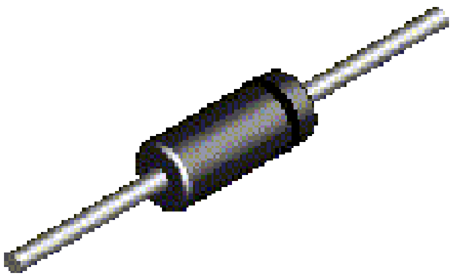
Active Circuits

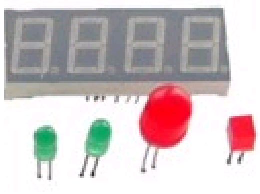
- Diodes
- BJT transistors, DC operation
- FET transistors, DC operation
- Operational amplifiers
- Power semiconductors

Diodes

- Normal (silicon) diode
- Zener diode
- Schottky diode
- Capacitance diode
- LED
- Photodiode



DO-35

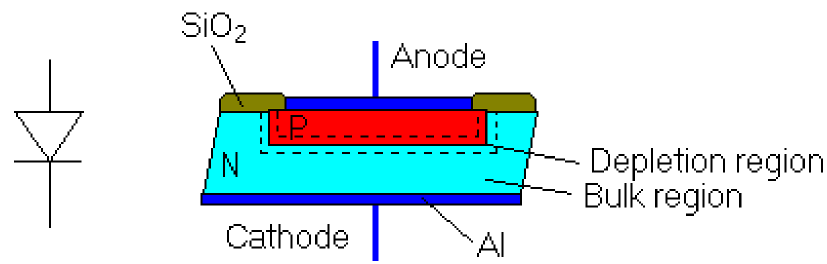


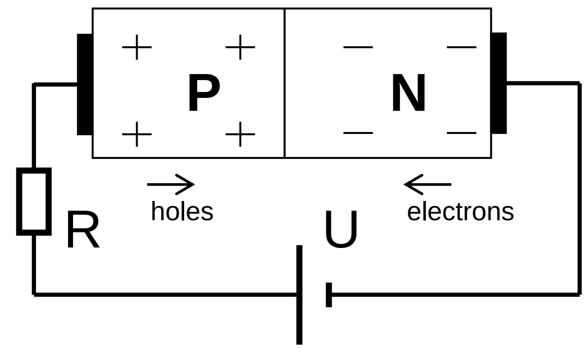
Basic Operation

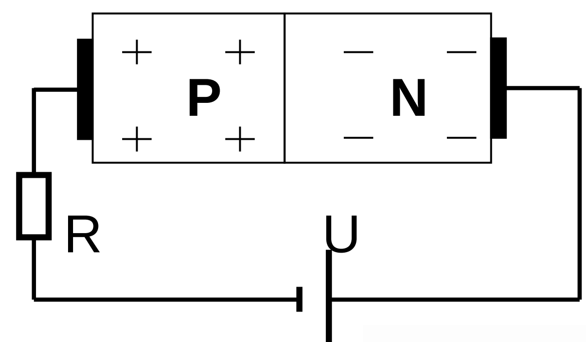
•When forward biased more electrons come from the supply to n region and more holes come from the supply

•This means continuous current flow

•Voltage across well-conducting silicon diode is about 0.7V

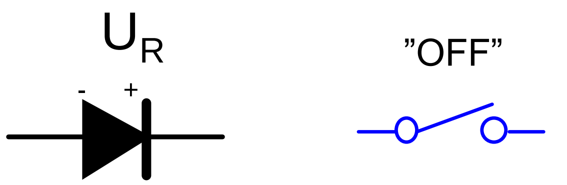






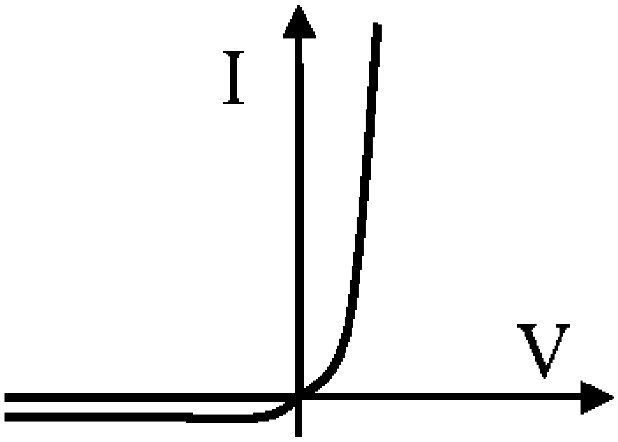
An Ideal Diode

- A forward-biased diode conducts (switch on)
- A reverse-biased diode doesn't conduct (switch off)
- On-resistance tends to zero
- Off-resistance tends to infinity



A Real Diode

- In a real diode there is a certain voltage across a diode when it is forward-biased. This voltage is typically about 0.7V for normal silicon diode. In germanium and in Schottky diode this voltage is lower and in LED it is higher.



$$I_D = I_0\left(e^{\frac{U_D}{U_T}} - 1\right)$$

I_D=diode current

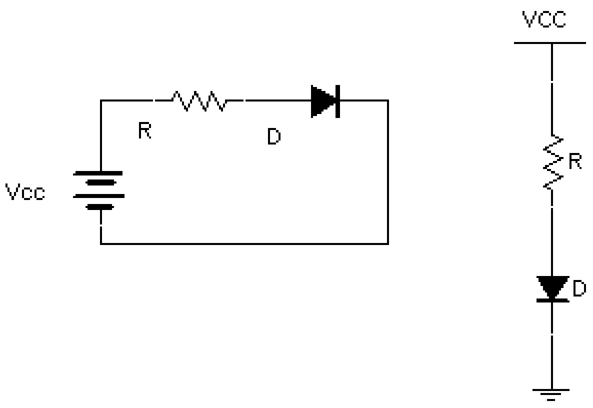
U_D=diode voltage

I_0=saturation current

U_T=kT/q (25,2mV at room temperature)

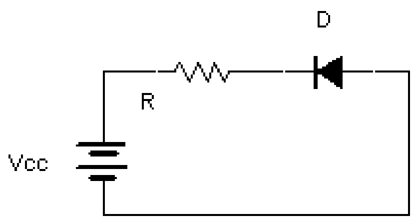
A Forward-biased Diode

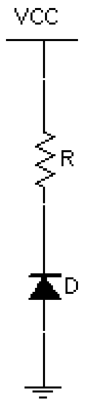
- When forward-biased a diode conducts very well. That's why a current limiting resistance is needed.
- Normally the value of the resistance is chosen according so that the current doesn't exceed the specified maximum ratings of a diode. Sometimes power dissipation requirements set the the value for the current limiting resistance.



A Reverse-biased Diode

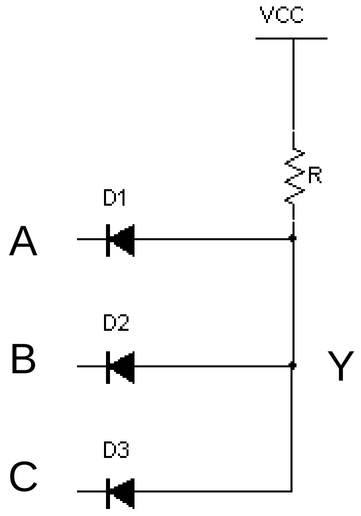
When reverse-biased the current in a diode is very small. In a high-voltage environment you must check that you don't exceed the maximum reverse voltage across the diode. A break-down as unrecoverable.





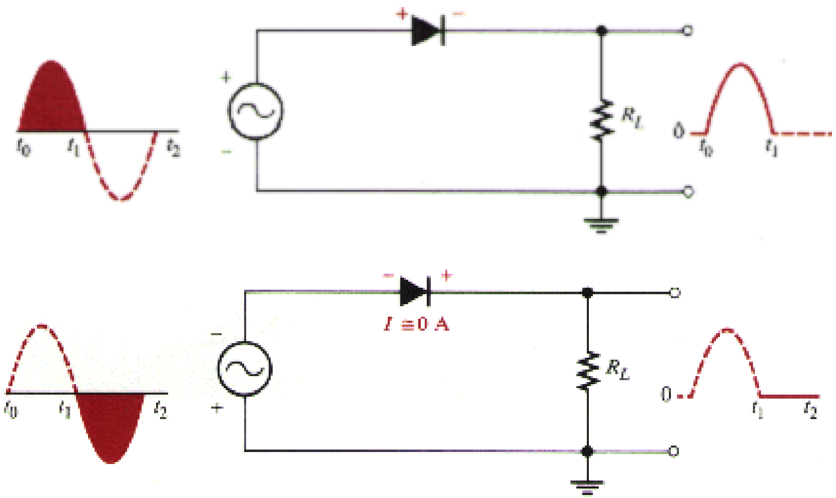
Diode-based Logic Gate

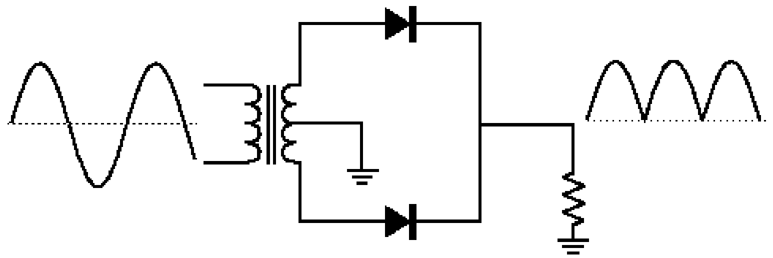
- If some of the inputs is low, it means that output is also low
- If all the inputs are high the output is also high
- AND-gate



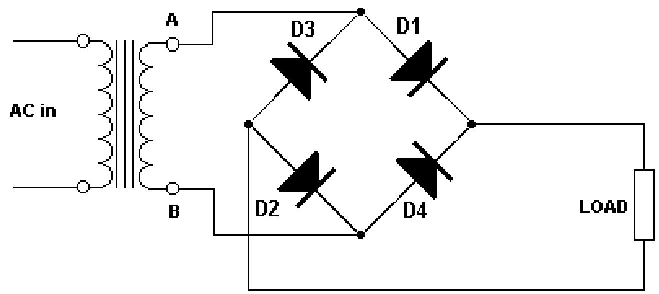
Diode as a Rectifier

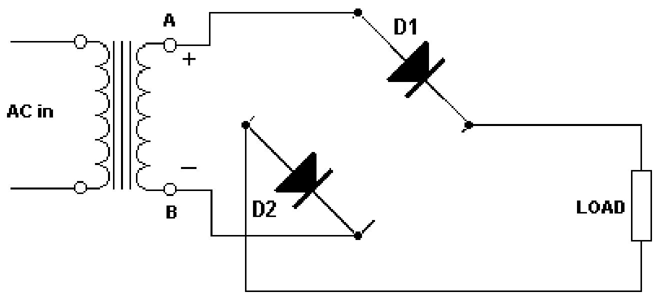
- Diode can be used to clip a part of the AC signal.
- In a half-wave rectifier a diode conducts during the positive half-cycle of the signal
- In a full-wave rectifier the negative half-cycle ”is converted” to positive

