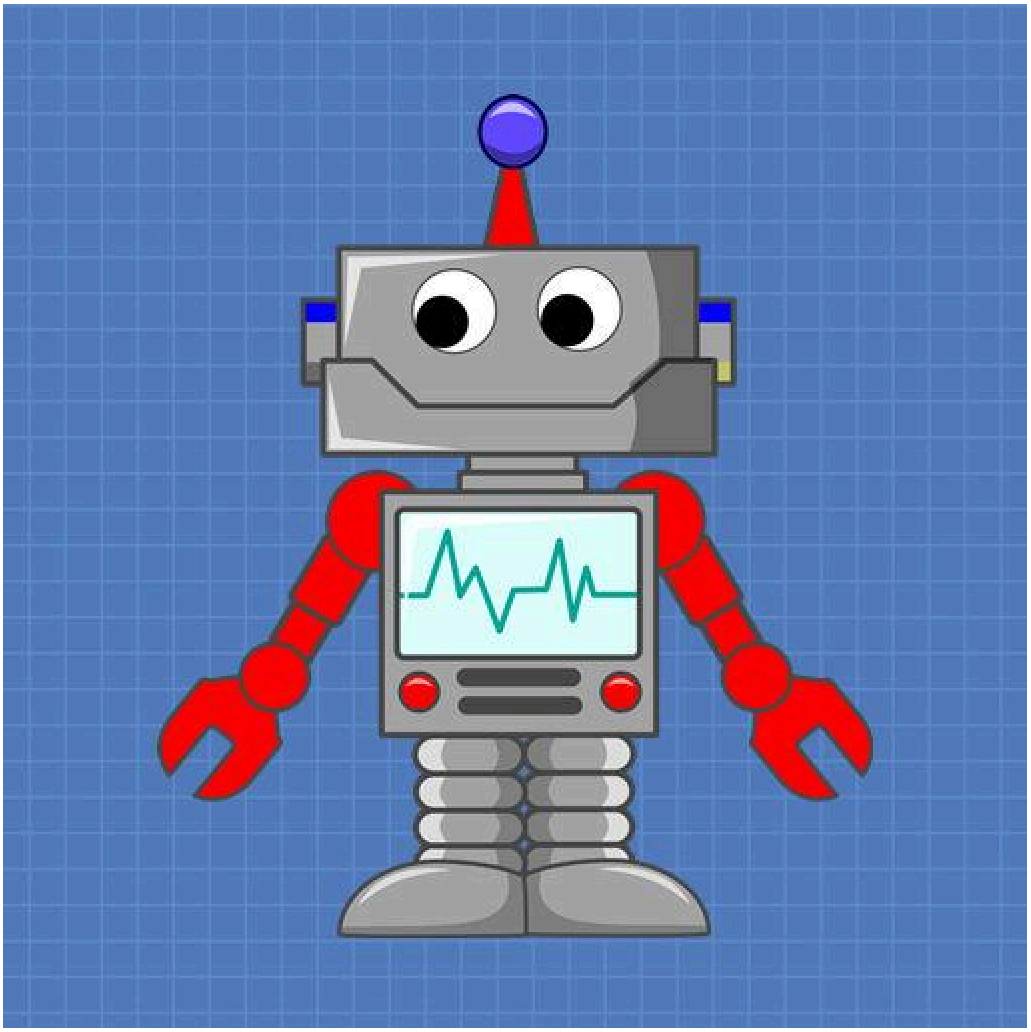
Diodes - A Practical Guide



DroneBot Workshop Tutorial

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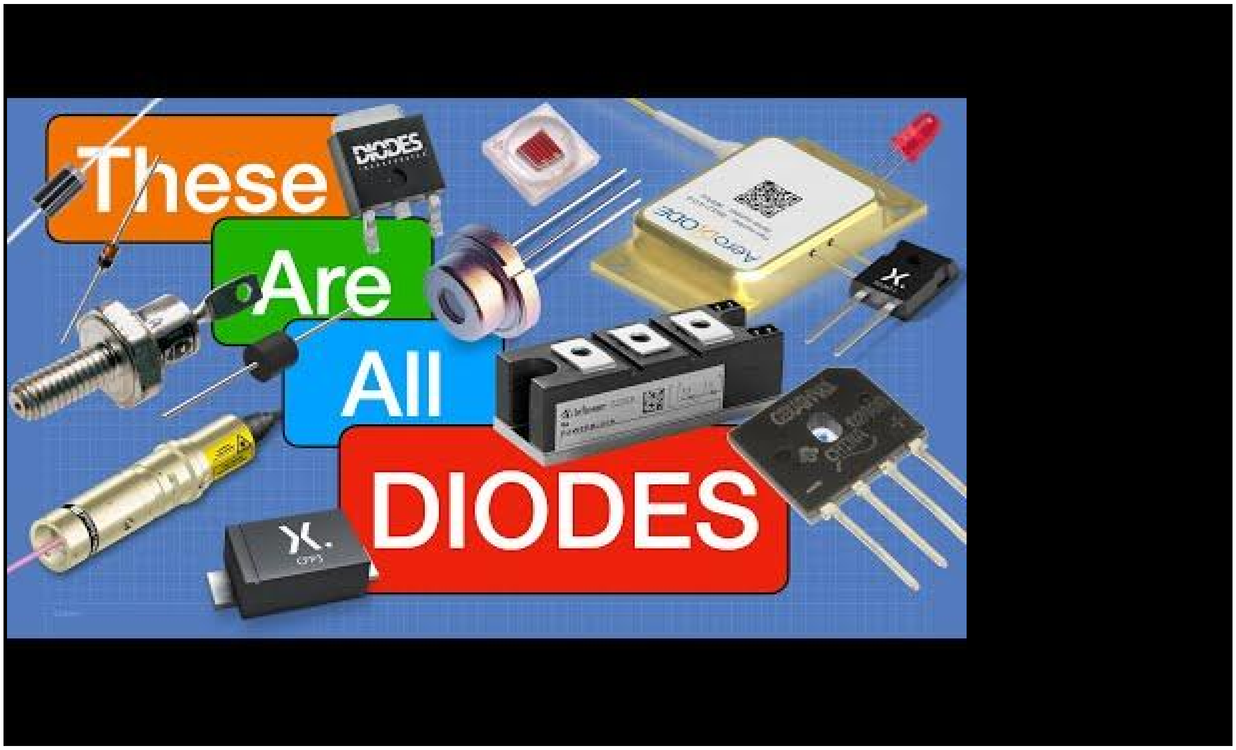
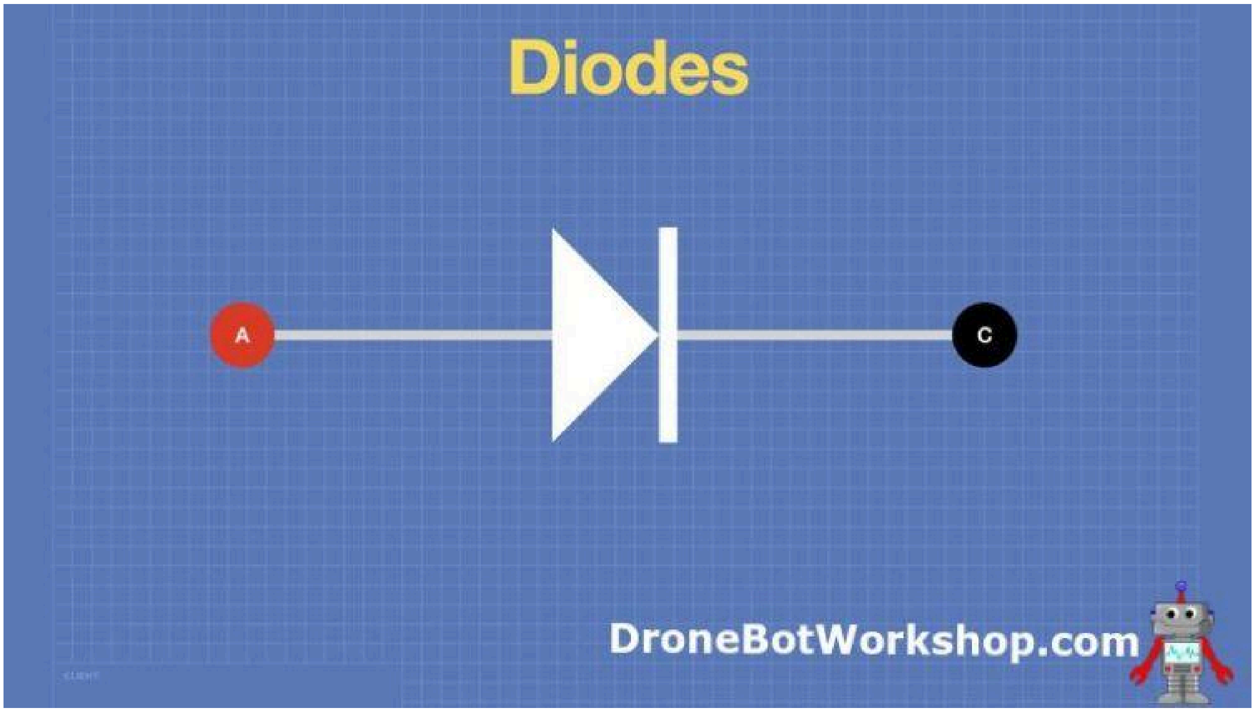
Let's work with an electronic component that dates back over a century yet still plays a vital part in modern electronics. There are a variety of diodes, each one with unique characteristics. Today we will learn how to use them.



Introduction

Electronic components can be grouped in several different ways. One method of categorizing components is to split them into two categories – active components and passive components.



Passive electronic components are things like resistors and capacitors. While they can be polarity-sensitive (electrolytic and tantalum capacitors are an example), they are actually electrical components based on electrical properties. They don't amplify signals or dynamically change them.

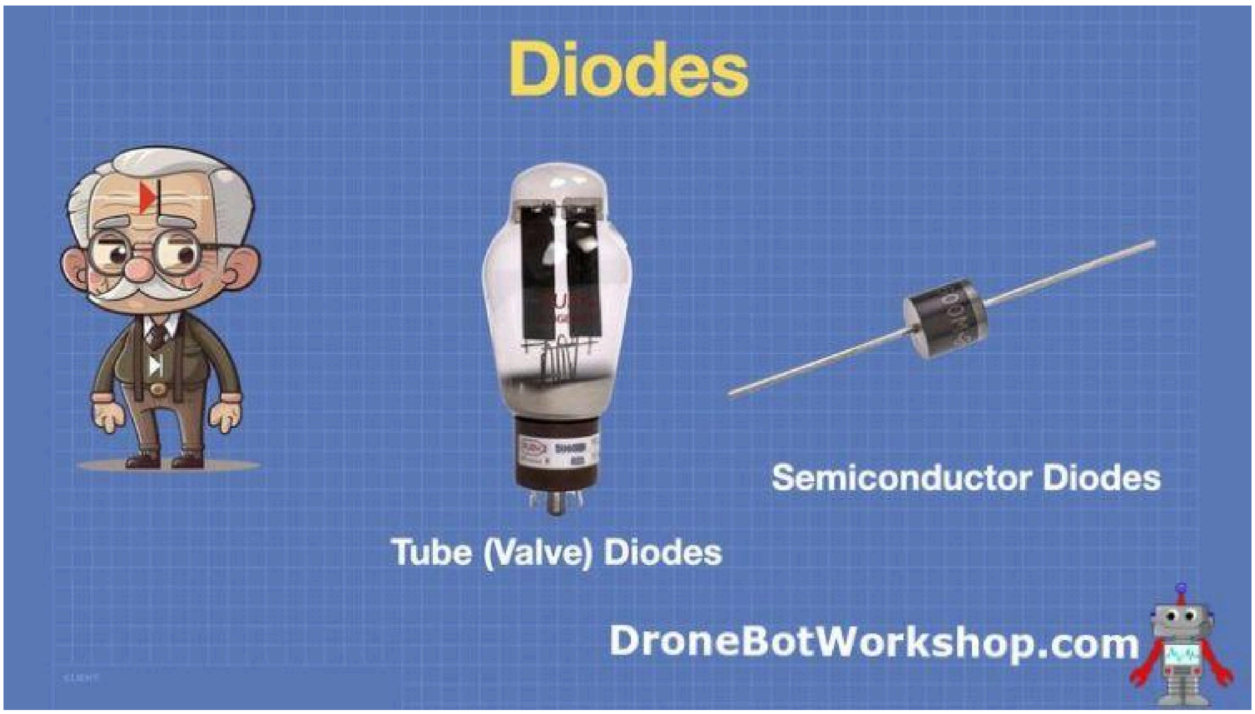
Active components are essentially semiconductors. I suppose that vacuum tubes could also fit into this category, but in 2024 they are really only encountered in specialized equipment. Active components can change and redirect signals. Complex active components, like microcontrollers, are made of millions of simpler active and passive components.

Diodes are the simplest active electronic component. Their principle function is to allow current to only flow in one direction. They come in a variety of formats and have many applications.

They have also been around, in one way or another, for a very, very long time!

History of Diodes

The developments that led to the creation of the first diodes started in the last quarter of the 19th century. Interestingly, both tube and semiconductor diodes were developed concurrently, and semiconductor diodes have been around for almost as long as their vacuum tube counterparts.



Development of both diodes began in the last quarter of the 19th century.

