A PRODUCT OF:

**RADIO SYSTEMS TECHNOLOGY INC.**

12493 Loma Rica Drive • Grass Valley, CA 95945 916/272-2203

# INTRODUCTION

For several years, Radio Systems Technology, Inc. has reprinted the following articles regarding plastic plane antennas in this booklet, simply titled "The Antenna Reference Text". All of the articles were written by Jim Weir, who at the time was RST's Vice President of Engineering. Since these articles were written, Jim has pursued other career opportunities apart from RST and is no longer involved with the operations of the company. We continue to publish this booklet (with his permission) as we believe the theoretical applications developed contain valuable information for any kit builder wishing to build concealed antennas. A few caveats apply, however. First and foremost, many of the articles reprinted are by now dated, at least from a chronological point of view. There may be references to products that are no longer available, advertisements (from the pages of the original articles) that are obsolete, etc. Secondly, Jim will not be available for antenna design work (which is made reference to in a couple of the articles). Should you need a question answered, please do not hesitate to contact our technical assistance line. In most cases, our technician will be able to walk you through any difficult moments.

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# PLASTIC PLANE ANTENNAS

## FOREWORD

In 1975, the Bellanca Aircraft company asked me if I would be interested in concealing a complete IFR antenna package into the wood wing of the Bellanca Viking. Since the results of that project were so promising, I approached a brilliant (and then) new airplane designer by the name of Rutan and asked if he would like to conceal the antennas on his brand new Vari-Eze design. Since then, the "ferrite-foil" antennas have been installed onto all 13 Rutan designs, into the Falco, the Quickies, the Glasair, and several other "plastic" airplane designs. I have been very pleased to provide my fellow home-builders with very inexpensive, high-performance hidden antennas for their plastic airplanes.

I regret that the pressure of my regular job (which have nothing to do with antenna design) prevent me from doing as much research on antennas as I might like. Since I have no first-hand experience with ADF, Omega and other HF and LF antennas on plastic airplanes, it would be quite unprofessional of me to guess how to install these antennas onto your airplane, and as a matter of professionalism, I will NOT venture a guess on subjects I do not know for a fact.

I would also hasten to point out that I offer a FREE service to the DESIGNER of any airplane to perform a full antenna package for that design. If you have an antenna problem that is not solved by any of the articles contained in this package, then I suggest that you have your designer call me. Once again, time pressures do not permit me to do custom designs for individual builders.

If you need to do some background work, I would suggest that your local library's copy of "The ARRL Radio Amateur's Handbook" might be useful. In addition, your local EAA chapter can request any of our library of videotapes covering antennas and other subjects.

Regards,

Jim Weir

# GENERAL PLASTIC-PLANE ANTENNA INSTALLATION
(P/N 82709)

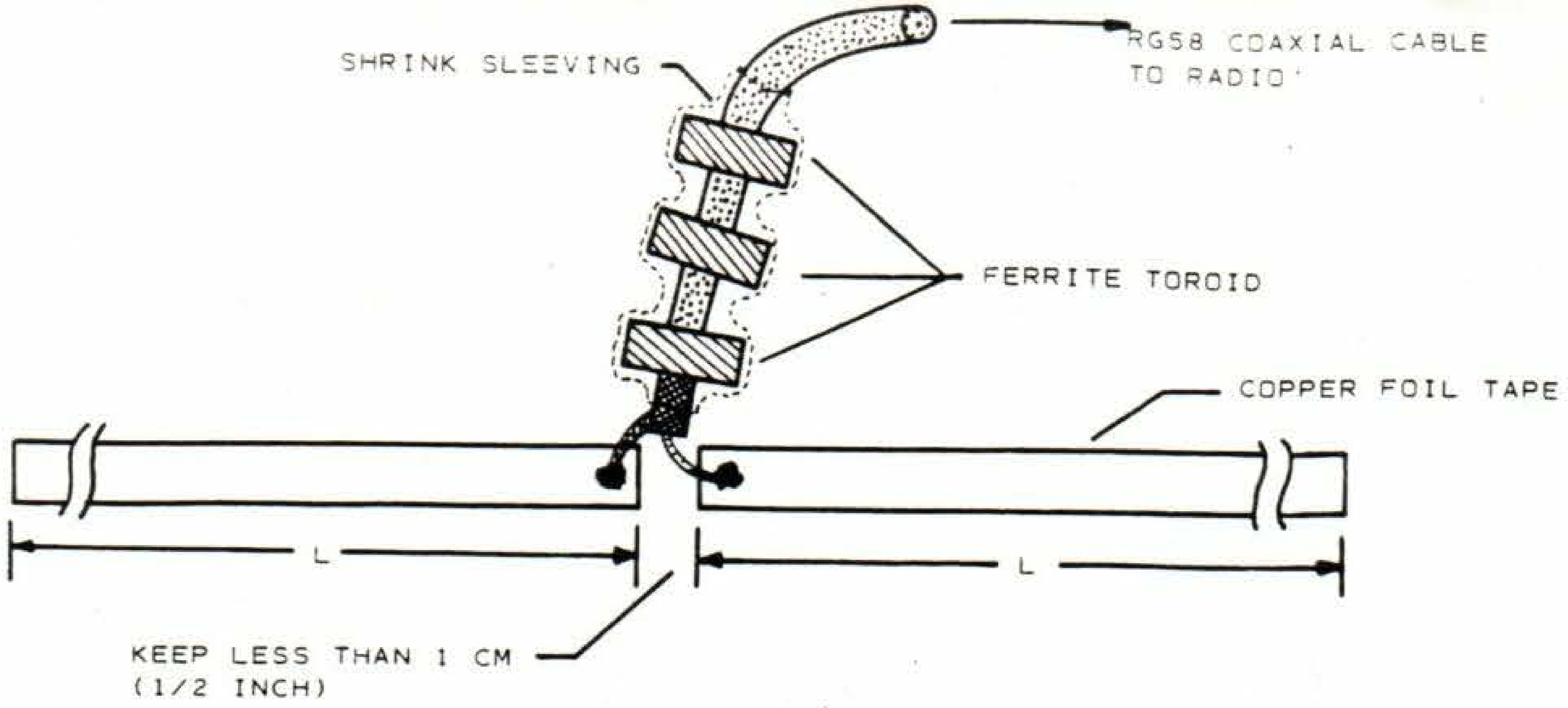
1. This sheet describes in general terms the installation of so-called "hidden" antenna systems on foam-fibreglas ("plastic") airplanes. We do NOT have, nor will we answer questions on ADF, CB, HF antennas, or antennas for part wood, part metal, part carbon cloth, part ? aircraft.