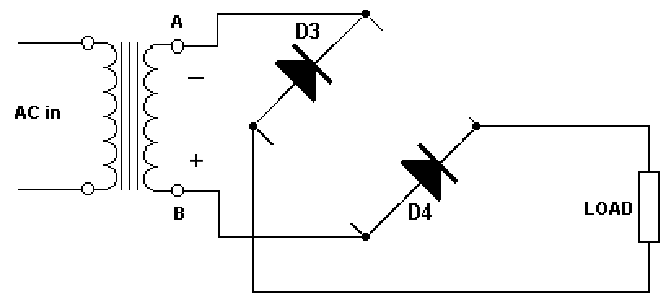


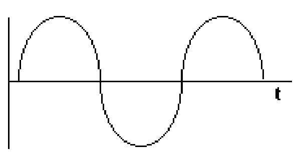


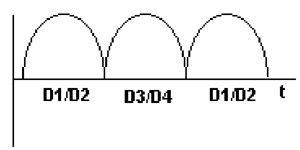
The Operation of a Bridge Rectifier





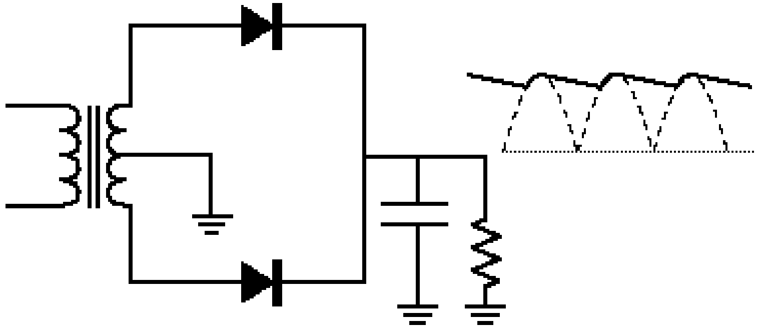






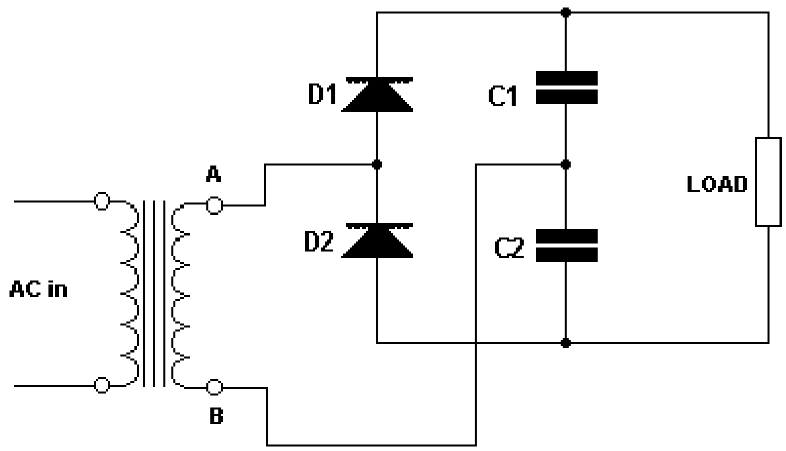
DC Power Supply

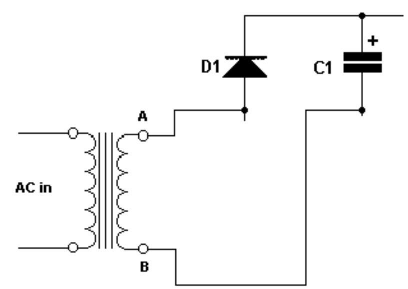
- A transformer is needed to change the amplitude of an AC signal
- Diodes with tapped transformer form a full-wave rectifier
- A capacitor is use for filtering to reduce the ripple
- To improve this DC supply A fuse and a regulator could be added

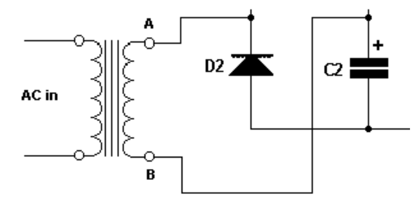


Voltage Doubler

- During the positive half-cycle D_1 conducts and C_1 is charged
- During the negative half-cycle D_2 conducts and C_2 is charged
- Totally across C_1 and C_2 is twice the input amplitude

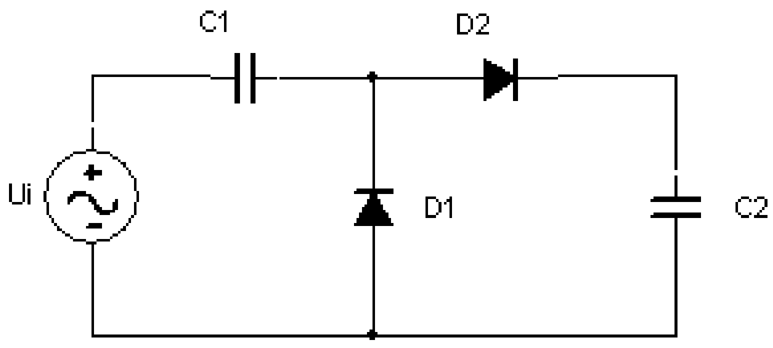




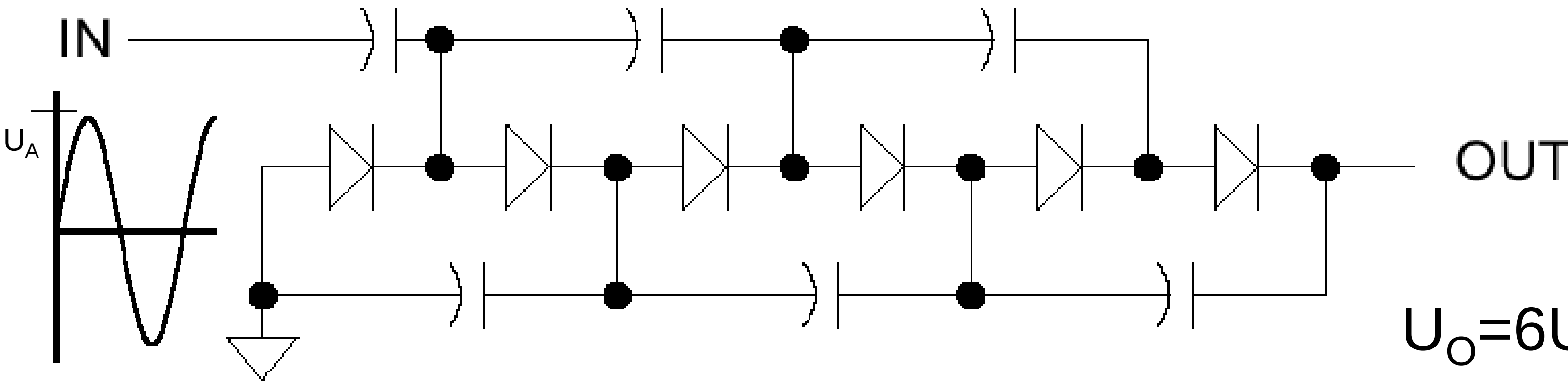


Another Voltage Doubler

- During the negative half-cycle D_1 conducts and C_1 is charged
- During the positive half-cycle D_2 conducts and C_2 is charged with the voltage supplied from the generator plus charged in the C_1 (during the negative half-cycle)



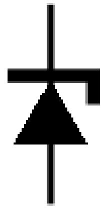
Voltage Multiplier

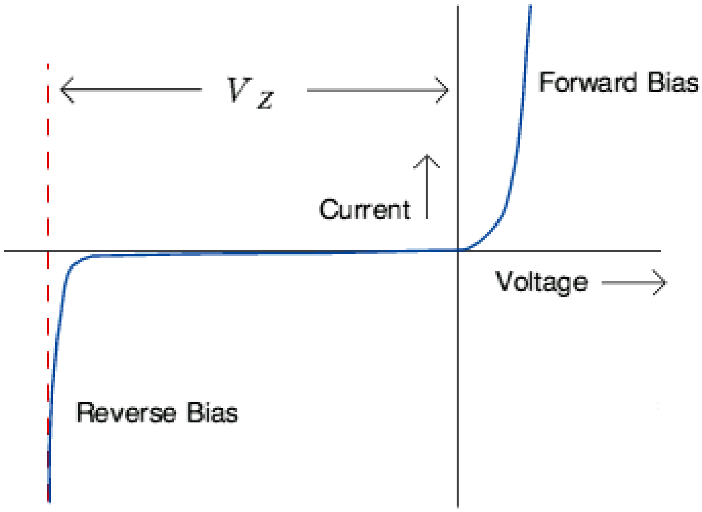


$U_O=6U_A$

Zener Diode

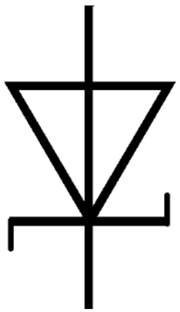
- When forward biased a Zener operates like a normal diode
- Zener (or avalance) breakdown when reverse biased and Zener voltage reached
- Zener tolerates a breakdown unlike a normal diode

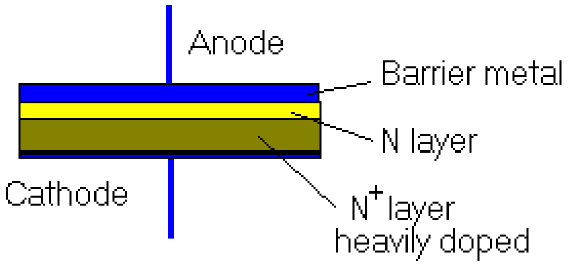




Schottky Diode

- Schottky diode is a junction of metal and n type semiconductor material
- Schottky diode is faster than a normal diode.
- Also a forward voltage (U_F) across Schottky diode smaller than in a normal diode

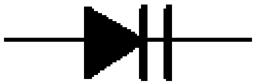


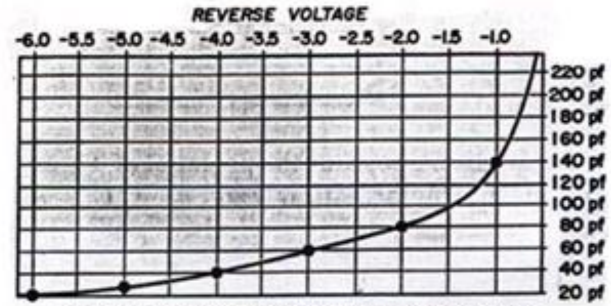


Capacitance Diode (Varactor

- The capacitance of the varactor can be changed by changing the reverse-biased voltage across the the varactor

- Used for example in voltage-controlled oscillators (VCXOs) for frequency adjusting

