CBET Certification Review

Fundamentals of Electricity, Electronics, and Solid-State Devices

Myron D. Hartman MS, SASHE, CCE, CRES, CBET
Myron.hartman@betcertification.com
www.betcertification.com

Topics of Discussion

- Math Review
- Ohm’s Law & DC Circuits
- AC Components & Circuits
- Diodes
- Power Supplies
- Power & Misc Devices
- Digital Logic Circuits
- Operational Amplifiers
- Transistors
- Field Effect Transistors
- Transducers
- Batteries

Math Review

Scientific Units of Measurement

Quantity	Unit	Symbol
Length	Meter	M
Mass (weight)	Kilogram	kg
Time	Seconds	Sec
Electric Current	Amps	A or I
Temperature	Kelvin	K
Luminous Intensity	Candela	cd
Amount of Substance	Mole	mol

Math Review

Electrical Units of Measurement

Quantity	Unit	Symbol
Electric Current	Ampere	A or I
Charge	Coulomb	C
Voltage	Volt	V or E
Resistance	Ohm	Ω
Power	Watt	P or W
Conductance	Siemens	G
Capacitance	Farads	f
Inductance	Henrys	h
Impedance	Reactance	Z

Math Review

Magnetic Units of Measurement

Quantity	Unit	Symbol
Flux Density	Tesla	T
Magnetic Flux	Weber	Wb
Magnetizing Force	Ampere-turns/meter	At/m
Magnetomotive Force	Ampere-turn	At
Permeability	Webers/ampere-turns-meter	Wb/Atm
Reluctance	Ampere-turns/weber	At/Wb

Math Review

Scientific and Engineering Notation

Large Numbers

Symbol	Unit	Power of 10
P	Peta	10^{15}
T	Tera	10^{12}
G	Giga	10^{9}
M	Mega	10^{6}
K	Kilo	10^{3}
C	Cent	10^{2}

Math Review

Scientific and Engineering Notation

Small Numbers

Symbol	Unit	Power of 10
m	Milli	10^{-3}
u	Micro	10^{-6}
n	Nano	10^{-9}
p	Pico	10^{-12}
f	Femt	10^{-15}

Math Review

Scientific and Engineering Notation

Number	Unit	Power of 10
1,000,000,000	Giga	10^9
100,000,00	100 Million	10^8
10,000,000	10 Million	10^7
1,000,000	Million M	10^6
100,000	100 Thousand	10^5
10,000	10 Thousand	10^4
1,000	Thousand K	10^3
100	Hundred C	10^2
10	Tens	10^1

Math Review

Scientific and Engineering Notation

Number	Unit	Power of 10
1	Ones	10^{-0}
0.1	Tenth	10^{-1}
0.01	Hundredth	10^{-2}
0.001	Milli	10^{-3}
0.000001	Micro	10^{-6}
0.000000001	Nano	10^{-9}
0.000000000001	Pico	10^{-12}
0.000000000000001	Femt	10^{-15}

Ohms Law & DC Circuits

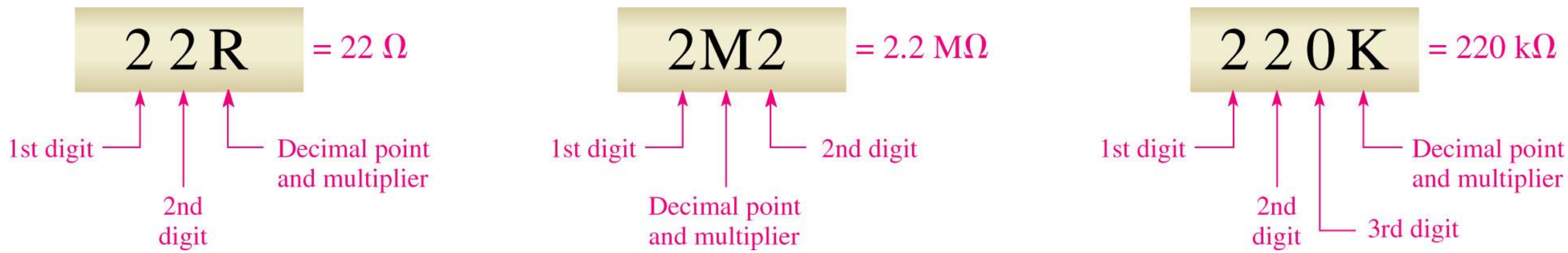
Resistance

	Color	Digit	Multiplier	Tolerance
Resistance value, first three bands: First band 1st digit Second band 2nd digit *Third band multiplier (number of zeros following the 2nd digit)	Black	0	10^0	
	Brown	1	10^1	1% (five band)
	Red	2	10^2	2% (five band)
	Orange	3	10^3	
	Yellow	4	10^4	
	Green	5	10^5	
	Blue	6	10^6	
	Violet	7	10^7	
	Gray	8	10^8	
	White	9	10^9	
Fourth band tolerance	Gold	5%	10^{-1}	5% (four band)
	Silver	10%	10^{-2}	10% (four band)
	No band	20%		

* For resistance values less than 10 , the third band is either gold or silver. Gold is for a multiplier of 0.1 and silver is fo
a multiplier of 0.01.

Resistance

- Alphanumeric Labeling
- Two or three digits, and one of the letters R, K, or M are used to identify a resistance value
- The letter is used to indicate the multiplier, and its position is used to indicate decimal point position.



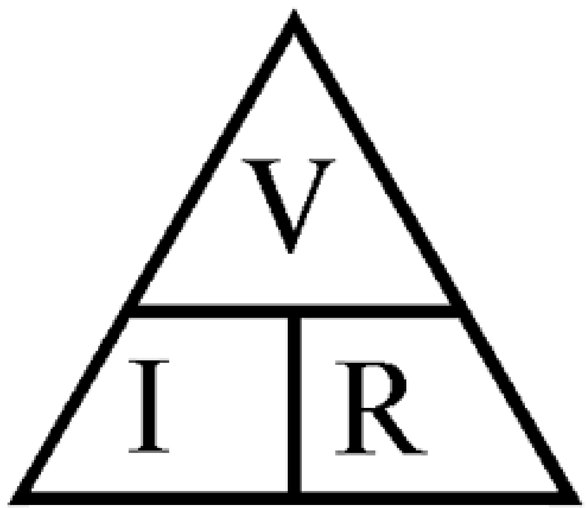
Ohms Law

The most important fundamental law in electronics is Ohm’s law, which relates voltage, current, and resistance

Georg Simon Ohm (1787-1854) studied the relationship between voltage, current, and resistance and formulated the equation that bears his name

Ohms Law

Voltage (V) = Current (I) X Resistance



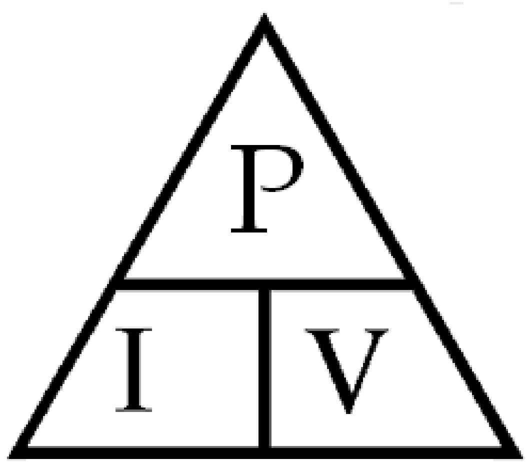
Ohms Law

Power Law

Power is the rate energy is "used" (actually converted to heat or another form)

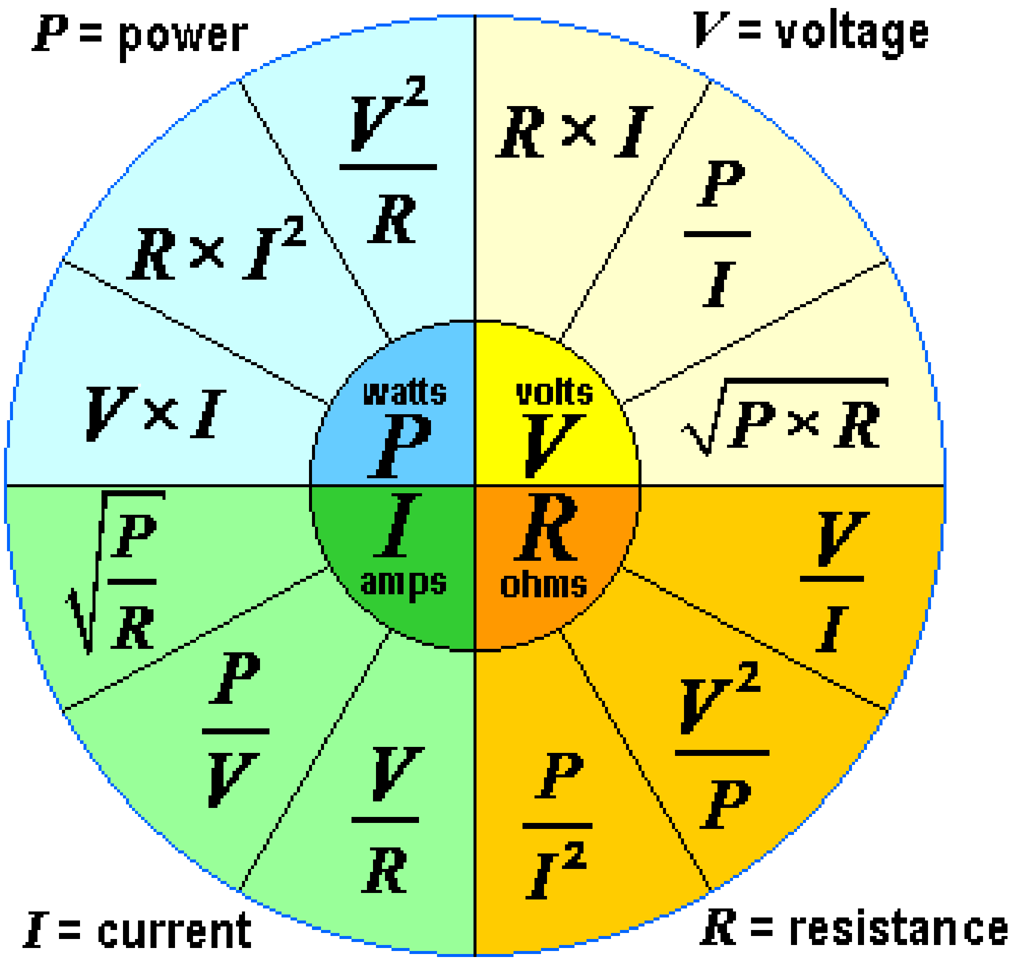
Power is measured in watts (or kilowatts).

Power (P) = Voltage (V) X Current (I)



Power Law

Ohms & Power Laws

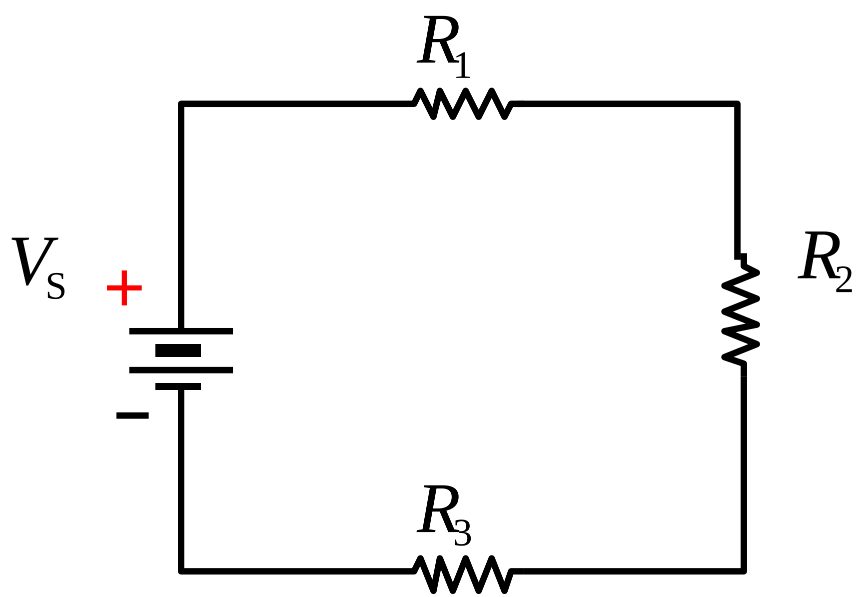


Series Circuits

All series circuits have three common characteristics:

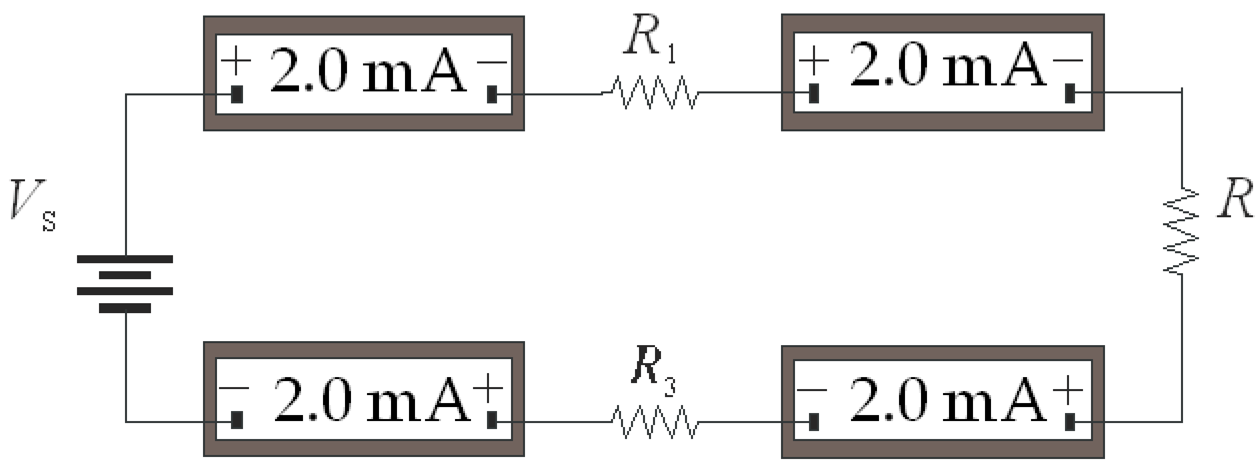
1. A source of voltage
2. A load
3. A complete path

A series circuit is one that has one current path



Series Circuits

Because there is only one path for the current, the current is the same at any point in the circuit

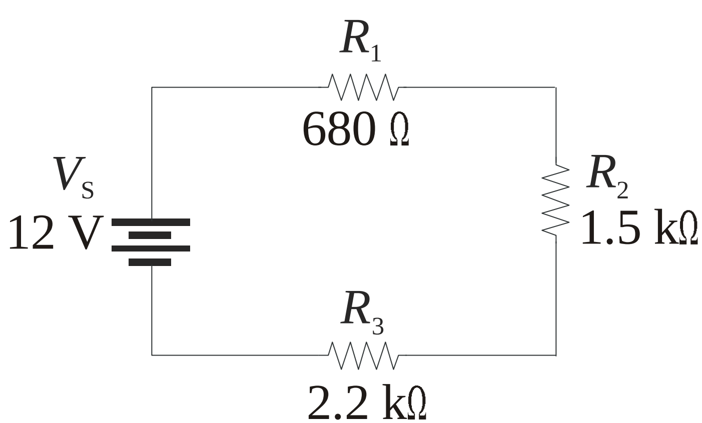


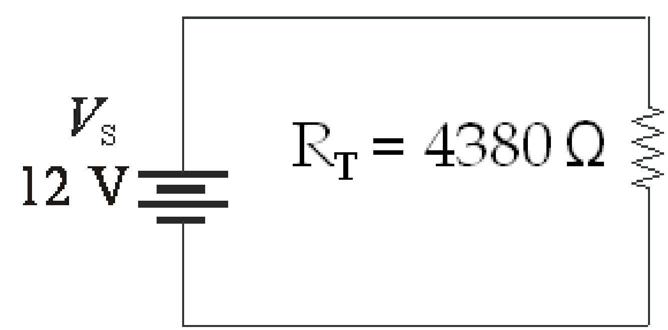
Series Circuits

If there is more than one resistor in a series circuit, the total resistance in the circuit is the sum of all resistors in the circuit

A circuit with more than one resistor can be simplified to one resistor

Example: $R_T = 680 + 1500 + 2200 = 4380\ \Omega$



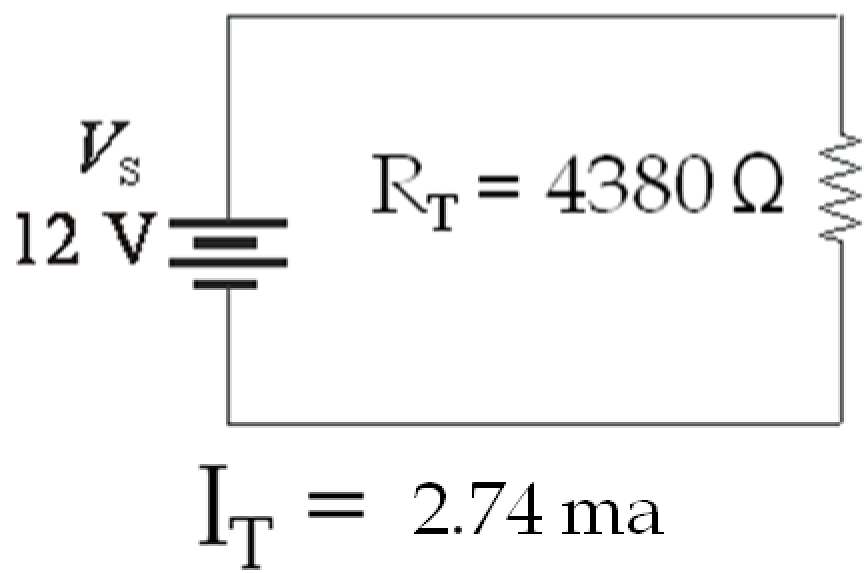


Series Circuits

Once the total resistance is calculated, the total current of the circuit can then be found

Current (I) = Voltage (V) / Resistance (R)

Example: $I_T = 12V / 4380\ \Omega = 2.74$ ma



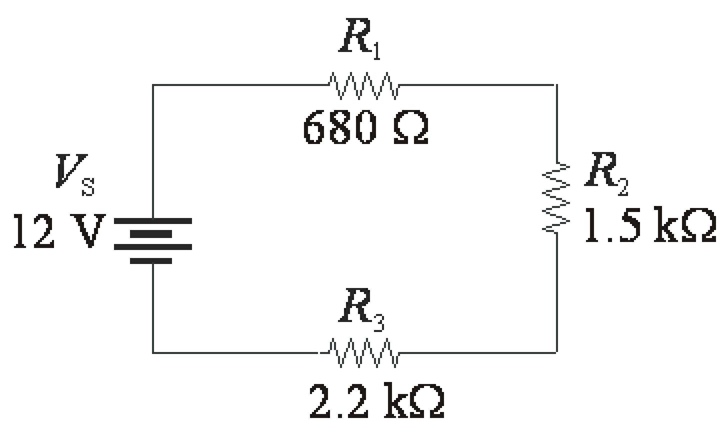
Series Circuits

Once the total current is found, the voltage drop on each resistor can be calculated

Example: $V_{R1} = 680\ \Omega \times 2.74\ \text{ma} = 1.86\ \text{V}$

$V_{R2} = 1500\ \Omega \times 2.74\ \text{ma} = 4.11\ \text{V}$

$V_{R3} = 2200\ \Omega \times 2.74\ \text{ma} = 6.03\ \text{V}$



$I_T = 2.74\ \text{ma}$

Series Circuits

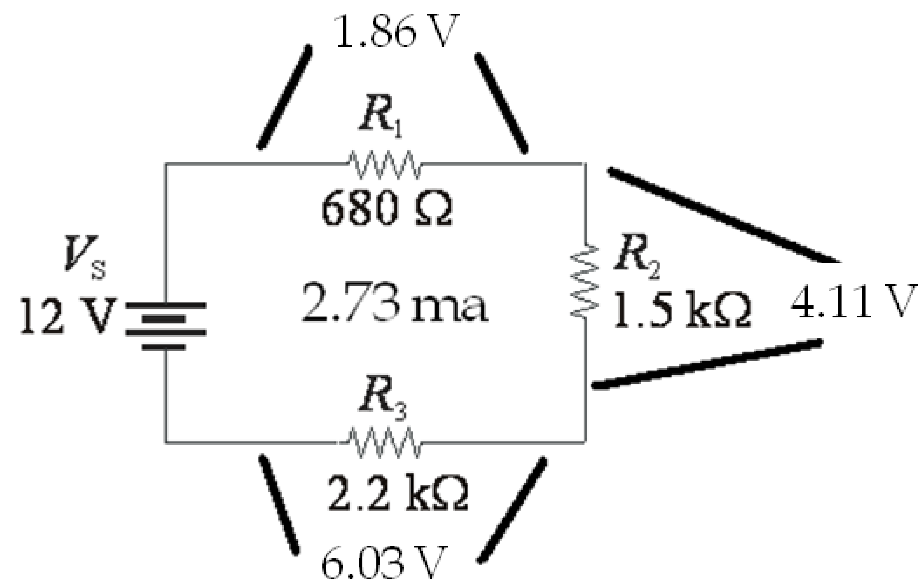
Now that each voltage is found on all resistor, the sum of all voltages must equal the power supply voltage

Example: $V_{R1} = 1.86$ V

$V_{R2} = 4.11$ V

$V_{R3} = 6.03$ V

$V_{Sum} = 12.0$



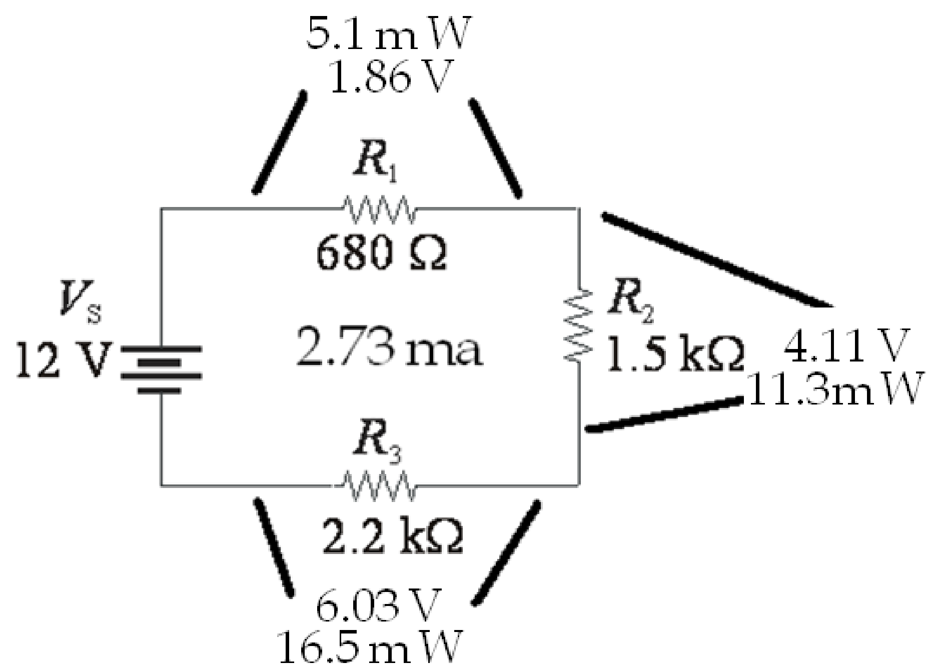
Series Circuits

Now the power for each resistor can be calculated:

Example: P_{R1} = 1.85 V X 2.74 ma = 5.1 m W

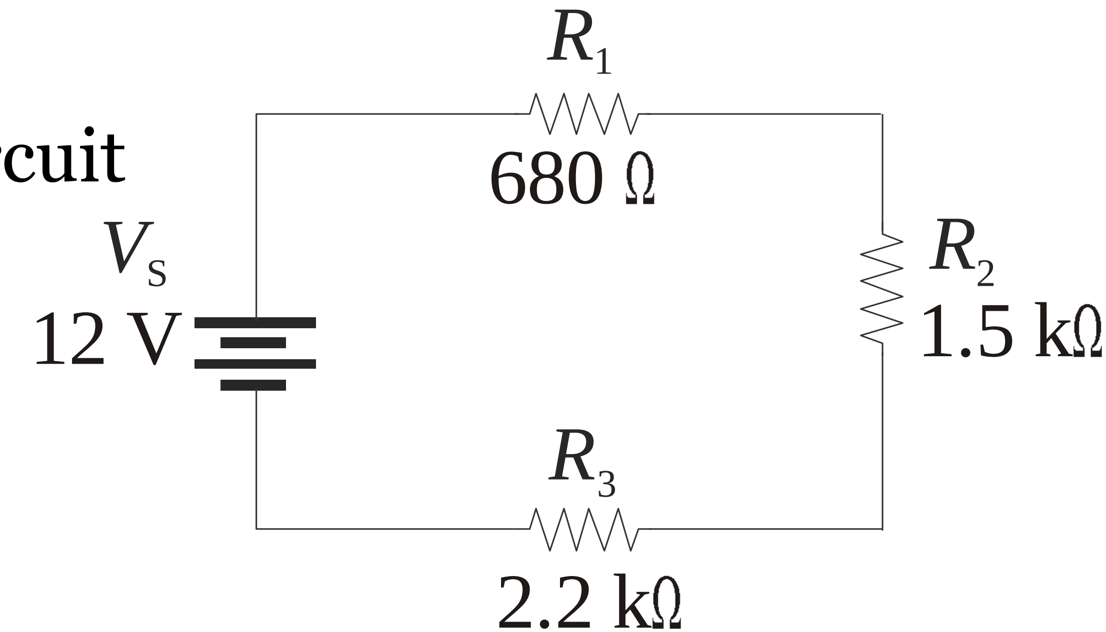
V_{R2} = 4.09 V X 2.74 ma = 11.3m W

V_{R3} = 6.03 V X 2.74 ma = 16.5 m W



Series Circuits

Summary for the circuit



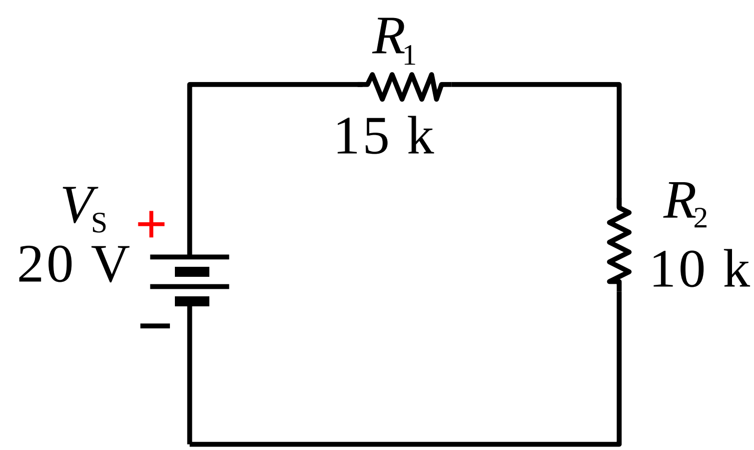
I_1= 2.74 mA	R_1= 0.68 kΩ	V_1=1.86 V	P_1= 5.1 mW
I_2= 2.74 mA	R_2= 1.50 kΩ	V_2=4.11 V	P_2= 11.3 mW
I_3= 2.74 mA	R_3= 2.20 kΩ	V_3=6.03 V	P_3= 16.5 mW
I_T= 2.74 mA	R_T= 4.38 kΩ	V_S= 12 V	P_T=32.9 mW

Kirchhoff's Voltage Law (KVL)

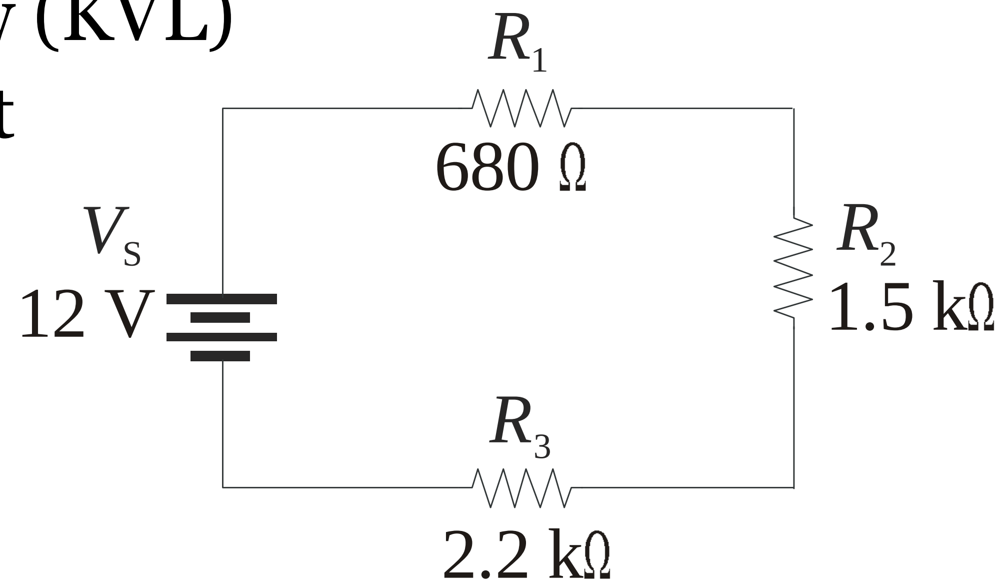
Kirchhoff's voltage law states that the voltage drop across any given resistor in a series circuit is equal to the ratio of that resistor to the total resistance, multiplied by source voltage

KVL applies to all circuits, but you must apply it to only one closed path. In a series circuit, this is the entire circuit

$$V_2 = V_S\left(\frac{R_2}{R_T}\right) = 20\text{ V}\left(\frac{10\text{ k}\Omega}{25\text{ k}\Omega}\right) = 8\text{ V}$$



Kirchhoff's Voltage Law (KVL)
Summary for the circuit



$$V_2 = V_S\left(\frac{R_2}{R_T}\right)$$

KVL

I_1= 2.74 mA	R_1= 0.68 kΩ	V_1=1.86 V	V_1=1.86 V	P_1= 5.1 mW
I_2= 2.74 mA	R_2= 1.50 kΩ	V_2=4.11 V	V_2=4.11 V	P_2= 11.3 mW
I_3= 2.74 mA	R_3= 2.20 kΩ	V_3=6.03 V	V_3=6.03 V	P_3= 16.5 mW
I_T= 2.74 mA	R_T= 4.38 kΩ	V_S= 12 V	V_S= 12 V	P_T=32.9 mW

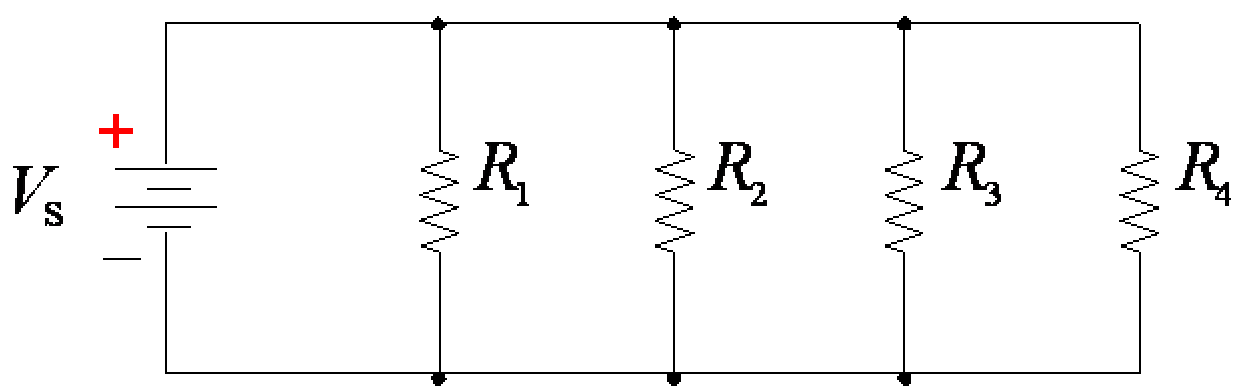
R_T = 4380 Ω

Parallel Circuits

Resistors that are connected to the same two points are said to be in parallel

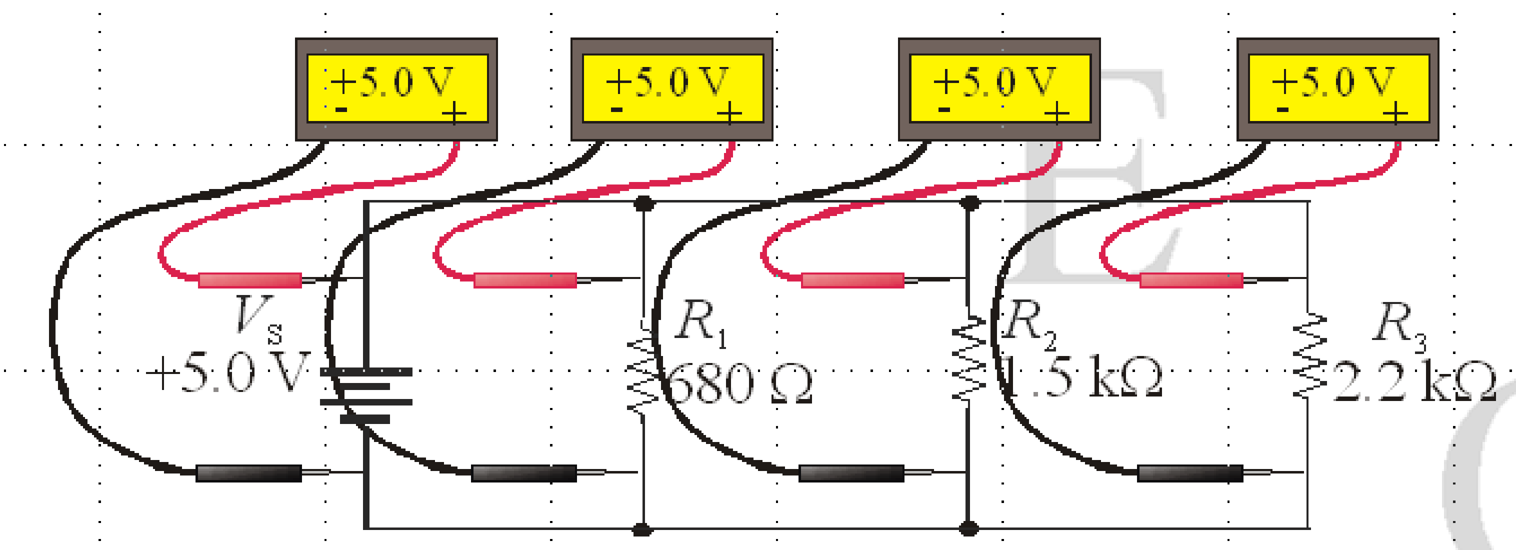
There is one common voltage source for the resistors

A parallel circuit has multiple current paths, one through each resistor



Parallel Circuits

As each resistor is connected to the same voltage source, the voltage on each resistor is the same value



Parallel Circuits

The total resistance of a parallel circuit can NOT be solved by adding the values together

The total resistance is the sum of the reciprocals of each resistor added together

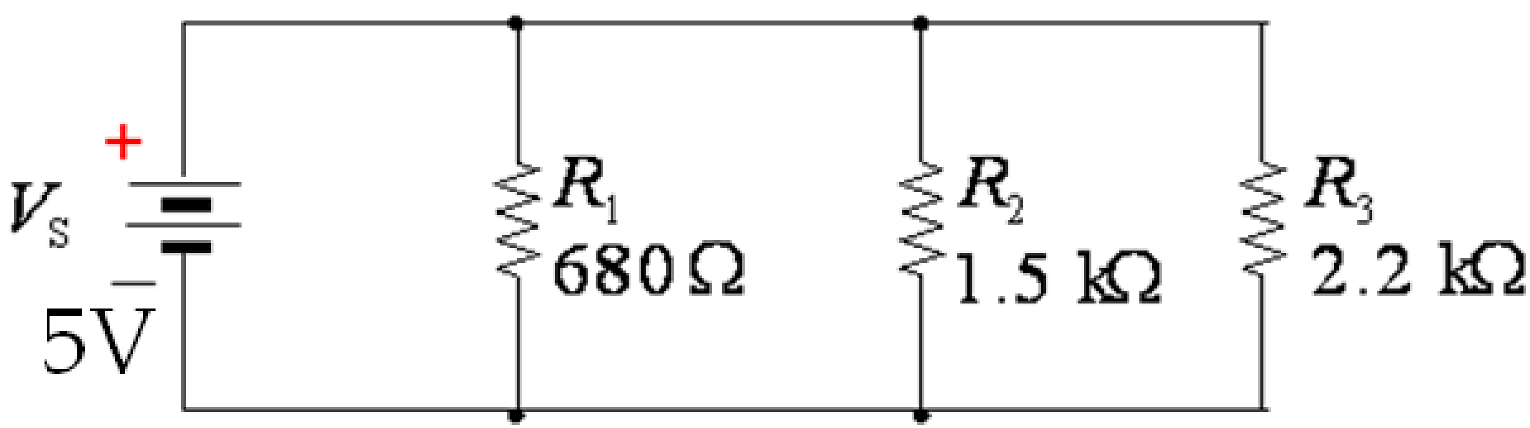
$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

Parallel Circuits

Example – Find the Total Resistance 5V

$$R_T = 385.8\ \Omega$$

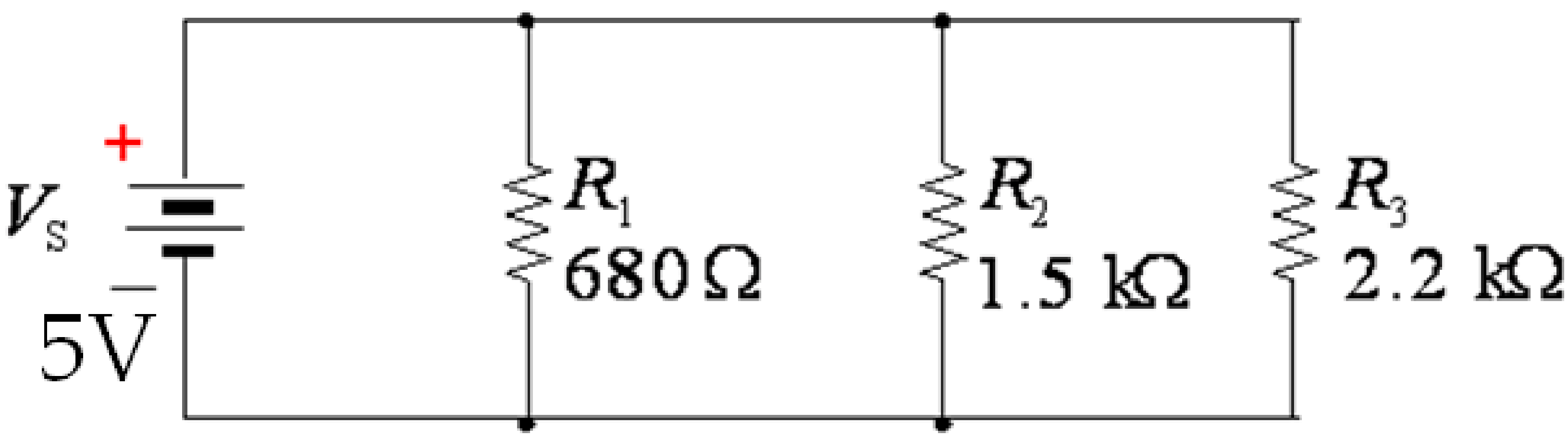
$$R_T = \frac{1}{\frac{1}{680} + \frac{1}{1.5\text{k}} + \frac{1}{2.2\text{ k}}}$$



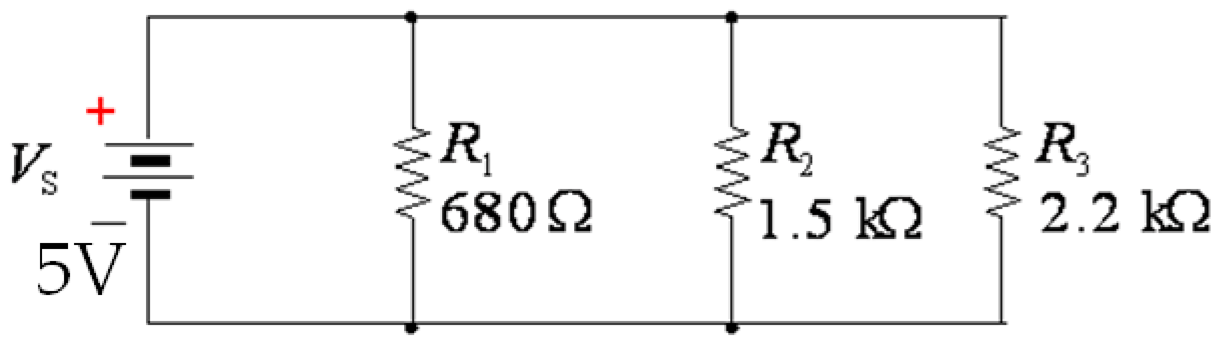
Parallel Circuits

Example – Find the Total Current

$I_T = 5\ V / 385.8\ \Omega = 13.0$ ma



Parallel Circuits
Example – All Calculations



I_1= 7.4 mA	R_1= 0.68 kΩ	V_1= 5.0 V	P_1= 36.8 mW
I_2= 3.3 mA	R_2= 1.50 kΩ	V_2= 5.0 V	P_2= 16.7 mW
I_3= 2.3 mA	R_3= 2.20 kΩ	V_3= 5.0 V	P_3= 11.4 mW
I_T=13.0 mA	R_T= 386 Ω	V_S= 5.0 V	P_T=64.8 mW

Kirchhoff's current law

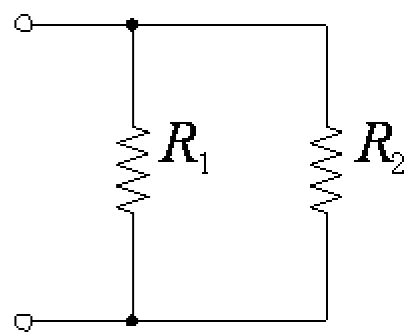
Kirchhoff's current law states that the sum of the currents entering a node is equal to the sum of the currents leaving the node

I_1= 7.4 mA	R_1= 0.68 kΩ	V_1= 5.0 V	P_1= 36.8 mW
I_2= 3.3 mA	R_2= 1.50 kΩ	V_2= 5.0 V	P_2= 16.7 mW
I_3= 2.3 mA	R_3= 2.20 kΩ	V_3= 5.0 V	P_3= 11.4 mW
I_T=13.0 mA	R_T= 386 Ω	V_S= 5.0 V	P_T=64.8 mW

Parallel Circuits

For parallel circuits that have only 2 resistors, a simpler formula can be used to calculate the new total resistance

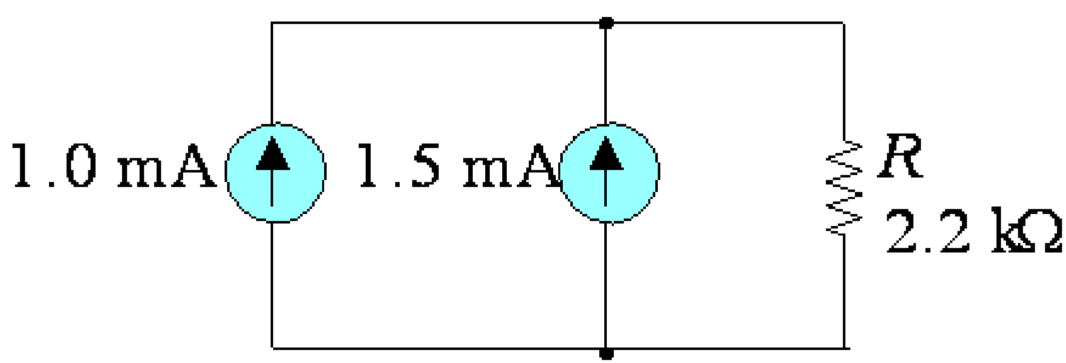
$$R_T = \frac{R_1 R_2}{R_1 + R_2} \quad \text{OR} \quad R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}}$$



Parallel Circuits

When there is more than one current source in parallel, the current sources can be added together to 1

Example: 1 ma + 1.5 ma = 2.5 ma

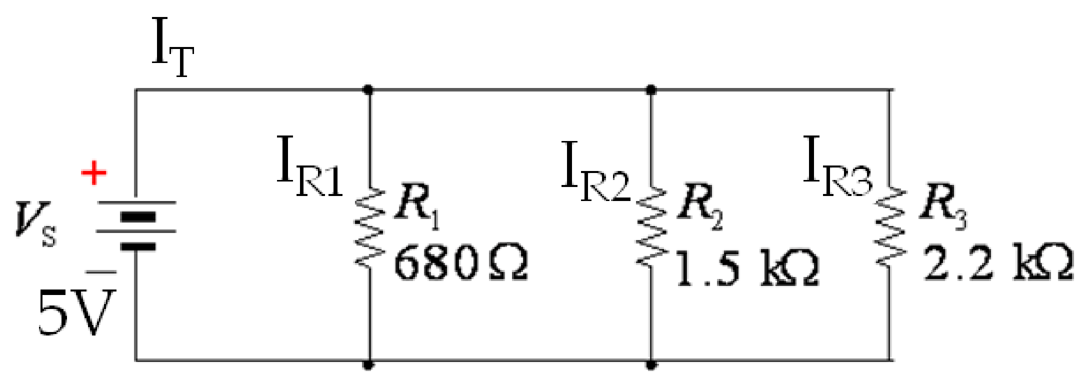


Parallel Circuits – Current Divider

When current enters a parallel circuit, the current will divide into each resistor

The total current is the circuit will be equal to the current in each resistor added together

$$I_T = I_{R1} + I_{R2} + I_{R3}$$



Combination Circuits

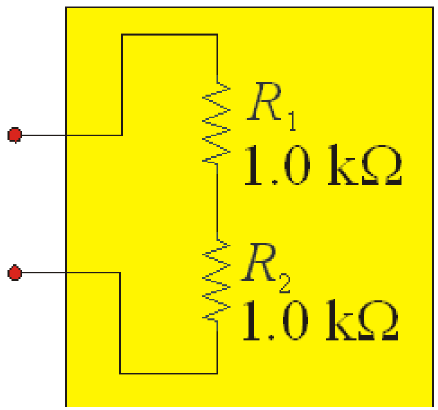
When a circuit has both series and parallel resistors, it can be simplified down to 1 resistor

There are no universal rules that apply on how to solve each unique circuit

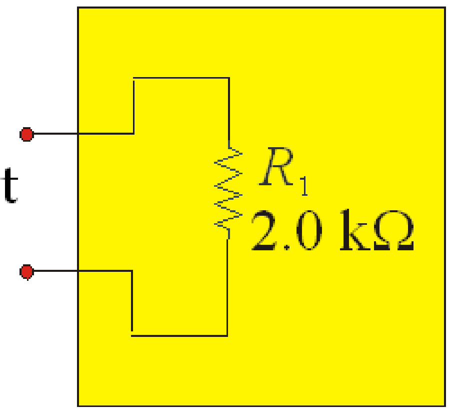
An analysis must be done for each circuit

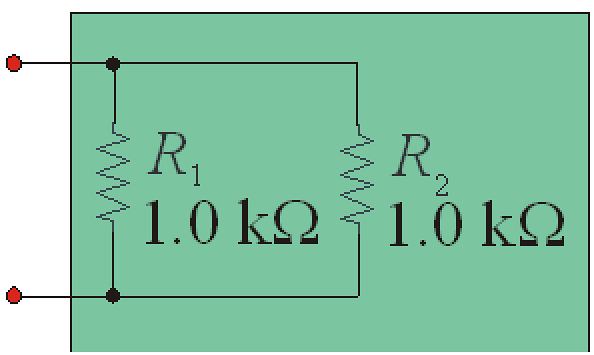
Combination Circuits

Examples

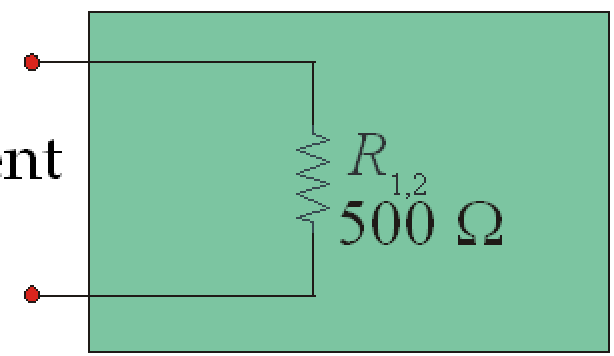


is equivalent to



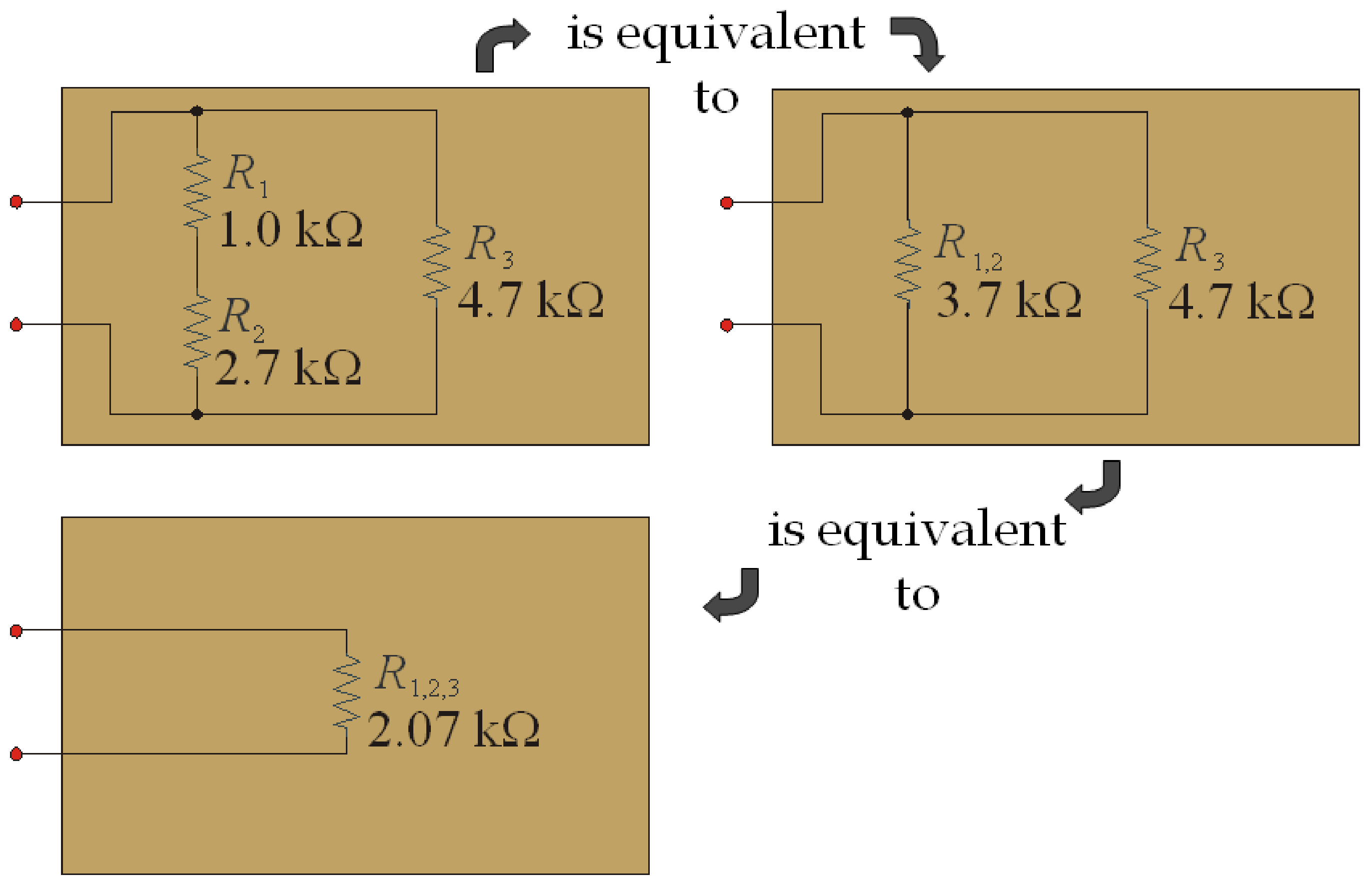


is equivalent to



Combination Circuits

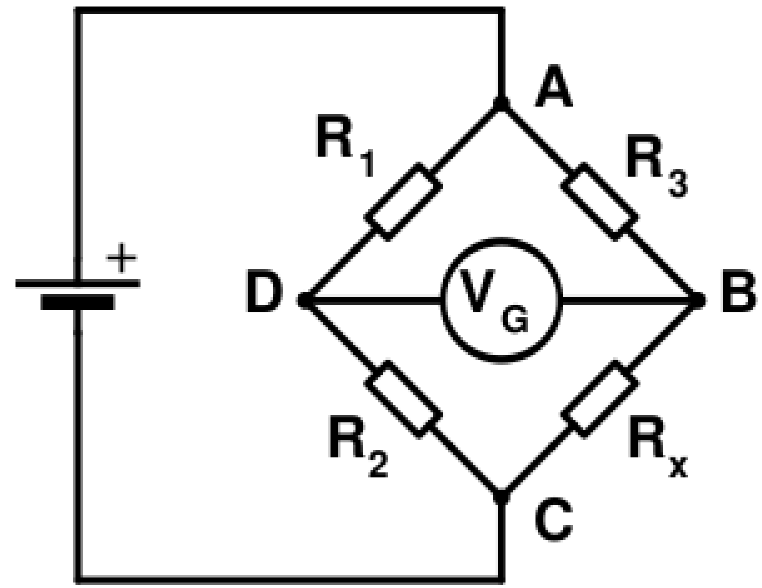
Examples



Combination Circuits

The Wheatstone Bridge consists of four resistive arms forming two voltage dividers and a dc voltage source

The output is taken between the dividers. Frequently, one of the bridge resistors is adjustable

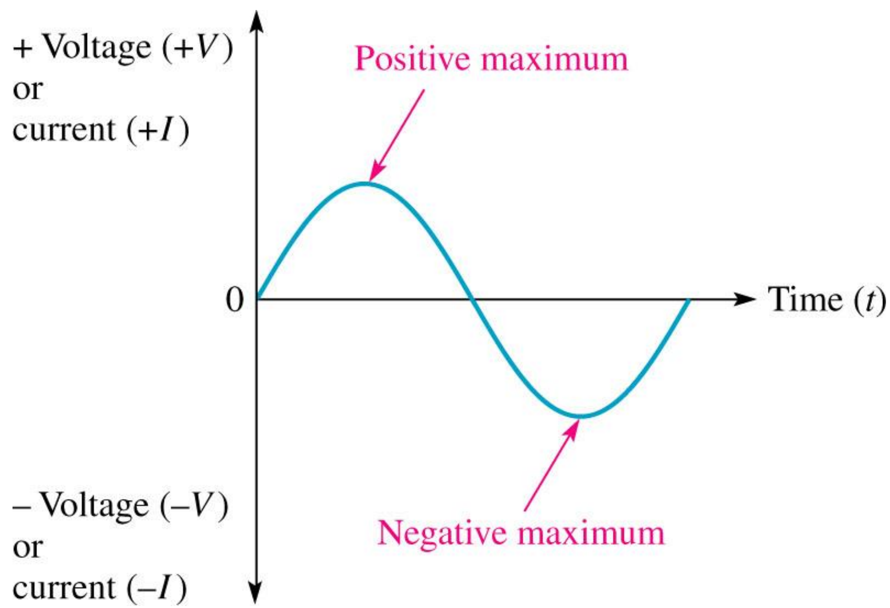


$$V_G = \left(\frac{R_x}{R_3 + R_x} - \frac{R_2}{R_1 + R_2}\right) V_s$$

AC Components & Circuits

The sinusoidal waveform (sine wave) is the fundamental alternating current (ac) and alternating voltage waveform

Electrical sine waves are named from the mathematical function with the same shape



Frequency

Frequency (f) is the number of cycles that a sine wave completes in one second

Frequency is measured in **hertz** (Hz)

In United States the frequency is 60 Hz

In Europe the frequency is 50 Hz

Some military applications use 400 Hz

Period and Frequency

The period and frequency are reciprocals of each other

$$f = \frac{1}{T} \qquad T = \frac{1}{f}$$

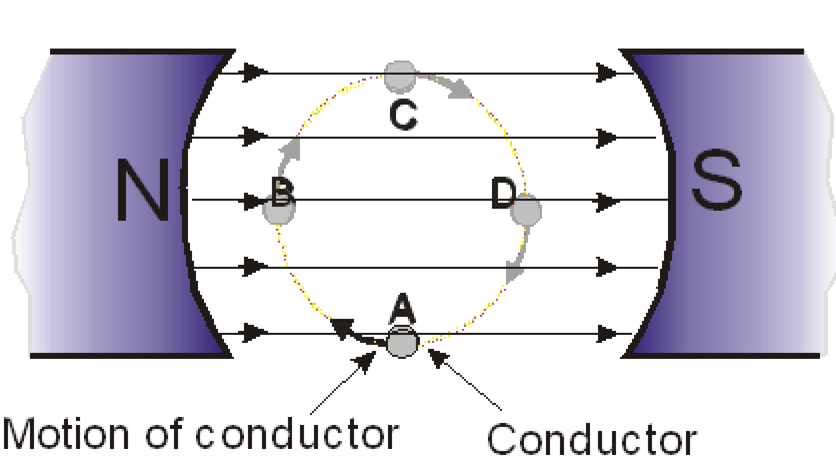
Example

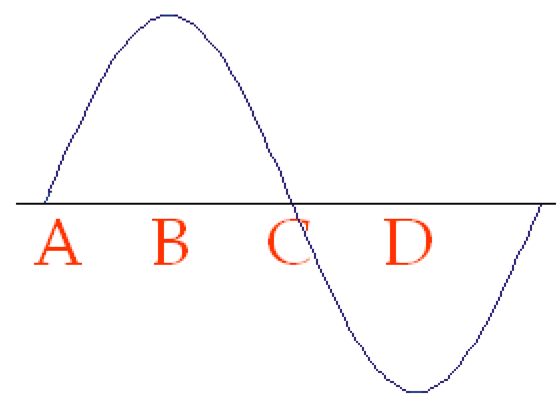
If the period is 50 μs, the frequency is 0.02 MHz = 20 kHz.

