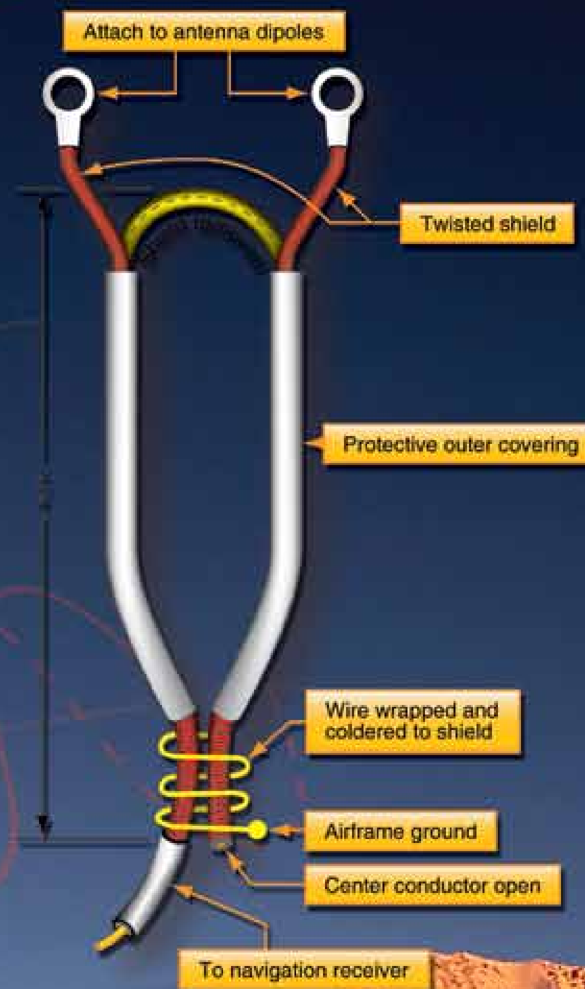
Chapter 11

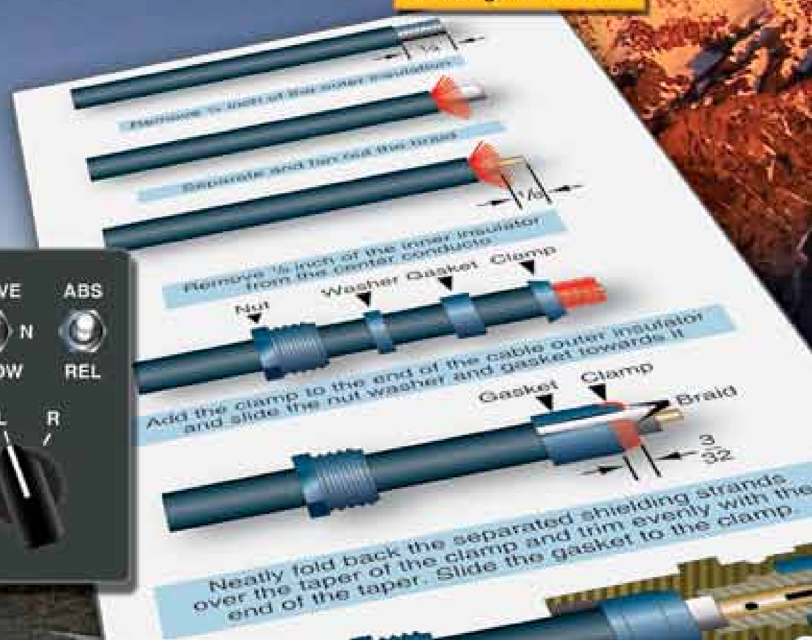
Communication and Navigation

Introduction

With the mechanics of flight secured, early aviators began the tasks of improving operational safety and functionality of flight. These were developed in large part through the use of reliable communication and navigation systems. Today, with thousands of aircraft aloft at any one time, communication and navigation systems are essential to safe, successful flight. Continuing development is occurring. Smaller, lighter, and more powerful communication and navigation devices increase situational awareness on the flight deck. Coupled with improved displays and management control systems, the advancement of aviation electronics is relied upon to increase aviation safety.

Clear radio voice communication was one of the first developments in the use of electronics in aviation. Navigational radios soon followed. Today, numerous electronic navigation and landing aids exist. Electronic devices also exist to assist with weather, collision avoidance, automatic flight control, flight recording, flight management, public address, and entertainment systems.





Avionics in Aviation Maintenance

Avionics is a conjunction of the words aviation and electronics. It is used to describe the electronic equipment found in modern aircraft. The term "avionics" was not used until the 1970s. For many years, aircraft had electrical devices, but true solid-state electronic devices were only introduced in large numbers in the 1960s.

Airframe and engine maintenance is required on all aircraft and is not likely to ever go away. Aircraft instrument maintenance and repair also has an inevitable part in aviation maintenance. The increased use of avionics in aircraft over the past 50 years has increased the role of avionics maintenance in aviation. However, modern, solid-state, digital avionics are highly reliable. Mean times between failures are high, and maintenance rates of avionics systems compared to mechanical systems are likely to be lower.

The first decade of avionics proliferation saw a greater increase in the percent of cost of avionics compared to the overall cost of an aircraft. In some military aircraft with highly refined navigation, weapons targeting, and monitoring systems, it hit a high estimate of 80 percent of the total cost of the aircraft. Currently, the ratio of the cost of avionics to the cost of the total aircraft is beginning to decline. This is due to advances in digital electronics and numerous manufacturers offering highly refined instrumentation, communication, and navigation systems that can be fitted to nearly any aircraft. New aircraft of all sizes are manufactured with digital glass cockpits, and many owners of older aircraft are retrofitting digital avionics to replace analog instrumentation and radio navigation equipment.

The airframe and powerplant (A&P) maintenance technician needs to be familiar with the general workings of various avionics. Maintenance of the actual avionics devices is often reserved for the avionics manufacturers or certified repair stations. However, the installation and proper operation of these devices and systems remains the responsibility of the field technician. This chapter discusses some internal components used in avionics devices. It also discusses a wide range of common communication and navigational aids found on aircraft. The breadth of avionics is so wide that discussion of all avionics devices is not possible.

History of Avionics

The history of avionics is the history of the use of electronics in aviation. Both military and civil aviation requirements contributed to the development. The First World War brought about an urgent need for communications. Voice communications from ground-to-air and from aircraft to aircraft were established. *[Figure 11-1]* The development of aircraft reliability and use for civilian purposes in the 1920s

Figure 11-1. *Early voice communication radio tests in 1917. Courtesy of AT&T Archives and History Center.*

led to increased instrumentation and set in motion the need to conquer blind flight—flight without the ground being visible. Radio beacon direction finding was developed for en route navigation. Toward the end of the decade, instrument navigation combined with rudimentary radio use to produce the first safe blind landing of an aircraft.

In the 1930s, the first all radio-controlled blind-landing was accomplished. At the same time, radio navigation using ground-based beacons expanded. Instrument navigation certification for airline pilots began. Low and medium frequency radio waves were found to be problematic at night and in weather. By the end of the decade, use of high-frequency radio waves was explored and included the advent of high-frequency radar.

In the 1940s, after two decades of development driven by mail carrier and passenger airline requirements, World War II injected urgency into the development of aircraft radio communication and navigation. Communication radios, despite their size, were essential on board aircraft. *[Figure 11-2]* Very high frequencies were developed for communication and navigational purposes. Installation of the first instrument landing systems for blind landings began mid-decade and, by the end of the decade, the very high frequency omni-directional range (VOR) navigational network was instituted. It was also in the 1940s that the first transistor was developed, paving the way for modern, solid-state electronics.

Civilian air transportation increased over the ensuing decades. Communication and navigation equipment was refined. Solid-state radio development, especially in the

Figure 11-2. *Bomber onboard radio station.*

1960s, produced a wide range of small, rugged radio and navigational equipment for aircraft. The space program began and added a higher level of communication and navigational necessity. Communication satellites were also launched. The Cold War military build-up caused developments in guidance and navigation and gave birth to the concept of using satellites for positioning.

In the 1970s, concept-validation of satellite navigation was introduced for the military and Block I global positioning system (GPS) satellites were launched well into the 1980s. Back on earth, the long range navigation system (LORAN) was constructed. Block II GPS satellites were commissioned in the mid-80s and GPS became operational in 1990 with the full 24-satellite system operational in 1994.

In the new millennium, the Federal Aviation Administration (FAA) assessed the national airspace system (NAS) and traffic projections for the future. Gridlock is predicted by 2022. Therefore, a complete overhaul of the NAS, including communication and navigational systems, has been developed and undertaken. The program is called NextGen. It uses the latest technologies to provide a more efficient and effective system of air traffic management. Heavily reliant on global satellite positioning of aircraft in flight and on the ground, NextGen combines GPS technology with automatic dependant surveillance broadcast technology (ADS-B) for traffic separation. A large increase in air system capacity is the planned result. Overhauled ground facilities accompany the technology upgrades mandated for aircraft. NextGen implementation has started and is currently scheduled through the year 2025.

For the past few decades, avionics development has increased at a faster pace than that of airframe and powerplant development. This is likely to continue in the near future. Improvements to solid-state electronics in the form of micro- and nano-technologies continue to this day. Trends are toward lighter, smaller devices with remarkable capability and reliability. Integration of the wide range of communication and navigational aids is a focus.

Fundamentals of Electronics

Analog Versus Digital Electronics

Electronic devices represent and manipulate real world phenomenon through the use of electrical signals. Electronic circuits are designed to perform a wide array of manipulations. Analog representations are continuous. Some aspect of an electric signal is modified proportionally to the real world item that is being represented. For example, a microphone has electricity flowing through it that is altered when sound is applied. The type and strength of the modification to the electric signal is characteristic of the sound that is made into the microphone. The result is that sound, a real world phenomenon, is represented electronically. It can then be moved, amplified, and reconverted from an electrical signal back into sound and broadcast from a speaker across the room or across the globe.

Since the flow of electricity through the microphone is continuous, the sound continuously modifies the electric signal. On an oscilloscope, an analog signal is a continuous curve. *[Figure 11-3]* An analog electric signal can be modified by changing the signal's amplitude, frequency, or phase.

A digital electronic representation of a real world event is discontinuous. The essential characteristics of the continuous event are captured as a series of discrete incremental values. Electronically, these representative samplings are successive chains of voltage and non-voltage signals. They can be transported and manipulated in electronic circuits. When the samples are sufficiently small and occur with high frequency, real world phenomenon can be represented to appear continuous.

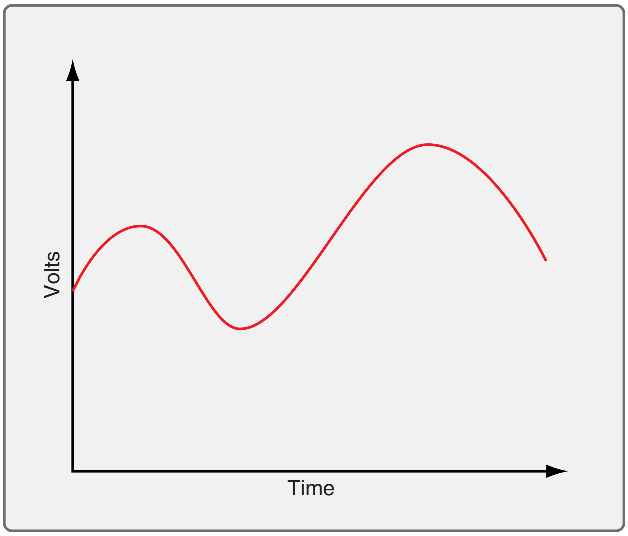


Figure 11-3. *An analog signal displayed on an oscilloscope is a continuous curve.*

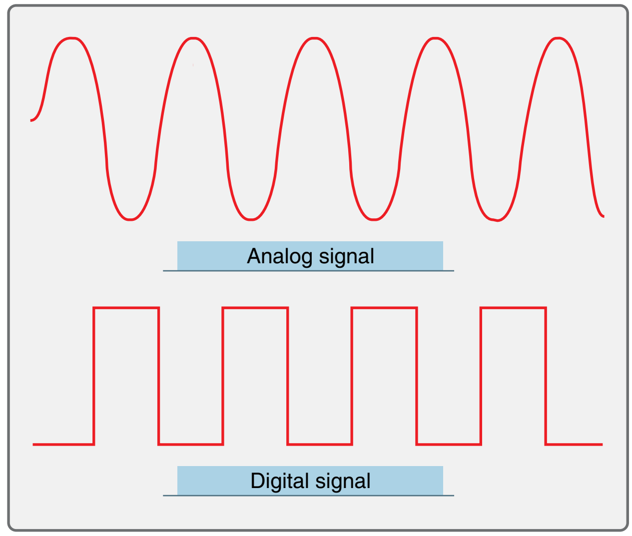


Figure 11-4. *Analog signals are continuous voltage modified by all external events including those that are not desired called noise. Digital signals are a series of voltage or no voltage that represent a desired event.*

Noise

A significant advantage of digital electronics over analog electronics is the control of noise. Noise is any alteration of the represented real world phenomenon that is not intended or desired. Consider the operation of a microphone when understanding noise. A continuous analog voltage is modified by a voice signal that results in the continuous voltage varying in proportion to the volume and tone of the input sound. However, the voltage responds and modifies to any input. Thus, background sounds also modify the continuous voltage as will electrostatic activity and circuitry imperfections. This alteration by phenomenon that are not the intended modifier is noise.

During the processing of digitized data, there is little or no signal degradation. The real world phenomenon is represented in a string of binary code. A series of ones and zeros are electronically created as a sequence of voltage or no voltage and carried through processing stages. It is relatively immune to outside alteration once established. If a signal is close to the set value of the voltage, it is considered to be that voltage. If the signal is close to zero, it is considered to be no voltage. Small variations or modifications from undesired phenomenon are ignored. *Figure 11-4* illustrates an analog sine wave and a digital sine wave. Any unwanted voltage will modify the analog curve. The digital steps are not modified by small foreign inputs. There is either voltage or no voltage.

Analog Electronics

Early aircraft were equipped with radio communication and navigational devices that were constructed with analog electronic circuits. They used vacuum tubes that functioned as electron control valves. These were later replaced by solid-state devices. Today, digital electronic circuits dominate modern avionics. A brief look at various electron control valves used on aircraft follows.

Electron Control Valves

Electron control valves are an essential part of an electronic circuit. Control of electron flow enables the circuit to produce the desired outcome. Early aircraft made use of vacuum tubes to control electron flow. Later, transistors replaced vacuum tubes. Semiconductors used in transistors and integrated circuits have enabled the solid-state digital electronics found in aircraft today.

Vacuum Tubes

Electron control valves found in the analog circuits of early aircraft electronics are constructed of vacuum tubes. Only antique aircraft retain radios with these devices due to their size and inability to withstand the harsh vibration and shock of the aircraft operating environment. However, they do function, and a description is included here as a foundation for the study of more modern electronic circuits and components.

Diodes

A diode acts as a check valve in an alternating current (AC) circuit. It allows current to flow during half of the AC cycle but not the other half. In this manner, it creates a pulsating direct current (DC) with current that drops to zero in between pulses. A diode tube has two active electrodes: the cathode and the plate. It also contains a heater. All of this is housed in a vacuum environment inside the tube. *[Figure 11-5]* The

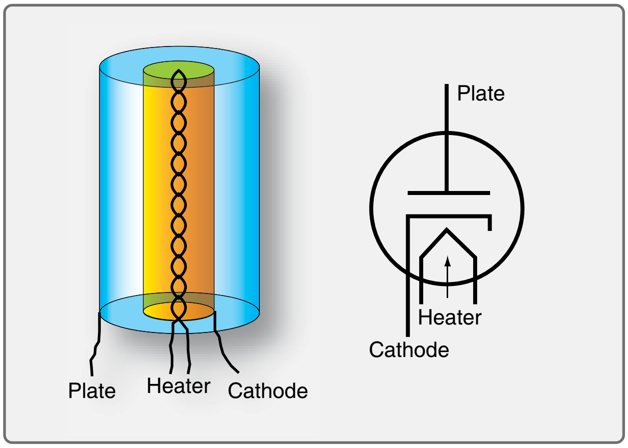


Figure 11-5. *A vacuum tube diode contains a cathode, heater, and plate. Note that the arrow formed in the symbol for the heater points to the direction of electron flow.*

heater glows red hot while heating the cathode. The cathode is coated with a material whose electrons are excited by the heat. The excited electrons expand their orbit when heated. They move close enough to the plate, which is constructed around the cathode and heater arrangement, that they are attracted to the positively-charged plate. When the AC current cycles, the plate becomes negatively charged and the excited cathode electrons do not flow to the plate. In a circuit, this causes a check valve effect that allows current to only flow in one direction, which is the definition of a diode. *[Figure 11-6]* The various symbols used to depict diodes are shown in *Figure 11-7*.

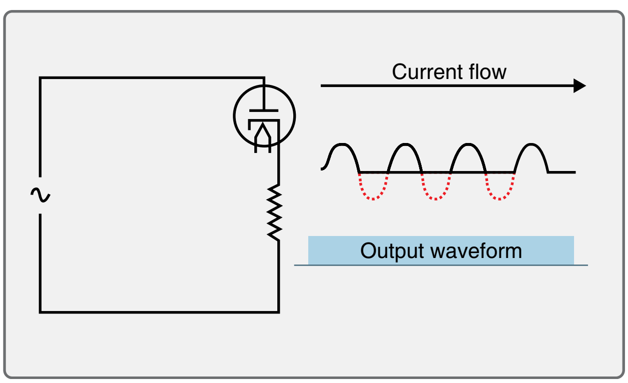


Figure 11-6. *A vacuum tube diode in a circuit allows current to flow in one direction only. The output waveform illustrates the lack of current flow as the AC cycles.*

Triodes

A triode is an electron control valve containing three elements. It is often used to control a large amount of current with a smaller current flow. In addition to the cathode, plate, and heater present in the diode, a triode also contains a grid. The grid is composed of fine wire spiraled between the

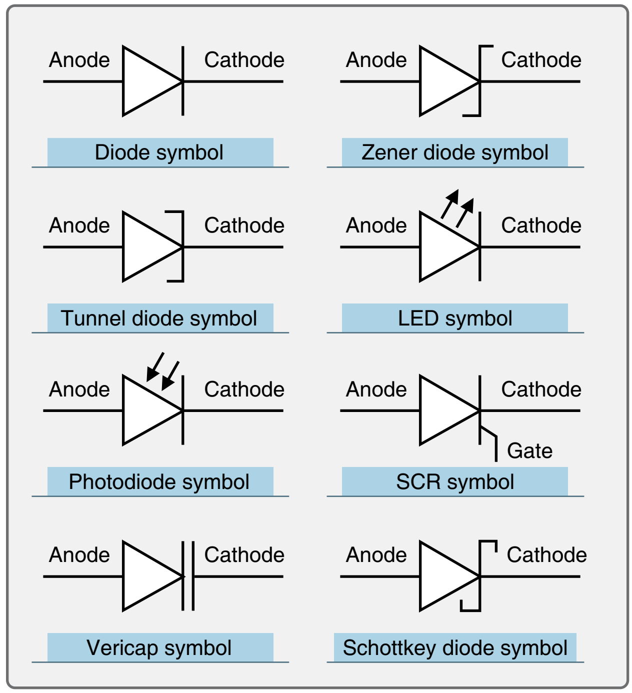


Figure 11-7. *Diode symbols.*

cathode and the plate but closer to the cathode. Applying voltage to the grid can influence the cathode's electrons, which normally flow to the plate when the cathode is heated. Changes in the relatively small amount of current that flows through the grid can greatly impact the flow of electrons from the cathode to the plate. *[Figure 11-8]*

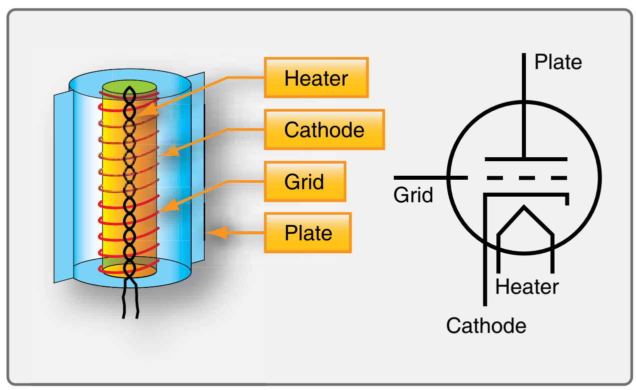


Figure 11-8. *A triode has three elements: the cathode, plate, and a grid.*

Figure 11-9 illustrates a triode in a simple circuit. AC voltage input is applied to the grid. A high-resistance resistor is used so that only minimum voltage passes through to the grid. As this small AC input voltage varies, the amount of DC output in the cathode-plate circuit also varies. When the input signal is positive, the grid is positive. This aids in drawing electrons from the cathode to the plate. However, when the AC input signal cycles to negative, the grid becomes negatively

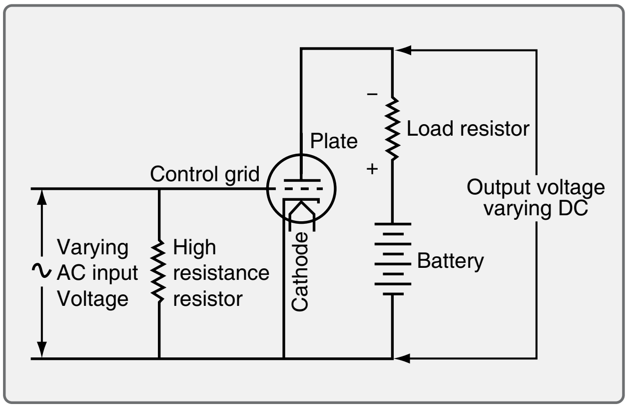


Figure 11-9. *Varying AC input voltage to the grid circuit in a triode produces a varying DC output.*

charged and flow from the cathode to the plate is cut off with the help of the negatively charged grid that repels the electrons on the cathode.

Tetrodes

A tetrode vacuum tube electron control valve has four elements. In addition to the cathode, plate, and grid found in a tridode, a tetrode also contains a screen grid. The cathode and plate of a vacuum tube electron control valve can act as a capacitor. At high frequencies, the capacitance is so low that feedback occurs. The output in the plate circuit feeds back into the control grid circuit. This causes an oscillation generating AC voltage that is unwanted. By placing a screen grid between the anode and the control grid windings, this feedback and the inter-electrode capacitive effect of the anode and cathode are neutralized. *[Figure 11-10]*

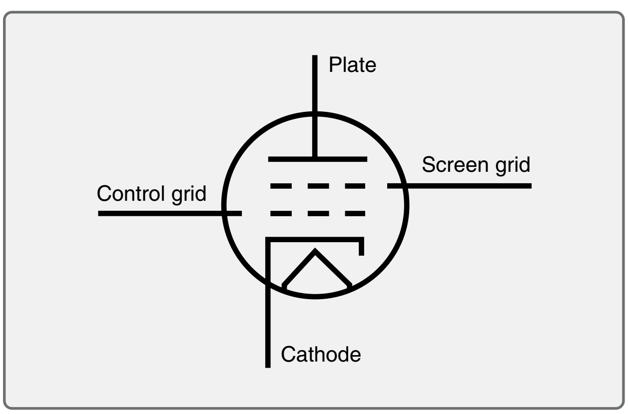


Figure 11-10. *A tetrode is a four element electron control valve vacuum tube including a cathode, a plate, a control grid, and a screen grid.*

Figure 11-11 illustrates a tetrode in a circuit. The screen grid is powered by positive DC voltage. The inter-electrode capacitance is now between the screen grid and the plate. A capacitor is located between the screen grid and ground. AC feedback generated in the screen grid goes to ground and does not oscillate. This allows use of the tetrode at higher frequencies than a triode.

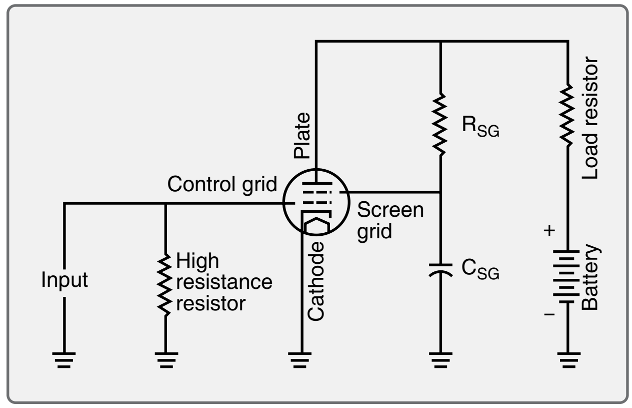


Figure 11-11. *To enable a triode to be used at high frequencies, a screen grid is constructed between the plate and the control grid.*

Pentodes

The plate in a vacuum tube can have a secondary emission that must be controlled. When electrons flow from the cathode through the control grid and screen grid to the plate, they can arrive at such high velocity that some bounce off. Therefore, the tendency is for those electrons to be attracted to the positively charged screen grid. The screen grid is not capable of handling large amounts of current without burning up. To solve this problem, a third grid is constructed between the plate and the screen grid. Called a suppression grid, it is charged negatively so that secondary electron flow from the plate is repelled by the negative charge back toward the plate and is not allowed to reach the screen grid. The five element pentode is especially useful in high power circuits where secondary emissions from the plate are high. *[Figure 11-12]*

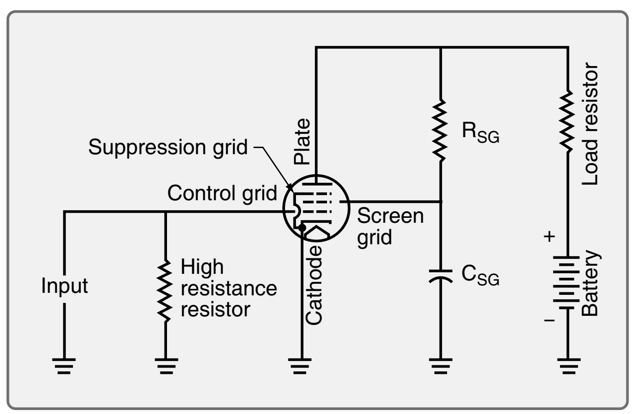


Figure 11-12. *A pentode contains a suppression grid that controls secondary electron emissions from the plate at high power. This keeps the current in the screen grid from becoming too high.*

Solid-State Devices

Solid-state devices began replacing vacuum tube electron control valves in the late 1950s. Their long life, reliability, and resilience in harsh environments make them ideal for use in avionics.

Semiconductors

The key to solid-state electronic devices is the electrical behavior of semiconductors. To understand semiconductors, a review of what makes a material an insulator or a conductor follows. Then, an explanation for how materials of limited conductivity are constructed and some of their many uses is explained. Semiconductor devices are the building blocks of modern electronics and avionics.

An atom of any material has a characteristic number of electrons orbiting the nucleus of the atom. The arrangement of the electrons occurs in somewhat orderly orbits called rings or shells. The closest shell to the nucleus can only contain two electrons. If the atom has more than two electrons, they are found in the next orbital shell away from the nucleus. This second shell can only hold eight electrons. If the atom has more than eight electrons, they orbit in a third shell farther out from the nucleus. This third shell is filled with eight electrons and then a fourth shell starts to fill if the element still has more electrons. However, when the fourth shell contains eight electrons, the number of electrons in the third shell begins to increase again until a maximum of 18 is reached. *[Figure 11-13]*

Shell or Orbit Number	1	2	3	4	5
Maximum number of electrons	2	8	18	32	50

Figure 11-13. *Maximum number of electrons in each orbital shell of an atom.*

The outer most orbital shell of any atom's electrons is called the valence shell. The number of electrons in the valence shell determines the chemical properties of the material. When the valence shell has the maximum number of electrons, it is complete and the electrons tend to be bound strongly to the nucleus. Materials with this characteristic are chemically stable. It takes a large amount of force to move the electrons in this situation from one atom valence shell to that of another. Since the movement of electrons is called electric current, substances with complete valence shells are known as good insulators because they resist the flow of electrons (electricity). *[Figure 11-14]*

In atoms with an incomplete valence shell, that is, those without the maximum number of electrons in their valence shell, the electrons are bound less strongly to the nucleus. The material is chemically disposed to combine with other materials or other identical atoms to fill in the unstable valence configuration and bring the number of electrons in the valence shell to maximum. Two or more substances may share the electrons in their valence shells and form a covalent bond. A covalent bond is the method by which atoms

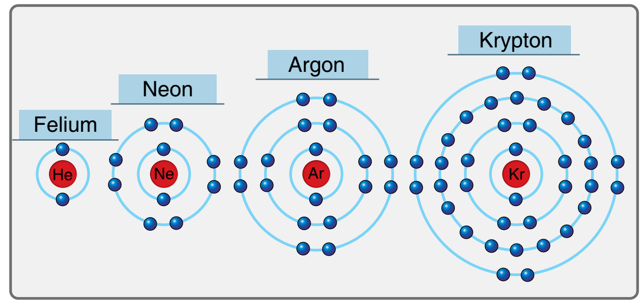


Figure 11-14. *Elements with full valence shells are good insulators. Most insulators used in aviation are compounds of two or more elements that share electrons to fill their valence shells.*

complete their valence shells by sharing valence electrons with other atoms.

Electrons in incomplete valence shells may also move freely from valence shell to valence shell of different atoms or compounds. In this case, these are known as free electrons. As stated, the movement of electrons is known as electric current or current flow. When electrons move freely from atom to atom or compound to compound, the substance is known as a conductor. *[Figure 11-15]*

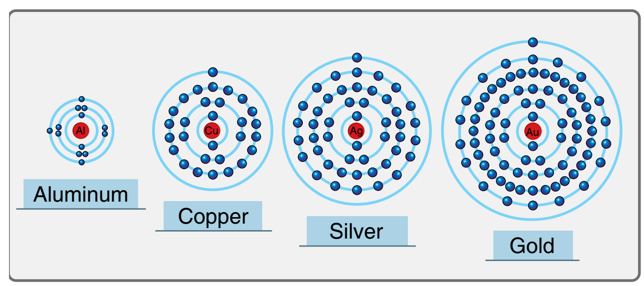


Figure 11-15. *The valence shells of elements that are common conductors have one (or three) electrons.*

Not all materials are pure elements, that is, substances made up of one kind of atom. Compounds occur when two or more different types of atoms combine. They create a new substance with different characteristics than any of the component elements. When compounds form, valence shells and their maximum number of electrons remain the rule of physics. The new compound molecule may either share electrons to fill the valence shell or free electrons may exist to make it a good conductor.

Silicon is an atomic element that contains four electrons in its valence shell. It tends to combine readily with itself and form a lattice of silicon atoms in which adjacent atoms share electrons to fill out the valance shell of each to the maximum of eight electrons. *[Figure 11-16]* This unique symmetric alignment of silicon atoms results in a crystalline structure.

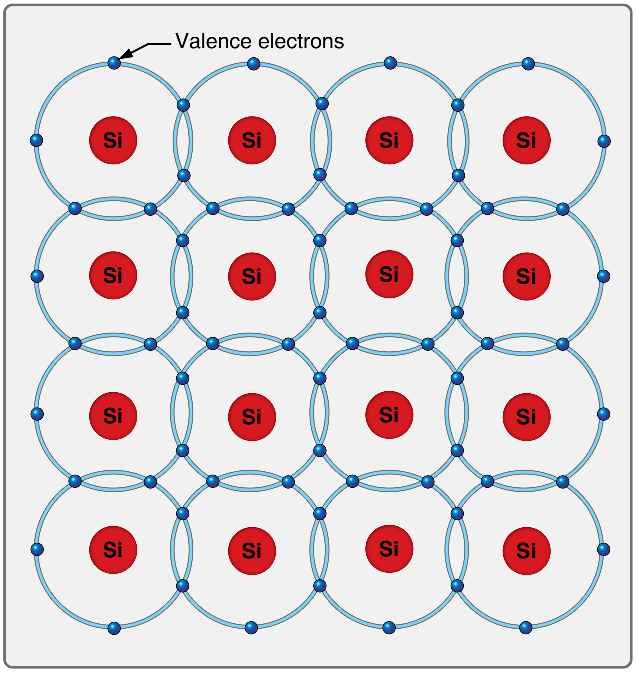


Figure 11-16. *The silicon atoms with just the valence shell electrons share these valence electrons with each other. By sharing with four other silicon atoms, the number of electrons in each silicon atom valence shell becomes eight, which is the maximum number. This makes the substance stable and it resists any flow of electrons.*

Once bound together, the valence shells of each silicon atom are complete. In this state, movement of electrons does not occur easily. There are no free electrons to move to another atom and no space in the valence shells to accept a free electron. Therefore, silicon in this form is a good insulator.

Silicon is a primary material used in the manufacture of semiconductors. Germanium and a few other materials are also used.

Since silicon is an insulator, it must be modified to become a semiconductor. The process often used is called doping. Starting with ultra-pure silicon crystal, arsenic, phosphorus, or some other element with five valence electrons in each atom is mixed into the silicon. The result is a silicon lattice with flaws. *[Figure 11-17]* The elements bond, but numerous free electrons are present in the material from the 5th electron that is part of the valence shell of the doping element atoms. These free electrons can now flow under certain conditions. Thus, the silicon becomes semiconductive. The conditions required for electron flow in a semiconductor are discussed in the following paragraphs.

When silicon is doped with an element or compound containing five electrons in its valence shell, the result is a negatively charged material due to the excess free electrons, and the fact that electrons are negatively charged. This is known as an N-type semiconductor material. It is also known as a donor material because, when it is used in electronics, it donates the extra electrons to current flow.

Doping silicon can also be performed with an element that has only three valence electrons, such as boron, gallium, or indium. Valence electron sharing still occurs, and the silicon atoms with interspersed doping element atoms form a lattice molecular structure. However, in this case, there are many valence shells where there are only seven electrons and not eight. This greatly changes the properties of the material. The absence of the electrons, called holes, encourages electron flow due to the preference to have eight electrons in all valence shells. Therefore, this type of doped silicon is also semiconductive. It is known as P-type material or as an acceptor since it accepts electrons in the holes under certain conditions. *[Figure 11-18]*

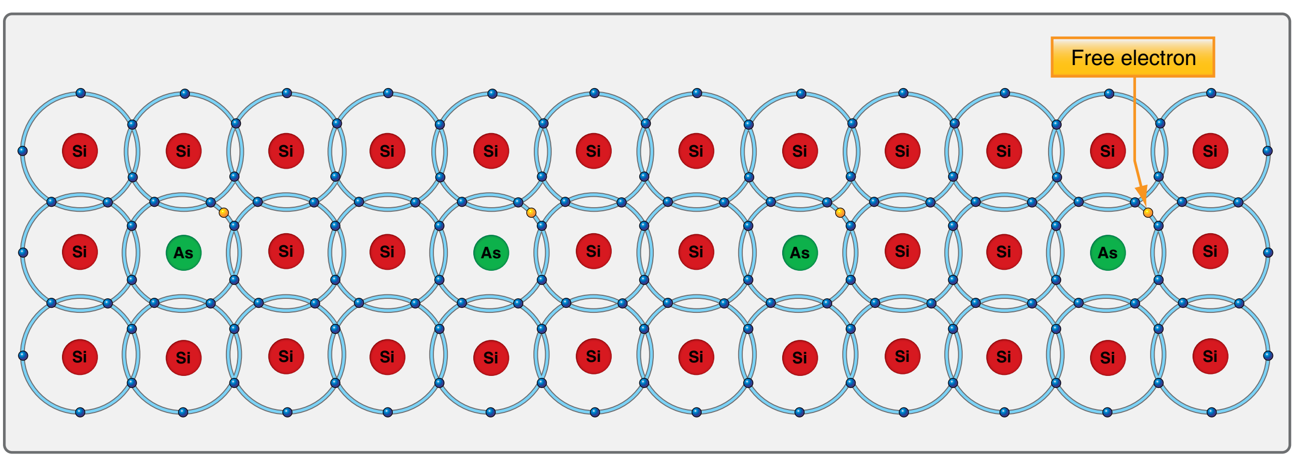


Figure 11-17. *Silicon atoms doped with arsenic form a lattice work of covalent bonds. Free electrons exist in the material from the arsenic atom's 5th valence electron. These are the electrons that flow when the semiconductor material, known as N-type or donor material, is conducting.*

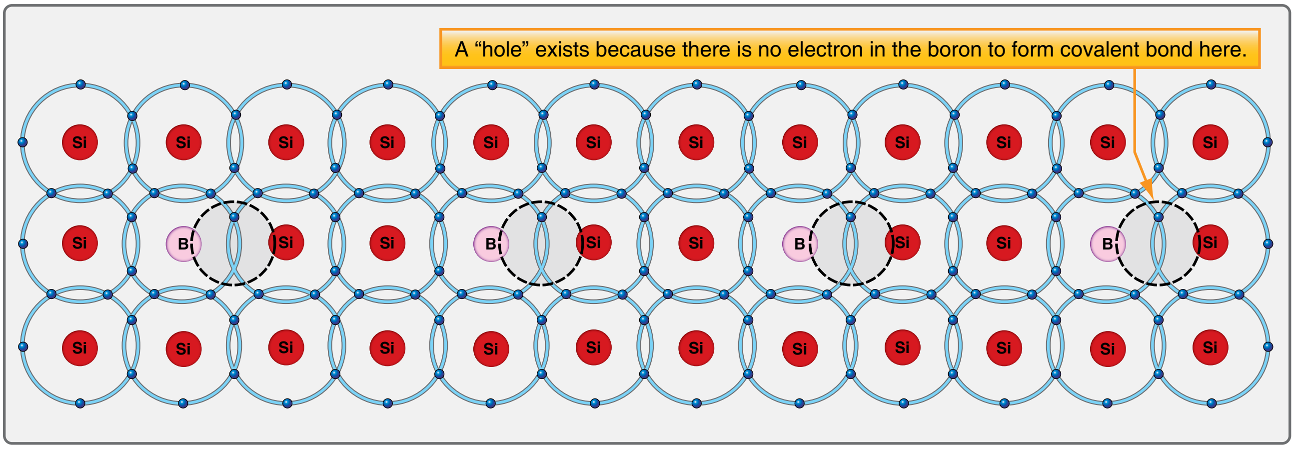


Figure 11-18. *The lattice of boron doped silicon contains holes where the three boron valence shell electrons fail to fill in the combined valence shells to the maximum of eight electrons. This is known as P-type semiconductor material or acceptor material.*

Combining N- and P-type semiconductor material in certain ways can produce very useful results. A look at various semiconductor devices follows.

Semiconductor Diodes

A diode is an electrical device that allows current to flow in one direction through the device but not the other. A simple device that can be made from N- and P-type semiconductors is a semiconductor diode. When joined, the junction of these two materials exhibits unique properties. Since there are holes in the P-type material, free electrons from the N-type material are attracted to fill these holes. Once combined, the area at the junction of the two materials where this happens is said to be depleted. There are no longer free electrons or holes. However, having given up some electrons, the N-type material next to the junction becomes slightly positively charged, and having received electrons, the P-type material next to the junction becomes slightly negatively charged.

The depletion area at the junction of the two semiconductor materials constitutes a barrier or potential hill. The intensity of the potential hill is proportional to the width of the depletion area (where the electrons from the N-type material have filled holes in the P-type material). *[Figure 11-19]*

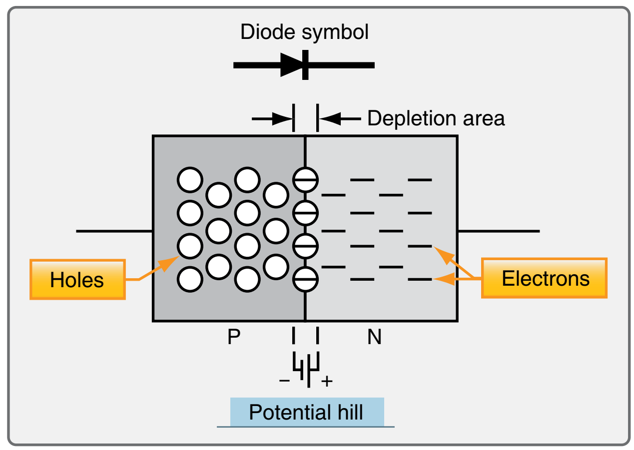


Figure 11-19. *A potential hill.*

The two semiconductors joined in this manner form a diode that can be used in an electrical circuit. A voltage source is attached to the diode. When the negative terminal of the battery is attached to the N-type semiconductor material and the positive terminal is attached to the P-type material, electricity can flow in the circuit. The negative potential of the battery forces free electrons in the N-type material toward the junction. The positive potential of the battery forces holes in the P-type material toward the other side of the junction. The holes move by the rebinding of the doping agent ions closer to the junction. At the junction, free electrons continuously arrive and fill the holes in the lattice. As this occurs, more room is available for electrons and holes to move into the area. Pushed by the potential of the battery, electrons and holes continue to combine. The depletion area becomes extremely narrow under these conditions. The potential hill or barrier is, therefore, very small. The flow of current in the electrical circuit is in the direction of electron movement shown in *Figure 11-20*.

In similar circuits where the negative battery terminal is attached to the N-type semiconductor material and the positive terminal is attached to the P-type material, current flows from N-type, or donor material, to P-type receptor material. This is known as a forward biased semiconductor. A voltage of approximately 0.7 volts is needed to begin the current flow over the potential hill. Thereafter, current flow is linear with the voltage. However, temperature affects the ease at which electrons and holes combine given a specific voltage.

