

What is a semiconductor?

A semiconductor is a substance that can either act as a conductor or insulator of electricity, making it an essential building block of computers, electronic devices, integrated circuits and other modern digital technologies.

Substances that conduct electricity are known as conductors, while substances that do not are known as insulators. Semiconductors have unique properties that apply to both, meaning that under certain conditions they can conduct electricity and under others, they can resist it. This unique classification makes semiconductors ideal for technologies such as computer chips, [artificial intelligence \(AI\) chips](#) and [Internet of Things \(IoT\) devices](#) that depend on conducting a large amount of power through a small area.

In most modern technologies, semiconductors act like tiny electrical switches, turning off and on repeatedly to enable the flow of electricity. A semiconductor's conductance—the ease or difficulty with which an electric current flows through it—varies depending on current and voltage.

Semiconductors are widely used across many industries, including personal computers (PCs), home electronics, automotive, industrial manufacturing and more. According to a recent report by the Semiconductor Industry Association (SIA), semiconductor sales have increased from USD 139 billion in 2001 to USD 526 billion in 2023. This growth represents a compound annual growth rate (CAGR) of 6%.¹

The semiconductor industry's rapid rate of innovation can be largely attributed to Moore's law—the rule that the speed and capability of computers double every two years. In the semiconductor industry, Moore's law applies to the number of transistors that a microchip must contain to keep up with the growing demands of computing devices. Leading manufacturers continually seek ways to double transistor counts biennially, ensuring advancements in semiconductor technology

How do semiconductors work?

Most semiconductors are made of crystals because of their unique atomic properties. Whereas most common conducting elements have a single electron in their outermost shell, semiconductors have four. This, and other factors, make semiconductor crystals (typically silicon) perfect for controlling the electrical currents that underpin complex, modern technological devices.

To control the flow of electricity through electronic circuits and devices, engineers manipulate the flow of electrons through semiconductors by creating regions with positive and negative charges, a process known as doping.
What is doping?

In the production of semiconductors, doping is a process where impurities, also known as impurity atoms, are intentionally introduced to a semiconductor's crystal lattice to modify its electrical properties. By introducing dopant atoms, engineers can make the material more or less conductive. There are two kinds of doping: N-type and P-type.

- **N-type doping:** N-type doping is where engineers add elements with more valence electrons than the host material. This change increases the number of free charge carriers in the atom, making the semiconductor material more conductive than it was previously.
- **P-type doping:** P-type doping also makes material more conductive, but by using a slightly different method. In P-type doping, elements with fewer valence electrons than the host material are added, creating what's known in computer science as a "hole": a place that's missing electrons that typically carry charges and increase conductivity.

Types of semiconductors

Semiconductors are typically classified into two main types: intrinsic and extrinsic. Here's a closer look at their differences.

- **Intrinsic semiconductors:** Intrinsic semiconductors are semiconductors that are made of a single, pure material that hasn't been manipulated in any way. Intrinsic semiconductors are often called 'elemental' semiconductors, as many of them are well-known elements on the periodic table, such as carbon, boron, silicon and germanium.
- **Extrinsic semiconductors:** Extrinsic semiconductors are semiconductors that have undergone doping, intentional contamination to alter a material's conductivity. Radio frequency (RF) semiconductors, for example, are considered extrinsic because they combine materials like gallium arsenide (GaAs), gallium nitride (GaN) and silicon (Si) that make semiconductors work at higher radio frequencies.

Transistors and semiconductor devices

Semiconductor devices are electronic components that use conductors and insulators to control the flow of electric currents. The most popular kind of semiconductor device is the widely used transistor, a small, durable, electronic component that powers most modern electronics.

Until transistors were invented in 1947, vacuum tubes were widely used for the same purpose. Transistors proved more compact and efficient than vacuum tubes and quickly replaced them. Today, transistors are used in a wide range of devices, including computer chips, [microprocessors](#), cars, robotic devices and more. Transistors are highly flexible; in addition to acting as conductors and insulators, they can act as switches, amplifiers and rectifiers as well.

- **Switches:** Components in semiconductor devices that are turned on or off to control the flow of an electric current.
- **Amplifiers:** Circuits that increase the magnitude of an input signal in an electronic device.
- **Rectifiers:** Rectifiers, or rectifier diodes, are small semiconductor devices that convert electric currents from alternating current (AC) to direct current (DC) by allowing electricity to flow in one direction.

What is a Transistor

The transistor is electronic equipment. It is made through a p and n-type semiconductor. When a semiconductor is placed in the center between the same type of semiconductors the arrangement is called transistors. We can say that a transistor is the combination of two diodes it is a connection back to back. A transistor is a device that regulates current or voltage flow and acts as a button or gate for electronic signals.

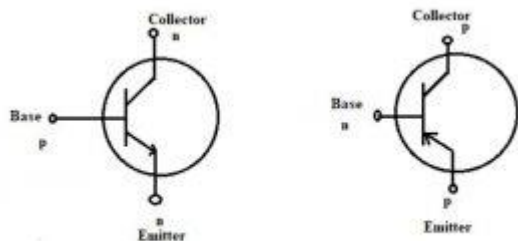


Types of Transistors

Transistors consist of three layers of a **semiconductor device**, each capable of moving a current. A semiconductor is a material such as germanium and silicon that conducts electricity in a “semi-enthusiastic” way. It’s anywhere between a genuine conductor such as a copper and an insulator (similar to the plastic-wrapped roughly wires).

Transistor Symbol

A diagrammatic form of n-p-n and p-n-p transistor is exposed. In-circuit is a connection drawn form is used. The arrow symbol defined the emitter current. In the n-p-n connection, we identify electrons flow into the emitter. This means that the conservative current flows out of the emitter as indicated by the outgoing arrow. Equally, it can be seen that for the p-n-p connection, the conservative current flows into the emitter as exposed by the inward arrow in the figure.



CElprocuz.com

PNP and NPN Transistors

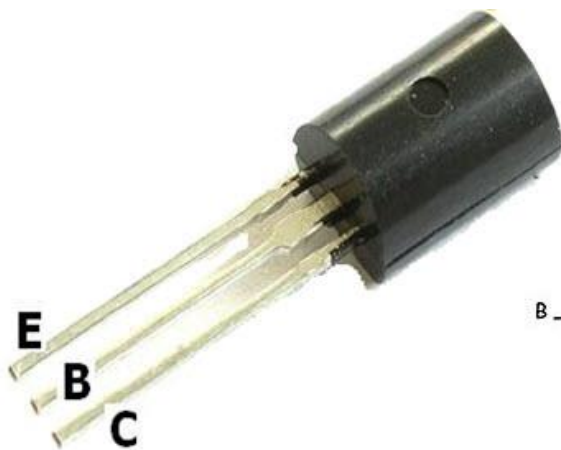
There are so many types of transistors and they each vary in their characteristics and each has its own advantages and disadvantages. Some types of transistors are used mostly for switching applications. Others can be used for both switching and amplification. Still, other transistors are in a specialty group all of their own, such as **phototransistors**, which react to the amount of light shining on it to produce current flow through it. Below is a list of the different types of transistors; we will go over the characteristics that create them each up

What are the Two Main Types of Transistors?

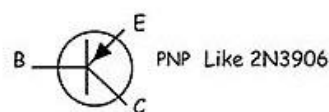
Transistors are classified into two types like BJTs and FETs.

Bipolar Junction Transistor (BJT)

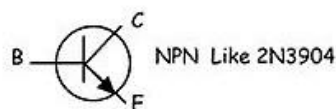
Bipolar Junction Transistors are transistors that are built up of 3 regions, the base, the collector, and the emitter. Bipolar Junction transistors, different FET transistors, are current-controlled devices. A small current entering the base region of the transistor causes a much larger current flow from the emitter to the collector region. Bipolar junction transistors come in two major types, NPN and PNP. An NPN transistor is one in which the majority of the current carriers are electrons. Electron flowing from the emitter to the collector forms the base of the majority of current flow through the transistor. The further types of charge, holes, are a minority. PNP transistors are the opposite. In PNP transistors, the majority of current carrier holes. BJT transistors are available in two types namely PNP and NPN



Transistor pins



PNP Like 2N3906



NPN Like 2N3904

Bipolar Junction

PNP Transistor

This transistor is another kind of BJT – Bipolar Junction Transistors and it contains two p-type semiconductor materials. These materials are divided through a thin n-

type semiconductor layer. In these transistors, the majority charge carriers are holes whereas the minority charge carriers are electrons.

In this transistor, the arrow symbol indicates the conventional current flow. The direction of current flow in this transistor is from the emitter terminal to the collector terminal. This transistor will be turned ON once the base terminal is dragged to LOW as compared with the emitter terminal. The PNP transistor with a symbol is shown below.

NPN Transistor

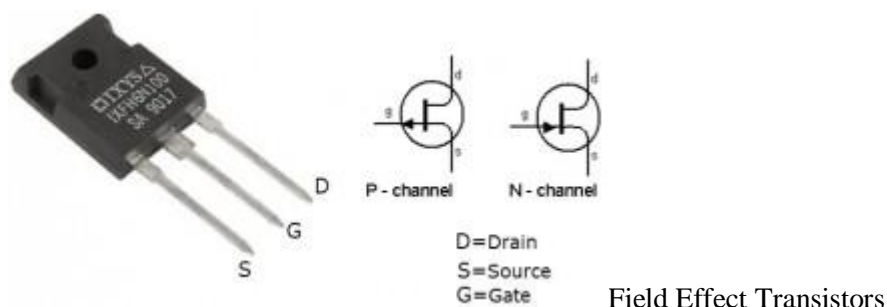
NPN is also one kind of BJT (Bipolar Junction Transistors) and it includes two n-type semiconductor materials which are divided through a thin p-type semiconductor layer. IN the NPN transistor, the majority charge carriers are electrons whereas the minority charge carriers are holes. The electrons flow from the emitter terminal to the collector terminal will form the current flow within the base terminal of the transistor.

In the transistor, the less amount of current supply at the base terminal can cause supply huge amount of current from the emitter terminal to the collector. At present, the commonly used BJTs are NPN transistors, as the electrons mobility is higher as compared with the mobility of holes. The NPN transistor with a symbol is shown below.

Field Effect Transistor

Field Effect Transistors are made up of 3 regions, a gate, a source, and a drain. Different bipolar transistors, FETs are voltage-controlled devices. A voltage placed at the gate controls current flow from the source to the drain of the transistor. Field Effect transistors have a very high input impedance, from several mega ohms (M Ω) of resistance to much, much larger values.

This high input impedance causes them to have very little current run through them. (According to ohm's law, the current is inversely affected by the value of the impedance of the circuit. If the impedance is high, the current is very low.) So FETs both draw very little current from a circuit's power source.



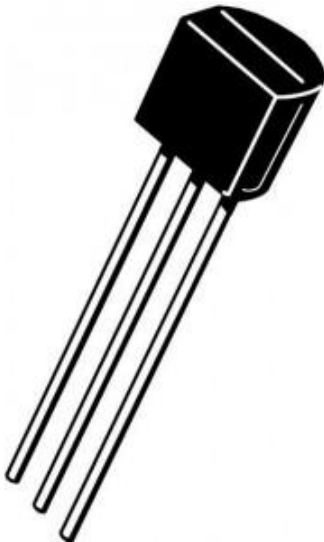
Thus, this is ideal because they don't disturb the original circuit power elements to which they are connected to. They won't cause the power source to be loaded down. The drawback of FETs is that they won't provide the same amplification that could be gotten from bipolar transistors.

Bipolar transistors are superior in the fact that they provide greater amplification, even though FETs are better in that they cause less loading, are cheaper, and easier to manufacture. Field Effect Transistors come in 2 main types: JFETs and MOSFETs. JFETs and MOSFETs are very similar but MOSFETs have even higher input impedance values than JFETs. This causes even less loading in a circuit. FET transistors are classified into two types namely JFET and MOSFET.

JFET

The JFET stands for Junction-Field-Effect transistor. This is simple as well as an initial type of FET transistors which are utilized like resistors, amplifiers, switches, etc. This is a voltage-controlled device and it doesn't use any biasing current. Once the voltage is applied among gate & source terminals then it controls the current flow among the source & drain of the JFET transistor.

The **Junction Field Effect Transistor** (JUGFET or JFET) has no PN-junctions but in its place has a narrow part of high resistivity semiconductor material forming a "Channel" of either N-type or P-type silicon for the majority carriers to flow through with two ohmic electrical connections at either end normally called the Drain and the Source respectively.