Generation of a Sine Wave

Sinusoidal voltages are produced by ac generators and electronic oscillators

When a conductor rotates in a constant magnetic field, a sinusoidal wave is generated





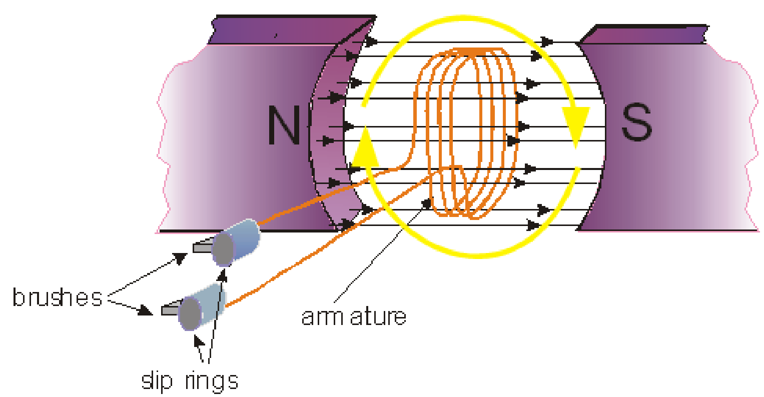
Generators

Generators convert rotational energy to electrical energy

A stationary field alternator with a rotating armature is shown

The armature has an induced voltage, which is connected through slip rings and brushes to a load

The armature loops are wound on a magnetic core

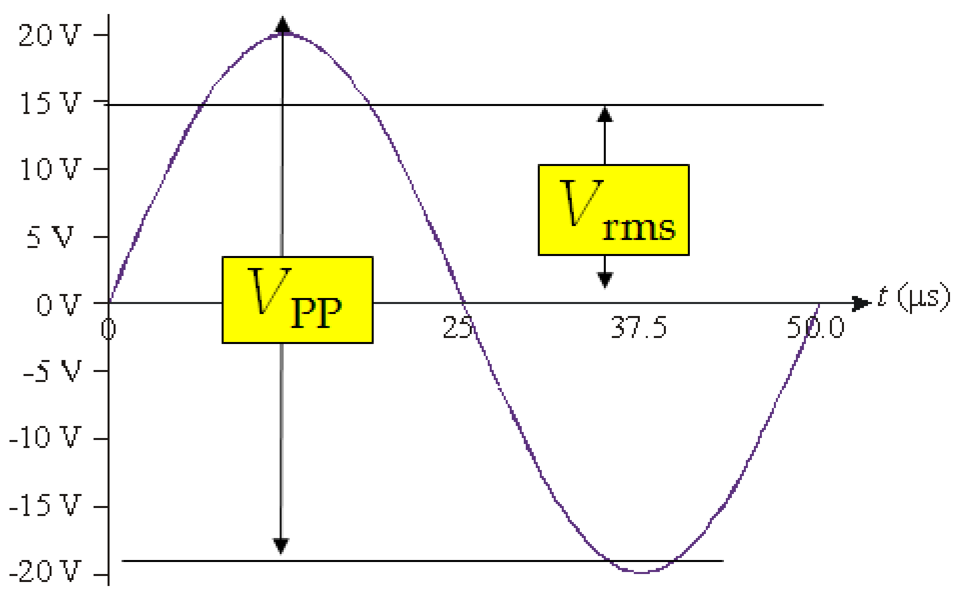


Sine wave voltage and current values

The voltage of a sine wave can also be specified as either the peak-to-peak or the rms value

The peak-to-peak is twice the peak value

The rms value is 0.707 times the peak value

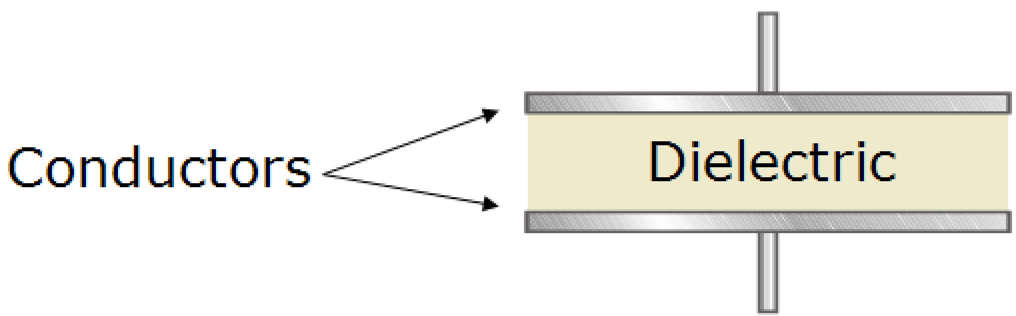


Capacitors

Capacitors are one of the fundamental passive components

In its most basic form, it is composed of two plates separated by a dielectric

The ability to store charge is the definition of capacitance



Capacitors

The capacitance of a capacitor depends on three physical characteristics

$$C = 8.85\times10^{-12}\,\text{F/m}\left(\frac{\varepsilon_r A}{d}\right)$$

C is directly proportional to

- the relative dielectric constant
- the plate area

C is inversely proportional to

- the distance between the plates

Capacitor Types – Series

When capacitors are connected in series, the total capacitance is smaller than the smallest one

The general equation for capacitors in series is

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots + \frac{1}{C_T}}$$

The total capacitance of two capacitors is

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2}}$$

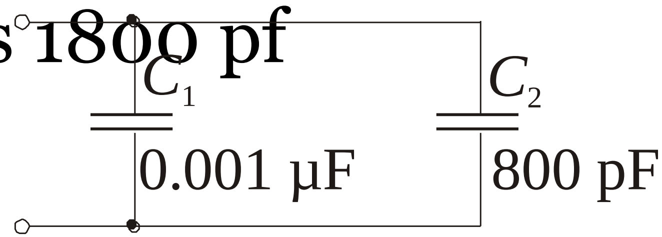
Capacitor Types – Parallel

When capacitors are connected in parallel, the total capacitance is the sum of the individual capacitors

The general equation for capacitors in parallel is

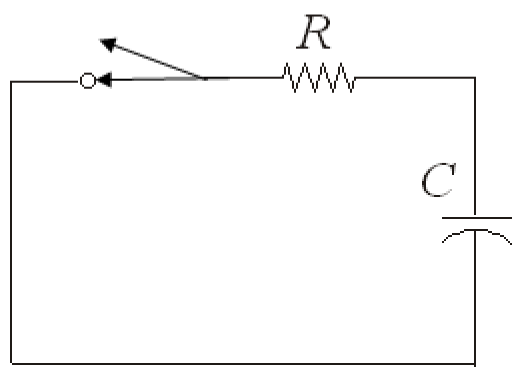
$$C_{\mathrm{T}} = C_1 + C_2 + C_3 + \ldots C_n$$

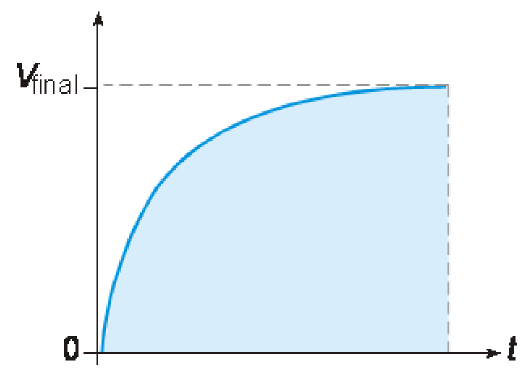
Example: A 0.001 μF capacitor is connected in parallel with an 800 pF capacitor, the total capacitance is 1800 pf



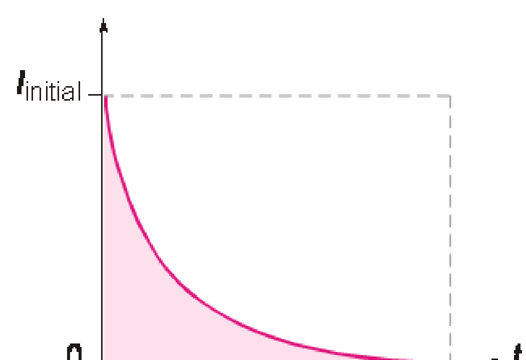
Capacitor in DC Circuits

When a capacitor is charged through a series resistor and dc source, the charging curve is exponential





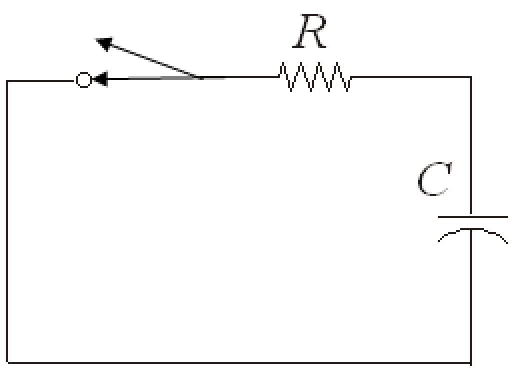
(a) Capacitor charging voltage

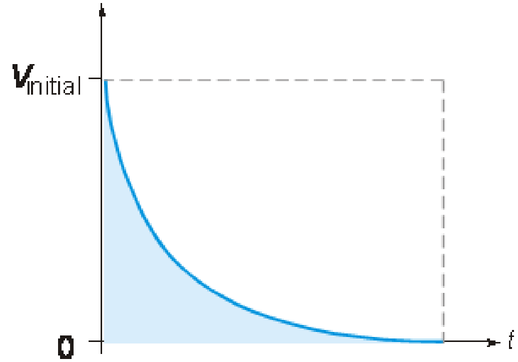


(b) Charging current

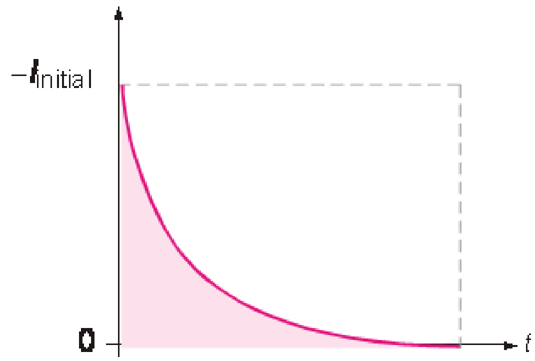
Capacitor in DC Circuits

When a capacitor is discharged through a resistor, the discharge curve is also an exponential





(a) Capacitor discharging voltage



(b) Discharging current

Capacitor - Capacitive Reactance

Capacitive reactance is the opposition to ac by a capacitor

This is similar to resistance in a DC circuit

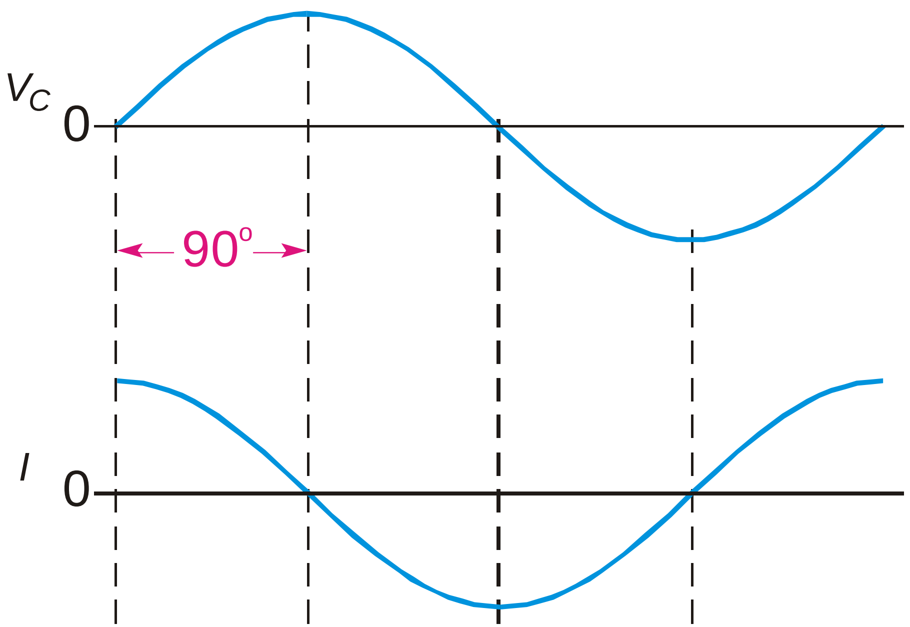
The equation for capacitive reactance is

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

The reactance of a 0.047 μF capacitor when a frequency of 15 kHz is applied is 226 ohms

Capacitor - Phase Shift

When a sine wave is applied to a capacitor, there is a phase shift between voltage and current such that current always leads the voltage by 90°

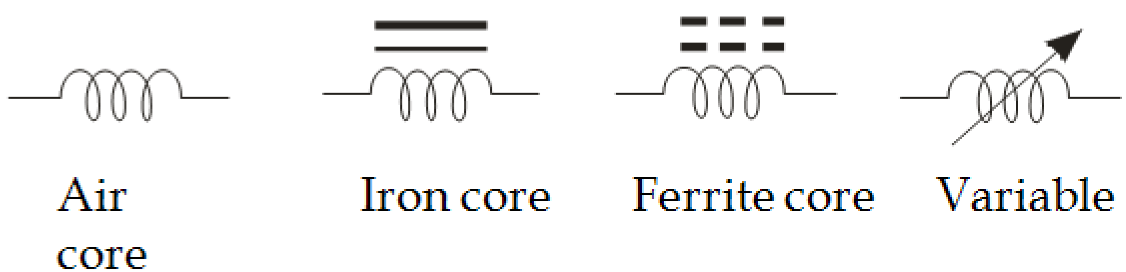


Inductance

Inductance is the property of a conductor to oppose a change in current

The effect of inductance is greatly magnified by winding a coil on a magnetic material

Common symbols for inductors (coils) are



Self Inductance

Self-inductance is usually just called inductance, symbolized by *L*

Self-inductance is a measure of a coil's ability to establish an induced voltage as a result of a change in its current

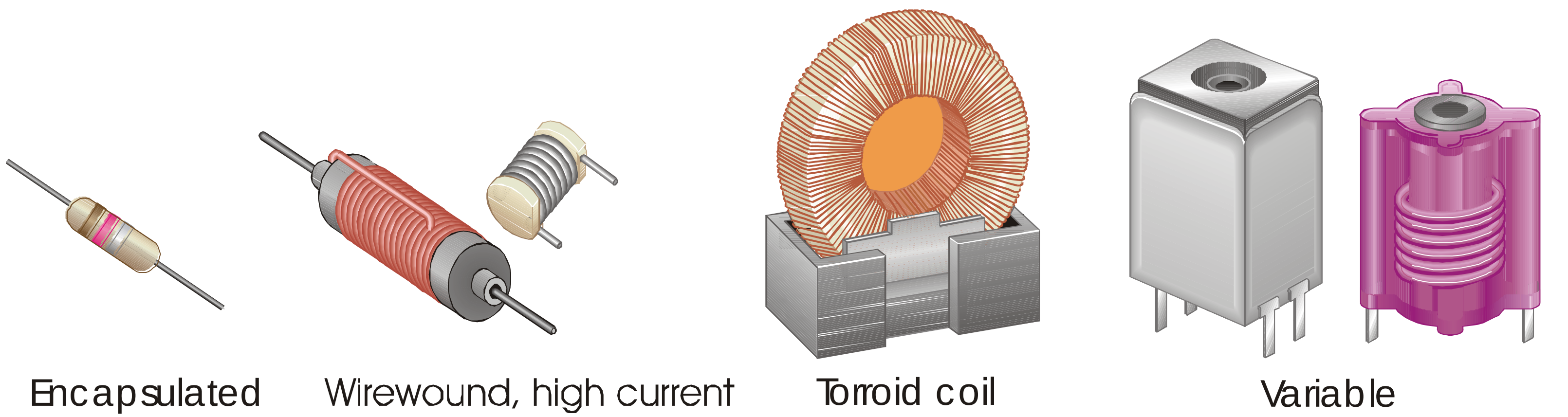
The induced voltage always opposes the change in current, which is basically a statement of Lenz's law

The unit of inductance is the henry (H)

One henry is the inductance of a coil when a current, changing at a rate of one ampere per second, induces one volt across the coil

Inductors

Inductors come in a variety of sizes. A few common ones are shown here



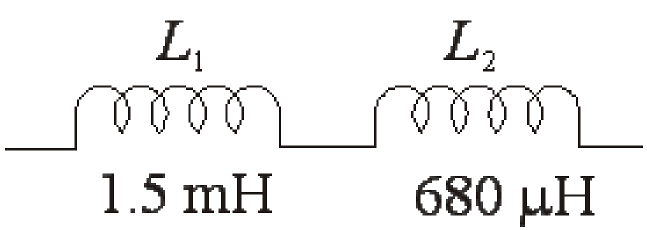
Inductors in Series

When inductors are connected in series, the total inductance is the sum of the individual inductors

The general equation for inductors in series is

$$L_T = L_1 + L_2 + L_3 + \ldots L_n$$

Example: If a 1.5 mH inductor is connected in series with an 680 μH inductor, the total inductance is 2.18 mH



Inductors in Parallel

When inductors are connected in parallel, the total inductance is smaller than the smallest one

The general equation for inductors in parallel is

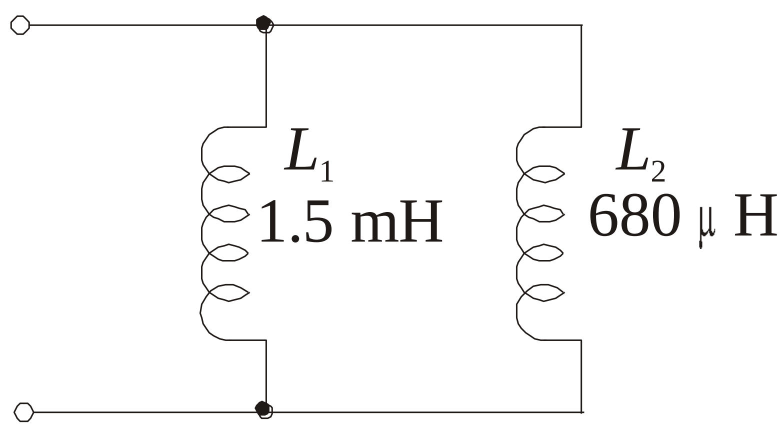
$$L_T = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \ldots + \frac{1}{L_T}}$$

The total inductance of two inductors is

$$L_T = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2}}$$

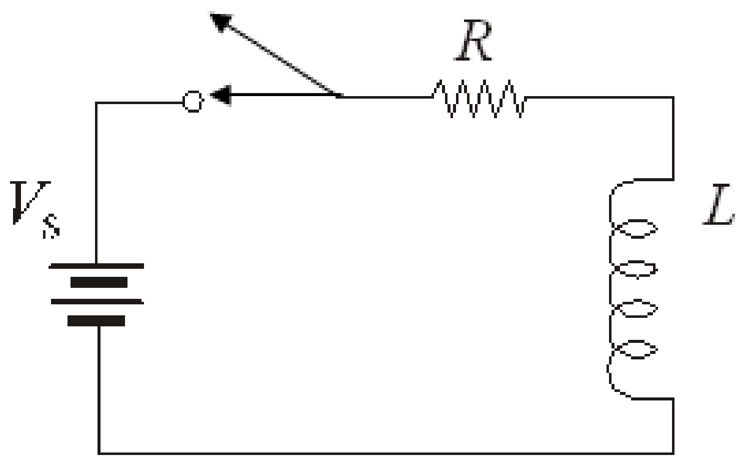
Inductors in Parallel

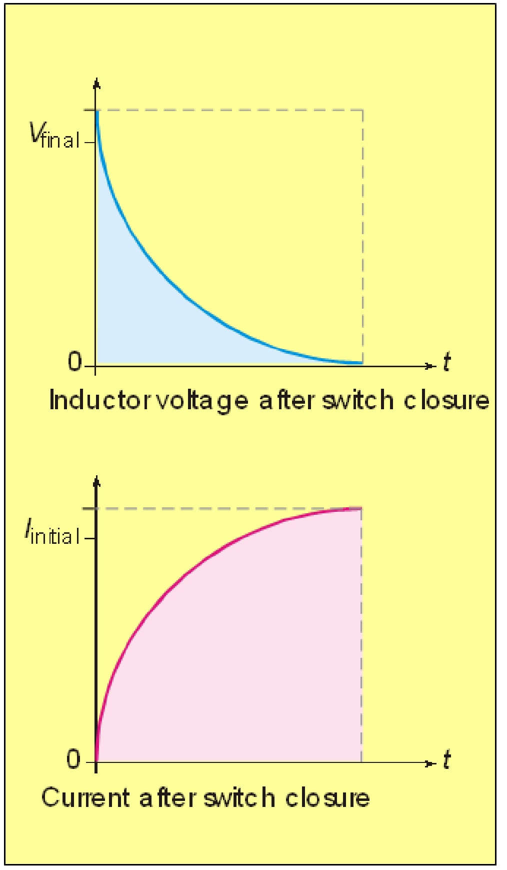
Example: If a 1.5 mH inductor is connected in parallel with an 680 μH inductor, the total inductance is 468 uH



Inductors in DC Circuits

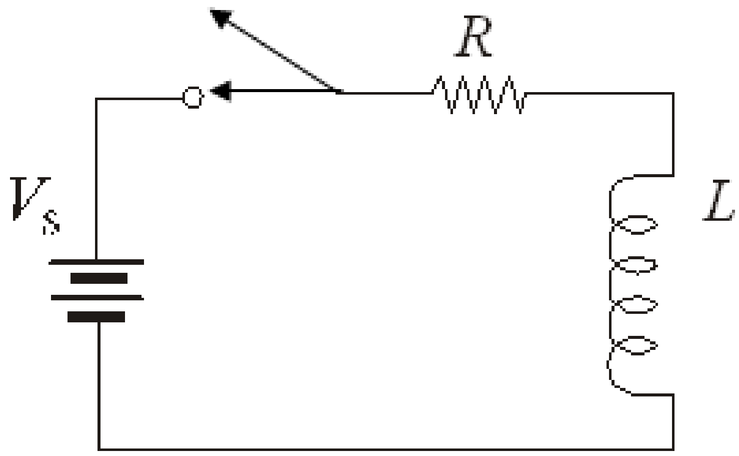
When an inductor is connected in series with a resistor and dc source, the current change is exponential

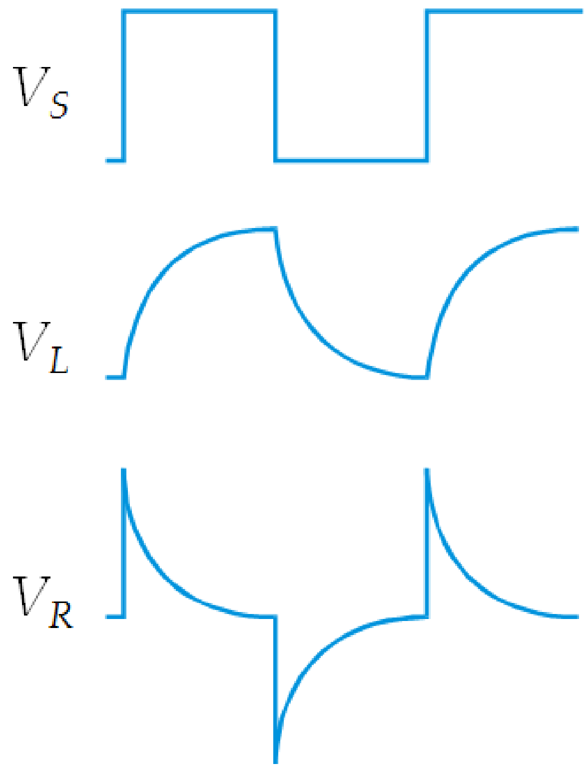




Inductors in DC Circuits

The same shape curves are seen if a square wave is used for the source





Inductors – Inductive Reactance

Inductive reactance is the opposition to ac by an inductor

The equation for inductive reactance is

$$X_L = 2\pi f L$$

Example: The reactance of a 33 μH inductor when a frequency of 550 kHz is applied is 114 Ω

Impedance (Z)

AC total impedance takes into account:

- Resistance (DC) Ω
- Capacitance – X_C
- Inductance – X_L

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

$$X_L = 2\pi fL$$

To calculate the total impedance (Z), the following formula is used:

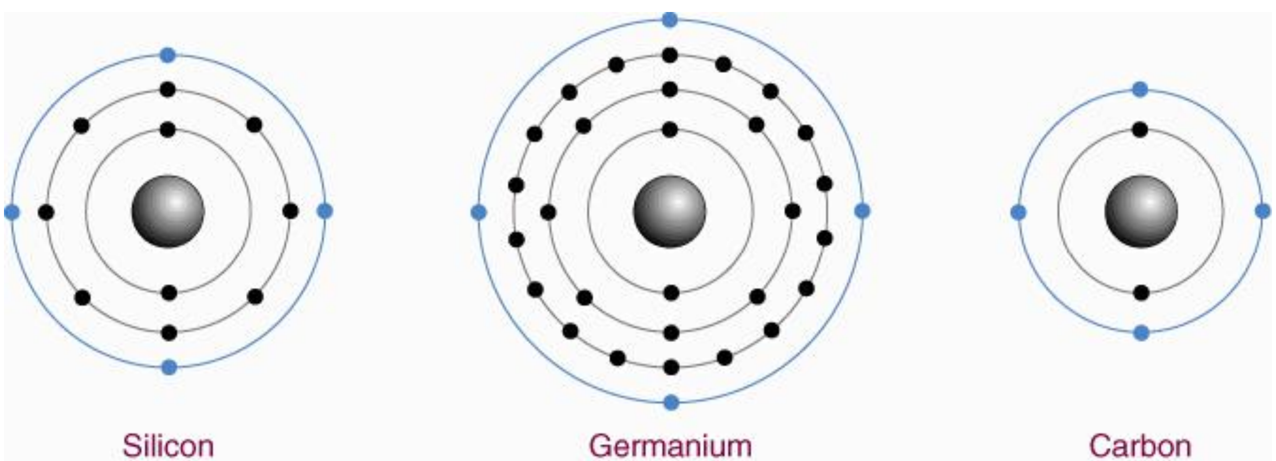
$$Z = \sqrt{(X_L - X_C)^2 + R^2}$$

Diodes

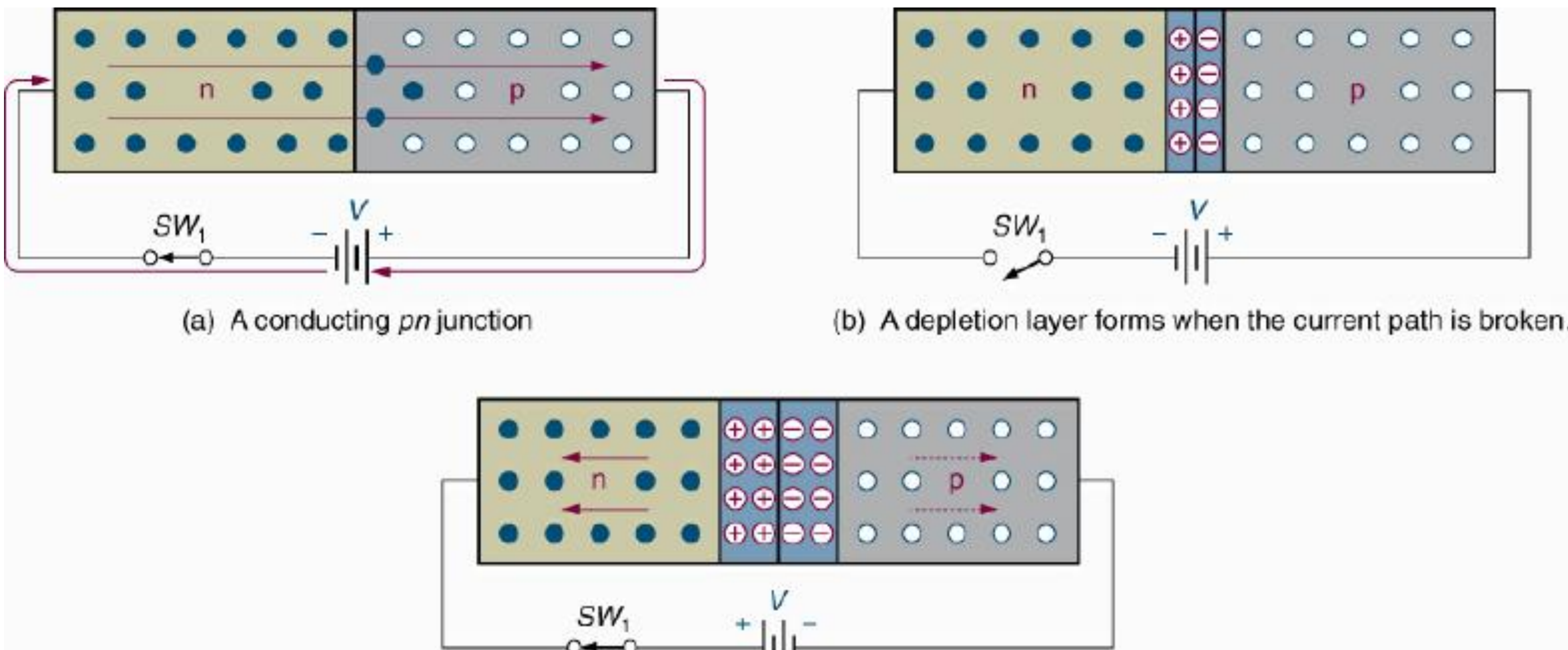
Semiconductors

There are 3 common types of material that make up diodes:

- Silicone (0.7 volt)
- Germanium (0.3 volt)
- Carbon (> 0.7 volt)



Bias – is a voltage (potential) applied to a PN junction to obtain a desired mode of operation

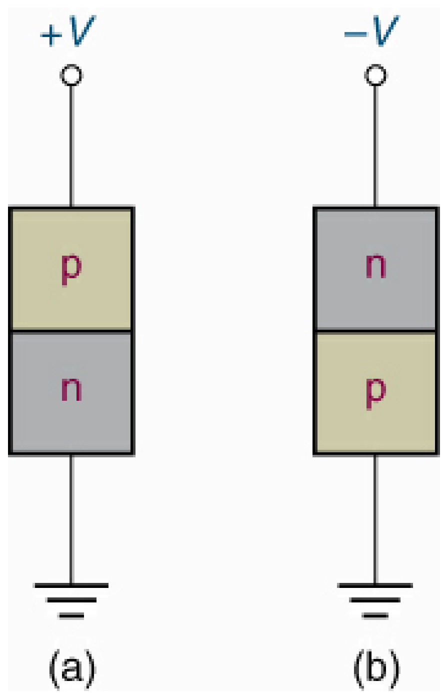


(a) A conducting *pn* junction

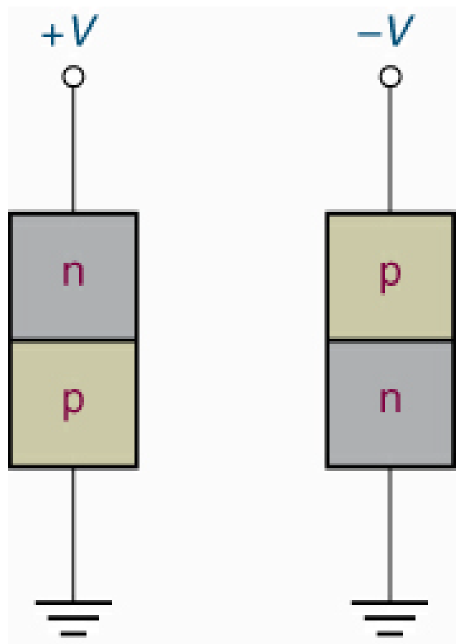
(b) A depletion layer forms when the current path is broken.

(c) When the polarity of *V* is reversed, the depletion layer widens as charge carriers move away from the junction.

Forward Bias – a voltage applied to a PN junction that will reduce the depletion layer resistance and allow current to flow through the device



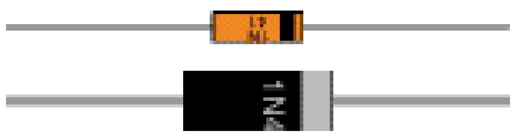
Reverse Bias – a voltage applied to a PN junction that will increase the depletion layer resistance and not allow current to flow through the device

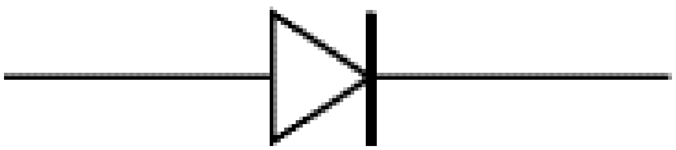


(a) (b)

Function

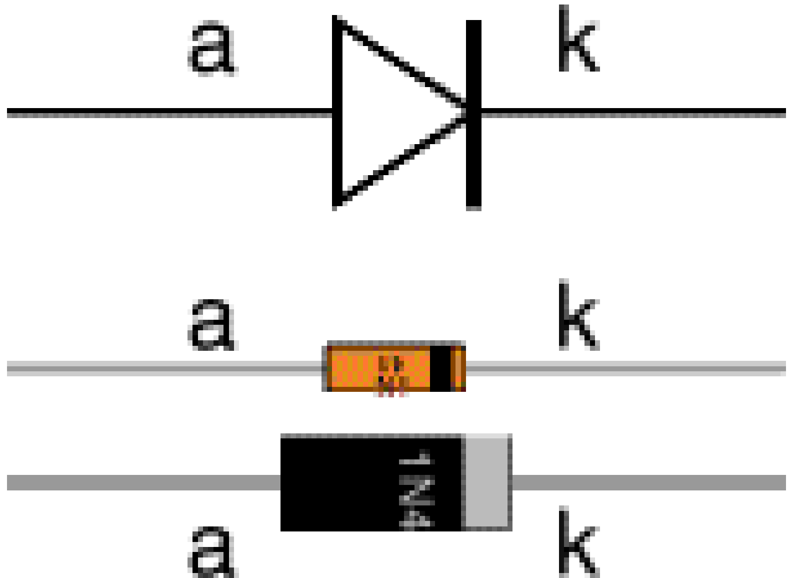
- Diodes allow electricity to flow in one direction only
- The arrow of the circuit symbol shows the direction in which the current can flow
- Diodes are the electrical version of a valve and early diodes were actually called valves





Connections

- All diodes have 2 different leads and must be installed in the circuit in the correct direction for them to work properly:
  - Anode or positive lead connection (a)
  - Cathode or negative lead connections (k)

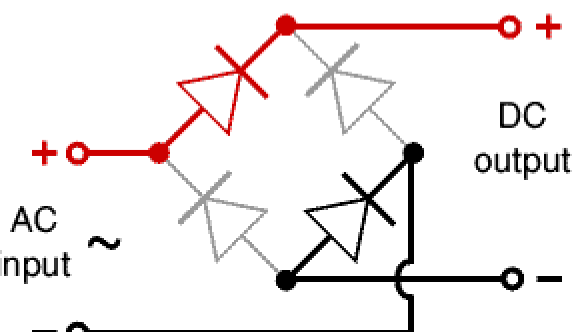


Bridge Rectifiers

- A bridge rectifier is a packages that contains four diodes that is designed as a rectifier circuit for a power supply
- They have four leads: 2 DC outputs (+ & -) and 2 AC inputs (~)
- Bridge rectifiers are rated by their maximum current and maximum reverse voltage



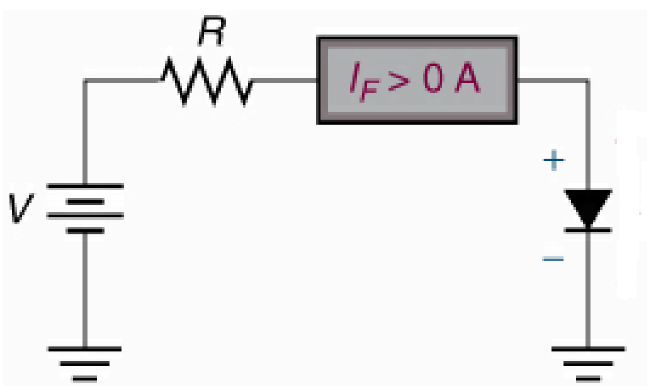


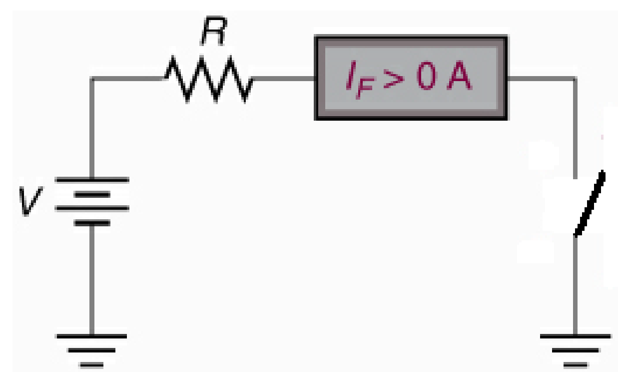


Diode Models - Ideal

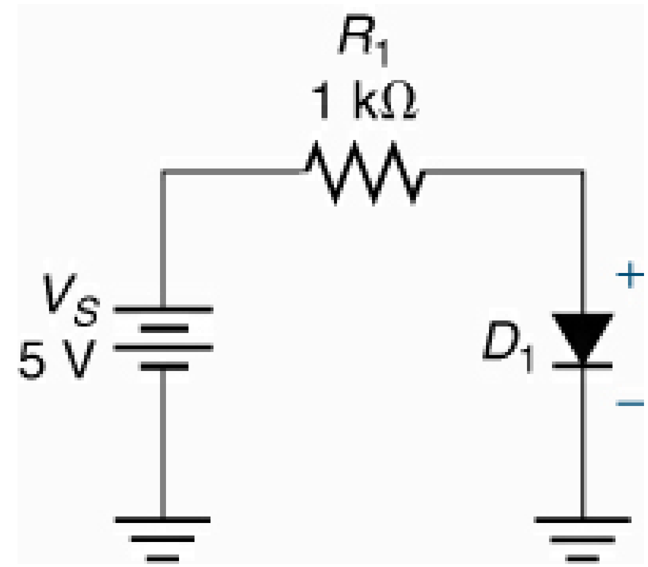
This model simulates the diode as a switch

- Open – No current flow, full voltage across the diode
- Closed – Maximum current flow, no voltage drop across the diode





Diode Models - Ideal



Example 1

Given

Vs = 5 V

R_1 = 1 K ohms

D_1 = Silicone

Find

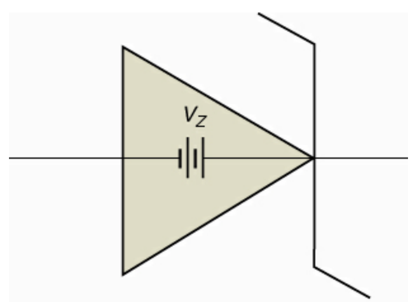
I_{R1} = ______________ I_{D1} = ______________

V_{R1} = ______________ V_{D1} = ______________

Diode Models - Practical

This model simulates the diode and takes into account the voltage drop of the diode (0.7 or 0.3) when in forward bias

- Forward Bias – Maximum current flow, 0.7 voltage drop across the diode
- Reverse Bias – No current flow, full voltage across the diode



Diode Models - Practical

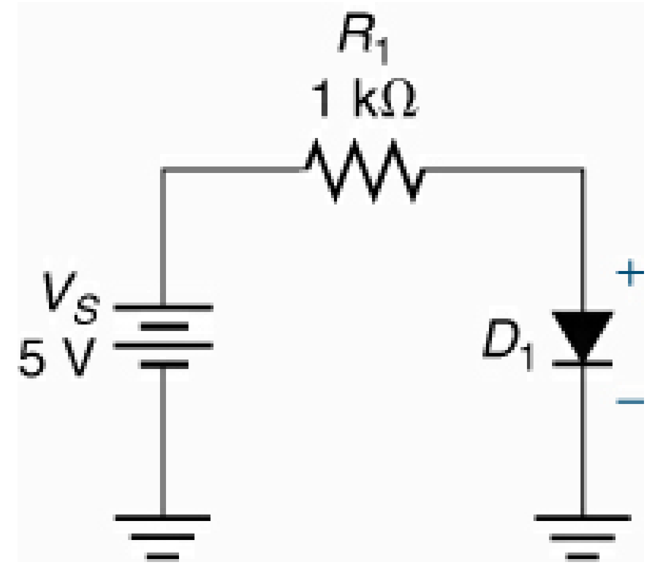
Example 1

Given

Vs = 5 V

R_1 = 1 K ohms

D_1 = Silicone



Find

I_{R1} = ______________ I_{D1} = ______________

V_{R1} = ______________ V_{D1} = ______________

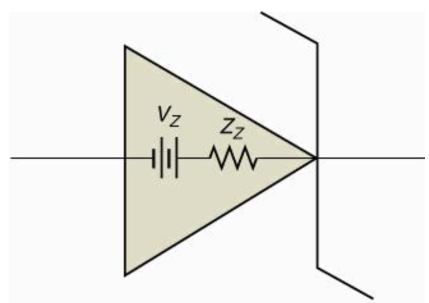
Diode Models - Practical

1. Determine if the diode is in forward or reverse bias
2. If in reverse bias – there will be no current flow and the diode will act like an open switch
3. If in forward bias
    1. Treat the diode as a component that has a set voltage drop across it at all time (0.7 silicone or 0.3 germanium)
    2. Simplify the circuit resistors down to one resistor
    3. Solve for the total current by subtracting the diode voltage from the power supply voltage
    4. Calculate the voltages across each resistor

Diode Models - Complete

This model simulates the diode and takes into account the voltage drop of the diode (0.7 or 0.3) when in forward bias and the internal resistance of the diode in the circuit (bulk resistance)

- Forward Bias – Maximum current flow, 0.7 voltage drop across the diode and diode bulk resistance
- Reverse Bias – No current flow, full voltage across the diode

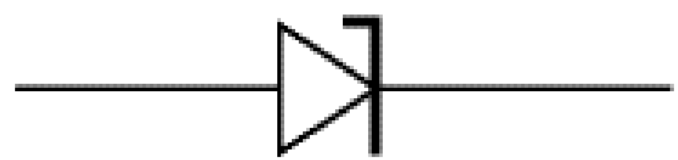


Diode Specifications

1. Diode Type – Silicone or Germanium
2. Peak Reverse Voltage (V_{RSM}) – The maximum voltage (peak) that can be applied to the diode one time
3. Peak Repetitive Reverse Voltage (V_{RRM}) – The maximum voltage (peak) that can be applied to the diode multiple times
4. Average Forward Current (I_O) – The maximum continuous DC current passing through the diode in forward bias
5. Peak Surge Current (I_{FSM}) – The maximum one time DC current passing through the diode in forward bias
6. Forward Power Dissipation (P_{DMax}) – The maximum forward DC power dissipation
7. Operating (T_J)and Storage Temperatures (T_{STG})- The minimum and maximum temperature ranges that the diode will function with the given specifications

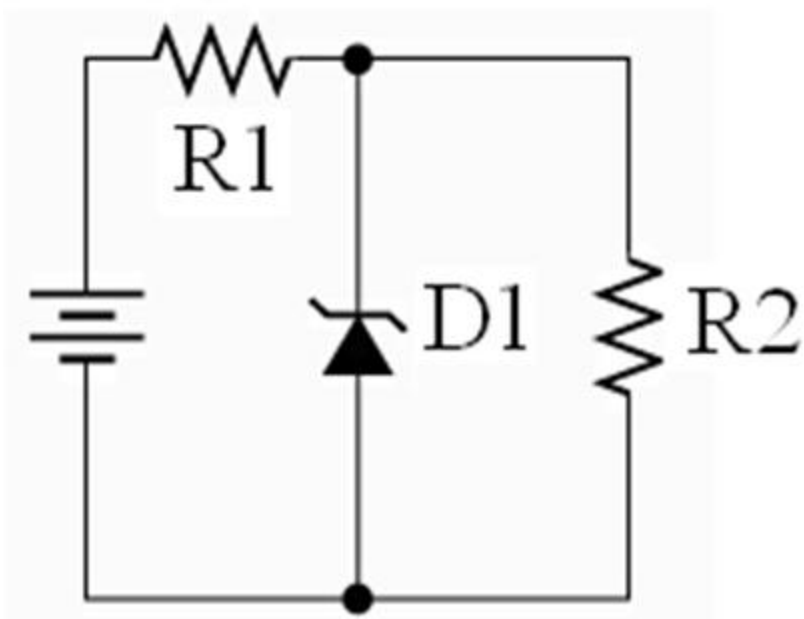
Zener Diodes

- Zener diodes are used to maintain a fixed voltage
- They are used in reverse bias rather than forward bias
- Zener diodes are rated by their reverse breakdown voltage and maximum power (watts)



Zener Diodes

1. The diode must be in reverse bias with a minimum of 2 other resistors
2. The DC supply must be larger that the zener voltage rating



Zener Diodes

3. Solve Circuit
   1. What ever the voltage rating is of the zener, apply this voltage to R_2
   2. Calculate the current through R_2 (diode voltage / resistor value)
   3. Calculate the current through R_1 by subtracting the diode voltage from the power supply (power supply – diode voltage)/ R_1
   4. The current in R_1 must be greater that the current through R_2
   5. Calculate the current through the Diode = (R_1 Current – R_2 Current)
   6. Calculate the zener power rating by multiplying the current through the diode by the zener voltage rating

Zener Diodes

Example 1

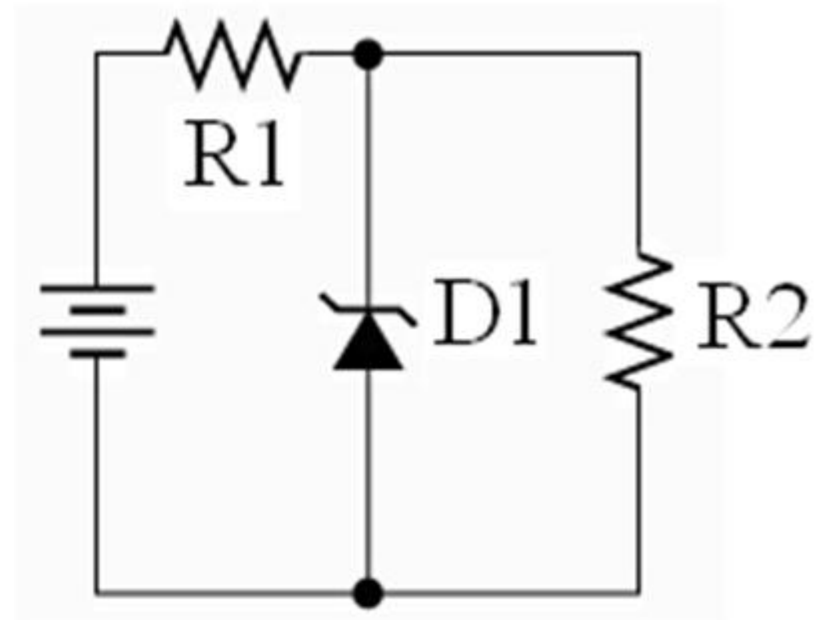
Given

Vcc = 12 V

R_1 = 1.2 K ohms

R_2 = 33 K ohms

D_1 = 5.6 Volts



Find

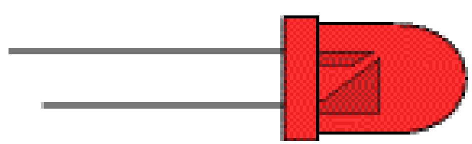
I_{R2} = ________________ I_{R1} = ________________

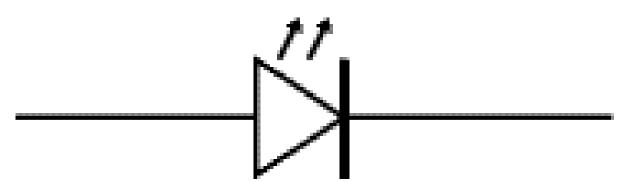
V_{R2} = ________________ V_{R1} = ________________

I_{D1} = ________________ P_{D1} = ________________

Light Emitting Diode (LED)

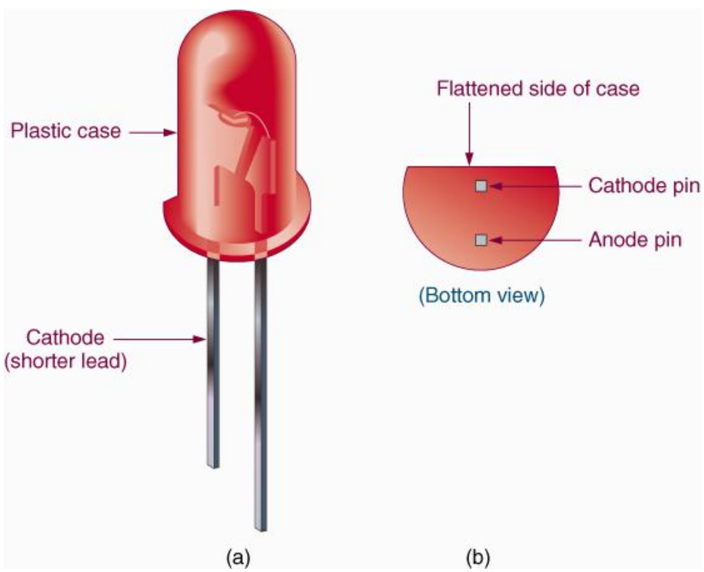
- LEDs emit light when an electric current passes through it
- LEDs must be connected in forward bias, the same as a rectifier diode
- LEDs will have an Forward Voltage rating and a maximum current limit
- The current through the LED will control the light intensity

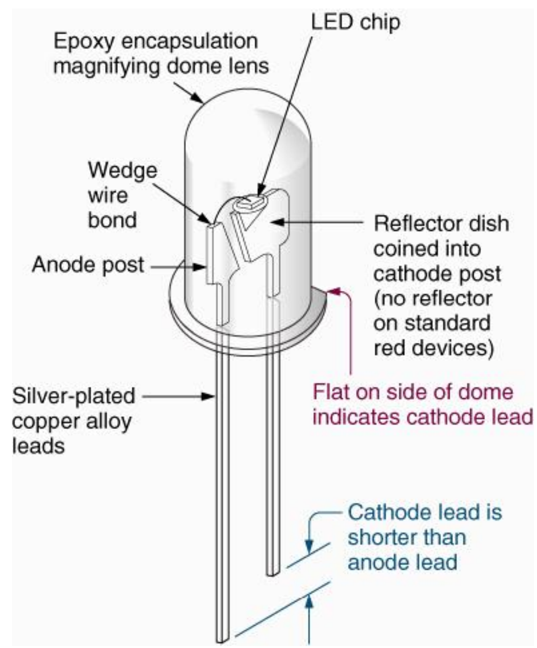




Light Emitting Diode (LED)

- LEDs will have a cathode (-) and anode (+) connections the same as other diodes
- They must be placed in forward bias to generate light



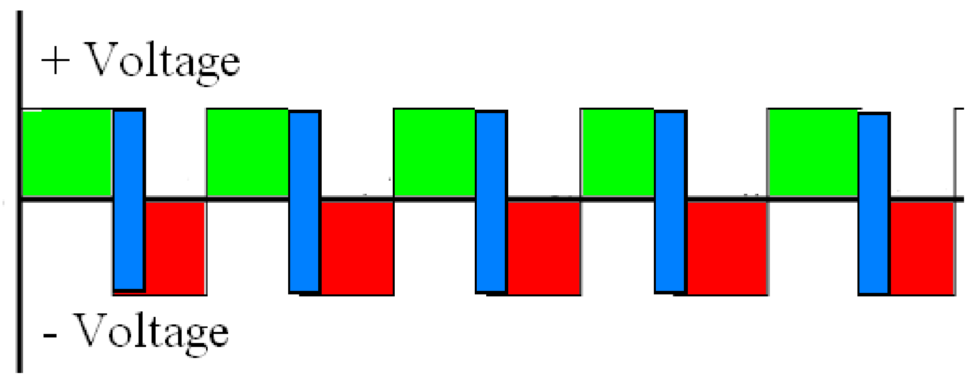


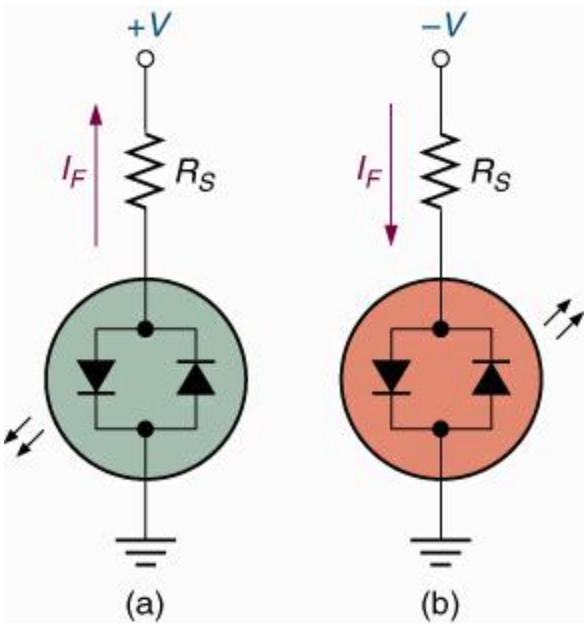
Light Emitting Diode (LED)

- For most applications, LEDs must have a series resistor to control the current (light brightness) of the diode and prevent it from exceeding the maximum current rating
- The maximum current rating of the LED will provide the maximum brightness
- By reducing the current through the diode, the diode brightness will be reduced
  - 100% brightness = max current rating
  - 50% brightness = 50% max current rating

Light Emitting Diode (LED)

