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VERSION	EFFECTIVE DATE	DESCRIPTION OF REVISION(S)
001	2016.01	Module creation and release.
002	2016.05	Minor corrections and layout adjustments.
003	2018.07	Adjusted content for alignment to Part 66, Appendix 1. Added *Static Electricity Protection* to Submodule 2; Removed *Logic Circuits* from Submodule 1, page 1.2; other minor corrections.
003.1	2022.06	Clarified number of electrons in *Orbital Shells*. Submodule 1, page 1.2
003.2	2023.04	Inclusion of Measurement Standards for clarification, page iv. Minor appearance and format updates.
004	2024.01	Regulatory update for EASA 2023-989 Compliance.

Module was reorganized based upon the EASA 2023-989 subject criteria. Enhancements included in this version:

4.1.1 *Diodes* - added Impurities on P and N materials.
4.1.2 *Transistors* - added Classification and identification of Transistors.
4.1.2 *Transistors* - added Logic Circuits.
4.3 Servomechanisms - added Servomechanism, Null, Overshoot, Hunting, Deadband, and Proximity Switches.
Additional minor non-regulatory adjustments throughout text and figures.

ELECTRONIC FUNDAMENTALS

applied voltage is applied to any load in the circuit downstream of the diode. In a series circuit where the diode is reverse biased, no current flows. In this simple battery circuit with PN junction diode, the applied voltage is DC from the battery.

With the application of AC voltage to the diode series circuit, the diode allows current to flow in only one direction and blocks it in the opposed direct. This is the definition of a diode. The diode in series also rectifies the AC voltage, that is, AC voltage is converted to DC voltage. So, in addition to being a diode, it can also be said that the diode is a rectifier. However, only half of the AC voltage is used when the diode is in series. The other half is wasted since current cannot flow across the reverse biased diode. The widened depletion zone acts as an open circuit and the potential is not used. This is known as half wave rectification and is shown in the diagram in **Figure 1-19**.

AC voltage applied to diodes in a parallel circuit creates similar results but with greatly improved efficiency. **Figure 1-20** illustrates diodes in a parallel circuit that supplied a load (R_L). The AC that is induced into the circuit flows from negative to positive as always. The full wave of the AC voltage is converted to DC, unlike in the series circuit. As a result, the DC pulses are not separated from each other. The arrows in the diagram show the direction of current flow during the positive and negative cycles of the voltage. Notice that the transformer coil is grounded in the center. This is known as a center tapped rectifier circuit. The positive and negative cycles of the AC are used but the magnitude of the AC voltage is half of what is supplied because of the center tap.

A widely used variation of the full wave rectifier is the bridge rectifier. [**Figure 1-21**] The arrows in the diagram show that current flows in each direction as the AC cycles. The entire applied voltage is used with a non-interrupted DC pulse voltage resulting at the output.

CHARACTERISTICS AND USE OF DIODES

LIGHT EMITTING DIODES

Light emitting diodes (LEDs) have become so commonly used in electronics that their importance may tend to be overlooked. Numerous avionics displays and indicators use LEDs for indicator lights, digital readouts, and backlighting of liquid crystal display (LCD) screens.

LEDs are simple and reliable and are constructed of semiconductor material. In a forward biased diode, electrons cross the junction and fall into holes. As the electrons fall into the valence band, they radiate energy. This is true in all semiconductor materials. In most diodes, this energy is dissipated as heat. However, in the light-emitting diode (LED), the energy is dissipated as light. By using elements, such as gallium, arsenic, and phosphorous, an LED can be designed to radiate colors, such as red, green, yellow, blue and infrared light. LEDs that are designed for the visible light portion of the spectrum are useful for instruments, indicators, and even cabin lighting. The advantages of the LED over the incandescent lamps are longer life, lower voltage, faster on and off operations, and less heat.

Figure 1-22 is a table that illustrates common LED colors and the semiconductor material that is used in the construction of the diode.