Junction Field Effect Transistors

There are two basic configurations of a junction field-effect transistor, the N-channel JFET and the P-channel JFET. The N-channel JFET's channel is doped with donor impurities meaning that the flow of current through the channel is negative (hence the term N-channel) in the form of electrons. These transistors are accessible in both P-channel and N-channel types.

MOSFET

MOSFET or Metal-Oxide-Semiconductor Field-Effect Transistor is most frequently used among all kinds of transistors. As the name suggests, it includes the terminal of the metal gate. This transistor includes four terminals like source, drain, gate & substrate, or body.



MOSFET

As compared with BJT and JFET, MOSFETs has several benefits as it provides high i/p impedance as well as low o/p impedance. MOSFETs are mainly used in low power circuits especially while designing chips. These transistors are available in two types like depletion & enhancement. Further, these types are categorized into P-channel & N-channel types.

The main **features of FET** include the following.

- It is unipolar because the charge carriers like either electrons or holes are accountable for transmission.
- In FET, the input current will flow because of the reverse bias. Therefore the input impedance of this transistor is high.
- When the o/p voltage of the field-effect transistor is controlled through the input voltage of the gate, then this transistor is named the voltage-controlled device.
- In the conduction lane, there are no junctions present. So FETs have less noise as compared with BJTs.
- The characterization of gain can be done with transconductance because it is the ratio of o/p change current and input voltage change
- The o/p impedance of the FET is low.

Advantages of FET

The advantages of FET as compared with BJT include the following.

- FET is a unipolar device whereas the BJT is a bipolar device
- FET is a voltage-driven device whereas the BJT is a current-driven device
- The i/p impedance of the FET is high whereas BJT has low
- The noise level of FET is low as compared with BJT
- In FET, thermal stability is high whereas BJT has low.

- The gain characterization of FET can be done through transconductance whereas in BJT with a voltage gain

Applications of FET

The applications of FET include the following.

- These transistors are used within different circuits to decrease the loading effect.
- These are used in several circuits like Phase shift Oscillators, Voltmeters & Buffer amplifiers.

FET Terminals

FET has three terminals like source, gate, and drain which are not similar to the terminals of BJT. In FET, the Source terminal is similar to the Emitter terminal of BJT, whereas the Gate terminal is similar to the Base terminal & Drain terminal to the Collector terminal.

Source Terminal

- In FET, the source terminal is the one through which the charge carriers enter the channel.
- This is similar to the emitter terminal of BJT
- The source terminal can be represented with 'S'.
- The flow of current through the channel on the source terminal can be specified like I_S .

Gate Terminal

- In a FET, the Gate terminal plays an essential role to control the flow of current throughout the channel.
- The flow of current can be controlled through the gate terminal by providing an external voltage to it.
- Gate terminal is a blend of two terminals which are internally connected and are doped heavily. The conductivity of the channel can be modulated through the Gate terminal.
- This is similar to the base terminal of BJT
- The gate terminal can be represented with 'G'.
- The flow of current through the channel at the Gate terminal can be specified as I_G .

Drain Terminal

- In FET, the drain terminal is the one through which the carriers leave the channel.
- This is analogous to the collector terminal in a Bipolar Junction Transistor.
- The Drain to Source voltage is designated as V_{DS} .
- The Drain terminal can be designated as D.

- The flow of current moving away from the channel at the Drain terminal can be specified as I_D

Amplifier

- An amplifier is one of the most commonly used electronic devices in the world. It's a basic building block of a vast number of circuits, and comes in various forms. Amplifiers can be defined simply as an electronic device that increases the power of a signal. In other words, it increases the amplitude of a signal, and makes it stronger than the given input.
- Although this sounds simple in theory, amplifiers have a lot of parameters and conditions in the real world. Amplification is never perfectly efficient, there are always losses, distortion and noise to deal with.
- Thus, there are a whole load of amplifiers created, that work best in different situations. Not all amplifiers provide optimal output in all situations, and there's always cost factors to consider. So here's all the types of amplifiers and all you need to know about them!
- **Important Characteristics of an Amplifier**
 - The quality of an amplifier is measured by a series of specifications called fi
 - **Bandwidth:** The frequency range at which the amplifier can operate.
 - **Noise:** The amount of unwanted extra information included in the output.
 - **Skew Rate:** The maximum rate of change of output.
 - **Gain:** Perhaps the most important, the ratio between the magnitudes of input and output signals.
- **Stability:** The ability to provide constant and reliable output.
- **Linearity:** The degree of proportionality between input and output signals.
- **Efficiency:** Another very important characteristic, it is the ratio between the output power and power consumed.
- **Output Dynamic Range:** Ratio between the largest and smallest useful output levels.

Types of Amplifiers

Although amplifiers are sometimes classified according to input and output parameters (we'll get to that), there are 4 basic types, which are:

- **Current Amplifier:** As the name suggests, an amplifier that makes the given input current higher. It is characterized by a low input impedance and high output impedance.
- **Voltage Amplifier:** An amplifier that amplifies given voltage for a larger voltage output. It is characterized by a high input impedance and low output impedance.
- **Transconductance Amplifier:** An amplifier that changes output current according to changing input voltage.
- **Transresistance Amplifier:** An amplifier that changes output voltage according to changing input current. It is also known as a current-to-voltage converter.

Apart from the basic types, there are several other types of amplifiers, categorized by their operation, application or characteristics. Some of them are:

- **Power Amplifiers:** Although not technically a type, [power amplifier](#) is a general term that refers to the amount of power provided by the power supply circuit or the amount of power delivered to the load. It is usually used in the last output stages of a circuit. Examples include: audio power amplifiers, servo motor controllers, push-pull amplifiers and RF power amplifiers. Again, we'll look at the classifications of power amplifiers specifically in a little bit, since they're very important.
- **Operational Amplifiers (Op-Amps):** Another very important type, an op-amp is an integrated circuit that acts as a voltage amplifier, and has differential input. It has a positive and negative input, but a single output with very high gain. Originally, op-amps were created using valves.
- Please refer to this link to know more about [operational amplifier MCQs](#)
- **Valve (or) Vacuum Tube Amplifiers:** An amplifier that uses vacuum tubes to provide an increased power or voltage output is known as a valve (or) vacuum tube amplifier. As mentioned above, op-amps were originally of the valve type, but were replaced by ICs once they got cheaper, in smaller applications at least. In high power applications, they're still in use because of their cost effectiveness and output quality. They are used in radar, military, high power radio and UHF transmitter applications.
- **Transistor Amplifiers:** A well known type of amplifier, specially to engineering students, a transistor amplifier is a multi configuration high output amplifier that uses transistors as the working base. These include bipolar junction transistors (BJTs) and metal oxide semiconductor field-effect transistors (MOSFETs).
- **Klystron:** A special type of linear beam vacuum tube, used as an amplifier in high radio frequencies. It is highly precise and used in large scale operations, usually comes under Microwave amplifiers.
- **Instrument Amplifiers:** Specially designed amplifiers to amplify sound, voice or music. Used mainly in musical instrument applications.
- **Distributed Amplifiers:** Amplifiers that use transmission lines to temporarily split the input and amplify each segment individually are called distributed amplifiers. They're commonly found in oscilloscopes.

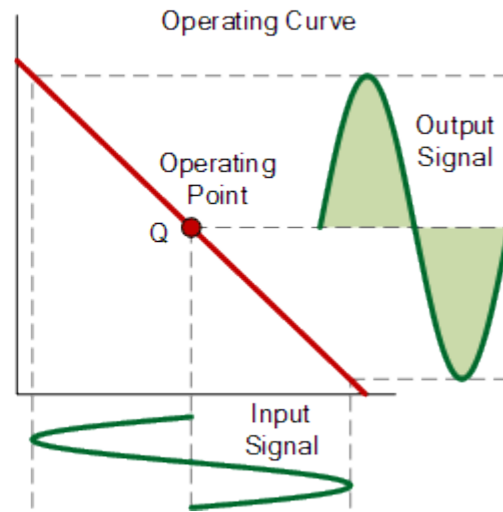
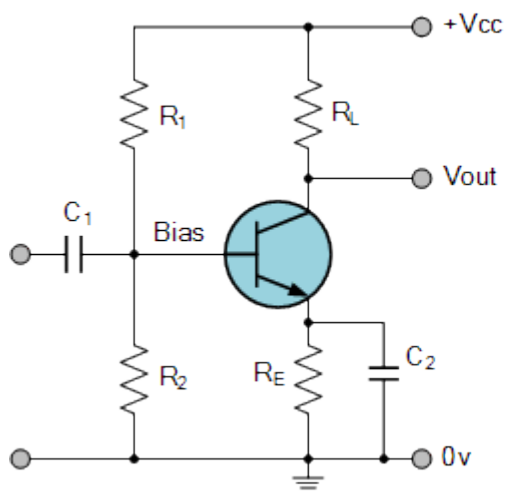
These are just a few types of amplifiers in use right now, and it's pretty obvious that each of them has an area of specialization, more or less. There are a vast number of applications in the world, and there's an amplifier for almost all of them.

Types of Power Amplifiers

Now, the most well known types of amplifiers aren't the ones described above, but power amplifier types. Often confused as the only categories of amplifiers, they are actually types of power amplifiers and are classified on the basis of the proportion of the input cycle during which the amplifier is giving an output. The proportion of the active input cycle is also known as conduction angle. For example, a 360 degrees conduction angle means that the device is always on, a conduction angle of 180 degrees means that the device is on only for half of each cycle. Now, the different types of power amplifiers are described below:

Please refer to this link to know more about [Transistor Audio Power Amplifiers MCQs](#)

Class A Power Amplifier



Discover more

integrated circuit

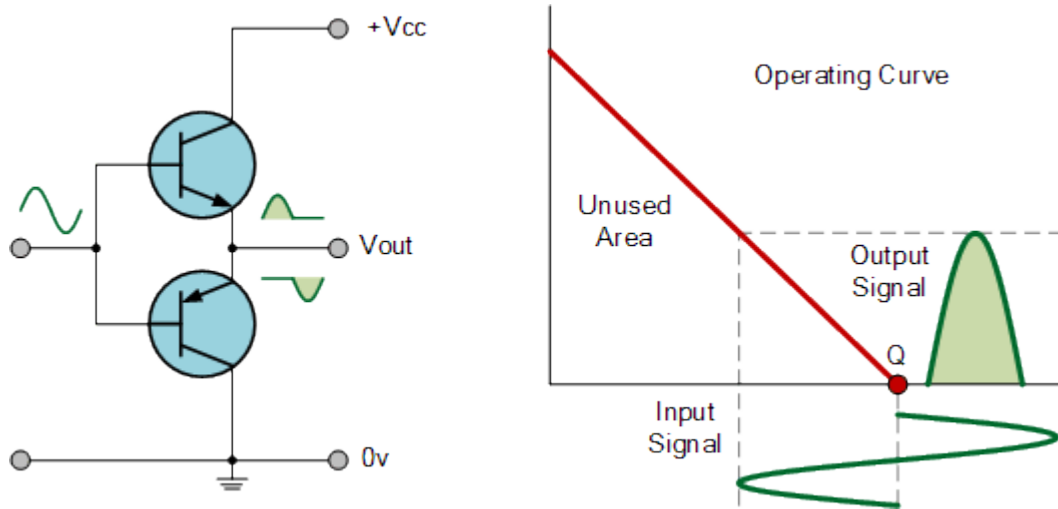
Amplifiers

IC

An amplifier that conducts during the full cycle, or has a conducting angle of 360 degrees is known as a Class A power amplifier. It is the simplest and most common type of power amplifier, because of low signal distortion levels. It has its fair share of disadvantages though, and is generally not used in high power applications. Some of its characteristics are:

- Low signal distortion levels
- Simple design
- The device is always conducting due to amplifying element bias
- No turn on time or charge storage problems
- Quite stable
- Highest linearity
- Low efficiency due to being on all the time, around the vicinity of 25-50%
- High heat output during operation

