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TITLE Military Curriculum Materials for Vocational and Technical Education. Aircraft Electrical Repairman Technician, 2-2.

INSTITUTION Ohio State Univ., Columbus. National Center for Research in Vocational Education.

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DESCRIPTORS Alarm Systems; *Aviation Technology; Behavioral Objectives; Electrical Occupations; *Electrical Systems; *Electric Circuits; *Electronic Equipment; *Electronic Technicians; Equipment Maintenance; Equipment Utilization; Instructional Materials; Learning Modules; Military Personnel; Military Training; Postsecondary Education; Secondary Education; Study Guides; Systems Analysis; *Technical Education; Workbooks

IDENTIFIERS Military Curriculum Project

ABSTRACT

These military-developed curriculum materials consist of a volume of text information; a student workbook containing objectives, reading assignments, chapter review exercises, and answers; a volume review exercise; and two illustration booklets for use with the student exercises. Covered in the course are the following topics: use and maintenance of electronic testing equipment, analyzing complex direct current (DC) circuits, reactors in circuit relationships, diagnosing malfunctions in a multi-generator DC power system, multi-generator alternating current (AC) system problems, and analyzing control and warning system problems. Designed for student self-study and evaluation in a shop or on-the-job learning situation, the course can be implemented as it is or used as supplemental material in both aircraft maintenance courses and advanced electrical application courses. (MN)

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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.

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Military Curriculum Materials
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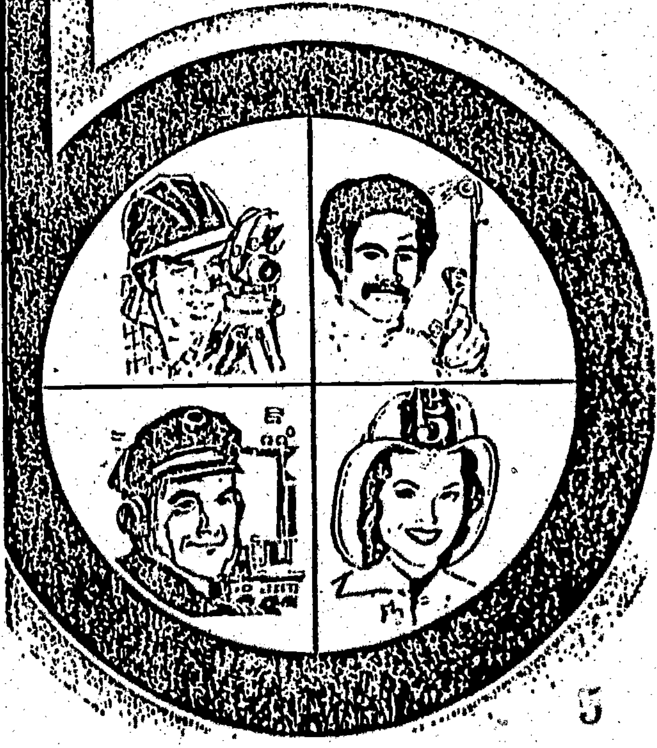
Military Curriculum Materials for Vocational and Technical Education

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

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

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

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

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

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

AIRCRAFT ELECTRICAL REPAIR TECHNICIAN

Table of Contents

AIRCRAFT ELECTRICAL REPAIR TECHNICIAN

Correspondence Course

2-2

Developed by:

United States Air Force

Development and Review Dates:

November 1975

Occupational Area:

Aviation

Cost: $4.00

Print Pages: 192

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

Suggested Background:

Basic electricity/electronics, successful completion of *Aircraft Electrical Repairman,* (2-1)

Target Audiences:

Grades 10-adult

Organization of Materials:

Student workbook with objectives, assignments, review exercises and answers, volume review exercises; text; illustrations

Type of Instruction:

Individualized, self-paced

Type of Materials:			No. of Pages:	Average Completion Time:
Aircraft Electrical Repair Technician				
Chapter 5	—	Use and Maintenance of Electronic Test Equipment	11	Flexible
Chapter 6	—	Analyzing Complex DC Circuits	13	Flexible
Chapter 7	—	Reactors in Circuit Relationships	7	Flexible
Chapter 8	—	Diagnosing Malfunctions in a Multi-Generator DC Power System	10	Flexible
Chapter 9	—	Multi-Generator AC Power System Problems	15	Flexible
Chapter 10	—	Analyzing Control and Warning System Problems	15	Flexible
Workbook			66	
Illustrations, Foldouts 1-16			19	
Illustrations, Figures 1-83			41	

Supplementary Materials Required:

None

Course Description:

This is the second course of a two-course series designed to upgrade an Aircraft Electrical Specialist (skilled) worker to an Aircraft Electrical Technician (advanced) level. It contains advanced information on trouble analysis, supervising, and problem solving of aircraft electrical systems. Course prerequisites are basic electricity/electronics and the *Aircraft Electrical Repairman,* 2-1, course.

This course contains one volume covering six chapters. An additional four chapters on careers, supervision, and shop equipment were deleted because of references to specific military organization and equipment.

Chapter 5 — *Use and Maintenance of Electronic Test Equipment* contains information on resistance, current, voltage measuring equipment, and special aircraft power systems test equipment.

Chapter 6 — *Analyzing Complex DC Circuits* covers magnetic circuits, analyzing conduction and complex DC circuits.

Chapter 7 — *Reactors in Circuit Relationships* discusses reactance and frequency in circuits and circuit application of reactors.

Chapter 8 — *Diagnosing Malfunctions in a Multi-Generator DC Power System* contains information on generator systems and component operation, power distribution systems, and systems analysis.

Chapter 9 — *Multi-Generator AC Power System Problems* covers AC generator system descriptions, generator system components and circuit operation, power distribution systems and system malfunctions.

Chapter 10 — *Analyzing Control and Warning System Problems* discusses fire warning systems, master caution circuits, fuel system circuits, nose wheel steering circuits, and logical troubleshooting.

This course contains one volume of text material; a student workbook containing objectives, reading assignments, chapter review exercises and answers; a volume review exercise; and two illustration booklets for use with the student exercises. The course was designed for student self-study and evaluation in a shop or on-the-job learning situation. It can be implemented as is or used as supplemental material in both aircraft maintenance courses and advanced electrical application courses.

CENTER FOR VOCATIONAL EDUCATION
THE OHIO STATE UNIVERSITY

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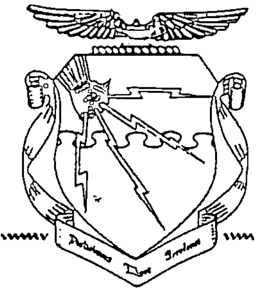
CDC 42370

AIRCRAFT ELECTRICAL REPAIR TECHNICIAN

(AFSC 42370)

Volume 1



Extension Course Institute 2-2

Air University

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DEPARTMENT OF THE AIR FORCE

UNITED STATES OF AMERICA

PREPARED BY CHANUTE AIR FORCE BASE, ILLINOIS, AIR TRAINING COMMAND

EXTENSION COURSE INSTITUTE, GUNTER AIR FORCE BASE, ALABAMA

THIS PUBLICATION HAS BEEN REVIEWED AND APPROVED BY COMPETENT PERSONNEL OF THE PREPARING COMMAND IN ACCORDANCE WITH CURRENT DIRECTIVES ON DOCTRINE, POLICY, ESSENTIALITY, PROPRIETY, AND QUALITY

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PREPARED BY CHANUTE AIR FORCE BASE, ILLINOIS, AIR TRAINING COMMAND

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Preface

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THE FIRST five chapters of this volume deal with the supervision and management of an electrical maintenance activity. Chapter 1 covers the specialty description for the aircraft electrical repair technician and discusses your duties and responsibilities as defined in AFM 39-1. The chapter also presents your responsibilities under the USAF Safety Program and provides a review of communications security.

Chapter 2 gives you the information you need to operate an electric shop-a typical shop organization, the levels and types of maintenance, how to establish bench stocks, acquire tools and equipment, and set up and maintain a technical order file.

Chapter 3 gives 7-level knowledges related to supervision and training in a maintenance environment. The discussion of supervision relates to the new worker, personnel relations in supervision, and how to improve work methods. The chapter also covers airman performance reports, the ATC graduate evaluation program, and training.

Chapters 4 and 5 deal with the operation, maintenance, and malfunctions of shop and electric test equipment and with the responsibility for the calibration and adjustment of such equipment. In addition, these chapters cover the use of resistance-, current-, and voltage-measuring equipment, discuss special test equipment, and provide information on the use of logic trees on modern-day aircraft.

Chapters 6 through 10 deal with the analysis of electrical and electronic control systems. They present a brief review and then an expansion on electrical principles, coupled with a general study of electrical/electronic systems for which you as a technician may be responsible. Chapters 6 and 7 are a review of dc and ac principles. Chapter 8 covers the operation and maintenance of a multi-generator dc power system. Chapter 9 is an in-depth look at a transistorized ac power system. It also includes the operation and maintenance of the system. Chapter 10 provides a detailed explanation of four of the most troublesome warning systems and explains the operating characteristics and maintenance of these systems. In this chapter you will also study logical troubleshooting procedures.

As you study the chapters that relate to systems, keep in mind that the discussion is general. The aircraft which you are presently assigned to maintain may be somewhat different, but the principles of operation are basically the same.

The 83 illustrations (figures 1-83) and the 16 schematic foldouts (numbered 1-16) are bound separately in two books of illustrations, one for illustrations and one for foldouts. When the text makes reference to a figure or a foldout, turn to the appropriate supplement and locate the referenced visual aid. Code numbers appearing in the lower right-hand corner of figures are for preparing agency use only.

If you have questions on the accuracy or currency of the subject matter of this text, or recommendations for its improvement, send them to Tech Tng Cen (TSOC), Chanute AFB IL 61866.

If you have questions concerning course enrollment or administration, or any of ECI's instructional aids (Your Key to Career Development, Study Reference Guides, Chapter Review Exercises, Volume Review Exercise, and Course Examination), consult your education officer, training officer, or NCO, as appropriate. If he cannot answer your questions, send them to ECI, Gunter AFB, Alabama 36114, preferably on ECI Form 17, Student Request for Assistance.

This volume is valued at 66 hours (22 points).

Material in this volume is technically accurate, adequate, and current as of November 1975.

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LIST OF CHANGES

COURSE 42370	CAREER FIELDS, POLICIES, PROCEDURES AND EQUIPMENT CHANGE. ALSO ERRORS OCCASIONALLY GET INTO PRINT. THE FOLLOWING ITEMS UPDATE AND CORRECT YOUR COURSE MATERIALS. PLEASE MAKE THE INDICATED CHANGES.
EFFECTIVE DATE OF SHIPPING LIST 30 Apr 76	

NOTE TO STUDENT: Save 42370 01 I01 0570 and 42370 01 I02 0570 as you will need these when you take the Course Examination.

l. Page 30, para 9-5, line 12: Change "CR32" to "CR23."

m. Page 35, para 10-8, line 18: Change "374" to "375."

n. Page 53, col 1, line 15: Change "36.2" to "38.8." Line 19: Change "36.2" to "38.8." Line 20: Change "1.74" to "1.87." Line 22: Change "1.74" to "1.87." Line 23. Change "7.66" to "7.53." Col 2, line 4: Change "7.66" to "7.53." Line 5: Change "38.3" to "37.7." Line 7: Change "1.74" to "1.87." Line 8: Change "34.8" to "37.4." Line 10: Change "38.3" to "37.7" and "34.8" to "37.4."

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LIST OF CHANGES

COURSE NO
42370

EFFECTIVE DATE OF SHIPPING LIST
30 Apr 76

CAREER FIELDS, POLICIES, PROCEDURES AND EQUIPMENT CHANGE. ALSO ERRORS OCCASIONALLY GET INTO PRINT. THE FOLLOWING ITEMS UPDATE AND CORRECT YOUR COURSE MATERIALS. PLEASE MAKE THE INDICATED CHANGES.

1. CHANGES FOR THE TEXT: VOLUME 1 (Continued)

n. (Continued) Page 53, col 2, line 16: Change "38.3" to "37.7" and "34.8" to "37.4." Line 17: Change "3.5" to ".3." Line 20: Change "$\frac{3.5}{1}$" to "$\frac{.3}{1}$." Line 21: Change "3.5" to ".3."

o. Page 59, para 15-10, line 1: Change "technician" to "repairman."

p. Page 101, Bibliography, AFR 205-1: Change title from "Safeguarding Classified Information" to "Information Security Program" dated "1 Feb 1973." AFM 39-62: Change date to "1 May 1974."

2. CHANGES FOR THE SUPPLEMENT: 42370 01 I01 0570, VOLUME 1, FIGURES 1-83

a. Eliminate the "Note" below Figures 15, 16, 17, 18 and 19.

b. Page 16, Fig 22: Install a switch symbol in the series circuit of the meter schematic.

c. Page 18, Fig 25 (A) & (B): Change "100 μ" to "100 μa" and shunting resistor "1.11 Ω" should be "11.1 Ω."

3. CHANGE FOR THE SUPPLEMENT: 42370 01 I02 0570, VOLUME 1, FOLDOUTS 1-16

Eliminate the "Note" below Foldout 2 (left side).

4. CHANGES FOR THE VOLUME WORKBOOK: VOLUME 1

b. Page 22, question 7: Add "not" between "important" and "to."

c. Page 52, Chapter Review Exercises, question 72: Delete.

d. Page 53, Chapter Review Exercises, questions 73 and 74: Delete.

e. Page 71, Chapter Review Exercises, answer 37: Change "E_1 = -99.8" to "E_1 = -9.98."

f. Page 79, Chapter Review Exercises, answers 72, 73 and 74: Delete.

g. Question 123 is no longer scored and need not be answered.

NOTE: Change the currency date to "November 1975."

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MODIFICATIONS

Pages 1 — 33 of this publication has (have) been deleted in adapting this material for inclusion in the "Trial Implementation of a Model System to Provide Military Curriculum Materials for Use in Vocational and Technical Education." Deleted material involves extensive use of military forms, procedures, systems, etc. and was not considered appropriate for use in vocational and technical education.

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CHAPTER 5

USE AND MAINTENANCE OF ELECTRONIC TEST EQUIPMENT

AS AN electrical technician you will be called upon to put new equipment into operation, to perform preventive or scheduled maintenance, and to repair equipment. Many types of test equipment are available to help you perform these jobs efficiently.

2. You must have a good understanding of the function, design, and operation of your test equipment in order to interpret the information given. Your knowledge of testing techniques will lighten your workload as well as add to your ability as a technician.

3. In this chapter we will very briefly review and then expand upon the operating principles of resistance, current, and voltage-measuring equipment. Also, to be discussed later in this chapter is special aircraft power systems test equipment.

10. Resistance, Current, and Voltage-Measuring Equipment

10-1. Measuring instruments are tools which make use of magnetism and electromagnetism to provide essential information about electrical circuits. Several types of instruments are designed for use in direct-current circuits, and others for use in alternating-current circuits. The power consumption of any electrical measuring device should be small in comparison with the power available in the circuit under test. The following paragraphs contain information on the construction and application of the types of equipment generally used for test purposes.

10-2. *Resistance-Measuring Devices.* The three types of resistance-measuring devices to be discussed are the ohmmeter, megger, and Wheatstone bridge. To use these instruments effectively you must be acquainted with the calibration of the meter scales, especially on the higher ranges, because it is not often possible to obtain accuracy on the maximum scale range of the meter. An ohmmeter used in field testing should be portable, convenient, and simple to operate. These factors are generally more important then extreme accuracy. The information in the following paragraphs will help you select the measuring device that best meets the needs of your job.

10-3. *Ohmmeter.* The ohmmeter is a device that uses a current-actuated meter and a fixed source of voltage for the measurement of resistance values. It is used for practical work where simplicity, portability, and ease of operation are more important than a high degree of precision. Ohmmeters may be of the series or shunt type. The first type of ohmmeter to be discussed will be the series type.

10-4. a. Series type ohmmeter. A simplified schematic of an ohmmeter is shown in figure 20. As you can see from the schematic, E is a source of emf, R1 is a variable resistor used to zero the meter, (M), and R2 is a fixed resistor used to limit the current in the meter movement. Points A and B are test terminals.

10-5. If A and B are connected together (short circuited), the meter, the battery, and resistors R1 and R2 form a series circuit. With R1 set so that the total resistance in the circuit is 4500 ohms, the current through the meter is 1 ma, and the needle deflects full scale. Since there is no resistance between A and B, this position of the needle is labeled zero. If a resistance equal to 4500 ohms is placed between terminals A and B, the total resistance is 9000 ohms, and the current is .5 ma. This action will cause the needle to deflect to half-scale. This half-scale reading is labeled 4500 ohms. This means that the half-scale reading is equal to the internal resistance of the meter.

10-6. If a resistance of 9000 ohms is placed between terminals A and B, the needle deflects one-third scale. The left side of the scale is, therefore, labeled infinity to indicate an infinite resistance. Resistances of 13.5-K and 1.5-K ohms placed between terminals A and B will cause a deflection of one-fourth and three-fourths of the scale, respectively.

10-7. To enable the meter to indicate any value being measured with the least error, scale multiplication features are incorporated in most ohmmeters. For example, a typical meter will have four test lead jacks marked as follows: Common, RX1, RX10, and RX100. The common jack is connected internally through the battery to one side of the moving coil of the ohmmeter. This is shown in figure 21. The jacks RX1, RX10, and RX100 are connected and labeled to show the three different size resistors located within the ohmmeter. Although the resistors are labeled in figure 21, on a meter the jacks are individually labeled.

10-8. Some ohmmeters are equipped with a selector switch for selecting the multiplication scale desired. In this way only two test lead jacks are necessary. Other meters have a separate jack for each range, as shown. The range to be used for measuring any particular unknown resistance, RX, depends upon the approximate ohmic value of the unknown resistance. For example, assume that the ohmmeter scale shown in figure 21 is calibrated in divisions from 0 to 1,000. If RX is greater than 1,000 ohms, and the RX1 range is being used, it cannot be measured by the ohmmeter. This occurs because the combined series resistance of resistor RX1 and RX is too great to allow sufficient battery current to flow to deflect the pointer away from infinity ∞. The test lead will have to be placed into the next range, RX10. Next, assume that the pointer deflects to indicate 375 ohms. This will indicate that RX has 374 x 10, or 3,750 ohms resistance. The change of range caused the deflection because resistor RX10 has only one-tenth the resistance of resistor RX1. Selecting the smaller series resistance permits enough battery current to flow to cause a notable pointer deflection. If the RX100 range were used to measure the same 3,750-ohm resistor, the pointer will deflect still further to the 37.5-ohm position. This increased deflection will occur because resistor RX100 has only one-tenth the resistance of resistor RX10. Some ohmmeters have a special scale called a low-ohm scale for reading low resistances. A shunt type ohmmeter circuit is used for this scale.

10-9. b. Shunt type ohmmeter. Shunt type ohmmeters are used to measure small values of resistance. In the schematic circuit shown in figure 22, E is applied across a limiting resistor R, and a meter movement in series. Resistance and battery values are chosen so that the meter movement deflects full scale when terminals A and B are open. When the terminals are short circuited, the meter shows zero. The unknown resistance, RX, is placed between terminals A and B. This is in parallel with the meter movement. The smaller the resistance value measured, the less the current flow through the meter movement. The scale of a shunt type ohmmeter is, therefore, a direct scale; that is, values increase from left to right.

10-10. The value of the limiting resistor, R, is usually made large compared to the resistance of the meter movement. Thus, the value of RX determines how much of this constant current flows through the meter and how much flows through RX. Note that in a shunt type ohmmeter current constantly flows from the battery through the meter movement and the limiting resistor. Therefore, when using an ohmmeter with a low-ohm scale, DO NOT leave the switch in the low-ohm position.

10-11. Ohmmeter applications include resistance measurements, continuity checks, and inductor, capacitor, and transformer tests. A transformer may be tested by checking for opens, shorts, low insulation resistance to ground, or improper continuity within the transformer windings. Also, capacitors may be tested to determine whether they are open or shorted. When an ohmmeter is placed in series with a capacitor, the ballistic kick of the meter, caused by the charging current, is proportional to the capacitance of the capacitor. The deflection obtained can be compared with the deflection of a capacitor of known value.

10-12. As you can see from the operation of the ohmmeter, it cannot be used to make precision measurements of very low or very high values of resistances. Low resistances requiring precision measurement should be measured with a bridge type of instrument. The megger type meter should be used to measure the higher resistances. The megger will be the next measuring device to be discussed.

10-13. *Megger.* When measuring high resistances, ohmmeters are limited because of the higher voltage required to produce readable indications. The higher voltage requirements are overcome by the megohmmeter (megger). A megger is used to measure resistance as high as 100 gigohms. A gigohm is 1 x 10^9 ohms.

10-14. The megger consists of two coils: A and B. These coils are rigidly mounted on a moving system located within a field assembly, as shown in figure 23. In contrast to the movements previously described, there is no restraining spring in the megger. Balance is accomplished by mounting the two coils at right angles to each other so that they will exert opposing forces on the moving system. The pointer will come to rest at a point of equality between the forces. Spring supported, jewel bearings provide a nearly frictionless motion around a C-shaped, soft-iron core. When no current is flowing in either coil, the pointer (which is said to be "floating") may come to rest anywhere along the scale. The voltage source is a hand-driven or motor-driven direct-current generator. Usually, the output is 500 volts, although some ratings are as high as 2500 volts.

10-15. Coil A, called the current coil, is connected in series with a resistance between one side of the generator and the ungrounded line terminal. Coil B, called the potential coil, is connected in series with another resistor across the full output of the generator. When there is nothing connected to the

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output terminals, no current can flow in the current coil (A). If the handcrank is turned under this condition, control is affected solely by the potential coil. It turns until it is aligned at right angles to the pole pieces. The pointer then indicates infinite resistance. When a resistance is connected across the output terminals, current flows in the current coils. The resulting torque turns the potential coil away from the infinite resistance position. This movement stops when there is a balance between the opposing forces. The new position depends upon the resistance connected to the output terminals of the megger. If a very low resistance is connected to the output terminals, the pointer will be pulled toward zero. The current coil is protected against excessive current by the series-connected resistor.

10-16. One of the outstanding features of the megger is the independence of the indications with respect to the speed at which the crank is turned, or the strength of the permanent magnet. This is true because the generator supplies current to both coils so that any change in its output voltage affects the coils in the same proportion. As a result, the pointer moves to the same position when a particular resistance is connected to the output terminals of the megger.

10-17. Before connecting the megger to the equipment to be measured, all power should be disconnected. Because of the small amount of torque and the lack of balance springs in the movement, the megger should be kept in an upright position and placed away from a strong external magnetic field so that the reading will not be affected. The test leads should be connected to the megger and the megger tested for leakage. With the test leads open, the meter should read infinity. When the test leads are short circuited, the meter should read zero.

10-18. Connect the test leads to the device whose insulation resistance is to be checked. Rotate the handcrank until a steady meter reading is indicated. A reading should be taken which should be compared to the proper value of insulation resistance. It is important that the insulation resistance be measured at the same temperature each time an insulation test is made. Why? Because the resistance of insulation drops sharply at high temperatures. For example, the insulation resistance between the stator winding of a certain slow-speed generator and the frame is 100 megohms at 85° F. The insulation resistance of this same equipment falls to only 10 megohms at 140° F.

10-19. We have discussed the application of the ohmmeter which is used for resistance and continuity tests and which has a range of a few megohms. We have also discussed the megger which is used to measure insulation resistance as high as 100 gigohms. For more accurate resistance measurements, the Wheatstone bridge may be used.

10-20. *Wheatstone bridge.* Bridges are one of the most accurate measuring devices used to measure values of resistance. Certain types of bridges are more suitable for the measurement of a specific characteristic of a circuit than are other types of bridge test equipment. The type of bridge to be discussed is the Wheatstone bridge. It is a very accurate instrument for making resistive measurements.

10-21. The circuit shown in figure 24 is that of a Wheatstone bridge. The comparing circuit contains branches A and B, and the provisions for changing the ratios of these branches with respect to each other. In this way, various measuring ranges can be obtained. The measuring circuit also contains two branches. The resistance to be measured is connected to branch X of the bridge measuring circuit. Branch S contains the variable control used to bring the bridge into a balanced condition. A potentiometer is used for this purpose in most bridge equipment because it offers a wide range of smoothly variable current changes within the measuring circuit. The third arm of the bridge is the detector circuit. The detector circuit may use a galvanometer for sensitive measurements requiring high accuracy. In the case of bridges using alternating current as the power source, the galvanometer must be adapted for use in an ac circuit.

10-22. The most unfavorable condition for making a measurement occurs when the resistance to be measured is completely unknown. In this case, the galvanometer cannot be protected by setting the bridge arms for approximate balance. In order to reduce the possibility of damage to the galvanometer, it is necessary to use an adjustable shunt (not shown in figure 24) circuit across the meter terminals. As the bridge is brought closer to the balanced condition, the resistance of the shunt can be increased. When the bridge is in balance, the meter shunt can be removed completely to obtain maximum detector sensitivity.

10-23. Figure 24 shows that the signal voltage in the A and B branches of the bridge will be divided in proportion to the resistance ratios of its component members, Ra and Rb, for the range of values selected. This same signal voltage is impressed across the branches of S and X of the bridge. The variable control, Rs, is rotated to change the current flowing through the S and X branches of the bridge. When the point is reached where the voltage drop across branch S is equal to the voltage drop across branch A, the voltage drop across branch X will be

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equal to the voltage drop across branch B. At this time the potentials across the detector circuit are the same, resulting in an indication of a zero current flow across the detector circuit. The bridge is balanced at these settings of its operating controls. They cannot be placed at any other settings and still maintain this balanced condition.

10-24. One of the most elementary precautions concerning the use of a bridge, when measuring low resistance, is to tighten the binding posts securely. You must do this to keep the contact resistance between the binding posts and the resistance to be measured at a minimum. In those cases where wire leads must be used to reach from the resistance under test to the bridge terminals, measure the ohmic value of the leads prior to measurement of the resistance under test. The resistance of the test leads can then be subtracted from the total resistance shown on the Wheatstone bridge.

10-25. The limitations of the Wheatstone bridge are encountered when very high or very low resistances are measured. This type of bridge circuit generally has a lower measuring limit of 0.1 ohm, and an upper limit of about 0.1 megohm. The accuracy of measurements made with the Wheatstone bridge are independent of the value of the supply voltages. Therefore, the bridge can be supplied by small flashlight batteries which make the unit light and portable.

10-26. This concludes the discussion on resistance-measuring devices. As you know, most of the measuring equipment used by an electrician on the flight line or in the shop will have a D'Arsonval meter movement. The objective of this chapter is to acquaint you with the various meter circuits, limitations, and special operating precautions. Our next discussion will be on current-measuring devices.

10-27. *Measuring Current.* An ammeter is designed to measure current. Therefore, it must be connected in series with the circuit so that all the current passes through it. This also means that, in order to prevent an appreciable decrease in circuit current, the total resistance of the ammeter must be low. In actual practice, it is often necessary to measure currents that are greater than the full current range of a given meter. To permit these measurements, it is necessary to use the laws of parallel circuits and to connect a low resistance conductor in parallel with the meter movement. When used for this purpose, the low resistance conductor is called a shunt, and it becomes part of the meter.

10-28. *Ammeter.* When the ammeter, consisting of a meter and shunt in parallel, is connected in series with the circuit, the current will divide in such a way that the moving coil and the shunt each carry a proportionate amount. Like any parallel circuit, the current in the two paths is proportional to the resistance of the branch. Therefore, by proper selection, a shunt can be found that will carry any desired proportion of the total current. Since this proportion between meter current and shunt current usually remains the same, the meter scale can then be calibrated to indicate the total current with only a portion of this current being carried by the moving coil.

10-29. It is important to select a suitable shunt when using an external shunt ammeter so that the scale indication is easily read. For example, if the scale has 150 divisions, and the load current to be measured is known to be between 50 and 100 amperes, a 150-ampere shunt will be suitable. If the scale deflection is 75 divisions, the load current is 75 amperes when using the same 150-ampere shunt.

10-30. A shunt having the same current rating as the estimated normal load current should never be used. Any abnormally high load would drive the pointer off scale and damage the movement. A good choice of a shunt will bring the needle somewhere near the midscale indication when the load is normal.

10-31. For limited current ranges (below 50 amperes), internal shunts are most often used. In this manner the range of the meter may be easily changed by selecting the correct internal shunt having the necessary current rating. Before the required resistance of the shunt for each range can be calculated, the resistance of the meter movement (Rm) must be known. For example, suppose it is desired to use a 100-microampere D'Arsonval meter (Im) having a resistance of 100 ohms (Rm) to measure line current up to 1 ampere. The meter deflects full scale when the current through the 100-ohm coil is 100 microamperes. Therefore, the voltage drop (Em) across the meter coil is IR:

Im X Rm = Em
0.0001 X 100 = 0.01

10-32. Because the shunt and coil are in parallel, the shunt must also have a voltage drop of 0.01 volt. The current that flows through the shunt is the difference between the full-scale meter current and the line current. In this case, the meter current is 100 x 10^{-6}, or 0.0001 ampere. This current is negligible compared with the line (shunt) current; therefore, the shunt current is approximately 1 ampere. The resistance of the shunt (R_S) is:

$$R_S = \frac{E_S}{I_S} = \frac{0.01}{1} = 0.01 \text{ ohm}$$

2i

and the range of the 100-microampere meter has been increased to 1 ampere by paralleling it with the 0.01-ohm shunt.

10-33. The 100-microampere instrument may also be converted to a 10-ampere meter by the use of a proper shunt. For full-scale deflection of the meter, the voltage drop, E_S, across the shunt (and across the meter) is still at 0.01 volt. The meter current is again considered negligible, and the shunt current is now approximately 10 amperes. The resistance R_S, of the shunt is therefore:

$$R_S = \frac{E_S}{I_S} = \frac{0.01}{10} = 0.001 \text{ ohm}$$

10-34. The same instrument may likewise be converted to a 50-ampere meter by the use of the proper type shunt. The current, I_S, through the shunt is approximately 50 amperes, and the resistance, R_S, of the shunt is:

$$R_S = \frac{E_S}{I_S} = \frac{0.01}{50} = 0.0002 \text{ ohm}$$

10-35. By means of a suitable switching arrangement, various values of the shunt resistance may be used to increase the number of current ranges that may be covered by the meter. Two switching arrangements are shown in figure 25. Figure 25 (A) is the simpler of the two arrangements from the point of view of calculating the value of the shunt resistors when a number of shunts are used. However, it has two disadvantages:

- When the switch is moved from one shunt resistor to another, the shunt is momentarily removed from the meter, and the line current flows through the meter coil. Even a momentary surge of current could easily damage the meter.
- The contact resistance (the resistance between the blades of the switch when they are in contact) is in series with the shunt, but not with the meter coil. In shunts that must pass high currents, the contact resistance becomes an appreciable part of the total shunt resistance. Because the contact resistance is of a variable nature, the ammeter indication may not be accurate.

10-36. A more generally accepted method of range switching is shown in figure 25 (B). Although only two ranges are shown, you can use as many as needed. In this type of circuit, the range selector switch contact resistance is external to the shunt and meter in each range position. Therefore, this contact resistance has no effect on the accuracy of the current measurement.

10-37. *Ammeter connections.* Current-measuring instruments should always be connected in series with a circuit and never in parallel with it. If an ammeter were connected across a constant potential source of appreciable voltage, the shunt would become a short circuit and the meter would burn out. If the approximate value of current in a circuit is not known, it is best to start with the highest range of the ammeter. Then switch to progressively lower ranges until a suitable reading is obtained.

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10-38. Most ammeter needles indicate the magnitude of the current by being deflected from left to right. If the meter is connected with reversed polarity, the needle will be deflected backward, and this action may cause damage to the movement of the meter. Now do you see why you should observe the proper polarity in connecting the meter to the circuit to be measured? The meter should always be connected so that the meter terminals are connected to like polarities in the circuit.

10-39. *Measuring Voltage.* Voltmeters are designed to measure electrical pressure in terms of volts. Therefore, the scale is calibrated directly in terms of volts. The D'Arsonval, or moving-coil, meter may be used in the construction of a voltmeter. However, there are a few things to be considered. In the first place, voltage is a difference in potential between two points. To measure it, the meter must be connected directly across the two points. A second factor that must be considered is that the coil of the meter is moved by the magnetic effect of an electrical current. Because the resistance of the coil is purposely kept low, the current flow must not be allowed to exceed that required for full-scale deflection. Thus, a voltmeter operates because of the current flow through it. The scale of the voltmeter is calibrated to indicate the voltage necessary to cause the current to flow in the coil. It is not calibrated to indicate current flow.

10-40. *Voltmeter.* The 100-microampere D'Arsonval meter used as the basic meter for the ammeter may also be used to measure voltage if a high resistance is placed in series with the moving coil of the meter. For low-range instruments, this resistance is mounted inside the case with the D'Arsonval movement. The resistance consists of resistance wire having a low-temperature coefficient and wound either on spools or card frames. For higher voltage ranges, the series resistance may be connected externally. When this is done, the unit containing the resistance is commonly called a multiplier.

10-41. The value of the necessary series resistance is determined by the current required for full-scale deflection of the meter and by the range of voltage to be measured. Because the current through the meter circuit is directly proportional to the applied voltage, the meter scale can be calibrated directly in volts for a fixed series resistance.

10-42. For example, assume that the basic meter (microammeter) is to be made into a voltmeter with a full-scale reading of 1 volt. The coil resistance of the basic meter is 100 ohms, and 0.0001 ampere (100 microamperes) causes a full-scale deflection. The total resistance, R, of the meter coil and the series resistance is:

$$R = \frac{E}{I}$$

The series resistance (R_S) alone is:

$$R_S = 10{,}000 - 100 = 9{,}900 \text{ ohms}$$

10-43. Multirange voltmeters use one meter movement with the required resistances connected in series with the meter by a convenient switching arrangement. The total circuit resistance for each of three ranges (1, 100, and 1000 volts), beginning with the 1 volt range is:

$$R = \frac{E}{I} = \frac{1}{100\,\mu A} = 0.01 \text{ megohm}$$

$$= \frac{100}{100\,\mu A} = 1 \text{ megohm}$$

$$= \frac{1{,}000}{100\,\mu A} = 10 \text{ megohms}$$

10-44. a. Sensitivity. The sensitivity of a voltmeter is given in ohms per volt (ΩE). It may be determined by dividing the resistance, R_m, of the meter, plus the series resistance, R_S, by the full-scale reading in volts:

$$\text{sensitivity} = \frac{R_m + R_S}{E}$$

This is the same as saying that the sensitivity is equal to the reciprocal of the current in amperes for full-scale deflection:

$$\text{sensitivity} = \frac{\text{ohms}}{\text{volts}} = \frac{1}{\frac{\text{volts}}{\text{ohms}}} = \frac{1}{\text{amperes}}$$

Thus, the sensitivity of a 100-microampere movement is the reciprocal of 0.0001 ampere, or 10,000 ohms per volt.

10-45. The sensitivity can be increased by increasing the strength of the permanent magnet, by using lighter weight materials for the moving element (consistent with the increased number of turns on the coil), and by using sapphire jewel bearings to support the moving coil.

10-46. The accuracy of a meter is generally expressed in percent. For example, a meter that has an accuracy of 1 percent should indicate a value that is within 1 percent of the correct value. That is, if the correct value is 100 units, the meter indication may be anywhere within the range of 99 to 101 units.

10-47. b. Voltmeter connections. Voltage-measuring instruments are connected across (in parallel with) a circuit. If the approximate value of the voltage to be measured is not known, it is best to start with the highest range of the voltmeter and switch progressively to the lower ranges until a suitable reading is obtained.

10-48. In many cases, the voltmeter is not a central zero-indicating instrument (needle centered with no input). Thus, it is necessary to observe the proper polarity when connecting the instrument to the circuit, as is the case in connecting the dc ammeter. When the voltage source is to be measured, place the positive terminal of the voltmeter on the positive terminal of the source and the negative terminal on the negative terminal of the source. In any case, the voltmeter is connected so that electrons will flow into the negative terminal and out of the positive terminal of the meter.

10-49. The function of a voltmeter is to indicate the potential difference between two points in a circuit. When the voltmeter is connected across a circuit, it shunts the circuit. If the voltmeter has low resistance, it will draw an appreciable amount of current. The effective resistance of the circuit will be lowered, and the voltage reading will, consequently, be lowered. When voltage measurements are made in high-resistance circuits, it is necessary to use a high-resistance voltmeter to prevent the shunting action of the meter. The effect is less noticeable in low-resistance circuits, because the shunting effect is less. A meter that is designed to measure voltages without loading the circuit is the vacuum tube voltmeter.

10-50. *Vacuum tube voltmeter.* The vacuum tube voltmeter (VTVM) is an instrument used for measuring ac or dc voltages. It uses one or more vacuum tubes in a special circuit containing a meter. The operating power for the tubes is usually obtained from a built-in power supply working off an ac line; however, batteries can be used. The VTVM is also known as an electronic voltmeter.

10-51. The primary advantage of the VTVM over ordinary meters, is its design to measure voltages without loading the circuit. Normal operating conditions are left more or less undisturbed. since the VTVM draws negligible current from the circuit under test. This is of special advantage in low-power circuits where the conventional voltmeter changes the circuit conditions and produces false readings.

10-52. The VTVM can be used to measure ac voltages over a frequency range extending from 5 to 10 Hertz to several hundred megahertz. The VTVM can also be used to measure low voltages in high-impedance circuits, since the input impedance of the VTVM is usually standardized at 10 megohms. The loading effect is negligible when this impedance is placed in shunt with the circuit under test, and low voltages can be measured with a high degree of accuracy. The conventional meter, having a much lower input impedance on the low-voltage ranges. loads the circuit and produces erroneous readings.

10-53. The basic dc VTVM circuit of figure 26 consists of a triode, a source of plate voltage and grid bias, and a dc milliammeter. The meter is calibrated to show the voltage applied between the grid and cathode of the tube. The negative 5-volt bias on the tube grid establishes the operating point at cutoff, as shown in the grid voltage plate current characteristic curve. No current flows through the tube with a 0 input voltage. and the meter in the plate circuit reads 0. When a voltage is applied to the input terminals, the plate current flows through the circuit, thereby actuating the meter pointer.

10-54. Since the applied voltage, EX, causes the tube to operate along the straight portion of the characteristic curve, the increase in plate current is directly porportional. For example, if a voltage, EX, equal to +2 volts is applied to the voltmeter, the bias on the grid of the tube is reduced to -3 volts, 4 ma of current flows in the plate circuit, and the meter pointer is deflected to indicate 2 volts. This is shown in the figure by the horizontal and vertical dashed lines which intercept the tube characteristic curve at the points indicated. When EX is equal to +4 volts, the grid bias become -1 volt and Ip is equal to 8 ma. Intermediate values of the voltage can be determined by means of the characteristic curve for the values of EX from 0 to +5 volts. The meter scale can then be calibrated directly in terms of the voltage.

10-55. A simple circuit for the measurement of ac voltages is shown in figure 27. Although this circuit is the same as that used for the measurement of dc voltages, it can be used to measure ac voltages from 0 to 5 volts over a wide frequency range.

10-56. When no voltage, EX = 0, is applied to the input terminals. the tube is at cutoff because of the negative 5-volt bias on the grid of the tube. The meter reading at this point will be zero. The fixed bias is marked on the plate-current grid-voltage curve, as shown. When an ac voltage is applied to the input terminals, the positive alternation reduces the negative grid bias in direct proportion to the value of the positive half-cycle, and the tube draws current. Since the tube is biased at cutoff, the negative alternation has no effect on the circuit condition.

10-57. Conduction of current on the positive alternations of the applied ac voltage produces current pulses having the waveforms as shown in figure 27. The meter pointer is unable to follow these current pulses to indicate peak values but responds to the average value of the current flowing in the circuit. An examination of the plate current waveform shows the average value of the pulse at maximum plate current to be 3.2 ma. By selecting a meter which requires 3.2 ma for full-scale deflection, maximum deflection is obtained when the peak positive alternation of the input voltage is equal to 5 volts, and the grid bias is reduced to 0. The meter can then be calibrated in terms of peak voltage, since the current through the meter is determined by the applied input voltage. AC vacuum tube voltmeters can be calibrated to read average. peak, or rms values.

10-58. Because the VTVM is a sensitive-measuring device, subjecting it to a voltage above its rated limit may damage the instrument. Always connect the voltmeter across a circuit with the range switch initially set on the highest range. If this does not give enough needle deflection, decrease the range by steps until a convenient reading is obtained.

10-59. When using probes for high-voltage checking, always grip the probe near the rear of the handle. This reduces the electric shock hazard and also decreases the capacitive effects of the hand on the circuit. If possible, connect the probe to the high-voltage circuit under test before turning on the voltage in the circuit. High dc voltages, when present in ac circuits under test. charge the input coupling

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capacitor of the meter. If the ac probe and a ground point are touched at the same time, a dangerous shock may result. To prevent this, ground the ac probe immediately after testing such circuits.

10-60. Other precautions to follow for high-voltage measurements are as follows:

- Locate all high voltage points in the circuit under test before making measurements.
- Make sure that no part of your body touches ground at any time.
- Always break the circuit at or near ground potential when measuring current in high-voltage circuits.

10-61. Another instrument used for measuring voltage is the cathode-ray oscilloscope. The usefulness of the oscilloscope lies in its design to portray graphically and instantaneously the fluctuating circuit conditions. The oscilloscope is the topic of our next discussion.

10-62. *Oscilloscope.* Operation of the oscilloscope is based upon the formation and control of a beam of electrons used for the purpose of producing a visible trace on a fluorescent screen. The general purpose oscilloscope, shown in figure 28, includes a cathode-ray tube, a sawtooth sweep generator, horizontal and vertical deflection amplifiers, and suitable controls, switches, and power supplies. Let's discuss the cathode-ray tube first.

10-63. *Cathode-ray tube.* The heart of any oscilloscope is the cathode-ray tube. This is a special type of electron tube in which electrons emitted by a cathode are focused and accelerated to form a narrow beam having a high velocity. The direction of this beam is then controlled and allowed to strike a fluorescent screen (see fig. 29). Light is emitted at the point of impact to produce a visual indication of the beam position. The electronic process of forming, focusing, accelerating, controlling, and deflecting the electron beam is accomplished by the electron gun. The gun consists of a heated cathode, a grid, a focusing anode (anode No. 1), and an accelerating anode (anode No. 2). Also contained in the tube is a deflection system for controlling the direction of the beam coming from the electron gun. All of these elements are contained in an evacuated glass bulb with a fluorescent screen. As you can see in the figure, the inside of the glass bulb is partially covered with an aquadag (graphite) coating. The aquadag provides a return path for electrons, and, at the same time, serves to electrostatically shield the electron beam from external electrical disturbances. Now that you have an idea of the elements contained in the cathode-ray tube, let us take a closer look at its electron gun, the beam deflection, and its fluorescent screen.

10-64. a. Electron gun. The simplified form of the electron gun, shown in figure 29, provides a concentrated beam of high-velocity electrons. The cathode is an oxide-coated metal cylinder, which, when properly heated, emits electrons. These electrons are attracted toward the accelerating and focusing anodes because of their high positive potential with respect to the cathode. In order to reach these anodes, the electrons are forced to pass through a cylindrical control grid having a tiny circular opening which concentrates the electrons and starts the formation of the beam. Electrons leaving the control grid opening are strongly attracted by the positive charge on the focusing anode (anode No. 1) and the accelerating anode (anode No. 2). These anodes are also cylindrical in shape and have small openings to permit electron beam passage. Between these anodes is an electrostatic field which influences the path of the electrons.

10-65. b. Beam deflection. Electrostatic beam deflection is accomplished through the use of two pairs of parallel plates located on each side and above and below the beam. Two plates are horizontally oriented so that they are perpendicular to the two vertical plates. Thus, the electrons must pass between each set of deflection plates. If no electric field exists between the plates of either pair, the beam will follow its normal straight line path, and the resulting spot will be at or near the center of the screen. A voltage potential applied to one set of plates will cause the beam to bend toward the plate that has the positive potential and away from the plate that has the negative potential. The bending is in direct proportion to the amplitude of the voltage applied to the plates. The second pair of plates influence the beam in the same manner, except that the bending occurs in a plane perpendicular to the first. A voltage that is variable and recurrent with time, when applied to either set of plates, will cause the spot to move back and forth across the screen along a straight line.

10-66. c. Fluorescent screen. In order to convert the energy of the electron beam into visible light, the area where the beam strikes is coated with a phosphor chemical. When bombarded by electrons, this coating has the property of emitting light. This property is known as fluorescence. The intensity of the spot on the screen depends upon the speed of the electrons in the beam and the number of electrons that strike the screen. In most cases, the intensity is controlled by varying the number of electrons that reach the screen. All fluorescent materials have some afterglow which varies with the screen material and with the amount of energy spent to cause the emission of light. The length of time required for the light output to diminish by a given amount, after excitation has ceased, is the persistence of the screen coating. The classification of screen materials is in terms of long, medium, or short persistence. White and blue-white phosphors, of short and very short persistence, are used where photographic records are taken of screen patterns. For general service work where visual observation is important, a green phosphor having medium persistence is used. In viewing a line or pattern that is traced by a moving spot of light, the persistence of human vision, as well as that of the screen material, plays an important part. When the pattern is retraced at a rate of 16 times a second, the persistence of the eye retains the image from each previous sweep. Therefore, the spot in its movement is no longer distinguishable as a spot, and the path traveled appears as a continuously illuminated line. In the case of long persistence phosphor materials, the persistence of the screen (rather than that of the eye) will govern, and the scanning rate required to produce a solid line will be substantially lower.

10-67. *Power supplies.* High-voltage and low-voltage power supplies are required for the operation of the oscilloscope. As may be seen in figure 28, the high-voltage power supply is used to provide operating potentials to the cathode-ray tube. The low-voltage power supply is used to supply operating potentials to the associated oscilloscope amplifiers and oscillators.

10-68. The output of the high-voltage power supply is usually over 1000 volts dc, depending upon the size of the cathode-ray tube. Its polarity is negative to permit the second anode and the deflection plates to be operated at ground potential. Half-wave rectification and a simple resistance-capacitance filter network are used for these high-voltage applications, because the current used to operate the cathode-ray tube is very small. A voltage divider, which includes the focus and intensity controls, provides the necessary operating potentials for the various cathode-ray tube electrodes.

10-69. The output of the low-voltage power supply is usually in the 250- to 400-volt range. Full-wave rectification and a pi type filter network are used in this power supply because of the moderate current, good regulation, and low-ripple voltage requirements.

10-70. As an experienced technician, you should warn your personnel not to operate an oscilloscope with the case removed. Doing so exposes high voltages and could lead to a fatal shock.

10-71. *Vertical and horizontal amplifiers.* The vertical and horizontal deflection systems of the cathode-ray tube are relatively insensitive. They require voltages on the order of several hundred volts for full-scale deflection. Therefore, it is necessary to use amplifiers to increase the amplitudes of the test signal voltages for both the vertical and horizontal deflection plates, so that low-amplitude test signals may be effectively presented.

10-72. Most oscilloscopes use a cathode follower input stage, followed by a push-pull amplifier, to obtain better linearity at the output of the vertical and horizontal deflection channels. One of the most important advantages of using push-pull amplifiers, instead of single-ended amplifiers, is that the deflection plates produce a uniformly balanced field with respect to the second anode of the cathode-ray tube. Also, the push-pull amplifier can deliver twice as great an output signal as a single-ended stage. This mode of operation also tends to reduce the noise generated in the oscilloscope amplifiers. In this way it reduces the addition of internal noise to the noise picked up in the test leads of the scope or circuit under test.

10-73. *Sweep generator.* When you are analyzing a waveform on the screen of a cathode-ray tube, you should bear in mind that the unknown signal is always plotted as a function of another signal whose characteristics are known. In most oscilloscope applications, the unknown signal is applied to the vertical axis and the sweep generator signal is applied to the horizontal axis. The conventional form of time base sweep is the sawtooth waveform. When applied to the horizontal deflection plates of the cathode-ray tube, the sawtooth produces a horizontal movement of the electron beam that is a direct measure of time as the spot moves from left to right. In order that time may always be indicated from left to right, the spot is returned to the left side of the viewing area at the completion of each sweep. When the pulse rate or frequency of the sawtooth time base is adjusted to synchronize with the unknown signal applied to the vertical deflections plates, the time variation or waveform of that signal is traced upon the cathode-ray tube. The sawtooth sweep voltage is produced by the circuitry which is included as part of the oscilloscope. This circuitry is known as the sweep, or time base, generator. By now you should have a good understanding of the basic function of each of the major units in figure 28.

10-74. Just like any other electronic device, the oscilloscope is subject to limitations and malfunctions. In the next paragraph we will discuss some of the safety precautions that must be exercised when operating the oscilloscope. These are in addition to the one previously mentioned; that is, not operating the oscilloscope with its case removed.

10-75. *Safety precautions.* When using the oscilloscope, it is advisable to use extreme caution

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when handling the cathode-ray tube. The glass envelope of the tube is under a high vacuum. Any undue stress or rough handling can cause serious injury due to tube implosion. When handling broken cathode-ray tubes, avoid direct contact with the glass. The fluorescent coating of the cathode-ray tube is extremely toxic.

10-76. When operating the oscilloscope, you must not permit a bright spot to remain in a stationary position on the fluorescent screen. The energy of the electron beam concentrated in a small area will burn the screen coating. This concludes our discussion of the oscilloscope. Next, we will discuss the frequency meter.

10-77. *Measuring Frequency.* In some ac systems it is necessary to know the frequency of the voltage source. The two types of frequency meters suitable for this purpose are the dynamometer type and the vibrating reed type. The dynamometer type uses the electrodynamometer principle. The vibrating reed type is an electromechanical instrument.

10-78. *Dynamometer-type frequency meter.* This type of frequency meter uses a dial and pointer to provide a visual indication of the frequency being measured. These are shown in figure 30. The commonly used frequency meter is the type A-1. It includes a basic dynamometer type of frequency meter circuit, also shown in figure 30. When no voltage is applied to the meter, the pointer rests on a stop at the end of the scale (350 Hertz). (Many of the older meters will still be calibrated in cps.) With the power off, the meter is adjusted to 350 Hertz by means of a zero-adjusting screw located on the front of the movement. The moving coil B of the dynamometer type movement is pivoted and under spring tension. Its position is determined by the actions of coils A and C. Coil A has a core, and is in series with a capacitor in the line. At any instant, coil A will have a polarity tending to rotate the moving coil to the right. Coil C has no core, (other than air) and is in series with both the moving coil and two current-limiting inductors. Coil C tends to rotate the moving coil to the left at any instant that current flows through it. Two limiting inductors are used rather than one; they are assembled adjacent to one another in such a manner that the exterior field of one will cancel the exterior field of the other. Therefore, their exterior fields have no appreciable affect on the moving coil.

10-79. As the frequency of the voltage applied to the meter is increased, the current through the limiting inductors is decreased. Therefore, the current in field or coil C and in the moving coil is reduced because of the increased reactance of the limiting inductors. The current flow through the capacitor and the field coil (coil A) increases considerably, because this coil and capacitor combination approaches a series-resonant circuit at some frequency above 450 Hertz. The sharp increase in current will magnetize coil A strongly enough to deflect the pointer to the right. The amount of deflection will be directly proportional to the increase in current through the iron-core field coil; this increase, of course, depends upon the increase in frequency. Such a meter can be calibrated to directly indicate the exact frequency. In this system, the current does not increase at a uniform rate but increases more rapidly as resonance is approached. Therefore, this type of meter can be used for only a small frequency range.

10-80. *Vibrating reed type frequency meter.* The vibrating reed type meter contains an electromagnet mounted near a metal plate. When the electromagnet is energized with alternating current, vibrations are set up which are identical in period with the flux reversals caused by the alternating current in the coil. The vibrations are transmitted to a metal plate, part of which consists of a set of carefully balanced metal reeds. The plate (A) and a vibrating reed (B) are shown in figure 31. Each reed is tuned to vibrate excessively at one particular frequency. If more than one reed is vibrating, the one vibrating the most indicates the nearest correct frequency, as shown on the dial (C).

11. Special Aircraft Power Systems Test Equipment

11-1. Many of the measurements you will be required to make on some of the newer type aircraft would be difficult to perform with a common meter. For this reason many special purpose systems testers have been developed. In the following paragraphs we will discuss two testers that are used to check the ac power systems on the fighter aircraft.

11-2. *Electrical Power Test Set.* The PSM-20B electrical power test set, shown in figure 32, is designed to be used during flight line checkout and troubleshooting of the aircraft electrical power generating system. Connection to the aircraft is made through two test cables to test receptacles in the rear cockpit, as shown in figure 33. In order to check out the aircraft power generating system, the aircraft engines must be operating, and external power must be applied to the aircraft. The test set is capable of checking the outputs of the aircraft generators either individually or in parallel. The generator outputs are checked for correct voltage, frequency, and phase relationship. The reactive generator loads, generator protective circuits, and control voltages may also be monitored. The AN/PSM-20B test set may also be used on aircraft that have 40 and 60-kv-a generating systems.

11-3. *Control panel.* As you can see in figure 32, the control panel consists of two kilowatt-kilovar meters, one ac voltmeter, one frequency meter, and one dc voltmeter. The six indicator lights provided on the control panel monitor generator phase sequence, generator synchronization, and aircraft electrical control circuitry. Switches are also provided to select the various circuits to be monitored by the test set and to introduce faults into the aircraft circuits for the purpose of testing various aircraft protective devices.

11-4. Because of the design of the wiring harnesses used on the F-4C and newer aircraft, many of the terminal strips, connectors, and junctions which were on older aircraft have been eliminated. With these troubleshooting test points eliminated, the use and operation of special aircraft systems testers are of prime importance to the electrical technician. To help the technician, the electrical systems technical order has a list of malfunctions that may be encountered, and a logic tree for each malfunction.

11-5. *Use of logic trees.* When making a functional check with the test set, make all checks in sequence. When one of the steps in the sequence does not check out, stop at that step. Next, make a note of this particular symptom, and, by using the table of malfunctions, be able to locate the applicable logic tree. For example, let us say that the generator voltage is not within allowable tolerance. He should then find this symptom in the table of malfunctions. Once found, this table will refer him to logic tree number 6.

11-6. The logic tree provides you with a means to logically pursue a trouble to a satisfactory conclusion by the process of elimination (see fig. 34). First the symptom is defined. Next, tests are chosen so that results will begin with the branches of a tree in the most logical order of occurrence. Notice in the figure that the first step is to check the static exciter regulator. You may be asked if continuity exists through all pins. If the answer is no, you will have to replace the static exciter regulator If the answer is yes, a check of the generator control panel will be necessary. The logic tree breaks the system down into subsections. These subsections can be checked as separate systems. By eliminating subsections, the trouble can be isolated to the section of the system which does not work, and this, in turn, can be traced to a specific unit.

11-7. *Electrical Power Test Harness.* The electrical power test harness (see fig. 35) can be used to perform a generator system functional check. It can also be used to great advantage in troubleshooting system faults to a specific system component.

11-8. A lockout switch (the center one in the group of three in the lower left corner) is provided to override the lockout relay in the control panel. This enables troubleshooting of an overvoltage fault. An underspeed switch (USS, just to the right of the lockout switch) is provided to override the underspeed switch in the constant-speed drive when troubleshooting an underfrequency fault or a defective underspeed switch. This tester also has test points which provide electrical connections to the control panel receptacle for measuring control panel output voltage while the generating system is in operation. As with any tester, you must use the TO instructions with this piece of equipment.

11-9. The test harness can be used on the flight line as well as for bench testing the generating system. The electrical power test harness is capable of a more thorough testing of the constant-speed drive and related circuitry than the PSM-20B tester. For this reason, the test harness is used mostly for in-shop testing. The electrical power harness has a functional checklist for flight line and in-shop applications. With each of these checklists, a logic tree is provided.

CHAPTER 6

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ANALYZING COMPLEX DC CIRCUITS

HOW MANY TIMES have you heard the squawk box from workload control sing out, "Dispatch a 7 level to 545 spot 20, on the double"? The fact that you are reading this chapter means that you are about to become the expert for your shop. You are soon to become the guy who gets the rough ones, and you will be expected to fix them in half the time. What is it that makes a 7 level so great on the job? You must be able to look at the symptoms of a malfunction, apply some basic logical thinking, and come up with the answer.

2. In this CDC we cannot give you the experience which you should have gained thus far, but we can help you in the area of fundamental knowledge. It has been some time since you attended tech school. Many of the things you learned have slipped deep into your memory. We will help you by giving a brief review of things you know, and then bring in some new material.

3. With the swing to solid state control devices in our modern aircraft, it is necessary to put more emphasis on dc circuits. Transistors and their associated circuits are generally dc circuits. As you troubleshoot these complicated circuits, you will have to apply some of the basic laws of electricity to arrive at a quick fix for the circuit. In this chapter we have covered many of the knowledges that will help you troubleshoot complex dc circuits. The first subject is that of magnetic circuits.

12. Magnetic Circuits

12-1. The forces which are responsible for the wonders of electronics are invisible electric and magnetic forces. These are the forces which make possible the operation of electric motors, generators, lights, doorbells, measuring equipment, and other electrical apparatus. They are the invisible forces which enable energy to travel through space at the speed of light. In this section we will deal with the effects associated with magnetic forces and the applications of these forces in magnetic amplifiers.

12-2. *Theories of Magnetism.* When a bar magnet, such as the one shown in part A of figure 36, is broken into two separate parts, as in part B of figure 36, you can see that each piece will have two poles. The piece which contains the north pole of the original magnet will have a south pole at the end where the break occurred. In like manner, the piece containing the south pole of the original magnet will have a north pole at the end where the break occurred. Each of the two pieces can be broken again, and you would have four magnets. This shows that each time a magnet is broken, a new pole is established at the newly broken end. This new pole is the opposite polarity of the other end. If you could continue to break the magnet in half until molecular size was obtained, you would find that the tiny molecule was a magnet. It would have its own magnetic field and both a north and a south pole. These tiny magnets, which are so small that they cannot be seen with a microscope, are the basis for the molecular theory of magnetism.

12-3. *Molecular theory.* The molecules in material not yet magnetized are thought of as being jumbled at random with no definite order. This is illustrated in part A of figure 37. Considering that the molecules are small magnets, you might expect them to automatically align themselves to form a larger magnet. There are several reasons why this does not occur. Even though the magnets tend to line up with their unlike poles facing each other, it does not mean that they will line up in a direction that will provide a maximum magnetic field. Internal stresses in the iron or steel can override the small magnetic fields of these magnets and hold them in their haphazard alignment. Many other factors also combine to keep the magnets in their haphazard positions, as shown in part A of figure 37.

12-4. The process of partially or fully magnetizing a steel bar consists of bringing it into contact or under the influence of a magnetic field, such as a bar magnet. All the molecules turn, as shown in part B of figure 37. An artificial magnet can be produced by stroking an iron or steel bar with a strong magnet, as shown in part A of figure 37. The molecules then line up as shown in part B of figure 37. Be sure that all the strokes are made in the same direction. Magnets that are created in this fashion are only moderately strong. To completely magnetize the bar requires a very strong magnetic field. You can use an electric current to generate the strong magnetic field.

12-5. Careful measurements indicate that a substance undergoes a series of changes in length when being magnetized. In general, the substance first expands and later contracts. This behavior of a substance being magnetized (and demagnetized) is known as *magnetostriction*.

12-6. The molecular theory of magnetism is supported by many facts which can be proven in your experience. During your time on the flight line you may have had generators lose their residual magnetism. Usually this occurs because the heat in the engine area is so great, or the generator has had a hard bang. These are facts that point directly to the molecular theory of magnetism. However, most scientists agree that the theory of magnetism goes into the realm of the atom itself, and is more thoroughly explained by means of the electron theory.

12-7. *Electron theory.* The electron theory is a very complicated study dealing with the energy level of electrons in orbit. The level of energy determines the polarity of spin. Some electrons have a positive spin, some a negative spin. The unbalanced conditions in an atom having more positive spin electrons is believed to correspond with a north pole, and a greater number of negative spin electrons is a south pole. This is believed to be the basic reason why some materials exhibit magnetic properties.

12-8. The atoms in ferromagnetic substances tend to bond together in an effort to acquire a greater equilibrium. They form domains within crystalline structures. A domain contains a maximum number of atoms, all oriented with their electron spins parallel, and resulting in a small, fully magnetized domain. From this point on, the theory is much the same as the molecular theory. Under the influence of a magnetic field, these domains will align and create a magnet.

12-9. *Application of Physics to Magnetic Force.* The amount of magnetic force surrounding a magnet can be estimated roughly by measuring its lifting power. However, there are other conditions which cause the lifting power of the magnet to vary. Some of these conditions are:

- The kind of magnetic material to be lifted.
- The shape of the material to be lifted.
- The manner in which the material is applied to the magnet.
- The shape of the magnet.

A more accurate and more commonly used method for measuring the strength of a magnet consists of measuring the force of attraction or repulsion that the magnet exerts on another magnet of known strength.

12-10. *Magnetic field.* One thing you should remember from tech school is that a magnetic field has direction. This can easily be seen by placing a compass near a magnet. The field leaves the north pole of the magnet and enters the south pole. We can say that the field moves north to south outside the magnet, and south to north inside the magnet.

12-11. *Magnetic lines of force.* By experimental means, scientists have discovered that the mutual force between two poles can be expressed by the mathematical relationship:

$$F = \frac{P_1\ P_2}{\mu\, d^2}$$

where F is the force between the two poles, P_1 and P_2 are the magnitudes of the pole strengths, d is the distance between the two poles, and μ is a constant which depends upon the medium surrounding the poles. The force expressed by this equation can be one of attraction (-F) or repulsion (+F). The direction of the force depends on whether P_1 and P_2 have opposite signs or the same sign. The dimensions of the equation depend upon the units in which each factor is measured. In the centimeter-gram-second (cgs) system of measurement, the force (F) will be expressed in dynes, and the distance (d) will be expressed in centimeters. The factor μ is then specified as 1 in a vacuum, and has no dimension, as is the case with P_1 and P_2, which can also be made equal to 1.

12-12. If values are substituted for the basic equation previously given, the results are as follows:

$$F = \frac{1 \times 1}{1 \times 1\ \text{cm}^2} = 1 \text{ dyne}$$

This is now the standard equation for the unit pole and can be stated, "When any two like poles of equal strength are placed in a vacuum, 1 centimeter apart, they will repel each other with a force of 1 dyne."

12-13. *Coulomb's law.* From this basic study of the theories of magnetism, you will see a direct connection to all the areas of electronics. Charles Coulomb discovered experimentally that the force of the attraction or repulsion between two point charges of magnitude or strength Q_1 and Q_2, separated by a distance of d, can be calculated. The equation you studied in the preceding paragraphs is an application of Coulomb's law.

12-14. Let us put it to work on a problem using two bar magnets. There are two bar magnets that are 10 cm in length shown in figure 38. They are separated by 10 cm and they have their north poles facing each other. The pole strength for each magnet is $P_1 = 30$ and $P_2 = 20$. One thing to keep in mind, as you work a problem like this, is that each pole of the magnet has an effect on both poles of the other magnet. Let us take the two north poles first. By following the equation for Coulomb's law, we find our problem to look something like this:

$$F = \frac{30 \times 20}{10^2} = \_\_\_\_ \text{ dynes of repulsion (like poles repel)}$$

$$F = \frac{600}{100} = 6 \text{ dynes of repulsion}$$

Remember, this is just for the north poles of the circuit. To compute the south poles we would solve:

$$F = \frac{30 \times 20}{30^2} = \_\_\_\_ \text{ dynes of repulsion}$$

$$F = \frac{600}{900} = \frac{6}{9} = 2/3 \text{ dyne of repulsion}$$

Total force of repulsion in this circuit would be 6 2/3 dynes. This is only half of the total circuit. We must compute the attraction forces, also.

12-15. In this problem the magnets are the same length. Therefore, we can compute the attraction of one pair of poles and double it. If the magnets were of different lengths, we would have to compute each force. The problem is set up the same:

$$F = \frac{30 \times 20}{20^2} = \text{dynes of attraction (unlike poles attract)}$$

$$F = \frac{600}{400} = 1\frac{1}{2} \text{ dynes of attraction}$$

Since the magnets are the same length and we are going to double the total force, the attraction would be:

$$1\frac{1}{2} \times 2 = 3 \text{ dynes of attraction for the circuit}$$

The forces of attraction and repulsion are opposite, so the total force for the circuit will be the difference between the two. This means that, with 6 2/3 dynes of repulsion and 3 dynes of attraction, the resultant force is 3 2/3 dynes of repulsion.

12-16. Being able to compute this problem will give you some insight of the interaction of magnetic forces. These forces are used in all the circuits on which you will work as an electrician. You may never have the need to compute such a circuit on the flight line. But, by knowing how, you can more easily understand how a circuit operates. These forces exist between electrons as well as magnets. They are the real key to such things as voltage generation, relay operation, and many of the electronic applications. One such device is the magnetic amplifier. By studying this unit, you can see these forces being put to work.

12-17. *Magnetic Amplifiers.* Magnetic amplifiers (mag amps) usually consist of such components as inductors, dry disk rectifiers, and resistors. These components are often potted in a single case. When operated within their design characteristics, they are extremely reliable, suffer little deterioration with time, and are exceptionally rugged. The amplifiers are well suited for use in control systems which are subjected to shock and vibration. An example of this is our fire warning systems.

12-18. The basic operation of the magnetic amplifier has already been covered in your previous training. However, we will review and expand upon its operation. It is an important controlling device for you to understand because it is used for many of the electronic circuits you are required to maintain.

12-19. The operation of a mag amp is based on the nonlinear B/H characteristics (the explanation follows) of magnetic core material. When the characteristic is plotted, it is known as the B/H curve, magnetization curve, or hysteresis loop. The B represents flux density, a measure of the amount of magnetization. H stands for the magnetizing force (or magnetic field intensity). Now look at figure 39. If the magnetizing force, H, is increased from zero (point 0) to a value K, as shown in part A of this figure, the flux density, B, increases linearly. However, as H is further increased, the core material becomes saturated, and a point is reached where a further increase in H gives no increase in B. As you increase the magnetizing force in the opposite direction the other half of the B/H curve is formed. The curve will vary in appearance with the type of core material used.

12-20. The basic reactor (a name commonly used for the transformer of the magnetic amplifier) consists of three windings on an E-type core. This arrangement is shown in figure 40. The center

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winding is the control winding and receives the control voltage. This voltage must be dc and is made variable by using a rheostat. The two outside windings are the controlled coils. They are connected in series-aiding and are placed in series with the load, as shown in figure 40.

12-21. With no current flowing in the dc control winding, the current flowing through the load is small because of the large inductance exhibited by the reactor. When dc is fed through the control winding, a residual flux appears in the core. The change in flux density decreases, resulting in less impedance to the load. By varying the dc control current from zero to saturation, the impedance in the ac circuit may be made to vary from a high value to almost zero. Any dc current change in the control winding causes a corresponding ac current change of greater value. Therefore, this circuit exhibits current gain characteristics. By connecting the ac windings in parallel, as shown in part A of figure 41, the loads can be handled with medium to high current consumption. However, the amplifier with parallel ac windings has somewhat slower response characteristics. Part B of figure 41 shows a variation that allows the use of a dc load. A bridge rectifier is used in the ac circuit to provide dc to the load while keeping any dc component of current out of the ac winding, thus preventing self-saturation. This arrangement is used in many of our circuits.

12-22. We have discussed, to some degree, the basic forces behind this phenomenon called electricity. In our discussion, we have made application of some of these principles. You, as a 7-level electrician, must be fully aware of what makes a circuit tick. This knowledge will make you a better electrician. In the next section of this chapter there is a review of some of the fundamentals involving conduction. If it is known what makes the electron move, the next step is to find out what can hinder that movement or make it easy. You must be able to analyze conduction.

13. Analyzing Conduction

13-1. Of course you remember Ohm's law from your previous training. You know how to find the values of current, resistance, and voltage in simple circuits. As you know, the aircraft contains very few of these simple circuits. As a 7-level electrician, you must be able to analyze any type of circuit quickly and with a minimum of known values. This process takes some logical thinking on your part. You must have a good grasp of the relationships between such things as voltage, current, resistance, point of reference, and polarity. In this section we will briefly review some of the basic laws and then show you some new ones.

13-2. *DC Currents and Voltages.* All types of electrical currents and voltages have one thing in common. They have an interrelationship between variations in amplitude and the element of time. Amplitude is the characteristic that represents the intensity of current or voltage with respect to zero. Thus, a current of 5 amperes simply means that the magnitude of the current is 5 amperes greater than zero. The time relationship governing the rapidity of amplitude of change involves seconds, minutes, and hours.