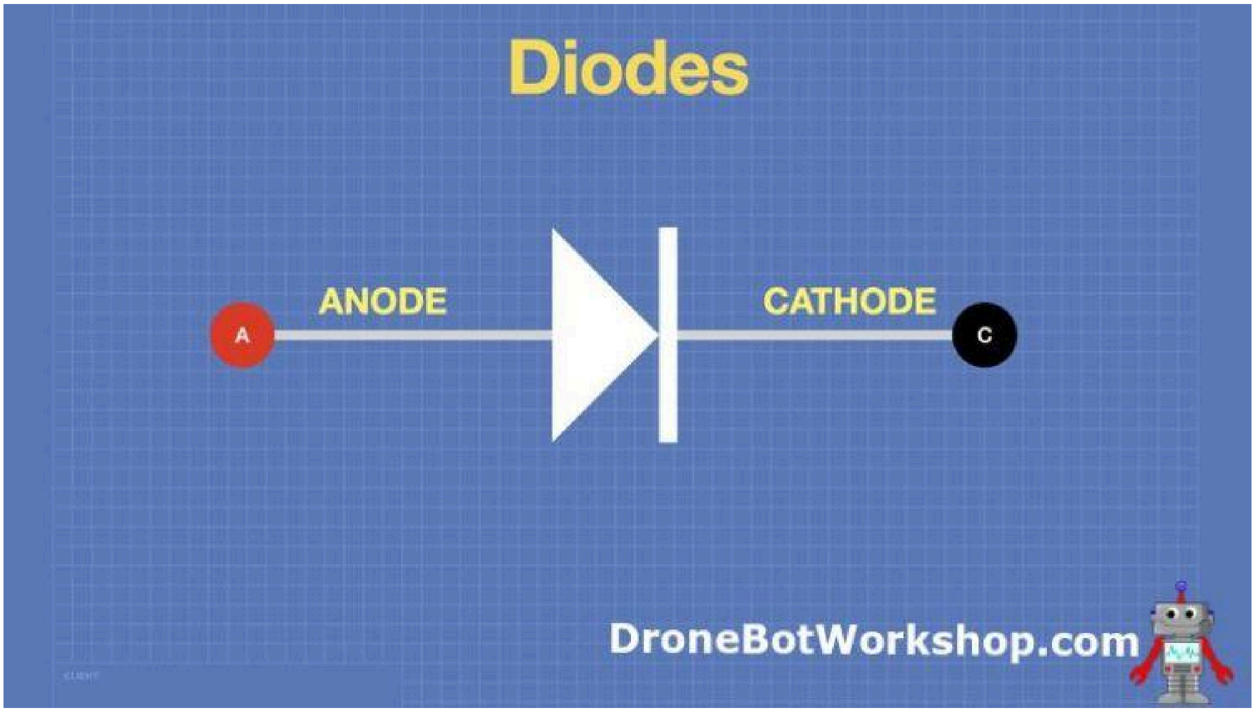
- **1873 – Frederick Guthrie** – Observed grounded hot metal ball discharged a positively-charged electroscope, but not a negatively-charged one.
- **1874 – Karl Ferdinand Braun** – Discovered “unilateral conduction” across a contact between a metal and a mineral.
- **1880 – Thomas Alva Edison** – Observed unidirectional current in a bulb between heated and non-heated elements. This was later called the “Edison Effect”.

- **1894 – Jagadish Chandra Bose** – First person to use a crystal to detect radio waves.
- **1903 – Greenleaf Whittier Pickard** – Invented the silicon crystal detector.
- **1904 – John Ambrose Fleming** – Invented the first thermionic (tube) diode. The diode became known as the Fleming Valve.
- **1905 – Fleming Valve Patented in the US**.
- **1906 – Silicon Crystal Detector Patented.**

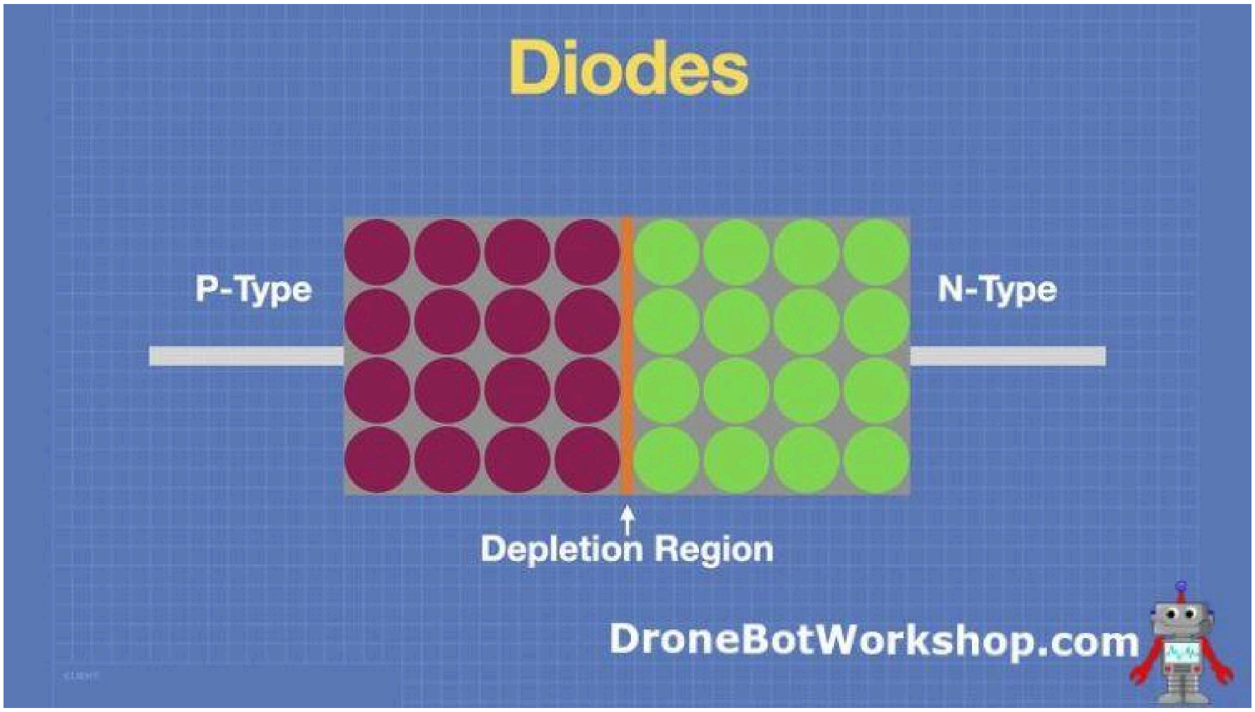
Some diodes manufactured over fifty years ago are still being produced today. A good example is the 1N34A, which is an update to the 1N34 germanium diode. It has been around since 1946.

How Diodes Work

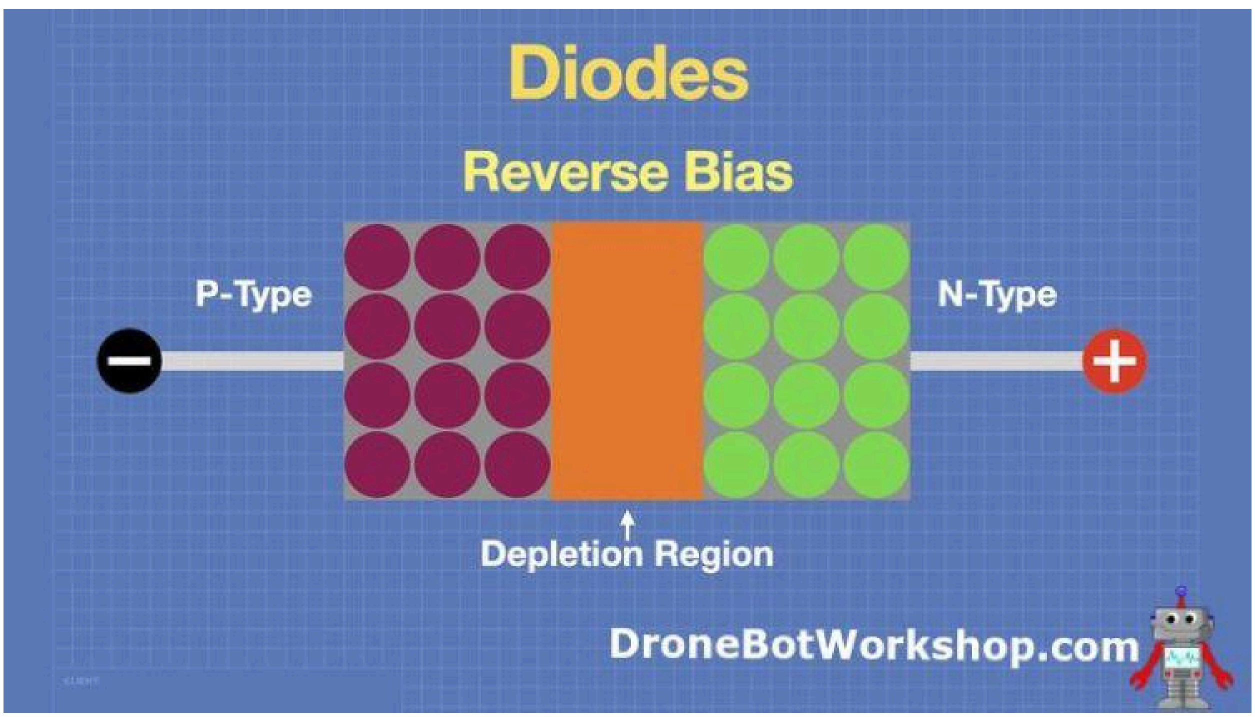
The schematic symbol for a diode is an arrow pointing into a line. The arrow side of the diode is its Anode, and the line side is the Cathode. These names were derived from the vacuum tube version of the diode.



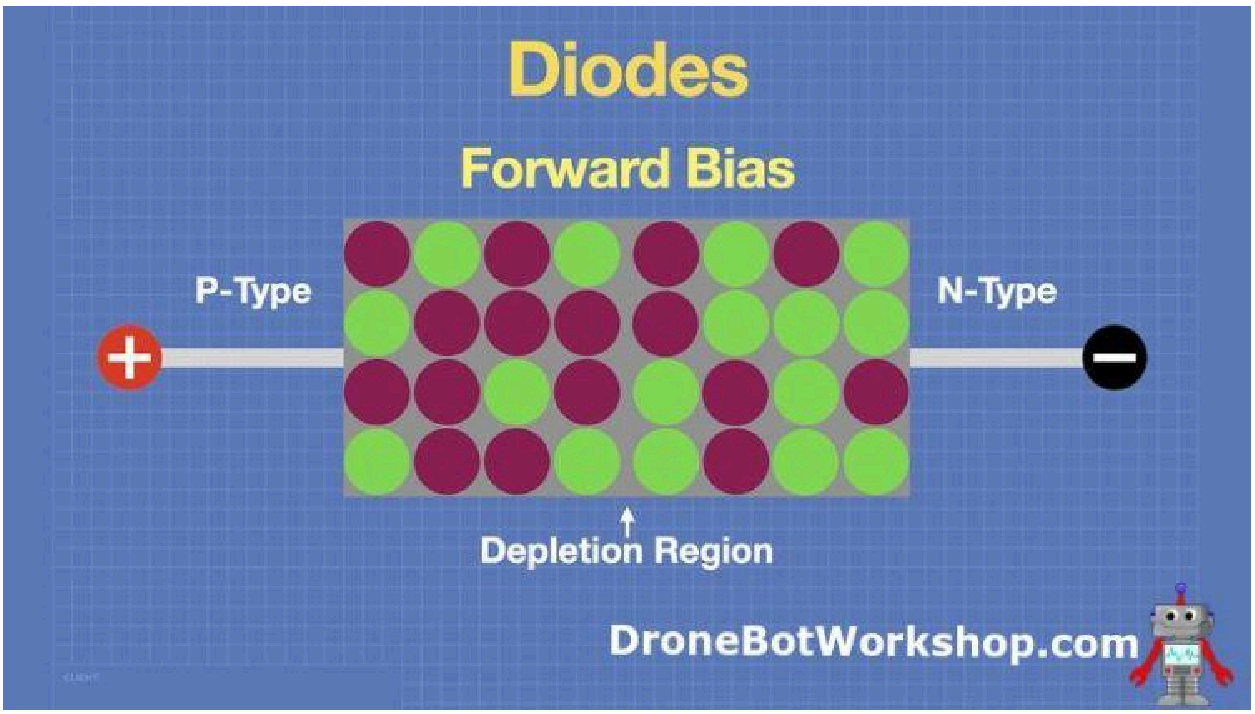
Diodes only permit current to flow in one direction. This property makes diodes very useful in converting AC to DC and separating a signal from a carrier wave (i.e. radio detector).



Internally, a diode is a semiconductor that is “doped” with p-type electrons on one side and n-type on the other, separated by a barrier called a “depletion region”.