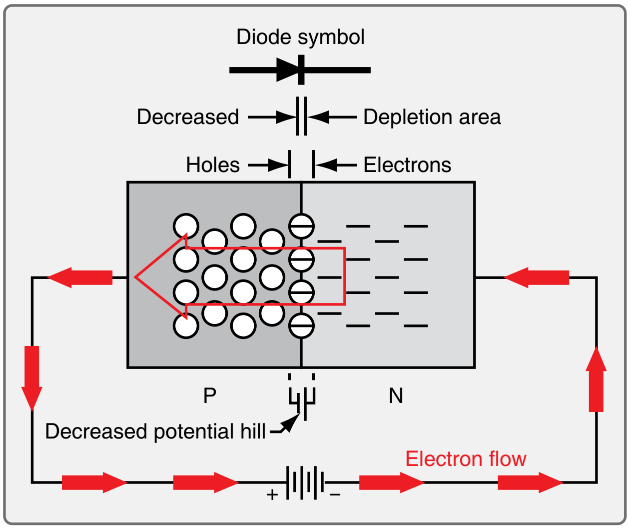


Figure 11-20. *The flow of current and the P-N junction of a semiconductor diode attached to a battery in a circuit.*

If the battery terminals are reversed, the semiconductor diode circuit is said to be reversed biased. *[Figure 11-21]* Attaching the negative terminal of the battery to the P-type material attracts the holes in the P-type material away from the junction in the diode. The positive battery terminal attached to the N-type material attracts the free electrons from the junction in the opposite direction. In this way, the width of the area of depletion at the junction of the two materials increases. The potential hill is greater. Current cannot climb the hill; therefore, no current flows in the circuit. The semiconductors do not conduct.

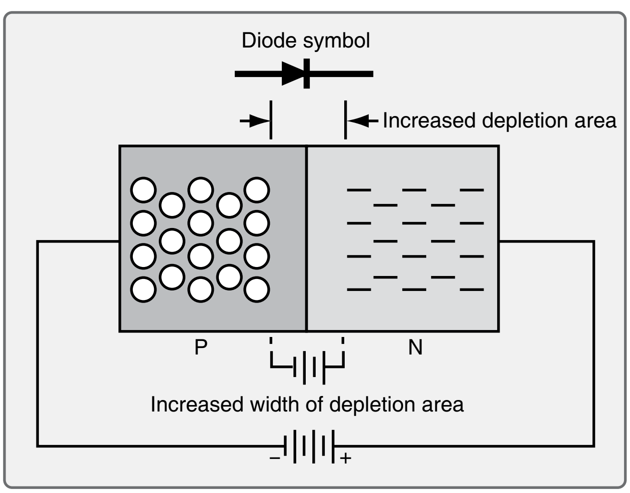


Figure 11-21. *A reversed biased condition.*

Semiconductor diodes are used often in electronic circuits. When AC current is applied to a semiconductor diode, current flows during one cycle of the AC but not during the other cycle. The diode, therefore, becomes a rectifier. When it is forward biased, electrons flow; when the AC cycles, electrons do not flow. A simple AC rectifier circuit containing a semiconductor diode and a load resistor is illustrated in *Figure 11- 22*. Semiconductor diode symbols and examples of semiconductor diodes are shown in *Figure 11-23*.

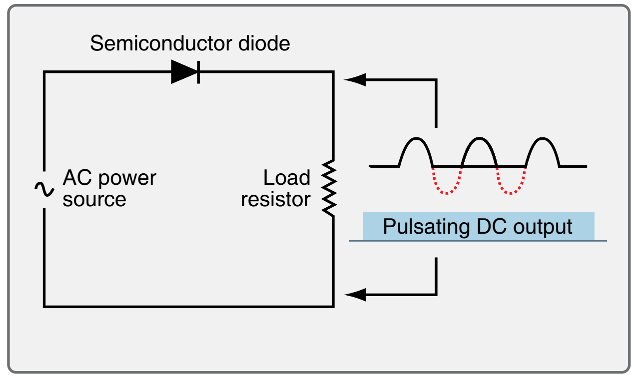


Figure 11-22. *A semiconductor diode acts as a check valve in an AC circuit resulting in a pulsating DC output.*

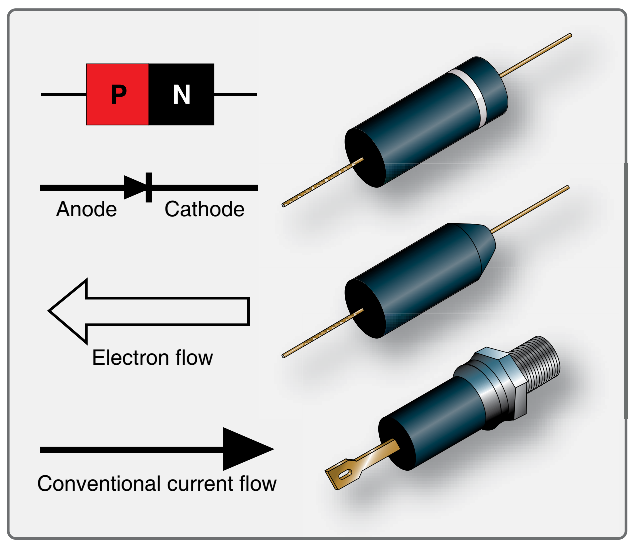


Figure 11-23. *Symbols and drawings of semiconductor diodes.*

NOTE: Electron flow is typically discussed in this text. The conventional current flow concept where electricity is thought to flow from the positive terminal of the battery through a circuit to the negative terminal is sometimes used in the field.

Semiconductor diodes have limitations. They are rated for a range of current flow. Above a certain level, the diode overheats and burns up. The amount of current that passes through the diode when forward biased is directly proportional to the amount of voltage applied. But, as mentioned, it is affected by temperature.

Figure 11-24 indicates the actual behavior of a semiconductor diode. In practice, a small amount of current does flow

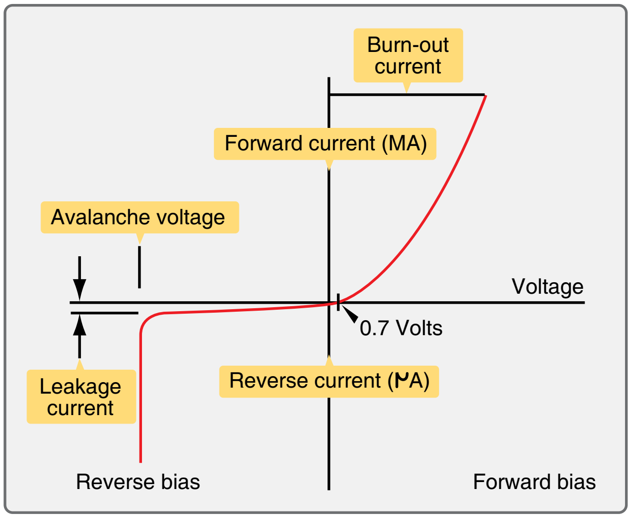


Figure 11-24. *A semiconductor diode.*

through a semiconductor diode when reversed biased. This is known as leakage current and it is in the micro amperage range. However, at a certain voltage, the blockage of current flow in a reversed biased diode breaks down completely. This voltage is known as the avalanche voltage because the diode can no longer hold back the current and the diode fails.

Zener Diodes

Diodes can be designed with a zener voltage. This is similar to avalanche flow. When reversed biased, only leakage current flows through the diode. However, as the voltage is increased, the zener voltage is reached. The diode lets current flow freely through the diode in the direction in which it is normally blocked. The diode is constructed to be able to handle the zener voltage and the resulting current, whereas avalanche voltage burns out a diode. A zener diode can be used as means of dropping voltage or voltage regulation. It can be used to step down circuit voltage for a particular application but only when certain input conditions exist. Zener diodes are constructed to handle a wide range of voltages. *[Figure 11-25]*

Transistors

While diodes are very useful in electronic circuits, semiconductors can be used to construct true control valves known as transistors. A transistor is little more than a sandwich of N-type semiconductor material between two pieces of P-type semiconductor material or vice versa. However, a transistor exhibits some remarkable properties and is the building block of all things electronic. *[Figure 11-26]* As with any union of dissimilar types of semiconductor materials, the junctions of the P- and N- materials in a transistor have depletion areas that create potential hills for the flow of electrical charges.

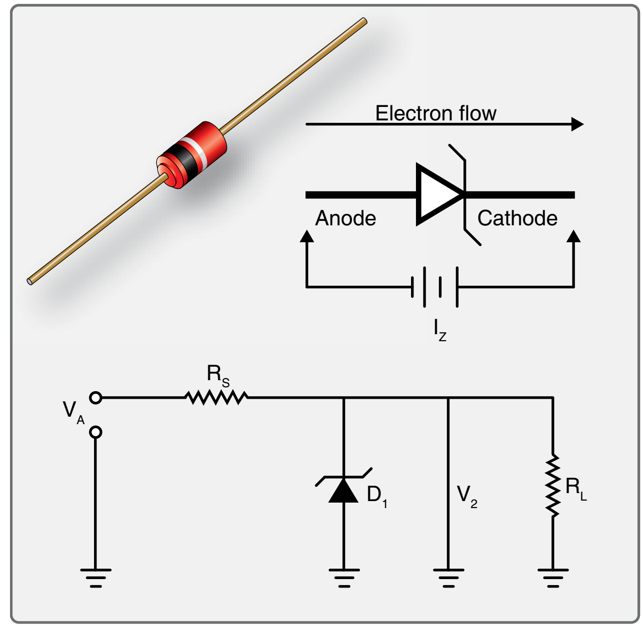


Figure 11-25. *A zener diode, when reversed biased, will break down and allow a prescribed voltage to flow in the direction normally blocked by the diode.*

Like a vacuum tube triode, the transistor has three electrodes or terminals, one each for the three layers of semiconductor material. The emitter and the collector are on the outside of the sandwiched semiconductor material. The center material is known as the base. A change in a relatively small amount of voltage applied to the base of the transistor allows a relatively large amount of current to flow from the collector to the emitter. In this way, the transistor acts as a switch with a small input voltage controlling a large amount of current.

If a transistor is put into a simple battery circuit, such as the one shown in *Figure 11-27*, voltage from the battery (EB) forces free electrons and holes toward the junction between the base and the emitter just as it does in the junction of a semiconductor diode. The emitter-base depletion area becomes narrow as free electrons combine with the holes at the junction. Current (IB) (solid arrows) flows through the junction in the emitter-base battery circuit. At the same time, an emitter-collector circuit is constructed with a battery (EC) of much higher voltage in its circuit. Because of the narrow depletion area at the emitter-base junction, current IC is able to cross the collector base junction, flow through emitter-base junction, and complete the collector-emitter battery circuit (hollow arrows).

To some extent, varying the voltage to the base material can increase or decrease the current flow through the transistor as the emitter-base depletion area changes width in response to the base voltage. If base voltage is removed, the emitter-

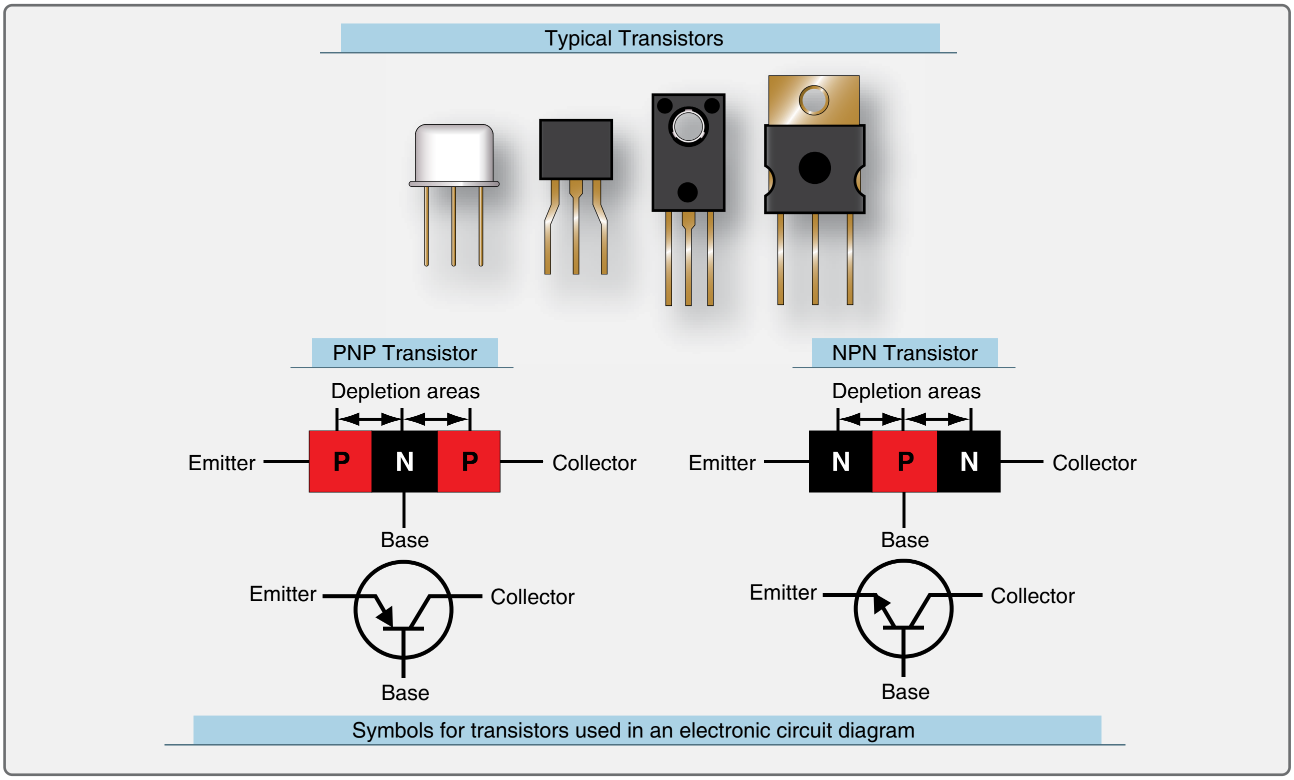


Figure 11-26. *Typical transistors, diagrams of a PNP and NPN transistor, and the symbol for those transistors when depicted in an electronic circuit diagram.*

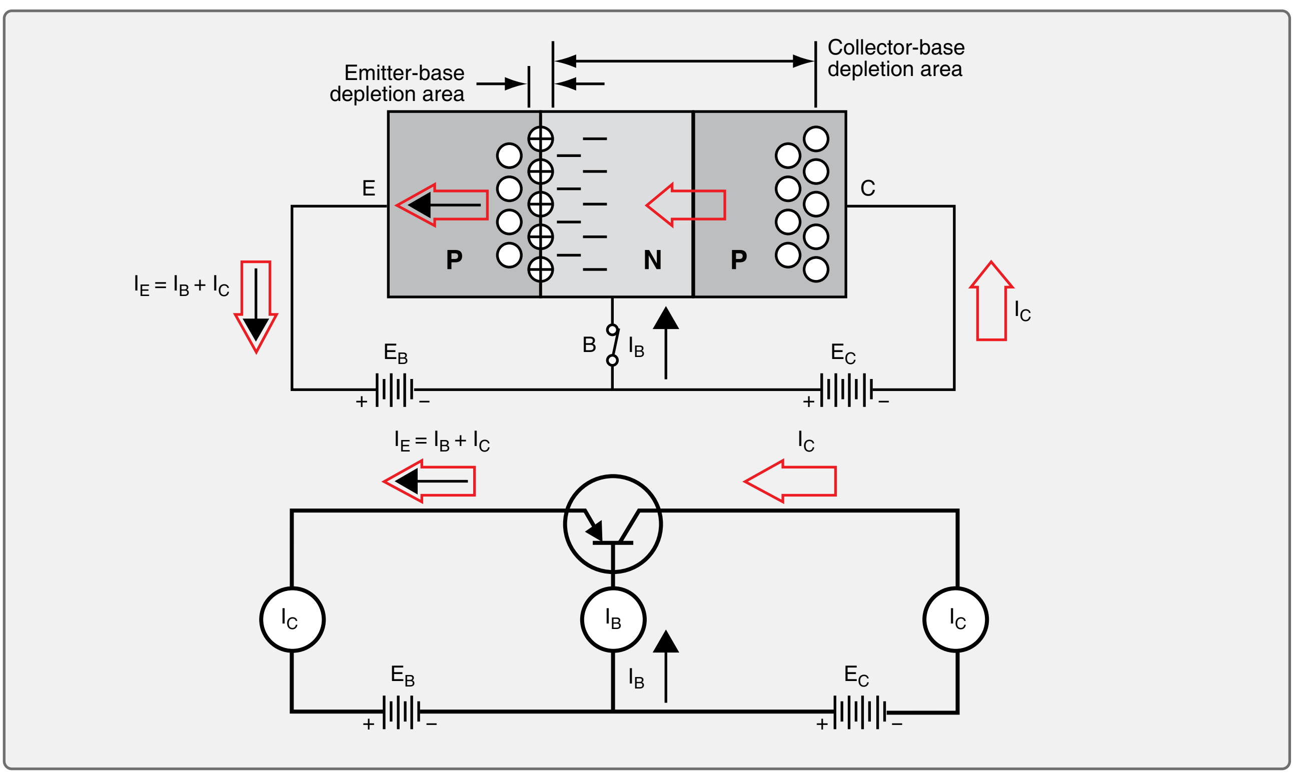


Figure 11-27. *The effect of applying a small voltage to bias the emitter-base junction of a transistor (top). A circuit diagram for this same transistor (bottom).*

base depletion area becomes too wide and all current flow through the transistor ceases.

Current in the transistor circuit illustrated has a relationship as follows: IE = IB + IC. It should be remembered that it is the voltage applied to the base that turns the collector-emitter transistor current on or off.

Controlling a large amount of current flow with a small independent input voltage is very useful when building electronic circuits. Transistors are the building blocks from which all electronic devices are made, including Boolean gates that are used to create micro processor chips. As production techniques have developed, the size of reliable transistors has shrunk. Now, hundreds of millions and even billions of transistors may be used to construct a single chip such as the one that powers your computer and various avionic devices.

Silicon Controlled Rectifiers

Combination of semiconductor materials is not limited to a two-type, three-layer sandwich transistor. By creating a four-layer sandwich of alternating types of semiconductor material (i.e., PNPN or NPNP), a slightly different semiconductor diode is created. As is the case in a two-layer diode, circuit current is either blocked or permitted to flow through the diode in a single direction.

Within a four-layer diode, sometimes known as a Shockley diode, there are three junctions. The behavior of the junctions and the entire four-layer diode can be understood by considering it to be two interconnected three-layer transistors. *[Figure 11-28]* Transistor behavior includes no current flow until the base material receives an applied voltage to narrow the depletion area at the base-emitter junction. The base materials in the four-layer diode transistor model receive charge from the other transistor's collector. With no other means of reducing any of the depletion areas at the junctions, it appears that current does not flow in either direction in this device. However, if a large voltage is applied to forward bias the anode or cathode, at some point the ability to block flow breaks down. Current flows through whichever transistor is charged. Collector current then charges the base of the other transistor and current flows through the entire device.

Some caveats are necessary with this explanation. The transistors that comprise this four-layer diode must be constructed of material similar to that described in a zener diode. That is, it must be able to endure the current flow without burning out. In this case, the voltage that causes the diode to conduct is known as breakover voltage rather than breakdown voltage. Additionally, this diode has the unique characteristic of allowing current flow to continue until the applied voltage is reduced significantly, in most cases, until it is reduced to zero. In AC circuits, this would occur when the AC cycles.

While the four-layer, Shockley diode is useful as a switching device, a slight modification to its design creates a silicon controlled rectifier (SCR). To construct a SCR, an additional terminal known as a gate is added. It provides more control and utility. In the four-layer semiconductor construction, there are always two junctions forward biased and one junction reversed biased. The added terminal allows the momentary application of voltage to the reversed biased junction. All three junctions then become forward biased and

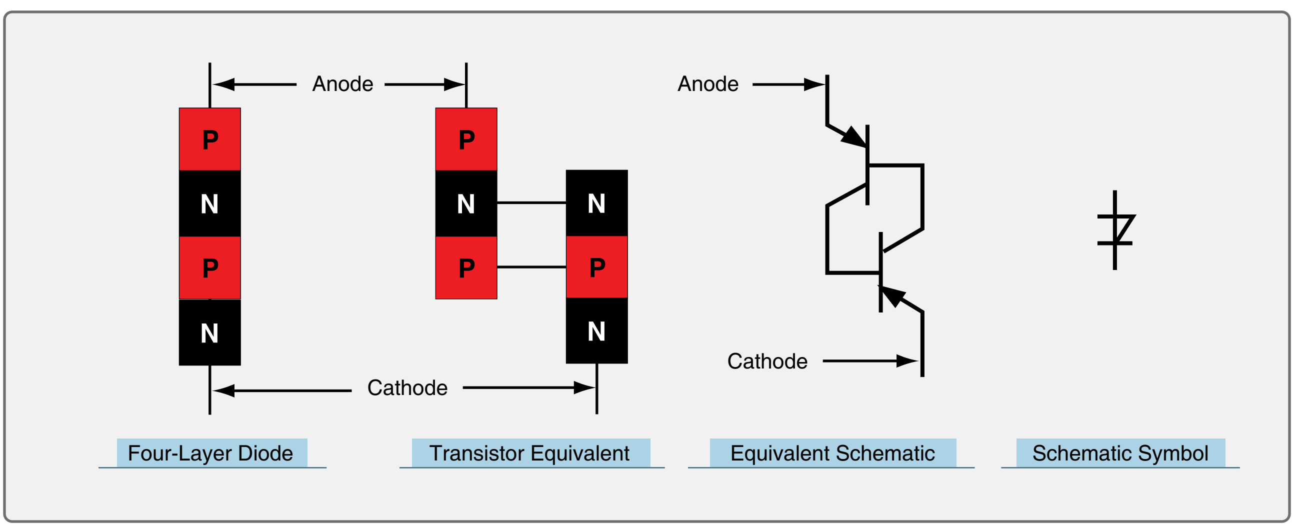


Figure 11-28. *A four-layer semiconductor diode behaves like two transistors. When breakover voltage is reached, the device conducts current until the voltage is removed.*

current at the anode flows through the device. Once voltage is applied to the gate, the SCR become latched or locked on. Current continues to flow through it until the level drops off significantly, usually to zero. Then, another applied voltage through the gate is needed to reactivate the current flow. *[Figures 11-29* and *11-30]*

SCRs are often used in high voltage situations, such as power switching, phase controls, battery chargers, and inverter circuits. They can be used to produce variable DC voltages for motors and are found in welding power supplies. Often, lighting dimmer systems use SCRs to reduce the average voltage applied to the lights by only allowing current flow during part of the AC cycle. This is controlled by controlling the pulses to the SCR gate and eliminating the massive heat dissipation caused when using resistors to reduce voltage. *Figure 11-31* graphically depicts the timing of the gate pulse that limits full cycle voltage to the load. By controlling the phase during which time the SCR is latched, a reduced average voltage is applied.

Triacs

SCRs are limited to allowing current flow in one direction only. In AC circuitry, this means only half of the voltage cycle can be used and controlled. To access the voltage in the reverse cycle from an AC power source, a triac can be used. A triac is also a four-layer semiconductor device. It differs from an SCR in that it allows current flow in both directions. A triac has a gate that works the same way as in a SCR; however, a positive or negative pulse to the gate triggers current flow in a triac. The pulse polarity determines the direction of the current flow through the device.

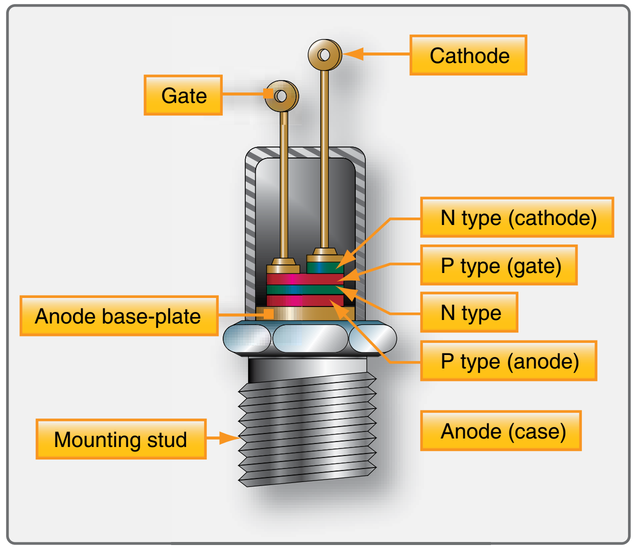


Figure 11-30. *Cross-section of a medium-power SCR.*

Figure 11-32 illustrates a triac and shows a triac in a simple circuit. It can be triggered with a pulse of either polarity and remains latched until the voltage declines, such as when the AC cycles. Then, it needs to be triggered again. In many ways, the triac acts as though it is two SCRs connected side by side only in opposite directions. Like an SCR, the timing of gate pulses determines the amount of the total voltage that is allowed to pass. The output waveform if triggered at 90° is shown in *Figure 11-32*. Because a triac allows current to flow in both directions, the reverse cycle of AC voltage can also be used and controlled.

When used in actual circuits, triacs do not always maintain the same phase firing point in reverse as they do when fired with a positive pulse. This problem can be regulated

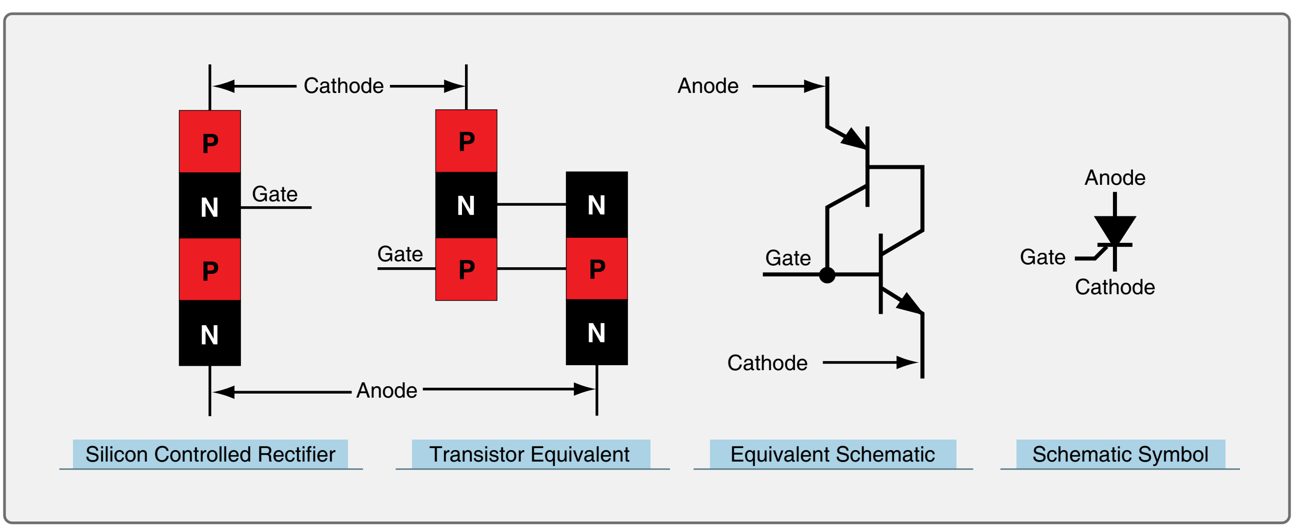


Figure 11-29. *A silicon controlled rectifier (SCR) allows current to pass in one direction when the gate receives a positive pulse to latch the device in the on position. Current ceases to flow when it drops below holding current, such as when AC current reverses cycle.*

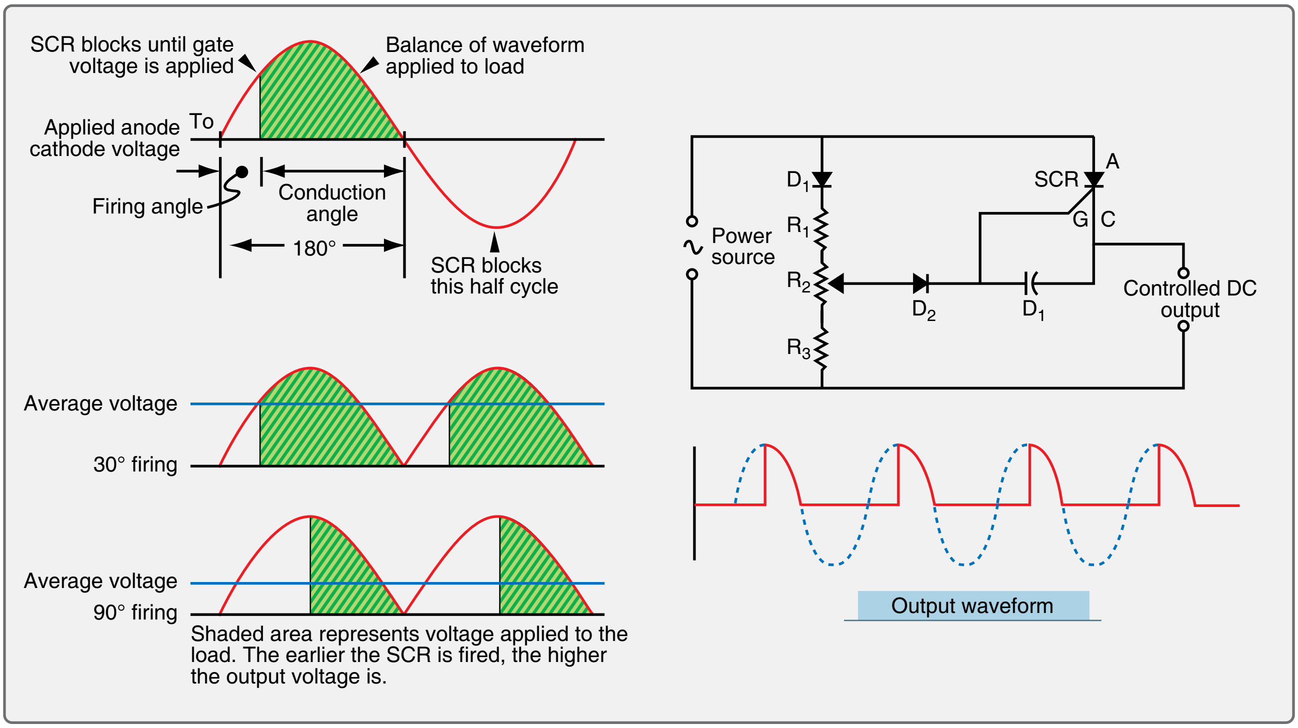


Figure 11-31. *Phase control is a key application for SCR. By limiting the percentage of a full cycle of AC voltage that is applied to a load, a reduced voltage results. The firing angle or timing of a positive voltage pulse through the SCR's gate latches the device open allowing current flow until it drops below the holding current, which is usually at or near zero voltage as the AC cycle reverses.*

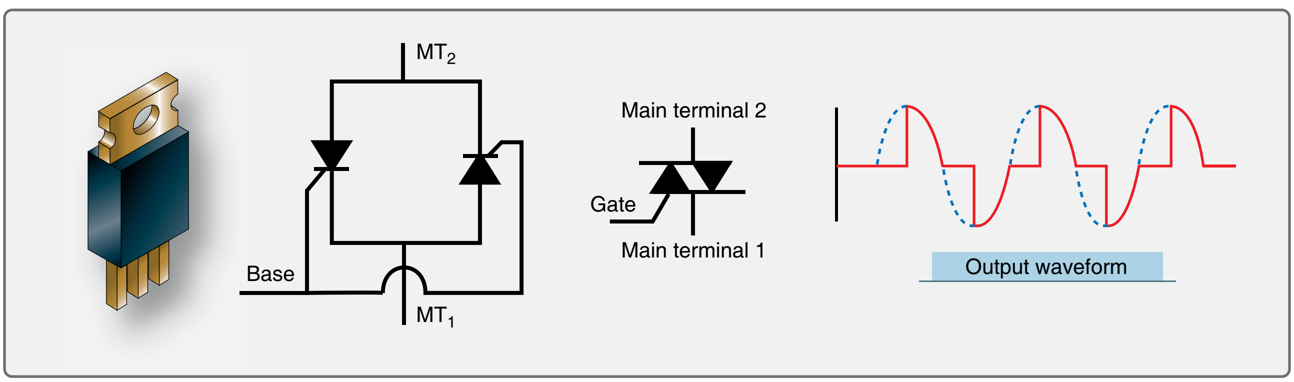


Figure 11-32. *A triac is a controlled semiconductor device that allows current flow in both directions.*

somewhat through the use of a capacitor and a diac in the gate circuit. However, as a result, where precise control is required, two SCRs in reverse of each other are often used instead of the triac. Triacs do perform well in lower voltage circuits. *Figure 11-33* illustrates the semiconductor layering in a triac.

NOTE: The four layers of N- and P-type materials are not uniform as they were in previously described semiconductor devices. None the less, gate pulses affect the depletion areas at the junctions of the materials in the same way allowing current to flow when the areas are narrowed.

Unijunction Transistors (UJT)

The behavior of semiconductor materials is exploited through the construction of numerous transistor devices containing various configurations of N-type and P-type materials. The physical arrangement of the materials in relation to each other yields devices with unique behaviors and applications. The transistors described above having two junctions of P-type and N-type materials (PN) are known as bipolar junction transistors. Other more simple transistors can be fashioned with only one junction of the PN semiconductor materials. These are known as unijunction transistors (UJT). [*Figure 11-34]*

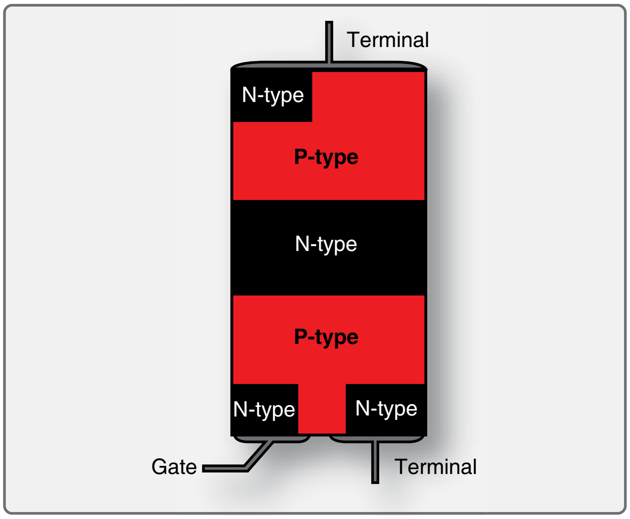


Figure 11-33. *The semiconductor layering in a triac. A positive or negative gate pulse with respect to the upper terminal allows current to flow through the devise in either direction.*

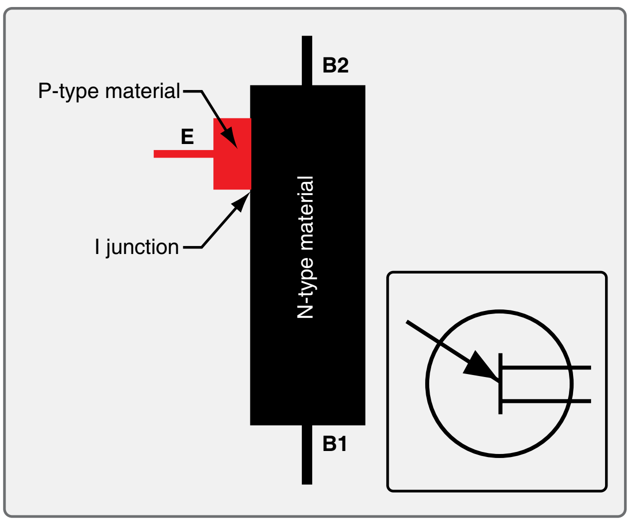


Figure 11-34. *A unijunction transistor (UJT).*

The UJT contains one base semiconductor material and a different type of emitter semiconductor material. There is no collector material. One electrode is attached to the emitter and two electrodes are attached to the base material at opposite ends. These are known as base 1 (B1) and base 2 (B2). The electrode configuration makes the UJT appear physically the same as a bipolar junction transistor. However, there is only one PN junction in the UJT and it behaves differently.

The base material of a UJT behaves like a resistor between the electrodes. With B2 positive with respect to B1, voltage gradually drops as it flows through the base. *[Figure 11-35]* By placing the emitter at a precise location along the base material gradient, the amount of voltage needed to be applied to the emitter electrode to forward bias the UJT base-emitter

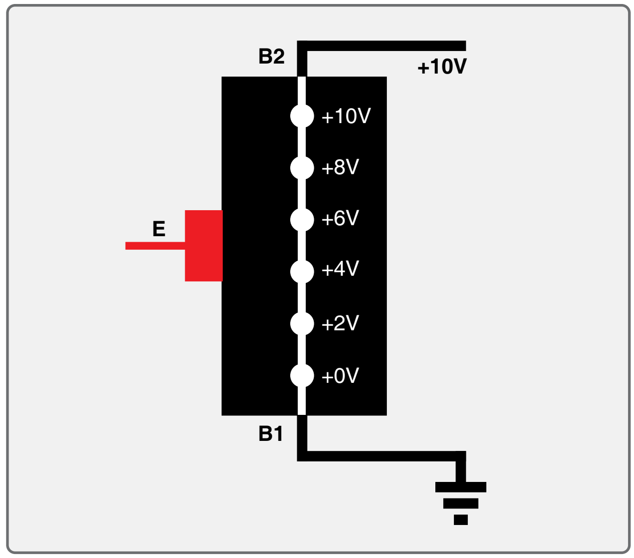


Figure 11-35. *The voltage gradient in a UJT.*

junction is determined. When the applied emitter voltage exceeds the voltage at the gradient point where the emitter is attached, the junction is forward biased and current flows freely from the B1 electrode to the E electrode. Otherwise, the junction is reversed biased and no significant current flows although there is some leakage. By selecting a UJT with the correct bias level for a particular circuit, the applied emitter voltage can control current flow through the device.

UJTs transistors of a wide variety of designs and characteristics exist. A description of all of them is beyond the scope of this discussion. In general, UJTs have some advantages over bipolar transistors. They are stable in a wide range of temperatures. In some circuits, use of UJTs can reduce the overall number of components used, which saves money and potentially increases reliability. They can be found in switching circuits, oscillators, and wave shaping circuits. However, four-layered semiconductor thyristors that function the same as the UJT just described are less expensive and most often used.

Field Effect Transistors (FET)

As shown in the triac and the UJT, creative arrangement of semiconductor material types can yield devices with a variety of characteristics. The field effect transistor (FET) is another such device which is commonly used in electronic circuits. Its N- and P-type material configuration is shown in *Figure 11-36*. A FET contains only one junction of the two types of semiconductor material. It is located at the gate where it contacts the main current carrying portion of the device. Because of this, when an FET has a PN junction, it is known as a junction field effect transistor (JFET). All FETs operate by expanding and contracting the depletion area at the junction of the semiconductor materials.

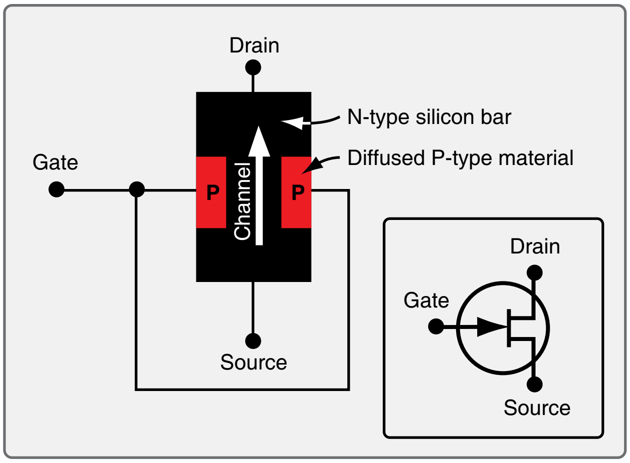


Figure 11-36. *The basic structure of a field effect transistor and its electronic symbol.*

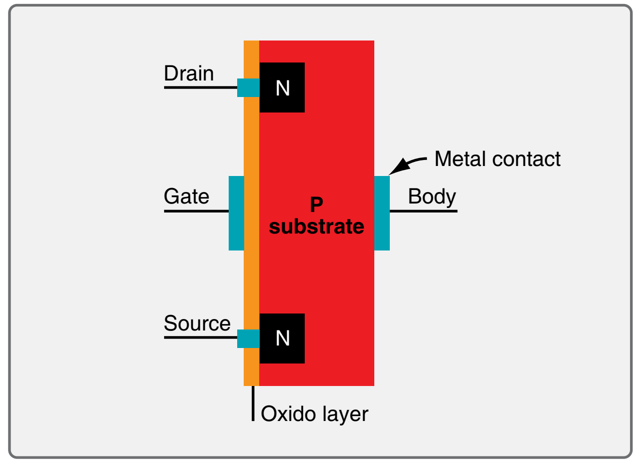


Figure 11-37. *A MOSFET has a metal gate and an oxide layer between it and the semiconductor material to prevent current leakage.*

One of the materials in a FET or JFET is called the channel. It is usually the substrate through which the current needing to be controlled flows from a source terminal to a drain terminal. The other type of material intrudes into the channel and acts as the gate. The polarity and amount of voltage applied to the gate can widen or narrow the channel due to expansion or shrinking of the depletion area at the junction of the semiconductors. This increases or decreases the amount of current that can flow through the channel. Enough reversed biased voltage can be applied to the gate to prevent the flow of current through the channel. This allows the FET to act as a switch. It can also be used as a voltage controlled resistance.

FETs are easier to manufacture than bipolar transistors and have the advantage of staying on once current flow begins without continuous gate voltage applied. They have higher impedance than bipolar transistors and operate cooler. This makes their use ideal for integrated circuits where millions of FETs may be in use on the same chip. FETs come in N-channel and P-channel varieties.

Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) and Complementary Metal Oxide Semiconductor (CMOS)

The basic FET has been modified in numerous ways and continues to be at the center of faster and smaller electronic component development. A version of the FET widely used is the metal oxide semiconductor field effect transistor (MOSFET). The MOSFET uses a metal gate with a thin insulating material between the gate and the semiconductor material. This essentially creates a capacitor at the gate and eliminates current leakage in this area. Modern versions of the MOSFET have a silicon dioxide insulating layer and many have poly-crystalline silicon gates rather than metal, but the MOSFET name remains and the basic behavioral characteristic are the same. *[Figure 11-37]*

As with FETs, MOSFETs come with N-channels or P-channels. They can also be constructed as depletion mode or enhancement mode devices. This is analogous to a switch being normally open or normally closed. Depletion mode MOSFETs have an open channel that is restricted or closed when voltage is applied to the gate (i.e., normally open). Enhancement mode MOSFETs allow no current to flow at zero bias but create a channel for current flow when voltage is applied to the gate (normally closed). No voltage is used when the MOSFETs are at zero bias. Millions of enhancement mode MOSFETs are used in the construction of integrated circuits. They are installed in complimentary pairs such that when one is open, the other is closed. This basic design is known as complementary MOSFET (CMOS), which is the basis for integrated circuit design in nearly all modern electronics. Through the use of these transistors, digital logic gates can be formed and digital circuitry is constructed.

