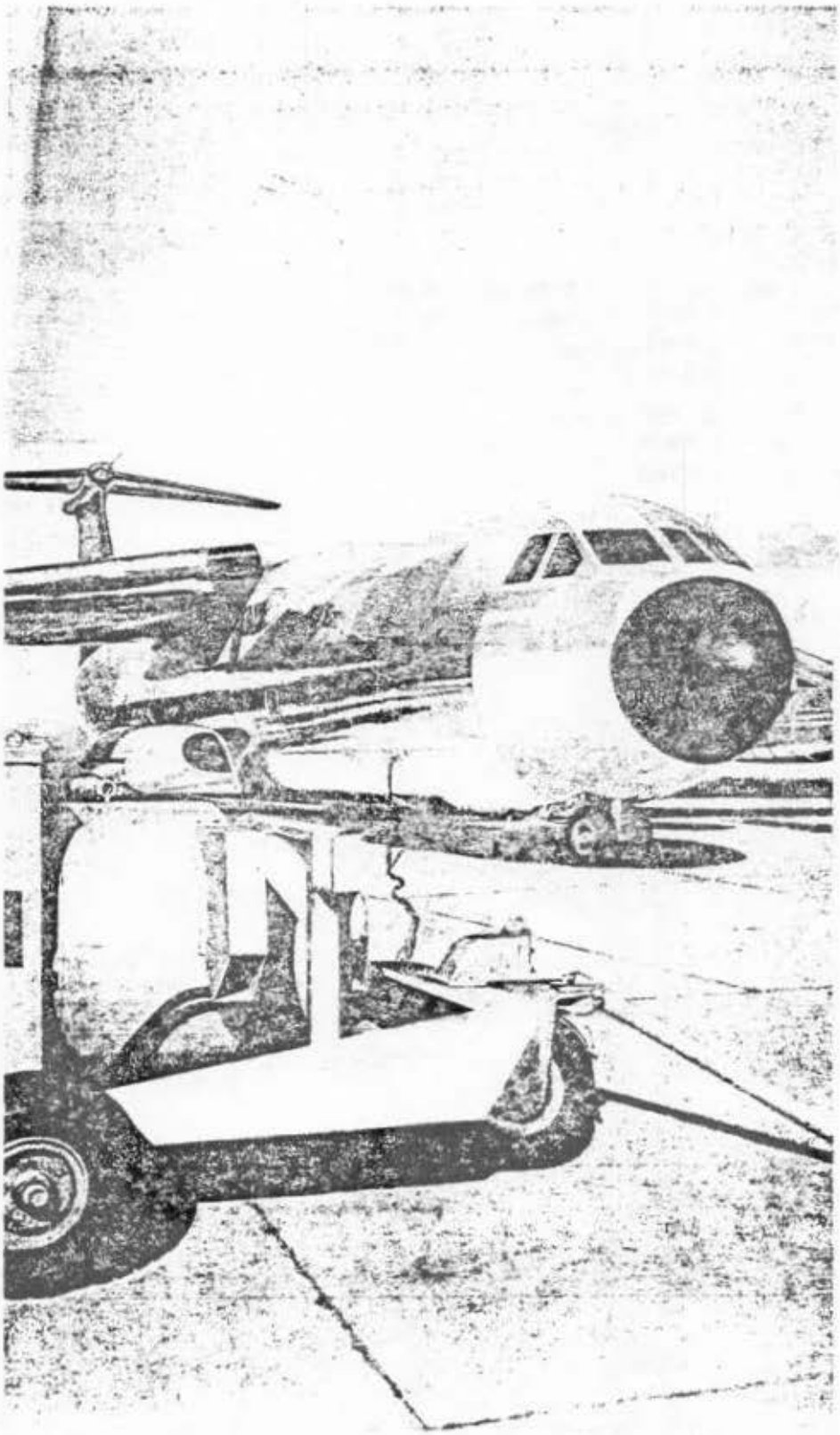
STARLIFTER TRAINING MANUAL • VOLUME III



ELECTRICAL

Customer Training Department • Lockheed - Georgia Company • Marietta, Georgia 30060

STARLIFTER TRAINING MANUAL

VOLUME III

ELECTRICAL

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ABBREVIATIONS, ACRONYMS, AND SYMBOLS*

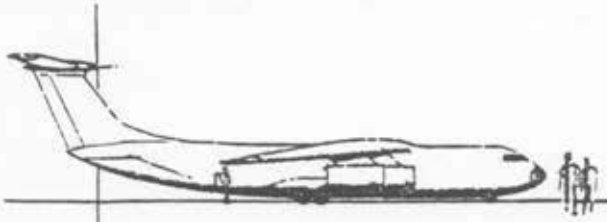
A	Amperes
AC	Alternating Current
AER	Auxiliary External Power Relay
AIL	Aileron
ALD	Automatic Load Disconnect
ALR	Automatic Paralleling Lockout Relay
AMPLS	Amplifier
APA	Automatic Paralleling Auxiliary Relay
APC	Auxiliary Power Contactor
APR	Automatic Paralleling Relay
APU	Auxiliary Power Unit
ASYM	Asymmetrical
AWG	American Wire Gauge
AUX	Auxiliary
BAR	BTC Auxiliary Relay
BAT	Battery
BPD	Bus Power Disconnect
BR	Battery Relay
BTC	Bus Tie Contactor
BTL	Bus Tie Lockout Relay
BTS	Bus Tie Switch
C	Capacity, in farads; Common Relay Contacts
CADC	Central Air Data Computers
CAR	Generator Contactor Auxiliary Relay
CSD	Constant Speed Drive
CT	Current Transformer
CUR	Current
DC	Direct Current (noun)
DEC	Decrease
DET	Detection
DIFF	Differential
DISC	Disconnect
DLR	Differential Lockout Relay (Trip-Reset)
DPCT	Differential Protection Current Transformer
DPR	Differential Protection Relay

* Metric system prefixes are shown on Page 1-1; symbols used on electrical schematics are shown on Page 1-13.

E	Electromotive Force (in volts)
EAR	External Power Auxiliary Relay
EBPR	Emergency Bus Power Relay
EGCR	Emergency Generator Control Relay
ELEC	Electric, Electrical
ELEV	Elevator
EMER, EMERG	Emergency
EMF	Electromotive Force
EMP	Empennage
ENG	Engine, Engineer
Ep	Applied Voltage in Primary of Transformer
EPC	External Power Contactor
EPR	Essential Bus Power Relay
Es	Induced Voltage in Secondary of Transformer
ESS, ESSEN	Essential
ETR	Emergency Power Test Relay
EXT	External
f	Frequency in Hertz (cycles-per-second)
FLT	Flight
FREQ	Frequency (in Hertz)
FSR	Frequency Sensitive Relay
FWD	Forward
GLC	Generator Line Contactor
GCS	Generator Control Relay
GEN	Generator
GLC	Generator Line Contactor
GPU	Ground Power Unit
GRD	Ground
HPT	High Phase Takeover
HI	High
HV	High Voltage
Hz	Hertz (cycles-per-second)
I	Current (in amperes)
IAS	Indicated Air Speed
IBPR	Isolated D-C Bus Power Relay
INC	Increase
IND	Indicator
INOP	Inoperative
INPH	Interphone
INST	Instrument
Ip	Current in Primary of Transformer
IPR	Isolated A-C Bus Power Relay

Is	Current is Secondary of Transformer
ISOL	Isolated
KVA	Kilovolt-Ampere
L	Inductance (in henrys); Left
L-C	Inductance-Capacitance (circuit)
LT	Light
LITS	Lights
LOR	Lockout Relay
LOX	Liquid Oxygen
MAG	Magnetic
MALFUNC	Malfunction
MAX	Maximum
MMF	Magnetomotive Force
MON	Monitor
N	Negative side of Transistors and Diodes (Base)
NBR	Navigation Bus Power Relay
NCR	Neutral Current Relay
N.C.	Normally Closed Relay Contacts
N.O.	Normally Open Relay Contacts
NORM	Normal
Np	Number of Turns in Primary Coil of Transformer
NPN	Type of Transistor
Ns	Number of Turns in Secondary Coil of Transformer
OVHT, OVERHT	Overheat
OXY	Oxygen
P	Power, (in watts); Positive Side of Transistor or Diode (Emitter)
PERM	Permanent
PLR	Power Lockout Relay
PMG	Permanent Magnet Generator
PNP	Type of Transistor
PRESS	Pressure
PREV	Prevention
PROT	Protection
PSR	Phase Sequence Relay
PSS	Power Select Switch
PWR	Power
Q	Charge (in coulombs)
QAD	Quick Attach-Detach

R	Resistance (in ohms); Right
RBC	Reactive Bias Circuit
R-C	Resistance-Capacitance (circuit)
RCCR	Reverse Current Cutout Relay
REC	Recorder
RECT	Rectifier
REG	Regulator
REL	Relay
RET	Retract
REV	Reverse
SBR	Synchronizing Bus Relay Circuit
SCR	Silicon Control Rectifier
SER	Synchronizing Bus Relay
SPLR	Spoiler
STAB	Stabilizer
SW	Switch
SYS	System
T	Time (in seconds)
TDR	Time Delay Relay
TEMP	Temperature
TR	Transformer-Rectifier
UER	Underexcitation Relay
UNDR	Under
USR	Underspeed Relay
USS	Underspeed Switch
UVR	Undervoltage Relay
VAR	Volt-Amperes Reactive
VR	Voltage Regulator
W	Work (in joules); Warning
WARN	Warning
WG	Wing
X_L	Inductive Reactance (in ohms)
X_C	Capacitive Reactance (in ohms)
Z	Impedance (in ohms)
Zp	Impedance in Primary of Transformer (in ohms)
Zs	Impedance in Secondary of Transformer (in ohms)



ELECTRICAL FUNDAMENTALS

REVIEW OF FUNDAMENTALS.

The metric system is a convenient system of units for measuring physical quantities. This system is almost universally used in studying electrical circuits.

The quantities that can be measured are length, mass, and time. In the metric system, the fundamental unit for length is the meter, the fundamental unit for mass is the gram, and the fundamental unit for time is the second.

Prefixes indicate the various possible multiples and subdivisions of the fundamental units. The metric system prefixes are as follows:

SYMBOL	PREFIX	MEANING OF PREFIX	SAMPLE USAGE
p	pico	one-trillionth of	picogram
n	nano	one-billionth of	nanogram
u	micro	one-millionth of	microgram
m	milli	one-thousandth of	milligram
c	centi	one-hundredth of	centigram
d	deci	one-tenth	decigram
	-----	----------	gram
dk	deka	ten times	dekagram
h	hecto	one hundred times	hectogram
k	kilo	one thousand times	kilogram
M	mega	one million times	megagram
G	giga	one billion times	gigagram
T	tera	one trillion times	teragram

The metric system is a decimal system; that is, all multiple units differ from each other by factors of ten. This mathematical relationship helps in writing very large or very small numbers. A special method of expressing these quantities is called scientific number notation. This special method is based upon use of exponents of the number 10. The exponent of a number is called the "power" of that number. Since 10 is the only number concerned here, these exponents are called power of

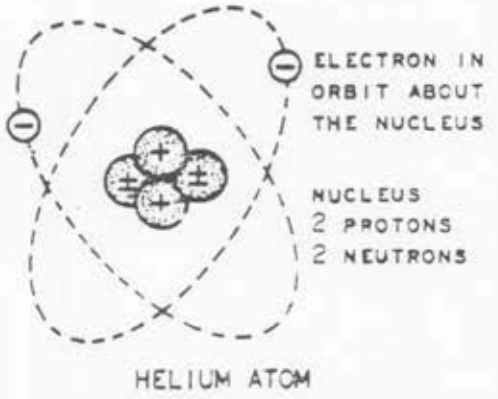
10. Positive and negative powers of 10 are reviewed in this table:

$10^1 = 10$	$10^{-1} = 1/10 = 0.1$
$10^2 = 100$	$10^{-2} = 1/10^2 = 1/100 = 0.01$
$10^3 = 1,000$	$10^{-3} = 1/10^3 = 1/1,000 = 0.001$
$10^4 = 10,000$	$10^{-4} = 1/10^4 = 1/10,000 = 0.0001$
$10^5 = 100,000$	$10^{-5} = 1/10^5 = 1/100,000 = 0.00001$
$10^6 = 1,000,000$	$10^{-6} = 1/10^6 = 1/1,000,000 = 0.000001$

Since 4,000,000 is the same as 4 x 1,000,000, it can be expressed as 4×10^6. Thus 4 megagrams = 4×10^6 grams. When numbers with more than a single digit are used, the decimal point is placed after the first non-zero digit, and the proper power of 10 is used as a multiplier. A decimal point placed here is said to be in "standard position." Examples: ($143,000 = 1.43 \times 10^5$), ($0.00344 = 3.44 \times 10^{-3}$). The number of positions the decimal is moved determines the exponent, and the direction it is moved determines the exponent's sign.

ATOMIC THEORY.

Matter is any substance having weight and occupying space. All matter is made up of basic elements. An element is a substance which cannot be broken down into simpler substances by chemical means. Oxygen, hydrogen, and iron are some of the elements.



HELIUM ATOM

A combination of elements is called a compound. Water is a combination of hydrogen and oxygen. The smallest part of an element is called the atom. When two atoms of hydrogen are combined with one atom of oxygen (H_2O), water is formed. This combination is the smallest part of a compound and is called a molecule.

The basis of all electrical flow goes back to the smallest part of an element, the atom. Each atom has a nucleus (center) which includes protons (charged positively) and neutrons (uncharged). Orbiting the atom's center is the same number of negatively charged electrons as there are protons in the center. In good conductors, these electrons move easily from one atom to another. This movement is called electrical flow.

STATIC ELECTRICITY.

Static electricity is generally associated with insulators or isolated

conductors. Whenever an electrical charge is unable to move through or on an object, it is said to be restricted or static, hence the name "static electricity."

CHARGE TRANSFER.

One of the general laws of electricity is <u>like charges repel each other while unlike charges attract each other</u>. Other important behavior characteristics of electrical charges follow:

1. The presence of a charged body affects some of the properties of any nearby object.

2. Charges remain on the outer surface conductors.

3. Charges tend to concentrate on surfaces where the curvature is greatest.

4. Charges tend to "leak off" at points.

5. Charges can be transferred from one object to another.

6. Charges can move through certain kinds of materials called conductors and are opposed in insulators.

7. A semiconductor is a material that presents more opposition to current than a conductor but not as much opposition as an insulator.

Charge is transferred through a solid conductor or insulator by movement of electrons. Conductors such as silver, copper, gold, and most other metals allow charge transfer with relative ease. Insulators or dielectrics on the other hand, offer considerable opposition to charge transfer. The best insulating materials are non-metallic substances like glass, rubber, and plastics. The most satisfactory insulators are compounds such as lucite, bakelite, and polyethylene. Common semiconductor materials are silicon, selenium, and germanium.

Charge transfer through semi-conductors is made by electrons and "holes." A hole is considered to be positive; an electron is considered to be negative. Holes are attracted to a negative terminal and electrons are attracted to a positive terminal. Impurity atoms have to be added to materials such as germanium or silicon to make them good semi-conductors. This is due to the fact that germanium and silicon in a pure state are good insulators.

Some liquids, such as water solutions of mineral compounds or chemical solutions of acids, bases, or salts, are excellent conductors of charge. The process of charge transfer is accomplished by the movement of positive and

and negative ions in the liquid solution. A positive ion is an atom which has lost electrons; a negative ion is an atom which has gained electrons.