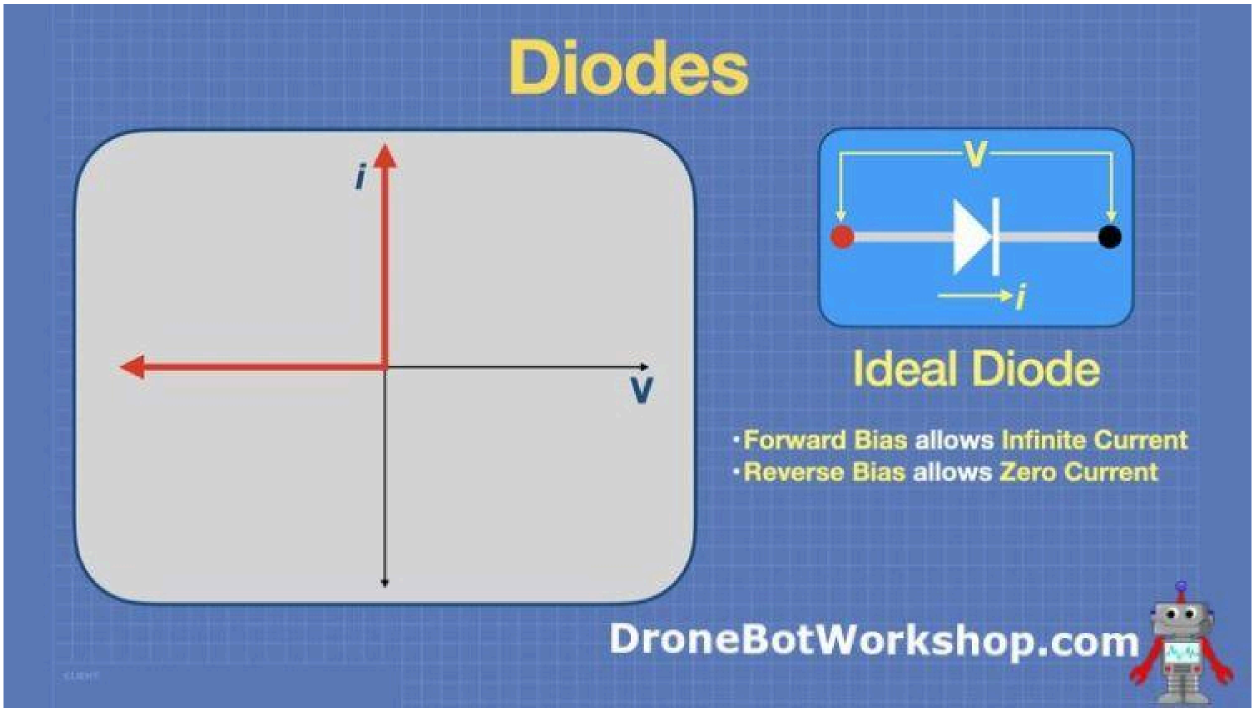


When the diode is “reverse biased”, meaning that voltage is applied to the diode the “wrong way”, the depletion region will grow and will prevent electrons from passing through the diode. If the polarity is reversed, the depletion region disappears and electrons can flow freely through the diode.

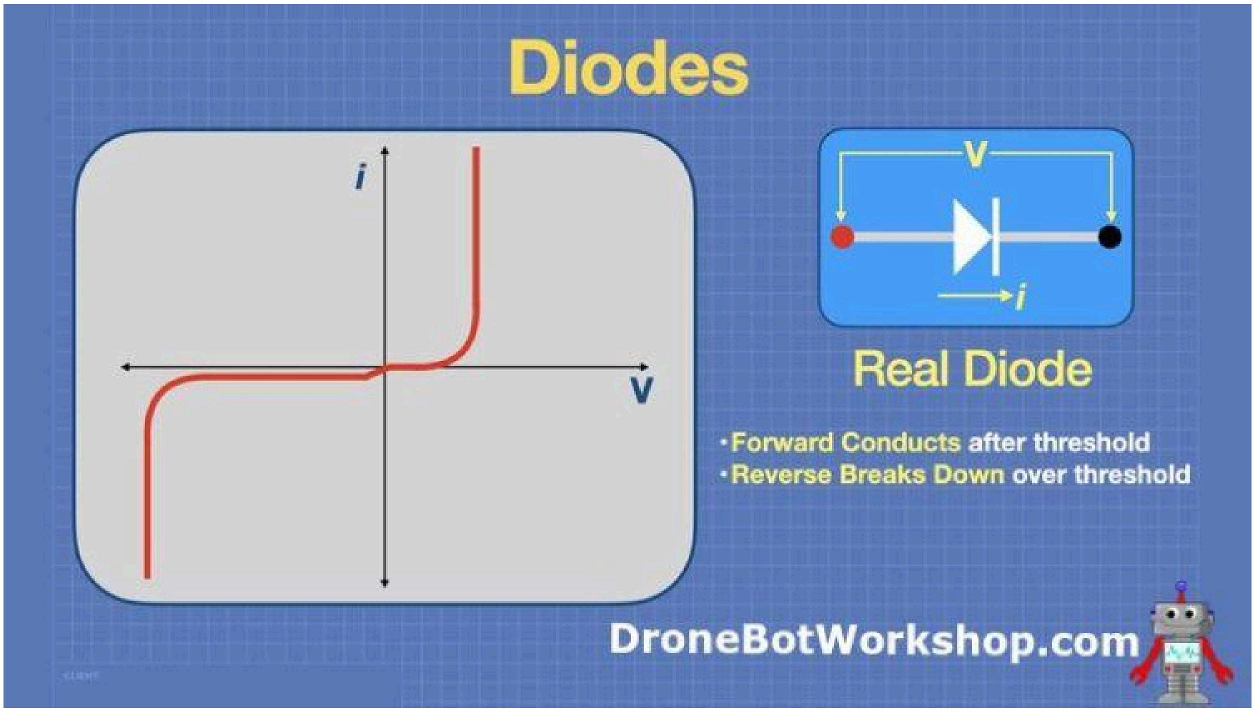


Diode Characteristics

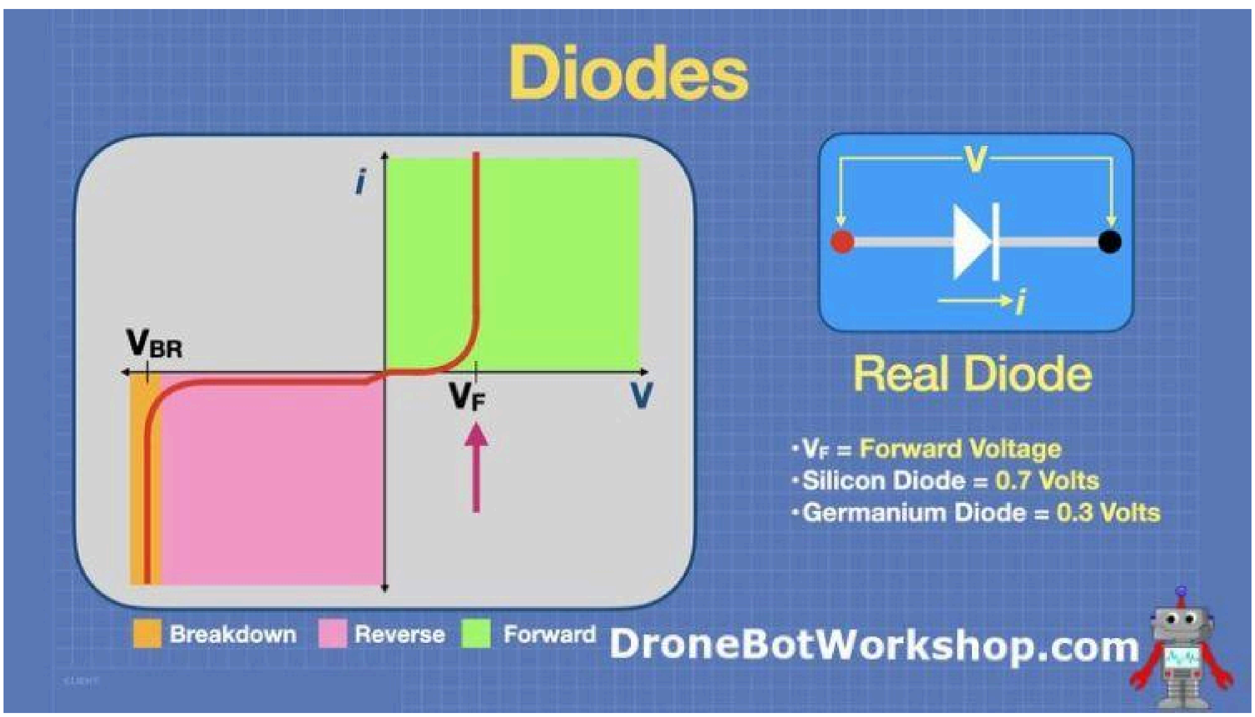
In a perfect world, we would have perfect diodes. When forward-biased, they would allow an infinite amount of current to pass. If reverse-biased, they would not permit any current to flow. The operation of this theoretical diode is shown on the following graph:



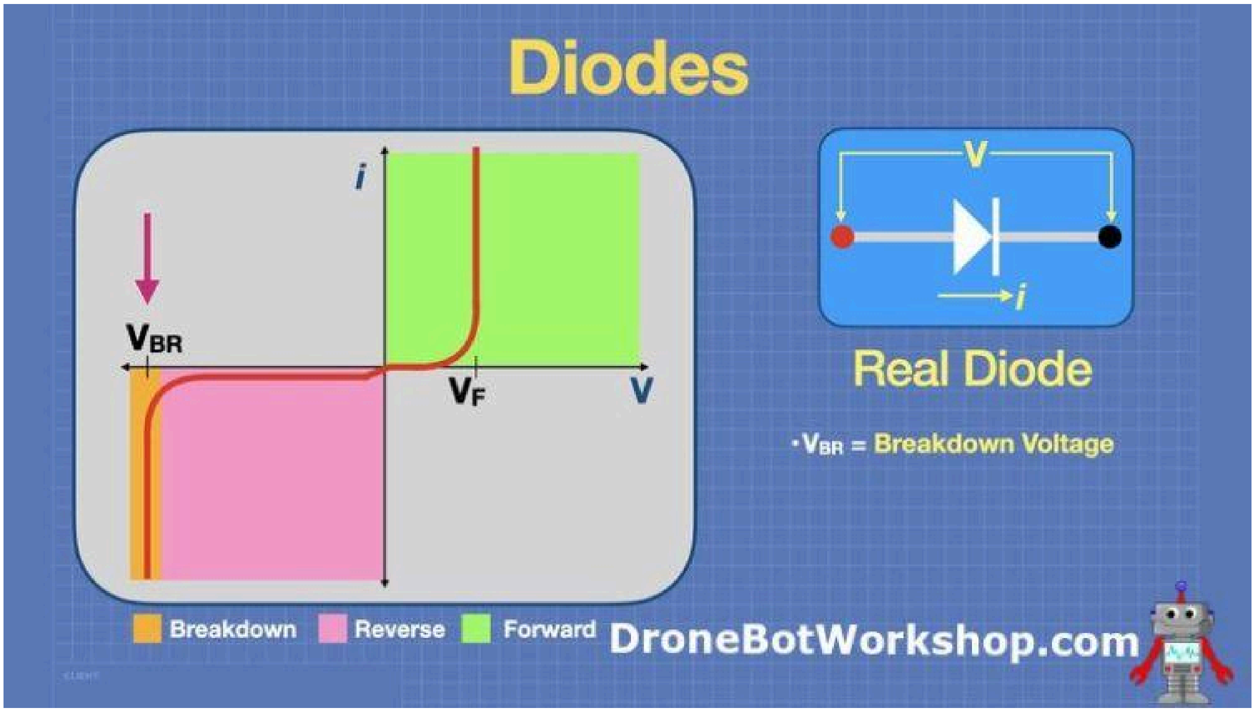
But in our real world, diodes are not perfect. When forward-biased, they only conduct after a specific voltage threshold is reached. And when they are reverse-biased, they will start to conduct after a specific voltage threshold.



The forward-biased voltage threshold is called the Forward Voltage. For most silicon diodes, this is 0.7 volts, and for germanium ones, it is 0.3 volts.



The reverse-biased threshold is called the Breakdown Voltage.



Diodes are also rated by their current handling capacity.

While the non-perfect characteristics of a diode may seem problematic, they are actually used to advantage in the design of many types of diodes. We'll look at a few of those further on.

Power Control with Diodes

One of the most common applications of diodes is power control. Diodes can be used to convert AC to DC and to prevent reverse-voltage situations.

Rectifier Diodes

Diodes that handle power are often called “rectifiers”. These diodes typically have current ratings of one or more amperes and voltage ratings of several hundred volts.

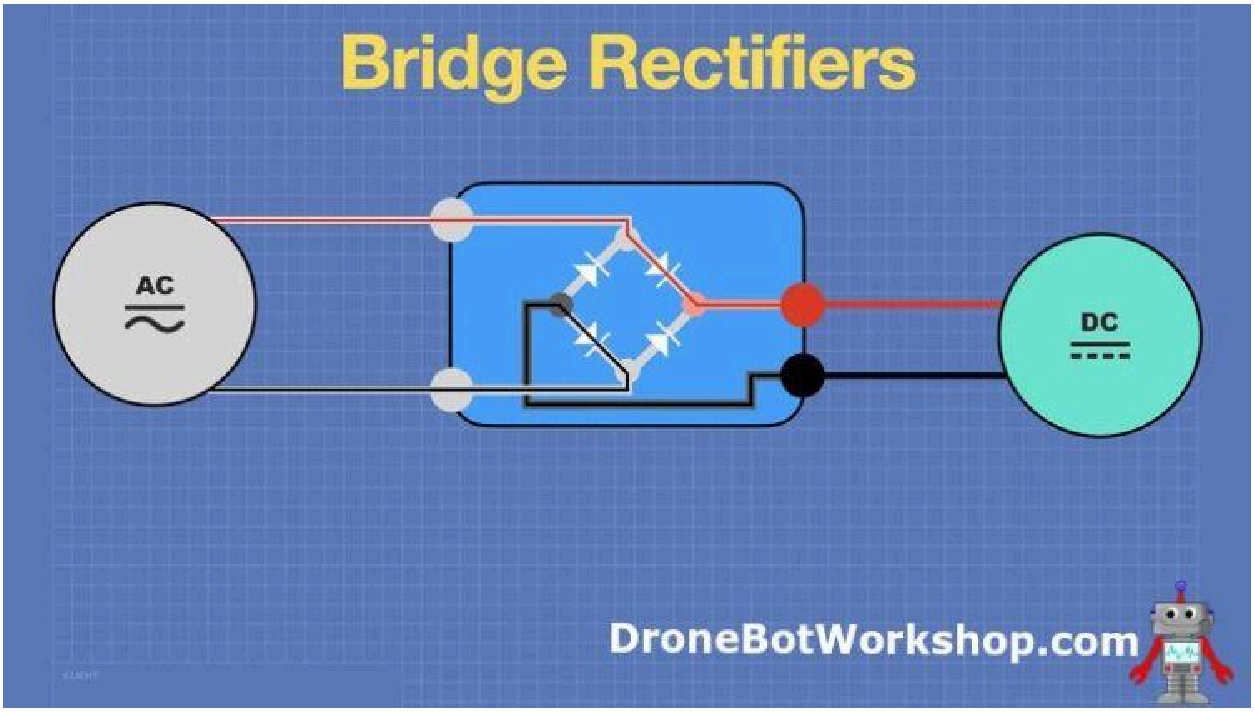
Rectifier diodes that handle large amounts of current are often packaged in cases that permit them to be attached to a heatsink.