Other more specialized FETs exist. Some of their unique characteristics are owed to design alterations and others to material variations. The transistor devices discussed above use silicon-based semiconductors. But the use of other semiconductor materials can yield variations in performance. Metal semiconductor FETs (MESFETS) for example, are often used in microwave applications. They have a combined metal and semiconductor material at the gate and are typically made from gallium arsenide or indium phosphide. MESFETs are used for their quickness when starting and stopping current flows especially in opposite directions. High electron mobility transistors (HEMT) and pseudomorphic high electron mobility transistors (PHEMT) are also constructed from gallium arsenide semiconductor material and are used for high frequency applications.

Photodiodes and Phototransistors

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

Figure 11-38 illustrates a photodiode in a coil circuit. In this case, the light striking the photodiode causes current to flow in the circuit whereas the diode would have otherwise blocked it. The result is the coil energizes and closes another circuit enabling its operation.

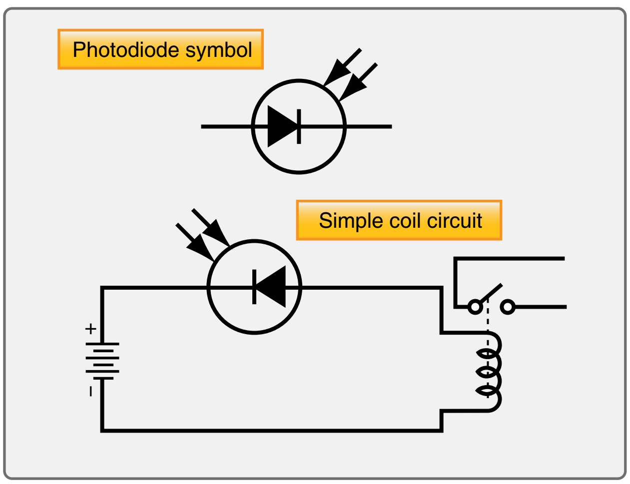


Figure 11-38. *The symbol for a photodiode and a photodiode in a simple coil circuit.*

A photon activated transistor could be used to carry even more current than a photodiode. In this case, the light energy is focused on a collector-base junction. This frees electrons in the depletion area and starts a flow of electrons from the base that turns on the transistor. Once on, heavier current flows from the emitter to the collector. *[Figure 11-39]* In practice, engineers have developed numerous ways to use the energy in light photons to trigger semiconductor devices in electronic circuits. *[Figure 11-40]*

Light Emitting Diodes

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

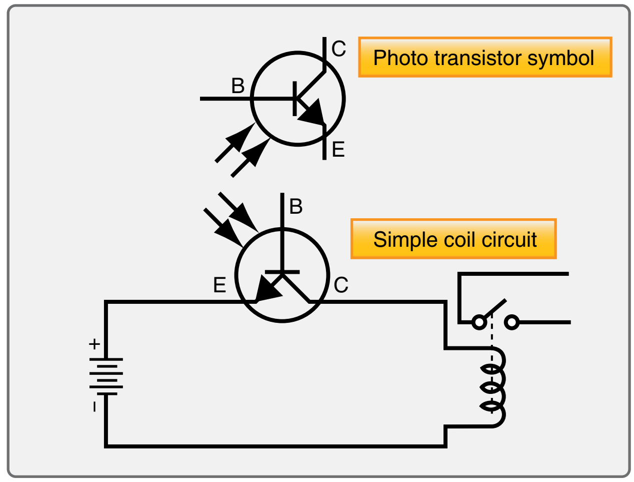


Figure 11-39. *A photo transistor in a simple coil circuit (bottom) and the symbol for a phototransistor (top).*

Figure 11-40. *Phototransistors.*

LEDs are simple and reliable. They are constructed of semiconductor material. When a free electron from a semiconductor drops into a semiconductor hole, energy is given off. This is true in all semiconductor materials. However, the energy released when this happens in certain materials is in the frequency range of visible light. *Figure 11-41* is a table that illustrates common LED colors and the semiconductor material that is used in the construction of the diode.

NOTE: When the diode is reversed biased, no light is given off. When the diode is forward biased, the energy given off is visible in the color characteristic for the material being used. *Figure 11-42* illustrates the anatomy of a single LED, the symbol of an LED, and a graphic depiction of the LED process.

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

Figure 11-41. *LED colors and the materials used to construct them as well as their wavelength and voltages.*

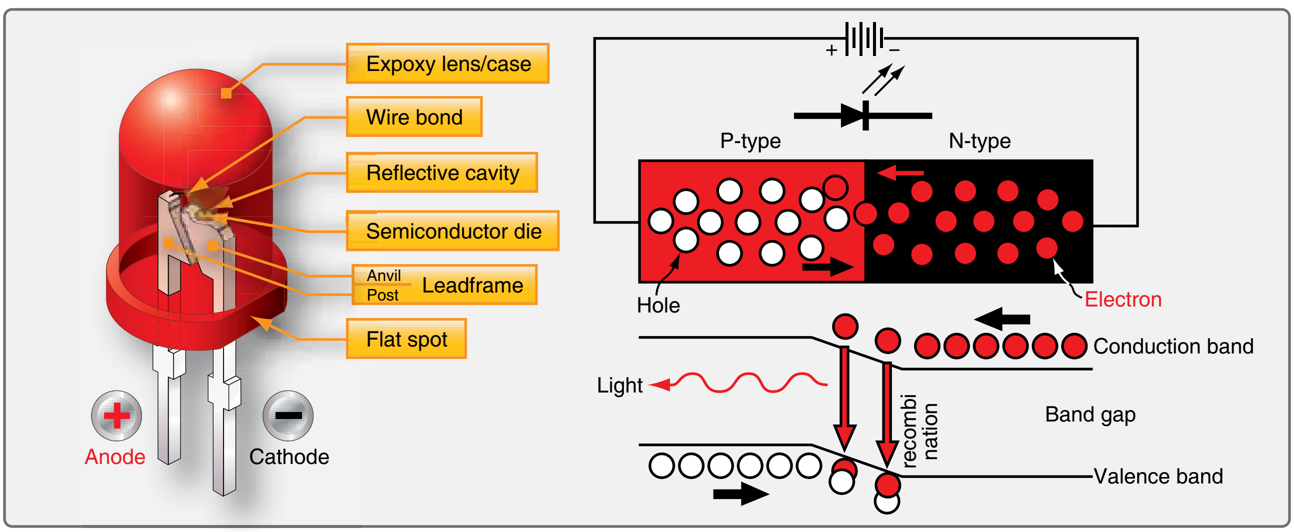


Figure 11-42. *A close up of a single LED (left) and the process of a semi-conductor producing light by electrons dropping into holes and giving off energy (right). The symbol for a light emitting diode is the diode symbol with two arrows pointing away from the junction.*

Basic Analog Circuits

The solid-state semiconductor devices described in the previous section of this chapter can be found in both analog and digital electronic circuits. As digital electronics evolve, analog circuitry is being replaced. However, many aircraft still make use of analog electronics in radio and navigation equipment, as well as in other aircraft systems. A brief look at some of the basic analog circuits follows.

Rectifiers

Rectifier circuits change AC voltage into DC voltage and are one of the most commonly used type of circuits in aircraft electronics. *[Figure 11-43]* The resulting DC waveform output is also shown. The circuit has a single semiconductor diode and a load resistor. When the AC voltage cycles below zero, the diode shuts off and does not allow current flow until the AC cycles through zero voltage again. The result is pronounced pulsating DC. While this can be useful, half of the original AC voltage is not being used.

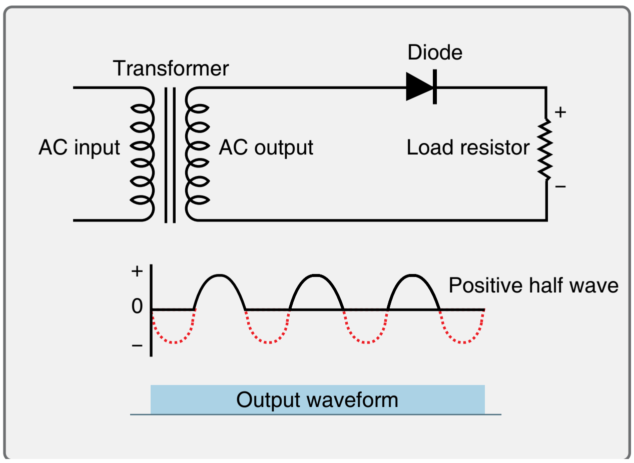


Figure 11-43. *A half wave rectifier uses one diode to produce pulsating DC current from AC. Half of the AC cycle is wasted when the diode blocks the current flow as the AC cycles below zero.*

A full wave rectifier creates pulsating DC from AC while using the full AC cycle. One way to do this is to tap the secondary coil at its midpoint and construct two circuits with the load resistor and a diode in each circuit. *[Figure 11-44]* The diodes are arranged so that when current is flowing through one, the other blocks current.

When the AC cycles so the top of the secondary coil of the transformer is positive, current flows from ground, through the load resistor (V_{RL}), Diode 1, and the upper half of the coil. Current cannot flow through Diode 2 because it is blocked. *[Figure 11-44A]* As the AC cycles through zero, the polarity of the secondary coil changes. *[Figure 11-44B]* Current then flows from ground, through the load resistor, Diode 2, and the bottom half of the secondary coil. Current flow through Diode 1 is blocked. This arrangement yields positive DC from cycling AC with no wasted current.

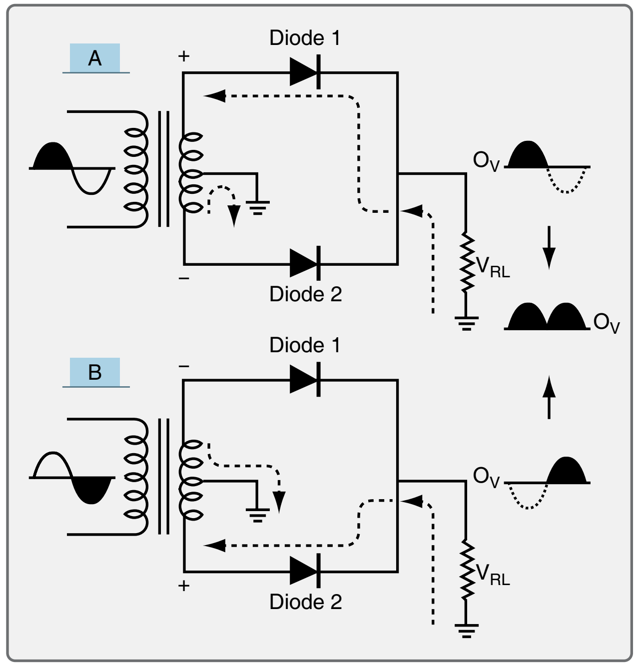


Figure 11-44. *A full wave rectifier can be built by center tapping the secondary coil of the transformer and using two diodes in separate circuits. This rectifies the entire AC input into a pulsating DC with twice the frequency of a half wave rectifier.*

Another way to construct a full wave rectifier uses four semiconductor diodes in a bridge circuit. Because the secondary coil of the transformer is not tapped at the center, the resultant DC voltage output is twice that of the two-diode full wave rectifier. *[Figure 11-45]* During the first half of the AC cycle, the bottom of the secondary coil is negative.

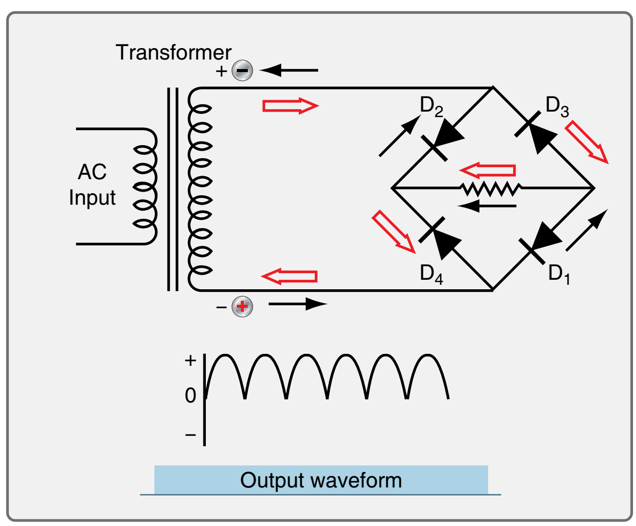


Figure 11-45. *The bridge-type four-diode full wave rectifier circuit is most commonly used to rectify single-phase AC into DC.*

Current flows from it through diode (D1), then through the load resistor, and through diode (D2) on its way back to the top of the secondary coil. When the AC reverses its cycle, the polarity of the secondary coil changes. Current flows from the top of the coil through diode (D3), then through the load resistor, and through diode (D4) on its way back to the bottom of the secondary coil. The output waveform reflects the higher voltage achieved by rectifying the full AC cycle through the entire length of the secondary coil.

Use and rectification of three-phase AC is also possible on aircraft with a specific benefit. The output DC is very smooth and does not drop to zero. A six diode circuit is built to rectify the typical three-phase AC produced by an aircraft alternator. *[Figure 11-46]*

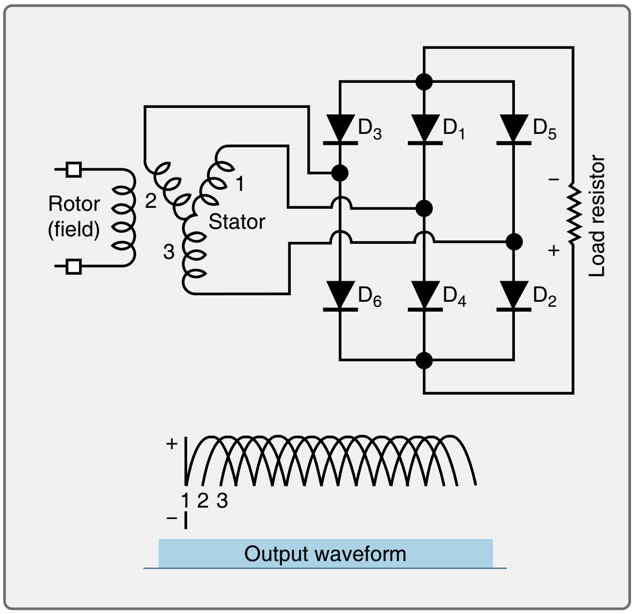


Figure 11-46. *A six-diode three-phase AC rectifier.*

Each stator coil corresponds to a phase of AC and becomes negative for 120° of rotation of the rotor. When stator 1 or the first phase is negative, current flows from it through diode (D1), then through the load resistor and through diode (D2) on its way back to the third phase coil. Next, the second phase coil becomes negative and current flows through diode (D3). It continues to flow through the load resistor and diode (D4) on its way back to the first phase coil. Finally, the third stage coil becomes negative causing current to flow through diode (D5), then the load resistor and diode (D6) on its way back to the second phase coil. The output waveform of this three-phase rectifier depicts the DC produced. It is a relatively steady, non-pulsing flow equivalent to just the tops of the individual curves. The phase overlap prevents voltage from falling to zero producing smooth DC from AC.

Amplifiers

An amplifier is a circuit that changes the amplitude of an electric signal. This is done through the use of transistors. As mentioned, a transistor that is forward biased at the base-emitter junction and reversed biased at the collector-base junction is turned on. It can conduct current from the collector to the emitter. Because a small signal at the base can cause a large current to flow from collector to emitter, a transistor in itself can be said to be an amplifier. However, a transistor properly wired into a circuit with resistors, power sources, and other electronic components, such as capacitors, can precisely control more than signal amplitude. Phase and impedance can also be manipulated.

Since the typical bi-polar junction transistor requires a based circuit and a collector-emitter circuit, there should be four terminals, two for each circuit. However, the transistor only has three terminals (i.e., the base, the collector, and the emitter). Therefore, one of the terminals must be common to both transistor circuits. The selection of the common terminal affects the output of the amplifier.

Since the typical bipolar junction transistor requires a base circuit and a collector-emitter circuit, there should be four terminals—two for each circuit. However, the transistor only has three terminals: the base, the collector, and the emitter. Therefore, one of the terminals must be common to both transistor circuits. The selection of the common terminal affects the output of the amplifier.

The three basic amplifier types, named for which terminal of the transistor is the common terminal to both transistor circuits, include:

1. Common-emitter amplifier
2. Common-collector amplifier
3. Common-base amplifier

Common-Emitter Amplifier

The common-emitter amplifier controls the amplitude of an electric signal and inverts the phase of the input signal. *Figure 11-47* illustrates a common-emitter amplifier for AC using a NPN transistor and its output signal graph. Common emitter circuits are characterized by high current gain and a 180° voltage phase shift from input to output. It is for the amplification of a microphone signal to drive a speaker. As always, adequate voltage of the correct polarity to the base puts the transistor in the active mode, or turns it on. Then, as the base input current fluctuates, the current through the transistor fluctuates proportionally. However, AC cycles through positive and negative polarity. Every 180°, the transistor shuts

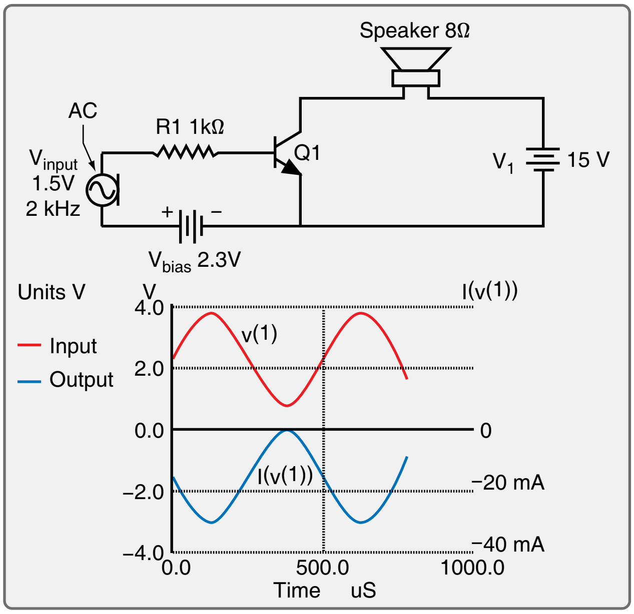


Figure 11-47. *A common-emitter amplifier circuit for amplifying an AC microphone signal to drive a speaker (top) and the graph of the output signal showing a 180 degree shift in phase (bottom).*

off because the polarity to the base-emitter junction of the transistor is not correct to forward bias the junction. To keep the transistor on, a DC biasing voltage of the correct polarity (shown as a 2.3 volts (V) battery) is placed in series with the input signal in the base circuit to hold the transistor in the active mode as the AC polarity changes. This way the transistor stays in the active mode to amplify an entire AC signal.

Transistors are rated by ratio of the collector current to the base current, or Beta (β). This is established during the manufacture of the unit and cannot be changed. A 100 β transistor can handle 100 times more current through a collector-emitter circuit than the base input signal. This current in *Figure 11-47* is provided from the 15V battery, V_1. So, the amplitude of amplification is a factor of the beta of the transistor and any in-line resistors used in the circuits. The fluctuations of the output signal, however, are entirely controlled by the fluctuations of current input to the transistor base.

If measurements of input and output voltages are made, it is shown that as the input voltage increases, the output voltage decreases. This accounts for the inverted phase produced by a common-emitter circuit. *[Figure 11-47]*

Common-Collector Amplifier

Another basic type of amplifier circuit is the common-collector amplifier. Common-collector circuits are characterized by high current gain, but vertically no voltage gain. The input circuit and the load circuit in this amplifier share the collector terminal of the transistor used. Because the load is in series with the emitter, both the input current and output current run through it. This causes a directly proportional relationship between the input and the output. The current gain in this circuit configuration is high. A small amount of input current can control a large amount of current to flow from the collector to the emitter. A common collector amplifier circuit is illustrated in *Figure 11-48*. The base current needs to flow through the PN junction of the transistor, which has about a 0.7V threshold to be turned on. The output current of the amplifier is the beta value of the transistor plus 1.

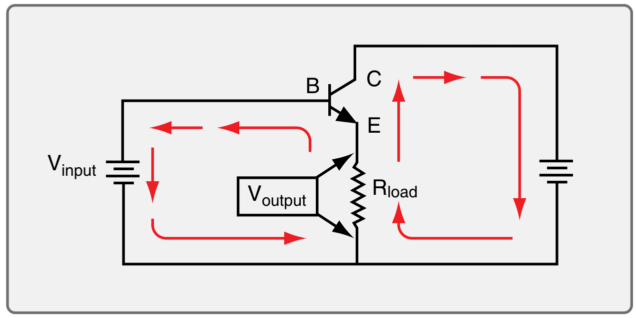


Figure 11-48. *A basic common-collector amplifier circuit. Both the input and output circuits share a path through the load and the emitter. This causes a direct relationship of the output current to the input current.*

During AC amplification, the common-collector amplifier has the same problem that exists in the common-emitter amplifier. The transistor must stay on or in the active mode regardless of input signal polarity. When the AC cycles through zero, the transistor turns off because the minimum amount of current to forward bias the transistor is not available. The addition of a DC biasing source (battery) in series with the AC signal in the input circuit keeps the transistor in the active mode throughout the full AC cycle. *[Figure 11-49]*

A common-collector amplifier can also be built with a PNP transistor. *[Figure 11-50]* It has the same characteristics as the NPN common-collector amplifier shown in *Figure 11-50*. When arranged with a high resistance in the input circuit and a small resistance in the load circuit, the common-collector amplifier can be used to step down the impedance of a signal. *[Figure 11-51]*

Common-Base Amplifier

A third type of amplifier circuit using a bipolar transistor is the common-base amplifier. In this circuit, the shared transistor terminal is the base terminal. *[Figure 11-52]* This causes a unique situation in which the base current is actually larger than the collector or emitter current. As such, the common base amplifier does not boost current as the other amplifiers do. It attenuates current but causes a high gain in voltage. A very small fluctuation in base voltage in the input circuit causes a large variation in output voltage. The effect

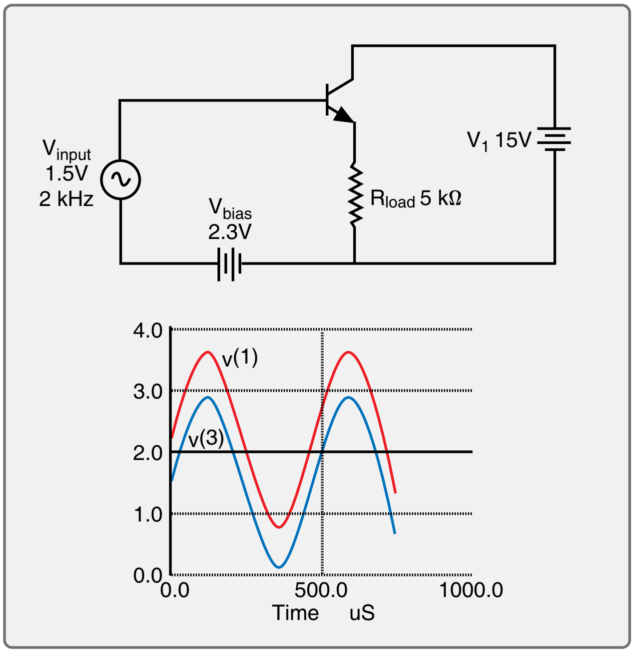


Figure 11-49. *A DC biasing current is used to keep the transistor of a common-collector amplifier in the active mode when amplifying AC (top). The output of this amplifier is in phase and directly proportional to the input (bottom). The difference in amplitude between the two is the 0.7V used to bias the PN junction of the transistor in the input circuit.*

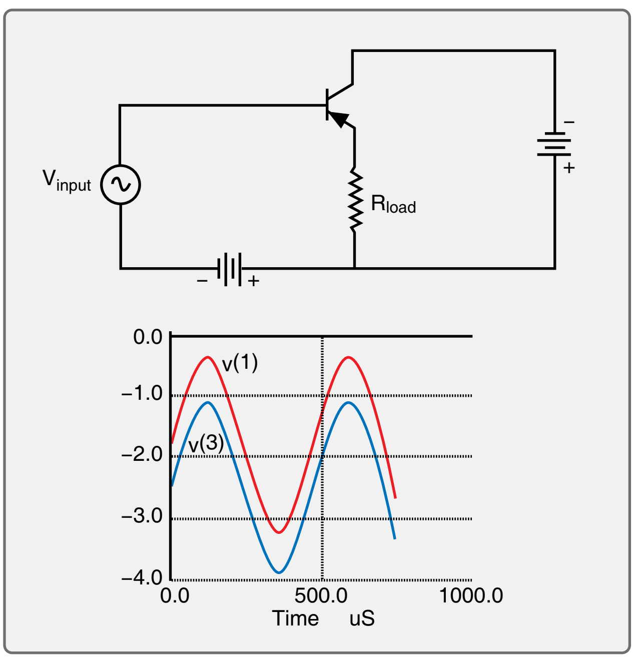


Figure 11-50. *A common-collector amplifier circuit with a PNP transistor has the same characteristics as that of a common-collector amplifier with a NPN transistor except for reversed voltage polarities and current direction.*

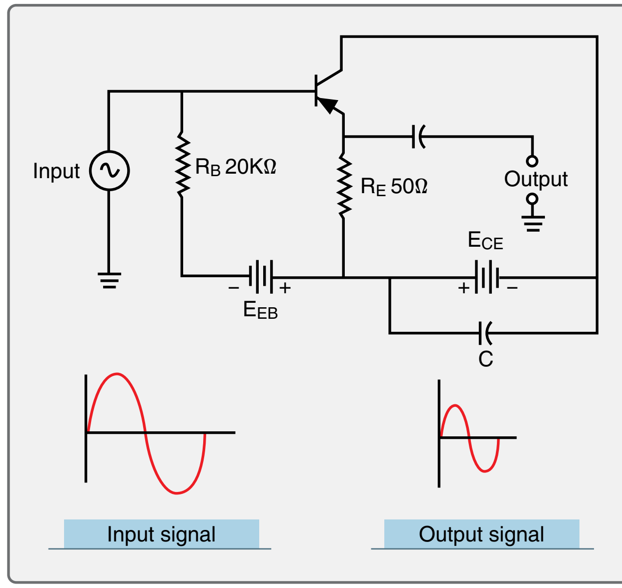


Figure 11-51. *This common-collector circuit has high input impedance and low output impedance.*

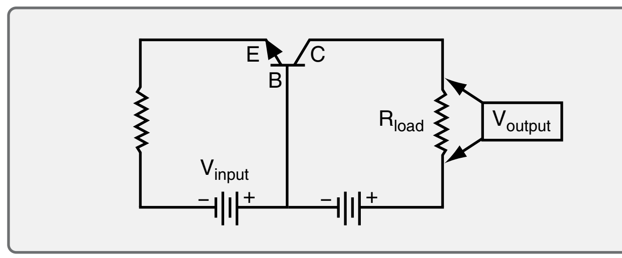


Figure 11-52. *A common-base amplifier circuit for DC current.*

on the circuit output is direct, so the output voltage phase is the same as the input signal but much greater in amplitude.

As with the other amplifier circuits, when amplifying an AC signal with a common-base amplifier circuit, the input signal to the base must include a DC source to forward bias the transistor's base-emitter junction. This allows current to flow from the collector to the emitter during both cycles of the AC. A circuit for AC amplification is illustrated in *Figure 11-53* with a graph of the output voltage showing the large increase produced. The common-base amplifier is limited in its use since it does not increase current flow. This makes it the least used configuration. However, it is used in radio frequency amplification because of the low input Z. *Figure 11-54* summarizes the characteristics of the bipolar amplifier circuits discussed above.

NOTE: There are many variations in circuit design. JFETs and MOSFETS are also used in amplifier circuits, usually in small signal amplifiers due to their low noise outputs.

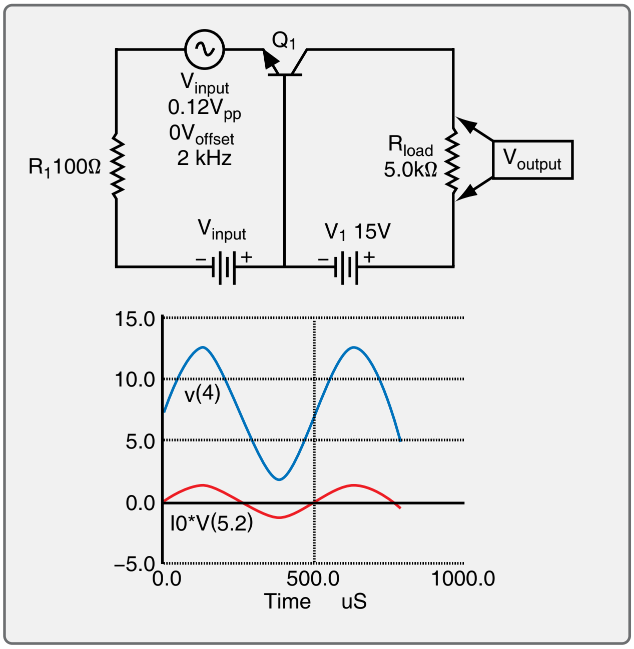


Figure 11-53. *In a common-base amplification circuit for AC (top), output voltage amplitude is greatly increased in phase with the input signal (bottom).*

Oscillator Circuits

Oscillators function to make AC from DC. They can produce various waveforms as required by electronic circuits. There are many different types of oscillators and oscillator circuits. Some of the most common types are discussed below.

A sine wave is produced by generators when a conductor is rotated in a uniform magnetic field. The typical AC sine wave is characterized by a gradual build-up and decline of voltage in one direction, followed by a similar smooth build-up to peak voltage and decline to zero again in the opposite direction. The value of the voltage at any given time in the cycle can be calculated by taking the peak voltage and multiplying it by the sine of the angle through which the conductor has rotated. *[Figure 11-55]*

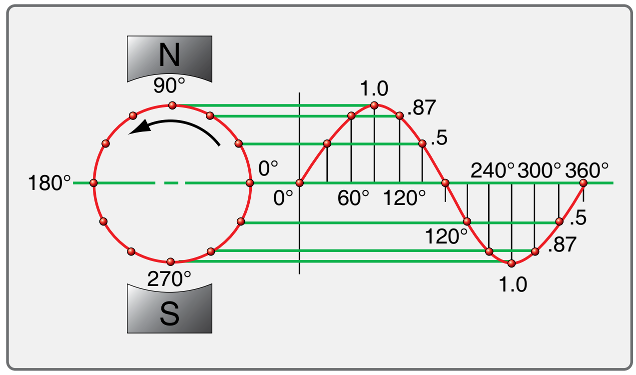


Figure 11-55. *Voltage over time of sine waveform electricity created when a conductor is rotated through a uniform magnetic field, such as in a generator.*

A square wave is produce when there is a flow of electrons for a set period that stops for a set amount of time and then repeats. In DC current, this is simply pulsing DC. *[Figure 11-56]* This same wave form can be of opposite polarities when passed through a transformer to produce AC. Certain oscillators produce square waves.

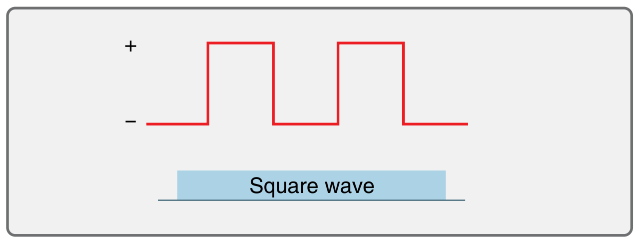


Figure 11-56. *The waveform of pulsing DC is a square wave.*

An oscillator known as a relaxation oscillator produces another kind of wave form, a sawtooth wave. A slow rise from zero to peak voltage is followed by a rapid drop-off of voltage back to almost zero. Then it repeats. *[Figure 11-57]* In the circuit, a capacitor slowly charges through a resistor. A neon bulb is wired across the capacitor. When its ignition voltage is reached, the bulb conducts. This short-circuits the charged capacitor, which causes the voltage to drop to nearly zero and the bulb goes out. Then, the voltage rises again as the cycle repeats.

Type of Amplifier	Impedance	Voltage Gain	Current Gain	Power Gain	Phase
Common-emitter	Input: fairly high Output: fairly high	Relatively large	Relatively large	Large	Inverts phase
Common-collector	Input: high Output: low	Always less than one	Relatively large	Relatively large	Output same as input
Common-base	Input: low Output: high	Large	Always less than one	Relatively large	Output same as input

Figure 11-54. *PN junction transistor amplifier characteristics.*

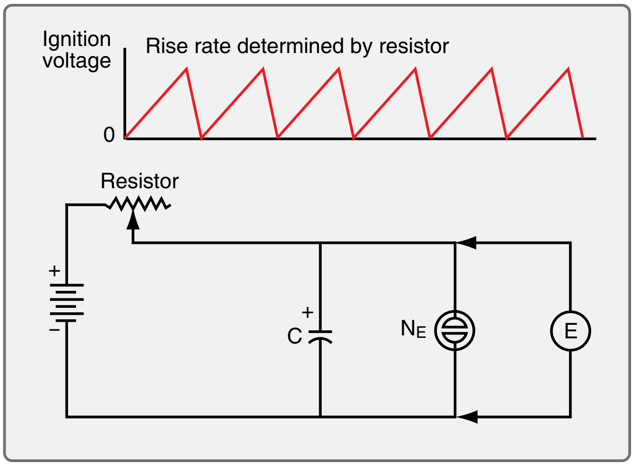


Figure 11-57. *A relaxation oscillator produces a sawtooth wave output.*

Electronic Oscillation

Oscillation in electronic circuits is accomplished by combining a transistor and a tank circuit. A tank circuit is comprised of a capacitor and coil parallel to each other. *[Figure 11-58]* When attached to a power source by closing switch A, the capacitor charges to a voltage equal to the battery voltage. It stays charged, even when the circuit to the battery is open (switch in position B). When the switch is put in position C, the capacitor and coil are in a closed circuit. The capacitor discharges through the coil. While receiving the energy from the capacitor, the coil stores it by building up an electromagnetic field. When the capacitor is fully discharged, the coil stops conducting. The magnetic field collapses, which induces current flow. The current charges the opposite plate of the capacitor. When completely charged, the capacitor discharges into the coil again. The magnetic field builds again and stops when the capacitor is fully discharged. The magnetic field collapses again, which induces current that charges the original plate of the capacitor and the cycle repeats.

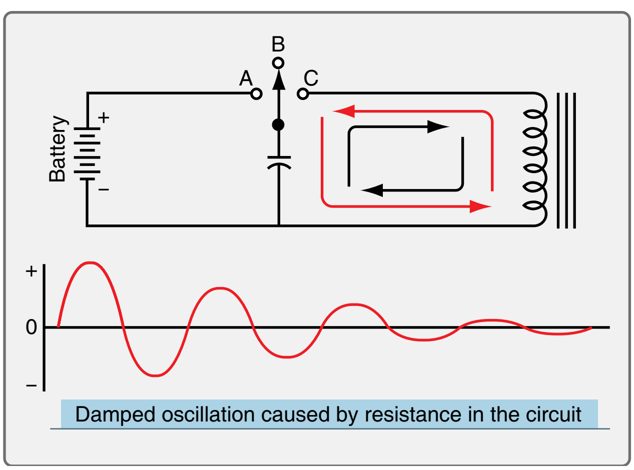


Figure 11-58. *A tank circuit alternately charges opposite plates of a capacitor through a coil in a closed circuit. The oscillation is an alternating current that diminishes due to resistance in the circuit.*

This oscillation of charging and discharging the capacitor through the coil would continue indefinitely if a circuit could be built with no resistance. This is not possible. However, a circuit can be built using a transistor that restores losses due to resistance. There are various ways to accomplish this. The Hartley oscillator circuit in *Figure 11-59* is one. The circuit can oscillate indefinitely as long as it is connected to power.

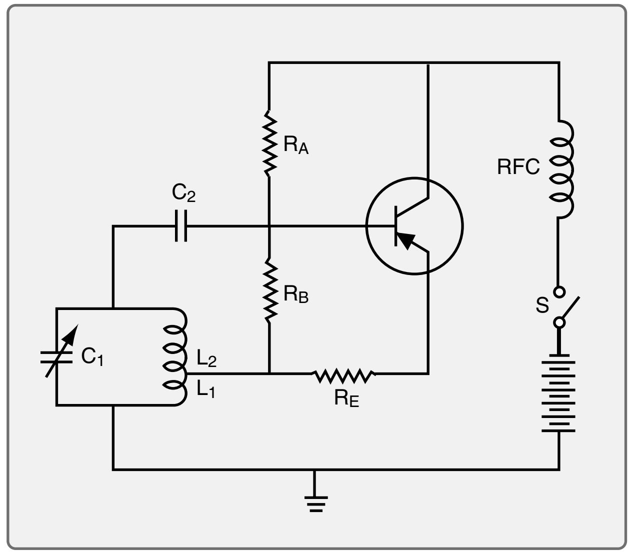


Figure 11-59. *A Hartley oscillator uses a tank circuit and a transistor to maintain oscillation whenever power is applied.*

When the switch is closed, current begins to flow in the oscillator circuit. The transistor base is supplied with biasing current through the voltage divider RA and RB. This allows current to flow through the transistor from the collector to the emitter, through RE and through the lower portion of the center tapped coil that is labeled L1. The current increasing through this coil builds a magnetic field that induces current in the upper half of the coil labeled L2 . The current from L2 charges capacitor C2, which increases the forward bias of the transistor. This allows an increasing flow of current through the transistor, RE, and L1 until the transistor is saturated and capacitor C1 is fully charged. Without force to add electrons to capacitor C1, it discharges and begins the oscillation in the tank circuit described in the previous section. As C1 becomes fully charged, current to charge C2 reduces and C2 also discharges. This adds the energy needed to the tank circuit to compensate for resistance losses. As C2 is discharging, it reduces forward biasing and eventually the transistor becomes reversed biased and cuts off. When the opposite plate of capacitor C1 is fully charged, it discharges and the oscillation is in progress. The transistor base becomes forward biased again, allowing for current flow through the resistor RE, coil L1, etc.

The frequency of the AC oscillating in the Hartley oscillator circuit depends on the inductance and capacitance values of the components used. Use of a crystal in an oscillator circuit can control the frequency more accurately. A crystal vibrates at a single, consistent frequency. When flexed, a small pulse of current is produced through the piezoelectric effect. Placed in the feedback loop, the pulses from the crystal control the frequency of the oscillator circuit. The tank circuit component values are tuned to match the frequency of the crystal. Oscillation is maintained as long as power is supplied. *[Figure 11-60]*

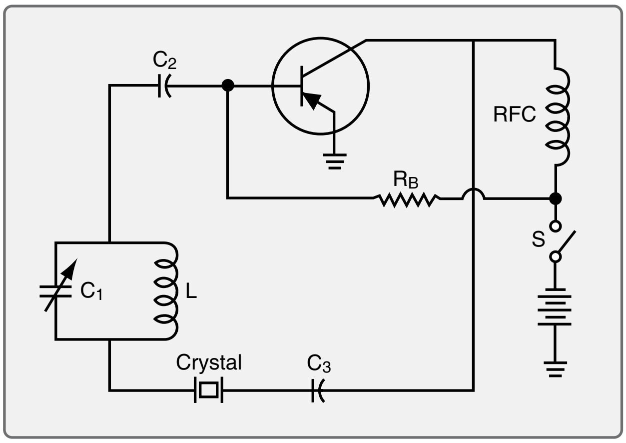


Figure 11-60. *A crystal in an electronic oscillator circuit is used to tune the frequency of oscillation.*

Other types of oscillator circuits used in electronics and computers have two transistors that alternate being in the active mode. They are called multi-vibrators. The choice of oscillator in an electronic device depends on the exact type of manipulation of electricity required to permit the device to function as desired.

Digital Electronics

The above discussion of semiconductors, semiconductor devices, and circuitry is only an introduction to the electronics found in communications and navigation avionics. In-depth maintenance of the interior electronics on most avionics devices is performed only by certified repair stations and trained avionics technicians. The airframe technician is responsible for installation, maintenance, inspection, and proper performance of avionics in the aircraft.

Modern aircraft increasingly employs digital electronics in avionics rather than analog electronics. Transistors are used in digital electronics to construct circuits that act as digital logic gates. The purpose and task of a device is achieved by manipulating electric signals through the logic gates. Thousands, and even millions, of tiny transistors can be placed on a chip to create the digital logic landscape through which a component's signals are processed.

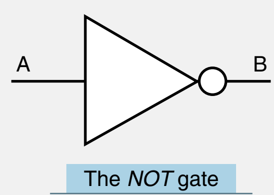
Digital Building Blocks

Digital logic is based on the binary number system. There are two conditions than may exist, 1 or 0. In a digital circuit, these are equivalent to voltage or no voltage. Within the binary system, these two conditions are called Logic 1 and Logic 0. Using just these two conditions, gates can be constructed to manipulate information. There are a handful of common logic gates that are used. By combining any number of these tiny solid-state gates, significant memorization, manipulation, and calculation of information can be performed.

The NOT Gate

The NOT gate is the simplest of all gates. If the input to the gate is Logic 1, then the output is NOT Logic 1. This means that it is Logic 0, since there are only two conditions in the binary world. In an electronic circuit, a NOT gate would invert the input signal. In other words, if there was voltage at the input to the gate, there would be no output voltage. The gate can be constructed with transistors and resistors to yield this electrical logic every time. (The gate or circuit would also have to invert an input of Logic 0 into an output of Logic 1.)