Charge transfer through gases, such as neon, argon, and mecury vapor, is accomplished by the movement of positive ions, negative ions, and free electrons. Free electrons are electrons which are free to move between the atoms when acted upon by electric forces. The time rate at which a charged particle moves is quite low; however, the speed of an electrical impulse is high. An electrical impulse travels close to the speed of light (1.86×10^5 miles/second) in short straight wires.

ELECTRICAL CURRENT.

Electric charge is measured in coulombs. A coulomb represents an exact, large number of electrons, positive ions, or negative ions. There are approximate 6.28×10^{18} electrons in one coulomb of negative electricity. The time rate of a charge is the number of charges moving past a given point in a circuit in some unit of time. The time rate of a charge is defined as current. The ampere is the basic unit of current, and is one coulomb per second. Expressed as a formula,

$$I \text{ (current)} = \frac{Q(\text{charge})}{T(\text{time})} \qquad 1 \text{ ampere} = \frac{1 \text{ coulomb}}{1 \text{ second}}$$

RESISTANCE.

Resistance is opposition to current. The basic unit of electrical resistance is the ohm(Ω). Good conductors have a low resistance to charge transfer; poor conductors have a high resistance. The resistance of a conductor varies with length, cross-sectional area, and type of material. If the length of a conductor is increased, the resistance increases. If the diameter of a conductor is doubled, the cross-sectional area increases four times, and the resistance of the wire is one-fourth as great. A convenient formula for finding resistance of a wire is $R = rL/A$. R is the total resistance, and r is the resistance per unit length. L is the total lenght, and A is the cross-sectional area. The standard unit of measurement of cross-sectional area is the circular mil.

ELECTRICAL POTENTIAL.

The potential energy possessed by electric charges determines the work which the charge can do. Work can appear in the form of heat, as in resistors, or in the form of motion, as in electric motors. The more potential energy a charge has, the more work it can do. In other words, the potential energy is the ability to do work.

The basic unit of work is the joule, which is the amount of work that would be done by lifting a 0.7-pound weight one foot. The amount of work per unit charge is defined to be electrical potential energy. The volt is the basic unit of electric

potential and is one joule per coulomb. Expressed as a formula,

$$E \text{ (volts)} = \frac{W \text{ (work)}}{Q \text{(charge)}} \qquad \text{or} \qquad 1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$$

Voltage is sometimes referred to as electromotive force, or EMF. This is the force produced in a generator, battery, or other source of electric energy.

OHM'S LAW.

Ohm's law can be mathematically stated $I = E/R$ where current (I) is measured in amperes, potential (E) in volts, and resistance (R) in ohms. Current varies directly with potential and inversely with resistance. The ohm is electrically defined by its relationship to other electrical quantities. A potential of one volt across a one-ohm resistor will cause a current of one ampere through it. The voltage appearing across a resistor is said to be "dropped" across the resistor.

KIRCHOFF'S LAWS.

Kirchoff's voltage and current laws for D-C circuits can be stated as follows:

1. Current Law: the algebraic sum of the currents at any junction of an electric circuit is zero.

2. Voltage Law: the algebraic sum of the supply voltage and the voltage drops in any continuous path of an electric circuit is zero.

These two laws have to be restated when used in A-C networks. The laws for A-C circuits are stated as follows:

1. Current Law: the vector sum of the currents at any junction of an electric circuit in zero.

2. Voltage Law: the vector sum of the supply voltage and the voltage drops in any continuous path of an electric circuit is zero.

Kirchoff's laws help in handling complex circuits, and particularly those containing more than one source of voltage (EMF).

POWER.

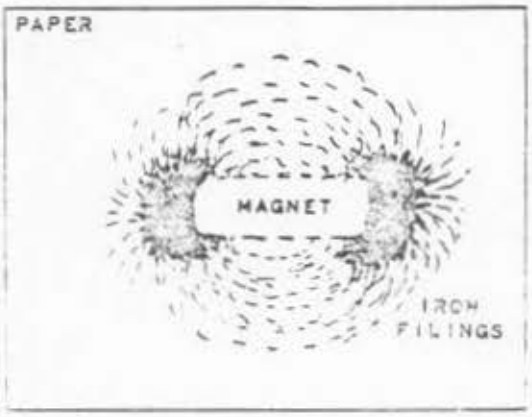
Power is the time rate or energy consumed. The basic unit of power is the watt. One watt is one joule of energy being used in one second. In electrical circuits, the power being dissipated is the product of current and voltage, or $P = EI$. By applying Ohm's Law, power can also be calculated as $P = EI = E^2/R = I^2R$.

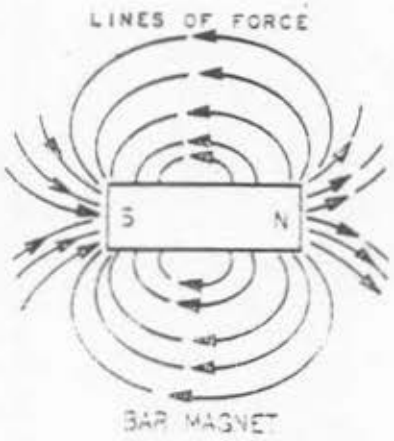
MAGNETISM.

Magnetism is a characteristic property exhibited by electric currents and certain materials. It is an invisible field through which action can be transferred. The field is considered to be made up of lines of force even though such lines do not actually exist. If iron filings are scattered on a surface over a magnetic field, they will appear to arrange themselves along these imaginary lines.

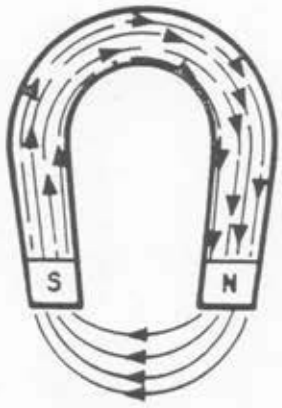
There are two types of man-made magnets: permanent and temporary. Hard steel (alloys of steel) and alnico (an alloy of aluminum, nickel, iron and cobalt) are used to make permanent magnets. Iron and soft steel are used for temporary magnets.

Each magnet has two poles: a north pole and a south pole. It is a fundamental law of magnetism that <u>like poles repel each other while unlike poles attract each other.</u>



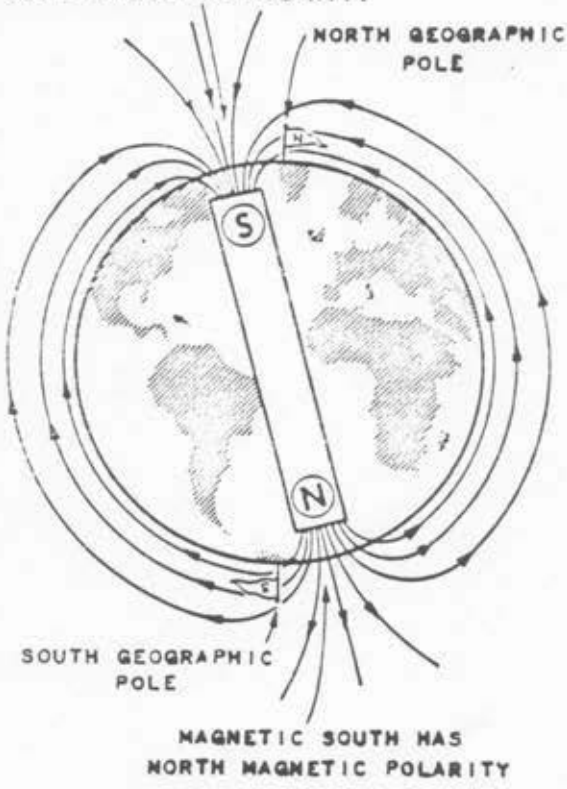


Each magnet has a magnetic field which is represented by "lines of force," or "flux lines." These "lines of force" actually represent the direction which the north pole of a compass would assume if a compass were placed in the field. Thus, the arrows will enter the south pole of a bar magnet, pass through the magnet, leave the north pole, and complete the path around the magnet. Magnetic lines of force are always closed loops, and will never cross one another.



MAGNETIC FIELD
(FLUX LINES)

If two like poles are placed near each other, the lines of force will try to cross one another. Since the lines of force cannot cross one another, the like poles will repel and move away from each other if possible. If two unlike poles are placed near each other, the lines of force will be in the same direction. A force of attraction will result between the two unlike poles, pulling the two together.



The force of attraction or repulsion decreases rapidly as the distance between the two magnets is increased.

If the earth is considered to be a bar magnet, the north pole of the bar magnet is located near the south geographic pole, and the south pole of the bar magnet is located near the north geographic pole. The magnetic poles of the earth are not fixed, but drift slowly with time.

The magnetizing effect which a magnet or coil of current-carrying wire can exert in a circuit is called magnetomotive force, abbreviated MMF. It corresponds to EMF in electrical circuits. The amount

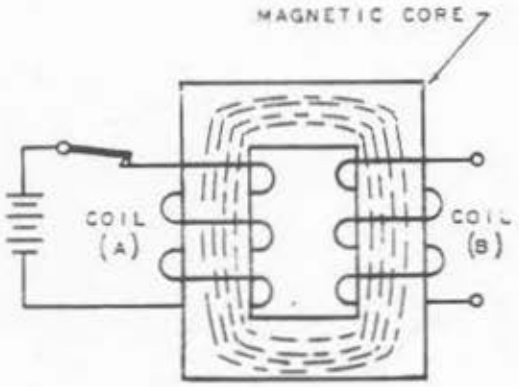
of MMF exerted is expressed in ampere turns. One ampere through one turn of a coil constitutes one ampere-turn. The pole of a generator having 30 turns of wire around it with 10 amperes through the wire will exert 300 ampere-turns of MMF.

Magnetic flux may be represented by lines of force which are imagined to exist in the circuit. Flux in a magnetic circuit is similar to current in an electrical circuit. The greater the number of ampere-turns the greater the magnetic flux.

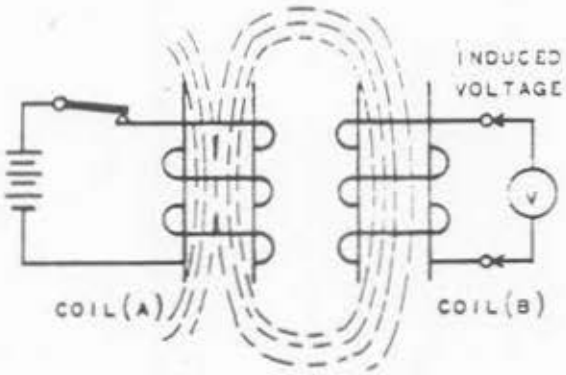
Reluctance in magnetic circuits is similar to resistance in an electrical circuit. Reluctance is opposition to lines of force and determines how much flux will be established by a given MMF. The shorter the length and the greater the cross-section of parts of a magnetic circuit, the lower the reluctance. The unit of reluctance is the oersted. Permeability, the reciprocal of reluctance, is the ratio of the number of flux lines produced by a coil with a core to the number of flux lines produced without a core.

INDUCTION.

Voltage and current can be produced by moving a conductor through magnetic lines of force or by varying the magnetic lines of force surrounding the conductor. Voltage and current obtained this way are produced by electromagnetic induction, or simply induction.



TIGHT COUPLING



LOOSE COUPLING

Induction explains how energy is transferred in magnetic circuits. Producing voltage in a circuit by changing the current in that circuit is called self-induction. Voltage produced in a circuit by the variation of the magnetic field of force in a nearby circuit is called mutual induction. If most of the lines of force from coil (A) are confined to a magnetic core, and are made to link coil (B), the two coils are tightly coupled. If there is no magnetic core, few of the lines of force from coil (A) will cut coil (B) and the two are loosely coupled. Tight coupling is usually most desirable. The amount of voltage induced in an inductor is determined by the rate of current through it and its inductance.

SELF INDUCTION

INDUCTANCE.

Any wire has inductance, but the amount of inductance can be increased by coiling the wire and by using magnetic material for the coil core. The basic unit of inductance is the henry. A coil has an inductance of one henry if a current change of one ampere per second induces one volt across its terminals.

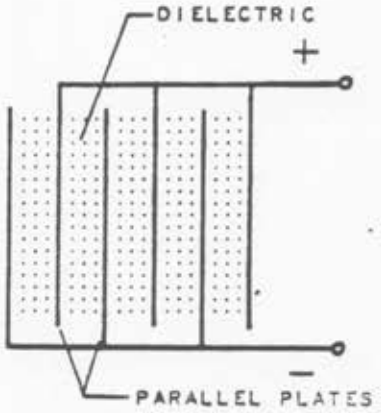
Inductance in a wire or coil opposes any change in current through it. The opposition to changing the current results in a voltage being induced across the coil terminals. Thus, inductance has no effect on pure direct current.

CAPACITANCE.

Capacitors, or condensers, are devices that temporarily store electrical energy. The essential parts of a capacitor are two plates, an insulator (called a dielectric) between the plates, and connecting leads to the circuit. The capacity of a capacitor depends on the area of the plates, the distance between the plates, and the material used as the dielectric. The capacity of a capacitor indicates the amount of electrical energy it can store. The basic unit of capacitance is the farad. A capacitor has a capacity of one farad if one coulomb of charge on the plates will cause a one-volt potential across its terminals. Capacitance opposes any change in voltage across its terminals. The opposition to changing the voltage results in a charging current into the capacitor.

The relationship between the charge stored in a capacitor, its capacity, and its voltage is given by the formula $Q = CE$ where Q is the charge in coulombs, C is the capacity in farads, and E is the EMF in volts.

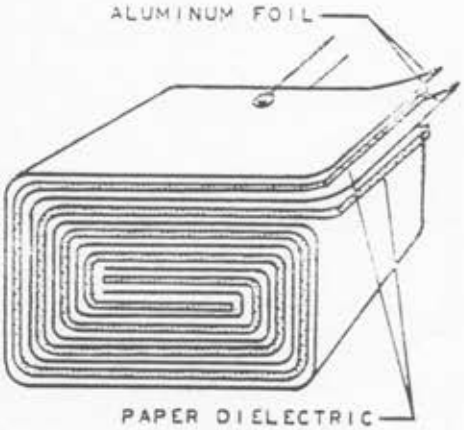
Conduction current, from free electron movement, does not exist in an ideal capacitor, but does exist as a small leakage current in real units. Normal capacitor current is the result of electron orbit displacement and is called displacement current which cannot exist except when the capacitor is charging or discharging. If DC is connected to a capacitor, a displacement current will exist in its external circuit until it is charged. Then, it acts as an open circuit until it is discharged. Since AC is continuously changing, it will cause a capacitor to charge or discharge continuously which creates an effective current in the external circuit.



STACKED TYPE CAPACITOR

It should be remembered that all electron movement is in the circuits external of the capacitor and not through the dielectric (except for leakage current.) If a capacitor's voltage limitations are exceeded, the dielectric will break down and may render the unit unusable.

When sinusoidal alternating current is applied to a pure capacitance, the current leads the voltage by 90 electrical degrees.



ROLLED TYPE CAPACITOR

WIRING AND CIRCUIT ELEMENTS.

Electrical energy is of little use unless a means to carry it from the source to the using equipment is provided. In most aircraft, single-wire circuits are used. In this type circuit, the metal of the aircraft structure serves as the second conductor. This is called a ground. The ground completes the circuit back to the source. This eliminates the need for a second wire, saving much weight.

The wires which connect electric energy sources to the operating units are of different sizes. Many wires are actually a group of smaller wires, or strands, twisted or braided together. The wires are stranded to make them more

flexible. These stranded wires have about the same current carrying capacities as solid wires of the same diameter.

