ANTENNA CONSIDERATIONS FOR HOMEBUILT AIRCRAFT

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THE PURPOSE OF this paper is to give an insight as to the operation of VHF aircraft antennas and their application to metal and wood aircraft structures. The radio frequencies of the VHF aircraft band are between 108 and 136 mHz. The 108 to 117.95 band is used for navigational purposes. This includes Omni and localizer service. Aircraft equipment in this range receives only frequencies from 118 to 136 mHz which are considered channels. Aircraft equipment may transmit and receive on these frequencies. The 75-mHz frequency has been set aside for marker-beacon service, and aircraft equipment received only on this frequency. Other bands are available for aircraft services, such as glide slope (329 to 333 mHz), transponder (1030 to 1090 mHz), and low-frequency broadcase for range and direction-finding use (200 to 1750 Kc). I will restrict this paper to the VHF 108 to 136-mHz band and 75 mHz marker-beacon frequency. The principles involved however are applicable to other bands as well.

The physical length of the antenna element is inversely proportional to frequency; that is, the higher the frequency, the shorter the antenna elements are. The simplest form of an antenna is an element of ¼ wavelength of the frequency involved. One may calculate this length by the following formula: ¼ wave element - 2952/mHz (inches). Fig. 1 shows a plot of this equation. For mid band of the communication frequency, the length is 22 in. This is an approximate dimension as other factors enter into the picture. Normally, the quarter wave element is mounted on an insulator perpendicular to a ground plane. The ground plane may be a solid conducting sheet of metal or made up of a series of radial elements. The length of these elements is generally equal to or longer than ¼ wave length. Fig. 2 shows a ¼ wave antenna mounted on a ground plane. On fabric or wooden structures, this ground plane may be made from strips of foil as shown in Fig. 3. Electrical connections to the antenna are made between the insulated end of the ¼ wave vertical element and the ground plane adjacent to the insulator. A coaxial cable is generally used for this purpose, the center conductor being connected to the ¼ wave vertical element and the shield to the ground plane.

Radio waves are polarized, depending on the structure that radiates the energy. Vertical antennas will radiate

