DOCUMENT RESUME

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TITLE	Electronic Principles VIII, 7-12. Military Curriculum Materials for Vocational and Technical Education.
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SPONS AGENCY	Department of Education, Washington, DC.
PUB DATE	75
NOTE	213p.; For related documents, see CE 039 201-210.
PUB TYPE	Guides - Classroom Use - Materials (For Learner) (051) -- Guides - Classroom Use - Guides (For Teachers) (052)
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DESCRIPTORS	Behavioral Objectives; Course Content; Course Descriptions; *Electronic Equipment; *Electronics; Individualized Instruction; Learning Activities; Learning Modules; Pacing; Postsecondary Education; Programed Instructional Materials; Secondary Education; *Technical Education
IDENTIFIERS	Electric Generators; Military Curriculum Project

ABSTRACT

This eighth of 10 blocks of student and teacher materials for a secondary/postsecondary level course in electronic principles comprises one of a number of military-developed curriculum packages selected for adaptation to vocational instruction and curriculum development in a civilian setting. Prerequisites are the previous blocks. This block on principles and applications of electron tubes contains seven modules covering 39 hours of instruction on electron tube characteristics and diodes (4 hours); triodes (7); multigrid electron tubes (4); special purpose electron tubes (5); electron tube audio amplifiers (5); electron tube RF amplifiers, cathode follows, DC amplifiers and triode limiters (5); and thyratron sawtooth generator, phantastron, and electron tube series voltage regulator (9). Printed instructor materials include a plan of instruction detailing the units of instruction, duration of the lessons, criterion objectives, and support materials needed. Student materials include a student text and seven guidance packages containing objectives, assignments, review exercises, and answers for each module. A digest of the modules in the block is provided for students who need only to review the material. Designed for self- or group-paced instruction, the material can be adapted for individualized instruction. Additional print and audiovisual materials are recommended but not provided. (YLB)

MILITARY CURRICULUM MATERIALS

The military-developed curriculum materials in this course package were selected by the National Center for Research in Vocational Education Military Curriculum Project for dissemination to the six regional Curriculum Coordination Centers and other instructional materials agencies. The purpose of disseminating these courses was to make curriculum materials developed by the military more accessible to vocational educators in the civilian setting.

The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

The National Center Mission Statement

The National Center for Research in Vocational Education's mission is to increase the ability of diverse agencies, institutions, and organizations to solve educational problems relating to individual career planning, preparation, and progression. The National Center fulfills its mission by:

- Generating knowledge through research
- Developing educational programs and products
- Evaluating individual program needs and outcomes
- Installing educational programs and products
- Operating information systems and services
- Conducting leadership development and training programs

FOR FURTHER INFORMATION ABOUT
Military Curriculum Materials
WRITE OR CALL

Program Information Office
The National Center for Research in Vocational Education
The Ohio State University
1960 Kenny Road, Columbus, Ohio 43210
Telephone: 614/486-3655 or Toll Free 800/848-4815 within the continental U.S. (except Ohio)

THE NATIONAL CENTER FOR RESEARCH IN VOCATIONAL EDUCATION
The Ohio State University · 1960 Kenny Road · Columbus, Ohio 43210
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Military Curriculum Materials for Vocational and Technical Education

Information and Field Services Division

The National Center for Research in Vocational Education

Military Curriculum Materials Dissemination Is . . .

an activity to increase the accessibility of military-developed curriculum materials to vocational and technical educators.

This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

The National Center for Research in Vocational Education is the U.S. Office of Education's designated representative to acquire the materials and conduct the project activities.

Project Staff:

Wesley E. Budke, Ph.D., Director
National Center Clearinghouse

Shirley A. Chase, Ph.D.
Project Director

What Materials Are Available?

One hundred twenty courses on microfiche (thirteen in paper form) and descriptions of each have been provided to the vocational Curriculum Coordination Centers and other instructional materials agencies for dissemination.

Course materials include programmed instruction, curriculum outlines, instructor guides, student workbooks and technical manuals.

The 120 courses represent the following sixteen vocational subject areas:

Agriculture	Food Service
Aviation	Health
Building & Construction Trades	Heating & Air Conditioning
Clerical Occupations	Machine Shop
Communications	Management & Supervision
Drafting	Meteorology & Navigation
Electronics	Photography
Engine Mechanics	Public Service

The number of courses and the subject areas represented will expand as additional materials with application to vocational and technical education are identified and selected for dissemination.

How Can These Materials Be Obtained?

Contact the Curriculum Coordination Center in your region for information on obtaining materials (e.g., availability and cost). They will respond to your request directly or refer you to an instructional materials agency closer to you.

CURRICULUM COORDINATION CENTERS

EAST CENTRAL
Rebecca S. Douglass
Director
100 North First Street
Springfield, IL 62777
217/782-0759

MIDWEST
Robert Patton
Director
1515 West Sixth Ave.
Stillwater, OK 74704
405/377-2000

NORTHEAST
Joseph F. Kelly, Ph.D.
Director
225 West State Street
Trenton, NJ 08625
609/292-6562

NORTHWEST
William Daniels
Director
Building 17
Airdustrial Park
Olympia, WA 98504
206/753-0879

SOUTHEAST
James F. Shill, Ph.D.
Director
Mississippi State University
Drawer DX
Mississippi State, MS 39762
601/325-2510

WESTERN
Lawrence F. H. Zane, Ph.D.
Director
1776 University Ave.
Honolulu, HI 96822
808/948-7834

ELECTRONIC PRINCIPLES VIII

Table of Contents

Developed by:
United States Air Force

Development and Review Dates.
November 7, 1975

D.O.T. No.:
003.081

Occupational Area:
Electronics

Target Audiences:
Grades 11-adult

Print Pages:
203

Cost:
$4.25

Availability:
Military Curriculum Project, The Center for Vocational Education, 1960 Kenny Rd., Columbus, OH 43210

Contents:	Type of Materials: Lesson Plans:	Programmed Text:	Student Workbook: No. of pages	Handouts:	Text Materials:	Audio-Visuals:	Instructional Design: Performance Objectives:	Tests:	Review Exercises:	Additional Materials Required:	Type of Instruction: Group Instruction:	Individualized:
Block VIII — *Principles and Applications of Electron Tubes*												
Module 56 — Electron Tube Characteristics and Diodes	•		8		•	★	•	★	•		•	•
Module 57 — Triodes	•		10		•	★	•	★	•		•	•
Module 58 — Multigrid Electron Tubes	•		6		•	★	•	★	•		•	•
Module 59 — Special Purpose Electron Tubes	•		11		•	★	•	★	•		•	•
Module 60 — Electron Tube Audio Amplifiers	•		11		•	★	•	★	•	★	•	•
Module 61 — Electron Tube RF Amplifiers, Cathode Followers, DC Amplifiers and Triode Limiters	•		8		•	★	•	★	•		•	•
Module 62 — Thyratron Sawtooth Generator, Phantastron, and Electron Tube Series Voltage Regulator	•		18		•	★	•	★	•	★	•	•

★ Materials are recommended but not provided.

Course Description

This block is the eighth of a ten-block course providing training in electronic principles, use of basic test equipment, safety practices, circuit analysis, soldering, digital techniques, microwave principles and troubleshooting basic circuits. Prerequisites to this block are Blocks I through VII covering DC circuits, AC circuits, RCL circuits, solid state principles, solid state power supplies and amplifiers, solid state wave generating and wave shaping circuits, and digital techniques. Block VIII—*Principles and Applications of Electron Tubes* contains seven modules covering 39 hours of instruction over electron tubes, diodes, triodes, audio amplifiers, cathode followers, limiters, thyratron sawtooth generators, phantastrons, and series voltage regulators. The module topics and respective hours follow:

Module 56 — **Electron Tube Characteristics and Diodes** (4 hours)
Module 57 — **Triodes** (7 hours)
Module 58 — **Multigrid Electron Tubes** (4 hours)
Module 50 — **Special Purpose Electron Tubes** (5 hours)
Module 60 — **Electron Tube Audio Amplifiers** (5 hours)
Module 61 — **Electron Tube RF Amplifiers, Cathode Follows, DC Amplifiers and Triode Limiters** (5 hours)
Module 62 — **Thyratron Sawtooth Generator, Phantastron, and Electron Tube Series Voltage Regulator** (9 hours)

This block contains both teacher and student materials. Printed instructor materials include a plan of instruction detailing the units of instruction, duration of the lessons, criterion objectives, and support materials needed. Student materials consist of a student text used for all the modules; seven guidance packages containing objectives, assignments, review exercises and answers for each module; and a digest of modules 56 through 62 for students who have some background in these topics and only need to review the major points of instruction.

This material is designed for self- or group-paced instruction to be used with the other nine blocks. Most of the materials can be adapted for individualized instruction. Some additional military manuals and commercially produced texts are recommended for reference, but are not provided. Audiovisuals suggested for use with the entire course consist of 143 videotapes.

PLAN OF INSTRUCTION

(Technical Training)

ELECTRONIC PRINCIPLES

(Modular Self-Paced)

AIR TRAINING COMMAND

KEESLER TECHNICAL TRAINING CENTER

6 November 1975 - Effective 6 January 1976 with Class 760106

Volume 8

7-12

DEPARTMENT OF THE AIR FORCE
USAF Sch of Applied Aerosp Sci (ATC)
Keesler Air Force Base, Mississippi 39534

PLAN OF INSTRUCTION 3AQR30020-1
6 November 1975

FOREWORD

1. PURPOSE: This publication is the plan of instruction (POI) when the pages shown on page A are bound into a single document. The POI prescribes the qualitative requirements for Course Number 3AQR30020-1, Electronic Principles (Modular Self-Paced) in terms of criterion objectives and teaching steps presented by modules of instruction and shows duration, correlation with the training standard, and support materials and guidance. When separated into modules of instruction, it becomes Part I of the lesson plan. This POI was developed under the provisions of ATCR 50-5, Instructional System Development, and ATCR 52-7, Plans of Instruction and Lesson Plans.

2. COURSE DESIGN/DESCRIPTION. The instructional design for this course is Modular Scheduling and Self-Pacing; however, this POI can also be used for Group Pacing. The course trains both non-prior service airmen personnel and selected re-enlistees for subsequent entry into the equipment oriented phase of basic courses supporting 303XX, 304XX, 307XX, 309XX and 328XX AFSCs. Technical Training includes electronic principles, use of basic test equipment, safety practices, circuit analysis, soldering, digital techniques, microwave principles, and troubleshooting of basic circuits. Students assigned to any one course will receive training only in those modules needed to complement the training program in the equipment phase. Related training includes traffic safety, commander's calls/briefings and end of course appointments.

3. TRAINING EQUIPMENT. The number shown in parentheses after equipment listed as Training Equipment under SUPPORT MATERIALS AND GUIDANCE is the planned number of students assigned to each equipment unit.

4. REFERENCES. This plan of instruction is based on Course Training Standard KE52-3AQR30020-1, 27 June 1975 and Course Chart 3AQR30020-1, 27 June 1975.

FOR THE COMMANDER

W. H. HORNE, Colonel, USAF
Commander
Tech Tng Gp Prov, 3395th

OPR: Tech Tng Gp Prov, 3395th
DISTRIBUTION: Listed on Page A

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE
	Electronic Principles

BLOCK NUMBER	BLOCK TITLE
VIII	Principles and Applications of Electron Tubes

1 COURSE CONTENT	2 DURATION (Hours)
1. Electron Tube Characteristics and Diodes (Module 56)	4 (3/1)

a. Given the following electron tube terms, match each with its description: Cutoff; Peak inverse voltage rating; Peak current rating; Peak voltage rating; Transit time; Plate dissipation rating; Saturation; Emission. CTS: 6a Meas: W

(1) Define four types of emission:

(a) Thermionic.

(b) Secondary.

(c) Photoelectric.

(d) Field.

(2) The Emitter.

(a) Material considerations.

(b) Providing the environment.

(c) Emitting elements.

(d) Schematic symbols.

(3) Diode.

(a) Schematic symbols.

(b) Physical construction.

(c) Operation.

(d) E_p - I_p curve.

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(4) Electron tube limitations and terms.

(a) Peak current rating.

(b) Peak voltage rating.

(c) Peak inverse voltage rating.

(d) Plate dissipation rating.

(e) Transit time.

(f) Cutoff.

(g) Saturation.

(h) DC plate resistance

(5) Rectification.

(6) Limiting.

(7) Clamping.

b. Given diode circuit diagrams indicating direction of current flow and polarity of applied voltage, select the one which represents the conditions during conduction. CTS: 6a Meas: W

c. Given the schematic diagram of a diode electron tube circuit which indicates the supply voltage and the tube and load resistances, compute the circuit voltages and currents. CTS: 6a Meas: W

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-56, Electron Tube Characteristics and Diodes
KEP-ST-VII, Principles and Application of Electron Tubes
KEP-110
KEP-ST/Digest VIII, Modules 56-62 Digests

Audio Visual Aids
TVK-30-400, Diode Tubes, Emission and Space Charge
TVK-30-402, Half-Wave and Full-Wave Rectifiers
TVK-30-404, Bridge Rectifiers
TVK-30-405, Voltage Doublers

Training Methods
Discussion (3 hrs) and/or Programmed Self Instruction
CTT Assignment (1 hr)

PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

Instructional Guidance
Make specific objective assignments to be completed during CTT time. Assign a review in KEP-ST/Digest VIII for this module.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE
	Electronic Principles

BLOCK NUMBER	BLOCK TITLE
VIII	Principles and Applications of Electron Tubes

1 COURSE CONTENT	2 DURATION (Hours)
2. Triodes (Module 57)	7 (5/2)

a. Given a list of statements, select the one that describes the function of the control grid. CTS: 6a Meas: W

(1) Physical structure of triode tubes.

(a) Shape of control grid.

(b) Position of control grid with respect to the cathode and plate.

(2) Schematic symbol for triode tubes.

(a) Directly and indirectly heated cathodes.

(b) Gas filled.

(3) Effect of the control grid.

b. From a list of statements, select the one that describes the effect of changing bias on tube conduction. CTS: 6a Meas: W

(1) Operation steps.

(2) Characteristic curves.

(a) Types of curves.

(b) Development of place family of curves.

(c) Uses of plate family of curves.

(3) Triode parameters.

(a) Amplification factor.

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(b) AC plate resistance.

(c) Transconductance.

(d) DC plate resistance.

(4) Graphical analysis of a triode with load.

(a) Plot a DC load line for different values of load resistance.

(b) Plot a DC load line for different values of supply voltage.

c. Using triode amplifier diagrams, identify the bias type shown in each diagram as either fixed, cathode, or grid leak. CTS: 6a Meas: W

(1) Define bias.

(2) Types of bias:

(a) Cathode self bias.

(b) Fixed bias.

(c) Grid leak bias.

(3) Class of operation.

d. Given a family of E_p - I_p characteristic curves with a load line, select from alternatives the value nearest to three of the following: Plate voltage for a specified bias; Plate current for a specified bias; Bias required for cutoff; Bias required for saturation; Output signal for a given input signal. CTS 6a Meas: W

e. Given the diagram of a triode electron tube which indicates supply voltage, load resistance, and circuit current, compute the voltage drop across the tube and load resistor; indicate the direction of current flow. CTS: 6a Meas: W

(1) Basic triode amplifier.

(a) Calculate gain on DC load line.

(b) Effect of changing R_L on gain.

(2) Phase comparison.

(a) Grid and plate voltages.

(b) Grid voltage and plate current.

PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

(3) Amplifier configurations.

(a) Common cathode.

(b) Common grid.

(c) Cathode followers.

(4) Applications of triodes.

(5) Interelectrode capacitance.

(a) Grid to cathode.

(b) Grid to plate.

(c) Plate to cathode.

(d) Input capacitance.

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-57, Triodes
KEP-ST-VIII
KEP-110
KEP-ST/Digest VIII

Audio Visual Aids
TVK-30-452A, Triode Tubes (Construction & Characteristics)
TVK-30-452B, Triode Tubes (Bias)
TVK-30-453A, Triode Tubes (Tube Constants)
TVK-30-453B, Triode Tubes (Load Lines)

Training Methods
Discussion (5 hrs) and/or Programmed Self Instruction
CTT Assignment (2 hrs)

Instructional Guidance
Insure that CTT time assignment is given in KEP-GP-57 and the Digest. The concept of bias for a vacuum tube triode circuit is confusing to the students. Students are required to identify the three types of bias for triode amplifiers. Of the three, they experience the most difficulty identifying fixed bias. Some students are unaware that fixed bias can be obtained from a battery source and voltage divider network. They often assume there is a difference between the two since the diagrams are different. Most students experience little difficulty in constructing a load line, but very few are able to interpret the results. Objective 2d might be confusing to the student. The student text does not provide a detailed description of using load lines to determine the operating characteristics of a tube, therefore, the instructor must provide individual attention in this area for many students. Extra problems may help.
Use Audio Visual Aids.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE
	Electronic Principles

BLOCK NUMBER	BLOCK TITLE
VIII	Principles and Applications of Electron Tubes

1 COURSE CONTENT	2 DURATION (Hours)
3. Multigrid Electron Tubes (Module 58)	4 (3/1)

a. From a list of statements, select the one that describes the function of the tetrode screen grid. CTS: 6a Meas: W

(1) Need and purpose of screen grid.

(2) Tube construction and schematic diagram.

(3) Screen grid current and voltage.

(4) Characteristic curves.

(a) Secondary emission.

(b) Negative resistance.

(5) Tetrode characteristics (Compare to triode).

(a) Transconductance.

(b) Amplification factor.

(c) AC plate resistance.

b. From a list of statements and a schematic diagram, select the statement that describes the function of the pentode suppression grid. CTS: 6a Meas: W

(1) Need and function of the suppressor grid.

(2) Value and polarity of suppressor grid voltage.

(3) Physical construction and schematic diagram.

(4) Characteristic curves.

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COURSE CONTENT

(5) Tube characteristics (compare to triodes and tetrodes).

(a) AC plate resistance.

(b) Transconductance.

(c) Amplification factor.

c. From a list of statements and a pictorial diagram, select the statement that describes the function of beam forming plates. CTS: 6a Meas: W

(1) Need and purpose of beam power tubes.

(2) Location and shape of elements.

(3) Grid windings.

(4) Suppression of secondary emission.

(5) Schematic symbol.

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-58, Multigrid Electron Tubes
KEP-ST-VIII
KEP-110
KEP-ST/Digest VIII

Audio Visual Aids
TVK-30-456, Triodes, Pentodes and Multipurpose Tubes

Training Methods
Discussion (3 hrs) and/or Programmed Self Instruction
CTT Assignment (1 hr)

Instructional Guidance
Assign specific objectives to be covered during CTT time in KEP-GP-58, and reading the Digest portion of this module. Have students view TVK-30-456.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE
	Electronic Principles

BLOCK NUMBER	BLOCK TITLE
VIII	Principles and Applications of Electron Tubes

1 COURSE CONTENT	2 DURATION (Hours)
4. Special Purpose Electron Tubes (Module 59)	5 (4/1)

a. Given the characteristic curves of a voltage regulator gas tube, identify the values of the breakdown voltage; the operating voltage; the current range; the deionization voltage. CTS: 6b Meas: W

b. Given a list of statements, identify the purpose of the control grid in a thyratron tube. CTS: 6b Meas: W

(1) Thyratron construction.

(a) Type gases used.

(b) Grid construction.

(2) Thyratron schematic symbol.

(3) Thyratron operation.

(a) Firing point

(b) Method of deionizing tube

(c) Control ratio

c. Given the pictorial diagram of a simple two-electrode photo tube, identify the cathode; the anode. CTS: 6b Meas: W

d. Given the schematic diagram of a photo multiplier, identify the cathode, the anode; the dynodes. CTS: 6b Meas: W

e. Given the pictorial diagram of six element electron gun, the type used in a cathode ray tube, match each of the following elements with its function: control grid; cathode; preaccelerating anode; focusing anode; accelerating anode. CTS: 6b Meas: W

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COURSE CONTENT

f. Given a list of descriptions, match the term electrostatic or electromagnetic as the method described to control cathode ray tube; focus; beam deflection. CTS: 6b Meas: W

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-59, Special Purpose Electron Tubes
KEP-ST-VIII
KEP-110
KEP-ST/Digest VIII

Audio Visual Aids
TVK-30-458, Cathode Ray and Special Purpose Tubes
TVK-30-459, Gas Tubes

Training Methods
Discussion (4 hrs) and/or Programmed Self Instruction
CTT Assignment (1 hr)

Instructional Guidance
Make a specific CTT assignment in KEP-GP-59 and Block VIII Digest. Insure that students can identify the values given on the characteristic curves of a voltage regulator gas tube and other elements of tubes given in objectives, 4b, 4c, and 4d. Draw a large pictorial diagram of the CRT in objective 4e.

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PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE
	Electronic Principles

BLOCK NUMBER	BLOCK TITLE
VIII	Principles and Applications of Electron Tubes

1 COURSE CONTENT	2 DURATION (Hours)
5. Electron Tube Audio Amplifiers (Module 60)	5 (4/1)

a. Given a schematic diagram, multimeter, oscilloscope, and a trainer having an electron tube audio amplifier, determine the effects of changing component values and circuit voltage on the output signal. CTS: <u>6c</u> Meas: PC

(1) Need and purpose of an audio amplifier.

(2) Purpose of components.

(3) Circuit operation.

(4) Factors affecting amplifier gain:

(a) Amplification factor.

(b) Plate load resistance.

(c) Cathode resistance.

(d) Bias.

(5) Frequency response.

(a) Factors affecting low frequency response.

(b) Factors affecting high frequency response.

(6) Neutralization "requirements."

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COURSE CONTENT

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-60, Electron Tube Audio Amplifiers
KEP-ST-VIII
KEP-110
KEP-ST/Digest VIII

Audio Visual Aids
TVK-30-454, Amplifier Principles
TVK-30-455, Audio Amplifiers

Training Equipment
Triode Tube Characteristic Trainer 5484 (1)
Oscilloscope (1)
Sine-Square Wave Generator 4864 (1)
Power Supply 4912 (1)
Multimeter (1)

Training Methods
Discussion (3.5 hrs) and/or Programmed Self Instruction
Performance (.5 hr)
CTT Assignment (1 hr)

Multiple Instructor Requirement
Supervision (2)

Instructional Guidance
Give students specific objectives to cover during CTT time in KEP-GP-60. All students should accomplish the laboratory exercise because it reinforces the material presented in the student text. Students have difficulty understanding the relationship of component values and low frequency response. It should be emphasized when necessary that the four components which affect low frequency response are Cc, Ck, Rg, and Rk. Further, increasing any one of these components will improve low frequency response.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE
	Electronic Principles

BLOCK NUMBER	BLOCK TITLE
VIII	Principles and Applications of Electron Tubes

1 COURSE CONTENT	2 DURATION (Hours)
6. Electron Tube RF Amplifiers, Cathode Followers, DC Amplifiers and Triode Limiters (Module 61)	5 (4/1)

a. Given the schematic diagram of a pentode RF amplifier with a tuned output,identify the effects of changing the tuned circuit component values and output circuit loading on the amplitude and bandwidth of the output. CTS: 6d(1) Meas: W

(1) Function of components.

(2) Circuit operation.

(a) Tuned input.

(b) Tuned output

(c) Q of the tuned tanks.

(d) Bandwidth.

(3) Parameter changes.

(a) Effect on Q.

(b) Effect on bandwidth.

(c) Effect on amplitude.

b. Given a cathode follower schematic diagram determine the effects of changing the circuit component values on the output amplitude and impedance. CTS: 6d(2) Meas: W

(1) Use.

(a) Impedance matching.

(b) Power amplification

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ATC FORM APR 75 133 ATC Keesler 6-1020 REPLACES ATC FORMS 337, MAR 73, AND 770, AUG 72, WHICH WILL BE USED.

COURSE CONTENT

(2) Operation.

(a) Output impedance.

(b) Input impedance.

(c) Gain.

c. Given a list of statements and schematic diagram, select the statement that describes the characteristics of the DC Amplifier. CTS: 6d(3) Meas: W

(1) Purpose.

(2) Input circuit comparison.

(a) Resistance - capacitance coupling.

(b) Direct coupling.

(3) Operation.

(4) Frequency response.

d. Given the schematic diagram of a triode limiter, identify the effects of changing the grid resistor and grid bias on the shape of the output. CTS: 6d(4) Meas: W

(1) Methods of accomplishing limiting.

(a) Grid limiting.

(b) Cutoff limiting.

(c) Saturation limiting.

(d) Overdriven amplifier limiting.

(2) Parameter changes for grid limiter.

(a) Size of grid resistor.

(b) Amount of bias.

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-61, Electron Tube RF Amplifiers, Cathode Followers, DC Amplifiers, and Triode Limiters
KEP-ST-VIII
KEP-110
KEP-ST/Digest VIII

Audio Visual Aids
TVK-30-551B, Triode Limiters
TVK-30-434, Cathode Followers
TVK-30-457, Video Amplifiers
TVK-30-553, RF and IF Amplifiers
TVK-30-823, Pentode RF Amplifier

Training Methods
Discussion (4 hrs) and/or Programmed Self Instruction
CTT Assignment (1 hr)

Instructional Guidance
Assign specific objectives to be covered during CTT time in KEP-GP-61, and/or the Digest. Students have difficulty with the concept of loading a tuned circuit and analyzing the resulting change in bandwidth and stage gain. Many students require a review of the basic tuned circuit and its operating characteristics. A review of Q and its effect on bandwidth and gain should be helpful to the students. Students have considerable difficulty understanding grid limiting. Many understand how the positive portion of the input is limited, but forget about the phase shift across the tube. Since the output is taken off the plate, the limiting that occurs at the output should be stressed. Students also fail to understand the relationship between the size of the grid resistor and the amount of limiting in a grid limiter.

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PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE
	Electronic Principles

BLOCK NUMBER	BLOCK TITLE
VIII	Principles and Applications of Electron Tubes

1 COURSE CONTENT	2 DURATION (Hours)
7. Thyratron Sawtooth Generator, Phantastron, and Electron Tube Series Voltage Regulator (Module 62)	9 (6/3)
a. Given the schematic diagram of a thyratron sawtooth generator identify the effect of changing circuit voltages; component values; input trigger frequency. CTS: 6d(5) Meas: W	(2)
(1) Changing Circuit Voltage.	
(a) Supply voltage.	
(b) Grid voltage.	
(2) Changing component values.	
(a) Capacitor value.	
(b) Resistor value.	
(3) Changing input trigger frequency.	
(a) Frequency relationships.	
(b) Trigger levels.	
b. Given the schematic diagram of a triggered phantastron circuit, identify the effects on the amplitude, frequency and pulse width of the output waveform when changing the pulse width potentiometer; the control grid resistor; the control grid to plate capacitor; the input trigger frequency. CTS: 6d(6) Meas: W	(2)
(1) Changing pulse width potentiometer.	
(a) Plate rundown time.	
(b) Delay time.	

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

SIGNATURE	DATE	SIGNATURE	DATE

PLAN OF INSTRUCTION NO.	DATE	PAGE NO.
3AQR30020-1	4 December 1975	35

ATC FORM APR 75 133 ATC Keesler 6-1029 REPLACES ATC FORMS 337, MAR 73, AND 770, AUG 72, WHICH WILL BE USED.

COURSE CONTENT

(2) Changing control and grid resistor.

(3) Changing control grid to place capacitor.

(4) Changing input trigger frequency.

c. Given the schematic diagram of an electron tube series voltage regulator, identify the effects of changing the input voltage; the load resistance; the potentiometer position. CTS: 6a, 6d(3), 6d(7), Meas: W (2)

8. Measurement and Critique I

a. Measurement test

b. Test critique

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-62, Thyratron Sawtooth Generator, and Electron Tube Series Voltage Regulator
KEP-ST-VIII
KEP-110
KEP-ST/Digest VIII

Audio Visual Aids
TVK-30-460, Vacuum Tube Voltage Regulators
TVK-30-858, Phantastron
TVK-30-859, Sawtooth Generators
NIK 62-1, Thyratron Sawtooth Sweep Generator
NIK 62-2, The Phantastron

Training Equipment
Thyratron Sweep Generator Trainer 4666 (1)
Phantastron Trainer 4687 (1)
Power Supply Voltage Regulator Trainer 4871 (1)
Oscilloscope (1)
Attenuator Probe 10:1 (1)
Multimeter (1)
Power Supply 4912 (1)
Sine-Square Wave Generator 4864 (1)

Training Methods
Discussion (5 hrs) and/or Programmed Self Instruction
Performance (1 hr)
CTT Assignments (3 hrs)

Multiple Instructor Requirements
Supervision (2)

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COURSE CONTENT

Instructional Guidance

Assign specific objectives to be covered during CTT time for the next module each student will enter. Students have difficulty understanding the effects on output amplitude, frequency and linearity when the bias or B+ voltage is varied in the thyratron sawtooth generator. The laboratory exercise should assist in this area, and the instructor should emphasize the relationship between voltage changes and output. In the phanastron circuit students have the most difficulty in determining the effects on the output of varying the pulse width potentiometer. The concept of rundown time is vague to most students. The waveshapes in the student text illustrate the effects of varying the pulse width potentiometer on the output waveshape.

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PREPARE THE MAN

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Prepared by Keesler TTC
KEP-ST-VIII

Basic and Applied Electronics Department

ELECTRONIC PRINCIPLES

VOLUME VIII

PRINCIPLES AND APPLICATIONS OF ELECTRON TUBES

1 October 1974

7-12

Keesler Technical Training Center
Keesler Air Force Base, Mississippi

Designed For ATC Course Use

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Basic and Applied Electronics Department
Keesler Technical Training Center, Mississippi

Student Text 3AQR30020-1
KEP-ST-VIII
1 October 1974

Electronic Principles

Block VIII

PRINCIPLES AND APPLICATIONS OF ELECTRON TUBES

This Student Text is the prime source of information for achieving the objectives of this block of instruction. This training publication is designed for training purposes only and should not be used as a basis for job performance in the field.

CONTENTS

Supersedes Student Text, KEP-ST-VIII, 1 January 1974, which may be used until supply is exhausted.

Chapter 1

ELECTRONIC TUBE CHARACTERISTICS AND DIODES

1-1. The development of the electron tube created a new field of science called ELECTRONICS. This is the science dealing with the control of electrons by means of electron tubes or solid state devices. Although solid state devices were studied first in this course, electron tubes were developed and used long before transistors. Hence, much of the equipment in use today still contains electron tubes. Also, in even the very newest electronic equipment certain circuit applications require the use of electron tubes because no adequate solid state devices have been developed. Therefore, it is necessary that the technician study electron tubes as well as solid state devices.

1-2. Emission.

1-3. All electron tubes have one characteristic in common: free electrons are forced to leave the surface of a conductor and enter the space around it. This process of forcing electrons from the surface of a material is ELECTRON EMISSION. In electron tubes, emission must occur before tube current can flow. Four types of electron emission are discussed: thermionic, secondary, photoelectric, and field. For electrons to be emitted, some form of energy must be supplied to the emitting material.

1-4. THERMIONIC EMISSION. Thermionic emission of electrons occurs if a substance emits electrons when heat is applied. Metallic substances conduct electricity as a result of the motion of free electrons. At ordinary room temperature, these free electrons cannot escape the surface barrier of the metal. As the metal is heated, the velocity of the free electrons increases and they acquire greater energy. When the electrons acquire enough energy to overcome the surface barrier, they escape the metal surface. The amount of thermionic emission depends on the type and temperature of the emitting material. Most electron tubes use thermionic emission. The conductor from which the electrons escape is referred to as the emitter or CATHODE.

1-5. Thermionic emission from a solid is similar to evaporation from a liquid. The number of vapor molecules leaving the liquid, or the rate of evaporation, increases as the temperature of the liquid increases. The rate at which electrons escape the emitter surface likewise increases with an increase in temperature.

1-6. Figure 1-1 shows a cloud of electrons, called the space charge, surrounding a heated metal emitter. The figure also shows electrons leaving and returning to the emitter. The negatively charged electrons being emitted leave a positive charge on the emitter. At the same time, the electrons occupying the space charge region give that region a negative charge. These negatively and positively charged regions create an electrostatic field called the space charge field. This field causes some of the emitted electrons to be repelled back to the metal. An equilibrium point is reached in which the number of electrons returning to the emitter equals the number leaving.

1-7. SECONDARY EMISSION. Secondary emission occurs if a substance emits electrons when bombarded by atomic particles

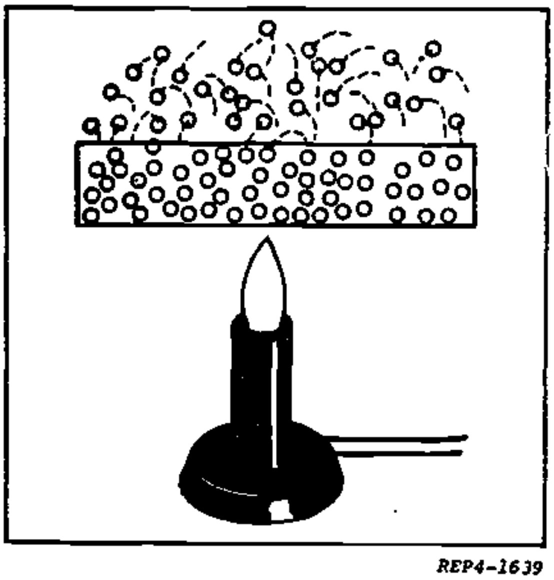

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Figure 1-1. Thermionic Emission

moving at high velocities. For instance, suppose a conductor with a large positive charge is placed near the emitted electrons in figure 1-1. If these electrons are accelerated so they strike the conductor with sufficient energy, free electrons will be dislodged from the surface of the positive conductor. Thus, electrons are emitted into the space surrounding the conductor as a result of secondary emission creating another space charge near the conductor.

1-8. The amount of secondary emission depends upon the number and velocity of the bombarding electrons and the substance they strike. Secondary emission in electron tubes is generally considered undesirable. In special applications, however, such as the photomultipliers, to be studied later, secondary emission is desirable.

1-9. PHOTOELECTRIC EMISSION. Photoelectric emission occurs if a substance emits electrons when exposed to light. This principle is widely used in such equipment as TV cameras, automatic door openers, and street light controls. Electron tubes utilizing photoelectric emission are discussed in chapter 4. The amount of emission depends upon the intensity and color of the light and the type of emitting material.

1-10. FIELD EMISSION is electron emission produced by strong electric fields. If a large difference of potential (voltage) exists between two conductors, the electrons in the negative conductor experience a strong attraction toward the positive conductor. When the voltage becomes large enough, the force of attraction overcomes the surface barrier of the negative conductor. Electrons are thus emitted from the conductor. The amount of emission depends on the value of the voltage and the distance between the conductors.

1-11. The Emitter.

1-12. MATERIAL CONSIDERATIONS. The material forming the emitter of an electron tube must be capable of emitting large quantities of electrons when heated. A good thermionic emitter requires low energy to transfer an electron from the emitter material to the surrounding space charge. The emitter must have good mechanical properties to withstand movement (shock). Also, its melting point must be higher than the temperature necessary for emission.

1-13. One pure metal which fulfills these requirements is tungsten, which requires a very high temperature for proper emission. Thorium oxide added to tungsten greatly improves emission at temperatures lower than those required by pure tungsten. Emitters made of thorium and tungsten are known as thoriated tungsten emitters.

1-14. Oxide-coated emitters operate at even lower temperatures. The oxide-coated emitter consists of a metal base--nickel or platinum alloy--coated with a layer of alkaline oxide, usually barium or strontium. Oxide-coated emitters have a long life and high emission efficiency. The chart in figure 1-2 illustrates the operational characteristics of the three emitter materials.

1-15. PROVIDING THE ENVIRONMENT. If an emitter were heated to its emission temperature in air, the oxygen in the air would oxidize the emitter and destroy its emitting properties in a short time. For this and other reasons, it is essential to enclose the elements of an electron tube in a controlled environment. Regarding environment, there are two types of electron tubes: high vacuum and gas.

1-16. The high vacuum or HARD tubes have their elements enclosed in a space where the pressure has been greatly reduced by removing most of the air.

MATERIAL	PHYSICAL STRENGTH	OPERATING TEMPERATURE	EFFICIENCY	USE
TUNGSTEN	VERY RUGGED	HIGH, 3390° C	LOW	HIGH POWER APPLICATIONS
THORIATED TUNGSTEN	RUGGED	MEDIUM 1650° C	MEDIUM	MEDIUM POWER APPLICATIONS
OXIDE COATED	STRONG	LOW, 800° C	HIGH	LOW POWER APPLICATIONS

Figure 1-2. Emitting Materials

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1-17. Without evacuation, the tube elements would be surrounded by the millions of gas molecules making up air. These molecules move in random directions at random speeds. Collisions between gas molecules and moving free electrons would be numerous. In such a situation, electron flow through the tube would be difficult. By reducing the pressure, the number of gas molecules is reduced drastically. This insures that a collision between a molecule of gas and a moving electron is very unlikely.

1-18. In the manufacture of high-vacuum tubes, many precautions are taken to insure the removal of gas even from the walls and electrodes within the tube. The electrodes are thoroughly cleaned and then heated in an atmosphere of hydrogen, which removes oxygen and water vapor. After the tube is assembled and connected to vacuum pumps, the electrodes are again heated by high frequency induction to remove other gases. Finally, the remaining gas is removed by the use of a GETTER - an active chemical substance such as barium, magnesium, aluminum, or tantalum in the form of a pellet which has the property of combining with gasses when it is vaporized. The pellet is vaporized by means of an induction coil and the result of this may be seen as a dark spot on the inside surface of glass tubes.

1-19. In gas or SOFT tubes, the air has been replaced by a specific gas. The gas substantially affects the electrical characteristics of the tube, as will be discussed later.

1-20. The container enclosing the tube elements in this high vacuum or gas environment is called the envelope. The envelope may be either glass, metal, or ceramic.

1-21. EMITTING ELEMENTS. The electron-emitting devices (cathodes) of electron tubes are divided into two general forms: directly heated cathodes and indirectly heated cathodes.

1-22. Figure 1-3 shows examples of directly heated cathodes made of wires (filaments) heated by the passage of electric current.

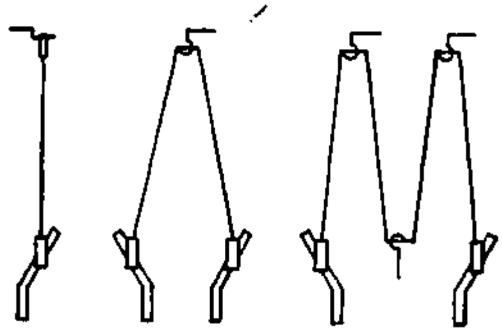

Figure 1-3. Directly Heated Cathode

The heat causes electron emission to take place directly from the wire. Since the heating current flows through the wire, the voltage drop across the wire is distributed along its length. Because all points of the wire are not at the same potential, the emission from the filament is not uniform. When AC is used to heat the filaments, alternating electrostatic fields and alternating voltages across the filament may produce undesirable variations in emission current (hum).

1-23. Figure 1-4 illustrates indirectly heated cathodes. A twisted (or folded loop of insulated tungsten wire is inserted in a

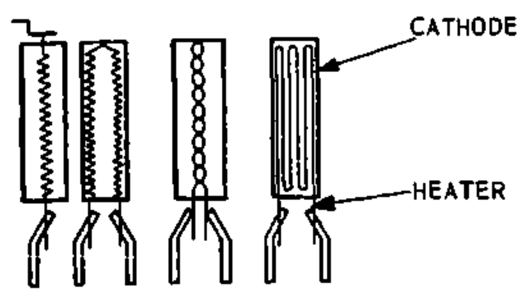

Figure 1-4. Indirectly Heated Cathode

thin-walled, hollow, metal cylinder usually made of nickel. An oxide coating on the outside of the cylinder emits electrons when heated. Heat is supplied by passing current through the tungsten wire (heater). Since no heating currents flow in the cylinder, all points on the cathode are at the same potential. The resulting emission current is then free of hum. The heater's only function is to heat the emitting material.

1-24. SCHEMATIC SYMBOLS. Figure 1-5 shows the schematic drawings for directly and indirectly heated cathodes. Note that a gas environment is indicated by a dot inside the circle.

1-25. Diodes.

1-26. Electron tubes are classified according to the number of electrodes they contain. Therefore, a diode (di-, meaning two; and -ode, meaning electrode) tube, as its name implies, is a two element tube. In a diode, the two electrodes are the plate (anode), which receives or collects the electrons, and the cathode, which emits the electrons.

1-27. SCHEMATIC SYMBOLS. Figure 1-6A shows the symbol for a directly heated cathode diode. Recall that the filament is both the cathode (emitter) and the source of heat. The indirectly heated cathode diode diagram in figure 1-6B displays the heater as well as the cathode. (The heater is not counted as one of the two electrodes in a diode because it only supplies heat.) For simplicity, the heater is not shown in many schematic diagrams.

1-28. PHYSICAL CONSTRUCTION. The electron tube diode is normally constructed in cylindrical form. Figure 1-7 shows this type structure. The plate is a cylinder placed around the cathode. Therefore, the electrons moving away from the cathode are in fact moving toward the plate.

1-29. OPERATION. The amount of current flow from cathode to plate in an electron tube depends on several factors. The most obvious factors (and the only ones of concern to the repairman) are the cathode temperature and the voltage difference between plate and cathode.

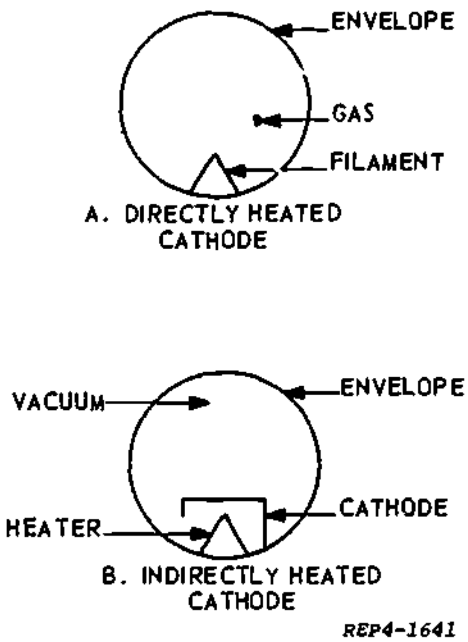

Figure 1-5. Schematic Symbols

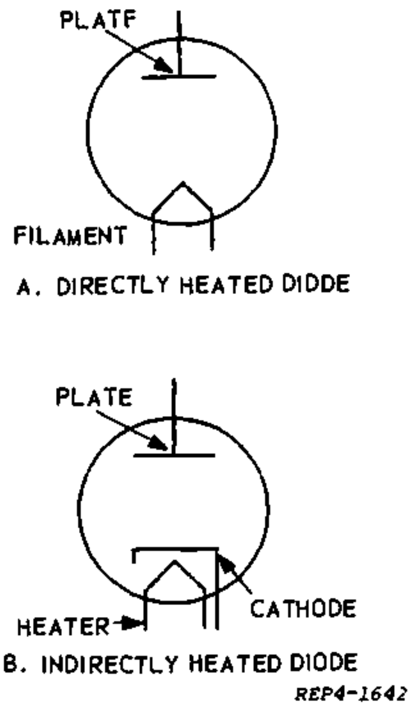

Figure 1-6. Diode Schematic Symbols

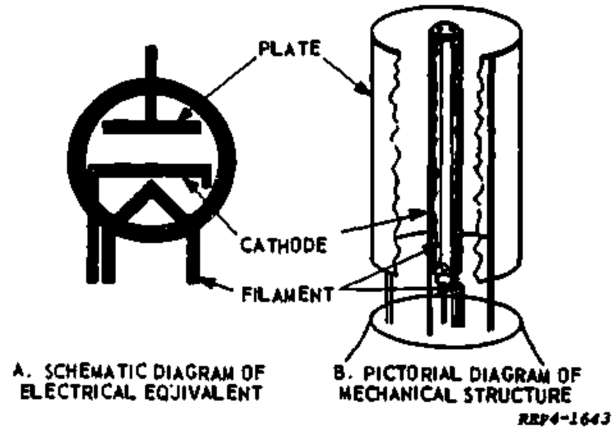

Figure 1-7. Diode Construction

1-30. The circuit in figure 1-8 is used to measure current flow and determine the effects of changing cathode temperature and plate-to-cathode voltage. The amount of current flow in a diode is known as the plate current and is abbreviated I_p. Plate current is measured by connecting an ammeter in series with the plate lead of the tube. The voltage between plate and cathode is known as the plate voltage and is abbreviated E_p. Plate voltage is measured by connecting a voltmeter between plate and cathode. Note that this voltage is not the same as the applied voltage, E_a. Also, E_p is ordinarily not the same as the plate-to-ground voltage because E_p is from PLATE-TO-CATHODE.

NOTE. E_p, E_{p-k}, and E_v are synonymous.

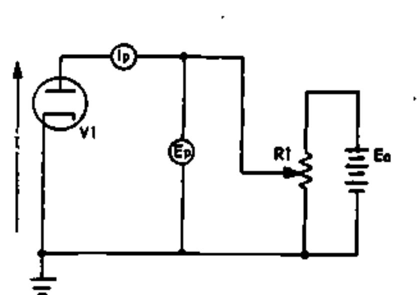

Figure 1-8. Diode Measurement Circuit

1-31. Recall that the cathode emits electrons and forms a space charge in the region surrounding the cathode. If E_p is negative, the plate repels the electrons in the space charge, and I_p is zero. This condition wherein plate current does not flow because the plate is negative with respect to the cathode is called CUT OFF. If E_p is positive, the plate attracts electrons from the space charge and plate current flows. The number of electrons attracted to the to the plate depends on the amount of attraction. As E_p increases in a positive direction, the attraction of the plate increases, and I_p increases.

1-32. The circuit in figure 1-8 can be used to determine the manner in which E_p affects I_p. I_p is measured for the different values of E_p obtained by adjusting potentiometer R1. The values of I_p and E_p are then plotted in a curve relating I_p to E_p. This curve is called an E_p - I_p curve.

1-33. Figure 1-9 is an example of an E_p - I_p curve for an electron tube diode. In region 1 to 2, curve A shows how I_p increases as E_p increases. Notice however, that I_p does not increase appreciably above point 2 as E_p increases further. At point 2, all the electrons are being attracted from the space charge, and the space charge is eliminated. The plate is attracting all the electrons the cathode is capable of emitting. Therefore, I_p cannot increase appreciably as E_p increases further. Region 2 to 3 is called the PLATE SATURATION region because I_p does not increase noticeably as E_p increases.

1-34. Curve B of figure 1-9 illustrates the effects of reduced filament or heater voltage. If this voltage is lower than the value specified by the manufacturer, the cathode temperature is too low. Because the cathode cannot emit as many electrons at the lower temperature, the current and voltage values for plate saturation are reduced in curve B. The overall effect is then to reduce the ability of the tube to pass large currents. For this reason, the filament or heater voltage must be correct for the tube to function properly.

1-35. The space charge of a diode does not reach equilibrium until the cathode reaches its normal operating temperature after warm-up. Because the plate of a tube attracts electrons from the space charge, the plate current will not stabilize during warm-up. Also, the cathode can be destroyed if a large plate voltage is applied before the tube is warmed up. Therefore, plate voltage is often not applied until the tube is warmed up.

1-36. Electron Tube Limitations and Terms.

1-37. Every electron tube has certain operating characteristics and limitations particular to that individual tube. These characteristics and limitations are normally published by the manufacturer in the data for the tube. A short description of selected characteristics and limitations follows.

1-38. PEAK CURRENT RATING. This limitation specifies the maximum instantaneous current a tube can pass in the normal direction of current flow without damage. The peak current rating is a function of the electron emission available and the duration of the pulses producing the peak currents.

1-39. THE PEAK VOLTAGE RATING is the maximum instantaneous voltage that can safely be applied to a tube in the normal direction (plate positive with respect to the cathode).

1-40. THE PEAK INVERSE VOLTAGE RATING lists the maximum instantaneous voltage that can safely be applied to a tube in the reverse direction. If the plate-to-cathode voltage exceeds this value, arc-over occurs, and the tube is damaged.

1-41. PLATE DISSIPATION RATING. When electrons are attracted from the space charge to the plate, the attracting force accelerates them. This acceleration gives them velocity and kinetic energy. As the electrons strike the plate, their kinetic energy is converted to heat in the plate. The amount of heat (power) dissipated by the plate is the difference between the power supplied by the plate voltage source and the power delivered to the load. Plate dissipation power for a tube is computed in the same manner as any other power. That is, plate dissipation = $E_p \times I_p$. The maximum amount of power that the plate can safely dissipate is called the PLATE DISSIPATION RATING. If this value is exceeded, the plate will overheat and be damaged or destroyed.

1-42. TRANSIT TIME. Because electrons have mass, they cannot be accelerated from cathode to plate in zero time. The time required for an electron to travel from cathode to plate is the TRANSIT TIME. If the transit time is comparable to the period of an applied signal, the tube no longer treats the signal as it should. Therefore, the transit time places a limit on the highest frequency that can be successfully used in many electron tube circuits. Special tubes for use only at high frequencies are presented later in this course.

1-43. CUT OFF. Recall that when the plate is negative compared to the cathode, plate current is zero. A diode tube is said to be CUT OFF any time I_p is zero because E_p is negative with respect to the cathode.

1-44. SATURATION. When a further increase in positive plate voltage fails to produce an increase in plate current, a tube is said to be SATURATED.

1-45. DC PLATE RESISTANCE. The DC plate resistance of a tube is the opposition the tube offers to plate current when DC voltage is applied. DC plate resistance, R_p is the ratio of DC plate voltage to DC plate current. That is, $R_p = E_p/I_p$. Since R_p is calculated from DC values, it is known as the STATIC resistance. The E_p - I_p curve for a diode is used to determine R_p for that diode. The E_p - I_p curve gives the value of I_p if E_p is known or the value of E_p if I_p is known. From these two quantities, the DC plate resistance can be calculated.

1-46. DC plate resistance is computed easily for the diode represented by figure 1-10. For instance, at point M, $E_p = 60$ V and $I_p = 86$ mA. Thus, $R_p = 60$ V/86 mA = 700 Ω. Likewise at point N, $E_p = 100$ V, $I_p = 95$ mA, and $R_p = 100$ V/95 mA = 1050 Ω.

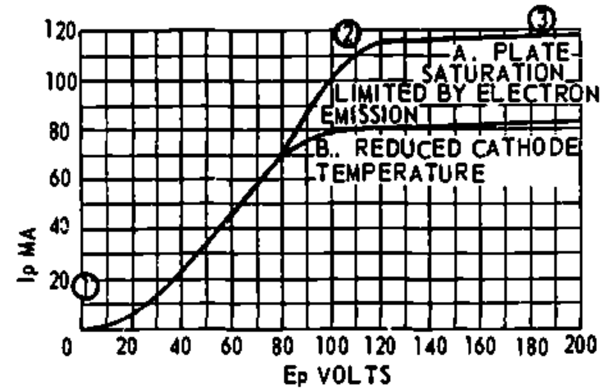

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Figure 1-9. Diode E_P - I_P Curve

Notice that the DC plate resistance is not the same for the two points. Because R_P is not constant, plate current flow is not directly proportional to plate voltage. Consequently, an electron tube diode is a NONLINEAR RESISTANCE. Tube diodes are nonlinear resistances not only in that they conduct current in only one direction, but also in that R_P is not constant during conduction.

1-47. Once determined, the value of R_P for a diode in a circuit can be used to calculate current and voltage values. For example, the total current, I_t, and the two voltage drops, E_P and E_R, can be computed for the circuit in figure 1-11.

$R_t = R_P + R_1 = 1.0\ k\Omega + 19\ k\Omega = 20\ k$

$I_T = E_A / R_t = 200\ V / 20\ k\Omega = 10\ mA$

$E_P = I_T R_P = 10\ mA \times 1.0\ k\Omega = 10\ V$

$E_R = I_T R_1 = 10\ mA \times 19\ k\Omega = 190\ V$

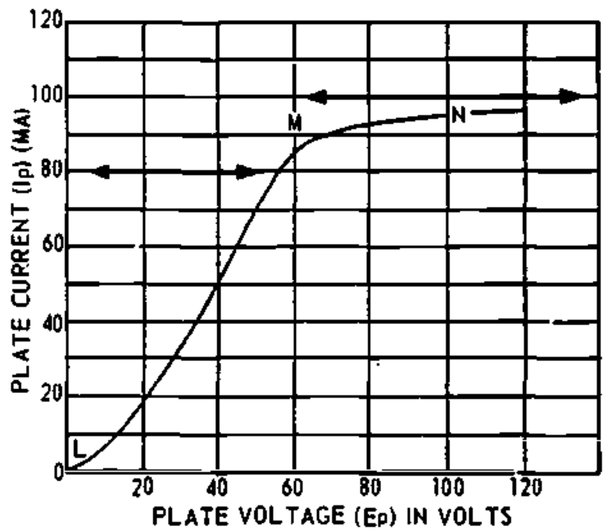

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Figure 1-10. E_p - I_p Curve

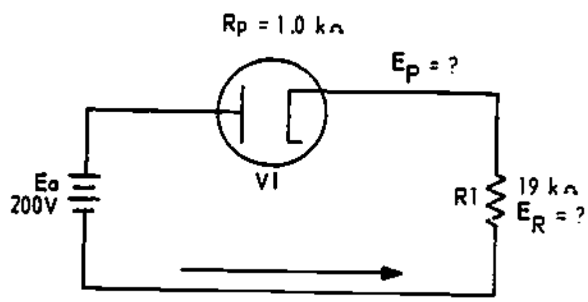

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Figure 1-11. Diode Circuit

1-48. Typical Diode Applications.

1-49. RECTIFICATION. As illustrated in figure 1-12, an electron tube diode can function as a rectifier. V_1 can rectify because it allows current to flow in only one direction. Between times T_1 and T_2 in figure 1-12B, the plate of V_1 is more positive than the cathode. Therefore, the diode conducts and allows current to flow as indicated in figure 1-12A. When current flows in this direction, a positive voltage is developed across R_1. The voltage across R_1 thus follows the secondary voltage between T_1 and T_2. Between times T_2 and T_3, the plate of V_1 is negative compared to the cathode. As a result, the diode does not conduct, no current flows, and the voltage across R_1 is zero.

1-50. Recall that the action of this rectifier is identical to the action of the solid state half wave rectifier studied previously. Similarly, electron tube diodes can be used as full wave, bridge, three phase, and voltage doubler rectifiers.

1-51. Figure 1-13 is an example of an electron tube diode limiter. The operation of this series positive limiter is almost the same as the operation of the solid state diode series positive limiter. Just as solid state diodes were used for series or shunt positive or negative limiters, electron tube diodes are used for these same circuits.

1-52. CLAMPING. An electron tube negative clamper is illustrated in figure 1-14. This circuit functions in the same manner as the solid state version. As expected, electron tube diodes may be used in positive clampers also.

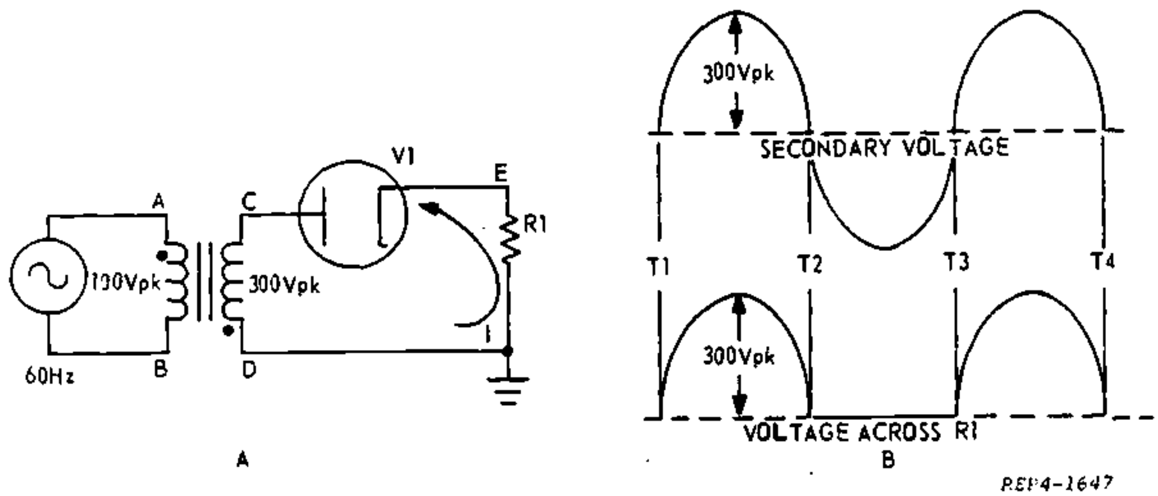
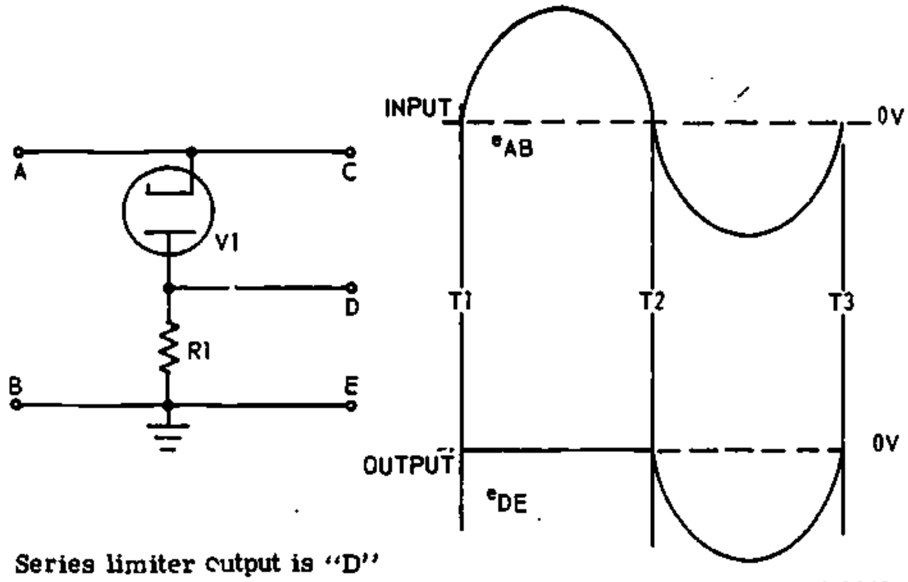


Figure 1-12. Diode Rectifier and Waveforms



Note: Series limiter cutput is "D" to "E" Sh'unt output is taken across C and D

REP4-1648

Figure 1-13. Shunt Negative or Positive Series Diode Limiter

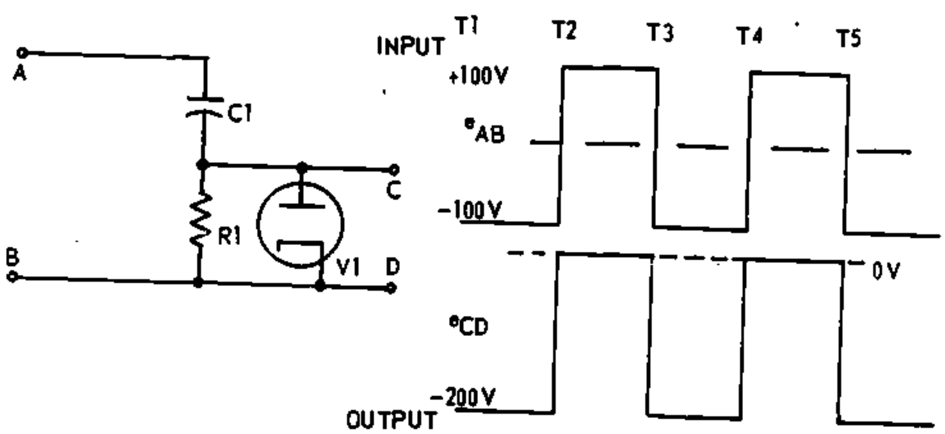


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Figure 1-14. Negative Shunt Clamper

Chapter 2

TRIODES

2-1. Diode electron tubes can be used as rectifiers, clampers, etc.; however, they can not be used to amplify electronic signals. A third element must be introduced to allow amplification in an electron tube. This new element, called the control grid, controls tube current and makes amplification possible because a small change in voltage applied to the grid causes a large change in tube current. With the addition of this third active electrode, the tube must now be called a TRIODE.

2-2. The Control Grid.

2-3. The control grid is a wire mesh positioned around and close to the cathode. This wire mesh is most often in the form of a wire wrapped in a coil, or helix. Figure 2-1A illustrates the physical construction of such a wire coil. Other grid structures also exist, such as the one shown in figure 2-1B. The position of the grid with respect to the plate and cathode is seen in figure 2-1C and 2-1D.

2-4. Figure 2-1D also shows the schematic symbol used for a triode and the relation of the parts of the symbol to the actual structure of the tube. Notice that the plate and cathode of the triode are represented in the same way as they are in a diode. The grid is represented by a dashed line located between plate and cathode. Triodes employ directly or indirectly heated cathodes and the schematic diagram will so indicate. If a triode is gas filled, a dot is placed inside the diagram to identify the presence of the gas.

2-5. The operation of the triode electron tube is basic to the operation of all other electron tubes except diodes. For this reason a clear understanding of the theory of operation of triodes is essential.

2-6. Effect of the Control Grid.

2-7. The important thing to remember about the control grid is that it is close to the cathode and that the space between the individual loops is relatively large. Being close to the cathode gives the grid the ability to control the electrons near the cathode, and the space between the loops permits the electrons to travel through the grid to the plate. The function of the control grid is to control the amount of current flowing between cathode and plate. In order to understand how the grid controls current flow, the effect on the grid of the electrons near the cathode must be studied.

