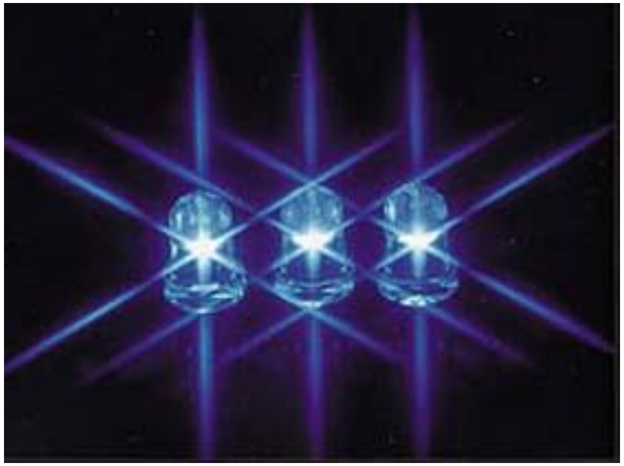
Mechatronics

Topic #6

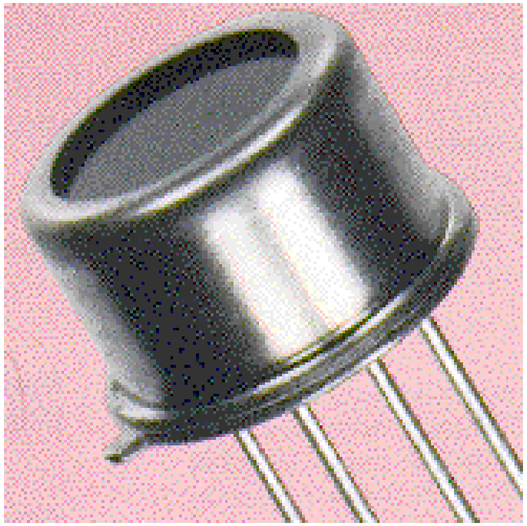
Optoelectronics (LED, photoresistor, photodiode, solar cell, phototransistor, & optoisoltaor) & comparator

Optoelectronics

- In optoelectronics we deal with 2 types of electronic devices.
- Light emitting electronic devices: ones that generate electromagnetic energy under the action of electrical field. Example: light emitting diodes (visible and infrared light).
- Light detecting devices: ones that transform electromagnetic energy input into electrical current/voltage. Examples: photoresistors, photodiodes, phototransistors, etc.



Light emitting diodes

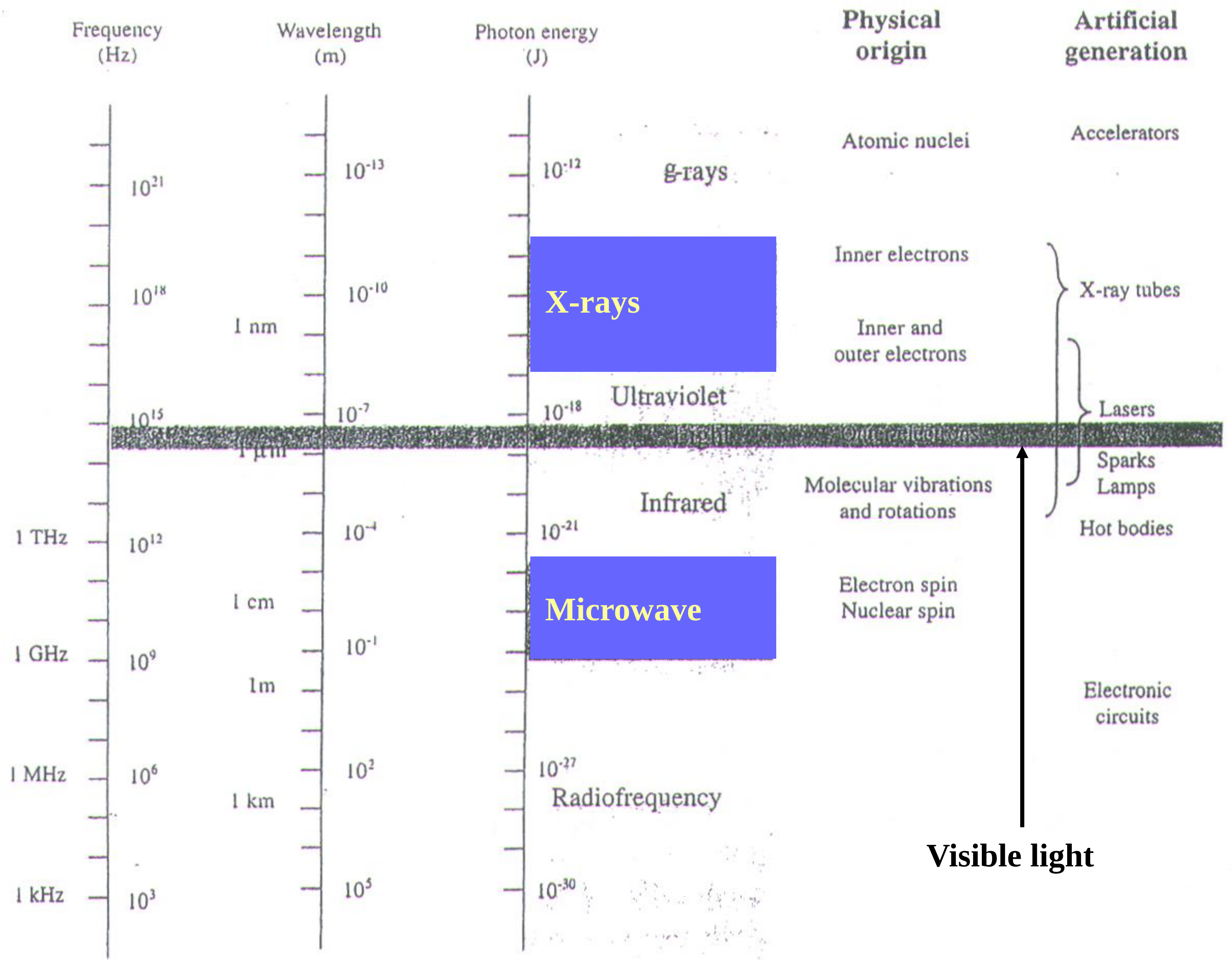


Infrared detector

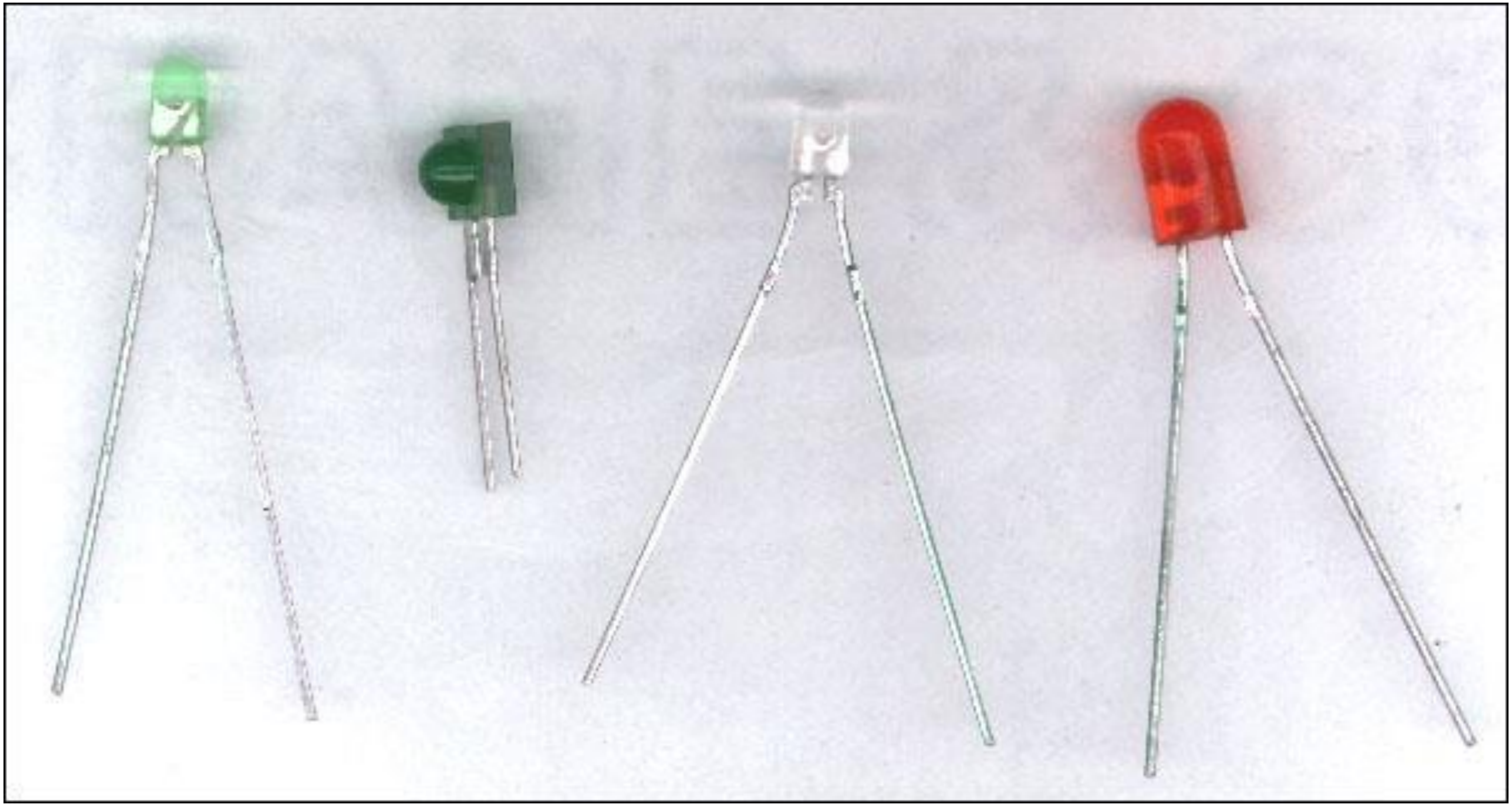
Electromagnetic Spectrum —I

- Photons are the fundamental particles of electromagnetic radiation.
- Photons of different wavelengths yield different portions of electromagnetic spectrum.
- Visible and infrared light are two narrow portions of the whole spectrum of electromagnetic radiation.

Electromagnetic Spectrum —II

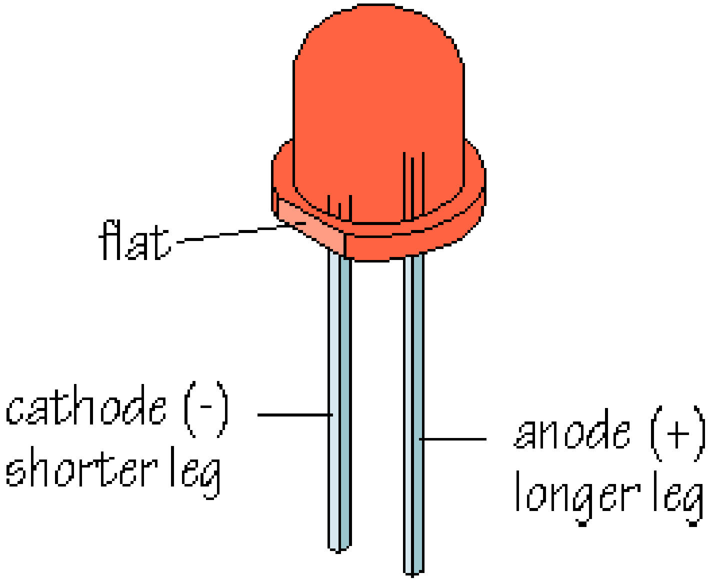


Light-Emitting Diodes (LEDs)



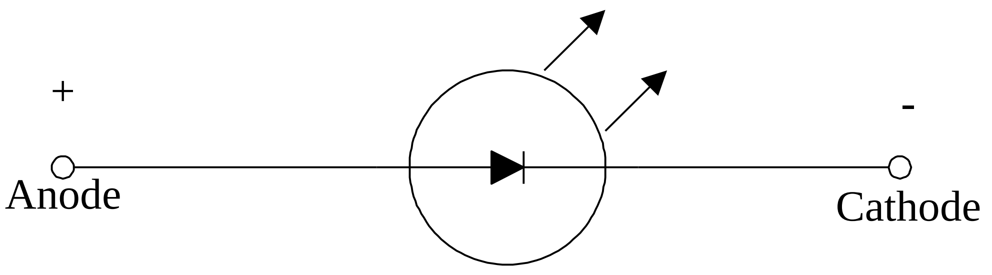
LED 101— I

- 2 lead semiconductor device.
- Light emitting PN-junction diode.
  - Visible or infrared light.
- Has polarity.
- Recall diodes act as a one way gate to current flow.
  - A forward-biased PN-junction diode allows current flow from anode to cathode.
- An LED conducts and emits light when its anode is made more positive (approx. 1.4V) than its cathode.
  - With reverse polarity, LED stops conducting and emitting light.



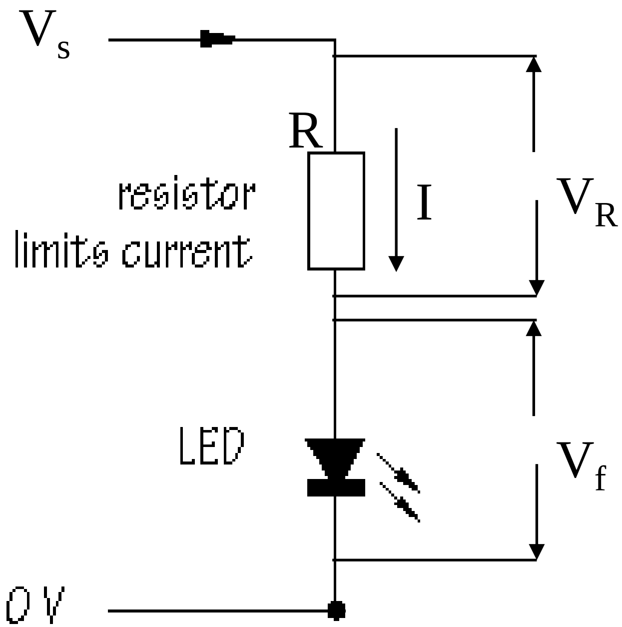
LED 101— II

- Similar to diodes, LEDs are current-dependent devices.
  - LED brightness is controlled by controlling current through LED.
    - Too little current through LED → LED remains OFF.
    - Small current through LED → dimly lit LED.
    - Large current through LED → brightly lit LED.
    - Too much current through LED → LED is destroyed.
- A resistor placed in series with LED accomplishes current control



LED symbol

LED 101—III



- Let V_s be the supply voltage.
- Let V_f be the required forward bias voltage for the LED.
- Let I be the desired current flow through LED.
- Then, the current limiting resistance R is sized as follow:

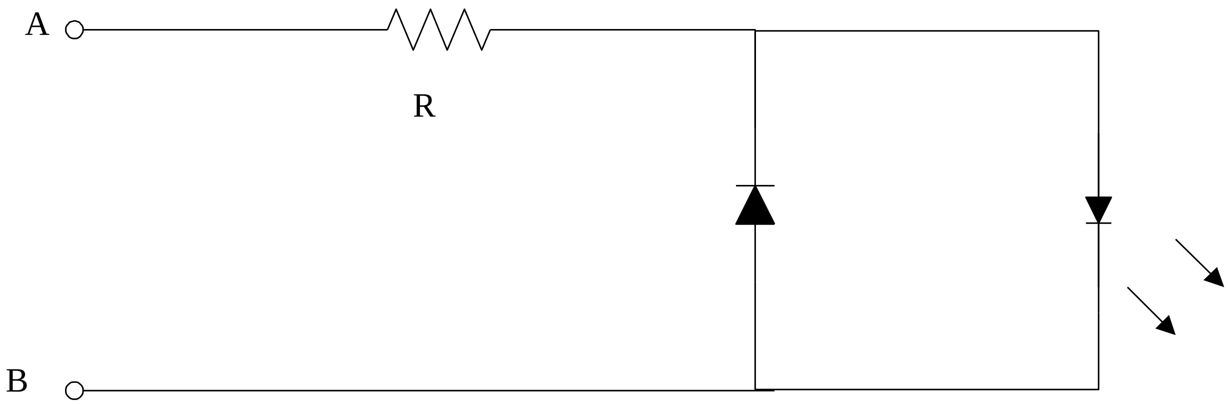
$$V_R = V_s - V_f$$

$$R = \frac{V_R}{I} = \frac{V_s - V_f}{I}$$

- If R is chosen smaller than the above value, a larger current will flow through the LED.
  - LEDs can handle only limited current (varies from 20mA to 100mA).
  - If current through LED is larger than the maximum allowed value, than the LED will be damaged.

LED 101—IV

- LEDs conduct only in forward bias mode.
- If a reverse bias is applied across an LED with reverse bias voltage greater than the reverse breakdown voltage (usually 5V), then the LED can be damaged.
- To prevent LED damage in the presence of reverse bias, the following circuit can be used.