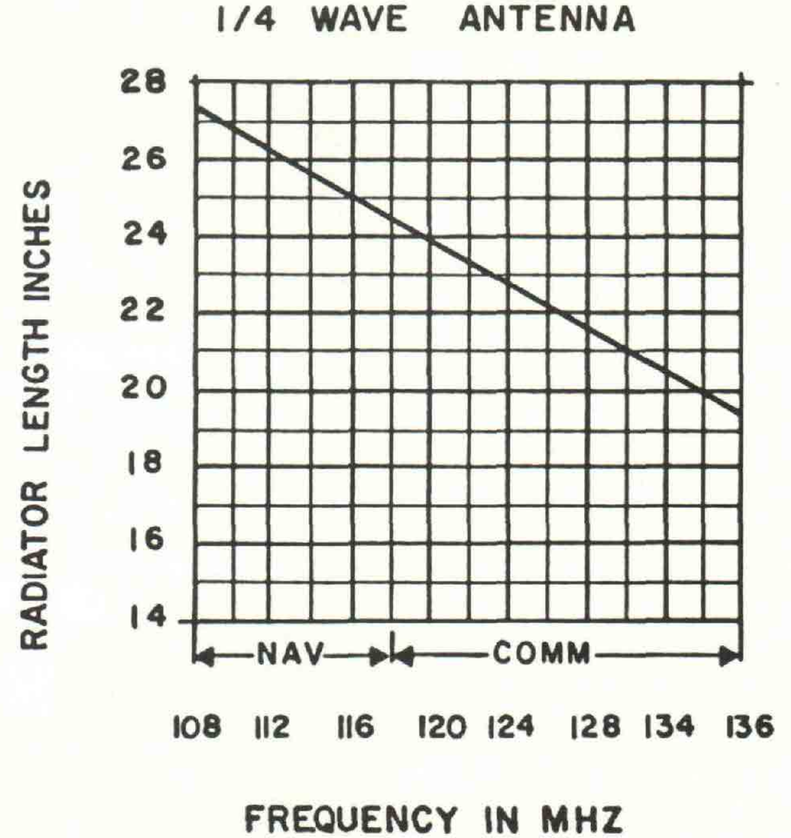


FIG. 1

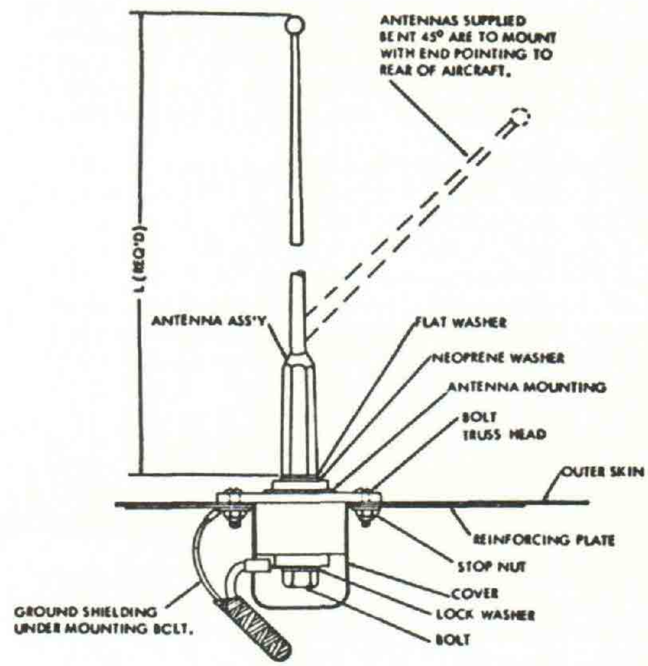
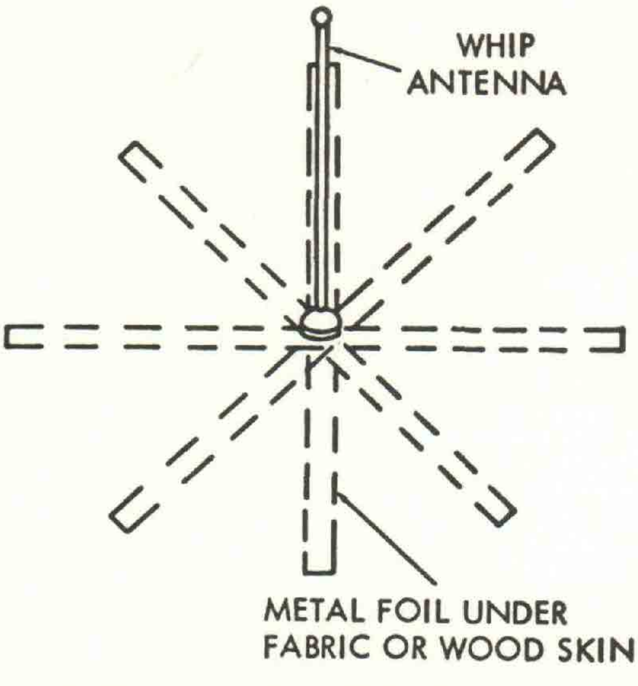


FIG. 2

vertically polarized waves while horizontal antennas radiate horizontally polarized waves. Receiving antennas are more efficient depending on their orientation to the direction of polarization of the radio wave. Hence, a vertical antenna will receive a vertically polarized wave more efficiently than the same antenna in a horizontal position. As previously noted, the aircraft band is divided into two parts, one for navigational and the other for communication use.

The polarization of the radio waves from the ground station is horizontal for navigational services while verti-



NOTE: THE LENGTH OF EACH FOIL RADIAL SHOULD BE AT LEAST EQUAL TO THE ANTENNA LENGTH.

FIG. 3

cal polarization is characteristic of the communication channels. It follows therefore, that one should use a vertically polarized antenna on the aircraft for the communication section of the radio equipment. This is indeed what is done. The ¼ wave antenna previously described is the logical choice for this use.

I wish next to discuss radiation patterns of different antennas before going to the horizontal polarized antennas. One of the rules of antenna design is that the characteristic radiation or sensitivity patterns of given antenna are the same for both transmitting and receiving conditions. With reference to Fig. 4(a), we see the Omnidirectional pattern of a ¼ wave vertical antennas as viewed from above. Fig. 4(b) shows the side view of the theoretical radiation pattern of the same antenna if the ¼ wave vertical element is operated over a perfectly conducting ground plane of infinite radius. Fig. 4(c) shows an actual pattern of a vertical antenna of approximately ¼ wave length operating over a ground plane of six wave lengths, approximately 48 ft. in diameter. The ground plane is represented by the horizontal line passing through the pattern.

