Transistors, Vacuum Tubes, Filtering and Amplifier

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Introduction to Transistors

The transistor is a three-terminal device primarily used to amplify signals and control current within a circuit. [Figure 10-206] The basic two-junction semiconductor must have one type of region sandwiched between two of the other type. The three regions in a transistor are the collector (C), which is moderately doped, the emitter (E), which is heavily doped and the base (B) significantly less in its doping. The alternating layers of semiconductor material type provide the common commercial name for each type of transistor. The interface between the layers is called a junction. Selenium and germanium diodes previously discussed are examples of junction diodes. Note that the sandwiched layer or base is significantly thinner than the collector or the emitter. In general this permits a "punching through" action for the carriers passing between the collector and emitter terminals.

Classification

The transistors are classified as either NPN or PNP according to the arrangement of their N and P-materials. The NPN transistor is formed by introducing a thin region of P-material between two regions of N-type material. The opposite is true for the PNP configuration.

The two basic types of transistors along with their circuit symbols are shown in Figure 10-207. Note that the two symbols are different. The horizontal line represents the base, and two angular lines represent the emitter and collector. The angular line with the arrow on it is the emitter, while the line without is the collector. The direction of the arrow on the emitter determines whether or not the transistor is a PNP or an NPN type. If the arrow is pointing in, the transistor is a PNP. On the other hand, if the arrow is pointing out, then it is an NPN type.

Transistor Theory

As discussed in the section on diodes, the movement of the electrons and holes can be considered current. Electron current moves in one direction, while hole current travels in the opposite direction. In transistors, both electrons and holes act as carriers of current.

A forward biased PN junction is comparable to a low-resistance circuit element because it passes a high current for a given voltage. On the other hand, a reverse-biased PN junction is comparable to a high-resistance circuit element. By using Ohm's law formula for power ($P = I^2R$) and assuming current is held constant through both junctions, it can be concluded that the power developed across the high resistance junction is greater than that developed across a low resistance junction. Therefore, if a crystal were to contain two PN junctions, one forward biased and the

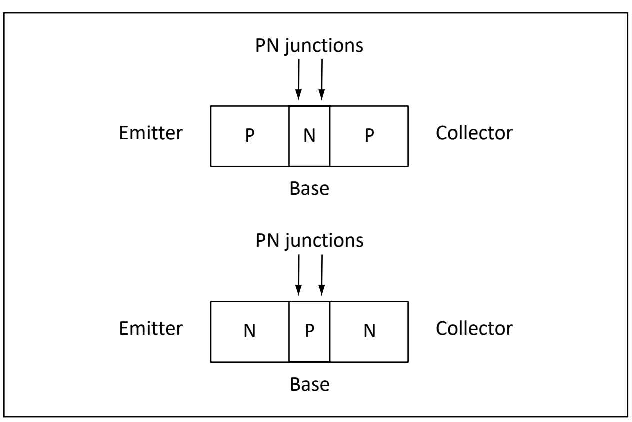

Figure 10-206. Transistor.

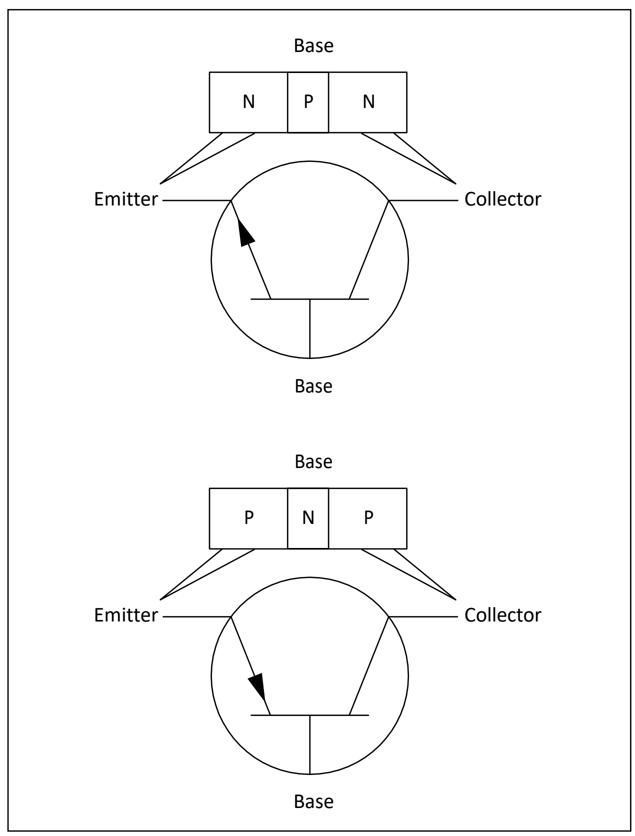

Figure 10-207. Two basic transistors with circuit symbols.

other reverse biased, and a low-power signal injected into the forward biased junction, a high power signal could be produced at the reverse-biased junction.

To use the transistor as an amplifier, some sort of external bias voltage must modify each of the junctions. The first PN junction (emitter-base) is biased in the forward direction. This produces a low resistance. The second junction, which is the collector-base junction, is reverse biased to produce a high resistance. Figure 10-208 illustrates the proper biasing of an NPN transistor.

With the emitter-base junction biased in the forward direction, electrons leave the negative terminal of the battery and enter the N-material. These electrons pass easily through the emitter, cross over the junction, and combine with the hole in the P-material in the base. For each electron that fills a hole in the P-material, another electron will leave the P-material, which creates a new hole and enters the positive terminal of the battery.

The second PN junction, which is the base-collector junction, is reverse biased. This will prevent the majority carriers from crossing the junction, thus creating a high resistance circuit. It is worth noting that there still is a small current passing through the reversed PN junction in the form of minority carriers—that is, electrons in the P-material and holes in the N-material. The minority carriers play a significant part in the operation of the NPN transistor.

Figure 10-209 illustrates the basic interaction of the NPN junction. There are two batteries in the circuit used to bias the NPN transistor. Vbb is considered the base voltage supply, rated in this illustration at 1 volt, and the battery voltage Vcc, rated at 6 volts, is called the collector voltage supply.

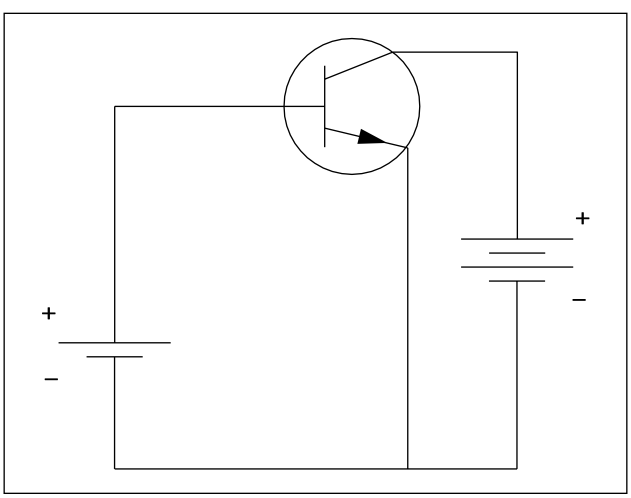

Figure 10-208. NPN transistor.

Current within the external circuit is simply the movement of free electrons originating at the negative terminal of the battery and flowing to the N-material. This is shown in Figure 10-209 as Ie or emitter-current.

As the electrons enter the N-material, they become the majority carrier and move through the N-material to the emitter-base PN junction. This emitter-base junction is forward biased at about 0.65 to 0.7 volts positive with respect to the emitter and presents no resistance to the flow of electrons from the emitter into the base, which is composed of P-material. As these electrons move into the base, they will drop into available holes. For every electron that drops into a hole, another electron exits the base by way of the base lead and becomes the base current or Ib. Of course, when one electron leaves the base, a new hole is formed. From the standpoint of the collector, these electrons that drop into holes are lost and of no use. To reduce this loss of electrons, the transistor is designed so that the base is very thin in relation to the emitter and collector, and the base is lightly doped.

Most of the electrons that move into the base will fall under the influence of the reverse bias of the collector. While collector-base junction is reverse biased with respect to the majority carriers, it behaves as if it is forward biased to the electrons or minority carriers in this case. The electrons are accelerated through the collector-base junction and into the collector. The collector is comprised of the N-type material; therefore, the electrons once again become the majority carrier. Moving easily through the collector, the electrons return to the positive terminal of the collector supply battery Vcc, which is shown in Figure 10-209 as Ic.

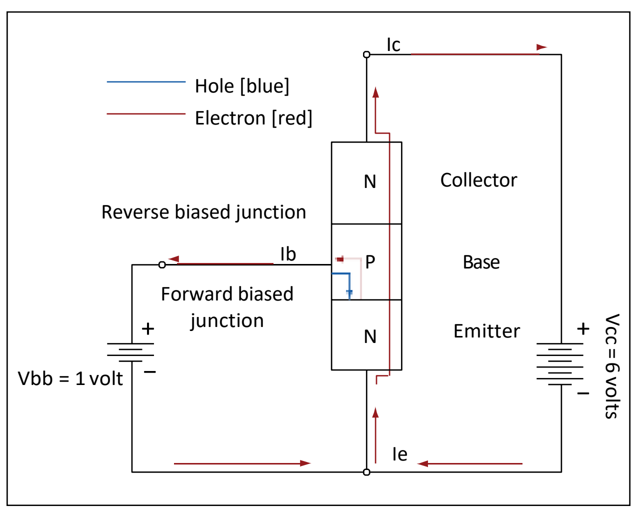

Figure 10-209. NPN Junction.

Because of the way this device operates to transfer current (and its internal resistances) from the original conduction path to another, its name is a combination of the words "transfer" and "resistor"—transistor.

PNP Transistor Operation

The PNP transistor generally works the same way as the NPN transistor. The primary difference is that the emitter, base, and collector materials are made of different material that the NPN. The majority and minority current carriers are the opposite in the PNP to that of the NPN. In the case of the PNP, the majority carriers are the holes instead of the electrons in the NPN transistor. To properly bias the PNP, the polarity of the bias network must be reversed.

Identification of Transistors

Figure 10-210 illustrates some of the more common transistor lead identifications. The methods of identifying leads will vary due to a lack of a standard and will require verification using manufacturer information to properly identify. However, a short description of the common methods is discussed below.

Illustration D in Figure 10-210 shows an oval-shaped transistor. The collector lead in this case is identified by the wide space between it and the lead for the base. The final lead at the far left is the emitter. In many cases, colored dots indicate the collector lead, and short leads relative to the other leads indicate the emitter. In a conventional power diode as seen in illustration E of Figure 10-210, the collector lead is usually a part of the mounting bases, while the emitter and collector are leads or tines protruding from the mounting surface.

Field Effect Transistors

Another transistor design that has become more important than the bipolar transistor is the field-effect transistor or FET. The primary difference between the bipolar transistor and the FET is that the bipolar transistor has two PN junctions and is a current controlled device, while the FET has only one PN junction and is a voltage controlled device. Within the FET family, there are two general categories of components. One category is called the junction FET (JFET), which has only one PN junction. The other category is known as the enhancement-type or metal-oxide JET (MOSFET).

Figure 10-211 shows the basic construction of the JFET and the schematic symbol. In this Figure, it can

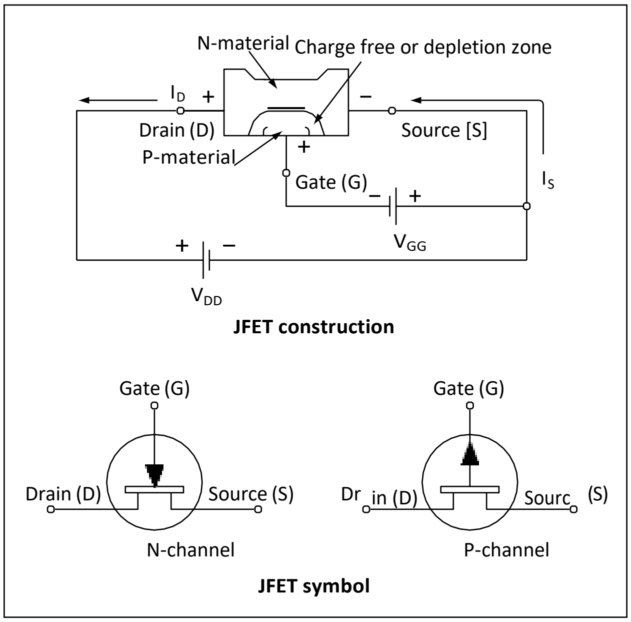

Figure 2-211. JFET and the schematic symbol.

