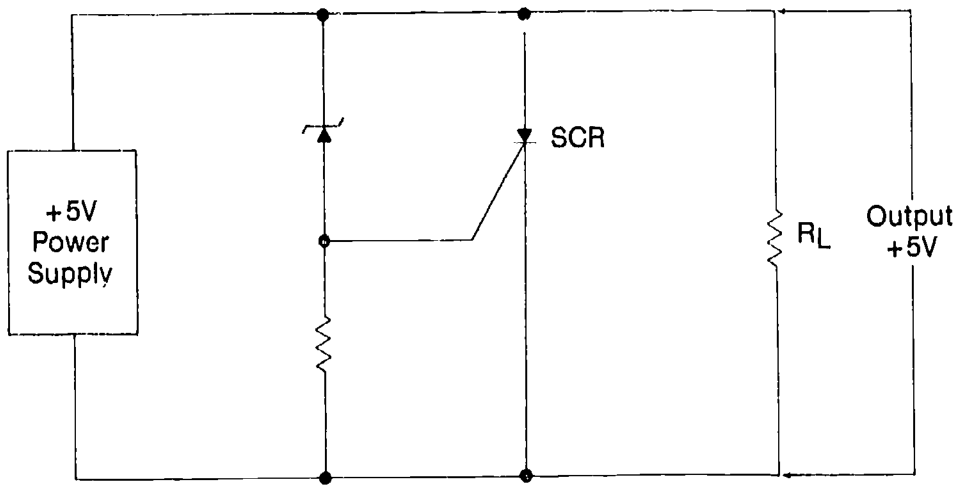
12.



13. a. Pulsing
    b. Step-up, step-down, inverting

ANSWERS TO TEST

14.



15.-16. Evaluated to the satisfaction of the instructor

17. Performance skills evaluated to the satisfaction of the instructor

LOGIC DEVICES
UNIT VIII

UNIT OBJECTIVE

After completion of this unit, the student should be able to apply theoretical knowledge related to logic devices, convert binary numbers, and construct and test various circuits. Competencies will be demonstrated by correctly performing the procedures outlined in the assignment and job sheets and by scoring a minimum of 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to logic devices with their correct definitions.
2. Complete statements concerning the fundamentals of number systems.
3. Select true statements concerning the fundamentals of basic logic gates.
4. Complete statements concerning the types of multivibrator circuits and their characteristics.
5. Explain the difference between synchronous and asynchronous counters.
6. Select true statements concerning characteristics of shift registers.
7. Complete statements related to the types of combinational logic circuits.
8. Match the basic types of digital integratea devices with their characteristics.
9. Complete statements concerning types of displays.
10. Convert binary numbers to decimal and octal numbers. (Assignment Sheet #1)
11. Convert binary numbers to hexadecimal and BCD (8421) numbers. (Assignment Sheet #2)

OBJECTIVE SHEET

12. Demonstrate the ability to:

    a. Construct and test an "AND" gate circuit. (Job Sheet #1)

    b. Construct and test an "OR" gate circuit. (Job Sheet #2)

    c. Construct and test a "NAND" gate circuit. (Job Sheet #3)

    d. Construct and test a "NOR" gate circuit. (Job Sheet #4)

    e. Construct and test an "exclusive-OR" gate circuit. (Job Sheet #5)

    f. Construct and test a four-bit shift register. (Job Sheet #6)

    g. Construct and test a flip-flop circuit. (Job Sheet #7)

    h. Construct and test J-K counter circuits. (Job Sheet #8)

    i. Construct and test an A/D converter. (Job Sheet #9)

    j. Construct and test a D/A converter. (Job Sheet #10)

    k. Construct and test a BCD to seven-segment decoder. (Job Sheet #11)

LOGIC DEVICES
UNIT VIII

SUGGESTED ACTIVITIES

A. Obtain additional materials and/or invite resource people to class to supplement/reinforce information provided in this unit of instruction.

(NOTE: This activity should be completed prior to the teaching of this unit.)

B. Make transparencies from the transparency masters included with this unit.

C. Provide students with objective sheet.

D. Discuss unit and specific objectives.

E. Provide students with information and assignment sheets.

F. Discuss information and assignment sheets.

(NOTE: Use the transparencies to enhance the information as needed.)

G. Provide students with job sheets.

H. Discuss and demonstrate the procedures outlined in the job sheets.

I. Integrate the following activities throughout the teaching of this unit:

1. Show films related to logic control systems or computer systems.
2. Give examples of logic control systems used by your local industries.
3. Demonstrate the role of logic devices in a simple control system.
4. Discuss the role that logic devices play in a computer system while tracing signal flow on the schematic of a small computer system.
5. Tour local facilities that manufacture or use logic devices.
6. Meet individually with students to evaluate their progress through this unit of instruction, and indicate to them possible areas for improvement.

J. Give test.

K. Evaluate test.

L. Reteach if necessary.

INSTRUCTIONAL MATERIALS INCLUDED IN THIS UNIT

A. Objective sheet

B. Suggested activities

C. Information sheet

D. Transparency masters

1. TM 1 — Binary to Decimal Conversions
2. TM 2 — Inverter (NOT Gate)
3. TM 3 — AND Gate Symbol and Truth Table
4. TM 4 — NAND Gate Symbol and Truth Table
5. TM 5 — OR Gate Symbol and Truth Table
6. TM 6 — NOR Gate Symbol and Truth Table
7. TM 7 — Exclusive OR Gate Symbol and Truth Table
8. TM 8 — Not Exclusive OR Gate Symbol and Truth Table
9. TM 9 — Multivibrators
10. TM 10 — R-S Flip-Flop
11. TM 11 — J-K Flip-Flop
12. TM 12 — Binary Counter
13. TM 13 — Decade Counter
14. TM 14 — Basic Decoder
15. TM 15 — BCD to Decimal Decoder
16. TM 16 — BCD to Seven-Segment Decoder
17. TM 17 — Basic Encoders
18. TM 18 — Basic Multiplexes
19. TM 19 — Demultiplexes
20. TM 20 — D/A Converter
21. TM 21 — A/D Converter
22. TM 22 — Digital Displays

INSTRUCTIONAL MATERIALS INCLUDED IN THIS UNIT

E. Assignment sheets

1. Assignment Sheet #1 — Convert Binary Numbers to Decimal and Octal Numbers
2. Assignment Sheet #2 — Convert Binary Numbers to Hexadecimal and BCD(8421) Numbers

F. Answers to assignment sheets

G. Job sheets

1. Job Sheet #1 — Construct and Test an "AND" Gate Circuit
2. Job Sheet #2 — Construct and Test an "OR" Gate Circuit
3. Job Sheet #3 — Construct and Test a "NAND" Gate Circuit
4. Job Sheet #4 — Construct and Test a "NOR" Gate Circuit
5. Job Sheet #5 — Construct and Test an "Exclusive-OR" Gate Circuit
6. Job Sheet #6 — Construct and Test a Four-Bit Shift Register
7. Job Sheet #7 — Construct and Test a Flip-Flop Circuit
8. Job Sheet #8 — Construct and Test J-K Counter Circuits
9. Job Sheet #9 — Construct and Test an A/D Converter
10. Job Sheet #10 — Construct and Test a D/A Converter
11. Job Sheet #11 — Construct and Test a BCD to Seven-Segment Decoder

H. Test

I. Answers to test

REFERENCES USED IN DEVELOPING THIS UNIT

(NOTE: The following is a list of references used in completing this unit.)

A. Cave and Terrell. *Digital Technology with Microprocessors*. Reston, VA: Reston Publishing Co., Inc., 1981.

B. Floyd, Thomas L. Digital Fundamentals, Second Edition. Columbus, OH: Charles E. Merrill Co., 1982.

C. Malvino, Albert P. *Digital Computer Electronics*, Second Edition. New York: McGraw-Hill Book Co., 1983.

D. Rutkowski, George B. and Olesky, Jerome E. *Fundamentals of Digital Electronics*. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1985.

LOGIC DEVICES
UNIT VIII

INFORMATION SHEET

I. **Terms and definitions**

A. Binary coded decimal (8421) — A digital code where a four bit binary character is used to represent each single digit decimal character

B. Binary number system — Number system which has digits zero (0) and one (1) only

C. Bit — A single binary digit, 0 or 1

D. Clear (CLR) — To reset, as in the case of a flip-flop, counter, or register

E. Combinational logic — A combination of gate circuits used to combine or generate specified functions

F. Digital circuit — A circuit that acts like a switch, either on or off

G. EPROM — Erasable programable read-only memory

H. Flip-flop — A bistable multivibrator circuit

I. Logic high — High voltage (usually five volts or more) representing binary 1

J. Logic low — Low voltage (usually 0 or near 0) representing binary 0

K. Preset (PR) — To initialize a digital circuit to a predetermined state

L. RAM — Random access memory

M. Ripple counter — A digital counter in which each flip-flop is clocked with the output of the previous stage

N. ROM — Read only memory

O. Sequential logic — A broad category of digital circuits whose logic gates are dependent on a specified time sequence

P. Shift register — A digital circuit that is capable of storing and shifting data

Q. Truth table — Summarizes the various combinations of input and corresponding output signals for logic gates

R. Word — A group of bits representing a complete piece of digital information

INFORMATION SHEET

II. Fundamentals of number systems

A. The base of a number system (radix) specifies the number of symbols available in that system.

Example: The base 10 (decimal) system uses ten symbols: 0 through 9. The base 2 (binary) system using 2 symbols: 0 and 1. Base 8 (octal) system uses eight symbols: 0 through 7.

B. In any number system, digits to the left and right of the decimal point have specified positional values or weights and are expressed as powers of the base.

Examples: Base 10: 10^{+3}, 10^{+2}, 10^{+1}, 10^{0}. 10^{-1}, 10^{-2}, 10^{-3}

Decimal Point

Base 2: 2^{+3}, 2^{+2}, 2^{+1}, 2^{0}. 2^{-1}, 2^{-2}, 2^{-3}

(NOTE: The positional values are restricted to only a few in the examples but may be expanded to an infinite number of positions.)

C. Numbers expressed in the octal system can be converted to the decimal system by multiplying the positional values by the corresponding octal digits, and then adding the results.

Example: Convert 417 base 8 to base 10

$$417_8 = 4(8^2) + 1(8^1) + 7(8^0)$$

$$= 4(64) + 1(8) + 7(1)$$

$$= 256 + 8 + 7$$

$$= 271_{10}$$

D. A number expressed in the decimal system can be converted to the octal system by successive divisions by eight.

Example: Convert 486 base ten to base 8

$486_{10}/8 = 60$ remainder 6

$60/8 = 7$ remainder 4
$7/8 = 0$ remainder 7

Therefore $486_{10} = 746_8$

INFORMATION SHEET

E. Decimal numbers may be converted to binary by successive division by two with the remainder of each division retained as a bit of the binary number, with the first remainder as the least significant bit.

Example: Convert 19 base 10 to binary

$19_{10}/2 = 9$ remainder 1

$9/2 = 4$ remainder 1

$4/2 = 2$ remainder 0

$2/2 = 1$ remainder 0

$0/2 = 0$ remainder 1

Therefore $19_{10} = 10011_2$

F. Binary numbers may be converted to base ten by adding the positional values. (Transparency #1)

Example: Convert 110 base two to base ten

$110_2 = 1(2) + 1( ) + 0(2)$

$= 1(4) + 1(2) + 0(1)$

$= 4 + 2 + 0$

$110_2 = 6_{10}$

G. The double-dabble method may be used to convert binary numbers to decimal numbers following a few special rules.

1. Beginning with the one (1) at the most left position write a one (1) over that digit
2. Move to the next digit.
   a. If the digit is a zero, double the number you wrote above the preceding digit and write it above the zero.
   b. If the digit is a one (1), double the number you wrote above the preceding digit and add one. Place this number above the one (1).
3. Continue this procedure through all digits in the binary number. The number you write above the last digit is the decimal equivalent.

Example: Convert 10001 base two to base ten

```
          1 2 4 8 17
10001 =   1 0 0 0 1
```

Therefore $1000101_2 = 17_{10}$

INFORMATION SHEET

H. Octal to binary and binary to octal conversions may be easily made by substituting groups of three binary bits for each octal digit.

Example: Convert 702 octal to base two

$7_8 = 111$

$0 = 000$

$2 = 010$

Therefore $702_8 = 111000010_2$

Example:

Convert 1101000011 base two to octal

001 101 000 011
 1   5   0   3

Therefore $1101000011_2 = 1503_8$

Conversion Chart

Octal	Binary
0	000
1	001
2	010
3	011
4	100
5	101
6	110
7	111

I. A binary number may be converted to the hexademical system simply by breaking the binary number into four-bit groups starting at the right and replacing each four-bit group by the hexadecimal equivalent.

Example: Convert 1100101001010111 binary to hexadecimal.

Break into 4-bit groups	1100	1010	0101	0111
	↓	↓	↓	↓
Write the hexadecimal equivalent	C	A	5	7

(NOTE: The decimal, binary, hexademical equivalent chart helps illustrate the conversion.)

Decimal	Binary	Hexademical
0	0000	0
1	0001	1
2	0010	2
3	0011	3
4	0100	4
5	0101	5
6	0110	6
7	0111	7
8	1000	8
9	1001	9
10	1010	A
11	1011	B
12	1100	C
13	1101	D
14	1110	E
15	1111	F

INFORMATION SHEET

J. To convert from a hexadecimal number to a binary number, replace each hexademical symbol with the appropriate four-bit binary group

Example: Convert CF83 hexademical to a binary number

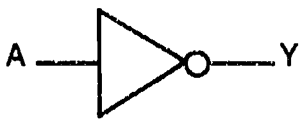
Octal	C	F	8	3_{16}
	↑	↑	↑	↑
Binary	1100	1111	1000	0011_2

III. Fundamentals of basic logic gates

A. The simplest form of logic element is the inverter (NOT gate). (Transparency #2)

1. The output of the inverter is the inverse, or complement of the input.

2. The circle on the symbol designates the inversion or complementary nature of the circuit.



$\bar{A}=Y$

A	Y
0	1
1	0

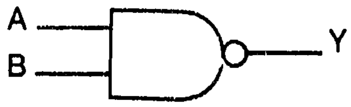
B. The AND gate is a logic circuit that has two or more inputs with a single output that is a logic high only if all inputs are a logic high. (Transparency #3)

$AB=Y$

A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

INFORMATION SHEET

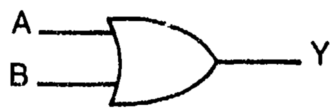
C. The NAND gate is an AND gate with the output inverted. (Transparency #4)



$\overline{AB} = Y$

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

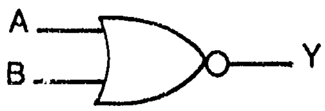
D. The OR gate is a logic circuit that has two or more inputs with a single output that is at a logic high if one or more inputs is a logic high. (Transparency #5)



$A + B = Y$

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

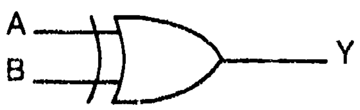
E. The NOR gate is an OR gate with the output inverted. (Transparency #6)



$\overline{A + B} = Y$

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

F. The XOR gate (exclusive-OR) is a logic circuit that provides a logic high output when any, but not all, inputs are logic high. (Transparency #7)



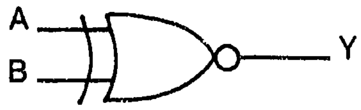
$\overline{A}B + A\overline{B} = Y$

$A \oplus B = Y$

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

INFORMATION SHEET

G. The XNOR gate (NOT exclusive-OR) is an exclusive OR gate with the output inverted. (Transparency #8)



$\overline{A \oplus B} = Y$

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

IV. Types and characteristics of multivibrator (flip-flop) circuits

A. There are three forms of multivibrator circuits: the bistable, monostable, and astable. (Transparency #9)

1. Bistable (flip-flop) multivibrators are used for counters, shift registers, and storage circuits.

2. Monostable (one-shot) multivibrators are used for delay circuits, waveshaping, and timing circuits.

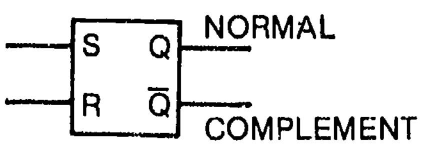
3. Astable (clock) multivibrators are used as timing oscillators or square wave generators.