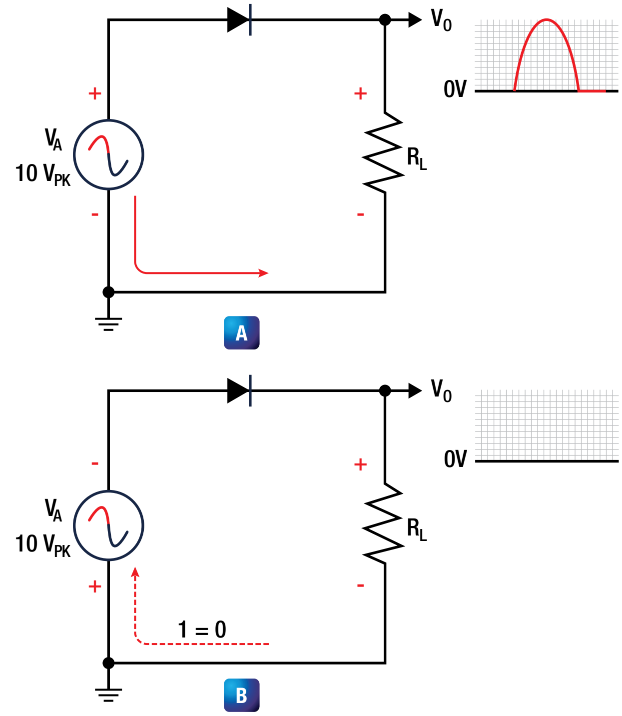

Figure 1-19. A diode and load in a series circuit with AC power applied rectifies the voltage. Only half of the AC voltage is used.

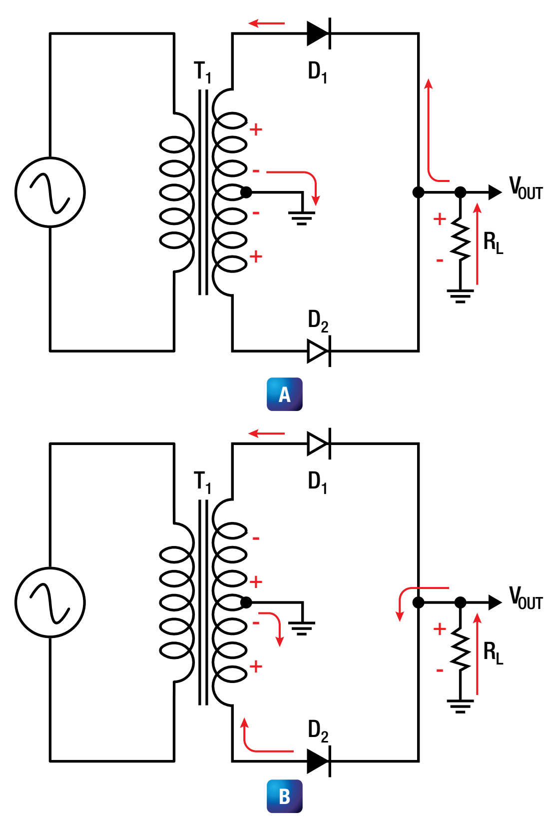

Figure 1-20. Diodes in a parallel circuit create a full wave rectifier.

