CHAPTER 9

BASIC ELECTRICAL PRINCIPLES AND OPERATIONAL AMPLIFIERS

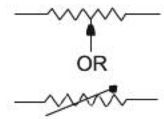
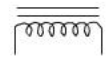
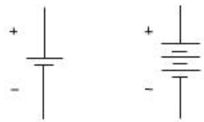
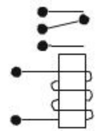
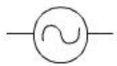
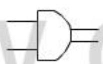
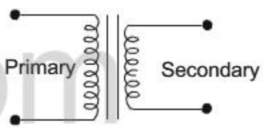
Conductor, Connected		Resistor, Variable	
Conductors, Not Connected		Solenoid Coil, Iron Core	
Battery, Dry Cell or DC Source		Relay	Common  N.C. N.O.
AC Source		Relay Contacts	N.O.  N.C.
AC Power Plug		Transformer, Iron Core	Primary  Secondary
Fuse		Diode	Cathode  Anode

Figure 9-1 Common electrical schematic symbols

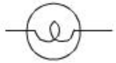
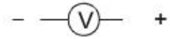
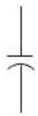
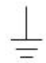
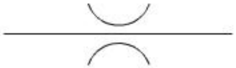
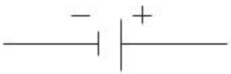
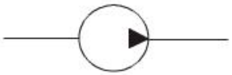
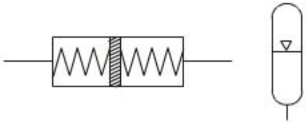
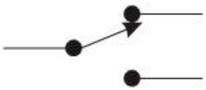
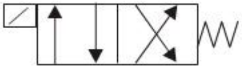
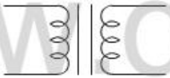
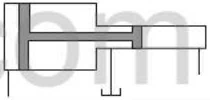
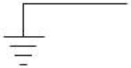
Lamp		Ammeter	
Switch Single Pole, Single Throw	SPST 	Voltmeter	
Switch Single Pole, Double Throw	SPDT 	Ohmmeter	
Capacitor		Earth Ground	
Resistor, Fixed		Chassis Ground	
Resistor, Tapped			

Figure 9-1 Common electrical schematic symbols (cont抎)

ELECTRICAL		**HYDRAULIC**	
Resistor		Restriction	
Power Supply		Pump	
Capacitor		Double Spring Loaded Piston or Accumulator	
Switch		Directional Valve	
Diode		Check Valve	
Transformer		Intensifier	
Ground		Tank	

VICKERS

Figure 9-2 Functional equivalence of electrical and hydraulic components

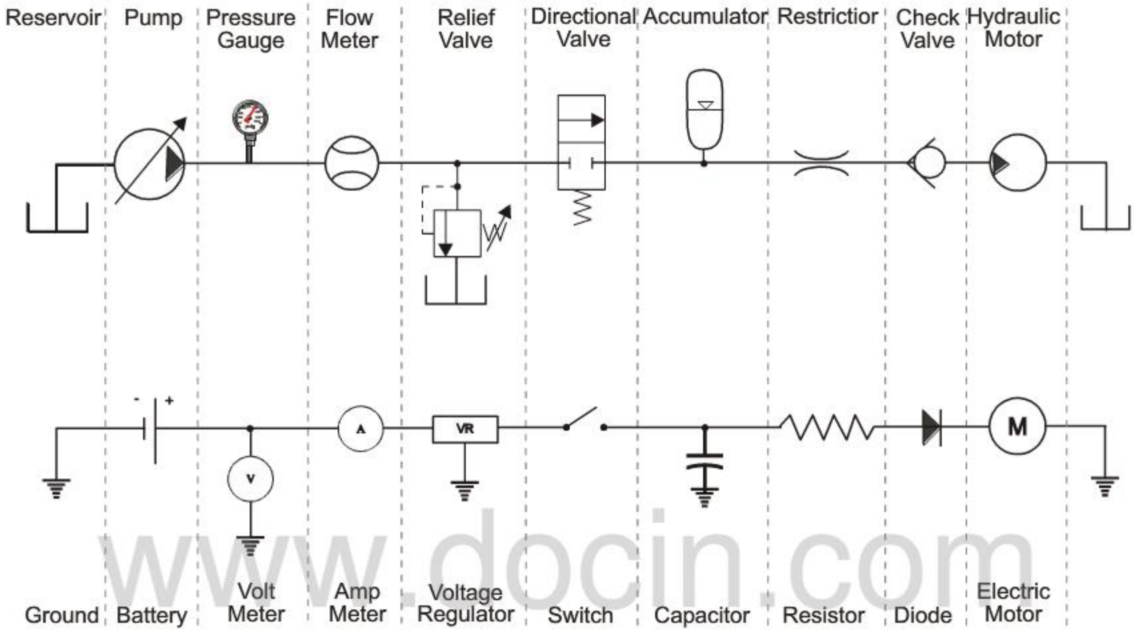
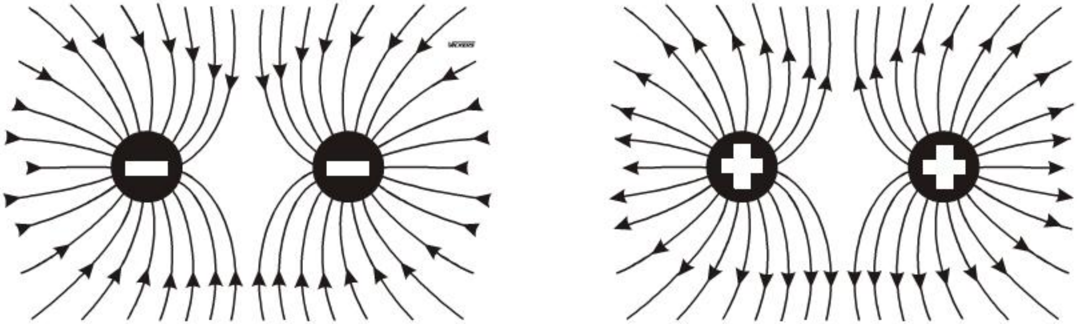
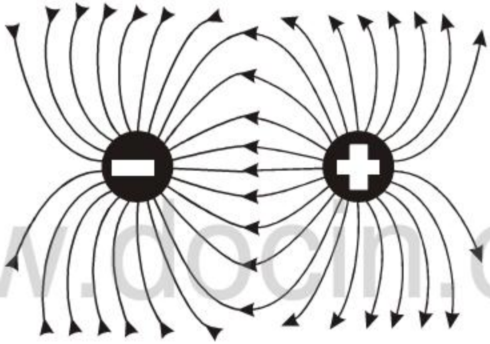