For lighter loads, the 1N4004 diodes make excellent and inexpensive rectifiers.

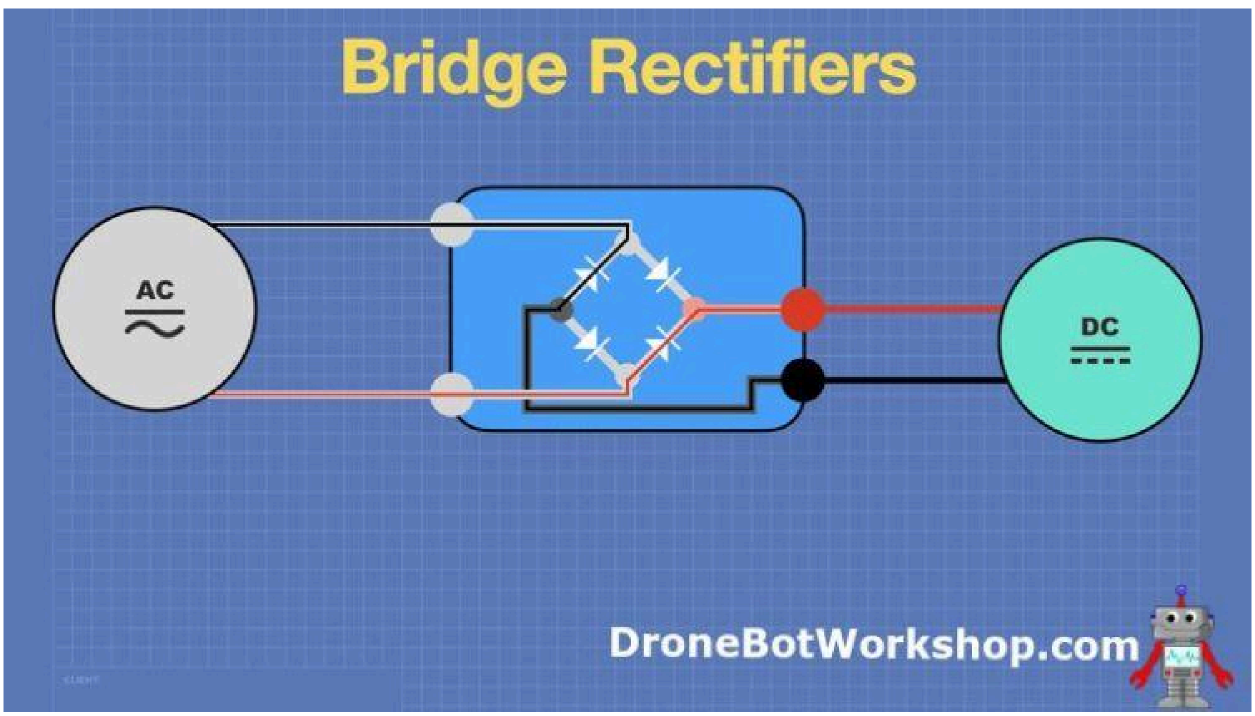
Bridge Rectifiers

A special arrangement of rectifiers is the “bridge” or “Full-wave” rectifier. It’s a common configuration used to convert AC to DC.

In a bridge rectifier, four diodes are arranged in a “diamond pattern”. Here we see the bridge passing the positive and negative side of the AC wave to the appropriate terminals:



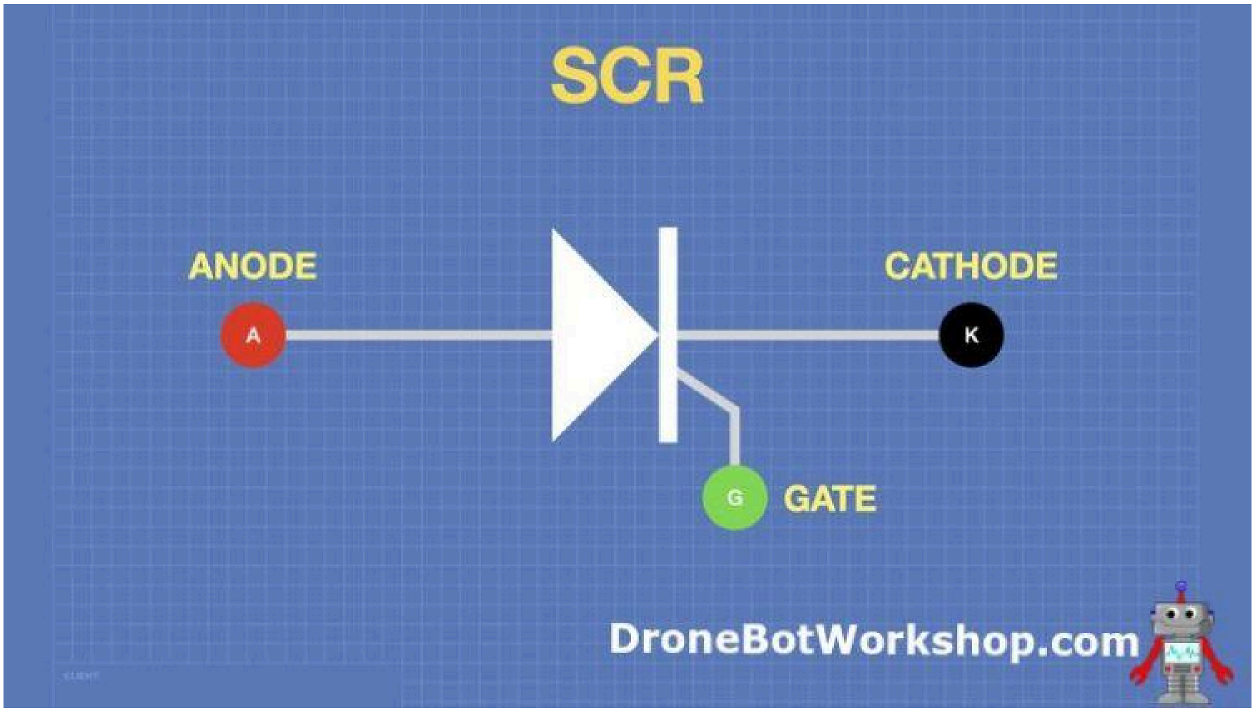
And here is what happens when the AC reverses polarity:



Bridge rectifiers can be constructed with four diodes or purchased in modules.

Silicon Controlled Rectifiers (SCRs)

An SCR, or Silicon Controlled Rectifier, is a member of a family of semiconductors known as Thyristors.



The symbol for an SCR looks a lot like a diode with a tail on it! This “tail” is the “trigger” or “Gate” lead. An SCR is a bit like a “switchable diode”; you need to trigger it to make it work.

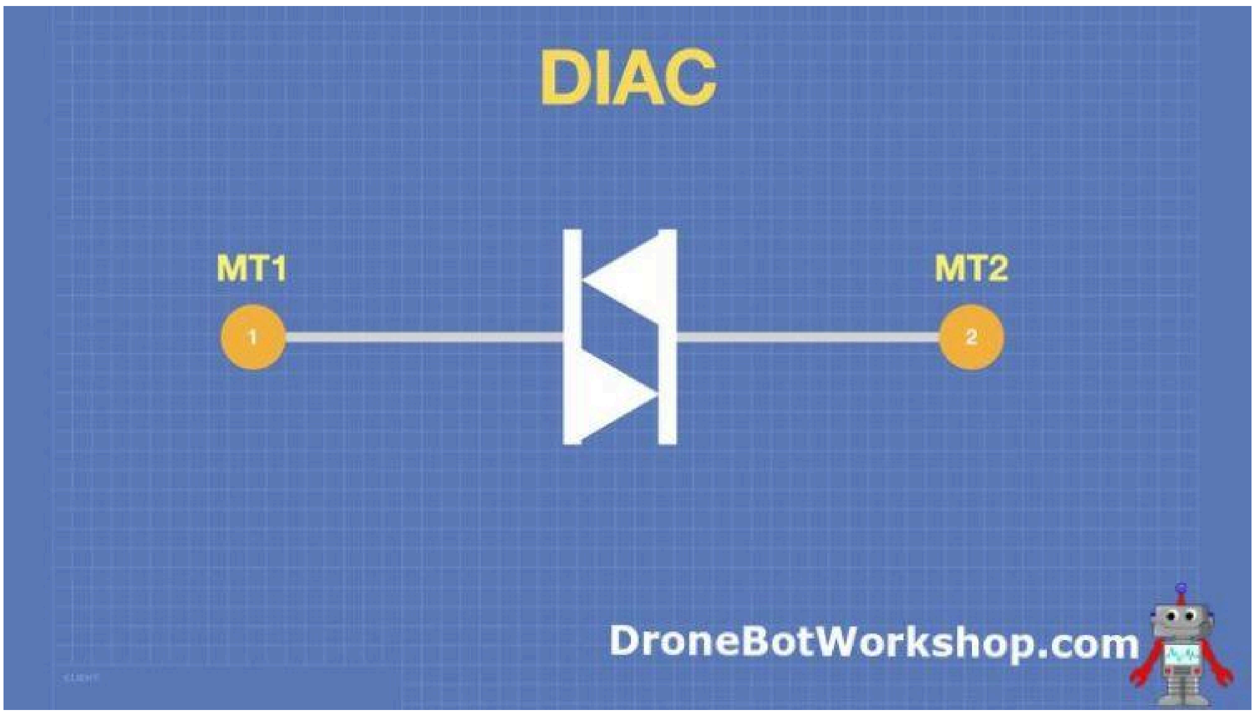
The trigger works with current, apply enough current to the Gate and the SCR will behave like a normal diode, allowing current to pass in one direction.

One interesting property is that once you trigger an SCR, it will remain conducting even when the trigger has ceased. This “latching” property is often used to advantage. The SCR will continue to conduct until the current falls below its specified “Holding Level”.

SCRs find use in switching DC power.

DIACs

The **DIAC**, which stands for “Diode for Alternating Current”, is a two-electrode bidirectional semiconductor device. A DIAC conducts electricity in both directions, but only after its breakdown voltage is reached. A DIAC is known for conducting smoothly between positive and negative voltage, making it ideal for use with alternating current.



A DIAC has two terminals:

- MT1 – Main Terminal 1
- MT2 – Main Terminal 2

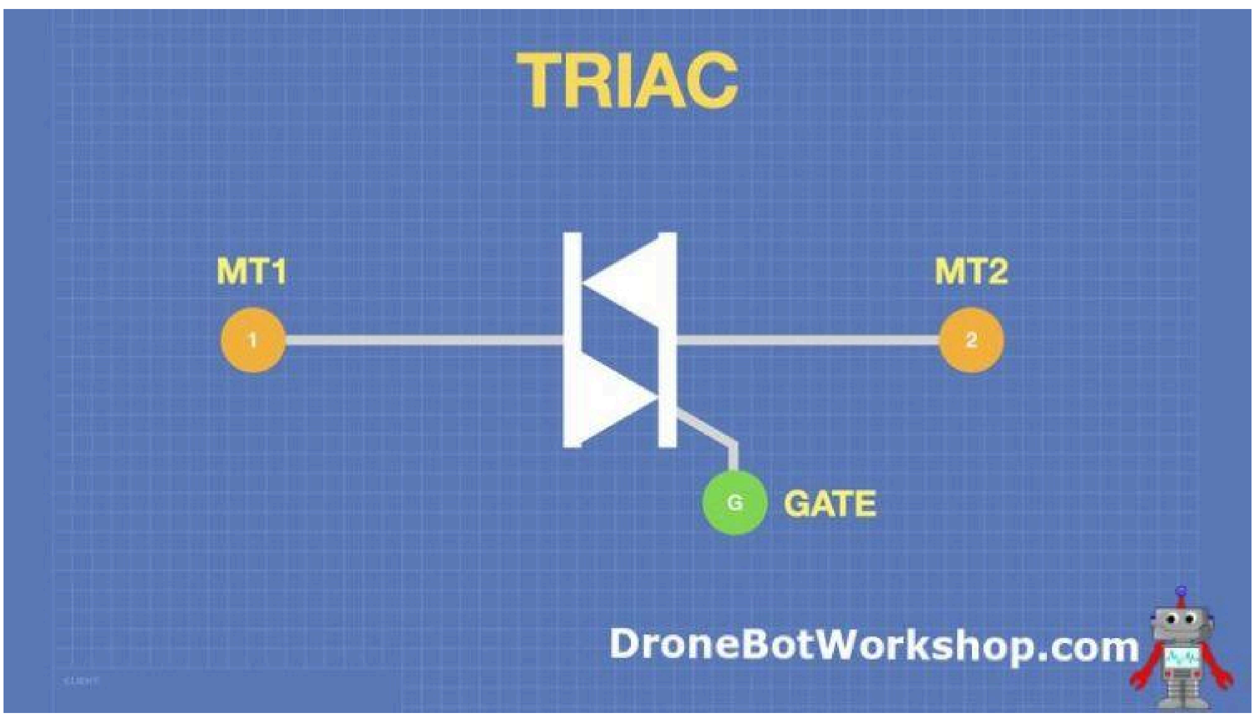
The advantage of a DIAC is that it can be turned completely off just by reducing the applied voltage. Unlike a TRIAC, a DIAC has no trigger lead, it's simply controlled by voltage.