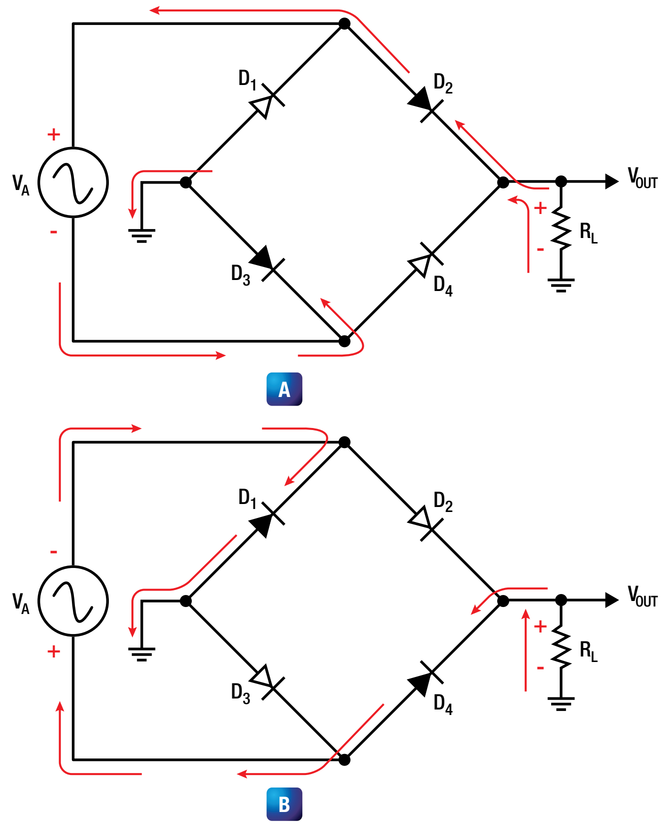

Figure 1-21. A bridge rectifier circuit converts the entire applied AC voltage to DC voltage.

Note that when the diode is reversed biased, no light is given off. When the diode is forward biased, the energy given off is visible in the color characteristic for the material being used. **Figure 1-23** illustrates the anatomy of a single LED, the symbol of an LED, and a graphic depiction of the LED process.

LEDs are used widely as "power on" indicators of current and as displays for pocket calculators, digital voltmeters, frequency counters, etc. For use in calculators and similar devices, LEDs are typically placed together in seven-segment displays, as shown in **Figure 1-24** (view A and B). This display uses seven LED segments, or bars (labeled A through G in the figure), which can be lit in different combinations to form any number from "0" through "9." The schematic, view A, shows a common-anode display. All anodes in a display are internally connected.

When a negative voltage is applied to the proper cathodes, a number is formed. For example, if negative voltage is applied to all cathodes except that of LED "E," the number "9" is produced, as shown in view A of **Figure 1-25**. If the negative voltage is changed and applied to all cathodes except LED "B," the number "9" changes to "6" as shown in view B.

Seven-segment displays are also available in common-cathode form, in which all cathodes are at the same potential. When replacing LED displays, you must ensure the replacement display is the same type as the faulty display. Since both types look alike,

Color	Wavelength (nm)	Voltage (V)	Semiconductor Material
Infrared	λ > 760	ΔV < 1.9	Gallium arsenide (GaAs) Aluminium gallium arsenide (AlGaAs)
Red	610 < λ < 760	1.63 < ΔV < 2.03	Aluminium gallium arsenide (AlGaAs) Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Orange	590 < λ < 610	2.03 < ΔV < 2.10	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Yellow	570 < λ < 590	2.10 < ΔV < 2.18	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Green	500 < λ < 570	1.9[32] < ΔV < 4.0	Indium gallium nitride (InGaN) / Gallium(III) nitride (GaN) Gallium(III) phosphide (GaP) Aluminium gallium indium phosphide (AlGaInP) Aluminium gallium phosphide (AlGaP)
Blue	450 < λ < 500	2.48 < ΔV < 3.7	Zinc selenide (ZnSe) Indium gallium nitride (InGaN) Silicon carbide (SiC) as substrate Silicon (Si) as substrate — (under development)
Violet	400 < λ < 450	2.76 < ΔV < 4.0	Indium gallium nitride (InGaN)
Purple	Multiple Types	2.48 < ΔV < 3.7	Dual blue/red LEDs, blue with red phosphor, or white with purple plastic
Ultraviolet	λ < 400	3.1 < ΔV < 4.4	diamond (235 nm)[33] Boron nitride (215 nm)[34][35] Aluminium nitride (AlN) (210 nm)[36] Aluminium gallium nitride (AlGaN) Aluminium gallium indium nitride (AlGaInN) — (down to 210 nm)[37]
White	Broad Spectrum	ΔV = 3.5	Blue/UV diode with yellow phosphor

Figure 1-22. LED colors and the materials used to construct them as well as their wavelength and voltages.