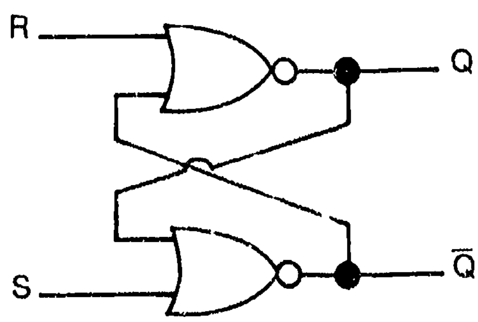
B. Flip-flop (or multivibrators) are widely used building blocks in sequential logic and digital memory circuits.

C. The simplest form of flip-flop circuit is the set-reset type flip-flop. (Transparency #10)

1. The set-reset flip-flop has two inputs, the Set (S) and the reset (R).

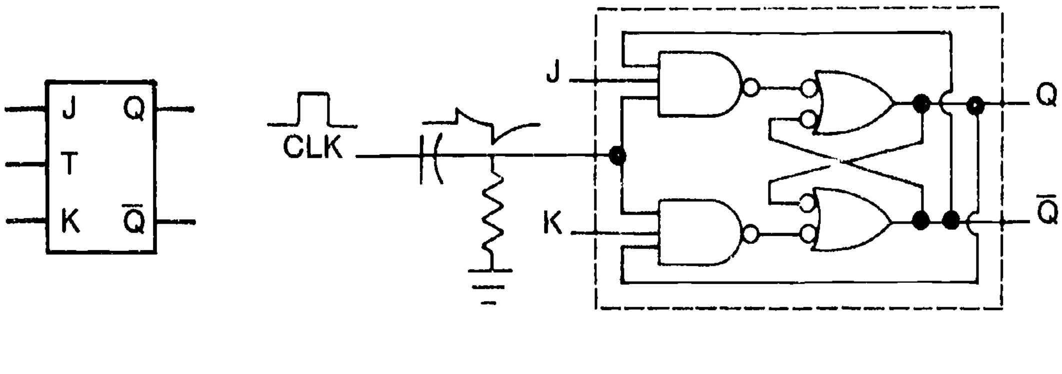
2. The set-reset flip-flop has two outputs called the normal (Q) and th complement (Q).





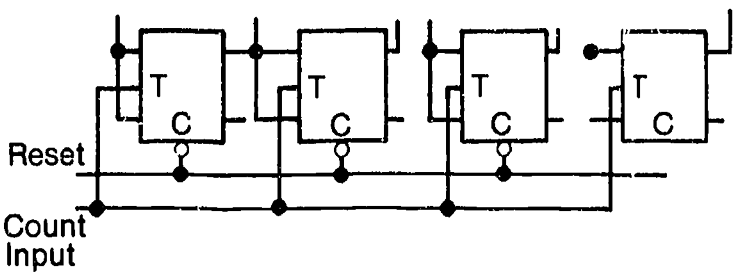
INFORMATION SHEET

D. The J-K type flip-flop (also called complementing or toggle flip-flop) changes state only when a clock pulse (or toggle) is present and provides one output pulse for each two input pulses. (Transparency #11)

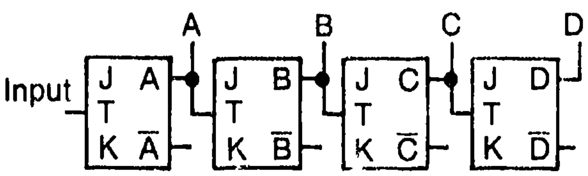


V. **Types of counters**

A. Synchronous counters are digital circuits in which all elements are synchronized to a master timing clock.



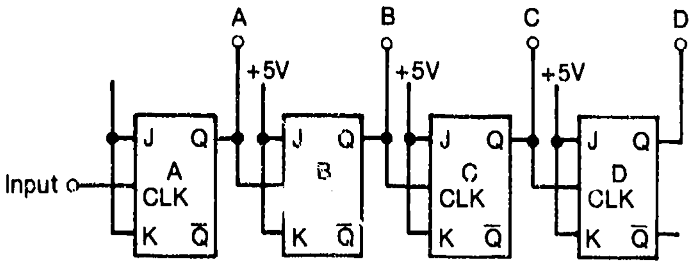
B. Asynchronous counters (ripple counters) consist of cascaded flip-flops with the output of one driving the input of the next with no common controlling clock pulse.

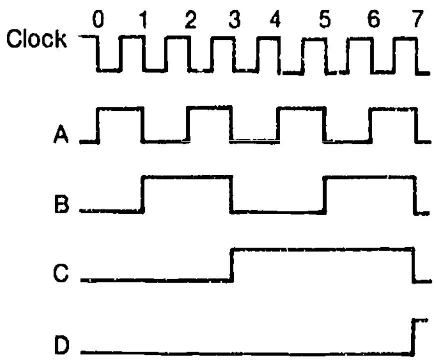


INFORMATION SHEET

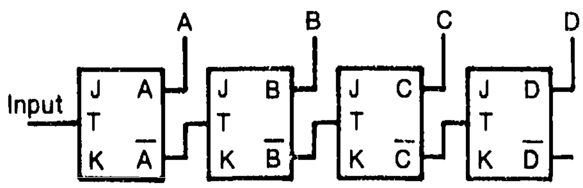
C. J-K flip-flops may be cascaded to operate as a binary counter. (Transparency #12)

(NOTE: The output of each flip-flop is one half the frequency of its input.)

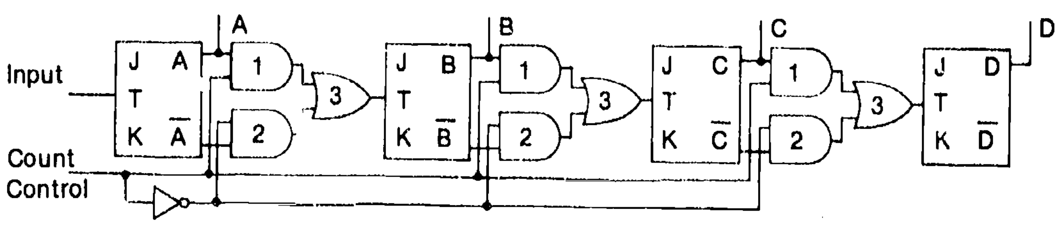




D. Counters may be constructed to decrement (down counter) rather than increment (up counter) with each input pulse.



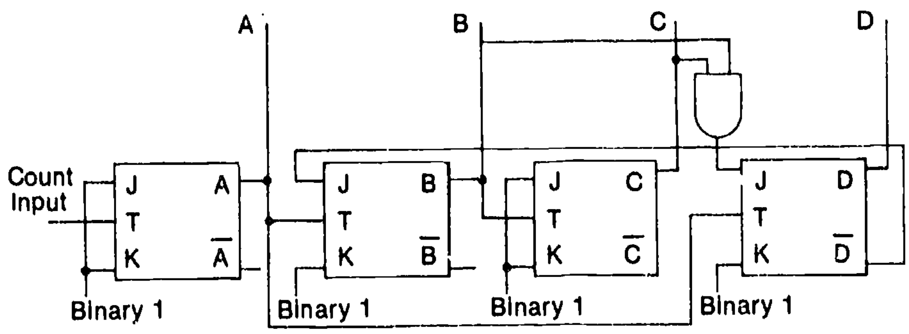
E. Up and down counting functions may be combined into a single counter by the addition of a count control input that select which counting function will be performed.



Count Control Binary 1 - Up
Binary 0 - Down

INFORMATION SHEET

F. The BCD counter has ten discrete states which represent the decimal numbers zero through nine. (Transparency #13)

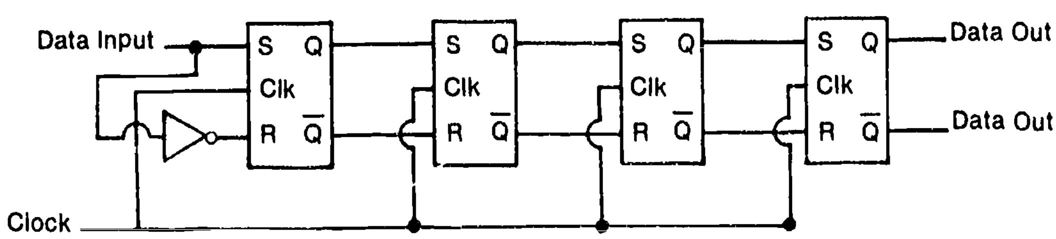


D	C	B	A
0	0	0	0
0	0	0	1
0	0	1	0
0	0	1	1
0	1	0	0
0	1	0	1
0	1	1	0
0	1	1	1
1	0	0	0
1	0	0	1

Recycle

VI. Characteristic of shift registers

A. Flip-flops may be connected in a sequential logic circuit configuration called a shift register to transfer serial data from one element to an adjacent element. (shift data to right or left)



B. Shift registers may be used to perform arithmetic operations, parallel to serial and serial to parallel data conversion, and perform counting and frequency dividing functions.

VII. Types of combinational logic circuits

A. Decoders are logic circuits which detect or identify the presence of a specific binary number or word. (Transparency #14)

B. The BCD to decimal decoder has a parallel four bit binary input (representing a decimal number 0 to 9) which is decoded and indicated at a specific output representing the BCD number. (Transparency #15)

C. The BCD to seven segment decoder accepts standard 8421 BCD input code and generates a special 7-bit output code used to operate a seven segment decimal output display. (Transparency #16)

D. An encoder is a combinational logic circuit that accepts one or more inputs and produces a multi-bit output code. (Transparency #17)

Example: A keyboard decimal input is translated and a binary or BCD output is generated as input to a computer.

INFORMATION SHEET

E. Multiplexers are electronic circuits that are used to select and route any one of a number of inputs to a single output. (Transparency #18)

F. A demultiplexer is a logic circuit which has a single input which may be routed to any one of multiple outputs. (Transparency #19)

G. Digital to analog (D/A) converters are used to convert digital values to equivalent analog voltages. (Transparency #20)

H. Analog to digital (A/D) converters are used to convert analog voltages to digital values. (Transparency #21)

VIII. Types of digital integrated devices and their characteristics

A. Transistor-transistor-logic devices (TTL)

1. Bipolar IC
2. Low cost
3. Wide variety of available circuits

B. Emitter-coupled-logic devices (ECL)

1. Non-saturating bipolar transistor elements
2. High speed
3. Higher cost
4. Consume more power than other types

C. Metal-oxide semiconductor devices (MOS)

1. Simple construction
2. Small in size
3. High impedance
4. Low power consumption
5. Lower speed

D. Complementary-metal-oxide-semiconductor devices (CMOS)

1. Ideal, balanced characteristics
2. Low power consumption

INFORMATION SHE

3. Excellent noise immunity

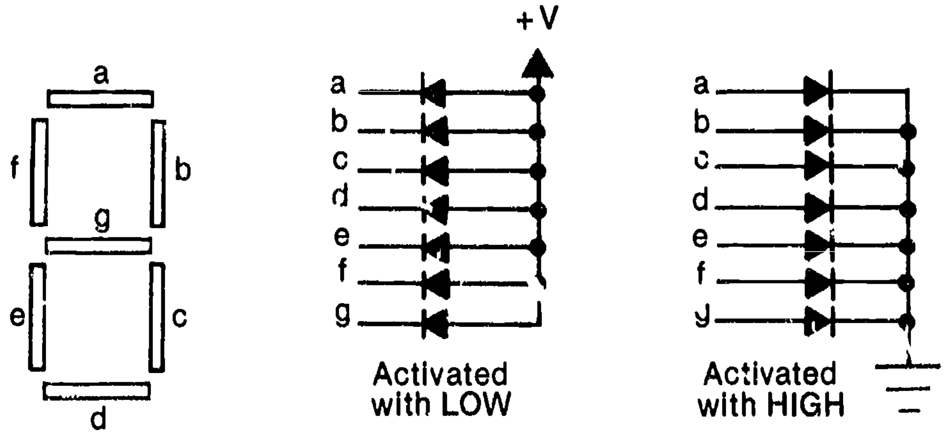
4. Moderately high speed

IX. **Types of displays** (Transparency #22)

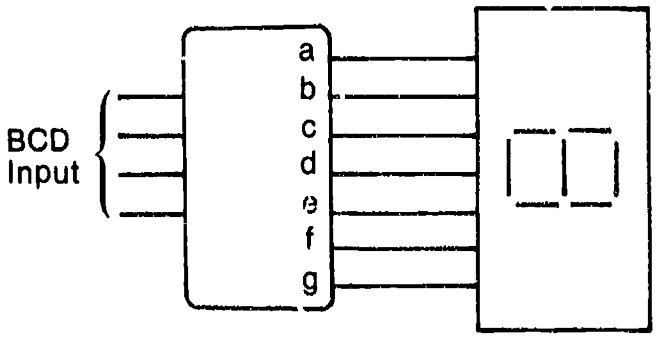
A. LED's and LCD's are the most common elements used in displays.

(NOTE: Two common display types are the common anode and common cathode.)

B. LED's and LCD's are commonly arranged to form seven-segment displays



C. Seven-segment displays are typically coupled to a decoder (such as a BCD to seven-segment) to display digital information



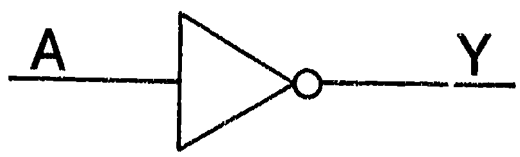
Binary to Decimal Conversions

A. $1011_2 = \underset{(8)}{\overset{2^3}{1}}\ \underset{(4)}{\overset{2^2}{0}}\ \underset{(2)}{\overset{2^1}{1}}\ \underset{(1)}{\overset{2^0}{1}} = (1x8)+(0x4)+(1x2)+(1x1) + 8+0+2+1 = 11_{(10)}$

B. $111_2 = \underset{(4)}{\overset{2^2}{1}}\ \underset{(2)}{\overset{2^1}{1}}\ \underset{(1)}{\overset{2^0}{1}} = (1x4)+(1x2)+(1x1) = 4+2+1 = 7_{(10)}$

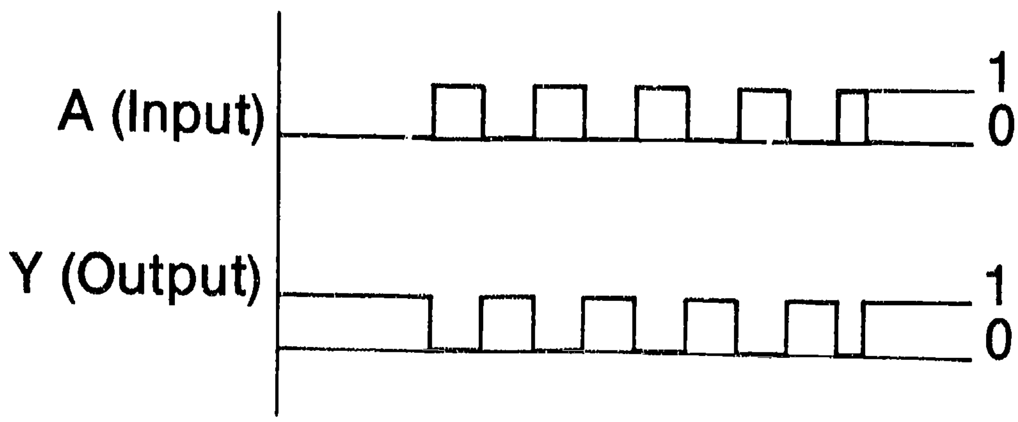
C. $11011_2 = \overset{2^4}{1}\ \overset{2^3}{1}\ \overset{2^2}{0}\ \overset{2^1}{1}\ \overset{2^0}{1} = (1x16)+(1x8)+(0x4)+(1x2)+(1x1) = 16+8+0+2+1 = 27_{10}$

Inverter
(NOT Gate)



