STUDENT STUDY GUIDE

AIR TRAINING COMMAND

DEPARTMENT OF MISSILE TRAINING

MISSILE LAUNCH/MISSILE OFFICER

ELECTRONICS FOR MISSILES
BLOCK II (1 thru 15)

Jnauary 1962

COURSE OBR1821B/3121-3
TECHNICAL TRAINING

FOR INSTRUCTIONAL PURPOSES ONLY

ABOUT STUDENT STUDY GUIDES AND WORKBOOKS

STUDENT STUDY GUIDES AND WORKBOOKS, are designed by the Air Training Command as student training publications for use in the training courses of this command. Each publication is prepared for a subject or Unit of Instruction as reflected in the course syllabus.

THE STUDENT STUDY GUIDE, contains the specific information required in the Unit of Instruction or it will refer to other publications which the student is required to read. It contains the necessary information which is not adaptable for student study in other available sources. The material included or referred to is normally studied either outside the classroom or during supervised study periods in the classroom. Also included are thought provoking questions which permit self-evaluation by the student and which will stimulate classroom discussion.

THE STUDENT WORKBOOK, contains specialized job procedures, important information about the job, questions to be answered, problems to be solved and/or work to be accomplished by the student during the classroom/laboratory, airplane/equipment activity. It serves as a job sheet, operations sheet, mission card, checklist, or exercise to be performed during classroom or laboratory periods. Also included are questions which will aid the student in summarizing the main points of the subject or Unit of Instruction.

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DAY 19

ELECTRICAL FUNDAMENTALS

OBJECTIVES:

To become familiar with the electron theory, electron flow, electrical terms and symbols, the concept of resistance, and the proper use of meters.

INTRODUCTION:

It isn't necessary to impress you with the vital role that electronics plays in the ballistic missile program. Without electronics there would be no flight control, no guidance, no power! Many of these missile electrical components are outgrowths of elementary electronic circuits.

In order to understand the sophisticated electronic circuits, a good, solid foundation that will support not only the many subjects in this portion of the fundamentals phase, but also those in the advanced phases of the course and your work in the missile field is essential.

REFERENCES:

AFM 101-8, "Fundamentals of Electronics", pages 3-18, 20 and 21, 69-78.

SUMMARY:

Matter is anything that occupies space and has weight and mass. It consists of elements or combinations of elements, the smallest particle of which is the atom. The atom has a nucleus consisting of protons (positive charges), neutrons (neutral charges), and planetary electrons (negative charges).

Static electricity is the study of electrical charges at rest. We know that fields of force exist around all charged bodies and that Coulomb's Law

states that "like charges repel and unlike charges attract". These forces are directly proportional to the amounts of the charges and inversely proportional to the square of the distance in between them.

Current is the rate of flow of electrons and is measured in amperes. Electrons flow more readily through some substances than through others. Those substances which permit a ready flow of electrons are called conductors; those which do not, insulators. In between these extremes are the resistors. The resistor offers more or less opposition to electron flow and the unit of this opposition or resistance is the ohm.

Potential difference forces electrons to move through a substance and the unit of this potential difference is the volt.

Electricity may be produced by mechanical, thermal, photoelectric, piezoelectric, and chemical means. The most common are mechanical and chemical. The current thus produced may be direct current, pulsating direct current, or alternating current.

A knowledge of electrical terms and symbols is important. The use of proper electrical terminology eliminates misunderstanding and makes the subject precise. The knowledge of electrical symbols is a must. Imagine what a road map would look like if there were no symbols for roads, rivers, dams, bridges or airports. An electrical "map" or schematic would be equally confusing and cluttered.

Various meters are used when repairing, maintaining and troubleshooting electronic equipment. The ammeter measures current, the voltmeter measures potential difference or voltage and the ohmmeter measures resistance. Most multimeters measure amperes, volts and ohms - all three in one unit. The proper use of these meters is important - not only from the standpoint of accurate measuring, but also from the maintenance or the dollar standpoint. Neglecting basic SOP's will result in damage or destruction of the meter.

QUESTIONS:

1. What is matter? Has weight or mass and occupies space.

2. What is the smallest portion of any substance that cannot be further subdivided without its properties being destroyed?
molecule

3. What is a positive ion? a Compound or element with fewer electrons than protons in the nucleus resulting in a positively charge

4. What is a "free" electron?

5. In what direction is the field of force about a negative ion?

6. What is the unit of resistance? It is the ohm and depends on the length and the specific resistance of the material and the temperature of the material divided by the cross sectional area.

7. What three items affect resistance? Formulate for these three factors. Temp

8. What is meant by the term "ground"?

9. Explain how you would connect an ammeter in a circuit?

10. Is the voltmeter inserted in series with or parallel to the component to be measured?

Missile Launch/Missile Officer
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OBR1821B/3121-3-II-2
Student Study Guide
28 November 1961

DAY 20, 21, 22A

FUNDAMENTALS OF DC CIRCUITS

OBJECTIVES:

To become familiar with Ohm's and Kirchoff's Laws and their application in electronic circuits.

To become familiar with series, parallel and series parallel DC resistive circuits.

To become familiar with voltage dividers and voltage polarity using ground as a reference.

INTRODUCTION:

The most intricate electronic circuits can be reduced to one of three types: series, parallel, or a combination of both. These three types of circuits and the laws governing their analysis are discussed in this lesson. Voltage dividers and the use of ground as a zero reference are also discussed. A thorough knowledge and understanding of this lesson will make the study of future lessons much easier.

REFERENCES:

AFM 101-8, "Fundamentals of Electronics", pages 19-21 and 27-40.

SUMMARY:

An electronic circuit is simply a complete path for electron flow. No matter what the electron does after it leaves the source, it must be able to return to complete the circuit.

Three values are extremely important in any circuit; voltage, resistance and current. These values determine the amount of power the circuit develops, the amount of work the electrons will do.

In 1827 George Simon Ohm published the results of much experimentation. Ohm's Law establishes a definite relationship among voltage, current, and resistance. He found that the current in a circuit is directly proportional to the voltage applied and inversely proportional to the resistance.

A few years later, G. R. Kirchoff extended Ohm's Law. He made two statements which are now known as Kirchoff's Laws:

> The algebraic sum of the current at any junction of conductors is zero. That is, at any point in a circuit, there is as much current flowing away from the point as there is flowing toward it.
>
> The algebraic sum of the electromotive forces and voltage drops around any closed circuit is zero. That is, in any closed circuit, the applied voltage is equal to the sum of all the voltage drops around the circuit.

When the electrons have but one path to take, the circuit is called a series circuit. All the electrical components in a series circuit are connected end to end, making a single loop. In this type circuit the rate of electron flow (the current) is the same in every part of the circuit.

Figure 1 is a schematic of a simple series resistive circuit.

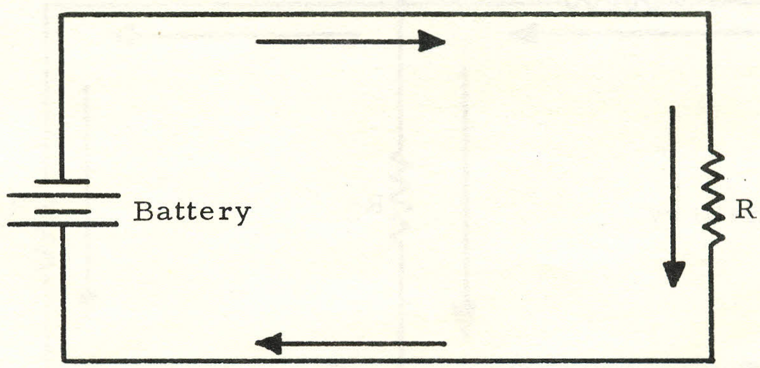


Figure 1

A Series Circuit

If there is more than one path for electron flow, the circuit is said to be parallel. As seen in Figure 2, the electrons proceed to point A where they split, some going to point B while others go to C. At B they join up again continuing their journey to the positive side of the source.

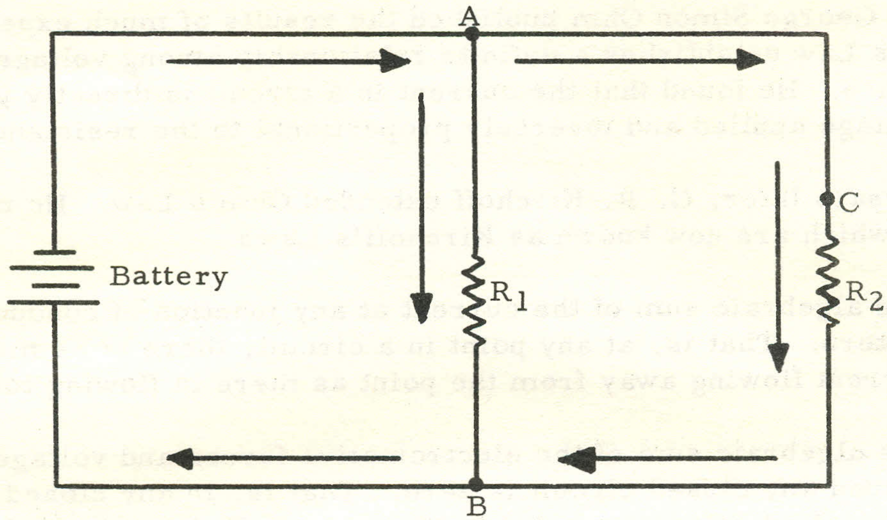


Figure 2

A Parallel Circuit

Figure 3 shows a simple series-parallel circuit. Here there is a single path for a time, then more than one path. For proper analysis of the series-parallel circuit it is necessary to combine the rules for both series and parallel circuits.

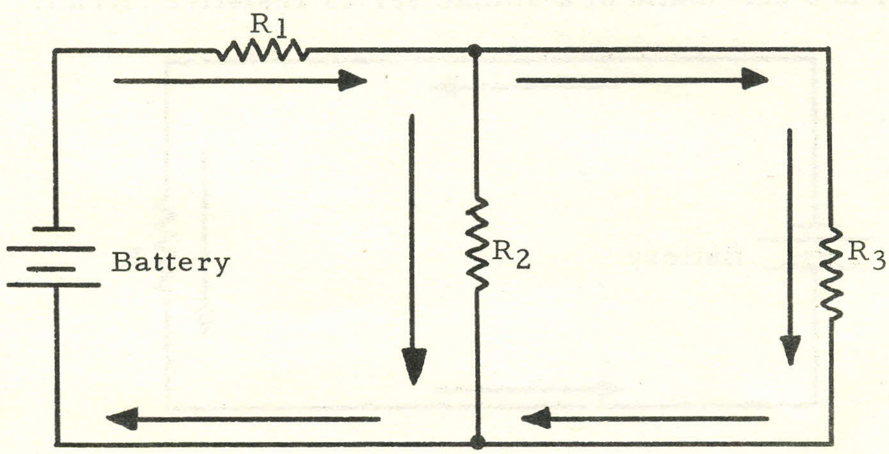


Figure 3

A Series-Parallel Circuit

Many times it becomes necessary to use but a portion of the total electromotive force available. To tap off the desired amount of voltage, a voltage divider is used which, in its simplest form, is nothing but a series of resistors. Each of these resistors requires a certain amount of the voltage available. A partial voltage can be tapped off and applied to an electrical component requiring that exact amount. Figure 4 shows a simple voltage divider.

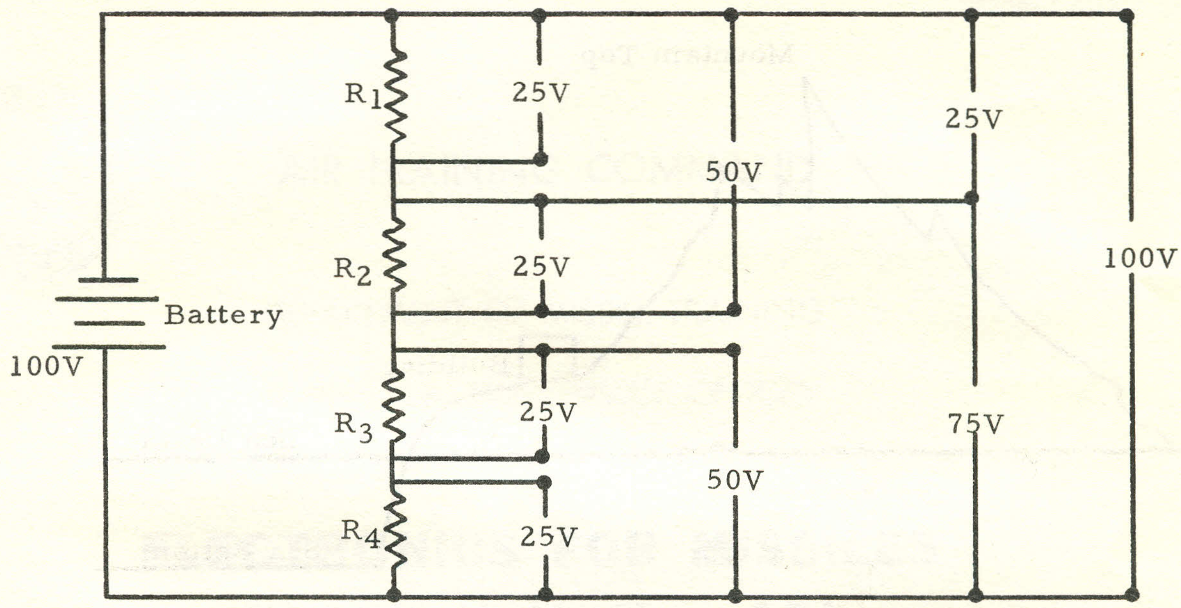


Figure 4

A Voltage Divider

The ground symbol as learned in the first lesson, signified a common electrical connection. This same symbol is also used to represent a starting point, a reference point or zero. Depending on the reference or ground, there can be positive or negative voltages. The practical application of reference ground will show itself more clearly in future lessons. In Figure 5 if sea level is used as a reference point or the zero starting point, then the building and the mountain top are higher (more positive) than sea level, and the sea bottom is lower (or more negative). If, however, the mountain top is used as the reference point, then the building becomes lower or more negative than the mountain top. Any of these levels can be used from which to start the measurement. Ground is that reference point in Figure 6.

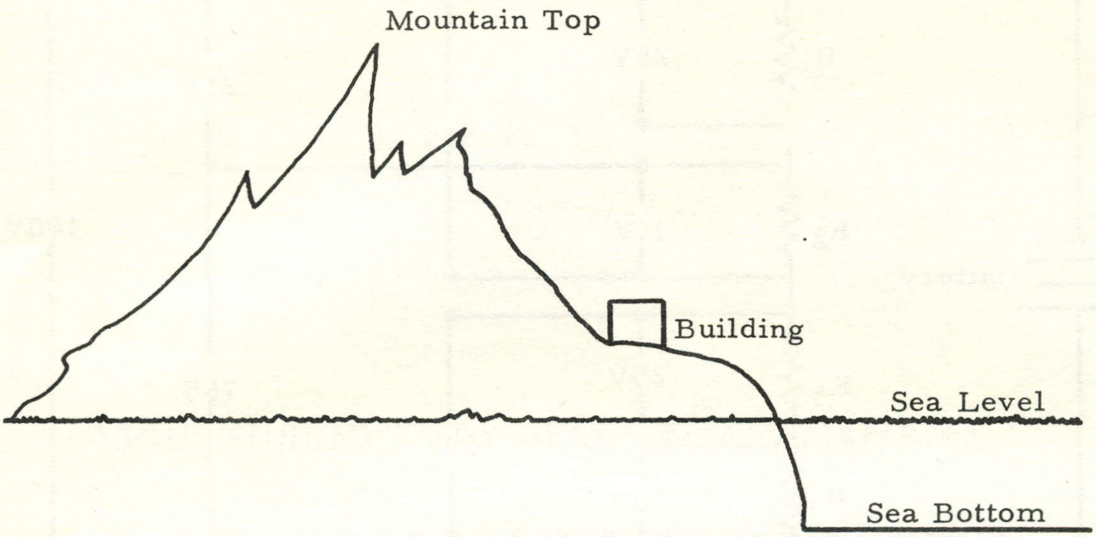


Figure 5

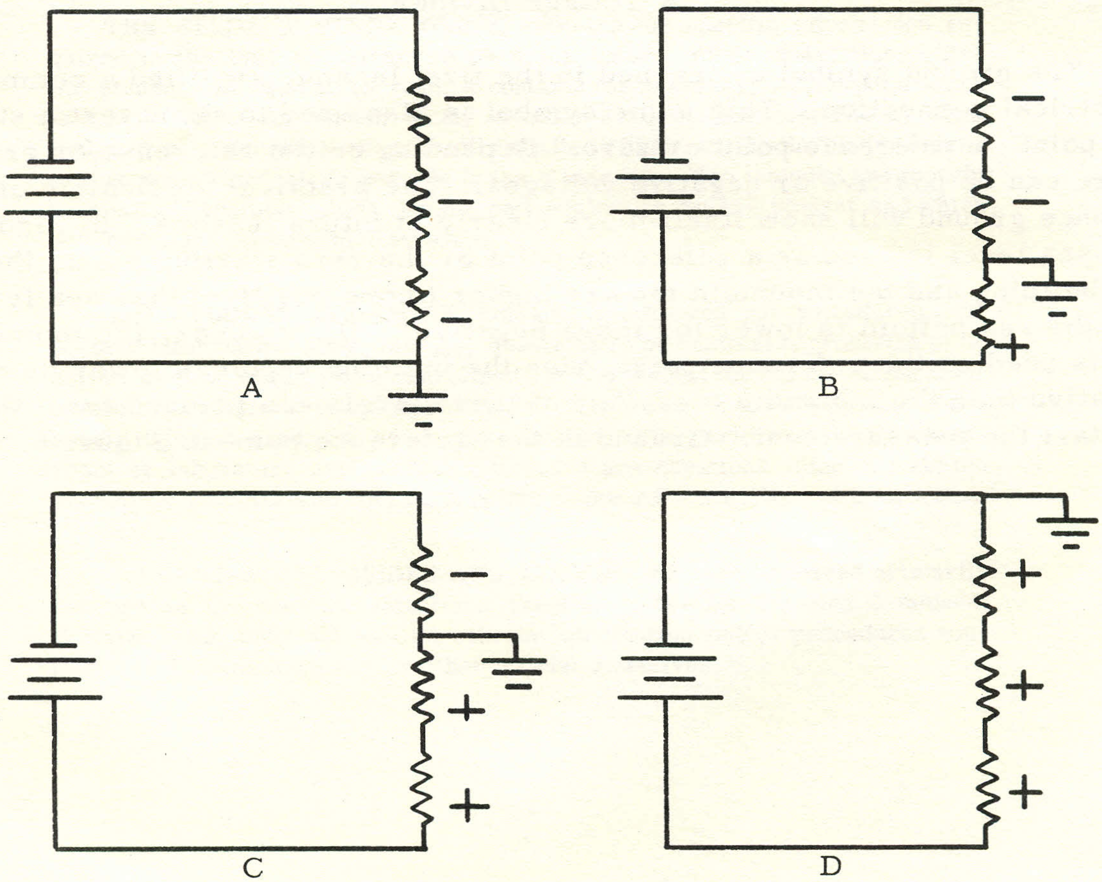


Figure 6

QUESTIONS:

1. State Ohm's Law in three different ways.

2. What is Kirchoff's Law for current?

3. What is Kirchoff's Law for voltage?

4. State three rules regarding current, voltage, and resistance in a series circuit.

5. Draw a schematic of three resistors in series with each other across a battery.

6. If the battery voltage in your schematic is 90 volts and the resistors had resistances in a 1:2:3 ratio, what is the voltage drop across each resistor?

7. State three rules regarding current, voltage, and resistance in a parallel circuit.

8. Why does the total current increase when more branches are added to a parallel circuit?

9. In a series-parallel circuit, how can you tell which resistors are in series with each other and which are in parallel?

10. What is electrical power? Formulate for power when only the voltage and resistance are known.

DAY 22B

BATTERIES, MAGNETISM, AND CONTROL DEVICES

OBJECTIVES:

To familiarize you with batteries, electromagnetism and various electrical control devices.

INTRODUCTION:

Although most of the power consumed is AC power, batteries are extremely important for supplying DC. Without them the ballistic missile would not reach its target since they furnish the current necessary to drive the missile generator.

Separated electrical charges have the potential to do work while magnetism is another phenomenon, which also has a work potential. Electricity and magnetism are so closely related that a study of one demands a study of the other. The application of magnetism and electro-magnetism is almost unlimited in ballistic missiles.

This lesson will also cover some of the more common electrical control devices such as switches, relays, fuses, rheostats, and potentiometers.

REFERENCES:

AFM 101-8, "Fundamentals of Electronics", pages 21-26 and 40-50.

SUMMARY:

Cells are of two major types, the primary cell and the secondary cell. Although the chemical action in each type is similar, there is a big difference between the two. The primary cell cannot be recharged, while the secondary can. The nickel-cadmium cell is a recent secondary cell development. It has many advantages over the older lead-acid cell. The chemical

action of a cell restricts the amount of potential it has and the size of the electrodes limit the current capability. To overcome these limitations we can connect cells in various ways to increase the potential, the current capability, or both.

Natural magnetism has been known to man for many centuries, but electro-magnetism and its resulting application is a fairly recent discovery. Electrons flowing in a coil cause the coil to act like a magnet with all its properties and characteristics. We can control the strength of this electromagnet by controlling the current.

Unless protective devices are used in electronic circuits, current can damage or destroy the equipment. Relays, switches, rheostats, potentiometers, and fuses are but a few of the devices that are used to keep these powerful electrons in check.

QUESTIONS:

1. What is a primary cell? A secondary cell?

2. You need 6 volts for a certain circuit and you have 1.5 volt cells available. Make a drawing of the proper cell hook-up to obtain the desired 6 volts.

3. Draw the magnetic field of a horseshoe magnet. Label the poles and show the direction of the magnetic lines.

4. What is the difference between a permanent magnet and an electromagnet?

5. State four characteristics of magnetic lines of force.

6. What characteristic of magnetic lines of force is used in magnetic shielding?

7. What is the left-hand rule for solenoids?

8. How can the polarity of an electromagnet be reversed?

9. What is the purpose of a rheostat? A potentiometer?

10. What is permeability? Retentivity?

11. How does a fuse protect a circuit?

DAY 23

INTRODUCTION TO ALTERNATING CURRENT

OBJECTIVES:

The goal for this lesson is to learn the basic terms and values associated with alternating current (AC) and to become familiar with the purpose, basic principles, and operation of AC generators, AC motors, and inverters.

INTRODUCTION:

DC is important and has a very definite place. But it has two major disadvantages which do not exist with AC. First, DC cannot be transmitted over long distances without a great loss of power. The resistance in the many miles of wire would eat up the power, ($P=I^2R$) and instead of being available at the end of the line where it is needed, the power would be dissipated along the way. This problem does not exist with AC. The other disadvantage is that DC energy cannot be radiated into space. The present-day wireless communications have been made possible with AC, because its energy can be directed into space and captured again.

About 90 percent of the power consumed in the world is AC, developed by AC generators. Most of this power is used by AC motors as they perform their many tasks. Inverters, or motor-generators, are used to change DC power to AC.

Since AC generators, AC motors and inverters are used in ballistic missiles, it is important to have an understanding of AC and the machines that produce and use it.

REFERENCES:

AFM 101-8 "Fundamentals of Electronics", chapter 12, pages 81-86, chapter 9, pages 51-53 and 55-57.

THE INDUCTION MOTOR

The induction motor operates on the principle of mutual induction between the rotor and a rotating magnetic field existing in the stator. In order to understand the operation of an induction motor we must first understand how a rotating magnetic field can be produced.

The three-phase induction motor has three pairs of poles upon which are wound three pairs of stator windings. Figure 1 shows that each pair of windings will be connected to a separate phase from a three phase AC generator. This means that:

Poles A1 and A2 are connected to phase A.

Poles B1 and B2 are connected to phase B.

Poles C1 and C2 are connected to phase C.

Poles A1, B1, and C1 are physically spaced 120° apart, and are controlled by phase A, B, and C respectively as shown on the three-phase sine wave in Figure 1. The same holds true for poles A2, B2, and C2.

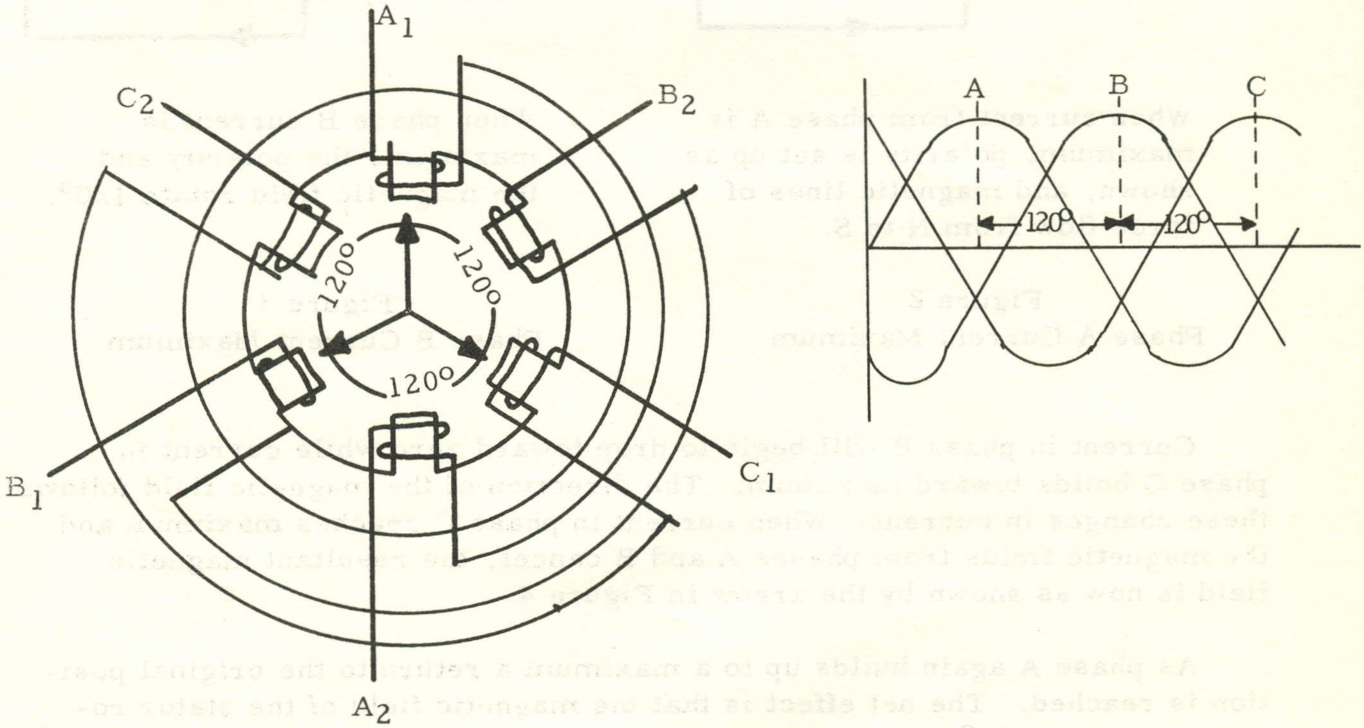
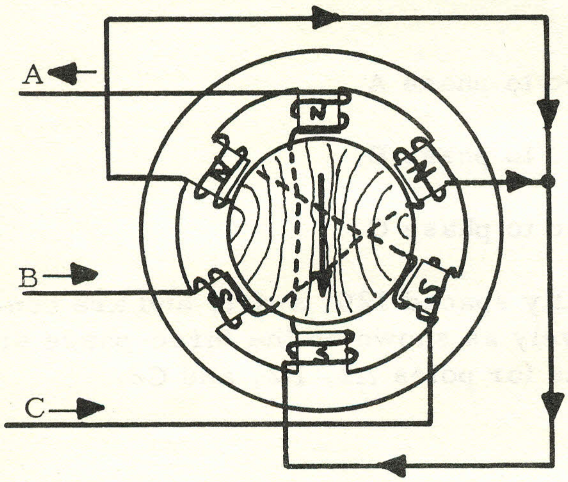


Figure 1
Three Phase Motor and Current Waves

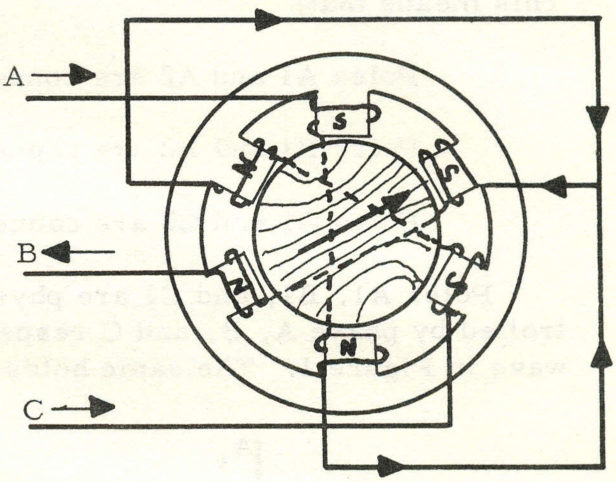
At point A on the sine wave, the current from phase A is maximum. At this point the magnetic fields set up by the currents from phases B and C are equal and opposite and will cancel. The resultant magnetic field at this time is as shown by the arrow in Figure 2.

As the current in phase A moves toward zero, the current in phase B builds up causing changes in the strength of the magnetic fields. When position B on the sine wave has been reached, phase B current is maximum. The magnetic fields created by phases A and C cancel, the resultant magnetic field of the stator is as shown by the arrow in Figure 3.



When current from phase A is maximum, polarity is set up as shown, and magnetic lines of force flow from N to S.