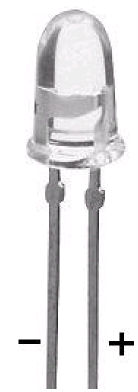


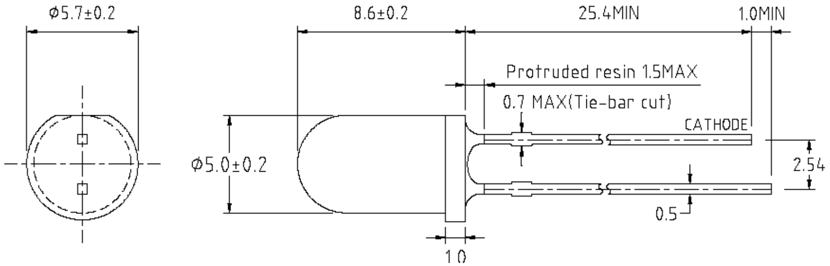


VARACTOR VOLTAGE-CAPACITANCE CURVE

LED (Light Emitting Diode)

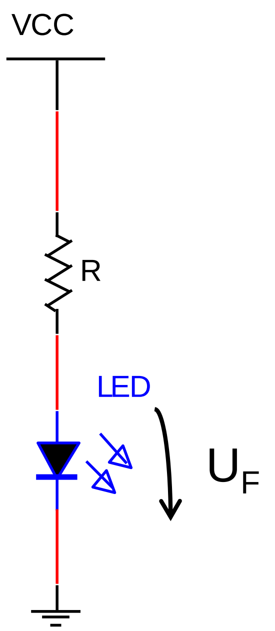
- When forward-biased the LED emits light
- The forward voltage is different for different colours, generally forward voltages of LEDs are higher than in normal diodes
- Light intensity is different for different colours





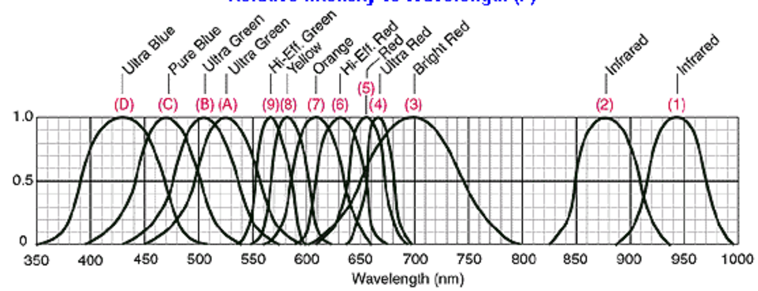
LED Biasing

- The current of a LED is limited by a resistor.
- Forward voltage as well as the recommend forward current shall be checked from the data sheet of LED.
- $U_{CC}=RI_{LED}+U_F$



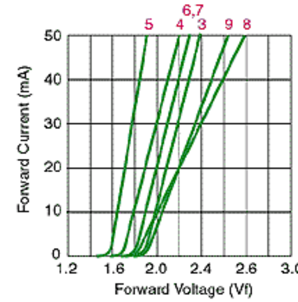
Wavelength (nm)	Color Name	Fwd Voltage (Vf @ 20ma)	Intensity 5mm LEDs	Viewing Angle	LED Dye Material
940	Infrared	1.5	16mW @50mA	15°	GaAlAs/GaAs -- Gallium Aluminum Arsenide/Gallium Arsenide
880	Infrared	1.7	18mW @50mA	15°	GaAlAs/GaAs -- Gallium Aluminum Arsenide/Gallium Arsenide
850	Infrared	1.7	26mW @50mA	15°	GaAlAs/GaAs -- Gallium Aluminum Arsenide/Gallium Aluminum Arsenide
660	Ultra Red	1.8	2000mcd @50mA	15°	GaAlAs/GaAs -- Gallium Aluminum Arsenide/Gallium Aluminum Arsenide
635	High Eff. Red	2.0	200mcd @20mA	15°	GaAsP/GaP - Gallium Arsenic Phosphide / Gallium Phosphide
633	Super Red	2.2	3500mcd @20mA	15°	InGaAIP - Indium Gallium Aluminum Phosphide
620	Super Orange	2.2	4500mcd @20mA	15°	InGaAIP - Indium Gallium Aluminum Phosphide
612	Super Orange	2.2	6500mcd @20mA	15°	InGaAIP - Indium Gallium Aluminum Phosphide
605	Orange	2.1	160mcd @20mA	15°	GaAsP/GaP - Gallium Arsenic Phosphide / Gallium Phosphide
595	Super Yellow	2.2	5500mcd @20mA	15°	InGaAIP - Indium Gallium Aluminum Phosphide
592	Super Pure Yellow	2.1	7000mcd @20mA	15°	InGaAIP - Indium Gallium Aluminum Phosphide
585	Yellow	2.1	100mcd @20mA	15°	GaAsP/GaP - Gallium Arsenic Phosphide / Gallium Phosphide
574	Super Lime Yellow	2.4	1000mcd @20mA	15°	InGaAIP - Indium Gallium Aluminum Phosphide
570	Super Lime Green	2.0	1000mcd @20mA	15°	InGaAIP - Indium Gallium Aluminum Phosphide
565	High Efficiency Green	2.1	200mcd @20mA	15°	GaP/GaP - Gallium Phosphide/Gallium Phosphide
560	Super Pure Green	2.1	350mcd @20mA	15°	InGaAIP - Indium Gallium Aluminum Phosphide
555	Pure Green	2.1	80mcd @20mA	15°	GaP/GaP - Gallium Phosphide/ Gallium Phosphide
525	Aqua Green	3.5	10,000mcd @20mA	15°	SiC/GaN - Silicon Carbide / Gallium Nitride
505	Blue Green	3.5	2000mcd @20mA	45°	SiC/GaN - Silicon Carbide / Gallium Nitride
470	Super Blue	3.6	3000mcd @20mA	15°	SiC/GaN - Silicon Carbide / Gallium Nitride
430	Ultra Blue	3.8	100mcd @20mA	15°	SiC/GaN - Silicon Carbide / Gallium Nitride

Relative Intensity vs Wavelength (P)



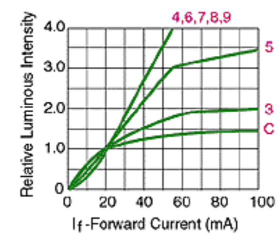
Forward Current vs Forward Voltage

Red 5, Ultra Red 4, HE Red 6, Orange 7, Bright Red 3,
HE Green 9, Yellow 8



Relative Luminous Intensity vs Forward Current

Ultra Red 4, HE Red 6, Orange 7, Yellow 8, HE Green 9
Red 5, Bright Red 3, Pure Blue C



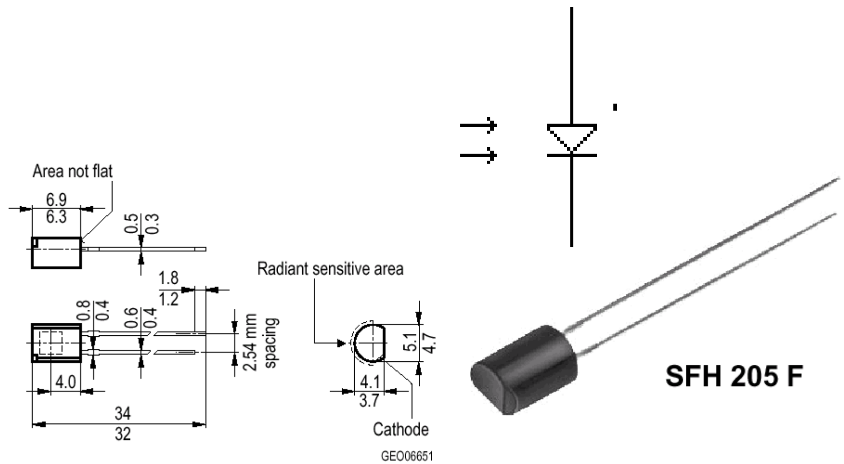
Photodiode

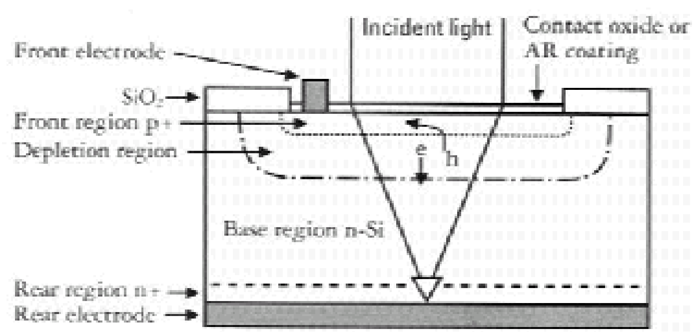
- Light is changed as current in a photodiode

- It is used as reverse-biased

•This structure is most commonly fabricated in a lightly to moderately doped, 200-500 mm thick, n-type silicon substrate. The front of the wafer is heavily doped with a p-type dopant, like Boron, by ion implantation, in such a way as to produce a shallow junction. The rear of the wafer is heavily doped with an n-type dopant, such as Phosphorous, by ion implantation for better ohmic contact. The contact oxide by thermal oxidation is the window allowing incident light in, while passivating the silicon surface.

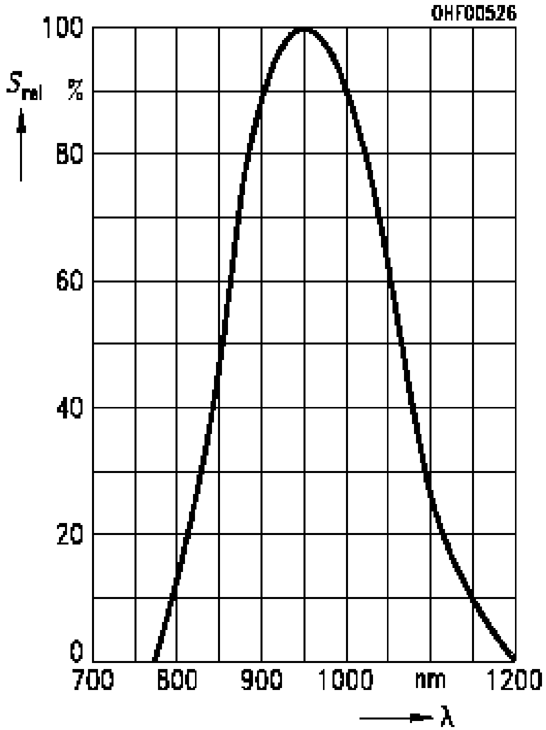
•When the energy of photon, hn, is larger than the forbidden gap of silicon, 1.12 eV (equivalent to about 1110 nm in wavelength), the absorbed photon may excite a electron from valence band to conduction band and leave a hole in valence band, in other words, generating a electron-hole pair.



