

RECTIFIERS & DIODE BRIDGES

Definitions

A **rectifier** is an electrical device, mainly consists of diodes, that converts alternating current to direct current or at least to current with only positive value, a process known as **rectification**.

A **diode bridge** or **bridge rectifier** is an arrangement of four diodes connected in a bridge circuit, that provides the same polarity of output voltage for any polarity of the input voltage.

Topics of Interest

A **rectifier** is an electrical device that converts alternating current to direct current or at least to current with only positive value, a process known as **rectification**. Rectifiers are used as components of power supplies and as detectors of radio signals. Rectifiers may be made of solid state diodes, vacuum tube diodes, mercury arc valves, and other components.

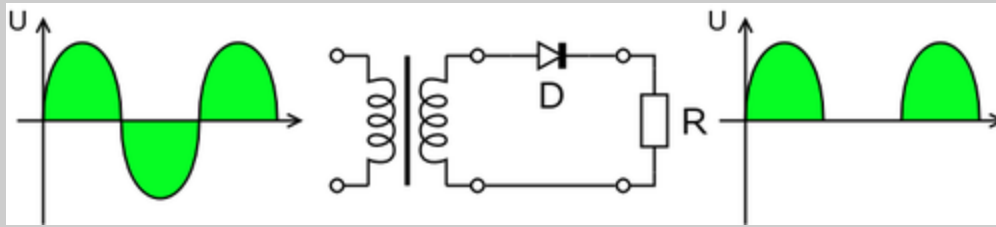
A circuit which performs the opposite function (converting DC to AC) is known as an inverter.

When only one diode is used to rectify AC (by blocking the negative or positive portion of the waveform), the difference between the term *diode* and the term *rectifier* is merely one of usage, i.e., the term *rectifier* describes a *diode* that is being used to convert AC to DC. Almost all rectifiers comprise a number of diodes in a specific arrangement for more efficiently converting AC to DC than is possible with only one diode. Before the development of silicon semiconductor rectifiers, vacuum tube diodes and copper(I) oxide or selenium rectifier stacks were used.

Early radio receivers, called crystal radios, used a "cat's whisker" of fine wire pressing on a crystal of galena (lead sulfide) to serve as a point-contact rectifier or "crystal detector". In gas heating systems **flame rectification** can be used to detect a flame. Two metal electrodes in the outer layer of the flame provide a current path and rectification of an applied alternating voltage, but only while the flame is present.

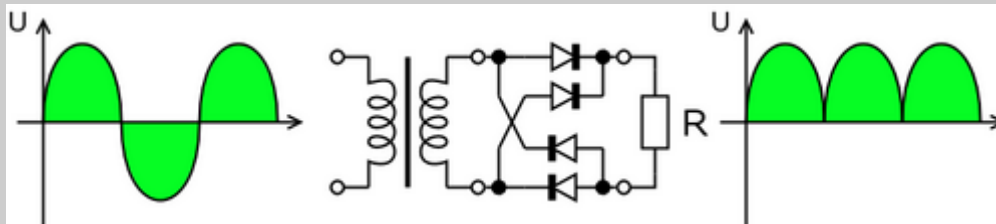
Half-wave rectification

A half wave rectifier is a special case of a clipper. In half wave rectification, either the positive or negative half of the AC wave is passed easily, while the other half is blocked, depending on the polarity of the rectifier. Because only one half of the input waveform reaches the output, it is very inefficient if used for power transfer. Half-wave rectification can be achieved with a single diode in a one phase supply.



Full-wave rectification

Full-wave rectification converts both polarities of the input waveform to DC (direct current), and is more efficient. However, in a circuit with a non-center tapped transformer, four diodes are required instead of the one needed for half-wave rectification. This is due to each output polarity requiring two rectifiers each, for example, one for when AC terminal 'X' is positive and one for when AC terminal 'Y' is positive. The other DC output requires exactly the same, resulting in four individual junctions (See semiconductors, diode). Four rectifiers arranged this way are called a diode bridge or bridge rectifier:



A full-wave rectifier converts the whole of the input waveform to one of constant polarity (positive or negative) at its output by reversing the negative (or positive) portions of the alternating current waveform. The positive (or negative) portions thus combine with the reversed negative (or positive) portions to produce an entirely positive (or negative) voltage/current waveform.

