LAB #1: PRACTICAL ASPECTS OF OP AMP

EE 370 – 2015

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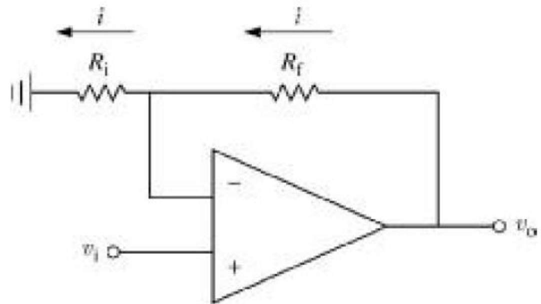
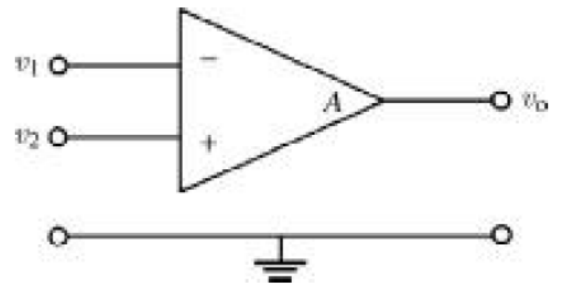
Questions

- What is the maximum gain for this circuit?
- What is the maximum output voltage range?
- Can we use it for any frequency?
- Are there any sources of error in the output?
- Can we choose any values for the resistances?
- What is the maximum power supply range that we can use?
- How to choose power supply range?
- How to select a suitable Op Amp for a particular application?

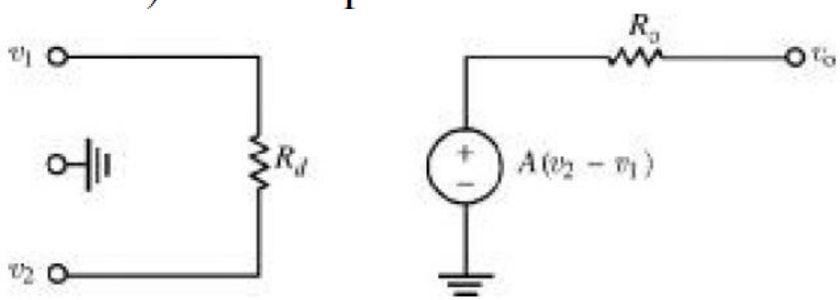


$$\frac{v_o}{v_i} = \frac{i(R_f + R_i)}{iR_i} = \frac{R_f + R_i}{R_i}$$

Ideal Op Amp Characteristics



1. $A = \infty$ (gain is infinity)
2. $v_o = 0$, when $v_1 = v_2$ (no offset voltage)
3. $R_d = \infty$ (input impedance is infinity)
4. $R_o = 0$ (output impedance is zero)
5. Bandwidth = ∞ (no frequency-response limitations) and no phase shift



$v_+ = v_-$

$i_+ = i_- = 0$

RULE 1 *When the op-amp output is in its linear range, the two input terminals are at the same voltage.*

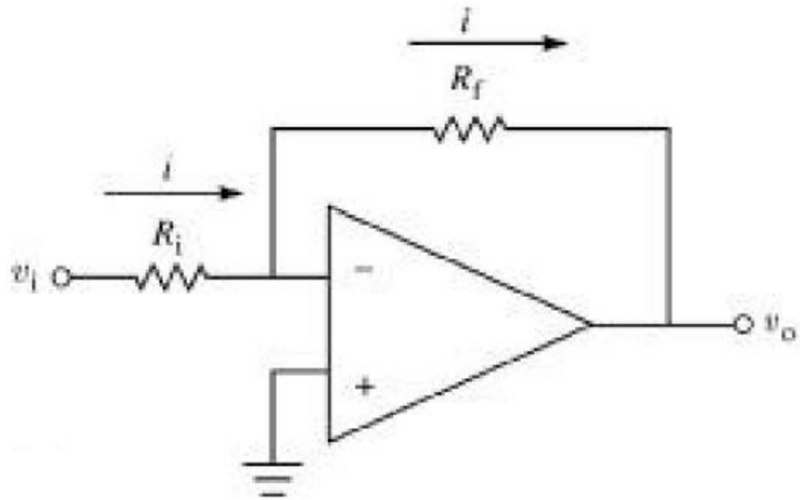
RULE 2 *No current flows into either input terminal of the op amp.*

Inverting Amplifier

$$v_o = -iR_f = -v_i \frac{R_f}{R_i}$$

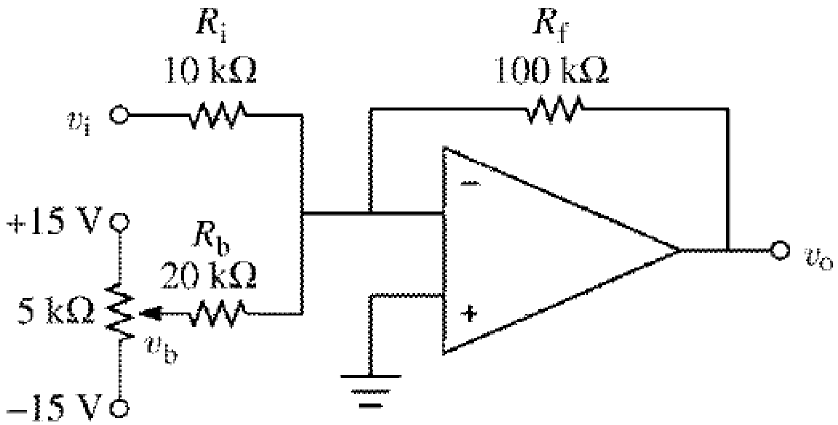
⇓

$$\frac{v_o}{v_i} = \frac{-R_f}{R_i}$$



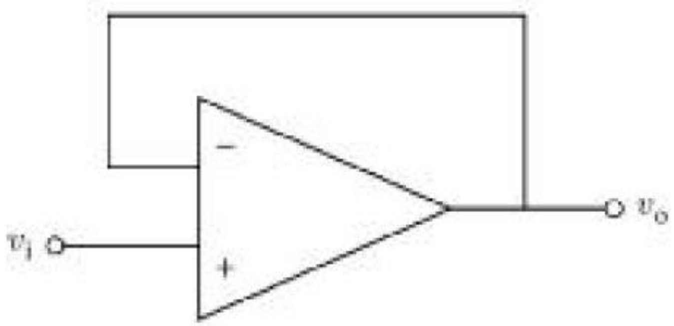
Summing Amplifier

$$v_o = -R_f\left(\frac{v_i}{R_i} + \frac{v_b}{R_b}\right)$$



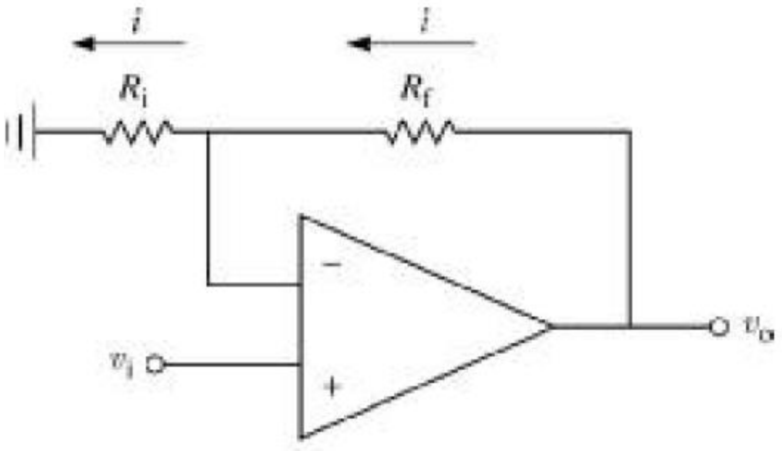
Voltage Follower

$$v_o = v_i$$



Noninverting Amplifier

$$\frac{v_o}{v_i} = \frac{i(R_f + R_i)}{iR_i} = \frac{R_f + R_i}{R_i}$$

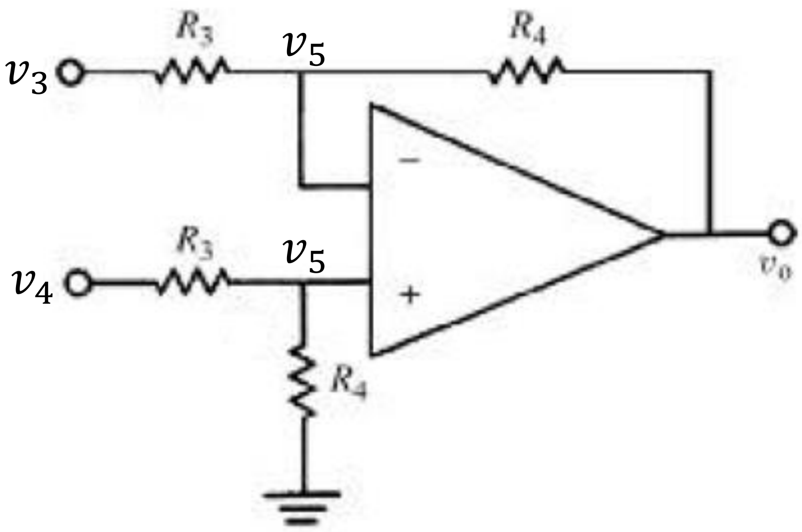


Differential Amplifier

$$v_5 = \frac{v_4 R_4}{R_3 + R_4}$$

$$i = \frac{v_3 - v_5}{R_3} = \frac{v_5 - v_o}{R_4}$$

$$v_o = \frac{(v_4 - v_3) R_4}{R_3}$$

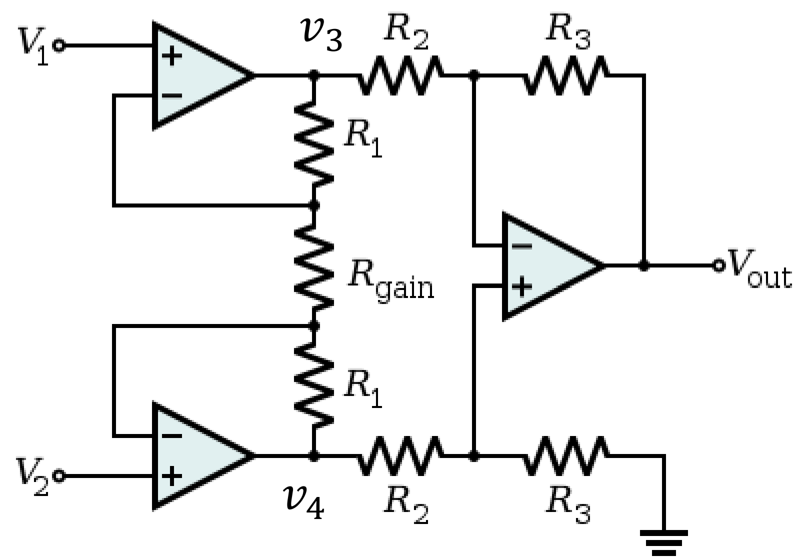


- Disadvantage: Low input impedance

Instrumentation Amplifier

$$v_3 - v_4 = (v_1 - v_2)\ / R_{gain}\ \ .\ \ (2R_1 + R_{gain})$$

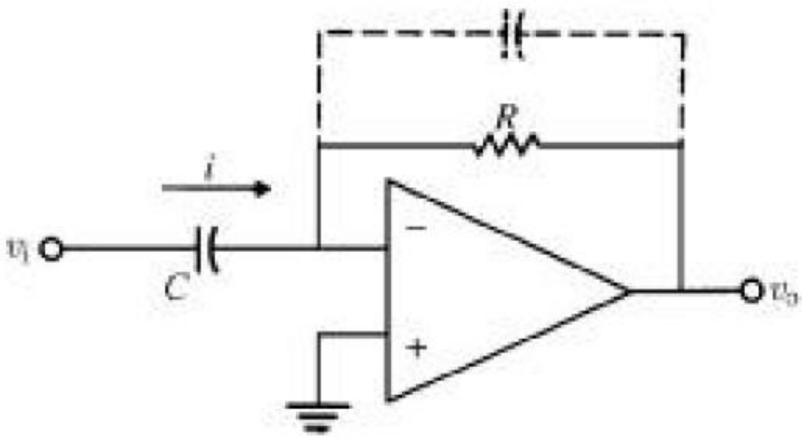
$$v_o = \frac{v_1 - v_2}{R_{gain}}\ .\ (2R_1 + R_{gain}) R_3 / R_2$$



- Advantage: High input impedance

Differentiator

$$v_o = -RC\frac{dv_i}{dt}$$

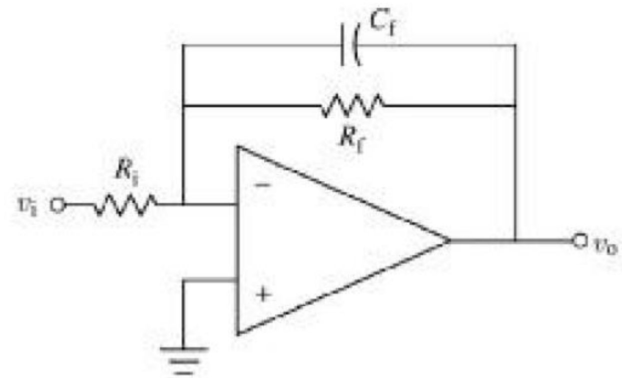


Active Filters

- Low-pass filter

$$\frac{V_o(j\omega)}{V_i(j\omega)} = -\frac{Z_f}{Z_i} = -\frac{\dfrac{(R_f/j\omega C_f)}{[(1/j\omega C_f)+R_f]}}{R_i}$$

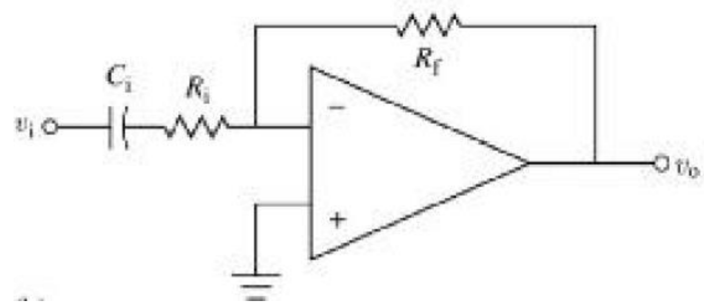
$$= \frac{R_f}{(1+j\omega R_f C_f)R_i} = -\frac{R_f}{R_i}\frac{1}{1+j\omega\tau}$$



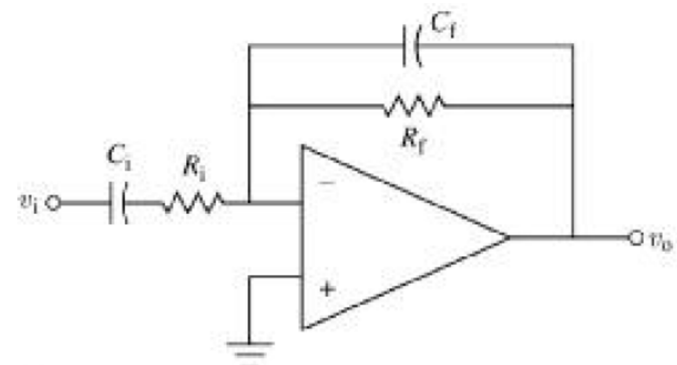
- High-pass filter

$$\frac{V_o(j\omega)}{V_i(j\omega)} = -\frac{Z_f}{Z_i} = -\frac{R_f}{1/j\omega C_i + R_i}$$

$$= -\frac{j\omega R_f C_i}{1+j\omega C_i R_i} = -\frac{R_f}{R_i}\frac{j\omega\tau}{1+j\omega\tau}$$