To understand logic gates, truth tables are often used. A truth table gives all of the possibilities in binary terms for each gate containing a characteristic logic function. For example, a truth table for a NOT gate is illustrated in *Figure 11-61*. Any input (A) is NOT present at the output (B). This is simple, but it defines this logic situation. A tiny NOT gate circuit can be built using transistors that produce these results. In other words, a circuit can be built such that if voltage arrives at the gate, no voltage is output or vice-versa.



A	B
1	0
0	1

Figure 11-61. *A NOT logic gate symbol and a NOT gate truth table.*

When using transistors to build logic gates, the primary concern is to operate them within the circuits so the transistors are either OFF (not conducting) or fully ON (saturated). In this manner, reliable logic functions can be performed. The variable voltage and current situations present during the active mode of the transistor are of less importance.

Figure 11-62 illustrates an electronic circuit diagram that performs the logic NOT gate function. Any input, either a no voltage or voltage condition, yields the opposite output. This gate is built with bipolar junction transistors, resistors, and a few diodes. Other designs exist that may have different components.

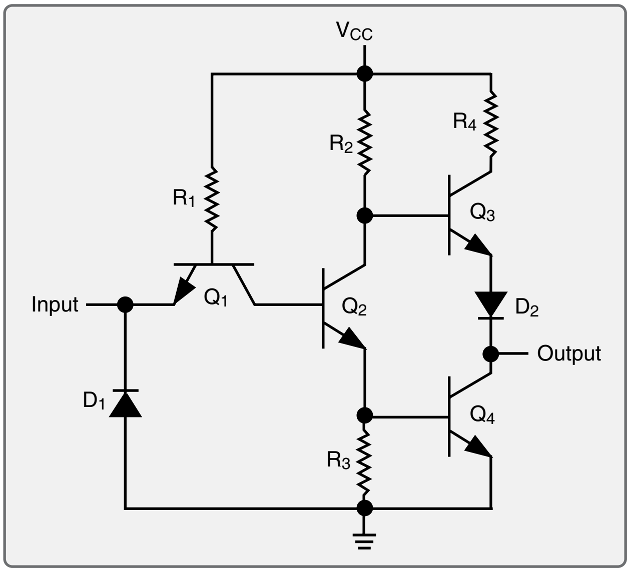


Figure 11-62. *An electronic circuit that reliably performs the NOT logic function.*

When examining and discussing digital electronic circuits, the electronic circuit design of a gate is usually not presented. The symbol for the logic gate is most often used. *[Figure 11-61]* The technician can then concentrate on the configuration of the logic gates in relation to each other. A brief discussion of the other logic gates, their symbols, and truth tables follow.

Buffer Gate

Another logic gate with only one input and one output is the buffer. It is a gate with the same output as the input. While this may seem redundant or useless, an amplifier may be considered a buffer in a digital circuit because if there is voltage present at the input, there is an output voltage. If there is no voltage at the input, there is no output voltage. When used as an amplifier, the buffer can change the values of a signal. This is often done to stabilize a weak or varying signal. All gates are amplifiers subject to output fluctuations. The buffer steadies the output of the upstream device while maintaining its basic characteristic. Another application of a buffer that is two NOT gates, is to use it to isolate a portion of a circuit. *[Figure 11-63]*

AND Gate

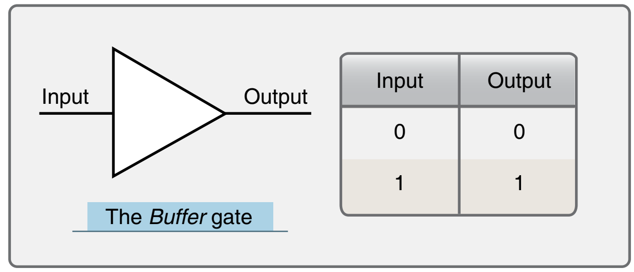


Figure 11-63. *A buffer or amplifier symbol and the truth table of the buffer, which is actually two consecutive NOT gates.*

Most common logic gates have two inputs. Three or more inputs are possible on some gates. When considering the characteristics of any logic gate, an output of Logic 1 is sought and a condition for the inputs is stated or examined. For example, *Figure 11-64* illustrates an AND gate. For an AND gate to have a Logic 1 output, both inputs have to be Logic 1. In an actual electronic circuit, this means that for a voltage to be present at the output, the AND gate circuit has to receive voltage at both of its inputs. As pointed out, there are different arrangements of electronic components that yield this result. Whichever is used is summarized and presented as the AND gate symbol. The truth table in *Figure 11-64* illustrates that there is only one way to have an output of Logic 1 or voltage when using an AND gate.

OR Gate

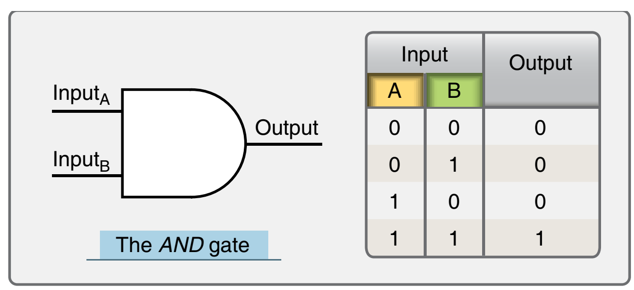
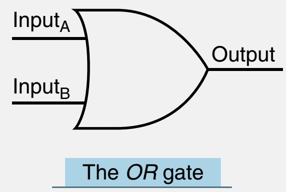


Figure 11-64. *An AND gate symbol and its truth table.*

Another useful and common logic gate is the OR gate. In an OR gate, to have an output of Logic 1 (voltage present), one of the inputs must be Logic 1. As seen in *Figure 11-65,* only one of the inputs needs to be Logic 1 for there to be an output of Logic 1. When both inputs are Logic 1, the OR gate has a Logic 1 output because it still meets the condition of one of the inputs being Logic 1.



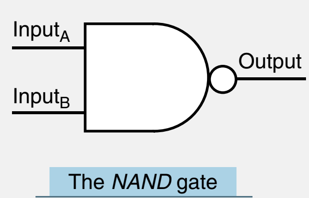
Input A	Input B	Output
0	0	0
0	1	1
1	0	1
1	1	1

Figure 11-65. *An OR gate symbol and its truth table.*

NAND Gate

The AND, OR, and NOT gates are the basic logic gates. A few other logic gates are also useful. They can be derived from combining the AND, OR, and NOT gates. The NAND gate is a combination of an AND gate and a NOT gate. This means that AND gate conditions must be met and then inverted. So, the NAND gate is an AND gate followed by a NOT gate. The truth table for a NAND gate is shown in *Figure 11-66* along with its symbol. If a Logic 1 output is to exist from a NAND gate, inputs A and B must not both be Logic 1. Or, if a NAND gate has both inputs Logic 1, the output is Logic 0. Stated in electronic terms, if there is to be an output voltage, then the inputs cannot both have voltage or, if both inputs have voltage, there is no output voltage.

NOTE: The values in the output column of the NAND gate table are exactly the opposite of the output values in the AND gate truth table.

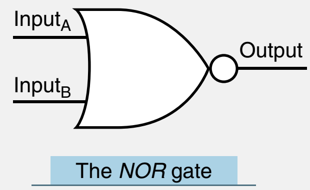


Input A	Input B	Output
0	0	1
0	1	1
1	0	1
1	1	0

Figure 11-66. *A NAND gate symbol and its truth table illustrating that the NAND gate is an inverted AND gate.*

NOR Gate

A NOR gate is similarly arranged except that it is an inverted OR gate. If there is to be a Logic 1 output, or output voltage, then neither input can be Logic 1 or have input voltage. This is the same as satisfying the OR gate conditions and then putting output through a NOT gate. The NOR gate truth table in *Figure 11-67* shows that the NOR gate output values are exactly the opposite of the OR gate output values.



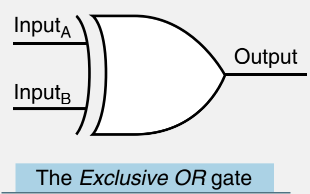
Input A	Input B	Output
0	0	1
0	1	0
1	0	0
1	1	0

Figure 11-67. *A NOR gate symbol and its truth table illustrating that the NOR gate is an inverted OR gate.*

The NAND gate and the NOR gate have a unique distinction. Each one can be the only gate used in circuitry to produce the same output as any of the other logic gates. While it may be inefficient, it is testimonial to the flexibility that designers have when working with logic gates, the NAND and NOR gates in particular.

EXCLUSIVE OR Gate

Another common logic gate is the EXCLUSIVE OR gate. It is the same as an OR gate except for the condition where both inputs are Logic 1. In an OR gate, there would be Logic 1 output when both inputs are Logic 1. This is not allowed in an EXCLUSIVE OR gate. When either of the inputs is Logic 1, the output is Logic 1. But, if both inputs are logic 1, the Logic 1 output is excluded or Logic 0. *[Figure 11-68]*



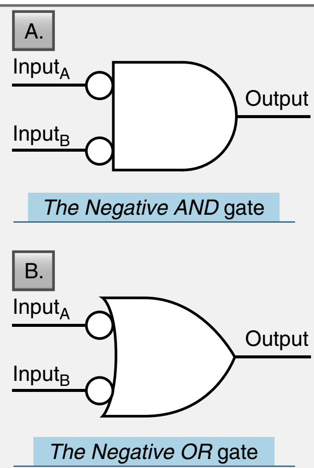
Input A	Input B	Output
0	0	0
0	1	1
1	0	1
1	1	0

Figure 11-68. *An EXCLUSIVE OR gate symbol and its truth table, which is similar to an OR gate but excludes output when both inputs are the same.*

Negative Logic Gates

There are also negative logic gates. The negative OR and the negative AND gates are gates wherein the inputs are inverted rather than inverting the output. This creates a unique set of outputs as seen in the truth tables in *Figure 11-69.* The negative OR gate is not the same as the NOR gate as is sometimes misunderstood. Neither is the negative AND gate the same as the NAND gate. However, as the truth tables reveal, the output of a negative AND gate is the same as a NOR gate, and the output of a negative OR gate is the same as a NAND gate.

In summary, electronic circuits use transistors to construct logic gates that produce outputs related to the inputs shown in the truth tables for each kind of gate. The gates are then



A.

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

B.

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

Figure 11-69. *The NEGATIVE AND gate symbol and its truth table (A) and the NEGATIVE OR gate symbol and truth table (B). The inputs are inverted in the NEGATIVE gates.*

assembled with other components to manipulate data in digital circuits. The electronic digital signals used are voltage or no voltage representations of Logic 1 or Logic 0 conditions. By using a series of voltage output or no voltage output gates, manipulation, computation, and storage of data takes place.

Digital Aircraft Systems

Digital aircraft systems are the present and future of aviation. From communication and navigation to engine and flight controls, increased proliferation of digital technology increases reliability and performance. Processing, storing, and transferring vital information for the operation of an aircraft in digital form provides a usable common language for monitoring, control, and safety. Integration of information from different systems is simplified. Self monitoring, built-in test equipment (BITE) and air-to-ground data links increase maintenance efficiency. Digital buss networking allows aircraft system computers to interact for a coordinated comprehensive approach to flight operations.

Digital Data Displays

Modern digital data displays are the most visible features of digital aircraft systems. They extend the functional advantages of state of the art digital communication and navigation avionics and other digital aircraft systems via the use of an enhanced interface with the pilot. The result is an increase in situational awareness and overall safety of flight. Digital data displays are the glass of the glass cockpit. They expand the amount, clarity, and proximity of the information presented to the pilot. *[Figure 11-70]*

Many digital data displays are available from numerous manufacturers as original equipment in new aircraft, or as retrofit components or complete retrofit systems for older aircraft. Approval for retrofit displays is usually accomplished through supplementary type certificate (STC) awarded to the equipment manufacturer.

Early digital displays presented scale indication in digital or integer format readouts. Today's digital data displays are analogous to computer screen presentations. Numerous aircraft and flight instrument readouts and symbolic presentations are combined with communication and navigational information on multifunctional displays (MFD). Often a display has a main function with potential to back-up another display should it fail. Names, such as primary flight display (PFD), secondary flight display, navigational display (ND), etc., are often used to describe a display by its primary use. The hardware composition of the displays is essentially the same. Avionics components and computers combine to provide the different information portrayed on the displays.

Figure 11-70. *A modern glass cockpit on a general aviation aircraft. Digital data displays replace many older instruments and indicators of the past.*

Controls on the instrument panel or on the display unit itself are used for selection. Some screens have limited display capability because they are not part of a totally integrated system; however, they are extremely power electronic units with wide capability. *[Figure 11-71]*

Figure 11-72. *A digital data display dedicated to the depiction of engine and airframe system parameter status.*

The basis of the information displayed on what is known as a primary flight display (PFD), is usually an electronic flight instrument system (EFIS) like representation of the aircraft attitude indicator in the upper half of the display, and an electronic horizontal situation indicator display on the lower half. Numerous ancillary readouts are integrated or surround the electronic attitude indicator and the horizontal situation indicator (HSI). On full glass cockpit PFDs, all of the basic T instrument indications are presented and much more, such as communication and navigation information, weather data, terrain features, and approach information. Data displays for engine parameters, hydraulics, fuel, and other airframe systems are often displayed on the secondary flight display or on an independent display made for this purpose. *[Figure 11-72]*

As with other avionics components, repair and maintenance of the internal components of digital data displays is reserved for licensed repair stations only.

Digital Tuners and Audio Panels

Numerous communication and navigation devices are described in the following sections of this chapter. Many of these use radio waves and must be tuned to a desired frequency for operation. As a flight progresses, retuning and changing from one piece of equipment to another can occur frequently. An audio panel or digital tuner consolidates various communication and navigation radio selection controls into a single unit. The pilot can select and use, or select and tune, most of the aircraft's avionics from this one control interface. *[Figure 11-73]*

Radio Communication

Much of aviation communication and navigation is accomplished through the use of radio waves. Communication by radio was the first use of radio frequency transmissions in aviation.

Figure 11-71. *A retrofit digital data display.*

Figure 11-73. *An audio panel in a general aviation aircraft integrates the selection of several radio-based communication and navigational aids into a single control panel (left). A digital tuner (right, Image © Rockwell Collins, Inc.) does the same on a business class aircraft and allows the frequency of each device to be tuned from the same panel as well.*

Radio Waves

A radio wave is invisible to the human eye. It is electromagnetic in nature and part of the electronic spectrum of wave activity that includes gamma rays, x-rays, ultraviolet rays, infrared waves, and visible light rays, as well all radio waves. *[Figure 11-74]* The atmosphere is filled with these waves. Each wave occurs at a specific frequency and has a corresponding wavelength. The relationship between frequency and wavelength is inversely proportional. A high frequency wave has a short wave length and a low frequency wave has a long wave length.

In aviation, a variety of radio waves are used for communication. *Figure 11-75* illustrates the radio spectrum that includes the range of common aviation radio frequencies and their applications.

NOTE: A wide range of frequencies are used from low frequency (LF) at 100 kHz (100,000 cycles per second) to super high frequency (SHF) at nearly 10gHz (10,000,000,000 cycles per second). The Federal Communications Commission (FCC) controls the assignment of frequency usage.

AC power of a particular frequency has a characteristic length of conductor that is resonant at that frequency. This length is the wavelength of the frequency that can be seen on an oscilloscope. Fractions of the wavelength also resonate, especially half of a wavelength, which is the same as half of the AC sign wave or cycle.

The frequency of an AC signal is the number of times the AC cycles every second. AC applied to the center of a radio antenna, a conductor half the wavelength of the AC frequency, travels the length of the antenna, collapses, and travels the length of the antenna in the opposite direction. The number of times it does this every second is known as the radio wave signal frequency or radio frequency as shown in *Figure 11-75*. As the current flows through the antenna, corresponding electromagnetic and electric fields build, collapse, build in the opposite direction, and collapse again. *[Figure 11-76]*

To transmit radio waves, an AC generator is placed at the midpoint of an antenna. As AC current builds and collapses in the antenna, a magnetic field also builds and collapses around it. An electric field also builds and subsides as the voltage shifts from one end of the antenna to the other. Both fields, the magnetic and the electric, fluctuate around the antenna at the same time. The antenna is half the wavelength of the AC signal received from the generator. At any one point along the antenna, voltage and current vary inversely to each other.

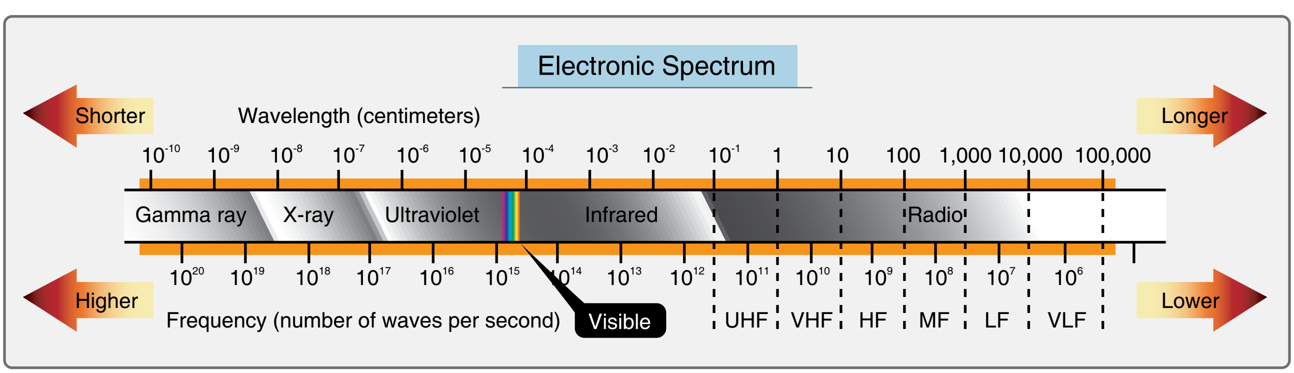


Figure 11-74. *Radio waves are just some of the electromagnetic waves found in space.*

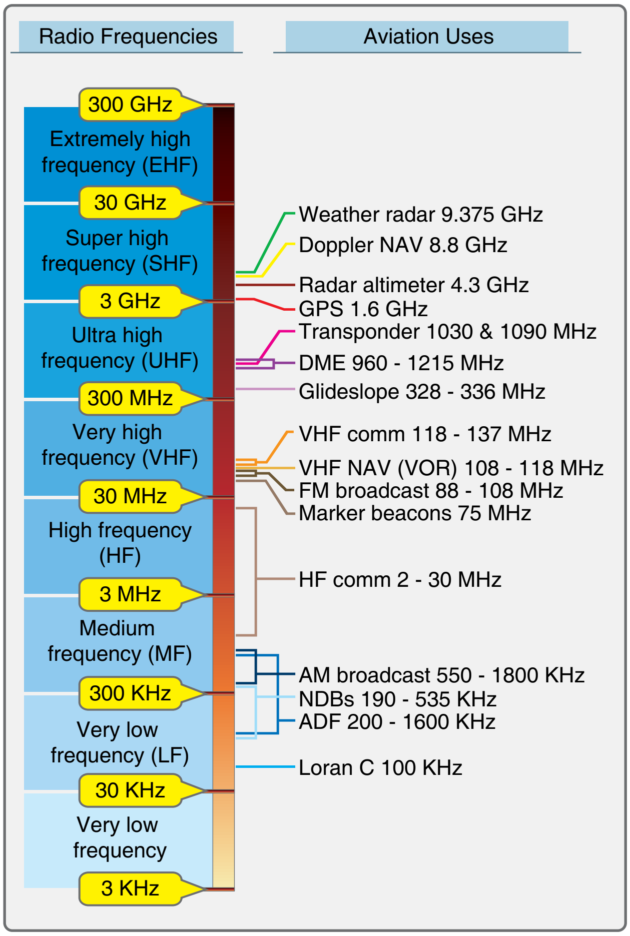


Figure 11-75. *There is a wide range of radio frequencies. Only the very low frequencies and the extremely high frequencies are not used in aviation.*

Because of the speed of the AC, the electromagnetic fields and electric fields created around the antenna do not have time to completely collapse as the AC cycles. Each new current flow creates new fields around the antenna that force the not-totally-collapsed fields from the previous AC cycle out into space. These are the radio waves. The process is continuous as long as AC is applied to the antenna. Thus, steady radio waves of a frequency determined by the input AC frequency propagate out into space.

Radio waves are directional and propagate out into space at 186,000 miles per second. The distance they travel depends on the frequency and the amplification of the signal AC sent to the antenna. The electric field component and the electromagnetic field component are oriented at 90° to each other, and at 90° to the direction that the wave is traveling. [*Figure 11-77*]

Types of Radio Waves

Radio waves of different frequencies have unique characteristics as they propagate through the atmosphere. Very low frequency (VLF), LF, and medium frequency (MF) waves have relatively long wavelengths and utilize correspondingly long antennas. Radio waves produced at these frequencies ranging from 3kHz to 3mHz are known as ground waves or surface waves. This is because they follow the curvature of the earth as they travel from the broadcast antenna to the receiving antenna. Ground waves are particularly useful for long distance transmissions. Automatic direction finders (ADF) and LORAN navigational aids use these frequencies. *[Figure 11-78]*

High frequency (HF) radio waves travel in a straight line and do not curve to follow the earth's surface. This would limit transmissions from the broadcast antenna to receiving antennas only in the line-of-sight of the broadcast antenna except for a unique characteristic. HF radio waves bounce off of the ionosphere layer of the atmosphere. This refraction extends the range of HF signals beyond line-of-sight. As a result, transoceanic aircraft often use HF radios for voice communication. The frequency range is between 2 to 25 MHz. These kinds of radio waves are known as sky waves. *[Figure 11-78]*

Above HF transmissions, radio waves are known as space waves. They are only capable of line-of-sight transmission and do not refract off of the ionosphere. *[Figure 11-78]* Most aviation communication and navigational aids operate with space waves. This includes VHF (30-300MHz), UHF (300MHz-3GHz), and super high frequency (SHF) (3Ghz-30Ghz) radio waves.

VHF communication radios are the primary communication radios used in aviation. They operate in the frequency range from 118.0 MHz to 136.975MHz. Seven hundred and twenty separate and distinct channels have been designated in this range with 25 kilohertz spacing between each channel. Further division of the bandwidth is possible, such as in Europe where 8.33 kilohertz separate each VHF communication channel. VHF radios are used for communications between aircraft and air traffic control (ATC), as well as air-to-air communication between aircraft. When using VHF, each party transmits and receives on the same channel. Only one party can transmit at any one time.

Loading Information onto a Radio Wave

The production and broadcast of radio waves does not convey any significant information. The basic radio wave discussed above is known as a carrier wave. To transmit and receive useful information, this wave is altered or modulated by an information signal. The information signal contains the unique voice or data information desired to be conveyed. The modulated carrier wave then carries the information from the transmitting radio to the receiving radio via their respective

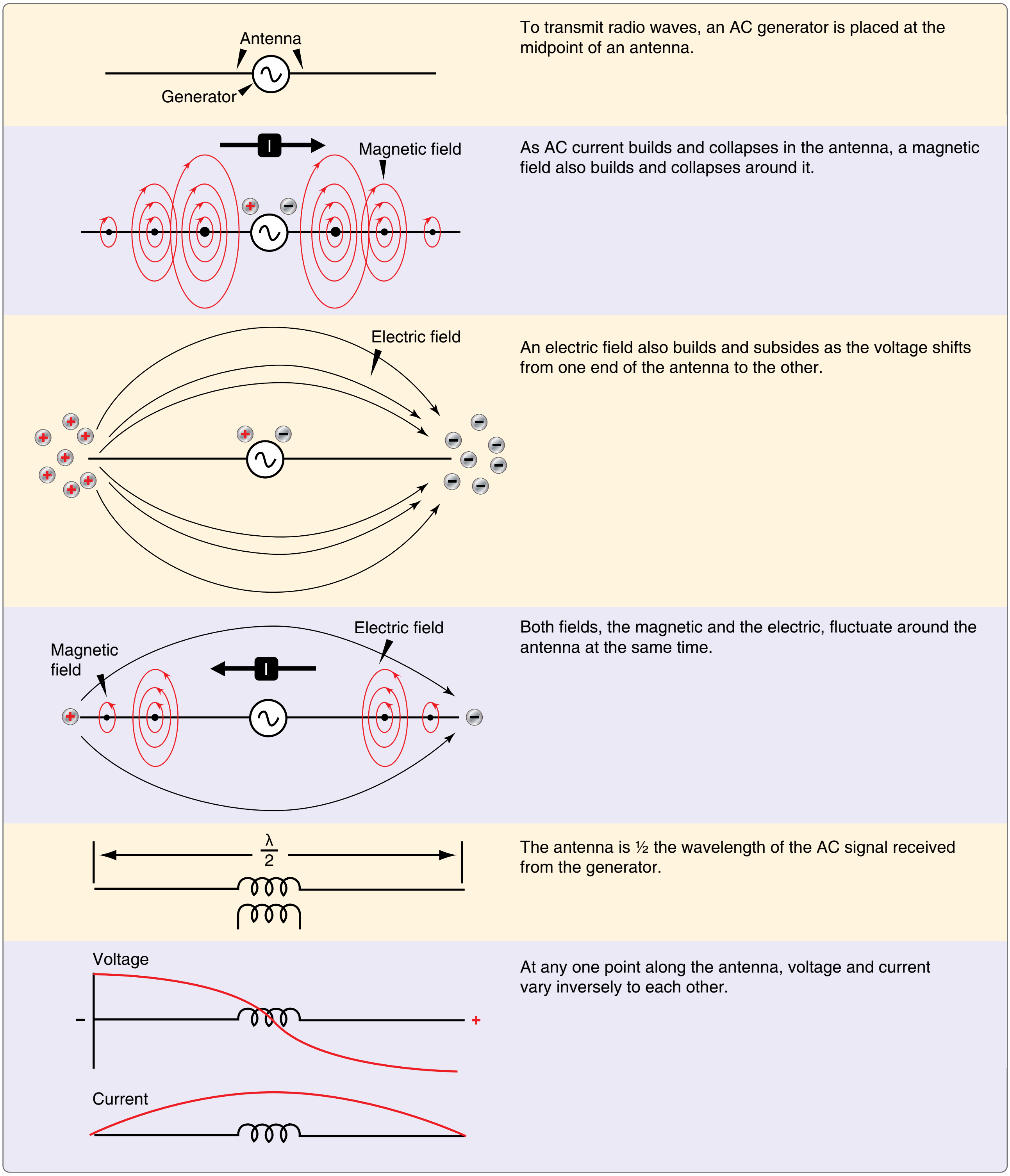


Figure 11-76. *Radio waves are produced by applying an AC signal to an antenna. This creates a magnetic and electric field around the antenna. They build and collapse as the AC cycles. The speed at which the AC cycles does not allow the fields to completely collapse before the next fields build. The collapsing fields are then forced out into space as radio waves.*

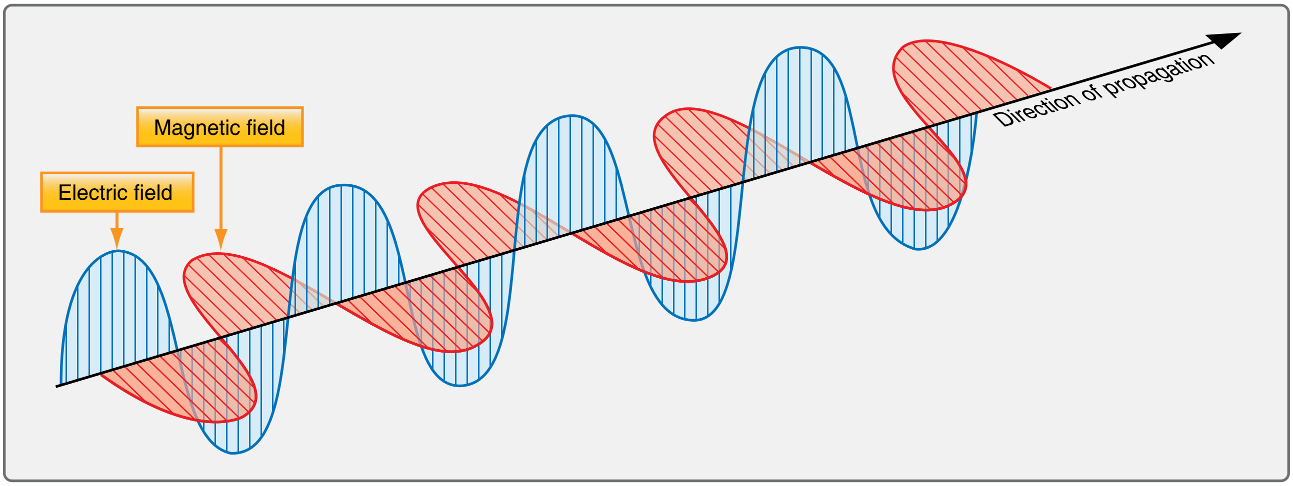


Figure 11-77. *The electric field and the magnetic field of a radio wave are perpendicular to each other and to the direction of propagation of the wave.*

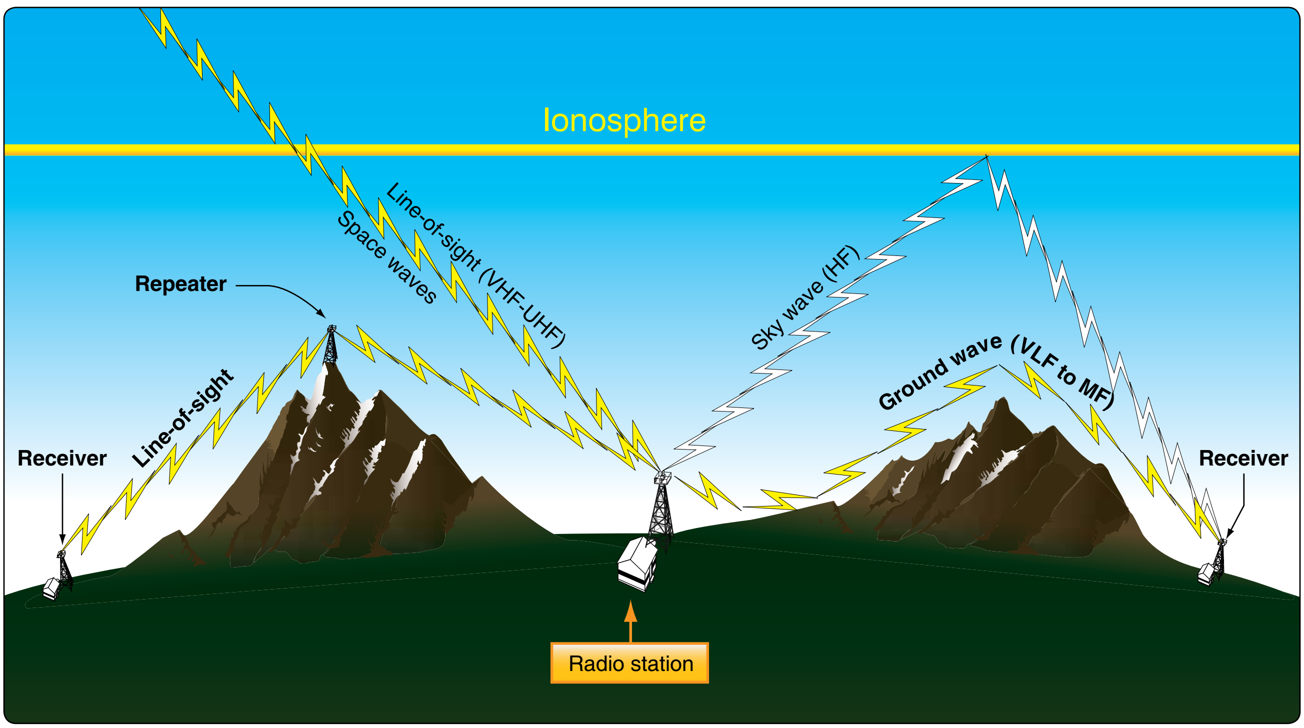


Figure 11-78. *Radio waves behave differently in the atmosphere depending in their frequency.*

antennas. Two common methods of modulating carrier waves are amplitude modulation and frequency modulation.

Amplitude Modulation (AM)

A radio wave can be altered to carry useful information by modulating the amplitude of the wave. A DC signal, for example from a microphone, is amplified and then superimposed over the AC carrier wave signal. As the varying DC information signal is amplified, the amplifier output current varies proportionally. The oscillator that creates the carrier wave does so with this varying current. The oscillator frequency output is consistent because it is built into the oscillator circuit. But the amplitude of the oscillator output varies in relation to the fluctuating current input. *[Figure 11-79]*

When the modulated carrier wave strikes the receiving antenna, voltage is generated that is the same as that which was applied to the transmitter antenna. However, the signal is weaker. It is amplified so that it can be demodulated. Demodulation is the process of removing the original information signal from the carrier wave. Electronic circuits containing capacitors, inductors, diodes, filters, etc., remove

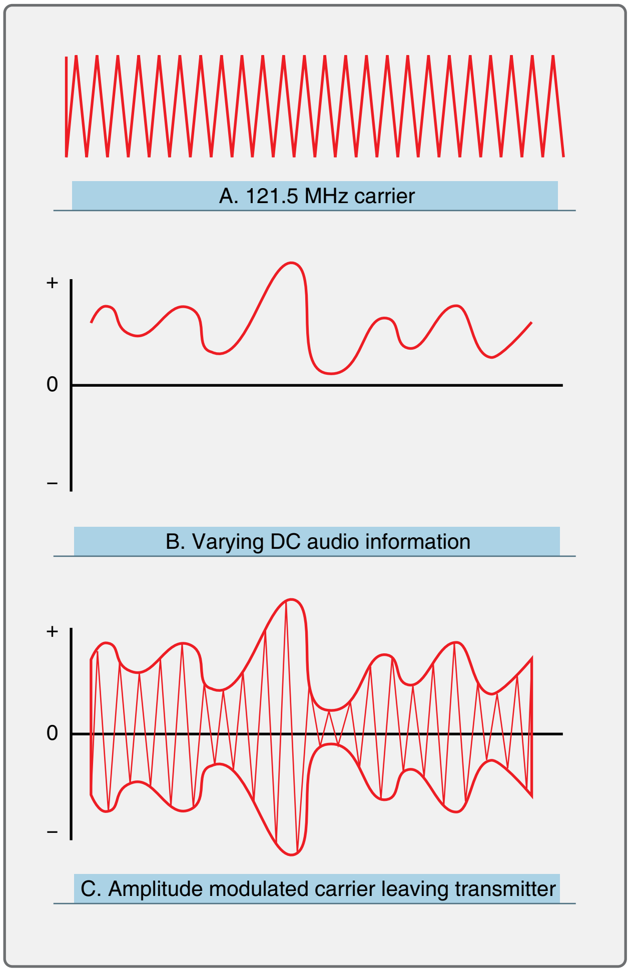


Figure 11-79. *A DC audio signal modifies the 121.5 MHz carrier wave as shown in C. The amplitude of the carrier wave (A) is changed in relation to modifier (B). This is known as amplitude modulation (AM).*

all but the desired information signal identical to the original input signal. Then, the information signal is typically amplified again to drive speakers or other output devices. *[Figure 11-80]*

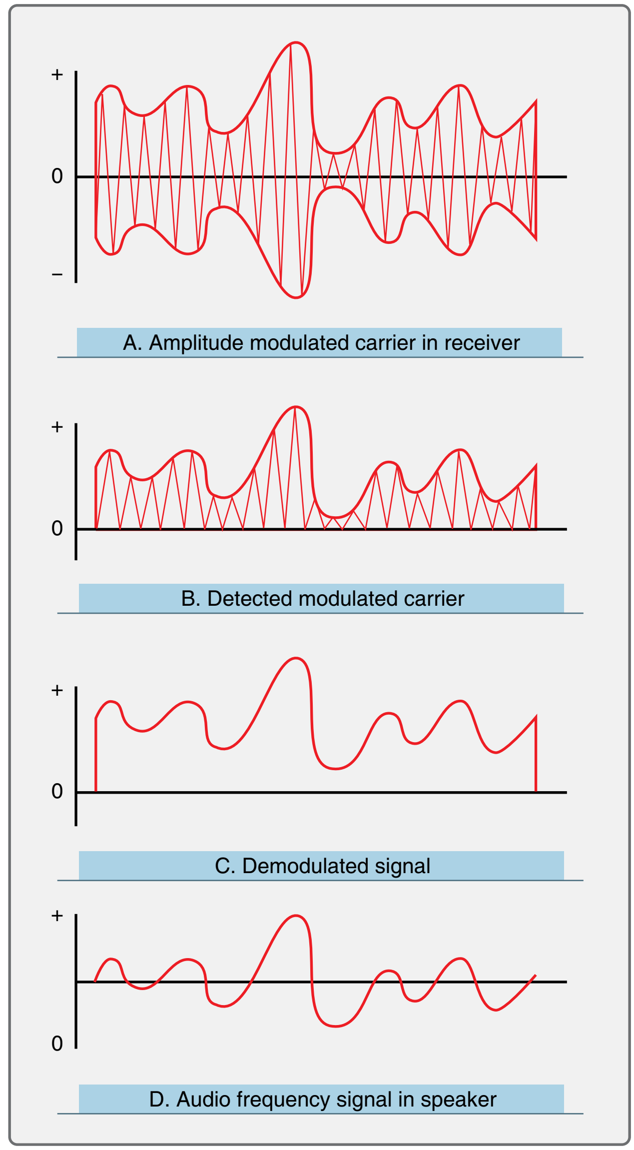


Figure 11-80. *Demodulation of a received radio signal involves separating the carrier wave from the information signal.*

AM has limited fidelity. Atmospheric noises or static alter the amplitude of a carrier wave making it difficult to separate the intended amplitude modulation caused by the information signal and that which is caused by static. It is used in aircraft VHF communication radios.

Frequency Modulation (FM)

Frequency modulation (FM) is widely considered superior to AM for carrying and deciphering information on radio waves. A carrier wave modulated by FM retains its constant amplitude. However, the information signal alters the frequency of the carrier wave in proportion to the strength of the signal. Thus, the signal is represented as slight variations to the normally consistent timing of the oscillations of the carrier wave. *[Figure 11-81]*

Since the transmitter oscillator output fluctuates during modulation to represent the information signal, FM bandwidth is greater than AM bandwidth. This is overshadowed by the ease with which noise and static can be removed from the FM signal. FM has a steady current flow and requires less power to produce since modulating an oscillator producing a carrier wave takes less power than modulating the amplitude of a signal using an amplifier.

Demodulation of an FM signal is similar to that of an AM receiver. The signal captured by the receiving antenna is usually amplified immediately since signal strength is lost as

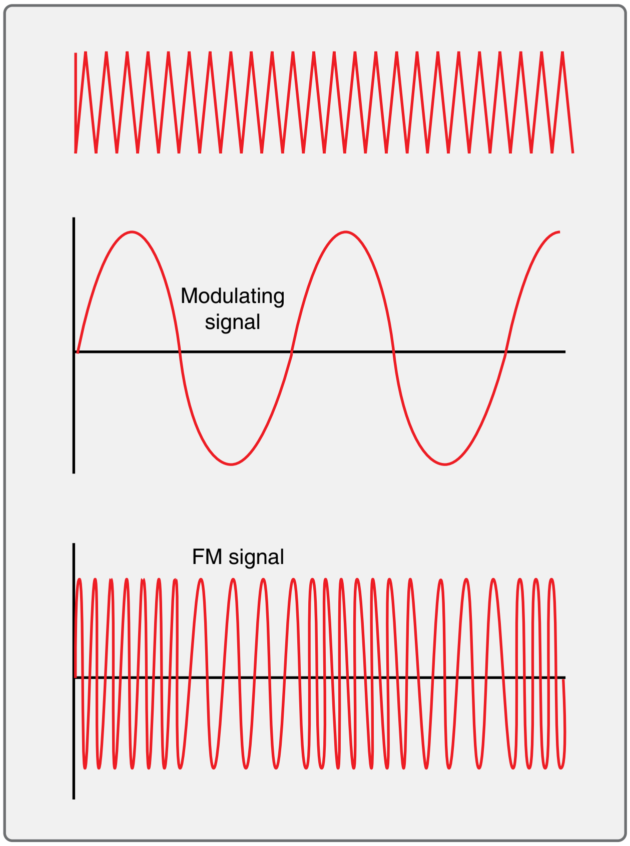


Figure 11-81. *A frequency modulated (FM) carrier wave retains the consistent amplitude of the AC sign wave. It encodes the unique information signal with slight variations to the frequency of the carrier wave. These variations are shown as space variations between the peaks and valleys of the wave on an oscilloscope.*

the wave travels through the atmosphere. Numerous circuits are used to isolate, stabilize, and remove the information from the carrier wave. The result is then amplified to drive the output device.

Single Side Band (SSB)

When two AC signals are mixed together, such as when a carrier wave is modulated by an information signal, three main frequencies result:

1. Original carrier wave frequency;
2. Carrier wave frequency plus the modulating frequency; and
3. Carrier wave frequency minus the modulating frequency.

Due to the fluctuating nature of the information signal, the modulating frequency varies from the carrier wave up or down to the maximum amplitude of the modulating frequency during AM. These additional frequencies on either side of the carrier wave frequency are known as side bands. Each side band contains the unique information signal desired to be conveyed. The entire range of the lower and upper sidebands including the center carrier wave frequency is known as bandwidth. *[Figure 11-82]*

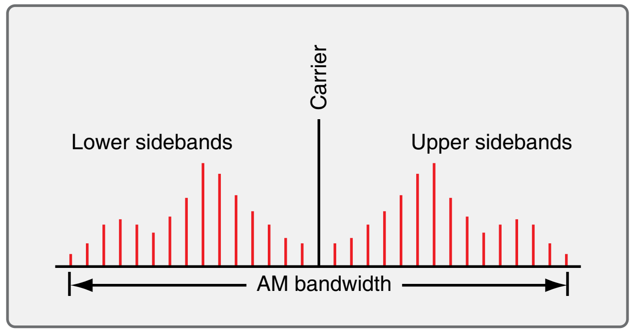


Figure 11-82. *The bandwidth of an AM signal contains the carrier wave, the carrier wave plus the information signal frequencies, and the carrier wave minus the information signal frequencies.*

There are a limited number of frequencies within the usable frequency ranges (i.e., LF, HF, and VHF). If different broadcasts are made on frequencies that are too close together, some of the broadcast from one frequency interfere with the adjacent broadcast due to overlapping side bands. The FCC divides the various frequency bands and issues rules for their use. Much of this allocation is to prevent interference. The spacing between broadcast frequencies is established so that a carrier wave can expand to include the upper and lower side bands and still not interfere with a signal on an adjacent frequency.