13-3. *Direct current.* Direct current is an electrical current which moves in only one direction and has a constant amplitude characteristic with reference to time. There is no pure direct current since electrical energy depends upon the source of power. The nearest approach to the production of pure direct current is the electrical energy obtained from the chemical reaction in a battery. Ionic transfer and electron motion within a battery occur entirely at random on an individual atomic basis. There is no way to predict the location of the next atom which will be ionized, nor is there any way to predict the actual number of electrons collected on the metallic electrode on an instantaneous basis. However, the actual number of electrons produced in the chemical reaction of the battery can be measured and predicted with a high degree of precision. The average number of electrons making up the electrical current is a measure of the amplitude of the direct current. Current is measured in amperes.

13-4. Direct current is unidirectional, that is, it can move in only one direction. This direction is always from negative or positive points. However, a reference point having the symbol ⏚ is always chosen in the associated circuit, so that the direct current is always moving toward or away from the reference point. The positive or negative signs affixed to a current value indicate the direction of the current with respect to the reference point.

13-5. *Direct voltage.* Direct voltage is usually called dc voltage. It is a unipolar (single direction) electrical force of constant amplitude. The terminals of a battery are oppositely charged, one being negative and the other positive. When the reference point is assigned or connected to either battery terminal, the battery is said to be poled or polarized. That is, all of its electrical force is exerted in one direction. If the reference point is located on the negative terminal, the battery is poled in the positive direction. If the reference point is on the positive terminal, the battery is poled in the negative direction. Therefore, the voltage can be made to have

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either a positive or negative polarity.

13-6. *Ohm's Law.* The relationships of current, voltage, and resistance were first demonstrated by Georg Simon Ohm, a German physicist. He performed a series of experiments which demonstrated two items. One was the way voltage is distributed through a circuit. The other was the relationships of voltage, current, and resistance. Ohm's law states that the current in a circuit is proportional to the voltage and inversely proportional to the resistance. This relationship is best stated in the following equations:

$$E = I \times R$$

$$I = \frac{E}{R}$$

$$R = \frac{E}{I}$$

E denotes voltage, I denotes current, and R denotes resistance. You should remember how to use these equations in the "magic circle." However, some problems which seem simple are not as easy as you might think. Ohm's law will not always solve your problems. You should also be familiar with Kirchhoff's laws.

13-7. *Kirchhoff's Laws.* Methods of treating complex circuits are based on Kirchhoff's laws. His laws are simple to state, but the methods of applying them are often quite difficult. Briefly stated, the two laws of Kirchhoff are as follows:

- The algebraic sum of the currents at any junction of conductors is zero.
- The algebraic sum of the applied voltages and of the voltage drops around any closed circuit is zero.

13-8. *Kirchhoff's first law.* The algebraic sum of the currents at any junction of conductors is zero. This law can be restated as follows: the amount of current entering a junction must be equal to the sum of the current leaving it. This law is actually a consequence of a more general one known as the principle of charge conservation. For example, assume that a current (I_1) of 1 ampere flows toward point A of figure 42, and a current of 5 amperes (I_2) flows away from point A. What is the current (I_3) flowing between points A and B?

13-9. Using a minus sign to represent a current flowing into a junction, and a plus sign to represent a current flowing away from a junction, current I_1 becomes -1 ampere and current I_2 becomes +5 amperes. Since the algebraic sum of the currents must equal zero, an equation can be written as follows:

$$I_1 + I_2 + I_3 = 0$$

Subtracting I_3 from both sides of the equation yields:

$$I_1 + I_2 + I_3 - I_3 = 0 - I_3$$

$$+I_1 + I_2 = -I_3$$

Then multiplying both sides of the equation by a -1 to make the $-I_3$ positive yields:

$$-I_1 - I_2 = I_3$$

Substituting known values for the currents I_1 and I_2 results in:

$$-(-1) - (+5) = I_3$$

$$-4 = I_3$$

This shows that -4 amperes is the value of the current flowing between points A and B. The minus sign shows that the current is flowing into junction point A. This is obvious since 1 ampere is arriving at junction A at the same time that 4 more amperes are arriving at junction A. Both currents join each other to leave the junction as 5 amperes.

13-10. *Kirchhoff's second law.* The algebraic sum of the applied voltages and the voltage drops around any closed circuit is zero. In order to understand what this law means, refer to figure 43. Assume that the current is flowing in the direction shown by the solid line arrow. The starting point and the direction are purely arbitrary, since the algebraic sum is zero. Starting at point A, and passing through the 100-volt battery, there is a voltage rise of +100 volts at point B. The current must pass through the 10-ohm resistor before it can arrive at point C. Since voltage is equal to IR, you can write -10I as the voltage drops across the 10-ohm resistor. Leaving point C, the current must pass through the 5-ohm resistor before it can reach point D. The voltage drop is -5I. Leaving point D, the circuit current must pass through the 50-volt battery before it can arrive at point E. So, from D to E there is a rise of +50 volts. In the circuit from E back to A there is a negligible voltage drop. Recording all data for the various circuit points you will get:

A to B	+100 volts
B to C	-10I volts
C to D	-5I volts
D to E	+50 volts
E to A	+0 volts

Since the algebraic sum must be equal to zero, equate the voltages in the circuit to zero as follows:

$$+100 - 10I - 5I + 50 + 0 = 0$$
$$+150 - 15I = 0$$
$$150 = 15I$$
$$I = 10 \text{ amperes}$$

Now that the value of I is known, it can be substituted in the original equation to check the algebraic sum of the voltages as follows:

$$+100 - 10 \times 10 - 5 \times 10 + 50 + 0 = 0$$
$$+100 - 100 - 50 + 50 = 0$$
$$0 = 0$$

Thus, the algebraic sum of the applied voltages and the voltage drops do equal zero.

13-11. Now assume the current direction to be in the direction indicated by the dotted-line arrow. This direction is opposite to that assumed previously. To show that the starting point is arbitrary, start at point C and work your way around the circuit. Although you may reverse the signs of the values, the answer you will get is still the same. The direction of current flow assumed and the starting point in the circuit are immaterial as long as you are consistent in the application of the principles involved.

13-12. These are just a few of the laws that you must deal with as you troubleshoot on today's modern aircraft. There are many more laws that you should be familiar with to really understand the operation of solid state circuitry. However, let us put these to work on some of the circuits that have given electricians the most trouble over the years. Two of the most difficult and yet most commonly used circuits are the bridge and the mesh circuits. These circuits are classed as complex dc circuits.

14. Complex DC Circuits

14-1. One of the hardest things for an electrician to remember when he starts to troubleshoot electronic circuits is that the point of reference is not fixed, as it is in the simple circuits. Voltages in solid state circuits may be positive or negative, depending on the reference point you select. In many cases, as you troubleshoot you will determine the point of reference by where you place your meter leads. We will start with the bridge circuit to discover just how important this point of reference is to a troubleshooter.

14-2. *Bridge Circuits.* As shown in figure 44, a resistive bridge circuit consists of two parallel circuits containing two series resistors in each arm. Resistor R_5 is the bridge resistor. Suppose that the resistance values for R_1, R_2, R_3, and R_4 are all equal, and for the time being, assume that the bridge resistor does not exist. When the applied voltage is connected to junction points 1 and 3, the voltage across all four resistors will be equal. Of course the reason for this is that the resistance values are the same. In reference to junction point 1, one-half of the applied voltage will be present at junction point 2. Also, with respect to junction point 1, one-half of the applied voltage will be present at junction point 4. Therefore, there is no difference in potential between junction points 2 and 4.

14-3. The total current arriving at junction point 1 divides into branches A and B according to the resistance of the branch circuits. Because the resistance in branch A of the circuit is equal to the resistance in branch B, the current divides equally. The current flowing past point 2 is the same as that flowing past point 4.

14-4. Suppose that resistor R_5, which may be of any value, is connected across junction points 2 and 4. Because the branch resistances were equal to begin with, whatever change that takes place at point 2 in branch A because of the addition R_5 also takes place in branch B and point 4. Therefore, the resistance of the upper delta (resistors 2, 4, and 5) remains equal in value to the lower delta (resistors 1, 3, and 5). The addition of resistor R_5 has not changed the relative value of resistance between points 2 and 4 to point 1.

14-5. Because the voltage distribution is equal across resistances of equal value, one-half of the applied voltage exists from points 2 and 4 to point 1. If the voltages at points 2 and 4 are equal, there is no difference in potential across resistor R_5. Since the voltage is zero across the resistor, there is no current flow through it. The total current then flows equally through branches A and B.

14-6. If branches A and B are adjusted so that the resistances are no longer equal, current flows in the bridging resistor. Under these conditions the bridge is said to be *unbalanced.* If the condition described in the above paragraphs shows no difference in potential between points 2 and 4 to exist, the bridge is said to be *balanced,* and no current appears in the bridging resistor. This is the basic operation of the bridge circuit.

14-7. It may be necessary, as you troubleshoot, to compute the resistance of a bridge. You may have to compute the resistance to determine the direction of the current through the bridging resistor. One means used to compute a bridge circuit is the delta-to-star transformation method. This method will resolve a bridge circuit to a simple series-parallel circuit. Now you can use Ohm's law to arrive at the values of the circuit.

14-8. *Delta-to-Star Method.* While examining part A of figure 45, notice that the bridge includes a delta circuit inclosed by points ABD or BCD Choosing delta circuit ABD, and remembering that it can be resolved in the corresponding star circuit, you should see that a simple series-parallel circuit will be obtained. Transforming delta circuit ABD into its equivalent star circuit is accomplished as follows:

$$R_a = \frac{R_1 \; R_5}{R_1 + R_5 + R_3}$$

$$= \frac{1 \times 2}{1 + 2 + 3}$$

$$= \frac{1}{3} \text{ ohm}$$

$$R_b = \frac{R_1 \; R_3}{R_1 + R_5 + R_3}$$

$$= \frac{1 \times 3}{1 + 2 + 3}$$

$$= \frac{1}{2} \text{ ohm}$$

$$R_c = \frac{R_3 \; R_5}{R_1 + R_5 + R_3}$$

$$R_c = \frac{3 \times 2}{1 + 2 + 3}$$

$$= 1 \text{ ohm}$$

The circuit now resolves itself into that shown in part B of the figure. The total resistance of the circuit can be calculated as follows:

$$R_T = R_b + \frac{(R_a + R_2) \quad (R_c + R_4)}{(R_a + R_2) + (R_c + R_4)}$$

$$= \frac{1}{2} + \frac{(\frac{1}{3} + 4) \; (1 + 5)}{\frac{1}{3} + 4 + 1 + 5}$$

$$= \frac{1}{2} + \frac{(\frac{1}{3} + \frac{12}{3}) \times 6}{\frac{1}{3} + \frac{12}{3} + \frac{18}{3}}$$

$$= 3.01 \text{ ohms}$$

The total current, I_T, drawn by the bridge circuit can be calculated as follows:

$$I_T = \frac{E_T}{R_T}$$

$$= \frac{10}{3.01}$$

$$= 3.32 \text{ amperes}$$

Current I_5, flowing through bridging resistor R_5, can be computed, but first the voltage applied across its terminals must be computed. The total applied voltage, E_T, less the voltage drop, E_{Rb}, across resistor R_b will provide the voltage applied to the parallel portion of the circuit. Therefore:

$$E = E_T - I_T R_b$$

$$= 10 - 3.32\ (0.5)$$

$$= 10 - 1.66$$

$$= 8.34 \text{ volts}$$

The current division between the two separate circuit branches can now be calculated as follows:

$$I_{BC} = \frac{E}{R_a + R_2}$$

$$= \frac{8.34}{0.333 + 4}$$

$$= 1.926 \text{ amperes}$$

$$I_{DC} = I_T - I_{BC}$$

$$= 3.32 - 1.926$$

$$= 1.39 \text{ amperes}$$

The voltage from points B and D to point C can now be calculated as follows:

$$E_B = I_{BC}R_2$$

$$= 1.926\ (4)$$

$$= 7.7 \text{ volts}$$

$$E_D = I_{DC}R_4$$

$$= 1.39\ (5)$$

$$= 6.95 \text{ volts}$$

Voltage E_5, applied across resistor R_5, is $E_5 = E_B - E_D = 7.7 - 6.95 = 0.75$ volt. With respect to point C in the figure, point B is 7.7 volts and point D is 6.95 volts. Thus, current I_5 flows from point B to point D by way of resistor R_5. Current I_5, through resistor R_5, is:

$$I_5 = \frac{E_5}{R_5}$$

$$= \frac{0.75}{2}$$

$$= 0.375 \text{ ampere}$$

14-9. A second bridge circuit is shown in part A of figure 46. The upper delta may be transformed into its equivalent star circuit as follows:

$$R_a = \frac{R_2\ R_4}{R_2 + R_4 + R_5}$$

$$= \frac{5 \text{ X } 20}{5 + 20 + 1}$$

$$= 3.85 \text{ ohms}$$

$$R_b = \frac{R_2\ R_5}{R_2 + R_5 + R_4}$$

$$= \frac{5 \text{ X } 1}{5 + 1 + 20}$$

$$= 0.192 \text{ ohm}$$

$$R_c = \frac{20 \text{ X } 1}{5 + 1 + 20}$$

$$= 0.769 \text{ ohm}$$

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The total resistance, R_T, of the circuit can now be calculated as follows:

$$R_T = R_a + \frac{(R_b + R_1)\ (R_c + R_3)}{(R_b + R_1) + (R_c + R_3)}$$

$$= 3.85 + \frac{(0.192 + 5)\ (0.769 + 20)}{(0.192 + 5) + (0.769 + 20)}$$

$$= 8.00 \text{ ohms}$$

The total current, I_T, drawn from the battery is:

$$I_T = \frac{E_T}{R_T}$$

$$= \frac{75}{8.00}$$

$$= 9.4 \text{ amperes}$$

The voltage, E, applied across the parallel branch can be calculated as the total applied voltage, E_T, minus the voltage drop across resistance R_a.

$$E = E_T - I_T R_a$$

$$= 75 - 9.4\ (3.85)$$

$$= 36.2 \text{ volts}$$

Currents I_{AD} and I_{AB} can now be calculated as follows:

$$I_{AD} = \frac{E}{R_3 + R_c}$$

$$= \frac{36.2}{20 + 0.769}$$

$$= 1.74 \text{ amperes}$$

$$I_{AB} = I_T - I_{AD}$$

$$= 9.4 - 1.74$$

$$= 7.66 \text{ amperes}$$

Voltage E_1 across resistor R_1 and voltage E_3 across resistor R_3 are to be calculated next.

$$E_1 = I_{AB} R_1$$

$$= 7.66\ (5)$$

$$= 38.3 \text{ volts}$$

$$E_3 = I_{AD} R_3$$

$$= 1.74\ (20)$$

$$= 34.8 \text{ volts}$$

If junction point A is taken as a reference point, point B is 38.3 volts, while point D is 34.8 volts. The voltage between points B and D is the difference of these two voltages. Because resistor R_5 is connected across these same terminals, voltage E_{BD} is also equal to E_5.

$$E_5 = E_B - E_D$$

$$= 38.3 - 34.8$$

$$= 3.5 \text{ volts}$$

Current I_5 through resistor R_5 is obtained as follows:

$$I_5 = \frac{E_5}{R_5}$$

$$= \frac{3.5}{1}$$

$$= 3.5 \text{ amperes}$$

14-10. The conditions that exist in a balanced bridge can be seen by solving the circuit of figure 47 for current I_5 through resistor R_5. The first step is, of course, to resolve one of the delta circuits into its equivalent star circuit, as follows:

$$R_a = \frac{R_1 \; R_3}{R_1 + R_3 + R_5}$$

$$= \frac{10 \times 10}{10 + 10 + 5}$$

$$= 4 \text{ ohms}$$

$$R_b = \frac{R_1 \; R_5}{R_1 + R_3 + R_5}$$

$$= \frac{10 \times 5}{10 + 10 + 5}$$

$$= 2 \text{ ohms}$$

The circuit resolves into that shown in part B of the figure. The total resistance of the circuit is then computed as follows:

$$R_T = R_a + \frac{(R_b + R_2) \quad (R_c + R_4)}{(R_b + R_2) + (R_c + R_4)}$$

$$= 4 + \frac{(2 + 10) \quad (2 + 10)}{(2 + 10) + (2 + 10)}$$

$$= 10 \text{ ohms}$$

The total current, I_T, is calculated next.

$$I_T = \frac{E_T}{R_T}$$

$$= \frac{100}{10}$$

$$= 10 \text{ amperes}$$

The total applied voltage, E_T, minus the voltage drop across resistance R_a, will be the voltage, E, applied to the parallel arms of the circuit.

$$E = E_T - I_T R_a$$

$$= 100 - (10 \times 4)$$

$$= 60 \text{ volts}$$

Calculating branch currents, I_{AB} and I_{AC}, yields:

$$I_{AB} = \frac{E}{R_2 + R_b}$$

$$= \frac{60}{12}$$

$$= 5 \text{ amperes}$$

$$I_{AC} = \frac{E}{R_4 + R_c}$$

$$= \frac{60}{12}$$

$$= 5 \text{ amperes}$$

Voltage E_4 across resistor R_4 and voltage E_2 across resistor R_2 are calculated as follows:

$$E_4 = I_{AC} R_4$$

$$= 5 \times 10$$

$$= 50 \text{ volts}$$

$$E_2 = I_{AB} R_2$$

$$= 5 \times 10$$

$$= 50 \text{ volts}$$

Voltage E_5 applied across resistor R_5 is:

$$E_5 = E_4 - E_2$$

$$= 50 - 50$$

$$= 0 \text{ volts}$$

Finally, current I_5 through resistor R_5 is:

$$I_5 = \frac{E_5}{R_5}$$

$$= \frac{0}{5}$$

$$= 0 \text{ amperes}$$

14-11. *Mesh Circuits.* The other difficult circuits mentioned in the discussion on complex dc circuits were the mesh circuits. They are good examples of difficult circuits which you will have to compute when troubleshooting electronic circuits. An example of a mesh circuit is shown in figure 48. Notice that there are two batteries connected in parallel with a 100-ohm resistor connected in series. Also, we can see that a complete circuit, called a loop, consists of the 50-volt battery, its internal resistance (0.3 ohm), and the 100-ohm resistor. A second complete circuit or loop is formed by the 10-volt battery, its internal resistance (0.1 ohm), and the 100-ohm resistor. The 100-ohm resistor is a common element to both loops. A series of interconnecting branches that form complete circuits, or loops, its termed a *mesh circuit*. Please note that although you know that electron flow is accepted as from negative to positive, we are using it differently here simply for the purpose of figuring the internal resistance of the batteries before considering the external circuit.

14-12. We can solve for the total current in a mesh circuit by using Kirchhoff's law. Since the 100-ohm resistor is common to both circuits, it will be necessary to work two equations at the same time. The values of the unknowns will satisfy both equations. The equations are called simultaneous equations. The number of equations necessary to solve simultaneous equations is equal to the number of unknowns involved.

14-13. Simultaneous equations are used to solve technical problems such as finding the current in mesh circuits or calculating the impedance in a bridge circuit. Such problems often involve several unknown quantities, and an equation for such a circuit cannot be written that involves only one unknown quantity. The two general methods that may be used to solve these equations are addition or subtraction, and substitution. You may use either of these methods.

14-14. *Addition or subtraction method.* Simultaneous equations can either be added or subtracted to eliminate all but one of the unknowns. The resulting equation can then be solved for the unknown quantity. The following guidelines can now be used to find the variable quantities in two simultaneous equations.

14-15. Write the equations so that the variable terms are on the left-hand side and the constant terms are on the right-hand side of the equation. The coefficients of one of the variable quantities must have an equal-absolute value in both equations. If necessary, multiply one or both of the equations by a number that will satisfy this condition.

14-16. If the two coefficients of equal-absolute value have like signs, subtract one equation from the other. If they have unlike signs, add the two equations. The resulting equations will have only one variable. Then solve the resulting equation of one variable in the following manner.

14-17. Substitute the value of the variable quantity in one of the original equations. Now solve for the remaining variable. Check the solution by substituting the values that have been found for the variables in both the original equations.

14-18. Simultaneous equations $2x = y$ and $6x + 2y = 25$ can be solved as shown below. Write the equations as follows:

$$2x - y = 0 \text{ (this is the same as } 2x = y)$$
$$6x + 2y = 25$$

Multiply the top equation by 2 and add the two equations.

$$\begin{array}{rcl} 4x - 2y & = & 0 \\ \underline{6x + 2y} & \underline{=} & \underline{25} \\ 10x \qquad & = & 25 \end{array}$$

$$x = \frac{5}{2}$$

Substitute 5/2 for x in equation $2x - y = 0$ and solve for y.

$$2x - y = 0$$

$$2\left(\frac{5}{2}\right) - y = 0$$
$$y = 5$$

Check the solution by substituting 5/2 for x and 5 for y in the equation $6x + 2y = 25$.

$$6x + 2y = 25$$
$$6(5/2) + 2(5) = 25$$
$$15 + 10 = 25$$
$$25 = 25$$

Therefore, the values for x and y satisfy both equations.

14-19. Inspection of the circuit in figure 48 shows all of the open circuited battery voltages; these are the applied voltages. All of the resistor values are shown, and you may compute the circuit currents using Kirchhoff's law. The voltages around loop ABCDEHA, according to Kirchhoff's law, are:

$$-100I_R + 10 - .1I_1 = 0$$

The voltages around loop ABCFGHA are:

$$-100I_R + 50 - 0.3I_2 = 0$$

Also, the circuit current I_R consists of a current I_1 delivered to the 100-ohm resistor by the 10-volt battery, and a current I_2 delivered to the same resistor by the 50-volt battery. Applying Kirchhoff's law, you will obtain:

$$I_R = I_1 + I_2$$

Three equations having three unknowns, and rearranged, will appear as follows:

$$100I_R + 0.1I_1 = 10$$

$$100I_R + 0.3I_2 = 50$$

$$I_1 + I_2 = I_R$$

In the above equations we have three unknowns. Before we can work the problem we must reduce that to two. We can do this by substituting for I_R. Since in the equations we have shown that $I_R = I_1 + I_2$, where I_R appears we can substitute $(I_1 + I_2)$. Thus, the first equation would be as follows:

$$100(I_1 + I_2) + 0.1I_1 = 10$$

$$100I_1 + 100I_2 + 0.1I_1 = 10$$

$$100.1I_1 + 100I_2 = 10$$

Similarly, for the second equation:

$$100(I_1 + I_2) + 0.3I_2 = 50$$

$$100I_1 + 100I_2 + 0.3I_2 = 50$$

$$100I_1 + 100.3I_2 = 50$$

14-20. *Substitution method.* We will use another method to solve the simultaneous equation, the substitution method. First, select one of the resulting equations which can be used to solve for the value of I_2 in terms of I_1, as follows:

$$100.1I_1 + 100I_2 = 10$$

$$I_2 = \frac{10 - 100.1I_1}{100}$$

This can now be used as a substitute in the other resultant equation to eliminate another unknown quantity, as follows:

$$100I_1 + 100.3\left(\frac{10 - 100.1I_1}{100}\right) = 50$$

$$10000I_1 + 100.3(10 - 100.1I_1) = 5000$$

$$10000I_1 + 1003.0 - 10040.03I_1 = 5000$$

$$-40.03I_1 = 3997$$

$$I_1 = \frac{3997}{-40.03}$$

$$I_1 = -99.8 \text{ amperes}$$

Substituting the value of current I_1 into the second equation and solving for the value of I_2 yields:

$$100\,(-99.8) + 100.3I_2 = 50$$

$$-9980 + 100.3I_2 = 50$$

$$100.3I_2 = 50 + 9980$$

$$100.3I_2 = 10030$$

$$I_2 = \frac{10030}{100.3}$$

$$I_2 = 100 \text{ amperes}$$

Substituting the values of current into the equation from Kirchhoff's second law, we find:

$$I_T = -99.8 + 100$$
$$I_T = .2 \text{ amperes}$$

14-21. Notice that the current I_1 is negative. This indicates that current I_1 is flowing in the opposite direction of that assumed for I_2. It is unwise to connect two batteries in parallel that have different output voltages, because the battery with the higher voltage will send a charging current through the battery with the lower voltage. However, it is not uncommon to find this circuit used in electronic equipment such as transistors where a different potential is connected in parallel to obtain certain circuit functions.

14-22. The voltage distribution in this circuit can now be calculated from the known values of current and resistance, using Ohm's law:

$$E_1 = I_1R$$
$$= -99.8 \times 0.1$$
$$= -9.98 \text{ volts}$$

$$E_2 = I_2R$$
$$= 100 \times 0.3$$
$$= 30 \text{ volts}$$

$$E_R = I_TR$$
$$= 0.2 \times 100$$
$$= 20 \text{ volts}$$

$$E_T = 30 + 20 - 9.98$$
$$= 40.02 \text{ volts}$$

14-23. Some of you may ask the question, "Where in the world will I ever use this stuff?" Well, during your next experience with circuit diagrams having transistors, you will see that they are nothing more than a simple mesh circuit. These circuits are connected with voltage divider networks that supply the different voltages. You can compute the current through the different legs of the circuit by knowing the junction resistances. There will be many times when the knowledge you have gained will aid you in understanding the overall operation of complicated generator circuits on our modern aircraft.

CHAPTER 7

REACTORS IN CIRCUIT RELATIONSHIPS

THE COUNTDOWN was proceeding as scheduled, 10... 9... 8; tension filled the room; 3... 2... 1,... ignition, ... liftoff. Three men were on their way to the moon. Several hours later two of those men became the first human beings to set foot on another planet. It's hard to believe that it was 10 short years ago that man first ventured outside of his own atmosphere. The great advances made in technology have made this feat possible. These same advances have changed your job as an aircraft electrician.

2. With the rapid growth of our technology has come a change in the systems we electricians are required to maintain. More and more our systems are becoming less mechanical and more electronic. Therefore, the need has increased for a broad background in the fundamentals of electronics. The days of the "shade tree electrician" are gone forever. Our major systems are so integrated with those of other major systems that you must be able to understand how the operation of each component will affect the efficiency of the entire aircraft. Relays are being replaced by solid state switching devices. Most modern generator control components have been transistorized. These are but a few of the changes that have taken place.

3. In the previous chapter we spent some time discussing complex dc circuits. Since most power and control systems are ac, we need to take a good look at how components react in ac circuits.

15. Reactance and Frequency in Circuits

15-1. The characteristics of alternating current were not clearly understood until the end of the last century. The efficient use of alternating current as a source of electrical power is a comparatively recent development. In fact, the older sections of some American cities, such as New York City, are still supplied with direct current. Alternating current gradually became recognized as a more suitable source of power. In addition, alternating current can be easily converted to direct current.

15-2. *Alternating Current.* Alternating current is an electrical current that is continually changing in amplitude and periodically changing in direction. A waveform of alternating electrical power is shown in figure 49. From a value of zero, alternating current builds to a maximum amplitude flowing toward a reference point, then decreases again to zero. This is followed by an increase in amplitude to maximum away from the reference point, then a decrease again to zero.

15-3. *Instantaneous and peak values.* The instantaneous value of a sine wave voltage or current is the value of the voltage or current generated at any instant in time. Instantaneous values are generally indicated by small letters, such as e (voltage) and i (current).

15-4. The peak value of a sign wave voltage or current is the maximum value that can be obtained with given circuit conditions. Peak values are indicated as E_{max} or I_{max}.

15-5. *Average value.* The average value of a complete sine wave of voltage or current, based on a zero reference level, is zero. The reason for this is that the negative loop of the wave has the same amplitude as the positive loop but is the opposite in sign. Average value is a term applied to alternating voltage or current and is restricted to the average value of one alternation.

15-6. *Phase.* Phase is defined as the difference in time between any point on a cycle with reference to either the beginning of that cycle or some other cycle. The beginning of a cycle is generally taken to be the point at which the cycle passes through zero amplitude while moving in a positive direction. Such consideration of phase is of immediate practical importance when the current and voltage cycles start at different times or when multiple currents or voltages are simultaneously present.

15-7. When two alternating currents or voltages, increasing in the same direction, cross all zero amplitude points at the same time, they are said to be *in phase.* This in-phase relationship is shown in figure 50. When two alternating currents are applied to *resistive* circuits, the voltage and current are always in phase. That is, they increase and decrease, and reverse direction at the same time.

15-8. When two alternating voltages or currents are not increasing in the same direction, or do not cross all zero amplitude points at the same instant, they are said to be *out of phase*. When alternating currents are applied to circuits that are not resistive, the voltage and current are normally out of phase. Conditions of out-of-phase relationships are shown in figure 51. Later in this section, more will be said about the conditions of lead or lag, as shown in parts A and B of the figure.

15-9. The refresher paragraphs you have just read should be reason enough for us to talk in the same language. Although you should remember most of the terms that deal with ac, it is good to review them to refresh your memory. In paragraph 15-8, we spoke of a circuit that was not resistive. If a circuit is not resistive, it is reactive. Circuit reactance and its causes and effects is the next topic for discussion.

15-10. *Reactors.* As an electrical technician, you have encountered the two basic reactors, the capacitor and the inductor (coil). These two reactors in a circuit cause reactance. This reactance is either capacitive reactance or inductive reactance. As our systems are changed to be more electronic, your knowledge of the reactors and their effects will become more and more important. Here is an example of a related and interesting problem. The electricians at a base having C141's were having much difficulty with the commode flushing circuit. This circuit was a simple RC time circuit. When questions were asked, it was apparent that training was needed on how capacitors worked. Therefore, we will briefly review and expand upon your knowledge of capacitors and inductors.

15-11. *Capacitors.* A capacitor is an electrical device constructed of conductive materials that are separated by an insulator. The conductive materials are referred to as the plates, while the insulating material is called the dielectric material. The dielectric may be in a solid, liquid, or gaseous state.

15-12. You should recall that the unit of measure of capacitance is the farad. This unit, however, is too large for practical circuits. A more convenient unit is the microfarad, which is equal to one-millionth of one farad (1×10^{-6} farad). The value of a capacitor is generally marked on the body of the capacitor by one of two methods:

- Color coding.
- Printing or stamping.

15-13. When the voltage appearing across the plates of a capacitor becomes too high, dielectric rupture or breakdown may occur. Such a breakdown would permit an electrical arc between the capacitor plates. If the dielectric ruptures on a permanent basis, the capacitor is useless. The voltage required to break down the dielectric varies with the kind of material used and with the thickness of the material. Thus, a large voltage would be required to break down a nearly perfect vacuum, but a capacitor using air dielectric one-thousandth of an inch thick would break down at 80 volts. If the air space is increased ten times this value (one-hundredth of an inch), the breakdown voltage increases in direct proportion up to 800 volts. Commercial capacitors are normally marked to indicate the working voltage. The working voltage of a capacitor designates the limit of safe peak ac, peak pulsating dc, or steady dc voltage that may be applied continuously across the capacitor without danger of voltage breakdown.

15-14. During their manufacture, capacitors may be subjected to production and environmental factors which can cause the value of an individual unit to be other than the intended value. Tolerance ratings are established by two different methods. The first method is by means of a set percentage variation, such as 5, 10, and 20 percent. The second method is expressed in terms of the actual picofarad variation of the capacitor. The prefix "pico" means 1×10^{-9}. This method is usually reserved for small capacitors of less than 10 picofarads. Enough said about the capacitor. You will remember most of the things we have mentioned here. The other reactor to be reviewed is the inductor, whose applications in circuits are many and varied.

15-15. *Inductors.* An inductor may take any number of physical forms or shapes. Basically, it is nothing more or less than a coil of wire and a core material. This unit operates according to the self-induction principle. Inductors can be broadly classified with respect to core material and also with respect to adjustability. Some inductors are classified with respect to their physical shape and to the manner in which wires are wound around the core. *Choke* and *reactor* are popular names used to designate an inductor.

15-16. Inductors, like capacitors, come in many shapes and sizes. Their shapes and sizes are as varied as their application. However, inductor ratings are different from those of the capacitor. The capacitor has a capacitance rating, whereas the inductor has an inductance rating. The unit of measurement of inductance is the henry. The number of henries is usually stamped or printed on the inductor. In many instances, you will find that the only identification is a number. This number is usually the manufacturers' code number for the specific unit. You must refer to some parts catalog to convert this code number into the inductance value. This is an average value, as the inductance will vary with frequency.

15-17. The current rating is that value of magnetizing current which places the permeability of the core material just below the knee of the saturation current curve. This is the same point where the inductance of the unit is at its specific value. This is not to be interpreted as being the maximum current through the windings without damaging the inductor. Insulation ratings are necessary in some applications, such as power supply filters, where operating voltages are normally high. Two fairly standard insulation ratings are 1500 volts rms and 3000 volts rms. Now that we have discussed the physical characteristics and ratings of the two most common reactors, the capacitor and the inductor, we shall discuss them in their proper environment for the purpose of better understanding the effect they have upon a circuit.

15-18. *Reactance.* The opposition offered to a specific change of current by a reactor is measured during any given instant in terms of counter emf, that is, the voltage which opposes the applied emf. In dc circuits, however, any opposition to current flow is termed resistance and is measured in ohms. In ac circuits, it is also convenient to measure reactive opposition in terms of ohms rather than in terms of volts or counter emf. This type of alternating-current opposition is called inductive reactance or capacitive reactance. It is assigned the symbol X_L for inductive reactance and X_C for capacitive reactance.

15-19. *Phase shifts.* Reactors used in ac circuits exhibit the same behavior as they do when placed in dc circuits. One reason that they appear to react differently is that ac is continuously changing in amplitude. As a result, the reactor is never permitted enough time to exhibit the characteristic exponential behavior observed in dc circuits. (This behavior was explained in your previous training.) Because a counter emf exists, there is a delayed current-voltage relationship. This delay between current and voltage is called phase shift. Phase shift may be either in the form of lag or lead, as shown in parts A and B of figure 51.

15-20. If we investigate the phase shift produced by an inductive circuit, as seen in part A of figure 52, it will show the relationship between voltage and current. These phase relationships are shown in part B of figure 52. The inductor current is zero when the applied voltage is maximum, and it is maximum when the applied voltage is zero. Consequently, the current through an inductance is said to lag the applied voltage by 90 electrical degrees.

15-21. The changing voltage across a capacitor produces the current through it. An examination of the voltage waveform across the capacitor, as shown in figure 53, shows its relationship to the current produced. As you can see on the figure, the phase of the circuit current can be taken with respect to either the applied voltage or the counter voltage. By conventional standards, the phase relationship of current and voltage is based upon the applied voltage. Therefore, the capacitor current leads the applied voltage by 90 electrical degrees. You should remember that if a circuit has an equal amount of inductive reactance and capacitive reactance, they will cancel each other and the total reactance will be zero.

15-22. *Reactance versus frequency.* The variation of reactance as a function of frequency can now be discussed. As you might reason from the reactance equations, the reactor has no set value of opposition to ac until a definite frequency is specified. There are two ways to investigate the characteristics of reactance.

(1) Maintain a given value of reactance while the frequency is changed.
(2) Maintain a given frequency while the value of the reactor is changed.

The formula for computing capacitive reactance (X_C) is as follows:

$$X_C = \frac{1}{2\pi f C}$$

The formula for computing inductive reactance (X_L) is as follows:

$$X_L = 2\pi f L$$

15-23. As you can see, the relationships of capacitance and inductance to frequency are opposite. As frequency increases, capacitive reactance decreases, while with the same increase in frequency, inductive reactance increases. It may be said that capacitive reactance is inversely proportional to frequency, and inductive reactance is directly proportional to frequency. Listed below are two problems involving the capacitive and inductive reactance formulas. These examples will help you better understand the principles of frequency versus capacitive and inductive reactances.

15-24. Suppose that a 0.05-microfarad capacitor is selected, and that the input frequency is 20 Hertz (Hz). The capacitive reactance can be worked as follows:

$$X_C = \frac{1}{2\pi f C}$$

$$= \frac{1}{2\pi(20)\ (0.05 \times 10^{-6})}$$

$$= \frac{1}{6.28\ (1 \times 10^{-6})}$$

$$= \frac{10^6}{6.28}$$

$$= 0.159 \times 10^6$$

$$= 159 \text{ K ohms}$$

15-25. Now you try one. Increase the frequency from 20 to 200 Hz in the same problem. If you work the problem correctly, you will find the relationship of frequency to reactance is the same as discussed earlier. Your answer should be 15.9 K ohms. Remember, capacitive reactance is inversely proportional to frequency. As the frequency increased 10 times, the capacitive reactance was lowered 10 times.

15-26. Inductive reactance is directly proportional to frequency. Suppose that an 88-millihenry inductor is selected. Assume the input frequency to be the same as in the capacitive problem, 20 Hz. You would compute the problem this way:

$$X_L = 2\pi f L$$

$$= 6.28\ (20)\ (0.088)$$

$$= 11 \text{ ohms}$$

Again increase the input frequency to 200 Hz.

$$X_L = 2\pi f L$$

$$= 6.28\ (200)\ (0.088)$$

$$= 110 \text{ ohms}$$

As the frequency was increased 10 times, the inductive reactance increased 10 times. You may need to review RC, RL, and RCL circuits. We will make some application of these circuits in the next section.

16. Circuit Application of Reactors

16-1. After resistance, inductance, capacitance, reactance, and impedance, what else can there be? By way of answer, let us say that there are only two more important factors that have to be considered.

16-2. Any combination of inductive reactance, capacitive reactance, and resistance forms the total opposition (impedance, or Z) to current flow in an alternating-current circuit. In circuits that contain both inductive reactance, X_L, and capacitive reactance, X_C, find the circuit impedance (Z) by subtracting the smaller reactance from the larger reactance. There is a special condition where X_C and X_L are exactly equal to each other. Since they are opposite, in effect, the impedance becomes zero. At this time the circuit is said to be in resonance.

16-3. *Series Resonance.* If a coil and a capacitor are connected in series with a variable-frequency source of alternating current, as in figure 54, the combination of parts is known as a series-tuned circuit. Since the windings of the coil in such a circuit have a certain amount of resistance, the effect of resistance must be considered in the operation of this circuit. The inherent resistance of the circuit and the coil is indicated in the figure as resistor R. If the ac source is set at a low frequency, the greatest opposition to the flow of current in the circuit results from the reactance of the capacitor. If the ac source is adjusted to a high frequency, the greatest opposition results from the reactance of the inductor. In other words, at low frequencies the reactance of the circuit is mainly capacitive, while at high frequencies the reactance is mainly inductive.

16-4. At only one frequency between the high and low extremes will the inductive reactance equal the capacitive reactance. This frequency is known as the resonant frequency of the circuit, and the series circuit is said to be tuned to that frequency. Since the inductive and the capacitive reactances produce opposite effects, they cancel each other. This means that the only opposition to the current flow is that offered by the resistance, R.

16-5. The current flowing in the circuit shown in figure 54 can be measured by an ammeter. If the source frequency is increased gradually from a low to a high value, the current will increase until it reaches a maximum value at the resonant frequency, then will decrease. These actions of increasing and decreasing current are shown in figure 55.

16-6. Remember, the current flow in the circuit is determined by the impedance of the circuit. Therefore, the impedance of a series-resonant circuit is at its lowest (minimum) value at the resonant frequency. This is shown in figure 55. The impedance is greater on either side of the resonant frequency, as shown.

16-7. The voltage drop across each element of the circuit is proportional to both the current flow and the opposition offered by each element. Since the current flowing in a series circuit is maximum at the resonant frequency, the voltage as measured across each unit is greatest at the resonant frequency. The voltages across the coil and the capacitor of the series circuits, as shown in figure 56, are equal in amount and opposite in polarity at the resonant frequency. These voltages are very high, even when a source voltage of only 1 volt is applied. Either one of these two voltages (across the capacitor or across the coil) may be used to operate other circuits, since a marked increase in voltage appears across each component at the resonant frequency. This voltage increase, at a particular resonant frequency, is one of the important effects of tuned circuits.

16-8. The preceding statements may seem hard to believe at first. However, the mathematics of electrical circuits further prove the truth of this seeming paradox. In the series-resonant circuit, shown in item A of figure 56, the reactances (X_C and X_L) are each equal to 940 ohms. Since they cancel each other in the impedance formula:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

the 7.5 ohms of resistance remain as the only opposition to current flow. With 1 volt impressed upon the circuit, the resultant current, as determined by Ohm's law, is 0.133 amp. To find the voltage across the capacitor or inductor, it is necessary to multiply X_L and X_C by the current flow in the circuit (940 X 0.133 = 125 volts). The voltage across the resistor is found by multiplying the value of the resistance by the current which is flowing through it (7.5 X 0.133 = 1 volt).

16-9. In item B of figure 56, a graph has been plotted to show the variation of current through the circuit as the frequency is varied from a point below resonance, through resonance, and then above the resonant frequency. Below resonance, the capacitive reactance is greater than the inductive reactance. In practical circuits the resistance, R, is purposely kept to a low value. Although it is shown on the figure as a separate component, it actually represents the inherent resistance of the inductor and the connecting leads. At frequencies appreciably above or below the resonant frequency, the current flow is determined chiefly by reactance. At these frequencies, the resistance (R) is so small in comparison with the total reactance that the resistance is no longer considered an important circuit factor.

16-10. When a circuit is at resonance and the value of either the coil or the capacitor is changed, the resonant frequency of the circuit is also changed. If either the capacitance (NOTE: capacitance, not capacitive reactance) or the inductance or both are increased, the resonant frequency of the circuit is decreased. Conversely, if either the capacitance or inductance or both are decreased, the resonant frequency is increased. By making either the inductor or the capacitor in the circuit variable, the circuit could be adjusted or "tuned" to be at resonance over a wide range of frequencies. The limits of the frequency range over which the circuit can be tuned will depend on the value of the fixed element and the maximum and minimum values of the variable element.

16-11. The resistance present in a resonant-tuned circuit determines the amount of selectivity of which the circuit is capable. Resonance curves for three different values of resistance (R), as shown in figure 54, are shown in figure 57. These curves are the same type as those shown in figures 55 and 56, where current is plotted against the frequency. The current flowing in a tuned circuit, when equal voltages of many different frequencies are applied to the terminals, is composed principally of frequencies at, and very near to, the resonant frequency of the circuit. As resistance is added to the circuit, the total resonant current is reduced in such a manner that a nearly uniform but reduced resonance curve is obtained.

16-12. *Parallel Resonance.* If a coil and a capacitor are connected in parallel, as in figure 58, the combination is known as a parallel-tuned circuit. As in the series-tuned circuit, whatever resistance is present in the circuit elements is indicated on the diagram by resistor R. Since the coil and the capacitor are both connected in parallel across a variable frequency source of alternating current, there are two paths through which the current may flow, one path through the inductor and the other through the capacitor. If the ac source is set at a low frequency, the greatest current will flow through the coil. The reason for this is that the reactance of the coil at the low frequency is small and the reactance of the capacitor is high. If the source of voltage is set to a high frequency, most of the current will flow in the capacitive branch. The reason for this is that the reactance of the capacitor at the higher frequency is low and the reactance of the inductor is high.

16-13. At the resonant frequency, the same as with the series-tuned circuit, the reactance of capacitor C is equal to the reactance of inductor L. Unlike the series circuit, the capacitor and inductor are in parallel. The current flowing through the inductor is opposite in polarity to the current flowing through the capacitor. With the inductive reactance equal to capacitive reactance at the resonant frequency, the currents flowing through the two reactances are equal in value as well as opposite in polarity. Consequently, they tend to cancel each other so that the current flowing in the line circuit is minimum.

16-14. The current flow may be read from the ammeter (A), as shown in figure 58. As the applied voltage is varied from a frequency well below the resonant frequency, through resonance, and to a higher frequency, the line current changes. It varies from a high value at the lower frequencies to a minimum at resonance, and then rises again to a high value at the higher frequencies.

16-15. The line current is the differnce between the currents flowing through the inductive and capacitive branches of the circuit, as shown in figure 59. Because of the presence of the inherent electrical resistance (straight dc resistance) in the inductor, while none is present in the capacitor, the two branch currents never cancel each other completely. As shown, the line current curve reaches a minimum value when the other two lines cross (resonance), but does not decrease to zero value. The lower the inherent resistance, the lower will be the current taken from the line. Although the line current draw may be very small, there is a current circulating between the coil and capacitor which may be very large.

16-16. Assume that a capacitor in a parellel-tuned circuit is charged by means of a battery, as in item A of figure 60. As the switch is moved away from the battery connection, the capacitor retains that stored charge. Next, the switch is moved to make contact with the terminal of the inductor (coil), as shown in item B of the figure. When connected to the coil, the voltage stored in the capacitor causes current to flow from the lower plate, through the coil, and toward the positive plate of the capacitor. As the current moves through the coil, a magnetic field is built up about the coil, as shown in item B. When the capacitor is discharged, a self-induced voltage is generated in the coil by the collapsing flux. This action is shown in item C of the figure. The direction of induced voltage maintains the current flow in the same direction.

16-17. Current flow, caused by self-induction of the coil, allows the condenser to become charged with an opposite polarity. Thus, before the magnetic field about the coil has completely collapsed, the capacitor is charged once again. Because of the newly stored voltage and a complete circuit, a current will begin to flow in the opposite direction, as shown in item D. Thus the whole process is repeated over again.

16-18. To summarize, the energy in the circuit which originally came from the battery is first stored in the capacitor. The energy is then transferred to the magnetic field about the inductor by the current flowing in the circuit. This current is alternating, since it reverses its direction at regular intervals. This process would repeat itself indefinitely if the circuit contained no resistance. Since all circuits contain some resistance, the process will continue only until the energy which has been applied to the circuit has been spent by the resistance of the circuit.

16-19. In order to produce a sustained alternating current, it is necessary to supply sufficient power to such a circuit to overcome the resistance losses. The current taken from the line is very small when compared to the current oscillating within the circuit.

16-20. The line current in a parallel-resonant circuit is minimum at the resonant frequency. This means that the impedance of the circuit must be maximum at the resonance. It also means that circuit impedance decreases at the frequencies on either side of the resonant frequency.

16-21. *Uses of Resonant Circuit.* As has been mentioned previously, one of the most common uses of the series-resonant circuit is to tune a radio to a station. This is what you do when you turn the tuning knob from one station to another in attempting to find a ballgame broadcast. The circuit components in the radio are set up where $X_L = X_C$ at any desired frequency. This allows only currents at that frequency to flow from the aerial into the receiver. All other frequencies are blocked by the high reactance of either the capacitor or the inductor.

16-22. Another application of the series-resonance principle is in the speed control circuit of certain motor-generator sets that are designed to operate at a predetermined speed. The electrical circuit for such a speed control circuit is shown in figure 61. Included in the design of the unit is a voltage winding, item C, in which an alternating voltage is generated as the motor rotates. The voltage generated is applied through the rectifier bridge, item B, whose function is to change the ac

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to dc within the motor control field, item A. The circuit is then completed through a fixed capacitor, item D, and a variable inductor, item E, which together form a series-resonant circuit. As the rpm of the motor rises above its predetermined operating speed, the frequency output of the voltage winding will cause a resonant condition in the control circuit. The large current resulting from this series-resonant circuit condition flows through the motor control field (A), where it reacts with the magnetic field of the armature to reduce motor speed. At low motor speeds, the frequency of ac generated in the voltage winding (C) is low, and the high impedance of the control circuit limits the current flow through the motor control field to a very low value. For this reason, at all frequencies other than the resonant frequency, the small amount of current allowed to flow through the motor control field will not affect motor speed. As the speed of the motor and the frequency output of the voltage winding increase, the value of inductive reactance approaches the capacitive reactance value in the control circuit. When the resonant frequency is reached, the two reactance values are exactly equal, at which time the only opposition to current flow through the motor control field is the comparatively small resistance of the speed control circuit. As the resulting high current reduces motor speed, the frequency output of the voltage coil decreases, and the circuit reactance increases to a point where the motor control field is no longer effective. This condition allows the motor speed to increase again, slightly, until resonance is reached, whereupon the same cycle of events will take place. The net effect of this control circuit is to maintain a motor rpm at that speed required to produce a resonant condition in the control circuit.

16-23. Since the voltage generated in the voltage winding is an alternating voltage, two different arrow lengths are used on the circuit schematic diagram to assist you in following the flow of current in the circuit. The short arrows indicate the path of current when the voltage is generated with one polarity, and the longer arrows indicate the path of current flow when the polarity of the voltage is reversed. Because the current flow through the rectifier bridge always passes through the motor control field in one direction, it is a direct current. Now that we have covered some of the uses of series-resonant circuits, what about uses of parallel-resonant circuits?

16-24. The impedance of parallel-tuned circuits is very high at the resonant frequency and low at all other frequencies. For this reason, they are used in vacuum tube circuits to generate, detect, and amplify small signals of a given frequency. You will find some applications of resonant-type circuits in multi-generator power systems. Since you have been in the electrical field for some time, you are very aware that troubles can occur in power systems. Therefore, let's discuss ways of diagnosing malfunctions in multi-generator power systems.

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CHAPTER 8

DIAGNOSING MALFUNCTIONS IN A MULTI-GENERATOR DC POWER SYSTEM

A DC GENERATOR system--an old hat, you say? Well maybe, but there are a number of aircraft whose primary power systems are dc. In fact, during a tour in Vietnam we were surprised to find that some 7-level electricians had trouble working on aircraft whose primary power systems were dc. Many of these electricians had never worked on a dc generator system before.

2. As a 7-level technician you will be required to work on many different types of aircraft. Some may be familiar, and others may not. In any case, you will have the job. In this chapter we will discuss a dc generator system, a type you may have to work on if you haven't done so already. The first thing that comes to mind is, what do we need to know to troubleshoot a dc generator system? How about operation? We cannot possibly know when something is wrong if we do not know what is considered to be right.

3. The above statement puts us right into the middle of a technical order, the place to find out how the system operates. Usually, you are presented this problem, that is, your troubleshooting job begins--when you are handed some kind of work order that tells you, among other things, that a trouble exists in the generator system. Then, to top it off, you realize that you have never worked on this type of aircraft before. Now let's assume that you go out to the aircraft and have a look.

17. Generator System and Component Operation

17-1. As you appraoch the aircraft, the engineer comes out to meet you. "We sure got one this time. Number 1 generator won't stay on the line, and that's all I can tell you." Now it looks like you have a good one on your hands. So, where are you going to start? You are right, get out the technical order and read up on the generator system. Now let's see what the technical order can tell you about the system.

17-2. *DC Power Supply System.* The primary dc power supply is furnished by six engine-driven, 30-volt-dc generators, rated at 350 amperes each. As a reserve supply of dc electrical power for operating certain electrical units, two 24-volt, 36-amp-hour batteries are provided. These generators and batteries are connected for parallel operation to supply electrical power to the distribution buses.

17-3. The generator system includes feeder and internal generator ground-fault protection, undervoltage protection, overvoltage protection, differential current, and reverse-polarity protection. Each generator is controlled by a carbon-pile type voltage regulator, an overvoltage control panel, and switches at the flight station.

17-4. Manual control of the dc generating system is provided by the following: six generator switches, six generator field circuit breakers, three dual dc ammeters, a dc voltmeter, six generator overheat warning lights, and six field relay trip warning lights. These controls are all mounted at the flight engineer's station.

17-5. The generator manual control switches are four-pole double-throw, with ON-OFF positions, and a momentary position identified on the switch panel by the marking GENERATOR SWITCHES DOWN TO RESET FIELD RELAYS. Moving the generator switch to the ON position will connect the generator to the bus if all circuit conditions are correct, if the generator is delivering rated voltage, and if enough load is applied to the bus to produce the required equalizer action.

17-6. Operating the generator switch to the momentary (down) position, with power on the bus, will reset the field relay if it has been tripped by overvoltage or inadvertently left in the tripped position. This also flashes the generator field through a current limiting resistor to assure correct polarity of the generator voltage.

17-7. Moving a generator switch to the OFF position will disconnect the generator from the bus. However, it will not open the field circuit. In this way, the generator voltage may be checked with the generator disconnected from the bus.

17-8. The generator field circuit breakers are switch-type automatic breakers for emergency use only. They are normally closed. They are to be opened to the OFF position only when it is necessary to deenergize the generators in the event of a malfunction of the system.

17-9. The dc voltmeter is connected to the line through a rotary-type selector switch. This makes possible voltage readings of the batteries, of each of the six engine-driven generators, and of the main bus. The dual dc ammeters indicate the output of each of the generators.

17-10. This brief description of the overall generator system has given you only a general working knowledge of the system. If you are going to determine why the generator will not stay on the line, you are also going to need a working knowledge of the generator system components.

17-11. *Generator System Components and Circuit Operation.* If you will check figure 62, you will see that the generator system contains a number of components, most of which can cause trouble. Our discussion will include all of these components and their operation. We will start with the generator.

17-12. *Generator.* The generator is self-excited, and has a shunt-connected field assembly (see fig. 62). When the engine-driven armature assembly is rotated within the yoke assembly, its armature coils cut the residual magnetic field existing in the field poles of the generator. The small voltages induced in the armature coils are collected from the armature by the brushes. These small armature-coil voltages cause a flow of direct current through the field coil assembly, increasing the intensity of the magnetic field. This, in turn, causes higher induced voltages, increased field current, and still higher field intensity. Since the value of the induced voltages is also proportional to the speed of armature rotation, generated voltage continues to build up as the speed of the generator increases. When generated voltage reaches a value coinciding with the setting of the voltage regulator, the voltage regulator prevents further increase in field current. The voltage regulator will maintain a constant generated voltage by automatically adjusting the field circuit resistance. However, the regulator allows the field current to increase when the voltage decreases, because of load application or decrease in speed.

17-13. *Voltage regulator.* The voltage regulator is, essentially, an automatic generator field rheostat that maintains a constant output voltage by automatically controlling the generator field current. A view of a voltage regulator and its circuitry is given in figure 63. The electrical schematic in figure 63 is an enlarged view of the one shown in the lower left corner of figure 62. The regulator voltage coil is connected through an adjustable rheostat across the dc output circuit, from L- to L+. The carbon pile is electrically connected in series with the generator field circuit, from G+ to F+. When generator voltage rises above the voltage at which the regulator has been set, the current in the voltage coil increases. This action increases the magnetic attraction of the armature core and relieves pressure of the armature diaphragm on the carbon pile. The carbon discs in the pile tend to separate, increasing the resistance of the pile. The result is a decreased generator field current and output voltage. When the generator voltage falls below the voltage at which the regulator has been set, reverse reactions take place. The carbon pile is compressed, thus increasing field current and output voltage.

17-14. In parallel generator operation, the voltage regulators equalize the output of the generators by reducing the voltage of the generator carrying the greater load and increasing the voltage of the generator carrying the lesser load. This action is accomplished through the voltage equalizing coil. This coil acts upon the carbon pile in a manner similar to the action of the voltage coil. The voltage drop in each generator series field is directly proportional to the current output of that generator. If there is an unequal division of the load, the voltage drops in the generator series fields will differ. This causes a current flow through the equalizing coils of the regulators, with a resultant change in carbon pile resistance. The result is a more equal division of the load.

17-15. *Armature shunting relay.* The armature shunting relay is shown in detail in figure 64. It is also shown in the upper center of figure 62. It is the magnetically latching type and is tripped, or reset, by power from the essential bus through contacts of the field relay. As the field relay is tripped by either the overvoltage sensing circuit or the feeder fault sensing circuit, the armature shunting relay shunts the generator armature through a total circuit resistance of about 0.02 ohm. It first isolates from each other the lead to the negative armature terminal D and the leads to the equalizer and fault sensing circuits. The contacts E and J part first to isolate these circuits, then the contacts A and B close to short-circuit the generator armature. Finally, the contacts H and I close to provide a ground connection for the field relay reset coil. Contacts F, L, C, and K on the relay interrupt its trip, or reset coil, circuits when either action is complete.

17-16. Following an overvoltage fault and resulting trip of the armature shunting relay, the generator draws reverse current from the bus before the line contactors have time to open. This current is limited by the total resistance of the generator series field, the shunted armature circuit and feeder wires, and by the internal resistance of the bus, as a power source. The peak value of this current never exceeds about one-quarter of the interrupting capacity of the main contactors.

17-17. Resistor R12 (connected between F and H in figs. 62 and 64) prevents tripping of the fault sensing circuit under certain overvoltage conditions. The resistor is connected from the essential bus to terminal H, through a set of contacts on the field relay, when the latter is tripped. A small voltage is applied through the resistor to the fault sensing circuit while the double-throw moving contact bar of the armature shunting relay is traveling from one set of contacts to the other. During the transient period following an overvoltage fault, increasing reverse current may be drawn while the contact bar is in motion. During this motion, the shunt coil of the fault sensing relay may close its contacts because of unopposed current in its series coil. Resistor R12 prevents a current from circulating (due to increasing reverse current in the current coil) through the shunt coil of the fault sensing relay, and through the forward-current relay coil in such a direction as to trip the forward-current relay. If this trip were not prevented for an overvoltage condition, it would be indicated that a feeder fault had caused trip of the protection system, and reset would not be possible without first resetting the forward-current relay.

17-18. *Field relay.* The field relay, shown in figure 62, is a latched relay with eight sets of contacts, a trip coil, and a reset coil. Operation of the overvoltage relay or the forward-current relay, due to a feeder fault, energizes the trip coil. When tripped, the field relay performs the following functions:

- Isolates the voltage regulator, thus opening the shunt-field circuit.
- Deenergizes the main contactor and auxiliary contactor coils to provide breaks between the generator feeder and the bus.
- Deenergizes the overvoltage relay and the equalizer relay.
- Turns on the trip indicator light.
- Energizes the armature shunting relay trip coil.
- Deenergizes the field relay trip coil.

17-19. *Undervoltage protection.* To prevent reduction of bus voltage to a value likely to become dangerous in normal operation, (due to equalizer action when one or more generators are slowed down, stopped, or deenergized with switches closed) an equalizer relay is provided on the overvoltage control panel. This relay is operated by the differential reverse-current relay, and adds resistance to the equalizer circuit when the reverse current relay opens (see fig. 65). This resistance is the maximum that will still permit enough equalizer action to bring the generator on the bus. With this value of resistance on a six-generator system, one dead generator with its switch on produces a drop in voltage of the other five of 0.6 volt, from no-load to full-load. The equalizer relay is a single-throw double-pole normally open relay. It has Palladium contacts for low contact resistance. The coil resistance is 235 ohms, and the contacts close at a minimum of 18 volts at room temperature.

17-20. *Reverse polarity protection.* Each overvoltage control panel contains a rectifier (CR1 in fig. 62) to prevent damage to the electrolytic condensers in the overvoltage circuit, due to reversed polarity of the generator. The rectifier is installed in series with a current-limiting resistor, between the negative side of the field relay trip coil and ground. If a generator with reversed polarity is installed or the polarity of an installed generator is inadvertently reversed during normal maintenance of the system, reverse current through the rectifier energizes the trip coil of the field relay. Operating the generator switch momentarily to the RESET position flashes the generator field and restores correct polarity.

17-21. *Overvoltage protection.* Overvoltage may be caused by failure of the voltage regulator or by short-circuiting of the generator field to a voltage source. The overvoltage protection system for each generator consists of two basic sections. One section contains the voltage sensing relay with its shunt capacitors and series resistor for time delay. The other section contains the selector relay which detects the generator responsible for the overvoltage.

17-22. The polarized selector relay (this relay is shown in fig. 66 as the selector relay) is a normally open, sensitive relay, with a 0.6-ohm coil connected in series with the equalizer circuit for its particular generator. Regardless of the magnitude of the load, the generator producing an overvoltage delivers higher current than the other generators. Since the potential at point D is negative with respect to ground, a higher current in the series field of generator No. 1 puts point D on generator No. 1 at a lower potential than point D on the other generators. The equalizer current of the high-voltage generator is sent in a direction away from the equalizer bus, while the equalizer current of the other generators is sent in a direction toward the equalizer bus.

17-23. The selector relay is connected in such a manner as to close its contacts when the equalizer signal is sent in a direction toward the equalizer bus. Its polarization prevents it from closing when the signal is sent in the opposite direction. Thus, with all generators operating in parallel, all selector relays (except the one for the high-voltage generator) close. When they close they shunt out their respective overvoltage relays and prevent their operation. The selector relay for the high-voltage generator will not operate, thereby permitting operation of the overvoltage relay. This assures that only the generator causing the overvoltage will be tripped and made inoperative. The 100-ohm resistor that is in series with the selector relay contacts prevents damage to these contacts by discharge of the capacitors. During single-generator operation there will be no equalizer current. Therefore, the selector relay contacts will remain open and overvoltage protection will be afforded the generator.

17-24. The overvoltage relay is a sealed, sensitive, normally open relay. Its coil has a resistance of 1000 ohms and is in series with a fixed 750-ohm resistor and an adjustable 500-ohm resistor. Two 75-mfd electrolytic capacitors are connected in parallel with the overvoltage relay coil. The relay coil is calibrated to trip at 30.1 (±.5) volts across the coil circuit, including the resistors and capacitors. The contacts of the relay are in series with the field relay trip coil, through a 20-ohm current-limiting resistor. The high value of series resistance limits the rate of charge of the capacitors, which must be charged before enough voltage is applied to the overvoltage coil. This provides the necessary time delay to prevent tripping on voltage transients.

17-25. *Feeder-fault protection.* The feeder protector relay assembly includes the differential current fault sensing relay, the differential voltage and reverse-current pilot relay, a potential relay, and a main contactor. These units are shown on the lower right-hand side of figure 62. The reverse-current relay contactor circuit of the relay assembly consists of the main contactor, the differential voltage and reverse-current pilot relay, and the potential relay. The differential voltage and reverse-current relay is the toggling type. It is polarized and has two coils wound on the same magnetic circuit. One coil has many turns and is connected to sense the differential voltage between the generator feeder and the bus. It closes the relay when this differential is +0.2 to +0.35 volt. The other coil is a heavy copper strap and carries the generator current. It opens the relay when the generator draws reverse current from the bus in excess of 30 amperes.

17-26. The relay contacts, in series with the generator switch, energize the coils of the main contactor, the auxiliary contactor, and the equalizer relay. The function of the potential relay is to protect the coil of the differential voltage and reverse-current relay against excessive terminal voltage. It is polarized, and its coil senses the voltage between the generator feeder and the ground when the generator switch is closed. The relay closes at 20 to 24 volts and opens at 18 volts.

17-27. The differential current fault sensing circuit of the relay assembly consists of a polarized, normally open relay having two coils on a common magnetic circuit. One coil is a single turn of heavy copper and is connected in series with the feeder at the main bus. The other coil consists of many turns of small wire. The coil is connected through temperature compensating and calibrating resistors across the series field of the generator. The relay closes if there is a substantial difference between the current in the generator series field and the current in the generator feeder at the bus, as would result from a feeder fault.

17-28. The auxiliary contactor is a heavy duty unit. It is identical to the main contactor in the reverse-current and fault sensing relay. As shown in figure 62, its contacts are connected in series and its coils are in parallel with the same parts of the main contactor. The two contactors disconnect the feeder from the bus and increase the interrupting capacity at high voltages. In the event that overvoltage is produced by a short circuit between the generator armature positive (terminal B of the generator) and the shunt field positive (terminal A) at high generator speed, and the armature-shunting relay is in operation, the two contactors in series become a double safety factor.

17-29. The forward-current relay (you can see this in the lower portion of fig. 62) is a polarized toggling-type relay. It can operate when the current in the series field is sent in the normal direction, but not when it is reversed. When the fault sensing relay operates, it closes the circuit to the forward-current relay. If the current in the series field is reversed, the relay will not operate. If the current is sent in the normal direction, the relay will toggle, operating the trip circuit of the field relay. This action, of course, deenergizes the system. The relay contacts remain in this position until mechanically reset. The forward-current relay can be reset only by means of the mechanical reset button on the relay cover case.

17-30. *Reset circuit.* If the field relay, as shown in detail in figure 67, has been tripped because of overvoltage or a generator feeder fault, it will not be immediately evident as to which malfunction has caused the trip. An attempt to reset the field relay may be made by opening the generator switch and closing it to the opposite (down) position. This is a momentary-on position.

17-31. If the trip has been due to an overvoltage condition, and the cause has been removed, the indicator light will go out and the circuit will be restored to normal. If the cause of overvoltage

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persists, the field relay will be reset but will immediately trip again. The tripping action is so rapid that the generator switch cannot be reclosed quickly enough to allow the overvoltage to be applied to the bus. Cycling of the field relay trip coil and reset coil at this time will be prevented by the action of the reset lockout relay. Resetting the field relay opens the negative side of the reset coil, thereby placing the reset coil and the lockout coil in series. Because the lockout coil has a greater coil resistance than the reset coil, the two in series will allow passage of enough current to actuate the lockout relay but not enough to actuate the reset coil. Thus, to make a second reset attempt, the generator switch must be released, then pressed again. If the cause of the overvoltage remains, the indicator light will go out momentarily, then come on each time this is done.

17-32. Following a feeder fault, the forward-current relay retrips to open the negative side of the field relay reset coil. The forward-current relay is remotely located and is reset manually by a button on its case. The system, therefore, cannot be reset by pressing the generator switch to the RESET position until the forward-current relay has been reset. The trip indicator light will burn continuously during such an attempt. This circuit prevents the reapplication of power to a feeder fault and distinguishes a feeder fault trip from an overvoltage trip. It is purposely made difficult to reset the circuit after a feeder fault in flight, because the fault should be located and corrected before a reset is attempted.

17-33. The two preceding paragraphs provide us with the answer as to why the generator will not stay connected to the main bus. From what we have learned about the system, checking for overvoltage is a good place to start. Assume that a short in the field circuit, between points B and A at the generator (figs. 62 and 67), is causing the trouble. All you have to do is to clear the short, and the aircraft can be on its way. Before we go into a detailed discussion of system malfunction, let's discuss power distribution. This discussion includes external power as well as the aircraft battery system.

18. Power Distribution System

18-1. In all aircraft generator systems, the generated power must be distributed throughout the aircraft before it can be put to work. Included in the power distribution system are provisions for connecting external power to the aircraft buses. Also associated with the distribution system is the aircraft battery power system. Our discussion will include each of these systems.

18-2. *System Description.* Figure 68 shows the power distribution for the generator system discussed. The power circuit and branch circuits of the distribution system are protected against sustained overloads by thermal-type automatic circuit breakers. With very few exceptions, circuit breakers consist of the trip-free type which cannot be held closed if overload conditions exist.

18-3. Current limiters are also used in the distribution system. A current limiter is an aircraft fuse especially designed to provide protection of aircraft electrical distribution systems against short circuits. The time/current characteristics of the limiter are designed to permit a temporary overload to be carried in the electrical wires but to assure that the limiters will promptly clear short circuits.

18-4. Power from the aircraft generators is fed through insulated copper wires to the main power panel (not shown in fig. 68) and to the main dc bus. From the main bus three wires transmit electrical power forward to the crew door bus. From this bus, power is transmitted to the station 260 bus, the main junction box (MJB) bus, connector panels, and various items of equipment.

18-5. Two number 1/0 wires are used between the generator and the nacelle firewall. The two wires are used to transmit the current from each generator to reduce the voltage drop and to assure enough current-carrying capacity to handle the aircraft dc load. The major dc loads required at the nacelles, such as starters, feather pump, and cowl flaps, are supplied from nacelle buses. Two sectionalizing relays, one for each wing, serve to isolate the nacelle buses from the main bus, except when the nacelle equipment is being used.

18-6. Other major dc loads, including inverter input power, are supplied directly from the main dc bus through current limiters. So much for the overall power distribution system. Now let's take a look at how external power is connected to the distribution system.

18-7. *External Power.* Two type MD-3, ac/dc external power supplies are recommended for use when the aircraft is to be checked out on the ground. One unit is used to supply ac power only; the other unit, dc power only. The combined output of both units is 45.0 KW. The total dc load for system checkout is about 24.8 KW.

18-8. Two 5-pronged receptacles are provided for connecting external power to the aircraft distribution system. These receptacles are shown in figure 69. One receptacle is provided for the main dc bus, and the other for the electronic dc bus. Both systems include a reverse-current relay (RCR). The RCRs are used to connect and disconnect external power from the aircraft distribution system. The relays are controlled by a single-pole single-throw switch on the engineer's panel.

18-9. Two green push-to-test indicator lights, one for the main dc bus and the other for the electronic dc bus (located next to the external power switch), give visual indications that one or both auxiliary power units (APU) are connected and turned on. Two white lights, one for each bus (located next to their associated receptacles), give visual indication to the ground crew that the ground power supply is connected to the aircraft distribution system. These lights are connected to the indicator terminal on the RCRs (see fig. 69).

18-10. The dc power to close the RCRs and connect dc auxiliary power to the aircraft bus is provided by the APU. This power is taken from the short pin of the receptacle, through a 5-amp circuit breaker, and through the external power isolation control relay to the SW terminal of the RCR. When the external power switch is put in the ON position, power is applied to the SW terminal of the RCR which closes it. When the RCR closes, dc power is applied to the aircraft dc distribution system. When auxiliary power is applied to the system, be sure to put the battery switch in the OFF position. Failure to do so can cause generation of explosive gases in the battery compartment.

