Light-Emitting Diodes (LEDs)

Optoelectronics is the technology that combines optics and electronics. This field includes many devices based on the action of a *pn* junction. Examples of optoelectronic devices are **light-emitting diodes** (**LEDs**), photodiodes, optocoupler, and laser diodes.

Light-Emitting Diode

LEDs have replaced incandescent lamps in many applications because of the LED's lower energy consumption, smaller size, faster switching and longer lifetime.

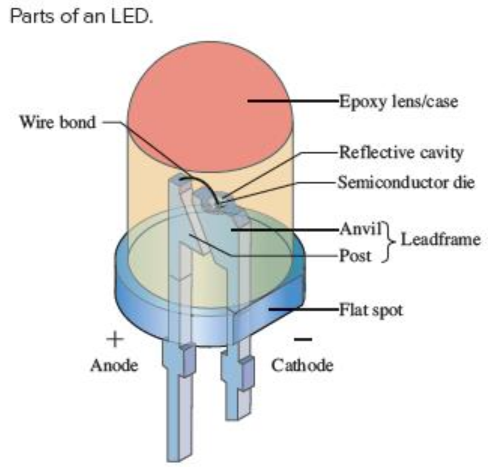


Fig 1: Parts of LED

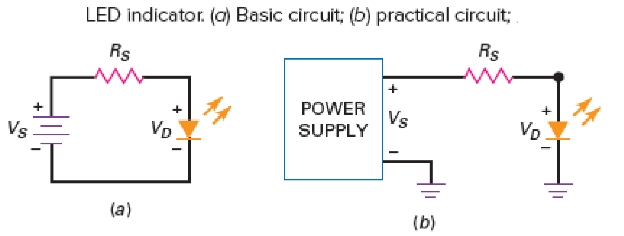


Fig 2:LED indicator

Figure 1 shows the parts of a standard low-power LED. Just as in an ordinary diode, the LED has an anode and a cathode that must be properly biased. The outside of the plastic case typically has a flat spot on one side which indicates the cathode side of the LED. The material used for the semiconductor die will determine the LED's characteristics.

Figure 2[*a*] shows a source connected to a resistor and an LED. The outward arrows symbolize the radiated light. In a forward-biased LED, free electrons cross the *pn* junction and fall into holes. As these electrons fall from a higher to a lower energy level, they radiate energy in the form of photons.

In ordinary diodes, this energy is radiated in the form of heat. But in an LED, the energy is radiated as light. This effect is referred to as **electroluminescence.**

The color of the light, which corresponds to the wavelength energy of the photons, is primarily determined by the energy band gap of the semiconductor materials that are used. By using elements like gallium, arsenic, and phosphorus, a manufacturer can produce LEDs that radiate red, green, yellow, blue, orange, white or infrared (invisible) light. LEDs that produce visible radiation are useful as indicators in applications such as instrumentation panels, internet routers, and so on. The infrared LED finds applications in security systems, remote controls, industrial control systems, and other areas requiring invisible radiation.

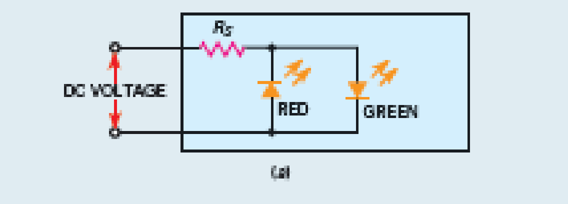
LED Voltage and Current

The resistor of Fig. 2[b] is the usual current-limiting resistor that prevents the current from exceeding the maximum current rating of the diode. Since the resistor has a node voltage of V_S on the left and a node voltage of V_D on the right, the voltage across the resistor is the difference between the two voltages. With Ohm's law, the series current is:

$$I_S = \frac{V_S - V_D}{R_S}$$

For most commercially available low-power LEDs, the typical voltage drop is from 1.5 to 2.5 V for currents between 10 and 50 mA. The exact voltage drop depends on the LED current, color, tolerance, along with other factors.