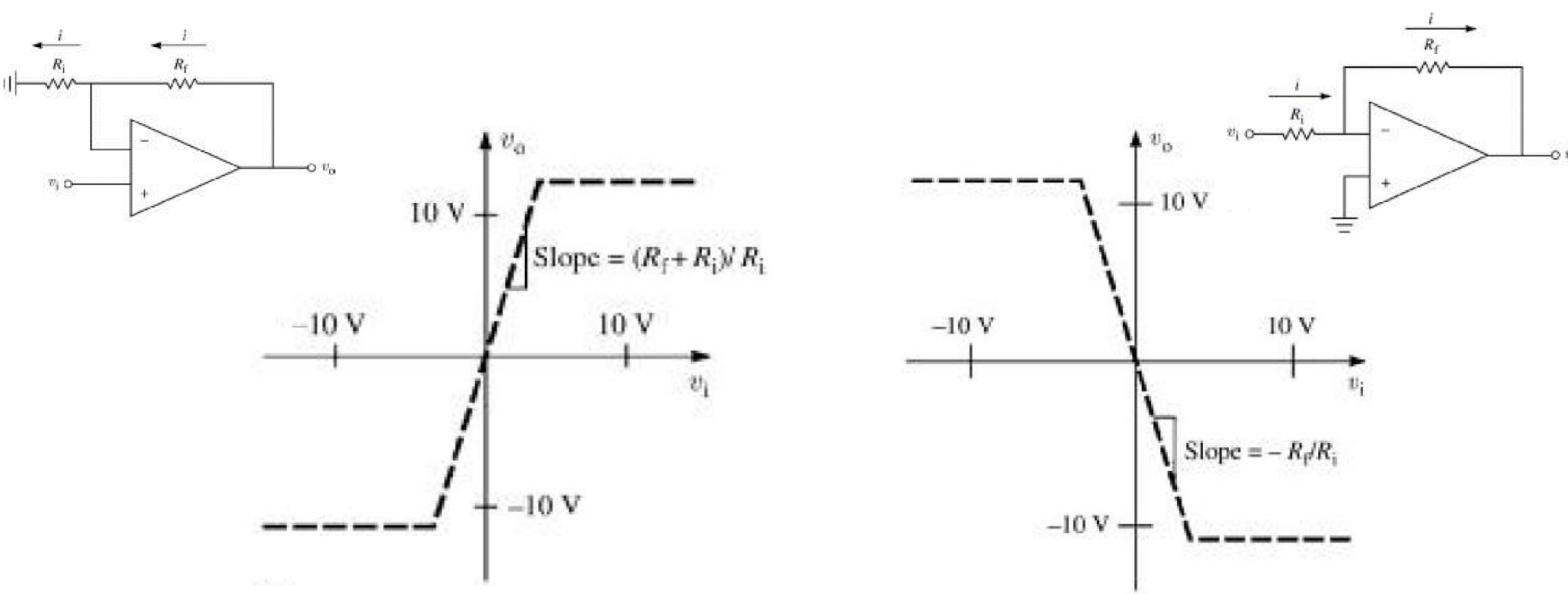


- Band-pass filter
  - Combination of the two



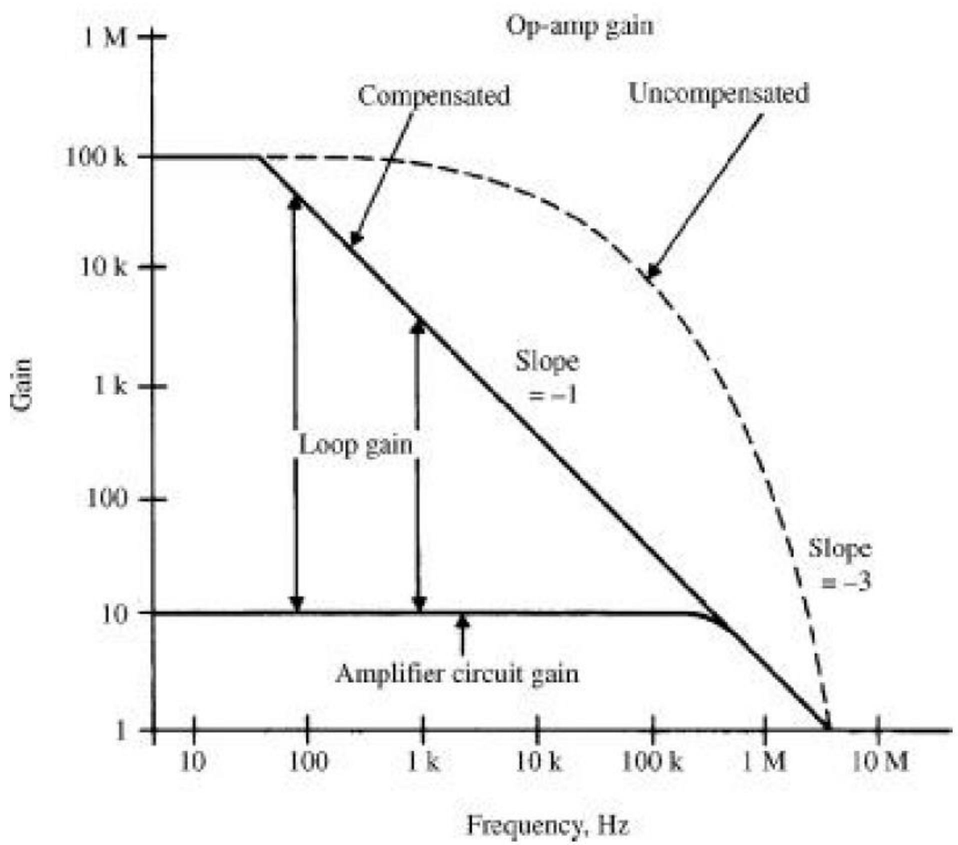
Practical Characteristics of Op Amps

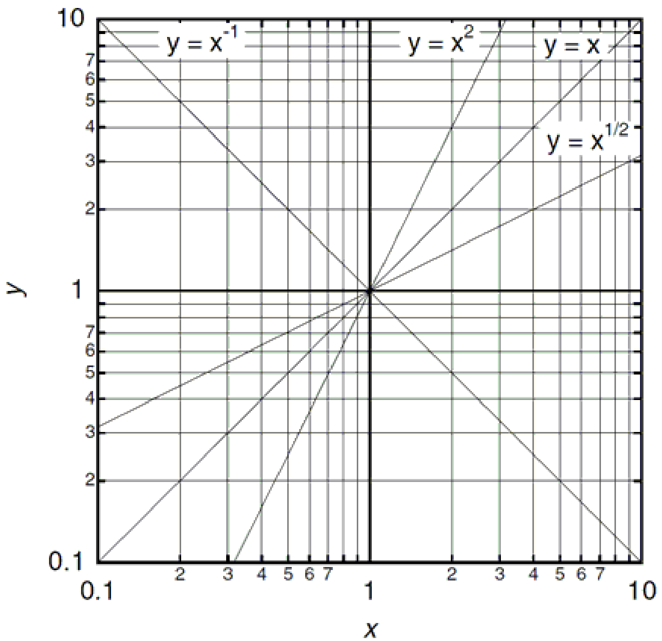
- Linear range limitations
  - Depends on power supply range (slightly less)



Practical Characteristics of Op Amps

- Gain-Bandwidth Product = Constant for a given Op Amp
  - Evaluate using Log-Log plots



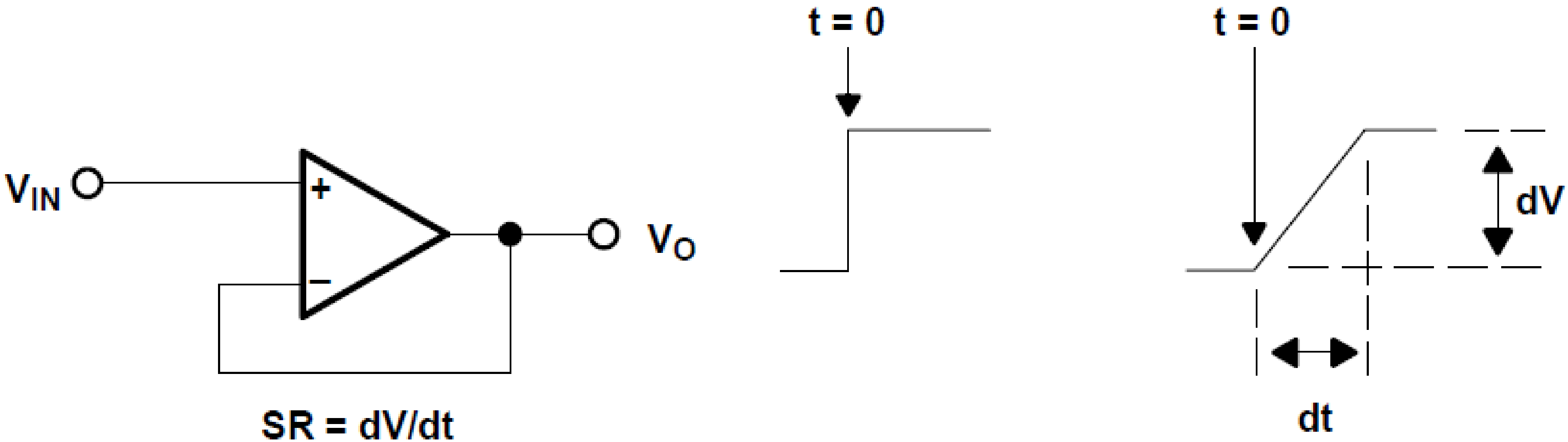


$$y = Bx^n$$

$$\log y = \log B + n \log x$$

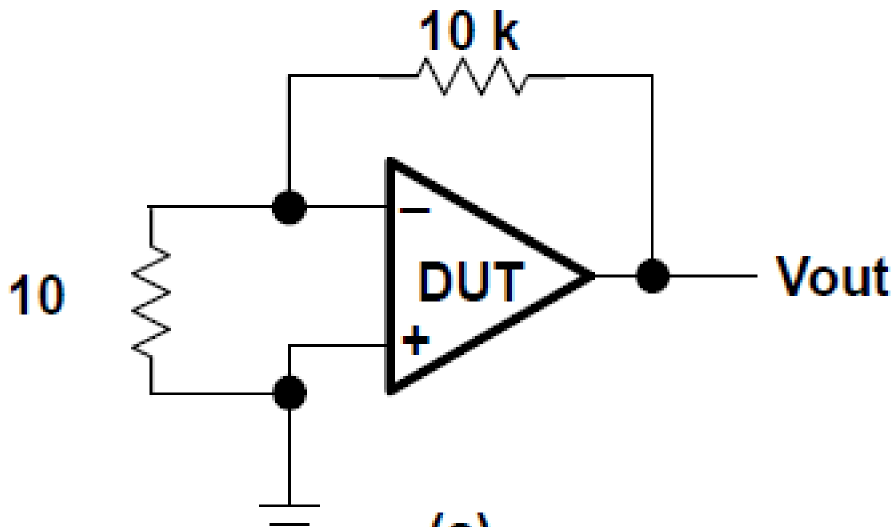
Practical Characteristics of Op Amps

- Slew Rate



Practical Characteristics of Op Amps

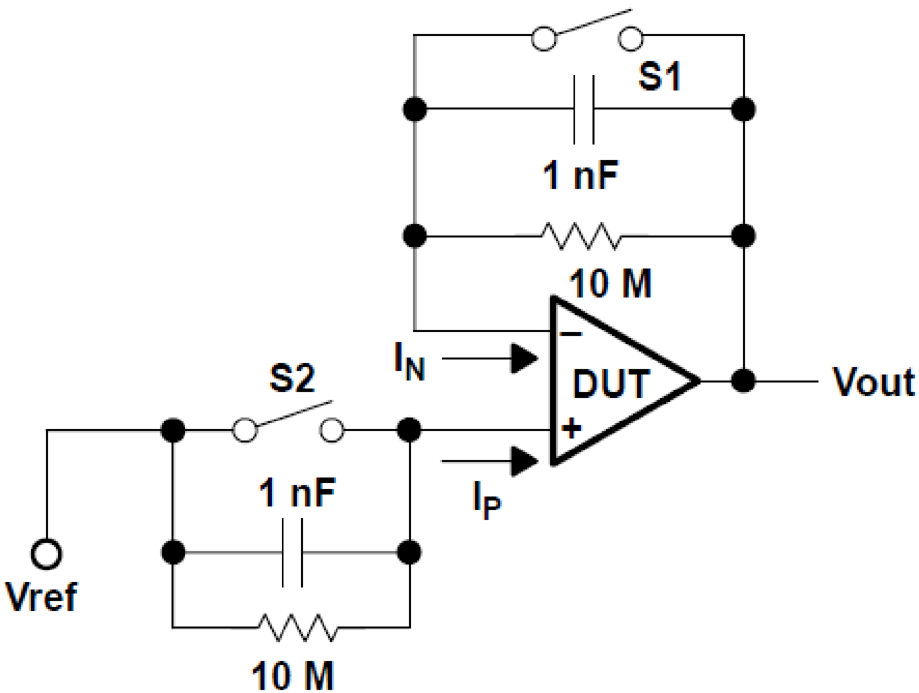
- Offset voltage
  - Small voltage between their inverting and noninverting inputs to balance mismatches due to unavoidable process variations
  - Input offset voltage is of concern anytime that DC accuracy is required of the circuit
  - Some Op Amps offer external offset nulling inputs



(a)

Practical Characteristics of Op Amps

- Input bias current
  - Input circuitry of all op amps requires a certain amount of bias current for proper operation
  - Input bias current is of concern when the source impedance is high



S1 Closed

$$I_P = \frac{Vout - Vref}{10^7}$$

S2 Closed

$$I_N = \frac{Vout - Vref}{10^7}$$

$$I_{IB} = \frac{(I_N + I_P)}{2}$$

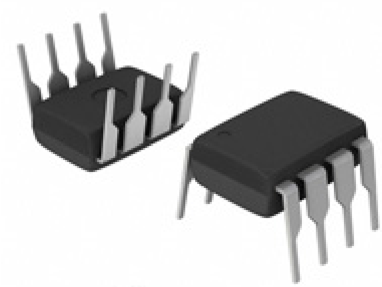
Example: 741 Op Amp

National Semiconductor

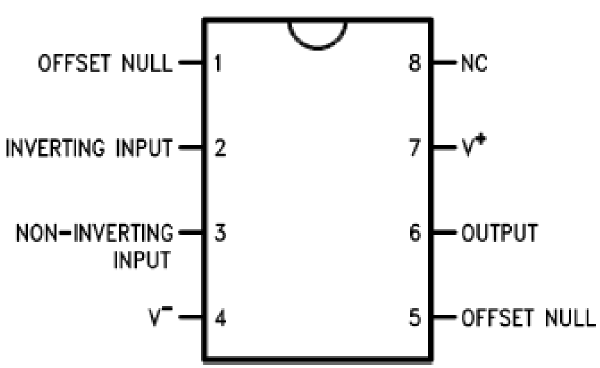
LM741
Operational Amplifier

Bandwidth (Note 6)	1.5	MHz
Slew Rate	0.7	V/µs

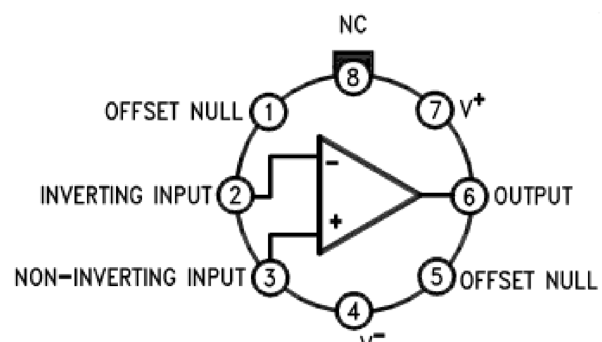
Output Voltage Swing	$V_S = \pm 20V$



Dual-In-Line or S.O. Package



Metal Can Package



Example: LH6702 Wideband Op Amp

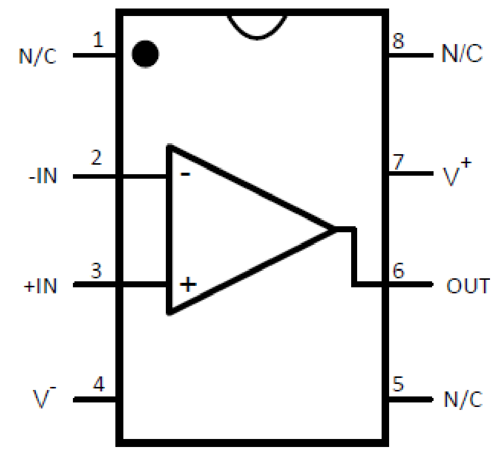
TEXAS INSTRUMENTS

LMH6702

www.ti.com SNOSA03F – NOVEMBER 2002 – REVISED MARCH 2013

LMH6702 1.7 GHz, Ultra Low Distortion, Wideband Op Amp

- −3dB Bandwidth (V_{OUT} = 0.5 V_{PP}) 1.7 GHz
- Fast Slew Rate 3100V/μs
- Low Noise 1.83nV/$\sqrt{Hz}$

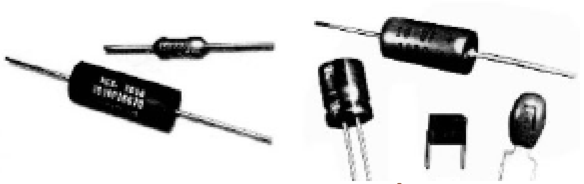


Basics of Electronic Components

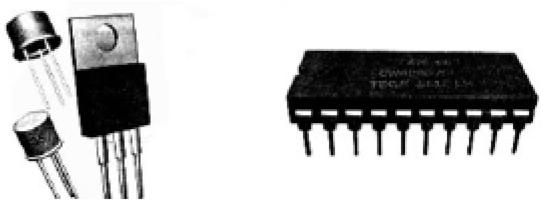
- An electronic component is any device that handles electricity
- Electronic components come in many different shapes and sizes, and perform different electrical functions depending upon the purpose for which they are used
- Electronic equipment make use of a variety of components

Active vs. Passive Components

- Passive
  - One that contributes no power gain (amplification) to a circuit or system
  - No control action and does not require any input other than a signal to perform its function



- Active
  - Capable of controlling voltages or currents and can create a switching action in the circuit
  - Can amplify or interpret a signal



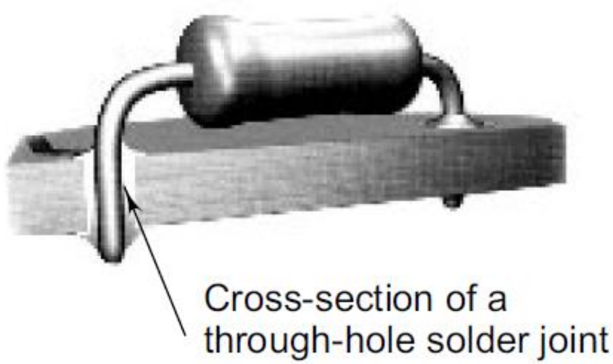
Discrete vs. Integrated Circuits

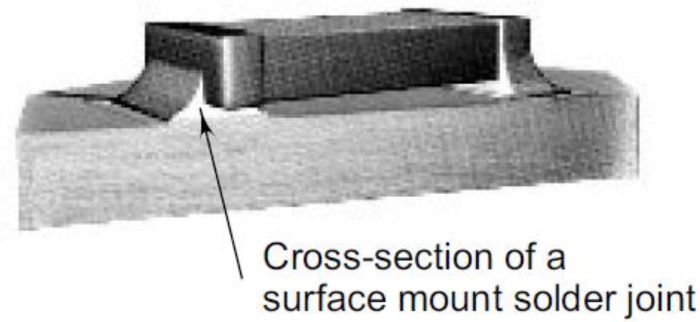
- When a component is packaged with one or two functional elements, it is known as a *discrete* component
  - Examples: resistors, inductors and capacitors

- An *integrated circuit* is a combination of several interconnected discrete components packaged in a single case to perform multiple functions
  - Examples: microprocessors and OP AMPs