The current rating of a wire is the amount of current which can pass through the wire without overheating it. In choosing a wire or cable for any particular use, the greatest amount of current the wire will have to carry must be considered.

If a long wire is used, the resistance is greater. High resistance can cause improper operation of a unit connected to the wire.

Several types of metal are used to make wire and cable. Probably the most widely used metal is copper. Pure copper is a good conductor because it has very low resistance (many free electrons). Pure copper is not practical to use because it is too soft and has little tensile strength. To make it more usable, various alloys of copper are used. This increases the tensile strength. It also increases the resistance of the wire. Of course, the resistance of the wire is taken into account when the circuit wiring system is designed. Aluminum alloys are often used for large wires in aircraft. Aluminum is a good conductor and is used because it weighs less than copper.

The electrical system in a large aircraft is extensive. A set of electrical drawings, called wiring diagrams, is supplied with each aircraft. They are used as aid in isolating trouble and checking systems.

Each wire is labeled according to its use, location, and size. A typical coding for one of the wires might be

3D 12SA20N

This is what the number means:

3 - UNIT NUMBER: It identifies the wiring of a particular unit if there is more than one identical unit on the aircraft.

D - FUNCTION LETTER: It identifies the function of the circuit in which the wire is connected. For example, the letter "D" means instruments other than engine or flight instruments.

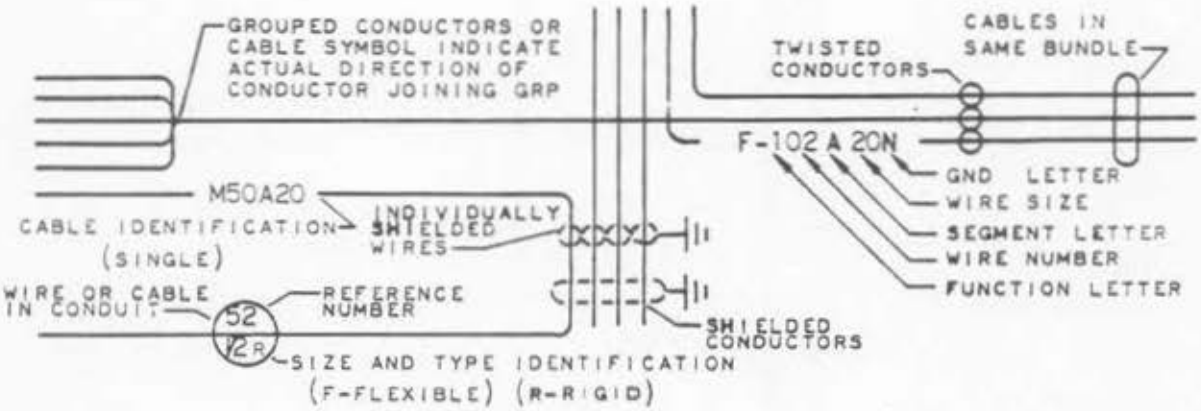
12S - WIRE NUMBER: A given wire might be a part of a larger system or bundle. This number is used to tell the difference between the wires in a particular system. The wire number may also be used to separate two identical systems.

A - WIRE SEGMENT LETTER: This letter identifies which part of the wire is

represented. For example, a given wire may start at some point on the wing and finally end in the fuselage. It might go through several terminal boards and quick disconnects. Therefore, a segment letter is assigned to identify each part of the circuit.

20 - WIRE SIZE NUMBER: This is referred to as wire gauge or American Wire Gauge (AWG). Coaxial or thermocouple wires do not carry sizes. Thermocouples use letters to identify the type wire, such as AL (alumel) and CH (chromel).

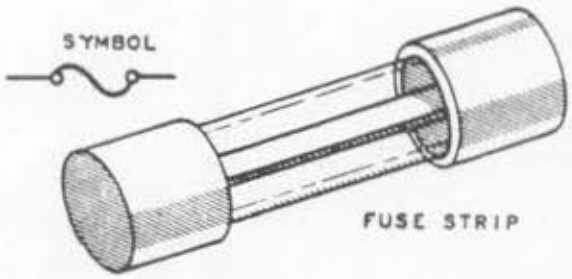
N - GROUND OR PHASE LETTER: This letter is not always included. It is added if the wire is used in a three-phase, A-C system, or if it is the neutral or ground lead in the system. A single-phase system carries the letter "V". The letter A = phase A; B = pnase B; and C = phase C in place of the letter N.



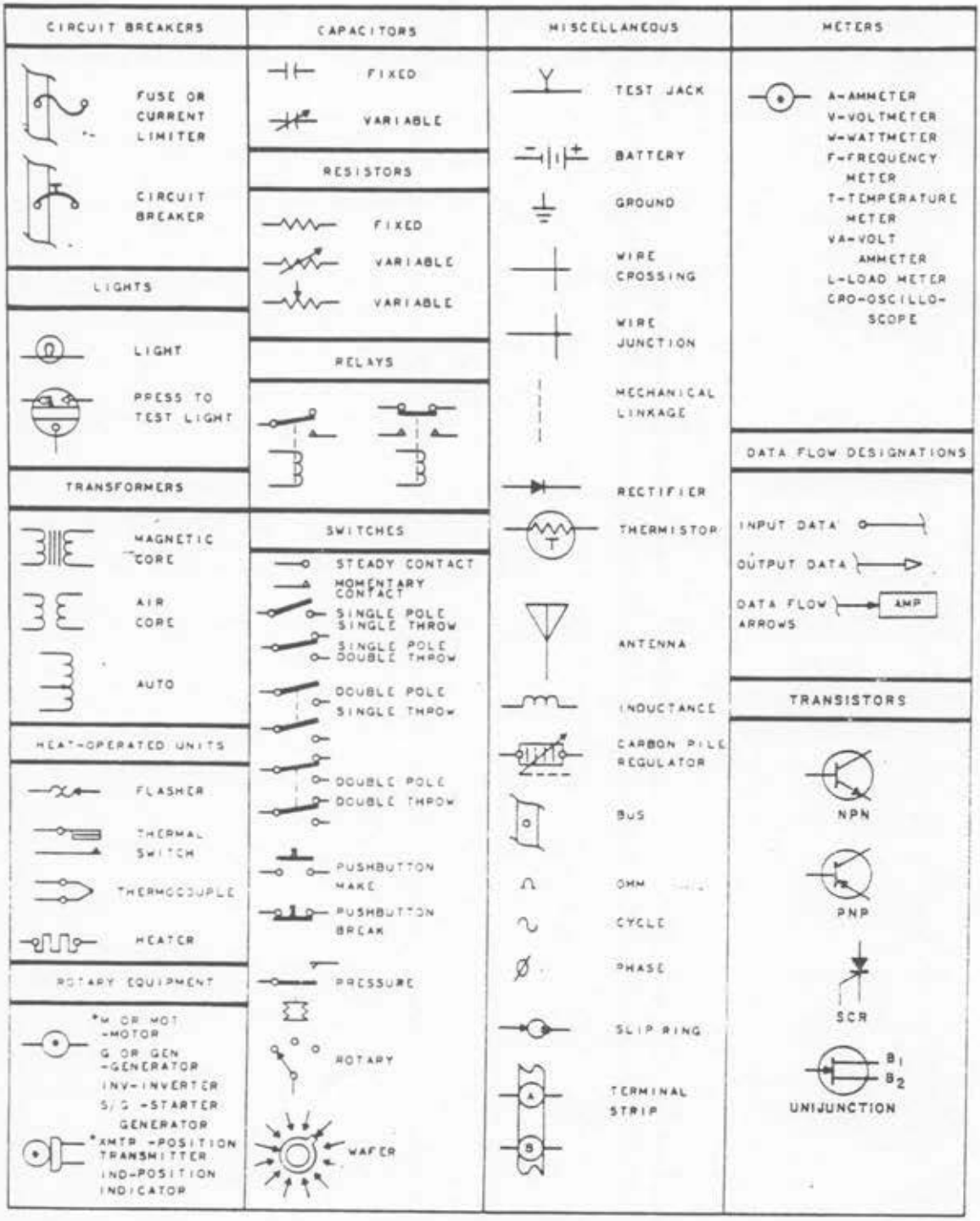
In a schematic diagram or in a wiring diagram different symbols are used to represent the various electrical units. This is often called the electrician's shorthand. The more common symbols are illustrated on the following page.

FUSES.

The primary purpose of a fuse is to protect the electrical wiring in the aircraft. The fuse is put in the line so that if anything goes wrong, it will prevent damage to the aircraft. Charge transfer through a conductor causes heat. The greater the charge flow the hotter the conductor will get. If the current is larger than the fuse is designed to carry, heat operates the fuse. The heat melts the fuse strip. This opens, or breaks, the circuits and stops the charge flow.

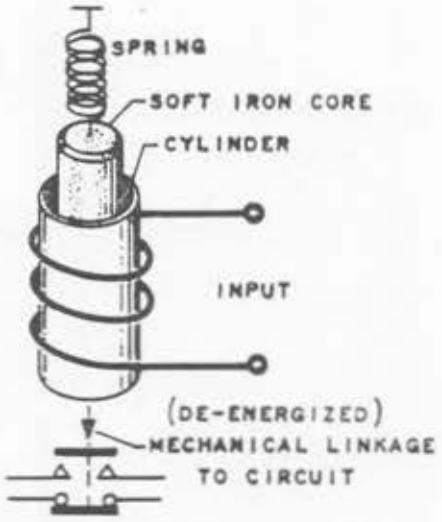


SYMBOLS


CIRCUIT BREAKERS
FUSE OR CURRENT LIMITER
CIRCUIT BREAKER
LIGHTS
LIGHT
PRESS TO TEST LIGHT
TRANSFORMERS
MAGNETIC CORE
AIR CORE
AUTO
HEAT-OPERATED UNITS
FLASHER
THERMAL SWITCH
THERMOCOUPLE
HEATER
ROTARY EQUIPMENT
*M OR MOT -MOTOR
G OR GEN -GENERATOR
INV-INVERTER
S/G -STARTER GENERATOR
*XMTR -POSITION TRANSMITTER
IND-POSITION INDICATOR
CAPACITORS
FIXED
VARIABLE
RESISTORS
FIXED
VARIABLE
VARIABLE
RELAYS
SWITCHES
STEADY CONTACT
MOMENTARY CONTACT
SINGLE POLE SINGLE THROW
SINGLE POLE DOUBLE THROW
DOUBLE POLE SINGLE THROW
DOUBLE POLE DOUBLE THROW
PUSHBUTTON MAKE
PUSHBUTTON BREAK
PRESSURE
ROTARY
WAFER
MISCELLANEOUS
TEST JACK
BATTERY
GROUND
WIRE CROSSING
WIRE JUNCTION
MECHANICAL LINKAGE
RECTIFIER
THERMISTOR
ANTENNA
INDUCTANCE
CARBON PILE REGULATOR
BUS
OHM
CYCLE
PHASE
SLIP RING
TERMINAL STRIP
METERS
A-AMMETER
V-VOLTMETER
W-WATTMETER
F-FREQUENCY METER
T-TEMPERATURE METER
VA-VOLT AMMETER
L-LOAD METER
CRO-OSCILLOSCOPE
DATA FLOW DESIGNATIONS
INPUT DATA
OUTPUT DATA
DATA FLOW ARROWS
AMP
TRANSISTORS
NPN
PNP
SCR
B1
B2
UNIJUNCTION

SOLENOID.

A solenoid consists of a coil of wire wound about a hollow cylinder. If a movable core of soft iron is placed inside the cylinder, the field of the coil will tend to center the core in the coil when current is turned on.



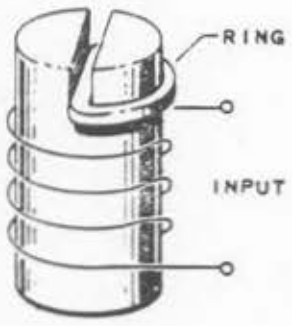
SOLENOID RELAY

Solenoids are used to operate various units such as valves and switches. A solenoid-operated switch is usually called a relay.

RELAYS.

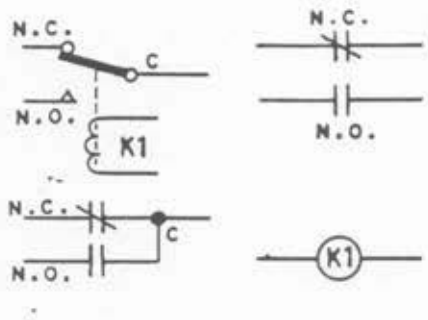
A relay is an electromagnet which positions switch contacts. The magnet can be energized from an A-C or D-C power source, depending on the type of relay. A switch actuator is held in the normal (deenergized) position by a spring. When a power source is connected to the electromagnet, the resulting magnetic field attracts the metal actuator. The relay is energized when the actuator positions the switch contacts in opposition to the spring. Since the field is stronger than the spring, the relay remains energized. When source voltage is removed, the field is collapsed and the spring returns the contacts to normal.

An A-C electromagnet is designed differently than a D-C electromagnet. The D-C electromagnet is energized by a continuous current. The coil is a wire wound around a soft iron core. An A-C electromagnet is energized from an A-C source and must remain energized when the current reverses. A shorted ring is placed in the core to hold the actuator when source current is zero. The collapsing magnetic field induces a current into the ring which keeps the relay energized.



AC ELECTROMAGNET

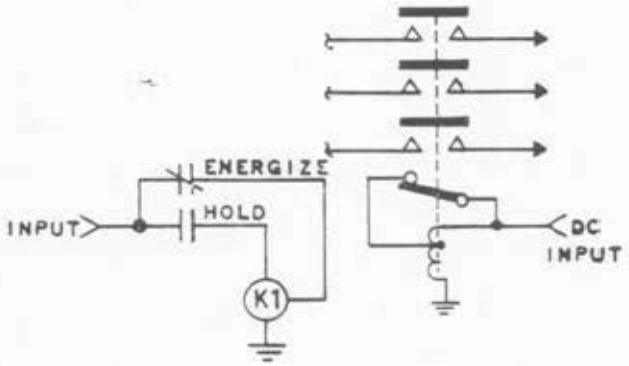
Relay contacts are normally open (N.O.), normally closed (N.C.), or common (C). A schematic symbol for a relay coil is an actual coil mechanically coupled to a switch arm, or a circle representing a coil. The relay is usually identified within the circle. Relay contacts are represented by switch contacts or by two parallel plates. The normally open contact is a triangle symbol indicating momentary and the normally closed contact is a circular contact. With the parallel plate symbol, the normally closed contact has a slanted line between the plates and the normally open does not have a line. When the



relay is energized, the N.O. contacts close and the N.C. contacts open.

A polarized relay is a DC relay which has a permanent magnet as the switch actuator. The magnet holds the contacts in one position or the other but is not strong enough to change the switch positions. The polarity of the power source to the coil determines contact position since the coil field either aids or opposes the permanent magnet field.

A solenoid can be used to actuate relay contacts where many heavy duty and lightweight contacts are required. A relay of this type is a contactor, used in generating and bus distribution systems.



CONTACTOR

The coil winding of a contactor is usually center tapped. One set of normally closed contacts bypass half the coil winding. The contactor coil is energized by current through half of the winding and held energized by the reduced current through the entire winding.