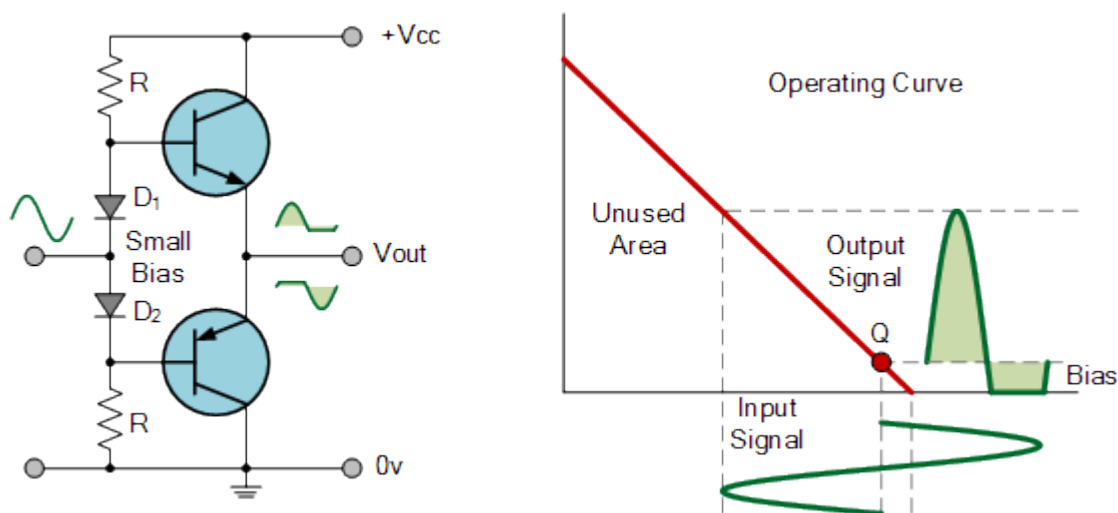
Class B Power Amplifier



Class B Power Amplifiers, unlike Class A, work for only half of each input cycle, which means they have a conducting angle of 180 degrees. In simple words, these amplifiers amplify only half of the input cycle. On paper that probably sounds unusable, but in reality, it's quite different. A Class B amplifier consists of a positive and negative transistor, which run alternatively, amplifying the positive and negative cycle respectively, which in the end is combined to form a full output cycle. It's a more efficient design, and has its own set of advantages and disadvantages compared to the Class A power amplifier. It's characterized by:

- Uses 2 complementary transistors, one each for the positive and negative cycle
- Much higher efficiency, around 75-78.5%
- Lesser heat output
- Stable and reliable
- Requires at least 0.7 V to start conducting, which means anything under it doesn't register, so cannot be used for precise applications
- Combines 2 half cycles to form one full cycle

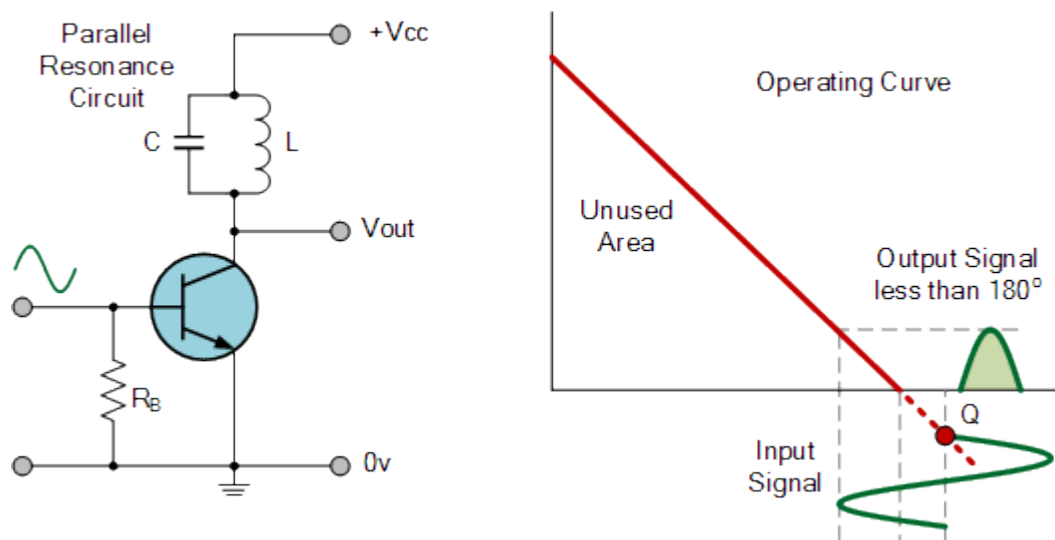
Class AB Power Amplifier



A Class AB Power Amplifier is, as the name suggests, a mix of Class A and Class B power amplifiers. Like the Class B amplifier, it also uses 2 conducting elements (transistors), but they both run at the same time. This eliminates the 'dead zone' from -0.7 V to +0.7 V seen in the Class B power amplifier. But in this case, while each transistor conducts for more than a half cycle, they conduct less than a full cycle completely. So the conduction angle is somewhere around 180 degrees and 360 degrees, commonly shown as 270 degrees in some cases. Here are its characteristics:

- Uses 2 transistors that work together
- Each transistor is active for slightly less than a full cycle but more than a half cycle
- Combines Class A and Class B characteristics
- No crossover distortion
- Fairly efficient, at around 50-60%
- Most common [audio amplifier](#) design

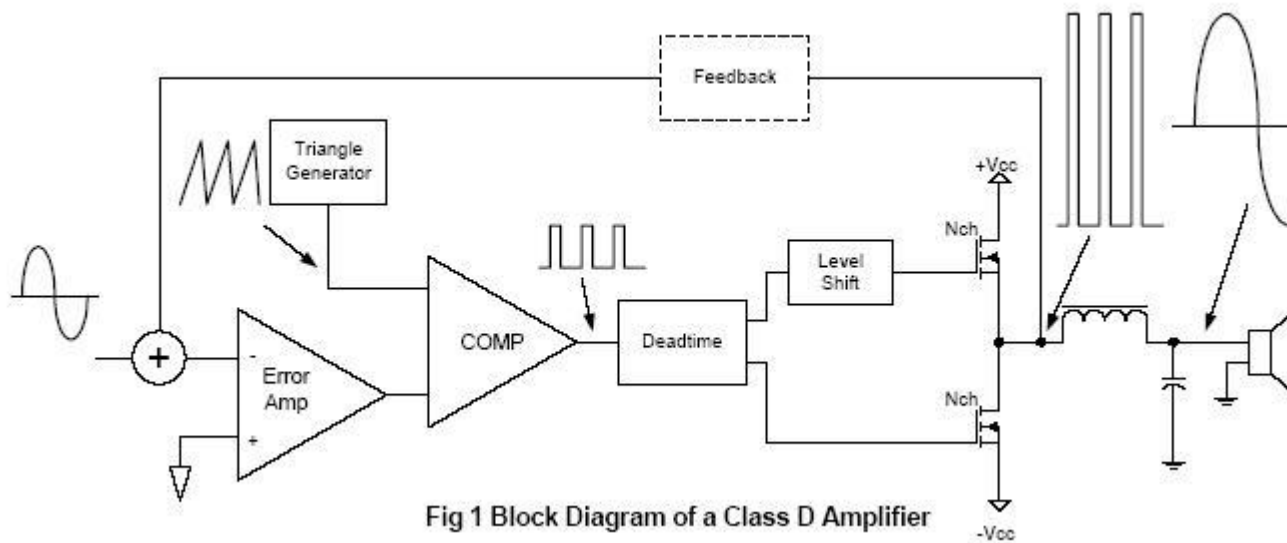
Class C Power Amplifier



A Class C Power Amplifier is something of an oddity compared to the other 3 types listed above. It's the most efficient, but has the lowest operating cycle and linearity. Since it's heavily biased, it stays on for less than half of an input cycle, and thus has a conducting angle somewhere around the vicinity of 90 degrees. This results in the high efficiency mentioned above, but also causes high distortion in the output signal, so Class C amplifiers are usually not used as audio amplifiers. They're used in certain radio frequency applications where efficiency is key. Its most important characteristics are:

- Least linear among power amplifiers
- Very high efficiency of around 80-90%
- High output distortion
- Two operating modes, tuned and untuned
- Low power dissipation

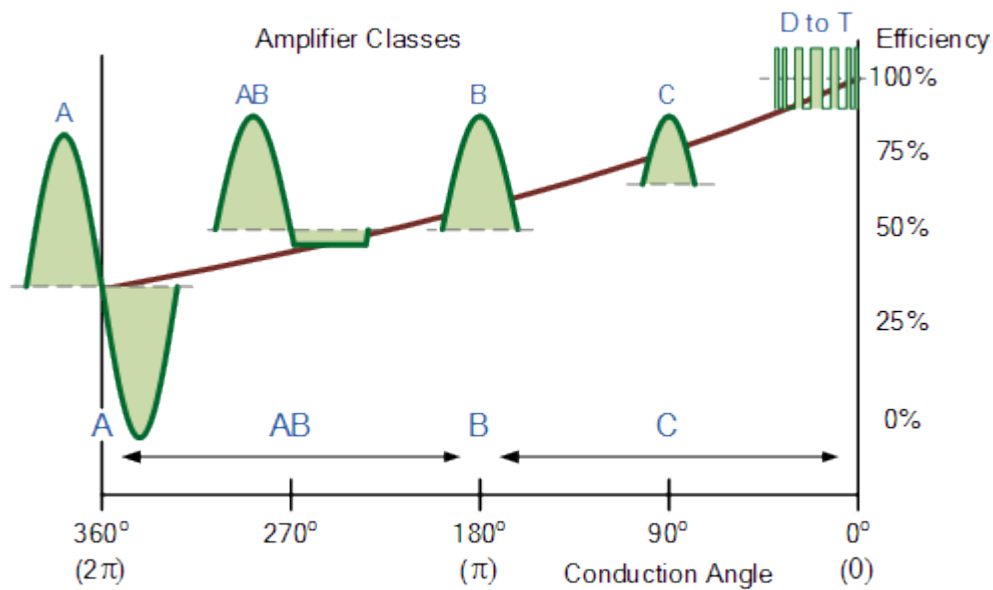
Class D Power Amplifier



And finally, we have Class D Power Amplifiers, which sometimes aren't considered among the 4 mentioned above. It's a non-linear switching amplifier in which the two transistors function as switches instead of linear gain devices. It converts the analog signal into digital via pulse width modulation, pulse density modulation or something similar before being amplified. The end result is a cycled output with high efficiency and gain, without too much distortion. Although originally used to control motors, they are now used as audio power amplifiers as well. Contrary to popular belief, the 'D' in the name doesn't stand for digital, because the converted signal is pulse width modulated analog, and not pulse width modulated digital. It is characterized by:

- High efficiency, can theoretically be 100%
- Low power dissipation
- Low power consumption
- More complex than other types of power amplifiers
- Precise and accurate output

And that's it about amplifiers! We hope that the types of amplifiers as well as the types of power amplifiers are clearer now, and if you have any questions about the information, feel free to comment below!



Transformer Types and Configurations

Distribution Transformers

Distribution transformers play a crucial role in electrical power distribution, carrying out the final voltage transformation stage before delivering electrical energy to the end user. The high voltage of the electrical power that is transferred over long distances is reduced by these transformers to lower voltage levels that are suited for usage in commercial, industrial, and residential settings. An examination of the properties, applications, and significance of distribution transformers within the context of the power distribution system is presented in this section.

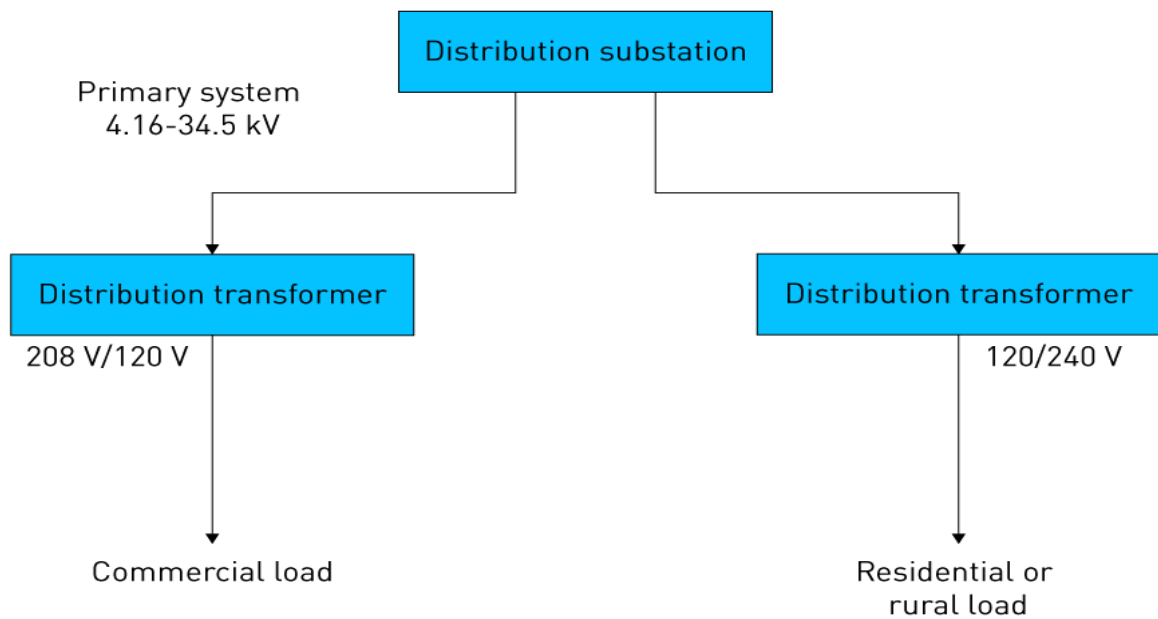


Figure 8: Role of distribution transformers

Characteristics of Distribution Transformers

In continuous operation, distribution transformers are intended to operate at voltage levels that are typically lower than those used in transmission equipment. This allows them to achieve high levels of efficiency and dependability. They are distinguished by their relatively tiny size and power rating, and they are intended to provide service to individual consumers, communities, or small industrial operations. Depending on the requirements of the distribution network and the end users, the usual output voltage can range anywhere from a few hundred volts to approximately 35 kilovolts.