Figure 9-3 Comparison of simple hydraulic and electrical circuits



Like Charges Repel



Unlike Charges Attract

Figure 9-4 The law of electrical charges

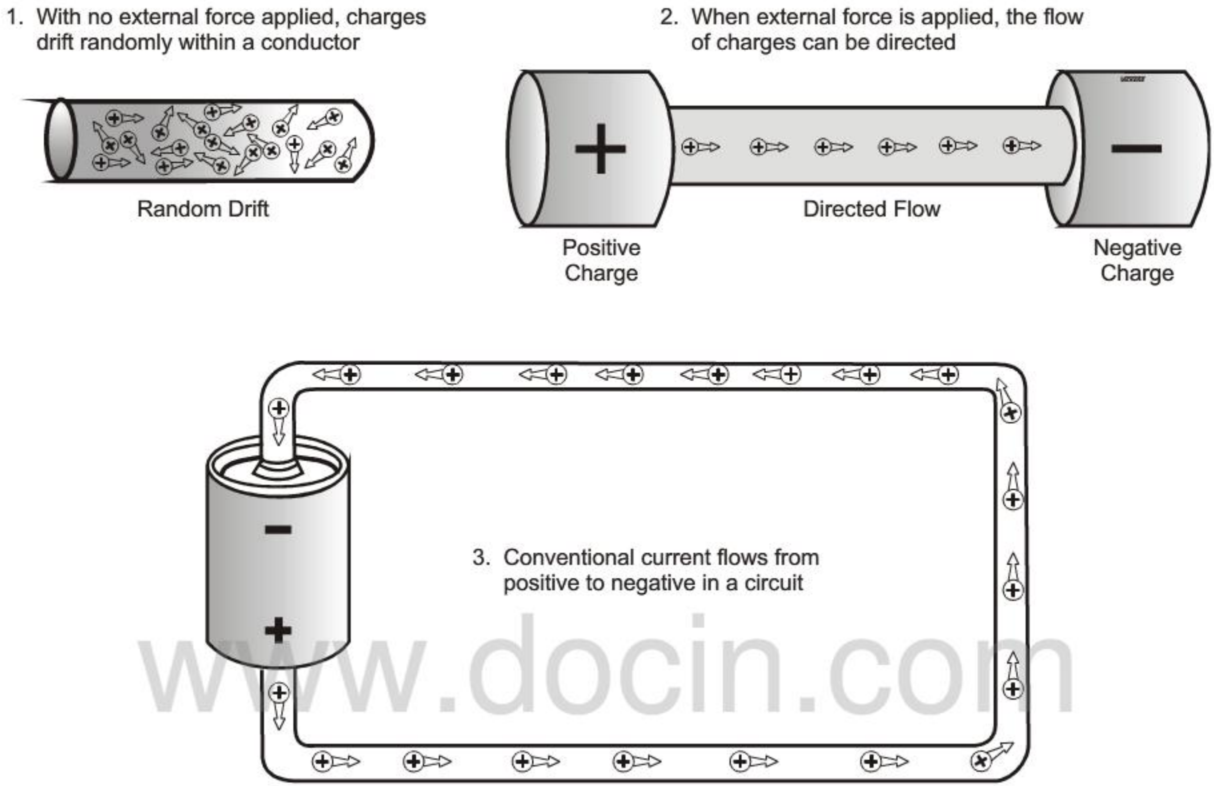


Figure 9-5 Conventional current flow

A. Current Flows in a Closed Circuit

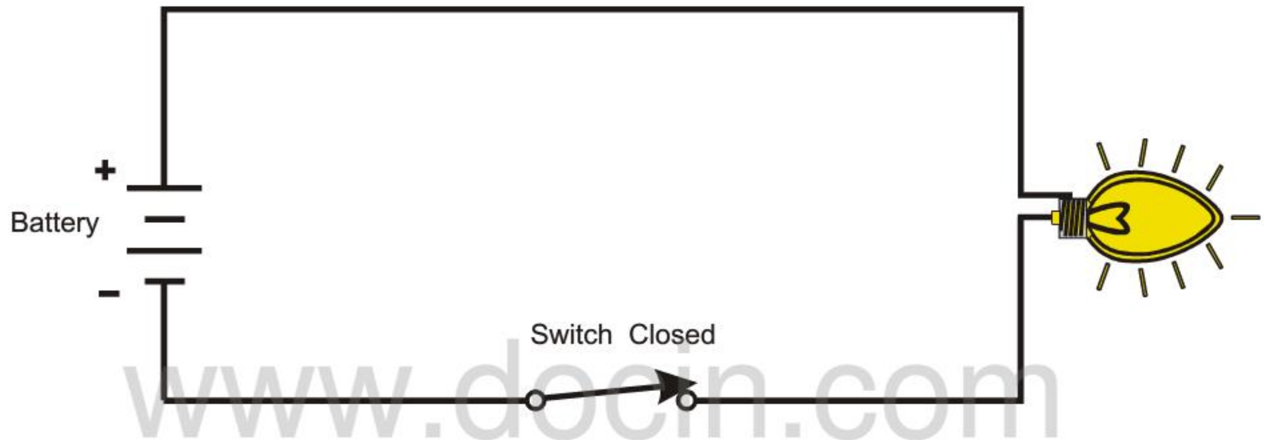


Figure 9-6 Closed and open circuits

B. Current Cannot Flow in an Open Circuit

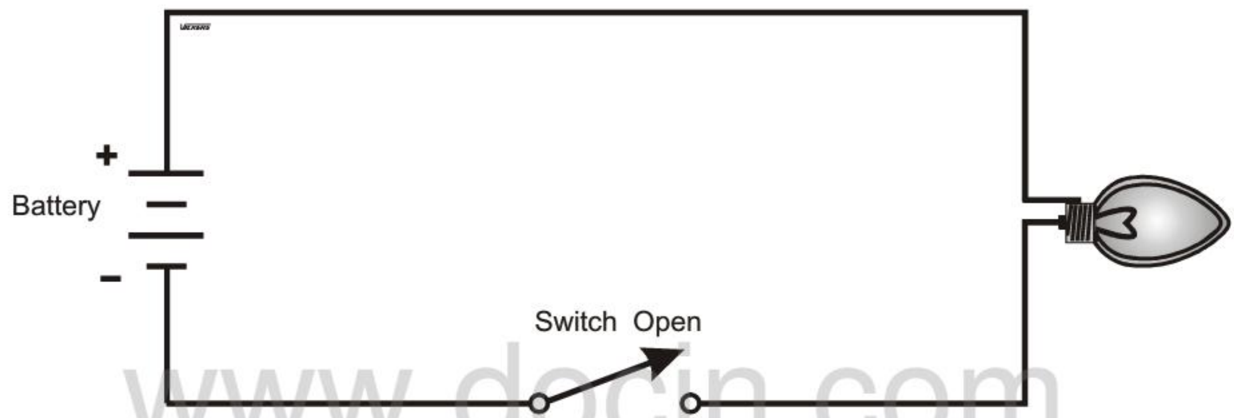
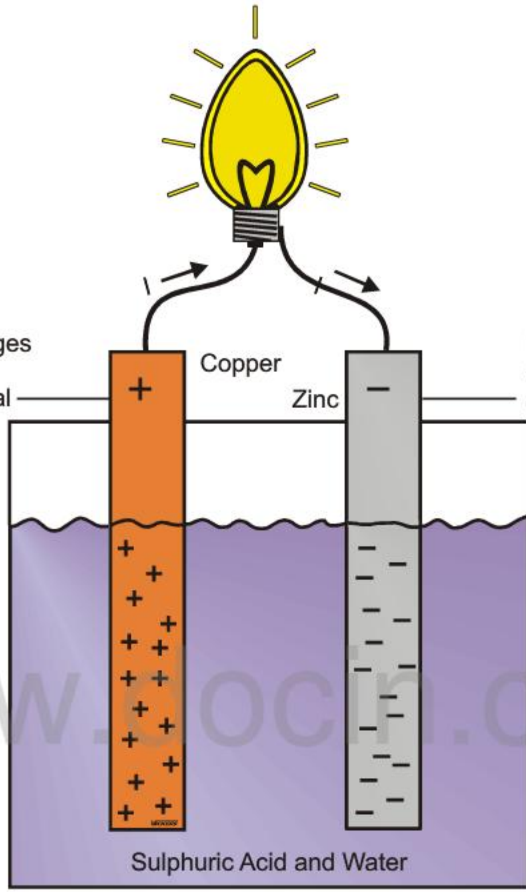


Figure 9-6 Closed and open circuits



The chemical reaction between the electrolyte and the copper and zinc strips produces a difference of potential between the positive and negative terminals of the battery. This difference of potential causes current to flow in an external circuit connected across the terminals

Figure 9-7 Battery as a power source

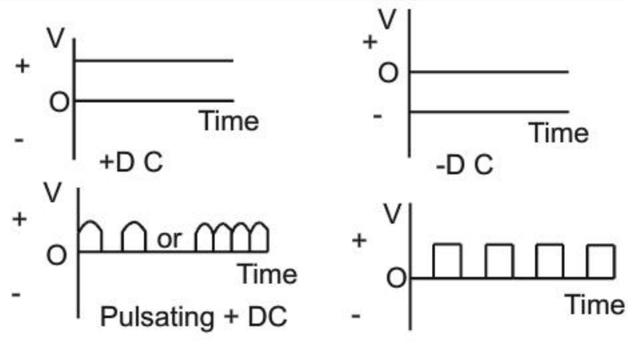
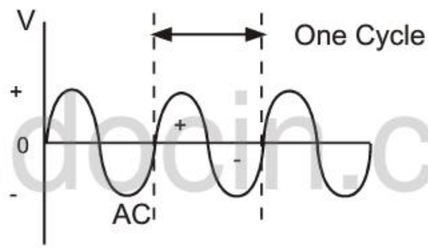
Direct Current Waveforms	
Alternating Current Waveforms	

Figure 9-8 DC and AC waveforms

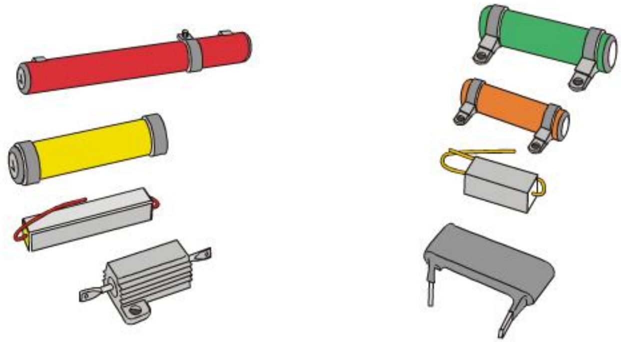
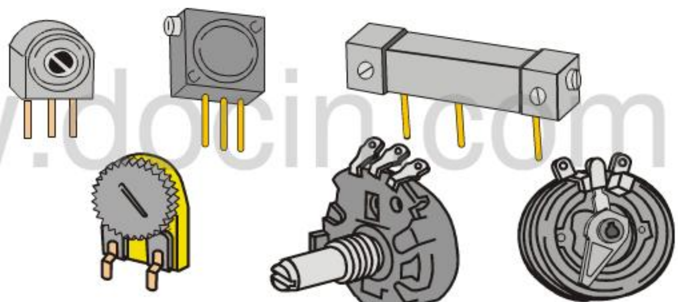
Typical Low Power Resistors (Fixed)	
Typical High Power Resistor (Fixed)	
Typical Variable Resistors	