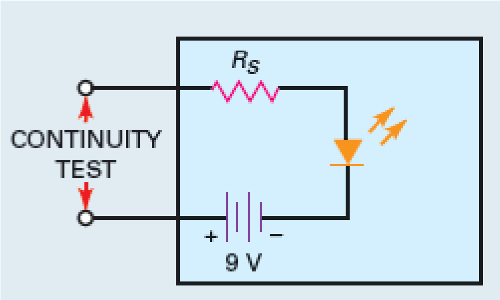
Example 1: Figure shows a voltage-polarity tester. It can be used to test a dc voltage of unknown polarity. When the dc voltage is positive, the green LED lights up. When the dc voltage is negative, the red LED lights up. What is the approximate LED current if the dc input voltage is 50 V and the series resistance is 2.2 kV?



SOLUTION: We will use a forward voltage of approximately 2 V for either LED.

$$I_S = \frac{50\text{ V} - 2\text{ V}}{2.2\text{ k}\Omega} = 21.8\text{ mA}$$

Example 2:

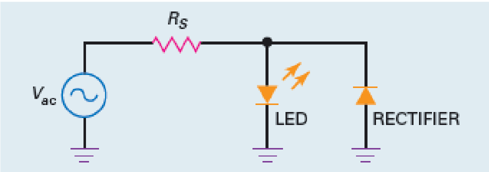


Given figure is a continuity tester. After you turn off all the power in a circuit under test, you can use this circuit to check for the continuity of cables, connectors, and switches. How much LED current is there if the series resistance is 470 V?

SOLUTION: When the input terminals are shorted (continuity), the internal 9-V battery produces an LED current of

$$I_S = \frac{9\text{ V} - 2\text{ V}}{470\ \Omega} = 14.9\text{ mA}$$

Example 3: LEDs are often used to indicate the existence of ac voltages. Figure 5-23 shows an ac voltage source driving an LED indicator. When there is ac voltage, there is LED current on the positive half-cycles. On the negative half-cycles, the rectifier diode turns on and protects the LED from too much reverse voltage. If the ac source voltage is 20 Vrms and the series resistance is 680 V, what is the average LED current? Also, calculate the approximate power dissipation in the series resistor.



SOLUTION The LED current is a rectified half-wave signal. The peak source voltage is 1.414 × 20 V, which is approximately 28 V. Ignoring the LED voltage drop, the approximate peak current is:

$$I_S = \frac{28\ \text{V}}{680\ \Omega} = 41.2\ \text{mA}$$

The average of the half-wave current through the LED is:

$$I_S = \frac{41.2\ \text{mA}}{\pi} = 13.1\ \text{mA}$$

Ignore the diode drops in Fig. ; this is equivalent to saying that there is a short to ground on the right end of the series resistor. Then the power dissipation in the series resistor equals the square of the source voltage divided by the resistance:

$$P = \frac{(20\ \text{V})^2}{680\ \Omega} = 0.588\ \text{W}$$

Seven-Segment Display

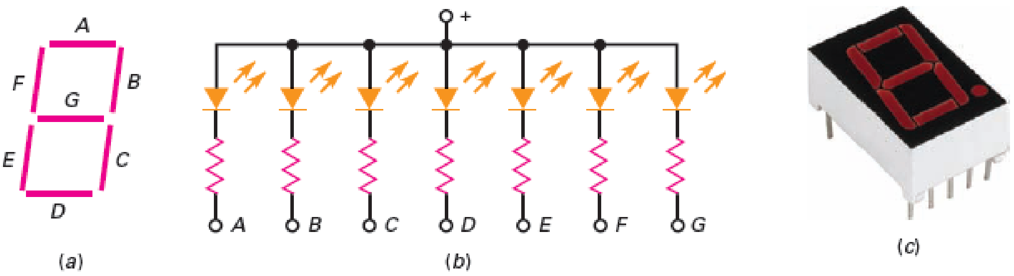


Fig 3: Seven-segment indicator. (*a*) Physical layout of segments; (*b*) schematic diagram; (*c*) Actual display withdecimal point.

Figure 3[*a*] shows a **seven-segment display.** It contains seven rectangular LEDs (*A* through *G*). Each LED is called a *segment* because it forms part of the character being displayed. Figure 3[b] is a schematic diagram of the seven-segment display. External series resistors are included to limit the currents to safe levels. By grounding one or more resistors; we can form any digit from 0 through 9.