18-11. To check the operation of the external power system, connect an APU to the separate electrical and electronic dc power receptacles and turn on the power units. The green lights for the main dc bus and for the electronic dc bus should be on. Place the external power switch in the ON position. The white lights in the external power receptacle box should come on. These indicate that external power is connected to the aircraft dc distribution system.

18-12. Place the external power switch in the OFF position. The white power-on lights should go out to indicate that external power has been disconnected from the aircraft distribution system. Shut down the auxiliary power units and disconnect them from the aircraft external power receptacles. The green power-on lights should go off to indicate that auxiliary power has been removed from the aircraft.

18-13. This completes our discussion of the external power system. There is one other source of power for the aircraft distribution system, and that is the batteries. The batteries are also considered an emergency source of power in case of a complete generator system failure.

18-14. *Aircraft Batteries.* The electrical power system under discussion is provided with two 24-volt, 36-ampere-hour batteries. These batteries are the covered type provided with a venting system which picks up rammed air through a tube and forces it through the space at the top of the battery. This air is then forced overboard through the acid trap (sump jar) to the atmosphere.

18-15. There is not much to the battery power system, and it should not present any problems. The batteries are connected to the bus by a relay (shown in fig. 68). The relay is controlled by a switch on the MJB No. 1 switch panel. In an emergency, battery power is connected through the rudder and elevator relay to the station 238 circuit breaker panel.

18-16. Remember, we have said that the battery provides emergency power in the event of complete generator system failure. This means that the condition of the battery is very important. How long has it been since you were required to service a battery, or even check one? Let's review and expand upon some of the more important points of servicing lead-acid batteries.

18-17. The state of charge of a lead-acid battery is determined by the specific gravity of its electrolyte. A fully charged battery should have an electrolyte reading between 1.275 and 1.300, when corrected for temperature. If an electrolyte reading is 1.240 or below, the battery should be replaced.

18-18. When it becomes necessary to add water to a battery, use distilled water. Clean drinking water may be used if distilled water is not available. Battery plates should be covered with electrolyte at all times, but this level should not be more than 3/8 inch at any time. Excessive filling of the battery will cause overflow and will probably result in weakening the battery. If the battery is going to be exposed to temperatures below freezing, do not add water unless the battery will be charged immediately after adding the water. Charging the battery will cause the water to mix with the electrolyte; otherwise it will stay on top and freeze.

18-19. Check the battery terminals for corrosion. Remove corrosion by brushing with a stiff, nonmetallic brush. Then wash the battery with a solution of sodium bicarbonate and water (1 pound per gallon of water) to neutralize any electrolyte remaining on the battery. Remember, corrosion (between the battery terminal and the battery cable) acts like a high resistance in a circuit. It can prevent the battery from providing its full rated power in an emergency. So, make sure that the battery terminals are clean and tight.

18-20. Check the battery vent system. Examine the felt pad in the sump jar. If it becomes covered with a white, flaky deposit or if the sump jar contains liquid, you must take the following definite actions. First, remove the felt pad and wash it in warm water. Second, saturate it with a concentrated solution of sodium bicarbonate and water. Third, remove any excess liquid from the jar. Finally, reinstall the pad.

18-21. This concludes our overall discussion of an aircraft dc power system. Now, we shall take another look at the same system and discuss some problems you may encounter when required to work on a dc generator system.

19. System Analysis

19-1. System analysis of the dc generator system is the detection, isolation, and correction of malfunctions which become evident during normal operation or checkout of the system. In all cases of failure or improper operation, immediately disconnect the generator by opening the generator field switch. Investigate the trouble as soon as possible. When troubleshooting, use an accurate, portable voltmeter with a range corresponding to that of the generator voltage. If one component of the system has been damaged, the entire system should be inspected for any additional damage. Before we continue our discussion of generator system malfunctions, let us review a method you can use in analyzing the type of problems we will be discussing.

19-2. System analysis is a test of ingenuity as well as of knowledge. For this reason, we will review a method of troubleshooting presented during your 5-level training. It is in this area of your duty assignment that your real value to an electrical maintenance activity can, and will, be measured.

19-3. System analysis procedures cannot be considered as ironclad rules. Experience has increased, and will continue to increase, your knowledge of electrical systems. Experience will also reveal new checks and more efficient methods of analyzing problems in these systems. Realistic system analysis is not a hit-or-miss, remove-and-replace, trial-and-error process; it must be an orderly sequence of *mental* and *physical* actions, ending with the identification and elimination of a system malfunction. A combination of maintenance skills, intimate knowledge of the operation of the system, and the use of logical steps in the problem-solving process is essential to a systematic analysis of any system malfunction.

19-4. *Method of Analysis.* Although there are numerous troubleshooting procedures that you might adopt, let us consider a procedure that experienced technicians have found very successful. We said earlier that you must use logical steps to identify and remedy system malfunctions. Consider the steps listed below:

(1) Identify the problem.
(2) Investigate the problem.
(3) Evaluate the findings.
(4) Isolate the exact cause.
(5) Repair or remedy.

19-5. Careful inspections and operational checks are the key to identifying system malfunctions. While operational checks are in progress, notice all indications given by the system warning lights, indicators, and meters, if any.

19-6. To investigate the problem, consult the technical manuals. Read about the affected system in the applicable publication for the aircraft, and study the circuit wiring diagram. The time required for this study is small compared with that required for hit-or-miss replacement of units. Now you are ready to evaluate your findings.

19-7. When you evaluate your findings, ask yourself this question. "What in this system will cause the symptoms I have observed?" If the problem appears complex, it might be a good idea to list on paper all the possibilities that come to mind as you work through the circuit diagram. When you have listed all those things that could cause the problem, you are ready to isolate the trouble.

19-8. In the fourth step of system analysis, you need to eliminate all those possibilities not actually responsible for the trouble. Where do you start first? I am sure your experience has made the answer to this obvious; check the easiest things first. In other words, check the circuit breakers first. This is a good check to make at the beginning of any troubleshooting situation. By checking the easiest things first, you may find the cause of the trouble before you perform other time-consuming checks. If so, you have saved time, work, and much wear and tear on the aircraft.

19-9. In the final step of this procedure, repair or remedy, you must decide what needs to be done to correct system malfunctions. Just remember: before you make a costly replacement, prove that your conclusions are correct. The downtime of an aircraft to change a component may be many hours, only to find that the trouble is still there.

19-10. We have now covered the steps that can help you analyze system malfunctions. In the paragraphs that follow we will discuss four problems in a dc generator system. As we discuss these problems, apply the procedures just outlined, and see if they will work for you.

19-11. *Problem Number 1.* The generator is disconnected from the load. A voltmeter connected between G+ and L- (as shown on fig. 62) at the voltage regulator base indicates a low output voltage. Let's discuss the most probable cause of a malfunction of this type first, then discuss the solution to the problem.

19-12. *Probable cause.* There are several things in a generator system that will cause a low-voltage condition. The following are the most frequently recorded causes for low voltage in a dc generator system:

- Faulty or improperly adjusted voltage regulator.
- High resistance in the internal or external connections of the generator circuit.
- Binding, worn, or improperly seated brushes.
- A short, ground, or open in the generator armature.

19-13. *Discussion.* Of all the probable causes for low voltage in a generator system, the voltage regulator rates number 1. In most cases a minor adjustment of the voltage adjusting rheostat, located on the voltage regulator (this is shown in fig. 63), will correct this condition. This is the only adjustment that should be made on the voltage regulator.

19-14. The voltage regulator is set at the factory, or overhaul activity, to regulate at 28.0 volts. The precision of this setting is plus or minus 0.7 volt over the full range of generator speed, load, and operating temperature. *Do not* adjust the core or pile adjusting screws at any time while the regulator is installed in the aircraft. These screws can change the voltage setting as well as the regulating characteristics of the unit.

19-15. If the adjustment of the rheostat on the voltage regulator does not correct the low-voltage reading (with the problem isolated to the regulator), replace the regulator. While the regulator is removed, inspect the regulator base. Be sure the regulator contacts are clean and free of corrosion. After you have replaced the regulator, an operational check of the system must be performed in accordance with the aircraft technical order.

19-16. Where in the generator system would high resistance most likely affect the generator output voltage? If you came up with the field circuit, you're right; it's better than an even chance that you will find the trouble in the field circuit. Just how extensive a check should be required to locate the trouble will depend upon the generator system which you are working. For the generator system just discussed, the field circuit can be checked with an ohmmeter. Turn back to figure 62 and we will check out the field circuit.

19-17 For example, connect the ohmmeter between F+ and L- at the voltage regulator, with the regulator removed from its base. You should read between 1/2 to 3 ohms. A reading higher than this may indicate trouble in this circuit. Suppose you did get a higher reading (9 ohms) than that considered normal. What component of the generator system would you check, and why?

19-18. Consider this fact. The only contacts in this part of the field circuit are in the field relay. Relay contacts are a weak point in any low power circuit, such as the field circuit of a generator system. An ohmmeter check between terminals 3 and 4 of the overvoltage control panel, shown in figure 62, will test both sets of contacts in the field relay. Any resistance across these contacts will require replacement of the field relay.

19-19. Generator output is applied through the field relay to the voltage regulator. This circuit also passes through contacts of the field relay. High resistance across these contacts can also cause a low output condition.

19-20. The generator may be at fault. Binding, worn, improperly seated, or loose fitting brushes will cause a low output voltage. An open or short in the armature will also cause this problem. In the event the problem is isolated to the generator, a good idea would be to remove it and send it to the shop for bench check. Now let's take a look at a high output voltage problem.

19-21. *Problem Number 2.* The generator is isolated from the load. A voltmeter connected between G+ and L- at the voltage regulator base shows a high output voltage. The cockpit voltmeter also shows a high output voltage. As with the low output voltage problem, the resistance of the field circuit is affected.

19-22. *Probable cause.* The following are the most frequently recorded causes for high voltage in the generator system:

- The voltage regulator.
- Power short between the generator output and the field circuit.

19-23. *Discussion.* This reading of high voltage is an indication of worse things to come unless the generator is immediately disconnected from the bus. Keep in mind that various protective devices in the system will automatically disconnect the generator from the bus before any appreciable damage can be done in the system due to high voltage. High-voltage readings in the generator system indicate that there is no control over the amount of current flowing through the shunt field coils. This, in turn, points to our two probable causes stated above.

19-24. Because of the protective devices in the system and the possible damage to the aircraft systems, the problem should be checked with an ohmmeter from the voltage regulator base. Remember, when checking any circuit with an ohmmeter, be sure that the battery switch is in the

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OFF position and that the generator is not running. The circuit being checked by ohmmeter must have no other source of electrical power than that contained in the ohmmeter itself.

19-25. In this system the voltage regulator is the easiest component to check first. If there is an open in the voltage coil circuit, the resistance of the shunt field circuit will be minimum, thereby permitting increased current flow in the field circuit. This will give you the high output voltage reading in the system. How will you isolate this type of problem? An ohmmeter reading between B and G on the regulator will show you the condition of the voltage coil.

19-26. If the voltage regulator is not the problem, the entire field circuit must be checked for a short between the generator output and the field circuit. Do not discount an open ground circuit at the voltage regulator base. With an open in the ground circuit, no current will flow in the voltage coil circuit. As a result, carbon pile resistance will again be at a minimum with increased current flow in the field circuit. Our next problem deals with a zero output voltage from the generator.

19-27 *Problem Number 3.* No generator output: the test meter reads zero. The generator was reset, but the output remained zero. The first thing that should come to mind is the generator. Why the generator? If the generator is turning, you should get a residual voltage reading. This reading, for most generators, should be 0.5 to 2 volts.

19-28. *Probable cause.* Here is a good case for a broken generator drive shaft. Look again at figure 62. When the generator was reset, the field was flashed but the generator output remained zero. That eliminates the loss of residual voltage as a probable cause.

19-29 An open lead in the system will give you a zero reading if you are depending on the cockpit meter, but your test meter also reads zero and is connected to terminal B at the generator. You will no doubt agree that the shaft should be checked next. Anyway, we know now that the trouble is in the generator. You check the generator and find the drive shaft broken. Before you install a new generator you had better do some thinking about the cause of the broken shaft.

19-30. *Discussion.* Any condition that will impose shock loads on the generator may cause failure of the drive shaft. The generators in this system are driven by reciprocating engines. This, in itself, can cause a problem. When the engines are started with the generator switch in the ON position, the initial acceleration of the engine imposes a load on the generator drive shaft. In this case be sure the generator switch is in the OFF position for the purpose of reducing the torque required to bring the generator up to speed.

19-31. When the engines are running *rough*, as they do right after starting, there is considerable speed fluctuation. The generators will assume and drop load, which in turn imposes large stresses on the generator drive shaft. Again, during this phase of starting, the generator switch must remain in the OFF position.

19-32. Operation of high load equipment during ground handling operations, while taxiing the aircraft, imposes stress on the generator drive shaft. While taxiing, engine speeds are often changed rapidly. The technical order says that high electrical loads should be avoided during taxiing operations. The only thing you can do about a problem like this, if it persists, is to bring it to the attention of the operations personnel.

19-33. Finally, bearing failure, but not to the extent of complete shaft seizure, will cause shaft failure. Serious roughness can develop, causing the air gap to vary or the brushes to bounce, which in turn will cause the output voltage to fluctuate. The fluctuating voltage will cause shock loads on the generator, which can cause the shaft to fail.

19-34. *Problem Number 4.* With the generator connected to the load, the system ammeter and voltmeter fluctuate excessively. This type of trouble can take many many hours of your time and tax your knowledge of a dc generator system to the limit. With this in mind, we will discuss some probable causes of fluctuating generator output.

19-35. *Probable cause.* There are three things that should come to mind with this type problem. They are:

- Loose connections in the aircraft wiring.
- Defective generator brushes.
- The condition of the commutator.

19-36. Of all the causes for this type trouble, loose connections in the aircraft wiring would be very difficult to find. We will discuss this area first.

19-37. *Discussion.* It's a good idea to check first for loose connections at the various generator system components. Experience with a system like this reveals that loose connections are often found at the voltage regulator base. If this is not the case, then a point-to-point check of the entire control system will be necessary. Don't overlook the possibility of corrosion on the voltage regulator base contacts, or the loss of contact tension. Trouble with the contacts on the voltage regulator base is considered to be a loose connection and could cause a fluctuating generator output.

19-38. If a complete check of the system does

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not reveal a loose connection, then the generator should be checked. Binding, worn, improperly seated, or loose fitting brushes will cause fluctuating output voltage. Low brush spring pressure, scored or pitted commutator, shorted, grounded, or open armature windings can also cause fluctuating output voltage. If the generator has any of the problems discussed above, it must be replaced.

19-39. This concludes our discussion of the entire dc generator system. There are many such systems in use today in USAF aircraft. They may not contain all of the same type components as the system just discussed, but the principles involved are the same. You will find that these same statements will be true of the ac system which will be discussed in the next chapter.

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CHAPTER 9

MULTI-GENERATOR AC POWER SYSTEM PROBLEMS

MOST OF OUR modern aircraft use a great deal of ac power: consequently, there has been a switch from a primary dc power system to a primary ac power system. One of the most important parts of your job, as an aircraft electrician, is troubleshooting malfunctions in electrical power systems. One of the basic requirements for a good troubleshooter is to have an intimate knowledge of the normal system operation. Without this knowledge, your troubleshooting efforts will be hit or miss.

2. In this chapter we will discuss systems operation, power distribution, external power systems, and troubleshooting of a multi-generator ac power system. Our first discussion will be on normal system operation.

20. AC Generator System Description

20-1. The generator system to be discussed is the 60-KVA main power supply system used on a fighter aircraft. This electrical system consists of two 30-KVA brushless generator systems. Each 30-KVA generator system consists of a 30-KVA, 200/115-vac, 3-phase, 400-Hz generator, a constant speed drive, and a voltage regulator/supervisory panel. An ac power control box and a frequency and load control are also used. Each of these serve both the left and right generating systems.

20-2. Since we discuss many transistorized circuits in this and the next chapter, it is necessary to review and expand upon the discussion of solid state devices in your previous training. In figure 70 we have presented a few of the symbols which are used throughout the text. In detail A of the figure is the symbol for a PNP transistor. You will remember that the emitter is identified with an arrow. The arrow indicates which way the positive hole charges should move. The letters IE, IC, and IB represent the current in the emitter, collector, and base of the transistor. The same applies to detail B, which is an NPN transistor. This time the arrow is pointing away from the base. When you have doubts as to what kind of transistor to use, remember, the arrow always points toward the N-type material.

20-3. The unijunction transistor that is shown in detail C is nothing more than a diode with two connections made to one portion of the semiconductor. Terminal E represents the emitter, terminal B1 represents one of the base connections, and B2 the other base connection. For all practical purposes you can consider the unijunction transistor to have the same operating characteristics as the conventional PN junction.

20-4. Detail D of figure 70 shows the symbol for a silicon controlled rectifier (SCR). The SCR can be considered as two separate transistors. The SCR consists of an anode, a cathode, and a gate. These elements control the turn-on and turn-off processes of the rectifiers.

20-5. The exacting requirements of the various electrical and electronic systems in the aircraft, in regard to input voltage and frequency, demand the ultimate in performance from an electrical power supply system. To handle this requirement, the brushless ac generator and its transistorized voltage regulator maintain the output voltage within ±2 percent, with rapid recovery from load changes. The constant speed drive and the frequency and load control box together provide frequency control within ±1 percent. Protective circuits in the voltage regulator/supervisory panel and the power control box remove the generators from the buses if their voltages drop to an undesirably low value or rise to an excessively high value.

20-6. *Generator Regulation and Excitation.* An ac generator requires an excitation voltage applied to its field before any output can be realized. This voltage is obtained from a permanent magnet generator (PMG) contained within the ac generator. The single-phase output of the PMG is applied to a transformer-rectifier (T/R) in the voltage regulator/supervisory panel (VR/SP). The dc output of the T/R (it is in the VR/SP) is applied through a transistorized amplifier (voltage regulator) to the exciter field of the generator, as shown in foldout 3.

20-7. The generator output voltage is maintained at a constant value by comparing the generator voltage to a reference, and adjusting the excitation accordingly. The voltage regulator circuitry is sensitive to small voltage changes, and responds quickly to adjust the excitation to the exciter field. The low transient reactance of the exciter and the gain between the exciter field and

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the rotor cause the main generator field strength to change rapidly. This action maintains the generator voltage relatively constant under varying load conditions.

20-8. When the generators are operated in parallel, a reactive load loop, consisting of two current transformers and a comparator circuit, supplies reactive load division signals to the voltage regulator. The excitation is increased to the generator supplying the least reactive power, and the excitation to the other generator is decreased. In this way the reactive load between the generators is equalized.

20-9. *Generator Frequency Control.* Each generator is driven by a constant speed drive. The drive is a mechanical-hydraulic transmission which converts the variable speed of the engine to a constant speed for driving the generators. The drive maintains the generator frequency at 400 Hz, with engine speeds varying from idle to full military rated power. Each drive contains an underspeed switch (USS) and a set of bias coils. The USS is a pressure-actuated switch which permits the generator to be energized and connected to the buses if its frequency is above approximately 375 Hz. If the generator frequency drops below 360 Hz, the USS trips the generator from the line. The bias coil in the drive biases the basic governor which allows the frequency and load control box (FLCB) to vary the speed of the drives, maintaining equal real load division between the generators.

20-10. *Generator System Control.* The ac generator system is controlled by the system's switching circuits. These circuits connect the generators to the aircraft buses when their output voltages and frequencies are correct. The generator control switch enables the pilot to place the system in operation or to reset the system in the event a malfunction causes a generator to be tripped off the line. The switching circuits also allow the output of a single generator to supply the entire aircraft electrical load if the other generator should become inoperative. The switching circuits work in conjunction with the fault protection circuits to remove a faulty generator from the bus without interrupting power to the buses.

20-11. *Generator System Fault Protection.* Circuitry in the VR/SP provides undervoltage, overvoltage, underexcitation, overexcitation, and unbalanced current protection. If an overvoltage, undervoltage, or excitation fault should occur, the sensing circuits detect the fault and provide signals to the system control circuits to remove the faulty generator from the bus. The unbalanced current sensing circuit senses the amount of current supplied by each generator during parallel operation. If one generator is furnishing excessively more current than the other, the sensing circuit provides a signal to the control circuits to split the buses. Time delays are provided in the various protective circuits to prevent nuisance tripping or momentary variations occurring during normal system operation.

20-12. *Generator Paralleling.* The generator paralleling circuit automatically parallels the generators when all the paralleling requirements are met. These requirements are as follows:

- Both generators operating.
- Both generator control switches on.
- Both line contactors energized.
- The generators' frequency within 6 Hz of each other.
- Phase angle between generators less than 135°.

The paralleling circuits are contained in the frequency and load control box. The circuit is essentially a phase detector which energizes an automatic paralleling relay (APR). The APR then provides a signal to the system control circuits to energize the tie contractor, thus paralleling the generators' output. Now that you have a basic understanding of the generator system components, let's discuss, in detail, the circuitry required for these components, and how the circuitry functions.

21. Generator System Components and Circuit Operation

21-1. When troubleshooting the 60-KVA main power supply system, or any aircraft electrical power system, you will find it very helpful if you can divide the system into subsystems. Then, by eliminating subsystems, the trouble can be isolated to the section of the system which does not work. To do this, you must have extensive knowledge of system component operation. You must also know the system's operational sequence. These subjects are discussed in the following paragraphs.

21-2. *AC Generator.* The 30-KVA generator is a brushless, 3-phase, oil-cooled, synchronous machine using an ac exciter. Also contained within the generator is a 12-pole permanent magnet generator (PMG) which provides power for excitation and system control. As you can see in figure 71, the generator is divided into three parts. The permanent magnets are mounted at the bearing end of the rotor, the main generator field windings make up the center portion, and the exciter ac windings are mounted at the drive end of the rotor. The generator field rectifiers are mounted in the portion of the rotor supporting the exciter's ac windings.

21-3. A brushless generator can be thought of

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as two alternators on a common shaft, one alternator acting as the exciter for the other. The exciter field is wound on the stator. This is schematically shown in figure 72. The exciter ac output windings, the main ac generator field winding, and the main generator field rectifiers are mounted on the rotor assembly, while the main ac generator output windings are contained in the stator assembly. The excitation voltage from the voltage regulator is applied to the exciter control field, which in turn is induced in the exciter rotor windings. This is rectified by the silicon diode generator field rectifiers and is applied to the rotating main ac generator field. In turn, the generator output voltage is obtained from the main ac generator windings. Thus, a dc excitation voltage is applied to the main rotating field without the use of brushes and sliprings.

21-4. *Voltage Regulator/Supervisory Panel.* The voltage regulator/supervisory panel (VR/SP) contains all the circuitry required for regulation, supervision, and protection for the generating system. Many of the functions of the VR/SP are shown in foldout 3. The voltage regulator portion of the VR/SP provides excitation to the generator and varies this excitation to maintain a constant generator output voltage. The supervisory portion of the VR/SP monitors the system operation and, upon detecting a malfunction, removes the defective system from the aircraft buses. To simplify the explanation of the VR/SP, we will discuss the voltage regulator first.

21-5. *Voltage Regulator.* The voltage regulator (VR) section of the VR/SP is completely transistorized. It supplies all the excitation to the brushless generator during buildup, normal operation, and fault conditions. The VR has two modes of operation. When the generators are not operating in parallel, the regulator controls the excitation to the generator's field to maintain a constant output voltage. When the generators are operating in parallel, in addition to the function of regulating generator voltage, one regulator operates in conjunction with the others to equalize the reactive load between the generators. At this point, let us break the voltage regulator down to see what makes it work.

21-6. The voltage regulator section of the VR/SP is schematically shown in foldout 4. It is made up of the following six basic circuits:

- Phase voltage reference circuit.
- Waveshaping circuit.
- Error sensing bridge.
- Current amplifier.
- Power supply circuit.
- Reactive current sensing circuit.

We will discuss these circuits one at a time, starting with the phase voltage reference circuit.

21-7. *Phase voltage reference circuit.* In reference to foldout 4, transformers T1, T2, and T3 are connected to phase A, phase B, and phase C respectively. The outputs of these transformers are full wave rectified by diodes CR1-CR6. The dc voltage output from the rectifiers is used as the generator phase voltage reference. The level of this dc voltage is representative of the average phase voltage. If the voltage on one phase rises appreciably above the others, this increases the average of the phase voltages, and the dc reference voltage increases. In this manner, high phase voltage limiting is accomplished. This pulsating dc voltage output is then applied to the waveshaping circuit.

21-8. *Waveshaping circuit.* The waveshaping circuit is made up of R1 and C1. The 2400-Hz ripple on the dc voltage output of the rectifiers is changed to a sawtooth wave by the time constant of R1 and C1. The output of this circuit is a 2400-Hz sawtooth (as shown on FO 4) superimposed on the dc phase reference voltage. This signal is then applied across the error sensing bridge.

21-9. *Error sensing bridge.* The bridge circuit is made up of resistor R2, thermistor RT1, potentiometer R7, Zener diode CR7, and resistor R12. The error sensing bridge performs two functions. The first function is to pulse-width modulate the first amplifier stage (Q2), with the sawtooth wave riding on the phase reference voltage. The second function is to detect a change in generator phase voltage and bias Q2 accordingly. If, for example, the phase voltage drops, the bridge will bias Q2 to conduct over a wider portion of the sawtooth pulse, thereby increasing the generator excitation. Conversely, if the phase voltage increases, the bridge will bias Q2 to conduct over a narrower portion of the sawtooth wave, thus reducing the generator excitation.

21-10. The bridge can best be thought of as two parallel resistive legs connected across the output of the waveshaping circuit. Components R2, RT1, and R7 make up one leg of the bridge, and CR7 and R12 make up the other leg. CR7 is a Zener diode which is used as a constant voltage reference. The temperature characteristics of thermistor RT1 are the same as those of the Zener diode CR7. Consequently, any temperature effects on CR7 are offset by RT1, and the bridge balance is not affected by temperature changes.

21-11. The output of the bridge is taken between the wiper of R7 and the junction of CR7 and R12. The polarity of this output, with respect to the junction of CR7 and R12, is dependent upon the direction of the generator voltage error. For example, if the generator voltage is low, the wiper of R7 is positive with respect to the junction of CR7 and R12. When the generator voltage is 115 volts, the potential difference across the output of the bridge is approximately zero, and the bridge is in a balanced condition.

21-12. *Current amplifier.* The current amplifier is divided into three stages, Q2, Q1, and Q3. Q2 is a waveshaping amplifier. As discussed earlier, Q2 is triggered by a sawtooth wave and produces a square wave in its output circuit. Q1, a voltage amplifier, increases the amplitude of the square wave output of Q2 sufficiently to drive Q3. Q3, a switching amplifier, applies the excitation to the generator. The excitation is a pulsating negative dc voltage in the form of a square wave. These square wave pulses of excitation are of a constant amplitude, the width of the pulse being varied to meet the excitation requirement of the generator.

21-13. *Power supply.* The permanent magnet generator transformer-rectifier provides two outputs, one used by the VR and the other by the supervisory portion of the VR/SP. The output used by the VR is obtained from a secondary winding of T5 connected to a full-wave bridge rectifier circuit. The positive side of the bridge rectifier output is connected to the chassis ground through a set of normally open generator control relay (GCR) contacts. The negative side of the rectifier output is filtered by C30 and C31 and applied to a voltage divider network consisting of R5 and R11. This same signal is applied to the emitters of Q2 and Q3 and to one side of the sensing bridge output.

21-14. *Reactive current sensing circuit.* The purpose of the reactive current sensing circuit (RCS) is to equalize the reactive load between the generators during parallel operation. Since reactive load division is a function of generator excitation, the output of the RCS circuit is used to bias the voltage regulator circuitry. This signal increases the excitation to the generator carrying the least reactive load and decreases the excitation to the generator carrying the greater reactive load.

21-15. The RCS circuit is made up of two identical bridge rectifier circuits. They are connected to the secondaries of T1, T2, and T4 (refer to fig. 73). The primary of T1 is connected to phase A, the primary of T2 is connected to phase B, and the primary of T4 is connected to the output of the phase C current transformer loop. The secondaries of T1 and T2, in each bridge circuit, are connected in series, and the voltage across them is representative of the phase A to phase B voltage. The voltage across the secondaries of T4 is proportional to the amount of reactive load unbalance, and the phase of the voltage is determined by the generator which is carrying the greater reactive load.

21-16. When the generators are carrying equal reactive loads, the output of the current transformer loop is zero. This is because the current transformers are connected with their outputs opposing each other. With the output of the current transformer loop being zero, only the phase A to phase B voltage appears across the rectifier bridges. and the output of bridge A, measured across C8, equals the output of bridge B, measured across C7. This results in no RCS output across the RCS load resistor R8.

21-17. As an example, let's assume that the left generator is carrying the greater portion of the reactive load. The output of the left C phase current transformer will exceed the output of the right C phase current transformer, and a voltage appears across the current transformer loop. This voltage is applied to the primary of T4 in both the left and right VR/SP. In the left RCS, T4 adds to the voltage applied to bridge B and opposes the voltage applied to bridge A. This causes a voltage to appear across R8. The end of R8 connected to the base of Q2 is negative with respect to the end connected to R7, because the output voltage of bridge B now exceeds that of bridge A. The voltage across R8 increases the negative bias on Q2, thereby decreasing the excitation to the left generator.

21-18. Since the wiring of the current transformer loop to the right VR/SP is 180° out of phase with the left VR/SP, the opposite action takes place in the right RCS. This increases the excitation to the right generator. As the right generator's excitation is increased, it assumes more of the reactive load; while decreasing the excitation to the generator causes it to relinquish part of its reactive load. This action will continue until the loading is equalized.

21-19. *Supervisory Panel.* The supervisory panel section of the VR/SP is completely transistorized, and uses only five relays. The supervisory panel performs its functions in groups of four operations that occur in sequence. These operations are as follows:

- Sensing.
- Time delay (where required).
- Logic decision.
- Control.

21-20. As you can see from this list of operations, the first objective of the panel is the sensing of an unsatisfactory condition in the system operation. Once this unsatisfactory condition has been noted, a time delay, where required, will occur before the sensing circuit could apply a signal to a

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logic decision circuit. The logic circuit will compare this signal with the signals from other sensing circuits and operate the appropriate system control circuit.

21-21. *Feeder fault sensing circuit.* One of the functions of the supervisory panel is feeder fault sensing. A simplified schematic of the feeder fault sensing circuit is shown on foldout 5. The feeder fault sensing (FFS) circuit performs the protective functions of feeder fault protection and generator burnout protection. This circuit is a low phase sensing circuit, and it detects feeder faults by comparing each phase voltage with the average of the three phase voltages appearing on the voltage regulator error sensing bridge.

21-22. When a feeder becomes faulty, the voltage on that phase drops. The voltage regulator detects the drop and increases the excitation to bring the voltage up. It is this action, plus the extremely low impedance of the generator, that causes an excessive amount of current to be supplied to the fault. If the fault does not clear immediately, and if the phase voltage does not drop sufficiently to be detected by the undervoltage sensing circuit allowing the generator to be tripped on undervoltage, the generator could burn out. Under these conditions, the FFS circuit reduces the excitation to the generator, thus preventing generator damage and allowing the generator to be tripped off the line on undervoltage.

21-23. The FFS circuitry consists of a half-wave rectifier circuit and a blocking diode in each phase, a transistor, Q25, connected across the voltage reference element, and CR7 of the voltage regulator error sensing bridge. During normal operation of the system, the dc output of the A, B, and C phase rectifier networks is compared to the base of Q25 by CR117, CR121, and CR125. Q25 is normally cut off, and the voltage functions in a normal manner. Q25 will remain cut off as long as the voltage between each phase and neutral does not differ by more than approximately 5 volts.

21-24. If a feeder for any phase faults, the voltage on that phase drops. The voltage regulator senses this drop and applies more excitation to the generator. When the generators are in parallel, the unbalanced current sensing circuit biases the voltage regulator for still more excitation. The dc output of the rectifier circuit on the faulted phase drops proportionally to the drop in the phase voltage. If the phase voltage drop is more than approximately 5 volts, the blocking diode between the faulted phase, the rectifier circuit, and the base of Q25 conducts. This also causes Q25 to conduct, shunting the Zener diode CR7. The lower voltage drop caused by Q25 conducting becomes the reference for the error sensing bridge. This new reference is such that it produces a generator output of approximately 70 vac on each phase. The new level of generator voltage is far below the trip-out point of the undervoltage sensing circuit (UVS). The generator will trip off the line on undervoltage, and because of the lower generator voltage the probability of damage to the generator from overcurrent during the UVS time delay is greatly reduced.

21-25. *Undervoltage sensing circuit.* The undervoltage sensing circuit provides the generator system with undervoltage protection. In conjunction with the reactive bias circuit, it provides underexcitation protection. The undervoltage sensing circuit monitors the lowest phase voltage. If this voltage is less than 102 volts, the undervoltage circuit provides a signal through a 3.8-second time delay circuit to trip the generator off the line.

21-26. If, during parallel operation, a voltage regulator malfunction should result in an unexcited condition of the generator, the undervoltage sensing circuit (in conjunction with the reactive bias circuit) trips the faulty generator system off the line. For example, if a generator is underexcited, its output voltage decreases. Since one generator is capable of supplying the entire aircraft electrical load without going into an undervoltage condition, the decrease in voltage from the underexcited generator causes only a slight decrease in the voltage on the buses. However, the underexcited generator supplies the smaller portion of the reactive current. The reactive bias circuit detects this current unbalance, and changes the trip-out points of the undervoltage sensing and overvoltage sensing circuits. The trip points for the generator supplying the most reactive current are lowered, and the trip points for the generator supplying the least reactive load are raised. Since the generators are paralleled and each undervoltage sensing circuit is detecting the same voltage, the underexcited generator trips off the line on an undervoltage fault and the other generator supplies the entire aircraft electrical load.

21-27. *Overvoltage sensing circuit.* The overvoltage sensing circuit (OVS) provides the generator system with overvoltage protection and, in conjunction with the reactive bias circuit, provides overexcitation protection. The OVS circuit responds to the highest phase overvoltage and, through its time delay, produces a trip circuit with the delay time being inversely proportional to the overvoltage level. If a generator becomes overexcited during parallel operation, the reactive bias circuit biases the OVS circuit to produce a trip signal with the same time delay characteristics as the overvoltage trip signal. If, during parallel operation, a voltage regulator malfunction causes a generator to become overexcited, both OVS circuits sense the overvoltage and trip both generators. This action results in a complete power loss to the aircraft. To prevent this from happening, the reactive bias circuit provides selective tripping signals to the OVS circuit, and the faulty generator will be tripped off the line on overvoltage. In the next few paragraphs we will discuss the operation of the reactive bias circuit during the time the system is in an overexcitation or underexcitation fault.

21-28. *Reactive bias circuit.* Let's assume that a failure of the voltage regulator in the left VR/SP causes the left generator to be overexcited, and its voltage increases to 125 volts ac. Because the generators are paralleled, both OVS circuits detect the overvoltage. However, the reactive bias circuit (RBC) biases the OVS circuit so that only the defective (overexcited) generator is tripped off the line. If it were not for this RBC action, both generators would be tripped. Of course this would result in complete loss of the aircraft power system.

21-29. Because the left generator is being overexcited, it is supplying the most reactive current. This causes an output from the C phase current transformer loop which is applied across T7, as shown in figure 74. The wiring to the VR/SP from the current transformer is such that the output of T7 adds to the voltage applied to bridge C of the generator supplying the greater amount of reactive current. Since the left generator is now overexcited and supplying the greater amount of reactive current, the voltage from secondary 2 of T7 is adding to the voltage of secondary 2 of T6 in the left RBC. This causes an increase in the positive output of bridge C. The voltage from secondary 3 of T7 is opposing the voltage from secondary 3 of T6. This causes a decrease in the negative output of bridge D. Since the magnitude of the positive voltage has been increased while the magnitude of the negative voltage has been decreased, a positive voltage now appears across the RBC load resistors in the left OVS and UVS circuits. Since the wiring of the current transformer loop to the right VR/SP is 180° out of phase with the left VR/SP, the opposite action takes place in the right OVS and UVS.

21-30. We will assume the degree of current unbalance between the generators is such that the positive voltage across the RBC load resistor R74 will lower the left generator overvoltage trip point to 120 volts. At the same time, the right generator overvoltage trip point is raised by the the same amount, making it 130 volts. Since the overexcitation in the example raised the phase voltage to 125 volts, the left generator trips on overvoltage. Because the right generator overvoltage trip point was increased to 130 volts, the right generator continues to operate normally and now assumes the entire electrical load. When the left generator tripped off the line, the loop shorting relay was deenergized by the system switching circuits, shorting the current transformer loop. The RBC output dropped to zero and the overvoltage trip point for the right generator returned to normal.

21-31. The action of the RBC during an underexcitation fault is the same as during an overexcitation fault. In either case, the RBC lowers the trip point of the UVS and the OVS circuits in the generator system supplying the most current, and raises the UVS and OVS trip points in the generator system supplying the least current. In the case of an overexcitation fault, the generator supplying the most current is the faulty one and it is tripped on overvoltage. In the case of an underexcitation fault, the generator supplying the least reactive current is the faulty one and it is tripped on undervoltage.

21-32. *Contactor logic circuit.* The contactor logic circuit is shown in foldout 6. It operates the generator control relay (GCR), the contactor control relay (CCR), and the isolate relay (IR). During generator buildup, the contactor logic circuit temporarily disables the UVS circuit and closes the GCR. This action applies excitation to the generator and system control voltage to the CCR circuitry. When the generator voltage builds up above 107 volts, the UVS circuit signals the contactor logic circuit to close the CCR, thus energizing the generator line contactor.

21-33. The contactor logic circuit responds to signals from the system protective circuits to open the line contactor, and deenergizes the generator in the event of a malfunction or fault within the system. If an overvoltage-overexcitation or undervoltage-underexcitation condition occurs, the contactor logic circuitry trips the isolate relay, thus opening the tie contactor to allow the protective circuits to trip the defective generator off the line. At this point we will take a closer look at the contactor logic circuitry. The circuitry shown on foldout 6 can be broken down into four basic circuits: the GCR close-coil circuit, the UVS disabling circuit, the CCR control circuit, and the GCR trip-coil circuit.

21-34. The GCR is a dual coil latching relay. The application of power to one coil closes the relay: power to the other coil opens the relay. The GCR close-coil circuit functions to energize (close) the relay. This will apply excitation to the generator and voltage to the CCR control circuit. The close-coil circuit functions in the following manner. When the generator control switch (GCS) is closed, voltage is applied to Q13. Since SCR1 is not normally conducting, Q13 is forward-biased and conducting. The voltage drop across R52 forward-biases Q14, and when the underspeed switch closes, Q14 conducts. This closes the GCR and at the same time a set of GCR contacts ground the base of Q14, causing it to turn off. The GCR now remains closed until the trip coil is energized.

21-35. *Undervoltage sensing disabling circuit.* The UVS must be disabled prior to the closing of the GCS and the underspeed switch (USS) to prevent an automatic lockout of the GCR. Transistor Q29 performs this operation. The UVS trip signal is blocked (until the USS closes) by transistor Q29. Transistor Q29 does this by keeping Q16 in a state of conduction. Normally, if an undervoltage condition exists, the UVS will function to trip the generator off the line. However, Q29 is cut off during initial buildup. Because Q17 of the UVS circuit is conducting, electron flow now exists from the collector of Q17 through R113, CR103 and R117, to the unregulated power supply. This applies sufficient voltage to the base of Q16 to keep it conducting, and keeps Q9 from firing. Thus no trip signal is applied to the contactor logic circuits, and when the USS closes, Q14 closes the GCR and the generator starts to build up.

21-36. *Contactor control relay control circuit.* The third basic circuit of the contactor logic circuit is the contactor control relay (CCR) circuit. The CCR control circuit energizes or deenergizes the CCR, which, in turn, energizes or deenergizes the line contactor. The circuit consists of transistors Q18 and Q19 and the CCR coil. Transistor Q18 energizes the CCR coil, and Q19 deenergizes the coil.

21-37. When the GCR is closed, a dc voltage is applied across the series circuit, consisting of CR53, Q19, the CCR coil, CR79, Q18, and CR67. Transistor Q19 is forward-biased by voltage divider network R70, R51, and R48. Q18 is reversed-biased because there is no electron flow from the UVS circuit through the voltage divider network R71 and R78. When the generator voltage builds up to 107 volts, Q16 in the UVS will conduct, causing electron flow through R71 and R78. This will cause Q18 to conduct, and the CCR closes, locking itself in through a set of auxiliary contacts and energizing the line contactor. The CCR remains closed until a system protective circuit causes SCR1 to fire and cut off Q19, or until the GCS or the USS is opened.

21-38. When the generator is shut down, either by manually placing the GCS to OFF or a protective circuit fires SCR1, the CCR and the GCR must operate in sequence. That is, the CCR must open before the GCR; otherwise the generator would be deenergized while still connected to the bus. This sequencing is accomplished by CCR contacts 2 and 4. Supply voltage is not applied to Q26 until after the CCR has deenergized, thus preventing the GCR from opening until the line contactor has opened.

21-39. *GCR trip-coil circuit.* The fourth section of the contactor logic circuit to be discussed is the GCR trip-coil circuit. The purpose of the GCR trip-coil circuit is to deenergize the GCR. The circuit is composed of Q11, Q12, and the relay trip coil. Transistor Q12 energizes the relay coil, while Q11 insures that Q12 is turned fully on. Normally, Q11 and Q12 are reversed-biased and not conducting. When a system protective circuit fires SCR1, Q26 being cut off causes Q12 to conduct, opening the GCR. With Q12 conducting, the base of Q11 is near ground potential. This causes Q11 to conduct, increasing the forward bias on Q12 and deenergizing the GCR.

21-40. *Unbalanced current sensing circuit.* The unbalanced current sensing circuit (UCS) functions during parallel operation to split the buses if the real load division between the generators becomes excessively unbalanced. If a CSD malfunction should occur, causing one generator to supply considerably more current than the other, the UCS detects the unbalance and applies a signal through a fixed time delay circuit to the isolate relay circuit. The isolate relay then energizes and opens the tie contactor, splitting the system.

21-41. When an unbalanced condition exists, a voltage proportional to the amount of current unbalance is applied across the bridge rectifier circuit. As shown on figure 75, this circuit consists of CR83, CR84, CR85, and CR86. The output of the bridge rectifier circuit, filtered by C24, is applied to the base of transistor Q21. Q21 is normally at cutoff. However, if the current unbalance becomes excessive, the positive output of the bridge will turn on Q21. When Q21 conducts, Q20 will conduct. This causes most of the power supply voltage to appear across R102. When Q20 conducts, the voltage on the cathode of CR88 becomes greater than the voltage on the anode, and the diode becomes reverse-biased. R89 is adjusted so that approximately 5 seconds is required for the voltage across C25 to increase to a level sufficient to fire unijunction Q22 and to close the isolate relay. This opens the circuit to the tie contactor, causing the generators to split. Now, the system protective circuits in the VR/SP will function to remove the defective generator system from the bus, and the switching circuits will reclose the tie contactors, allowing the remaining generator to supply the entire electrical load.

21-42. This completes our discussion of the VR/SP. As you can see, there are many circuits contained in this single unit. Looking at foldout 3 again, you will notice that for each generator there are only six major units that can malfunction. So far we have discussed two of them. Next, we will discuss the frequency and load control box.

21-43. *Frequency and Load Control Box.* The frequency and load control box (FLCB) contains the circuitry required to perform three generator system control functions. These functions are fine frequency control, automatic paralleling, and real load division. The FLCB is made up of six major circuits, as shown on foldout 7. Let's identify these circuits one at a time, beginning with the dc power supply. This power supply provides the operating voltage for the transistorized circuits. The frequency reference provides a 400 ± 0.2-Hz reference signal. The frequency comparator samples the generator frequency and compares it to the reference signal. The load division demodulator detects a real load unbalance between the parallel generators. It also provides a pulse amplitude correction signal to the power output and mixing circuit. The power output and mixing circuit combines the frequency comparator and load division demodulator signals in a correction signal which is applied to the bias coils in the CSD. Finally, the automatic paralleling circuit will close the tie contactor when the generator outputs are within prescribed limits as to phase angle and frequency difference. Now we will discuss these circuits separately, starting with the dc power supply.

21-44. *DC power supply.* The dc power supply is a conventional full-wave center-tapped transformer rectifier circuit. The power supply receives its input from C phase of the left generator, as shown in foldout 8. As previously mentioned, the dc power supply provides the operating voltage for the transistorized circuits of the FLCB.

21-45. *Frequency reference circuit.* The frequency reference circuit provides a 400 ± 0.2-Hz signal, which is used as a standard by the frequency comparator circuit. The frequency reference circuit consists of two separate circuits, the tuning fork oscillator circuit and the fork scale-of-two circuit. The tuning fork oscillator circuit produces an 800 ± 0.4-Hz signal which is applied to the frequency comparator circuit.

21-46. When the dc voltage from the power supply is applied to the tuning fork, the fork starts vibrating. The tuning fork circuit is shown in the lower right corner of foldout 8 and in detail in figure 76. The vibration of the fork produces an 800-Hz signal, which is amplified by Q801, and appears in the form of a modified square wave at the junction of R802 and C802. This signal is stepped down to 400 Hz by the fork scale-of-two circuit.

21-47. The fork scale-of-two circuit has two stable conditions. The circuit is stable when Q503 is conducting with Q504 cut off, and also, when Q504 is conducting with Q503 cut off. For the purpose of explanation, we will assume that Q503 is conducting and Q504 cut off. The modified square wave signal from the tuning fork oscillator is formed into a clamped square wave by Zener diode CR505. This clamped square wave is coupled to the scale-of-two circuit by C503 and C504. When the input signal goes negative, Q503 will cut off. When Q503 cuts off, the collector voltage will increase. This causes an increase in the voltage drop across R516, causing Q504 to conduct. This completes the shift of the scale-of-two circuit from one stable state to the other.

21-48. The next negative pulse from the tuning fork circuit turns Q504 off. When Q504 cuts off, collector voltage increases, causing an increase in the voltage drop across R515. This turns on Q503, and the scale-of-two circuit is now back to the original stable state. The transition from one stable state to the other occurs on each negative pulse of the input square wave. This results in an output signal across R503 in the form of a square wave exactly one-half the frequency of the input signal.

21-49. *Frequency comparator circuit.* The frequency comparator circuit consists of three reference scale-of-two circuits, three generator scale-of-two circuits, and a phase demodulator circuit. Looking at the frequency comparator circuit of figure 77, you will notice that the generator frequency input is to the generator scale-of-two circuit No. 1. Now three circuits of the generator scale-of-two circuit will reduce the generator's input signal to one-eight its original frequency. As an example, let's say that the generator input frequency to the generator scale-of-two circuits is 400 Hz. Each scale-of-two circuit will reduce its input signal to one-half the original value. Therefore, the signal entering the phase demodulator will be 50 Hz. On the other side of the circuit at the same time, the reference scale-of-two circuits are reducing the input signal from the frequency reference circuit. This signal is also reduced to 50 Hz and applied to the phase demodulator circuit. The phase demodulator will now combine these two signals and provide an output signal to the power output and mixing circuit in proportion to the amount of frequency difference between the reference signal and the generator frequency signal.

21-50. If the generator frequency is greater than the reference frequency, the feedback circuit blocks the final generator scale-of-two signal. This results in the pulse width of the signal from CR401 being the greater, and the power output and mixing circuit reduce the speed of the drives. This brings the generator frequency down to that of the reference frequency. The same also applies when a generator is operating at the same frequency as the reference, but the phase of the generator signal is lagging the phase of the reference signal. In this case, the width of the output signal from CR401 is greater than the width of the output signal from CR402. These output signals are applied to the power output and mixing circuit, causing drive speed to increase and bring the generator and reference in phase with each other.

21-51. *Load division demodulator circuit.* The load division demodulator circuit provides a voltage amplitude modulated signal to the power output and mixing circuit. It does this to correct for an unbalanced real load condition between the paralleled generators. The input signal to the load division demodulator circuit is supplied by a current transformer loop in the ac power control box.

21-52. When current is flowing in the C phase generator lead, a voltage proportional to the amount of C phase current is induced within the C phase current transformer, as shown on foldout 9. The C phase current transformer for each generator is connected with its outputs opposing within a loop. When the generators are supplying equal currents, the output of the current transformer loop is zero. However, if one generator is supplying more current than the other, an output voltage appears across the current transformer loop. If the right generator is supplying more current than the left generator, pin R of the FLCB connector is positive with respect to pin P. If the left generator is supplying more current than the right generator, pin P is positive with respect to pin R.

21-53. The load division demodulator contains two bridge rectifier circuits. Bridge A and bridge B are powered by separate secondaries of T1 through separate secondaries of T3. The secondaries of T3 are so connected in the circuit that when the output of one T3 secondary is adding voltage to its bridge circuit, the other T3 secondary is subtracting voltage from its bridge circuit. This results in one bridge applying a greater voltage to the power output and mixing circuit than to the other bridge. This action causes one CSD to speed up slightly and the other to slow down slightly, thus balancing the real load between the generators.

21-54. To illustrate the operation of the circuit, we will assume that the right generator is supplying a greater amount of current than the left generator. This will cause the instantaneous polarity of pin R to be positive with respect to pin P. Normally, no voltage is present across the primary of T3, and the only voltage applied across bridges A and B is that from the secondaries of T1. Thus, the bridge A and bridge B voltages applied to the power output and mixing circuit are equal. However, one generator is now producing more current than the other, and a voltage is applied to the primary of T3 from the current transformer loop. The voltage from the secondary of T3, connected to bridge B, is opposing the voltage from the secondary of T1, thereby reducing the bridge B output voltage. The voltage from the T3 secondary, connected to bridge A, is adding to the voltage from the secondary of T1, thereby increasing the bridge A output voltage. The power output and mixing circuit reduces the speed of the right CSD and increases the speed of the left CSD. Because the generators are in parallel, the actual speed of the drives does not change. It is the torque of the drives that actually changes, resulting in an equalizing of the real load.

21-55. *Power output and mixing circuit.* The power output and mixing circuit is shown on foldout 10. It consists of digital circuitry which integrates the frequency error signals from the frequency reference circuit with the unbalanced load signals from the load division demodulator circuits. The resultant output signals are applied to the drives to correct the off frequency or unbalanced load conditions.

21-56. For example, we will assume that the real load is balanced between the generator, and the generator frequency is synchronized with the reference frequency. Under these conditions, the voltages from bridges A and B of the load division demodulator circuit are equal, and the widths of the pulses from the frequency comparator circuit, through CR401 and CR402, are equal. When a positive signal is present from CR402, transistors Q201 and Q202 conduct. This allows current flow through the left CSD "increase" coil and through the right CSD "increase" coil. When a positive signal appears from CR401, CR402 is negative, cutting off Q201 and Q202 with Q203 and Q204 conducting. This cuts off the current flow through the left and right "increase" coils. Now current is permitted through the left and right "decrease" coils. With no frequency or load error, the "increase" and "decrease" coils in the drives are energized alternately with pulses of equal width and amplitude, thus resulting in no change in the drive speed.

21-57. When the generator frequency is low, the width of the pulses from CR402 will be greater than the width of the pulses from CR401. This will

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cause Q201 and Q202 to conduct longer than Q203 and Q204. This action energizes the "increase" coils for a greater period of time than that of the "decrease" coils. This causes the drives to increase speed until the pulses from CR401 and CR402 are equal. If the generator frequency were high, the width of the pulses from CR401 would be greater and the opposite action would take place.

21-58. If the left generator was supplying the greater load current, the voltage from bridge B in the load demodulator circuit would be greater than the voltage from bridge A. This results in the voltage on the right "increase" and left "decrease" coils being greater than the voltage on the right "decrease" and left "increase" coils. The net result of these voltage differences causes the left drive to slow down and the right drive to speed up. This action equalizes the real load by changing the torque on the drives. Any combination of frequency and load errors can be corrected by the power output and mixing circuit.

21-59. *Automatic paralleling circuit.* The last circuit contained in the FLCB to be discussed is the automatic paralleling circuit. This circuit is shown in foldout 11. It consists of a phase-shift transformer, bridge rectifier, and K1, the automatic paralleling relay (APR). It will parallel the generator outputs (close the tie contactor) when conditions of phase angle and frequency between the generators are suitable for paralleling.

21-60. The automatic paralleling circuit functions as a phase sensitive detector. When the left and right generators are placed in operation, phase C voltage from the left generator is applied directly to one side of the bridge circuit (refer to FO 11), and phase C voltage from the right generator is applied to the other side of the bridge through T2. When these two voltages are beat together across the bridge, the resultant dc output of the bridge will vary from zero vdc, when the generators are 180° out of phase, to approximately 230 vdc, when the phase angle between the generators is zero degrees. The dc voltage varies at a rate equal to the beat frequency of the generators (refer to details A and B of FO 11).

21-61. The dc output of the bridge is then applied to the APR coil. When the phase angle difference between the generators is approximately 90°, the output of the bridge is enough to close the APR. The relay remains closed until the phase angle between the generators exceeds approximately 140°. At this phase angle the output of the bridge is too low to hold in the APR, and it will open. Thus, it can be seen how the APR will pulse with the beat frequency of the generators. The generator system control voltage is applied to the tie contactor coil through the normally open contacts of the APR. As the APR pulses, the tie contactor attempts to pulse also. However, due to the physical characteristics of the tie contactor, such as armature size, friction between the movable parts, etc., the pulses from the APR must be approximately 90 milliseconds or longer before the tie contactor can close. The closing of the tie contactor parallels the generator outputs, the generators lock in phase, and the APR remains closed.

21-62. *AC Power Control Box.* The ac power control box is the main connecting unit between the generator and the aircraft loads. By looking at foldout 12, you can see that the unit contains the following major components:

- Left and right line contactors, LLC and RLC.
- Tie contactor, TC.
- External power contactor, EPC.
- Loop shorting relay, LSR.
- Current transformers, CT.

21-63. *Contactors.* The ac power control box contains four contactors. Each contactor has three main contacts to complete the 3-phase power leads and several auxiliary contacts used in the switching sequence. The left and right line contactors connect the output of the left and right generators to the aircraft loads. The tie contactor is used to parallel these two outputs. The external power contactor connects the aircraft loads to the external power receptacle. The operation of these contactors is controlled mainly by the voltage regulator/supervisory panels.

21-64. *Loop-shorting relay.* The loop-shorting relay shorts the three current transformer loops whenever the tie contactor is deenergized. This is done since the only time the current transformer loops are used is when the generators are paralleled.

21-65. *Current transformers.* Two current transformers are connected to the C phase of each generator, and one to the B phase of each generator. The current induced within each current transformer is proportional to the amount of current flowing within the line monitored. The current transformers are connected in a loop and phased so their outputs are opposing. The output of the loop is then proportional to the difference in the amount of current produced by each generator. The six current transformers make up three loops, one for reactive biasing, one for real load division, and one for the operation of the difference current relay and the open phase relay. As stated previously, all three loops of the current transformers are shorted by the loop shorting relay whenever the tie contactor is deenergized.

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21-66. *Constant Speed Drive.* The constant speed drive is a mechanical-hydraulic device. By controlled differential action, it adds to or subtracts from the variable input speed of the aircraft engine in order to maintain a constant output speed. The three most important units in the constant speed drive for the electrical specialist are the basic governor, the limit governor, and the underspeed switch.

21-67. To provide for load division, the basic governor is provided with a magnetic trim solenoid. The frequency and load control box furnishes a corrective signal to the trim head to maintain a correct real load division when the generators are operated in parallel.

21-68. The limit governor provides two functions. It controls the actuation of the underspeed switch and actuates the trip valve. As the engines are started and the increasing output speed becomes equivalent to 375 Hz, the limit governor ports oil pressure to the underspeed switch. After engine shutdown the opposite action occurs--the governor drains oil from the underspeed switch and actuates the trip valve. The action of the trip valve drains oil from the control cylinder, reducing the drive output speed to minimum. Once the drive is placed in this underspeed condition, the engine must be stopped to allow pressure to be removed from the trip valve, returning the drive to normal. The underspeed switch prevents the generators from being connected to the aircraft bus until the generator frequency has built up to approximately 375 Hz.

21-69. Now that we have discussed the major units of the generator system, we will describe the operational sequence of the system during normal generator buildup and operation.

21-70. *Normal System Buildup.* Referring to foldout 13, we will start the left engine before the right engine. As the left generator builds up speed, the PMG output builds up and is applied to the PMG transformer rectifier. The output of the transformer rectifier is used for generator excitation as a dc control voltage for operation of system relays and contactors. It is also used as a power supply for the semiconductor circuits in the VR/SP. When the GCS is closed, the control voltage is applied to the USS, and through CR25, to the main dc control bus in the ac power control box. The USS will close when the generator frequency reaches 375 ± 5 Hz. This action applies the dc control voltage to the GCR close-coil logic circuit and the GCR-1 contacts. The logic circuitry energizes the GCR close coil, closing the GCR. The GCR-1 contacts apply control voltage to the contactor control relay (CCR) and its logic circuitry. The GCR-2 and GCR-3 contacts apply excitation voltage from the voltage regulator to the generator field. When the generator output rises above 107 vac, the left UVS circuit provides a "close" signal to the CCR logic circuitry. The CCR closes, locks in through a logic circuit, and energizes the left line contactor (LLC) through TC-1 contacts. The LLC locks in through the LLC-1 contacts, and the left generator powers the left 115-vac bus through LLC-10 contacts. The relay's LLC-9 contacts will then extinguish the LH GEN OUT light, but the remaining warning lights are still illuminated through TC-7, TC-8, and RLC-9 contacts.

21-71. The main dc control bus voltage is applied through RLC-3 and LLC-2 contacts, the normally closed side of TCR-2, and the EPC-2 contacts to the TC coil. This closes the TC-10 contacts, and the left generator also powers the right 115-vac bus. The LH GEN OUT and the BUS TIE OPEN lights now being extinguished indicate that the left generator is operating normally, powering both the left and right buses.

21-72. As the right engine is brought up to speed, the right generator system builds up in the same manner as the left system, up to the time the CCR closes. The CCR cannot energize the right line contactor (RLC) because the TC-2 contacts are now open. The TC must be deenergized to allow the RLC to close, as well as to allow the automatic paralleling circuits in the FLCB to check the generators for proper frequency and phase relationship prior to paralleling.

21-73. When the right CCR closes, contacts TC-4 and RLC-4 energize TCR-2. TCR-2 locks in through its normally open contacts, and its normally closed contacts deenergize the TC. The TC-10 contacts open and remove the right bus from the left generator. At the same time the TC-4 contacts open and reset, TCR-2 and the TC-2 contacts close and energize the RLC. The RLC locks in through the RLC-1 contacts. RLC-9 contacts open and extinguish the RH GEN OUT light. Also, contacts RLC-10 close and connect the right generator to the right 115-vac bus.

21-74. The LH GEN OUT and the RH GEN OUT warning lights are now extinguished. This indicates that both generating systems are functioning properly and are supplying their respective buses. The BUS TIE OPEN light is illuminated by contacts TC-8, and indicates that the generators are not yet in parallel. When conditions are right for paralleling, the APR closes the TC. Voltages from the main dc control bus are applied through the LLC-7 and RLC-7 contacts, the normally closed contacts of TCR-1, the APR contacts, the normally closed side of TCR-2,

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and the external power contactor-2 (EPC-2) contacts to the TC coil. The loop shorting relay is also energized through the LLC-8 and RLC-8 contacts. This removes the short from the current transformers, allowing the sensing of reactive current and unbalanced current. Contact TC-8 will open and the BUS TIE OPEN light will be extinguished. All three warning lights are now extinguished, indicating that the generating systems are operating normally and in parallel.

21-75. This concludes our discussion of the generating system and its components. As an electrical specialist, I am certain that you are aware of the importance of the external power system. Not only do we use this sytem to perform operational checks on electrical and electronic equipment, but other maintenance activities must also depend upon it. In the next section we will discuss the external power and battery power distribution system.

22. Power Distribution System

22-1. The power distribution system consists basically of the left and right 115-vac, 3-phase buses and low-voltage ac and dc bus systems. Refer to foldout 14 during this discussion. Power from the left generator is connected to the left 3-phase, 200/115-volt system through the left line contactor. Power from the right generator is connected to the right 3-phase, 200/115-volt system through the right line contactor. Under normal operating conditions, the left and right 3-phase, 200/115-volt systems are paralleled through the tie contacts. The autotransformer supplies 14/28-volt ac power to the left 14/28-volt buses and 28-volt power to the right and left instrument 28-vac buses. This enables the cockpit warning lights to be switched from 28 vac for day operation to 14 vac for night operation of the warning light system.

22-2. External 200/115-volt, 400-Hz, 3-phase power is used for ground operation. The system we are about to discuss makes use of an external power transformer rectifier for converting one phase of the external power source to dc for energizing the external power contactor which connects external power to the aircraft buses. Let's discuss this system in more detail with the help of foldout 14.

22-3. *External Power.* The aircraft external power control circuit includes the generator control switches, external power contactor (EPC), external power transformer rectifiers, external power receptacle, and instrument ground power switch. On foldout 14, you can see that A phase of the external power is connected directly to the external power transformer rectifier. The 28-vdc output of the transformer rectifier is applied to the EPC solenoid. When the EPC contactor energizes, the external 3-phase, 115-vac power is applied to the left 115-volt, 3-phase bus. The left 3-phase bus then energizes the left T/R, and its 28-vdc output energizes the tie contactor solenoid through a set of normally open EPC contacts. As you can see, the energizing of the contactor applies external power to the right 115-volt, 3-phase bus. Actuating the instrument ground power switch will apply power to the instrument 115-volt, 3-phase bus through the external power switching relay and the instrument bus lock-in relay. Also contained in the system are 28- and 14-volt ac buses which supply the aircraft's low-voltage requirements. Looking at the diagram you will notice that each ac bus is powered independently from an autotransformer. Each autotransformer is protected from overloads by a circuit breaker. The rest of the power distribution system will be discussed with the battery power system.

22-4. *Battery Power System.* Batteries are by far the most misunderstood components in the aircraft electrical systems, yet there is no other single piece of electrical equipment more important. Aircraft have been lost because a battery had not been properly maintained, and thus failed to provide the necessary emergency power to operate essential flight equipment during an emergency.

22-5. The servicing, charging, repairing, and testing of the battery as well as troubleshooting its control system are some of your responsibilities. The knowledge requirements for you to perform these tasks are presented in this section. Because the battery and the battery power system are so important, let's start our discussion with a review of the nickel-cadmium battery.

22-6. *Nickel-Cadmium battery.* The plates of a nickel-cadmium battery are made of a powder sintered to a nickel wire screen. The active materials, nickel oxide on the positive plate and metallic cadmium on the negative plate, are electrically bonded to the basic plate structure. The electrolyte used in the nickel-cadmium battery is a 30-percent (by weight) solution of potassium hydroxide in distilled water. It provides a conducting path for the current which flows between the positive and negative plates. The electrolyte does not take part in the chemical reaction as does the sulphuric acid in lead-acid storage batteries. The specific gravity of the electrolyte is the same whether the battery is charged or discharged.

22-7. A cell is the fundamental unit of a battery. The cell consists of the positive and negative plate structures, separators, and electrolyte and container. The positive and negative plates, which are assembled as a cell core, are separated from each other by two layers of nylon cloth and one layer of cellophane. The plate structure is housed in a cell case of molded nylon. The nominal open-circuit cell voltage is 1.30 volts. This voltage varies with the rate and state of charge. Generally, the higher the current drawn from the battery and the lower the state of charge, the lower will be the cell voltage. Nickel-cadmium batteries for 24-volt systems consist of 19 individual cells connected in series.

22-8. Nickel-cadmium batteries have several major advantages over the other commonly used storage batteries, as follows: (1) delcted. (2) they maintain a relatively steady voltage when being discharged at high currents; (3) they are not permanently damaged if overcharged, overdischarged, or charged in the wrong direction; (4) they can stand idle in any state of charge for an indefinite time; (5) they retain their charge if stored in a charged condition for prolonged periods of time; (6) they are not damaged by freezing; (7) they are not subject to failure by vibration or severe jolting; (8) they do not normally exude corrosive fumes; (9) they are composed of individually replaceable cells.

22-9. These batteries are not adversely affected by extremely low temperatures. The lower the temperature, the better they will retain their charge when in idle storage or standby service. They do not have to be removed from the aircraft during cold weather under normal operating conditions. Nickel-cadmium batteries will accept a charge at temperatures as low as -65° F. While charging at low temperatures, a longer period is required to bring the batteries up to full charge. Generally, the lower the temperature, the longer will be the charging time. The voltage on discharge is lower at low temperatures than at normal temperatures. Voltage decreases with a decrease in temperature, and with an increase in discharge rate. The capacity is similarly affected. However, the batteries need not be operated intermittently at low temperatures as must other commonly used battery systems.

22-10. The state of charge of nickel-cadmium batteries cannot be determined by the battery voltage or by the specific gravity of the electrolyte. A reading of approximately 24 volts means that the batteries may be completely charged or almost completely discharged. The state of charge cannot be determined by the specific gravity of the electrolyte, because the electrolyte is not changed by the chemical reaction which occurs in the batteries; the specific gravity is the same whether the batteries are charged or discharged.

Paragraphs 22-11 and 22-12 deleted.

22-13. *Battery power circuit.* Referring to foldout 14, you can see that the battery power system is a very simple circuit consisting of a nickel-cadmium battery, a 24/28-volt dc bus, the battery relay, and the essential 28-vdc bus. The purpose of the battery in this system is to provide electrical power for the engine ignition, four white flood lights, and the EGT indicator inverter. The main source of emergency power for this aircraft system comes from the emergency ac generator, which is ram air turbine driven. Because this system does incorporate a separate emergency power source, you can see from the diagram that the battery can only be connected to the essential bus by one of the following conditions:

- When either engine master switch is in the ON position.
- Whenever the ground refueling control switch is in the REFUEL or DEFUEL position.

22-14. When either switch gives the battery relay a ground, the battery bus will assume a voltage of 28 vdc, which is provided by the left and right transformer rectifiers. So far in this discussion no mention has been made of some of the associated systems that operate in conjunction with the battery power systems and the battery charging systems. This omission is intentional because of the wide differences in these systems and because some are peculiar to only one type of aircraft. For example, most battery systems provide some means of monitoring or indicating battery voltage and the amount of charging power available. Other battery systems use a variety of warning lights to indicate whether the battery is charging or discharging, or whether it has reached the end of its usefulness. In the next section we will discuss some of the malfunctions and indications of the systems discussed so far in this chapter.

23. System Malfunctions

23-1. Trouble analysis is a test of ingenuity as well as of knowledge. For this reason, trouble analysis procedures cannot be considered as ironclad rules. Experience will increase your knowledge of various electrical systems, and reveal new checks and more efficient methods of troubleshooting. By adopting these new methods, you can devise shortcuts to eliminate lengthy checks for similar troubles.

23-2. Although you have a firm background in electrical fundamentals, this is still not enough to enable you to do your job with ease. In addition to the fundamental information you possess, you must have a thorough understanding of troubleshooting procedures. Realistic troubleshooting is not a hit-or-miss, remove-and-replace, or trial-and-error process. It is an orderly sequence of mental and physical actions ending with the identification and elimination of a system malfunction.

23-3. As you gain experience you will find that in most cases certain troubles are caused only by certain components in the electrical system, and that you will be wasting your time if you check items that have nothing to do with the trouble. For this reason we can break these malfunctions down into three main categories: frequency, voltage, and load division. Let's start our discussion with the frequency problems.

23-4. *Frequency Problems.* In almost all cases, frequency problems consist of either constant frequencies which are higher or lower than normal system frequency. Since only certain units are used to control the generator frequency, troubles of this nature usually present no great difficulty. For example, higher or lower than normal frequency may be caused by a defective frequency and load control box or by the drive governor system. To determine which unit is malfunctioning, you would have to remove the connector from the frequency and load control box. After this is done, operate the engines and build up the generator with the frequency problem. If the generator comes on the line, and its frequency is within 400 ± 4 Hz, the frequency and load control box is defective. If the frequency is not within these limits, the CSD may be faulty or out of adjustment. If the frequency varies as the engine speed is varied, the CSD is defective. If, however, the frequency remains steady as the engine speed is varied, but is not within 400 ± 4 Hz, adjustment of the CSD basic governor is necessary. Before you replace a drive unit, however, it is best to test the frequency and load control box with the electrical power test harness as discussed earlier.

23-5. *Voltage Problems.* Another common trouble that you will encounter is one in which the generator or bus voltage is higher or lower than normal, or there is no voltage at all. If the trouble is a complete loss of voltage from one generator, the first step is to determine if the CSD is turning the generator. This can be determined by measuring the voltage output of the permanent magnet generator. If a good voltage indication is obtained from the permanent magnet generator (PMG), the CSD and PMG are operating normally. This leaves only the voltage regulator or the generator control relay circuitry in the VR/SP.