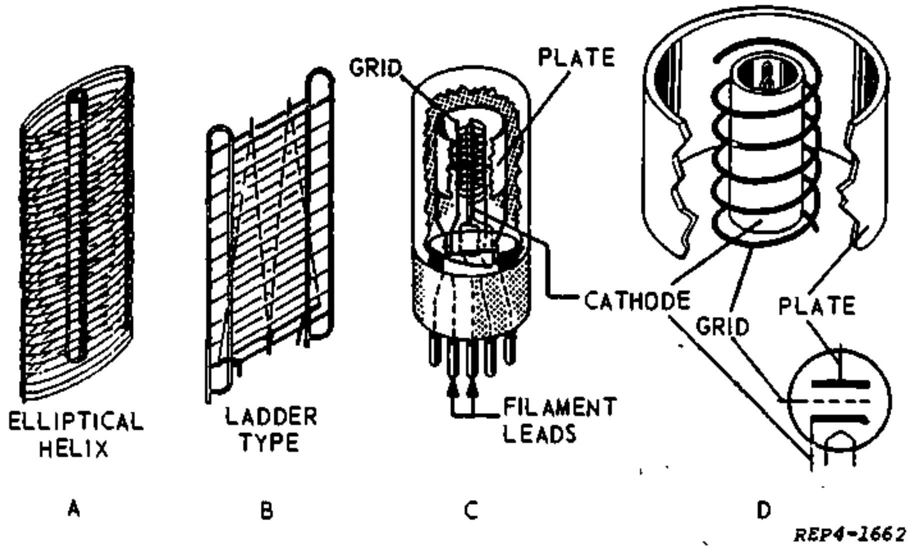

Figure 2-1. Physical Structure and Schematic Symbol for Triodes

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2-8. During the operation of a triode tube, voltages are applied to the tube electrodes with respect to each other and with respect to a common reference (usually ground). These voltages establish electrostatic fields between the tube electrodes. The direction and strength of these fields are governed by the polarity and value of the applied voltages. The behavior of the electrons within the tube depends on the forces of attraction or repulsion caused by these electric fields.

2-9. A very important detail concerning the operating voltages for triodes (as well as other electron tubes) is the reference point of the applied electrode voltages. All electrode voltages are measured with respect to the cathode. Thus, "the plate voltage is 200 volts," means that the plate is +200 volts with respect to the cathode. Likewise, "grid voltage," means grid voltage measured with respect to the cathode. If a DC reference voltage is applied between the grid and cathode, it is referred to as the, "BIAS".

2-10. An imaginary view of the electrodes of a triode is shown in figure 2-2. Voltages have not been applied to the plate or grid, but the cathode is at emitting temperature. The letter "K" designates the electron emitting cathode, "G"-the control grid, and "P" the plate or anode. The separation between the grid wires is large enough to allow electrons to travel between the wires toward the plate. The space charge (made up of a cloud of electrons) is shown by the tiny dots between the cathode and the control grid.

2-11. With zero volts applied to all electrodes, there are no electrostatic forces on the electrons between the tube elements. The electrons emitted from the heated cathode form a space charge close to the cathode surface. Since the emission velocity of the electrons is low, few electrons have sufficient energy to travel as far as the grid or plate. For this reason, the greatest space charge dentsity exists near the cathode.

2-12. In figure 2-2, note the physical locations of the control grid and the plate relative to the space charge. The control grid is

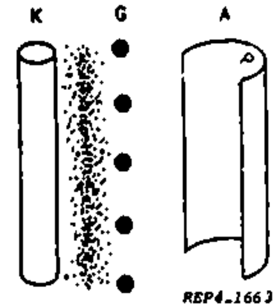

Figure 2-2. Triode Electrodes and Space Charge

much closer to the space charge than the plate. In fact, the entire space charge is assumed to be located between the cathode and the control grid. The electrons comprising the plate current of a triode must flow between the grid wires. Therefore, the voltages on both the grid and plate are effective in controlling plate current. The grid, however, being closer to the space charge (and cathode), has more control over plate current than does the plate. It is this feature which produces amplification in a triode electron tube.

2-13. ZERO GRID VOLTAGE. Explanation of the effect of the control grid will begin with the condition where grid voltage, E_g, is held at zero volts while plate voltage (E_p) is varied. Consider the circuit of figure 2-3 in which ammeter M1 is connected in series with the plate to measure plate current (I_p). Plate voltage is supplied by a variable DC source which can be adjusted to any desired value.

2-14. If E_p is adjusted to zero volts, all the electrodes are at the same potential (zero). Therefore, no electrostatic forces affect the emitted electrons and the electrons are neither attracted nor repelled by any of the electrodes. As a result, M1 reads zero, and a space charge builds up near the cathode.

2-15. If the control grid is held at zero volts while the plate voltage is increased to +100 volts, an electrostatic field is established between the plate and cathode. The grid remains at zero volts so it has no

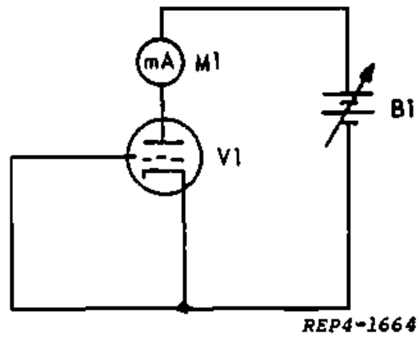

Figure 2-3. Triode with E_g = 0 V

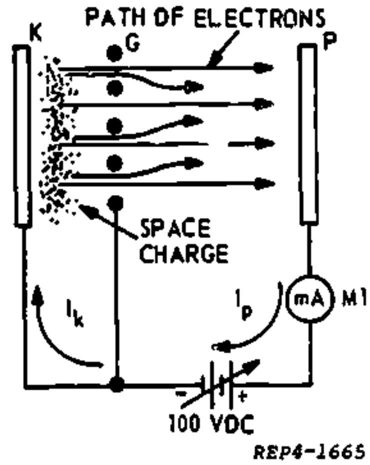

Figure 2-4. Electron Movement with E_g = 0 V

influence on the electrons. However, because the plate is now positive, it exerts a force of attraction on the electrons. Since the electrons in the space charge are free to move, the positive plate pulls the electrons toward it. In doing so, the electrons pass through the spaces between the control grid wires and move toward the plate as shown in figure 2-4.

2-16. For each electron removed from the space charge by the positive plate, another electron is supplied to the space charge by the cathode. This action creates a continuous current flow from the cathode to the plate, through the DC source, and back to the cathode. This current path forms a series circuit with M1 indicating the amount of current flow. Plate current, I_p, is the current flowing between the plate and the DC source. Cathode current, I_k, flows between the DC source and the cathode and is equal to the plate current for this example.

2-17. So far, the action of the triode is like that of a diode. The control grid, at cathode potential, contributes very little to the behavior of the triode. It is important to know, however, that a voltage applied to the control grid can control the amount of plate current. In the following discussion the effect of a positive or negative voltage applied to the grid is discussed.

2-18. NEGATIVE GRID VOLTAGE. Now, if a negative voltage is applied to the grid, it will exert a force on the electrons in the space charge. The positively charged plate tries to attract the electrons. The negatively charged grid tries to repel the electrons back toward the cathode. The relative strength of these two forces determines the number of electrons allowed to move through the openings in the grid and on to the plate.

2-19. When a 1 volt battery is inserted as in figure 2-5, the grid becomes 1 volt negative with respect to the cathode. The rest of the circuit is identical to the circuit in figure 2-4. Compared to the case where E_g = 0, the -1 volt negative grid acts to repel some of the electrons back toward the cathode. Since the plate's force of attraction has not changed, fewer electrons travel to the plate.

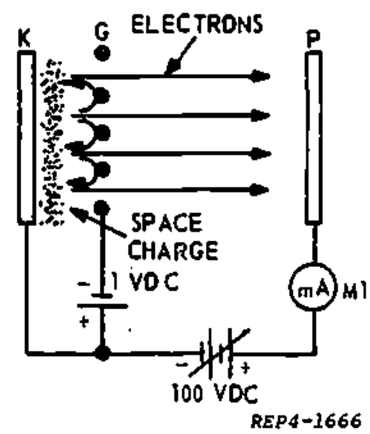

Figure 2-5. Electron Movement with E_g = -1 V

Hence, plate current is reduced and M1 indicates a lower current reading than that indicated when $E_g = 0$. The resultant electron paths are seen in figure 2-5.

2-20. From the simple relationship between numbers, it would seem that the +100 volts on the plate would overpower the -1 volt on the grid. However, this is not the case because the control grid is much closer to the space charge than the plate. Therefore, a small voltage on the grid can exert much more force on the electrons than a large voltage on the more distant plate.

2-21. As the grid is made increasingly negative, it repels more and more electrons back toward the cathode. As a result, plate current decreases accordingly. Eventually, a point is reached where the grid is sufficiently negative to repel all the electrons back into the space charge. When the grid reaches this negative voltage and plate current ceases to flow, the tube is said to be CUT OFF. The negative grid voltage required to achieve this condition is called the cut off voltage. Figure 2-6 illustrates the movement of electrons when the grid voltage is equal to or greater than the cut off voltage.

2-22. POSITIVE GRID VOLTAGE. The voltage applied to the control grid is sometimes positive. Although it is not the most common situation, an explanation is of value because a positive grid is used in several triode applications.

2-23. Reversing the polarity of the control grid voltage reverses the direction of force caused by the grid. Because the grid is now positive, it no longer repels the space charge electrons but rather attracts electrons from the space charge. The positive plate still exerts the same force of attraction on the electrons as before. Therefore, the total force of attraction is larger, and the total number of electrons attracted from the space charge is larger. As a result, an increased number of electrons pass through the grid openings and travel to the plate. This situation is seen in figure 2-7. Because more electrons are now moving from cathode to plate, plate current is larger than in any previous case.

2-24. As the positive grid voltage is increased, plate current increases up to a point. When a further increase in positive grid voltage fails to produce an increase in plate current, the tube is said to be SATURATED.

2-25. It was mentioned earlier that positive grid voltage is seldom used. Positive grid voltage is avoided in most cases because grid current flows when E_g is positive. With E_g positive, the positive grid wires attract and intercept many of the electrons passing through the grid openings. These intercepted electrons flow out through the grid connection of the tube and result in grid current. Grid

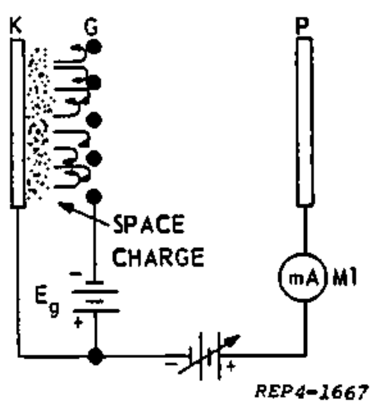

Figure 2-6. Electron Movement at or Beyond Cut Off

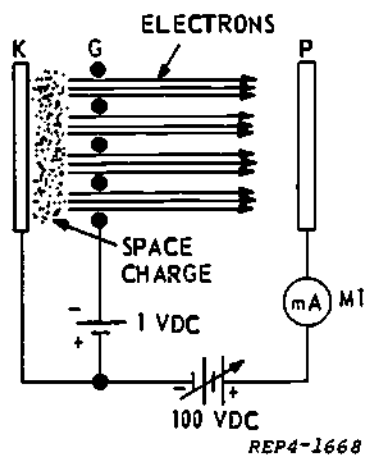

Figure 2-7. Electron Movement with $E_g = +1$ V

current is generally undesirable because it dissipates wasted power in the grid circuit. Note that when grid current flows, cathode current must equal the sum of the grid current and the plate current.

2-26. When the grid is negative, the grid wires intercept only an extremely small number of electrons because most of the electrons are repelled. Because only a few electrons flow in the grid circuit, a tube with negative E_g presents a high impedance to the grid circuit. However, because many electrons flow in the grid circuit, a tube with a positive E_g presents a low input impedance to the grid circuit. This low impedance can easily cause signal distortion, thus indicating another reason why positive grid voltages are rare.

2-27. The extent to which a grid voltage controls plate current is determined by the design of the tube. The degree of control provided by the grid depends on the spacing of the grid wires and the position of the grid with respect to the plate and cathode. Changing the grid voltage by 1 volt may then have the same effect on the plate current as changing the plate voltage by 20, 50, or even 100 volts.

2-28. It should be pointed out that the effect of plate voltage on plate current for a triode is similar to the effect for a diode. That is, if E_p decreases, I_p decreases, etc.

2-29. Characteristic Curves.

2-30. The relationships between the voltages applied to the triode and their effects on the plate current are very important. These relationships between grid voltage, plate current, and plate voltage are expressed graphically with CHARACTERISTIC CURVES. Characteristic curves illustrate the behavior of an electron tube as the electrode voltages are varied. In the case of the triode, there are three possible sets of curves that can be developed. These are the (1) grid family of curves, (2) plate family of curves, and (3) constant current family of curves. The plate family of curves will be developed in this chapter because these curves are the most useful in analyzing electron tube circuits. An understanding of these characteristic curves and what they reveal about the triode is necessary when studying triode circuits.

2-31. From this point forward, changes in cathode temperature will be disregarded. It will be assumed that the filament or heater has the proper voltage applied. The remaining basic factors contributing to variations in plate current are grid voltage and plate voltage. The circuit in Figure 2-8 can be used to determine the effects of these voltages and develop the characteristic curves. Note that only DC voltages are applied and that there is no resistor in the plate circuit.

2-32. PLATE CHARACTERISTIC CURVES. The plate curves for triodes are developed by holding the grid voltage constant and varying the plate voltage to determine its effect on plate current. Since it is the plate voltage that is varied, these curves are called the PLATE CHARACTERISTIC or E_p - I_p curves.

2-33. The plate characteristic curves are easily developed using the circuit in figure 2-8. To obtain the first curve (E_g = 0)

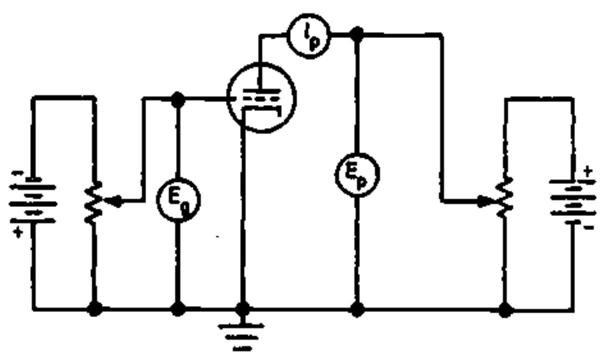

Figure 2-8. Circuit for Plotting Characteristic Curves

shown in figure 2-9, the grid potential is adjusted to zero volts. The plate voltage is then increased in steps, starting at zero volts, and the plate current is plotted for each of the values of plate voltage. The result is the curve labeled $E_g = 0$. The second, third, etc., curves are plotted using the same procedure with grid voltages of -2 volts, -4 volts, etc. Notice that the curves representing the more negative grid voltages are displaced farther to the right along the plate voltage axis.

2-34. Each of the curves represents a plot of plate current (I_p) against plate voltage (E_p). The individual curves can be compared to the static E_p - I_p curves developed for the diode in Chapter 1. The similarity between the diode E_p - I_p curves and the triode E_p - I_p curves is quite apparent. The curves are similar because when the grid voltage of a triode is maintained at a fixed value the grid contributes nothing to the change of plate current. Under this condition, the triode is essentially a DIODE with the change of plate current being a function of plate voltage only. Since the shape and position of the curves depend on internal construction, each different tube type will have a different family of characteristic curves.

2-35. Because the plate family of curves is the most convenient to use, it is the one most often published in tube manuals. It should be noted that all three families of curves mentioned previously contain essentially the same

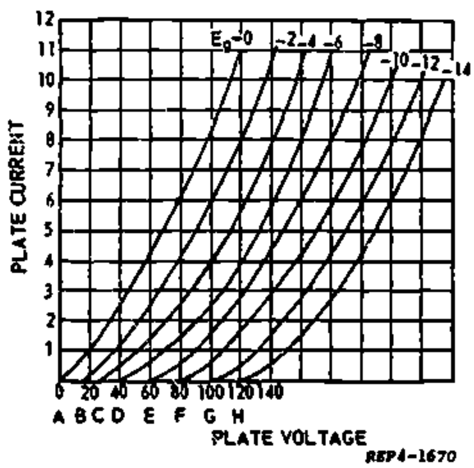

Figure 2-9. A Family of E_p - I_p Curves

information. The two families not treated herein can be derived from the E_p - I_p curves.

2-36. One use of the plate family of curves can be shown by the following example. Assume that it is necessary to determine the amount of plate current that would exist at a plate voltage of 100 volts and a grid voltage of -2 volts. First, locate the vertical line in figure 2-9 that represents 100 volts plate voltage. Find the point where this line intersects the -2 volt curve. Reading from the plate current (I_p) axis, this point of intersection represents a plate current of 6 mA.

2-37. It is quite apparent that the family of curves reveals much about the behavior of an electron tube. As noted previously, only DC voltages were applied to the tube and no components other than the tube were included in the circuit of figure 2-8. The curves that were obtained under these conditions are called STATIC CURVES. The use of the word STATIC in connection with the characteristic curves means that the curve represents the tube behavior under no-load conditions with only DC voltages applied. When a load is inserted in the circuit, DYNAMIC CURVES can be developed.

2-38. Triode Parameters.

2-39. The suitability of any particular triode tube for a specific circuit application is dependent on the behavior of that tube as its electrode voltages are varied. The behavior of the plate current is a function of the separation between the electrodes, the shape and size of the electrodes, and other physical details. This behavior is expressed by a series of electrical quantities known as TUBE PARAMETERS. These quantities may be referred to as CHARACTERISTICS or COEFFICIENTS in other applicable literature. The tube parameters are simply specifications which reveal the capabilities and limitations of a tube, the same as engine specifications reveal the capabilities and limitations of an automobile engine.

2-40. The parameters of interest are the: (1) amplification factor (μ), (2) AC plate resistance (r_p), and (3) transconductance (g_m). Notice that the parameters of a tube determine the tube's behavior and that this behavior is illustrated in the tube's characteristic curves. Therefore, the tube parameters can be determined from the characteristic curves developed previously.

2-41. AMPLIFICATION FACTOR. By definition, the amplification factor is the ratio of a change in plate voltage to a change in grid voltage, with plate current constant. It is an indication of the effectiveness of the control grid voltage relative to the plate voltage in controlling the plate current. Expressed mathematically it is:

$$\mu = \frac{\Delta E_p}{\Delta E_g} (I_p \text{ constant})$$

μ (mu) is the amplification factor, ΔE_p is the change in plate voltage, ΔE_g is the change in grid voltage, and I_p is the plate current.

2-42. The amplification factor is a number without units. For example, assume a certain tube has a μ of 20. This means that if a change in grid voltage produces a certain change in plate current, the change in plate voltage required to return the plate current to the original value is 20 times as large. In other words, the grid voltage is 20 times more effective than the plate voltage in its influence upon the space charge and, consequently, on the plate current.

2-43. To illustrate, suppose that a grid change from -2.0 to -2.3 volts produces a plate current change from 6 mA to 5 mA, and that the plate voltage must be changed from 100 to 109 volts to return the plate current to 6 mA. Then:

$$\mu = \frac{\Delta E_p}{\Delta E_g} = \frac{109 - 100}{2.3 - 2.0} = \frac{9 \text{ V}}{0.3 \text{ V}} =$$

$$(I_p \text{ constant} = 30 \text{ at } 6\text{mA})$$

Thus the amplification factor is 30.

Emphasis is placed on the fact that it is the change in plate voltage and the change in grid voltage that are important and not the individual values of plate and grid voltage.

2-44. The amplification factor can be determined from the plate family of characteristic curves. The method used is now presented using the E_p - I_p curves shown in figure 2-10. In this determination, a center point is chosen on the characteristic curves, and all parameter calculations are based on this same reference point. For this example. center point "A" is chosen because it is located where the curves are nearly parallel and equally spaced. The formula for μ indicates that current must be constant. The horizontal 10.3 mA line is therefore chosen because it passes through point "A". Two points on the current (10.3 mA) line are now chosen, usually at E_g lines. Use the points where the 10.3 mA line intersects the 0 volt and -4 volt E_g lines.

2-45. The point where the 10.3 mA line intersects E_g = 0 volts indicates that the plate voltage will be 110 volts. Likewise, the second point shows that the plate current will remain at 10.3 mA if the grid voltage changes to -4 volts and the plate voltage changes to 190 volts. The change in plate voltage (110 to 190) is 80 volts; the change in grid voltage (0 to -4) is 4 volts. The necessary values are substituted into the formula, and the solution is as follows:

$$\mu = \frac{E_p}{E_g} (I_p \text{ constant})$$

$$\mu = \frac{190 - 110}{4 - 0} = \frac{80}{4}$$

$$\mu = 20$$

2-46. TRANSCONDUCTANCE. Conductance (G) is defined as the reciprocal of resistance (R). The relationship is expressed as $G = \frac{1}{R}$

where G is the conductance in MHOS and R is the resistance in OHMS. (Observe that mho is ohm spelled backwards.) Conductance may be calculated by dividing CURRENT BY VOLTAGE just as resistance may be determined by dividing VOLTAGE BY CURRENT. This relationship is expressed as $G = \frac{I}{E}$ where G is conductance in mhos, I is current in amperes, and E is voltage in volts.

2-47. The term "transconductance" in electron tubes is used to express the ratio of change in plate current to a change in grid voltage. This grid-to-plate transconductance may be called the MUTUAL CONDUCTANCE of the tube in other applicable literature.

2-48. More accurately, transconductance is the ratio of a change in plate current to the change in grid voltage that produced it-with plate voltage remaining constant. The symbol for transconductance is g_m; the unit is the mho. Since the mho is a relatively large unit, transconductance is usually listed by manufactureres in terms of micromhos. This parameter is calculated from the formula:

$$g_m = \frac{\Delta I_p}{\Delta E_g} \text{ (} E_p \text{ constant)}$$

g_m is the transconductance in mhos, ΔI_p is the change in plate current in amperes, ΔE_g is the change in grid voltage, and E_p is the plate voltage.

2-49. Assume that a tube manual shows that a certain tube has a g_m of 3000 micromhos. The significance of this figure is simply that a change of 1 volt on the grid will cause a change of 3 mA in the plate current.

2-50. Transconductance for a triode may be calculated from the $E_p - I_p$ curves using the g_m formula. Again, figure 2-10 will be used to show the example. Because point A was used as the center point for computing μ, it must also be used to compute g_m. The formula for g_m indicates that plate voltage must remain constant. The vertical 150 volt line is then chosen because it passes through point A. Two points on the voltage line are now chosen, usually at E_g lines. Use the points where the 150 volt line intersects the 0 and -4 volt E_g lines. I_p is seen to be 15 mA and 6 mA respectively. g_m is computed as follows:

$$g_m = \frac{\Delta I_p}{\Delta E_g} \text{ (} E_p \text{ constant)}$$

$$= \frac{0.015 - 0.006\text{A}}{4 - 0 \text{ V}} = \frac{0.009\text{A}}{4 \text{ V}} = 0.00225 \text{ mho}$$

g_m = 0.00225 mho or 2,250 micromhos

2-51. AC PLATE RESISTANCE. A third parameter is AC plate resistance, whose symbol is r_p. The AC or dynamic resistance (r_p) is a measure of the opposition the tube presents to a changing plate voltage. It is defined as the ratio of a change in plate voltage to the change it causes in plate current, with grid voltage remaining constant, r_p is calculated from the static $E_p - I_p$ curve by the formula:

$$r_p = \frac{\Delta E_p}{\Delta I_p} \text{ (} E_g \text{ constant)}$$

2-52. Figure 2-10 is again used for the example. Also, point A is still the center point for the computation. Since E_g must be held constant, the -2 volt grid line is chosen. Two additional points are chosen on this line, such as those where E_p = 175 volts and I_p = 13.2 mA and where E_p = 125 volts and I_p = 7.6 mA. Applying the formula gives:

$$r_p = \frac{\Delta E_p}{\Delta I_p} \text{ (} E_g \text{ constant)}$$

$$= \frac{175 - 125 \text{ V}}{13.2 - 7.6 \text{ mA}} = \frac{50 \text{ V}}{0.0056\text{A}} = 8{,}900\,\Omega$$

r_p = 8,900 or 8.9 k

2-53. None of these parameters are fixed, constant values within a given tube. Their

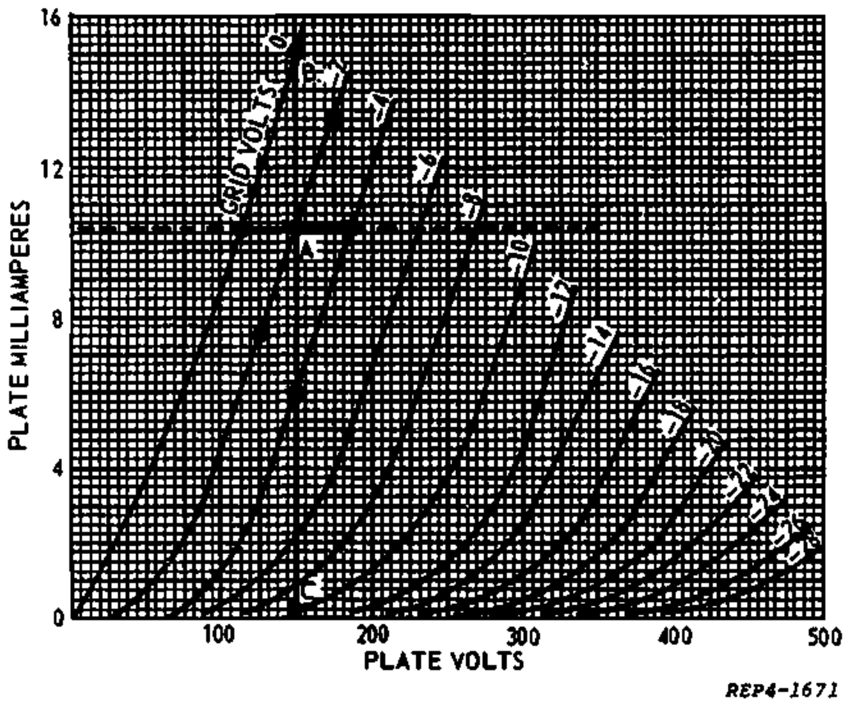

Figure 2-10. Plate Characteristics

values depend on the chosen location of the center point. However, the values will remain fairly constant as long as only the straight portions of the curves are used. Nevertheless, all the parameters may change in value drastically if any of the curved portions of the characteristic curves are used.

2-54. RELATIONSHIP OF PARAMETERS. The construction of a tube and the operating voltages applied to the electrodes determine the exact values of μ, g_m, and r_p. These values are related to each other in a very definite manner.

2-55. For a given tube, the amplification factor remains relatively constant under most conditions. AC plate resistance, on the other hand, varies greatly with operating voltages. This occurs especially through the region of potentials that result in low values of plate current. Usually, the higher the amplification factor of a triode, the higher the AC plate resistance of that tube.

2-56. The transconductance will vary with the AC plate resistance. That is, the higher the AC plate resistance of a given tube, the lower the transconductance, and vice versa. All triodes with high transconductance values have low AC plate resistance values.

2-57. The mathematical relationship existing between the three constants can now be developed. Multiplying g_m by r_p gives:

$$g_m \times r_p = \frac{\Delta I_p}{\Delta E_g} \times \frac{\Delta E_p}{\Delta I_p} = \frac{\Delta E_p}{\Delta E_g}$$

Since $\mu = \dfrac{\Delta E_p}{\Delta E_g}$, it is seen that $g_m \times r_p = \mu$.

2-58. Using g_m = 2,250 micromhos and r_p = 8,900 Ω from the previous example, the formula predicts that:

$$\mu = g_m \times r_p = 0.00225 \times 8{,}900 = 20$$

which is the correct value.

2-59. The formula expresses the relationship between the three tube parameters derived from the static E_p - I_p curves. It may also be written as:

$$g_m = \frac{\mu}{r_p} \quad \text{or} \quad r_p = \frac{\mu}{g_m}$$

Thus, when any two of the parameters are known, the third may be calculated.

2-60. DC PLATE RESISTANCE. The DC resistance for triodes has exactly the same meaning as for diodes. That is, R_p for triodes is the opposition of the tube to DC plate current flow. R_p is calculated in the same manner; thus:

$$R_p = \frac{E_p}{I_p}$$

Point B in figure 2-10 is used as an example. At point B, E_p = 150 V, I_p = 15 mA, and E_g = 0 V. Then:

$$R_p = \frac{E_p}{I_p} = \frac{150 \text{ V}}{15 \text{ mA}} = 10 \text{ k}\Omega$$

2-61. R_p for triodes varies over a much wider range than any of the previous parameters. This variation is demonstrated if R_p is calculated at point C in figure 2-10. Plate voltage remains the same (150 V) but I_p = 0.2 mA and E_g = -10 V. Then,

$$R_p = \frac{E_p}{I_p} = \frac{150 \text{ V}}{0.2 \text{ mA}} = 750 \text{ k}\Omega$$

Notice that making the grid much more negative, while leaving the plate voltage the same, has increased the DC plate resistance greatly. The grid voltage thus controls the amount of current flow and the DC resistance of the tube. As the grid is made more negative, plate current decreases and DC plate resistance increases.

2-62. Graphical Analysis of a Triode with Load.

2-63. Graphical analysis is widely used to analyze electron tube circuits because it is one of the easiest and most universal methods of analysis. Although a graphical analysis is quite easy to perform, it supplies a great deal of information. However, the analysis is meaningful only if its basis is fully understood. A brief discussion of the basis for graphical analysis will now be presented.

2-64. Suppose, as an example, that the individual voltage drops (E1 and E2) and the total current (I_t) are to be determined for the circuit of figure 2-11. A conventional application of DC principles predicts that:

E1 = 100 V, E2 = 200 V, and I_t = 3.3 mA

These same results can be obtained through graphical analysis.

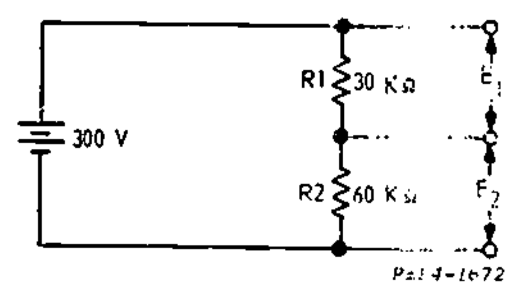

Figure 2-11. Series Circuit

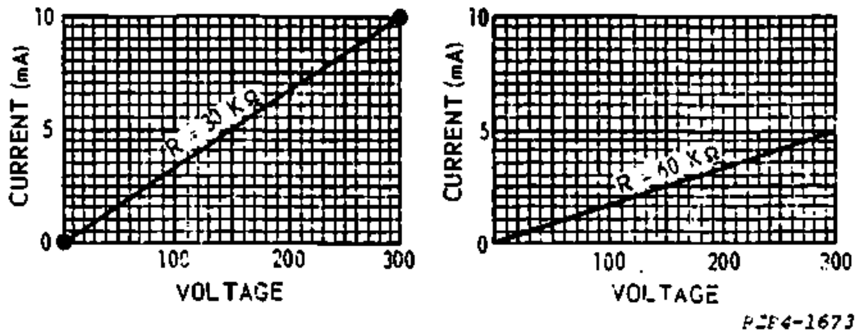

Figure 2-12. Current Plots for R1 and R2

2-65. A plot of current against voltage for each resistor by itself appears in figure 2-12. These plots can be obtained by connecting each individual resistor to a 0-300 V variable DC source and measuring the current for different voltages. Notice that for the 30 kΩ resistor, I = 5 mA when E = 150 V, and I = 10 mA when E = 300 V, just as Ohm's Law predicts.

2-66. These plots can also be derived strictly from Ohm's Law. Since a resistor is a linear component, a straight line plot can be drawn through any two points representing the current produced by any two different voltages. The easiest point to locate is when E = 0; if E = 0, I = 0. A second easy point is when E_a = 300 V: if E = 300 V and R = 30 kΩ, I = 10 mA for figure 2-12A. These two points are seen in figure 2-12A. The straight line connecting them yields the same plot as the current measurement system. Figure 2-12B can be derived in a similar manner.

2-67. Now, imagine that figure 2-12A is flipped over from left to right to appear as in figure 2-13. Observe that the current versus voltage relationship has not changed. The only difference is that voltage increases toward the left from zero instead of toward the right as in figure 2-12A.

2-68. Kirchoff's Law states that E1 + E2 must equal E_a (300 V). Therefore, the plots in figures 2-12B and 2-13 are superimposed to locate the point where E1 + E2 = E_a. The plots are arranged so that 300 V on figure 2-12B is aligned with 0 V on figure 2-13, and vice versa. This arrangement appears in figure 2-14.

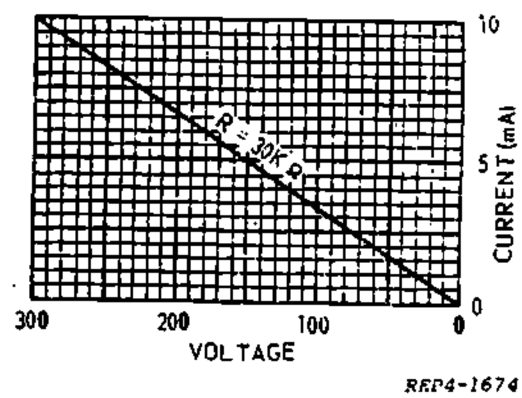

Figure 2-13. Reversed Form of Current Plot for R1

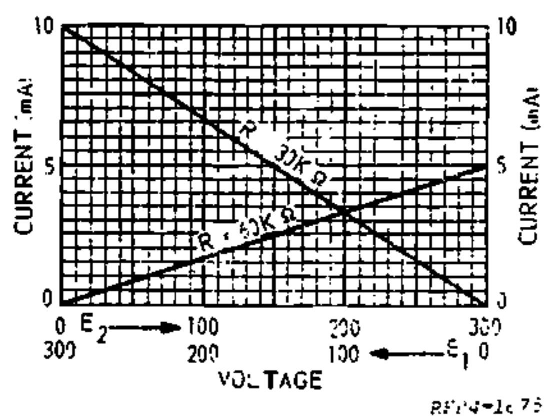

Figure 2-14. Superimposed Current Plots

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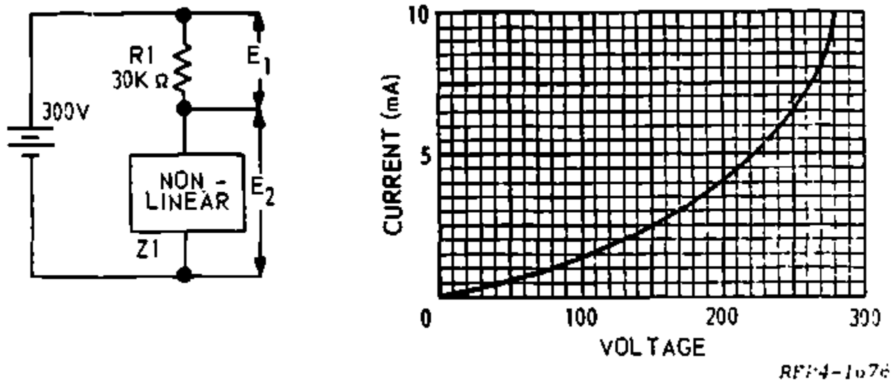

Figure 2-15. Non Linear Circuit

2-69. The upper set of voltage scale markings applied to R2 (60 k Ω) while the lower set applies to R1 (30 k Ω). The intersection point of the lines is the graphical solution. From the plots, the solution is:

E1 = 100 V, E2 = 200 V, and I_t = 3.3 mA

This solution is seen to be identical to the solution obtained using DC principles.

2-70. The advantage of graphical analysis is that it can also be used for circuits containing nonlinear components, whereas DC principles can not. For example, consider the circuit in figure 2-15A. The current versus voltage curve for the nonlinear component is shown in figure 2-15B.

2-71. The graphical solution in figure 2-16 is obtained in the manner used previously. Note that the reversed set of scale markings has been left off. The reversed set is not printed but always understood to be present in any graphical analysis. The solution is:

E1 - 105 V, E2 = 195 V, and I_t = 3.5 mA

Recall that this solution can not be determined from DC principles because Z does not obey Ohm's Law.

2-72. Quite naturally, a graphical solution can also be obtained easily for a circuit containing a triode electron tube. The characteristic curves for the particular triodes are used to represent the electrical behavior of the tube in its circuit. Consider the circuit in figure 2-17. This circuit is merely a triode tube with a resistor connected in series with the DC power source. A variable DC grid voltage is provided so that plate current can be varied.

2-73. The graphical analysis for this circuit appears in figure 2-18. The line connecting points A and B represents the 30 k Ω resistor just as before. Recall that point A is determined by dividing E_a by R_L (300 V/30 k Ω = 10 mA). Remember also that, if E_a = 300 V, 0 volts for the resistor is in the same location as 300 V for the tube. Therefore, point B is placed such that zero current flow for the resistor coincides with E_a for the triode. E_p is read from the scale for plate voltage. E_R is found by reading to the left from point B and considering point B to be zero volts.

2-74. If E_g is adjusted to -8 V, the characteristic curve for E_g = -8 V is the curve representing the tube's behavior. The

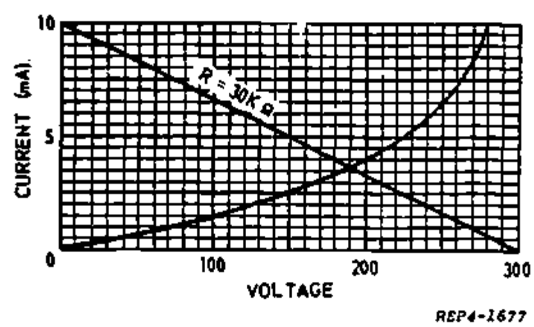

Figure 2-16. Graphical Analysis Figure 2-15

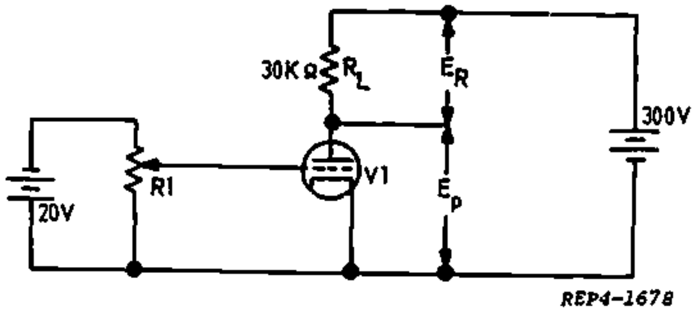

Figure 2-17. Triode Circuit

graphical solution is then E_p = 200 V, E_R = 100 V, and I_p = 3.3 mA. Point C, the solution point is known as the OPERATING POINT because it establishes the DC voltage and current levels when no signal is applied. These levels are known as the QUIESCENT levels. Any AC signals applied to the circuit merely add to or subtract from the quiescent DC levels. Because R_L is called the PLATE LOAD resistor for the triode, the line connecting points A and B is called the DC LOAD LINE.

2-75. Notice that changing the grid voltage makes a different curve represent the tube's behavior. Thus, if E_g = -4 V, the operating point is E_p = 140 V, E_R = 160 V, and I_p = 5.2 mA. DC grid voltage, E_a, and R_L therefore act together to determine the operating point. Changing any one of the three will move the operating point to a new location.

2-76. The grid voltage required to produce SATURATION in figure 2-18 is seen to be 0 volts. At saturation in figure 2-18, E_p = 80 V and I_p = 7.4 mA. If the grid is made more positive than 0 volts, plate current will not increase appreciably. The grid voltage required to produce CUT OFF in figure 2-18 is -18 volts. Any grid voltage equal to or more negative than -19 volts will prevent plate current flow. At cut off in figure 2-18, E_p = E_a = 300 V and I_p = 0.

2-77. Biasing.

2-78. If an AC signal were applied to the control grid of a triode amplifier as shown in figure 2-19A, the signal would not be amplified correctly. (B^+ is a standard symbol for the positive DC plate voltage supply.) The negative alternation of the input signal would control plate current in the normal manner. However, the positive alternations would allow grid current to flow and cause the tube to saturate. Due to the saturation, the output signal would be highly distorted, as seen in figure 2-19B. Also, power would be wasted in the grid circuit.

2-79. To prevent this undesirable situation, a DC voltage source is placed in series with the AC signal. This DC voltage, called a BIAS voltage, is a negative voltage large enough to keep the grid from ever being positive. Since the AC signal in figure 2-19 was 5 volts in amplitude, a negative voltage of more than -5 volts must be used.

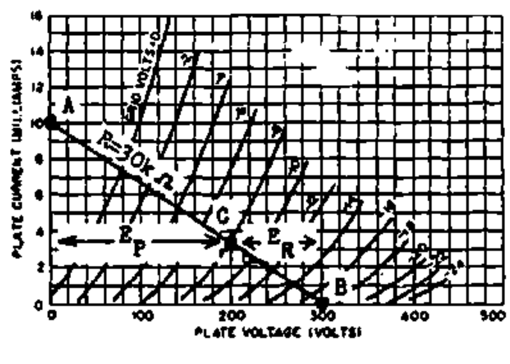

Figure 2-18. Graphical Analysis for a Triode Circuit

2-80. Figure 2-20A illustrates the use of a -6 V battery to maintain a negative voltage on the grid at all times. Recall that since the bias voltage and AC signal are in series, the resultant grid voltage is the sum of the bias and signal voltages. The input signal, bias voltage, and resultant grid voltage are shown in figure 2-20B. Notice that since the grid is never positive, the plate current waveform in figure 2-20C contains no saturation distortion.

2-81. Because the bias voltage is not normmally obtained with a simple battery, a more general definition of bias is needed. BIAS is the AVERAGE DC VOLTAGE BETWEEN GRID AND CATHODE and is used to establish the operating point. Recall that the DC grid voltage establishes the operating point on the load line for the circuit. If grid bias is a negative voltage, an INCREASE in negative bias means that the grid is made MORE NEGATIVE, and vice versa. Three basic forms of bias exist: cathode self bias, fixed bias, and grid leak bias.

2-82. CATHODE SELF BIAS. In figure 2-21, cathode self bias is present because the tube current develops a voltage across the cathode resistor. As the tube conducts, a voltage $I_k \times R_k$ is developed across R_k. For example, if 2 mA of current is flowing in the cathode circuit and R_k is 2 kΩ, then 4 volts with respect to ground, and the DC grid voltage is 0 volts. Therefore, the GRID TO CATHODE voltage is -4 volts. Hence, the grid bias is -4 volts.

2-83. The cathode self bias voltage regulates the tube current. If the tube current decreases, the voltage across R_k decreases. This makes the grid less negative which increases tube current. The end effect is that the original decrease in current is nearly cancelled. A tube can not bias itself to cut off with cathode self bias because the bias is developed only when the tube conducts. The amount of bias is determined by the amount of current and the value of R_k.

2-84. When a signal is applied as indicated in figure 2-21, tube current increases on the positive alternation of the input and decreases on the negative alternation. These current changes produce proportional changes in the cathode self bias voltage. If the cathode voltage varies up and down with the input voltage, the full amplitude of the input signal does not appear between the grid and cathode. As an example, assume that the grid voltage increases to +2 V. This increase causes the tube current to increase, which increases the cathode voltage by perhaps +1.5 V. Since the GRID TO CATHODE voltage has increased by only +0.5 V, it is readily seen that the full +2 V change did not appear between the grid and cathode. This effect is known as degeneration or negative feedback.

2-85. The effect of negative feedback is reduced by placing a capacitor, C_k, across the cathode resistor, as shown in figure 2-22. The capacitor holds a steady DC voltage across R_k by filtering out the AC changes. Because the capacitor bypasses the AC signals to ground through its low AC reactance, it is called the cathode bypass capacitor. With C_k added, the full AC voltage changes appear between the grid and cathode, and the plate current varies by the expected amount. C_k must be large enough so that its reactance is low for the lowest frequency present.

2-86. FIXED BIAS. If the bias voltage is supplied by a battery or some other DC voltage source, it is called fixed bias. Examples of bias from batteries are shown in figure 2-23. In figure 2-23A, the cathode is at ground potential and the grid is made negative by the battery voltage. A large resistance is placed in series with the battery, and the input signal is applied between grid and ground. Without the resistor, the input signal would be shorted to ground through the low AC impedance of the battery. In figure 2-23B, the grid is at DC ground potential and the cathode is made positive compared to ground. Once again, a positive cathode establishes a negative GRID TO CATHODE voltage. The input is applied to the grid and the large resistor is connected between grid and ground. This grid resistor provides a path to ground for the very few electrons intercepted by the grid mesh even when E_g is negative.

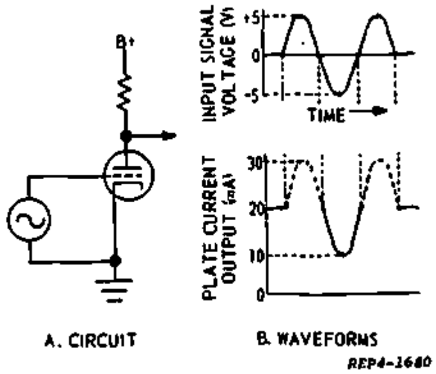

Figure 2-19. AC Signal Applied to Triode Path

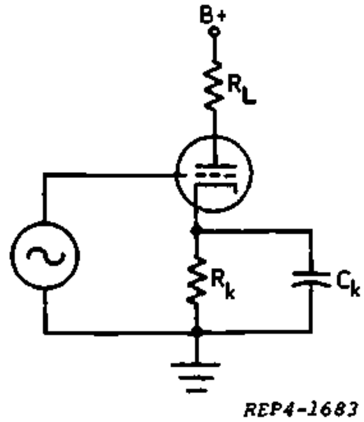

Figure 2-22. Addition of Cathode Bypass Capacitor

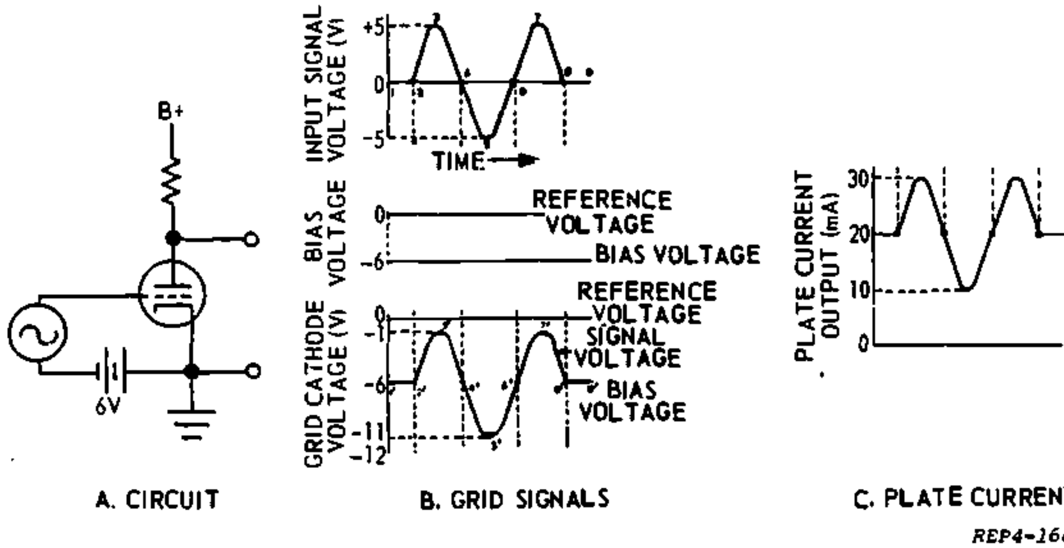

Figure 2-20. AC Bias Applied to Triode Grid

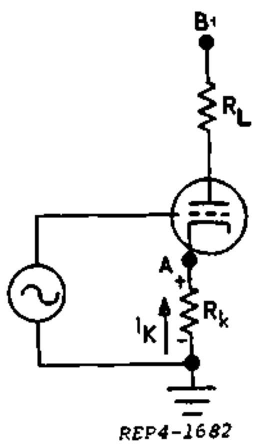

Figure 2-21. Cathode Self Bias

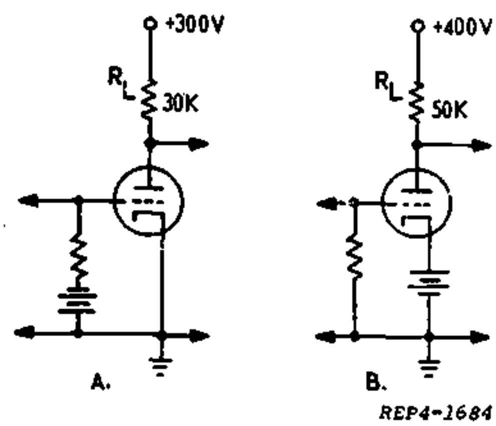

Figure 2-23. Fixed Bias Using Batteries

2-87. Examples of voltage divider bias, another form of fixed bias, are shown in figure 2-24. In figure 2-24A, a negative grid voltage is obtained from the -10 V source through a voltage divider. The amount of bias is determined by the relative sizes of R1 and R_g. In figure 2-24B, a positive cathode voltage is developed by current flow through the voltage divider composed of R1 and R_k. The fixed bias provided by R1 and R_k may be less than the bias required to cut off the tube. If this is the case, the tube will conduct and the resulting tube current will also flow through R_k. The additional current through R_k adds a cathode self bias voltage to the original fixed bias voltage. Note that Ck will hold the cathode voltage constant and reduce negative feedback.

2-88. GRID LEAK BIAS. A circuit employing the third form of bias, grid leak bias, is illustrated in figure 2-25. This form of bias depends upon the input signal and conduction through the tuoe. When an AC signal is applied to the input, the grid draws current on the positive half cycle. C1 charges through the parallel resistance of the large grid resistor, R1, and the small grid-to-cathode resistance. Because the grid-to-cathode resistance is very small, the grid goes only slightly positive and the capacitor charges quickly. As the input swings in a negative direction, C1 discharges through the grid resistor, R1, and produces a negative grid voltage. Due to the large value of R1, the discharge current is small and C1 discharges slowly.

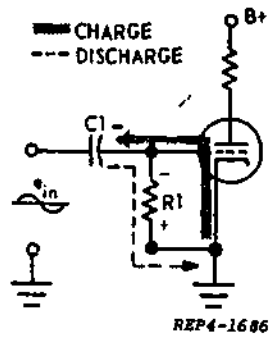

Figure 2-25. Grid Leak Bias

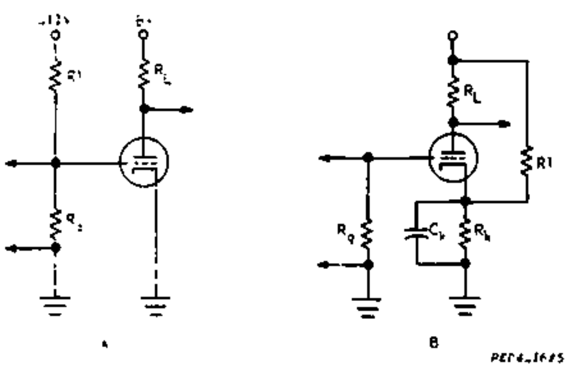

Figure 2-24. Fixed Bias Using Voltage Dividers

2-89. The effect has been to clamp the grid signal so that the most positive voltage is nearly zero volts. Therefore, the average grid voltage is negative; the average negative value of the grid voltage establishes the grid leak bias. Because the average negative grid voltage is a function of the input signal amplitude, the amount of grid leak bias depends on the amplitude of the input. The R1-C1 discharge time constant and the frequency of the input also affect the amount of bias.

2-90. CLASS OF OPERATION. The amount of forward bias for a transistor determines its operating point and, therefore, its class of operation. Likewise, the grid bias for a tube will determine its class of operation for a given input signal. The definitions of the various classes of operation are identical to the definitions used in transistor circuits. If plate current in a tube flows for 360 degrees of each input cycle (the tube is never cut off), the tube is operating Class A. Grid bias for class A must be such that the grid can never reach the cutoff voltage. If plate current flows for more than 180 but less than 360 degrees of each input cycle, the class of operation is AB. For class AB, the negative grid bias voltage must be less than the cutoff voltage, but yet negative enough to cause the tube to cut off for some portion of each input cycle. For class B operation, plate current flows for 180 degrees of each input cycle. Negative grid bias for class B must be equal to the cut off voltage. Class C operation occurs if plate current flows for less than 180 degrees of each input cycle. Negative grid bias must be greater than the cut off voltage for class C operation.

2-91. Basic Triode Amplifier.

2-92. The schematic in figure 2-26 illustrates a simple triode amplifier. The plate load is 40 kΩ and the cathode self bias resistor is 2.5 kΩ. If the plate current is 4.0 mA, what are the voltage drops across the tube (E_p) and the load resistor (E_{R_L})?

$$E_{R_L} = I_p \times R_L = 4.0 \text{ mA} \times 40 \text{ k} = 160 \text{ V}$$

$$E_{R_k} = I_k \times R_k = 4.0 \text{ mA} \times 2.5 \text{ k} = 10 \text{ V}$$

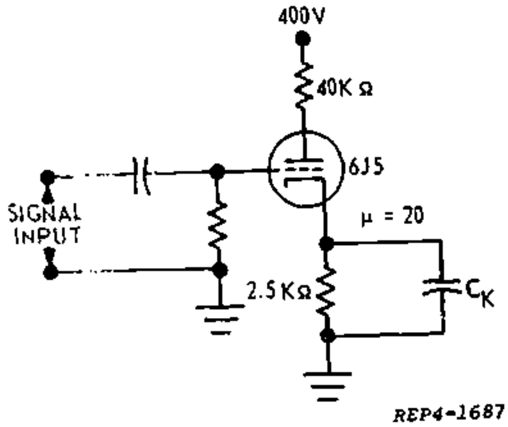

Figure 2-26. Basic Triode Amplifier

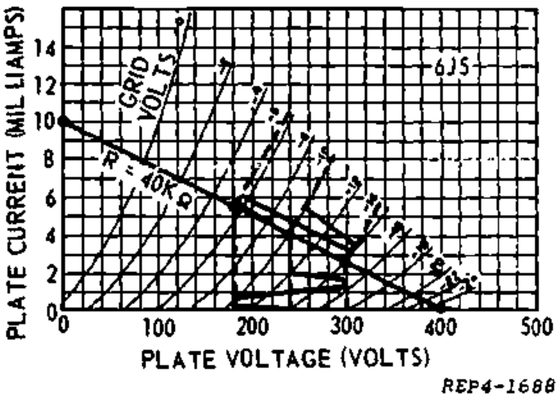

Figure 2-27. Computing Circuit Gain

$$E_p = B^+ - E_{R_L} - E_{R_k} = 400 \text{ V} - 160 \text{ V} - 10 \text{ V} = 230 \text{ V}$$

Note that the PLATE-TO-GROUND voltage would be 240 V.

2-93. GAIN. An AC signal of 8 V peak-to-peak amplitude is applied to the input of the circuit in figure 2-26. Figure 2-27 demonstrates the method used to determine the voltage gain of the circuit. The 8 V peak-to-peak input signal is drawn along the E_g lines and centered on the operating point. The resulting plate voltage changes are read on the plate voltage scale. When the input signal is zero, the grid to cathode voltage is -10 V and E_p = 240 V. When the input signal swings to its maximum +4 V value, E_g becomes -6 V and E_p drops to 180 V. When the input signal swings to its -4 V value, E_g becomes -14 V and E_p increases to 300 V. Voltage gain, A_v, is:

$$A_v = \frac{e_{out}}{e_{in}} = \frac{300 - 180}{14 - 6} = \frac{120 \text{ V}}{8 \text{ V}} = 15$$

Since an 8 V peak-to-peak grid signal has caused a 120 V peak-to-peak plate signal, the tube has clearly amplified the input. Notice that A_v is smaller than μ. A_v will always be smaller than μ but will approach μ as R_L is made larger.

2-94. AC LOAD LINE. For many circuits, the AC plate load of a tube is not the same value as the DC plate load. Figure 2-28 shows an example of a circuit where the AC load is smaller than the DC load. R_i represents the input impedance of the circuit connected to the output of this amplifier. The DC load is 40 k Ω just as before. However, the AC load consists of R_L in parallel with R_i (the reactance of C_c is assumed to be small for AC signals). Since R_i = 40 k Ω, the AC load value, Z_L, is:

$$Z_L = \frac{R_L \times R_i}{R_L + R_i} = \frac{40 \times 40}{40 + 40} = \frac{1600}{80} = \text{k}\,\Omega$$

2-95. The AC load line in figure 2-29 is constructed by drawing a line through two points. One point is the DC operating point, and the other point (point A) is the plate voltage intercept. Point A is determined from the formula:

$$\text{Point A} = E_p + (I_p \times Z_L)$$

where E_P = quiescent plate voltage

I_p = quiescent plate current

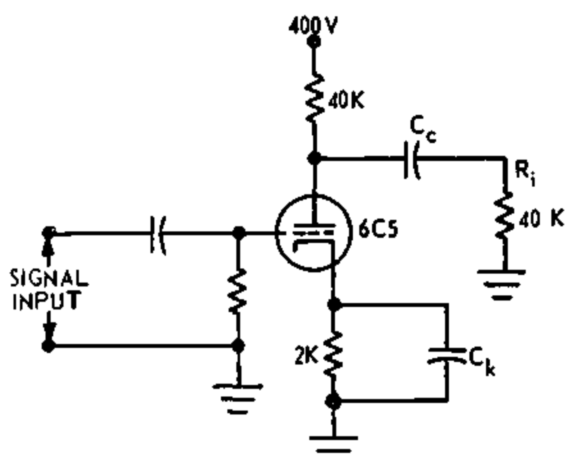

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Figure 2-28. Amplifier with AC Load

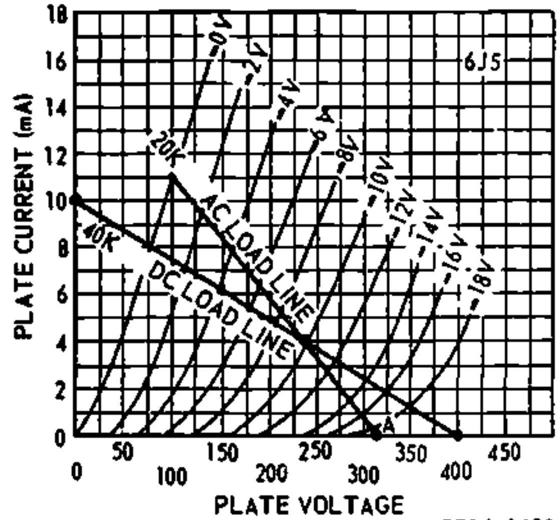

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Figure 2-29. AC and DC Load Lines

For this example,

point A = 240 V + (4 mA x 20 k Ω) = 240 V + 80 V = 320 V. If the same 8 V peak-to-peak AC signal is applied, the plate voltage swings from 190 V to 290 V. The gain is then:

$$A_v \quad \frac{e_{out}}{e_{in}} \quad \frac{290 - 190}{14 - 6} \quad \frac{100}{8} = 12.5$$

2-96. Notice that since the AC load impedance is smaller than the DC load impedance, the voltage gain has been reduced. A general rule relating voltage gain to load impedance can now be stated. A LARGER LOAD IMPEDANCE (flatter load line) will always yield MORE VOLTAGE GAIN than a SMALLER LOAD IMPEDANCE (steeper load line), and vice versa.

2-97. PHASE COMPARISONS. A simple AC amplifier appears in figure 2-30A. The waveforms in figure 2-30B for grid voltage and plate current are in phase because as the grid goes more positive, plate current increases, etc. However, plate current and plate voltage are 180 degrees out of phase. As plate current increases, the voltage dropped across R_L increases. But, since $E_p = B+ - E_{R_L}$, the increase in E_{R_L} causes plate voltage to decrease. The end result is

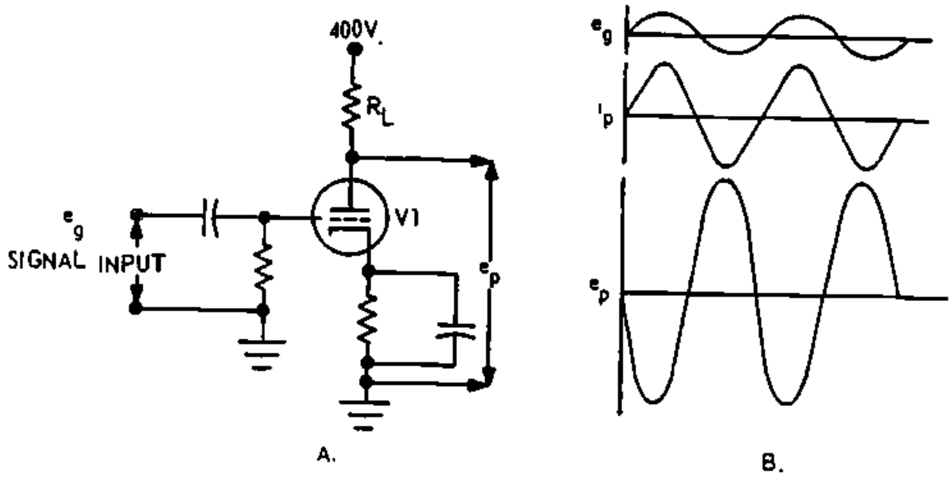

Figure 2-30. AC Amplifier

that the plate voltage waveform, e_p, is 180 degrees out of phase with the grid voltage waveform, e_g. Note that the AC signals I_p and E_p vary above and below the DC quiescent levels I_p and E_p.

2-98. AMPLIFIER CONFIGURATIONS. Recall that transistor amplifiers could exist in either common emitter, common base, or emitter follower configurations. As is expected, triodes may be used in similar configurations - namely, common cathode, common grid, or cathode follower. The common cathode configuration has been shown in all previous examples due to its widespread usage. Cathode followers are treated in a succeeding chapter. The same general impedance, gain and phase relationships that held for the various transistor configurations also hold for the corresponding electron tube configurations.

2-99. APPLICATIONS. Triodes are utilized in just as wide a variety of circuit applications as transistors. Thus, triodes may be found in oscillator, amplifier, multivibrator, switching, impedance matching, phase-splitting, and waveshaping circuits. A triode amplifier may be a power, voltage, push-pull, wideband, narrowband, or DC amplifier. Quite naturally, the same considerations that were necessary for transistor circuits are required for triode circuits. For example, AC plate resistance, r_p, must equal AC load impedance, Z_L, for maximum power transfer.

2-100. INTERELECTRODE CAPACITANCE. Capacitance exists between any two conductors separated by a dielectric. The amount of capacitance is dependent upon the size of the conductors, the distance between them, and the type of dielectric. The electrodes of an electron tube exhibit a characteristic known as interelectrode capacitance, illustrated schematically for a triode in figure 2-31. The direct capacitances that exist in a triode are the grid-to-cathode (C_{gk}), the grid-to-plate (C_{gp}), and the plate-to-cathode (C_{pk}) capacitances.