For instance, by grounding *A*, *B*, and *C*, we get a 7. Grounding *A*, *B*, *C*, *D*, and *G* produces a 3. A seven-segment display can also display capital letters *A*, *C*, *E*, and *F*, plus lowercase letters *b* and *d*. Microprocessor trainers often use seven-segment displays that show all digits from 0 through 9, plus *A*, *b*, *C*, *d*, *E*, and *F*.

The seven-segment indicator of Fig.3 [b] is referred to as the **common anode** type because all anodes are connected together. Also available is the **common-cathode** type, in which all cathodes are connected together. Figure 3[c] shows an actual seven-segment display with pins for fitting into a socket or for soldering to a printed-circuit board. Notice the extra dot segment used for a decimal point.

Optocoupler

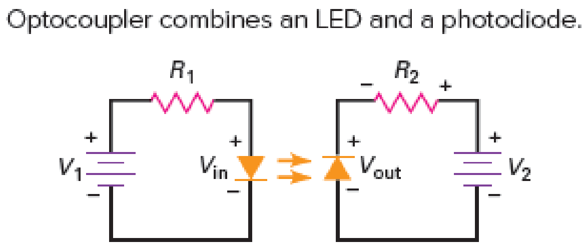


Fig 4: An optocoupler

An optocoupler (also called an *optoisolator*) combines an LED and a photodiode in a single package. Figure 4 shows an optocoupler. It has an LED on the input side and a photodiode on the output side. The left source voltage and the series resistor set up a current through the LED. Then the light from the LED hits then photodiode, and this sets up a reverse current in the output circuit. This reverse current produces a voltage across the output resistor. The output voltage then equals the output supply voltage minus the voltage across the resistor.

When the input voltage is varying, the amount of light is fluctuating. This means that the output voltage is varying in step with the input voltage. This is why the combination of an LED and a photodiode is called an **optocoupler.** The device can couple an input signal to the output circuit. Other types of optocouplers use phototransistors, photothyristors, and other photo devices in their output circuit side.

The key advantage of an optocoupler is the electrical isolation between the input and output circuits. With an optocoupler, the only contact between the input and the output is a beam of light. Because of this, it is possible to have an insulation resistance between the two circuits in the thousands of megohms. Isolation like this is useful in high-voltage applications in which the potentials of the two circuits may differ by several thousand volts.

The Varactor

Fig5: Varactor.(*a*) Doped regions are like capacitor plates separated by a dielectric;(*b*) ac-equivalent circuit; (*c*) schematic symbol; (*d*) graph of capacitance versus reverse voltage

The **varactor** (also called the *voltage-variable capacitance, varicap, epicap,* and *tuning diode*) is widely used in television receivers, FM receivers, and other communications equipment because it can be used for electronic tuning.

In Fig. 5 [a], the depletion layer is between the *p* region and the *n* region. The *p* and *n* regions are like the plates of a capacitor, and the depletion layer is like the dielectric. When a diode is reverse biased the width of the depletion layer increases with the reverse voltage. Since the depletion layer gets wider with more reverse voltage, the capacitance becomes smaller. It's as though you moved apart the plates of a capacitor. The key idea is that capacitance is controlled by reverse voltage.

Figure 5[b] shows the ac-equivalent circuit for a reverse-biased diode. In other words, as far as an ac signal is concerned, the varactor acts the same as a variable capacitance. Figure 5[c] shows the schematic symbol for a varactor. The inclusion of a capacitor in series with the diode is a reminder that a varactor is a device that has been optimized for its variable-capacitance properties.

Figure 5[d] shows how the capacitance varies with reverse voltage. This graph shows that the capacitance gets smaller when the reverse voltage gets larger. The really important idea here is that reverse dc voltage controls capacitance.

Varactor is connected in parallel with an inductor to form a parallel resonant circuit. This circuit has only one frequency at which maximum impedance occurs. This frequency is called the *resonant frequency*. If the dc reverse voltage to the varactor is changed, the resonant frequency is also changed. This is the principle behind electronic tuning of a radio station, a TV channel, and so on.