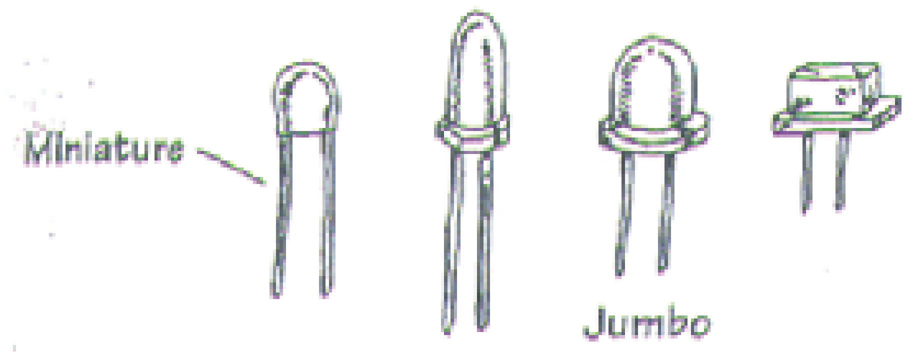


With $V_A > (V_B+1.6)$ volts LED conducts

With $(0.6+V_A)<V_B$ diode conducts

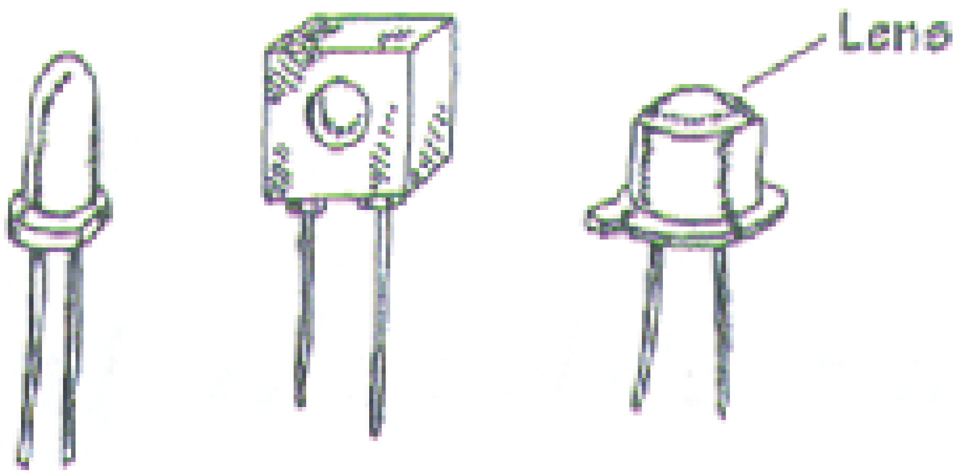
Visible-Light LED

- Inexpensive and durable.
- Typical usage: as indicator lights.
- Common colors: green (~565nm), yellow (~585nm), orange (~615nm), and red (~650nm).
- Maximum forward voltage: ≈ 1.8V.
- Typical operating currents: 1 to 3mA.
- Typical brightness levels: 1.0 to 3.0mcd/1mA to 3.0mcd /2mA.
- High-brightness LEDs exist.
  - Used in high-brightness flashers (e.g., bicycle flashers).



Infrared LED

- Designed to emit infrared photons with wavelength ≈ 880 to 940 nm.
- IR LEDs are used in remote-control circuits in conjunction with photosensors.
- IR LEDs have a narrower viewing angle *vis-a-vis* visible-light LEDs.
  - Allows to efficiently direct information to be transmitted.
- Photon output is characterized in terms of output power per specific forward current.
  - Typical outputs range from around 0.50mW/20mA to 8.0mW/50mA.
- Maximum forward voltage at specific forward currents range from 1.6V@20mA to 2V@100mA.

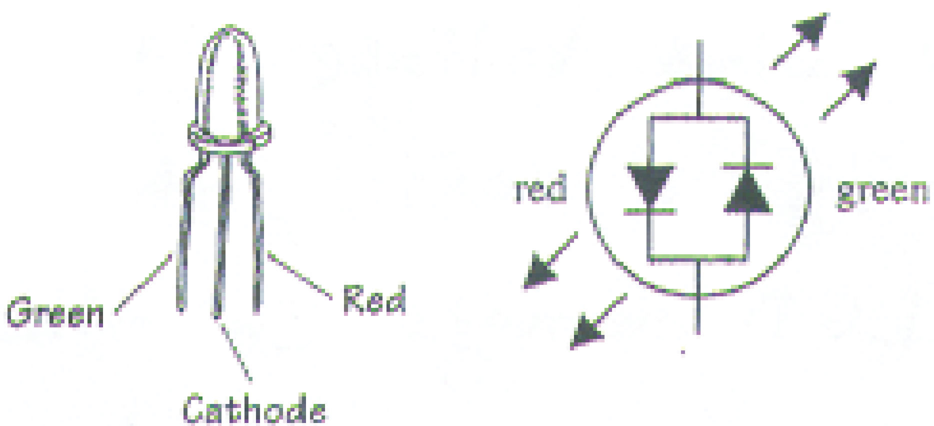


Blinking LED

- Contain a miniature integrated circuit that causes LED to flash from 1 to 6 times/second.
- Typical usage: indicator flashers. May also be used as simple oscillators.

Tricolor LED

- Two LEDs placed in parallel facing opposite directions.
- One LED is red or orange, the other is green.
- Current flow in one direction turns one LED ON while the other remains OFF due to reverse bias.
- Current flow in the other direction turns the first LED OFF and the second LED ON.
- Rapid switching of current flow direction will alternatively turn the two LEDs ON giving yellow light.
- Used as a polarity indicator.
- Maximum voltage rating: 3V
- Operating range: 10 to 20mA

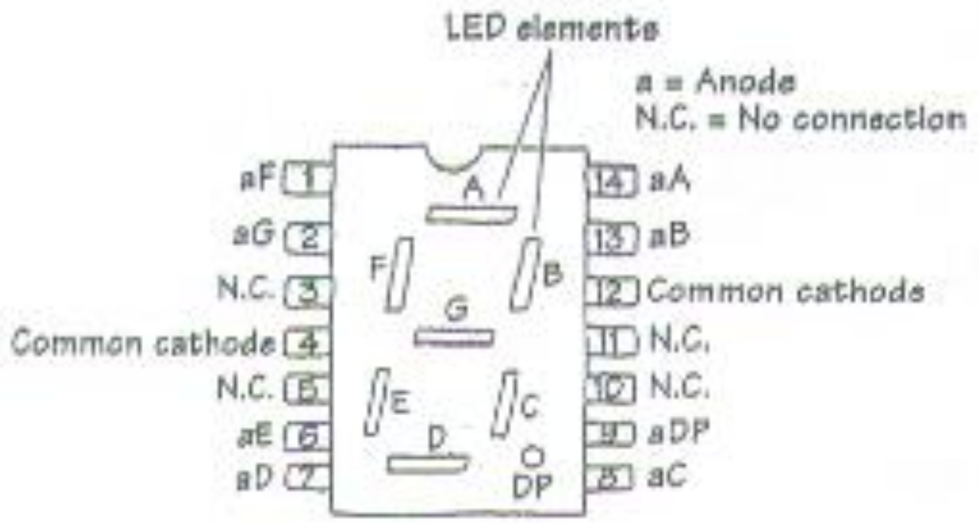


LED Specs

MNFR #	TYPE OF LED	COLOR	TYPICAL FORWARD VOLTAGE DROP (V) V_F	MAX. REVERSE BREAKDOWN VOLTAGE (V) V_R	MAX. DC FORWARD CURRENT (mA) I_F
NTE3000	Indicator	Clear red	1.65	5	40
NTE3010	Indicator	Green	2.2	5	35
NTE3026	Tristate	Red/green	1.65, red	—	70, red
			2.2, green	—	35, green
NTE3130	Blinker (3 Hz)	Yellow blink	5.25	0.4	20
NTE3017	Infrared	900 nm	1.28	6	100

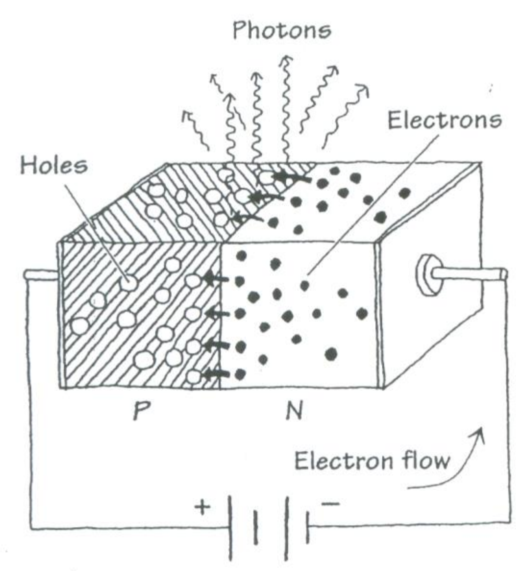
7-Segment LED Display

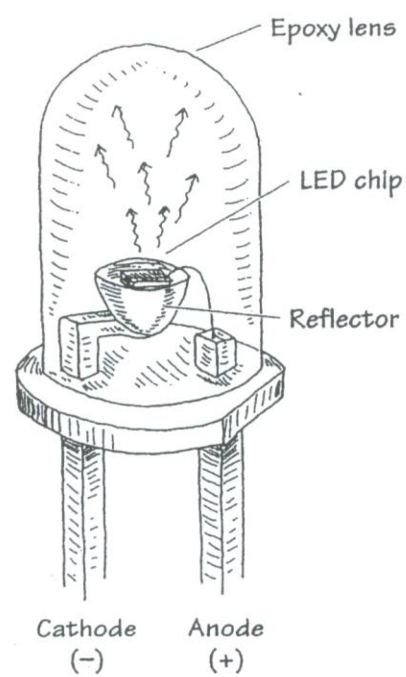
- Used for displaying numbers and other characters.
- 7 individual LEDs are used to make up the display.
- When a voltage is applied across one of the LEDs, a portion of the 8 lights up.
- Unlike liquid crystal displays (LCD), 7-segment LED displays tend to be more rugged, but they also consume more power.



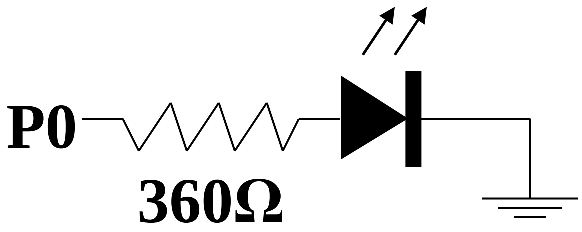
How LED Works

- The light-emitting section of an LED is made by joining n-type and p-type semiconductors together to form a pn junction.
- When the pn junction is forward-biased, electrons in the n side are excited across the pn junction and into the p side, where they combine with holes.
- As the electrons combine with the holes, photons are emitted.
- The pn-junction section of an LED is encased in an epoxy shell that is doped with light scattering particles to diffuse light and make the LED appear brighter.
- Often a reflector placed beneath the semiconductor is used to direct the light upward.

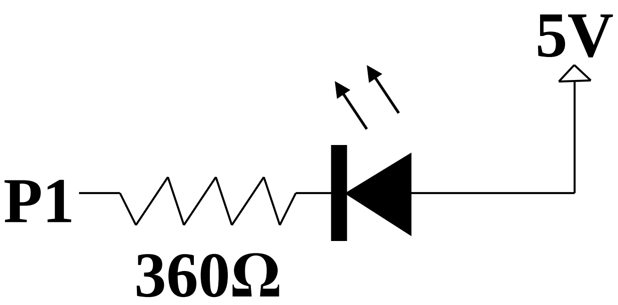




Connecting LED to BS2 —I



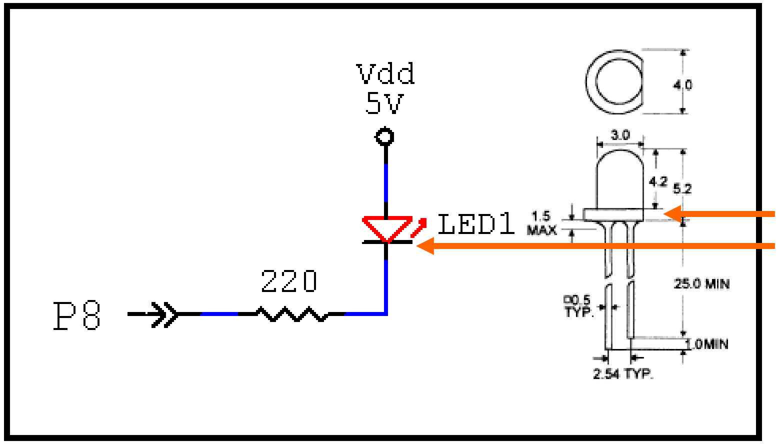
LED is on when P0 is driven high.



LED is on when P1 is driven low.

Connecting LED to BS2 —II

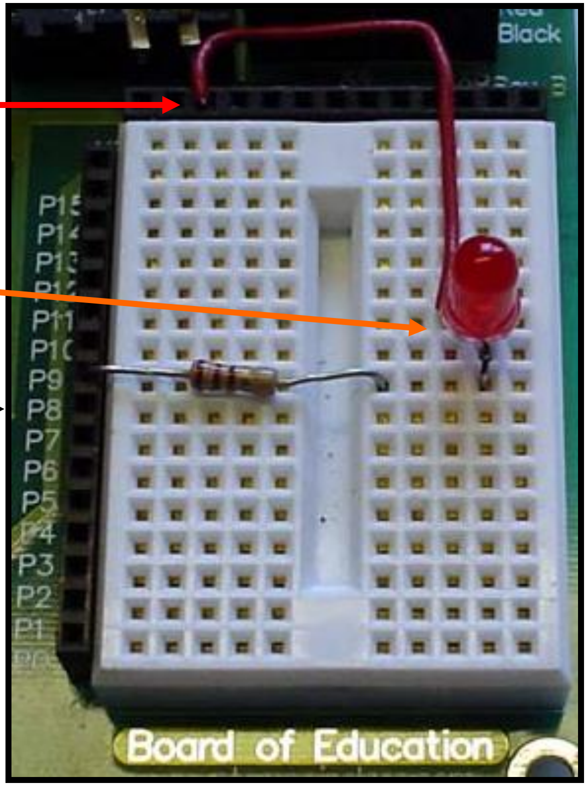
Connect an LED to P8 as shown:



Vdd, NOT Vin.

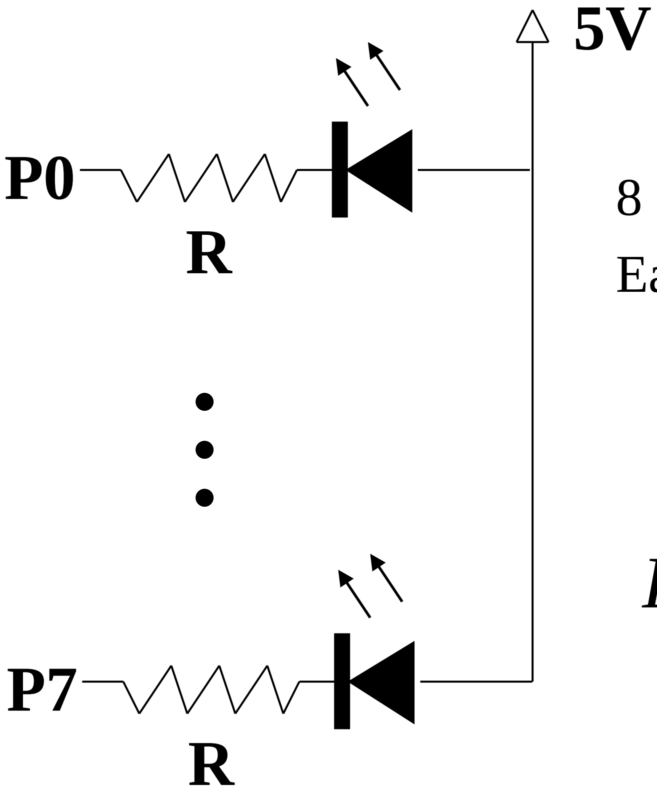
Note cathode: the 'flat side' of LED

Connected on P8. Angle of shot makes it appear to be on P9.



- In this configuration a LOW, or 0V, at P8 will allow current to flow through the LED to Vdd (+5V) lighting it. When P8 is HIGH (+5V), no current will flow and the LED will not light. The LED is Active Low.

Connecting Multiple LEDs to BS2

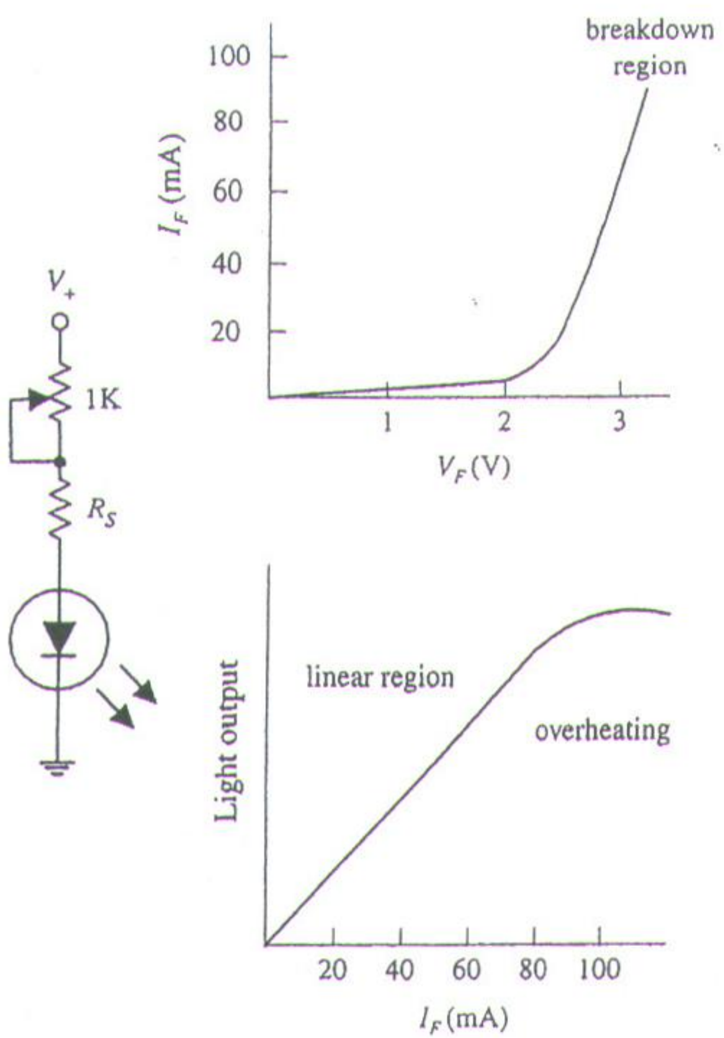


8 LEDs are connected to BS2

Each I/O/pin (P0-P7) is allowed to sink 6.25mA

$$R = \frac{V}{I} = \frac{3.6}{6.25 \times 10^{-3}} = 576\Omega$$

Basic LED Operations —LED Brightness Control



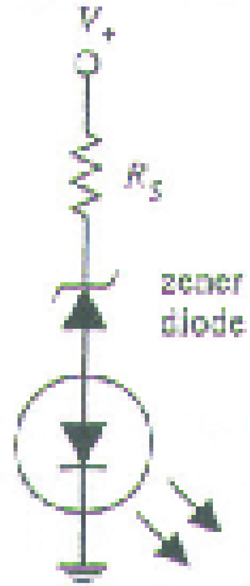
- The 1-K variable resistor controls the amount of current passing through the LED thus controlling its brightness. We term this as a "LED Dimmer."
- R_s is used to protect the LED from excessive current. R_s sizing:

$$R_s = \frac{V_+ - V_F}{I_F}$$

- When an LED begins to conduct, the voltage increase gradually, while the current increases rapidly. Too much current will overheat the LED.