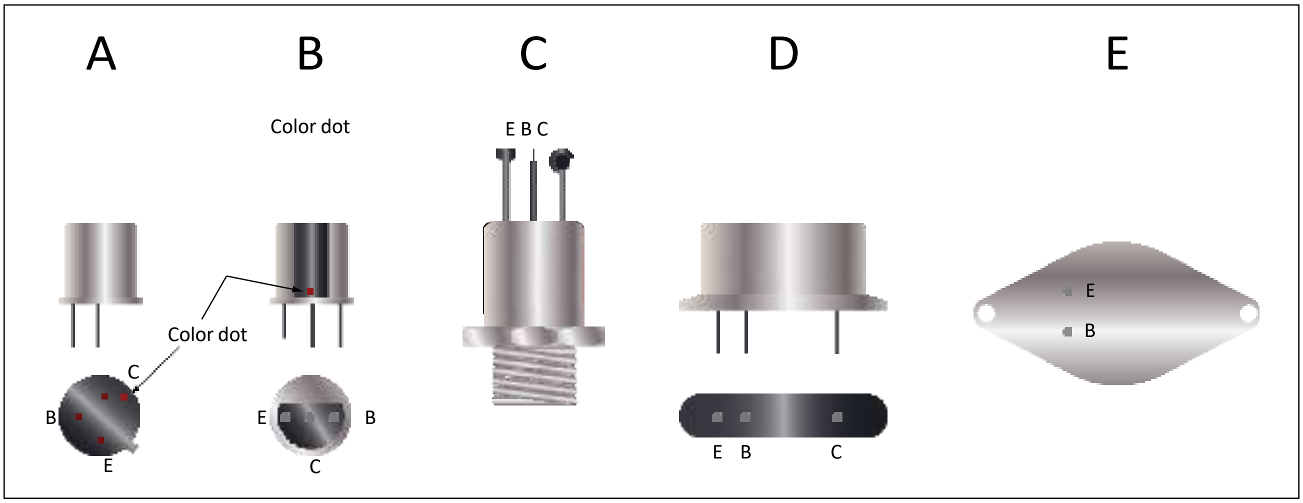

Figure 10-210. Common transistor lead identifications.

be seen that the drain (D) and source (S) are connected to an N-type material, and the gate (G) is connected to the P-type material. With gate voltage Vgg set to 0 volts and drain voltage Vdd set to some positive voltage, a current will flow between the source and the drain, through a narrow band of N-material. If then, Vgg is adjusted to some negative voltage, the PN junction will be reverse biased, and a depletion zone (no charge carriers) will be established at the PN junction. By reducing the region of noncarriers, it will have the effect of reducing the dimensions of the N-channel, resulting in a reduction of source to drain current.

Because JFETs are voltage-controlled devices, they have some advantages over the bipolar transistor. One such advantage is that because the gate is reverse biased, the circuit that it is connected to sees the gate as a very high resistance. This means that the JFET has less of an insertion influence in the circuit. The high resistance also means that less current will be used.

Like many other solid-state devices, careless handling and static electricity can damage the JFET. Technicians should take all precautions to prevent such damage.

Metal-Oxide-Semiconductor FET (MOSFET)

Figure 10-212 illustrates the general construction and the schematic symbol of the MOSFET transistor. The biasing arrangement for the MOSFET is essentially the same as that for the JFET. The term "enhancement" comes from the idea that when there is no bias voltage applied to the gate (G), then there is no channel for current conduction between the source (S) and the drain (D). By applying a greater voltage on the gate (G), the P-channel will begin to materialize and grow in size. Once this occurs, the source (S) to drain (D) current Id will increase. The schematic symbol reflects this characteristic by using a broken line to indicate that the channel does not exist without a gate bias.

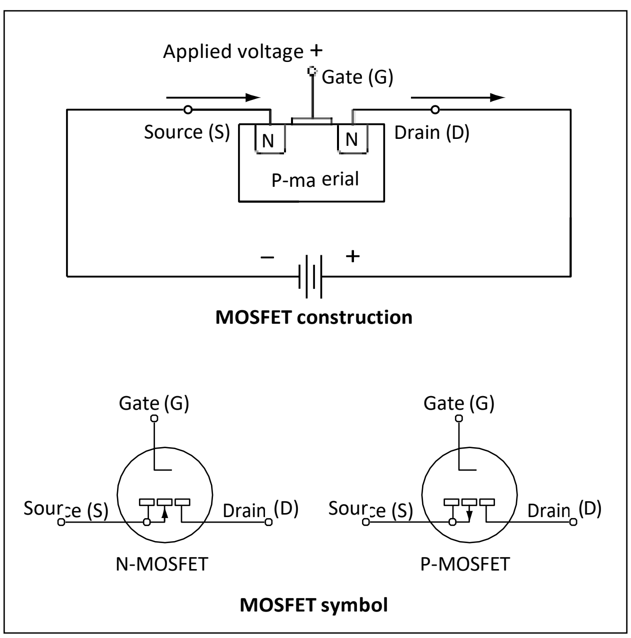

Figure 10-212. General construction and schematic symbol of MOSFET transistor.

Common Transistor Configurations

A transistor may be connected in one of three different configurations. The three basic configurations are: common-emitter (CE), common-base (CB), and common-collector (CC). The term "common" is used to indicate which element of the transistor is common to both the input and the output. Each configuration has its own characteristics, which makes each configuration suitable for particular applications. A way to determine what configuration you may find in a circuit is to first determine which of the three transistor elements is used for the input signal. Then, determine the element used for the output signal. At that point, the remaining element, (base, emitter, or collector) will be the common element to both the input and output, and thus you determine the configuration.

Common-Emitter Configuration

This is the configuration most commonly used in amplifier circuits because they provide good gains for voltage, current, and power. The input signal is applied to the base-emitter junction, which is forward biased (low resistance), and the output signal is taken off the collector-emitter junction, which is reverse biased (high resistance). Then the emitter is the common element to both input and output circuits. [Figure 10-213]

When the transistor is connected in a common-emitter configuration, the input signal is injected between the base and emitter, which is a low resistance, low-current circuit. As the input signal goes positive, it causes the base to go positive relative to the emitter. This causes a decrease in the forward bias, which in turn reduces the collector current I_C and increases the collector voltage (E_C being more negative). During the negative portion of the input signal, the voltage on the base is driven more negative relative to the emitter. This increases the forward bias and allows an increase in collector current I_C and a decrease in collector voltage (E_C being less negative and going positive). The collector current, which flows through the reverse-biased junction, also flows through a high resistance load resulting in a high level of amplification.

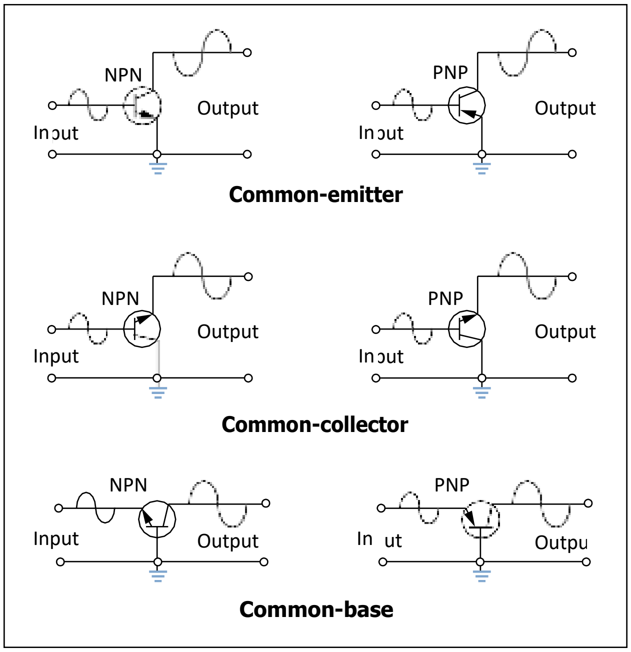

Figure 10-213. Transistor configurations (common-emitter, common-collector, common-base).

Because the input signal to the common-emitter goes positive when the output goes negative, the two signals are 180° out of phase. This is the only configuration that provides a phase reversal. The common-emitter is the most popular of the three configurations because it has the best combination of current and voltage gain. Gain is a term used to indicate the magnitude of amplification. Each transistor configuration has its unique gain characteristics even though the same transistors are used.

Common-Collector Configuration

This transistor configuration is usually used for impedance matching. It is also used as a current driver due to its high current gain. It is also very useful in switching circuits since it has the ability to pass signals in either direction. [Figure 10-213]

In the common-collector circuit, the input signal is applied to the base, and the output signal is taken from the emitter, leaving the collector as the common point between the input and the output. The input resistance of the CC circuit is high, while the output resistance is low. The current gain is higher than that in the common-emitter, but it has a lower power gain than either the common-emitter or common-base configuration. Just like the common-base configuration, the output signal of the common-collector circuit is in phase with the input signal. The common-collector is typically referred to as an emitter-follower because the output developed on the emitter follows the input signal applied to the base.

Common-Base Configuration

The primary use of this configuration is for impedance matching because it has low input impedance and high output resistance. Two factors, however, limit the usefulness of this circuit application. First is the low input resistance and second is its lack of current, which is always below 1. Since the CB configuration will give voltage amplification, there are some applications for this circuit, such as microphone amplifiers. [Figure 10-213]

In the common-base circuit, the input signal is applied to the emitter and the output signal is taken from the collector. In this case, both the input and the output have the base as a common element. When an input signal is applied to the emitter, it causes the emitter-base junction to react in the same manner as that in the common-emitter circuit. When an input adds to the bias, it will increase the transistor current; conversely, when the signal opposes the bias, the current in the transistor decreases.

The signal adds to the forward bias, since it is applied to the emitter, causing the collector current to increase. This increase in I_C results in a greater voltage drop across the load resistor RL, thus lowering the collector voltage E_C. The collector voltage, in becoming less negative, will swing in a positive direction and is therefore in phase with the incoming positive signal.

Vacuum Tubes

The use of vacuum tubes in aircraft electrical and electronic systems has rapidly declined due to the many advantages of using transistors. However, some systems still employ vacuum tubes in special applications, and possibly some older model aircraft still in service are equipped with devices that use vacuum tubes. While these components may still be in service, their infrequent occurrence does not warrant a detailed discussion.

Originally, vacuum tubes were developed for radio work. They are used in radio transmitters as amplifiers for controlling voltage and current, as oscillators for generating audio and radio frequency signals, and as rectifiers for converting alternating current into direct current. While there are many types of vacuum tubes for a variety of applications, the most common types fall into one of the following families: (1) diode, (2) triode, (3) tetrode, and (4) pentode. Each of these vacuum tube types operates on the following fundamental principles.

When a piece of metal is heated, the speed of the electrons in the metal is increased. If the metal is heated to a high enough temperature, the electrons are accelerated to the point where some of them actually leave the surface of the metal. In a vacuum tube, electrons are supplied by a piece of metal called a cathode, which is heated by an electric current. Within limits, the hotter the cathode, the greater the number of electrons it will give off or emit.

To increase the number of electrons emitted, the cathode is usually coated with special chemical compounds. If an external field does not draw the emitted electrons away, they form about the cathode into a negatively charged cloud called the space charge. The accumulation of negative electrons near the emitter repels others coming from the emitter. The emitter, if insulated, becomes positive because of the loss of electrons. This establishes an electrostatic field between the cloud of negative electrons and the now positive cathode. A balance is reached when only enough electrons flow from the cathode to the area surrounding it to supply the loss caused by diffusion of the space charge.

Filtering

One of the more common uses of the capacitor and inductor that the technician may find in the field is that of the filter.

Filtering Characteristics of Capacitors

The nature of capacitance opposes a voltage change across its terminal by storing energy in its electrostatic field. Whenever the voltage tends to rise, the capacitor converts this voltage change to stored energy. When the voltage tends to fall, the capacitor converts this stored energy back to voltage. The use of a capacitor for filtering the output of a rectifier is illustrated in Figure 10-214. The rectifier is shown as a block, and the capacitor C_1 is connected in parallel with the load R_1.

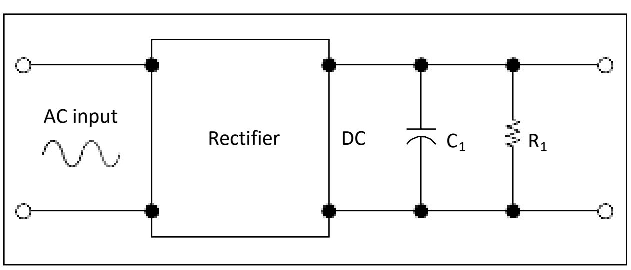

Figure 10-214. A capacitor used as a filter.