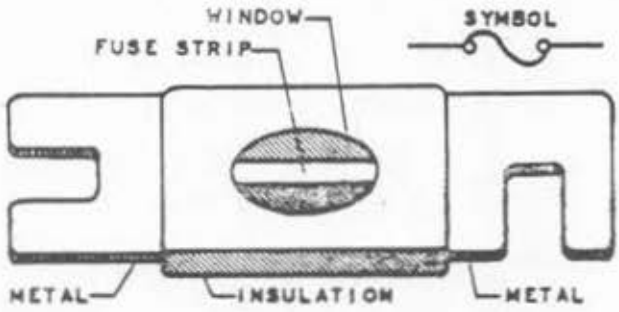
When the current is below the safe maximum, the fuse lets charge flow to the using equipment. If a short occurs somewhere in the circuit and the current is excessive, the fuse strip melts or "blows." These fuses can be made "blow" at any desired current by choosing the right kind of material for the fuse strip and making it the right size. When the fuse "blows," power is removed from the system.

When a fuse is replaced, use a fuse with the current and voltage rating required by the system.

CURRENT LIMITERS.

A current limiter is a special type of fuse used to protect alternators and generators. Alternators and generators can operate up to 50 percent overloads for short to medium intervals of time without excessive overheating or damage. The current limiter is a fuse with a built-in overload delay. This is accomplished by

providing a controlled method of heat removal from the fuse element. The heat conduction path is such that too rapid production of heat does not delay the element burnout. If, however, the overload is within the current limiter overload range, the element is cooled by heat conduction into the terminals and case. This conduction can continue only until the case and terminal temperature increases to about the melting point of the element. Then the element melts and the limiter opens the circuit.



CIRCUIT BREAKERS.

Another protective device is a circuit breaker. A circuit breaker acts as a fuse or current limiter, except that it does not melt on overload. It is a spring-loaded switch which opens when too much current exists in a circuit. It can be reset only after the fault is corrected.

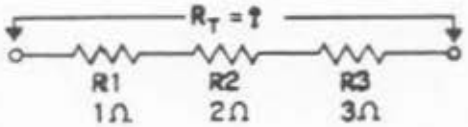
RESISTORS IN SERIES.

Resistors can be connected in series. This means that they are connected end-to-end so that any current in the circuit must pass through each of them. When resistors, or resistive loads, are connected in series, the total resistance of the circuit is simply the sum, or total, of all resistors in series. The total resistance of the resistors in the illustration would be:

$R_t = R_1 + R_2 + R_3$

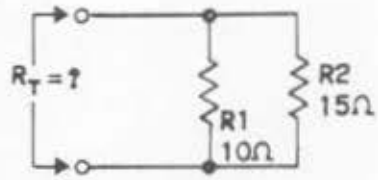
$R_t = 1 + 2 + 3$

$R_t = 6$ ohms



RESISTORS IN PARALLEL.

Another way resistors can be connected is in parallel; that is, connected across each other. In a parallel connection, the total resistance is found in a completely different way than in the series circuit.



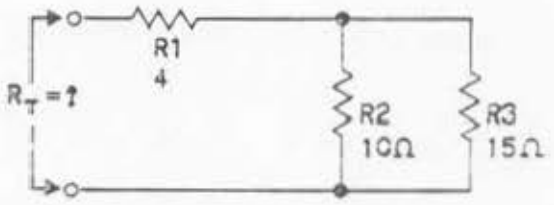
Here the resistors add as reciprocals:

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_1 + R_2}{R_1 \times R_2} \qquad R_t = \frac{1}{\frac{R_1 + R_2}{R_1 \times R_2}}$$

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{10 \times 15}{10 + 15} = \frac{150}{25} = 6 \text{ ohms}$$

RESISTORS IN SERIES-PARALLEL.

Series and parallel resistors can be combined to form a series-parallel circuit. If three resistors are connected as shown in the diagram, both principles from the two separate methods must be applied.



$$R_t = R_1 + \frac{R_2 \times R_3}{R_2 + R_3} = 4 + \frac{10 \times 15}{10 + 15}$$

$$R_t = 4 + \frac{150}{25} = 4 + 6$$

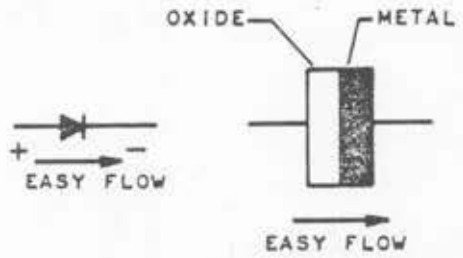
$$R_t = 10 \text{ ohms}$$

In normal practice, most circuits are combinations of series-parallel connections.

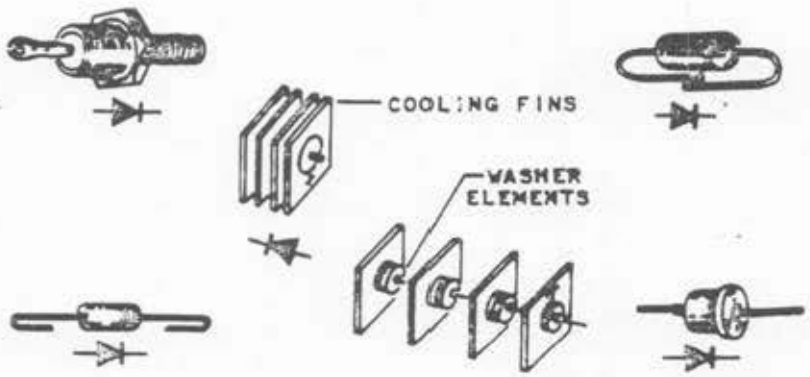
RECTIFIERS.

A rectifier is a device which will allow charge to flow in one direction only. It is often a metal washer with an oxide coating on one side. Because of barrier properties which exist between the metal and the oxide, charge can flow easily from the oxide through the metal. Charge cannot flow easily in the other direction.

In use, the oxide is connected (by wire or terminal) to one point in a circuit. The metal is connected to another. In this illustration, the assumed direction of charge flow is determined by the conventional current theory.



Shown here is the symbol for a rectifier. Physically, a rectifier assembly might look somewhat like the units in this illustration. They are made in many sizes and various other shapes. Rectifiers will be used in later explanations of circuits.



TYPICAL RECTIFIERS

THERMISTORS.

Thermistors (or thermal resistors) are heat-sensitive resistors that are used to sense temperature variations. They are made of materials selected for their temperature coefficients to enable electrical circuits (such as a wheatstone bridge) to detect temperature changes. This information can be used as visual indications or as controlling signals. If the thermal resistor used has a negative temperature coefficient, the resistance decreases as the temperature around it increases. The opposite is true for one with a positive temperature coefficient.

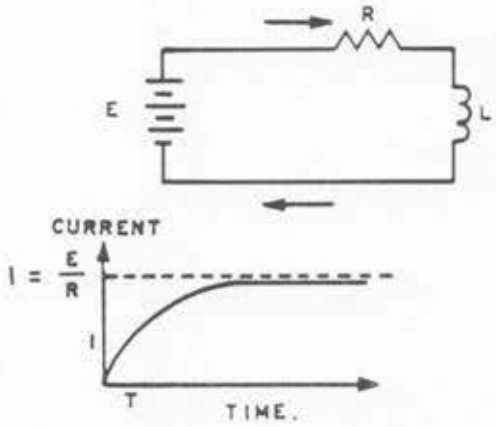
INDUCTORS.

An inductor is a coil, with or without an iron core. Inductors oppose current changes. This is due to self-inductance. If a coil is connected across a battery as shown in the illus-

THERMISTOR

tration below, the charge flow through the coil will follow the graph shown. It will build up slowly and finally reach a maximum value of $I = E \div R$. R is the D-C resistance of the windings of the coil. The reason the current builds up slowly is due to the characteristics of a coil.

At the instant the coil is connected to the battery, the current is zero. As the current increases, the magnetic field around the loops of the coil also increases. As the field around the loops of the coil changes, it induces a voltage in the coil.



Due to the direction of the changing field, this induced voltage is of opposite polarity to the battery. That is, it will buck the applied voltage of the battery and tend to reduce the charge flow through the coil. This bucking effect, or voltage, is known as the back EMF (electromotive force).

As the current approaches its greatest value, its rate of change decreases. This, in turn, decreases the change in the magnetic field. The process continues until the current is no longer changing. When the current stops changing, the field stops changing and the back EMF disappears. The current assumes a constant value which is determined by the voltage of the battery and the D-C resistance of the coil.

If the coil is connected across an A-C source, the back EMF will have quite an effect on the charge flow. Because the current is constantly changing, a constantly changing magnetic field will be created. In this case, the back EMF never completely disappears.

The back EMF factor of the coil inpedance is known as its reactance. Since the reactance is brought about by the changing magnetic field which is dependent on changing current, it follows that the reactance will be dependent on the rate of change of the current. This means that it will be dependent on the frequency. As the frequency goes up, the back EMF, and hence the reactance, goes up. This type reactance, which is called "inductive", is given the symbol "X_L." It may be expressed in a mathematical formula as:

$$X_L = 2\pi fL \qquad (2\pi = 6.28)$$

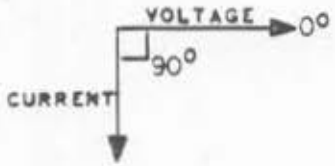
where "f" is the frequency and "L" is the inductance of the coil.

The inductance of the coil is determined mainly by the number of turns, their spacing, and the type core used. As previously stated, the basic unit of inductance is the henry.

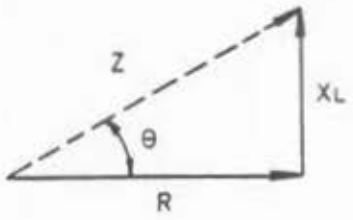
The back EMF factor, or reactance, introduces a new concept. This new concept is phase. In the graph showing the current rise in a coil which is connected to a D-C source, the current lags the voltage across the coil. This is due to induced back EMF retarding the current.

As the current tries to rise, it creates the back EMF which tries to furnish a current in opposition to the original current. This opposition makes the current rise slow down and take longer to reach its maximum.

This same lag of the current behind the voltage takes place in AC. The voltage and current can be shown by the vector diagram. The length of a vector represents the size, or magnitude. Its arrow indicates the direction. For the time being, the coil is considered as having no resistance. In this case, the current lags the voltage by 90 degrees if the AC is a sine wave. In vector diagrams, the applied voltage (and anything in phase or at the same angle with it) is usually shown as being the reference or zero-degree point.



It is the combination of two factors, the resistance of the winding and the back EMF, that determine the impedance of the coil. Impedance in an A-C circuit is the total opposition to a current. In this respect, it is like resistance in a D-C circuit.



The actual coil has both resistance and reactance. The impedance of the coil is the vector sum of the two. Since the resistance has zero degrees phase (the same as voltage), it is drawn horizontally. Since the inductive reactance causes a lag in current, it is drawn 90 degrees ahead of the resistance vector.

Impedance, given the symbol Z, is the slanted line connecting the end of the two (resistance and reactance) vectors. Because

of the relationship between the side of the right triangle, $Z = \sqrt{R^2 + X^2}$. The angle that the impedance vector makes with the resistance vector is called the phase angle. It is usually given the symbol Θ (the Greek letter theta).

If a coil with a known inductance is given, its reactance at any frequency can be calculated. The equation $X_L = 2\pi fL$ is used. Then, knowing the reactance and the resistance, the impedance at that frequency can be found. For this, the equation $Z = \sqrt{R^2 + X_L^2}$ is used. Impedance is expressed in ohms.

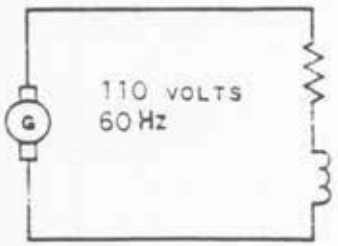
Example: Compute the impedance of a coil having an inductance of 10 henrys and a resistance of 1,000 ohms at a frequency of 60 Hertz (cycles per second).

Step 1: $X_L = 2\pi fL = 2 \times 3.14 \times 60 \times 10$

$X_L = 3,768$ ohms

Step 2: $Z = \sqrt{R^2 + X_L^2} = \sqrt{(1,000)^2 + (3,768)^2}$

$Z = 3,900$ ohms



Impedance can be used in a form of Ohm's law to solve A-C circuit problems. The equation is written $I = E/Z$.

The coil is now connected across an A-C source as shown. Its resistance and reactance are shown as separate quantities, even though they are both actually within the coil itself.

To compute the current in the coil, simply apply OHM's law and use impedance instead of resistance.

$I = E \div Z = 110 \div 3,900$ $I = 0.0282$ amperes or 28.2 milliamperes

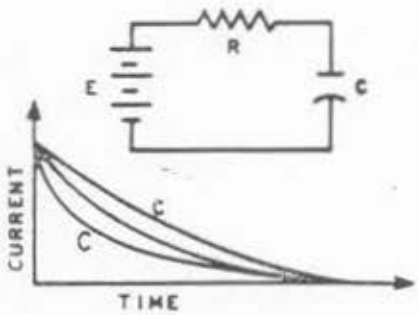
The phase angle in degrees is equal to the cosine of R/Z in the trigonometric table.

$$\frac{R}{Z} = \frac{1000}{3900} = 0.256$$

The cosine of 0.256 is 75.1°. Circuit current lags voltage by 75.1°.

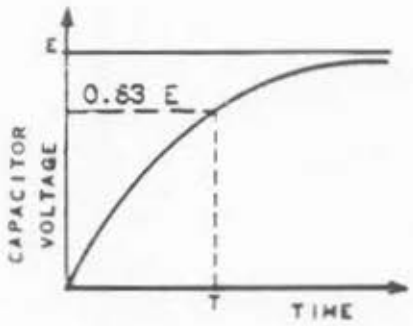
CAPACITORS.

The term capacitor is another name for an electrical condenser. A capacitor is capable of storing electrical energy. When a capacitor is connected across a battery as shown, there is an initial surge of current that charges the capacitor until the charge equals the battery voltage. When this occurs there is no further flow of charge from the battery. When the capacitor is disconnected from the battery, the charge will gradually leak off and neutralize the capacitor. The capacitor can be discharged rapidly by connecting a wire to both plates.



The capacitor is connected to a battery through a resistor. At the instant the connection is made, there is a high surge of current. This is due to the charging of the capacitor. As the capacitor nears full charge, the current decreases until, for all practical purposes, it is zero. When the charge stops flowing in the circuit, the full voltage of the battery will be across the capacitor. This is true because there is no more current to cause a voltage drop across the resistor.

If an R-C circuit is connected to a battery, the voltage across the capacitor terminals will rise as shown. The length of time required for the capacitor to charge to 0.63E or 63% of its final voltage, is the time constant for that R-C circuit. The relationship between the time constant T (in sec), the capacitance C (in farads), and the resistance R (in ohms) is

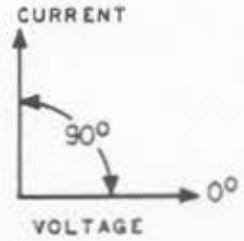


$$T = RC$$

Time constants in electrical circuits are sometimes very important because the operating time of relays is affected. The time constant can be used to provide a desired delay in the operation of a circuit.

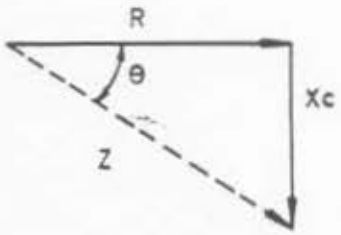
The phase relationship graph for a capacitor is shown here. It is the exact opposite of the graph for an inductance. This means that the current through the

capacitor leads the voltage. So, the same type of vector diagram, as before, can be drawn except that now the current lead the voltage. It would not lead it by 90 degrees if there were any resistance involved.