As the ground plane decreases in diameter, the maximum radiation vector occurs at slightly higher angles above the horizon, and grating lobes are characteristically broader and fewer in number. You will note that some energy is radiated in the downward direction, but the maximum sensitivity or gain of the antenna is predominantly upward.

This would suggest one should mount the ¼ wave vertical antenna on the underside of the aircraft which would indeed be the best position. If the antenna is bent rearward 45 degrees or even 90 degrees, the pattern becomes unsymmetrical. Also, the shape of the airplane structure has much to do with the radiation pattern. Now, let us look at Fig. 4(d). This pattern is of the same antenna as in Fig. 4(a) except two ¼ wave vertical parasitic elements are located one on each side of the ¼ wave vertical antenna and spaced ¼ wave each side. These elements are grounded to the ground plane. One will notice how the pattern is distorted from a circular omni-directional pattern to an

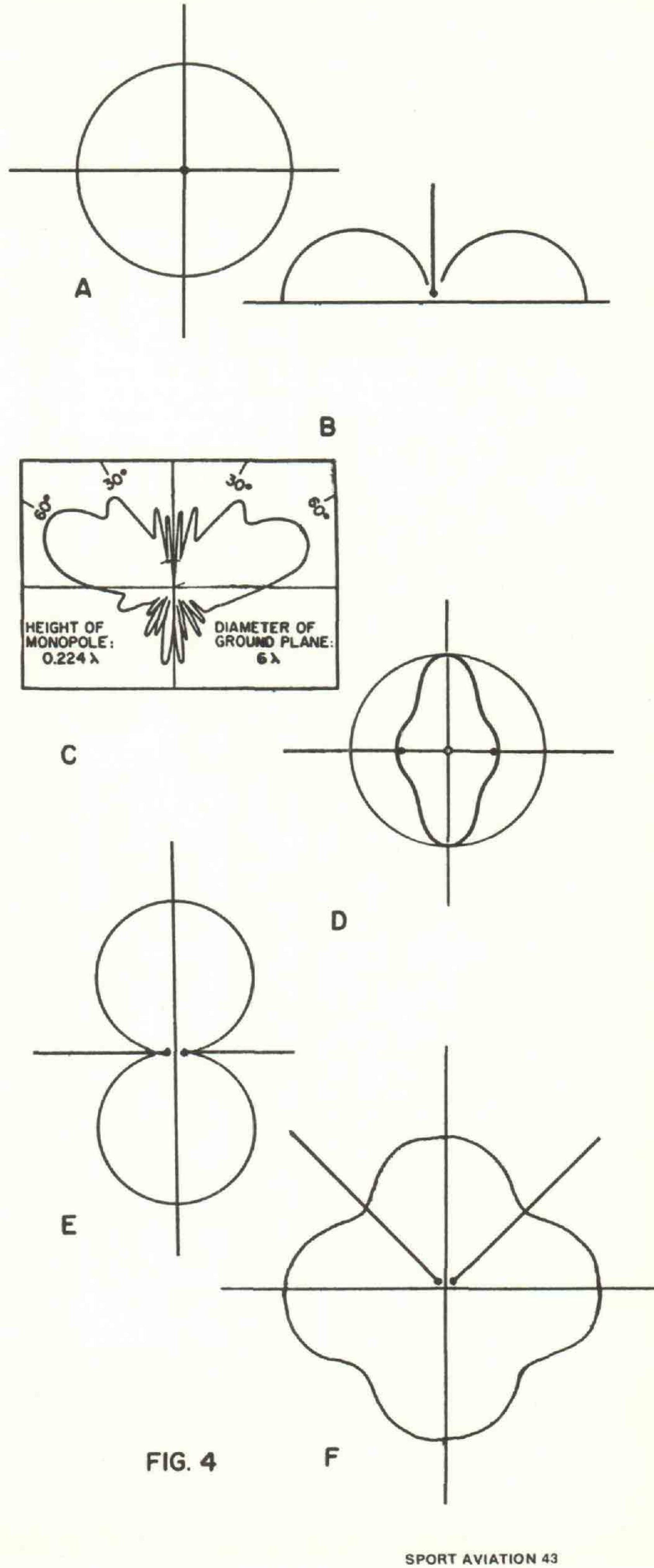


FIG. 4

ANTENNA CONSIDERATIONS . . .