$\overline{A} = Y$

Symbol

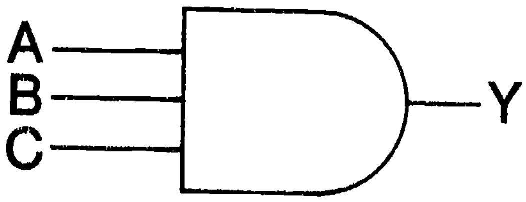


A	Y
0	1
1	0

Truth Table

0 = Logic Low   1 = Logic High

AND Gatc Symbol and Truth Table



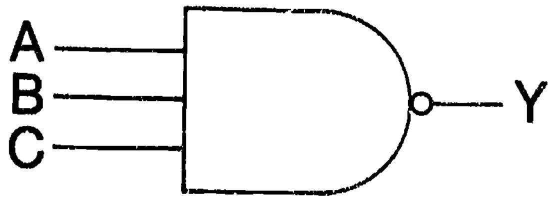
ABC = Y

Symbol

A	B	C	Y
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

Truth Table

NAND Gate Symbol and Truth Table



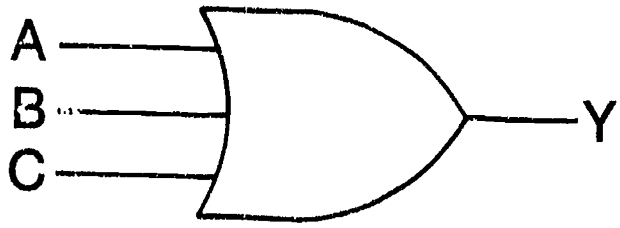
$\overline{ABC} = Y$

Symbol

A	B	C	Y
0	0	0	1
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	0

Truth Table

OR Gate Symbol and Truth Table



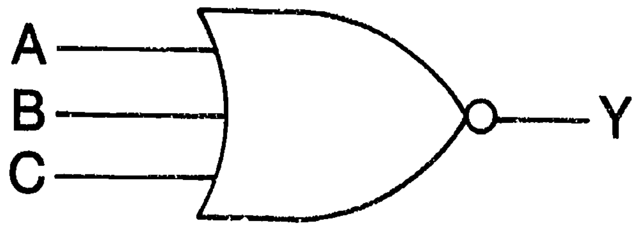
A+B+C=Y

Symbol

A	B	C	Y
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	1

Truth Table

NOR Gate Symbol and Truth Table



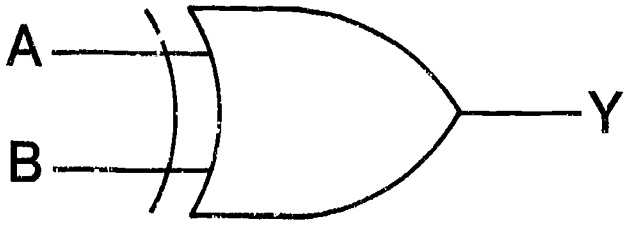
$$\overline{A+B+C}=Y$$

Symbol

A	B	C	Y
0	0	0	1
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	0

Truth Table

Exclusive OR Gate Symbol and Truth Table



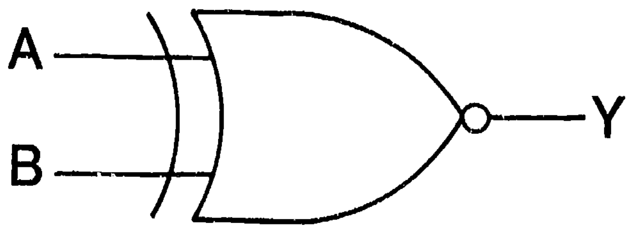
$A \oplus B = Y$

Symbol

A	B	$A \oplus B$
0	0	0
0	1	1
1	0	1
1	1	0

Truth Table

Not Exclusive OR Gate Symbol and Truth Table



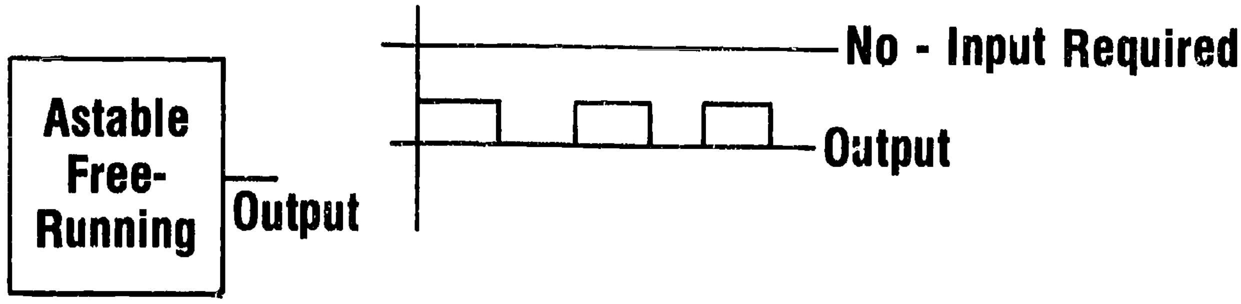
$\overline{A \oplus B} = Y$

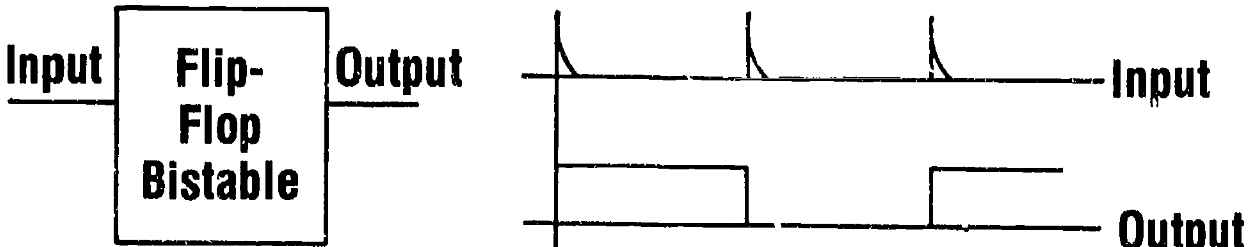
Symbol

A	B	$\overline{A \oplus B}$
0	0	1
0	1	0
1	0	0
1	1	1

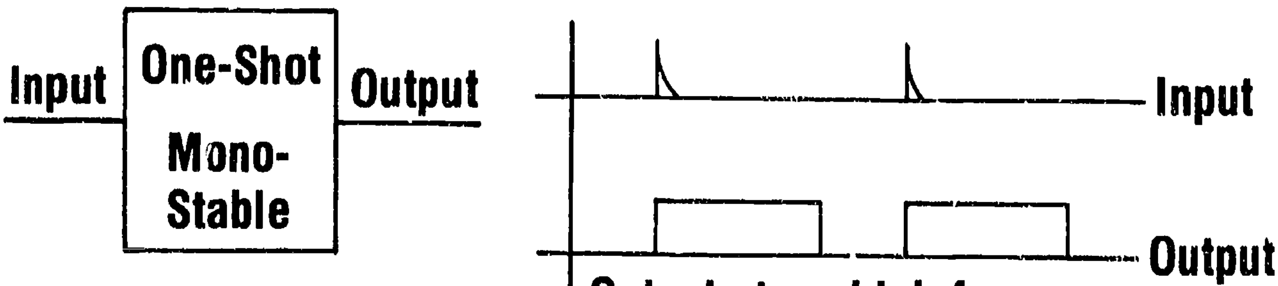
Truth Table

Multivibrators





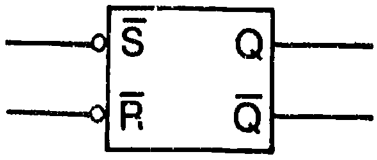
Output changes with each input pulse



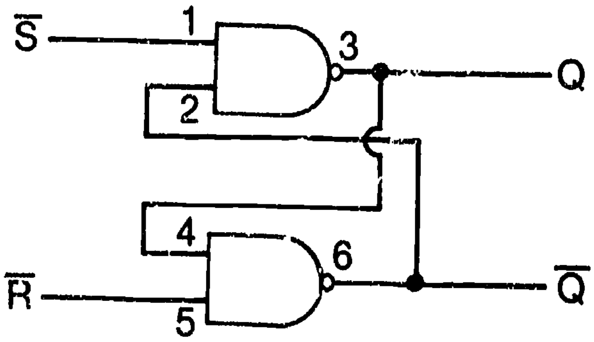
Output stays high for a period of time then goes back to its normally low state

Multivibrators may be made from either discrete devices or integrated circuits

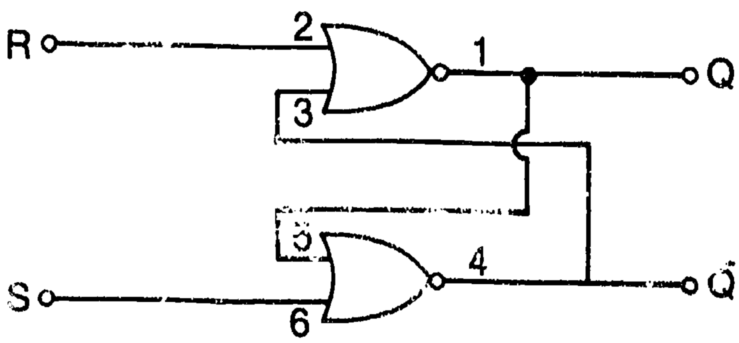
R-S Flip-Flop



Symbol

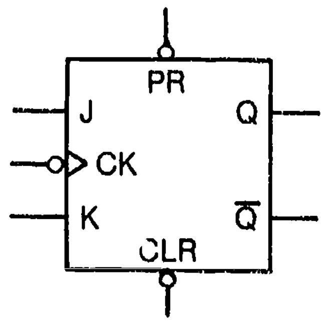


R-S Flip-Flop (NAND Gate Type)

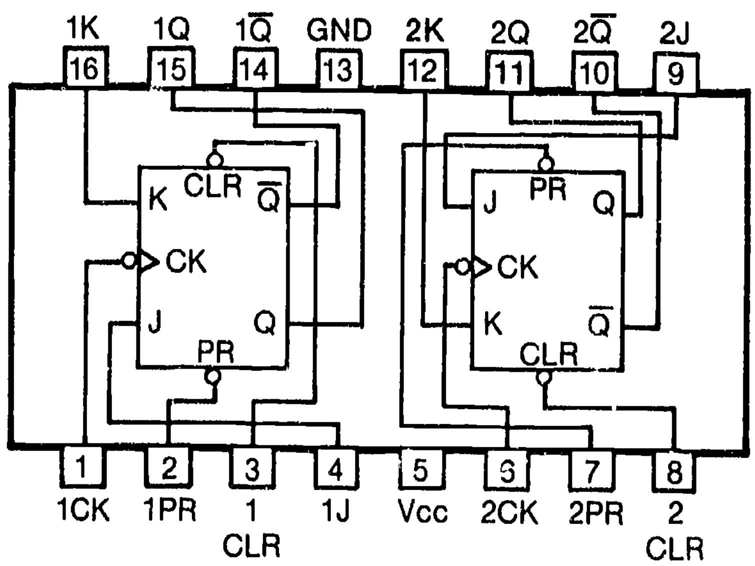


R-S Flip-Flop (NOR Gate Type)

J-K Flip-Flop



Symbol

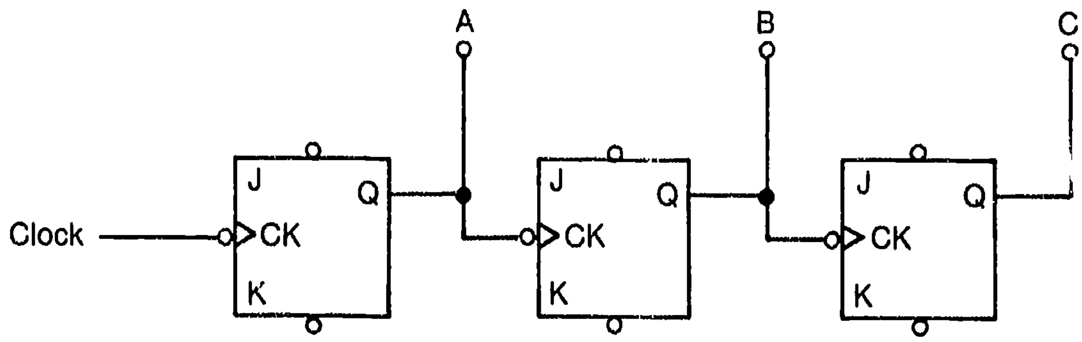


Pinout for 7476
dual J-K Flip-Flop

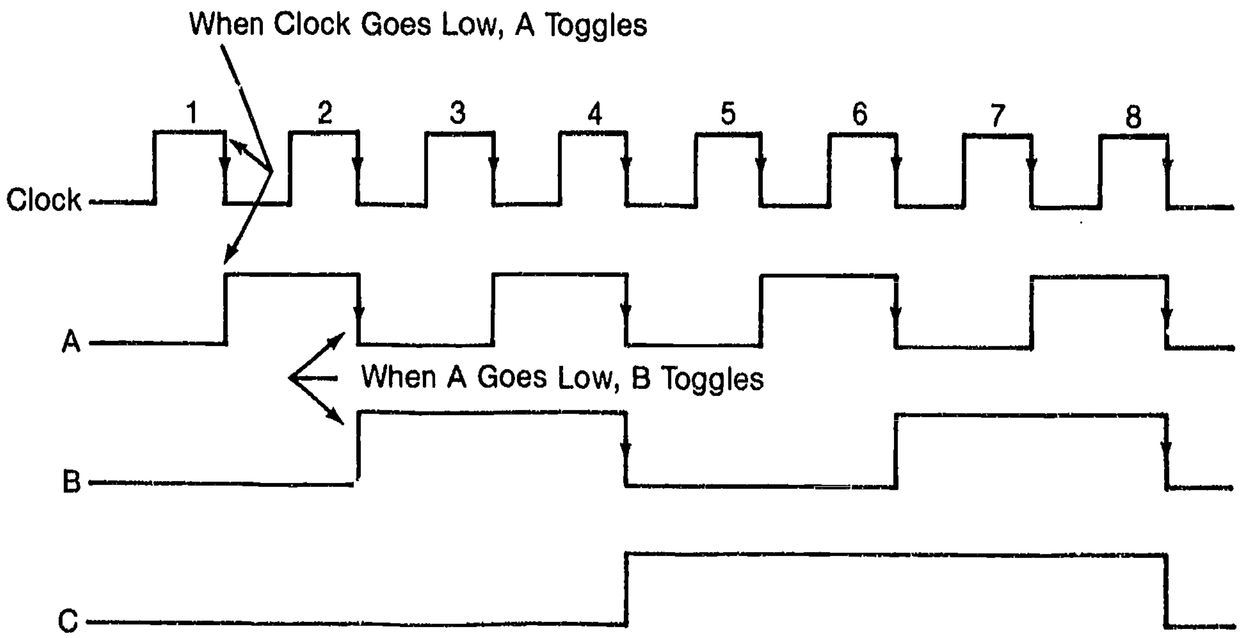
J	K	Mode	
0	0	Inhibit	Q output will not change when clocked
0	1	Reset	Q output will go low when clocked
1	0	Set	Q output will go high when clocked
1	1	Toggle	Q output will change to opposite state when clocked