This leads to the formula for the reactance of the capacitor,

$$X_C = \frac{1}{2\pi fC} = \frac{0.159}{fC}$$



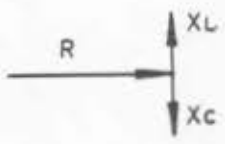
This time, as the <u>frequency goes up the reactance goes down.</u> To represent the impedace of a capacitor, the vector diagram would be just like the one for the coil except that now the reactance vector points down. As far as any calculations go, they are the same for both, with one exception. The phase angle for the impedance of the capacitor is negative.

Once the reactance or impedance has been calculated, it can be treated the same as resistance, except for the phase angle. Reactances or impedances in parallel add like resistors in parallel. Reactances or impedance in series add like resistors in series. The main difference is that the reactance or impedances vary with frequency.

A capacitive reactance is cancelled by an equal inductive reactance due to the phase angle. (Example: X_C of $10 \angle -90^\circ$ is cancelled by an X_L of $10 \angle 90^\circ$ which results in a pure resistive circuit). Capacitors in series act the same as resistors in parallel and capacitors in parallel act the same as resistors in series.

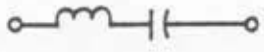
RESONANCE.

Resonance occurs at the frequency at which a given coil and capacitor have the same reactance (equal in number but opposite in sign). There are only two ways a coil and capacitor can be connected: in series or in parallel. Either way, this point can be shown with another vector diagram. When $X_C = X_L$,



the two 90-degree components cancel each other since they are opposite in sign. The resistance of the coil and capacitor is neglected in the following discussion.

If a coil and capacitor are connected in series as shown here, the circuit offers the least reactance or impedance to current at the frequency when $X_C = X_L$. This is called the resonant frequency. The relationship between the inductance, capacitance, and resonant frequency are found as follows:



$$X_C = X_L$$

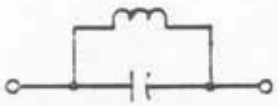
$$\frac{1}{2\pi fC} = 2\pi fL$$

or

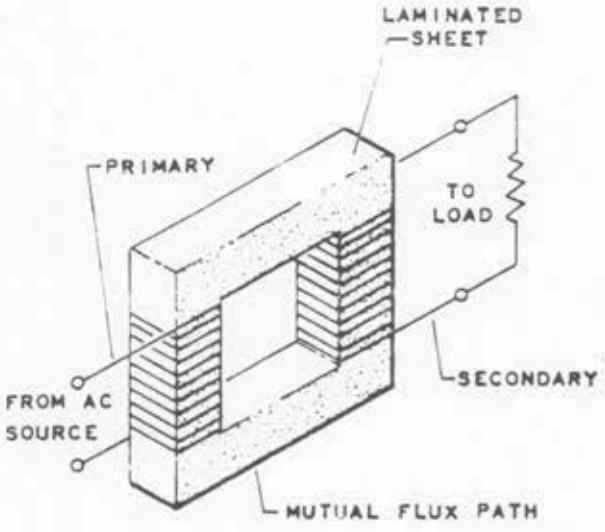
$$f = \frac{1}{2\pi\sqrt{LC}}$$

PARALLEL RESONANCE.

A coil and a capacitor can also be in parallel, as shown. This gives a resonant frequency which is generally the same as for the series circuit. The resonant frequency for the parallel circuit is calculated as if the circuit were a series circuit. In a parallel L-C circuit, the impedance is maximum and circuit frequency is minimum at resonance.



PARALLEL RESONANCE



TRANSFORMERS.

A transformer transfers A-C electric energy from one electrical circuit to another. It does this without a frequency change. The principle used is electromagnetic induction, where electrical circuits are linked by a common magnetic circuit.

This illustration shows the basic construction of a transformer. The primary coil is connected to an A-C source, causing the current and resulting flux to periodically change magnitude and direction. The flux variation

is concentrated in the laminated steel core. The varying flux induces an EMF in the secondary coil. If the secondary coil terminals are connected to a load, a charge flows through the load. Thus, electrical energy is transferred from one electrical circuit to another by means of mutual inductance. The action that created the EMF in the secondary is known as transformer action. The EMF is referred to as transformer voltage.

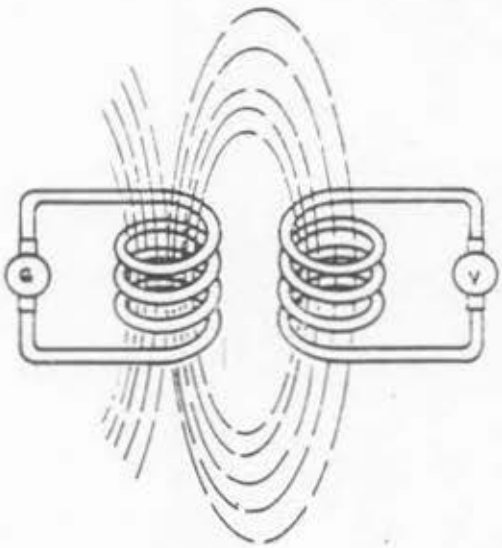
If all lines of flux link both the primary and secondary of a transformer, several useful relationships between the turns, voltage, and current ratios can be found. The primary coil is supplied from an A-C source. The voltage read at the secondary coil is the same as the source voltage (neglecting transformer losses) if both coils have the same number of turns. If the secondary contains more turns than the primary, the secondary voltage is higher than the primary voltage. If the secondary contains fewer turns than the primary, the secondary voltage is lower than the primary voltage. The formula for voltage and turns ration is $\frac{Ep}{Es} = \frac{Np}{Ns}$ where:

Np = number of primary turns
Ns = number of secondary turns
Ep = applied voltage in primary
Es = induced voltage in secondary

Transformers are normally used to increase or decrease a voltage. If the voltage is increased, it is called a step-up transformer. The current ration of a transformer is inversely proportional to the voltage ratio

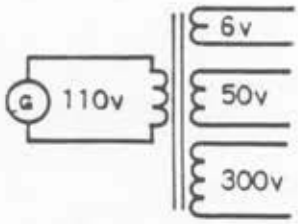
$\frac{Np}{Ns} = \frac{Ep}{Es} = \frac{Is}{Ip} = \sqrt{\frac{Zp}{Zs}}$ where

Is = the current in the secondary
Ip = the current in the primary
Zp = the primary inpedance
Zs = the secondary impedance



POWER TRANSFORMER.

Electronic equipment frequently requires more than one A-C voltage. Power transformers are normally designed



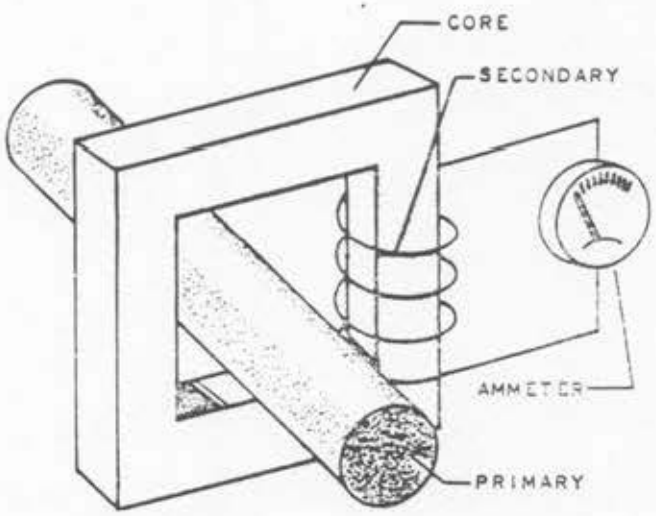
with more than one secondary winding wound on the same core. This illustration shows a typical power transformer. It has a 6-volt winding, a 50-volt winding, and a 300-volt winding.

CURRENT TRANSFORMERS.

Current transformers are used to measure alternating current in a line without breaking the circuit. The current-carrying conductor passes through the core and acts as a single-turn primary. The secondary is made of many turns of fine wire. The voltage in the secondary is stepped up because the secondary contains more turns than the primary. The current is stepped down in the same ratio that the voltage is stepped up. An ammeter rated at five amperes full-scale deflection is normally used. Thus, if the current transformer has a ratio of 100:5, full scale deflection on the 5-ampere meter scale indicates that there is 100 amperes flowing in the primary.

AUTOTRANSFORMERS.

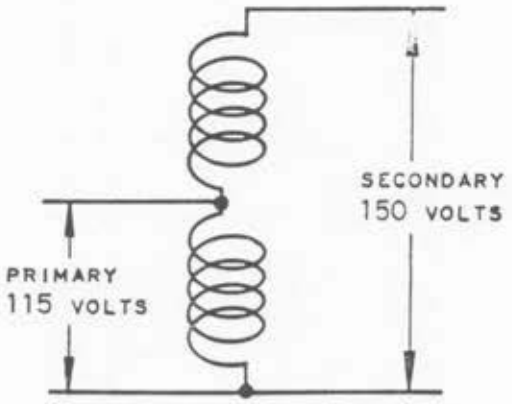
The autotransformer differs from the conventional two-winding transformer in the way in which the primary and secondary are constructed. In the conventional transformer, the primary and secondary winding are completely insulated from each other but are magnetically linked by a common core. In the autotransformer, the two windings, primary and secondary, are both electrically and magnetically connected. The autotransformer may be constructed in either of two ways. In one arrangement there is a single, continuous winding with taps brought out at convenient points. The position of the tap is determined by the desired secondary voltages. In the other arrangement, there are two or more coils which are electrically connected to form a continuous winding. In either case, the same laws governing conventional two-winding transformers also apply to autotransformers.



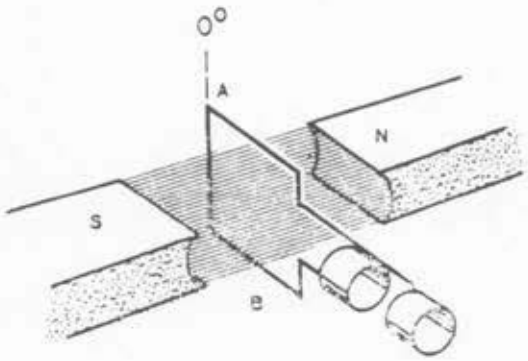
CURRENT TRANSFORMER

GENERATOR PRINCIPLES.

When electrons pass through a magnetic field, a force is exerted upon them. If these electrons are in a wire, and if the wire is moved in a magnetic field, the force is still exerted on them. When the force acts on the electrons, the electrons move within the wire. This causes a current or voltage to be induced within the wire by its movement in the field. In other words, when magnetic lines of force are "cut" by, or when they "cut" across, a conductor such as a wire, a current or voltage is produced in the conductor. The amount of this voltage is dependent on the rate or speed at which the lines are "cut," the number of lines "cut", and the number of turns on the generator.

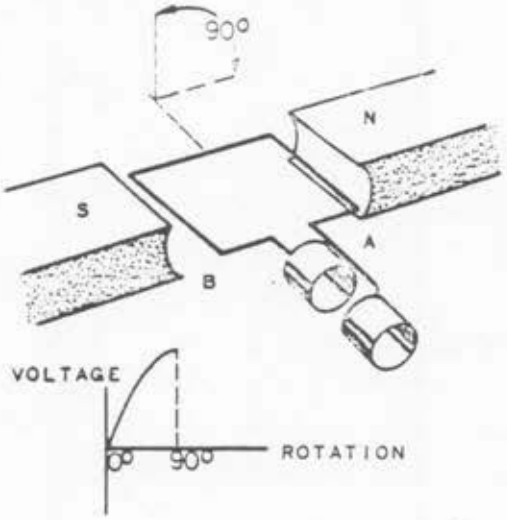


AUTOTRANSFORMER

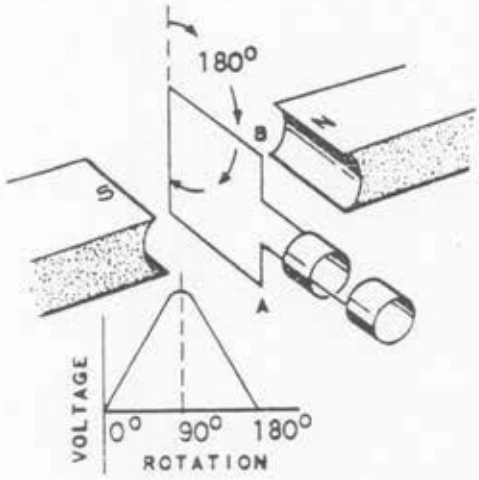


A simple generator can be made by turning a loop of wire in a magnetic field. The ends of the loop can be connected to "slip rings". This allows the generated voltage to be used while the loop is turning. The largest number of lines of force is found between the opposite poles of a permanent magnet. With the loop in the position shown no voltage is induced in the first position, because the sides of the loop are moving parallel to the lines of force. In other words, they are not cutting across them.

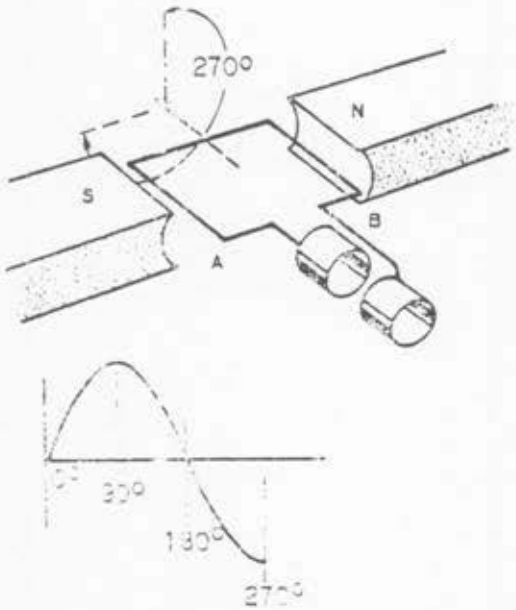
Start the turning at this point, which will be called 0 degrees. As the loop is turned clockwise (to the right), it reaches the 90-degree position. At this point the loop is cutting directly across, or at right angles to, the lines of force, and the greatest voltage is induced in the loop. A graph is made of this voltage against the angular rotation of the loop. The voltage is zero when the rotation is zero, and increases to its maximum at 90 degrees.



As the rotation continues to 180 degrees, the sides of the loop again travel parallel to the lines of force. The induced voltage is again zero.



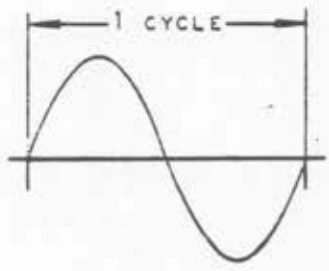
The rise and fall of this voltage is not a straight line. Rather, it is curved since it is a function of the angle of rotation, or turning. In trigonometry this is known as the function of the sine of the angle of rotation.



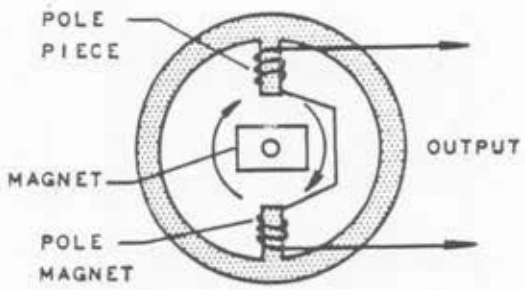
this varying voltage can be produced over and over again. Each rotation of the loop produces one "cycle" of the voltage. The number of cycles per second, called a "Hertz" (Hz) is known as the frequency of the voltage. The frequency produced, then, depends on how fast the loop is rotated. The arrangement shown and described is a simple A-C generator, or alternator.