2. VHF NAV, VHF COM, MKR BCN, and other VHF-UHF aircraft antennas are made of copper foil elements, fed with RG-58 coaxial cable, with 3 small ferrite toroids ("doughnuts") around the coax at the dipole end as shown in Figure 1 (reverse). This figure also shows that the only difference between NAV, COM, MKR, etc. is the length of the copper foil elements. Normally, we try to make all COM antennas vertical to the earth's surface and all navigation antennas (VHF NAV, MKR, etc.) horizontal to the surface of the earth. A little thought will show that NAV antennas can be placed in a large number of places in most plastic airplanes (i.e. canard, main wing, etc.), but vertical surfaces are a little harder to come by. In the E-Z class of aircraft, the winglets are used, and in the Quickie, the vertical fin is used. If the whole antenna will not fit inside of one surface, then the copper foil may be "bent" to conform with the airframe shape.

3. The copper foil and "balun" (toroids) may be placed anywhere in or on the foam or fibreglas; the surface, inside the glass but on the foam, or buried within the foam are all valid locations for the antenna. However, no matter the location of the antenna it ABSOLUTELY MUST have the balun - foil/coax attach area firmly "potted" (using microballons & resin or flox) to prevent the solder joints from breaking under load and flex.* Please be sure that placement of the antenna does not degrade the aerodynamic performance of the aircraft.

4. Some general comments: The coax should run at right angles to the foil elements as far as reasonably possible before making any bends. Keep the foil TIPS sway from large metal surfaces or other wires, even if it means sacrificing perfect positioning or bending the elements around. If you have the choice, connect the coax center conductor to the highest or furthest outboard of the two foil elements.

5. Transponder and DME antennas are made of a flat aluminum plate called a "ground plane" and a pencil-thick rod threaded on one end called a "radiating rod", assembled with insulating washers as shown in Figure 2. The antenna should be installed with the ground plane horizontal with respect to the earth's surface, and the tip of the radiating rod pointing down. The tip of the rod may be as close to the fibreglas "skin" as you please, but there should be no metal for 25 cm or so away from the rod. Remember, if the airplane were made out of clear glass, and if a person at the radar site couldn't "see" the radiating rod (and that includes looking through engines, fuel tanks, people, etc.), then the radar (or DME) will NOT be able to respond to the aircraft radio. Finally, put an aluminum foil shield between the antenna and the pilot's/copilot's body.



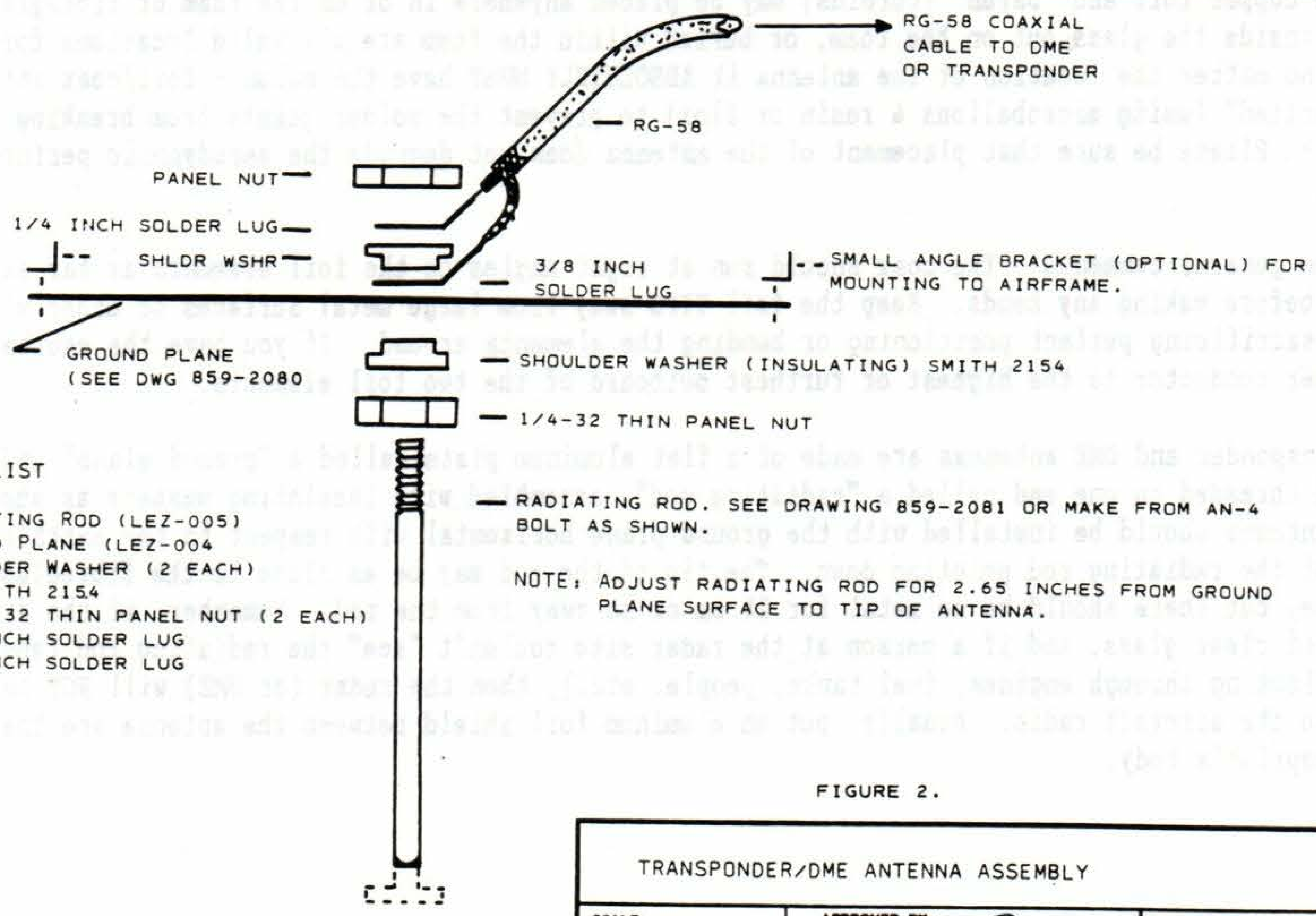

| | L (INCHES) |
|---|---|
| COM | 20.3 |
| NAV | 22.8 |
| MKR | 34.3 |
| G/S | 7.5 |

FIGURE 1

GENERAL FERRITE-FOIL ANTENNA ASSEMBLY

SCALE: NTS
APPROVED BY:
DRAWN BY OWJ
DATE: 29 OCT 80
REVISED

RADIO SYSTEMS TECHNOLOGY
GRASS VALLEY, CALIFORNIA 95945
DRAWING NUMBER 855-4081




PARTS LIST

- RADIATING ROD (LEZ-005)
- GROUND PLANE (LEZ-004
- SHOULDER WASHER (2 EACH) SMITH 2154
- 1/4 - 32 THIN PANEL NUT (2 EACH)
- 3/8 INCH SOLDER LUG
- 1/4 INCH SOLDER LUG

FIGURE 2.