23-6. High- or low-voltage troubles are usually caused by the VR/SP, the generator, or in some cases, the generator drive. Some other possible causes of low output voltage are high resistance in either the exciter input or output circuit to the generator. Also, an open in the exciter output circuit of a brushless generator can cause low generator output voltage. High voltage output is most generally caused by a defective VR/SP, CSD, or ac generator. Another cause for excessive generator output is the higher than normal output from the exciter generator. This

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can usually be detected by measuring the PMG output. A thorough knowledge of the information contained on foldout 13 should give a technician enough information to be able to isolate any malfunction of the ac power system to one or two main units.

23-7. *Load Division Problems.* Load division problems are probably the most difficult and thought-provoking problems that you will encounter. These are the types of problems that really test your knowledge of the electrical power systems and your ingenuity in troubleshooting.

23-8. Load division problems show themselves in many ways. A generator in parallel operation may not carry its share of the KW or KVAR load, or it may try to "hog" the load and carry more than its share. In some cases you may notice a marked tendency for generators operating in parallel to swap the load back and forth between them. In some cases of extreme load underbalance, one or more of the bus tie relays may split the buses. For example, an overexcited generator, in parallel, will tend to carry more than its share of the reactive load, and the overexcitation protective device will automatically take the generator off the line.

23-9. Suppose you have discovered a load division problem. After testing the frequency and load control box or the VR/SP, you find that they are functioning properly. Obviously the trouble must be somewhere in the sensing circuits for these components. You should recall from previous discussions that the load division circuits receive their input signals from current transformers located in the ac power control box. The current transformers are the source of many malfunctions in the load division circuits. Their characteristics are very easily changed, either by installing them incorrectly or by failing to short them when operating the affected system. If maintenance has recently been performed on the affected system, it is worthwhile to check the current transformers of the system for proper connection. Another check you should make is to find out whether the transformer had been shorted or left disconnected when the system was operated. If a current transformer is not shorted when it is disconnected from an operating system, extremely high current will flow through the transformer and change its characteristics.

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CHAPTER 10

ANALYZING CONTROL AND WARNING SYSTEM PROBLEMS

IF YOU SHOULD accidentally put your hand on a hot soldering iron, a certain series of events will normally occur. First, you should feel some pain as the extreme heat burns you. Secondly, the normal reaction is to pull your hand away quickly. Two specific body systems have been used. The nerves in your hand act as a warning system telling you the iron is hot. This causes the second body system, the brain, to respond, which activates a control circuit to move your hand away. Whereas the brain is the control center for your body, the pilot is the control center for the aircraft. Warning circuits feed information to him so that he can respond with corrective action.

2. As you know from your experiences, a great number of manhours are spent maintaining the aircraft control and warning systems. The systems are as varied as the aircraft. These systems become more complicated with each new weapon. In this chapter we have chosen four areas that seem to cause most of the trouble. The technique that you have developed to troubleshoot the systems will apply to most control and warning circuits. Let us begin with the fire warning system.

24. Fire Warning System

24-1. Fire is one of the most dreaded emergencies that can happen to an aircraft. The maintenance of the fire warning system must be of prime concern to you as a technician. The system's proper operation must be counted upon. False indications due to malfunctions cost the Air Force thousands of dollars per year in missed flights. Proper maintenance by you and your men, coupled with your complete understanding of system operation, can greatly reduce the manhours expended on this task. Before we start our discussion on system operation we will review the most common systems.

24-2. *Types of Systems.* There are several basic fire warning systems being used on the aircraft in our inventory. Some of the older planes which were thought to be heading for obsolescence have been returned to prime importance due to their supporting role in Vietnam. We will begin with an earlier system used on most aircraft equipped with the R4360 engine, the Edison thermocouple system.

24-3. *The Edison thermocouple system.* The Edison thermocouple system is designed to detect fires that occur in the engine nacelles or around the auxiliary electrical power plant. Each engine has three zones or circuits. A circuit consists of a number of thermocouples located in the power plant nacelle. Also, a sensitive relay, a test unit and slave relay in the fire detector relay shield, and a test switch and indicator light combine to complete the circuit.

24-4. As you should remember, this system operates on the principle of rate of temperature rise. The *difference* in temperature rise between the hot and cold junctions of the thermocouple can produce up to 50 millivolts. This millivolt signal activates the system.

24-5. *The photoelectric (fireye) system.* Some aircraft still use this system as the prime fire detector, while most cargo aircraft use a variation of it in their cargo compartments. This system consists of a number of photoelectric detectors, a power unit, two signal lamps, a relay, and a rotary test switch located on the fire emergency panel.

24-6. The operation of the photoelectric system depends upon the varying radiation of the flame. As the rediation varies, the resistance of the detector varies. This establishes an output of pulsating dc. If the output signal is in a given frequency range, the signal lamp will light, providing the pilot with a visual indication of a fire. Because the system is frequency sensitive, light sources such as the sun will normally not trigger it.

24-7. *The Fenwall fire and overheat detector system.* The Fenwall system is used on both reciprocating and on some older jet engines. It consists of a series of adjustable thermal switches, an indicator light, and a test switch. The thermal switches or detectors may be set for various predetermined temperatures. This system normally gives an indication of a fire or overheat condition when the temperature setting of a detector is exceeded.

24-8. *Fire detection cable assemblies.* This system is most commonly referred to as the continuous cable system. It is used on most aircraft that are familiar to you. Because this system is most commonly used, we will discuss it in depth. An electrical schematic of a continuous cable circuit is shown in figure 78. The fire detection cable system consists of a fire detection cable assembly, a fire detection control assembly, a fire pull switch, a red warning lamp, a fire detection test switch, and a fire detection test relay. The sensing cable assembly consists of as many series connected sensing elements as necessary for the installation. The cable assembly is routed through the engine nacelle and around the engine in the paths where fire is most likely to occur.

24-9. The sensing elements in the cable assembly usually consist of two inconel wires that are encased in a temperature-sensitive ceramic material. This material is encased in an inconel shield, which is a good conductor. The ceramic between the wires acts as a dielectric and insulates them from each other under normal temperatures. One lead is connected to a power source, and the other is grounded through the shield.

24-10. *Continuous Cable System Operation.* When heated, the ceramic decreases in resistance until current flows between the wires. This current flow provides a signal to the fire detection control unit which operates to turn on the red light. The system which you are presently responsible for may vary. For example, some sensing elements have just a single conductor running through the center of the element and use the shield as the second conductor. There are actually two different types of continuous cable fire warning systems. One uses a transistorized detection control circuit, while the other uses a magnetic amplifier. We shall restrict our discussion to the transistorized system. The entire circuit for this system can be divided into four basic circuits as follows:

- Power supply circuit.
- Sensing circuit.
- Amplifier circuit.
- Warning circuit.

Each circuit will be discussed in the above sequence with respect to normal conditions. Following this is a discussion relating to the complete operation of the system.

24-11. *Power supply circuit.* Dc power for the detection control circuit is supplied by the aircraft power system through a voltage regulator circuit containing transistor Q3, resistors R10 and R12, and diode CR2. A 28-volt dc potential is applied to the normally open set of contacts of relay K1 and the collector of transistor Q3. The regulated output from this transistor, which is connected as a common collector amplifier, is used to bias transistors Q1 and Q2 in the amplifier circuit.

24-12. *The sensing circuit.* The sensing circuit contains the sensing element, resistors R1, R2, and R3, diode CR1, and capacitor C1. Normally, the impedance of the sensing element is large (equivalent approximately to an open circuit). It will affect the network only if it is heated. It has a negative temperature coefficient of resistance. This means that if the temperature should increase, its resistance will decrease.

24-13. During normal operation, a constant potential is applied to the circuit from the voltage regulator. Because all components in the circuit have constant values (here we assume the impedance of the sensing element to be equivalent to an open circuit) current flow through the emitter-base junction of transistor Q1 and resistor R1, R2, and R3 establishes a maximum positive potential at the base of transistor Q1. Therefore, the emitter-base junction of transistor Q1, in the amplifier circuit, is forward-biased at a maximum value, and diode CR1 is reversed-biased.

24-14. *The amplifier circuit.* The amplifier circuit is a two-stage amplifier composed of transistors Q1 and Q2, the coil of relay K1, and various resistors. Both transistors are connected as common emitter amplifiers and are directly coupled together. Furthermore, the coil of relay K1 (in series with the collector of transistor Q2) is deenergized when transistor Q2 is cut off. It has already been shown that the emitter-base junction of transistor Q1 normally has a maximum forward bias. However, since this is a common emitter amplifier, its output voltage will be at a minimum positive value. This voltage, when applied to the base of transistor Q2, reverse-biases its emitter-base junction, which cuts off transistor Q2. Therefore, relay K1 is normally deenergized.

24-15. *The warning circuit.* The normally open contacts of relay K1 and the fire warning light make up the warning circuit. Under normal flight conditions, the relay is deenergized, which opens the circuit to the fire warning light. It is obvious that the light should illuminate only if a fire occurs.

24-16. *Circuit operation.* It has already been established that under normal conditions, if the impedance of the sensing element is equivalent to an open circuit, the potential applied to the base of transistor Q1 is at its maximum positive value. This causes its output voltage to be at a minimum value, which is applied to the base of transistor Q2, cutting it off. Therefore, transistor Q2 does not conduct, relay K1 is deenergized, and the warning light is out.

24-17. When a fire occurs, the impedance of the sensing element decreases. This additional path for current flow is from the junction of resistors R1 and R2, diode CR1, and capacitor C1 through the sensing element. Therefore, the voltage at this point decreases as the impedance of the sensing element decreases, decreasing the reverse bias of diode CR1. At a certain temperature (and therefore impedance) of the sensing element, diode CR1 becomes forward-biased. When this occurs, the voltage at the base of transistor Q1 is reduced, thereby increasing its output voltage. This forward-biases transistor Q2 enough to energize relay K1 and complete the circuit for the fire warning light. If the temperature of the element decreases, its impedance again increases, and diode CR1 again becomes reverse-biased. In this way the entire circuit reestablishes itself to its normal condition.

24-18. *Maintaining Fire Warning Systems.* The secret of success in maintaining the fire warning system is preventive maintenance. A direct relationship exists between your inspection procedures and the reliability of the system. The shop to which you are presently assigned may have all of the types of systems we have discussed. The technical data for each assigned aircraft will provide you with the inspection procedures. You, as a 7-level technician, must see that the inspections are performed in accordance with that technical data.

24-19. *Inspecting Inspections.* One of your major responsibilities as a technician will be supervisory inspections. These may be thought of as inspecting inspections. How can your inspections keep the fire warning systems operating? One menace to good system operation is corrosion. The rapid temperature changes encountered in the engine area make it a perfect breeding ground for this culprit. We as electricians fail sometimes to place the proper emphasis on corrosion control of the fire warning system. Good inspections will reveal the highly corrosive areas, allowing you to take preventive action.

24-20. The F-106 is equipped with the continuous cable system. When the test switch is placed in the TEST position, a ground is provided for the cable assembly. This operation checks the cable assembly for continuity. Since each segment has a specific resistance, the system will not function correctly if any one of the interconnectors has become corroded. It is not feasible to break each connection in the system to inspect for corrosion, nor is it called for in the inspection requirements. However, because of the high rate of malfunctions, a method for checking this item had to be devised. It was discovered that if the detector control unit was removed and the test relay closed, a continuity check could be made from the detector unit connector plug. From the technical order the maximum total resistance of each loop was determined. With this information the system could be checked for corroded connections. An increased total loop resistance would indicate the need to clean those connectors in the loop being checked. This check greatly reduced the number of problems encountered in the F-106 system.

24-21. Another menace to the fire warning system is the maintenance personnel that work in the engine bay area. One of the last inspections before the engine is cowled, or in the case of a jet before the engine is installed, is a visual and operational check of the fire warning system. You as a supervisor must insure that the system is correct before the area is closed. Many manhours have been expended by having to repeat work because we have failed to pay attention to details such as this.

24-22. We would be at fault if we did not discuss the other inspection requirements. Proper safety wiring, frayed wire, bent or kinked cable assemblies, bent or broken mounting brackets, and the condition of the insulators are some of the things that you should be concerned about during a periodic inspection. A saying from the "Ole Sarge" might fit here. "Anything worth doing is worth doing right." Good inspections can save you many hours of headaches in the fire warning system. Another system that is involved in warning the pilot that unsafe conditions exist is the master caution system. This system is our next topic for discussion.

25. Master Caution Circuits

25-1. Most of today's modern aircraft are equipped with a master caution and warning light system. This system is designed to caution the aircrew that an unsafe or potentially unsafe condition exists. Once the light is activated, some member of the aircrew must reset it to cause it to go out. This is to insure that there is an awareness of the warning.

25-2. There are several types of master caution and warning systems in use today. This discussion will be limited to solid state circuitry. However, many of the concepts used are similar to older systems. As you study the master caution and warning circuits, compare them with the one used on your aircraft and notice their similarities.

25-3. *System Characteristics.* The entire system is primarily contained in two separate units, namely, the main caution light panel and the master control light assembly. This system is composed of the individual caution lights, the master caution light, a shutter, and the electronic circuitry required for its operation. This circuitry can be divided into three separate circuits as follows:

The individual caution light circuit.
The master caution light circuit.
The reset circuit.

For our analysis of the operational characteristics of the master caution system, refer to figure 79. You should be familiar with the electronic symbols used from our review in Chapter 9. Let's begin with the individual caution light circuit.

25-4. *The Individual Caution Light Circuit.* The individual caution light circuit is located in the main caution light panel. This circuit includes diodes CR1, CR2, CR3, CR4, the caution light module, and a bright-dim switch. When a 28-volt dc signal is applied to the fault input or test input, a circuit is completed through the individual light module. If the ground is available through the bright-dim switch, the lights will be bright. If not, the circuit will be completed through Zener diode CR1, causing the lights to be dim. The application of this fault signal also applies a positive voltage through diode CR5 to the master caution input circuit. This allows the operation of the master caution light if silicon controlled rectifier SCR1 in the reset circuit is not conducting.

25-5. *Master Caution Light Circuit.* The master caution light circuit is made up of two lights, a shutter coil, transistor Q1, unijunction transistor Q2, silicon controlled rectifier SCR2, diodes CR5 and CR6, capacitor C2, and resistors R4 through R10. The application of 28-vdc to this circuit provides the power to illuminate the lights, operate the shutter, and bias the circuit. When a positive voltage is applied to the master caution input circuit, the master caution lights illuminate and the shutter opens after a time delay. If this input signal is reduced, the lights go out and the shutter closes.

25-6. Under normal conditions (no aircraft malfunctions), transistor Q1 is biased at cutoff. The emitter is at a positive potential established by a voltage dividing network consisting of resistor R10 and diode CR6. However, the base is at ground potential because no input signal exists. This reverse-biases the emitter-base junction of transistor Q1. Since transistor Q1 cannot be conducting, the master caution light is out and the shutter is closed.

25-7. Where a system fault occurs, a positive potential is applied to the junction of resistors R4 and R5. A voltage is then simultaneously applied to base 1 and base 2, as well as to the emitter of unijunction transistor Q2. However, these positive potentials are not necessarily the same or constant.

25-8. With the initial application of a fault signal, the emitter of Q2 is near ground potential, because capacitor C2 charges through resistor R4. At the same instant the potentials at base 1 and base 2 are at different positive values. These potentials are determined by a voltage dividing network consisting of resistors R5, R6, R7, and the N-section of Q2. This reverse-biases Q2 upon the initial application of a fault signal. Therefore, transistor Q1 remains cut off because the potential at its base has not changed.

25-9. As the time interval increases from the initial application of a fault signal, the potential at the emitter of Q2 increases with time. At some instant during the charging cycle of C2, the emitter of Q2 becomes positive with respect to gradient voltage directly across from its emitter. When this occurs, Q2 becomes forward-biased and conducts. This creates enough positive potential at the gate of SCR2 for it to conduct. This results in the application of a positive potential to the base of transistor Q1 with respect to its emitter, forward-biasing its emitter-base junction. Transistor Q1 conducts, allowing the master caution lamps to illuminate and the shutter to open.

25-10. The lamps continue to glow and the shutter remains open as long as SCR2 is conducting. Furthermore, SCR2 conducts as long as a high enough input voltage is applied to the master caution input circuit. To turn off the light and close the shutter, the input voltage need only be reduced in magnitude. This can be achieved by either one of two methods. One, obviously would be the removal of the initial fault condition. The other is done by pressing the master caution light cover. This operates a reset switch which activates the reset circuit.

25-11. *The Reset Circuit.* The reset circuit is made up of one reset switch, resistors R2 and R3, capacitor C1, and a tripping device, SCR1. The circuit affords a method of turning off the master caution light and closing the shutter after the condition is noticed.

25-12. Depressing the cover of the master caution light assembly activates the reset switch. This applies a positive 28-volt dc potential to one side of resistor R3. The potential on the other side, at the gate of SCR1, is initially zero, because capacitor C1 must charge through resistor R3. As this voltage increases exponentially with time, the voltage to the gate of SCR1 also increases. When the gate voltage reaches the firing potential for SCR1, it conducts and reduces the potential at the junction of resistor R1 and diode CR5. Because this reduced voltage is coupled to the master caution input circuit, the magnitude of the master caution input voltage is reduced.

25-13. This reduction in the master caution input voltage reduces the voltage at the cathode of SCR2, turning it off. The voltage at the base of Q1 is also reduced, which again reverse-biases its emitter-base junction. This cuts off transistor Q1, which turns off the master caution light and closes the shutter. Unijunction transistor Q2 is also cut off, because the voltage at its base 1 and base 2 is reduced to a level sufficient to reverse-bias its junction. We should note here that the master caution light cannot be relit from the original fault condition if it is uninterrupted. However, if a fault should occur in another system, the master caution light would then come on. Also, you should notice that the individual caution light is in no way affected by the operation of the master caution light circuit. This light will remain on until the fault is corrected. One of the many systems that have inputs to the master caution system is the fuel warning circuits. The pilot must have constant control over his fuel supply. The next system which we shall discuss is the fuel system and its circuitry.

26. Fuel System Circuits

26-1. Many of the troubles you have encountered on the aircraft have been in the fuel system circuits. If you are like most electricians, several long nights have been spent troubleshooting this system. Most of this time could have been saved if more had been known about the operation of this system.

26-2. Until recently, the responsibility for fuel system maintenance belonged to several career fields. Although we now have fuel system specialists, you as an electrician must be able to troubleshoot the circuitry. This requires a solid understanding of system operation. You must also be able to train your men in system troubleshooting. This again requires you to know how the complete system operates. In this section we will discuss fuel system operation and circuitry. The system we have selected to discuss is a typical system found on fighter aircraft. You may work on another type system, but you should find the operating characteristics and basic circuitry of this system much like your own. We will break our discussion into several specific areas, such as:

- Engine fuel supply.
- Fuselage fuel supply.
- External fuel supply.
- Air refueling system.

A good place to begin our discussion is with the engine fuel supply.

26-3. *Engine Fuel Supply.* The engine fuel supply system is defined as that portion of the fuel system which maintains a continuous supply of fuel to the engines during all attitudes of flight. This is done by two ac motor-driven, centrifugal-type boost pumps. They are located in the bottom of the number 1 fuel cell. These pumps supply fuel under pressure directly to the engines. Provision is also made for a gravity fuel system in case of a double-pump failure. The gravity rate of fuel flow is enough to keep the engine running at reduced power settings.

26-4. Both boost pumps feed into a common manifold which separates to direct fuel to each engine. A motor-driven shutoff valve and a flapper check valve are located in each of these engine manifold lines. Also located in the lines are the right and left fuel hydraulic radiators and boost pump pressure transmitters.

26-5. Fuel is pumped from the number 1 fuel cell by the two submerged double-ended boost pumps mounted in the bottom of the cell. Each pump is driven by a 115/208-volt, 3-phase, 400-Hz ac motor. Both boost pumps operate continuously during normal flight conditions or when external power is applied and either of the following conditions exist:

- When either engine master switch is placed in the ON position.
- When the ground fueling switch is placed in either the REFUEL or DEFUEL position with both engine master switches off.
- When either boost pump check switch is placed in the CHECK position.

26-6. The engine fuel shutoff valves, located in each manifold, open when the engine master switch is placed in the ON position, and the corresponding engine throttle is advanced to the IDLE position. This allows fuel to flow to the engine-driven pumps. The pressure in each engine manifold causes the boost pump pressure transmitter to send a signal to the boost pump pressure indicator on the pilot's console.

26-7. The number 1 fuel cell that supplies fuel to the engine fuel system receives fuel from the fuselage fuel supply system. Now that we know how fuel is fed to the engine, we need to find out how we move fuel from the other cells. The fuel is moved by the fuselage fuel supply system.

26-8. *Fuselage Fuel Supply.* The fuselage fuel supply system (see FO 15) consists of cells 2 through 7. Cells numbers 4 and 6 each contain an electrically driven fuel transfer pump and a hydraulically driven fuel transfer pump. These four pumps feed a common manifold which transfers fuel into cells 1 and 2. The flow of fuel is controlled by pilot valves and control valves located in cells 1 and 2. The pressure switches in the system are energized during the transfer pump checks.

26-9. The electrically driven transfer pumps run continuously whenever power is available and either engine master switch is on, or both engine master switches are off, and the ground refueling switch is in the REFUEL or DEFUEL position. The hydraulically driven transfer pumps run during the four specific operations that follow:

- Afterburner operation on either engine.
- Air refuel switch to EXTEND.
- Fuel load in cells 1 and 2 falls below 1800 pounds.
- Hydraulic transfer pump check switch in the CHECK position.

As long as electrical power is maintained on the hydraulic transfer pump control valve by the hydraulic transfer pump and fuel transfer relay, the hydraulic system pressure is held off the pump. When power is removed by the hydraulic transfer pump control relays on the master switches, the control valve allows hydraulic pressure which causes the pump to run. As you can see, if the aircraft experienced an electrical power failure, the hydraulic pumps would transfer the fuel to cells 1 and 2.

26-10. You should begin to see the relationship of system to system. When you are called upon to analyze a fuel problem, you must be able to isolate the specific system having difficulty. Once you have made this determination, your knowledge of specific system operation should lead you to the malfunctioning component. The next portion of the fuel system to be discussed is the external fuel supply.

26-11. *External Fuel Supply.* The external fuel system is composed of two 370-gallon external wing tanks, one 600-gallon external centerline tank, and the lines and valves necessary to control fuel transfer from the external tanks to the fuselage cells. These tanks and their related components are shown in foldout 16. External fuel is transferred to fuselage cells 1, 3, and 5 when the external transfer switch (refer to FO 16) is placed in either the CENTER or OUTBOARD position. When the external transfer switch is placed in the OFF position, external fuel transfer stops.

26-12. When the external transfer switch is placed in the CENTER position and a centerline tank is aboard, the system is configured as follows:

a. The refueling shutoff valve and the centerline shutoff valve are both energized open.

b. The fuel flow transmitter is energized to illuminate the CTR EXT FUEL light when the flow from the centerline tank stops.

When the external transfer switch is placed in the OUTBOARD position with either external wing tank aboard, the system is configured as follows:

a. The external wing tank shutoff valves are energized open.

b. The fuel flow transmitters are energized to illuminate the L EXT FUEL and R EXT FUEL lights when fuel from each tank stops. If the external tanks are not installed, all pressure regulators, pressure vacuum relief valves, and fuel shutoff valves are energized closed. Additionally, the mechanical disconnects are closed to prevent loss of fuel in the event a shutoff valve malfunctions.

26-13. Fuel is transferred from the external centerline tank into the aircraft by air pressure. The pressure is maintained by an aircraft mounted pressure regulator and vent valve combination. During refueling, the fuel level in the tank is controlled by the tank control valve and pilot valve located in the tank. All tanks contain a float assembly which actuates a FULL light in the cockpit. The pressure regulators and pressure vacuum relief valves that control the air pressure for the internal wing tanks are located in the wings. When either external wing tank quick-disconnect is connected, a circuit from the external wing tank pressurization relay is completed. The tanks will pressurize as soon as external electrical power is applied or if a generator is put on the line. This energizes the pressure vacuum relief valves closed and opens the pressure regulators.

26-14. The pilot may then transfer fuel from the external wing tanks by placing the external transfer switch in the OUTBOARD position. This opens the two external wing tank shutoff valves. When the external wing tanks are empty, a float lowers to the bottom of the tank and closes the control valve. So far we have discussed the systems that provide fuel for engine operation. We have looked at those systems while the fuel is being moved into the feed cells. There is one important system left for us to discuss, the air refueling system.

26-15. *The Air Refueling System.* The air refueling system provides a means for transferring fuel from a tanker aircraft to the fuel cells during flight. The tanker boom connnects to the fuel system through a receptacle mounted on the top of the fuselage above the number 2 fuel cell. A hydraulic actuator raises and lowers the receptacle as required. In addition to the actuator (refer to fig. 80), the receptacle package incorporates an induction coil, a nozzle lock limit switch, a nozzle contact limit switch, a receiver retract limit switch, a receptacle illuminating light, and a sequencing valve. An air refuel switch, a boom release switch, a receptacle downlock timer, a control amplifier, a demagnetizing relay, and a reset switch are located in the cockpit. Each controls some function of the air refueling system. A green DISENGAGE light and a green READY light are mounted at eye level in the forward

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cockpit. The receptacle is illuminated for night refueling operations.

26-16. To prepare the air refueling system for air refueling from the tanker, the air refuel switch is moved to EXTEND (refer to fig. 80), and the number 1 solenoid in the nozzle lock sequencing valve is energized to extend the receptacle. The receiver retract limit switch is actuated to the EXTEND position, and the receptacle illuminating lights come on. The green READY light comes on when the receptacle is in the EXTEND position. When contact is completed between the tanker and the receiver, and the boom is seated in the receptacle, the nozzle contact limit switch is actuated. This completes the circuit to the coil of the nozzle lock sequencing relay. When the relay actuates, both solenoids on the nozzle lock sequencing valve are energized. The nozzle locks will move to the LOCK position and actuate the nozzle lock limit switch. This causes the thyratron in the signal amplifier to fire and actuate relays K1 and K2 in the amplifier. At the same time, it sends a signal to the tanker through the induction coils in the receptacle and in the boom, to indicate that the system is ready to receive fuel.

26-17. When refueling is completed, a disconnect action can be initiated from either the receiver aircraft or the tanker. From the receiver aircraft, the pilot initiates disconnect action by depressing the boom release switch on the stick grip. This causes the thyratron to fire through relays K3 and K4. The DISENGAGE light comes on, the coil of the nozzle lock sequencing relay becomes deenergized, and the nozzle locks are released. At the same time, the coil of the demagnetizing relay is energized. When this relay actuates, a pulse of current passes through the receptacle induction coil. This signal is picked up by the induction coil on the boom and shuts off the flow of fuel from the tanker. When the receiver aircraft has disengaged from the tanker, the air refuel switch can be moved to RETRACT. This energizes the receptacle downlock timer, deenergizes the number 1 coil, and energizes the number 2 coil of the nozzle lock sequencing valve, retracting the receptacle. When the receptacle retracts fully it opens the receiver retract limit switch, disengaging the air refueling receiver timer. After a 60-second delay, the air refueling receiver timer deengerizes the receptacle manifold selector valve. With the air refuel switch in RETRACT, all power is removed from the amplifier. All relays in the amplifier reset, and the DISENGAGE light goes out. All remaining relays in the system revert to the normal in-flight position, and the fuel system is set up for normal operation.

26-18. We have discussed the four major sections of the aircraft fuel system. You must be able to analyze malfunctions and quickly isolate the trouble to one of these systems. Another system that has given the electrician much trouble is the nose gear steering system. Next in our discussion of systems, we shall cover modern transistorized nose gear steering.

27. Nose Wheel Steering Circuits

27-1. The need for the pilot to have positive control of the aircraft during ground operation created the need for the development of nose gear steering systems. As aircraft have become more sophisticated, so have their systems. The rapidity of advancement in technology has created a situation where you may have some aircraft with the earliest mechanical system and some with the latest transistorized system. For our discussion in this section, we will use a typical transistorized control box, as seen in figure 81.

27-2. *Operational Analysis.* The nose gear steering system may be energized when the nose gear is down and locked and the main gear struts are compressed. As the pilot moves the rudder pedals back and forth, he varies the output voltage of the nose gear steering command (input) potentiometer. This signal is then applied to a differential amplifier in the nose gear steering control unit. The output of the differential amplifier determines which coil will receive more current in the nose gear steering servo valve. This valve controls the right or left turn function of the nose gear steering power unit. Geared to the power unit is the nose gear steering followup potentiometer. The followup output signal is also applied to the differential amplifier. If an error signal exists between the output of the followup and command potentiometers, the differential amplifier produces a differential current to the servo valve, which directs hydraulic flow to the vane motor in the power unit. The vane motor turns the wheels in the desired direction to reduce this error signal. As outputs of the two potentiometers become equal, the error signal is reduced, and the differential amplifier reduces differential current to stop the wheels at the desired angle of turn.

27-3. In the event of an open or short circuit in one of the inputs to the control unit, a failure detection network detects this and removes hydraulic pressure from the steering system. This network consists of a dual three-input AND gate which drives a lockout network consisting of a timing network and a silicon controlled rectifier (SCR). When a failure exists, transistors Q1 and/or Q2 will cut off and start the timing process which fires the SCR. These

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devices are shown in figure 81. Action of the SCR causes a relay to deenergize, interrupting the ground path from the solenoid in the nose gear steering selector valve. When the solenoid in the selector valve is deenergized, hydraulic pressure is removed from the steering system. Recycling of the steering switch resets the SCR and allows normal operation to resume, providing the cause of the original failure is removed.

27-4. *Right turn theory.* When the right rudder pedal is moved forward to execute a right turn, the command potentiometer wiper arm, mechanically linked to the rudder pedal, produces an increasing voltage through pin M into the differential amplifier (A1). In A1. the voltage is applied through CR7 and CR8 to the base of Q4. The emitter of Q4 applies an increasing current to the base of Q3. Current from the emitter of Q3 passes through R12, and off the wiper arm of R14 to the collector of Q5. Q5 acts as a current stabilizer. Current from the emitter of Q5 passes through R17 to the -24-vdc power supply. Increased current to the base of Q4 and Q3 results in increased conduction (reduced impedance) in the return path of the right turn coil in the servo valve. Current from the power supply to the center tap (neutral) of the servo valve increases through the right turn coil, back into pin L to A1, and through CR9 and CR11 to the collectors of Q4 and Q3. From Q4 and Q3, current follows the same path as current from the wiper arm of the command potentiometer. The servo valve is now subjected to a differential current, and directs hydraulic flow to the vane motor for the purpose of turning the wheels. As the wheel turns, the wiper arm of the followup potentiometer moves to produce an increasing voltage to pin N. From pin N the voltage is applied to A1, through CR13 and CR14, to the base of Q7. The emitter of Q7 applies an increasing current to the base of Q6. Current from the emitter of Q6 passes through R16 and R14. Q7 and Q6 increase conduction (reduce impedance) in the return path of the servo valve left turn coil. When voltage from the followup potentiometer equals voltage from the command potentiometer, the error signal is zero and current equalizes in the left and right turn coils of the servo valve. The servo valve with no differential current holds the wheels at the desired degree of right turn

27-5. *Left turn theory.* As the left rudder pedal is moved forward to execute a left turn, the command potentiometer wiper arm produces a decreasing voltage through pin M, and along the same path as the increasing right turn voltage. Q4 and Q3 decrease in conduction, which provides higher impedance in the servo valve right turn coil. Current from the power supply to the center tap of the servo valve connector increases through the left turn coil back to pin J, and through CR10 and CR12 to Q7 and Q6. Current flows from the emitter of Q6 through R16 to R14, and from the wiper arm of R14 the path for current is the same as that for a right turn.

27-6. As the wheels turn, the wiper arm of the followup potentiometer produces a decreasing voltage. This voltage enters the control unit to A1. Q7 and Q6 decrease conduction in the return path of the servo valve right turn coil. When voltage from the followup potentiometer equals voltage from the command potentiometer, the error signal reduces, and current between the left and right turn coils of the servo valve equalizes to hold the wheels at the desired degree of left turn.

27-7. *Failure detection theory.* The failure detection circuit detects a short, open, or intermittent signal from the command potentiometer, followup potentiometer, and servo valve. Depressing the nose gear steering switch provides 28 vdc to the control unit power supply (A2), and through R2 and R3. Voltage through R2 is applied to K1 and to the anode of SCR2. Voltage through R3 is applied to the collector of Q1 of the dual three-input AND gate network. If signals from the command potentiometer, followup potentiometer, or servo valve become shorted or open, negative voltage through R13 and R15 will be applied to the bases of Q1 and Q2. Q1 and/or Q2 no longer conducts, thus opening the ground path from R3 of A2. Voltage now passes from R3 through CR3 to the gate of SCR2. It fires and provides a short circuit to ground for voltage applied to the coil of K1. K1 deenergizes, and the ground path for the selector valve solenoid opens, causing the solenoid to deenergize, removing hydraulic pressure from the system. Because SCR2 is self-healing, when the cause for failure is removed, the system may be recycled and normal operation resumed. This will complete our discussion on the operational characteristics of the nose gear steering system. Your system may be characteristically the same. If it is not, many of these operating principles will apply to your system. We will also spend some time discussing the major components in this system.

27-8. *Detailed Component Theory.* As a technician responsible for maintaining the nose gear steering system you must become familiar with each component. Each system varies in its makeup, but you should be able to make application of these operating principles to the components in your system. Let's begin our discussion with the nose gear switches.

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27-9. *Nose gear steering switches.* Depressing the nose gear steering switch applies 28 vdc to the control unit, through pin C to the failure detection circuitry in the power supply (A2). From A2, power is supplied to energize relay K1. The now closed contacts, A1 and A2 of relay K1, provide the ground path for the selector valve solenoid. Should any one of the nose gear steering switches fail to make contact, the failure detection circuitry locks out the system.

27-10. *Nose gear steering command potentiometer.* The command potentiometer is a silicone-oil-filled device with a nonlinear resistance characteristic. This potentiometer produces a high system gain for coarse steering near the outer limits of nose wheel travel, and a low system gain for fine steering around the neutral point of nose wheel travel. The electrical connections to this potentiometer are shown in figure 82. A 500-ohm resistor is placed in series with the wiper for its protection. Beyond the resistance function are shorting bars (zero resistance) for a finite wiper position change. This function covers 124°. The remaining portion of the 360° rotation presents an open circuit to the wiper. The wiper arm of the command potentiometer is mechanically linked to the rudder pedal torque tube. When the rudder pedals are in any position other than neutral, the error signal produced is fed into the differential amplifier of the control unit, and the nose wheel starts to move in the desired direction. When the nose gear is at neutral, the wiper arm output is approximately 27 vdc. The wiper arm output at 70° right is approximately 42 vdc. At 70° left the output is approximately 12 vdc. This type command potentiometer has unusual wiper noise characteristics which must not be interpreted as a defective unit.

27-11. *Nose gear steering followup potentiometer.* The followup potentiometer is a linear device with the wiper arm connected to the gears inside the hydraulic power unit. The output of the wiper arm determines the degree in which the nose wheel will turn. The electrical connections to this potentiometer are shown in figure 83. The followup output lags but is the same as the output of the command potentiometer. Care must be taken when you check the unit not to interpret the opening or shorting bars inside this potentiometer as a defect in the unit.

27-12. *Selector valve.* The selector valve is a remotely controlled, three-way, two-position, single-solenoid valve employed to direct utility hydraulic system pressure to the nose gear steering system. The selector valve should be energized when the relay inside the control unit is energized, because the ground path for the selector valve is through the energized contacts of the control relay.

27-13. *Servo valve.* The servo valve is composed of a sliding piston, receiver pipes, feedback spring, and a flexible pipe which is connected to two solenoids. When the left or right turn transistor, located in the control unit, starts to conduct, the ground for one of the solenoids is completed and the solenoid is energized. As the solenoid is energized, the flexible pipe is directed to one of the receiver pipes at one end of the sliding piston. Hydraulic fluid flows through to one end of the piston. The hydraulic pressure shifts the piston and opens a port to the hydraulic motor which turns the wheel. The piston will remain in this position as long as the ground path through the control unit is made. When the ground is opened, the solenoid will deenergize, and hydraulic pressure will reposition the piston to a neutral or normal position. When the piston shifts back to normal, hydraulic pressure is removed from the hydraulic motor, stopping the nose wheel.

27-14. *Ac power supply.* To conclude our discussion of the nose wheel steering system, we will discuss briefly the power supplied to the system. This system is shown in the lower left side of figure 81. Single-phase 115 vac is applied through pin Y to transformer T1. T1 provides two outputs of 100 vac, each with respect to the center tap. These voltages are used to develop three resistor-capacitor power supplies. Diodes CR6 and CR8 rectify the in-phase portion of the T1 output to produce full-wave rectification to feed 41 vdc to the command and followup potentiometers and 58 vdc to the servo valve. CR7 and CR9 rectify the out-of-phase portion of the output of T1 to produce -24 vdc to bias the failure detection circuitry.

28. Logical Troubleshooting

28-1. Today we live in an age of automation. Complex systems of all kinds are automated, even to the point of automatic checkouts, self-checking procedures, and self-repair capability. Complex systems still fail in spite of all the self-troubleshooting capabilities built into them, and in spite of the flow charts and troubleshooting "cookbooks" prepared for the technician. Someone must fix the system, and get the "bird" back into the air. Who is this person, and how does he do the job?

28-2. The man who will be called upon to perform these difficult nonroutine jobs is the troubleshooting expert. He does not rely on magic or guessing to get the system operating again; he relies on logical systematic troubleshooting techniques. The expert knows there are the following four parts in troubleshooting.

- Knowing in detail how the system works.
- Knowing how to use the test equipment.
- Using technical orders and maintenance manuals effectively.
- Logically analyzing the troubleshooting information he obtains from the malfunctioning system.

All four parts listed are necessary, but the first three have been well covered in this CDC as well as in your previous training. In this section we will concentrate on the last part, the logical analysis of the information the troubleshooter has available. The general principles and techniques to be discussed apply to most troubleshooting situations.

28-3. *Troubleshooting Principles.* As we have discussed throughout this chapter, having specific experience with each system is one way of becoming a good troubleshooter. When you find a man who has worked on a specific aircraft for any length of time you can say he is a good troubleshooter. But should he be transferred, will he still be a good troubleshooter? Learning how to use sound troubleshooting principles will help you improve your technique and possibly make you an expert. Troubleshooting principles came from years of practical experience and many research studies. These principles are not startling, new, or different. They emphasize practicality, efficiency in checking, and maximum use of information. Systematic application of these principles will lead the troubleshooter to success when using a reasonable number of checks. Ask yourself these two questions at each step or check in the troubleshooting process:

- Where to check?
- What type of check to make?

The troubleshooting principles will help you answer these questions.

28-4. *Initial bracketing.* The first question you have to answer is "where to check?" This question can be answered by a logical sequence of general steps. You first determine the broad limits that encompass the location of the defects or difficulties. This is called the area of uncertainty. It should be inclosed with brackets, either physically on the diagram or mentally as you analyze. For instance, if you have a work order on the fire warning system, it most likely will read "Fire warning light came on after 10 minutes of flight." At this point it could be anything in the system, including normal operation. The entire system is now the area of uncertainty. Now you must narrow the limits so that the area of uncertainty becomes smaller, and until the specific defects are pinpointed. You do this by making appropriate tests or checks. This is a repetitive process. After you have established each pair of brackets, you should make a check somewhere between the brackets, interpret this check, and reposition your brackets. Repeat this until you have the trouble isolated to just one component. Where do we begin? Let us look at the symptoms.

28-5. *Symptom-pattern recognition.* If we look carefully, we will find the symptoms indicating a malfunction. Look at all the indicators available, such as the voltmeters, ammeters, frequency meters, and indicating lights. Answer the following questions. Is the voltage correct? Is the current high or low? What warning lamps are on? From this information you should be able to determine the symptoms. In the case of a fire warning writeup, you need to check the system's present condition. Did the warning light remain on? Is there any evidence of fire in the engine area? Assuming there was no fire, and the warning light is still on, where do we go from here? You are right! You must check the diagram to find the abnormal circuits that could turn the light on. You should concentrate on the warning light part of the circuit. From this you can determine what may or may not cause the light to come on. Check those circuits that could cause this symptom. The problem is obviously not in these circuits that have no control over the light.

28-6. *Establishing the brackets.* Remember, the area in which the trouble could be located is called the area of uncertainty, because this is the area in which the status of the circuitry is uncertain. As you look at the diagram(see fig. 78), you must determine the boundary of this area. If the fire pull switch is good, that is, not shorted, there are three parts of the circuit that could turn the light on; namely, the cable assembly, the control assembly, and the test relay. Your brackets should include these circuits. Remember, the abnormal circuit is the portion of circuitry which is affected by the troubles in the system. It may coincide with the area of uncertainty, but only for initial bracketing. You can obtain at least two benefits by using brackets. First, determining the area of uncertainty makes it easier to avoid pointless checks. And secondly, the brackets help you to pick the best check from among the possible good checks. We are all guilty of pointless checks. An irrelevant check is one that we might make outside of the trouble brackets. A check like this adds no new information, and the trouble brackets remain the same. A redundant check is a check made within the trouble brackets which adds no new information and which brings us no closer to finding the trouble. A premature check is also to be avoided. We may end up changing parts, and still have troubles in the system. As we make each move, we should stop and think about what the information from the check tells us concerning the size of the trouble brackets. Where are our trouble brackets now? We must plan our checks to include new information within the new brackets. We may have to use all of our previous information in order to decide upon the next appropriate check.

28-7. *Analysis Application.* Let us look again at the diagram for the fire warning system. Select a central point, and determine what check we will make. If we should choose to check pin 1 of the control assembly with an ohmmeter to see if we have a ground, that is a good choice. If we do not find a ground, we must check both the cable assembly and the test relay. The brackets have moved. The problem is most likely in the control assembly. A voltage check reveals 28 vdc at pin 4 on the control assembly. This indicates shorted contacts at relay K1. Again, the brackets have moved. To confirm our finding, a continuity check of pin 2 to pin 4 of ~~the~~ control assembly will show that the contacts of relay K1 are shorted.

28-8. This has been an easy problem, but the principles used apply to any troubleshooting job. You solved the fire warning problem with two checks, and make a third to confirm your findings. That's not bad. Let's see how you should proceed in the master caution system. The writeup reads, "The master caution light will not reset." What is your first step? Good, you must remember to check the symptoms. Are there any individual caution lights on? No! Is the master caution light bright? Yes! So far, so good. What should you do now? Yes, look at the diagram (refer to fig. 79). As we establish our brackets, we should note certain conditions. First, the 28-vdc input must be good because the lights are on. Secondly, this leaves only two paths to be abnormal, the reset circuit and the master caution input circuit. The two circuits come together in the master caution input circuit. If you check the voltage input of the reset circuit to the master caution input circuit, you can check the entire reset circuit. When the reset switch is closed, the voltage at our check point should go down. It does not. You have moved our brackets. Now you need to check the reset circuit input. When the reset switch is closed, you read 28 vdc. Again the brackets have moved. You now know the problem is in the reset triggering circuit in the Main Caution light panel. A continuity check from the gate of SCR1 to the reset input indicates an open. What's the malfunction? R3 is open. You can readily see the advantages to logical step-by-step troubleshooting. When you transfer you will still be an expert troubleshooter. The Air Force spends millions of dollars in manhours and for parts--dollars that need not be spent if you and your people become expert troubleshooters.

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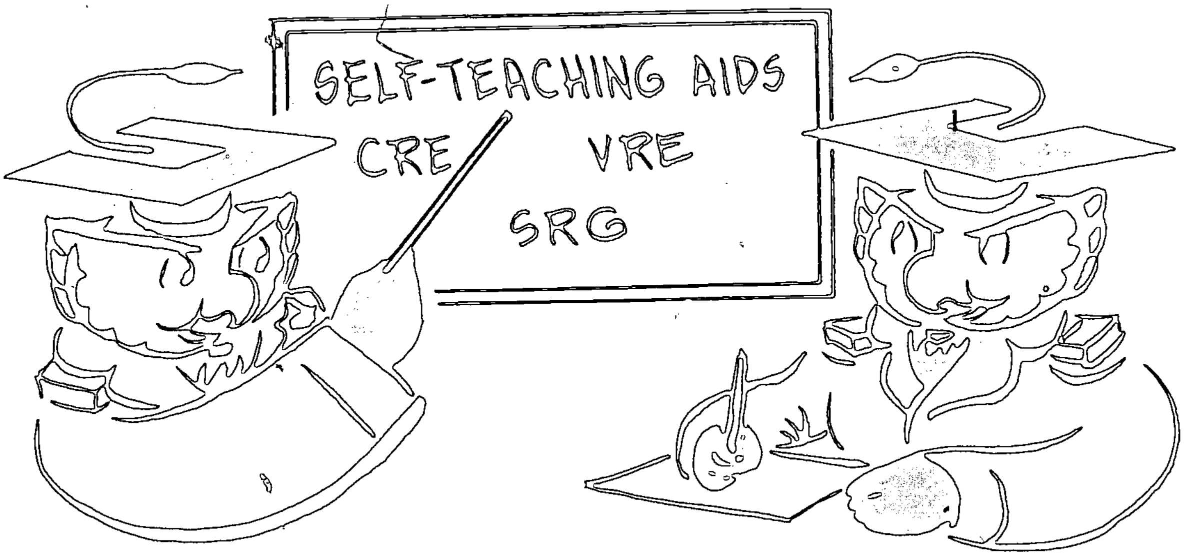
WORKBOOK

Aircraft Electrical Repair Technician



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STUDY REFERENCE GUIDE

1. *Use this Guide as a Study Aid.* It emphasizes all important study areas of this volume.

2. *Use the Guide as you complete the Volume Review Exercise and for Review after Feedback on the Results.* After each item number on you VRE is a three digit number in parenthesis. That number corresponds to the Guide Number in this Study Reference Guide which shows you where the answer to that VRE item can be found in the text. When answering the items in your VRE, refer to the areas in the text indicated by these Guide Numbers. The VRE results will be sent to you on a postcard which will list the *actual VRE items you missed.* Go to your VRE booklet and locate the Guide Number for each item missed. List these Guide Numbers. Then go back to your textbook and carefully review the areas covered by these Guide Numbers. Review the entire VRE again before you take the closed-book Course Examination.

3. *Use the Guide for Follow-up after you complete the Course Examination.* The CE results will be sent to you on a postcard, which will indicate "Satisfactory" or "Unsatisfactory" completion. The card will list *Guide Numbers* relating to the questions missed. Locate these numbers in the Guide and draw a line under the Guide Number, topic, and reference. Review these areas to insure your mastery of the course.

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100	Introduction to the Aircraft Electrical Repair Technician; Specialty Description, pages 1-3
101	Safety and the Supervisor, pages 3-6
102	Security and the Supervisor, pages 6-7
103	Introduction to the Electric Shop; Scope of Maintenance, pages 8-12
104	Shop Publications, pages 12-17
105	Introduction to Supervision and Training in a Maintenance Environment; Supervision: General; The New Worker, pages 18-20
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MODIFICATIONS

Pages 3 - 21 of this publication has (have) been deleted in adapting this material for inclusion in the "Trial Implementation of a Model System to Provide Military Curriculum Materials for Use in Vocational and Technical Education." Deleted material involves extensive use of military forms, procedures, systems, etc. and was not considered appropriate for use in vocational and technical education.

CHAPTER 5

Objective: To be able to analyze various situations and resolve the selection and use of the proper electronic test equipment.

1. What major factor must be considered before selecting any piece of measuring equipment? (10-1)

2. Name the three most common devices used to measure resistance. (10-2)

3. For what purpose do most ohmmeters have a scale multiplication feature? (10-7)

4. What type ohmmeter circuit is used for the low-ohm scale? (10-8)

5. How does the current through the meter movement differ between the series and shunt type ohmmeter? (10-9)

6. What is meant by the saying a shunt type ohmmeter has a direct scale? (10-9)

7. When using an ohmmeter with a low-ohm scale, why is it important to leave it in the low-ohm position? (10-10)

8. How can an ohmmeter be used to check a capacitor? (10-11)

9. On a megger, what is meant by the term floating pointer? (10-14)

10. What is the value of output voltage for most meggers? (10-14)

11. Is the following statement true or false? One of the outstanding features of the megger is the independence of the indications with respect to the speed at which the crank is turned, or the strength of the permanent magnet. (10-16)

12. When the megger is tested for leakage, you should read ____________ with the leads open and ____________________ with the leads shorted. (10-17)

13. What measuring instrument is the most accurate for making resistive measurement? (10-20)

14. What type meter movement is commonly used in the detector circuit of a bridge? (10-21)

15. When is the detector in a bridge at maximum sensitivity? (10-22)

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16. Name an elementary precaution that you must use when measuring low resistance with a bridge. (10-24)

17. The limitations of a Wheatstone bridge are encountered when ______ ____________ or __________ ____________ resistances are measured. (10-25)

18. What consideration must be given when choosing a shunt for operation of an ammeter? (10-30)

19. The ammeter should always be connected so that the meter terminals are in what relationship to the circuit polarities? (10-38)

20. What unit must be used with a D'arsonval meter movement to measure high voltages? (10-40)

21. Name three things that can be changed on a voltmeter to increase its sensitivity. (10-45)

22. How is the accuracy of a voltmeter generally expressed? (10-46)

23. Describe the shunting effect of a voltmeter. (10-49)

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24. What is the primary advantage of the VTVM over ordinary voltmeters? (10-51)

25. What is the purpose of the negative 5-volt bias on the tube grid in a basic VTVM? (10-53)

26. An ac vacuum tube voltmeter can be calibrated to read __________, __________ or __________ values. (10-57)

27. Why is it important to ground the ac probe immediately after testing an ac circuit that has high dc present? (10-59)

28. Operation of the oscilloscope is based upon the ____________ and ____________ of a beam of electrons used for the purpose of producing a visible trace on a fluorescent screen. (10-62)

29. What two functions are performed by the aquadag coating on a CRT? (10-63)

30. When the cathode has emitted electrons, what starts their movement toward the screen? (10-64)

31. Why should the case be on the oscilloscope before you operate it? (10-70)

32. Name the two main hazards involved in handling a CRT? (10-75)

33. What two types of frequency meters are suitable for measuring voltage source frequency? (10-77)

34. What is the major limitation of the dynamometer type frequency meter? (10-79)

35. When using the PSM-20B electrical power test set, the generator outputs are checked for __________ __________, __________ and __________ __________. (11-2)

36. What is the purpose of a logic tree? (11-6)

37. What is the function of the electrical power test harness? (11-7)

38. What are the major advantages of the electrical power test harness compared to the PSM-20B tester? (11-9)

39. The electrical power test harness has a functional checklist for what applications? (11-9)

CHAPTER 6

Objective: To be able to relate facts about and draw conclusions about the fundamentals involved in analyzing complex dc circuits.

1. What is the smallest particle into which a magnet can be divided and still remain a magnet? (12-2)

2. The magnet in question 1 is a basis for what? (12-2)

3. How are the molecules in unmagnetized material aligned prior to being magnetized? (12-3)

4. Given a ferromagnetic substance, how would you produce a moderately strong magnet? (12-4)

5. What is meant by magnetostriction? (12-5)

6. What can happen to a generator due to engine heat or a hard jar? (12-6)

7. Complete the following statement: The level of energy of the electron determines the polarity of spin. Some electrons have a __________ spin, some a __________ spin. (12-7)

8. Why do atoms in ferromagnetic substances tend to bond together? (12-8)

9. List four conditions which cause the lifting power of a magnet to vary. (12-9)

10 Complete the following statement: The magnet field leaves the ______ __________ of the __________ and enters the ______ ______. (12-10)

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11. What is expressed by the mathematical equation $F = \frac{P_1 \quad P_2}{\mu d^2}$? Also, explain what each part of the equation stands for. (12-11)

12. How can the equation $F = \frac{1 \times 1}{1 \times 1\ \text{cm}^2}$ = 1 dyne be stated? (12-12)

13. Using figure 38 of the text and the equation $F = \frac{P_1 \quad P_2}{\mu d^2}$, find the dynes for the forces of attraction and repulsion of the north and south poles. (12-14, 15; Fig. 38)

14. Complete the following statement: The study of the magnetic amplifier will show the __________ __________ being put to work. (12-16)

15. What components do you usually find in a magnetic amplifier? (12-17)

16. Complete the following statement: As the __________ __________, H, is increased to a point of __________, an __________ in H, gives no __________ in B. (12-19)

17. Draw a diagram of a basic reactor, and label each winding, control, load, and voltage. (12-10; Fig. 40)

18. What controls the reactance of a reactor? (12-21)

19. What variation in a magnetic amplifier circuit permits a magnetic amplifier to be used with a dc load? (12-21)

20. Define what is meant by direct current. (13-2, 3)

21. Complete the following statement: Direct current is unidirectional, that is, it moves in only one direction. This directions is always from ________________. (13-4)

22. In what direction is a battery poled if the reference point is on the negative terminal of the battery? (13-5)

23. Why does higher applied voltage with the same resistance result in more current? (13-6)

24. Why does more resistance with the same applied voltage result in less current? (13-6)

25. State Kirchhoff's first law. (13-7, 8)

26. State Kirchhoff's second law. (13-7, 10)

27. Is the following statement concerning Kirchhoff's second law true or false? The algebraic sum of the applied voltages equals zero only if the current flow is from negative to positive. (13-10, 11)

28. In figure 44, if E_T equals 26.5 volts, R_3 and R_4 equal 10 ohms, R_1 and R_2 equal 10 ohms, and R_5 equals 2 ohms, what is the voltage at point 2 in reference to point 1? (14-2-5; Fig. 44)

29. In figure 45, change the values of the circuit as follows:

E_T = 20 volts R_3 = 6 ohms

R_1 = 2 ohms R_4 = 10 ohms

R_2 = 8 ohms R_5 = 4 ohms

Solve each of the following:

a. $$R_a = \frac{R_1 R_5}{R_1 + R_5 + R_3}$$

b. $$R_b = \frac{R_1 R_3}{R_1 + R_5 + R_3}$$

c. $$R_c = \frac{R_3 R_5}{R_1 + R_5 + R_3}$$

d. $$R_T = R_b + \frac{(R_a + R_2)\ (R_c + R_4)}{(R_a + R_2) + (R_c + R_4)}$$

e. $$I_T = \frac{E_T}{R_T}$$

f. $$E = E_T - I_T R_b$$

g. $$I_{BC} = \frac{E}{R_a + R_2}$$

h. $$I_{DC} = I_T - I_{BC}$$

i. $E_B = I_{BC}R_2$

j. $E_D = I_{DC}R_4$

k. $I_5 = \dfrac{E_5}{R_5}$

(14-8-10; Figs. 45, 46, 47)

30. Define the term mesh circuit. (14-11)

31. What type of equations must be used to solve for current in mesh circuits? (14-12, 13)

32. How many general methods are there to solve simultaneous equations? What are they? (14-13)

33. Solve the equations $2x = y$ and $6x + 2y = 25$ for x and y. (14-14-18)

34. According to Kirchhoff's law, what is the voltage in figure 48 around ABCDEHA and ABCFGHA? (14-19; Fig. 48)

35. Using the following equations, solve for I_1, I_2, and I_T.

$100I_R + 0.1I_1 = 10$

$100I_R + 0.3I_2 = 50$

$I_1 + I_2 = I_R$

(14-19, 20)

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36. Why is the current I_1 negative? (14-21)

37. Using the values for I_1, I_2, and I_T in question 35, find E_1, E_2, E_R, and E_T using Ohms law. (14-22)

CHAPTER 7

Objective: To be able to relate facts about and draw conclusions from the principles involved in the relationship of reactors in ac circuits.

1. Complete the following statement: Alternating current is an electrical current that continually changes in __________ and periodically changes in __________. (15-2)

2. Indicate whether the following statement is true or false: The instanteous value of a sine wave voltage is indicated by the letter "e." (15-3)

3. The maximum value of voltage which can be attained with given circuit conditions is referred to as __________. (15-4)

4. Indicate whether the following statement is true or false: The average value as applied to alternating voltage refers to the positive and negative loop. (15-5)

5. Define the word "phase" as related to alternating current. (15-6)

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6. Complete the following statement: Two alternating currents are said to be "in phase" when they are __________ in the same direction, and crossing all __________ __________ points at the same time. (15-7)

7. Indicate whether the following statement is true or false: When two alternating currents are applied to a resistive circuit, they are always out of phase. (15-7)

8. What is the phase relationship between voltage and current when ac is applied to a nonresistive circuit? (15-8)

9. Complete the following statement: If a circuit is not resistive, it is __________. (15-9)

10. Complete the following statement: The ________ and the ________ are examples of basic reactors. (15-10)

11. Complete the following statement: In a capacitor, the insulating material is referred to as the ________. (15-11)

12. Complete the following statement: The unit of measure which is equal to one-millionth of one farad is called a __________. (15-12)

13. Explain what is meant by the working voltage which is indicated on commercial capacitors. (15-13)

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14. Indicate whether the following statement is true or false: To establish the tolerance rating of a capacitor, the actual picofarad variation is usually reserved for small capacitors with a value of less than 10 picofarads. (15-14)

15. Complete the following statement: Two popular names used to designate an inductor are ________ and ________. (15-15)

16. What is the unit of measurement of inductance? (15-16)

17. What is meant by the current rating of an inductor? (15-17)

18. Explain what is meant by inductive reactance. (15-18)

19. Why do reactors appear to act differently in ac circuits as opposed to dc circuits? (15-19)

20. What is the value of inductor current when the applied voltage is maximum? (15-20)

21. In a capacitor, the phase relationship of voltage and current is based upon the applied voltage. Does current lead or lag the applied voltage? (15-21)

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22. What must be specified in an ac circuit before a reactor can have a set value of opposition? (15-22)

23. Explain the relationship between frequency and capacitive reactance. (15-23)

24. Explain the relationship between frequency and inductive reactance. (15-23)

25. State the formula required to determine capacitive reactance. (15-24)

26. Indicate whether the following statement is true or false: Inductive reactance is inversely proportional to frequency. (15-25)

27. When is a circuit containing both capacitive reactance and inductive reactance in a resonant state? (16-2)

28. In a series-tuned circuit with the ac source adjusted to a high frequency, what determines the greatest opposition to current flow? (16-3)

29. What is meant by the resonant frequency of a circuit? (16-4)

30. In a tuned circuit, when is the current flow at maximum? (16-5)

31. How does the resonant frequency of a series-resonant circuit affect the impedance? (16-6)

32. How does the resonant frequency of a circuit affect the voltage across the capacitor or coil? (16-7)

33. What are you determining when you use this formula:

$$\cancel{Z =} \quad R^2 + (X_L - X_C)^2 \qquad (16\text{-}8)$$

34. At what frequency is a circuit operating when the capacitive reactance is greater than the inductive reactance? (16-9)

35. How can the resonant frequency of a tuned circuit be changed? (16-10)

36. In a resonant-tuned circuit, what determines the amount of selectivity of which it is capable? (16-11)

37. In a parallel-tuned circuit with the ac source set at a low frequency, why does the greatest amount of current flow through the coil? (16-12)

38. Explain why the current flow in the line circuit, in a parallel-tuned circuit, is minimum at resonant frequency. (16-13)

39. If the applied voltage frequency is varied from a value below resonance, through resonance, to a higher frequency, what happens to line current? (16-14)

40. Define line current as the term is applied to a parallel-tuned circuit. (16-15)

41. Referring to figure 60 and the text, what electrical process causes the current flow to be maintained in the same direction when the capacitor is discharged? (16-16; Fig. 60)

42. How does current flow caused by self-induction of the coil affect the capacitor? (16-17)

43. In a tuned circuit, energy stored in the capacitor is transferred to the magnetic field around the inductor by current flowing in the circuit. How long does this process continue? (16-18)

44. How could a sustained alternating current be produced in the circuit referred to in the previous question? (16-19)

45. What is the value of impedance in a parallel-resonant circuit at resonance? (16-20)

46. What are you accomplishing in a series-resonant circuit that is part of a radio, when you manually select a specific station? (16-21)

47. How is the series-resonant principle applied to certain motor-generator sets? (16-22)

48. What is the effect of a speed control circuit in a motor generator? (16-22)

CHAPTER 8

Objective: To be able to relate facts and draw conclusions about a dc generator system and component operation, and to show an ability to analyze a system for malfunctions and isolate the most likely causes.

1. What is the rating of the dc generator for the system under discussion? (17-2)

2. What protection is provided the generator system discussed in the text? (17-3)

3. Where are the various controls for the generator system located? (17-4)

4. How is the momentary position of the generator switch identified? (17-5)

5. What actions will result when the generator switch is placed in the down position? (17-6)

6. You are required to check generator voltage with the engine running and with the generator *not*, connected to the aircraft bus. How is this done? (17-7, 9)

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7. With a constant field current, a dc generator's output voltage would be proportional to __________ __________. (17-12)

8. If the generator voltage falls below the regulator setting, how will the carbon-pile resistance be affected? (17-13)

9. How is load division controlled when dc generators are operated in parallel? (17-14)

10. Under what conditions will the armature-shunting relay be tripped? (17-15)

11. What is the indication when the generator system cannot be reset? (17-17)

12. Under what conditions will the field relay be tripped? (17-18)

13. How is the equalizer relay operated in the undervoltage protection circuit? (17-19)

14. What component is installed in the generator system to protect the electrolytic condensers in the overvoltage circuit? (17-20; Fig. 62)

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15. What is the purpose of the selector relay in the overvoltage protection circuit? (17-21)

16. When will the selector relay contacts be closed? (17-23)

17. Complete the following statement: The selector relay for the high-voltage generator __________ ______ __________, thereby permitting operation of the overvoltage relay. (17-23)

18. The overvoltage relay is calibrated to trip at __________. (17-24)

19. How is the necessary time delay obtained to prevent tripping on voltage transients? (17-24)

20. The feeder fault protection circuit will operate with a __________ to __________ volt differential between the generator feeder and the bus. (17-25)

21. What is the function of the potential relay in the feeder fault protection circuit? (17-26)

22. How are the coils of the auxiliary and main contactors connected with respect to each other? (17-28)

23. How is the forward-current relay reset? (17-29)

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24. How is cycling of the field relay trip and reset coil prevented? (17-31)

25. What two functions are provided by the forward-current relay control circuit for the generator system? (17-32)

26. How are the power circuits and branch circuits protected against sustained overloads? (18-2)

27. What type of protection is provided for a temporary overload of the distribution system? (18-3)

28. Why are two number 1/0 wires used from the generator to the firewall? (18-5)

29. What is the total dc load requirement for ground checking all aircraft systems? (18-7)

30. Why are two reverse-current relays (RCRs) used in the external power system? (18-8)

31. What do the green lights which are used in the external power system indicate? (18-9)

32. How is dc power provided which operates the RCRs in the external power system? (18-10)

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33. When should the white lights come on which are located in the external power receptacle box? (18-11)

34. How is battery power connnected to the station 238 circuit breaker panel during an emergency? (18-15)

35. When corrected for temperature, a fully charged battery should have an electrolyte reading between _______ and _______. (18-17)

36. At what level should the electrolyte be maintained above the plates of a battery? (18-18)

37. What effect will corrosion between the battery terminal and the battery cable have upon the battery power system? (18-19)

38. What is used to service the felt pad of a lead-acid vent system? (18-20)

39. What additional precaution should be taken if any one component of the generator system has been damaged? (19-1)

40. System analysis is an orderly sequence of _______ and _______ actions which ends with the identification and elimination of a system malfunction. (19-3)

41. What is the key to identifying generator system malfunctions? (19-5)

42. When troubleshooting, where do you start first to eliminate possible causes? (19-8)

43. What is the most probable cause of a low generator output voltage? (19-12, 13)

44. Why should the core or pile adjusting screws *not* be adjusted when the regulator is installed in an aircraft? (19-14)

45. Where would high resistance in the generator system most likely affect generator output voltage? (19-16)

46. How does improperly seated or worn brushes affect generator output voltage? (19-20)

47. What does a high-voltage reading in a generator system indicate? (19-23)

48. How will an open in the voltage coil circuit affect the generator output voltage? (19-25)

49. What is the probelm when a zero voltage reading at terminal B of the generator is evident? (19-29)

50. Under what condition can the generator shaft fail? (19-30-32)

51. What can cause the generator system ammeter and voltmeter to fluctuate excessively? (19-34-36

CHAPTER 9

Objective: To be able to draw conclusions and relate facts about the duties and responsibilities of the aircraft electrical repair technician, as related to the multi-generator ac power system, by analyzing, diagnosing, and isolating malfunctions in its systems.

1. The generator system of a typical fighter aircraft consists of how many generators and what are their ratings? (20-1)

2. Each generator is driven by a ______ __________ ______, and controlled by a _________ __________. (20-1)

3. The unijunction transistor is nothing more than a __________. (20-3)

4. What is the function of the gate of a silicon controlled rectifier (SCR)? (20-4)

5. The two units which maintain system voltage output to within ∓2 percent are the _______ __________ and its transistorized _________ __________. (20-5)

6. What two units together provide frequency control? (20-5)

7. Each generator obtains its excitation from the ________ ________ ________ contained within the generator. (20-6)

8. Where is the single-phase output of the PMG applied? (20-6)

9. What action maintains the generator voltage relatively constant under varying load conditions? (20-7)

10. When operating the generators in parallel, what units supply reactive load division signals to the voltage regulator? (20-8)

11. What is the purpose of the constant speed dirve (CSD)? (20-9)

12. What function does the underspeed switch (USS) perform on the constant speed drive? (20-9)

13. When will it be necessary for the pilot to use the generator control reset switch? (20-10)

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14. Generator system fault protection circuitry in the voltage regulator/supervisory panel provides for __________, __________, __________, __________, and unbalanced current protection. (20-11)

15. Why are time delays provided in the various protective circuits? (20-11)

16. What unit provides the signal to energize the tie contactor when all requirements are met for the paralleling of generators? (20-12)

17. List the three main parts of the 30-KVA brushless generator. (21-2)

18. What is the prime function of the voltage regulator in the VR/SP? (21-4)

19. List the functions of the supervisory portion of the VR/SP. (21-4)

20. In addition to regulating voltage, voltage regulators operate in conjunction with each other to equalize the __________ __________ between generators. (21-5)

21. Where does the voltage regulator obtain power for its phase voltage reference circuit? (21-7)

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22. What is the frequency of the sawtooth signal applied to the error sensing bridge, and where is it obtained? (21-8)

23. Why is the error sensing bridge *not* affected by temperature changes? (21-10)

24. What determines the polarity of the error sensing bridge? (21-11)

25. List the three stages of the current amplifier. (21-12)

26. How are the two outputs of the permanent magnet generator transformer rectifier used? (21-13)

27. What is the function of the reactive current sensing circuit (RSC)? (21-14)

28. How does the reactive current sensing circuit (RCS) function to keep the generators operating in parallel? (21-14)

29. What is the electrical difference between the right and left VR/SP current transformers? (21-18)

30. What are the results of having the current transformer loop wired 180° out of phase? (21-18)

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31. List the four functions of the supervisory panel in the sequence in which they occur. (21-19)

32. What is the purpose of the feeder fault sensing (FFS) circuit? (21-21)

33. How does the feeder fault sensing circuit perform its function? (21-21)

34. What action does the feeder fault sensing circuit take to prevent generator burnout? (21-22)

35. How does the undervoltage sensing circuit detect an undervoltage condition? (21-25)

36. How does the overvoltage sensing (OVS) circuit detect an overvoltage condition? (21-27)

37. What prevents both generators from being tripped off the line, if a voltage regulator malfunction causes overexcitation while in parallel operation? (21-28)

38. If the left generator is being overexcited, what causes the right VR/SP to take the opposite action in its OVS and UVS circuits? (21-29)

39. The generators are operating in parallel, and the left one becomes overexcited. Which one will be tripped off the line by the action of the RBC? (21-31)

40. List the three relays which the contactor logic circuit operates. (21-32)

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41. List the four basic circuits in the contactor logic circuit. (21-33)

42. What is the function of the GCR close-coil circuit? (21-34)

43. Why must the undervoltage sensing disabling circuit be disabled prior to closing the GCR and the underspeed switch? (21-35)

44. What is the function of the contactor control relay circuit? (21-36)

45. When the generator is shut down manually or by a protective circuit, why must the CCR and the GCR operate in sequence? (21-38)

46. What is the function of the GCR trip-coil circuit? (21-39)

47. What condition will cause the isolate-relay circuit to energize the isolate-relay and open the tie contactor? (21-40)

48. List the three functions of the frequency and load control box (FLCB). (21-43)

49. What is the frequency produced by the tuning fork oscillator circuit in the FLCB? (21-45)

50. What is the function of the load division demodulator circuit? (21-51)

51. Why is the resultant of the power of the output and mixing circuit applied to the drives? (21-55)

52. What is the function of the automatic paralleling circuit? (21-60)

53. What phase angle difference is required between the generators to close the APR? (21-61)

54. List the five major components in the ac power control box. (21-62)

55. What is the function of the loop shorting relay? (21-64)

56. Why are the current transformers connected in a loop and phased so that their outputs are opposing? (21-65)

57. What are the three most important units in the constant speed drive? (21-66)

58. How does the basic governor provide for real load division when the generators are operating in parallel? (21-67)

59. What are the two functions of the limit governor? (21-68)

60. What is the prime function of the underspeed switch? (21-68)

61. What are the purposes of the PMG transformer rectifier output? (21-70)

62. Which contacts must be closed to allow the left generator to power the right 115-vac bus? (21-71)

63. What are the indications when all three warning lights (LH GEN OUT, RH GEN OUT, and BUS TIE OPEN) are extinguished? (21-74)

64. What power sources are available from the power distribution system? (22-1).

65. What are the power sources available for the cockpit warning lights? (22-1).

66. List the five major components in the external power control circuit. (22-3)

67. From where does the external power T/R unit obtain its power? (22-3)

68. Who has the responsibility for servicing, charging, repairing, and testing the battery as well as troubleshooting its control system? (22-5)

69. What is the composition of the electrolyte solution in the nickel-cadmium battery? (22-6)

70. What is the nominal open-circuit cell voltage of the nickel-cadmium battery? (22-7)

71. How many cells are required for a 24-volt system when using a nickel-cadmium battery? (22-7)

72. What method is recommended for the normal charging of nickel-cadmium batteries? (22-11)

73. What is the normal power requirement for charging nickel-cadmium batteries on a constant-potential charger? (22-11)

74. Describe the constant-current method of charging. (22-12)

75. What is the purpose of the aircraft battery? (22-13)

76. From what source does the aircraft get its main emergency power? (22-13)

77. What is considered to be realistic troubleshooting? (23-2)

78. What are the three main categories of malfunctions found in the ac power system? (23-3)

79. What two units normally cause frequency malfunctions? (23-4)

80. What three units usually cause high- or low-voltage malfunctions? (23-6)

81. Why are the current transformers the cuase of many malfunction in the load division circuits? (23-9)

CHAPTER 10

Objective: To be able to draw conclusions about system operation and maintenance on control and warning systems.

