Antennas and Feedlines

Antennas have been around since before Marconi's feeble signals were first received from across the Atlantic ocean in 1901. As a class of device, antennas are quite simple in theory of operation and methods of construction. Antennas used on airplanes are certainly very simple. None-the-less, there's a sort of aura about antennas that borders on mystical. After all, here's a simple piece of conductive material that literally launches energy from transmitters into the atmosphere. Still more amazing, the same antenna will gather tiny, 0.0000000000000002 watt signals from the atmosphere and conduct them to a feedline for transport to a receiver.

Not too many years ago, in fact as late as 1953, books referred to a substance called "ether." It was thought to be a medium though which electromagnetic waves would conduct and was used to give foundation to suspect theories on propagation of light and radio. Scientists have how abandoned the concept of the "ether" but they didn't replace it with a more suitable term. I think they should have simply changed the definition of "ether" to include atmosphere and space for indeed, both radio and light travel readily in each medium.

WHAT IS THIS RADIATION STUFF?

Recall from chapter 7, a magnetic field is generated every time electrons flow. Electrons will flow whenever a conducting path is provided between different electrostatic potentials. The converse is true also. If a magnet is shoved into a coil of wire you can sense a voltage being generated as the magnet moves past turns of wire. If voltage is conducted away on wires to do work then it may be called an electro-motive force. If the terminals of our experiment coil are not connected, the voltage is still there but it might be called electro-static. Alternators use very strong moving magnetic fields to generate large values of electromotive force or voltage.

But suppose our coil of wire experiment were conducted with steel wire versus copper wire. The electrostatic force would be the same but steel's higher resistance would produce some losses if you try to draw current. Consider further that if you wind our coil with some exotic wire with a very high resistance. Again, if you draw no current a measurement of electrostatic potential would be the same but the ability to draw it off is nearly zero. Now suppose the wire has infinite resistance (wire made from air if you will). It's no leap of faith to acknowledge that an electrostatic potential is still there in spite of the fact that no conductor exists to carry it elsewhere. The major difference between our somewhat static demonstrations of magnetic and electric fields and propagating radio or light energy is frequency. If voltage fields or magnetic fields are generated in a cyclical or periodic manner, they produce a wave capable propagating energy and requires no conductor to do so.

Figure 13-1 is an excerpt from Figure 12-2. In chapter 12 we were interested in wavelengths and frequencies of light. Both figures speak of other electromagnetic emitters, namely well known radio communication and navigation aids. Each service has a frequency range and a wavelength range. For example, localizer, VOR and VHF communications frequencies lay between 108 and 135 megahertz which corresponds to a wavelength of 2.78 to 2.22 meters. These numbers are derived by dividing the speed of light (299;999,997 meters per second) by frequency in Hertz (108,000,000) which yields a wavelength of 2.78 meters. In each example, the transmitter generates a cyclical electromotive and/or magnetomotive forces (remember, you can't have one without the other!) which are conducted along feedlines to antennas.

On the antenna they become electrostatic and magnetostatic fields with cyclical properties measured in hundreds of millions of excursions per second. Once placed on the antenna, energy propagates freely into space around the antenna. The fact that simple wires, stuck into the air will do such amazing things has often prompted fertile imaginations to believe that more complex designs might do even better. I recall strange devices that used to sit on top of people's television receivers in the 50's and 60's. They were true *objects*

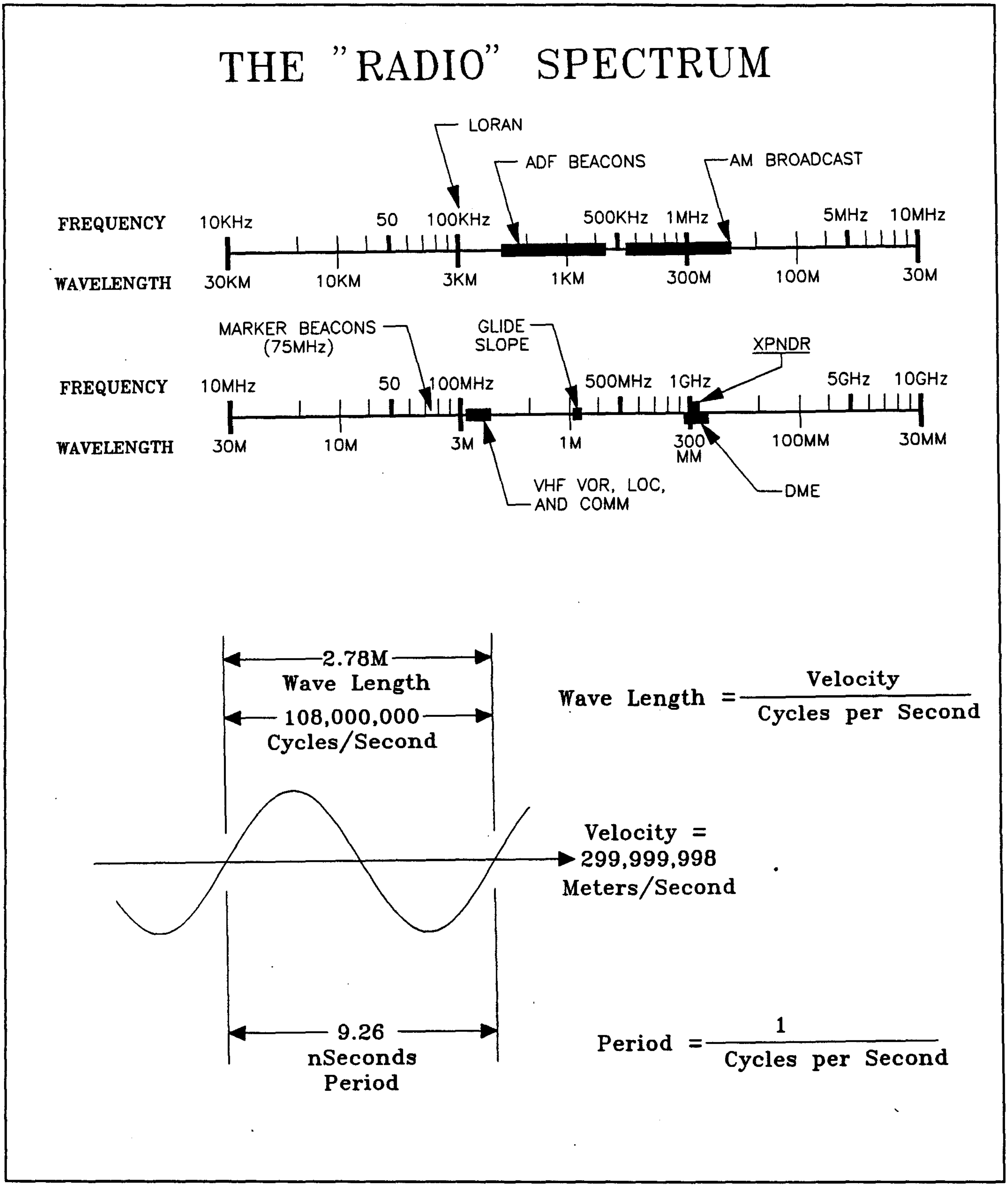


Figure 13-1. Radio Spectrum and Wavelength.

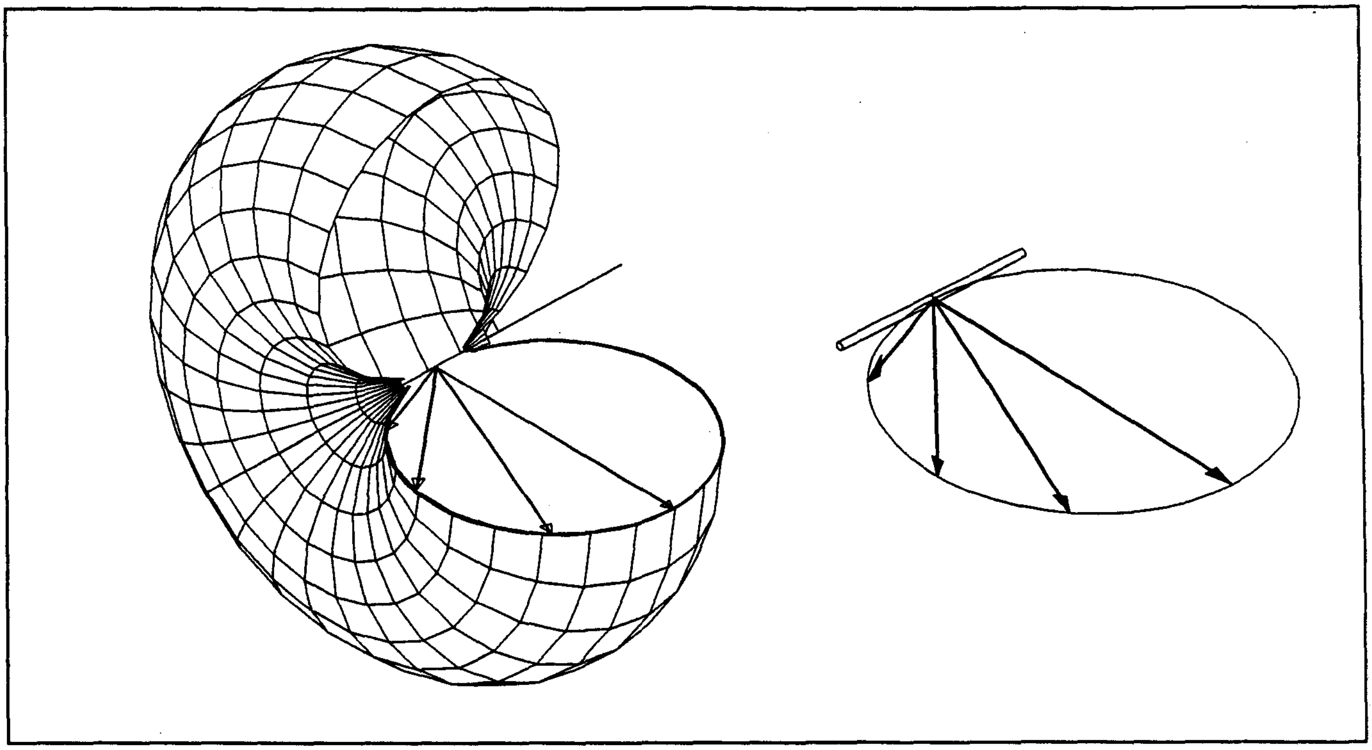


Figure 13-2. Three-D and "Slice" Views of Dipole Radiation Pattern.

d'art. Simple "rabbit ears" simply had to be outperformed by these gold anodized, multi-jointed testimonies to the metal smith's art!

Citizen's band antennas suffered from equivalent maladies. During the heyday of citizen's band activity in the 60's and 70's many an operator paid dearly for what he believed would provide that "little edge" over his neighbor's signal. The most noteworthy feature for some designs was the prodigious rate at which they blew away in Kansas storms compared to their simpler brethren.

Figure 13-2 shows a simple dipole antenna with a slice out of its radiation (or reception) pattern on the right The arrows are **signal strength vectors.** The arrow points the direction from which the signal is to be observed. The length of the arrow shaft is proportional to signal strength radiated in that direction. Note the longest arrow extends outward from center of the antenna at right angles. As the arrows rotate more toward the ends, they get shorter. An arrow pointing off the end of the antenna would have zero length. Obviously, the best place to receive a signal is broad-side to this antenna. Sharp nulls do exist off the ends. The view on the right is a single slice through a three-dimensional radiation pattern which wraps completely around the antenna as shown on the left.

If you transmit with this antenna, most energy would radiate in directions other than toward an intended receiver. Figure 13-3 shows **parasitic elements** placed adjacent to the radiator. These elements focus otherwise errant energy into a major lobe out the front. This basic antenna shape is very familiar to all; similar devices stick from the tops of houses and buildings everywhere. The parasitic elements are called **"directors"** and **"reflectors."** Even their names suggest an ability to modify energy patterns.

Some antennas are said to have **"gain"** over it's poorer performing cousins. The word gain is somewhat misleading. The same word is used to describe amplifier performance; 10 volts out for 0.4 volts in says the device has a voltage gain of 25. Does this mean an antenna with gain amplifies your outgoing or incoming signal? Not really. No energy is added created; available energy is simply focused. A similar situation exists with more familiar devices. For example, a modern halogen lamp flashlight may produce a light visible at perhaps 5 miles away. If the bare bulb with no reflector were simply held up in the dark from such a distance, I dare say it would be invisible. In both cases, total radiated energy is the same. A reflector focuses at least half of available light in one direction.

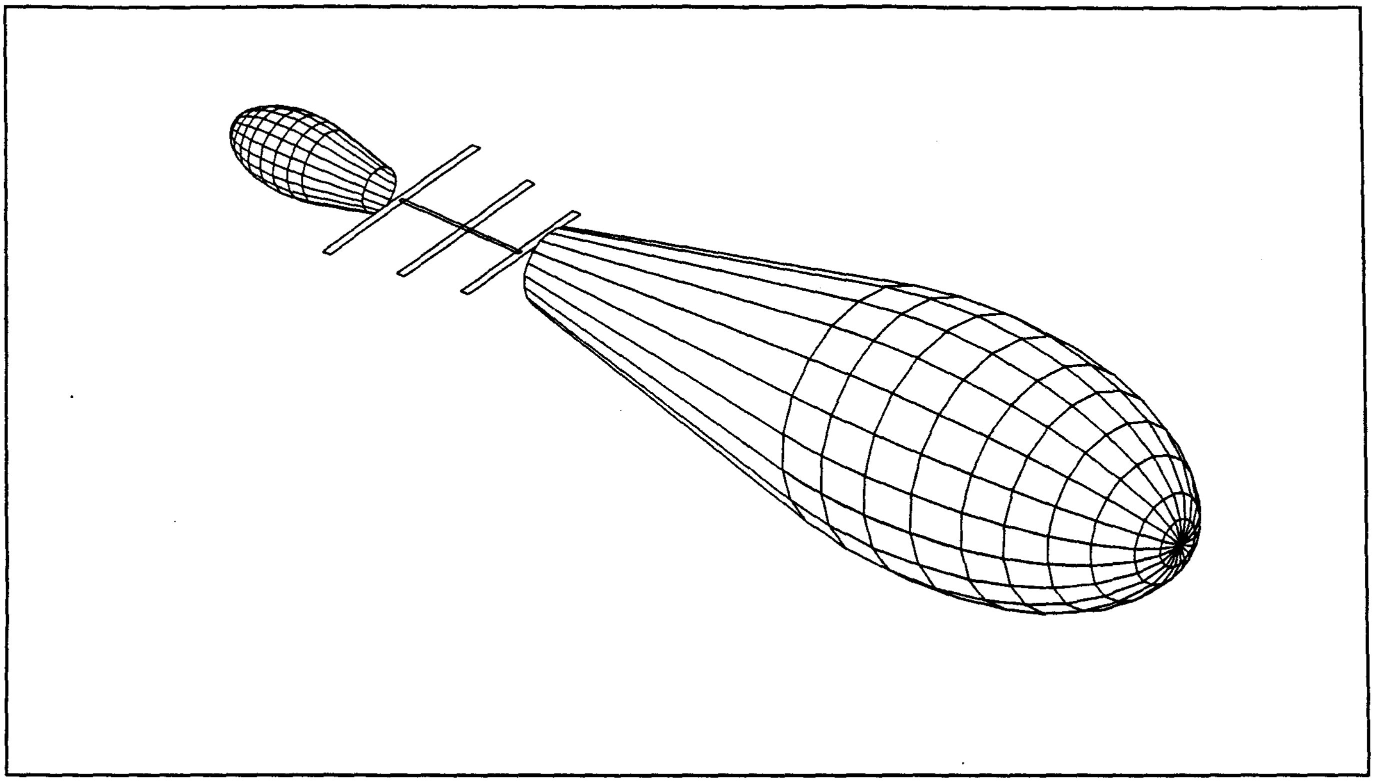


Figure 13-3. Parasitic Elements Focus Energy into "Beams".