TRANSPONDER/DME ANTENNA ASSEMBLY

SCALE: NTS
APPROVED BY:
DRAWN BY OWJ
DATE: 29 OCT 80
REVISED

RADIO SYSTEMS TECHNOLOGY
GRASS VALLEY, CALIFORNIA 95945
DRAWING NUMBER 859-4080

14 September 1982

COPPER FOIL TAPE FLEX

The past few years have witnessed several thousand antennas on plastic airplanes made from small strips of copper tape foil and ferrite toroids. In a few isolated cases, the copper tape has failed in tension, and the antenna was thus detuned, rendering it useless.

An analysis of the circumstances surrounding these failures leads to the conclusion that antennas installed on fiberglass surfaces subject to flex are the most likely to break. Although the tape is really quite strong, it cannot survive the strain imposed by a half-ton airplane bouncing along the runway. All of the reported failures have been on gear leg antennas or canard-gear antennas, especially after hard landings.

The problem is that the gear leg or the canard-gear surface may be your best electrical location for he antenna. With this problem in mind, here are some tips to keep the foil from breaking:

1. If you are installing the antenna in foam, you might sandwich the foil between wax paper, thus allowing the foil to "float" between the plies of wax paper.

2. If the tape is going onto a semi-rigid surface, solder a small brass brazing rod or copper tube the full length of each element. Then, should a microscopic crack occur in the foil, the metal rod will keep the foil (electrically) in one piece.

3. "Pot" the coax-ferrite-copper strip junction area in a small amount of flexible rubber sealant (RTV). This will provide a "cushion" for the solder joint area from sharp jolts, vibration etc.

4. If possible, install the foil so that any stress will cause compression instead of tension.

In conclusion, the best thing to remember is that copper foil tape is not structural, and that the foil tape is much more likely to fail in tension that any other mode. Comments, as usual, are always appreciated.

Regards,

Jim Weir

# HIDDEN ANTENNAS CUT CLUTTER

*How to install a "full house" antenna system onto your Quickie without adding a single ounce of drag*

*By Jim Weir*

REPRINTED FROM HOMEBUILT AIRCRAFT

**IT SEEMS AS** though half the pilots in the world are building, have built, intend to build, or would like to build the Mojave inspiration known as the Quickie. The other half, of course, are interested in the Quickie 2.

It is also true that a Quickie is the apple of its builder's eye, and it would appear that some owners have more money tied up in the instrument panel than in the entire airframe and engine. Of course each and every one of those radios in the panel needs an antenna, which is the reason that this article was written. Although the diagrams and photos in this article are written about the Q-2, these designs are directly applicable to the single-seat Quickie. It is also true that Dragonfly, ultralight and other plastic-plane builders ought to be able to take these concepts and apply them directly to their designs.

This article will describe how to install a "full house" antenna system onto your Quickie without adding a single ounce of drag. Each antenna is fully separate and independent from the others, so that you may install one, some, or all of these antennas as you see fit.

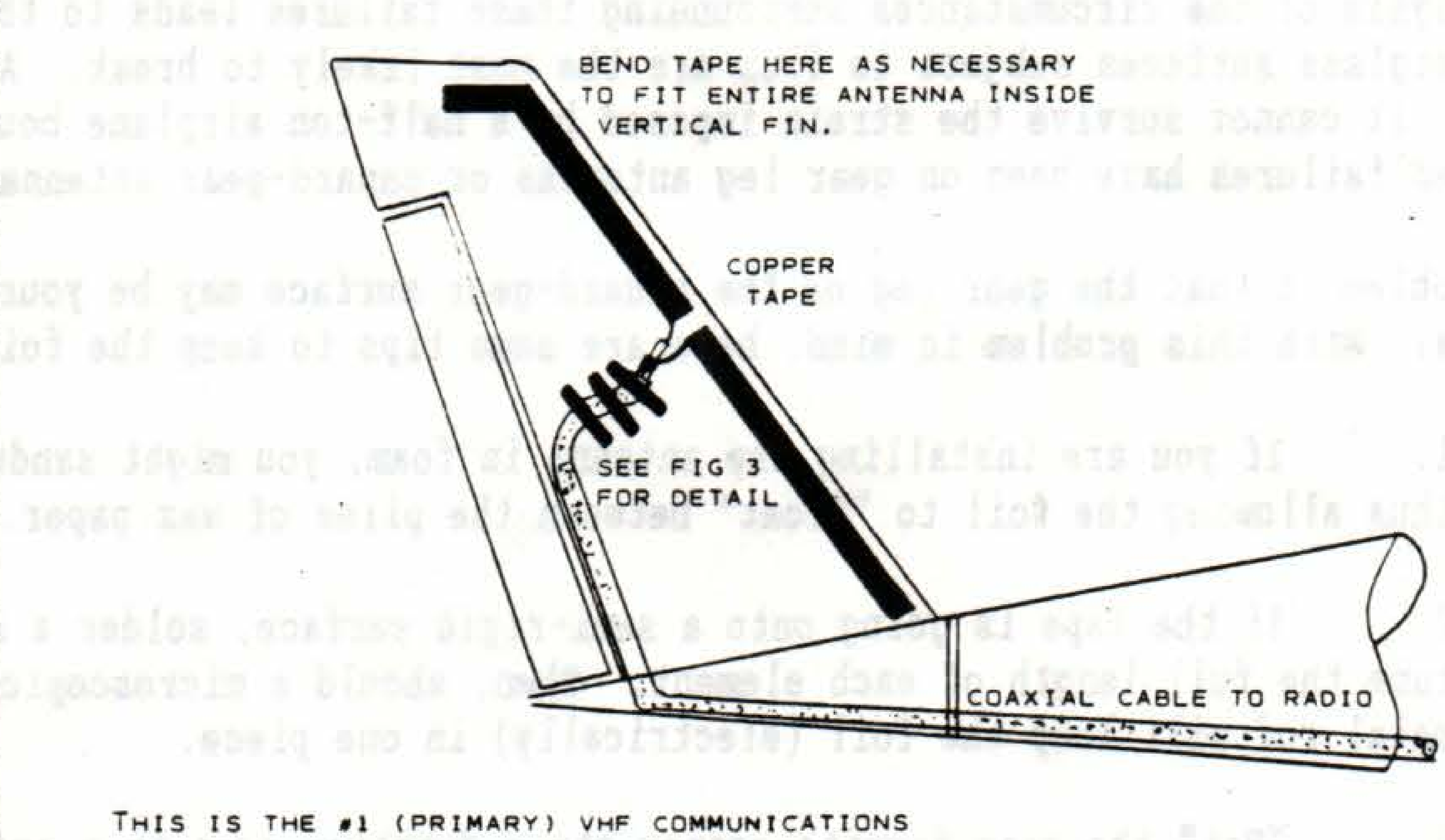



**FIGURE 1**

## Ferrite-Foil Dipole

All of the antennas in this article (except the ADF, DME and transponder) are versions of an antenna that we call a ferrite-foil dipole. A "dipole" simply means that the antenna has two elements, like the old television "rabbit ears," as opposed to the "monopole," or single element whip-above-a-ground-plane type of antenna. Since the Quickie has no large metal surfaces to act as a whip's ground plane, the dipole is the smallest, most lightweight, efficient structure possible for an antenna in this ship.