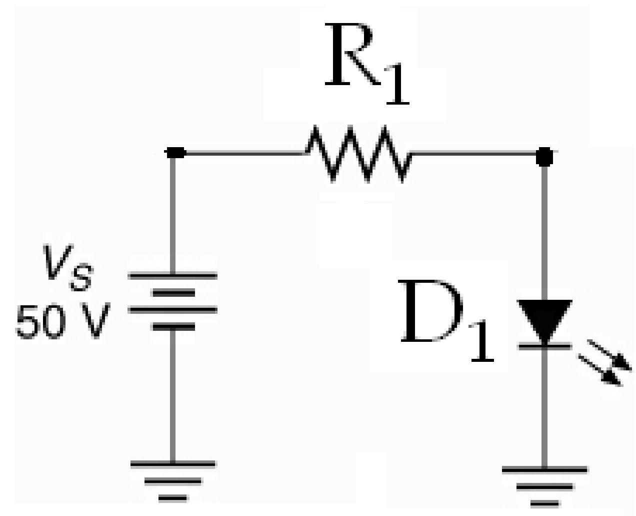
- Some LEDs can produce 2 different colors of light and if pulsed, can create a 3rd color
- Example of a multi-color LED
  - Bias in one direction creates GREEN
  - Bias in the other direction creates RED
  - Pulsing the diode creates a BLUE





Light Emitting Diode (LED)

Example 1



Given

Vs = 50 V

D_1 = 2.3 Volts @ 35 ma (max)

Find

R_1 = ______________ Full Brightness

R_1 = ______________ 1/2 Brightness

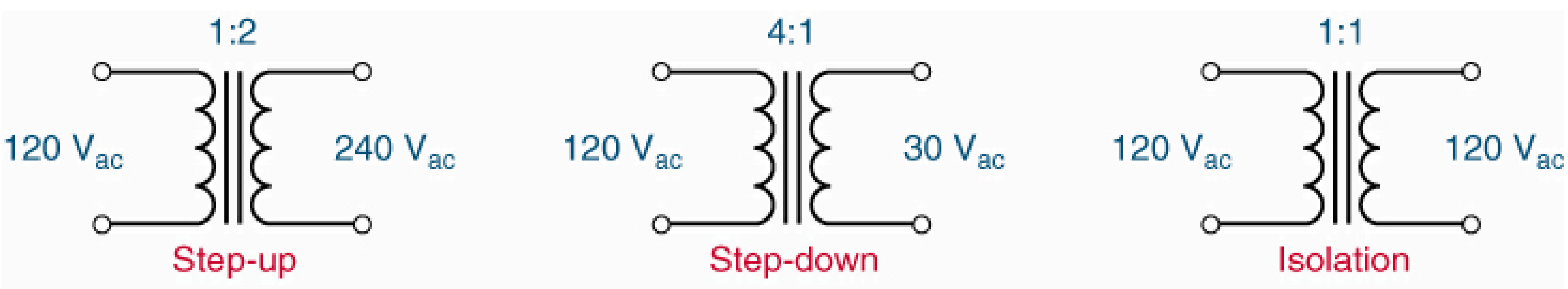
R_1 = ______________ 1/3 Brightness

Power Supplies

Transformer

There are three basic types of power transformers

- Step-Up – This is when the input voltage to the primary is increased on the secondary winding (output)
- Step-Down – This is when the input voltage to the primary is decreased on the secondary winding (output)
- Isolation – This is when the input voltage to the primary is the same on the secondary winding (output)

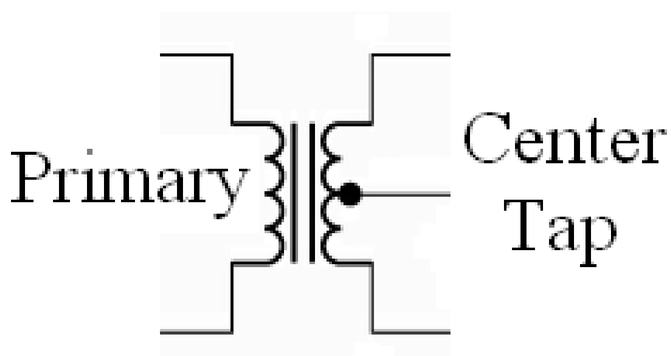


Transformer

Center Tap Transformers have three (3) leads on the secondary and are commonly used for power supplies

The turns ratio is for the outside windings, with the third connection in the center

The voltage from the center tap to one secondary lead is ½ the voltage of the secondary



Transformer

- Another type of transformer used in high voltage power supplies is called a flyback transformer
- Flyback transformers are a step-up transformer, but their turns ratio for stepping up the voltage is very high
- The current on the secondary is very low
- They normally have a unique shape like a "C" with the large winding in the middle
- They may also be connected directly to CRT anodes

Transformer

Voltage, Current and Power Relationships

- Step-Up
  - Low voltage & high current on primary winding
  - High voltage & low current on the secondary winding
  - $POWER_{in} = POWER_{out}$
- Step-Down
  - High voltage & low current on primary winding
  - Low voltage & high current on the secondary winding
  - $POWER_{in} = POWER_{out}$
- Isolation
  - Voltage & current on primary winding is the same as the secondary winding
  - $POWER_{in} = POWER_{out}$

Transformer

Transformer power in must always equal power out

Transformers change the voltage and current from the primary to the secondary by the ratio of the windings

The formula for making the calculations is:

$$N_2 / N_1 \quad = \quad V_2 / V_1$$

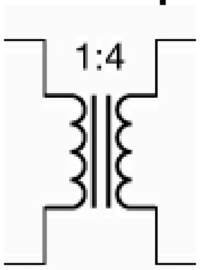
N is the number of turns of wire

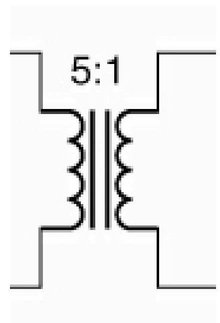
In most cases, the turns ration is expressed with one side being a 1 and the other the ratio

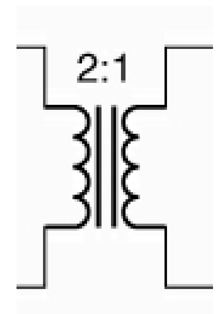
Hint: The side of the ratio that has the larger number has the larger voltage or the side that has more turns has the higher voltage

Transformer

Examples







Given

1:4 Ratio

$V_{Pri} = 120\ V_{RMS}$

Find

V_{Sec} = __________

Given

5:1 Ratio

$V_{Pri} = 120\ V_{RMS}$

Find

V_{Sec} = __________

Given

2:1 Ratio

$V_{Pri} = 120\ V_{RMS}$

Find

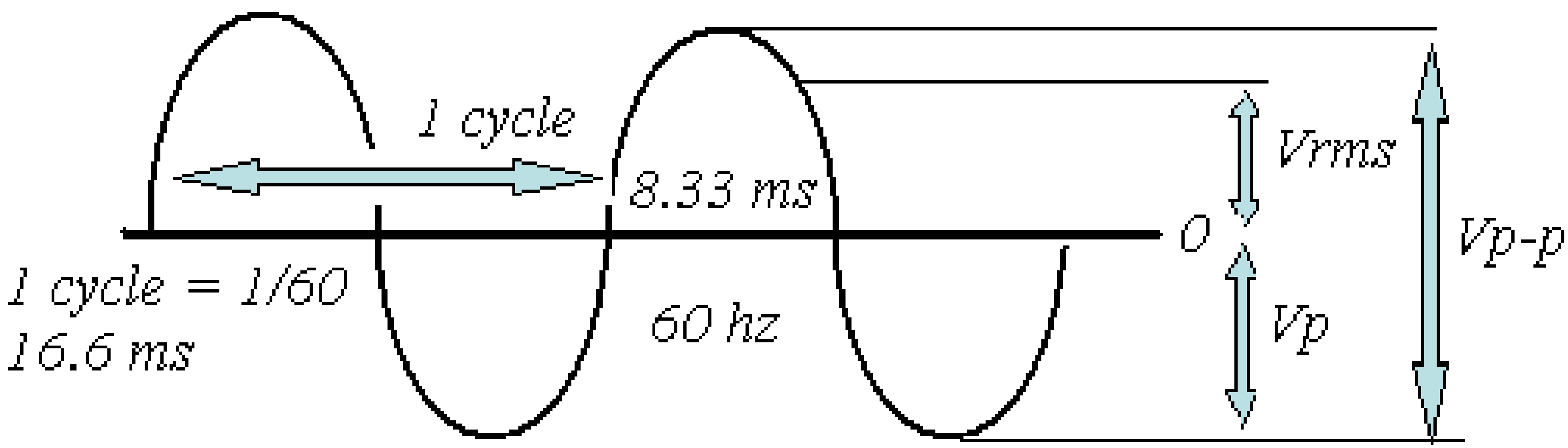
V_{Sec} = __________

AC Voltage Conversions

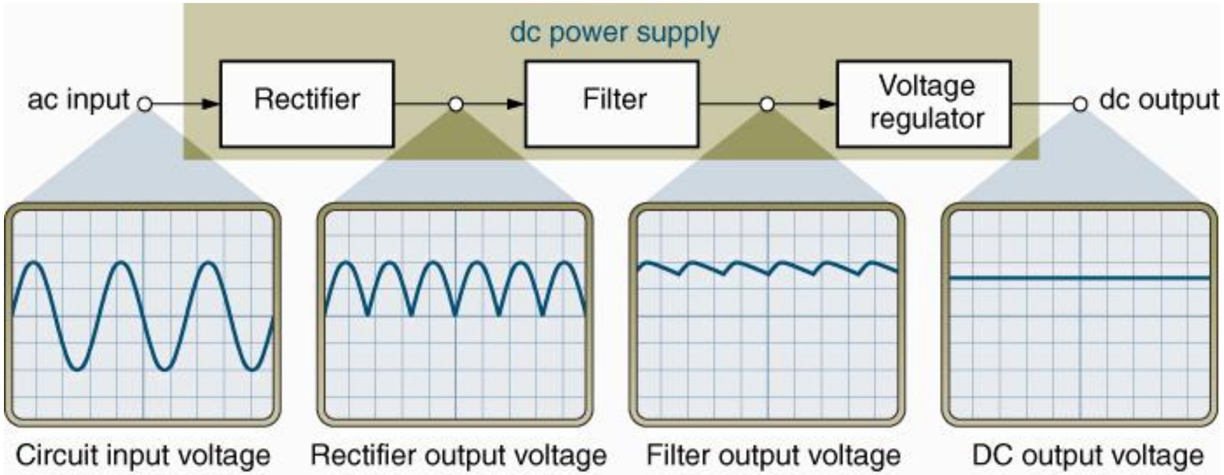
Root Mean Squared (RMS) = V_P X 0.707

Peak Voltage = V_{RMS} X 1.414

Peak-Peak Voltage (V_{PP}) = V_P X 2

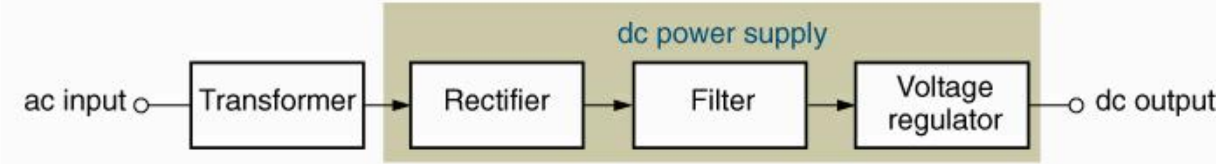


Linear DC Power Supply



Basic power supply block diagram and waveforms

(a)



Basic power supply with a transformer input

(b)

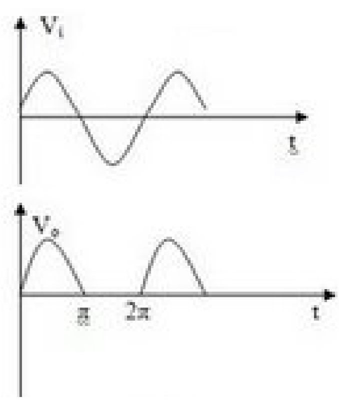
Half Wave Power Supply

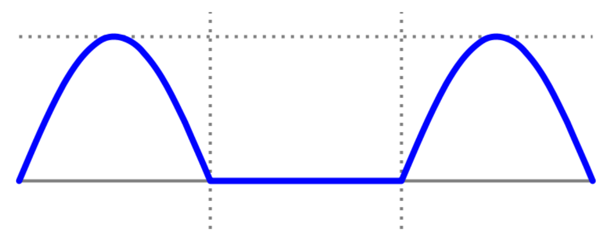
Input power is 120V @ 60 Hz Sine Wave

A half wave rectifier will convert AC voltage to DC

The diode will be forwarded biased only one half of the sine waveform

The output voltage will have either the positive or negative portion of the wave, based upon diode direction

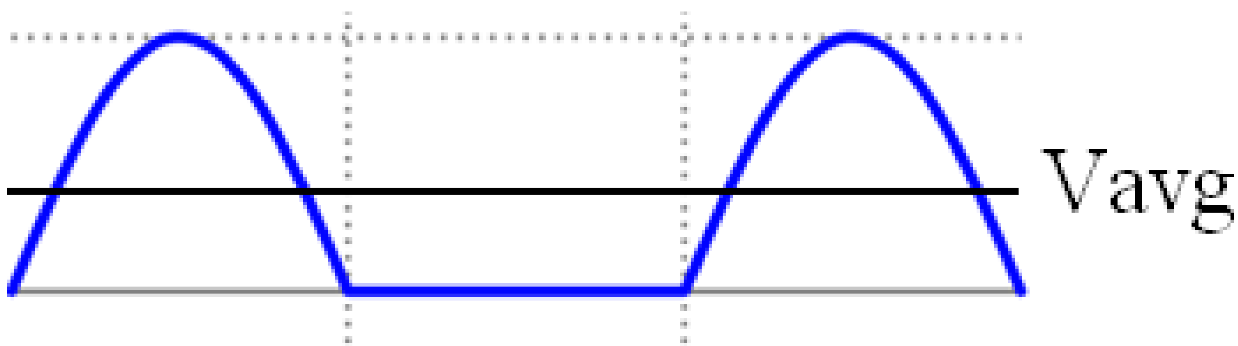




Half Wave Power Supply

The factor for calculating the average DC voltage is:

Peak Voltage multiplied by DC factor of 0.318

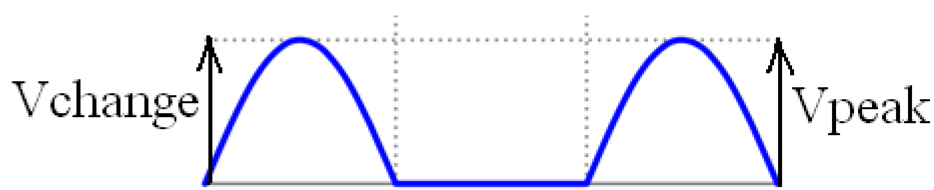


Half Wave Power Supply

The pulses may appear to be AC voltage, but the current is only moving in one direction, so the diode (or rectifier) converts the AC to DC current

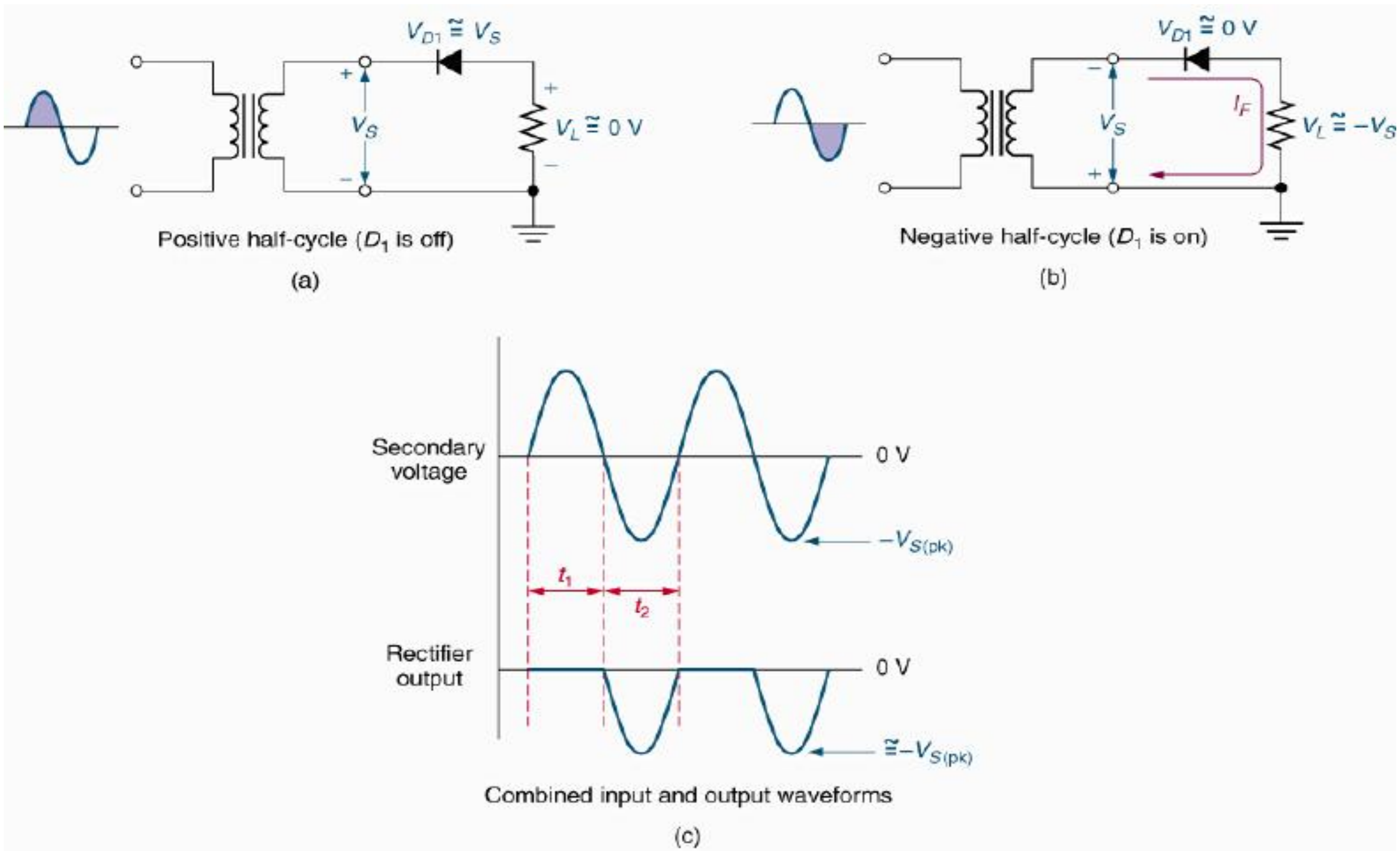
Ripple Voltage is the percentage of variation on the rectified voltage from the peak to the baseline (0V)

Half Wave rectifiers have a 100% ripple voltage



Ripple Voltage = (Vchange / Vpeak) X 100%

Half Wave Power Supply



Full Wave Center Tap Power Supply

Input power is 120V @ 60 Hz Sine Wave

A full wave rectifier will convert AC voltage to DC

Two diodes will be used with a center tap transformer, changing the direction of one sine waveform to the other direction

Twice as many peaks will be created in comparison to the half wave rectifier

The output voltage will have either the positive or negative portion of the wave, based upon diode direction

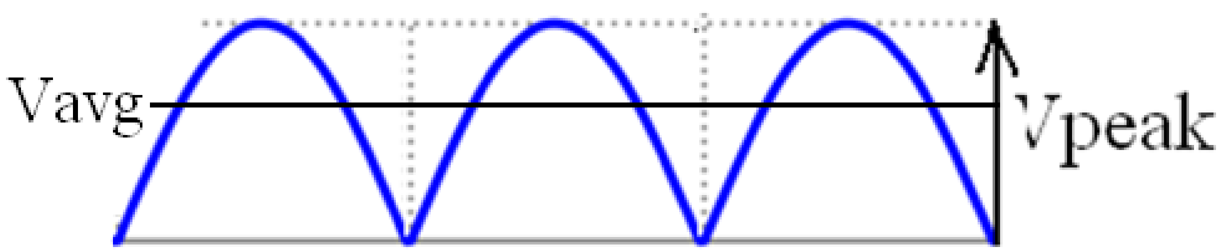
Full Wave Center Tap Power Supply

The center tap transformer will be used from one winding to the center, therefore the voltage on the secondary voltage must be divided by 2

Because there are twice as many pulses as a half wave rectifier circuit, the average DC voltage is increased

The factor for calculating the average DC voltage is:

Peak Voltage multiplied by DC factor of 0.636

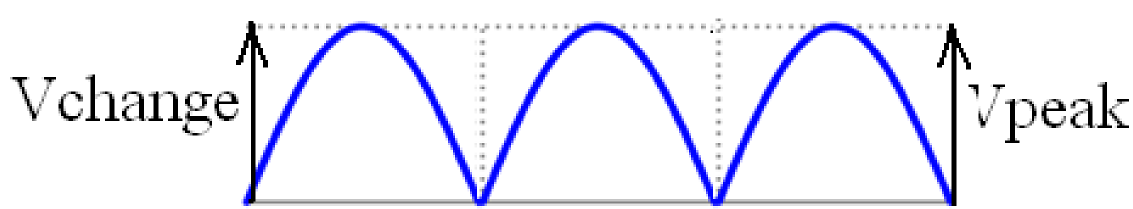


Full Wave Center Tap Power Supply

The pulses may appear to be AC voltage, but the current is only moving in one direction, so the diode (or rectifier) converts the AC to DC current

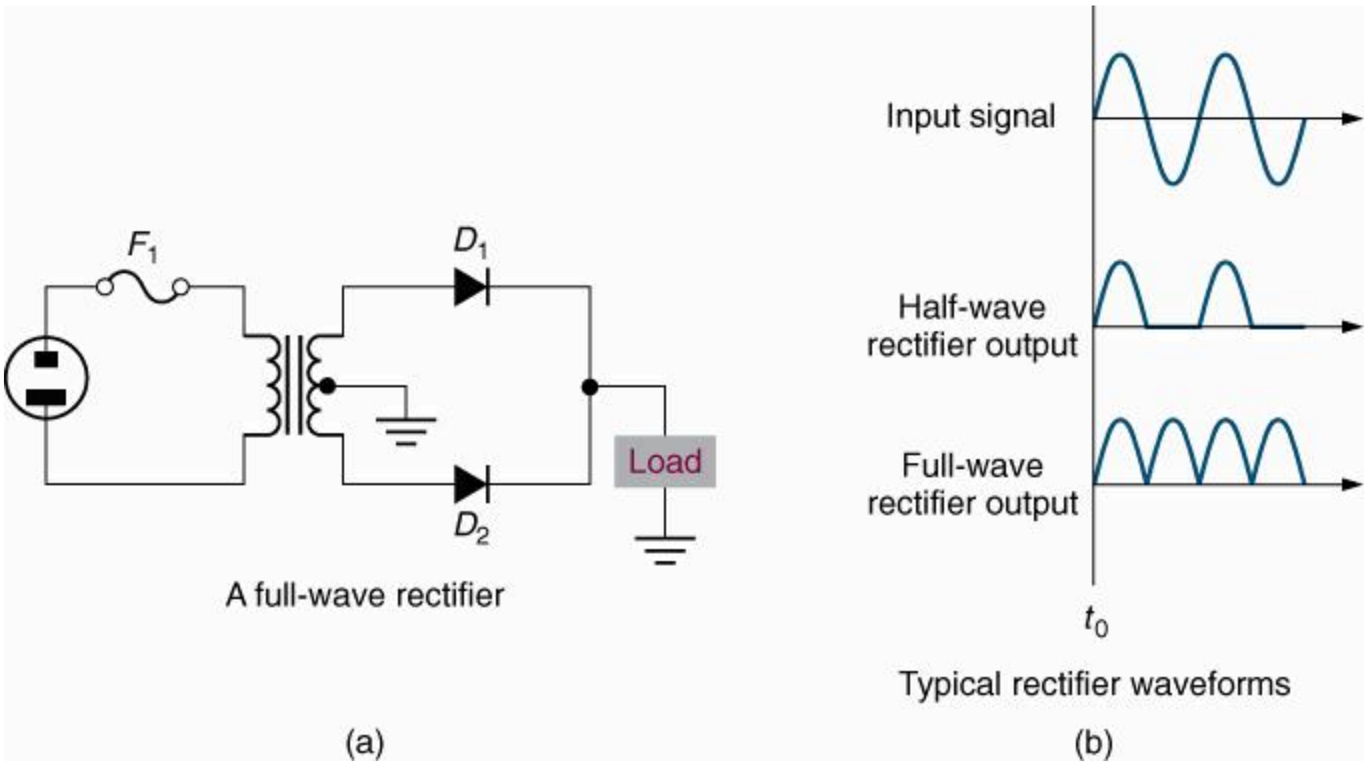
Ripple Voltage is the percentage of variation on the rectified voltage from the peak to the baseline (0V)

Half Wave rectifiers have a 100% ripple voltage

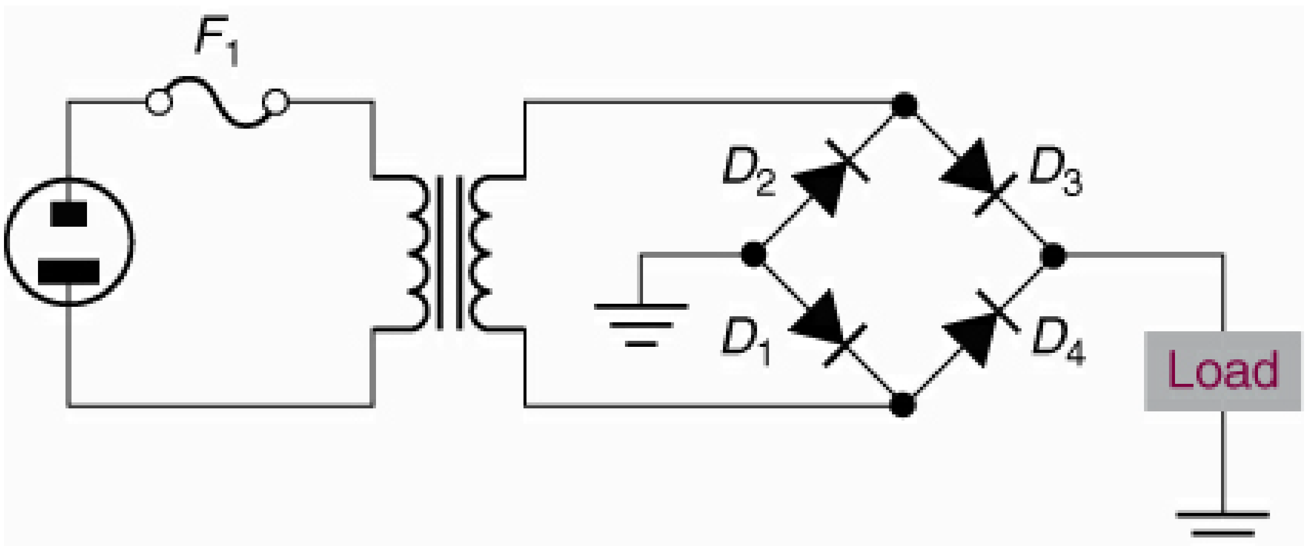


Ripple Voltage = (Vchange / Vpeak) X 100%

Full Wave Center Tap Power Supply



Full Wave Bridge Power Supply



Full Wave Bridge Power Supply

Input power is 120V @ 60 Hz Sine Wave

A full wave rectifier will convert AC voltage to DC

Four (4) diodes will be used with a transformer, changing the direction of one sine waveform to the other direction

Twice as many peaks will be created in comparison to the half wave rectifier

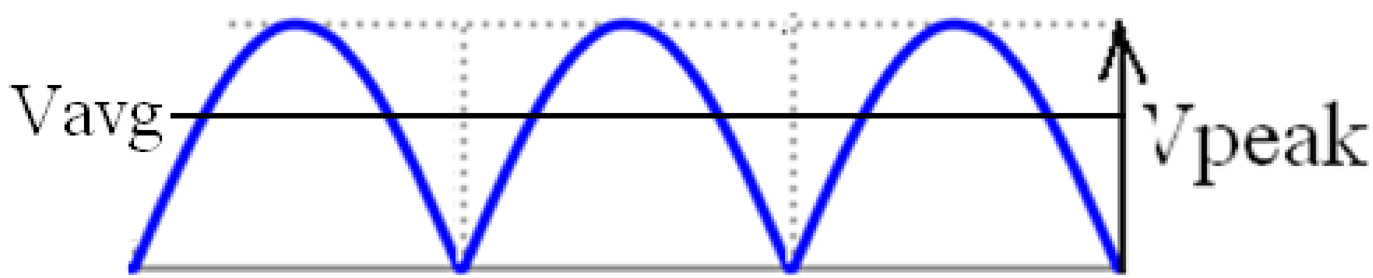
The output voltage will have either the positive or negative portion of the wave, based upon diode direction

Full Wave Bridge Power Supply

Because there are twice as many pulses as a half wave rectifier circuit, the average DC voltage is increased

The factor for calculating the average DC voltage is:

Peak Voltage multiplied by DC factor of 0.636

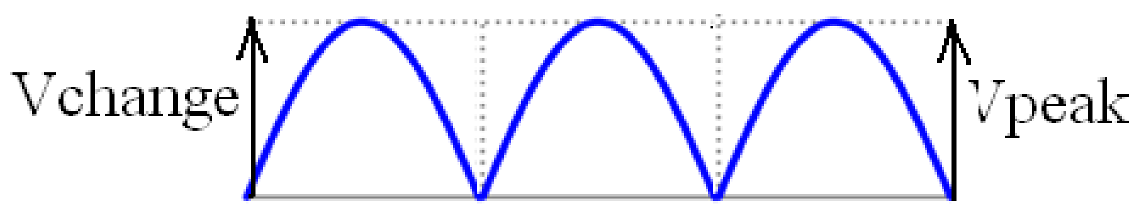


Full Wave Bridge Power Supply

The pulses may appear to be AC voltage, but the current is only moving in one direction, so the diode (or rectifier) converts the AC to DC current

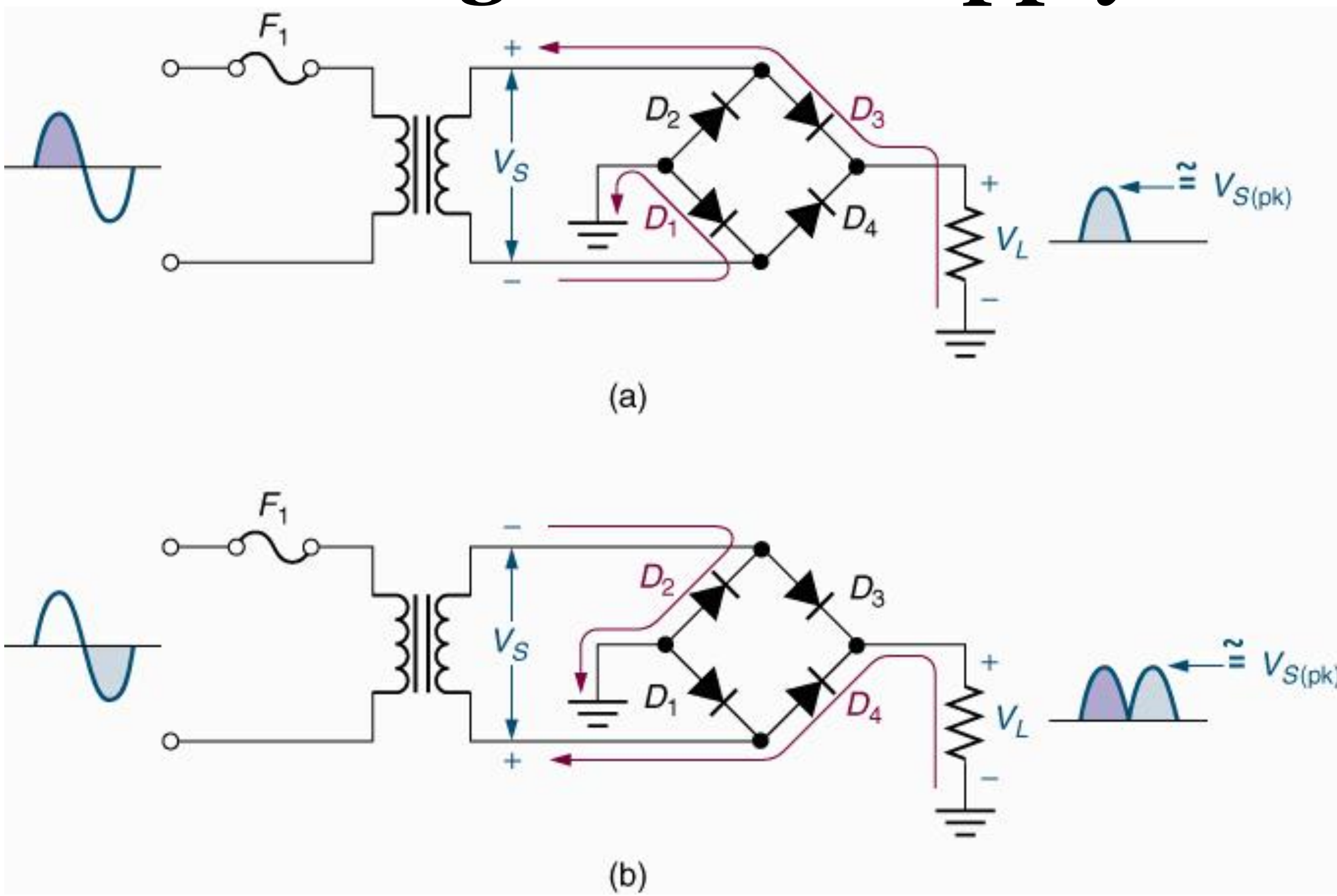
Ripple Voltage is the percentage of variation on the rectified voltage from the peak to the baseline (0V)

Half Wave rectifiers have a 100% ripple voltage



Ripple Voltage = (Vchange / Vpeak) X 100%

Full Wave Bridge Power Supply



Filtration

Filtration is used to reduce the ripple voltage on a DC power supply

Large amplitudes of ripple voltage can cause interferences and noise to sensitivity electronic circuits

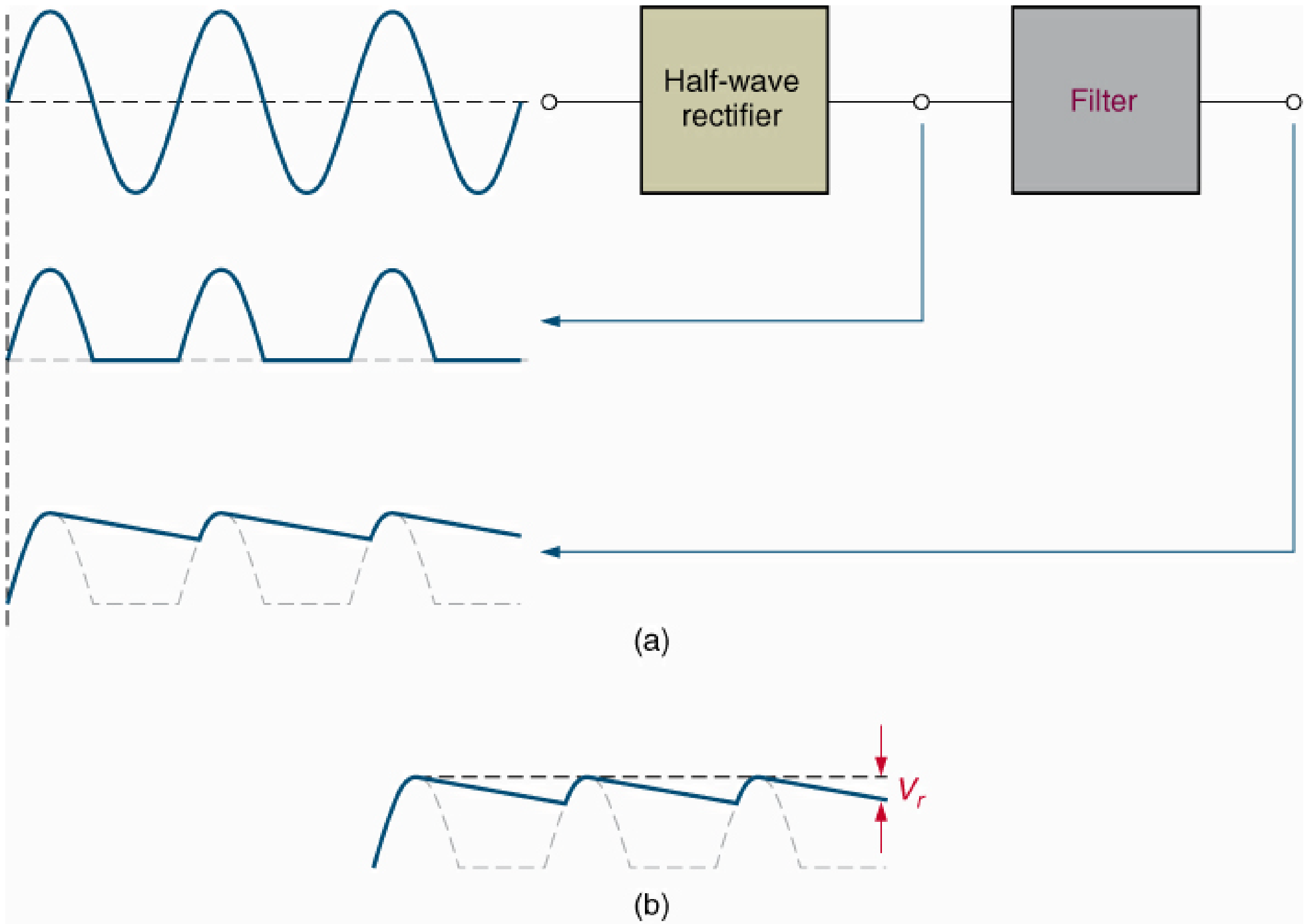
Ideal ripple voltage would be 0%, this is what a DC battery would provide

Filtration

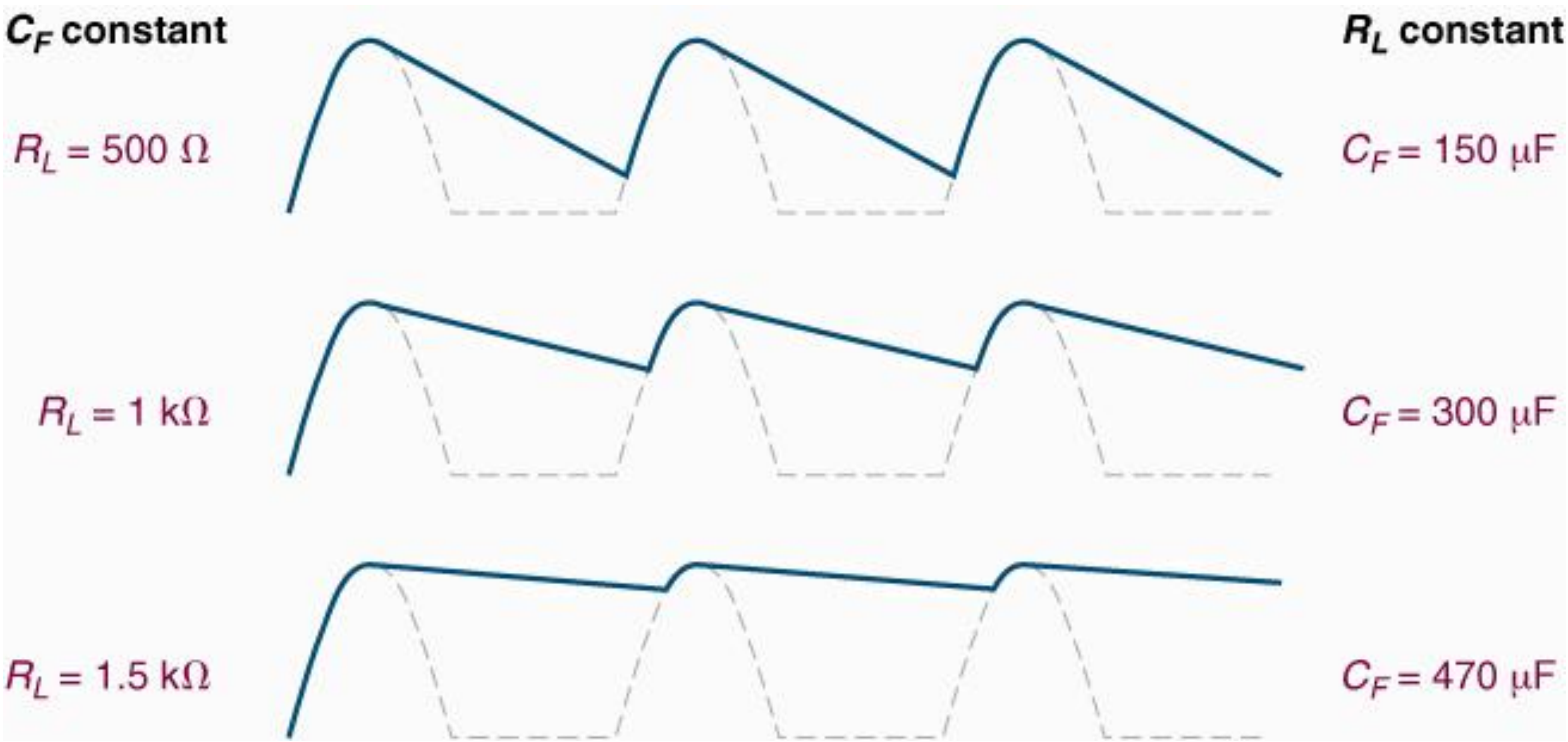
There are several methods and component connections to reduce the ripple voltage, but the use of an electrolytic capacitor(s) is the most common

The capacitor will charge to the peak voltage, then discharge current to "fill in" the space between the peaks

Filtration

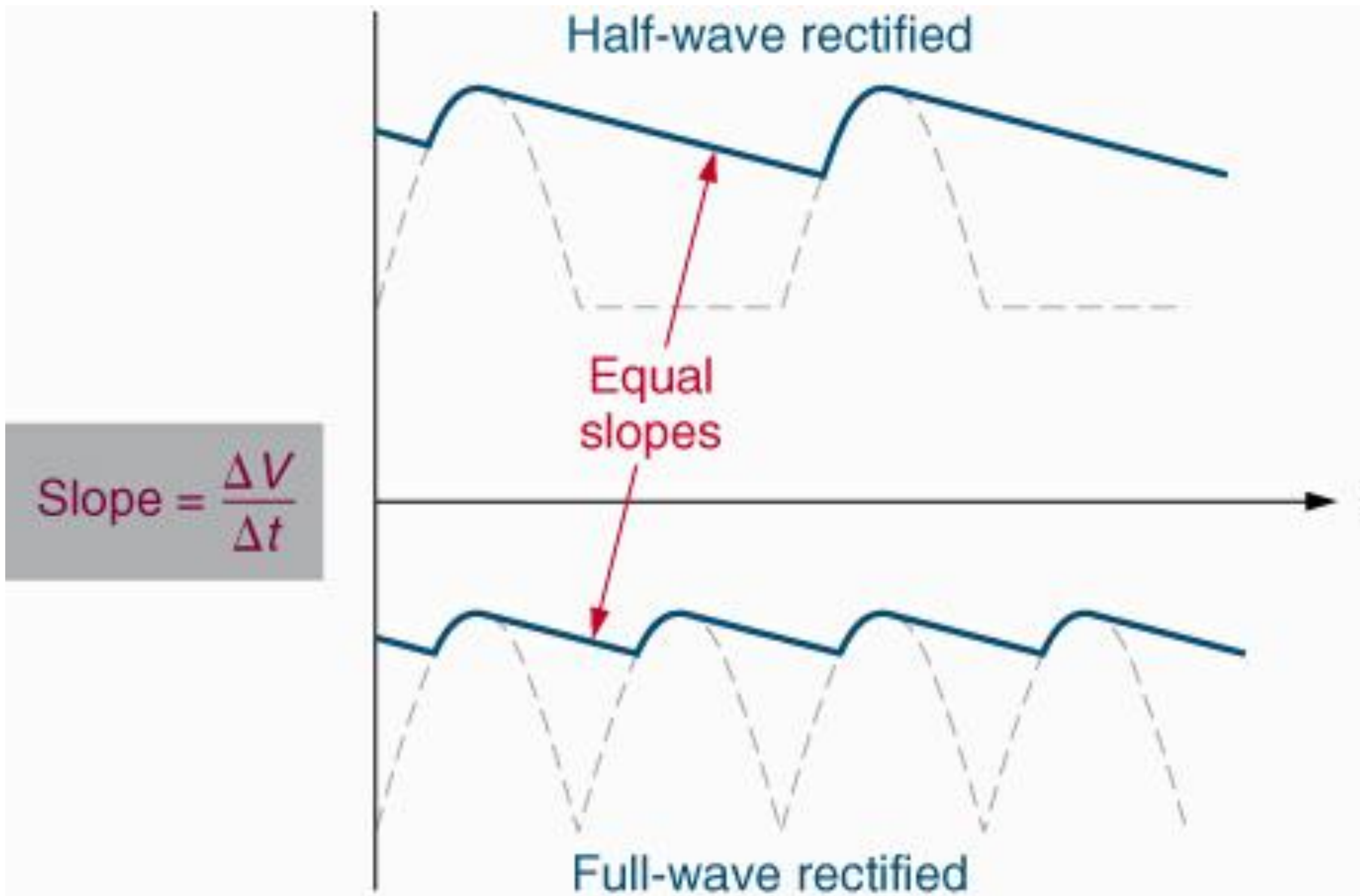


Filtration

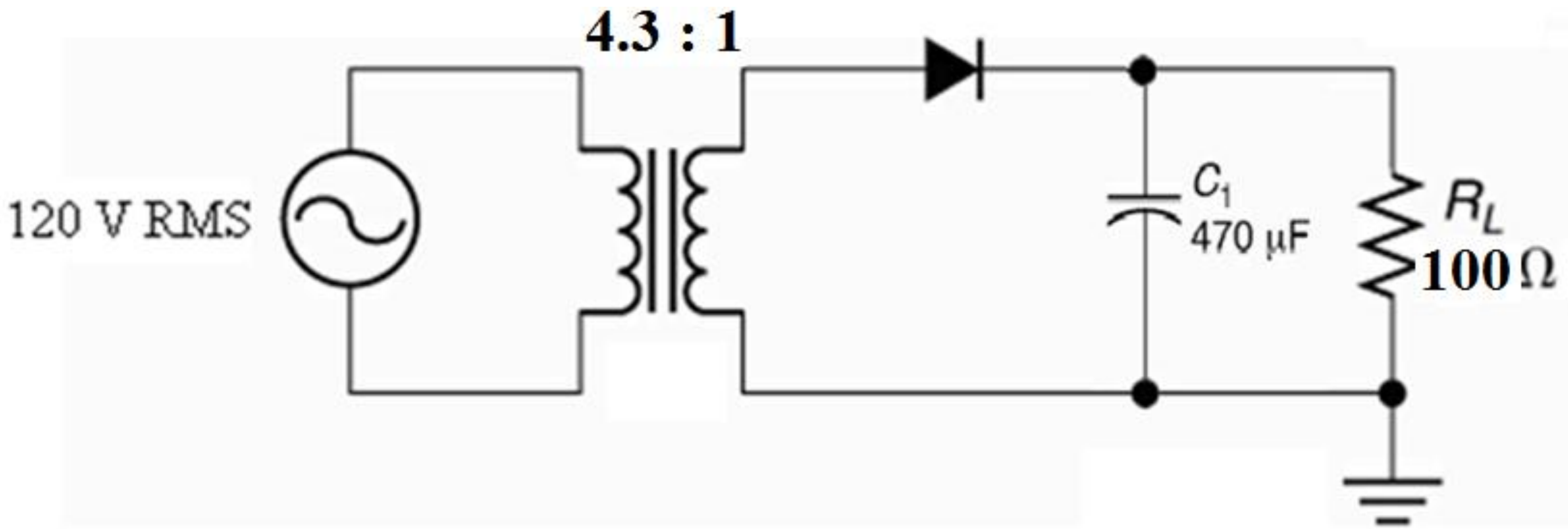


C_F constant
R_L constant
R_L = 500 Ω
C_F = 150 μF
R_L = 1 kΩ
C_F = 300 μF
R_L = 1.5 kΩ
C_F = 470 μF

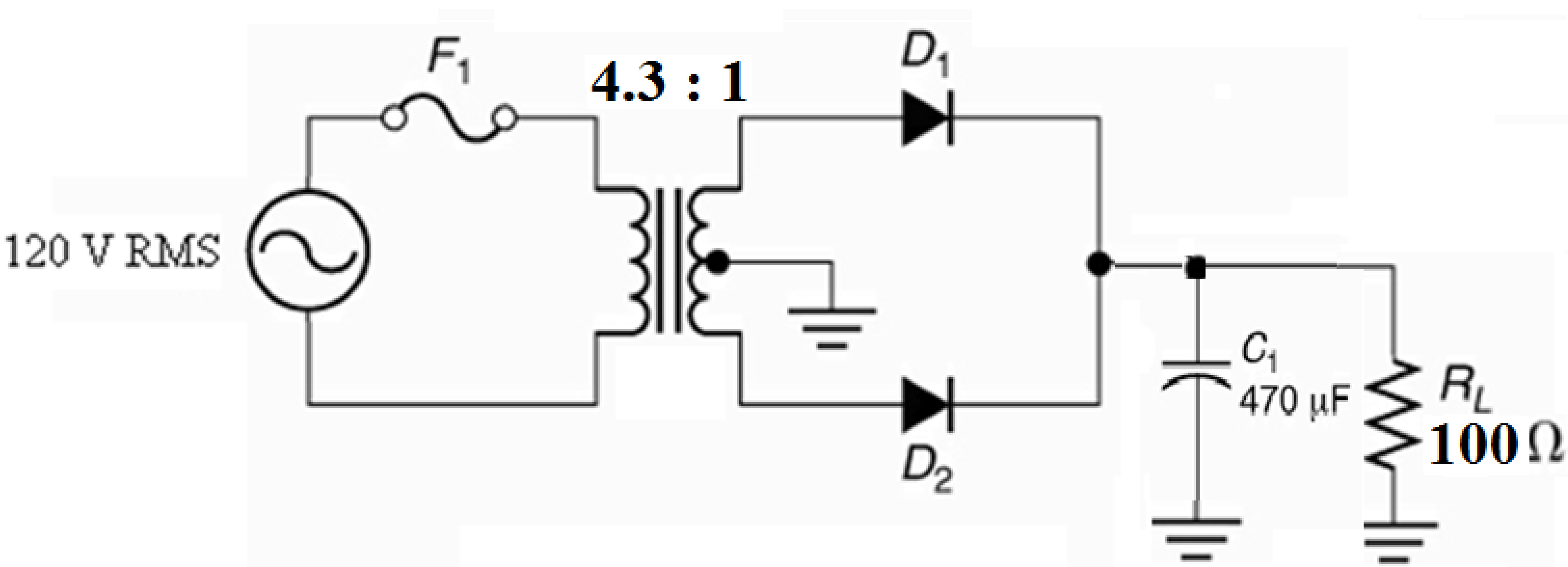
Filtration


Half-wave rectified
Equal slopes
Slope = $\frac{\Delta V}{\Delta t}$
t
Full-wave rectified

Filtration - Half Wave Power Supply



Filtration - Full Wave Center Tap Power Supply



Filtration

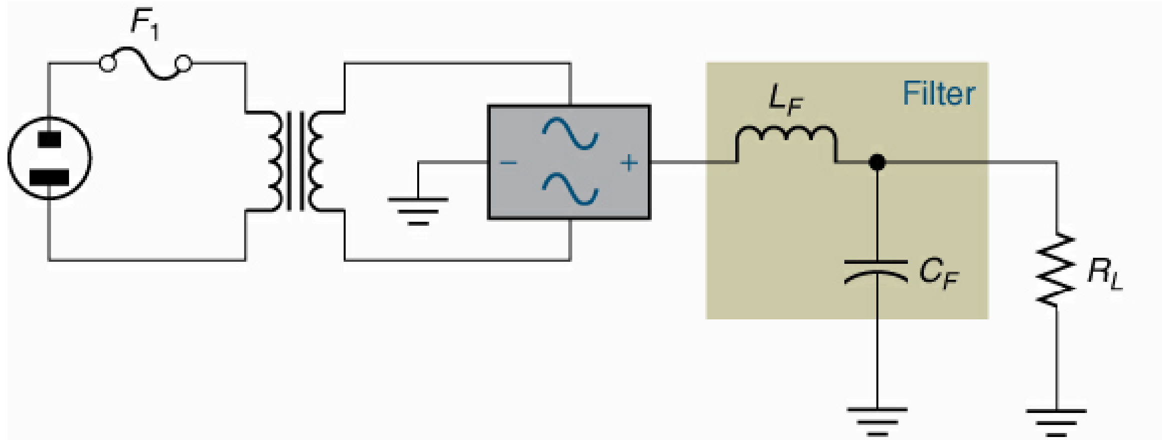
Additional filtering can be achieved by using inductors in series with the laod current

The inductor acts as a low pass filter, only allowing low frequencies to pass

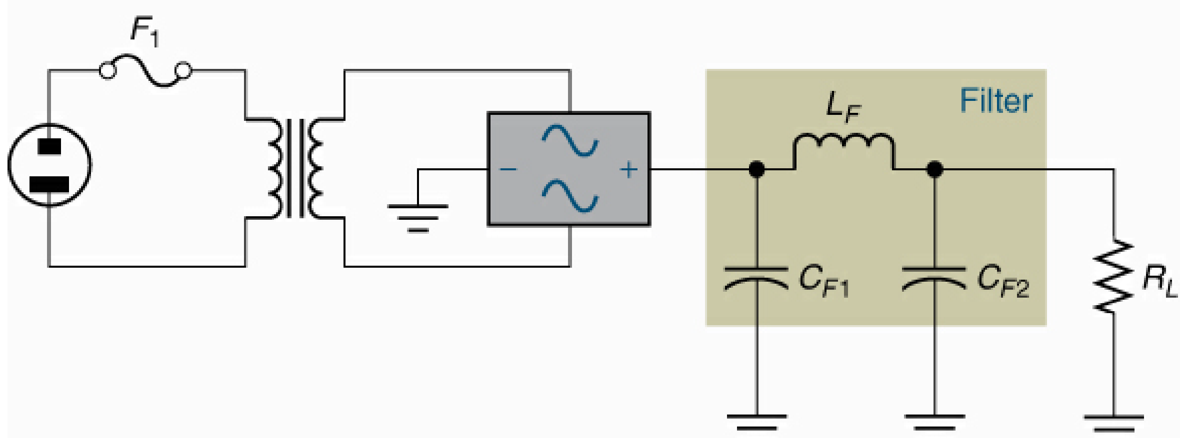
There are:

- L-C Filters (inductor and capacitor)
- L-C Filters (inductor and 2 capacitors)