Operation

Binary Counter

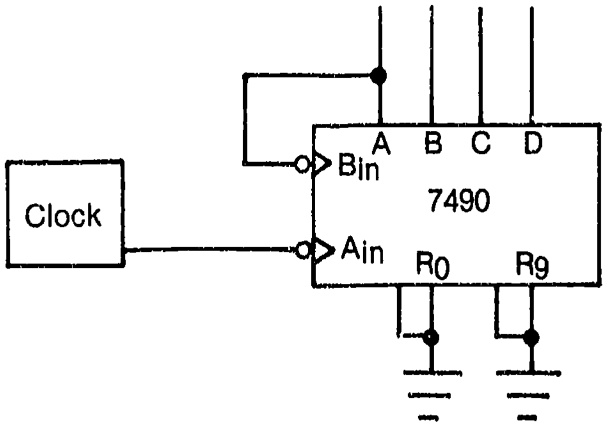


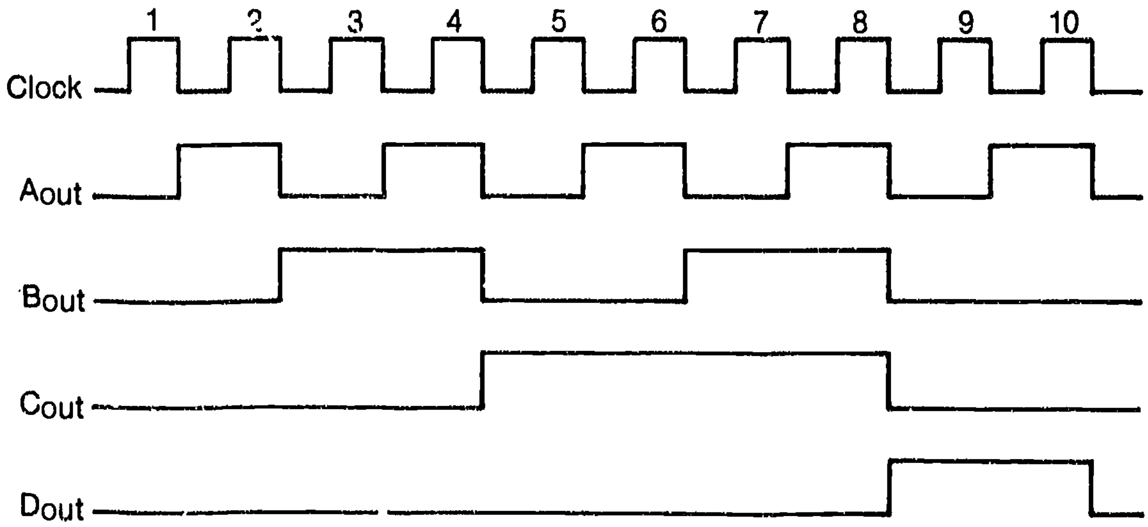
3 - Bit Binary Counter
Block Diagram



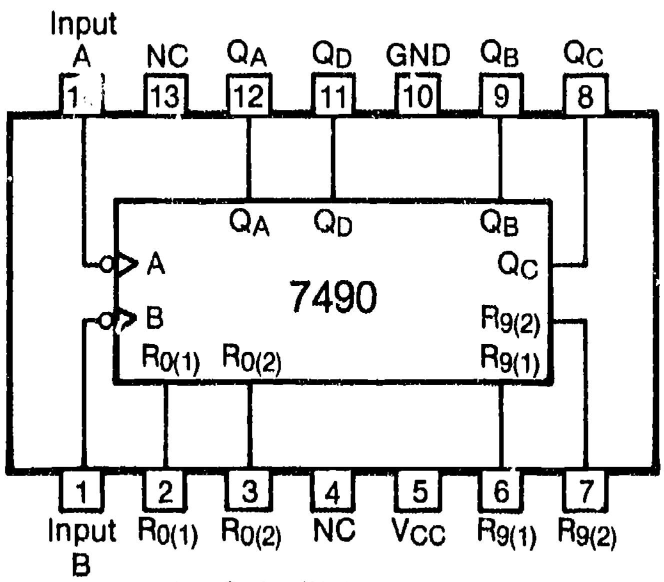
Output Waveforms

Decade Counter



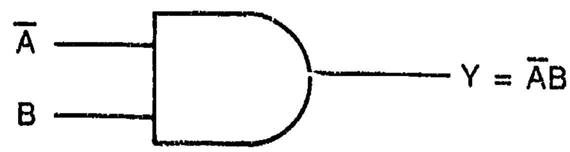


Waveforms

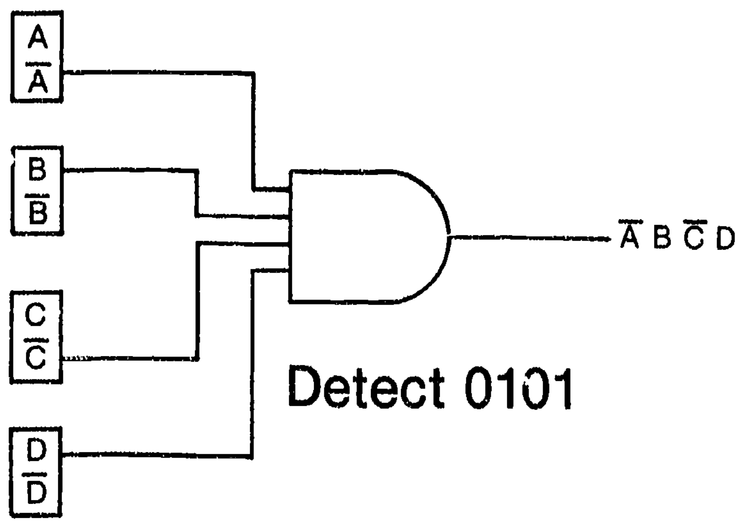


7490 Pinouts

Basic Decoder

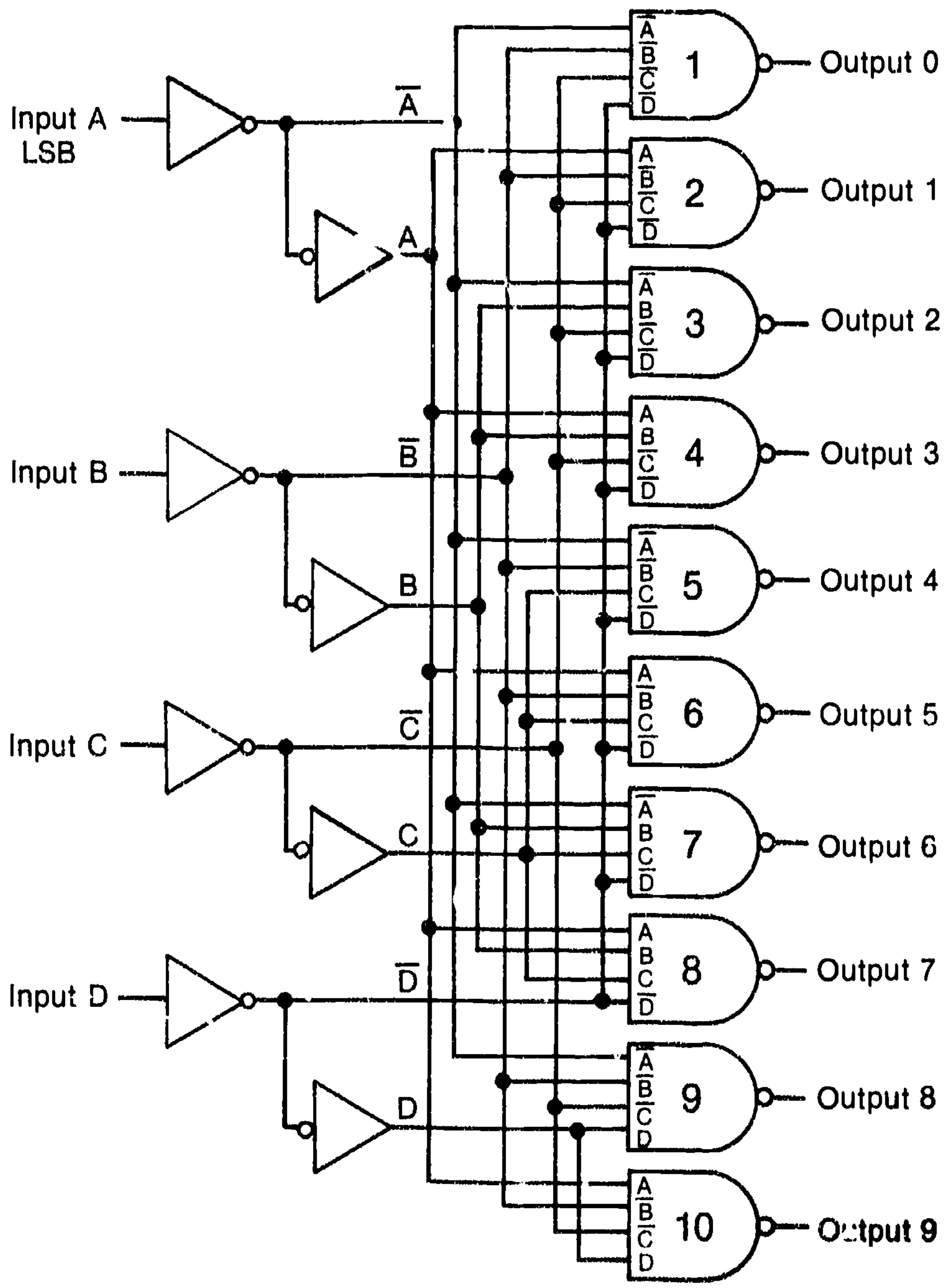


2 - Input AND Gate Decoder
(Detects Number 01)