Component Leads

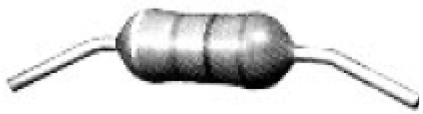
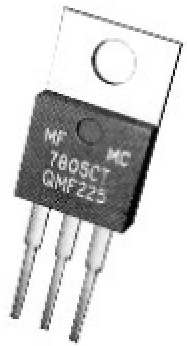
- Two types on the basis of the method of their attachment to the circuit board
  - Through-hole components
  - Surface mount components

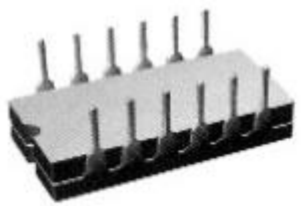


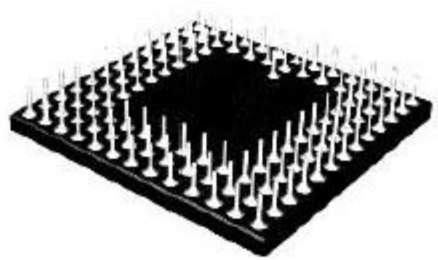
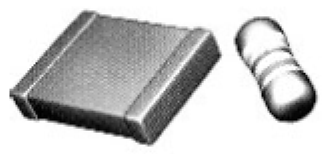


Component Leads: Examples

- Components with axial leads
- Components with radial leads
- Single-in-line package (SIL)
- Dual-inline package (DIP)
- Pin grid arrays (PGA)
- Ball grid arrays (BGA)
- Leadless components

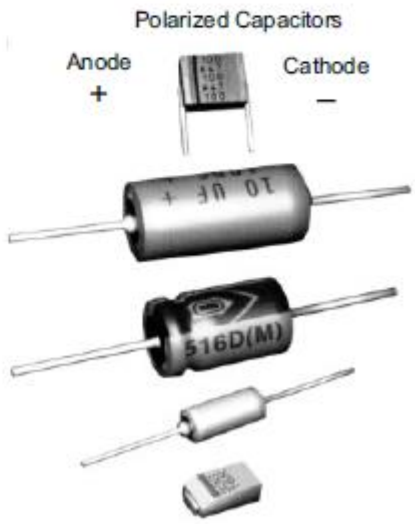



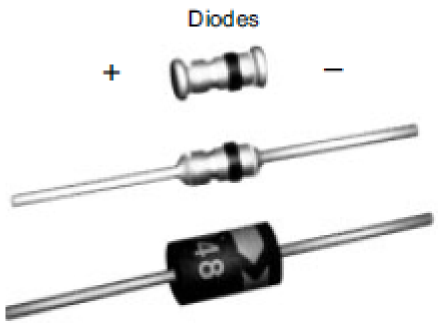



Polarity in Components

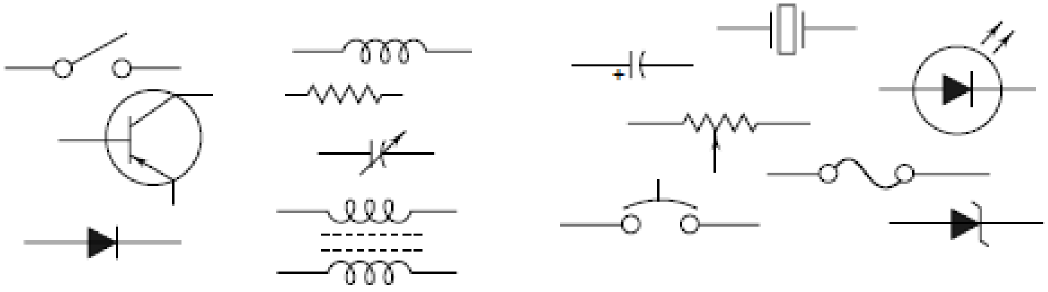
- Some components are polarized and therefore have leads which are marked with positive and negative polarity
  - Must be placed on the board in the correct orientation
  - Examples: electrolytic capacitors and diodes





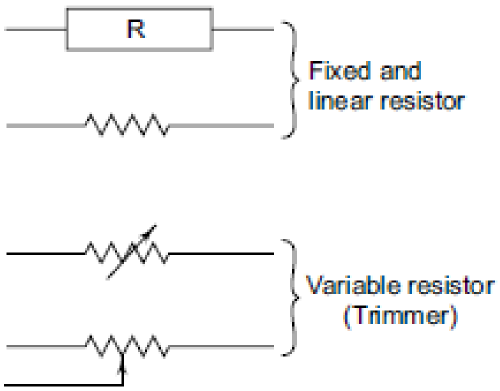
Component Symbols

- Each discrete component has a specific symbol when represented on a schematic diagram
  - Standardized and specified in the IEEE standard 315 and 315A (ANSI Y32.2)
- Integrated circuits are generally represented by a block in the schematic diagram
  - Do not have a specific symbol



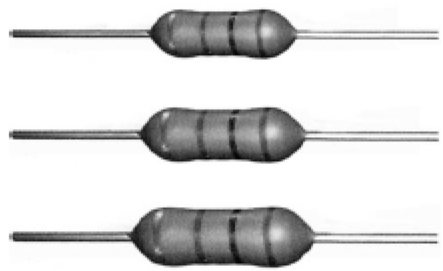
Resistors

- Fixed or variable
- Carbon
  - Good in high frequency
  - Limited accuracy to 1%
  - Drift with temperature and vibration
- Metal film
  - stable under temperature and vibration
  - Reach accuracies of 0.1% in precision films
- Wire-wound Resistors
  - Very high accuracy possible

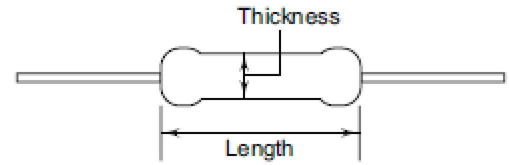


Resistors: Examples

- Carbon film



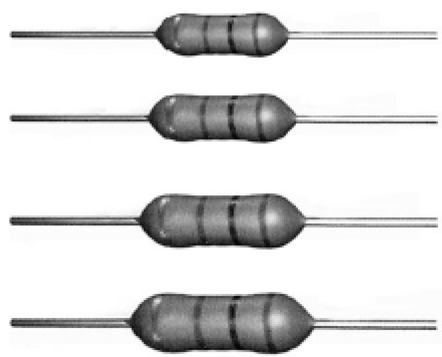
From the top of the photograph
1/8W
1/4W
1/2W



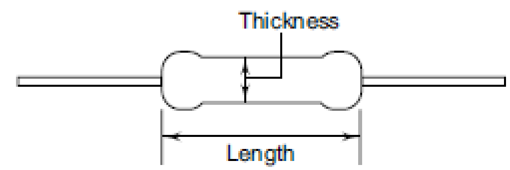
Approximate size

Rating power (W)	Thickness (mm)	Length (mm)
1/8	2	3
1/4	2	6
1/2	3	9

- Metal Film



From the top of the photograph
1/8W (tolerance ± 1%)
1/4W (tolerance ± 1%)
1W (tolerance ± 5%)
2W (tolerance ± 5%)

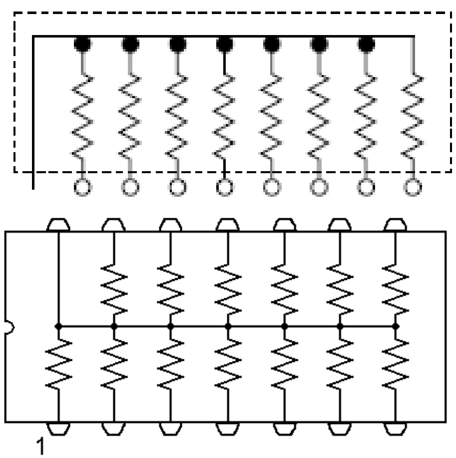


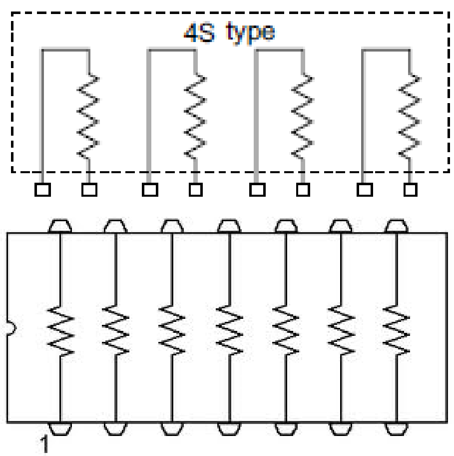
Approximate size

Rating power (W)	Thickness (mm)	Length (mm)
1/8	2	3
1/4	2	6
1	3.5	12
2	5	15

Resistors: Thick Film Networks

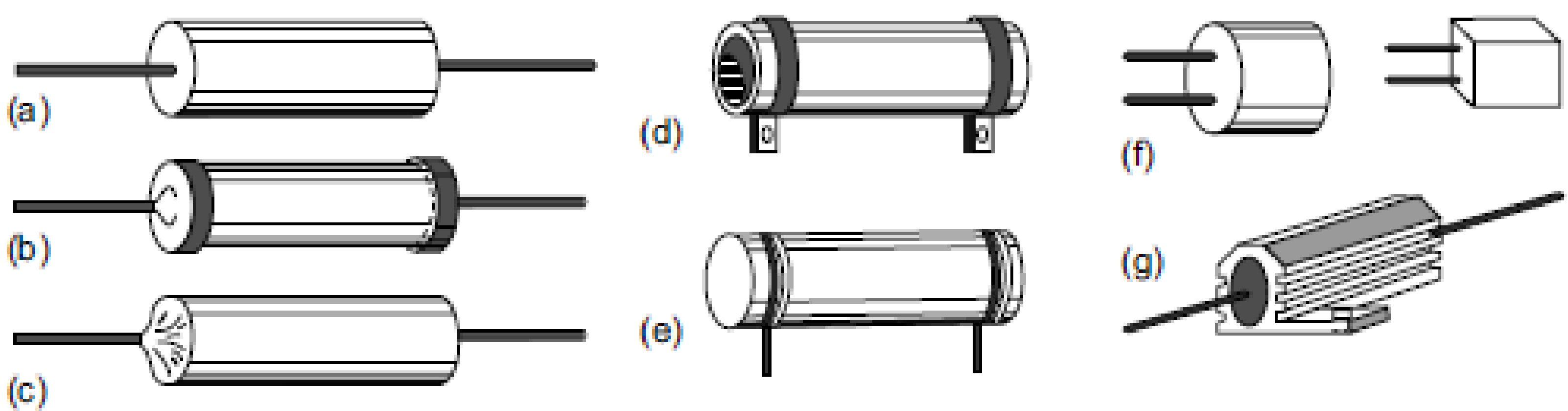
- precious metals in a glass binding system which have been screened on to a ceramic substrate and fired at high temperatures
  - Miniaturization and rugged construction
  - Inherently reliable, not subject to catastrophic failures
  - SIL or DIP packages





Resistors: Packages

- (a),(b),(c) Cylindrical package with axial leads
- (d), (e) Cylindrical package with radial leads
- (f) radial package with radial lead
- (g) high-power package, with axial leads and copper body for increased heat dissipation



Resistors: Characteristics

- Resistance
- Tolerance
- Power Rating
- Temperature Coefficient (hot spot temperature)
- Stability or Drift
- Noise
- Parasitic Effects
- Maximum Voltage
- Identification

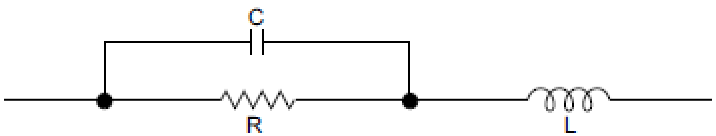


Fig. 2.10 Lumped model of a resistor C = 0.1-2 pf, L = 0.1 μH (for a leaded component)

Resistors: Values

- Code

F = ± 1%   G = ± 2%   j = ± 5%

K = ± 10%   M = ± 20%±

R 68M is a 0.68 Ω ± 20% resistor

5K 6J is a 5.6 kΩ ± 5% resistor

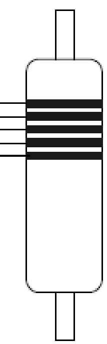
82KK is 82 kΩ ± 10% resistor

Four Band Resistors

1st Band		2nd Band		3rd Band		4th Band (tolerance)	
Black	0	Black	0	Silver	Divide by 100	Red	± 2%
Brown	1	Brown	1	Gold	Divide by 10	Gold	± 5%
Red	2	Red	2	Black	Multiply by 1	Silver	± 10%
Orange	3	Orange	3	Brown	Multiply by 10		
Yellow	4	Yellow	4	Red	Multiply by 100		
Green	5	Green	5	Orange	Multiply by 1,000		
Blue	6	Blue	6	Yellow	Multiply by 10,000		
Violet	7	Violet	7	Green	Multiply by 100,000		
Grey	8	Grey	8	Blue	Multiply by 1,000,000		
White	9	White	9				

Five Band Resistors

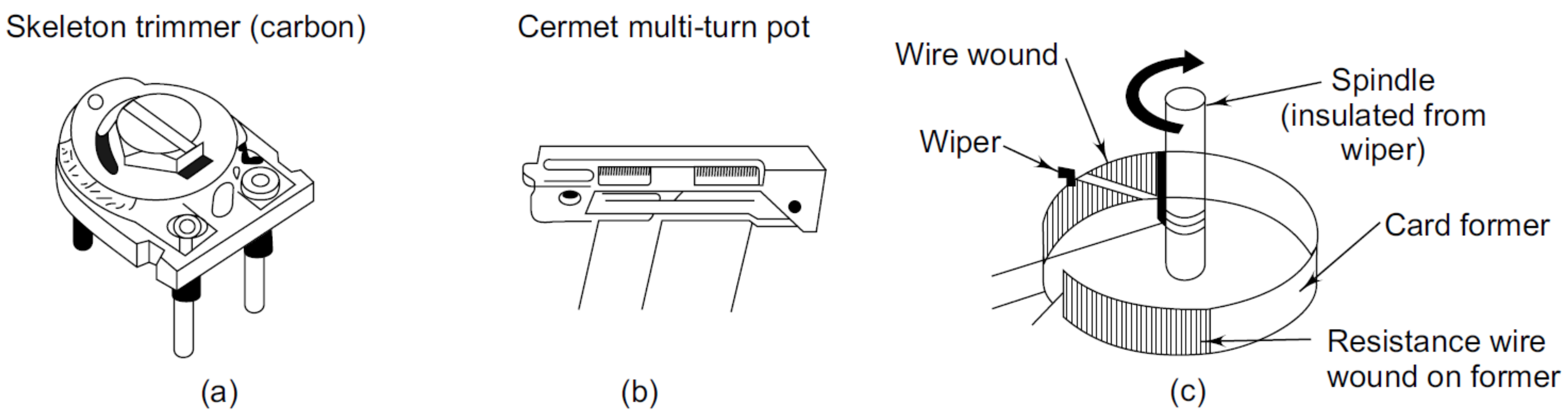
1st Band		2nd Band		3rd Band		4th Band		5th Band (tolerance)	
Black	0	Black	0	Black	0	Silver	Divide by 100	Brown	± 1%
Brown	1	Brown	1	Brown	1	Gold	Divide by 10	Red	± 2%
Red	2	Red	2	Red	2	Black	Multiply by 1	Gold	± 5%
Orange	3	Orange	3	Orange	3	Brown	Multiply by 10	Silver	± 10%
Yellow	4	Yellow	4	Yellow	4	Red	Multiply by 100		
Green	5	Green	5	Green	5	Orange	Multiply by 1,000		
Blue	6	Blue	6	Blue	6	Yellow	Multiply by 10,000		
Violet	7	Violet	7	Violet	7	Green	Multiply by 100,000		
Grey	8	Grey	8	Grey	8	Blue	Multiply by 1,000,000		
White	9	White	9	White	9				



- Preferred range:
  - E 12 series (common): 10, 12, 15, 18, 22, 27, 33, 39, 47, 56, 68, 82
  - E 96 series: for ± 1%

Variable Resistors or Potentiometers

- "Pots" consist of a track of some type of resistance material with which a movable wiper makes contact
- 3 Categories: (a) Carbon (b) Cermet (c) Wire wound

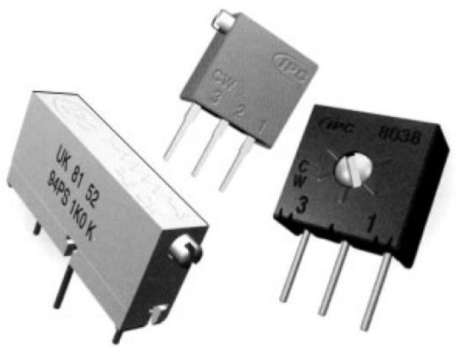


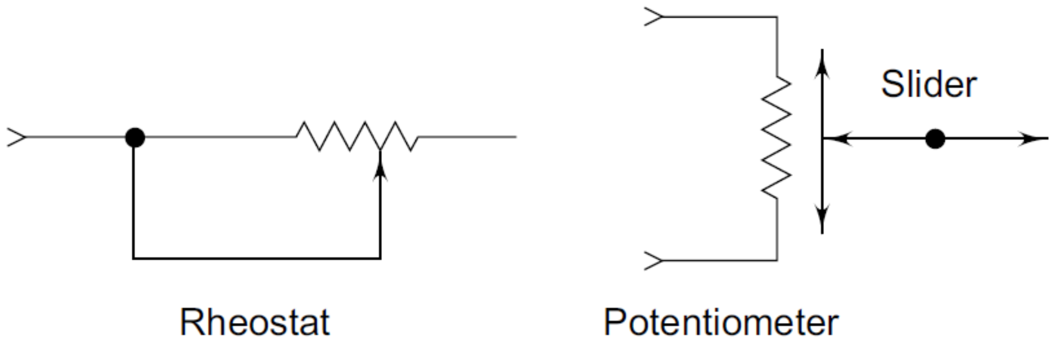
Variable Resistors or Potentiometers

- Pots can be categorized into the following types depending upon the number of resistors and control arrangement used:
  - *Single Potentiometers: Pot control with one resistor*
  - *Tandem Potentiometers*: Two identical resistor units controlled by one spindle
  - *Twin Potentiometers*: Two resistor units controlled by two independent concentric spindles
  - *Multi-turn Potentiometers*: Potentiometer with knob or gear wheel for resistance adjustment; they may have up to 40 rotations of spindle
  - *Potpack*: Rectangular pots, either single or multi-turn

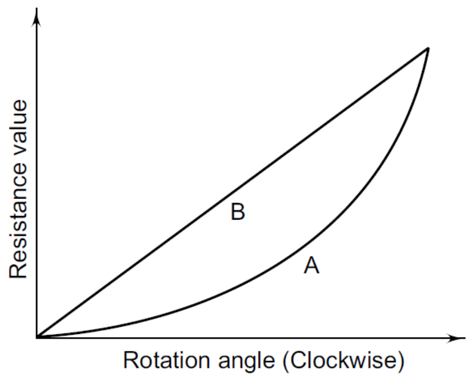
Variable Resistors or Potentiometers

- Variable resistor can be used either as a rheostat or potentiometer



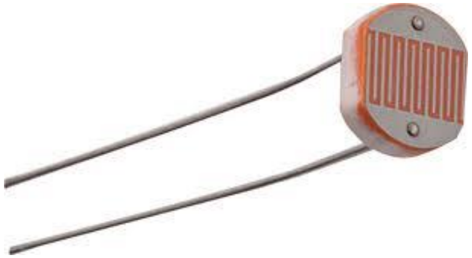


- Construction resistance laws:
  - Linear
  - Logarithmic
  - Sine-Cosine



Light-dependent Resistors (LDRs)

- Made of cadmium sulphide and contain very few free electrons
  - When kept in complete darkness and therefore, exhibit very high resistance.
  - When in light, electrons are liberated and the material becomes more conducting.
- Typical dark resistance of LDRs is 1-10 MOhms.
- Typical light resistance is 75 -300 ohms.
- LDRs take some finite time to change its state and this time is called the recovery time.
  - Typical recovery rate is 200 kOhms/sec.