Filtration



(a) *LC* filter



(b) *LC* π filter

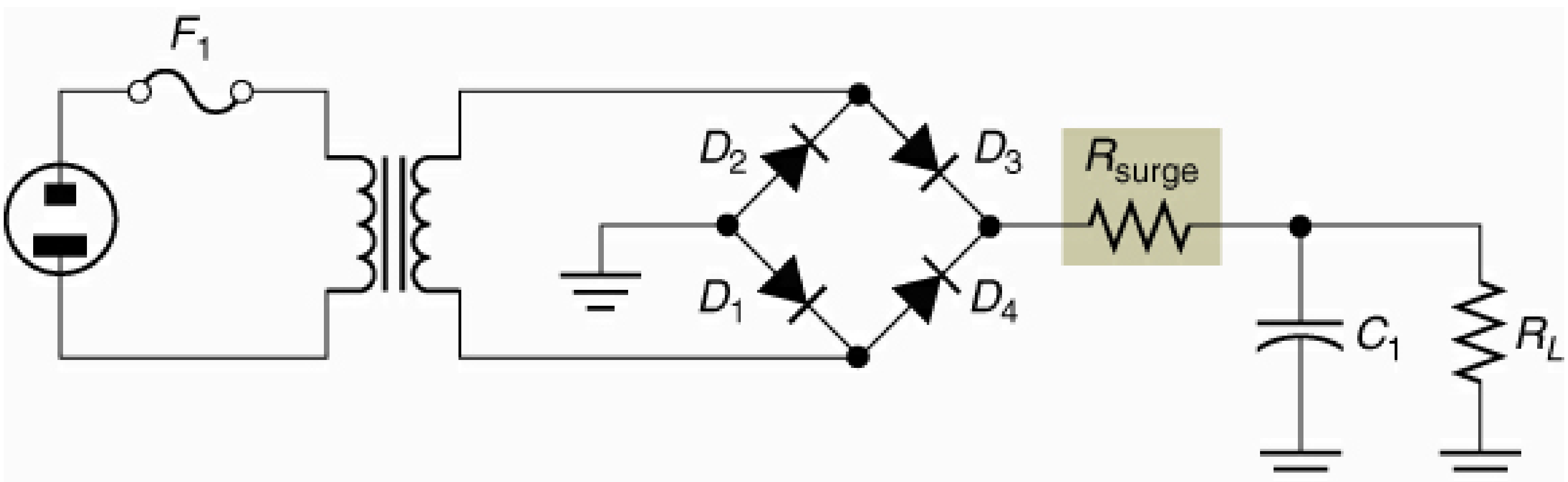
Filtration

When the power supply is first turned on, the filter capacitor must be charged, which can cause a very high in-rush of current

To control the charging current to the filter capacitor, a surge resistor is sometimes used in series

This is a low value of resistance, but must be a high wattage, as all current flows through the resistor

Filtration



Regulation

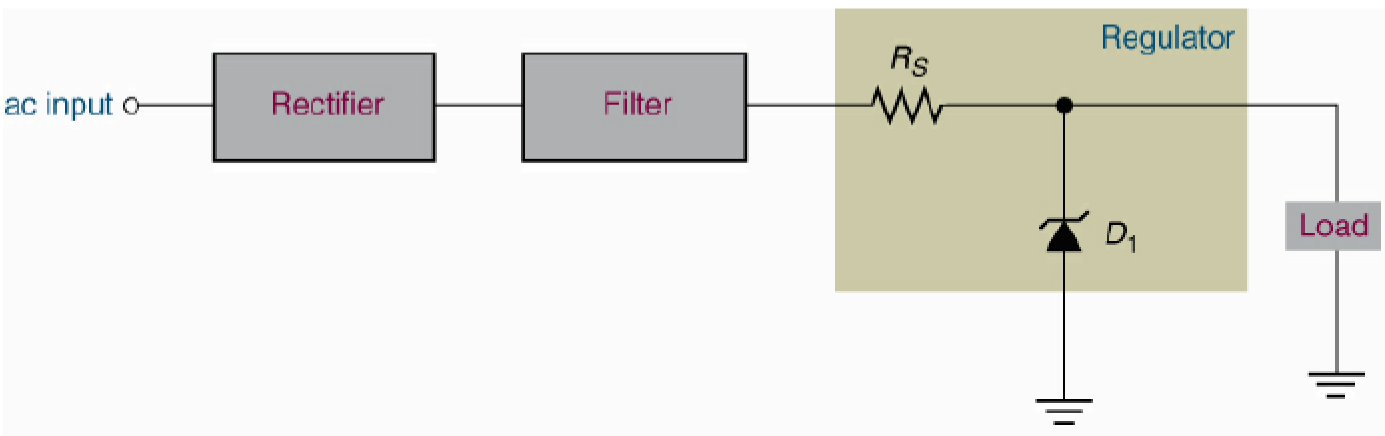
Regulation is the process on maintaining a constant output voltage or current with a changing load

In most cases, voltage is regulated and the load resistance is changed, thus changing the load resistance

The regulated voltage will be held constant, but only within limits of the regulator circuit

Regulation – Zener Diode

The simplest regulator circuit uses the zener diode and a series resistor



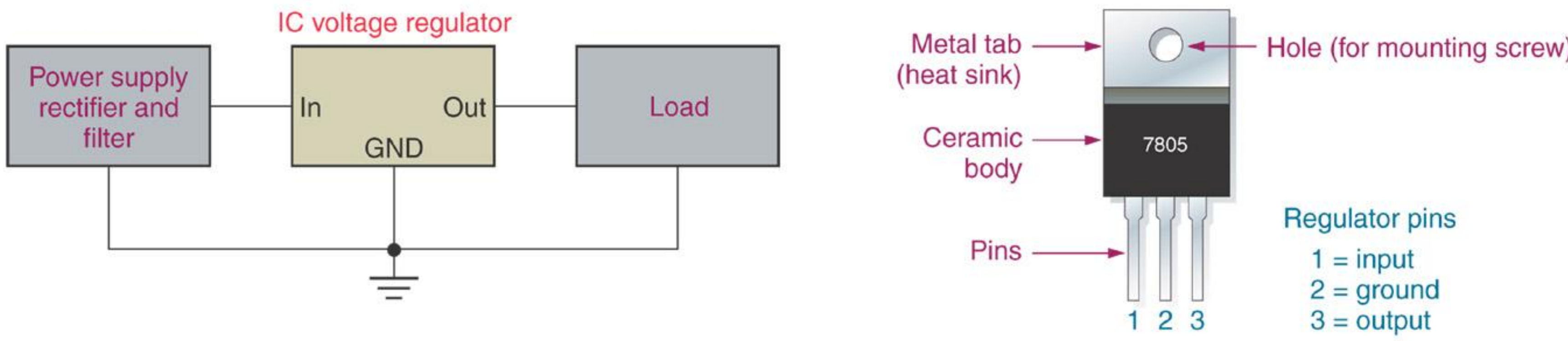
Regulation – Linear

The most common, simplest and best regulator circuit uses an integrated circuit voltage regulator called a linear regulator

These devices have three connections

- Input
- Ground
- Output

Regulation – Linear



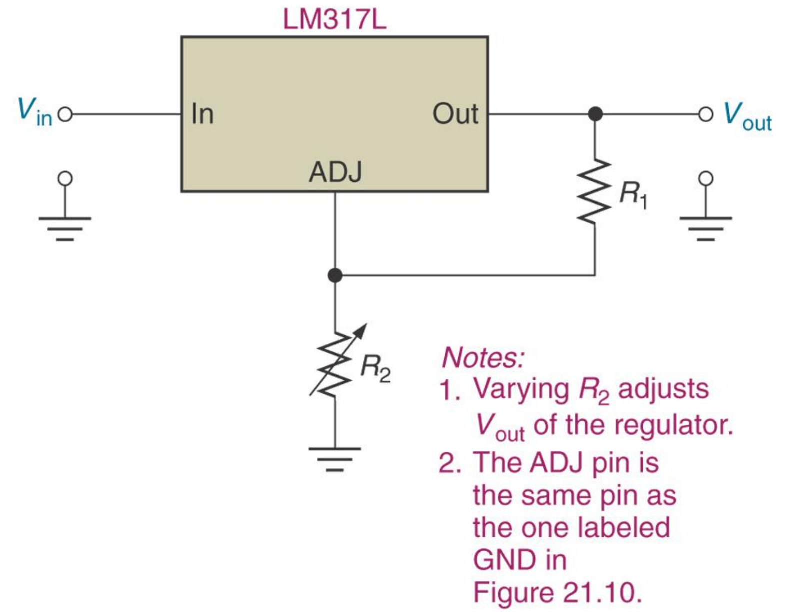
(a) (b)

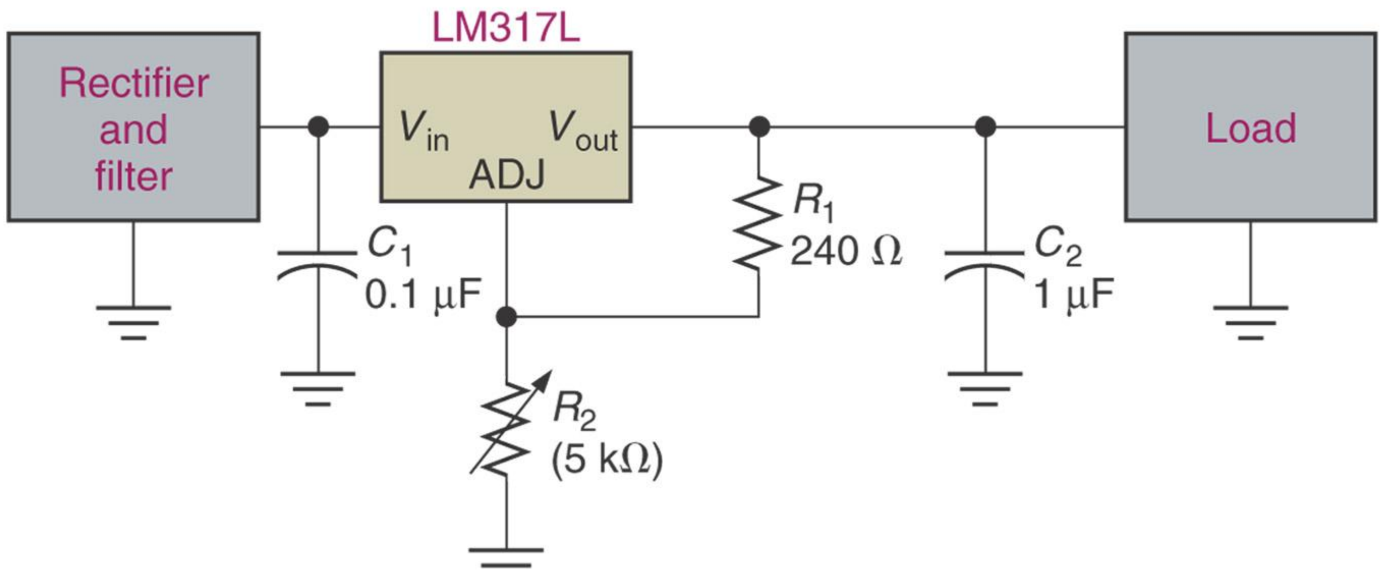
Regulation – Linear

The linear regulators can be for positive or negative supplies

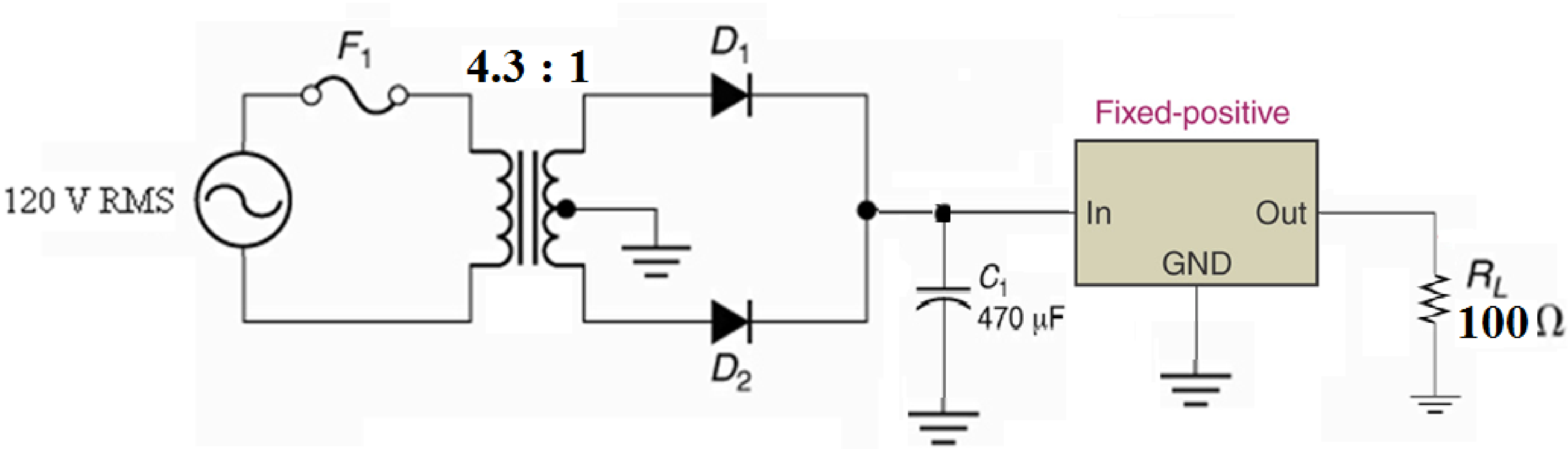
There is also variable voltage liner regulators that use several external components (resistors & variable resistor) so a very specific voltage can be set

Regulation – Linear

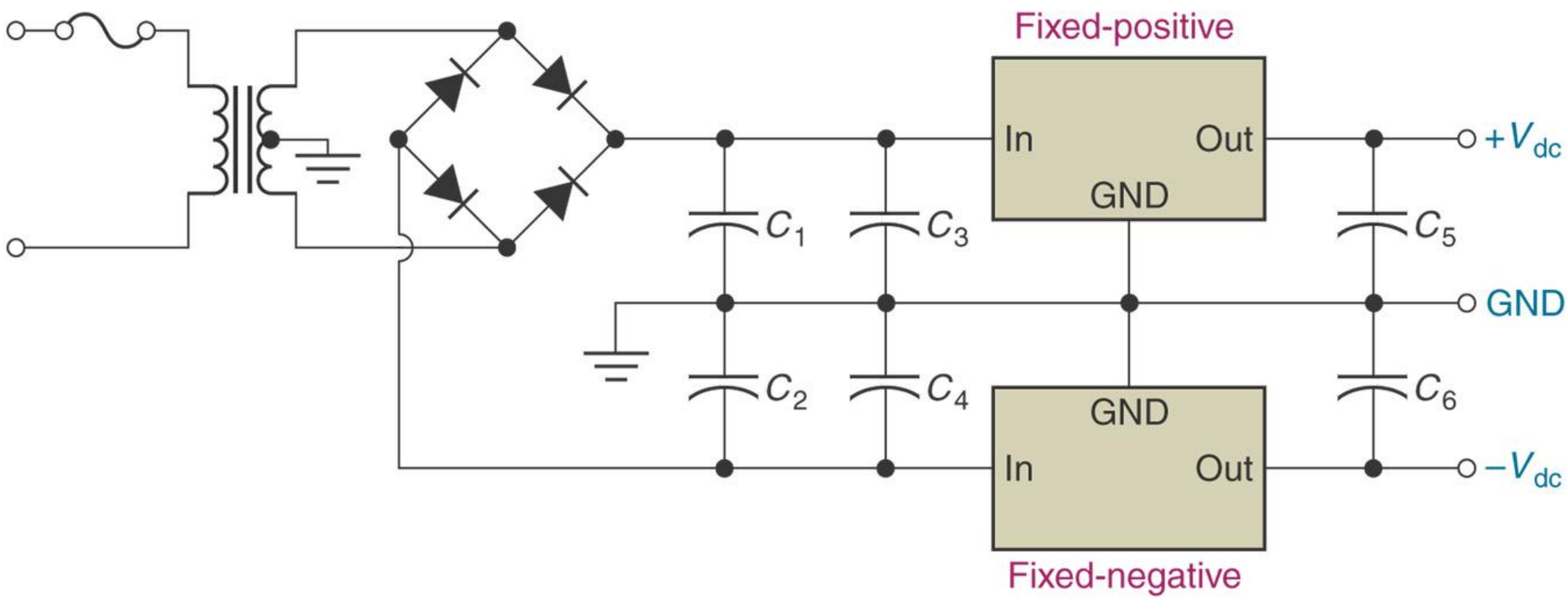




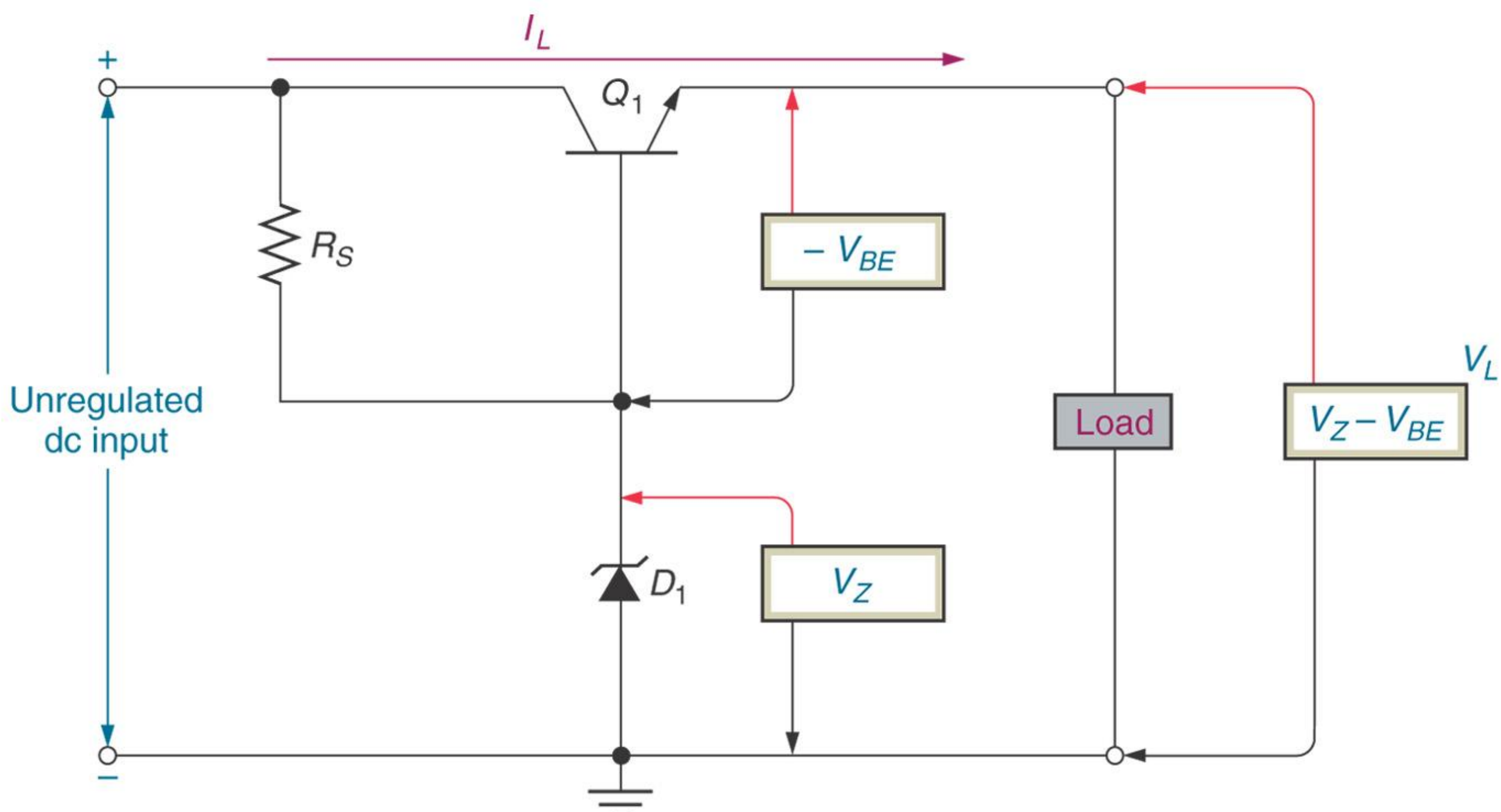
Regulation – Linear



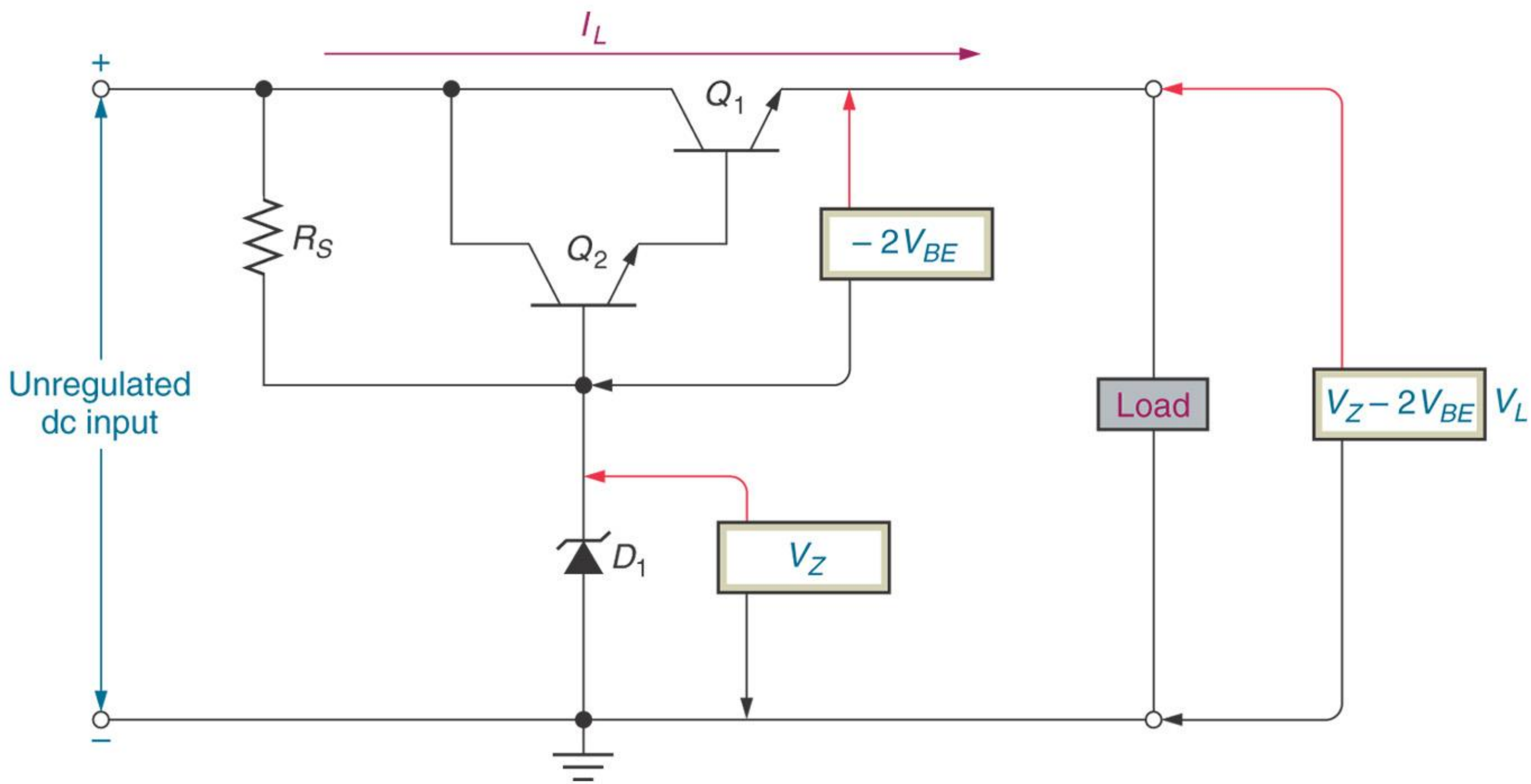
Regulation – Linear



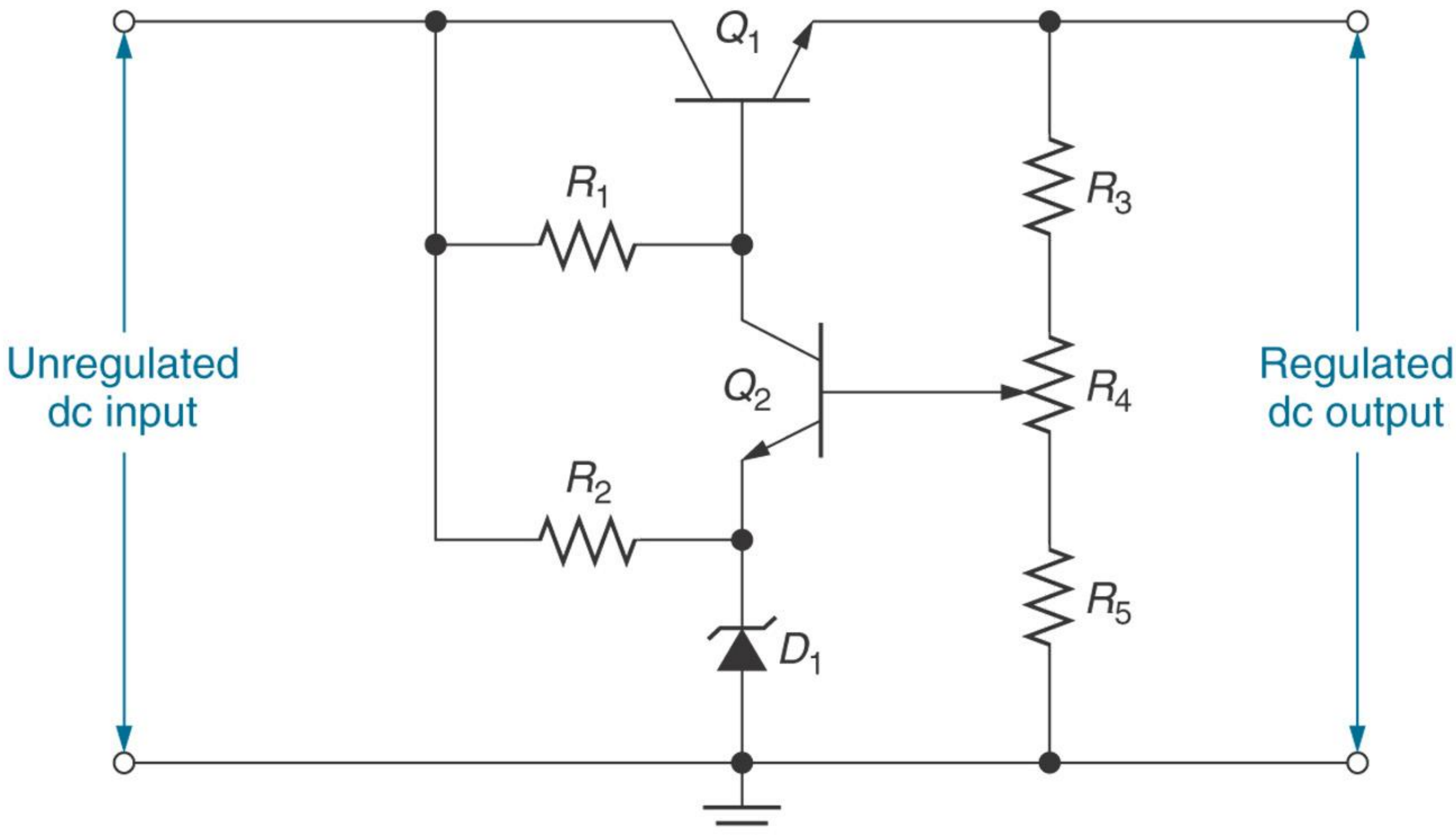
Regulation – Pass Transistor



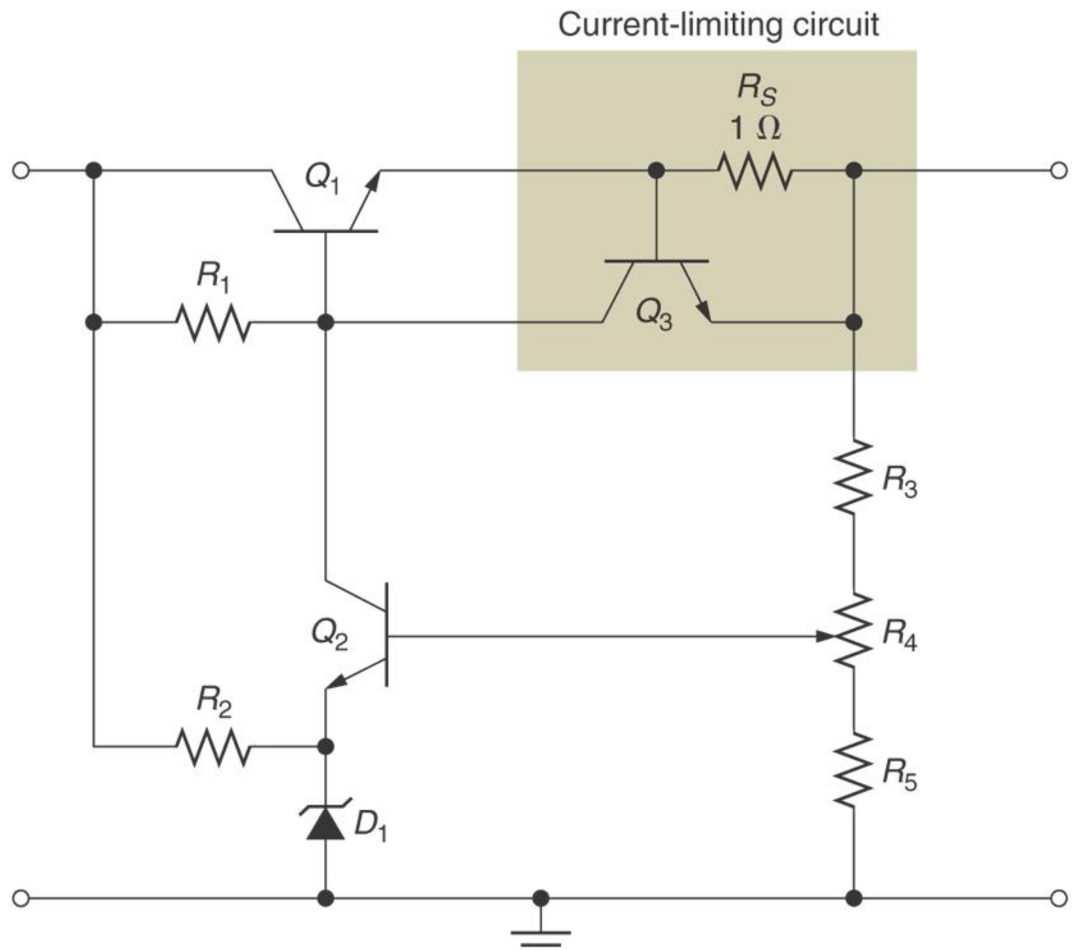
Regulation – Darlington Pass Transistor



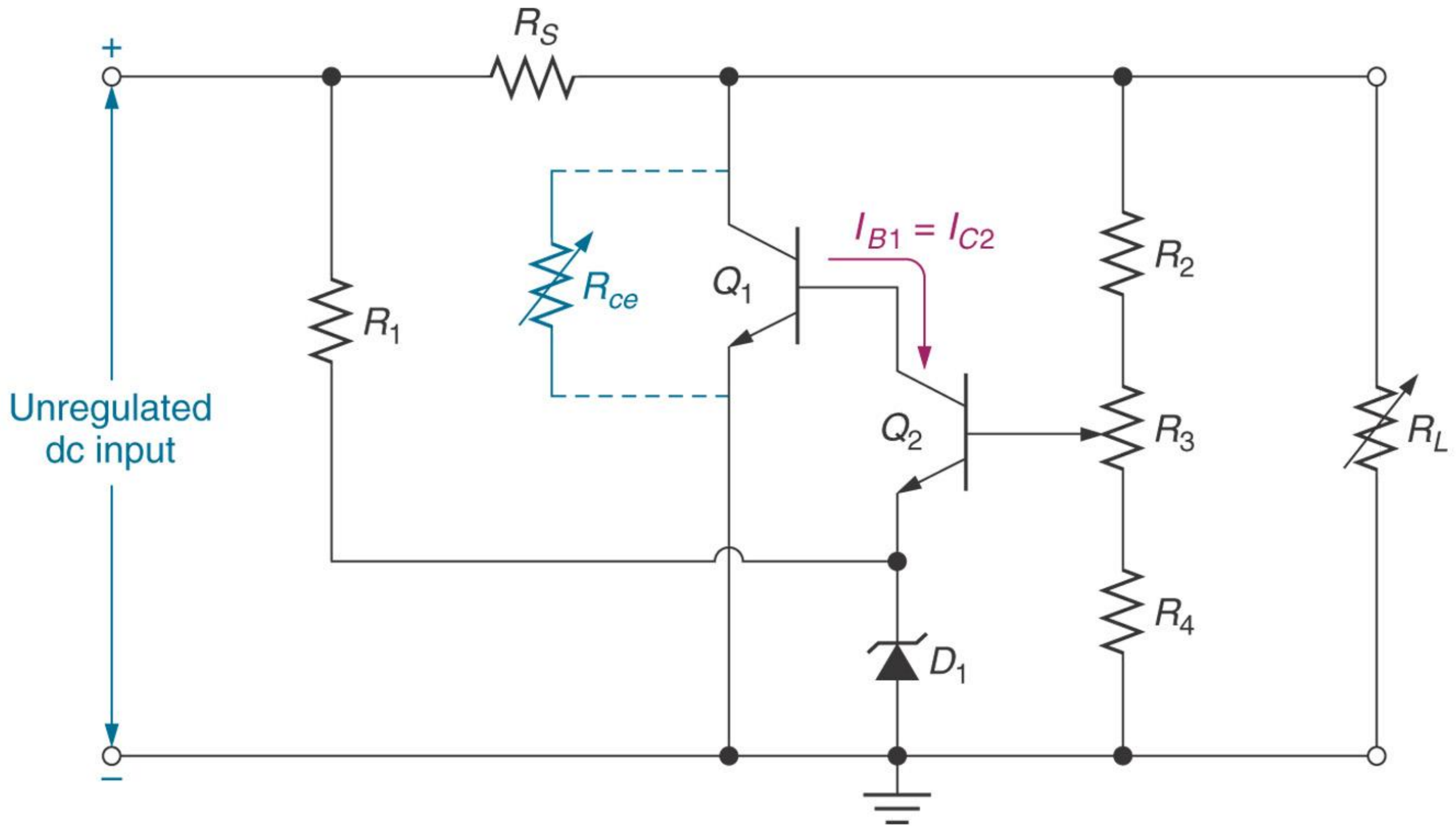
Regulation – Series Feedback



Regulation – Series Current Limiting



Regulation – Shunt Feedback



Switching Mode Power Supply (SMPS)

The most common and best quality power supply is the SMPS

These power supplies have several advantages over liner power supplies

- Multiple Outputs
- Very low ripple voltage
- Lower weight
- Safety/Current limiting circuits
- Multiple input voltages (US and European)

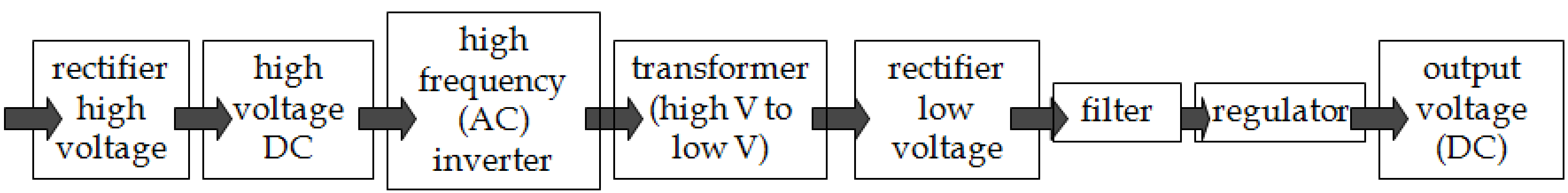
Switching Mode Power Supply (SMPS)

In general, here is a description of the block diagram of a SMPS

1. AC input Voltage (US or European)
2. Input voltage is filtered to:
   1. Prevent incoming voltage disturbances
   2. Prevent SMPS frequencies going out to utility system
3. AC is Rectified to High Voltage DC
4. An oscillator (10s K hz) switches the HV DC through a transformer primary winding
5. The transformer steps down the voltage

Switching Mode Power Supply (SMPS)

6. The transformer has multiple windings so many different outputs can be derived
7. The transformer SC secondary voltage is rectified
8. The DC voltages are filtered
9. The DC voltages are regulated
10. Some SMPS have feedback voltage sensing circuits so if a DC output voltage is out of specification, it can shut down the SMPS, this preventing additional damage to other circuits



Switching Mode Power Supply (SMPS)

One of the main advantages of the SMPS is the ripple voltage

With the oscillator operating in the 10's K Hz (20 – 50 K Hz), the time factor used in the ripple voltage calculation is very small

Switching Mode Power Supply (SMPS)

For example, if we used the half wave rectifier circuit calculations from above and assumed SMPS 40 K Hz:

Calculate the Ripple Voltage $V_r = (I_t \text{ X } t) / C$

- $I_t = 5.18 \; V_{avg} \; / \; 51 = 101$ ma
- $t = 16.6$ msec (half wave) $C = 470$ uf
- $V_r = 3.56$

The new calculation would be:

Calculate the Ripple Voltage $V_r = (I_t \text{ X } t) / C$

- $I_t = 5.18 \; V_{avg} \; / \; 51 = 101$ *ma*
- $t = 12.5$ *usec (half wave)* $C = 470$ *uf*
- $V_r = 0.0025$

Power & Misc. Devices

Transistor Switch

The Transistor can be used as a solid state switch

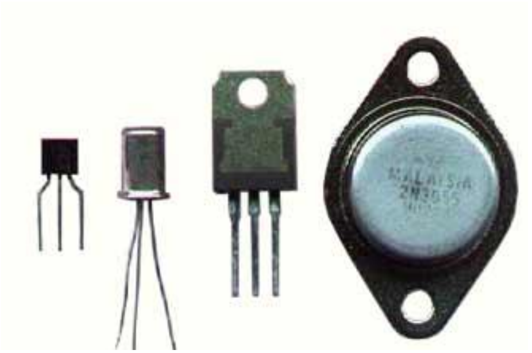
This enables a low voltage signal to control a high voltage or high current

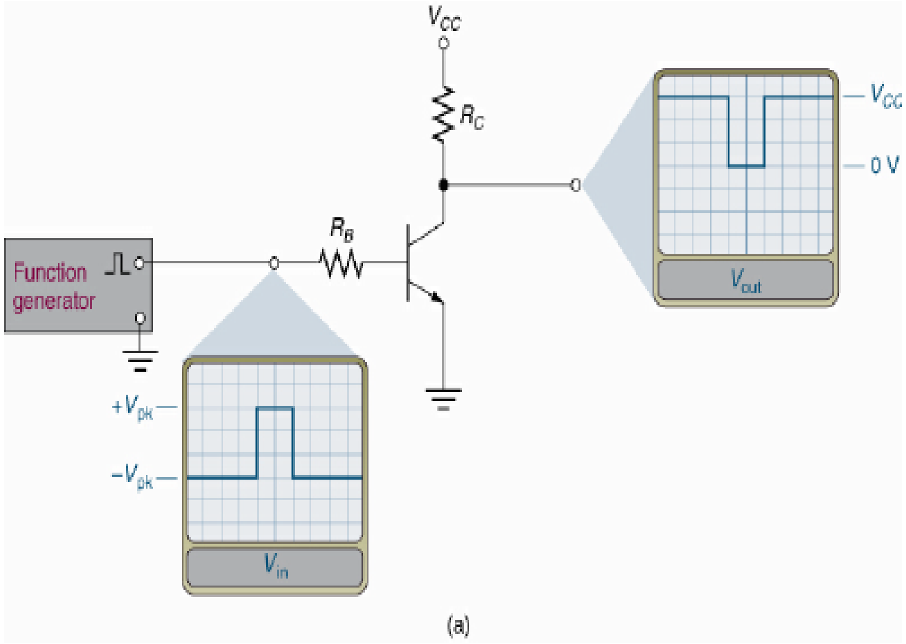
The transistor can also respond much faster than a mechanical switch (thousands of times a second)

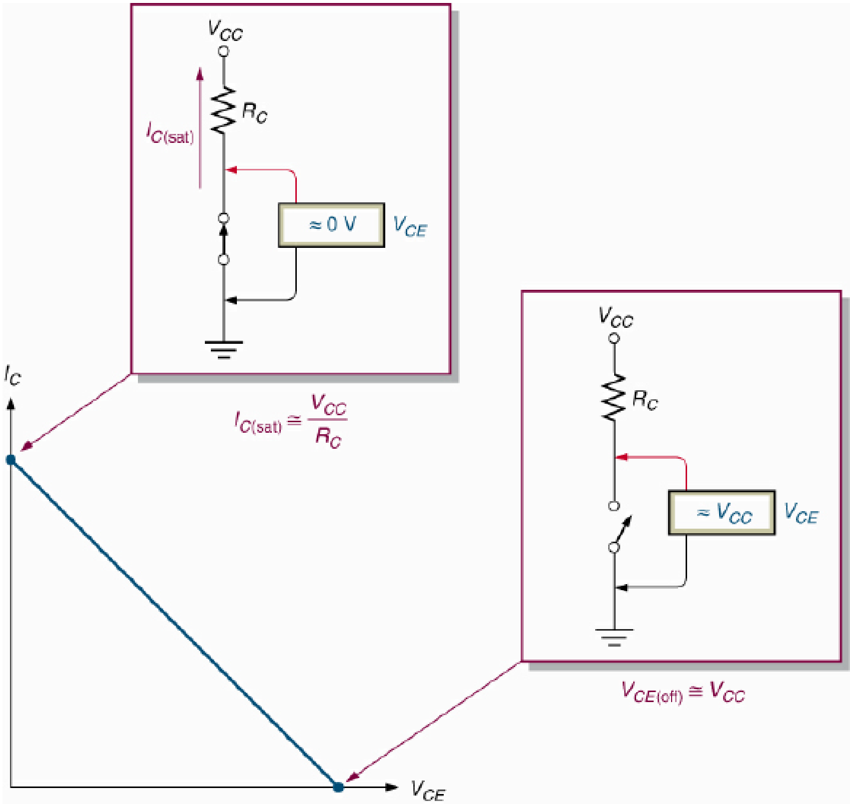
With no moving parts, there is less chance for failures

With no open air contacts, there is no chance for electrical sparking

Transistor Switch







555 Timer

The 555 timer has been the standard component in the industry for creating a clock signal

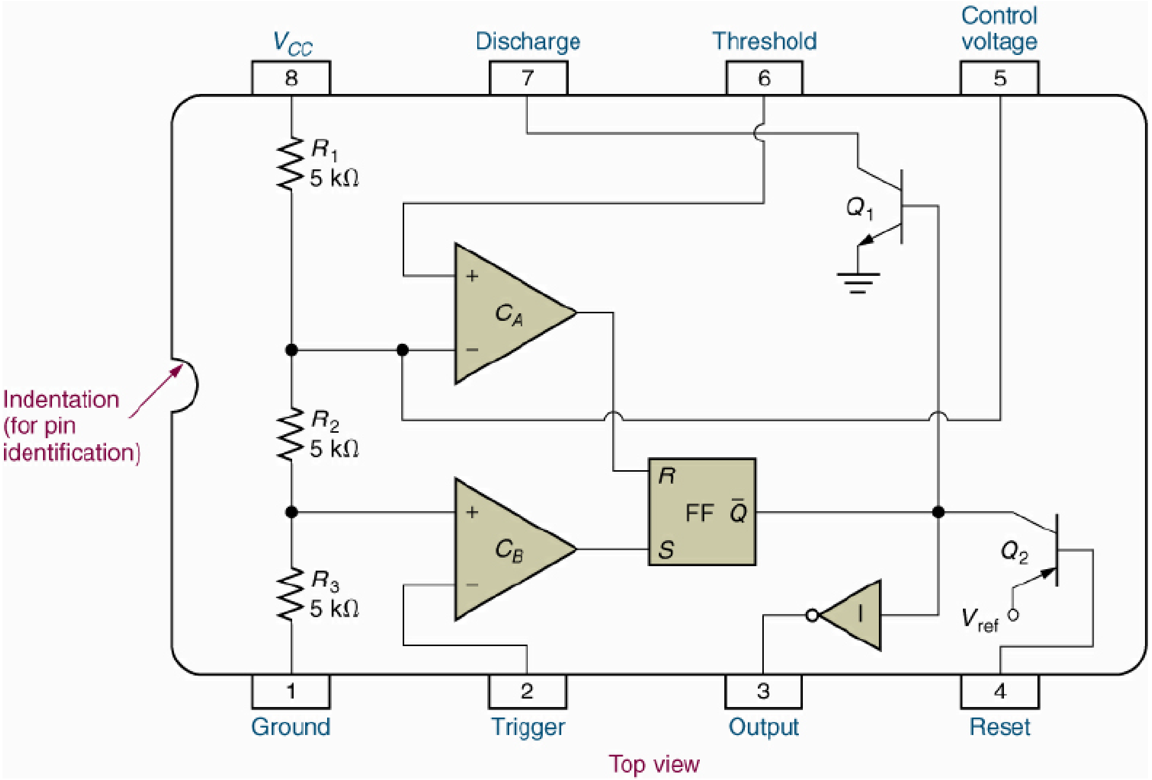
The output of the 555 is a square wave that can have an adjustable frequency and duty cycle

External components (resistors and capacitors) control the type of timer, frequency and duty cycle

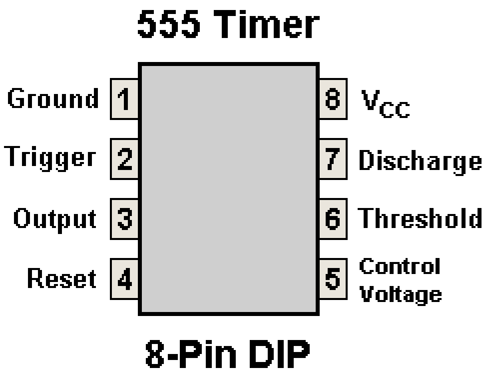
The 555 requires DC voltage to power the device

The output is always on pin 3

555 Timer



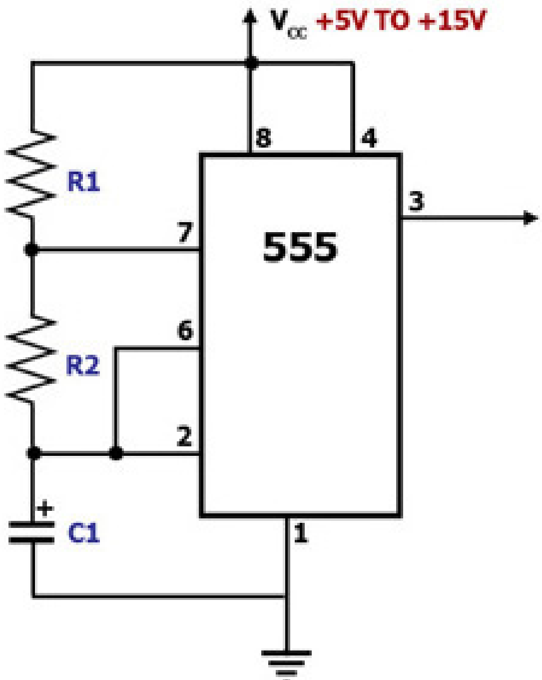
V_{CC}
8
Discharge
7
Threshold
6
Control voltage
5
R_1 5 kΩ
R_2 5 kΩ
R_3 5 kΩ
Q_1
Q_2
C_A
C_B
R
FF $\bar{Q}$
S
I
V_{ref}
Indentation (for pin identification)
1
Ground
2
Trigger
3
Output
4
Reset
Top view

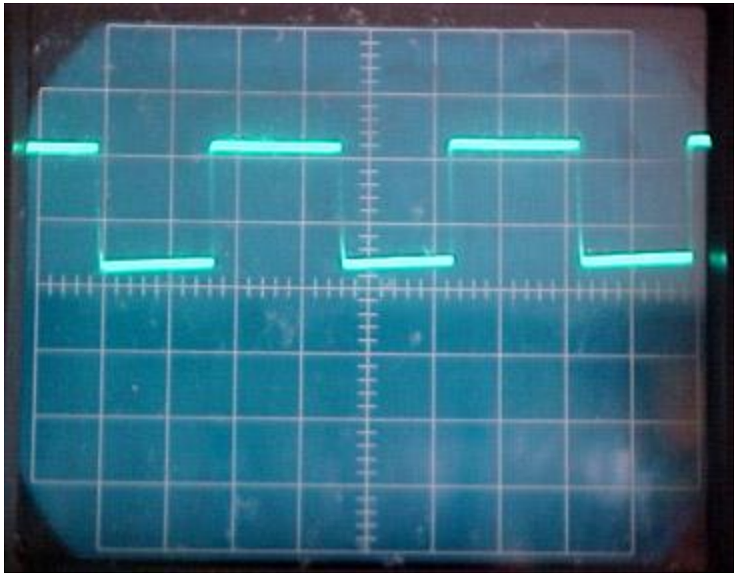


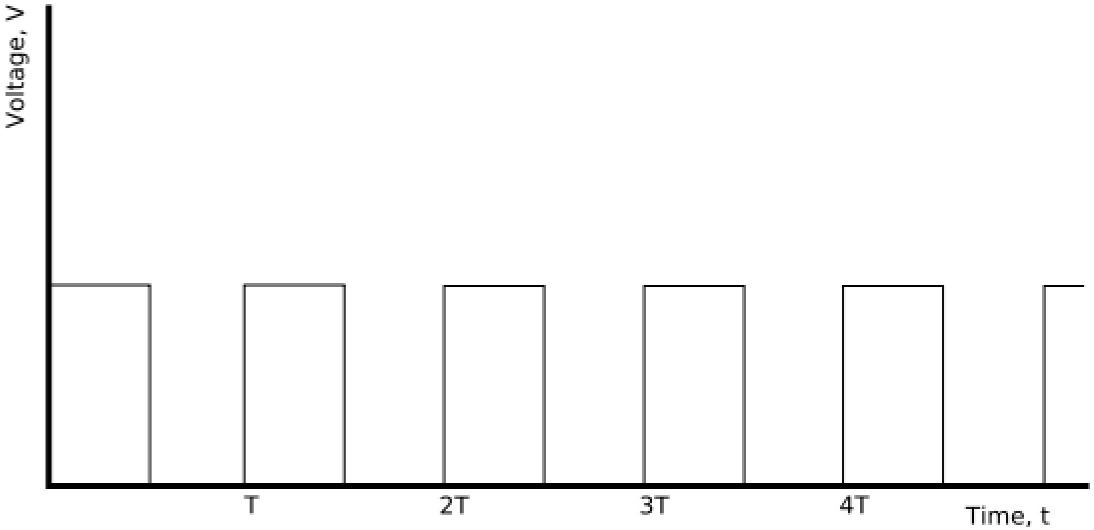
555 Timer
Ground 1
Trigger 2
Output 3
Reset 4
8 V_{CC}
7 Discharge
6 Threshold
5 Control Voltage
8-Pin DIP

A small circle marks the top of the 555 CMOS Timer
pin 1
2
3
4
pin 8
7
6
5
555 CMOS Timer
www.ClarkZapper.net

CBET Review – Electronics & Solid State Devices

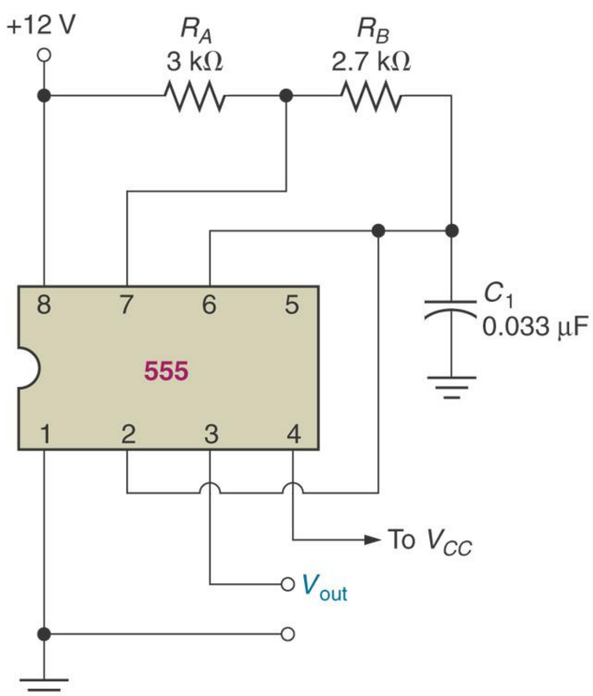


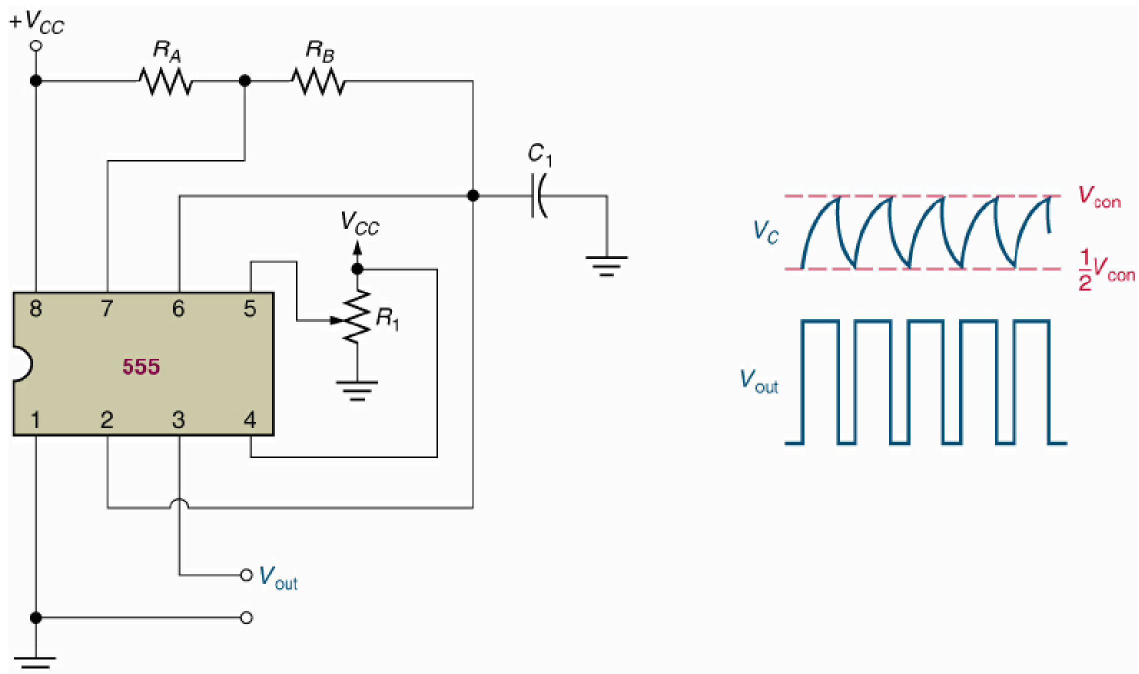




555 Astable Multivibrator

This configuration produces continuous output square wave pulses without an input signal

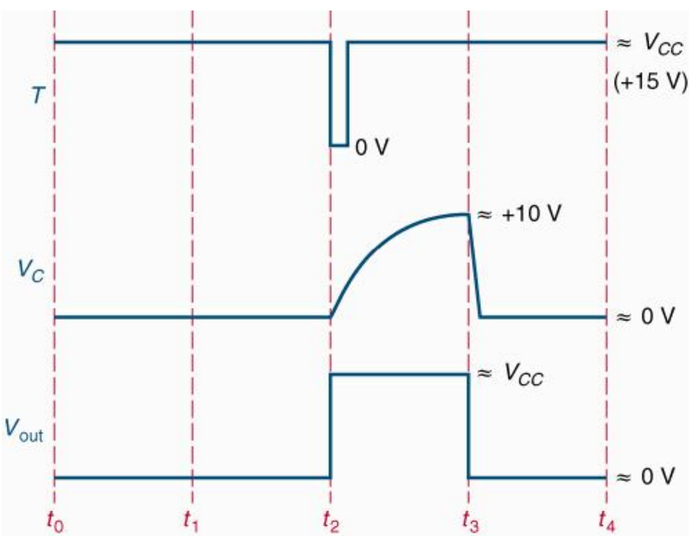


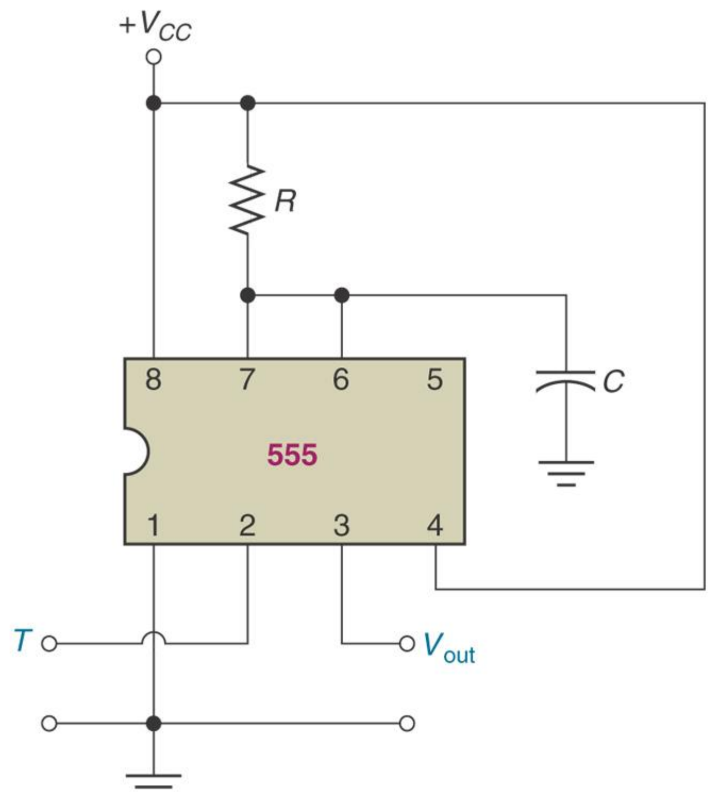


(a) (b)