As use of the radio frequencies increases, more efficient allocation of bandwidth is imperative. Sending information via radio waves using the narrowest bandwidth possible is the focus of engineering moving forward. At the same time, fully representing all of the desired information or increasing the amount of information conveyed is also desired. Various methods are employed to keep bandwidth to a minimum, many of which restrict the quality or quantity of information able to be transmitted.

In lower frequency ranges, such as those used for ground wave and some sky wave broadcasts, SSB transmissions are a narrow bandwidth solution. Each side band represents the initial information signal in its entirety. Therefore in an SSB broadcast, the carrier wave and either the upper or lower sidebands are filtered out. Only one sideband with its frequencies is broadcast since it contains all of the needed information. This cuts the bandwidth required in half and allows more efficient use of the radio spectrum. SSB transmissions also use less power to transmit the same amount of information over an equal distance. Many HF long-distance aviation communications are SSB. *[Figure 11-83]*

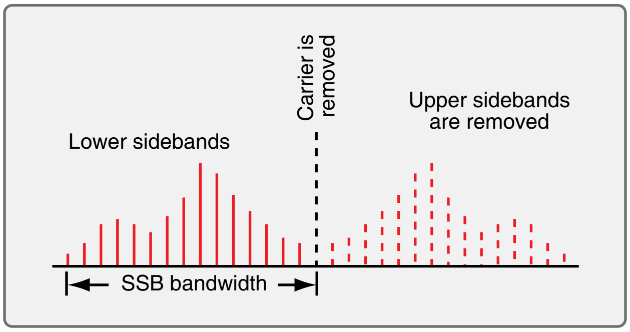


Figure 11-83. *The additional frequencies above and below the carrier wave produced during modulation with the information signal are known as sidebands. Each sideband contains the unique information of the information signal and can be transmitted independent of the carrier wave and the other sideband.*

Radio Transmitters and Receivers

Radio transmitters and receivers are electronic devices that manipulate electricity resulting in the transmission of useful information through the atmosphere or space.

Transmitters

A transmitter consists of a precise oscillating circuit or oscillator that creates an AC carrier wave frequency. This is combined with amplification circuits or amplifiers. The distance a carrier wave travels is directly related to the amplification of the signal sent to the antenna.

Other circuits are used in a transmitter to accept the input information signal and process it for loading onto the carrier wave. Modulator circuits modify the carrier wave with the processed information signal. Essentially, this is all there is to a radio transmitter.

NOTE: Modern transmitters are highly refined devices with extremely precise frequency oscillation and modulation. The circuitry for controlling, filtering, amplifying, modulating, and oscillating electronic signals can be complex.

A transmitter prepares and sends signals to an antenna that, in the process described above, radiates the waves out into the atmosphere. A transmitter with multiple channel (frequency) capability contains tuning circuitry that enables the user to select the frequency upon which to broadcast. This adjusts the oscillator output to the precise frequency desired. It is the oscillator frequency that is being tuned. *[Figure 11-84]* As shown in *Figure 11-84*, most radio transmitters generate a stable oscillating frequency and then use a frequency multiplier to raise the AC to the transmitting frequency. This allows oscillation to occur at frequencies that are controllable and within the physical working limits of the crystal in crystal-controlled oscillators.

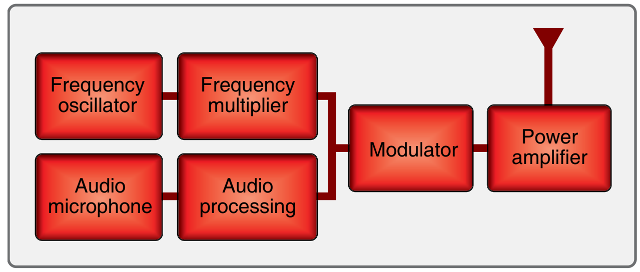


Figure 11-84. *Block diagram of a basic radio transmitter.*

Receivers

Antennas are simply conductors of lengths proportional to the wavelength of the oscillated frequency put out by the transmitter. An antenna captures the desired carrier wave as well as many other radio waves that are present in the atmosphere. A receiver is needed to isolate the desired carrier wave with its information. The receiver also has circuitry to separate the information signal from the carrier wave. It prepares it for output to a device, such as speakers or a display screen. The output is the information signal originally introduced into the transmitter.

A common receiver is the super heterodyne receiver. As with any receiver, it must amplify the desired radio frequency captured by the antenna since it is weak from traveling through the atmosphere. An oscillator in the receiver is used to compare and select the desired frequency out of all of the frequencies picked up by the antenna. The undesired frequencies are sent to ground.

A local oscillator in the receiver produces a frequency that is different than the radio frequency of the carrier wave. These two frequencies are mixed in the mixer. Four frequencies result from this mixing. They are the radio frequency, the local oscillator frequency, and the sum and difference of these two frequencies. The sum and difference frequencies contain the information signal.

The frequency that is the difference between the local oscillator frequency and the radio frequency carrier wave frequency is used during the remaining processing. In VHF aircraft communication radios, this frequency is 10.8 MHz. Called the intermediate frequency, it is amplified before it is sent to the detector. The detector, or demodulator, is where the information signal is separated from the carrier wave portion of the signal. In AM, since both sidebands contain the useful information, the signal is rectified leaving just one sideband with a weak version of the original transmitter input signal. In FM receivers, the varying frequency is changed to a varying amplitude signal at this point. Finally, amplification occurs for the output device. *[Figure 11-85]*

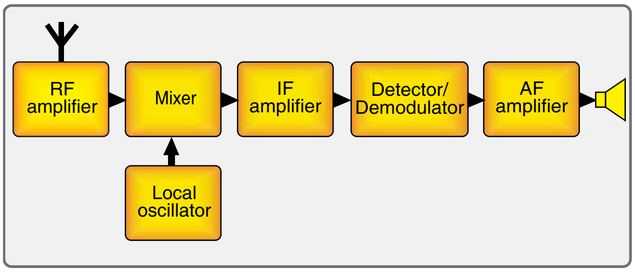


Figure 11-85. *The basic stages used in a receiver to produce an output from a radio wave.*

Over the years, with the development of transistors, microtransistors, and integrated circuits, radio transmitters and receivers have become smaller. Electronic bays were established on older aircraft as remote locations to mount radio devices simply because they would not fit in the flight deck. Today, many avionics devices are small enough to be mounted in the instrument panel, which is customary on most light aircraft. Because of the number of communication and navigation aids, as well as the need to present an uncluttered interface to the pilot, most complicated aircraft retain an area away from the flight deck for the mounting of avionics. The control heads of these units remain on the flight deck.

Transceivers

A transceiver is a communication radio that transmits and receives. The same frequency is used for both. When transmitting, the receiver does not function. The push to talk (PTT) switch blocks the receiving circuitry and allows the transmitter circuitry to be active. In a transceiver, some of the circuitry is shared by the transmitting and receiving functions of the device. So is the antenna. This saves space and the number of components used. Transceivers are half duplex systems where communication can occur in both directions but only one party can speak while the other must listen. VHF aircraft communication radios are usually transceivers. *[Figure 11-86]*

Antennas

As stated, antennas are conductors that are used to transmit and receive radio frequency waves. Although the airframe technician has limited duties in relation to maintaining and repairing avionics, it is the responsibility of the technician to install, inspect, repair, and maintain aircraft radio antennas.

Three characteristics are of major concern when considering antennas:

1. Length
2. Polarization
3. Directivity

The exact shape and material from which an antenna is made can alter its transmitting and receiving characteristics. Also note that some non-metallic aircraft have antennas imbedded into the composite material as it is built up.

Length

When an AC signal is applied to an antenna, it has a certain frequency. There is a corresponding wavelength for that frequency. An antenna that is half the length of this wavelength is resonant. During each phase of the applied AC, all voltage and current values experience the full range of their variability. As a result, an antenna that is half the wavelength of the corresponding AC frequency is able to allow full voltage and full current flow for the positive phase of the AC signal in one direction. The negative phase of the full AC sign wave is accommodated by the voltage and current simply changing direction in the conductor. Thus, the applied AC frequency flows through its entire wavelength, first in one direction and then in the other. This produces the strongest signal to be radiated by the transmitting antenna. It also facilitates capture of the wave and maximum induced voltage in the receiving antenna. *[Figure 11-87]*

Figure 11-86. *VHF aircraft communication transceivers.*

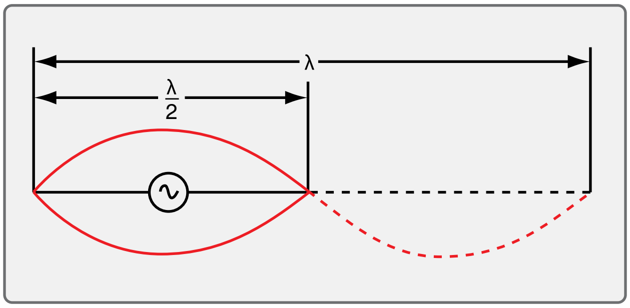


Figure 11-87. *An antenna equal to the full length of the applied AC frequency wavelength would have the negative cycle current flow along the antenna as shown by the dotted line. An antenna that is ½ wavelength allows current to reverse its direction in the antenna during the negative cycle. This results in low current at the ends of the ½ wavelength antenna and high current in the center. As energy radiates into space, the field is strongest 90° to the antenna where the current flow is strongest.*

Most radios, especially communication radios, use the same antenna for transmitting and receiving. Multichannel radios could use a different length antenna for each frequency, however, this is impractical. Acceptable performance can exist from a single antenna half the wavelength of a median frequency. This antenna can be made effectively shorter by placing a properly rated capacitor in series with the transmission line from the transmitter or receiver. This electrically shortens the resonant circuit of which the antenna is a part. An antenna may be electrically lengthened by adding an inductor in the circuit. Adjusting antenna length in this fashion allows the use of a single antenna for multiple frequencies in a narrow frequency range.

Many radios use a tuning circuit to adjust the effective length of the antenna to match the wavelength of the desired frequency. It contains a variable capacitor and an inductor connected in parallel in a circuit. Newer radios use a more efficient tuning circuit. It uses switches to combine frequencies from crystal controlled circuits to create a resonant frequency that matches the desired frequency. Either way, the physical antenna length is a compromise when using a multichannel communication or navigation device that must be electronically tuned for the best performance.

A formula can be used to find the ideal length of a half wavelength antenna required for a particular frequency as follows:

$$\text{Antenna Length (feet)} = \frac{468}{\text{F MHz}}$$

The formula is derived from the speed of propagation of radio waves, which is approximately 300 million meters per second. It takes into account the dielectric effect of the air at the end of an antenna that effectively shortens the length of the conductor required.

VHF radio frequencies used by aircraft communication radios are 118–136.975 MHz. The corresponding half wavelengths of these frequencies are 3.96 – 3.44 feet (47.5–41.2 inches). Therefore, VHF antennas are relatively long. Antennas one-quarter of the wavelength of the transmitted frequency are often used. This is possible because when mounted on a metal fuselage, a ground plane is formed and the fuselage acts as the missing one-quarter length of the half wavelength antenna. This is further discussed in the following antenna types section.

Polarization, Directivity, and Field Pattern

Antennas are polarized. They radiate and receive in certain patterns and directions. The electric field cause by the voltage in the conductor is parallel to the polarization of an antenna. It is caused by the voltage difference between each end of the antenna. The electromagnetic field component of the radio wave is at 90° to the polarization. It is caused by changing current flow in the antenna. These fields were illustrated in *Figure 11-76* and *11-77*. As radio waves radiate out from the antenna they propagate in a specific direction and in a specific pattern. This is the antenna field. The orientation of the electric and electromagnetic fields remains at 90° to each other, but radiate from antenna with varying strength in different directions. The strength of the radiated field varies depending on the type of antenna and the angular proximity to it. All antennas, even those that are omnidirectional, radiate a stronger signal in some direction compared to other directions. This is known as the antenna field directivity.

Receiving antennas with the same polarization as the transmitting antenna generate the strongest signal. A vertically polarized antenna is mounted up and down. It radiates waves out from it in all directions. To receive the strongest signal from these waves, the receiving antenna should also be positioned vertically so the electromagnetic component of the radio wave can cross it at as close to a 90° angle as possible for most of the possible proximities. *[Figure 11-88]*

Horizontally polarized antennas are mounted side to side (horizontally). They radiate in a donut-like field. The strongest signals come from, or are received at, 90° to the length of the antenna. There is no field generated off of the end of the antenna. *Figure 11-89* illustrates the field produced by a horizontally polarized antenna.

Many vertical and horizontal antennas on aircraft are mounted at a slight angle off plane. This allows the antenna to receive a weak signal rather than no signal at all when the

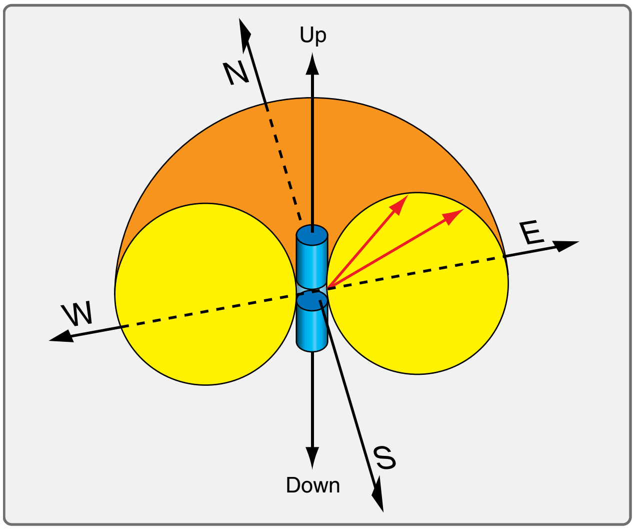


Figure 11-88. *A vertically polarized antenna radiates radio waves in a donut-like pattern in all directions.*

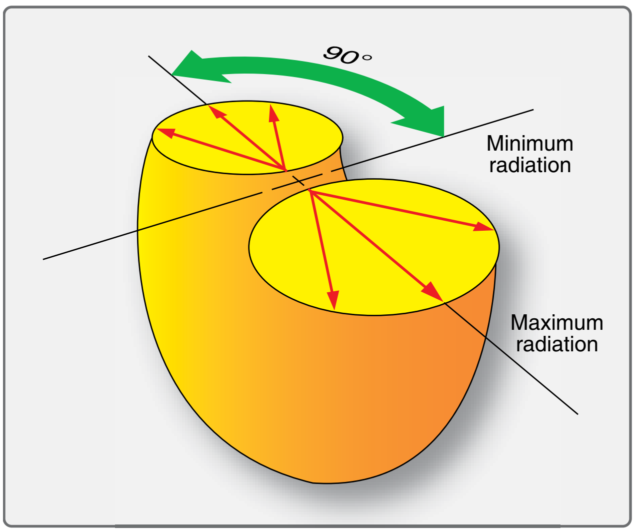


Figure 11-89. *A horizontally polarized antenna radiates in a donut-like pattern. The strongest signal is at 90° to the length of the conductor.*

polarization of the receiving antenna is not identical to the transmitting antenna. *[Figure 11-90]*

Types

There are three basic types of antennas used in aviation:

1. Dipole antenna
2. Marconi antenna
3. Loop antenna.

Dipole Antenna

The dipole antenna is the type of antenna referred to in the discussion of how a radio wave is produced. It is a conductor, the length of which is approximately equal to half the

Figure 11-90. *Many antenna are canted for better reception.*

wavelength of the transmission frequency. This sometimes is referred to as a Hertz antenna. The AC transmission current is fed to a dipole antenna in the center. As the current alternates, current flow is greatest in the middle of the antenna and gradually less as it approaches the ends. Then, it changes direction and flows the other way. The result is that the largest electromagnetic field is in the middle of the antenna and the strongest radio wave field is perpendicular to the length of the antenna. Most dipole antennas in aviation are horizontally polarized.

A common dipole antenna is the V-shaped VHF navigation antenna, known as a VOR antenna, found on numerous aircraft. Each arm of the V is one-fourth wavelength creating a half wave antenna which is fed in the center. This antenna is horizontally polarized. For a dipole receiving antenna, this means it is most sensitive to signals approaching the antenna from the sides rather than head-on in the direction of flight. *[Figure 11-91]*

Marconi Antenna

A Marconi antenna is a one-fourth wave antenna. It achieves the efficiency of a half wave antenna by using the mounting surface of the conductive aircraft skin to create the second one-fourth wavelength. Most aircraft VHF communications antennas are Marconi antennas. They are vertically polarized and create a field that is omnidirectional. On fabric skinned

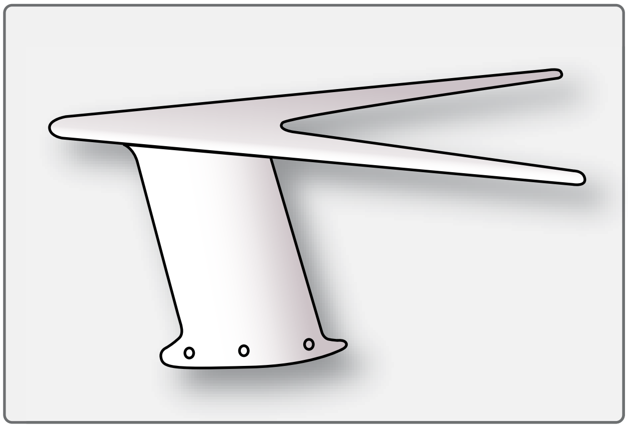


Figure 11-91. *The V-shaped VOR navigation antenna is a common dipole antenna.*

aircraft, the ground plane that makes up the second one-fourth wavelength of the antenna must be fashioned under the skin where the Marconi antenna is mounted. This can be done with thin aluminum or aluminum foil. Sometimes four or more wires are extended under the skin from the base of the vertical antenna that serve as the ground plane. This is enough to give the antenna the proper conductive length. The same practice is also utilized on ground based antennas. *[Figure 11-92]*

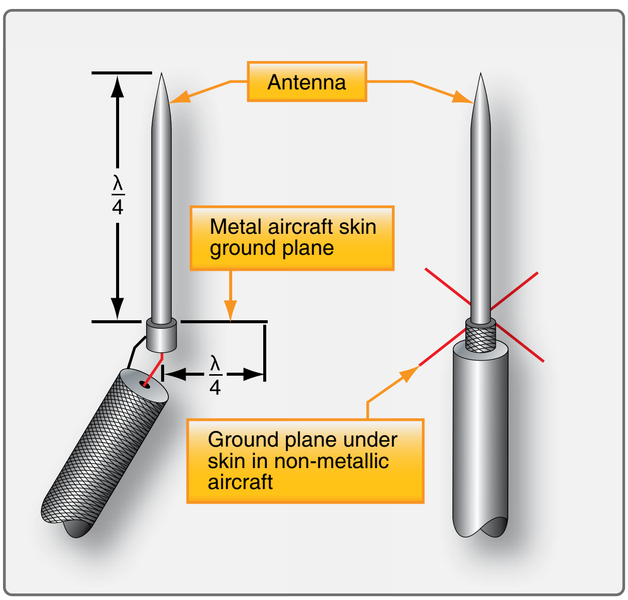


Figure 11-92. *On a metal-skinned aircraft, a ¼ wavelength Marconi antenna is used. The skin is the ground plane that creates the 2nd quarter of the antenna required for resonance (left). On a non-metallic-skinned aircraft, wires, conductive plates or strips equal in length to the antenna must be installed under the skin to create the ground plane (right).*

Loop Antenna

The third type of antenna commonly found on aircraft is the loop antenna. When the length of an antenna conductor is fashioned into a loop, its field characteristics are altered significantly from that of a straight-half wavelength antenna. It also makes the antenna more compact and less prone to damage.

Used as a receiving antenna, the loop antenna's properties are highly direction-sensitive. A radio wave intercepting the loop directly broadside causes equal current flow in both sides of the loop. However, the polarity of the current flows is opposite each other. This causes them to cancel out and produce no signal. When a radio wave strikes the loop antenna in line with the plane of the loop, current is generated first in one side, and then in the other side. This causes the current flows to have different phases and the strongest signal can be generated from this angle. The phase difference (and strength) of the generated current varies proportionally to the angle at which the radio wave strikes the antenna loop. This is useful and is discussed further in the section on automatic direction finder (ADF) navigational aids. *[Figure 11-93]*

Transmission Lines

Transmitters and receivers must be connected to their antenna(s) via conductive wire. These transmission lines are coaxial cable, also known as coax. Coax consists of a center wire conductor surrounded by a semirigid insulator. Surrounding the wire and insulator material is a conductive, braided cover that runs the length of the cable. Finally, a waterproof covering is set around the braided shield to protect the entire assembly from the elements. The braided cover in the coax shields the inner conductor from any external fields. It also prevents the fields generated by the internal conductor from radiating. For optimum performance, the impedance of the transmission line should be equal to the impedance of the antenna. In aviation antenna applications, this is often approximately 50 ohms. *[Figure 11-94]* Special connectors are used for coaxial cable. A variety can be seen in Advisory Circular 43.13-1b. The technician should follow all manufacturer's instructions when installing transmission lines and antenna. Correct installation is critical to radio and antenna performance.

Radio Navigation

In the early years of aviation, a compass, a map, and dead reckoning were the only navigational tools. These were marginally reassuring if weather prevented the pilot from seeing the terrain below. Voice radio transmission from

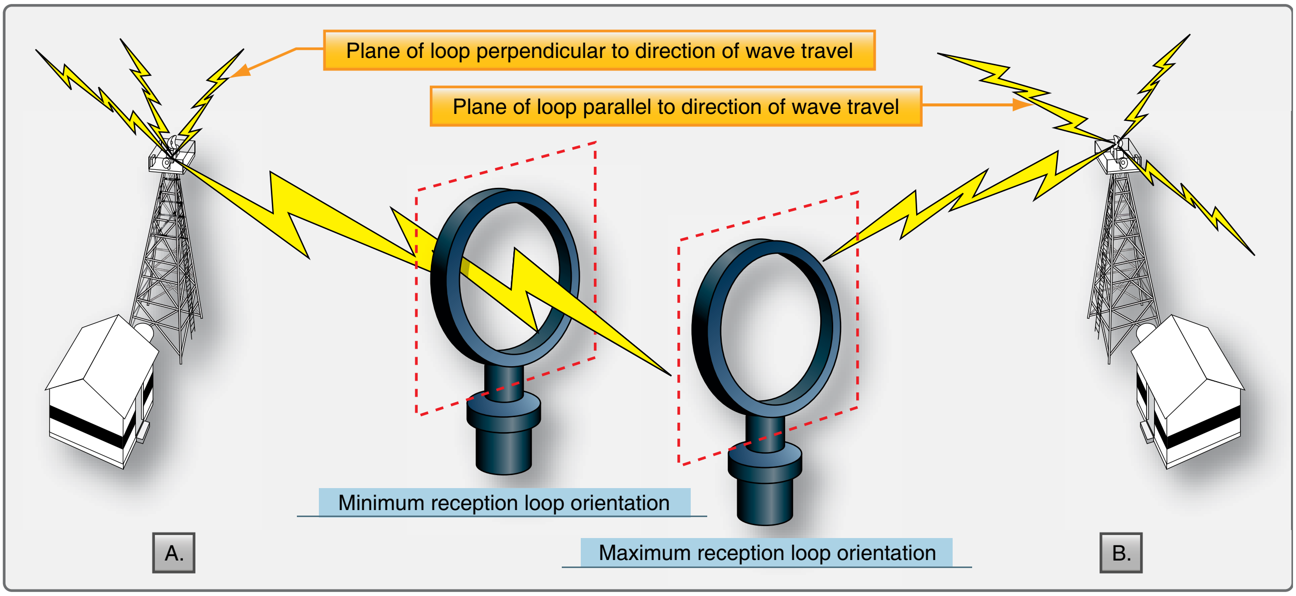


Figure 11-93. *A loop antenna is highly direction-sensitive. A signal origin perpendicular or broadside to the loop creates a weak signal (A). A signal origin parallel or in the plain of the loop creates a strong signal (B).*

someone on the ground to the pilot indicating that the aircraft could be heard overhead was a preview of what electronic navigational aids could provide. For aviation to reach fruition as a safe, reliable, consistent means of transportation, some sort of navigation system needed to be developed.

Early flight instruments contributed greatly to flying when the ground was obscured by clouds. Navigation aids were needed to indicate where an aircraft was over the earth as it progressed towards its destination. In the 1930s and 1940s, a radio navigation system was used that was a low frequency, four-course radio range system. Airports and selected navigation waypoints broadcast two Morse code signals with finite ranges and patterns. Pilots tuned to the frequency of the broadcasts and flew in an orientation pattern until both signals were received with increasing strength. The signals were received as a blended tone of the highest volume when the aircraft was directly over the broadcast area. From this beginning, numerous refinements to radio navigational aids developed.

Radio navigation aids supply the pilot with intelligence that maintains or enhances the safety of flight. As with communication radios, navigational aids are avionics devices, the repair of which must be carried out by trained technicians at certified repair stations. However, installation, maintenance and proper functioning of the electronic units, as well as their antennas, displays, and any other peripheral devices, are the responsibilities of the airframe technician.

VOR Navigation System

One of the oldest and most useful navigational aids is the VOR system. The system was constructed after WWII and

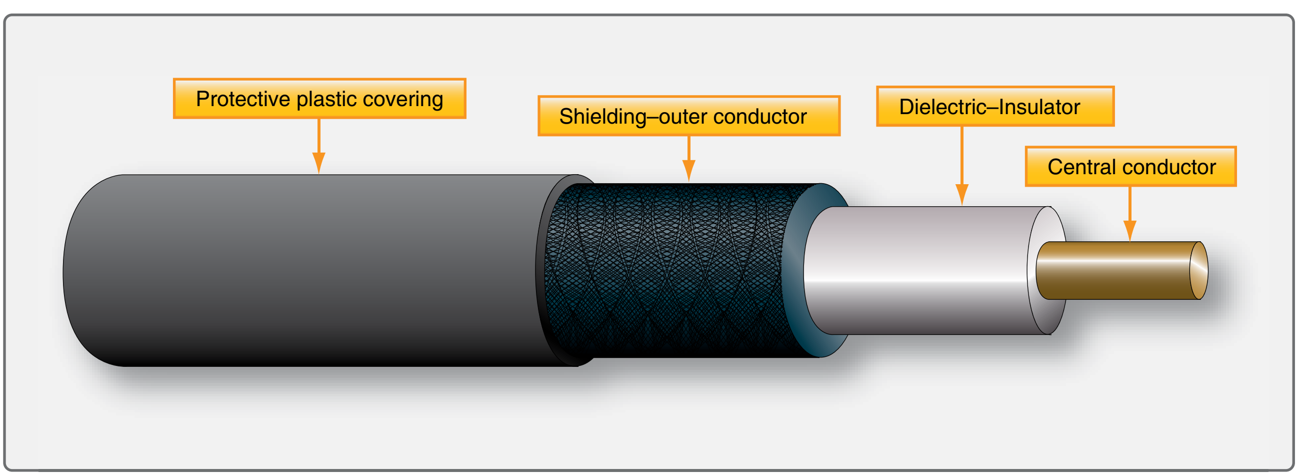


Figure 11-94. *Coaxial cable is used as the transmission line between an antenna and its transmitters and/or receiver.*

is still in use today. It consists of thousands of land-based transmitter stations, or VORs, that communicate with radio receiving equipment on board aircraft. Many of the VORs are located along airways. The Victor airway system is built around the VOR navigation system. Ground VOR transmitter units are also located at airports where they are known as TVOR (terminal VOR). The U.S. Military has a navigational system known as TACAN that operates similarly to the VOR system. Sometimes VOR and TACAN transmitters share a location. These sites are known as VORTACs.

The position of all VORs, TVORs, and VORTACs are marked on aeronautical charts along with the name of the station, the frequency to which an airborne receiver must be tuned to use the station, and a Morse code designation for the station. Some VORs also broadcast a voice identifier on a separate frequency that is included on the chart. *[Figure 11-95]*

VOR uses VHF radio waves (108–117.95 MHz) with 50 kHz separation between each channel. This keeps atmospheric interference to a minimum but limits the VOR to line-of-sight usage. To receive VOR VHF radio waves, generally a V-shaped, horizontally polarized, bi-pole antenna is used. A typical location for the V dipole is in the vertical fin. Other type antennas are also certified. Follow the manufacturer's instructions for installation location. *[Figure 11-96]*

The signals produced by a VOR transmitter propagate 360° from the unit and are used by aircraft to navigate to and from the station with the help of an onboard VOR receiver and display instruments. A pilot is not required to fly a pattern to intersect the signal from a VOR station since it propagates out in every direction. The radio waves are received as long as the aircraft is in range of the ground unit and regardless of the aircraft's direction of travel. *[Figure 11-97]*

A VOR transmitter produces two signals that a receiver on board an aircraft uses to locate itself in relation to the ground station. One signal is a reference signal. The second is produced by electronically rotating a variable signal. The variable signal is in phase with the reference signal when at magnetic north, but becomes increasingly out of phase as it is rotated to 180°. As it continues to rotate to 360° (0°), the signals become increasingly in phase until they are in phase again at magnetic north. The receiver in the aircraft deciphers the phase difference and determines the aircraft's position in degrees from the VOR ground based unit. *[Figure 11-98]* Most aircraft carry a dual VOR receiver. Sometimes, the VOR receivers are part of the same avionics unit as the VHF communication transceiver(s). These are known as NAV/COM radios. Internal components are shared since frequency bands for each are adjacent. *[Figure 11-99]* Large aircraft may have two dual receivers and even dual antennas. Normally, one receiver is selected for use and the

Figure 11-95. *A VOR ground station.*

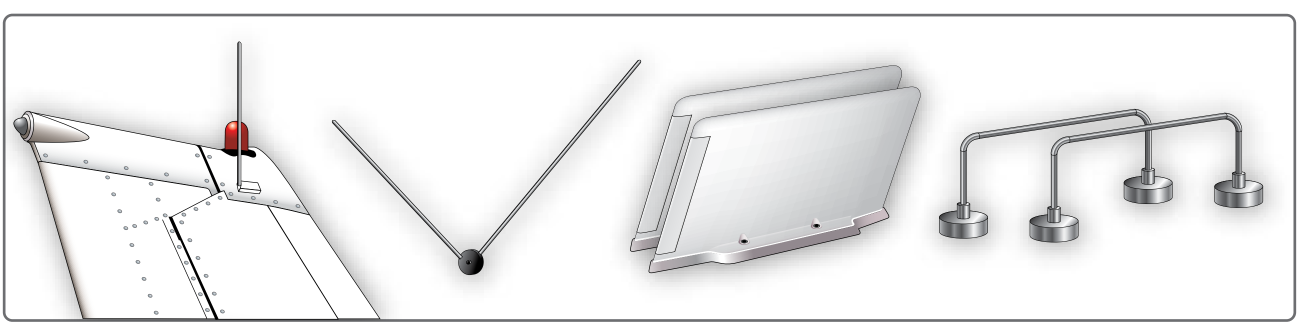


Figure 11-96. *V-shaped, horizontally polarized, bi-pole antennas are commonly used for VOR and VOR/glideslope reception. All antenna shown are VOR/glideslope antenna.*

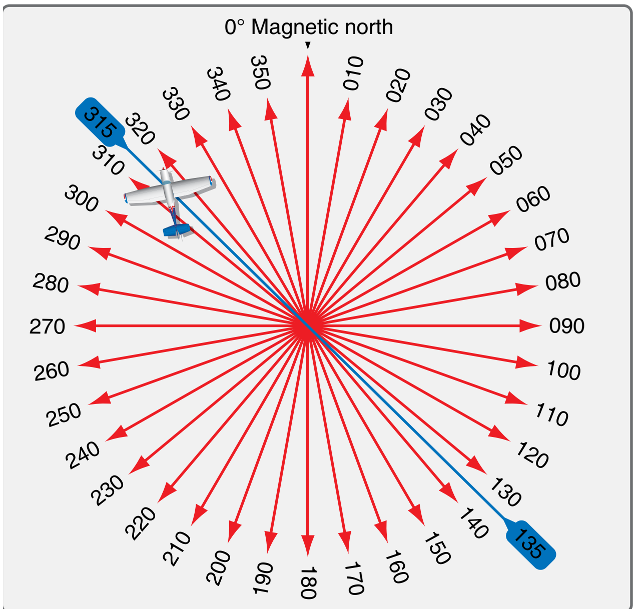


Figure 11-97. *A VOR transmitter produces signals for 360° radials that an airborne receiver uses to indicate the aircraft's location in relation to the VOR station regardless of the aircraft's direction of flight. The aircraft shown is on the 315° radial even though it does not have a heading of 315°.*

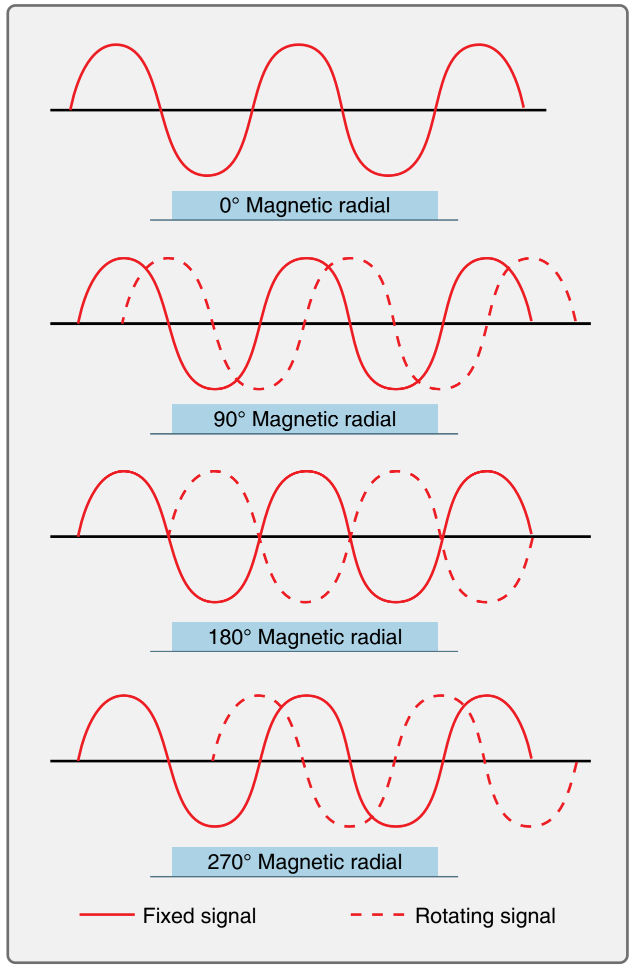


Figure 11-98. *The phase relationship of the two broadcast VOR signals.*

Figure 11-99. *A NAV/COM receiver typically found in light aircraft.*

second is tuned to the frequency of the next VOR station to be encountered en route. A means for switching between NAV 1 and NAV 2 is provided as is a switch for selecting the active or standby frequency. *[Figure 11-100]* VOR receivers are also found coupled with instrument landing system (ILS) receivers and glideslope receivers.

A VOR receiver interprets the bearing in degrees to (or from) the VOR station where the signals are generated. It also produces DC voltage to drive the display of the deviation from the desired course centerline to (or from) the selected station. Additionally, the receiver decides whether or not the aircraft is flying toward the VOR or away from it. These items can be displayed a number of different ways on various instruments. Older aircraft are often equipped with a VOR gauge dedicated to display only VOR information. This is also called an omni-bearing selector (OBS) or a course deviation indicator (CDI). *[Figure 11-101]*

The CDI linear indicator remains essentially vertical but moves left and right across the graduations on the instrument face to show deviation from being on course. Each graduation represents 2°. The OBS knob rotates the azimuth ring. When in range of a VOR, the pilot rotates the OBS until the course deviation indicator centers. For each location of an aircraft, the OBS can be rotated to two positions where the CDI will center. One produces an arrow in the TO window of the gauge indicating that the aircraft is traveling toward the VOR station. The other selectable bearing is 180° from this. When chosen, the arrow is displayed in the FROM window indicating the aircraft is moving away from the VOR on the course selected. The pilot must steer the aircraft to the heading with the CDI centered to fly directly to or from the VOR. The displayed VOR information is derived from deciphering the phase relationship between the two simultaneously transmitted signals from the VOR ground station. When power is lost or the VOR signal is weak or interrupted, a NAV warning flag comes into view. *[Figure 11-101]*

Figure 11-100. *An airliner VOR control head with two independent NAV receivers each with an active and standby tuning circuit controlled by a toggle switch.*

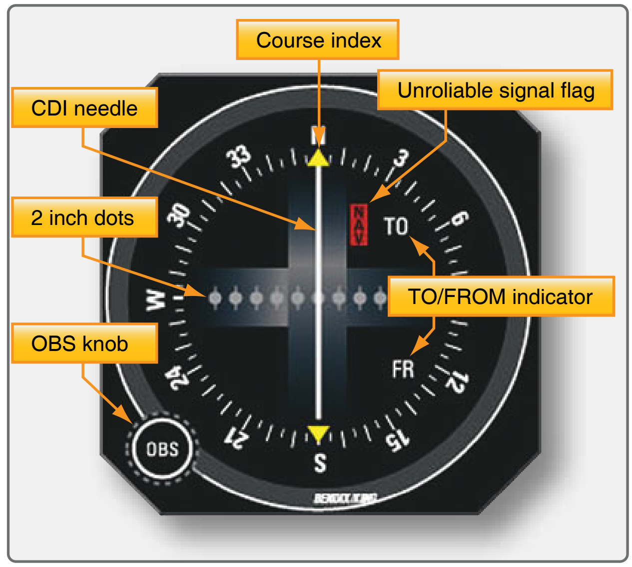


Figure 11-101. *A traditional VOR gauge, also known as a course deviation indicator (CDI) or an omni-bearing selector(OBS).*

A separate gauge for the VOR information is not always used. As flight instruments and displays have evolved, VOR navigation information has been integrated into other instruments displays, such as the radio magnetic indicator (RMI), the horizontal situation indicator (HSI), an EFIS display or an electronic attitude director indicator (EADI). Flight management systems and automatic flight control systems are also made to integrate VOR information to automatically control the aircraft on its planned flight segments. Flat panel MFDs integrate VOR information into moving map presentations and other selected displays. The basic information of the radial bearing in degrees, course deviation indication, and to/from information remains unchanged however. *[Figure 11-102]*

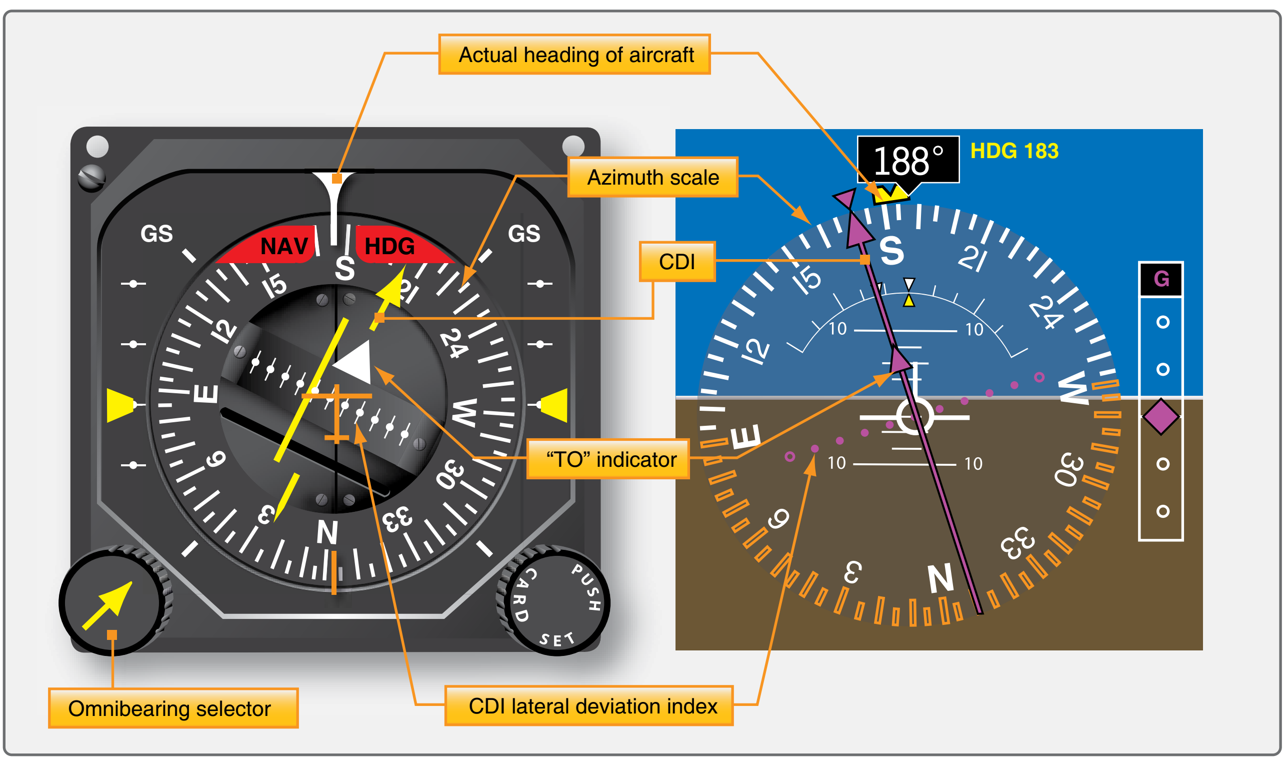


Figure 11-102. *A mechanical HSI (left) and an electronic HSI (right) both display VOR information.*

At large airports, an instrument landing system (ILS) guides the aircraft to the runway while on an instrument landing approach. The aircraft's VOR receiver is used to interpret the radio signals. It produces a more sensitive course deviation indication on the same instrument display as the VOR CDI display. This part of the ILS is known as the localizer and is discussed below. While tuned to the ILS localizer frequency, the VOR circuitry of the VOR/ILS receiver is inactive.