1. In the Edison thermocouple system, each engine has how many zones or circuits? (24-3)

2. The difference in temperature rise between the hot and cold junctions of the thermocouple can produce a potential of how many volts? (24-4)

3. The operation of the photoelectric fire detection system depends upon what factor? (24-6)

4. What change occurs when the ceramic core of a continuous cable fire warning circuit is heated? (24-10)

5. Name the four basic circuits in a transistorized continuous cable fire detector system. (24-10)

6. In figure 78, what type coupling is used to couple Q1 and Q2 in the fire detector control assembly? (24-14; Fig. 78)

7. With no fire signal, how is transistor Q2 biased? (24-14)

8. What component turns on the fire warning light? (24-17; Fig. 78)

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When inspecting a fire warning system, name one item that is often overlooked. (24-19)

What is the purpose of the master caution system? (25-1)

What are the three basic circuits in a solid state master caution system? (25-3)

Refer to figure 79. What is the function of the Zener diode, CR1, in the individual light circuit? (25-4; Fig. 79)

In figure 79, what component forward-biases Q1 to turn on the master caution light? (25-9; Fig 79)

How does the reset circuit of the master caution system affect the individual caution lights? (25-13)

The engine fuel supply system has provisions for two methods of supplying fuel to the engine. What are they? (26-3)

With external power applied to the aircraft, what conditions must exist to cause the boost pumps to operate? (26-5)

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17. Refer to foldout 15. In the fuselage fuel system, which of the conditions listed below would cause the hydraulic transfer pumps to operate? Write a T or an F for true or false beside each condition.

a. Anytime hydraulic power is on the aircraft.

b. Afterburner operation on either engine.

c. Either engine master switch is on.

d. Air refuel switch to EXTEND.

e. Fuel load in cells 1 and 2 falls below 1800 pounds.

f. Hydraulic transfer pump check switch is placed in the CHECK position.

(26-9; FO 15)

18. Is the following statement true or false? The center, right, and left external fuel lights will illuminate while fuel is flowing. (26-12; FO 16)

19. How is the fuel transferred into the aircraft from the external system? (26-13)

20. What unit controls the FULL lights in the external fuel system? (26-13)

21. Refer to figure 80. When the air refuel switch is moved to EXTEND, what component is energized to to extend the air refuel receptacle? (26-16; Fig. 80)

22. Who can initiate disconnect action when refueling is completed? (26-17)

23. What conditions must exist on the aircraft for the nose gear steering system to be energized? (27-2) 117

24. What protects the nose gear steering system control unit from an open or short circuit in one of the inputs? (27-3)

25. What causes the servo valve to direct dydraulic flow to the vane motor for the purpose of turning the nose wheel? (27-4)

26. If an intermittent fault occurs and the failure detection system trips the ground path for the servo valve, how can the system be reset? (27-7)

27. What unit supplies power to the control unit of the nose gear steering system? (27-9)

28. Refer to figure 82. What is the purpose of the 500-ohm resistor in series with the wiper arm of the command potentiometer? (27-10; Fig. 82)

29. What determines the degree of turn of the nose wheel? (27-11)

30. The ac power supply transformer T1 provides two outputs of 100 vac. These voltages are used to develop three ____________ ____________ power supplies. (27-14)

31. Name the four parts in troubleshooting. (28-2)

32. Describe the term "area of uncertainty." (28-4)

33. What are the two major benefits of using brackets in your troubleshooting? (28-6)

MODIFICATIONS

Pages 39-66 of this publication has (have) been deleted in adapting this material for inclusion in the "Trial Implementation of a Model System to Provide Military Curriculum Materials for Use in Vocational and Technical Education." Deleted material involves extensive use of military forms, procedures, systems, etc. and was not considered appropriate for use in vocational and technical education.

CHAPTER 5

The power consumption of any electrical measuring device should be small in comparison to the power available in the circuit under test. (10-1)

Ohmmeter, megger, and Wheatstone bridge. (10-2)

To enable the meter to indicate any value being measured with the least error. (10-7)

A shunt type ohmmeter circuit is used on the low-ohm scale. (10-8)

In the shunt type meter, the smaller the value of resistance measured, the less the current flow through the meter movement. (10-9)

Values on the scale increase from left to right. (10-9)

In the low-ohm position, current flows constantly from the battery through the meter movement and the limiting resistor. (10-10)

By comparing the ballistic kick of the meter with the deflection caused by a capacitor of known value. (10-11)

When no current is flowing in either coil, the pointer may come to rest anywhere along the scale. (10-14)

500 volts. (10-14)

True. (10-16)

Infinity, zero. (10-17)

The Wheatstone bridge. (10-20)

The detector circuit may use a galvanometer for sensitive measurements requiring high accuracy. (10-21)

When the meter shunt has been removed, the detector is at maximum sensitivity. (10-22)

16. You must tighten the binding posts securely so that the contact resistance between the binding posts and the resistance to be measured is kept to a minimum. (10-24)

17. Very high, very low. (10-25)

18. The current rating of a shunt should never be the same as the estimated normal load current, because any high load current would drive the pointer off scale and might damage the movement. (10-30)

19. The ammeter terminals are connected to like polarities in the circuit. (10-38)

20. For higher voltage ranges, the series resistance is contained in a unit commonly called a multiplier. (10-40)

21. To increase the sensitivity of a voltmeter, increase the strength of the permanent magnet, use lighter weight materials for the moving element, and use sapphire jewel bearings to support the moving coil. (10-45)

22. The accuracy of a voltmeter is generally expressed in percent. (10-46)

23. When a voltmeter is connected across a circuit and the meter has low interval resistance, it will draw an appreciable amount of current. Because the effective resistance of the circuit is lowered, the voltage reading will also be lowered. (10-49)

24. The primary advantage of the VTVM over ordinary meters is its design to measure voltages without loading the circuit. (10-51)

25. The negative 5-volt bias on the tube grid establishes the operating point of the tube at cutoff. (10-53)

26. Average, peak, rms. (10-57)

27. The input coupling capacitor will become charged and could result in a dangerous shock. (10-59)

28. Formation, control. (10-62)

29. The aquadag coating provides a return path for electrons and serves to shield the electron beam from external electrical disturbances. (10-63)

30. These electrons are attracted toward the accelerating and focusing anodes because of their relative high positive potential. (10-64)

31. You should not operate the oscilloscope with the case removed, because high voltages are exposed and could cause fatal shock. (10-70)

32. Because the tube is under a high vacuum, any undue stress or rough handling can cause serious injury because of tube implosion. Also, if broken, the pieces become a hazard because of the fluorescent coating, which is extremely toxic. (10-75)

33. Two types of frequency meters that are suitable for measuring voltage source frequency are the dynamometer type and the vibrating-reed type. (10-77)

34. The dynamometer type frequency meter can be used for only a small frequency range. (10-79)

35. Correct voltage, frequency, phase relationship. (11-2)

36. The logic tree provides you with a means to logically pursue a trouble to a satisfactory conclusion by the process of elimination. (11-6)

37. The electrical power test harness can be used to perform a generating system check and for troubleshooting systems faults identified to a specific component. (11-7)

38. Compared to the PSM-20B tester, the electrical power test harness is capable of a more thorough testing of the constant-speed drive and related circuitry. (11-9)

39. The electrical power test harness has a functional checklist for flight line and in-shop applications. (11-9)

CHAPTER 6

1. The smallest a magnet can be divided and still remain a magnet is down to a molecule. (12-2)

2. The tiny magnet in question 1 is the basis for the molecular theory of magnetism. (12-2)

3. The molecules in unmagnetized materials are thought of as being jumbled at random, with no definite order. (12-3)

4. To produce a moderately strong magnet having a ferromagnetic substance, you would stroke it with a strong magnet. All strokes must be in the same direction. (12-4)

5. Magnetostriction is the behavior of a substance being magnetized and demagnetized to expand and contract. (12-5)

6. Engine heat or a hard jar can cause a generator to lose its residual magnetism. (12-6)

7. Positive; negative. (12-7)

8. Atoms in ferromagnetic substances tend to bond together in an effort to acquire a greater equilibrium, forming domains within crystalline structures. (12-8)

9. Four conditions which cause the lifting power of a magnet to vary are the
   (1) kind of magnetic material to be lifted.
   (2) shape of the material to be lifted.
   (3) manner in which the material is applied to the magnet.
   (4) shape of the magnet.
   (12-9)

10. North pole; magnet; south pole. (12-10)

11. $F = \dfrac{P_1 P_2}{\mu d^2}$ stands for the mutual force between two poles.

    F = force between the two poles.
    P_1 and P_2 = magnitudes of the pole strengths.
    d = distance between the two poles.
    μ = constant that depends upon medium surrounding the poles.
    (12-11)

12. The equation $F = \frac{1 \times 1}{1 \times 1 \text{ cm}^2} = 1$ dyne can be stated as: when any two poles of equal strength are placed in a vacuum, 1 centimeter apart, they repel each other with a force of 1 dyne. (12-12)

13. The repulsion of the north pole equals 6 dynes, while the repulsion of the south pole equals 2/3 dyne. Total repulsion equals to 6 2/3 dynes. The attraction of the circuit is equal to 3 dynes, 1.5 dynes for each magnet. (12-14, 15; Fig. 38)

14. Magnetic forces. (12-16)

15. The components usually found in a magnetic amplifier are inductors, dry disk rectifiers, and resistors. (12-17)

16. Mangetizing force; saturation; increase; increase. (12-19)

17. Should be like figure 40 of the text. (12-20; Fig. 40)

18. The amount of current through the dc coil controls the reactance of a saturable reactor. (12-21)

19. The addition of a bridge rectifier. (12-21)

20. Direct current moves in only one direction and has a constant amplitude characteristic with reference to time. (13-2, 3)

21. Negative or positive points. (13-4)

22. The battery is poled in the positive direction. (13-5)

23. Ohm's law states that the current in a circuit is proportional to the voltage. (13-6)

24. Ohm's law states that the current in a circuit is inversely proportional to the resistance. (13-6)

25. Kirchhoff's first law states: The algebraic sum of the currents at any junction of conductors is zero. (13-7, 8)

26. Kirchhoff's second law states: The algebraic sum of the applied voltages and of the voltage drops around any closed circuit is zero. (13-7, 10)

27. False. Polarity has nothing to do with Kirchhoff's laws. (13-10, 11)

28. The voltage at point 2 is 13.25 volts. This is due to all resistors in the series-parallel legs being equal. R_5 is not considered due to no current flow through it. (14-2-5; Fig. 44)

29. a. $R_a = 2/3$ ohm.
    b. $R_b = 1$ ohm.
    c. $R_c - 2$ ohms.
    d. $R_T = 6.02$ ohms.
    e. $I_T = 3.32$ amps.
    f. $E = 16.68$ volts.
    (14-8-10; Figs. 45, 46, 47)
    g. $I_{BC} = 1.93$ amps.
    h. $I_{DC} = 1.39$ amps.
    i. $E_B = 15.41$ volts.
    j. $E_D = 13.99$ volts.
    k. $I_5 = .38$ amp.

30. A mesh circuit is a series of interconnecting branches that form complete circuits or loops. (14-11)

31. Simultaneous equations are used to solve for current in mesh circuits due to solving two equations at the same time. (14-12, 13)

32. There are two general methods that can be used to solve simultaneous equations. They are addition or subtraction, and substitution. (14-13)

33. $x = 5/2$; $y = 5$. Check text for procedure. (14-14-18)

34. Kirchhoff's law states the voltage is zero. In simple form Kirchhoff's laws state that: The voltage around any closed loop is equal to zero. (14-19; Fig. 13)

35. $I_1 = -99.8$ amperes.
$I_2 = 100$ amperes.
$I_T = 0.2$ ampere.
Check text for proper procedure. (14-19, 20)

36. Current I is negative due to the different size batteries used. With the larger 50-volt battery a large charging current is being sent to the 10-volt battery. (14-21)

37. $E_1 = I_1 R$
$E_1 = -99.8 \times 0.1$
$E_1 = -99.8$ volts

$E_2 = I_2 R$
$E_2 = 100 \times 0.3$
$E_2 = 30$ volts

$E_R = I_T R$
$E_R = 0.2 \times 100$
$E_R = 20$ volts
(14-22)

$E_T = E_1 + E_2 + E_R$
$E_T = -9.98 + 30 + 20$
$E_T = 40.02$ volts

CHAPTER 7

1. Alternating current is an electrical current that continually changes in amplitude and periodically changes in direction. (15-2)

2. The statement is true. (15-3)

3. The peak value. (15-4)

4. The statement is false. The average value as applied to alternating voltage is restricted to one alternation. (15-5)

5. Phase is a difference in time between any point on a cycle and the beginning of the cycle. (15-6)

6. Increasing; zero amplitude. (15-7)

7. The statement is false. When two alternating currents are applied to a resistive circuit they are always *in* phase. (15-7)

8. When alternating currents are applied to a circuit which is not resistive, the voltage and current are out of phase. (15-8)

9. Reactive. (15-9)

10. Capacitor; inductor. (15-10)

11. Dielectric. (15-11)

12. Microfarad. (15-12)

13. The working voltage of a capacitor is the maximum voltage which may be continuously applied across the capacitor without danger of voltage breakdown. (15-13)

14. The statement is true. (15-14)

15. Choke; reactor. (15-15)

16. The unit of measurement of inductance is the henry. (15-16)

17. The current rating of an inductor is the value of the magnetizing current which places the permeability of the core material just below the knee of the saturation current curve. (15-17)

18. Inductive reactance is a type of opposition to current flow in an ac circuit. (15-18)

19. The continuously changing amplitude in an ac circuit causes a counter emf, which in turn causes a phase shift between voltage and current. (15-19)

20. The inductor current is *zero* when the applied voltage is maximum. (15-20)

21. The capacitor current *leads* the applied voltage by 90 electrical degrees. (15-21)

22. A definite frequency. (15-22)

23. As frequency increases, capacitive reactance *decreases.* (15-23)

24. As frequency increases, inductive reactance *increases.* (15-23)

25. $X_C = \dfrac{1}{2\pi fC}$. (15-24)

26. The statement is false. Inductive reactance is directly proportional to frequency. (15-25)

27; When X_L and X_C are exactly equal to each other. (16-2)

28. The reactance of the inductor. (16-3)

29. The one frequency between high and low extremes where X_L and X_C are equal. (16-4)

30. At the resonant frequency. (16-5)

31. The impedance of the circuit is at its lowest value (minimum) when the circuit is at resonant frequency. (16-6)

32. The voltage measured across each unit is greatest at the resonant frequency. (16-7)

33. The impedance of the circuit. (16-8)

34. Below resonance. (16-9)

35. By changing the value of either the coil or the capacitor. (16-10)

36. The resistance present in the circuit. (16-11)

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37. With a low-frequency alternating current, the reactance of the coil is low and the reactance of the capacitor is high. This condition reverses if the source voltage is set to a high frequency. (16-12)

38. Current flow through the inductor is opposite in polarity to current flow through the capacitor; thus, at resonant frequency, the currents flowing through the two reactances are equal in value and opposite in polarity. They tend to cancel each other; therefore, current flow in the line circuit is minimum. (16-13)

39. The line current decreases from a high value at low frequency to minimum at resonance, and then rises again to a high value at higher frequency. (16-14)

40. The line current is the difference between the currents flowing through the inductive and capacitive branches of the circuit. (16-15)

41. When the capacitor is discharged, a self-induced voltage is generated in the coil by the collapsing flux. The direction of this induced voltage maintains the current flow in the same direction. (16-16; Fig. 60)

42. Current flow caused by self-induction of the coil allows the capacitor to become charged with an opposite polarity. (16-17)

43. Until such time as required to expend energy by the resistance of the circuit. (16-18)

44. By supplying just enough power to the circuit to overcome resistance losses. (16-19)

45. The impedance is maximum at resonance. (16-20)

46. You are manually selecting or "tuning" the circuit to a specific frequency. (16-21)

47. In a speed control circuit when the motor-generator is designed to operate at a predetermined speed. (16-22)

48. The net effect of the speed control circuit is to maintain a motor rpm at the speed required to produce a resonant condition in the circuit. (16-22)

CHAPTER 8

1. 30 volts at 350 amperes. (17-2)

2. The generator system includes feeder and internal ground-fault, undervoltage, overvoltage, differential current, and reverse-polarity protection. (17-3)

3. The generator system controls are located at the flight engineer's station. (17-4)

4. The momentary position of the generator control switch is marked GENERATOR SWITCHES DOWN TO RESET FIELD RELAYS. (17-5)

5. The field relay will be reset and the generator field will be flashed. (17-6)

6. Move the generator switch to the off position and place the voltmeter selector switch to GENERATOR position of the affected generator. (17-7, 9)

7. Armature speed. (17-12)

8. Carbon-pile resistance will decrease (17-13)

9. By the voltage regulator through the equalizing coil circuit. (17-14)

10. An overvoltage or a feeder fault will trip the armature-shunting relay. (17-15)

11. If the generator system cannot be reset, the forward-current relay will be tripped. (17-17)

12. Operation of the overvoltage relay or the forward-current relay due to a feeder fault. (17-18)

13. The equalizer relay is operated by the reverse-current relay. (17-19)

14. CR1 of the overvoltage protection panel. (17-20; Fig. 62)

15. The selector relay detects the generator responsible for the overvoltage. (17-21)

16. When an equalizer signal is sent in the direction of the equalizer bus. (17-23)

17. Will not operate. (17-23)

18. 30.1 (± .5). (17-24)

19. Series resistance is used to limit the charging reate of the capacitors used in the overvoltage coil circuit. (17-24)

20. +0.2; +0.35 volt. (17-25)

21. The function of the potential relay is to protect the coil of the differential voltage and reverse-current relay against excessive terminal voltage. (17-26)

22. The auxiliary and main contactor coils are connected in parallel with each other. (17-28)

23. The forward-current relay can be mechanically reset only. (17-29)

24. By a lockout relay in the overvoltage control panel. (17-31)

25. The forward-current relay control circuit prevents reapplication of power to a feeder fault and distinguishes a feeder fault trip from an overvoltage trip. (17-32)

26. By thernal-type automatic circuit breakers. (18-2)

27. Current limiters are used in the system to allow for a temporary overload. (18-3)

28. To reduce the voltage drop and to assure sufficient current-carrying capacity for the aircraft dc systems. (18-5)

29. About 24.8 KW. (18-7)

30. Two RCRs, one for the main dc bus and one for the electronic dc bus, are used to connect and disconnect external power from the aircraft distribution system. (18-8)

31. The green lights, when on, indicate that an auxiliary power unit (APU) is connected to the external power receptacle and is turned on. (18-9)

32. DC power is provided by an APU to operate the RCRs. (18-10)

33. When the external power switch is placed in the ON position. (18-11)

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34. Through the rudder and elevator relay. (18-15)

35. 1.275: 1.300. (18-17)

36. 3/8 inch. (18-18)

37. Corrosion between the battery terminal and the battery cable could prevent the battery from providing its full rated power in an emergency. (18-19)

38. The pad is saturated with a solution of sodium bicarbonate and water. (18-20)

39. The entire system should be inspected for any additional damage. (19-1)

40. Metal; physical. (19-3)

41. The key to identifying system malfunctions is careful inspection and operational checks. (19-5)

42. Check the easiest things first, such as the circuit breaker. (19-8)

43. A faulty or improperly adjusted voltage regulator. (19-12, 13)

44. Both the core and pile adjusting screws can change the voltage setting as well as the characteristics of the regulator. (19-14)

45. High resistance in the field circuit would affect generator output voltage. (19-16)

46. Improperly seated or worn brushes cause low output voltage. (19-20)

47. No control over shunt field current. (19-23)

48. With an open in the voltage coil circuit, generator output voltage will be high. (19-25)

49. A broken generator shaft. (19-29)

50. Under any condition that imposes shock loads on the generator. (19-30-32)

51. The following can cause ammeter and voltmeter fluctuations:
    a. Loose connections in the aircraft wiring.
    b. Defective generator brushes.
    c. The condition of the commutator.
    (19-34-36)

CHAPTER 9

1. The generator power system consists of two 30-KVA 200/115-vac, 3-phase, 400-Hz generators. (20-1)

2. Constant speed drive (CSD); voltage regulator/supervisory panel. (20-1)

3. Diode. (20-3)

4. The gate of the silicon controlled rectifier (SCR) controls the turn-on/turn-off process of the rectifier. (20-4)

5. AC generator; voltage regulator. (20-5)

6. The constant speed drive (CSD) and the frequency and load control box (FLCB) provide frequency control. (20-5)

7. Permanent magnet generator. (20-6)

8. The single-phase output of the PMG is applied to a transformer rectifier (T/R) in the voltage regulator/supervisory panel (VR/SP). (20-6)

9. The voltage regulator circuitry is sensitive to small voltage changes and quickly responds to adjust the excitation to the exciter field. (20-7)

10. A reactive load loop consisting of two current transformers and a comparator circuit supply reactive load division signals to the voltage regulator. (20-8)

11. The constant speed drive (CSD) converts the variable speed of the engine to a constant speed for driving the generators. (20-9)

12. The underspeed switch permits the generator to be energized and connected to the buses if its frequency is above 375 Hertz. (20-9)

13. It will be necessary for the pilot to use the generator control reset switch in the event a malfunction causes a generator to be tripped off the line. (20-10)

14. Undervoltage, overvoltage, underexcitation, overexcitation. (20-11)

15. Time delays are provided in the various protective circuits to prevent nuisance tripping or momentary variations occurring during normal system operation. (20-11)

16. The APR provides the signal to the system control circuits to energize the tie contactor. (20-12)

17. The three main parts of the 30-KVA brushless generator are the permanent magnet generator windings, main generator field windings, and exciter windings. (21-2)

18. The voltage regulator portion of the VR/SP provides excitation to the generator and varies it to maintain a constant output voltage. (21-4)

19. The functions of the supervisory portion of the VR/SP are to monitor system operation and, when sensing a malfunction, remove the defective system from the aircraft buses. (21-4)

20. Reactive load. (21-5)

21. The voltage regulator obtains power for its phase voltage reference circuit from the full-wave transformer rectifier. (21-7)

22. The frequency of the sawtooth signal applied to the error sensing bridge is 2400 Hz; it is obtained from the waveshaping amplifier, and switching amplifier. (21-12)

23. The temperature characteristics of thermistor RT1 are the same as those of Zener diode CR7, and the bridge balance is not affected by temperature changes. (21-10)

24. The polarity of the error sensing bridge, with respect to the junction of CR7 and R12, is dependent upon the direction of the generator error. The polarity is positive with low generator voltage and negative with high generator voltage. (21-11)

25. The three stages of the current amplifier are the voltage amplifier, waveshaping amplifier, and switching amplifier. (21-12)

26. The two outputs of the permanent magnet generator transformer rectifier are used by the voltage regulator power supply and the supervisory portion of the VR/SP. (21-13)

27. The reactive current sensing circuit (RSC) functions to equalize the reactive load between generators operating in parallel. (21-14)

28. The output of the RCS circuit is used to bias the voltage regulator circuitry, which increases the excitation to the generator carrying the least reactive load. (21-14)

29. The right VR/SP current transformer is wired 180° out of phase. (21-18)

30. The results of having the current transformer loop wired 180° out of phase are that opposite action takes place in the opposite RCS. (21-18)

31. Sensing, time delay (where needed), logic decision, and control. (21-19)

32. The feeder fault sensing circuit performs the protective functions of feeder fault and generator burnout protection. (21-21)

33. The feeder fault sensing circuit is a low phase sensing circuit, and it detects feeder faults by comparing each phase voltage with the average of the three phase voltages appearing on the voltage regulator error sensing bridge. (21-21)

34. The feeder fault sensing circuit reduces the excitation to the generator, which allows the generator to be tripped off the line by undervoltage. (21-22)

35. The undervoltage sensing circuit monitors the lowest phase voltage, which, when less than 102 volts, provides a signal to trip the generator off the line. (21-25)

36. The overvoltage sensing circuit responds to the highest phase overvoltage and, through its time delay, produces a trip circuit with delay time inversely proportional to overvoltage level. (21-27)

37. The reactive bias circuit (RBC) biases the OVS circuit so that only the defective (overexcited) generator is tripped off the line. (21-28)

38. The wiring of the current transformer loop to the right VR/SP is 180° out of phase iwth the left VR/SP, which causes the opposite action to take place. (21-29)

39. In the case of an overexcitation fault, the generator supplying the most current is the faulty one, and it is tripped on overvoltage. (21-31)

40. The contactor logic circuit operates the generator control relay (GCR), contactor control relay (CCR), and isolate relay (IR). (21-32)

41. The GCR close-coil circuit, UVS disabling circuit, CCR control circuit, and GCR trip-coil circuit. (21-33)

42. The GCR close-coil circuit functions to energize (close) the relay. (21-34)

43. The undervoltage sensing disabling circuit must be disabled prior to closing the GCR and USS to prevent an automatic lockout of the GCR. (21-35)

44. The CCR circuit energizes or deenergizes the CCR, which, in turn, energizes or deenergizes the line contactor. (21-36)

45. The CCR must open before the GCR; otherwise the generator will be deenergized while still connected to the bus. (21-38)

46. The purpose of the GCR trip-coil circuit is to deenergize the GCR. (21-39)

47. The isolate relay circuit will energize the isolate relay and open the tie contactor when the unbalance current sensing circuit detects an excessive unbalanced real load division between generators. (21-40)

48. The functions of the FLCB are fine frequency control, automatic paralleling, and real load division. (21-43)

49. The frequency produced by the tuning fork oscillator circuit in the FLCB is 800 ± 0.4 Hz. (21-45)

50. The load division demodulator circuit provides a voltage amplitude modulated signal to the power output and mixing circuit to correct for an unbalanced real load condition between the paralleled generators. (21-51)

51. The resultant of the power output and mixing circuit is applied to the drives to correct the off frequency or unbalanced load conditions. (21-55)

52. The automatic paralleling circuit functions as a phase-sensitive detector. (21-60)

53. The phase angle difference between the generators should be approximately 90°. (21-61)

54. The five major components in the ac power control box are the left and right line contactors, tie contactor, external power contactor, loop shorting relay, and current transformers. (21-62)

55. The loop shorting relay shorts the three current transformer loops whenever the tie contactor is deenergized. (21-64)

56. The current transformers are connected in a loop and phased so their outputs are opposing and proportional to the difference in the amount of current produced by each generator. (21-65)

57. The three most important units in the CSD are the basic governor, limit governor, and underspeed switch. (21-66)

58. By using a signal from the frequency and load control box to supply a corrective signal to the trim head of the CSD. (21-67)

59. The two functions of the limit governor are the actuation of the underspeed switch and the trip valve. (21-68)

60. The underspeed switch prevents connection of the generators to the bus until generator frequency is approximately 375 Hz. (21-68)

61. The PMG transformer rectifier output is used for generator excitation, as a dc control voltage for operation of system relays and contactors, and as a power supply for the semiconductor circuits in the VR/SP. (21-70)

62. TC-10 contacts. (21-71)

63. When all three warning lights are extinguished, the generator systems are operating normally and in parallel. (21-74)

64. The power distribution system consists basically of the left and right 115-vac, 3-phase buses and low-voltage ac and dc dc bus systems. (22-1)

65. The cockpit warning lights have 28 vac for day operation and 14 vac for night operation. (22-1)

66. The five major components in the external power control circuit are the generator control switches, external power contactor (EPC), external power transformer rectifiers, external power receptacle, and instrument ground power switch. (22-3)

67. The external power T/R unit obtains its power directly from A phase of the external power receptacle. (22-3)

68. The aircraft electrical repairman has the responsibility for servicing, charging, repairing, and testing the battery as well as troubleshooting its control systems. (22-5)

69. The composition of the electrolyte solution in the nickel-cadmium battery is 30 percent (by weight) potassium hydroxide in distilled water. (22-6)

70. The nominal open-circuit cell voltage of the nickel-cadmium battery is 1.30 volts. (22-7)

71. Nickel-cadmium batteries for 24-volt systems consist of 19 individual cells. (22-7)

72. The constant-potential method is recommended for the normal charging of nickel-cadmium batteries. (22-11)

73. The normal power required for charging nickel-cadmium batteries on a constant-potential charger is 28.5-volt dc and at least 300 amperes. (22-11)

74. Charging by the constant-current method is done by using a rectifier-type battery charger. The charger is connected in series with the batteries and also selects and regulates battery current. (22-12)

75. The purpose of the aircraft battery is to provide electrical power for the engine ignition, four white flood lights, and the EGT indicator inverter. (22-13)

76. The main source of emergency power for the aircraft comes from the emergency ac generator, which is driven by a ram air turbine. (22-13)

77. Realistic troubleshooting is an orderly sequence of mental and physical actions ending with the identification and elimination of a system malfunction. (23-2)

78. The three main categories of malfunctions found in the ac power system are frequency, voltage, and load division. (23-3)

79. Frequency malfunctions are normally caused by the constant speed drive or the frequency and load control box. (23-4)

80. The VR SP, the generator, or in some cases the generator drive, usually cause high- or low-voltage malfunctions. (23-6)

81. Current transformers are the cause of many load division circuit malfunctions because their characteristics are easily changed by incorrect installation or failure to short them before operating the affected system. (23-9)

CHAPTER 10

1. In the Edison thermocouple system each engine has three zones or circuits. (24-3)

2. The difference in temperature rise between the hot and cold junctions of the thermocouple can produce up to 50 millivolts. (24-4)

3. The operation of the photoelectric fire detector system depends upon the varying radiation of the flame. (24-6)

4. When heated, the ceramic decreases in resistance until current flows between the wires. (24-10)

5. The system can be divided into four basic circuits as follows: power supply circuit, sensing circuit, amplifier circuit, and warning circuit. (24-10)

6. The two amplifiers Q1 and Q2 are directly coupled. (24-14; Fig. 78)

7. Transistor Q2 is normally reverse-biased, which puts it at cutoff. (24-14)

8. The fire warning light circuit is completed when relay K1 is energized. (24-17; Fig. 78)

9. Corrosion control of the fire warning system is often overlooked. (24-19)

10. This system is designed to caution the aircrew that an unsafe or potentially unsafe condition exists. (25-1)

11. The master caution circuitry can be divided into the following three separate circuits: the individual caution light circuit, the master caution light circuit, and the reset circuit. (25-3)

12. The Zener diode functions as a voltage regulator to dim the individual caution lights. (25-4; Fig. 79)

13. The silicon controlled rectifier SCR2 fires and forward-biases transistor Q1. (25-9; Fig. 79)

14. The reset circuit has no effect on the individual caution lights. It will only turn off the master caution light. (25-13)

15. One of the methods used to supply fuel to the engine is the two ac motor-driven boost pumps located in the bottom of the number 1 fuel cell. The other method is a gravity feed system which will supply sufficient fuel to operate the engine at lower power settings. (26-3)

16. For the boost pumps to operate with external power applied, the following conditions must exist: when either engine master switch is placed in the ON position, when the ground fueling switch is placed in either the REFUEL or DEFUEL position with both engine master switches off, when either boost pump check switch is placed in the CHECK position. (26-5)

17. a. F.
b. T.
c. F.
d. T.
e. T.
f. T.
(26-9; FO 15)

18. False. The external fuel lights come on only when fuel flow stops. (26-12; FO 16)

19. Fuel is transferred from the external system into the aircraft by air pressure. (26-13)

20. All tanks contain a float assembly which actuates a FUEL light in the cockpit. (26-13)

21. When the air refuel switch is moved to the EXTEND position, the number 1 solenoid in the nozzle lock sequencing valve is energized to extend the receptacle. (26-16; Fig. 80)

22. When refueling is completed, a disconnect action can be initiated from either the receiver aircraft or the tanker. (26-17)

23. The nose gear steering system may be energized when the nose gear is down and locked and the main gear struts are compressed. (27-2)

24. In the event of an open or short circuit in one of the inputs to the control unit, a failure detection network detects this and removes hydraulic pressure from the steering system. (27-3)

25. The servo valve is subjected to a differential current determined by the positioning of the command potentiometer. (27-4)

26. Because SCR2 is self-healing, when the cause for failure is removed, the system can be recycled and normal operation resumed. (26-7)

27. The nose gear steering switches, when depressed, apply power to the control unit. (27-9)

28. The 500-ohm resistor is placed in series with the wiper arm to protect it. (27-10; Fig. 82)

29. The output of the wiper arm of the followup potentiometer determines the degree of turn of the nose wheel. (27-11)

30. Resistor capacitor. (27-14)

31. The expert knows there are four parts in troubleshooting. These are: knowing in detail how the system works, knowing how to use the test equipment, using technical orders and maintenance manuals effectively, and logically analyzing the information he obtains from the malfunctioning system. (28-2)

32. When you determine the broad limits where the defects or difficulties may be located, it is called the area of uncertainty. (28-4)

33. You can obtain at least two benefits by using brackets. First, determining the area of uncertainty makes it easier to avoid pointless checks. Secondly, the brackets are an aid in selecting the best check from among the possible good checks. (28-6)

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STOP– 1. MATCH ANSWER SHEET TO THIS EXERCISE NUMBER. 2. USE NUMBER 1 PENCIL.

42370 01 21

VOLUME REVIEW EXERCISE

Carefully read the following:

DO'S:

1. Check the "course," "volume," and "form" numbers from the answer sheet address tab against the "VRE answer sheet identification number" in the righthand column of the shipping list. If numbers do not match, take action to return the answer sheet and the shipping list to ECI immediately with a note of explanation.
2. Note that numerical sequence on answer sheet alternates across from column to column.
3. Use only medium sharp # 1 black lead pencil for marking answer sheet.
4. Circle the correct answer in this test booklet. After you are sure of your answers, transfer them to the answer sheet. If you *have* to change an answer on the answer sheet, be sure that the erasure is complete. Use a clean eraser. But try to avoid any erasure on the answer sheet if at all possible.
5. Take action to return entire answer sheet to ECI.
6. Keep Volume Review Exercise booklet for review and reference.
7. If *mandatorily* enrolled student, process questions or comments through your unit trainer or OJT supervisor.
   If *voluntarily* enrolled student, send questions or comments to ECI on ECI Form 17.

DON'TS:

1. Don't use answer sheets other than one furnished specifically for each review exercise.
2. Don't mark on the answer sheet except to fill in marking blocks. Double marks or excessive markings which overflow marking blocks will register as errors.
3. Don't fold, spindle, staple, tape, or mutilate the answer sheet.
4. Don't use ink or any marking other than with a # 1 black lead pencil.

Note: The 3-digit number in parenthesis immediately following each item number in this Volume Review Exercise represents a Guide Number in the Study Reference Guide which in turn indicates the area of the text where the answer to that item can be found. For proper use of these Guide Numbers in assisting you with your Volume Review Exercise, read carefully the instructions in the heading of the Study Reference Guide.

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MODIFICATIONS

Pages 83- 87 of this publication has (have) been deleted in adapting this material for inclusion in the "Trial Implementation of a Model System to Provide Military Curriculum Materials for Use in Vocational and Technical Education." Deleted material involves extensive use of military forms, procedures, systems, etc. and was not considered appropriate for use in vocational and technical education.

Chapter 5

57. (113) What is the voltage drop across the meter movement of an ammeter having an internal shunt with a voltage drop of 0.01 volt at 100 microamperes?

   a. 0.01 volt.
   b. 0.001 volt.
   c. 0.00001 volt.
   d. 0.000001 volt.

58. (112) When using a megger to test insulation resistance, one item that requires special attention is the

   a. output voltage of the megger.
   b. temperature of the item under test.
   c. strength of the permanent magnet.
   d. speed at which the hand crank is turned.

59. (112) So they may cover a wide range of values most ohmmeters are equipped with

   a. multiple scales.
   b. a mirror.
   c. an external shunt.
   d. a scale multiplication feature.

60. (113) What value of shunt resistance would you use with a meter movement that drops 0.01 volt at full scale deflection and is going to be used as a 100 ampere meter?

   a. 0.0001 ohm.
   b. 0.001 ohm.
   c. 0.0002 ohm.
   d. 0.002 ohm.

61. (112) Which resistance measuring device is the most accurate?

   a. Megger.
   b. Ohmmeter.
   c. Dynamometer.
   d. Wheatstone bridge.

62. (112) An adjustable shunt is provided on bridge type measuring devices to

   a. protect the detector unit.
   b. provide range selection.
   c. balance the bridge.
   d. provide an accurate reading.

63. (112) Why should you move the range selector switch on the ohmmeter away from the low-ohm scale position when you have completed your check?

   a. The batteries would overcharge.
   b. To reduce constant flow.
   c. The movement would not be locked.
   d. The pointer would stay far to the right.

64. (115) What is the major operational difference between the PSM-20B and the Electrical Power Test Harness?

   a. The PSM-20B is designed for in-shop testing.
   b. The PSM-20B is capable of locking out and overriding system problems.
   c. The Electrical Power Test Harness was primarily designed for flight line use.
   d. The Electrical Power Test Harness is capable of more thorough CSD testing.

65. (114) The sensitivity of a voltmeter is expressed in

   a. percentage.

b. millivolts.
c. microamps per volt.
d. ohms per volt.

66. (114) Why should an oscilloscope not be operated with the case removed?

a. It presents a shock hazard.
b. It will cause erroneous readings.
c. Outside fields will affect the CRT.
d. The low amplitude test signal will be affected.

67. (112) The accuracy of measurements made with the Wheatstone bridge is independent of the

a. value of the supply voltage.
b. resistance of the test leads.
c. security of the binding posts.
d. value of the resistance to be measured.

68. (113) How should current measuring instruments be connected to a circuit?

a. In shunt.
b. In series.
c. In parallel.
d. In series-parallel.

69. (114) The purpose of the sweep generator signal in the oscilloscope is to

a. reduce persistence.
b. increase tube sensitivity.
c. establish time-base on the vertical axis.
d. establish time-base on the horizontal axis.

70. (114) The reason for grounding the VTVM ac probe after checking a circuit where high dc voltage was present is to

a. reset the meter movement.
b. remove the negative grid bias.
c. discharge the coupling capacitor.
d. break the circuit at ground potential.

71. (114) The electronic process of forming, focusing, accelerating, controlling, and deflecting the electron beam is accomplished by what unit in the cathode ray tube?

a. Electron gun.
b. Aquadag coating.
c. Deflection system.
d. The accelerating anode.

72. (112) If a high degree of precision is not required, when measuring resistance, you should choose

a. a megger.
b. a test light.
c. an ohmmeter.
d. a Wheatstone bridge.

Chapter 6

73. (117) Who is responsible for the statement "The algebraic sum of the currents at any junction of conductors is zero"?

a. Lenz.
b. Kirchhoff.
c. Ohm.
d. Faraday.

74. (117) When 10 volts are applied across a 5 ohm resistance, the current in the resistor equals

a. 2 amp.
b. 5 amp.
c. 10 amp.
d. 15 amp.

Note to Student: Use figure 38 in illustration booklet 101 as an aid when responding to items 75 and 76. However, for P_1 use the value 40 and for P_2 the value 15 as the respective pole strengths of the magnets. Keep both magnets 10 cm. long and oriented as shown in figure 38, except their north poles are 5 cm. apart.

75. (116) What is the approximate total force of attraction for the circuit in figure 38, using the substituted values in the figure?

a. 0.67 dyne.
b. 2.67 dynes.
c. 5.33 dynes.
d. 10.60 dynes.

76. (116) What is the approximate total net force (attraction or repulsion) of the circuit in figure 38, using the substituted values in the figure?

a. 5.33 dynes of repulsion.
b. 5.33 dynes of attraction.
c. 19.63 dynes of repulsion.
d. 19.63 dynes of attraction.

77. (117) When a constant source of voltage is applied across a decreasing resistance, the power supplied by the voltage source

- a. decreases because there is less current.
- b. increases because there is more current.
- c. stays the same although the current decreases.
- d. stays the same although the current increases.

78. (116) The smallest a magnet can be broken down and still retain its north and south pole is

- a. an atom.
- b. a proton.
- c. an electron.
- d. a molecule.

79. (116) The tendency of a substance to expand and contract when being magnetized is known as

- a. paramagnetic.
- b. magnetomotive.
- c. magnetostriction.
- d. magnetic induction.

Note to Student: Refer to figure 48 in illustrations booklet I01 as an aid when responding to item 80. However, for certain values given in the figure substitute the following: battery 1 is 28 volts and its internal resistance is 0.2 ohm, battery 2 is 60 volts and its internal resistance remains 0.3 ohm. The fixed resistance between points A and B is 80 ohms.

80. (119) Using the substituted values in figure 48, what is the approximate value of the current through the fixed resistor between points A and B?

- a. 0.112 amp.
- b. 0.509 amp.
- c. 1.362 amp.
- d. 3.004 amp.

81. (119) In the two equations $6y - 2x = 0$ and $3x - 4y - 20 = 0$, what values have x and y?

- a. $x = 3$, $y = 1$.
- b. $x = 6$, $y = 2$.
- c. $x = 9$, $y = 3$.
- d. $x = 12$, $y = 4$.

82. (117) A battery is placed in a circuit with the reference point on the negative terminal. What direction is the battery poled?

- a. In the positive direction.
- b. In the negative direction.
- c. The reference point has no effect on the battery.
- d. A battery is always poled in the negative direction only.

83. (117) The nearest approach to the production of pure direct current is the electrical energy from

- a. a dry disk rectifier.
- b. a shunt type generator.
- c. a dc inverter.
- d. the chemical reaction in a battery.

84. (117) When working with current or voltage, amplitude is the characteristic which represents

- a. intensity.
- b. velocity.
- c. density.
- d. time.

Note to Student: Refer to figure 45A in illustrations booklet I01 as an aid when responding to item 85.

85. (118) Refer to figure 45A. What is the current flow between points B and C and between points D and C?

- a. $I_{BC} = 1.39$ amps $I_{DC} = 1.926$ amps.
- b. $I_{BC} = 1.82$ amps $I_{DC} = 7.88$ amps.
- c. $I_{BC} = 1.926$ amps $I_{DC} = 1.39$ amps.
- d. $I_{BC} = 7.88$ amps $I_{DC} = 1.82$ amps.

Chapter 7

86. (120) The difference between ac and dc voltage is that

- a. ac voltage has a constant value.
- b. ac voltage alternates its direction.
- c. dc voltage reverses its direction.
- d. ac voltage has constant polarity.

87. (12') If a capacitor is being charged by means of a battery, electrons will flow from the

a. negative side of the battery, through the capacitor, to the positive side of the battery.
b. positive side of the battery to one side of the capacitor, while other electrons flow from the other side of the capacitor to the negative side of the battery.
c. negative side of the capacitor, through the battery, to the positive side of the capacitor.
d. negative side of the battery to one side of the capacitor, while other electrons flow from the other side of the capacitor to the positive side of the battery.

88. (120) The unit of measure of capacitance is the

a. ohm.
b. henry.
c. farad.
d. maxwell.

89. (120) A capacitor is composed of

a. two pieces of conducting material separated by an insulator.
b. a piece of material which has a great amount of resistance.
c. a piece of conducting material which can carry a large amount of current.
d. two pieces of conducting material that connect a battery to a very small resistance.

90. (121) In a parallel-tuned circuit at the resonant frequency, the

a. line current is maximum.
b. line current is minimum.
c. total impedance is minimum.
d. inductive branch current is minimum.

91. (120) When a voltage value is preceded by the letter "e", the value indicated is

a. peak.
b. average.
c. instantaneous.
d. root mean square.

92. (120) To be in phase, two voltages or currents must

a. have the same values for each corresponding value of θ.
b. have opposite values for each corresponding value of θ.
c. attain their greatest and least values for the same values of θ.
d. start from zero in a positive direction at the same time.

93. (121) In a parallel-tuned circuit at resonant frequency, the

a. total impedance is maximum.
b. total impedance is minimum.
c. line current is maximum.
d. capacitive branch current is minimum.

Chapter 8

94. (122) The voltage regulator maintains a constant voltage output of a dc generator by controlling the

a. generator field current.
b. current through the armature.
c. strength of the series field.
d. resistance of the field and armature circuit.

95. (123) Corrosion should be removed from the terminals of a lead-acid battery by use of

a. a wire brush.
b. sodium bicarbonate.
c. liquid cleaner, PS661.
d. a stiff non-metallic brush.

96. (122) In a dc system, when should the generator field circuit breakers be placed in the OFF position?

a. During normal system shutdown.
b. In the event of a malfunction.
c. When the field relay is tripped.
d. During a systems operational check.

97. (122) The differential current fault-sensing relay in the dc generator circuits operates when there is a substantial difference in current between the

a. series field and the bus.
b. shunt field and the bus.
c. battery and the generator shunt field.
d. battery and the generator series field.

98. (1[illegible]) Operating the generator switch to the momentary down position will do which of the following?

a. Trip the armature shunting relay.
b. Close the forward current relay.
c. Flash the generator field.
d. Trip the field relay.

99. (123) When should an installed aircraft battery be replaced?

a. When it becomes necessary to add water.
b. When the specific gravity reads 1.240 or below.
c. When the specific gravity reading is below 1.275.
d. When the battery sump jar needs to be serviced.

100. (124) Any condition that will impose a shock load on a generator may cause

a. shaft failure.
b. brush failure.
c. bearing failure.
d. regulator failure.

101. (122) Following a feeder fault, how is the forward-current relay in the dc generator circuit reset?

a. By the armature shunting relay.
b. Electrically by the field relay.
c. Manually by a button on its case.
d. Electrically by the generator switch.

102. (124) Which of the following will cause a zero voltage output from a dc generator?

a. An open field lead.
b. A shorted generator switch.
c. An open voltage coil circuit.
d. Broken generator shaft.

103. (122) During parallel generator operation, the voltage regulators equalize the output of the generators by

a. increasing the field current of the low generator, only.
b. increasing the field current of the high generator, and decreasing the field current of the low generator.
c. reducing the field current of all generators operating in parallel.
d. reducing the field current of the high generator, and increasing the field current of the low generator.

104. (123) What type of protective device is used in the distribution system which will allow it to carry temporary overloads?

a. Switch-type circuit breakers.
b. Thermal-type automatic circuit breakers.
c. Current limiters.
d. Special-protection type relays.

105. (124) When checking a generator system for a high voltage malfunction, use

a. an ohmmeter.
b. a voltmeter.
c. an ammeter.
d. a megger.

106. (123) What are the sectionalizing relays in the dc power distribution system used to isolate?

a. The nacelle buses from the main bus.
b. The generator feeder from the main bus.
c. The main bus from the external power system.
d. The generator feeders in the nacelle bus.

107. (122) At what minimum voltage do the equalizer relay contacts in the dc generator circuit normally close?

a. 16.
b. 18.
c. 20.
d. 22.

Chapter 9

Note to Student: Refer to foldout 13 in illustrations booklet 102 as an aid when responding to items 108 and 109.

108. (129) Refer to foldout 13. Which of the following sets of warning lights will be extinguished when the left generator is put on the line?

a. LH GEN OUT and RH GEN OUT.

b. RH GEN OUT and BUS TIE CLOSED.
c. RH GEN OUT and BUS TIE OPEN.
d. LH GEN OUT and BUS TIE OPEN.

109. (129) Refer to foldout 13. What is the purpose of the GCR-2 contacts?

a. To energize LLC-10 contact.
b. To ground the bridge rectifier.
c. To energize the tie contactor.
d. To apply excitation voltage to the generator.

Note to Student: Refer to foldout 14 in the illustrations booklet 102 as an aid when responding to item 110.

110. (130) Refer to foldout 14. Which of the following conditions will cause 28 vdc to be applied to the battery bus?

a. RH ignition switch energized.
b. LH ignition switch energized.
c. Ground fueling control switch off.
d. Left engine master switch energized.

Note to Student: Refer to foldout 4 in illustrations booklet 102 as an aid when responding to items 111 through 114.

111. (126) Refer to foldout 4. Polarity of the error sensing bridge output is determined by the

a. current amplifier.
b. direction of generator voltage error.
c. time constant of R1 and C1.
d. PMG transformer rectifier.

112. (126) Refer to foldout 4. The type of wave form which is applied to the error sensing bridge is known as

a. half.
b. square.
c. sawtooth.
d. sinusoidal.

113. (126) Refer to foldout 4. The excitation from transistor Q3 to the generator is a pulsating negative dc voltage in the form of a

a. full wave.
b. square wave.
c. half wave.
d. saw-tooth wave.

114. (126) Refer to foldout 4. What is the purpose of R1 and C1 in this circuit?

a. Signal rectifier.
b. Current sensing.
c. Wave shaping.
d. Time delay.

Note to Student: Refer to foldout 8 in illustrations booklet 102 as an aid when responding to items 115 and 116.

115. (128) Refer to foldout 8. Which of the following transistors is part of the power output and mixing circuit?

a. Q201.
b. Q301.
c. Q504.
d. Q601.

116. (128) Refer to foldout 8. Which of the following components is part of the dc power supply in the frequency and load control box?

a. Tuning fork.
b. Signal amplifier.
c. Frequency divider.
d. Transformer rectifier.

117. (127) When a generator is tripped from the line the current transformer loop

a. is opened.
b. is grounded.
c. is shorted.
d. continues to operate.

Chapter 10

118. (134) The three external fuel lights come on when

a. the tanks are armed.
b. fuel flow stops from each tank.
c. the external tanks have been jettisoned.
d. the aircraft is in refueling operation.

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119. (134) Which of the following conditions will cause the hydraulic transfer pumps in the fuselage fuel supply system to operate?

a. 100% rpm on both engines.
b. Afterburner in operation on either engine.
c. Upon completion of an air refuel operation.
d. Fuel in the external tanks falls below 1800 pounds.

120. (132) In a continuous cable fire warning system the sensing elements undergo what changes when heated?

a. Decrease in reactance.
b. Decrease in resistance.
c. Increase in reactance.
d. Increase in resistance.

121. (135) What will be the result if a nose gear steering switch fails to make?

a. The system will be locked out.
b. The system will be locked in.
c. The power supply A2 will increase its output.
d. The nose wheel will lock in the direction of the open switch.

122. (135) In the nose gear steering system, what happens when the voltage from the follow-up potentiometer equals the voltage from the command potentiometer?

a. The nose wheel returns to center.
b. The system disengages.
c. The servovalve directs hydraulic flow to the vane motor.
d. The nose wheel remains at the desired degree of turn.

123. (134) The boost pumps in the engine fuel feed system operate only when

a. external power is not being applied.
b. the aircraft is in normal flight.
c. external power is applied and either master switch is on.
d. internal power is applied, both master switchs are off, and the refuel switch is off.

124 (134) Fuel is transferred from the external fuel system by

a. gravity feed.
b. electric pumps.
c. air pressure.
d. hydraulic pumps.

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ILLUSTRATIONS

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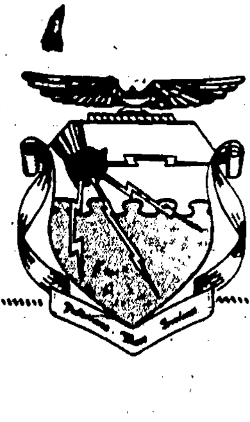
AIRCRAFT ELECTRICAL REPAIR TECHNICIAN

Volume 1

Foldouts 1–16



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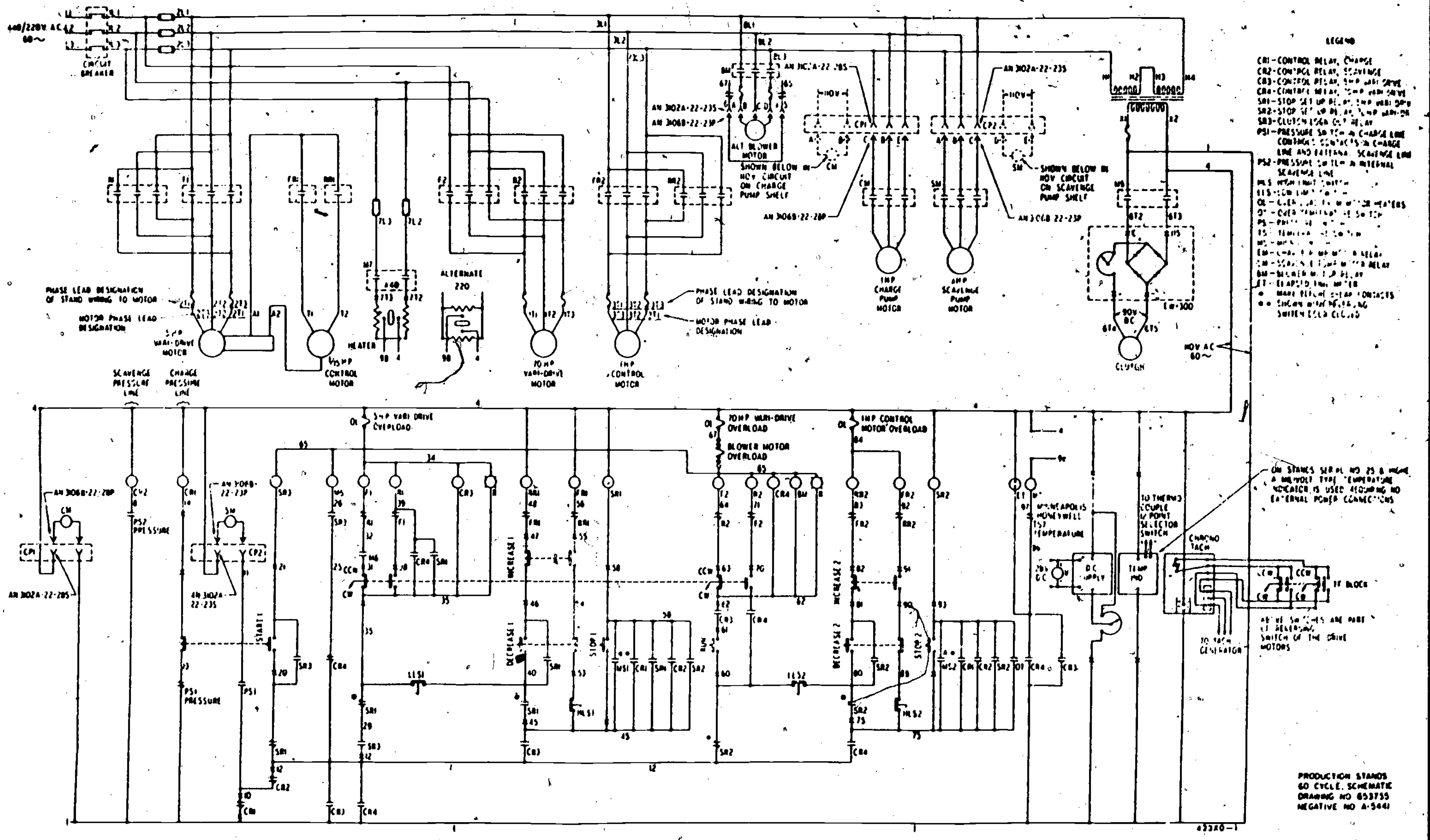
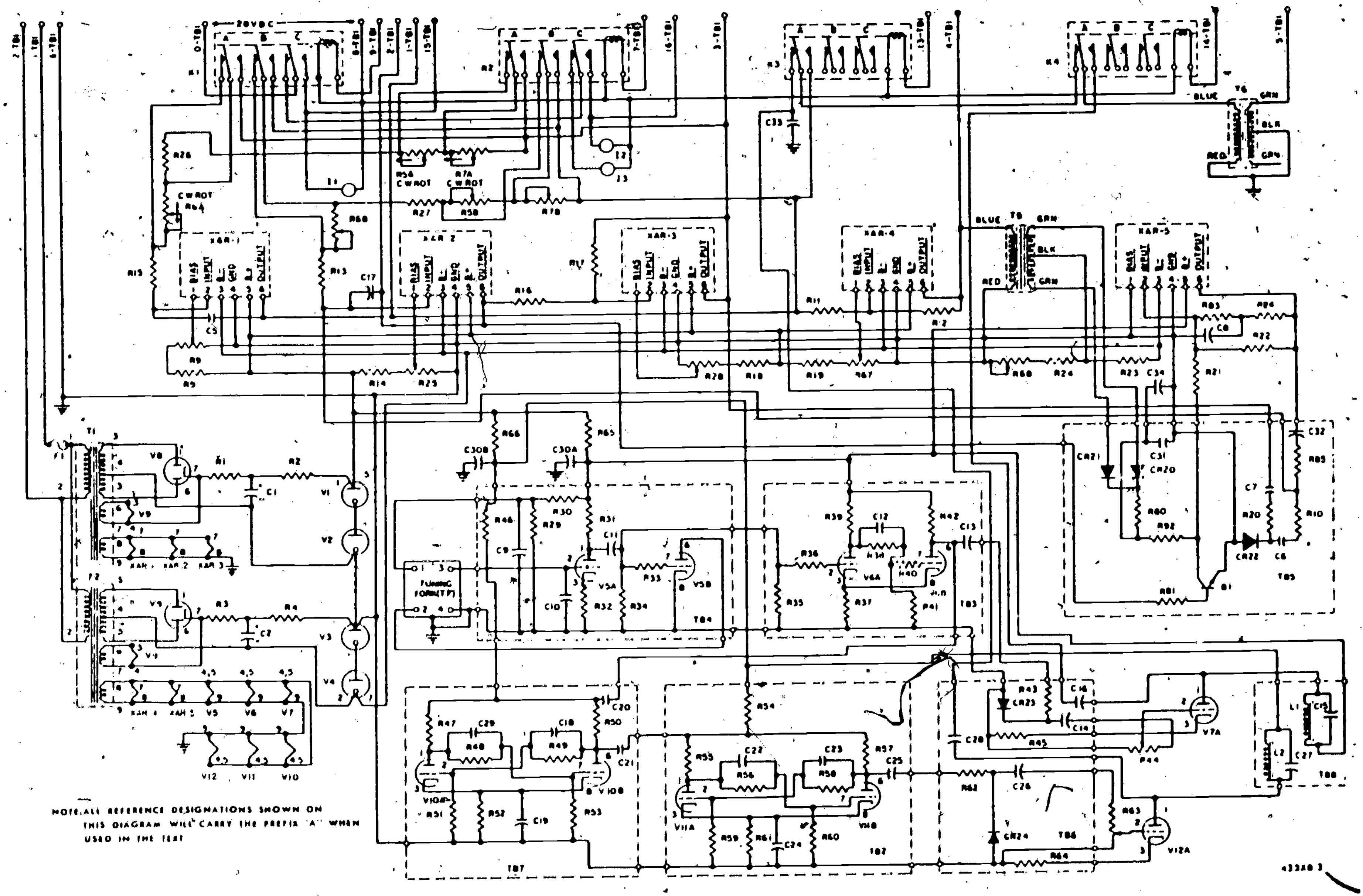
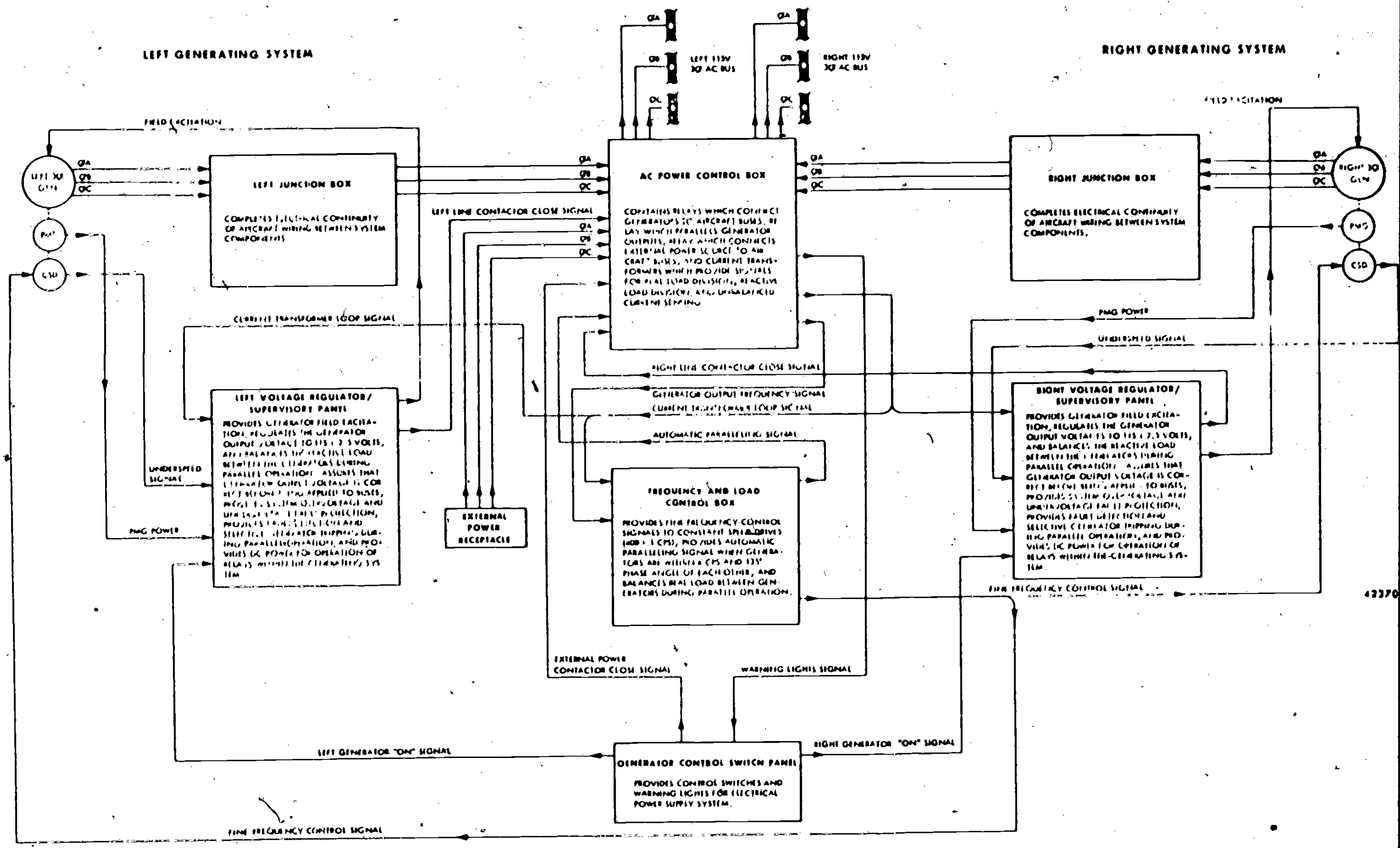


Foldout 1. MC-2 60-Hertz schematic.

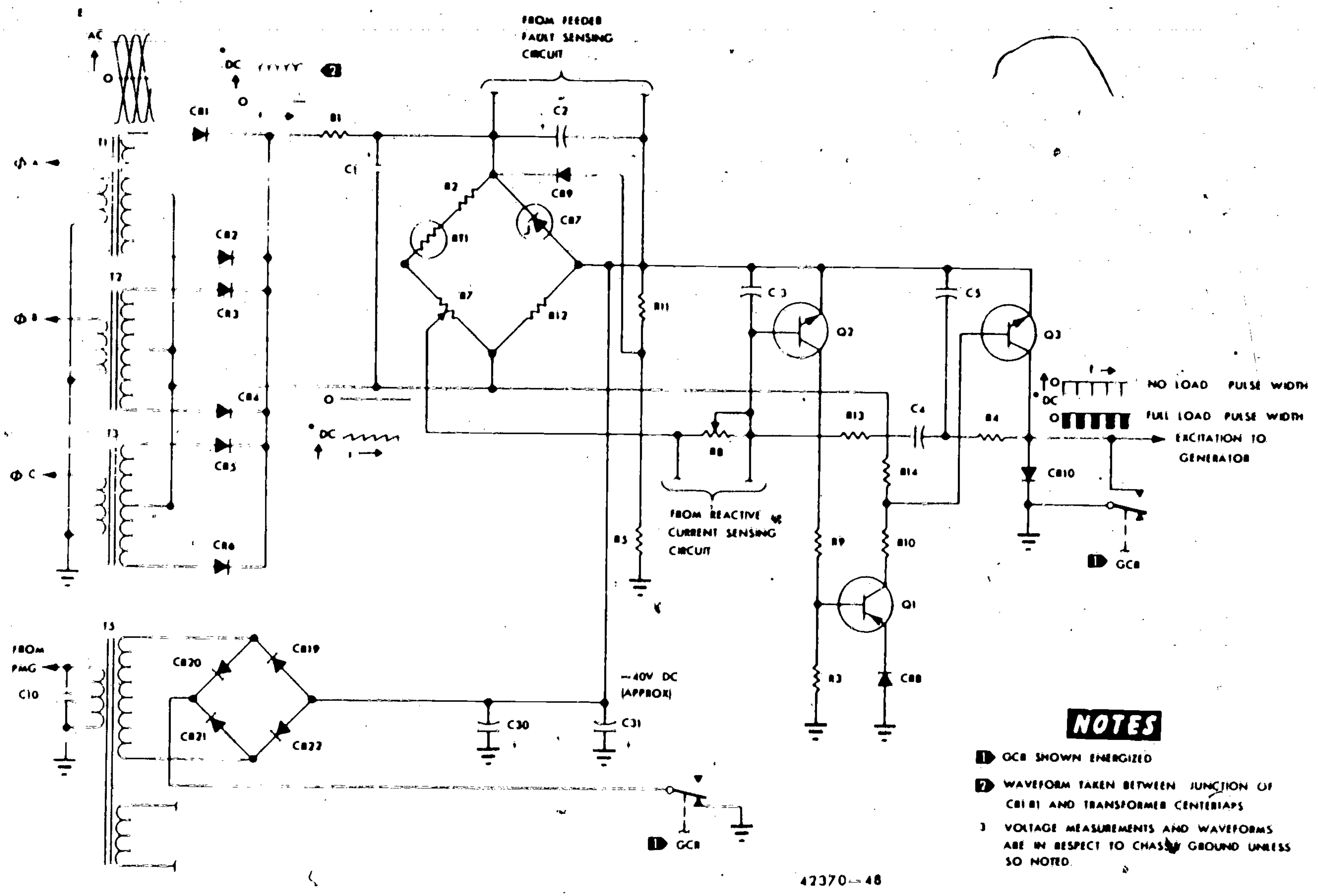


NOTE: ALL REFERENCE DESIGNATIONS SHOWN ON THIS DIAGRAM WILL CARRY THE PREFIX "A" WHEN USED IN THE TEXT

Foldout 2. AC electronic generator



Foldout 3. System data flow dia



NOTES

1. GCR SHOWN ENERGIZED
2. WAVEFORM TAKEN BETWEEN JUNCTION OF CR1 R1 AND TRANSFORMER CENTERTAPS
3. VOLTAGE MEASUREMENTS AND WAVEFORMS ARE IN RESPECT TO CHASSIS GROUND UNLESS SO NOTED.

Foldout 4. Voltage regulator circuit.