555 Monostable Multivibrator

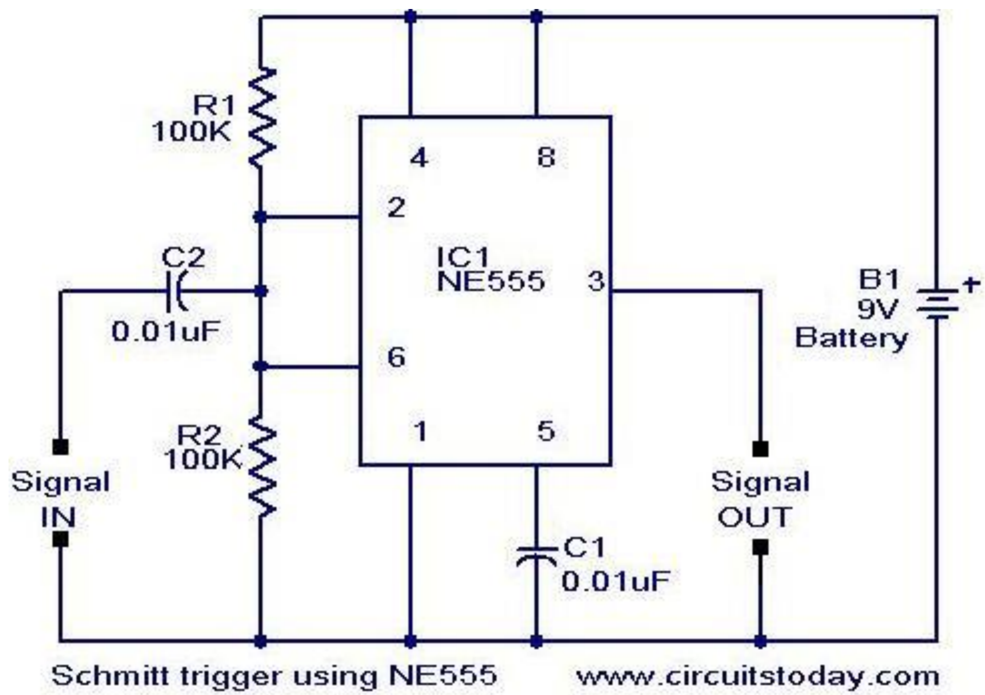
This configuration produces a one time square wave pulse with a set pulse width when the input is triggered



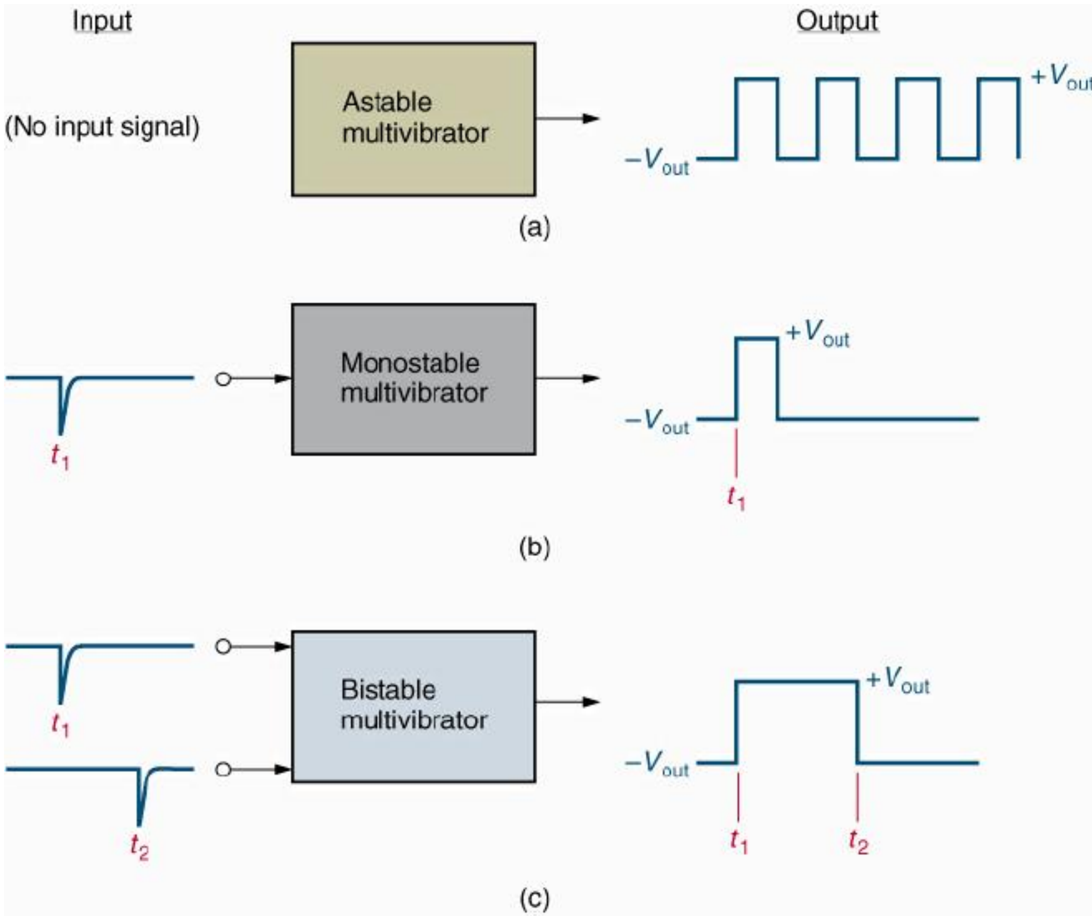


555 Bistable Multivibrator

This configuration produces a one time square wave pulse that starts with an input trigger and end with another input trigger



555 Multivibrator input/output relationships



DIAC

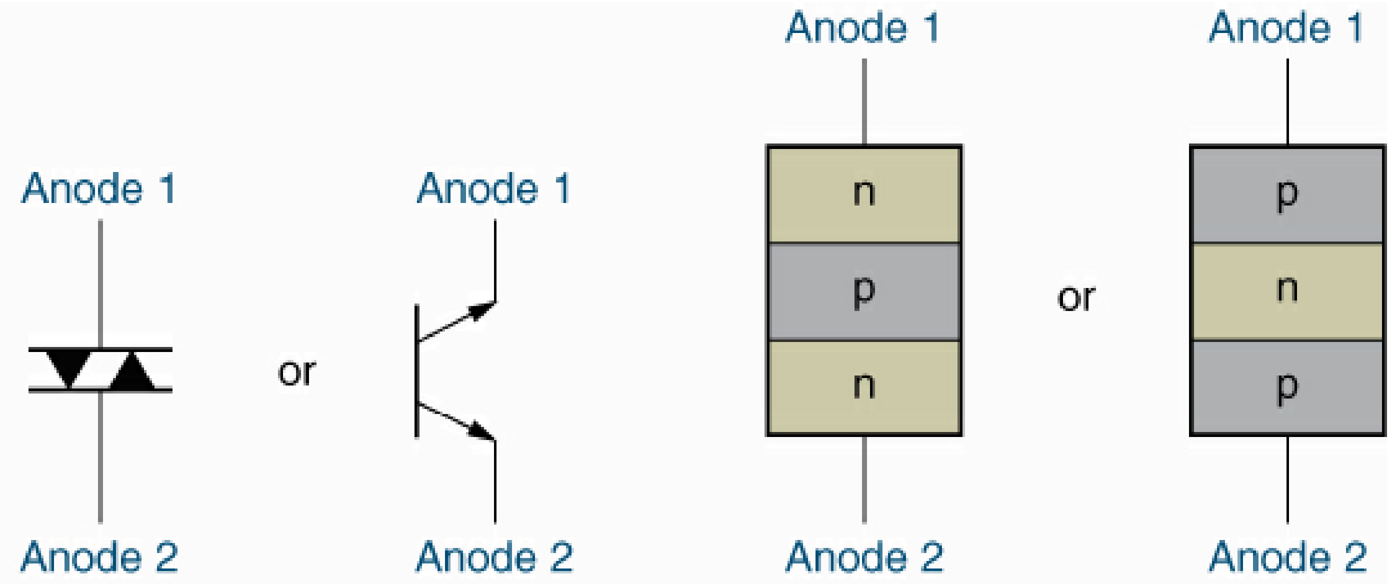
This is a solid state switching device that acts like a 2 diodes back to back in opposite directions

There are only 2 leads to a DIAC

These are also call Bidirectional Diodes

A DIAC is used for removing noise and establishing a minimum voltage for triggering another device (like SCR or TRIC)

DIAC



(a) Commonly used symbols (b) Construction

Silicone Controlled Rectifier (SCR)

This is a solid state switching device that acts like a diode with one additional lead – gate

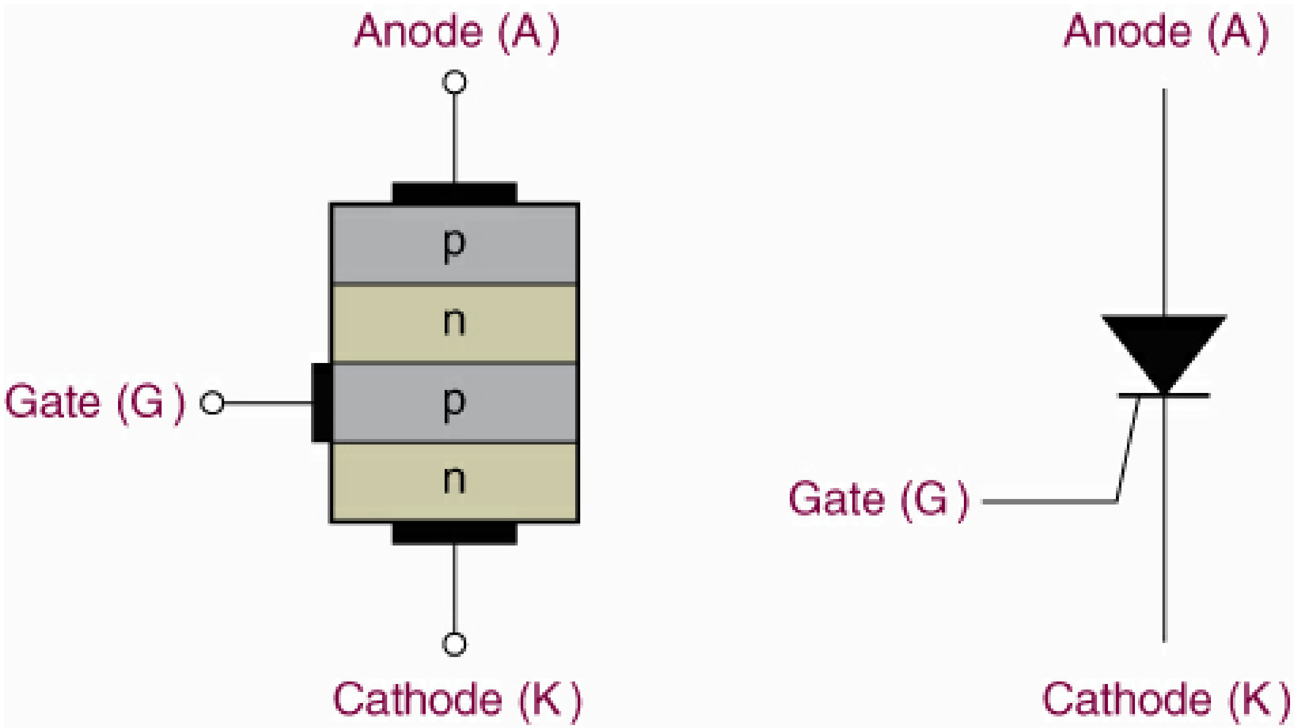
A low voltage on the gate can control a high voltage and/or high current through the device

For the SCR to be in forward bias, the gate must have a positive voltage applied to it

If the gate has 0 volts, then the diode acts as an open switch

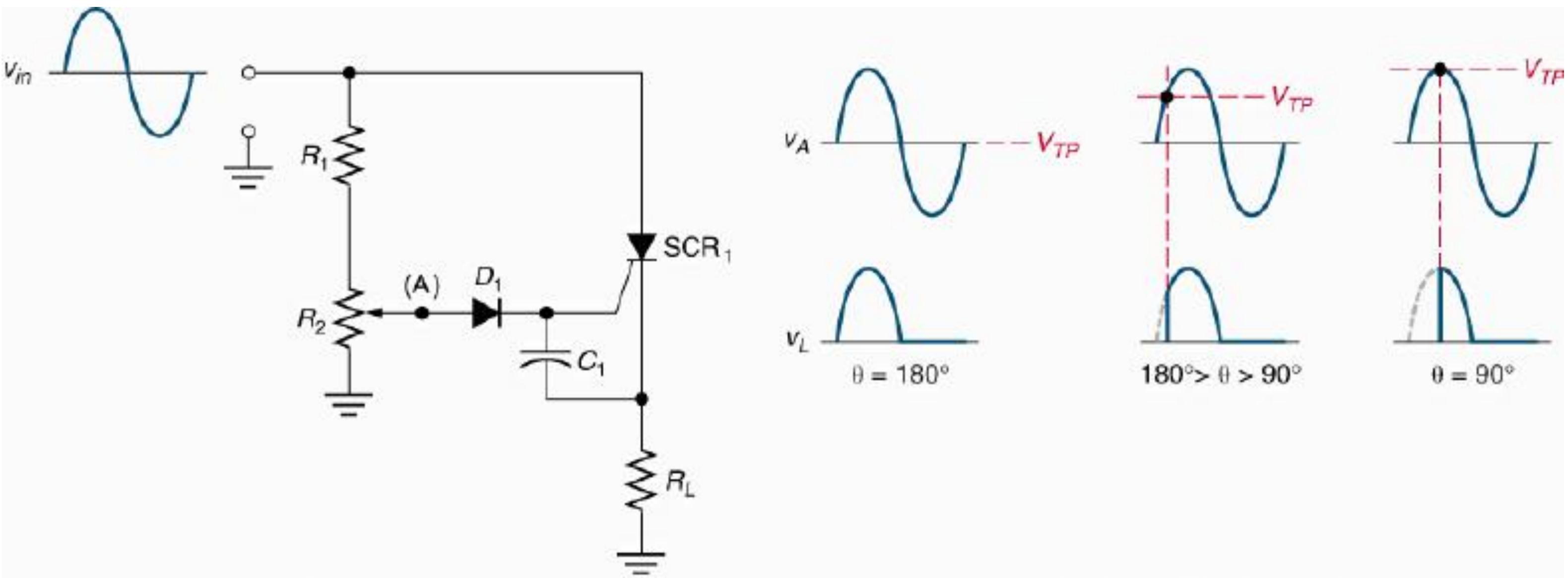
The triggering on the gate can be very fast

Silicone Controlled Rectifier (SCR)



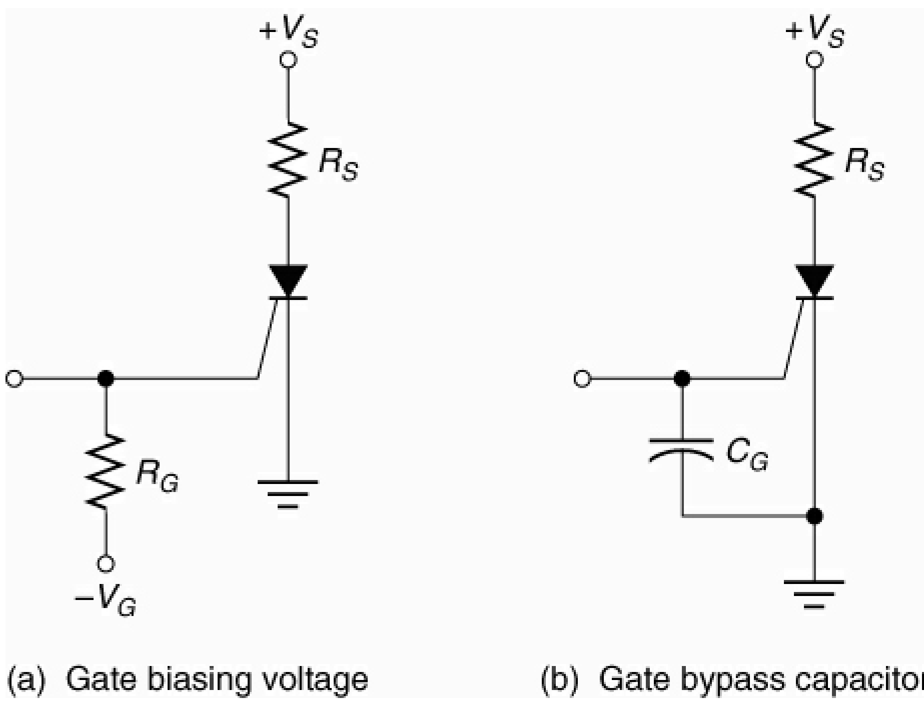
Silicone Controlled Rectifier (SCR)

Phase Controller Circuit – Light dimmer or motor speed control



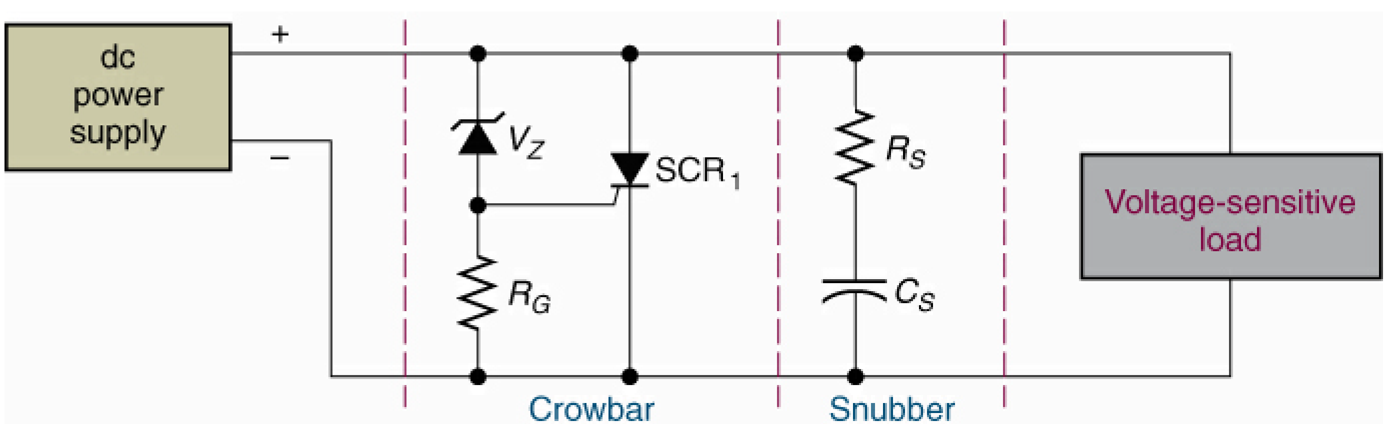
(a) (b) V_{TP} and load conduction

Silicone Controlled Rectifier (SCR) Circuit to Preventing False Triggering



Silicone Controlled Rectifier (SCR)

SCR crowbar circuit used to prevent over voltage in a power supply



TRIAC

This is a solid state switching device that acts like a 2 diodes back to back in opposite directions with one additional lead – gate

These are also call Triodes and Bidirectional Triode Thyristors

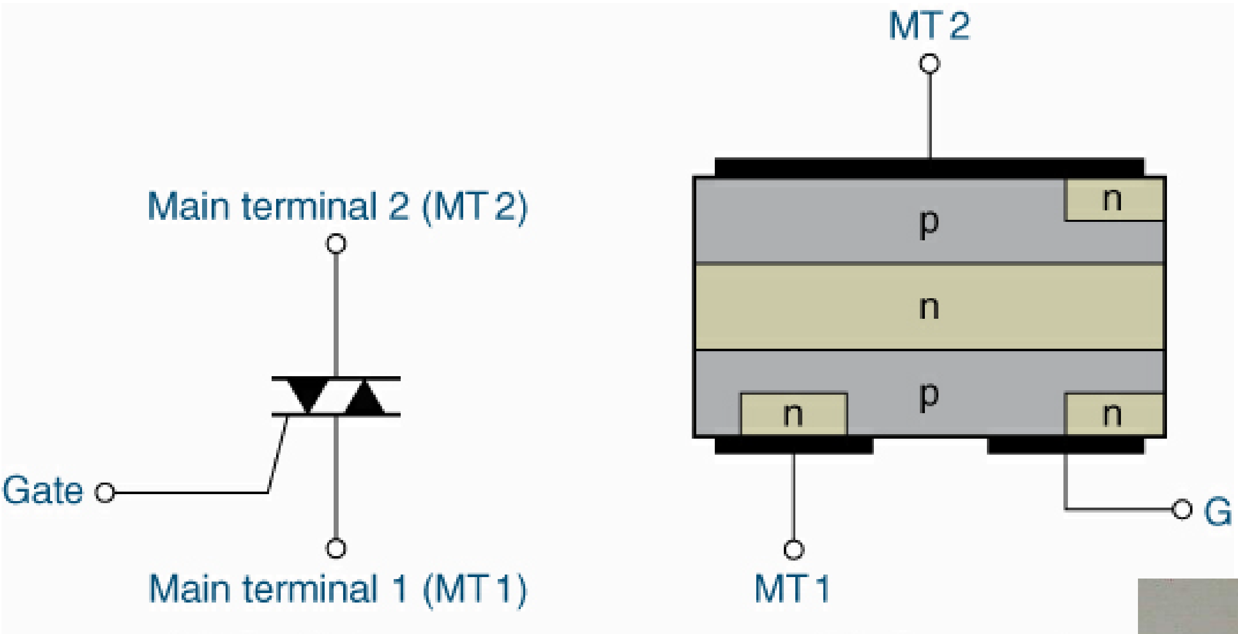
A low voltage on the gate can control a high voltage and/or high current through the device

For the TRIAC to be in forward bias, the gate must have a positive voltage applied to it

If the gate has 0 volts, then the diode acts as an open switch

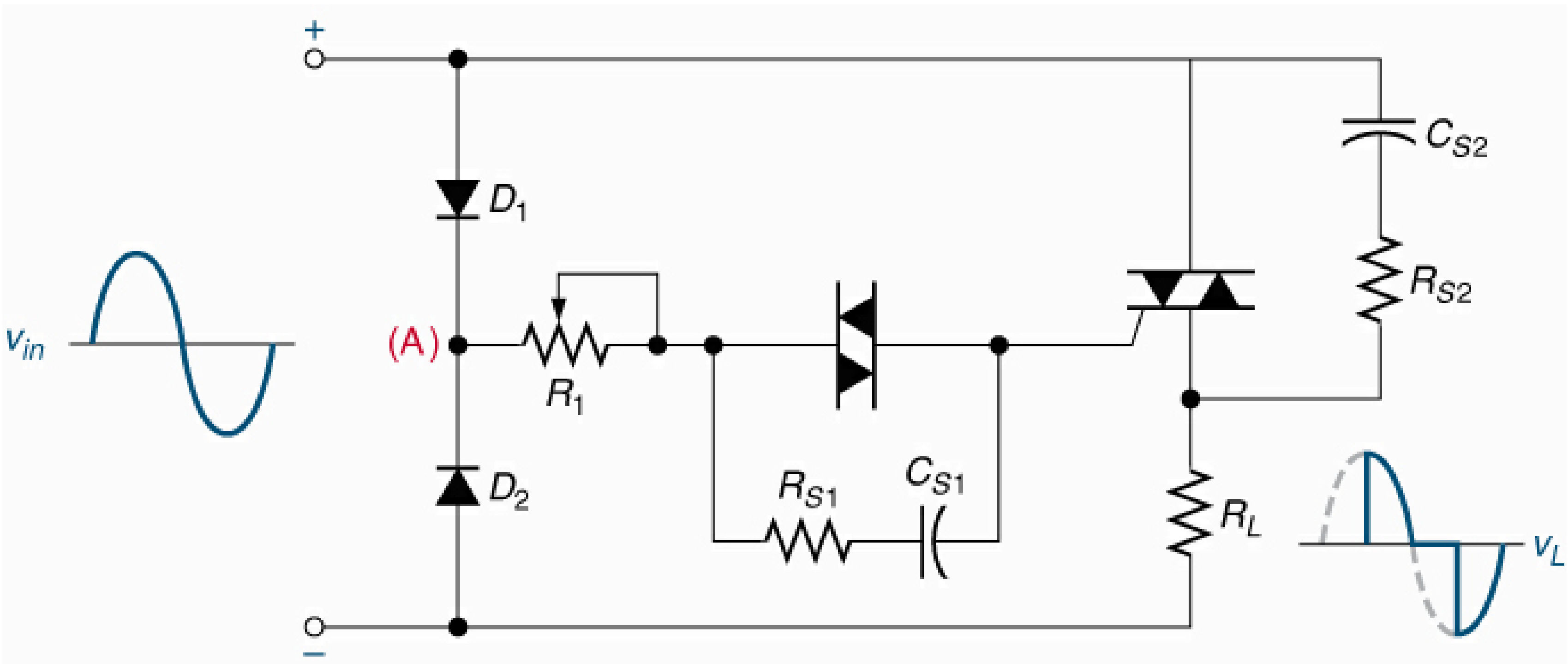
The triggering on the gate can be very fast

TRIAC



(a) Symbol (b) Construction

TRIAC



Light Emitter-Detector Combination

This is a 2 part component:

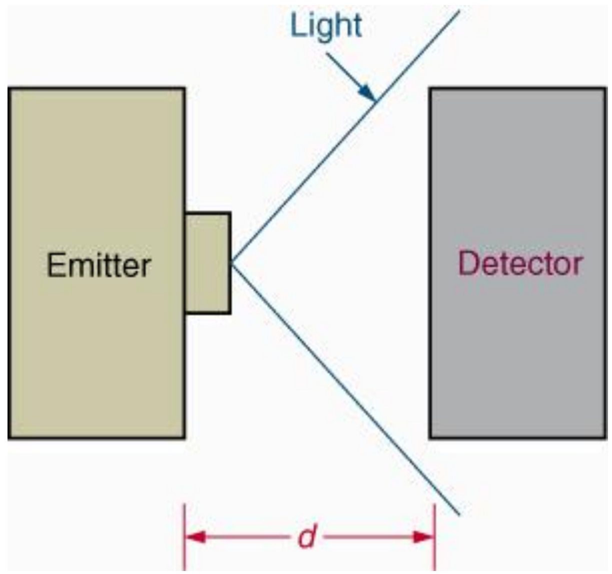
- One device is an LED that transmits light (various frequencies that could be visible or invisible)
- One device is a light detector that receives the light

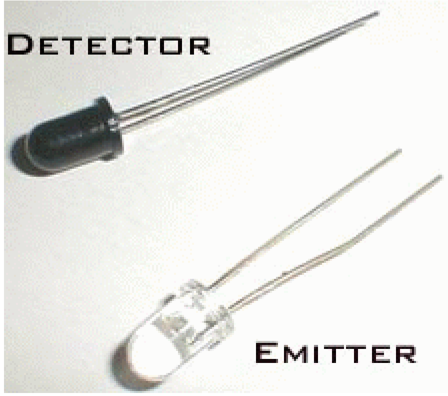
The 2 components can be individual devices or constructed into 1 device

There are many different applications of the light transmitter and receiver:

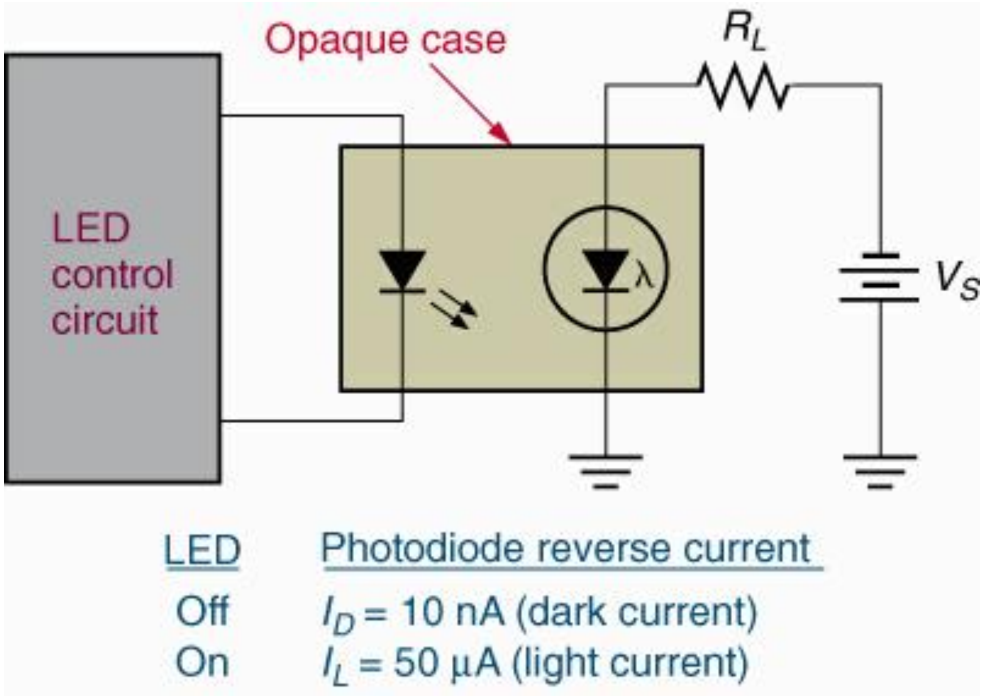
- Used as a switch – an object breaks the light beam
- Used to optically transmit a signal – A signal is modulated to the transmitter and then received and demodulated on the detector
- Used to provide electrical isolation from one circuit to another

Light Emitter-Detector Combination

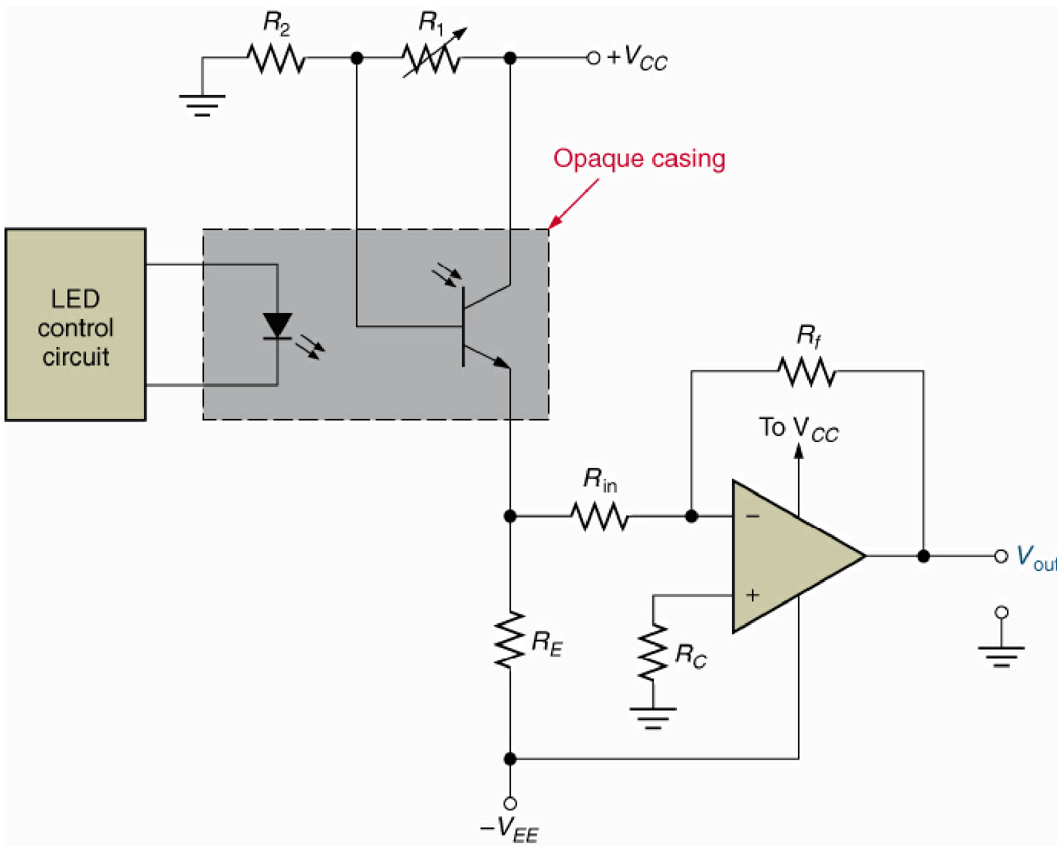




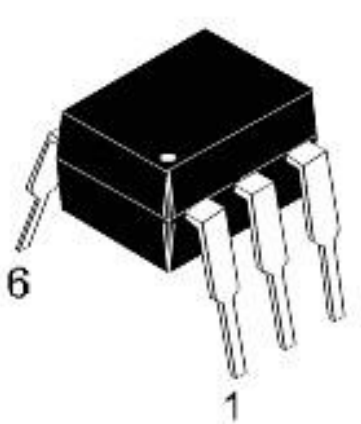
Light Emitter-Detector Combination

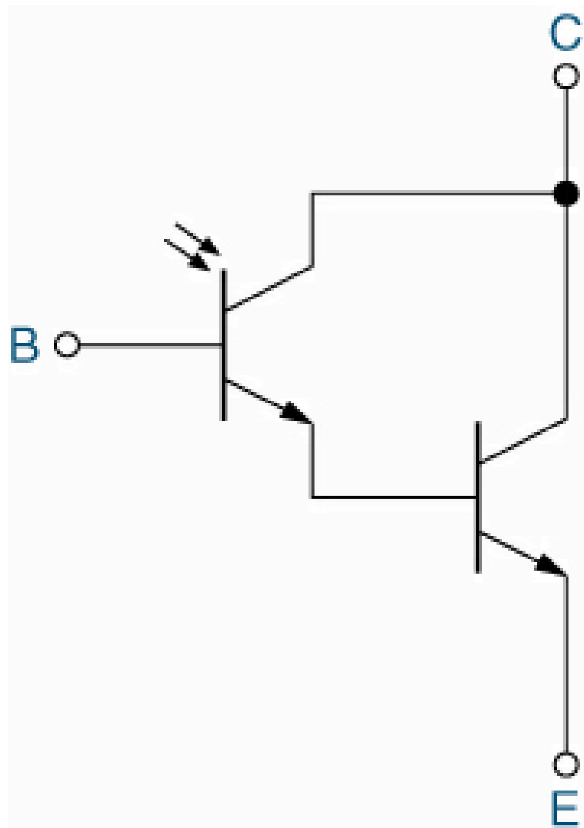


Light Emitter-Detector Combination
LED to Transistor

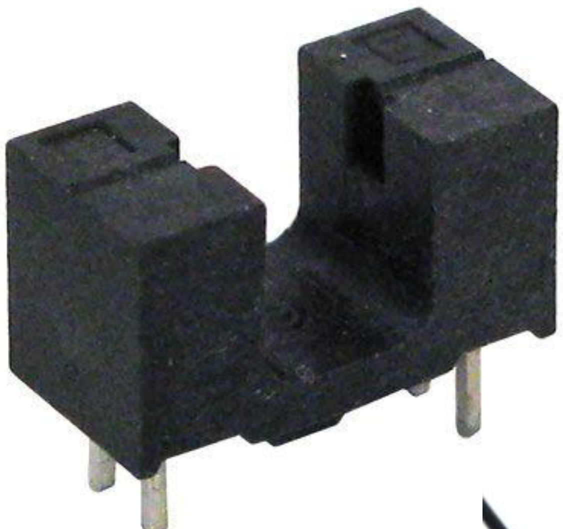


Light Emitter-Detector Combination
LED to Darlington Transistor





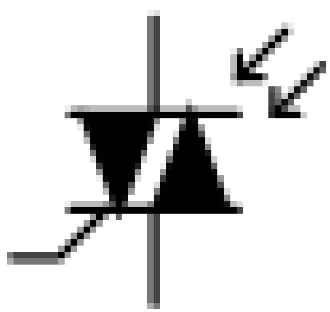
Light Emitter-Detector Combination
Optical Switch

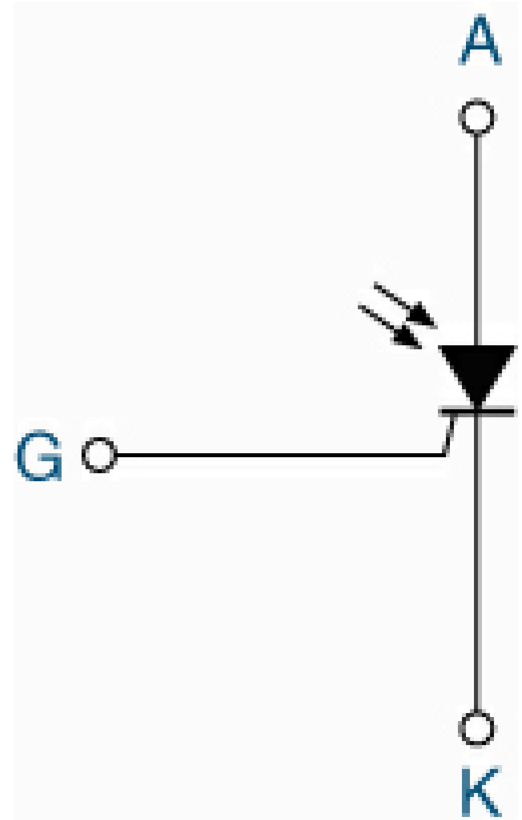


Light Emitter-Detector Combination

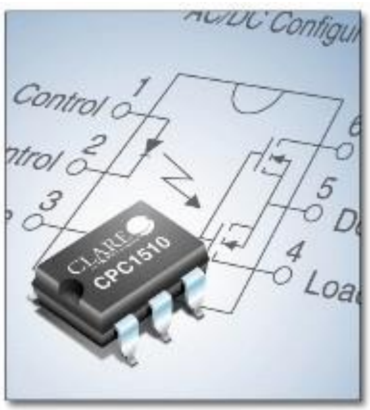
LASCR

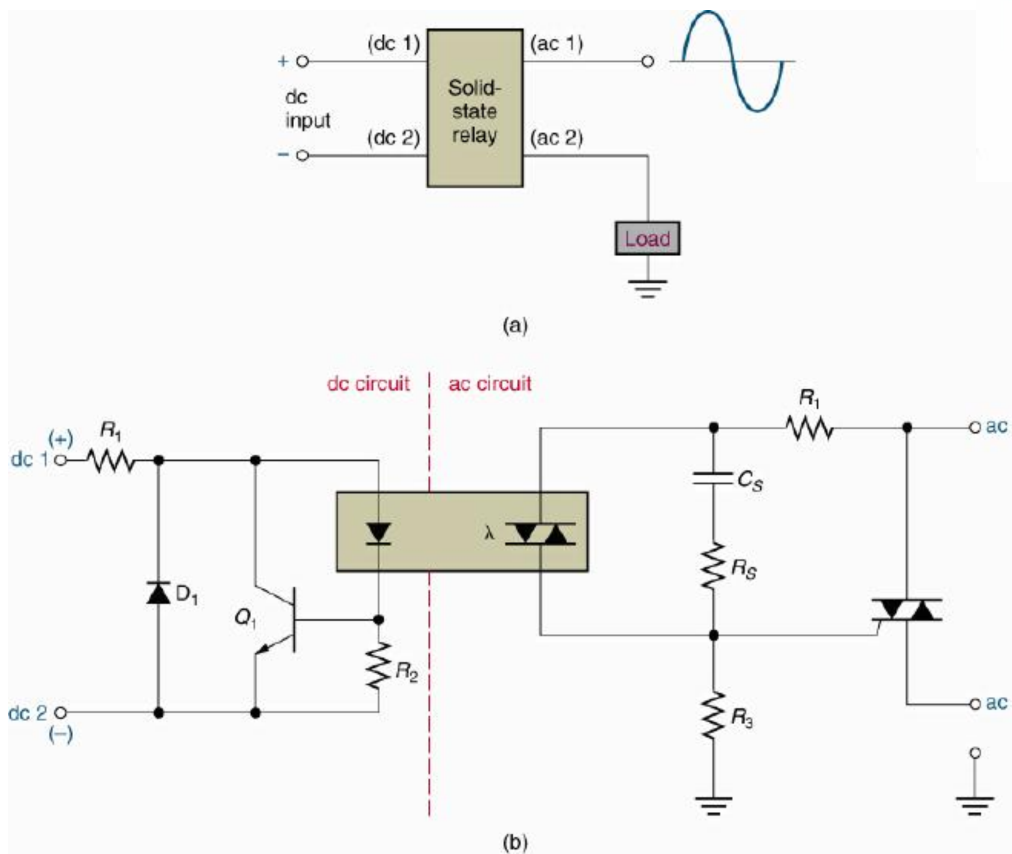
Opto-TRIAC





Light Emitter-Detector Combination
Solid State Relay

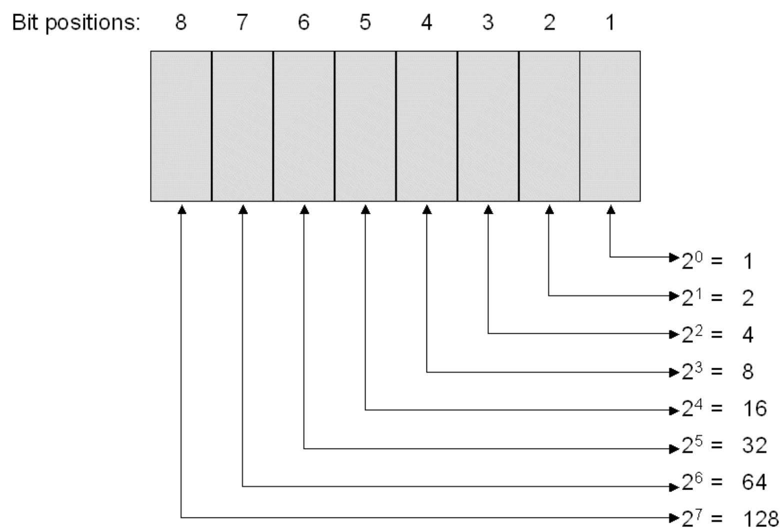




Digital Logic Circuits

Binary Code

- A hexadecimal number has 8 locations to encode for 1 number
- Each digit location of a digital number (8 bit word for this example) 1 or 0 represents a value
- If there is a “1” in that location, it represents that value
- The numbers are read from right to left
- This is called an 8 bit word



Binary Code

Example: 10101010 8 bit word is equal to:

0 = 0 (no 1 in 1s location) far right digit

1 = 2

0 = 0 (no 1 in 4s location)

1 = 8

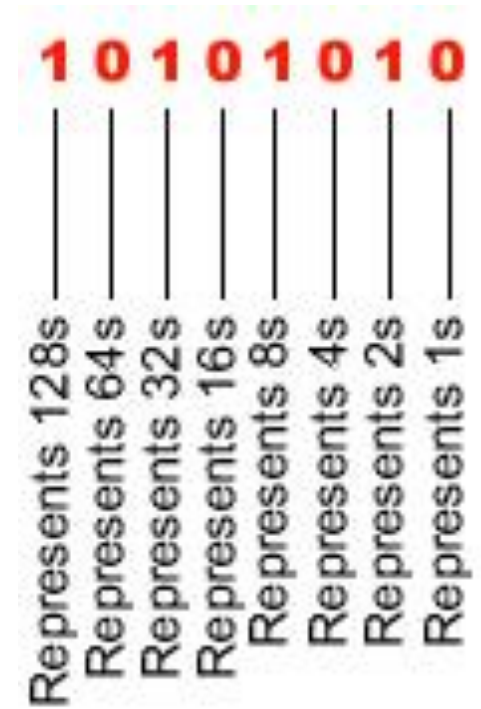
0 = 0 (no 1 in 16s location)

1 = 32

0 = 0 (no 1 in 64s location)

1 = 128

Answer = 2 + 8 + 32 + 128 = 170



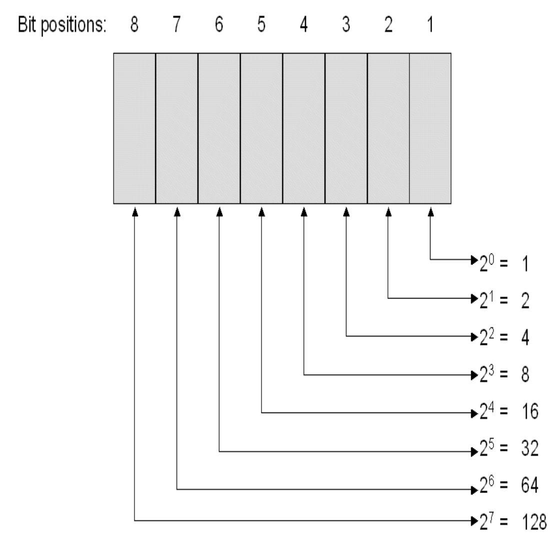
Binary Code

Example: Convert 105 to an 8 bit word:

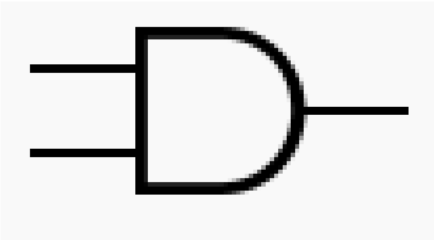
Start from the left and work to the right

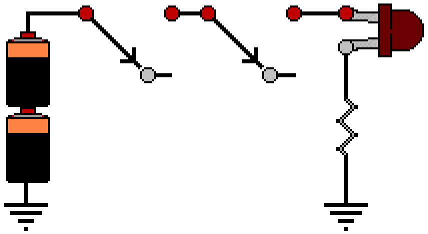
128	will not go into 105	0 for128s
64	105 - 64 = 41	1 for 64s
32	41 – 32 = 9	1 for 32s
16	16 will not go into 9	0 for 16s
8	9 – 8 = 1	1 for 8s
4	4 will not go into 1	0 for 4s
2	2 will not go into 1	0 for 2s
1	1 – 1 = 0	1 for 1s

Answer = 01101001

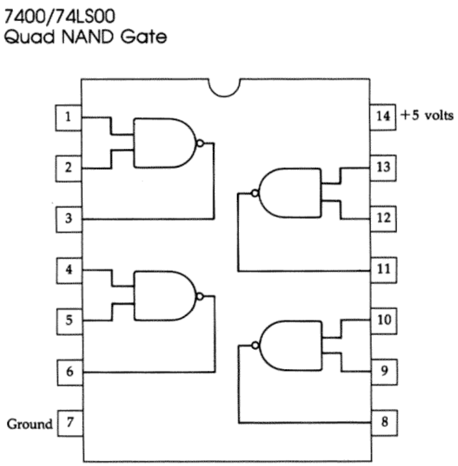


Digital Logic Gates - AND

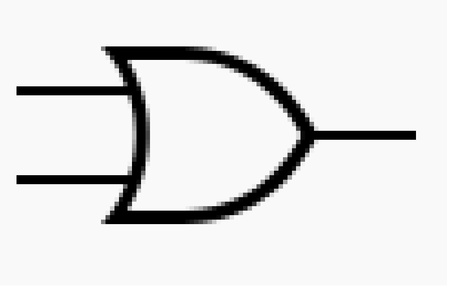


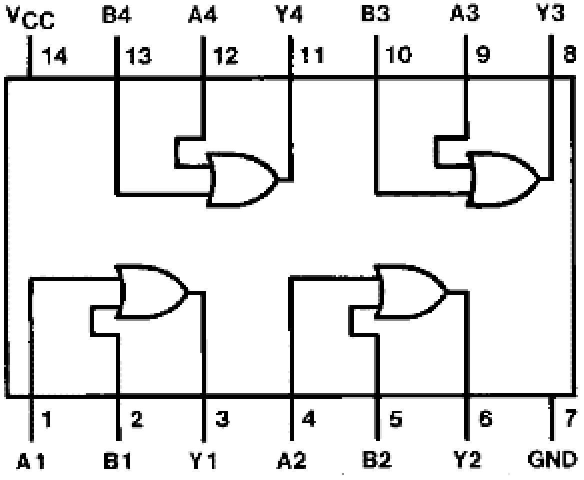


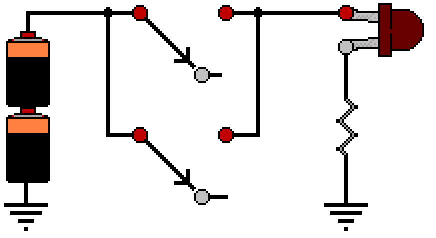
INPUT		OUTPUT
A	B	A AND B
0	0	0
0	1	0
1	0	0
1	1	1



Digital Logic Gates - OR

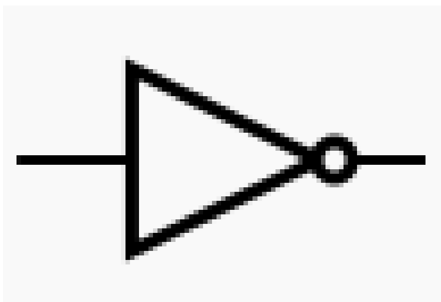




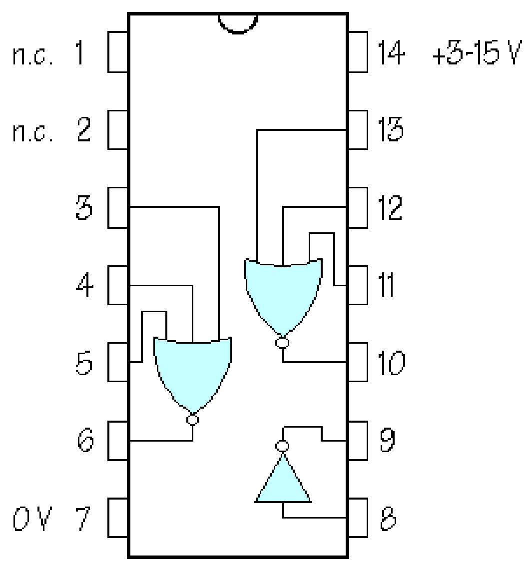


INPUT		OUTPUT
A	B	A OR B
0	0	0
0	1	1
1	0	1
1	1	1

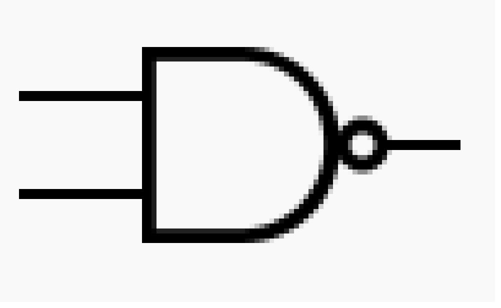
Digital Logic Gates - NOT



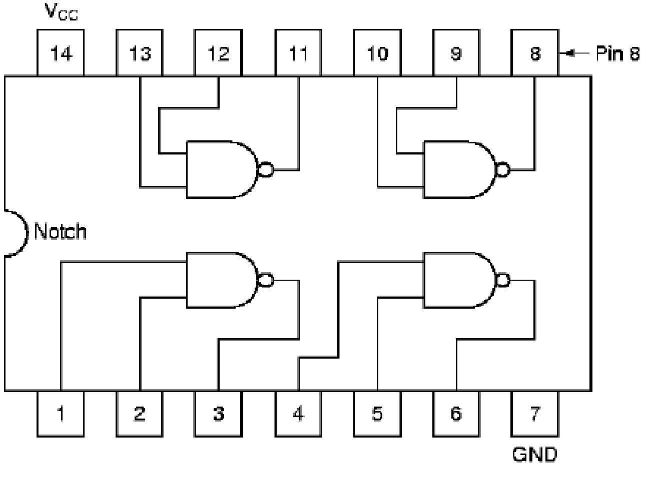
INPUT	OUTPUT
A	NOT A
0	1
1	0



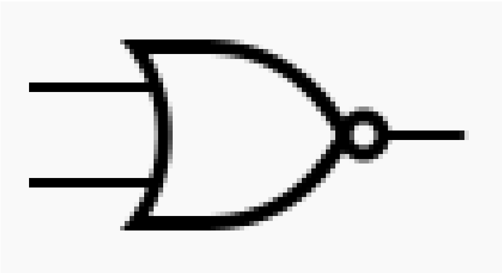
Digital Logic Gates - NAND



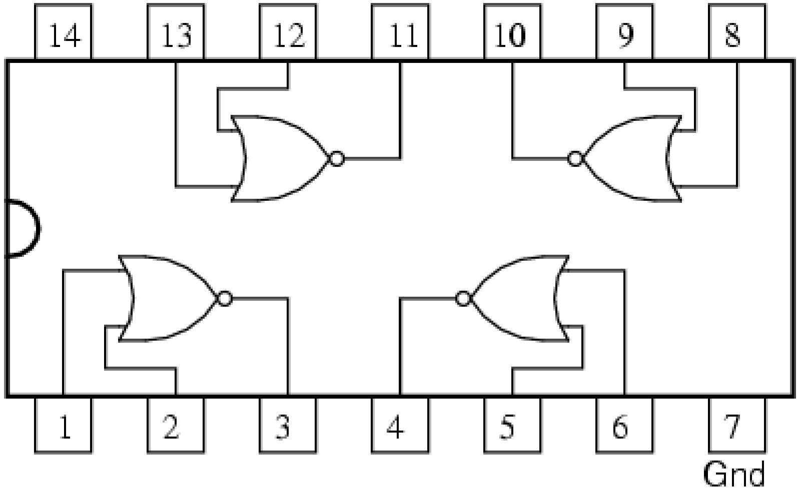
INPUT		OUTPUT
A	B	A NAND B
0	0	1
0	1	1
1	0	1
1	1	0