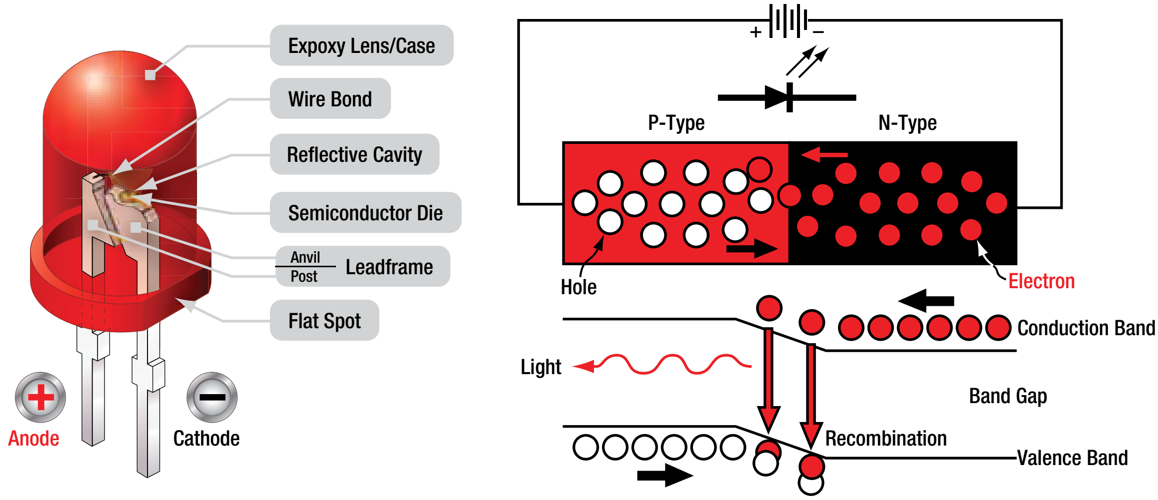

Figure 1-23. A close up of a single LED (left) and the process of a semi-conductor producing light by electrons dropping into holes and giving off energy (right). The symbol for a light emitting diode is the diode symbol with two arrows pointing away from the junction.

you should always check the manufacturer's number. LED seven-segment displays range from the very small, often not much larger than standard typewritten numbers, to about an inch. Several displays may be combined in a package to show a series of numbers, such as the one shown in **Figure 1-26**.

Figure 1-26. Stacked seven segment LED display.

LIQUID CRYSTAL DISPLAYS (LCD)

The liquid crystal display (LCD) has an advantage over the LED in that it requires less power to operate. Where LEDs commonly operate in the milliwatt range, the LCD operates in the microwatt range. The liquid crystal is encapsulated between two glass plates. When voltage is not applied to the LCD, the display is clear. However, when voltage is applied, the result is a change in the orientation of the atoms of the crystals. The incident light is then reflected in a different direction. A frosted appearance results in the regions that have voltage applied and permits distinguishing of numeric values.

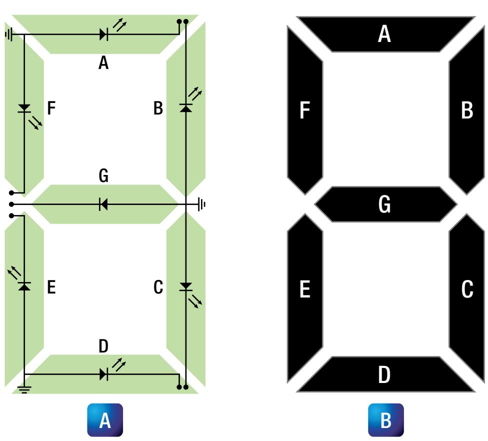

Figure 1-24. Seven segment LED display.