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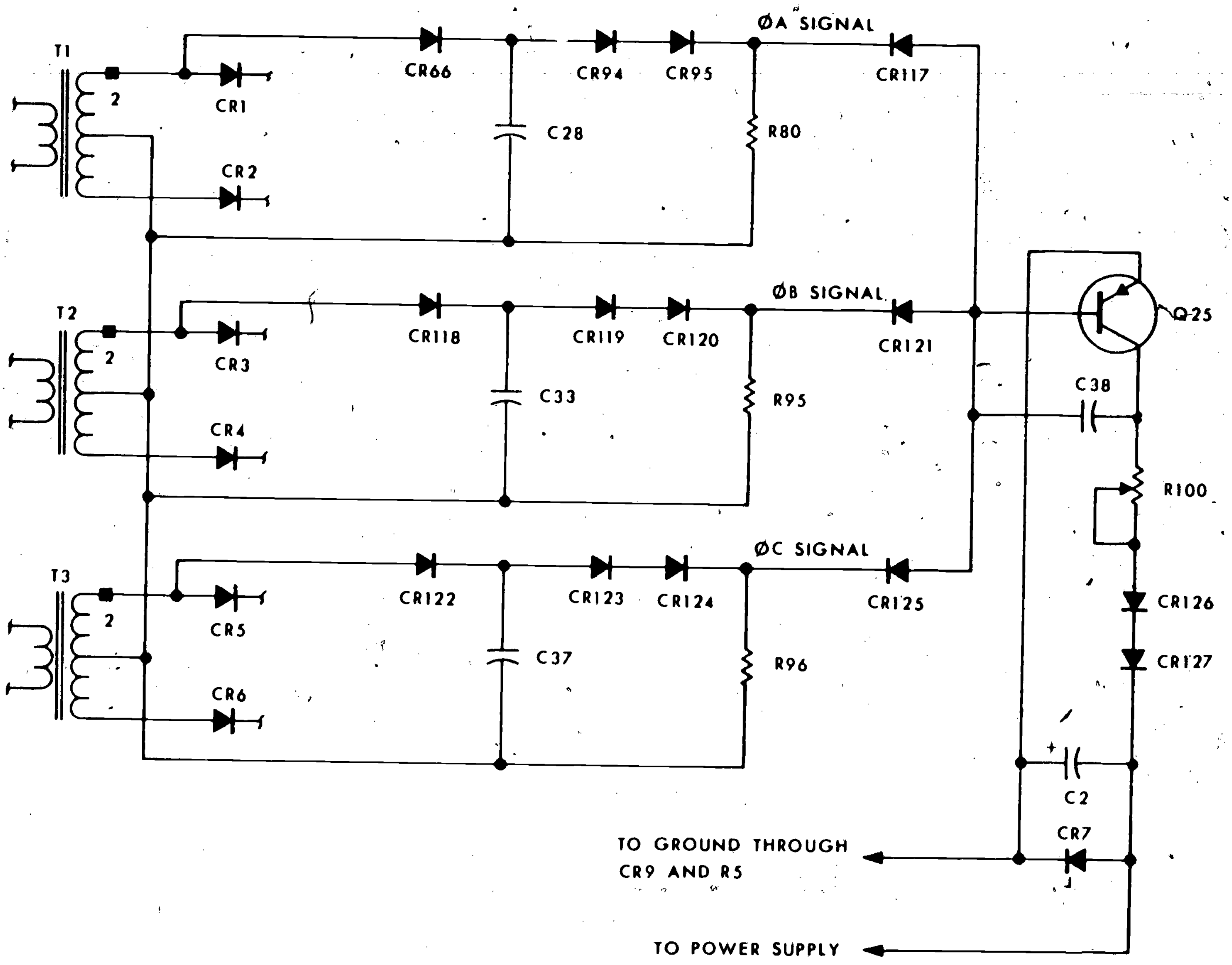

Foldout 5. Feeder fault sensing circuit.

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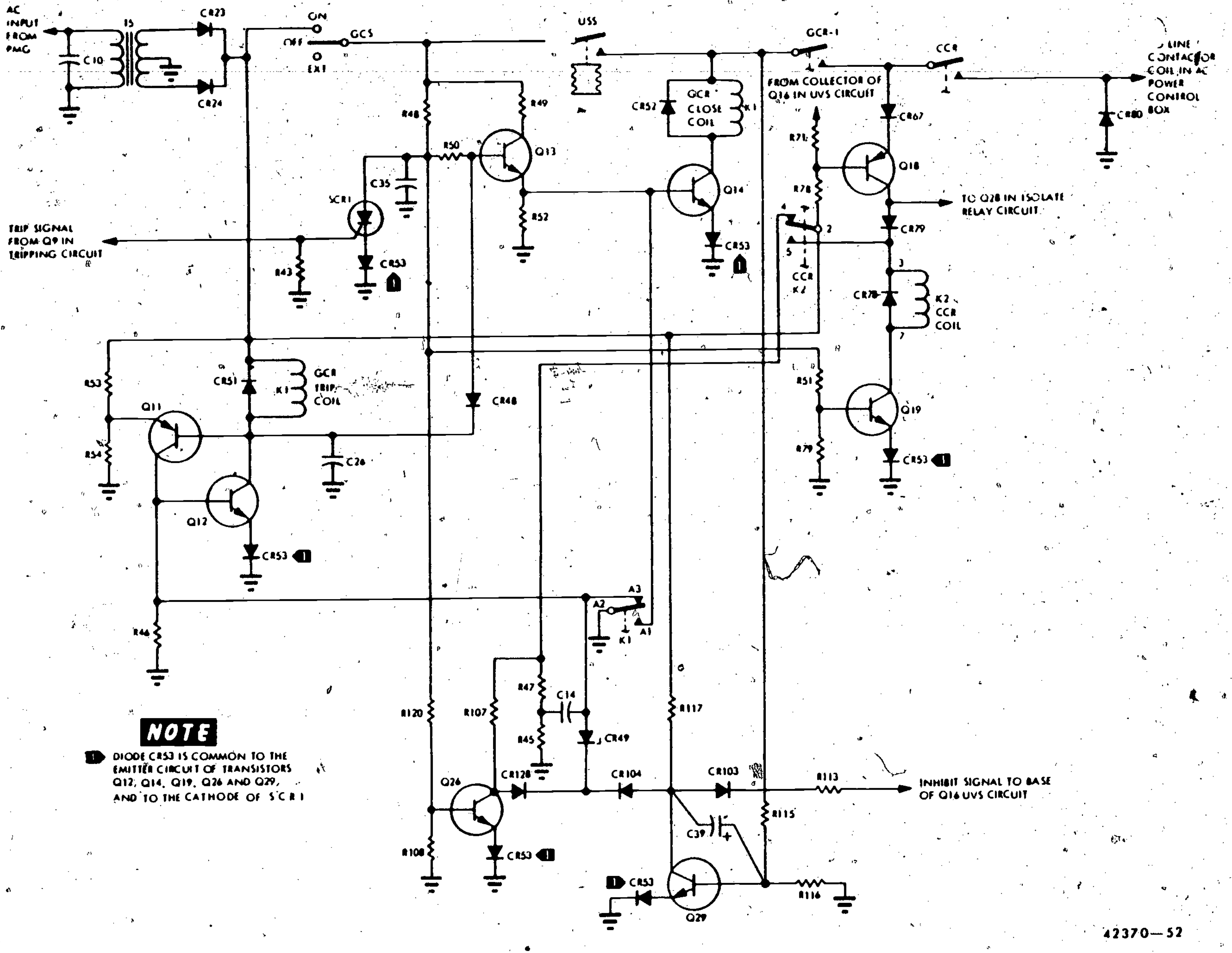
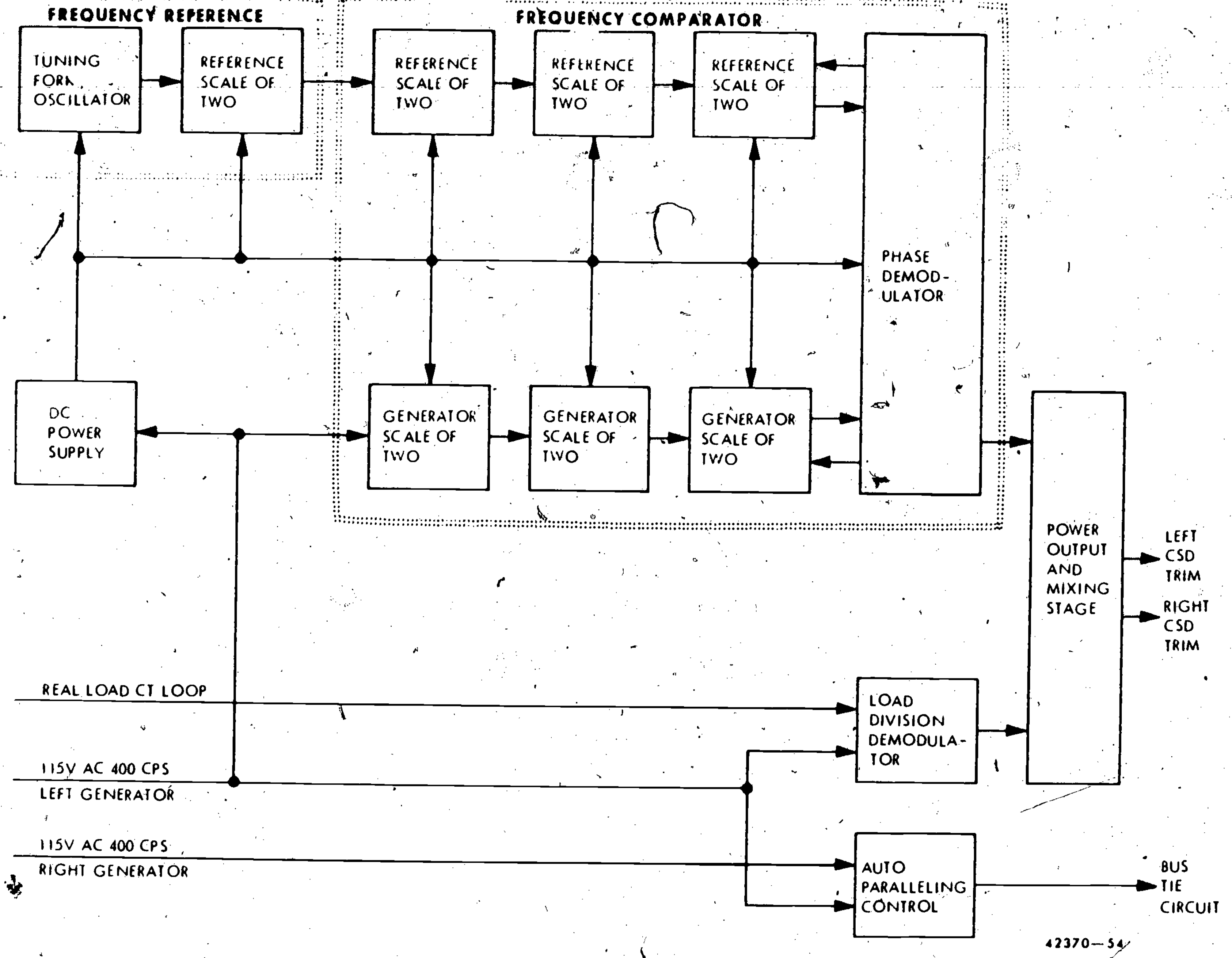


NOTE

DIODE CR53 IS COMMON TO THE EMITTER CIRCUIT OF TRANSISTORS Q12, Q14, Q19, Q26 AND Q29, AND TO THE CATHODE OF SCR1

Foldout 6. VR/SP contactor logic circuit.



Foldout 7. Frequency and load control box.

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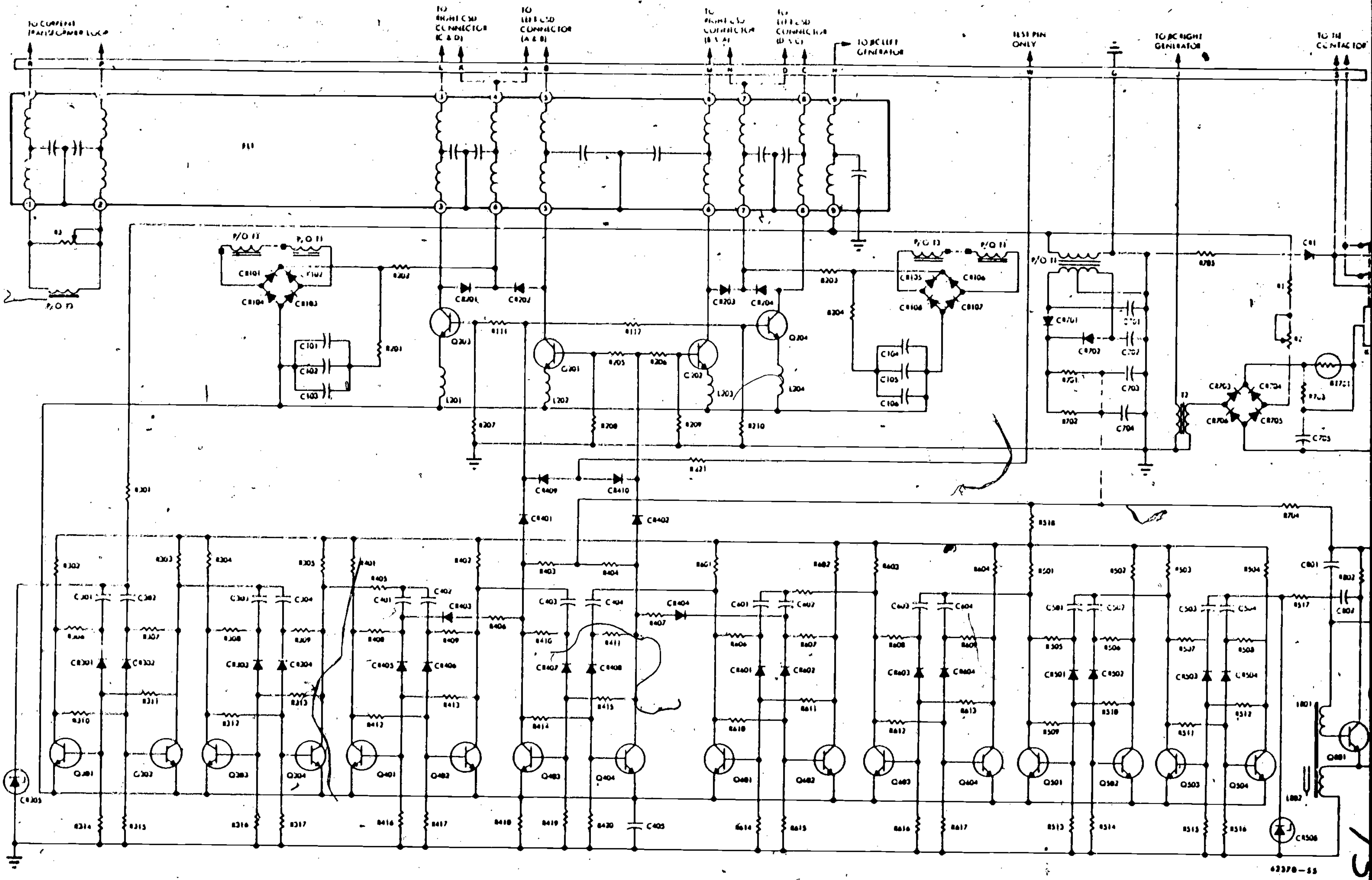
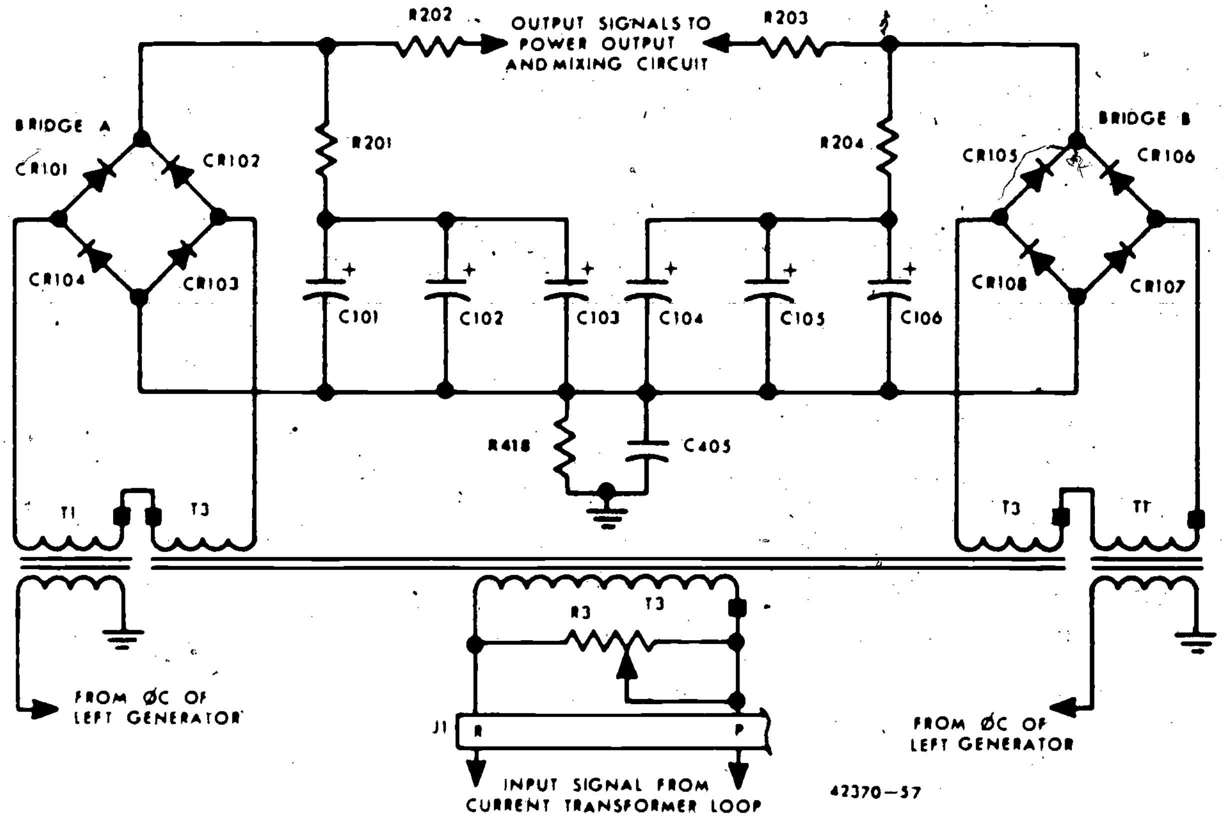
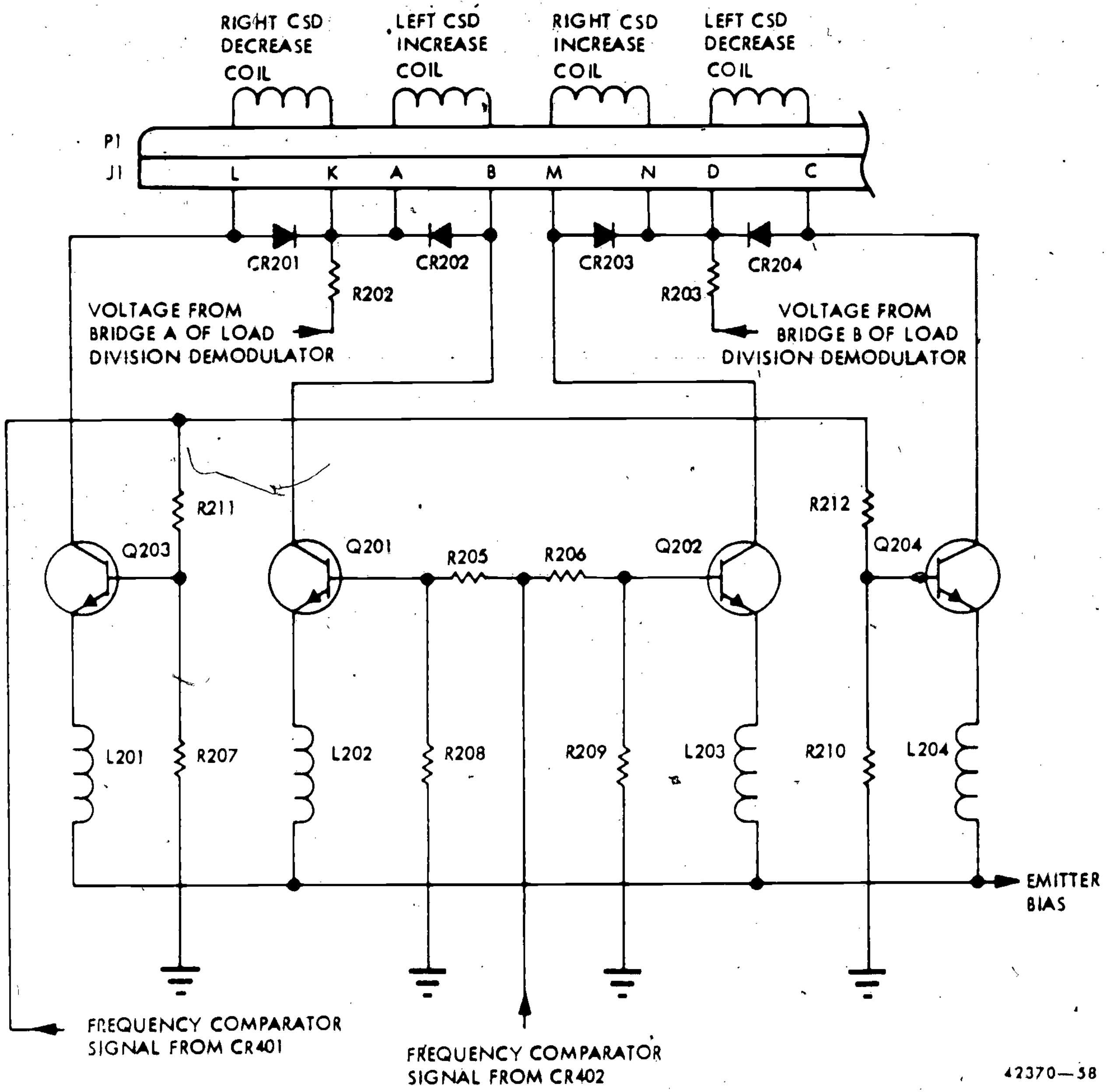


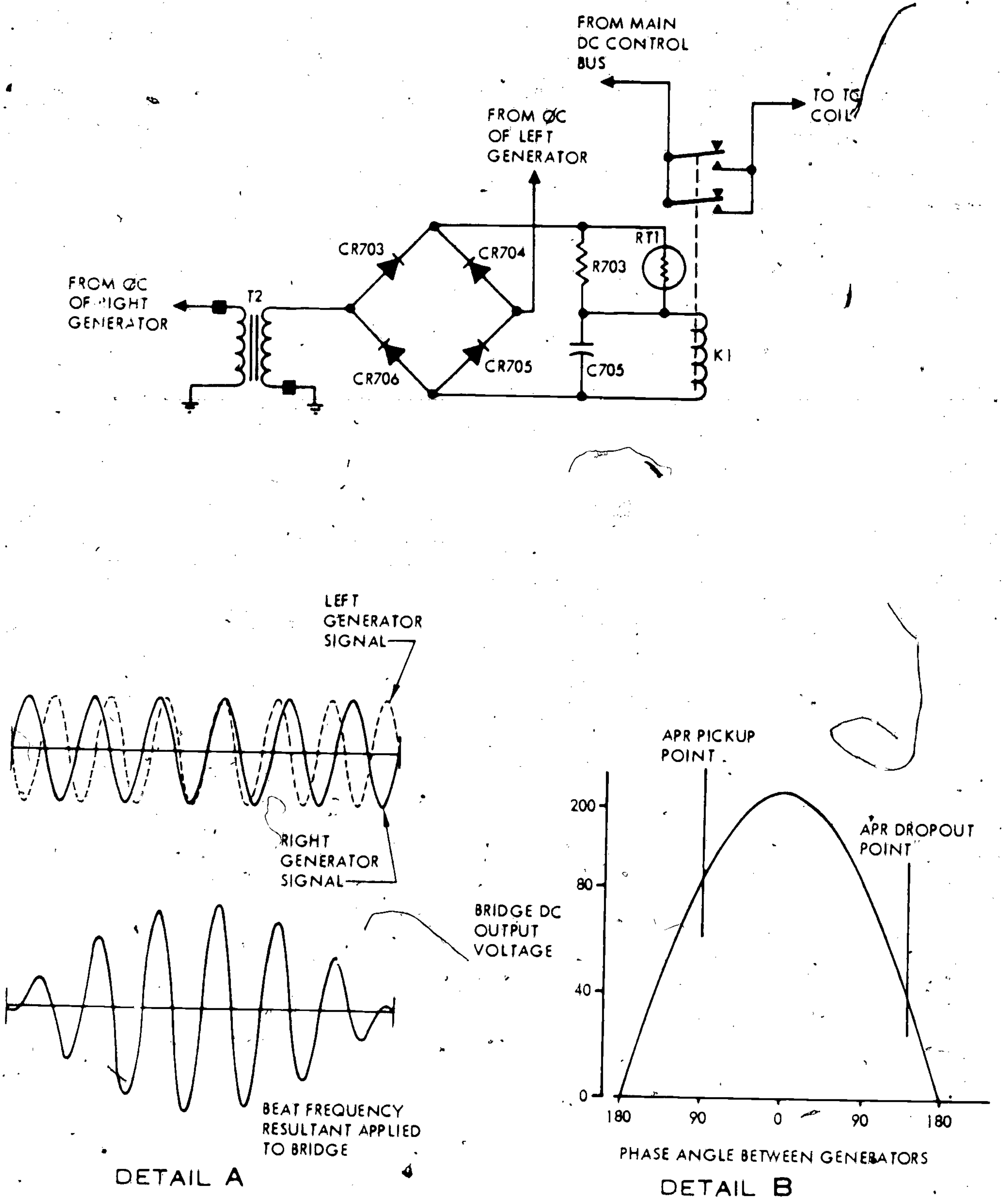
Foldout 8. Frequency and load control box sche



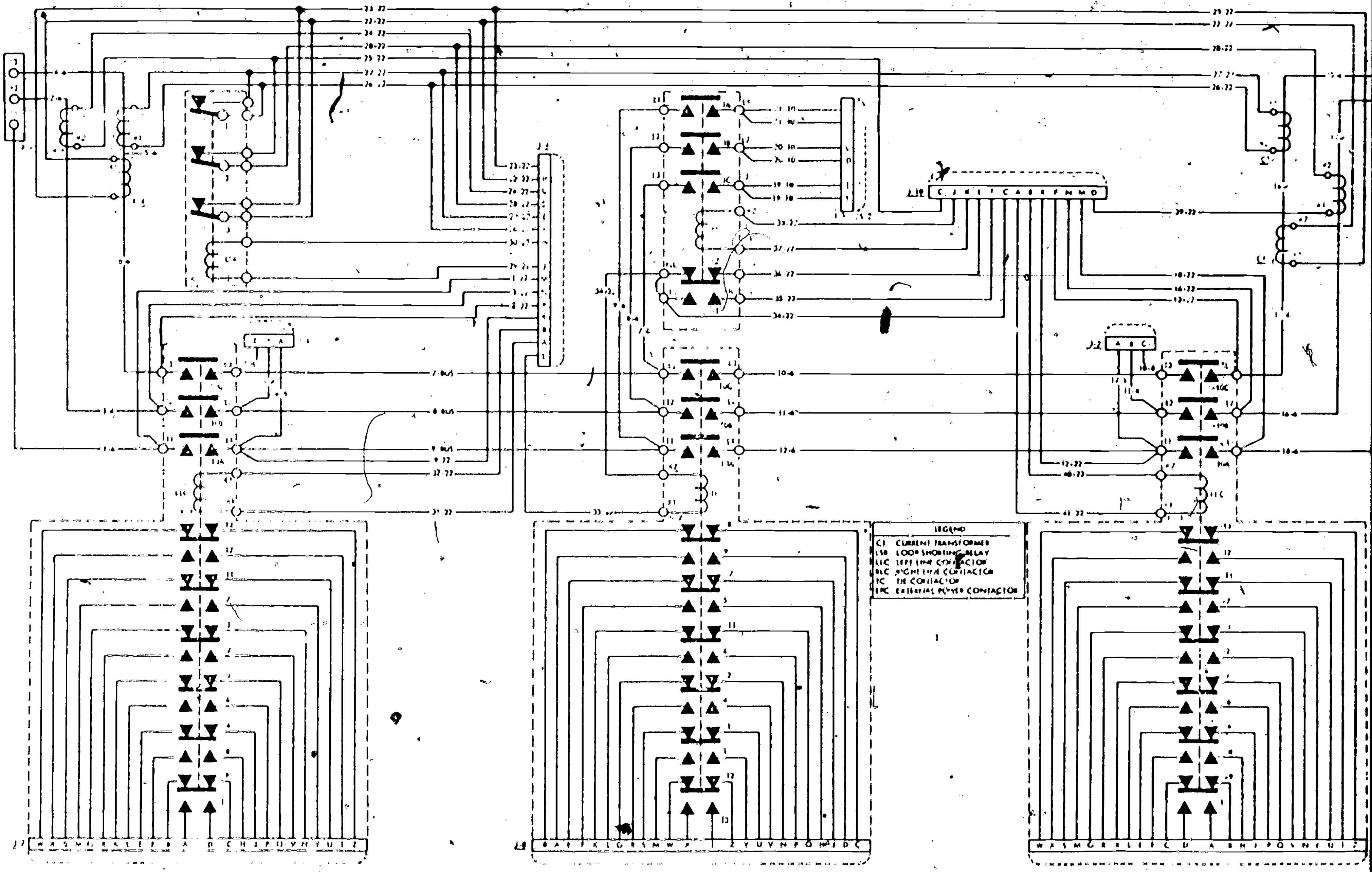
Foldout 9. Load division demodulator circuit.



Foldout 10 Power output and mixing circuit.



Foldout 11. Automatic paralleling circuit.



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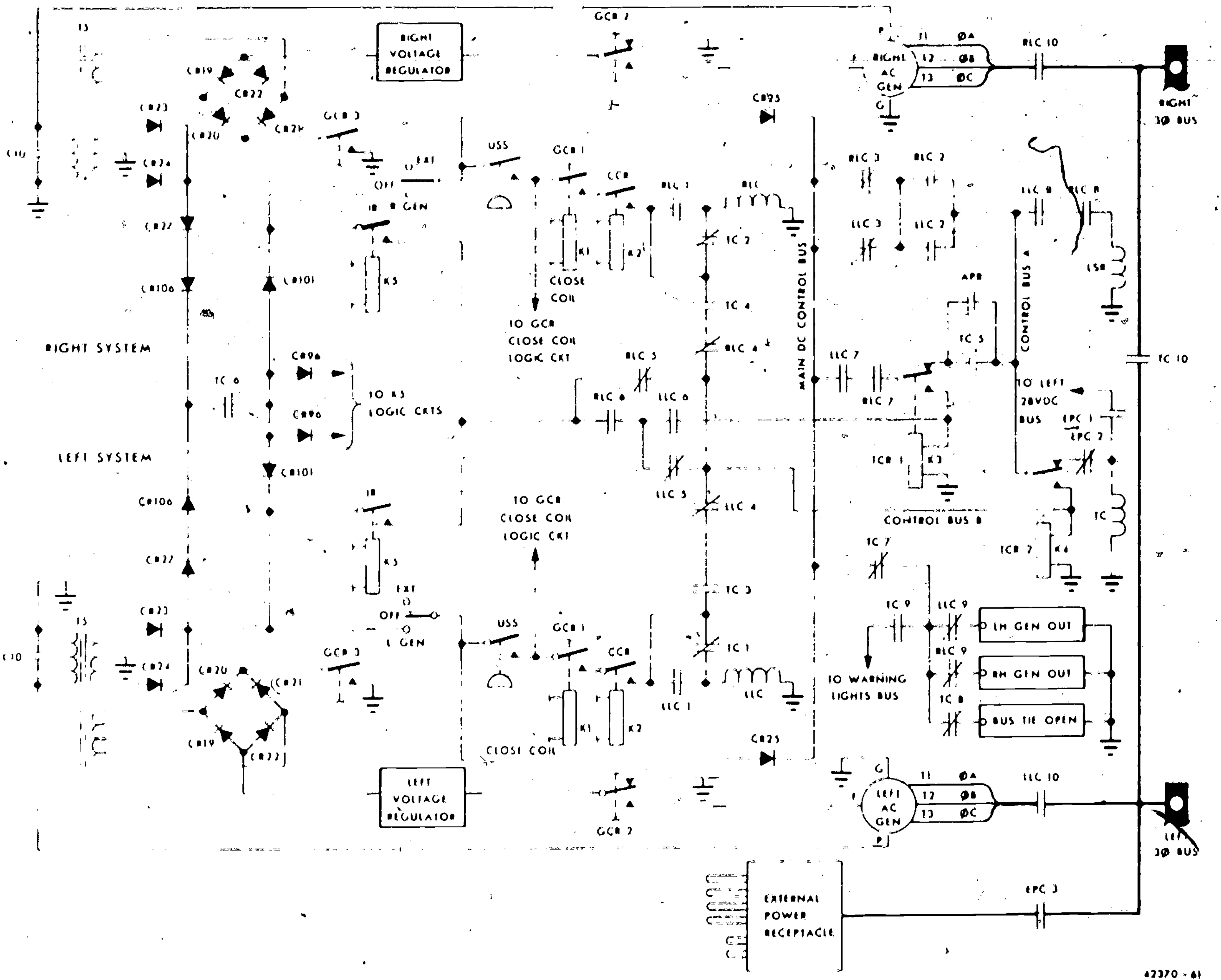
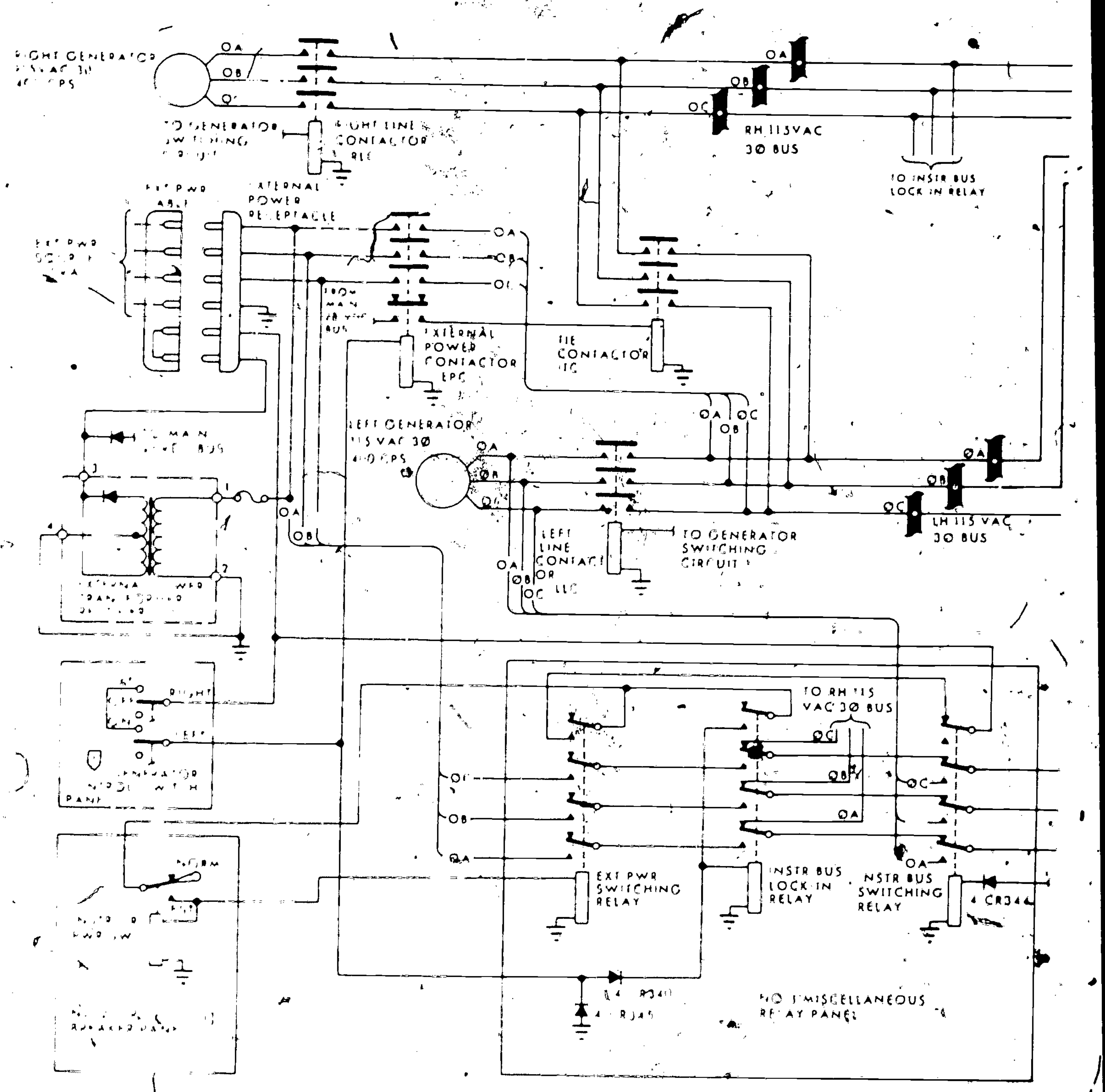
Foldout 12. Ac power cont



Foldout 13. Generator switching circuit.


RIGHT GENERATOR 115 VAC 3Ø 400 CPS
ØA
ØB
ØC
TO GENERATOR SWITCHING CIRCUIT
RIGHT LINE CONTACTOR RLC
RH 115VAC 3Ø BUS
TO INSTR BUS LOCK IN RELAY
EXT PWR CABLE
EXT PWR SOURCE
EXTERNAL POWER RECEPTACLE
FROM MAIN 28 VDC BUS
EXTERNAL POWER CONTACTOR EPC
TIE CONTACTOR TC
LEFT GENERATOR 115 VAC 3Ø 400 CPS
TO MAIN 28 VDC BUS
EXTERNAL POWER TRANSFORMER
LEFT LINE CONTACTOR LLC
TO GENERATOR SWITCHING CIRCUIT
LH 115 VAC 3Ø BUS
RIGHT
LEFT
GENERATOR MODE SWITCH PANEL
NORM
EXT PWR SW
TO RH 115 VAC 3Ø BUS
EXT PWR SWITCHING RELAY
INSTR BUS LOCK IN RELAY
INSTR BUS SWITCHING RELAY
4 CR344
4 CR340
4 CR345
NO 1 MISCELLANEOUS RELAY PANEL

Foldout 14.

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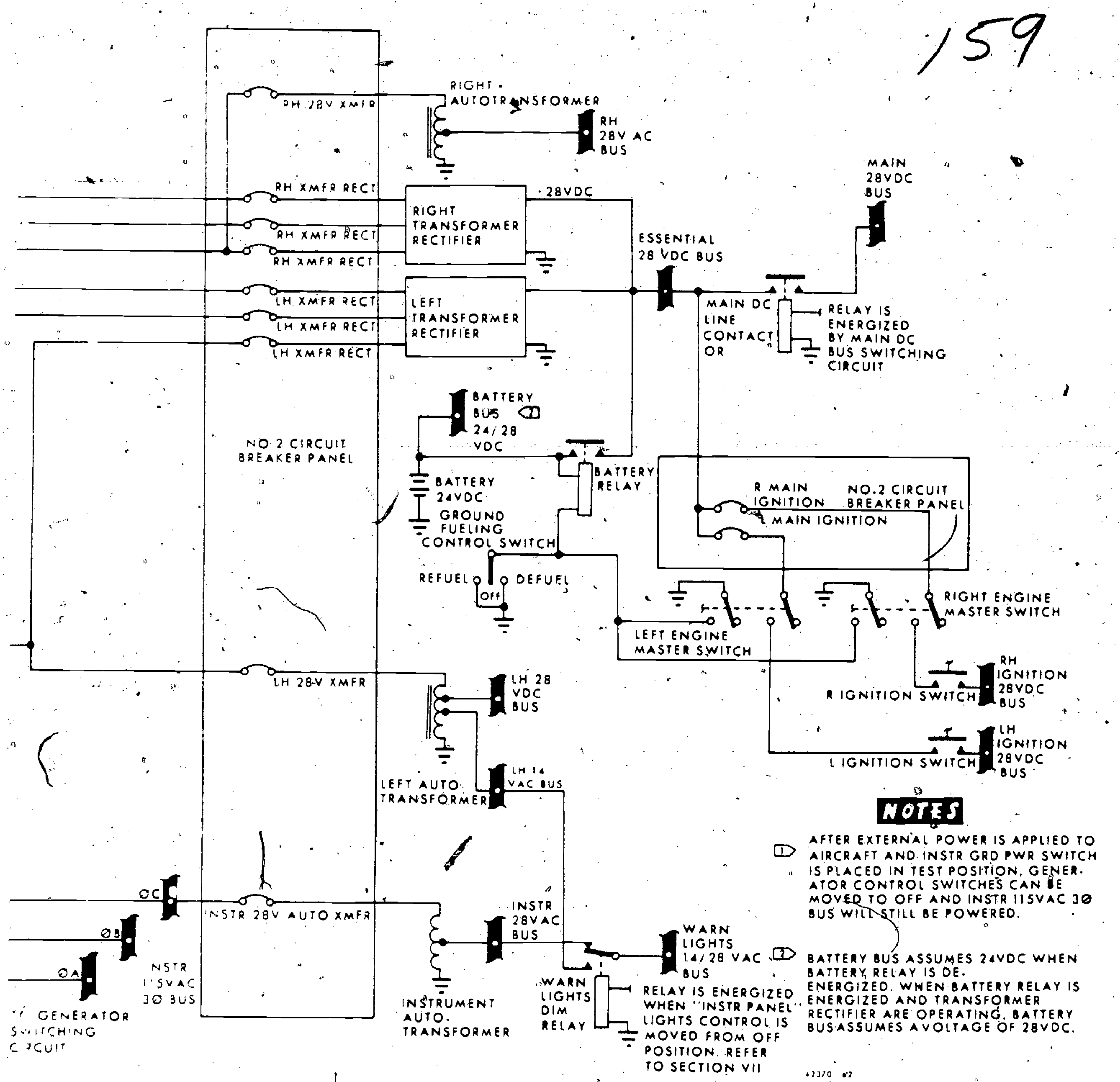
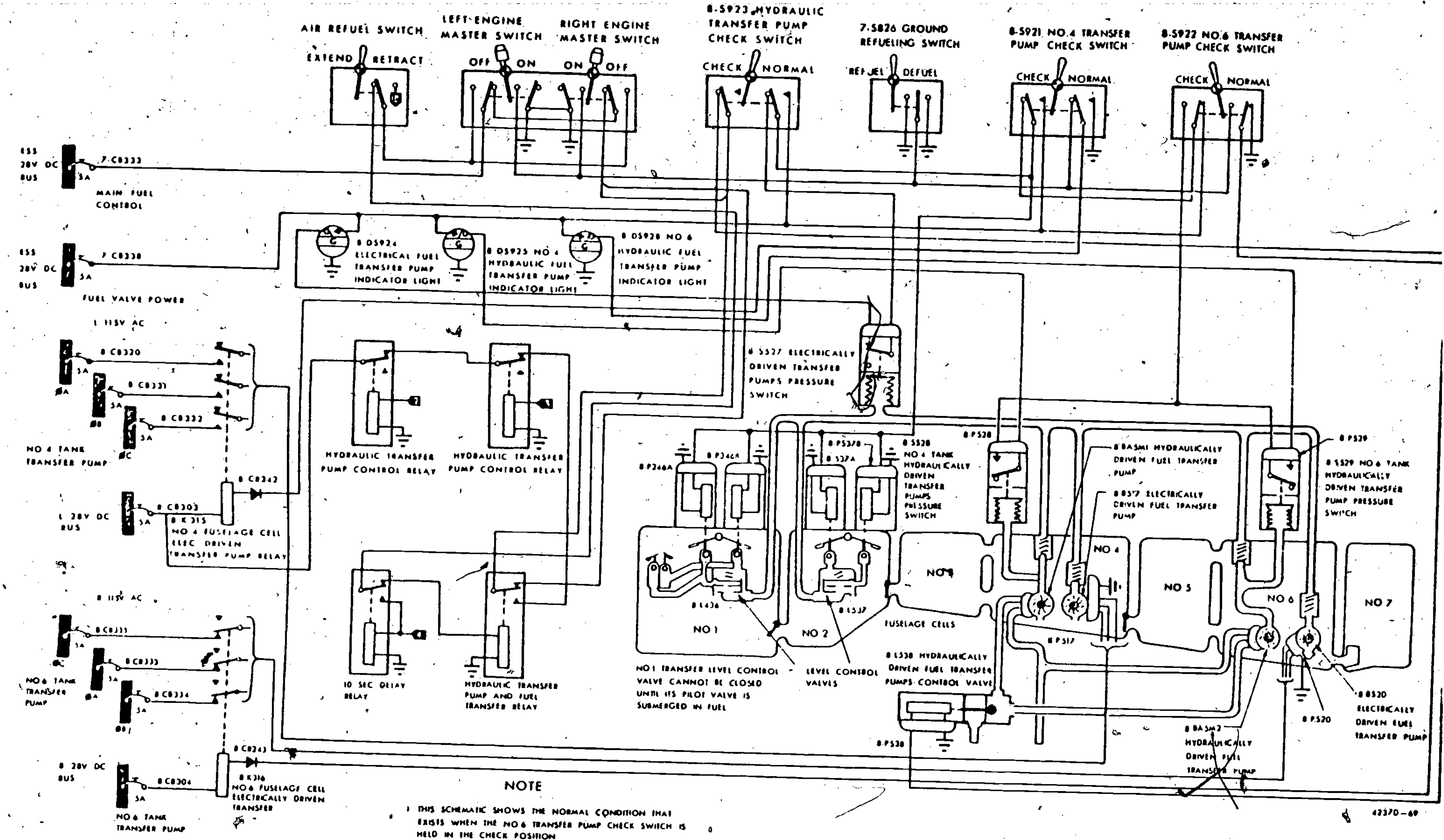


NOTES

1. AFTER EXTERNAL POWER IS APPLIED TO AIRCRAFT AND INSTR GRD PWR SWITCH IS PLACED IN TEST POSITION, GENERATOR CONTROL SWITCHES CAN BE MOVED TO OFF AND INSTR 115VAC 3Ø BUS WILL STILL BE POWERED.

2. BATTERY BUS ASSUMES 24VDC WHEN BATTERY RELAY IS DE-ENERGIZED. WHEN BATTERY RELAY IS ENERGIZED AND TRANSFORMER RECTIFIER ARE OPERATING, BATTERY BUS ASSUMES A VOLTAGE OF 28VDC.

Foldout 14. Bus control circuit.



NOTE

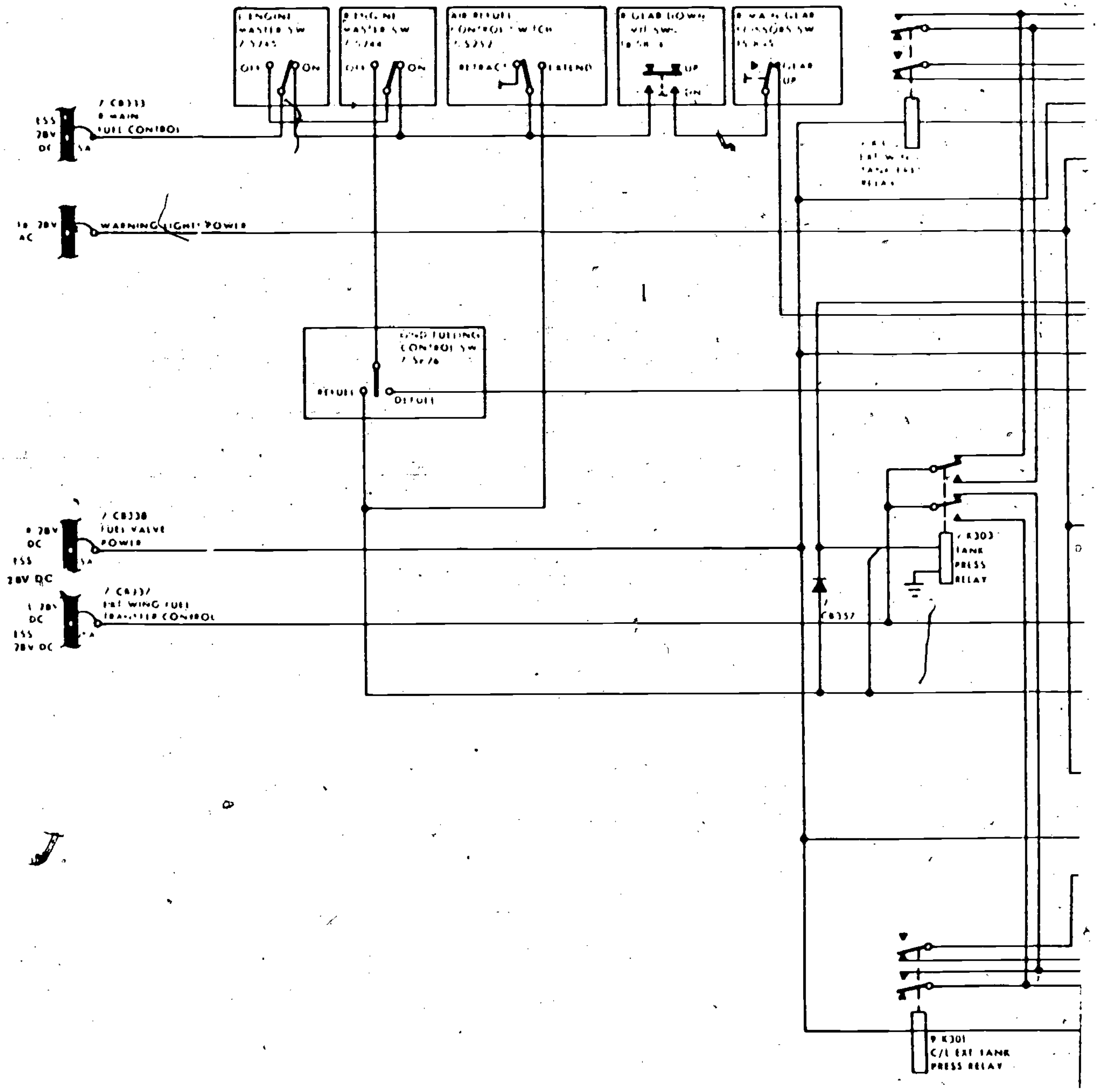
1 THIS SCHEMATIC SHOWS THE NORMAL CONDITION THAT EXISTS WHEN THE NO 6 TRANSFER PUMP CHECK SWITCH IS HELD IN THE CHECK POSITION

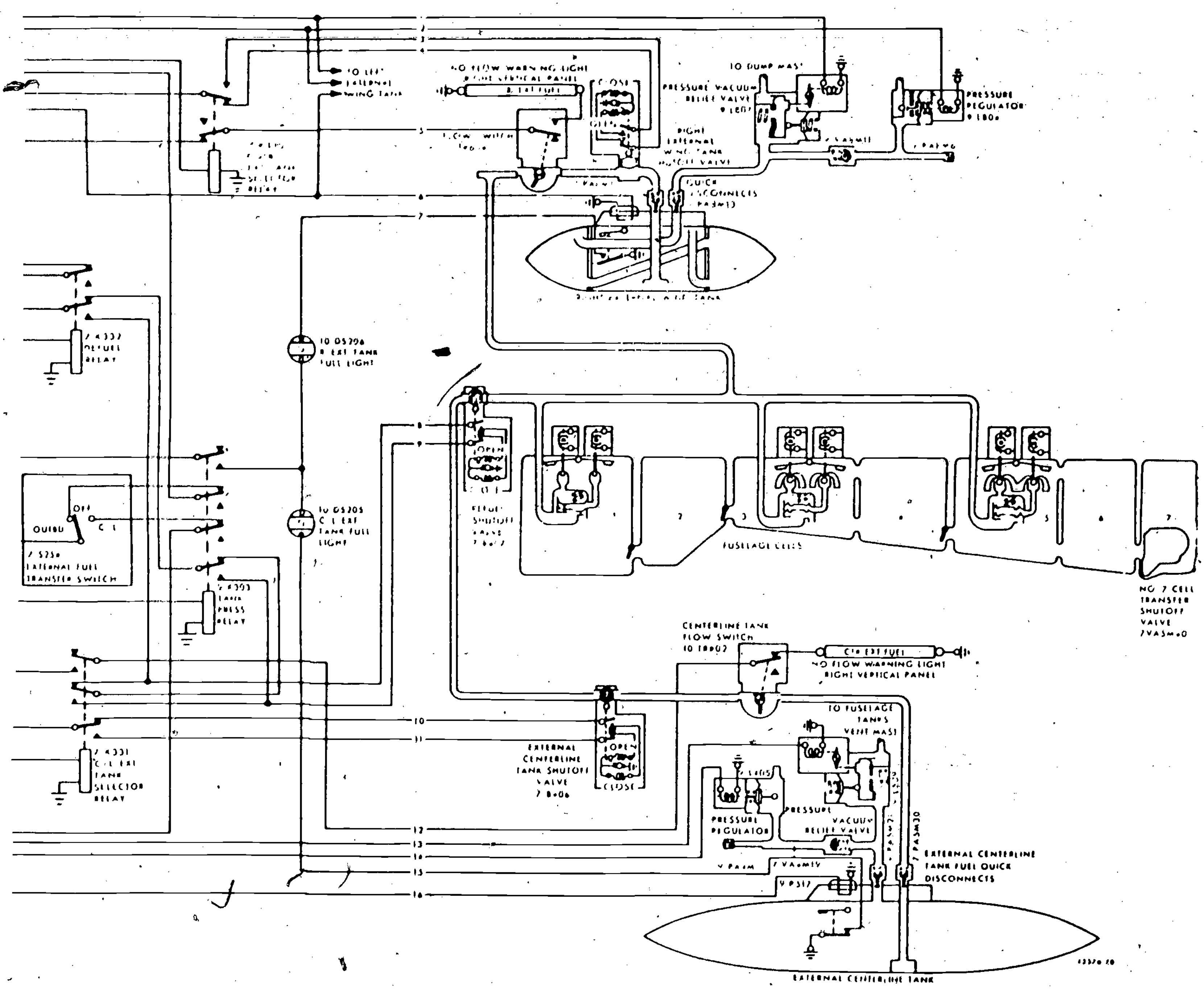
2 ENERGIZED BY THE LEFT ENGINE AFTERBURNER IGNITION SWITCH

2 ENERGIZED BY THE RIGHT ENGINE AFTERBURNER IGNITION SWITCH

3 ENERGIZED WHEN THE FUEL LEVEL DROPS TO 1800 POUNDS IN FUSELAGE CELLS ONE AND TWO

Foldout 15. Fuselage fuel supply system schematic.


L ENGINE MASTER SW / S745
OFF
ON
R ENGINE MASTER SW / S744
OFF
ON
AIR REFUEL CONTROL SWITCH / S257
RETRACT
EXTEND
R GEAR DOWN ... SW
UP
DN
R MAIN GEAR SCISSORS SW
GEAR UP
ESS 28V DC
/ CB333 R MAIN FUEL CONTROL
5A
28V AC
WARNING LIGHT POWER
GND FUELING CONTROL SW / S276
REFUEL
DEFUEL
EXT WING TANK ... RELAY
R 28V DC
ESS 28V DC
/ CB338 FUEL VALVE POWER
5A
L 28V DC
ESS 28V DC
/ CB337 EXT WING FUEL TRANSFER CONTROL
/ K303 TANK PRESS RELAY
CB357
R K301 C/L EXT TANK PRESS RELAY



Foldout 16. External fuel supply system schematic.

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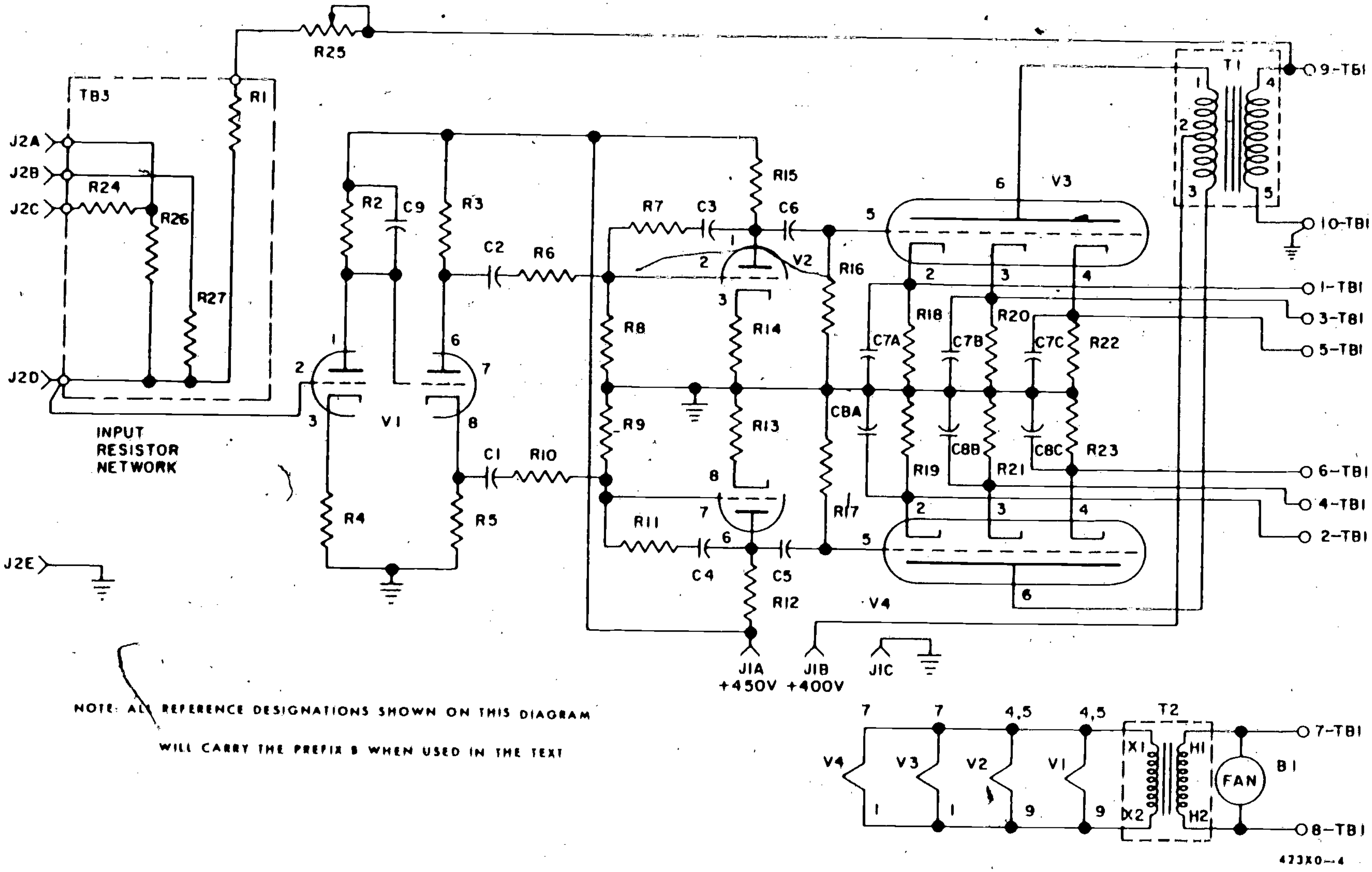
MODIFICATIONS

Pages 1 - 12 of this publication has (have) been deleted in adapting this material for inclusion in the "Trial Implementation of a Model System to Provide Military Curriculum Materials for Use in Vocational and Technical Education." Deleted material involves extensive use of military forms, procedures, systems, etc. and was not considered appropriate for use in vocational and technical education.



NOTE: ALL REFERENCE DESIGNATIONS SHOWN ON THIS DIAGRAM WILL CARRY THE PREFIX B WHEN USED IN THE TEXT

Figure 15. Power amplifier.

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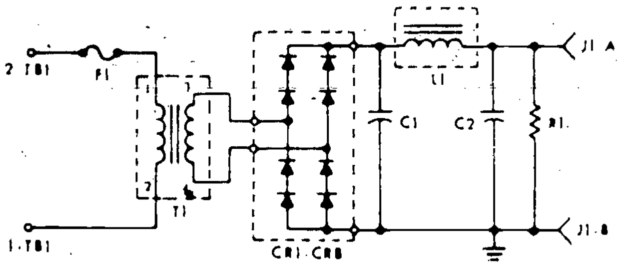
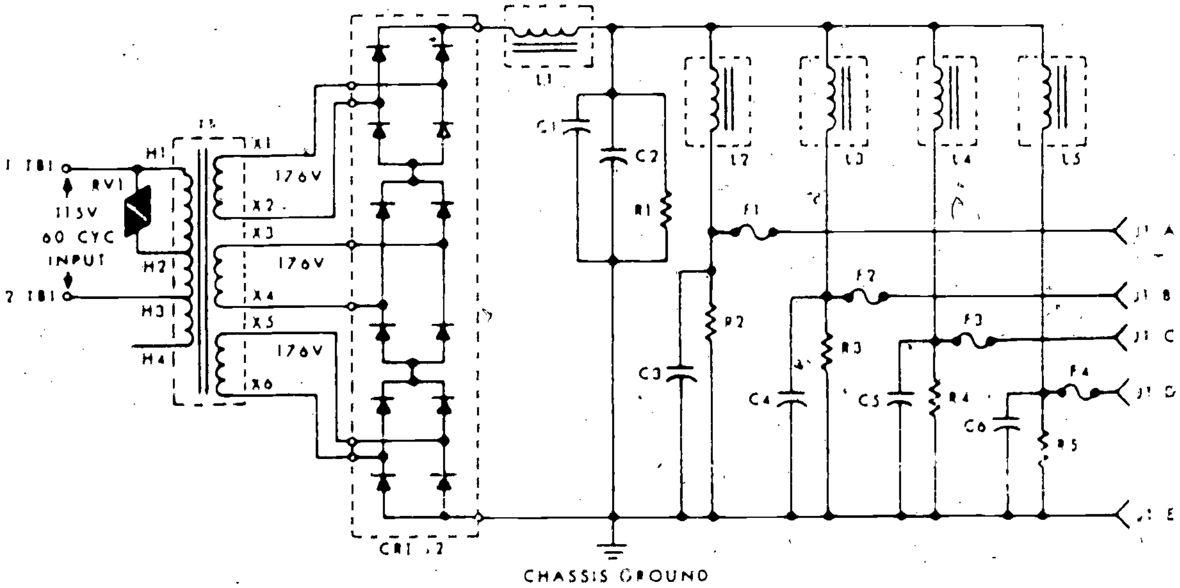


NOTE: ALL REFERENCE DESIGNATIONS SHOWN ON THIS DIAGRAM WILL CARRY THE PREFIX C WHEN USED IN THE TEXT

423X0-5

Figure 16. Preamplifier power supply.

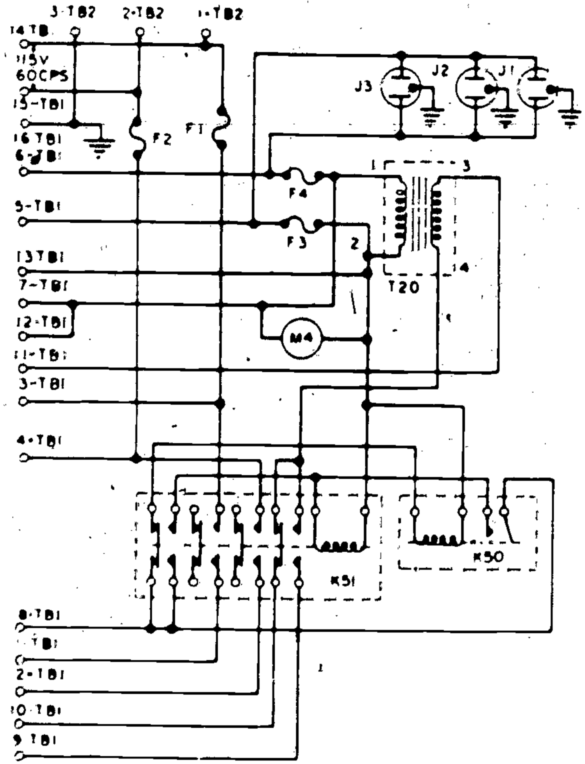


NOTE: ALL REFERENCE DESIGNATIONS SHOWN ON THIS DIAGRAM WILL CARRY THE PREFIX [illegible] WHEN USED IN THE TEXT

423X0-6

Figure 17. DC power supply for output amplifier.

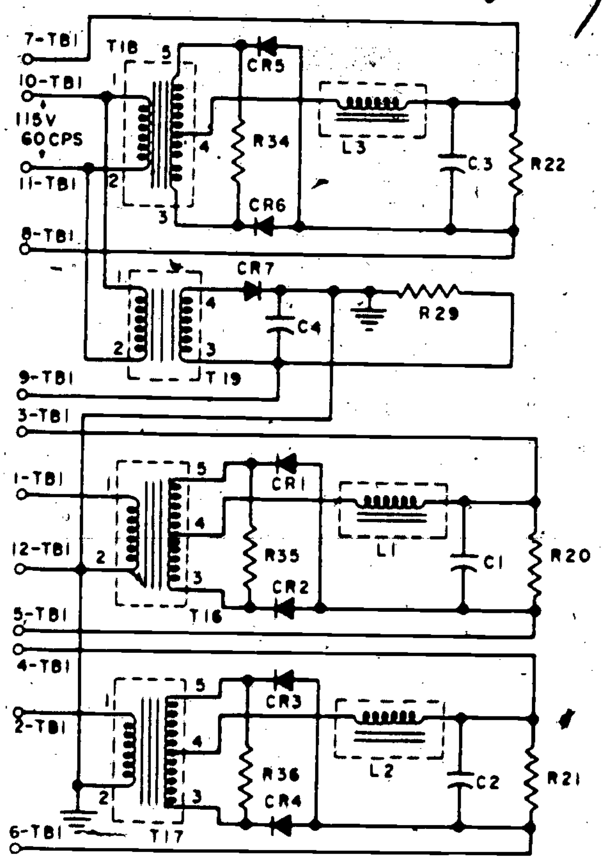
150



NOTE ALL REFERENCE DESIGNATIONS SHOWN ON THIS DIAGRAM WILL CARRY THE PREFIX E WHEN USED IN THE TEXT

473X0 8

Figure 18. Power distribution unit.



NOTE: ALL REFERENCE DESIGNATIONS SHOWN ON THIS DIAGRAM WILL CARRY THE PREFIX 'J' WHEN USED IN THE TEXT.

423X0-7

Figure 19. Control dc power supplies.

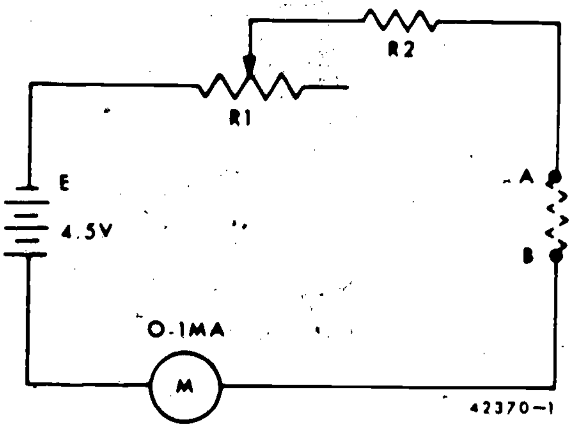


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Figure 20. Series type Ohmmeter.

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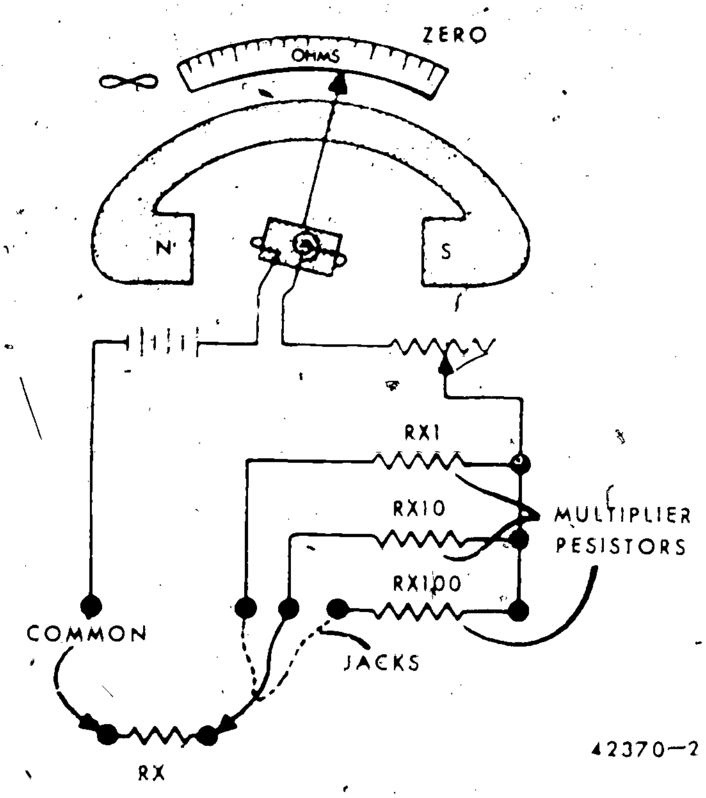

Figure 21. Ohmmeter with jacks.