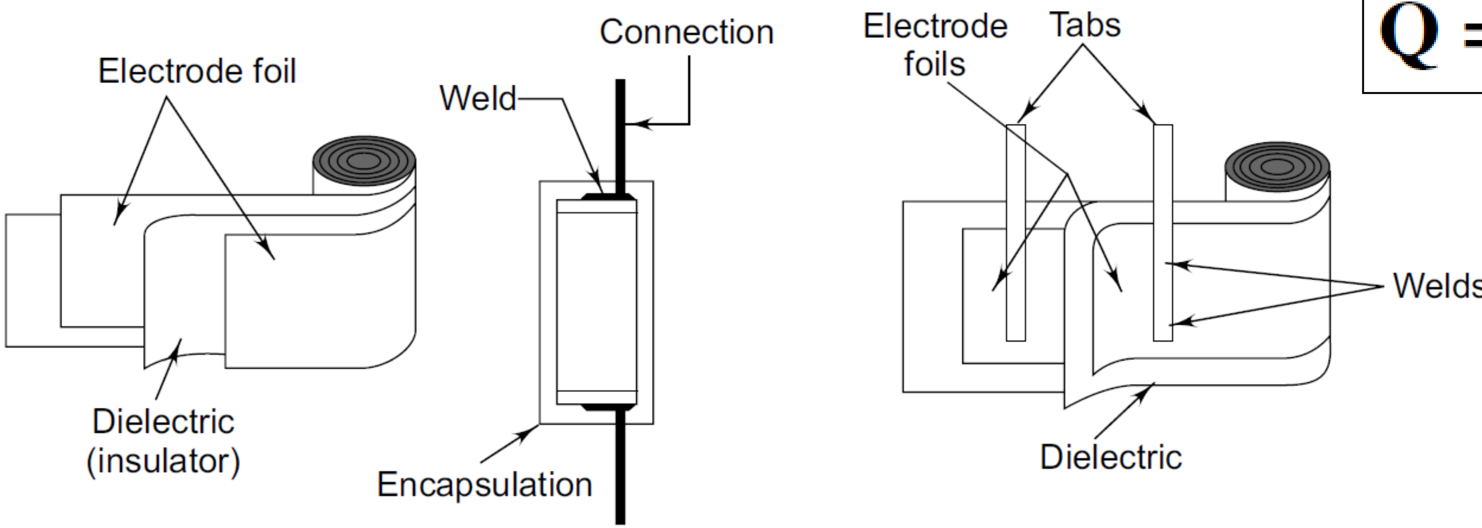
Thermistors

- Resistors with high temperature co-efficient of resistance
- Two types:
  - Positive temperature coefficient (PTC)
  - Negative temperature coefficient (NTC) (most popular)
- Available in a wide variety of shapes and forms suitable for use in different applications.
- Inherently nonlinear resistance–temperature curve
  - Can be linearized by proper circuit

Capacitors (Condensers)

- Passive component that can be used to store electrical charge – measured in Farads (F)
- Consists of two facing conductive plates called electrodes, which are separated by a dielectric or insulator

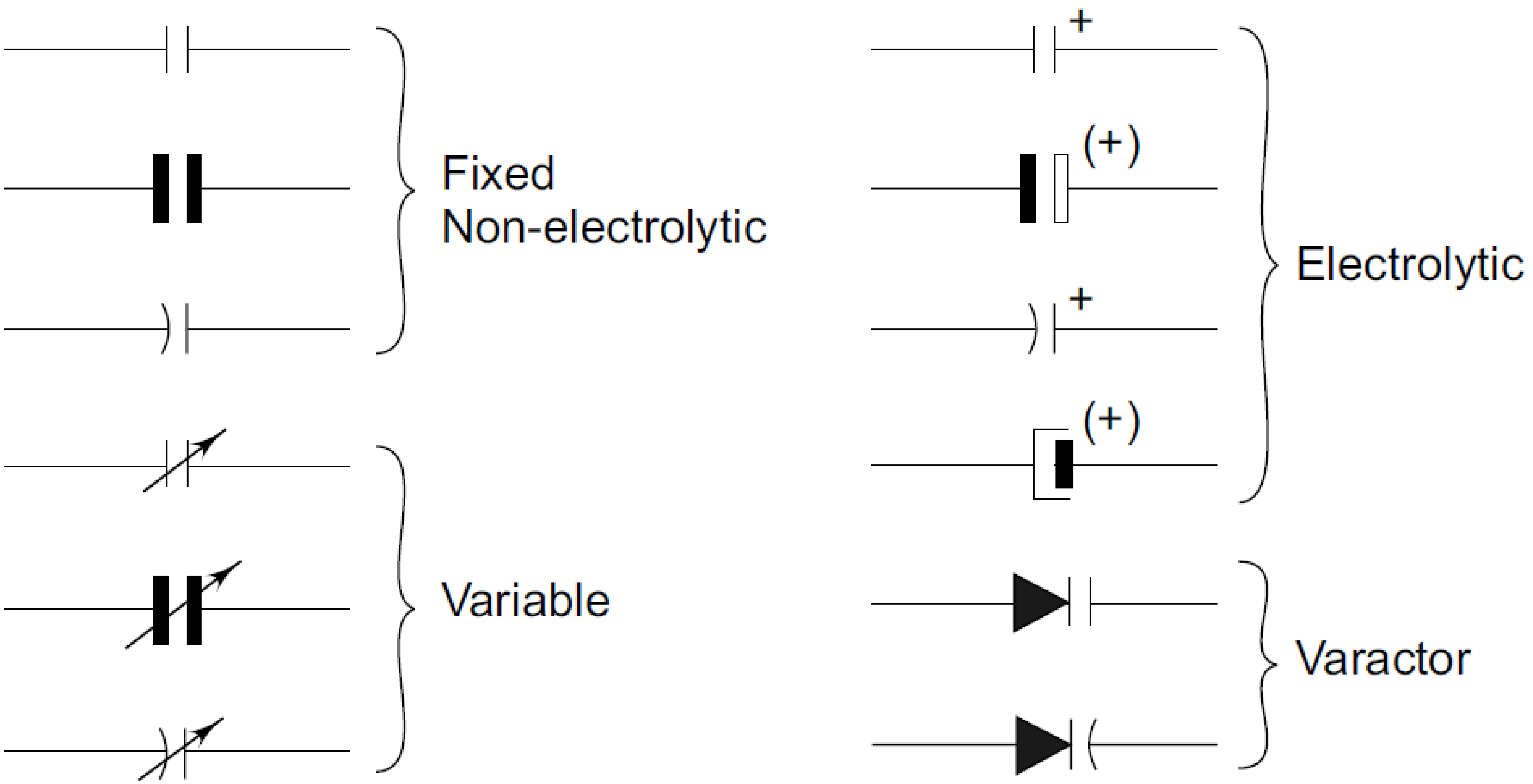
$$Q = CV$$



(a) Extended foil type (b) Buried foil type

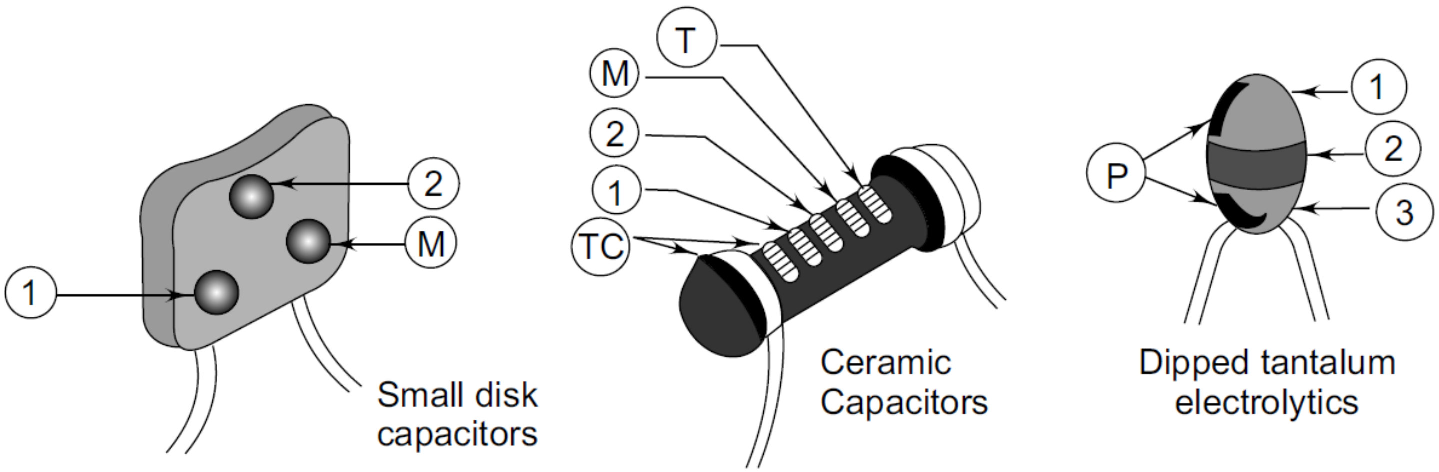
Capacitors (Condensers)

- Graphical symbols



Capacitors (Condensers)

- Color code



Colour code

(1) (2) and (3) 1st, 2nd and 3rd significant figs.

(M) Multiplier (T) Tolerance

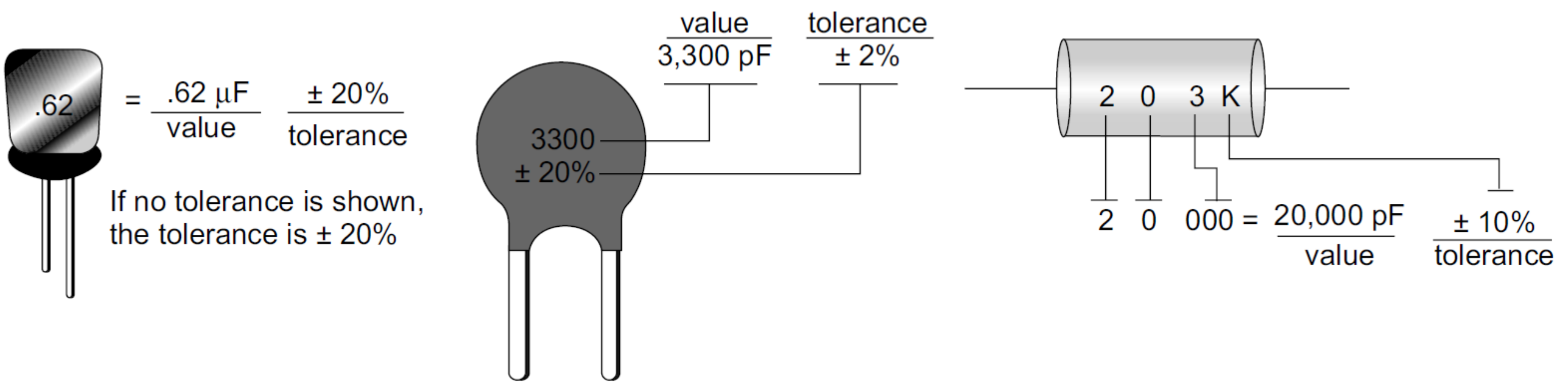
(TC) Temperature coefficient

(T) and/or (TC) Colour code may not be present on some capacitors

(P) Positive (+) polarity and voltage ratings

Capacitors (Condensers)

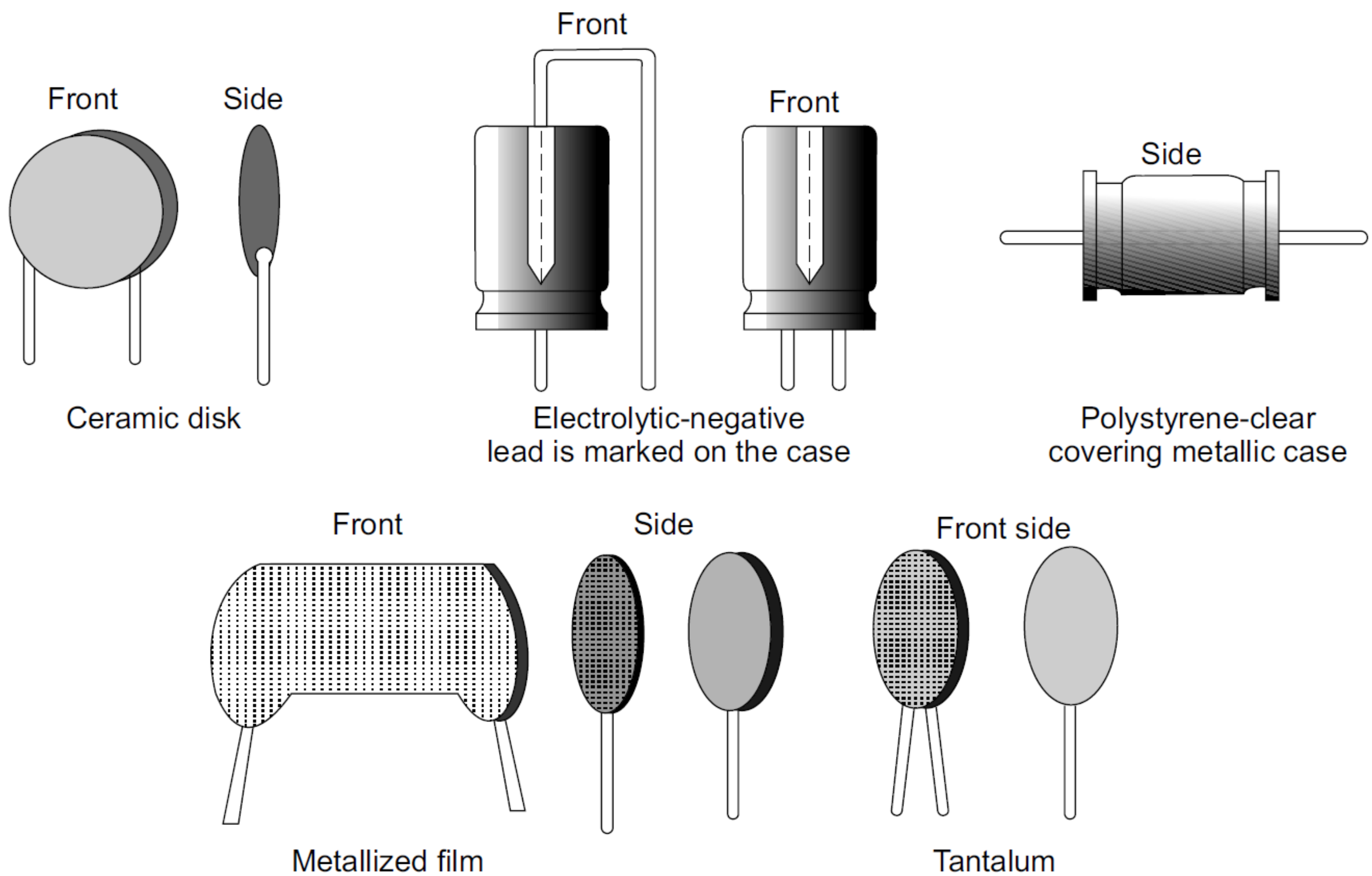
- Code for numbered capacitors



F = ±1%, G = ±2%, J = ±5%, K = ±10%, M = ±20% and Z = +80 to –20%

Capacitors (Condensers)

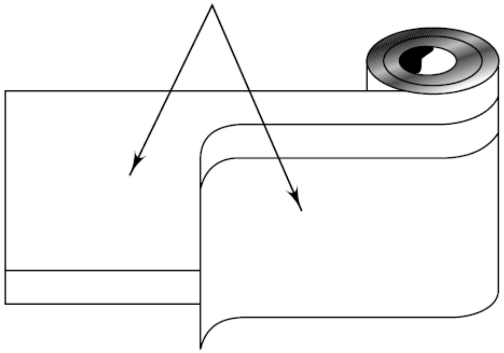
- Types



Capacitors (Condensers)