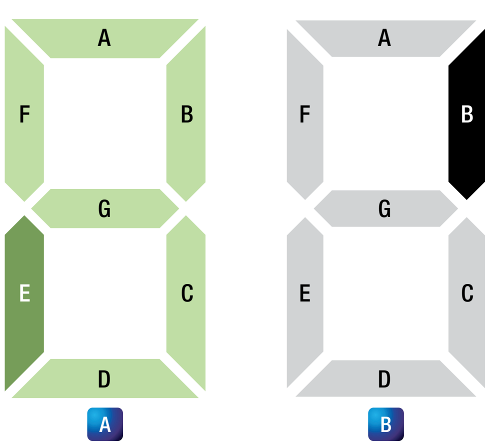

Figure 1-25. Seven segment LED display examples.

PHOTODIODES

Light contains electromagnetic energy that is carried by photons. The amount of energy depends on the frequency of light of the photon. This energy can be very useful in the operation of electronic devices since all semiconductors are affected by light energy. When a photon strikes a semiconductor atom, it raises the energy level above what is needed to hold its electrons in orbit. The extra energy frees an electron enabling it to flow as current. The vacated position of the electron becomes a hole. In photodiodes, this occurs in the depletion area of the reversed biased PN junction turning on the device and allowing current to flow.

Figure 1-21 illustrates a photodiode in a coil circuit. In this case, the light striking the photodiode causes current to flow in the circuit whereas the diode would have otherwise blocked it. The result is the coil energizes and closes another circuit enabling its operation.

Thermal energy produces minority carriers in a diode. The higher the temperature, the greater the current in a reverse current diode. Light energy can also produce minority carriers. By using a small window to expose the PN junction, a photodiode can be built. When light fall upon the junction of a reverse-biased photodiode, electrons-hole pairs are created inside the depletion layer. The

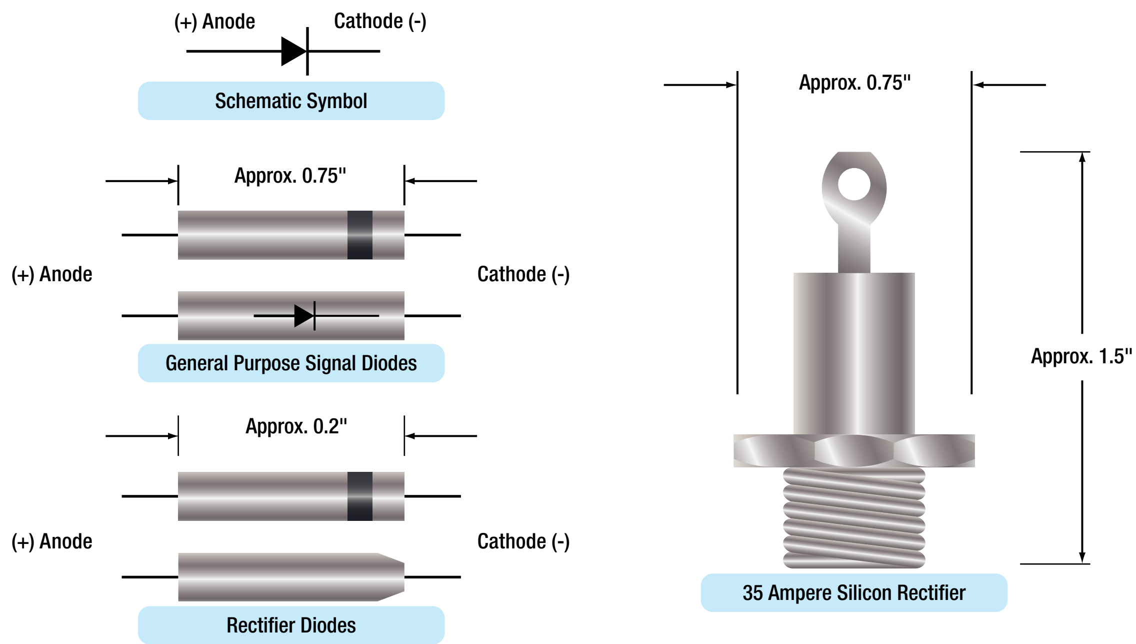

Figure 1-27. Examples of power rectifier diodes with the one on the right encased in metal to provide a heat shrink.

stronger the light, the greater the number of light-produced carriers, which in turn causes a greater magnitude of reverse current. Because of this characteristic, the photodiode can be used in light detecting circuits.