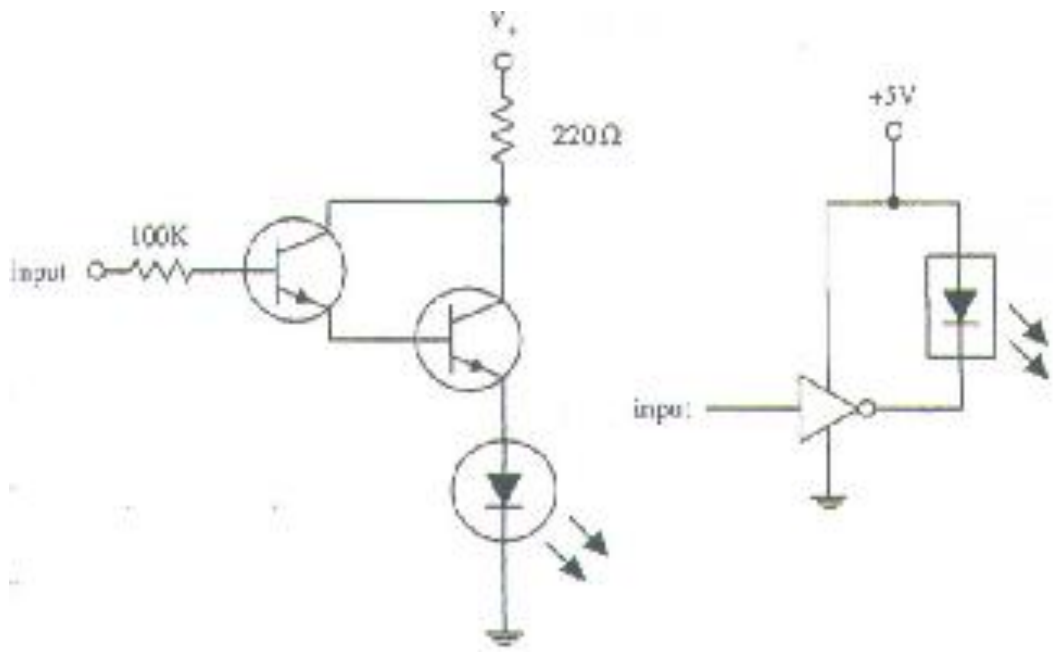
Basic LED Operations —Voltage-Level Indicator

- An LED along with a zener diode can be used to make a voltage-level indicator circuit.
- Whenever V_+ exceeds the breakdown voltage of the zener diode, the zener diode conducts and allows current to pass through the LED.
- Zener diodes come with various breakdown voltages, so it is possible to connect a number of these types of circuits in parallel to form a voltage indicator display



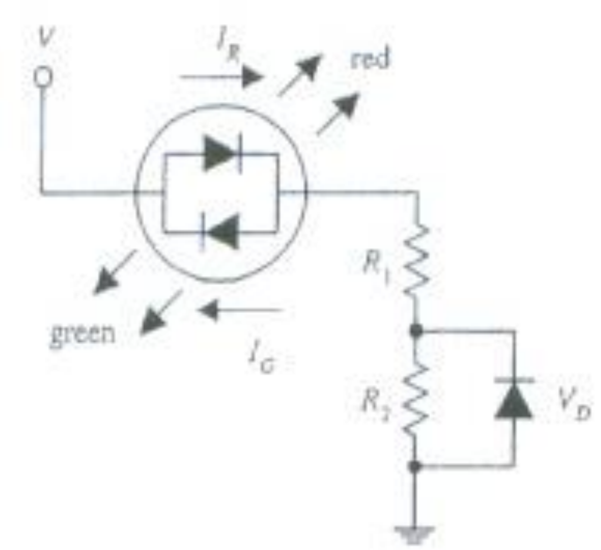
Basic LED Operations —Logic Probes

- An LED can be used to display the status of a logic gate.
- Left Circuit:
  - The output of a logic gate is attached to the input of the left NPN transistor.
  - A high input will turn on the transistors and will light the LED.
  - A low input will turn the LED off.
- Right Circuit:
  - A flasher LED can be used to do the same as above. This circuit works with TTL gates and with high-output CMOS gates.



Basic LED Operations —Tristate Polarity Indicator

- A tristate LED can be used to indicate the direction and type of current flow.
  - If V is positive dc voltage, the device emits red light.
  - If V is a negative dc voltage, the device emits green light.
  - If V is a high-frequency ac voltage, the device appears to emit a yellow light.
  - R1 and R2 are chosen to protect the LEDs.
  - Diode is used to provide reversed-voltage protection when the applied voltage exceeds the maximum reverse voltage.



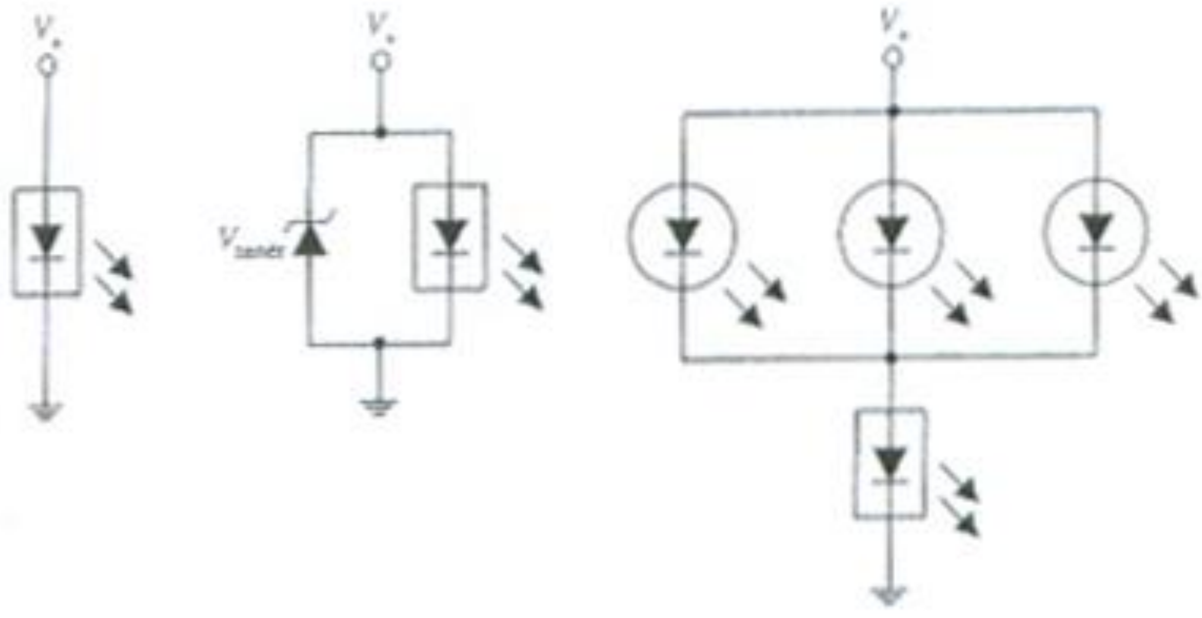
V	Color
+	red
−	green
AC	yellow

$$R_1 = \frac{V - (V_G + V_D)}{I_G}$$

$$R_2 = \frac{V - V_R}{I_R} - R_1$$

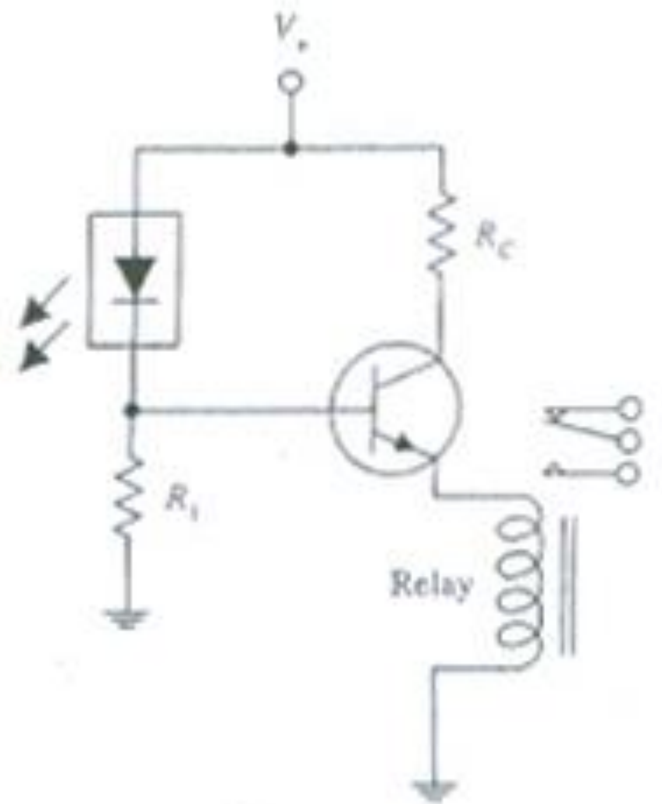
Basic LED Operations —LED Flasher Circuits

- Flasher LED does not require a current-limiting resistor like the other LEDs.
- Typically allowable voltage across flasher LED: 3 to 7 V.
- Flasher LED protection from excessive forward voltage: use a zener diode placed in parallel.
- A single flasher LED as shown in the rightmost circuit can be used to flash a number of ordinary LEDs



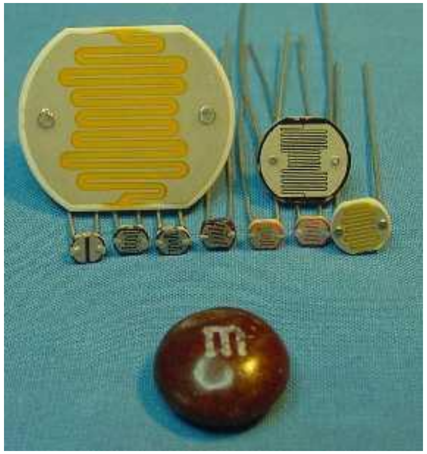
Basic LED Operations —Relay Driver

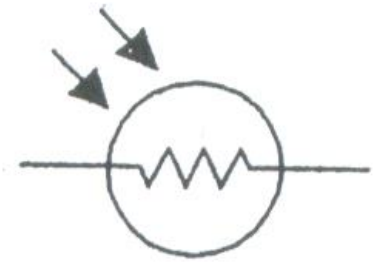
- A flasher LED can be used to supply a series of on/off pulses of current/voltage to the base of a BJT.
- When the flasher LED goes into conduction, the BJT base receives a positive voltage and input current needed to turn it on, thus providing power to drive the relay.
- R_1 sets the biasing voltage for the transistor and R_c sets the collector current.



Photoresistors —I

- Light sensitive variable resistors.
- Its resistance depends on the intensity of light incident upon it.
  - Under dark condition, resistance is quite high (MΩ: called dark resistance).
  - Under bright condition, resistance is lowered (few hundred Ω).
- Response time:
  - When a photoresistor is exposed to light, it takes a few milliseconds, before it lowers its resistance.
  - When a photoresistor experiences removal of light, it may take a few seconds to return to its dark resistance.





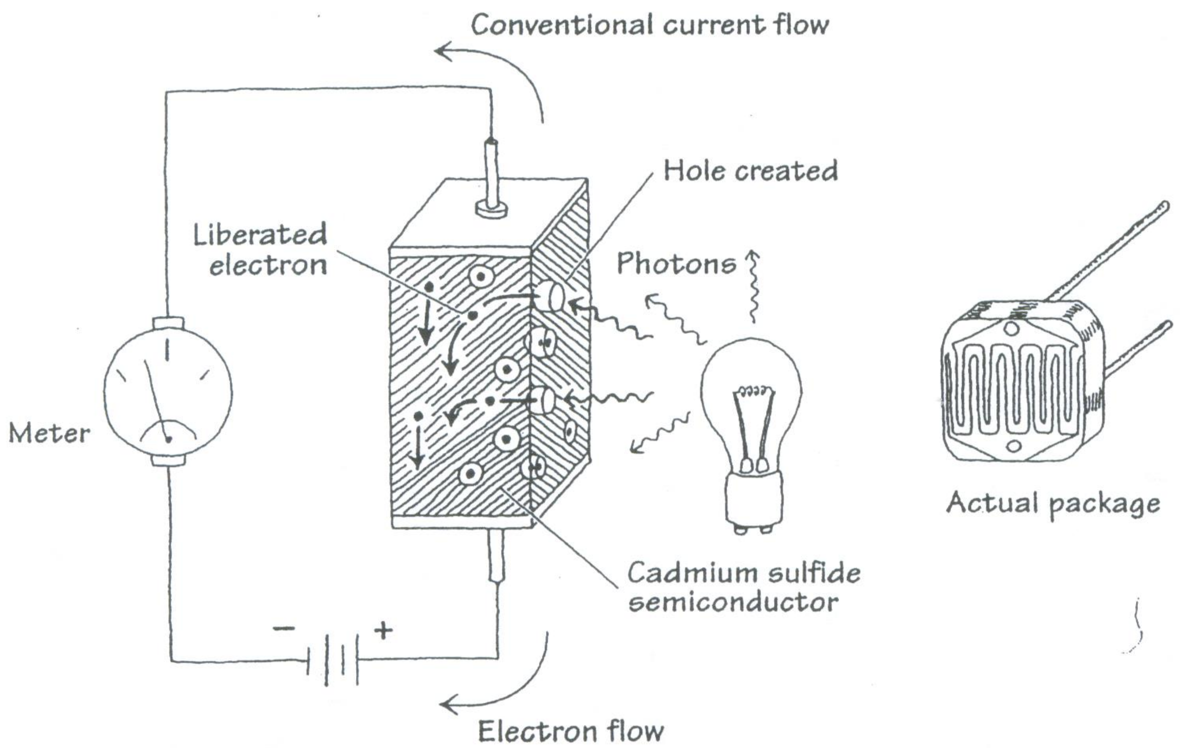
Symbol

Photoresistors —II

- Some photoresistors respond better to light that contains photons within a particular wavelength of spectrum.
  - Example: Cadmium-sulfide photoresistos respond to light within 400-800nm range.
  - Example: Lead-sulfide photoresistos respond to infrared light.

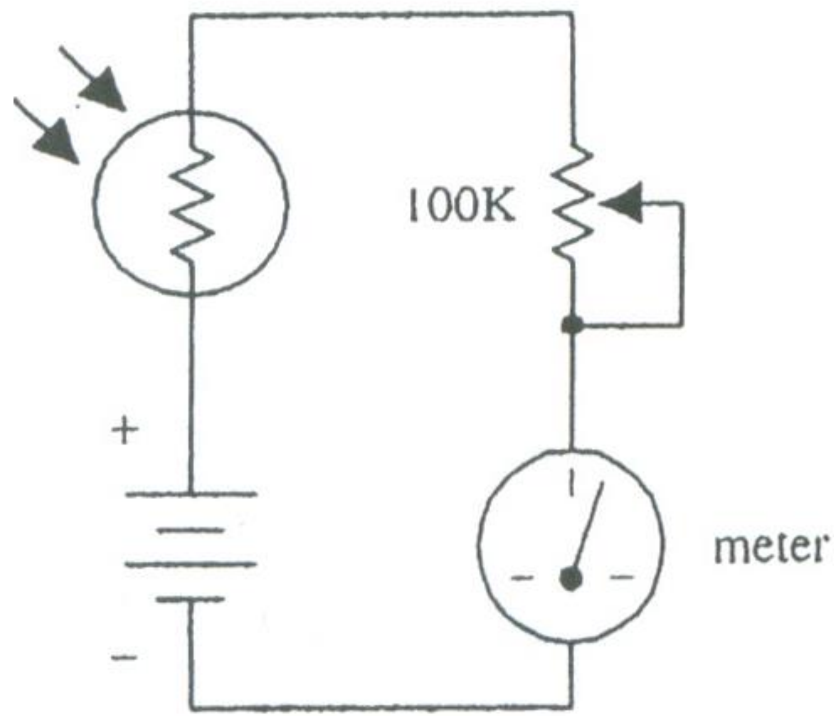
How Photoresistor Works

- Special semiconductor crystal, such as cadmium sulfide or lead sulfide is used to make photoresistors.
- When this semiconductor is placed in dark, electrons within its structure resist flow through the resistor because they are too strongly bound to the crystal's atoms.
- When this semiconductor is illuminated, incoming photons of light collide with the bound electrons, stripping them from the binding atom, thus creating holes in the process.
- Liberated electrons contribute to the current flowing through the device.