Figure 2
Phase A Current Maximum



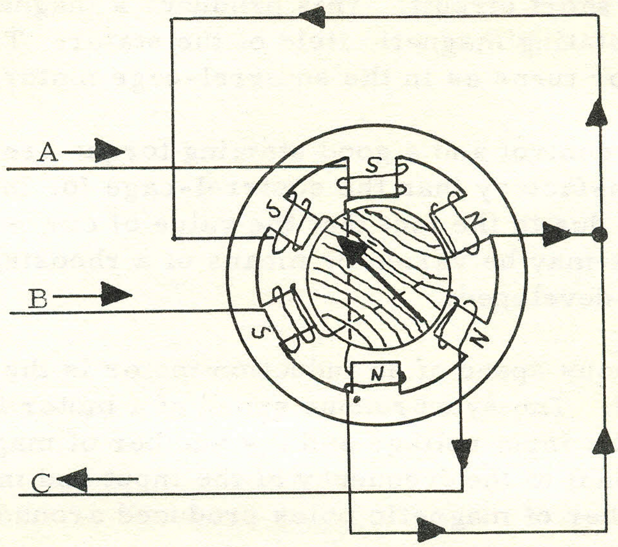
When phase B current is maximum, the polarity and the magnetic field rotate 120°.

Figure 3
Phase B Current Maximum

Current in phase B will begin to drop toward zero while current in phase C builds toward maximum. The direction of the magnetic field follows these changes in current. When current in phase C reaches maximum and the magnetic fields from phases A and B cancel, the resultant magnetic field is now as shown by the arrow in Figure 4.

As phase A again builds up to a maximum a return to the original position is reached. The net effect is that the magnetic field of the stator rotates covering 360° of physical rotation during one cycle of the AC current.

The rotors used in induction motors are of two types: the squirrel cage rotor and the wound rotor. These rotors differ slightly in construction and



When Phase C current is maximum, the polarity and the the magnetic field rotates 120°.

Figure 4

Phase C Current Maximum

somewhat in principle of operation. The squirrel cage rotor looks somewhat like a cage in which pet squirrels are kept. It consists of an iron core mounted on a shaft. Copper bars run in slots the length of the core and are welded to copper end rings. Thus the rotor is an absolute short circuit. It is important that these rotors be good short circuits because currents are produced in the rotor only through mutual induction.

The rotor turns because of the mutual induction that occurs between it and the rotating magnetic field of the stator windings. As the rotating field passes the rotor conductors, currents are produced in the rotor. These currents set up magnetic fields in the rotor whose poles are opposite to that of the rotating magnetic field. The rotor therefore is attracted by the rotating magnetic field, and the interaction of the two fields causes a turning torque to be produced. Thus the rotor turns in the same direction as the field. There is no electrical connection between the rotor and the stator of an induction motor.

The wound rotor uses wire windings instead of copper bars. These windings are carried out to slip rings and short-circuited through a rheostat. The would-rotor induction motor employs the same principles of operation as the squirrel-cage motor. A voltage is induced in the rotor, and current flows through the short circuit. This produces a magnetic field which is attracted to the rotating magnetic field of the stator. Thus a torque is produced and the rotor turns as in the squirrel-cage motor.

Where speed control and a good starting torque are desired, the wound rotor is more satisfactory than the squirrel-cage for induction motors. This advantage is due to the fact that the value of current which flows through the rotor windings may be varied by means of a rheostat. This in turn varies the torque that is developed.

The synchronous speed of an induction motor is the speed of rotation of the magnetic field. The synchronous speed of a motor is dependent upon the frequency of the input voltage and the number of magnetic poles. It is directly proportional to the frequency of the input and inversely proportional to half the number of magnetic poles produced around the stator. Expressed mathematically:

$$S = \frac{F \times 60}{\frac{P}{2}} = \frac{f \times 120}{P}$$

where S is the synchronous speed in RPM, f is the frequency of the input in CPS, and P is the number of magnetic poles produced around the stators. The number 60 is for conversion from RPS (revolutions per second) to RPM (60 seconds per minute).

Although the rotor (armature) and the stator (field) rotate in the same direction, there is relative motion between the two because the speed of rotation of the field is greater than that of the rotor. The relative motion between rotor and field satisfy the conditions necessary for producing a torque; hence the rotor continues to turn when three-phase voltages are applied. The difference in speed between the rotating magnetic field and the rotor is called slip. The amount of slip in RPM is found by subtracting the rotor speed from the synchronous speed of the rotating magnetic field. Percent of slip is found by dividing the amount of slip by the synchronous speed. At no load the rotor turns at almost the same speed as the magnetic field; hence, the slip is approximately zero. At full load, however, the rotor must run at a speed that is from 3 to 20 percent slower than the magnetic field rotation to develop the necessary torque.

SINGLE PHASE INDUCTION MOTORS

Motors which are run from a single phase AC voltage supply are called single phase motors. The series universal motor is one type. All other types of single phase motors operate on the principle of mutual induction like the polyphase induction motor does. However, a difficulty which a single-phase/input to an AC motor raises is caused by the fact that it is impossible to set up a rotating magnetic field with a voltage of only one phase applied. Therefore, a single phase induction motor cannot start automatically but continues to run if started by some means. The problem therefore resolves itself to finding methods of starting a single phase induction motor. For this reason, single-phase motors are often classified according to the method used in starting them. Two examples of these single phase induction motors are the split-phase and capacitor start motor.

Split-phase motors are motors that start by splitting the single phase applied voltage into two voltages which are 90° out of phase with each other. The two phases produce a rotating magnetic field and the motor starts. After the motor has attained sufficient speed, one phase is cut out by a centrifugal switch and the motor continues to run as an induction motor.

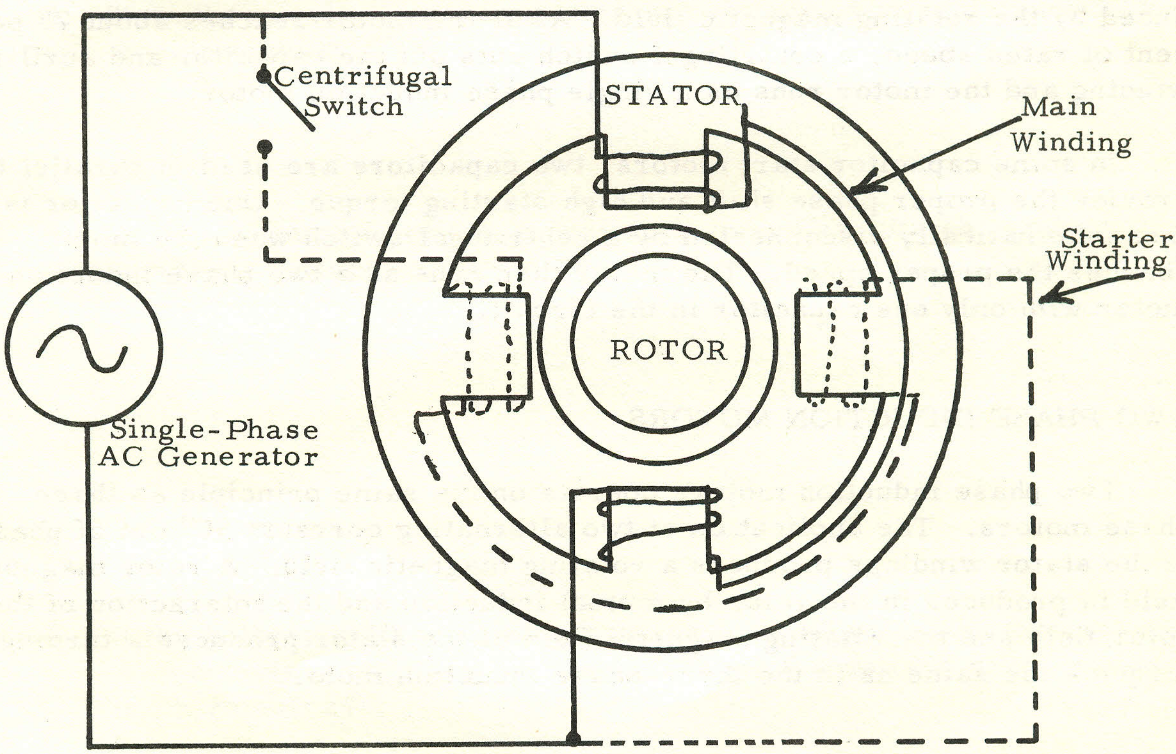


Figure 5

Split Phase Induction Motor

A common type of split-phase motor is shown in Figure 5. The stator has a main winding and an auxilliary winding for starting, displaced 90° from the main winding. The main coils are constructed of heavy wires and have low resistance and high inductance. The starter winding is constructed of fine wire and has high resistance and low inductance. Both windings are connected across the single phase input but the currents produced are out of phase with one another. This produces a rotating magnetic field and the motor starts. The main windings of high inductance remain in the circuit but the high resistance starter winding is cut out by a centrifugal switch after the motor has attained a speed which is about 75 percent of the rated speed. The motor then continues to run as a single phase induction motor.

A second type of single-phase induction motor is the capacitor start motor. Capacitor start motors are split-phase motors in which the two phase voltages necessary for developing a starting torque are produced by means of a capacitor placed in series with the auxiliary winding. See Figure 6. In this type of motor, the phase difference between the currents in the two windings is almost 90°. A greater starting torque is therefore produced by the rotating magnetic field. After the motor reaches about 75 percent of rated speed, a centrifugal switch cuts out the capacitor and auxiliary winding and the motor runs as a single phase induction motor.

In some capacitor start motors, two capacitors are used in parallel to provide the proper phase shift and high starting torque. One capacitor is then automatically disconnected by a centrifugal switch when the motor reaches the proper speed. The motor then runs as a two phase induction motor with only one capacitor in the circuit.

TWO PHASE INDUCTION MOTORS

Two phase induction motors operate on the same principle as three phase motors. The application of two alternating currents 90° out of phase to the stator windings produces a rotating magnetic field. A rotor magnetic field is produced in the rotor by mutual induction and the interaction of the rotor field and the rotating magnetic field of the stator produces a turning torque - the same as in the three-phase induction motor.

SYNCHRONOUS MOTORS

A synchronous motor is one which operates at synchronous speed; hence the slip is zero. This type of motor is not an induction motor. However, the stator of this type of motor is similar to that of the three-phase induction motor. It has a magnetic field which rotates at the speed of the AC generator supplying the three-phase voltages. This motor, therefore, rotates at the same speed as the AC generator.

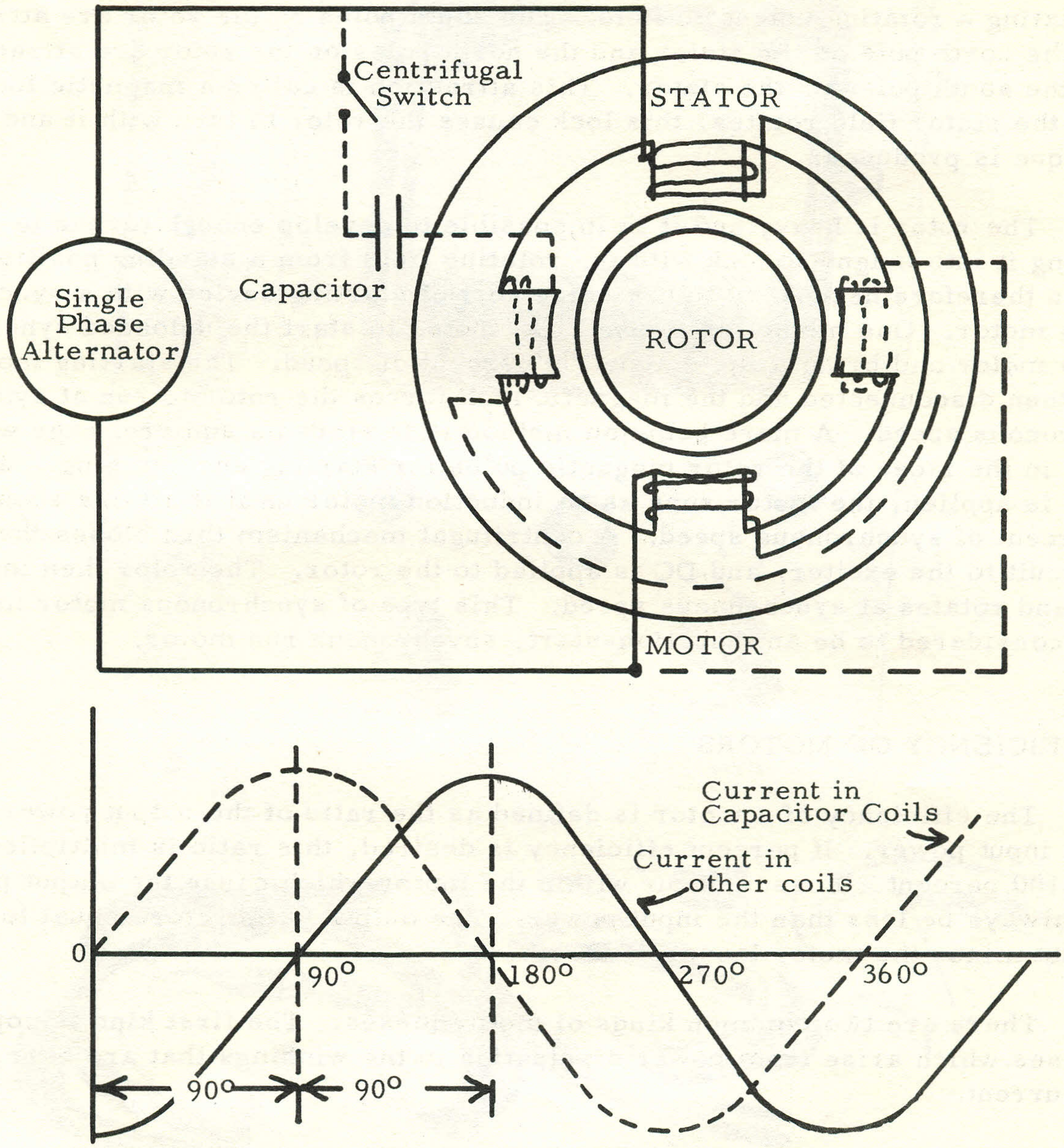


Figure 6

Split Phase Induction Motor and Current Waves

Two sources of power are required for a synchronous motor. In addition to the three phase AC for the stator, DC from a small generator, called an exciter, is fed to the rotor through slip rings. In a four-pole synchronous motor both the rotor and the stator have four magnetic poles; those on the rotor are permanent while those on the stator are continuously changing - creating a rotating magnetic field. The south poles on the rotor are attracted to the north pole on the stator and the north poles on the rotor are attracted to the south poles on the stator. This attraction is called a magnetic lock. As the stator field rotates, this lock causes the rotor to turn with it and a torque is produced.

The rotor is heavy and it is impossible to develop enough torque to bring it into magnetic lock with the rotating field from a standing position. It is therefore necessary to use some sort of starting device with a synchronous motor. One method is to use a DC motor to start the unloaded synchronous motor and bring it up to about 90 percent of speed. The starting motor is then disconnected and the magnetic lock forces the rotor to run at synchronous speed. A more common method is to embed a squirrel cage winding in the faces of the rotor magnetic poles for starting and damping. When AC is applied, the motor runs as an induction motor until it attains about 95 percent of synchronous speed. A centrifugal mechanism then closes the circuit to the exciter, and DC is applied to the rotor. The rotor then locks in and rotates at synchronous speed. This type of synchronous motor may be considered to be an induction-start, snychronous run motor.

EFFICIENCY OF MOTORS

The efficiency of a motor is defined as the ratio of the output power to the input power. If percent efficiency is desired, this ratio is multiplied by 100 percent. Losses occur within the motor which cause the output power to always be less than the input power. The output is therefore equal to the input minus the motor losses.

There are two common kinds of motor losses. The first kind is copper losses which arise from power dissipation in the windings that are carrying a current.

The second kind of motor losses are known as iron losses. These fall into two general categories: eddy current losses and hysteresis. Eddy current losses are caused by small random currents flowing in the iron cores upon which the windings are placed. These losses can be reduced by laminating the core material.

Hysteresis losses arise from residual magnetism within the iron due to the switching of the molecular alignment of the molecules of the material.

These losses can be reduced by using a soft iron material for the core.

Since the output power can never be as high as the input power, the efficiency of a motor can never be 100 percent.

THE UNIVERSAL MOTOR

If AC is applied to a series wound DC motor, the same current flows through the field coil and the armature since the field and the armature are in series. Thus the fluctuations in magnitude and the reversals in polarity occur in the field and armature current at the same time. Their magnetic fields are always in proper phase to develop a torque which rises and falls with the magnitudes of the current but never reverses direction. A series-wound motor which may be used with an AC or a DC power source is called a universal motor.

Universal motors operate under full load at speeds which range from 5000 to 10,000 RPM. When operated with no load, universal motors may rotate at speeds as high as 16,000 RPM. Such motors are used for portable drills, saws, vacuum cleaners, and many household appliances. They are fractional horsepower motors usually ranging in size from 1/100 to 1/3 HP. They are not built in sizes greater than one horsepower, except for special cases.

Since additional armature and field losses occur when universal motors are operated from an AC source, they operate more efficiently with DC. However, many alterations are made in the construction of a series-wound motor so that it will operate more efficiently with AC.

INVERTERS

An inverter is sometimes described as a unit which changes direct current into alternating current. Actually it is a DC motor driving an alternator. To make the unit more compact the armature of the motor and the rotor of the alternator are on the same shaft as in Figure 7.

The motor and the alternator are mounted in the same housing as shown in Figure 8.

The inverter motor is compound wound. The series winding gives the motor high starting torque and reduces the tendency to stall when the load is increased. The shunt winding helps hold the speed constant.

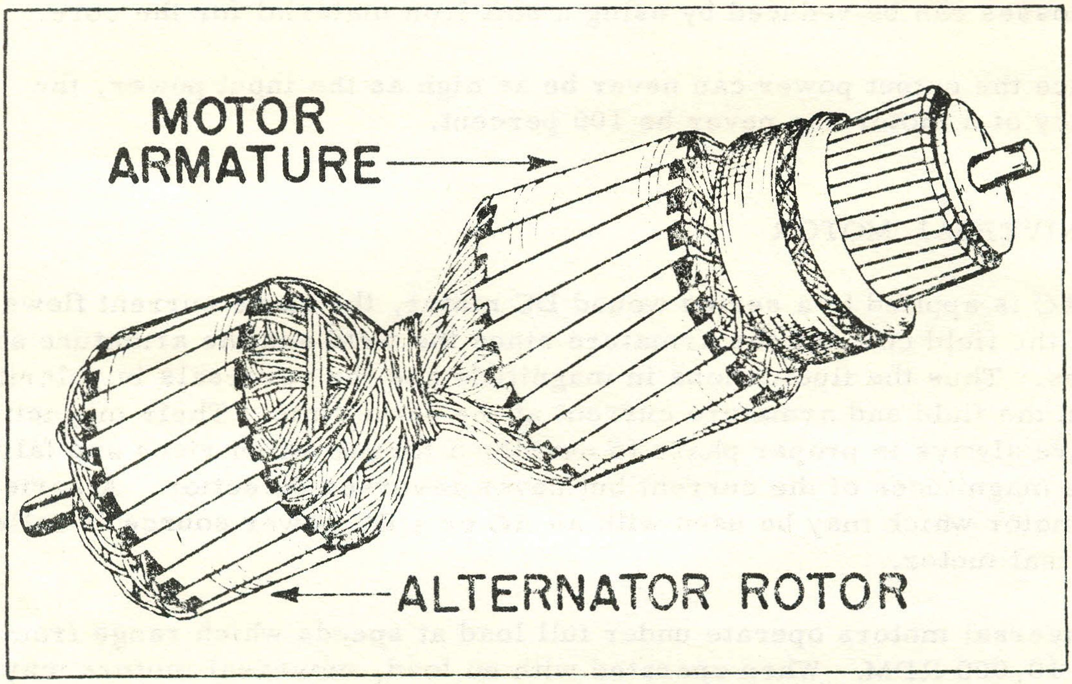


Figure 7

Inverter Rotor

The brush assembly resembles that of any DC motor, except that some models have an extra brush. This is a special high altitude lubricating brush that deposits a thin film of lubrication on the commutator. This lubricant reduces arcing and brush wear at high altitude.

Inverter Operation

Part of the DC current entering the motor also flows through the rotating field or rotor of the alternator. As the rotor turns, the lines of force in its magnetic field cut across the stator windings and induce a voltage in them.

One complete cycle of AC is generated each time a north and south pole in the rotating field moves past a stator coil.

Various output voltages are obtainable from an inverter according to its design. Single phase outputs at 400 cycles include 26 volts, and both 26 volts and 115 volts. Some machines deliver 400 cycle three phase voltages of 115 volts per phase and 200 volts line to line.

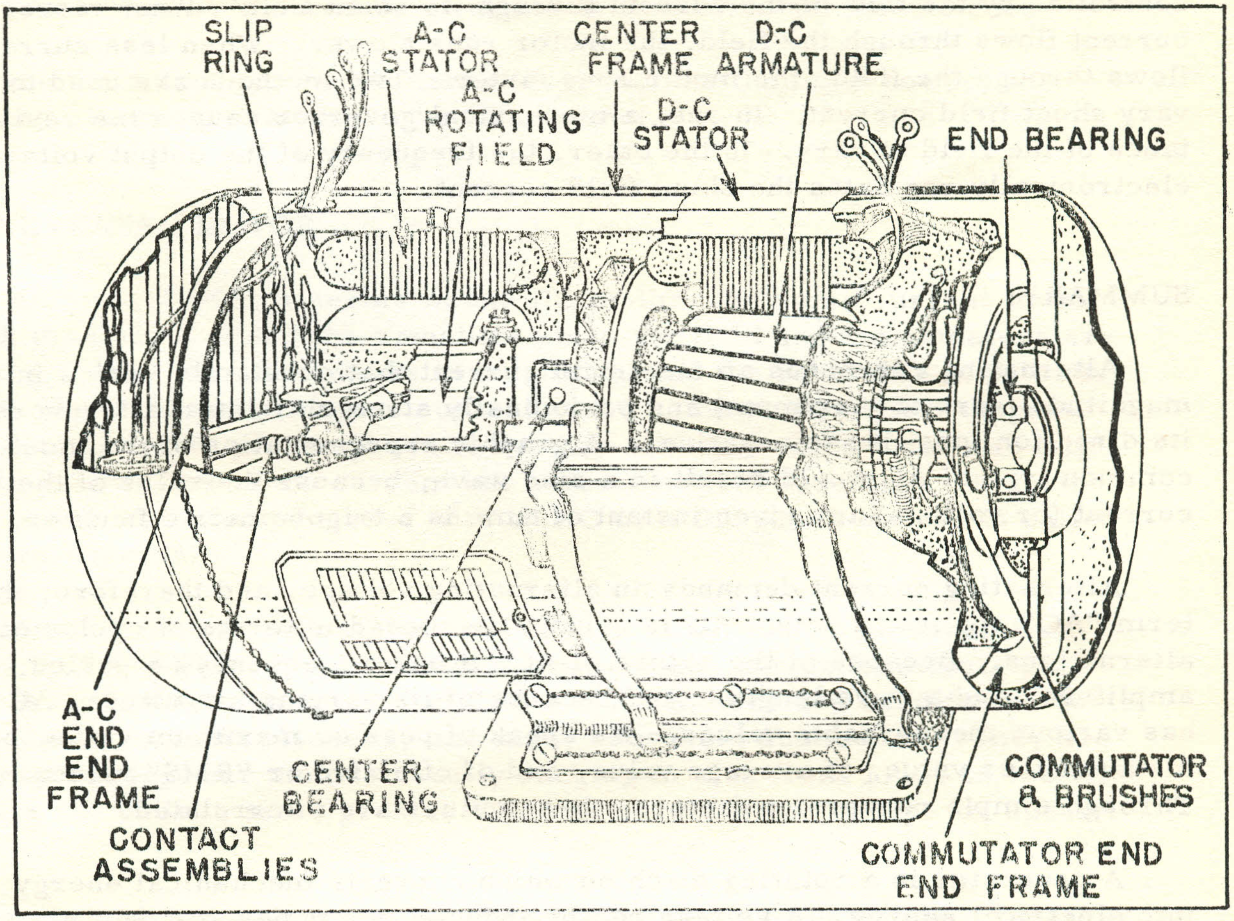


Figure 8

Cutaway Inverter Showing Location of Parts

Voltage Control

The regulator circuit is connected to the AC output of the inverter and increases or decreases the resistance in the circuit that supplies the DC to the rotor. As the DC supplied to the rotor is varied, the magnetic strength of the rotor is varied. The magnetic strength of the rotor determines the AC voltage generated in the stator.

Frequency Control

The inverter should produce 400 cycles per second. Since the frequency depends on the motor speed and the number of poles in the electromagnet, the motor must run evenly at a specified speed. The speed of the motor is controlled by the flow of the current through its shunt field. When more current flows through the field, the motor runs slower. When less current flows through the field, the motor runs faster. Two methods are used to vary shunt field current. In one, a mechanical governor causes the resistance of the field to vary. In the other, the frequency of the output voltage electronically regulates the shunt field current.

SUMMARY:

Alternating current is an electrical current that constantly varies in magnitude (zero to maximum) and periodically at regular intervals reverses its direction (positive to negative). A graphic representation of the most common type of AC would result in a sine wave, because the value of the current (or voltage) any given instant of time is a trigonometric function.

Alternating current demands an alternating voltage, and therefore, the term "AC" applies to both. AC is usually discussed in terms of cycles or alternations. Because of the nature of AC, it has a frequency, a period, an amplitude, and a wave length. And because of its varying magnitude, AC has various measureable values. We speak of peak or maximum value, of instantaneous value, of average value, and of effective or "RMS" value. Through simple conversion factors, these values are interrelated.

A generator is a rotating machine which converts mechanical energy into electrical energy. A voltage can be induced in a conductor by a magnetic field if there is relative motion between the two. A generator is based on this principle. By rotating a coil in a magnetic field (or by rotating a magnetic field within a coil) an EMF is induced. The speed of rotation, the strength of the field, and the number of turns of coil determine the magnitude of the EMF. The left-hand generator rule, based on Lenz's law, is used to determine the polarity of the induced voltage.

The generator's output is connected to the external circuit by means of slip-rings and brushes or by a straight wire hook-up, depending on the generator construction. A graphic representation of this output would result in a sine wave and knows as AC.

Depending upon how the coils are connected, we can have a single-phase or a polyphase generator. A common type of polyphase generator is the three phase generator in which there are three coils, each producing its maximum voltage 120 degrees after the one before it.

A motor is a rotating machine which converts electrical energy into mechanical energy. Motors operate on the principle that a magnetic field will exert a physical force on a current-carrying conductor or coil. An AC motor uses AC in this current carrying conductor. There are two common types of AC motors: the induction motor and the synchronous motor. Both types employ a variation of the basic principle, namely, the electrically rotating magnetic field. A third type, called the universal motor, can operate on either AC or DC.

Both generators and motors have inherent power losses. Some of these losses can be reduced and others cannot. The efficiency of the generator or the motor depends upon the amount of loss. Because of power losses, therefore, these machines are less than 100 percent efficient.

An inverter is a machine which converts DC into AC. Basically, the inverter consists of a DC motor and an AC generator. The motor uses direct current fed to the coils through a brush and commutator arrangement. The shaft of the motor drives an AC generator, which produces alternating current. The input is therefore DC and the output is AC.

QUESTIONS:

1. What is an alternation?

2. What is the period of an alternating voltage?

3. Define amplitude of an alternating voltage.

4. If you know the frequency of the AC, how can you determine the period?

5. If you know the period, how can you determine the frequency?

6. What factors affect the amount of voltage induced in a generator armature?

7. What is the basic principle behind the operation of a motor?

8. a. What are the inherent power losses in an AC generator?

   b. A motor?

   c. Can any of these losses be reduced?

   d. How?

9. Define:
   a. Generator -

   b. Motor -

   c. Inverter -

10. The input of an AC motor is 1000 watts. The power losses amount to 150 watts. What is the efficiency of this motor?

OBR1821B/3121-3-II-5
Student Study Guide
28 November 1961

DAY 24A

INTRODUCTION TO AC TEST EQUIPMENT

OBJECTIVE:

This lesson will acquaint you with the operation of the vacuum tube voltmeter, audio oscillator, and the oscilloscope, and the use of this equipment to analyze AC signals.

INTRODUCTION:

The vacuum tube voltmeter (VTVM) is a test instrument designed to permit the accurate measurement of resistance and voltage. The instrument uses a special vacuum tube bridge circuit that minimizes the loading effect on the circuit under test thereby decreasing an error in voltage measurement which is common to ordinary voltmeters.

The audio oscillator is an instrument designed to generate a stable AC signal suitable for testing the operating characteristics of electronic equipment. The AC signal generated is continuous and may be varied in amplitude and frequency.

The oscilloscope is a device, similar to a television set, that is designed to display electrical signals upon a screen so that they may be examined or measured.

You will learn to examine and measure the phase, frequency and voltage of typical AC circuits using the VTVM, audio oscillator, and the oscilloscope.

REFERENCES:

AFM 101-8 "Fundamentals of Electronics", Chapter 12, pages 84, 85, and 86, Chapter 23, pages 189-193.

THE VTVM

A study of Figure 1 and the related information will provide an understanding of the model 1600 VTVM.