The "foil" refers to the material used to manufacture the dipole elements, and is 1 cm (1/2-inch) copper foil tape. You can substitute brass brazing rod or copper fuel line for the copper tape, but whatever you use needs to be at least 1 cm wide in one dimension. Thus, you would have to use 1 cm diameter copper tube or brass rod (which is heavy) to equal the performance of the 1 cm copper tape.

It is also true that the thin copper tape will lie flat on the foam, allowing a fiberglass-resin overcoat to completely conceal the dipole elements, thus producing a completely drag-free antenna. (A note for you theory freaks — the bandwidth of a dipole is a function of the width of the elements. The wider the element, the more "broadband" an antenna is said to be. One cm tape width gives a bandwidth of about 20 percent, just right for the aircraft "com" and "nav" VHF frequencies.)

The "ferrite" refers to the little round iron "doughnuts" placed around the end of the coaxial cable. The function of these doughnuts (which we engineering types call "ferrite toroids") is to prevent any RF power from traveling on the coax braid back to the transmitter. This "reflected power" has a nasty way of blowing up expensive transmitter parts, causing distortion of your modulation, and in general, messing up the works.

One toroid cuts the reflections down 95 percent, the next one cuts 95 percent the airframe to mount the nav antenna. At any rate, the dipoles are all constructed identically, the only difference from nav and com to MKR being the foil element length.

## Nav 1 Antenna

The nav antenna is intended to receive the navigation signals from VOR, LOC and glideslope ground-based transmitters. Since these navaid transmitters may be ahead of, behind or to either side of the ship, the antenna should be located so that it does not have to "look through" any large metal masses (i.e. engine) or pilot and copilot to "see" the ground transmitter. Remembering that VHF travels in line-of-sight, any metal or people placed between the antenna and the transmitter would place a "null" (area of sharply reduced reception) in the antenna's reception pattern for these angles. For example, if I put the antenna in the main right wing, the antenna would have to look through two pilots and the engine assembly to see transmitters forward and to the left, and my opinion is that signals coming from 280 to 350 degrees relative to the aircraft nose would be virtually unusable. (SEE FIG.4)

Instead, let's put the nav antenna in the left (or right, your choice) forward canard, as far outboard as possible, and in a "V" pointing forward as shown in Fig. 2. This has gained us a whole bunch and lost us a little. Now the antenna looks under the engine and pilot's compartment to see the ground, and there is practically no metal between the antenna and any ground-based transmitter. The only possible hiccup is the metal elevator torque tube, and if the antenna elements are placed on the canard bottom surface, even then the antenna will not have to "look through" this thin metal tube. In addition, placing the V of the antenna forward keeps the sensitive antenna tips as far away as possible from the torque tube.

When installing this antenna, as well as all the rest of these ferrite-foil antennas, remember that vibration of any sort will break the coax-foil solder joints, and I really don't think you want to rip your canard apart to fix a solder joint. Epoxy, micro-balloons, and "flox" have no effect on this antenna, so please "pot" these joints well. After the foil elements have been glued to the foam, the normal fiberglass-resin covering is applied over the elements, so that no trace of the antenna is visible in the final product.

The antenna is fed with 50 ohm coaxial cable of any length you choose. The thin stuff (RG174) is very light and small (3 mm), but the heavy stuff (RG58) has about half the loss. I recommend the RG58. You may route it along the torque tube (and I want to hear from the first genius who figures out a way to route it *inside* the torque tube) in a routed-out cavity, or down a carved-out center hole in the canard. Keep it as far away from the antenna as reasonably possible, and come away from the antenna aft at a right angle for as far as possible before starting inboard. Metal around the coax has no effect one way or the other.

So far we have an antenna that will give VOR and LOC signals to the VHF nav receiver. To get glideslope signals, you have your choice of putting a ferrite-foil GS antenna inboard in the same wing as your nav antenna (see Fig. 1 for element length) or using a commercial splitter similar to the RST-514/GS (Radio Systems Technology). Actually, it is six of one, half-dozen of the other, but so long as we've got the room, I recommend a separate glideslope antenna for those of you who intend on full ILS instrumentation.

## Nav 2 (Or FM Music) Antenna

So far we've filled the left canard with one VHF nav and one glideslope antenna. For the super-cautious, I will comment that a mirror-image setup in the right main wing will give fail-safe backup * to the antennas in the left canard. Also, a second nav antenna placed in the right main wing will very nicely serve as an antenna for an FM-cassette radio until (if and when) it is needed as a backup for the left canard nav antenna. I suggest you cut it in length for a nav antenna — the slight mismatch on the FM music radio will never be noticed.

## Com 1 Antenna

Since the com antenna should be vertical for best results, and since there is only one vertical surface in the whole airplane long enough to accept a 1.2 meter (44 inch) or so vertical dipole, the vertical fin is pretty much a forced-choice for this antenna.

Install the foil strips as far forward as possible, running the strips at the angle necessary to contain the whole antenna within the fin assembly, yet keeping the antenna elements as vertical as possible. Run the coax at right angles to the elements as far as possible, and then down the leading edge of the rudder cavity, alongside one of the rudder cables (separated, of course, to prevent chafing) forward to the instrument panel. If you wish to have a split in this (or any other) coax run, do not splice the coax back together; use a UG-88/UG-89

*SEE FIG. 5.