Photoresistor Application—Simple Light Meter

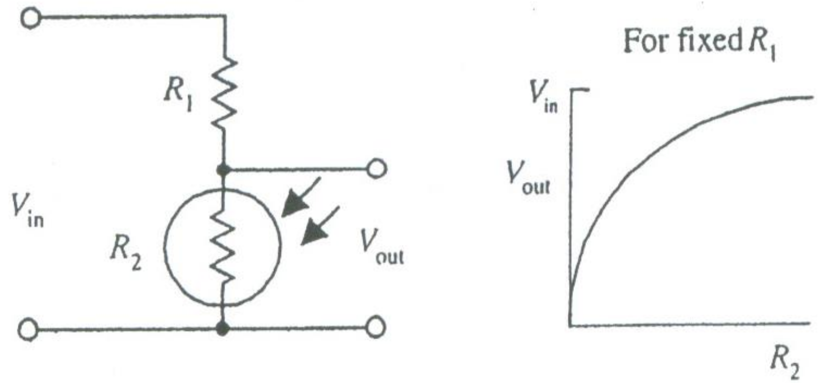
- Photoresistor is acting as the light-sensing element in a simple light meter.
- In dark condition, the photoresistor is very resistive, and little current flows through the series loop; the meter is at its lowest deflection level.
- When an increasingly bright light source shines on the photoresistor. the photoresistor’s resistance begins to decrease, and more current begins to flow through the series loop, the meter stats to deflect.
- The potentiometer is used to calibrate the meter.



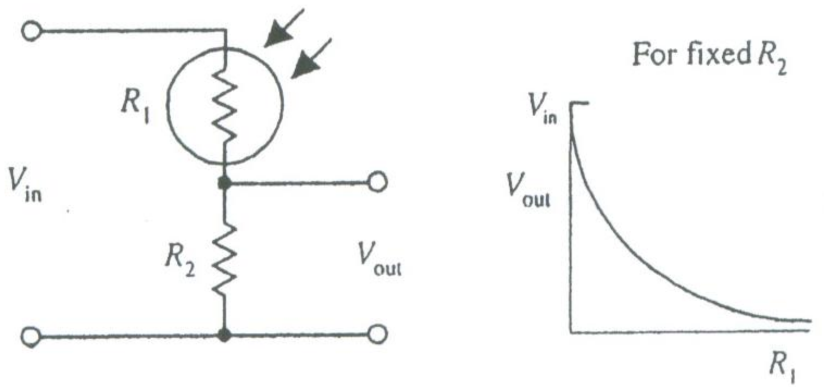
Photoresistor Application—Light Sensitive Voltage Divider

- Voltage-divider circuit output is give by:

$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$

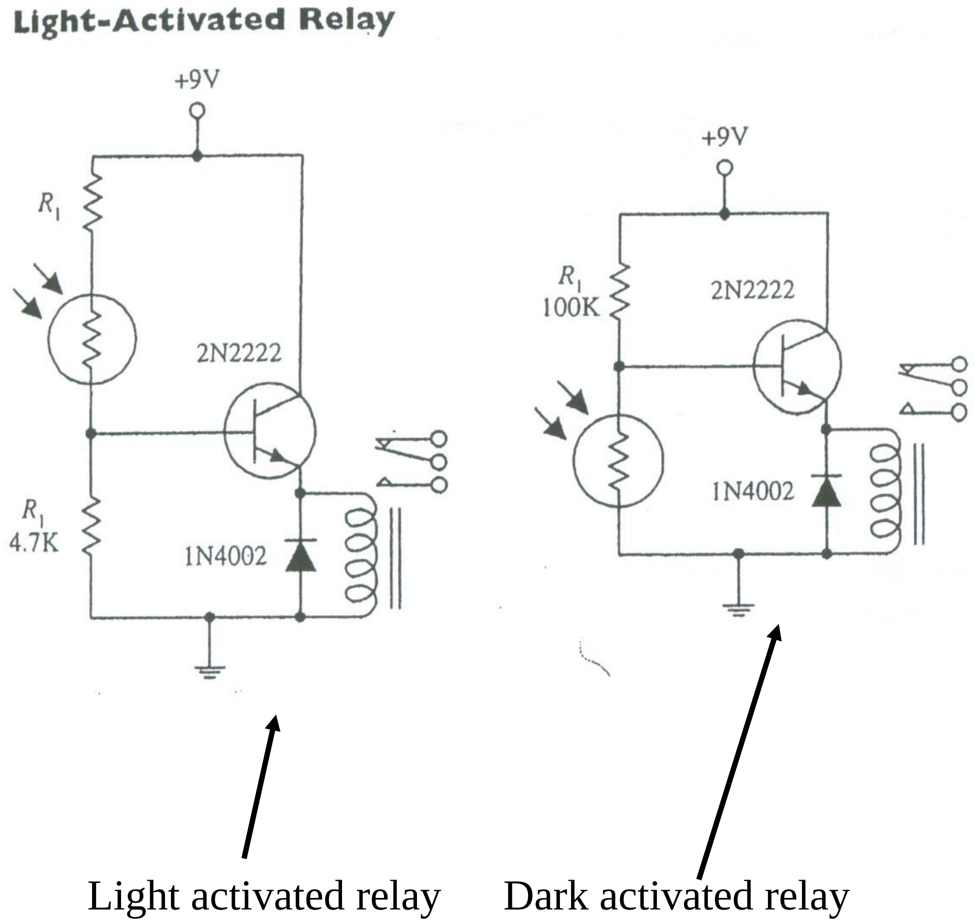


- As the intensity of light increases, the resistance of the photoresistor decreases. As more light falls upon the photoresistor:
  - V_{out} in the top circuit gets smaller.
  - V_{out} in the lower circuit gets larger.



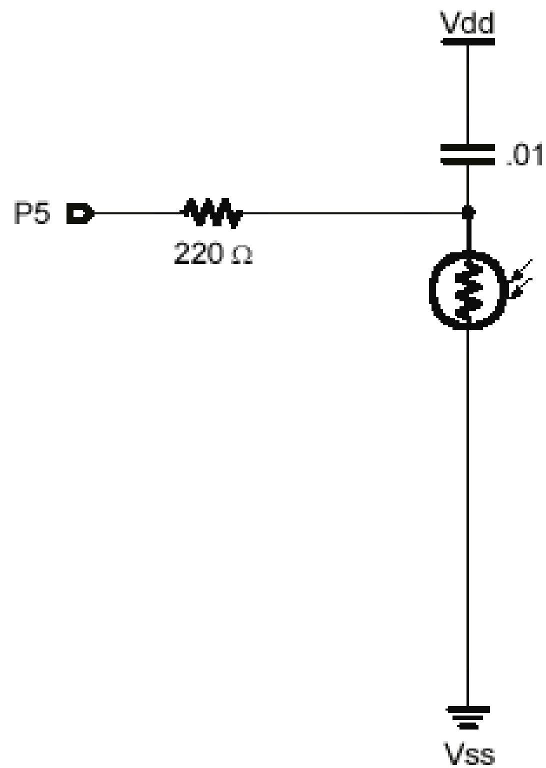
Photoresistor Application —Light Activated Relay

- Light-sensitive voltage divider is being used to trip a relay whenever the light intensity change.
- Light-activated circuit:
  - When the photoresistor is exposed to light, its resistance decreases.
  - → Transistor's base current and voltage increase and if the base current and voltage are large enough, the collector-emitter pair of the transistor conducts triggering the relay.
- The value of R_1 in the light-activated circuit should be around 1 KΩ but may have to be adjusted.
- Dark-activated relay works in a similar but opposite manner.
- R_1 in the dark-activated circuit (100KΩ) may also have to be adjusted.
- A 6 to 9-V relay with a 500Ω coil can be used in either circuit.

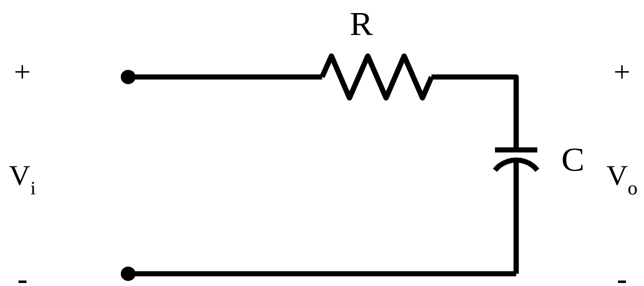


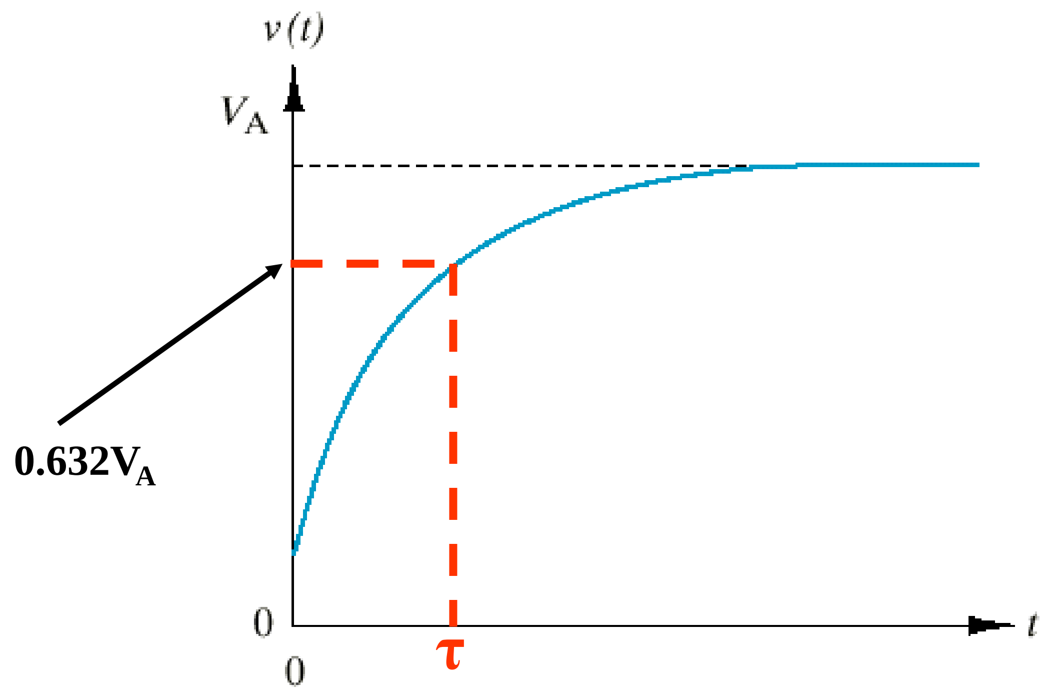
Photoresistor with BS2

- Usually connect with a capacitor in series.
- Use “RCTime” command to find out light intensity incident upon the photoresistor.



RC Circuit



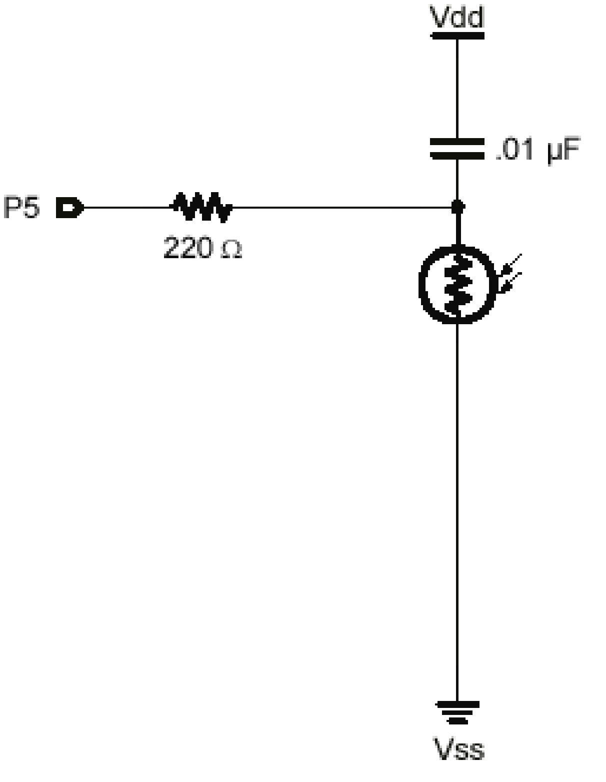


$$\frac{V_o(s)}{V_i(s)} = \frac{1}{RCs+1}$$

- Time constant τ=RC.
- Time constant τ is time at which voltage output in the series RC circuit reaches 63.2% of the applied voltage.

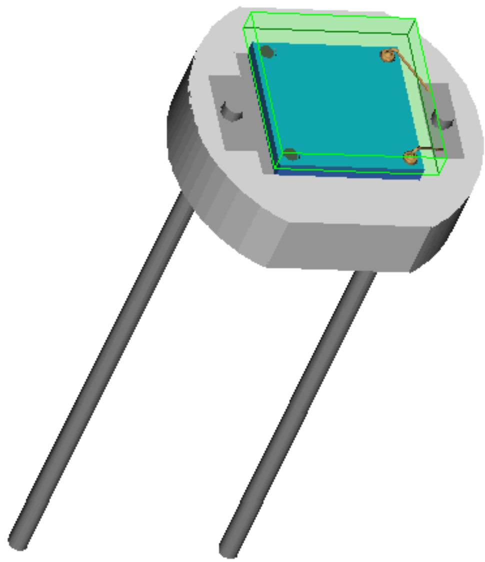
Rctime with BS2

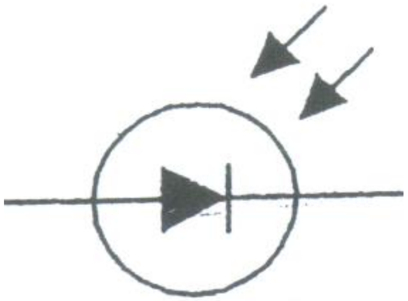
- Low-cost analog to digital converter using software.
- Pbasic rctime command:
  – Rctime Pin#, state, variable
- Example code:
  – High 3
  – Pause 3
  – Rctime 3,1, tau



Photodiode

- Photodiode is a 2 lead semiconductor device that transforms light energy to electric current.
- Suppose anode and cathode of a photodiode are wired to a current meter.
  - When photodiode is placed in dark, the current meter displays zero current flow.
  - When the photodiode is exposed to light, it acts a a current source, causing current flow from cathode to anode of photodiode through the current meter.
- Photodiodes have very linear light v/s current characteristics.
  - Commonly used as light meters in cameras.
- Photodiodes often have built-in lenses and optical filters.
- Response time of a photodiode slows with increasing surface area.
- Photodiodes are more sensitive than photoresistor.

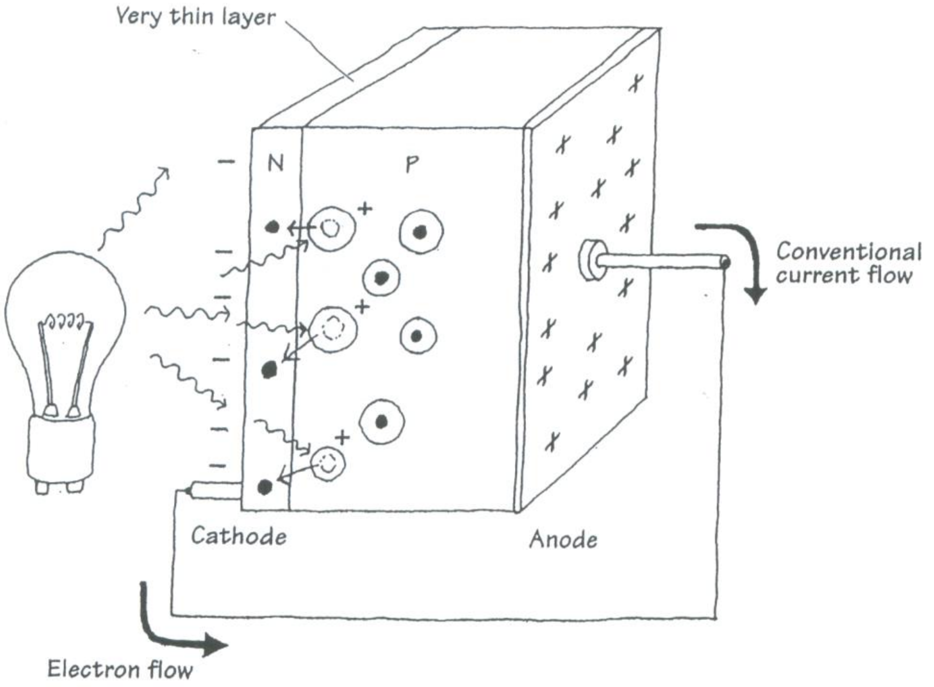




Symbol

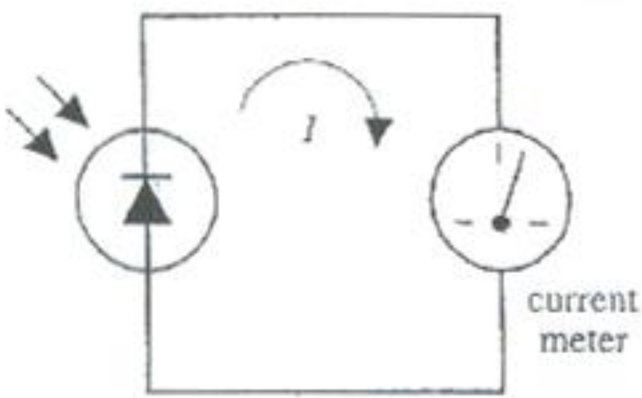
How Photodiode Works

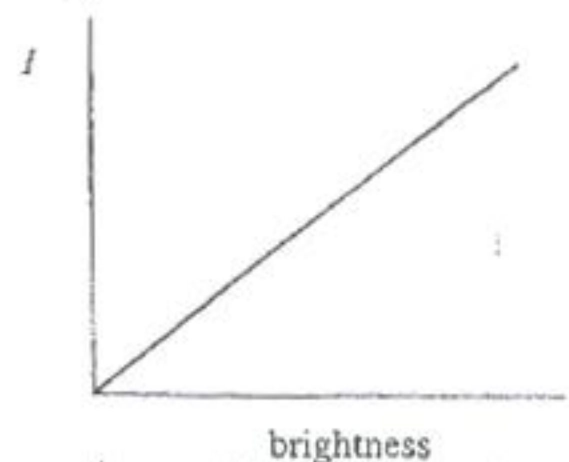
- Photodiode: A thin n-type semiconductor sandwiched with a thicker p-type semiconductor.
- N-side is cathode, p-side is anode.
- Upon illumination, a # of photons pass from the n-side and into the p-side of photodiode.
  - Some photons making it into p-side collide with bound electrons within p-semiconductor, ejecting them and creating holes.
  - If these collisions are close to the pn-interface, the ejected electrons cross the junction, yielding extra electrons on the n-side and extra holes on the p-side.
  - Segregation of +ve and -ve charges leads to a potential difference across the pn-junction.
  - When a wire is connected between the cathode and anode, a conventionally positive current flow from the anode to cathode



Photodiode Applications—Photovoltaic Current Source

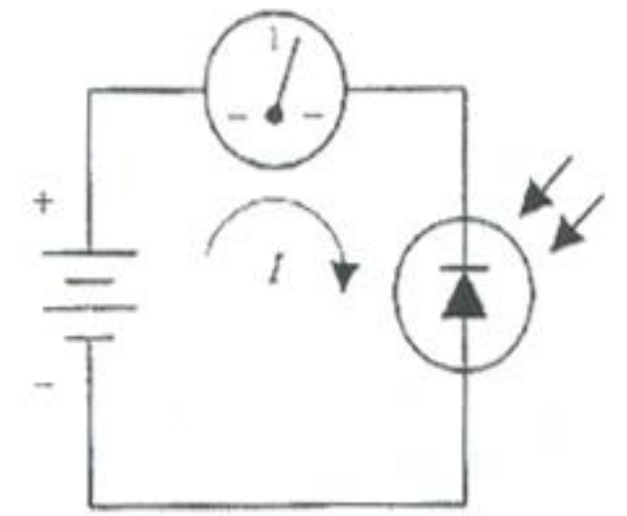
- Photodiode converts light energy directly into electric current that can be measured with meter.
- The input intensity of light and the output current are nearly linear.