Peak loss

An aspect of most rectification is a loss from peak input voltage to the peak output voltage, caused by the threshold voltage of the diodes (around 0.7 V for ordinary silicon p-n-junction diodes and 0.1 V for Schottky diodes). Half-wave rectification and full-wave rectification using two separate secondaries will have a peak voltage loss of one diode drop. Bridge rectification will have a loss of two diode drops. This may represent significant power loss in very low voltage supplies. In addition, the diodes will not conduct below this voltage, so the circuit is only passing current through for a portion of each half-cycle, causing short segments of zero voltage to appear between each "hump".

Rectifier output smoothing

While half- and full-wave rectification suffice to deliver a form of DC output, neither produces constant-voltage DC. In order to produce steady DC from a rectified AC supply, a smoothing circuit, sometimes called a filter, is required. In its simplest form this can be what is known as a reservoir capacitor, Filter capacitor or smoothing capacitor, placed at the DC output of the rectifier. There will still remain an amount

of AC ripple voltage where the voltage is not completely smoothed.

Sizing of the capacitor represents a tradeoff. For a given load, a larger capacitor will reduce ripple but will cost more and will create higher peak currents in the transformer secondary and in the supply feeding it. In extreme cases where many rectifiers are loaded onto a power distribution circuit, it may prove difficult for the power distribution authority to maintain a correctly shaped sinusoidal voltage curve.

For a given tolerable ripple the required capacitor size is proportional to the load current and inversely proportional to the supply frequency and the number of output peaks of the rectifier per input cycle. The load current and the supply frequency are generally outside the control of the designer of the rectifier system but the number of peaks per input cycle can be affected by the choice of rectifier design.

A half-wave rectifier will only give one peak per cycle and for this and other reasons is only used in very small power supplies. A full wave rectifier achieves two peaks per cycle and this is the best that can be done with single-phase input. For three-phase inputs a three-phase bridge will give six peaks per cycle and even higher numbers of peaks can be achieved by using transformer networks placed before the rectifier to convert to a higher phase order.

To further reduce this ripple, a capacitor-input filter can be used. This complements the reservoir capacitor with a choke and a second filter capacitor, so that a steadier DC output can be obtained across the terminals of the filter capacitor. The choke presents a high impedance to the ripple current.

If the DC load is very demanding of a smooth supply voltage, a voltage regulator will be used either instead of or in addition to the capacitor-input filter, both to remove the last of the ripple and to deal with variations in supply and load characteristics.

Voltage-doubling rectifiers

The simple half wave rectifier can be built in two versions with the diode pointing in opposite directions, one version connects the negative terminal of the output direct to the AC supply and the other connects the positive terminal of the output direct to the AC supply. By combining both of these with separate output smoothing it is possible to get an output voltage of nearly double the peak AC input voltage. This also provides a tap in the middle which allows use of such a circuit as a split rail supply.

A variant of this is to use two capacitors in series for the output smoothing on a bridge rectifier then place a switch between the midpoint of those capacitors and one of the AC input terminals. With the switch open this circuit will act like a normal bridge rectifier with it closed it will act like a voltage doubling rectifier. In other words this makes it easy to derive a voltage of roughly 320V (+/- around 15%) DC from any mains supply in the world, this can then be fed into a relatively simple switched mode power supply.

Applications

The primary application of rectifiers is to derive usable DC power from an AC supply. Virtually all electronics except simple motor circuits such as fans require a DC supply but mains power is AC so

rectifiers find uses inside the power supplies of virtually all electronic equipment.

Converting DC voltage from one level to another is much more complicated. One method of such DC-to-DC conversion is to first convert to AC (using a device called an inverter), then use a transformer to change the voltage, and finally rectify it back to DC.

Rectifiers also find a use in detection of amplitude modulated radio signals. The signal may or may not be amplified before detection but if unamplified a very low voltage drop diode must be used. When using a rectifier for demodulation the capacitor and load resistance must be carefully matched. Too low a capacitance will result in the high frequency carrier passing to the output and too high will result in the capacitor just charging and staying charged.

Rectifiers are also used to supply polarised voltage for welding. In such circuits control of the output current is required and this is sometimes achieved by replacing some of the diodes in bridge rectifier with thyristors, whose voltage output can be regulated by means of phase fired controllers.

High-power rectification

Vacuum tubes, metal oxide rectifier stacks and semiconductor diodes are useful in the range of milliamperes to several thousand amperes of current in a single device.