Varactor Characteristics

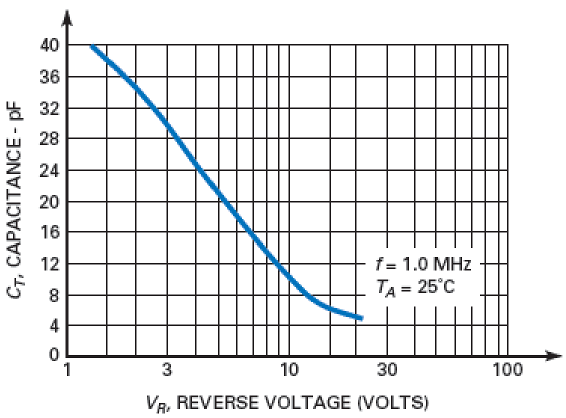
Because the capacitance is voltage controlled, varactors have replaced mechanically tuned capacitors in many applications such as television receivers and automobile radios. Data sheets for varactor list a reference value of capacitance measured at a specific reverse voltage, typically -3 V to - 4 V. Figure below shows a partial data sheet for an MV209 varactor diode. It lists a reference capacitance *Ct* of 29 pF at –3 V.

In addition to providing the reference value of capacitance, data sheets normally list a

MV209 Partial Data Sheet. (Used with permission from SCILLC dba ON Semiconductor.)

	C_t, Diode Capacitance V_R = 3.0 Vdc, f = 1.0 MHz pF			Q, Figure of Merit V_R = 3.0 Vdc f = 50 MHz	C_R, Capacitance Ratio C_3/C_{25} f = 1.0 MHz (Note 1)	
Device	**Min**	**Nom**	**Max**	**Min**	**Min**	**Max**
MMBV109LT1, MV209	26	29	32	200	5.0	6.5

1. C_R is the ratio of C_t measured at 3 Vdc divided by C_t measured at 25 Vdc.



DIODE CAPACITANCE

capacitance ratio C_R, or tuning range associated with a voltage range. For example, along with the reference value of 29 pF, the data sheet of an MV209 shows a minimum capacitance ratio of 5:1 for a voltage range of –3 V to –25 V. This means that the capacitance, or tuning range, decreases from 29 to 6 pF when the voltage varies from –3 V to –25 V.

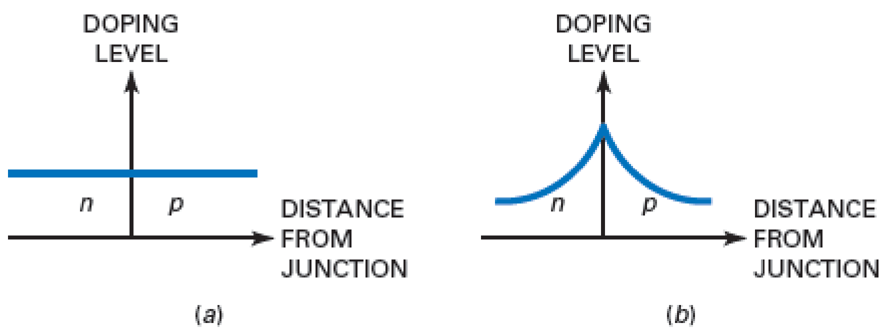


Fig5: Doping profiles. (*a*) Abrupt junction; (*b*) hyperabrupt junction.

The tuning range of a varactor depends on the doping level. For instance, Fig. 6[a] shows the doping profile for an abrupt-junction diode (the ordinary type of diode). The profile shows that the doping is uniform on both sides of the junction. The tuning range of an abrupt-junction diode is between 3:1 and 4:1.To get larger tuning ranges, some varactors have a *hyperabrupt junction,* one whose doping profile looks like Fig. 6[b]. This profile tells us that the doping level increases as we approach the junction. The heavier doping produces a narrower depletion layer and a larger capacitance. Furthermore, changes in reverse voltage have more pronounced effects on capacitance. A hyperabrupt varactor has a tuning range of about 10:1, enough to tune an AM radio through its frequency range of 535 to 1605 kHz.

Applications of Varactor Diodes

- FM modulator
- Automatic Frequency Control (AFC) in radio receiver.
- Automatic tuning circuit
- TV receiver