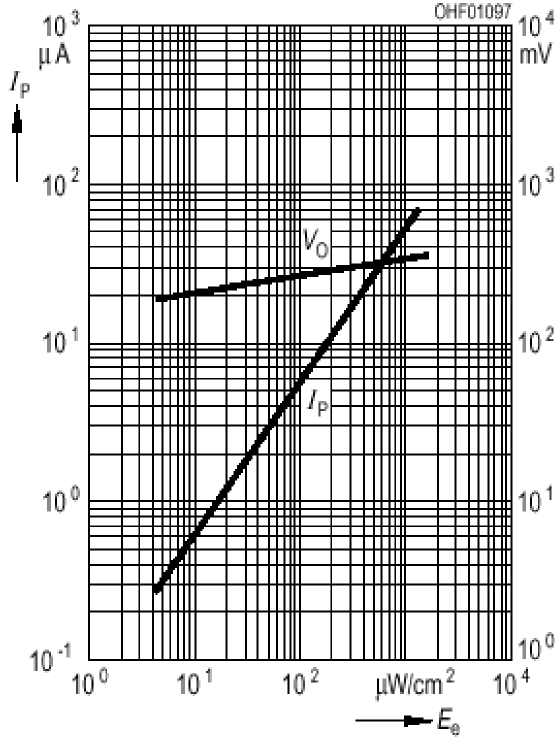


Sensitivity of Example Photodiode

Relative spectral sensitivity
$S_{rel} = f\ (\lambda)$



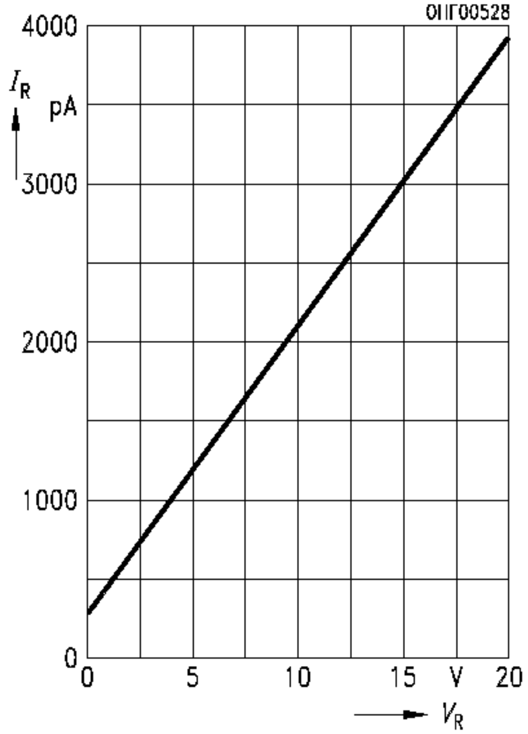
Photocurrent $I_P = f\ (E_e)$, $V_R = 5$ V
Open-circuit voltage $V_O = f\ (E_e)$



Dark Current of Example Photodiode

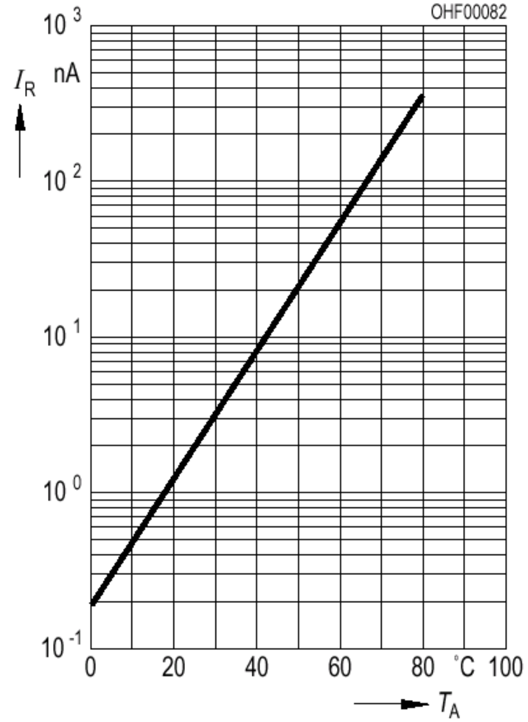
Dark current

$I_R = f\ (V_R),\ E = 0$



Dark current

$I_R = f\ (T_A),\ \ V_R = 10\ V,\ E = 0$



BJT transistors

NPN transistor

PNP transistor

PINNING

PIN	DESCRIPTION
1	emitter
2	base
3	collector, connected to case

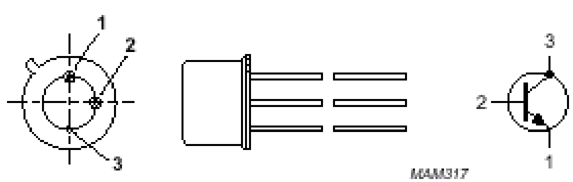
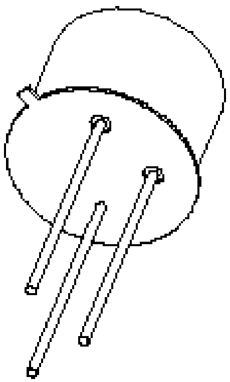


Fig.1 Simplified outline (TO-39) and symbol.



PINNING

PIN	DESCRIPTION
1	emitter
2	base
3	collector, connected to case

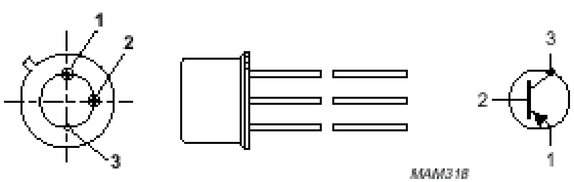


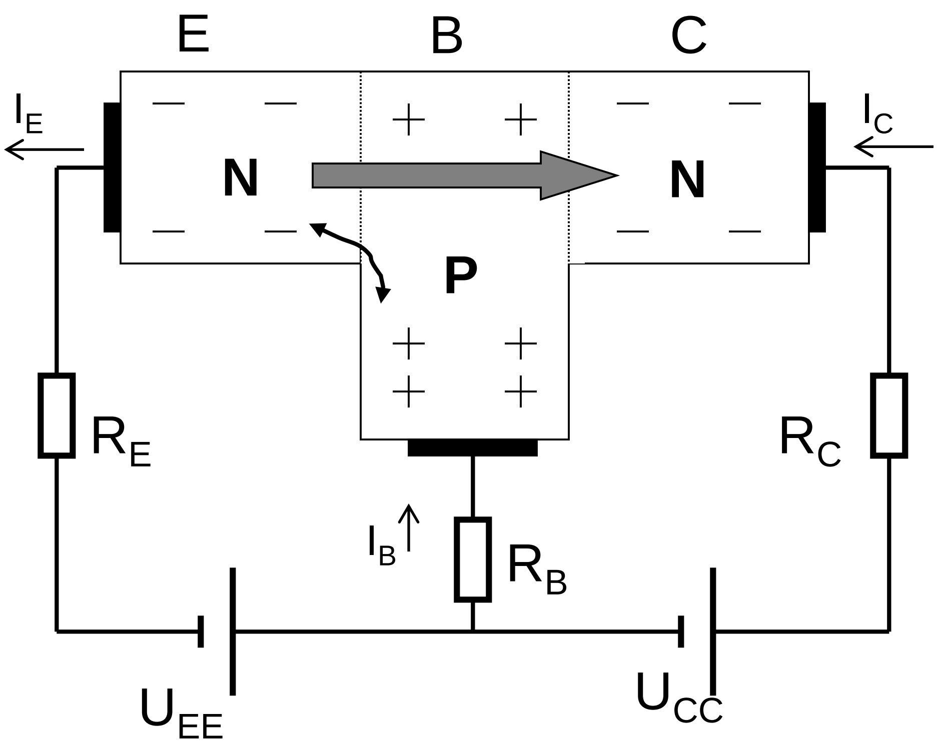
Fig.1 Simplified outline (TO-39) and symbol.

NPN Transistor

•Because of biasing charge carriers start to recombine at EB junction

•More electrons comes to the emitter from the supply

•Because the base is narrow most of the electrons pass the base to the collector =>continuos current flow