As the rotation continues to 270 degrees, the voltage is again at a maximum. This maximum voltage is reversed in polarity, however, from that produced when the coil was at 90 degrees. This is true because the sides of the loop are now moving in the opposite direction. The graph now shows the other half or the negative swing of the voltage. Then, as the rotation is completed back to 0 degrees, the voltage again is zero.

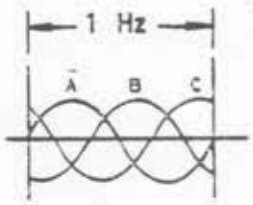
So, for one complete rotation of the loop, the generator produces a voltage which varies both in sign (polarity) and magnitude (amount). This is known as A-C (alternating current) voltage. If the rotation of the loop is continued,



Another form, in which an A-C generator may be represented, is shown in the adjacent illustration. When the rotating magnet is in the position shown, the voltage produced in the stator, or stationary windings, will be at a minimum. As the magnet turns, the magnetic lines "cut" across the stator windings and produce an A-C voltage. Frequency of the produced voltage depends on how fast the magnet is rotated. The output of this, and the previous simple generator, is called "single-phase" A-C voltage.

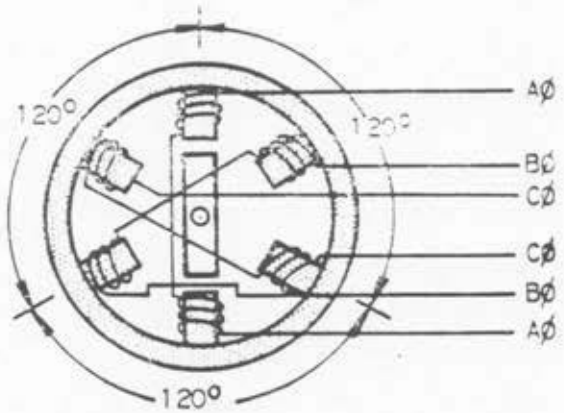


Alternators are often wound to produce a different type of AC. This type is called "three-phase" A-C voltage. Three-phase A-C means that three different voltages are developed at once, with the peaks of the voltages occurring at different times. Each voltage is called a "phase" and each one is lettered A, B, or C. The graph shown here indicates how these three voltages vary with respect to each other. Equipment which uses three-phase power will receive three times as many pulses of voltage per second as single-phase equipment. Three-phase equipment can be made smaller and lighter than single-phase equipment of the same power rating.



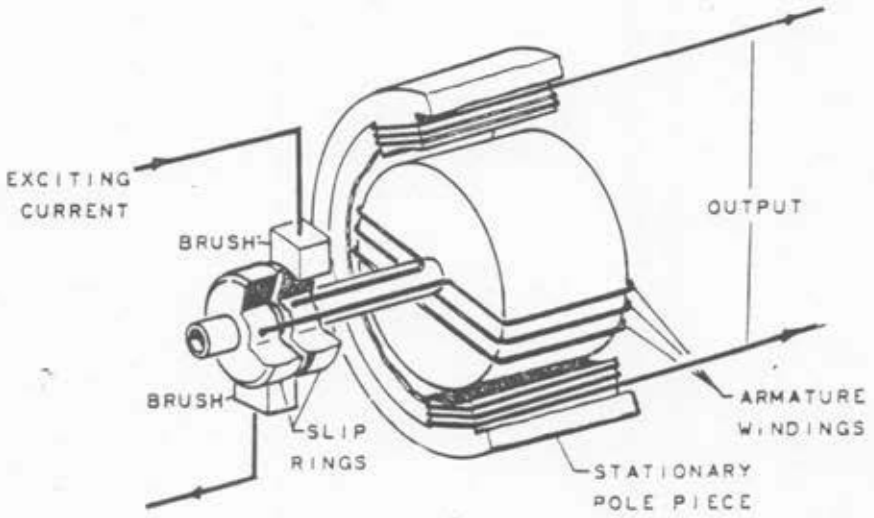
Some changes in the simplified generator must be made to produce three-phase A-C voltage. Instead of just one stator winding, three are wound on pole pieces which are evenly spaced around the generator. The winding are 120 degrees apart.

The phase difference of the voltages produced will be the same as the difference of spacing between the pole pieces, or 120 degrees. As shown, the magnet rotates from pole A to pole B to pole C. This causes coils A, then B, then C to produce voltages. Therefore, the phase "rotation is ABC.



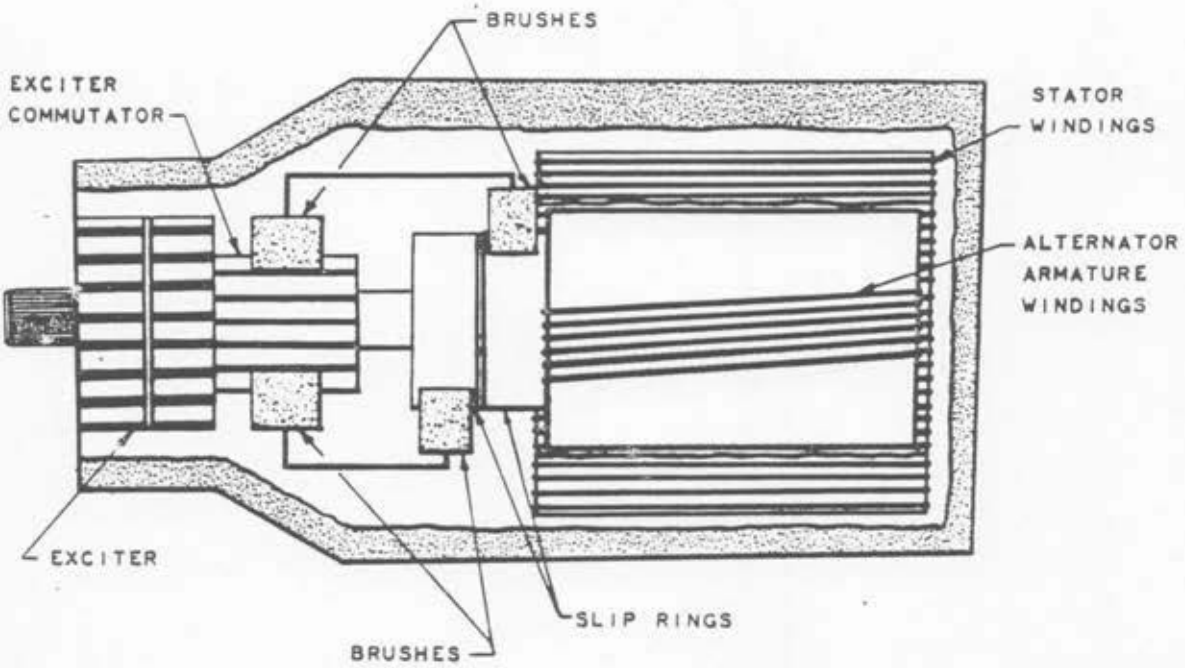
Now take the principles of the simplified generator and see how they are used in actual alternators. So far, a permanent magnet has been used as a source for the magnetic field. Because of regulation, some other means of creating the magnetic field in the actual alternator is needed. An electromagnet

is used for this purpose. The electromagnet in this case is a rotating coil, or winding, which has an "exciting" current flowing through it. The coil, or armature, set up a magnetic field. As it rotates, the lines of force of the magnetic field cut across the stator winding which are wound on the stationary pole pieces. This induces a voltage in the stator windings that is the output.



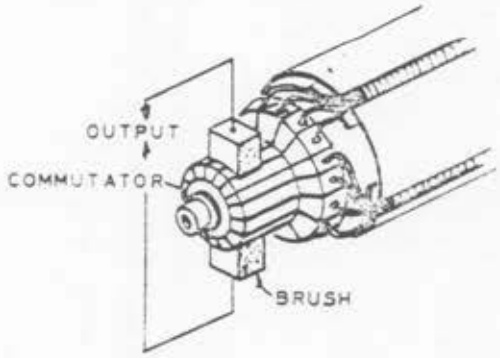
The "brushes" shown in the previous illustration are small blocks (usually made of carbon) with one end curved to fit the metal "slip rings." These brushes are held against the slip rings by springs to provide good electrical contact between the two. Exciting current is applied to the brushes. It flows through the slip rings to the armature assembly rotates but the brushes ride on them and maintain electrical contact at all times.

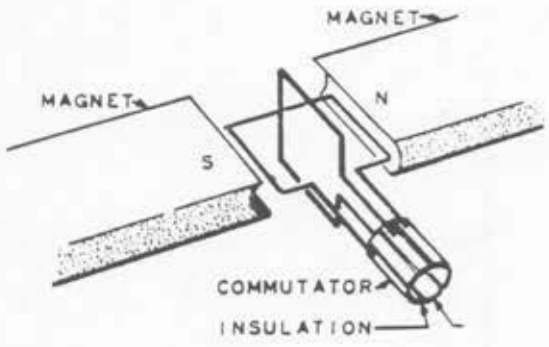
The source of exciting current has not been discussed. In order to have a self-contained generating unit some further additions must be made. These will cause the alternator to supply its own exciting current once it wtarts developing voltage. It will then be a self-excited A-C generator. To produce the exciting current, a D-C generator is built on the same shaft as the alternator armature. When the shaft turns, the D-C generator produces a voltage which is applied to the slip rings on the armature shaft. Direct current then flows through the armature win winding of the A-C generator and develops a magnetic field. As the shaft turns, the magnetic field rotates, cutting across the windings of the alternator and producing the three-phase A-C output voltage. The entire unit is built into one



housing to provide a complete, self-excited, alternator. The D-C generator is the exciter unit. A D-C generator can be made by refining the simplified A-C generator described earlier. Two or more loops of wire for the armature can be used.

Each end of a loop connects to a metal commutator segment. The metal commutator segments are separated by insulation. The segments form a slotted cylinder that makes contact with the brushes. Contact is made in such a way that the output of the generator is rectified DC, or a pulsating D-C voltage.

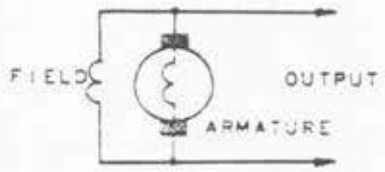




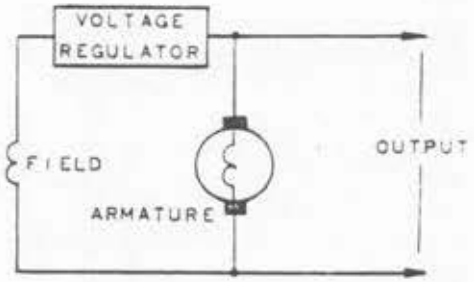
The amplitude of the pulses can be reduced by using more loops in the generator. Of course, with more loops more metal commutator segments are needed. The output of a D-C generator with several loops is shown in the adjacent illustration.

The D-C generator's magnetic field is set up by an electromagnet. As in the simplified A-C generator with the rotating magnet, the "field" winding of the generator is wound on stationary pole pieces.

In order to produce the necessary magnetic field, charge must flow in the field winding. If the field winding is connected to the armature brushes so the generator furnishes its own field current, it is a self-excited D-C generator. Some magnetic field is necessary to start the build-up of armature voltage. The voltage build-up may result from residual magnetism, or it may result from the magnetic field created by a momentary current from an external source. When a generator is first used, a momentary current from an external source is needed to created a magnetic field so that the generator will have an output. Once the generator is used, there is generally enough residual magnetism to start the voltage build-up.



In this illustration, the field is connected directly across the output of the generator. The output voltage causes a current through the field winding which creates the magnetic field needed for operation of the generator. As the output voltage goes up, the field current increases. In turn, the output voltage increases because the magnetic field is stronger. Of course, this process must be controlled in order to get the desired voltage. Usually, a "voltage regulator" of some type is connected so that the field current regulates the generator output to the desired voltage.



The A-C output voltage of the A-C generator alternator described earlier depends on the strength of the rotating magnetic field. The strength of this field depends upon the voltage output of the D-C exciter. So, in practice, the voltage regulator mentioned above "measures" the A-C voltage. If this is too high, the regulator causes the exciter output voltage to decrease. In this way, the alternator output is kept at the desired voltage value.

INVERTED CONVERTER.

A converter is used to change alternating current to direct current. The A-C input causes the machine to operate as a synchronous motor at a constant speed, regardless of field excitation or load. A generator attached to the motor then generates DC.

A converter can also be used to change DC to AC. When used in this manner, it is called an inverted converter, but is more commonly referred to as an inverter. It does not operate at an absolutely constant speed, as does a synchronous motor. Because the motor operates as a D-C motor, its load and field strength both determine its speed. This type of machine is equipped with voltage and frequency regulating devices. In practice, the speed is usually held nearly constant in order to generate a desired frequency.

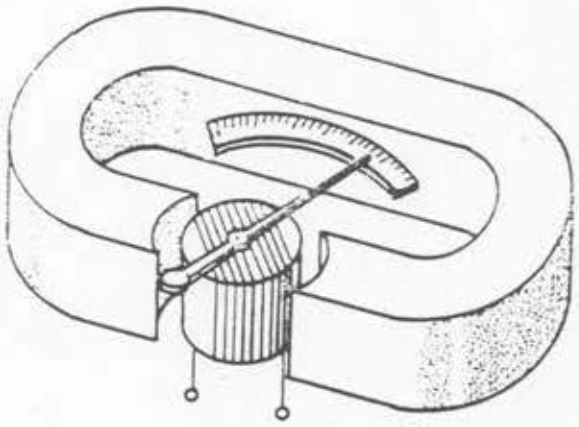
MEASURING INSTRUMENTS.

In the inspection, maintenance, and operation of any electrical system the voltage, current, and resistance must often be measured. Many types of meters are used for this purpose.

GALVANOMETER.

A galvanometer is a very sensitive meter which measures very small currents. The most common type of galvanometer uses a D'Arsonval meter movement. In the D'Arsonval movement, a coil rotates within a magnetic field.

As illustrated, the coil is mounted on a "drum." The "drum" is mounted on nearly friction-free pivot points. It is spring-loaded to return the pointer to the zero position. The coil is placed between the poles of a permanent magnet. If a current exists in the coil, it will produce a magnetic field. This field will act against the field of the magnet. The action results in a force on the coil. Since it is mounted on pivots, it will turn and extend the spring until the spring tension exactly counteracts the force.



The coil will stay in this position as long as the current through it remains constant. It follows that the amount of deflection, or movement, of the coil depends on the amount of current through it. An indicator or needle can be attached to the drum. It then shows the angular deflection of the coil.

The D'Arsonval movement forms the basic meter inside most instruments used today. The magnet, coil, and spring can be designed so that the full-scale deflection represents a particular current. Due to the delicate spring and balance, however, the amount of current that can be sent through the coil is limited.

It may seem strange that this type of meter is so widely used when its range is so limited. But its accuracy, small size, and ruggedness more than make up for its limited range. The range limitation can be overcome with the use of external resistors.

AMMETERS.

The ammeter is a meter that measures current.

Most modern ammeters are basically D'Arsonval movements. These meters come in various ranges. One of the most common has a maximum current-carrying capacity, or full-scale deflection, of 0.01 ampere, or 10 milli-amperes. (A milliampere is 0.001 ampere.)