Some interesting electromechanical solutions have been devised and were used before the advent of electron devices. For example, to convert AC current into DC current in electric locomotives, a **synchronous rectifier** may be used. It consists of a synchronous motor driving a set of heavy-duty electrical contacts. The motor spins in time with the AC frequency and periodically reverses the connections to the load just when the sinusoidal current goes through a zero-crossing. The contacts do not have to *switch* a large current, but they need to be able to *carry* a large current to supply the locomotive's DC traction motors. In the past, the vibrators used in battery-to-high-voltage-DC power supplies often contained a second set of contacts that performed synchronous mechanical rectification of the stepped-up voltage.

In recent years semiconductor synchronous rectifiers have been designed; using MOSFET transistors, they can also rectify with a very low forward voltage drop and have the additional advantage of being able to switch at extremely high speeds. Semiconductor synchronous rectifiers are now widely used in those electronic power supply units designed for very low output voltages (where the voltage drop in an ordinary rectifier would represent an unacceptable fraction of the total output voltage).

Another type of rectifier used in high-voltage direct current power transmission systems and industrial processing between about 1909 to 1975 is a **mercury arc rectifier** or mercury arc valve. The device is enclosed in a bulbous glass vessel or large metal tub. One electrode, the cathode, is submerged in a pool of liquid mercury at the bottom of the vessel and one or more high purity graphite electrodes, called anodes, are suspended above the pool. There may be several auxiliary electrodes to aid in starting and maintaining the arc. When an electric arc is established between the cathode pool and suspended anodes, a stream of electrons flows from the cathode to the anodes through the ionized mercury, but not the other way. These devices can be used at power levels of hundreds of kilowatts, and may be built to handle one to six phases

of AC current. Mercury arc rectifiers have largely been replaced by silicon semiconductor rectifiers from the mid 1970s onward. The most powerful mercury arc rectifiers ever built were installed in the Manitoba Hydro Nelson River Bipole HVDC project, with a combined rating of more than one million kilowatts and 450,000 volts.

The General Electric Tungar rectifier was an argon gas-filled electron tube device with a tungsten filament cathode and a carbon button anode. It was useful for battery chargers and similar applications from the 1920's until low-cost solid state rectifiers supplanted it. These were made up to a few hundred volts and a few amperes rating, and in some sizes strongly resembled an incandescent lamp with an additional electrode.

Another type of rectifier, a **motor-generator set** or the similar rotary converter, is not a rectifier in the strict sense. Here, an AC motor is mechanically coupled to a DC generator. The DC generator produces a multiphase alternating current in its windings, but a commutator is used to convert the alternating currents into a direct current output; or a homopolar generator directly produces direct current without need for a commutator. Such devices are useful for producing thousands of amperes of direct current at tens to hundreds of volts.

Diode Bridge Operation

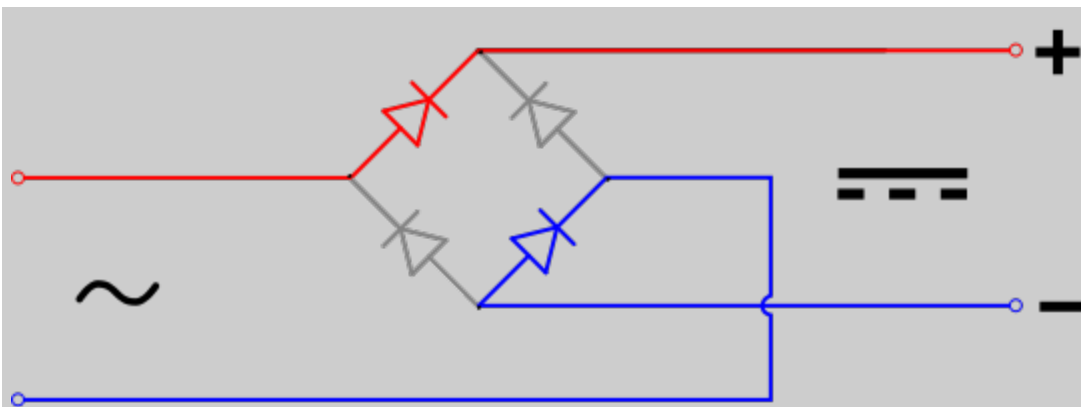
A **diode bridge** or **bridge rectifier** is an arrangement of four diodes connected in a bridge circuit, that provides the same polarity of output voltage for any polarity of the input voltage. When used in its most common application, for conversion of alternating current (AC) input into direct current (DC) output, it is known as a bridge rectifier. The bridge rectifier provides full wave rectification from a two wire AC input (saving the cost of a center tapped transformer) but has two diode drops rather than one reducing efficiency over a center tap based design for the same output voltage.