Figure 9-9 Fixed and variable resistors

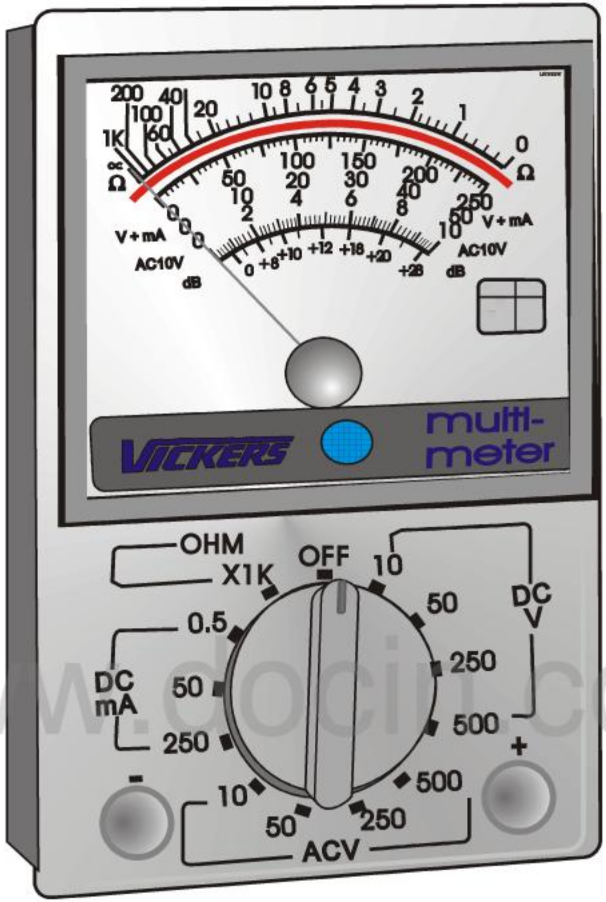


Figure 9-10 Analog meter

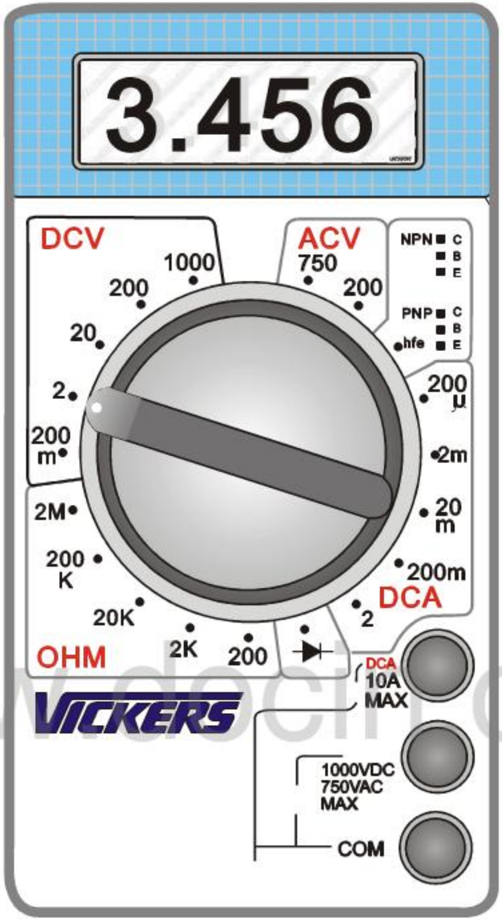
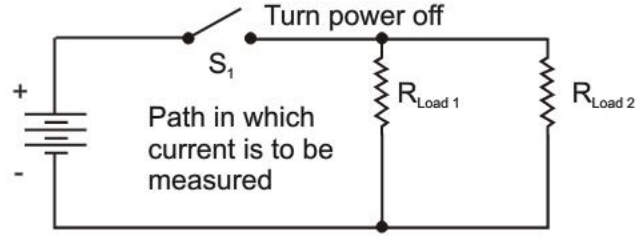
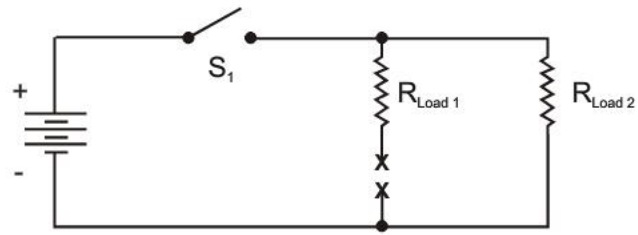


Figure 9-11 Digital meter

Remove power from circuit to be tested



Break the circuit at point where current is to be measured



Connect the ammeter in series with the circuit. Observe polarity. Then turn on the circuit power and measure the current flow

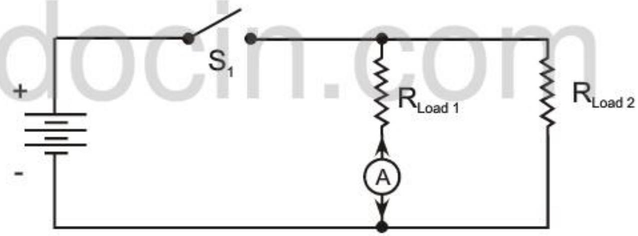
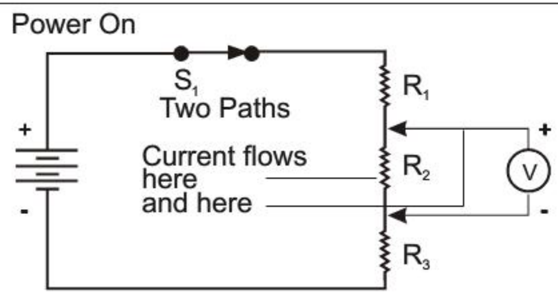


Figure 9-12 Series connection of ammeter

A. Voltmeter Measuring A Voltage Drop

Voltmeter connected in parallel with circuit by touching test leads to each side of component. Meter reads voltage drop if current flows in circuit



B. Voltmeter Measuring A Voltage Rise

Voltmeter measures voltage rise even though no current is flowing in circuit. Voltmeter provides a path across positive and negative terminals of power source

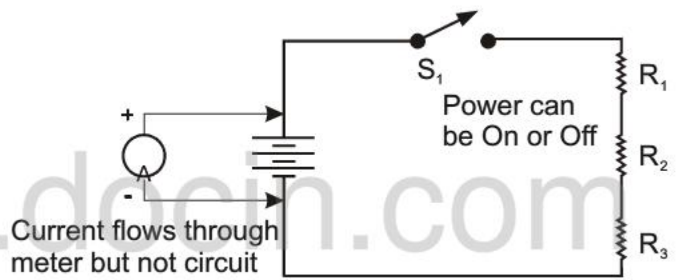


Figure 9-13 Voltmeter measuring voltage drop and voltage rise

Voltmeter cannot measure voltage drop if current is not flowing in the circuit

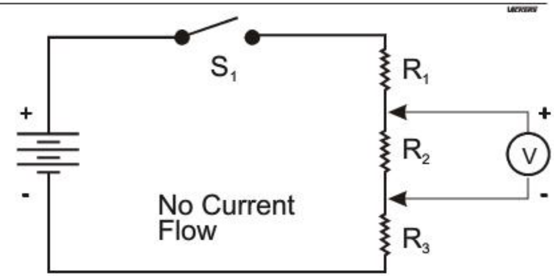
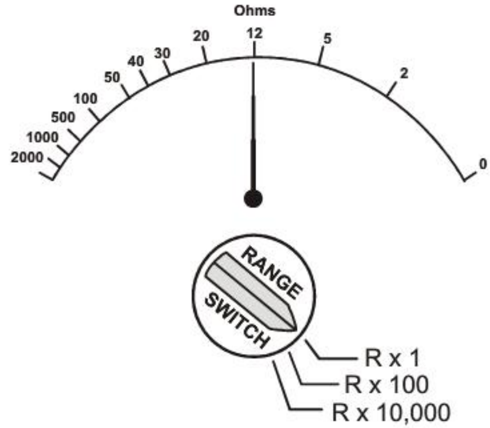


Figure 9-14 Voltmeter across component with no current flowing

After zero adjusting the meter and connecting the component between the test probes, the meter pointer indicates 12 on the Ohms scale. Since the range switch is set to R x 1, the resistance equals 12 x 1 = 12 Ohms



In this measurement, the meter pointer indicates 12, but the range switch is set to R x 100. The resistance being measured equals 12 x 100 = 1200 Ohms

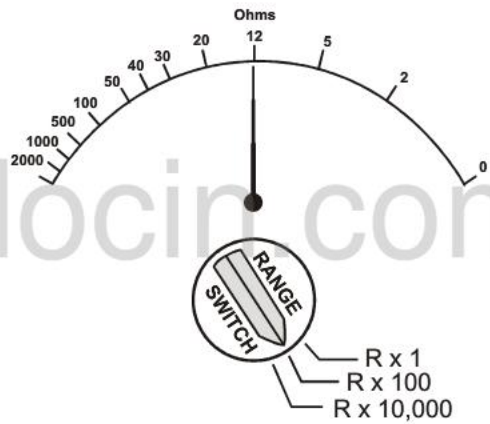
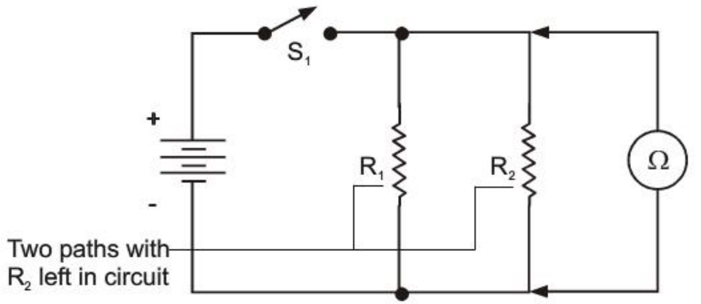


Figure 9-15 Ohmmeter measurements

When connecting an ohmmeter across a component (R_2) a false reading will be obtained if the component is not disconnected from the circuit. When the ohmmeter is connected as shown, meter current can flow through both R_2 and R_1. The measurement will be a combination of R_1 and R_2 values resulting in a false reading - lower than expected



When the component to be measured with the ohmmeter is disconnected from the circuit, meter current has only one path it can follow. This allows a true measurement of the component with the ohmmeter

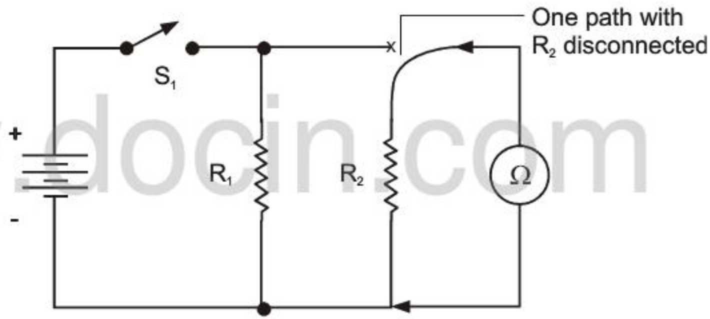


Figure 9-16 False ohmmeter readings

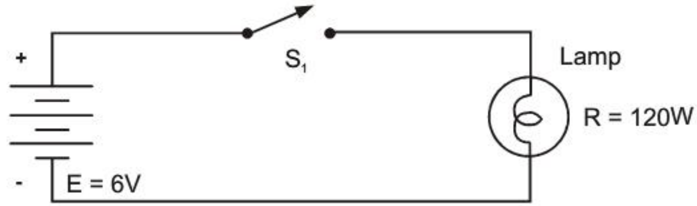
A. Simple Flashlight Circuit

Use Ohm's Law to solve for I:

I= E/R = 6V/120W = 0.05A

Convert A to mA:

0.05A x 1000 = 50 mA

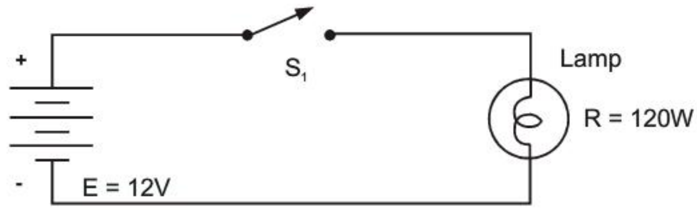


B. Voltage Increased (to 12V)

Voltage has been doubled. According to Ohm's Law, the current should also be doubled (direct relationship).