The capacitor C_1 is chosen to offer very low impedance to the AC ripple frequency and very high impedance to the DC component. The ripple voltage is therefore bypassed to ground through the low impedance path of the capacitor, while the DC voltage is applied unchanged to the load. The effect of the capacitor on the output of the rectifier can be seen in the waveshapes shown in Figure 10-215. Dotted lines show the rectifier output, while the solid lines show the effect of the capacitor. In this example, full-wave rectifier outputs are shown. The capacitor C_1 charges when the rectifier voltage output tends to increase and discharges when the voltage output tends to decrease. In this manner, the voltage across the load R_1 is kept fairly constant.

Filtering Characteristics of Inductors

The inductance provided by an inductor may be used as a filter, because it opposes a change in current through it by storing energy in its electromagnetic field. Whenever the current increases, the stored energy in the electromagnetic field increases. When the current through the inductor decreases, the inductor supplies the energy back into the circuit in order to maintain the existing flow of current. The use of an inductor for filtering the output of a rectifier is shown in Figure 10-216. Note that in this network the inductor L_1 is in series with the load R_1.

The inductance L_1 is selected to offer high impedance to the AC ripple voltage and low impedance to the DC component. The result is a very large voltage drop across the inductor and a very small voltage drop across the load R_1. For the DC component, however, a

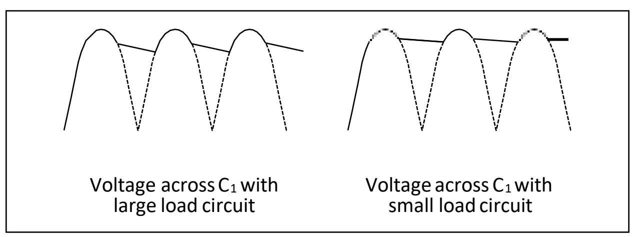

Figure 10-215. Half-wave and full-wave rectifier outputs using capacitor filter.

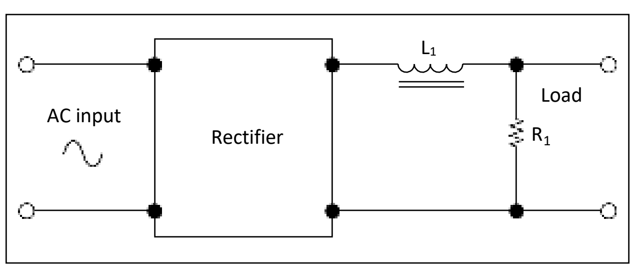

Figure 10-216. An inductor used as a filter.

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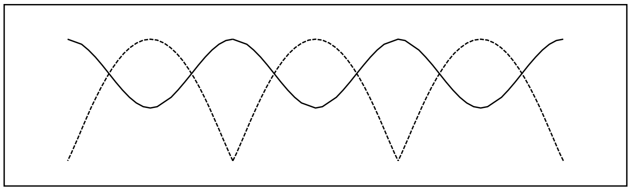


Figure 10-217. Output of an inductor filter rectifier.

very small voltage drop occurs across the inductor and a very large voltage drop across the load. The effect of an inductor on the output of a full-wave rectifier in the output waveshape is shown in Figure 10-217.

Common Filter Configurations

Capacitors and inductors are combined in various ways to provide more satisfactory filtering than can be obtained with a single capacitor or inductor. These are referred to collectively as "LC filters." Several combinations are shown schematically in Figure 10-218. Note that the L, or inverted L-type, and the T-type filter sections resemble schematically the corresponding letters of the alphabet. The pi-type filter section resembles the Greek letter pi (π) schematically.

All the filter sections shown are similar in that the inductances are in series and the capacitances are in parallel with the load. The inductances must, therefore, offer very high impedance and the capacitors very low impedance to the ripple frequency. Since the ripple frequency is comparatively low, the inductances are iron core coils having large values of inductance (several henries). Because they offer such high impedance to the ripple frequency, these coils are called chokes. The capacitors must also be large (several microfarads) to offer very little opposition to the ripple frequency. Because the voltage across the capacitor is DC, electrolytic capacitors are frequently used as filter capacitors. Always observe the correct polarity in connecting electrolytic capacitors.

LC filters are also classified according to the position of the capacitor and inductor. A capacitor input filter is one in which the capacitor is connected directly across the output terminals of the rectifier. A choke input filter is one in which a choke precedes the filter capacitor.

If it is necessary to increase the applied voltage to more than a single rectifier can tolerate, the usual solution is to stack them. These rectifiers are similar to resistors added in series. Each resistor will drop a portion of the applied voltage rather than the total voltage. The same theory applies to rectifiers added in series, or stacked. Series stacking increases the voltage rating. If, for

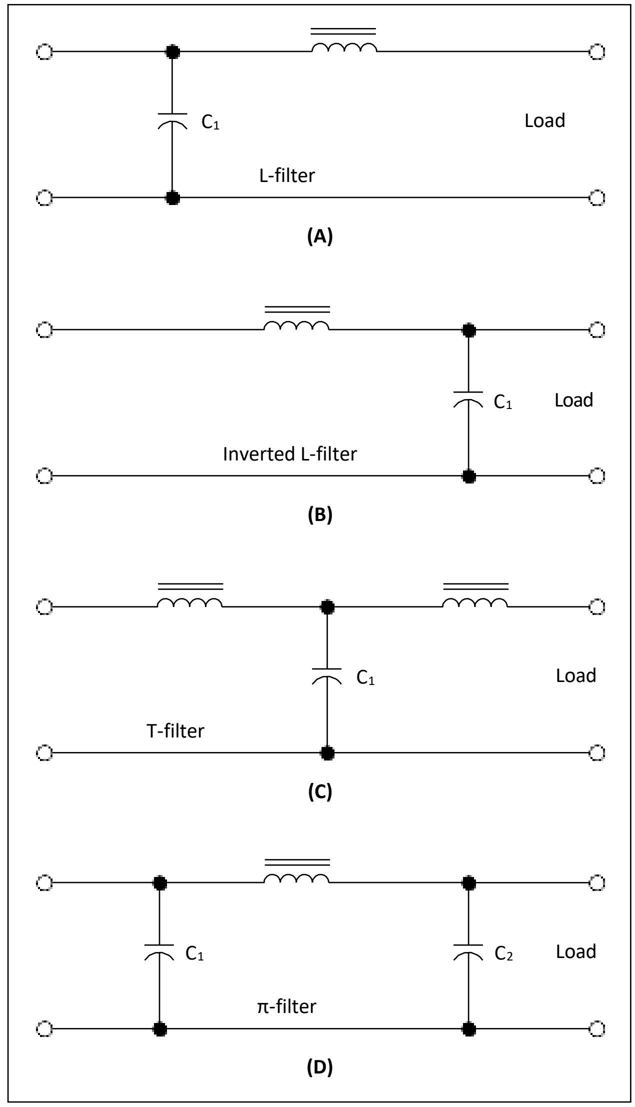


Figure 10-218. LC filters.

example, a rectifier will be destroyed with an applied voltage exceeding 50 volts, and it is to be used in a circuit with an applied voltage of 150 volts, stacking of diodes can be employed. The result is shown in Figure 10-219.

Basic LC Filters

Analog filters are circuits that perform signal processing functions, specifically intended to remove unwanted signal components such as ripple and enhance desired signals. The simplest analog filters are based on combinations of inductors and capacitors. The four basic categories of filters discussed are: low-pass, high-pass, band-pass and band-stop. All these types are collectively known as passive filters, because they do not depend on any external power source.

The operation of a filter relies on the characteristic of variable inductive and capacitive reactance based on

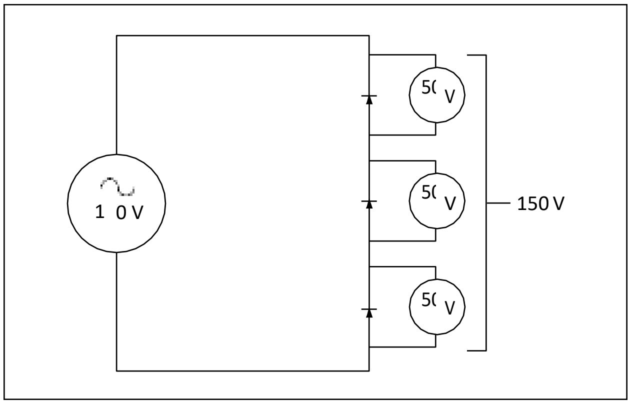


Figure 10-219. Stacking diodes in a circuit.

the applied frequency. In review, the inductor will block high-frequency signals (high reactance) and conduct low-frequency signals (low reactance), while capacitors do the reverse. A filter in which the signal passes through an inductor, or in which a capacitor provides a path to earth, presents less attenuation (reduction) to a low-frequency signal than to a high-frequency signal and is considered a low-pass filter. If the signal passes through a capacitor, or has a path to ground through an inductor, then the filter presents less attenuation to high-frequency signals than low-frequency signals and is then considered a high-pass filter. Typically after an AC signal is rectified the pulses of voltage are changed to usable form of DC by way of filtering.

Low-Pass Filter

A low-pass filter is a filter that passes low frequencies well, but attenuates (reduces) higher frequencies. The so-called cutoff frequency divides the range of frequencies that are passed and the range of frequencies that are stopped. In other words, the frequency components higher than the cutoff frequency will be stopped by a low-pass filter.

The actual amount of attenuation for each frequency varies by filter design.

An Inductive low-pass filter inserts an inductor in series with the load, where a capacitive low-pass filter inserts a resistor in series and a capacitor in parallel with the load. The former filter design tries to "block" the unwanted frequency signal while the latter tries to short it out. Figure 10-220 illustrates this type of circuit and the frequency/current flow response.

High-Pass Filter

A high-pass filter (HPF) is a filter that passes high frequencies well, but attenuates (reduces) frequencies lower than the cutoff frequency. The actual amount of attenuation for each frequency varies once again depending on filter design. In some cases it is called a low-cut filter. A high-pass filter is essentially the opposite of a low-pass filter.

It is useful as a filter to block any unwanted low frequency components of a signal while passing the desired higher frequencies. Figure 10-221 illustrates this type of circuit and the frequency/current flow response.

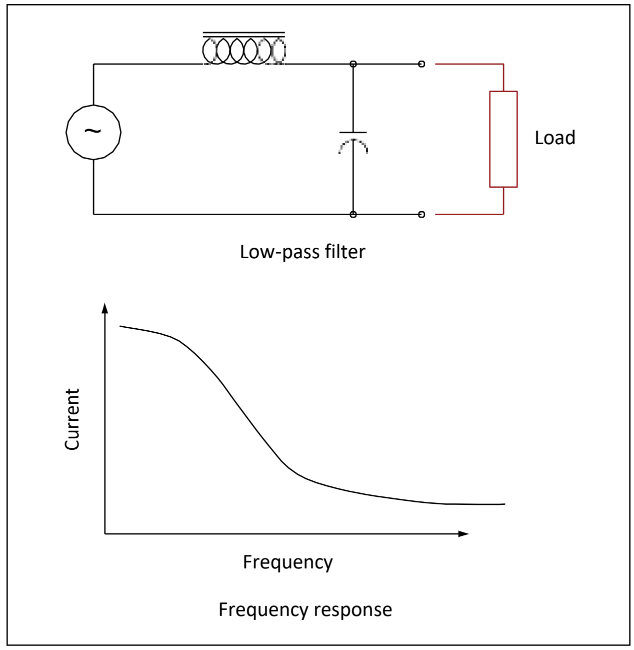


Figure 10-220. Low-pass filter.

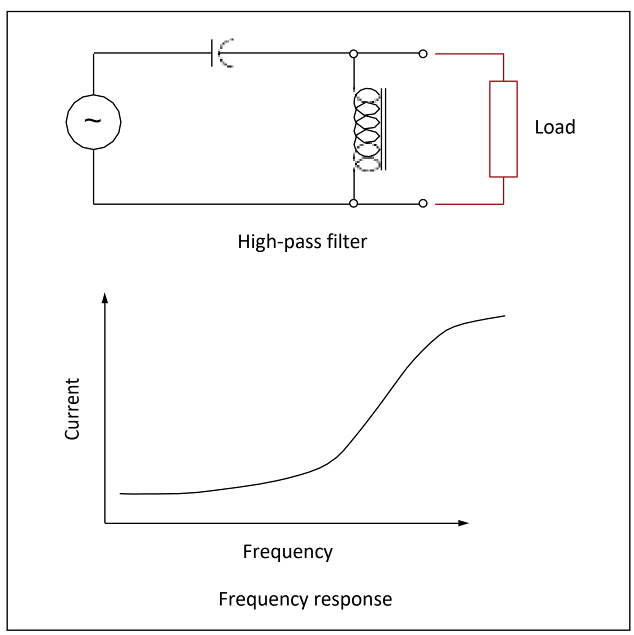


Figure 10-221. High-pass filter.