The main application of DIACs is for triggering thyristors like SCRs and TRIACs. This allows the TRIAC to be triggered by voltage level.

A device similar to a DIAC is a **SIDAC**, or "**S**ilicon **D**iode for **A**lternating **C**urrent." It operates on the same principle but has a higher breakdown voltage and greater current handling capability.

TRIAC's

The three-terminal TRIAC is a Triode for Alternating Current. As with the SCR, it is a member of the thyristor family.



A TRIAC operates similarly to an SCR, except a TRIAC conducts current in both directions. This makes it an ideal for switching alternating current, and TRIACs are used extensively in products like AC lamp dimmers and heater controllers.

The TRIAC has three leads:

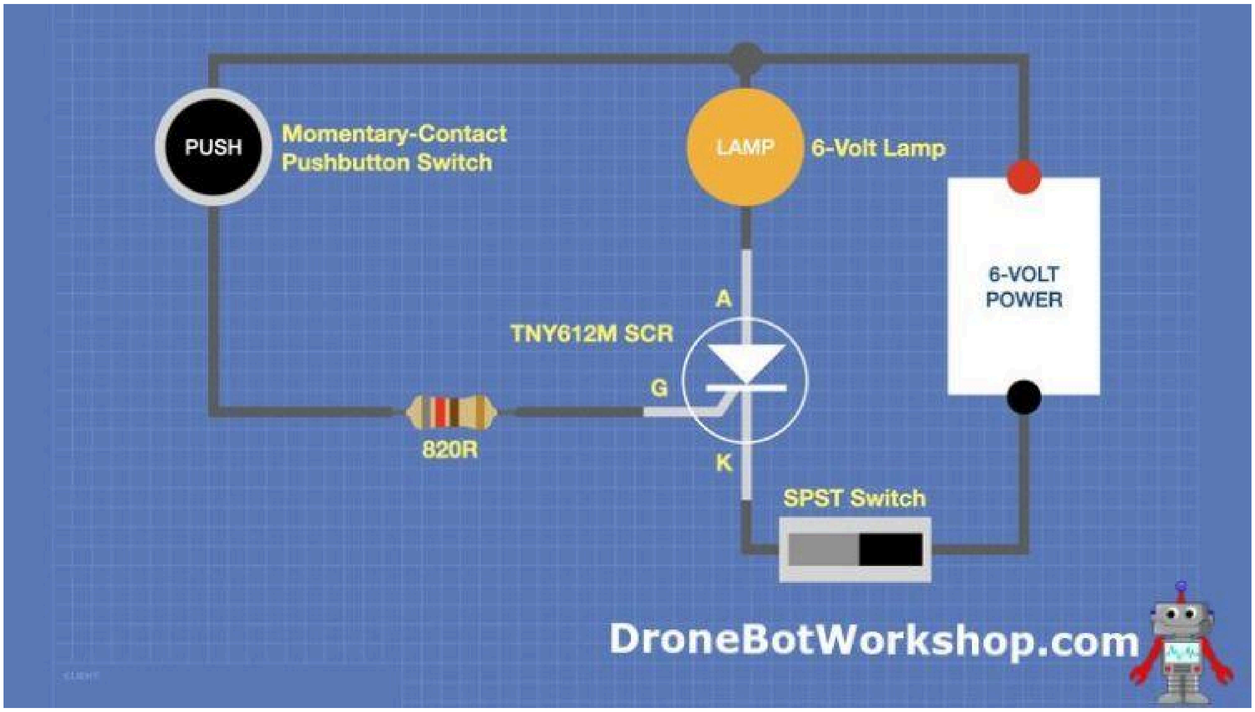
- MT1 – Main Terminal 1
- MT2 – Main Terminal 2
- G – Gate

The Gate triggers the TRIAC when the current is high enough. As with an SCR, once triggered, the TRIAC continues to conduct, even if the gate current ceases. Conduction will only stop when the main current drops below a threshold called the Holding Level.

GTOs, or Gate Turn-Off Thyristors, are similar to TRIACs but will turn off the current when the gate current is removed.

SCR Latch Experiment

The following circuit will illustrate the latching properties of an SCR:



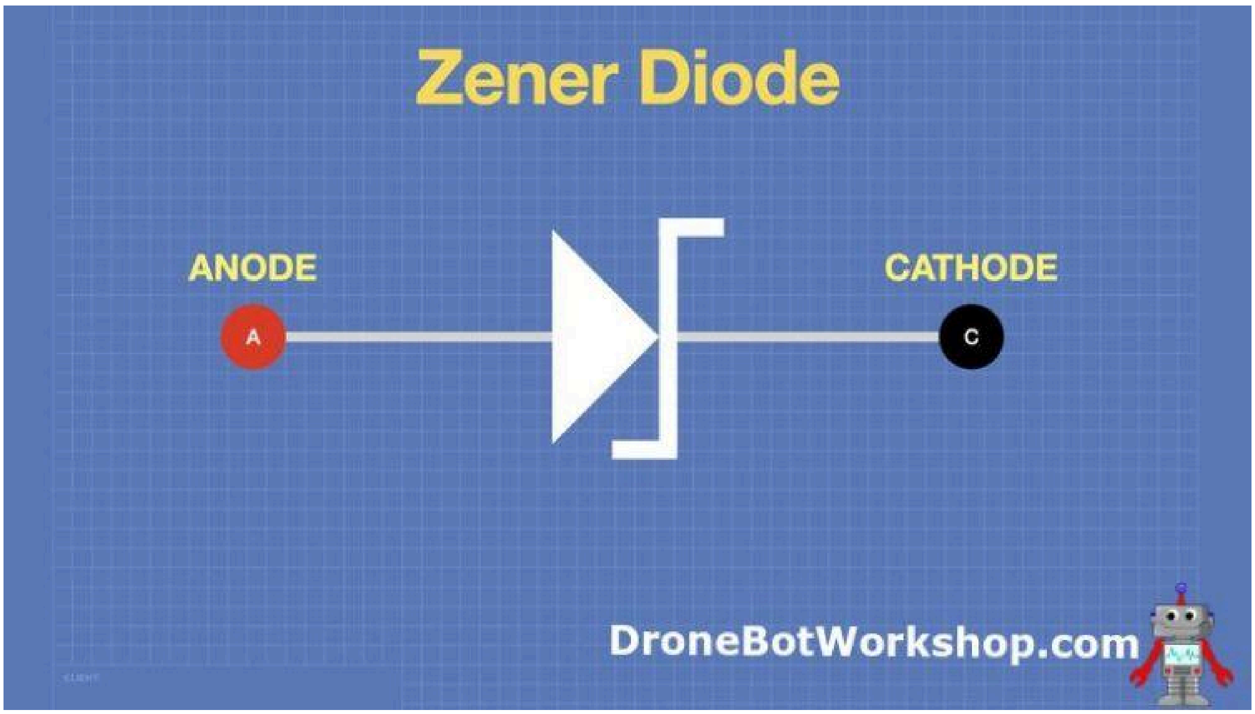
The circuit uses a 6-volt battery and incandescent bulb, but you can substitute a 12-volt one if you wish. Otherwise, it uses a TNY612M SCR, an 820-ohm resistor, and two switches.

In operation, the SPST switch is closed. Pressing the pushbutton switch will allow current to flow through the Gate of the SCR. This will turn on the SCR and illuminate the lamp.

Releasing the pushbuton will not stop the current to the lamp from flowing. The only way to shut off the lamp is to turin off the SPST switch.

Zener Diodes

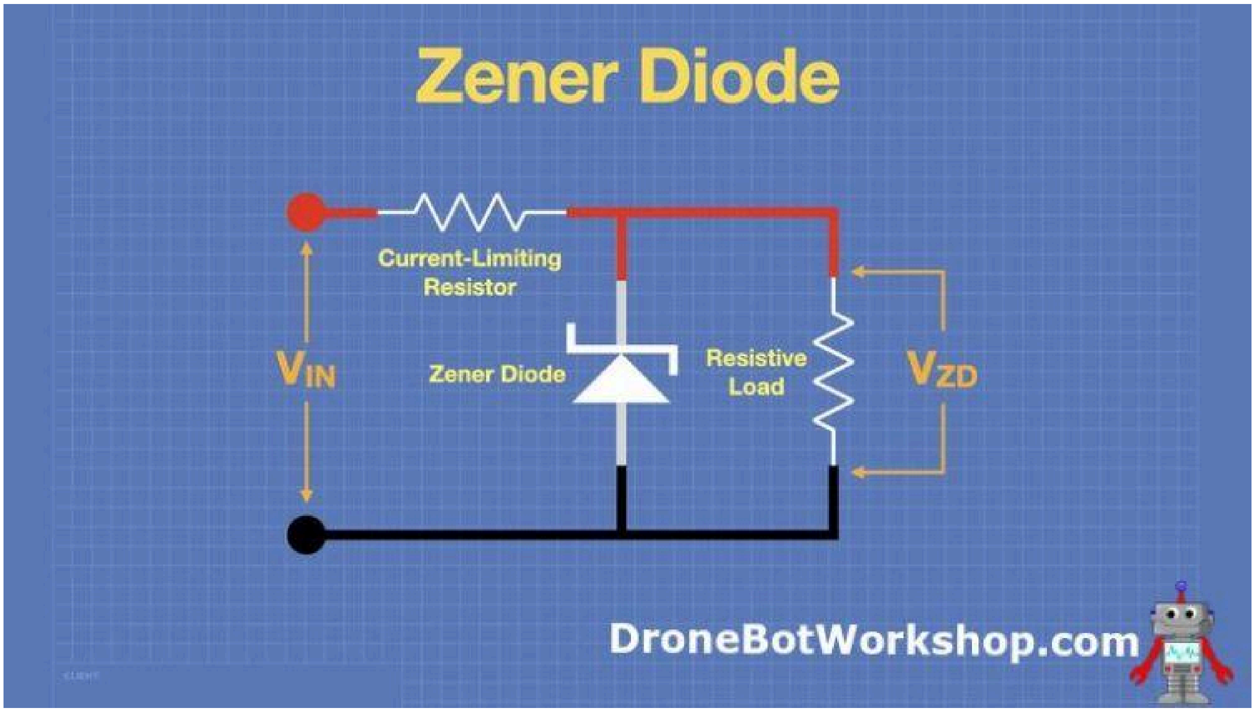
In 1934, Clarence Zener, an American physicist, was studying the breakdown of electrical insulators when he encountered an odd effect. He observed a sudden reversed current in a reversed-biased p-n diode. This effect became known as the "Zener Effect".



Zener Diodes allow current to flow backward (in reverse) after reaching a specific threshold voltage. This voltage is called the "Zener Voltage", and Zener diodes are manufactured in a wide range of voltages.

These diodes are used to stabilize and regulate voltages. They can also be used as voltage limiters.

The following diagram shows the hookup of a Zener diode. Note that the output voltage will equal the Zener voltage.