It is common at VOR stations to combine the VOR transmitter with distance measuring equipment (DME) or a nondirectional beacon (NDB) such as an ADF transmitter and antenna. When used with a DME, pilots can gain an exact fix on their location using the VOR and DME together. Since the VOR indicates the aircraft's bearing to the VOR transmitter and a co-located DME indicates how far away the station is, this relieves the pilot from having to fly over the station to know with certainty his or her location. These navigational aids are discussed separately in the following sections.

Functional accuracy of VOR equipment is critical to the safety of flight. VOR receivers are operationally tested using VOR test facilities (VOT). These are located at numerous airports that can be identified in the Airport Facilities Directory for the area concerned. Specific points on the airport surface are given to perform the test. Most VOTs require tuning 108.0 MHz on the VOR receiver and centering the CDI. The OBS should indicate 0° showing FROM on the indicator or 180° when showing TO. If an RMI is used as the indicator, the test heading should always indicate 180°. Some repair stations can also generate signals to test VOR receivers although not on 108.0 MHz. Contact the repair station for the transmission frequency and for their assistance in checking the VOR system. A logbook entry is required.

NOTE: Some airborne testing using VOTs is possible by the pilot.

An error of ±4° should not be exceeded when testing a VOR system with a VOT. An error in excess of this prevents the use of the aircraft for IFR fight until repairs are made. Aircraft having dual VOR systems where only the antenna is shared may be tested by comparing the output of each system to the other. Tune the VOR receivers to the local ground VOR station. A bearing indication difference of no more than ±4° is permissible.

Automatic Direction Finder (ADF)

An automatic direction finder (ADF) operates off of a ground signal transmitted from a NDB. Early radio direction finders (RDF) used the same principle. A vertically polarized antenna was used to transmit LF frequency radio waves in the 190 kHz to 535 kHz range. A receiver on the aircraft was tuned to the transmission frequency of the NDB. Using a loop antenna, the direction to (or from) the antenna could be determined by monitoring the strength of the signal received. This was possible because a radio wave striking a loop antenna broadside induces a null signal. When striking it in the plane of the loop, a much stronger signal is induced. The NDB signals were modulated with unique Morse code pulses that enabled the pilot to identify the beacon to which he or she was navigating.

With RDF systems, a large rigid loop antenna was installed inside the fuselage of the aircraft. The broadside of the antenna was perpendicular to the aircraft's longitudinal axis. The pilot listened for variations in signal strength of the LF broadcast and maneuvered the aircraft so a gradually increasing null signal was maintained. This took them to the transmitting antenna. When over flown, the null signal gradually faded as the aircraft became farther from the station. The increasing or decreasing strength of the null signal was the only way to determine if the aircraft was flying to or from the NDB. A deviation left or right from the course caused the signal strength to sharply increase due to the loop antenna's receiving properties.

The ADF improved on this concept. The broadcast frequency range was expanded to include MF up to about 1800 kHz. The heading of the aircraft no longer needed to be changed to locate the broadcast transmission antenna. In early model ADFs, a rotatable antenna was used instead. The antenna rotated to seek the position in which the signal was null. The direction to the broadcast antenna was shown on an azimuth scale of an ADF indicator in the flight deck. This type of instrument is still found in use today. It has a fixed card with 0° always at the top of a non-rotating dial. A pointer indicates the relative bearing to the station. When the indication is 0°, the aircraft is on course to (or from) the station. *[Figure 11-103]*

As ADF technology progressed, indicators with rotatable azimuth cards became the norm. When an ADF signal is received, the pilot rotates the card so that the present heading is at the top of the scale. This results in the pointer indicating the magnetic bearing to the ADF transmitter. This is more intuitive and consistent with other navigational practices. *[Figure 11-104]*

In modern ADF systems, an additional antenna is used to remove the ambiguity concerning whether the aircraft is heading to or from the transmitter. It is called a sense antenna. The reception field of the sense antenna is omnidirectional. When combined with the fields of the loop antenna, it forms a field with a single significant null reception area on one side. This is used for tuning and produces an indication in the

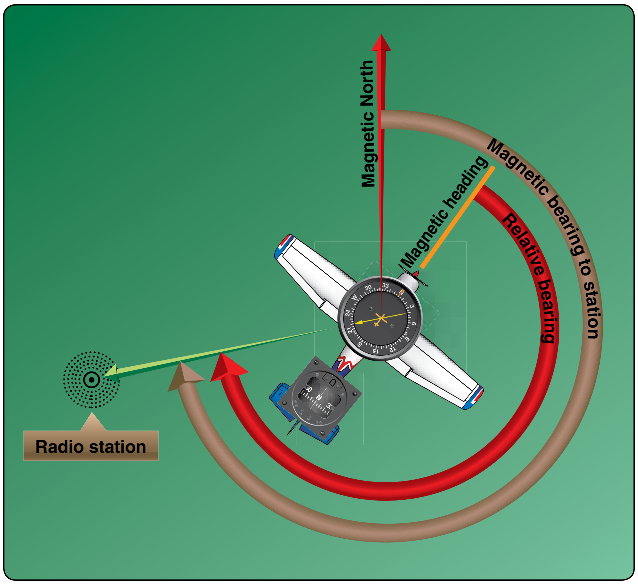


Figure 11-103. *Older ADF indicators have nonrotating azimuth cards. 0° is fixed at the top of the instrument and the pointer always indicates the relative bearing to the ADF transmission antenna. To fly to the station, the pilot turns the aircraft until the ADF pointer indicates 0°.*

Figure 11-104. *A movable card ADF indicator can be rotated to put the aircraft's heading at the top of the scale. The pointer then points to the magnetic bearing the ADF broadcast antenna.*

direction toward the ADF station at all times. The onboard ADF receiver needs only to be tuned to the correct frequency of the broadcast transmitter for the system to work. The loop and sense antenna are normally housed in a single, low profile antenna housing. *[Figure 11-105]*

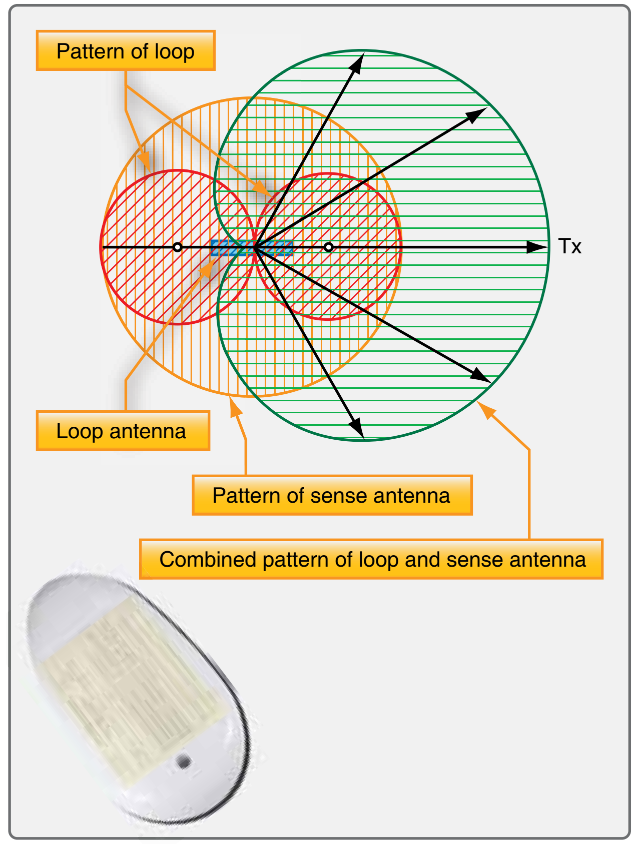


Figure 11-105. *The reception fields of a loop and sense antenna combine to create a field with a sharp null on just one side. This removes directional ambiguity when navigating to an ADF station.*

Any ground antenna transmitting LF or MF radio waves in range of the aircraft receiver's tuning capabilities can be used for ADF. This includes those from AM radio stations. Audible identifier tones are loaded on the NDB carrier waves. Typically a two-character Morse code designator is used. With an AM radio station transmission, the AM broadcast is heard instead of a station identifier code. The frequency for an NDB transmitter is given on an aeronautical chart next to a symbol for the transmitter. The identifying designator is also given. *[Figure 11-106]*

ADF receivers can be mounted in the flight deck with the controls accessible to the user. This is found on many general aviation aircraft. Alternately, the ADF receiver is mounted in a remote avionics bay with only the control head in the flight deck. Dual ADF receivers are common. ADF information can be displayed on the ADF indicators mentioned or it can be digital. Modern, flat, multipurpose electronic displays usually display the ADF digitally. [*Figure 11-107*] When ANT is selected on an ADF receiver, the loop antenna is cut out and only the sense antenna is active. This provides better multi-directional reception of broadcasts in the ADF frequency range, such as weather or AWAS broadcasts.

Figure 11-106. *Nondirectional broadcast antenna in the LF and medium frequency range are used for ADF navigation.*

Figure 11-107. *A cockpit mountable ADF receiver used on general aviation aircraft.*

When the best frequency oscillator (BFO) is selected on an ADF receiver/controller, an internal beat frequency oscillator is connected to the IF amplifier inside the ADF receiver. This is used when an NDB does not transmit a modulated signal.

Continued refinements to ADF technology has brought it to its current state. The rotating receiving antenna is replaced by a fixed loop with a ferrite core. This increases sensitivity and allows a smaller antenna to be used. The most modern ADF systems have two loop antennas mounted at 90° to each other. The received signal induces voltage that is sent to two stators in a resolver or goniometer. The goniometer stators induce voltage in a rotor that correlates to the signal of the fixed loops. The rotor is driven by a motor to seek the null. The same motor rotates the pointer in the flight deck indicator to show the relative or magnetic bearing to the station. *[Figure 11-108]*

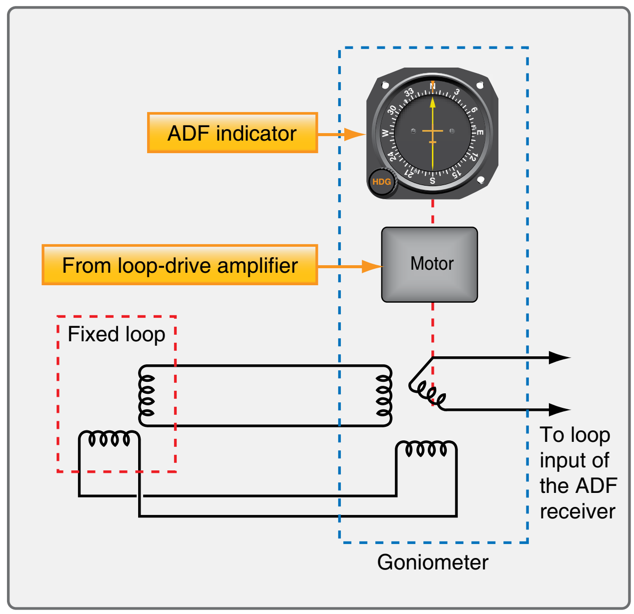


Figure 11-108. *In modern ADF, a rotor in a goniometer replaces a the rotating loop antenna used in earlier models.*

Technicians should note that the installation of the ADF antenna is critical to a correct indication since it is a directional device. Calibration with the longitudinal axis of the fuselage or nose of the aircraft is important. A single null reception area must exist in the correct direction. The antenna must be oriented so the ADF indicates station location when the aircraft is flying toward it rather than away. Follow all manufacturer's instructions.

Radio Magnetic Indicator (RMI)

To save space in the instrument panel and to consolidate related information into one easy to use location, the radio magnetic indicator (RMI) has been developed. It is widely used. The

RMI combines indications from a magnetic compass, VOR, and ADF into one instrument. *[Figure 11-109]*

Figure 11-109. *A radio magnetic indicator (RMI) combines a magnetic compass, VOR, and ADF indications.*

The azimuth card of the RMI is rotated by a remotely located flux gate compass. Thus, the magnetic heading of the aircraft is always indicated. The lubber line is usually a marker or triangle at the top of the instrument dial. The VOR receiver drives the solid pointer to indicate the magnetic direction TO a tuned VOR station. When the ADF is tuned to an NDB, the double, or hollow pointer, indicates the magnetic bearing to the NDB.

Since the flux gate compass continuously adjusts the azimuth card so that the aircraft heading is at the top of the instrument, pilot workload is reduced. The pointers indicate where the VOR and ADF transmission stations are located in relationship to where the aircraft is currently positioned. Push buttons allow conversion of either pointer to either ADF or VOR for navigation involving two of one type of station and none of the other.

Instrument Landing Systems (ILS)

An ILS is used to land an aircraft when visibility is poor. This radio navigation system guides the aircraft down a slope to the touch down area on the runway. Multiple radio transmissions are used that enable an exact approach to landing with an ILS. A localizer is one of the radio transmissions. It is used to provide horizontal guidance to the center line of the runway. A separate glideslope broadcast provides vertical guidance of the aircraft down the proper slope to the touch down point. Compass locator transmissions for outer and middle approach marker beacons aid the pilot in intercepting the approach navigational aid system. Marker beacons provide distance-from-the-runway information. Together, all of these radio signals make an ILS a very accurate and reliable means for landing aircraft. *[Figure 11-110]*

Localizer

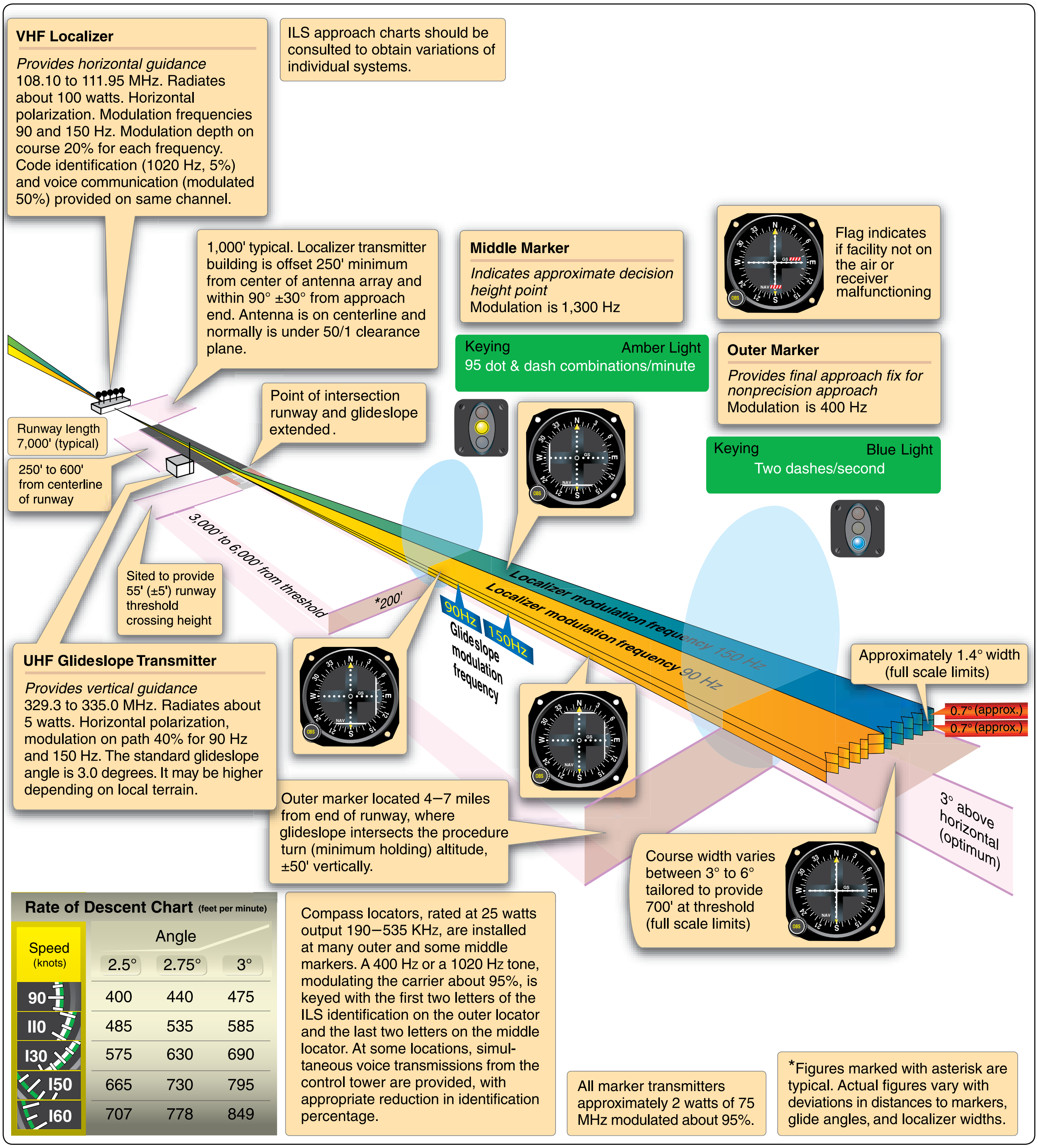
The localizer broadcast is a VHF broadcast in the lower range of the VOR frequencies (108 MHz–111.95 MHz) on odd frequencies only. Two modulated signals are produced from a horizontally polarized antenna complex beyond the far end of the approach runway. They create an expanding field that is 2½° wide (about 1,500 feet) 5 miles from the runway. The field tapers to runway width near the landing threshold. The left side of the approach area is filled with a VHF carrier wave modulated with a 90 Hz signal. The right side of the approach contains a 150 MHz modulated signal. The aircraft's VOR receiver is tuned to the localizer VHF frequency that can be found on published approach plates and aeronautical charts.

The circuitry specific to standard VOR reception is inactive while the receiver uses localizer circuitry and components common to both. The signals received are passed through filters and rectified into DC to drive the course deviation indicator. If the aircraft receives a 150 Hz signal, the CDI of the VOR/ILS display deflects to the left. This indicates that the runway is to the left. The pilot must correct course with a turn to the left. This centers course deviation indicator on the display and centers the aircraft with the centerline of the runway. If the 90 Hz signal is received by the VOR receiver, the CDI deflects to the right. The pilot must turn toward the right to center the CDI and the aircraft with the runway center line. *[Figure 11-111]*

Glideslope

The vertical guidance required for an aircraft to descend for a landing is provided by the glideslope of the ILS. Radio signals funnel the aircraft down to the touchdown point on the runway at an angle of approximately 3°. The transmitting glideslope antenna is located off to the side of the approach runway approximately 1,000 feet from the threshold. It transmits in a wedge-like pattern with the field narrowing as it approaches the runway. *[Figure 11-112]*

The glideslope transmitter antenna is horizontally polarized. The transmitting frequency range is UHF between 329.3 MHz and 335.0 MHz. The frequency is paired to the localizer frequency of the ILS. When the VOR/ILS receiver is tuned for the approach, the glideslope receiver is automatically tuned. Like the localizer, the glideslope transmits two signals, one modulated at 90 Hz and the other modulated at 150



Speed (knots)	Angle 2.5°	2.75°	3°
90	400	440	475
110	485	535	585
130	575	630	690
150	665	730	795
160	707	778	849

Figure 11-110. *Components of an instrument landing system (ILS).*

Figure 11-111. *An ILS localizer antenna.*

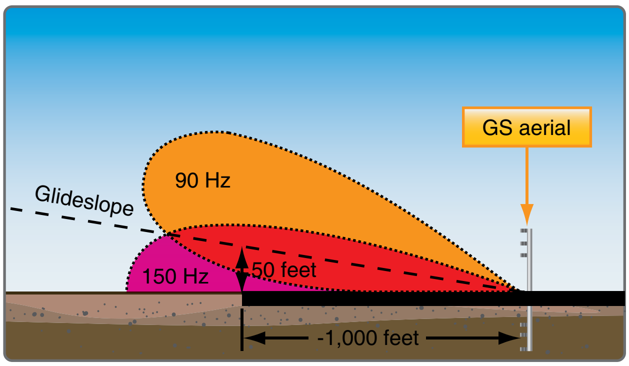


Figure 11-112. *A glideslope antenna broadcasts radio signals to guide an aircraft vertically to the runway.*

Hz. The aircraft's glideslope receiver deciphers the signals similar to the method of the localizer receiver. It drives a vertical course deviation indicator known as the glideslope indicator. The glideslope indicator operates identically to the localizer CDI only 90° to it. The VOR/ILS localizer CDI and the glideslope are displayed together on whichever kind of instrumentation is in the aircraft. *[Figure 11-113]*

The UHF antenna for aircraft reception of the glideslope signals comes in many forms. A single dipole antenna mounted inside the nose of the aircraft is a common option. Antenna manufacturers have also incorporated glideslope reception into the same dipole antenna used for the VHS VOR/ILS localizer reception. Blade type antennas are also used. *[Figures 11-114] Figure 11-115* shows a VOR and a glideslope receiver for a GA aircraft ILS.

Compass Locators

It is imperative that a pilot be able to intercept the ILS to enable its use. A compass locator is a transmitter designed for this purpose. There is typically one located at the outer marker beacon 4-7 miles from the runway threshold. Another may be located at the middle marker beacon about 3,500 feet from the threshold. The outer marker compass locator is a 25 watt NDB with a range of about 15 miles. It transmits omnidirectional LF radio waves (190 Hz to 535 Hz) keyed with the first two letters of the ILS identifier. The ADF

Figure 11-113. *A traditional course deviation indicator is shown on the left. The horizontal white line is the deviation indicator for the glideslope. The vertical line is for the localizer. On the right, a Garmin G-1000 PFD illustrates an aircraft during an ILS approach. The narrow vertical scale on the right of the attitude indicator with the "G" at the top is the deviation scale for the glideslope. The green diamond moves up and down to reflect the aircraft being above or below the glidepath. The diamond is shown centered indicating the aircraft is on course vertically. The localizer CDI can be seen at the bottom center of the display. It is the center section of the vertical green course indicator. LOC1 is displayed to the left of it.*

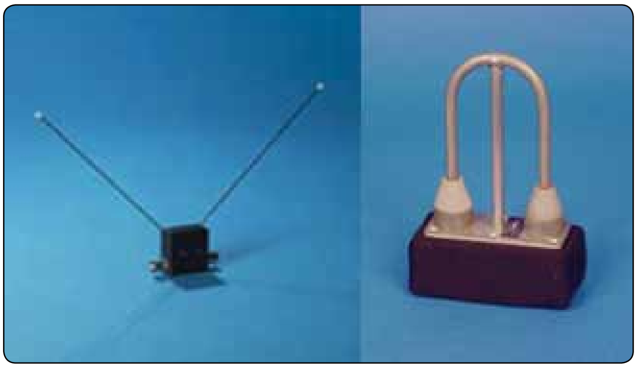


Figure 11-114. *Glideslope antennas—designed to be mounted inside a non-metallic aircraft nose (left), and mounted inside or outside the aircraft (right).*

receiver is used to intercept the locator so no additional equipment is required. If a middle marker compass locator is in place, it is similar but is identified with the last two letters of the ILS identifier. Once located, the pilot maneuvers the aircraft to fly down the glidepath to the runway.

Marker Beacons

Marker beacons are the final radio transmitters used in the ILS. They transmit signals that indicate the position of the aircraft along the glidepath to the runway. As mentioned, an outer marker beacon transmitter is located 4–7 miles from the threshold. It transmits a 75 MHz carrier wave modulated with a 400 Hz audio tone in a series of dashes. The transmission is very narrow and directed straight up. A marker beacon receiver receives the signal and uses it to light a blue light on the instrument panel. This, plus the oral tone in combination with the localizer and the glideslope indicator, positively locates the aircraft on an approach. *[Figure 11-115]*

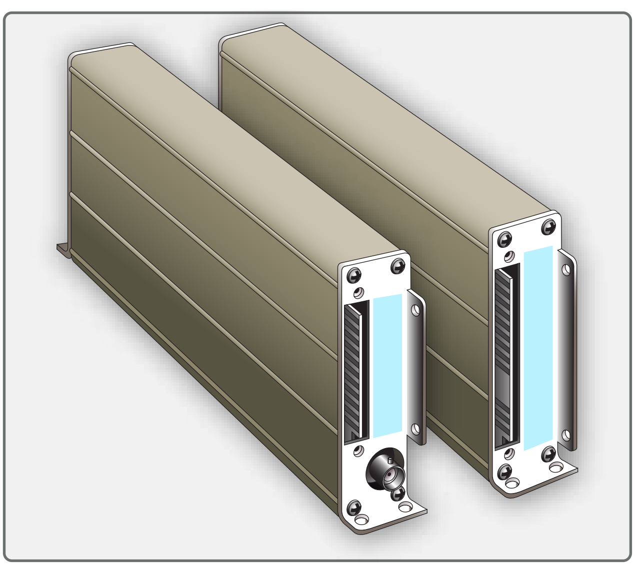


Figure 11-115. *A localizer and glideslope receiver for a general aviation aircraft ILS.*

A middle marker beacon is also used. It is located on approach approximately 3,500 feet from the runway. It also transmits at 75 MHz. The middle marker transmission is modulated with a 1300 Hz tone that is a series of dots and dashes so as to not be confused with the all dash tone of the outer marker. When the signal is received, it is used in the receiver to illuminate an amber-colored light on the instrument panel. *[Figure 11-116]*

Figure 11-116. *Various marker beacon instrument panel display lights.*

Some ILS approaches have an inner marker beacon that transmits a signal modulated with 3000 Hz in a series of dots only. It is placed at the land-or-go-around decision point of the approach close to the runway threshold. If present, the signal when received is used to illuminate a white light on the instrument panel. The three marker beacon lights are usually incorporated into the audio panel of a general aviation aircraft or may exist independently on a larger aircraft. Electronic display aircraft usually incorporate marker lights or indicators close to the glideslope display near attitude director indicator. *[Figure 11-117]*

ILS radio components can be tested with an ILS test unit. Localizer, glideslope, and marker beacon signals are generated to ensure proper operation of receivers and correct display on flight deck instruments. *[Figure 11-118]*

Distance Measuring Equipment (DME)

Many VOR stations are co-located with the military version of the VOR station, which is known as TACAN. When this occurs, the navigation station is known as a VORTAC station. Civilian aircraft make use of one of the TACAN features not originally installed at civilian VOR stations–distance measuring equipment (DME). A DME system calculates the distance from the aircraft to the DME unit at the VORTAC ground station and displays it on the flight deck. It can also display calculated aircraft speed and elapsed time for arrival when the aircraft is traveling to the station.

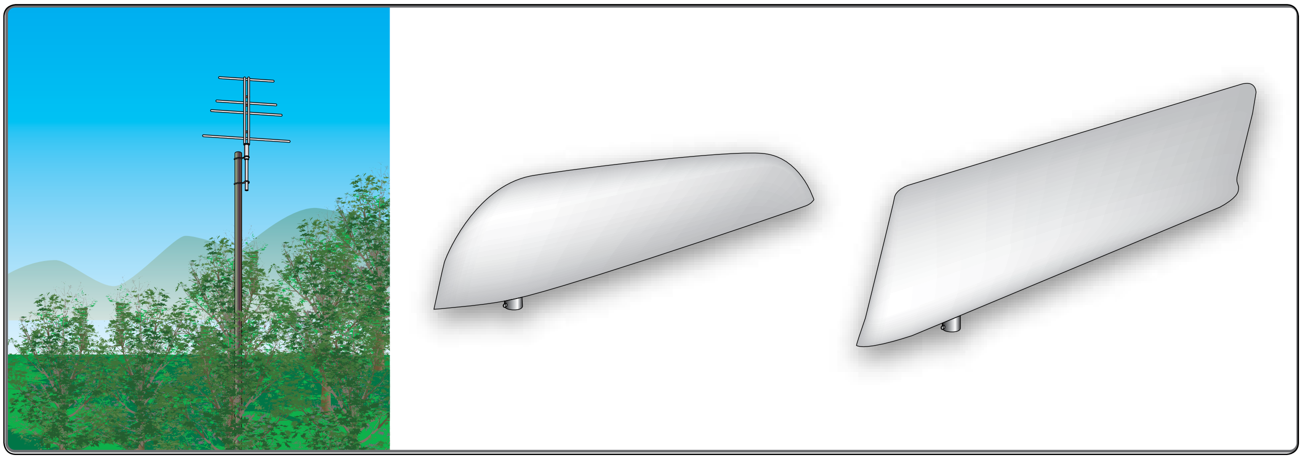


Figure 11-117. *An outer marker transmitter antenna 4 –7 miles from the approach runway transmits a 75 MHz signal straight up (left). Aircraft mounted marker beacon receiver antennas are shown (center and right).*

Figure 11-118. *An ILS test unit.*

DME ground stations have subsequently been installed at civilian VORs, as well as in conjunction with ILS localizers. These are known as VOR/DME and ILS/DME or LOC/DME. The latter aid in approach to the runway during landings. The DME system consists of an airborne DME transceiver, display, and antenna, as well as the ground based DME unit and its antenna. *[Figure 11-119]*

The DME is useful because with the bearing (from the VOR) and the distance to a known point (the DME antenna at the VOR), a pilot can positively identify the location of the aircraft. DME operates in the UHF frequency range from 962 MHz to 1213 MHz. A carrier signal transmitted from the aircraft is modulated with a string of integration pulses. The ground unit receives the pulses and returns a signal to the aircraft. The time that transpires for the signal to be sent and returned is calculated and converted into nautical miles for display. Time to station and speed are also calculated and displayed. DME readout can be on a dedicated DME display or it can be part of an EHSI, EADI, EFIS, or on the primary flight display in a glass cockpit. *[Figure 11-120]*

Figure 11-119. *A VOR with DME ground station.*

Figure 11-120. *Distance information from the DME can be displayed on a dedicated DME instrument or integrated into any of the electronic navigational displays found on modern aircraft. A dual display DME is shown with its remote mounted receiver.*

The DME frequency is paired to the co-located VOR or VORTAC frequency. When the correct frequency is tuned for the VOR signal, the DME is tuned automatically. Tones are broadcast for the VOR station identification and then for the DME. The hold selector on a DME panel keeps the DME tuned in while the VOR selector is tuned to a different VOR. In most cases, the UHF of the DME is transmitted and received via a small blade-type antenna mounted to the underside of the fuselage centerline. *[Figure 11-121]*

Figure 11-121. *A typical aircraft mounted DME antenna.*

A traditional DME displays the distance from the DME transmitter antenna to the aircraft. This is called the slant distance. It is very accurate. However, since the aircraft is at altitude, the distance to the DME ground antenna from a point directly beneath the aircraft is shorter. Some modern DMEs are equipped to calculate this ground distance and display it. *[Figure 11-122]*

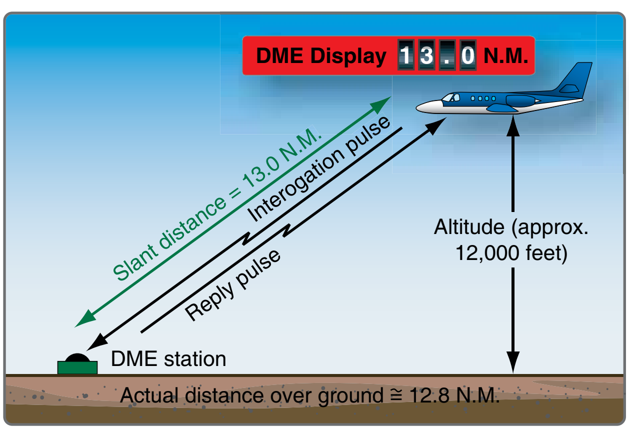


Figure 11-122. *Many DME's only display the slant distance, which is the actual distance from the aircraft to the DME station. This is different than the ground distance due to the aircraft being at altitude. Some DMEs compute the ground distance for display.*

Area Navigation (RNAV)

Area navigation (RNAV) is a general term used to describe the navigation from point A to point B without direct over flight of navigational aids, such as VOR stations or ADF non-directional beacons. It includes VORTAC and VOR/DME based systems, as well as systems of RNAV based around LORAN, GPS, INS, and the FMS of transport category aircraft. However, until recently, the term RNAV was most commonly used to describe the area navigation or the process of direct flight from point A to point B using VORTAC and VOR/DME based references which are discussed in this section.

All RNAV systems make use of waypoints. A waypoint is a designated geographical location or point used for route definition or progress-reporting purposes. It can be defined or described by using latitude/longitude grid coordinates or, in the case of VOR based RNAV, described as a point on a VOR radial followed by that point's distance from the VOR station (i.e., 200/25 means a point 25 nautical miles from the VOR station on the 200° radial).

Figure 11-123 illustrates an RNAV route of flight from airport A to airport B. The VOR/DME and VORTAC stations shown are used to create phantom waypoints that are overflown rather than the actual stations. This allows a more direct route to be taken. The phantom waypoints are entered into the RNAV course-line computer (CLC) as a radial and distance number pair. The computer creates the waypoints and causes the aircraft's CDI to operate as though they are actual VOR stations. A mode switch allows the choice between standard VOR navigation and RNAV.

VOR based RNAV uses the VOR receiver, antenna, and VOR display equipment, such as the CDI. The computer in the RNAV unit uses basic geometry and trigonometry calculations to produce heading, speed, and time readouts for each waypoint. VOR stations need to be within line-of sight and operational range from the aircraft for RNAV use. *[Figure 11-124]*

RNAV has increased in flexibility with the development of GPS. Integration of GPS data into a planned VOR RNAV flight plan is possible as is GPS route planning without the use of any VOR stations.

Radar Beacon Transponder

A radar beacon transponder, or simply, a transponder, provides positive identification and location of an aircraft on the radar screens of ATC. For each aircraft equipped with an altitude encoder, the transponder also provides the pressure altitude of the aircraft to be displayed adjacent to the on-screen blip that represents the aircraft. *[Figure 11-125]*

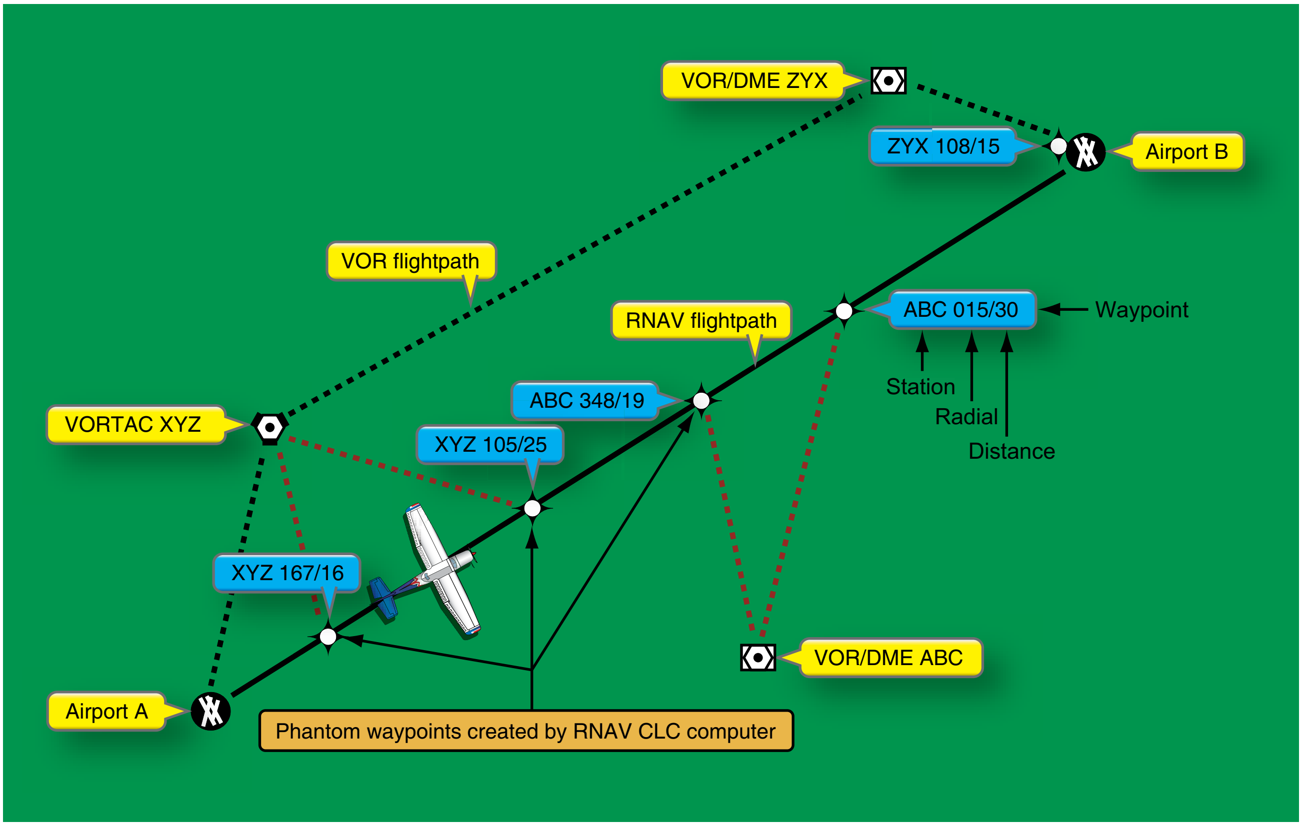


Figure 11-123. *The pilot uses the aircraft's course deviation indicator to fly to and from RNAV phantom waypoints created by computer. This allows direct routes to be created and flown rather than flying from VOR to VOR.*

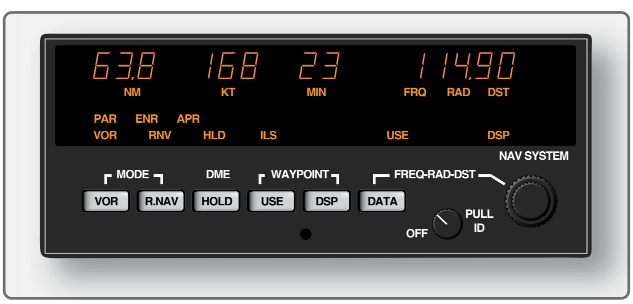


Figure 11-124. *RNAV unit from a general aviation aircraft.*

Radar capabilities at airports vary. Generally, two types of radar are used by air traffic control (ATC). The primary radar transmits directional UHF or SHF radio waves sequentially in all directions. When the radio waves encounter an aircraft, part of those waves reflect back to a ground antenna. Calculations are made in a receiver to determine the direction and distance of the aircraft from the transmitter. A blip or target representing the aircraft is displayed on a radar screen also known as a plan position indicator (PPI). The azimuth direction and scaled distance from the tower are presented giving controllers a two dimensional fix on the aircraft. *[Figure 11-126]*

A secondary surveillance radar (SSR) is used by ATC to verify the aircraft's position and to add the third dimension of altitude to its location. SSD radar transmits coded pulse trains that are received by the transponder on board the aircraft. Mode 3/A pulses, as they are known, aid in confirming the location of the aircraft. When verbal communication is established with ATC, a pilot is instructed to select one of 4,096 discrete codes on the transponder. These are digital octal codes. The ground station transmits a pulse of energy at 1030 MHz and the transponder transmits a reply with the assigned code attached at 1090 MHz. This confirms the aircraft's location typically by altering its target symbol on the radar screen. As the screen may be filled with many confirmed aircraft, ATC can also ask the pilot to ident. By pressing the IDENT button on the transponder, it transmits in such a way that the aircraft's target symbol is highlighted on the PPI to be distinguishable.