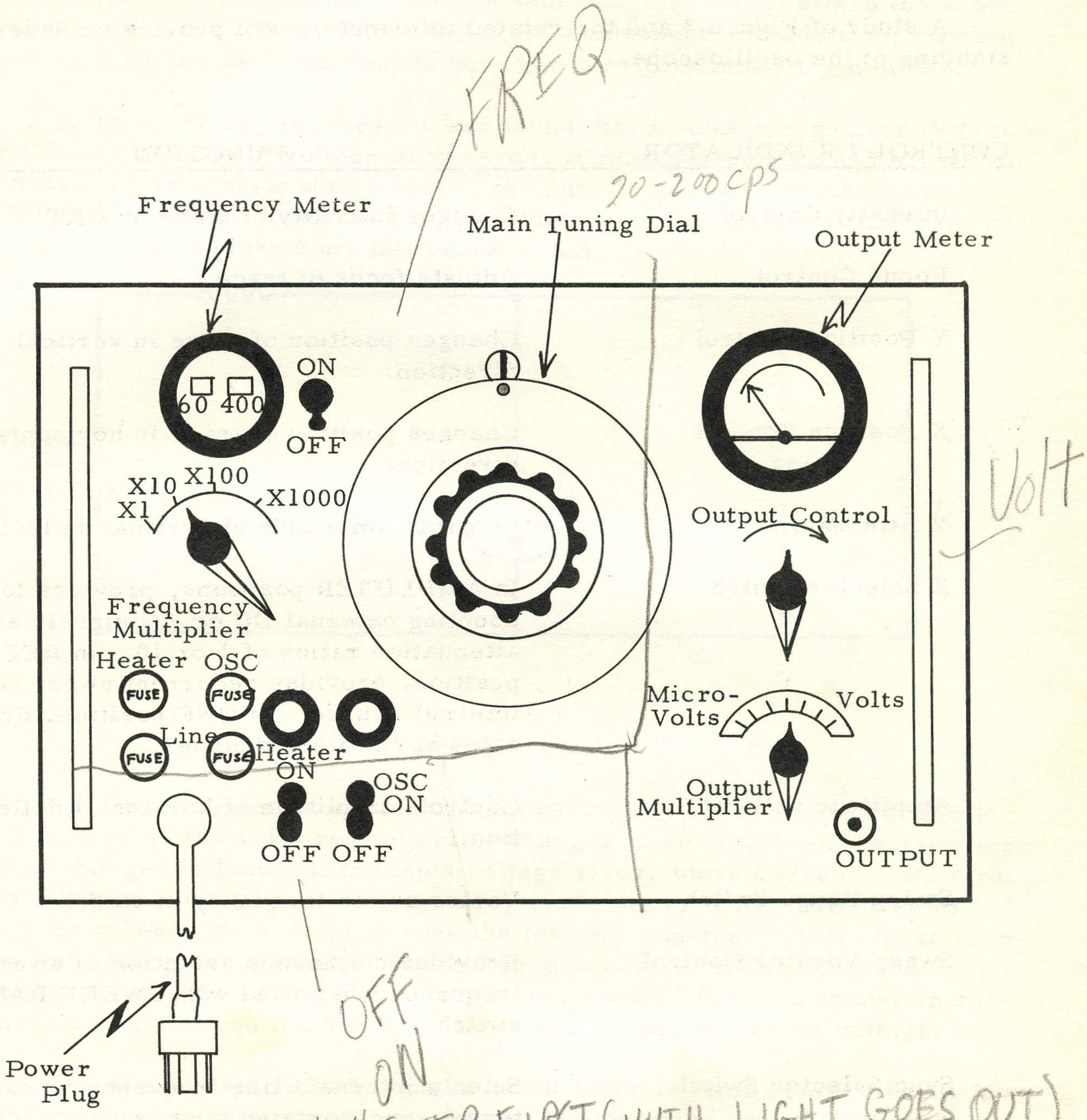
CONTROL OR INDICATOR	FUNCTION
DC Zero Adjust	Adjusts the meter to zero before making a DC voltage measurement.
AC Zero Adjust	Adjusts the meter to zero before making and AC voltage measurement.
Ohms Adjust	Adjusts the meter to zero before making a resistance measurement.
Function Switch	Places power on the instrument when not in the OFF position, selects the polarity of DC voltage to be read and selects either DC, AC or OHMS for proper measurement.
Range Switch	Selects the proper range on the meter for correct measurements.
AC Probe	To measure AC voltages.
DC Probe	To measure DC voltages.
Ohms Probe	To measure resistance.
Common Probe	To establish a common ground.

Figure 1
Vacuum Tube Voltmeter

THE AUDIO OSCILLATOR

A study of Figure 2 and the related information will provide an understanding of the model 382 audio oscillator.

CONTROL OR INDICATOR	FUNCTION
Frequency Meter	Indicates when the oscillator frequency is exactly 60 CPS or 400 CPS.
Frequency Multiplier	Selects the frequency range of operation and provides the multiplier to be used with the reading on the tuning dial.
Heater Switch	Provides power for the heaters.
Oscillator Switch	Provides power for the oscillator section.
Tuning Dial	Varies the frequency of the AC signal from 20 to 200,000 cycles per second depending upon position of FREQUENCY MULTIPLIER switch.
Output Multiplier	Selects the voltage range of operation and provides the multiplier to be used with the reading on the output meter.
Output Terminal	A signal output connector.
Output Control	Varies the output level of the AC voltage from 0 to 12 volts depending upon the position of the output multiplier.
Output Meter	Indicates the amplitude of the AC voltage output.



1. HEATER FIRST (UNTIL LIGHT GOES OUT)
2. TURN OUTPUT CONTROL ALL THE WAY DOWN BEFORE MAKING OR BREAKING CONNECTION

Figure 2

Audio Oscillator TS-382

THE OSCILLOSCOPE

A study of Figure 3 and the related information will provide an understanding of the oscilloscope.

CONTROL OR INDICATOR	FUNCTION
Intensity Control	Changes intensity of trace on CRT.
Focus Control	Adjusts focus of trace.
Y Position Control	Changes position of trace in vertical direction.
X Position Control	Changes position of trace in horizontal direction.
Y Attenuator	Controls amplitude of vertical deflection.
X Selector Switch	In AMPLIFIER positions, provides for coupling external DC or AC signals at attenuation ratios of 1 or 10. In RECUR position, provides recurrent sweep from internal source. In OFF position, disables horizontal amplifier.
Amplitude Control	Controls amplitude of horizontal deflection.
Sweep Range Switch	Varies sweep frequency in steps.
Sweep Vernier Control	Provides continuous variation of sweep frequency when used with SWEEP RANGE switch.
Sync Selector Switch	Selects internal, line frequency or external synchronizing signals.
Sync Amplitude Control	Selects phase and varies amplitude of synchronizing voltage.
Scale Control	Varies intensity of illumination of CRT scale. Includes switch for turning power on and off.

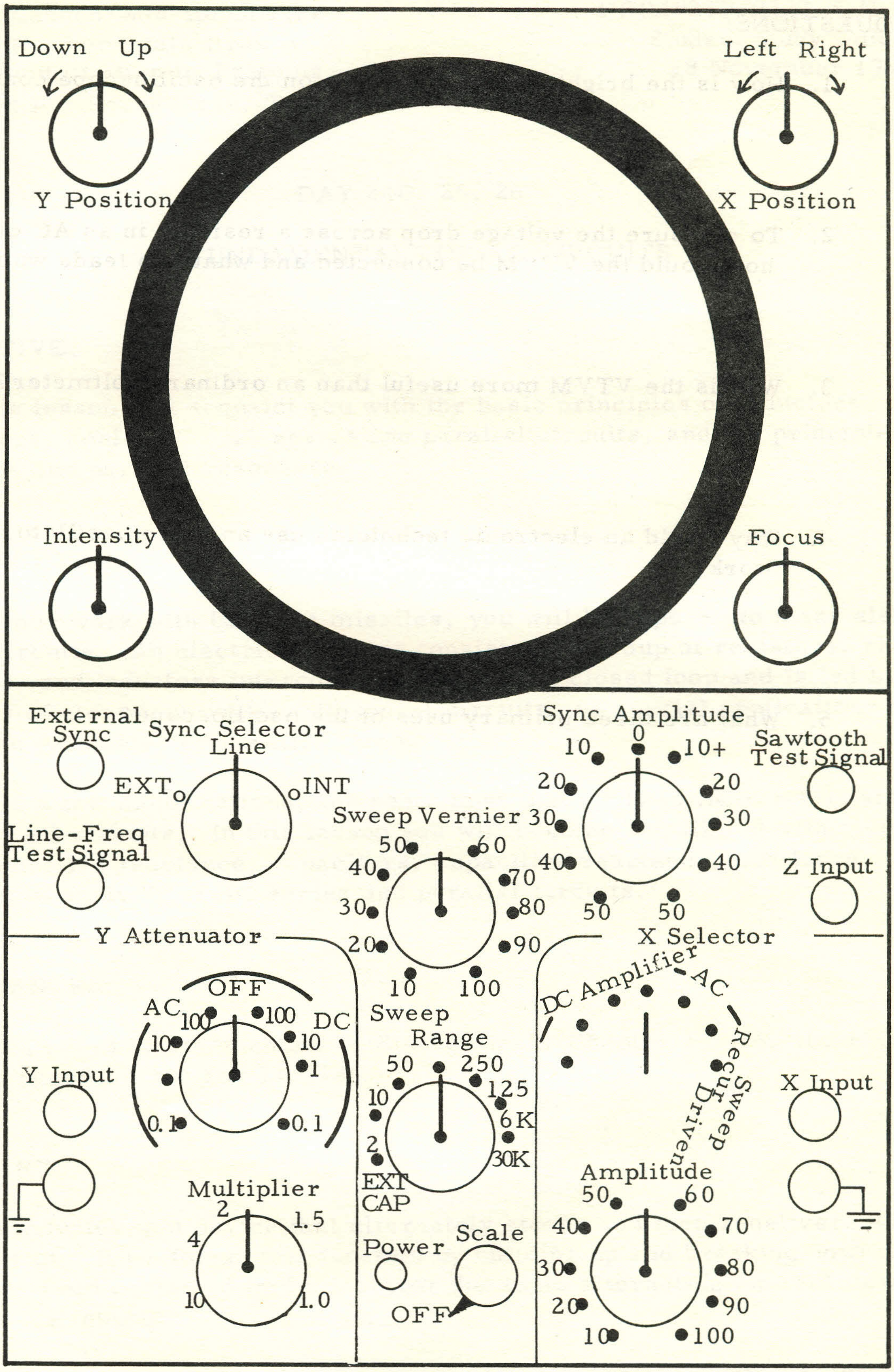


Figure 3
Oscilloscope Dumont 304

QUESTIONS:

1. How is the brightness of the sweep on the oscilloscope controlled?

2. To measure the voltage drop across a resistor in an AC circuit, how would the VTVM be connected and what two leads would be used?

3. Why is the VTVM more useful than an ordinary voltmeter?

4. Why would an electronic technician use an audio oscillator in repair work?

5. What are three primary uses of the oscilloscope?

DAY 24B, 25, 26

FUNDAMENTALS OF AC CIRCUITS

OBJECTIVE:

This lesson will acquaint you with the basic principles of inductors, capacitors, analysis of AC series and parallel circuits, and the principles of series and parallel resonance.

INTRODUCTION:

In your work with ballistic missiles, you will be exposed to many electrical circuits. An electrical circuit consists of a group of resistors, capacitors, and inductors interconnected to form a closed loop and is fed by a supply of electrical power. Resonant circuits are special applications of the basic AC series or parallel circuit.

With a few modifications, the basic laws that apply to DC circuits also apply to AC circuits. In this lesson you will become acquainted with inductors, inductive reactance, capacitors, capacitive reactance, and learn methods of analysis of AC series and parallel circuits.

REFERENCES:

AFM 101-8 "Fundamentals of Electronics", Chapter 13, 14, 16, 17, and 18, pages 87-106 and 115-148.

SUMMARY:

An inductor is a device that alternately stores and then redelivers energy to a circuit. It performs this function by building up and breaking down a magnetic field contained in the inductor due to an alternating current flowing through the inductor.

Inductive reactance is dependent upon the amount of inductance present in the circuit and the frequency of the AC applied to the circuit.

A capacitor is a device utilized for the same general purpose as an inductor except that the capacitor performs the similar function by the building up and subsequent releasing of an electric charge.

Capacitive reactance is dependent upon the amount of capacitance present and the frequency of the AC signal applied to the circuit.

AC circuits are various combinations of resistors, capacitors, and inductors connected in a closed loop fed by a supply of AC power. These circuits are constructed as either series or parallel depending upon the desired output of the circuit.

All series or parallel circuits are of three basic forms: resistive-inductive (RL), resistive-capacitive (RC), and resistive-capacitive-inductive (RCL).

The phase relationship between the voltage and current is different for RC, RL, and RCL circuits. In a RCL circuit, the phase relationship may be computed if the magnitudes of the resistance, inductance, and capacitance are known.

The magnitude of the impedance of an RL, RC, or RCL circuit may be computed if the magnitudes of the various components of the circuit are known.

An RCL circuit can present either an inductive or capacitive load to the AC power supply. It can be determined whether the load is capacitive or inductive by observing the phase relationship between the voltage and the current.

Resonant circuits are special applications of series and parallel LC or RCL circuits. A resonant circuit presents a purely resistive load to the power supply.

By using the laws and theories presented in this lesson, you will be able to analyze series and parallel AC circuits.

QUESTIONS:

1. Define inductive reactance.

2. What is the effect on total inductive reactance of connecting inductors:

   a. in series?

   b. in parallel?

3. Define capacitive reactance.

4. What is the effect on total capacitive reactance of connecting capacitors:

   a. in series?

   b. in parallel?

5. Define impedance.

6. What is the phase relationship between the voltage and current in an RL circuit?

7. What is the phase relationship between the voltage and current in a RC circuit?

8. What is the total impedance in Figure 1?

9. Determine the phase angle between the voltage and current in Figure 1.

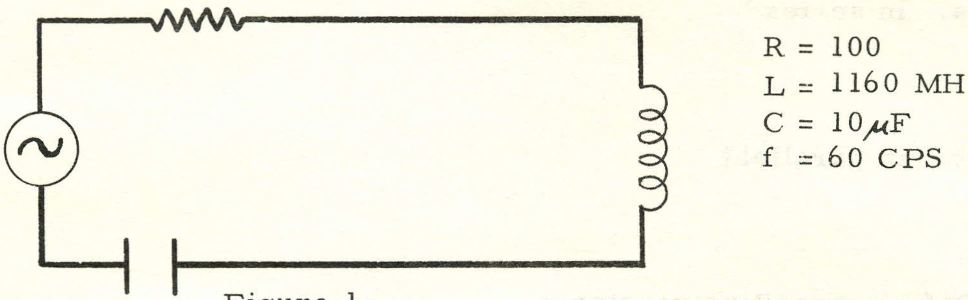


Figure 1

10. Determine the total capacitance of the circuit in Figure 2.

11. Determine the total impedance of the circuit in Figure 2.

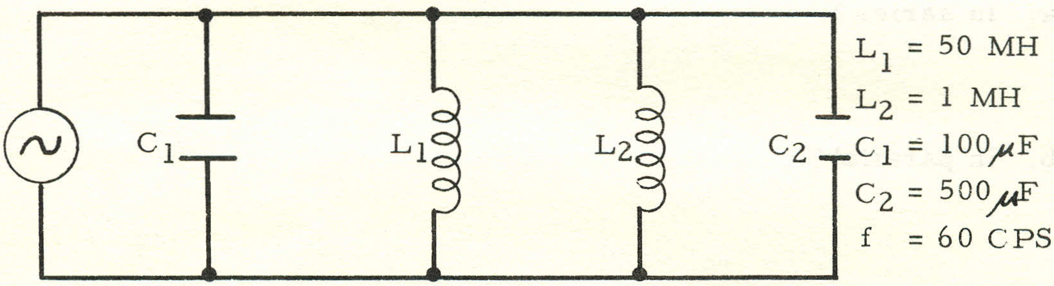


Figure 2

12. What condition is necessary for resonance?

13. What is the resonant frequency of the circuit in Figure 3?

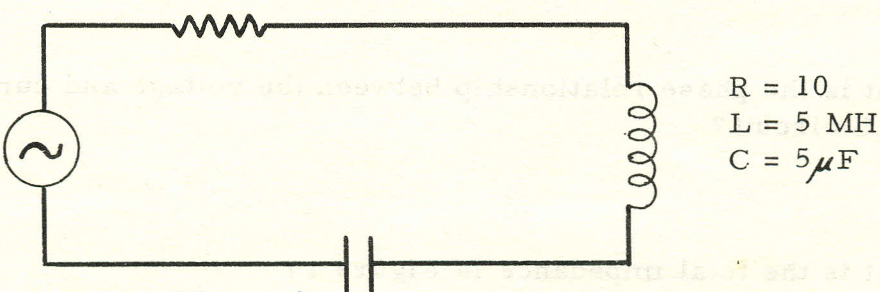


Figure 3

DAY 27 & 28A

DIODE VACUUM TUBES AND POWER SUPPLIES

OBJECTIVES:

To familiarize you with the basic construction, types, purpose and operation of vacuum tubes in various circuits.

To become familiar with the principles and purpose of transformers, rectification, and filtering in AC circuits.

To gain an understanding of the part rectification plays in the construction and operation of a power supply.

To familiarize you with voltage regulators and voltage regulation.

INTRODUCTION:

The success of modern weapon systems depends to a great degree on electronics. On the ground, in the air, or below the surface of the seas, electronic devices are in daily use, and in these uses the electron tube is a vital element. The functions performed by electron tubes are many and varied. Two major uses as discussed in this lesson are the vacuum tubes function in power supplies and in voltage regulators.

REFERENCES:

AFM 101-8 "Fundamentals of Electronics", Chapter 15, pages 107-114, chapter 19, pages 149-158, chapter 22, pages 184-186, chapter 25, pages 203-210.

SUMMARY:

A transformer is a device used to stop up or step down voltage from the primary winding to the secondary. The turns ratio (the ratio between the number of primary and secondary turns) determines whether the voltage will be increased or decreased from primary to seconday. There are many types of transformers in use today, but most of them are for the purpose of converting some input voltage into a useable output voltage.

Electronics has been defined as the science dealing with the control of electron flow in a vacuum or gas; later, it was extended to include transistors and semiconductors. The terms electron tube and vacuum tube are interchangeable when referring to a tube in which a flow of current takes place in an enclosed space. A vacuum tube is one from which the air has been removed to form a partial vacuum. However, in some instances certain gases are introduced inside the tube. Although the enclosed space is not a vacuum, the gas tubes are also included in the category of vacuum tubes.

There are numerous types of vacuum tubes manufactured; each type differs from the other and has specific characteristics. Electron tubes are classified as diodes, triodes, tetrodes, or pentodes according to the number of elements. This study will be confined to diodes. The diode performs three basically important functions - that of a rectifier, limiter and detector.

Diode rectifiers are used in power supplies to convert an AC supply to DC to be used by other tubes in the equipment. Rectifier tubes having only one plate and one cathode are called half-wave rectifiers because current can flow during only one half of the AC cycle. When two plates are used in the same tube or when two tubes are used, current may be obtained on both halves of the AC cycle and are called full-wave rectifiers.

It has been seen that the rectifier changes AC voltage to DC voltage; however, the DC output is a pulsating voltage. This pulse or ripple must be removed or reduced, otherwise distortion will occur in the other vacuum tube circuits. The filter portion of the power supply is the device which removes or reduces the magnitude of the AC component (ripple) of a rectifier.

A capacitor may be used as a filter since it opposes a voltage change across its terminal. Whenever the voltage tends to rise, the capacitor converts this voltage change to stored energy. When the voltage tends to fall, the capacitor feeds this stored energy back into the circuit.

An inductor may be used as a filter, because it opposes a change in current. When current tends to increase the energy is stored in the inductor's magnetic field. When the current through the inductor tends to decrease, the energy is released and maintains the flow of current.

Capacitors and inductors are combined in various ways to provide more satisfactory filtering than can be obtained with a single capacitor or inductor.

A resistor may also be used in a filter network to save expense. It is used in place of the inductor with a disadvantage in that it offers the same impedance to the DC as it does to the AC component. In addition, current flow through the resistor causes power to dissipate in the form of heat.

In the study of gas tubes, it was found that a voltage regulator (VR) tube maintains a constant voltage drop across it when the current is held within limits. In the circuit shown below, the output voltage is regulated by the VR150-30 tube at 150 volts as long as the current through the tube does not exceed 30 MA and does not fall below 5 MA.

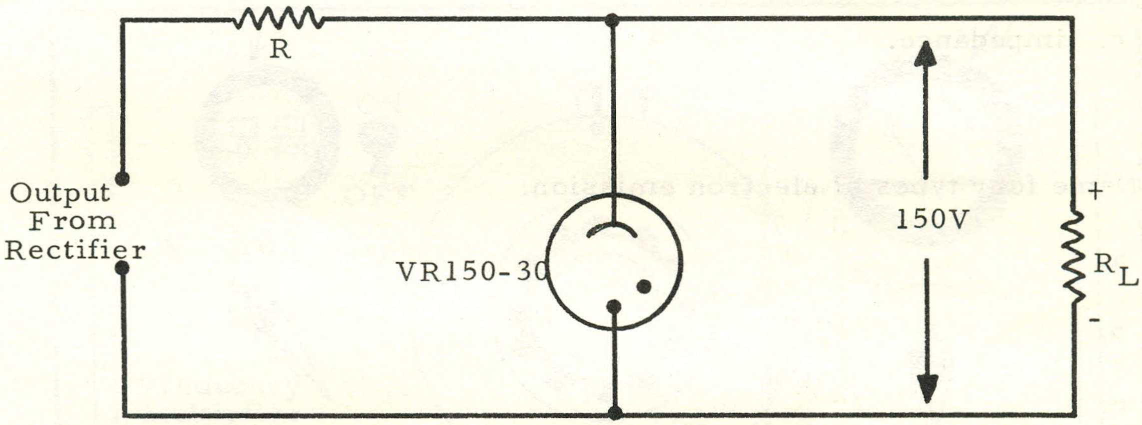


Figure 1

Voltage Regulator

By proper selection of the limiting resistor (R), the output voltage is maintained at 150 volts regardless of changes in voltage from the rectifier or of changes in load. If the input voltage rises, more current flows through the VR tube and a greater voltage drop occurs across R. This greater voltage drop keeps the voltage across the load R_L constant. A decrease in input voltage causes a smaller voltage drop across R and so keeps the output voltage constant. A change in load is compensated for by a change in current flowing through the VR tube, therefore a constant output voltage.

One of the major disadvantages of VR tubes is their comparatively low voltage rating. This may be overcome by connecting several VR tubes in series.

QUESTIONS:

1. Define mutual inductance.

2. State the relationship that exists between the turns ratio of a transformer and the primary and secondary:

a. voltage.

b. current.

c. impedance.

3. Name four types of electron emission.

a.

b.

c.

d.

4. What are the two classifications of electron tubes as distinguished by the presence or absence of gas within them?

a.

b.

5. What feature of diode operation makes possible its use as a rectifier?

6. Why is the output from a full wave rectifier easier to filter than the output from a half wave rectifier?

7. How can you recognize a capacitor input filter and a choke input filter from a schematic diagram?

8. A VR 105-40 and a VR 105-30 are placed in series, what is the maximum current this circuit will handle and still maintain 5% voltage regulation?

9. What is the advantage of a capacitor input filter?

10. In Figure 2, what would be the probable results if C_1 shorted? If L shorted?

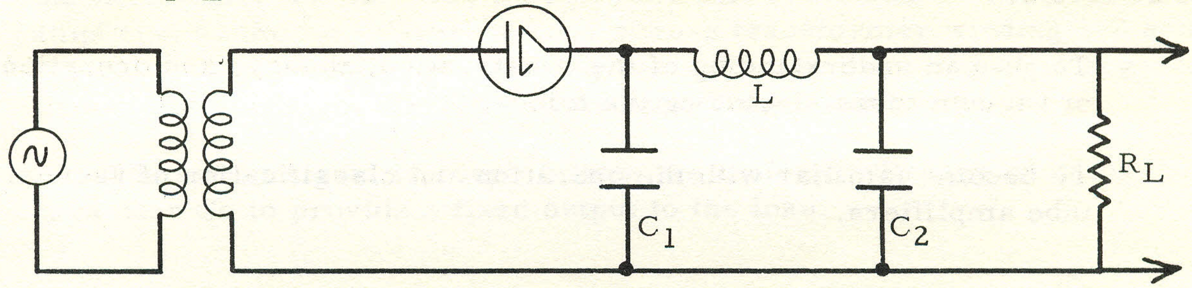


Figure 2

Power Supply

DAY 29 & 30A

VACUUM TUBES AND AMPLIFIERS

OBJECTIVES:

To gain an understanding of the construction, theory, and operation of vacuum tubes, including the triode.

To become familiar with the operation and classification of vacuum tube amplifiers.

INTRODUCTION:

There are many uses for vacuum tubes in missile radio guidance, telemetry, and much of the support equipment. Thus, it is important to have a basic understanding of these tubes.

One of the specific uses of the vacuum tube is amplification where small signals are reproduced in a much larger form.

In most cases one vacuum tube is not sufficient and, therefore, several tubes are coupled together. In today's lesson, the vacuum tube amplifier and coupling circuits will be studied.

REFERENCE:

AFM 101-8, pages 159-163, 165-180, 187-188, 215-228.

SUMMARY:

The triode is a three element vacuum tube consisting of a cathode, anode (plate) and a control grid. The cathode emits electrons which are controlled by the grid and collected by the plate.

The triode has some disadvantages which are overcome by the addition of a second grid known as the screen grid. This four element tube is called a tetrode. A third grid (suppressor grid) is sometimes used and in this case the tube is known as a pentode. There are also many other special purpose tubes.

The amplifier circuit in Figure 1 shows an input from grid to ground and an output from the plate to ground. The output of this tube may well be the input to a second tube which would further amplify the signal. It is understood that a battery or power supply completes the circuit between B+ and ground.

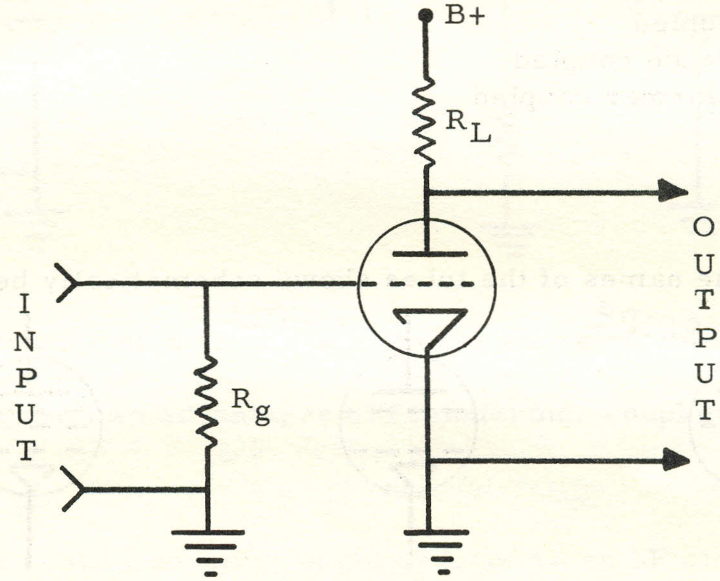


Figure 1

Basic Amplifier

It is desirable that the grid be negative with respect to the cathode. This negative grid voltage is called bias (fixed or self). Fixed bias may be obtained with a battery or a voltage divider network. Self bias may be either cathode self bias or grid leak bias.

Amplifiers may be classified several ways as shown below.

According to use.

Voltage
Power

According to the amount of bias.

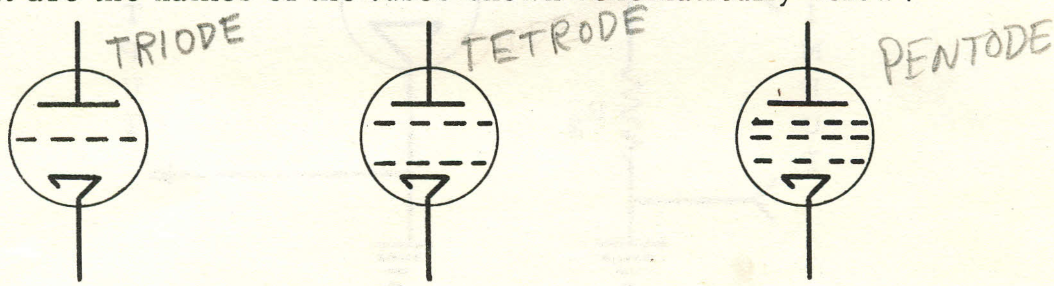
- Class A
- Class B
- Class AB
- Class C

According to coupling.

- Direct coupled
- RC coupled
- Impedance coupled
- Transformer coupled

QUESTIONS:

1. What are the names of the tubes shown schematically below?



2. How does the input of an amplifier compare to the output in phase relationship?

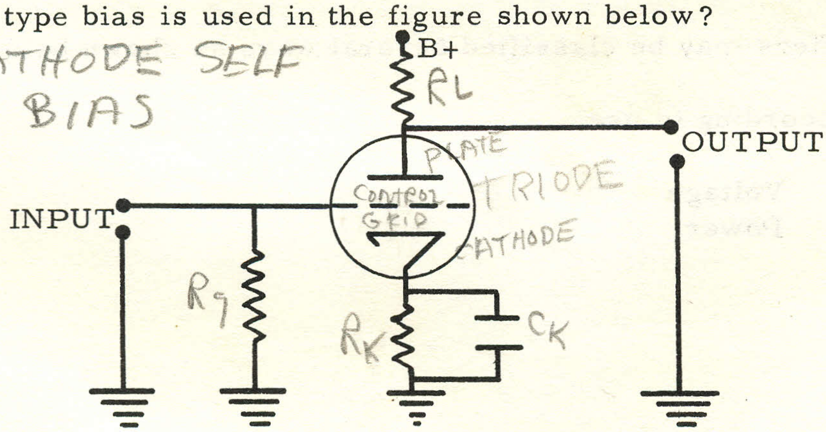
   180° OUT OF PHASE

3. How is the gain of an amplifier determined?

   $\frac{AC\ OUT}{AC\ IN}$

4. What type bias is used in the figure shown below?

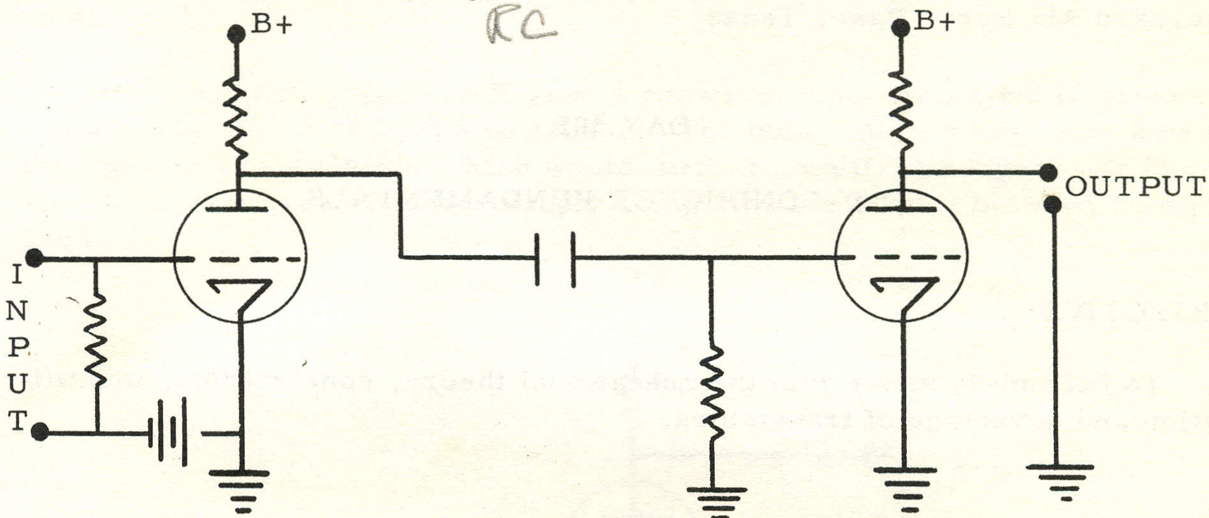
   CATHODE SELF BIAS



5. Label the component in the above circuit.

6. What type of coupling is used in the circuit shown below?

RC



7. What types of bias are used in the above circuit?

Battery GRID LEAK

8. What are two advantages of transformer coupling?

1 STEP UP GAIN
2. IMPEDANCE MATCHING

9. What type of coupling would be used in an IF amplifier?

TUNED TRANSFORMER COUPLE

10. What class bias would be used for a one tube audio amplifier?

CLASS A

DAY 30B

SEMI-CONDUCTOR FUNDAMENTALS

OBJECTIVE:

To become familiar with the operational theory, construction, identification and advantage of transistors.