Zener Diode
Current-Limiting
Resistor
VIN
Zener Diode
Resistive
Load
VZD
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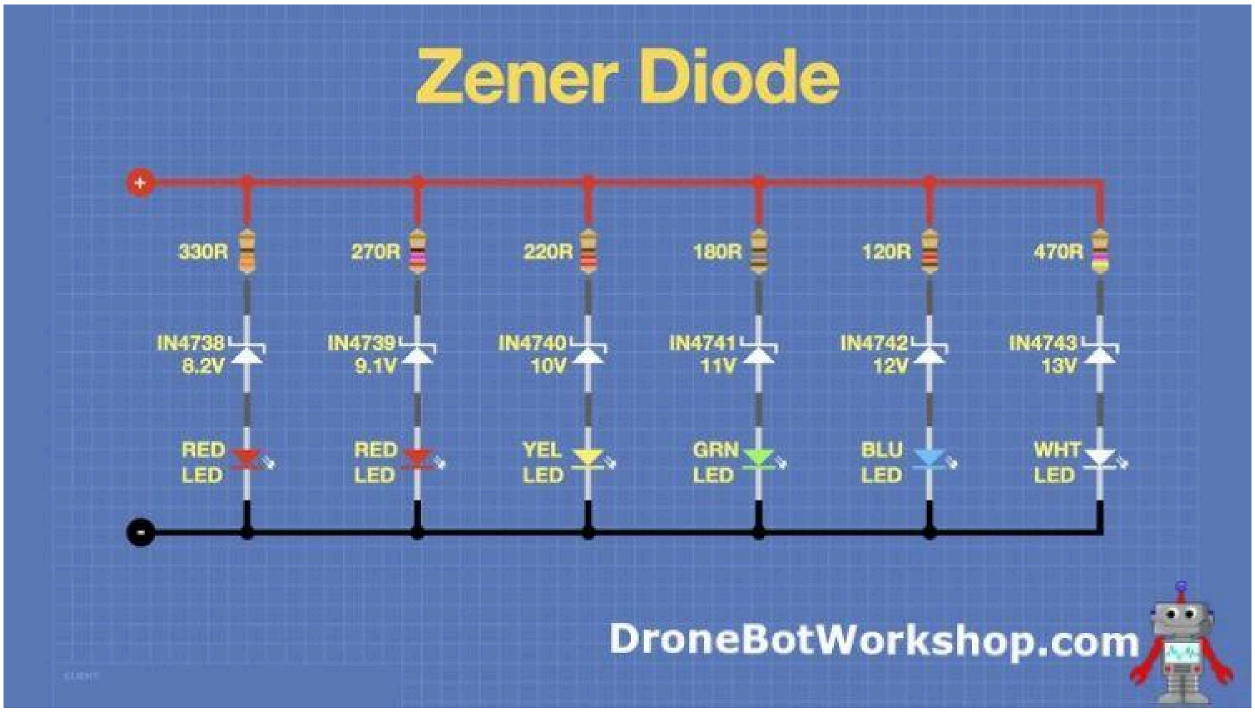
Zener Diode “Voltmeter” Experiment

We can use Zener diode to make a crude but useful “voltmeter”. Aside from being a somewhat useful bit of test equipment, this is also a great way to observe Zener Diodes in action.



In this circuit, you’ll notice that we have six “legs”, each one with a Zener diode, current-limiting resistor, and LED. Each “leg” has a different Zener, dropping resistor, and a colored LED.

The resistors are different because, at the higher voltages, the lower-value Zener diodes won’t bleed off a lot of voltage, leaving the rest to be handled by the LED and resistor. The white LED at the end is an exception, I used a 470 ohm resistor just because my LED was so bright!

Now remember, the LED will NOT light at the Zener voltage. The LED itself takes about 2 volts, so that needs to be factored in.

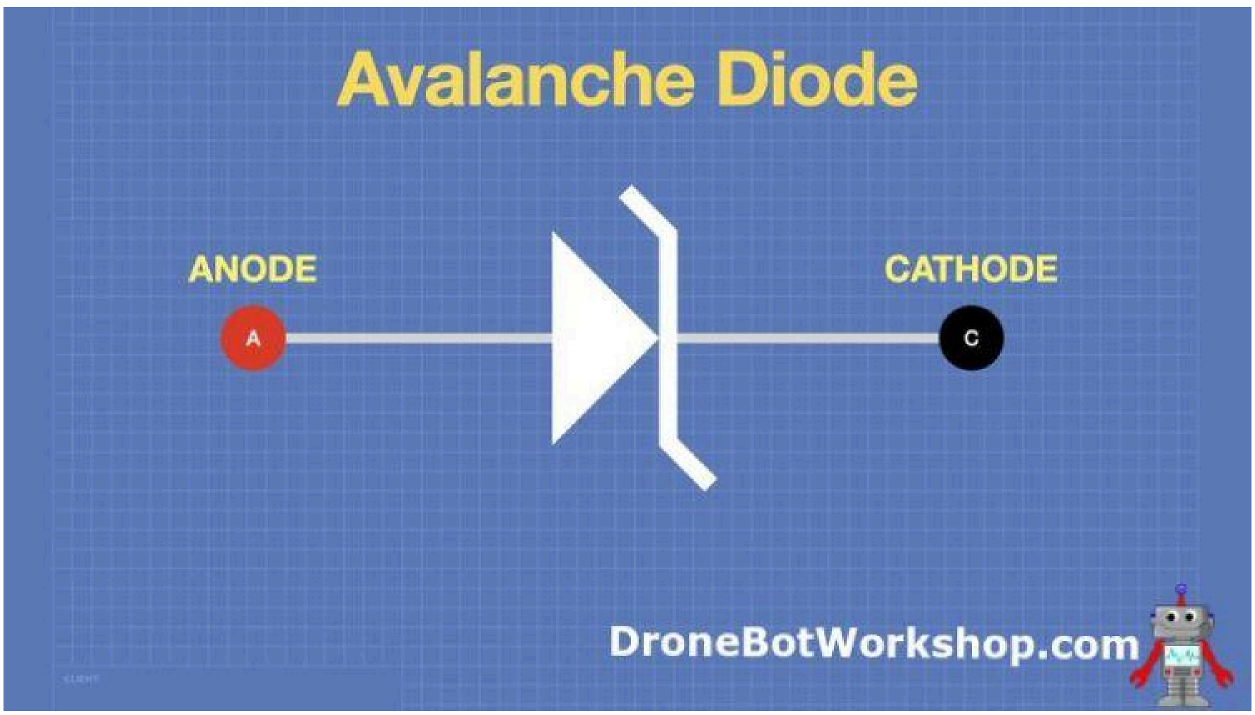
Try it out, if you have a variable power supply you can easily test it. You can also build this with other Zeners and LEDs, use more (or less) of them, and make a custom “voltmeter” for automotive or other applications.

“Exotic” Diodes

OK, perhaps the word “exotic” is a bit of an overkill. I could have easily said “other diodes”, but “exotic” sounds better!

Avalanche Diode

An Avalanche Diode is similar to a Zener Diode in many ways. Like a Zener, it experiences a Reverse Breakdown voltage, only in this case due to the Avalanche Effect.



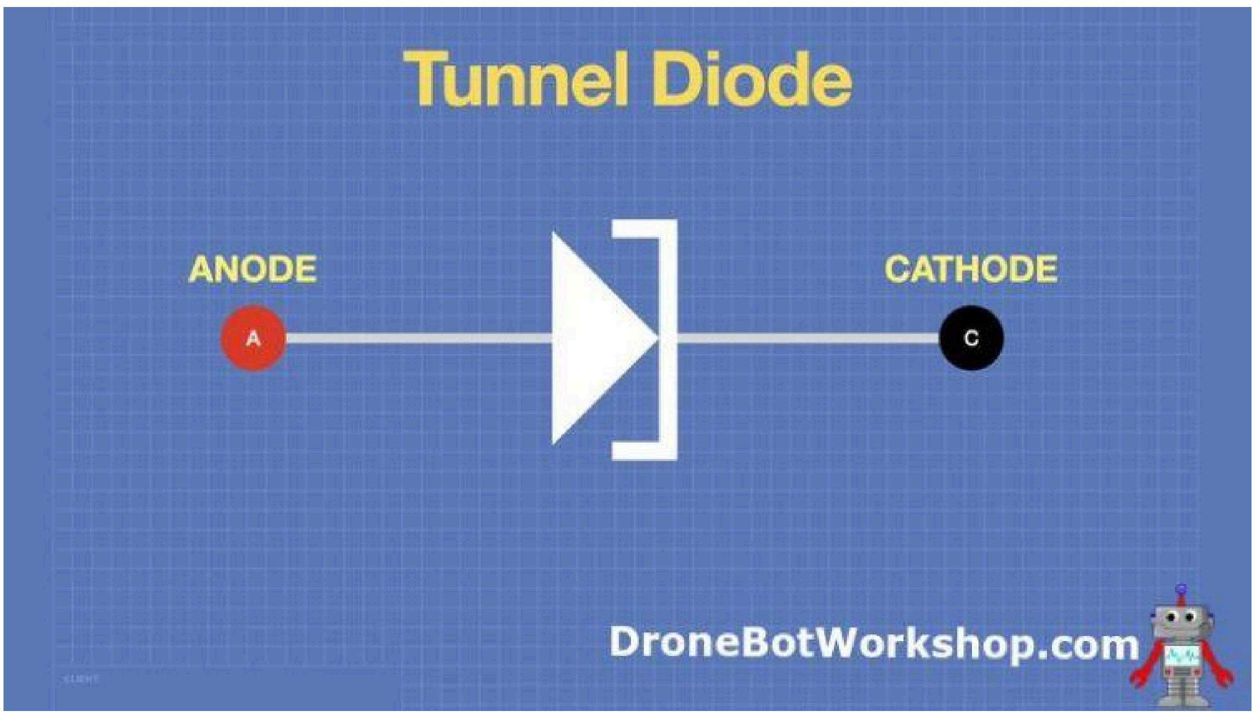
Avalanche diodes are used for surge protection, and in this application, they outperform Zener Diodes or Gas Discharge tubes.

Another property of Avalanche Diodes is that they generate noise. This can be used to advantage in radio circuits, such as RF and Microwave noise generators. The electrical noise can also be used as a seed for a random number generator.

Avalanche Diodes can be manufactured to be very sensitive to photons. In this application, the diode is used as a very sensitive light detector.

Tunnel Diode

Another of the “exotic” diodes is the Tunnel Diode.



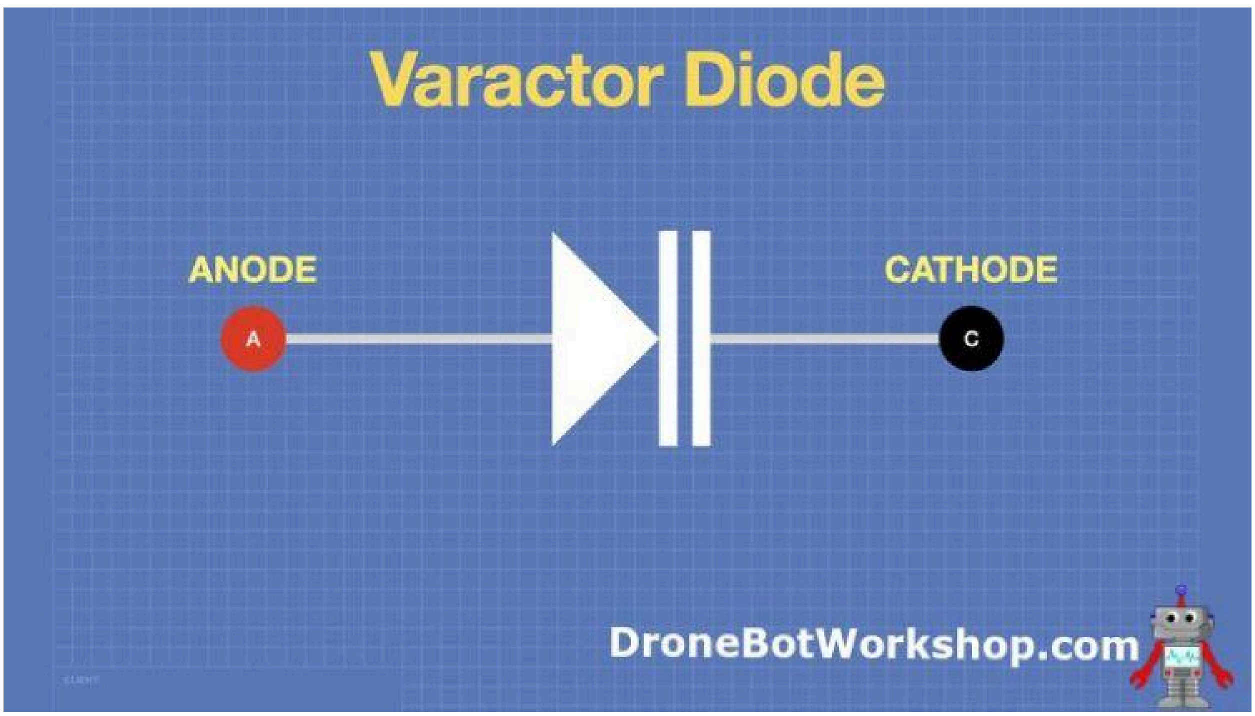
This is sometimes referred to as an Esaki Diode, in honor of its inventor Leo Esaki, who developed the diode while working at Tokyo Tsushin Kogyo (now known as Sony) in 1957. Esaki received the 1973 Nobel Prize in Physics for demonstrating the electron tunneling effect upon which this diode is based.

The principal advantage of a Tunnel Diode is its speed, these diodes can switch at 1GHz or higher. Tunnel diodes are often used in RF and Microwave oscillators and detectors.

Most Tunnel diodes are composed of Germanium, but they can also be manufactured from Gallium Arsenide or Silicon.

Varactor Diode

A Varactor Diode can also go by many other names – Varicap Diode, Variable Capacitance Diode, Variable Reactance Diode or Tuning Diode.