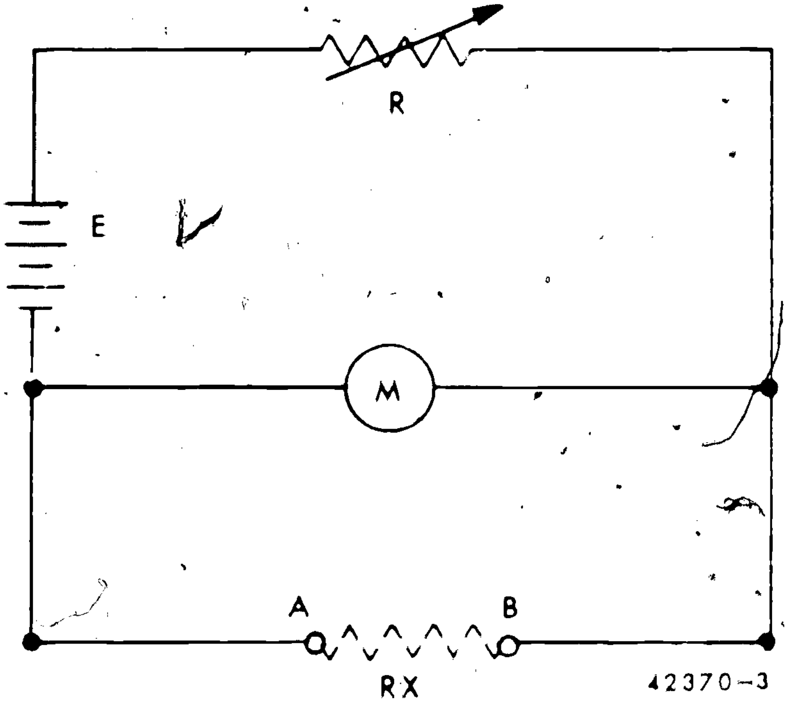

Figure 22. Shunt type ohmmeter

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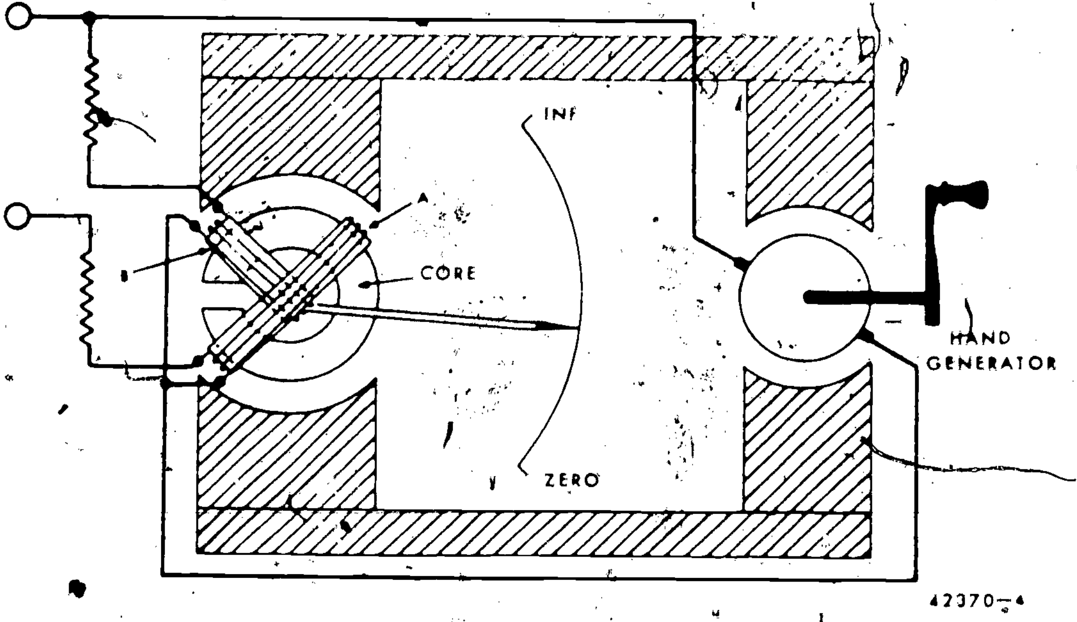


A. CURRENT COIL B. POTENTIAL COIL

Figure 23. Megger mechanism.

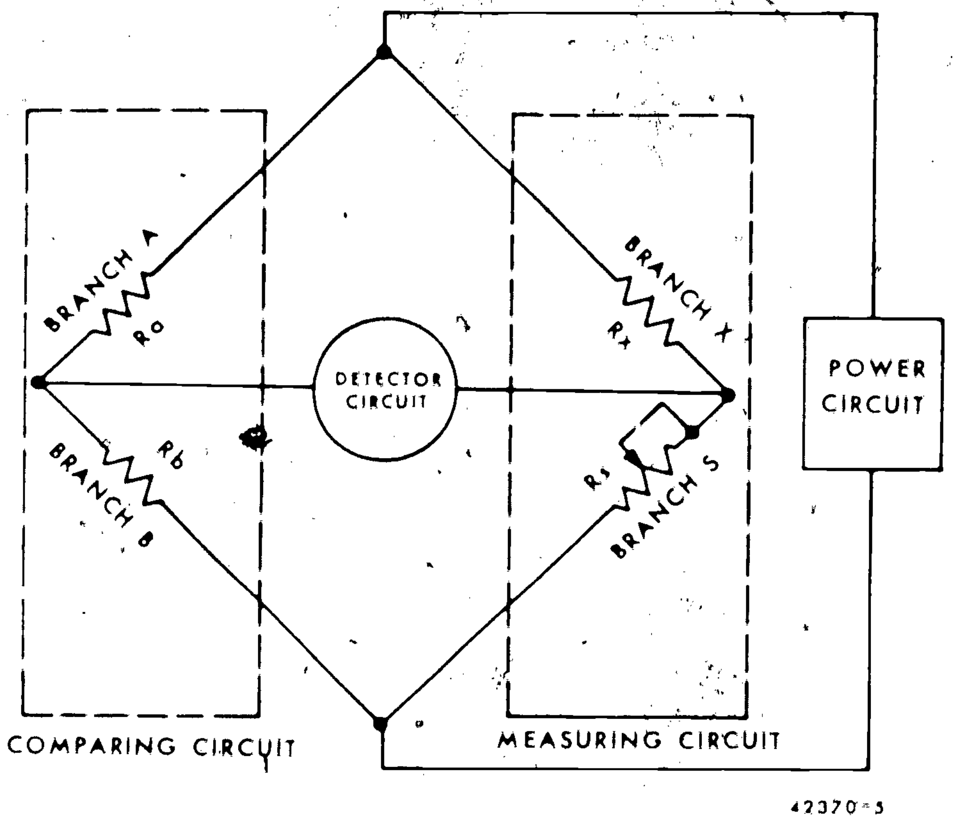
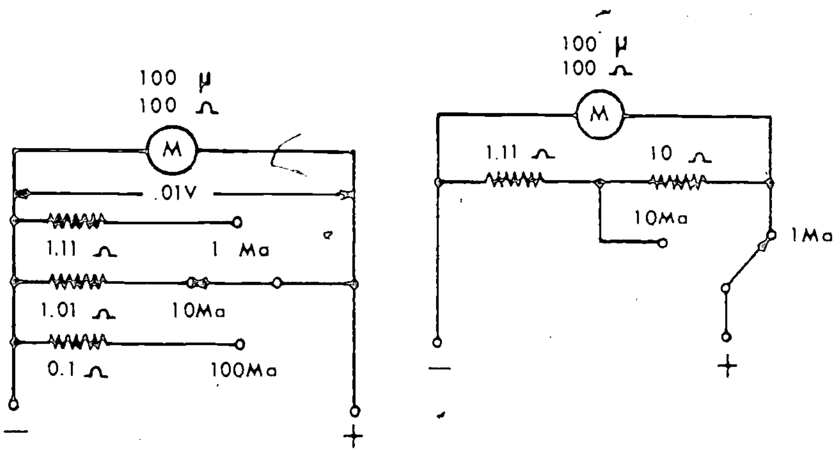


Figure 24 Wheatstone bridge.



SIMPLE ARRANGEMENT
(A)

PREFERRED ARRANGEMENT
(B)

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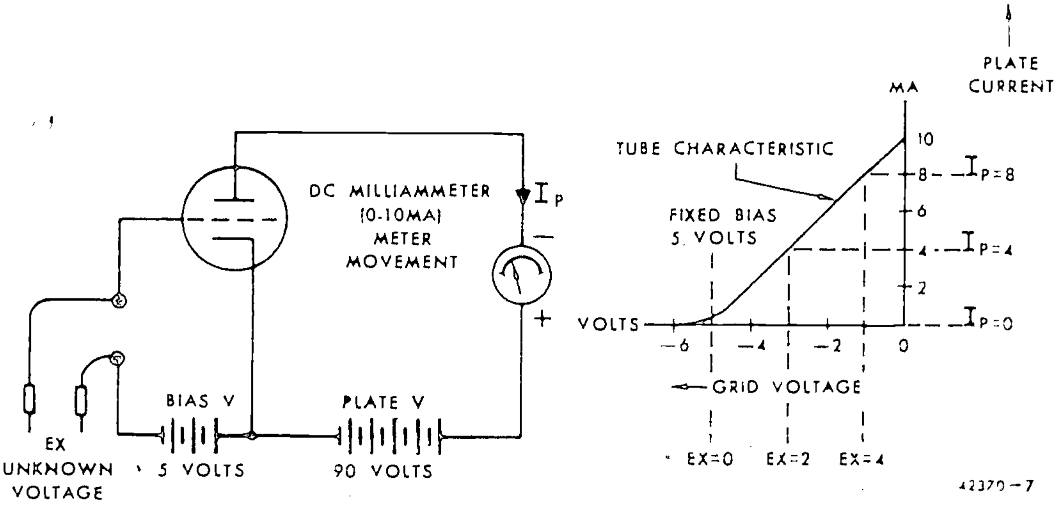
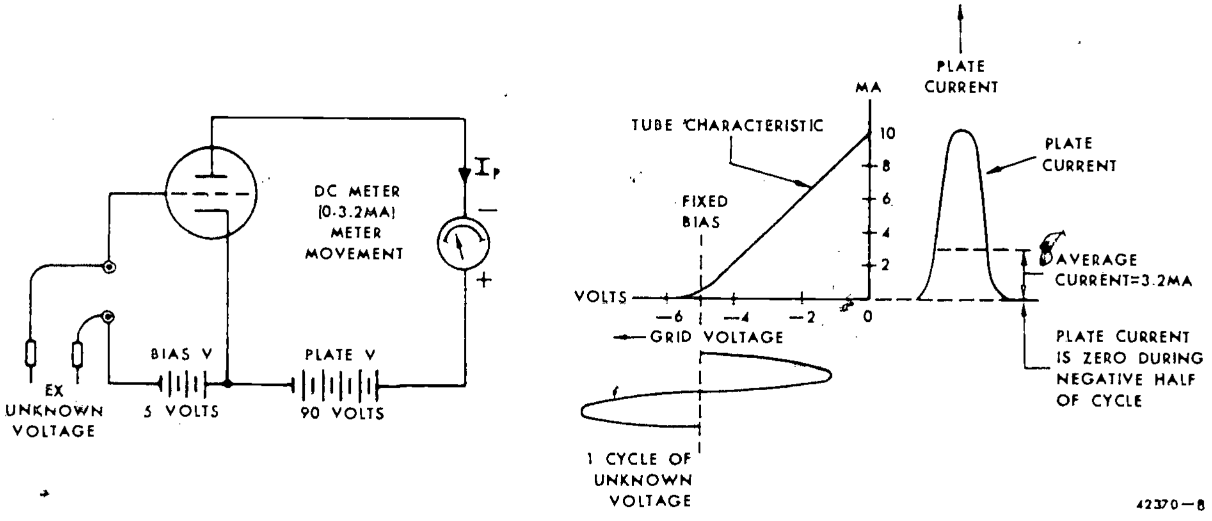
Figure 25. Ways of connecting internal shunts.



SIMPLE DC
VACUUM-TUBE VOLTMETER

PLATE-CURRENT
GRID-VOLTAGE CURVE

Figure 26. DC VTVM circuit.



SIMPLE AC
VACUUM-TUBE VOLTMETER

PLATE-CURRENT
GRID-VOLTAGE CURVE

Figure 27. AC VTVM circuit.

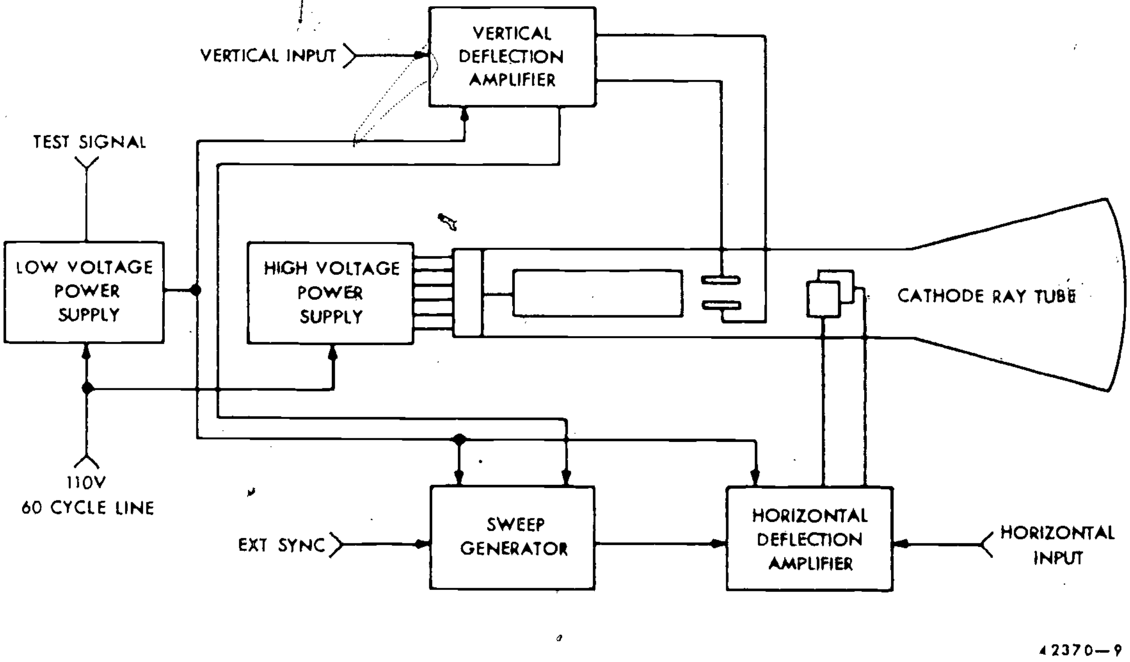


Figure 28. Oscilloscope.

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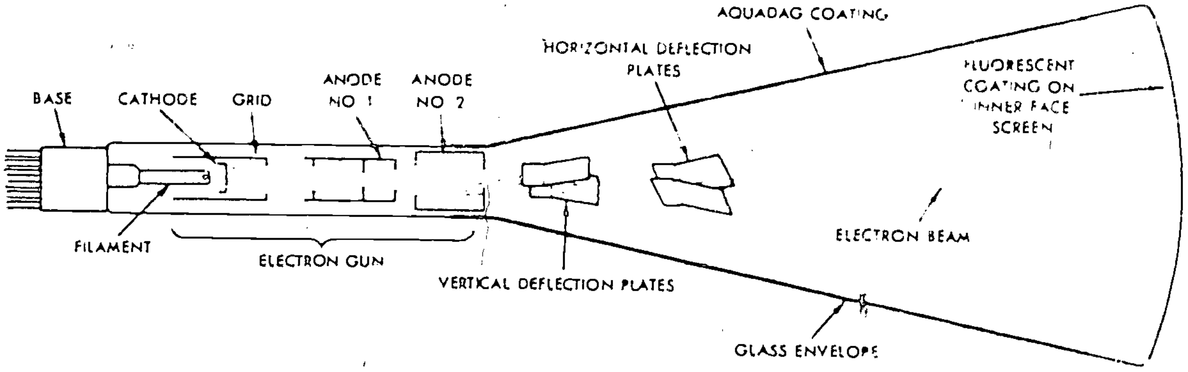


Figure 29. Cathode-ray tube.

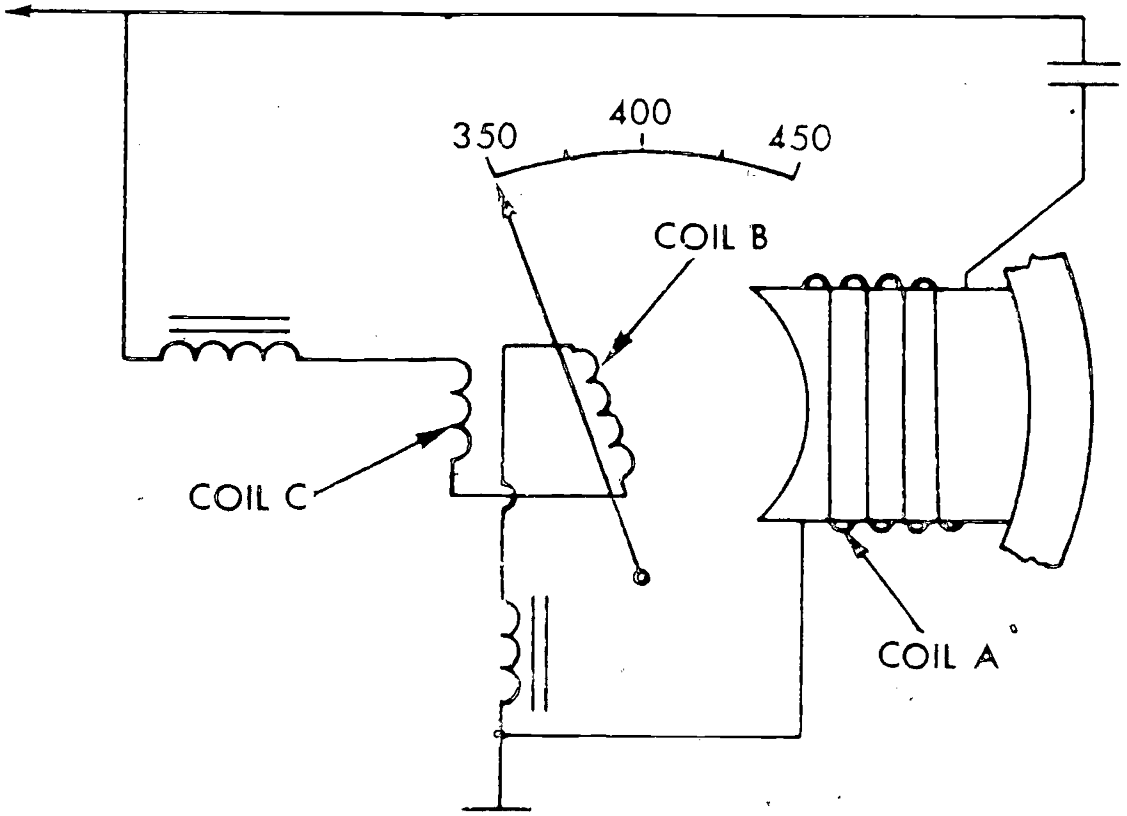
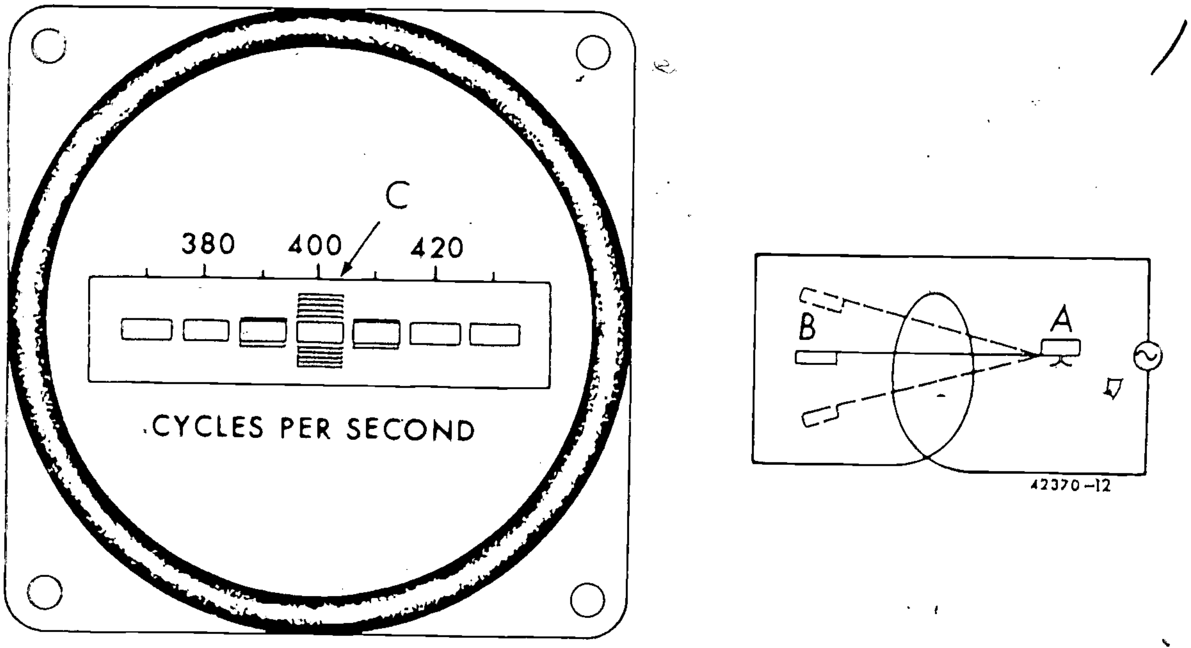


Figure 30. Dynamometer type frequency meter.



A. PLATE B. REED C. DIAL

Figure 31. Vibrating reed typd frequency meters.

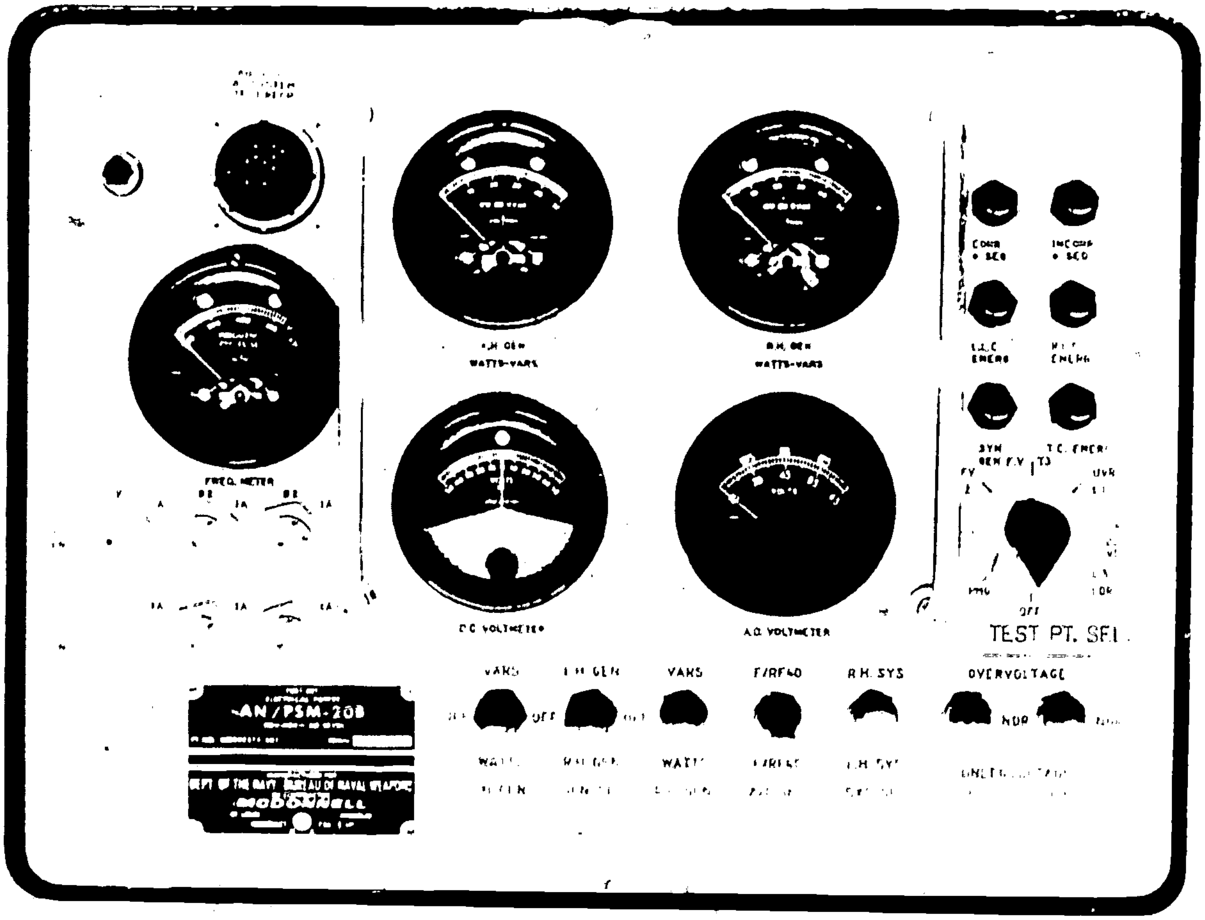


Figure 32. AN/PSM-20B tester (picture).

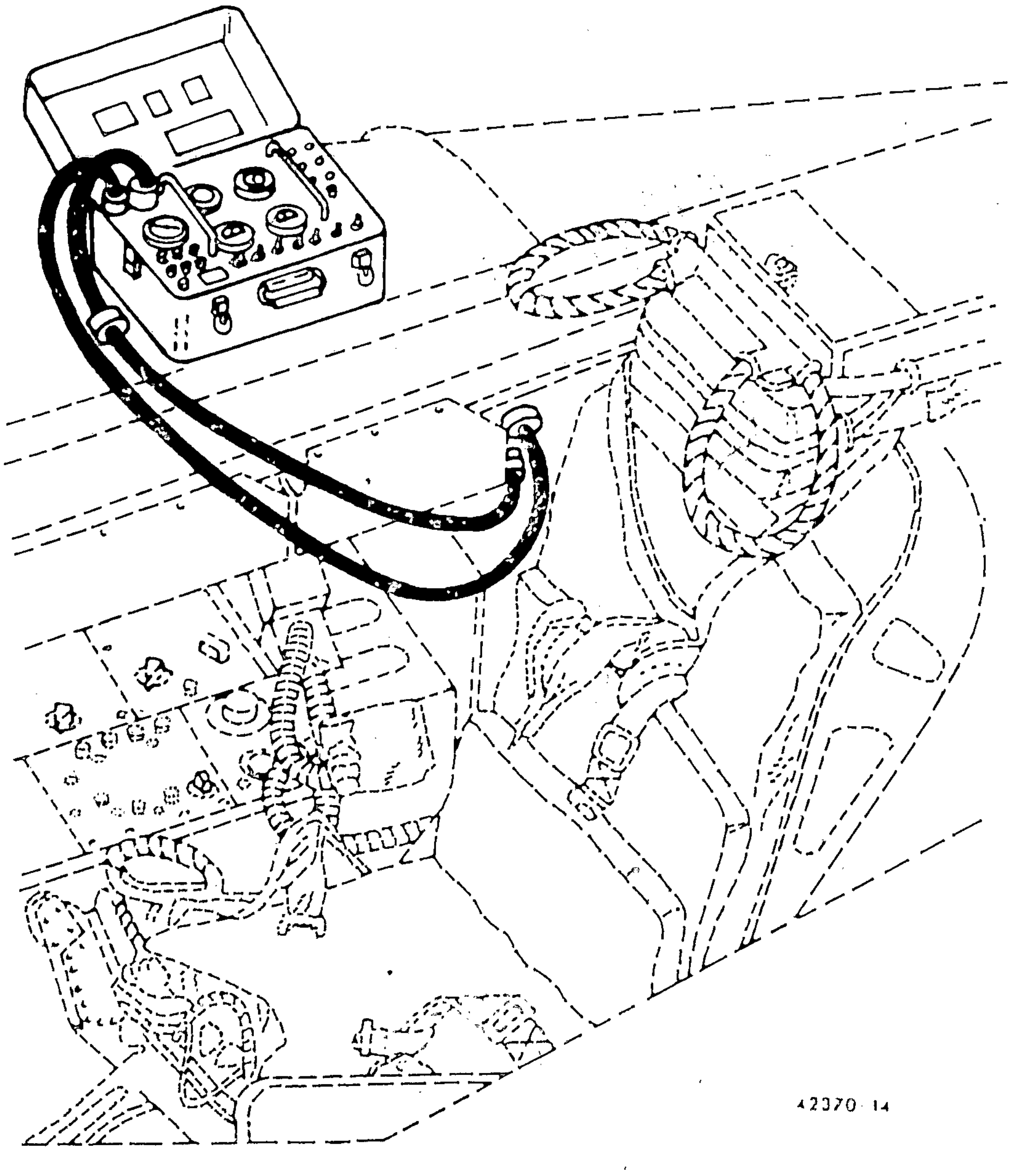


Figure 33. Test set hookup.

TEST EQUIPMENT

Generator power test set	AN/PSM-20A
Multimeter	AN/PSM-6
Vacuum tube voltmeter	HP410B
External electrical power source	200/115V /400 CPS, 3φ

MANPOWER REQUIREMENTS
Six men required

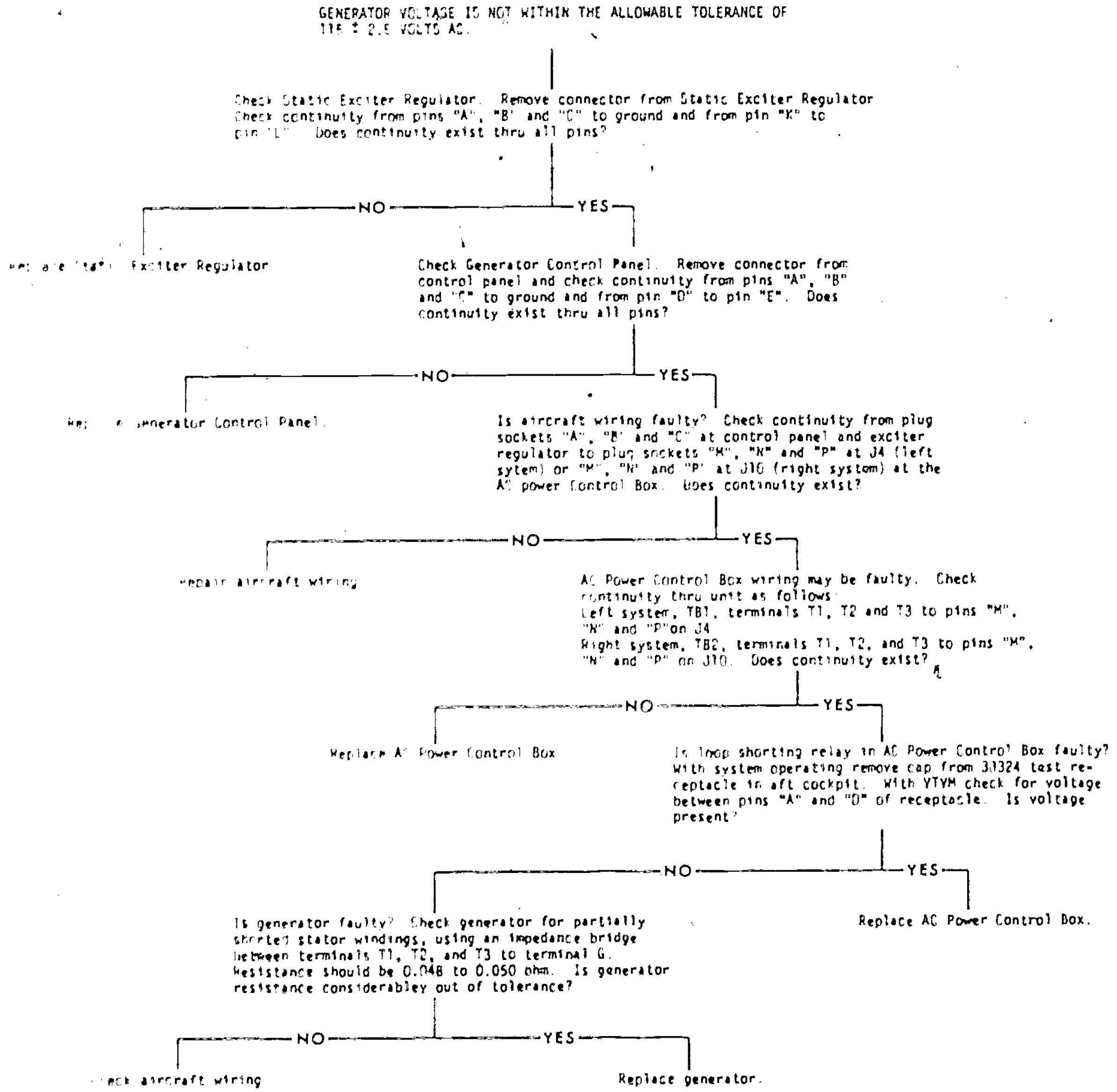


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Figure 34. Logic tree number 6.

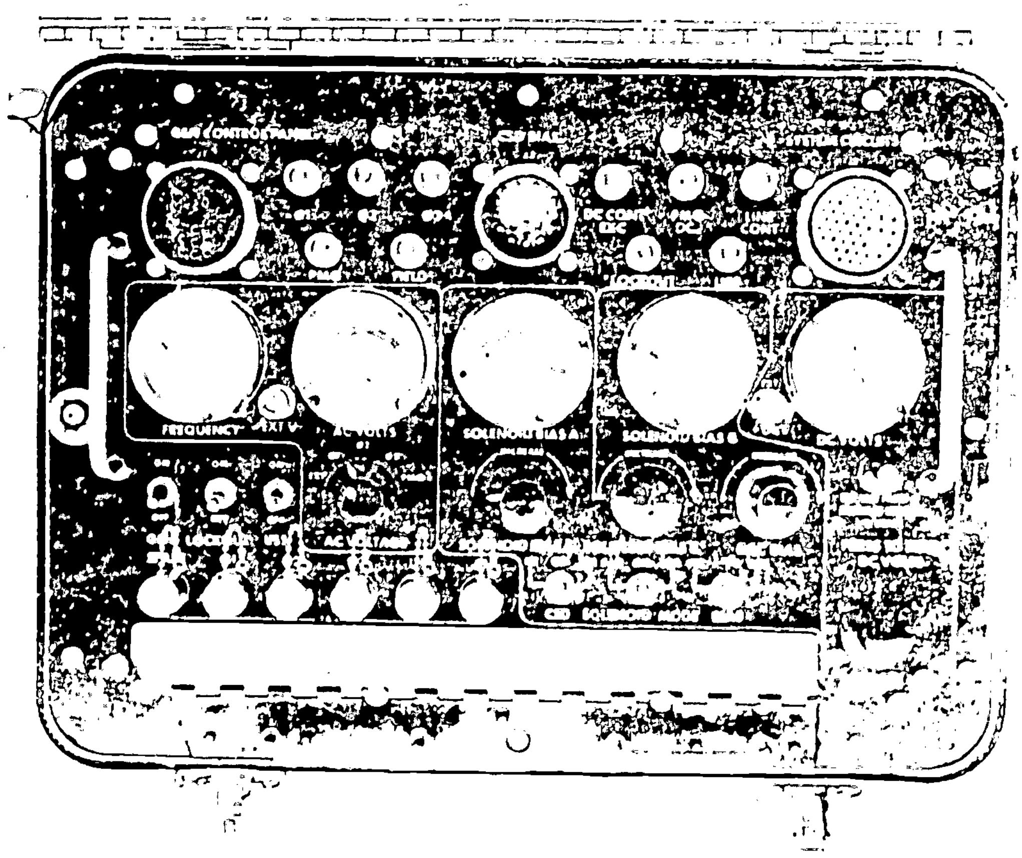

Figure 35. Electrical power test harness.

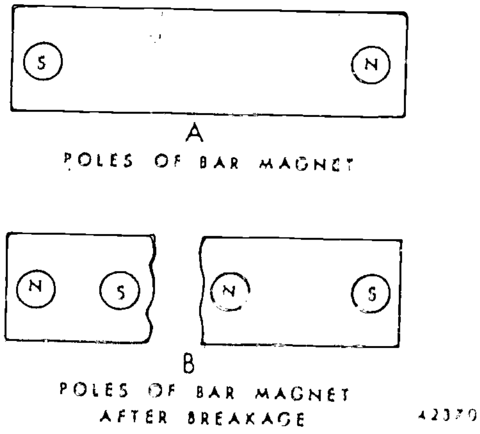

Figure 36. Poles of a bar magnet

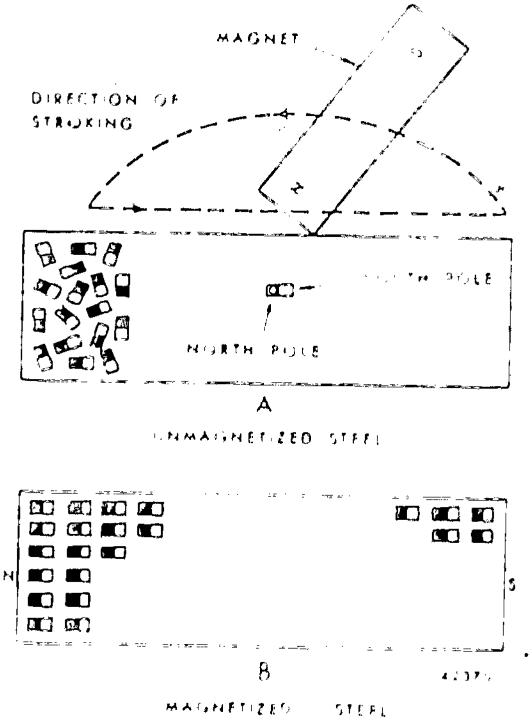

Figure 37. Magnetizing steel

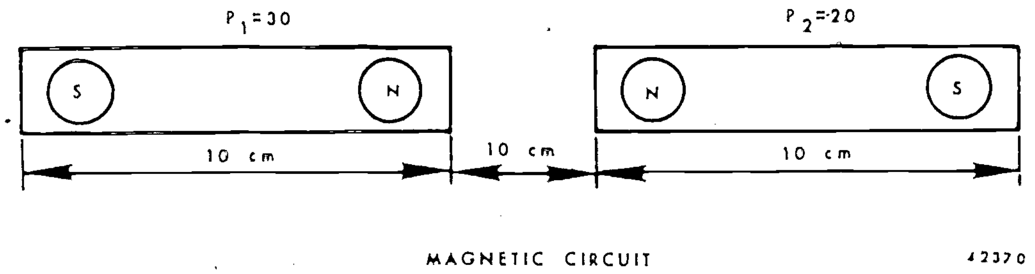

Figure 38. Magnetic circuit.

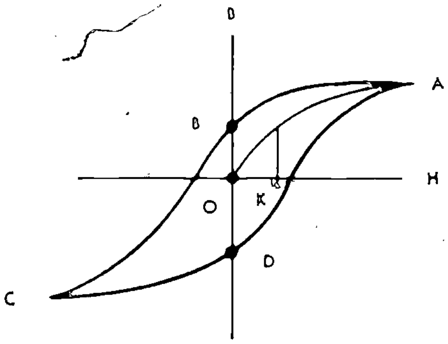

Figure 39. Typical B/H characteristic curve.

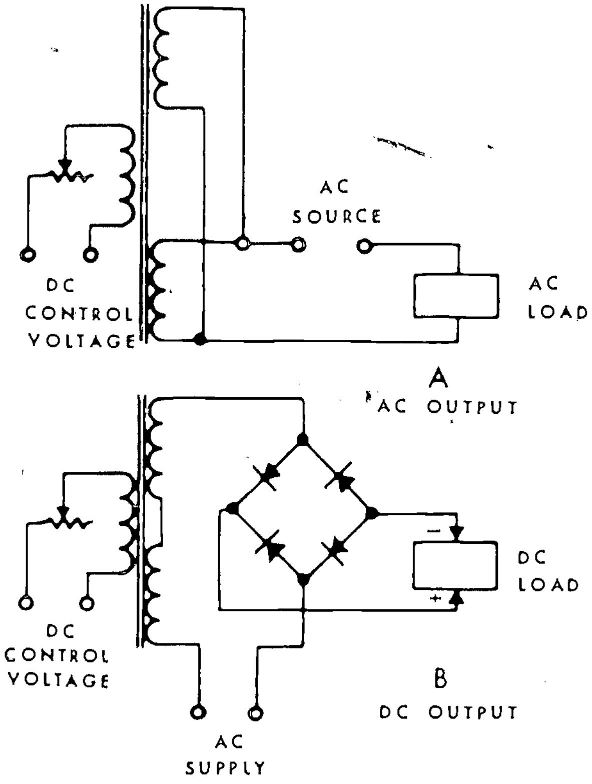

Figure 41. Magnetic amplifiers used for control of ac and dc loads.

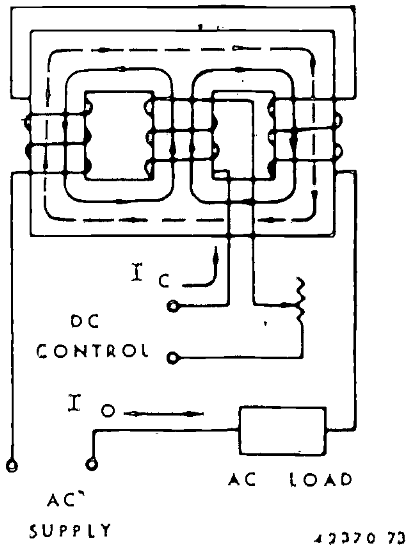

Figure 40. Basic magnetic amplifier.

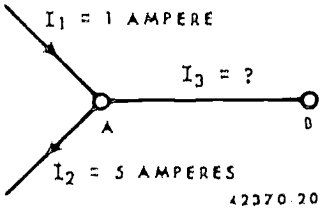

Figure 42. Example of Kirchhoff's first law.

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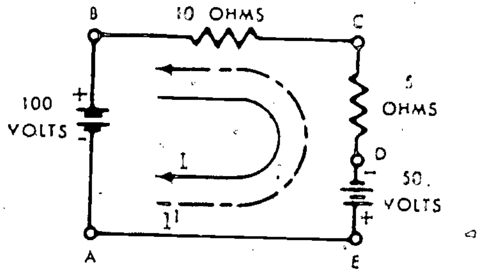


Figure 43. Example of Kirchhoff's second law.

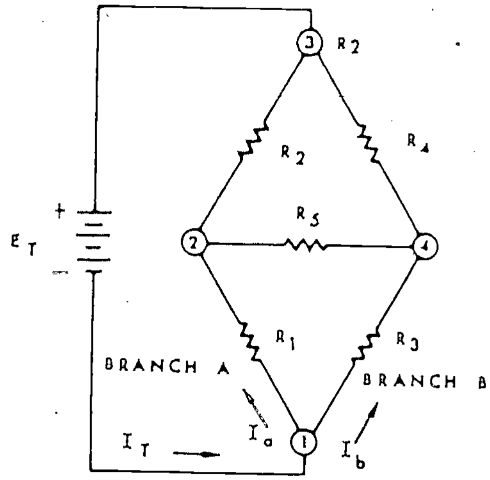


Figure 44. Resistive bridge circuit.

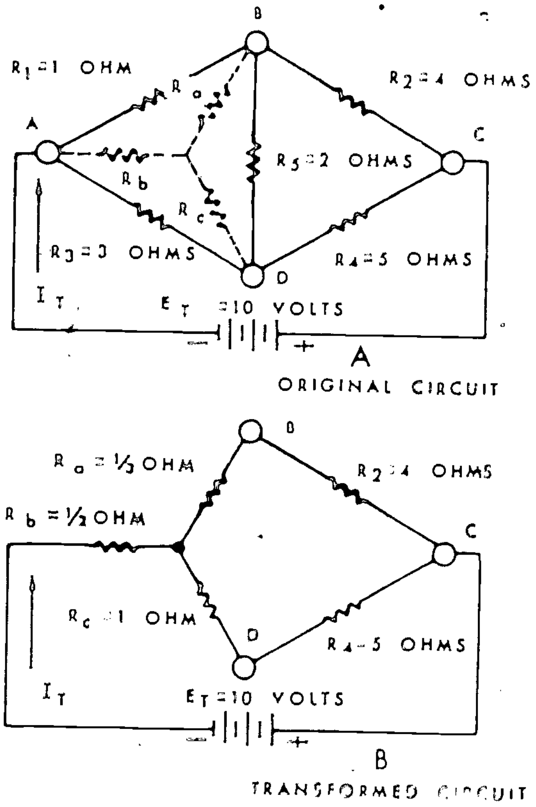


Figure 45. Bridge circuit No. 1 using delta-to-star transformation.

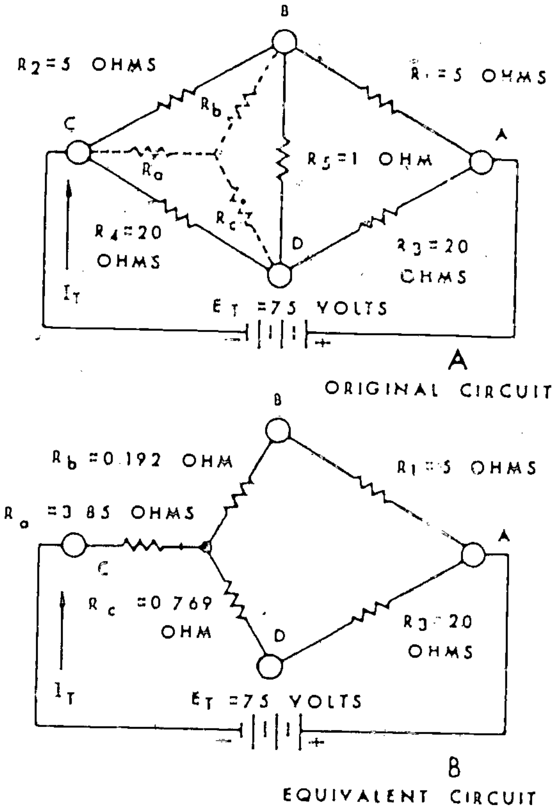


Figure 46. Bridge circuit No. 2 using delta-to-star transformation.

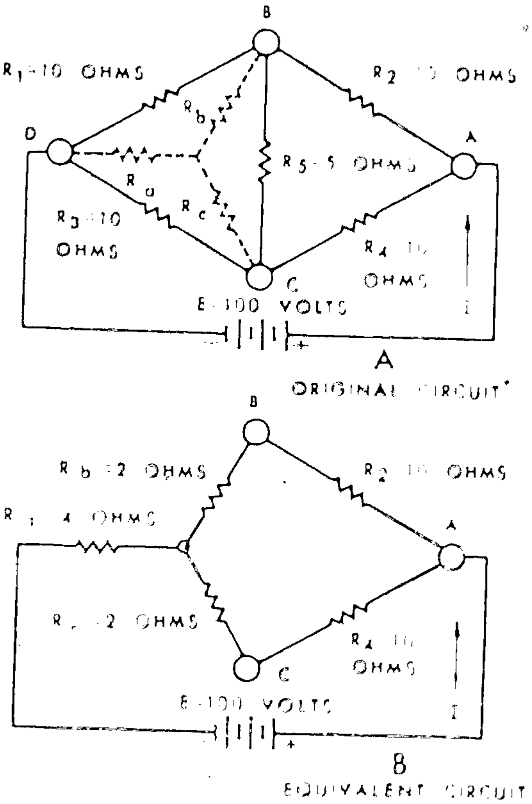


Figure 47. Balanced bridge circuit using delta-to-star transformation.

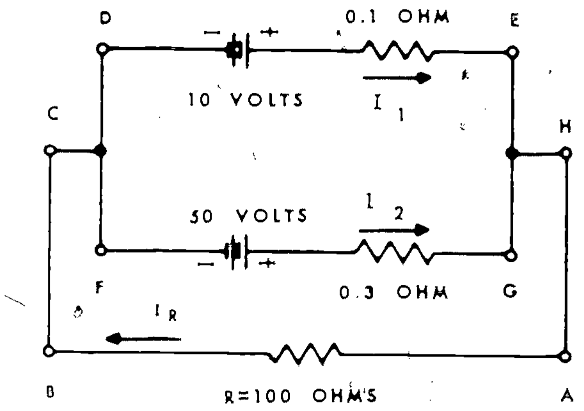
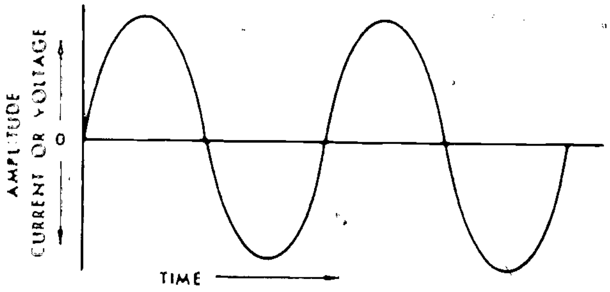


Figure 48. Simple mesh circuit.



SINE WAVEFORM

Figure 49. Alternating-current or voltage waveform

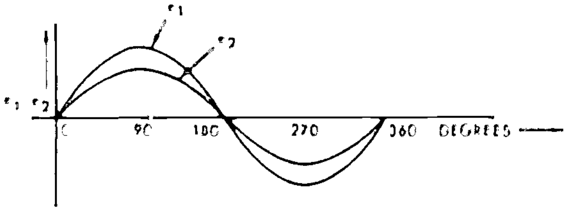
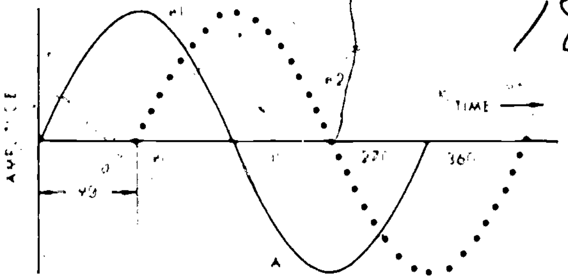
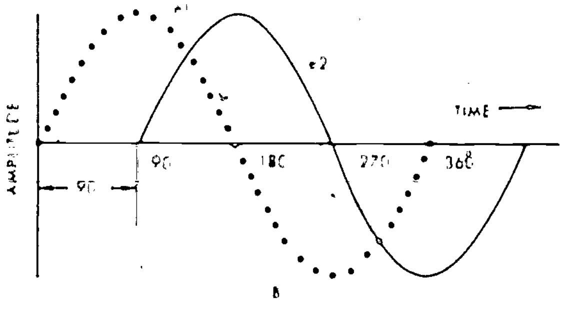


Figure 50 In-phase voltages

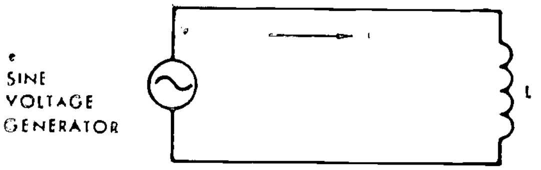


PHASE LAG



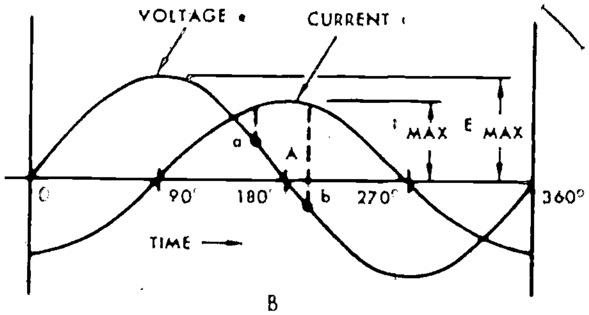
PHASE LEAD

Figure 51. Out-of-phase voltages.



A

ACTUAL CIRCUIT



B

PHASE RELATIONS

Figure 52. Phase relationships in inductive circuits.

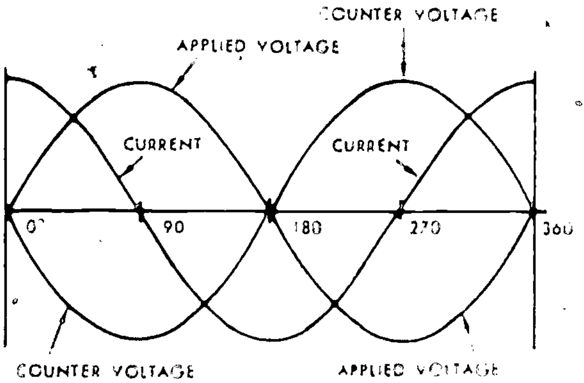


Figure 53. Relationships of current to applied and counter voltages.

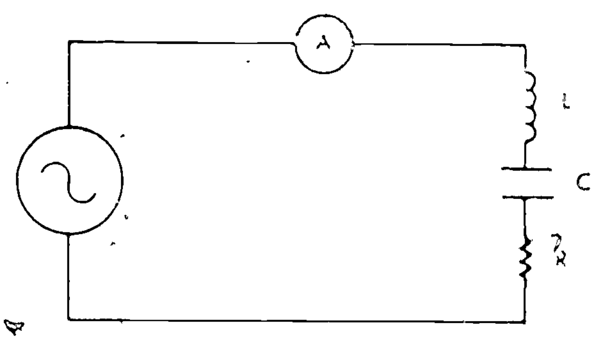


Figure 54. Series-tuned circuit.

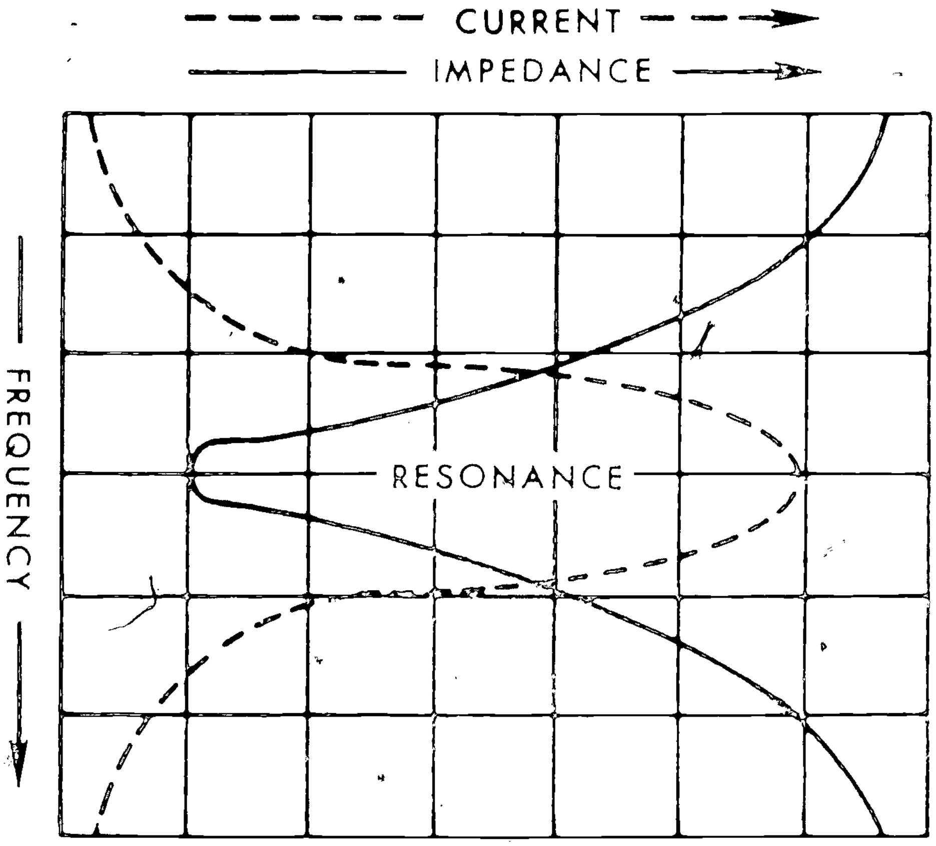


Figure 55. Impedance-current relationship in a series-tuned circuit.

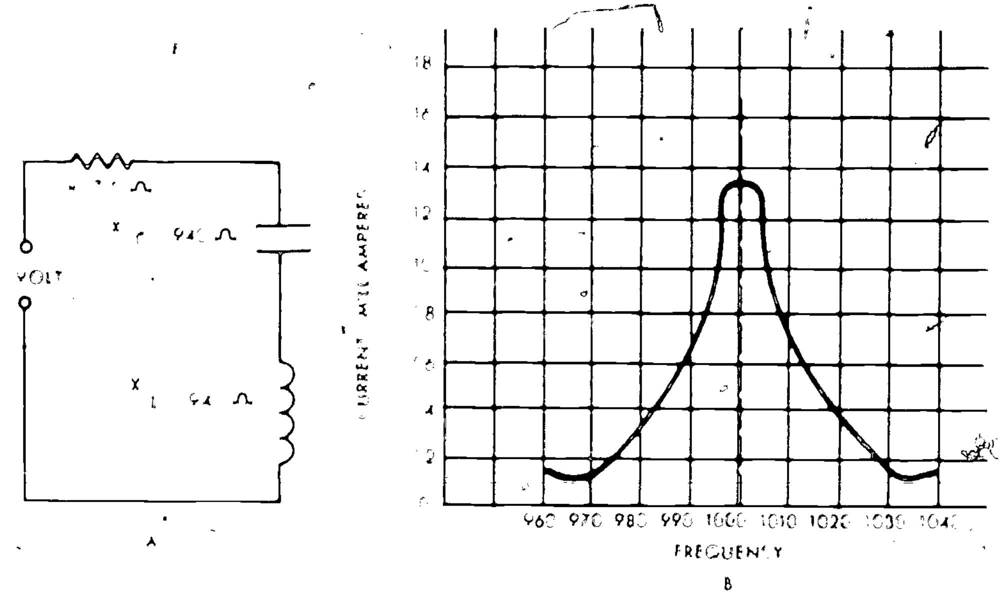


Figure 56. Series-resonant circuit.

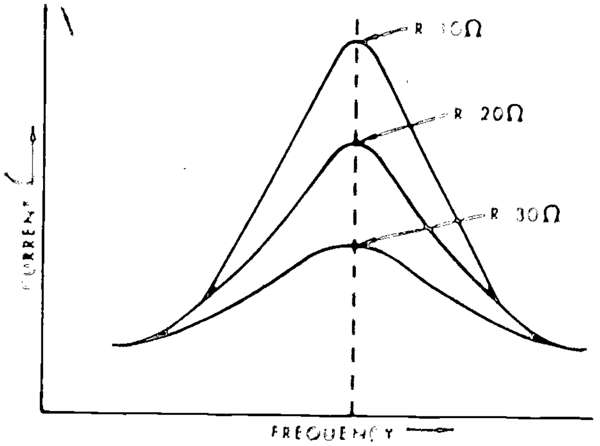


Figure 57. Resonance curves showing the effect of resistance.

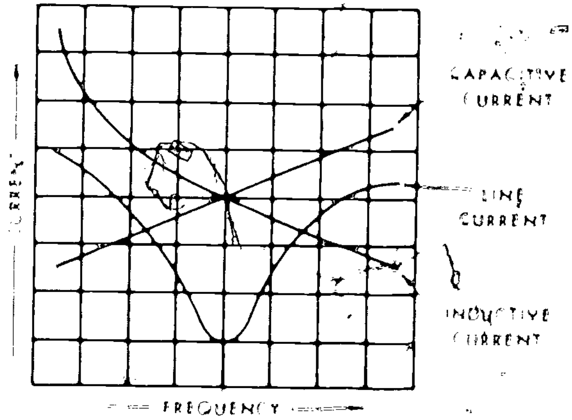


Figure 59. Current flow through branches of a parallel-tuned circuit.

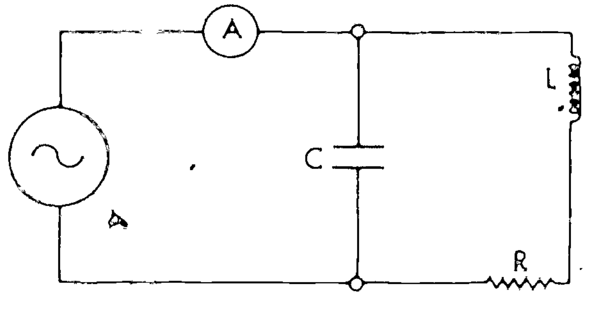


Figure 58. Parallel tuned circuits

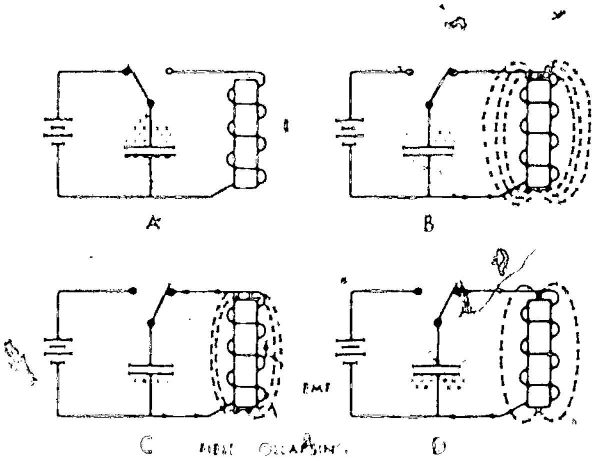


Figure 60. Operation of a tank circuit.

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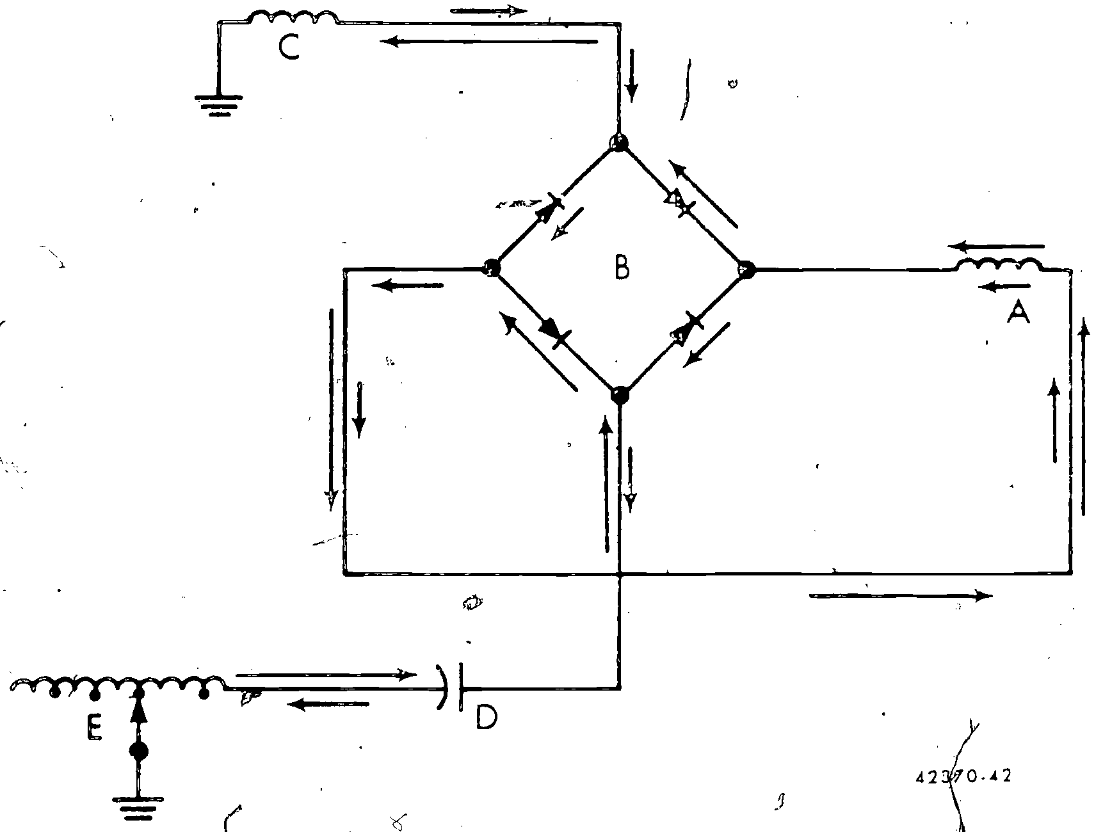

A. MOTOR CONTROL FIELD
B. RECTIFIER BRIDGE
C. VOLTAGE WINDING
D. FIXED CAPACITOR
E. VARIABLE INDUCTOR

Figure 61. Series-resonant speed control circuit.

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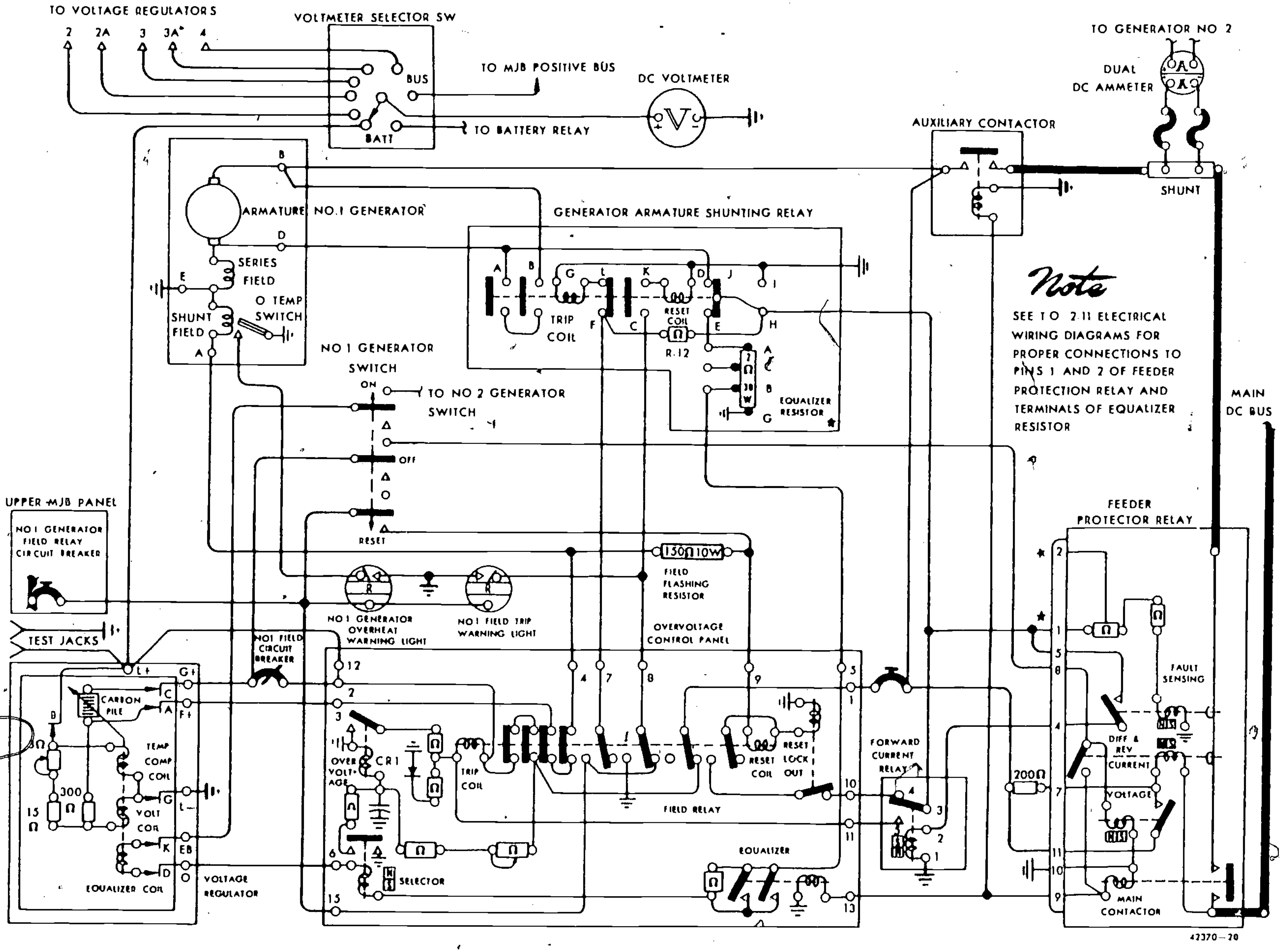

Note

SEE T O 2-11 ELECTRICAL WIRING DIAGRAMS FOR PROPER CONNECTIONS TO PINS 1 AND 2 OF FEEDER PROTECTION RELAY AND TERMINALS OF EQUALIZER RESISTOR

Figure 62. Direct-current generator circuit.