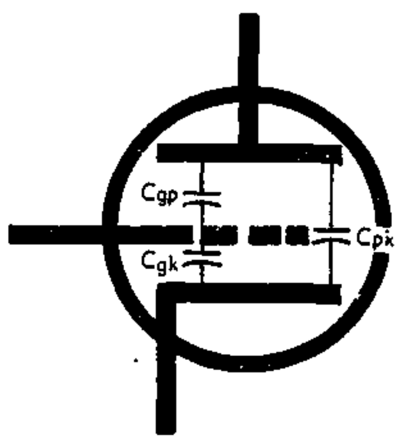

Figure 2-31. Interelectrode Capacitance

2-101. The input capacitance, C_i, of a tube is a larger value than would normally be expected just from the sizes of C_{gp}, C_{gk}, and C_{pk}. The input capacitance of an operating triode may be many times the expected value due to the influence of the plate voltage on the grid to plate capacitance. C_i depends not only on C_{gk}, but also on C_{gp} and A_v, the gain of the amplifier. The following formula specifies this relationship:

$$C_i = C_{gk} + C_{gp} (1 + A_v)$$

This dependency of the input capacitance on the gain of the amplifier is called the Miller Effect. To illustrate this effect, assume a tube with $C_{gk} = 3.2$ pF and $C_{gp} = 1.6$ pF is used in an amplifier with $A_v = 50$. Instead of C_i being 4.8 pF, the sum of C_{gk} and C_{gp}, C_i is 84.8 pF, a considerable increase. A method of avoiding this limitation is presented in the next chapter. The high frequency response of triode amplifiers is limited by these interelectrode capacitances.

Chapter 3

MULTIGRID ELECTRON TUBES

3-1. Although triode electron tubes are found in a wide variety of applications, they have certain unavoidable disadvantages. These include poor performance as IF or RF amplifiers. This poor performance can be traced to the capacitive coupling that exists between the plate and grid. The relatively low gain of a triode amplifier also places the triode at disadvantage. Tetrode and pentode tubes were developed to overcome these basic disadvantages.

3-2. Tetrodes.

3-3. A method for reducing the capacitive coupling in a triode is to place an electrostatic shield inside the tube, between the control grid and the plate. This shield is called the "screen grid" (G_2). Figure 3-1 shows the screen grid inserted between the control grid and plate of the tube. This tube has four electrodes and is therefore called a tetrode.

3-4. FUNCTION OF THE SCREEN GRID. The primary purpose of the screen grid is to act as an electrostatic shield between the control grid and the plate.

3-5. Normally the screen grid is operated at a positive voltage with respect to the cathode. As a result of this, most of the electrostatic forces within the tube are set up between the screen grid and space charge. The plate is able to supply only a small amount of force to the electrons of the space charge. It is therefore the screen grid voltage that attracts electrons toward the plate.

3-6. Since the plate exerts only a small force on the electrons in the space charge, changes in plate voltage have little effect on the number of electrons leaving the space charge and the cathode. This makes the number of electrons striking the plate (plate current) nearly independent of plate voltage. Due to the shielding effect of the screen grid, the plate becomes merely a collector of electrons.

3-7. Like any other positive element in a vacuum tube the screen grid draws a certain amount of current. This current is called screen grid current (I_{sg}). Since most of the electrons traveling toward the plate pass through the openings in the screen grid and strike the plate, screen grid current is normally much less than plate current. The cathode current must now be the sum of the screen current and the plate current.

3-8. The reason why the screen grid is positive must be throughly understood. In a tetrode without positive screen grid voltage,

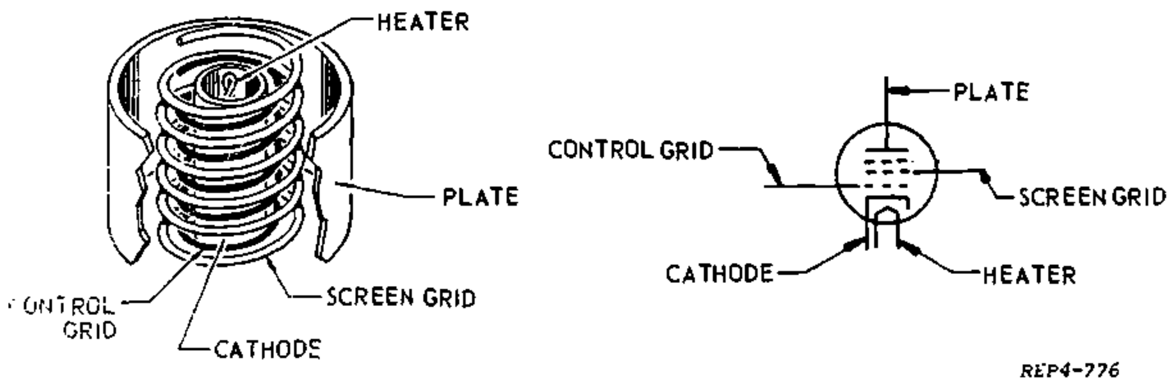

Figure 3-1. Tetrode Tube Construction and Schematic Symbol

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plate current will be essentially zero. The screen grid must have a positive voltage to attract electrons toward the plate. The screen grid is usually less positive than the plate. The positive screen grid voltage can be obtained from the same B+ supply which provides voltage for the plate. The screen is merely connected to the B+ supply through a voltage dropping resistor, R_{sg}.

3-9. As shown in figure 3-2, the voltage-dropping resistor R_{sg} (also called the screen-dropping resistor) is connected between the screen grid and B+. That part of the cathode current which flows to the screen grid (I_{sg}) returns to the B+ supply through R_{sg}. The screen grid voltage is less than the B+ voltage by the amount dropped across R_{sg}; $E_{sg} = (B+) - (I_{sg} R_{sg})$. For this example, the voltage across R_{sg} is 200 volts and B+ is 300 V, so the screen grid voltage (E_{sg}) is 100V.

3-10. The screen grid bypass capacitor, C_{sg}, is connected between the screen grid and ground for two reasons. First, C_{sg} maintains a constant DC voltage on the screen grid. This eliminates the unwanted changes in plate current that would result from AC voltage appearing on the screen grid. Second, the effectiveness of the electrostatic shield in reducing the control grid to plate capacitance is increased when the screen grid is connected to an AC ground. Obviously this cannot be a direct connection since the screen grid must be at a positive DC voltage for proper operation of the tube. The screen capacitor, because of its very low AC reactance, bypasses all AC signals to ground. Thus, the screen grid is placed at AC ground potential, and the control grid to plate capacitance is greatly reduced. As an example, C_{gp} is reduced to 0.1 PF or less for tetrodes. C_{sg} must have sufficient capacitance to present a very low reactance to the lowest frequency present.

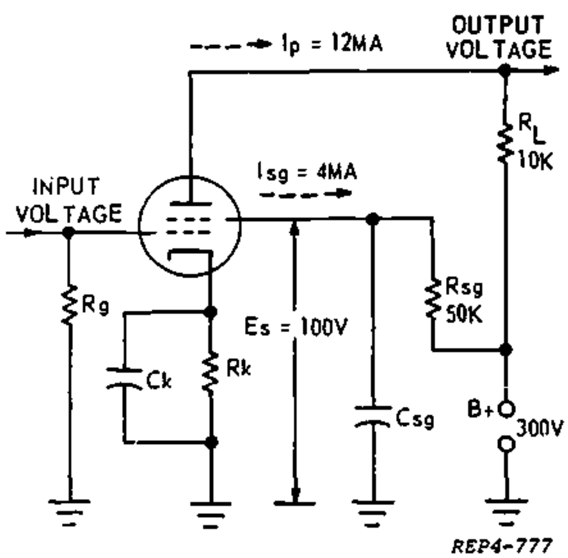

Figure 3-2. Tetrode Amplifier

3-11. E_p-I_p CHARACTERISTIC CURVES. The conventional method used to analyze the operation of an electron tube is to use characteristic curves. Figure 3-3 shows a tetrode circuit with voltages labeled and the resulting characteristic curves. Normally, the screen grid voltage is less than the plate supply voltage.

3-12. To plot the characteristic curves in figure 3-3B, the control grid voltage is fixed at a constant -3 volts and the screen grid voltage is fixed at a constant +100 volts. The plate voltage is then increased from zero to some positive voltage indicated as E_p.

3-13. With the plate at zero volts, the positive screen grid attracts electrons from the space charge. Since the screen grid is an open mesh, most of the electrons pass through it. The electrons that pass through the screen grid and travel to the plate form the plate current, I_p. The electrons intercepted by the positive screen grid form the screen current, I_{sg}.

3-14. With the control grid and screen grid voltages held constant, the plate voltage is increased to the small positive value indicated by point A in figure 3-3B. The slightly positive plate causes more of the electrons approaching the screen grid to pass through the screen and move to the plate. Thus, I_p increases and I_{sg} decreases, as seen at point A in figure 3-3B.

3-15. When the plate voltage increases from point A to point B, an unusual effect is noticed -- plate current DECREASES rather

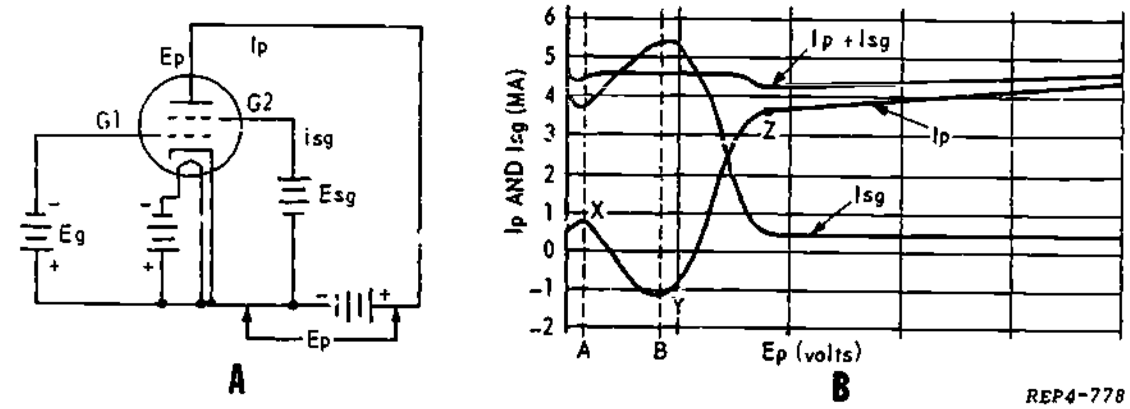

Figure 3-3. Tetrode Characteristics

than increases. With plate voltage at this higher value, the combined attractions of the screen and plate are large enough to give the electrons traveling to the plate sufficient velocity to cause secondary emission at the plate. Recall that secondary emission results when high velocity electrons bombard a material and dislodge electrons from the material. Many of the secondary electrons are attracted to the screen because it is more positive than the plate. As plate voltage increases from point A to point B, the amount of secondary emission increases. Thus, I_p decreases and I_{sg} increases until point B is reached in figure 3-3B.

3-16. Secondary emission may occur in diodes or triodes if the electrons reaching the plate have sufficient speed. However, because the plate is the only element which can attract the secondary electrons, they end up being attracted back to the plate. Consequently, the secondary electrons form part of the regular plate current and the effect is not noticed. The introduction of the positive screen grid in tetrodes causes the secondary electrons to be attracted to it, thus reducing the plate current.

3-17. The downward sloping line from X to Y represents the region in which I_p decreases as E_p increases. Because an INCREASE IN VOLTAGE in this area produces a DECREASE IN CURRENT, the region is known as a NEGATIVE RESISTANCE region.

3-18. Increasing the plate voltage above point B makes the plate sufficiently positive to attract an increasing number of the secondary electrons. Thus, plate current increases and screen current decreases until point Z is reached. At point Z, all of the secondary electrons are returned to the plate.

3-19. Beyond point Z, plate current does not increase appreciably with additional increases in plate voltage. This is due to the positive voltage on the screen grid. The plate is only able to attract those electrons that were initially attracted by the screen grid. The screen grid shields the cathode and space charge from the plate voltage. The screen voltage has more effect on the plate current than does the plate voltage. This has the advantage of making the plate current essentially independent of plate voltage.

3-20. Figure 3-4 illustrates the family of characteristic curves for a tetrode tube. The normal operating point of the tetrode is to the right of point Z. The bend in any given plate current curve, near point Z for instance, is known as the KNEE of that curve.

3-21. AC PLATE RESISTANCE. The AC plate resistance, r_p of a tetrode is computed in the exact same manner that was used for triodes. Figure 3-5 shows that, with the control grid held constant at -3V, a change in E_p of 200V causes a change in I_p of 0.5 mA. Thus,

$$r_p = \frac{\Delta E_p}{\Delta I_p} \quad (E_g \text{ constant})$$

$$r_p = \frac{200 \text{ V}}{0.5 \text{ mA}} = 400 \text{ k}\Omega$$

3-22. Note that the value of the AC plate resistance for a tetrode is considerably higher than that for a triode. Since the screen grid functions as an electrostatic shield between the plate and the space charge, a large change in E_p produces only a small change in I_p. Therefore, the AC plate resistance is quite large.

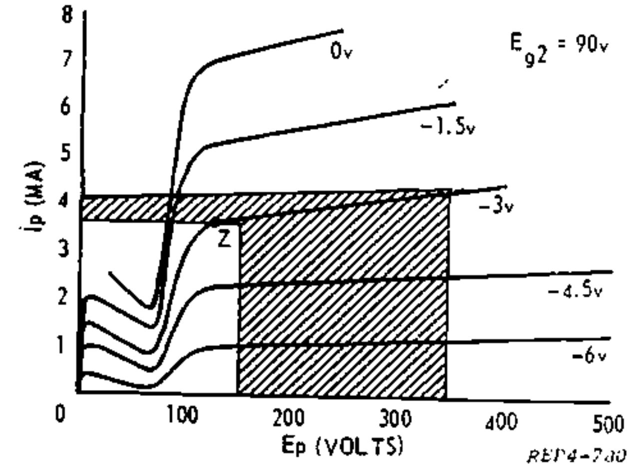

Figure 3-5. Computing AC Plate Resistance (r_p)

3-23. TRANSCONDUCTANCE. The procedure for computing g_m is likewise identical to the one used for triodes. From figure 3-6, with E_p constant at 250 V, a change in plate current of 3.6 mA. Thus,

$$g_m = \frac{\Delta I_p}{\Delta E_g} \quad (E_p \text{ constant})$$

$$g_m = \frac{3.6 \text{ mA}}{3.0\text{V}} = 1200 \text{ micromhos}$$

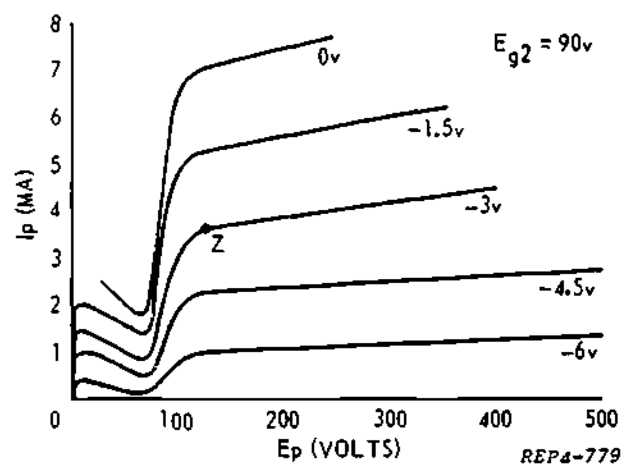

Figure 3-4. Tetrode E_p-I_p Characteristics

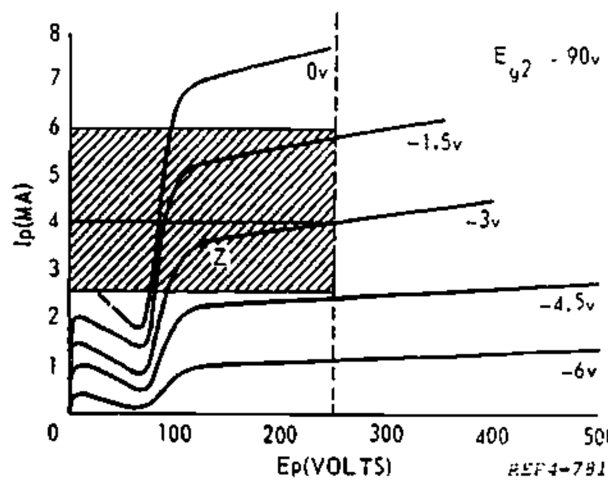

Figure 3-6. Computing Transconductance (g_m)

3-24. AMPLIFICATION FACTOR. The E_g lines in figures 3-4, 3-5, and 3-6 would need to be extended to allow μ to be determined graphically. Therefore, μ must be computed from g_m and r_p. $\mu = g_m \times r_p$ = (1200 micromhos) x (400 k Ω) = 480.

3-25. Thus, μ for a tetrode is seen to be much higher than μ was for a triode. Whereas μ may range from 5 to 100 for triodes, it may be as high as 600 for tetrodes. A change in the grid voltage of a tetrode can then produce a very large change in plate voltage. As a result, a tetrode amplifier can have a much higher gain than a triode amplifier.

3-26. Pentodes.

3-27. In tetrodes, secondary emission from the plate may reduce the overall amplification or cause unwanted oscillations. Also, the secondary emission region limits the useful plate voltage swing available in tetrodes. To overcome the effects of secondary emission in tetrodes, a third grid is inserted between the plate and the screen grid.

3-28. This grid, called a "suppressor" grid (G_3), is connected to a voltage that is negative with respect to the plate. Secondary electrons are thus repelled and forced to return to the plate. This third grid is called the suppressor grid because it suppresses or eliminates the flow of electrons from the plate to the screen grid. Because the effects of secondary emission are eliminated, the negative resistance region of the tetrode is eliminated. Note that it is not the secondary emission that has been eliminated, but rather the EFFECTS of secondary emission. The secondary electrons still exist; however, they are returned to the plate so their effects are not observable.

3-29. The physical construction of the suppressor grid is similar to that of other grids. When the third grid is added, making a total of five active elements, the tube is called a PENTODE. Schematic symbols for the pentode are shown in figure 3-7. Note that two symbols are shown. One shows an external suppressor connection and the other has the suppressor grid connected to the cathode inside the tube.

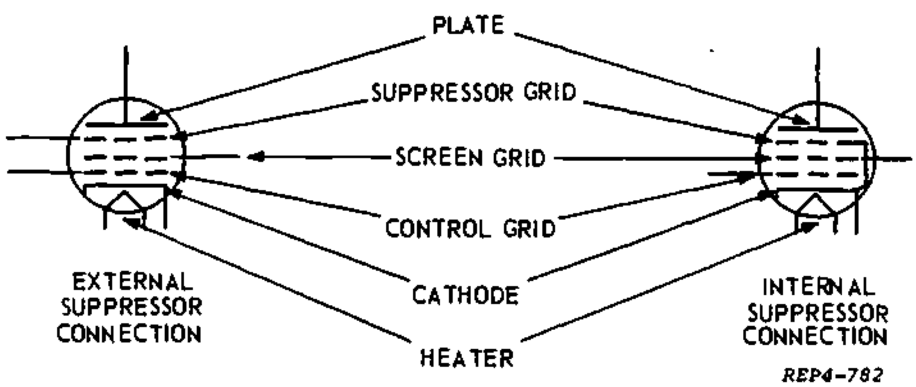

Figure 3-7. Pentode Schematic Symbols

3-30. E_p-I_p CURVES. Because the effects of secondary emission are eliminated by the action of the suppressor grid, the shape of the characteristic curves for a pentode differs considerably from that for a tetrode. A family of plate characteristic curves for a pentode is shown in figure 3-8.

3-31. Notice that the negative resistance is absent, and that the plate potential can be changed several hundred volts without causing a substantial change in plate current. This results from the high degree of electrostatic shielding provided by the screen and suppressor grids. Since changes in plate voltage have little effect on plate current, the amplification factor and plate resistance of a typical pentode are high. When compared to a triode or tetrode, the pentode has a larger output signal with a given input signal.

3-32. AC PLATE RESISTANCE. The AC plate resistance of a pentode is computed in exactly the same manner as for tetrodes and triodes. From the curve in figure 3-9, a change in plate voltage of 300 volts is seen to cause a change in plate current of 0.5 mA. Then,

$$r_p = \frac{\Delta E_p}{\Delta I_p} \quad (E_g \text{ constant})$$

$$r_p = \frac{300\text{V}}{0.5 \text{ mA}} = 600 \text{ k}\Omega$$

3-33. TRANSCONDUCTANCE. g_m is computed exactly as before. From the curve in figure 3-10, a change of 2 volts on the grid causes a change of 8 mA in the plate current. Hence,

$$g_m = \frac{\Delta I_p}{\Delta E_g} \quad (E_p \text{ constant})$$

$$g_m = \frac{8 \text{ mA}}{2\text{V}} = 4{,}000 \text{ micromhos}$$

3-34. AMPLIFICATION FACTOR. The grid voltage lines would have to be greatly extended in order to determine μ from the curves. Therefore, μ is computed from the equation relating μ to g_m and r_p. Thus,

$$\mu = g_m \times r_p = (4{,}000 \text{ micromhos})$$

$$(600 \text{ k}\Omega) = 2400$$

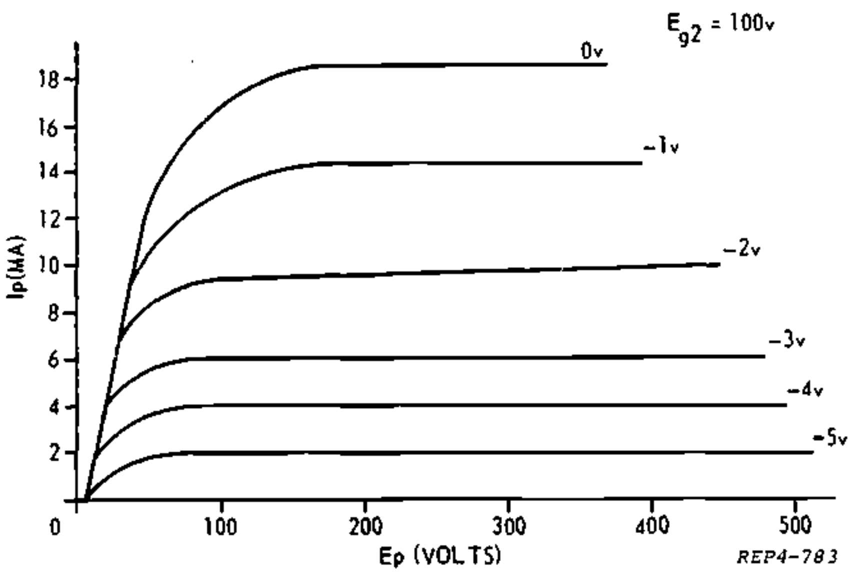

Figure 3-8. Pentode E_p-I_p Curves

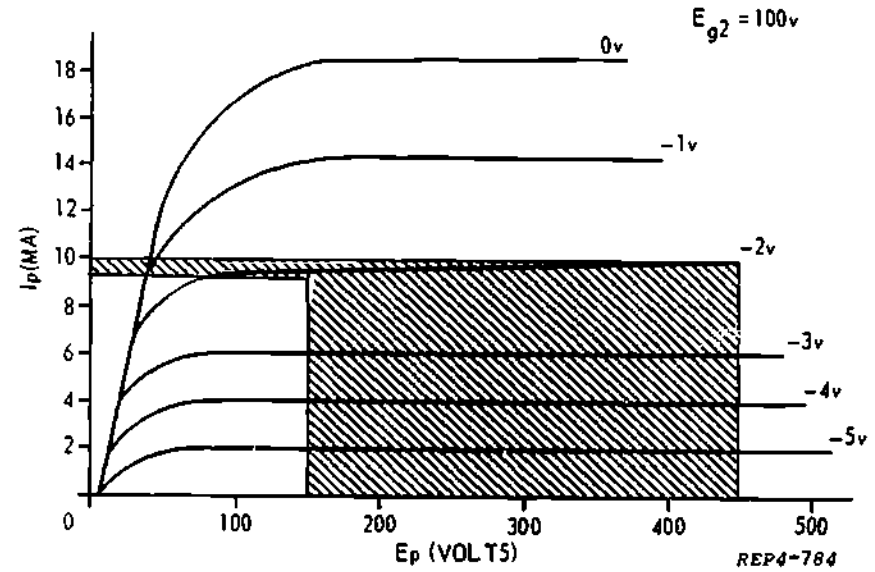

Figure 3-9. Determining AC Plate Resistance

3-35. This amplification factor is seen to be quite large for this pentode. For this reason a small control grid voltage change will produce a much larger plate voltage change in a pentode than in a triode. Due to the extensive electrostatic shielding, the input capacitance is very low for pentodes. These two advantages, high μ and low C_i, enable pentodes to be used extensively as high gain, high frequency amplifiers.

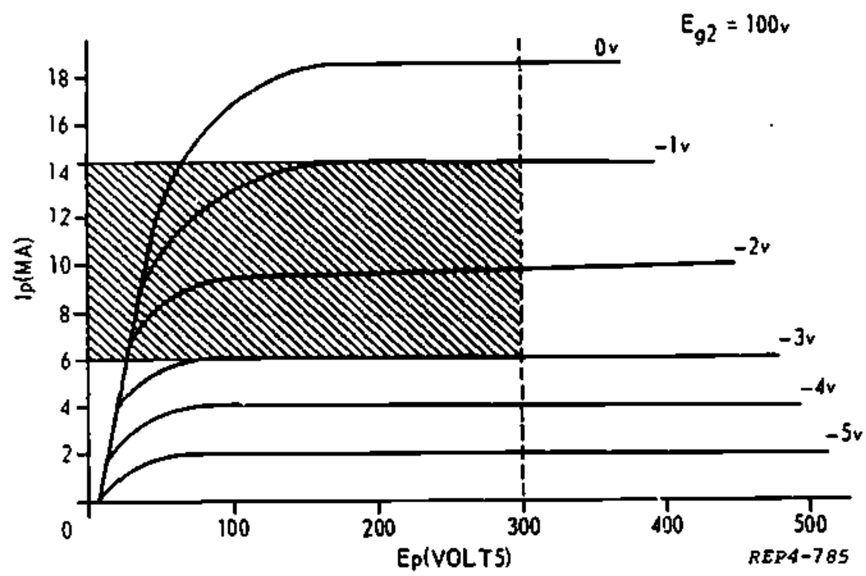

Figure 3-10. Computing Transconductance

3-36. PENTODE GRIDS. Pentodes are often classified according to their grid characteristics. Two classes exist: sharp cutoff pentodes and remote cutoff pentodes. Figure 3-11 illustrates the grid structures for these two classes. A sharp cutoff tube has control grid wires that are evenly spaced as shown in figure 3-11A. Figure 3-11B illustrates how the control grid wires are unevenly spaced for a remote cutoff pentode. Notice that the grid wires for the remote cutoff tube are closely spaced near the ends of the structure but widely spaced at the center.

3-37. The terms sharp and remote cutoff are related to the manner in which the grid voltages affect the plate current. As the negative bias of a remote cutoff tube is increased, a point is reached where the electrostatic field between the closely spaced end grid wires cuts off plate current through the ends of the grid. At this point, plate current still flows through the widely spaced center of the grid. As bias increases further, the cutoff region will move closer and closer to the center. A point is finally reached where even the center is cut off, thus cutting off all plate current. Because a LARGE NEGATIVE BIAS VOLTAGE is required for complete plate current cutoff, this type grid structure is called REMOTE CUTOFF.

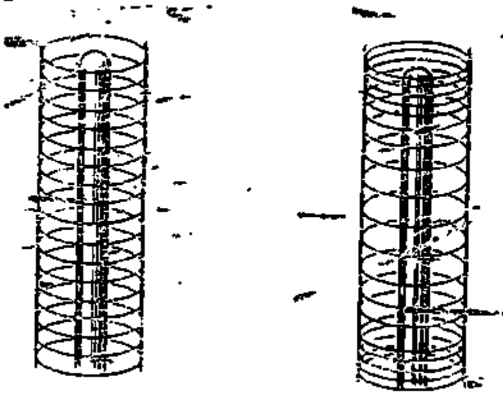

Figure 3-11. Sharp and Remote Cutoff Grid Structures

3-38. In contrast, only a SMALL NEGATIVE BIAS VOLTAGE is required to cut off plate current through the entire uniform and closely spaced grid structure of the SHARP CUTOFF tube. The difference between the two classes then is that, as negative bias is increased, the sharp cutoff tube reaches cutoff quickly while the remote cutoff tube reaches cutoff gradually with much more bias voltage required.

3-39. When a remote cutoff grid is biased so that only the ends of the grid have cut off plate current, plate current still flows through the center. The grid wires are widely spaced in the center of the grid. Hence the center does not have as much control over plate current as the ends. Consequently, the μ of the tube is lower when the center of the grid allows plate current. As bias increases and the cutoff regions increase in size, μ and gain decrease progressively. Because the μ for remote cutoff pentodes changes from high to low, these tubes are also known as VARIABLE MU tubes.

3-40. Beam Power Tubes.

3-41. Power amplifier circuits normally use vacuum tubes which are specifically designed for power amplification. One such tube is the "beam power tube". Its special design gives it the ability to handle high values of current. The plate characteristics of a beam power tube are similar to the characteristics of a pentode tube. The primary difference between the the two tubes is that in the beam power tube the electrons are concentrated into beams by a set of beam-forming plates located inside the tube.

3-42. The location and shape of all elements of a beam power tube are shown in figure 3-12. The cathode is flat to provide a large emitting surface. The plate is usually corrugated to increase the effective plate area, thereby increasing its power dissipation capability.

3-43. Another basic difference in the beam tube is the way in which the grids are wound. In the beam power tube, the screen grid is wound directly in line with the control grid. This reduces the likelihood of electrons striking the screen grid on their way to the plate. Figure 3-13A shows how the ordinary tetrode control grid and screen grid wires determine the electron paths. The tetrode grids are out of alignment, so that many of the electrons which pass through the control grid strike the screen grid. This produces a high screen current, which reduces the plate current. The need for a very large plate current in power tubes makes this characteristic undesirable.

3-44. In figure 3-13B, the screen grid wires are directly in line with the control grid wires so that the screen grid is "shaded" from the electron stream. As a result, the screen grid intercepts fewer electrons. This results in a lower value of screen grid current.

3-45. Another important function of the beam-forming plates is the suppression of secondary electrons from the plate. Figures 3-12 and 3-14 show how the electrons pass through the control grid and screen grid, past the ends of the beam- forming plates, and to the plate.

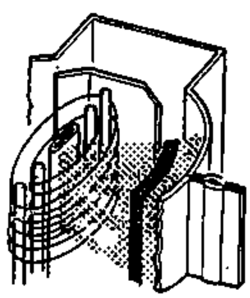

Figure 3-12. Beam Power Tube

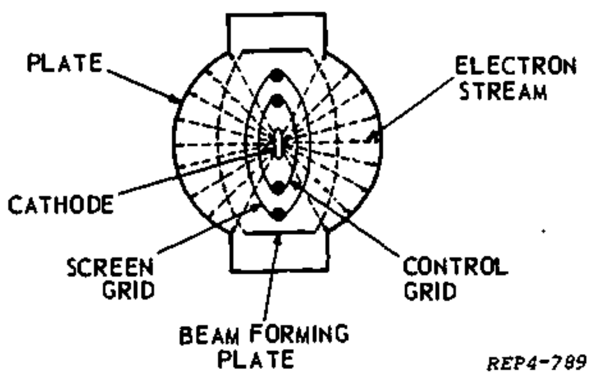

Figure 3-14. Top View of a Beam Power Tube

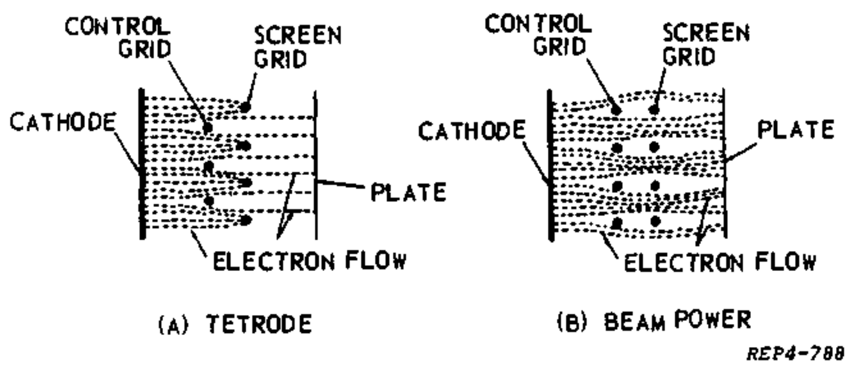

Figure 3-13. Electron Movement in Tetrode and Beam Power Tubes

3-46. The beam-forming plates are connected to the cathode, making them negative with respect to the plate. Because of this, the beam-forming plates produce a space charge in the area between the screen and the plate. Its effect is to repel the secondary electrons emitted from the plate and prevent them from reaching the screen grid. In regular pentodes, the suppressor grid achieves this same effect.

3-47. In a beam power tube, beam-forming plates are added, the screen grid is shaded, and a corrugated plate is used. Therefore, this tube can handle a substantial amount of electrical power without a great deal of distortion. The plate and control grid of a beam power tube are electrically isolated because the screen grid provides shielding. Compared to a pentode used for a voltage amplifier, a beam power tube has high plate current, low screen current, and relatively low plate resistance. The schematic symbol for a beam power tube is the same as the one for a pentode. This is because the effects of secondary emission are eliminated just as if a suppressor grid were present.

3-48. Multielectrode and Multiunit Tubes.

3-49. For certain special applications, more grids may be added to achieve special effects. If four grids are used, the tube is a hexode. If five grids are used, the tube is a heptode or a pentagrid tube. Likewise, if a tube has six grids, it is an octode.

3-50. In many circuit applications, space and weight must be conserved. For this reason, many tubes have been designed in which two or more complete electrode systems are enclosed within the same envelope. For instance, a tube may contain both a triode and a pentode. Nearly any combination of units may be found within the same envelope. However, the number and type of units are limited by the envelope size and the number of connections available.

3-51. Generally, an electron tube does not have a long life expectancy. To provide for easy removal and replacement, the base of a tube is constructed in the form of a connector (plug) which is inserted into a receptacle

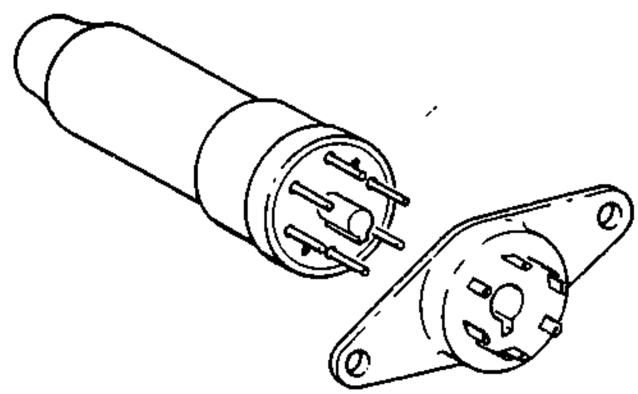

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Figure 3-15. Tube Base and Socket of an Octal Type Tube

(socket). This plug-socket arrangement provides the mechanical support for the tube and the electrical connections between the tube elements and the circuit. The metal connectors on the tube are usually referred to as PINS. An example of this plug-socket and pin arrangement appears in figure 3-15.

3-52. Figure 3-16 shows a schematic diagram of an electron tube. The numbers shown around the outside illustrate that a certain pin is connected to a certain tube element. In figure 3-16, the plate is connected to pin #3. However, because each tube type has its own particular schematic diagram, the plate may be connected to pin #5 in another tube.

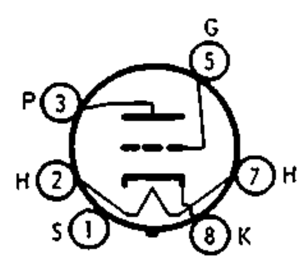

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Figure 3-16. Socket Schematic Diagram

3-53. In order to measure voltages, observe waveshapes, and measure resistances, a particular pin must be found. The tube base and socket are constructed so that the tube may be inserted into the socket in only one way. This is to assure that the tube electrodes are connected to the circuit properly. This is accomplished by the use of a key or pin arrangement such as those shown in figure 3-17.

3-54. Regardless of the type of pin-socket arrangement, the method of locating or counting the pins is as follows. When looking at the BOTTOM of the tube or tube socket, the pins are numbered in sequence in a CLOCK - WISE direction beginning at the key, the first pin past the space, or the last large pin. When looking down on the top of the tube socket, count counterclockwise from the starting point.

3-55. Many tube types are given numbers such as 5Y3, 6AK5, or 12SN7 by the manufanturer. The number, or numbers, preceding the letters indicates the approximate filament voltage required for the particular tube. Thus, the filament voltages for the above tube are 5.0, 6.3, and 12.6 volts respectively. The number, or numbers, following the letters often indicates the number of elements employed. The heater may be included in this count. The 5Y3 is a dual diode with common cathode (3 elements heater excluded); the 6AK5 is a pentode (5 elements-heater excluded); and the 12SN7 is a dual triode (7 elements heater included). The letters themselves may reveal information regarding the type of tube. If the letters are a single U, V, W, X, or Y, the tube may be a diode rectifier. As has been implied, this tube numbering system has not been standardized.

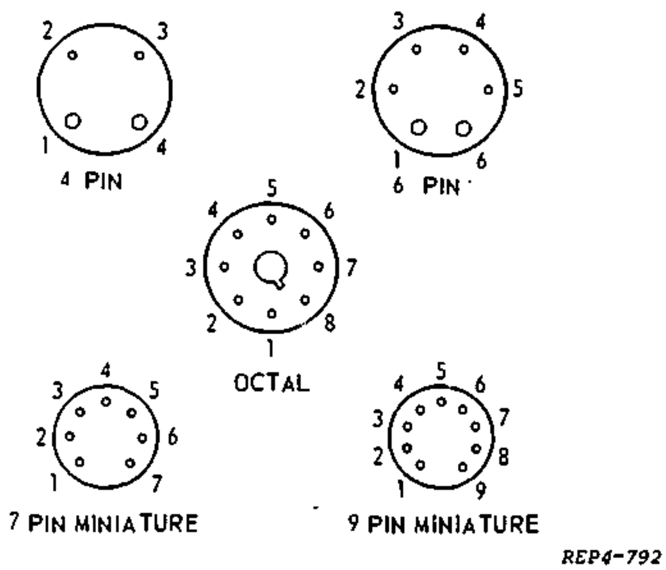

Figure 3-17. Base Types and Numbering Systems

Chapter 4

SPECIAL PURPOSE ELECTRON TUBES

4-1. Many electron tubes exist that are not just simple diodes, triodes, pentodes, etc. These tubes have been designed to fulfill circuit requirements that can not be met by the tubes discussed previously. The special purpose tubes presented herein are gas tubes, phototubes, and cathode ray tubes.

4-2. Gas Tubes.

4-3. The envelopes of gas tubes are first completely evacuated and then filled with a gas under low pressure. The most frequently used gases are argon, neon, xenon, and mercury vapor. Gas filled tubes are often referred to as SOFT tubes in contrast to the HARD or high vacuum tubes. Two basic types of gas tubes exist: hot cathode and cold cathode. In the hot cathode type, the cathode is heated in the normal manner to provide thermionic emission. In the cold cathode type, no external heat is supplied; however, the cathode may become hot because of gas ion bombardment.

4-4. COLD CATHODE GAS TUBES. Since the cathodes of these tubes are not supplied with heat, thermionically emitted electrons are not present. However, if a positive voltage is applied between the plate and cathode, plate current flows.

4-5. The reason for current flow in the absence of thermionic electrons may be explained as follows: A few ions and free electrons are always present in gases in their normal state. When a voltage is applied between the tube's two electrodes, the free electrons drift toward the positive electrode while the positive ions move toward the negative electrode. As the charged particles move, collisions occur between the particles and have sufficient speed, electrons are dislodged from the neutral atoms. (The neutral atoms are IONIZED.) This then increases the number of electrons and positive ions which can move toward the electrodes. With more particles moving, the likelihood of further collisions increases. Thus, the number of charged particles increases further and the current increases. This entire process of causing current to flow because gas atoms are ionized is called IONIZATION.

4-6. The effect of ionization may be observed by measuring current flow as the electrode voltage is varied. Plotting the values of current against the corresponding values of voltage yields a curve similar to the one appearing in figure 4-1. An analysis of the curve produces information about the process of ionization. Several points on the curve are lettered to identify specific regions.

4-7. Region A-B. In this region, the applied voltage causes the charged particles (electrons and ions) to drift through the gas. Because the particles do not have sufficient speed, few collisions produce more charged particles. As a result only a small amount of current flows. This current is often referred to as the DARK CURRENT and is about one microampere.

4-8. Region B-C. As the voltage is increased, the number of atoms ionized increases, but they are neutralized as quickly as they are formed. This accounts for the failure of current to increase over most of this region. However, at some voltage near C, the velocity of the charged particles is sufficient to ionize the gas to a

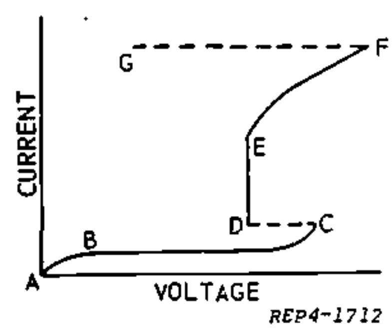

Figure 4-1. Cold Cathode Gas Tube Characteristic Curve

greater extent, and current rises sharply. The current at point C, the threshold current, is about one or two microamperes. This voltage at which the degree of ionization becomes noticeable is the FIRING POINT of the tube.

4-9. Region C-D. At point C, the large increase in the amount of ionization decreases the resistance of the tube greatly. As a result, the voltage drop (I x R) across the tube decreases abruptly, as shown by the dashed line from C to D.

4-10. Region D-E. Throughout this region, the voltage drop across the tube remains constant as the current increases. This is the region most frequently used and is referred to as the OPERATING REGION or CURRENT RANGE. This region exists because as the current increases, the amount of ionization increases, and the resistance of the tube decreases. Therefore, the value of I x R (the voltage) remains constant. The ionization of the gas and the resulting electron flow cause a glow within the tube, the color of which is characteristic of the gas used. A cold cathode gas tube is therefore, called a glow tube; the current flow is called the glow-discharge.

4-11. Region E-F. In this region, an increase in current produces a noticeable increase in voltage drop.

4-12. Region F-G. The voltage reached at point F is so high that an excessive number of positive ions are produced. The heavy ions strike the negative electrode with great velocity because of the higher voltage. The resulting bombardment heats the electrode to a high temperature so that it emits electrons thermionically. The addition of these electrons reduces the resistance of the tube sharply, and the voltage drops abruptly to point G.

4-13. Region G-H. The increase in electron emission and ionization is cumulative, and the current continues to increase until the tube is destroyed. This intense current flow is called an ARC DISCHARGE in comparison to the glow discharge of the operating region. The voltage AT POINT F, at which the arc discharge is started, in the BREAKDOWN VOLTAGE of the tube.

4-14. The characteristics of cold cathode gas tubes are thus seen to be much different than those of high vacuum thermionic diodes. For gas tubes, the voltage drop across the tube remains essentially constant for any current change within the operating region. However, recall that the voltage across a vacuum tube diode always changes as the current changes.

4-15. Two examples of cold cathode gas tubes are shown in figure 4-2. The voltage regulator diode consists of a normal plate and a cathode that is not heated. In order to have current flow, the plate of the diode must be made positive with respect to the cathode. However, the neon glow tube in figure 4-2B can pass current in either direction. As the schematic symbol shows, the two electrodes are identical. Either one can function as the plate or the cathode. For this reason, the tube exhibits the characteristics of figure 4-1 regardless of which way the voltage is applied.

4-16. Because the gasses are ionized, these tubes produce a small amount of light in the region of the negative electrode during conduction. The color of the light depends upon the type of gas in the tube. Since the light is produced near the negative electrode, only one electrode of a neon tube will glow when

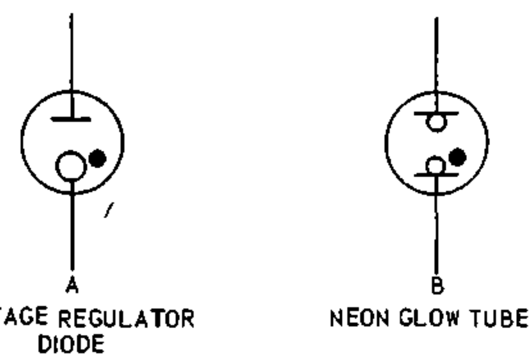

Figure 4-2. Cold Cathode Tube Symbols

DC is applied. However, both electrodes will glow when AC is applied because each electrode is negative during one half of each AC cycle.

4-17. VOLTAGE REGULATORS. The characteristics of cold cathode gas diodes are used in voltage regulation (VR). Some typical VR tubes are the VR-75-30, VR-105-30, and VR-150-30. The designation for these tubes indicates the following:

VR = voltage regulator

75,105,150 = operating voltage in volts

30 = maximum current in mA (Minimum current for proper regulation is 5 mA.)

4-18. The circuit in figure 4-3A is used to determine the characteristic curve shown in figure 4-3B for a VR-75-30 tube. As the potentiometer in the circuit is varied, the resulting values of plate current and plate voltage are plotted to form the curve. After the voltage and current have been increased to point E, they are decreased from point E to points D, C, and F. Notice that the path does not return to point B, but rather goes to point F. This is because the voltage and current are not large enough to keep the tube ionized below point C. When point F is reached, the tube deionizes and current drops to the original low value that existed before the tube ionized. The voltage at point F is known as the EXTINCTION VOLTAGE or the DEIONIZATION VOLTAGE.

4-19. The following information is obtained from the characteristic curve in figure 4-3B.

Firing potential	=	82 V
Operating voltage	=	75 V
Current range	=	5 to 30 mA
Break· wn voltage	=	90 V
Deionization voltage	=	68 V

4-20. The purpose of a voltage regulator tube is to maintain a constant voltage applied to the load connected across the tube. The regulator tube is capable of maintaining a constant voltage when the input voltage and load resistance vary within certain limits. If the input voltage increases for instance,

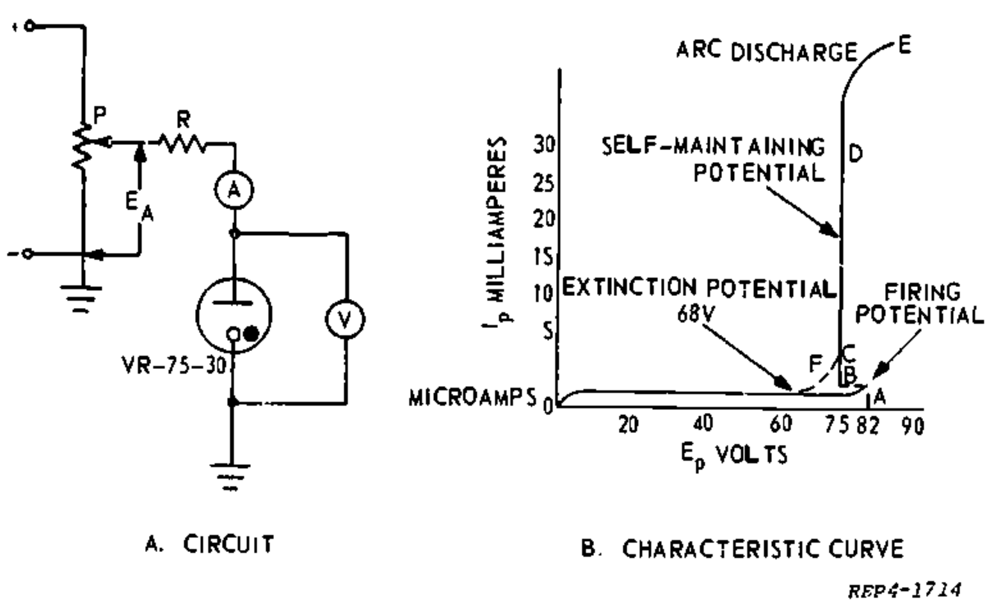

Figure 4-3. VR-75-30 Voltage Regulator

more current will flow through the tube but the output voltage will not change. This is because voltage is essentially constant throughout the operating range of the tube. If the load resistance decreases, more current flows through the load, and less current flows through the tube. However, the output voltage will not change because the voltage across the tube remains the same when the current decreases.

4-21. HOT CATHODE DIODES. Where large currents must be rectified, gas-filled diodes with thermionic cathodes are used in preference to high vacuum thermionic diodes. The gas used in such tubes may be any of those mentioned previously. However, mercury vapor is used most often for this application. The heated thermionic filament vaporizes the mercury and the plate voltage ionizes the vapor. Because the gas is ionized during conduction and thermionic electrons are present, a hot cathode gas diode has a low conducting resistance.

4-22. The ability of mercury vapor tubes to pass large currents results from the low voltage drop across the tube. The power dissipated by a diode is = $E_p \times I_p$. Therefore, the power dissipated for a given value of current is proportional to the voltage drop across the tube. Because the conducting resistance of a gas diode is low, the voltage dropped across the tube is small. Less power is then dissipated for the given value of current. Consequently, more current may flow before the power dissipated by the tube becomes excessive and the tube overheats. High vacuum diodes normally conduct currents of less than one ampere. However, some mercury vapor diodes are capable of conducting several hundred amperes of current.

4-23. THYRATRONS. The addition of a control grid to a hot cathode gas diode yields a gas filled triode known as a thyratron tube. Mercury vapor, argon, helium, or any other inert gas may be used in thyratrons.

4-24. The schematic representation and physical construction of a thyratron appear in figure 4-4. The grid structure is a metal

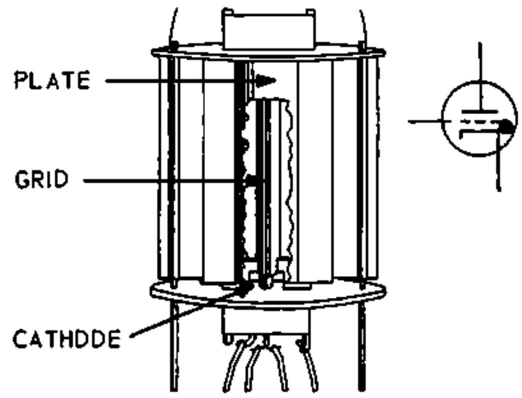

Figure 4-4. Thyratron Construction and Schematic Symbol

cylinder with a small vertical slot. The control grid acts as an electrostatic shield between the cathode and plate. The size of the slot in the grid and the voltage on the grid determine how many of the electrons emitted by the cathode enter the space between the grid and the plate. The number of electrons in this space and the plate voltage determine whether or not the gas will ionize. Just as with high vacuum triodes, a small negative voltage on the grid is capable of cancelling the effects of a much larger positive voltage on the plate.

4-25. When the grid and plate voltages are such that the gas becomes ionized, the tube conducts, and current flows. The amount of current depends only on the impedance of the external circuit because the grid loses control. This loss of control by the grid may be explained as follows.

4-26. The positive ions produced when the gas ionizes are attracted to the negative grid. Because the positive ions form a sheath around the grid, the negative voltage on the grid is neutralized. If the grid voltage is made more negative, additional positive ions are attracted to it, and the grid remains neutral. Once ionization occurs, the thyratron thus conducts like a hot cathode gas diode. That is, the voltage drop across the tube will be low, and large currents may flow. Since the grid loses control over current flow when the tube ionizes, it can not be used to cut off the tube or reduce the flow of current. The plate voltage must be reduced to a value below the deionization voltage in order to deionize the gas and stop the flow of current.

4-27. The grid voltage of a thyratron determines the firing point of the tube. If the grid is made more negative, the plate voltage necessary to ionize the tube will be greater. The effect of grid voltage on the firing point of a thyratron appears in figure 4-5.

4-28. Since the plot in figure 4-5 is nearly a straight line, a simple relationship exists between a change in grid voltage and the resulting change in firing point. The ratio of a change in firing point to a change in grid voltage is called the CONTROL RATIO. If the grid voltage in figure 4-5 changes from -2 to -4 volts, the firing point increases from 250 to 470 volts. Thus,

$$\text{Control Ratio} = \frac{470 - 250 \text{ V}}{4 - 2 \text{ V}} = \frac{220}{2} = 110$$

The control ratio of 110 in this example means that if the grid is made 1 volt more negative the firing point will increase by 110 volts. Because the grid of a thyratron is capable of controlling the firing point, thyratrons find many important applications in all fields of electronics. They are used as electronic switches in a wide variety of

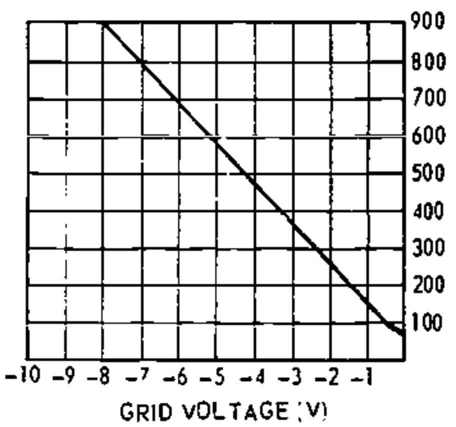

Figure 4-5. Thyratron Firing Point as a Function of Grid Voltage

circuits--such as, counting, control, sweep and modulator circuits, to list only a few.

4-29. Photoelectric Tubes.

4-30. Recall that certain materials are capable of emitting electrons when exposed to light. The emission that occurs is termed photoelectric emission and is used in photoelectric electron tubes (phototubes). The actual number of electrons emitted depends on the intensity and color of the light, the size of the cathode, and the type of cathode material.

4-31. The construction of a phototube is similar to that of a conventional thermionic diode. However, the envelope is made of carefully selected glass, the cathode is in the form of a half cylinder, and the plate (anode) is in the form of a slender wire or rod. The physical construction of a typical phototube appears in figure 4-6 along with the schematic symbol for a phototube. In order to allow the maximum amount of light to strike the cathode, the plate is designed to cast as little shadow as possible on the cathode. A filament or heater is not used in phototubes because thermionic electrons are not necessary or even desirable.

4-32. The plate of a phototube is made positive with respect to the cathode so that the emitted electrons are attracted to the plate. The amount of photoelectric emission is directly proportional to the intensity of the light falling on the cathode. Therefore, as the light intensity varies, the amount of current in the phototube circuit varies accordingly. The result is that a phototube is a device which converts variations of light intensity into variations of current. The effect of light intensity on current flow is shown in figure 4-7. As the light intensity increases from zero to level 1 to level 4, the current increases linearly.

4-33. The amount of photoelectric emission for a particular material depends on the color of light used. Hence, phototubes can be designed to respond to a particular color or a range of colors. If a phototube

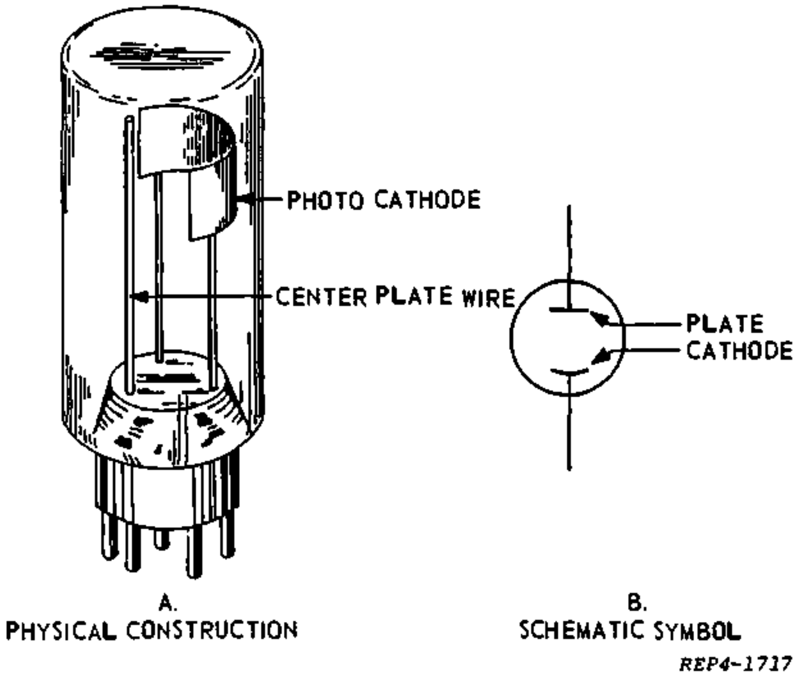

Figure 4-6. Phototube Diode

is to respond to only a single color, a material is used for the cathode which emits electrons only when excited by the desired color. If a phototube is to respond to a range of colors, a material or combination of materials is used that will emit electrons throughout the range of colors.

4-34. As seen in figure 4-7, the amount of current produced by a phototube is extremely small--so small that it is measured in MICROAMPERES. Certain applications may require that more current is

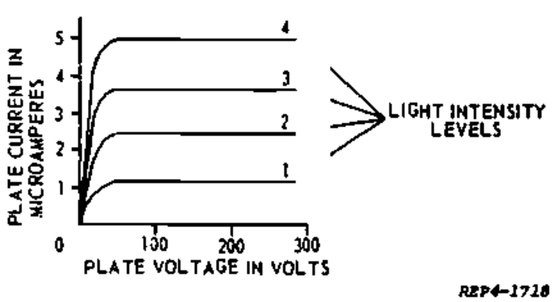

Figure 4-7. Phototube Characteristic Curves

produced for low levels of light intensity. If this is the case, the amount of current flow may be increased in two ways. One method is to put a small amount of gas in the tube. When emission occurs, the total current is larger because the gas ionizes. The other method is to use a photomultiplier tube, the principles of which are discussed in the following section.

4-35. PHOTOMULTIPLIER TUBES. In photomultiplier tubes, the total number of electrons available at the anode is greatly increased because of intentional secondary emission within the tube. Several additional electrodes, known as DYNODES, are added to produce the secondary emission. The physical location of the dynodes for one type of photomultiplier tube appears in figure 4-8A. Figure 4-8B shows the schematic symbol for photomultipliers in general.

4-36. As shown in figure 4-9, each dynode is connected so that it is more positive than the preceding electrode. Also, the anode is positive with respect to the last dynode. Since dynode #1 is made sufficiently positive, the electrons striking it from the cathode produce secondary emission at the dynode. Because dynode #2 is more positive than dynode #1, the secondary electrons from dynode #1 are attracted to dynode #2. Secondary emission alsc occurs at dynode #2. so an even greater number of electrons are available to travel to dynode #3, etc. The dynodes are specifically designed to produce a large number of secondary electrons. As a result, the number of electrons finally reaching the anode is many times larger than the number that left the cathode. When several dynodes are used in a photomultiplier, a multiplication factor of SEVERAL THOUSAND is achieved. In some photomultipliers, a focusing electrode is added to guide the emitted electrons along the desired path.

4-37. Cathode Ray Tubes.

4-38. The cathode ray tube (CRT) is a special electron tube in which a beam of electrons strikes a phosphor coated screen which produces light. Moving the beam over the phosphor screen produces patterns of light which are a visual representation of the signals producing the movement.

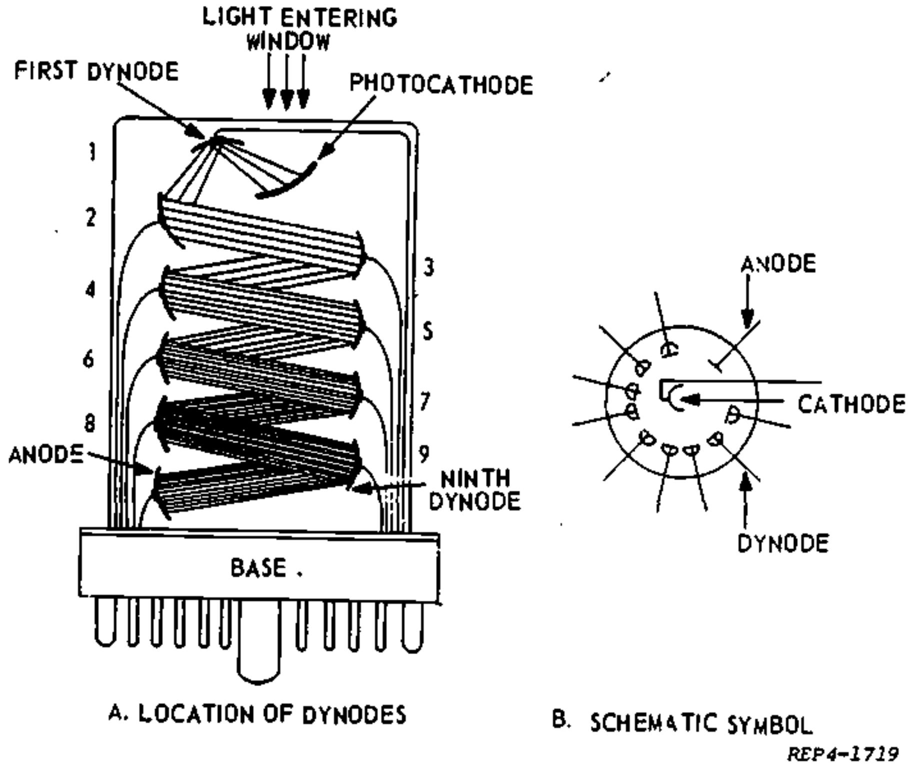

Figure 4-8. Photomultiplier Tubes

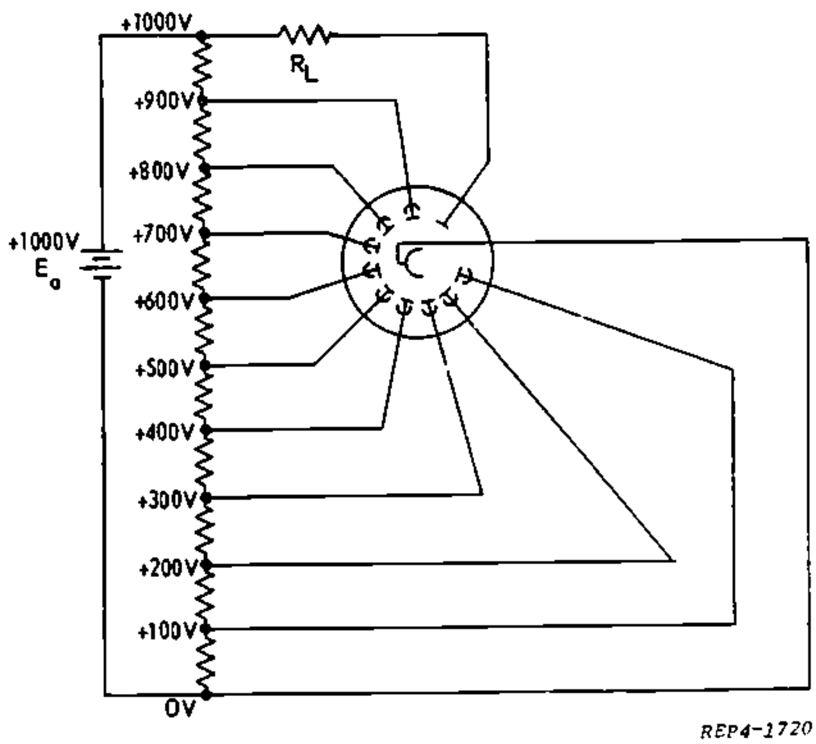

Figure 4-9. Photomultiplier Circuit

Thus, the voltage waveforms existing at some point in a circuit can be displayed in the screen.