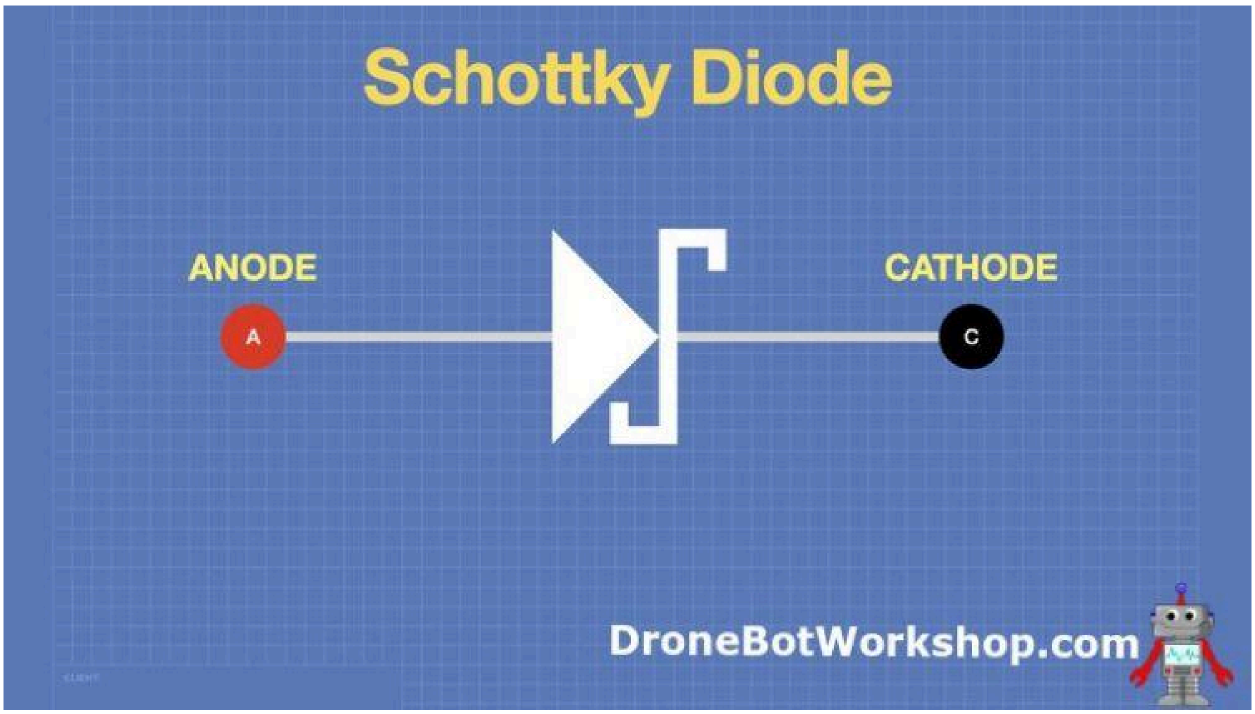


The Varactor Diode exploits a property of the depletion zone in the diode. Al diode depletion zones exhibit capacitance; in a Varactor, this effect is enhanced. The result is a diode whose capacitance can be changed by regulating the amount of reverse bias.

As you might expect, Varactor Diodes are used in tuning circuits and filters. They are used in radio receivers and transmitters and are a key component in the Phase Locked Loop, a circuit used to stabilize oscillators in radios.

Schottky Diode

The Schottky Diode is also called a Hot Carrier Diode or Schottky Barrier Diode.



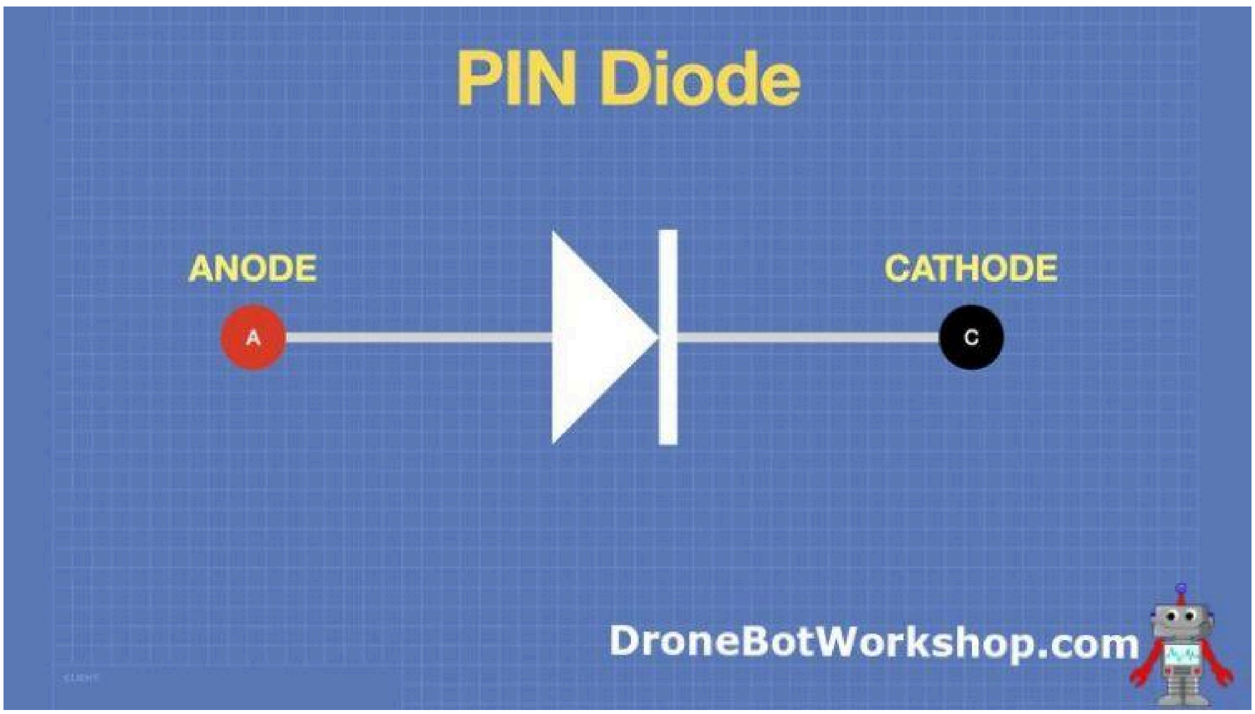
This diode is unique in its composition, as it is constructed with a junction of a semiconductor and metal. This results in a fast diode with an extremely low Forward Voltage Drop.

These characteristics make Schottky diodes ideal for rectifiers in high-speed switching power supplies. Their low Forward Voltage Drop makes them useful in power-sensitive applications.

Schottky Diodes can also be used in analog sample-and-hold circuits.

PIN Diode

A PIN Diode is fabricated by placing an undoped Intrinsic Semiconductor material between the P and N-doped material normally used to manufacture diodes. This is where the device gets its name.



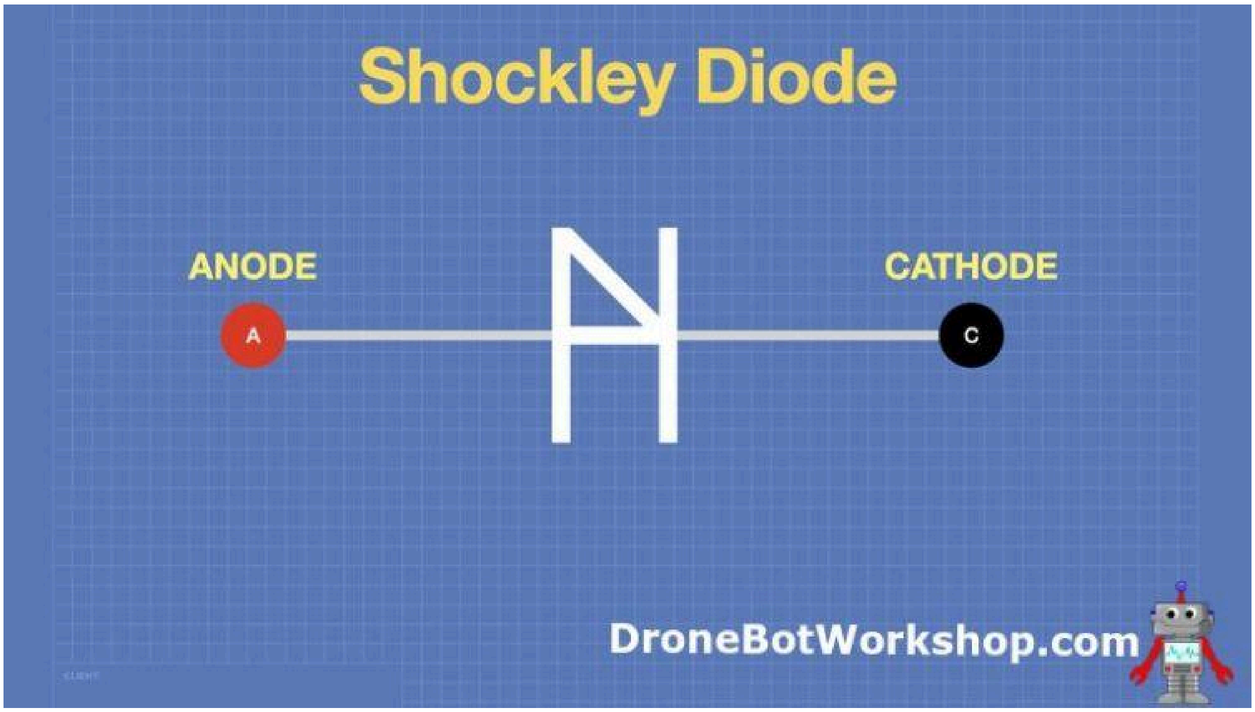
PIN Diodes are not suitable as rectifiers, instead, they work like a voltage-controlled resistor. This makes them suitable for use in attenuators.

PIN Diodes are also very fast and can switch high frequencies at high currents.

Another use for PIN diodes is as a photodetector. PIN Photodiodes are very sensitive light detectors.

Shockley Diode

Not to be confused with Schottky Diodes, the Shockley Diode is a four-layer semiconductor device. It has a very high resistance until the voltage reaches a trigger value, after which it has very low resistance.



Shockley Diodes are used as trigger devices for SCRs and TRIACs, just like a DIAC.

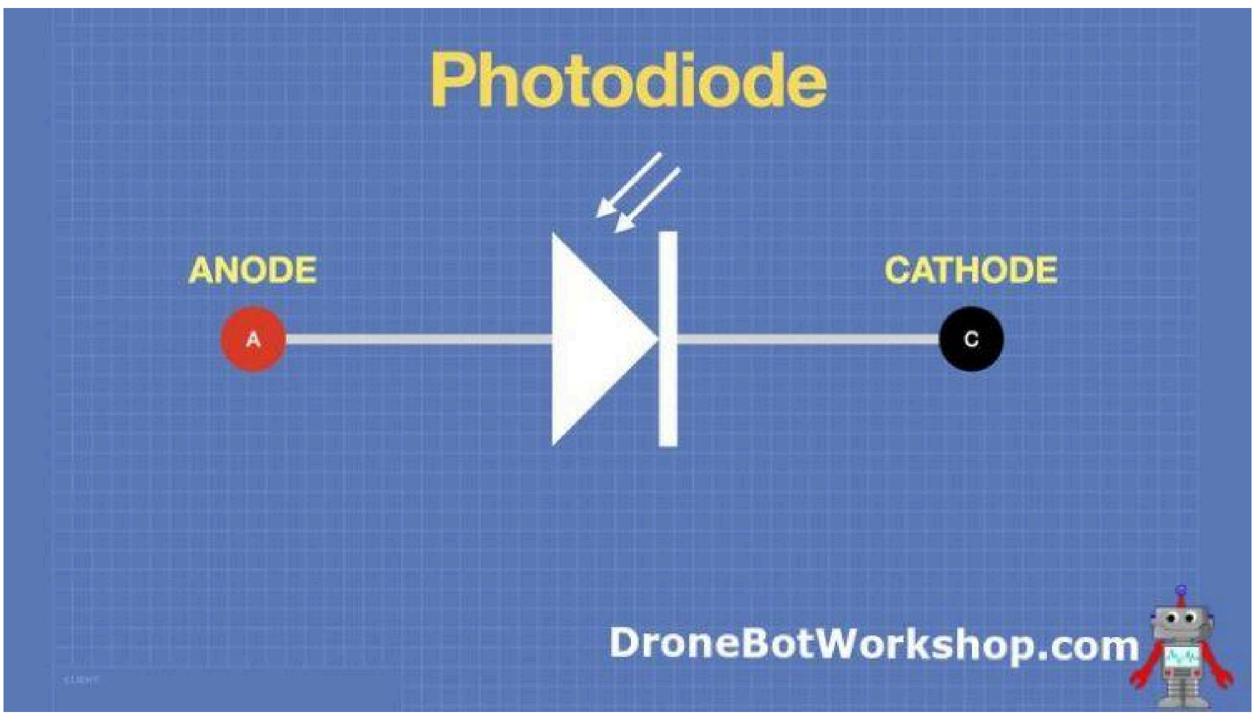
These devices are not very common and have sometimes been referred to as a “Transistor Diode”. There is also a similar device called a Dynistor.

Producing & Detecting Light with Diodes

Diodes can also be used to detect and produce light. There are several types of diodes that have these properties.

Photodiode

There are (or, more accurately, were) two types of Photodiodes – vacuum tubes and semiconductors. We will, of course, focus just on semiconductor devices.



Photodiodes convert light into electricity. Not huge amounts of electricity like solar cells, but tiny electrical currents known as Photo Currents.