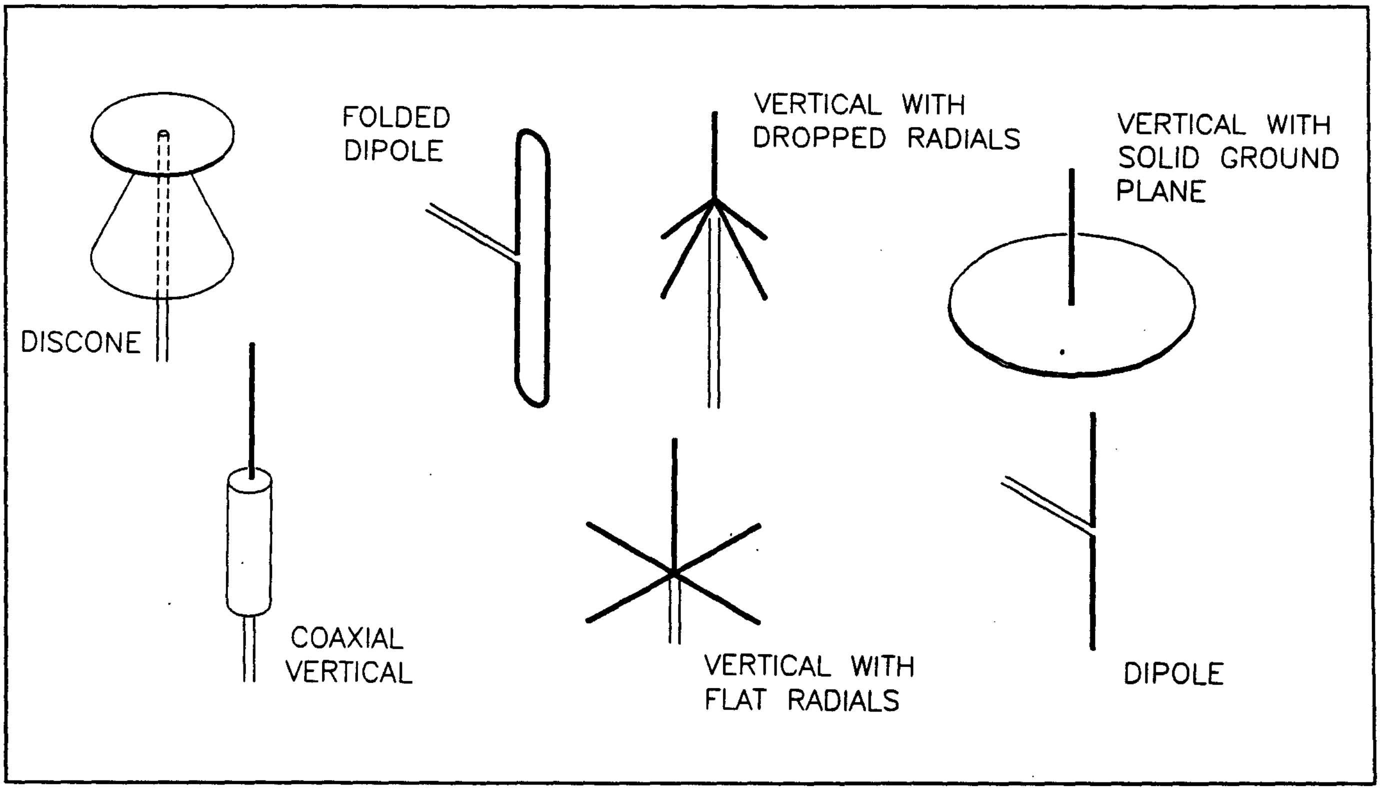


Figure 13-4. A Collection of "Vertical" Antennas.

Of course, if you are not positioned exactly in the beam at five miles, you might not see it even with a reflector. **Parasitic** elements added to antennas will modify a driven element's radiation pattern so as to concentrate transmitted energy. Therefore, antenna **gain** is a function of how well the antenna **focuses** available energy in the desired direction.

Multi-element antennas are often called "beams" and are rotated by remote control to point at a station of interest. Amateur radio and citizens band beams are evident in most communities. Television antennas in remote communities are often situated on tall towers and rotated as needed to receive distant signals. Fringe area television antennas tend to be large also with many parasitic elements. The longer the antenna, the more tightly focused is it's beam which yields more gain.

"So what?" you might ask. "Rotated beams are not practical for service on airplanes. Why bother with them here?" The point to be observed is that judicious placement of conductors in the vicinity of an antenna will strongly modify the antenna's radiation pattern in a predictable and useful way. The converse is true also, random or careless placement of conductors in the vicinity of an antenna may strongly modify the antenna's radiation pattern in unpredictable and useless ways.

Figure 13-4 illustrates several different types of antennas. Each is uniquely constructed but interestingly enough, from a performance standpoint, all the illustrated antennas perform nearly the same! There **are** small differences but you would be unable detect the "hotter" design simply by listening to signals received on it. Laboratory equipment is required to accurately quantify the differences. There are several features common to the antennas illustrated. Except for the discone, they are all "resonant" antennas and all vertically polarized. The "vertical" aspect of these antennas is rather apparent from just looking at them (except perhaps for the discone). None of these antennas has parasitic elements so their radiation patterns are "omni directional." This means that all these antennas transmit and receive from any direction.

IT"S ALWAYS BEST TO RESONATE

The "resonant" feature requires a little explanation. Resonance is most easily conceptualized as response which repeats an external stimulus. At more pedestrian frequencies, like those you can hear, I can think of many examples of resonant response. I recall a photography job for a music store several years ago when a showroom full of grand pianos were being demonstrated. When the pianist played a single chord loudly and then muted her instrument, I could hear the chord carry on from several instruments around it. Strings tuned to the same frequencies being played would begin to vibrate in resonance with the applied stimulus. In this case, sounds from the played piano. Pipe organs use resonant tubes excited by a stream of air to produce notes of music. Each pipe's or string's resonant frequency is predictable if you know the laws of physics which govern it's performance.

The basic **dipole** antenna is resonant when it's length is equal to **1/2 wavelength for the frequency of interest**. Figure 13-5 shows a dipole antenna with an adjacent graph. The graph depicts voltage and current distribution along the antenna's length when excited with energy at its resonant frequency. Note that voltage is highest at the ends while current is highest in the center. The high current point or center turns out to be the easiest place to make connections with feedline to conduct energy to or from the antenna. I'll point out here that the lion's share of energy from an antenna radiates from the highest current points; in the center. Therefore, if you ever need to mount a dipole in restricted space, it's okay to bend up to 30% or so of the length at each end with little effect on radiation pattern or antenna efficiency. I can put 85-foot ham antennas in my 65-foot long attic; a 10-foot dogleg in each end makes it fit!

Antennas for airplanes are almost always "resonant" meaning that they are cut to length for the frequency of interest, well, almost. Marker beacons and LORAN are the only services that work on a single frequency. Therefore, their antennas may be optimized at a single frequency. All other services such as VHF communications, VOR navigation, DME, Transponder, ADF, and glideslope operate on a range of frequencies. **Bandwidth** is a term used to describe the useful operating frequency range for antennas. For airplanes, optimum antenna designs are not necessary. Systems which operate above 100 MHz are essentially line of sight services. Since airplanes operate high off the ground and away most manmade noises, they enjoy adequate access to facilities in spite of less than ideal antenna situations. This is fortunate because optimized antennas, and antennas with "gain" usually mean larger size, more weight and more expense or restrictions to an otherwise omnidirectional performance pattern.

There are a number of factors which interact with antenna length to determine its point of resonance. One important factor has to do with length to diameter ratio.

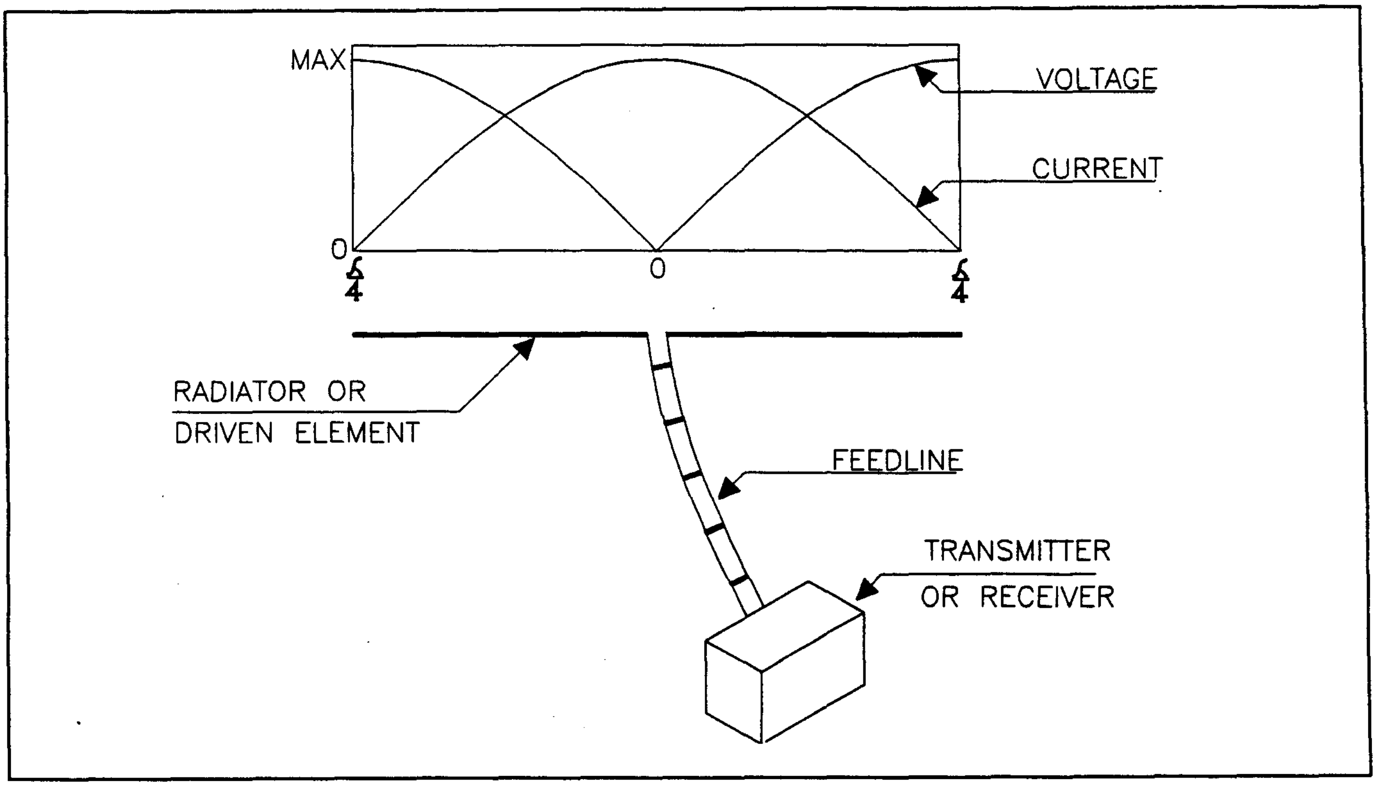


Figure 13-5. Half-Wave Voltage & Current Distribution.

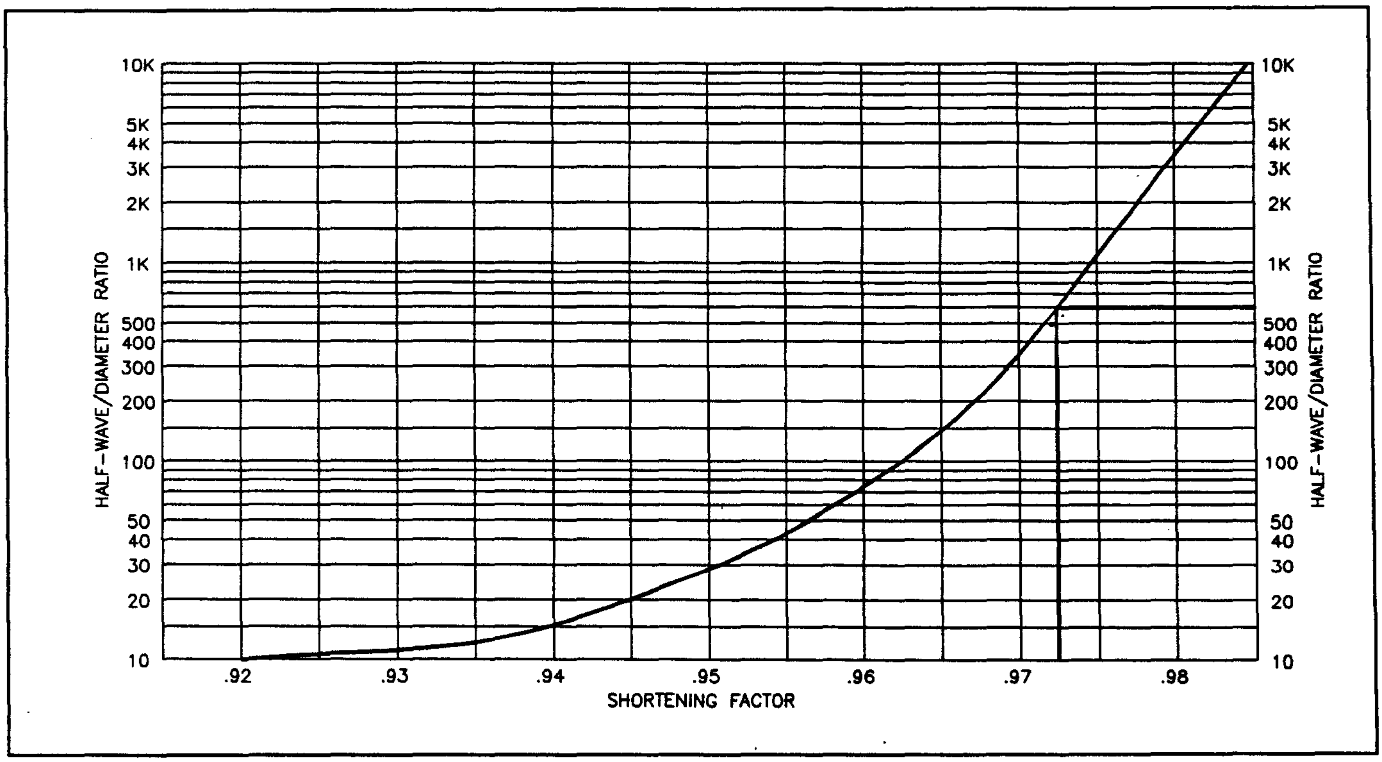


Figure 13-6. Length/Diameter Ratio Shortening Factor.