I = E/R = 12V/120W = 0.1A

0.1A x 1000 = 100 mA



C. Resistance Increased (to 240W)

Resistance has been doubled. According to Ohm抯 law, the current should also be halved (inverse relationship).

I = E/R = 12V/120W = 0.05A

0.05A x 1000 = 50 mA

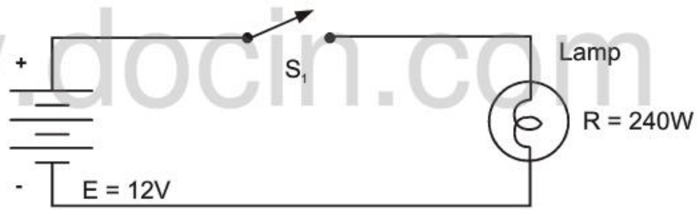
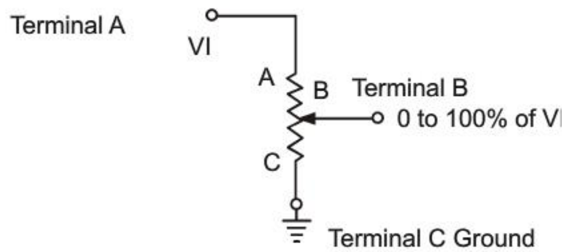


Figure 9-17 Ohm抯 law proof

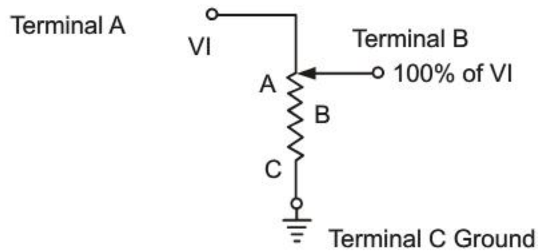
CIRCUIT ELEMENT	DEFINITION	UNIT OF MEASUREMENT	UNIT SYMBOL	MEASURED WITH	FUNCTION SWITCH POSITION	OHM扴 OR WATT扴 LAW
Current	The flow of electrons from + to - around a circuit	Amperes (amps)	A	Ammeter	ACmA or DCmA	$I = E / R$ $I = P / E$ $I = \sqrt{P/R}$
Voltage (EMF)	The force which causes current to flow	Volts	V	Voltmeter	ACV or DCV	$E = I \times P$ $E = P / I$ $E = \sqrt{P/R}$
Resistance	The opposition to current flow	Ohms	W	Ohmmeter	Ohms	$R = E / I$ $R = E^2 / P$ $R = P / I^2$
Power	The rate of doing electrical work	Watts	W	Wattmeter or Calculated	N/A	$P = I \times E$ $P = I^2 R$ $P = E^2 / R$

Figure 9-18 Electrical circuit element summary chart

A. Attenuator Circuit
The voltage available at terminal B is some percentage of the input voltage (VI). The exact percentage (from 0 to 100) depends on the potentiometer setting



B. Attenuator set for 100% of Input
Current flow bypasses resistance if attenuator is adjusted for minimum attenuation. Terminal B is electrically connected to terminal A



C. Attenuator set for 0% of Input
Current flow bypasses resistance if attenuator is adjusted for minimum attenuation. Terminal B is electrically connected to terminal A