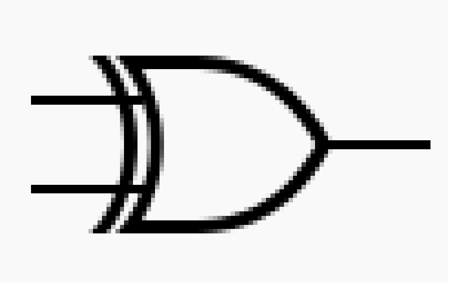
Digital Logic Gates - NOR

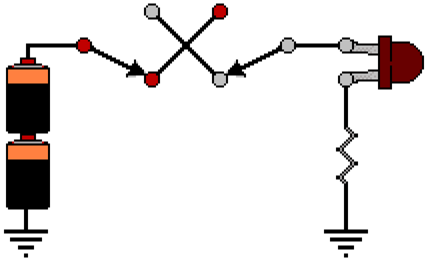


INPUT		OUTPUT
A	B	A NOR B
0	0	1
0	1	0
1	0	0
1	1	0

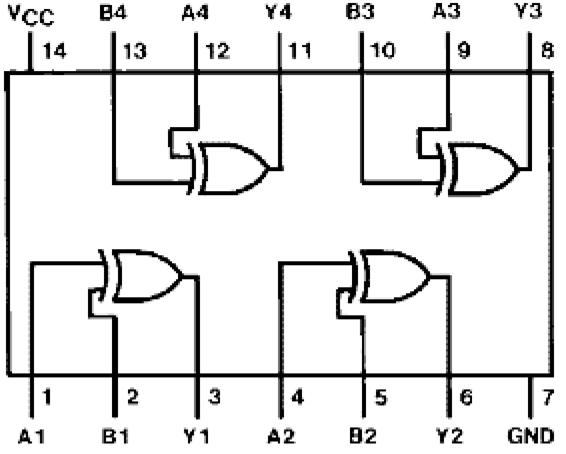


Digital Logic Gates - XOR

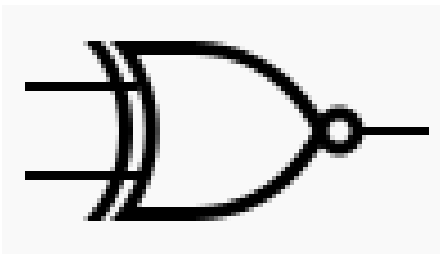


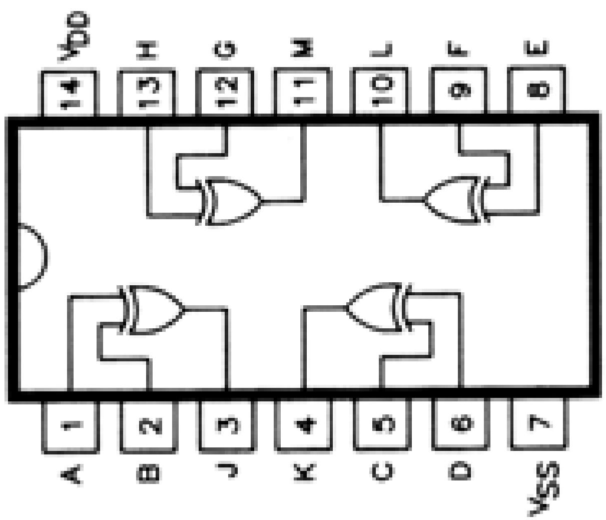


INPUT		OUTPUT
A	B	A XOR B
0	0	0
0	1	1
1	0	1
1	1	0



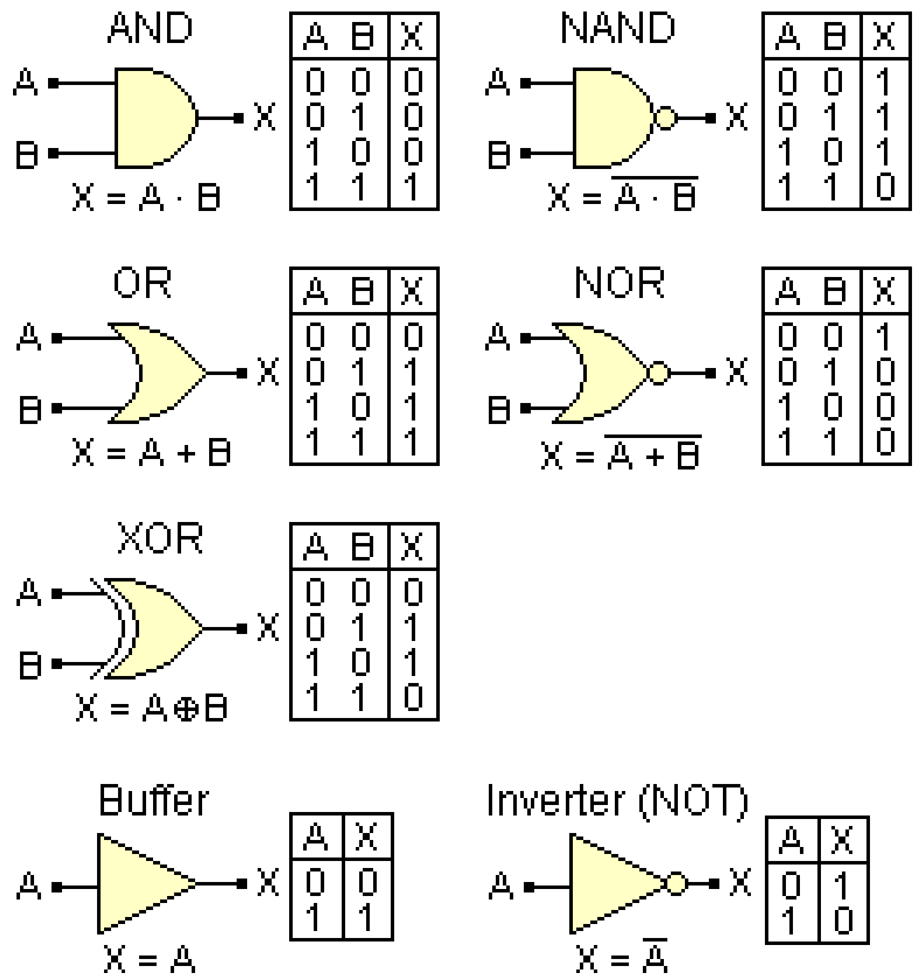
Digital Logic Gates - XNOR





INPUT		OUTPUT
A	B	A XNOR B
0	0	1
0	1	0
1	0	0
1	1	1

Digital Logic Gates



AND

A	B	X
0	0	0
0	1	0
1	0	0
1	1	1

NAND

A	B	X
0	0	1
0	1	1
1	0	1
1	1	0

OR

A	B	X
0	0	0
0	1	1
1	0	1
1	1	1

NOR

A	B	X
0	0	1
0	1	0
1	0	0
1	1	0

XOR

A	B	X
0	0	0
0	1	1
1	0	1
1	1	0

Buffer

A	X
0	0
1	1

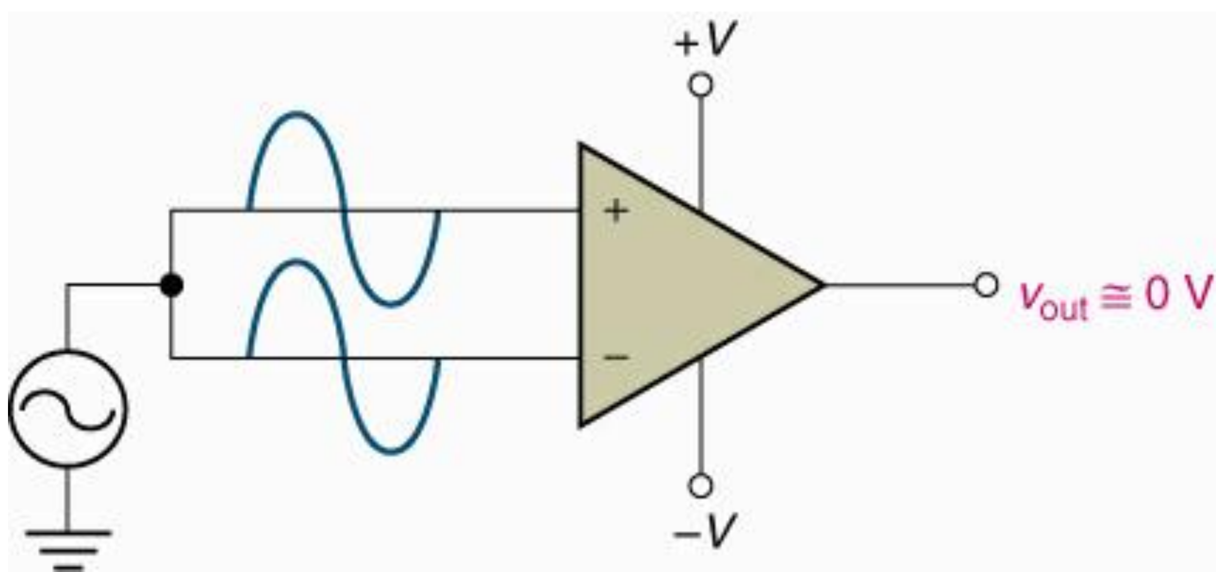
Inverter (NOT)

A	X
0	1
1	0

Operational Amplifiers

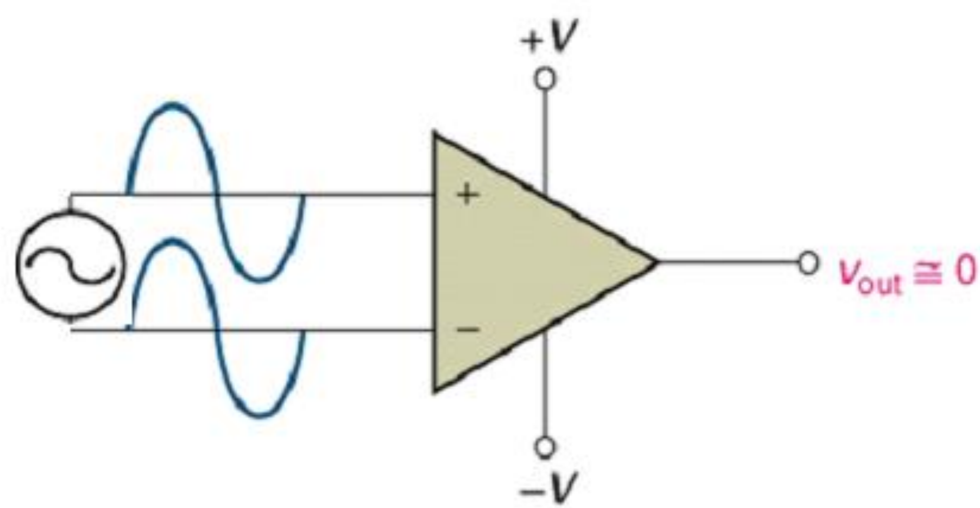
Common Mode

- Gain: Very Small
- Output Voltage: Very Small
- Input Impedance: Very High
- Output Impedance: Low



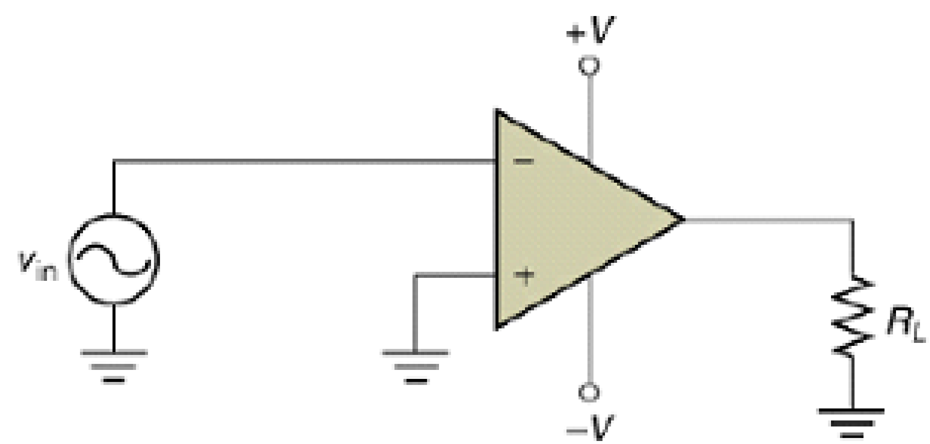
Differential Mode

- Gain: Very Small
- Output Voltage: Very Small
- Input Impedance: Very High
- Output Impedance: Low



Open Loop Mode

- Gain: Very High (100,000 – 200,000)
- Output Voltage: Supply Voltage
- Input Impedance: Very High
- Output Impedance: Low



Frequency Response

Manufacturers rate OP Amps with a frequency response rating called Slew-Rate (V / u sec)

A typical slew rate for an AP Amp may be:

0.5 V/u sec

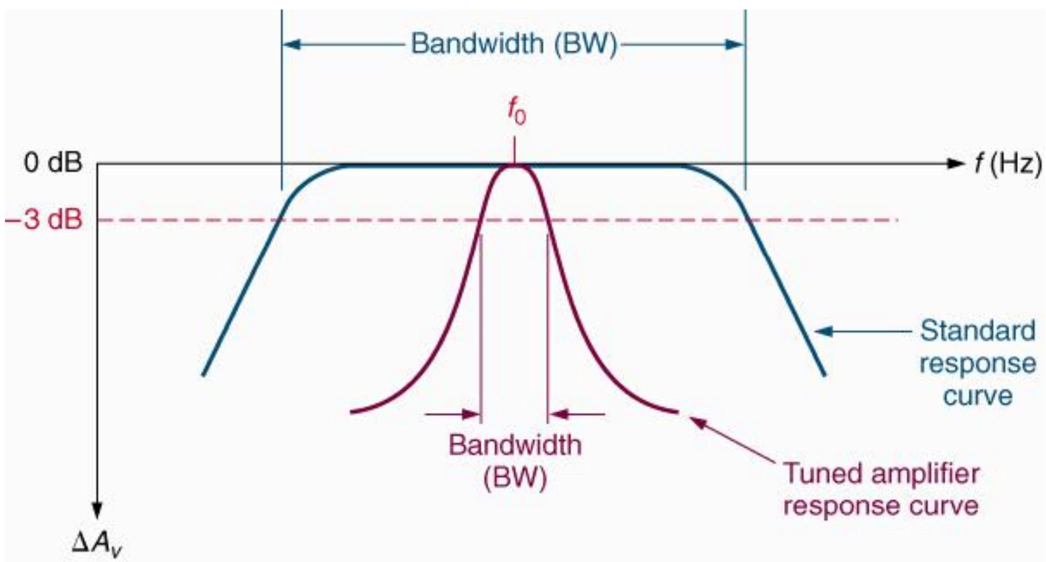
Frequency $_{MAX}$ = Slew Rate / (2 X ˝ X V_p)

As you can see, the output voltage V_p is a part of the formula to calculate the high frequency point and as it increases, the frequency decreases

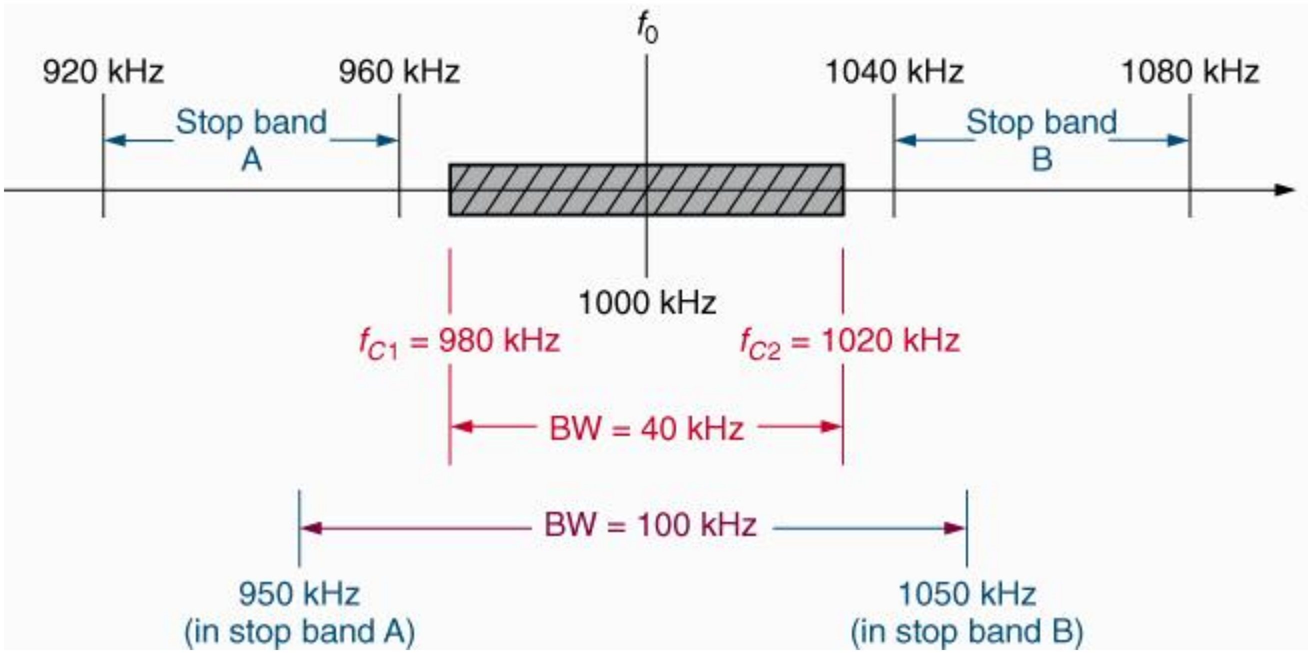
Bandwidth

Bandwidth is the High Frequency – Low Frequency of an amplifier

It is the frequency range that the amplifier can amplify a signal with no loss in gain

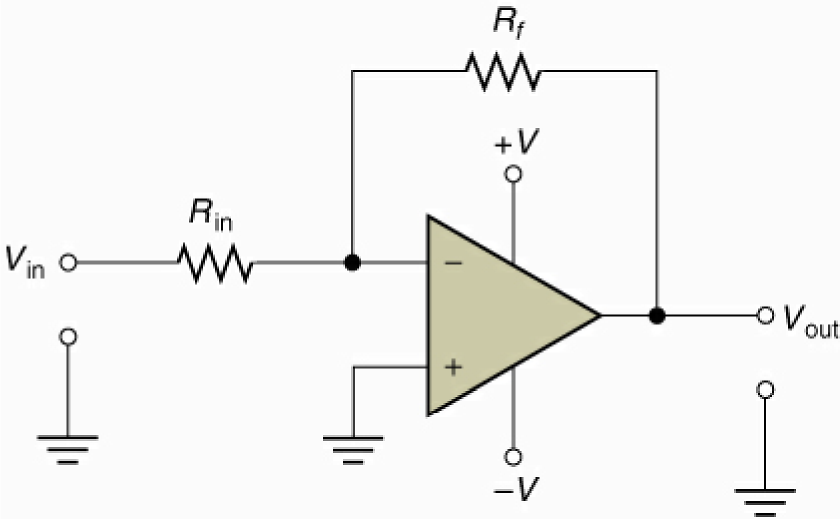


Bandwidth


f_0
920 kHz
960 kHz
1040 kHz
1080 kHz
Stop band A
Stop band B
f
1000 kHz
f_{C1} = 980 kHz
f_{C2} = 1020 kHz
BW = 40 kHz
BW = 100 kHz
950 kHz (in stop band A)
1050 kHz (in stop band B)

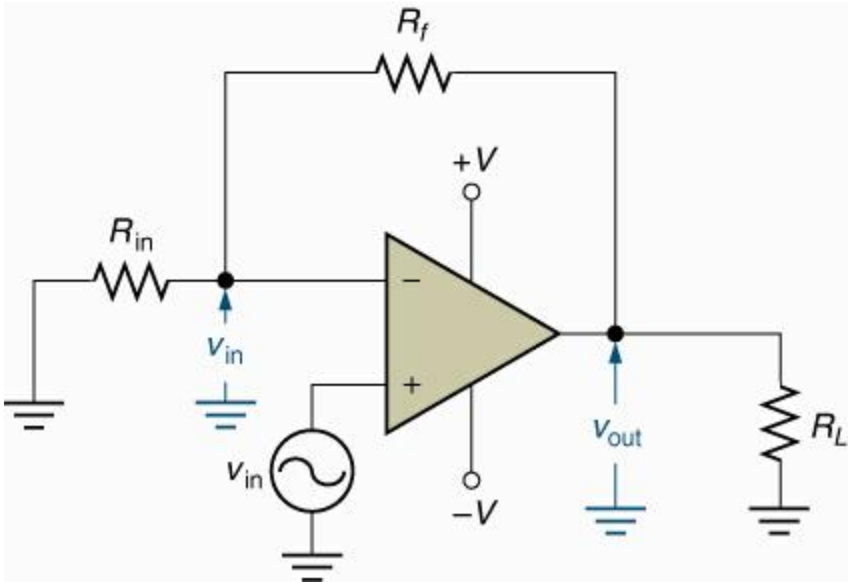
Inverting Amplifier

- Gain: $A_V = R_f / R_i$
  Controlled by the selection of 2 resistors
- Output Voltage: Vin $_{peak}$ X A_V = Output Voltage $_{peak}$
- Input Impedance: R_i
- Output Impedance: Low



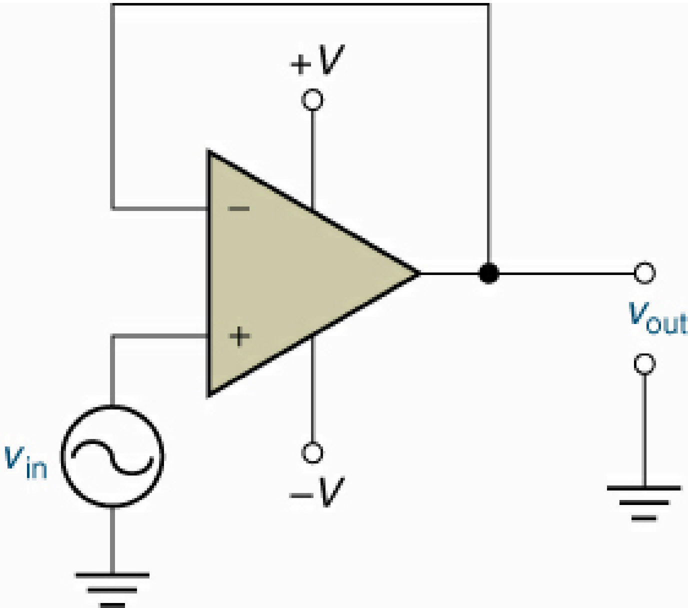
Non-Inverting Amplifier

- Gain: $A_V = (R_f / R_i) + 1$
  Controlled by the selection of 2 resistors
- Output Voltage: $Vin_{peak} \times A_V = \text{Output Voltage}_{peak}$
- Input Impedance: Very High (OP Amp)
- Output Impedance: Low



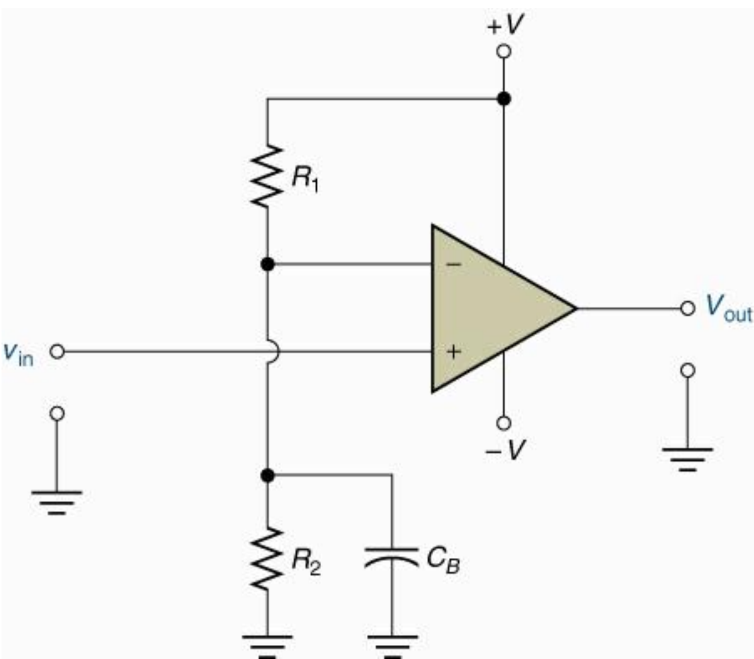
Unity Gain Amplifier

- Gain: $A_V = 1$
- Output Voltage: $\text{Vin}_{\text{peak}} \times 1 = \text{Output Voltage}_{\text{peak}}$ (same)
- Input Impedance: Very High (OP Amp)
- Output Impedance: Low



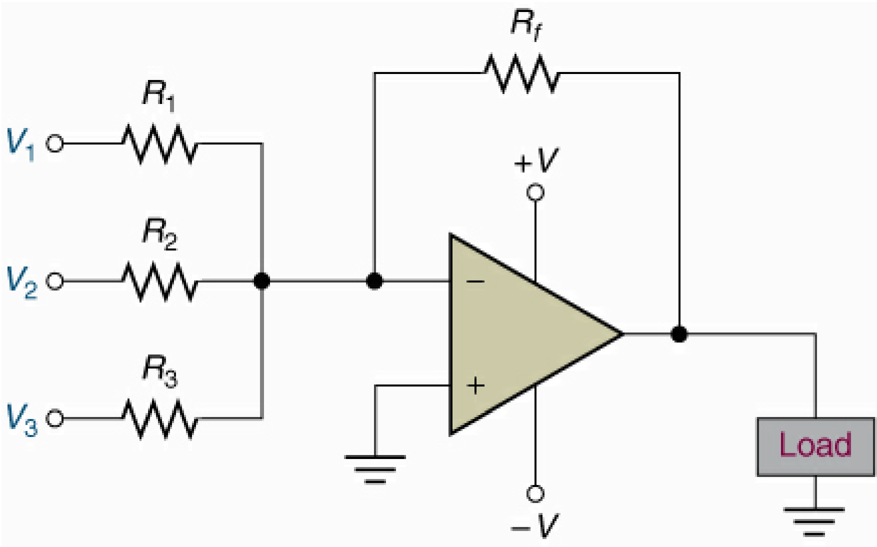
Comparator Amplifier

- Gain: Open Loop
- Output Voltage: +V, 0 or –V and is based upon the inverting and non-inverting inputs (which is larger)
- Input Impedance: Very High (OP Amp)
- Output Impedance: Low



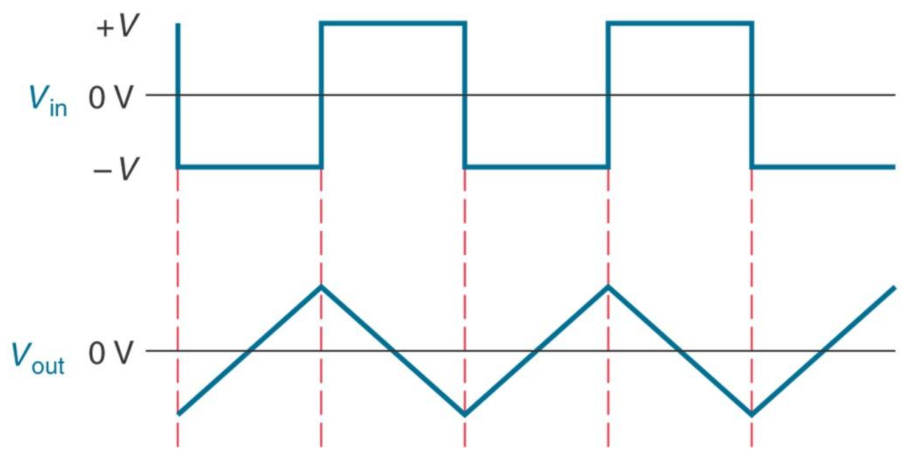
Summing Amplifier

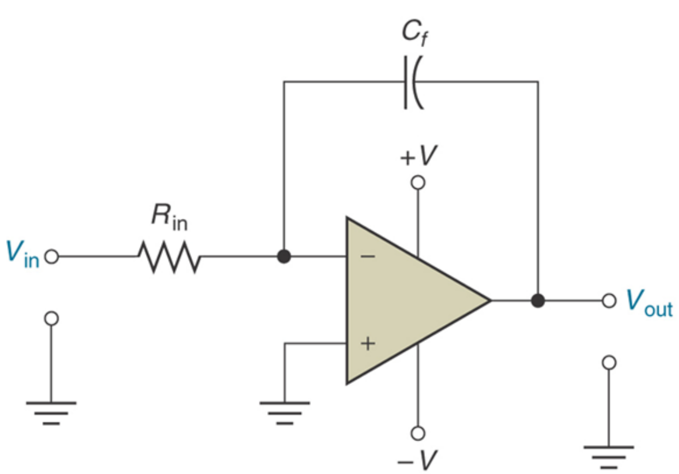
- Gain: $A_V = R_f / R_i$ (for each input voltage)
  Controlled by the selection of 2 resistors
- Output Voltage: $V_{out} = - R_f \{ (V_1/R_1)+ (V_2/R_2 + (V_3/R_3)\}$
- Input Impedance: R_1 or R_2 or R_3
- Output Impedance: Low



Integrator Amplifier

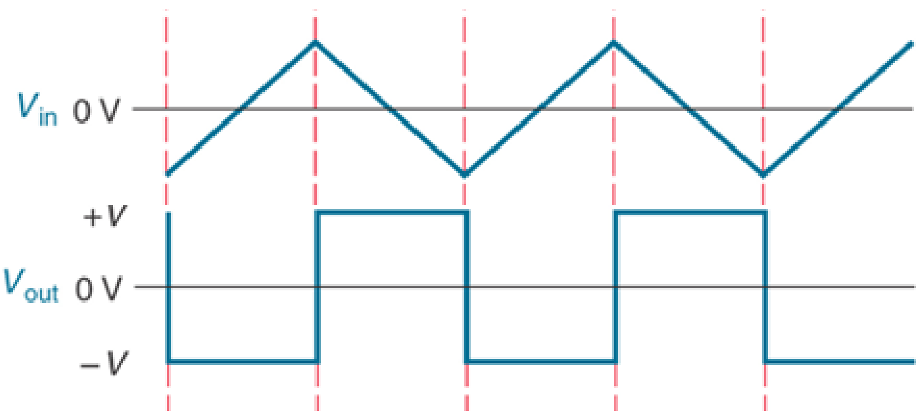
- Input Voltage: Square Wave
- Output Voltage: Triangular Wave
- Input Impedance: R_{in}
- Output Impedance: Low

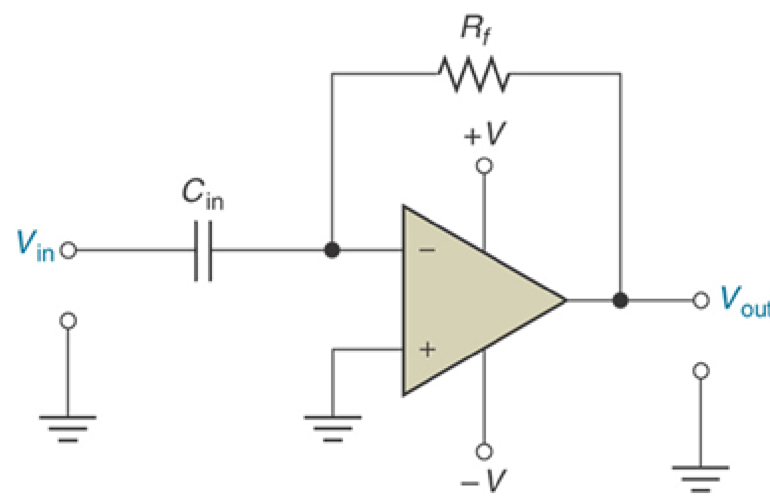




Differentiator Amplifier

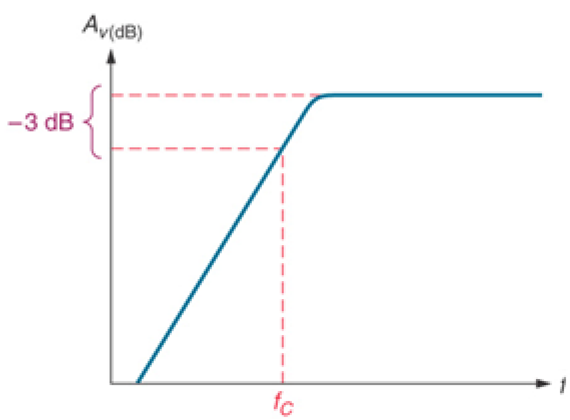
- Input Voltage: Triangular Wave
- Output Voltage: Square Wave
- Input Impedance: R_{in}
- Output Impedance: Low



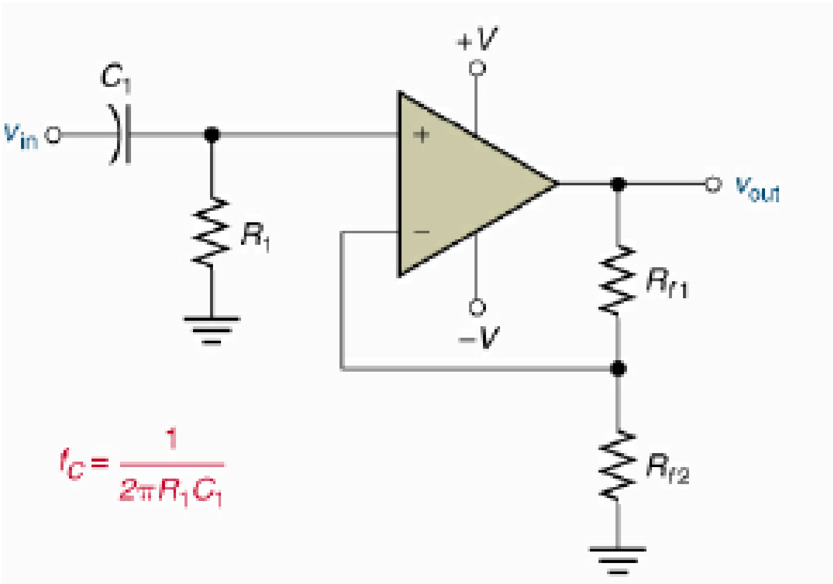


High Pass Active Filter

An OP Amp used to filter out all low frequencies and only allow high frequencies to pass

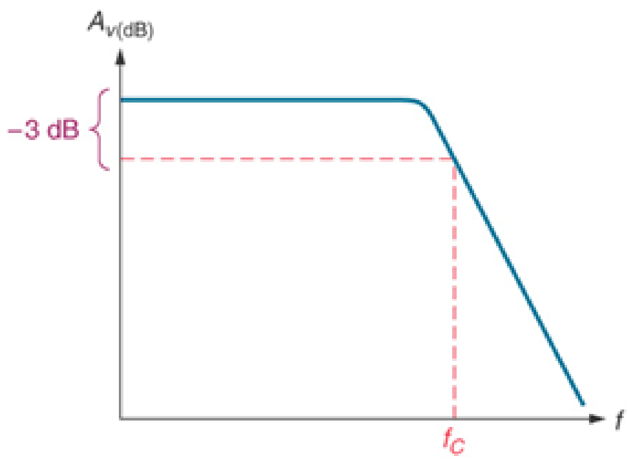


(b) High-pass

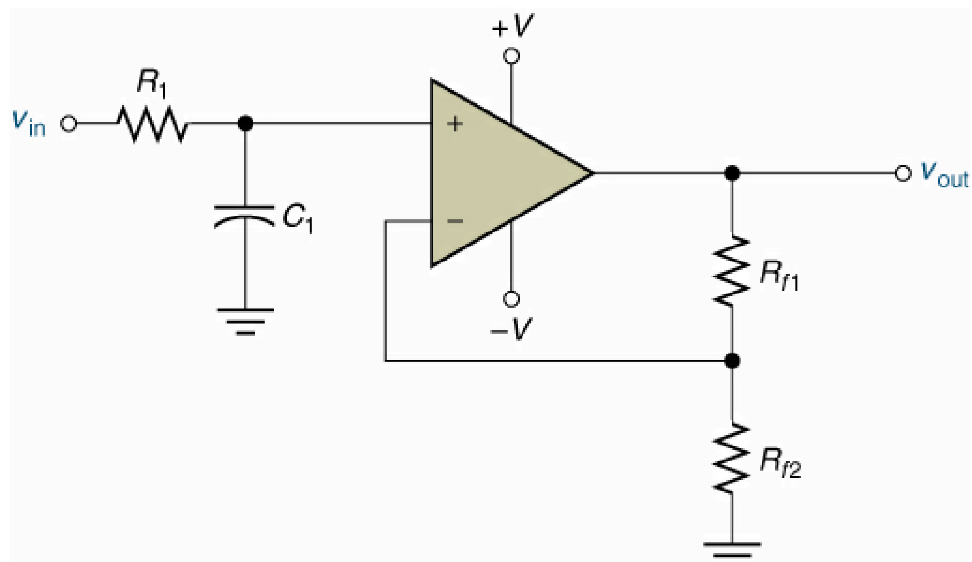


Low Pass Active Filter

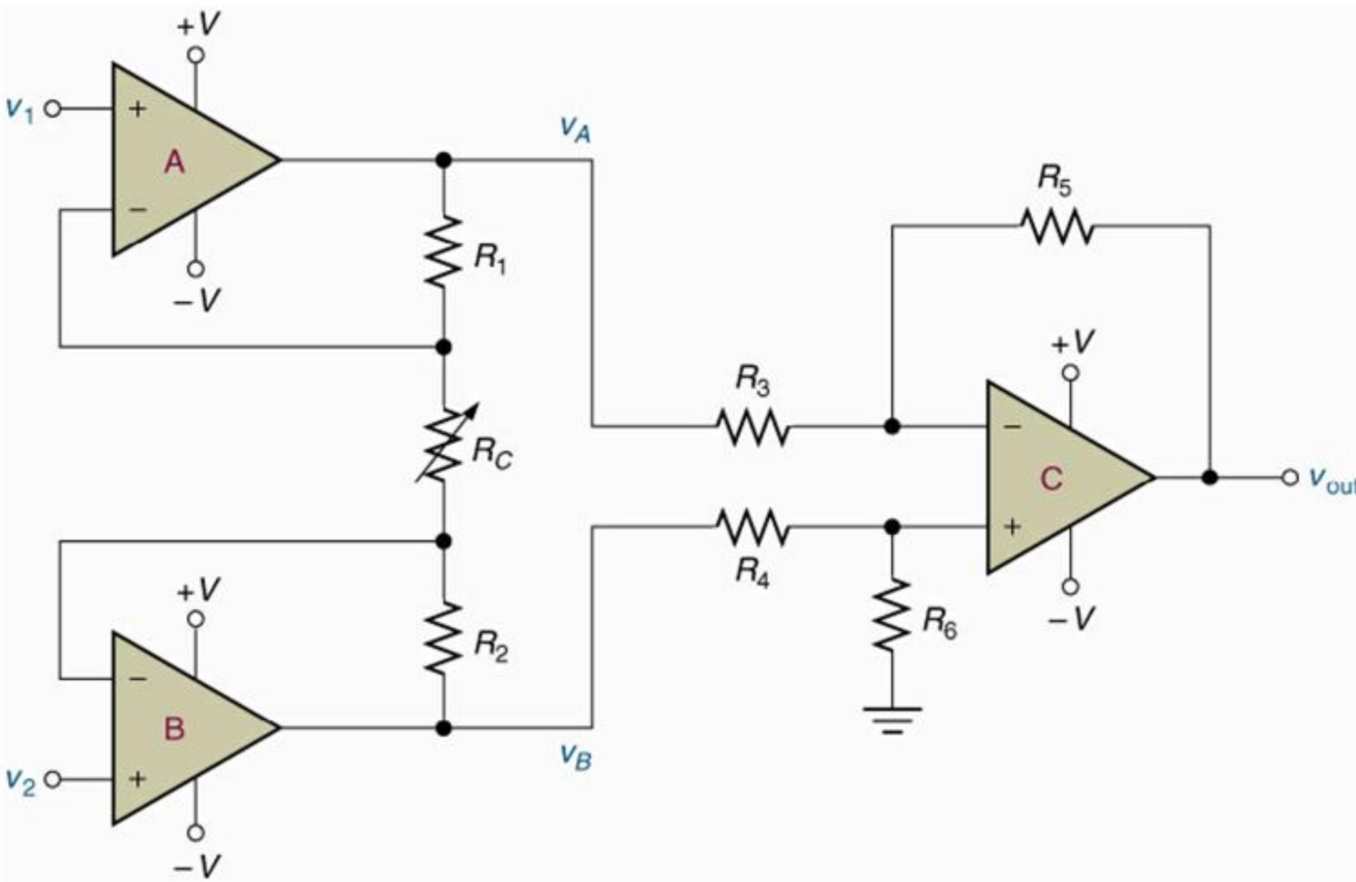
An OP Amp used to filter out all high frequencies and only allow low frequencies to pass



(a) Low-pass



Instrumentation Amplifier



Transistors

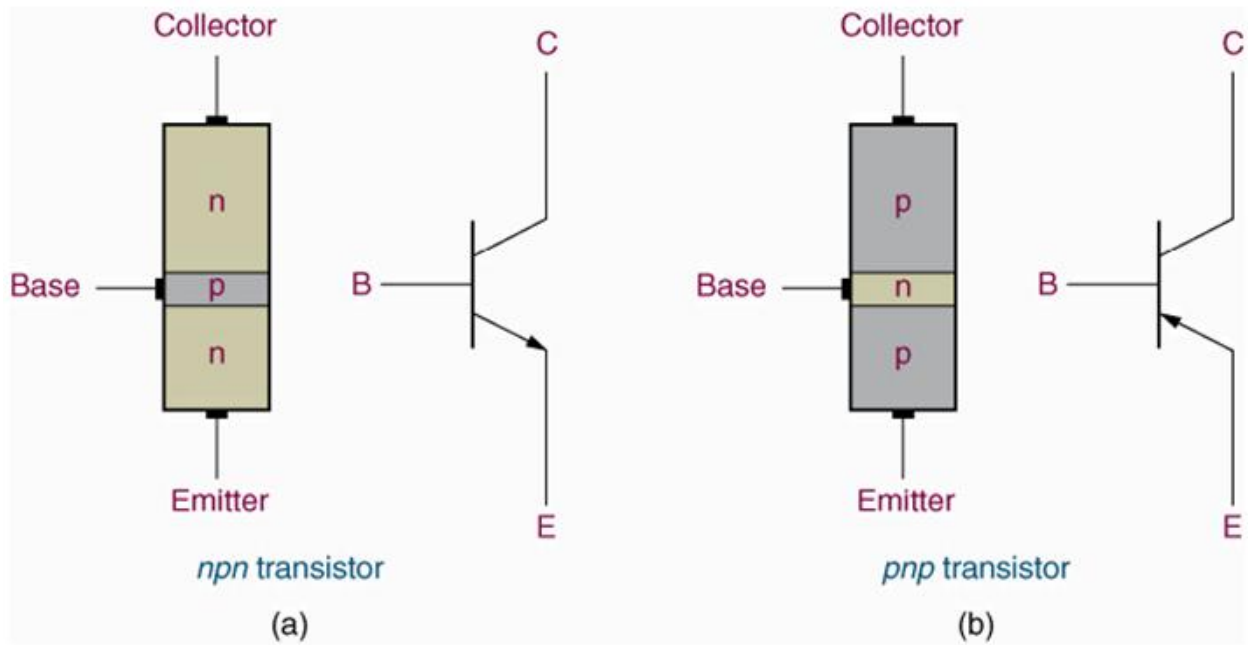
Bipolar Junction Transistor (BJT) – is a three terminal device whose output current, voltage and power are controlled by input current

There are 2 main applications for BJTs

- Amplifier – A circuit used to increase the signal of an AC signal
- Switch – An electronic switch that is controlled by input current and can switch DC current through the other two leads

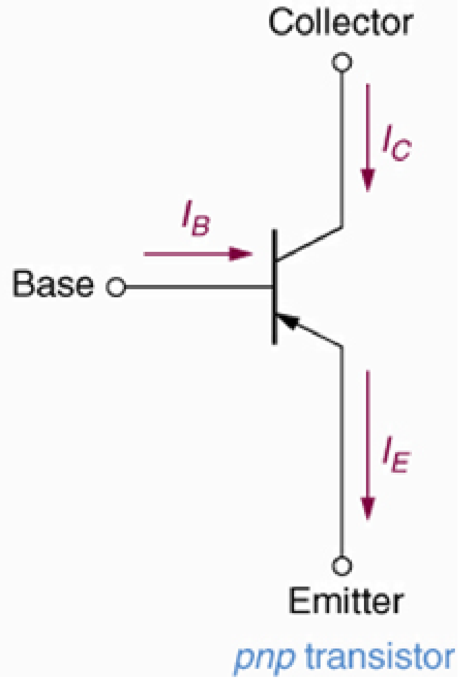
Bipolar Junction Transistor (BJT) - Transistor

- Types
  - NPN
  - PNP
- Leads
  - Base
  - Emitter
  - Collector



Current Gain – Beta (β) the factor by which current increases from the base of a transistor to it's collector

- $I_C = \beta * I_B$



Amplifier – the transistor is used in the Active state and has current flowing

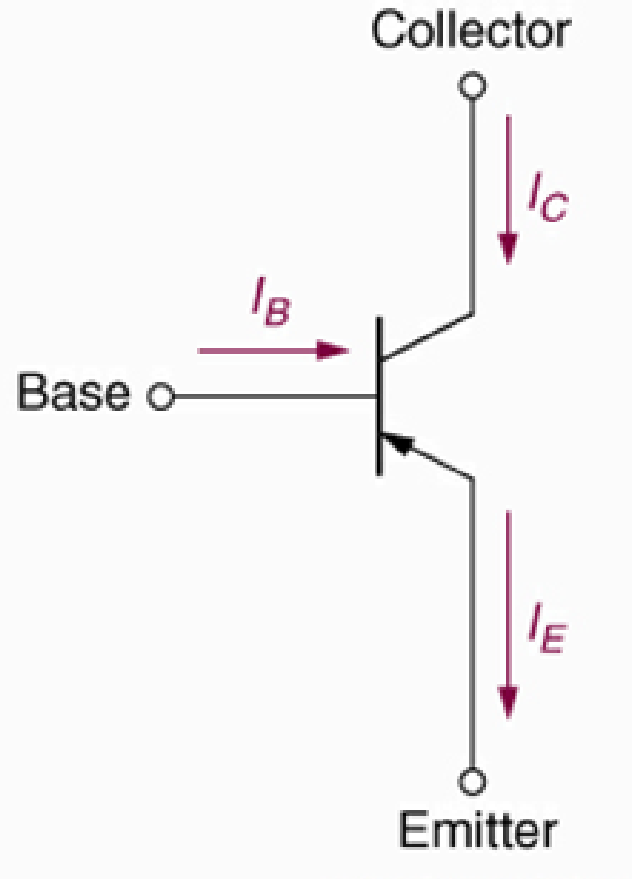
- Base-Emitter is forward biased
- Collector-Base is reversed biased
- $I_C > 0$ and less than Max

Switch – the transistor is on or off and operates in the:

- Cutoff – No Current Flow in transistor $I_C = 0$
- Saturation – Max current through collector $I_C = Max$

Transistor Currents

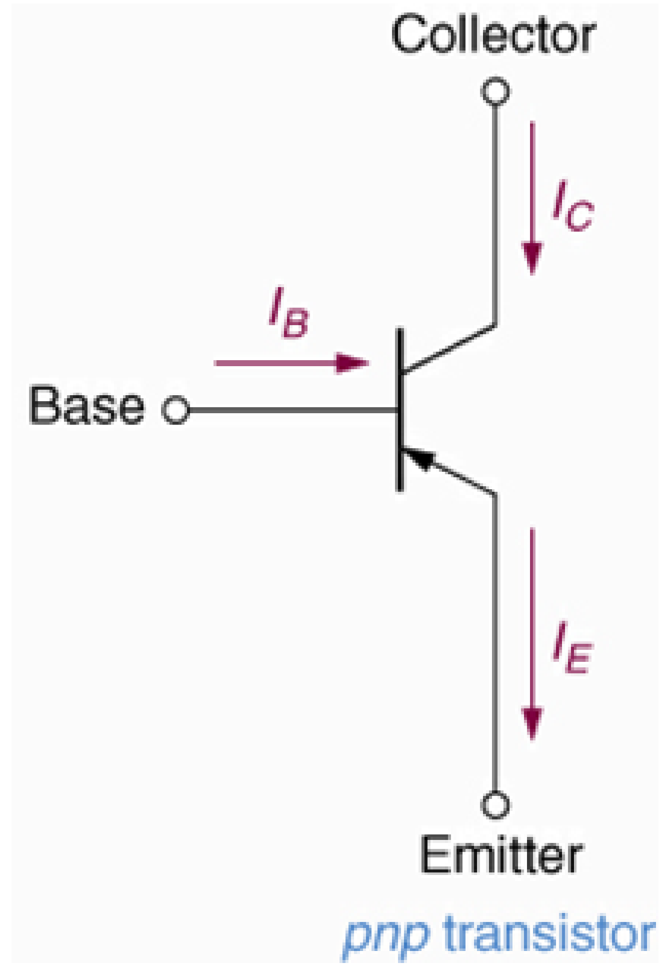
- $I_C = \beta * I_B$
- $I_E = I_B + I_C$
- $I_E \sim I_C$



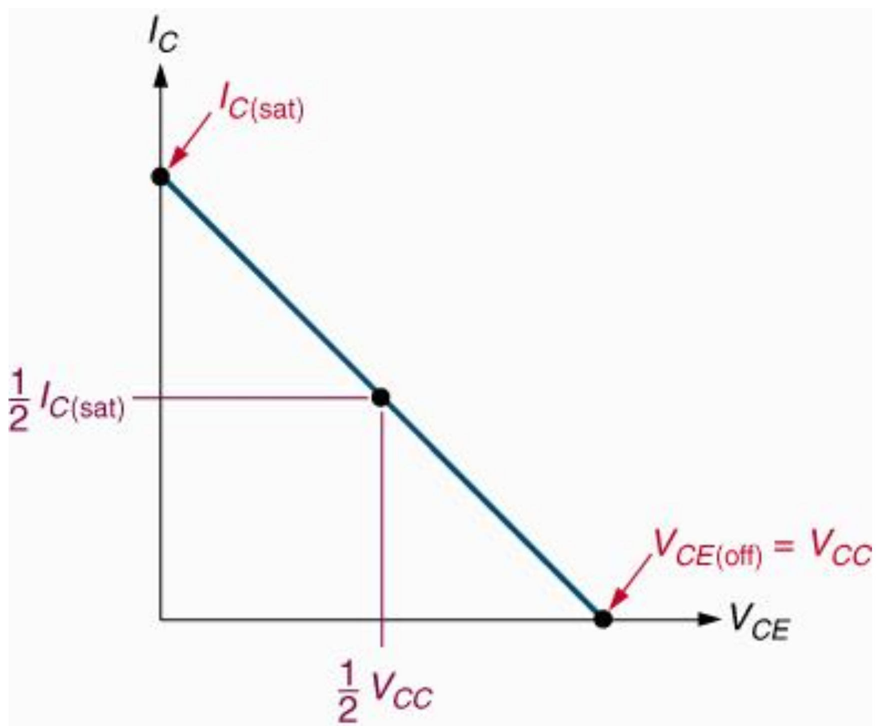
pnp transistor

Transistor Currents - Beta

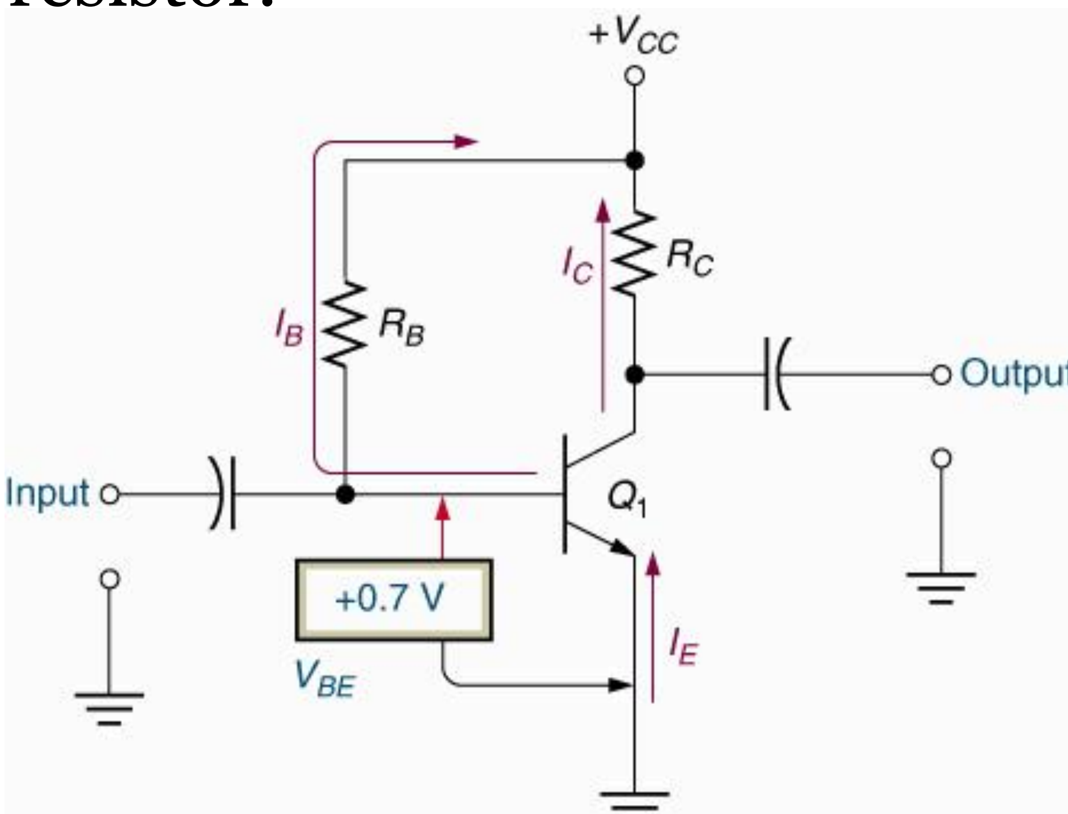
- $I_C = \beta * I_B$
- $I_E = I_B (\beta + 1)$
- $\alpha = I_C / I_B$
- $\alpha = \beta / (\beta + 1)$



Q Point – A point on the DC load line that indicates the values of V_{CE} and I_C for the amplifier at rest. This point is found by taking ½ of the $I_{C(sat)}$ and $V_{ce(off)}$



Base Bias – Consists of a single base resistor between the base terminal and V_{CC} and no emitter resistor.