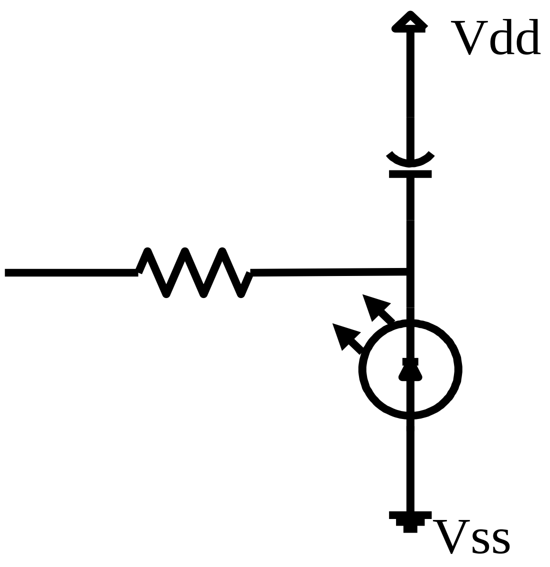
Photodiode Applications—Photoconductive Operation

- A single photodiode may not produce enough current needed to drive a particular light-sensitive circuit.
- Incorporate a photodiode along with a voltage source.
- That is, connect a photodiode in reversed-bias with a battery.
- In darkness, a small current called the dark current flows through the photodiode.
- When the photodiode is illuminated, a larger current flows.
- A resistor is placed in series with the diode and battery to calibrate the meter.



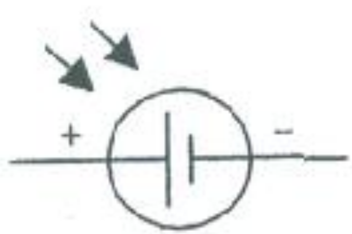
Interfacing Photodiode with BS2

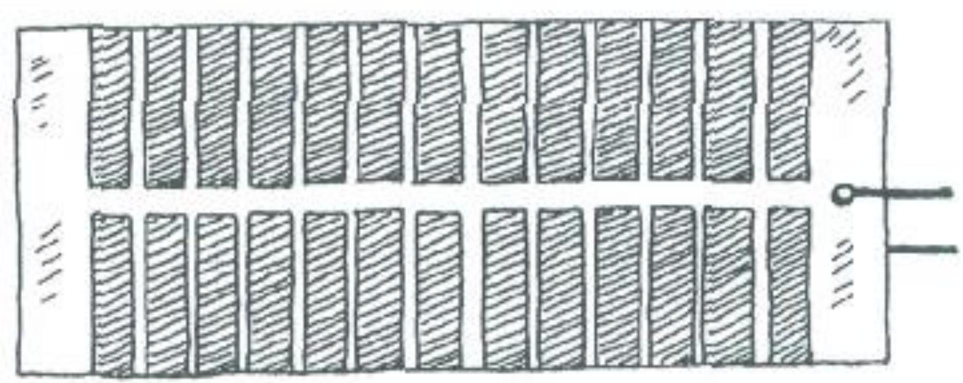
- Polarity: Anode is connected to the ground.



Solar Cell—I

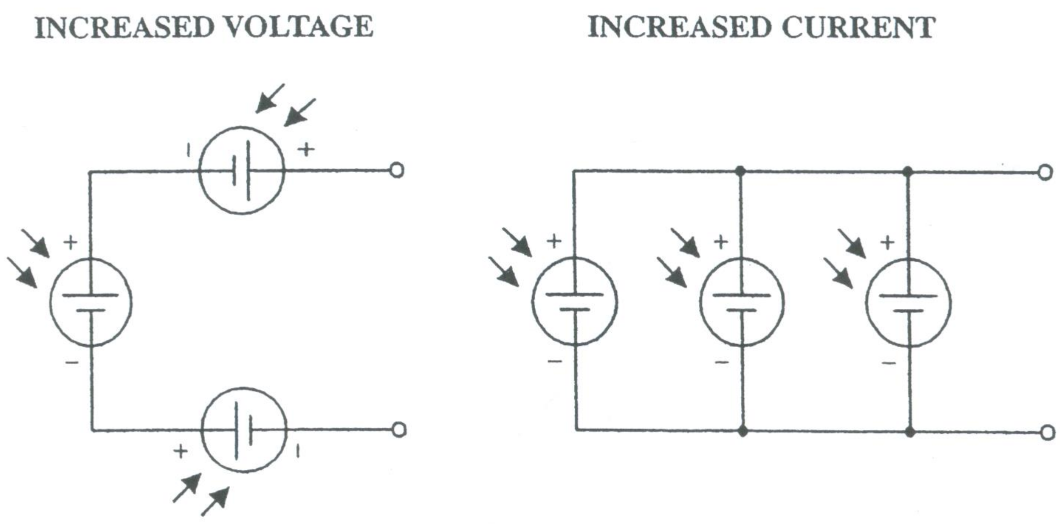
- Solar cells are photodiodes with very large surface areas.
- Compared to usual photodiodes, the large surface area in photodiode of a solar cell yields
  - a device that is more sensitive to incoming light.
  - a device that yields more power (larger current/volts).
- Solar cells yield more power.
- A single solar cell may provide up to 0.5V that can supply 0.1A when exposed to bright light.





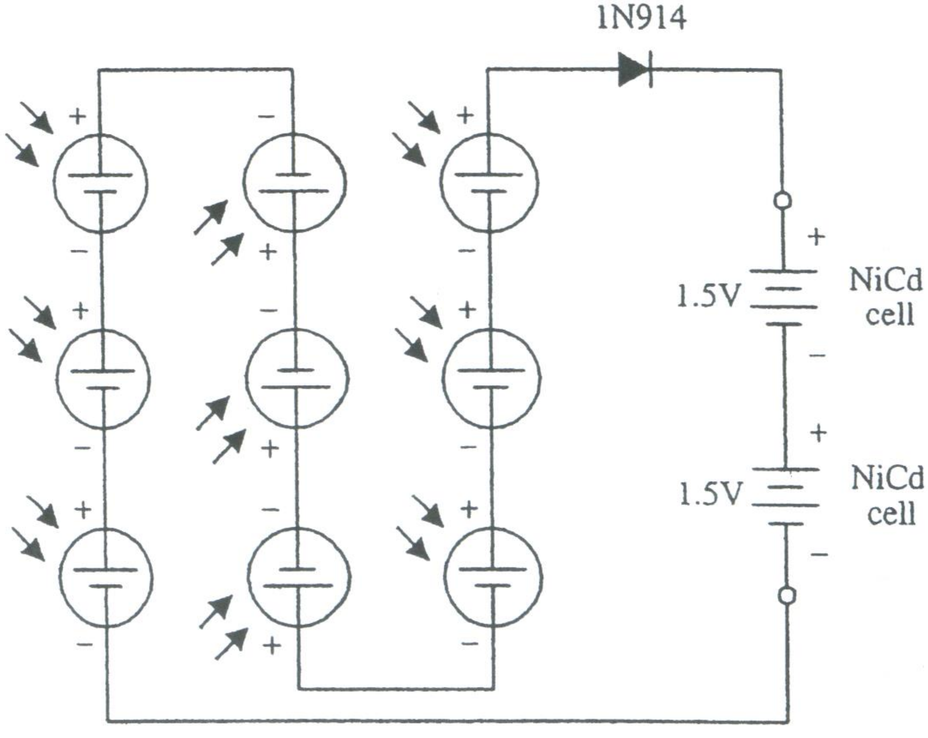
Solar Cell—II

Solar Cell Basic Operation—Power Sources



- Each solar cell produces an open-circuit voltage from around 0.45 to 0.5 V and may generate as much as 0.1 A in bright light.
- Similar to batteries, solar cells can be combined in series or parallel.
- Adding cells in series, yields output voltage that is the sum of the individual cell voltages.
- Adding solar cells in parallel, yields an increased output current *vis-à-vis* a single solar cell.

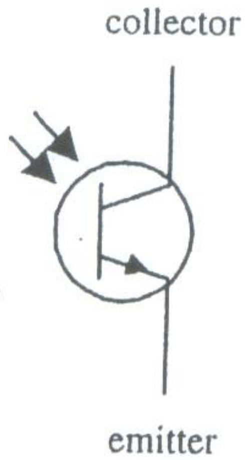
Solar Cell Basic Operation—Battery Charger



- Nine solar cells placed in series can be used to recharge two 1.5 V NiCd cells.
- The diode is added to the circuit to prevent the NiCd cells from discharging through the solar cell during times of darkness.
- It is important not to exceed the safe charging rate of NiCd cells. To slow the charge rate, a resistor can be placed in series with the batteries.

Phototransistor

- Phototransistor is a light sensitive transistor.
- In one common type of phototransistor, the base lead of a BJT is replaced by a light sensitive surface.
- When the light sensitive surface @ the base is kept in darkness, the collector-emitter pair of the BJT does not conduct.
- When the light sensitive surface @ the base is exposed to light, a small amount of current flows from the base to the emitter. The small base-emitter current controls the larger collector-emitter current.
- Alternatively, one can also use a field-effect phototransistor (Photo FET).
    - In a photo FET, the light exposure generates a gate voltage which controls a drain-source current.



Phototransistor

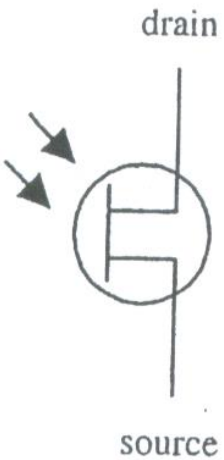
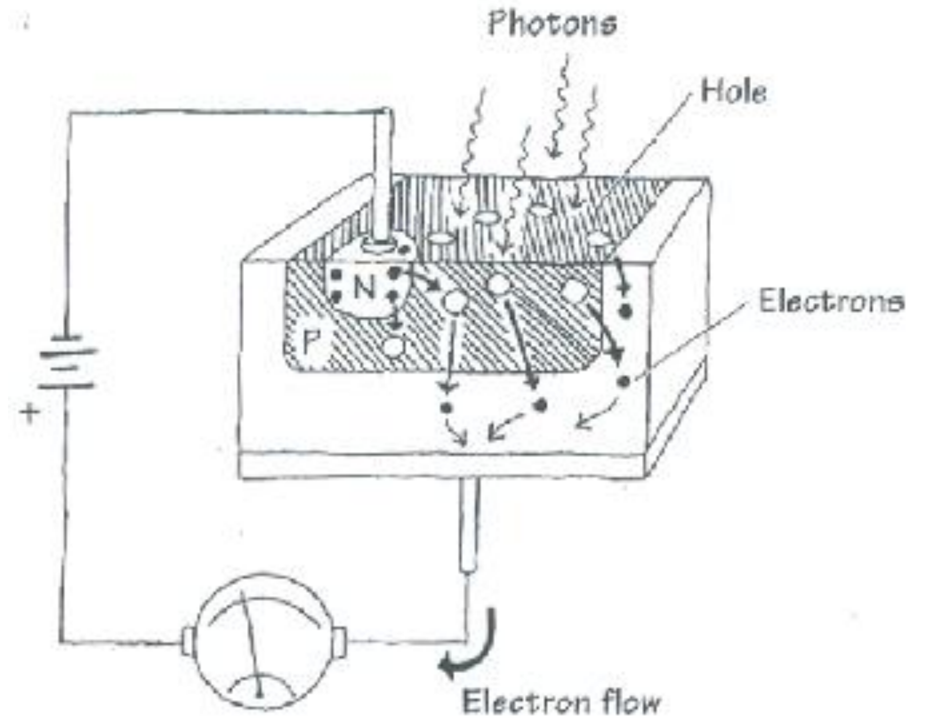
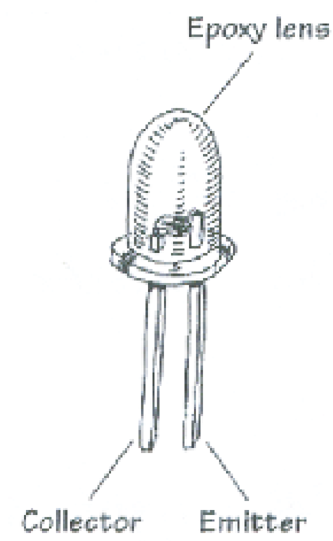


Photo FET

How Phototransistor Works

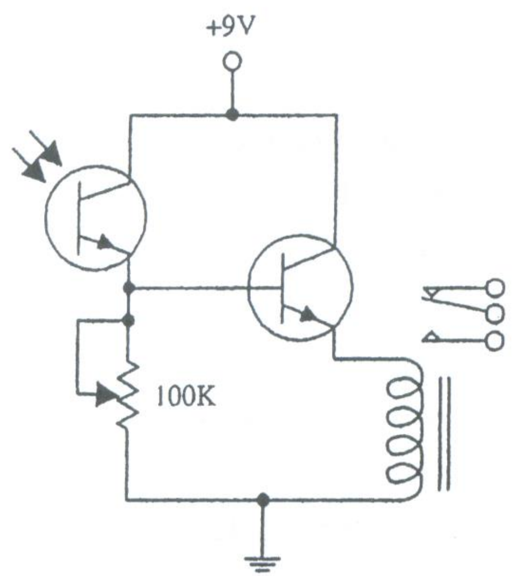
- The bipolar phototransistor resembles a bipolar transistor that has extra large p-type semiconductor region that is open for light exposure.
- When photons from a light source collide with electrons within the p-type semiconductor, they gain enough energy to jump across the pn-junction energy barrier-provided the photons are of the right frequency/energy.
- As electrons jump from the p-region into the lower n-region, holes are created in the p-type semiconductor.
- The extra electrons injected into the lower n-type slab are drawn toward the positive terminal of the battery, while electrons from the negative terminal of the battery are draw into the upper n-type semiconductor and across the np junction, where they combine with the holes, the net result is an electrons current that flows from the emitter to the collector.





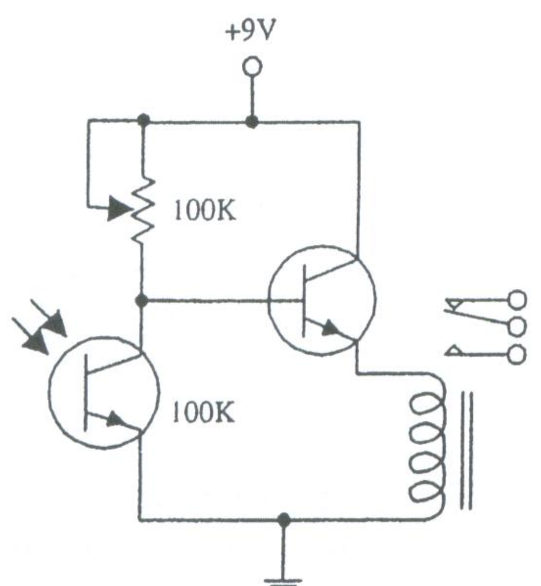
Phototransistor Applications—Light Activated Relay

- A phototransistor is used to control the base current supplied to a power-switching transistor that is used to supply current to a relay.
- When light comes in contact with the phototransistor, the phototransistor turns on, allowing current to pass from the supply into the base of the power-switching transistor.
- This allows the power-switching transistor to turns on, and current flows through the relay, triggering it to switch states.
- The 100K pot is used to adjust the sensitivity of device by controlling current flow through the phototransistor.