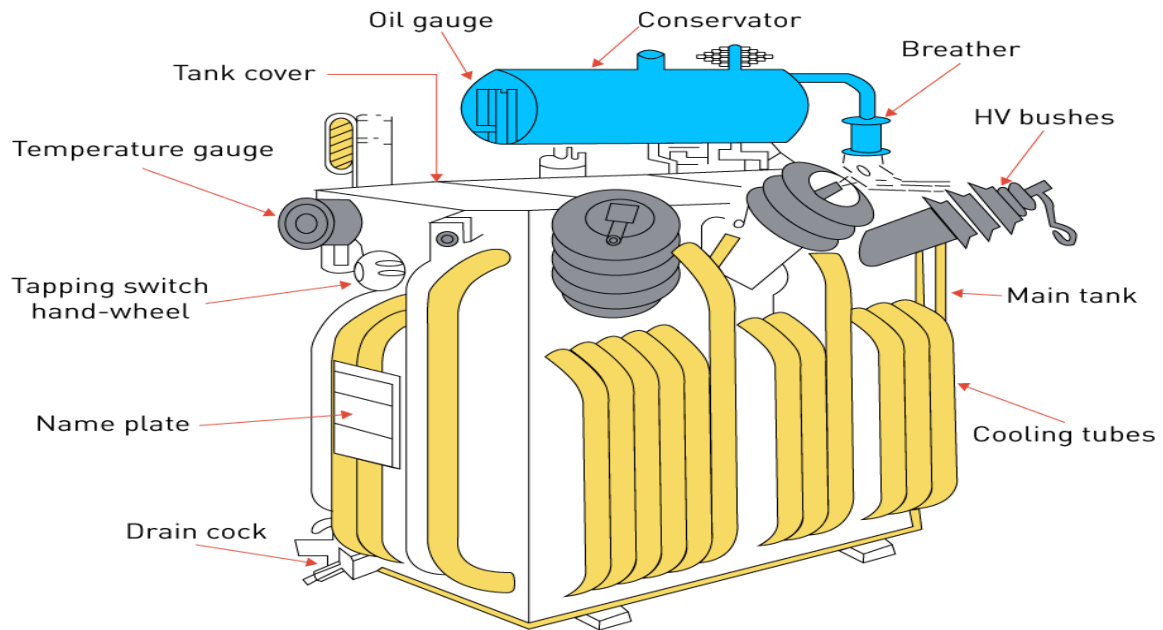


Figure 9: Oil immersed natural cooled distribution transformer

Distribution transformers are characterized by their great efficiency, which frequently exceeds 95%. This is of utmost importance because of the constant operation of these transformers. Even little enhancements in efficiency can result in huge savings in terms of both energy and money over the course of time. However, regardless of whether they are mounted on utility poles, housed in underground vaults, or set on ground pads, they are constructed to be able to endure the environmental conditions that are present at the locations where they are installed.

Applications of Distribution Transformers

The most important function of distribution transformers is to reduce the voltage carried by the distribution lines to a level that is suitable for use in residential and commercial buildings, as well as small industrial plants. When it comes to supplying consumers with power, they are omnipresent in both urban and rural areas, where they do so in a quiet and dependable manner. Distribution transformers, in addition to transforming voltage, also offer electrical isolation between the high-voltage distribution network and consumers. This isolation has the dual purpose of boosting safety and protecting against electrical problems.

Pole-Mounted vs. Pad-Mounted Distribution Transformers

Broadly speaking, distribution transformers fall into two primary categories: pole-mounted and pad-mounted.

Pole-Mounted Transformers: Rural or suburban regions with a high prevalence of overhead distribution lines for power distribution frequently use transformers mounted on poles. Utility poles have affixed them at a height that prevents accidental contact between them. Pole-mounted transformers typically cater to a limited number of clients, like a single residence or a small group of buildings.

Pad-Mounted Transformers: To ensure safety, pad-mounted transformers are installed on concrete pads at ground level and encased in secured metal cabinets. Urban areas and residential subdivisions with underground electricity delivery typically feature pad-mounted transformers. They are designed to be more aesthetically beautiful and less intrusive than pole-mounted units, and they are able to serve a greater number of clients or commercial and industrial buildings.

Power Transformers

Power transformers are essential components that comprise the electrical power generation, transmission, and distribution system. These transformers are intended to manage high voltages and enormous loads over extended distances. They play a crucial part in the processes of step-up and step-down voltage levels that occur between the power plant and the distribution network. This aids in the efficient transfer of electrical energy over extensive geographic regions. In this section, we will look into the properties, applications, and relevance of power transformers within the larger framework of power systems.

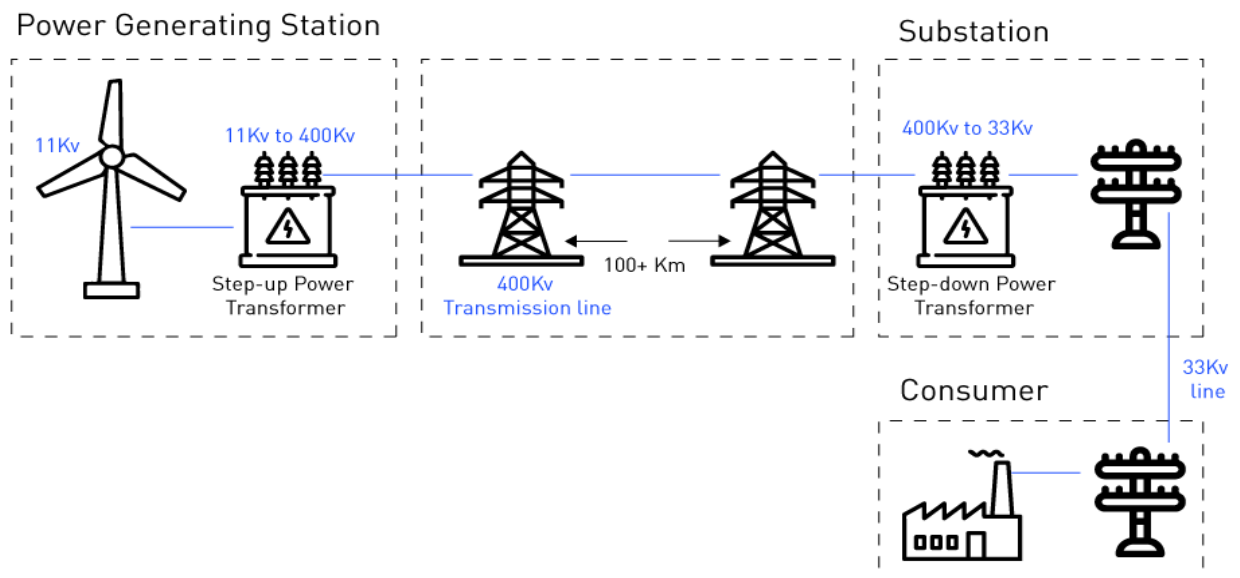


Figure 10: Power transformer

Characteristics of Power Transformers

The capacity of power transformers can range from several hundred megavolt-amperes (MVA) and often exceed 200 kilovolts (kV). High power ratings and their ability to function at high voltages distinguish power transformers. These transformers strive for maximum efficiency, typically exceeding 99%, to minimize losses during energy transmission. Given their significant role in the power grid, their construction prioritizes stability and dependability, enabling them to endure the harsh conditions of high voltage operations.

Figure 11: Power transformer schematic

Substations typically install power transformers due to their size and exposure to high voltages. This is because substations are better equipped to provide necessary maintenance and monitoring. Oil or gas insulation is commonly used to offer cooling and additional electrical insulation. Their construction and insulation systems are carefully built to handle the severe electrical stresses that they are subjected to.

Applications of Power Transformers

One of the most important applications for power transformers is in the transmission network of the power system, where they provide two basic functions:

Voltage Step-Up: Power transformers on the generation side raise the voltage of the generated power to increased levels, causing a step-up in voltage. As a result of this step-up process, the current is decreased for a given power level, which in turn minimizes the resistive losses that occur in the transmission lines that are located at great distances from the load centers.

Voltage Step-Down: Power transformers, which are located closer to the places of consumption, either within sub-transmission or main distribution substations, reduce the voltage from high transmission levels to lower levels that are suitable for distribution networks. When it comes to securely supplying power to end-users and distribution transformers, this step-down procedure is absolutely necessary. Distribution transformers further reduce the voltage for use in residential, commercial, or industrial settings.

Significance of Power Transformers

The effectiveness and dependability of the electrical grid are directly correlated to the presence of power transformers. They make it possible to transmit electrical power across enormous distances, which is an essential component of

contemporary electrical distribution networks. This enables the generation of power in a centralized manner, which might include the generation of power from renewable sources. Power transformers play a significant role in minimizing transmission losses, improving grid stability, and ensuring that electricity is delivered to end-users in the most efficient manner possible. They do this by optimizing the voltage levels for transmission and distribution.

In addition, because of their capacity to manage enormous power flows, they are vital in the process of interconnecting grids in different regions. This makes it possible to interchange power and provide backup, which in turn improves the overall dependability and resilience of the power system in the face of power outages and peak demand.

Different Types of Rectifiers & Their Working

In a large number of **electrical and electronic circuits**, DC voltage is required for its operation. We can simply alter the AC voltage into DC voltage by using a device called a PN junction diode. One of the most significant applications of a **PN junction diode** is the rectification of AC into DC. A PN junction diode permits electric current in only one direction i.e, forward bias condition, and blocks electric current in reverse bias condition. This single property of the diode lets it perform like a rectifier. This article discusses different types of rectifiers, working, and their comparisons.

What are Rectifiers?

A **rectifier is an electrical device** comprised of one or more diodes that allow the flow of current only in one direction. It basically converts alternating current into direct current. Rectifiers can be mold in several shapes as per necessity like semiconductor diodes, SCRs (**silicon controlled rectifiers**), vacuum tube diodes, mercury-arc valves, etc. In our previous articles, we have explained diodes, types of diodes in detail. But in this, we are going to give details of rectifiers, types of rectifiers and their applications, etc.

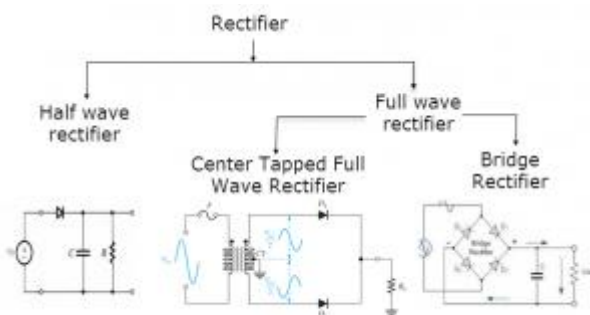


Different Types of Rectifiers

For signal discovery and power rectification, **diode rectifier circuits** are extensively used in designing electronic circuits, which are used in various devices like radio signals or detectors, DC power supplies, household appliances like video game systems, laptops, televisions, etc.

Different Types of Rectifiers

Rectifiers are categorized into a variety of designs depends on factors namely, type of supply, bridge configuration, components used, control nature, etc. Majorly these are classified into two types they are single-phase and three-phase rectifier. Further rectifiers are classified into three types namely uncontrolled, half controlled, and full controlled rectifiers. Let us see in brief about some of these types of rectifiers. Rectifiers are classified into two types like uncontrolled rectifiers and controlled rectifiers.



Types of Rectifiers

Uncontrolled Rectifiers

The output voltage of a rectifier that cannot be controlled is known as an uncontrolled rectifier. A rectifier works with switches and these are available in different types like controllable as well as uncontrollable. A two-terminal component like a diode is a unidirectional device and the main function of this is to allow the flow of current is simply one direction. This device cannot be controlled because it will perform only if it is connected in forward biased.