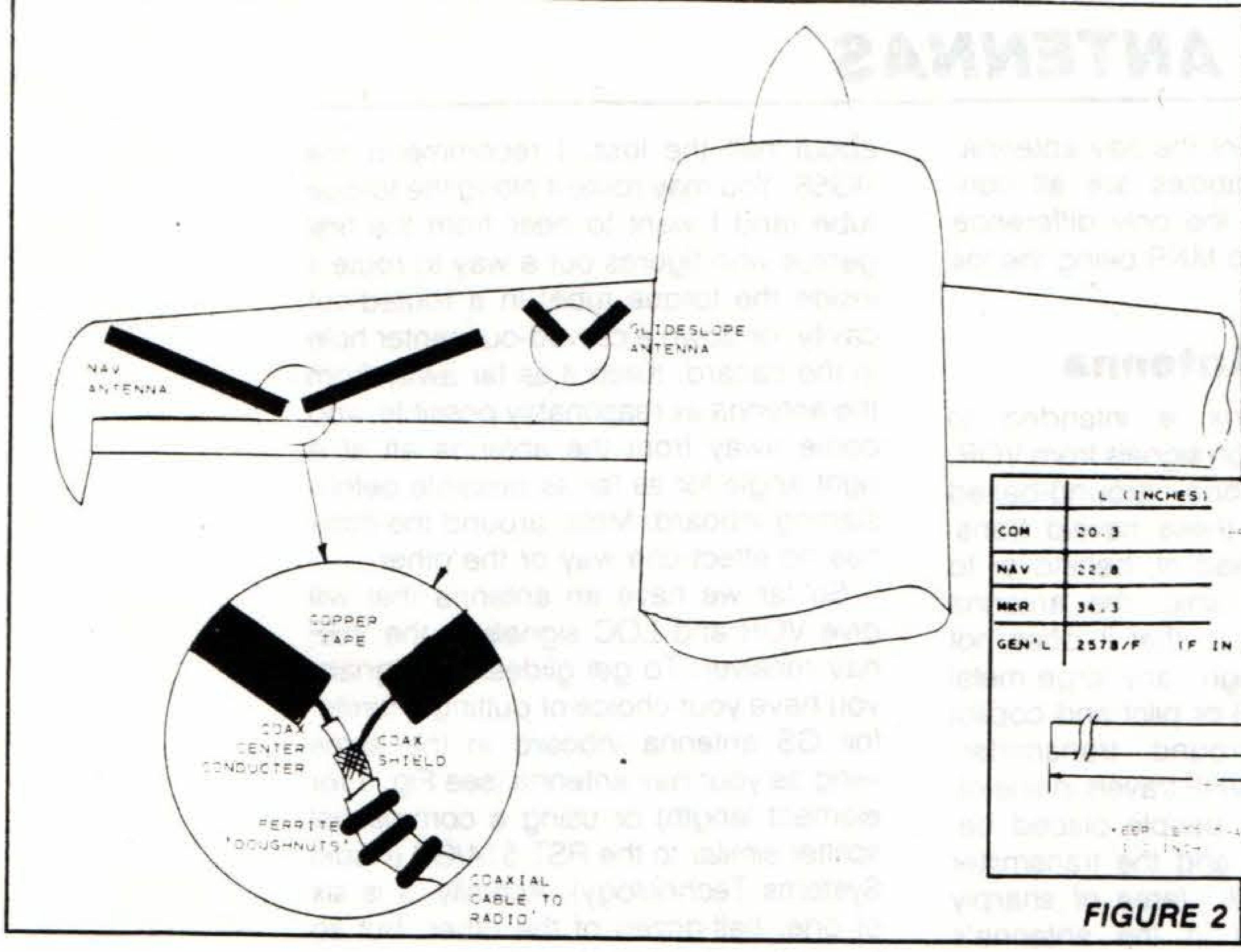



FIGURE 2

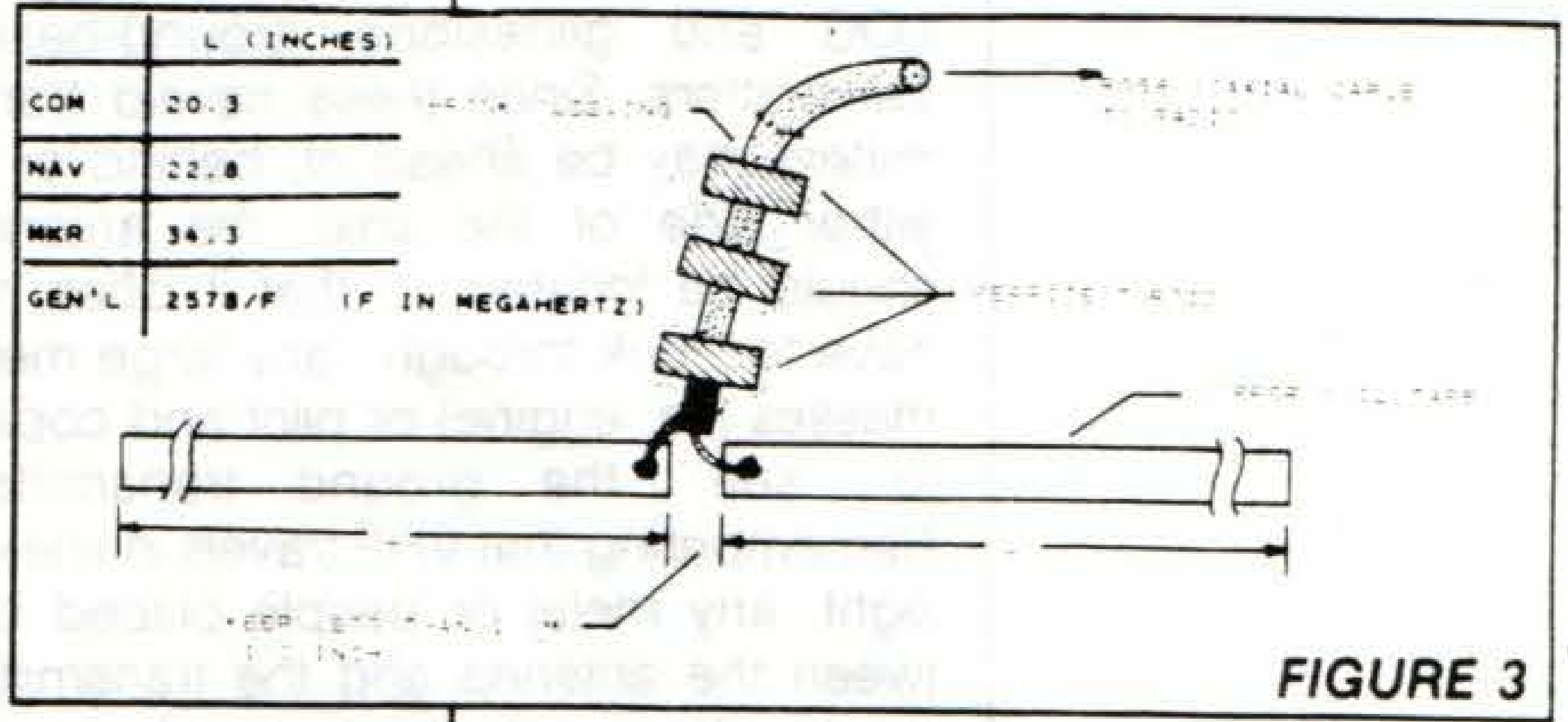
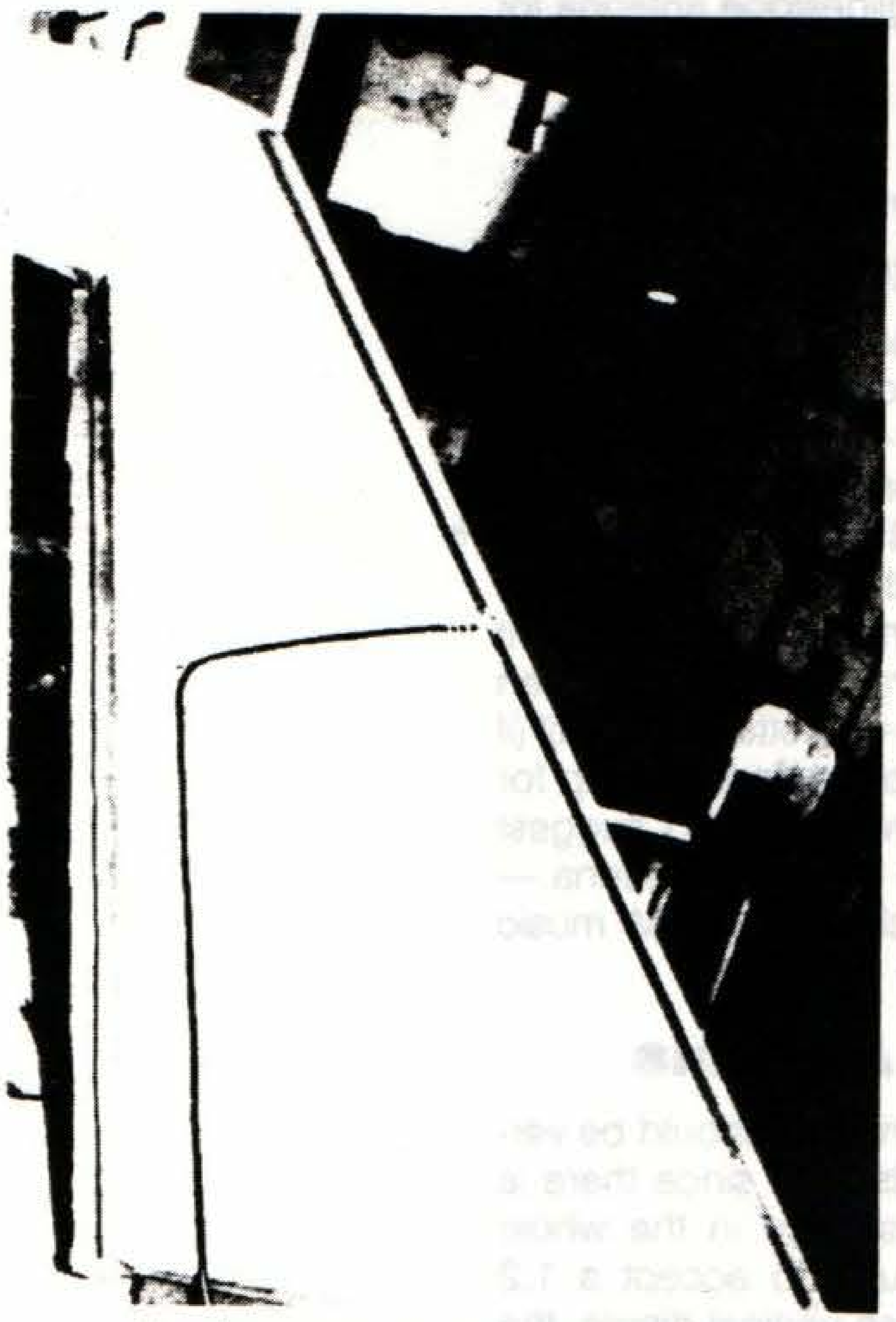
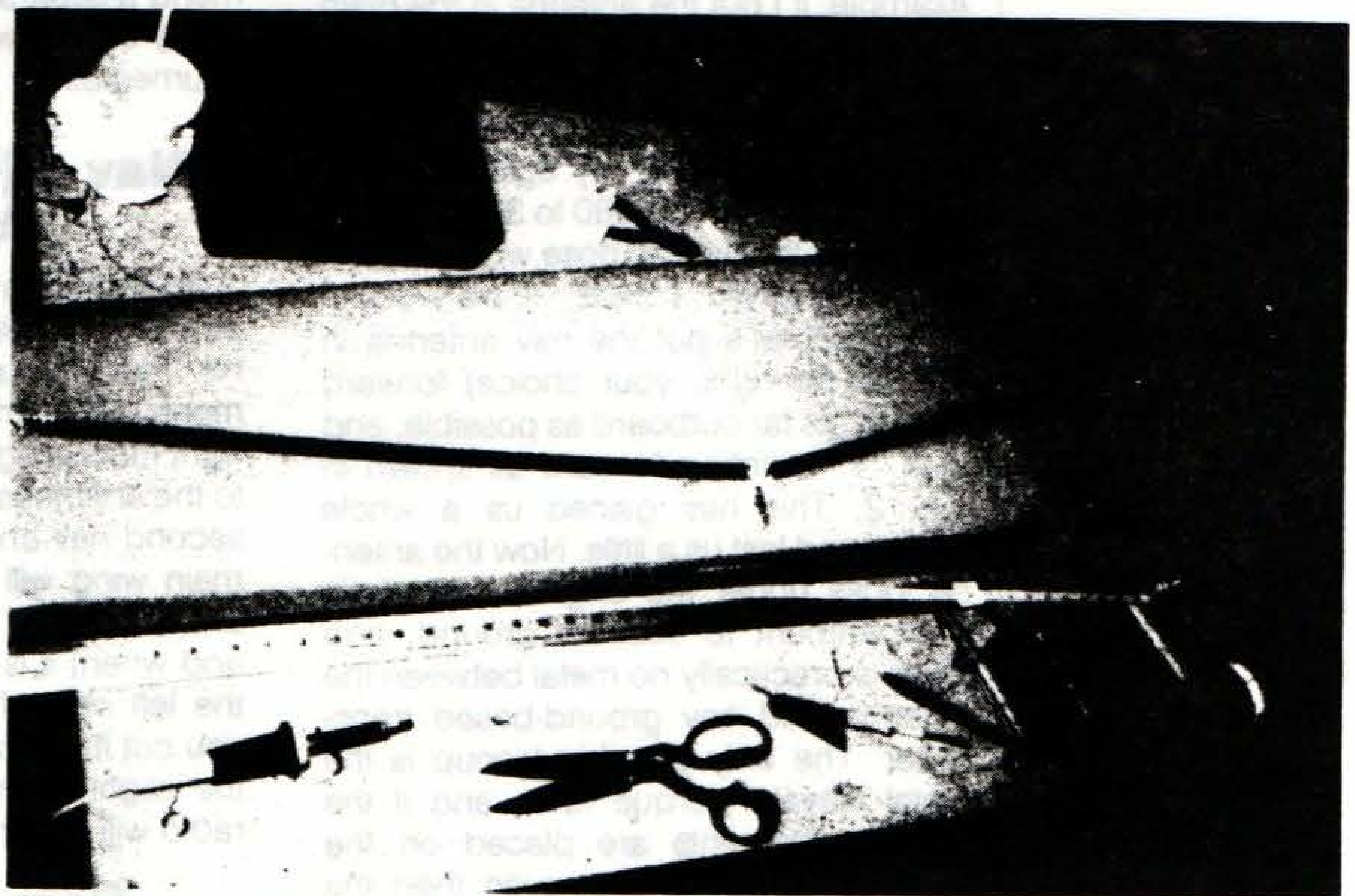



FIGURE 3



*Communication antenna prior to being set in micro.*



*Nav antenna installed on the underside of the right wing.*

of the 5 percent the first one let through (0.25 percent), and the third one cuts any remaining garbage down below measurement. Three is the number of toroids I choose to use, but you may see designs using from one to five of these little rascals. It's a little like wearing socks in the wintertime — you've got to have one pair, two pair keep you warm, three pair is the practical limit, and after that all you get are fat feet.