4-39. The oscilloscope used thus far to analyze voltage waveforms has a cathode ray tube with supporting circuitry. The oscilloscope is used to observe waveforms and measure voltage, frequency, phase, and time. The versatility of the oscilloscope arises from its ability to visually display a waveform on the CRT. The electron beam can be deflected almost instantaneously, permitting the observation of very high frequencies and pulse waveforms of short duration. If the light intensity produced by the beam is varied, the cathode ray tube is capable of displaying pictures. Hence, the CRT is used as the picture tube in television sets.

4-40. CRT CONSTRUCTION. The envelope of a cathode ray tube consists of a large glass vessel, shaped as shown in figure 4-10. The long, cylindrical glass portion between the base and the tapered section is called the NECK. The front of the CRT is called the FACEPLATE, and a phosphor screen is deposited on the internal surface of the faceplate to form the viewing screen.

4-41. The electrodes which shape and accelerate the electron beam make up the section called the ELECTRON GUN. The electron gun assembly is in the neck of the tube and receives its operating voltages through the pins on the base. Cathode ray tubes are classified as either ELECTROSTATIC or ELECTROMAGNETIC depending on the method used to deflect the electron beam. If electrostatic deflection is used as in figure 4-10, the electron beam is moved by electric fields. Two pairs of DEFLECTION PLATES within the CRT establish the fields necessary to move the electron beam horizontally and vertically. If electromagnetic deflection is used, magnetic fields are used to move the electron beam. The magnetic fields are established by passing current through coils of wire placed around the neck of the CRT.

4-42. The inside surface of the tapered portion of a CRT is covered with a conductive graphite coating. As shown in figure 4-10, this coating is called aquadag. Since it is conductive, the coating shields the electron beam from unwanted electric fields. The aquadag also prevents light from striking the back of the phosphor screen and gathers the secondary electrons emitted from the screen. The aquadag may also provide additional acceleration to the electron beam by applying a high positive voltage to it to give a brighter screen image.

4-43. Once the electron beam is formed by the gun assembly, the electrons must travel some distance before reaching the screen. Even a small number of collisions between the moving electrons and air molecules would hinder the operation of the CRT. Hence, the tube is highly evacuated. The high vacuum and large surface area of the tube make the tube especially vulnerable to DANGEROUS IMPLOSIONS OF TREMENDOUS FORCE. In many cases, sudden jarring or slight nicks or scratches in the glass are sufficient

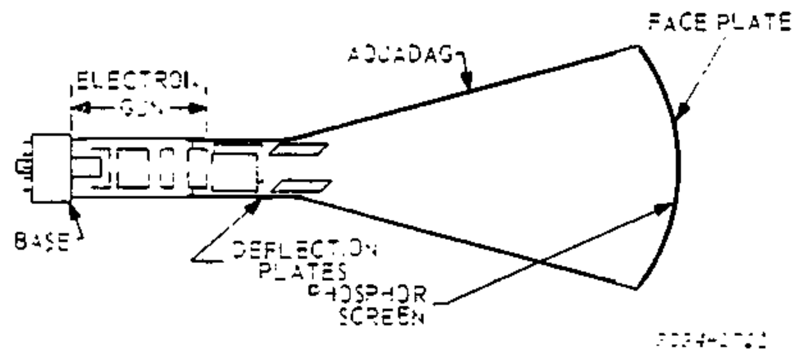

Figure 4-10. Cathode Ray Tube Construction

to cause implosion. Therefore, great care should be exercised when handling cathode ray tubes. Do not attempt to install or remove these tubes WITHOUT THE PROTECTION OF SAFETY GOGGLES AND HEAVY GLOVES. When servicing equipment containing cathode ray tubes, take care that the tube is not bumped or scratched by tools.

4-44. The phosphor screen converts the kinetic energy of the moving electrons into light. The color of light emitted by the phosphor screen may range from ultraviolet to infrared. Thus, both light and heat are given off by the screen. If too many electrons bombard the screen, the phosphor coating will overheat and the screen will be burned. Once burned, the screen is permanently damaged and cannot produce light from the burned area. When using a CRT, the intensity of the beam should never be greater than that required to produce a usable amount of light.

4-45. The characteristics of the phosphor screen depend upon its basic chemical composition. Phosphor screens are classified according to the color of light produced and the length of time light is released. After the excitation has been removed, the length of time required for the light intensity to decay to 1% of its maximum value is termed the PERSISTENCY of the phosphor. Depending on the decay time, the persistency is said to be long, medium, or short. Table 4-1 lists four typical screen coatings and their characteristics. Notice that the coatings are identified by the letter P followed by a number.

4-46. ELECTROSTATIC FORCES. An electrostatic field exerts a force with both magnitude and direction on any charged body within the field. Consequently, an electrostatic field will determine the path taken by an electron placed in the field. The actual path followed by the electron will depend on the initial movement of the electron and the force exerted on the electron by the field.

4-47. Recall that electrostatic fields are represented graphically by lines. The lines leave the positive charge and terminate at the negative charge, as shown in figure 4-11. Because electrons are negatively charged,

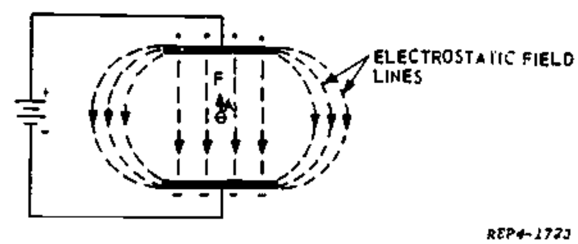

Figure 4-11. Electrostatic Force on an Electron

Table 4-1

CRT Screen Coatings

COATING	APPLICATION	PERSISTANCE	DECAY TIME	FLUORES-CENCE	PHOSPHORES-CENCE
P1	General Oscilloscope	Medium	30 ms	Green	Green
P4	Television	Medium	60 ms	White	White
P5	High Speed Photography	Very Short	35 µs	Blue	Blue
P7	Radar, sonar	Long	3 s	Greenish-Yellow	Blue

the force on them is parallel to the field lines but in the opposite direction. Thus, an electron placed at point A in figure 4-11 would experience the force, F, toward the positive plate as shown. Electrostatic forces are used to both shape and deflect the electron beam in cathode ray tubes.

4-48. ELECTRON GUNS. Depending on the use of the CRT, the electron gun will have from four to six elements placed end-to-end within the neck of the tube. The arrangement of elements in four, five, and six element guns is shown in figure 4-12. The four element gun in figure 4-12A is used in cathode ray tubes which employ electromagnetic beam shaping. However, the five or six element guns of figures 4-12B and 4-12C are used when beam shaping is electrostatic.

4-49. Since the gun assembly must shape the electron stream into a fine beam, the electrodes are shaped like cylinders. Disc-shaped baffle plates, containing a small hole at their centers are placed within the various cylinders. These baffle plates intercept all electrons except those traveling down the center of the gun. The heater is not shaped like a cylinder because its only function is to heat the indirectly heated cathode.

4-50. The cathode is a nickel cylinder with one flat end. The emitting oxides are placed on only the end of the cylinder. Thus, the emitted electrons are moving in the proper direction when they leave the cathode.

4-51. The control grid is cylindrical with one flat end and almost completely encloses the cathode. A small hole in the center of the flat end allows electrons to travel from the cathode to the screen. Just as in conventional tubes, the control grid determines the number of electrons allowed to leave the cathode region, if the grid is made more negative, fewer electrons are allowed to pass through the hole in the grid. This decreases the density of electrons in the beam and decreases the amount of light produced on the screen. The intensity control of an oscilloscope adjusts the grid voltage to vary the amount of light produced. If the grid is made sufficiently negative, electron flow through the grid is stopped. The CRT is then cut off, and no light is produced on the screen.

4-52. The accelerating anode has a large positive voltage applied to it. Therefore, it exerts a strong force of attraction on the electrons coming through the hole in the control grid. This strong attraction accelerates the electrons to a high velocity. Thus, the electrons pass on through the accelerating anode and travel to the screen. The baffle plate in the accelerating anode prevents off-axis electrons from reaching the screen and keeps the electron beam narrow.

4-53. ELECTROSTATIC FOCUSING. A CRT must display intricate waveforms without masking or losing fine details. In order to accomplish this, the electron beam must be shaped, or focused, until only a small dot of light is produced on the screen.

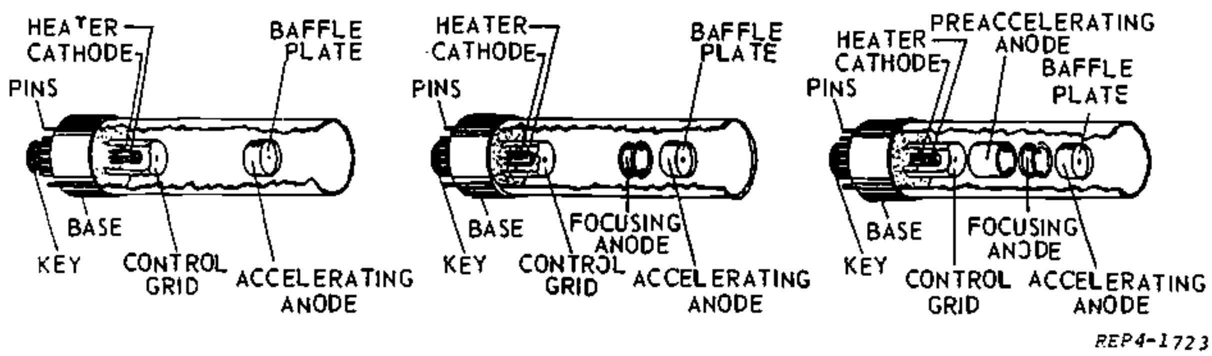

Figure 4-12. Electron Gun Element Arrangements

Electrostatic fields can be used to focus the beam by adding one or two anodes to the electron gun. Figures 4-12B and 4-12C illustrate electron guns which provide electrostatic focusing.

4-54. The focusing anode is operated at a positive voltage much lower than the voltage applied to the accelerating anode. Because a large voltage difference exists between these anodes, an electrostatic field is established between them. The shape of the field forces all electrons toward the center of the beam. The field thus converges the electron beam and makes it form a small spot on the screen.

4-55. If the voltage difference between the anodes is varied, the shape of the field and the focus are controlled. The FOCUS control on an oscilloscope adjusts the focusing anode voltage and controls the size of the dot. The control should be adjusted until the beam forms the smallest spot possible.

4-56. The preaccelerating anode in figure 4-12C is often added to improve the sharpness of focus of the electron gun. It is usually connected, either externally or internally, to the accelerating anode. The resulting electrostatic fields converge the beam more completely and produce a sharper dot on the screen.

4-57. ELECTROSTATIC DEFLECTION. In order to display a waveform on the CRT screen, the electron beam must move in accordance with the signals to be observed. The electron beam (moving negative charges) can be bent, or deflected, by either electric fields or magnetic fields. By passing the beam through either of these fields, the beam can be made to strike the screen at any point. Nearly all oscilloscope cathode ray tubes utilize electrostatic deflection.

4-58. In electrostatic deflection, the beam is deflected by applying a voltage between two parallel metal plates. The DEFLECTION plates are positioned near the end of the electron gun assembly, as shown in figure 4-13. Thus, the beam can be bent to strike the screen at any point along the vertical line passing through the center of the screen.

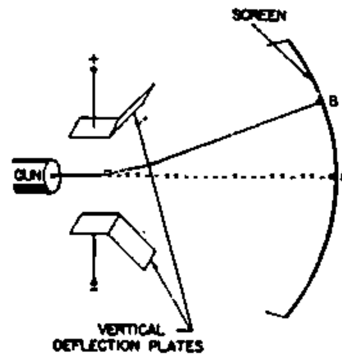

Figure 4-13. Electrostatic Deflection

4-59. When no difference in voltage exists between the deflection plates, the beam is not bent. Therefore, it passes directly down the center of the tube and strikes the screen at point A. However, when a voltage is applied between the plates, the area between the plates contains an electrostatic field. For the example shown in figure 4-13, the top plate is positive with respect to the bottom plate. An electron moving in the space between the plates is attracted by the top plate and repelled by the bottom plate. Thus, the electron is deflected in an upward direction.

4-60. Since each electron in the beam passes between the deflection plates, each electron is deflected by the force exerted by the electric field. Therefore, the entire electron beam is deflected upward during the time it is within the influence of the plates. After leaving the plates, the beam travels in a straight line, striking the screen at point B.

4-61. The amount of upward deflection depends on the value of the voltage between the deflection plates. An increase in the voltage between the plates causes more force to be exerted on the beam. Thus, the amount of deflection increases, and the beam strikes the screen farther from the center.

4-62. To deflect the beam downward from the center of the screen, the polarity of the voltage applied between the plates is reversed. The upper plate then repels the beam

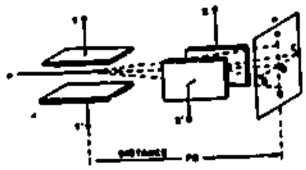

Figure 4-14. CRT Deflection Plates

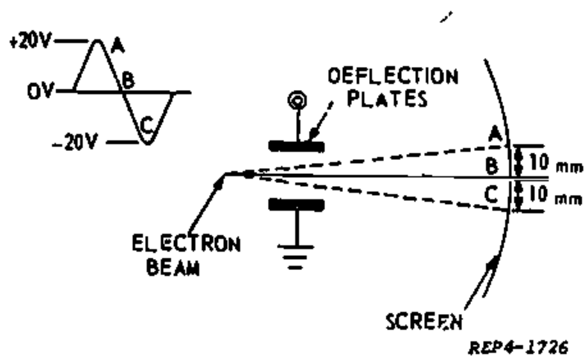

Figure 4-15
Deflection Sensitivity = 0.5 mm/v

and the lower plate attracts it. Since the up and down movement of the beam is vertical deflection, the plates causing this movement are called the vertical deflection plates. Do not be confused by the fact that the plates, themselves, are horizontal.

4-63. A second pair of plates, just beyond the vertical deflection plates, moves the beam horizontally. The beam in a CRT thus passes through the two pairs of plates in succession, as a shown in figure 4-14.

4-64. The horizontal deflection plates (X and X') are mounted so that side-to-side motion of the beam is produced. The beam can be moved to any point on the screen by applying the voltages between both pairs of plates at the same time.

4-65. Deflection Sensitivity. Deflection sensitivity is a constant which indicates how far the spot on the screen moves for each volt applied between the deflection plates. For example, assume that a given CRT has a deflection sensitivity of 0.2 millimeter per volt (mm/v). This means that every volt applied between the plates causes the dot to move 0.2 mm from its undeflected position.

4-66. In figure 4-15, an AC signal is applied to the vertical deflection plates. The +20 volt peak of the signal is seen to move the spot 10 mm on the screen. The deflection sensitivity for this CRT is then:

Sensitivity = 10 mm/20 v = 0.5 mm/v

4-67. MAGNETIC FORCE. Magnetic fields are represented graphically by lines with arrows indicating the direction of the fields. Recall that magnetic fields exist around any moving charge; hence, a moving electron is surrounded by magnetic fields. When a moving electron encounters an external magnetic field, interaction occurs between the two fields, as shown in figure 4-16.

4-68. Assume that the electron is moving away from the observer (into the page) and through the indicated magnetic field. The left-hand rule shows that the electron's magnetic field is counterclockwise since it is moving away. Because the two magnetic fields are in the same direction above the electron, the electron is repelled downward. Likewise, the two fields below the electron are opposite, which attracts the electron downward. The result is that both sets of fields act to force the electron downward.

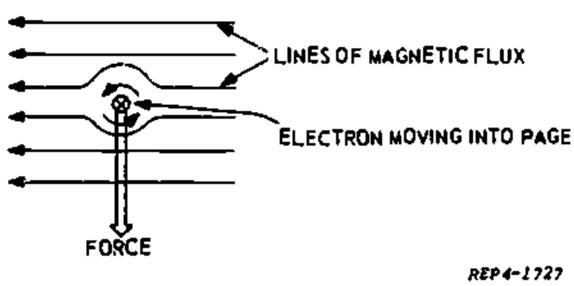

Figure 4-16. Force on a Moving Electron

4-69. The effect of this downward force can be seen by viewing the situation in figure 4-16 from a different position. If the situation is viewed so that the electron moves to the right instead of away, the situation appears as in figure 4-17. The magnetic field is now directed away from the observer (into the page).

4-70. If the electron were not affected by the magnetic field, it would follow the path indicated by the dashed line. However, the electron experiences a downward force as it passes through the magnetic field. It is, therefore, deflected downward, as shown by the solid line, as it moves to the right in the magnetic field. The amount of deflection is determined by the strength of the magnetic field. Just as with electrostatic fields, the electron follows a straight path when it leaves the magnetic field. An electron beam is composed of individual electrons. Thus, an electron beam is deflected in exactly the same manner as a single electron.

4-71. It should be noted that an electron must be traveling at some angle to the magnetic field in order to experience a force and be deflected. In other words, if an electron travels parallel to the magnetic field, it will not experience a force and will not be deflected.

4-72. ELECTROMAGNETIC DEFLECTION. Electromagnetic deflection systems use magnetic fields to move the spot to the desired position on the screen. The magnetic fields are produced by passing current through coils or wire placed next to the neck of the CRT.

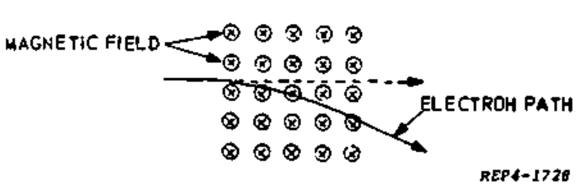

Figure 4-17. Magnetic Electron Deflection

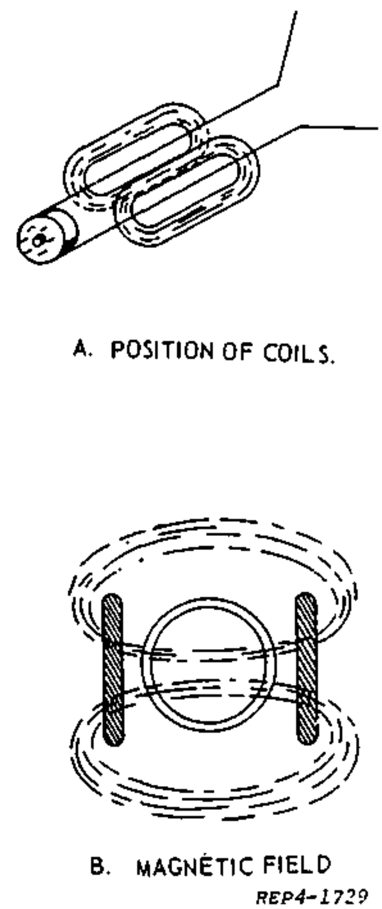

Figure 4-18. Electromagnetic Deflection

The coils, as shown in figure 418A, are connected to produce a magnetic field through the neck of the CRT, as shown in figure 4-18B.

4-73. Since the magnetic field produced by the set of deflection coils in figure 4-18 is horizontal, the beam is deflected vertically. (Recall figures 4-16 and 4-17.) The amount and direction of deflection depends on the strength and direction of the magnetic field, which in turn depends on the value and direction of current flow through the coils. These coils produce vertical deflection; thus, they are called the vertical deflection coils. In a similar manner, coils placed above and below the neck produce horizontal deflection.

4-74. In practice, the deflection coils are usually shaped to conform to the neck of the tube, as in figure 4-19. The horizontal and vertical deflection coils are mounted around the neck in one assembly called the YOKE. The yoke is located next to the tapered section of the CRT envelope.

4-75. The amount of deflection produced is directly proportional to the intensity of the magnetic field. Also, the intensity of the magnetic field is directly proportional to the amount of current flowing in the coils. Thus, the amount of deflection varies directly with the value of current in the coils. As a result, if the dot is to move at a constant rate on the screen, the current in the coils must change at a constant rate. If the dot is to SWEEP across the screen repeatedly, the current waveform must be a sawtooth.

4-76. As is expected, the deflection coils exhibit inductance because of their physical construction. Therefore, a trapezoidal voltage must be applied to the deflection coils to produce a sawtooth current. Recall the trapezoidal waveform generators studied previously. The size of the JUMP voltage will depend on the inductance and resistance of the coils.

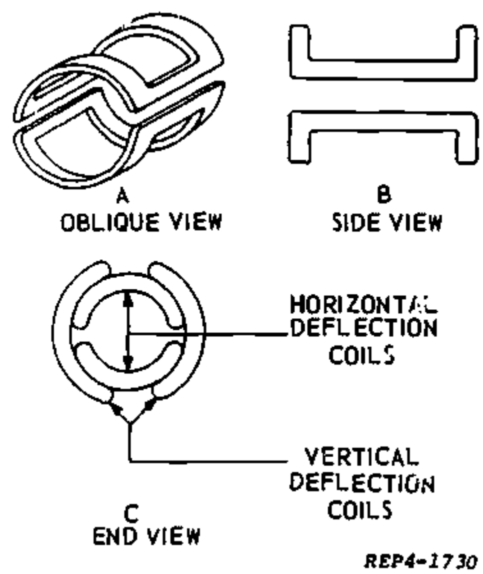

Figure 4-19. Electromagnetic Deflection Yoke

4-77. ELECTROMAGNETIC FOCUSING. To accomplish electromagnetic focusing, a coil is placed around the neck of the CRT, as shown in figure 4-20A. When the coil is connected as in figure 4-20B, the magnetic field produced is parallel to the electron beam.

4-78. Remember, that if an electron travels parallel to a magnetic field, it experiences no force from the field. For this reason, an electron traveling straight down the desired path toward the screen is not acted upon by the field. However, any electron traveling away from the desired path moves at some angle to the magnetic field. Thus, the straying electron experiences a force which causes it to return to the path and strike the screen

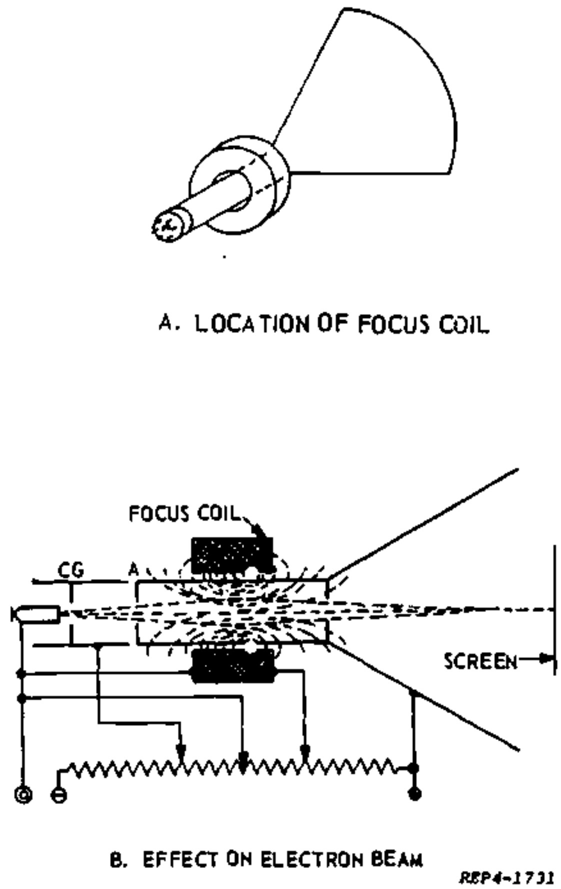

Figure 4-20. Electromagnetic Focusing

at the desired spot. The net effect is that all electrons entering the magnetic field strike the same spot, resulting in a focused beam.

4-79. Voltage is applied to the focus coil in a manner similar to the one indicated in figure 4-20B. Varying the voltage adjusts the current in the coil, the intensity of the magnetic field, and the amount of force exerted on the electrons. The FOCUS CONTROL is adjusted until the smallest possible dot is formed on the screen. Notice that the aquadag coating in figure 4-20B is connected to a high, positive voltage. In electromagnetic systems, the aquadag is often used in this manner as the final accelerating anode.

Chapter 5

ELECTRON TUBE AUDIO AMPLIFIERS

5-1. Because they find such wide application, electron tube audio amplifiers are analyzed in detail at this point. Two circuits have been chosen for discussion because they closely resemble a great number of practical circuit applications. An RC coupled triode audio amplifier is presented to determine the effects of changes in component values within the circuit. An RC coupled pentode audio amplifier is used as the example in determining the effects of faulty circuit components (troubleshooting).

5-2. Effects of Component Value Changes.

5-3. The schematic diagram of the circuit selected for study is seen in figure 5-1. The components shown have been discussed previously but will be reviewed at this time.

5-4. Purpose of Components.

- C_c - Couple the AC input signal to the grid and block any DC voltage from the input.
- C_k - Maintain a constant DC voltage on the cathode by filtering out the AC cathode signals. Prevents negative (degenerative) feedback.
- R_g - Provide a DC path to ground for the small number of electrons intercepted by the control grid.
- R_k - Develop cathode self bias voltage.
- R_L - Develop the output voltage of the triode.
- V1 - Provide amplification.

5-5. CIRCUIT OPERATION. The input signal, e_i, is applied (through C_c) to the grid of V1. V1 amplifies the signal at its grid and produces the amplified signal at its plate. The output signal, e_o, is taken from the plate of V1.

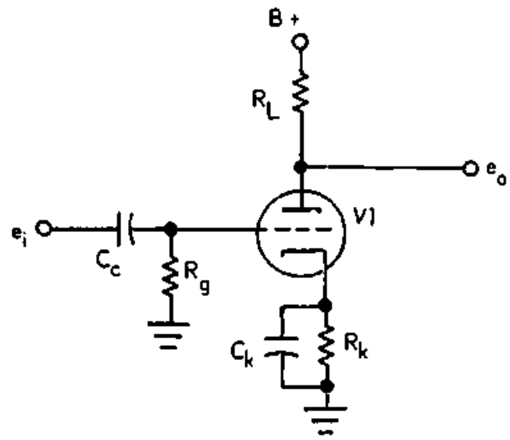

Figure 5-1. RC Coupled Triode Audio Amplifier

5-6. As discussed earlier, the plate voltage waveform is 180° out of phase with the grid voltage waveform. The plate voltage signal and e_o are then 180° out of phase with e_i.

5-7. FACTORS AFFECTING AMPLIFIER GAIN. The gain of the amplifier is primarily determined by (1) the μ of V1, (2) R_k, and (3) R_L. Quite naturally, a tube with a higher μ will produce more amplification than one with a lower μ. R_k has an effect on gain because it determines the grid bias. For any given load line, the μ of most tubes decreases as the negative bias increases. Thus, R_k affects μ and therefore, gain. If R_k increases, negative grid bias increases, μ decreases, and gain decreases.

5-8. As presented in Load Line Analysis, in Chapter 2, as the value of R_L increases, gain increases. This effect is readily seen in the

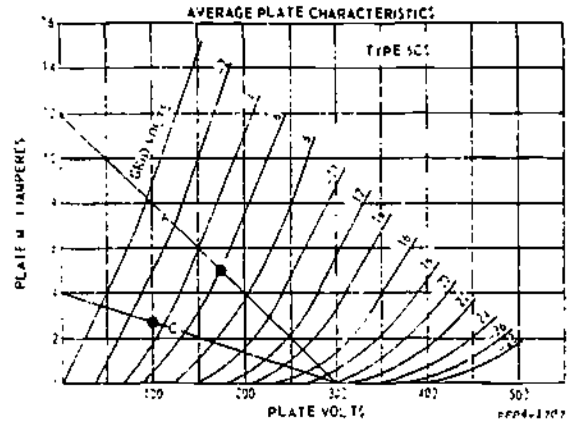

Figure 5-2. Effect of R_L on Gain

Table 5-1

FACTORS AFFECTING GAIN

FACTOR	GAIN
μ ↑	↑
R_k ↑	↓
R_L ↑	↑

example of figure 5-2. Assume that initially R_L is 25 kΩ, and R_k develops -6 volts of grid bias. The operating point is then the point indicated on the load line A. If a 2 volt peak-to-peak signal is applied, the plate voltage swing is 30 volts for a gain of 15. If R_L is increased to 75 kΩ, R_k develops only -3 volts grid bias because with the larger R_L less current flows through V1. The operating point is now seen on load line C. If the same 2 volt peak-to-peak signal is now applied, the plate voltage swing is 35 volts for a gain of 17.5. As a result of increasing R_L, the gain of the amplifier has clearly increased.

5-9. The value of B+ may also affect gain. However, if B+ changes, the direction of the effect will depend on whether the operating point moves in a region of higher μ or lower μ.

5-10. The load connected to the plate of V1 will also affect the gain. Recall the consideration of AC load lines in Chapter 2. As the impedance of the load decreases, the impedance of the parallel combination of R_L and the load decreases. Thus, the AC load line becomes steeper, and gain decreases.

5-11. The effects of μ, R_k, and R_L on amplifier gain are summarized in Table 5-1.

5-12. Because of certain circuit limitations, the amplifier of figure 5-1 will not amplify all frequencies applied to its input. The FREQUENCY RESPONSE of the amplifier indicates the range of frequencies which will be amplified properly. The circuit limitations prevent frequencies outside this range from being amplified to a usable level. A typical amplifier frequency response curve is seen in figure 5-3.

5-13. The amplifier gain discussed in the preceding paragraphs applies to the gain for medium frequencies in figure 5-3. The gain for low and high frequencies is limited by various circuit components. The lowest frequency for which the voltage gain is at least 70.7% of maximum is called the lower half-power frequency (f_1). Likewise, the frequency at the upper 70.7% gain point is the upper half-power frequency (f_2).

5-14. An increase in low frequency response means that more low frequencies are amplified to a usable level. That is, if low frequency response increases, the lower half-power frequency moves to the LEFT in figure 5-3. (The value of f_1 decreases.)

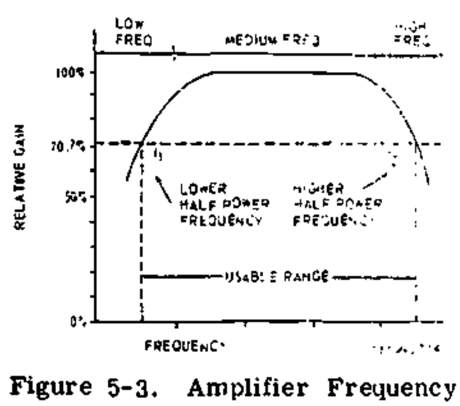

Figure 5-3. Amplifier Frequency Response Curve

Similarly, if the high frequency response increases, the upper half-power frequency moves to the RIGHT. (The value of f_2 increases.)

5-15. FACTORS AFFECTING LOW FREQUENCY RESPONSE. The primary factors affecting low frequency response are: C_c, R_g, C_k, and R_k. The input coupling network for V1 is composed of C_c and R_g. C_c and R_g effectively form a voltage divider network with the voltage developed across R_g applied to V1. For medium and high frequencies, X_{C_c} is much smaller than the value of R_g. Consequently, the entire input signal for these frequencies is developed across R_g. However, decreasing the input frequency into the low frequency range causes X_{C_c} to increase. For sufficiently low frequencies, X_{C_c} becomes large enough to drop a portion of the input voltage. Thus, the voltage across R_g decreases as the frequency decreases within the low frequency range. As a result, the output voltage of the amplifier is not as large for the same input voltage.

5-16. Increasing the value of either R_g or C_c improves the low frequency response. This results from the voltage divider action of X_{C_c} and R_g. If R_g increases in value, it develops a larger percentage of the input voltage. Thus, the input frequency can be decreased to a lower value before the voltage across R_g becomes too small.

5-17. Increasing the value of C_c decreases X_{C_c}. With X_{C_c} smaller, the input frequency can decrease to a lower value before too much voltage is dropped across C_c. Thus, the low frequency response is improved.

5-18. Unfortunately, a limit exists as to the maximum values of C_c and R_g. If the value of C_c is made too large, C_c may be too large physically, or the amplifier may tend to oscillate at a very low frequency (motorboat). If the value of R_g is made too large, the DC path to ground for the grid of V1 is inadequate. This results in unstable grid bias and possible distortion. In practice, X_{C_c} is designed to equal 1/10 the resistance of R_g at the lowest frequency to be amplified. The minimum value of R_g is limited by the maximum amount of loading the preceding circuit can tolerate.

5-19. The cathode bias network consists of R_k and C_k. X_{C_k} is very small compared to the value of R for medium and high frequencies. This bypasses all AC signals and prevents any reduction in gain caused by negative feedback. For sufficiently low frequencies, however, X_{C_k} becomes larger and fails to bypass R_k. If bypassing is not complete, negative feedback occurs, and gain is reduced. Low frequency response is limited to those frequencies for which bypassing is nearly complete.

5-20. If C_k is increased in value, X_{C_k} decreases. This allows the input frequency to decrease to a lower value before X_{C_k} becomes large enough to allow any reduction in gain. Low frequency response is thus improved. If R_k increases in value, C_k is more effective in bypassing R_k This is because X_{C_k} is comparatively smaller when R_k is larger. Low frequency response is thus improved because the input frequency can decrease to a lower value and still have complete bypassing. In practice, X_{C_k} is designed to equal 1/10 the resistance of R_k at the lowest operating frequency.

5-21. The effects of C_c, R_g, and R_k on low frequency response are presented in table 5-2.

Table 5-2

Factors Affecting Low Frequency Response

FACTOR	LOW FREQUENCY RESPONSE
C_c ↑	↑
C_k ↑	↑
R_g ↑	↑
R_k ↑	↑

5-22. FACTORS AFFECTING HIGH FREQUENCY RESPONSE. The high frequency response of any amplifier is limited by three forms of shunt capacitance. These capacitances exist between various points in the circuit and electrical ground, as shown in figure 5-4.

5-23. One of these capacitances is the input capacitance of the tube, C_i. Recall from Chapter 2 that $C_i = C_{gk} + C_{gp}(1 + A)$. Both the physical capacitances of the tube and the gain of the amplifier contribute to the final value of C_i. Another shunt capacitance, C_d, represents the stray capacitance between all of the circuit wiring and the metal chassis. The third shunt capacitance is C_o, the output capacitance of V1. C_o is considered to be equal to the plate-to-cathode capacitance of the tube.

5-24. The high frequency response of the amplifier circuit is limited by the shunting effect of the above listed capacitances. Electrically, these capacitances appear in parallel with either the plate load or R_g. As the frequency of the input signal increases, the reactances of these capacitances decreases accordingly. For sufficiently high frequencies, R_g and the plate load are effectively shorted out. This effectively shorts the grid and plate of V1 to ground, resulting in lower gain. Thus, the high frequency response is limited to those frequencies for which gain does not go below 70.7% because of the shunting effect.

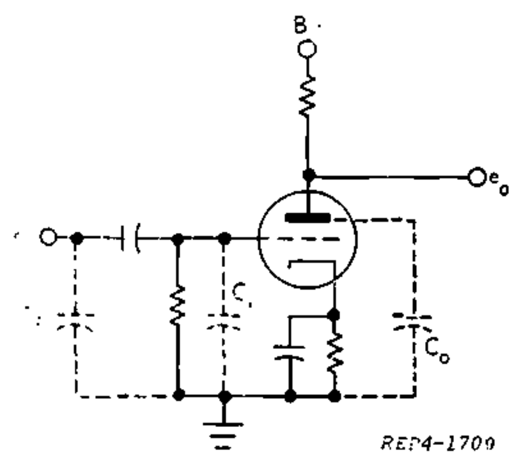

Figure 5-4. Location of Shunt Capacitances

5-25. Any increase in the values of these shunt capacitances will decrease their reactances. The resulting increase in shunting will clearly decrease the high frequency response. In addition to the physical values of capacitance, the amplifier gain also affects high frequency response. As indicated in paragraph 5-23, gain has a direct effect on C_i. If gain increases, C_i increases, and once again high frequency response decreases. The factors affecting high frequency response are shown in table 5-3.

5-26. The preceding discussion of factors affecting gain and frequency response considers only those components within the amplifier. The circuitry before or after the amplifier may also affect either gain or frequency response or both.

5-27. Another factor which affects the overall operation and utility of an amplifier is unintentional feedback. The feedback of concern is that which occurs between plate and grid through C_{gp}. This feedback can be negative (out of phase), and reduce the gain for certain frequencies as discussed previously. However, it can also be positive (in phase) and cause unwanted oscillations. The phase relationship of the feedback depends upon the following: frequency of the input signal, impedance of the grid circuit, transit time, value of C_{gp}, and the type of loading on the amplifier.

Table 5-3

FACTORS AFFECTING HIGH FREQUENCY RESPONSE

FACTOR	HIGH FREQUENCY RESPONSE
GAIN (A_v) ↑	↓
C_{gk} OR C_{gp} ↑	↓
C_o OR C_d ↑	↓

5-28. If positive feedback produces undesirable effects, the amplifier must be NUETRALIZED. Neutralization is the process of cancelling the voltage fed back through C_{gp} with a voltage of equal amplitude but opposite polarity. Figure 5-5 illustrates a neutralized amplifier.

5-29. The voltage at point B is opposite in polarity to the voltage at point A. Therefore, the polarity of the signal fed back through C_n (the neutralizing capacitor) is opposite in polarity to the signal fed back through C_{gp}. If C_n has the correct value, both feedback signals have the same amplitude. As a result, the undesired feedback through C_{gp} is cancelled, and the amplifier is neutralized.

5-30 Troubleshooting a Pentode Audio Amplifier.

5-31. Because pentodes also find wide usage, a pentode audio amplifier is used as the troubleshooting example. The RC coupled pentode audio amplifier circuit selected as the example is seen in figure 5-6.

5-32. FAULTY COMPONENTS AND CIRCUIT SYMPTOMS. If C_c shorts, whatever DC voltage exists at point A is applied to the grid. Depending on the polarity and value of the DC voltage, V1 may be cut off, saturated, or not appreciably affected. If the grid bias is affected, signal distortion is probable. If C_c opens, the input is not coupled to the grid, and there is no output. All DC voltages are normal since C_c has no effect on the operating point.

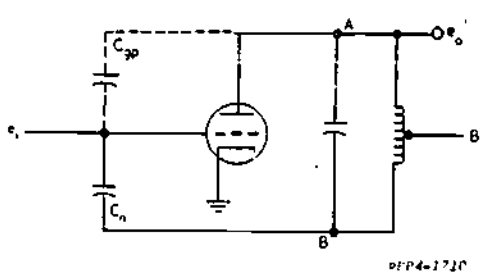

Figure 5-5. Neutralization

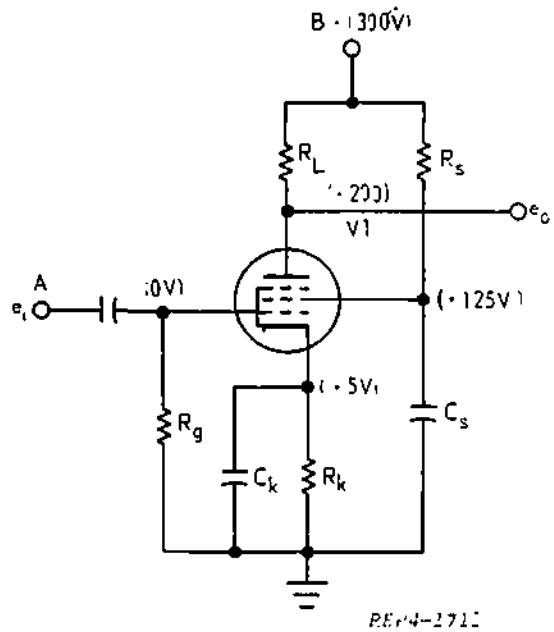

Figure 5-6. RC Coupled Pentode Audio Amplifier with Electrode Voltages

5-33. If R_g shorts, the grid is shorted to ground. All DC voltages remain unchanged, but there is no output because the input to V1 is shorted. If R_g opens, the DC path to ground for the grid is broken. With no DC path, the grid may not stay at zero volts, and grid bias may be unstable. Signal distortion results any time the grid bias becomes unstable.

5-34. If C_k shorts, the cathode resistor is shorted out, and grid bias drops to zero ($E_k = 0$), saturating the tube. Signal distortion results if the input amplitude is large enough to cause grid current on the positive alternations. If C_k opens, R_k is not bypassed. The resulting negative feedback reduces gain and output amplitude.

5-35. If R_k shorts, cathode self bias is eliminated, $E_k = 0$, and V1 saturates. If the input signal amplitude is sufficient, distortion occurs on the positive alternations. If R_k opens, no path exists from ground to cathode for plate and screen current flow. Without current flow, voltage is not developed across R_L and R_S, so E_p and E_S equal B+. An output signal is not possible without current flow through R_L.

5-36. If R_L shorts, it is not capable of developing a voltage. As a result, the plate of V1 is shorted to B+ and E_p = B+. Since R_L can not develop a voltage from the plate current variations, no output signal is possible. If R_L opens, the path for plate current is opened between the plate and B+. Thus, E_p = 0. Since current can not flow through R_L, an output signal is not developed.

5-37. Up to this point, the purpose of each component in the pentode amplifier has been identical to the purpose of the corresponding component in the triode amplifier. However, R_s and C_s were not present in the triode amplifier because the triode did not contain a screen grid. In the pentode amplifier, the purpose of R_s is to provide a DC screen voltage that is lower than B+. In this example, the screen current causes a 175 volt drop across R_s, so that E_s = 125 V (B+ = 300 V). C_s bypasses R_s in order that all AC variations are filtered out. With a constant DC voltage on the screen grid, negative feedback does not occur, and gain is normal.

5-38. If R_s shorts, the screen is connected directly to B+ so E_s = B+. The higher voltage on the screen grid may produce signal distortion as the output. If R_s opens, the screen has no connection to a positive voltage source; thus, E_s = 0. Without the attraction of the screen, electrons are not attracted from the space charge, and plate current does not flow. Without plate current, no output signal is possible.

5-39. If C_s shorts, the screen is shorted to ground. Thus, E_s = 0, and the screen once again does not attract electrons from the space charge. The resulting lack of plate current prevents an output signal from being developed. If C_s opens, R_s is not bypassed. Thus, negative feedback occurs which reduces gain and output signal amplitude.

5-40. The results of the preceding troubleshooting analysis are summarized in table 5-4. As expected, different circuit configurations may produce symptoms other than those discussed herein.

Table 5-4

SYMPTOMS OF FAULTY COMPONENTS

COMPONENT	FAULT	PRIMARY DC VOLTAGE SYMPTOMS	PRIMARY OUTPUT SIGNAL SYMPTOMS
C_g	SHORTED	E_g = ?	Probable Distortion
	OPEN	All Voltages Correct	No Output
R_g	SHORTED	All Voltages Correct	No Output
	OPEN	E_g = ?	Possible Distortion
C_k	SHORTED	E_k = 0	Probable Distortion
	OPEN	All Voltages Correct	Reduced Amplitude
R_k	SHORTED	E_k = 0	Probable Distortion
	OPEN	E_p = B+ E_s = B+	No Output
R_1	SHORTED	E_p = B+	No Output
	OPEN	E_p = 0	No Output
R_s	SHORTED	E_s = B+	Possible Distortion
	OPEN	E_s = 0	No Output
C_s	SHORTED	E_s = 0	No Output
	OPEN	All Voltages Correct	Reduced Amplitude

Chapter 6

ELECTRON TUBE RF AMPLIFIERS, CATHODE FOLLOWERS, DC AMPLIFIERS, AND TRIODE LIMITERS

6-1. Pentode RF Amplifiers.

6-2. Radio-frequency (RF) amplifiers can be classed as voltage or power amplifiers. RF voltage amplifiers are used in radio receivers to increase the amplitude of the received signal, whereas RF power amplifiers are used in radio transmitters.

6-3. As was explained in chapter 3 of this module, triode tubes used in amplifier circuits have certain disadvantages. These disadvantages are poor performance at higher frequencies and low gain. For these reasons a pentode tube is normally used in an RF amplifier circuit. The screen grid and suppressor grid in a pentode tube decrease interelectrode capacitance and increase the gain. This higher gain is very desirable when an RF amplifier is used to amplify the very small input signal voltage to a receiver.

6-4. FUNCTION OF COMPONENTS. The only real difference between the audio amplifier and the RF amplifier using the pentode tube are the value of the components and the type of coupling used for the input and output signal. The audio amplifier uses RC coupling which is efficient for audio frequencies (20 to 20,000 hertz). The RF amplifier is designed to amplify a small band of frequencies within the radio frequency band. To select this small band of frequencies to be amplified, tuned circuits are used in the input and output. The input and output tank circuits may be tuned to the same frequency for high selectivity (narrow bandwidth), or they may be stagger-tuned to provide less selectivity (wide bandwidth).

6-5. Frequency response of the RF amplifier is also affected by the Q of the tanks. Since narrow frequency response may distort the signal, Q is very important. The circuit can be made so selective that the bandwidth will pass only a portion of the desired frequencies and therefore the output signal will not be a true reproduction of the input signal.

6-6. The function of each component of the pentode RF amplifier shown in figure 6-1 is listed below.

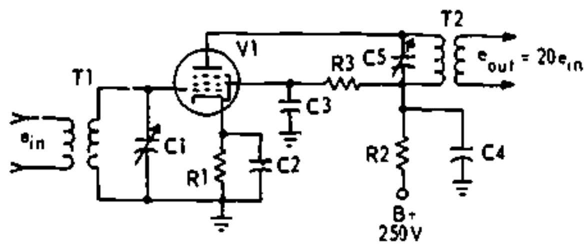

Figure 6-1. Pentode RF Amplifier

T1-RF transformer couples the input signal into the circuit.

SECONDARY OF T1 and C1-Tuned circuit to select the desired signal to be coupled to the grid.

V1-Amplifier

R1-Develops cathode self bias.

C2-Cathode by-pass capacitor. Prevents AC signal from affecting bias.

C3-Screen grid by-pass capacitor. Prevents AC signal from affecting screen grid voltage.

R3-Screen grid voltage dropping resistor.

PRIMARY OF T2 and C5-Tuned circuit to develop the desired output signal.

T2-Transformer couples the output signal to the next stage.

R2 and C4-Decoupling network. Keeps the AC signal out of the B+ power supply.

6-7. CIRCUIT OPERATION. The circuit in figure 6-1 will be used to explain the operation of the pentode RF amplifier. The input signal, which could be any frequency in the radio frequency band, is transformer coupled from the primary to the secondary of T1. C1 and the secondary of T1 forms a tuned circuit that is resonant at the desired frequency. The Q of the tuned tank will determine the selectivity of the amplifier. A high Q tuned circuit is usually desired and is normally produced by using powdered iron cores in the transformers.

6-8. R1 is used to develop cathode self bias for class A operation of the tube. Class A operation is necessary so that the input signal will not be distorted. Also the grid-to-cathode resistance is very high during class A operation. If the grid was ever allowed to draw current, the grid-to-cathode resistance would become very small. This decreased resistance results in a decreased Q and an increased bandwidth. This can be seen by the following formulas:

$$Q = \frac{R}{X_L} \quad \text{and} \quad BW = \frac{fr}{Q}$$

This formula for Q is used when there is a resistance in parallel with the tuned tank. As can be seen by the formula, when the resistance decreases, the Q decreases. The formula for bandwidth shows that BW is inversely proportional to Q when the Q decreases, BW increases. Extensive BW results in amplifying unwanted frequencies.

6-9. C2 is a cathode by-pass capacitor which is used to keep a constant voltage on the cathode and short AC variations to ground. C3 serves the same purpose for the screen grid. Any voltage variations on the cathode or screen grid would cause degenerative feedback and would decrease the gain of the circuit.

6-10. R3 is a screen grid voltage dropping resistor and its size determines the amount of DC voltage that will be on the screen grid. This positive DC voltage on the screen grid determines plate current.

6-11. R2 and C4 are called a decoupling network. They are used to keep any AC voltage variations that appear on the tuned tank of C5 and the primary of T2 from going to the power supply. C4 acts as a short circuit to RF variations and will by-pass them to ground. This keeps a relatively constant DC potential on the top of R2.

6-12. The signal that is developed by the tuned tank circuit of C1 and the secondary to T1 is felt on the control grid of the pentode tube V1. This signal is amplified by V1 and developed across the tuned tank of C5 and the primary of T2. The plate circuit is tuned to the same frequency as the control grid circuit and offers a very high impedance to the desired frequency. This high impedance will cause maximum voltage to be developed across the tuned tank at the desired frequency. This voltage will be transformer coupled to the secondary of T2. All other frequencies that may be present would be filtered out at the tuned tank and would be shorted to ground through C4.

6-13. PARAMETER CHANGES. The RF amplifier that has been discussed here could be used as an intermediate frequency (IF) amplifier if the Q of the tuned tank circuits were very high and both tuned tanks were tuned to the same frequency. An IF amplifier is used to amplify only one frequency in the radio frequency band. An RF amplifier is usually used to amplify a small band of frequencies in the radio frequency band. Thus, to use this circuit as an RF amplifier the Q of the tuned tanks could be lowered slightly or the tuned tanks could be tuned to different frequencies (stagger-tuned). Both of these methods would widen the bandwidth and allow a band of frequencies to be passed.

6-14. Capacitors C1 and C5 are tunable so that the tanks can be tuned to be at resonance at the desired frequency. If they are tuned so that both tanks are resonant at the same frequency, the amplitude of the output signal will be high and the bandwidth will be narrow. If they are stagger-tuned the bandwidth will be wider and the amplitude of the output signal will be less. This can be seen in the response curve shown in figure 6-2. The

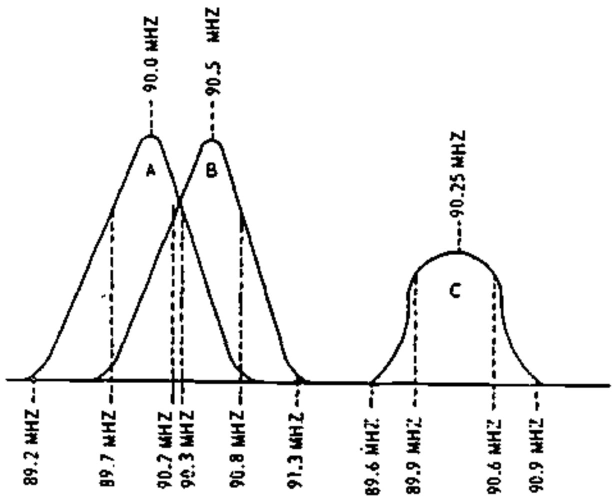

Figure 6-2. Frequency Response Curve

response curve labeled A is for the tuned tank in the grid circuit of the RF amplifier in figure 6-1. The response curve labeled B is for the tuned tank in the plate circuit and the response curve labeled C is the resultant response curve obtained by stagger-tuning the two tanks.

Notice that the bandwidth at the half-power points is 600 kHz for each of the tuned tanks. By stagger-tuning, the bandwidth is increased to 700 kHz. Also notice that the amplitude decreases considerably.

6-15. In paragraph 6-8 it was shown that a resistance in parallel with the tuned tank will affect the bandwidth and amplitude by affecting the Q of the tank. This has to be considered for the tuned tank in the plate circuit as well as the one in the grid circuit. The load in the secondary of a transformer reflects an impedance back to the primary winding. The load for the secondary winding of T2 in figure 6-1 would be the grid circuit of the next amplifier. This impedance has to be kept very high so that a high impedance will be reflected back to the primary. This is to insure that the Q of the tuned tank remains high.

6-16. Cathode Follower.

6-17. USE OF THE CATHODE FOLLOWER. It is necessary at times to transfer a wide band of frequencies from a high impedance circuit to a low impedance circuit with maximum power transfer. Recall that maximum power transfer occurs when the impedances are matched. We provide this impedance matching and wide frequency response with a cathode follower.

6-18. A cathode follower amplifier is a single-stage degenerative amplifier in which the output is taken from across the cathode resistor. Its voltage output is always less than the input voltage, but it is capable of power amplification. A cathode follower is shown in figure 6-3.

6-19. CIRCUIT COMPARISON. Comparing this circuit to that of a conventional amplifier, we find that the input may employ RC coupling. The load resistor is not in the plate circuit, but in the cathode circuit. Notice that the cathode resistor is unbypassed.

6-20. Operation. A positive input signal applied to the grid causes tube current to increase. This current increases the voltage drop across R_k and makes the top of R_k more positive. As the signal goes negative, tube current decreases and the voltage drop across R_k decreases. The cathode voltage "follows" the input voltage.

6-21. The bias for the cathode follower is provided by the cathode resistor, R_k. Aside from the quiescent bias, the tube current is determined by the signal voltage that exists between the cathode and grid. This voltage will be the difference between the grid-to-ground and the cathode-to-ground voltages. The cathode resistor is common to both input and output. Being unbypassed, the cathode voltage follows the input voltage. This as you recall is called negative or degenerative feedback. This feedback subtracts from the input voltage, resulting in the signal voltage between grid and cathode to be less than the original input signal. Because the output voltage subtracts from the input signal, the output can never be equal to the input. The gain of a cathode follower will always be less than one. By increasing the value of R_k, the gain will approach but never equal unity.

6-22. OUTPUT IMPEDANCE. The output impedance of a cathode follower is low and is determined by the value of r_p and R_k. The output is taken across R_k, but since r_p and R_k are in parallel, the value of the output impedance is less than R_k. In selecting the proper size cathode resistor, it is possible to match the output impedance to the load. This can be seen by the formula for output impedance.

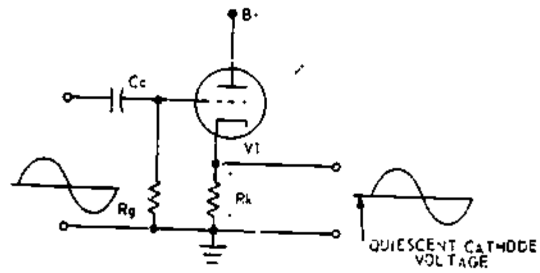

Figure 6-3. Cathode Follower

$$Z_{out} = \frac{R_K \cdot r_p}{r_p + R_k \quad (\mu + 1)}$$

Below is a list of values that we can insert in this formula so that you can see what happens to the output impedance as R_k changes in value.

$r_p = 30\ k\ \Omega$

$R_k = 20\ k\ \Omega$

$\mu = 40$

$$Z_{out} = \frac{20 \times 10^3 \cdot 30 \times 10^3}{30 \times 10^3 + 20 \times 10^3 \quad (40 + 1)}$$

$$= \frac{600 \times 10^6}{30 \times 10^3 + 820 \times 10^3}$$

$$= \frac{600 \times 10^6}{850 \times 10^3}$$

$$= 706\ \Omega$$

Thus we find that with a cathode resistor of 20 kΩ we have an output impedance of 706Ω. By changing the cathode resistor to 10 kΩ and inserting this value in the formula we have:

$$Z_{out} = \frac{10 \times 10^3 \cdot 30 \times 10^3}{30 \times 10^3 + 10 \times 10^3 (40 + 1)}$$

$$= \frac{300 \times 10^6}{30 \times 10^3 + 10 \times 10^3 (40 + 1)}$$

$$= \frac{300 \times 10^6}{30 \times 10^3 + 410 \times 10^3}$$

$$= \frac{300 \times 10^6}{440 \times 10^3} = 682\,\Omega$$

You can see from this example that the output impedance decreases as you make R_k smaller. To increase the output impedance, R_k would have to be made larger.

6-23. GAIN OF CATHODE FOLLOWER. Using the formula for gain ($A = \frac{\mu R_k}{r_p + R_k(\mu + 1)}$) you can see that the size of R_k determines the gain. From the above example when a 20 Ω resistance was used for R_k the gain would be .94 and it would decrease to .47 when we used the 10 KΩ resistor. Usually it is desirable to have high gain and also have the proper output impedance so care has to be taken in selecting a tube with an r_p, that when used with the proper size R_k, will fill both of these requirements.

6-24. INPUT IMPEDANCE. The input impedance of a cathode follower is high compared to that of a conventional amplifier. The input impedance of a tube is primarily the capacitive reactance offered by the input capacitance. Since there is no gain in the plate circuit, the plate-to-grid capacitance is small. The grid-to-cathode capacitance is effectively made smaller because it is only charging to a fraction of the applied signal. This accounts for the low input capacitance of the cathode follower, which gives us a higher input impedance than the conventional amplifier.

6-25. Since the input capacitance of an amplifier determines the high frequency response, the cathode follower has a wide frequency handling capability. The negative feedback accounts for minimum distortion in the cathode follower. The output is fed back to the input and what little distortion is in the output is combined with the input signal, resulting in a decrease in overall distortion.

6-26. DC AMPLIFIERS.

6-27. Direct current amplifiers are used to amplify DC or low frequency AC. A simple DC amplifier consists of a single tube with a grid resistor across the input terminals, and with the load in the plate circuit. The load may be some sort of mechanical device such as a relay or a meter, or the output voltage may be used to control the gain of another amplifier.

6-28. The voltage to be amplified must be applied directly to the grid of the DC amplifier tube. For this reason, only direct coupling can be used in the amplifier input circuit. For a comparison of capacitor-input and direct-input see figure 6-4 and figure 6-5. The graphs above the circuits show the signal voltage, grid voltage, and plate voltage.

6-29. INPUT CIRCUIT COMPARISON. The graphs above the capacitor-input circuit in figure 6-4 indicate how the capacitor blocks the DC signal. The applied DC signal charges the capacitor, and momentarily the voltage drop across R_g equals the applied voltage: the voltage at this time is felt on the grid of the tube. However, when the capacitor is charged to the value of the DC input voltage, the current stops flowing through R_g and the grid reverts to its original value, that of the bias voltage. Thus, except for the original surge of plate current, which occurs when the capacitor is charging, there is no increase in voltage across R_L, and hence no amplification.

6-30. OPERATION. The input signal applied to the direct-input circuit illustrated in figure 6-5 is the same as that of the capacitor-input circuit but here the similarity ends. With no input signal the negative bias voltage is present on the grid of the tube, and a steady value of plate current flows. This action causes a fixed voltage drop across R_L. When a direct voltage of the polarity indicated is applied across the input terminals, there is no blocking action by the capacitor. Instead, the applied signal continues as a steady voltage drop across R_g, canceling a portion of the negative bias. The net bias then drops to the new value indicated in the grid-voltage graph. This reduction in grid bias causes a greater current flow in the plate circuit, and a greater voltage drop across R_L. Thus, the increase in plate current is sustained as long as the input signal voltage exists.

6-31. In a DC amplifier, the plate of one tube is connected directly to the grid of the next tube without going through a capacitor, a transformer, or any similar coupling device. This arrangement presents a problem of voltage distribution. Since the plate of a tube must have a positive voltage with respect to its cathode, and the grid of the next tube must have a negative voltage with respect to its cathode, therefore the two cathodes cannot operate at the same potential. Proper voltage distribution is obtained by connecting each succeeding cathode to a source of voltage more positive than the plate of the preceding tube.

6-32. When the tube voltages are properly adjusted to give class A operation, the circuit serves as a distortionless amplifier whose response is uniform over a wide frequency range. This type of amplifier is especially effective at the lower frequencies because the impedance of the coupling elements does not vary with the frequency. Thus, a DC amplifier may be used to amplify very low frequency variations or DC voltages.

6-33. Figure 6-6 shows a comparison of the frequency response curves for an audio frequency amplifier and a direct current amplifier. Notice that response curve A, which is the response curve for the audio frequency amplifier, does not amplify down to zero frequency, therefore, it could not be used to amplify DC voltage.

6-34. Response curve B, which is the frequency response curve for the DC amplifier, starts at zero frequency and goes up through the audio frequency range. Although the DC amplifier can be used to amplify audio frequencies, it is not practical because of the large supply voltages required if more than one stage is used.

6-35. TRIODE LIMITERS.

6-36. Limiters. The triode limiter is the vacuum tube equivalent of the transistor limiter. The vacuum tube amplifier, like the transistor amplifier, can be operated at cutoff or at saturation. Therefore, using these two extremes, either the positive or the negative alternations of the input signal can be limited.

6-37. METHODS OF ACCOMPLISHING LIMITING. There are four general methods of accomplishing limiting action, depending upon the desired application. The first method is "grid limiting"; this method limits the positive peaks of the input signal to a constant level, but because of the grid-to-plate phase inversion, it is the negative peaks that are limited in the output voltage. The second method is "cutoff limiting": this method limits the positive peaks of the output voltage by making use of the plate current cutoff characteristics of the tube. The third method is "saturation limiting": this method limits the negative peaks of the output voltage. The fourth method employs an "overdriven amplifier"; this method limits both positive and negative peaks of the output voltage.

6-38. GRID LIMITING. When a large limiting resistor is connected in series with the grid of a triode, the grid-to-cathode circuit may be used as a limiter circuit in exactly the same manner as the plate-to-cathode circuit of a shunt-diode limiter. What this means is that when the grid is positive with respect to the cathode, the grid will attract electrons just as does the plate in a diode.