Only an antenna of zero diameter will be resonant at it's free space calculated length. Figure 13-6 shows a graph for shortening an antenna to compensate for its diameter. The vertical scale is half-wave-length to diameter ratio. Let's use marker beacon antennas as a handy example. 300 (million meters/second) divided by 75 (million cycles per second) yields 4 meters per cycle (a full wave length). A meter is 39.37 inches long so a half-wave antenna at for 75 MHz is 39.37 times 4 divided by 2 or 78.75 inches. Not having any zero diameter wire to make the antenna from, let's select .125" brass rod. 78.75 inches divided by .125 inches yields 629 for a half-wave/diameter ratio. Entering the graph at 600 and travel horizontally to intersect the graph, then down to .972 along the bottom. 78.75 inches times .972 yields 76.5 inches. Hold on, before you get out your yardstick and hacksaw, know that proximity to other conductors adds **capacitance** to the resonance equation causing the resonant frequency to shift lower. This requires the antenna to be further shortened still. Capacity due to adjacent structures is really significant when antennas are bent so as to become more parallel with their mounting surface. Examples of this type will occur several times in the following discussions. So, when you make a measurement of someone's hot performing antenna and it appears "short" with respect to calculated length, know that there is a good reason for it. If the antenna seems to be "right on", it probably "isn't."

Years ago, most single engine manufactures fabricated their own comm, omni, glide slope, marker beacon and ADF sense antennas. Comm antennas were steel rods poked through the skin on ceramic cone insulators. Glideslope antennas were simple dipoles mounted at the top of the windshield. "Sled runners" were to be found on the belly of airplanes with marker beacon receivers. A single copper-clad steel wire was stretched from cabin top to vertical fin tip for ADF receivers. I don't think any airframe folk undertook to build DME or Transponder antennas but they could have. DMEs and Transponders were rare installations during the heyday of airframer built antennas. About everyone buys antennas nowadays but that doesn't mean you have to.

Things to consider for antenna selection include performance, strength, drag, esthetics, cost and ease of installation. On the performance side, commercially built antennas work about the same as homebred devices. There just isn't much you can do to improve on basic physics of these things. However, poor grounding on a 1/4-wave vertical can cause an otherwise adequate antenna to perform badly, purchased or fabricated. Commercially built communications and VOR antennas will sometimes include some form of matching network in their base which is of marginal benefit (we'll discuss it later). The word "drag" brings everyone but J-3 owners right up in their chairs! For both esthetics and drag considerations, composite airplane builders may build antennas inside the structure during fabrication of the airplane. I don't personally get too excited about drag from antennas. I've seen the numbers crunched by some pretty good aero guys and antennas simply are not a big issue with respect to aircraft performance. A word of caution for antennas built into composite airframes . . . If the antenna is to be buried into a canard or wing and glassed over, make sure you build it solidly. The antenna cannot be repaired later when some joint goes bad or a wire breaks.

Strength and ease of installation are mechanical issues. Strength has to be considered for an antenna sticking out into a 200+ MPH airstream. Making proper mechanical connections between antenna and airframe requires attention to potential failure modes. Jim Wier, formerly of RST electronics, has written a number of articles on antenna fabrication for both metal and composite airframes (See notes at end of this chapter). You may wish to acquire them. I don't agree with everything Jim has written but his fundamentals of antenna fabrication and installation are solid and his writing is fun to read.

If cost in dollars is a factor, then do consider building your own. If cost in hours is an issue, it may be a toss-up between build or buy.

Table 13-1 lists common type of antennas found on airplanes categorized by service. Each service denotes style, frequency range and operating mode. More explanation of style and mode will be forthcoming in detail discussions for each antenna.

WE HAVEN'T FORGOTTEN GPS

I had occasion to work with GPS systems on an RPV project a number of years ago. I thought I was in a good position to expound on GPS antennas when I began this chapter. I was researching a few questions of my own on GPS and discovered that there was too much I **didn't** know about the system to write with confidence now. We'll add discussions on GPS antenna systems in later revisions to this chapter.

Service	Antenna Style	Freq.	Antenna Operating Mode
VHF Comm	1/4 Wave Vertical w/Ground-Plane	118-136 Mhz	Resonant E-Field
Transponder	1/4 Wave Vertical w/Ground-Plane	1030-1090Mhz	Resonant E-Field
DME	1/4 Wave Vertical w/Ground-Plane	950-1225Mhz	Resonant E-Field
VHF VOR	1/2 Wave Horizontal Dipole	108-118 Mhz	Resonant E-Field
Glide Slope	1/2 Wave Horizontal Dipole	329-335 MHz	Resonant E-Field
Marker Beacon	1/4 Wave Horizontal w/Ground-Plane	75Mhz	Resonant E-Field
LORAN	Random Length Wire	100 Khz	Non-Resonant E-Field
ADF Sense	Random Length Wire	200-1600Khz	Non-Resonant E-Field
ADF Loop	Ferrite Core Loop	200-1600Khz	Non-Resonant H-Field

Table 13-1. Antenna Styles and Operating Modes

QUARTER-WAVE GROUND PLANE ANTENNAS (or HOW TO GET "GROUNDED" AT 5000 FEET)

The first three antennas listed in Table 13-1 are quarter-wave ground-plane type antennas. In the table and throughout this chapter, the term ground-plane appears frequently. It is always associated with discussions of quarter-wave vertical antennas. Back when Marconi and associates were exploring new territory in the early days of radio, it was a well known fact that transmitting and receiving "aerials" performed better when used in conjunction with a "ground." The term was quite literal in those days; connections to the earth were made by burying or driving long conductors into the ground. In an earlier chapter on grounding, we discussed three types of grounds in airplanes that, for the most part, have nothing to do with each other. Grounds for antennas is one of them.

Looking at half-wave dipole antennas in preceding figures, we note the **balanced** nature of their design. Currents and voltages of equal amplitude exist on either side of a center feed point. Dipoles need no ground or ground-plane because they are balanced. A quarter-wave antenna is **un-balanced.** In order to drive energy into the base, you must have some connection for the other side of the feedline and a ground is it. On metal airplanes, the airframe skin is used to provide a ground, on composite airplanes, or on tops of antenna masts, some form of artificial ground or ground-plane is needed. A satisfactory replacement for good connections to mother earth is a series of radials which are the same length as the antenna. Quarter-wave ground-plane antennas seen around airports and on tops of towers and buildings generally have four radials spaced evenly about the base of the antenna. Purists may add four to six more but differences in performance are slight, differences in weight and cost are great. That is until you build an antenna for very high frequencies, like a DME or Transponder antenna. Here it is more practical to .co

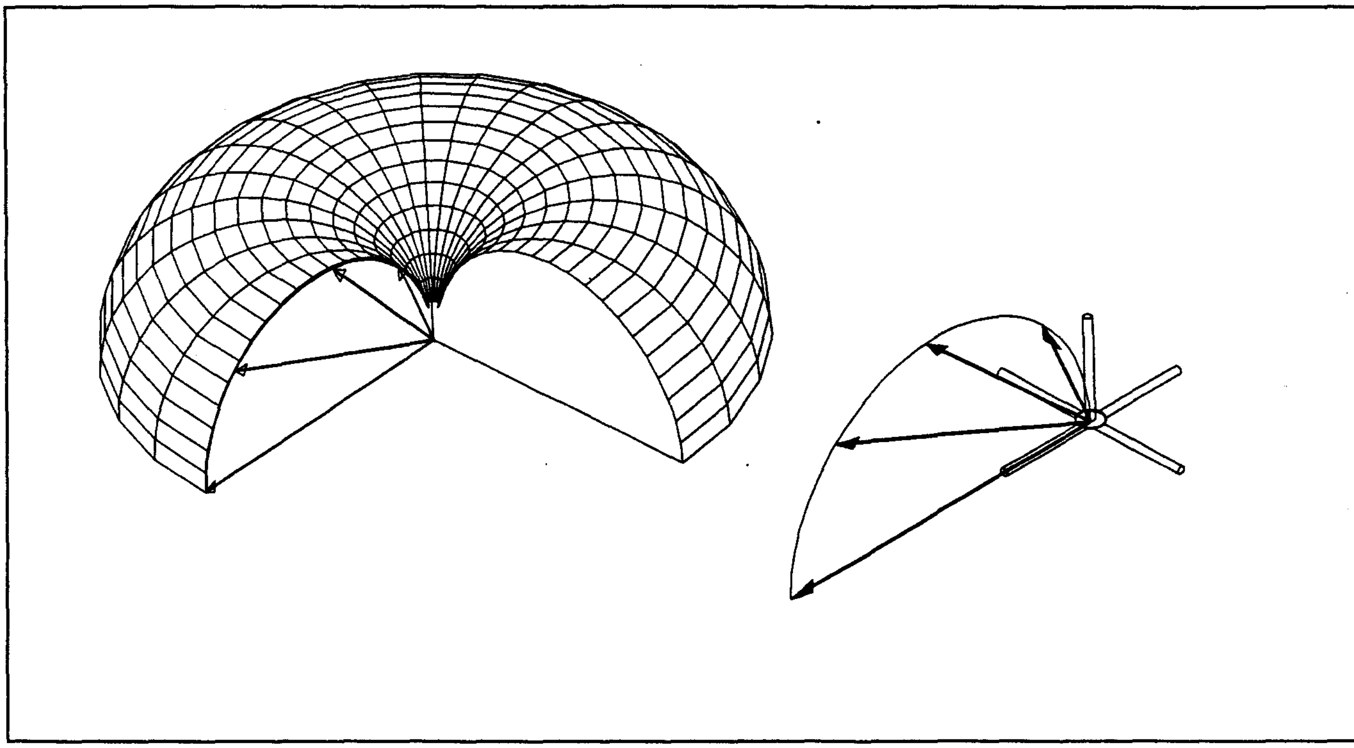


Figure 13-7. Three-D and "Slice" Views of 1/4-Wave Ground Plane Radiation Pattern.

make a ground-plane from an infinite number of 1/4 wave radials; like a solid disk of aluminum or copper.

The quarter wave antenna is 1/2 of a half wave. It has a slight performance loss over the half wave dipole but it is much easier to mount on an airplane than a vertically polarized, half wave dipole. **Polarization** is a term used to describe how the antenna couples to electromagnetic fields zipping through space all around us. Generally speaking, if an antenna's voltage gradient is vertical to the surface of the earth, the antenna is said to be vertically polarized. Best performance between two stations is achieved when they use the same polarization. Television and FM broadcast stations transmit horizontal polarized waves, therefore, antennas used to receive these services lay flat. *[In recent years, FCC has mandated FM stations to ADD vertically polarized components to their radiated signals to accommodate a proliferation of automobile receivers.]* Ground facilities for VHF communications use quarter-wave verticals with ground-planes. It behooves you to mount a VHF Comm antenna with the most vertical orientation possible on their airplane.

Figure 13-7 shows the radiation pattern from a 1/4-wave, ground-plane antenna. Note this pattern is a subset of the single slice and 3-D models shown for the 1/2-wave dipole in earlier figures. Unlike a horizontally disposed dipole, with a radiation pattern that includes ground and sky, the 1/4-wave vertical has a very desirable omni directional pattern. Response for this antenna peaks on the horizon; very appropriate for DME, Transponder and Communications services.

When pilots were first given the ability to speak to the ground via radio, their transmitters operated around 2-5 Mhz as I recall. High performance antennas for these frequencies are difficult to obtain on an airplane. A quarter-wave resonant antenna would be 50-feet long! However, you needed to talk only a few miles during approach to an airport so shortened, low efficiency antennas sufficed. Antennas for the 2-30 MHz range are referred to as **HF** antennas. Energy emissions in this range are noted for an ability to propagate long distances. HF transceivers are often installed in aircraft which cross oceans or travel to remote locations. The most efficient antennas are **long-wire** antennas up to 2000' long which are literally reeled out in flight and retracted for landing. The Voyager Around-the-World aircraft carried an HF installation. The "stinger" which

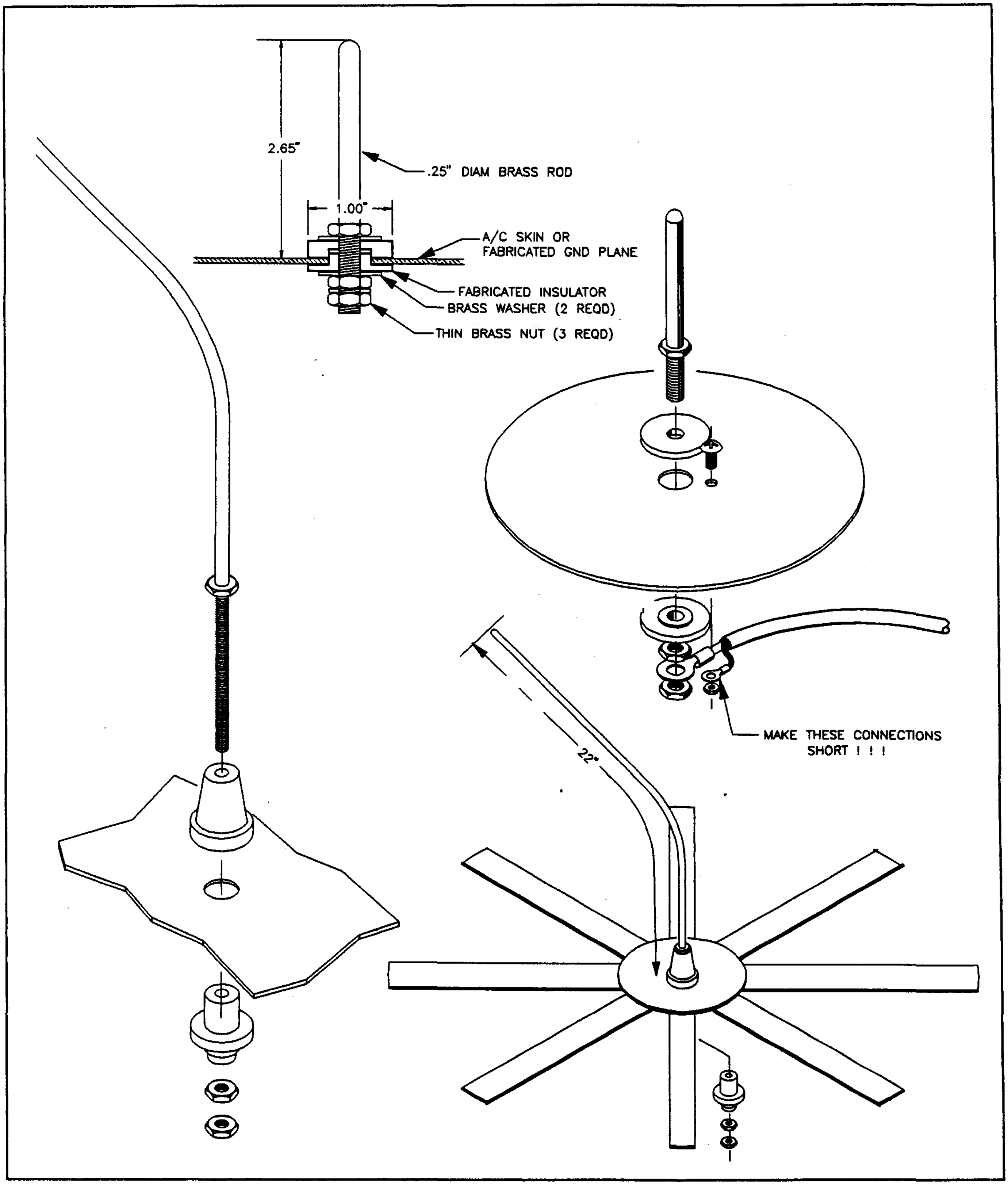


Figure 13-8. Variations on the Quarter-Wave Ground Plane.

protrudes from the left boom is the total length of Voyagers HF antenna. King Radio built some fancy footwork into the base of this antenna to optimize it's performance but it was still a compromise from a resonant, multi-wavelength trailing wire.