Band-Pass Filter

A band-pass filter is basically a combination of a high-pass and a low-pass. There are some applications where a particular range of frequencies need to be singled out or filtered from a wider range of frequencies. Band-pass filter circuits are designed to accomplish this task by combining the properties of low-pass and high-pass into a single filter. Figure 10-222 illustrates this type of circuit and the frequency/current flow response.

Band-Stop Filter

In signal processing, a band-stop filter or band-rejection filter is a filter that passes most frequencies unaltered, but attenuates those in a range to very low levels. It is the opposite of a band-pass filter. A notch filter is a band-stop filter with a narrow stopband (high Q factor). Notch filters are used in live sound reproduction (Public Address systems, also known as PA systems) and in instrument amplifier (especially amplifiers or preamplifiers for acoustic instruments such as acoustic guitar, mandolin, bass instrument amplifier, etc.) to reduce or prevent feedback, while having little noticeable effect on the rest of the frequency spectrum. Other names include "band limit filter," "T-notch filter," "band-elimination filter," and "band-rejection filter."

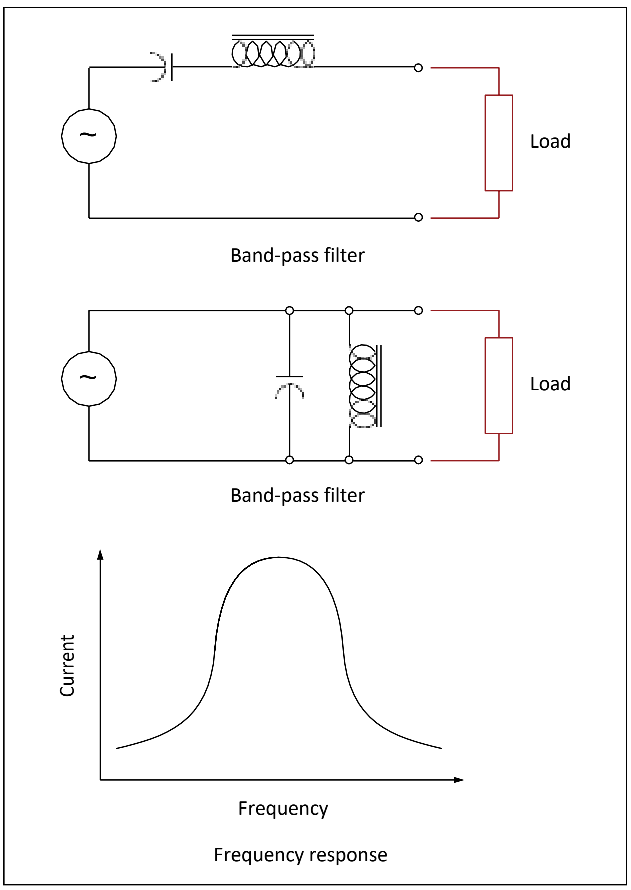


Figure 10-222. Band-pass filter.

Typically, the width of the stop-band is less than 1 to 2 decades (that is, the highest frequency attenuated is less than 10 to 100 times the lowest frequency attenuated). In the audio band, a notch filter uses high and low frequencies that may be only semitones apart.

A band-stop filter is the general case. A notch filter is a specific type of band-stop filter with a very narrow range.

Also called band-elimination, band-reject, or notch filters, this kind of filter passes all frequencies above and below a particular range set by the component values. Not surprisingly, it can be made out of a low-pass and a high-pass filter, just like the band-pass design, except that this time we connect the two filter sections in parallel with each other instead of in series. Figure 10-223 illustrates this type of circuit and the frequency/current flow response.

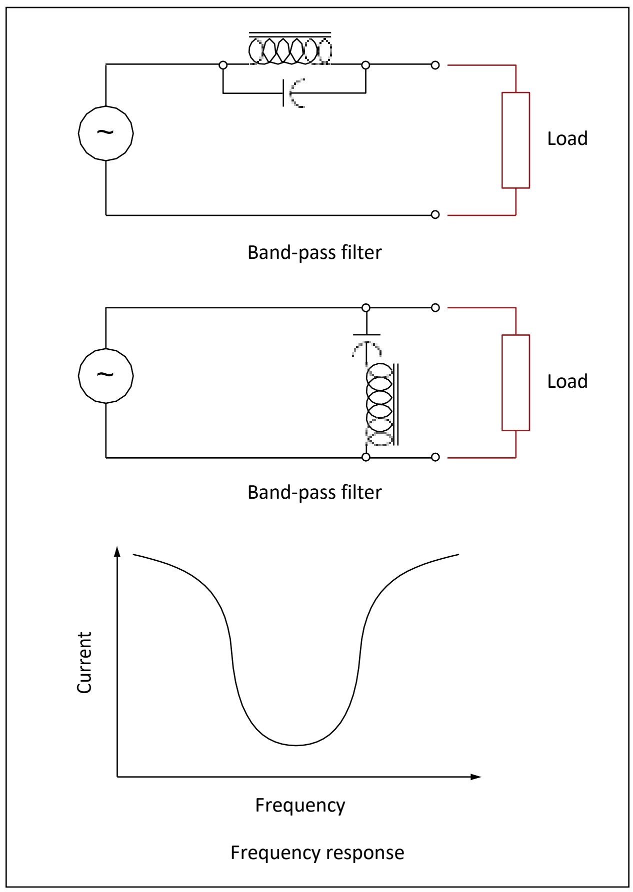


Figure 10-223. Band-stop filter.

Amplifier Circuits

An amplifier is a device that enables an input signal to control an output signal. The output signal will have some or all of the characteristics of the input signal but will generally be a greater magnitude than the input signal in terms of voltage, current, or power. Gain is the basic function of all amplifiers. Because of this gain, we can expect the output signal to be greater than the input signal. If for example we have an input signal of 1 volt and an output signal of 10 volts, then the gain factor can be determined by:

Gain = Signal out /Signal in
Gain = 10V/1V = 10

Voltage gain is usually used to describe the operation of a small gain amplifier. In this type of an amplifier, the output signal voltage is larger than the input signal voltage. Power gain, on the other hand, is usually used to describe the operation of large signal amplifiers. In the case of power gain amplifiers, the gain is not based on voltage but on watts. A power amplifier is an amplifier in which the output signal power is greater than the input signal power. Most power amplifiers are used as the final stage of amplification and drive the output device. The output device could be a cockpit or cabin speaker, an indicator, or antenna. Whatever the device, the power to make it work comes from the final stage of amplification. Drivers for autopilot servos are sometimes contained in line replaceable units (LRUs) called autopilot amplifiers. These units take the low signal commands from the flight guidance system and amplify the signals to a level usable for driving the servo motors.

Classification

The classification of a transistor amplifier circuit is determined by the percentage of the time that the current flows through the output circuit in relation to the input signal. There are four classifications of operation: A, AB, B, and C. Each class of operation has a certain use and characteristic. No individual class of amplifiers is considered the "best." The best use of an amplifier is a matter of proper selection for the particular operation desired.

Class A

Figure 10-224, shows a simplified Class A amplifier circuit. In the Class A operation, the current in the transistor flows for 100 percent or 360° of the input signal. Class A operation is the least efficient class of operation but provides the best fidelity. Fidelity simply means that the output signal is a good reproduction of the input signal in all respects other than the amplitude, which is amplified. In some cases, there may be some phase shifting between the input signal and the output signal. Typically, the phase difference is 180°. If the output signal is not a good reproduction of the input signal, then the signal is said to be distorted. Distortion is any undesired change to the signal from the input to the output.

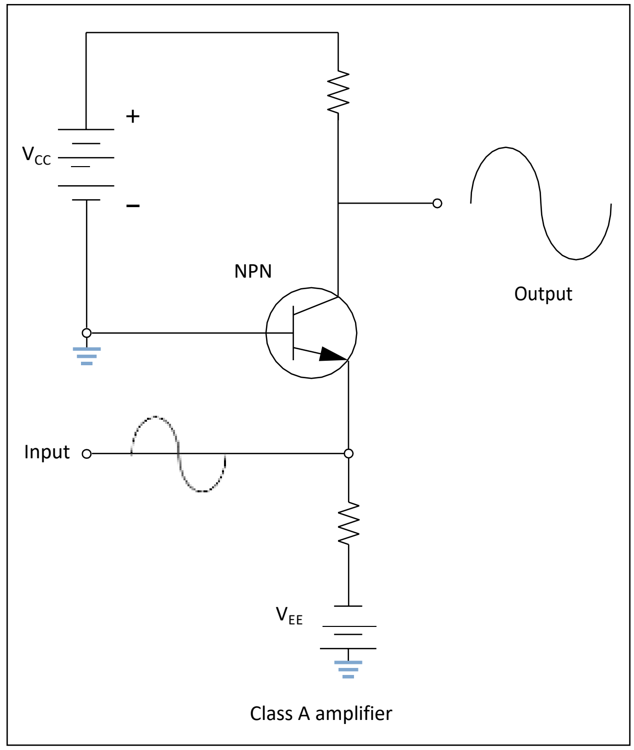


Figure 10-224. Simplified Class A amplifier circuit.

The efficiency of an amplifier refers to the amount of power delivered to the output compared to the power supplied to the circuit. Every device in the circuit consumes power in order to operate. If the amplifier operates for 360° of input signal, then it is using more power than if it was using only 180° of input signal. The more power consumed by the amplifier, the less there is available for the output signal. Usually the Class A amplifier is used where efficiency is of little concern and where fidelity in reproduction is desired.

Class AB

Figure 10-225, shows a simplified Class AB amplifier circuit. In the Class AB operation, the transistor current flows for more than 50 percent but less than 100 percent of the input signal. Unlike the Class A amplifier, the output signal is distorted. A portion of the output circuit appears to be truncated. This is due to the lack of current through the transistor during this point of operation. When the emitter in this case becomes positive enough, the transistor cannot conduct because the

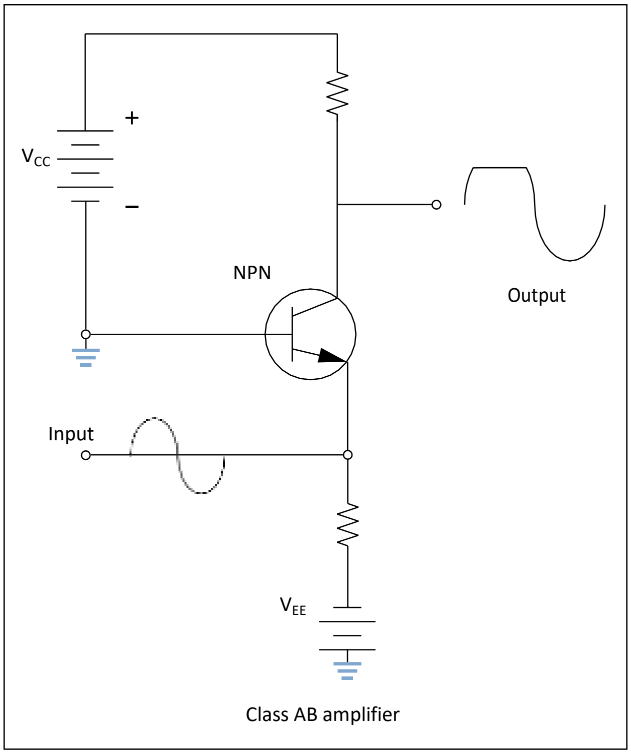


Figure 10-225. Simplified Class AB amplifier circuit.

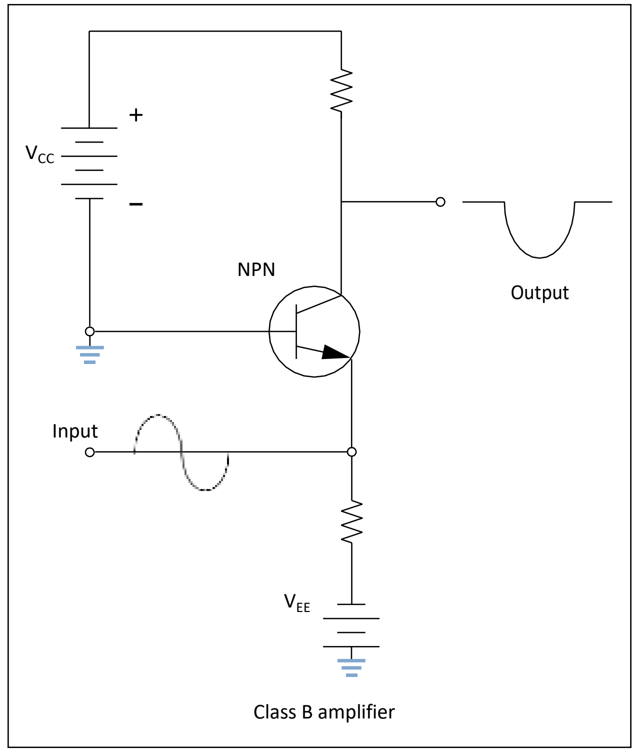


Figure 10-226. Simplified Class B amplifier circuit.

base to emitter junction is no longer forward biased. The input signal going positive beyond this point will not produce any further output and the output will remain level.