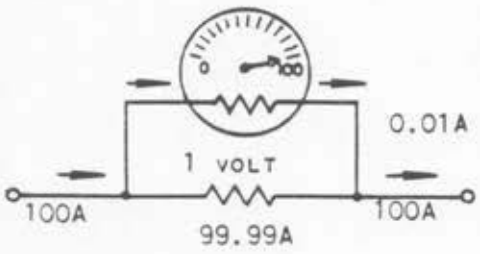
The internal resistance of its coil may vary but is usually around 100 ohms. For an illustration, use a meter with 100 ohms internal resistance and a full-scale deflection of 0.01 ampere (10 milli-amperes). From Ohm's law, the voltage across the meter at full scale deflection is

$$E = I \times R$$

$$E = 0.01 \times 100$$

$$E = 1 \text{ volt}$$

Suppose this meter is to be used as a meter capable of measuring up to 100 amperes at full scale. Since the meter itself can carry only 0.01 ampere, another path for the current must be provided for the 99.99 amperes remaining. A current of 0.01 ampere through the meter, together with the 99.99 amperes, make a total of 100 amperes. The additional path is provided by connecting a resistor across the meter terminals. The value of this resistor has to be calculated so that it will conduct 99.99 amperes of current when a voltage of 1 volt (the voltage across the meter at full scale) is impressed across



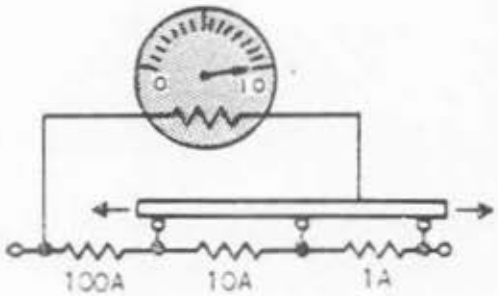
it. To make this calculation, again use Ohm's law and find

$$R = \frac{E}{I} = \frac{1}{99.99}$$

$$R = 0.010001 \text{ ohm}$$

This, of course, is a very small resistance. It would have to be made of a metal bar of some sort. If the meter is to be accurate, the value of the resistor must be accurate. A resistor paralleled across the meter in this manner is usually referred to as as ammeter shunt. The meter gives an accurate measurement of 100 amperes although only 0.01 ampere flows through the meter. If the values are accurate, any amount of current in the line will be measured proportionately by the meter.

This same type of calculation can be made to convert any basic meter to almost any desired scale. However, its internal resistance and full scale deflection must be known. Most commercial test meters are made with more than one scale by using several shunts. Each shunt is designed to give a particular full scale reading on the meter. A switching arrangement can be used so that the proper shunt is selected to give a desired range.



Extreme care must be used in connecting an ammeter in a circuit. Polarity must be correct when using D-C meters. The terminals must be connected so that the meter pointer will move up scale. Improper terminal connection will cause the pointer, or indicator, of the meter to be driven backwards against its peg. A meter can be very easily damaged in this way. Since it measures current, an ammeter must be connected in series with the line in which the current is to be measured.

VOLTMETERS.

As was the case with ammeters, nearly all voltmeters use the basic D'Arsonval movement. Take the same basic meter that was converted to a high-scale ammeter and make it a voltmeter. It had a full scale deflection of 10 milliamperes with an internal resistance of 100 ohms. By Ohm's law it was shown that a voltage of one volt would deflect it full scale. In the case of the ammeter, most of the current had to be shunted. For the voltmeter, all but one volt of the applied voltage must

be dropped across a series resistor, which is called a multiplier. Ohm's law can be used to determine the value of the multiplier.

Now, convert the meter to measure up to 100 volts. The meter takes 1 volt at full scale. Calculate the value of the multiplying resistor needed to develop 99 volts at a current of 10 milliamperes. For this,

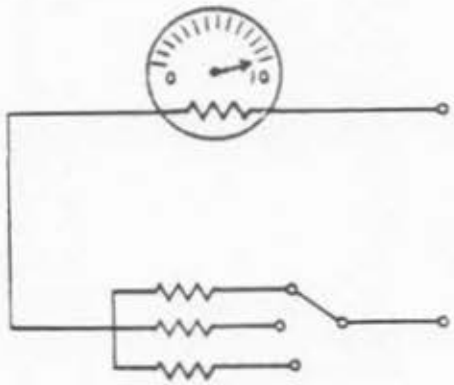
$$R = \frac{E}{I}$$

$$R = \frac{99}{0.01}$$

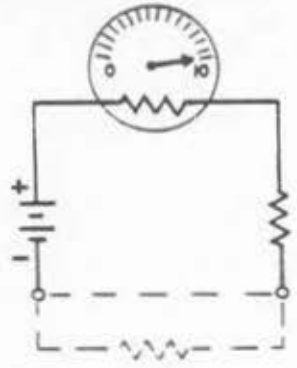
$$R = 9,900 \text{ ohms}$$

Unlike an ammeter, a voltmeter is connected <u>across</u> a voltage source. Its high resistance (including the multiplying resistor) prevents most damage to the meter if it is connected in series. However, this high resistance in the line will prevent the using equipment from operating properly.

The voltmeter can also be made as a multi-range meter. To do so, use several multiplier resistors and a selector switch as illustrated. The values of these resistors can be calculated for the desired scales and connected as shown.



The voltmeter has very definite polarity, which must be observed just as with the ammeter.



OHMMETERS.

As its name implies, an ohmmeter measures resistance. An ohmmeter can be built from the same basic D'Arsonval movement. When a multiplying resistor and a battery are connected in series with the meter as shown, the circuit is a series ohmmeter. Suppose a 3-volt battery is chosen. First, the value of

the multiplying resistor must be found. To do this, short, or connect, the two terminals together as shown. Find the value of total resistance (multiplier plus internal) that will allow exactly 0.01 ampere from the battery. Therefore:

$$R + 100 = \frac{E}{I} = \frac{3}{0.01}$$

$$R + 100 = 300$$

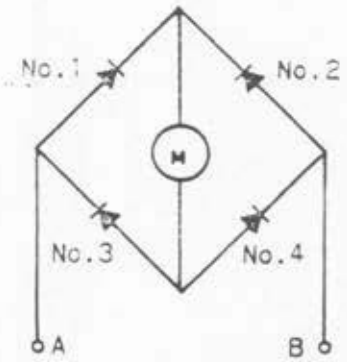
$$R = 200 \text{ ohms}$$

Now, with a 200-ohm multiplying resistor, the meter reads full scale when the measured resistance is zero (the terminals are shorted). It is important to note that most commercial ohmmeters read zero resistance at full scale deflection of the meter. The meter can now be calibrated. Suppose an unknown resistance will be measured when the meter reads 0.005, or half-scale deflection. Since the internal resistance is 300 ohms, 300 more ohms to be measured would give a half-scale reading. Using Ohm's law, the meter can be calibrated at points all along the scale. The ohmmeter scale is non-linear, which differs from both the voltmeter and the ammeter whose scales are linear.

A-C METERS.

All the meters that have been described have been D-C meters. To make an A-C meter, the meter is built exactly the same as for DC, with one addition. A rectifier circuit is necessary since current must pass in only one direction through the meter.

The arrangement of rectifiers, shown here, will let current pass in only one direction through the meter. When point (A) is positive and point (B) is negative, current passes through rectifier No. 1. It cannot pass through No. 3 or No. 2, but it passes through the meter, through Rectifier No. 4, and back to point (B) .



Now consider the other half of the A-C cycle: when point (B) is positive and point (A) negative, current passes from point (B) through No. 2. Since it cannot pass through No. 4, it passes through the meter. Since it cannot pass through No. 1, it passes through No. 3 and back to point (A) . Either way it always passes in the same direction through the meter. A shunt or multiplying resistor can be connected with this rectifier-meter circuit and make either an A-C ammeter or voltmeter.

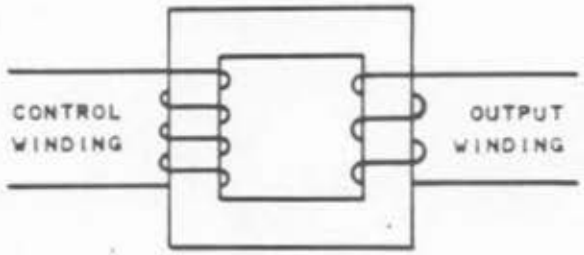
MAGNETIC AMPLIFIERS.

GENERAL. Because of its long life, excellent reliability, and high efficiency, the magnetic amplifier is widely used on modern aircraft. Neither shock nor vibration affect its operation.

The magnetic amplifier permits one electric circuit to magnetically control another. Developed from the saturable reactor, the basic unit is a combination saturable reactor and rectifying diode.

THE SATURABLE REACTOR.

The basic saturable reactor consists of two coils wound on a high permeability iron core. Essentially, this is a transformer whose primary is called the control winding and whose secondary is the output winding.



The control winding has a larger number of turns than the output winding. The control winding is connected to a D-C source. The output winding is connected in series with an A-C source and its load. The control winding creates flux lines in only one direction in the iron core.

The output winding creates an alternating set of fluxlines that add to the control-winding flux lines for one-half cycle. During the following one-half cycle, the two oppose and cancel. When the flux forces add, saturation of the core occurs. When the core becomes saturated, the permeability of the core drops, and the inductance of the output winding drops. With a smaller inductance, the inductive reactance of the output winding is smaller. Thus, when the core saturates, the load current increases. The relationship between core saturation, inductance, and inductive reactance of the control winding, and the load current are summarized as follows:

CORE SATURATION	OUTPUT WINDING		
	INDUCTANCE	REACTANCE	CURRENT
Unsaturated	High	High	Low
Saturated	Low	Low	High

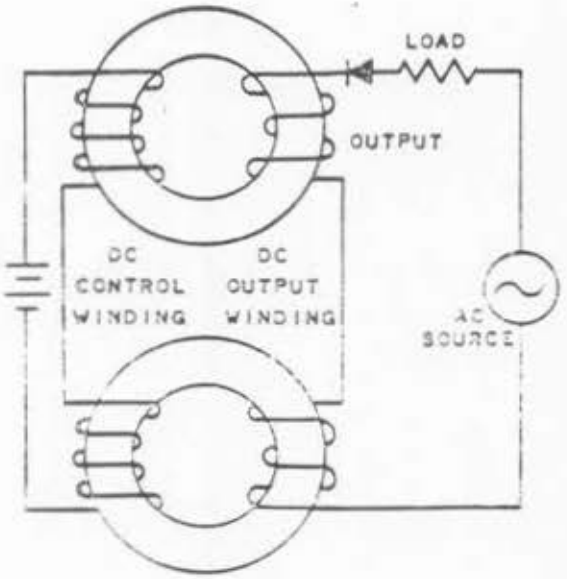
Core saturation can be produced by a small direct current in the control winding. Very small control currents saturate the core only when the A-C source voltage is close to its peak. This produces small pulses of current in the load. Increasing the control current causes the core to saturate at a lower instantaneous value of the A-C cource voltage. Saturation thus occurs earlier in the cycle and continues longer. The amplitude of the pulses in the load also increase. Further increases in control current causes further increases in the duration of the saturation period until the core saturates for an entire one-half cycle.

The basic saturable reactor has four serious disadvantages:

1. Transformer action between input and output windings
2. Core losses due to saturation and desaturation
3. Quiescent current (load current even though the control current is zero)
4. No polarization

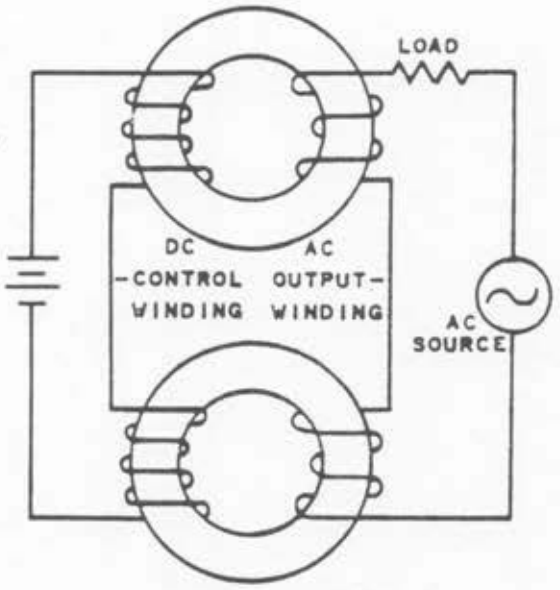
Transformer action can be best cancelled by using two saturable reactors connected in a series opposing arrangement.

If the saturable reactors illustrated are alike, then the control windings are connected so that the A-C voltage induced in the two winding will oppose and cancel. The control flux lines will still saturate the core and thereby control the load current. The doughnut shaped or toroidal core has fewer losses, and is preferred over rectangular cores. Other arrangements can be used to eliminate the high voltage induced in the control winding by the output winding. In any case, the final results make operation of the control loop independent of output loop operation.



HALF-WAVE MAGNETIC AMPLIFIER

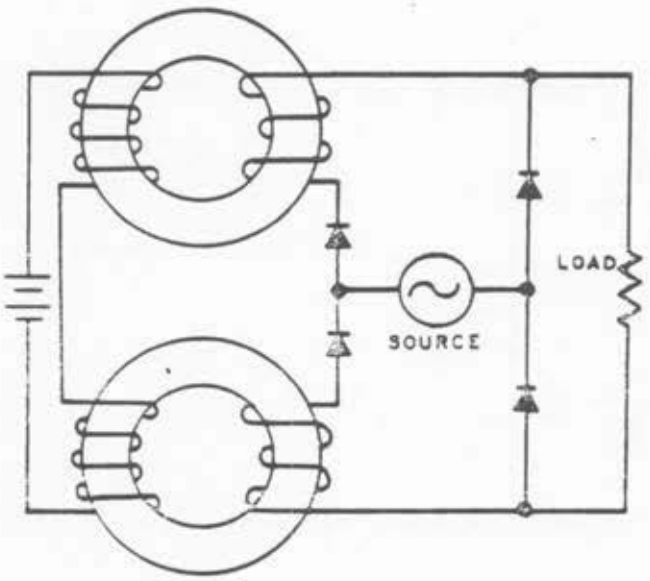
The desaturation of the cores is eliminated by permitting current in only one direction in the output winding. By placing a diode in series with the output loop, no reverse current can exist. Core losses decrease sharply, and the overall circuit operation is improved.



SATURABLE REACTORS

MAGNETIC AMPLIFIERS.

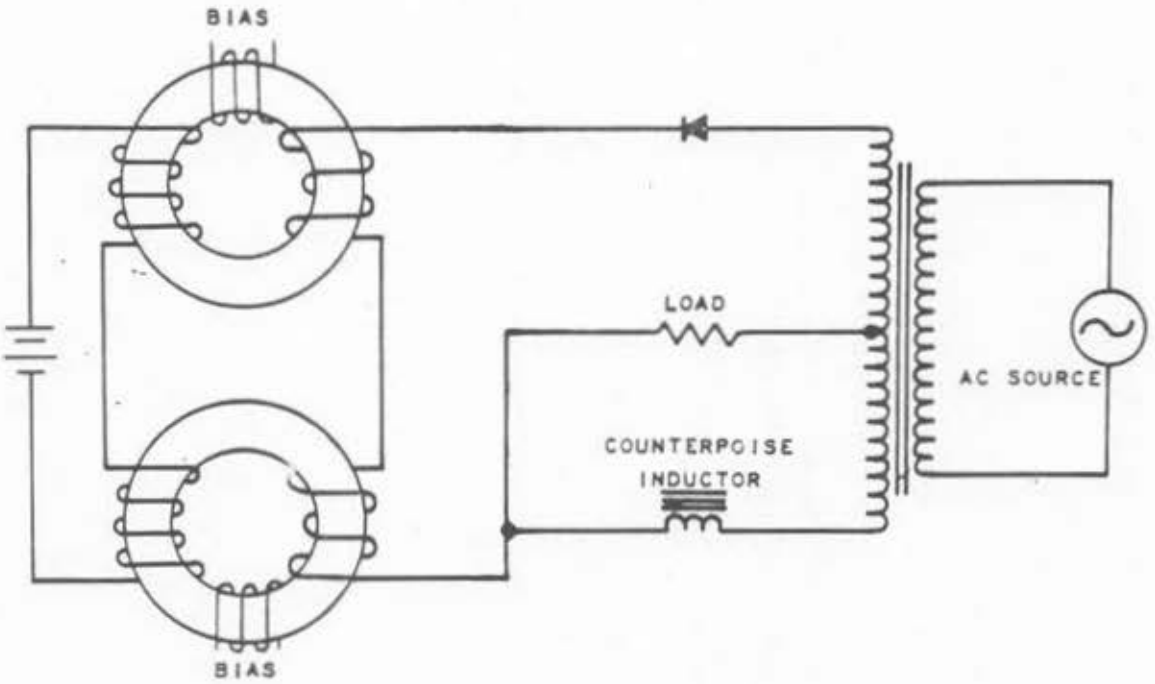
The addition of the diode to the two saturable reactors makes the circuit a basic half-wave magnetic amplifier.