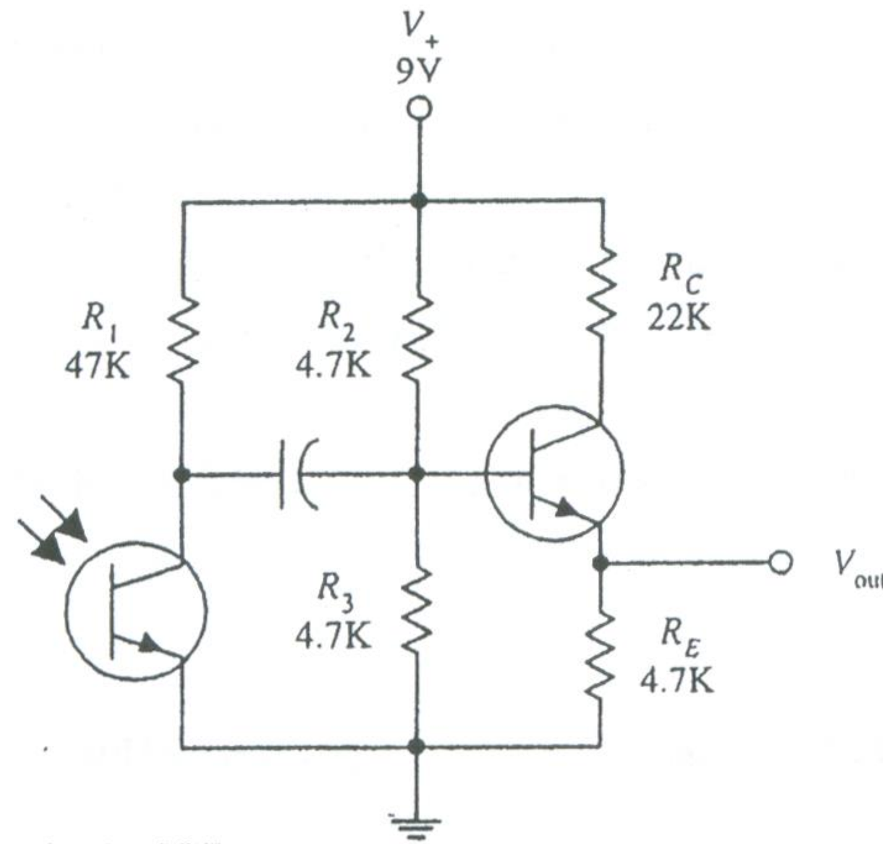
Phototransistor Applications—Dark Activated Relay

- A phototransistor is used to control the base current supplied to a power-switching transistor that is used to supply current to a relay.
- When light is removed from the phototransistor, the phototransistor turns off, allowing more current to enter into the base of the power-switching transistor.
- This allows the power-switching transistor to turns on, and current flows through the relay, triggering it to switch states.
- The 100K pot is used to adjust the sensitivity of device by controlling current flow through the phototransistor.



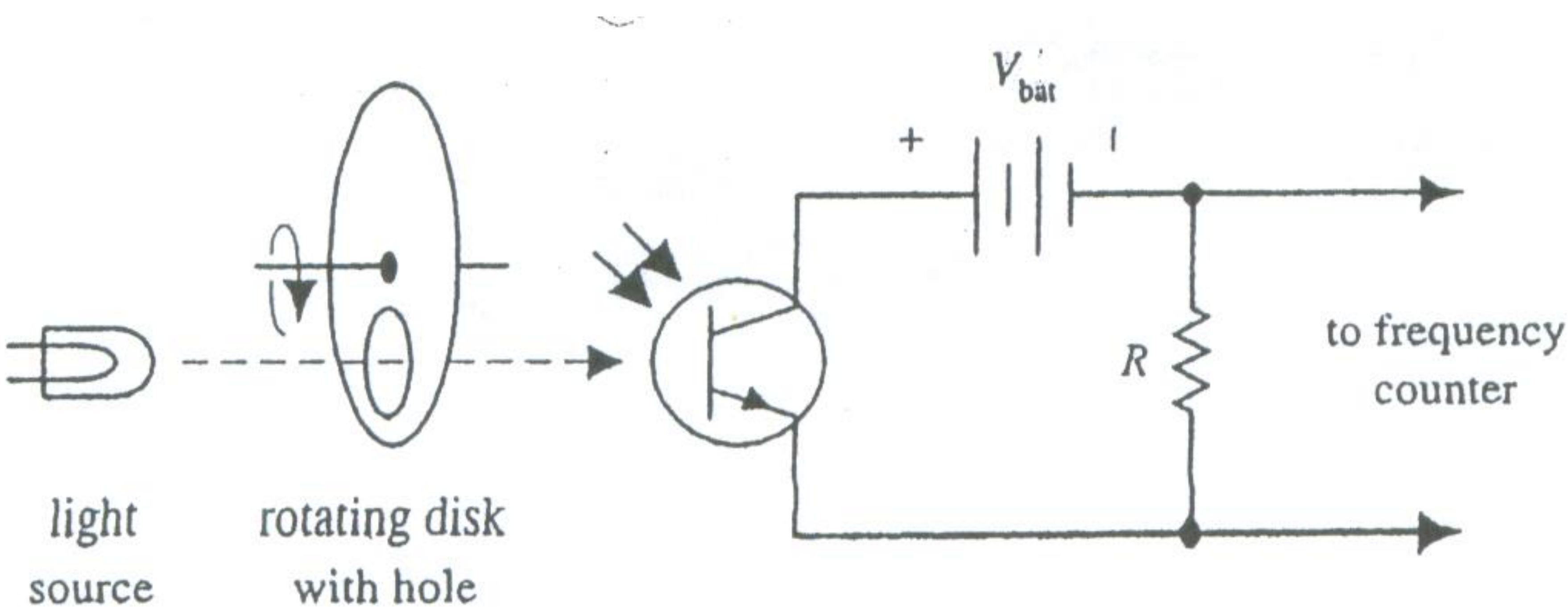
Phototransistor Applications—Receiver

- A phototransistor can be used as a modulated light-wave detector with an amplifier section (current gain amplifier).
- R2 and R3 are used to set the dc operating point of the power-switching transistor.
- R1 is used to set the sensitivity of the phototransistor.
- The capacitor acts to block unwanted dc signals from entering the amplifier section.



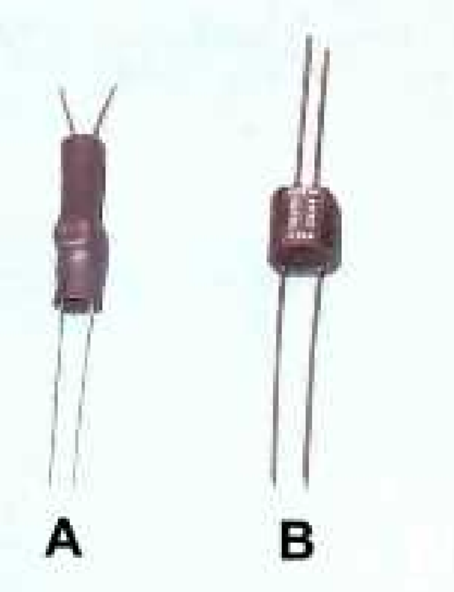
Phototransistor Applications—Tachometer

- A phototransistor is being used as a frequency counter or tachometer.
- A rotating disk is connected to a rotating shaft. The rotating disk has one hole in it.
- For the given setup, the disk will allow light to pass through the hole once every revolution.
- The light passing through the disk triggers the phototransistor into conduction.
- A frequency counter is used to count the number of electrical pulses generated.



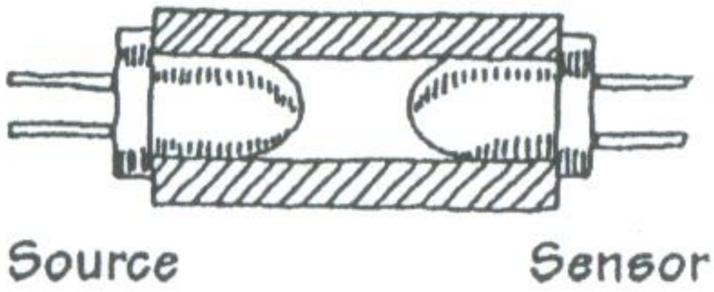
Optoisolators—I

- Optoisolator/optocouplers are devices that interconnect two circuits by means of an optical (i.e., light) interface.
- A typical optoisolator may consist of an LED and a phototransistor enclosed in a container isolated from external light.
  - The LED portion of the optoisolator is connected to the source circuit.
  - The phototransistor portion is connected to the detector circuit.
- Whenever the Led is supplied current, it emits photons that are detected by the phototransistor.
- In terms of application, optoisolators are used frequently to provide electrical isolation between two separate circuits



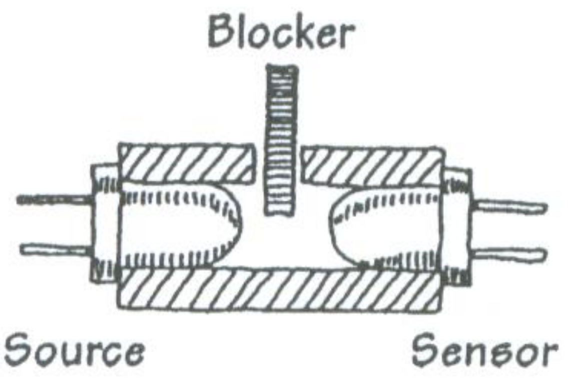
Optoisolators —Closed Pair

- Closed Pair: Source and sensor encased in a dark container with both of them facing each other.
- Usage: Electrical isolation, level conversions, and solid-state relaying.



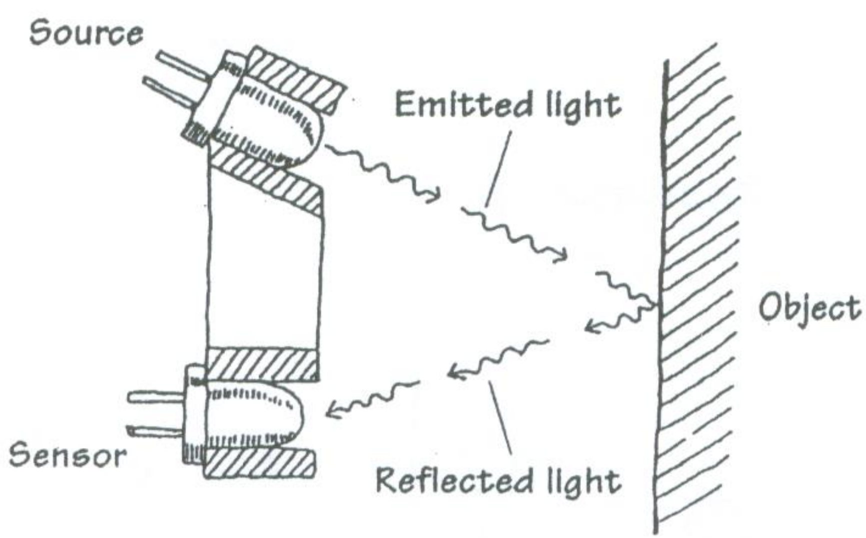
Optoisolators—Slotted Pair

- Slotted Pair: A device containing an open slot between source and sensor through which a blocker can be inserted to interrupt light signals.
- Usage: object detection, bounce free switching, and vibration detection.



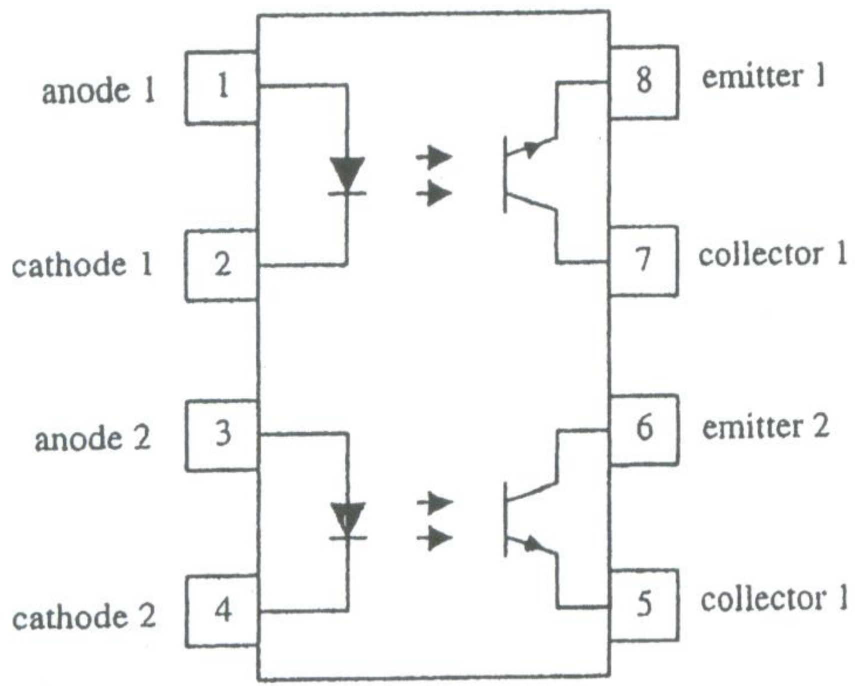
Optoisolators —Reflective Pair

- Slotted Pair: Has a source and sensor arrangement wherein the source signal is sensed by the sensor once it has reflected off an object.
- Usage: object detection, reflectance monitor, tachometer, movement detector. bounce free switching, and vibration detection.



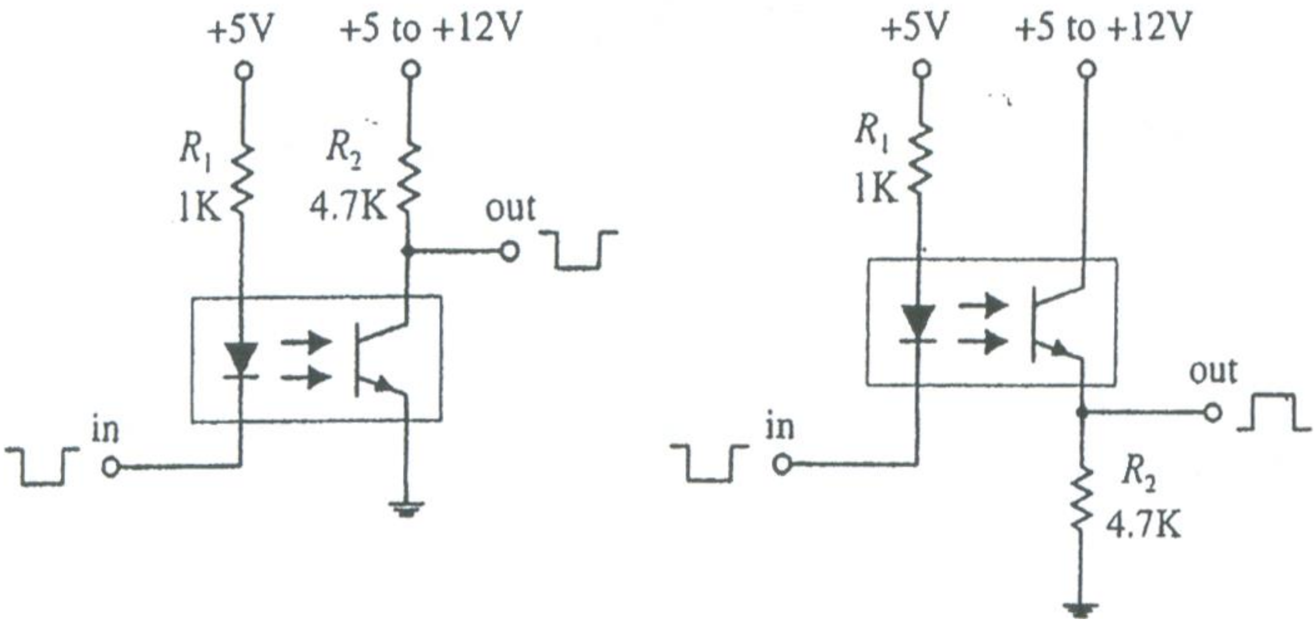
Optoisolators—Integrated Circuit

•Closed-pair optoisolators usually come in integrated package.



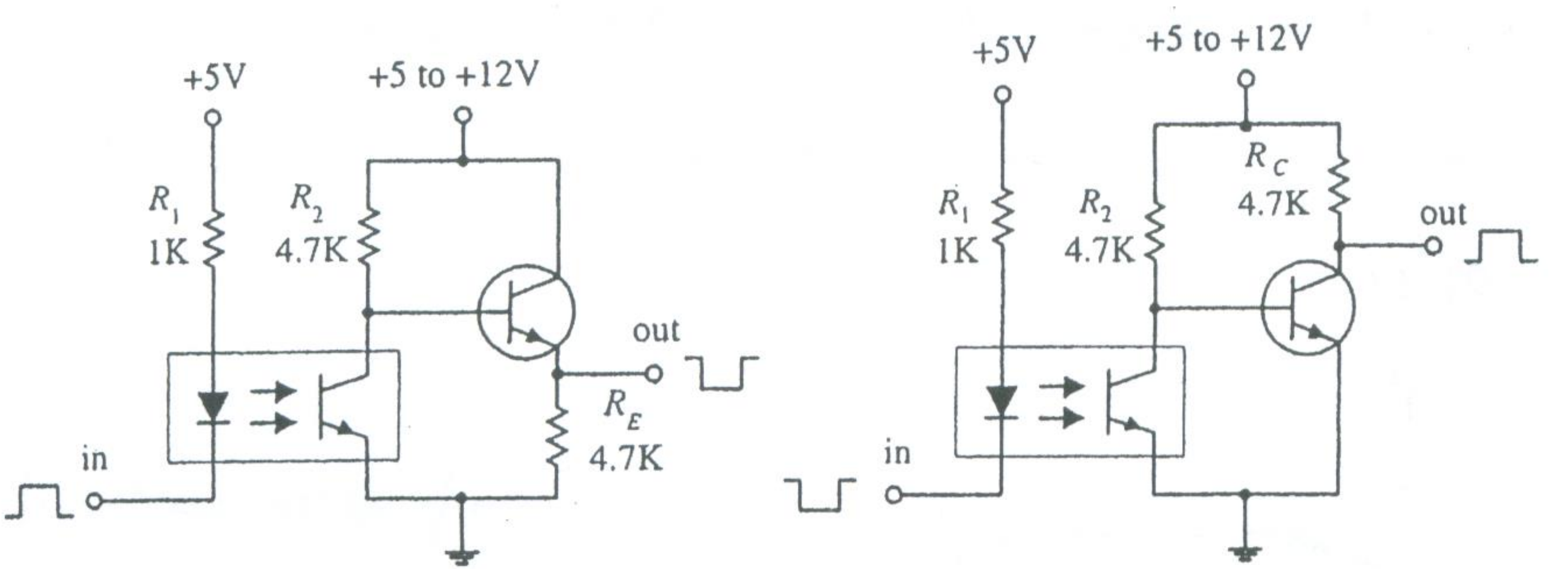
Optoisolator Application—Isolator/Level Shifter

- A diode/phototransistor optoisolator is used to provide:
  - –electrical isolation between the source circuit and the sensor circuit and
  - –a dc level shift in the output.
- Left circuit: the o/p is non-inverted.
- Right circuit: the o/p is inverted



Optoisolator Application—Optocoupler with Amplifier

- In some optoelectronic applications, the phototransistor section of an optoisolator may not be able to provide enough power-handling capacity to switch large currents..
- Incorporating a power-switch transistor can solve this problem.