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elongated shape. Whereas this is not exactly the same condition — one would have to say if you mounted the antenna on the bottom of the aircraft between the landing gear — but I think it illustrates the problem.

The point is that pattern distortion and attenuation does occur from surrounding conductors lying in the plane of the plane of the antenna. Remember this, as we will touch on the same thing later. You may say, let's move the antenna forward on the bottom of a conventional-gear airplane for better ground clearance considerations. Fine, if you have a wooden propeller! Here again, if a metal prop is used and the blade is 2 ft. or 3 ft. radius, then one would expect pattern fluctuation, or propeller modulation as it is called. At 2400 rpm, which is 4800 blade elements/minute or 80 elements/second, one would expect to hear this pulsing on his radio receiver. Likewise, the transmission may be distorted. A ¼ wave vertical antenna may be bent to the rearward 45 degrees without markedly affecting performance.

Let us look at Fig. 4(e).This is a typical pattern of a half wave dipole. That is, two ¼ wave elements mounted in line and fed in the middle. This antenna is referred to as a balanced antenna, while the ¼ wave monopole is unbalanced. That is, one side works against ground. You will note on the half wave dipole that its maximum sensitivity is broadside with no response on the ends. Actually, the field pattern is a torus or "doughnut without a hole" if you wish to imagine the field in three dimension. This antenna is said to be horizontally polarized when used parallel to the ground. This antenna would make a fine glide slope receiving antenna, but a poor VOR antenna for navigational purposes as it receives very little from the side. Fig. 4(f) shows the pattern of the same half wave dipole antenna when the elements are bent back so the included angle is 90 degrees. This is referred to as a quadrant antenna. You will at once notice the quasi omni directional pattern. The pattern amplitude is never less than 70 percent of its peak value and therefore receives well in all directions. Most of the omni navigational antennas are modifications of this design. One will find that the included angle between elements varies and even may be bent in the shape of a U or ram's horn. The patterns are not as uniform as shown in Fig. 4(f) but have been optimized according to the manufacturers' design specifications. It almost goes without saying, as you might have already suspected, that the Omni navigational signal is transmitted by a horizontally polarized antenna. Again, vertical polarization is used for communication, and horizontal polarization is used for navigation.

Now let's look at applications of navigational or omni antennas. Since homebuilts are either metal or wood, that is, conducting surfaces or non-conducting surfaces, let's develop an understanding as to how this difference shows up. There are two distinct types of omni antennas. Those mounted on masts and those that are not. You may say, well the ones that are not on masts mount on the vertical fin structure and the ones on masts mount on the fuselage. Fine, as far as you go, but what about the popular teardrop insulator design in the center, which will not mount on the tail fin. Remember, I said "distortion and attenuation occurs from surrounding conductors lying in the plane of the antenna". Let's imagine I mount the teardrop insulator design on the top of a metal fuselage or metal wing. One should realize at once the shielding effects of the surrounding conductive surface. If the fuselage was wood, this would be a fine antenna location. Now since you are probably ahead of me and are thinking about aluminum pigments in dopes, I will comment briefly. This is not as bad as it seems. First of all, each aluminum flake has an insulator of aluminum oxide around it. This is surrounded by dope or insulating paint. So one does not have such a perfect conductor as one would first expect. True, one loses a little, but it's not all that bad. A fuselage that curves away from the elements causes even less effects.

Now let's look at the fin mounted swept half wave dipole. Some are mounted with the sweep to the front of the airplane. Some want it to look more modern or swept back. I want performance, not looks. The rule again: "no conductors in the plane of the antenna". Wood structures: sweep them back and look speedy! Metal fins: mount on the fin as close to the front as possible with the dipoles point forward. May not look as fast, but it probably will keep up with the rest of the plane anyhow. Now you know when to use the mast type. They are used on metal fuselages generally above the cabin area. The mast keeps the dipoles up away from the conducting surface.