In the 40's, the FCC allocated VHF spectrum space in the 108-130 MHz range (just above the FM broadcast band) for radio navigation and communications. This was a welcome change in terms of antenna efficiencies but radio designers were pressed harder. In those days 100 MHz was an edge to the frontier. Vacuum tubes that operated well at VHF frequencies were harder to build. None-the-less, the new system caught on quickly. The higher frequencies were almost totally free of atmospheric noises and "skip" from other services around the world. The line of site nature of VHF systems seemed to be made for airplanes. Antennas from that day through the present are simple quarter-wave, base-fed sticks poked through the skin of the airplane.

ROLLING YOUR OWN IN QUARTER-WAVE ANTENNAS

Figure 13-8 shows several variations on the quarter-wave antenna installation. The longer "whip" antenna would be suited to VHF Comm uses while the short stubby fellow is for DME or Transponder applications. Irrespective of application, all quarter-wave ground-plane antennas have these things in common: (1) The are one quarter wavelength at the center of operating frequency range. (2) They require an artificial ground consisting of (a) many square feet of aluminum airframe skin or (b) a practical number of quarter-wave radials. (3) They are fed with a coaxial cable feedline with the center conductor attached to the base of an insulated radiator and a shield "grounded" as close to the base as possible.

Deviations from flat ground-planes and straight radiators are permitted. The length is important with respect to obtaining a resonant antenna components. The high current areas in both radiator and ground plane have primary responsibility for determining performance. Therefore, if a rakish look is desired, the top half to two thirds of VHF Comm antennas may be bent backward up to 45 degrees from vertical. However, foxtails flown from the tip are not recommended. Further, if the surface which mounts the antenna is not a perfectly flat plane, little performance is lost.

In a composite airplane, VHF ground-planes can be fabricated from radial strips of copper foil, soldered to a commoning disk a the base of the antenna. Make these strips 1" wide and trim them off 22" from the base of the vertical. 4 to 10 strips is recommended. These may be cemented to the underside of the skin and structure. By fabricating a commoning disk from copper, the entire assembly can be soldered. You might even consider soldering the feedline shield directly to the commoning disk. With the UHF antennas for DME and transponder, a ground-plane disk of copper (preferred) or aluminum, 5-1/2" in diameter is sufficient. Now, there is some hangar wisdom circulating around that suggests, "the bigger the ground the better. Tie every piece of metal in the airplane together for increased performance." In the case of ground-planes just described, we went to a lot of trouble to make them "resonant." Resonance is a function of length compared to operating frequency. No performance gains are to be expected by adding connections to other "grounds." Further, there is a risk of noise problems by conducting stray currents to the communications antenna system via bogus ground connections.

MOUNTINGS FOR QUARTER WAVE VERTICALS, METAL AIRPLANES

Mounts for quarter-wave verticals have two requirements: they have to be good insulating material and strong enough to hold the antenna to the airframe. For the little DME and transponder antennas, strength isn't a great problem. Figure 13-8 illustrates a single hole, two piece bushing. I like to make these little guys from Delrin. A very tough, machinable plastic available from suppliers in the form of 1" rod stock. Lexan, and polycarbonate are other good materials. Nylons should be avoided. Sunlight and oil degrades nylon. Nylon also absorbs moisture. A few minutes on a lathe will make several sets of these. I cut a raised boss on the lower half which extends through the skin (and doubler) into a recess on the upper half.

For longer antennas, you may purchase two-piece glazed ceramic feed-thru insulators like that shown in View B or fabricate a larger, sturdier version of the little guy in View A. For the larger fabricated base insulator, consider 1/2" Plexiglas or cloth filled phenolic. In both cases, doublers riveted to the skin are used to spread loads over a wide area of skin. If a rib or bulkhead is close by, build a flange on the doubler to include this structure as doubler support. When fabricating a base from 1/2" sheet stock drill a close fitting clearance hole for the radiator. Clamp up in the insulator really snug with the radiator mounting nuts.

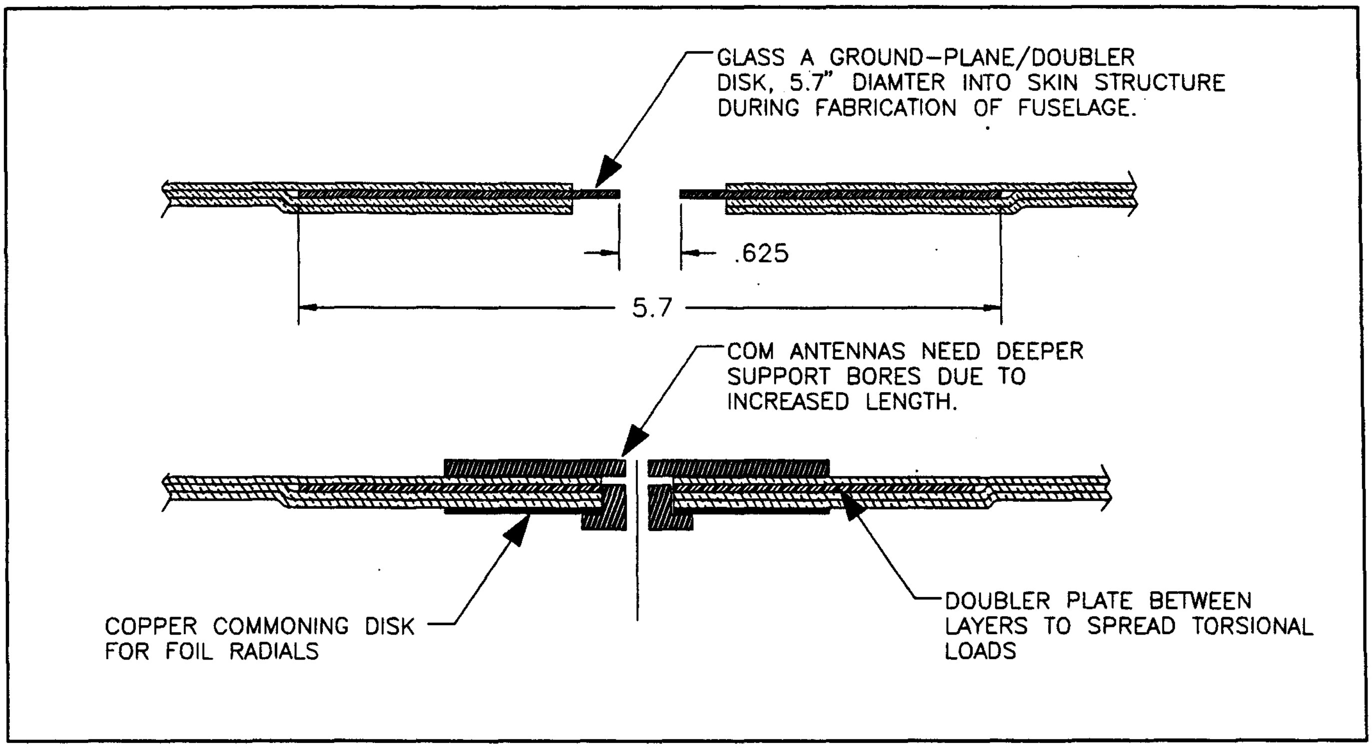


Figure 13-9. Embedded Ground Planes for Composite Airplanes.

MOUNTINGS FOR QUARTER WAVE VERTICALS, COMPOSITE AIRPLANES

Composite airplanes require a different approach. A few layers of BID glass and glue are a whole lot stiffer and tougher than .025" aluminum! Figure 13-9 shows DME and transponder ground-plane disks between layers of glass during fuselage fabrication. Many variations on this theme have been published by designers of composite airplanes so we won't go into a lot of details here. The most important difference between antenna installations on glass versus metal airplanes is an additional requirement for a resonant ground in the form of multiple 1/4-wave radials or a 1/2-wave diameter, ground-plane disk.

Copper foil in coiled tape form is available from 3M with an adhesive backing. Check with a 3M dealer for part number 1181 or 1245. Specify 1" width. The tape may be soldered to commoning disks at the base of 1/4-wave verticals or soldered directly to coax feedlines when ferrite beads are included on the feedline (see later paragraphs). The adhesive backing will hold the foil in place during installation but I wouldn't depend on it for long term support inside fuselages, etc. A layer of glass and resin over the finished foil is recommended.

TRANSPONDERS AND DME ANTENNAS, A HEALTH RISK?

I've read articles with admonishments to builders of plastic airplanes to mount transponder antennas far from the cabin as possible and/or provide shielding between the antenna and occupants. Aluminum foil applied under seat structures is recommended for very male concerns for protection of the "family jewels." The "200-watt" output rating of the transponder is often compared with the 600-watt rating of microwave ovens. While the peak power of your transponder may be 200 watts, the output occurs for microseconds at a time and only when replying to a radar interrogation. Average power at the antenna is only a few watts during pulse time. The 600-watt rating of your microwave is an average power directly related to an ability to cook. Your transponder can't warm anything up much less cook it. At Boeing in the 60's we worked on radar sets with 200,000 watts peak output. Average continuous power to the antenna was under 50 watts! I've not seen any studies in the engineering literature that confirm a hazard from this source. Energy densities as low as 5 milliwatts per cubic centimeter have been suggested as a threshold for

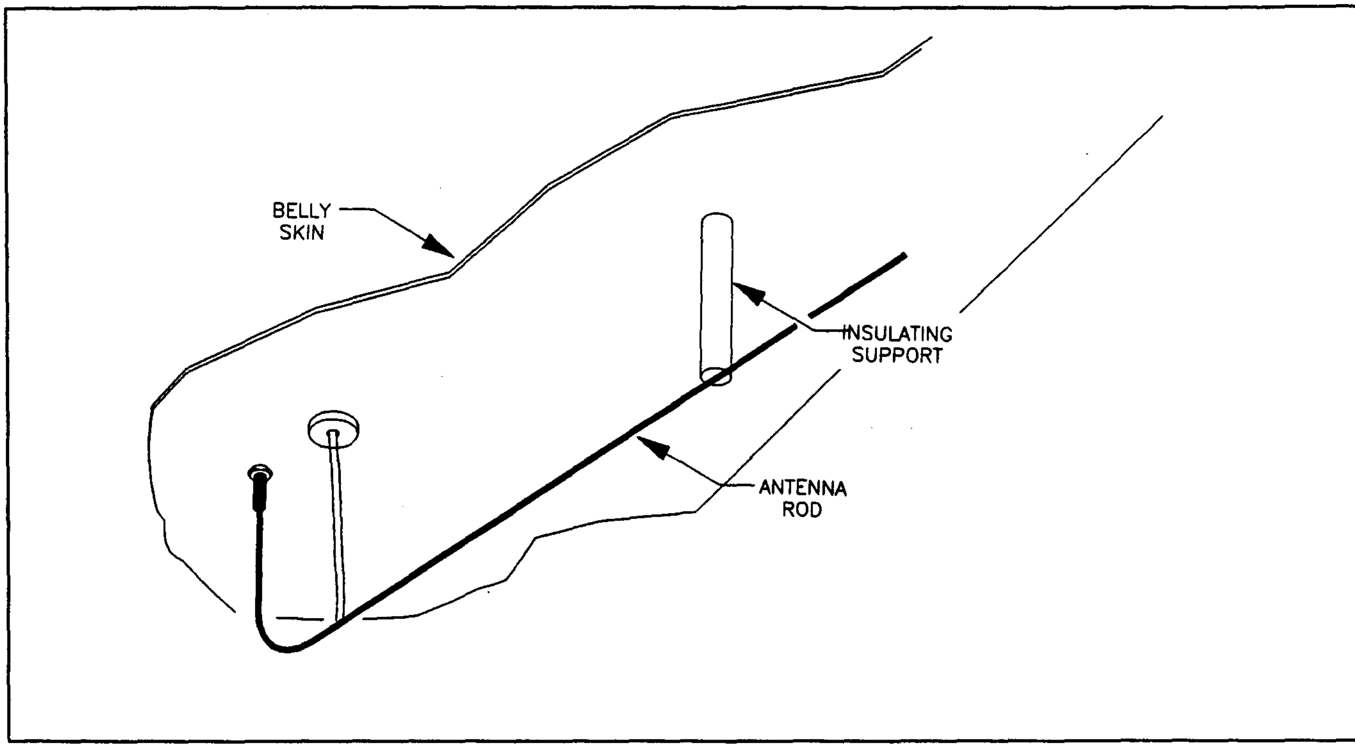


Figure 13-10. "Sled-Runner" Marker Beacon Antenna.

harm. Power delivered to any body parts from above a DME antenna ground plane will be well below this level. Most of the serious proponents of shielding take the "better safe than sorry route." Besides, if you are really worried about biological effects of electromagnetic radiation, the eyes are much more susceptible to damage. Mmmm, perhaps Bausch and Lomb would be interested in a new aviator's product. Grounded gold frames with screen wire shields embedded in the lenses? Shield your buns if it makes you feel better but don't loose any sleep over it if you don't.

MARKER BEACON ANTENNAS

Marker beacon transmitters put out about 5 watts into an antenna with a narrow beam directed straight up. Indeed some old books refer to them as "fan" markers in deference to the shape of their radiation patterns above the ground. At one time, 75 MHz marker transmitters were used for locators along traffic airways and high altitude performance was needed. Nowadays, one receives the outer marker from about 1000 feet up. Figure 13-10 illustrates the classic "sled-runner" may be seen on thousands of single engine airplanes. It extends vertically from the belly skin for about 4-6 inches then bends 90 degrees aft to be supported by an insulated post. A feedwire taps onto the antenna a few inches from its grounded attach point forward. Position of the tap is adjusted for best match to the 50-ohm feedline.

Newer antennas may be housed in molded plastic aerodynamic shapes with considerable shortening of length compared to sled-runners. This shortening does affect performance but performance isn't much of an issue from 1000 feet up! For plastic airplanes, just about any approximately 1/4 wave (about 75") of wire strung out as straight as possible in the tail cone will work nicely. Something of a "ground-plane" could be formed by wrapping a 75" conductor around the inside of the tailcone parallel to station lines. This is an odd mutation of the neat dipoles and verticals we use elsewhere but it is permissible and understandable given the unusual length of the antenna and strong marker beacon signals.

HALF-WAVE DIPOLES

The next two antennas listed in table 13-1 are also resonant but these are horizontally polarized. VOR, localizer and glide Slope signals are radiated with horizontally polarized antenna systems.