Base Bias Design

$I_{C(sat)} = (V_{cc} / R_c)$

$V_{ce(Q)} = V_{cc} / 2$

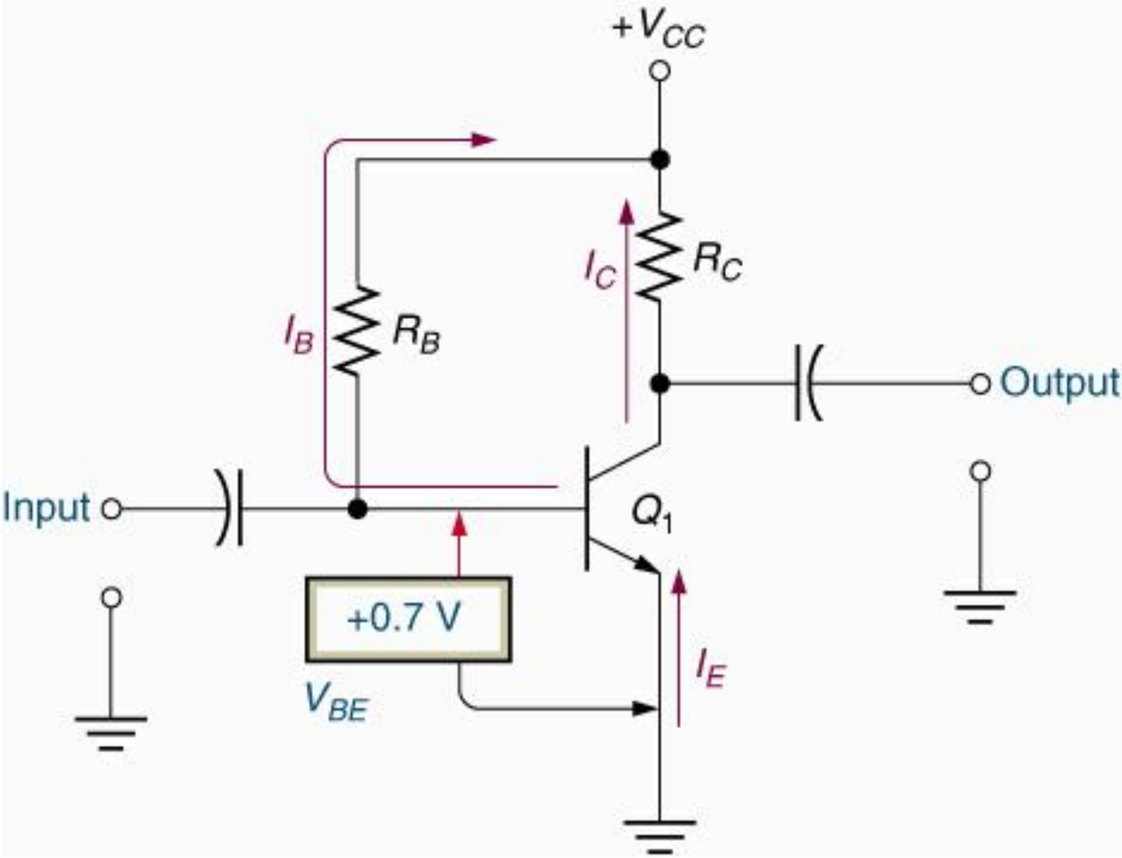
$V_{RB} = V_{cc} - 0.7$

$I_B = V_{RB} / R_B$

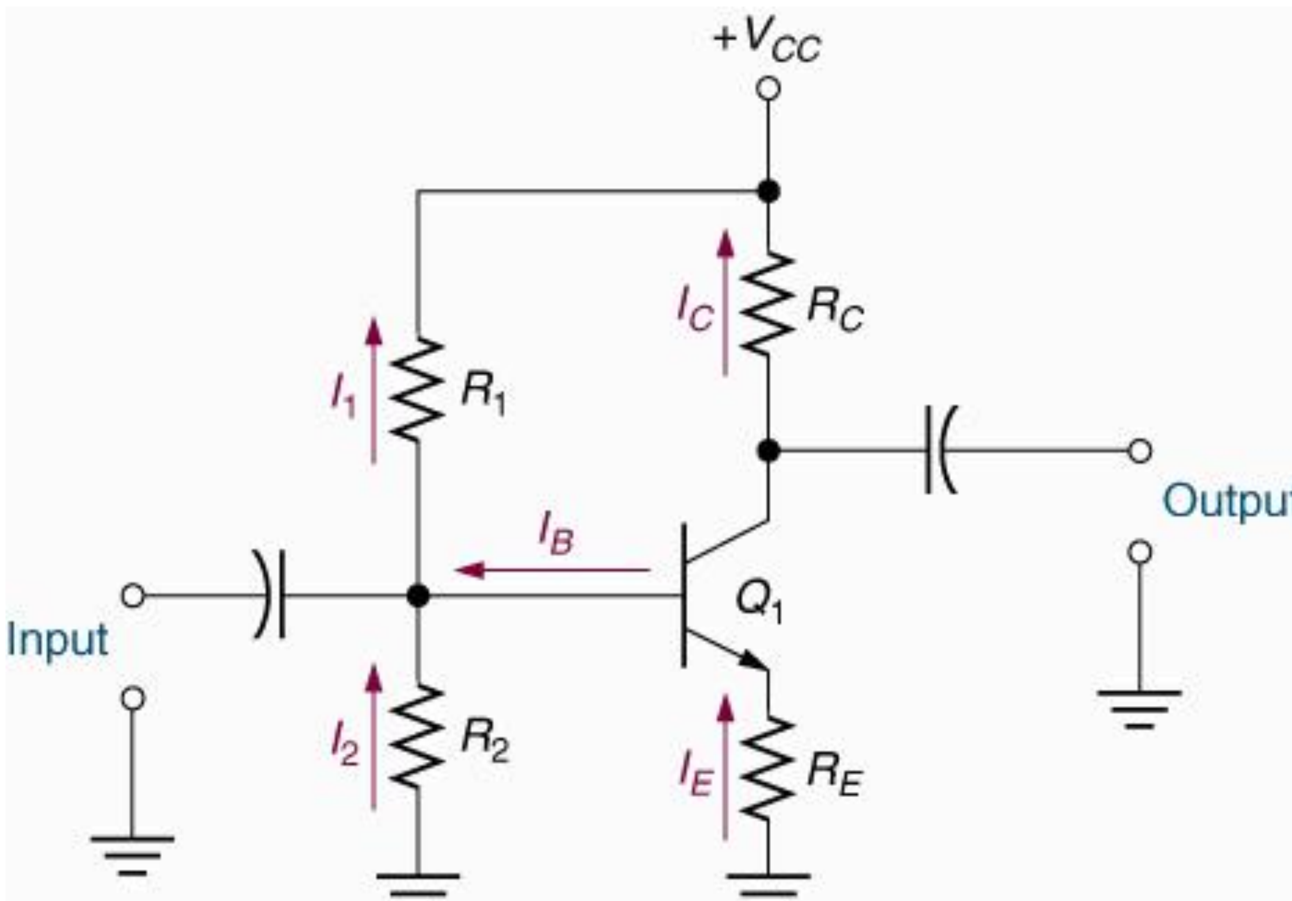
$I_C = h_{FE} \times I_B$

$V_{RC} = R_C \times I_C$

$V_{CE} = V_{CC} - V_{RC}$



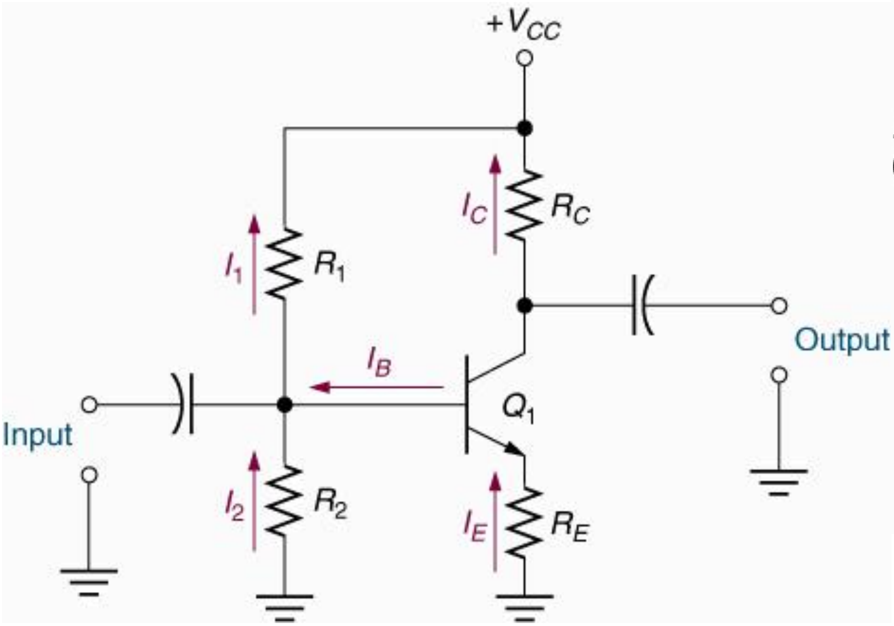
Voltage Divider Bias – A biasing circuit that contains a voltage divider in it's base circuit. Also called a Universal Bias.

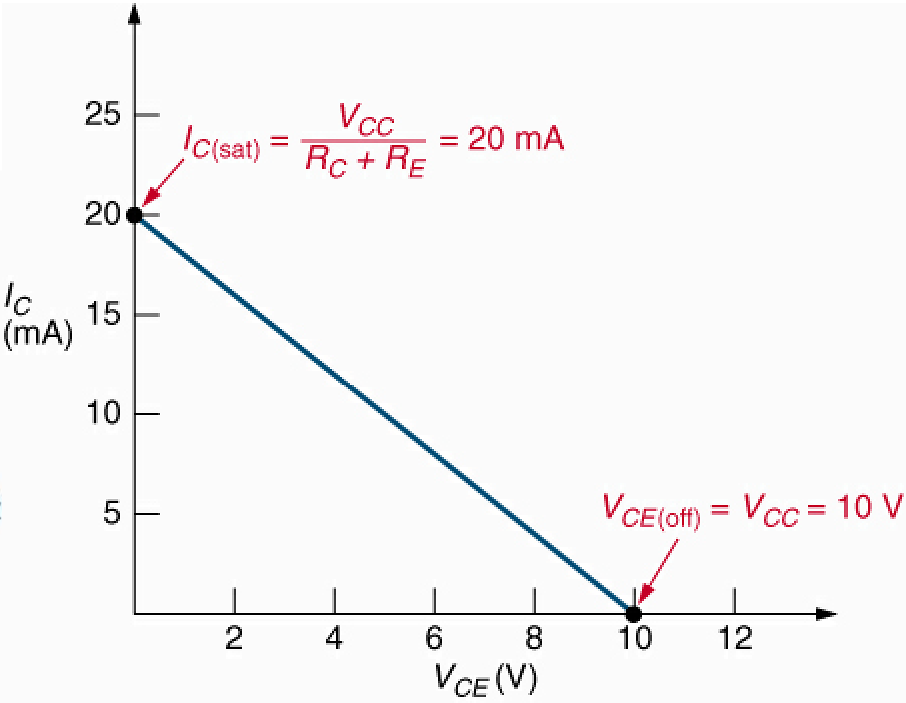


Voltage Divider Bias Design

$I_{C(sat)} = V_{cc} / (R_c + R_E)$

$V_{ce(off)} = V_{cc}$





Voltage Divider Bias Design

$R_t = R_1 + R_2$ $I_t = V_{cc} / R_t$

$V_B = R_2 X I_t$

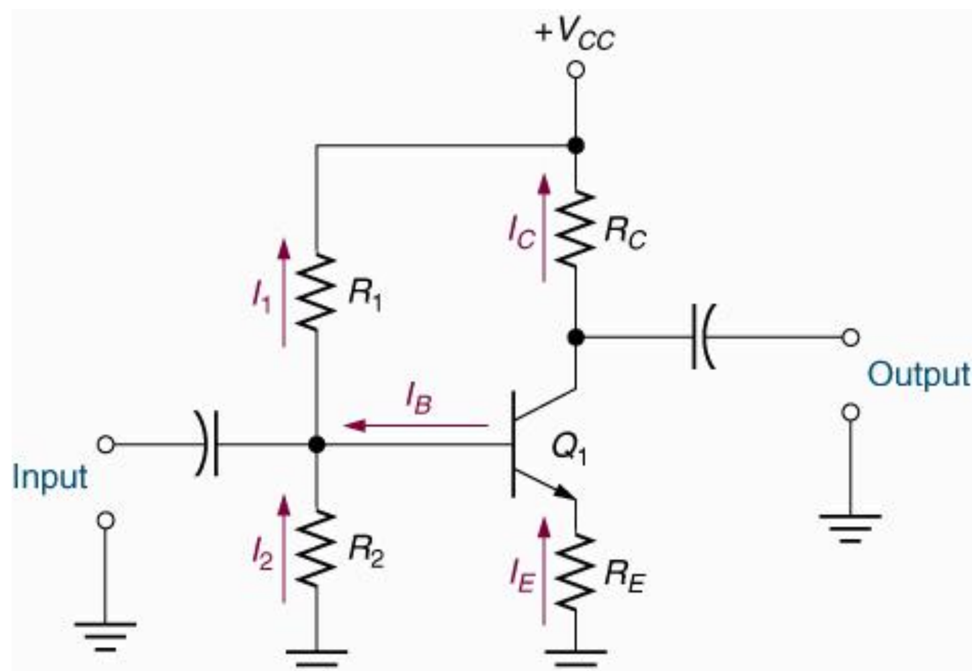
$V_E = V_B - 0.7$

$I_E = V_E / R_E$ $I_C = I_E$

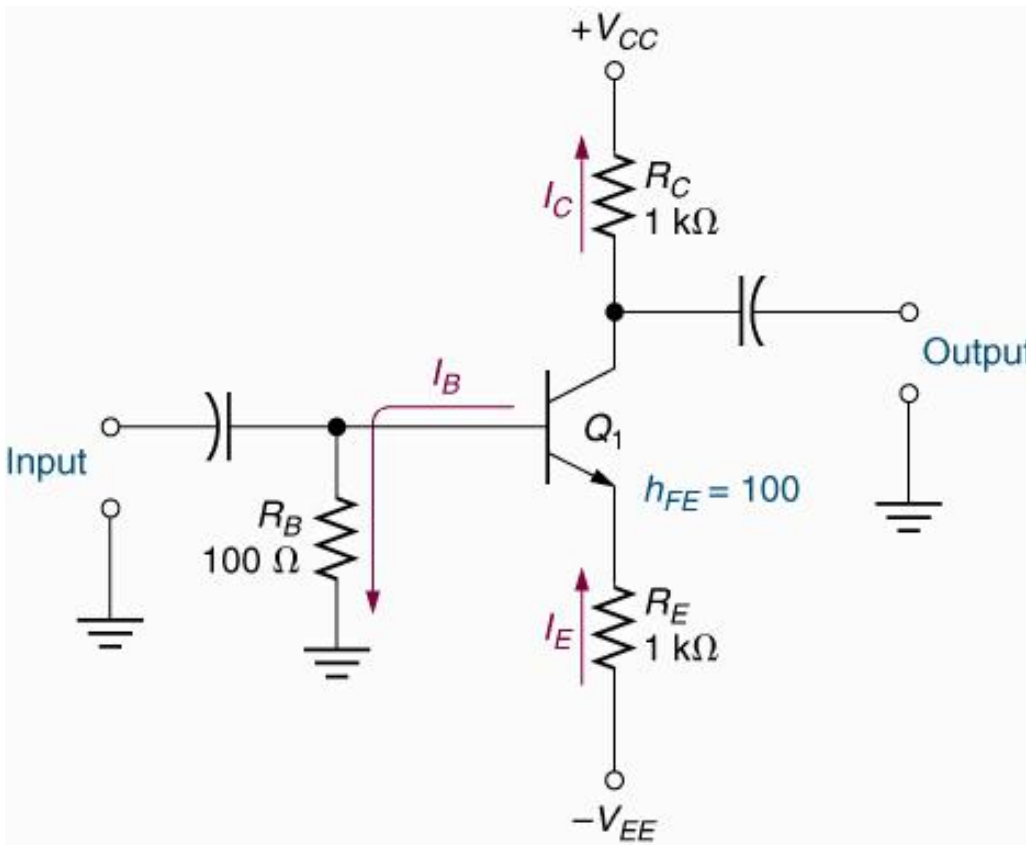
$I_B = I_E / (h_{FE} + 1)$

$V_{Rc} = R_C X I_C$

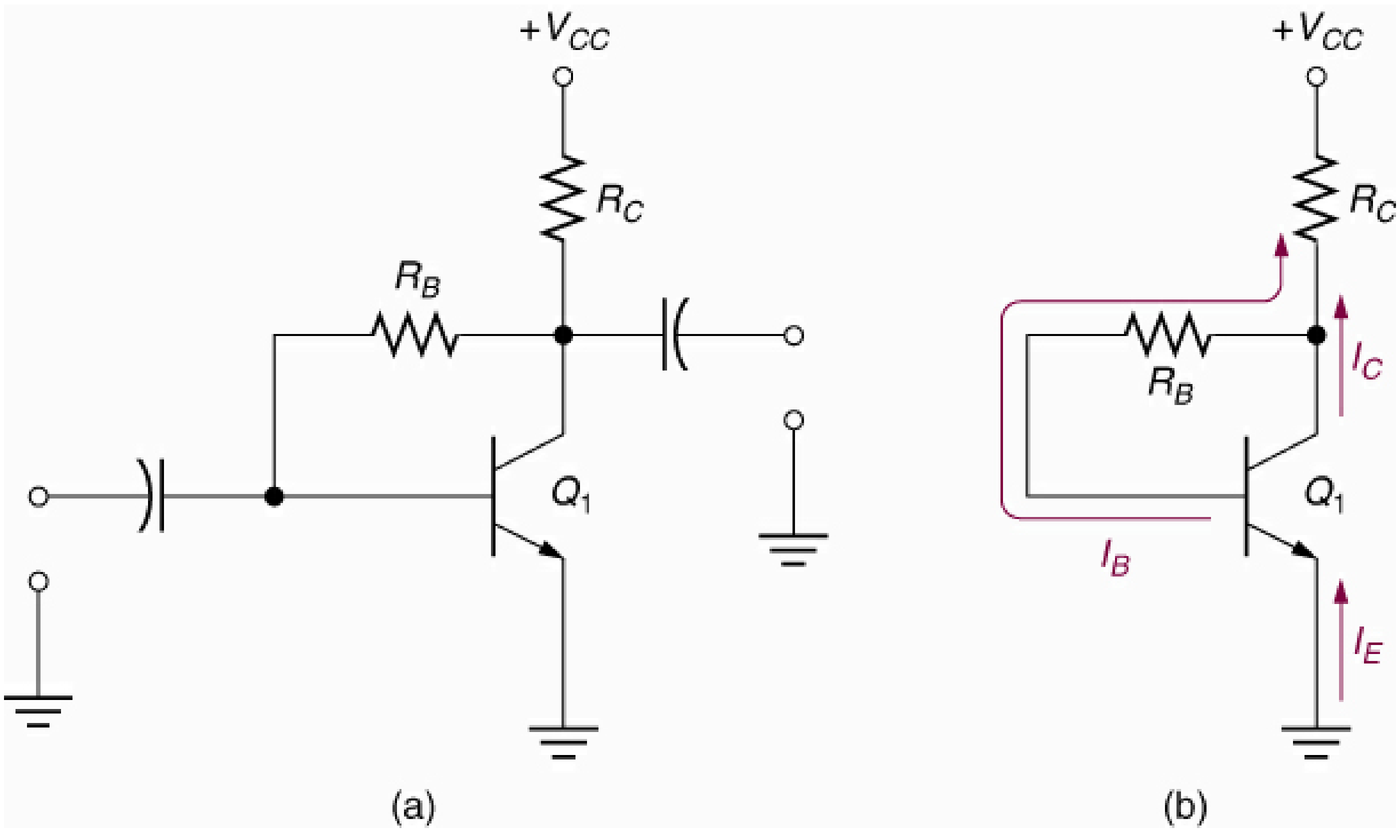
$V_{CE} = V_{CC} - V_{Rc} - V_E$



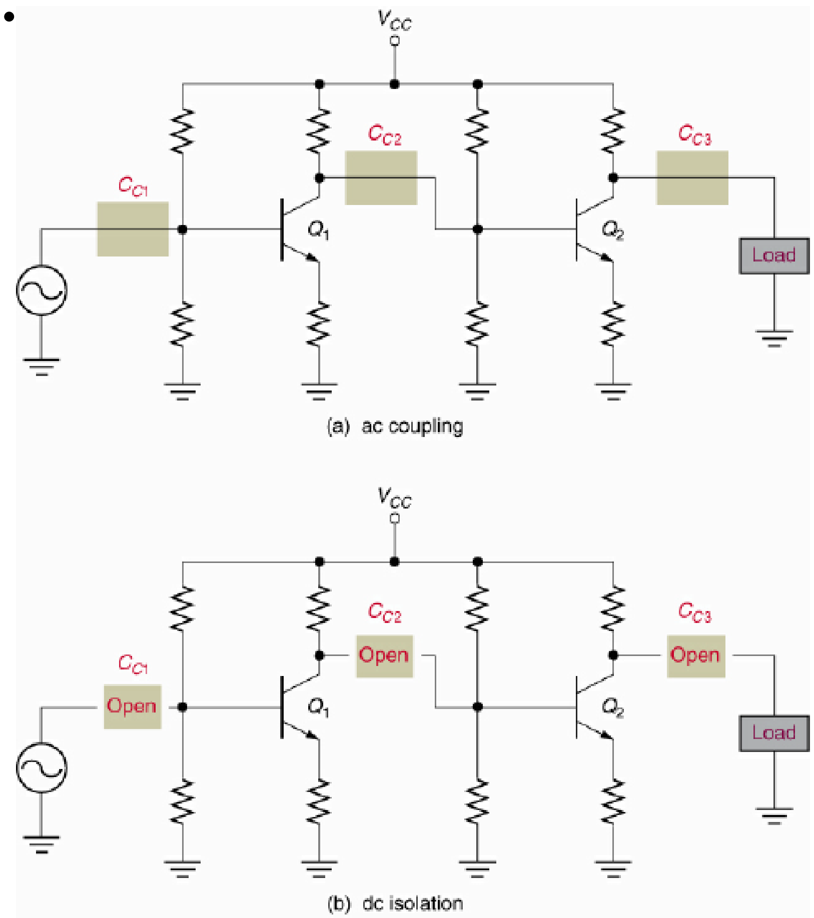
Emitter Bias – A biasing circuit that contains a dual polarity power supply and a grounded base resistor.



Feedback Bias – A biasing circuit that is constructed so that V_E will directly affect V_B.



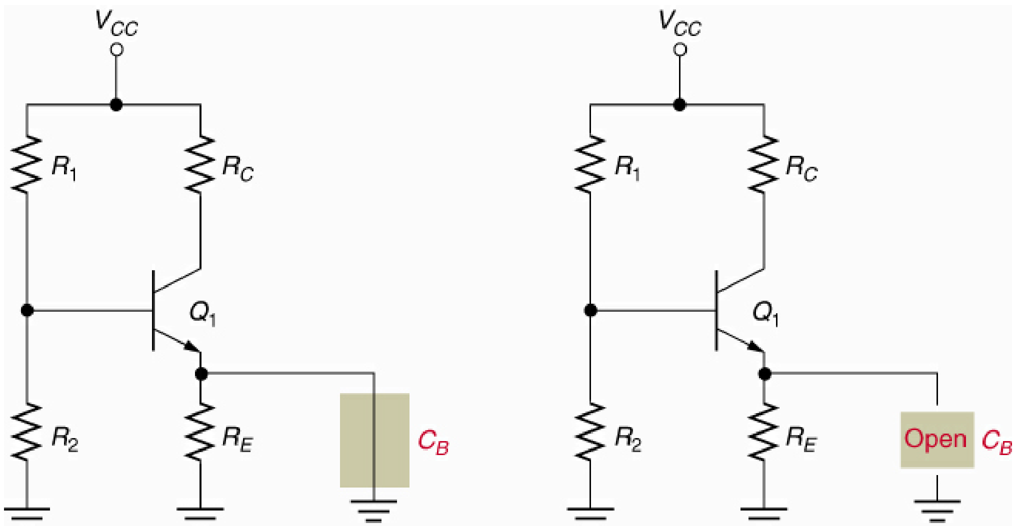
Coupling Capacitor – used between amplifier stages to block dc between the stages, while allowing the ac signal to pas through without distortion.



(a) ac coupling

(b) dc isolation

Bypass capacitor – a capacitor used to establish an ac ground at a specific point in a circuit.



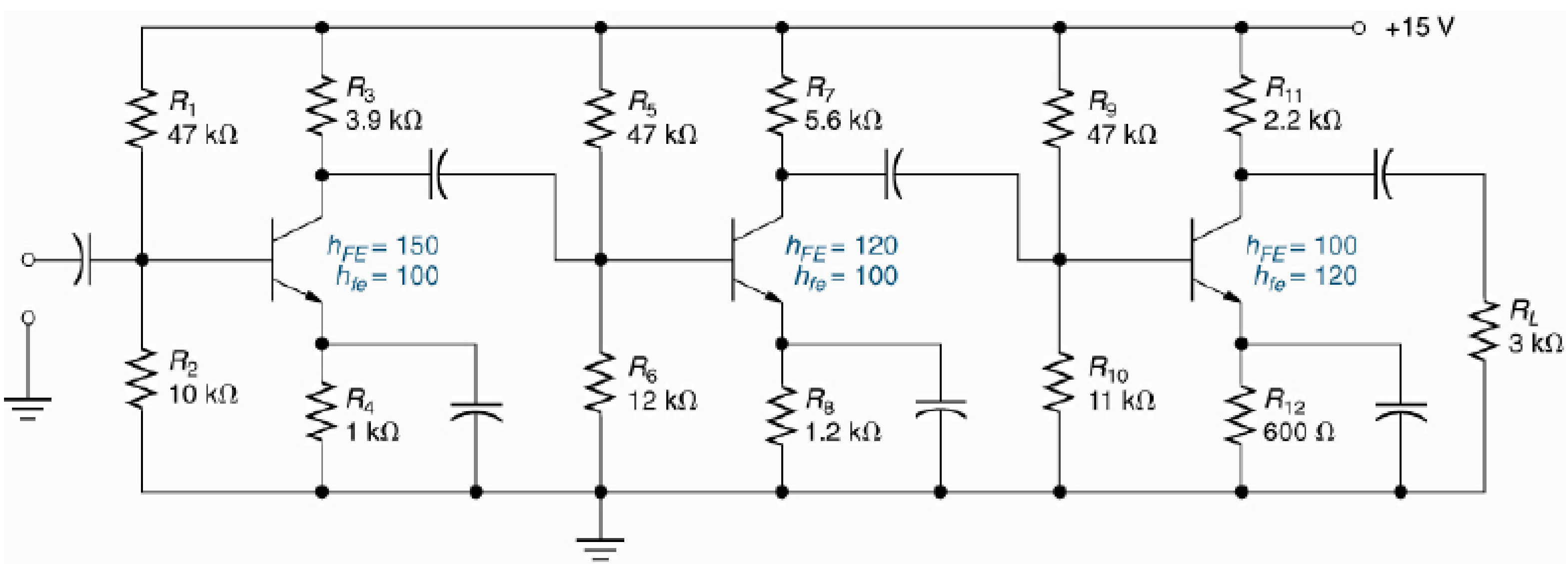
(a) The bypass capacitor as an ac short

(b) The bypass capacitor as a dc open

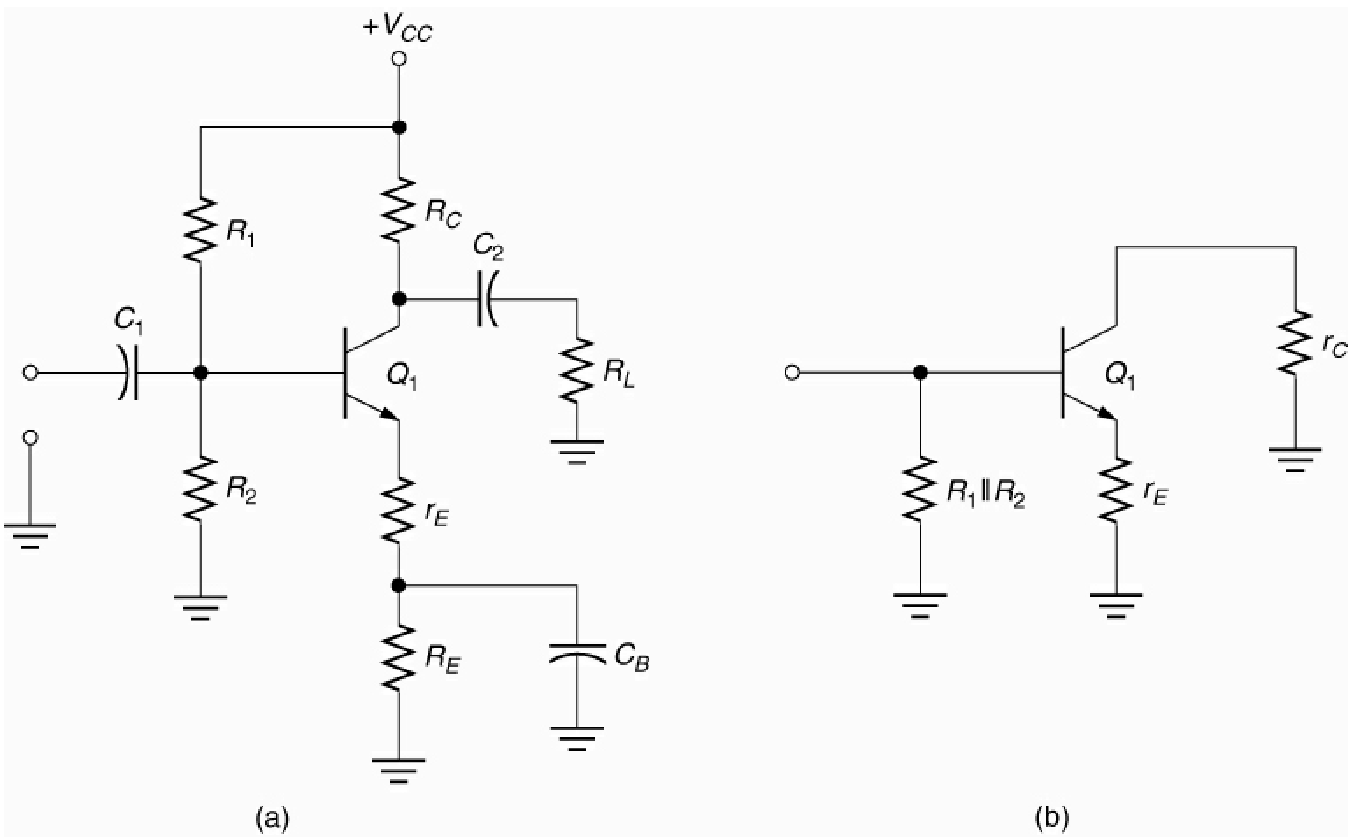
Multistage amplifier gain calculations are made by taking the gain of each individual stage times the gain of each stage

Example: DC A_{VT} = 150 x 120 x 100 = 1,800,000 or 1.8M

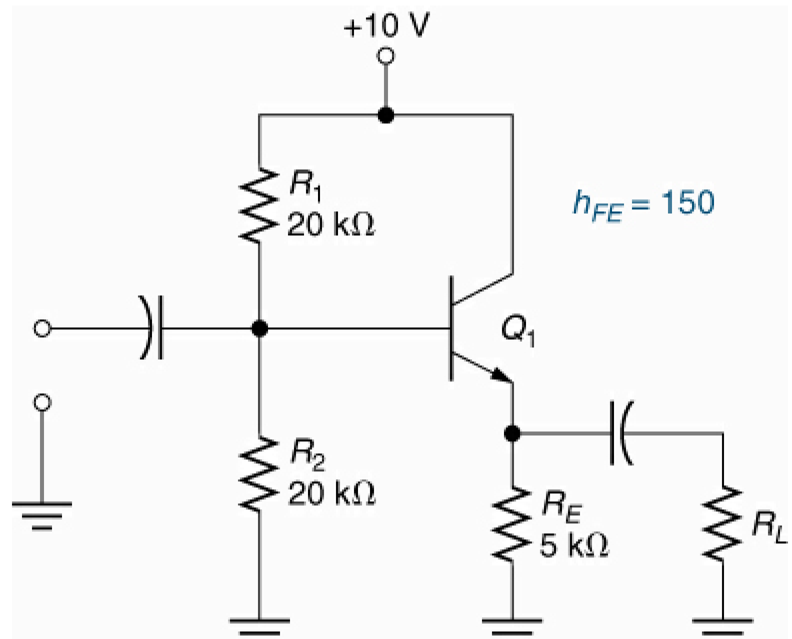
Example: AC A_{VT} = 100 x 100 x 120 = 1,200,000 or 1.2M



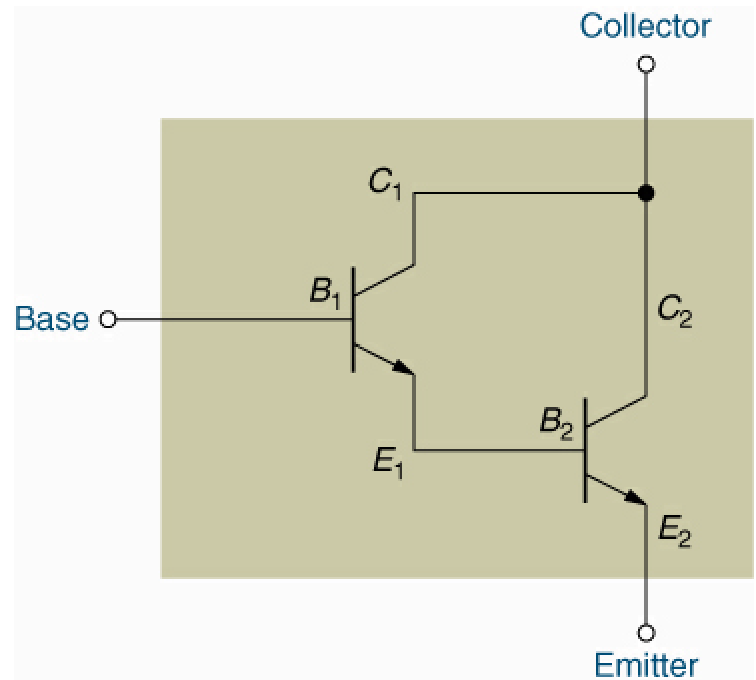
Swamped Amplifier – is an amplifier that uses a partially bypassed emitter resistance to increase the ac emitter resistance.



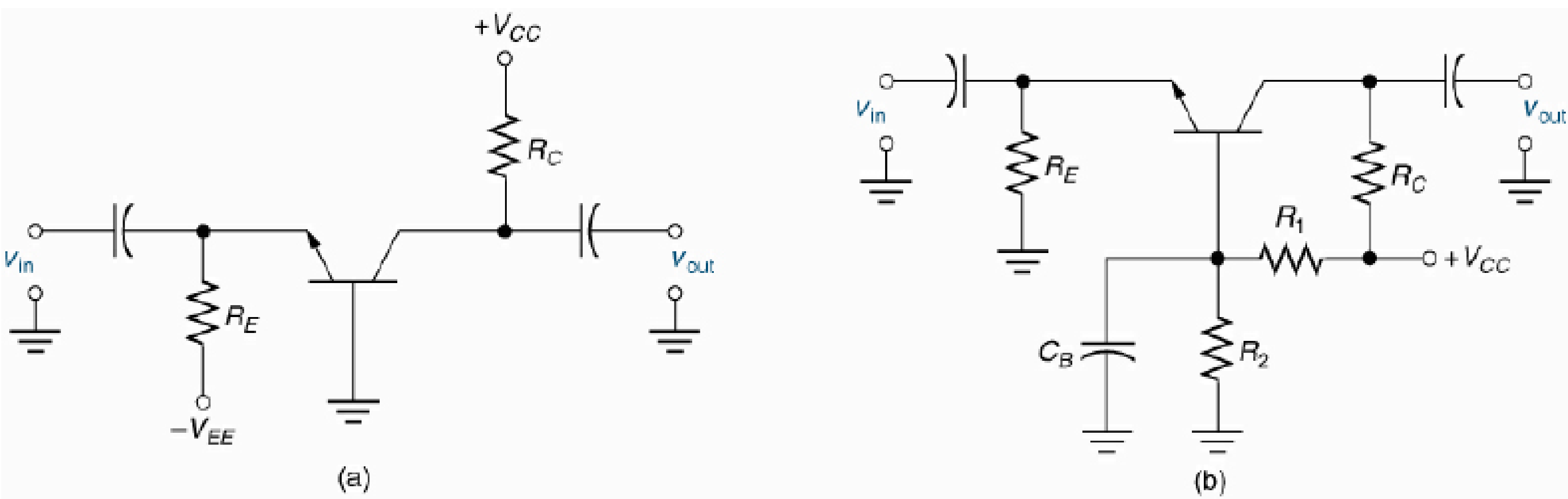
Common-collector or emitter follower amplifier – is a BJT amplifier that provides only current gain and power gain.



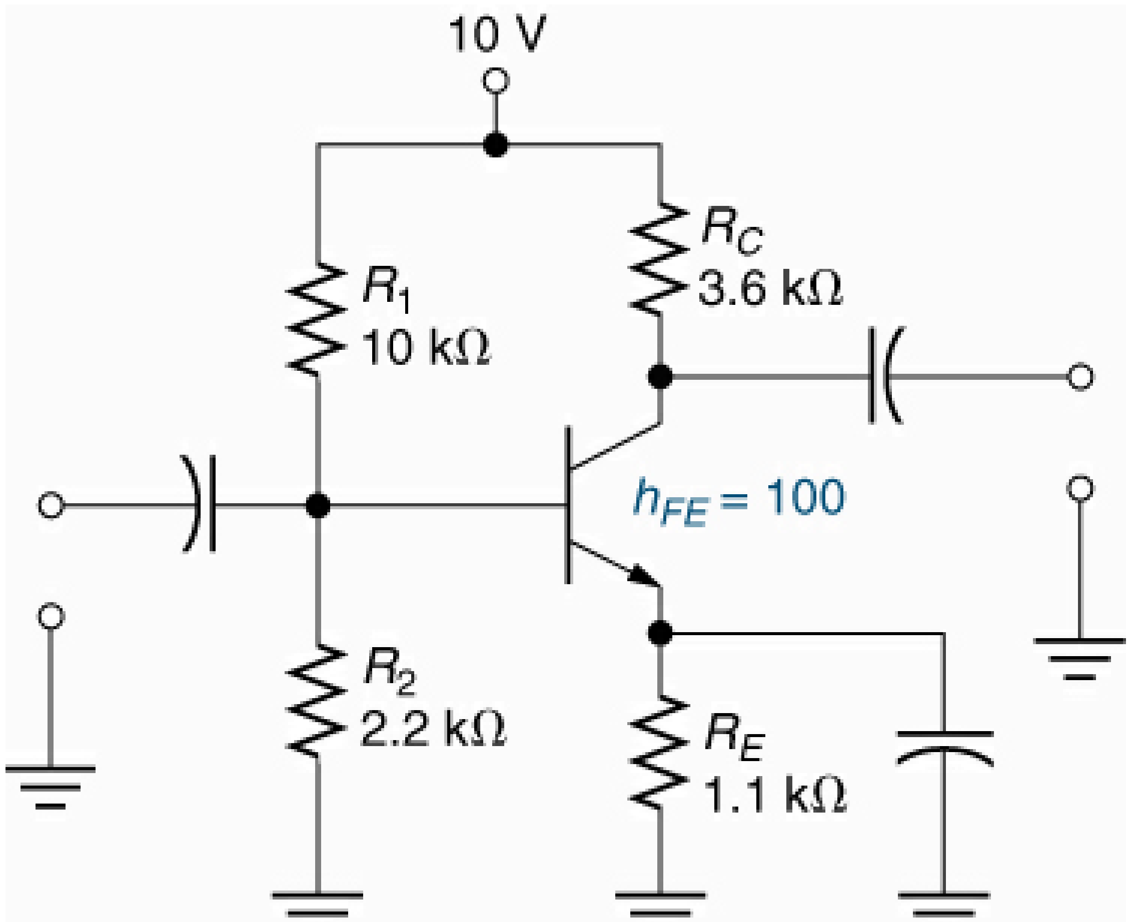
Darlington Pair – is an emitter follower that uses a specific 2-transistor configuration to provide higher values of current gain and input impedance. Two (2) transistors packaged in one case.



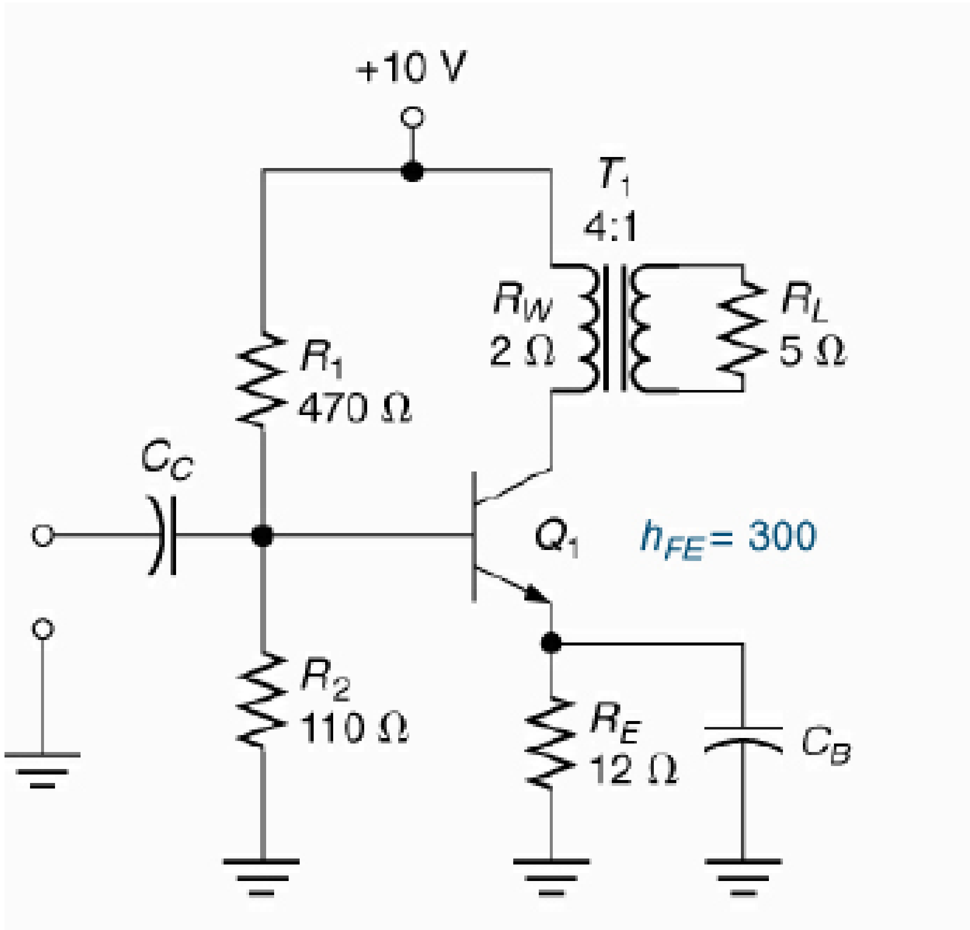
Common Base Amplifier – is an amplifier that is used to provide voltage gain with no current gain and can be used in high-frequency buffer applications.



RC Coupled Class "A" Amplifier

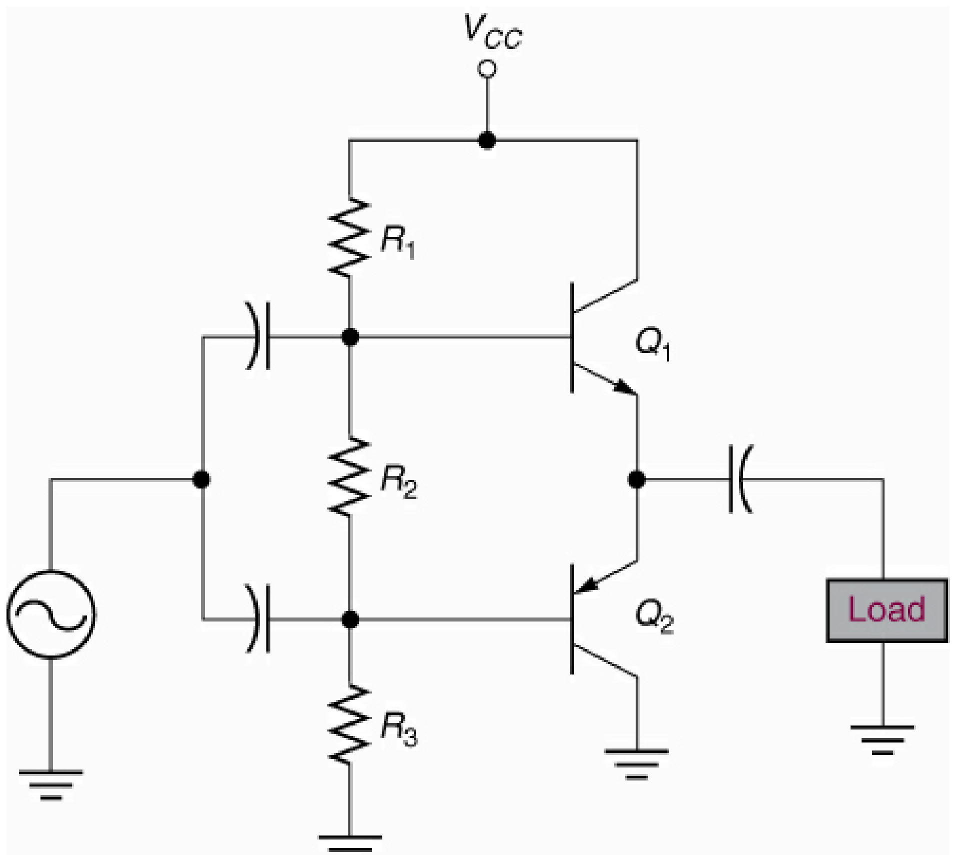


Transformer Coupled Class "A" Amplifier

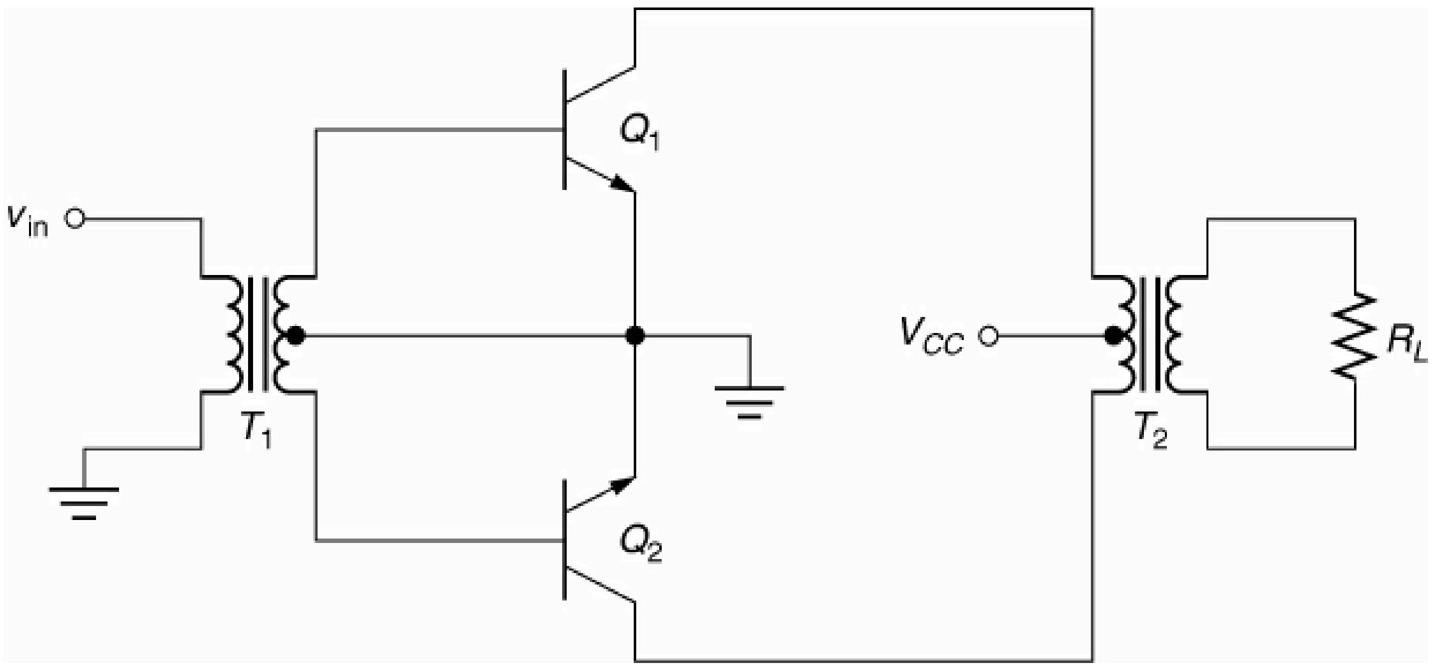


(a)

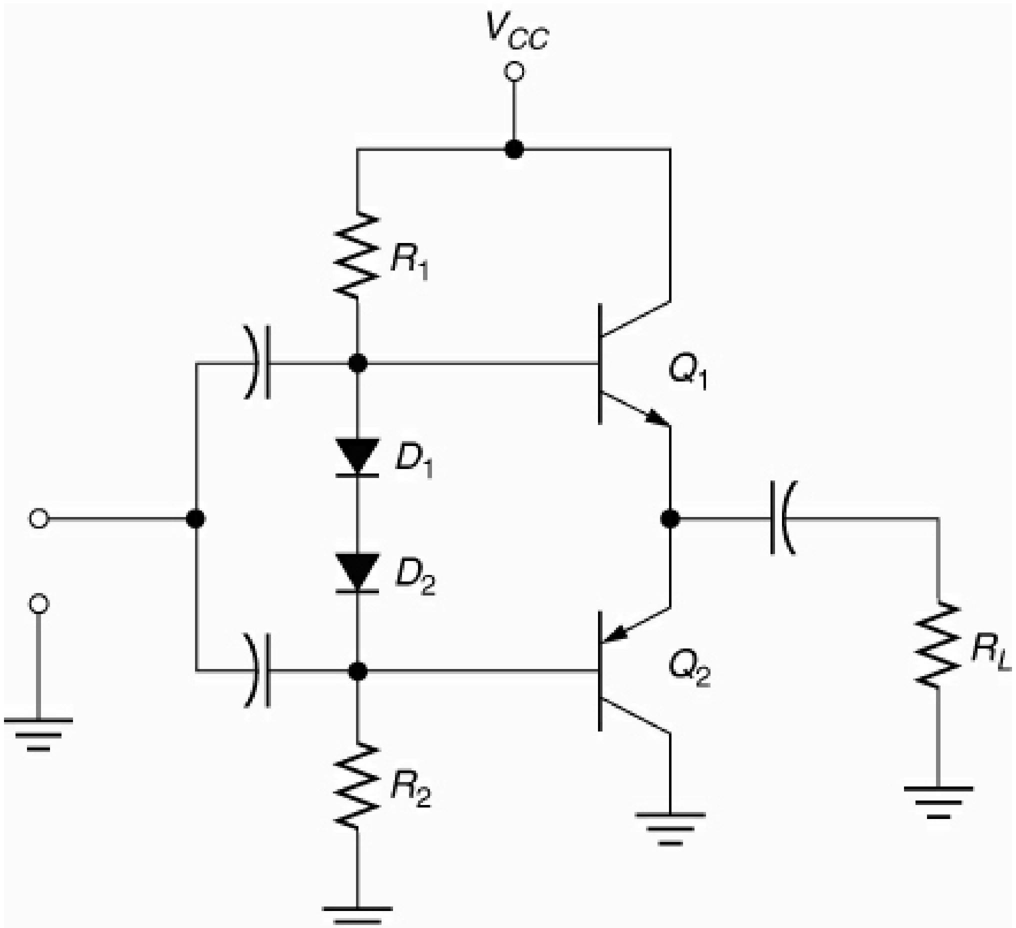
Class "B" Amplifier – Complementary-Symmetry Amplifier



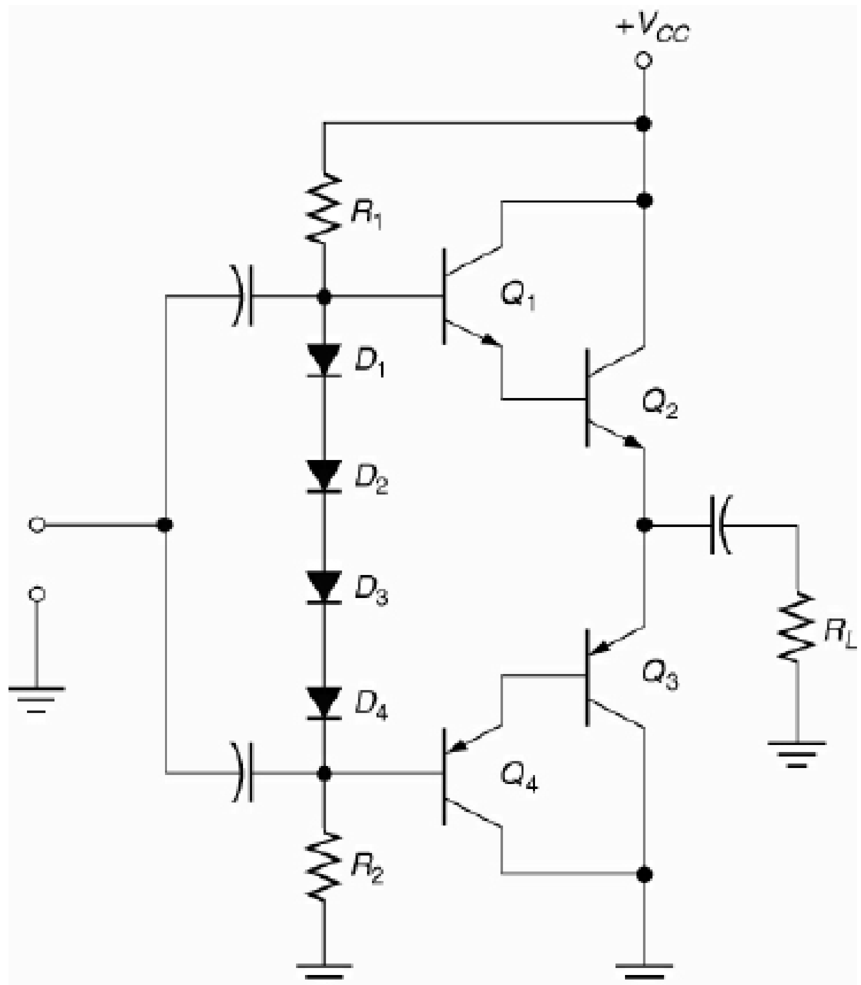
Class "B" Amplifier – Standard Push-Pull Amplifier



Class "AB" Amplifier – Diode Bias Amplifier



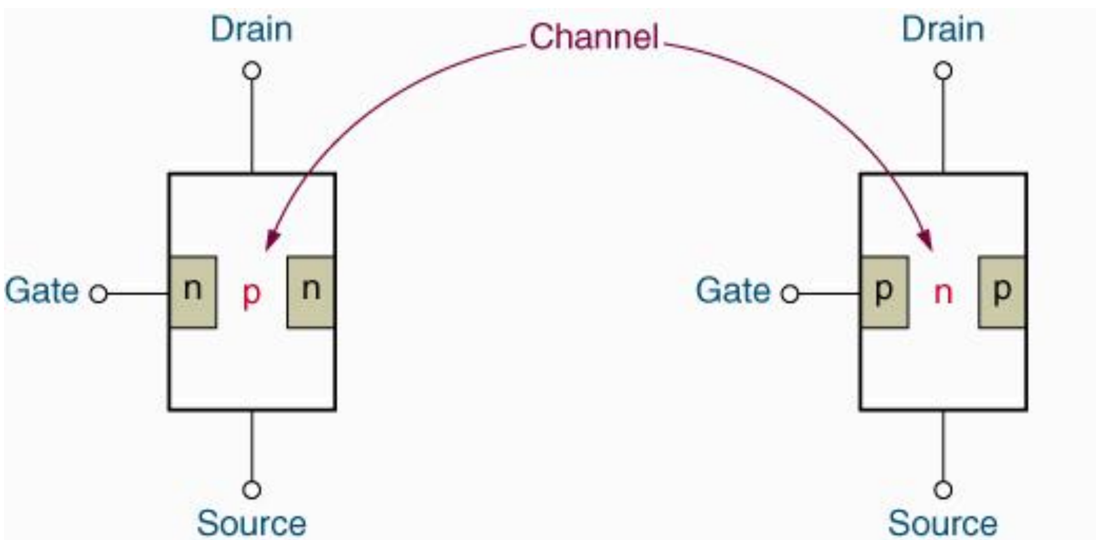
Darlington Class "AB" Amplifier



Field Effect Transistors

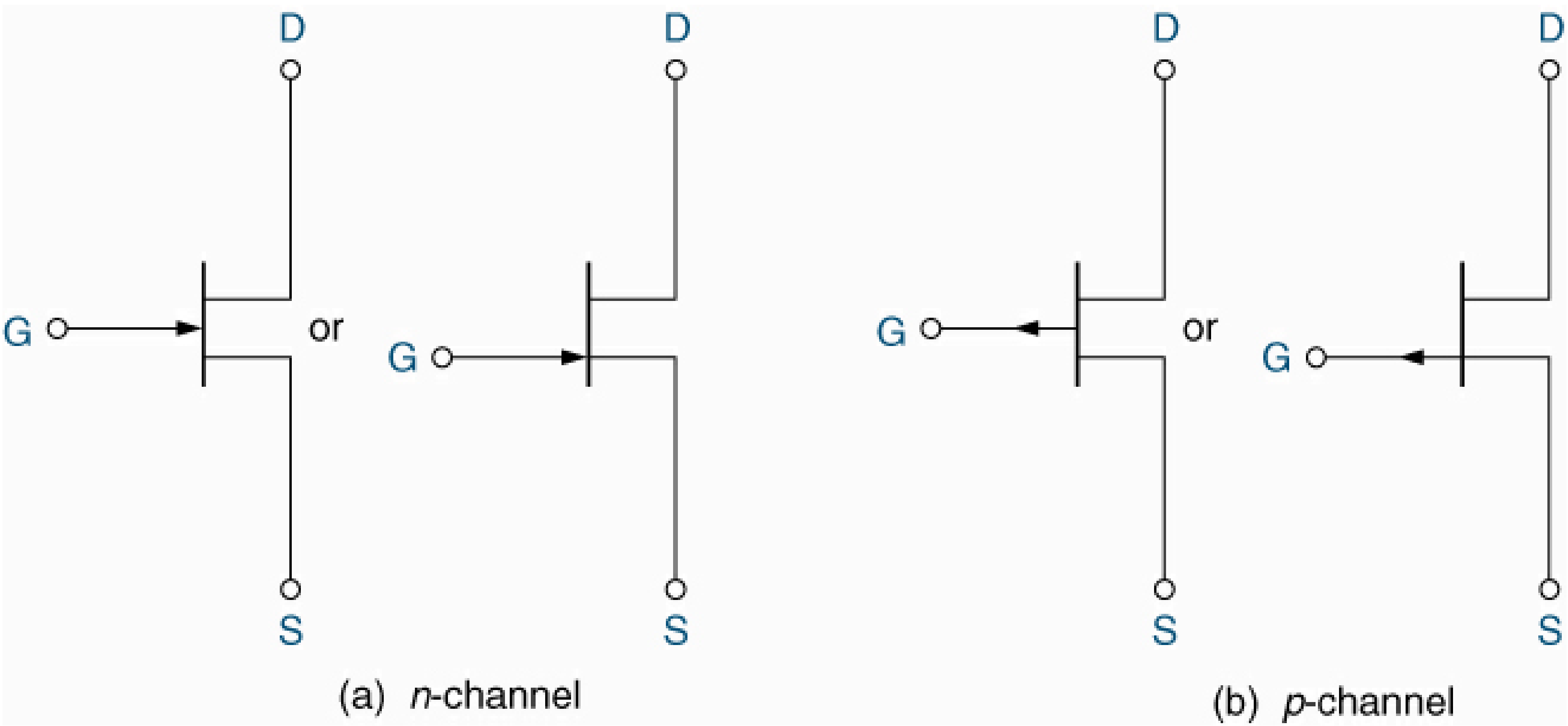
FET – is a Field Effect Transistor that is a three terminal voltage controlled device used in amplifier and switching applications.