The essential feature of this arrangement is that for both polarities of the voltage at the bridge input, the polarity of the output is constant.

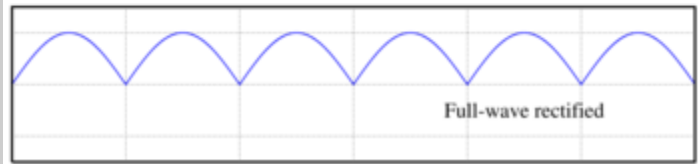
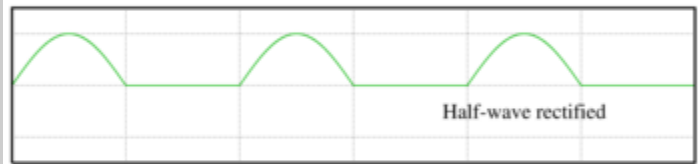
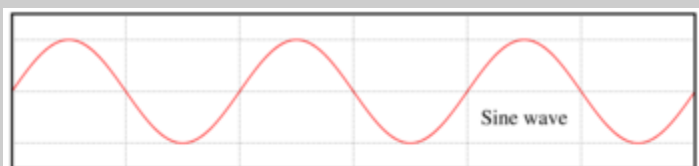
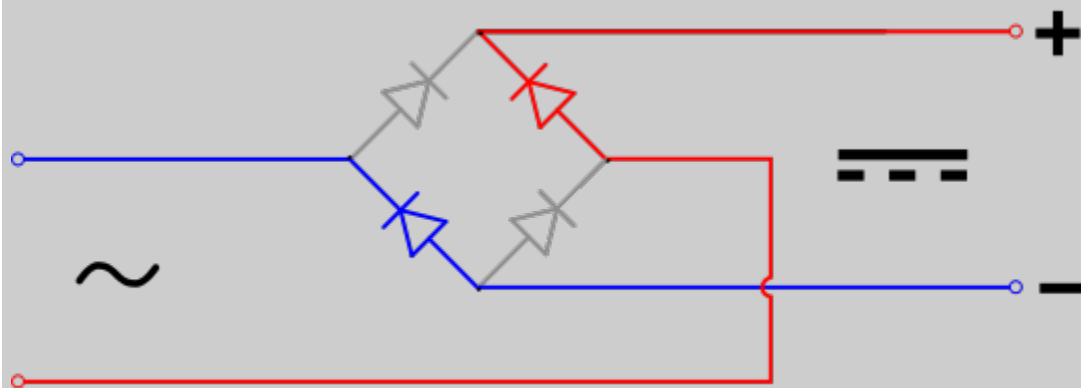
The diode bridge circuit is also known as the *Graetz circuit* after its inventor, the physicist Leo Graetz.

Basic operation

When the input connected at the left corner of the diamond is positive with respect to the one connected at the right hand corner, current flows to the right along the upper colored path to the output, and returns to the input supply via the lower one.



When the right hand corner is positive relative to the left hand corner, current flows along the upper colored path and returns to the supply via the lower colored path.



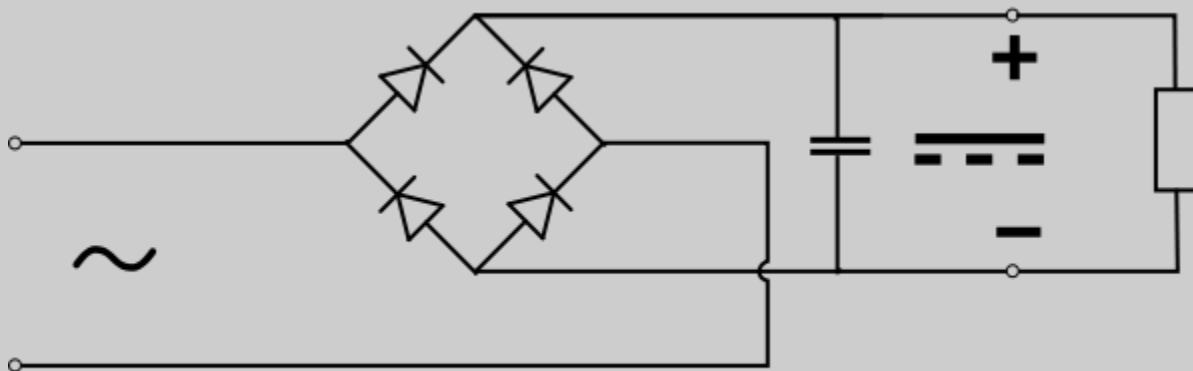
AC, half-wave and full wave rectified signals