The resonant frequency of the antenna is a direct function of the length of the elements. The antenna will only be "perfect" at exactly one frequency, and will begin to get worse going in either direction. How fast it gets worse is controlled by the width of the elements (remember bandwidth?), and the usual deterioration when it gets worse is a reflection of the transmitted power (remember ferrites?) down the coax. Usually we cut the antenna elements to be resonant at the geometric center of the band, and we express the "goodness" of our antenna as either a computed reflection coefficient ("VSWR") or as a reflection percentage at the band edges.

Figure 3 shows the element lengths for the dipoles, keeping in mind that these lengths are for each element, two elements per dipole. If you want to impress your friends at the next builder's meeting, tell the troops that you installed a VHF com antenna with bandwidth center at 127 MHz (the geometric mean of 118 and 136 MHz), and a VSWR (pronounce vizz'-war) of 2.0:1 at the band edges, with a reflection percentage of less than 15 percent.

One last item, and we can begin the individual designs for the Quickie. Most ground com stations use what is called "vertical polarization," which means that the radiating element(s) of the antenna are perpendicular to the surface of the earth. Go out to your friendly local airport some day and look at the Unicom antenna on top of the FBO. Sure, there are a lot of horizontal "ground plane" wires (whose only function, by the way, is to simulate the surface of the earth up high, away from trees and buildings and people and such), but the heavy, main radiating rod points straight up and down, perpendicular to the ground plane and the earth's surface.

To receive the best signal from this ground-based vertically polarized com signal, the aircraft com antenna should also be vertically polarized. By contrast, all the nav signals (VOR, LOC, MKR & GS) are horizontally polarized, and we will want to find a horizontal surface on coaxial connector pair to achieve the "splice." If you are not installing transponder or DME antennas, you may run this coax forward along the belly if you wish.

## Com 2 Antenna

SEE FIG. 5

There just isn't any "good" place for the #2 com antenna, but the right canard will have to do, even though it is horizontal. Install the #2 com antenna (cut to com length, of course) in the outboard section of the right canard, V forward, identical (except dipole length) to the nav antenna in the left canard. It will produce results — sometimes superb, sometimes barely passable — but it beats the heck out of no backup com antenna at all.

## MKR BCN Antenna

SEE FIG. 5

This is a long son of a gun, practically two meters (6 feet) from tip to tip, and it needs to be horizontally polarized. The only place we've got left is the left main wing, and this antenna will fairly fill the wing. This setup is only fair. Remember that if you are off to the left of the final approach course, the antenna is looking through you (pilot) and engine to see the marker transmitter, but the marker pattern is so broad and the range so short, that this should really not present much of a problem.

## ADF

SEE FIG. 6

The ADF is a "black magic" radio that is made even more of a mystery when installed in "plastic" airplanes. The best luck seems to be installations using a combined sense-loop antenna. In this case I recommend fabricating an aluminum foil ground plane on top of the main wing between the fuselage sides and placing the loop-sense antenna in the center of this ground plane. You may wish to use copper screen in place of the aluminum foil, as the copper is easier to make electrical connections to.

For radios requiring separate loop and sense antennas, the loop should still be placed on the same ground plane on the main wing, but the sense antenna should be glued to the fuselage top, starting at the FS94 bulkhead and running aft as far as the manufacturer recommends — usually two meters or so. Any wire larger than #18 should be fine and can be either bare or insulated. Don't forget to ground the sense antenna coax braid to the loop's ground screen with a short jumper.

## DME-Transponder

SEE FIG. 7

Both DME and transponder use absolutely identical antennas, but not (as some articles would have you believe) the same antenna. If you have both a DME and a transponder, you will need two identical antennas.

Since the DME-transponder ("D-t") antenna is so small (element length = 67 mm), the plan of attack is to manufacture a metal ground plane that will simulate a metal skin aircraft and mount a standard D-t antenna to this ground plane. You will note in Fig. 1 that the ground plane is specified as .062 aluminum. This is fairly thick and heavy (the design was originally for Bellanca), but you are certainly welcome to use thin foam covered with aluminum, copper foil or screen. The antenna radiating rod is specified for "homebrewers," but a commercial D-t antenna mounted in the center of the ground plane is quite acceptable.

ADJUST ROD FOR 2.65 IN. BETWEEN GND PLANE AND TIP OF ROD.

Mount the ground plane-radiating rod assembly to the FS120 bulkhead with the tip of the rod as reasonably close to the fuselage bottom (belly) as possible. Keep the rod as far away from the rudder cables as possible. If you are mounting two antennas (one DME and one transponder), then mount one to the forward face of the bulkhead and one to the aft face of the bulkhead, maintaining a minimum of 30 cm between the two antennas. Note that on the ground-plane side of the antennas, metal pieces (rudder cables, electrical cables, etc.) may be as close as you please, but on the radiating rod side, they should be as far away as possible. Brace the ground plane against vibration.