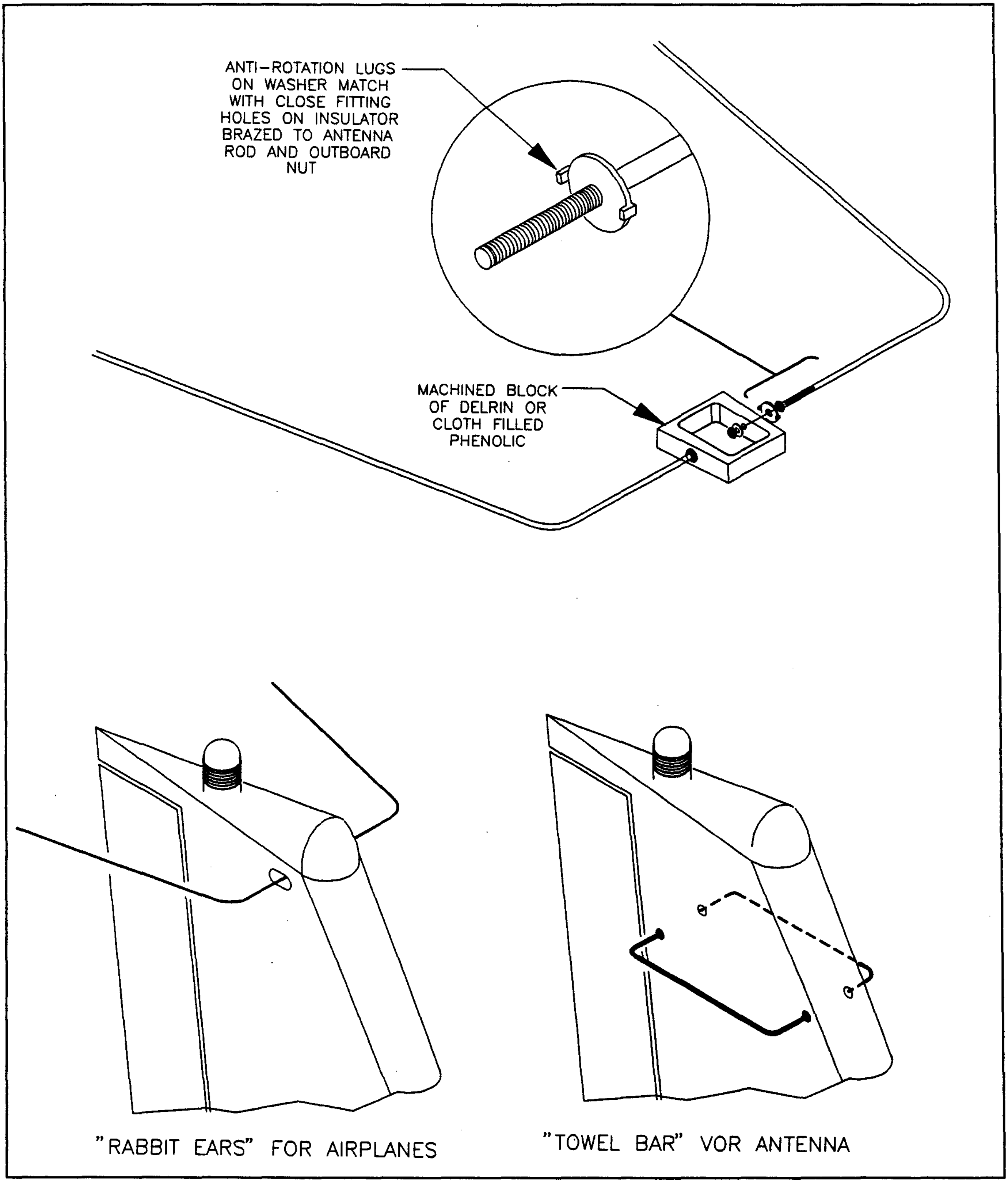


Figure 13-11. VOR Antennas

VOR/LOC ANTENNAS

VOR/LOC antennas are a pain in the you-know-what. They are twice the insulated elements as a communications antenna and they have to lay horizontal. The classic vertical fin installation requires a molded or machined insulator block not unlike that shown in Figure 13-11. The side surfaces are contoured to fit the inside surface of the vertical fin skin. Some form of mounting structure must be provided along with access for installation and maintenance. Quite often, VOR antennas are mounted on the vertical fin fairing itself which does make installation and maintenance access easier. These antennas are not difficult to construct but consider the following: A threaded stud stuck through an insulator block has almost no resistance to rotation under extremes of windage, temperature and vibration. Anti-rotation washers should be fabricated with tabs to engage holes in the insulator block. These can be brazed in place on the antenna rod along with the outboard nut before the rod is mounted and bent. This will keep the critter laying flat. Insulator blocks may be machined from Delrin or cloth filled phenolic with Delrin being the preferred material.

Figure 13-11 also illustrates the very common, swept back horizontal dipole and a relative newcomer to general aviation antennas. Nicknamed for their shape, they are called "towel bars." These are mounted in pairs on either side of a vertical fin and fed with a special feedline harness. If you are building a metal airplane, the vertical fin is a location of choice for the VOR/LOC antenna. Consider using a single antenna to drive two VOR receivers plus a glide slope receiver using a feedline signal splitter which we'll discuss later in this chapter.

THE WINGTIP ALTERNATIVE

I attended an RV forum in Fredericksburg and picked up a hand-out on a concealed wing tip VOR/LOC antenna developed by some RV builders. This "new" antenna, shown in figure 13-12, are a close cousin to the "sledrunner" marker beacon antennas. It is a quarter-wave, grounded base antenna with a "gamma matching" network for the coaxial feedline. This type of antenna has some obvious advantages over the classic dipoles hung out in the wind. First it is concealed and it is easier to build and install. However, it will suffer shadowing effects for signals arriving off the opposite wing. If this proves to be a problem, a second antenna on the opposite wing could be used to drive the #2 NAV receiver. Perhaps an antenna switch might be installed to permit selection of the antenna with the stronger signal.

CAUTION

A centered-needle ILS approach when receiving the localizer on a wing-tip antenna will place you off the runway centerline by 1/2 the wingspan of your airplane. Be prepared for a small side step maneuver toward the antenna when breaking out at minimums.

This type of antenna should be fitted to the airplane and adjusted for each installation. Folding the antenna back close to structure has a marked capacity effect cited earlier. These antennas are best trimmed in place. The RV gathering handout went into very specific construction details with an obvious goal of allowing one to reproduce the results with no test equipment. While writing this chapter I perceive a need to supply a small, mailable test set for 'Connection readers to make antenna adjustments in place on an airplane. If you are interested in pursuing wing tip antennas, get in touch with me and I'll work with you through your particular installation. In the mean time, I will put some thought into development of the test set to be made available to 'Connection subscribers. This test set will be capable of covering 75 to 350 Mhz for in-place trimming and matching of marker beacon, VHF COM, VOR/LOC and glide slope antennas.

GLIDE SLOPE ANTENNAS

Glide slope antennas are scaled down to about 1/3 size from VOR/LOC antennas. Figure 13-13 shows one method for fabricating a glide-sloped antenna. Lengths given are considerably shorter than calculated free-space. These antennas are often installed at the top of the windshield in single engine airplanes. The close proximity of windshield structure lowers the resonant frequency which requires further shortening of the antenna for best performance. Again, compared to VOR or COM antenna performance, glide slope antennas can be pretty sloppy. G.S. signals are seldom utilized more than 5 or 6 miles out from the end of the runway and G.S. transmitters are strong.

For pusher airplanes, glide slope antennas are good candidates for building into the nose or canard. Jim Wier's articles cited at the end of this section describe a number of alternatives for antenna fabrication and installation in plastic airplanes. Rather than duplicate his information here, I suggest you obtain the data package from RST. For high wing metal airplanes, the top of the

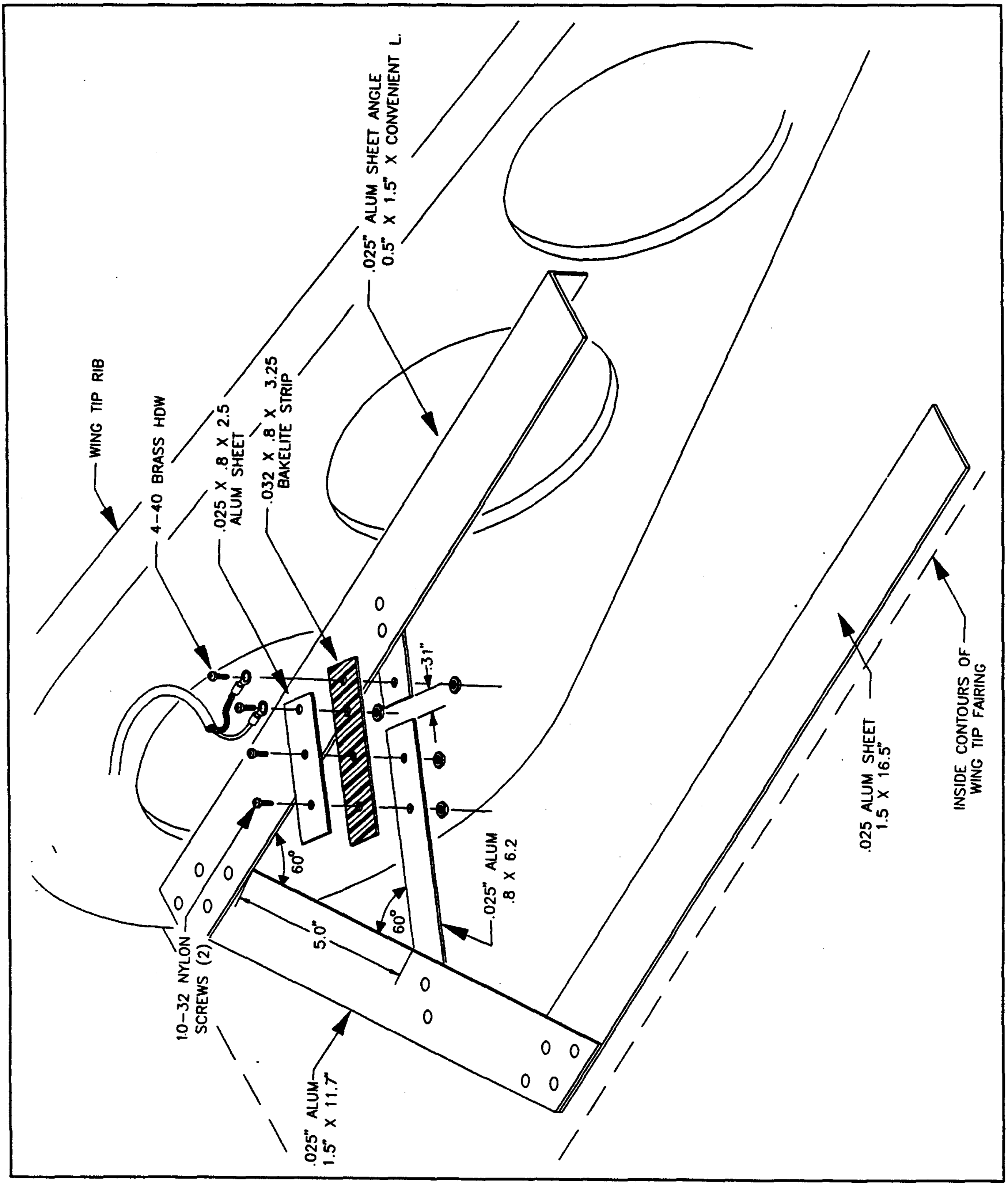


Figure 13-12. Wing-Tip VOR Antenna.

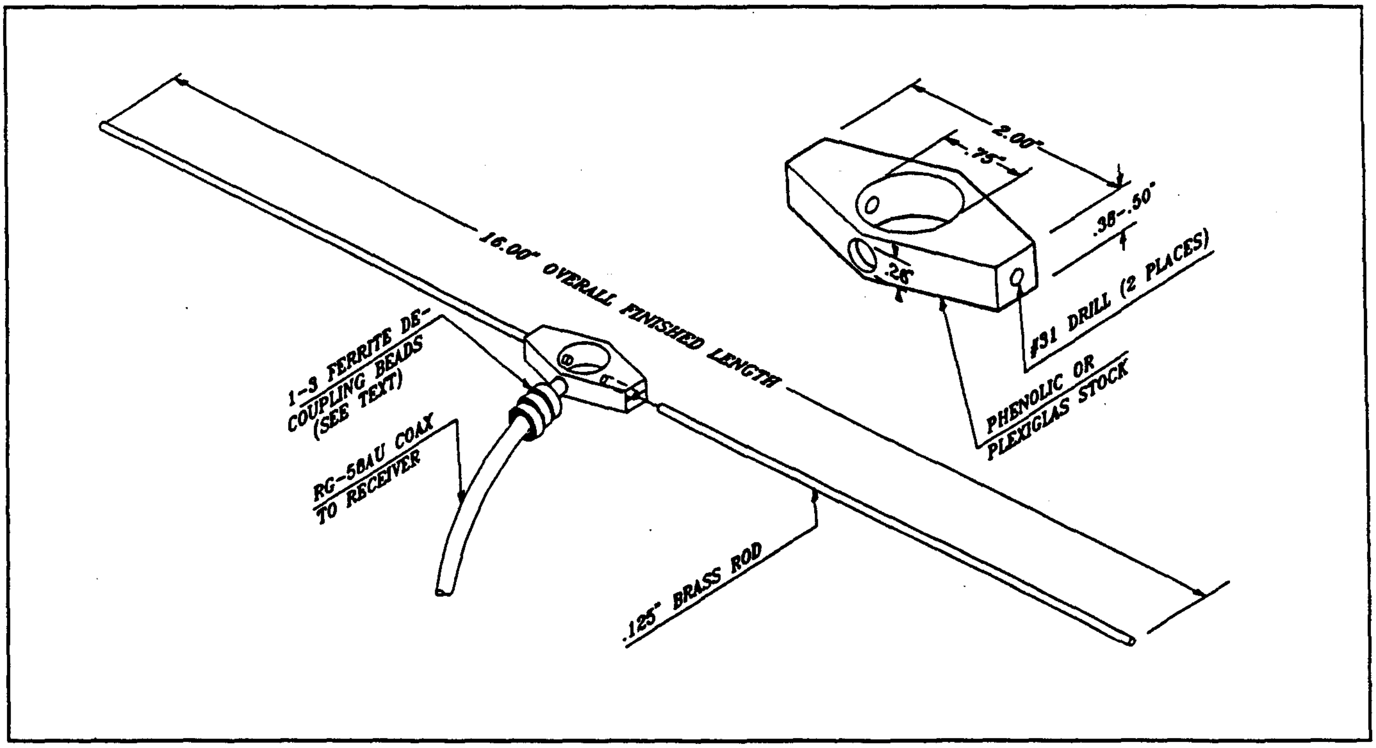


Figure 13-13. A Fabricated Glide Slope Antenna.

windshield is still a good bet. On low wing airplanes, consider a mounting a glide slope antenna on the plastic leading edge cover over a landing light. The light blocked by the antenna is negligible and, the antenna may have to be folded at the ends to stay inside the cutout length but it seems like a reasonable thing to consider. Of course, one could consider using a multi-set coupler as described in the next paragraph:

WHEN IS ONE ANTENNA IS BETTER THAN THREE?

The answer is, "when you can leave two of the three on the ground." For dual navigation and or navigation + glideslope installations, consider use of a feedline splitter to service multiple receivers with one antenna. This isn't a something for nothing situation, we're talking about sharing a finite amount of energy. In the case of dual VOR receivers, each receiver gets 1/2 the available signal. This does translate into a loss of range for both receivers compared to each having its own antenna. We're not talking about cutting range in half, it's more like taking 30% off at the fringes. Given the close proximity of most OMNI stations to each other, you may fly a long time and only over the desert southwest before you experience any degradation of utility due to feedline splitter losses.

The other situation uses a VOR antenna for both VOR and Glide Slope. It turns out that dipoles perform fairly well on the third harmonic of their fundamental operating frequency. Hence, a VOR/LOC antenna with a 108-118 operating range could be expected to be a fair performer at 324-354 Mhz as well. G.S. receivers operate at 329-335 Mhz. Here the trade-offs are better. A two frequency splitter has fairly low losses for each frequency. Also, I believe splitters are available to supply two VOR/LOC receivers AND a Glide Slope receiver from a single antenna. Check with your local avionics shop and see what they recommend. You certainly don't want to carry more antennas than necessary!!!!

CAUTION

When using splitters, keep in mind that loss of one antenna or feedline will disable all receivers fed from the single antenna system. If complete redundancy is required by your design philosophy, splitters should not be used.

NON-RESONANT, E-FIELD ANTENNAS

Meet the worst antennas ever bolted to an airplane, LORAN and ADF sense antennas. In all fairness, they really can't help it. ADF frequencies (190 - 1600 KHz) and LORAN (100 KHz) have quarter wavelengths starting at a paltry 47 and ranging out to 400 meters! Unless you fly an AN-124 or a C-5, there just isn't enough good real estate to effect a good low-frequency antenna system on an airplane. None-the-less, there are techniques which provide useful compromise between the ideal and the useless.