- Paper capacitors

Typical range	:	10 nF to 10 μF
Typical dc voltage	:	500 V(max.)
Tolerance	:	± 10%



- Mica capacitors

Typical range	:	5 pF to 10 nF
Typical dc voltage	:	50 to 500 V
Tolerance	:	± 0.5%

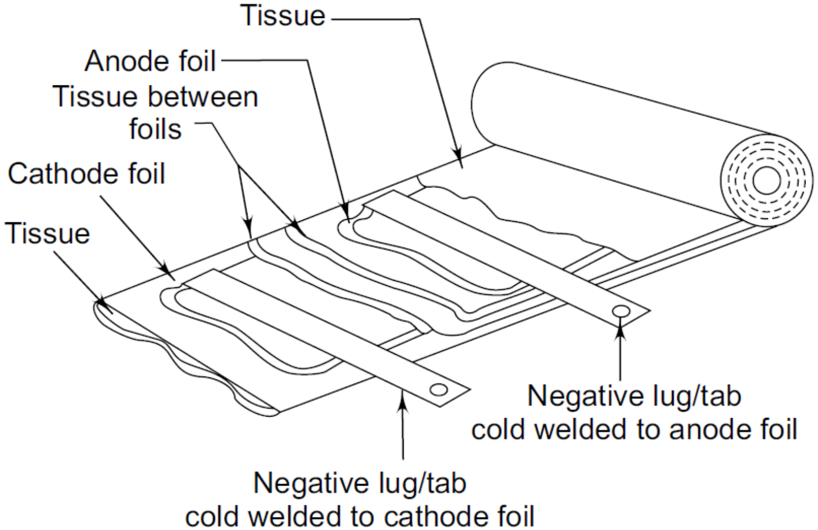
- Ceramic capacitors

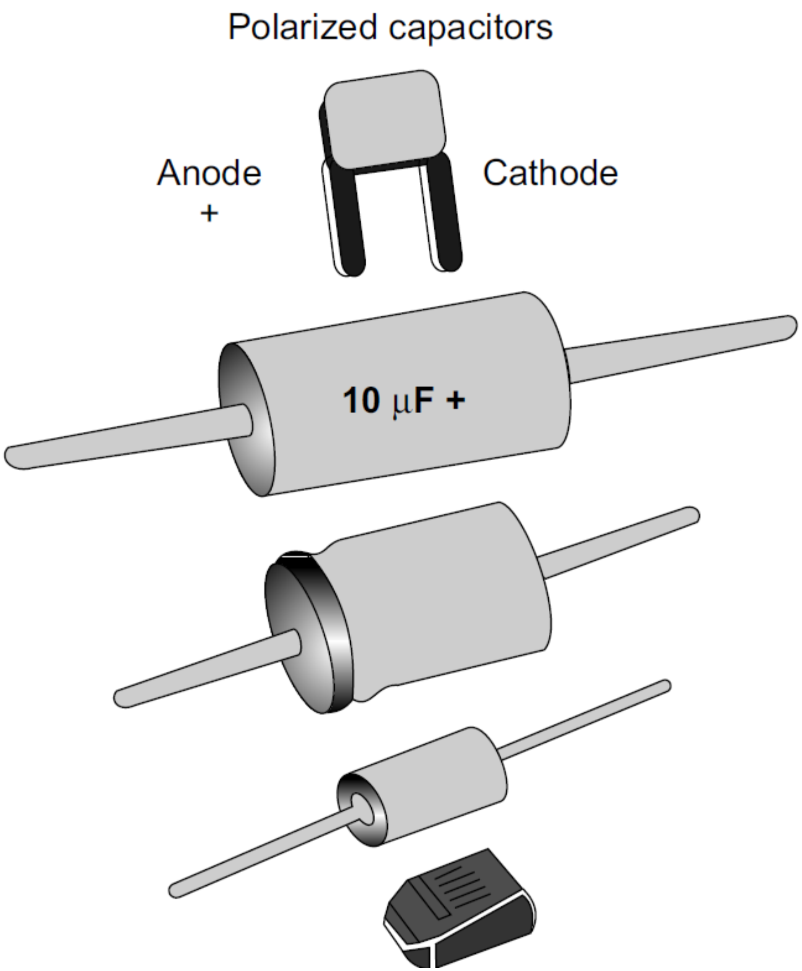
Typical range	:	(a) Low loss (steatite) 5 pF to 10 nF (b) Barium titanate 5 pF to 1 μF (c) Monolithic 1 nF to 47 μF

Typical voltage range	:	For a and b 60 V to 10 kV For c: 60 V to 400 V
Tolerance	:	± 10% to ± 20%

Capacitors (Condensers)

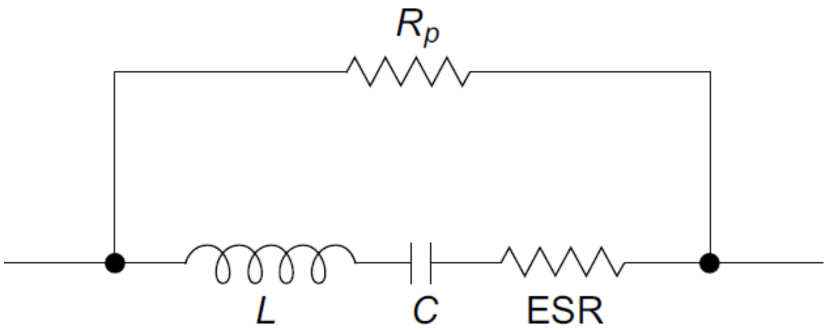
- Electrolytic capacitors
  - Aluminum
  - Tantalum





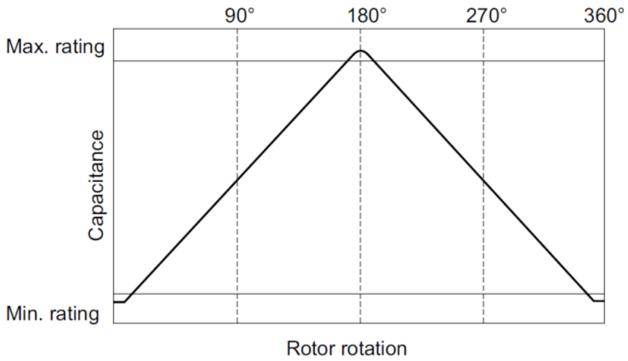
Capacitors (Condensers)

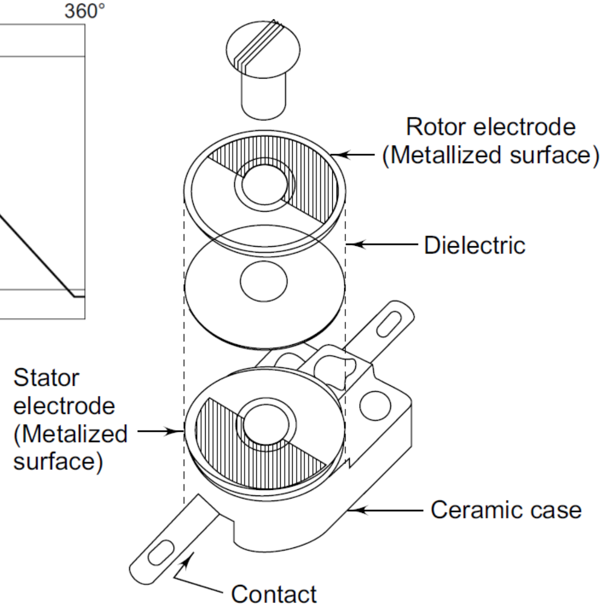
- Capacitance
- Tolerance
- Working Voltage (= ½ *breakdown voltage)*
- Temperature Coefficient
- DC Leakage
- Parasitic Effects
  - dissipation factor (DF)=1/Q

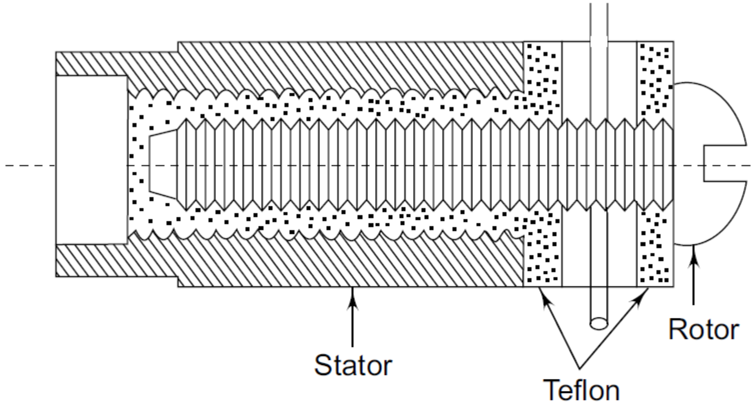


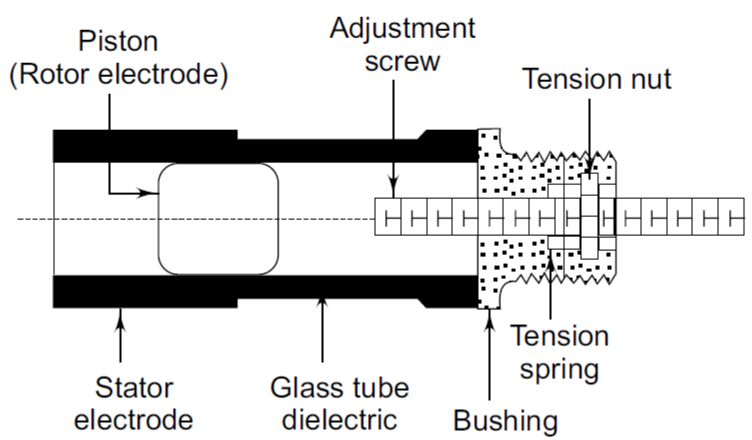
Variable Capacitors

- Variable capacitor has a stator and a rotor to change area
  - Button type
  - Tubular type





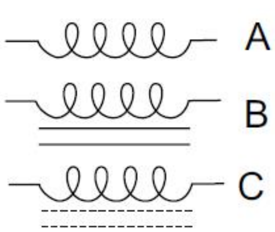




Inductors

- A device that resists change in the current through the device.
- Inductors work on the principle that when a current flows in a coil of wire, a magnetic field is produced, which collapses when the current is stopped.
- The collapsing magnetic field produces an electromotive force which tries to maintain the current.

$$e = -L\frac{di}{dt}$$



Inductors

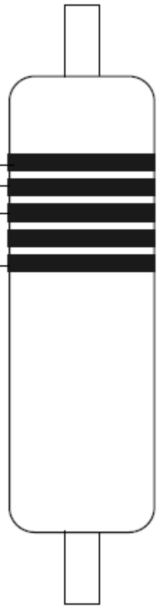
Inductor Band Colour Codes

1st Band (Value)	
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

2nd Band (Value)	
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

3rd Band (Multiplier)	
Black	× 1 or no zeros
Brown	× 10 or +1 zero
Red	× 100 or +2 zeros
Orange	× 1k or +3 zeros
Yellow	× 10k or +4 zeros
Green	× 100k or +5 zeros
Blue	× 1m or +6 zeros
Gold	× .1
Silver	× .01

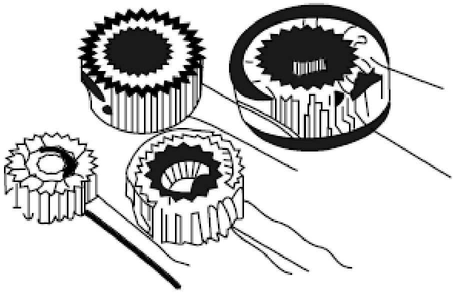
4th Band (tolerance)	
Red	± 2%
Gold	± 5%
Green	± 5%
Blue	± .25%
Violet	± .1%
Gold	± 5%
Silver	± 10%

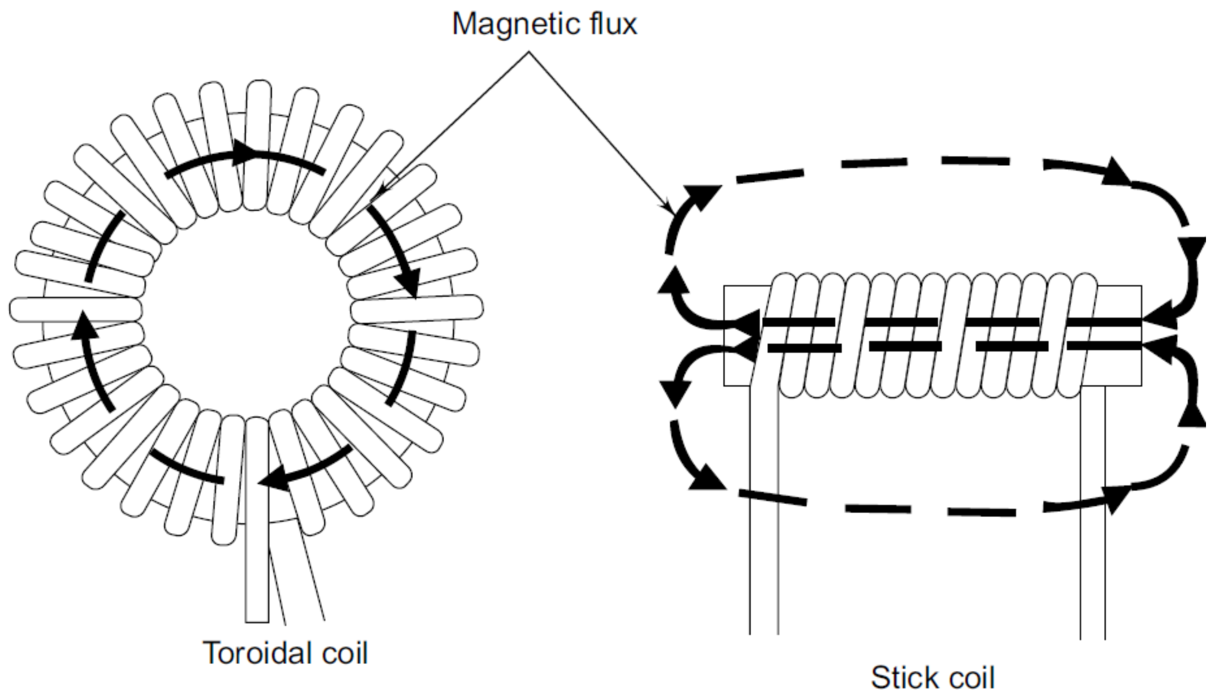


Inductors

- The primary use of an inductor is filtering.
  - High current inductors wound around a large core are used in power supply filters
  - Low current air core inductors are used in signal filters
- Basic components of an inductor are the former (or bobbin), winding wire (with or without separating material) and the core material
  - Bobbins are normally made of molded plastic
  - Winding is usually enameled copper wire
  - Core material can be laminated steel, powdered iron or ferrite – Shape also varies

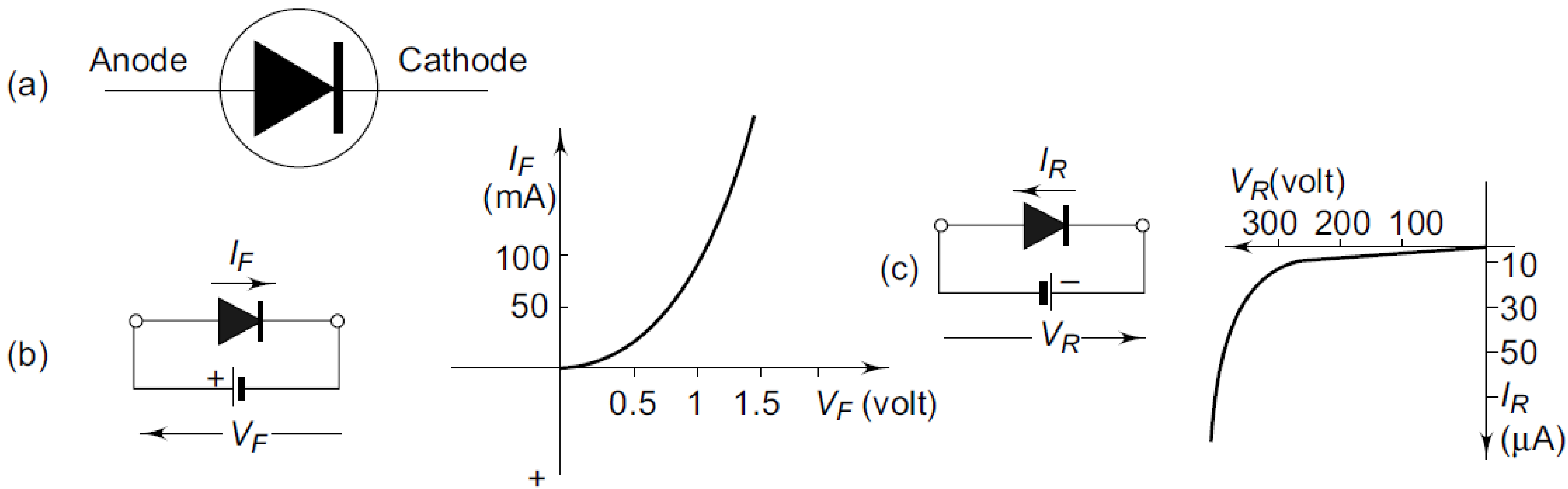
Inductors



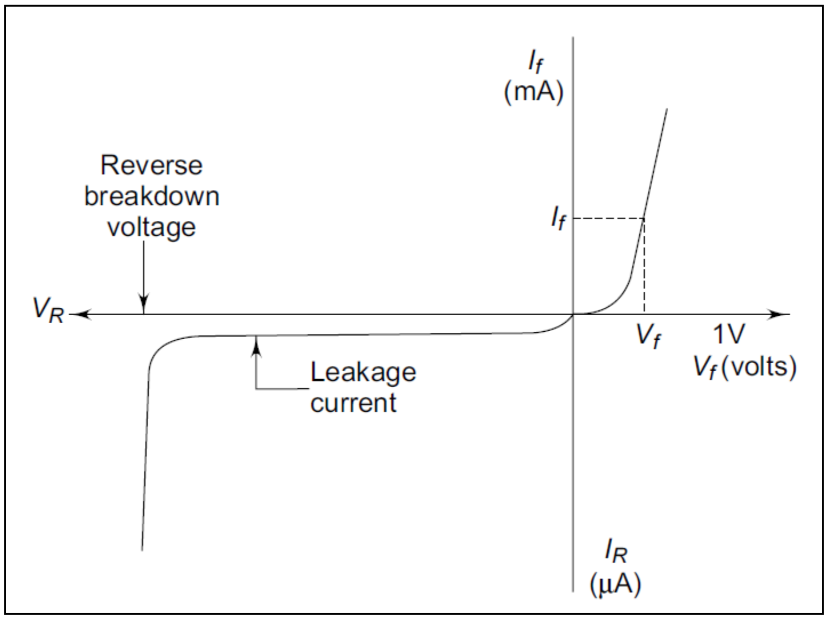


Diodes

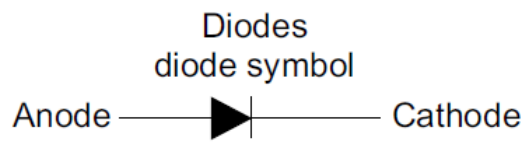
- A diode is an active component made of semiconductor material through which the current flows more easily in one direction than in the other