When a diode is connected with a rectifier in any configuration then the rectifier cannot completely under the control of an operator which is known as uncontrolled rectifiers. It does not let the power change based on the requirement of the load. So

this kind of rectifier is normally used in fixed or stable power supplies. This kind of rectifier simply uses diodes and provides stable output voltage based on the input of AC only.

Further, uncontrolled rectifiers are classified into two types a half-wave and full-wave rectifiers.

Half-wave Rectifier

In this type of rectifier, when AC supply is applied at the input, only the positive half cycle becomes visible across the load while the negative half cycle is covered up. In a single-phase supply, it needs a single diode while in a three-phase supply it needs three diodes.

It is not capable because only half of the i/p waveforms reach the output. To reduce the ripples of the AC frequency from the o/p, more filtering is required in the half-wave rectifier circuit. Please refer to the link to know more about [Half-wave Rectifier Circuit Working Principle and Characteristics](#)

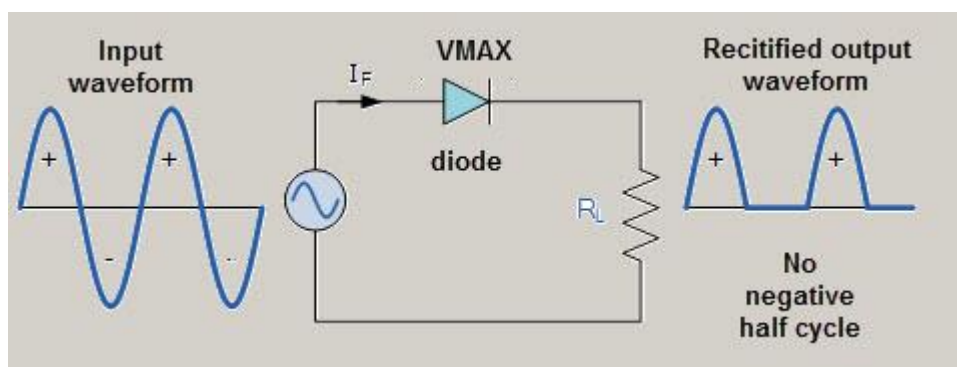
Positive Half Wave Rectifier

A rectifier that simply changes the positive half cycle & blocks the negative half cycle is known as. Positive Half Wave Rectifier

Negative Half Wave Rectifier

A rectifier that simply changes the negative half cycle of the AC into DC is known as a negative half-wave rectifier. As compared with all kinds of rectifiers, a half-wave rectifier is a simple type because it is designed with a single diode only.

A diode simply allows the flow of current in one direction which is called forward bias. This diode is connected with a load resistor 'RL' in series.



Positive Half Wave Rectifier

A rectifier that simply changes the positive half cycle & blocks the negative half cycle is known as. Positive Half Wave Rectifier

Negative Half Wave Rectifier

A rectifier that simply changes the negative half cycle of the AC into DC is known as a negative half-wave rectifier. As compared with all kinds of rectifiers, a half-wave rectifier is a simple type because it is designed with a single diode only.

A diode simply allows the flow of current in one direction which is called forward bias. This diode is connected with a load resistor 'RL' in series.

Positive Half Cycle

The anode terminal of a diode throughout the positive half cycle will turn into positive whereas the cathode terminal will turn into negative is known as forward bias. It will permit the positive cycle to supply through.

Negative Half Cycle

The anode terminal of a diode will turn negative throughout the negative half cycle whereas the cathode terminal will turn into positive, which is called reverse bias. So the negative cycle will be blocked by the diode.

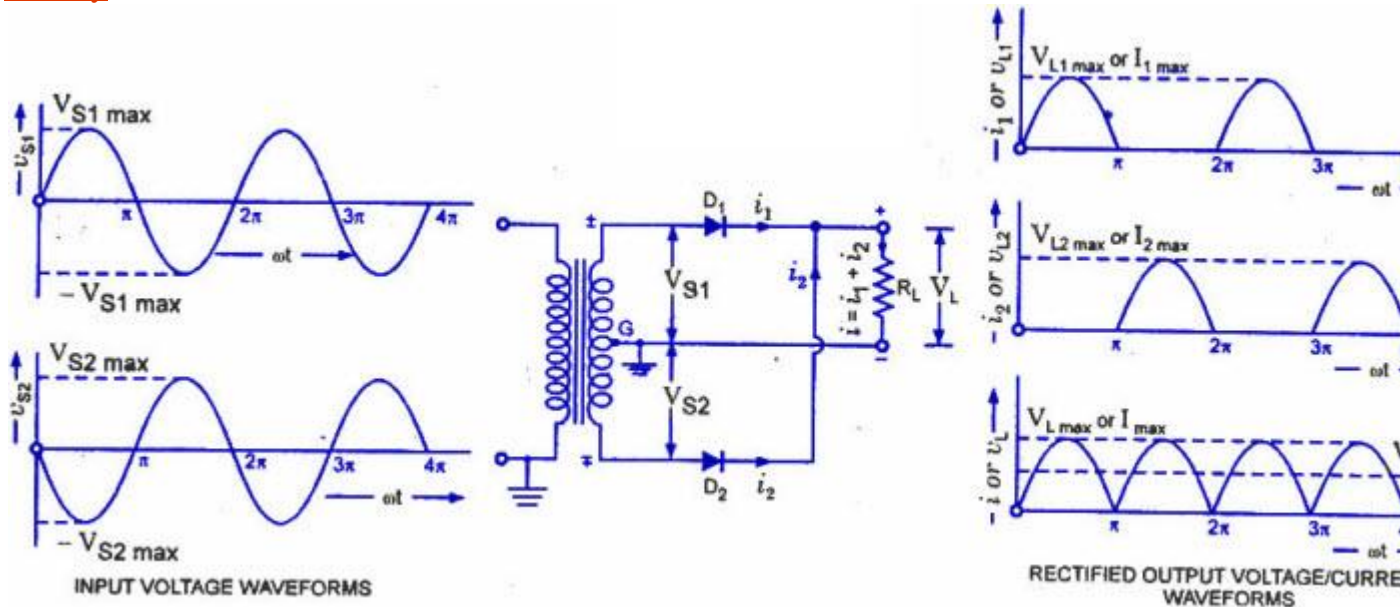
So once an AC source is connected toward the half-wave rectifier, then a half cycle will supply through it. The rectifier's output can be taken across the RL or load resistor. So output waveform of this will be a pulsating +ve half cycle of the input.

The half-wave rectifier's output has several ripples and it is not used as a DC source. To level this output, a capacitor is connected across the resistor that will charge throughout the positive cycle & discharge throughout the negative cycle to provide a level output signal.

Full Wave Rectifier

In this type of rectifier, during both the half cycles when AC supply is applied to the i/p, the flow of current through the load flows in the same direction. This circuit yields a higher standard output voltage by altering both polarities of the i/p waveform to pulsating DC. This sort of rectification can be achieved by using at slightest two crystal diodes, conducting current differently.

During the positive as well as the negative half-cycle of the input AC, the following two circuits that is the [center tap full wave rectifier and full-wave bridge rectifier](#) is used to get the same direction of current flow in the load resistor. Please refer to the link to know more about [Full-wave Rectifier Circuit with Working Theory](#)



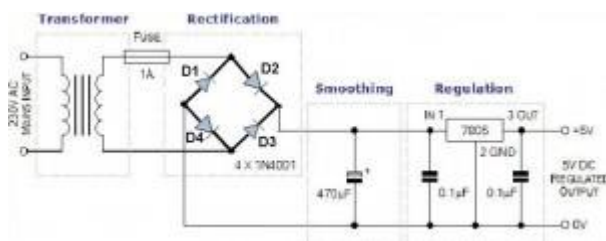
Full Wave Rectifier

A full-wave rectifier circuit is designed with above one diode. These rectifiers are classified into two types like bridge rectifier and center tap rectifier.

Bridge Rectifier

A bridge rectifier circuit can be built with four diodes which are used to change both input AC half-cycle to DC output. So, in this kind of rectifier, the four diodes are mainly connected in an exact form.

In the positive half cycle of the bridge rectifier, the two diodes like D_1 & D_2 will become forward bias whereas diodes D_3 & D_4 will become reverse bias. From a closed loop, the diodes D_1 & D_2 will provide a +Ve output voltage across the R_L (load resistor).



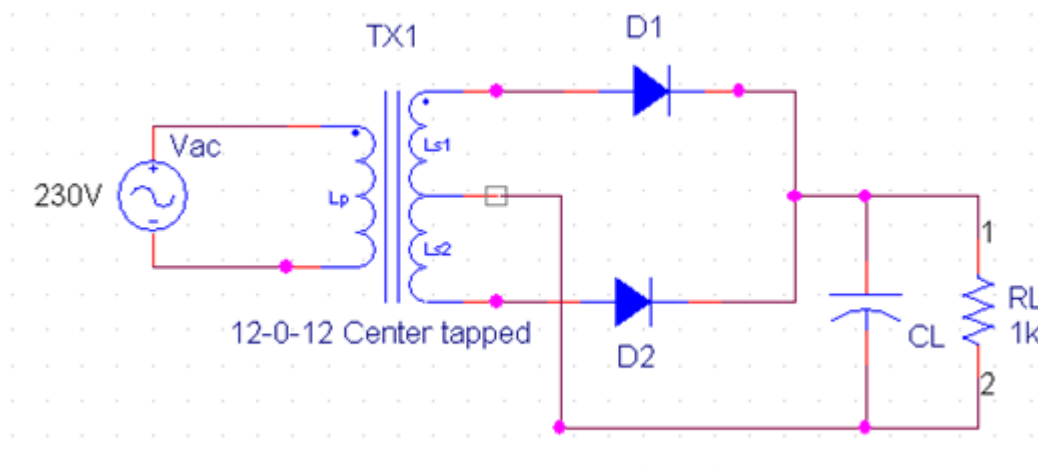
Bridge Rectifier

In the negative half cycle of the bridge rectifier, the diodes like D_3 & D_4 will become forward bias whereas D_1 & D_2 diodes will become reverse bias. However, the polarity across the R_L stays the same & gives a positive o/p across the load.

The full-wave rectifier's output includes fewer ripples as compared to the half-wave rectifier although it's not level and stable. To make the o/p voltage level, a capacitor is used at the output of the circuit. The charge and discharge of this capacitor will make level transitions among the half cycles.

Center Tap Full-wave Rectifier

This type of rectifier circuit uses a transformer with secondary winding tapped at the center point. Two diodes are connected in the circuit so that each one of them uses the one-half cycle of the input AC voltage. For rectification, one diode uses the ac voltage showing the upper half of the secondary winding while the other diode uses the lower half of the secondary winding. The o/p and efficiency of this circuit are high because the AC supply brings power throughout both halves.



Center Tap

Full-wave Rectifier

This transformer has dual-voltage and also two inputs like I1 & I2 & 3 output terminals like T1, T2, and T3. The terminal like T2 is connected to the middle of the output coil that works like a reference ground. The terminal like T1 generates +Ve voltage & the terminal 'T3' generates negative voltage to the terminal 'T2'.

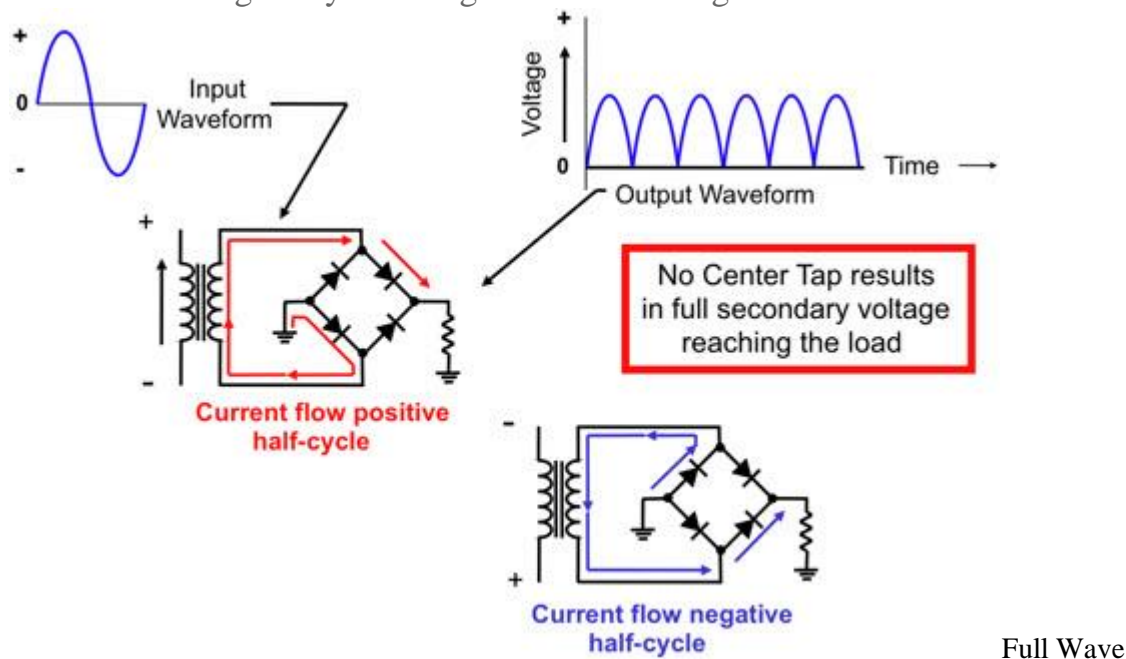
Throughout the positive half cycle, the terminals like T1 & T2 will generate positive & negative voltage. So, the D1 diode will turn into forward bias and the D2 diode will turn into a reverse bias. From terminals T1 to T2, it will make a close path using the load resistor.