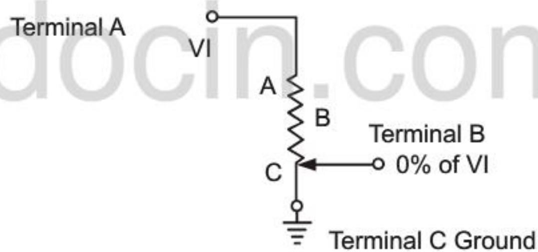


Figure 9-19 Potentiometer operation

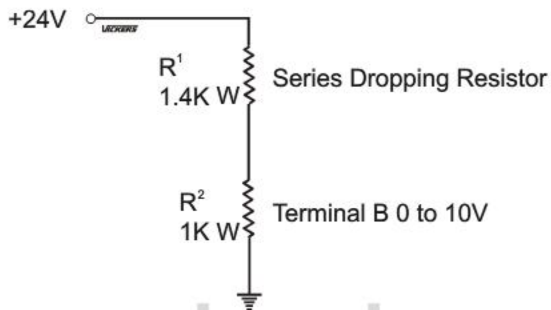


Figure 9-20 Potentiometer with series dropping resistor

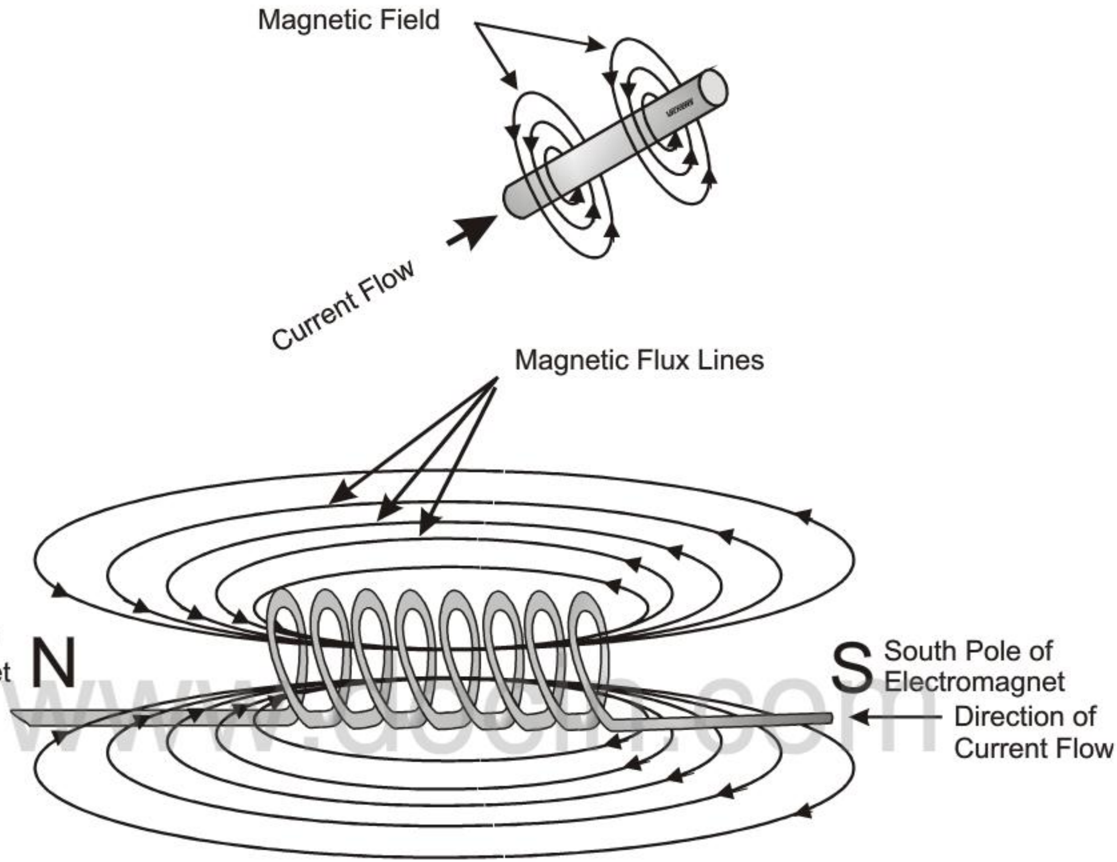


Figure 9-21 Magnetic field around solenoid coil

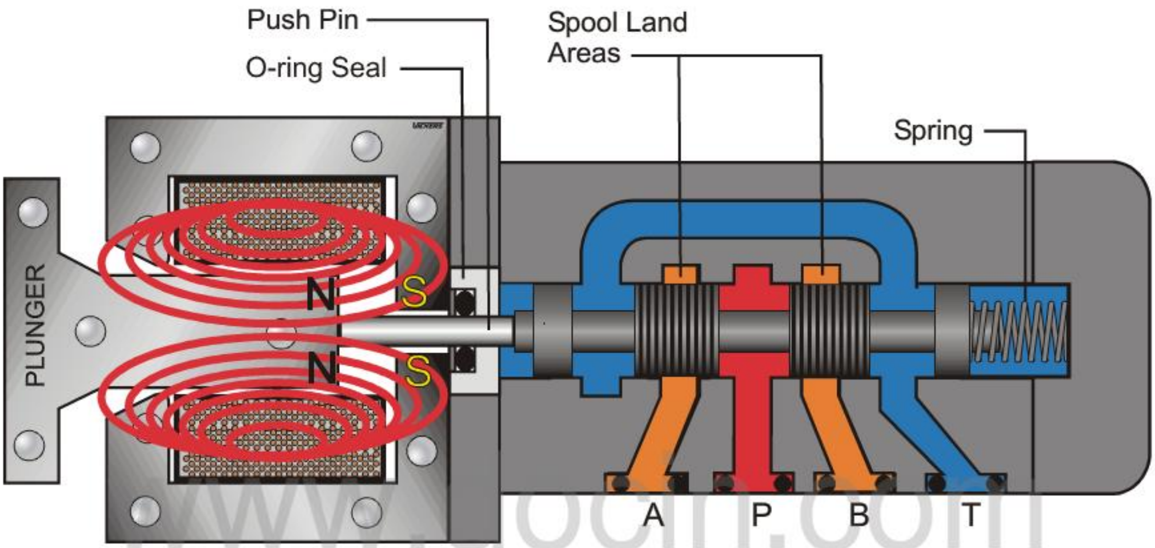


Figure 9-22 Air gap solenoid construction

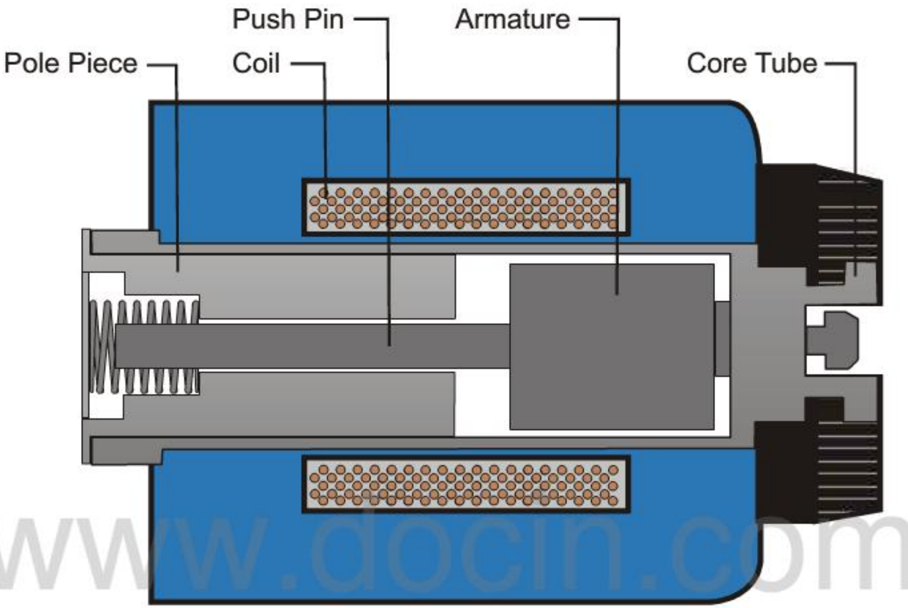


Figure 9-23 Wet armature solenoid construction

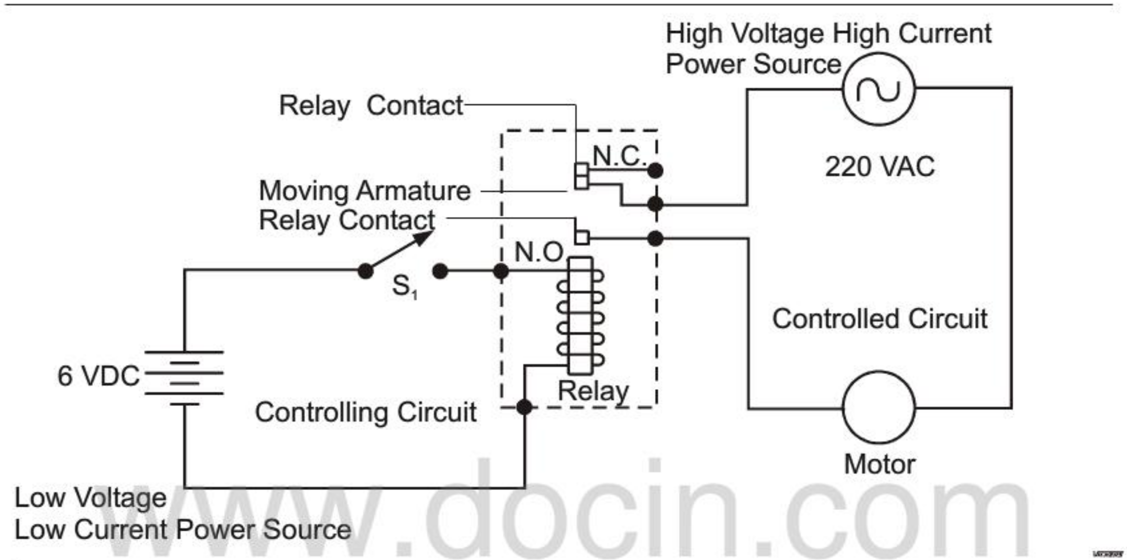


Figure 9-24 Simple relay circuit

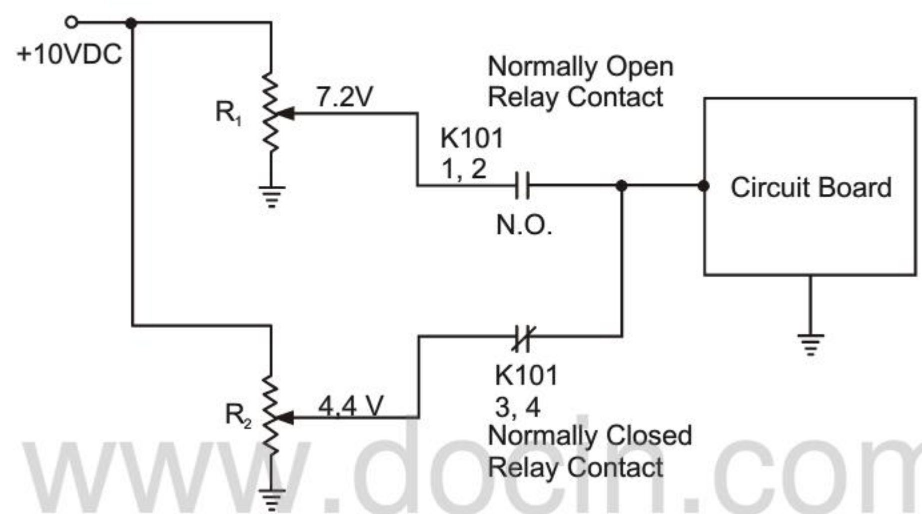


Figure 9-25 Relay controlling two input voltages

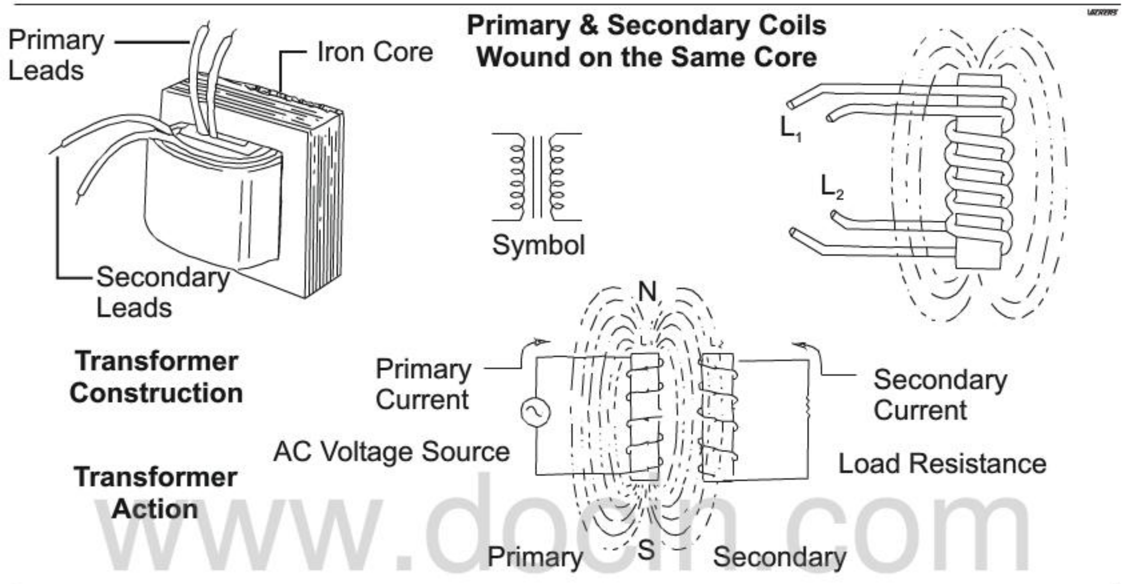
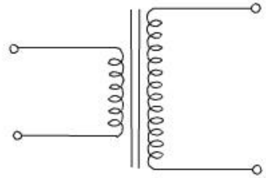


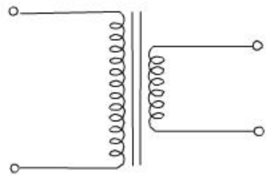
Figure 9-26 Iron core transformer

A. Step-Up Transformer
Turns = 1000
E = 115V
I = 4A
P = 460W



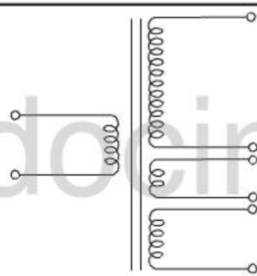
Secondary
Turns = 2000
E = 230V
I =2A
P = 460W