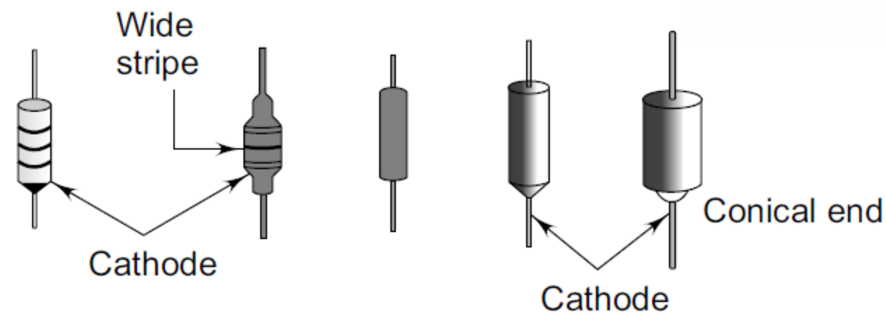
Diodes



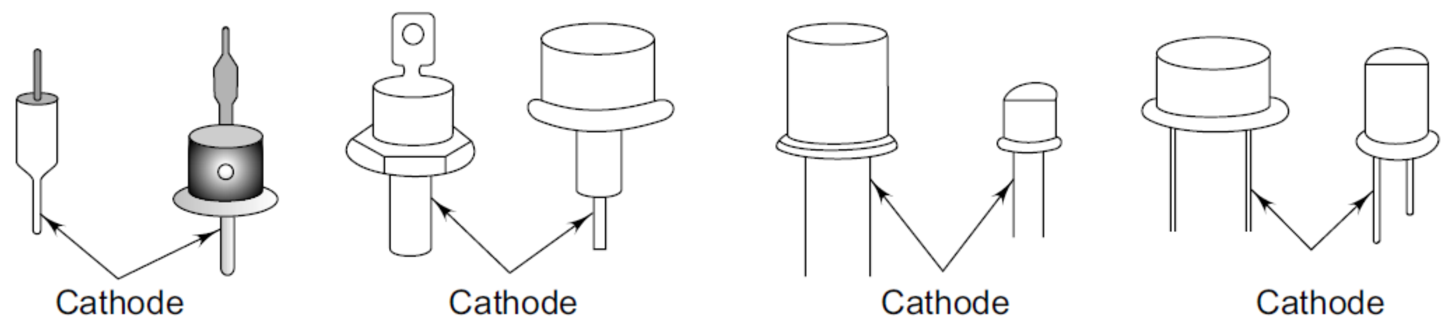
I_f
(mA)
Reverse
breakdown
voltage
I_f
V_R
V_f
1V
V_f (volts)
Leakage
current
I_R
(µA)



Diodes
diode symbol
Anode
Cathode



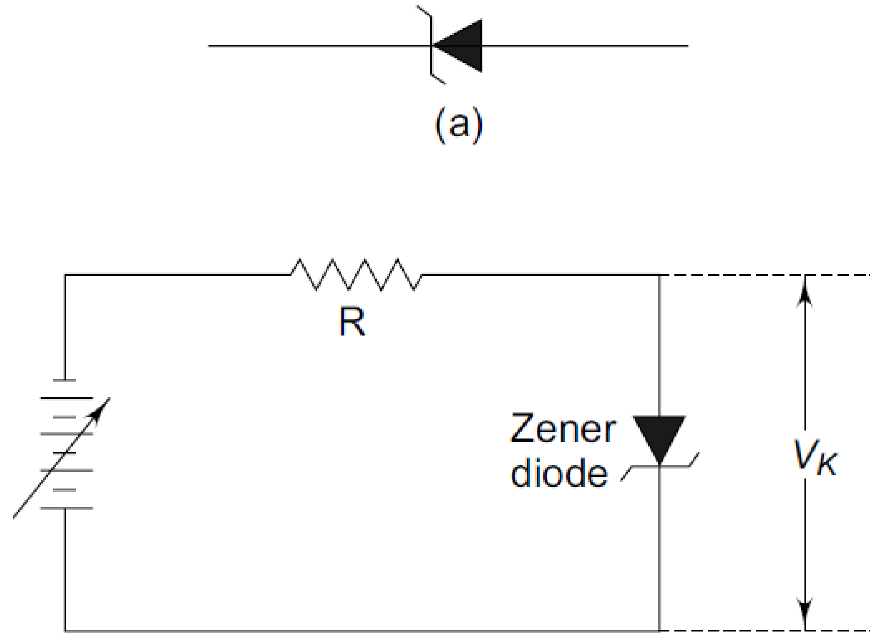
Wide
stripe
Cathode
Conical end
Cathode



Cathode
Cathode
Cathode
Cathode

Zener Diodes

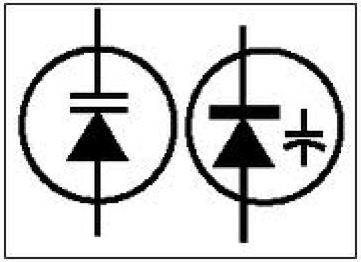
- Breakdown avalanche or the Zener voltage
  - Range from 1 volt to several hundred volts
  - Behaves like a voltage source in the Zener region
- Distinguish Zener diode from a general purpose diode by being usually labelled with its specified breakdown voltage

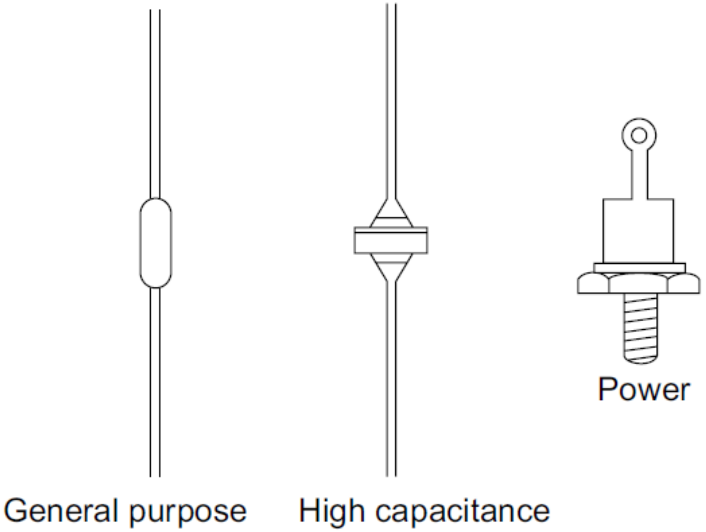


(a)
(b)

Varactor Diode

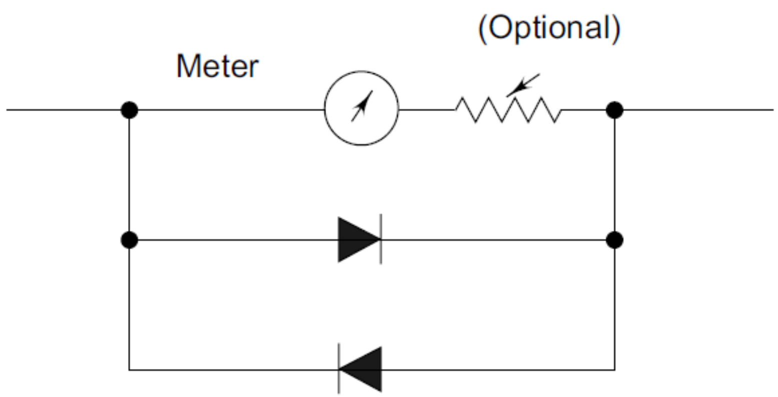
- Silicon diode that works as a variable capacitor in response to a range of reverse voltage values
  - Nominal capacitance values ranging from 1 to 500 pF
  - Maximum rated operating voltages from 10 to 100 volts

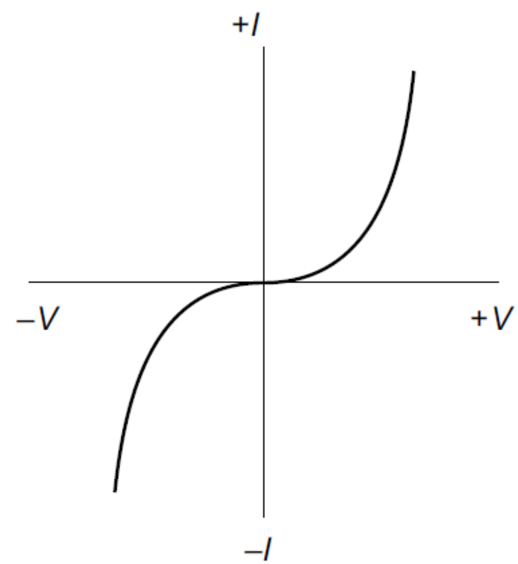




Varistor

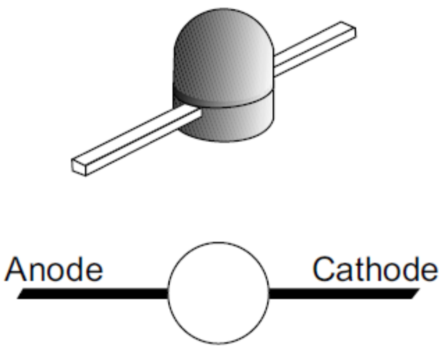
- Semiconductor device having voltage-dependent non-linear resistance that drops as applied voltage is increased
- Symmetrical varistor arrangements are used in meter protection circuits



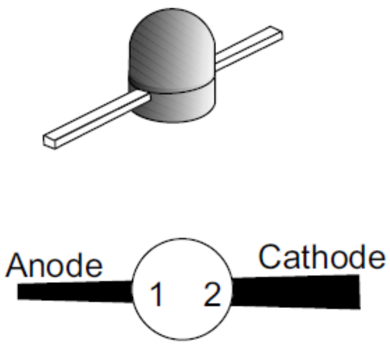


Light Emitting Diodes (LEDs)

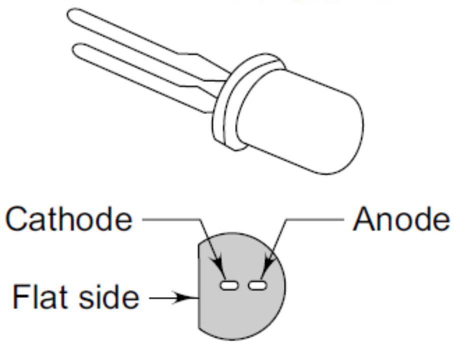
- A LED is basically a p-n junction that emits light when forward biased
  - Different colors and shapes



(Cathode identified by small plastic protrusion)



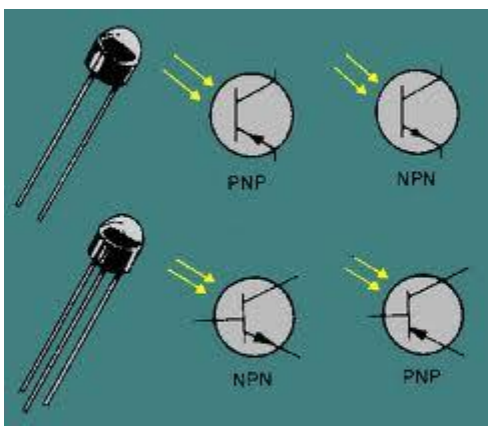
(Cathode identified by larger lead)

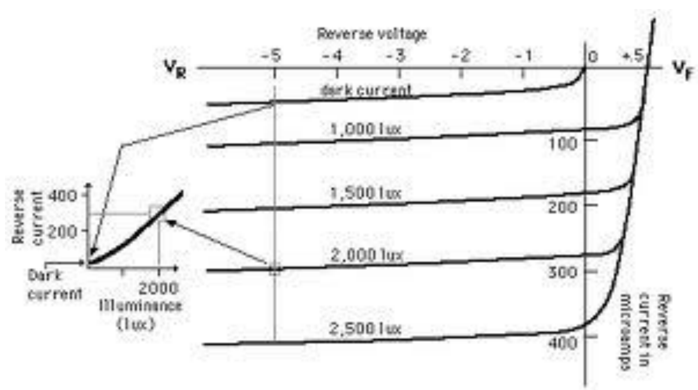


(Cathode identified by flat on side of case)

Photodiode

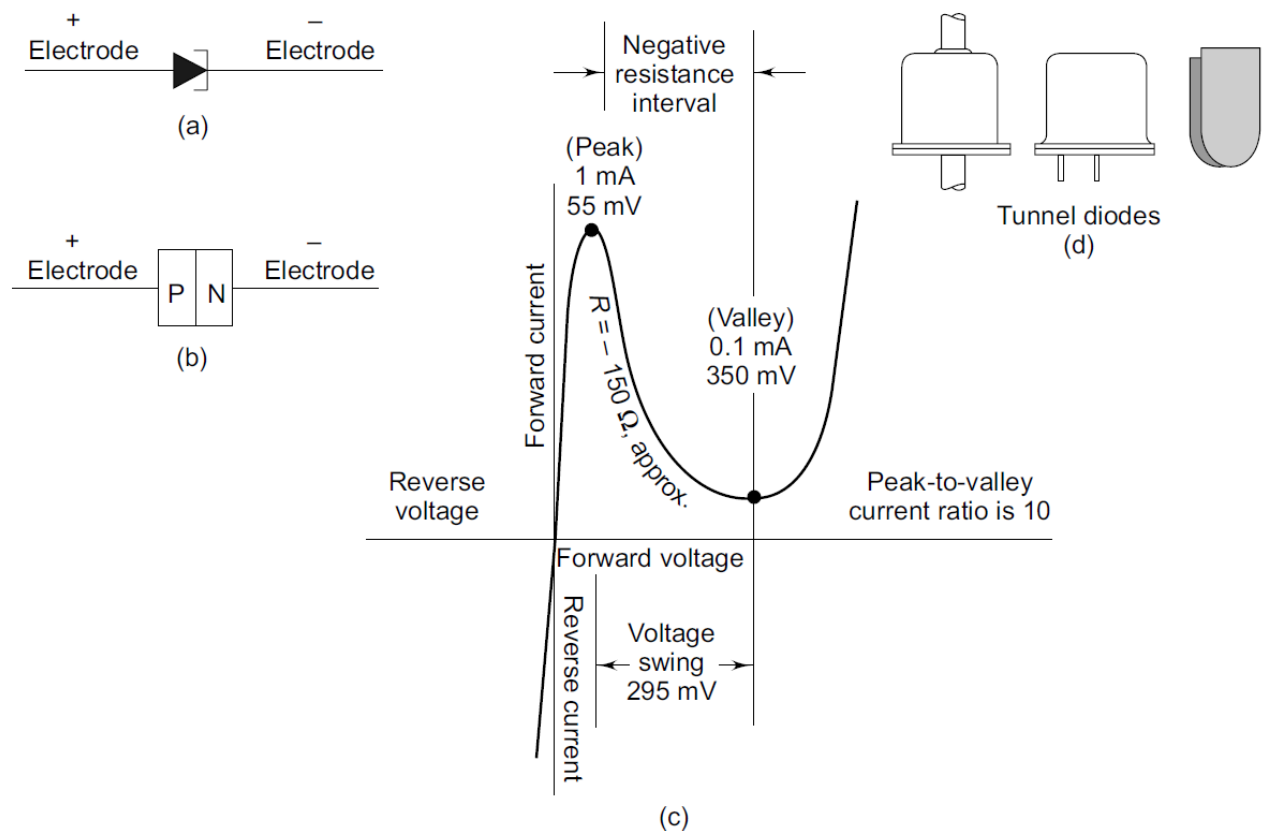
- A photodiode is a solid state device, similar to a conventional diode, except that when light falls on it, it causes the device to conduct
  - Practically an open circuit in darkness, but conducts a substantial amount of current when exposed to light.