Non-resonant, E-field antennas are very small compared to a wavelength at the frequency of interest. Two things happen with very short antennas: First, the amount of signal they are able to intercept is reduced and second, their feedpoint impedances are very high. Recall the discussion on internal resistance of batteries back in chapter 2, we spoke of an ability of a battery to deliver energy at high rates due to very low internal resistance. Obviously, if the internal resistance of you airplane battery went up to several thousand ohms and its open terminal voltage fell to a few microvolts, one would consider it quite dead and useless. Fortunately in this instance, we're not dealing so much with energy as we are with a small **signal**. Small signals, if handled carefully and applied to appropriate amplifiers, can be elevated to very useful levels.

An AM car radio antenna is an excellent example of a short E-field antenna. Since the feedpoint impedance is very high (like thousands of ohms!), 50-ohm coaxial cable would be inappropriate for use between the antenna base and receiver chassis. If you open the feedline on an old car radio aerial, you will find a very fine center conductor routed down a semi-rigid and oversized insulating tube around which a shield braid is formed. We get more on the special nature of this feedline later. Input circuitry of an automotive AM receiver is also designed to present a very high impedance (low current) load to the antenna. These conditions allow the signal of interest to propagate from wavefronts in air to the input of a receiver with minimal attenuation in spite of the high impedances involved.

Once inside the receiver enclosure, amplifiers and filters go a long way toward making an otherwise poor receiving system into a useful tool. ADF sense antennas have classically been 8 to 15 feet of wire strung from cabin top to leading edge of the vertical fin. Actually, this same wire would make a pretty good LORAN antenna as well. I've heard that antenna couplers may be available which permit dual usage. However, LORAN receivers may take advantage of another technology known as the **active antenna**. Now here's an antenna that really does have **gain**. Well, actually the antenna is still just a passive piece of wire but there is an amplifier built into a little box right at the antenna's feedpoint. The amplifier does two things. It puts some gain on the signal and provides a low impedance output so that the signal will propagate adequately on ordinary 50-ohm coaxial feedline. Due to the single frequency nature of LORAN, it is possible to design a receiver front end that permits low impedance coax to be used with a passive antenna design. However, it's too easy to add the amplifier at the feedpoint and really do a better job of getting signals conducted from air and into the receiver.

ADF's are hold-overs from the early days of radio range stations which operated in the 190-450 KHz spectrum space. Even after the range stations were decommissioned in favor of VOR navigation, many of the transmitters were left on the air as low frequency beacons. Few homebuilders of compact airplanes are putting ADF systems in their ships. Further, given the rate at which GPS and LORAN are growing, one or both will replace the ADF as a non-precision approach aid in the foreseeable future. Meanwhile, making adequate installations of LORAN antennas is the plague of the moment, especially on composite ships.

There's no single magic potion for composite airplane LORAN antennas. Metal airplanes all seem to do well with the little whip (about 30 inches long) mounted on tail cone or in "sled-runner" fashion. A popular LORAN antenna for canard-pusher airplanes is illustrated in Figure 13-14. Most of the installed wiring is in the wing to provide a counterpoise ground. A short length of wire running up the tip sale is the actual antenna. Again, we hear some hangar-wisdom floating around that sez, "tie all the ground wires to every other loose piece of metal in the airplane, including electrical system ground."

When eight wires of about 8 feet in length are compared together with the 40-50 inch piece of wire that is the antenna, adding miscellaneous chunks of other "stuff" to the ground system holds little prospect for performance gains. It is more likely that noises from other system components cause by conduction and/or ground loops will be fed to the LORAN. Unless there is a compelling reason to do so, I keep antenna grounds separate from all others.

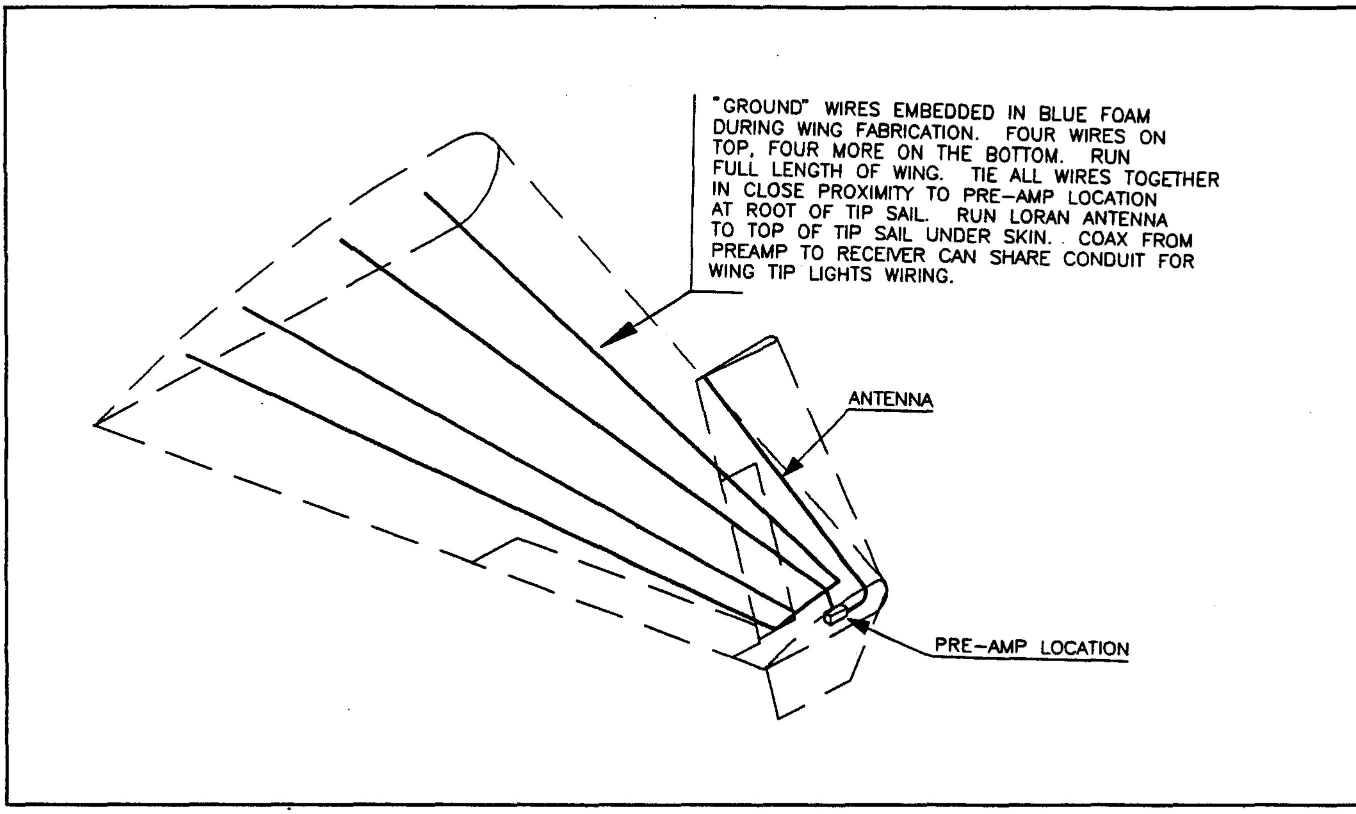


Figure 13-14. LORAN Antenna for Canard-Pusher Tip-Sails.

You can't have a LORAN antenna that's too long. Further, LORAN is vertically polarized so the most effective part of a LORAN antenna is that portion which is vertical to the surface of the earth. However, a long horizontal wire is better than a very short vertical wire. Experiment before deciding on a permanent installation. I would try a long wire running from wing tip to wing tip held on to the bottom with tape. Feed it from the center. At LORAN frequencies, there's nothing magic about grabbing the wire on the end. It seems to me that the best antenna for LORAN on plastic airplanes would be a version of the no moving parts ADF loop. A diversity or voting circuit to switch between multiple elements looking for the best signal would be in order. The problem is that plastic airplanes are a minority market, for now at least. With the heavy iron evaporating at 10,000 airplanes per year, I expect the LORAN people to take a serious look at engineering antennas for plastic airplanes. But they'd better hurry, before GPS blows them completely out of the water! The ADF loop is quite compact and operates in a unique mode as we'll see in the next few paragraphs:

NON-RESONANT, H-FIELD ANTENNAS (OR FINDING YOUR WAY HOME IN THE DARK!)

Like non-resonant, E-field antennas, H-field antennas are also much smaller than a wavelength at the frequency of interest. Further, they are characterized by their construction as having one or more turns of wire in the form of a "loop." Instead of sampling a small portion of a wavefront's electric field, loops sample the magnetic field. Loop antennas have been around just about as long as wire antennas. It didn't take early experimenters long to find out that special things would happen if the antenna were wound into a large coil instead of stretching it out between poles. As such antennas were rotated, a received signal was perceived to fade to nothing and then peak, two times per antenna revolution. It seems that when the antenna was broadside to the direction from which the signal was arriving, it had near zero response. 90 degrees of rotation would put the coils edgewise to the oncoming signal and maximum volume occurred.

My grandfather used a loop antenna to great advantage in a radio we had on the farm when I was a kid. Some living room consoles of the late 30's and early 40's had loops which could be rotated by means of a front panel knob. AM stations around the country share their frequencies with several other stations. During the day, short-haul propagation hid the problem locally. However, out in the Boonies at night, an interfering, perhaps even stronger station on the same frequency could be nulled out by judicious loop adjustment.

The significance of this phenomenon was not lost on early pioneers of radio aboard ships. Loop antennas can be seen mounted on the radio shack of many ships. The antenna had two purposes. First, if you took a relative bearing on two or more stations with known locations, lines of bearing marked on a map would cross at your location at sea. Second, ships transmitting distress signals could be located by cooperating rescue ships who would trade bearing information as they steamed toward the distressed vessel. Even if only one ship had such antenna equipment it could be used to "home" in on the troubled ship. There was a problem when only one DF system was available. If two nulls were observed for each antenna revolution, how do you decide which way to go? Most times a distressed ship could give rough position data which would help rescuers resolve directional ambiguities. Occasionally, erroneous information would cause a rescuer to steam in the opposite direction with serious consequences for those who needed help. A marvelous story about rescues at sea can be had in a book by Farley Mowatt called Gray Seas Under. Radio DF equipment figured prominently throughout the story. Mowatt is a consummate story teller. I don't often pick up a book I can't put down but this was one of them. Check it out, you're in for a treat.

I helped an uncle install a manually rotatable loop on the belly of his Cessna 170 back about 1952. It had a speedometer type cable running from the loop gearbox up to a crank and bearing dial between the seats. With headphones on his low frequency receiver, he listened for the sharp null in received signal as the loop was rotated in flight. Since one usually knows approximately where they are, the null ambiguity could be resolved. Any town with an AM radio station could be used as a navigation aid.

Later, designers found that if you took a sample of the signal from a non-directional antenna and mixed it with the signal from the loop, the two nulls would remain sharp but the peaks would be markedly different. By rotating the antenna a full 360, the direction of the loudest peak would be noted and used to resolve the proper null just 90 degrees away. The second antenna came to be called a "sense" antenna. Figure 13-15 illustrates the response pattern of a loop antenna with and without a sense sample. Manually rotated direction finding antennas soon gave way to devices driven by servo motors which automatically maintained the antenna in an unambiguous null condition on the received signal and the automatic direction finder (ADF) was born.

The first DF antennas for aircraft looked just like the devices shown in figure 13-16. As electronics capability grew, antennas could be made smaller and they were housed in tear-drop shaped housings for streamlining. By about 1960, they were small enough to be enclosed in a small plastic dome, usually on the belly. About this time the circular, air core construction was replaced by much smaller ferrite core, bar shaped devices. In figure 13-16 I have shown vertically polarized, E-field wavefront advancing on two loops oriented 90 degrees to each other. As you should expect by now, the horizontally polarized H-field is at right angles to the E-field. The H-field lines are in a proper orientation to couple nicely with the turns of wire in a loop antenna. However, when the loop is broadside to the oncoming wave front, each side of the loop develops equal but opposite voltages causing cancellation of the received signal at the feedline. A loop turned 90 degrees gets a different portion of the wavefront coupled to its wires for each instant in time which yields maximum signal.

Try this experiment with a little pocket AM radio: The antenna in most cheap radios is a piece of ferrite wound with many turns of wire. Tune the radio to a station several miles away and then rotate the radio while listening to the strength of received signals. When either end of the antenna core points to the station, the turns of wire are broadside to the oncoming wavefront and a null will be detected. Back in high school, about 1959, I managed to acquire a Regency TR-1 pocket radio. This was one of the first transistor radios on the market. I used to amaze my friends by having them tune the radio to any station and then put it into a sock and hand it back to me. I could tell them which station it was tuned to by appearing to wave it around a bit. Actually, I knew were the stations were located around the city and was listening for the nulls as I "waved". The parlor trick backfired when I tried to repeat it inside the building for the benefit of my electronics shop teacher. Steel and wiring in the structure badly distorted received signals and made "pocket radio direction finding" impossible.

Modern day loops used for ADF work don't have to be rotated mechanically. The antenna assembly on the belly

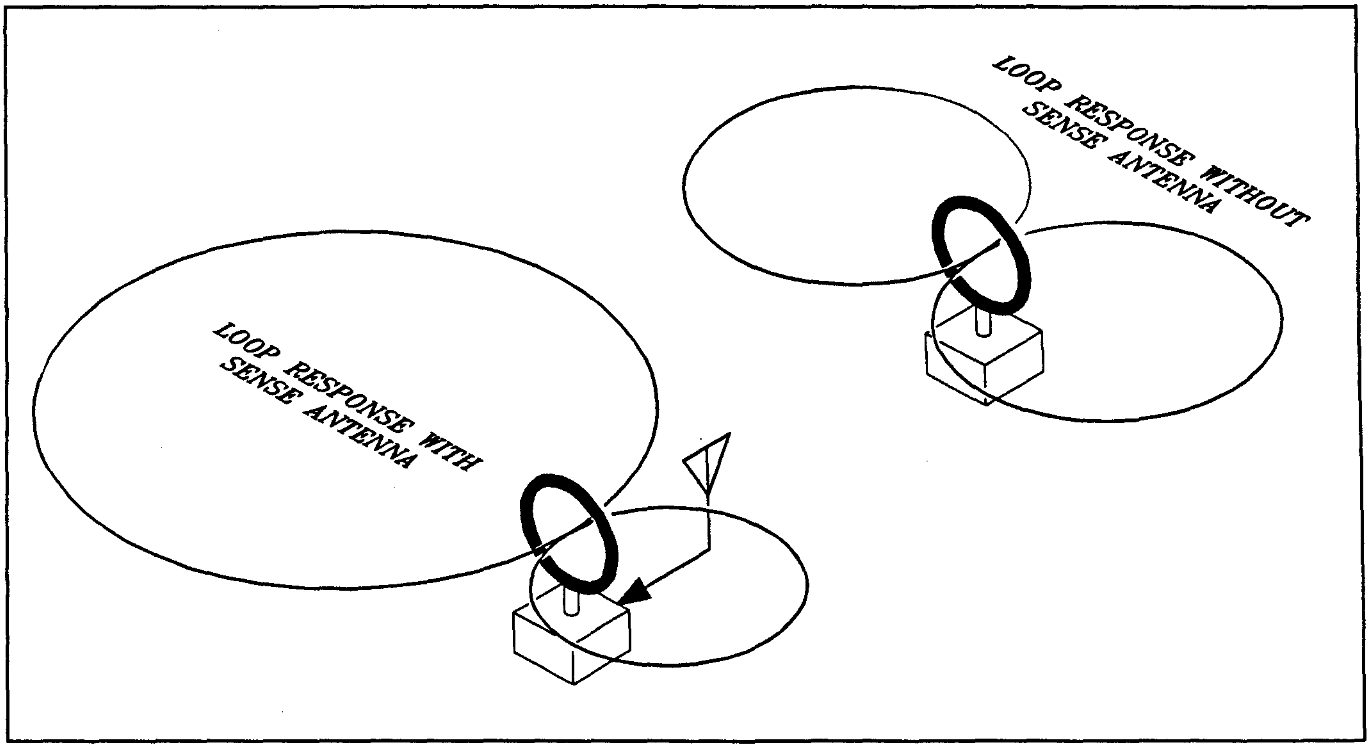


Figure 13-15. Loop Antenna Patterns.