INTRODUCTION:

The word Transistor is derived from TRANSfer and resISTOR. Transistors are semi-conductor devices capable of amplifying electric signals, thus they can perform many of the functions of a vacuum tube. Furthermore, transistors are smaller, lighter, more rugged and efficient than vacuum tubes. For this reason, they are becoming widely used in the missile field.

REFERENCES:

AFM 101-8 "Fundamentals of Electronics", Pages 182 - 183.
Mann G. B. The ABC's of Transistors, Chapter 1 and 2, pages 7-26.

SUMMARY:

Transistors are capable of amplifying signals because of the unique properties of semi-conductors. Two types of transistors are the junction and point contact. Junction transistors are a recent development and are more widely used. Because of their light weight, small size, efficiency and ruggedness transistors are extremely useful for missile equipment.

QUESTIONS:

1. What is a semi-conductor?

4 VALENCE ELECTRONS

2. Explain the difference between P & N type germanium.

N TYPE - DONOR 5 VALENCE
P TYPE - ACCEPTOR 3 VAL

3. Explain why there is a low opposition to the flow of current in only one direction through a PN germanium diode.

Battery REDUCES BARRIER IN ONE DIR BUT AIDS IT IN THE OTHER.

4. What is the emitter-to-collector carrier in the PNP and the NPN transistors?

PNP = HOLES
NPN = ELECTRONS

5. What is the reason for a thin base region in transistors?

ALLOW CURRENT CARRIERS TO GO THROUGH BASE TO THE COLLECTOR

6. What is the meaning of the term "potential hill" as used in transistor theory?

PREVENTS CURRENT FLOW

7. If you are observing a transistor with a red dot on one side, how would you determine the emitter terminal?

COLLECTOR RED
COUNTERCLOCKWISE TO E

DAY 31 & 32A

TRANSISTOR AMPLIFIERS AND OSCILLATORS

OBJECTIVE:

To become familiar with basic transistor amplifier circuits, bias, input and output signals, classification and coupling.

To become familiar with the types of oscillators, conditions necessary for oscillation, and principles of oscillators as to circuit structure and frequency of oscillation.

INTRODUCTION:

Like vacuum tubes, transistors are used in amplifier circuits. There are many similarities as well as certain differences between vacuum tube and transistor amplifiers. Most of the differences arise from the necessity to compensate for temperature changes in transistors. Many transistor amplifiers are used in missile equipment and it is important for you to understand these differences.

Most of the commonly used vacuum-tube oscillator circuits may be transistorized in order to adapt them to low-power, miniaturized circuitry. Because of the difference in component values, polarities, and general circuit arrangement, a detailed analysis to transistor oscillator circuity is essential for an understanding of missile systems' operation.

Oscillator circuits may be externally excited or self-excited. Our discussion will deal with the self-excited type of oscillators. In the self-excited type, some of the power of the output is fed back in phase to the input in order to sustain the oscillatory action.

While several types of the most commonly used oscillators will be discussed, several features are common to all oscillators. The following statements are true of all oscillators.

They will contain an amplifying device (in our case, a transistor).

A power source to replace I^2R losses.

A feedback arrangement to cause oscillation.

A frequency-selective system.

REFERENCE:

ABC's of Transistors, Pages 26-61.

ABC's of Transistors, Page 37.

TICKLER COIL OSCILLATORS

A transistor oscillator using a tickler coil for inductive feedback is shown in A of Figure 1. DC bias circuits have been omitted for simplicity. The currents and voltages indicated in the Figure are AC and are instantaneous. The waveforms of emitter and collector currents are shown in B of Figure 1.

Oscillations begin in the circuit when the bias conditions of the transistor are normal and power is applied. The amplitude of current flow in the circuit will increase steadily as shown between points X and Y and B, in Figure 1. This increase is due to the regenerative feedback coupled from the collector circuit to the emitter circuit by the transformer windings.

A point (Y) is reached at which time the collector current can no longer increase. The transistor is saturated, and since no further change in collector current exists, feedback ceases and emitter current begins to fall. This decrease in emitter current results in a decrease in collector current.

The decrease in collector current causes the induced feedback voltage to reverse and the emitter current decreases. The emitter current decreases steadily as shown between points Y and Z in B of Figure 1 because of the regenerative feedback until another point (Z) is reached at which time the emitter current is cut off. The emitter-base diode is reverse-biased at this point. Collector current ceases to flow causing the feedback current to cease flowing. Once the feedback current, which had driven the transistor to cutoff, ceases, the bias conditions begin to revert to their original state and the process is repeated.

Basically, the transistor is driven to saturation, then to cutoff, then back to saturation, etc. The time for change from saturation to cutoff is primarily determined by the tank circuit, which, in turn, determines the frequency of oscillation.

FEED BACK
CRYSTAL CONTROL
MORE STABLE

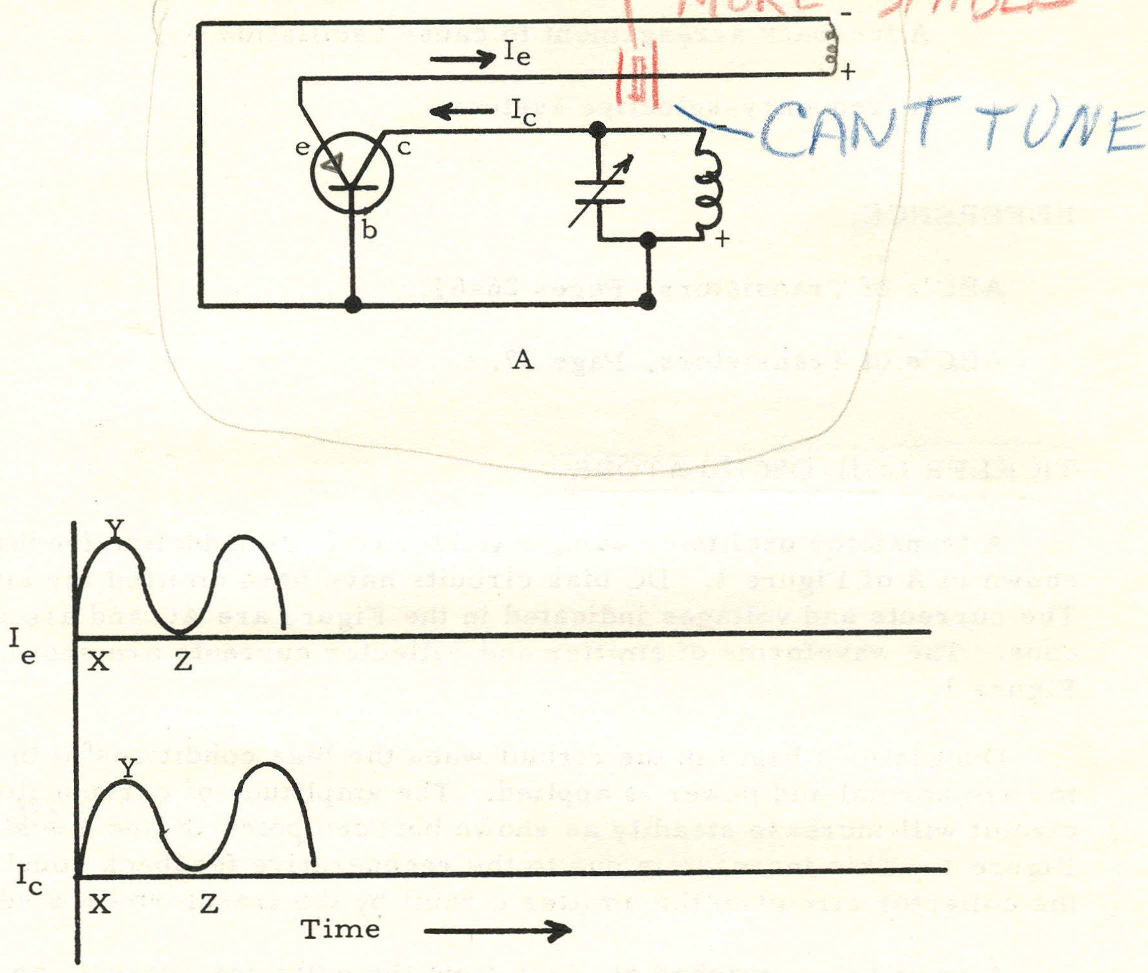


Figure 1

Typical Transistor Oscillator and Current Waveforms, Bias Circuits Omitted

TUNED-BASE OSCILLATION

The tuned-base oscillator shown in Figure 2 is similar to the electron tube tuned-grid oscillator. In this application, one battery is used to provide bias for the common-emitter configuration. Resistors R_b, R_c, and R_F provide the necessary bias conditions. Resistor R_e is the emitter swamping resistor. The components within the dotted lines comprise the transistor amplifier. The collector shunt-fed arrangement prevents DC current flow through tickler winding 1-2 of transformer T_1. Feedback is accomplished by the mutual inductance between the windings of the transformer.

The tank circuit consists of transformer winding 3-4 and variable capacitor C1 and constitutes the frequency determing components of the oscillator. Variable capacitor C1 permits tuning the oscillator through a range of frequencies. Capacitor Cc couples the oscillatory signal to the base of the transistor and also blocks the DC. Without capacitor Cc, the base bias condition would be determined primarily by the low DC resistance of transformer winding 3-4. Capacitor Cc bypasses the AC signal around emitter swamping resistor Re and prevents degeneration.

Oscillations in this circuit are started the moment the DC power is connected in the circuit. At that moment, a surge of current flows through the transistor, and the base circuit goes into oscillation. The oscillations, amplified by the transistor, appear across transformer winding 1-2 and are coupled to transformer winding 3-4. The feedback signal is regenerative and of sufficient magnitude to sustain oscillations.

The output signal is coupled from the collector through coupling capacitor Co to provide a fixed output to the load.

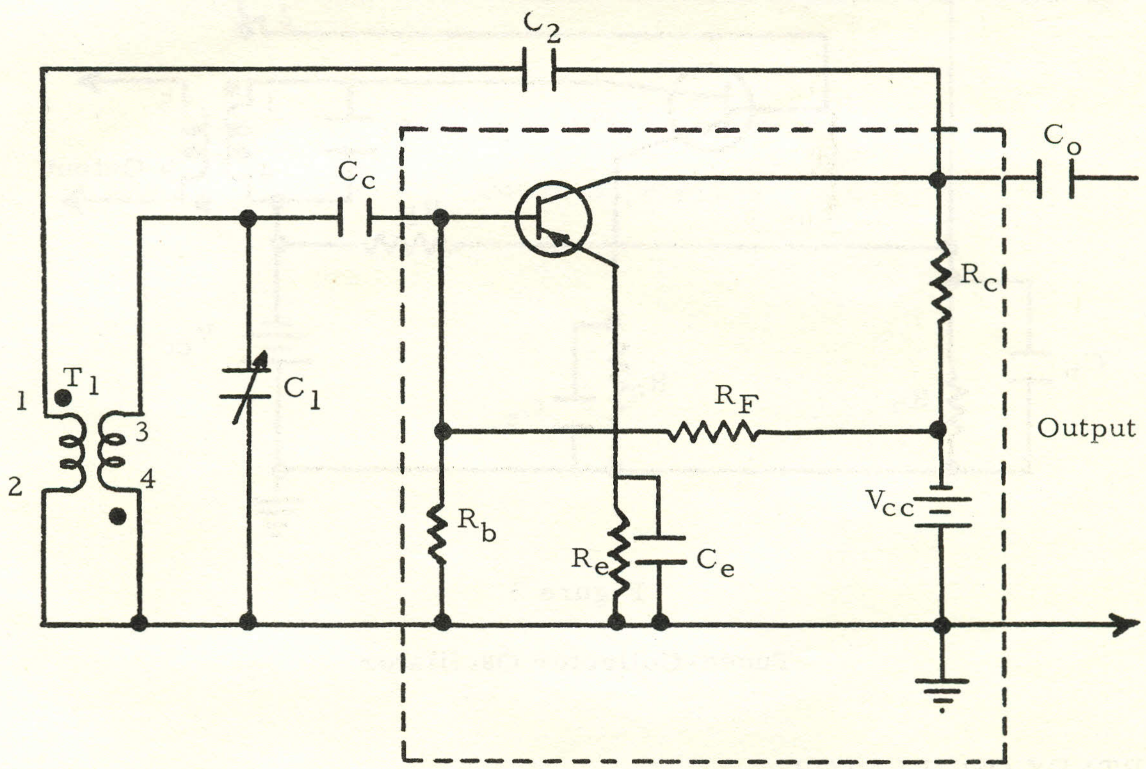


Figure 2

Tuned-Base Oscillator

TUNED-COLLECTOR OSCILLATOR

The tuned-collector transistor shown in Figure 3 is similar to the electron tube tuned-plate oscillator. Resistors R_f and R_b establish the base bias. Resistor R_e is the emitter swamping resistor. Capacitor C_b and C_e bypass AC around resistor R_b and R_e respectively. Although a series-fed arrangement of the tuned-collector oscillator is also possible with slight circuit modification.

The tuned circuit consists of transformer winding 3-4 and variable capacitor C1. Capacitor C1 permits tuning the oscillator through a range of frequencies. Oscillations in this circuit are started the moment the DC power is applied. Regeneration is accomplished by coupling the feedback signal from transformer winding 3-4 to transformer winding 1-2. Transformer winding 5-6 couples the signal output to the load.

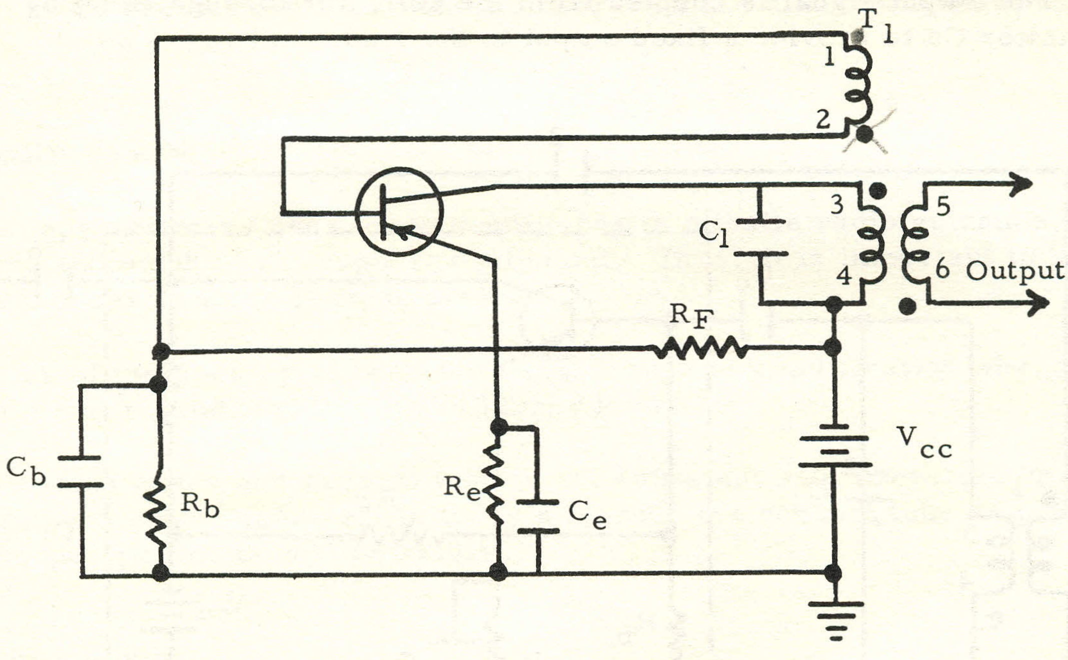


Figure 3

Tuned-Collector Oscillator

HARTLEY OSCILLATOR

The shunt-fed oscillator shown in Figure 4 and the series-fed oscillator shown in Figure 5 are operationally similar. They differ primarily in the method of obtaining collector bias.

SHUNT-FED HARTLEY OSCILLATOR

Resistor R_b, R_c, R_f in the shunt-fed oscillator of Figure 4 provide the necessary bias conditions for the circuit. The frequency determining network consists of the series combination of transformer windings 1-2 and 2-3 in parallel with capacitor C1. Since capacitor C1 is variable, the circuit may be tuned through a range of frequencies. Capacitor C2 is a DC blocking capacitor. Capacitor C_e provides an AC bypass around emitter swamping resistor R_e.

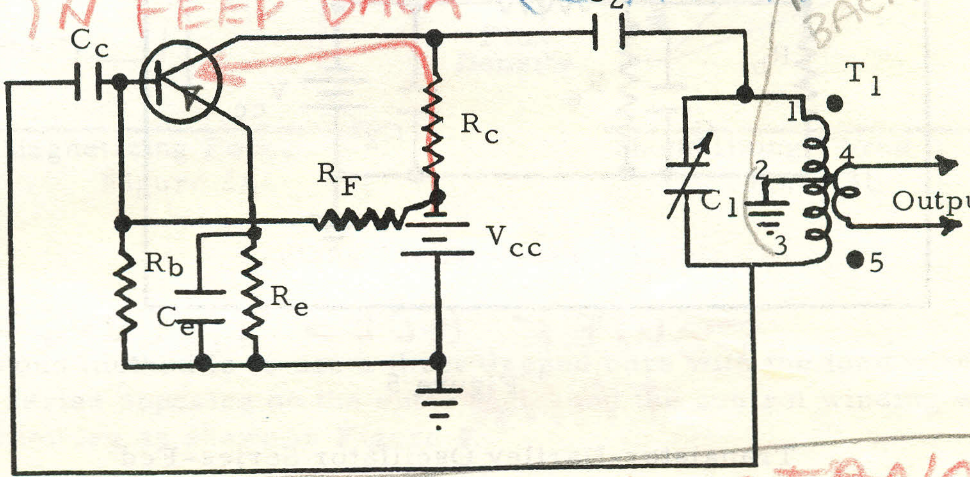


Figure 4

Transistor Hartley Oscillator, Shunt-Fed

The inductance functions has an autotransformer to provide the regenerative feedback signal. The feedback is obtained from the induced voltage in transformer winding 2-3, coupled through capacitor C_c to the base of the transistor. By shunt feeding the collector through resistor R_c, direct-current flow through transformer T1 primary is avoided.

SERIES-FED HARTLEY OSCILLATOR

Resistors R_b and R_f of Figure 5 provide the necessary bias for the base-emitter circuit. Collector bias is obtained through transformer winding 1-2. Capacitor C_e provides an AC bypass around emitter swamping resistor R_e.

The feedback is obtained from the induced voltage in transformer winding 2-3 coupled through capacitor C_c to the base of the transistor. Capacitor C_2 places terminal 2 of transformer T_1 at AC ground potential.

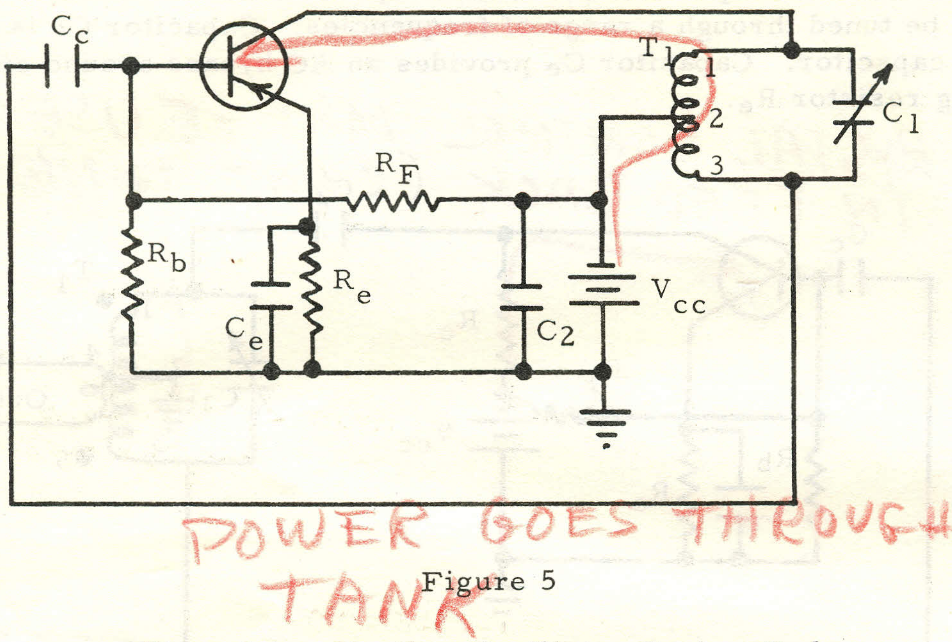


Figure 5

Transistor-Hartley Oscillator Series-Fed

REFERENCE:

Read chapter 5 in "ABC's of Transistors" for additional information pertaining to oscillators.

SUMMARY:

There are three basic transistor circuit configurations; common emitter, common base, and common collector. The configuration used will affect the characteristics of the amplifier. There are three general classes of transistor amplifiers as to the mode of operations, A, B, and C. In class A, the bias sets the collector current halfway between maximum and cutoff; in class B, the collector current is set at cutoff and in class AB it is between that in A and that in B. Transistor amplifiers may use transformer, capacitor or DC coupling.

Although the components and the polarities may be different, the transistor oscillator may be a LC, RC, RL, or crystal oscillator like its vacuum-tube counterpart.

The tickler-coil transistor oscillator may take the form of a tuned-base or a tuned-collector circuit. These are analogous to the vacuum-tube tuned-grid and tuned-plate oscillator circuits.

The Hartley oscillator utilized a split inductance rather than a split capacitance. Several modifications of the basic Hartley oscillator are available. They differ mainly in the method of obtaining collector bias.

An oscillator that produces a sine wave output from an RC network is useful because of its clean sine wave and frequency stability. The Wien Bridge type oscillator is one such oscillator. It is used mainly in Test Equipment.

QUESTIONS:

1. What are the three basic configurations and how does each affect amplification? COMMON BASE (VOLTAGE)
   " EMITTER (VOLTAGE + CURRENT)
   " COLLECTOR (CURRENT)

2. From which configuration can maximum current amplification be obtained? COMMON COLLECTOR

3. By what other name is the common collector configuration known? How is it used? EMITTER FOLLOWER
   IMPEDANCE MATCHING

4. Why is it ~~necessary~~ Advantageous to use a voltage divider or ~~current feedback~~ in biasing a transistor? ELIMINATE BATTERY

5. What are the classes of transistor amplifiers according to mode of operation? A, B, C

6. How are transistor amplifiers coupled?

DIR, RC, IMPED, TRANS

7. What is ~~the~~ an advantage of each type coupling?

DIR - GAIN AT LOW FREQ
RC - WIDE BAND
~~IMPED~~ - EFFICIENT
TRANS Z MATCH STEP UP GAIN

8. Name the four requirements necessary for transistor feedback oscillators to operate.

a. POWER SOURCE

b. AMPLIFIER

c. FEEDBACK

d. FREQ DET DEVICE

9. Explain the function of each of the four requirements in question #~~1~~8 ~~and how they affect the circuit~~.

POWER AMP
REPLACE CIRCUIT LOSS
REPLACE TANK "
AC

10. How can the frequency of a tuned-collector oscillator be varied?

VARRIABLE CAPICTOR IN TANK

11. How is feedback obtained in the Series-fed Hartley Oscillator?

SPLIT INDUCTANCE

DAY 32B & 33

TRANSMITTER AND RECEIVER PRINCIPLES

OBJECTIVE:

To become familiar with the electronic principles of radio transmission and reception.

INTRODUCTION:

The success or failure of any military operation depends on the efficiency of its communication system. This is particularly true of all missile operations, both in the communication systems themselves and in the radio guidance systems used to direct the missile weapon to its target. This lesson will acquaint you with the basic principle of radio transmission and reception of intelligence, whether it be voice communication or guidance data.

REFERENCES:

AFM 101-8 "Fundamentals of Electronics", pages 197 - 202 and 251 - 282.

SUMMARY:

A transmitter consists of two parts. These are the RF generator section and the modulator. The generator section generates radio frequency waves. This section also amplifies the radio frequency waves so that they have sufficient output power. The modulator section modulates the amplified radio frequency waves. The modulator varies the carrier wave so that it can convey a message. This is called modulation. The message is called the modulating signal and the changed carrier wave is called the modulated wave. There are three basic ways of varying a carrier wave. These are amplitude modulation, frequency modulation, and ~~phase~~ Pulse modulation.

The high energy modulated wave is fed to the antenna. The antenna in turn radiates the signal into space where it travels with the speed of light until it is picked up by another antenna. The pickup antenna feeds the signal into a receiver.

A receiver also consists of two basic parts. These are the detector and the reproducer. The detector separates the information or modulating signal and amplifies it. The reproducer changes the information to a form which can be seen or heard.

QUESTIONS:

1. Why is knowledge of transmitter and receiver principles important?

   SUCCESS

2. Name two types of communications systems where a transmitter, antenna system, and a receiver are employed.

   RADIO, TV, RADAR, SONAR,

3. What are the 3 basic types of modulation? Which kind is most commonly used? CW, AM, FM

   AM

4. Why is a reproducer necessary in a receiver?

   TO HEAR

5. Draw a block diagram of a basic communication system.

DAY 34A

MAGNETIC AMPLIFIERS

OBJECTIVES:

To become familiar with:

Theory and characteristics of saturable reactors.

Operating characteristics of magnetic amplifiers.

Magnetic amplifier circuits.

INTRODUCTION:

Saturable reactors and magnetic amplifiers are not new; the principles of the saturable core were used as early as 1885, although they were not identified as such. Their development in the United States has been slow. Today the uses of magnetic amplifiers for military and civilian purposes are many. They are highly efficient, small and compact, rugged and stable, and they are replacing vacuum tubes in many circuits. They are also used in servomechanisms, voltage regulators, and high speed analog and digital computers.

BASIC PRINCIPLES OF SATURABLE REACTORS

Basically the saturable reactor consists of a coil of wire wound around a magnetic material. The saturable reactor makes use of two properties of coils that utilize magnetic cores. The first is SATURATION. This is the ability of a core to reach a limit to the number of lines of flux it can pass. The second useable property, REACTANCE, is the ability of a coil to oppose the flow of alternating current. A saturable reactor is a coil in which opposition to AC can be changed by controlling the flux density of its core.

PROPERTIES OF A COIL

To understand how core saturation causes reactance of a coil to change, we must review the properties which affect reactance. REACTANCE is determined by the frequency of AC and the inductance of the coil. Written in a formula, the relationship would appear as follows:

$$X_L = 2\pi fL$$

Therefore, we can see that by increasing frequency or inductance, we can increase reactance. In the same manner, if frequency or inductance were reduced, reactance would also drop.

Inductance is the property we control in the operation of a saturable reactor. The inductance of a coil is dependent upon the flux density and magnetic intensity of the magnetic field of the core. The inductance is directly proportional to the flux density and inversely proportional to the magnetic field:

$$L = K\frac{BN^2a}{Hl}$$

where K is a constant
B is flux density
H is magnetic intensity
a is the cross-sectional area of the coil
l is the length of the coil
N is the number of turns.

If the coil contains an iron core, it is found that as the core saturates the flux density becomes constant while the magnetic intensity continues to increase. Therefore, the inductance of the coil decreases. Conversely, as the core comes out of saturation (de-saturates) the inductance increases.

Since the flux density and magnetic intensity are directly dependent upon the amount of current in the coil, we can vary the inductance of the coil by varying the amount of current flow. It is this fact that allows us to vary the reactance of a coil. A coil that has the above characteristics is called a variable inductance coil.

THE SATURABLE REACTOR

Figure 1 shows the circuit of a saturable reactor. It is composed of a DC (control) circuit, an AC (load) circuit and an iron core.