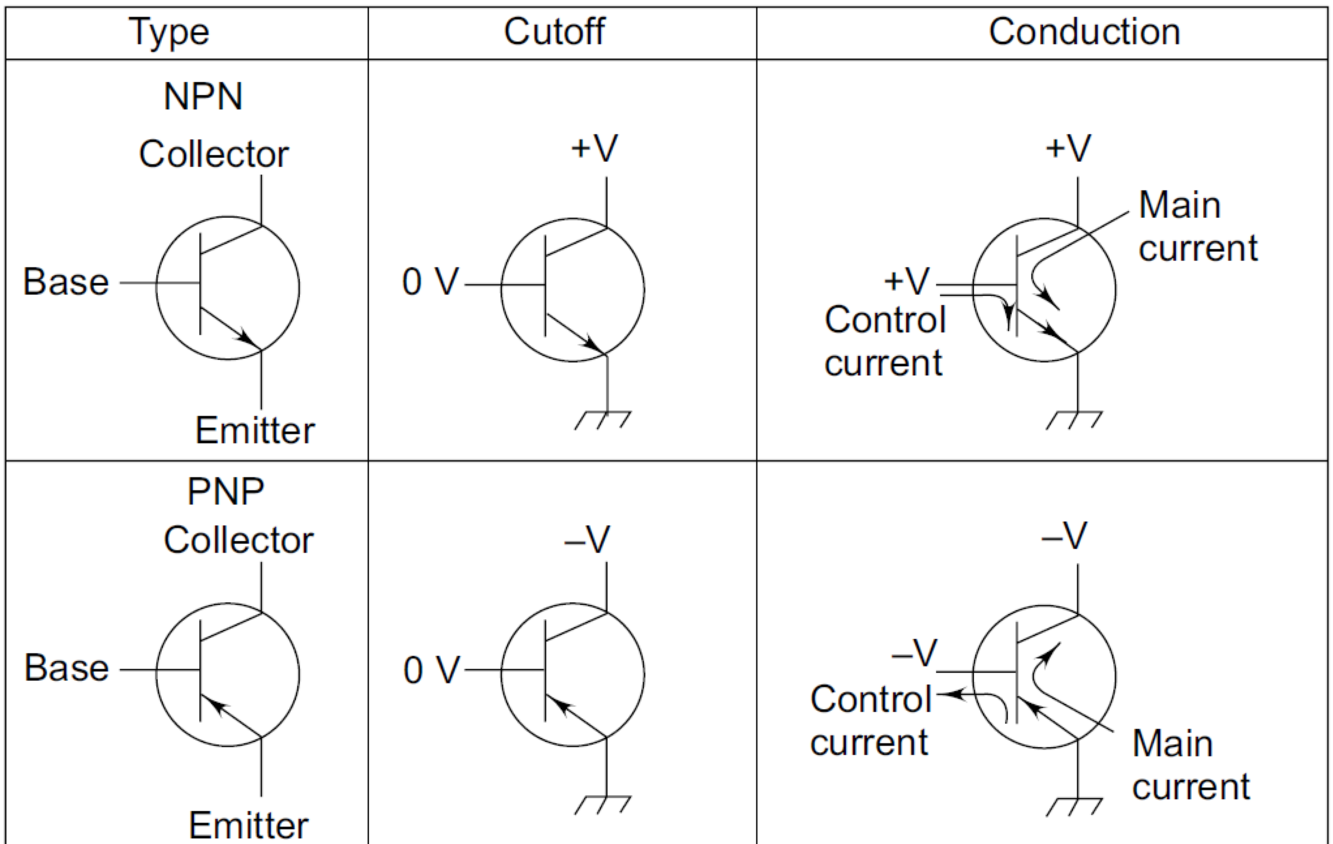
Tunnel Diode (TD)

- A tunnel diode is a p-n junction which exhibits a negative resistance interval

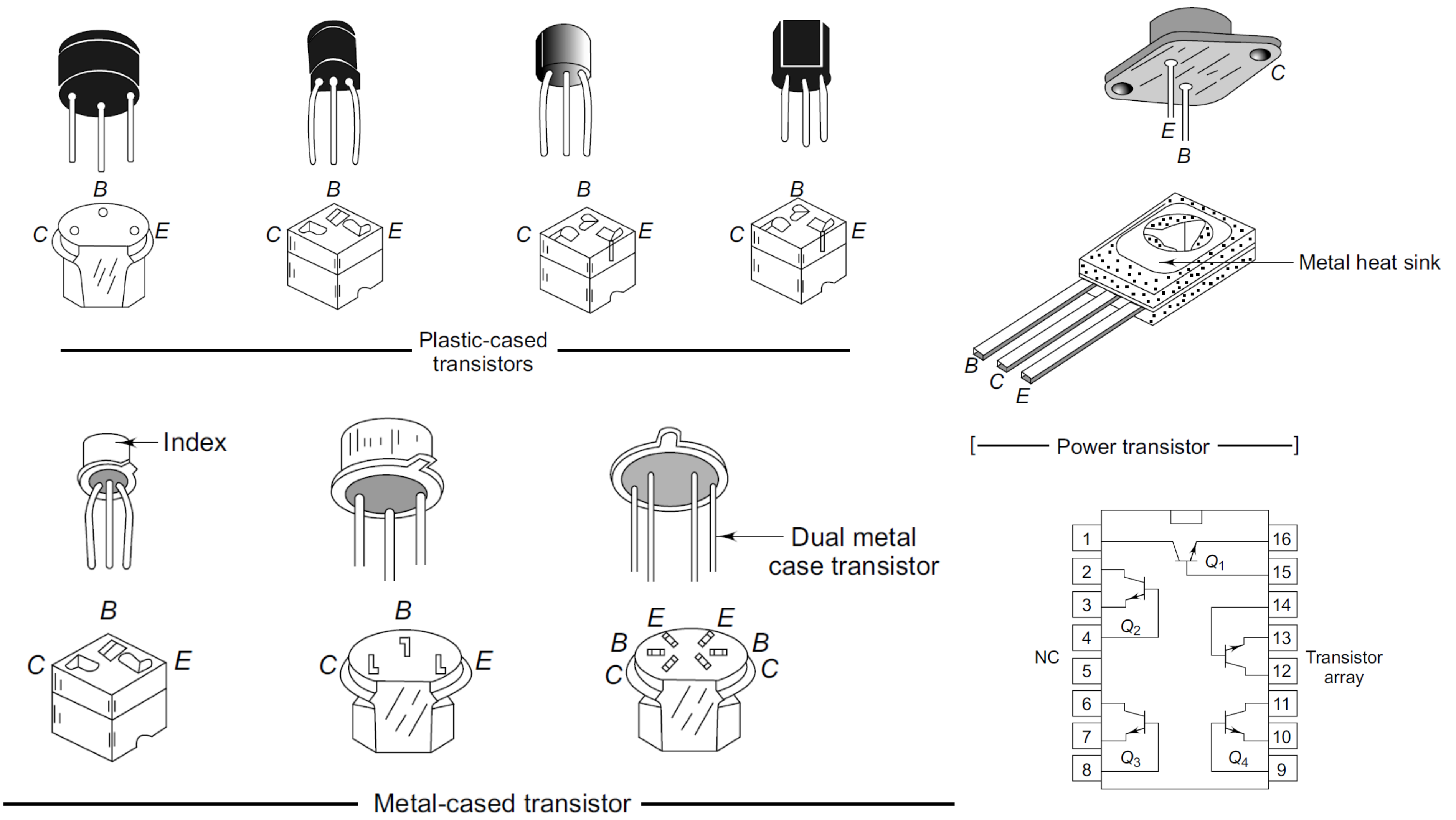


Transistors

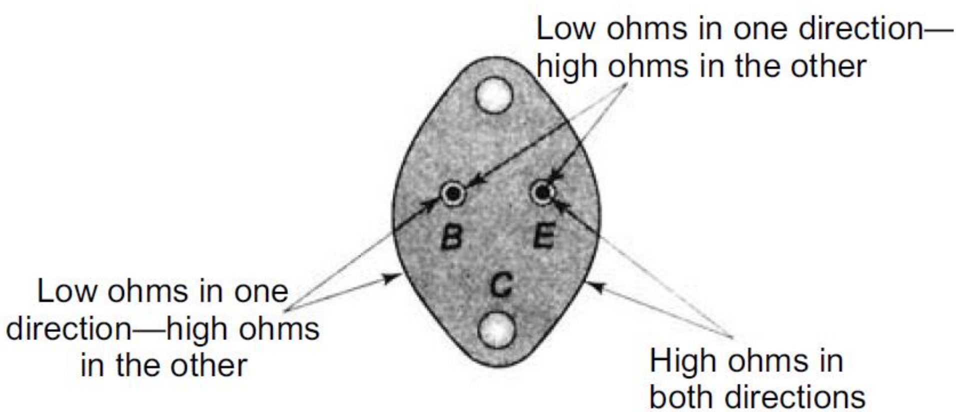
- Bipolar junction transistors (BJT)