Throughout the negative half cycle, the terminal 'T1' will produce a negative cycle and terminal 'T2' will produce a positive cycle. This will connect the D1 diode into reverse bias and the D2 diode will connect into forward bias.

However, the polarity across the RL is similar to the flow of current obtains the lane from the terminals T3 to T1. This rectifier's DC output also includes ripples but it is not level as well as steady DC. At the output of the circuit, a capacitor will eliminate the ripple to make a stable DC output.

Full Wave Bridge Rectifier

A Bridge rectifier circuit is one of the capable forms of a full-wave rectifier that uses four diodes in a bridge topology. In place of the center tap transformer, a normal transformer is used. The AC supply to be rectified is applied to the diagonally differing ends of the bridge and the load resistor is connected across the residual two diagonally differing ends of the bridge.



Bridge Rectifier

Full Wave

Controlled Rectifiers

When the output voltage of a rectifier changes or varies then it is known as a controlled rectifier. The need for a controlled rectifier is clear once we look into the faults of an uncontrolled bridge rectifier. The current controlled devices like SCRs, IGBTs, MOSFETs are used to change a rectifier from uncontrolled to controlled.

Once SCRs are turned ON/OFF depending on the applied gate signals then we will have complete control. Generally, these are preferred mostly as compared to their counterparts which are uncontrolled. A silicon-controlled rectifier (SCR) is also called a thyristor. It is a three-terminal diode where the terminals are Anode, Cathode & Gate.

Similar to a normal diode, this will perform in forward bias whereas, in reverse bias, it blocks current however it starts only in forward conduction once there is a signal at the input of the gate terminal. So this gate output plays a key role in controlling the output voltage.

Types of Controlled Rectifier

Controlled rectifiers are two types like half wave controlled rectifier and full wave controlled rectifier.

Half Wave Controlled Rectifier

The half-wave controller rectifier can be designed with a single Silicon Controlled Rectifier (SCR). Similar to the design of a half-wave uncontrolled rectifier, the half-wave controlled rectifier is the same apart from we alter the diode through an SCR.

In reverse bias, a silicon-controlled rectifier does not perform, so it will block the negative half cycle. Throughout the positive half cycle, the SCR will conduct current on only a single condition once a pulse is given to the input of the gate terminal like a periodic pulse signal. The main function of this signal is to turn on the SCR at every positive half cycle.

In this method, the output voltage can be controlled for the rectifier. The output of the silicon-controlled rectifier is a pulsating DC or voltage. These pulses are detached with the help of a capacitor which is connected parallel to the RL.

Full Wave Controlled Rectifier

The rectifier which changes both the half cycles of the AC into DC like positive and negative and controls the o/p amplitude is called a full-wave controlled rectifier. Similar to the uncontrolled rectifier, the classification of a controlled full-wave rectifier can be done into two types like controlled bridge and controlled center tapped.

Controlled Bridge Rectifier

In a controlled bridge rectifier, the diode bridge can be changed with an SCR bridge using a similar configuration to the bridge rectifier.

Throughout the positive cycle, the terminals of SCR like T1 & T2 will perform once the gate signal is applied and the terminals like T3 & T4 will be connected in

reversed bias because they will block the flow of current. So the o/p voltage will be created across the RL.

Throughout the positive cycle, the terminals of thyristor like T3 & T4 will turn into forward bias by considering the input pulse of the gate and the terminals like T1 & T2 will turn into a reverse bias. So, across the RL, the output will come into view. At the output end, a capacitor can be connected to eliminate the ripples so that the output will be smooth and stable

Controlled Center-Tap Rectifier

Similar to the center-tap uncontrolled rectifier, controlled center tap rectifier design mainly utilizes two SCR in place of the two diodes. The switching of these SCRs will be differently timed based on the i/p AC frequency. Its operation is the same as the uncontrolled rectifier.

Single Phase & Three Phase Types of Rectifiers

The classification of a rectifier can be done depending on the working of an input type. Once the input of the rectifier is a single-phase, then it is called a single-phase rectifier. Similarly, when the input of the rectifier is 3-phase, then it is known as a 3-phase rectifier.

The designing of a single-phase bridge rectifier can be done by using four diodes, while a 3-phase rectifier can be done with six diodes which are arranged in a specific pattern to obtain the required output.

These rectifiers are controlled/uncontrolled rectifiers based on the switching components utilized in every kind of rectifier like thyristors, diodes, etc.

What is an Operational Amplifier?

An operational amplifier (op amp) is an analog circuit block that takes a differential voltage input and produces a single-ended voltage output.

Op amps usually have three terminals: two high-impedance inputs and a low-impedance output port. The inverting input is denoted with a minus (-) sign, and the non-inverting input uses a positive (+) sign. Operational amplifiers work to

amplify the voltage differential between the inputs, which is useful for a variety of analog functions including signal chain, power, and control applications.

Operational Amplifier Clasifications

There are four ways to classify operational amplifiers:

- Voltage amplifiers take voltage in and produce a voltage at the output.
- Current amplifiers receive a current input and produce a current output.
- Transconductance amplifiers convert a voltage input to a current output.
- Transresistance amplifiers convert a current input and produces a voltage output.

Because most op amps are used for voltage amplification, this article will focus on voltage amplifiers.

Operational Amplifiers: Key Characteristics and Parameters

There are many different important characteristics and parameters related to op amps (**see Figure 1**). These characteristics are described in greater detail below.

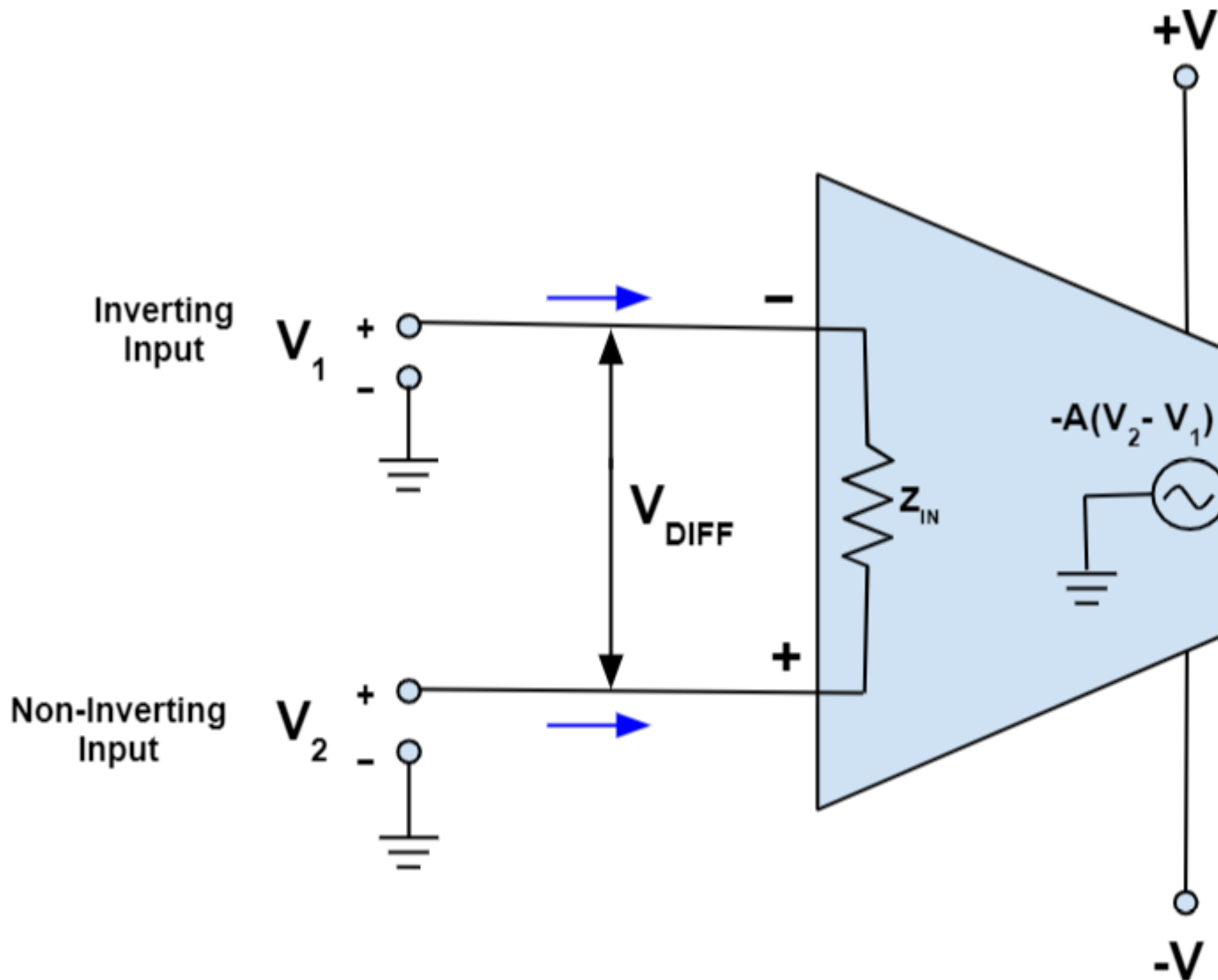


Figure 1: Operational Amplifier Schematic

Open-loop gain

Open-loop gain: The open-loop gain (“A” in **Figure 1**) of an operational amplifier is the measure of the gain achieved when there is no feedback implemented in the circuit. This means the feedback path, or loop, is open. An open-loop gain often must be exceedingly large (10,000+) to be useful in itself, except with voltage comparators.

Voltage comparators compare the input terminal voltages. Even with small voltage differentials, voltage comparators can drive the output to either the positive or

negative rails. High open-loop gains are beneficial in closed-loop configurations, as they enable stable circuit behaviors across temperature, process, and signal variations.

Input impedance

Another important characteristic of op amps is that they generally have high input impedance (“ Z_{IN} ” in **Figure 1**). Input impedance is measured between the negative and positive input terminals, and its ideal value is infinity, which minimizes loading of the source. (In reality, there is a small current leakage.) Arranging the circuitry around an operational amplifier may significantly alter the effective input impedance for the source, so external components and feedback loops must be carefully configured. It is important to note that input impedance is not solely determined by the input DC resistance. Input capacitance can also influence circuit behavior, so that must be taken into consideration as well.

Output impedance

An operational amplifier ideally has zero output impedance (“ Z_{OUT} ” in **Figure 1**). However, the output impedance typically has a small value, which determines the amount of current it can drive, and how well it can operate as a voltage buffer.

Frequency response and bandwidth (BW)

An ideal op amp would have an infinite bandwidth (BW), and would be able to maintain a high gain regardless of signal frequency. However, all operational amplifiers have a finite bandwidth, generally called the “-3dB point,” where the gain begins to roll as frequency increases. The gain of the amplifier then decreases at a rate of -20dB/decade while the frequency increases. Op amps with a higher BW have improved performance because they maintain higher gains at higher frequencies; however, this higher gain results in larger power consumption or increased cost.