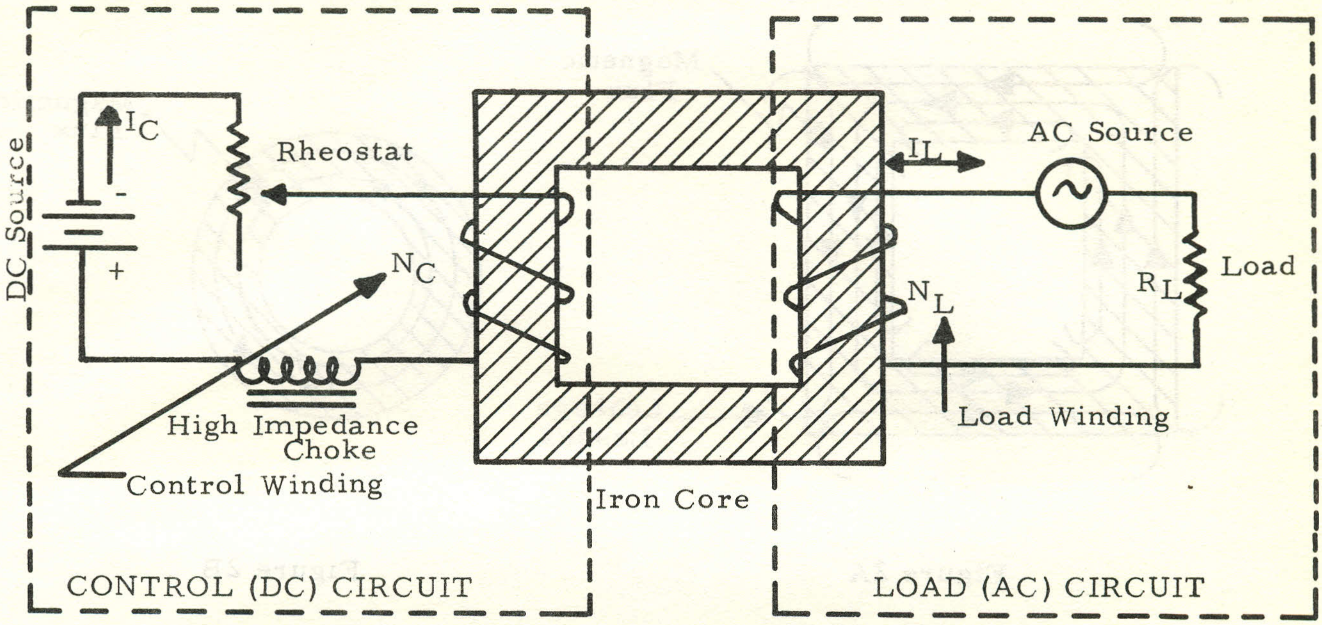


Figure 1

Simple Saturable Reactor

By varying the DC (control) current, I_C we are able to vary the amount of AC (load) current, I_L, delivered to the load, R_L. As the DC current is increased it sets up a flux that saturates the core. As the core saturates the inductance, and thus the reactance, of the AC (load) coil decreases resulting in an increased AC current being delivered to the load. As the DC current is decreased the core de-saturates. The inductance of the AC coil increases resulting in a decreased AC current delivered to the load.

Core Characteristics

The characteristics of the iron core determine the efficiency, gain and power output of a saturable reactor. Several types of losses occur in iron cores. These losses considerably decrease the efficient operation of a saturable reactor. Three common types of core losses will be considered.

The first type is known as leakage losses (see Figure 2A). These losses are caused by the leakage of magnetic flux from the core. Magnetic lines of force are reluctant to turn sharp corners. Therefore, a rectangular core is inadequate for efficient operation. To reduce leakage losses round cores, called toroids, are used in magnetic amplifiers. See Figure 2B.

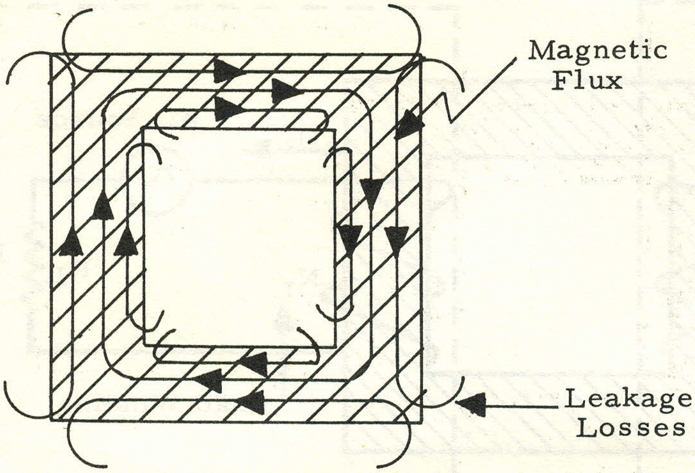


Figure 2A

Rectangular Core

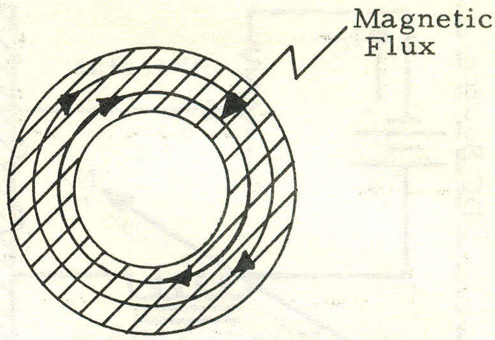


Figure 2B

Toroidal Core

The second type of loss is known as eddy current loss. These arise from small random currents, called eddy currents, that flow in the core. Eddy current losses are actually heat (I^2R) losses. These losses are reduced by laminating the core. The third type of loss is called hysteresis loss and results from residual magnetism in the core. This may be reduced slightly by using a soft core material.

Core materials that have a rectangular hysteresis loop are desirable for use in saturable reactors, because they reach saturation quickly. Figure 3A illustrates the ideal type of rectangular hysteresis loop, while Figure 3B illustrates what is actually used in saturable reactors.

The problem of improvement of the core characteristics is critical, and many design difficulties are encountered in this area.

Transformer Action

The AC flux set up in the core by the load coil will attempt to induce an AC current in the DC (control) circuit by transformer action. This AC current must be eliminated from the DC circuit for efficient amplifier operation. Two common methods are used for this purpose. The first method is to insert a high impedance choke in the DC circuit. The choke will be a short circuit to DC but will effectively block AC from entering the DC circuit.

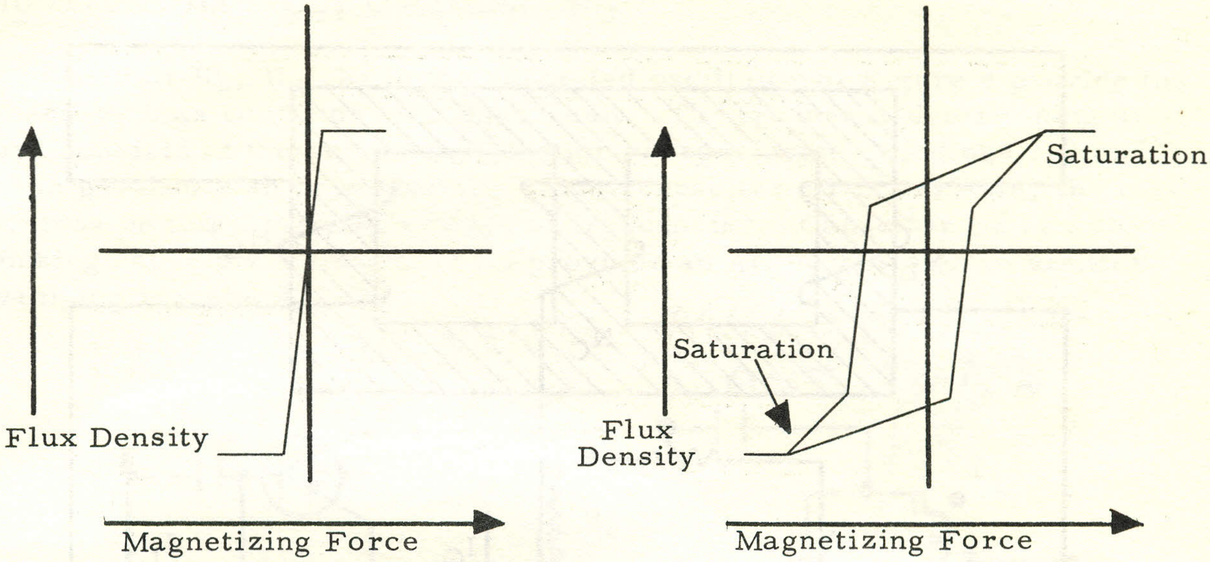


Figure 3A Figure 3B

Rectangular Hysteresis Loops

A second method is to use a three-legged core with the load windings wound in series opposing on the outer legs, and the control winding wound on the center leg as shown in Figure 4.

The AC flux set up in the core by NL opposes the AC flux set up by N_L^1. Therefore, no AC flux will be present in the center leg and no AC current will be induced in the DC circuit.

SELF SATURATING MAGNETIC AMPLIFIERS

The addition of a rectifier in the AC (load) circuit will eliminate the AC current flow during one half cycle of the AC supply. Therefore, the AC flux that tended to oppose the DC flux in the core, causing core de-saturation, will not be present. This effect is called self-saturation, and magnetic amplifiers using this principle are self-saturating magnetic amplifiers. The effect of self-saturation allows us to have a higher gain and greater efficiency than is possible to obtain with the simple saturable reactor.

Figures 5, 6, and 7 illustrate three basic types of self-saturating magnetic amplifier circuits. Figure 5 is an example of a half-wave magnetic amplifier. The output of this circuit is half-wave rectified AC (pulsating DC).

Figure 6 shows the circuit of a full wave AC magnetic amplifier. This

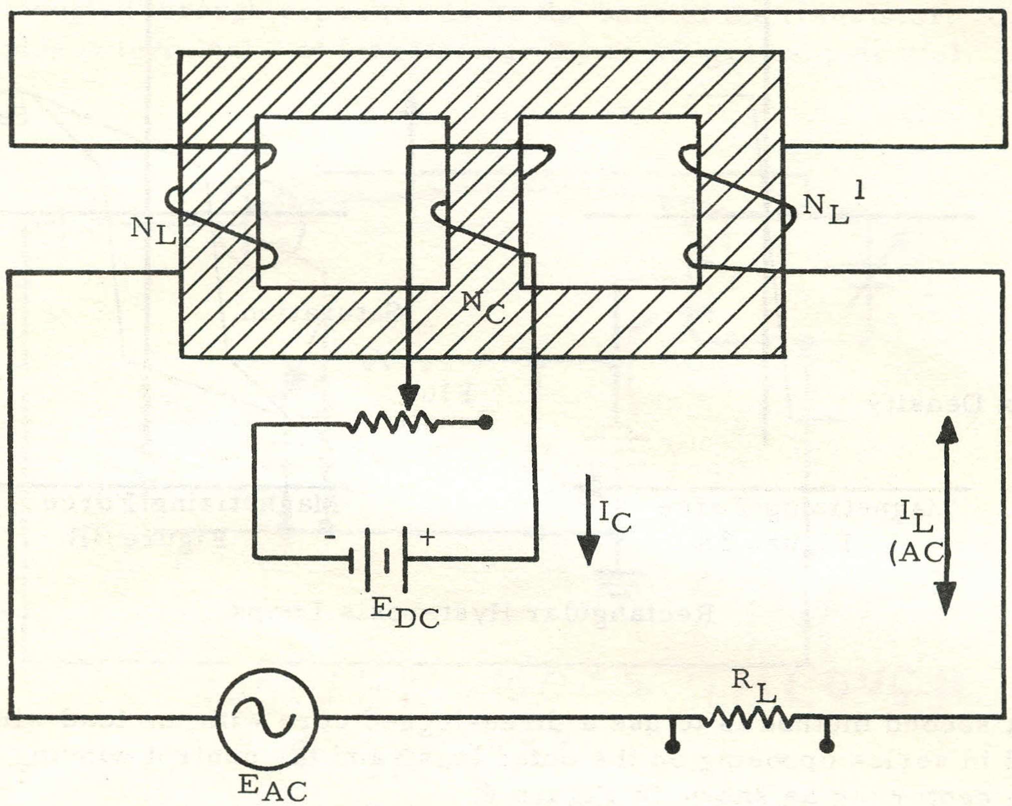


Figure 4

Three Legged Core

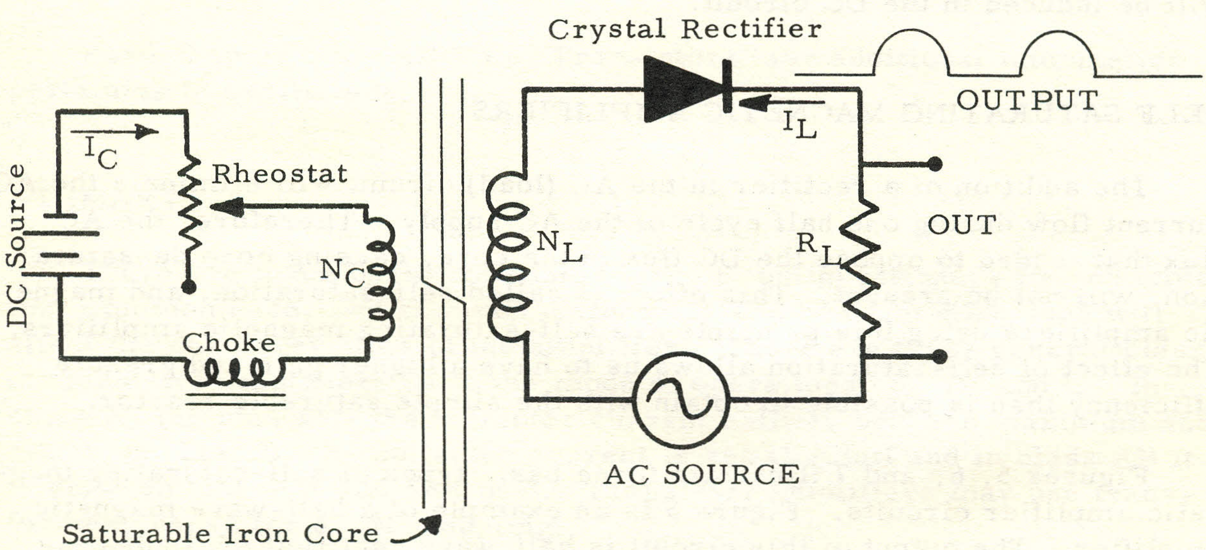


Figure 5

Half Wave Magnetic Amplifier

device utilizes two rectifiers in its output circuit to produce a full wave AC output. This magnetic amplifier is similar to a vacuum tube or transistor push-pull amplifier.

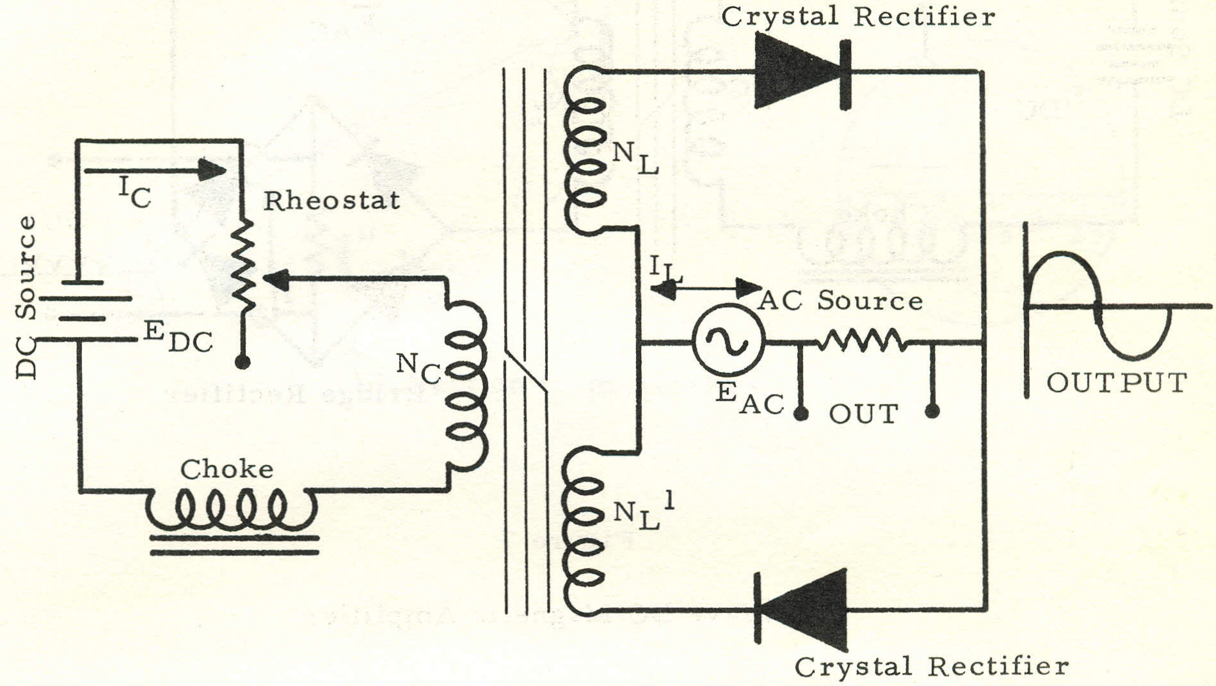


Figure 6

Full Wave AC Magnetic Amplifier

Figure 7 is an illustration of a DC magnetic amplifier. The output of this device is full wave rectified AC (pulsating DC) which is obtained through the utilization of a bridge rectifier in the output circuit.

The magnetic amplifier circuits shown above are three basic types of self-saturating amplifiers. These circuits are combined in many ways to form highly complex magnetic amplifiers such as those used in autopilots, missile guidance and motor speed control.

Bias

Many applications of magnetic amplifiers utilize bias to improve the output characteristics of the amplifier. Bias is obtained by winding an additional coil about the iron core and applying a DC source of power to the bias winding. The flux set up by the bias winding aids the flux set up by the control winding allowing us to utilize the smaller DC (input) current for control purposes. Bias affects magnetic amplifiers by changing the range of control.

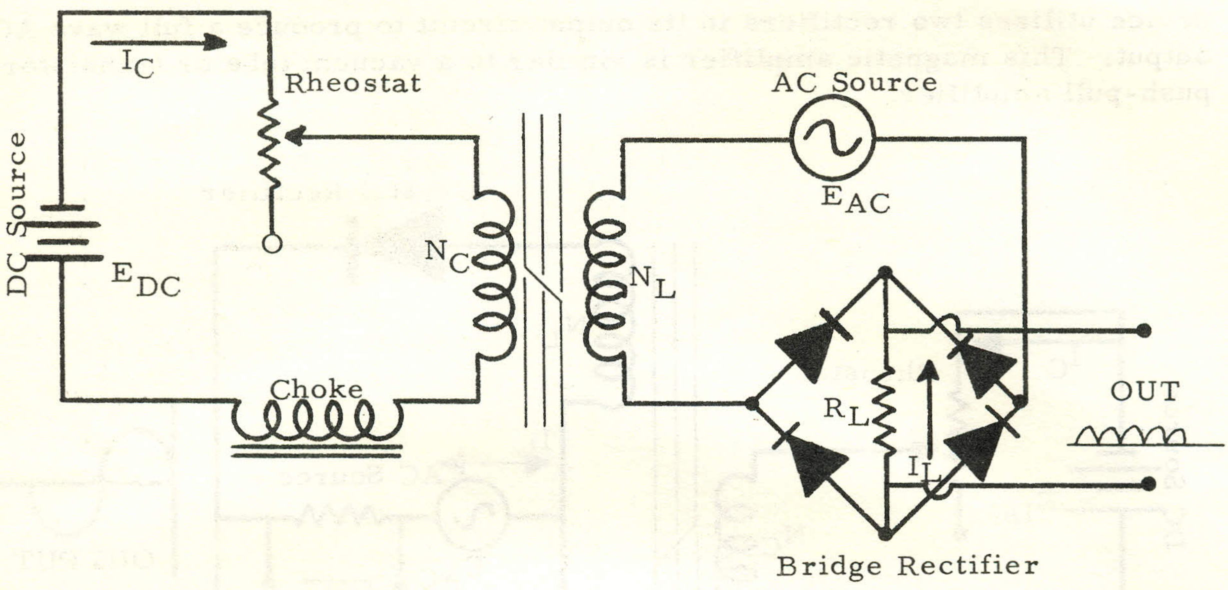


Figure 7

Full Wave DC Magnetic Amplifier

Certain advantages are obtained by using bias such as greater sensitivity, polarity sensitive operation, and reduced quiescent current (Q current). Quiescent current is the amount of output current flowing when there is zero input (control) current. The use of bias shifts the operating point of a magnetic amplifier by laterally shifting the control characteristics curve as shown in Figure 8.

Feedback

A feedback winding is often added to the magnetic amplifier core and a portion of the output signal is fed back to the input. The feedback used in magnetic amplifiers is always DC. The flux set up in the core by the feedback coil either aids or opposes the flux from the control coil. If the flux is aiding, the feedback is called regenerative and we obtain an increased output signal. If the flux opposes the DC control flux, it is degenerative feedback. Use of degenerative feedback decreases the output signal, but increases the stability (linearity) of the magnetic amplifier.

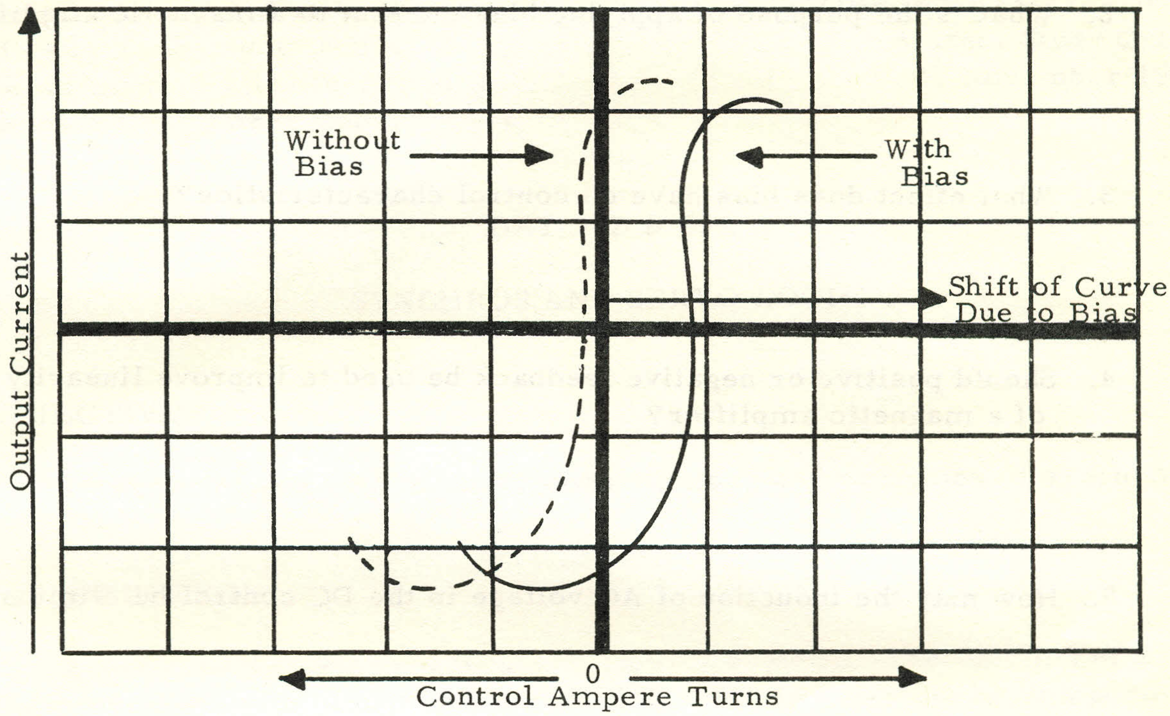


Figure 8
Effects of Bias on Control Characteristics

SUMMARY:

The magnetic amplifier makes use of the operating principle of the saturable reactor. It offers advantages of ruggedness, high efficiency, and adaptability. A small control signal may be applied to control a large AC output. Bias is used to change the range of control of the magnetic amplifier. Feedback, either positive or negative, may be used to alter the control characteristics to fit individual needs. Magnetic amplifiers are used in missile systems for frequency control, operation of servomechanisms, and in computers.

QUESTIONS:

1. How may the reactance of a coil be changed?

2. What is the purpose of applying bias current to a magnetic amplifier?

3. What effect does bias have on control characteristics?

4. Should positive or negative feedback be used to improve linearity of a magnetic amplifier?

5. How may the induction of AC voltage in the DC control be eliminated?

6. Which type of self-saturating magnetic amplifier produces a full wave AC output?

REFERENCE:

Magnetic Amplifiers Theory and Application by Sidney Platt.

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REFERENCE:

Magnetic Amplifiers Theory and Application by Sidney Platt.

DAY 34B & 35A

SYNCHROS AND SERVO LOOPS

OBJECTIVE:

To acquaint you with the use, construction, and operation of synchros.

INTRODUCTION:

A servomechanism is a feedback control system. The function of a servomechanism is to correct errors that arise in a system by comparing the output with the desired input. If the output is unequal to the input, the error is detected. The error is then "zeroed" by the servomechanism causing the output to become equal to the desired system input. A synchro is an error sensing device, and is a part of the servomechanism. Since synchros and servomechanisms are used to a great extent in the field of ballistic missiles, it is necessary for you to understand the operation of synchros and servomechanisms.

REFERENCES:

AFM 101-8 "Fundamentals of Electronics", Chapter 39, pages 471 - 504.

SUMMARY:

A synchro is a machine which converts mechanical position into electrical position or vice versa. A synchro may be known by any of the following names: Selysn, Autosyn, Telesyn, or Snychrotie. The synchro consists of two basic units - a generator and a motor. The construction of the synchro generator and motor are identical electrically, but differ in that the rotor of the synchro motor has a heavy metal fly wheel mounted on one end of the shaft. The stator windings of the motor or generator consist of three groups of coils connected in a Y-connection, and the rotor windings consist of two coils wound on a soft iron core and connected in series. The voltages applied

to the stator are single-phase instead of 3-phase as is common in Y-connected AC motors or generators.

The operation of a synchro is simple. The stator leads of the generator are connected to the corresponding leads of the motor stator. Therefore, the voltages of the stator coils of the motor and generator are equal and oppose each other, and no current will flow in the windings when the two rotors are in corresponding positions. However, when the generator rotor is turned mechanically, stator voltages of the generator and motor are no longer equal. A current is then induced in the windings which causes the motor rotor to turn to a position corresponding to that of the generator rotor.

A control transformer is similar to a synchro. However, it differs from a synchro in that its output is a voltage instead of a shaft position. The control transformer transforms an electrical input into a electrical output that may be used to control the position of some device to correspond to that of the input shaft.

A servomechanism amplifies and transmits mechanical position from one location to another by electrical means. A typical servomechanism consists of a synchro generator, a control transformer, a servoamplifier, and a servo-motor. There are two basic types of control systems, the open loop, and the closed loop or feedback control system. A true servomechanism is a system of the latter type.

When the rotor of the synchro of a servomechanism is turned, an error voltage is developed across the rotor terminals of the control transformer. This error signal is amplified and applied to the servo-motor and the motor turns proportionally as the amplitude and phase of the applied error signal. As the motor turns, both the load and the rotor of the control transformer also turn until they reach a position which corresponds to the position of the control shaft of the synchro rotor.

The motor of a servomechanism (servo-motor) is either a DC motor or a two-phase AC motor whose direction and speed of rotation may be varied.

Servomechanisms are used extensively in military applications such as the turning of radar antennas, the positioning of large guns for firing, and in the guidance systems of ballistic missiles.

QUESTIONS:

1. What is meant by electrical zero of a synchro?

2. How is electrical zero of a synchro determined?

3. What is a synchro differential?

4. What are the differences between an ordinary synchro and a control transformer?

5. What is electrical zero of a control transformer?

6. What is the difference between the electrical zero of a synchro and a control transformer?

DAY 35B

RADAR FUNDAMENTALS

OBJECTIVE:

To become familiar with the principles of radar, pulse modulation and detection, high frequency oscillators, and RF transmission devices.

INTRODUCTION:

The word RADAR is a contraction of RAdio Detection And Ranging. Radar is an application of radio principles by means of which it is possible to detect the presence of objects, and to determine their direction and range.

Radar is used in Ground Guidance Systems to determine the exact air position of a missile. This information is then fed to computers which determine the corrections the missile will have to make to hit a specific target. In this lesson you will study the principles of radar and the components of a basic radar set.

PRINCIPLES OF OPERATION

Basic radar detection is accomplished by directing a beam of radio frequency energy over a region to be searched. When the beam strikes a reflecting object (target), energy is reradiated. A very small part of this reradiated energy is returned to the radar system. A sensitive receiver can detect the echo signal and therefore the presence of the object or target. The determination of the actual range and direction (azimuth) is based on the facts that radio frequency energy travels at the constant velocity of light and that the receiving system can be made directional.

SOUND WAVE REFLECTION

The principle upon which radar operates is very similar to the following principles of sound echoes or wave reflection. If a person shouts in the direction of a cliff, or some other sound reflecting surface, he hears his shout "return" from the direction of the cliff. What actually takes place is that the sound waves, generated by the shout, travel through the air until they strike the cliff, they are reflected or "bounced off" and some are returned to the original spot, where the person is then able to hear the echo. Some time elapses between the instant the sound originates and the time when the echo is heard because sound waves travel through air at approximately 1100 feet per second. The farther the shouter is from the cliff the longer this time interval will be. If a person is 2200 feet from the cliff, 4 seconds will elapse before he hears the echo - that is, 2 seconds for the sound waves to reach the cliff and 2 seconds for the waves to return.

RADIO WAVE REFLECTION

All radar sets work on a principle very much like that described for sound waves. In radar sets, however, a radio wave of extremely high frequency (10,000 MC) is used instead of a sound wave. The energy sent out by a radar set is similar to that sent out by an ordinary radio transmitter.

The radar set has one outstanding difference in that it picks up its own signals. It transmits a short pulse and receives its echoes, then transmits another pulse and receives its echoes. This out - and - back cycle is repeated 60 - 4000 times per second, depending on the design of the set.

Radio waves of extremely high frequencies travel in straight lines at the speed of light (186,000 miles per second). There will be an extremely short time interval between the sending of a pulse and the reception of its echo. It is possible, however, to measure the interval of elapsed time between transmitted and received pulse with great accuracy. The forming, timing, and presentation of these pulses are accomplished by a number of special circuits and devices.