FULL-WAVE MAGNETIC AMPLIFIER

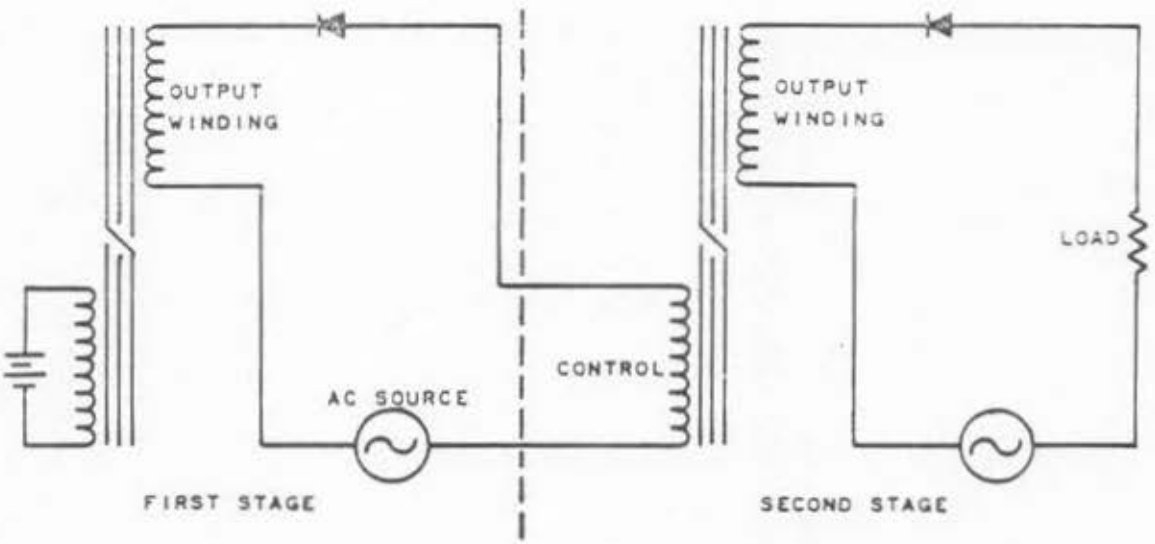
A slight rearrangement of the circuit and the addition of three diodes makes the circuit a full-wave magnetic amplifier.

In all the circuits shown, there is a quiescent current. The quiescent current is the current in the load loop when control current is zero. If more than two stages of magnetic amplifiers are to be used, the quiescent current is undesirable. To eliminate this current, a counterpoise inductor and a center-tapped transformer can be used. The counterpoise inductor cancels quiescent current, but does not appreciably affect circuit operation.



The saturable reactor and the magnetic amplifier can be polarized by the addition of a bias winding. The bias winding is a second control winding. When a saturable reactor has more than one control winding, the additional windings are named for the function they perform. The additional control windings can be used for bias, feedback, reference, or stabilization.

A complete magnetic amplifier may consist of more than one stage in order to get more amplification. In the two-stage amplifier shown, the output of the first stage is used as the control current for the second. Bias and other windings are omitted for simplicity.

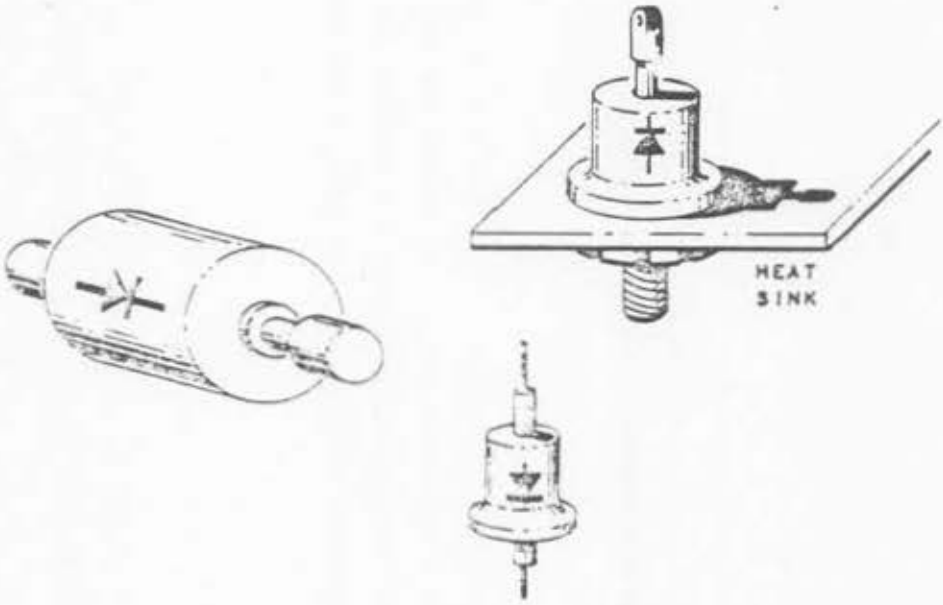


SEMI-CONDUCTORS

A semi-conductor is an element such as silicon, selenium, or germanium, which has resistance. Semi-conductors are not conductors or insulators but have a resistance value somewhere between that of conductors and insulators. Semi-conductor materials are used in the design of solid state devices, such as diodes and transistors. Impurities are added to the semi-conductor materials to form P (positive) and N (negative) type crystals. The type impurity determines the type crystal. The crystals are combined to form diodes and transistors.

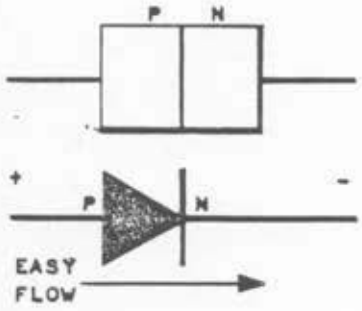
DIODES

A diode is a two-terminal device which allows current to pass in one direction and opposes the flow of current in the reverse direction. Diodes are frequently used for D-C circuit isolation between several control circuits and a load and for rectification in power supplies. A rectifier changes AC to pulsating DC.



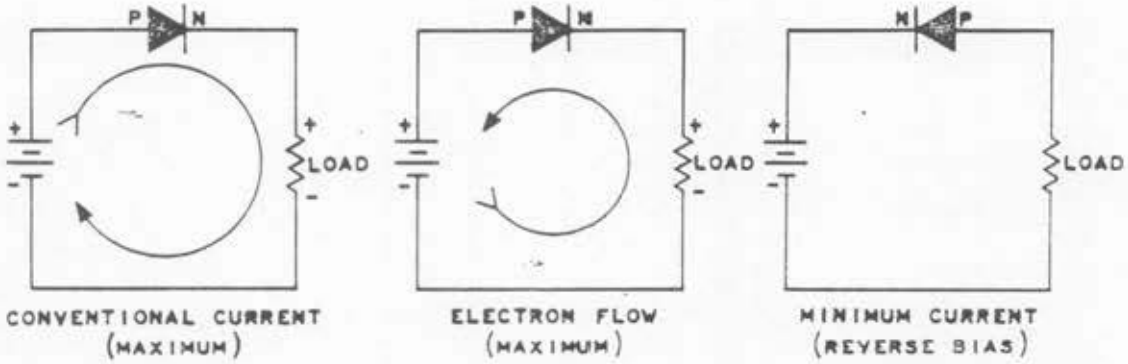
DIODES

Many types of diodes exist which can be used for these purposes. The most common diodes are made of selenium, germanium or silicon. In aircraft systems the silicon diode is most often used due to small physical size, high current rating, temperature characteristics, and reliability.

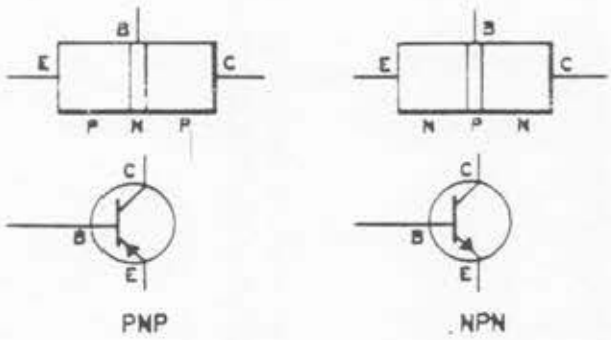


The arrow symbol used for a diode indicates the direction of conventional current (+ to - flow) through the diode. Electron flow is opposite to the arrow (- to + flow).

The junction diode is contructed of P and N crystals. When the crystals are joined, a diode is formed.

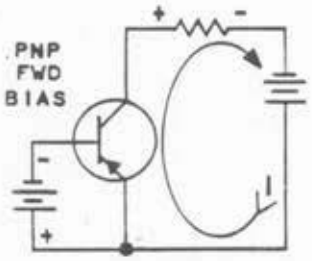


If a D-C source is connected across the silicon diode with the positive potential to the arrowhead (forward bias), the diode conducts, allowing maximum current. If the source is reversed, current would be minimum.

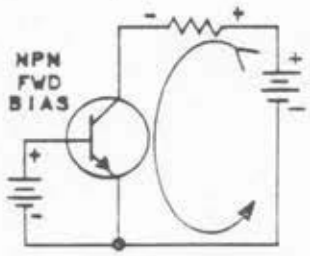


TRANSISTORS

The transistor is a further development of the junction diode. A transistor is a three-element device, either PNP or NPN combination. A transistor can be used as a current amplifier, voltage amplifier, electronic switch, or gate. The elements are emitter (arrow), base (center), and collector. The emitter and collector are made of the same type material. The base is a thin layer of crystal sandwiched between emitter and base. A transistor must be forward-biased into conduction. The emitter base junction is forward-biased, the same as a diode. If the junction is PN (emitter P, base N), a negative on the base in respect to emitter allows conduction. Reverse bias prevents conduction.



An NP material type must be forward-biased by a positive voltage on the base in respect to emitter. The collector is reverse biased in both type transistors, and base-emitter bias determines collector current. The majority of current in a transistor is between emitter and collector.

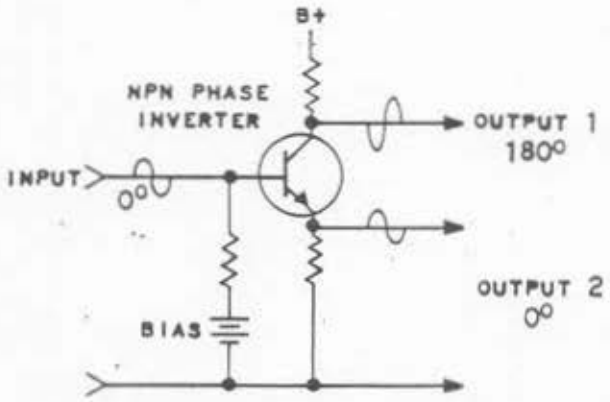


On a schematic, the direction of the emitter arrowhead indicates the type transistor (NPN or PNP). The arrow also indicates the direction of conventional current in the circuit. Electron flow is reversed to the arrow and the flow is between emitter and collector.

An emitter arrow pointing into the transistor indicates a PNP transistor, and the arrow pointing out indicates an NPN transistor. In most cases, the type transistor can be determined by the bias voltages.

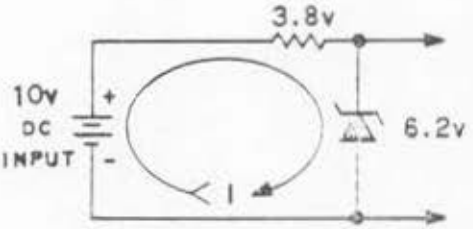
In transistor amplifiers, the input signal is normally applied to the base, and outputs are taken from the collector or emitter. When the signal polarity is forward biased, collector current increases; the reverse signal decreases collector current.

An output signal from the collector is phase reversed 180 degrees in respect to the base input signal. An output from the emitter is in phase with the base signal. The input signal can also be applied to the emitter and the output taken from the collector. In this case, input and output voltages are in phase.

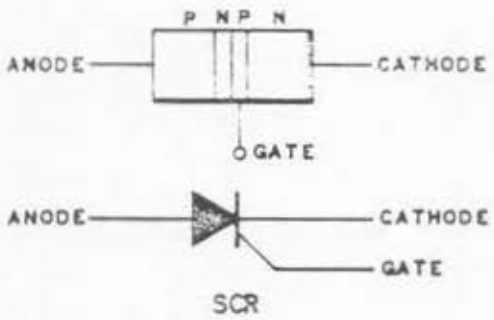


A phase inverter is an amplifier with an input on the base and outputs from the emitter and collector. The outputs are 180 degrees out of phase. Phase inverters are used in servo-loop indicating systems. When properly biased, the NPN or PNP transistor can be used to accomplish the desired result.

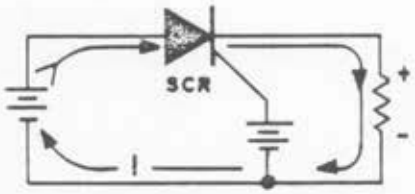
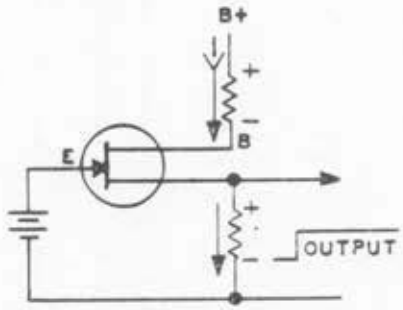
SPECIAL PURPOSE DIODES



A zener diode is a PN junction used as a voltage regulator. When the diode is reverse-biased sufficiently to breakdown the junction, the diode conducts and maintains a constant voltage across the terminals. Until breakdown, the diode functions as a normal reverse biased diode (minimum current). At breakdown, reverse current is limited by a series resistor to prevent damage to the diode. Zener diodes are designed for use as low-voltage regulators and may be combined in series to obtain high voltages.



A silicon-controlled rectifier (SCR) is a gated diode used as a controlled switch. The SCR is a four-layer, three-terminal device consisting of PNPN junctions. An SCR conducts as a normal diode when forward biased and a positive gate potential is applied. Once the diode is conducting, the gate has no effect and can be removed. The SCR continues to conduct until the forward bias is removed. If reverse bias is applied, the diode functions as a normal diode (minimum current).



A unijunction transistor is a diode with three terminals. An emitter junction controls current between the two base junctions. When the emitter potential is large enough to overcome the base potential, the transistor conducts. Current between the bases produces a switched high amplitude DC output. When emitter voltage is removed, the base current decreases to zero.