B. Step-Down Transformer
Turns = 800
E = 120A
I = 1A
P = 120W



Secondary
Turns = 200
E = 30V
I = 4A
P = 120W

C.Transformer With Three Secondaries
Turns = 800
E = 120V
I = 1A
P = 120W



Secondary 1
Turns = 1600

Secondary 2
Turns = 400

Secondary 3
Turns = 800

Figure 9-27 Transformer types

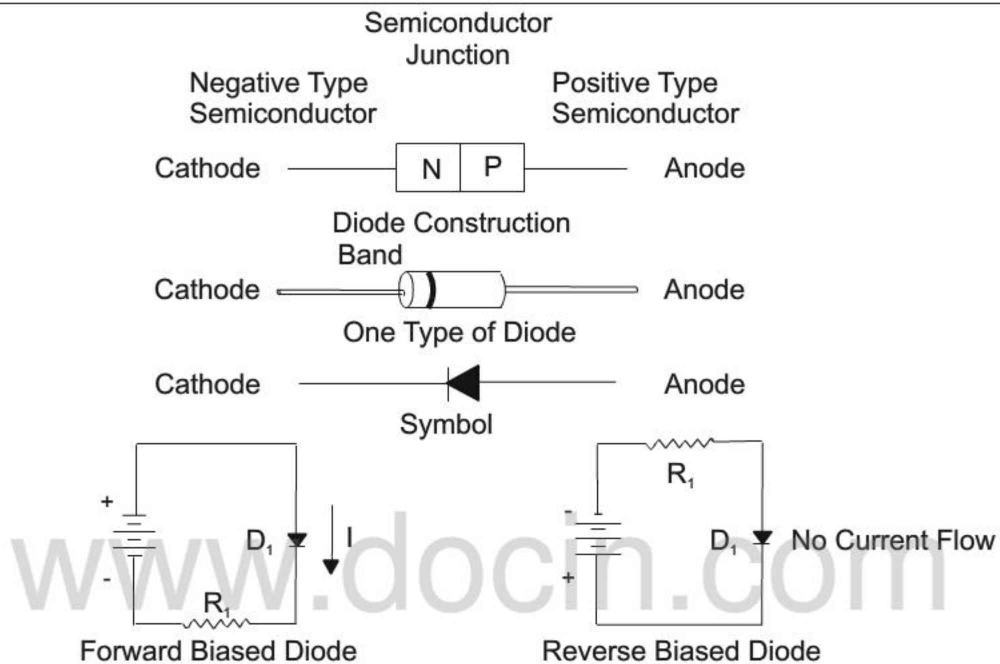


Figure 9-28 Semiconductor diode

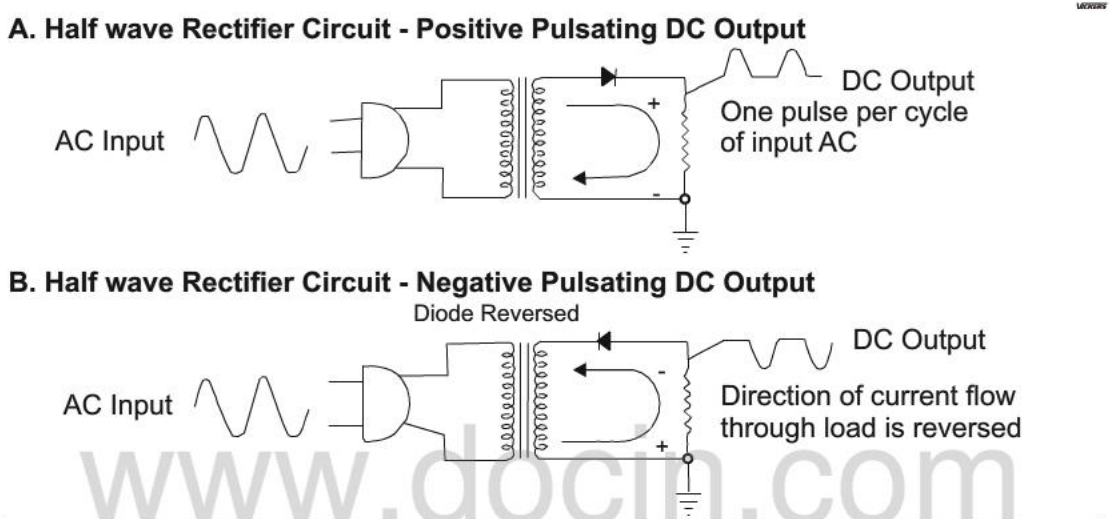


Figure 9-29 Half wave rectifier circuits

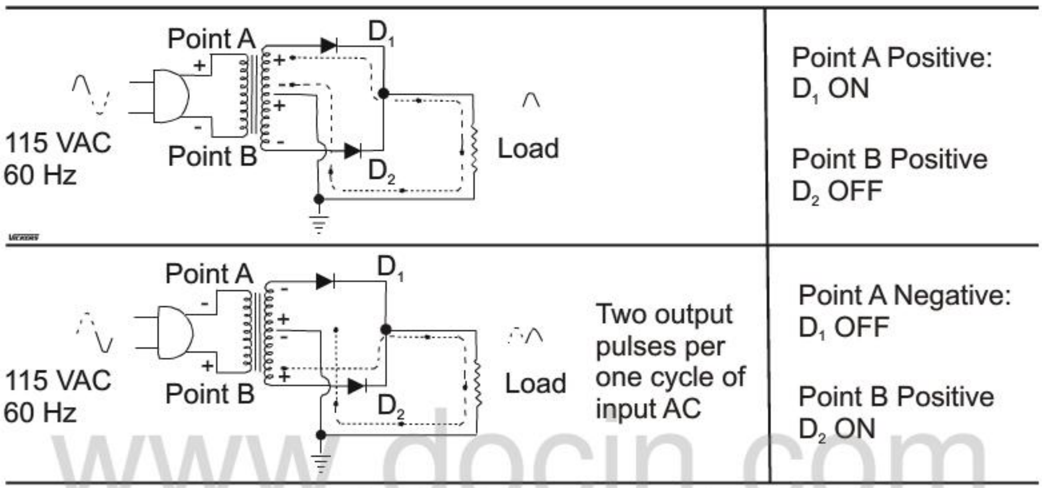


Figure 9-30 Full wave rectifier circuit operation

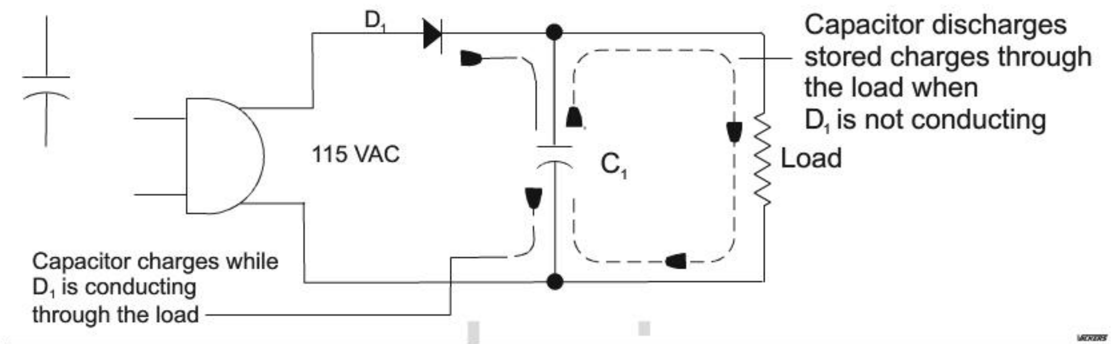
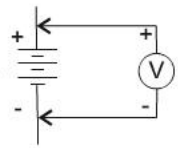
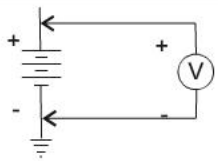


Figure 9-31 Capacitor used as filter for rectifier circuit

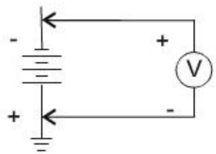
A. Voltage reading without ground



B. Negative terminal grounded



C. Positive terminal grounded



D. Placement of ground provides both positive and negative voltage

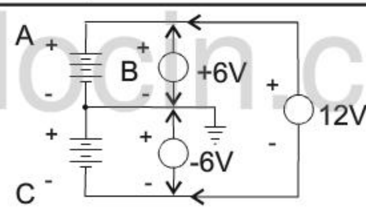


Figure 9-32 Significance of zero reference point

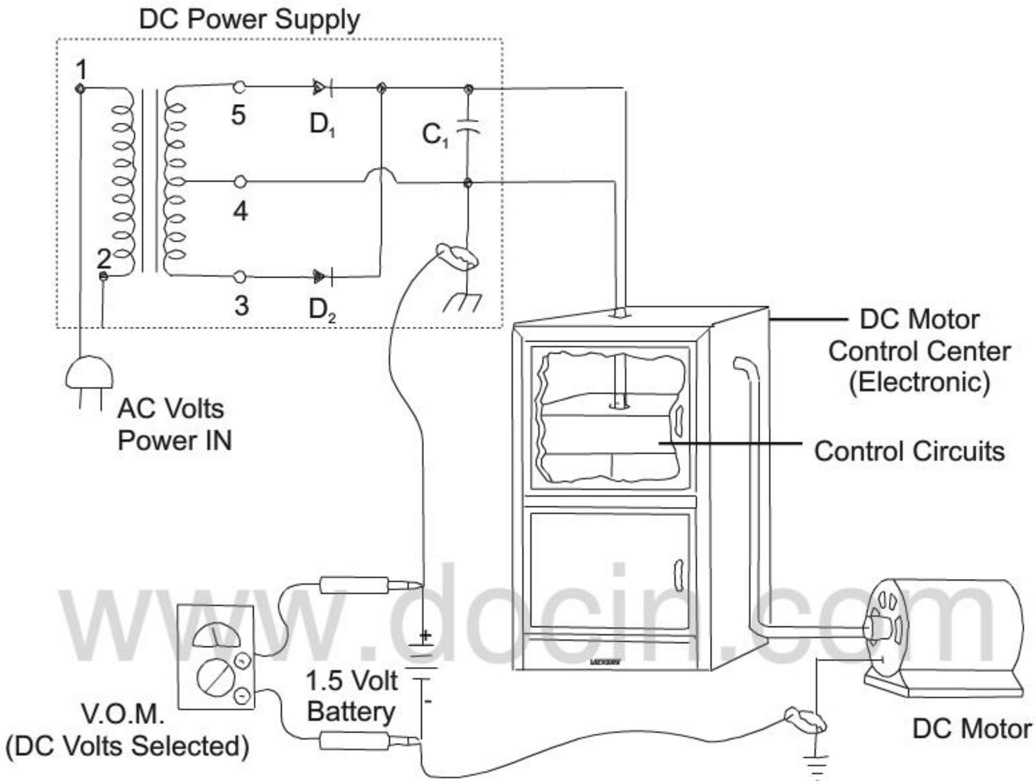


Figure 9-33 Testing for inadvertent connection of earth ground and chassis ground

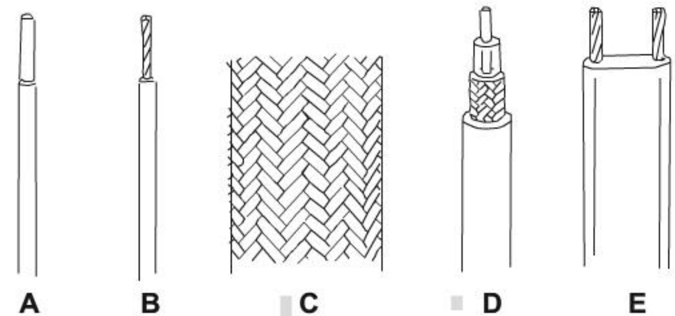
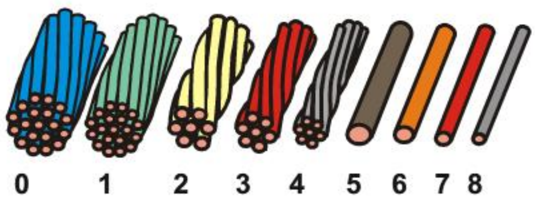
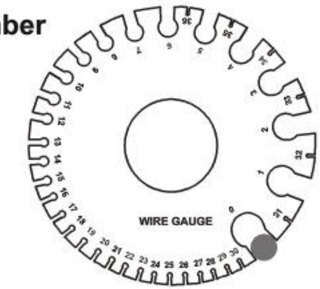