The Class AB amplifier has a better efficiency and a poorer fidelity than the Class A amplifier. These amplifiers are used when an exact reproduction of the input is not required but both the positive and negative portions of the input signals need to be available on the output.

Class B

Figure 10-226, shows a simplified Class B amplifier circuit. In Class B operation, the transistor current flows for only 50 percent of the input signal. In this illustration, the base-emitter bias will not allow the transistor to conduct whenever the input signal is greater than zero. In this case, only the negative portion of the input signal will be reproduced. Unlike the rectifier, the Class B amplifier will not only reproduce half of the input signal, but it will also amplify it. Class B amplifiers are twice as efficient as the Class A amplifier because the amplifying device only uses power for half of the input signal.

Class C

Figure 10-227, shows a simplified Class C amplifier circuit. In Class C operations, transistor current flows for less than 50 percent of the input signal. This class of operation is the most efficient. Because the transistor does not conduct except during a small portion of the input signal, this is the most efficient class of amplifier. The distortion of the Class C amplifier is greater (poor

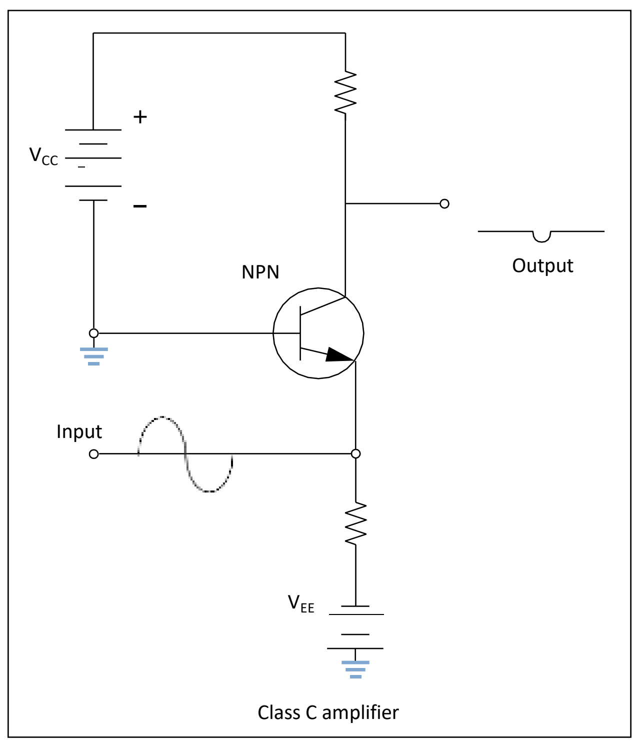


Figure 10-227. Simplified Class C amplifier circuit.

fidelity) than the Class A, AB, and B amplifiers because a small portion of the input signal is reproduced on the output. Class C amplifiers are used when the output signal is used for only small portions of time.

Methods of Coupling

Coupling is used to transfer a signal from one stage on an amplifier to another stage. Regardless of whether an amplifier is a single stage or one in a series of stages, there must be a method for the signal to enter and leave the circuit. Coupling is the process of transferring the energy between circuits. There are a number of ways for making this transfer and to discuss these methods in detail goes beyond the scope of this text. However, four methods are listed below with a brief description of their operation.

Direct Coupling

Direct coupling is the connection of the output of one stage directly to the input of the next stage. Direct coupling provides a good frequency response because no frequency-sensitive components such as capacitors and inductors are used. Yet this method is not used very often due to the complex power supply requirements and the impedance matching problems.

RC Coupling

RC coupling is the most common method of coupling and uses a coupling capacitor and signal developing resistors. Figure 10-228, shows a simplified RC coupling circuit. In this circuit, R1 acts as a load resistor for Q1 and develops the output signal for that stage. The capacitor C1 blocks the DC bias signal and passes the AC output signal. R2 then becomes the load over which the passes AC signal is developed as an input to the base of Q2. This arrangement allows for the bias voltage of each stage to be blocked, while the AC signal is passed to the next stage.

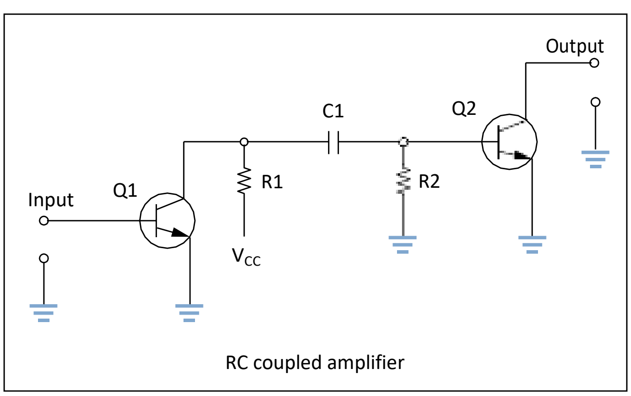


Figure 10-228. Simplified RC coupling circuit.

Impedance Coupling

Impedance coupling uses a coil as a load for the first stage but otherwise functions just as an RC coupling. Figure 10-229 shows a simplified impedance coupling circuit. This method is similar to the RC coupling method. The difference is that R1 is replaced with inductor L1 as the output load. The amount of signal developed on the output load depends on the inductive reactance of the coil. In order for the inductive reactance to be high, the inductance must be large; the frequency must be high or both. Therefore, load inductors should have relatively large amounts of inductance and are most effective at high frequencies.

Transformer Coupling

Transformer coupling uses a transformer to couple the signal from one stage to the next. Figure 10-230, shows a simplified transformer coupling circuit. The transformer action of T1 couples the signal from the first stage to the second stage. The primary coil of T1 acts as a load for the output of the first stage while the secondary coil acts as the developing impedance for the second stage Q2. Transformer coupling is very efficient and the transformer can aid in impedance matching.

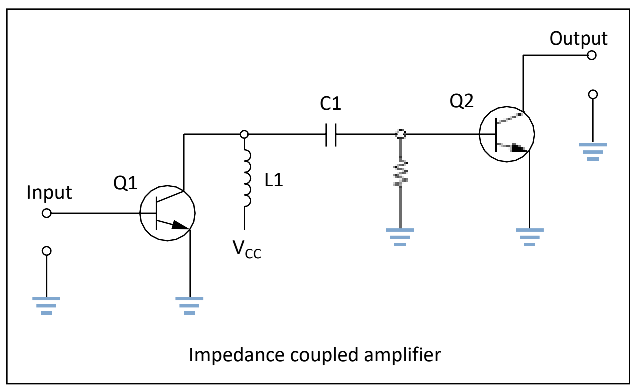


Figure 10-229. Simplified impedance coupling circuit.

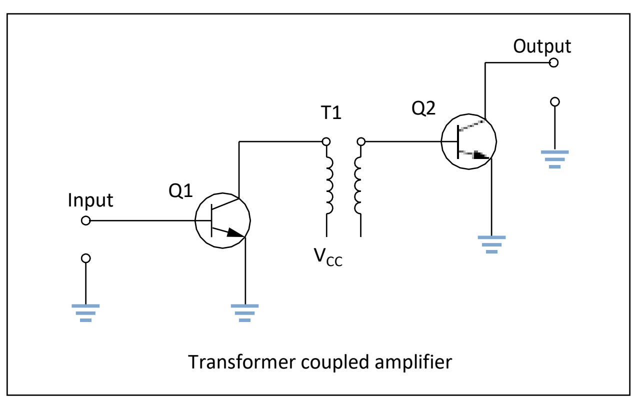


Figure 10-230. Simplified transformer coupling circuit.

Feedback

Feedback occurs when a small portion of the output signal is sent back to the input signal to the amplifier. There are two types of feedback in amplifiers:

1. Positive (regenerative)
2. Negative (degenerative)

The main difference between these two signals is whether the feedback signal adds to the input signal or if the feedback signal diminishes the input signal.

When the feedback is positive, the signal being returned to the input is in phase with the input signal and thus interferes constructively. Figure 10-231 illustrates this concept applied in the amplifier circuit through a block diagram. Notice that the feedback signal is in phase with the input signal, which will regenerate the input signal. This results in an output signal with amplitude greater than would have been without the constructive, positive feedback. This type of positive feedback is what causes an audio system to squeal.

Figure 10-231 also illustrates with a block diagram how negative or degenerative feedback occurs. In this case, the feedback signal is out of phase with the input signal. This causes destructive interference and degenerates the input signal. The result is a lower amplitude output signal than would have occurred without the feedback.

Operational Amplifiers

An operational amplifier (OP AMP) is designed to be used with other circuit components and performs either computing functions or filtering. Operational amplifiers are usually high-gain amplifiers with the amount of gain governed by the amount of feedback.

Operational amplifiers were originally developed for analog computers and used to perform mathematical functions. Today many devices use the operational amplifier for DC amplifiers, AC amplifiers, comparators, oscillators, and filter circuits. The widespread use is due to the fact that the OP AMP is a versatile device, small, and inexpensive. Built into the integrated chip, the operational amp is used as a basic building block of larger circuits.

Figure 10-232 shows the schematic symbol for the operational amplifier. There are two inputs to the

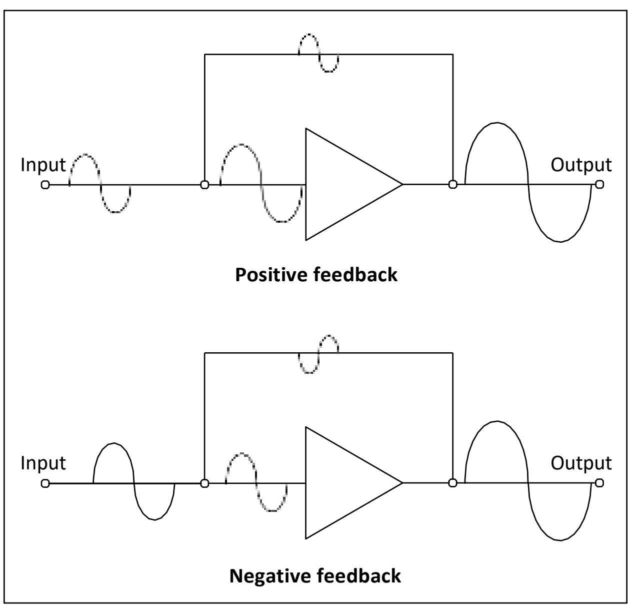


Figure 10-231. Feedback.

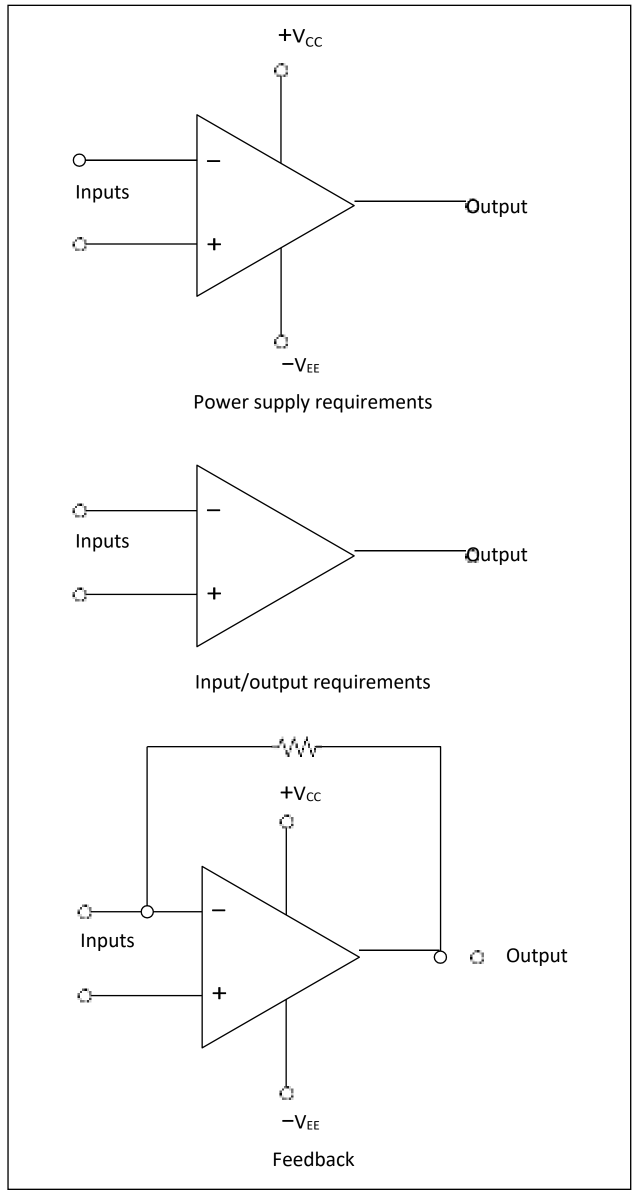


Figure 10-232. Schematic symbol for the operational amplifier.

operational amplifier, inverting (−) and non-inverting (+), and there is one output. The polarity of a signal applied to the inverting input (−) will be reversed at the output. A signal applied to the non-inverting (+) input will retain its polarity on the output. To be classified as an operational amplifier, the circuit must have certain characteristics:

1. Very high gain.
2. Very high input impedance.
3. Very high output impedance.

This type of a circuit can be made up of discrete components, such as resistors and transistors. However, the most common form of an operational amplifier is found in the integrated circuit. This integrated circuit or chip will contain the various stages of the operational amplifier and can be treated as if it were a single stage.