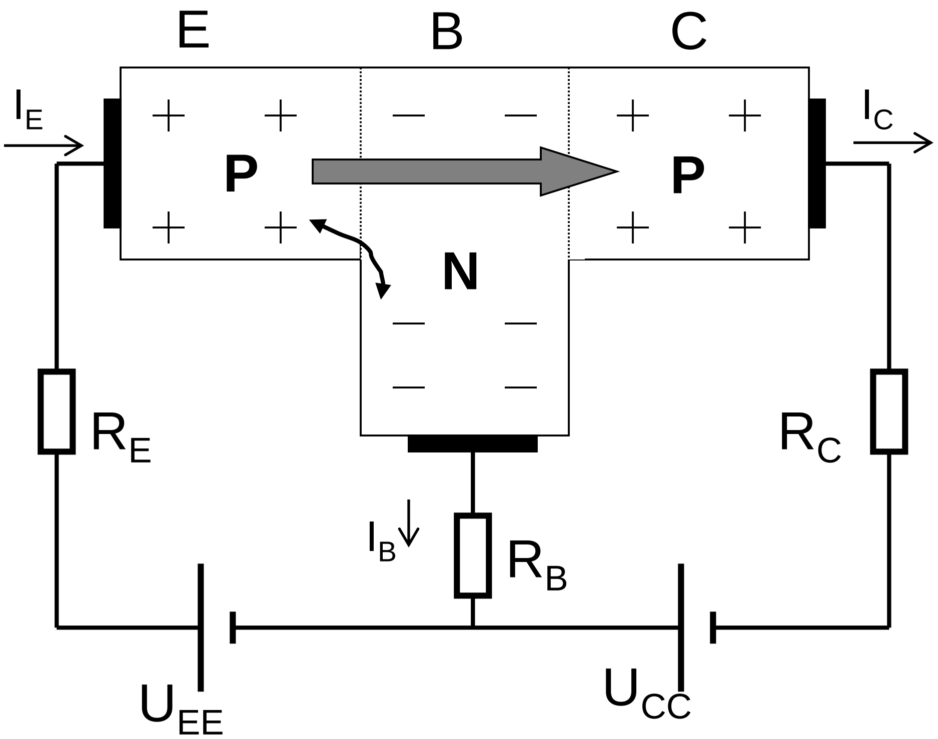


PNP Transistor

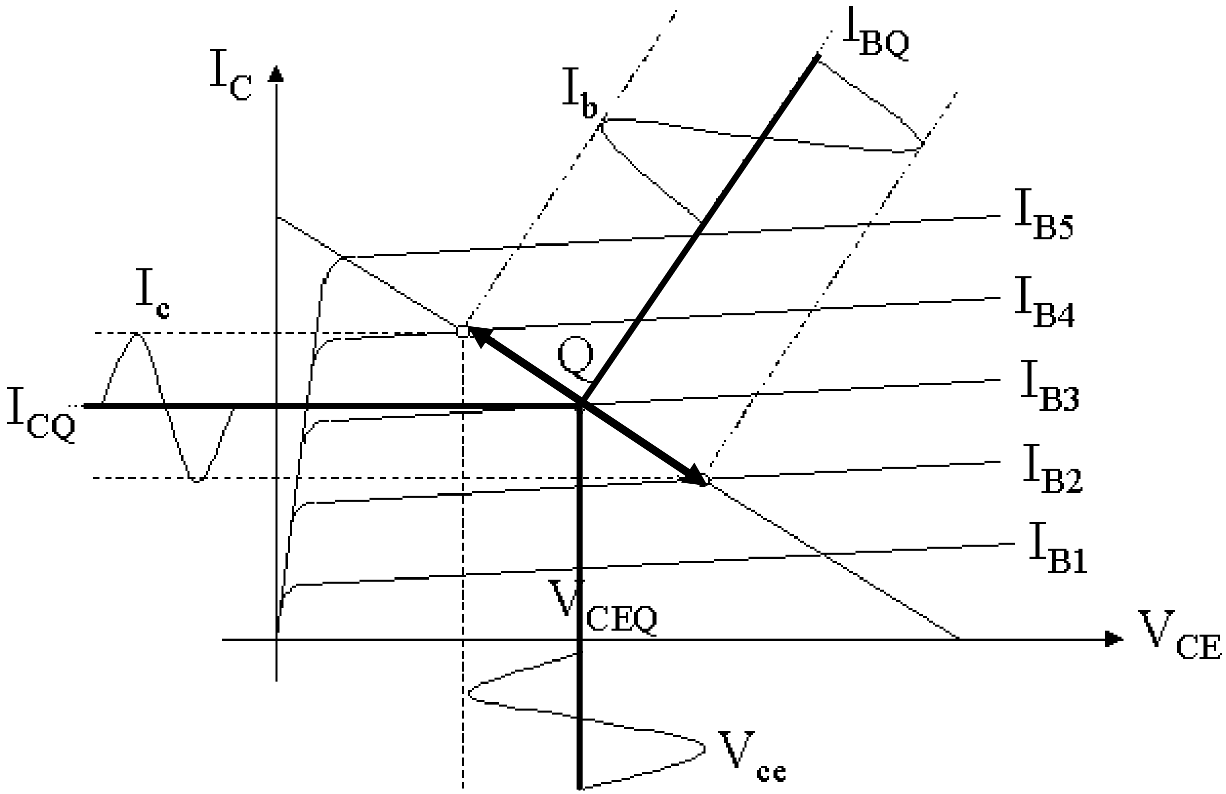
•Because of biasing charge carriers start to recombine at EB junction

•More holes comes to the emitter from the supply

•Because the base is narrow most of the holes pass the base to the collector =>continuous current flow



BJT Load Line, $I_C=f(U_{CE})$



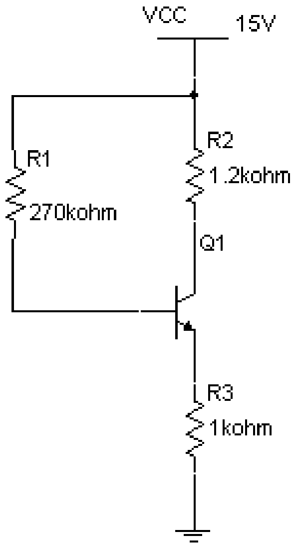
DC Analysis of the BJT Stage

$I_C = \beta I_B$

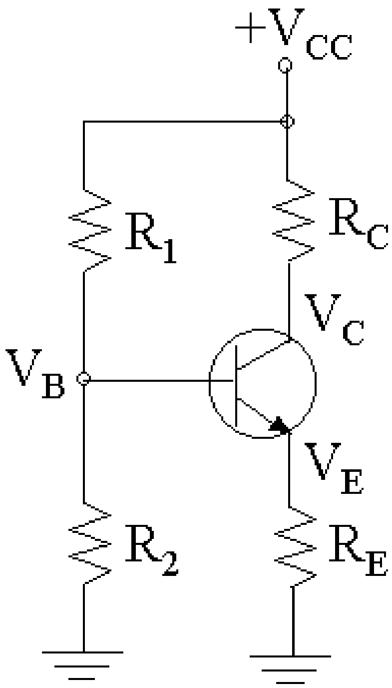
$I_E = I_C + I_B = (\beta + 1) I_B$

$U_{CC} = R_1 I_B + U_{BE} + R_3 I_E$

$U_{CC} = R_2 I_C + U_{CE} + R_3 I_E$



DC Analysis of the CE BJT Amplifier



$$V_B = \left(\frac{R_2 // \beta_{DC} R_E}{R_1 + R_2 // \beta_{DC} R_E} \right) V_{CC}$$

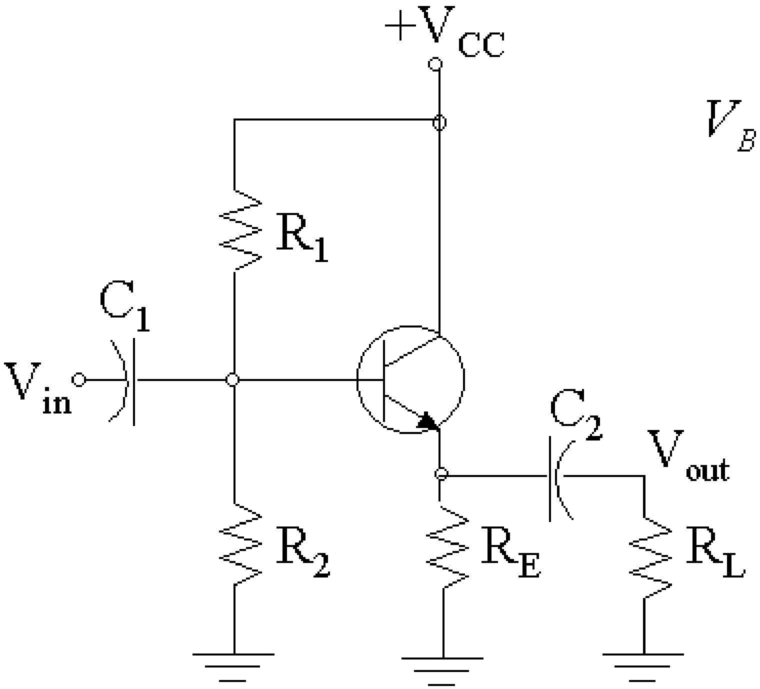
If $\beta_{DC} R_E = R_{IN(base)} >> R_2$, then

$$V_B \cong \left(\frac{R_2}{R_1 + R_2} \right) V_{CC}$$

$$V_E = V_B - V_{BE} \; ; \quad I_C \cong I_E = \frac{V_E}{R_E}$$

$$V_C = V_{CC} - I_C R_C$$

DC Analysis of the CC BJT Amplifier



DC analysis:

$$V_B = \left(\frac{R_2 \,//\, \beta_{DC} R_E}{R_1 + R_2 \,//\, \beta_{DC} R_E} \right) V_{CC}$$

$V_E = V_B - V_{BE}$

$I_E = V_E / R_E$

$V_C = V_{CC}$

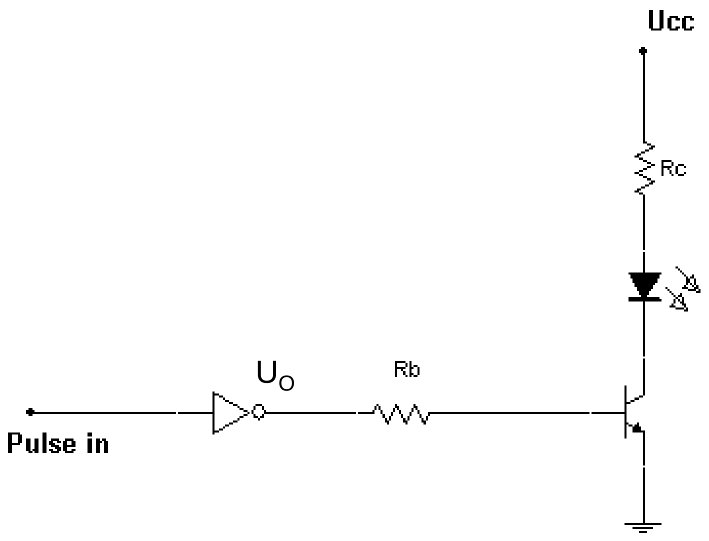
The CC amplifier is also known as an emitter-follower since V_{out} follows V_{in} in phase and voltage.

BJT as a Switch

- When output of the gate is high transistor conducts and the LED transmits light. Base resistance is chosen so that the transistor saturates all the current gain values.

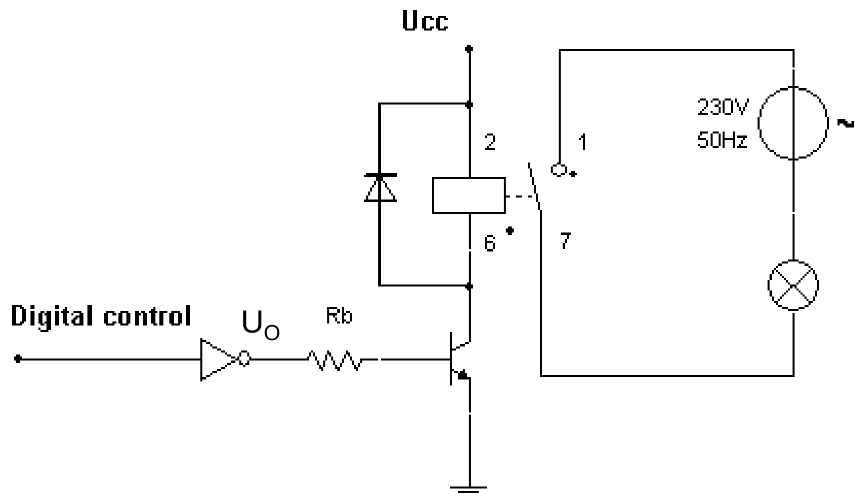
- When Uo is low, the transistor doesn't conduct and no light transmitted