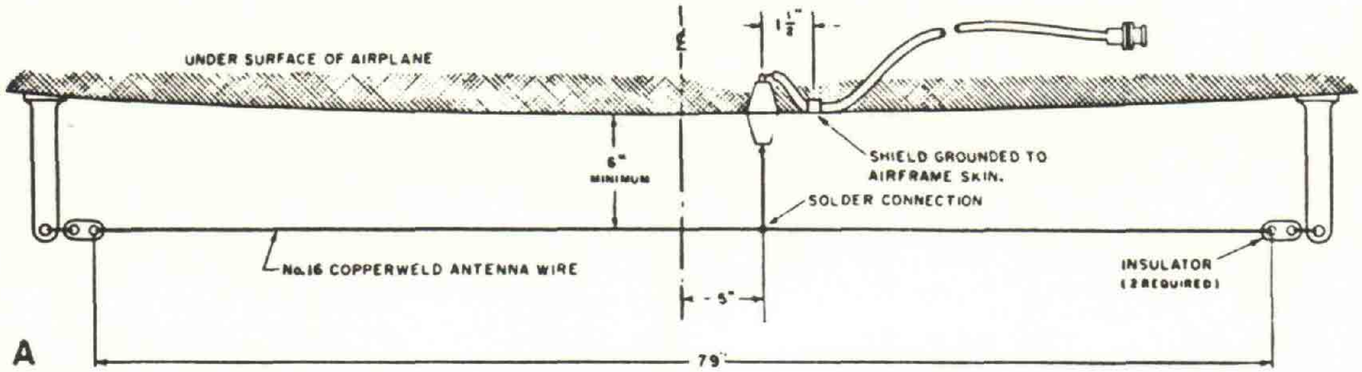
We have almost neglected saying anything about ¼ wave vertical stubs on metal planes. You can mount them just about anywhere as long as you stay reasonably away from other vertical surfaces. The top of a vertical fin has been shown in actual test measurements not to be an optimum place to mount a ¼ wave vertical antenna. On wood and fabric airplanes one needs to build in a ground plane. Strips of brass or copper foil may be soldered together in the middle so one can connect the coaxial shield to it. These strips need be only a couple of thousandths of an inch thick. One can use a roll of shim stock from which to cut the strips. Aluminum foil is not recommended as it is difficult to get a good electrical connection. Radials of the ground plane should be at least 24 inches long. For homebuilts this is not generally feasible due to the limited dimensions of the aircraft. For wooden airplanes — say on a rounded fuselage — the radials would curve with the structure and give a drooping ground plane effect. This would be satisfactory, but some pattern distortion would result.

An additional subject I would like to discuss is the marker beacon receiver antennas. Most homebuilts are not IFR equipped, but a short review may prove interesting. The marker beacon receiver frequency is 75 mHz. A half wave length at this frequency is 79 in. Fig. 5(a) shows a half wave antenna for 75 mHz. Since marker beacons radiate horizontally polarized radio energy, this type of antenna can be used. Notice this antenna is connected off center in an unbalanced fashion and one may use a piece of coax directly. This connection gives a reactive mismatch but, since one is generally directly over the station he is receiving, gain is not a problem. A bent ¼ wave antenna, Fig. 5(b) is both vertically and horizontally polarized. In this case, we are primarily using the horizontal polarization pattern of the antenna. Fig. 5(c) shows a blade type marker beacon antenna.

The outer element is actually a tuned circuit at 75 mHz, and the received energy is the transformer coupled to the small loop connected to coaxial cable. This antenna is not as efficient as the ¼ wave or ½ wave counterpart, but size reduction at the expense of gain was the criteria. Fig. 5(d) shows a flush mounted antenna similar in design to Fig. 5(c). Fig. 5(c) and Fig. 5(d) are shown in an inverted position.

Coaxial cable is generally used to connect both communication and navigational antennas to the radio equipment. RG 8/U, .405 in. diameter, or RG 58A/U, .195 in. diameter, are most commonly used. Both have stranded center conductors and are nominal 50 ohm characteristic impedance (RG 58/U has a solid center conductor). RG 8/U is a little less lossy than RG 58A/U, but the latter is more flexible. A ¼ wave vertical antenna has a theoretical radiation resistance of approximately 36 ohms. Using a coaxial cable of 50 ohms to connect to this antenna gives a mismatch of about 1.5 to 1, which is acceptable. The inner wire of the cable is connected to the ¼ wave vertical