Applications

The number of applications for OP AMPs is too numerous to detail in this text. However, the technician will occasionally come across these devices in modern aircraft and should be able to recognize their general purpose in a circuit. Some of the basic applications are:

1. Go/No Go detectors.
2. Square wave circuits.
3. Non-inverting amplifier.
4. Inverting amplifier.
5. Half-wave rectifier.

Magnetic Amplifiers

Magnetic amplifiers do not amplify magnetism but use electromagnetism to amplify a signal. Essentially, the magnetic amplifier is a power amplifier with a very limited frequency response. The frequency range most commonly associated with the magnetic amplifier is 100 hertz and less, which places it in the audio range. As a technical point, the magnetic amplifier is a low-frequency amplifier.

Advantages of the magnetic amplifier are:

1. Very high efficiency, on the order of approximately 90 percent.
2. High reliability.
3. Very rugged, able to withstand vibrations, moisture, and overloads.
4. No warm-up time.

Some of the disadvantages of the magnetic amplifier are:

1. Incapacity to handle low voltage signals.
2. Not usable in high-frequency applications.
3. Time delay associated with magnetic affects.
4. Poor fidelity.

The basic operating principles of the magnetic amplifier are fairly simple. Keep in mind that all amplifiers are current control devices. In this particular case, power that is delivered to the load is controlled by a variable inductance.

If an AC voltage is applied to the primary winding of an iron core transformer, the iron core will be magnetized and demagnetized at the same frequency as that of the applied voltage. This, in turn, will induce a voltage in the transformers secondary winding. The output voltage across the terminals of the secondary will depend on the relationship of the number of turns in the primary and the secondary of the transformer.

The iron core of the transformer has a saturation point after which the application of a greater magnetic force will produce no change in the intensity of magnetization. Hence, there will be no change in transformer output, even if the input is greatly increased. The magnetic amplifier circuit in Figure 10-233 will be used to explain how a simple magnetic amplifier functions.

1. Assume that there is 1 ampere of current in coil A, which has 10 turns of wire. If coil B has 10 turns

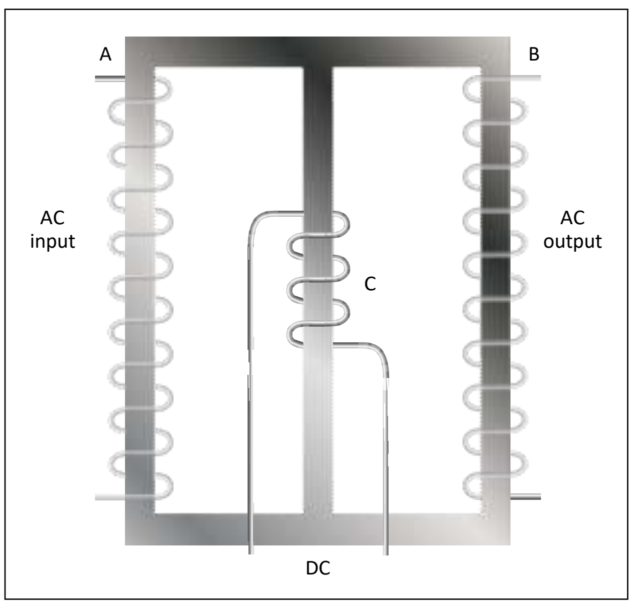


Figure 10-233. Magnetic amplifier circuit.

of wire, an output of 1 ampere will be obtained if coil B is properly loaded.

2. By applying direct current to coil C, the core of the magnetic amplifier coil can be further magnetized. Assume that coil C has the proper number of turns and, upon the application of 30 milliamperes, that the core is magnetized to the point where 1 ampere on coil Aresults in only 0.24 ampere output from coil B.
3. By making the DC input to coil C continuously variable from 0 to 30 milliamperes and maintaining an input of 1 ampere on coil A, it is possible to control the output of coil B to any point between 0.24 ampere and 1 ampere in this example.

The term “amplifier” is used for this arrangement because, by use of a few milliamperes, control of an output of 1 or more amperes is obtained.

Saturable-Core Reactor

The same procedure can be used with the circuit shown in Figure 10-234. A saturable-core reactor is a magnetic-core coil whose reactance is controlled by changing the permeability of the core. Varying the unidirectional flux controls the permeability of the core.

By controlling the extent of magnetization of the iron ring, it is possible to control the amount of current flowing to the load, since the amount of magnetization controls the impedance of the AC input winding. This type of magnetic amplifier is called a simple saturable reactor circuit.

Adding a rectifier to such a circuit would remove half the cycle of the AC input and permit a direct current to flow to the load. The amount of DC flowing in the load circuit is controlled by a DC control winding (sometimes referred to as bias). This type of magnetic amplifier is referred to as being self-saturating.

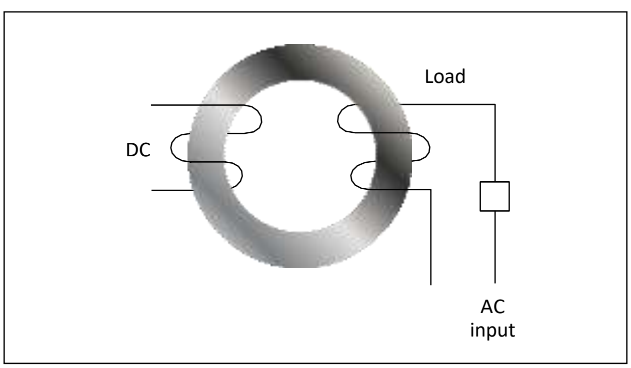


Figure 10-234. Saturable CORE reactor circuit.

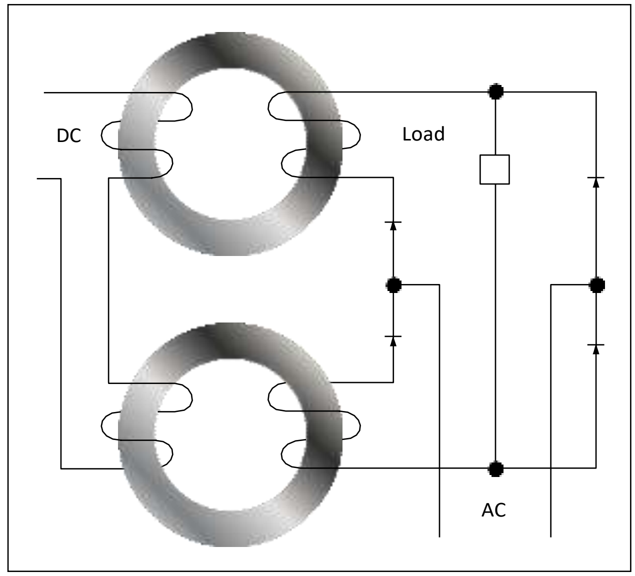


Figure 10-235. Self-saturating, full-wave magnetic amplifier.

To use the full AC input power, a circuit such as that shown in Figure 10-235 may be used. This circuit uses a full-wave bridge rectifier. The load will receive a controlled direct current by using the full AC input. This type of circuit is known as a self-saturating, full-wave magnetic amplifier.

In Figure 10-236 it is assumed that the DC control winding is supplied by a variable source, such as a sensing circuit. To control such a source and use its variations to control the AC output, it is necessary to include another DC winding that has a constant value. This winding, referred to as the reference winding, magnetizes the magnetic core in one direction.

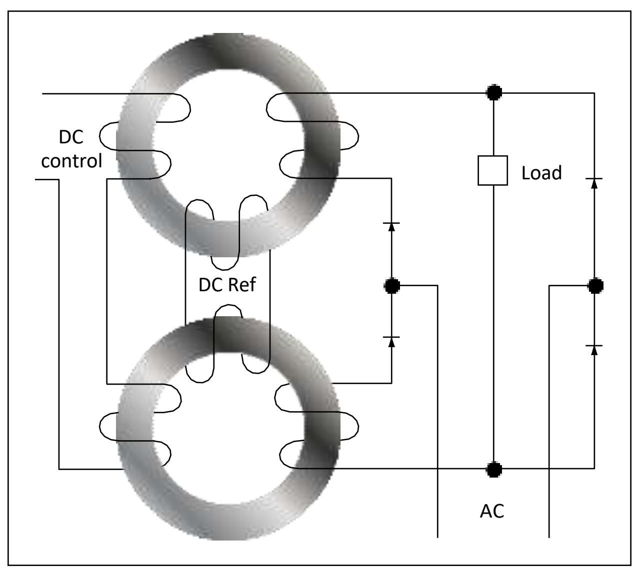


Figure 10-236. Basic preamplifier circuit.

The DC control winding, acting in opposition to the reference winding, either increases (degenerative) or decreases (regenerative) the magnetization of the core to change the amount of current flowing through the load. This is essentially a basic preamplifier.

Logic Circuits

Logic is considered the science of reasoning — the development of a reasonable conclusion based on known information. Human reasoning tells us that certain propositions are true if certain conditions or premises are true. An annunciator being lit in the master warning panel is an example of a proposition, which is either true or false. For example, predetermined and designed conditions must be met in order for an annunciator in a master warning panel to be lit. A "LOW HYDRAULIC PRESS" annunciator may have a simple set of conditions that will cause it to be illuminated. If the conditions are met, such as a hydraulic reservoir that is low on fluid, causing the line press to be low, then the logic is true and the annunciator will light. Several propositions, when combined will form a logical function. In the example above, the "LOW HYDRAULIC PRESS" annunciator will be on if the LED is not burned out AND the hydraulic press is low OR if the LED is not burned out AND the annunciator test is being asserted.

This section on logic circuits only serves as an introduction to the basic concepts. The technician will encounter many situations or problems in everyday life that can be expressed in some form of a logical function. Many problems and situations can be condensed down to simple yes⁄no or true⁄false statements, which if logically ordered can filter a problem down to a reasonable answer. The digital logic circuits are well suited for this task and have been employed in today's integrated circuits found in virtually all of the devices that we take for granted in modern aircraft. These logical circuits are used to carry out the logical functions for such things as navigation and communications. There are several fundamental elements that form the building blocks of the complex digital systems found in line replaceable units (LRUs) and avionics card cages. The following is a very basic outline of what those elements are and what logic conditions they will process. It is far beyond the scope of this text to cover digital logic systems due to the vast body of knowledge that it represents. However, this serves as an introduction and in some limited cases will be useful in reading system block diagrams that use logic symbols to aid the technician in understanding how a given circuit operates.

Logic Polarity

Electrical pulses can represent two logic conditions and any two differing voltages can be used for this purpose. For example, a positive voltage pulse could represent a true or 1 condition and a negative voltage pulse could then represent a false or 0 logic condition. The condition in which the voltage changes to represent a true or 1 logic is known as the logic polarity. Logic circuits are usually divided into two broad classes known as positive and negative polarity. The voltage levels used and a statement indicating the use of positive or negative logic will usually be specified in the logic diagrams provided by the original equipment manufacturers (OEMs).