The directional antennas, employed in radar equipment, transmit and receive the energy in a sharply defined beam. When a target signal is picked up, the antenna can be rotated until the received signal is maximum. The direction of the target is then determined by the position of the antenna.

DETERMINATION OF RANGE

In pulse modulated radar sets, RF energy is transmitted in short pulses, the time duration of which may vary from 1 - 50 microseconds. If the transmitter is turned off before the reflected energy returns from the target, the receiver can distinguish between the transmitted pulse and the reflected pulse. After all reflections have returned, the transmitter can be turned on again and the process repeated. The receiver output is applied to an indicator that measures the time interval between the transmitted energy and the reflected return. Because the energy travels at a constant velocity, one half the total time interval times the velocity is equal to the distance or range to the target. There is a direct relationship between time and range. Radar energy travels 186,000 miles per second, or one nautical mile (2,000 yards) in 6.2 microseconds. If a target is one nautical mile from the transmitter then it will take 6.2 microseconds for the transmitted energy to travel to the target and another 6.2 microseconds for the reflected energy to return to the receiver. The total elapsed time for the transmitted energy to return to the receiver was 12.4 microseconds. This is the time it takes radio energy to travel one radar nautical mile (out and back).

TIME MEASUREMENT

In order to employ the time range relationship, the radar system must have a time-measuring device. In addition, since there may be more than one target in the region under search, some means of separating and identifying pulses must be included. The cathode-ray oscilloscope is well suited to such a task. The time scale is provided by using a linear sweep to produce a known rate of motion of the electron beam across the face of the CRT.

The measurement of time is illustrated in the following example. Assume that a CRT is used with a horizontal linear sweep which produces a beam whose velocity across the screen is 1 inch per 100 microseconds. The signals received from the targets are applied to the scope as vertical deflection.

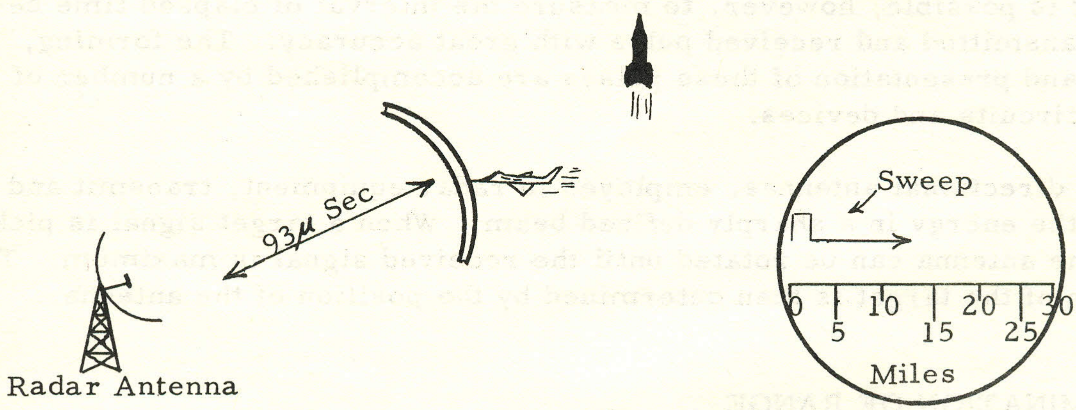

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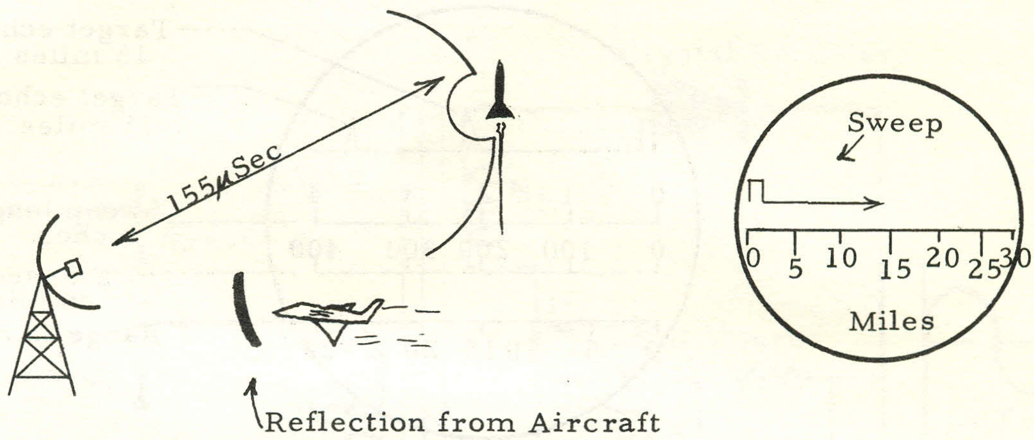
Figure 1



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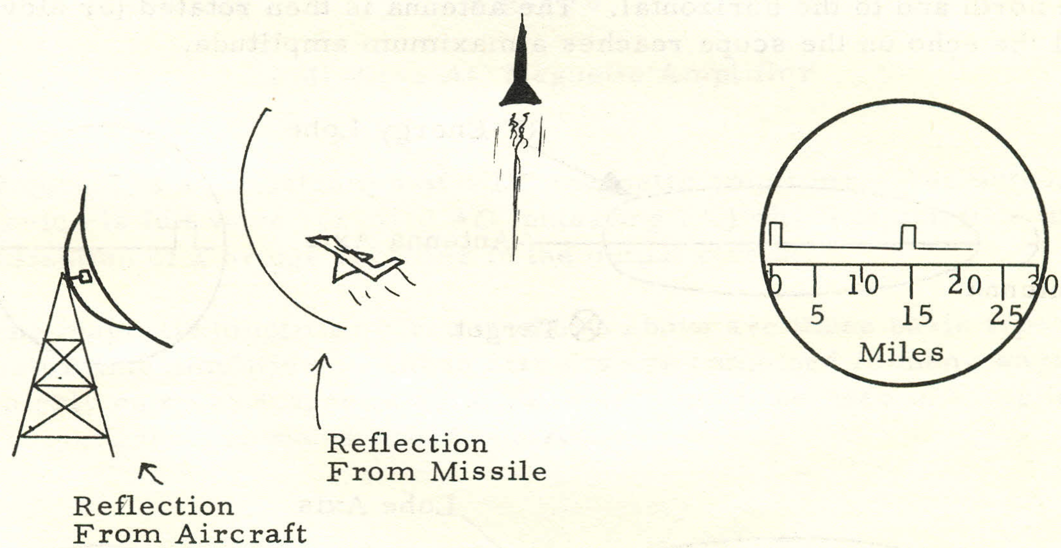
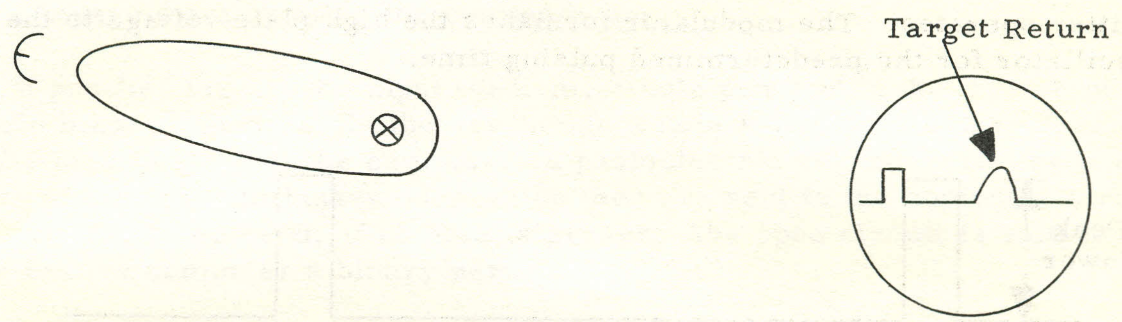


C

Figure 1 (Cont)

C



C of Figure 2

COMPONENTS OF A RADAR SET

Radar systems now in existance vary greatly in detail. The principles of operation, however, are essentially the same for all systems.

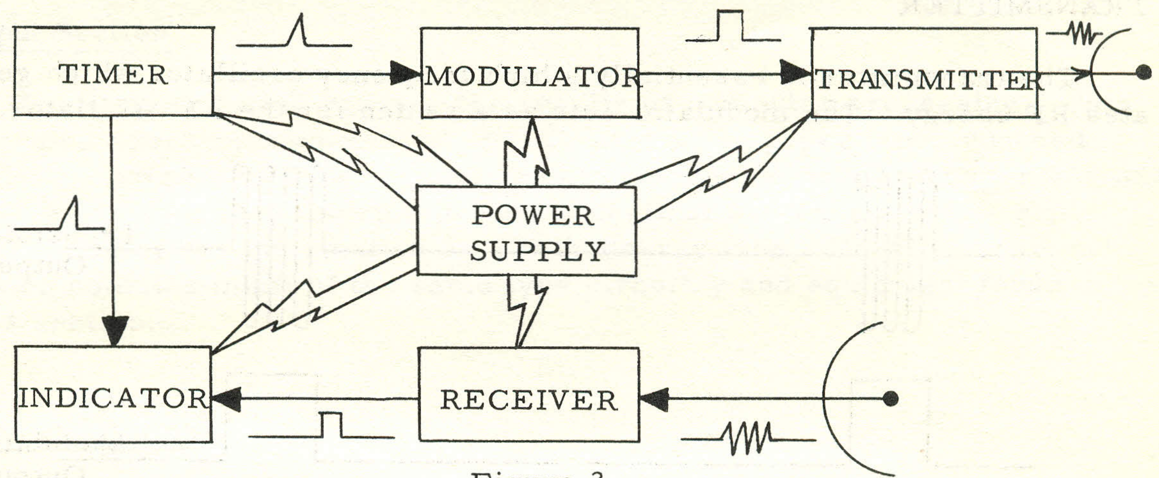


Figure 3

TIMER - (also referred to as synchronizer) produces the synchronizing signals that trigger the transmitter and the indicator and coordinates the other associated circuits.

The function of the timer is to insure that all circuits connected with the radar system operate in a definite time relationship with each other and that the interval between transmitted pulses is of proper length.

MODULATOR

The modulator determines the pulse shape which activates the transmitter and therefore determines the output power and the time the transmitter operates. The modulator furnishes the high plate voltage to the RF oscillator for the predetermined pulsing time.

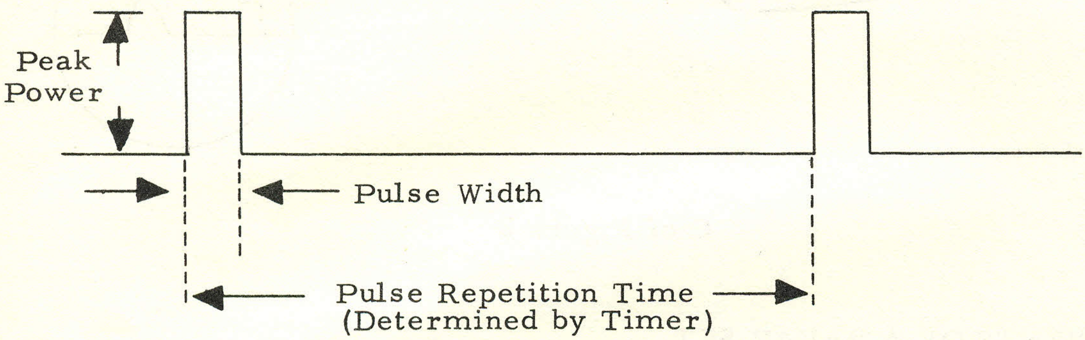


Figure 4

TRANSMITTER

The transmitter is essentially a high frequency oscillator which generates RF energy. The modulator acts as a switch for the RF oscillator.

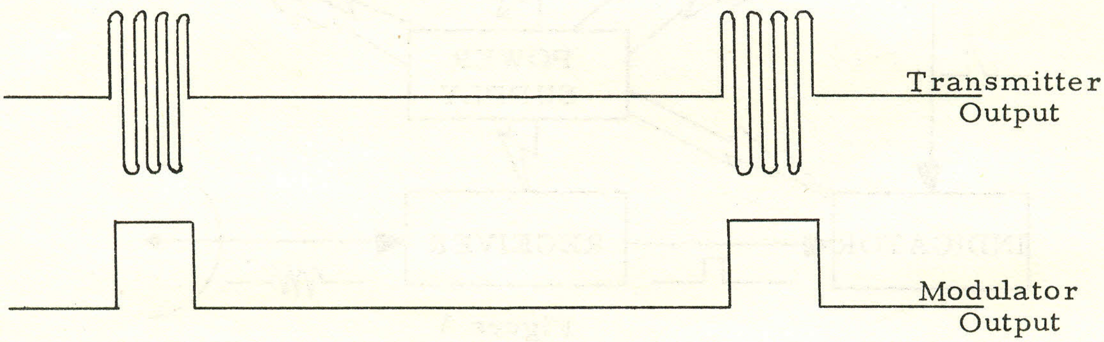


Figure 5

The radar oscillator differs from the oscillators previously discussed in that it produces a higher frequency at a much higher power output.

Because of the superhigh frequencies transmitted ordinary vacuum tube oscillators will not operate properly, primarily due to electron transit time from cathode to plate. A different type of oscillator, called a magnetron, is used. The magnetron is essentially a diode. The diode is placed in a powerful magnetic field produced by a permanent magnet. The magnetic field in conjunction with resonant cavities allows the magnetron to utilize electron transit time to maintain oscillations.

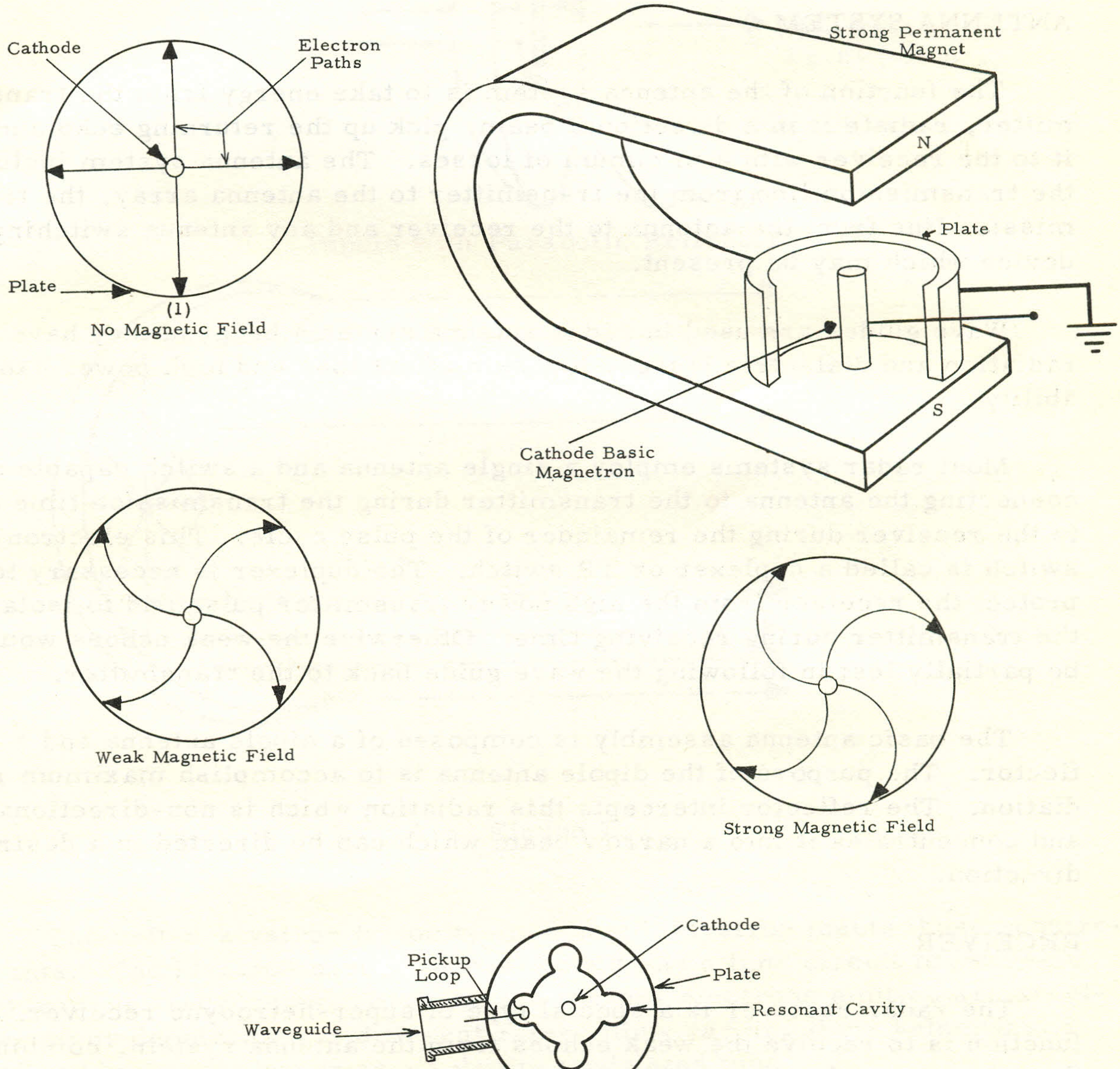


Figure 6
Simple Magnetron Cutaway

As the electrons pass the cavities they give up energy to maintain oscillations. The frequency depends on the size of the cavities, the strength of the magnetic field, and the difference in potential between cathode and plate.

Energy is coupled out of the magnetron by a loop or probe; it is then transmitted to the antenna by the waveguide.

ANTENNA SYSTEM

The function of the antenna system is to take energy from the transmitter, radiate it in a directional beam, pick up the returning echo and pass it to the receiver with a m nimum of losses. The antenna system includes the transmission line from the transmitter to the antenna array, the transmission line from the antenna to the receiver and any antenna switching device which may be present.

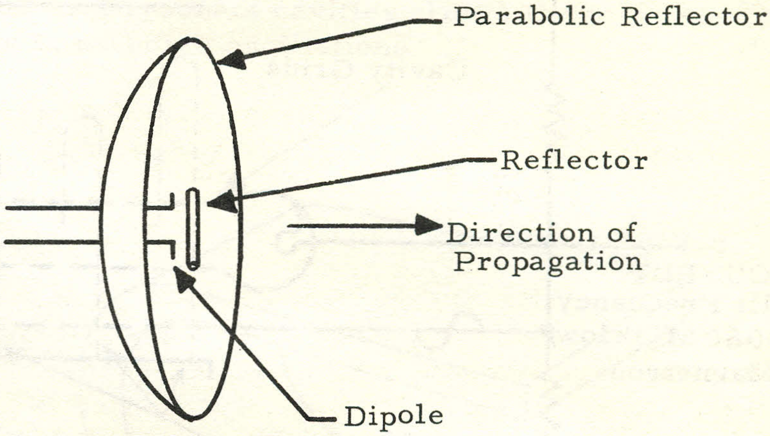
Wave guides are used in radar antenna systems because they have low radiation and dialectric losses, low skin effect loss and high power handling ability.

Most radar systems employ a single antenna and a switch capable of connecting the antenna to the transmitter during the transmission time and to the receiver during the remainder of the pulse cycle. This electronic switch is called a duplexer or TR switch. The duplexer is necessary to protect the receiver from the high power transmitter pulse and to isolate the transmitter during receiving time. Otherwise the weak echoes would be partially lost in following the wave guide back to the transmitter.

The basic antenna assembly is composed of a dipole antenna and a reflector. The purpose of the dipole antenna is to accomplish maximum radiation. The reflector intercepts this radiation which is non-directional and concentrates it into a narrow beam which can be directed in a desired direction.

RECEIVER

The radar receiver is a special type of super-hetrodyne receiver. Its function is to receive the weak echoes from the antenna system, combine them in a crystal mixer with RF signals from a local oscillator (klystron), amplify the resultant IF signal, detect the pulse envelope, amplify the resulting video pulses, and feed them to the indicator. At the high frequencies used in radar it is not possible to use a stage of RF amplification ahead of the mixer, therefore the RF signals are fed directly to the mixer from the duplexer. Most radar receivers use 30 or 60 MC intermediate frequencies. The local oscillator must be stable and it must also be tunable to compensate for shifts in the transmitter frequency.



Dipole with Parabolic Reflector

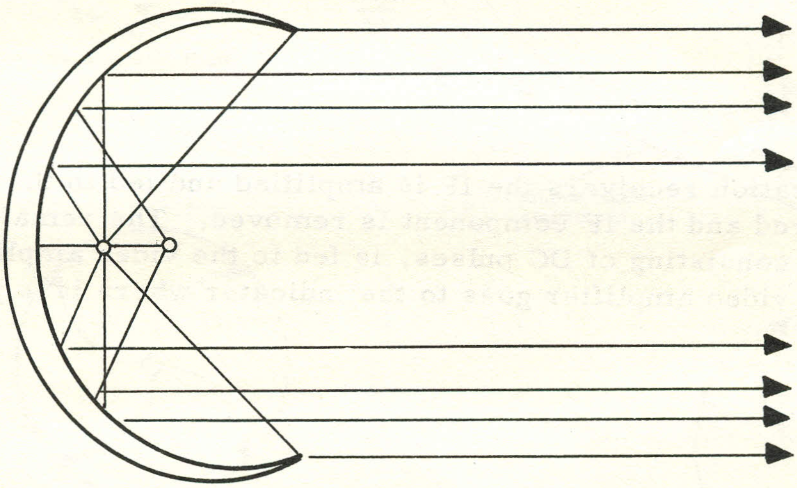


Figure 7

The reflex-klystron (velocity-modulated) klystron meets these requirements. The klystron uses a resonant cavity as a tank circuit to generate microwave frequencies. Because the various electrons emitted are accelerated or decelerated at different rates, (thus varying their velocities) a reflex klystron is known as a velocity modulated tube.

The velocity of all electrons, emitted by the cathode, is controlled (accelerated or decelerated) by the repeller plate voltage so that they pass back through the cavity grids at the same time, giving up energy to the cavaties.

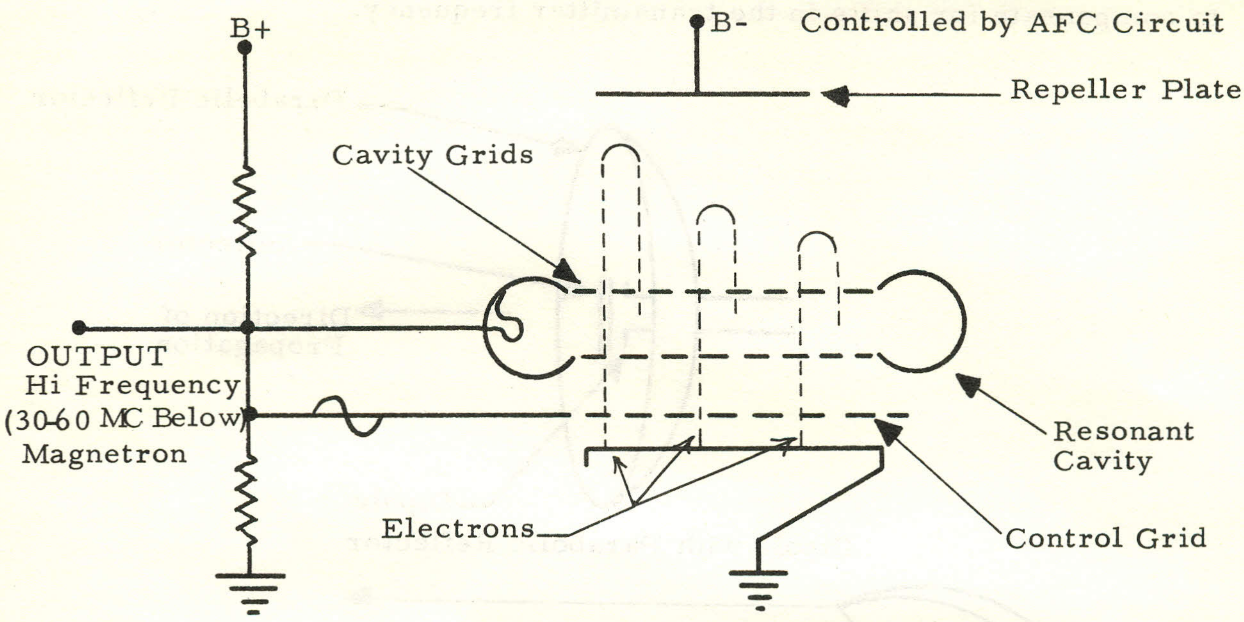


Figure 8

As in communication receivers the IF is amplified and fed to the detector where it is filtered and the IF component is removed. The remaining modulation pattern, consisting of DC pulses, is fed to the video amplifier. The output from the video amplifier goes to the indicator where it is produced visually.

INDICATOR

The indicator presents visually all the information necessary to determine range, azimuth or size or a combination of these. The usual indication is basically the same as that for the test oscilloscope. Focusing, intensity and positioning controls are similar. The sweep frequency is determined by the PRF of the system and the sweep duration is established by the setting of the range selector switch.

POWER SUPPLY

The power supply furnishes all AC and DC voltages necessary for the operation of the system components.

SUMMARY

Radar is an application of radio principles by means of which it is possible to determine the range, azimuth, and size of an object. Detection is accomplished by directing a beam of radio frequency energy over a region to be searched. When the beam strikes a reflecting object energy is reflected back to the receiver. The determination of range and direction is based on the fact that radio energy travels at a constant velocity and that the system is directional.

REFERENCES:

AFM 101-8 "Fundamentals of Electronics", Chapters 33, 34, 35, and 36, pages 323-410.

T. O. 16-1-145 Radar System Fundamentals, pages 1-32.

QUESTIONS:

1. What type of information is given in type A presentation?

2. How long does it take a radio wave to travel 1 nautical mile?

3. What is the function of the timer in a radar system?

4. What type of pulse is needed to trigger a magnetron?

5. Why is an RF amplifier not used in a radar receiver?

DAY 36 & 37

COMPUTERS AND COMPUTER CIRCUITS

OBJECTIVE:

To become familiar with the purpose, components, and operating principles of digital computers.

INTRODUCTION:

Men have always sought a quick method of computing mathematical problems. This has long been a goal of scientists, for while they are challenged and fascinated by the solving of mathematical problems, the drudgery of long, laborious computations has been a boring and tedious task. And today, the increased demand for quick, accurate answers to complex problems of research has added more cogent reasons for the development of high speed automatic computing devices.

The latest tool devised to meet these scientific demands is the electronic digital computer. It is the fastest, most versatile tool yet produced. This study guide will provide a general discussion of the purpose, construction and operation of digital computers.

DEVELOPMENT OF COMPUTERS

The family of computing aids has been developed along two distinct branches. One branch is descended from the abacus, which is a mechanical extension of the idea of finger counting. The devices that stem from the abacus and use digits to express numbers are often called digital computers. The other branch, analog computers, arose from the straight edge-and-compass construction of the ancient surveyors. Analogies are assumed between the boundaries of fields or buildings on the one hand and lines drawn by the surveyor or architect on the other. Thus, through a gradual process of evolution, there has developed a long line of analog computing devices which includes charts, slide rules, and differential analyzers. In many of the analog computers, this analogy has become so slight that it really seems more appropriate to call them by the title of "continuous" computers, because they rely on the measurement of some continuous quantity like the length of a steel bar or the distance between two pins within the computer.

On the other hand, digital computers may be called "discrete" because they recognize only discrete values such as 0, 1, a, etc., and represent these values by reference to countable physical things, like the teeth of a gear or the steps in a ratchet.

Each branch of the computer family has pursued its own development independently of the other. And while there are a few rare examples of devices that combine the two principles of the two branches of computers, this study guide will consider only the principles of digital computers.

BASIC SECTIONS OF A DIGITAL COMPUTER

All electronic digital computers contain six distinct sections. These are usually called the input, output, memory, arithmetic, control, and timing sections. While all are indispensable to the operation of the computer, each of the sections forms a separate and distinct entity in terms of purpose and operation.

Figure 1 is a block diagram showing the inter-relationship of the sections of a digital computer. All information and instructions are fed into the computer through the input section. This information is placed in the memory and must pass through the control section. The control section controls the flow of information to and from the other sections and is sometimes compared to a railroad switchboard, since its function is to control the action of the computer by opening and closing circuits in the proper order and at the proper time. The timing of this whole operation is controlled by the timing section.

The information stored in the memory includes instructions so that once the computer is started, instructions will flow in the proper order to the control which will direct the action of the computer. This is shown in Figure 1 by the arrow indicating the flow from the memory to the control.

Arrows also show a flow path both to and from the control section to the arithmetic section. This section performs the computing functions of the computer when directed to do so. In response to instruction the control section will close the proper circuits allowing the prearranged information to flow from the memory to the arithmetic section, where calculations will be performed. The results of the computations will then flow back to the control section as indicated in Figure 1, where the information may be directed to the output section or to the memory section or to both. The output circuit will make available the results to the operator, and if desired, the information may be permanently stored in the memory. Let us now consider each section in more detail.