To gain altitude clarification, the transponder control must be placed in the ALT or Mode C position. The signal transmitted back to ATC in response to pulse interrogation is then modified with a code that places the pressure altitude of the aircraft next to the target symbol on the radar screen. The transponder gets the pressure altitude of the aircraft

Figure 11-125. *A traditional transponder control head (A), a lightweight digital transponder (B), and a remote altitude encoder (C) that connects to a transponder to provide ATC with an aircraft's altitude displayed on a PPI radar screen next to the target that represents the aircraft.*

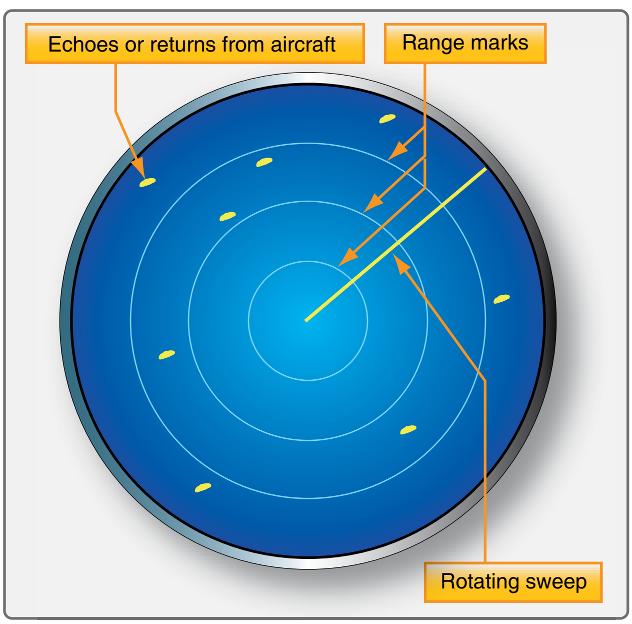


Figure 11-126. *A plan position indicator (PPI) for ATC primary radar locates target aircraft on a scaled field.*

from an altitude encoder that is electrically connected to the transponder. Typical aircraft transponder antennas are illustrated in *Figure 11-127.*

The ATC/aircraft transponder system described is known as Air Traffic Control Radar Beacon System (ATCRBS). To increase safety, Mode S altitude response has been developed. With Mode S, each aircraft is pre-assigned a unique identity code that displays along with its pressure altitude on ATC radar when the transponder responds to SSR interrogation. Since no other aircraft respond with this code, the chance of two pilots selecting the same response code on the transponder is eliminated. A modern flight data processor computer (FDP) assigns the beacon code and searches flight plan data for useful information to be displayed on screen next to the target in a data block for each aircraft. *[Figure 11-128]*

Mode S is sometimes referred to as mode select. It is a data packet protocol that is also used in onboard collision avoidance systems. When used by ATC, Mode S interrogates one aircraft at a time. Transponder workload is reduced by not having to respond to all interrogations in an airspace. Additionally, location information is more accurate with Mode S. A single reply in which the phase of the transponder reply is used to calculate position, called monopulse, is sufficient to locate the aircraft. Mode S also contains capacity

Figure 11-127. *Aircraft radar beacon transponder antennas transmit and receive UHF and SHF radio waves.*

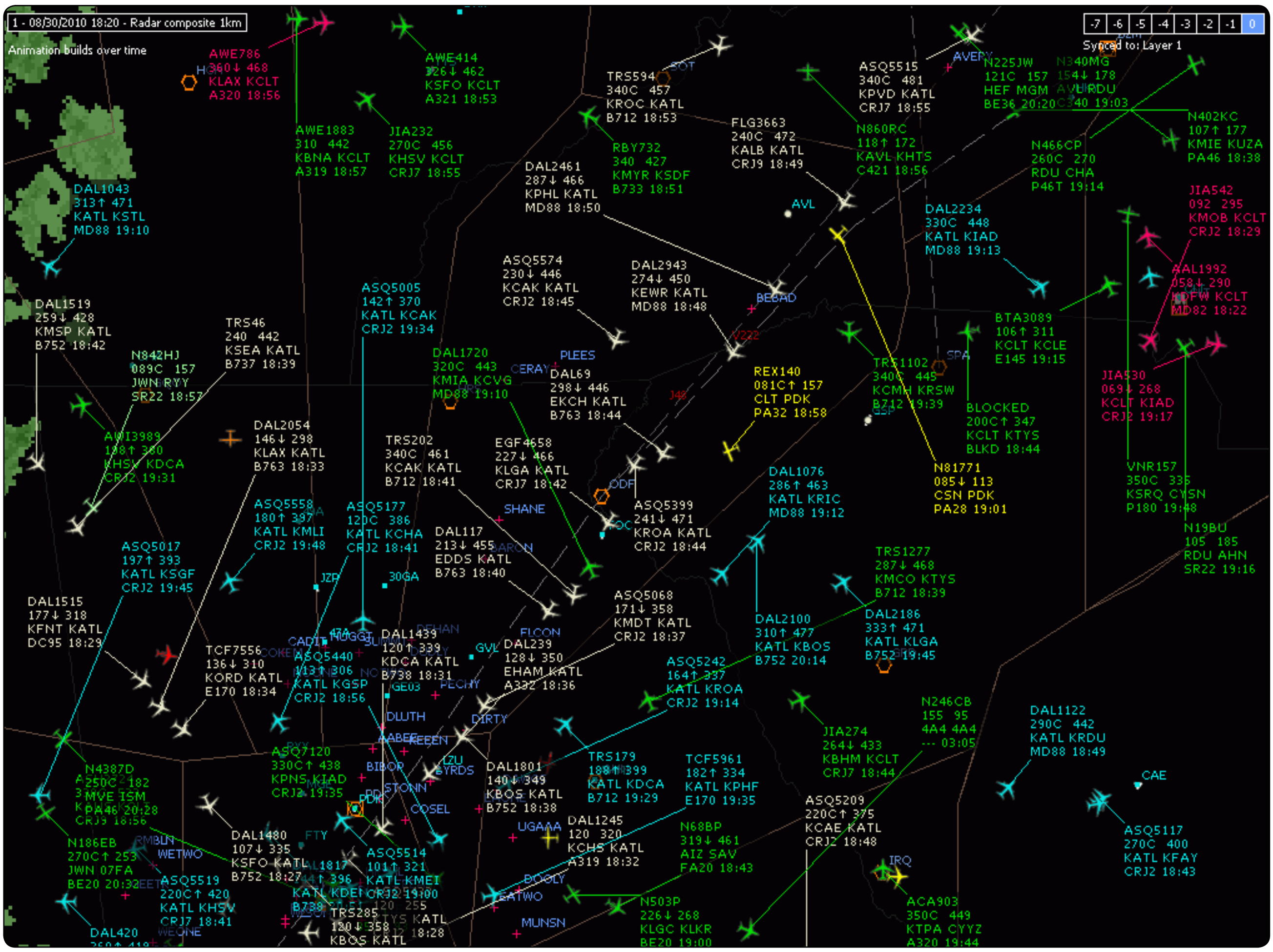


Figure 11-128. *Air traffic control radar technology and an onboard radar beacon transponder work together to convey and display air traffic information on a PPI radar screen. A modern approach ATC PPI is shown. Targets representing aircraft are shown as little aircraft on the screen. The nose of the aircraft indicates the direction of travel. Most targets shown above are airliners. The data block for each target includes the following information either transmitted by the transponder or matched and loaded from flight plans by a flight data processor computer: call sign, altitude/speed, origination/destination, and aircraft type/ETA (ZULU time). A "C" after the altitude indicates the information came from a Mode C equipped transponder. The absence of a C indicates Mode S is in use. An arrow up indicates the aircraft is climbing. An arrow down indicates a descent. White targets are arrivals, light blue targets are departures, all other colors are for arrivals and departures to different airports in the area.*

for a wider variety of information exchange that is untapped potential for the future. At the same time, compatibility with older radar and transponder technology has been maintained.

Transponder Tests and Inspections

Title 14 of the Code of Federal Regulations (CFR) part 91, section 91.413 states that all transponders on aircraft flown into controlled airspace are required to be inspected and tested in accordance with 14 CFR part 43, Appendix F, every 24 calendar months. Installation or maintenance that may introduce a transponder error is also cause for inspection and test in accordance with Appendix F. Only an appropriately rated repair station, the aircraft manufacturer (if it installed transponder), and holders of a continuous airworthy program are approved to conduct the procedures. As with many radio-electronic devices, test equipment exists to test airworthy operation of a transponder. *[Figure 11-129]*

Figure 11-129. *A handheld transponder test unit.*

Operating a transponder in a hangar or on the ramp does not immunize it from interrogation and reply. Transmission of certain codes reserved for emergencies or military activity must be avoided. The procedure to select a code during ground operation is to do so with the transponder in the OFF or STANDBY mode to avoid inadvertent transmission. Code 0000 is reserved for military use and is a transmittable code. Code 7500 is used in a hijack situation and 7600 and 7700 are also reserved for emergency use. Even the inadvertent transmission of code 1200 reserved for VFR flight not under ATC direction could result in evasion action. All signals received from a radar beacon transponder are taken seriously by ATC.

Altitude Encoders

Altitude encoders convert the aircraft's pressure altitude into a code sent by the transponder to ATC. Increments of 100 feet are usually reported. Encoders have varied over the years. Some are built into the altimeter instrument used in the instrument panel and connected by wires to the transponder. Others are mounted out of sight on an avionics rack or similar out of the way place. These are known as blind encoders. On transport category aircraft, the altitude encoder may be a large black box with a static line connection to an internal aneroid. Modern general aviation encoders are smaller and more lightweight, but still often feature an internal aneroid and static line connection. Some encoders use microtransistors and are completely solid-state including the pressure sensing device from which the altitude is derived. No static port connection is required. Data exchange with GPS and other systems is becoming common. *[Figure 11-130]*

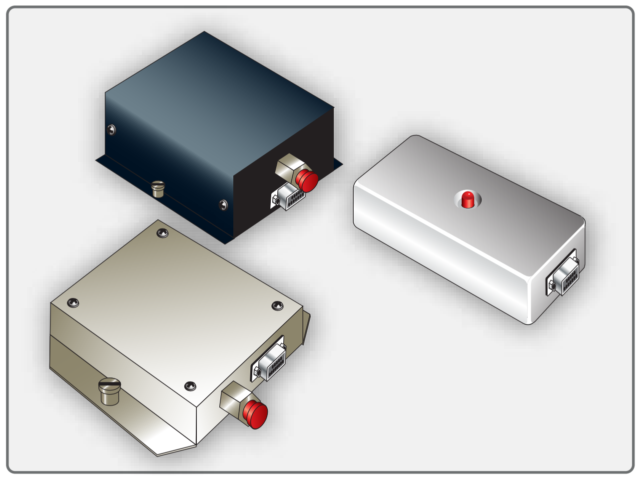


Figure 11-130. *Modern altitude encoders for general aviation aircraft.*

When a transponder selector is set on ALT, the digital pulse message sent in response to the secondary surveillance radar interrogation becomes the digital representation of the pressure altitude of the aircraft. There are 1280 altitude codes, one for each 100 feet of altitude between 1200 feet mean sea level (MSL) and 126,700 feet MSL. Each altitude increment is assigned a code. While these would be 1280 of the same codes used for location and IDENT, the Mode C (or S) interrogation deactivates the 4096 location codes and causes the encoder to become active. The correct altitude code is sent to the transponder that replies to the interrogation. The SSR receiver recognized this as a response to a Mode C (or S) interrogation and interprets the code as altitude code.

Collision Avoidance Systems

The ever increasing volume of air traffic has caused a corresponding increase in concern over collision avoidance. Ground-based radar, traffic control, and visual vigilance are no longer adequate in today's increasingly crowded skies. Onboard collision avoidance equipment, long a staple in larger aircraft, is now common in general aviation aircraft. New applications of electronic technology combined with lower costs make this possible.

Traffic Collision Avoidance Systems (TCAS)

Traffic collision avoidance systems (TCAS) are transponder based air-to-air traffic monitoring and alerting systems. There are two classes of TCAS. TCAS I was developed to accommodate the general aviation community and regional airlines. This system identifies traffic in a 35–40 mile range of the aircraft and issues Traffic Advisories (TA) to assist pilots in visual acquisition of intruder aircraft. TCAS I is mandated on aircraft with 10 to 30 seats.

TCAS II is a more sophisticated system. It is required internationally in aircraft with more than 30 seats or weighing more than 15,000 kg. TCAS II provides the information of TCAS I, but also analyzes the projected flightpath of approaching aircraft. If a collision or near miss is imminent, the TCAS II computer issues a Resolution Advisory (RA). This is an aural command to the pilot to take a specific evasive action (i.e., DESCEND). The computer is programmed such that the pilot in the encroaching aircraft receives an RA for evasive action in the opposite direction (if it is TCAS II equipped). *[Figure 11-131]*

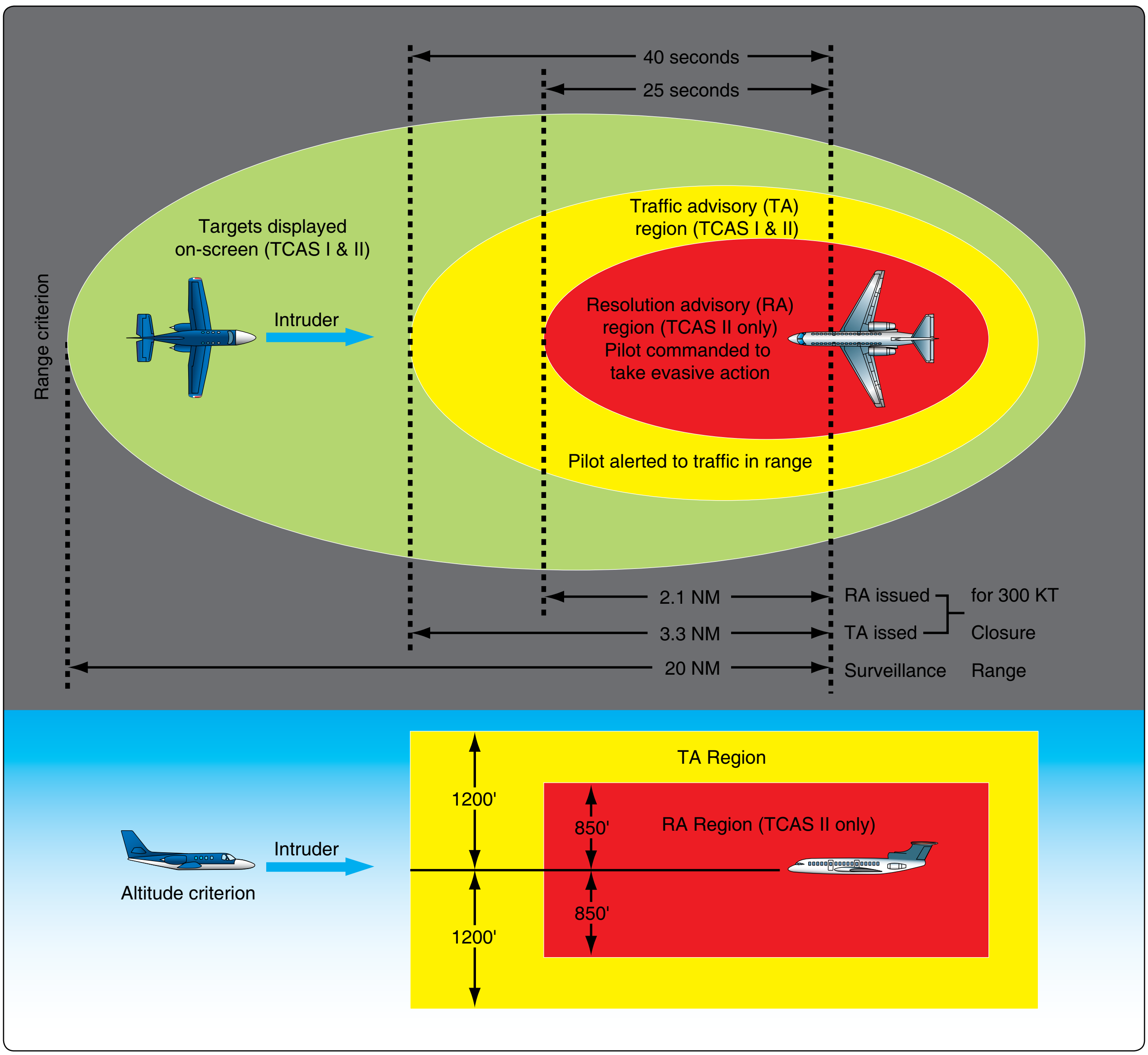


Figure 11-131. *Traffic collision and avoidance system (TCAS) uses an aircraft's transponder to interrogate and receive replies from other aircraft in close proximity. The TCAS computer alerts the pilot as to the presence of an intruder aircraft and displays the aircraft on a screen in the cockpit. Additionally, TCAS II equipped aircraft receive evasive maneuver commands from the computer that calculates trajectories of the aircraft to predict potential collisions or near misses before they become unavoidable.*

The transponder of an aircraft with TCAS is able to interrogate the transponders of other aircraft nearby using SSR technology (Mode C and Mode S). This is done with a 1030 MHz signal. Interrogated aircraft transponders reply with an encoded 1090 MHz signal that allows the TCAS computer to display the position and altitude of each aircraft. Should the aircraft come within the horizontal or vertical distances shown in *Figure 11-131*, an audible TA is announced. The pilot must decide whether to take action and what action to take. TCAS II equipped aircraft use continuous reply information to analyze the speed and trajectory of target aircraft in close proximity. If a collision is calculated to be imminent, an RA is issued.

TCAS target aircraft are displayed on a screen on the flight deck. Different colors and shapes are used to depict approaching aircraft depending on the imminent threat level. Since RAs are currently limited to vertical evasive maneuvers, some stand-alone TCAS displays are electronic vertical speed indicators. Most aircraft use some version of an electronic HSI on a navigational screen or page to display TCAS information. *[Figure 11-132]* A multifunction display may depict TCAS and weather radar information on the same screen. *[Figure 11-133]* A TCAS control panel *[Figure 11-134]* and computer are required to work with a compatible transponder and its antenna(s). Interface with EFIS or other previously installed or selected display(s) is also required.

Figure 11-132. *TCAS information displayed on an electronic vertical speed indicator.*

TCAS may be referred to as airborne collision avoidance system (ACAS), which is the international name for the same system. TCAS II with the latest revisions is known as Version

Figure 11-133. *TCAS information displayed on a multifunction display. An open diamond indicates a target; a solid diamond represents a target that is within 6 nautical miles of 1,2000 feet vertically. A yellow circle represents a target that generates a TA (25-48 seconds before contact). A red square indicates a target that generates an RA in TCAS II (contact within 35 seconds). A (+) indicates the target aircraft is above and a (-) indicates it is below. The arrows show if the target is climbing or descending.*

Figure 11-134. *This control panel from a Boeing 767 controls the transponder for ATC use and TCAS.*

7. The accuracy and reliability of this TCAS information is such that pilots are required to follow a TCAS RA over an ATC command.

ADS-B

Collision avoidance is a significant part of the FAA's NextGen plan for transforming the National Airspace System (NAS). Increasing the number of aircraft using the same quantity of airspace and ground facilities requires the implementation of new technologies to maintain a high level of performance and safety. The successful proliferation of global navigation satellite systems (GNSS), such as GPS, has led to the development of a collision avoidance system known as automatic dependant surveillance broadcast (ADS-B). ADS-B is an integral part of NextGen program. The implementation of its ground and airborne infrastructure is currently underway. ADS-B is active in parts of the United States and around the world. *[Figure 11-135]*

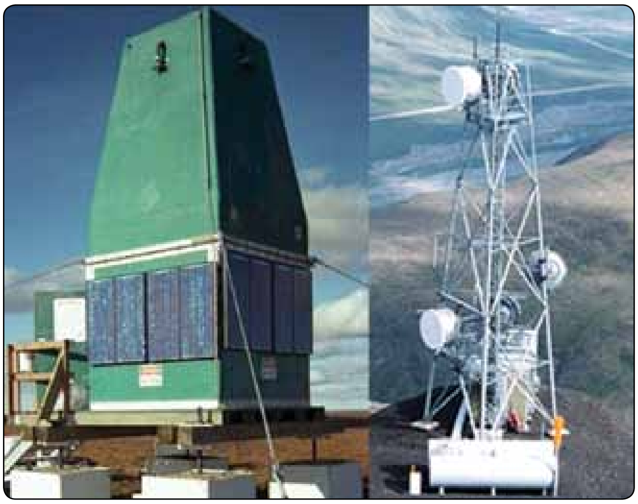


Figure 11-135. *Low power requirements allow remote ADS-B stations with only solar or propane support. This is not possible with ground radar due to high power demands which inhibit remote area radar coverage for air traffic purposes.*

ADS-B is considered in two segments: ADS-B OUT and ADS-B IN. ADS-B OUT combines the positioning information available from a GPS receiver with on-board flight status information, i.e. location including altitude, velocity, and time. It then broadcasts this information to other ADS-B equipped aircraft and ground stations. *[Figure 11-136]*

Two different frequencies are used to carry these broadcasts with data link capability. The first is an expanded use of the 1090 MHz Mode-S transponder protocol known as 1090 ES. The second, largely being introduced as a new broadband solution for general aviation implementation of ADS-B, is at 978 MHz. A 978 universal access transceiver (UAT) is used to accomplish this. An omni-directional antenna is required in addition to the GPS antenna and receiver. Airborne receivers of an ADS-B broadcast use the information to plot the location and movement of the transmitting aircraft on a flight deck display similar to TCAS. *[Figure 11-137]*

Inexpensive ground stations (compared to radar) are constructed in remote and obstructed areas to proliferate ADS-B. Ground stations share information from airborne ADS-B broadcasts with other ground stations that are part of the air traffic management system (ATMS). Data is transferred with no need for human acknowledgement. Microwave and satellite transmissions are used to link the network.

For traffic separation and control, ADS-B has several advantages over conventional ground-based radar. The first is the entire airspace can be covered with a much lower expense. The aging ATC radar system that is in place is expensive to maintain and replace. Additionally, ADS-B provides more accurate information since the vector state is generated from the aircraft with the help of GPS satellites. Weather is

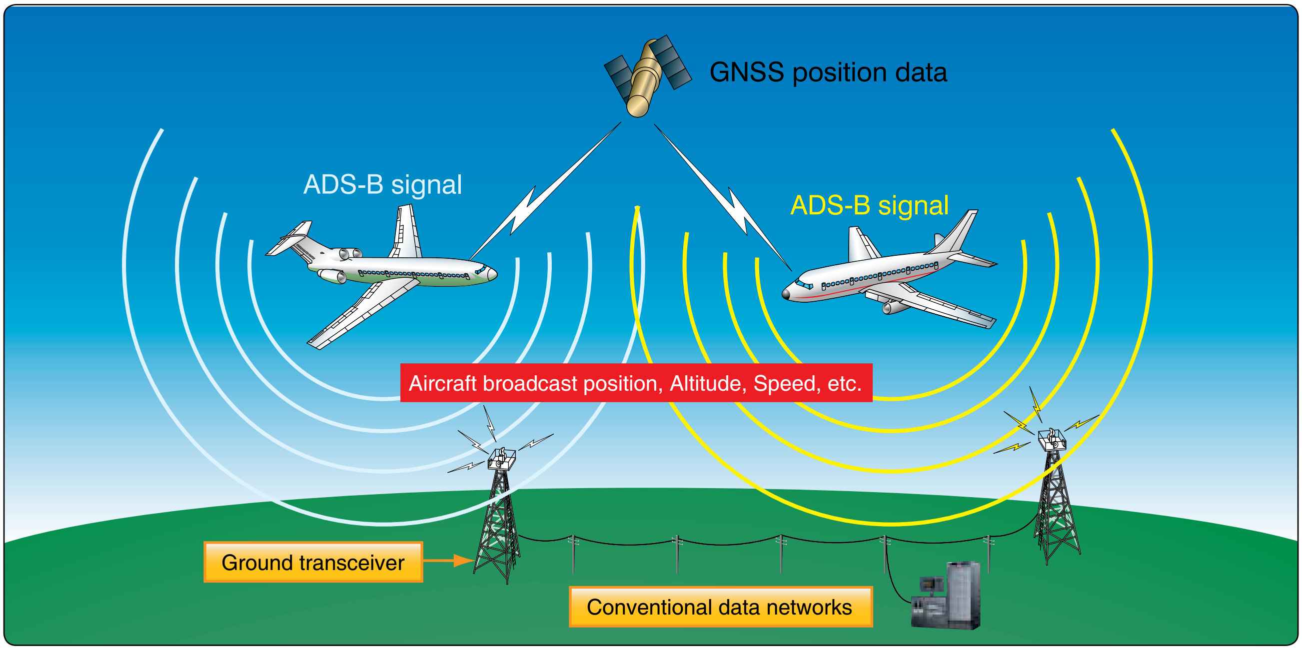


Figure 11-136. *ADS-B OUT uses satellites to identify the position aircraft. This position is then broadcast to other aircraft and to ground stations along with other flight status information.*

Figure 11-137. *A cockpit display of ADS-B generated targets (left) and an ADS-B airborne receiver with antenna (right).*

a greatly reduced factor with ADS-B. Ultra high frequency GPS transmissions are not affected. Increased positioning accuracy allows for higher density traffic flow and landing approaches, an obvious requirement to operate more aircraft in and out of the same number of facilities. The higher degree of control available also enables routing for fewer weather delays and optimal fuel burn rates. Collision avoidance is expanded to include runway incursion from other aircraft and support vehicles on the surface of an airport.

ADS-B IN offers features not available in TCAS. Equipped aircraft are able to receive abundant data to enhance situational awareness. Traffic information services-broadcast (TIS-B) supply traffic information from non-ADS-B aircraft and ADS-B aircraft on a different frequency. Ground radar monitoring of surface targets, and any traffic data in the linked network of ground stations is sent via ADS-B IN to the flight deck. This provides a more complete picture than air-to-air only collision avoidance. Flight information services-broadcast (FIS-B) are also received by ADS-B IN. Weather text and graphics, ATIS information, and NOTAMS are able to be received in aircraft that have 987 UAT capability. *[Figure 11-138]*

ADS-B test units are available for trained maintenance personnel to verify proper operation of ADS-B equipment. This is critical since close tolerance of air traffic separation depends on accurate data from each aircraft and throughout all components of the ADS-B system. *[Figure 11-139]*

Radio Altimeter

A radio altimeter, or radar altimeter, is used to measure the distance from the aircraft to the terrain directly beneath it. It is used primarily during instrument approach and low level or night flight below 2500 feet. The radio altimeter supplies the primary altitude information for landing decision height. It incorporates an adjustable altitude bug that creates a visual or aural warning to the pilot when the aircraft reaches that altitude. Typically, the pilot will abort a landing if the decision height is reached and the runway is not visible.

Using a transceiver and a directional antenna, a radio altimeter broadcasts a carrier wave at 4.3 GHz from the aircraft directly toward the ground. The wave is frequency modulated at 50 MHz and travels at a known speed. It strikes surface features and bounces back toward the aircraft where a second antenna receives the return signal. The transceiver processes the signal by measuring the elapsed time the signal traveled and the frequency modulation that occurred. The display indicates height above the terrain also known as above ground level (AGL). *[Figure 11-140]*

A radar altimeter is more accurate and responsive than an air pressure altimeter for AGL information at low altitudes. The transceiver is usually located remotely from the indicator. Multifunctional and glass cockpit displays typically integrate decision height awareness from the radar altimeter as a digital number displayed on the screen with a bug, light, or color change used to indicate when that altitude is reached. Large aircraft may incorporate radio altimeter information into a ground proximity warning system (GPWS) which aurally alerts the crew of potentially dangerous proximity to the terrain below the aircraft. A decision height window (DH) displays the radar altitude on the EADI in *Figure 11-141*.

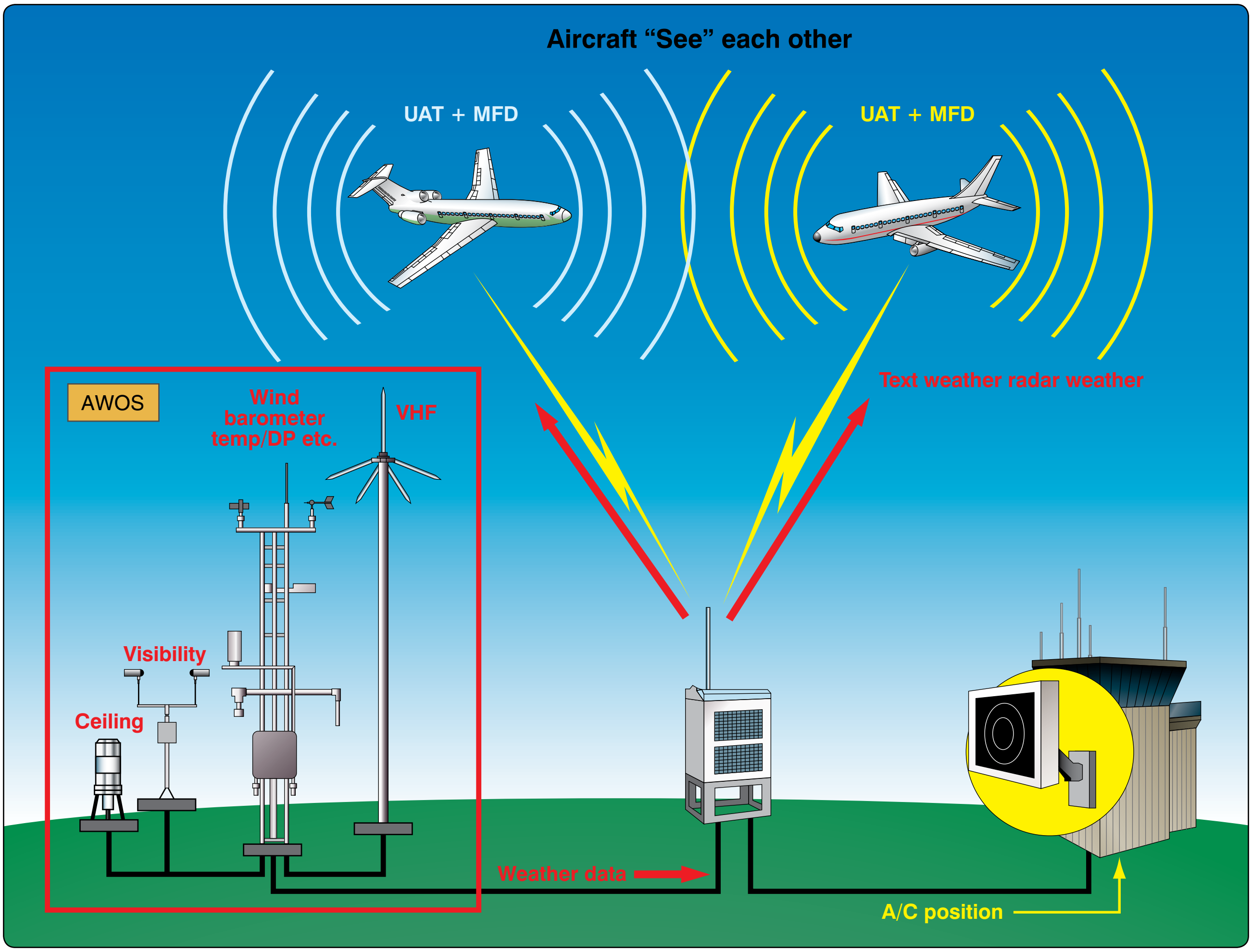


Figure 11-138. *ADS-B IN enables weather and traffic information to be sent into the flight deck. In addition to AWOS weather, NWS can also be transmitted.*

Figure 11-139. *An ADS-B test unit.*

Figure 11-140. *A digital display radio altimeter (top), and the two antennas and transceiver for a radio/radar altimeter (bottom).*

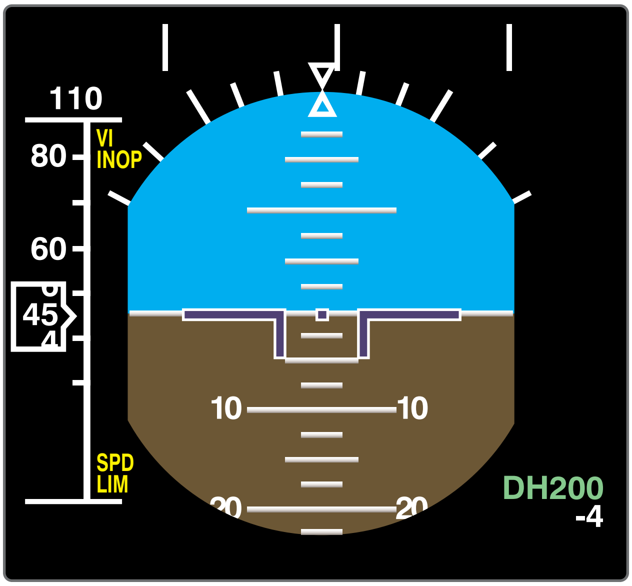


Figure 11-141. *The decision height, DH200, in the lower right corner of this EADI display uses the radar altimeter as the source of altitude information.*

Weather Radar

There are three common types of weather aids used in an aircraft flight deck that are often referred to as weather radar:

1. Actual on-board radar for detecting and displaying weather activity;
2. Lightning detectors; and
3. Satellite or other source weather radar information that is uploaded to the aircraft from an outside source.

On-board weather radar systems can be found in aircraft of all sizes. They function similar to ATC primary radar except the radio waves bounce off of precipitation instead of aircraft. Dense precipitation creates a stronger return than light precipitation. The on-board weather radar receiver is set up to depict heavy returns as red, medium return as yellow and light returns as green on a display in the flight deck. Clouds do not create a return. Magenta is reserved to depict intense or extreme precipitation or turbulence. Some aircraft have a dedicated weather radar screen. Most modern aircraft integrate weather radar display into the navigation display(s). *Figure 11-142* illustrates weather radar displays found on aircraft.

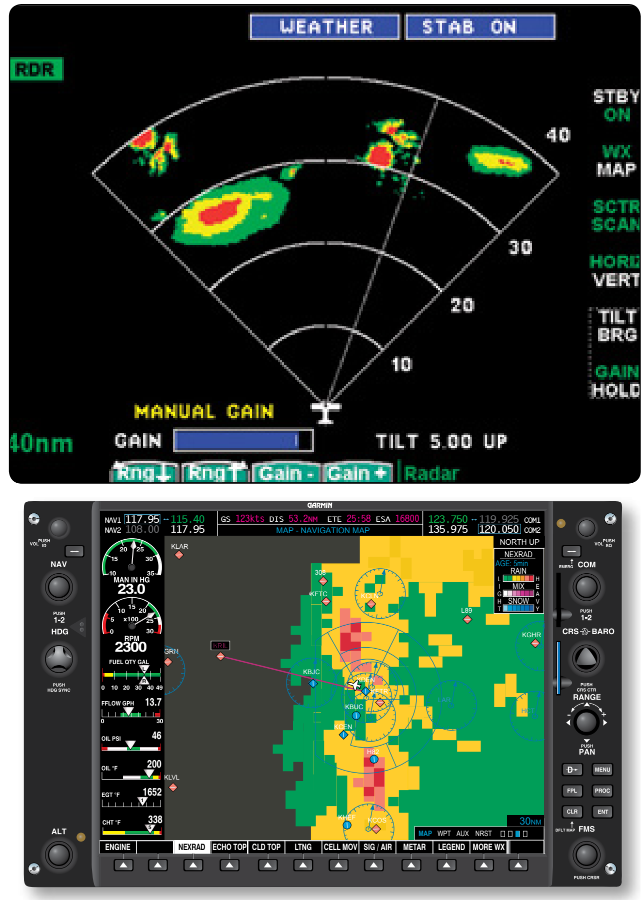


Figure 11-142. *A dedicated weather radar display (top) and a multifunctional navigation display with weather radar overlay (bottom).*

Radio waves used in weather radar systems are in the SHF range such as 5.44 GHz or 9.375 GHz. They are transmitted forward of the aircraft from a directional antenna usually located behind a non-metallic nose cone. Pulses of approximately 1 micro-second in length are transmitted. A duplexer in the radar transceiver switches the antenna to receive for about 2500 micro seconds after a pulse is transmitted to receive and process any returns. This cycle repeats and the receiver circuitry builds a two dimensional image of precipitation for display. Gain adjustments control the range of the radar. A control panel facilitates this and other adjustments. *[Figure 11-143]*

Severe turbulence, wind shear, and hail are of major concern to the pilot. While hail provides a return on weather radar, wind shear and turbulence must be interpreted from the movement of any precipitation that is detected. An alert is annunciated if this condition occurs on a weather radar system so equipped. Dry air turbulence is not detectable. Ground clutter must also be attenuated when the radar sweep includes any terrain features. The control panel facilitates this.

Special precautions must be followed by the technician during maintenance and operation of weather radar systems. The radome covering the antenna must only be painted with approved paint to allow the radio signals to pass unobstructed. Many radomes also contain grounding strips to conduct lightning strikes and static away from the dome.

Figure 11-143. *A typical on-board weather radar system for a high performance aircraft uses a nose-mounted antenna that gimbals. It is usually controlled by the inertial reference system (IRS) to automatically adjust for attitude changes during maneuvers so that the radar remains aimed at the desired weather target. The pilot may also adjust the angle and sweep manually as well as the gain. A dual mode control panel allows separate control and display on the left or right HSI or navigational display.*

When operating the radar, it is important to follow all manufacturer instructions. Physical harm is possible from the high energy radiation emitted, especially to the eyes and testes. Do not look into the antenna of a transmitting radar. Operation of the radar should not occur in hangars unless special radio wave absorption material is used. Additionally, operation of radar should not take place while the radar is pointed toward a building or when refueling takes place. Radar units should be maintained and operated only by qualified personnel.

Lightning detection is a second reliable means for identifying potentially dangerous weather. Lightning gives off its own electromagnetic signal. The azimuth of a lightning strike can be calculated by a receiver using a loop type antenna such as that used in ADF. *[Figure 11-144]* Some lightning detectors make use of the ADF antenna. The range of the lightning strike is closely associated with its intensity. Intense strikes are plotted as being close to the aircraft.

Stormscope is a proprietary name often associated with lightning detectors. There are others that work in a similar manner. A dedicated display plots the location of each strike within a 200 mile range with a small mark on the screen. As time progresses, the marks may change color to indicate their age. Nonetheless, a number of lightning strikes in a small area indicates a storm cell, and the pilot can navigate around it. Lightning strikes can also be plotted on a multifunctional navigation display. *[Figure 11-145]*

Figure 11-144. *A receiver and antenna from a lightning detector system.*

A third type of weather radar is becoming more common in all classes of aircraft. Through the use of orbiting satellite systems and/or ground up-links, such as described with ADS-B IN, weather information can be sent to an aircraft in flight virtually anywhere in the world. This includes text data as well as real-time radar information for overlay on an aircraft's navigational display(s). Weather radar data produced remotely and sent to the aircraft is refined through consolidation of various radar views from different angles and satellite imagery. This produces more accurate depictions of actual weather conditions. Terrain databases are integrated to eliminate ground clutter. Supplemental data includes the entire range of intelligence available from the National Weather Service (NWS) and the National

Figure 11-145. *A dedicated stormscope lightning detector display (left), and an electronic navigational display with lightning strikes overlaid in the form of green "plus" signs (right).*

Oceanographic and Atmospheric Administration (NOAA). *Figure 11-146* illustrates a plain language weather summary received in an aircraft along with a list of other weather information available through satellite or ground link weather information services.

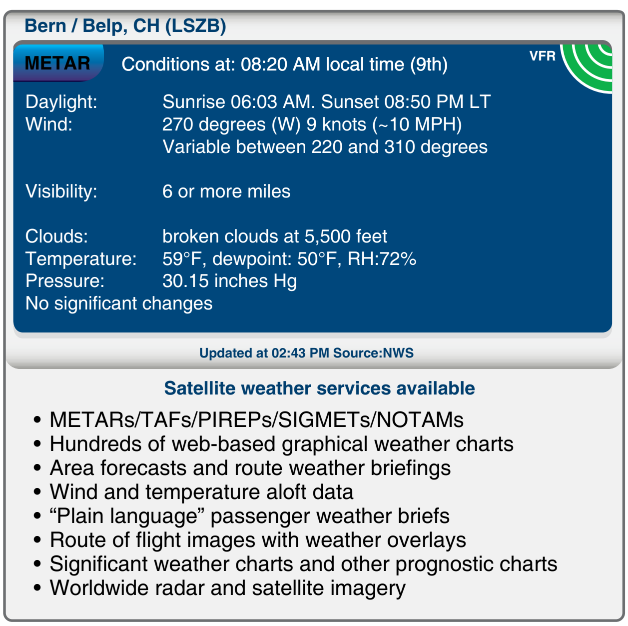


Figure 11-146. *A plain language METAR weather report received in the cockpit from a satellite weather service for aircraft followed by a list of various weather data that can be radioed to the cockpit from a satellite weather service.*

As mentioned, to receive an ADS-B weather signal, a 1090 ES or 970 UAT transceiver with associated antenna needs to be installed on board the aircraft. Satellite weather services are received by an antenna matched to the frequency of the service. Receivers are typically located remotely and interfaced with existing navigational and multifunction displays. Handheld GPS units also may have satellite weather capability. *[Figure 11-147]*

Emergency Locator Transmitter (ELT)

An emergency locator transmitter (ELT) is an independent battery powered transmitter activated by the excessive G-forces experienced during a crash. It transmits a digital signal every 50 seconds on a frequency of 406.025 MHz at 5 watts for at least 24 hours. The signal is received anywhere in the world by satellites in the COSPAS-SARSAT satellite system. Two types of satellites, low earth orbiting (LEOSATs) and geostationary satellites (GEOSATs) are used with different, complimentary capability. The signal is partially processed and stored in the satellites and then relayed to ground stations known as local user terminals (LUTs). Further deciphering of a signal takes place at the LUTs, and appropriate search and rescue operations are notified through mission control centers (MCCs) set up for this purpose.

NOTE: Maritime vessel emergency locating beacons (EPIRBs) and personal locator beacons (PLBs) use the exact same system. The United States portion of the COSPAS-SARSAT system is maintained and operated by NOAA. *Figure 11-148* illustrates the basic components in the COSPAS-SARSAT system.

Figure 11-147. *A satellite weather receiver and antenna enable display of real-time textual and graphic weather information beyond that of airborne weather radar. A handheld GPS can also be equipped with these capabilities. A built-in multifunctional display with satellite weather overlays and navigation information can be found on many aircraft.*

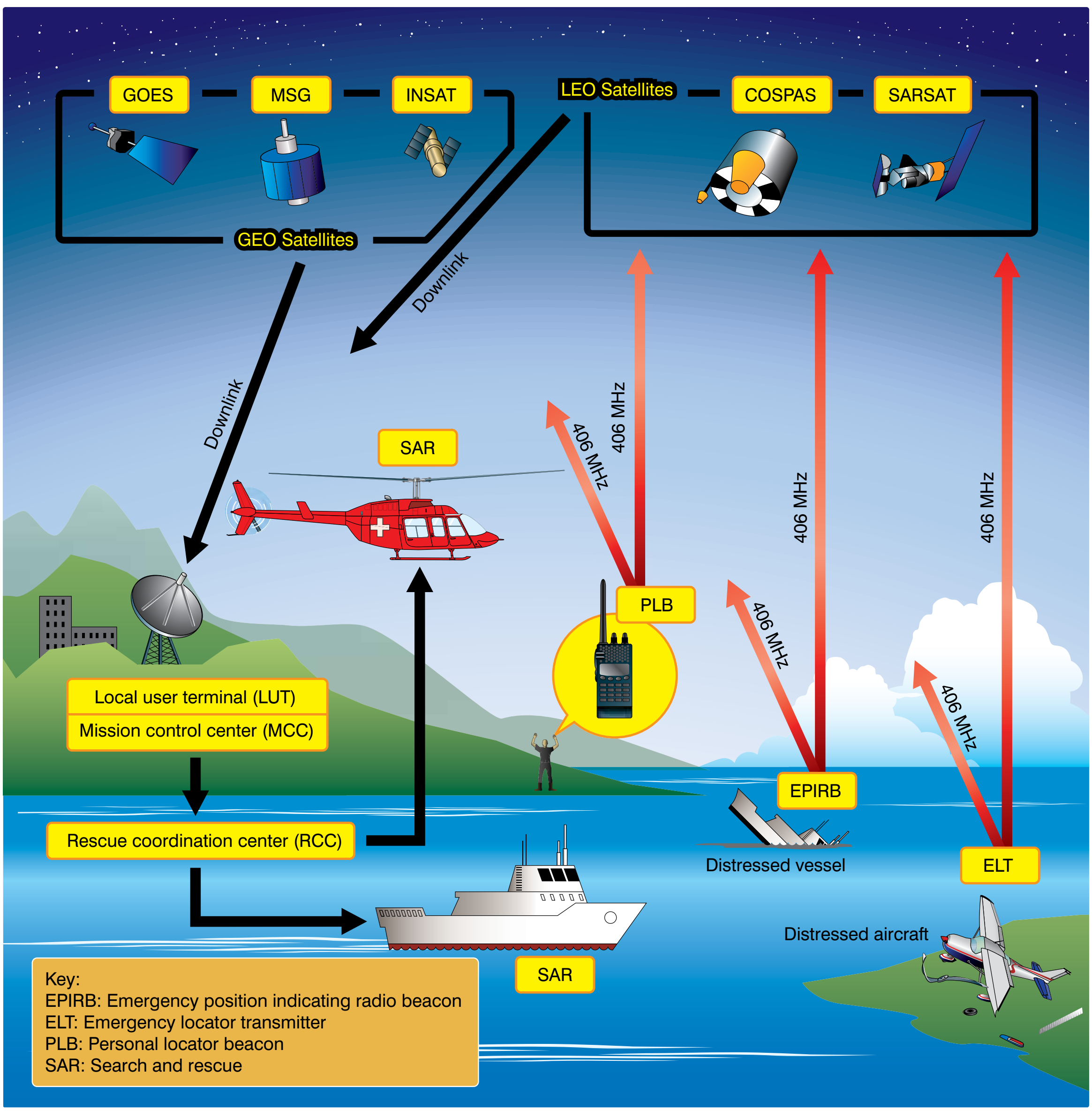


Figure 11-148. *The basic operating components of the satellite-based COSPAS-SARSAT rescue system of which aircraft ELTs are a part.*

ELTs are required to be installed in aircraft according to FAR 91.207. This encompasses most general aviation aircraft not operating under Parts 135 or 121. ELTs must be inspected within 12 months of previous inspection for proper installation, battery corrosion, operation of the controls and crash sensor, and the presence of a sufficient signal at the antenna. Built-in test equipment facilitates testing without transmission of an emergency signal. The remainder of the inspection is visual. Technicians are cautioned to not activate the ELT and transmit an emergency distress signal. Inspection must be recorded in maintenance records including the new expiration date of the battery. This must also be recorded on the outside of the ELT.