Comparator—I

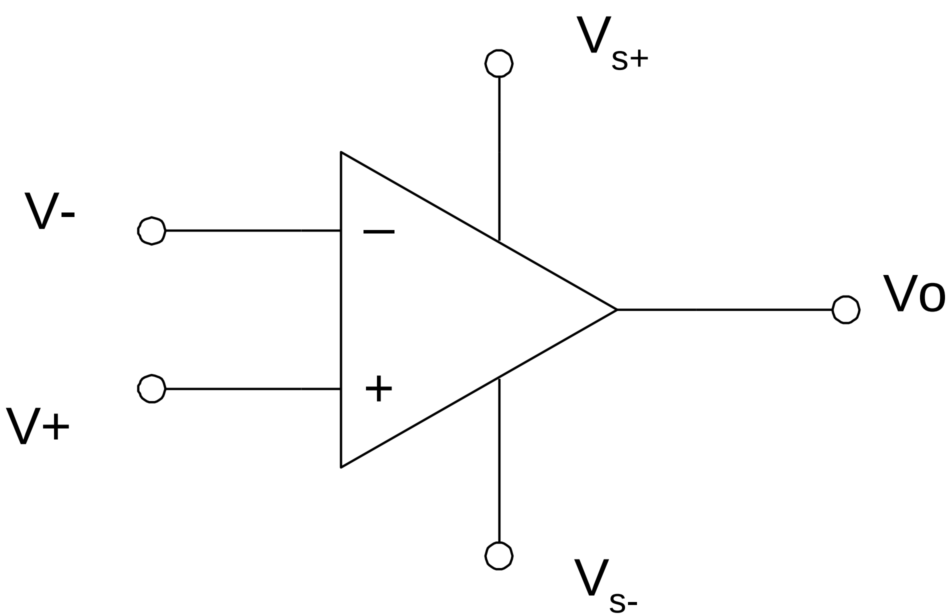
- In a comparator, whenever:

$$\varepsilon \triangleq V_+ - V_- > 0 \Rightarrow V_o = V_{up}$$

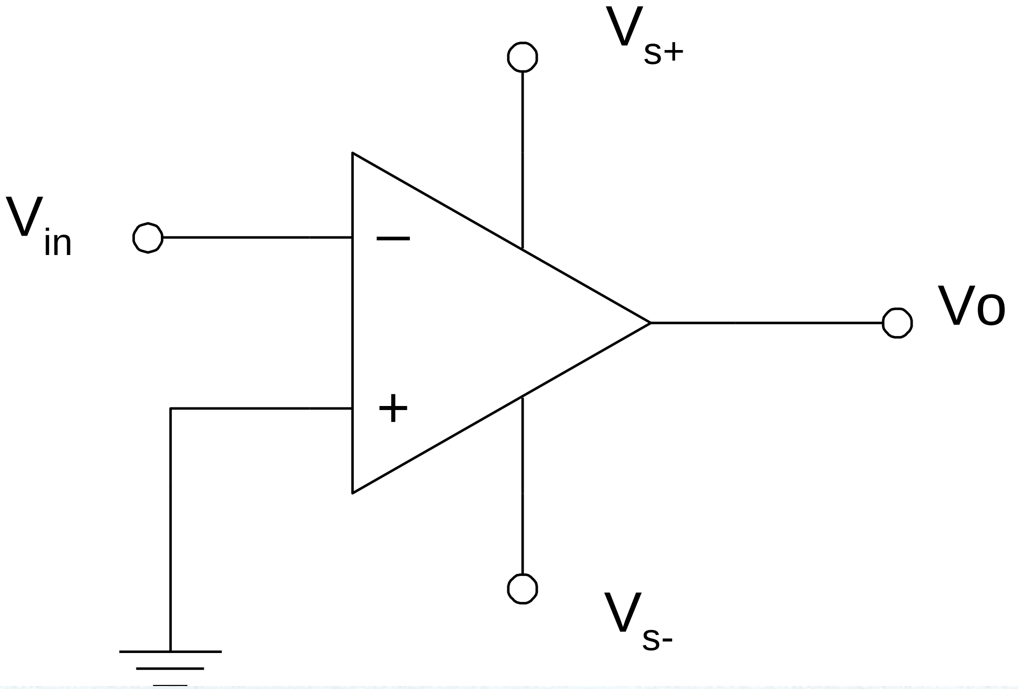
- Similarly, whenever

$$\varepsilon < 0 \Rightarrow V_o = V_{low}$$

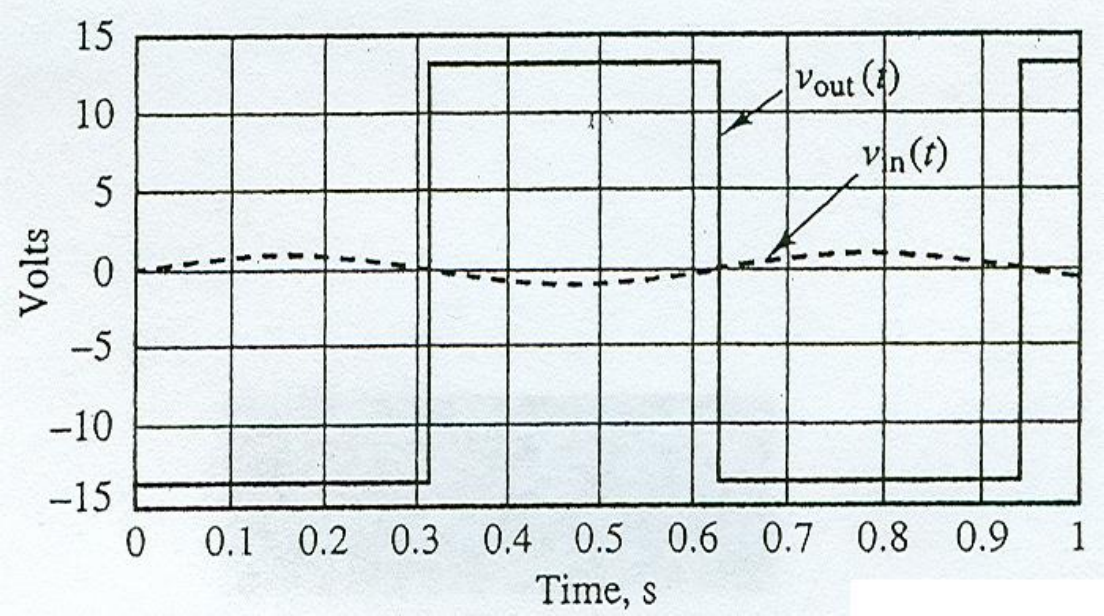
- Here,
  - V_{up} is the upper saturation limit at output ($\approx V_{s+}$).
  - V_{low} is the lower saturation limit at output ($\approx V_{s-}$).



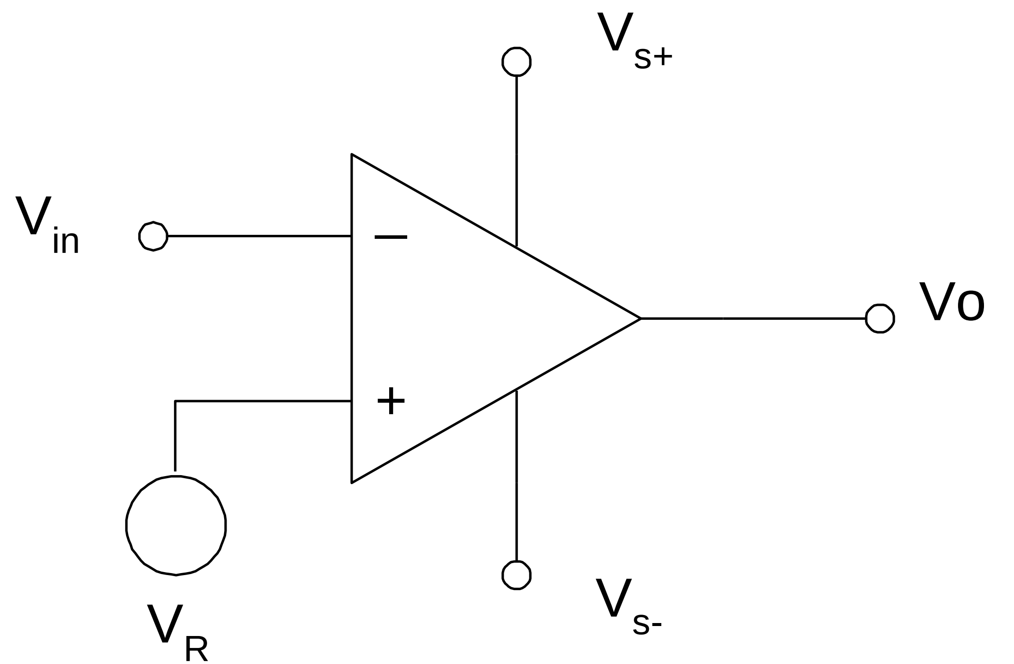
Zero Detecting Comparator



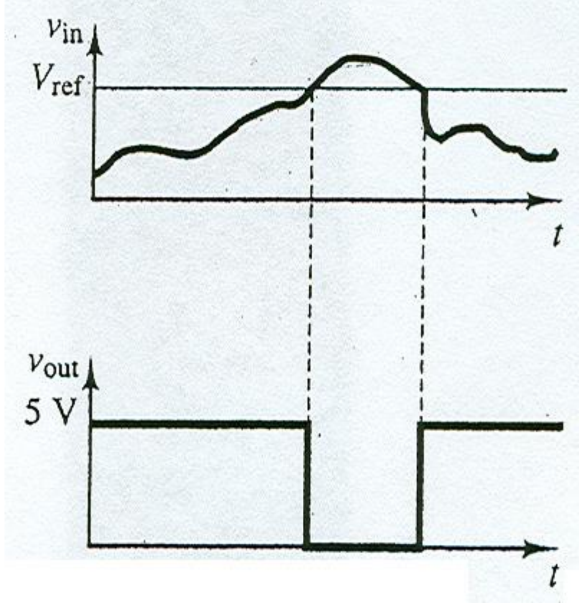
- Connect input signal at the inverting input of the comparator.
- Connect the noninverting terminal of the comparator to ground.
- With $V_{-} > 0 \rightarrow V_o = V_{low}$.
- With $V_{-} < 0 \rightarrow V_o = V_{up}$.
- Here V_{s+}=15V and V_{s-}=-15V.



Comparator with Offset

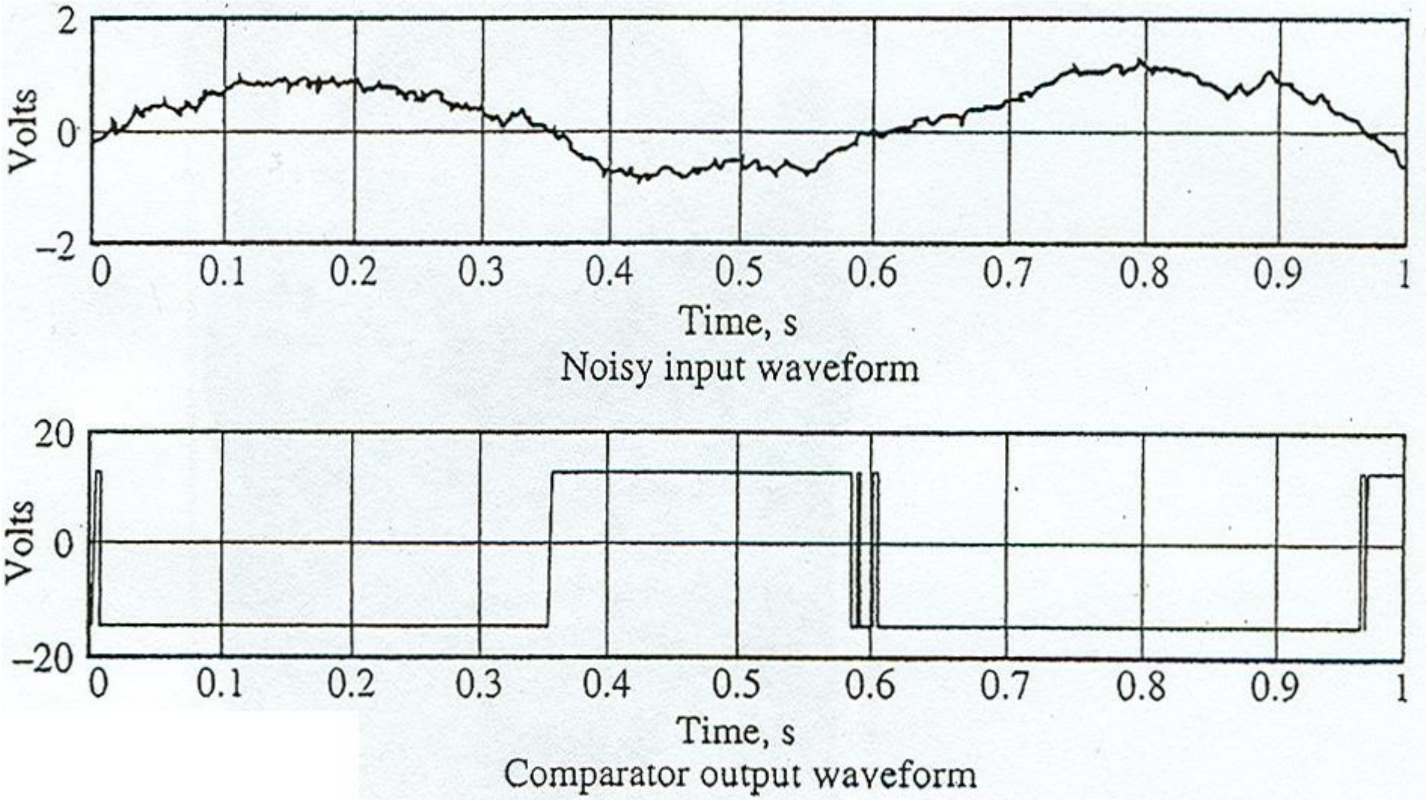


- Connect input signal at the inverting input of the comparator.
- Connect the noninverting terminal of the comparator to a nonzero reference voltage V_R.
- $V_- > V_R \rightarrow V_o = V_{low}$.
- $V_- < V_R \rightarrow V_o = V_{up}$.
- If V_{in} is noisy, the noise will cause the output V_o to chatter!
- Here V_{s+}=5V and V_{s-}=0V.



Chattering @ the Comparator O/P

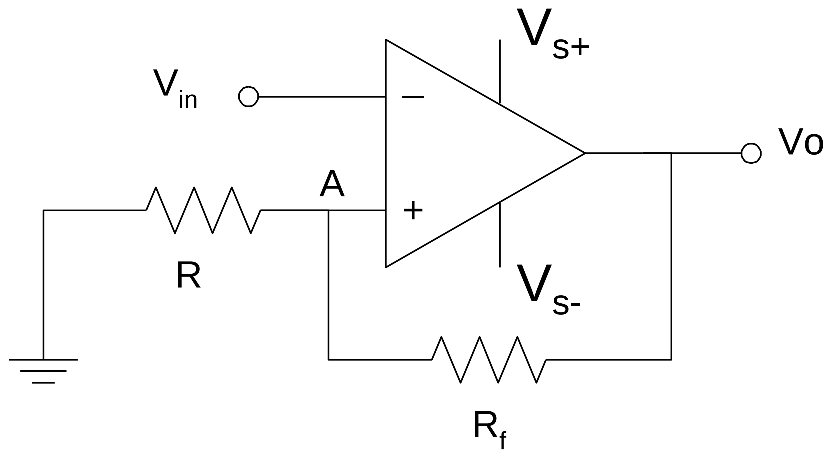
- In a zero-detecting comparator circuit, if V_{in} is noisy:
  - –the noise will cause the output V_o to chatter!
- The same phenomenon will happen in a comparator with offset.



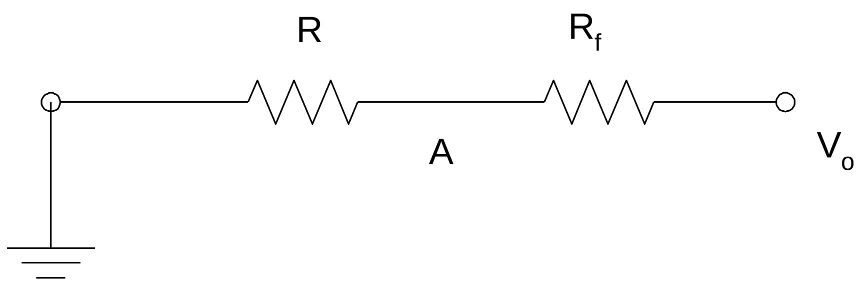
Comparator response to noisy inputs

Comparator with Positive Feedback—I

- To prevent chattering at the comparator output, positive feedback is used.