  - $U_O=R_BI_B+U_{BE}$
  - $U_{CC}=R_CI_C+U_{CE}(sat)+U_F$

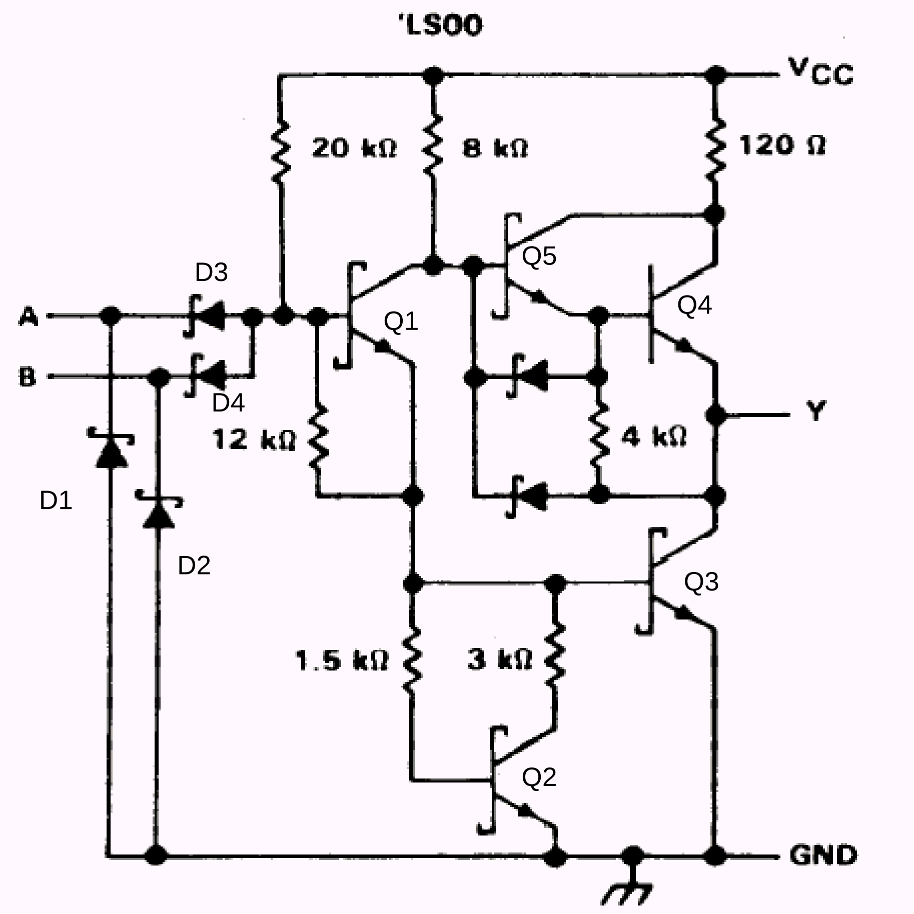


BJT Based Relay Control

- When the output of the gate is high, the transistor conducts. The current through the relay coil closes the relay switch and the lamp turns on.
- The diode protects the transistor
- The benefit of the relay in this case is that the high voltage part is totally isolated from the low voltage part.
  - $U_O = R_B I_B + U_{BE}$
  - $U_{CC} = R_R I_C + U_{CE}(sat)$

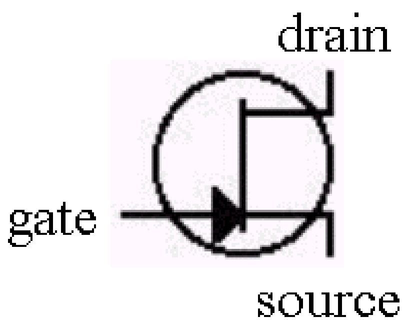


BJT Based Logic Gate



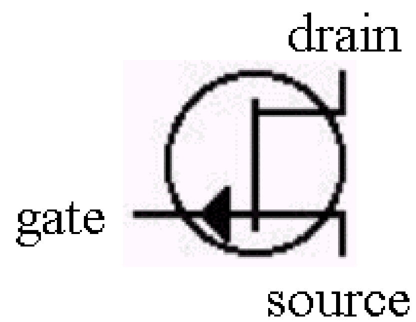
Field-Effect Transistors

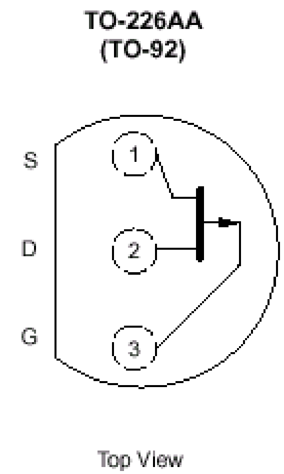
N-channel JFET



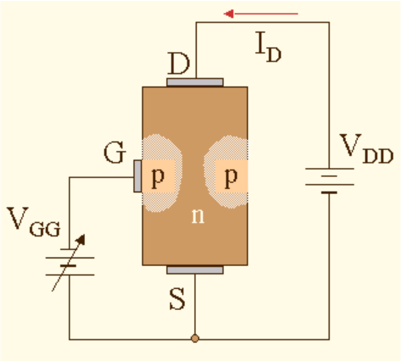
P-channel JFET

P1086

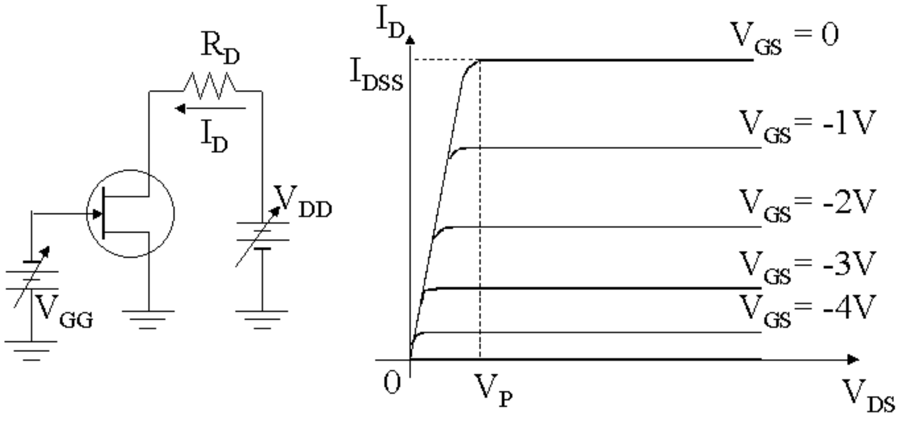




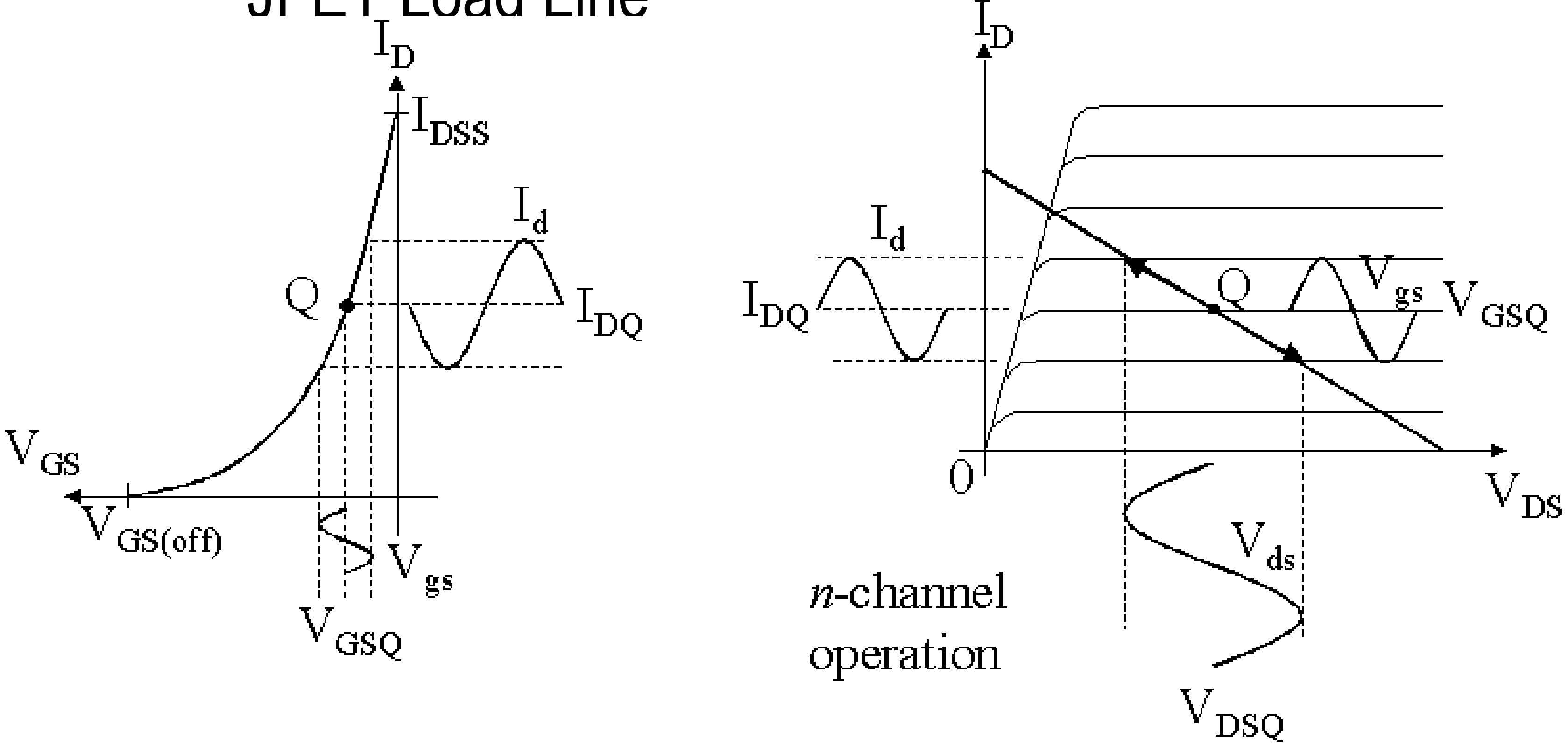
The Operation of JFET



- By changing the voltage between gate and source terminals the conductivity of channel can be controlled
- Channel off =>U_{GS}=U_P
- U_{GS}=0 =>I_D=I_{DSS}