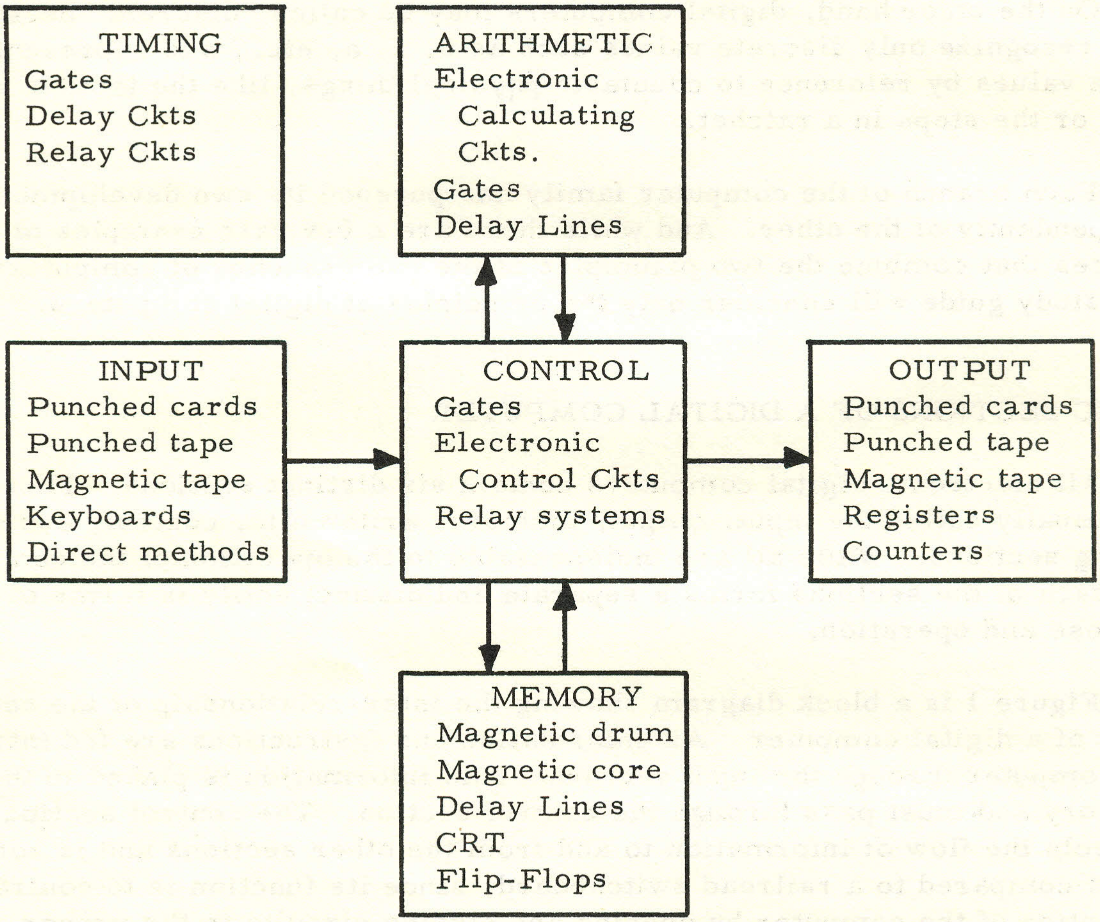


Figure 1

Six Sections of a Digital Computer

Input Section

The input section feeds information and instructions to the computer. A number of input methods are available, such as magnetic tape, punched tape, and punched cards. Less commonly used methods are direct inputs and inputs from keyboards. The binary system is now used exclusively in modern computers, and the information is coded by an auxiliary device which puts the information and instructions in a sequence called the program. The preparation of this program is performed by a trained technician called the programmer.

If magnetic tape is used as the input medium, binary-coded information is stored on the tape in the form of small magnetized spots along the surface of a tape made of a plastic base which has a thin surface of magnetic oxide. Elaborate codes are available which can translate words as well as numbers into a binary form suitable for computer use.

If punched tape is the input medium, a hole punched in the tape stands for the binary "one", while the absence of a hole indicates a binary "zero". As the tape is fed into the computer, a photoelectric cell converts the presence of the holes to binary ones which then are sent to the computer circuitry. On the other hand, if no hole is present, the open circuit is said to have fed the computer a binary zero.

Paper cards are somewhat similar to punched tape, except that the location of the holes on the card can indicate a binary one that could mean 2^0, 2^1, 2^2, etc., depending entirely on its location on the standard sized card.

All three of these methods, as well as other types, are used as input methods. Indeed, some computers are so versatile that any of the three methods described may be used.

Output Section

The output section records the results of computer processing. This recording may be accomplished on magnetic tape, paper tape, punched cards, or printed on paper. Some output devices contain a decoder to translate the binary-coded information to its decimal equivalent, while still others display the information on a cathode-ray tube. Usually the output section contains much of the same type circuitry and equipment found in the input section.

Memory Section

The memory section of a computer stores both instructions and information. The information may be numbers to be used in calculations, or it may be partial answers, obtained in the early steps of a calculation, which may be required in a later step. Final answers are also stored in the memory and, at some convenient time, can be transferred to a printout device in the output section, such as an electric typewriter.

Several types of storage devices are available, the one used being determined by considerations of cost and computer function.

Arithmetic Section

This section, sometimes called the mill, performs the computing functions of the computer. It is made up of electronic circuits called logic circuits. It is these logic circuits that perform the function of mathematical computation. In order to analyze the arithmetic section it is necessary to become acquainted with some of these logic circuits. These logic blocks are discussed within this study guide.

Control Section

The control section directs and coordinates all operations called for by instructions. This involves control of input-output devices, entry or removal of information from memory and the arithmetic section. Through the action of the control section, automatic, integrated operation of the entire computer system is achieved. In many ways, the control section can be compared to a telephone exchange. All possible data transfer paths already exist, just as there are connecting lines between all telephones serviced by a central exchange. The path of conversation between one telephone and another is set up by appropriate controls in the exchange itself. In the computer, execution of an instruction involves opening and closing many paths or gates for a given operation. The control section can start or stop an input-output unit, turn a signal device on or off, rewind a tape reel, or direct some process of calculation.

The control section, like the arithmetic section, is made up of logic circuitry.

Timing Section

Digital computers require precise timing of their various operations. Digital computer operations must begin and end precisely on time. This can be accomplished in several ways.

One method is to produce exact timing signals with which the whole computer may be synchronized. This serves the purpose of giving the computer a rhythm. This can be done through the use of a sine wave generator whose output is modified to produce a steady train of pulses. Another method is to synchronize computer operations with the memory section such as a clock pulse on a rotating drum.

Basically there are two types of computer timing. These are synchronous and asynchronous. Synchronous timing means that every component in operation is operating in harmony with every other component. Also, a great many operations can be taking place at precisely the same time.

Asynchronous timing refers to sequential operations. In other words, before one step can occur, the preceding step must be accomplished. This is accomplished through the use of elaborate gating and sensing networks connected to the central control section.

THE BINARY SYSTEM

The binary numbering system is the numbering code used in digital computers. The binary system uses a radix of two as opposed to the radix of ten found in the decimal system. In the binary system, the symbols 0 and 1 have the same significance as in the decimal system. That is, they represent no units and one unit respectively; and the positional location of a binary digit has the same significance as in the decimal system except that the base is 2 instead of ten.

The rules for addition and subraction of binary numbers are very similar to those of the decimal system.

Rules for Binary Addition

0 plus 0 equals 0 with no carry.

0 plus 1 equals 1 with no carry.

1 plus 0 equals 1 with no carry.

1 plus 1 equals 0 with a carry of 1.

Rules for Binary Subtraction

0 minus 0 equals 0 with no borrow.

1 minus 0 equals 1 with no borrow.

1 minus 1 equals 0 with no borrow.

0 minus 1 equals 1 with a borrow of 1.

Multiplication and division are simply an extension of addition and subtraction respectively.

Binary numbers are especially useful in electronic circuits as they represent only 1 of 2 conditions.

BLOCK DIAGRAM LOGIC

In block diagram logic or logic algebra, only two values or numbers are to be considered; namely 0 and 1. The 0 signifies "false" or "no" or in the actual circuitry, the absence of a signal. The 1 signifies "true", "yes", or the presence of a signal.

Logic diagrams can be broken into 3 basic relationships. These are AND, OR, and INVERT. The 3 blocks with modifications can be combined to represent many relationships. They are the decision making elements in a computer.

The AND block can provide a yes or true answer providing all the inputs are yes. If any one of the inputs is not true, the answer will be false or no.

In block symbols an AND gate is represented as follows:

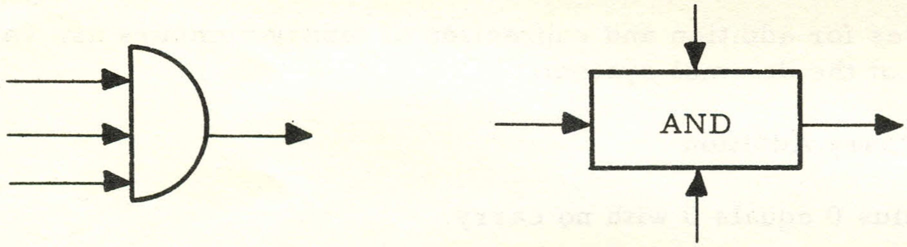


Figure 2

AND Gate

The OR block can provide a yes answer if any one of the inputs are yes. If all the inputs are no or false, the output will be false. In block symbols, an OR gate is represented as follows:

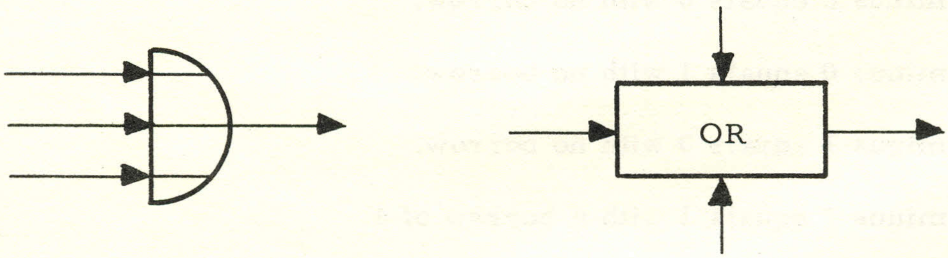


Figure 3

OR Gate

The INVERTER block serves only one purpose. That is changing 1's to 0's or 0 to 1. For example:

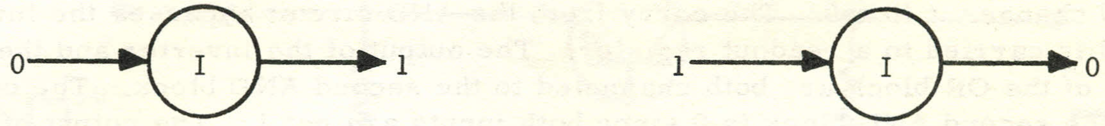


Figure 4

Inverter

The standard symbols are:

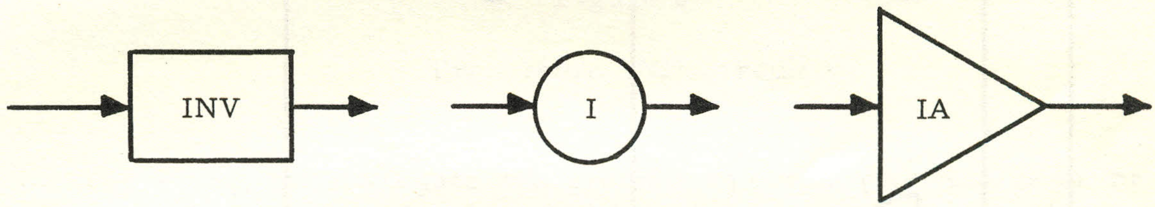


Figure 5

Inverter Symbols

To give the student an example of how these blocks can be combined to perform a useful function, employ logic blocks to add 1 and 1.

Use two AND blocks, an OR block and an INVERTER. The first 1 is channeled into input A and the second into input B. Input A is channeled to both the AND block and the OR block as follows:

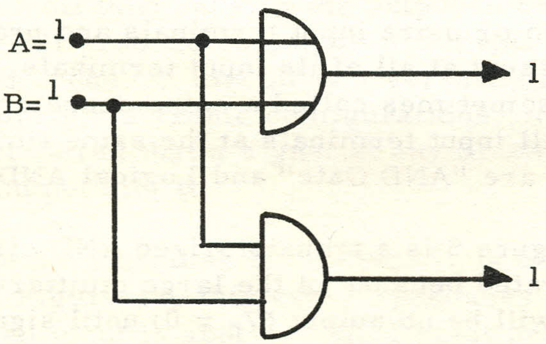


Figure 6

AND - OR Blocks

The output of the OR circuit is a 1 because the inputs contain a 1. The output of the AND circuit is 1 because both inputs are 1. The output of the AND circuit is channeled through an INVERTER circuit which takes the 1 and changes it to a 0. The carry from the AND circuit bypasses the inverter and is carried to a readout register. The output of the inverter and the output of the OR block are both channeled to the second AND block. The output of the second AND block is 0 since both inputs are not 1. The output of the second AND circuit is sent to the register where the answer is recorded as 10 which in binary is equal to 2.

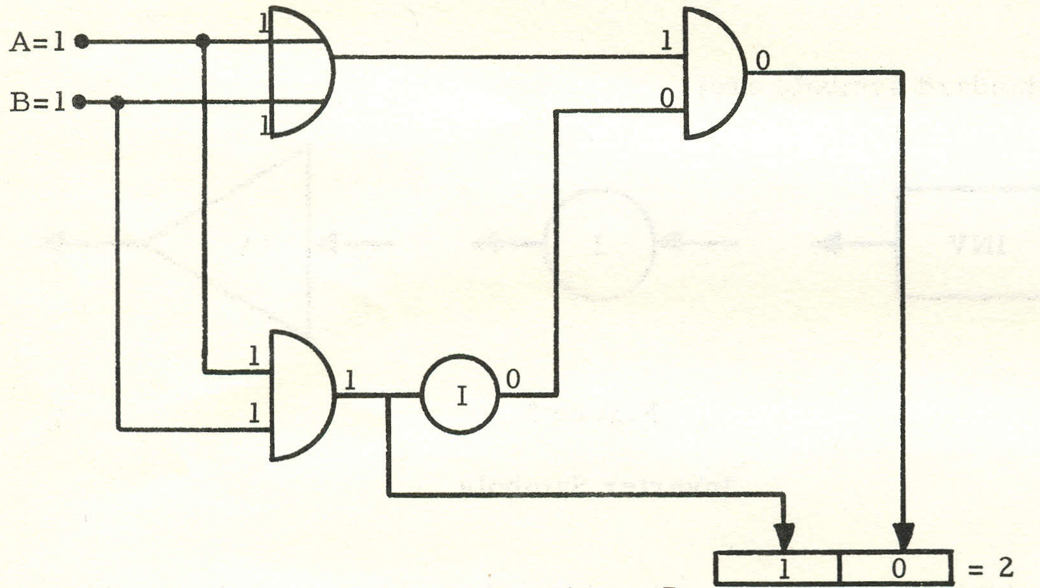


Figure 7

AND, OR, INVERTER and Register Operation

COMPUTER CIRCUITS

The AND circuit has two or more input terminals and produces an output only when an input is present at all of its input terminals. For this reason, the AND circuit is sometimes called a coincidence circuit; input signals must be present at all input terminals at the same time. Two other names for this same circuit are "AND Gate" and Logical AND circuit.

The circuit shown in Figure 8 is a transistorized AND circuit. The transistor is normally saturated because of the large emitter-base bias battery. Therefore, there will be no output ($V_C = 0$) until signals are felt at all inputs, which will overcome the bias voltage, thereby cutting off the transistor.

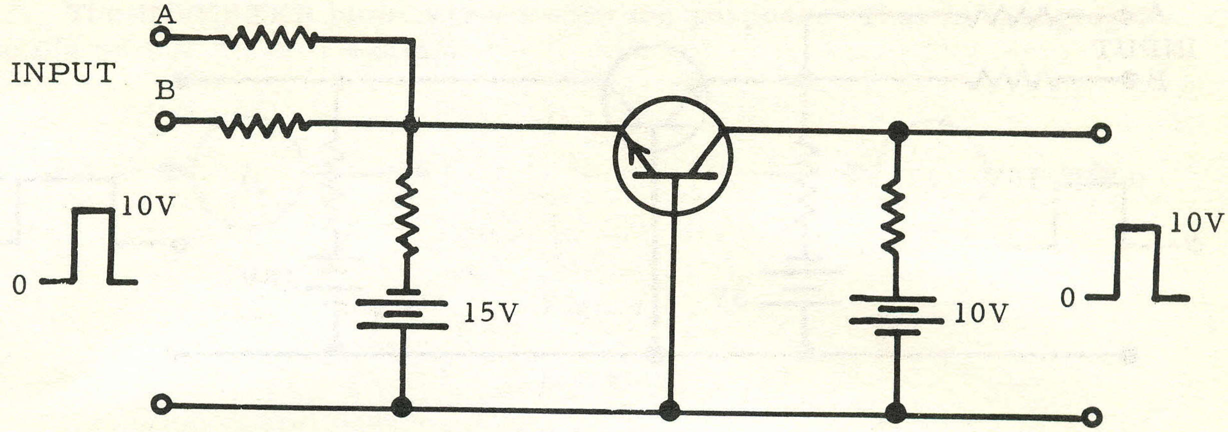


Figure 8

Transistor AND Circuit

Therefore, the AND gate will produce an output (the voltage of the collector supply battery) only when all of the inputs receive a signal. If a positive ten volt pulse is assigned the value of binary 1, then the circuits output will only be a one when all of the inputs receive a one. Under all other conditions, i.e., when any or all of the inputs receive a zero, the output will be zero.

OR CIRCUIT

The OR circuit produces an output when an input is applied to at least one of its inputs. In the circuit shown in Figure 9, the output of the transistor is 0 because it is saturated. However, one input of ten volts is sufficient to reverse the bias (the bias battery is equal to only 5 volts) and cut the transistor off thus causing the output to be equal to ten volts. Therefore, the OR gate will produce an output (a ten volt pulse) when any of its inputs are activated. The OR circuit is a versatile logic circuit, and while it will be found in many electronic configurations, its function will not be confused if it is remembered that a signal at any or all of the circuits' inputs will produce an output signal.

The inverter, another logic circuit, is also known as a "NOT" circuit. As shown in Figure 10, this circuit produces an output when an input is not applied. If an input is applied, the circuit produces no output. The circuit thus represents the function of negation or inversion.

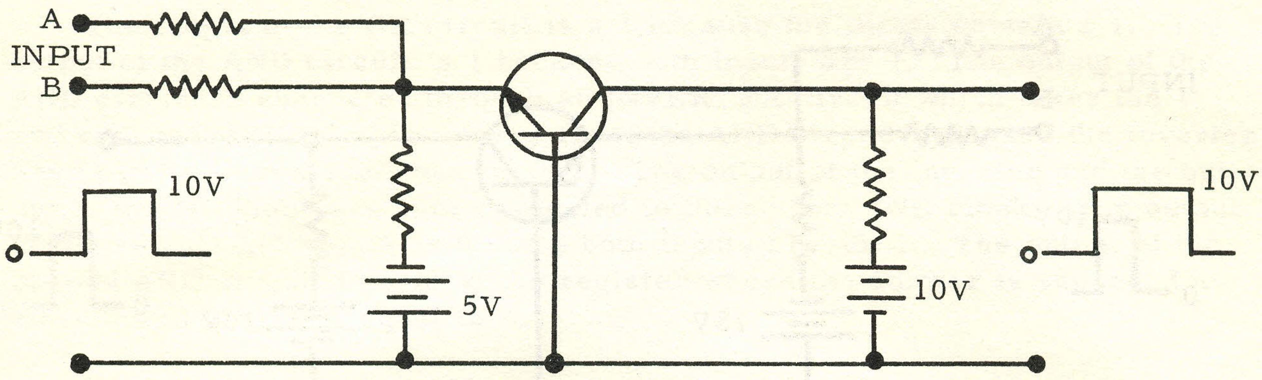


Figure 9

Transistor OR Circuit

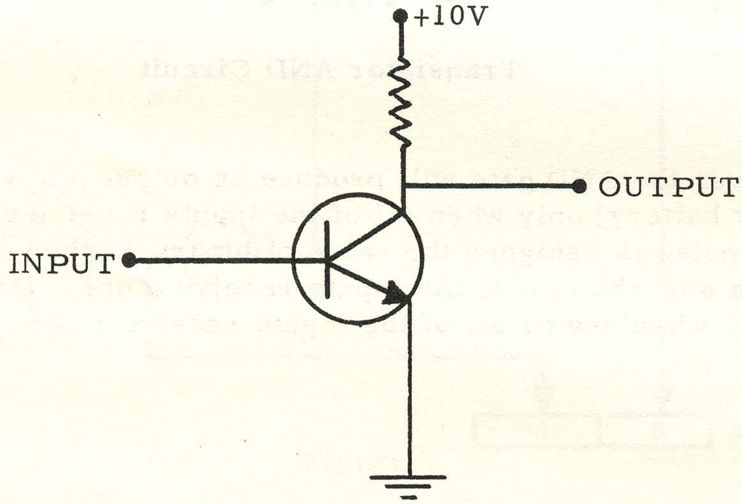


Figure 10

Inverter Circuit

The inverter circuit shown consists essentially of a conventional amplifier stage. In the circuit shown in Figure 10, if the input is zero, the output is positive ten volts. If the input is positive ten volts, the output is zero. Both conditions are due to the transistor being either at saturation or cutoff.

TRANSISTOR MULTIVIBRATOR

Multivibrators are a type of oscillator. They find wide application in missile circuitry. Most of the standard vacuum tube multivibrators have a transistorized counterpart. The Missile Launch/Missile Officer must be familiar with the components, polarities, and the overall operation of transistor multivibrator circuits in order to understand many of the timing and logic circuits found in missile systems and computers.

The multivibrator (relaxation oscillator) uses a regenerative circuit in conjunction with RC components to provide switching action. The charge and discharge times of the reactive elements are used to produce square or pulse output waveforms. Multivibrators may be further classified as free-running (astable), monostable, or bistable oscillators.

Astable Multivibrator

The basic astable transistor multivibrator is shown in Figure 11. It is a two-stage resistance-capacitance coupled common-emitter amplifier. The output of the first stage is coupled to the input of the second stage and the output of the second stage is coupled to the input of the first stage. The signal in the collector circuit of a common-emitter amplifier is reversed in phase with respect to the input of the stage. A portion of the output of each stage is fed to the other stage in phase with the signal on the base. This regenerative feed-back with amplification is required for oscillation. Bias and stabilization is established identically for both transistors.

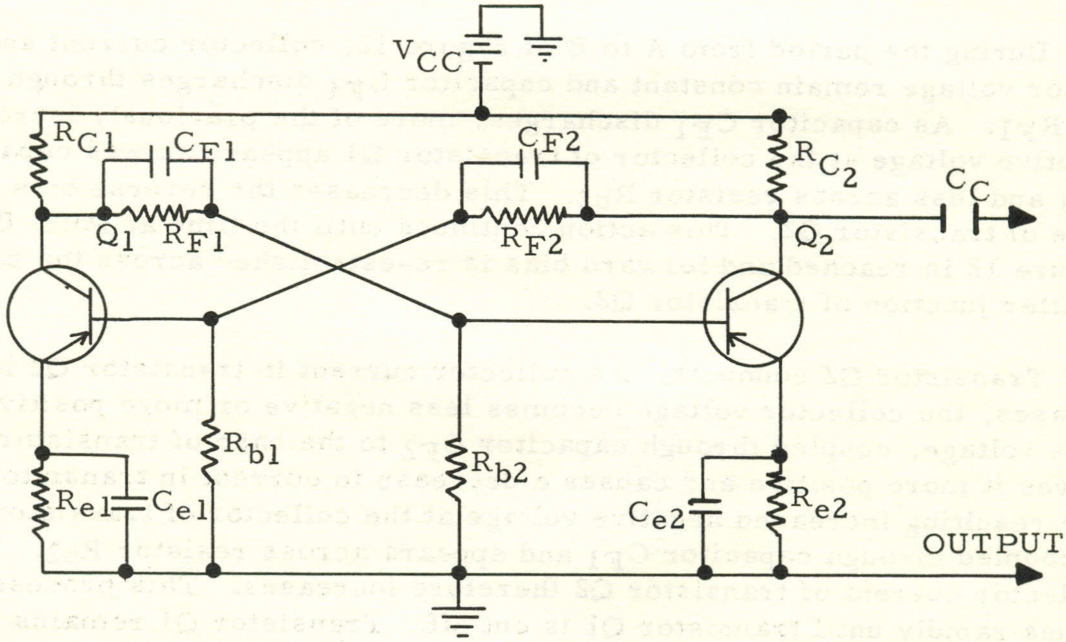


Figure 11

Astable Multivibrator

Because of the variation in tolerances of the components, one transistor of Figure 11 will conduct before the other or will conduct more heavily than the other.

Assuming transistor Q1 is conducting more heavily than transistor Q2, more electrons will flow in the base circuit of transistor Q1 than in the base circuit of Q2. Collector current in transistor Q1 increases rapidly causing collector voltage, and the voltage at the junction of resistor R_{C1} and R_{F1} to decrease, and approach zero. This increasing positive voltage is applied through capacitor C_{F1} to the base of transistor Q2.

As base voltage of transistor Q2 becomes more positive, the forward bias decreases, resulting in a rapid decrease in base current, and collector current in transistor Q2. Collector voltage, and thus the voltage at the junction of resistor R_{C2} and R_{F2} becomes more negative. This negatively increasing voltage is fed back through capacitor C_{F2} to the base of transistor Q1, increasing the forward bias.

This process continues until a point is reached where base voltage of transistor Q2 is cut off (reverse bias is applied) and transistor Q1 is saturated (total DC voltage appears across resistor R_{C1}). That is, the current through transistor Q1 increases steadily as the current through Q2 decreases steadily until transistor Q2 is cut off. Point A of Figure 12 represents this action. This entire action happens so quickly that capacitor C_{F1} does not get a chance to discharge and the increased positive voltage at the collector of transistor Q1 appears entirely across resistor R_{b2}.

During the period from A to B of Figure 12, collector current and collector voltage remain constant and capacitor C_{F1} discharges through resistor R_{F1}. As capacitor C_{F1} discharges, more of the previously increased positive voltage at the collector of transistor Q1 appears across capacitor C_{F1} and less across resistor R_{b2}. This decreases the reverse bias on the base of transistor Q2. This action continues until the time at Point B of Figure 12 is reached and forward bias is re-established across the base-emitter junction of transistor Q2.

Transistor Q2 conducts. As collector current in transistor Q2 increases, the collector voltage becomes less negative or more positive. This voltage, coupled through capacitor C_{F2} to the base of transistor Q1, drives it more positive and causes a decrease in current in transistor Q1. The resulting increased negative voltage at the collector of transistor Q1 is coupled through capacitor C_{F1} and appears across resistor R_{b2}. The collector current of transistor Q2 therefore increases. This process continues rapidly until transistor Q1 is cut off. Transistor Q1 remains cut off and transistor Q2 conducts until capacitor C_{F2} discharges through resistor R_{F2} enough to decrease the reverse bias on the base of transistor Q1 as shown in C of Figure 12.

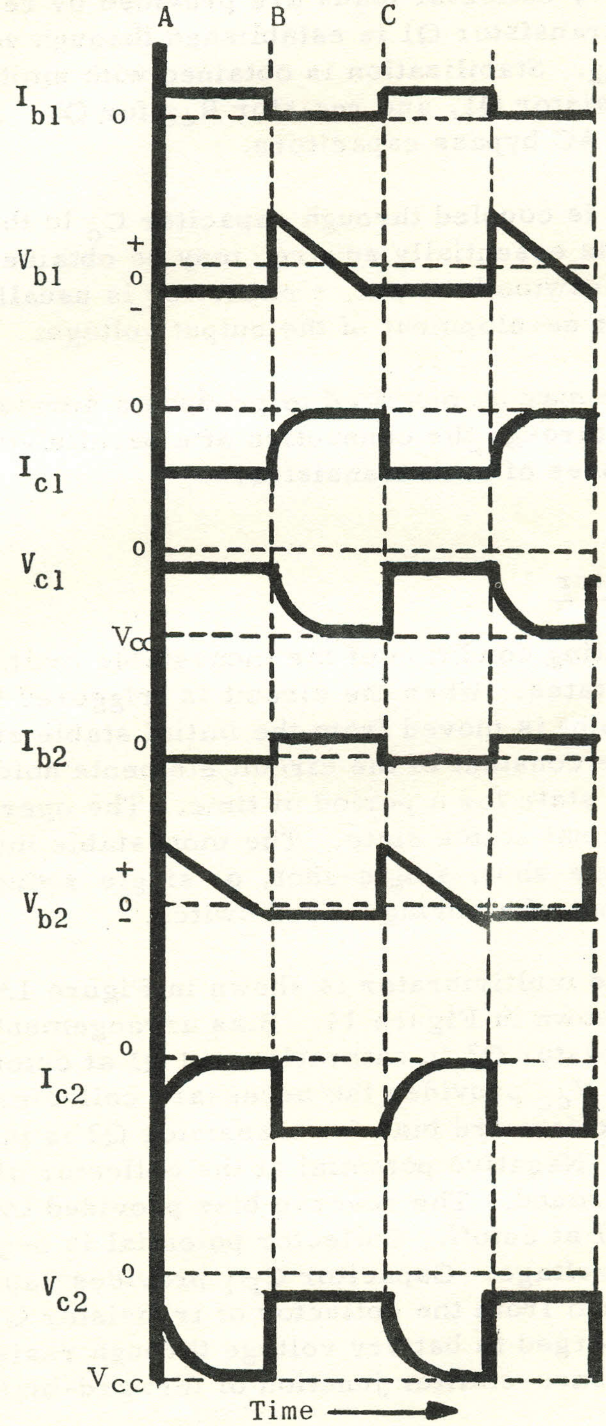


Figure 12

Multivibrator Waveforms

The oscillating frequency of the multivibrator is usually determined by the values of resistance and capacitance in the circuit. In the astable multivibrator of Figure 11, collector loads are provided by resistor R_{C1} and R_{C2}. Base bias for transistor Q1 is established through voltage divider resistors R_{F1} and R_{b2}. Stabilization is obtained with emitter swamping resistor R_{e1} for transistor Q1, and resistor R_{e2} for Q2. Emitter capacitors C_{e1} and C_{e2} are AC bypass capacitors.

The output signal is coupled through capacitor C_c to the load. This output waveform, which is essentially square, may be obtained from either collector. To have a sawtooth output, a capacitor is usually connected from collector to ground for development of the output voltage.

The multivibrator may be modified to produce a sinusoidal output wave. This is accomplished through the connection of a parallel-tuned circuit between the base electrodes of each transistor.