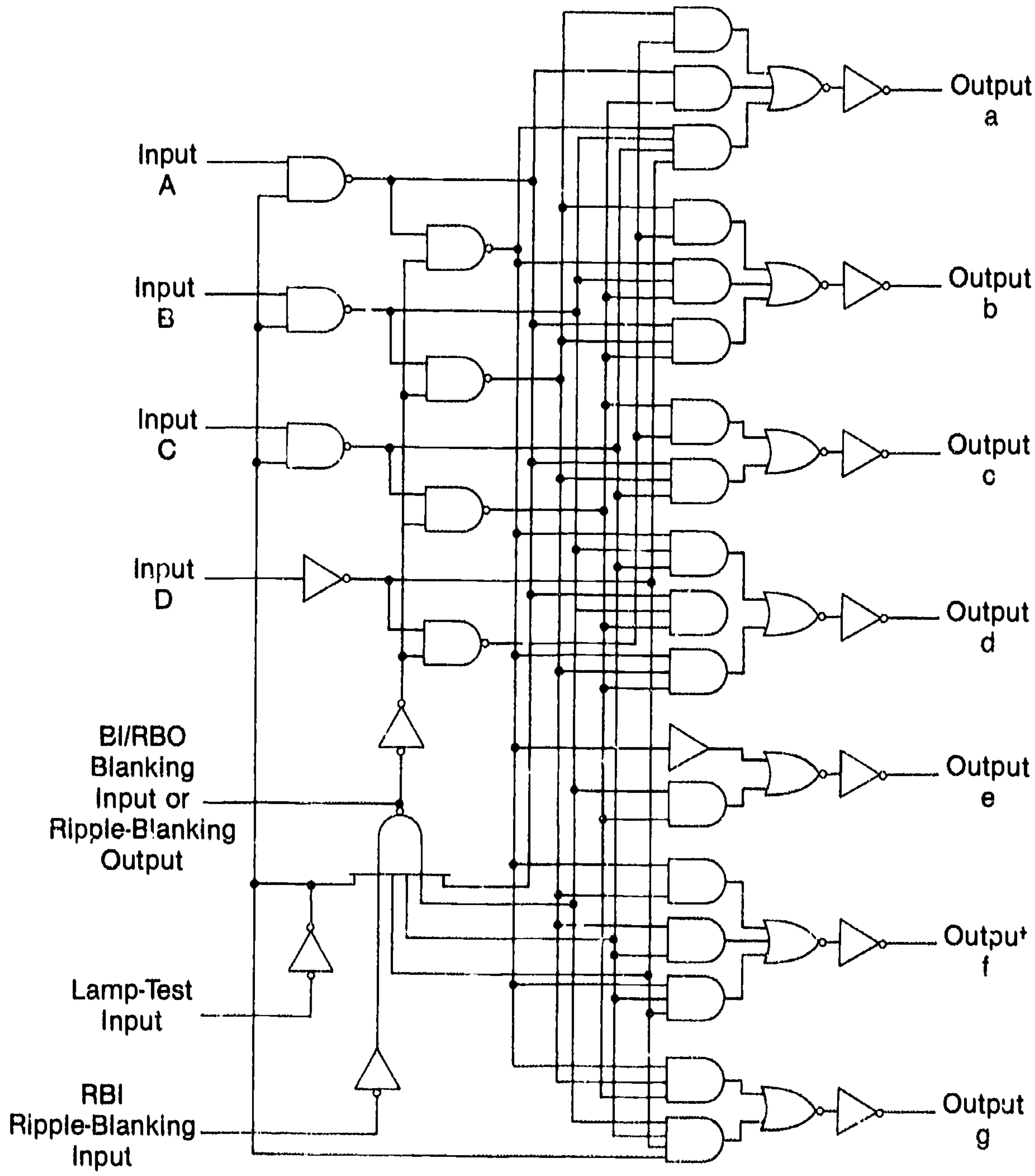


4 - Input AND Decoder

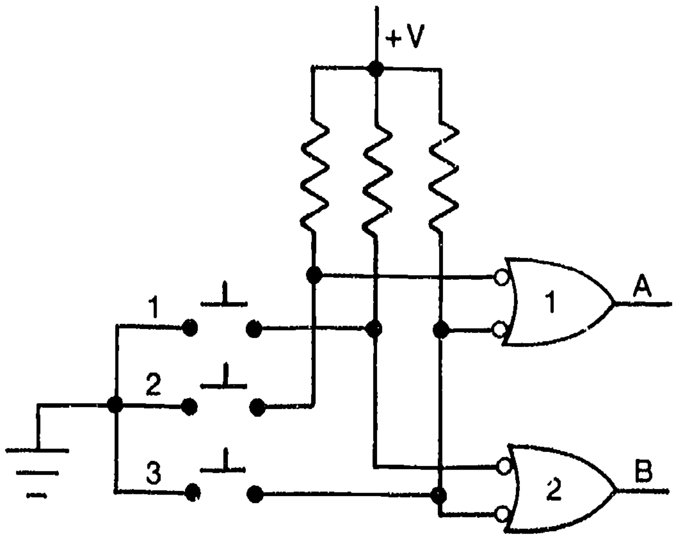
BCD to Decimal Decoder



BCD to Seven-Segment Decoder

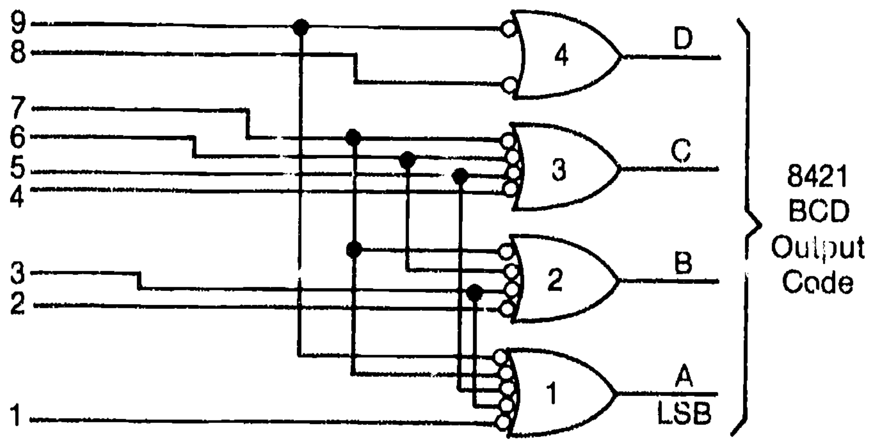


Basic Encoders



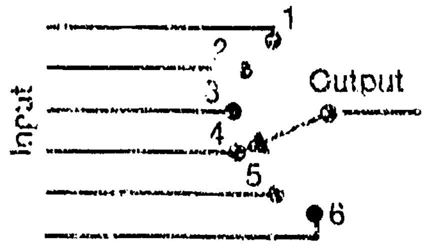
Input	Output	
	A	B
1	0	1
2	1	0
3	1	1

Simple Encoder Circuit

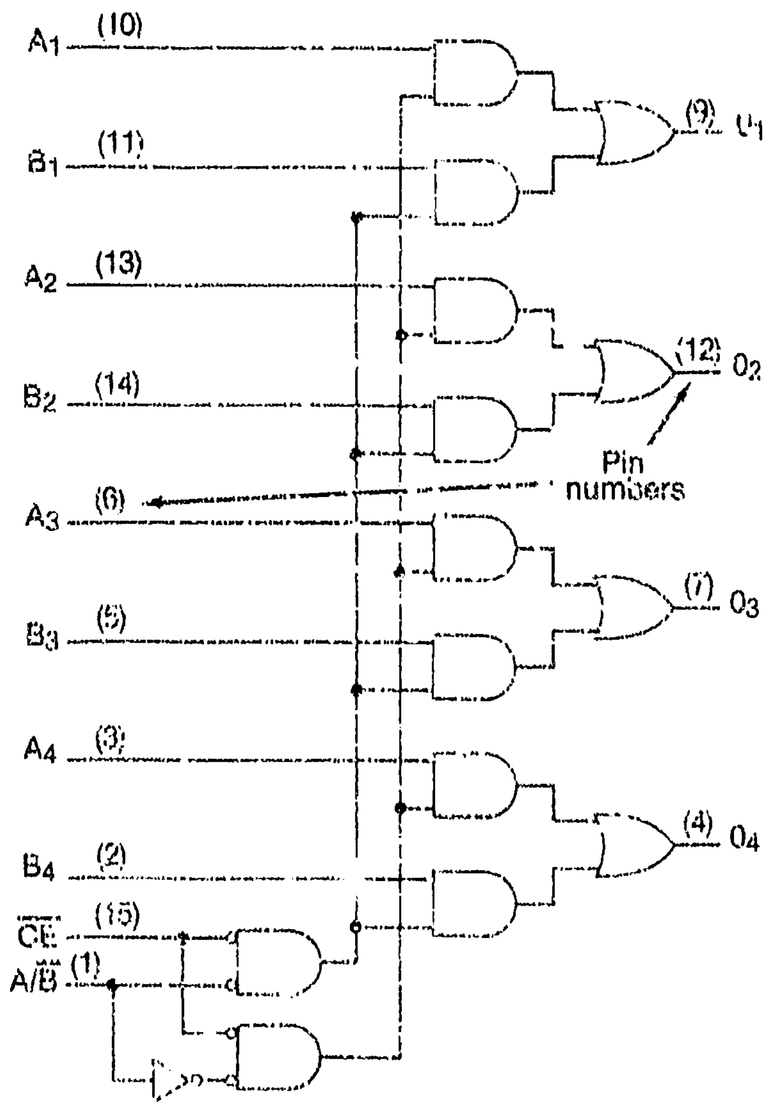


Decimal to BCD Encoder

Basic Multiplexers

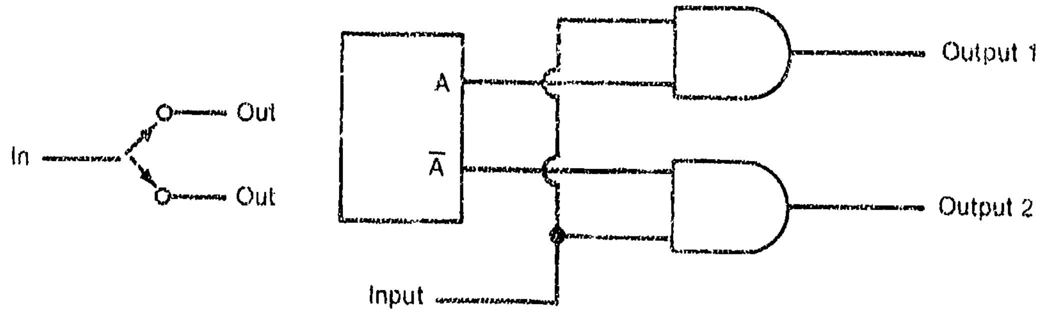


Switch used as a Multiplexer

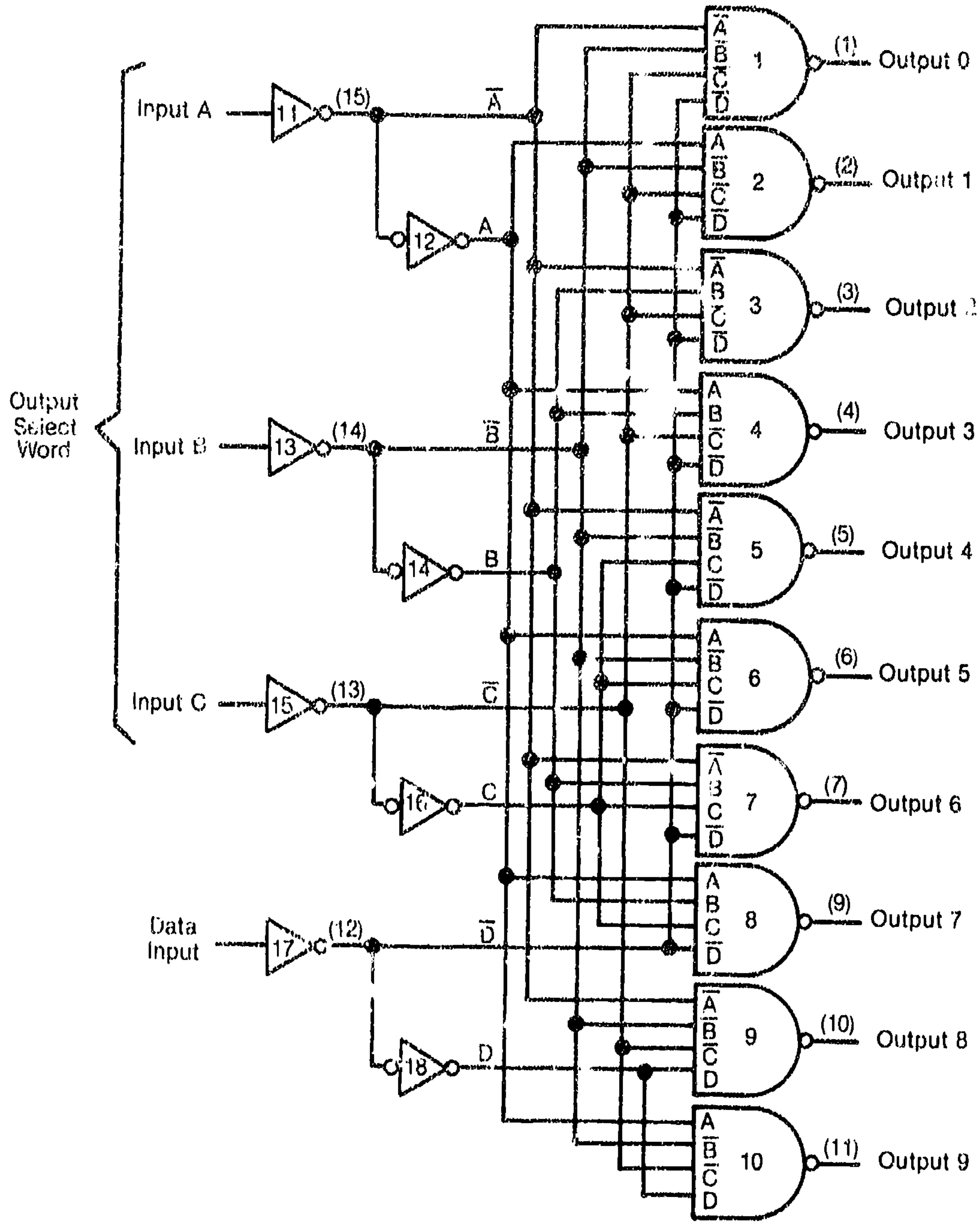


74157 Multiplexer Circuit

Demultiplexers

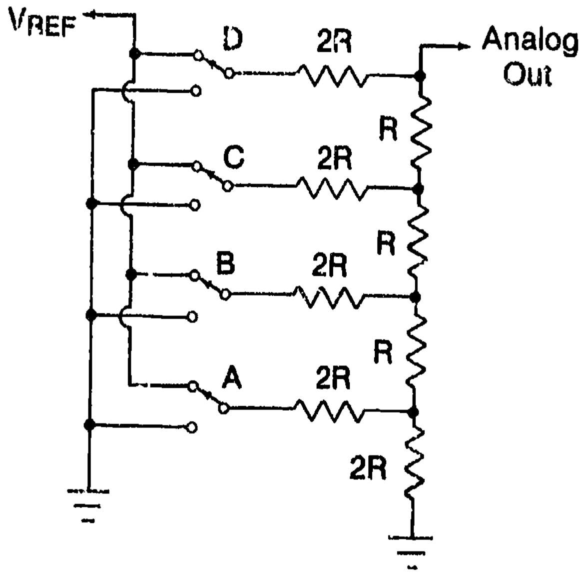


Basic Two - Output Demultiplexer

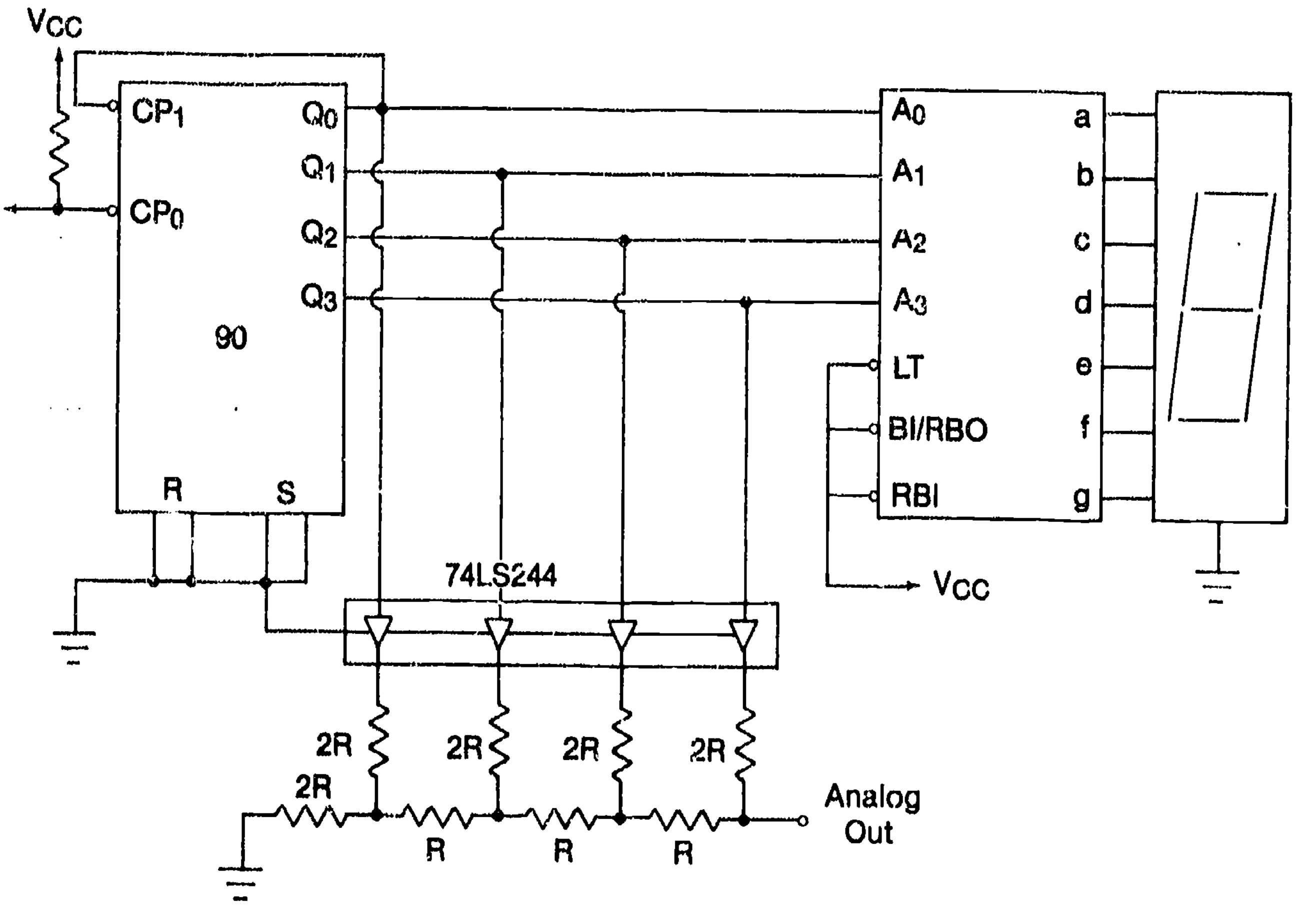


7442 Decoder

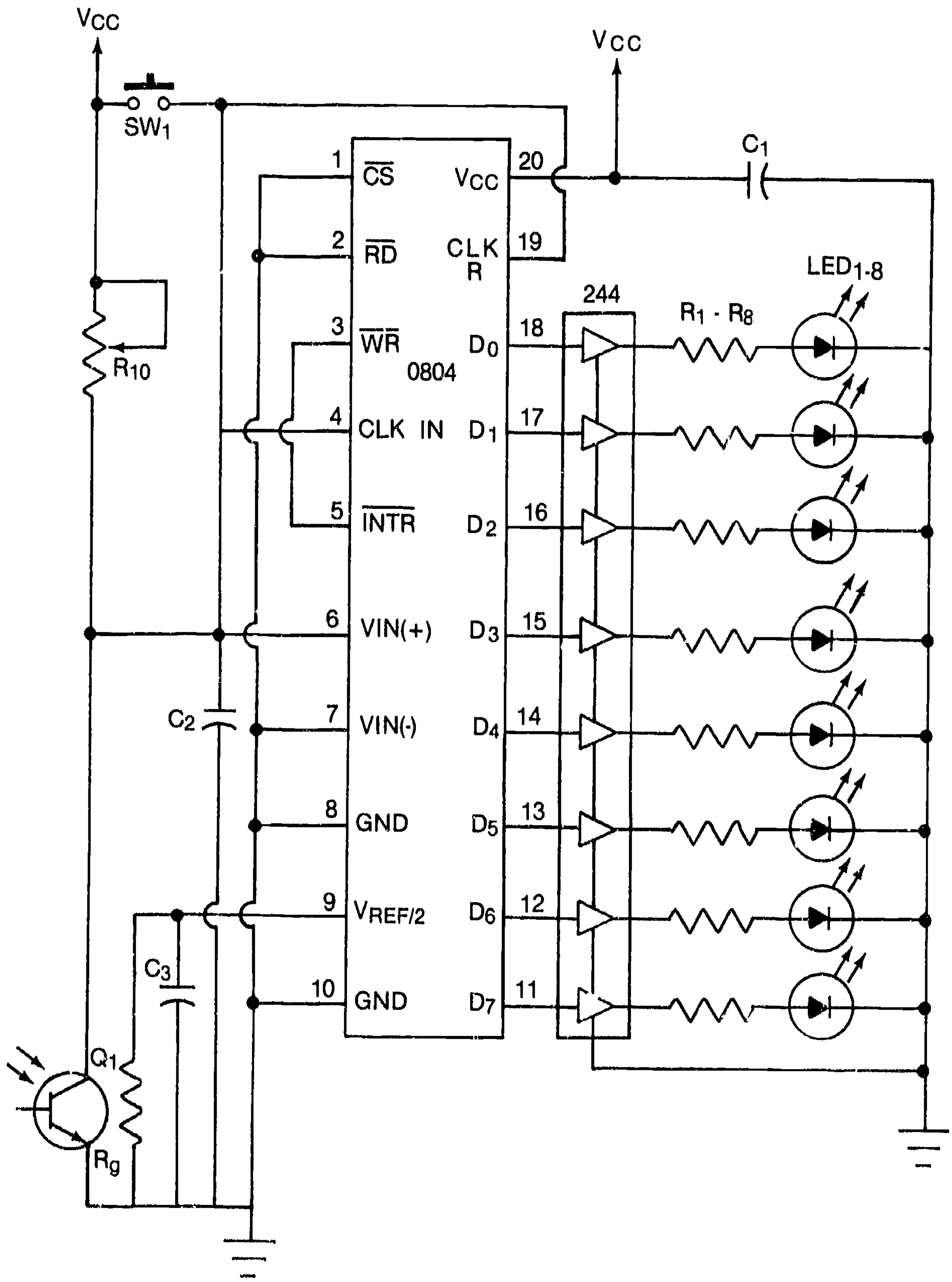
D/A Converter



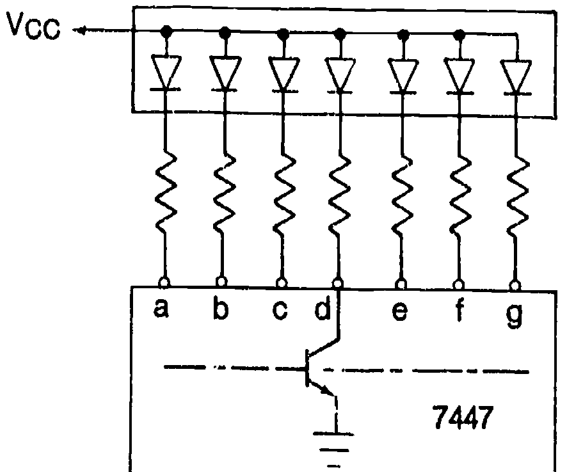
Basic Ladder D/A Converter



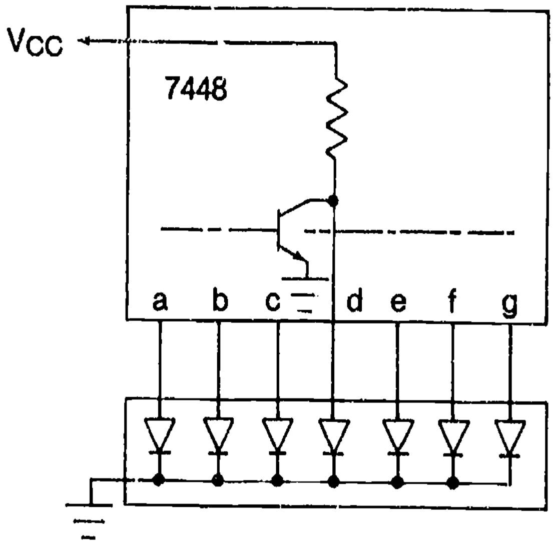
A/D Converter



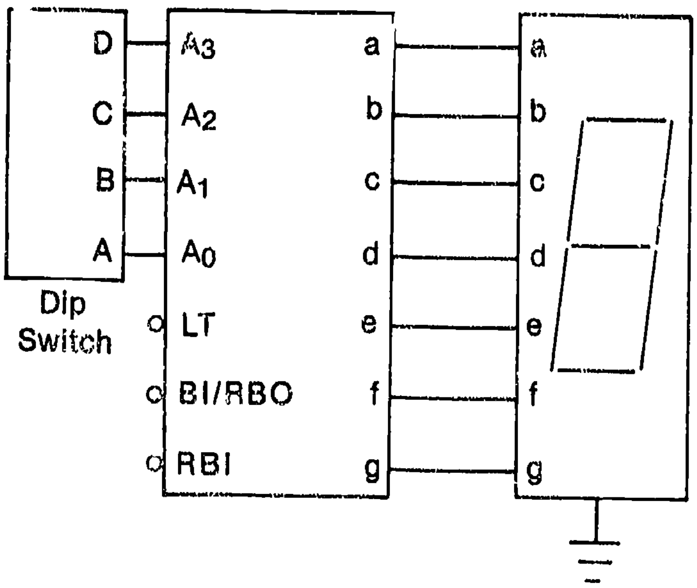
Digital Displays



Common Anode



Common Cathode



BCD to 7-Segment Decoder and Display

LOGIC DEVICES
UNIT VIII

ASSIGNMENT SHEET #1 — CONVERT BINARY NUMBERS TO DECIMAL AND OCTAL NUMBERS

1. Convert the following binary numbers to their decimal equivalents.

   a. 10_2

   b. 111_2

   c. 1101_2

   d. 10001_2

   e. 1110101_2

   f. 10000001_2

2. Convert the following binary numbers to their octal equivalents.

   a. 10_2

   b. 111_2

   c. 1101_2

   d. 10001

   e. 111011

   f. 1000000

LOGIC DEVICES
UNIT VIII

ASSIGNMENT SHEET #2 — CONVERT BINARY NUMBERS TO HEXADECIMAL AND BCD(8421) NUMBERS

1. Convert the following binary numbers to their hexadecimal equivalents.

   a. 00111100_2

   b. 11001101_2

   c. 01010111_2

   d. 00101000_2

   e. 11110001_2

   f. 11010100_2

   g. 01000000_2

   h. 01110111_2

2. Convert the following hexadecimal numbers to their binary equivalents.

   a. 1F

   b. 3E

   c. 3A

   d. 21

   e. 28

   f. 84

   g. C3

   h. 77

LOGIC DEVICES
UNIT VIII

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #1

1. a. 2
   b. 7
   c. 13
   d. 17
   e. 117
   f. 129

2. a. 2
   b. 7
   c. 15
   d. 21
   e. 73
   f. 100

Assignment Sheet #2

1. a. 3C
   b. CD
   c. 57
   d. 28
   e. F1
   f. D4
   g. 40
   h. 77

2. a. 0001 1111
   b. 0011 1110
   c. 0011 1010
   d. 0010 0001
   e. 0010 1000
   f. 1000 0100
   g. 1100 0011
   h. 0111 0111

LOGIC DEVICES
UNIT VIII

JOB SHEET #1 — CONSTRUCT AND TEST AN "AND" GATE CIRCUIT

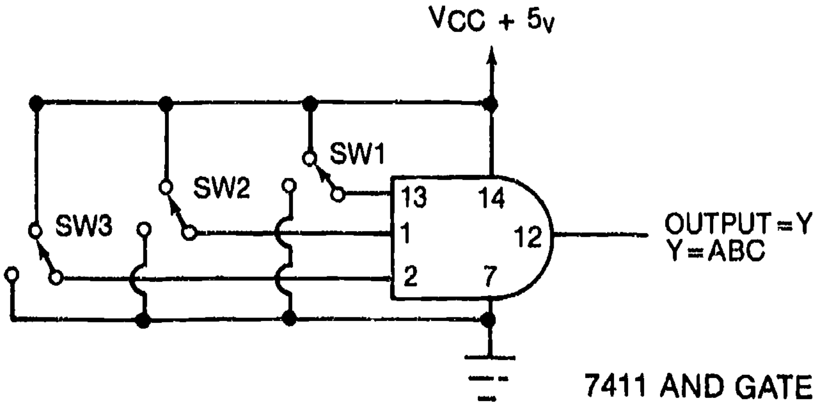
A. Equipment and materials needed

1. SN7411 triple 3-input positive-AND gates
2. Three SPDT switches
3. DC power supply (+5 Volt)
4. Multimeter
5. Proto-board or equipment system for connecting ICs
6. LED and a 470 ohm resistor (optional)

B. Procedure

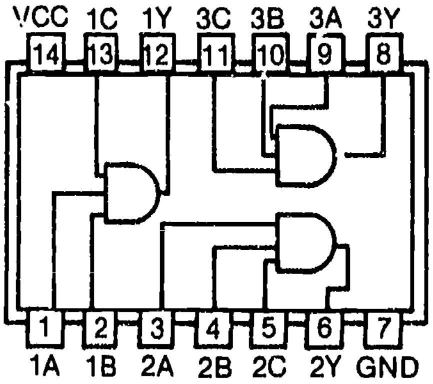
1. Connect the following logic AND gate circuit.

   (NOTE: This device, 7411, contains three AND gates on one chip, but only one of the gates will be tested.)



7411 AND GATE

Top View



2. Check with your multimeter to be sure switches are as shown in the above diagram.

   (NOTE: The switches may be replaced by simply connecting the inputs to +5 volts or ground.)

3. Connect the multimeter to the output of the gate.

   (NOTE: A visual output indication may be made by placing an LED and a series resistor [approximately 470 ohms] from the output to ground. The diodes cathode must be connected to ground.)

JOB SHEET #1

4. Complete the following truth table by switching the three input switches into all possible combinations and recording whether the output is a "1" (high voltage) or a "0" (low voltage).

SW-1 Input A	SW-2 Input B	SW-3 Input C	Y Output
0	0	0	
1	1	1	

5. Compare the output results with the truth table given on TM 3.
6. Check your results with your instructor.
7. Return equipment and materials to their proper storage area.