6-39. The triode limiter circuit in figure 6-7 is normally held at zero bias. During the positive portion of the input signal the grid tries to swing positive. Due to grid current flowing when the grid is positive with respect to the cathode, the input signal

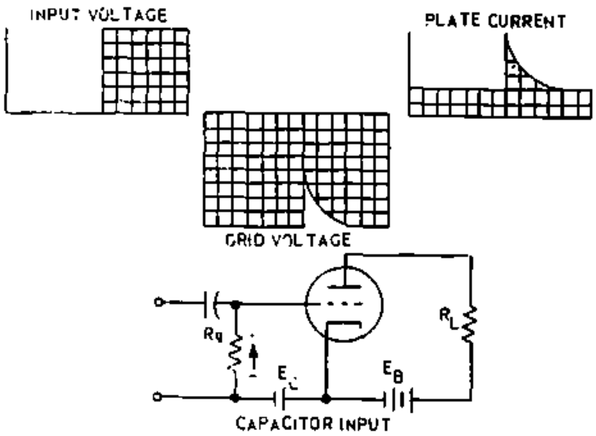

Figure 6-4. Capacitor-Input

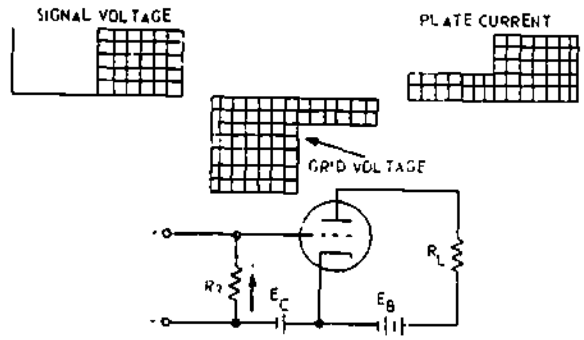

Figure 6-5. Direct-Input

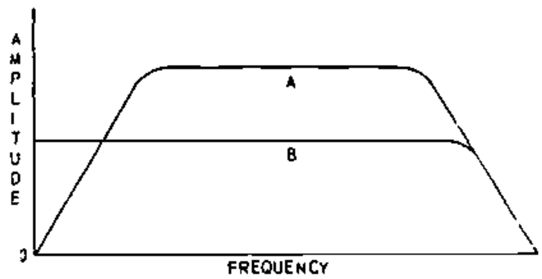

Figure 6-6. Frequency Response Curve Comparison of an Audio Frequency

voltage is divided between R_g and the grid-to-cathode resistance. R_g is a very large resistor in comparison to the grid-to-cathode resistance, therefore, most of the input signal voltage will be dropped across R_g and very little of it will appear on the grid-to-cathode resistance. This very small positive voltage felt on the grid-to-cathode resistance causes only a small increase in plate current which causes just a small decrease in plate voltage. This can be seen by the output voltage waveshapes e_o in figure 6-7.

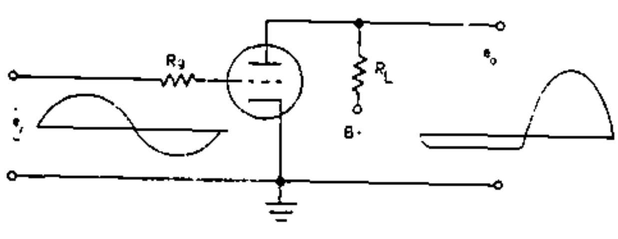

Figure 6-7. Triode Limiter Used for Grid Limiting

6-40. The ratio of R_g to the grid-to-cathode resistance determines the amount of the positive portion of the input signal voltage that will be felt on the grid-to-cathode resistance and, therefore, determines the amplitude of the negative portion of the output signal voltage. The higher the ratio, the more limiting that will occur. The amount of limiting can also be controlled by the amount of negative bias that is applied to the tube. The more the negative bias the less the limiting action that will occur.

6-41. The amount of limiting is not affected by changes in the amplitude of the input signal. When grid current flows, the grid-to-cathode resistance decreases to a lower value: the more positive the grid is driven, the lower the value of the grid-to-cathode resistance. This increases the ratio of R_g to the grid-to-cathode resistance which keeps the voltage drop from grid-to-cathode relatively constant.

6-42. Notice in figure 6-7 that the positive portion of the output signal voltage, which was obtained when the input signal voltage went negative, has not been limited. The negative portion of the input signal voltage was not high enough in amplitude to cut the tube off, therefore, the positive portion of the output signal voltage has not been limited. It was however, increased in amplitude because of the amplifying characteristics of the circuit.

6-43. SATURATION LIMITING. Limiting of the positive half of an input signal voltage can be accomplished by saturation limiting as well as grid limiting. Saturation limiting occurs when an increase in positive grid signal causes no further increase in plate current. If there is no increase in plate current then there can be no decrease in plate voltage. Thus, the negative portion of the output signal voltage will be limited.

6-44. Saturation limiting results from the operation of a triode tube at a very low plate voltage. The grid resistor is eliminated from the circuit. (See figure 6-8). Under these conditions, as the control grid is made increasingly positive, the plate current

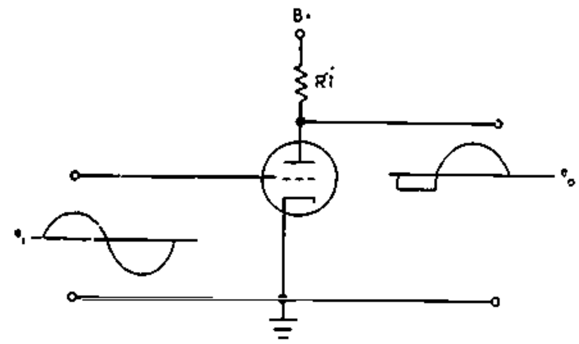

Figure 6-8. Triode Limiter used for Saturation Limiting

approaches the value $B+/R_1$. However, since a small plate voltage must remain across the tube to produce plate current, the plate current cannot become equal to $B+/R_1$, no matter how positive the control grid is driven. Instead, the plate current reaches its maximum at a certain value of control grid voltage, and this maximum determines the lowest value to which the plate voltage can fall. Further increases in control grid voltage will produce no further change in the plate current; therefore, the negative half cycle of the output signal voltage will be flattened, or limited.

6-45. Notice that the positive portion of the output signal voltage in figure 6-8 was not limited. Just as in the grid limiter, the negative portion of the input signal was not high enough in amplitude to cut the tube off, so the positive portion of the output signal voltage was not limited but was amplified.

6-46. CUTOFF LIMITING. Biasing the tube near cutoff will also produce limiter action. When the grid of a tube is driven to cutoff, the plate current is reduced to zero and remains at zero as long as the grid is below the cutoff value. Since there is no plate current when the tube is cutoff, there is no voltage drop across the plate load resistor and the plate voltage is at the full value of the plate-supply voltage. The effect of this limiting of current by the grid being driven negative beyond cutoff is a flattening of the positive portion of the output signal voltage.

6-47. OVERDRIVEN AMPLIFIER LIMITER. The overdriven amplifier limiter uses a combination of saturation limiting and cutoff limiting to cause the input voltage to be converted into essentially a square-wave in the output. The input signal must be large enough to saturate the tube during the positive alternation and cut the tube off during the negative alternation.

Chapter 7

THYRATRON SAWTOOTH GENERATOR, PHANTASTRON, AND ELECTRON TUBE SERIES VOLTAGE REGULATOR

7-1. Thyratron Sawtooth Generator.

7-2. Sawtooth generators, as was explained in Chapter 6 of Volume VI, are used to develop a current or voltage waveshape resembling a tooth in a saw. Hence, the name sawtooth. One of the uses of this sawtooth waveshape is to move the electron beam across the face of an oscilloscope.

7-3. BASIC CIRCUITS. The thyratron sawtooth generator is composed of two basic parts, each being an integral part of the other. The first is a resistance-capacitance circuit to actually shape the wave and the second is a switch circuit which is used to discharge the capacitor. The sawtooth waveshape is the voltage developed across the capacitor while the capacitor is charging through the resistor and discharging through the switch, which is the thyratron tube.

7-4. PRODUCING SAWTOOTH WAVEFORM. Figure 7-1 illustrates the use of resistance and capacitance to produce a sawtooth waveform. When the switch is in position 1, the series combination of the capacitor and resistor are connected across a 200-volt source. The instant the switch is closed, the capacitor will begin to charge at an exponential rate. This will produce the voltage rise of the sawtooth waveform. In order to have a nearly linear rise, only a small portion of the exponential curve is used. Notice that figure 7-1 uses only the very beginning of the capacitors charge curve.

7-5. If the manual switch were replaced by an electronic device which would perform the same function, a continuous sawtooth wave could be generated. The thyratron tube is just such a device.

6-6. IONIZATION AND DEIONIZATION POTENTIALS. The thyratron tube presents an almost infinite impedance when it is deionized. However, once ionized, the tube has a low impedance. The tube can be

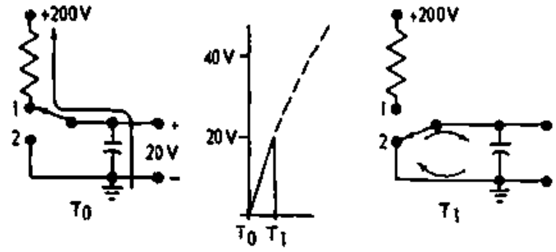

Figure 7-1. Generation of a Sawtooth Voltage Waveform

considered as a switch which is open when the tube is not ionized and closed when it is ionized.

7-7. When the switch in figure 7-1 is replaced with a thyratron tube, the circuit becomes a simple thyratron sawtooth generator. The manner in which the thyratron sawtooth generator creates a sawtooth waveform is illustrated in figure 7-2.

7-8. OPERATION OF THE THYRATRON SAWTOOTH GENERATOR. When a constant voltage is applied to the circuit in figure 7-2, the voltage across the capacitor rises from zero, approaching the full supply voltage along a normal RC charging curve (figure 7-3). The charge path of the capacitor is through the relatively large value resistor, R. The voltage across the thyratron is the same as the voltage across the capacitor because these components are in parallel.

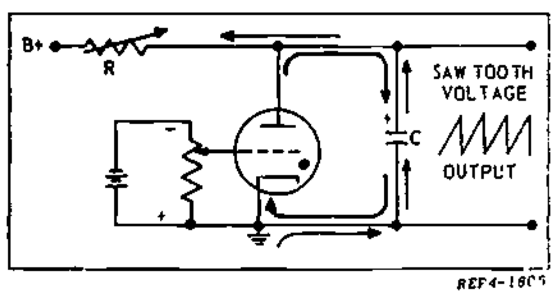

Figure 7-2. Simple Thyratron Sawtooth Generator

The thyratron tube acts as an open switch until the voltage across it reaches the firing point. At the firing potential, the thyratron tube ionizes and provides a discharge path for the capacitor. The capacitor discharges very rapidly until the voltage falls to the deionizing potential of the thyratron tube, at which time, the tube conduction stops and the tube becomes an open switch again. Notice in figure 7-3 that the capacitor did not discharge down to zero volts. This is because the thyratron tube deionized before the plate voltage reached zero volts. This leaves a small charge on the capacitor. When the next cycle starts the capacitor starts charging from this value.

7-9. The amplitude of the voltage rise on the capacitor is controlled by the negative bias on the grid of the thyratron tube. This bias is supplied by a voltage divider. The amplitude and frequency of the output sawtooth waveform is determined by the negative potential on the grid of the thyratron. This is shown in figure 7-3.

7-10. Note that when bias is increased, firing potential increases and amplitude increases, but frequency decreases, because the capacitor takes longer to reach the higher firing potential. This higher firing potential was explained in Chapter IV, paragraphs 4-27 and 4-28. Also, the output has a less linear voltage rise when the amplitude is increased because a larger portion of the charge curve is used.

7-11. METHODS OF CONTROLLING FREQUENCY. In addition to the effect the grid has on the frequency of a thyratron sawtooth generator, the frequency also may be varied by changing the value of the resistor, the value of the capacitor, or the magnitude of the supply voltage. Since the resistor and capacitor form a time-constant circuit, an increase in the value of either component increases the charge time. Therefore, a lower frequency may be expected with increased capacitance or resistance. This condition is shown in figure 7-4.

7-12. Very often the thyratron sawtooth generator will have two controls for varying the RC time constant and, therefore, varying the frequency. This is shown in figure 7-5. The switch which changes the capacitance is called the course frequency control. The variable resistor is the fine frequency control. By using a variation in the value of R and C to change the frequency, the linearity of the output sawtooth voltage is not affected. This is true because the linearity is determined by the percent or the amount of the charge curve that is used. The percentage of the charge curve used when the capacitor charges can be changed only by changing B+, changing the ionization potential, or changing the deionization potential of the thyratron tube. In other words if the capacitor in the thyratron sawtooth generator charges to 63% of the B+ value before the tube ionizes, it will be this same 63% of the charge curve regardless of changes in the value of R or C. Thus the linearity of the voltage rise time will not change when R or C are varied, even though the duration of the rise time and the frequency will change.

7-13. The frequency of the thyratron sawtooth generator may also be changed by varying the supply voltage (B+). If the supply voltage is increased, the capacitor can charge to the firing potential of the tube faster because the firing potential is a smaller portion or percent of the new supply voltage. Thus, the output frequency increases when the supply voltage is increased as shown in figure 7-6. Because the firing potential is a smaller percent of the supply voltage, a smaller portion of the charge curve is used and, thus, linearity has been increased.

7-14. You can see in figure 7-6 that in order to produce a linear rise in the sawtooth waveform, the firing potential of the thyratron tube must be kept very low with reference to the B+ value. Thus, a smaller part of the charge curve can be used. The internal resistance of the thyratron tube, when ionized, is very low so that the capacitor can discharge quickly, keeping fall time very short.

7-15. SYNCHRONIZATION. The thyratron sawtooth generator is not very stable in frequency. Any slight change in R, C, B+, or the firing potential, will cause the frequency to change.

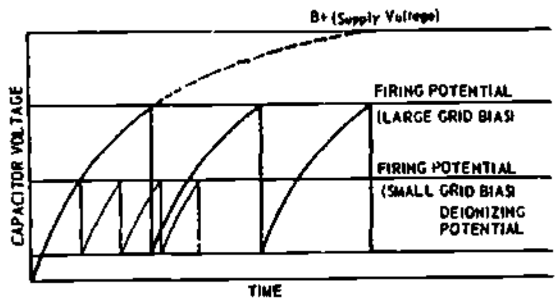

Figure 7-3. Change of Amplitude and Frequency of a Thyratron Sawtooth Generator by Change of Grid Bias

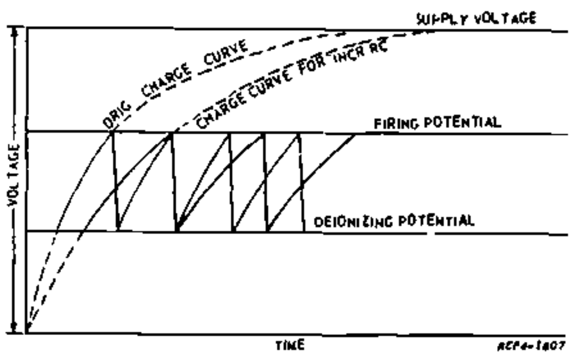

Figure 7-4. Increase in RC Causing Decrease in Frequency

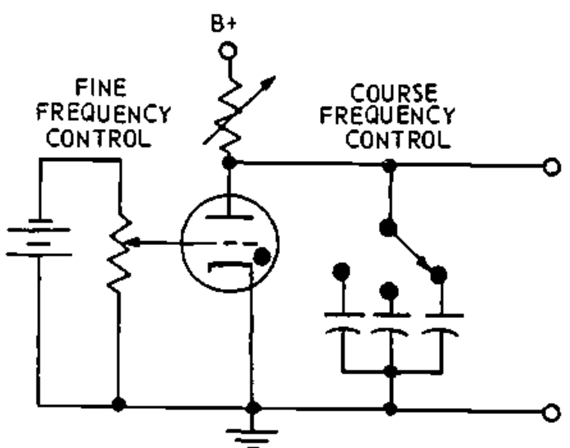

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Figure 7-5. Frequency Control by Varying Resistance or Capacitance

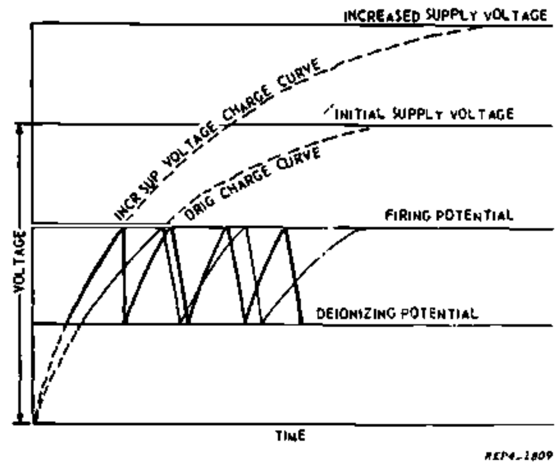

Figure 7-6. Frequency Change Due to Increased Supply Voltage

7-16. The thyratron sawtooth generator, however, can be synchronized. We can accomplish this by coupling a signal of the desired frequency and proper amplitude to the grid of the thyratron rather than a DC signal as in figure 7-5.

7-17. The waveforms of a synchronized thyratron sawtooth generator are shown in figure 7-7. The free-running frequency (shown dotted) is adjusted to a value slightly lower than the desired output frequency. The desired output frequency for example is 500 Hz. The free-running frequency is set to 490 Hz and a 500 Hz AC sync signal is applied to the grid. The frequency of the sync signal is the exact desired output frequency. You can see by the dotted sawtooth wave in figure 7-7 that, without synchronization, the thyratron would fire at point A. However, with synchronization, it fires at point B. The thyratron is "triggered" by the positive alternation of the sync signal. At the bottom of figure 7-7 we have the sync signal riding the fixed bias. The fixed bias, being a negative voltage, is decreased each time a positive alternation of the sync signal is present. At the top of the sawtooth waveform in figure 7-7 you can see that the firing potential decreases each time the positive alternation of a sync signal decreases the bias. This causes the thyratron to fire slightly ahead of time (point B). The time of each cycle of the sawtooth waveform is thus reduced and the thyratron sawtooth generator is now locked to the frequency of the synchronizing signal.

7-18. SYNCHRONIZATION WITH A MULTIPLE FREQUENCY. The thyratron sawtooth generator can also be operated at a submultiple of the synchronizing frequency. Assume, for example, that two cycles of a given signal are to be viewed on the screen of an oscilloscope and that the horizontal sweep voltages are generated with a thyratron sawtooth oscillator. In order for two cycles to appear on the trace, each cycle of the sawtooth sweep voltage must last twice as long as each cycle of the signal to be viewed. In terms of frequency, the sweep frequency must be one half the frequency of the signal frequency. The sweep generator can be triggered by every second cycle of the signal voltage as shown in figure 7-8.

7-19. In this illustration, the signal to be viewed has a frequency of 1000 Hz. When used as a sync, this signal causes the firing potential of the thyratron to rise and fall at the rate of 1000 Hz.

7-20. By adjusting the time constant of the sawtooth-forming capacitor so that the free-running frequency of the sweep is 490 Hz, every other positive alternation of the signal will lower the firing potential of the tube slightly ahead of the point at which the tube would have fired without sync. This forces the sawtooth generator to lock in at a frequency of 500 Hz, one-half the signal frequency.

7-21. IMPROPER SYNC AMPLITUDES. Due to the operating features of the thyratron sawtooth generator, it is possible to apply too little or too much synchronizing voltage to the tube. If too small a synchronizing signal is applied, the firing potential will not be lowered sufficiently to induce reliable triggering on each sweep, thereby causing jitter in the sweep pattern.

7-22. If too large a sync voltage is applied to the thyratron, severe distortion of the screen pattern can result. The reason for this is shown in figure 7-9. The first cycle of operation shows normal conditions and proper sync amplitude. The remaining cycles illustrate the effects of over-synchronization. Notice, that as the sync amplitude is increased, the firing potential is lowered to such an extent as to cause the tube to fire twice during ths same alternation of sync voltage. Thus, as the positive alternation of the sync signal begins, the thyratron is triggered, causing the sweep to commence. Before the sweep can trace very far across the screen, the firing potential is reached again, initiating retrace and the start of a second and longer sweep during the same alternation of the sync signal.

7-23. To properly sst the level of the sync voltage, the sawtooth generator should be adjusted to a frequency slightly lower than the desired sweep frequency with no sync applied. Then, just enough sync should be applied to lock in the pattern.

7-24. PARAMETER CHANGES. A parameter change chart has been included to aid in summarizing the characteristics of the thyratron sawtooth generator. For example, the chart in figure 7-10 shows that an increase in B+ (plate supply voltage) causes an increase in sawtooth generator frequency, no change in sawtooth amplitude, and improved linearity.

7-25. Phantastron.

7-26. INTRODUCTION. The phantastron is a relaxation type oscillator, free-running or triggered, which produces a variety of waveforms. The major characteristics of the phantastron are its insensitivity to fluctuations in supply voltage and an extremely linear plate waveform. Also, the output duration can be made a linear function of a DC control voltage. The highly linear plate waveform in the phantastron is developed by the use of a "Miller Sweep" or "Miller Integrator." The Miller Sweep, in turn, makes use of a phenomenon called "Miller Effect." The phantastron may be free running or triggered but we will only discuss it as a Miller Integrator set up for one shot operation.

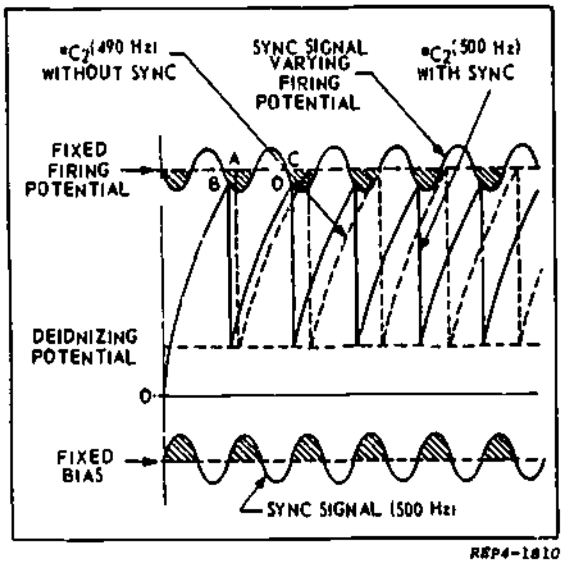

Figure 7-7. Synchronization of Thyratron Sawtooth Generator with Sine Wave

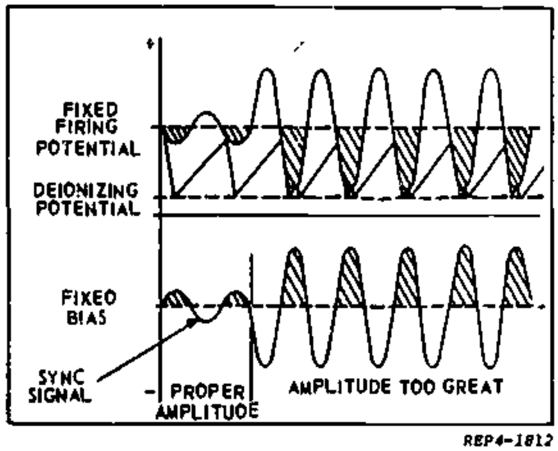

Figure 7-9. Effects of Large Amplitude Sync Signal

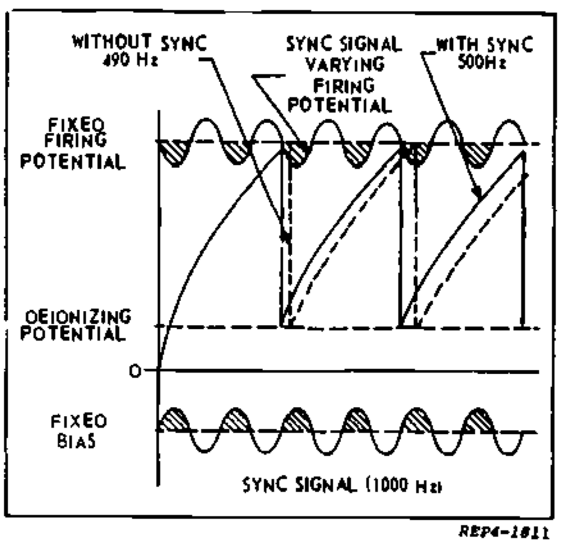

Figure 7-8. Synchronization with a Multiple Frequency

QUANTITY	FREQUENCY	AMPLITUDE	LINEARITY
INCR R	DECR	NC	NC
INCR C	DECR	NC	NC
INCR B+	INCR	NC	IMPROVED
INCR BIAS (MORE NEG)	DECR	INCR	POOR

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Figure 7-10. Parameter Change Chart

7-27. MILLER EFFECT. "Miller Effect" is the effect of stage gain on the input capacitance of an amplifier. The input capacitance of an amplifier is that capacitance which is "seen" by a signal being applied to the grid of an amplifier. The input capacitance is a combination of the grid-to-cathode and grid-to-plate capacitance of the tube and is affected by the amount of gain of the stage.

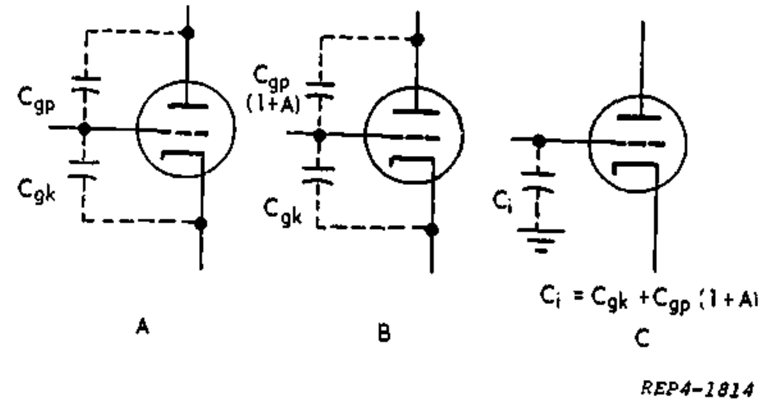


Figure 7-11. Formulation of Vacuum Tube Input Capacitance

7-28. Figure 7-11A shows a triode amplifier with the grid to cathode (C_{gk}) and grid to plate (C_{gp}) capacitance dotted in. Figure 7-11B shows the same interelectrode capacitances but with the gain of the amplifier taken into account. The grid to plate capacitance is now multiplied by a factor equal to 1 plus the gain of the stage. If an amplifier has a gain of 20, the grid to plate capacitance is 21 times that shown in the tube manual. The total input capacitance (C_i), seen by a signal is shown in figure 7-11C. This input capacitance is the sum of the grid-to-cathode and the grid-to-plate capacitance multiplied by one plus the stage gain, or $C_i = C_{gk} + C_{gp} (1 + A)$.

7-29. The reason for the large effect of gain on the grid-to-plate capacitance is shown in the equivalent circuit of figure 7-12. The signal voltage, e_g, represents an AC signal applied to the grid of an amplifier, and e_p is the amplified version of the grid signal. The grid-to-cathode capacitance has been omitted since it is not affected by the gain. As in any amplifier with a purely resistive load, the grid and plate signals are 180 degrees out of phase (using the cathode as a reference); however, in the series circuit consisting of C_{gp} and e_g, the plate and grid voltages are in series aiding. The sum of e_g and e_p is acting between plate and grid, that is, across C_{gp}. The greater the gain, the greater the sum of $e_g + e_p$, and the greater the current. The greater the current, the greater the apparent capacitance between grid and plate.

7-30. The source of the grid signal must furnish the current which flows into and out of C_{gp}, and for this reason the Miller effect is undesirable (although unavoidable) from the standpoint of a standard amplifier. We can, however, make use of the effect to generate a linear sweep voltage, gate, or timing pulse in a circuit called a Miller integrator, Miller sweep, or phantastron.

7-31. MILLER INTEGRATOR. We said earlier the effective grid-to-plate capacitance of an amplifier is dependent on the gain of the stage. If we put an actual capacitor between the grid and plate of an amplifier, the effective capacitance would be $C(1 + A)$ just as before. If C were part of an RC circuit its time constant would be $RC (1 + A)$ while the tube was conducting

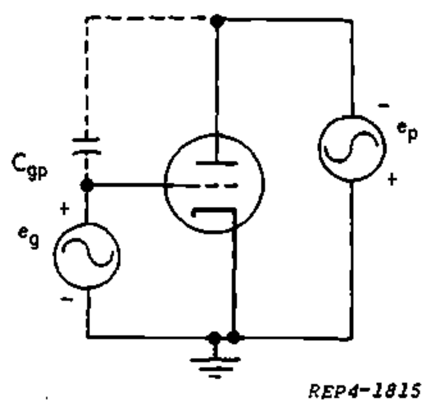


Figure 7-12. Equivalent Circuit

and amplifying and simply RC when the tube was cutoff. This is one of the key factors in the Miller integrator. A simplified Miller integrator circuit is shown in figure 7-13.

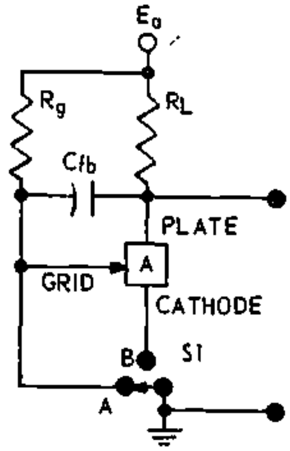
7-32. The block marked A represents an amplifier. R_L is the plate load, C_{fb} is the capacitor connected between plate and grid of the amplifier, and R_g is the grid resistor.

7-33. With S1 in position A no current flows through the amplifier; however, C_{fb} can charge to E_a through R_L in a time equal to 5 R_L C_{fb}. Prior to time T_0, C_{fb} is charged to E_a.

7-34. Lets assume that the amplifier in figure 7-13 has a gain of 25. Also assume that at T_0, S1 is moved to position B.

7-35. The instant S1 is placed in position B, plate current starts to flow and plate voltage drops sharply. The drop is shown on the graph between point A and B and is labeled e_j. The amount of jump will depend on E_a and R_L and the amplifier characteristics. The jump occurs almost instantaneously and C_{fb} will be a short circuit to the sudden change. The jump appears across R_g, driving the grid of the amplifier negative by the amount of jump but is not large enough to cut the tube off. The grid controls the plate current, and the tube is now in a condition to amplify.

7-36. A voltage change appears across C_{fb} and it attempts to discharge an amount equal to the jump. As C_{fb} discharges, the bottom of R_g goes in a positive direction from its most negative point, and since the bottom of R_g is connected to the grid, it also goes in a positive direction. The plate current is under control of grid voltage at this time and the tube is amplifying with a gain of 25. This means that the discharge current from C_{fb} will change at a rate which is inversely proportional to R_g C_{fb} (1 + 25). The grid, therefore, is going positive at the rate the discharge current decreases, and as the grid goes positive, plate current increases and causes plate voltage to drop. For each volt the grid goes positive, the plate drops by 25 volts since the tube has a gain of 25. It is easy to see, then, that the plate voltage is



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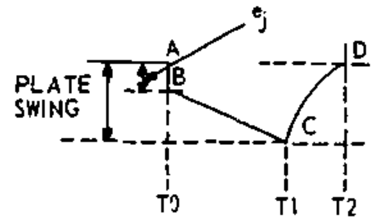

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Figure 7-13. Simplified Miller Integrator

changing 25 times as fast as the grid voltage. The plate voltage change is shown between points B and C on the graph in figure 7-13. This change is known as the "plate rundown."

7-37. Consider for a moment what is happening between points B and C on figure 7-13. C_{fb} is discharging through R_g and the decreasing discharge current allows the grid to go in a positive direction which, in turn, causes plate current to increase. The increase in plate current causes the plate voltage to drop. This determines the rate at which the discharge current will decrease. The decreasing discharge current allows the grid voltage to continue in a positive direction, but at a slower rate. These actions will occur at two different rates. The capacitive discharge current will change at a rate which is inversely proportional to R_g C_{fb} (1 + 25), and the grid voltage will change at this same rate. At the same time the plate will change at a rate which is gain times as fast. The voltage change in the plate is only a small percentage of the discharge curve of C_{fb} and is therefore linear, as the drop between points B and C on the curve indicates.

7-38. At time T_1, assume that we change S1 back to position A. Plate current stops flowing and the plate voltage will rise at an exponential rate controlled by the time constant of R_L C_{fb}. This is shown between points C and D on the curve.

7-39. Lets review the circuit action a moment. Prior to time T_0, C_{fb} has charged. At T_0, S1 is placed in position B. Plate current flows and a sharp drop in plate voltage occurs. This drop is coupled to the grid, driving it negative. C_{fb} starts to discharge at point B the start of the linear rundown of plate voltage between points B and C. The plate rundown is linear because it only amounts to a small percentage of the discharge curve of C_{fb}. This is true because the amplifier gain causes C_{fb} to discharge as though it were much larger than it actually is. At T_1, S1 is placed back in position A and plate voltage returns to E_a at a rate determined by the time constant of R_L C_{fb}.

7-40. The circuit is called a Miller integrator because it uses Miller effect to form a long time constant RC circuit. The Miller integrator and the phantastron are almost the same circuit. The phantastron is self gating and may be started by a trigger.

7-41. Figure 7-14 is the schematic of a phantastron and figure 7-15 shows the various waveshapes of the circuit. Before going into the circuit lets compare this circuit with the Miller integrator we talked about earlier. In the circuit of figure 7-13 we used a mechanical switch to change the tube from an amplifying to a non-amplifying condition. Mechanical switching is not practical so it must be done electronically. In the phantastron, switching is done by the application of a trigger from an external source. Lets identify the circuit components in figure 7-15, then we will discuss circuit operation.

7-42. R1 and R2 form a voltage divider network. The quiescent suppressor grid (G3) voltage comes from this voltage divider. R3 is the control grid (G1) bias resistor tied to B+. C2 couples feedback from plate to grid and, along with R3, forms the RC network which helps to control the output duration. R4 is the plate load, R5 is the

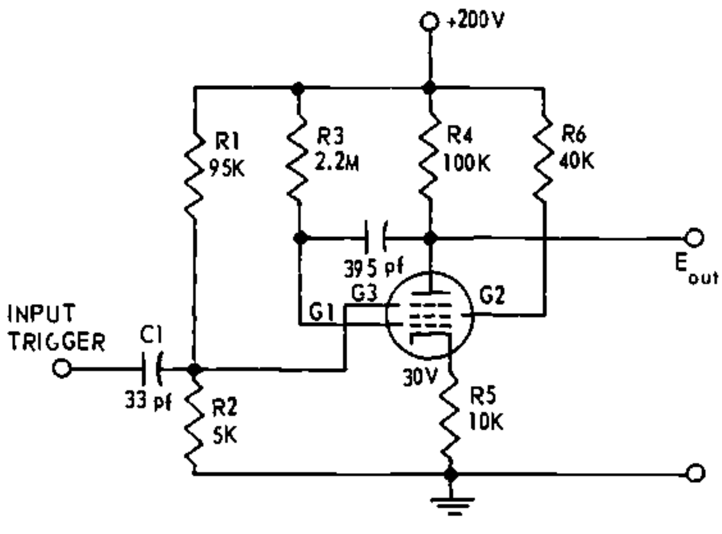

Figure 7-14 . Phantastron

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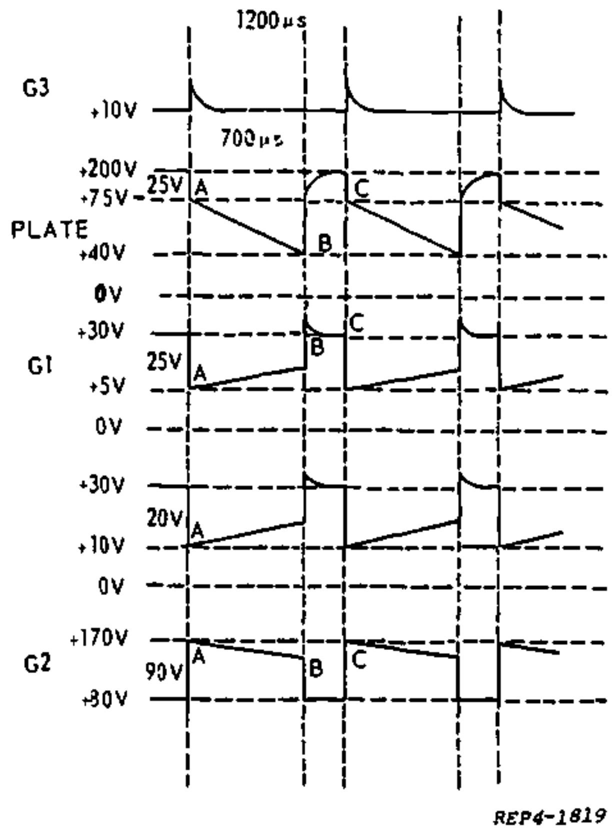

Figure 7-15. Phantastron Waveshapes

cathode resistor, and R6 is the screen grid resistor. C1 couples the positive trigger to the suppressor grid. V1 is a sharp cutoff pentode.

7-43. We will talk about static conditions first, then see what happens when a trigger is applied. No plate current flows when the circuit is quiescent, but screen grid (G2) current is allowed to flow. The voltage divider network is arranged so that +10 volts is applied to the suppressor grid. Screen grid current and control grid current through R5 place the cathode at +30V. The suppressor grid is at +10 volts and the difference of potential between it and the cathode is -20 volts, enough to cut plate current off. The control grid is returned to B+ through R3 and with grid current C2 charges through R5, the grid to cathode resistance of the tube, and R4. The flow of grid current maintains the grid slightly positive with respect to the cathodes' +30 volts because of the grid to cathode resistance. Screen grid current through R6 places the screen grid at +80 volts.

7-44. These conditions exist prior to the time a trigger is applied: Screen grid and control grid currents are flowing, the cathode is positive and the control grid is at approximately the same potential. No plate current is flowing due to the bias between suppressor grid and cathode. C2 has charged in a time proportional to R5 X R4 X C2 because the tube is non-amplifying and there is no Miller effect. We now have the same conditions as when S1 was in position A in figure 7-13.

7-45. At time T_0 in figure 7-15, a positive trigger is applied to the suppressor grid through C1. The positive trigger causes plate current to flow. The instant plate current flows, the plate voltage drops. C2 couples this plate change to the grid which goes in a negative direction by the amount of change. The drop in grid voltage causes a decrease in total tube current and, therefore, the cathode voltage drops. The drop in cathode voltage reduces the difference between suppressor grid and cathode voltages, which causes an increase in plate current. This is a regenerative action which continues until the jump point is reached (point A, figure 7-15). In this circuit the jump is 25 volts. Notice that the control grid also changes by 25 volts.

7-46. The decrease in total tube current causes the cathode to drop to +10 volts at point A. This means that there is zero volts difference between suppressor grid and cathode. C2 discharges because of the 25 volts change at the plate, and the plate rundown begins. Since plate current is flowing, the tube is amplifying, and the change in C2's discharge current is at a rate which is inversely proportional to R3C2 (1 + A). The plate change is gain times as fast as the grid. As C2 discharges, the grid goes positive gradually as the rate of discharge decreases. As the grid goes positive, plate current increases, causing plate voltage to drop even further. The drop in plate voltage slows the rate at which the discharge current decreases. Notice the linearity of the plate rundown. This is because the plate rundown time amounts to a small percentage of the capacitors discharge curve. The C2 discharge current decrease is at a rate inversely proportional to R3C2 (1 + A), and the plate potential drops at $\frac{Ea}{R3C2}$ volts per second. The plate swing (figure 7-13) is fixed by such constants as plate load, tube characteristics, and applied voltage. In figure 7-15, the plate swing is 160 volts and is changing at $\frac{Ea}{R3C2}$ volts per second. At this rate, it takes approximately 700 microseconds for the plate to drop 160 volts.

7-47. During the plate rundown, the grid of V1 gradually goes positive. This increases plate current but also increases screen grid current and, thus, total tube current. As tube current increases, the cathode gradually goes more positive and the screen grid less positive. The plate, control grid, screen grid, and cathode voltages continue to change during the rundown until the plate "bottoms" (point B, figure 7-15). This is the point where plate voltage can no longer change, even with an increase in grid voltage.

7-48. When point B is reached, the plate can drop no further, and the tube stops amplifying. With no amplification, C2 discharges at a rate determined by C2 and R3 because there is no feedback.

7-49. The fact that there is no feedback causes the grid to go rapidly positive, which increases the difference between the suppressor grid and cathode. This cuts plate current off. As plate current stops, control grid current starts to flow, and C2 rapidly charges. The charging current of C2 flowing through R4 prevents the plate from reaching B+ instantaneously. At point C of figure 7-15, all voltages have reached quiescence, and another trigger arrives. C2 does not charge to B+ because of the quiescent grid voltage.

7-50. PARAMETER CHANGES. The rundown time of the phantastron can be varied by changing the control grid resistance (R3) or feedback capacitance (C2) or both. An increase in R or C will increase rundown time. A change in R3 affects only rundown time but a change in C2 would affect both rundown and recovery time.

7-51. A variation in B+ would change all voltages proportionally so very little change in duration would occur.

7-52. Changing the plate swing of the tube is an effective way to vary the rundown time. Changing the plate swing changes rundown time but does not affect recovery time.

7-53. There are two ways to change plate swing. One way is to change the plate load resistor. This changes the rundown time, but it also affects the jump voltage, recovery time, and total tube current. A much more effective way to change the plate swing is to hold the plate at a lower starting level than B+. This changes nothing but rundown time.

7-54. PHANTASTRON WITH DISCONNECT DIODE. A way to control the starting plate voltage without affecting other circuit parameters is shown in figure 7-16 and the associated waveshapes in figure 7-17. The actual phantastron circuit has not been changed. C3 and R8 have been added to differentiate the positive gate at the screen grid so that a variable delay trigger can be available at E_0. The only other changes are the addition of the potentiometer R1 and diode V2. R1 is in the suppressor grid voltage divider network, but the total resistance is the same as before so that +10 volts is maintained at the suppressor grid. V2 is called a "disconnect" or "plate-catching" diode. Its purpose, along with R1, is to control the starting plate voltage of V1. It isolates the plate circuit from the voltage divider during plate rundown. Controlling starting plate voltage controls plate swing and rundown time. Lets see how this is accomplished.

7-55. Assume, for a moment, that we have no trigger. Without V2, the circuit would be static with V1 cut off and its plate at +200 volts. The plate of V2 is now connected to the plate of V1 so it would be at +200 volts. If we place the cathode resistor of V2 at position A, the cathode is at +200 volts as well as the plate, and V2 does not conduct.

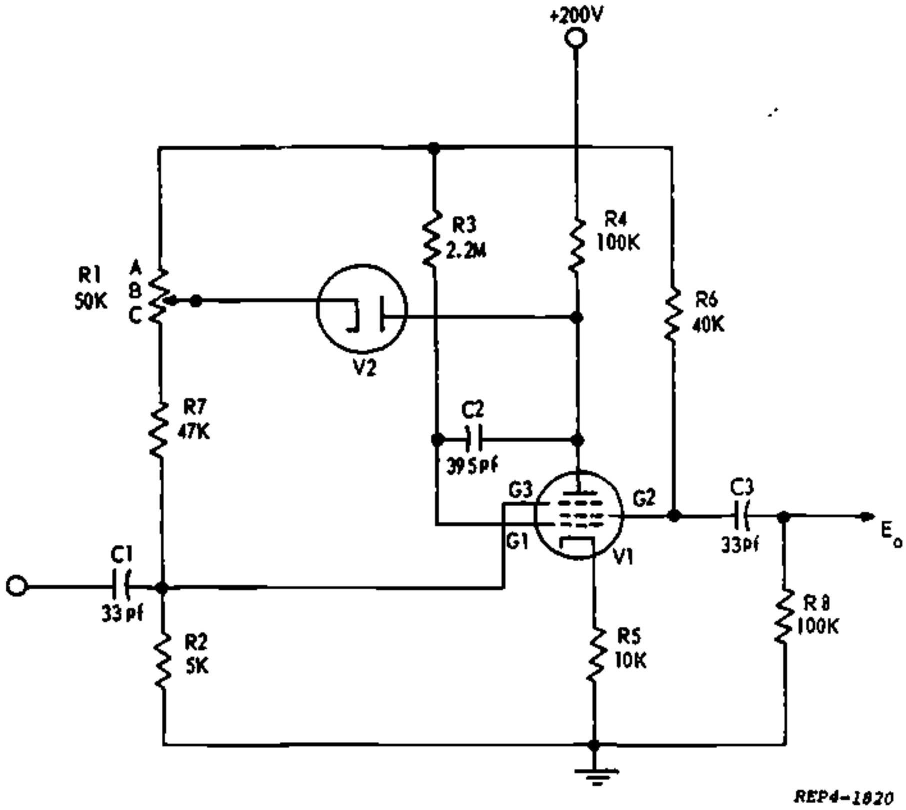

Figure 7-16. Phantastron with Disconnect Diode

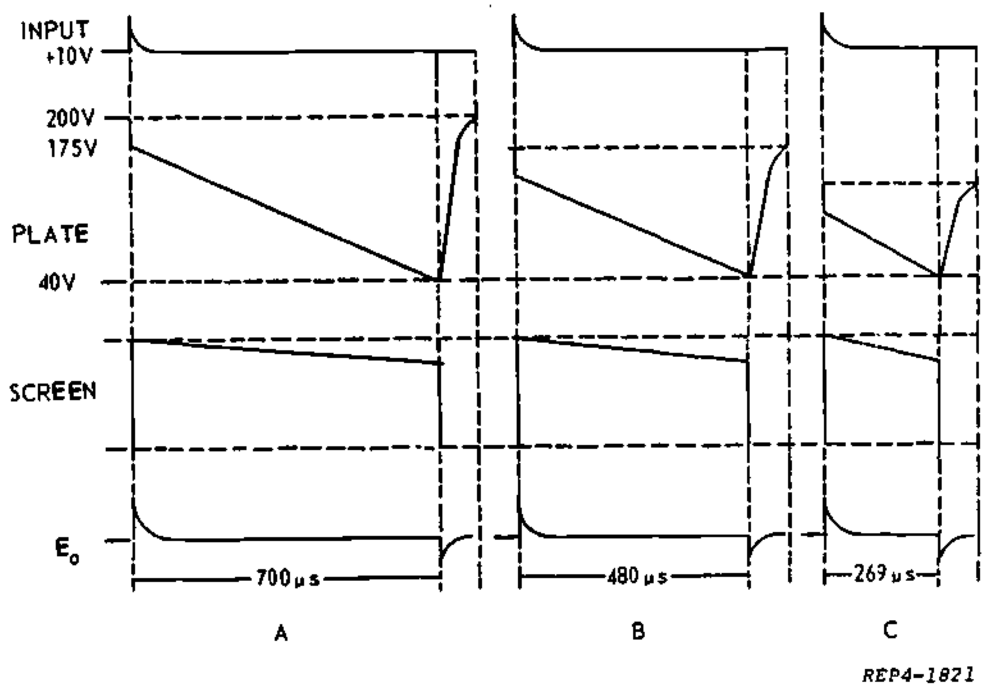

Figure 7-17. Phantastron Waveshapes

If triggers were applied to V1, the circuit would operate as in figure 7-14. The plate swing would be 160 volts and the output duration 700 microseconds as before. This is shown in figure 7-17A.

7-56. Now, placing R1 at position B puts the cathode of V2 at +150 volts, and V2 will conduct since its plate is returned to 200 volts through R4. When V2 conducts its resistance is low, so the plates of V2 and V1 are at +150 volts. Now when a trigger arrives, the plate of V1 starts its rundown from 150 volts, rather than 200 volts. The plate swing will be 110 volts instead of 160 volts because B+, the RC network, and the bottom point of the plate rundown have not changed. The rundown time decreases to 480 microseconds. At trigger time, when the plate jump of V1 occurs, the plate voltage of V2 drops below its cathode potential and it cuts off until V1 plate current cuts off again. At the end of the gate, the plate of V1 attempts to rise to 200 volts, but when it reaches 150 volts V2 conducts and "catches" the plate at that point. The resultant waveshapes are shown in figure 7-17B.

7-57. If R1 is placed at position C, the starting plate voltage will be 100 volts, the plate swing will be 60 volts, and the rundown time 260 microseconds, as shown in figure 7-17C. The voltage changes and rundown times shown are approximate, and are given to illustrate the principles of operation.

7-58. Controlling the starting plate voltage of V1 is a very effective way to control rundown time. Since only DC voltage is involved, the duration control (R1) can be changed remotely without the use of coaxial cable.

7-59. In our discussion we have used positive triggers applied to the suppressor grid to start the plate rundown. The trigger can also be applied to other elements of the tube to start the plate rundown. Any trigger that will reduce the difference of potential between suppressor grid and cathode can be used. A negative trigger applied to the control grid or the cathode will reduce this difference of potential.

7-60. The frequency of the input triggers will determine the spacing between the output pulses. As we decrease the plate rundown time, the spacing between the output pulses will increase if the frequency of the input triggers remains the same.

7-61. Electron Tube Series Voltage Regulator.

7-62. NEED FOR VOLTAGE REGULATION. All devices used to supply DC power to a load have internal resistance. If current varies through this internal resistance, the output voltage will also vary. Typical devices used to supply DC power to a load are batteries, DC generators, and electronic power supplies.

7-63. Figure 7-18 shows a battery with internal resistance (R_i) connected to a variable load resistance. If R_L decreases, the circuit current increases causing an increased voltage drop across the internal resistance of the battery. This reduces the voltage (E_t) to the load resistance. Conversely if R_L increases in resistance, E_t increases. It would be desirable to have no internal resistance within the battery, resulting in a constant voltage across the load regardless of current variations.

7-64. Due to the resistance of the wire used in the construction of DC generators, such devices also have internal resistance. The effects of current variations through this internal resistance are the same as those explained for a battery circuit.

7-65. An electronic power supply has internal resistance which is a combination of the diode tube resistance, transformer

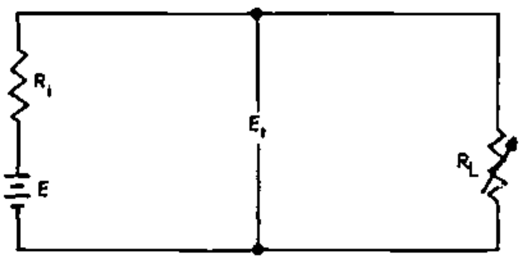

Figure 7-18. Battery with R_i in Series with Variable R_L

secondary winding resistance, and filter choke resistance. Again, variations in current through this internal resistance will cause changes of voltage at the output of the power supply.

7-66. The output voltage of a power supply is also dependent on the amount of input voltage to the power supply. Since neither changes in the input voltage nor internal power supply resistance can be eliminated, some means of reducing their effects is desirable. A nearly constant output voltage can be achieved through the use of a series or shunt voltage regulator.

7-67. One method used to provide a regulated or constant voltage across the load will be discussed. This method of voltage regulation can be illustrated by a variable resistor connected in series with the load. This method of voltage regulation is called SERIES REGULATION.

7-68. METHODS OF VOLTAGE REGULATION. Since the series regulator compensates for variations in either line voltage or load resistance, its discussion will be considered in two steps. Figure 7-19 will be used to explain series regulation for variations in line voltage, while figure 7-20 will be explained to show how regulation is accomplished when load resistance varies.

7-69. In figure 7-19, the DC power supply is represented as a variable battery having internal resistance. R_L represents a constant load resistance, R_R the series regulating resistance, and R_i the internal resistance of the power supply.

7-70. If we desire to have a constant 80 V across R_L, the resistance of R_R would have to be adjusted so the voltage drop across it and R_i would be 20 V. Assume R_L to be 20 k ohms. R_i is 1 k ohm, to have 4 mA of current in the circuit R_R would have to be adjusted to 4 k ohms.

7-71. If the battery voltage increased to 110 V, R_R would have to be increased to 6.5 k ohms to limit the current to 4 mA. Under this condition 80 V is still developed across the load resistance. We can see, in this case, that R_R provides voltage regulation by maintaining a constant current through the load.

7-72. In figure 7-20, the DC power supply is shown as a constant potential battery having internal resistance. R_R is the series regulating resistor and R_L is shown as a variable load resistance. In this circuit, R_R will compensate for variations in load resistance.

7-73. With a load resistance of 20 k ohms, the constant potential of 100 V developed by the battery will cause 80 V to be felt across the load if R_R has a value of 4 k ohms. If R_L were to decrease to 10 k ohms, R_R must decrease its value to 1.5 k ohms to maintain 80 V across the load resistance Since this is a series circuit, 8 mA will be the total current in the circuit. With a total voltage of 100 V, total resistance is found to be 12.5 k ohms. The values of R_i and R_L are known, leaving only R_R to be computed. Since resistance is additive in a series circuit, R_R is found by subtracting the sum of R_L and R_i from total resistance. This gives a value of 1.5 k ohms for R_R. Through the use of a variable series resistance, a constant potential may be maintained despite variations in load resistance.

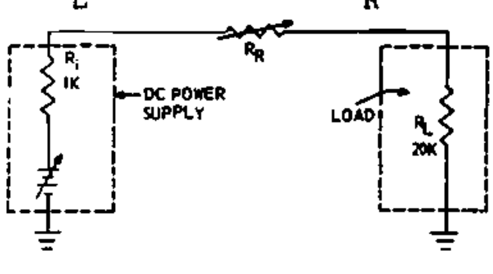

Figure 7-19. Basic Series Regulator

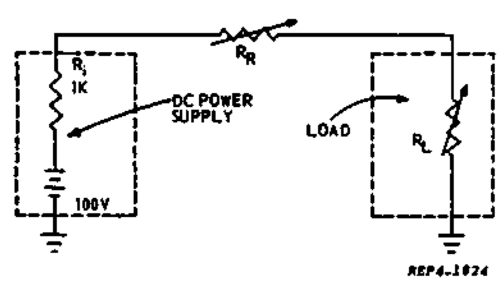

Figure 7-20. Regulation as R_L Varies

7-74. In many electronic systems a voltage regulator circuit is included between the power supply and the load. This is necessary due to changes in load current and variations in B+. One method of regulation is the electron tube voltage regulator.

7-75. ELECTRON TUBE VOLTAGE REGULATOR. The first electron tube regulator considered here is a simple series regulator circuit using a triode as the regulating element. The circuit is illustrated in figure 7-21.

7-76. An electron tube acts as a variable resistor. With DC current flow from cathode to plate, the DC plate resistance (R_p) of the tube is equal to E_p/I_p. Since I_p can be controlled by E_g, changes in bias will cause changes in R_p. This variable resistance characteristic can be used to control the voltage applied to the load.

7-77. The input voltage to this circuit is taken from the filter section of the power supply. Triode V1 acts as the regulating element and is connected in series with the load. Potentiometer R2 and battery E_{cc} supply grid bias for V1. R1 is included to limit grid current.

7-78. Refer to figure 7-21. In this example, assume that R2 has been adjusted so that the load voltage equals 100 V. Cathode voltage (E_k) of V1 is equal to the load voltage. Since the input is 200 V, this gives a difference of potential of 100 V between the plate and cathode. The grid-to-ground voltage is +90 V. The bias is equal to the difference between grid and cathode or 90 V - 100 V equals -10 V bias. Note that V1 is in series with the load.

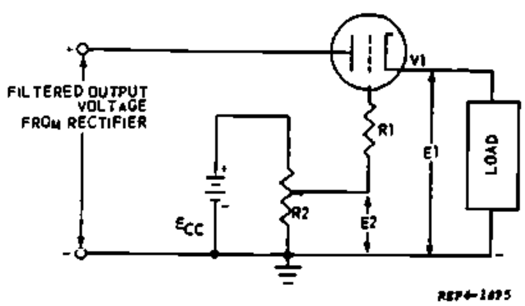

Figure 7-21. Series Regulator with Controllable Bias

7-79. If an increase in power supply voltage occurs, the load voltage will tend to increase, causing an increase in the cathode potential of V1. R_p of the tube increases due to the increase in bias, and the voltage drop across V1 increases. The increase in voltage across V1 is approximately equal to the increase in power supply output, and the load voltage remains essentially constant. Actually, there must be an increase in load voltage to cause an increase of the bias of V1. This increase in load voltage is small, however, compared to the increase in voltage across V1.

7-80. This regulator will also compensate for changes in load current. If the load resistance decreased, load voltage would tend to decrease. A slight reduction in load voltage would reduce the bias on V1 and cause a large reduction in the R_p of V1. The decrease in R_p would cause a reduced voltage drop across V1, and load voltage would again remain essentially constant.

7-81. The fixed battery and variable resistor R2 may be eliminated by the use of a VR tube. This is illustrated in figure 7-22. In this case, a VR tube holds the grid of V1 at a fixed potential. Circuit operation is the same as in figure 7-21. This method of providing bias has a distinct disadvantage. There is no method of changing bias to compensate for changes in tube parameters and the circuit is insensitive to small voltage changes.

7-82. SHUNT DETECTED SERIES REGULATOR. A voltage regulator with a high degree of stability and sensitivity is illustrated in figure 7-23. The regulator consists of two sections - the regulator circuit and the control circuit. Triode V1 acts as the

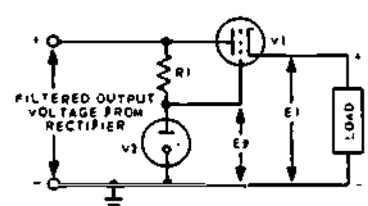

Figure 7-22. Series Regulator with VR Tube Bias

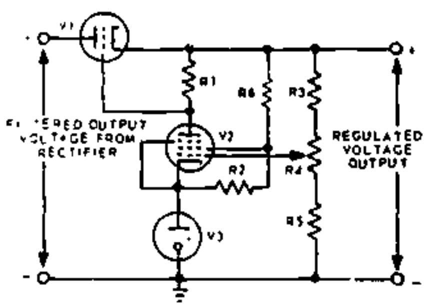

Figure 7-23. Shunt Detected Series Regulator

series regulator circuit. The control circuit is composed of pentode V2 and its associated circuitry.

7-83. OPERATION. V1 acts like a variable resistor to control the output voltage to the load. The bias on V1, which controls its DC plate resistance, is the voltage dropped across R1. The amount of voltage dropped across R1 is determined by the amount of current flowing through V2. The current flowing through V2 is controlled by the voltage drop across V3 and the voltage felt on the wiper arm of R4.

7-84. The cathode of V2 is held at a constant positive potential by voltage regulator (VR) tube, V3. The plate of the VR tube is connected to the regulator output through R2 and R6. This allows the VR tube to ionize when V1 conducts. Resistor R3, R5, and potentiometer R4 acts as a voltage divider network in shunt with the load. A positive voltage is tapped from R4 and applied to the control grid of V2. The positive potential applied to the control grid is lower than the positive potential on the cathode of V2. The voltage adjust resistor R4, sets the grid to cathode (bias) voltage on V2. This allows a certain amount of current to flow through V2 and R1. Since the bottom of R1 is connected to the grid of V1 and the top is connected to the cathode, this makes the grid negative with respect to the cathode. The voltage drop across R1 controls the bias on V1. For example, if the plate current of V2 increases, the voltage drop across R1 increases, causing the bias applied to V1 to increase.

7-85. The bias on V1 allows a certain amount of current to flow through the tube and, therefore, through the load. The current through the load drops a voltage across the load. If the bias on V1 is changed, causing a current change through the load, the voltage dropped across the load will change.

7-86. REGULATION WHEN INPUT VOLTAGE CHANGES. The input voltage from the power supply will be divided between V1 and the load because they are in series. The amount of voltage dropped across each of these resistances will be determined by the ratio of the DC plate resistance of V1 to the resistance of the load. R4 is initially adjusted to establish a normal value of DC plate resistance for V1, which produces the desired load voltage. If the load voltage were to increase, due to an increase in input voltage, the positive voltage at the wiper arm of R4 would increase. Since the cathode of V2 is being held at a constant potential by V3, the positive increase in grid potential causes the bias on V2 to decrease. The decrease in bias causes the plate current of V2 to increase, increasing the voltage drop across R1. The increased voltage drop across R1 causes the bias on V1 to increase, increasing its DC plate resistance. The voltage drop across V1 increases, counteracting the increase in load voltage.

7-87. REGULATION WHEN LOAD RESISTANCE CHANGES. As was stated above, the ratio of the DC plate resistance of V1 to the load resistance determines the amount of voltage that will be dropped across the load. We can see then that a decrease in load resistance will cause a decrease in load voltage. The voltage divider network consisting of R3, R5, and potentiometer R4 are in parallel with the load so this decrease in load voltage would be felt across this network. A decrease in the positive potential on the wiper arm of R4 would cause an increase in the bias of V2. This would decrease the plate current of V2 and cause a decrease in the voltage drop across R1. A decrease in voltage drop across R1 decreases the bias on V1 causing the DC plate resistance to decrease, thus bringing the ratio back to the proper proportion.

7-88. ADJUSTMENT OF OUTPUT VOLTAGE. R4 is adjustable so the output voltage to the load can be changed if it is desired. If more output voltage is needed, R4 would be moved down. This would make the control grid of V2 less positive which increases the bias. In turn, this would cause a decrease in bias on V1 which lets more current flow through the load and increase the voltage drop across the load.

7-89. Although this regulator has a high degree of stability and sensitivity, it does not have perfect regulation because the circuit has to feel a change before it can react. The reaction takes place so fast that the change is not noticeable and, therefore, this regulator is sufficient for most of our needs.

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ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULES 56-62

DIGEST

December 1975

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ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULES 56-62

DIGEST

These Digests provide a summary for each Module, 56-62, in the Electronic Principles Course. The Digest is designed as a refresher for students with electronics experience and/or education who do not need to study any of the other resources in detail.

After reading a Digest, if you feel that you can accomplish the objectives of the Module, take the Module Self-Check in the back of the Guidance Package. If you decide not to take the self-check, select another resource and begin study.

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Supersedes KEP-ST/Digest VIII 1 April 1975. Previous editions may be used.

Module 56

ELECTRON TUBE CHARACTERISTICS AND DIODES

The process of forcing electrons from the surface of a material is called ELECTRON EMISSION. There are four types of electron emission:

Thermionic
Secondary
Photoelectric
Field

For electrons to be emitted, some form of energy must be supplied to the emitting material.

Thermionic emission of electrons occurs if a substance emits electrons when heat is applied. The amount of thermionic emission depends on the type and temperature of the emitting material. Most electron tubes use thermionic emission.