JFET Load Line



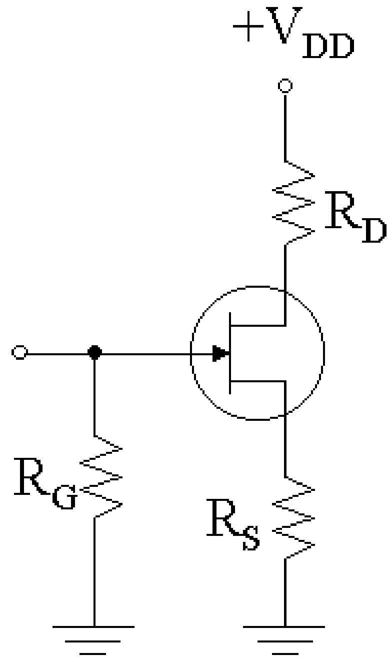
DC Analysis of the JFET Stage

$U_G=0,\ I_G=0$

$U_G=U_{GS}+R_SI_D$

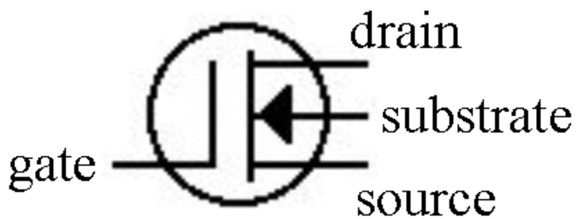
$I_D=I_{DSS}(1-U_{GS}/U_P)^2$

$U_{DD}=R_DI_D+U_{DS}+R_SI_D$



Field-Effect Transistors

N-channel depletion type MOSFET



N-channel

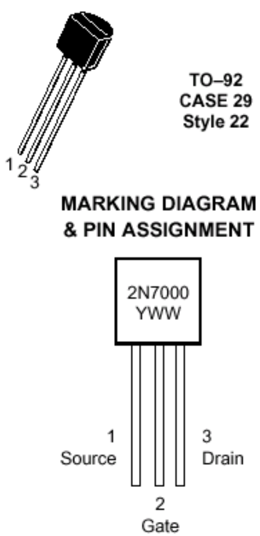
P-channel depletion type MOSFET

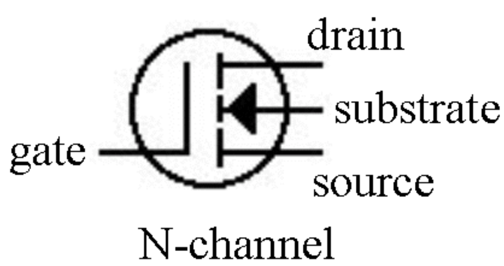
P-channel

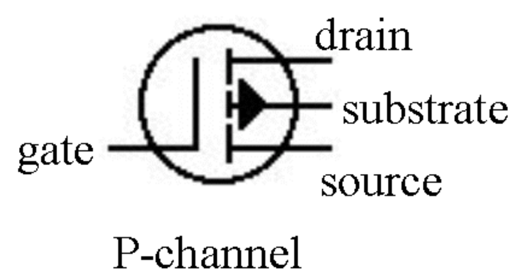
Field-Effect Transistors

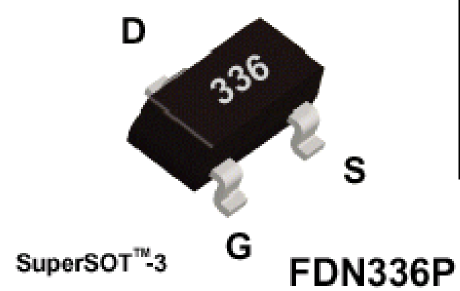
N-channel enhancement type MOSFET

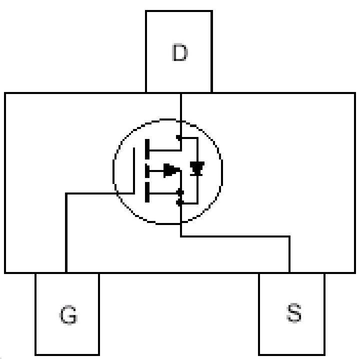
P-channel enhancement type MOSFET











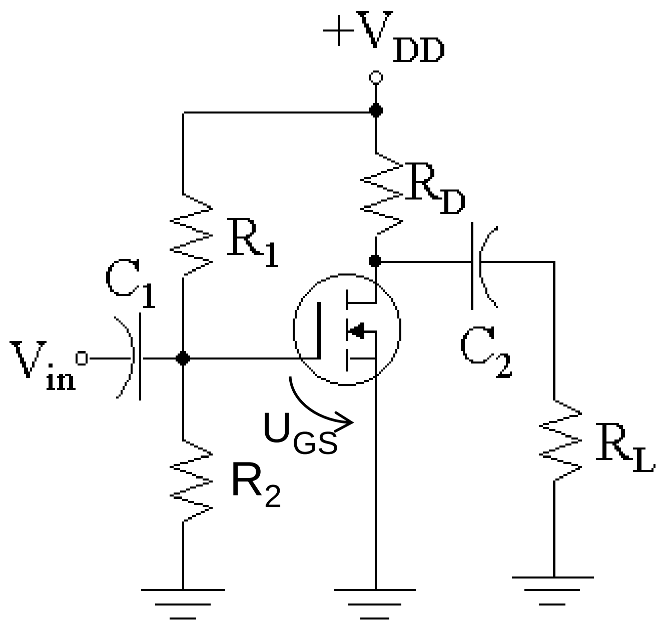
DC Analysis Of the Enhancement-type Mosfet

$I_D = 0.5 \mu_n C_{OX} (W/L)(U_{GS} - U_T)2$

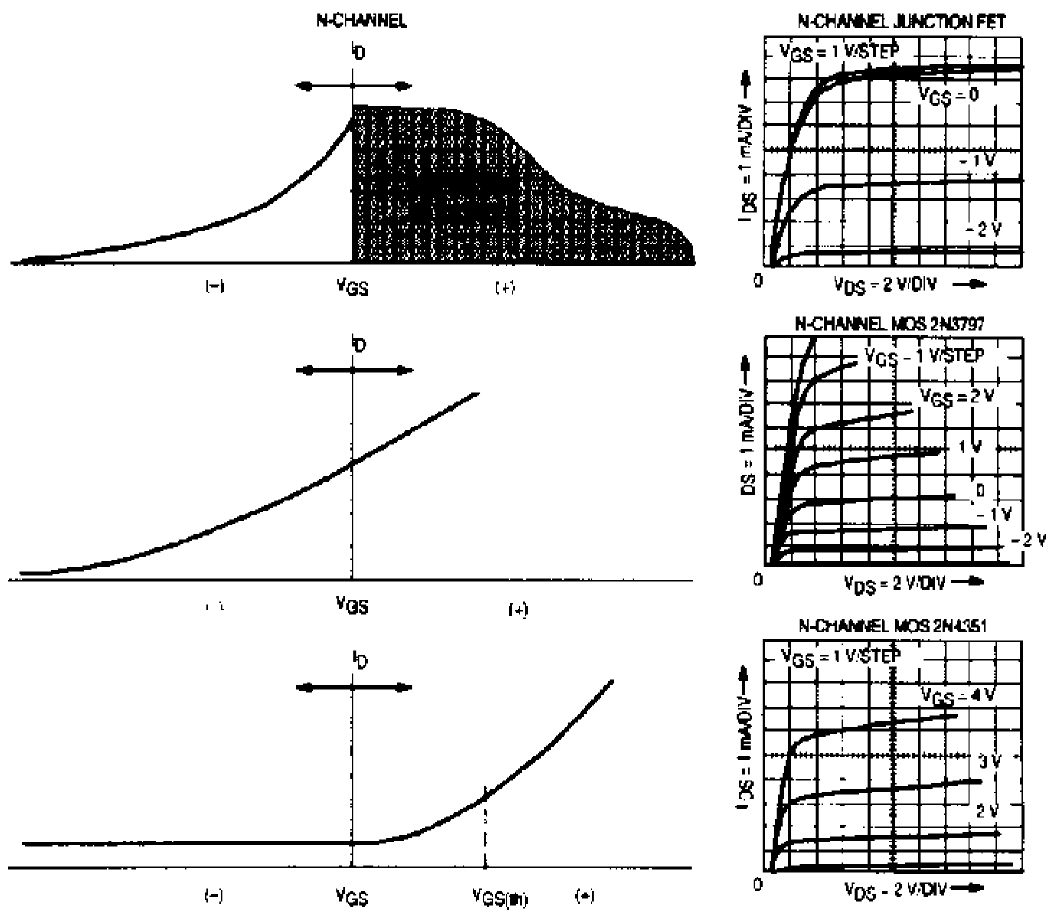
$I_D = K(U_{GS} - U_T)2$

$U_{R2} = U_{GS} = R_2 U_{DD} / (R_1 + R_2)$

$U_{DD} = R_D I_D + U_{DS}$



$f(U_{GS}, I_D)$ for Different FET Types

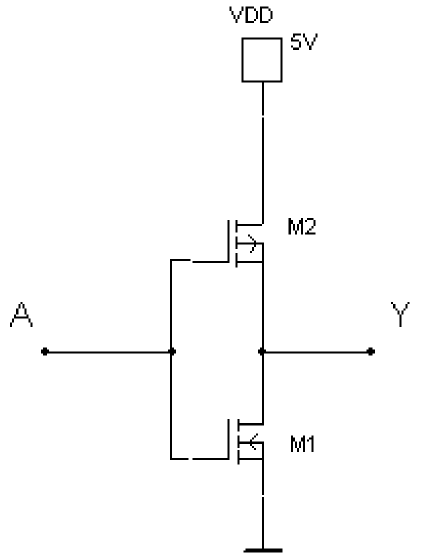


MOSFET as a Switch

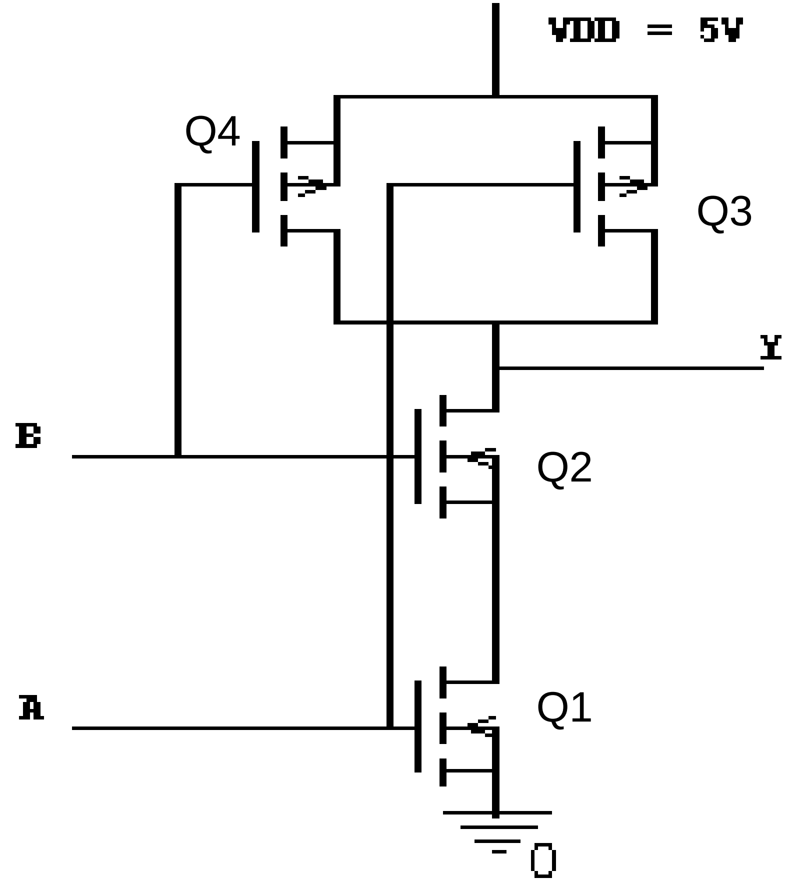
•If A is high M1 conducts and the output Y is low