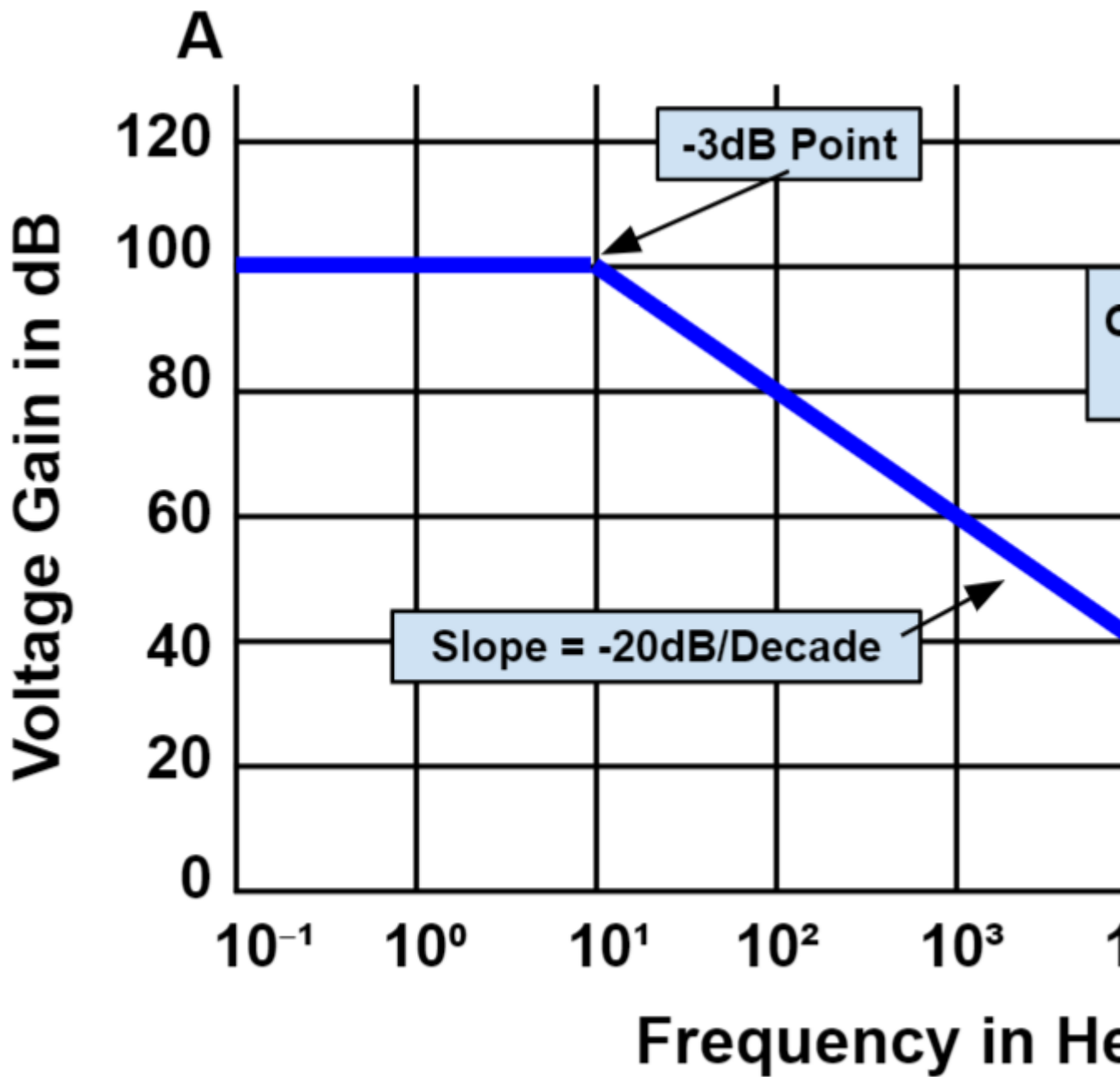


Figure 2: Operational Amplifier Open-Loop Frequency Response Curve

Gain bandwidth product (GBP)

As the name suggests, GBP is a product of the amplifier's gain and bandwidth. GBP is a constant value across the curve, and can be calculated with **Equation (1)**:

$$\text{GBP} = \text{Gain} \times \text{Bandwidth} = A \times \text{BW}$$

GBP is measured at the frequency point at which the operational amplifier's gain reaches unity. This is useful because it allows the user to calculate the device's open-loop gain at different frequencies. An operational amplifier's GBP is

generally a measure of its usefulness and performance, as op amps with a higher GBP can be used to achieve better performance at higher frequencies.

These are the major parameters to consider when selecting an operational amplifier in your design, but there are many other considerations that may influence your design, depending on the application and performance needs. Other common parameters include input offset voltage, noise, quiescent current, and supply voltages.

Negative Feedback and Closed-Loop Gain

In an operational amplifier, negative feedback is implemented by feeding a portion of the output signal through an external feedback resistor and back to the inverting input (see Figure 3).

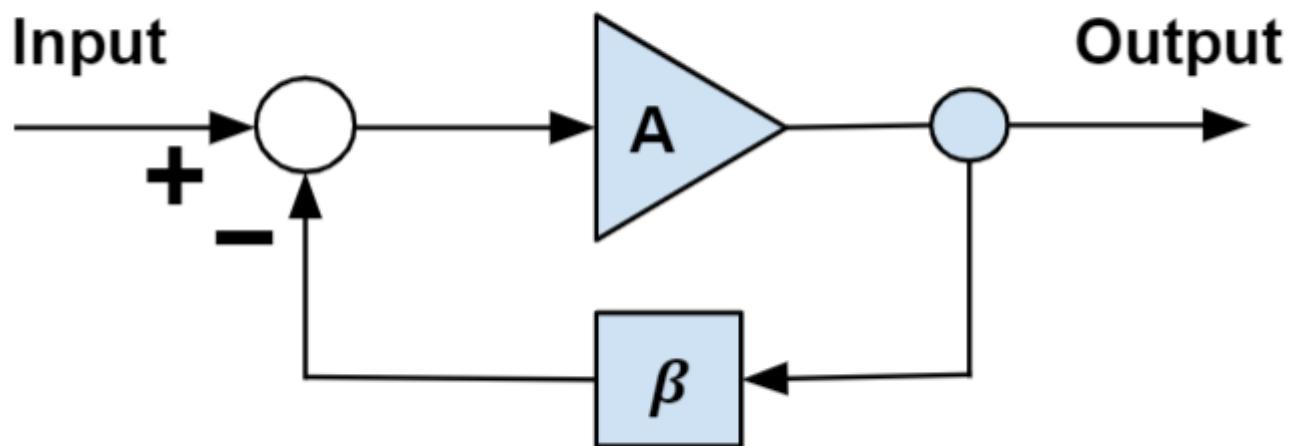


Figure 3: Negative Feedback with Inverting Operational Amplifier

Negative feedback is used to stabilize the gain. By using a negative feedback, the closed-loop gain can be determined via external feedback components that can have higher accuracy compared to the operational amplifier's internal components. This is because the internal op amp components may vary substantially due to process shifts, temperature changes, voltage changes, and other factors. The closed-loop gain can be calculated with **Equation (2)**:

$$V_{OUT} = -A_{CL} V_{IN}$$

Operational Amplifiers: Advantages and Limitations

There are many advantages to using an operational amplifier. Operational amplifiers often come in the form of an IC, and are widely available, with countless selectable performance levels to meet every application's needs. Op amps have a broad range of usages, and as such are a key building block in many analog applications — including filter designs, voltage buffers, comparator circuits, and many others. In addition, most companies provide simulation support, such as PSPICE models, for designers to validate their operational amplifier designs before building real designs.

The limitations to using operational amplifiers include the fact they are analog circuits, and require a designer that understands analog fundamentals such as loading, frequency response, and stability. It is not uncommon to design a seemingly simple op amp circuit, only to turn it on and find that it is oscillating. Due to some of the key parameters discussed earlier, the designer must understand how those parameters play into their design, which typically means the designer must have a moderate to high level of analog design experience.

Operational Amplifier Configuration Topologies

There are several different op amp circuits, each differing in function. The most common topologies are described below.

Voltage follower

The most basic operational amplifier circuit is a voltage follower (**see Figure 4**). This circuit does not generally require external components, and provides high input impedance and low output impedance, which makes it a useful buffer. Because the voltage input and output are equal, changes to the input produce equivalent changes to the output voltage.

$$V_{OUT}=V_{IN}$$

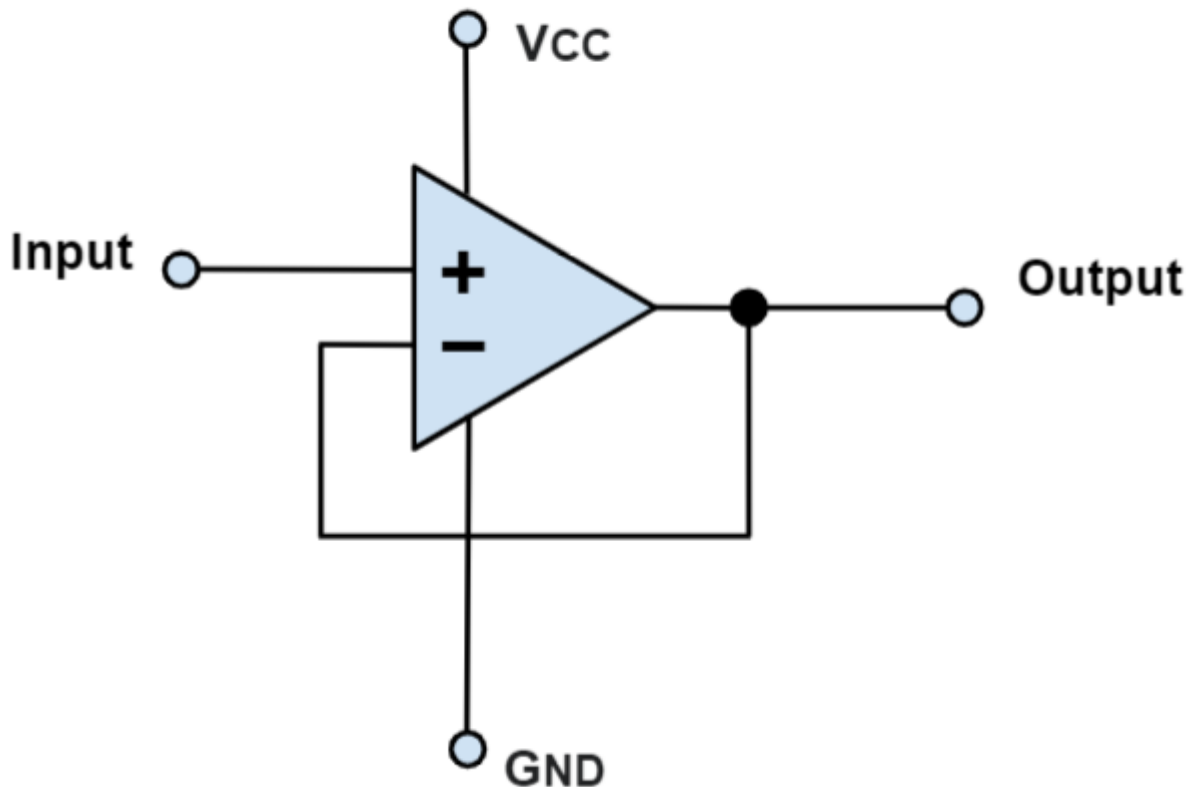


Figure 4: Voltage Follower

The most common op amp used in electronic devices are voltage amplifiers, which increase the output voltage magnitude. Inverting and non-inverting configurations are the two most common amplifier configurations. Both of these topologies are closed-loop (meaning that there is feedback from the output back to the input terminals), and thus voltage gain is set by a ratio of the two resistors.

Inverting operational amplifier

In inverting operational amplifiers, the op amp forces the negative terminal to equal the positive terminal, which is commonly ground. Therefore, the input current is determined by the V_{IN} / R_1 ratio (see **Figure 5**).