LOGIC DEVICES
UNIT VIII

JOB SHEET #2 — CONSTRUCT AND TEST AN "OR" GATE CIRCUIT

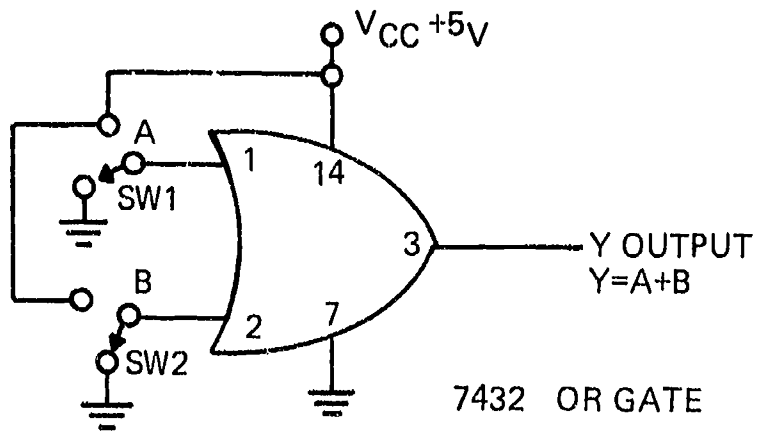
A. Equipment and materials needed

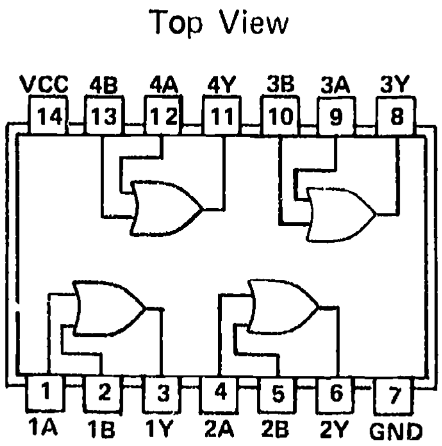
1. SN7432 Quadruple 2-input positive-OR gates
2. 2-SPDT switches
3. DC power supply
4. Multimeter
5. Proto-board or equipment system for connecting ICs
6. LED and a 470 ohm resistor (optional)

B. Procedure

1. Connect the following logic OR circuit.

   (NOTE: This device, 7432, contains four OR gates on one chip but only one of the gates will be tested.)





2. Check with your multimeter to be sure switches are as shown in the above diagram.

3. Connect the multimeter (DC volts) to the output of the gate.

   (NOTE: A visual output indication may be made by placing an LED and a series resistor [approximately 470 ohms] from the output to ground. The diodes cathode must be connected to ground.)

JOB SHEET #2

4. Complete the following truth table by switching the two input switches into all possible combinations and record whether the output is a "1" (high voltage) or a "0" (low voltage).

SW-1 Input A	SW-2 Input B	Y Output
0	0	
1	1	

5. Compare the output results with the truth table given on TM 5.

6. Check your results with your instructor.

7. Return equipment and materials to their proper storage area.

LOGIC DEVICES
UNIT VIII

JOB SHEET #3 — CONSTRUCT AND TEST A "NAND" GATE CIRCUIT

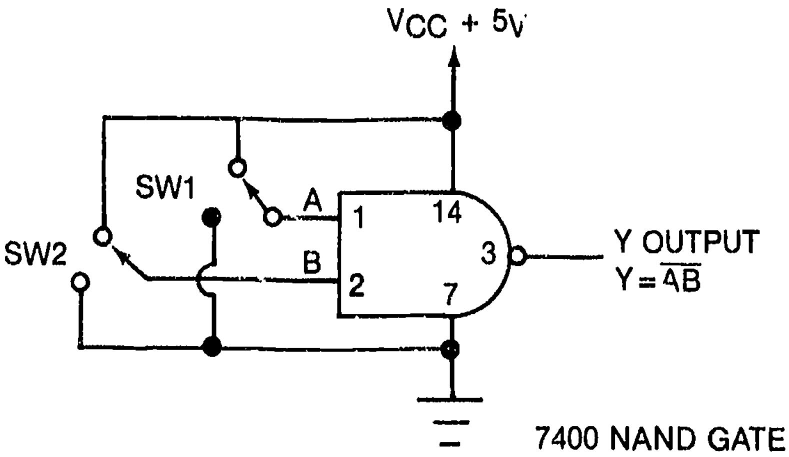
A. Equipment and materials needed

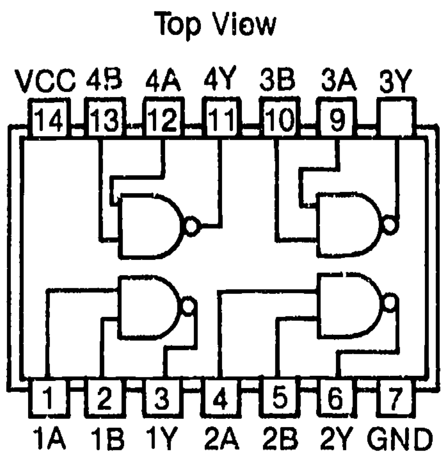
1. SN7400 Quadruple 2-input positive-NAND gates
2. 2 SPDT switches
3. Regulated DC power supply
4. Multimeter
5. Proto-board or equipment system for connecting ICs
6. LED and a 470 ohm resistor (optional)

B. Procedure

1. Connect the following logic NAND gate circuit.

   (NOTE: Only one of the four gates on the chip will be tested. This device, SN7400, contains four NAND gates on one chip but only one of the gates will be tested.)





2. Check with your multimeter to be sure switches are as shown in the above diagram.

3. Connect the multimeter to the output of the gate.

   (NOTE: A visual output indication may be made by placing an LED and a series resistor [approximately 470 ohms] from the output to ground. The diodes cathode must be connected to ground.)

JOB SHEET #3

4. Complete the following truth table by switching the two input switches into all possible combinations and record whether the output is a "1" (high voltage) or a "0" (low voltage).

SW-1 Input A	SW-2 Input B	Y Output
0	0	
1	1	

5. Compare the output results with the truth table given on TM 4.

6. Check your results with your instructor.

7. Return equipment and materials to their proper storage area.

LOGIC DEVICES
UNIT VIII

JOB SHEET #4 — CONSTRUCT AND TEST A "NOR" GATE CIRCUIT

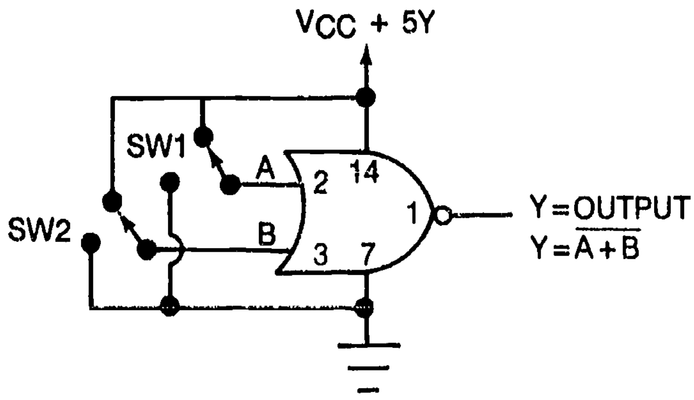
A. Equipment and materials needed

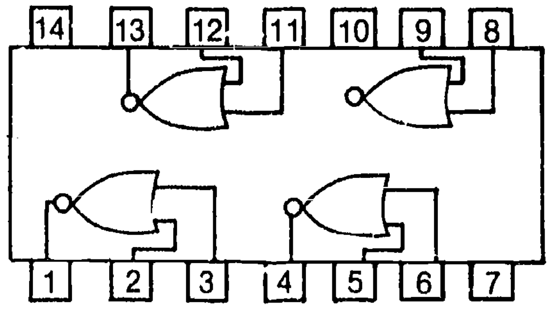
1. SN7402 Quadruple 2-input NOR gate
2. Two SPDT switches
3. Regulated DC power supply
4. Multimeter
5. Proto-board
6. LED and a 470 ohm resistor (optional)

B. Procedure

1. Connect the following logic NOR gate circuit.

   (NOTE: Only one of the four gates on the chip will be tested. This device, SN7402, contains four NOR gates on one chip.)





2. Apply power.
3. Check with your multimeter to be sure switches are as shown in the diagram above.
   4. Connect the multimeter to the output of the gate.

      (NOTE: A visual output indication may be made by placing an LED and a series resistor [approximately 470 Ω] from the output to ground. The cathode of the LED must be connected to ground.)

JOB SHEET #4

5. Complete the following truth table by changing the inputs with the switches. Record all possible combinations of inputs with their respective outputs in the chart below.