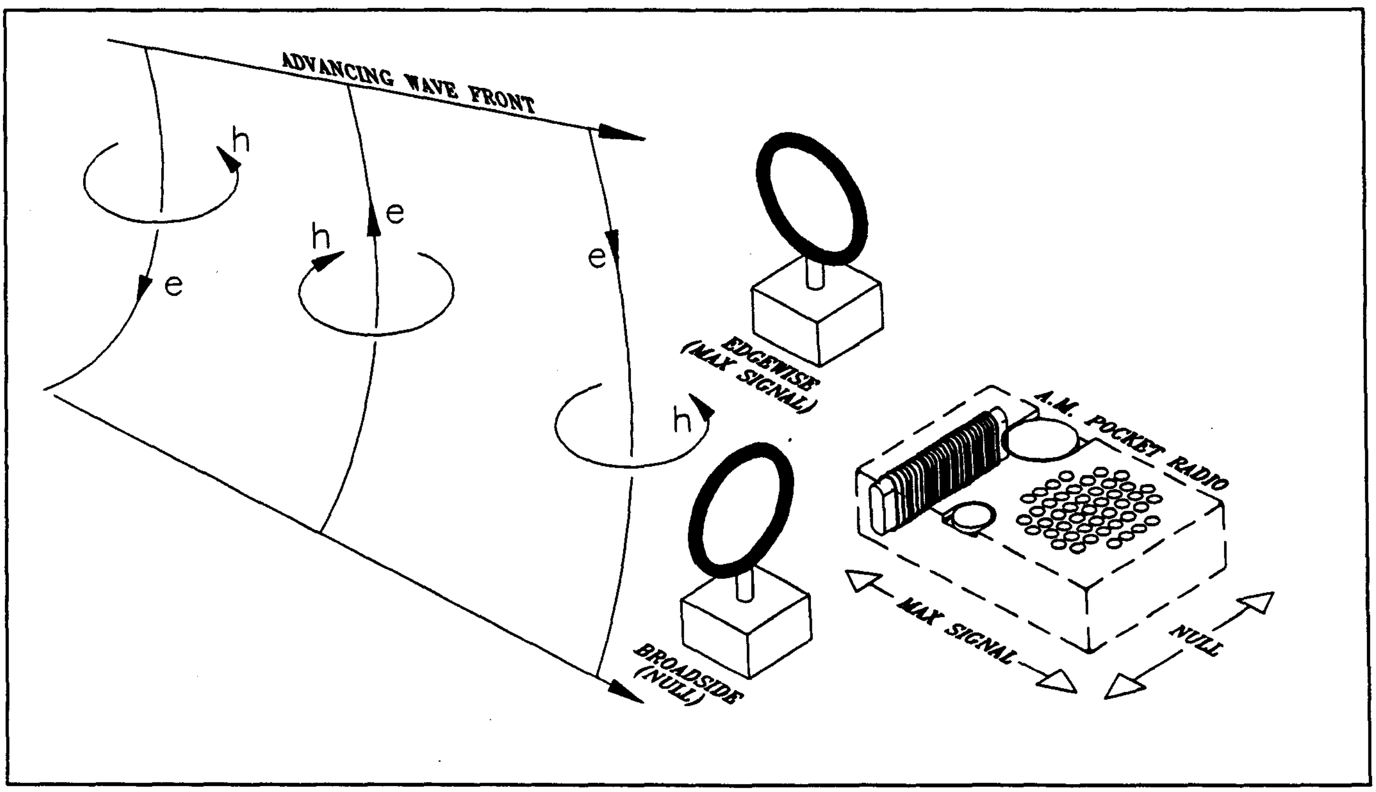


Figure 13-16. Direction Finding with Loop Antennas.

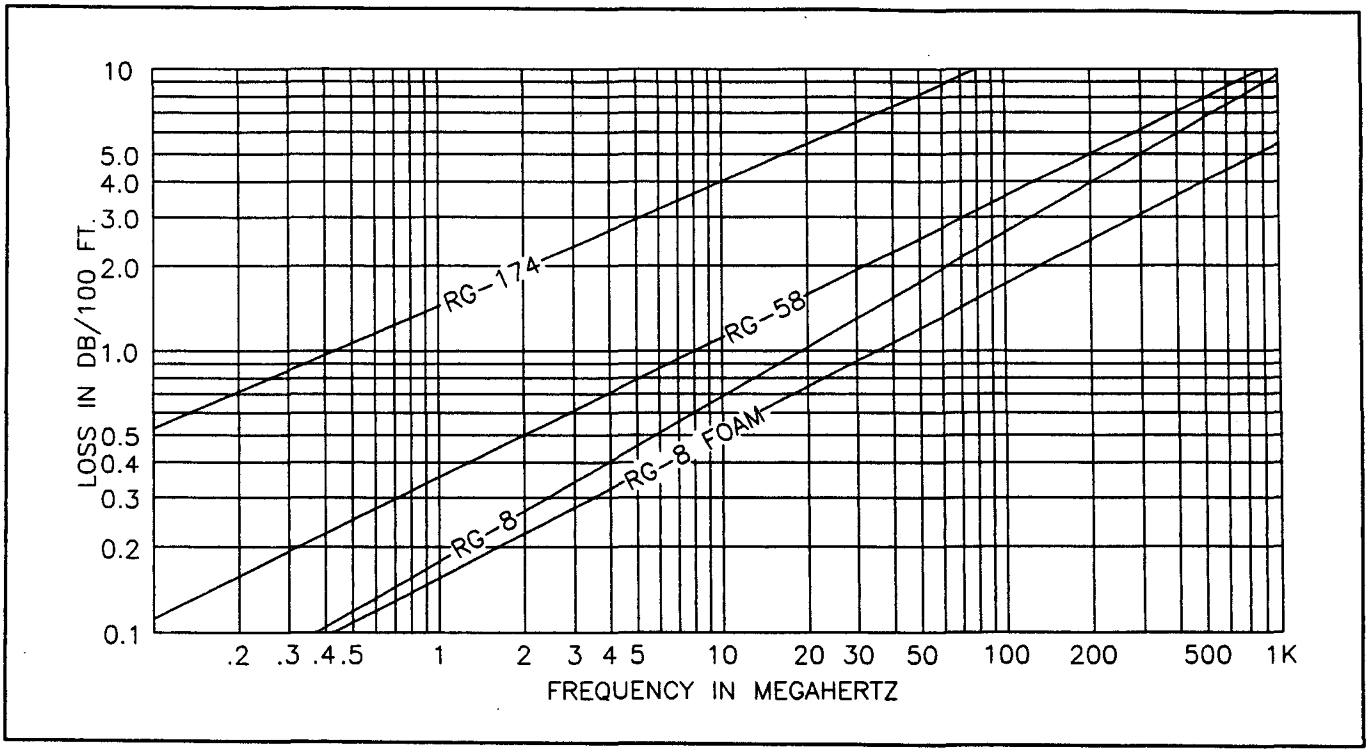


Figure 13-17. Losses versus Feedline Type and Frequency.

has two or three ferrite core coils, not unlike those found in the little pocket radio. All solid-state resolvers compare signals from a sense antenna with those from the ferrite "loops" and calculate direction of the oncoming wavefront electronically.

FEEDLINES: NOT YOUR ORDINARY SHIELDED WIRE

Radio frequency energy is seldom generated or gathered at the place where it is needed. Antennas may be located a considerable distance from a receiver or transmitter. The intervening wire is called a **feedline**. Unlike ordinary wire specified by gage, stranding and insulation, feedlines add specifications under headings of impedance, losses and power handling capabilities. Let's talk about impedance ratings which are always stated in ohms. Aha! We know about those critters; or do we? I've had more than one conversation with individuals who called about a defective roll of 50-ohm, coaxial cable they had just purchased. They "checked" the wire with an ohmmeter and it didn't read any where near 50 ohms! Had another fellow try to check some television twin-lead and he couldn't seem to read 300 ohms either. For coaxial cable impedance is a function of ratio of inside conductor o.d. to outside conductor i.d. For parallel feedlines like television twinlead impedance is a function of ratio of conductor diameters to conductor spacing.

While the unit of measurement has the same name (ohms), techniques for measuring resistance versus impedance are different. Resistance is measured with a common ohmmeter. The simple hand held instrument has a battery, microammeter and some scaling resistors to measure current through the resistor to be tested. The volts divided by amps = ohms equation is solved and you read ohms directly from the meter scale. **Impedance is an a.c. measurement.** Further, it may include **reactive** components which cause impedance to vary with frequency. Reactive devices are capacitors and inductors which combine with resistors to make up complex impedances.

A LITTLE ENERGY GETS LOST ALONG THE WAY . . .

Irrespective of how you conduct energy from one place to another, it's nigh well impossible to transport it without some losses. We studied some examples of resistive losses in the chapter on wire. Coax cables carrying radio energy has resistive losses like any other wire. Feedline materials suffer from additional losses due to insulation (or dielectric) quality. Furthermore, losses are directly related to operating frequency; higher frequencies suffer higher losses.

The ideal insulator for feedlines is air. Feedlines operating a very high frequencies or high power often use center conductors supported by occasional plastic spacers inside an outer jacket of copper pipe. Except for the center conductor and occasional spacers most of the volume inside the outer conductor is filled with air. However, to fabricate a practical feedline for running in wire bundles and under floorboards, a center-conductor is sleeved with plastic insulation and braided wire shielding is placed over the plastic for an outer conductor.

Depending on feedline size, center conductor insulation and length, coaxial cables for antennas will have some unavoidable losses. Generally speaking, the larger the coax, the lower will be its losses at any frequency. Figure 13-17 compares coaxial cables commonly used in avionics installations. Losses expressed in Db per 100 feet are seen to vary with operating frequency and cable type. *[Decibels, a very handy system for discussing power ratios]* We'll talk more about Db in the chapter on noise but for now, know that for each 3 Db power is diminished by 1/2, it follows that 6 Db loss means 1/4 power, 9 DB is 1/8th and 10 Db is 1/10th power, etc. This system allows you to work very large power ratios with rather ordinary numbers. For example: 60 Db describes a power ratio of 1 million to 1!

Referring to figure 13-17, we see typical losses for a few common coax cables. RG-174 is a very flexible, small cable about .1" in diameter. The first time I ever worked with some I was about ready to use it everywhere . . . . until I looked up its performance at high frequencies. I've included it here as a comparison but I would not recommend its use in any but the most vexing space problems. Keep in mind that 50-ohm coax is 50-ohm coax. The radio cannot tell if you have more than one type of coax in the feedline. RG-174 could be considered for bringing glide slope signals off a windshield centerline antenna to a space over the upholstery. Once the coax is out of sight, appropriate connectors could be used to switch to RG-58 for the rest of the run. Use RG-174 in short runs, a few inches only, before transitioning to "better" stuff. At 300 MHz, RG-174 has a loss of 22 Db per 100 feet. A 1-foot piece would, therefore, have a loss of .22 Db which would be acceptable. RG-58 can be used for 95% of all installations. Even 1000 MHz DME and transponder signals are not seriously affected by short runs (less than 10'). However, if you want the very best performance from these two radios, use RG-8 Foam type coax for feedlines. Purchase this coax from a two-way radio service firm. The so called RG-8X foam coax sold by Radio Shack and others should not be used in an airplane. Radio Shack's RG-58 is okay. RG-59 is a 70-ohm coax for television systems and not suited for aircraft antennas. Don't let anyone sell you some with the idea that it's "close enough."

There is some "leakage" of energy from within a coax cable especially if the SWR is not exactly 1:1. If the DME or Transponder makes little clicking or buzz-burst noises in your radios or audio system, try a double-shielded coax. RG-214 is suitable replacement for RG-8, RG-223 is a double-shielded version of RG-58.

STANDING WAVE RATIOS

Coaxial cables used in 95% or more of all aircraft feedline installations is rated at 50 or perhaps 52 ohms. Looking into the end of a 50-ohm coax terminated at the far end by a 50-ohm load you will see 50-ohms. If the far end is terminated by something else, say 100 ohms load, then the impedance you see looking into your end may be anywhere from 25 to 100 ohms depending upon the length of the feedline! This impedance transformation occurs along with a phenomenon known as **standing waves.**

If you've ever had occasion to install a c.b. antenna on a vehicle, the instructions will recommend and outline a procedure for adjusting the antenna for minimum VSWR or simply SWR (Standing Wave Ratio). Some c.b. transceivers even have SWR instrumentation systems built into the radio! The procedure generally tells you adjust the length of the antenna to achieve an SWR as close to 1:1 as possible. When and if 1:1 is achieved, you are assured that the antenna now presents a 50-ohm load to your 50-ohm feedline.

Quite often, an exact 1:1 is not achievable, perhaps 1.5:1 is the best you can get. Or, in the case of multichannel radios, you might achieve 1:1 on one frequency only to see the SWR figure climb on other frequencies. This is simply a manifestation of two characteristics ascribed to all antennas: **feedpoint impedance** and **bandwidth.** For example, our hypothetical antenna is exactly resonant on only one frequency so it is quite natural to see shifts in feedpoint impedance as frequency changes. Further, the antenna may never present an

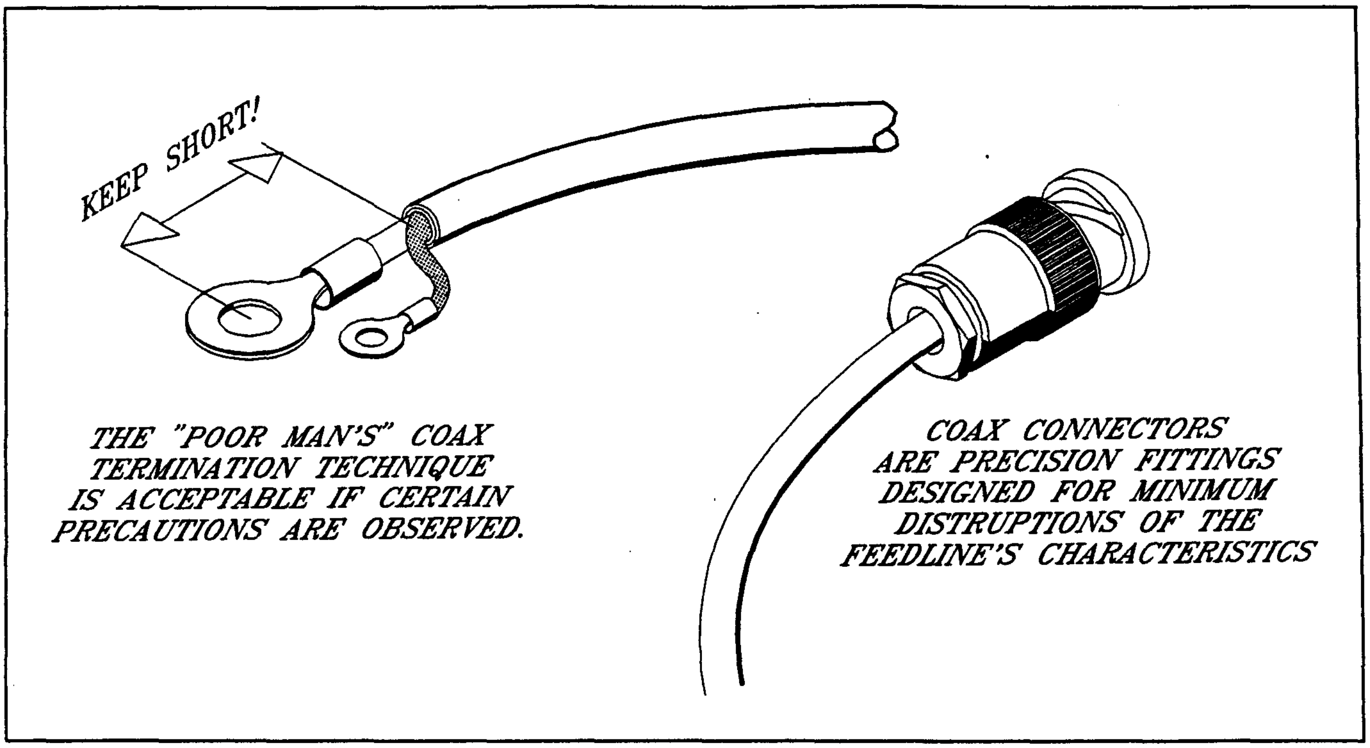


Figure 13-18. Two Styles of Coax Cable Termination.

exact 50-ohm load to the feedline even on its resonant frequency. The theoretical feedpoint impedance at the base of a 1/4-wave vertical is about 35 ohms. This means that the SWR on 50-ohm coax feeding this antenna will never be better than 1.4:1. Some commercially built antennas may have specialized matching transformers built into their bases which provide a better match over the antenna's design operating range. These antennas can be quite confusing when checked with an ohmmeter; they quite often look like a dead short! You can bet that when 120 Mhz energy arrives at the base, the antenna will look very close to a 50-ohm load . . .