•If A is low M2 conducts and the output Y is high

=>Inverter



CMOS NAND



Operational Amplifiers

Ideal operational amplifier

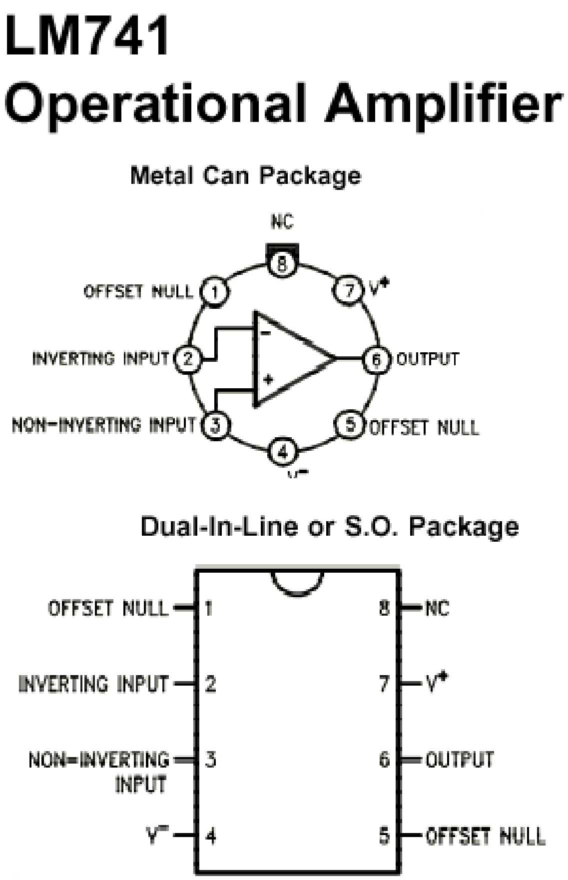
Inverting configuration

Non-inverting configuration

Buffer amplifier

Summer

Differential amplifier



An Ideal Op Amp

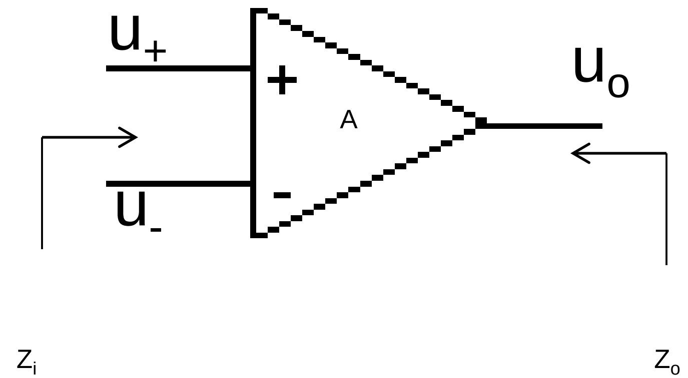
$A \gg$

$Z_i \gg$

$Z_o \ll$

$u_o = A(u_+ - u_-)$

If $A \gg u_+ = u_-$, virtual short-circuit



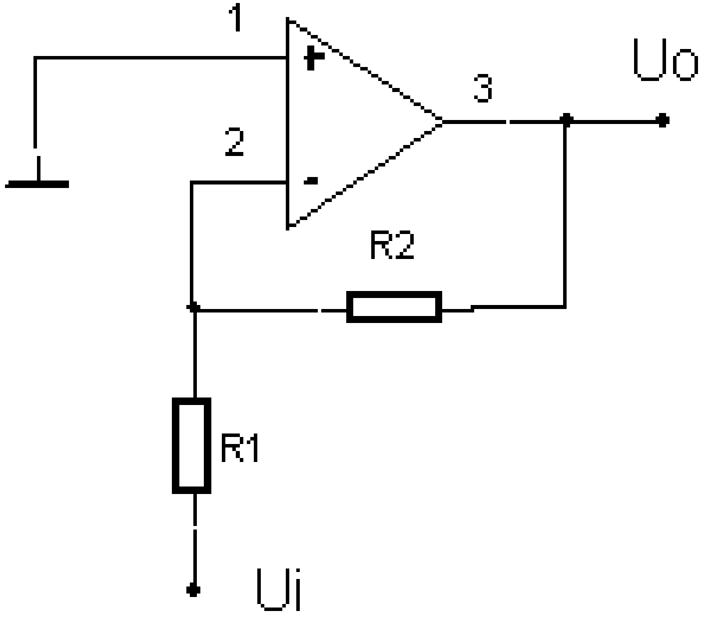
Inverting Configuration

$u_+ = 0$

$u_- = u_o R_1/(R_1+R_2)+u_i R_2/(R_1+R_2)$

If A>>, then $u_+= u_-$

$u_o = -u_i R_2/R_1$



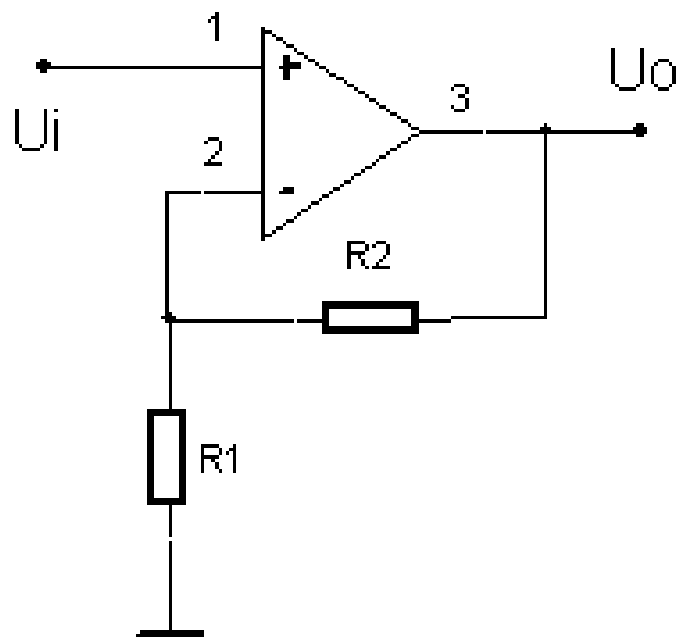
Non-inverting Configuration

$u_+ = u_i$

$u_- = u_o R_1/(R_1+R_2)$

If A>>, then $u_+ = u_-$

$u_o=(R_1+R_2)u_i/R_1$

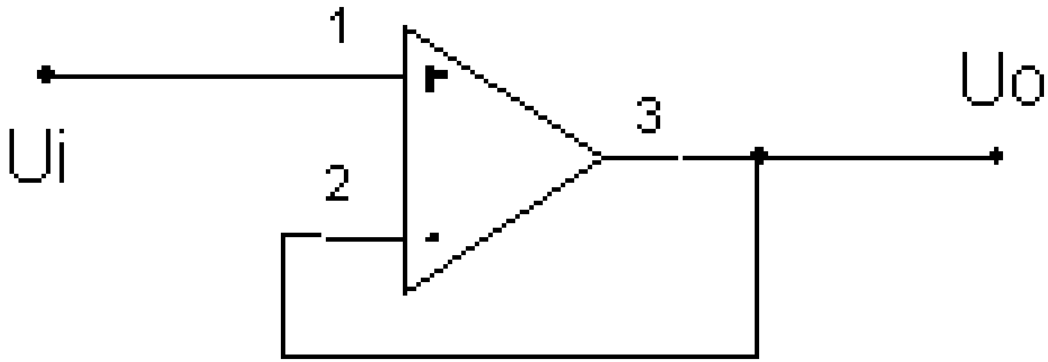


Buffer Amplifier

$u_+ = u_i$

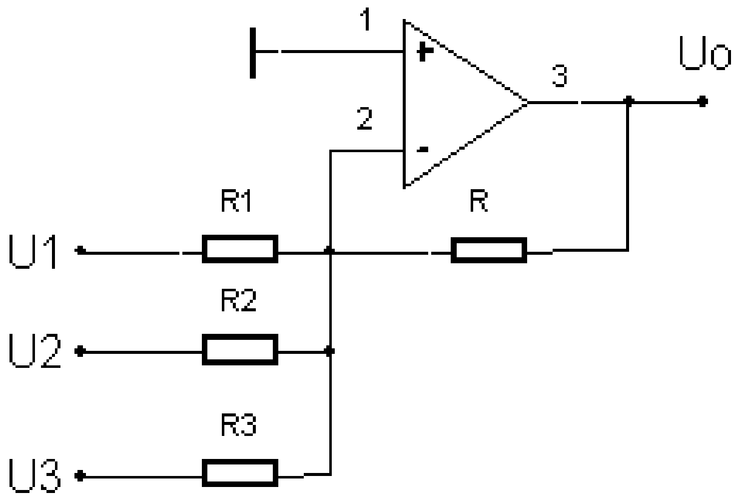
$u_- = u_o$

If A>>, then $u_o = u_i$



Summer (inverting)

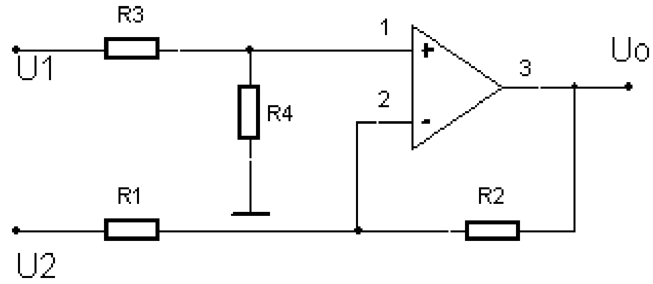
$$u_o=-(Ru_1/R_1+Ru_2/R_2+Ru_3/R_3)$$



Differential Amplifier

•If the resistors are equal, then

$u_o = U_1 - U_2$

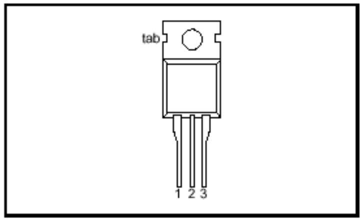


Power Semiconductors

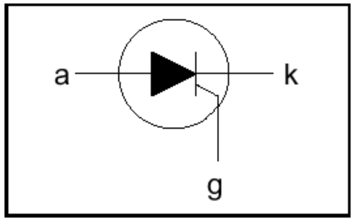
4-layer diode

Thyristor

PIN CONFIGURATION



SYMBOL



PINNING - TO220AB

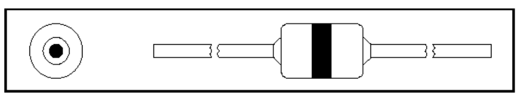
PIN	DESCRIPTION
1	cathode
2	anode
3	gate
tab	anode

BT151 series

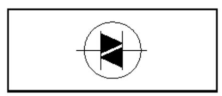
Power Semiconductors

Diac

OUTLINE - SOD27



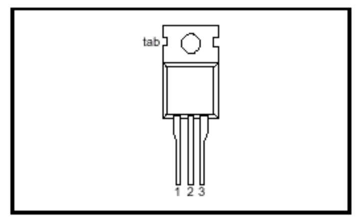
SYMBOL



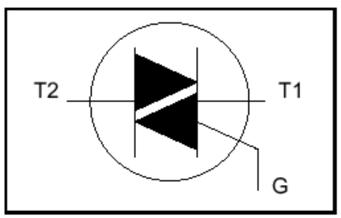
BR100/03

Triac

PIN CONFIGURATION



SYMBOL



PINNING - TO220AB

BT138 series

PIN	DESCRIPTION
1	main terminal 1
2	main terminal 2
3	gate
tab	main terminal 2

Dimmer Circuit