Positive

When a signal that activates a circuit to a 1, true or high condition, has an electrical level that is relatively more positive that the other stated, then the logic polarity is said to be positive. An example would be:

Active State: 1 or True = +5 VDC
0 or False = −5 VDC

Negative

When the signal that actives a circuit to a 1, true or high condition, has an electrical level that is relatively more negative than the other stated, then the logic polarity is said to be negative. An example would be:

Active State: 1 or True = 0 VDC
0 or False = +5 VDC

Pulse Structure

Figure 10-237 illustrates the positive and negative pulse in an idealized form. In both forms, the pulse is

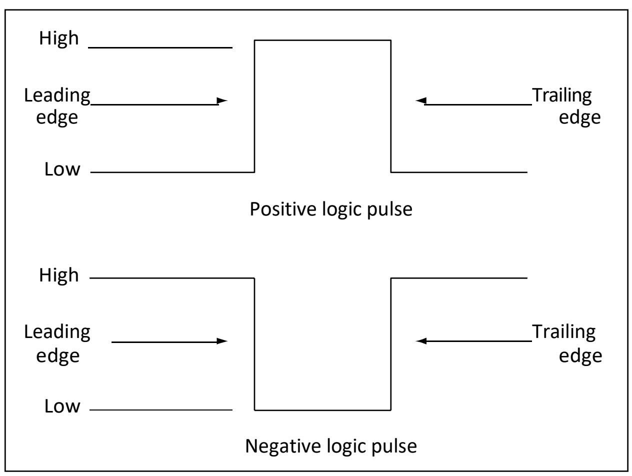


Figure 10-237. Positive and negative pulse in an idealized form.

FDA, Inc.

composed of two edges — one being the leading edge and the other the trailing edge. In the case of the positive pulse logic, the positive transition from a lower state to a higher state is the leading edge and the trailing edge is the opposite. In the case of the negative logic pulse, the negative transition from a higher state to a lower state is the leading edge while the rise from the lower state back to the higher state is the trailing edge. Figure 10-237 is considered an ideal pulse because the rise and fall times are instantaneous. In reality, these changes take time, although in actual practice, the rise and fall can be assumed as instantaneous. Figure 10-238 shows the non-ideal pulse and its characteristics. The time required for a pulse to go from a low state to a high state is called the rise time, and the time required for the pulse to return to zero is called the fall time. It is common practice to measure the rise and fall time between 10 percent amplitude and 90 percent amplitude. The reason for taking the measurements in these points is due to the non-linear shape of the pulse in the first 10 percent and final 90 percent of the rise and fall amplitudes. The pulse width is defined as the duration of the pulse. To be more specific, it is the time between the 50 percent amplitude point on both the pulse rise and fall.

Basic Logic Circuits

Boolean logic is a symbolic system used in representing the truth value of statements. It is employed in the binary system used by digital computers primarily because the only truth values (true and false) can be represented by the binary digits 1 and 0. A circuit in computer memory can be open or closed, depending on the value assigned to it. The fundamental operations of Boolean logic, often called Boolean operators, are "and," "or," and "not"; combinations of these make up 13 other Boolean operators. Six of these operators are discussed.

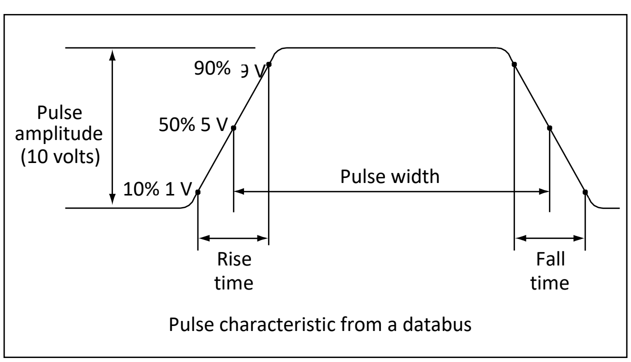


Figure 10-238. Non-ideal pulse and its characteristics.

The Inverter Logic

The inverter circuit performs a basic logic function called inversion. The purpose of the inverter is to convert one logic state into the opposite state. In terms of a binary digit, this would be like converting a 1 to a 0 or a 0 to a 1. When a high voltage is applied to the inverter input, low voltage will be the output. When a low voltage is applied to the input, a high voltage will be on the output. This operation can be put into what is known as a logic or truth table. Figure 10-240 shows the possible logic states for this gate. The standard logic symbol is shown in Figure 10-239. This is the common symbol for an amplifier with a small circle on the output. This type of logic can also be considered a NOT gate.

The AND Gate

The AND gate is made up of two or more inputs and a single output. The logic symbol is shown in Figure 10-241. Inputs are on the left and the output is on the right in each of the depictions. Gates with two, three, and four inputs are shown; however, any number of inputs can be used in the AND logic as long as the number is greater than one. The operation of the AND gate is such that the output is high only when all of the inputs are high. If any of the inputs are low, the output will also be low. Therefore, the basic purpose of an AND gate is to determine when certain conditions have been met at the same time. A high level on all inputs will produce a high level on the output. Figure 10-242 shows a simplified diagram of the AND logic with two switches and a light bulb. Notice that both switches need to be closed in order for the light bulb to turn on. Any other combination of switch positions will be an open circuit and the light will not turn on. An example of AND logic could possibly be engage logic, found in an autopilot. In this case, the autopilot would not be allowed to be engaged unless certain

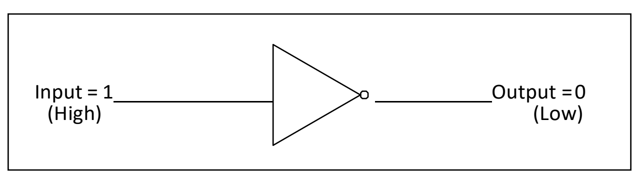


Figure 10-239. Standard logic symbol.

Input	Output
High	Low
Low	High

Figure 10-240. Possible logic states.

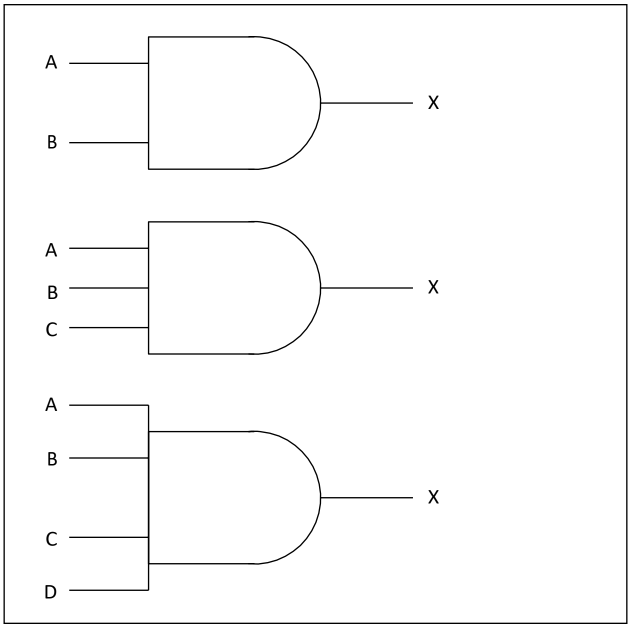


Figure 10-241. AND gate logic symbol.

conditions are first met. Such conditions could be: Vertical gyro is valid AND directional gyro is valid AND all autopilot control knobs are in detents AND servo circuits are operational. Only when these conditions are met will the autopilot be engaged. Figure 10-243 shows the logic of this system found in the aircraft wiring diagrams.

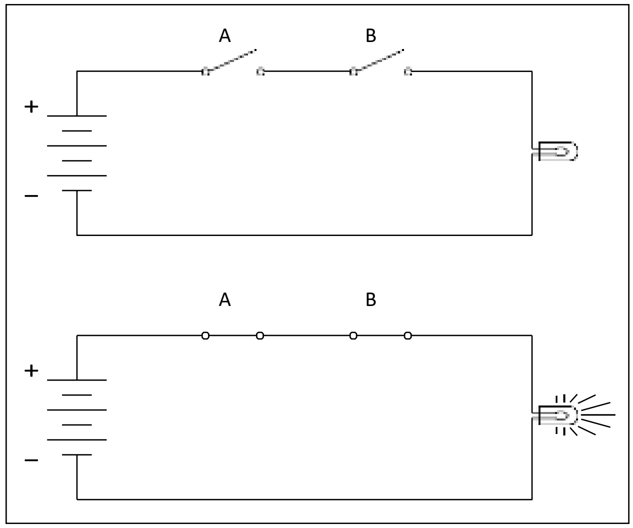


Figure 10-242. Simplified diagram of the AND logic.

The OR Gate

The OR gate has two or more inputs and one output, and is normally represented by the standard logic symbol and truth table as shown in Figure 10-244. In this Figure, notice that the OR gate can have any number of inputs as long as it is greater than one. The operation of the OR gate is such that a high on any one of the inputs will produce a high on the output. The only time that a low is produced on the output is if there are no high levels on any input. Figure 10-245

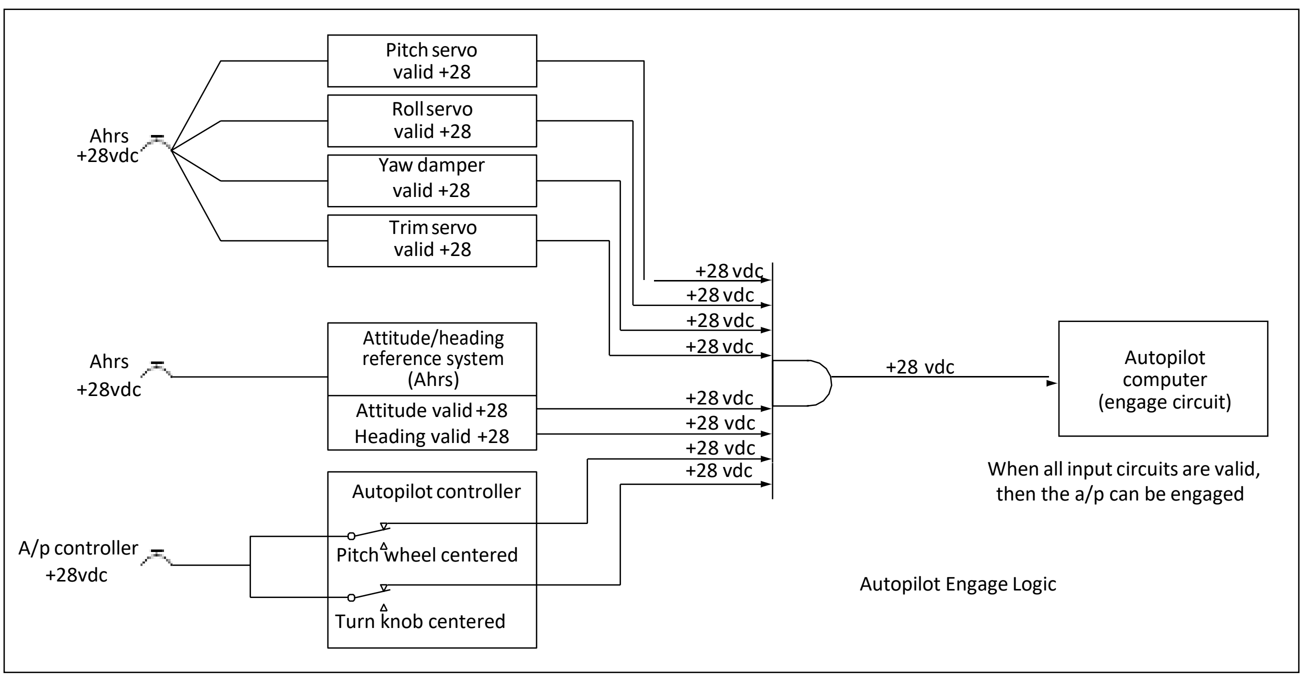
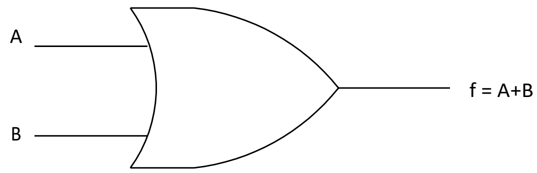


Figure 10-243. AND logic of system found in the aircraft wiring diagrams.



OR gate input/output

A	B	f
0	0	0
1	0	1
0	1	1
1	1	1

Truth table

Figure 10-244. OR gate.