MUCH ADO ABOUT LITTLE . . .

For some people, achieving 1:1 SWR on feedlines is a passion. In the real world, an SWR as high as 3:1 will make little if any perceivable difference in how your communications system performs. Some early solid state transmitters had problems with high SWR; it would cause output amplifier transistors to fail. Many of these sets had SWR instrumentation built in which shut down the amplifier in case a feedline became disconnected or an antenna was damaged. Modern communications transmitters are well protected against feedline failure. In any case, it's usually quite easy to keep antenna SWR below 3:1. How bad is it? Well, if you have a run of coax which gives 1.0 Db loss at 118 Mhz when the SWR is 1:1, total losses will rise to only 1.5 Db if the SWR rises to 3:1.

ADJUSTING

The very best way to adjust a communications antenna system is after it is installed. The radiator is cut perhaps 2" longer than you calculate. Make a temporary installation of a through-line wattmeter in the feedline between antenna and transmitter. Make SWR measurements at 120, 128 and 135 Mhz using the ships VHF transceiver as a signal source. Observe repeated measurements as the antenna is shortened 1/4" per measurement. Stop cutting the antenna when the lowest SWR measurement occurs at or near 128 Mhz. If a signal source strong enough to operate the wattmeter in the VOR frequency ranges is available, the same technique may be used to trim the VOR receiving antenna. By adjusting antennas for the best transmitting characteristics, idealized receiving adjustments are also realized. Start with elements which are too long. Make measurements at the low, center and high ends of the frequency range of interest. Trim for lowest SWR at the center frequency and observe that it does not exceed 3:1 at the ends.

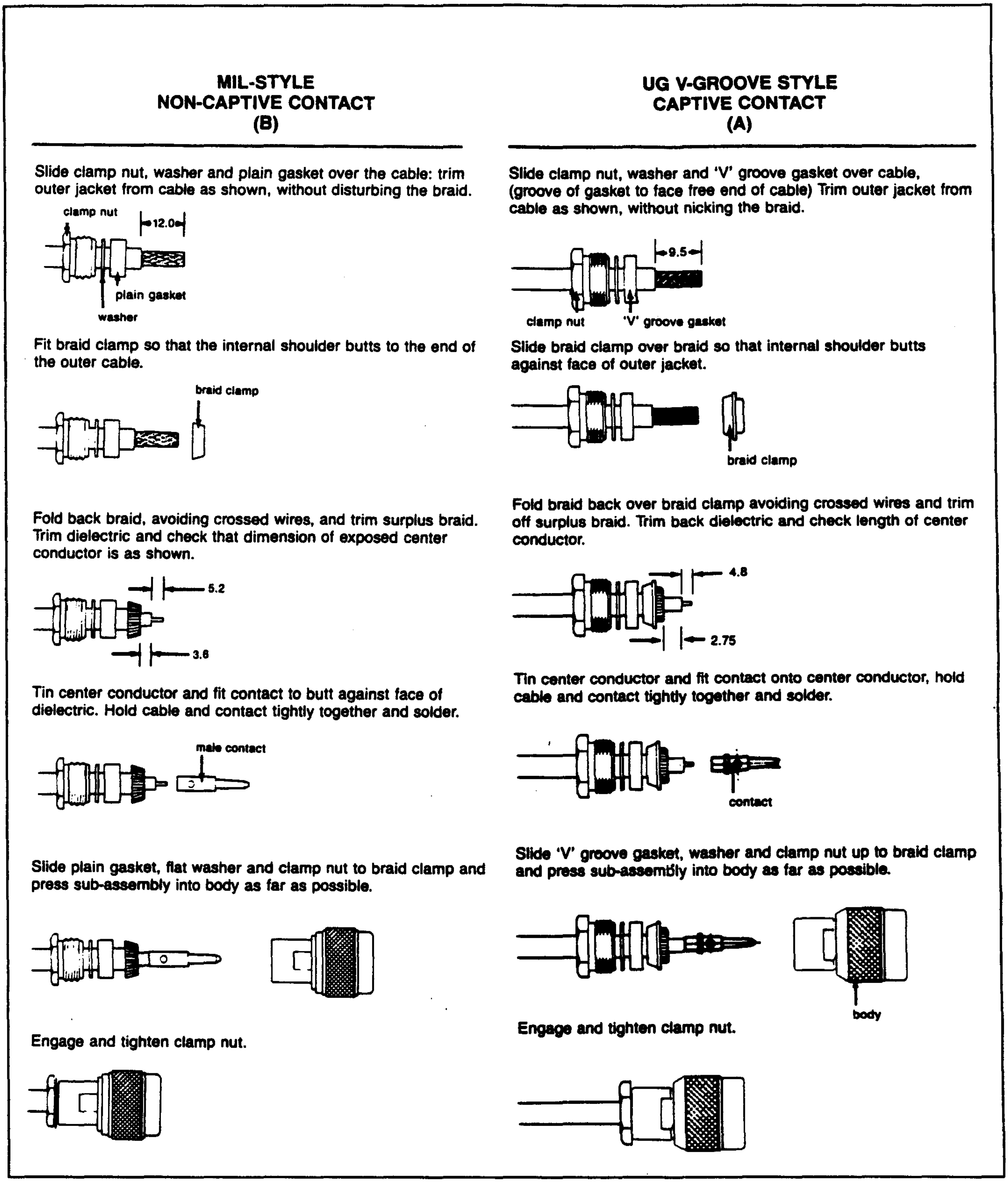
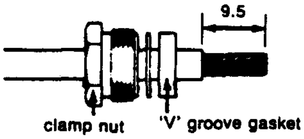


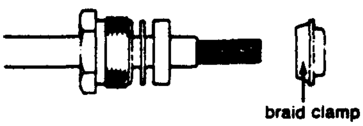
Figure 13-19. Type N and Type TNC Connector Installations.

V GROOVE STYLE
NON-CAPTIVE CONTACT
(A)

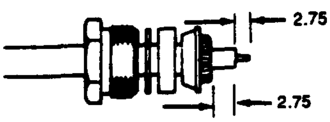
Slide clamp nut, washer and 'V' groove gasket over cable, (groove of gasket to face free end of cable) Trim outer jacket from cable as shown, without disturbing the braid.



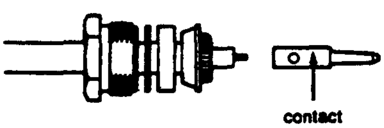
Slide braid clamp over braid so that internal shoulder butts against face of outer sheath.



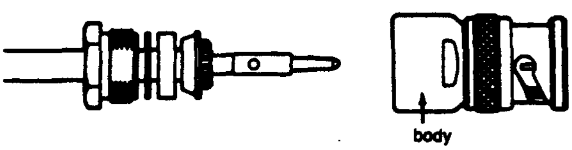
Fold braid back over braid clamp avoding crossed wires and trim off surplus braid. Trim back dielectric and check length of center conductor.



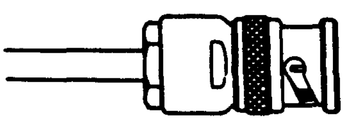
Tin center conductor and fit contact onto center conductor, hold cable and contact tightly together and solder.



Slide 'V' groove gasket, washer and clamp nut up to braid clamp and press sub-assembly into body as far as possible.

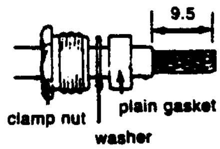


Engage and tighten clamp nut.

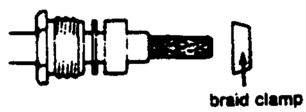


UG-STYLE
NON-CAPTIVE CONTACT
(B)

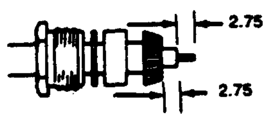
Slide clamp nut, washer and plain gasket over cable trim outer jacket from cable as shown, without disturbing the braid.



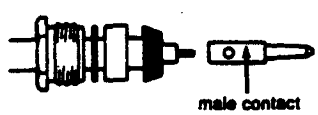
Fit braid clamp so that the internal shoulder butts to the end of the outer cable.



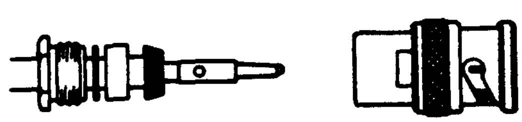
Fold back braid, avoding crossed wires, and trim surplus braid. Trim dielectric and check that dimension of exposed center conductor.



Tin center conductor and fit contact to butt against face of dielectric. Hold cable and contact tightly together and solder.



Slide plain gasket, flat washer and clamp nut to braid clamp and press sub-assembly into body as far as possible.



Engage and tighten clamp nut.

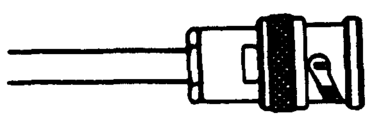


Figure 13-20. Two Types of BNC Connector Installations.

CONNECTORS

There is a do-it-yourself connection not recommended by any cable manufacturer but it performs well if precautions are observed. Figure 13-18 shows terminals crimped or soldered onto prepared coax braid and center-conductor. This works very well at marker-beacon, VHF and glide-slope frequencies but take care with DME/Transponder applications. Coax is "coaxial" only if the conductor is inside the shield. Once the center conductor is exposed, it becomes a common piece of wire. At 1000 MHz it can add considerable inductance to the system if not kept as short as possible.

Coax connectors are specially designed to join concentric cables to devices or other cables without breaking shield integrity and to minimize impedance "lumps" in the feedline system. The majority of general aviation avionics use BNC, TNC or N-series connectors. Some radios use mounting trays with captive connectors built into the back. A radio chassis will make proper connections to the airplane wiring via special connectors on the rear which mate with connectors on the tray when the radio slides home.

There are a number of vendors for coax connectors listed in Appendix-A. Catalog listings often break down connectors by several attachment styles such as clamp/crimp, crimp/crimp, clamp/solderless, clamp/soldered, etc. Quality of "solderless" connections can vary with manufacturer. Crimped joints often require expensive tools. My own favorites are connectors which clamp the shield braid and solder the center conductor pin. These take a little more skill in measuring, cutting, preparing and assembling than high volume production versions but . . . I can put one on anywhere with minimal tools and the connector is often cheaper than the high-volume part. Figures 13-19 and 13-20 illustrate installation details on a few styles of coax connectors found in airplanes. Installations shown here are some common variations on a broad theme. When ordering connectors, ask the vendor if they can provide detail assembly sheets or a manufacturers installation manual. Most vendors have or can get such data and should be willing to supply it.

BALANCED ANTENNAS AND UNBALANCED FEEDLINES

The balanced nature of dipoles and unbalanced nature of 1/4-wave verticals is somewhat obvious. Further, for best performance in driving such antennas, the feedlines should be compatible. The biggest reason for compatibility is for interference reduction between systems. If you had nothing but a omni receiver in your airplane and no other susceptible systems, it wouldn't matter if your antenna and/or feedline had compatibility problems. Many of you will be installing a major sampling of systems listed in Table 13-1 so let's minimize the potential for problems with some simple precautions.

At the end of this chapter, there are a number of publications I recommend for general and specific information on antennas. None of them are expensive and some can be checked out of the library. These publications will describe a number of ways to deal with feedline/antenna compatibility when going from unbalanced feedline to balanced antennas. Many of these techniques have been used from time to time on airplanes but I'd bet there's never been a real study of their effectiveness; not in Wichita at least! A few years ago, coaxes were bolted to dipoles with indifference until someone read an article and became a little embarrassed about lack of "engineering." So, in spite of the fact that no problems could be specifically traced to the evil practice, various "baluns" were fabricated and installed on VOR/LOC and glide slope antennas.

The problem with baluns (contraction of words BALance/UNbalance) was that they are cut to specific wavelengths at the frequency of interest. When the frequency of interest was a **range** of frequencies, addition of simple wave-length cut baluns could often be demonstrated to hurt more than help. Nowadays, we can attack the problem with new technology. Toroidal ferrite cores (sometimes called "beads") can be slipped over the coax close to the joint between feedline and antenna. Normally, magnetic fields due to currents conducted on conductor and shield of a coaxial feedline will cancel each other out. No external magnetic field is generated. Any extraneous currents due to antenna mismatching cause external fields to be created outside the coaxial shield. These will concentrate in the ferrite beads and not propagate down the outside of the coax. Further, ferrite beads are not frequency selective. They perform their intended tasks over the full frequency range of the antenna. RST sells a dipole kit for roll-your-own glide slope and VOR/LOC antennas which includes the appropriate ferrite beads. Two or three beads over the coax as shown in Figure 13-13 will preclude any foreseeable difficulties. This technique applies to any situation where an unbalanced antenna is being driven by a coaxial feedline.

BIBLIOGRAPHY

New antennas for airplanes is an area that has not received much attention from the certified side of aviation. Builders of metal airplanes who would like to hide antennas under fairings and wingtips might just have the drive to do some serious and ultimately successful antenna experiments. Plastic airplanes have special problems not addressed by any large commercial ventures. I'll be glad to work with anyone who is willing to try something different. Successes and failures need to be written up in these pages or in Hot Flashes. The successes should be shared so everyone can benefit, the failures need to be shared to keep someone from wasting their time on something that is already known not to work. If you are inclined to work further in antennas for airplanes, check into the following publications:

The Radio Amateur's Handbook, any issue. Published by the American Radio Relay League, Newington, Connecticut.

The Radio Amateur's Antenna Manual, any issue. Published by the American Radio Relay League, Newington, Connecticut.

ARRL publications are available through most bookstores and amateur radio supplies stores. Or, order direct from ARRL, Newington, CT 06111