Figure 9-34 Common types of conductors

B. Relationship between Wire Size and Gauge Number





C. American Wire Gauge (AWG)

Figure 9-35 Wire gauge numbers - characteristics and measurements

A. Wire Gauge Numbers and Characteristics

Gauge Number	Diameter (mils)	Area Circular mils	Ohms per 1000 ft 25 deg C. Mils	Gauge Number	Diameter (mils)	Area Circular mils	Ohms per 1000 ft 25 deg. C mils
0000	460.0	212,000.0	0.0500	19	36.0	1,290.0	8.21
000	410.0	168,000.0	.0630	20	32.0	1,020.0	10.4
00	365.0	133,000.0	.0795	21	28.5	810.0	13.1
0	325.0	106,000.0	.100	22	25.3	642.0	16.5
1	289.0	87,700.0	.126	23	22.6	509.0	20.8
2	258.0	66,400.0	.159	24	20.1	404.0	26.2
3	229.0	52,600.0	.201	25	17.9	320.0	33.0
4	204.0	41,700.0	.253	26	15.9	254.0	41.6
5	182.0	33,100.0	.319	27	14.2	202.0	52.5
6	162.0	26,300.0	.403	28	12.6	160.0	66.2
7	144.0	20,800.0	.508	29	11.3	127.0	83.4
8	128.0	16,500.0	.641	30	10.0	101.0	105.0
9	114.0	13,100.0	.808	31	8.9	79.7	133.0
10	102.0	10,400.0	1.02	32	8.0	63.2	167.0
11	91.0	8,230.0	1.28	33	7.1	50.1	211.0
12	81.0	6,530.0	1.62	34	6.3	39.8	266.0
13	72.0	5,180.0	2.04	35	5.6	31.5	335.0
14	64.0	4,110.0	2.58	36	5.0	25.0	423.0
15	57.0	3,260.0	3.25	37	4.5	19.8	533.0
16	51.0	2,580.0	4.09	38	4.0	15.7	673.0
17	45.0	2,050.0	5.16	39	3.6	12.5	848.0
18	40.0	1,620.0	6.51	40	3.1	9.9	1,070.0

Figure 9.35A Wire Gauge Numbers and Characteristics

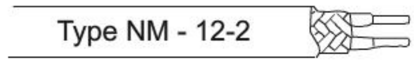
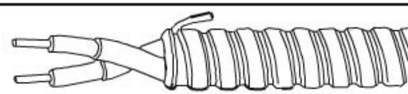
A. Nonmetallic sheathed cable	
B. Armored cable consists of two or more insulated wires protected by a flexible metal cover	Insulated Wires  Metal Flexible Cover
C. Flexible cord is very tough and durable	

Figure 9-36 Types of cable

WIRE SIZE	In conduit, cable, or buried directly in the earth		Single conductors in free air		
	Types T, TW	Types RH RHW, THW	Types T, TW	Types RH RHW, THW	Weatherproof
	A	B	C	D	E
14	15	15	20	20	30
12	20	20	25	25	40
10	30	30	40	40	55
8	40	45	55	65	70
6	55	65	80	95	100
4	70	85	105	125	130
2	95	155	140	170	175
1/0	125	150	195	230	235
2/0	165	175	225	265	275
3/0	195	200	260	310	320

Figure 9-37 Ampacity of copper wires

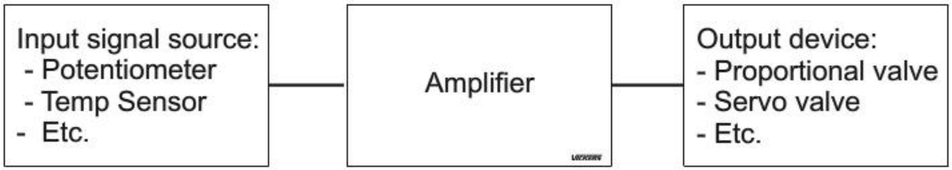
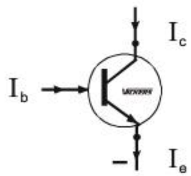


Figure 9-38 Functional block diagram of input device, amplifier and output device