Secondary emission occurs if a substance emits electrons when bombarded by atomic particles moving at high velocities. The amount of secondary emission depends upon the number and velocity of the bombarding electrons and the substance they strike. Secondary emission in electron tubes is generally undesirable. In special applications, however, such as in photo multipliers, secondary emission is desirable.

Photoelectric emission is when a substance emits electrons when exposed to light. The amount of emission depends upon the intensity and color of the light and the type of emitting material. Photoelectric emission is used in TV cameras, control circuits, and phototubes.

Field emission is electron emission produced by strong electric fields. The amount of emission depends on the value of the voltage applied and the distance between the conductors.

The material forming the emitter of an electron tube must be capable of emitting large quantities of electrons when heated. Thoriated tungsten is a good material for emitters but requires a high temperature for proper emission. Oxide-coated emitters operate at low temperatures, have a long life and high emission efficiency. Oxide-coated emitters consist of a metal base, nickel or platinum alloy, coated with a layer of alkaline oxide, usually barium or strontium.

Emitters are enclosed in a controlled environment, such as a high vacuum or gas, to prevent them from being destroyed when heated. The electrodes in a high vacuum or HARD tube are thoroughly cleaned and heated before assembly to remove oxygen and water vapor. After assembly the tube is connected to a vacuum pump and the electrodes are again heated by high frequency induction to remove other gases. A GETTER, made of a chemical substance such as barium, magnesium, aluminum, or tantalum, is installed in the tube to remove any final traces of gas.

In gas or SOFT tubes, the air has been replaced by a specific gas. The container enclosing the tube elements in this high vacuum or gas environment is called the ENVELOPE. The envelope may be glass, metal, or ceramic.

The electron emitting devices (cathodes) of electron tubes are divided into two general forms: directly heated cathodes and indirectly heated cathodes. Directly heated cathodes are made of wires (filaments) heated by the passage of electric current. The heat causes emission to take place directly from the wire. When AC is used to heat the filaments, alternating voltages across the filament may produce undesirable variations in emission (hum). Indirectly heated cathodes consist of an insulated tungsten wire inserted in a thin-wall, hollow, metal cylinder usually made of nickel. An oxide coating on the outside of the cylinder emits electrons when heat is supplied by current passing through the tungsten wire (heater). The resulting emission is hum free.

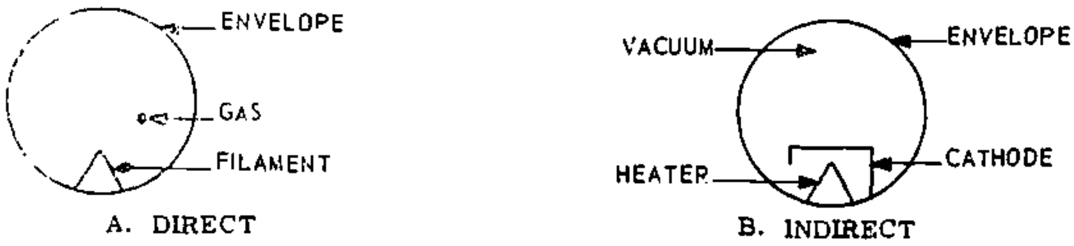

Figure 56-1. Directly and Indirectly Heated Cathodes

Figure 56-1 shows the schematic symbols for directly heated and indirectly heated cathodes. Note that a gas environment is indicated by a dot inside the circle.

Electron tubes are classified according to the number of electrodes they contain. A diode tube has two elements: the plate (anode) and the cathode. Figure 56-2 shows the schematic symbols for the diode. The heater is not counted as one of the elements.

The amount of current flow from cathode to plate depends on the cathode temperature and the voltage difference between plate and cathode. The amount of current flow in a diode is known as plate current (I_p). The cathode emits electrons when heated and forms a space charge in the region surrounding the cathode. If plate voltage (E_p) is negative, the electrons in the space charge are repelled and I_p is zero. When I_p does not flow, the tube is said to be CUTOFF. If E_p is positive, the plate attracts electrons from the space charge and I_p flows. The number of electrons attracted to the plate depends on the value of E_p. An ammeter can be connected in series with the plate lead of a diode to determine I_p with different values of E_p. When these different values of E_p and I_p are plotted on a graph, it is called an E_p-I_p curve. When E_p is increased to a value where all the electrons are being attracted from the space charge and a further increase in E_p does not cause a noticeable increase in I_p, it is called PLATE SATURATION.

The characteristics and limitations of each type of electron tube are published by the manufacturer. Some of the most important characteristics and limitations are:

1. PEAK CURRENT RATING: The largest instantaneous current a tube can pass in the normal direction of current flow without damage to the tube.

2. PEAK VOLTAGE RATING: The maximum instantaneous voltage that can safely be applied to a tube in the forward direction.

3. PEAK INVERSE VOLTAGE RATING: The maximum instantaneous voltage that can safely be applied to a tube in the reverse direction.

4. PLATE DISSIPATION RATING: The maximum amount of power that the plate can safely dissipate.

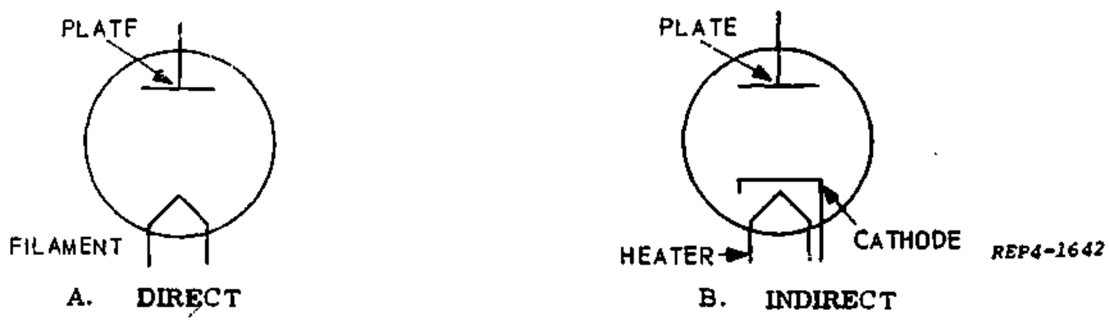

Figure 56-2. Directly and Indirectly Heated Diodes

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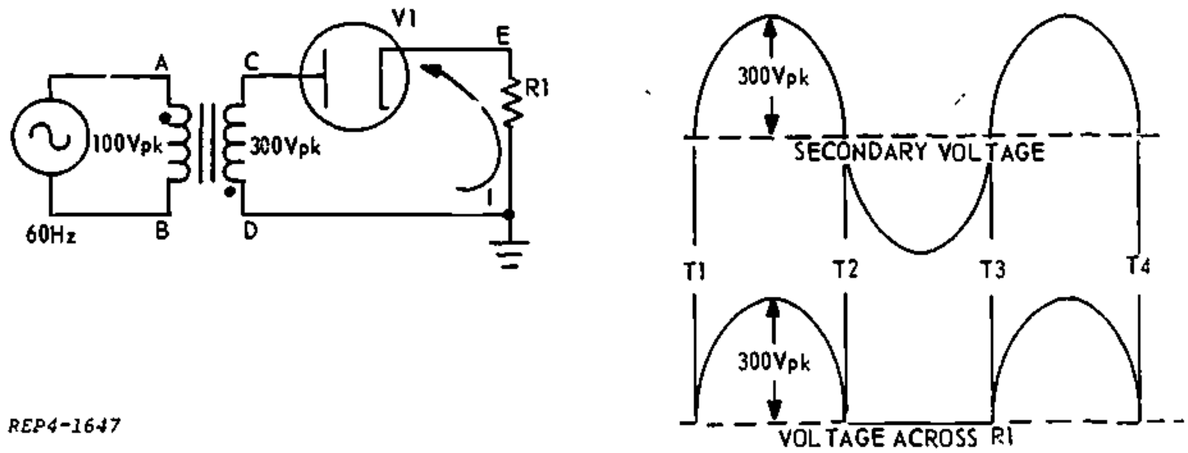


A. SCHEMATIC

B. WAVESHAPES

Figure 56-3. Simple Rectifier Circuit and Input/Output Voltage Waveshapes

5. TRANSIT TIME: The time it takes for an electron to travel from the cathode to the plate.

6. CUTOFF: When the plate of the tube is not attracting any of the electrons from the space charge.

7. DC PLATE RESISTANCE: The opposition the tube offers to plate current when DC voltage is applied.

DC plate resistance (Rp) is the ratio of DC plate voltage to DC plate current.

$$R_p = E_p/I_p$$

Because the E_p-I_p curve is not linear, the DC plate resistance will be different for different values of E_p; therefore, a diode tube is a NONLINEAR RESISTANCE. Another characteristic that makes the diode a nonlinear resistance is that it conducts in only one direction, from cathode to plate. This characteristic makes the diode useful as a rectifier. Figure 56-3 is a simple rectifier circuit schematic and the input and output voltage waveshapes.

Between times T_1 and T_2 the plate of V1 is more positive than the cathode and the diode conducts allowing current to flow as indicated. When current flows in this direction, a positive voltage is developed across R1. The voltage across R1 thus follows the secondary voltage between T_1 and T_2. Between T_2 and T_3, the plate of V1 is negative with respect to the cathode and the diode does not conduct. No current flows and the voltage across R1 is zero. Electron tube diodes can also be used as full-wave, bridge, three-phase, and voltage-doubler rectifiers.

Electron tube diodes may also be used for clampers and limiters.

MODULE 57

TRIODES

Due to the inability of a diode tube to amplify electronic signals, a third tube element must be introduced. This new element, called the CONTROL GRID, controls the current and makes amplification possible. A small change in voltage applied to the control grid causes a large change in tube current. With the addition of this third active electrode, the tube is now called a TRIODE.

The control grid is a wire coil or helix, positioned around and close to the cathode. The function of the control grid is to control

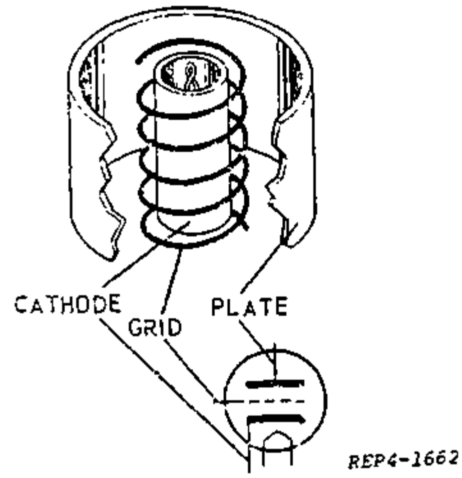


Figure 57-1. Schematic Symbol and Physical Construction of a Triode Tube

the amount of current flowing between cathode and plate. The schematic symbol and physical construction of a triode tube is shown in figure 57-1.

During the operation of a triode tube, voltages are applied to the electrodes to produce electrostatic fields. The duration and strength of these fields are governed by the polarity and value of the applied voltages. Therefore, the voltages on both the grid and plate are effective in controlling plate current. The electrons emitted from the cathode form a space charge close to the cathode surface. The grid, being closer to the space charge, has more control over plate current than does the plate. It is this feature which produces amplification in a triode tube.

If a negative voltage is applied to the grid, it will exert a force on the electrons opposite to the force the plate is exerting on them. The relative strength of these two forces determines the number of electrons that move through the openings in the grid and on to the plate. A small voltage on the grid can exert much more force on the electrons than a large voltage on the more distant plate. As the grid is made increasingly negative, a point is reached where all the electrons are repelled back to the space charge. When the grid reaches this negative voltage and plate current ceases to flow, the tube is said to be CUTOFF.

The voltage applied to the control grid is sometimes positive and will attract electrons from the space charge. The force of attraction created by the positive grid voltage aids the force of attraction created by the positive plate voltage and causes more plate current to flow. As the positive grid voltage is increased, plate current increases. When a further increase in positive grid voltage fails to produce an increase in plate current, the tube is said to be SATURATED.

The relationship between grid voltage, plate current, the plate voltage is expressed graphically with CHARACTERISTIC CURVES. Characteristic curves illustrate the behavior of an electron tube as the electrode voltages are varied. In the case of a triode, there are three possible sets of curves that can be developed. These are the:

1. Grid family of curves,
2. Plate family of curves, and
3. Constant current family of curves.

The plate family of curves is the most useful in analyzing electron tube circuits. The plate curves for triodes are developed by holding the grid voltage constant and varying the plate voltage to determine its effect on plate current. Since it is the plate voltage that is varied, these curves are called the PLATE CHARACTERISTIC or E_p-I_p curves. The curves that are obtained under these conditions are called STATIC CURVES. The use of the word STATIC in connection with the characteristic curves means that the curve represents the tube behavior under no-load conditions with only DC voltage applied. When a load is inserted in the circuit, DYNAMIC CURVES can be developed.

The operation of any particular triode tube in a specific circuit application is dependent upon the behavior of that tube as its electrode voltages are varied. This behavior is expressed by a series of electrical quantities known as TUBE

PARAMETERS. The tube parameters are simply specifications which reveal the capabilities and limitations of a tube. The parameters of interest are the:

1. Amplification factor (μ),

2. AC plate resistance (r_p), and

3. Transconductance (g_m).

The amplification factor is the ratio of a change in plate voltage to a change in grid voltage, with plate current constant. Expressed mathematically, it is:

$$\mu = \frac{\Delta E_p}{\Delta E_g} \quad (I_p \text{ constant})$$

Transconductance is the ratio of a change in plate current to a change in grid voltage with plate voltage remaining constant. The symbol is g_m and the unit is the mho. This parameter is calculated with the formula:

$$g_m = \frac{\Delta I_p}{\Delta E_g} \quad (E_p \text{ constant})$$

Transconductance may be calculated from the E_p-I_p curves by using this formula.

AC plate resistance (r_p) is defined as the ratio of a change in plate voltage to a change in plate current, with grid voltage remaining constant. The r_p is calculated from the E_p-I_p curve by the formula:

$$r_p = \frac{\Delta E_p}{\Delta I_p} \quad (E_g \text{ constant})$$

The construction of a tube and the operating voltages applied to the electrodes determine the exact values of g_m and r_p. For a given tube, the amplification factor remains relatively constant under most conditions. AC plate resistance, on the other hand, varies greatly with operating voltages. The transconductance will vary inversely with the AC plate resistance. The DC plate resistance (R_p) for triodes has exactly the same meaning as for diodes.

One purpose of a triode tube is to amplify AC signals. In amplifying this AC signal, both the positive and negative alternations should be amplified equally. This could not be done if we had zero volts on the control grid because on the positive alternation of the input signal, the tube would saturate and distort the signal. To prevent this a DC voltage is placed in series with the AC signal. This DC voltage, called a BIAS voltage, is a negative voltage large enough to keep the grid from ever becoming positive. BIAS is the AVERAGE DC VOLTAGE DIFFERENCE BETWEEN GRID AND CATHODE and is used to establish the tube's operating point. If the grid bias is a negative voltage, an increase in bias means that the grid is made MORE negative. Three basic forms of bias exist:

Cathode self-bias.

Fixed bias, and

Grid leak bias.

In figure 57-2, cathode self-bias is present because the tube current develops a voltage across the cathode resistor.

If the tube current causes +4 V to be dropped across R_k, then the voltage difference between grid and cathode is 4V. The grid is -4V with respect to the cathode. Thus we have a -4V bias.

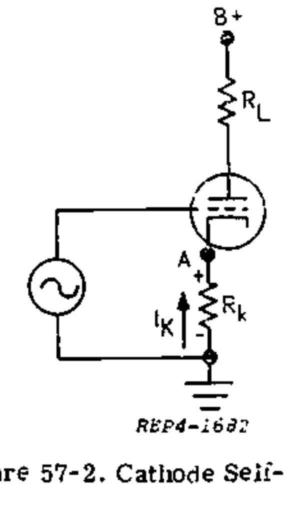


Figure 57-2. Cathode Self-Bias

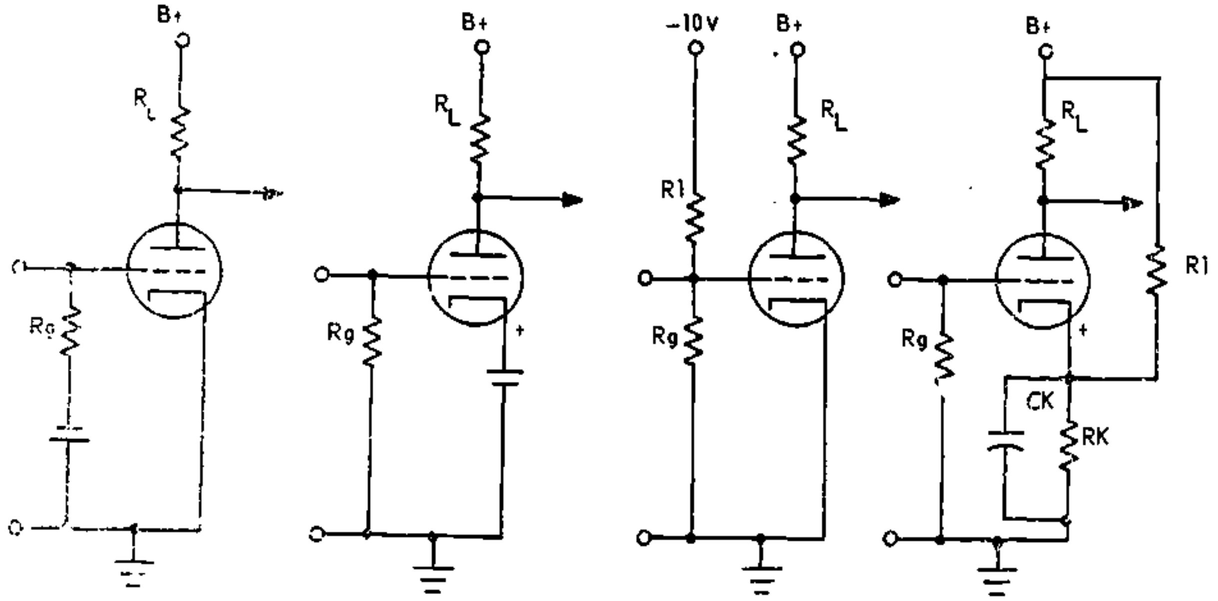


Figure 57-3. Fixed Bias REP4-1652

The cathode self-bias voltage regulates tube current. If tube current decreases, the voltage across R_K decreases. This makes the bias less negative, which increases tube current. The end effect is that the original decrease in current is nearly cancelled. Because the bias is developed only when the tube conducts, a tube cannot cut itself off with cathode self-bias.

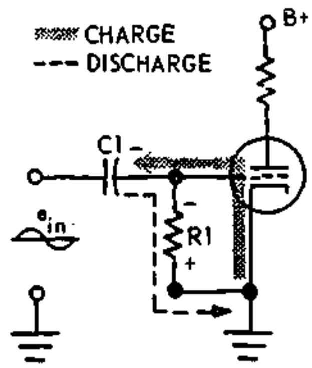
An AC signal applied to a tube with cathode self-bias would cause the cathode voltage to increase on the positive alternation and decrease on the negative alternation. This is negative feedback. The effect of negative feedback is reduced by placing a capacitor in parallel with the cathode resistor. The capacitor holds a steady DC voltage across the cathode resistor by filtering out the AC changes.

If the bias voltage is supplied by a battery or some other DC voltage source, it is called FIXED BIAS. Figure 57-3 shows examples of fixed bias.

Bias is the difference of potential between grid and cathode. A negative voltage can be applied to the grid or a positive voltage can be applied to the cathode. These circuits illustrate both methods.

The value of grid leak bias depends upon the amplitude of the input signal and conduction through the tube. Figure 57-4 shows how grid lead bias is obtained.

On the positive alternation of the nput signal, the capacitor charges through the shunt resistance of R1 and the grid-to-cathode resistance. The grid-to-cathode resistance is very small when the grid is positive so the capacitor charges very fast. On the negative alternation, the grid is no longer positive and the grid-to-cathode resistance is very large. The capacitor tries to discharge through R1. R1 is a high resistance and the capacitor will only discharge a



REP4-1686

Figure 57-4. Grid Leak Bias

small amount. This keeps a negative potential at the top of R1 and on the grid of the tube. This makes the grid negative with respect to the cathode.

The amount of grid bias will determine the class of operation for a given input signal. If plate current flows for 360° of the input signal, the tube is operating class A. If plate current flows for more than 180° but less than 360° of the signal, the class of operation is AB. For class B operation, plate current flows for 180° of the input signal and for class C operation, plate current flows for less than 180° of the input signal.

A triode tube can be used as an amplifier because a small voltage change on the grid causes a large change in plate voltage. The plate voltage change can be obtained from the characteristic curve for a given input signal and inserted in the formula for voltage gain.

$$A_v = \frac{\Delta E_p}{\Delta E_g}$$

This indicates how much the signal has been amplified. The value of plate voltage change was obtained using a DC loadline on the plate characteristic curves. This DC load-line was obtained by finding the current through the plate load resistor.

However, the grid resistor of the next amplifier stage is in parallel with the plate load resistor as far as the signal is concerned. For this reason, an AC loadline is constructed. The actual voltage gain is a little lower on the AC loadline than it was on the DC loadline. This is because the output signal is developed across a resistance that is smaller than the plate load resistor.

The grid and plate voltage waveforms are always 180° out of phase. When the positive alternation of the input signal is felt on the grid, plate current increases and plate voltage decreases. The end result is that the plate voltage is going in a negative direction when the grid voltage is going in a positive direction.

Another characteristic of electron tubes that has to be taken into consideration is INTERELECTRODE CAPACITANCE. This is the capacitance existing between the electrodes of the tube. A triode tube has capacitance between plate and grid (C_{gp}), between grid and cathode (C_{gk}), and between plate and cathode (C_{pk}). The high frequency response of triode amplifiers is limited by these interelectrode capacitances.

MODULE 58

MULTIGRID ELECTRON TUBES

Triode tubes have poor performance as IF or RF amplifiers or as high gain audio amplifiers. This is due in part to the interelectrode capacitance between the tube elements. Tetrode tubes were developed to overcome this disadvantage.

An electrostatic shield is placed between the control grid and plate to reduce the effects of interelectrode capacitance. This shield is called the SCREEN GRID (G_2). Adding another grid to the tube gives it four electrodes and therefore it is called a TETRODE. The primary purpose of the screen grid is to act as an electrostatic shield between the control grid and the plate. Normally the screen grid is operated at a positive potential with respect to the cathode. The screen grid, being physically closer to the space charge than the plate, will exert more force on the electrons in the space charge than the plate. Since the plate exerts only a small force on the electrons in the space charge, changes in plate voltage have little effect on the number of electrons leaving the space charge. This makes plate current nearly independent of plate voltage. Due to the shielding effect of the screen grid, the plate becomes merely a collector of electrons.

Due to the positive potential on the screen grid, it draws current. This current is called SCREEN GRID CURRENT (I_{sg}). When the plate has a higher positive potential than the screen grid, most of the electrons pass through the openings in the screen grid and strike the plate. This makes plate current higher than screen grid current. Cathode current is the sum of screen current and plate current. The screen grid is normally connected to the B+ supply through a voltage dropping resistor (R_{sg}). A capacitor (C_{sg}) is connected between the screen grid and ground to maintain a constant DC voltage on the screen grid. This capacitor also increases the shielding effect of the screen grid.

Tetrode tubes have an unusual characteristic known as the NEGATIVE RESISTANCE REGION. When plate voltage is being increased from zero volts, plate current increases up to a point. Beyond this point, as plate voltage increases, plate current decreases. This is due to secondary emission. The positive plate voltage has given the electrons sufficient velocity to cause secondary emission at the plate. Many of the secondary electrons are attracted to the screen grid which increases screen grid current. As plate voltage is increased further, the amount of secondary emission increases, causing plate current to decrease further. This will continue up to a point where plate voltage becomes higher than the screen grid voltage and the plate begins attracting some of the secondary electrons causing plate

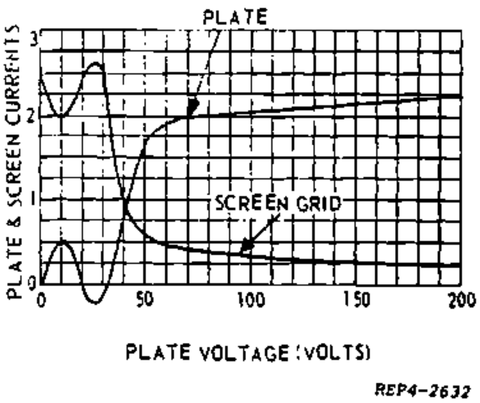


Figure 58-1. E_p-I_p Curve

current to increase and screen grid current to decrease. Increasing plate voltage even further causes plate current to continue increasing until the plate is attracting all the electrons that were initially attracted by the screen grid. The E_p-I_p curve shown in figure 58-1 shows the action of I_p, and I_{sg} as E_p increases.

AC plate resistance (r_p) for a tetrode is considerably higher than that for a triode. The screen grid functions as an electrostatic shield; therefore a large change in E_p produces only a small change in I_p. Since

$$r_p = \frac{\Delta E_p}{\Delta I_p} \quad (E_g \text{ constant})$$

the AC plate resistance is quite large. Using the formula

$$g_m = \frac{\Delta I_p}{\Delta E_g} \quad (E_p \text{ constant})$$

transconductance will be quite large because a small change in control grid voltage causes a large change in plate current. Amplification factor (μ), being directly proportional to both g_m and r_p, would be high. This can be seen by the formula,

$$\mu = g_m \times r_p$$

Where μ may range from 5 to 100 for triodes, it may be as high as 600 for tetrodes.

In tetrodes, secondary emission may reduce the overall amplification or cause unwanted oscillations. Also, the secondary emission region limits the useful plate voltage swing available. To overcome the effects of secondary emission in tetrodes, a third grid is inserted between the plate and the screen grid. This grid, called a SUPPRESSOR grid (G_3), is connected to a voltage that is negative with respect to the plate. Secondary electrons are thus repelled and forced to return to the plate. By eliminating the effects of secondary emission, the negative resistance region of the tetrode is eliminated. This tube with the third grid is called a PENTODE.

Because the effects of secondary emission are eliminated, the shape of the characteristic curves for a pentode differs considerably from that for a tetrode. The plate voltage can be changed several hundred volts without causing a substantial change in plate current. Since changes in plate voltage have little effect on plate current, the amplification factor and AC plate resistance of a typical pentode are high. Due to the extensive electrostatic shielding and the high μ pentodes are used extensively as high gain, high frequency amplifiers.

Pentodes are often classified according to their grid characteristics. Two classes exist: sharp cutoff pentodes and remote cutoff pentodes. A sharp cutoff pentode has control grid wires that are evenly spaced. A remote cutoff tube has control grid wires that are unevenly spaced. The remote cutoff tube requires a much larger bias voltage to cut the tube off. The biasing of the remote cutoff pentode affects the μ of the tube. Because the μ for remote cutoff pentodes changes from high to low with a change of bias, these tubes are also known as VARIABLE MU tubes.

Vacuum tube power amplifier circuits normally use tubes which are specifically designed for power amplification. One such tube is the BEAM POWER TUBE. Its special design gives it the ability to handle high values of current. In this tube the electrons are concentrated into beams by a set of beam-forming plates located inside the tube. These beam-forming plates are connected to the cathode, which makes them negative with respect to the plate. They repel the secondary electrons back to the plate. The beam power tube has high plate current, low screen current, and relatively low plate resistance.

In many circuit applications space and weight must be conserved. For this reason, many tubes have been designed in which two or more complete electrode systems are enclosed within the same envelope. For instance, a tube may contain both a triode and a pentode. Nearly any combination of units may be found within the same envelope.

To provide for easy removal and replacement of electron tubes, the base of the tube is constructed in the form of a connector (plug) which is inserted into a receptacle (socket). The tube base and socket are constructed so the tube may not be inserted into the socket incorrectly. This is accomplished by the use of a key or pin arrangement. When looking at the BOTTOM of the tube or tube socket, the pins are numbered in sequence in a clockwise direction beginning at the key, or the first pin past the space, or the last large pin. When looking down on the top of the tube socket, count counterclockwise from the starting point.

MODULE 59

SPECIAL PURPOSE ELECTRON TUBES

Many electron tubes have been designed to fulfill circuit requirements that cannot be met by the tubes discussed previously. The special purpose tubes presented herein are gas tubes, phototubes, and cathode ray tubes.

The most frequently used gases in gas-filled tubes are argon, neon, xenon, and mercury vapor. Two basic types of gas tubes exist: hot cathode and cold cathode. In the hot cathode type, the cathode is heated in the normal manner to provide thermionic emission. In the cold cathode type, no external heat is supplied: however, the cathode may become hot because of gas ion bombardment.

In the cold cathode tube, thermionically emitted electrons are not present. However, if a positive voltage is applied between the plate and cathode, plate current flows. This small current flow, called DARK CURRENT, occurs because a few ions and free electrons are always present in gases in their normal state. As the voltage is increased, the moving particles gain sufficient speed to strike and dislodge electrons from neutral atoms. The neutral atoms are now ionized and current rises sharply. Once the tube ionizes, the plate voltage will remain constant because as current increases, the resistance of the tube decreases. Due to the plate voltage remaining constant, the cold-cathode gas tube can be used as a voltage regulator. The purpose of a voltage regulator tube is to apply a constant voltage to a load.

Hot-cathode gas tubes are normally used where large currents must be rectified. Mercury vapor is normally used in these tubes because when th e gas is ionized, the conducting rsistance is low and the voltage drop across the tube is small. Mercury vapor diodes are capable of conducting several hundred amperes of current.

When a control grid is added to a hot-cathode gas tube, you have a triode known as a THYRATRON tube. The control grid makes it possible to control the ionization potential of the tube. Once the thyratron ionizes, it conducts like a hot cathode diode. That is, the voltage drop across the tube will be low, and large currents may flow. After the thyratron ionizes, the control grid has no control over current flow and cannot be used to cut the tube off. The plate voltage must be reduced to a value below the deionization voltage in order to deionize the gas and stop the flow of current, Since the grid controls the ionization potential, a smple relationship exists between a change in grid voltage and the resulting change in the firing point. The ratio of a change in firing point to a change in grid voltage is called the CONTROL RATIO.

Photoelectric emission occurs if electrons are emitted when a material is struck by light. Photoelectric emission is used in photoelectric electron tubes (phototubes). The actual number of electrons emitted depends on the intensity and color of the light, the size of the cathode, and the type of cathode material. A heater is not used in phototubes because thermionic electrons are not necessary or even desirable. The amount of current produced by a phototube is extremely small, usually measured in microamperes.

The amount of current flow may be increased in two ways. One method is to put a small amount of gas in the tube and the other method is to use secondary emission.

In photomultiplier tubes, the total number of electrons available at the plate (anode) is greatly increased because of intentional secondary emission within the tube. Several additional electrodes, known as DYNODES, are added to the basic phototube to produce secondary emission. When several dynodes are used in a photomultiplier, a multiplication factor of several thousand is achieved.

The cathode ray tube (CRT) is a special electron tube in which a beam of electrons strikes a phosphor screen and produces light. Moving the beam over the phosphor screen produces patterns of light which are a visual representation of the signals producing the movement. The oscilloscope uses a CRT and is used to observe waveforms and to measure voltage, frequency, phase, and time. If the light intensity produced by the beam is varied, the cathode ray tube is capable of displaying pictures. Hence, the CRT is used as the indicating device in television sets.

The envelope of the CRT is made of glass. The electrodes which shape and accelerate the electron bam are called the ELECTRON GUN. The electron gun is in the neck of the tube. The inside surface of the tapered portion of a CRT is covered with a graphite coating and is called the AQUADAG. The aquadag shields the electron beam from unwanted electric fields, prevents light from striking the back of the phosphor screen, and gathers the secondary electrons emitted from the screen. Due to the high vacuum and large surface area of the cathode ray tube, it is especially vulnerable to DANGEROUS IMPLOSIONS OF TREMENDOUS FORCE.

The phosphor screens are classified according to the color of light produced and the length of time light is released after the excitation has been removed. The length of time required for the light intensity to decay to 1 percent of its maximum value is termed PERSISTENCY of the phosphor.

In order to display a waveform on the CRT screen, the electron beam must move in accordance with the signals to be observed. The electron beam (moving negative charges) can be bent, or deflected, by either electric fields or magnetic fields. By passing the beam through either of these fields, the beam can be made to strike the screen at any desired point. Nearly all oscilloscope cathode-ray tubes utilize electrostatic deflection. Two pairs of DEFLECTION PLATES within the CRT establish the electrostatic fields necessary to move the electron beam horizontally or vertically. DEFLECTION SENSITIVITY is a constant which indicates how far the spot on the screen moves for each volt applied between the deflection plates.

Electromagnetic deflection systems use magnetic fields to move the electron beam to the desired position on the screen. The magnetic fields are produced by passing current through coils of wire placed next to the neck of the CRT. The coils are connected to produce a magnetic field through the neck of the CRT. The amount and direction of deflection depends on the strength and direction of the magnetic field, which in turn depends on the value and direction of current flow through the coils. In practice, the deflection coils are shaped to conform to the neck of the tube. The horizontal and vertical deflection coils are mounted around the neck in one assembly called the YOKE. The yoke is located on the neck, next to the tapered sectin of the CRT envelope. As is expected, the deflection coils exhibit inductance because of their physical construction. Therefore, a trapezoidal voltage must be applied to the deflection coils to produce a sawtooth current.

Electromagnetic focusing is accomplished by passing DC current through a coil placed around the neck of the CRT to provide the necessary magnetic field.

MODULE 60

ELECTRON TUBE AUDIO AMPLIFIERS

Audio amplifiers are used in equipment such as public address systems, sound recorders, sound reproducers, and radio and television receivers. The frequencies of the signals amplified are in the range of 10 Hz to 20,000 Hz. The triode audio amplifier in figure 60-1 will be used to discuss the operation.

The input signal, e_i, is applied through the coupling capacitor, C_c, to the grid of V1. V1 produces the amplified signal at its plate.

The output signal, e_o, is taken from the plate of V1. The gain of the amplifier is determined by the μ of V1, the value of R_K, the value of R_L, and the value of B+. A tube with a high μ will produce more amplification than one with a low μ. The value of R_K will have an effect on gain because it determines the grid bias and bias affects the μ. R_L and B+ affect gain because they determine the steepness of the DC loadline on the characteristic curve. This

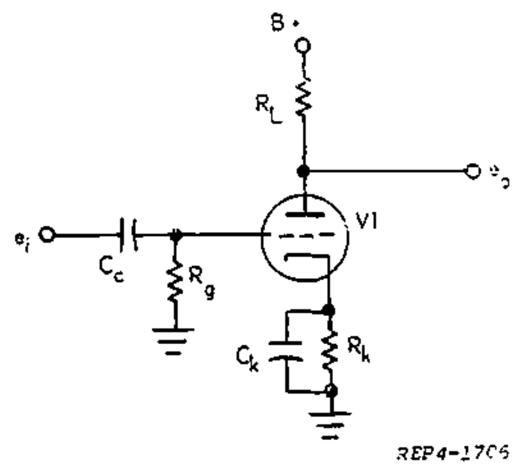


Figure 60-1. Audio Amplifier

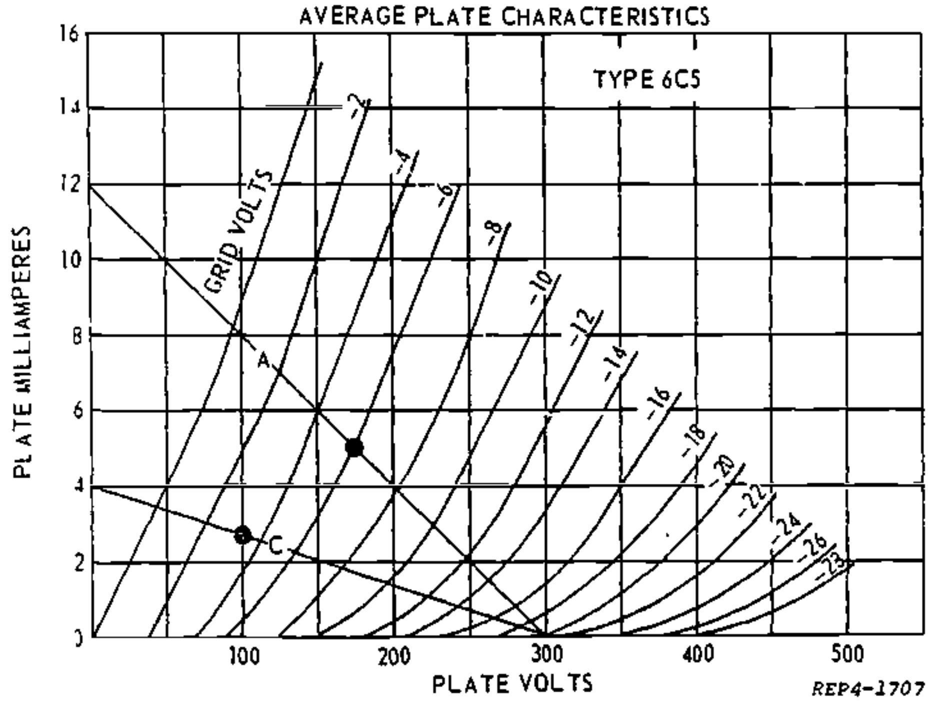


Figure 60-2. Loadlines

can be seen on the characteristic curve in figure 60-2. The DC loadline labeled A was obtained with a 25 k ohm plate load resistor and a B+ of 300 V. With a 4-volt peak-to-peak input signal, the plate swing would be approximately 55 volts. The DC loadline labeled C was obtained with a 75 k ohm plate load resistor. With the same 4-volt peak-to-peak input signal, the plate swing would be approximately 60 volts. Therefore, with the larger plate load resistor, the gain is higher.

Because of certain circuit limitations of this amplifier, it will not amplify all frequencies equally. The frequency response curve, figure 60-3, shows that the gain of the low frequencies and high frequencies is not as high as that of the medium frequencies. The lowest and highest useable frequencies are the frequencies that have a gain of 70.7 percent of maximum. The lowest useable frequency is called the LOWER HALF-POWER frequency and the highest useable frequency is called the HIGHER HALF-POWER frequency.

The primary factors affecting the low frequency response are the input coupling network consisting of C_c and R_g and the cathode bias network consisting of C_k and R_k. C_c and R_g effectively form a voltage divider network with a voltage developed across R_g applied to the grid of V1. As frequency decreases, the X_c of C_c increases causing a larger voltage drop across C_c and less across R_g. Therefore, the voltage applied to the grid of V1 decreases. Increasing the value of either R_g or C_c improves the low frequency response of the amplifier.

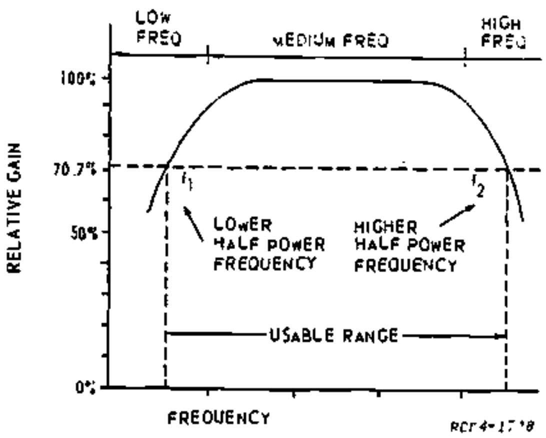


Figure 60-3. Frequency Response Curve

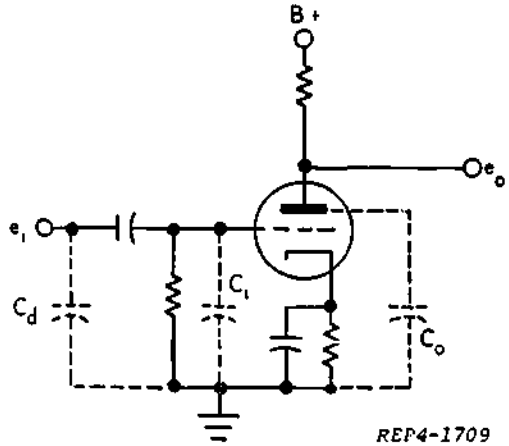


Figure 60-4. Shunt Capacitance

The cathode self-bias is developed across R_k. C_k bypasses all AC signals and prevents negative feedback. X_c of C_k for the lower frequencies becomes larger and negative feedback occurs. This negative feedback reduces the gain.

The high frequency response is limited by shunt capacitance. This capacitance exists between various points in the circuit and electrical ground. This is shown in figure 60-4.

One place where this capacitance is found is in the input capacitance of the tube, C_i. Both the physical capacitances of the tube and the gain of the amplifier contribute to the final value of the C_i. Another shunt capacitance is the distributed stray wiring capacitance, C_d. C_d represents the stray capacitance between all of the circuit components, wirtng, and the metal chassis. The third shunt capacitance is the plate-to-cathode capacitance, C_o.

The high frequency response of the amplifier circuit is limited by the shunting effect of all the listed capacitances. Electrically, these capacitances appear in parallel with either R_L or R_g. As the frequency of the input signal increases the reactances of these capacitances decrease resulting in lower gain. Thus, the high frequency response is limited to those frequencies for which the gain does not go below 70.7 percent.

The pentode audio amplifier shown in figure 60-5 will be used for explaining troubleshooting.

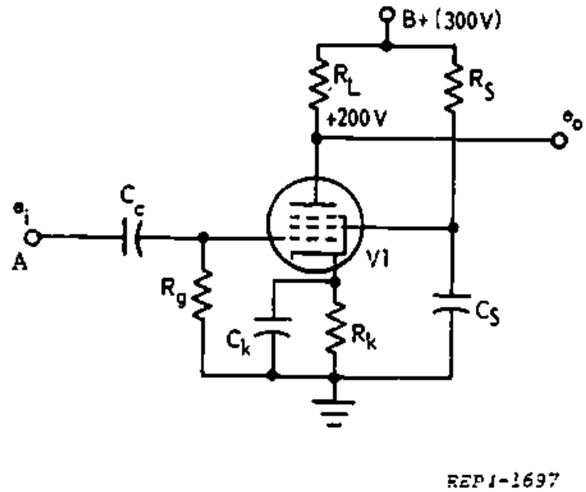


Figure 60-5. Pentode Audio Amplifier

If C_c shorts, whatever DC voltage exists at point A is applied to the grid. Depending on the polarity and value of the DC voltage, V1 may be cut off, saturated, or not appreciably affected. If C_c opens, the input signal is not coupled to the grid; and there is no output signal at the plate. If R_g shorts, the grid is shorted to ground; and there will be no output signal at the plate. If R_g opens, the DC path to ground for the grid is broken; and grid bias may be unstable. Signal distortion results any time the grid bias becomes unstable. If C_k shorts, the cathode resistor is shorted out; and bias drops to zero, saturating the tube. If C_k opens, R_k will be unbypassed; and negative feedback will be developed. If R_k shorts, bias goes to zero and saturates the tube. If R_k opens, no path exists from ground to the cathode; and the tube will not conduct. If R_L shorts, there is no resistance to develop the output signal across; and there will be no output signal. If R_L opens, the plate will have no voltage; so there will be no plate current. Therefore, there will be no output signal. If R_S opens, there will be no screen grid voltage and no output. If C_X shorts, there will be no screen grid voltage and no signal output from the plate. If C_S opens, R_S is not bypassed. Thus, negative feedback occurs which reduces gain and output signal amplitude. As expected, different circuit configurations may produce symptoms other than those discussed.

MODULE 61

ELECTRON TUBE RF AMPLIFIERS, CATHODE FOLLOWERS DC AMPLIFIERS, AND TRIODE LIMITERS

RF AMPLIFIERS

Due to the poor performance and low gain of the triode tube, it is seldom used as an RF or IF amplifier; therefore, a pentode tube is normally used for these circuits. The screen grid and suppressor grid in a pentode tube decrease the effects of interelectrode capacitance and increase the gain. The only real differences between the audio amplifier and the RF amplifier using a pentode tube are the values of the components and the types of coupling used for the input and output signals.

The RF amplifier is designed to amplify a small band of frequencies within the radio frequency band which is from 20 kHz to over 300 MHz. To select this small band of frequencies, tuned circuits are used in the input and output circuits. The input and output tank circuits may be tuned to the same frequency for high selectivity (narrow bandwidth), or they may be stagger-tuned to provide less selectivity (wide bandwidth).

Frequency response of the RF amplifier is also affected by the Q of the tanks. Since a narrow bandwidth may distort the signal, Q is very important. The circuit in figure 61-1 will be used for our discussion of the pentode RF amplifier.

The input tank, consisting of the secondary of T1 and C1, allows the maximum voltage to be developed across it at resonance. This voltage is applied to the control grid of the tube. Bias voltage is developed across R1 for class A operation. Class A operation is necessary so that the input signal will not be distorted and also to maintain a high input impedance. If the grid were allowed to draw current, the grid-to-cathode resistance would become very small. This decreased resistance results in an increased bandwidth. This can be seen by the formulas:

$$Q = \frac{R}{X_L}$$

$$BW = \frac{f_r}{Q}$$

Increasing BW results in amplifying unwanted frequencies and decreasing the amplitude of the desired frequency.

The signal that is applied to the control grid is amplified by the tube and developed across the tuned tank consisting of C5 and the primary of T2. This tank offers a high impedance to the frequency to which it is tuned. This high impedance will cause maximum voltage to be developed across the tuned tank at the desired frequency and will

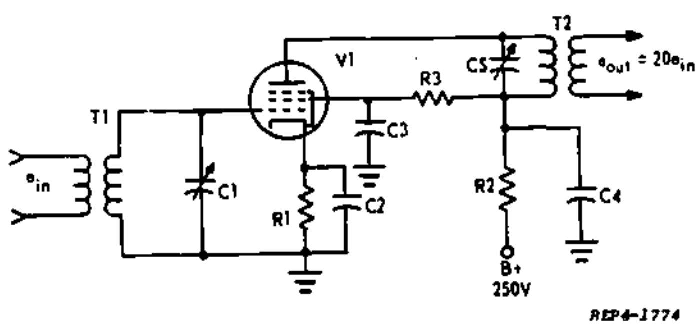


Figure 61-1. Pentode RF Amplifier

be inductively coupled to the secondary of T2. All other frequencies that may be present would see a low impedance at the tuned tank and would be shorted to ground through C4.

The load across the secondary winding of T2 can affect the Q of the output tank. The load for the secondary winding would be the grid circuit of the next amplifier. This impedance has to be high to insure that the Q of the tuned tank remains high.

CATHODE FOLLOWERS

It is necessary at times to transfer a wide band of frequencies from a high impedance circuit to a low impedance circuit with maximum power transfer. Recall that maximum power transfer occurs when the impedances are matched. This impedance matching and wide frequency response is provided by a CATHODE FOLLOWER.

A cathode follower amplifier is a single-stage degenerative amplifier in which the output is taken across the cathode resistor. Its output voltage is always less than the input voltage, but it is capable of power amplification. A cathode follower circuit is shown in figure 61-2.

The input may employ RC coupling. The load resistor is in the cathode circuit. The cathode resistor is unbypassed. A positive input signal applied to the grid causes tube current to increase. This current increase makes the top of R_k more positive. As the signal goes negative, tube current decreases

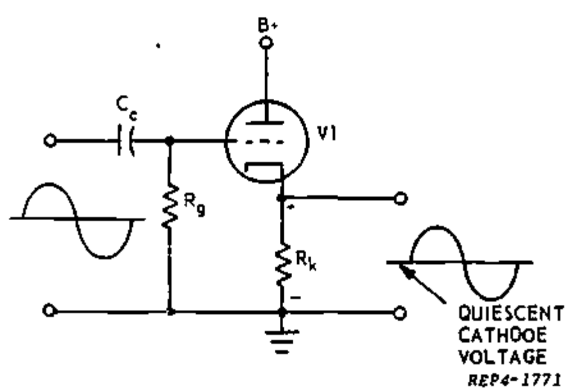


Figure 61-2. Cathode Follower

and the voltage at the top of R_k decreases. The cathode voltage "follows" the grid voltage. The gain will approach but never be equal to unity.

The output impedance of a cathode follower is low and is determined by the value of r_p and R_k. The output is taken across R_k; so by selecting the proper size cathode resistor, it is possible to match the output impedance to the load.

The input impedance of a cathode follower is high. The input impedance of a tube is primarily the capacitive reactance offered by the input capacitance. Since there is no gain in the plate circuit, the plate-to-grid capacitance is small. The grid-to-cathode capacitance is effectively made smaller because it is charging to only a fraction of the input signal. This accounts for the low input capacitance of the cathode follower, which gives a high input impedance.

Since the input capacitance of an amplifier determines the high frequency response, the cathode follower has a wide frequency response. The negative feedback accounts for minimum distortion in the cathode follower.

DC AMPLIFIERS

Direct current amplifiers are used to amplify low frequency or DC voltages. A simple DC amplifier consists of a single tube with a grid resistor across the input terminals and with the load in the plate circuit. The DC voltage that is to be amplified must be applied directly to the grid of the amplifier tube. For this reason, only direct coupling can be used in the amplifier input circuit. A DC amplifier is illustrated in figure 61-3. Notice that there is no coupling capacitor in the grid circuit.

With no input signal, the negative bias voltage is present on the grid of the tube, and a steady value of plate current flows. This action causes a fixed voltage drop across R_L. When a direct voltage of the polarity indicated is applied across the input terminals, a portion of the negative bias is cancelled. This reduction in grid bias causes

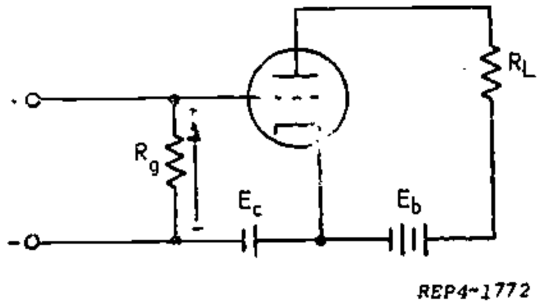


Figure 61-3. DC Amplifier

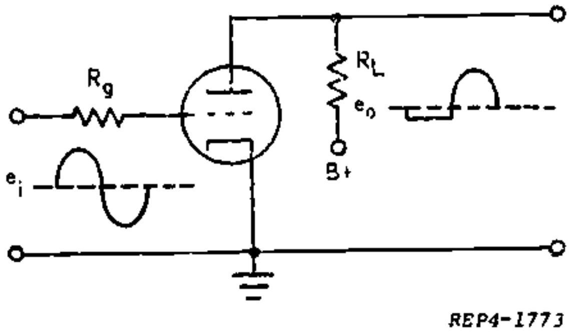


Figure 61-4. Triode Limiter

a greater current flow in the plate circuit and a greater voltage drop across R_L. The increase in plate current is sustained as long as the input signal voltage is applied.

If more than one DC amplifier stage is used, the plate of one tube is connected directly to the grid of the next tube. This arrangement presents a problem of voltage distribution. Proper voltage distribution is obtained by connecting each succeeding cathode to a source of voltage more positive than the plate of the preceeding tube.

Because there is no coupling impedance to vary with frequency, the frequency response of the DC amplifier is uniform over a wide frequency range. This type of amplifier is effective for very low frequency variations of voltage. The response curve for the DC amplifier starts at zero frequency and goes up through the audio frequency range. Although the DC amplifier can be used to amplify audio frequencies, it is not practical because of the large supply voltages required if more than one stage is used.

TRIODE LIMITERS

The triode limiter (figure 61-4) is the vacuum tube equivalent of the transistor limiter. The vacuum tube amplifier can be operated at cutoff or saturation. Therefore, using these two extremes, both the positive and the negative alternations of the input signal can be limited. A triode limiter is normally held at zero bias.

During the positive alternation of the input signal, the grid tries to swing positive. Due to grid current flowing, the input signal voltage is divided between R_g and the grid-to-cathode resistance. R_g, being a very large resistance, drops most of the signal voltage and the grid goes just slightly positive. This small positive potential on the grid causes a small increase in plate current and a small decrease in plate voltage. The ratio of R_g to the grid-to-cathode resistance determines the amplitude of the negative portion of the output signal voltage. The amount of limiting can also be controlled by the amount of negative bias that is applied to the tube.

Limiting of the positive portion of the input signal can also be accomplished by saturation limiting. Saturation imiting occurs when an increase in positive grid signal causes no further increase in plate current. Saturation limiting results from the operation of a triode tube at a very low plate voltage. The grid resistor is eliminated. Under these conditions, as the grid is made increasingly positive, the plate current approaches the value $B+/R_L$. However, since a small plate voltage must remain to produce plate current, the plate current cannot become equal to $B+/R_L$. Instead, the plate current reaches a maximum value, and this maximum determines the lowest value to which the plate voltage can fall.

The positive portion of the output signal can be limited by biasing the tube near cutoff. The negative portion of the input signal will cause the tube to cut off and plate current will stop flowing. This is clled CUTOFF LIMITING.

The overdriven amplifier limiter uses a combination of saturation limiting and cutoff limiting to cause the input signal voltage to be converted into essentially a square wave in the output. The input signal must be large enough to saturate the tube during the positive alternation.

MODULE 62

THYRATRON SAWTOOTH GENERATOR PHANTASTRON AND ELECTRON TUBE SERIES VOLTAGE REGULATOR

THYRATRON SAWTOOTH GENERATOR

The thyratron sawtooth generator is composed of two basic parts: a resistance-capacitance circuit to actually shape the wave and a switch circuit which is used to discharge the capacitor. The sawtooth waveshape is the voltage developed across the capacitor while the capacitor is charging and discharging.

The thyratron tube presents an almost infinite impedance with it is deionized. However, once ionized, the tube has a very low impedance. The potential at which the gas ionizes and conduction begins is called the FIRING POTENTIAL of the tube and that at which deionization takes place is known as the DEIONIZATION POTENTIAL. The tube can be considered as a switch which is open when the tube is not ionized and closed when it is ionized. A simple sawtooth generator is illustrated in figure 62-1.

When a voltage is applied to the circuit, the voltage across the capacitor rises from zero, approaching the supply voltage along a normal RC charging curve. The charge path of the capacitor is through resistor, R. The voltage across the thyratron is the same as the voltage across the capacitor. The thyratron tube acts as an open until the voltage across it reaches the firing point.

The firing point of the thyratron tube is determined by the ratio of control grid voltage to plate voltage. This is called The CONTROL RATIO. At the firing potential, the thyratron tube ionizes and provides a discharge path for the capacitor. The capacitor discharges very rapidly until the voltage falls to the deionization potential of the tube, at which time, the tube conduction stops and the tube appears as an open again. The negative grid voltage has no influence on deionizing the tube. To deionize the tube, plate voltage must be reduced to the deionization potential.

The amplitude and frequency of the output sawtooth waveform is determined by the potential on the grid of the thyratron. The output has a less linear voltage rise when the amplitude is increased because a larger portion of the charge curve is used. You can see this in the illustration in figure 62-2. When the amplitude is changed, the frequency also changes.

In addition to the effect of grid bias on frequency, the frequency of a thyratron sawtooth generator may be varied by changing the value of the resistor, the capacitor, or the supply voltage.

The thyratron sawtooth generator is not very stable in frequency. Any slight change in R, C, or the firing potential will cause the

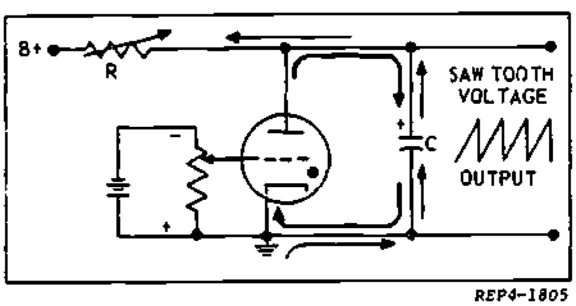


Figure 62-1. Thyratron Sawtooth Generator

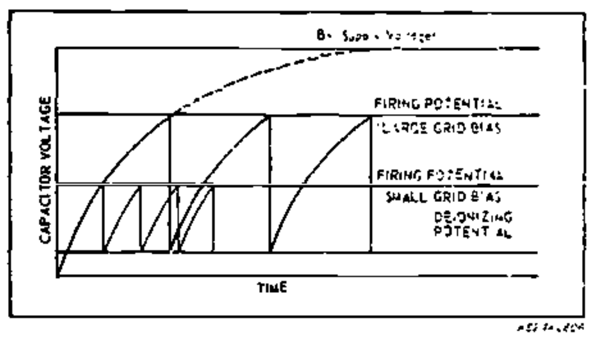


Figure 62-2. Output Sawtooth Waveform

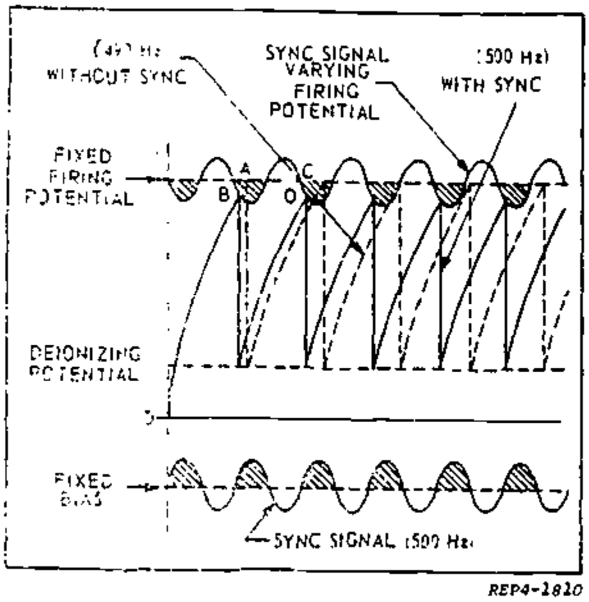


Figure 62-3. Synchronized Sawtooth Waveforms

frequency to change. It can, however, be synchronized with a constant frequency. The waveforms of a synchronized thyratron sawtooth generator are shown in figure 62-3.

The free-running frequency (shown dotted) is adjusted to a value slightly lower than the desired output frequency. Then an AC sync signal is applied to the grid. The frequency of the sync signal is the exact desired

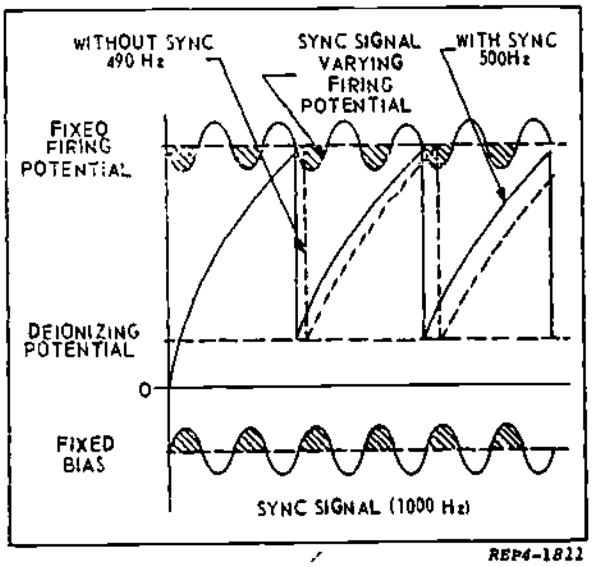


Figure 62-4. Second Positive Alternation

output frequency of the sawtooth waveform. The thyratron tube ionizes on each positive alternation of the sync signal.

The thyratron sawtooth generator can also be operated at a submultiple of the synchronizing frequency. In this case, the thyratron tube is made to fire on every second positive alternation of the sync signal. See illustration in figure 62-4.

Due to the operating features of the thyratron sawtooth generator, it is possible to apply too little or too much synchronizing voltage to the tube. If too small a synchronizing signal is applied, the firing potential will not be lowered sufficiently to induce reliable triggering on each pulse. If too large a sync voltage is applied to the thyratron, the sawtooth waveforms will not be equal in amplitude. This is due to the sync signal causing the thyratron to fire at the wrong time. This is shown in figure 62-5.