POWER RECTIFIER DIODES

The rectifier diode is usually used in applications that require high current, such as power supplies. The range in which the diode can handle current can vary anywhere from one ampere to hundreds of amperes. One common example of diodes is the series of diodes, part numbers 1N4001 to 1N4007. The "1N" indicates that there is only one PN junction, or that the device is a diode. The average current carrying range for these rectifier diodes is about one ampere and have a peak inverse voltage between 50 volts to 1 000 volts. Larger rectifier diodes can carry currents up to 300 amperes when forward biased and have a peak inverse voltage of 600 volts. A recognizable feature of the larger rectifier diodes is that they are encased in metal in order to provide a heat sink. **Figure 1-27** illustrates a few types of rectifier diodes.

SILICON CONTROLLED RECTIFIERS

Silicon controlled rectifiers are discussed in detail in the following section *4.1.2 Transistors*.

ZENER DIODE

Diodes can be designed with a zener voltage. This is similar to avalanche flow. When reversed biased, only leakage current flows through the diode. However, as the voltage is increased, the zener voltage is reached. The diode lets current flow freely through the diode in the direction in which it is normally blocked. The diode is constructed to be able to handle the zener voltage and the resulting current, whereas avalanche voltage burns out a diode. A zener diode can be used as means of dropping voltage or voltage regulation. It can be used to step down circuit voltage for a particular application but only when certain input conditions exist. Zener diodes are constructed to handle a wide range of voltages. [**Figure 1-28**]

SIGNAL DIODES

Signal diodes are common semiconductor diodes that are typically used in radio signal processing. They pass small current usually up to 100 milliamps. [**Figure 1-29**]

SCHOTTKY DIODES

A Schottky diode is designed to have a metal, such as gold, silver, or platinum, on one side of the junction and doped silicon, usually

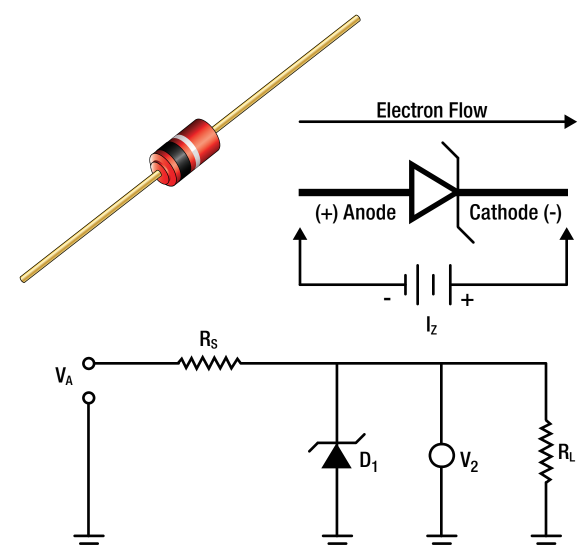

Figure 1-28. A Zener diode, when reversed biased, will break down and allow a prescribed voltage to flow in the direction normally blocked by the diode.

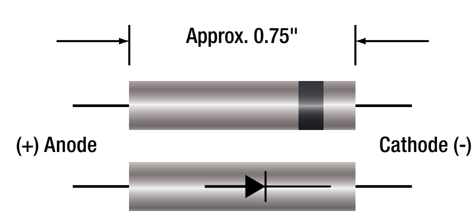

Figure 1-29. General purpose signal diodes.