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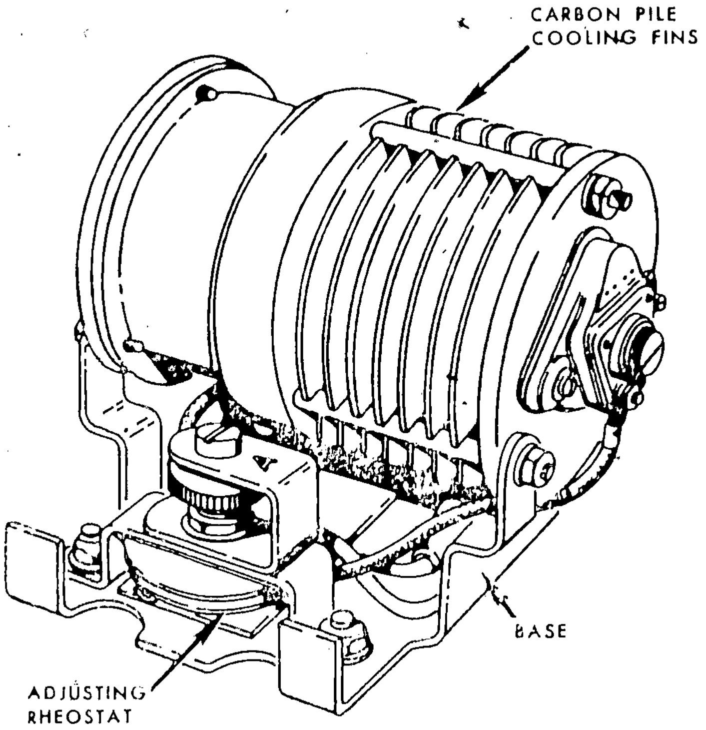
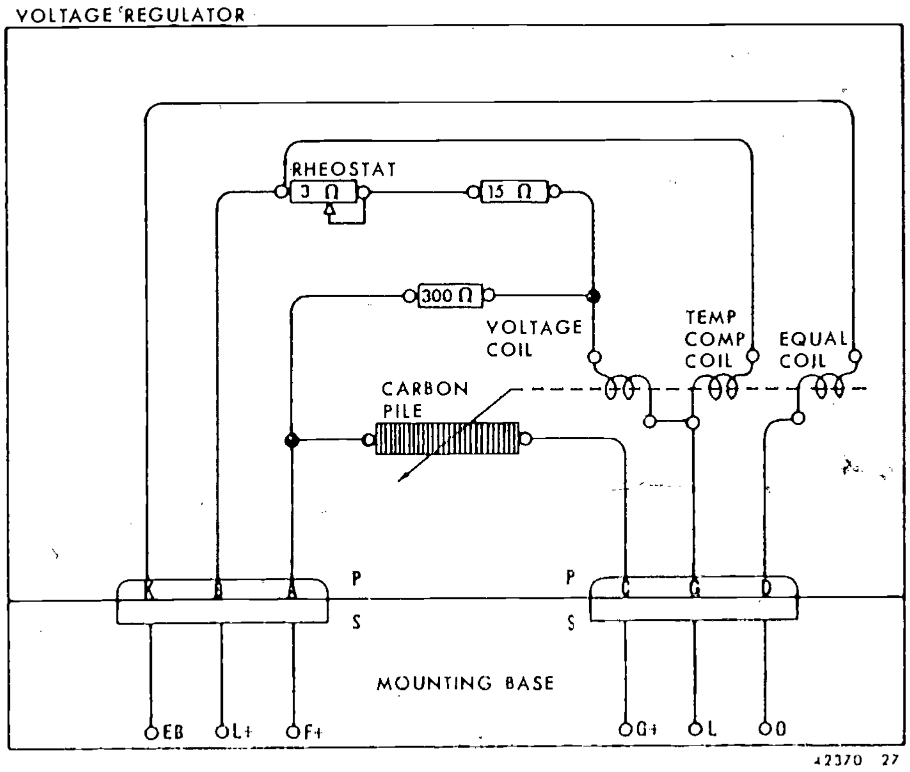


Note

ELECTRICAL CONNECTIONS TO REGULATOR ARE COMPLETE WHEN REGULATOR IS PLUGGED INTO MOUNTING BASE



ELECTRICAL SCHEMATIC

Figure 63. Direct-current voltage regulator.

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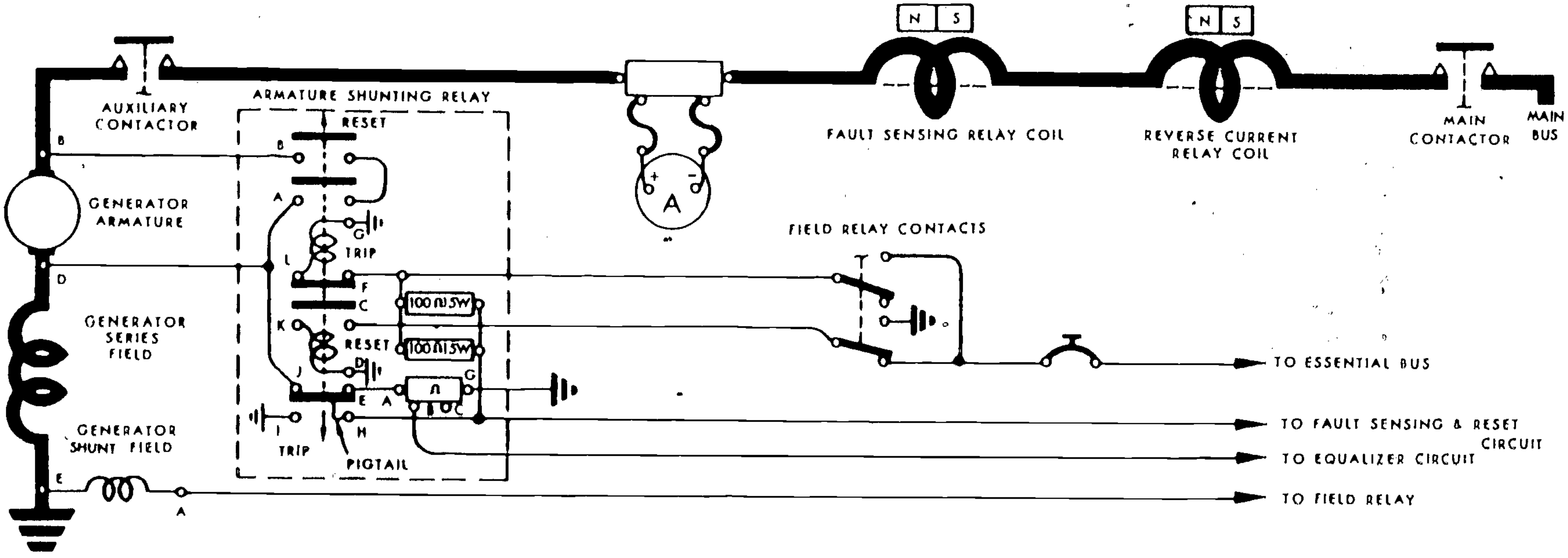

Figure 64. Armature shunting relay.

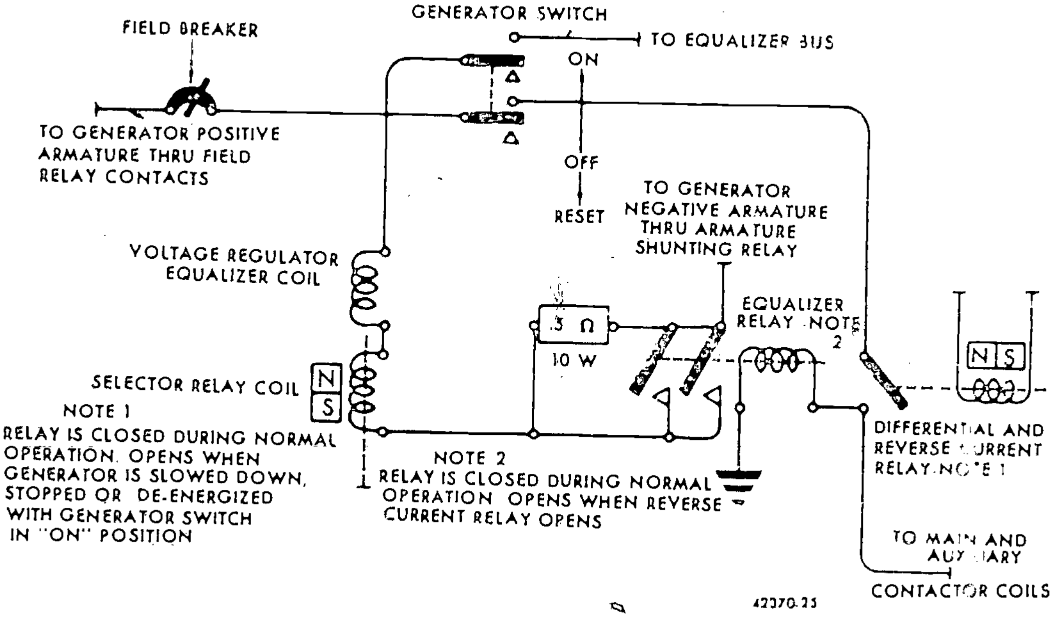

Figure 65. Generator undervoltage protection circuit.

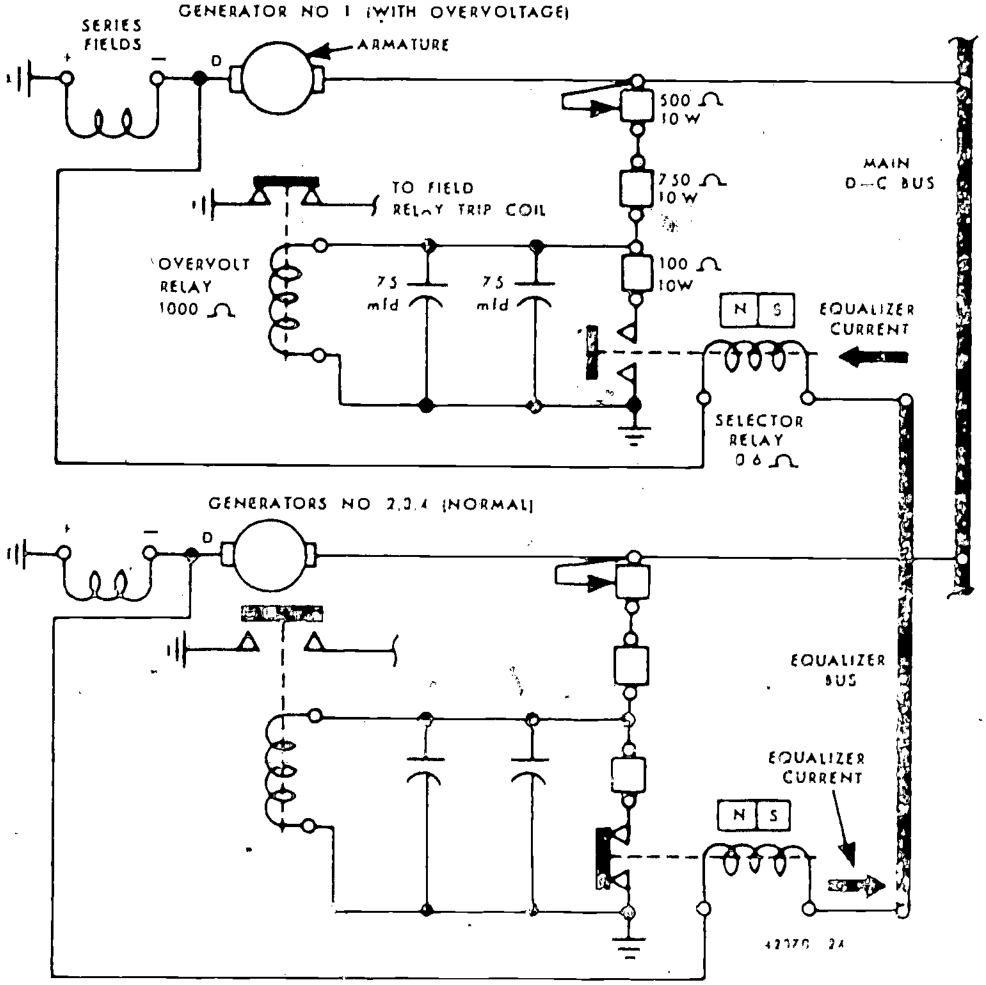

Figure 66. Generator overvoltage protection circuit.

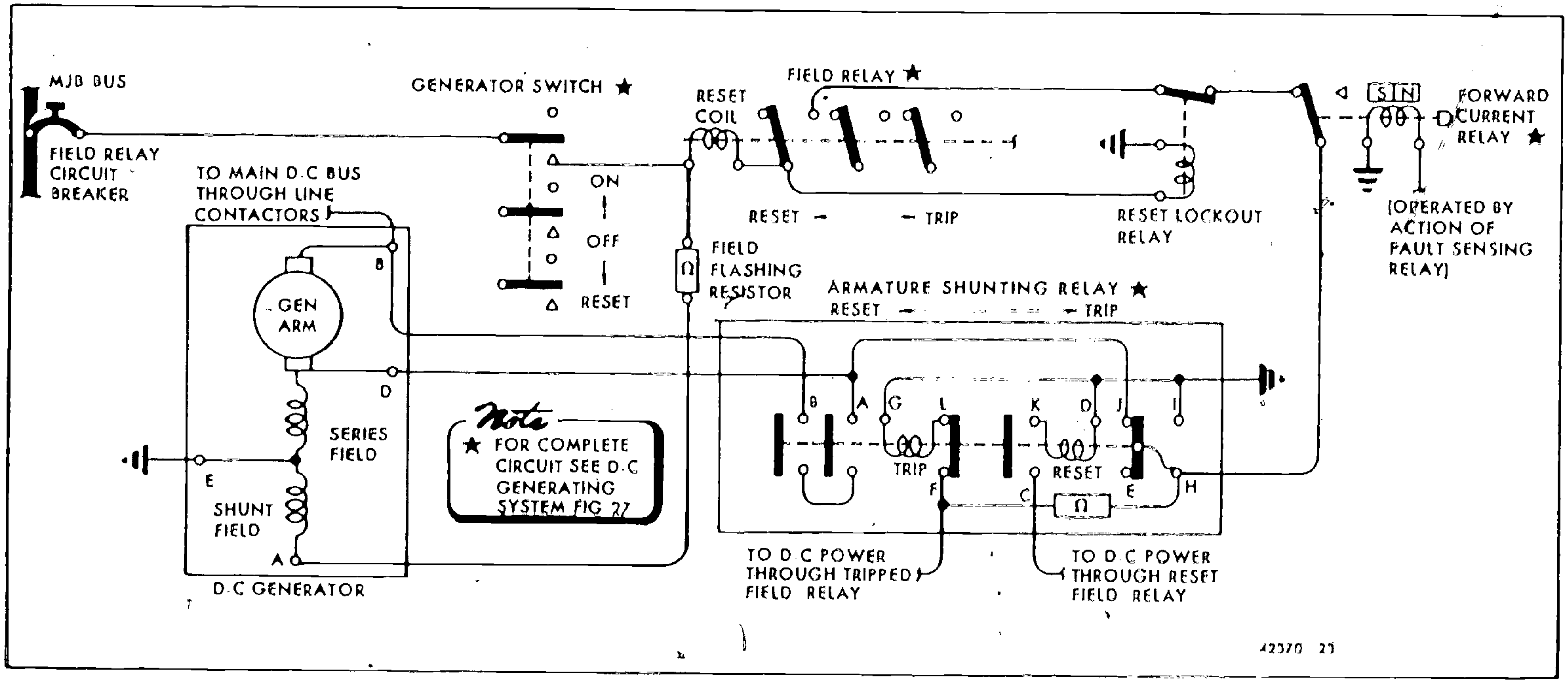

Figure 67. Generator reset circuit.

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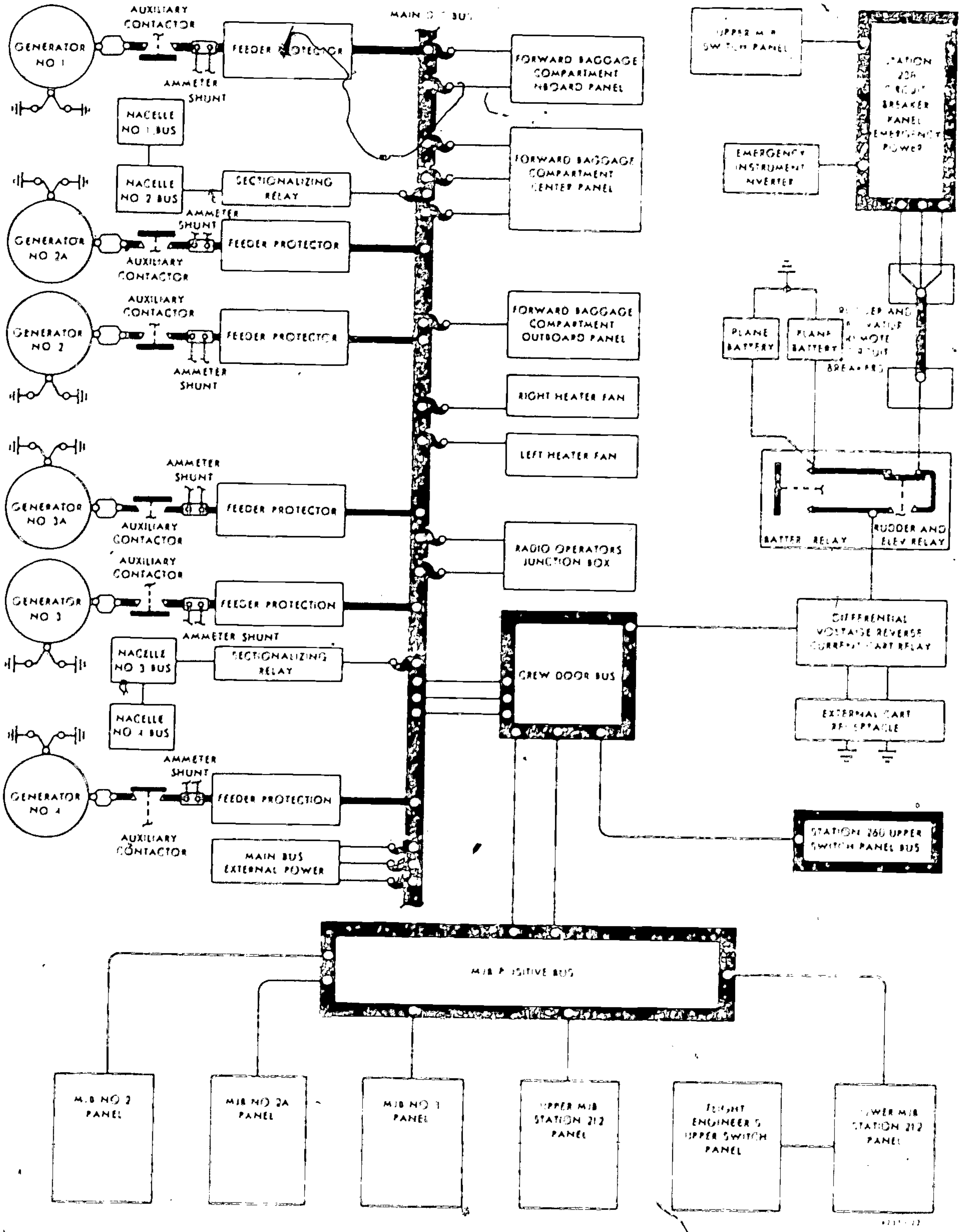


Figure 68. Direct-current distribution circuit.

21

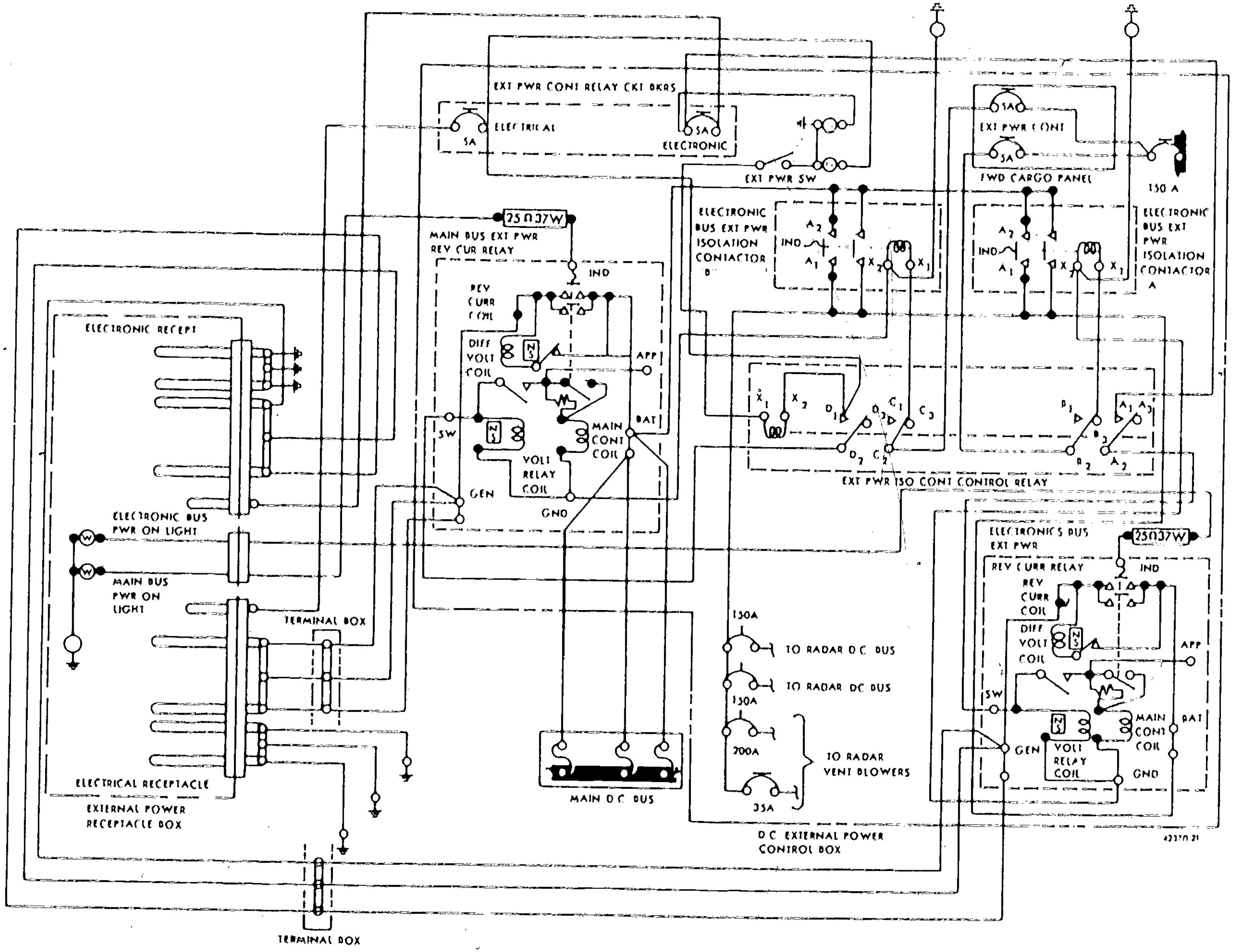


Figure 69. External direct-current power system.

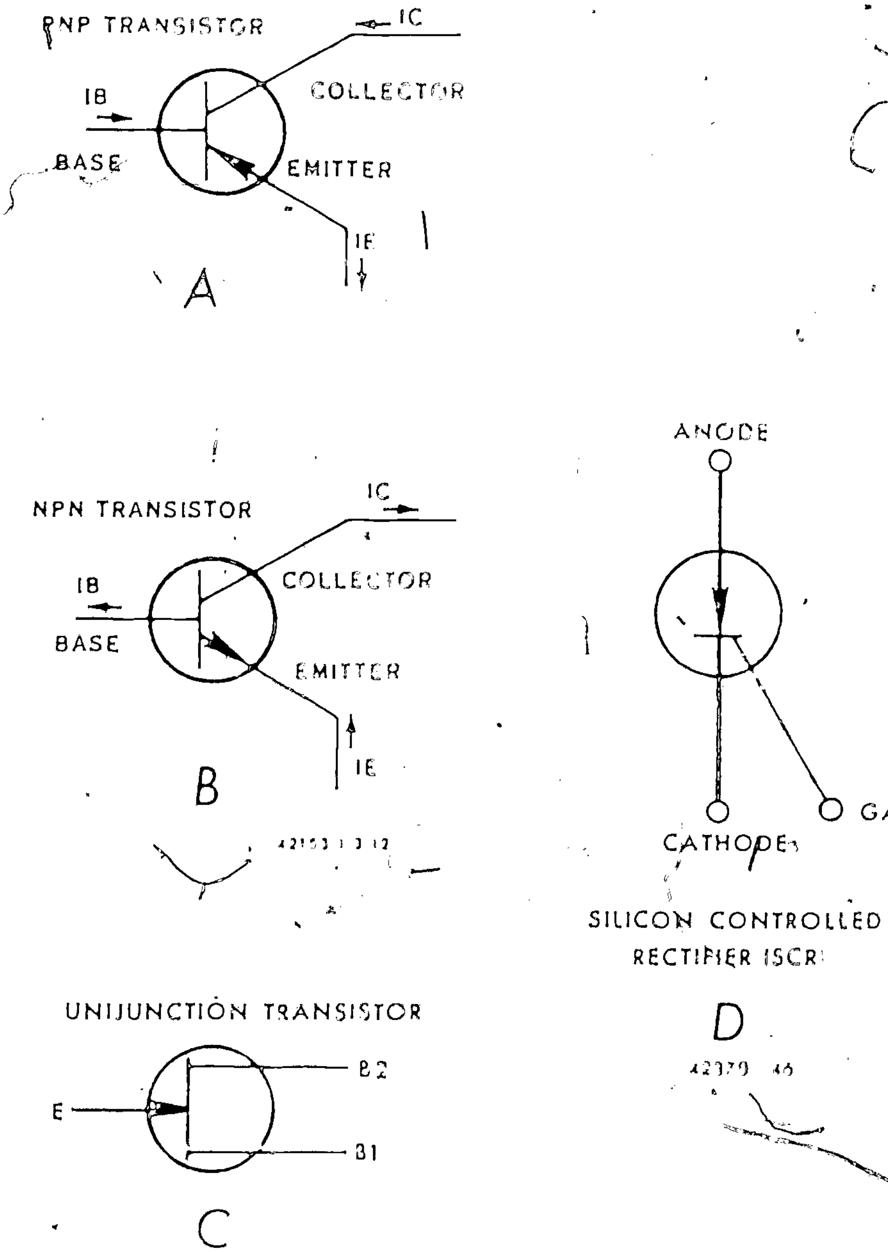


Figure 70. Symbols used with transistors.

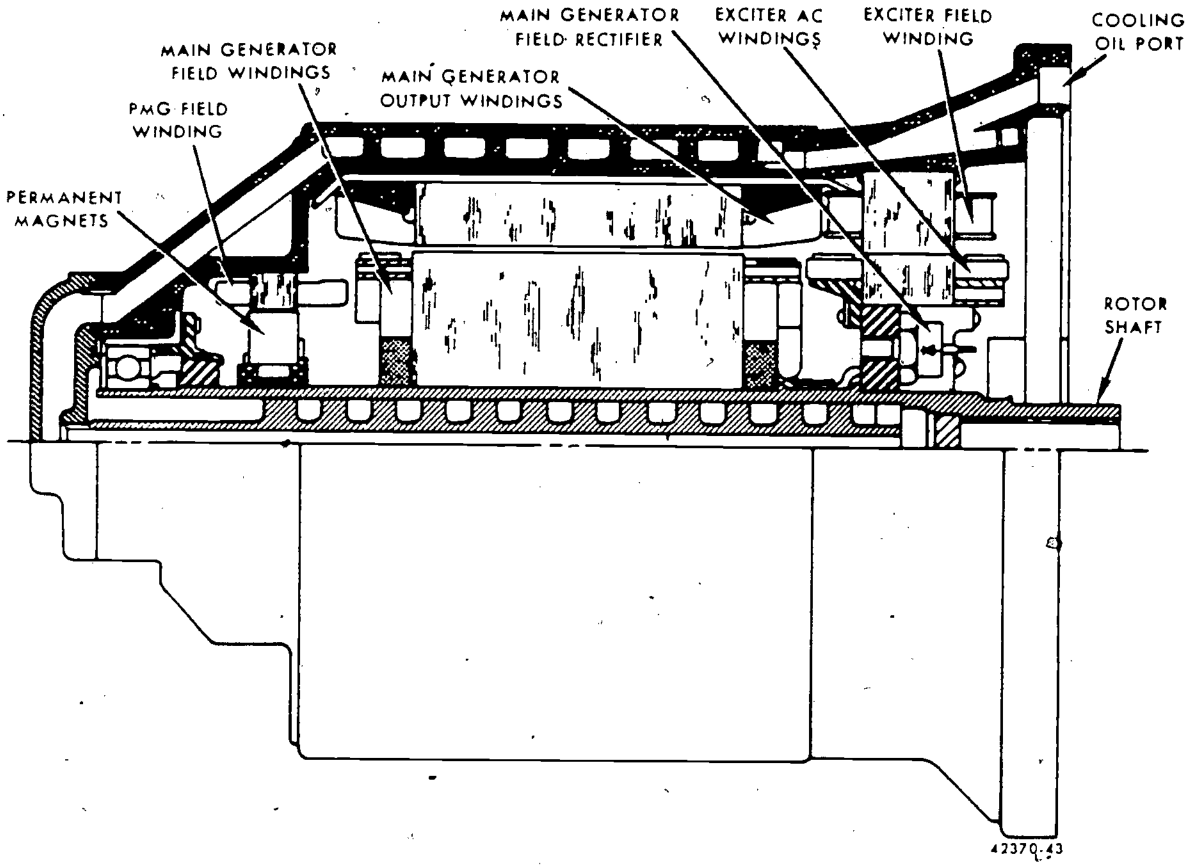


Figure 71. Brushless generator cutaway.

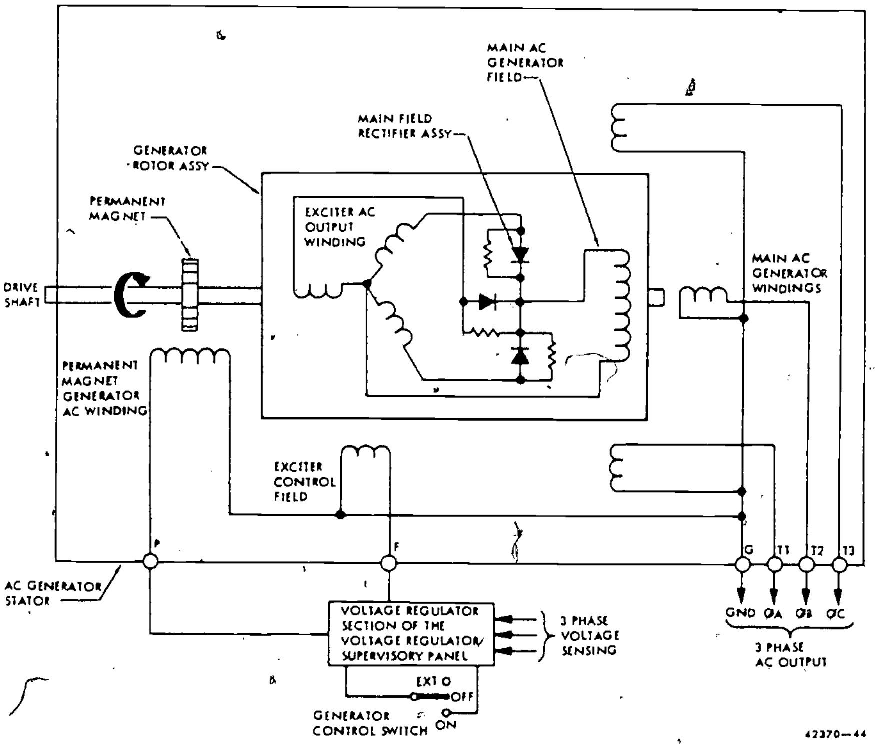
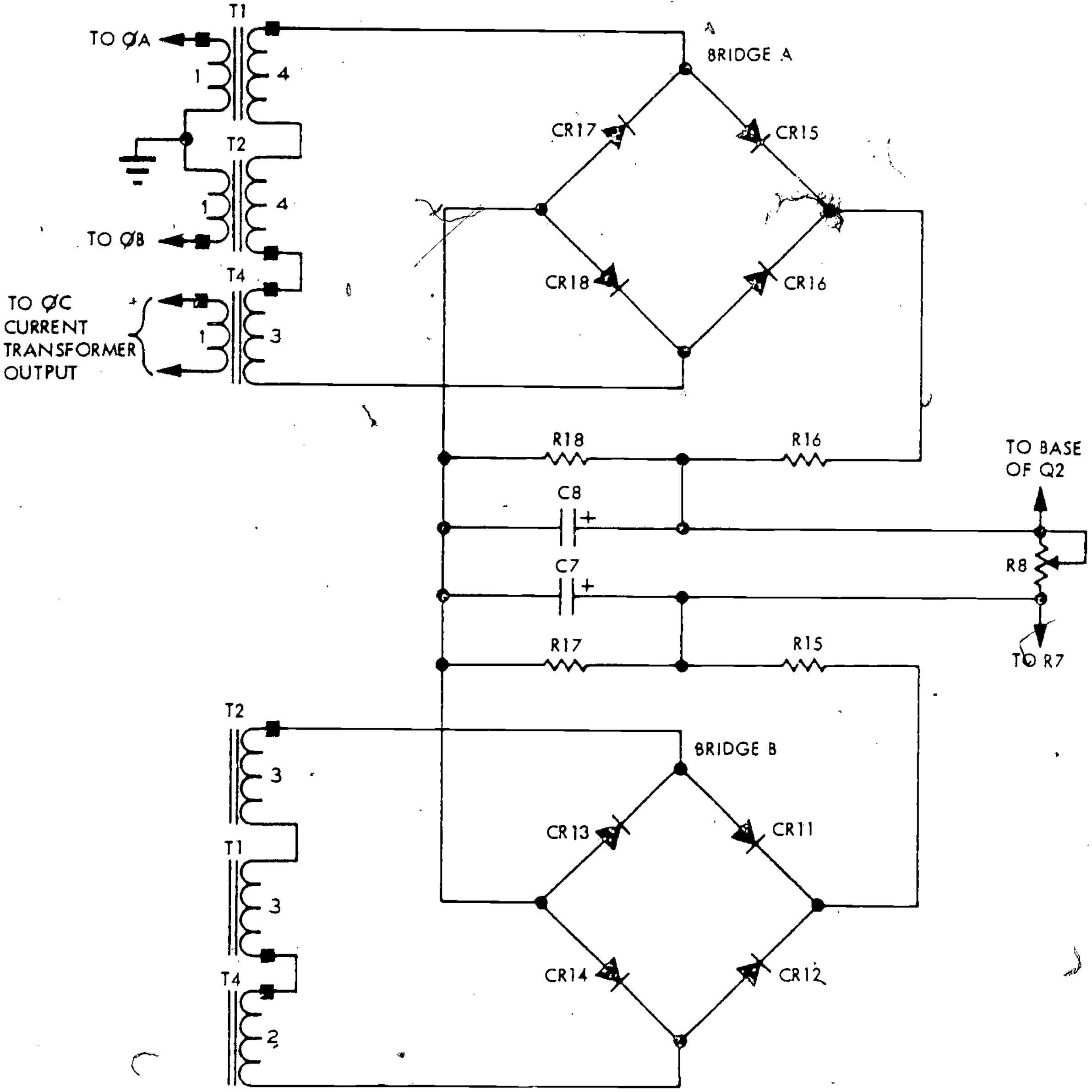


Figure 72. Brushless generator schematic.



NOTE

THE SECONDARIES OF T1, T2, AND T4 HAVE BEEN SEPARATED FOR SIMPLICITY.

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Figure 73. Reactive current sensing circuit.

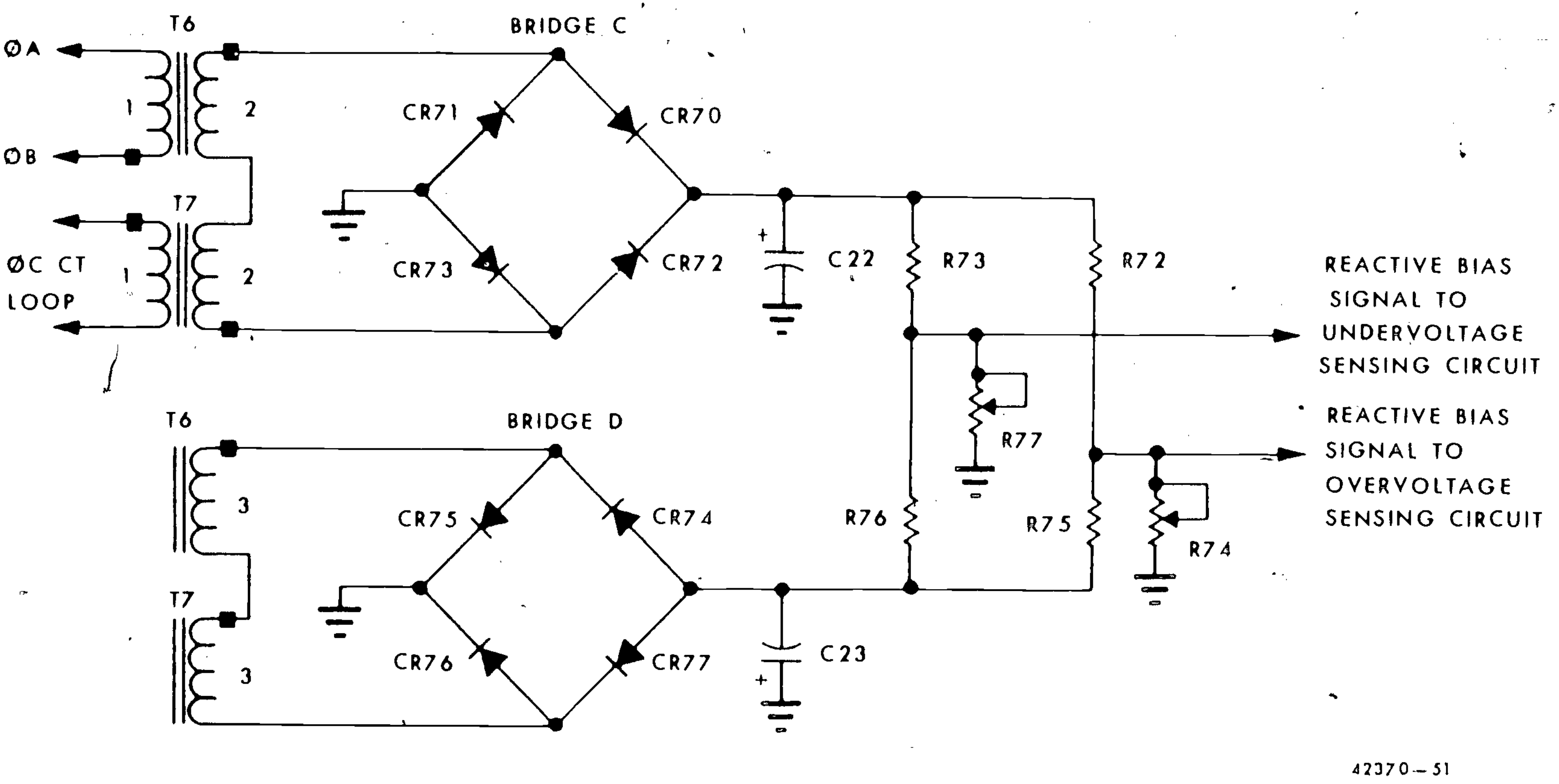

Figure 74. RBC schematic.

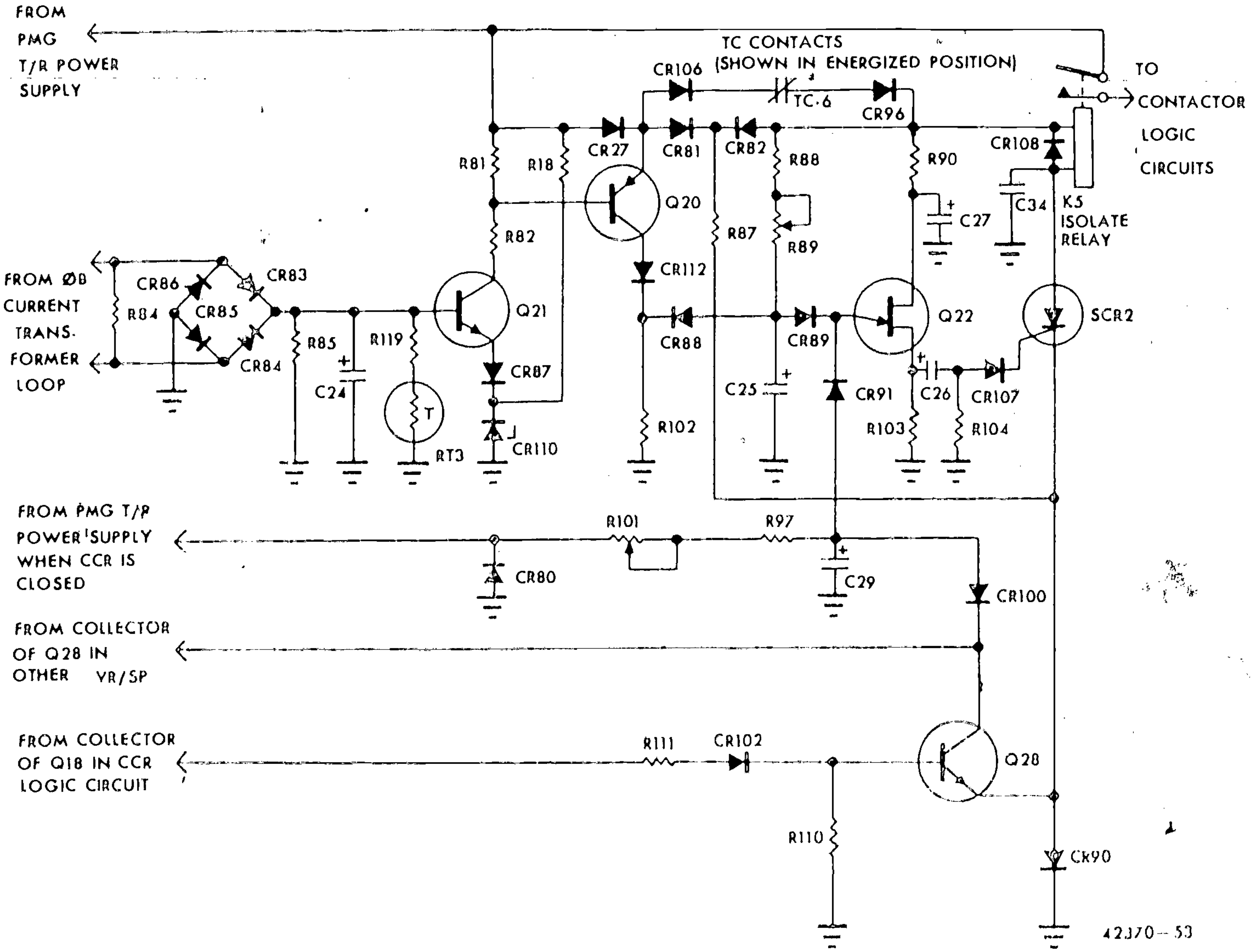

Figure 75. Unbalanced current sensing circuit.

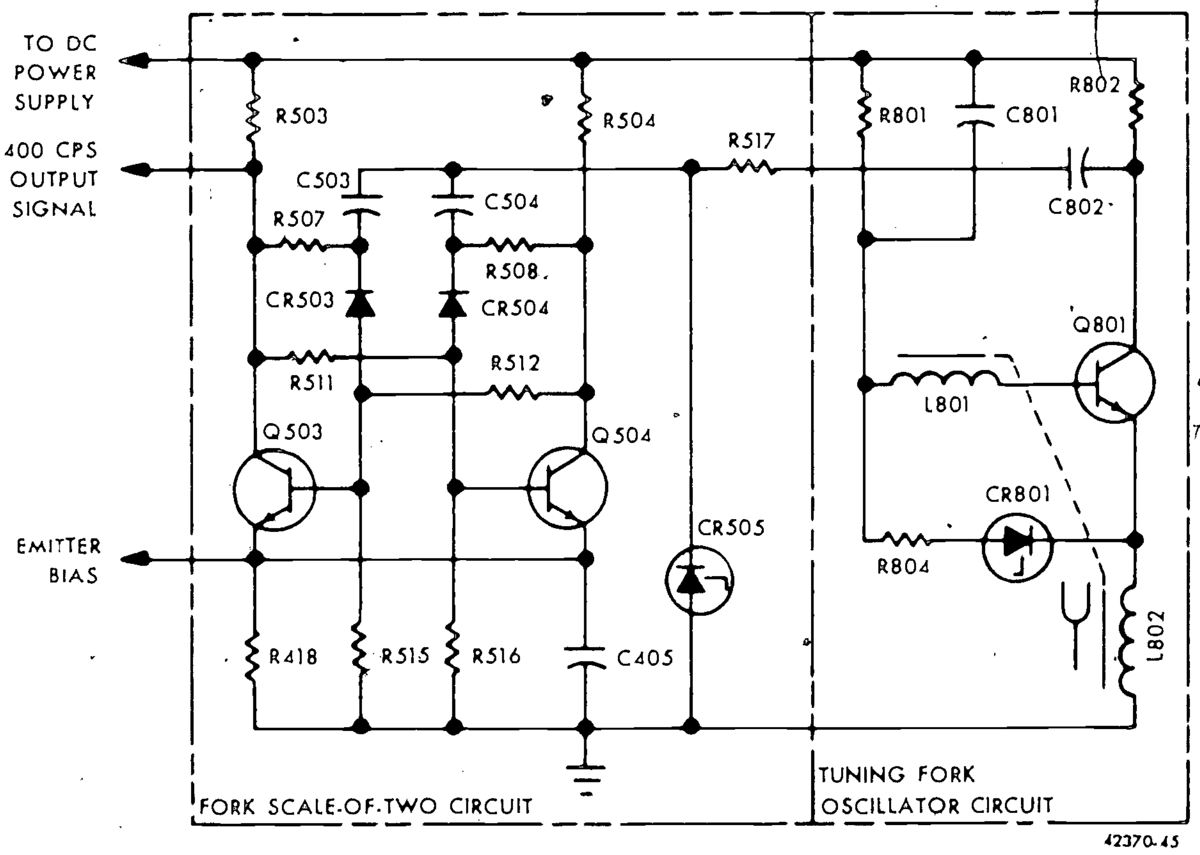

Figure 76. Frequency reference circuit.

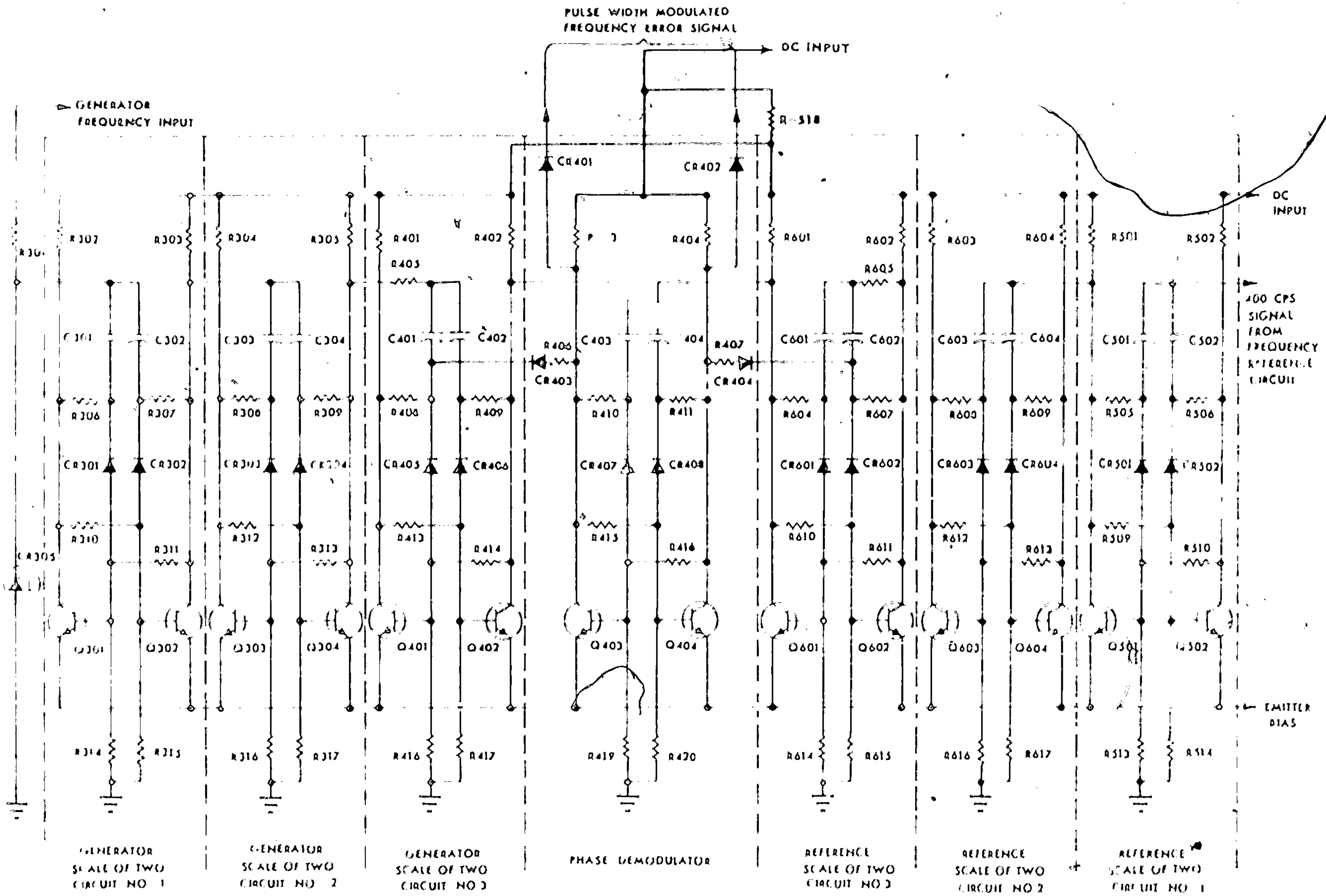

Figure 77. Frequency comparator circuit.

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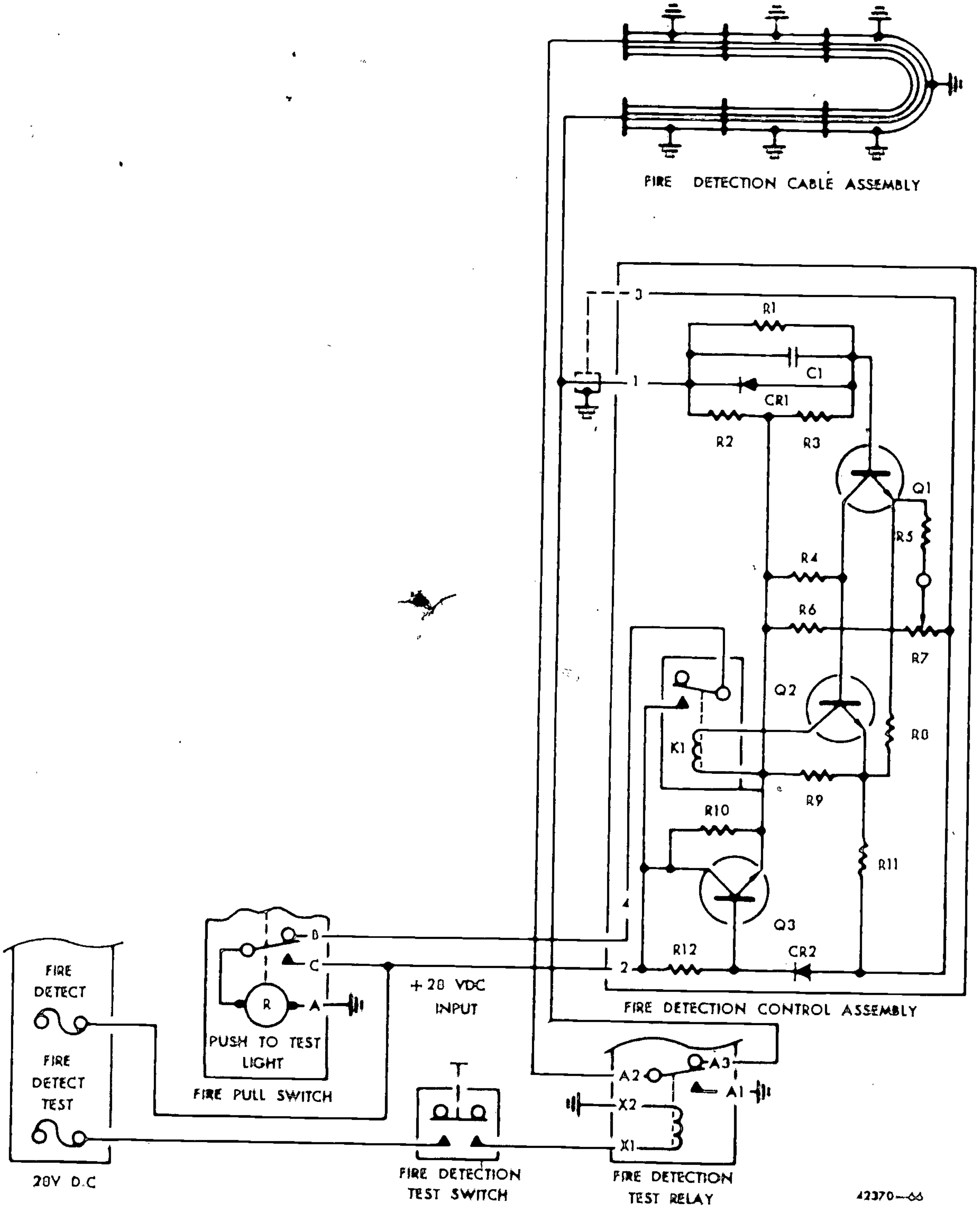

Figure 78. Continuous cable circuit.

221

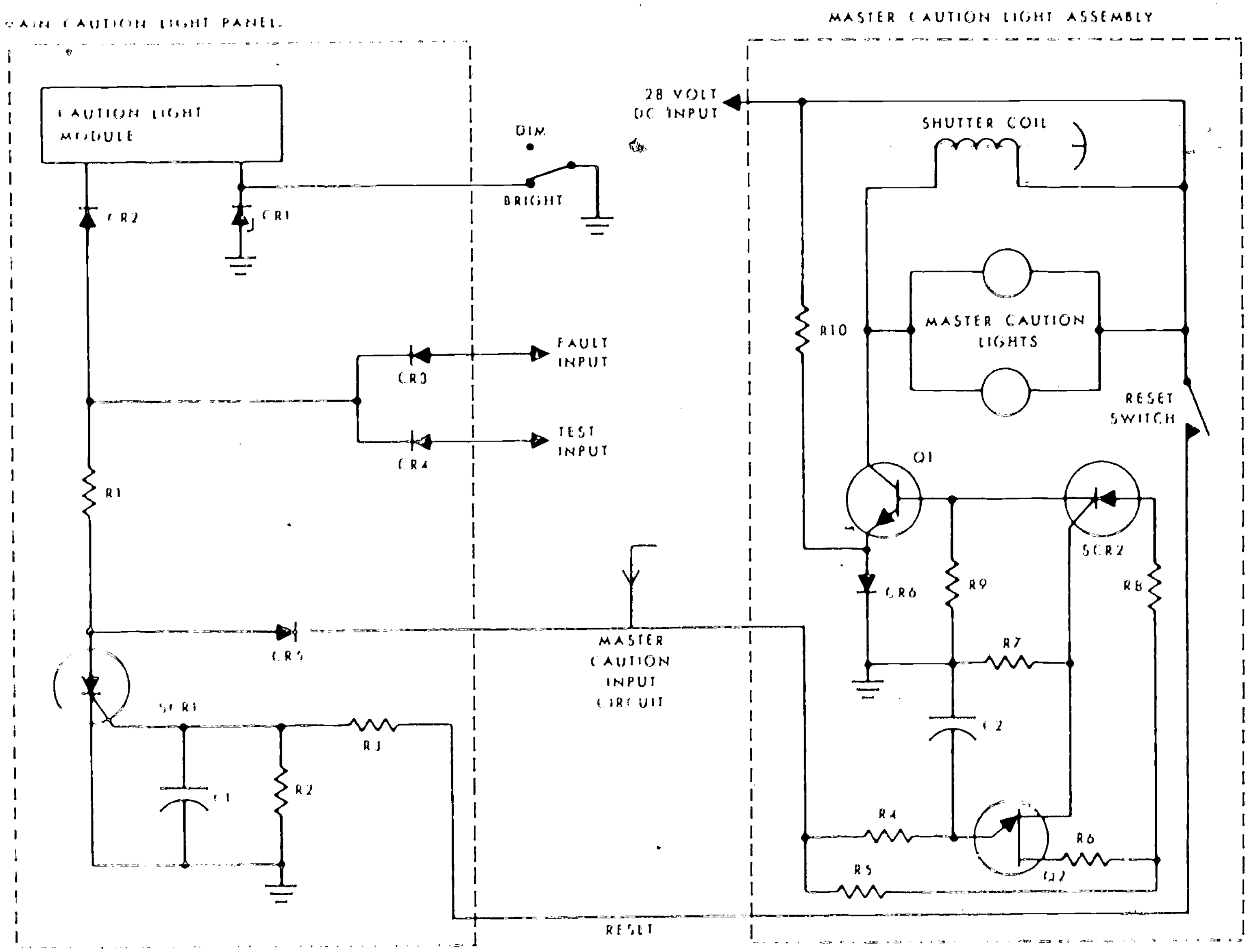

Figure 79. Master caution and warning light system schematic.

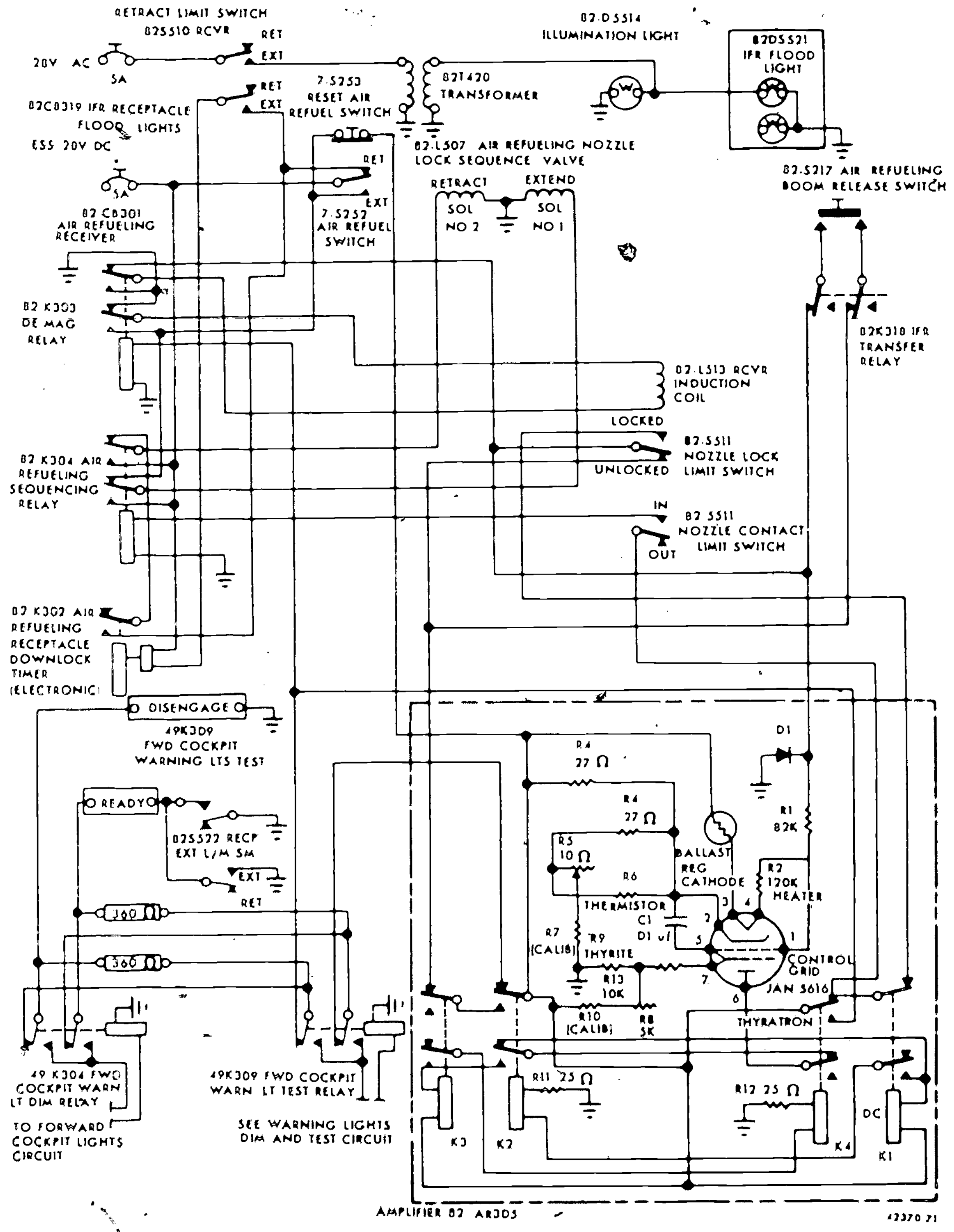

Figure 80. Air refueling system electrical schematic.

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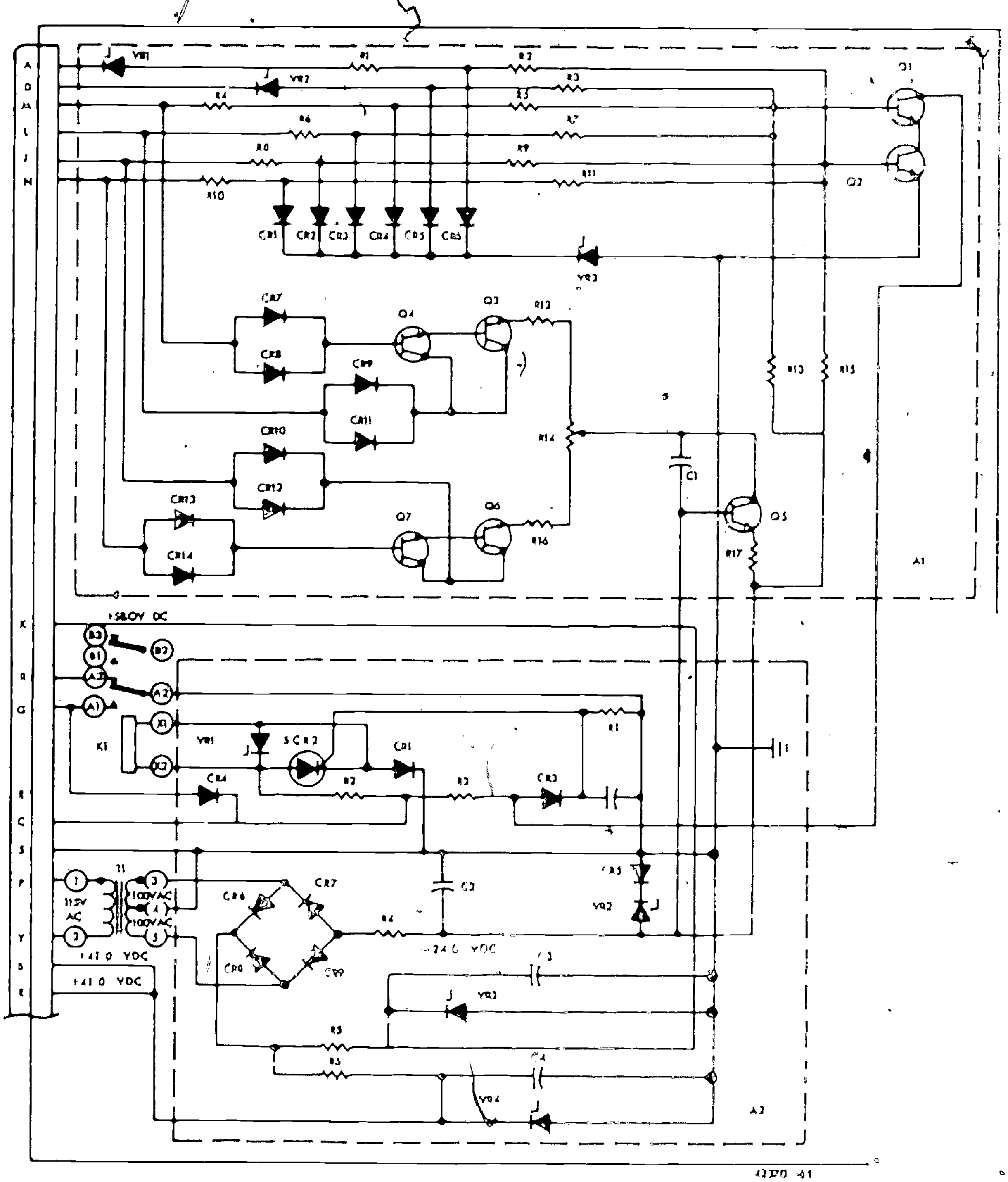

Figure 11. Control box schematic

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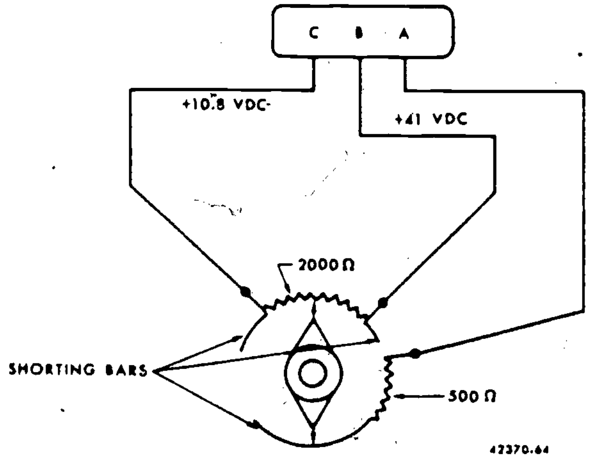

Figure 82. Command potentiometer schematic.

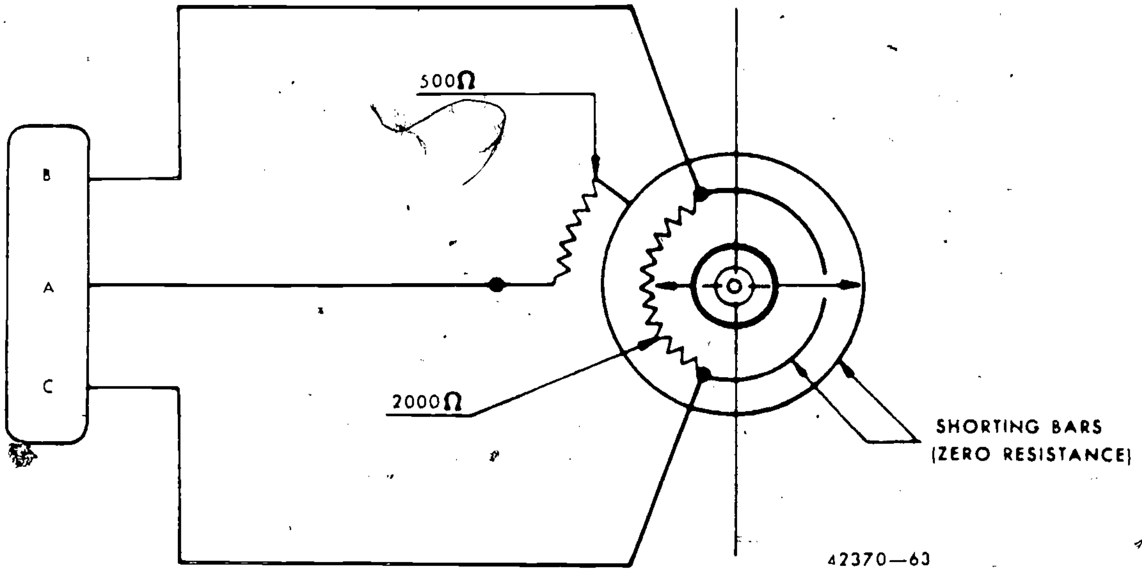

Figure 83. Followup potentiometer.