PHANTASTRON

The phantastron is a relaxation-type oscillator which can be used to produce a trigger delay or sweep waveform. It is insensitive to fluctuations in supply voltage and has an extremely linear plate waveform. The highly linear plate waveform is due to a phenomenon called MILLER EFFECT. Miller effect is the effect of stage gain on the input capacitance of an amplifier. The formula for input capacitance is:

$$C_i = C_{gk} + C_{gp}\,(1 + A)$$

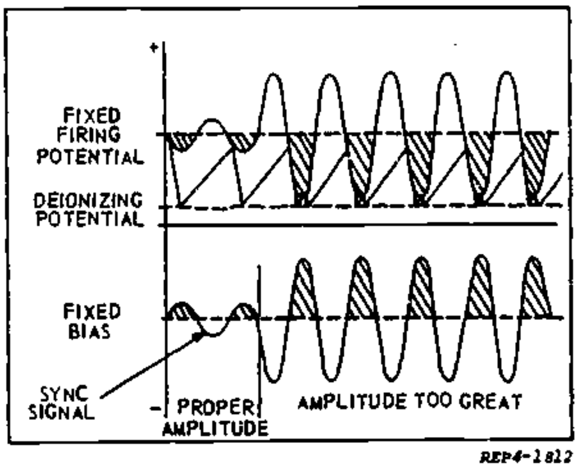


Figure 62-5. Large Sync Voltage

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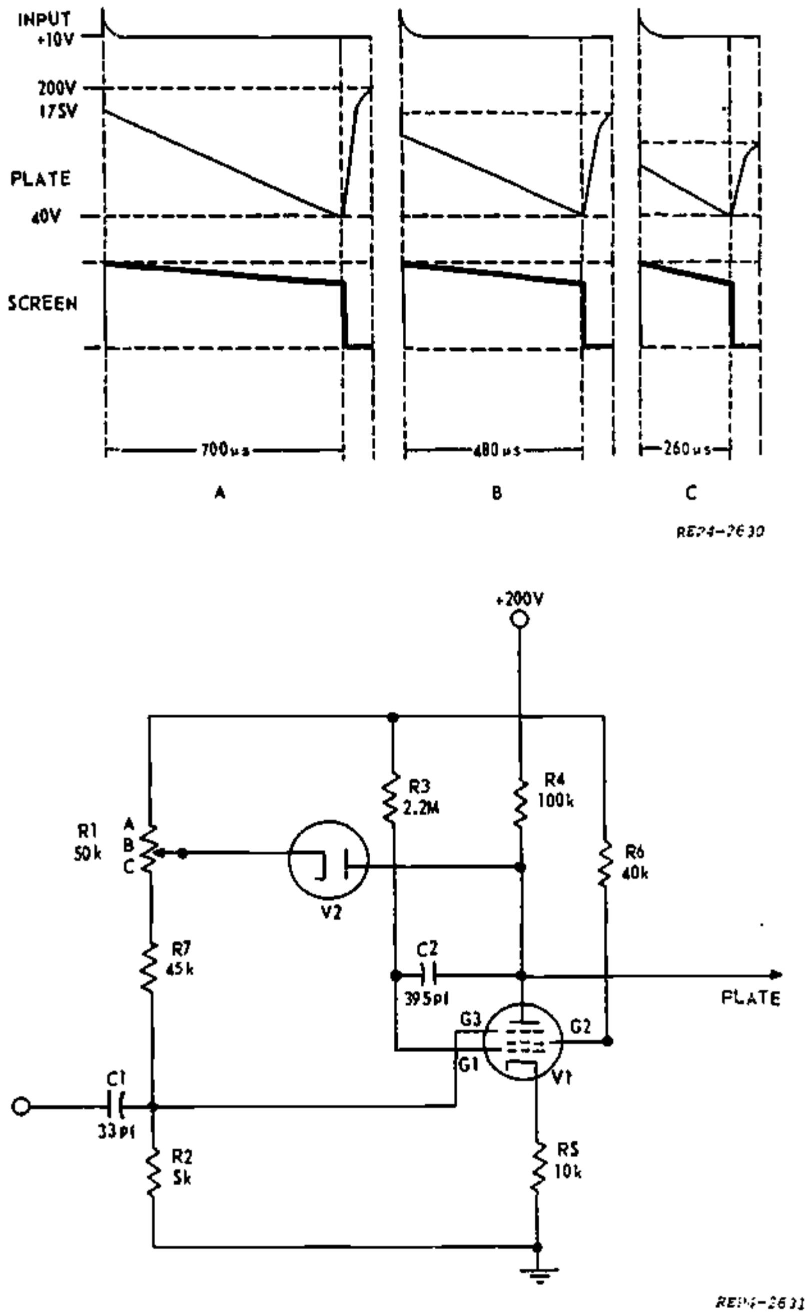

Figure 62-6. Phantastron Circuit

If we put an actual capacitor between the grid and plate of an amplifier, the effective capacitance would be:

$$C\ (1 + A)$$

If C were part of an RC circuit, its time constant would be RC (1 + A) while the tube was amplifying and simply RC when the tube was not amplifying. This is one of the key factors in the phantastron oscillator. The phantastron circuit and its output waveshapes are shown in figure 62-6.

C2 is the capacitor that has been connected between the grid and plate. When V1 is not amplifying, the time constant of C2 and R3 determines the discharge time of C2. When V1 is amplifying, the time constant is the product of R3C2(1 +A). This increases the discharge time of C2 tremendously. This results in keeping the percent of discharge of C2 low on the discharge curve which keeps the decreasing plate voltage linear.

To see how the circuit operates, first look at the static condition and then bring in a trigger and see how the circuit reacts. V2 is called a DISCONNECT or PLATE CATCHING diode. It allows the voltage that is felt on the wiper arm of R1 to be coupled to the plate of V1. With the wiper arm of R1 in position A, 200V is applied to the plate of V1. In the static condition the cathode has +20V and G3 has +10V, so plate current is cutoff. The difference of potential between the cathode and G3 will determine if plate current is flowing or cutoff. When G3 is 12 volts negative with respect to the cathode, no plate current flows. Cathode current is flowing to G2.

At this time a positive trigger, 10V in amplitude, is coupled through C1 to G3. This momentarily makes G3 positive 20 Volts. The difference of potential between G3 and the cathode decreases to 10 Volts. Plate current starts flowing, plate voltage decreases 25V. The amount of drop depends on E_a, R4, and the amplifier characteristics. C2 appears as a short to this sudden change causing G1 to go negative by 25 volts, decreasing total tube current. This decrease in total tube current causes the cathode voltage to decrease to +10V which means that the potential difference between the cathode and G3 has decreased, allowing plate current to continue flowing.

C2 now starts to discharge to the 25V change in plate voltage. As it discharges 1 volt, it causes G1 to go positive by 1 volt. This 1V change on G1 is amplified by the tube causing the plate voltage to decrease even further. The plate voltage decrease is linear because the tube is now amplifying and causing the discharge time constant of C2 to be much longer. When the cathode voltage reaches a point where the difference of potential between G3 and the cathode is negative 12 volts, plate current stops flowing and plate voltage rises to 200 volts again. C2 charges again through the cathode and G1 resistance and R4 to B+. The circuit is now ready for another trigger.

The amplitude and duration of the plate waveform can be changed by changing the plate voltage of V1. Changing the value of C2 and R3 would change the duration of the plate waveform. Changing the plate voltage of V1 is the most effective way of changing the output amplitude and duration. When the wiper arm of R1 is changed from position A to position B, 150 volts is felt on the cathode of V2, and it will conduct. When V2 conducts, it acts as a short circuit so the 150 volts that is on its cathode is on the plate of V1. With V1 starting at a lower plate voltage, its rundown time will be shorter; therefore, the output amplitude and duration has decreased. Putting the wiper arm of R1 at position C decreases the rundown time even further. The frequency of the output waveform is determined by the frequency of the input triggers. For each trigger in, there is one waveform out.

In our discussion we have used positive triggers applied to the suppressor grid to start the plate rundown. Triggers can be applied to other elements of the tube to start the plate rundown. Any trigger that will reduce the difference of potential between suppressor grid and cathode can be used. A negative trigger applied to the control grid or the cathode will reduce this difference of potential.

The phantastron is not affected by variations in B+ because a variation in B+ would change all voltages proportionally and very little change in waveform would occur.

VOLTAGE REGULATORS

Some electronic circuits react to variations in B+ and cause undesirable effects, so some form of regulated power supply is required. A voltage regulator circuit is often included between the power supply and the load. This is necessary due to changes in load current and variatins in B+. One method of regulation is the electron tube voltage regulator. A shunt detected series regulator is shown in figure 62-7.

V1 acts like a variable resistor to control the output voltage to the load. The bias on V1, which controls its DC plate resistance,

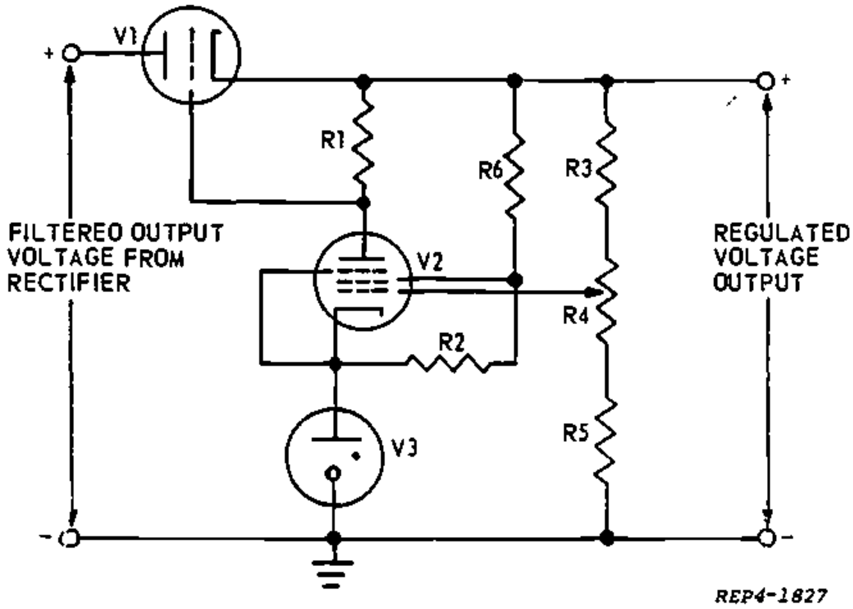

Figure 62-7. Shunt Detected Series Regulator

is the voltage dropped across R1. The amount of voltage dropped across R1 is determined by the amount of current flowing through V2. The current flowing through V2 is controlled by the voltage drop across V3 and the voltage felt on the wiper arm of R4.

The cathode of V2 is held at a constant positive potential by the voltage regulator tube, V3. Resistors R3, R4, and R5 act as a voltage divider network in shunt with the load. A positive voltage is tapped from R4 and applied to the control grid of V2. The positive potential on the cahtode of V2 is higher than the positive potential on the control grid, so V2 has a negative bias. This allows a certain amount of current to flow through V2 and R1. Since the bottom of R1 is connected to the grid of V1 and the top is connected to the cathode, this makes the grid negative with respect to the cathode. The voltage drop across R1 controls the bias on V1.

The bias on V1 allows a certain amount of current to flow through the tube and, therefore, through the load. If the bias on V1 is changed, causing a current change through the load, the voltage dropped across the load will change. The input voltage from the power supply is divided between V1 and the load. The amount of voltage dropped across each of these resistances will be determined by the ratio of the resistance of the load. R4 is initially adjusted to establish a normal value of DC plate resistance for V1, which produces the desired load voltage. If the load voltage were to increase, due to an increase in input voltage, the positive voltage at the wiper arm of R4 would increase. This positive increase in grid potential causes the bias on V2 to decrease, increasing the voltage drop across R1. This increases the bias on V1, increasing its DC plate resistance. The voltage drop across V1 increases, counteracting the increase in load voltage.

A decrease in load resistance will cause a decrease in load voltage. The voltage at R4 decreases. A decrease in the positive potential on the wiper arm of R4 would increase the bias on V2. This would cause a decrease in the voltage drop across R1. A decrease in the bias on V1, causes the DC plate resistance of V1 to decrease, thus counteracting the decrease in load voltage.

This regulator has a high degree of stability and sensitivity. The regulation takes place so fast that the change is not noticeable and, therefore, this regulator is sufficient for our needs.

PREPARE THE MAN

ATC GP 3AQR3X020-X
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KEP-GP-56

Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 56

ELECTRON TUBE CHARACTERISTICS AND DIODES

1 September 1975

AIR TRAINING COMMAND

7-12

Designed For ATC Course Use

ATC Keesler 6-1085

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Radar Principles Branch
Keesler Air Force Base, Mississippi

ATC GUIDANCE PACKAGE 3AQR3X020-X
KEP-GP-56
1 September 1975

ELECTRONIC PRINCIPLES

MODULE 56

ELECTRON TUBE CHARACTERISTICS AND DIODES

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

OVERVIEW

1. SCOPE: This module introduces you to electron tubes. How electrons are emitted from a material, the most common electron emitting materials, and the environments required for emission are discussed. The basic construction, the schematic symbol, and ratings for the diode electron tube are also explained.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. Given the following electron tube terms, match each with its description:

(1) Cutoff

(2) Peak inverse voltage rating

(3) Peak current rating

(4) Peak voltage rating

(5) Transit time

(6) Plate dissipation rating

(7) Saturation

(8) Emission

b. Given diode circuit diagrams indicating direction of current flow and polarity of applied voltage, select the one which represents the conditions during conduction.

c. Given the schematic diagram of a diode electron tube circuit which indicates the supply voltage and the tube and load resistances, compute the circuit voltages and currents.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text, Volume VIII

Supersedes Guidance Package, KEP-GP-56, 1 June 1974

AUDIO-VISUALS

Television Lesson, 30-400, Diode Tubes, Emission and Space Charge
Television Lesson, 30-402, Half-Wave and Full-Wave Rectifiers
Television Lesson, 30-404, Bridge Rectifiers
Television Lesson, 30-405, Voltage Doublers

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the back of this Guidance Package.

Contact your instructor if you experience any difficulty.

Begin the program.

Although solid state devices are new, much of the equipment in use today still contains electron tubes. Also, in the newest electronic equipment, certain circuit applications require the use of electron tubes. Therefore, it is necessary that you study electron tubes as well as solid state devices.

A. Turn to Student Text, Volume VIII and study paragraphs 1-1 through 1-24. Return to this page and answer the following questions.

1. The process of forcing electrons from the surface of a material is called

____________ ____________.

2. ____________ emission of electrons occurs if a substance emits electrons when heat is applied.

3. The conductor from which the electrons escape is referred to as the

____________ or ____________.

4. The cloud of electrons that surrounds the heated metal is called the

____________ ____________.

5. Secondary emission in electron tubes is desirable. (True/False)

6. What type of emission occurs if a substance emits electrons when exposed to light?

7. The final traces of gas in a vacuum tube are removed by an active chemical substance called a ____________.

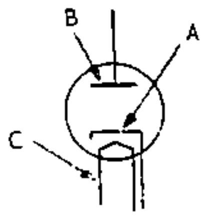
8. Which of the following schematic symbols (A or B) represents an indirectly heated cathode?

REP4-1734

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

B. Turn to Student Text, Volume VIII and study paragraphs 1-25 through 1-52. Return to this page and answer the following questions.

1. Match the letters with the name of each of the elements of the diode below.



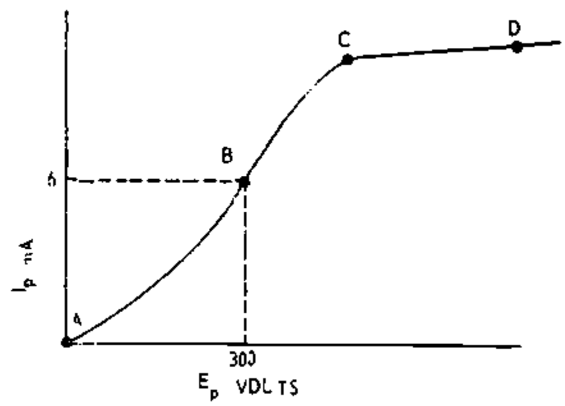
_____ PLATE
_____ CATHODE
_____ FILAMENT

REP4-1733

2. When the different values of I_p and E_p are plotted on a graph, it is called an

_______________ curve.

Refer to the diode curve below for questions 3, 4, and 5.



REP4-1732

3. Which point on the curve represents cutoff?

4. Which point on the curve represents the start of tube saturation?

5. What is the plate resistance at point B? $(R_p = \frac{E_p}{I_p})$

_____ a. 5 k ohm

_____ b. 18 k ohm

_____ c. 50 k ohm

_____ d. 75 k ohm

6. Which characteristic of a diode tube gives it the ability to function as a rectifier?

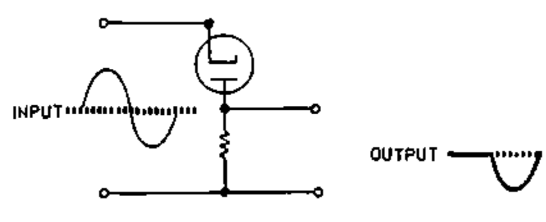
_____ a. It has a long transit time.

_____ b. The DC plate resistance limits plate current.

_____ c. Too much plate voltage will cause plate saturation.

_____ d. It allows current to flow in only one direction.

7. What type of circuit is shown in the illustration below?



REP4-1735

_____ a. Series positive limiter.

_____ b. Shunt positive limiter.

_____ c. Series negative limiter.

_____ d. Shunt negative limiter.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

MODULE SELF-CHECK

QUESTIONS:

Match the following electron tube terms with their description by placing the correct letters in the space provided.

_____ 1. Cutoff

_____ 2. Peak inverse voltage rating

_____ 3. Peak current rating

_____ 4. Peak voltage rating

_____ 5. Transit time

_____ 6. Plate dissipation rating

_____ 7. Saturation

_____ 8. Emission

a. The process of forcing electrons from the surface of a material.

b. The condition where plate current does not flow.

c. The largest instantaneous current a tube can pass in the normal direction without damage.

d. The time required for an electron to travel from cathode to plate.

e. The maximum instantaneous voltage that can safely be applied to a tube in the reverse direction.

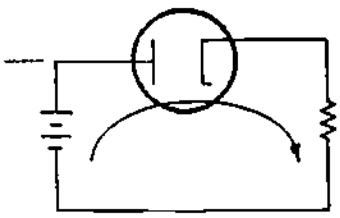
f. The maximum amount of power that the plate can safely dissipate.

g. The maximum instantaneous voltage that can safely be applied to a tube in the normal direction.

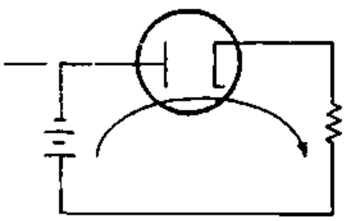
h. The plate is attracting all the electrons the cathode is capable of emitting.

9. Select the diagram below that depicts the correct polarity and direction of current flow by checking the correct letter.

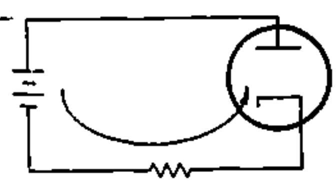
a.



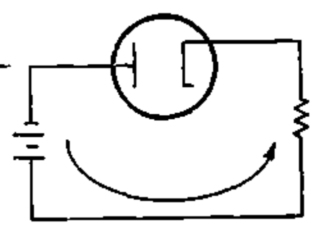
b.



c.



d.



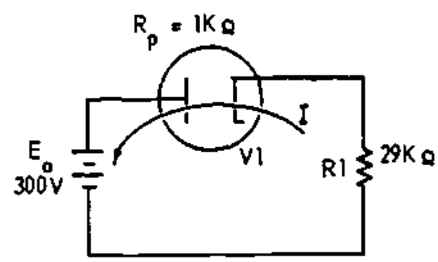
REP4-1803

Use the figure given below to compute:

10. E_{V1} =

11. E_{R1} =

12. I =



REP4-1736

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

NOTES

ANSWERS TO A - ADJUNCT GUIDE

1. electron emission
2. Thermionic
3. emitter or cathode
4. space charge
5. False
6. Photoelectric
7. getter
8. A

If you missed ANY questions, review the material before you continue.

ANSWERS TO B - ADJUNCT GUIDE

1. B-Plate
   A-Cathode
   C-Filament
2. $E_p - I_p$
3. A
4. C
5. c
6. d
7. a

If you missed ANY questions, review the material before you continue.

ANSWERS TO MODULE SELF-CHECK:

1. b
2. e
3. c
4. g
5. d
6. f
7. h
8. a
9. c
10. 10 volts
11. 290 volts
12. 10 mA

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

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PREPARE THE MAN

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KEP-GP-57

Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 57

TRIODES

1 September 1975

AIR TRAINING COMMAND

7-12

Designed For ATC Course Use

ATC Keesler 6-1065

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ATC GP 3AQR3X020-X
KEP-GP-57
1 September 1975

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 57

TRIODES

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

OVERVIEW

1. SCOPE: This module introduces you to triode electron tubes and how the addition of another tube element allows amplification. The basic construction, schematic symbol, and biasing requirements are also explained.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. Given a list of statements, select the one that describes the function of the control grid.

b. From a list of statements, select the one that describes the effect of changing bias on tube conduction.

c. Using triode amplifier diagrams, identify the bias type shown in each diagram as either

(1) fixed.

(2) cathode.

(3) grid leak.

d. Given a family of E_p - I_p characteristic curves with a load line, select from alternatives the value nearest to three of the following:

(1) Plate voltage for a specified bias.

(2) Plate current for a specified bias.

(3) Bias required for cutoff.

(4) Bias required for saturation.

Supersedes Guidance Package KEP-GP-57, 1 June 1974.

e. Given the diagram of a triode electron tube which indicates supply voltage, load resistance, and circuit current

(1) compute the voltage drop across the tube and load resistor.

(2) indicate the direction of current flow.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text VIII

AUDIOVISUAL AIDS:

TV Lesson, Triode Tubes (Construction and Characteristics), TVK30-452A

TV Lesson, Triode Tubes (Bias), TVK30-452B

TV Lesson, Triode Tubes (Tube Constants), TVK30-453A

TV Lesson, Triode Tubes (Load Lines), TVK30-453B

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the back of this Guidance Package.

Contact your instructor if you experience any difficulty.

Begin the program.

Due to the diode tube having limited applications, the triode tube was developed. One of the applications of the triode is to amplify AC signals. To understand how the triode amplifies, an understanding of how the tube operates is needed.

A. Turn to Student Text, Volume VIII and read paragraphs 2-1 through 2-28. Return to this page and answer the following questions.

1. What is the element called that is placed between the cathode and plate to control tube current? ____________

2. Why does the grid voltage have more control over plate current than does the plate voltage? ____________

____

____

3. As the grid is made increasingly negative, the plate current (increases) (decreases) accordingly.

4. When the grid voltage is increased to a high enough value to stop plate current from flowing, the tube is said to be ____________

____________.

5. A tube with a negative grid voltage presents a (high) (low) impedance to the grid circuit, and with positive grid voltage presents a (high) (low) impedance to the grid circuit.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

B. Turn to Student Text, Volume VIII and read paragraphs 2-29 through 2-76. Return to this page and answer the following questions.

1. The relationships between grid voltage, plate current, and plate voltage are expressed graphically with ____________________.

For questions 2 through 7, refer to the E_p - I_p curve, shown in figure 1.

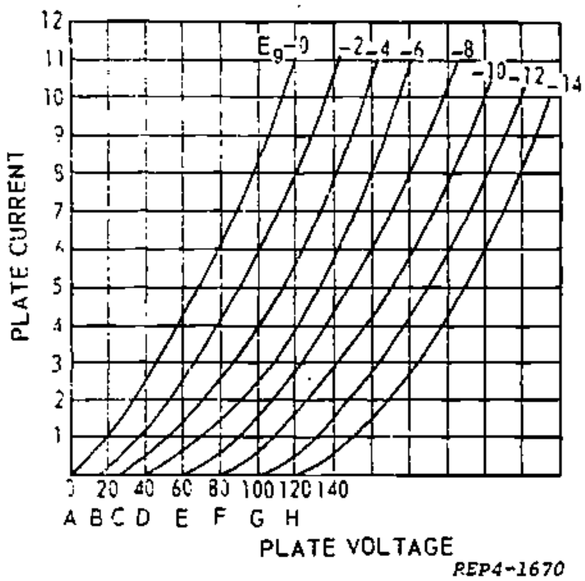


Figure 1

2. What is the plate current when plate voltage is 90V and grid voltage is -2V?

____

3. What is the grid voltage when plate voltage is 100V and plate current is 4 mA?

____

4. How much grid voltage would be required to cut off plate current when plate voltage is 100V?

____

5. What is the amplification factor if the grid voltage changes from -2V to -4V?

$$\mu = \frac{\Delta E_p}{\Delta E_g} \qquad (I_p = 8\text{ mA}) \quad \_\_\_\_\_\_\_\_$$

6. What is the transconductance if the grid voltage changes from -2V to -4V?

$$g_m = \frac{\Delta I_p}{\Delta E_g} \qquad (E_p = 100\text{V}) \quad \_\_\_\_\_\_\_\_$$

7. What is the AC plate resistance if the plate current changes from 6 mA to 8 mA?

$$r_p = \frac{\Delta E_p}{\Delta I_p} \qquad (E_g = -2) \quad \_\_\_\_\_\_\_\_$$

For questions 8 through 11, refer to the amplifier circuit and E_p - I_p curve, shown in figure 2 on page 3.

8. Draw a DC load line on the E_p - I_p curve for the amplifier circuit.

9. What is the plate voltage at the operating point? ____________________

10. What is the plate current at the operating point? ____________________

11. What is the value of E_{RL} when the tube is conducting? ____________________

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

____

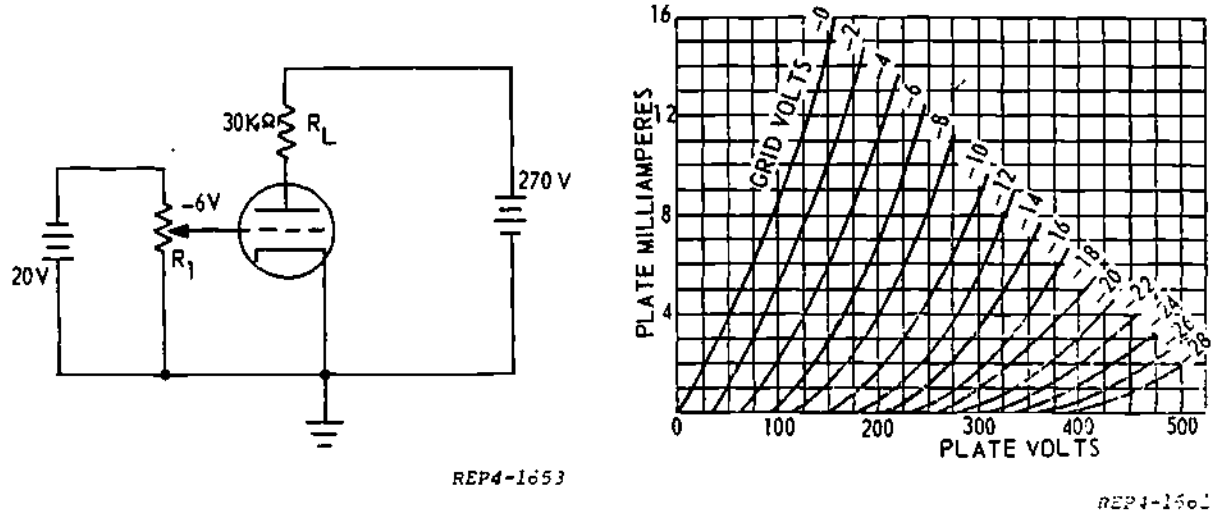


Figure 2

C. Turn to Student Text. Volume VIII and study paragraphs 2-77 through 2-90. Return to this page and answer the following questions.

1. What is bias? ____________________

2. In the circuits shown in figure 3, name the type of bias used for each circuit.

A = ____________________

B = ____________________

C = ____________________

3. What type of feedback is obtained when using cathode self bias? ____________________

____

4. What determines the value of bias voltage when using grid leak bias? ____________________

____

5. If plate current flows for 180° of the input signal. what is the class of operation?

____

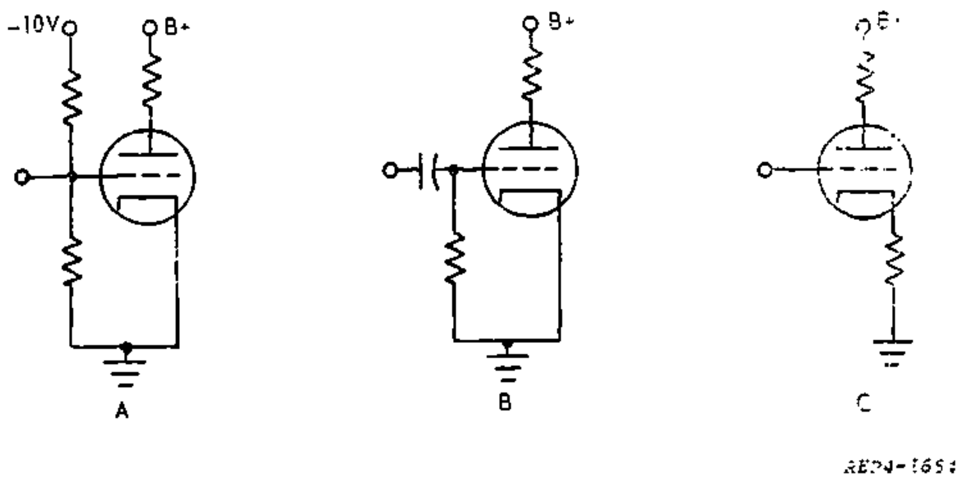


Figure 3

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

D. Turn to Student Text, Volume VIII and study paragraphs 2-91 through 2-101. Return to this page and answer the following questions.

For problems 1 through 6, use the schematic diagram of the amplifier and the E_p - I_p curve shown in figure 4.

1. Draw a DC load line for the values given on the amplifier schematic.

2. What is the value of E_p at the operating point? ____________________

3. What is the A_V of the circuit? $\left(A_V = \dfrac{\Delta E_p}{\Delta E_g}\right)$

4. Draw an AC load line on the E_p - I_p curve for the amplifier.

5. The voltage gain is (higher) (lower) on the AC load line than it was on the DC load line.

6. What is the phase relationship between the signal on the grid and the signal on the plate? ____________________

7. The capacitance between the electrodes of a tube is known as ____________ capacitance.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

MODULE SELF-CHECK

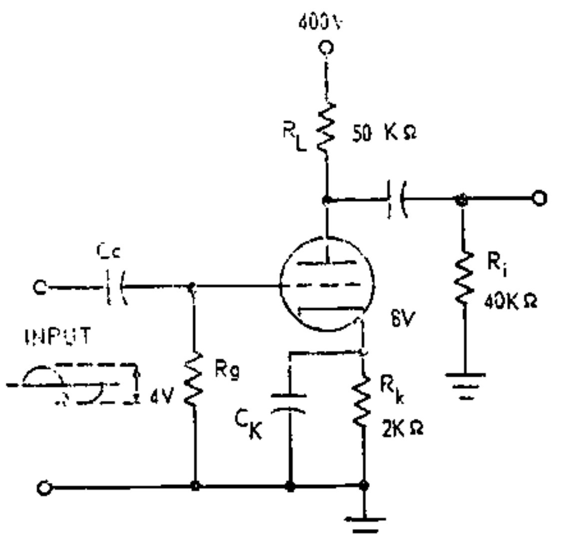
1. From the following list of statements, select the one that describes the functions of the control grid:

____a. Limits electron emission from the cathode.

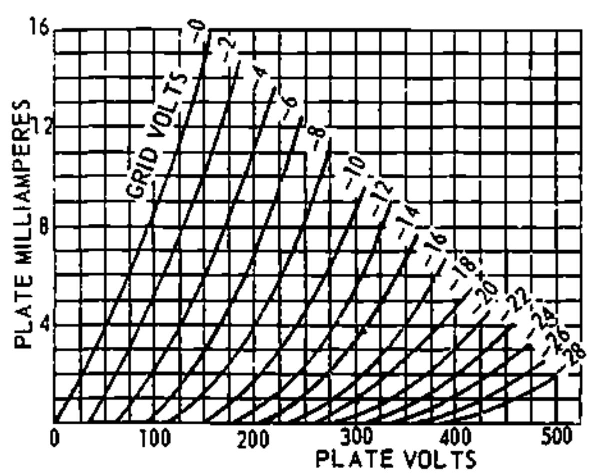
____b. Collects the electrons emitted from the cathode.

____c. Controls tube current.

____d. Compensates for fluctuations in plate voltage.



REP4-1658



REP4-1661

Figure 4

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2. Increasing negative bias

____a. increases tube conduction.

____b. decreases tube conduction.

____c. has no effect on tube conduction.

____d. only affects tube conduction when plate voltage is held constant.

In questions 3 through 5, identify the type bias used as either fixed bias, cathode self bias, or grid leak bias.

3. ______________________________

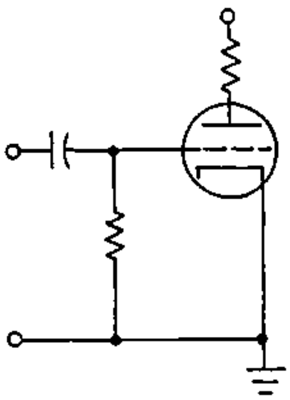


Figure 5

4. ______________________________

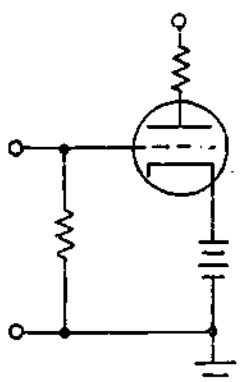


Figure 6

5. ______________________________

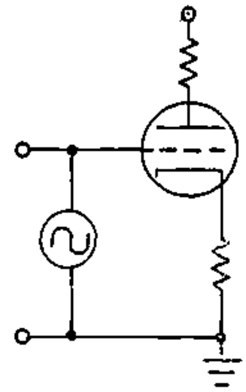


Figure 7

Use figure 8 for questions 6 through 9.

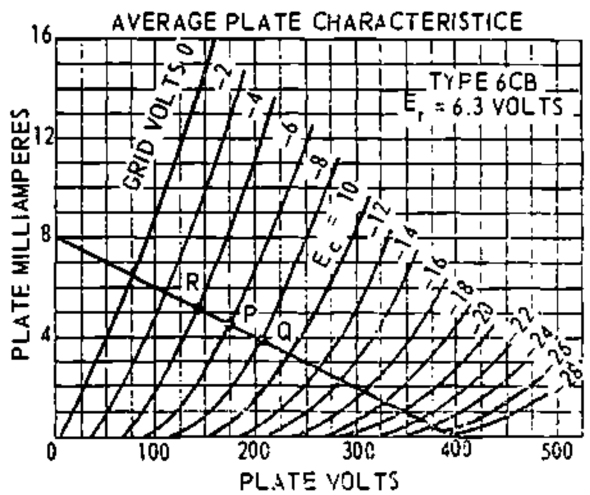


Figure 8

6. For a grid bias of -4 volts, plate voltage will be approximately

____a. 205 volts.

____b. 175 volts.

____c. 140 volts.

____d. 100 volts.

7. With grid bias of -6 volts, plate current is approximately

____a. 5.2 mA.

____b. 4.5 mA.

____c. 3.5 mA.

____d. 0.1 mA.

8. The bias voltage required for cutoff is approximately

____a. 0 volts.

____b. [illegible]

____c. -16 volts.

____d. -26 volts.

9. Saturation would occur at a bias of approximately

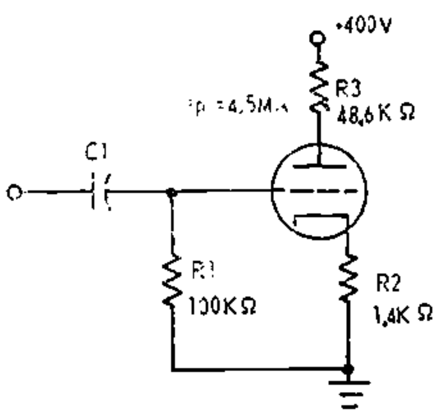
____a. -26 volts.

____b. -8 volts.

____c. -4 volts.

____d. 0 volts.

Use figure 9 for questions 10 through 12.



REP4-1659

Figure 9

10. The voltage drop across R3 is

____a. 219 volts.

____b. 175 volts.

____c. 150 volts.

____d. 143 volts.

11. The voltage drop across V1 is

____a. 219 volts.

____b. 200 volts.

____c. 175 volts.

____d. 148 volts.

12. In figure 9, the direction of current flow is:

____a. From ground through R1, grid to plate and R3 to B+.

____b. From B+ through R3, plate to cathode and R2 to ground.

____c. From ground through R2, cathode to plate and R3 to B+.

____d. From grid to cathode through R2 to ground.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

ANSWERS TO A:

1. control grid

2. It is closer to the cathode (and space charge).

3. decreases

4. cut off

5. high, low

If you missed ANY questions, review the material before you continue.

ANSWERS TO B:

1. characteristic curves

2. 5 mA

3. -4V

4. -12V

5. 10

6. 1000 micromhos

7. 10 kilohms

8. The DC load line should extend from 9 mA to 270V.

9. 160V ±5V

10. 3.6 mA

11. 108V

If you missed ANY questions, review the material before you continue.

ANSWERS TO C:

1. Average DC voltage difference between grid and cathode

2. A = fixed

   B = grid leak

   C = cathode self

3. degenerative or negative

4. amplitude of the input signal

5. Class B

If you missed ANY questions, review the material before you continue.

ANSWERS TO D:

1. The DC load line should extend from 400V to 10 mA.

2. 192V

3. 15

4. The AC load line should extend from 200V to 205V to 12.2 mA.

5. lower

6. 180° out of phase

7. interelectrode

If you missed ANY questions, review the material before you continue.

ANSWERS TO MODULE SELF-CHECK:

1. c
2. b
3. grid leak bias
4. fixed bias
5. cathode self bias
6. c
7. b
8. d
9. d
10. a
11. c
12. c

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

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PREPARE THE MAN

ATC ST 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-58

Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 58

MULTIGRID ELECTRON TUBES

1 October 1975

AIR TRAINING COMMAND

7-12

Designed For ATC Course Use

ATC Keesler 6-1086

DO NOT USE ON THE JOB

Radar Principles Branch
Keesler AFB, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-58
1 October 1975

ELECTRONIC PRINCIPLES

MODULE 58

MULTIGRID ELECTRON TUBES

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

OVERVIEW

1. SCOPE: Triode electron tubes have some unavoidable disadvantages which are the result of interelectrode capacitance, and low gain. This module explains how these disadvantages are greatly reduced by employing additional tube grid elements. With the additional grids, these tubes are referred to as MULTIGRID ELECTRON TUBES.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives.

a. From a list of statements, eelect the one that describes the function of the tetrode screen grid.

b. From a list of statements, and a schematic diagram, select the statement that describes the function of the pentode suppressor grid.

c. From a list of statements and a schematic diagram, select the statement that describes the function of beam forming plates.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text, Volume VIII

AUDIO VISUAL AIDS:

TV Lesson, Tetrodes, Pentodes, and Multipurpose Tubes, TVK-30-456.

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

Supersedes Guidance Package KEP-GP-58, 1 June 1974.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the back of this Guidance Package.

If you experience any difficulty, contact your instructor.

Begin the program.

Triode tubes have certain unavoidable limitations. These limitations include poor performance as IF or RF amplifiers and high gain audio amplifiers. These limitations are overcome with the use of multigrid electron tubes. A thorough understanding of multigrid tubes will aid you in your future work in electronics.

A. Turn to Student Text, Volume VIII and read paragraphs 3-1 through 3-25. Return to this page and answer the following questions.

1. A tetrode tube has (three, four, five) electrodes.

2. The primary purpose of the screen grid is to act as an ________ ________ between the control grid and the plate.

3. In the tetrode tube, the plate exerts a (large, small) force on the electrons in the space charge. Because of this, changes in plate voltage have a (large, small) effect on the number of electrons leaving the space charge.

4. In a tetrode, cathode current is the sum of ________________ current and ________________ current.

5. If B+ is 400 V, the screen dropping resistor is 75 k ohm, and screen current is 4 mA, the screen grid voltage will be ________________ volts.

6. The screen by-pass capacitor keeps a (constant, fluctuating) DC voltage on the screen grid and (increases, decreases) the effectiveness of the screen grid as an electrostatic shield.

7. Normally, the screen grid voltage is (greater, less) than the plate supply voltage.

8. On the E_p-I_p characteristic curves of a tetrode, the region where increasing plate voltage decreases plate current is known as the ________ ________ region.

9. In a given tetrode tube, a change in E_p of 100 V causes a change in I_p of .25 mA.

The AC plate resistance of this tube is ________________________.

(Note: $r_p = \frac{E}{I_p}$. E_g constant.)

10. Typical values of AC plate resistance for tetrodes are (higher, lower) than that for triodes.

11. μ for a tetrode is (higher, lower) than μ for a triode.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

B. Turn to Student Text, Volume VIII and read paragraphs 3-26 through 3-39. Return to this page and answer the following questions.

1. An electron tube with 5 active elements is called a ________________ tube.

2. The suppressor grid in a pentode tube eliminates the effects of ________________ ________________.

3. In a pentode tube the suppressor grid is (negative, positive) with respect to the plate.

4. Characteristic curves for pentodes do not have a ________ ________ region because the effects of ________ ________ have been eliminated.

5. AC plate resistance and amplification factor for pentodes is (higher, lower) than that for tetrodes.

6. Pentodes are classified as either sharp cutoff or remote cutoff according to their ________ ________ characteristics.

7. Remote cutoff pentodes are also known as ________ ________ tubes.

8. Sharp cutoff pentodes require a (large, small) bias voltage to cutoff plate current.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

C. Turn to Student Text, Volume VIII and read paragraphs 3-40 through 3-50. Return to this page and answer the following questions.

1. Beam power tubes are specifically designed for ________________ amplification.

2. The schematic symbol for a beam power tube is the same as that for a pentode. TRUE or FALSE

3. The cathode of a beam power tube has a large emitting surface because it is ________________.

4. Winding the screen grid wires directly in line with the control grid wires results in a much (higher, lower) value of screen grid current.

5. The beam forming plates do not repel secondary electrons emitted from the plate. TRUE or FALSE

6. The number and type of units in the same envelope is limited by the envelope size and the number of connections available. TRUE or FALSE

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

D. Turn to Student Text, Volume VIII and read paragraphs 3-51 through 3-55. Return to this page and answer the following questions.

1. To provide for easy removal and replacement, the base of a tube is in the form of a ________________ which is inserted into a ________________.

2. The metal connectors on a tube are referred to as ________________.

3. The electrodes in a tube always have the same pin numbers regardless of the type of tube. TRUE or FALSE

4. When looking at a tube socket from the bottom, pin numbers are counted (clockwise, counterclockwise) from the key.

5. A 6AK5 uses filament voltage of ________________ volts.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF CHECK.

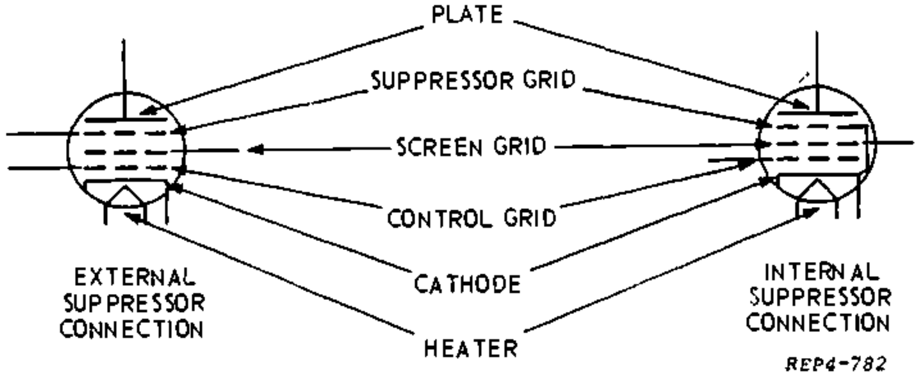

Figure 1

MODULE SELF-CHECK

QUESTIONS:

1. From the following list of statements, select the one that describes the function of the tetrode screen grid.

_____ a. Limits the cathode current to a safe value.

_____ b. Suppresses secondary emission from the plate.

_____ c. Increases the effect that plate voltage has on plate current.

_____ d. Acts as an electrostatic shield between the plate and control grid.

2. Using the tube schematic of figure 1, select from the following list of statements, the one that describes the function of the pentode suppressor grid.

_____ a. Increases the effect that plate voltage has on plate current.

_____ b. Increases the negative resistance region found in the tetrode.

_____ c. Keeps the control grid from going positive with respect to the cathode.

_____ d. Virtually eliminates the flow of electrons from the plate to the screen grid.

3. Using the schematic of figure 1, select from the following list of statements, the one that describes the function of the beam forming plates of a beam power tube.

_____ a. Limits the cathode current to a safe value.

_____ b. Electrostatically shields the control grid from the plate.

_____ c. Decreases the current handling capability normally found in a pentode tube.

_____ d. Suppresses secondary electrons from the plate and concentrates the electrons into a beam.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

ANSWERS TO A - ADJUNCT GUIDE

1. four
2. electrostatic shield
3. small, small
4. screen, plate
5. 100 volts
6. constant, increases
7. less
8. negative resistance
9. 400 k ohm
10. higher
11. higher

If you missed ANY questions, review the material before you continue.

ANSWERS TO B - ADJUNCT GUIDE

1. pentode
2. secondary emission
3. negative
4. negative resistance, secondary emission
5. higher
6. control grid
7. variable mu
8. small

If you missed ANY questions, review the material before you continue.

ANSWERS TO C - ADJUNCT GUIDE

1. power
2. True
3. flat
4. lower
5. False
6. True

If you missed ANY questions, review the material before you continue.

ANSWERS TO D - ADJUNCT GUIDE

1. plug, socket
2. pins
3. False
4. clockwise
5. 6.3 volts

If you missed ANY questions, review the material before you continue.

ANSWERS TO MODULE SELF-CHECK.

1. d
2. c
3. d

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

PREPARE THE MAN

ATC ST 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-59

Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED

MODULE 59

SPECIAL PURPOSE ELECTRON TUBES

1 October 1975

AIR TRAINING COMMAND

7-12

Designed For ATC Course Use

ATC Keesler 6-1099

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Radar Principles Branch
Keesler AFB, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-59
1 October 1975

ELECTRONIC PRINCIPLES

MODULE 59

SPECIAL PURPOSE ELECTRON TUBES

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specified information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

OVERVIEW

1. SCOPE: There are many circuit requirements that cannot be fulfilled by the tubes discussed previously. This module introduces you to the more widely used special purpose electron tubes and how their special design satisfies these requirements. Also explained is the basic construction and schematic symbols for the various special purpose electron tubes.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. Given the characteristic curves of a voltage regulator gas tube, identify the values of the

(1) breakdown voltage.
(2) operating voltage.
(3) current range.
(4) deionization voltage.

b. Given a list of statements, identify the purpose of the control grid in a thyratron tube.

c. Given the pictorial diagram of a simple two electrode phototube, identify the:

(1) cathode.
(2) anode.

d. Given the schematic diagram of a photomultiplier, identify the:

(1) cathode.
(2) anode.
(3) dynodes.

e. Given the pictorial diagram of a six element electron gun, the type used in a cathode ray tube, match each of the following elements with its function:

(1) control grid.
(2) cathode.

Supersedes KEP-GP-59, 1 July 1974.

(3) preaccelerating anode.
(4) focusing anode.
(5) accelerating anode.

f. Given a list of descriptions, match the term electrostatic or electromagnetic as the method described to control cathode ray tube:

(1) focus.
(2) beam deflection.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text, Volume VIII

VISUAL AIDS:

TV Lesson, Cathode Ray and Special Purpose Tubes, TVK 30-458.
TV Lesson, Gas Tubes, TVK 30-459.

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the back of this Guidance Package.

Contact your instructor if you experience any difficulty.

Begin the program.

There are many circuit requirements, that the tubes you have studied thus far, will not fulfill. The tubes designed to fill these special requirements are called special purpose electron tubes. Some of the most common types are the voltage regulator tube, thyratron, phototube and cathode ray tube. These tubes will play an important role in the electronic equipment that you will study in the future and a thorough understanding of their characteristics will be of great value to you.

A. Turn to Student Text, Volume VIII and read paragraphs 4-1 through 4-16. Return to this page and answer the following questions.

1. The most commonly used gases in soft tubes are ______________, ______________, ______________ and ______________ ______________.

2. Two basic types of gas tubes exist, they are ______________ cathode and ______________ cathode.

3. The process of causing current to flow because gas atoms are ionized is called ______________.

4. In a gas tube the point at which the degree of ionization becomes noticeable is the ______________ point of the tube.

5. In the operating region of a cold-cathode gas tube, small changes in current through the tube cause large changes in voltage across the tube. TRUE or FALSE.

6. After the breakdown voltage has been exceeded current flow is called an ______________.

7. In a neon glow tube either electrode can function as the plate or cathode. TRUE or FALSE.

8. The color of light that a gas tube produces depends upon the type of gas in the tube. TRUE or FALSE.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

B. Turn to Student Text, Volume VIII and read paragraphs 4-17 through 4-22. Return to this page and answer the following questions.

In the designation VR-105-30:

1. VR indicates ____________

2. 105 indicates ____________

3. 30 indicates ____________

Use figure 1 for questions 4 through 9.

4. Firing potential = __________ volts.

5. Operating voltage = __________ volts.

6. Current range = __________ mA.

7. Breakdown voltage = __________ volts.

8. Extinction voltage = __________ volts.

9. For proper operation the tube should be operated in region D to E. TRUE or FALSE.

10. Hot cathode diodes normally use __________ gas.

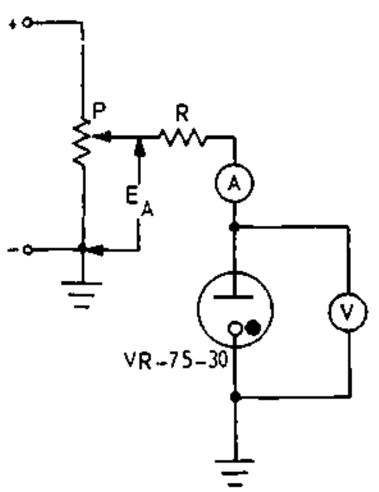
11. Hot cathode diodes have a (high)(low) conducting resistance.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

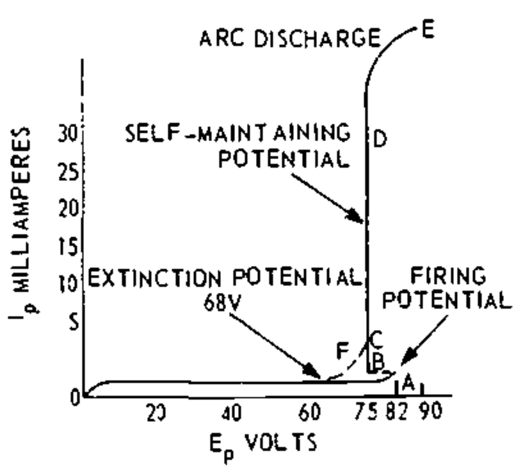
C. Turn to Student Text, Volume VIII and read paragraphs 4-23 through 4-28. Return to this page and answer the following questions.

1. In a thyratron tube, the control grid allows us to vary the __________ point of the tube.

2. In a thyratron, increasing the negative grid voltage (increases, decreases, does not affect) the deionization potential.



A. CIRCUIT



B. CHARACTERISTIC CURVE

REP4-1714

Figure 1

3. Increasing the negative grid voltage in a thyratron will cause the firing potential to (decrease, increase).

4. A control ratio of 10:1 means that the grid has ten times as much control over tube current as does the plate. TRUE or FALSE.

5. The thyratron is used primarily as a ______________________.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

D. Turn to Student Text, Volume VIII and read paragraphs 4-29 through 4-36. Return to this page and answer the following questions.

1. Electron emission that occurs when a material is exposed to light is called ______________ emission.

2. The cathode of a phototube is in the form of a slender wire or rod. TRUE or FALSE.

3. In a phototube the plate should cast as much shadow as possible on the cathode. TRUE or FALSE.

4. Thermionic emission is desirable in a phototube. TRUE or FALSE.

5. The amount of emission in a phototube depends on the color and intensity of light used. TRUE or FALSE.

6. Secondary emission in a photomultiplier tube is undesirable. TRUE or FALSE.

7. Dynodes are specifically designed to produce a large number of ______________ ______________.

8. The first dynode is (positive, negative) with respect to the cathode.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

E. Turn to Student Text, Volume VIII and read paragraphs 4-37 through 4-52. Return to this page and answer the following questions.

1. In a CRT, the long cylindrical portion of the tube envelope between the base and the tapered section is called the ______________________.

2. The fr[illegible] of the CRT is called the ______________________.

3. The section that shapes and accelerates the electron beam is called the ______________________.

4. The conductive graphite coating within a CRT is called ______________________.

5. The high vacuum and large surface area of a CRT make the tube especially vulnerable to ______________________.

6. The phosphor screen converts the ______________ energy of the moving electrons into ______________.

7. If an excessive number of electrons strike the screen in one spot the screen will be ______________.

8. The intensity of the beam should be just that required to produce a usable amount of light. TRUE or FALSE.

9. How long it takes for the light intensity to decay is termed the ______________ of the phosphor.

10. Electrostatic forces are used to ________ and ________ the electron beam in a CRT.

11. Four element electron guns are used when beam shaping is ______________.

12. The ______________________ shape of the electrodes in an electron gun allow them to shape the electron stream into a fine beam.

13. In an electron gun the entire cathode surface is coated with emitting oxides to increase emission. TRUE or FALSE.

14. The intensity control of an oscilloscope adjusts the ______________________ to vary the amount of light produced.

15. The baffle plate in the accelerating anode is for the purpose of improving the acelerating properties of this anode. TRUE or FALSE

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

F. Turn to Student Text, Volume VIII and read paragraphs 4-53 through 4-66. Return to this page and answer the following questions.

1. The electrostatic field between the focusing anode and accelerating anode forces the electrons toward the ______________ of the beam.

2. The focusing control on an oscilloscope adjusts the ______________ anode voltage.

3. The preaccelerating anode is often added to improve the ______________________ of the electron gun.

4. ______________________ deflection is nearly always used in oscilloscopes.

5. The electrostatic field between the ______________________ deflection plates moves the beam up and down.

6. The electrostatic field between the ______________________ deflection plates moves the beam from side to side.

7. If a 30 volt peak signal moves the spot on the screen 15 mm, the deflection sensitivity of the CRT is ______________ ______________.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

G. Turn to Student Text, Volume VIII and read paragraphs 4-67 through 4-79. Return to this page and answer the following questions.

1. The amount of deflection in an electromagnetic system depends on the ______________ of the ______________.

2. If the magnetic field is in the vertical plane, the electron beam will be deflected ______________.

3. For a linear sweep the current waveform through a deflection coil should be ______________________ therefore, the voltage waveform must be ______________________.

4. In the electromagnetic focusing system, electrons moving parallel to the magnetic field are not affected. TRUE or FALSE.

5. The focus control in an electromagnetic system varies the current through the focusing coil. TRUE or FALSE.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

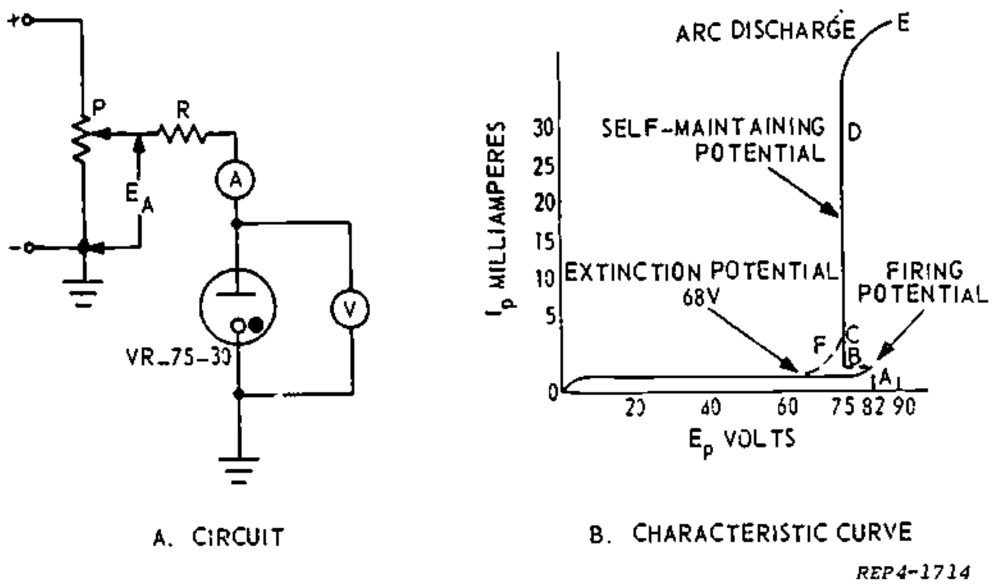


Figure 1

MODULE SELF-CHECK

QUESTIONS:

Use figure 1 for questions 1 through 4.

1. Breakdown voltage for the tube in figure 1 is approximately

_____ a. 90 volts.

_____ b. 82 volts.

_____ c. 75 volts.

_____ d. 68 volts.

2. The operating voltage for the tube of figure 1 is

_____ a. 90 volts.

_____ b. 82 volts.

_____ c. 75 volts.

_____ d. 68 volts.

3. The current range for a VR-75-30 tube is

_____ a. 1 mA to 40 mA.

_____ b. 5 mA to 30 mA.

_____ c. 10 mA to 25 mA.

_____ d. 25 mA to 30 mA.

4. The deionization voltage for a VR-75-30 tube is

_____ a. 40 volts.

_____ b. 68 volts.

_____ c. 75 volts.

_____ d. 82 volts.

5. From the following list of statements, select the one that identifies the purpose of the control grid in a thyratron tube:

_____ a. Provides a means for varying the firing potential.

_____ b. Provides a means for varying the deionization potential.

_____ c. Keeps temperature variations from affecting the firing potential.

_____ d. Limits the amount of current flow once the gas has ionized.

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Use figure 2 for questions 6 and 7.

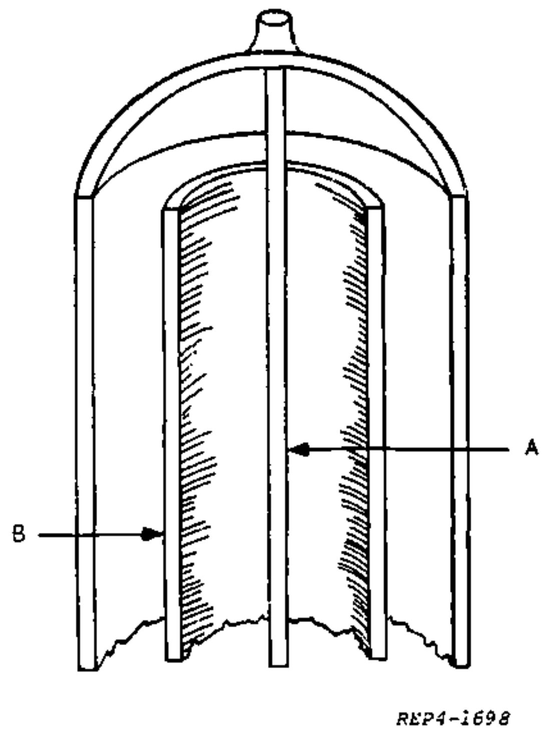

Figure 2

6. In figure 2 the letter A identifies the

_____ a. Dynode.

_____ b. Light entering window.

_____ c. Cathode.

_____ d. Anode.

7. The letter B in figure 2 identifies the

_____ a. Light entering window.

_____ b. Cathode.

_____ c. Anode.

_____ d. Dynode.

Use figure 3 for questions 8 through 10.

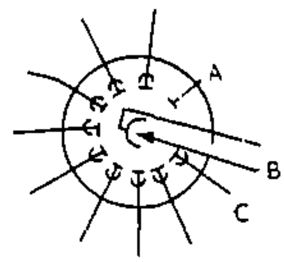

Figure 3

8. In figure 3 the letter A identifies the:

_____ a. Cathode.

_____ b. Dynode.

_____ c. Anode.

_____ d. Control grid.

9. Letter B in figure 3 identifies the:

_____ a. Cathode.

_____ b. Dynode.

_____ c. Anode.

_____ d. Control grid.

10. Letter C in figure 3 identifies the:

_____ a. Cathode.

_____ b. Dynode.

_____ c. Anode.

_____ d. Control grid.

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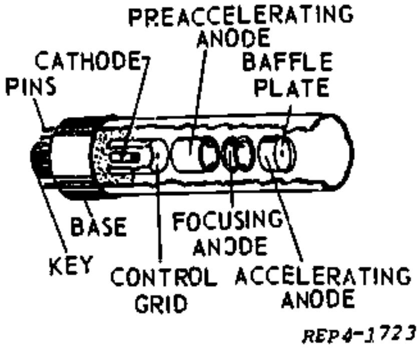

Figure 4

Use figure 4 for questions 11 through 15.

Match the function of the electrode, in the electron gun assembly, by placing the appropriate letter(s) in the space provided:

ELECTRODE

_____ 11. Cathode

_____ 12. Control Grid

_____ 13. Preaccelerating Anode

_____ 14. Focusing Anode

_____ 15. Accelerating Anode

FUNCTION

a. improves the sharpness of focus.

b. Converges the electron beam.

c. Increases the speed of the electrons to a high velocity.

d. Thermionically emits the electrons that make up the electron stream.

e. Determines the number of electrons allowed to leave the cathode area.

After each of the following descriptions write the word electrostatic or electromagnetic as applicable.

16. Deflection system that uses deflection plates. ______________________

17. Focusing is accomplished by varying the current through a focusing coil.

____

18. Deflection system that uses coils.

____

19. Focusing is accomplished by varying the voltage on one of the anodes.

____

20. Current required for deflection is very high. ______________________

21. Voltage required for deflection is very great. ______________________

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

ANSWERS TO A - ADJUNCT GUIDE

1. argon. neon, xenon, and mercury vapor
2. hot, cold
3. ionization
4. firing
5. False
6. arc discharge
7. True
8. True

If you missed ANY of the questions, review the material before you continue.

ANSWERS TO B - ADJUNCT GUIDE

1. voltage regulator
2. operating voltage
3. maximum current
4. 82 volts
5. 75 volts
6. 5 to 30 mA
7. 90 volts
8. 68 volts
9. False
10. mercury vapor
11. low

If you missed ANY of the questions, review the material before you continue.

ANSWERS TO C - ADJUNCT GUIDE

1. firing
2. does not affect
3. increase
4. False
5. switch

If you missed ANY of the questions, review the material before you continue.

ANSWERS TO D - ADJUNCT GUIDE

1. photoelectric
2. False
3. False
4. False
5. True
6. False
7. secondary electrons
8. positive

If you missed ANY of the questions, review the material before you continue.

ANSWERS TO E - ADJUNCT GUIDE

1. neck
2. faceplate
3. electron gun
4. aquadag
5. implosion
6. kinetic, light
7. burned
8. True
9. persistency
10. shape, deflect
11. electromagnetic
12. cylindrical
13. False
14. grid voltage or bias
15. False

If you missed ANY questions, review the material before you continue.

ANSWERS TO F - ADJUNCT GUIDE

1. center
2. focusing
3. sharpness of focus
4. electrostatic
5. vertical
6. horizontal
7. 0.5 mm/v.

If you missed ANY questions, review the material before you continue.

ANSWERS TO G - ADJUNCT GUIDE

1. intensity, magnetic field
2. horizontally
3. sawtooth, trapexoidal
4. True
5. True

If you missed ANY questions, review the material before you continue.