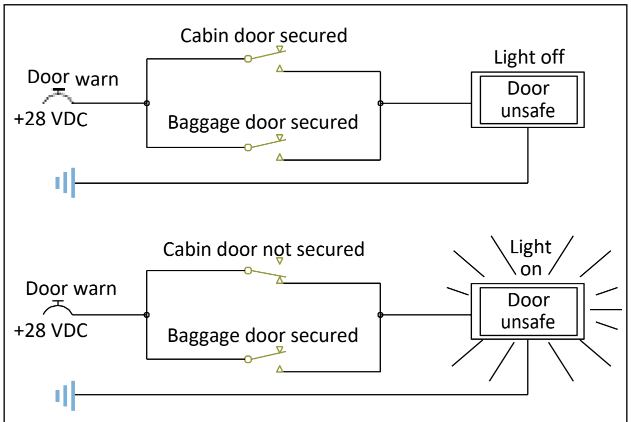


Figure 10-245. Smplified circuit that illustrates OR logic.

is a simplified circuit that illustrates the OR logic. The example used is a "DOOR UNSAFE" annunciator. Let's say in this case that the plane has one cabin door and a baggage door. In order for the annunciator light on the master warning panel to extinguish, both doors must be closed and locked. If any one of the doors is not secured properly, the baggage door OR the cabin door, then the "DOOR UNSAFE" annunciator will illuminate. In this case, two switches are in parallel with each other. If either one of the two switches is closed, the light bulb will light up. The lamp will be off only when both switches are open.

The NAND Gate

The term NAND is a combination of the NOT-AND gate and indicates an AND function with an inverted

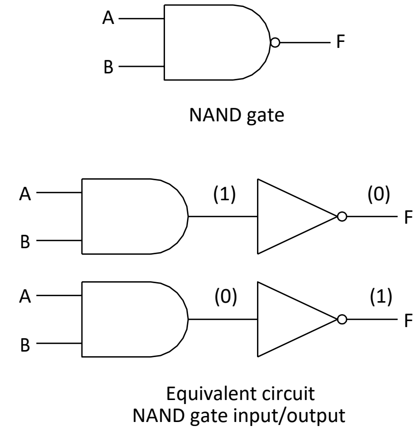
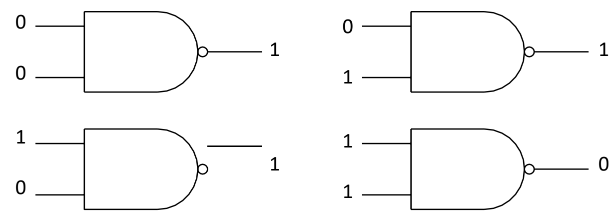


Figure 10-246. Standard logic symbol for two input NAND gate.



NAND gate input/output

A	B	f
0	0	1
1	0	1
0	1	1
1	1	0

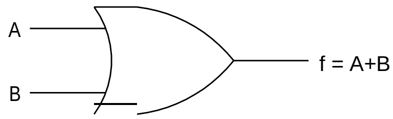
NAND gate truth table

Figure 10-247. Two input NAND gate and corresponding truth table.

output. A standard logic symbol for a two input NAND gate is shown in Figure 10-246. Notice that an equivalent AND gate with an inverter is also shown. The logical operation of the NAND gate is such that a low output occurs only if all inputs are high. If any of the inputs are low, the output will be high. An example of a two input NAND gate and its corresponding truth table are shown in Figure 10-247.

The NOR Gate

The term NOR is a combination of the NOT and OR and indicates an OR function with an inverted output. The standard logic symbol for a two-inputs NOR gate is shown in Figure 10-248. Notice that an equivalent AND gate with an inverter is also shown. The logical

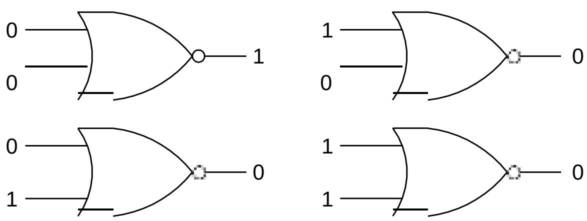


OR gate input/output

A	B	f
0	0	0
1	0	1
0	1	1
1	1	1

Truth table

Figure 10-248. Standard logic symbol for two inputs NORgate.



NOR gate input/output

A	B	f
0	0	1
0	1	0
1	0	0
1	1	0

NOR gate truth table

Figure 10-249. Logical operation of two-input NOR gate and truth table.

operation of the NOR gate is such that a low output happens when any of its inputs are high. Only when all of its inputs are low is the output high. The logic of this gate produces resultant outputs that are the opposite of the OR gate. In the NOR gate, the low output is the active output level. Figure 10-249 illustrates the logical operation of a two-input NOR gate for all of its possible combinations and the truth table.

Exclusive OR Gate

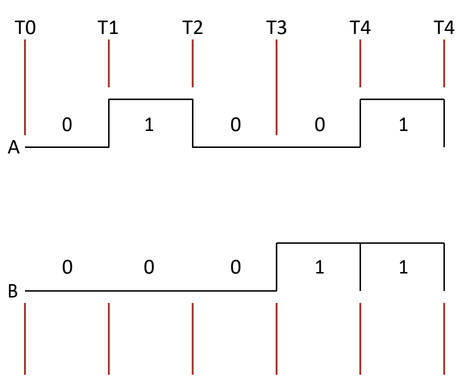
The exclusive OR gate is a modified OR gate that produces a 1 output when only one of the inputs is a 1. The abbreviation often used is X-OR. It is different from the standard OR gate in that when both inputs are a 1, then the output remains at a 0. The standard symbol and truth table for the X-OR gate are shown in Figure 10-250.

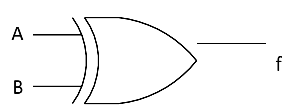
Exclusive NOR Gate

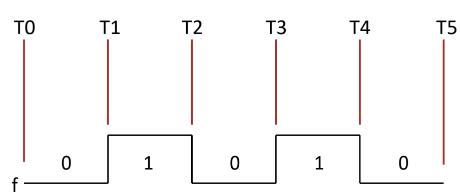
The exclusive NOR (X-NOR) gate is nothing more than an X-OR gate with an inverted output. It produces a 1 output when all inputs are 1s and also when all inputs are 0s. The standard symbol is shown in Figure 10-251.

The Integrated Circuit

All of the logic functions so far discussed plus many other components are available in some form of an integrated circuit. The digital systems found in today's aircraft owe their existence to a large extent to the design of the integrated circuit (IC). In most cases, the IC has an advantage over the use of discrete components in that they are smaller, consume less power, are very reliable, and are inexpensive. The most noticeable characteristic of the IC is its size and in comparison





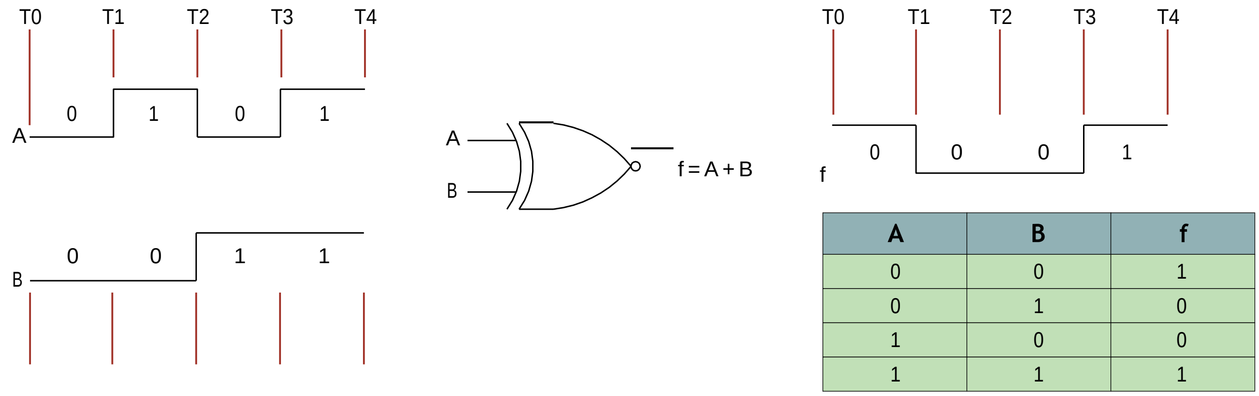


A	B	f
0	0	0
0	1	1
1	0	1
1	1	0

Truth table

X-OR gate input/output

Figure 10-250. Standard symbol and truth table for X-OR gate.



A	B	f
0	0	1
0	1	0
1	0	0
1	1	1

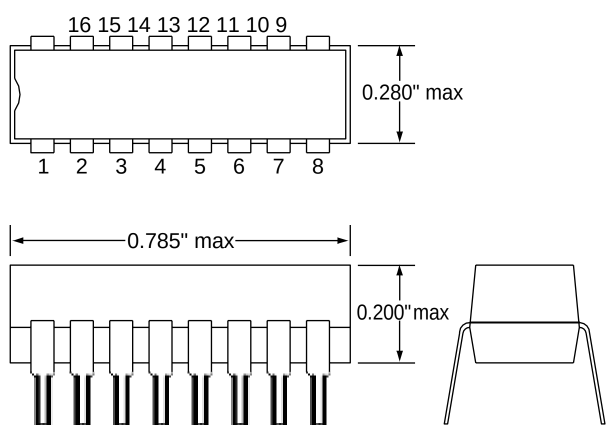
Truth table

X-NOR gate input/output

Figure 10-251. Standard Symbol for X-NOR gate.

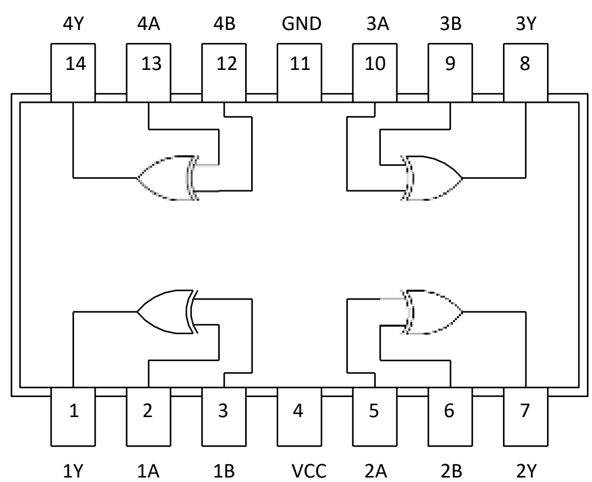
to the discrete semiconductor component, can easily be on the order of thousands of times smaller. [Figure 10-252]

A monolithic integrated circuit is an electronic circuit that is constructed entirely on a single chip or wafer of semiconductor material. All of the discrete components, such as resistors, transistors, diodes, and capacitors, can be constructed on these small pieces of semiconductor material and are an integral part of the chip. There are a number of levels of integration. Those levels are: small-scale integration, medium-scale integration, large-scale integration, and microprocessors. The small-scale integration is considered the least complex design of the digital ICs. These ICs contain the basic components such as the AND, OR, NOT, NOR and NAND gates. Figure 10-253 illustrates the schematic form of this type of circuit. The medium-scale integration can contain the same components as found in the small-scale design but in larger numbers ranging from 12 to 100. The medium-scale designs are house circuits that are more complex, such as encoders, decoders, registers, counters, multiplexers, smaller memories, and arithmetic circuits. Figure 10-254 illustrates the schematic form of this type of circuit. The large-scale integrated circuits contain even more logic



Typical integrated logic circuit

Figure 10-252. Integrated circuit.



Quad exclusive-OR circuit

Input		Output
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

Figure 10-253. Small-scale integration schematic form.

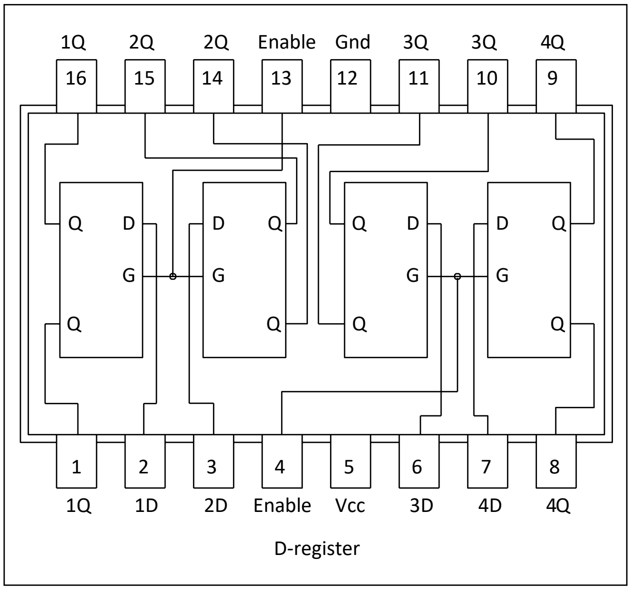


Figure 10-254. Medium-scale integration schematic form.

gates, larger memories than the medium-scale circuits, and in some cases microprocessors.

Microprocessors

The microprocessor is a device that can be programmed to perform arithmetic and logical operations and other functions in a preordered sequence. The microprocessor is usually used as the central processing unit (CPU) in today's computer systems when it is connected to other components, such as memory chips and input/output circuits. The basic arrangement and design of the circuits residing in the microprocessor is called the architecture.