I_b (mA)	I_c (mA)	I_e (mA)
0	0	0
0.5	50	50.5
1	100	101
1.5	150	151.5

Figure 9-39 Schematic symbol and characteristics for a transistor

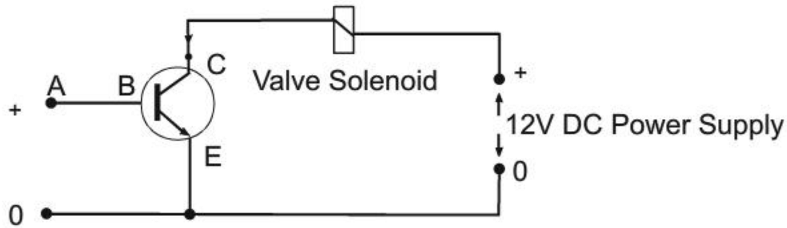


Figure 9-40 Amplifier circuit

Figure 9-41 Stages of amplification

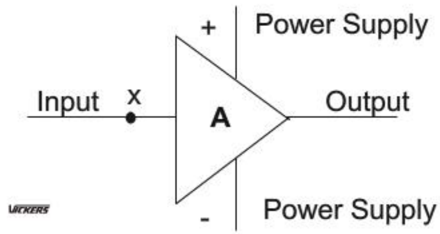


Figure 9-42 Schematic symbol for an amplifier card

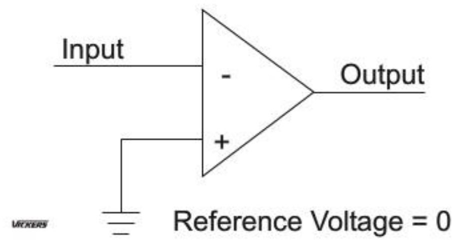


Figure 9-43 Amplifier with grounded input terminal for zero reference

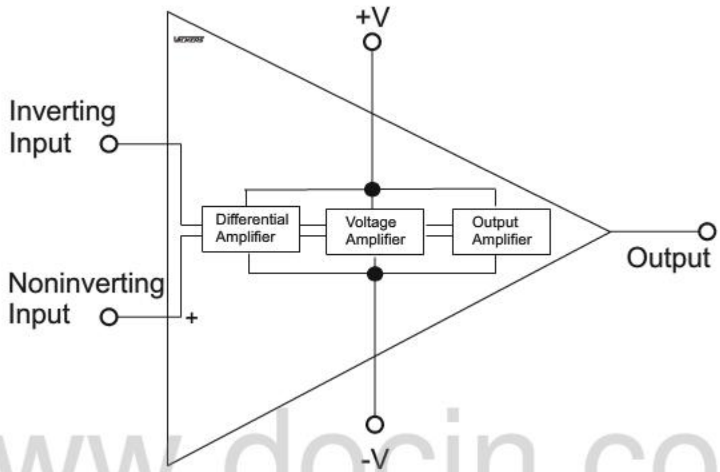


Figure 9-44 Basic operational amplifier

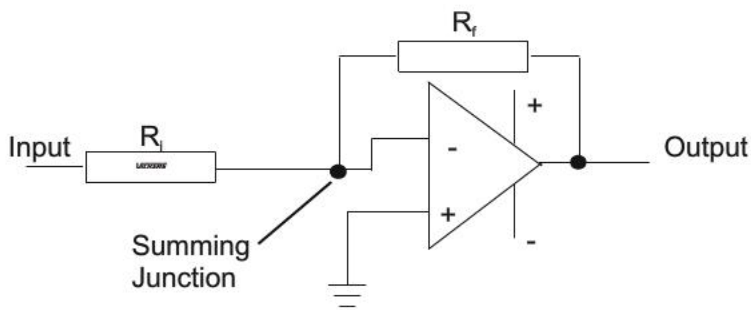


Figure 9-45 Typical Op Amp connections

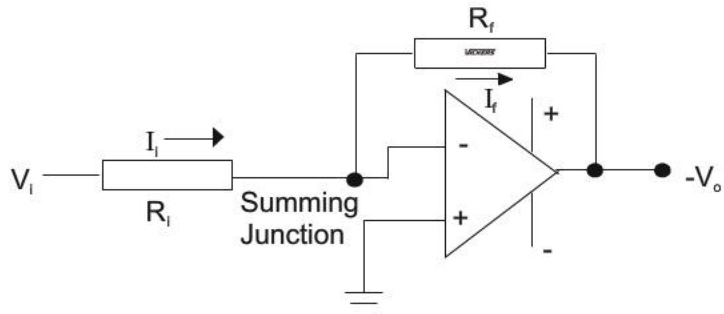


Figure 9-46 Typical Op Amp with voltage applied to input

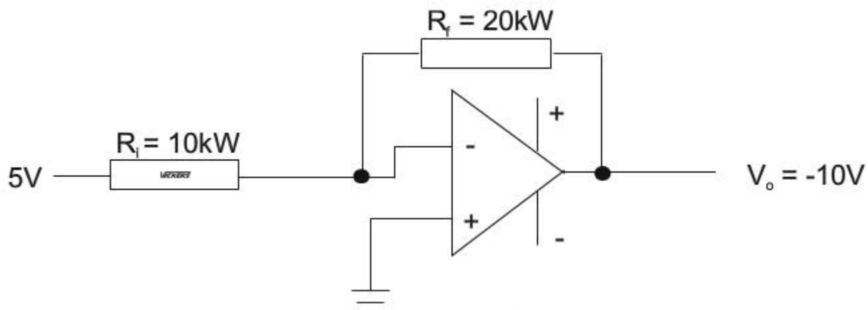


Figure 9-47 Example inverting amplifier circuit

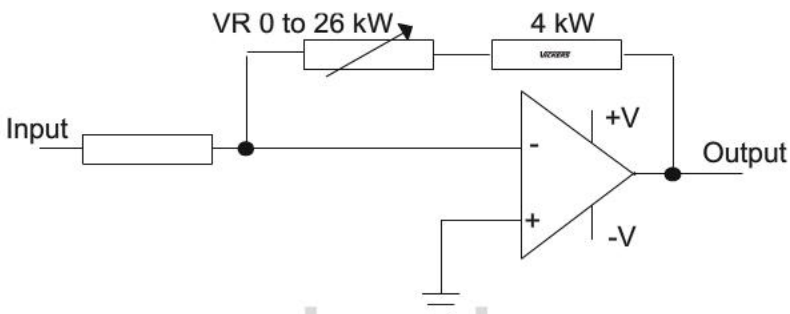


Figure 9-48 Op Amp with variable gain

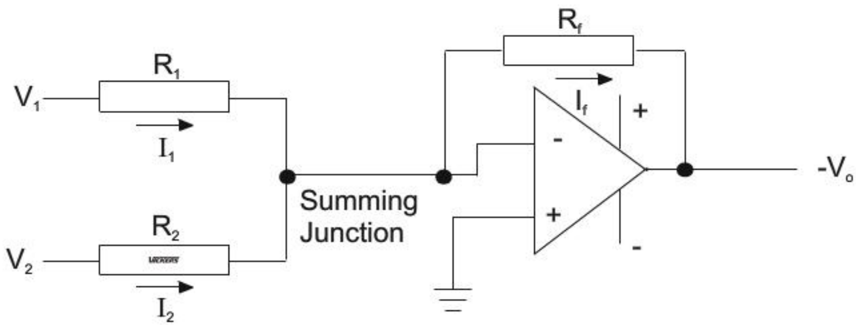


Figure 9-49 Op Amp with two inputs at the summing junction

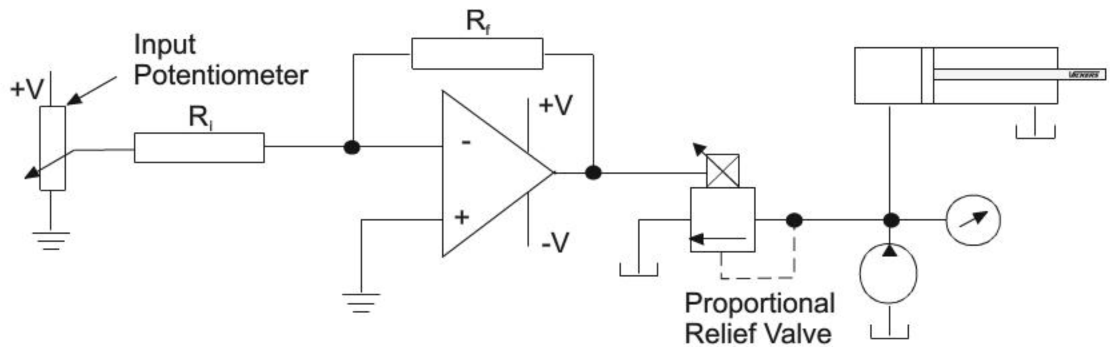


Figure 9-50 Pressure control circuit with op Amp including input potentiometer

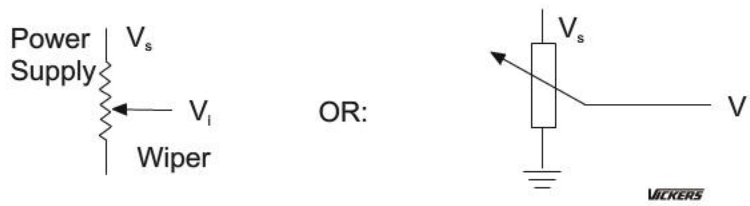


Figure 9-51 Potentiometer as a voltage divider

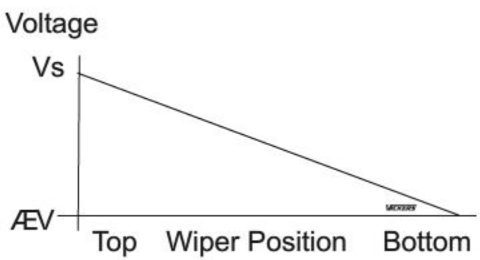


Figure 9-52 Linear relationship between wiper position and wiper voltage

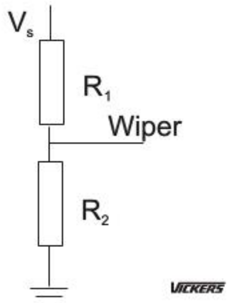


Figure 9-53 Potentiometer shown as two series resistor

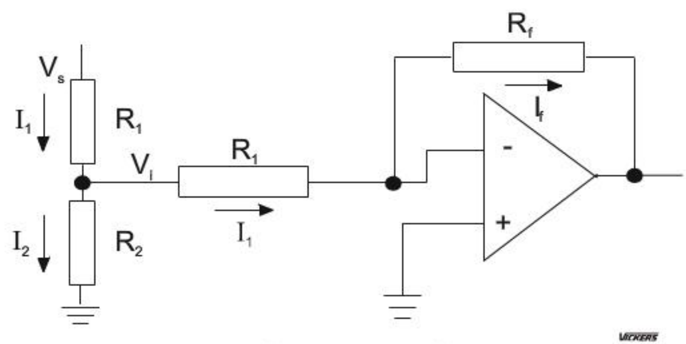


Figure 9-54 Potentiometer used to vary the input voltage

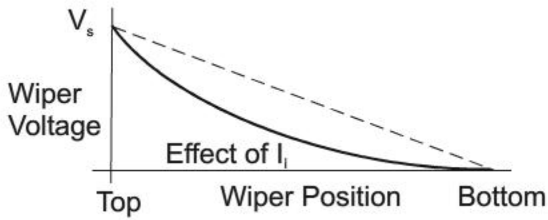
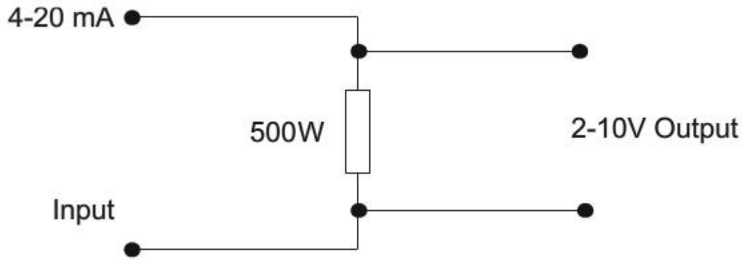


Figure 9-55 Nonlinear relationship between wiper position and wiper voltage



VICKERS

Figure 9-56 Circuit for converting a current signal to a voltage signal

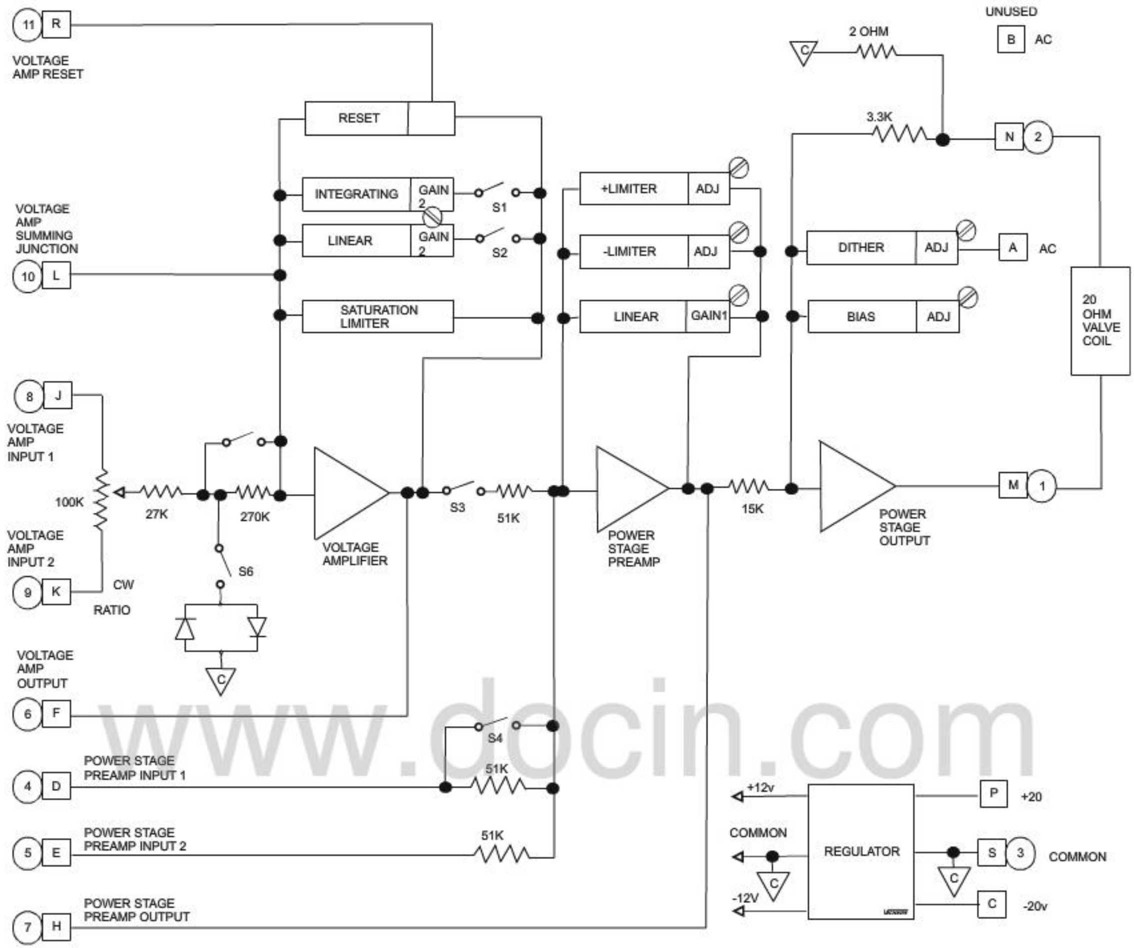


Figure 9-57 Typical industrial amplifier control module