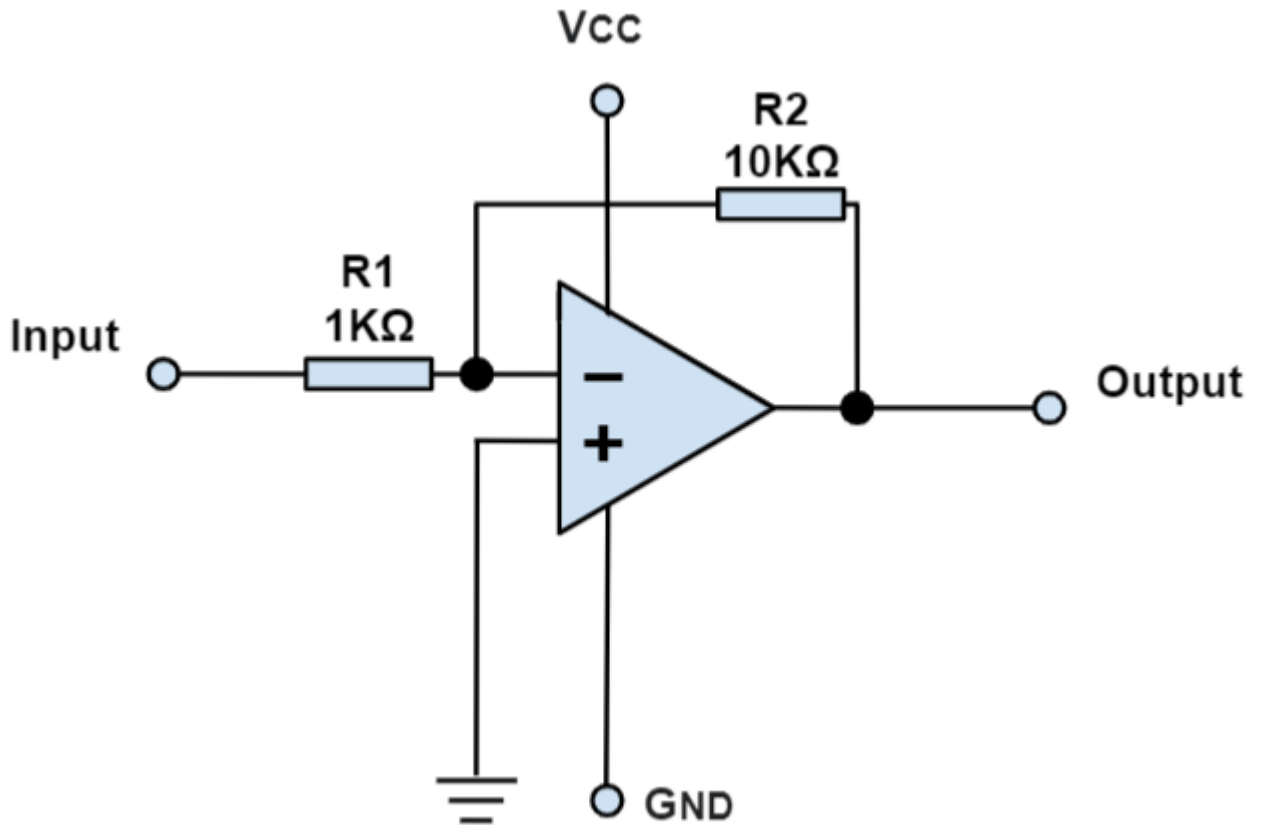


Figure 5: Inverting Operational Amplifier

In this configuration, the same current flows through R2 to the output. Ideally, current does not flow into the operational amplifier's negative terminal due to its high Z_{IN} . The current flowing from the negative terminal through R2 creates an inverted voltage polarity with respect to V_{IN} . This is why these op amps are labeled with an inverting configuration. Note that the op amp's output can only swing between its positive and negative supplies, so creating a negative output voltage requires an op amp with a negative supply rail. V_{OUT} can be calculated with **Equation (3)**:

$$V_{OUT} = -(R_2/R_1) \times V_{IN}$$

Non-inverting operational amplifier

In a non-inverting amplifier circuit, the input signal from the source is connected to the non-inverting (+) terminal (see **Figure 6**).

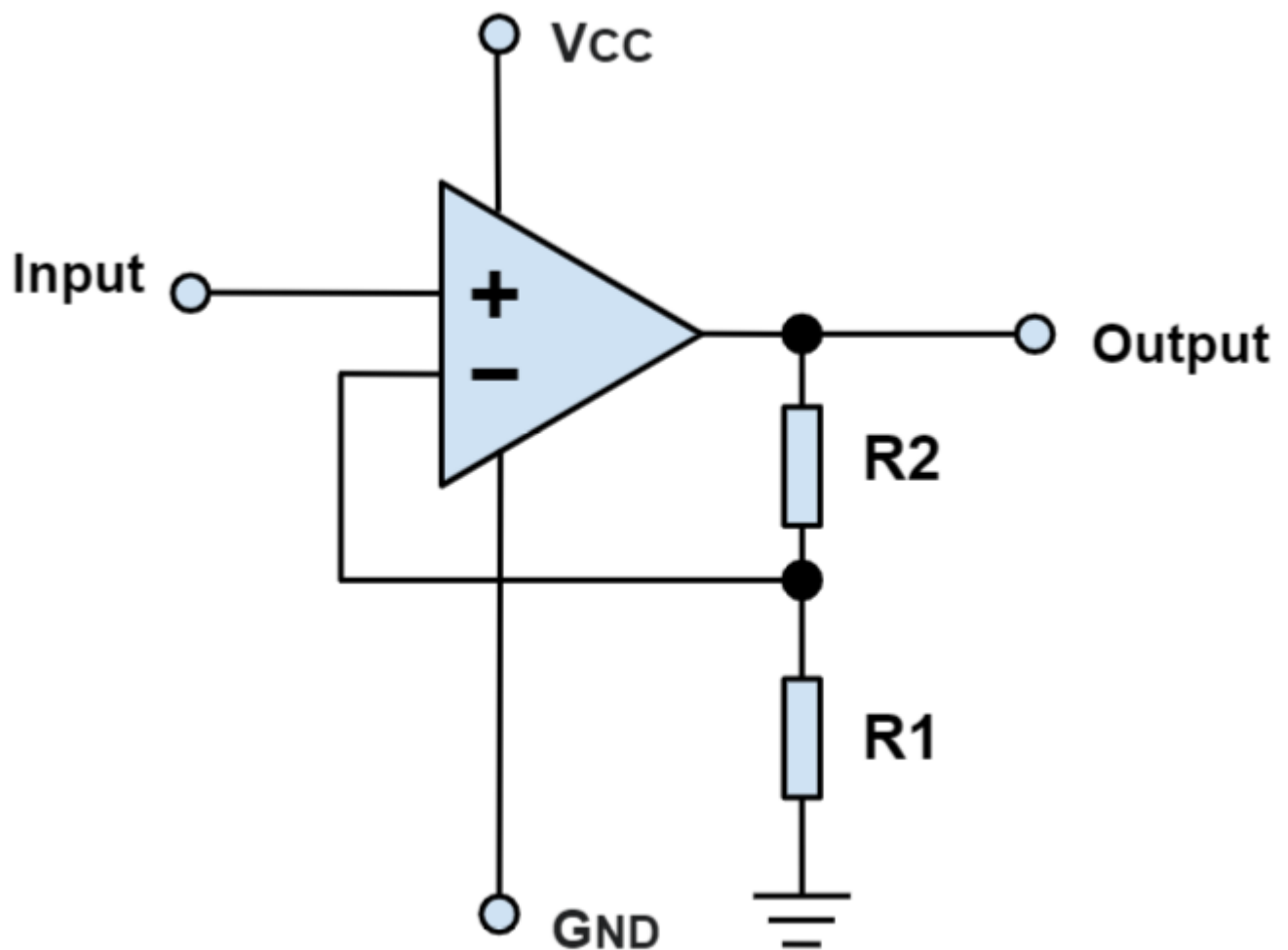


Figure 6: Non-Inverting Operational Amplifier

The operational amplifier forces the inverting (-) terminal voltage to equal the input voltage, which creates a current flow through the feedback resistors. The output voltage is always in phase with the input voltage, which is why this topology is known as non-inverting. Note that with a non-inverting amplifier, the voltage gain is always greater than 1, which is not always the case with the inverting configurations. V_{OUT} can be calculated with **Equation (4)**:

$$V_{OUT} = (1 + R_2/R_1) \times V_{IN}$$

Voltage comparator

An operational amplifier voltage comparator compares voltage inputs, and drives the output to the supply rail of whichever input is higher. This configuration is considered open-loop operation because there is no feedback. Voltage comparators have the benefit of operating much faster than the closed-loop topologies discussed above (see **Figure 7**).

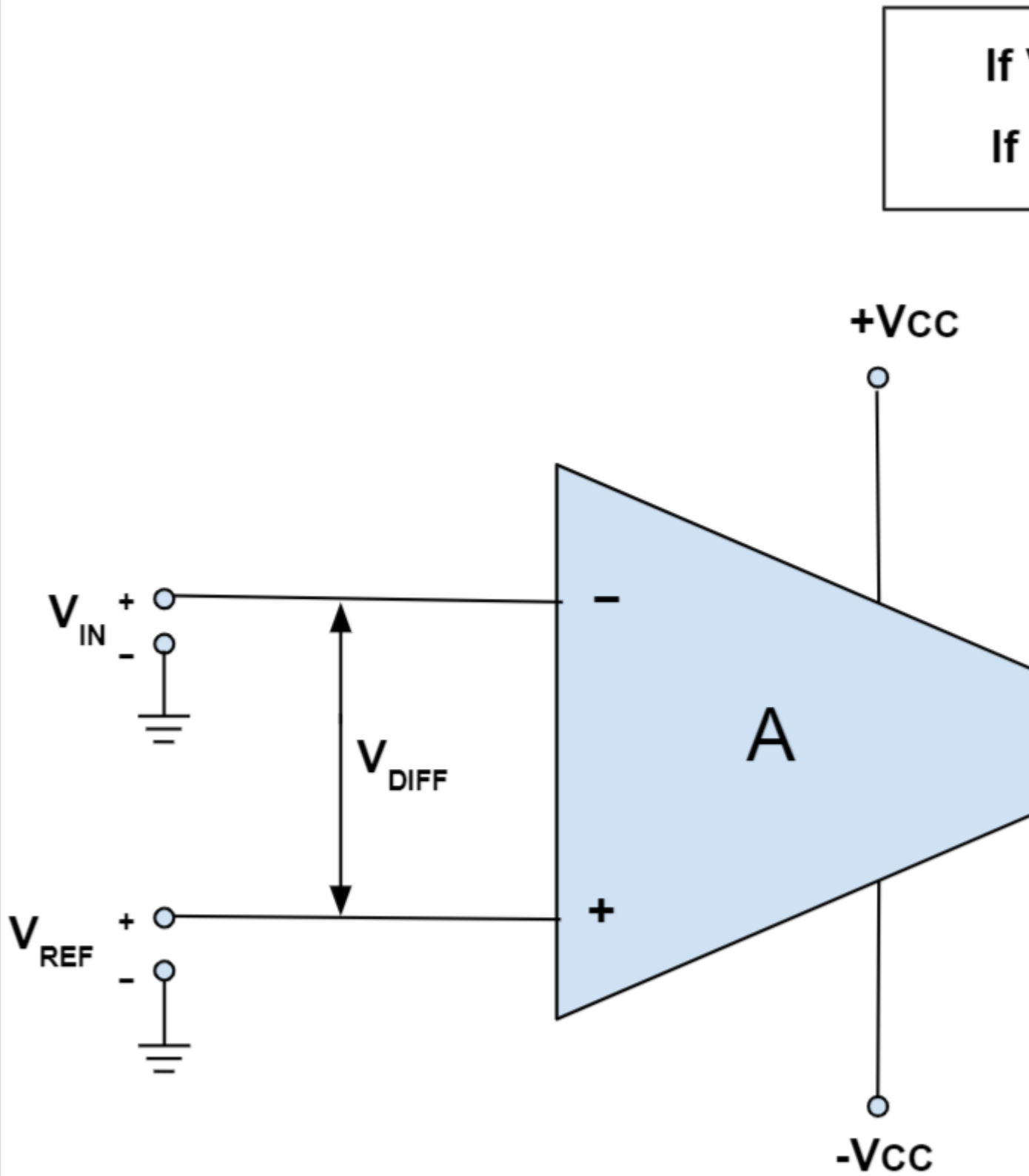


Figure 7: Voltage Comparator

The section below discusses certain considerations when selecting the proper operational amplifier for your application.

Firstly, [choose an op amp that can support your expected operating voltage range](#). This information can be obtained by looking at the amplifier's power supply voltages. The supply voltages will likely either be V_{DD} (+) and ground (single supply), or the amplifier may be able to support both a positive and negative supply. A negative supply is useful if the output needs to support negative voltages.

Secondly, consider the amplifier's GBP. If your application needs to support higher frequencies, or requires a higher performance and reduced distortion, consider op amps with higher GBPs.

One should also consider the power consumption, as certain applications may require low-power operation. The recommended power requirements can typically be found in the part's datasheet, and are usually listed as supply current and power consumption. Power consumption can also be estimated from the product of the supply current and supply voltage. Generally, op amps with lower supply currents have lower GBP, and correspond with lower circuit performance.

For applications that require higher accuracy, the designer should pay special attention to the amplifier's input offset voltage, as this voltage leads to an offset in the amplifier's output voltage.