ANSWERS TO MODULE SELF-CHECK

1. a
2. c
3. b
4. b
5. a
6. d
7. b
8. c
9. a
10. b
11. d
12. e
13. a
14. b
15. c
16. electrostatic
17. electromagnetic
18. electromagnetic
19. electrostatic
20. electromagnetic
21. electrostatic

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

PREPARE THE MAN

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ATC ST 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-60

Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 60

ELECTRON TUBE AUDIO AMPLIFIERS

1 August 1975

AIR TRAINING COMMAND

7-12

Designed For ATC Course Use

ATC Keesler 6-0613

DO NOT USE ON THE JOB

Radar Principles Branch
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-60
1 August 1975

ELECTRONIC PRINCIPLES

MODULE 60

ELECTRON TUBE AUDIO AMPLIFIERS

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

OVERVIEW

1. SCOPE: This module is designed to teach you the characteristics and general trouble-shooting techniques for Electron Tube Audio Amplifiers. Changes in component values are analyzed with a triode amplifier and trouble-shooting is discussed using a pentode circuit.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. Given a schematic diagram, multimeter, oscilloscope and a trainer having an electron tube audio amplifier, determine the effects of changing component values and circuit voltage on the output signal.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training experience, and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text, Volume VIII

AUDIO VISUAL AIDS:

TVK-30-454, Amplifier Principles
TVK-30-455, Audio Amplifiers

LABORATORY EXERCISE:

Laboratory Exercise 60-1

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

Supersedes KEP-GP-60, 1 May 1974

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the back of this Guidance Package.

Contact your instructor if you experience any difficulty.

Begin the program.

A. Turn to Student Text, Volume VIII and read paragraphs 5-1 thru 5-11. Return to this page and answer the following questions.

1. In an electron tube audio amplifier the plate voltage waveform is in phase with the grid voltage waveform. (True)(False)

2. Increasing μ (increases)(decreases) gain.

3. Decreasing R_k (decreases) (increases) gain.

4. Increasing R_k decreases gain because it (increases)(decreases) negative grid bias.

5. Increasing the load impedance on an audio amplifier increases the gain. (True)(False)

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

B. Turn to Student Text, Volume VIII and read paragraphs 5-12 thru 5-25. Return to this page and answer the following questions.

1. Voltage gain at the upper and lower half-power frequencies is ________% of maximum.

2. If the highest operating signal frequency capability is increased, high frequency response is (increased)(decreased.)

3. Increasing the size of Cc (increases) (decreases) low frequency response.

4. Decreasing R_k (increases)(decreases) low frequency response.

5. Decreasing the value of the C_k (increases) (decreases) low frequency response.

6. Increasing the gain of an amplifier DECREASES the input capacitance. (True) (False)

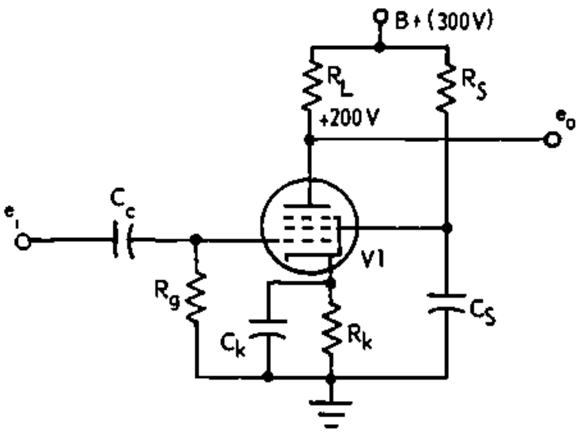
7. Increasing input capacitance (increases) (decreases) high frequency response.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

C. Turn to laboratory exercise 60-1. This exercise will show you the effects of changing component values and circuit voltages. As you do the exercise take particular care to notice that practical operation can be predicted very accurately with theoretical analysis. After you have completed the laboratory exercise and progress check, return and continue with this program.

D. Turn to Student Text, Volume VIII and read paragraphs 5-26 thru 5-40. Return to this page and answer the following questions.

1. If the signal feedback through the grid to plate capacitance has been cancelled, the amplifier has been ________.



REP4-1697

Figure 1. RC Coupled Pentode Audio Amplifier

Use figure 1 for questions 2 thru 11.

2. If C_c opens there is no signal output at e_o. (True)(False)

3. There is an output but it is very weak. A possible cause is R_g shorted. (True)(False.)

4. C_k has shorted. This causes the plate voltage to (increase)(decrease.)

5. When C_k opens, gain (increases)(decreases.)

6. If R_k were to open, plate voltage would be ______________ volts.

7. R_L is open. Plate voltage is ______________ volts.

8. R_L is shorted. Plate voltage is ______________ volts.

9. If C_S were to open, gain would (increase)(decrease.)

10. C_S is shorted. Screen grid current is approximately ______________ mA and screen grid voltage is ______________ volts.

11. R_S is open. Plate voltage is ______________ volts.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

LABORATORY EXERCISE 60-1

PRINCIPLES AND APPLICATIONS OF ELECTRON TUBES

ELECTRON TUBE AUDIO AMPLIFIERS

OBJECTIVES:

1. Given a schematic diagram, multimeter, oscilloscope, and a trainer having an electron tube audio amplifier, determine the effects of changing component values and circuit voltage on the output signal.

EQUIPMENT:

1. Triode Tube Characteristic Trainer, #5484.
2. Oscilloscope
3. Sine-Square Signal Generator, #4864.
4. Power Supply, #4912.
5. Multimeter.

REFERENCE:

Student Text, Volume VIII, Chapter 5.

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS. FOLLOW THE PROCEDURES CAREFULLY.

PROCEDURES:

1. Analysis of the trainer:

a. A vacuum tube amplifier schematic diagram is shown in the faceplate of the trainer.

b. Switching arrangements and various test points are incorporated in the trainer for:

(1) changing the plate load resistance (S7).

(2) changing the cathode resistance (S5).

(3) changing input coupling (S2).

(4) varying fixed bias.

(5) inserting and removing a cathode by-pass capacitor.

(6) inserting, removing and monitoring various signals and voltages within the trainer (test points).

2. Preparation of the equipment:

a. Oscilloscope

Controls	Position
(1) Power	ON
(2) Vertical Mode	Alternate
(3) Volts/Div	A = .5, B = .2
(4) Polarity	A & B, AC Norm
(5) Horiz. Display	Norm.
(6) Time/Div	.1 mSEC
(7) Trigger Selector	Ext +
(8) Trigger Mode	Auto
(9) Focus and Intensity	Well defined trace

b. Power Supply

Controls	Position
(1) Power	OFF
(2) Neg. V. adj.	Min (FCCW)
(3) Pos. V. adj.	Min (FCCW)
(4) Volt Meter	Pos.

c. Signal Generator

Controls	Position
(1) Amplitude (Square Wave)	Slightly clockwise
(2) Freq. Multiplier	100
(3) Frequency (CPS)	50
(4) Range	1 V
(5) Amplitude (Sine Wave)	Min (FCCW)

d. Trainer

Controls	Position
(1) S1	Midway between Position 2 and 3
(2) R1	Max (FCW)
(3) R2	Min. (FCCW)
(4) S2	Position 3, C1 (0.1 MF)
(5) S3	Position 2, R3 (100 k ohm)
(6) S4	Position 2 (left)
(7) S5	Position 2, R5 (1.2 M ohm)
(8) S6	Out (C3 removed)
(9) S7	Position 2, R7

e. Position the multimeter controls as required to measure circuit voltages.

f. Connect the power supply voltage source to the trainer by using a prefabricated cable. (Note: Receptacle is located on rear panel of the power supply.)

g. Oscilloscope to trainer:

(1) Ground oscilloscope to trainer.

(2) Connect A channel Vert. Input to sinewave output of the signal generator.

(3) Connect B channel Vert. Input to TP7 using a 10:1 attenuator probe.

(4) Connect trigger input to TP5.

h. Signal generator to trainer:

(1) Ground generator to trainer.

(2) Connect sinewave output to TP2.

3. Activity

a. Power supply adjustment.

(1) Turn ON

(2) Using the Pos. position on the power supply volt meter, adjust B+ to 250V with the Pos. V. Adj.

(3) Switch the voltmeter to Neg. and adjust Neg. V. Adj. to 100V.

b. Observing "A" channel on the oscilloscope, adjust the sinewave output on the signal generator to 1 volt Pk to Pk.

c. Measure the output amplitude and compute the actual voltage gain of V1.

(Note: $A_v = \frac{E_o}{E_i}$.)

Voltage gain = ____________

d. Adjust the signal generator to 20 Hz and recompute the voltage gain. (Frequency Mult. in X I position).

(1) Voltage gain = ____________

(2) Why did the gain decrease?

____

(3) The lower half power point on the frequency response curve of this amplifier is (above)(below) 20 Hz.

e. Turn S2 to position 2 and note that the output signal virtually disappeared. Adjust the signal generator to 10 kHz, measure the output amplitude, and compute the voltage gain.

(1) Output amplitude = ____________ V Pk to Pk

(2) Voltage gain = ____________

While maintaining the input at 1 V Pk to Pk, decrease the signal generator frequency until the output voltage is 70.7% of the value obtained in step 3e(1).

(3) Lower half power frequency = ____________ Hz.

(4) When C2 was selected as the input coupling capacitor, why did the low frequency response deteriorate?

____

f. Switch S2 to position 3 and measure the output amplitude.

(1) Output amplitude = ____________ V Pk to Pk.

(2) If the input voltage is held constant, the output voltage at the upper half power point would be ____________ V Pk to Pk.

Now, keeping the input voltage constant, increase the signal generator frequency until the output voltage drops to the value obtained in step 3f(2).

(3) The upper half power frequency = ____________ kHz.

(4) Will an increase in gain affect the high frequency response?

Let's find out. Return the signal generator to 10 kHz. If necessary readjust the input for 1 V Pk to Pk. Turn S7 to position 3 and notice that the gain has increased. Using

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the procedure of 3f(1) and 3f(2), recheck the upper half power frequency.

(5) Upper half power frequency = ______ kHz.

(6) This deterioration oı .igh frequency response was caused by an increase in

______.

g. (1) Return signal generator to 10 kHz. Place the trigger mode to AC LF reject. Place S5 in position 1 and S7 in position 2. Disconnect the oscilloscope cable from TP5 and set the trigger select switch to Int. Pos. Observing polarity measure the bias on V1 with the PSM-6. (Note: TP5 is negative with respect to TP6.) Slowly turn R2 clockwise and observe the increase in bias.

Increasing bias (increased) (decreased) gain.

(2) Readjust R2 until bias is minimum. Switch S5 to position 2.

Bias (increased) (decreased).

Gain (increased) (decreased).

(3) Turn S5 to position 3.

Bias (increased) (decreased).

Gain (increased) (decreased).

Increasing cathode resistance,

______ bias and

______ gain.

(4) Disconnect the multimeter and using channel "B" monitor the signal at TP6 with the oscilloscope. (Note: Use Auto Mode and Ext + triggering on scope.) Obtain trigger signal from TP5.

The cathode signal is (in phase) (out of phase) with signal on grid.

The cathode signal represents (degenerative) (regenerative) feedback.

(5) Place S6 to the IN position.

Why did the AC signal on the cathode disappear?

(6) Using channel "B," monitor the signal at TP7 and switch C3 in and out a couple of times.

Inserting the cathode by-pass capacitor (increased) (decreased) gain.

(7) Place S7 in position 3.

Increasing plate load resistance (increased) (decreased) gain.

h. Using the information gained in this laboratory project, answer the following questions.

(1) Low frequency response is primarily

limited by ______ ______.

(2) Increasing gain (increases) (decreases) high frequency response.

(3) Increasing cathode resistance (increases) (decreases) bias and (increases (decreases) gain.

(4) Why does insertion of a cathode by-pass capacitor increase gain?

(5) Decreasing plate load resistance (increases) (decreases) gain.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

MODULE SELF-CHECK

ELECTRON TUBE AUDIO AMPLIFIERS

Use figure 1 for questions 1 thru 6.

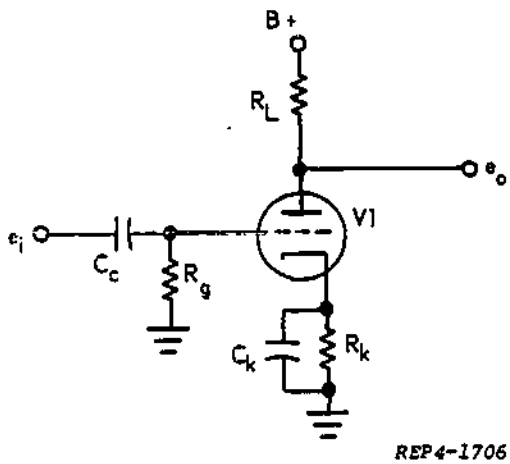

Figure 1. RC Coupled Triode Audio Amplifier

1. Increasing the value of C_c

_____ a. Increases high frequency response.

_____ b. Increases low frequency response.

_____ c. Does not affect frequency response.

_____ d. Decreases gain.

2. Increasing the value of R_k

_____ a. Decreases negative grid bias.

_____ b. Decreases plate voltage.

_____ c. Decreases voltage gain.

_____ d. Does not affect gain.

3. Increasing the value of R_L

_____ a. Increases negative grid bias.

_____ b. Improves low frequency response.

_____ c. Decreases voltage gain.

_____ d. Increases voltage gain.

4. Increasing the value of R_g

_____ a. Increases low frequency response.

_____ b. Decreases low frequency response.

_____ c. Increases negative grid bias.

_____ d. Decreases negative grid bias.

5. Increasing the value of R_L

_____ a. Increases high frequency response.

_____ b. Decreases high frequency response.

_____ c. Increases low frequency response.

_____ d. Decreases low frequency response.

6. Decreasing the value of C_k

_____ a. Increases low frequency response.

_____ b. Decreases low frequency response.

_____ c. Increases high frequency response.

_____ d. Decreases high frequency response.

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Use figure 2 for questions 7 and 8.

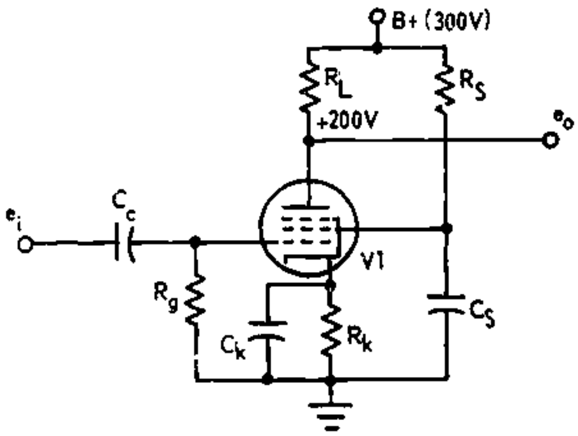

Figure 2. RC Coupled Pentode Audio Amplifier

7. All DC voltages are normal, there is no signal on the control grid, and no output, a possible cause is

_____ a. R_g open

_____ b. R_k open

_____ c. C_k shorted

_____ d. C_c open

8. There is no output, screen grid voltage and plate voltage are both 300 volts. A possible cause would be:

_____ a. C_k shorted

_____ b. R_L open

_____ c. R_s shorted

_____ d. R_k open

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

ANSWERS TO A - ADJUNCT GUIDE

1. False
2. increases
3. increases
4. increases
5. True

If you missed ANY questions, review the material before you continue.

ANSWERS TO B - ADJUNCT GUIDE

1. 70.7
2. increased
3. increases
4. decreases
5. decreases
6. False
7. decreases

If you missed ANY questions, review the material before you continue.

ANSWERS TO D - ADJUNCT GUIDE

1. Neutralized
2. True
3. False
4. decrease
5. decreases
6. 300
7. 0
8. 300
9. decrease
10. 0, 0
11. 300

If you missed ANY questions, review the material before you continue.

ANSWERS TO LAB EXERCISE 60-1

3c. Voltage gain = 4.5

3d(1) Voltage gain = 3.5

(2) As you approach the lower half power point, coupling capacitor reactance increases

(3) The increased voltage drop across the coupling capacitor subtracts from C_i.

3e(1) Output Amplitude = 3.6 V Pk to Pk

(2) Voltage gain = 3.6

(3) Lower half power frequency = 1350 Hz.

(4) Decreasing capacitance increased X_C

3f(1) Output amplitude = 4 V Pk to Pk

(2) The output voltage at the upper half power point would be 2.8 V Pk to Pk.

(3) The upper half power frequency = 360 kHz.

(4) Yes

(5) Upper half power frequency = 75 kHz.

(6) Gain.

3g(1) Increasing bias decreased gain.

(2) Bias increased. Gain decreased.

(3) Bias increased. Gain decreased. Increasing cathode resistance increased bias and decreased gain.

(4) The cathode signal is in phase with signal on grid. The cathode signal represents degenerative feedback.

(5) C3 filtered out the AC cathode signal.

(6) Inserting the cathode by-pass capacitor increased gain.

(7) Increasing plate load resistance increased gain.

3h(1) Low frequency response is primairly limited by input coupling capacitance.

(2) Increasing gain decreases high frequency response.

(3) Increasing cathode resistance increases bias and decreases gain.

(4) The cathode by-pass capacitor removes the AC (degenerative) signal on the cathode.

(5) Decreasing plate load resistance decreases gain.

ANSWERS TO MODULE SELF-CHECK

1. b
2. c
3. d
4. a
5. b
6. b
7. d
8. d

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER INSTRUCTIONS.

PREPARE THE MAN

180

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-61

Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 61

ELECTRON TUBE RF AMPLIFIERS, CATHODE FOLLOWERS, DC AMPLIFIERS, AND TRIODE LIMITERS

1 September 1975

AIR TRAINING COMMAND

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ELECTRONIC PRINCIPLES

MODULE 61

ELECTRON TUBE RF AMPLIFIERS, CATHODE FOLLOWERS DC AMPLIFIERS, AND TRIODE LIMITERS

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

OVERVIEW

1. SCOPE: This module is designed to teach you the characteristics of RF amplifiers, cathode followers, DC amplifiers and triode limiters. Schematic analysis and component function are discussed along with the results of component value changes.

2. OBJECTIVES: Upon completion of this module, you should be able to satisfy the following objectives:

a. Given a schematic diagram of a pentode RF amplifier with a tuned output, identify the effects of changing the tuned circuit component values and output circuit loading on the amplitude and bandwidth of the output.

b. Given a cathode follower schematic diagram, determine the effects of changing the circuit component values on the output amplitude and impedance.

c. Given a list of statements and a schematic diagram, select the statement that describes the characteristics of a DC amplifier.

d. Given the schematic diagram of a triode limiter, identify the effects of changing the grid resistor and grid bias on the shape of the output.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text, Vol VIII

AUDIO-VISUAL AIDS

TV Lesson, Triode Limiters, TVK 30-551B

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Supersedes Guidance Package, KEP-GP-61, 1 June 1974.

TV Lesson, Cathode Followers, TVK 30-434

TV Lesson, Video Amplifiers, TVK 30-457

TV Lesson, RF and IF Amplifiers, TVK 30-553

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the back of this Guidance Package.

Contact your instructor if you experience any difficulty.

Begin the program

This lesson will discuss four common electron tube circuits. They are RF amplifiers, cathode followers, DC amplifiers, and triode limiters. These circuits find wide application in the field of electronics and a knowledge of their operational characteristics is essential.

A. Turn to Student Text, Volume VIII and read paragraphs 6-1 through 6-15. Return to this page and answer the following questions.

1. Pentode tubes are normally used in RF amplifiers because of their

_____ a. low gain and stability.

_____ b. high interelectrode capacitance.

_____ c. performance at low frequencies.

_____ d. low interelectrode capacitance and high gain

2. Stagger tuning provides

_____ a. less selectivity.

_____ b. more selectivity.

_____ c. higher gain.

_____ d. decreased stability.

3. For high selectivity, use a tank circuit with

_____ a. high losses.

_____ b. low Q.

_____ c. high Q.

_____ d. low shunt resistance.

4. To increase selectivity, you should

(increase, decrease) bandwidth.

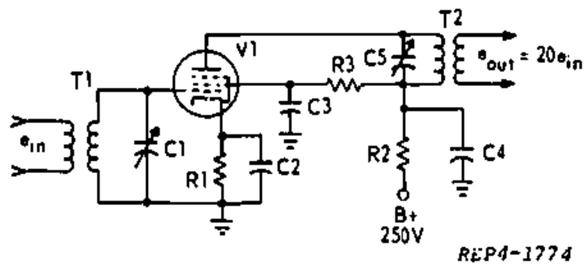


Figure 1

Use figure 1 for questions 5 through 12.

5. C3 is a

_____ a. cathode bypass capacitor.

_____ b. screen grid bypass capacitor.

_____ c. plate decoupling capacitor.

_____ d. part of the tuned plate circuit.

6. The secondary of T1 along with C1

_____ a. develops grid bias.

_____ b. tunes the grid circuit to the desired frequency.

_____ c. shorts out the signal variation on the grid.

_____ d. keeps the amplifier from having any frequency response limitations.

7. When V1 is operated class A, it has a (high) (low) grid to cathode resistance.

8. Decreasing the grid to cathode resistance would (increase) (decrease) bandwidth.

9. The decoupling components in figure 1 are _____________ and _____________.

10. Tuning the plate tank to a slightly different frequency than the control grid tank for the purpose of increasing bandwidth is called _____________ _____________.

11. Placing a resistor in parallel with C5 would cause V1 to have a (high, low) gain and a (wide) (narrow) bandwidth.

12. RF amplifiers do not generally employ RC coupling because

_____ a. of insufficient selectivity.

_____ b. bandwidth would be too narrow.

_____ c. the capacitor will not pass high frequencies.

_____ d. the impedance of the grid circuit is too high.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

B. Turn to Student Text, Volume VIII and read paragraphs 6-16 through 6-25. Return to this page and answer the following questions.

1. Voltage gain of a cathode follower is (high, low).

2. In a cathode follower, a cathode bypass capacitor is not used. TRUE or FALSE.

3. In a cathode follower the output signal is (in phase) (180° out of phase) with the input and the output acts as (regenerative) (degenerative) feedback.

4. Increasing the cathode resistor in a cathode follower (increases) (decreases) output impedance.

5. Part of the reason for a cathode follower's high input impedance is the fact that the input capacitance is (high)(low).

6. A cathode follower circuit has a relatively (wide)(narrow) frequency response.

7. A cathode follower has (high)(low) distortion.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

C. Turn to Student Text, Volume VIII and read paragraphs 6-26 through 6-34. Return to this page and answer the following questions.

1. DC amplifiers employ (direct)(RC) coupling.

2. The frequency response curve for a DC amplifier is (wider)(narrower) than that for a comparable RC coupled amplifier.

3. Multistage DC amplifiers become impractical because of

_____ a. voltage distribution problems.

_____ b. low input impedance

_____ c. high input impedance.

_____ d. decoupling problems.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

D. Turn to Student Text, Volume VIII and read paragraphs 6-35 through 6-47. Return to this page and answer the following questions.

1. The four general methods of limiting are

a. _______________

b. _______________

c. _______ _______

d. _______________

2. When using grid limiting, it is necessary to use a large resistor in (series)(parallel) with the grid to cathode circuit.

3. The amount of grid limiting can be changed by changing grid _______________.

4. Decreasing the value of the grid resistor in a grid limiter (increases)(decreases) the amount of limiting.

5. In a saturation limiter, when limiting occurs, plate voltage is at its (maximum)(minimum) value and plate current is at its (minimum)(maximum) value.

6. In a saturation limiter the (positive)(negative) peaks of the output signal are limited.

7. Cutoff limiting occurs when the grid is driven highly (positive)(negative) with respect to the cathode.

8. When cutoff limiting occurs, plate voltage is equal to _______________.

9. In a cutoff limiter the (positive)(negative) half cycles of the output wave are limited.

10. In an overdriven amplifier limiter, limiting occurs when the tube is driven into _______________ and _______________.

11. Overdriven amplifier limiters limit both the positive and negative half cycles. TRUE or FALSE.

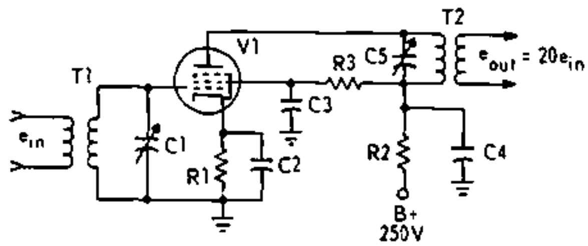
CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

MODULE SELF-CHECK

QUESTIONS:

Use figure 1 for questions 1 through 3.



REP4-1774

Figure 1

1. Increasing the load on the secondary of T2 will

_____ a. not affect bandwidth.

_____ b. increase the gin of V1.

_____ c. decrease the bandwidth.

_____ d. increase the bandwidth.

2. Tuning the output tank to a slightly different frequency than the input tank will

_____ a. increase output amplitude and decrease bandwidth.

_____ b. decrease output amplitude and increase bandwidth.

_____ c. increase output amplitude and increase bandwidth.

_____ d. decrease output amplitude and decrease bandwidth.

3. Increasing the Q of the primary winding of T2 or the secondary winding of T1 will

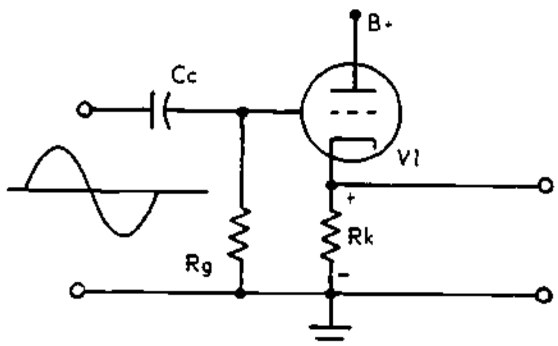
_____ a. increase gain and decrease bandwidth.

_____ b. decrease gain and increase bandwidth.

_____ c. decrease gain and decrease bandwidth.

_____ d. increase gain and increase bandwidth.

Use figure 2 for questions 4 and 5.



REP4-1775

Figure 2

4. Increasing the value of R_k,

_____ a. decreases output impedance.

_____ b. decreases voltage gain.

_____ c. increases output impedance.

_____ d. does not affect voltage gain.

5. Decreasing the value of R_k,

_____ a. increases voltage gain.

_____ b. decreases voltage gain.

_____ c. increases output impedance.

_____ d. does not affect voltage gain.

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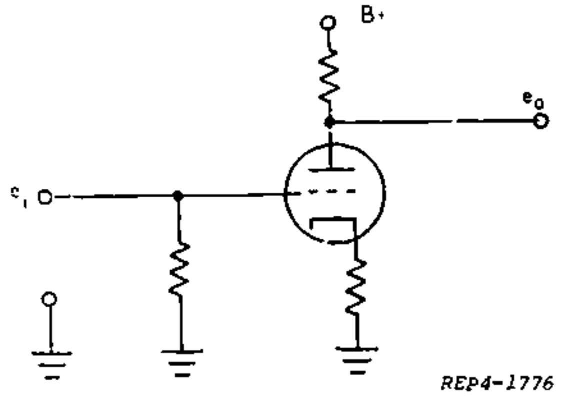

Figure 3

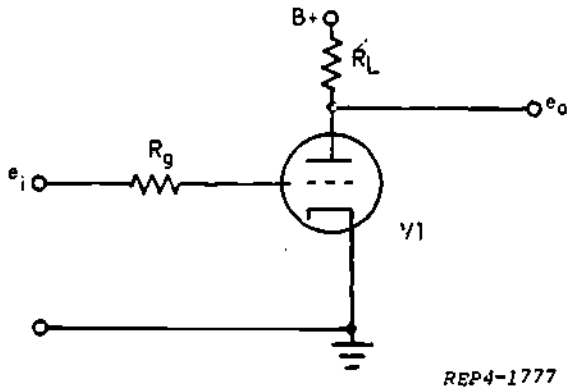

Figure 4

Use figure 3 for question 6.

6. The DC amplifier in figure 3

_____ a. has a very narrow frequency response.

_____ b. has a wider frequency response than a comparable RC coupled amplifier.

_____ c. amplifies high frequencies very well but will not amplify low frequencies.

_____ d. has a voltage gain of less than one.

Use figure 4 for questions 7 and 8.

7. Decreasing the value of R_g,

_____ a. increases limiting of the positive half cycle in the output.

_____ b. decreases limiting of the positive half cycle in the output.

_____ c. increases limiting of the negative half cycle in the output.

_____ d. decreases limiting of the negative half cycle in the output.

8. Applying a negative bias voltage to the grid of V1 would

_____ a. increase limiting of the positive half cycle in the output.

_____ b. decrease limiting of the positive half cycle in the output.

_____ c. increase limiting of the negative half cycle in the output.

_____ d. decrease limiting of the negative half cycle in the output.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

ANSWERS TO A - ADJUNCT GUIDE

1. d
2. a
3. a
4. decrease
5. b
6. b
7. high
8. increase
9. R2 and C4
10. stagger tuning
11. low, wide
12. a

If you missed ANY questions, review the material before you continue.

ANSWERS TO B - ADJUNCT GUIDE

1. low
2. True
3. in phase, degenerative
4. increases
5. low
6. wide
7. low

If you missed ANY questions, review the material before you continue.

ANSWERS TO C - ADJUNCT GUIDE

1. direct
2. wider
3. a

If you missed ANY questions, review the material before you continue.

ANSWERS TO D - ADJUNCT GUIDE

1. grid, saturation, cutoff, overdriven amplifier
2. series
3. bias
4. decreases
5. minimum, maximum
6. negative
7. negative
8. B+ (plate supply voltage)
9. positive
10. saturation, cutoff
11. True

If you missed ANY questions, rview the material before you continue.

ANSWERS TO MODULE SELF-CHECK:

1. d
2. b
3. a
4. c
5. b
6. b
7. d
8. d

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

Prepared by Keesler TTC

KEP-GP-62

Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

THYRATRON SAWTOOTH GENERATOR, PHANTASTRON, AND ELECTRON TUBE SERIES VOLTAGE REGULATOR

MODULE 62

1 August 1975

AIR TRAINING COMMAND

7-12

Designed For ATC Course Use

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Radar Principles Branch
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-62
1 August 1975

ELECTRONIC PRINCIPLES

MODULE 62

THYRATRON SAWTOOTH GENERATOR, PHANTASTRON, AND ELECTRON TUBE SERIES VOLTAGE REGULATOR

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

OVERVIEW

1. SCOPE: This module is designed to teach you the characteristics of thyratron sawtooth generators, phantastron circuits, and electron tube series voltage regulators. Schematic analysis includes component functions and value changes. Also discussed are circuit voltages and output signal characteristics.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. Given the schematic diagram of a thyratron sawtooth generator, identify the effect of changing

(1) circuit voltages.
(2) component values.
(3) input trigger frequency.

b. Given the schematic diagram of a triggered phantastron circuit, identify the effects on the amplitude, frequency and pulse width of the output waveform when changing the

(1) pulse width potentiometer.
(2) control grid resistor.
(3) control grid to plate capacitor.
(4) input trigger frequency.

c. Given the schematic diagram of an electron tube series voltage regulator, identify the effects of changing the

(1) input voltage.
(2) load resistance.
(3) potentiometer position.

Supersedes KEP-GP-62, 1 May 1974.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text, Vol VIII

AUDIO VISUAL AIDS:

TV Lesson, Phantastron, TVK-30-858
TV Lesson, Sawtooth Generators, TVK-30-859
TV Lesson, Vacuum Tube Voltage Regulators, TVK-30-460

LABORATORY EXERCISES:

Laboratory Exercise 62-1, Thyratron Sawtooth Generator
Laboratory Exercise 62-2, Phantastron
Laboratory Exercise 62-3, Series Voltage Regulator

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELFCHECK. CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

ADJUNCT GUIDE

Instructions:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the back of this Guidance Package.

Contact your instructor if you experience any difficulty.

Begin the program.

This adjunct guide will assist you in learning three basic circuits. They are the thyratron sawtooth generator, phantastron, and electron tube series voltage regulator.

A. Turn to Student Text, Volume VIII, and read paragraphs 7-1 through 7-24. Return to this page and answer the following questions on the thyratron sweep generator:

1. In a thyratron sawtooth generator, the sawtooth waveshape is developed across the ______________________ while ______________ and __________.

2. A linear rise in voltage is produced across the capacitor when a (large, small) percentage of the charge curve is used.

3. When the thyratron is deionized, it presents a (high, low) impedance in parallel with the capacitor.

4. When the thyratron ionizes, the capacitor (charges, discharges) through it very quickly.

5. Once the thyratron ionizes, the ______________________ potential must be reached before it will stop conducting.

6. Increasing the grid bias on a thyratron (increases, decreases) the firing potential.

7. In a thyratron sawtooth generator, decreasing the grid bias (increases, decreases) sawtooth amplitude and (increases, decreases) frequency.

8. Increasing grid bias (increases, decreases) linearity because a (larger, smaller) portion of the capacitor charge curve is used.

9. Changing grid bias changes the deionization potential of the thyratron tube and thus changes output linearity. (True or False)

10. Increasing the value of resistance or capacitance in the RC circuit, will (increase, decrease, not affect) frequency and will (increase, decrease, not affect) linearity.

11. Increasing the supply voltage (increases, decreases) frequency and (increases, decreases) linearity.

12. When synchronization is used, the free running frequency is adjusted slightly (higher, lower) than the desired output frequency.

13. Improper synchronizing signal amplitudes

will cause ____________________ operation.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

B. If you wish to do the laboratory exercise on the thyratron sawtooth generator, turn to laboratory exercise 62-1 at this time and complete it. The exercise is designed to show you the effects of changing component values and circuit voltages on the output signal and to enhance your knowledge of circuit analysis. After you have completed the laboratory exercise, return and continue with this program.

C. Turn to Student Text, Volume VIII, and read paragraphs 7-25 through 7-60. Return to this page and answer the following questions on the phantastron circuit:

1. "Miller Effect" is the effect of

____________ ____________

on the input capacitance of an amplifier.

2. If the actual grid to plate capacitance of an amplifier is .1pF and the stage gain is 20, the effective grid to plate capacitance is ____________________ pF.

3. During plate rundown in a phantastron circuit, the discharge current rate (increases, decreases).

4. The recovery time of a phantastron is controlled by the RC time constant of the feedback capacitor and the

____________ ____________

____________.

5. A miller integrator uses the miller effect to form a (long, short) time constant RC circuit.

6. For phantastron switching, external

____________________ are used.

7. Immediately after the phantastron has recovered, plate current does not flow because the suppressor grid is (positive, negative) with respect to the cathode.

8. Increasing the value of the feedback capacitor in a phantastron circuit (increases, decreases) rundown time and (increases, decreases) recovery time.

9. The most effective way to control plate rundown time is to change the plate starting potential. (True or False.)

10. When a disconnect diode is used, the plate rundown time is controlled by varying the

____

voltage on the diode.

11. Input triggers must be applied in such a way that the difference in potential between the cathode and suppressor grid is reduced enough to start plate current. (True or False).

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

D. If you wish to do the Laboratory exercise on the phantastron turn to laboratory exercise 62-2 and complete it. This exercise will show you the various waveshapes in the phantastron circuit and the effects of changing the cathode voltage of the disconnect diode. After you have completed the laboratory exercise, return and continue with this program.

E. Turn to Student Text, Volume VIII, and read paragraphs 7-61 through 7-89. Return to this page and answer the following questions on the electron tube series voltage regulator:

1. Decreasing the load resistance, will cause the output voltage of an unregulated power supply to (increase, decrease).

2. Most electronic voltage regulators use a variable resistance in (series, parallel) with the output to provide regulation.

3. The output voltage of a series regulated power supply has increased. To bring this voltage back to the proper value the series resistance must be (increased, decreased).

Use figure 1 for questions 4 thru 9.

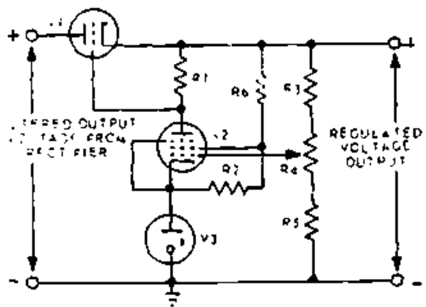


Figure 1

4. Moving the wiper arm on R4 up (increases, decreases) the regulated output voltage.

*5. When the load (current) is increased, the current through V1 (increases, decreases).

*6. If the load decreases, the plate voltage on V2 will (increase, decrease). This will cause the current through V1 to (increase, decrease).

*7. An increase in load resistance will momentarily cause the voltage at the wiper arm of R4 to become (more, less) positive with respect to ground.

*8. When the load resistance increases, the voltage across V1 (increases, decreases).

9. Increasing the gain of V1 or V2 would improve regulation. (True or False).

10. The voltage across V3 is constant. (True or False).

*5-8 are initial changes prior to electronic regulation or recovery.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

F. If you wish to do the laboratory exercise on the series voltage regulator, turn to laboratory exercise 62-3 and complete it. This exercise will show you the effects of changing input voltage, load resistance and the voltage adjust potentiometer. When you have completed the laboratory exercise, return and continue with this program.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

LABORATORY EXERCISE 62-1

THYRATRON SAWTOOTH GENERATOR

OBJECTIVES: Given a thyratron sweep generator trainer, schematic diagram, DC power supply, multimeter, audio signal generator and oscilloscope, identify the effect of:

1. Changing circuit voltages.

2. Changing component values.

3. Applying and changing input trigger frequency.

EQUIPMENT:

1. Thyratron Sweep Generator, Trainer #4665.

2. Oscilloscope, with 10:1 attenuator probe.

3. Multimeter

4. Power Supply, 4912

5. Sine-Square Wave Generator, #4864

REFERENCE: Student Text, Vol VIII, Chapter 7.

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS. FOLLOW THE PROCEDURES CAREFULLY.

PROCEDURES:

1. Analysis of the trainer.

a. The schematic diagram of the thyratron sawtooth generator is located on the faceplate of trainer #4666.

b. The trainer incorporates a switching arrangement, rheostat, potentiometer and various test points for:

(1) Inserting and monitoring circuit signals and voltages.

(2) Varying input trigger levels.

(3) Changing RC time constant by

(a) varying resistance.
(b) changing capacitance.

2. Preparation of the equipment:

a. Oscilloscope Controls	Position
(1) Power	ON
(2) Vertical Mode	"A"
(3) Volts/Div	2 Calibrated
(4) Polarity	Normal DC
(5) Trigger Selector	INT. +
(6) Mode	Auto
(7) Horizontal Display	Normal
(8) Time/Div	As Required
(9) Focus and Intensity	Well defined trace

b. Multimeter controls; position multimeter controls as required, to measure circuit voltages.

c. Power Supply Controls	Position
(1) Power	OFF
(2) Neg. V. Adj.	Min(FCCW)
(3) Pos. V. Adj.	Min (FCCW)
(4) Voltmeter	Positive

d. Sine Wave Generator Controls	Position
(1) Squarewave Amplitude	Slightly clockwise
(2) Freq. Multiplier	X 100
(3) Frequency (CPS)	52
(4) Sine wave Range	1 V
(5) Sinewave Amplitude	Mid-Range

e. Trainer Controls	Position
(1) S101	C103
(2) R101	Mid-Range
(3) R104	Mid-Range

f. Trainer to the oscilloscope connections.

(1) Ground oscilloscope to the trainer.

(2) Connect channel A to TP105 using 10:1 attenuator probe.

g.

(1) Connect power supply output on rear panel to trainer by using the prefabricated cable.

(2) Turn the power supply ON.

3. Activity

a. Using the voltmeter on power supply, set B+ with the Positive Volt. Adjust to 250 V. Monitor the negative voltage at TP102 with the multimeter on 50 V range and adjust for -5 V with Neg Voltage Adj on power supply.

b. Measure the output amplitude and frequency at TP105.

Amplitude = ____________ V Pk to Pk. (10:1 probe).

Frequency = ____________kHz.

c. Draw the waveshape present at TP105 and label the ionization and de-ionization points. (Note: adjust the oscilloscope Time/Div control until 2 or 3 cycles are observed).

At what potential is the thyratron ionizing?

____________________________ V

At what potential is the thyratron de-ionizing?

____________________________ V

d. Now adjust the bias voltage at TP102 for -10 V DC. With the Time/Div control adjusted for 2 or 3 cycles, draw the waveshape at TP105 and label the ionizing and de-ionizing points as point A (ionization point) and point B (de-ionization point).

Did linearity increase or decrease? ________

Why? ____________________________

Amplitude (increased/decreased).

Frequency (increased/decreased).

Firing potential (increased/decreased) by

____________________________ V.

What is the control ratio of V101?

____

e. Readjust the bias voltage for -5 V DC. Observe the output waveshape. Now switch S101 to C104 to increase capacitance. How did this increase in capacitance affect the linearity?

f. Increase the value of R104 by turning the control CCW. Then slowly turn R104 CW to decrease the value of R104. Carefully observe the waveshape.

(1) Decreasing R104 (increased/decreased) frequency and

_______________ linearity.

(2) What effect does increasing the bias have on frequency and linearity?

(3) What effect does changing the RC time constant have on frequency and linearity?

(4) When S101 was changed from the C103 position to C104, did the firing potential change?

(5) Did the de-ionization potential change?

(6) Should the deionization potential have changed?

This change is caused by another factor that wasn't considered in the text. When a thyratron deionizes the ions and electrons are moving at tremendous velocities. When the potential is reached where the ionization stops, it takes time for the gas to return to its deionized state. This time is called deionization time and is usually on the order of fifty to several hundred μ sec. Depending on temperature, anode current and grid voltage.

At low frequencies this time is insignificant in relation to the capacitor discharge time, but at higher frequencies it becomes noticeable.

It is obvious from the lab exercise that if the capacitor is discharging faster, it will discharge to a LOWER VOLTAGE during this deionization time.

g. Turn S101 to C105. Verify that frequency has decreased, but linearity did not change.

h. Turn S101 to C103 position. Adjust the Time/Div control to .1 mSEC calibrated. Adjust R104 until each sawtooth is electrically 2 cm long. The output frequency

is _______________ Hz.
Turn R101 fully CCW and connect the sine wave output of the signal generator to TP101. Ground the signal generator to the trainer and using B channel on the oscilloscope, adjust the signal at TP101 for 2 V Pk to Pk. Adjust the sinewave generator for 5.2 kHz. Now, using the alternate mode on the oscilloscope, observe both input and output waveshapes. Turn R101 clockwise until the jitter stops. Now vary the sine wave frequency slightly higher and lower.

With the trigger signal applied, what is the relationship between trigger frequency and output frequency?

Adjust the trigger frequency to 10.2 kHz.

Are the waveshapes synchronized? _______________

What is the relationship between input and output frequency?

i. Using the information just gained in this exercise, answer the following questions:

(1) Increasing negative grid bias, ______________________ the firing potential.

(2) Increasing the RC time constant, ______________________ frequency.

(3) Decreasing the RC time constant, ______________________ linearity.

(4) Decreasing negative grid bias, ______________________ frequency.

(5) Decreasing negative grid bias, ______________________ linearity.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

LABORATORY EXERCISE 62-2

OBJECTIVES:

1. Given a phantastron trainer, power supply, schematic diagram and oscilloscope, identify signal characteristics within the phantastron circuit.

2. Given a phantastron trainer, power supply, schematic diagram and oscilloscope, calculate delay time and identify the effect of changing pulse width potentiometer.

EQUIPMENT:

1. Phantastron Trainer, #4687
2. Power Supply, #4912.
3. Oscilloscope.

REFERENCE: Student Text, Volume VIII, Chapter 7.

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS. FOLLOW THE PROCEDURES CAREFULLY.

PROCEDURES:

1. Analysis of the trainer.

a. The schematic diagram of a phantastron circuit is located on the face-plate of trainer #4687.

b. A variable resistor (R103) is incorporated in the trainer to permit variations of output pulse width (PW).

2. Preparation of the equipment.

a. Oscilloscope Controls	Position
(1) Power	ON
(2) Vertical Mode	Chopped
(3) Volts/Div	A and B = 20 V
(4) Polarity	A and B channel AC Norm.
(5) HORZ. Display	Norm.
(6) Time/Div	2 m SEC
(7) Trigger selector	Ext +
(8) Trigger Mode	Auto
(9) Focus and Intensity	Well Defined Trace

b. Power Supply Controls

Power Supply Controls	Position
(1) Power	OFF
(2) Pos. V. Adj.	Min. (FCCW)
(3) Neg. V. Adj.	Min. (FCCW)
(4) Voltmeter	Positive

c. On trainer adjust R103 for maximum resistance (FCW).

d. Oscilloscope to trainer connections:

(1) Ground oscilloscope to trainer.

(2) Connect A channel vertical input to TP104.

(3) Connect B channel vertical input to TP107.

(4) Connect trigger input to TP106.

e. Connect the power supply output to trainer using a prefabricated cable (NOTE: Output connector is on rear panel of power supply).

f. Turn the power supply ON.

3. Activity

a. Using the voltmeter on power supply, adjust the positive voltage to 150 V using Pos. Volt Adjust.

b. Draw the waveshape present at TP104 and label:

(1) Jump voltage.

(2) Plate rundown.

(3) Recovery time.

c. Change polarity on oscilloscope to DC NORM. Note the peak plate voltage. Now turn R103 on the trainer counter-clockwise.

(1) The peak plate voltage (increased, decreased).

(2) Jump voltage ____ ________

(3) Rundown time (increased, decreased).

(4) Why did the peak plate voltage on V102 change when the value of R103 was decreased?

(5) Why did plate rundown time change?

d. Using B channel monitor the signal at TP101 and note that the trigger and jump voltage occur at the same time.

e. Using B channel, monitor the signal at TP106.

(1) Does the positive transition on the screen grid occur at the same time as the jump on the plate? Why?

____

(2) Does the positive transition on the screen grid occur at the same time as the negative input trigger? Why?

(3) Does the time of the positive screen grid transition vary as R103 is varied? Why?

(4) Does the time of the negative screen grid transition vary as R103 is varied? Why?

f. Monitor the signal at TP101 on "A" channel and TP107 on "B" channel. Note that the input trigger occurs simultaneously with the positive output trigger.

(1) Measure the time delay between the negative input trigger and the negative output trigger.

NOTE: Be sure R103 is fully clockwise.

Time delay = ________________ mSEC.

(2) Decreasing the value of R103 (increases, decreases) delay time.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

LABORATORY EXERCISE 62-3

SERIES VOLTAGE REGULATOR

OBJECTIVES: Given a power supply voltage regulator trainer, multimeter, and schematic diagram, identify the effects of changing the:

1. input voltage.
2. load resistance.
3. potentiometer position.

EQUIPMENT:

1. Power Supply Voltage Regulator Trainer, #4871
2. Multimeter

REFERENCE: Student Text, Volume VIII, Chapter 7.

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS. FOLLOW THE PROCEDURES CAREFULLY.

PROCEDURES:

1. Analysis of the trainer.

a. A schematic diagram of the power supply voltage regulator trainer is shown in figure 1-1.

b. Switching arrangements, variable resistors and test points are incorporated in the trainer for:

(1) Inserting and removing regulator circuitry.

(2) varying load resistance.

(3) adjusting output voltage.

(4) monitoring circuit voltages.

2. Preparation of the equipment.

a.

Trainer Controls	Position
(1) Off/On Switch	ON
(2) Rectifier	Half Wave
(3) Regulator	Unregulated
(4) Voltage	Mid-Range
(5) Load Adjust	Max. Resistance (FCCW)

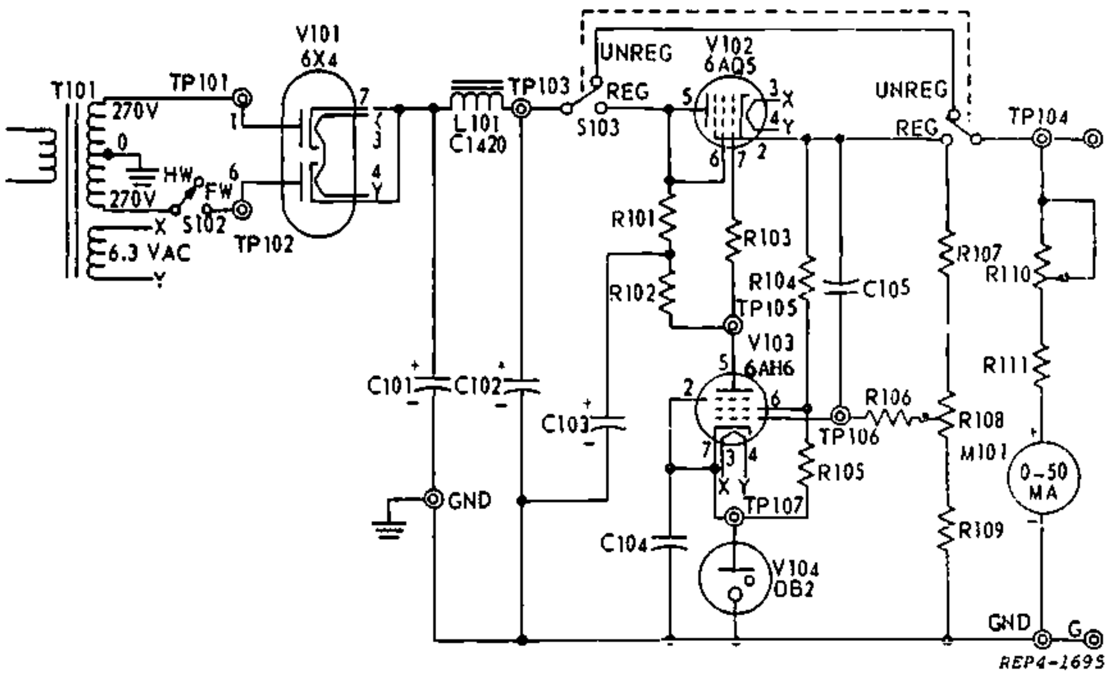


Figure 1-1. Power Supply Voltage Regulator Trainer

b. Multimeter Controls — Position

(1) Function — DCV (20 k/v)

(2) Range — 500 V/DC

3. Activity

a. (1) Adjust the load adjust for maximum output current. Record the output voltage (TP104 to ground).

Output voltage = ____________ V DC

(2) Adjust the load adj. for min load, and record the output voltage.

Output Voltage = ____________ V DC

(3) Without regulation, the power supply output voltage varies from

____________ V DC to

____________ V DC.

This is a variation of ____________ V.

(4) Switch "Rectifier Switch" from HW to FW. Output voltage variation without a load is approximately ____________ V.

b. Flip the regulation switch to the regulated position and adjust the output voltage to 200 V DC with the voltage adjust potentiometer. Using the procedures in step 3a(1) and 3a(2) adjust the load adjust between the maximum extremes. The output voltage variation with regulation is approximately ________ V.

c. With the load adjusted for 15 mA at 200 V, measure the input to the regulator (TP103) in both HW and FW configurations.

Input voltage to the regulator changes

____________ V.

d. To this point we have observed that changes in load or input voltage have negligible affect on the output voltage of a voltage regulator circuit.

To determine why this happens we will first measure the voltages under a given set of of conditions. Then we will change the load and determine the effect on these voltages.

(1) Insure that the output voltage is 200 V, load current is 15mA, and rectifier switch is in FW, then measure the voltages at the following test points.

(a) TP107 = __________ V DC

(b) TP106 = __________ V DC

(c) TP105 = __________ V DC

(d) TP104 = __________ V DC

(e) TP103 = __________ V DC

(f) TP104 (neg) to TP103 (pos) =

__________ V DC

(2) Adjust the load to 20 mA. Remeasure the voltages.

(a) TP107 = __________ V DC

(b) TP106 = __________ V DC

(c) TP105 = __________ V DC

(d) TP104 = __________ V DC

(e) TP103 = __________ V DC

(f) TP104 (neg) to TP103 (pos) =

__________ V DC

(3) Analysis of the values obtained in steps 3d(1) and 3d(2) shows that when load or input voltage tries to change, the voltage across the regulator tube V102 simply changes and the output remains fairly constant.

e. Readjust the load to 15 mA at 200 V, and calculate the value of load resistance.

(1) Load Resistance = __________ kΩ.

(2) If we increase the load current 1 mA without changing the load resistance the output voltage will (increase, decrease)

by __________ V.

(3) Adjust the voltage adjust until output current increases 1 mA (DO NOT change load adj.). Verify that the output voltage changed in accordance with step 3e(3).

(4) With the load current at 16 mA and load voltage at 213.3 V, measure the following test point voltages and compare them with the values obtained in step 3d(1).

(a) TP107 = __________ V DC

(b) TP106 = __________ V DC

(c) TP105 = __________ V DC

(d) TP104 = __________ V DC

(e) TP103 = __________ V DC

(f) TP104 (neg) to TP103 (pos) =

__________ V DC

(5) You should have noticed that the extremely small changes in voltage on the grid of V103 (TP106) have a tremendous affect on the current through V102. Obviously, the gain in the control circuitry determines the degree of regulation

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

MODULE SELF-CHECK

QUESTIONS

1. Increasing the voltage on the grid of V1 will:

a. Increase output amplitude and linearity.

b. Increase output amplitude and decrease linearity.

c. Decrease frequency and increase linearity.

d. Increase frequency and increase linearity.

Use figure 1 for questions 1 thru 4.

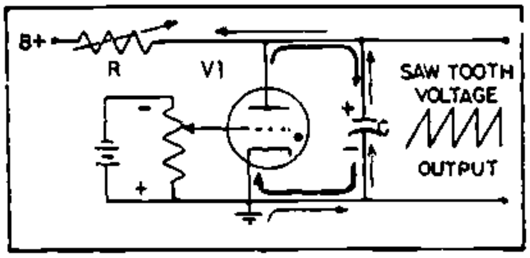


Figure 1

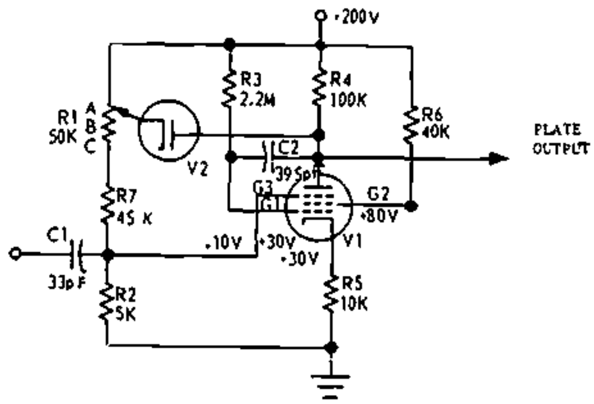


Figure 2

2. Decreasing the voltage on the grid of V1 will:

a. Increase the firing potential of V1.

b. Decrease the deionization potential of V1.

c. Increase the deionization potential of V1.

d. Decrease the firing potential of V1.

3. Increasing the value of R or C will:

a. Increase frequency and decrease linearity.

b. Decrease frequency and decrease linearity.

c. Decrease frequency but not affect linearity.

d. Increase frequency but not affect linearity.

4. In a synchronized thyratron sawtooth generator, increasing the trigger frequency:

a. Decrease output frequency.

b. Increases output amplitude.

c. Increases output frequency.

d. Decreases output linearity.

Use figure 2 for questions 5 thru 8.

5. Moving the wiper arm on R1 toward point A will:

a. Increase pulse width and decrease output frequency.

b. Increase pulse width and not affect output frequency.

c. Decrease pulse width and decrease output frequency.

d. Increase pulse width and increase output frequency.

6. Decreasing the value of R3 would:

a. Increase rundown time and decrease recovery time.

b. Decrease rundown time and increase recovery time.

c. Decrease rundown time and not affect recovery time.

d. Increase rundown time and not affect recovery time.

7. Increasing the value of C2 would:

a. Increase rundown and recovery time.

b. Decrease rundown and recovery time.

c. Increase rundown time and decrease recovery time.

d. Decrease rundown time and increase recovery time.

8. Increasing the input trigger frequency:

a. Increases output frequency and decreases pulse width.

b. Decreases output frequency and increases pulse width.

c. Decreases output frequency but does not affect pulse width.

d. Increases output frequency but does not affect pulse width.

Use figure 3 for questions 9 thru 11.

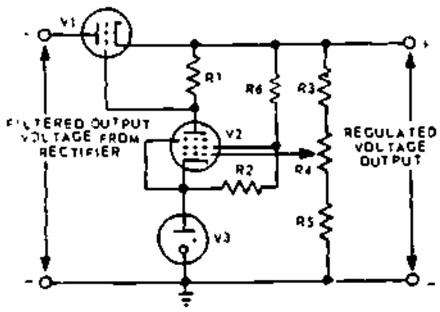


Figure 3

9. If the voltage from the rectifier increases:

a. The output voltage of the regulator decreases.

b. The voltage drop across V1 increases.

c. The voltage drop across V1 remains the same.

d. The voltage drop across V1 decreases.

10. Increasing the load resistance causes the:

a. Current through V2 to increase and current through V1 to decrease.

b. Current through V2 to decrease and current through V1 to increase.

c. Current through V1 and V2 to increase.

d. Voltage at the wiper arm of R4 to go less positive with respect to ground.

11. Moving the wiper arm on R4 down:

a. Increases plate current of V1 and increases output voltage.

b. Decreases plate current of V1 and decreases output voltage.

c. Does not affect V1 plate current or output voltage.

d. Decreases plate current of V1 and increases output voltage.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

ANSWERS TO A - ADJUNCT GUIDE

1. capacitor, charging, discharging
2. small
3. high
4. discharges
5. deionization
6. increases
7. decreases, increases
8. decreases, larger
9. false
10. decrease, not affect
11. increases, increases
12. lower
13. unstable (or erratic)

If you missed ANY questions, review the material before you continue.

ANSWERS TO E - ADJUNCT GUIDE

1. decrease
2. series
3. increased
4. decreases
5. increases
6. decrease, decrease
7. more
8. decreases
9. true
10. true

If you missed ANY questions, review the material before you continue.

ANSWERS TO C- ADJUNCT GUIDE

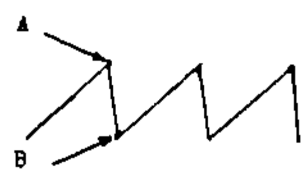
1. stage gain
2. 2.1 pF
3. decreases
4. plate load resistor.
5. long
6. triggers
7. negative
8. increases, increases
9. true
10. cathode
11. true

If you missed ANY questions, review the material before you continue.

ANSWERS TO LAB EXERCISE 62-1.

3b. Amplitude = 40 V Pk - Pk
Frequency = 4.5 kHz

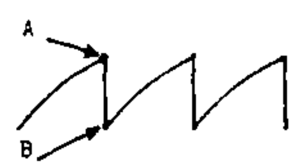
3c.



A = Ionization point = 64 volts

B. = Deionization point = 20 volts

3d.



A. Ionization point

B. Deionization point

Linearity decreased because the increase in bias increased the firing potential. This allowed C103 to charge to a higher voltage, thus, a greater portion of the capacitor charge curve was used.

Amplitude increased
Frequency decreased
Firing (ionization) potential increased by approximately 50 volts
Control Ratio 10:1

3e. The change in capacitance caused an increase in linearity

3f.

(1) Decreasing R104 increased frequency and did not affect linearity.
(2) Increasing bias decreases frequency and linearity.
(3) Changing the RC time constant changes frequency but does not affect linearity.
(4) Changing from C103 to C104 did not change the firing potential.
(5) The deionization potential changed.
(6) No. An explanation on why the deionization potential appeared to change is contained in the Laboratory project.

3h. The output frequency is 5 kHz.

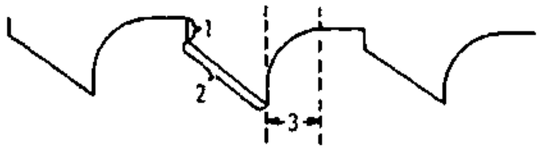
With the trigger signal applied the output frequency is exactly the same as the input frequency.
The waveshapes are also synchronized when the input trigger frequency is 10.2 kHz.
The relationship between input and output frequency is 2:1.

3i. (1) Increasing negative grid bias increases the firing potential.
(2) Increasing the RC time constant decreases frequency.
(3) Decreasing the RC time constant does not affect linearity.
(4) Decreasing neg. grid bias increases frequency.
(5) Decreasing neg. grid bias improves linearity.

RETURN TO THE RESOURCE FROM WHICH YOU CAME AND CONTINUE WITH THAT PROGRAM. YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

ANSWERS TO LAB EXERCISE 62-2.

3b



(1) Jump voltage.
(2) Plate rundown.
(3) Recovery time.

3c (1) decreased.
(2) did not change.
(3) decreased.
(4) The plate voltage on V102 can be only slightly positive with respect to the cathode of V101. Decreasing the value of R103 decreased the cathode potential on V101, thus, limited the plate of V102 to this lower value.
(5) With a lower starting voltage on the plate, it takes less time to reach the potential where V102 goes into cut off.

3e(1) Yes. The positive transition on the screen grid occurs at the same time as the jump on the plate because screen grid current decreases.

(2) YES. The positive screen grid transition occurs simultaneously with the negative input trigger because the circuit is triggered into pulse width (rundown time).
(3) NO. The positive screen grid transition does not vary as R103 is varied since R103 controls delay time.

(4) YES. The time of the negative screen grid transition varies as R103 is varied since R103 controls delay time.

3f (1) Time delay = 5.3 mSEC
(2) Decreasing the value of R103 delay time.

RETURN TO THE RESOURCE FROM WHICH YOU CAME AND CONTINUE WITH THAT PROGRAM.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

ANSWERS TO LAB EXERCISE 62-3:

3a(1) Output Voltage = 330 V DC

3a(2) Output Voltage = 300 V DC

3a(3) Without regulation the power supply output voltage varies from 330 V DC to 300 V DC, this is a variation of 30V.

3a(4) Output voltage variation = 25 V.

3b The output voltage variation with regulation is approximately 1 V.

3c Input voltage to the regulator changes 18 V.

3d(1) (a) TP107 = 109 DC
(b) TP106 = 107.5 V DC
(c) TP105 = 190 V DC
(d) TP104 = 200 V DC
(e) TP103 = 359 V DC
(f) TP104 (neg) to TP103 (pos) = 158 V DC

3d(2) (a) TP107 = 109 V DC
(b) TP106 = 107.2 DC
(c) TP105 = 191 V DC
(d) TP104 = 200 V DC
(e) TP103 = 350 V DC
(f) TP104 (neg) to TP103 (pos) = 150 V DC

3e(1) Load resistance = 13.33 kΩ

3e(2) Increasing load current 1 mA without changing load resistance increases output voltage 13.3 V.

3e(4) (a) TP107 = 109 V DC
(b) TP106 = 107 V DC
(c) TP105 = 204 V DC
(d) TP104 = 213.4 V DC
(e) TP103 = 356 V DC
(f) TP104 (neg) to TP103 (pos) = 143 V DC

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

ANSWERS TO MODULE SELF-CHECK:

1. b
2. d
3. c
4. c
5. b
6. c
7. a
8. d
9. b
10. a
11. a

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.