SW-1 Input A	SW-2 Input B	Y Output
0	0	
0	1	
1	0	
1	1	

6. How do the output results compare to that of an:

   a. "OR" circuit. ______________________________

   b. "AND" circuit. ______________________________

   c. "NAND" circuit. ______________________________

7. Return equipment and materials to their proper storage area.

LOGIC DEVICES
UNIT VIII

JOB SHEET #5 — CONSTRUCT AND TEST AN "EXCLUSIVE-OR" GATE CIRCUIT

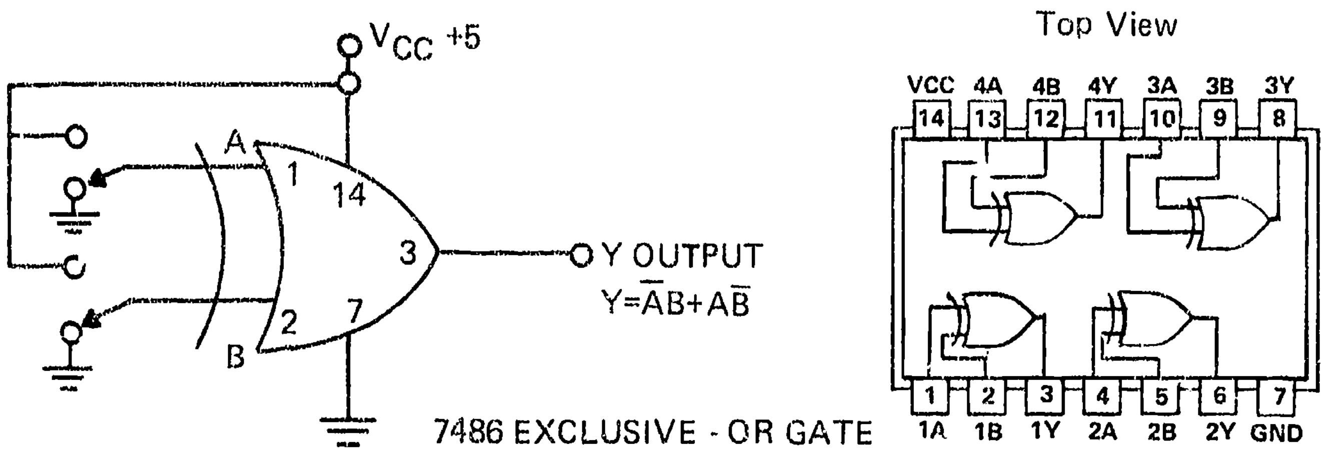
A. Equipment and materials needed

1. SN7485 Quadruple 2-input Exclusive-OR gate
2. Two SPDT switches
3. Regulated DC power supply
4. Multimeter
5. Proto-board or equipment system for connecting ICs
6. LED and a 470 ohm resistor (optional)

B. Procedure

1. Wire the following logic exclusive OR gate circuit.

   (NOTE: This device, SN7485, contains four Exclusive-OR gates on one chip, but only one of the gates will be tested.)



2. Check with your multimeter to be sure switches are as shown in the above diagram.

3. Connect the multimeter to the output of the gate.

   (NOTE: A visual output indication may be made by placing an LED and a series resistor [approximately 470 ohms] from the output to ground. The diodes cathode must be connected to ground.)

JOB SHEET #5

4. Complete the following truth table by switching the two inputs in all possible combinations and recording whether the output is a "1" (high voltage) or a "0" (low voltage).

SW-1 Input A	SW-2 Input B	Y Output
0	0	
1	1	

5. Compare the output results with the truth table given on TM

6. Return equipment and materials to their proper storage area.

LOGIC DEVICES
UNIT VIII

JOB SHEET #6 — CONSTRUCT AND TEST A FOUR-BIT SHIFT REGISTER

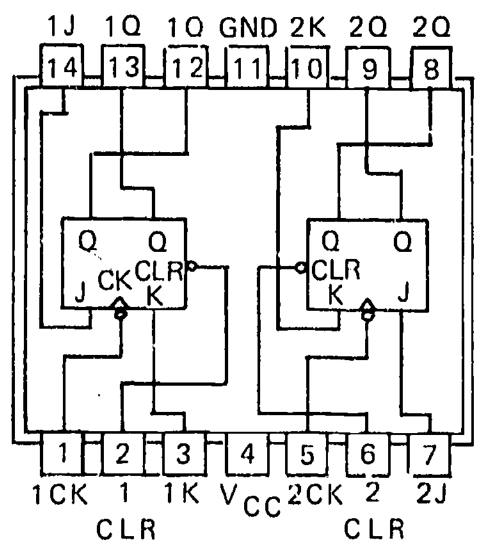
A. Equipment and materials needed

1. Two SN7473 Dual J-K Flip-flops
2. Regulated DC power supply (+5 volts)
3. Four LEDs
4. Four 470 ohm resistors
5. Proto-board or equivalent system for connecting ICs
6. Function generator or means of producing a square wave pulse with a single step capability
7. One SN7404 HEX inverter

(NOTE: This experiment will use four flip-flops (J-K Flip-flops) to transfer the contents of the first flip-flop (register) into a second flip-flop (register) and so on, one bit at a time. This type of circuit is called a shift register.)

'73,'H73,'L73
FUNCTION TABLE

INPUTS				OUTPUTS	
CLEAR	CLOCK	J	K	Q	$\overline{Q}$
L	X	X	X	L	H
H	⎍	L	L	Q_0	$\overline{Q}_0$
H	⎍	H	L	H	L
H	⎍	L	H	L	H
H	⎍	H	H	TOGGLE	

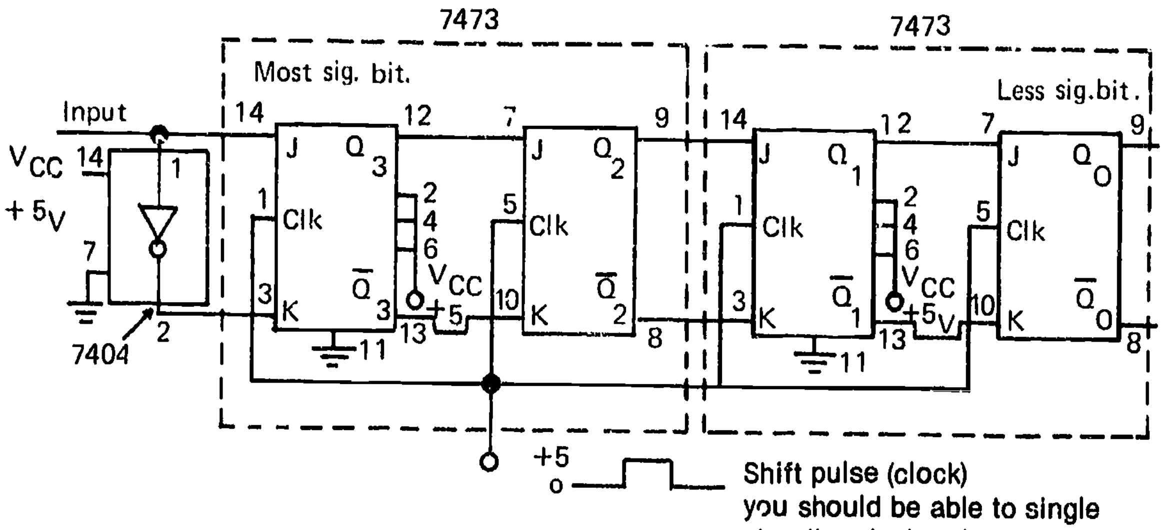


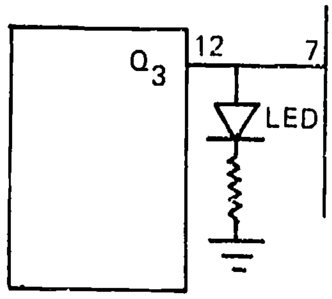
JOB SHEET #6

B. Procedure

1. Connect the following circuit.

(NOTE: If data books are available, study the logic diagrams for the 7473 and the 7404 logic chips.)





Output indicators place an LED and resistor on each of the flip-flops Q output (Q_3, Q_2, Q_1, Q_0)

(NOTE: The outputs of all flip-flops should be "0" before you start. If not, momentarily ground the clear pin (2 or 6) for the output which is high. You may want to try shifting additional numbers through the four bit binary shift register.

The binary number 1 0 1 1 will be shifted through the shift register one bit at a time starting with the least significant bit (the far right bit) and moving from right to left.)

2. Place a logic level "1" on the input terminal by connecting the input terminal to + Vcc (5v).

3. Push the shift pulse switch or clock pulse switch one time.

JOB SHEET #6

4. Record the outputs of each flip-flop; X_3, X_2, X_1, X_0.

   (NOTE: The LED should light for "1" and be off for a "0".)

5. The next bit to be entered is also a "1" (1 0 1 1) so push the shift pulse switch one time.

6. Record the outputs of each flip-flop.

7. Place a "0" on the input terminal by changing the input from +5 volts to ground.

8. Push the shift pulse switch.

9. Record the outputs of each flip-flop.

10. Place a "1" on the input terminal by changing the input from ground to +5v (Vcc).

11. Push the shift pulse switch.

12. Record the outputs of each flip-flop.

13. Check your results with your instructor.

14. Return equipment and materials to their proper storage area.

LOGIC DEVICES
UNIT VIII

JOB SHEET #7 — CONSTRUCT AND TEST A FLIP-FLOP CIRCUIT

A. Equipment and materials needed

1. 7476 J-K Flip-Flop
2. Logic pulser
3. Logic probe
4. Oscilloscope
5. Function generator
6. 5 volt regulated power supply
7. 4.7 KΩ, 1/4 watt resistor

B. Procedure

1. Obtain a 7476 5-K flip-flop integrated circuit and its pin-out diagram.
2. Connect the CP (clock) to V_{CC} through a 4.7 KΩ resistor.
3. Apply power.
4. Connect C_D (clear) to low and S_D (set) to high. The Q output should go low. Did it? ______
5. Connect C_D and S_D low. The Q output should go high. Did it? ______
6. Connect C_D and S_D both low. This is an illegal state, since both Q and $\bar{Q}$ go high. Did Q and $\bar{Q}$ go high? ______
7. Connect C_D and S_D both high. Under this condition the J, K, and CP (clock) take control of the circuit.
8. Set J and K both low. Inject a pulse, then several pulses on the CP line with a logic pulser. Measure Q and $\bar{Q}$ and record your observation.

   Q = ________ $\bar{Q}$ = ________

   Did the outputs change with a sequence of CP pulses? ______

JOB SHEET #7

9. Set J low and K high. Inject a pulse, and then several pulses in sequence, on the CP line with the logic pulser. Observe the Q and $\overline{Q}$ outputs and record your observations.

   Q = ________ $\overline{Q}$ = ________

   Did the outputs change with the sequence of pulse inputs? ______

10. Set J high and K low. Inject several pulses on the CP line with the logic pulser. Describe the behavior of the Q output. ________________________

    ____

11. Set J high and K high. Inject several pulses on the CP line with the logic pulser. Observe the Q output and describe its behavior. ________________

    ____

12. Leave the J and K inputs at high. Remove the input to the CP terminal.

13. Connect CP to a pulse input from a function generator.

14. With a dual-trace oscilloscope, monitor the clock (CP) and the Q output. (Trigger from clock.)

15. Record your observations from the two traces on the oscilloscope.

    Clock (CP) ________________________________

    Q ________________________________

16. Explain your observations.

17. Return equipment and materials to their proper storage area.

LOGIC DEVICES
UNIT VIII

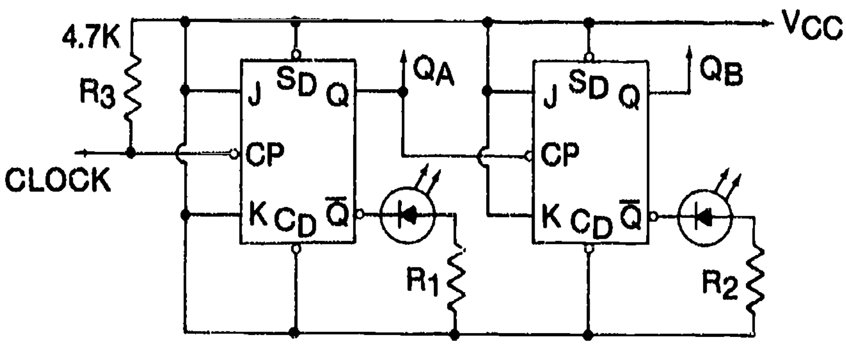
JOB SHEET #8 — CONSTRUCT AND TEST J-K COUNTER CIRCUITS

A. Equipment and materials needed

1. 7476 J-K flip-flop
2. Two LED's
3. Two 270-ohm, 1/4 watt, resistors
4. Logic pulser
5. Oscilloscope
6. Power supply
7. Function generator (square wave)

B. Procedure

1. Connect the circuit in the figure below.



2. Apply power.
3. Using a logic pulser, inject pulses on the CP line. Observe the LED's and record the count sequence.

   ____

4. Remove the 4.7 KΩ resistor at CP and connect CP to approximately 100 Hz square wave.
5. Observe the clock (Q_A and Q_B) waveforms with the oscilloscope triggered from the clock. Record your observations.

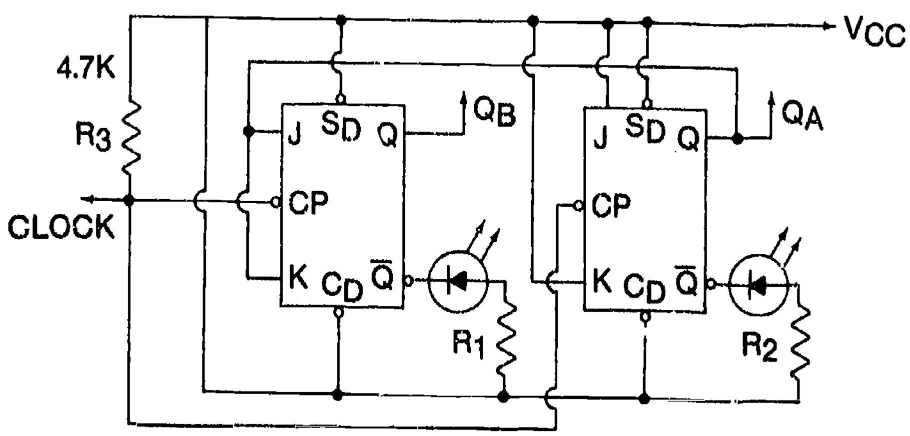
   CLK ____

   Q_A ____

   Q_B ____

JOB SHEET #8

6. Remove power and connect the circuit below.



7. Apply power.

8. Apply a pulse to the clock line with the logic pulser.

9. Observe the LED's and record the count sequence.

____

10. Remove the 4.7 KΩ resistor at CP and connect CP to approximately 100 Hz pulse.

11. Observe the clock, Q_A and Q_B waveforms with an oscilloscope triggered from the clock. Record your observations.

CLK ____

Q_A ____

Q_B ____

12. Explain the similarities and differences in the two circuit arrangements and your waveform observations.

____

____

____

13. Dismantle the circuit.

14. Return equipment and materials to their proper storage area.

LOGIC DEVICES
UNIT VIII

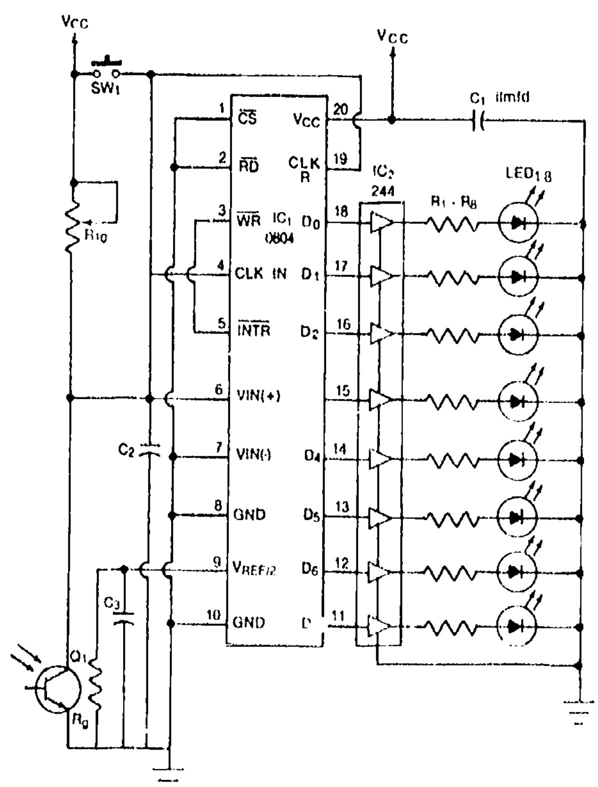
JOB SHEET #9 — CONSTRUCT AND TEST AN A/D CONVERTER