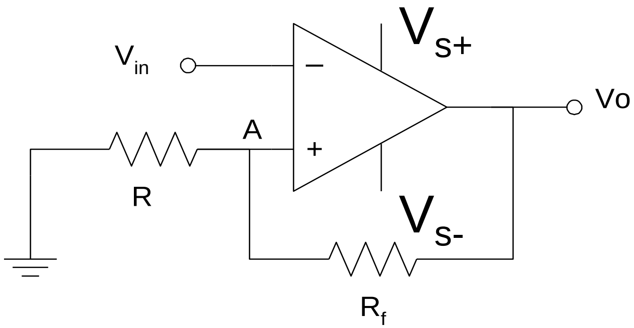
- Use of positive feedback introduces a hysteresis phenomenon.
- The voltage at A can be found by considering the following circuit and using the law of voltage division.



$$V_A = \frac{R}{R+R_f} V_o$$

Comparator with Positive Feedback—II

- Assume $V_o = V_{up}$. In this case:



$$V_+ = V_A = \frac{R}{R+R_f} V_{up}$$

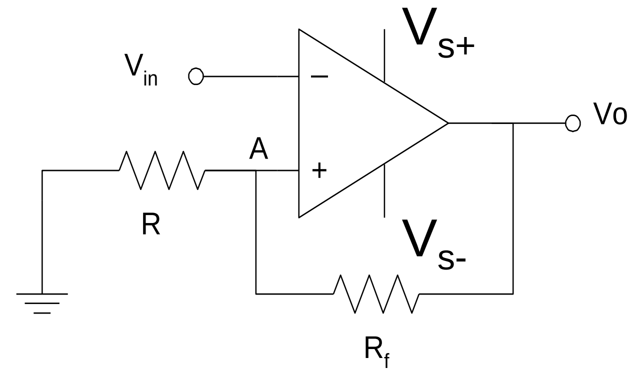
- This condition will hold to be true until $V_- < V_+$ (with V_+ given above).
- Thus, we define an upper threshold voltage as follows.

$$V_{UT} \triangleq \frac{R}{R+R_f} V_{up}$$

- If V_- becomes larger than V_{UT} then V_o switches from V_{up} to V_{low}.

Comparator with Positive Feedback—III

- Assume $V_o = V_{low}$. In this case:



$$V_+ = V_A = \frac{R}{R+R_f} V_{low}$$

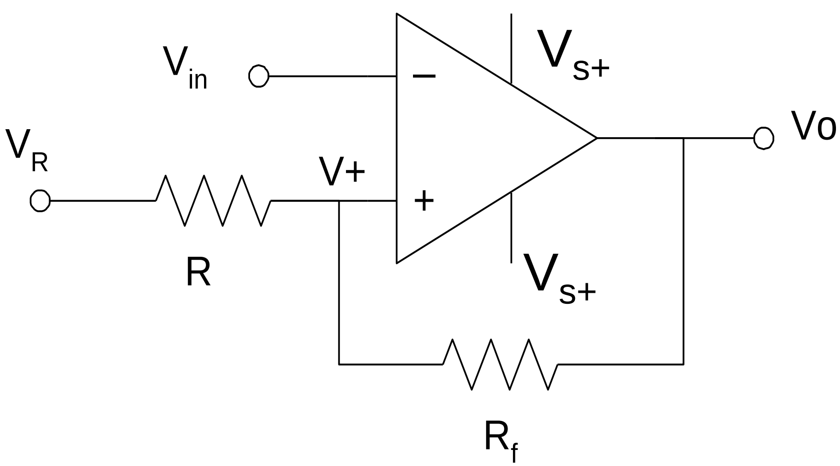
- This condition will hold true until $V_- > V_+$, (with V_+ given above).
- Thus, we define a lower threshold voltage as follows.

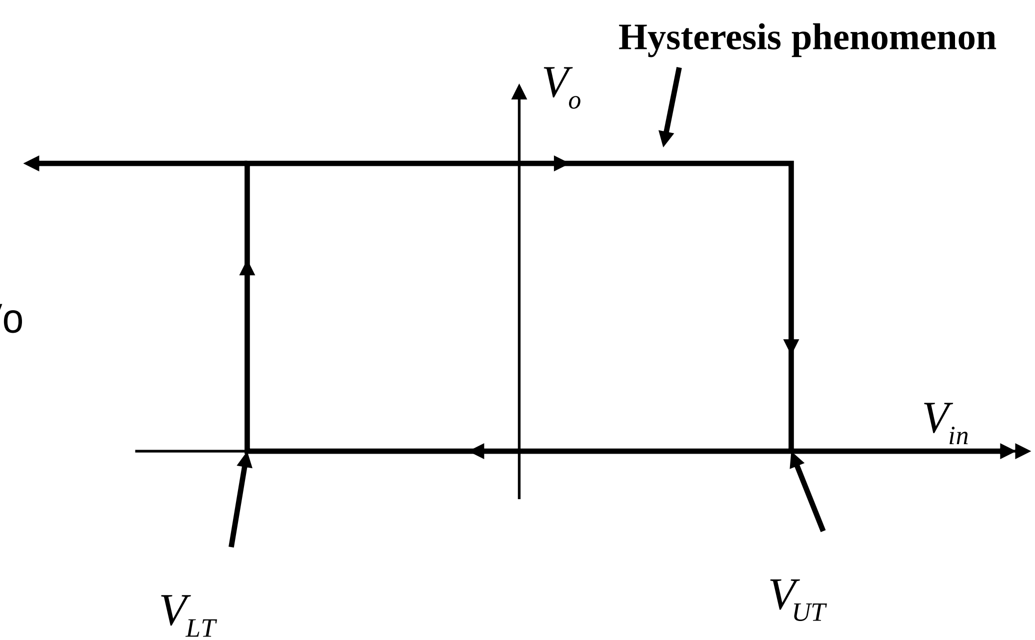
$$V_{LT} \triangleq \frac{R}{R+R_f} V_{low}$$

- If V_- becomes lower than V_{LT} then V_o switches from V_{low} to V_{up}.

Comparator with Positive Feedback—IV

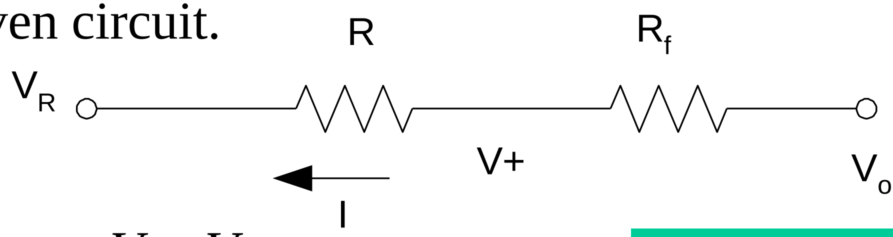
- Comparator with offset and positive feedback is used to detect an input signal's level relative to some desired (non-zero) voltage level.
- Inclusion of positive feedback adds hysteresis, which eliminates chattering at the comparator output.
- The following circuit is used for the above stated purpose.
- Recall: If V_{in} becomes larger than V_{UT} then V_o switches from V_{up} to V_{low}.
- Recall: If V_{in} becomes lower than V_{LT} then V_o switches from V_{low} to V_{up}.





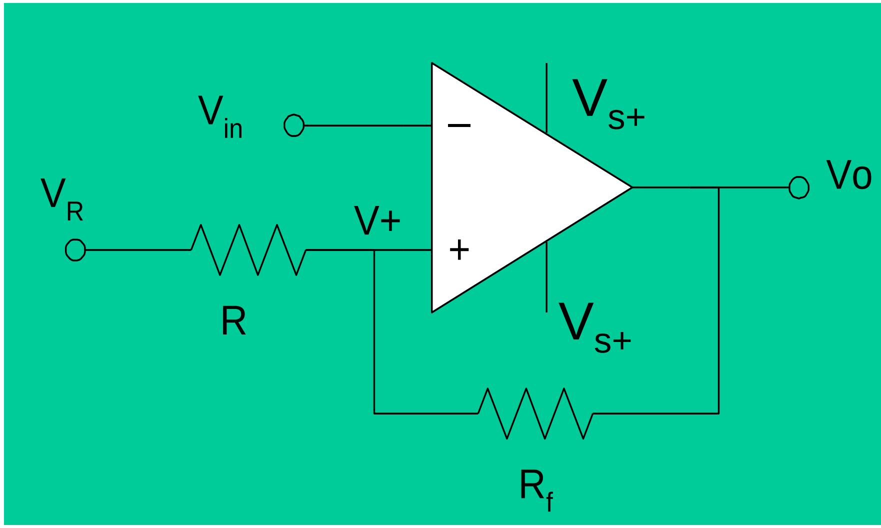
Comparator with Positive Feedback—IV

- Consider the given circuit.



- Note

$$I = \frac{V_o - V_R}{R + R_f}$$



- and

$$V_o - V_+ = IR_f \Rightarrow V_+ = V_o - IR_f$$

$$V_+ = V_o - \frac{V_o - V_R}{R + R_f} R_f = \frac{V_o R + V_R R_f}{R + R_f}$$

- Now, assume V_o=V_{up}. In this case

$$V_+ = \frac{V_{up} R + V_R R_f}{R + R_f} \leftarrow V_{UT}$$

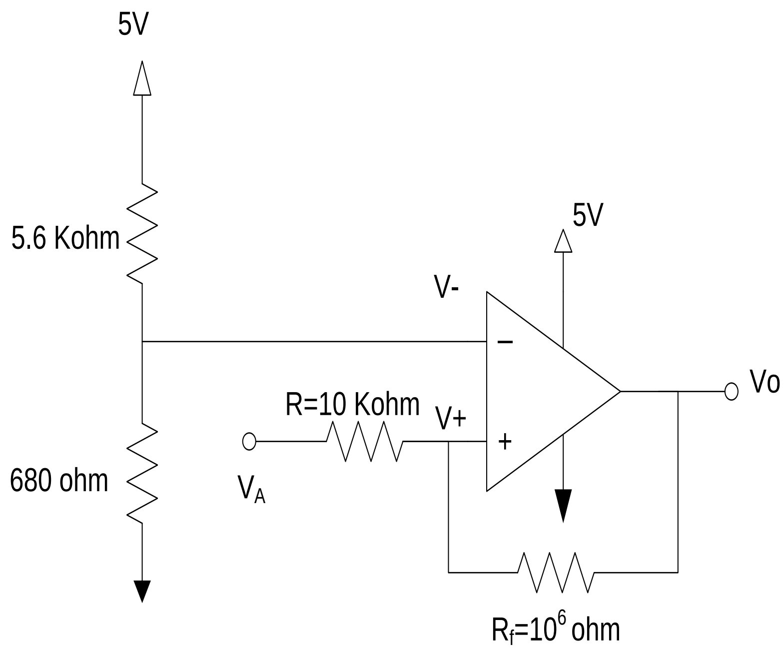
- Similarly, assume V_o=V_{low}. In this case

$$V_+ = \frac{V_{low} R + V_R R_f}{R + R_f} \leftarrow V_{LT}$$

Comparator with Positive Feedback—V

- Consider the circuit given below.
- Using voltage division on the series combination of 5.6 KΩ and 680Ω resistors we obtain:

$$V_{-} = \frac{5 \times 680}{680 + 5600} = 0.541V$$



Comparator with Positive Feedback—VI

- For a comparator with offset and hysteresis:

$$V_+ = \frac{V_o R}{R+R_f} + \frac{V_A R_f}{R+R_f}$$

- Now with $V_o=V_{up}=5V$, if

$$V_+ = \frac{V_{up} R}{R+R_f} + \frac{V_A R_f}{R+R_f} < V_- = 0.541$$

  – then, V_o will switch from V_{up} to V_{low}.

- In this case,

$$\frac{5\times 10^4}{10^4+10^6} + \frac{V_A \times 10^6}{10^4+10^6} < 0.541$$

$$V_A < \frac{0.541\times 101\times 10^4}{10^6} - \frac{5\times 10^4}{101+10^4}$$

$$V_A < 0.4969 \approx 0.5 volts$$

- Thus, if we start with some V_A value such that $V_o=V_{up}= 5.0$V and then bring V_A down to 0.5V, V_o will switch to $V_o= V_{low}= 0$V.

Comparator with Positive Feedback—VII

- Let $V_o = V_{low} = 0$V.
- To make V_o switch to V_{up}, the following must happen:

$$V_+ = \frac{V_o R}{R+R_f} + \frac{V_A R_f}{R+R_f} > 0.541$$

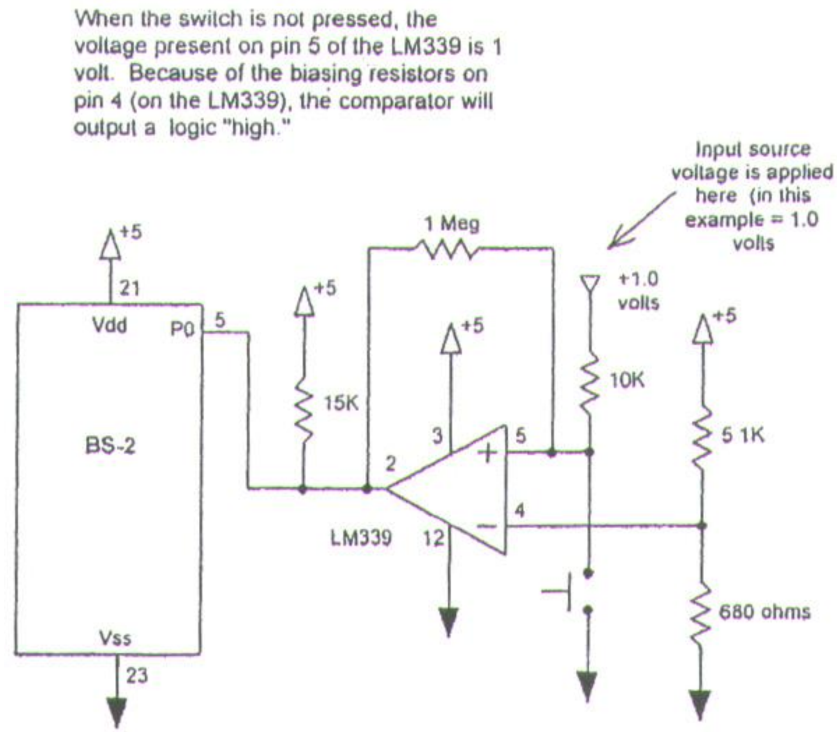
$$\Rightarrow \frac{0\times 10^4}{10^4+10^6} + \frac{V_A \times 10^6}{10^4+10^6} > 0.541$$

$$V_A > 0.546V$$

- Conclusion:
  - If $V_A > 0.546$V, then V_o will output high.
  - $V_A < 0.5$V, then V_o will output low.
- When $V_A \approx 1$V, the comparator will output 5V and when $V_A \approx 0$V, the comparator will output 0V. Hence, this technique can be used to scale up a digital input that switches between 0V and 1V so that it can be interfaced to BS2.

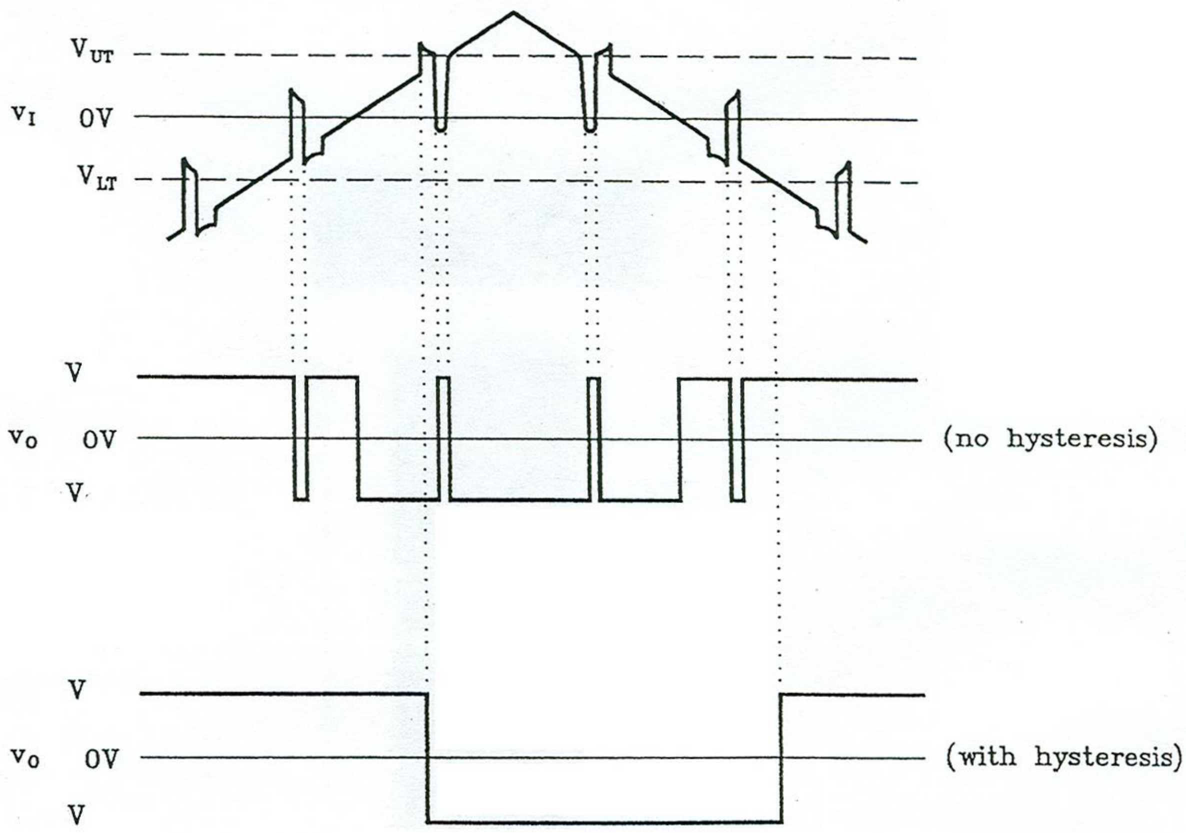
Upward Shift in Signal Level Using a Comparator

- When a sensor outputs 0V (off) and 1V (on), a comparator can be used to interface the sensor to BS2.
- Comparator outputs a digital signal and works as follow.
  - When voltage input at comparator's noninverting terminal (V_+) is higher than voltage input at comparator's inverting terminal (V_-), comparator output is equal to its upper saturating voltage.
  - When $V_+ < V_-$, comparator output is equal to its lower saturating voltage.
  - Positive feedback in a comparator introduces a hysteresis behavior in its I/O relationship and eliminates chattering (as just detailed).



  - $V_+ > 0.59$, o/p high, $V_+ < 0.55$, o/p low
  - LM339 has an open collector output. To get a valid logic level, a 15K pull-up resistor is included at the output of LM339.

Zero Crossing Detector with Positive Feedback



Hysteresis makes the zero-crossing detector less sensitive to noise.