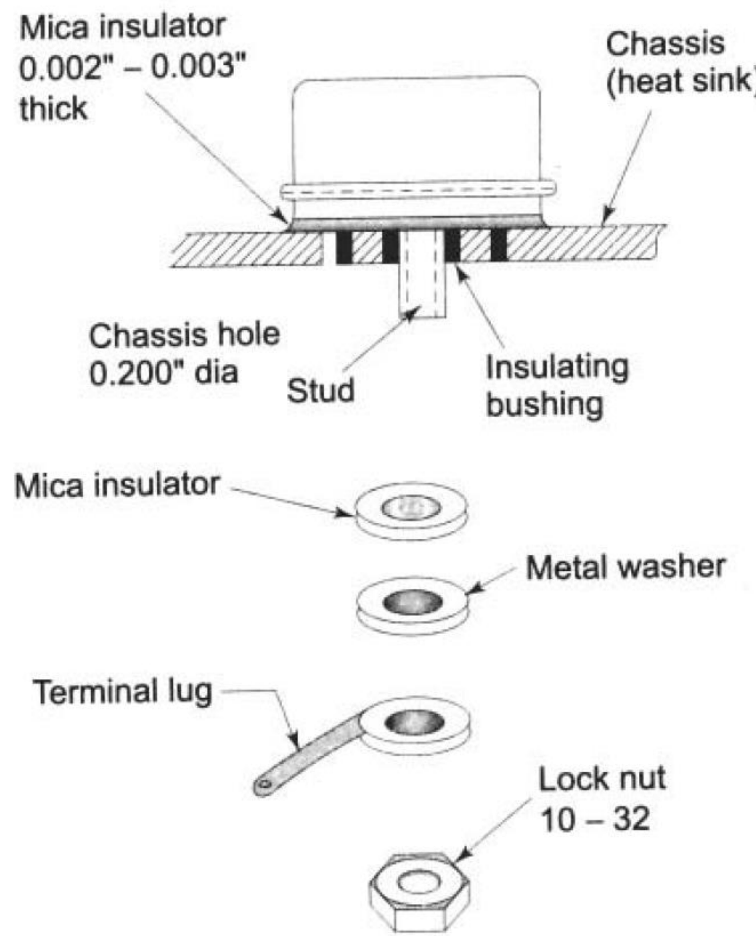


Transistors



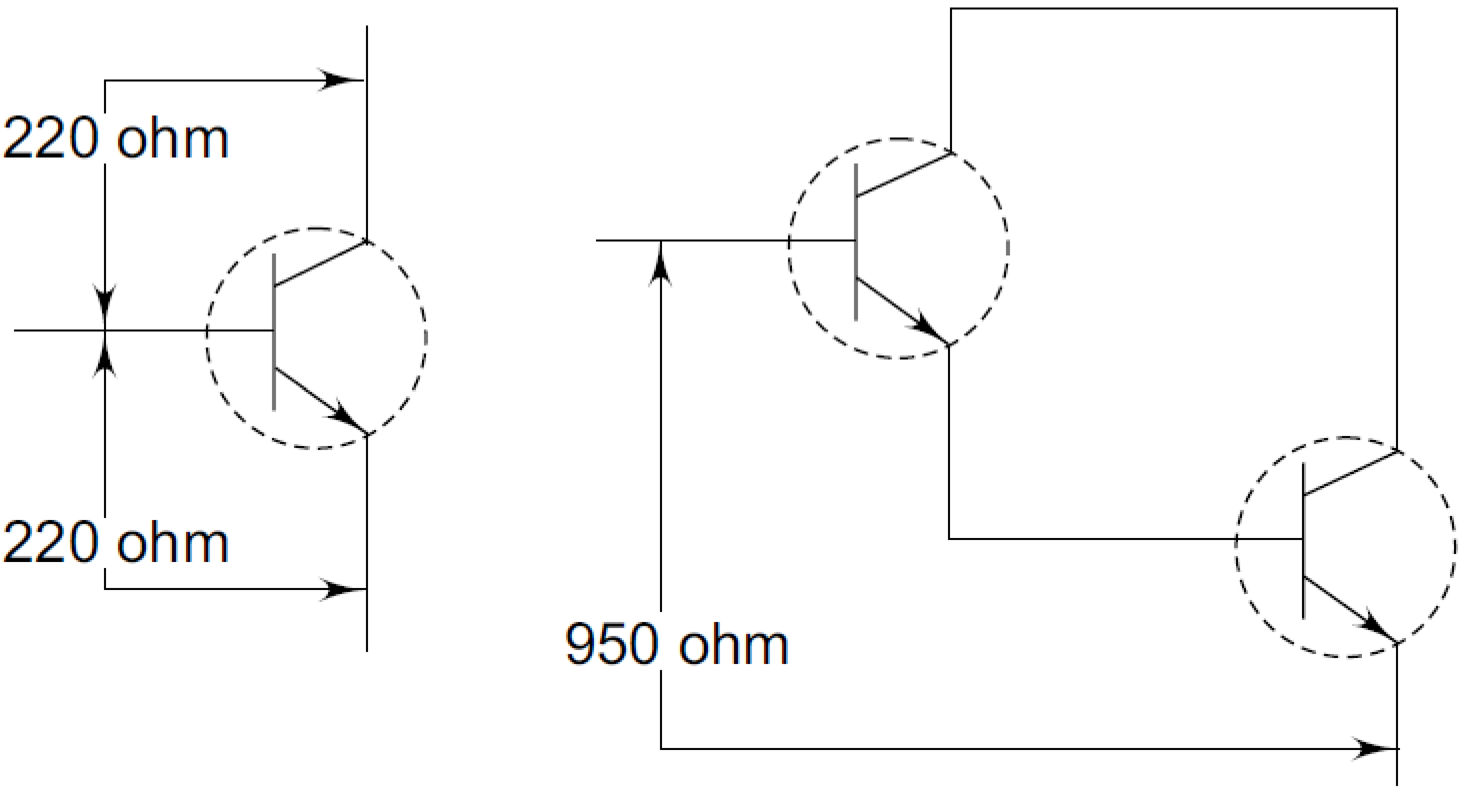
Power Transistors



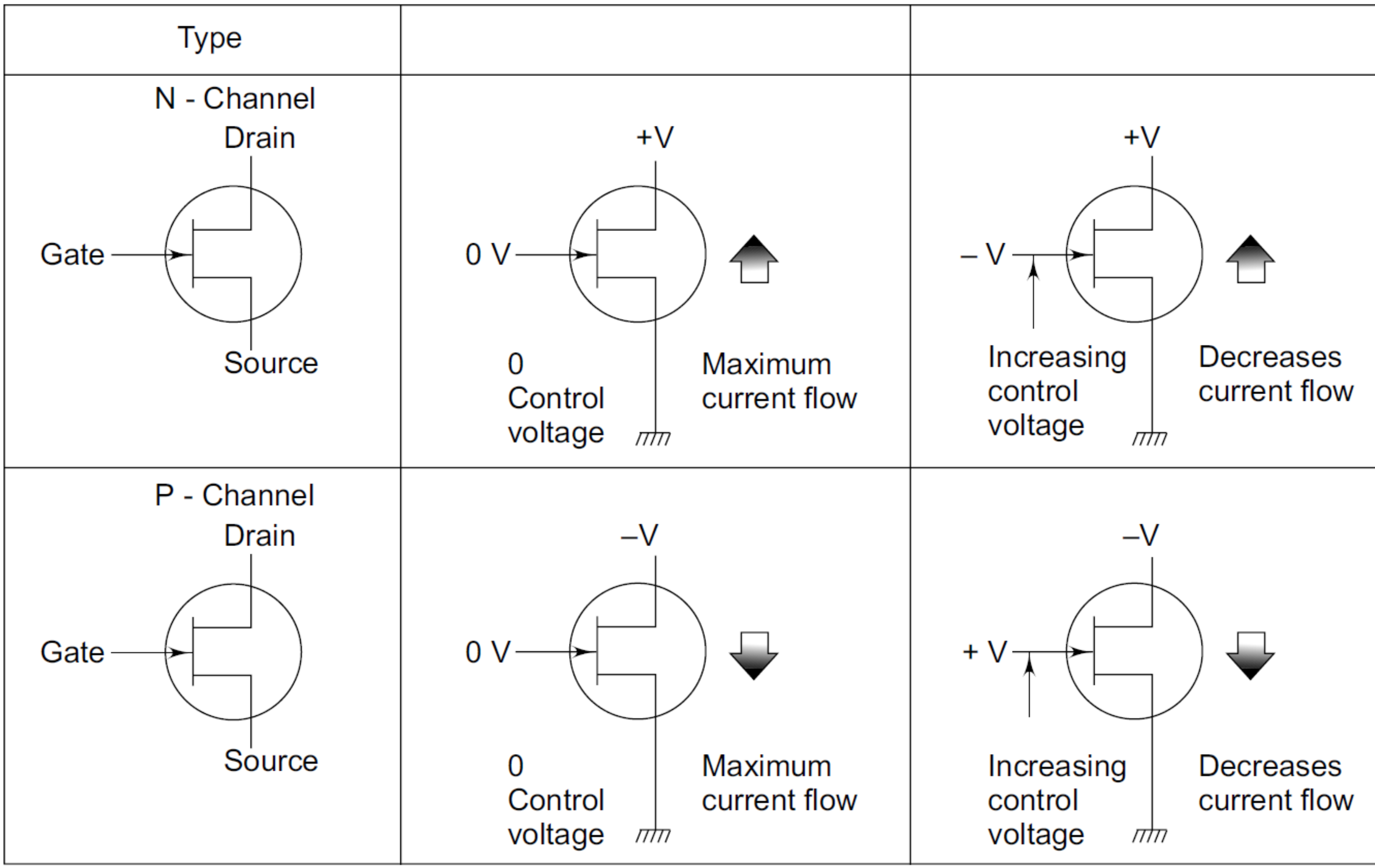


Darlington Pair Transistors

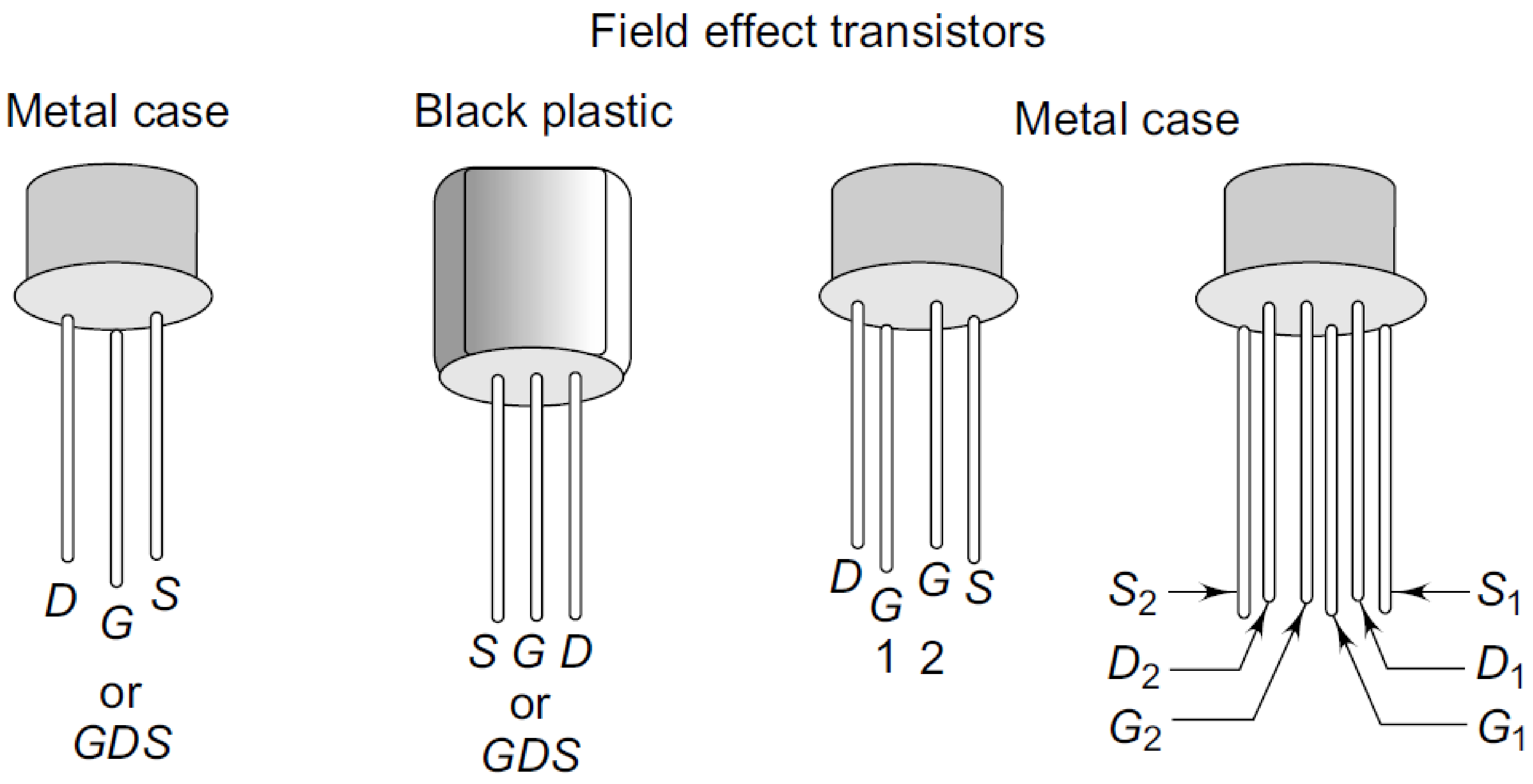
- Higher current gain



Field-Effect Transistor (FET)



Field-Effect Transistor (FET)



Transistor Type Numbers

- Joint Electron Device Engineering Council (JEDEC)
  - Digit, letter, serial number, (suffix),
  - Letter is always ‘N’, the serial number runs from 100 to 9999 (arbitrary),optional suffix indicates the gain (hfe) group of the device.

A	=	low gain	B	=	medium gain
C	=	high gain	No suffix	=	ungrouped (any gain)

Transistor Type Numbers

- Japanese Industrial Standard (JIS)
  - Digit, two letters, serial number, (suffix)

SA	=	PNP HF transistor	SB	=	PNP AF transistor
SC	=	NPN HF transistor	SD	=	NPN AF transistor
SJ	=	P-channel FET/MOSFET	SK	=	N-channel FET/MOSFET

  - Examples: 2SA1187, 2SB646, 2SC733.

Transistor Type Numbers

- Pro-electron System (European)
  - Two letters, (letter), serial number, (suffix)
  - First letter: material

A = Germanium (Ge)

B = Silicon (Si)

C = Gallium Arsenide (GaAs)

R = Compound materials

  - Second letter: device application

C = Transistor, AF, small signal

D = Transistor, AF, power

F = Transistor, HF, small signal

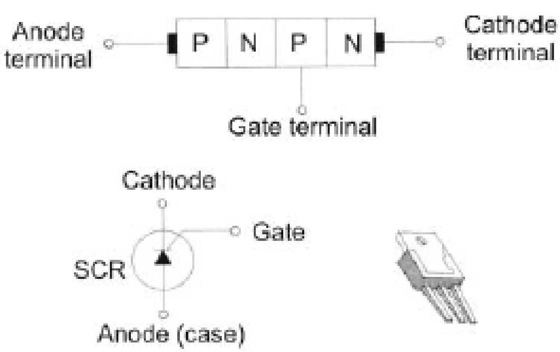
L = Transistor, HF, power

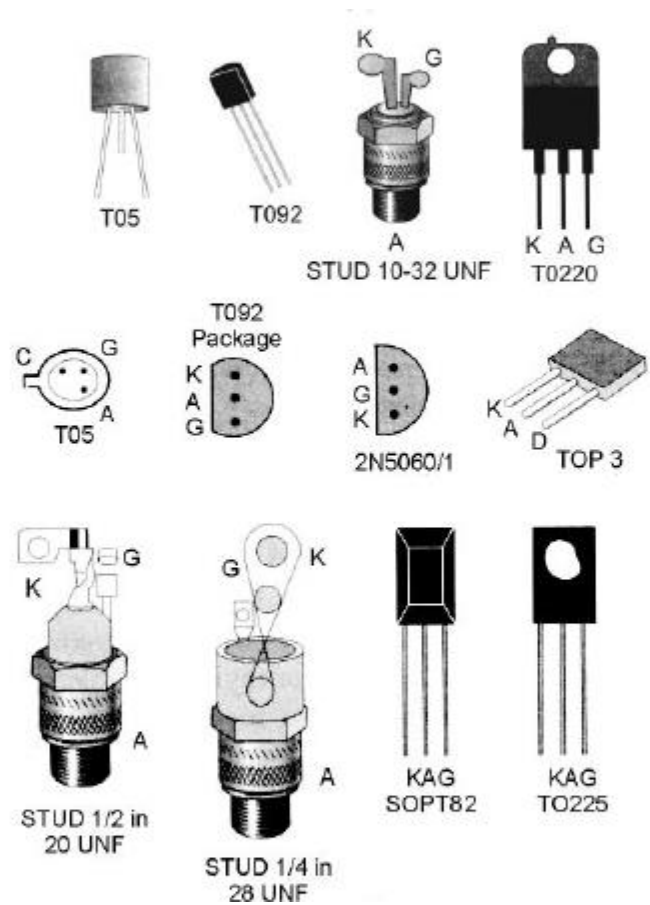
U = Transistor, power, switching

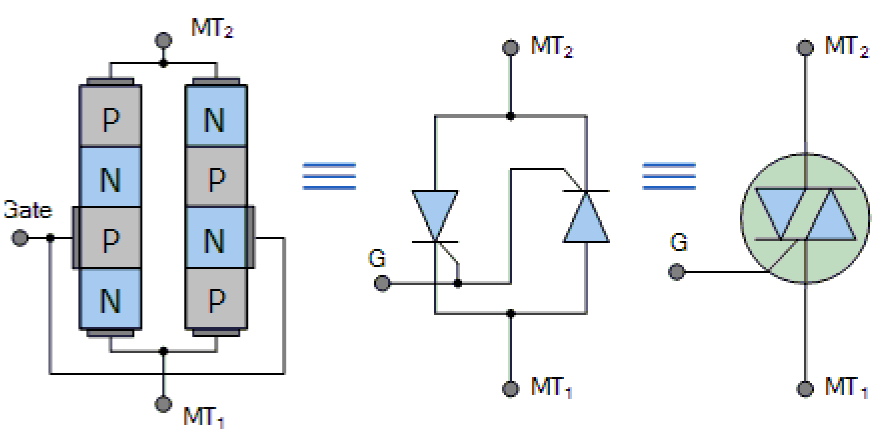
  - Suffix: like JEDEC
  - Examples: BC108A, BAW68, BF239, BFY51

Thyristors

- Silicon-controlled rectifier (SCR)
- Triac (bidirectional triode thyristor)

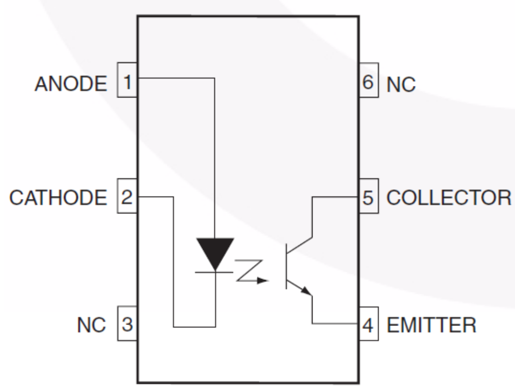




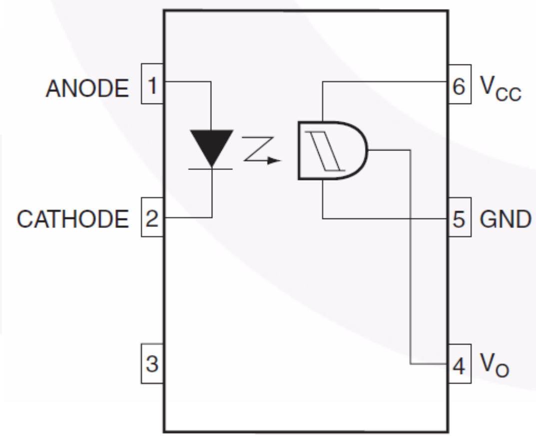


Optocoupler/Optoisolator/Optotriac

- Digital
- Transistor
- Triac/SCR

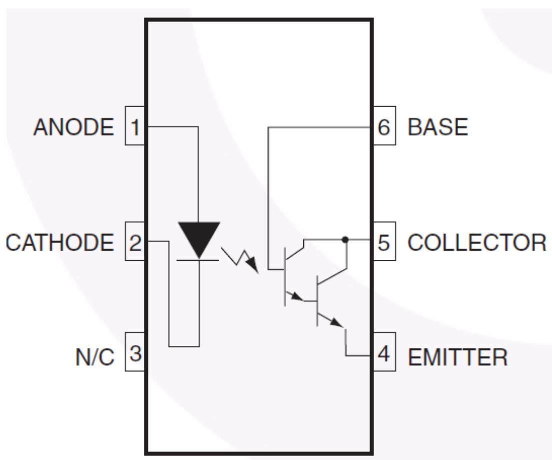


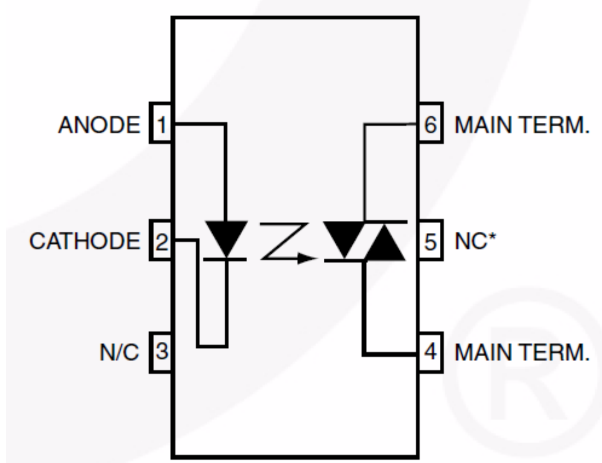
CNY17F1M/2M/3M/4M
MOC8106M/7M



Truth Table

Input	Output
H	L
L	H





*DO NOT CONNECT
(TRIAC SUBSTRATE)

Oscilloscope

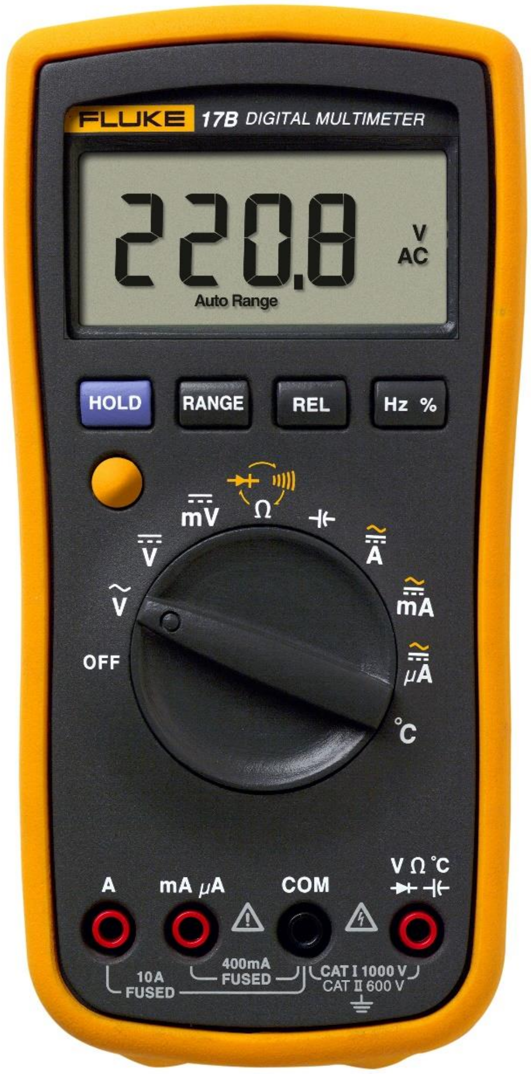
- Cathode ray oscilloscope (CRO) (old – analog)
- Digital storage oscilloscope (DSO) (new – digital)

Function Generator

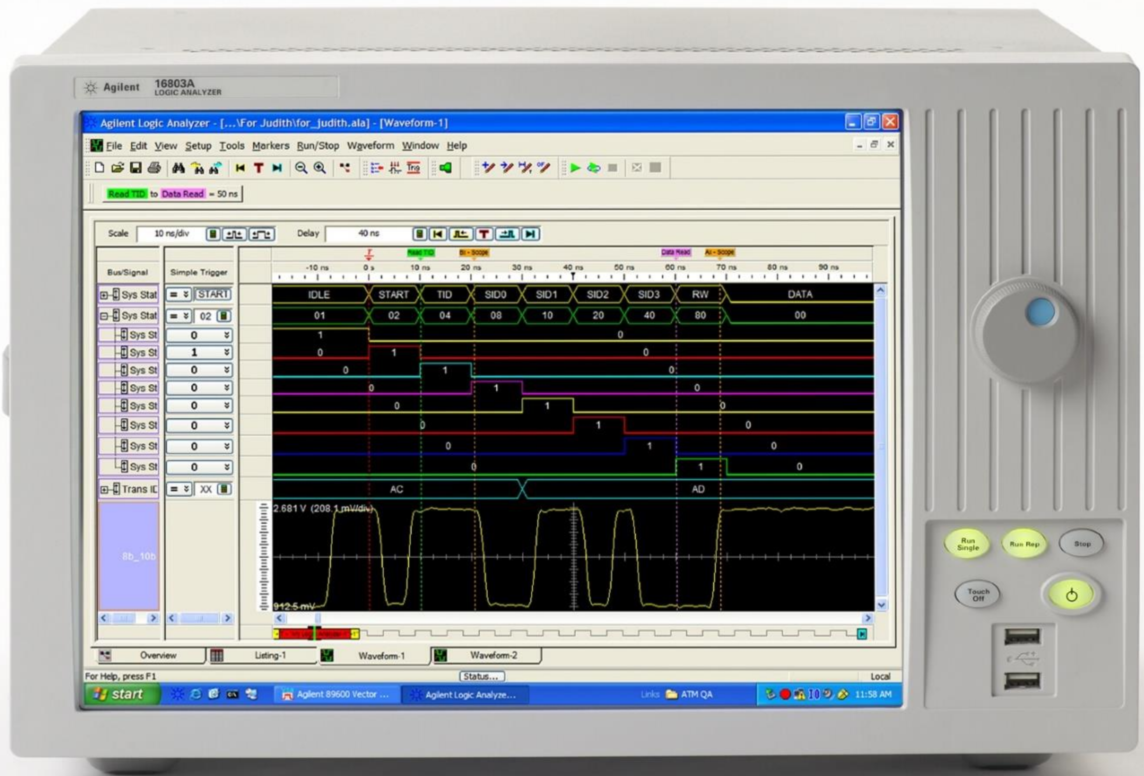
Power Supply

Multimeter


A-V-Ω-C-Hz
VOLTCRAFT
VC-5070
DCV
ACV~
DC10A
-COM
DCmA
OFF


FLUKE 17B DIGITAL MULTIMETER
220.8 V AC
Auto Range
HOLD
RANGE
REL
Hz %
OFF
mV
A
mA
μA
°C
mA μA
COM
V Ω °C
10A FUSED
400mA FUSED
CAT I 1000 V
CAT II 600 V

Logic Analyzer



Cables / Connectors

- Banana connectors
- Alligator (Crocodile) connectors
- BNC connector
- Oscilloscope probe
- Multimeter test leads






Suggested Readings and Assignments

- Laboratory Introduction handout on class web site
- Lab #1 requirements posted on web site