A. Equipment and materials needed

1. ADC 0804 A/D converter IC
2. 74LS244 octal buffer
3. Eight 270 ohm resistors (R1 – R8)
4. 22 MF tantalum capacitor (C1)
5. Two 0.1 MF capacitor (C2, C3)
6. 4.7 KΩ resistor (R9)
7. 100 KΩ potentiometer (R10)
8. Photo-transistor (Q1)
9. Eight LED's

B. Procedure

1. Connect the circuit below.



JOB SHEET #9

2. Apply power.

3. Monitor the analog voltage at point A with a voltmeter.

4. Adjust R_{10} so that the voltage at point A is one volt with full light striking the light-sensitive device.

5. Momentarily close switch S_{W_1}.

6. Record the analog voltage and digital output with various amounts of light striking the light-sensitive device.

7. Record your observations.

Voltage at point A	Digital output
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________

8. Remove power.

9. Dismantle the circuit.

10. Return equipment and material to their proper storage area.

LOGIC DEVICES
UNIT VIII

JOB SHEET #10 — CONSTRUCT AND TEST A D/A CONVERTER

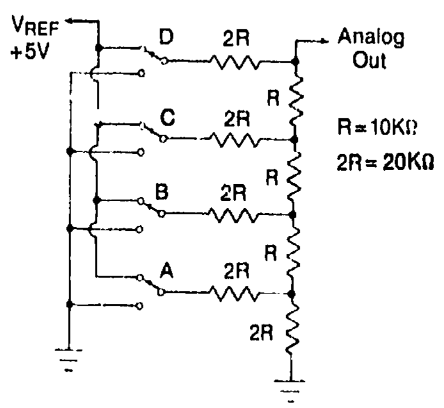
A. Equipment and materials needed

1. Three 10 KΩ, 1/4 watt resistors
2. Five 20 KΩ, 1/4 watt resistors
3. 7490 decade counter IC
4. 7448 BCD to 7-segment decoder IC
5. Common cathode 7-segment display
6. 74LS244 octal buffer IC
7. 4.7 KΩ resistor
8. Power supply
9. Voltmeter

B. Procedure

1. Connect the resistor-ladder network below.

   (NOTE: You may use jumper wires for the switches.)

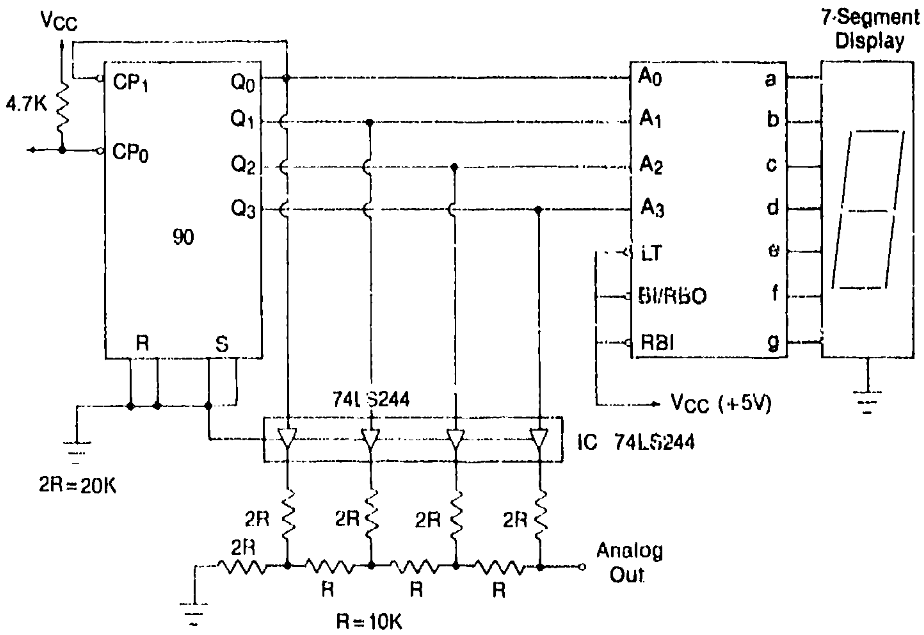


2. Apply power.
3. Connect a voltmeter to the analog output.
4. Record the analog voltage as the switches are adjusted to each number from 0 through 9 and record the voltage in the chart below.

JOB SHEET #10

	D	C	B	A	Analog Output Circuit #1	Analog Output Circuit #2
0	GND	GND	GND	GND	______	______
1	GND	GND	GND	Vcc	______	______
2	GND	GND	Vcc	GND	______	______
3	GND	GND	Vcc	Vcc	______	______
4	GND	Vcc	GND	GND	______	______
5	GND	Vcc	GND	Vcc	______	______
6	GND	Vcc	Vcc	GND	______	______
7	GND	Vcc	Vcc	Vcc	______	______
8	Vcc	GND	GND	GND	______	______
9	Vcc	GND	GND	Vcc	______	______

5. Remove power and connect the circuit below.



6. Connect a voltmeter to the analog output.

7. Using a logic pulser, step the 7490 through its count (zero through nine) and record the analog voltage output for each count alongside those you recorded for the previous circuit.

JOB SHEET #10

8. If any difference exists in the readings between the first and second circuit, to what do you contribute the difference? ____________________

____

9. Connect the counter CP line to a 100 Hz square wave. Using an oscilloscope triggered from the CP input, observe and sketch the waveforms of the CP input and the analog output.

   Clock (CP) waveform ____________________

   Analog output waveform ____________________

10. Dismantle the circuit.

11. Return equipment and materials to their proper storage area.

LOGIC DEVICES
UNIT VIII

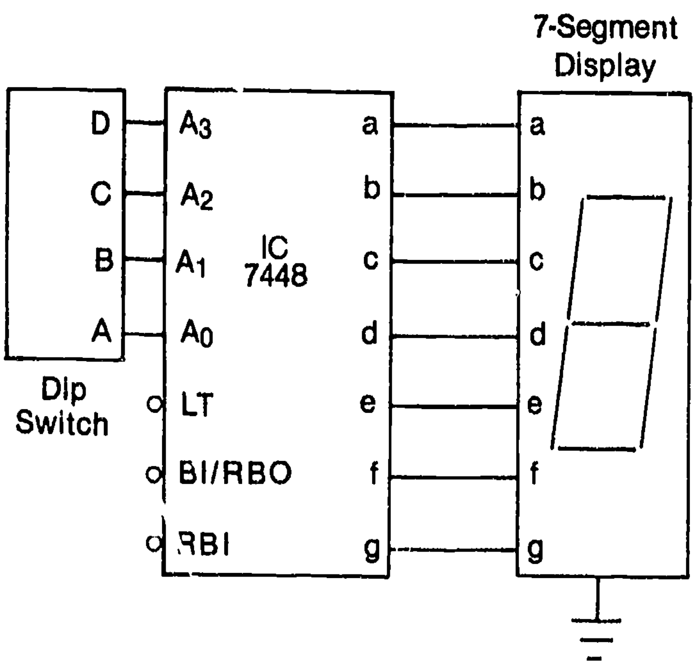
JOB SHEET #11 — CONSTRUCT AND TEST A BCD TO SEVEN-SEGMENT DECODER

A. Equipment and materials needed

1. 7448 BCD to seven-segment decorder IC
2. Common cathode seven-segment display
3. 74LS244 octal buffer IC
4. Power supply
5. DIP switch

B. Procedure

1. Connect the circuit below. Connect LT, BI/BRO, and RBI to a logic high (Vcc).



2. Apply power.
3. Set the DIP switch to each binary number from zero through nine and observe the seven-segment display.
4. Did the display show a digital number for each corresponding binary number? ______

JOB SHEET #11

5. Assimilate a problem by disconnecting a line from the DIP switch. Follow a logical troubleshooting procedure and locate the problem with the logic probe. Describe the behavior of the defective circuit and the procedure you used to locate the problem.

____

____

____

____

____

6. Dismantle the circuit.

7. Return equipment and materials to their proper storage area.

LOGIC DEVICES
UNIT VIII

NAME ______________________

TEST

1. Match the terms on the right with their correct definitions.

_____a.	Number system which has digits zero (0) and one (1) only	1.	ROM
_____b.	A single binary digit, 0 or 1	2.	RAM
_____c.	A bistable multivibrator circuit	3.	Sequential logic
_____d.	A digital code where a four bit binary character is used to represent each single digit decimal character	4.	Combinational logic
_____e.	Summarizes the various combinations of input and corresponding output signals for logic gates	5.	Word
_____f.	A circuit that acts like a switch, either on or off	6.	Ripple counter
_____g.	A digital circuit that is capable of storing and shifting data	7.	Shift register
_____h.	A broad category of digital circuits whose logic gates are dependent on a specified time sequence	8.	EPROM
_____i.	A combination of gate circuits used to combine or generate specified functions	9.	Flip-flop
_____j.	Erasable programable read-only memory	10.	Binary number system
_____k.	Read only memory	11.	Bit
_____l.	Random access memory	12.	Truth table
_____m.	A group of bits representing a complete piece of digital information	13.	Digital circuit
_____n.	A digital counter in which each flip-flop is clocked with the output of the previous stage	14.	Binary coded decimal
_____o.	To reset as in the case of a flip-flop, counter, or register	15.	Logic high
		16.	Logic low
		17.	Preset
		18.	Clear

TEST

______p. To initialize a digital circuit to a predetermined state

______q. Low voltage (usually zero or near zero) representing binary 0

______r. High voltage (usually 5 volts or more) representing binary 1

2. Complete the following statements concerning the fundamentals of number systems by inserting the word(s) that best completes each statement.

   a. The ____________ of a number system specifies the number of symbols available in that system.

   b. In any number system, digits to the left and right of the decimal point have specific positional values or weights and are expressed as ____________ of the base.

   c. Numbers expressed in the octal system can be converted to the decimal system by ____________ the positional values by the corresponding octal digits, and then adding the results.

   d. A number expressed in the decimal system can be converted to the octal system by successive ____________ by eight.

   e. Decimal numbers may be converted to binary by successive ____________ by two with the remainder of each division retained as a bit of the binary number, with the first remainder as the least significant bit.

   f. Octal to binary and binary to octal conversions may be easily made by substituting groups of ____________ binary bits for each octal digit.

   g. A binary number may be converted to the hexadecimal system simply by breaking the binary number into ____________ groups starting at the right and replacing each group by the hexademical equivalent.

   h. To convert from a hexademical number to a binary number, replace each hexademical symbol with the appropriate ____________ binary group.

3. Select true statements concerning the fundamentals of basic logic gates by placing an "X" in the blanks preceding the true statements.

______a. The simplest form of logic element is the inverter.

______b. The output of an inverter is the inverse, or complement of the input.

______c. The NAND gate is a logic circuit that has two or more inputs with a single output that is a logic high only if all inputs are a logic high.

TEST

_____d. The NAND gate is an AND gate with the output inverted.

_____e. The OR gate is a logic circuit that has two or more inputs with a single output that is a logic high if all inputs are a logic high.

_____f. The NOR gate is an OR gate with the output inverted.

_____g. The XNOR gate is a logic circuit that provides a logic high output when any, but not all, inputs are logic high.

_____h. The XOR gate is an exclusive-OR gate with the output inverted.

4. Complete the following statements concerning the types of multivibrator circuits and their characteristics by inserting the word(s) that best completes each statement.

   a. There are three forms of multivibrator circuits: the __________, __________, and __________.

   b. __________ (or multivibrators) are widely used building blocks in sequential logic and digital memory circuits.

   c. The __________ flip-flop has two inputs, the Set (S) and the reset (R).

   d. The J-K type flip-flop changes state only when a __________ pulse is present and provides one output pulse for each two input pulses.

5. Explain the difference between the synchronous and asynchronous types of counters.

   a. Synchronous counters ______________________________

   ____

   b. Asynchronous counters ______________________________

   ____

6. Select true statements concerning characteristics of shift registers by placing an "X" in the blanks preceding the true statements.

_____a. Flip-flops may be connected in a sequential logic circuit configuration called a shift register to transfer serial data from one element to an adjacent element.

_____b. Shift registers may be used to perform arithmetic operations, parallel to serial and serial to parallel data conversion, and perform counting and frequency dividing functions.

TEST

7. Complete the following statements related to types of combinational logic circuits by inserting the word(s) that best completes each statement.

   a. ______________ are logic circuits which detect or identify the presence of a specific binary number or word.

   b. An ______________ is a combinational logic circuit that accepts one or more inputs and produces a multi-bit output code.

   c. ______________ are electronic circuits that are used to select and route any one of a number of inputs to a single output.

   d. A ______________ is a logic circuit which has a single input which may be routed to any one of multiple outputs.

   e. Digital to analog (D/A) converters are used to convert ______________ values to equivalent ______________ voltages.

   f. Analog to digital (A/D) converters are used to convert ______________ voltages to ______________ values.

8. Match the basic types of digital integrated devices on the right with their characteristics.

_____a.	1. Simple construction	1. TTL
	2. Small in size	2. ECL
	3. High impedance	3. MOS
	4. Low power consumption	4. CMOS
	5. Lower speed	
_____b.	1. Ideal, balanced characteristics	
	2. Low power consumption	
	3. Excellent noise immunity	
	4. Moderately high speed	
_____c.	1. Bipolar IC	
	2. Low cost	
	3. Wide variety of available circuits	
_____d.	1. Non-saturating bipolar transistor elements	
	2. High speed	
	3. Higher cost	
	4. Consume more power than other types	

TEST

9. Complete the following statements concerning types of displays by inserting the word(s) that best complete(s) each statement.

   a. ____________ and ____________ are the most common elements used in displays

   b. ____________ ____________ displays are typically coupled to a decoder to display digital information

(NOTE: If the following activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

10. Convert binary numbers to decimal and octal numbers. (Assignment Sheet #1)

11. Convert binary numbers to hexadecimal and BCD (8421) numbers. (Assignment Sheet #2)

12. Demonstrate the ability to:

    a. Construct and test an "AND" gate circuit. (Job Sheet #1)

    b. Construct and test an "OR" gate circuit. (Job Sheet #2)

    c. Construct and test a "NAND" gate circuit. (Job Sheet #3)

    d. Construct and test a "NOR" gate circuit. (Job Sheet #4)

    e. Construct and test an "exclusive-OR" gate circuit. (Job Sheet #5)

    f. Construct and test a four-bit shift register. (Job Sheet #6)

    g. Construct and test a flip-flop circuit. (Job Sheet #7)

    h. Construct and test J-K counter circuits. (Job Sheet #8)

    i. Construct and test an A/D converter. (Job Sheet #9)

    j. Construct and test a D/A converter. (Job Sheet #10)

    k. Construct and test a BCD to seven-segment decoder. (Job Sheet #11)

LOGIC DEVICES
UNIT VIII

ANSWERS TO TEST

1.

a.	10	h.	3	o.	18
b.	11	i.	4	p.	17
c.	9	j.	8	q.	16
d.	14	k.	1	r.	15
e.	12	l.	2		
f.	13	m.	5		
g.	7	n.	6		

2. a. Base
   b. Powers
   c. Multiplying
   d. Divisions
   e. Division
   f. Three
   g. Four-bit
   h. Four-bit

3. a, b, d, f

4. a. Bistable, monostable, astable
   b. Flip-flops
   c. Set-reset
   d. Clock (or toggle)

5. a. Synchronous counters have all elements synchronized to a common clock
   b. Asynchronous counters have the output of one element driving the input of the following element

6. a, b

7. a. Decoder
   b. Encoder
   c. Multiplexers
   d. Demultiplexers
   e. Digital, analog
   f. Analog, digital

8. a. 3
   b. 4
   c. 1
   d. 2

9. a. LED's, LCD's
   b. Seven-segment

10.-11. Evaluated to the satisfaction of the instructor

12. Performance skills evaluated to the satisfaction of the instructor