- Source – counter part to the BJT emitter
- Drain – counter part to the BJT collector
- Gate – counter part to the BJT base
- Channel – the material that connects the source and drain

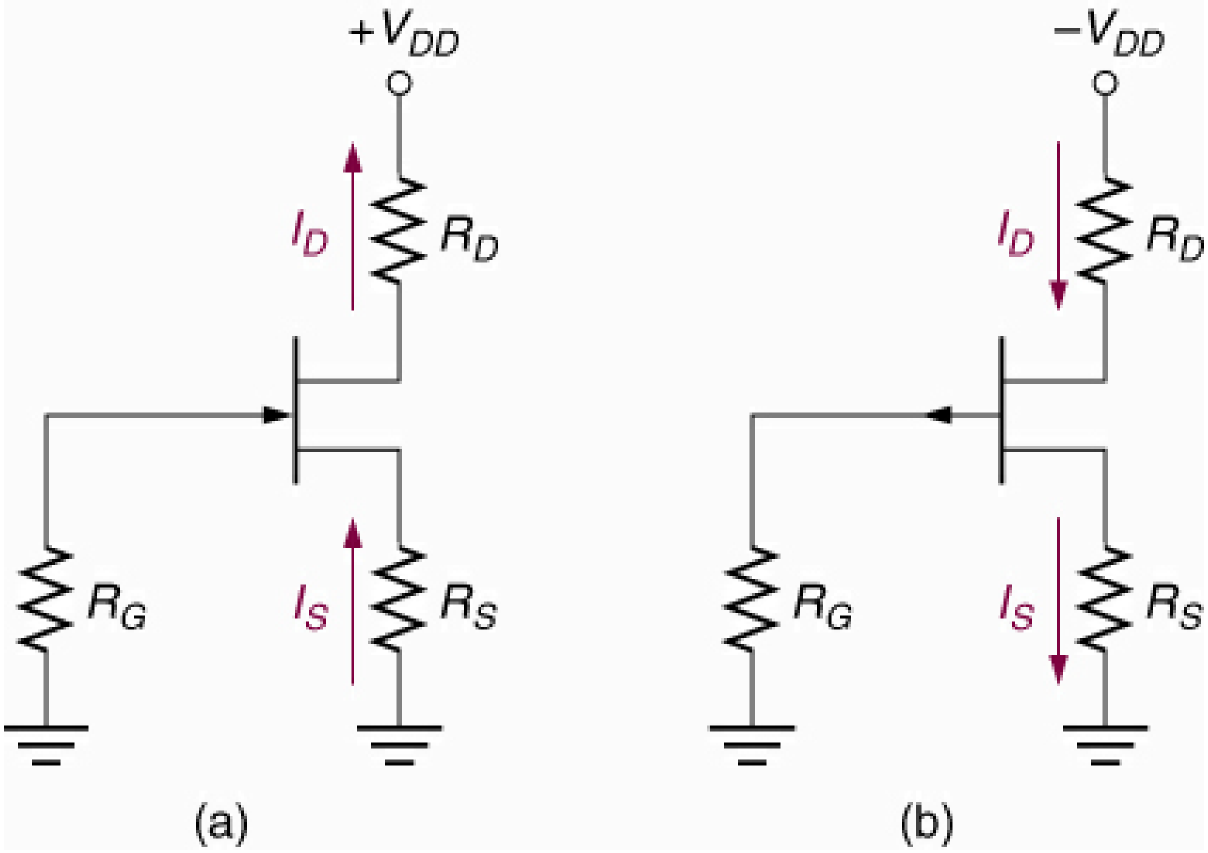


(a) *p*-channel (b) *n*-channel

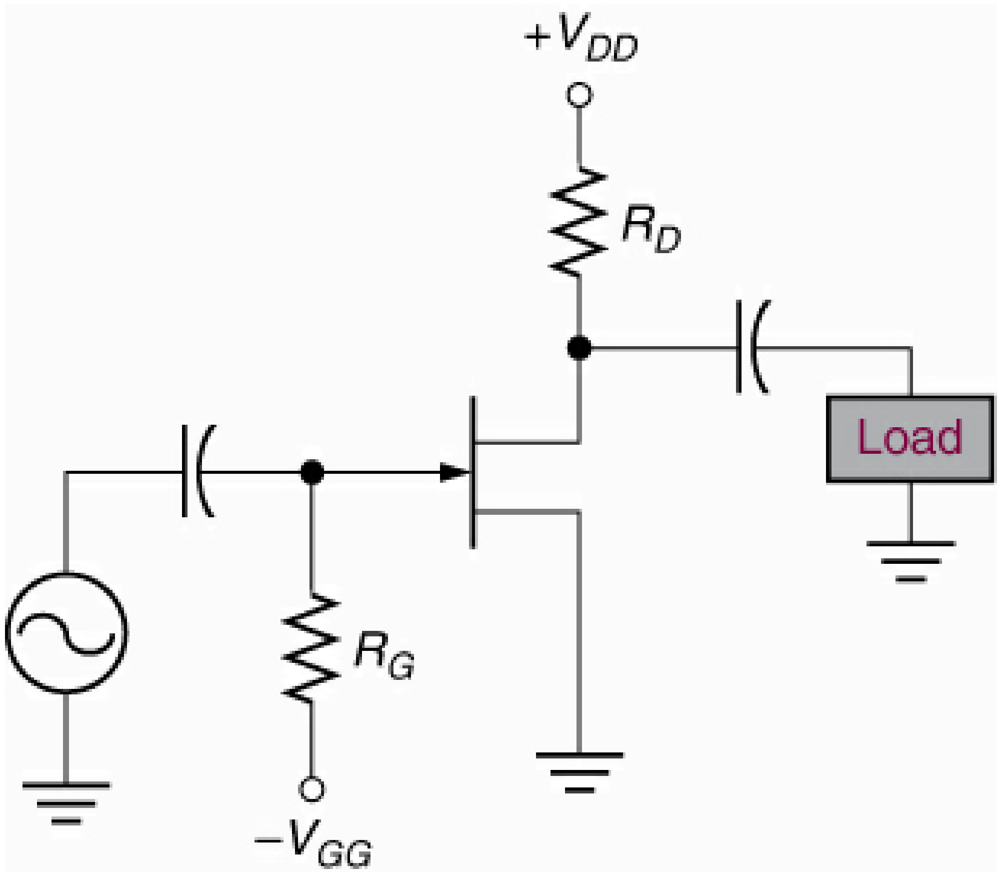
N-Channel JFET – arrow points inward
P-Channel JFET – arrow points outward



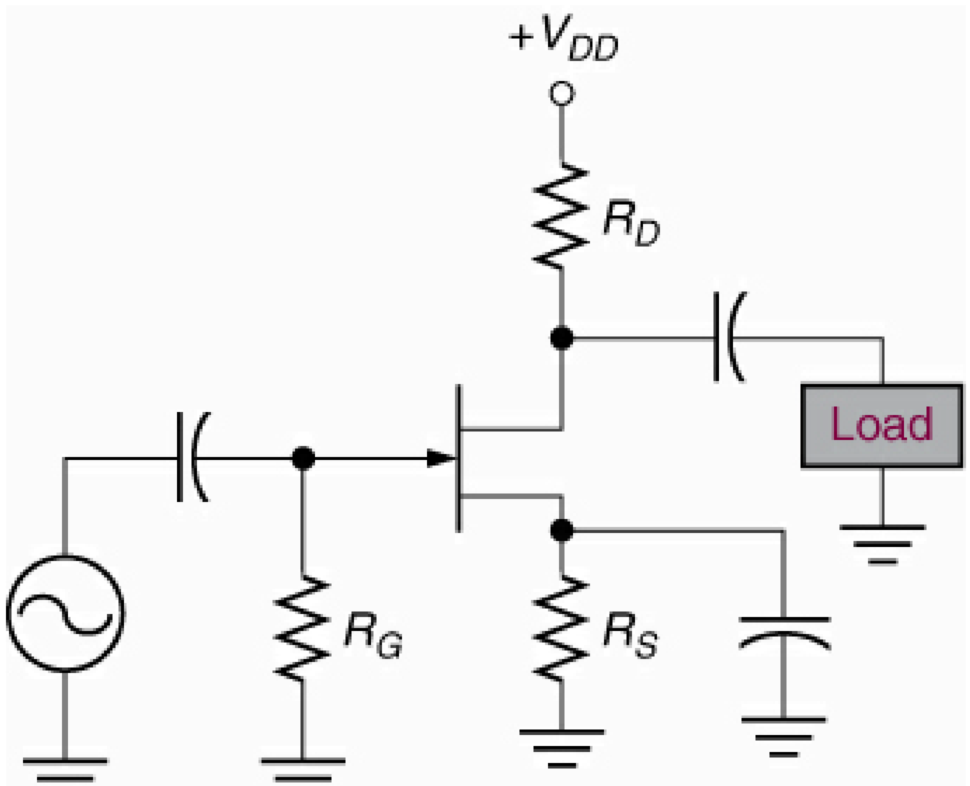
JFET Bias Voltages



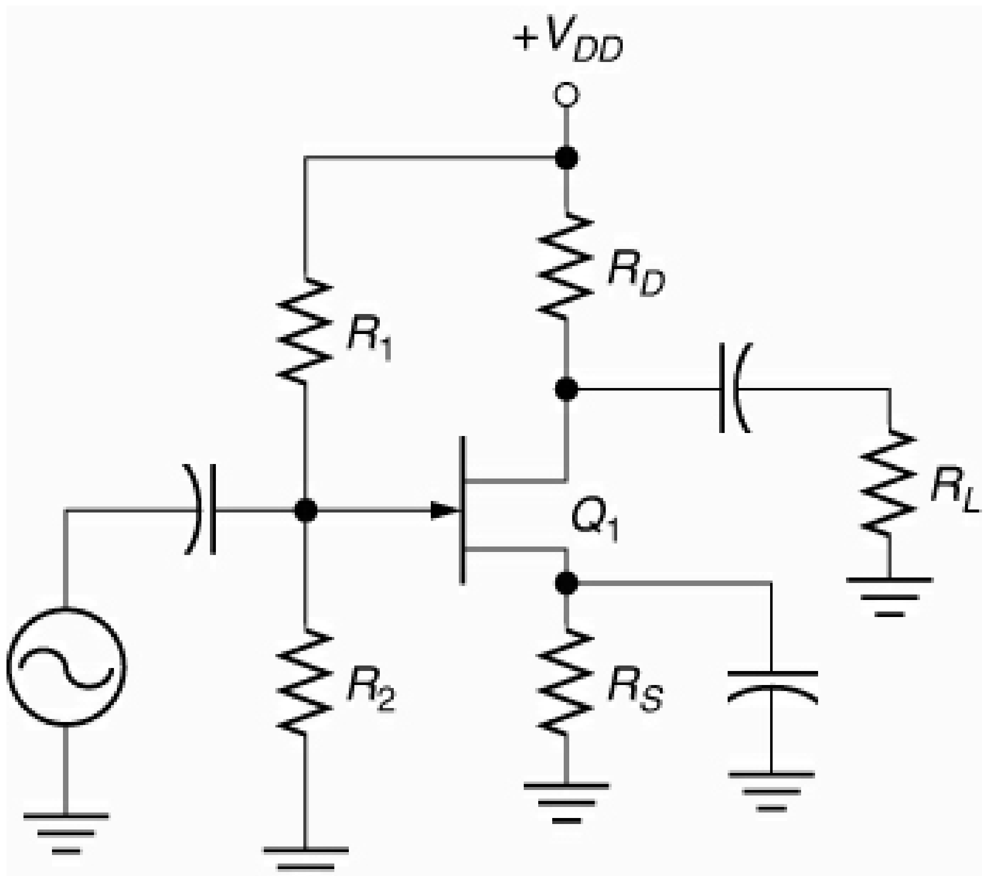
Gate Bias – counter part to the BJT base bias



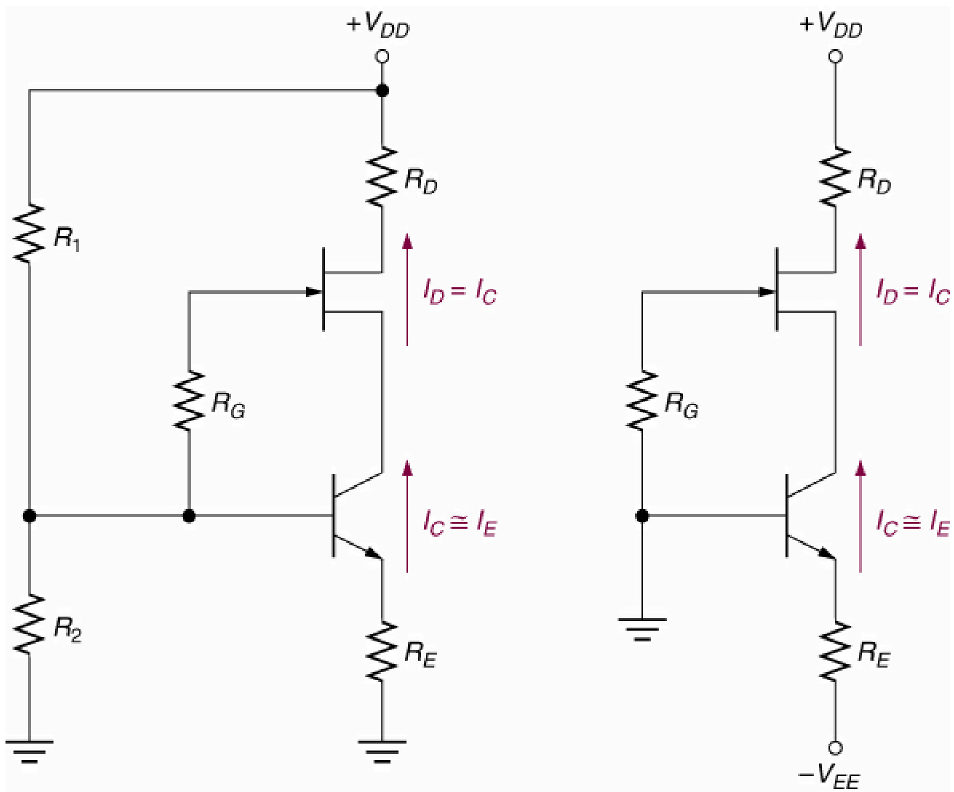
Self Bias – is a biasing circuit that uses a source resistor to help establish a negative V_{GS}



Voltage Divider Bias – is the counter part to the BJT voltage divider bias



Current Source Bias – is a JFET biasing circuit that uses a BJT to maintain a constant value of drain current I_D



Voltage-divider circuit
(a)

Emitter bias circuit
(b)

MOSFET – Metal-oxide semiconductor FET

Depletion-mode operation – is using an input voltage to effectively decrease the channel size of an FET

Enhancement-mode operation – is using an input voltage to effectively increase the channel size of an FET

D-MOSFET – is a MOSFET that can be operated in both the depletion and the enhancement mode

E-MOSFET is a MOSFET that is restricted to enhancement mode operation

MOSFETS use much less power that TTL chips

An advantage of a D-MOSFET is that it has a higher input impedance than a comparable JFET

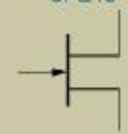
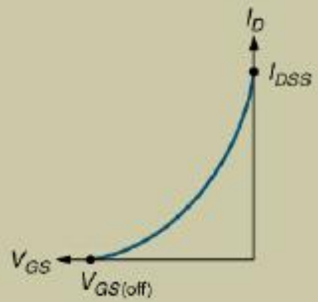
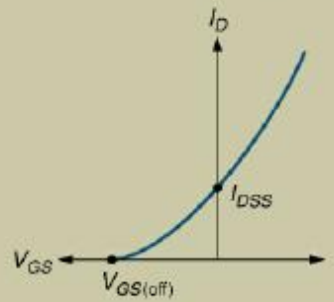
Zero Bias – is a D-MOSFET biasing circuit that has quiescent values of Vgs = 0V and ID = I_{DSS}

Threshold voltage – is the the value of V_{GS} that turns the E-MOSFET on

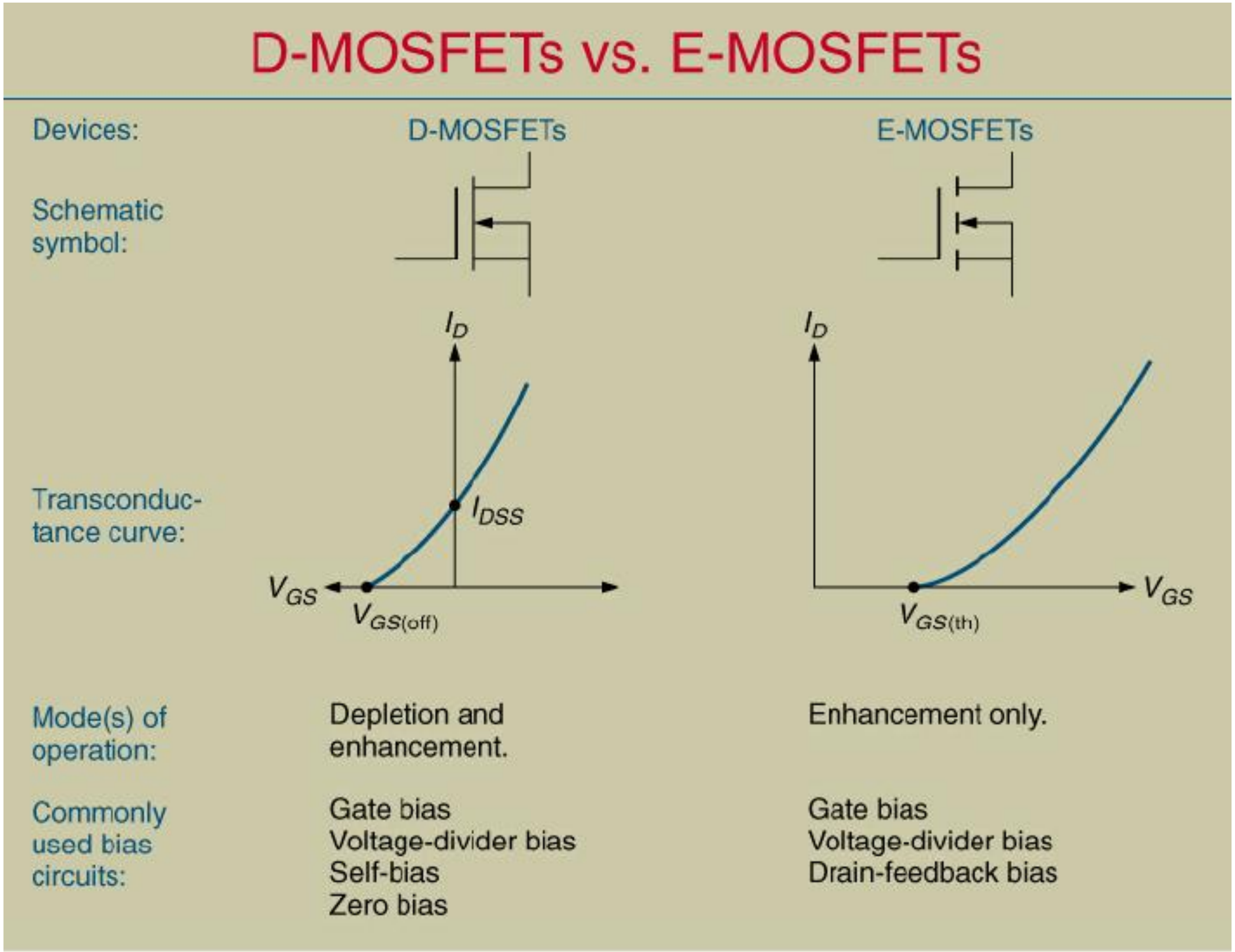
Collector-Feedback – is the equivalent for a MOSFET drain-feedback bias

CMOS - is abbreviation for Complementary MOS

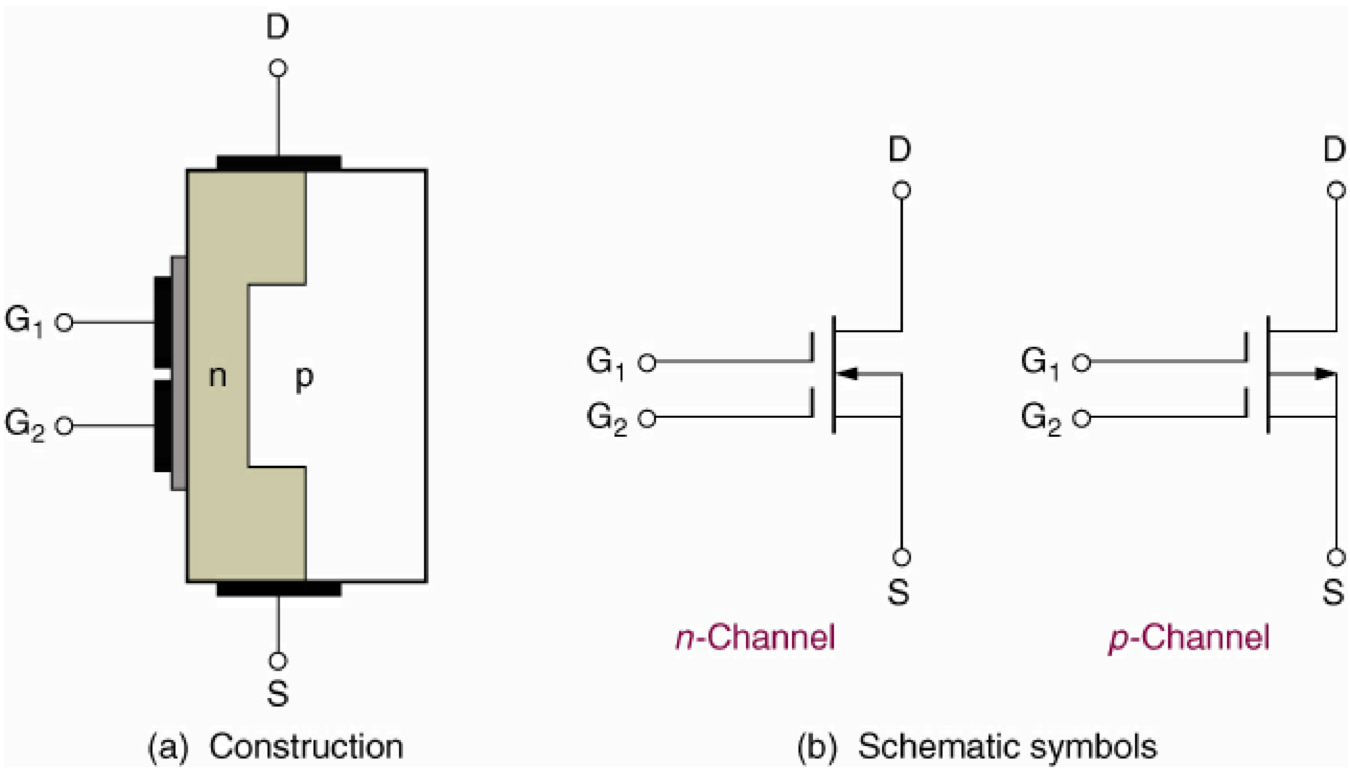
JFETs vs. D-MOSFETs

Devices:	JFETs	D-MOSFETs
Schematic symbol:		
Transconductance curve:		
Mode(s) of operation:	Depletion only	Depletion and enhancement
Commonly used bias circuits:	Gate bias Self-bias Voltage-divider bias	Gate bias Self-bias Voltage-divider bias Zero bias
Advantages:	Extremely high input impedance.	Higher input impedance than a comparable JFET. Can operate in both modes (depletion *and* enhancement).
Disadvantages:	Bias instability. Can operate only in the depletion mode.	Bias instability. More sensitive to changes in temperature than the JFET.

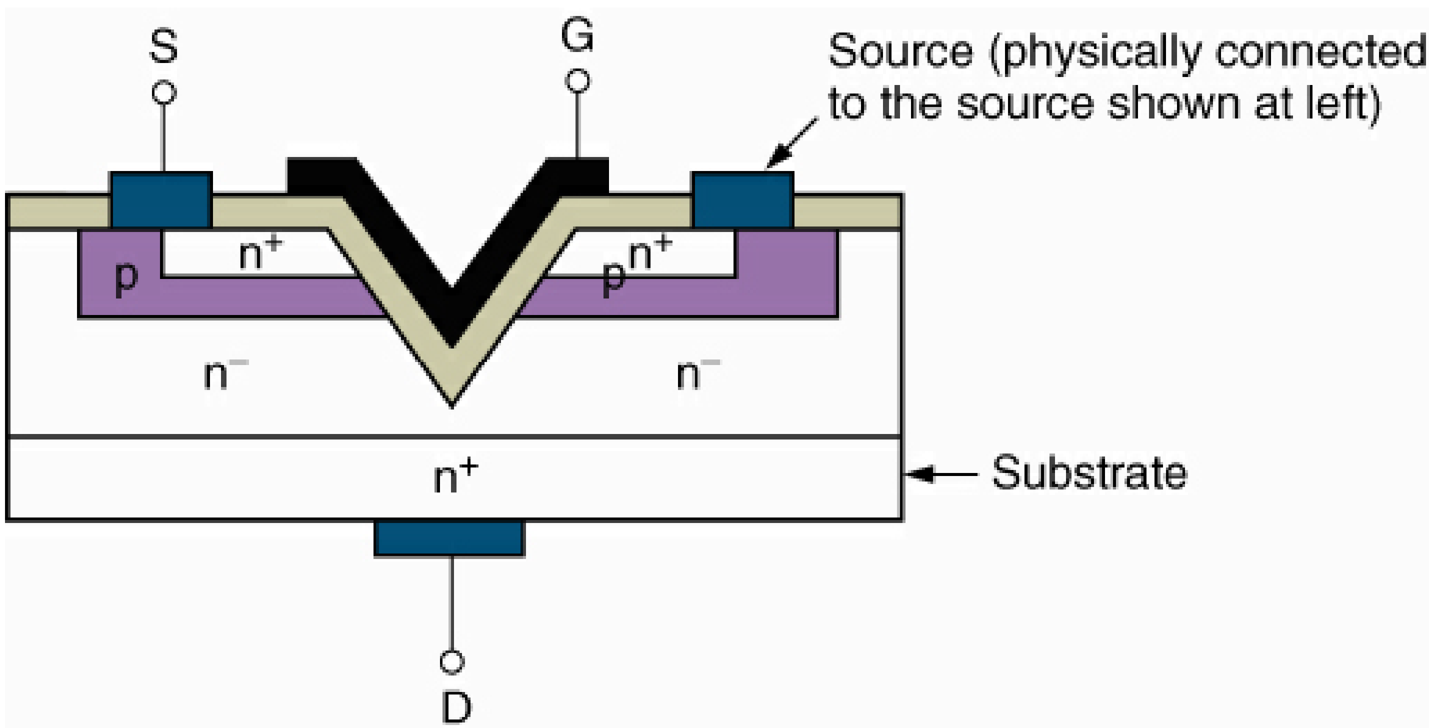
CBET Review – Electronics & Solid State Devices



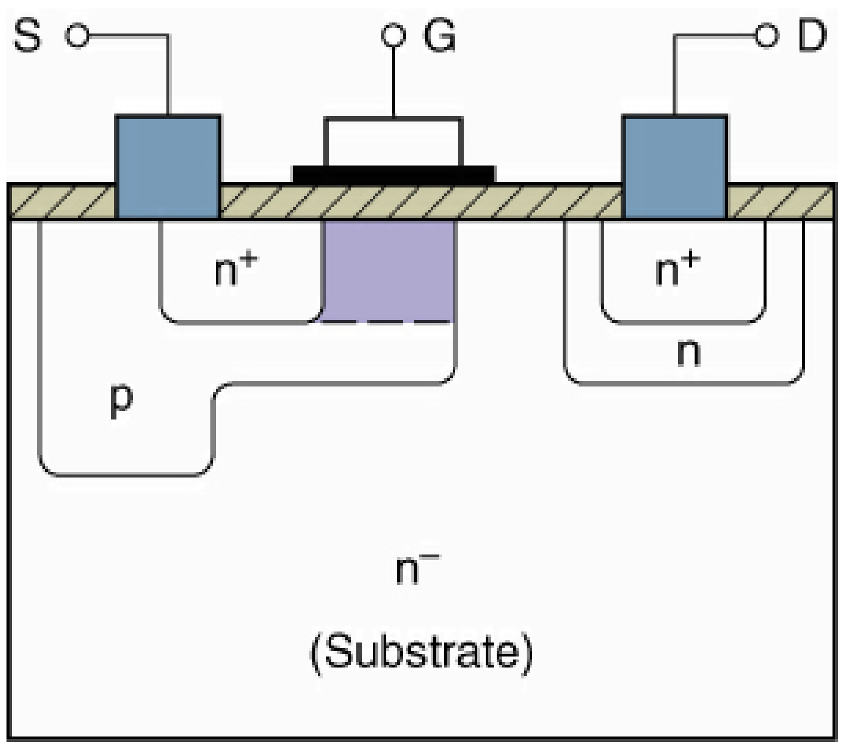
Dual Gate MOSFET – is a MOSFET constructed with two (2) gates to reduce gate input capacitance



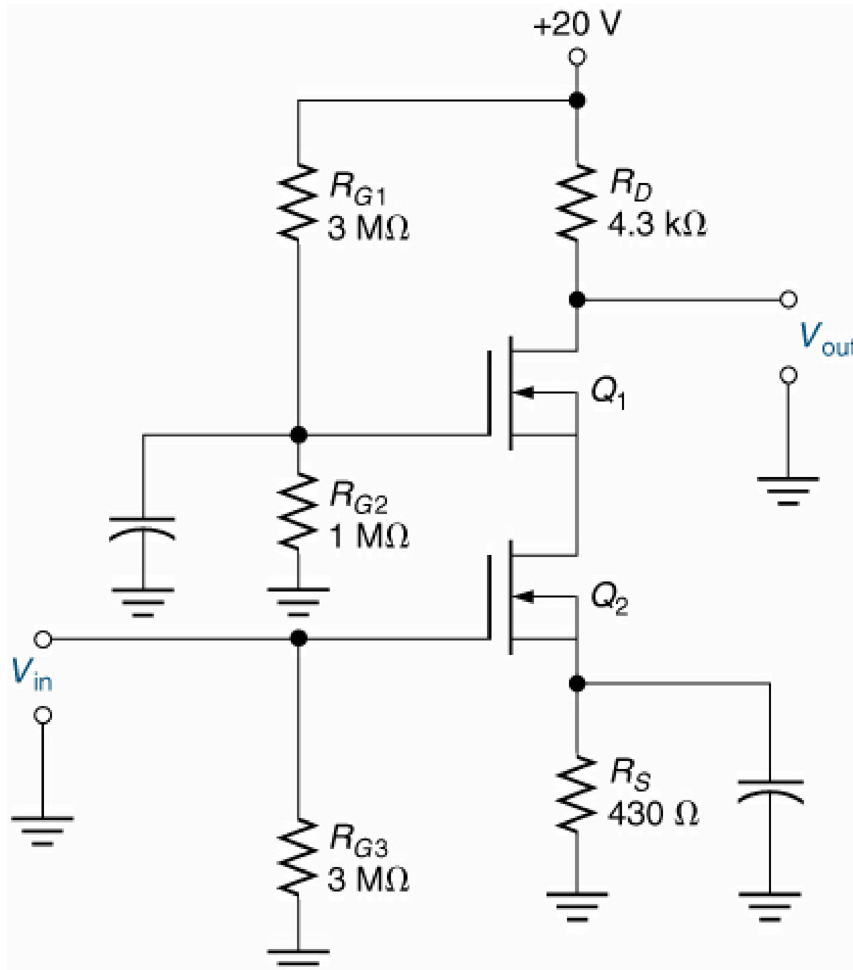
V-MOSFET Device – is an E-MOSFET designed to handle high values of drain current



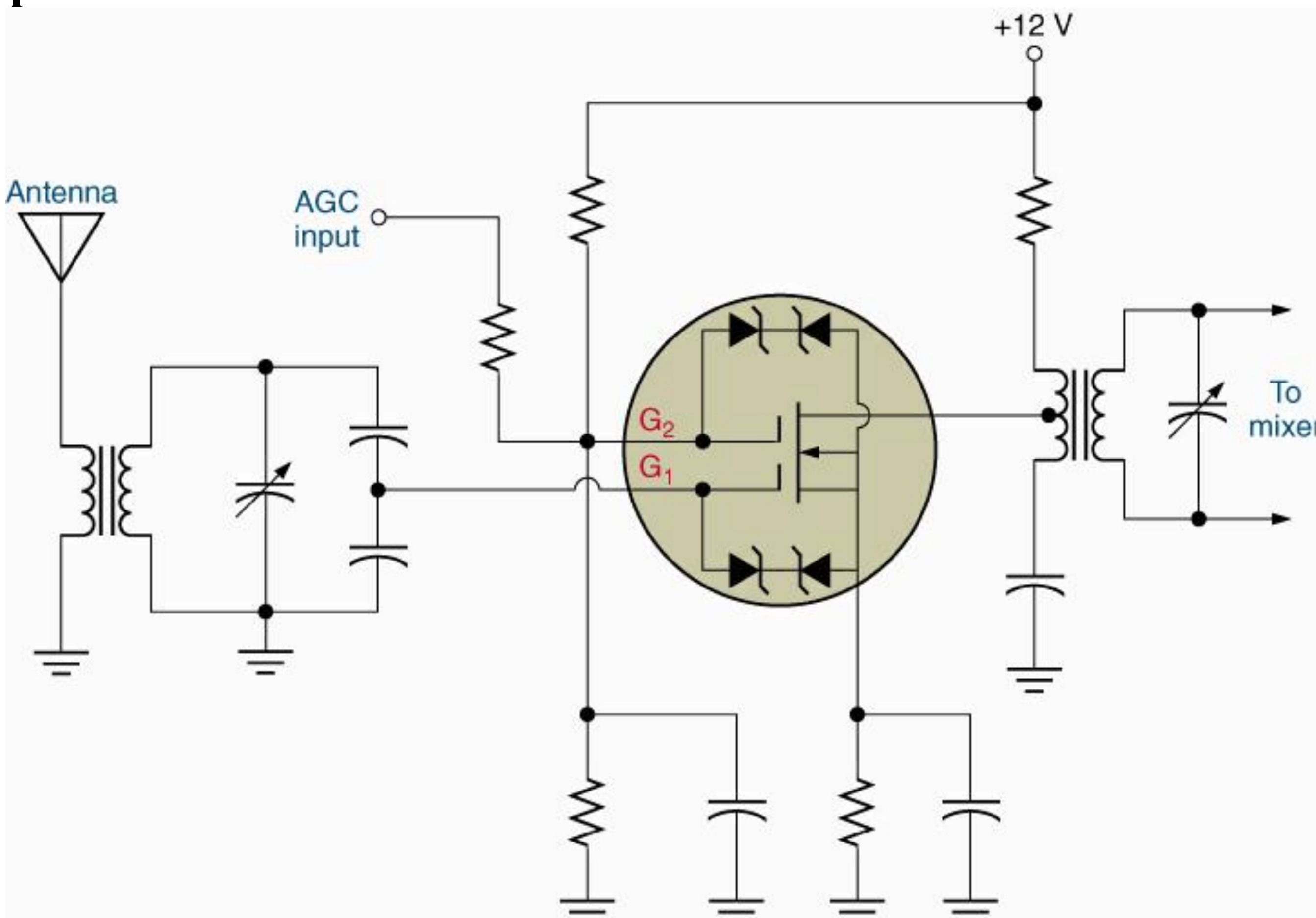
LDMOSFET Device – is a high power MOSFET that uses a narrow channel and a heavily doped n-type regions to obtain a high I_D and a low r_d



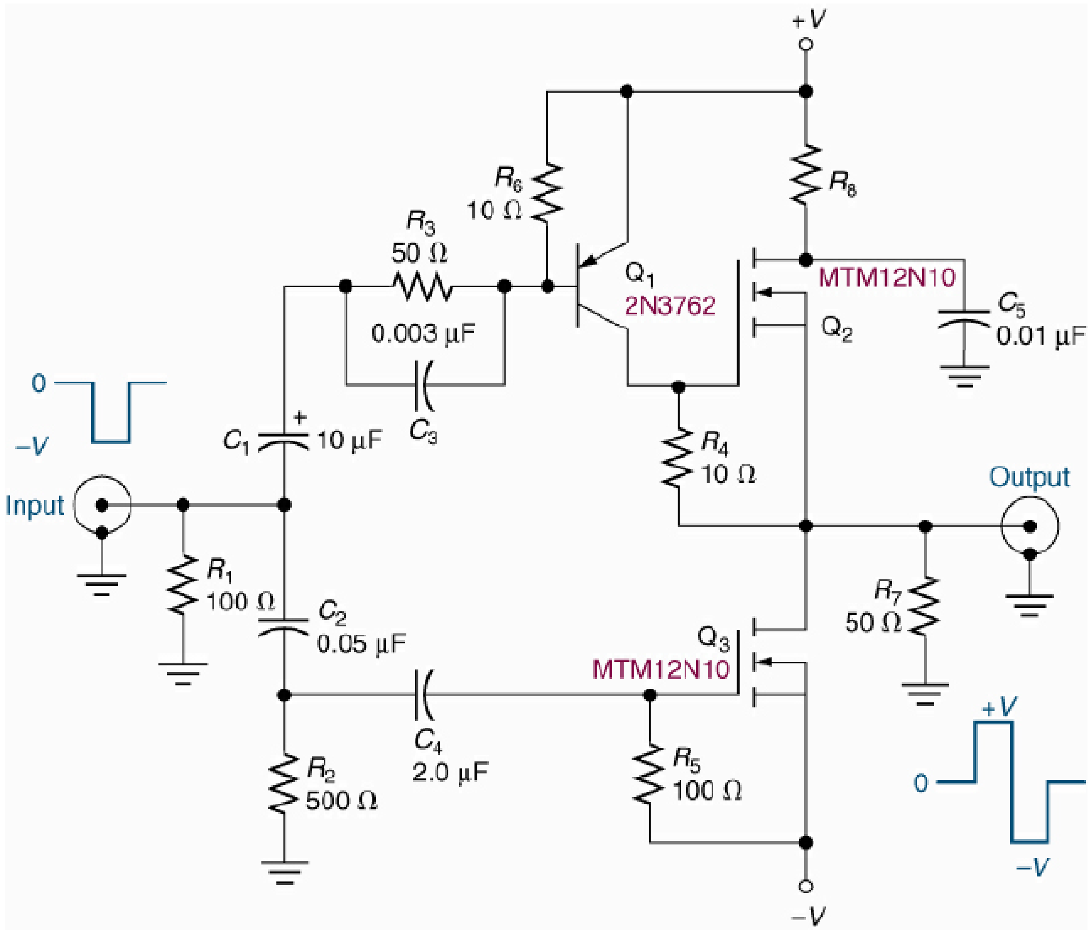
Cascode Amplifier – is used for high frequency applications



RF Amplifier



Power MOSFET Driver



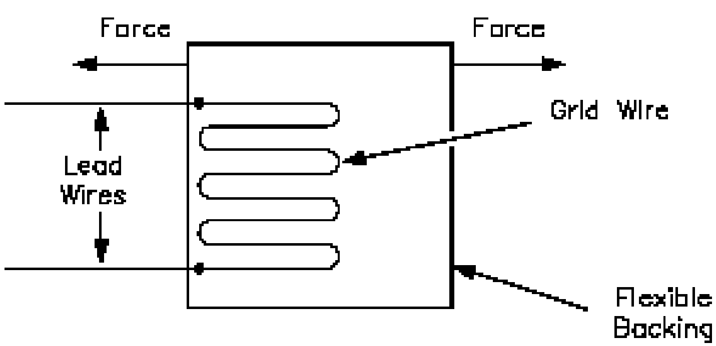
Transducers

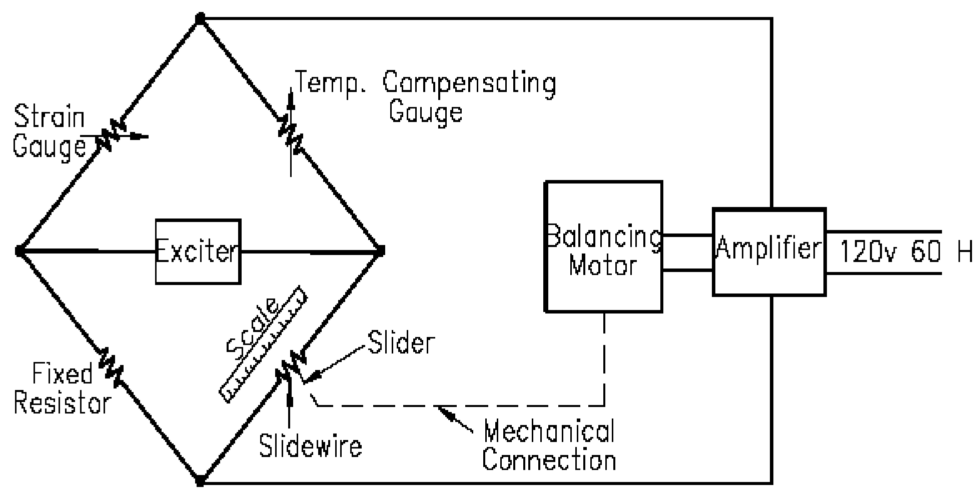
Strain Gauge Pressure Transducer

If a wire is held under tension, it gets slightly longer and its cross-sectional area is reduced.

This changes its resistance (R) in proportion to the strain sensitivity (S) of the wire's resistance.

Sensitivity = 5 uv/v/mmhg





Quartz Pressure Transducer

Piezoelectric or quartz pressure transducer use the electrical properties of naturally occurring crystals.

The crystals generate an electrical charge when they are strained.

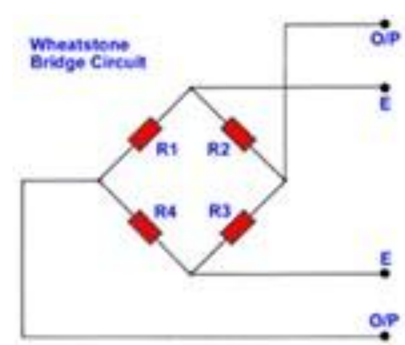
Not sensitive to temperature or scratches on the face

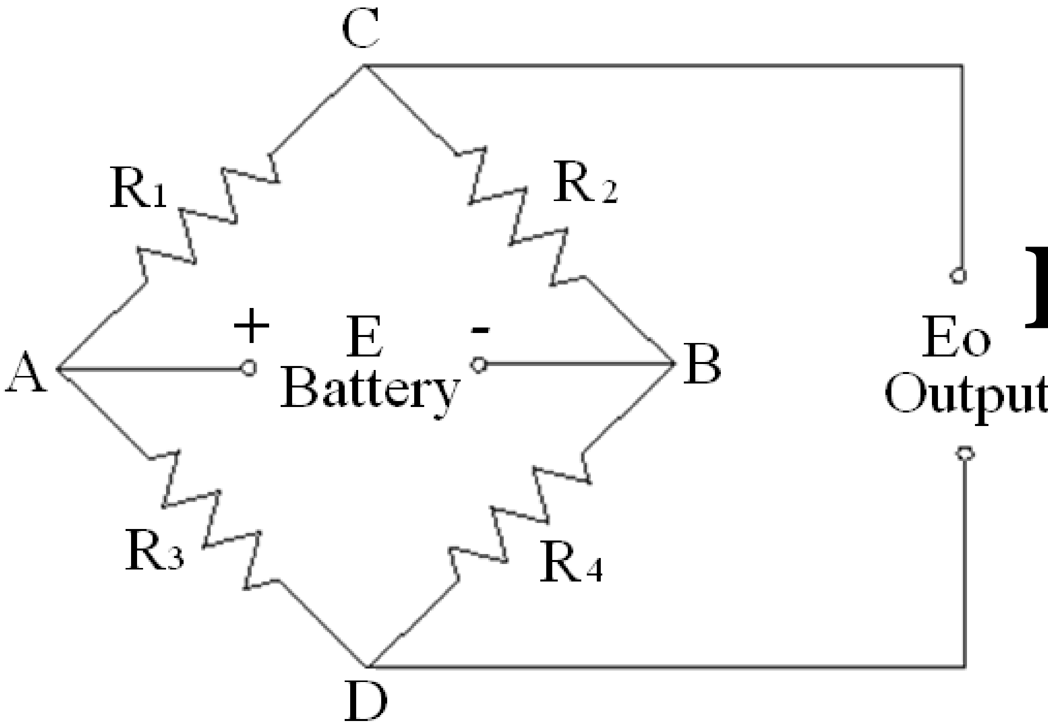
Sensitivity = 40 uv/v/mmhg

Silicon Pressure Transducer

This type of pressure sensor consists of a micro-machined silicon diaphragm.

- The resistors have a value of approx. 3.5 k Ohm.
- Pressure induced strain increases the value of the radial resistors (r), and decreases the value of the resistors (t) transverse to the radius. This resistance change can be high as 30%.
- The resistors are connected as a Wheatstone Bridge, the output of which is directly proportional to the pressure.
- Sensitivity = 5 uv/v/mmhg





Wheatstone Bridge Circuit

$$E_o = E\left(\left(\frac{R_2}{(R_1 + R_2)}\right) - \left(\frac{R_4}{(R_3 + R_4)}\right)\right)$$

Calculating Output Voltages of Pressure Transducers

Transducer Sensitivity = Voltage change produced / applied voltage to the transducer / pressure applied to the transducer

Strain Gauge Sensitivity = 5 uv/v/mmhg

Silicone Sensitivity = 5 uv/v/mmhg

Quartz Sensitivity = 40 uv/v/mmhg

Example: If a 12 volt power supply is used on a strain gauge pressure transducer and the patient has a blood pressure of 120/80 mmhg, what is the output voltage?

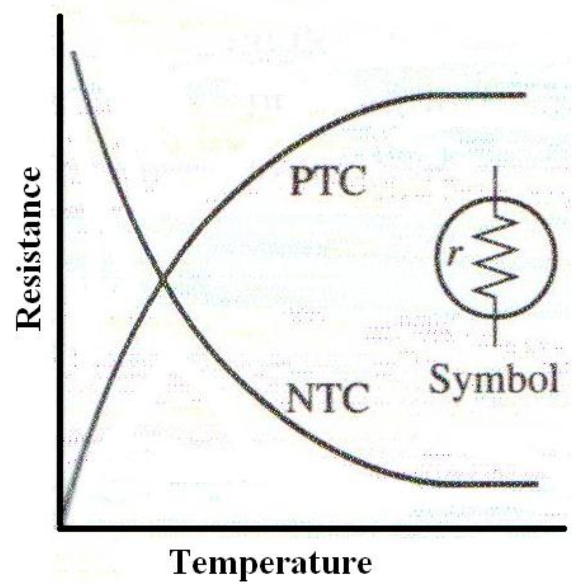
To solve, simply multiple the given variables:

5 uv *x* 12v *x* 120 mmgh = 7.2 mv

5 uv *x* 12v *x* 80 mmgh = 4.8 mv

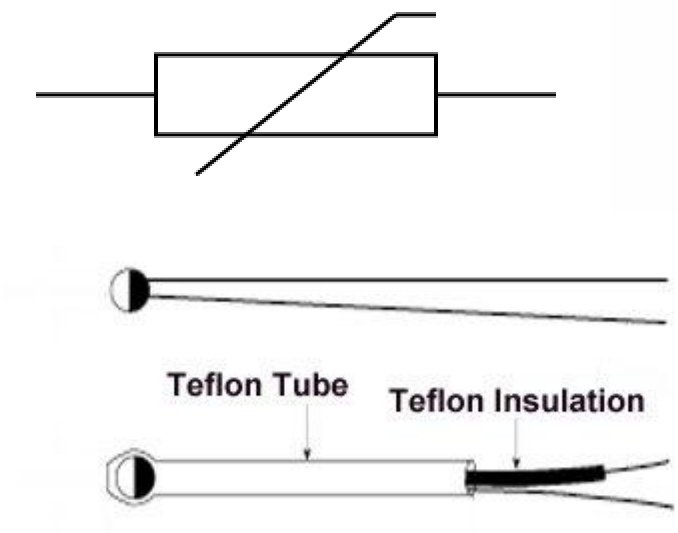
Temperature Transducer – Thermocouple

- Thermocouples are the most popular temperature sensors. They are cheap, interchangeable, have standard connectors and can measure a wide range of temperatures. The main limitation is accuracy, system errors of less than 1°C can be difficult to achieve.



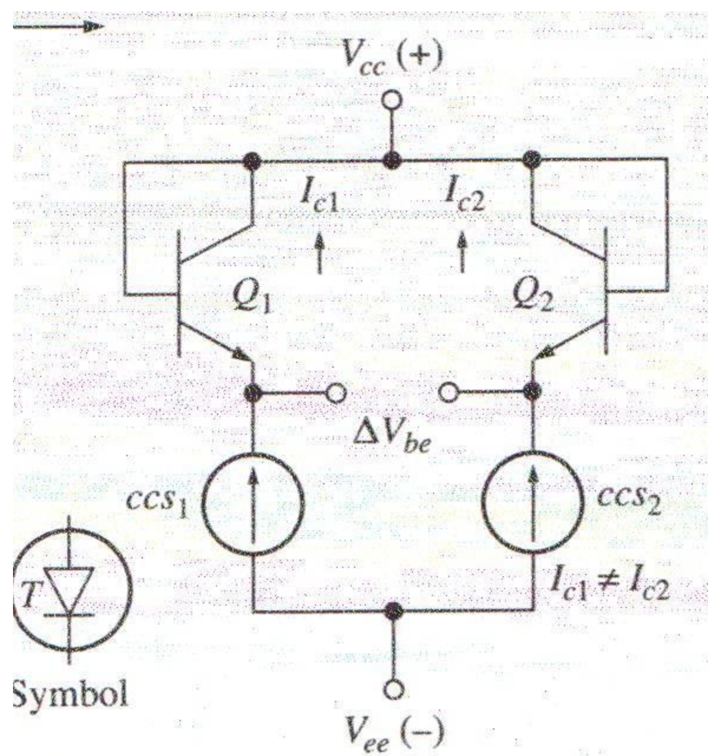
Temperature Transducer – Thermistor

- A **thermistor** is a type of resistor used to measure temperature changes, relying on the change in its resistance with changing temperature.
- Thermistors are thermally sensitive resistors and have, according to type, a negative (NTC), or positive (PTC) resistance/temperature coefficient.



Temperature Transducer – Solid State PN Junction

- A **solid state PN Junction diode** is a semiconductor device that as the temperature rises on the device, the forward biased resistance decreases,



Photocell

1) A light dependent resistor uses a chemical that changes resistance when exposed to light.
2) A silicon photocell (or solar cell) generates electricity from light. Photons (light particles) hit the silicon and cause electrons to flow out of the silicon (a little more complicated, but you asked for simple).
3) A photo transistor uses light to turn on a transistor. Actually all "regular" transistors are light sensitive. A photo transistor is made to be sensitive and has a window in the can to let the light in.
4) A photo diode is sort of like a photo transistor but used a diode.

Battery

Battery Types

- **Zinc-carbon battery** - Also known as a **standard carbon** battery, zinc-carbon chemistry is used in all inexpensive AA, C and D dry-cell batteries. The electrodes are zinc and carbon, with an acidic paste between them that serves as the electrolyte.
- **Alkaline battery** - Alkaline chemistry is used in common Duracell and Energizer batteries, the electrodes are zinc and manganese-oxide, with an alkaline electrolyte.
- **Lithium-iodide battery** - Lithium-iodide chemistry is used in pacemakers and hearing aides because of their long life.
- **Lead-acid battery** - Lead-acid chemistry is used in automobiles, the electrodes are made of lead and lead-oxide with a strong acidic electrolyte (rechargeable).

Battery

Battery Types

- **Nickel-cadmium battery** - The electrodes are nickel-hydroxide and cadmium, with potassium-hydroxide as the electrolyte (rechargeable).
- **Nickel-metal hydride battery** - This battery is rapidly replacing nickel-cadmium because it does not suffer from the memory effect that nickel-cadmiums do (rechargeable).
- **Lithium-ion battery** - With a very good power-to-weight ratio, this is often found in high-end laptop computers and cell phones (rechargeable).
- **Zinc-air battery** - This battery is lightweight and rechargeable.
- **Zinc-mercury oxide battery** - This is often used in hearing-aids.
- **Silver-zinc battery** - This is used in aeronautical applications because the power-to-weight ratio is good

Battery

Battery Memory

- One common problem in nickel-cadmium rechargeable batteries is something known as the **memory effect**. This is when the battery is continually recharged before it has discharged more than 50 percent of its power, causing it to essentially forget that it could fully discharge to begin with. Memory effect is caused by the formation of hard-to-dissolve cadmium crystals deep within the battery. Cadmium crystals are an unavoidable by-product of discharge; the trick is to keep them small enough to be reformed as cadmium during the charging process. When a battery is not fully discharged, the crystals deep within the battery are not affected by the influx of electrical current, so they are not reformed as cadmium and can grow into the troublesome larger cadmium crystals. The battery will still function normally, but is maxed out at 50 percent. The memory effect can be avoided by fully cycling the battery once every two to three weeks by allowing it to discharge completely, and then fully recharge.

Battery

Battery Rating

Batteries have several ratings that must be met when replacing them:

- Voltage: The voltage created on the electrodes
- Type: The acids and electrodes of the battery
- AH Rating: Amp-Hour rating is the current the battery can supply over a given time. For example, a battery with a 2 AH rating could supply
  - 1 amp for 2 hours
  - 0.5 amps for 4 hours
  - 2 amps for 1 hour