Monostable Multivibrator

The normal operating condition of the monostable multivibrator is in one of the two stable states. When the circuit is triggered by an external pulse, its operating point is moved from the initial stable state to the other stable state. The time constant of the circuit elements holds the operating point in the new stable state for a period of time. The operating point then moves back to the original stable state. The monostable multivibrator is also referred to as a one-shot, single-shot, or single-swing multivibrator. Its action resembles that of a spring loaded switch.

A basic monostable multivibrator is shown in Figure 13. Circuit voltage wave forms are shown in Figure 14. Bias arrangements and transistor regeneration hold transistor Q2 in saturation and Q1 at cutoff during the normal state. Battery V_{cc} provides the necessary collector bias voltages for both transistors and forward bias for transistor Q2 is in saturation during the normal period. Negative potential at the collector of transistor Q2 is effectively zero or ground. The reverse bias provided by the battery maintains transistor Q1 at cutoff. Collector potential is negative and equal to the value of battery voltage. Capacitor C_{F1} provides rapid application of the regenerative signal from the collector of transistor Q1 to the base of transistor Q2. It is charged to battery voltage through resistor R_{L1} and the effectively shorted base-emitter junction of forward-biased transistor Q2.

The circuit will be described with a negative pulse applied to the input, but other means of triggering may be used.

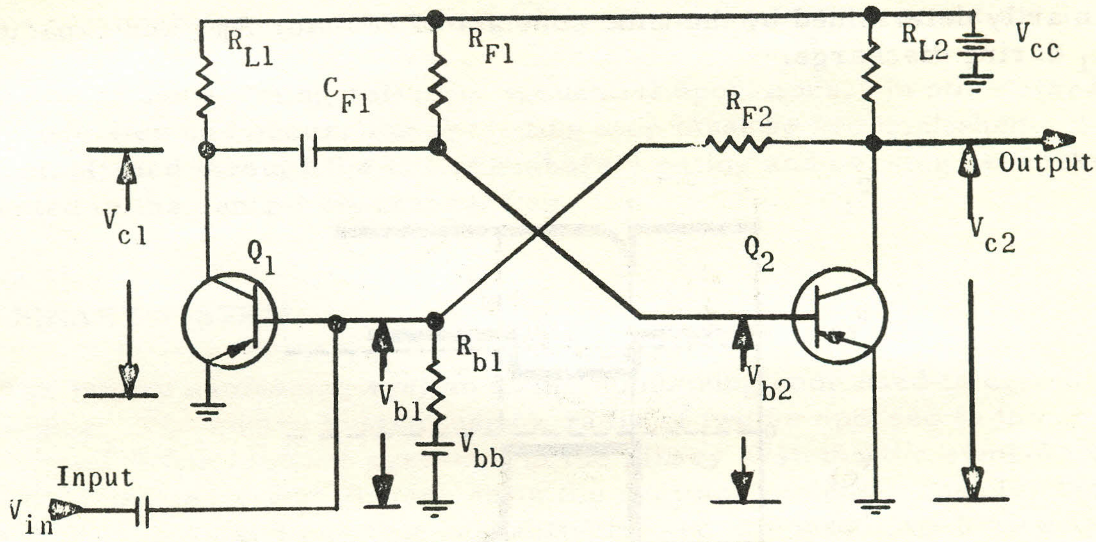


Figure 13

Monostable Multivibrator

A negative pulse is applied through coupling capacitor C_c to the base of transistor Q1, and transistor Q1 begins to conduct. The high negative voltage at the collector of transistor Q1 begins to fall (approaches zero). This positive-going voltage is coupled to the base of transistor Q2, and the forward-bias is decreased. The base current and collector current of transistor Q2 begin to decrease. The collector voltage of transistor Q2 increases negatively. A portion of this voltage is coupled through resistor R_{F2} to the base of transistor Q1, increasing its negative potential. This regeneration results in a rapid change of both transistors; it drives transistor Q1 into saturation and transistor Q2 into cutoff. Since capacitor C_{F1} was initially charged to a potential almost equal to battery voltage, the base of transistor Q2 is at a positive potential almost equal to the magnitude of battery voltage.

Capacitor C_{F1} discharges through resistor R_{F1}. When the base potential of transistor Q2 becomes slightly negative, transistor Q2 again conducts. The collector potential is coupled to the base of transistor Q1, driving it into cutoff. Transistor Q1 is again at cutoff and transistor Q2 is in saturation with its collector voltage almost at zero. This stable condition is maintained until another pulse triggers the circuit.

The output is taken from the collector of transistor Q2. The wave form at this point is essentially square. Time duration of the output pulse is primarily determined by the time constant of resistor R_{F1} and capacitor C_{F1} during discharge.

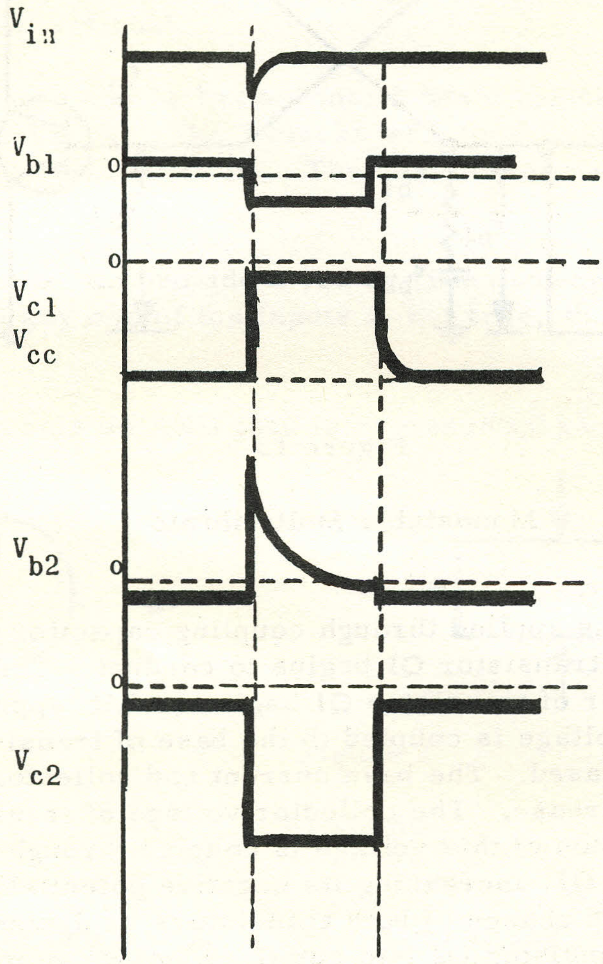


Figure 14

Monostable Multivibrator Waveforms

Bistable Multivibrator

A bistable circuit is initially at rest in either one of the two stable states. When triggered by an input pulse, the circuit switches to the second stable state where it remains until triggered by another pulse. This type of operation is useful for providing a unit step voltage. The circuit is often referred to as a flip-flop. Its action is comparable to an ON-OFF switch.

A basic Eccles-Jordan bistable multivibrator is shown in Figure 15. In the stable state, one transistor is in the ON state while the other is OFF. The states of the transistor are switched with the application of a properly applied trigger pulse.

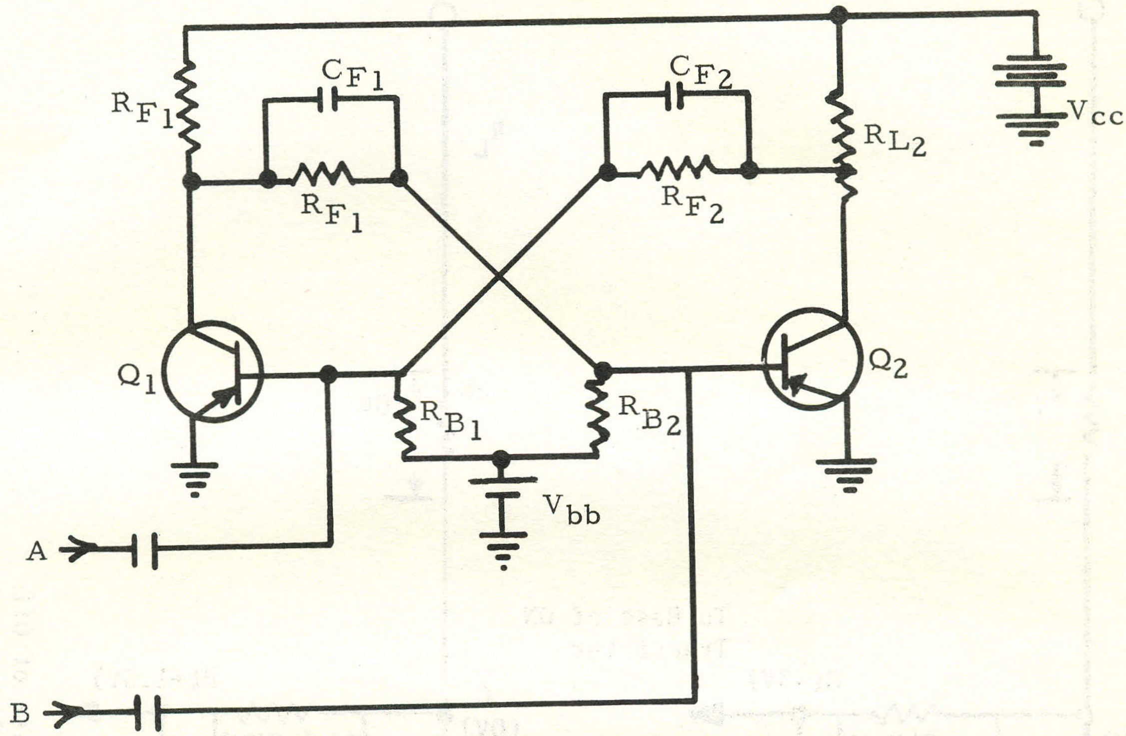


Figure 15

Conventional Bistable Multivibrator

With the initial application of DC power, one transistor will be caused to turn on while the other will be cut off. Each transistor is held in its particular state by the condition of the other. A numerical example is shown in Figure 16. In Figure 16 resistor R_L, R_F, and R_b correspond to the voltage divider networks in Figure 15.

When a transistor is cut off as shown in Figure 16A, its output resistance is high and its collector current is effectively zero. However, current in the voltage divider network (resistors R_L, R_F, and R_b) causes definite voltage drops across each resistor because of collector battery voltage (-28 volts) and base battery voltage (2 volts). $E_{R_{L1}}$ is two volts, leaving approximately the full value of collector battery voltage at point C. The voltage drops across resistors R_{F_1} and R_{b_1} are 21 volts and 7 volts, respectively. This provides a negative voltage (-5 volts) at point B and causes forward bias, and transistor Q2 conducts. (For NPN type transistors, the polarities are reversed.) The resistive and bias values are chosen to drive the ON transistor into saturation.

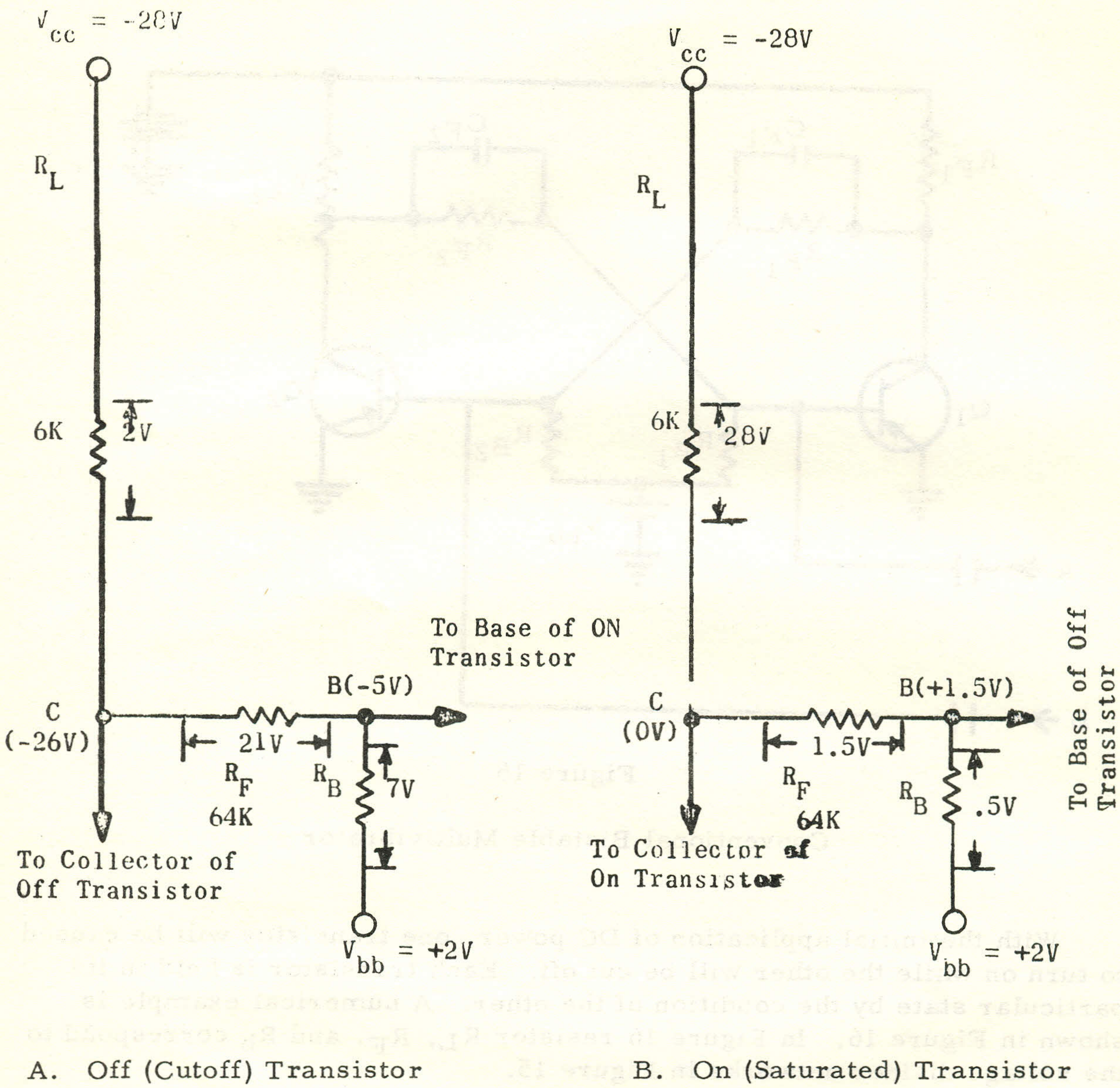


Figure 16

Voltage Divider Network Showing Saturated and Cutoff Conditions Conditions of a Bistable Multivibrator

The high collector current of the on transistor present in resistor R_L, causes a voltage drop equal to collector battery voltage, so that point C, of

Figure 16B is effectively zero. Division of base battery voltage by resistors R_{F_1} and R_{b_1} results in a positive voltage at point B. This is a reverse bias and the transistor is held at cutoff.

The application of a negative trigger pulse to the base of the off transistor or a positive pulse to the base of the on transistor will switch the conducting state of the circuit. Collector triggering may be similarly accomplished. Two separate inputs are shown in Figure 15. A trigger pulse at input A will change the state of the circuit. Once the state of the circuit is changed, an input of the same polarity at input B or an input of opposite polarity at input A will again trigger the circuit. Alternate methods for controlling the application of the trigger pulse are possible.

Assume that transistor Q1 is cut off and transistor Q2 is conducting. A negative trigger pulse applied at input A causes transistor Q1 to conduct. The rise in collector current in transistor Q1 causes the collector voltage to fall. This change in voltage is coupled to the base of transistor Q2 and reduces its forward bias; conduction in transistor Q2 begins to decrease. The Q2 collector current decreases, and the collector voltage changes from zero to a negative value (approaching the value of battery voltage). This change in voltage is coupled to the base of transistor Q1, making the base more negative and increasing the conduction of the transistor. The regenerative feedback continues until transistor Q1 is in saturation and transistor Q2 is cutoff. The time constant of capacitor C_{F_1} and R_{F_1} an that of capacitor C_{F_2} and resistor R_{F_2} essentially determines the fall time (from conduction to cutoff) of transistor Q1 and Q2, respectively. In addition, the capacitors rapidly couple the changing voltages to the bases to insure rapid switching action of the transistors.

The output, taken between collector and ground, is a unit step voltage when one trigger is applied. A square wave output could be obtained through continuous pulsing or triggering of the input. Frequency division is thus obtained, with a ratio of 1 to 2.

MULTIVIBRATOR SUMMATION

Multivibrators are a type of relaxation oscillator. A regenerative circuit in conjunction with RC components provide switching action. They are generally classified as free-running (astable), monostable or bistable oscillators.

The output waveform, which may be used for a number of different purposes, is usually a square wave. It is generally coupled through a capacitor to the load. This output is obtained from either of the two collectors in the circuit.

The monostable multivibrator is also referred to as a one-shot, single-shot, or single-swing multivibrator. Its action resembles that of a spring loaded switch.

A bistable is at rest in either one of the two stable states. When triggered, the circuit switches to the other stable state where it remains until triggered by another pulse. This type of operation is useful for providing a unit step voltage. The circuit is referred to as a flip-flop. Its action resembles that of an ON-OFF switch.

COMPUTER MEMORY DEVICES

Magnetic Tape Storage

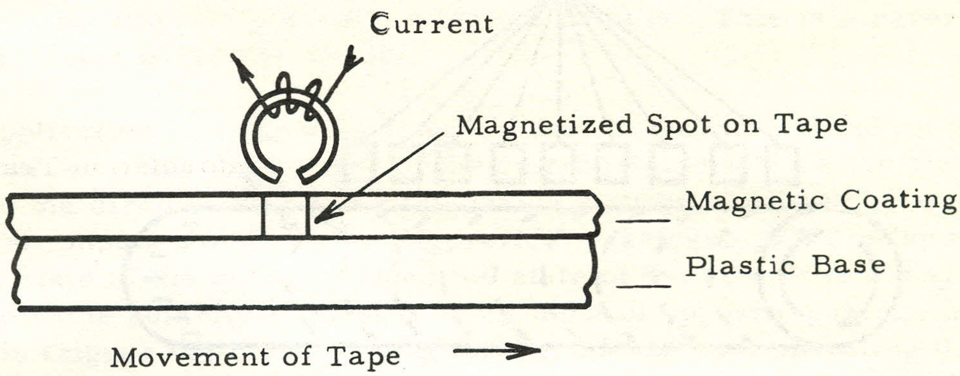
The magnetic tape recorders used for data storage in digital computers differ in physical detail, but not in basic principle, from those used for audio recording. This basic principle is shown in Figure 17A. The tape is moved through the machine by a motor-driven transport mechanism. The path of the tape is such that the magnetic coating is passed adjacent to the air gap in the "write" head. If a pulse of current is passed through the coil of the write head, magnetic lines of force will be established in the core. These lines of force bridge the air gap by flowing through the magnetic coating of the tape. The section of tape under the air gap therefore becomes magnetized as a result of the current flow through the write coil.

Playback, known as "reading" is accomplished by moving the tape adjacent to the air gap of a "read" head. As shown in Figure 17B, the magnetized tape passes the gap, a magnetic field is established in the core, and the lines of force cut across the coil. The voltage induced in the coil constitutes the output. In computer practice, the same head is used for both writing and reading.

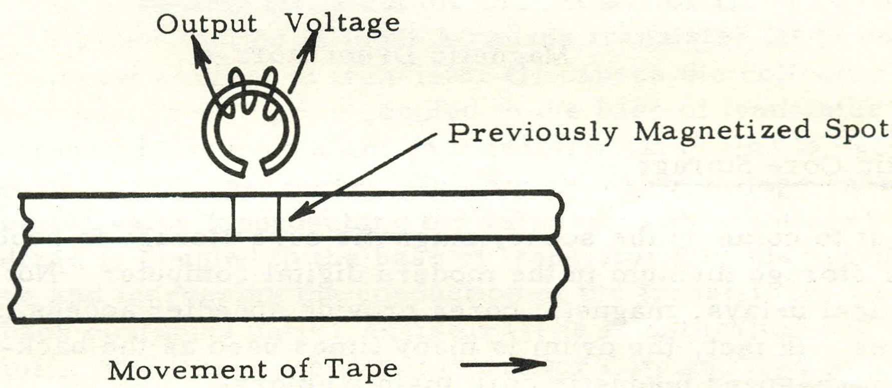
Magnetic tape, as a storage medium, offers the advantage of very great capacity. One disadvantage of this type memory is its relatively long access time. Since the information required at some particular instant may be out at the far end of the tape, several minutes may be required to bring it under the reading heads. For this reason, computers utilize magnetic tape for reserve storage, but use a medium having a shorter access time for the main memory.

Magnetic Drum

This unit consists of a motor-driven, aluminum cylinder coated with a



(A)



(B)

Figure 17

Magnetic Tape Recording and Playback

thin layer of magnetic oxide. Writing and reading are accomplished in a manner similar to that used in magnetic tape. As shown in Figure 18, many parallel tracks can be recorded on the drum. A twelve-inch drum, for example, may hold 200 tracks of information.

Magnetic drums are normally provided with separate heads for each track. The time required to bring stored information under a head depends on the diameter of the drum and the speed of drum rotation. A common value of drum speed is 3600 RPM, but rates in excess of 12,000 RPM have been used.

While magnetic drum storage offers a more limited capacity than does magnetic tape, its access time is much faster. For this reason many computers use the magnetic drum as the high-speed main memory, with magnetic tape as secondary, back-up storage.

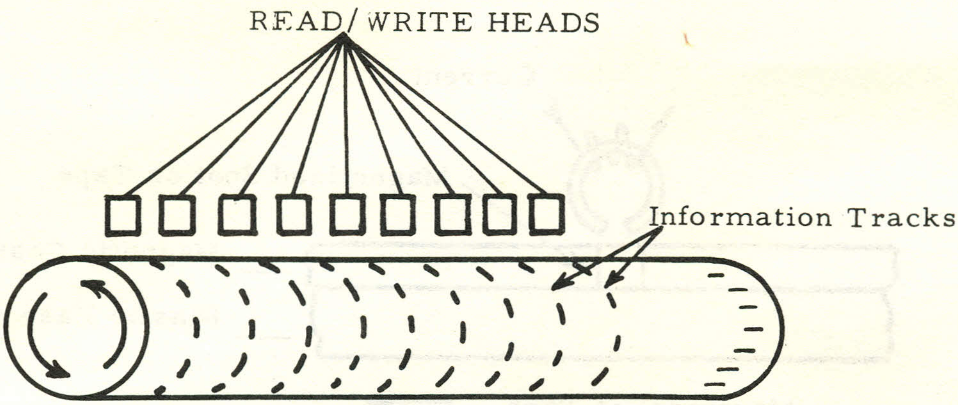


Figure 18

Magnetic Drum Storage

Magnetic Core Storage

Last to come on the scene, magnetic core storage is probably the most popular storage medium in the modern digital computer. Not limited by mechanical delays, magnetic cores provide speedier access time than tape or drums. In fact, the drum is many times used as the back-up storage for the high-speed magnetic core main memory.

The magnetic core is a ring-shaped piece of magnetic material. Measuring only hundreds of an inch in diameter, the core can be magnetized in either of two directions (clockwise or counterclockwise), to store a bit of binary information. Magnetization of the core in one direction can be used as a representation of binary one, and magnetization in the opposite direction can represent binary zero. The binary number 10101, for example, can be stored in five magnetic cores as shown in Figure 19.

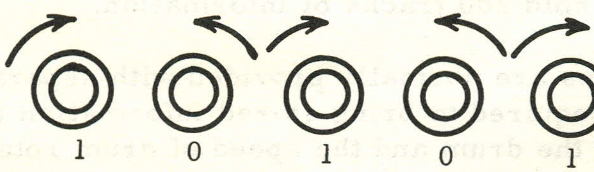


Figure 19

Core Storage of Binary Number 10101

Physically, the magnetic cores are placed on an array of perpendicular sets of wires as shown in Figure 20. For simplicity, a 3-by-3 array of cores is shown, but 32-by-32 and 64-by-64 arrays are commonly used in practice.

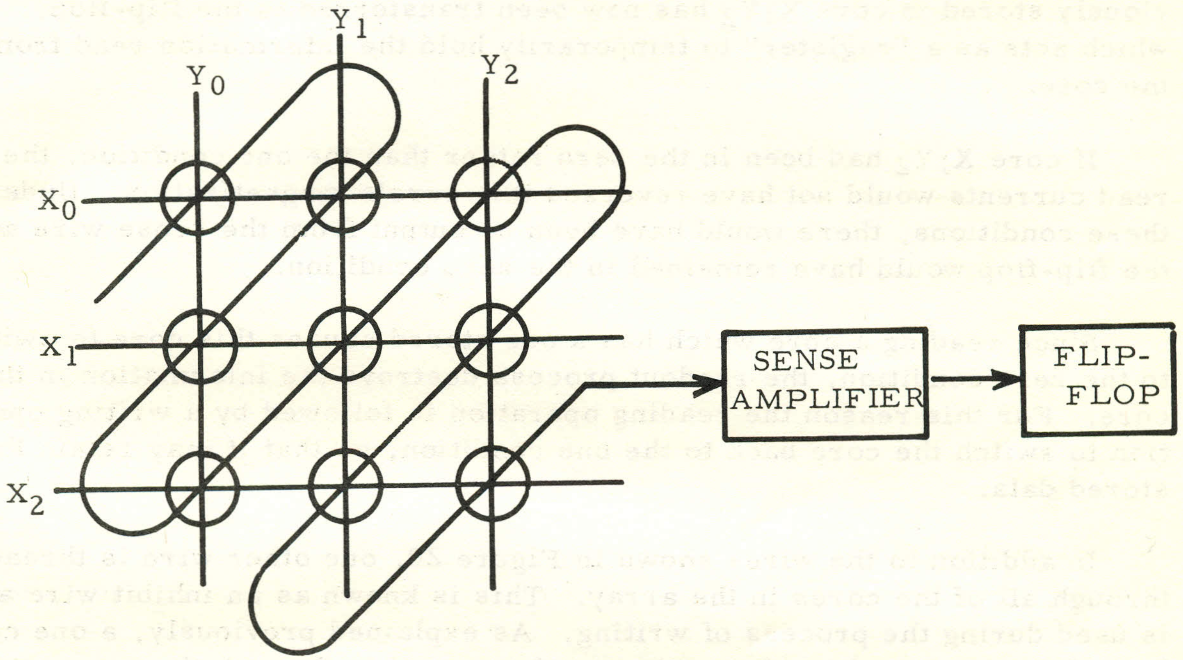


Figure 20

Magnetic Core Storage

Information is written into a core by passing currents through the wires on which the core is mounted. Assume, for example, that all of the cores in Figure 14 are initially magnetized in the zero direction, and that it is desired to store a one in the core located at the intersection of wires X_1 and Y_2. This would be accomplished by passing currents through wires X_1 and Y_2 simultaneously. The values chosen for these two currents are such that either one individually is not sufficient to reverse the magnetization of the core, but the combined effect of both at the intersection X_1Y_2 is sufficient to reverse the core at this location.

The process of reading a core is somewhat similar to the writing process, except that the currents are passed through the X and Y wires in a direction opposite that used for writing. Assume, for example, that the core at X_1Y_2 is to be read. This would be accomplished by passing half-value "read" currents through wires X_1 and Y_2 simultaneously. These read currents are always in such direction as to switch the selected core to the zero direction of magnetization. The read currents will therefore switch core X_1Y_2 to the zero direction, and the reversing magnetic field will induce a voltage in the sense wire shown in Figure 14. This output, which is a few millivolts in amplitude, is amplified by the sense amplifier and then used to trigger a flip-flop stage. The flip-flop counter shown in Figure 14 is now switched to the one condition, and the one which was previously stored in core X_1Y_2 has now been transferred to the flip-flop, which acts as a "register" to temporarily hold the information read from the core.

If core X_1Y_2 had been in the zero rather than the one condition, the read currents would not have reversed this core's magnetization. Under these conditions, there would have been no output from the sense wire and the flip-flop would have remained in the zero condition.

Since reading a core which has a one stored causes this core to switch to the zero condition, the readout process destroys the information in the core. For this reason the reading operation is followed by a writing operation to switch the core back to the one condition, so that it may retain the stored data.

In addition to the wires shown in Figure 20, one other wire is threaded through all of the cores in the array. This is known as an inhibit wire and is used during the process of writing. As explained previously, a one can be written into a selected core by passing currents through the associated X and Y wires. If, however, a zero is to be written into the core, something must be done to prevent the write currents from switching this core to the one state. This is accomplished by passing a half-current through the inhibit wire at the same time the two half-currents are passed through the X and Y wires. The inhibit current is in such direction that it opposes the write currents and thus prevents the selected core from being switched to the one state.

Since the cores in an array are selected for reading or writing on a one-at-a-time basis, this type of storage would be relatively slow if all of the bits of a given number were stored in the same array. Under these conditions, a number would have to be written or read one bit at a time. For this reason, each bit of a number is stored in a separate array of cores. Each of these arrays is known as a plane. Thus, the total capacity of a core memory is determined by the number of cores in each plane and the number of planes.

SUMMARY:

There are two basic types of computers, digital and analog. Digital computers are concerned with discrete, exact values such as digits. Many examples of digital computers exist. The electronic digital computer is the most versatile and rapid computing machine yet devised by man.

An electronic digital computer contains separate but interconnected units. Most computers contain a memory, input and output devices, a control unit, an arithmetic unit, and a timing section.

The memory holds all working data, and makes them available to the data-processing circuits at high speeds when they are needed.

The control circuits cause the other units to function together as an integrated system in a fully automatic manner.

Other units within sections of the computer include registers, comparators, accumulators, inverters, and complementers.

QUESTIONS:

1. What is the function of the memory unit of the computer?

2. Name three different types of input devices.

3. Why does the memory require an address system?

4. What is meant by a "bit"?

5. What code is most commonly used in computers?

6. What is the purpose of a magnitude comparator?

7. What functions of the adder require a complementer?

8. What is the purpose of a reset pulse?

9. How many inputs can be used to an OR gate?

10. What is the Boolean symbol for an OR circuit?

11. What purpose does the NOT function serve?

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