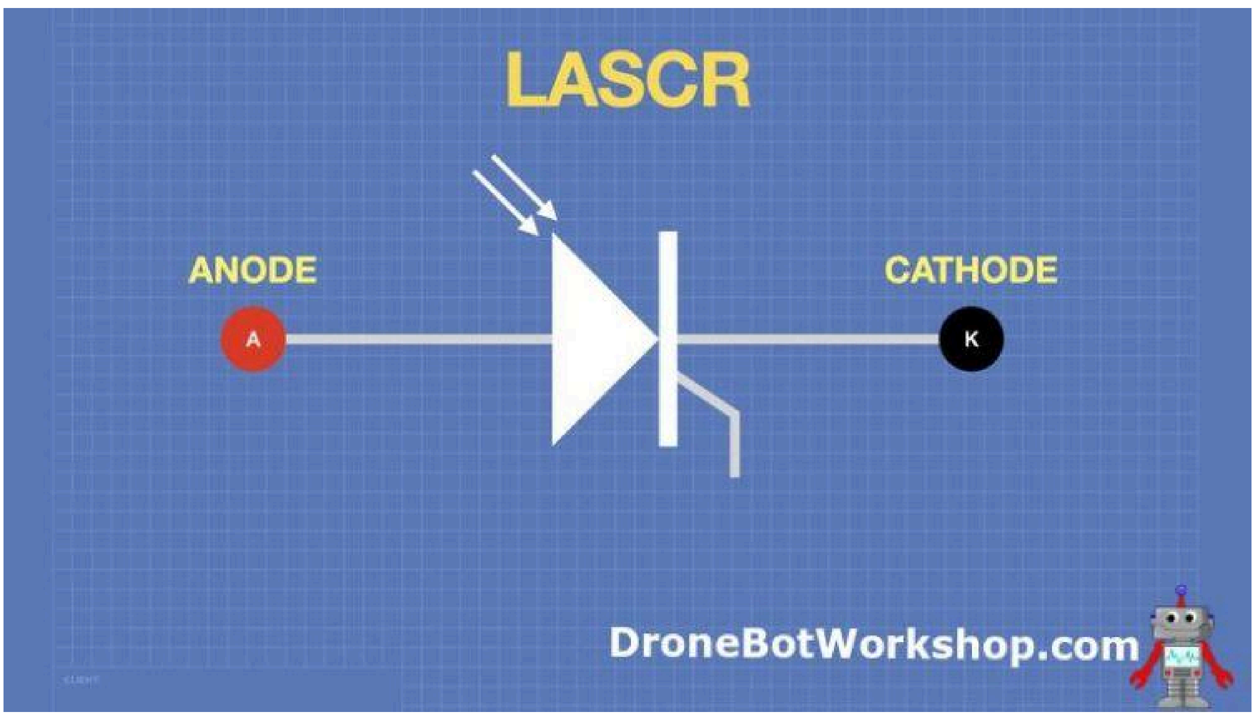
Photodiodes work when photons hit the Depletion Zone, the area between the P and N-doped semiconductor material. Photons hitting on or near the Depletion Zone will excite electrons, causing a small current to be produced.

Photodiodes can be operated in two different ways:

- **Photovoltaic Mode** – In this mode, the Photo Diode is not biased. The diode will produce electricity when exposed to light.
- **Photovoltaic Mode** – In this mode, the diode is reverse-biased. It will change conductance when exposed to light.

LASCR

The Light Activated Silicon Controlled Rectifier, or LASCR, does pretty well what its rather long name would imply.

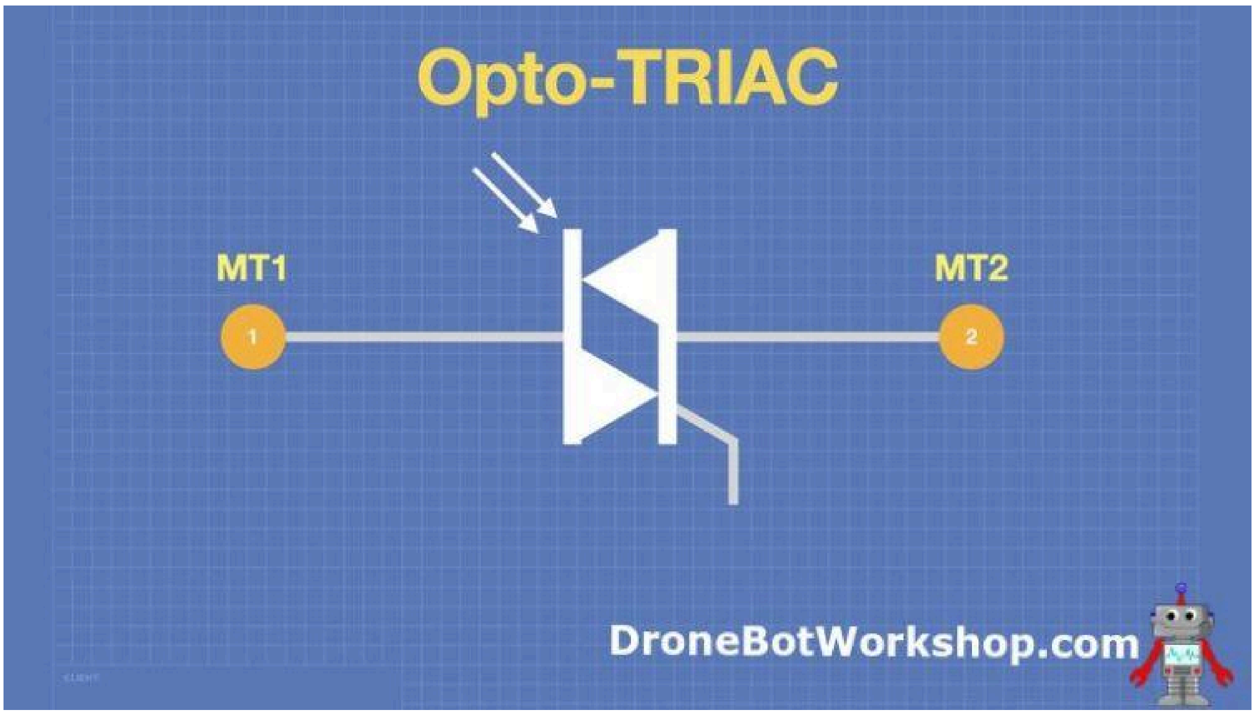


This is essentially an SCR triggered by photons instead of gate currents. It can be used as an onto-isolator, switching large DC loads using light.

As with a standard SCR, the LASCR continues to conduct current after exposure to light. The current needs to drop below the Holding Level to stop conduction.

Opto-TRIAC

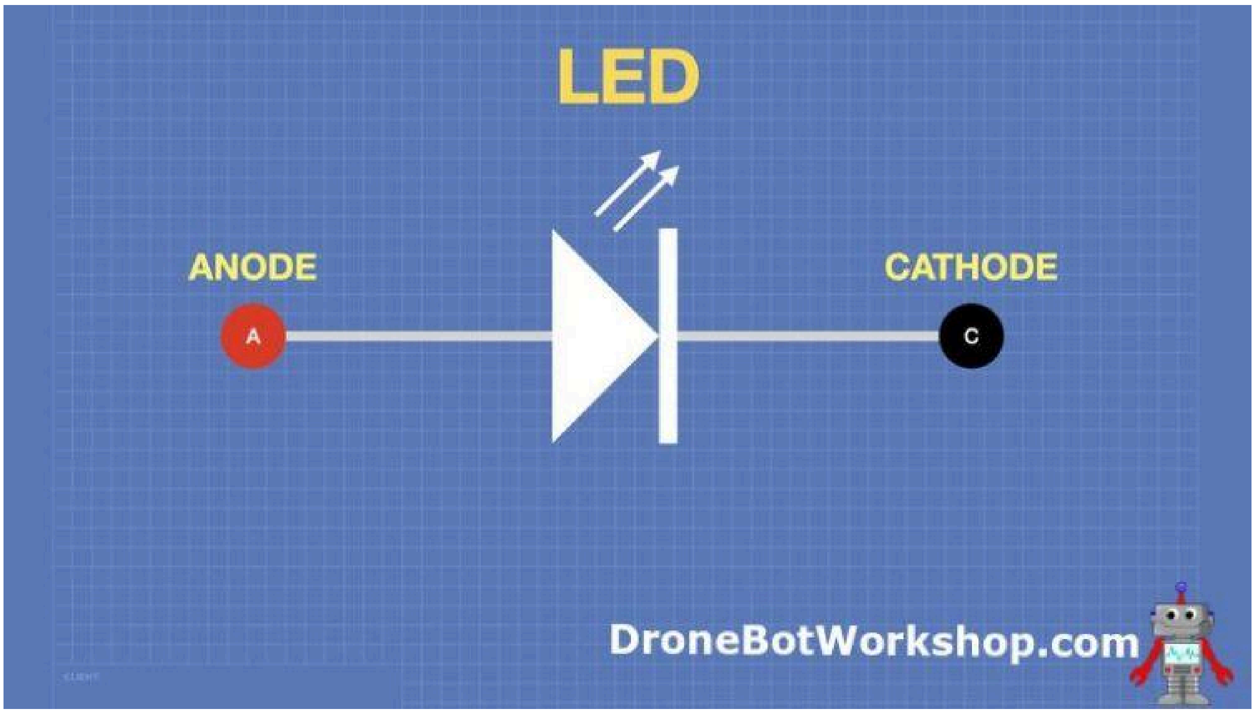
Once again, a component that does exactly what it sounds like.



This is the TRIAC version of the LASCR, it is like a standard TRIAC but triggered by light. It operates like a standard TRIAC and is used for switching alternating current.

Light-Emitting Diode (LED)

If there were a popularity contest for diodes, the LED would easily win. LEDs are everywhere, from display indicators to lights in our homes, offices, and vehicles. They are used for video displays and display backlights. They are an efficient and economical method of producing light on a wide spectrum of colors.



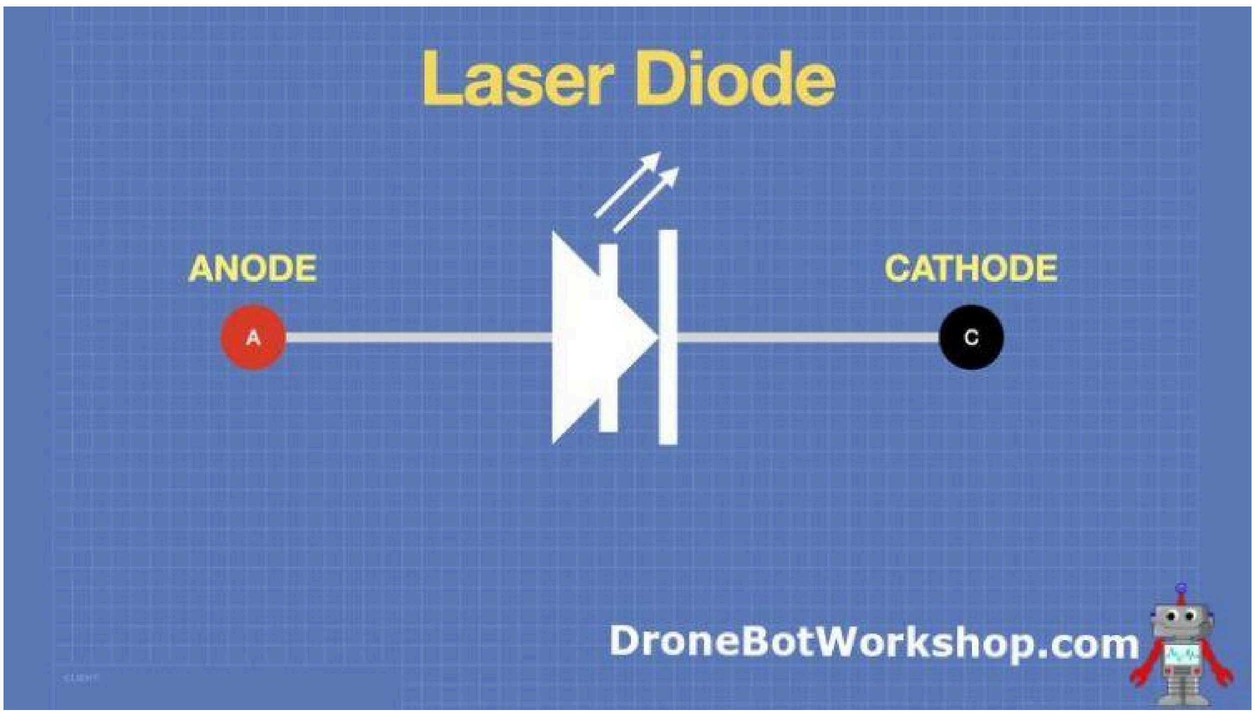
LEDs emit light when current is passed through them. The color, or wavelength, of that light, is determined by the *Band Gap* in the semiconductor. A *Band Gap* is an energy range where no electronic state exists. White LEDs are a bit different; they either use multiple layers with different Band Gaps or a layer of light-emitting phosphor.

LEDs are available in a wide spectrum, from Infrared to Visible to Ultraviolet. We have used LEDs in all spectrums here in the DroneBot Workshop.

When using an LED, you must limit the current applied to the device. With most LEDs, this is accomplished with a current-limiting resistor.

LASER Diodes

LASER is an acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. The first laser was built in 1960 by Theodore Maiman at Hughes Research Laboratories.



A LASER is unique in that it emits coherent light, that is, light that does not contain any interfering waves. Most light consists of multiple waves and is incoherent. The focused energy of a LASER makes it suitable for a wide range of applications.

A LASER Diode can also be called an LD or ILD (**I**njection **L**aser **D**iode). It creates a Lasing Condition at the diode junction when current is applied. This stimulates photon emission through molecular transitions – when an electron transitions from one level to another, it produces a photon. When this process is repeated, Stimulated Emission occurs.

LASER Diodes have multiple uses, from medical and industrial to communications and data storage.

Driving LASER Diodes

LASER Diodes require a constant-current source to operate. Simply applying voltage to them will burn them out instantly.

Many commercially available LASER Diodes have the constant-current source built-in. These diodes can be powered directly from a power supply.

Conclusion

Diodes may seem simple, but when you peek under the hood they have a number of interesting characteristics. There is a lot more to diodes than meets the eye.

Of course, diodes that produce light are really in a class of their own. We have used LEDs several times here in the DroneBot Workshop, and soon, we will be presenting another video dedicated to LASER Diodes. So stay tuned for that.