MARKER BEACON ANTENNA



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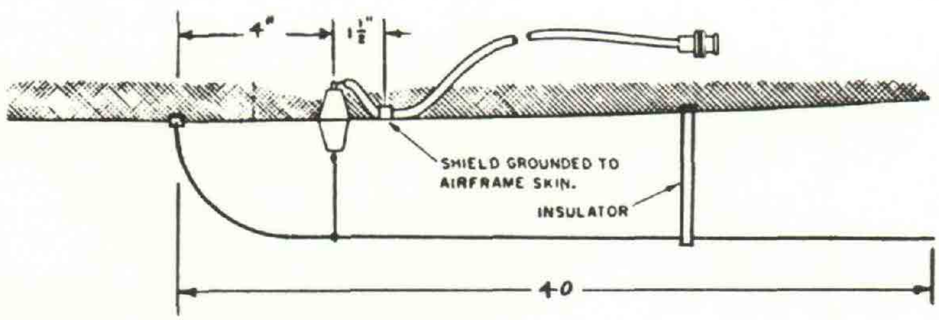

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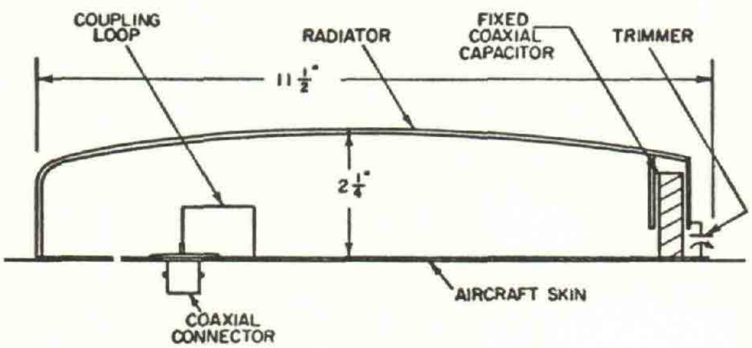
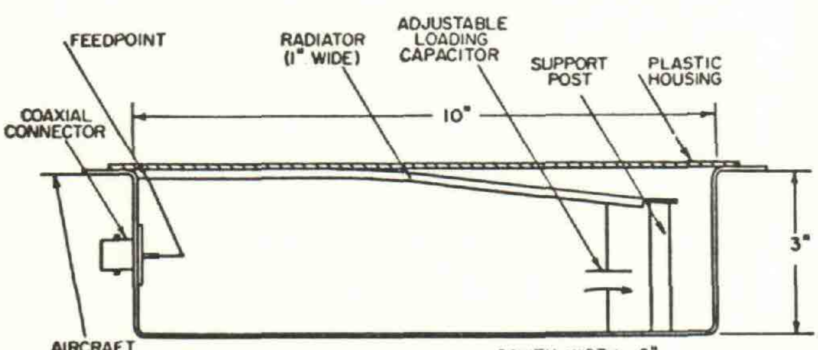


C SCHEMATIC OF THE COLLINS 37X-1 MARKER BEACON ANTENNA



SCHEMATIC OF THE ELECTRONIC RESEARCH INC. AT-134/ARN FLUSH MARKER BEACON ANTENNA

D

FIG. 5

element while the outer shield is connected to the ground plane. The radiation resistance of a half wave dipole is approximately 72 ohms. The impedance of the quadrant antenna approximates the half wave dipole. Connecting the coaxial cable directly to this antenna gives a mismatch probably less than with the ¼ wave antenna. One finds on the market baluns, which are impedance matching networks, used to connect balanced antennas to unbalanced lines. The ones generally used for navigational aircraft service are ½ wave coaxial cable matching sections.

The impedance transformation ratio is 4 to 1. Using a balun of this type would make the antenna look like an 18 ohm load to the 50 ohm cable, which would give a mismatch of 3 to 1. It is debatable that using this kind of a balun would give any gain over connecting the coaxial cable directly to the antenna. I prefer to keep this installation as simple as possible and not use this type of balun. There are other types of baluns available and each would have to be evaluated on its application. Several manufacturers build the balun in the mast of mast-mounted navigational antennas.

In summary I would like to review a few points:

* The ¼ wave vertical antennas used in the aircraft-communications band should be mounted vertical either on the top or bottom of the fuselage away from other vertical conducting structures.

* Ground planes for ¼ wave vertical antennas should be built into the structure of wood aircraft.

* Dipole navigational antennas mounted on metal aircraft should be either of the mast type or mounted high on the forward edge of the vertical fin with the elements pointing forward.

* Coaxial cable with a characteristic impedance of 50 ohms may be used for either ¼ wave vertical communications antennas or dipole navigational antennas.