ELTs are typically installed as far aft in the fuselage of an aircraft as is practicable just forward of the empennage. The built-in G-force sensor is aligned with the longitudinal axis of the aircraft. Helicopter ELTs may be located elsewhere on the airframe. They are equipped with multidirectional activation devices. Follow ELT and airframe manufacturer's instructions for proper installation, inspection, and maintenance of all ELTs. *Figure 11-149* illustrates ELTs mounted locations.

Figure 11-149. *An emergency locator transmitter (ELT) mounting location is generally far aft in a fixed-wing aircraft fuselage in line with the longitudinal axis. Helicopter mounting location and orientation varies.*

Use of Doppler technology enables the origin of the 406 MHz ELT signal to be calculated within 2 to 5 kilometers. Second generation 406 MHz ELT digital signals are loaded with GPS location coordinates from a receiver inside the ELT unit or integrated from an outside unit. This reduces the location accuracy of the crash site to within 100 meters. The digital signal is also loaded with unique registration information. It identifies the aircraft, the owner, and contact information, etc. When a signal is received, this is used to immediately research the validity of the alert to ensure it is a true emergency transmission so that rescue resources are not deployed needlessly.

ELTs with automatic G-force activation mounted in aircraft are easily removable. They often contain a portable antenna so that crash victims may leave the site and carry the operating ELT with them. A flight deck mounted panel is required to alert the pilot if the ELT is activated. It also allows the ELT to be armed, tested, and manually activated if needed. *[Figure 11-150]*

Figure 11-150. *An ELT and its components including a cockpit-mounted panel, the ELT, a permanent mount antenna, and a portable antenna.*

Modern ELTs may also transmit a signal on 121.5 MHz. This is an analog transmission that can be used for homing. Prior to 2009, 121.5 MHz was a worldwide emergency frequency monitored by the CORPAS-SARSAT satellites. However, it has been replaced by the 406 MHz standard. Transmission on 121.5 MHz are no longer received and relayed via satellite.

The use of a 406 MHz ELT has not been mandated by the FAA. An older 121.5 MHz ELT satisfies the requirements of FAR Part 91.207 in all except new aircraft. Thousands of aircraft registered in the United States remain equipped with ELTs that transmit a .75 watt analog 121.5 MHz emergency signal when activated. The 121.5 MHz frequency is still an active emergency frequency and is monitored by over-flying aircraft and control towers.

Technicians are required to perform an inspection/test of 121.5 MHz ELTs within 12 months of the previous one and inspect for the same integrity as required for the 406MHz ELTs mentioned above. However, older ELTs often lack the built-in test circuitry of modern ELTs certified to TSO C-126. Therefore, a true operational test may include activating the signal. This can be done by removing the antenna and installing a dummy load. Any activation of an ELT signal is required to only be done between the top of each hour and 5 minutes after the hour. The duration of activation must be no longer than three audible sweeps. Contact of the local control tower or flight service station before testing is recommended.

It must be noted that older 121.5 MHz analog signal ELTs often also transmit an emergency signal on a frequency of 243.0 MHz. This has long been the military emergency frequency. Its use is being phased out in favor of digital ELT signals and satellite monitoring. Improvements in coverage, location accuracy, identification of false alerts, and shortened response times are so significant with 406 MHz ELTs, they are currently the service standard worldwide.

Long Range Aid to Navigation System (LORAN)

Long range aid to navigation system (LORAN) is a type of RNAV that is no longer available in the United States. It was developed during World War II, and the most recent edition, LORAN-C, has been very useful and accurate to aviators as well as maritime sailors. LORAN uses radio wave pulses from a series of towers and an on-board receiver/computer to positively locate an aircraft amid the tower network. There are twelve LORAN transmitter tower "chains" constructed across North America. Each chain has a master transmitter tower and a handful of secondary towers. All broadcasts from the transmitters are at the same frequency, 100 KHz. Therefore, a LORAN receiver does not need to be tuned. Being in the low frequency range, the LORAN transmissions travel long distances and provide good coverage from a small number of stations.

Precisely-timed, synchronized pulse signals are transmitted from the towers in a chain. The LORAN receiver measures the time to receive the pulses from the master tower and two other towers in the chain. It calculates the aircraft's position based on the intersection of parabolic curves representing elapsed signal times from each of these known points.

The accuracy and proliferation of GPS navigation has caused the U.S. Government to cease support for the LORAN navigation system citing redundancy and expense of operating the towers as reasons. The LORAN chain in the Aleutian Island shared with Russia is the only LORAN chain at the time of printing of this handbook which had not yet been given a date for closure. Panel-mounted LORAN navigation units will likely be removed and replaced by GPS units in aircraft that have not already done so. *[Figure 11-151]*

Figure 11-151. *Panel-mounted LORAN units are now obsolete as LORAN signals are no longer generated from the tower network.*

Global Positioning System (GPS)

Global positioning system navigation (GPS) is the fastest growing type of navigation in aviation. It is accomplished through the use of NAVSTAR satellites set and maintained in orbit around the earth by the U.S. Government. Continuous coded transmissions from the satellites facilitate locating the position of an aircraft equipped with a GPS receiver with extreme accuracy. GPS can be utilized on its own for en route navigation, or it can be integrated into other navigation systems, such as VOR/RNAV, inertial reference, or flight management systems.

There are three segments of GPS: the space segment, the control segment, and the user segment. Aircraft technicians are only involved with user segment equipment such as GPS receivers, displays, and antennas.

Twenty-four satellites (21 active, 3 spares) in six separate plains of orbit 12, 625 feet above the planet comprise what is known as the space segment of the GPS system. The satellites are positioned such that in any place on earth at any one time, at least four will be a minimum of 15° above the horizon. Typically, between 5 and 8 satellites are in view. *[Figure 11-152]*

Two signals loaded with digitally coded information are transmitted from each satellite. The L1 channel transmission on a1575.42 MHz carrier frequency is used in civilian aviation. Satellite identification, position, and time are conveyed to the aircraft GPS receiver on this digitally modulated signal along with status and other information. An L2 channel 1227.60 MHz transmission is used by the military.

The amount of time it takes for signals to reach the aircraft GPS receiver from transmitting satellites is combined with each satellite's exact location to calculate the position of

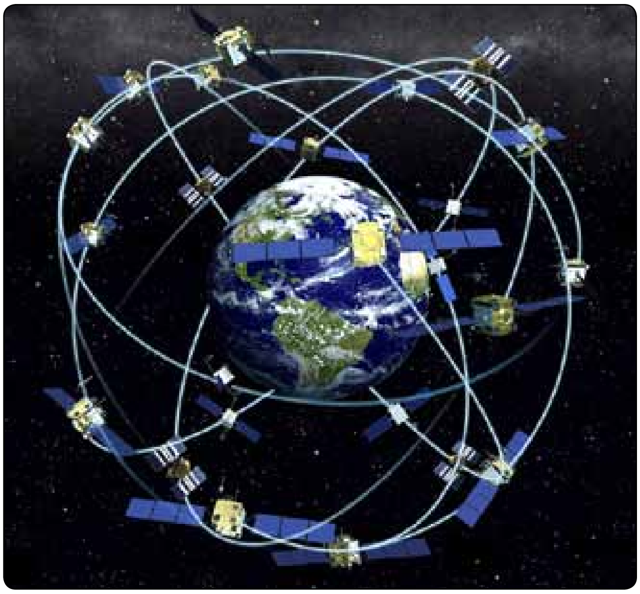


Figure 11-152. *The space segment of GPS consists of 24 NAVSTAR satellites in six different orbits around the earth.*

an aircraft. The control segment of the GPS monitors each satellite to ensure its location and time are precise. This control is accomplished with five ground-based receiving stations, a master control station, and three transmitting antenna. The receiving stations forward status information received from the satellites to the master control station. Calculations are made and corrective instructions are sent to the satellites via the transmitters.

The user segment of the GPS is comprised of the thousands of receivers installed in aircraft as well as every other receiver that uses the GPS transmissions. Specifically, for the aircraft technician, the user section consists of a control panel/display, the GPS receiver circuitry, and an antenna. The control, display and receiver are usually located in a single unit which also may include VOR/ILS circuitry and a VHF communications transceiver. GPS intelligence is integrated into the multifunctional displays of glass cockpit aircraft. *[Figure 11-153]*

The GPS receiver measures the time it takes for a signal to arrive from three transmitting satellites. Since radio waves travel at 186,000 miles per second, the distance to each satellite can be calculated. The intersection of these ranges provides a two dimensional position of the aircraft. It is expressed in latitude/longitude coordinates. By incorporating the distance to a fourth satellite, the altitude above the surface of the earth can be calculated as well. This results in a three dimensional fix. Additional satellite inputs refine the accuracy of the position.

Figure 11-153. *A GPS unit integrated with NAV/COM circuitry.*

Having deciphered the position of the aircraft, the GPS unit processes many useful navigational outputs such as speed, direction, bearing to a waypoint, distance traveled, time of arrival, and more. These can be selected to display for use. Waypoints can be entered and stored in the unit's memory. Terrain features, airport data, VOR/RNAV and approach information, communication frequencies, and more can also be loaded into a GPS unit. Most modern units come with moving map display capability.

A main benefit of GPS use is immunity from service disruption due to weather. Errors are introduced while the carrier waves travel through the ionosphere; however, these are corrected and kept to a minimum. GPS is also relatively inexpensive. GPS receivers for IFR navigation in aircraft must be built to TSO-129A. This raises the price above that of handheld units used for hiking or in an automobile. But the overall cost of GPS is low due to its small infrastructure. Most of the inherent accuracy is built into the space and control segments permitting reliable positioning with inexpensive user equipment.

The accuracy of current GPS is within 20 meters horizontally and a bit more vertically. This is sufficient for en route navigation with greater accuracy than required. However, departures and approaches require more stringent accuracy. Integration of the wide area augmentation system (WAAS) improves GPS accuracy to within 7.6 meters and is discussed below. The future of GPS calls for additional accuracy by adding two new transmissions from each satellite. An L2C channel will be for general use in non-safety critical application. An aviation dedicated L5 channel will provide the accuracy required for category I, II, and III landings. It will enable the NEXTGEN NAS plan along with ADS-B. The first replacement NAVSTAR satellites with L2C and L5 capability have already been launched. Full implementation is schedule by 2015.

Wide Area Augmentation System (WAAS)

To increase the accuracy of GPS for aircraft navigation, the wide area augmentation system (WAAS) was developed. It consists of approximately 25 precisely surveyed ground stations that receive GPS signals and ultimately transmit correction information to the aircraft. An overview of WAAS components and its operation is shown in *Figure 11-154*.

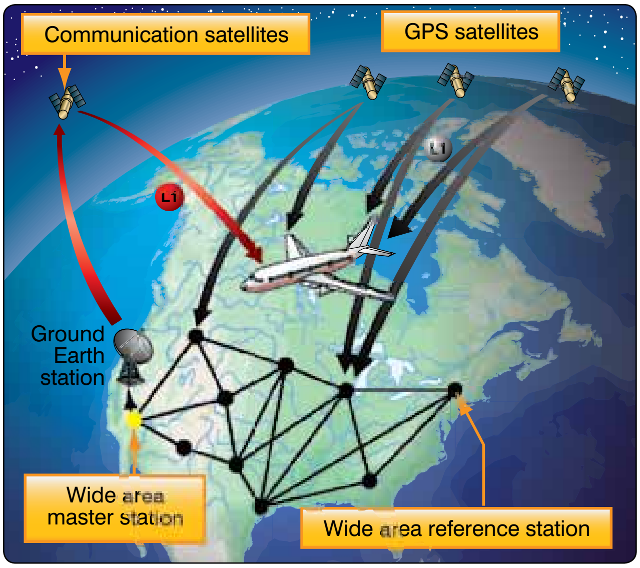


Figure 11-154. *The wide area augmentation system (WAAS) is used to refine GPS positions to a greater degree of accuracy. A WAAS enabled GPS receiver is required for its use as corrective information is sent from geostationary satellites directly to an aircraft's GPS receiver for use.*

WAAS ground stations receive GPS signals and forward position errors to two master ground stations. Time and location information is analyzed, and correction instructions are sent to communication satellites in geostationary orbit over the NAS. The satellites broadcast GPS-like signals that WAAS enabled GPS receivers use to correct position information received from GPS satellites.

A WAAS enable GPS receiver is required to use the wide area augmentation system. If equipped, an aircraft qualifies to perform precision approaches into thousands of airports without any ground-based approach equipment. Separation minimums are also able to be reduced between aircraft that are WAAS equipped. The WAAS system is known to reduce position errors to 1–3 meters laterally and vertically.

Inertial Navigation System (INS)/Inertial Reference System (IRS)

An inertial navigation system (INS) is used on some large aircraft for long range navigation. This may also be identified as an inertial reference system (IRS), although the IRS designation is generally reserved for more modern systems. An INS/IRS is a self contained system that does not require input radio signals from a ground navigation facility or transmitter. The system derives attitude, velocity, and direction information from measurement of the aircraft's accelerations given a known starting point. The location of the aircraft is continuously updated through calculations based on the forces experienced by INS accelerometers. A minimum of two accelerometers is used, one referenced to north, and the other referenced to east. In older units, they are mounted on a gyro-stabilized platform. This averts the introduction of errors that may result from acceleration due to gravity.

An INS uses complex calculation made by an INS computer to convert applied forces into location information. An interface control head is used to enter starting location position data while the aircraft is stationary on the ground. This is called initializing. *[Figure 11-155]* From then on, all motion of the aircraft is sensed by the built-in accelerometers and run through the computer. Feedback and correction loops are used to correct for accumulated error as flight time progresses. The amount an INS is off in one hour of flight time is a reference point for determining performance. Accumulated error of less than one mile after one hour of flight is possible. Continuous accurate adjustment to the gyro-stabilized platform to keep it parallel to the Earth's surface is a key requirement to reduce accumulated error. A latitude/longitude coordinate system is used when giving the location output.

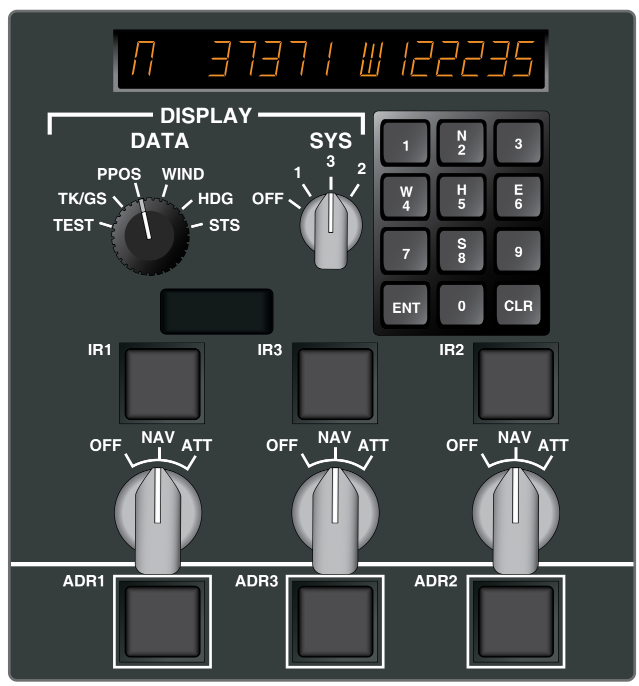


Figure 11-155. *An interface panel for three air data and inertial reference systems on an Airbus. The keyboard is used to initialize the system. Latitude and longitude position is displayed at the top.*

INS is integrated into an airliner's flight management system and automatic flight control system. Waypoints can be entered for a predetermined flightpath and the INS will guide the aircraft to each waypoint in succession. Integration with other NAV aids is also possible to ensure continuous correction and improved accuracy but is not required.

Modern INS systems are known as IRS. They are completely solid-state units with no moving parts. Three-ring, laser gyros replace the mechanical gyros in the older INS platform systems. This eliminates precession and other mechanical gyro shortcomings. The use of three solid-state accelerometers, one for each plane of movement, also increases accuracy. The accelerometer and gyro output are input to the computer for continuous calculation of the aircraft's position.

The most modern IRS integrate is the satellite GPS. The GPS is extremely accurate in itself. When combined with IRS, it creates one of the most accurate navigation systems available. The GPS is used to initialize the IRS so the pilot no longer needs to do so. GPS also feeds data into the IRS computer to be used for error correction. Occasional service interruptions and altitude inaccuracies of the GPS system pose no problem for IRS/GPS. The IRS functions continuously and is completely self contained within the IRS unit. Should the GPS falter, the IRS portion of the system continues without it. The latest electronic technology has reduced the size and weight of INS/IRS avionics units significantly. *Figure 11-156* shows a modern micro-IRS unit that measures approximately 6-inches on each side.

Figure 11-156. *A modern micro-IRS with built-in GPS.*

Installation of Communication and Navigation Equipment

Approval of New Avionics Equipment Installations

Most of the avionics equipment discussed in this chapter is only repairable by the manufacturer or FAA-certified repair stations that are licensed to perform specific work. The airframe technician; however, must competently remove, install, inspect, maintain, and troubleshoot these ever increasingly complicated electronic devices and systems. It is imperative to follow all equipment and airframe manufacturers' instruction when dealing with an aircraft's avionics.

The revolution to GPS navigation and the pace of modern electronic development results in many aircraft owner operators upgrading flight decks with new avionics. The aircraft technician must only perform airworthy installations. The avionics equipment to be installed must be a TSO'd device that is approved for installation in the aircraft in question. The addition of a new piece of avionics equipment and/or its antenna is a minor alteration if previously approved by the airframe manufacturer. A licensed airframe technician is qualified to perform the installation and return the aircraft to service. The addition of new avionics not on the aircraft's approved equipment list is considered a major alteration and requires an FAA Form 337 to be enacted. A technician with an inspection authorization is required to complete a Form 337.

Most new avionics installations are approved and performed under an STC. The equipment manufacturer supplies a list of aircraft on which the equipment has been approved for installation. The STC includes thorough installation and maintenance instructions which the technician must follow. Regardless, if not on the aircraft's original equipment list, the STC installation is considered a major alteration and an FAA Form 337 must be filed. The STC is referenced as the required approved data.

Occasionally, an owner/operator or technician wishes to install an electronic device in an aircraft that has no STC for the model aircraft in question. A field approval and a Form 337 must be filed on which it must be shown that the installation will be performed in accordance with approved data.

Considerations

There are many factors which the technician must consider prior to altering an aircraft by the addition of avionics equipment. These factors include the space available, the size and weight of the equipment, and previously accomplished alterations. The power consumption of the added equipment must be considered to calculate and determine the maximum continuous electrical load on the aircraft's electrical system.

Each installation should also be planned to allow easy access for inspection, maintenance, and exchange of units.

The installation of avionics equipment is partially mechanical, involving sheet metal work to mount units, racks, antennas, and controls. Routing of the interconnecting wires, cables, antenna leads, etc. is also an important part of the installation process. When selecting a location for the equipment, use the area(s) designated by the airframe manufacturer or the STC. If such information is not available, select a location for installation that will carry the loads imposed by the weight of the equipment, and which is capable of withstanding the additional inertia forces.

If an avionics device is to be mounted in the instrument panel and no provisions have been made for such an installation, ensure that the panel is not a primary structure prior to making any cutouts. To minimize the load on a stationary instrument panel, a support bracket may be installed between the rear of the electronics case or rack and a nearby structural member of the aircraft. *[Figure 11-157]*

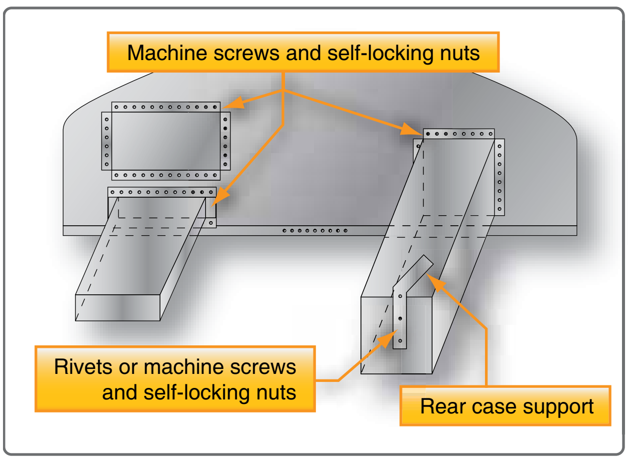


Figure 11-157. *An avionics installation in a stationary instrument panel may include a support for the avionics case.*

Avionics radio equipment must be securely mounted to the aircraft. All mounting bolts must be secured by locking devices to prevent loosening from vibration. Adequate clearance between all units and adjacent structure must be provided to prevent mechanical damage to electric wiring or to the avionic equipment from vibration, chafing, or landing shock.

Do not locate avionics equipment and wiring near units containing combustible fluids. When separation is impractical, install baffles or shrouds to prevent contact of the combustible fluids with any electronic equipment in the event of plumbing failure.

Cooling and Moisture

The performance and service life of most avionics equipment is seriously limited by excessive ambient temperatures. High performance aircraft with avionics equipment racks typically route air-conditioned air over the avionics to keep them cool. It is also common for non-air conditioned aircraft to use a blower or scooped ram air to cool avionics installations. When adding a unit to an aircraft, the installation should be planned so that it can dissipate heat readily. In some installations, it may be necessary to produce airflow over the new equipment either with a blower or through the use of routed ram air. Be sure that proper baffling is used to prevent water from reaching any electronics when ducting outside air. The presence of water in avionics equipment areas promotes rapid deterioration of the exposed components and could lead to failure.

Vibration Isolation

Vibration is a continued motion by an oscillating force. The amplitude and frequency of vibration of the aircraft structure will vary considerably with the type of aircraft. Avionics equipment is sensitive to mechanical shock and vibration and is normally shock mounted to provide some protection against in-flight vibration and landing shock.

Special shock mounted racks are often used to isolate avionics equipment from vibrating structure. *[Figure 11-158]* Such mounts should provide adequate isolation over the entire range of expected vibration frequencies. When installing shock mounts, assure that the equipment weight does not exceed the weight-carrying capabilities of the mounts. Radio equipment installed on shock mounts must have sufficient clearance from surrounding equipment and structure to allow for normal swaying of the equipment.

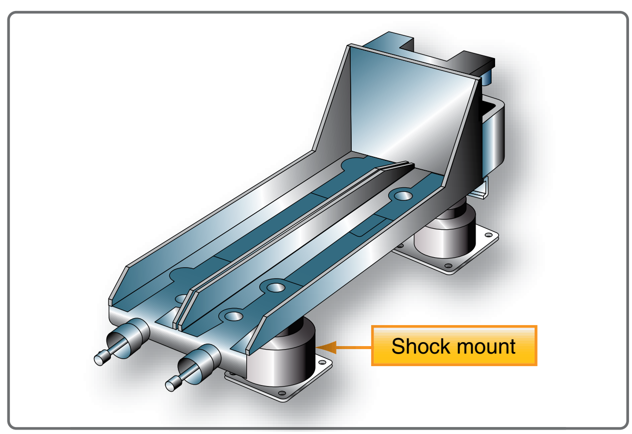


Figure 11-158. *A shock mounted equipment rack is often used to install avionics.*

Radios installed in instrument panels do not ordinarily require vibration protection since the panel itself is usually shock mounted. However, make certain that the added weight of any added equipment can be safely carried by the existing mounts. In some cases, it may be necessary to install larger capacity mounts or to increase the number of mounting points.

Periodic inspection of the shock mounts is required and defective mounts should be replaced with the proper type. The following factors to observe during the inspection are:

1. Deterioration of the shock-absorbing material;
2. Stiffness and resiliency of the material; and
3. Overall rigidity of the mount.

If the mount is too stiff, it may not provide adequate protection against the shock of landing. If the shock mount is not stiff enough, it may allow prolonged vibration following an initial shock.

Shock-absorbing materials commonly used in shock mounts are usually electrical insulators. For this reason, each electronic unit mounted with shock mounts must be electrically bonded to a structural member of the aircraft to provide a current path to ground. This is accomplished by secure attachment of a tinned copper wire braid from the component, across the mount, to the aircraft structure as shown in *Figure 11-159*. Occasional bonding is accomplished with solid aluminum or copper material where a short flexible strap is not possible.

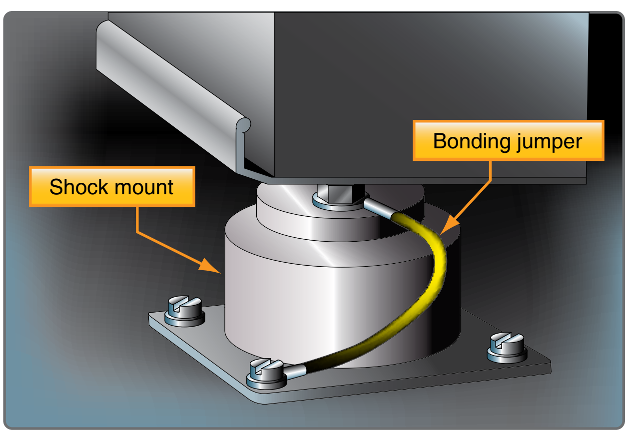


Figure 11-159. *A bonding jumper is used to ground an equipment rack and avionics chassis around the non-conductive shock mount material.*

Reducing Radio Interference

Suppression of unwanted electromagnetic fields and electrostatic interference is essential on all aircraft. In communication radios, this is noticeable as audible noise. In other components, the effects may not be audible but pose a threat to proper operation. Large discharges of static electricity can permanently damage the sensitive solid-state microelectronics found in nearly all modern avionics.

Shielding

Many components of an aircraft are possible sources of electrical interference which can deteriorate the performance and reliability of avionics components. Rotating electrical devices, switching devices, ignition systems, propeller control systems, AC power lines, and voltage regulators all produce potential damaging fields. Shielding wires to electric components and ignition systems dissipates radio frequency noise energy. Instead of radiating into space, the braided conductive shielding guides unwanted current flows to ground. To prevent the build-up of electrical potential, all electrical components should also be bonded to the aircraft structure (ground).

Isolation

Isolation is another practical method of radio frequency suppression to prevent interference. This involves separating the source of the noise from the input circuits of the affected equipment. In some cases, noise in a receiver may be entirely eliminated simply by moving the antenna lead-in wire just a few inches away from a noise source. On other occasions, when shielding and isolation are not effective, a filter may need to be installed in the input circuit of an affected component.

Bonding

The aircraft surface can become highly charged with static electricity while in flight. Measures are required to eliminate the build-up and radiation of unwanted electrical charges. One of the most important measures taken to eliminate unwanted electrical charges which may damage or interfere with avionics equipment is bonding. Charges flowing in paths of variable resistance due to such causes as intermittent contact from vibration or the movement of a control surface produce electrical disturbances (noise) in avionics. Bonding provides the necessary electric connection between metallic parts of an aircraft to prevent variable resistance in the airframe. It provides a low-impedance ground return which minimizes interference from static electricity charges.

All metal parts of the aircraft should be bonded to prevent the development of electrical potential build-up. Bonding also provides the low resistance return path for single-wire electrical systems. Bonding jumpers and clamps are examples of bonding connectors. Jumpers should be as short as possible. Be sure finishes are removed in the contact area of a bonding device so that metal-to-metal contact exists. Resistance should not exceed .003 ohm. When a jumper is used only to reduce radio frequency noise and is not for current carrying purposes, a resistance of 0.01 ohm is satisfactory.

Static Discharge Wicks

Static dischargers, or wicks, are installed on aircraft to reduce radio receiver interference. This interference is caused by corona discharge emitted from the aircraft as a result of precipitation static. Corona occurs in short pulses which produce noise at the radio frequency spectrum. Static dischargers are normally mounted on the trailing edges of the control surfaces, wing tips and the vertical stabilizer. They discharge precipitation static at points a critical distance away from avionics antennas where there is little or no coupling of the static to cause interference or noise.

Flexible and semi-flexible dischargers are attached to the aircraft structure by metal screws, rivets, or epoxy. The connections should be checked periodically for security. A resistance measurement from the mount to the airframe should not exceed 0.1 ohm. Inspect the condition of all static dischargers in accordance with manufacturer's instructions. *Figure 11-160* illustrates examples of static dischargers.

Installation of Aircraft Antenna Systems

Knowledge of antenna installation and maintenance is especially important as these tasks are performed by the aircraft technician. Antennas take many forms and sizes dependent upon the frequency of the transmitter and receiver to which they are connected. Airborne antennas must be mechanically secure. The air loads on an antenna are significant and must be considered. Antennas must be electrically matched to the receiver and transmitter which they serve. They must also be mounted in interference free locations and in areas where signals can be optimally transmitted and received. Antennas must also have the same polarization as the ground station.

The following procedures describe the installation of a typical rigid antenna. They are presented as an example only. Always follow the manufacturer's instructions when installing any antenna. An incorrect antenna installation could cause equipment failure.

1. Place a template similar to that shown in *Figure 11-161* on the fore-and-aft centerline at the desired location. Drill the mounting holes and correct diameter hole for the transmission line cable in the fuselage skin.

Figure 11-160. *Static dischargers or wicks dissipate built up static energy in flight at points a safe distance from avionics antennas to prevent radio frequency interference.*

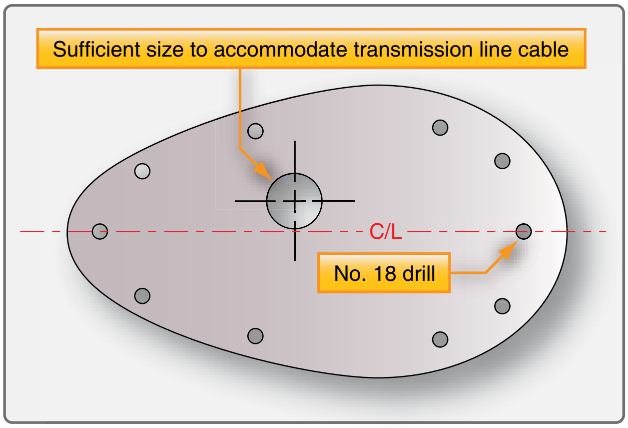


Figure 11-161. *A typical antenna mounting template.*

2. Install a reinforcing doubler of sufficient thickness to reinforce the aircraft skin. The length and width of the reinforcing plate should approximate the example shown in *Figure 11-162*.

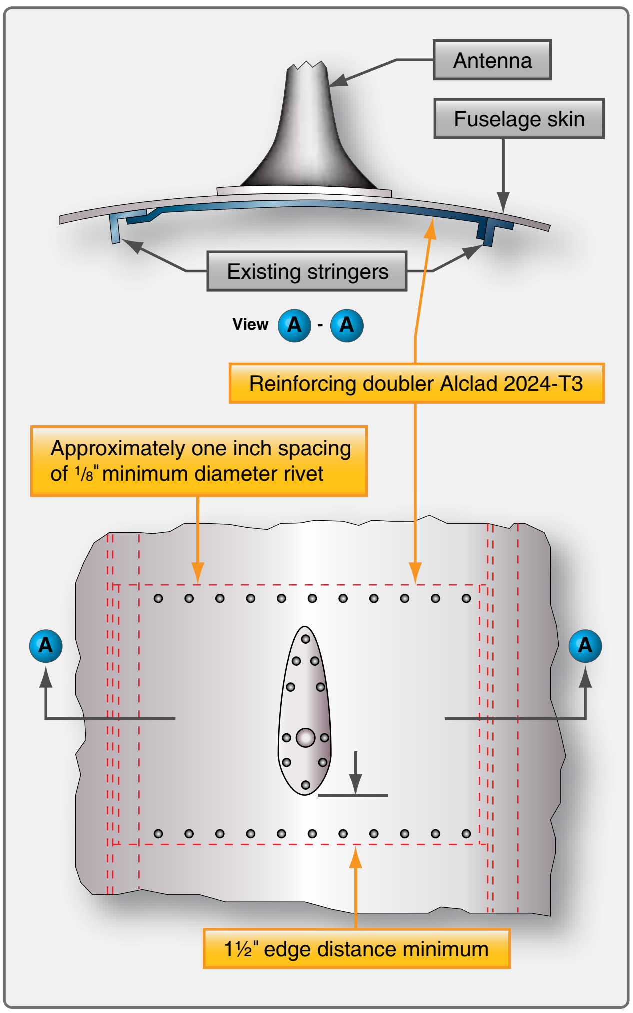


Figure 11-162. *A typical antenna installation on a skin panel including a doubler.*

3. Install the antenna on the fuselage, making sure that the mounting bolts are tightened firmly against the reinforcing doubler, and the mast is drawn tight against the gasket. If a gasket is not used, seal between the mast and the fuselage with a suitable sealer, such as zinc chromate paste or equivalent.

The mounting bases of antennas vary in shape and sizes; however, the aforementioned installation procedure is typical of mast-type antenna installations.

Transmission Lines

A transmitting or receiving antenna is connected directly to its associated transmitter or receiver by a transmission line. This is a shielded wire also known as coax. Transmission lines may vary from only a few feet to many feet in length. They must transfer energy with minimal loss. Transponders, DME and other pulse type transceivers require transmission lines that are precise in length. The critical length of transmission lines provides minimal attenuation of the transmitted or received signal. Refer to the equipment manufacturer's installation manual for the type and allowable length of transmission lines.

To provide the proper impedance matching for the most efficient power transfer, a balun may be used in some antenna installations. It is formed in the transmission line connection to the antenna. A balun in a dipole antenna installation is illustrated in *Figure 11-163*.

Coax connectors are usually used with coax cable to ensure a secure connection. Many transmission lines are part of the equipment installation kit with connectors previously installed. The aircraft technician is also able to install these connectors on coax. *Figure 11-164* illustrates the basic steps used when installing a coax cable connector.

When installing coaxial cable, secure the cables firmly along their entire length at intervals of approximately 2 feet. To assure optimum operation, coaxial cables should not be routed or tied to other wire bundles. When bending coaxial cable, be sure that the bend is at least 10 times the size of the cable diameter. In all cases, follow the equipment manufacturer's instructions.

Maintenance Procedure

Detailed instructions, procedures, and specifications for the servicing of avionics equipment are contained in the manufacturer's operating manuals. Additional instructions for removal and installation of the units are contained in the maintenance manual for the aircraft in which the equipment is installed. Although an installation may appear to be a simple procedure, many avionics troubles are attributed to

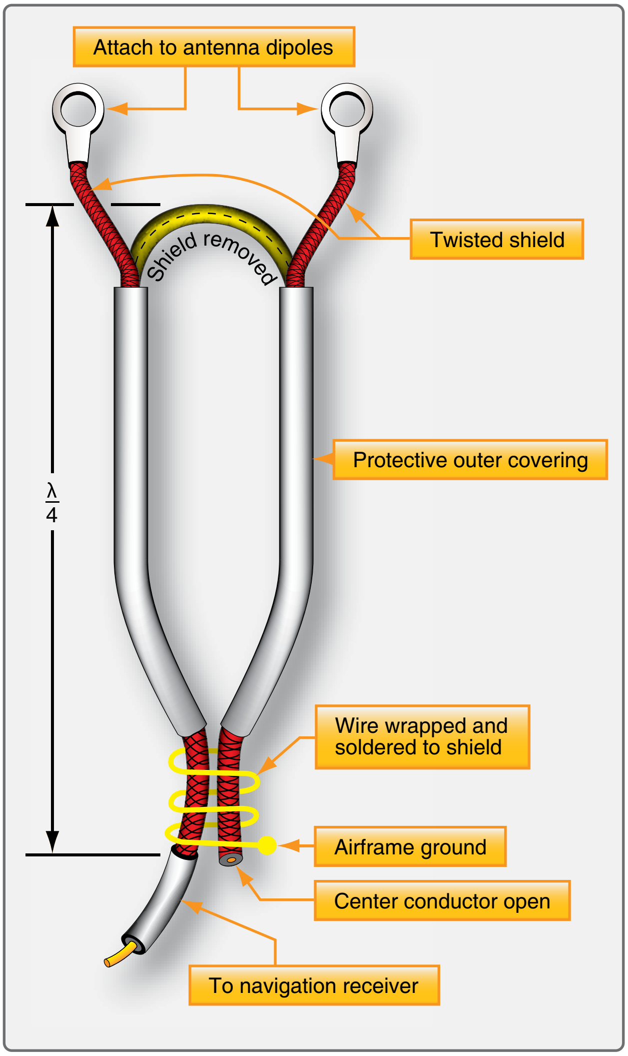


Figure 11-163. *A balun in a dipole antenna installation provides the proper impedance for efficient power transfer.*

careless oversights during equipment replacement. Loose cable connections, switched cable terminations, improper bonding, worn shock mounts, improper safety wiring, and failure to perform an operational check after installation may result in poor performance or inoperative avionics.

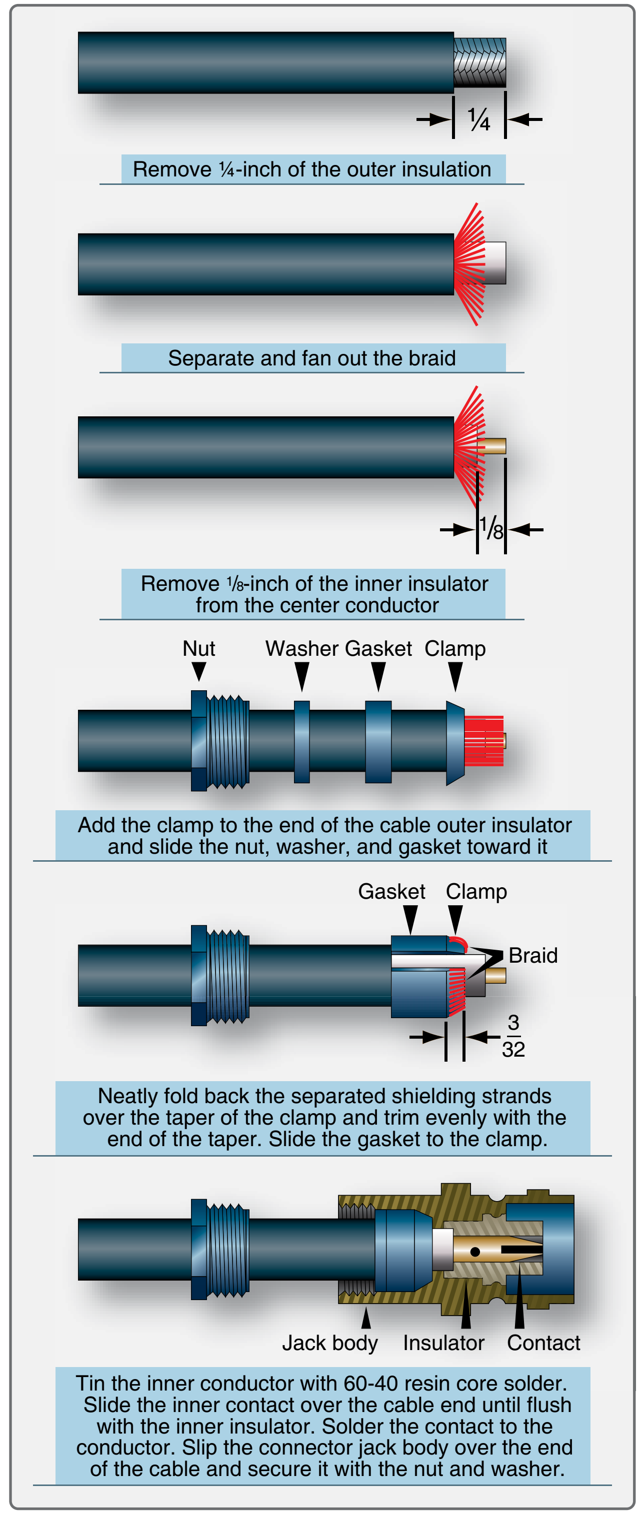


Figure 11-164. *Steps in attaching a connector to coax cable used as antenna transmission lines.*