In each case, the upper right output remains positive with respect to the lower right one. Since this is true whether the input is AC or DC, this circuit not only produces DC power when supplied with AC power: it also can provide what is sometimes called "reverse polarity protection". That is, it permits normal functioning when batteries are installed backwards or DC input-power supply wiring "has its wires crossed" (and protects the circuitry it powers against damage that might occur without this circuit in place).

Prior to availability of integrated electronics, such a bridge rectifier was always constructed from discrete components. Since about 1950, a single four-terminal component containing the four diodes connected in the bridge configuration became a standard commercial component and is now available with various voltage and current ratings.

Output smoothing

For many applications, especially with single phase AC where the full-wave bridge serves to convert an AC input into a DC output, the addition of a capacitor may be important because the bridge alone supplies an output voltage of fixed polarity but pulsating magnitude (see diagram above).



The function of this capacitor, known as a 'smoothing capacitor' (see also filter capacitor) is to lessen the variation in (or 'smooth') the raw output voltage waveform from the bridge. One explanation of 'smoothing' is that the capacitor provides a low impedance path to the AC component of the output, reducing the AC voltage across, and AC current through, the resistive load. In less technical terms, any drop in the output voltage and current of the bridge tends to be cancelled by loss of charge in the capacitor. This charge flows out as additional current through the load. Thus the change of load current and voltage is reduced relative to what would occur without the capacitor. Increases of voltage correspondingly store excess charge in the capacitor, thus moderating the change in output voltage / current. Also see rectifier output smoothing.

The simplified circuit shown has a well deserved reputation for being dangerous, because, in some applications, the capacitor can retain a *lethal* charge after the AC power source is removed. A practical circuit should *always* include an assured way to safely discharge the capacitor. If the normal load can not be guaranteed to perform this function, perhaps because it can be disconnected, the circuit should include a so-called bleeder resistor connected as close as practical across the capacitor. Because a bleeder sets a

minimum current drain, the regulation of the circuit, defined as percentage voltage change from minimum to maximum load, is improved.

The capacitor and the load resistance have a typical time constant $\tau = RC$ where C and R are the capacitance and load resistance respectively. As long as the load resistor is large enough so that this time constant is much longer than the time of one ripple cycle, the above configuration will produce a well smoothed DC voltage across the load resistance. In some designs, a series resistor at the load side of the capacitor is added. The smoothing can then be improved by adding additional stages of capacitor-resistor pairs, often done only for sub-supplies to critical high-gain circuits that tend to be sensitive to supply voltage noise.

The idealized waveforms shown above are seen for both voltage and current when the load on the bridge is resistive. When the load includes a smoothing capacitor, both the voltage and the current waveforms will be greatly changed. While the voltage is smoothed, as described above, current will flow through the bridge only during the time when the input voltage is greater than the capacitor voltage. For example, if the load draws an average current of n Amps, and the diodes conduct for 10% of the time, the average diode current during conduction must be $10n$ Amps. This non-sinusoidal current leads to harmonic distortion and a poor power factor in the AC supply.

In a practical circuit, when a capacitor is directly connected to the output of a bridge, the bridge diodes must be sized to withstand the current surge that occurs when the power is turned on at the peak of the AC voltage and the capacitor is fully discharged. Sometimes a small series resistor is included before the capacitor to limit this current.

Output can also be smoothed using a choke, a coil of conductor enclosed by an iron frame (similar to a transformer in construction). This tends to keep the current (rather than the voltage) constant. Due to the relatively high cost of an effective choke compared to a resistor and capacitor this is not employed in modern equipment. Some early console radios created the speaker's constant field with the current from the high voltage ("B +") power supply, which was then routed to the consuming circuits, rather than using a permanent magnet to create the speaker's constant magnetic field. The speaker field coil thus acted as a choke.

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