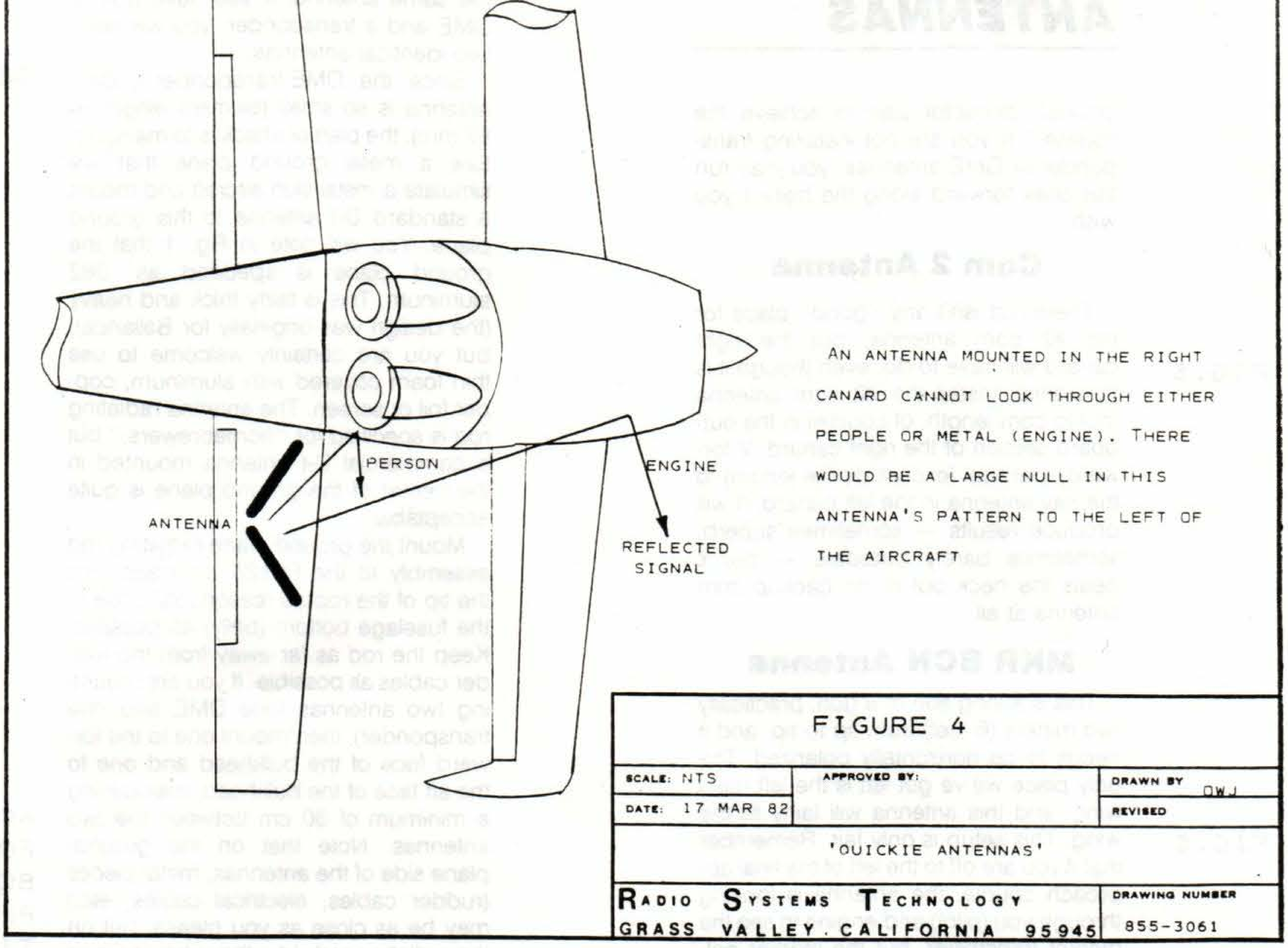
## Note: Health Hazard

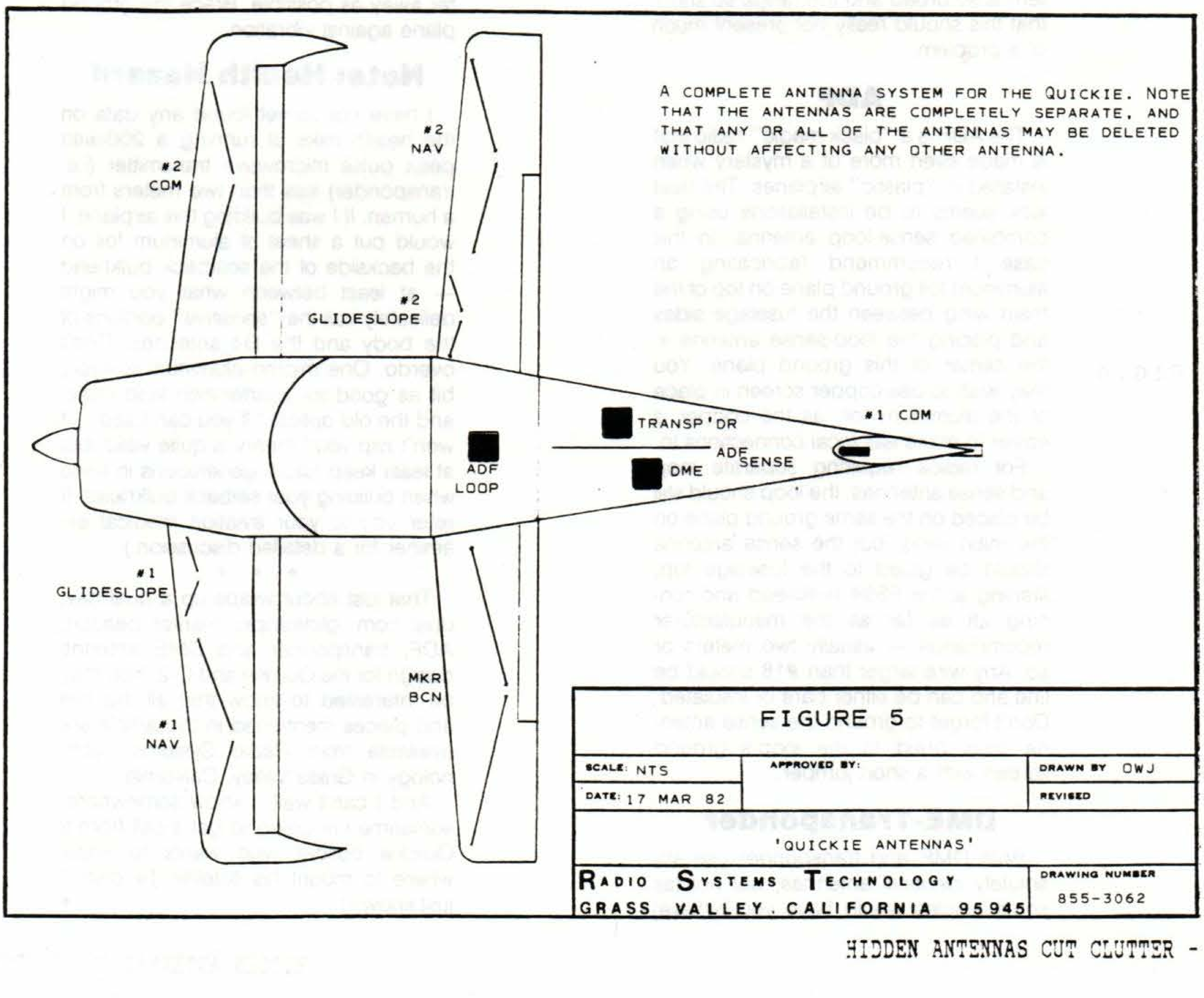
I have not as yet found any data on the health risks of running a 200-watt peak pulse microwave transmitter (i.e. transponder) less than two meters from a human. If I was building this airplane, I would put a sheet of aluminum foil on the backside of the seatback bulkhead — at least between what you might delicately call the "sensitive" portions of the body and the D-t antennas. Don't overdo. One micron aluminum is every bit as good as quarter-inch lead plate, and the old optical "if you can't see it, it won't zap you" theory is quite valid, but at least keep future generations in mind when building your setback bulkhead. (I refer you to your aviation medical examiner for a detailed discussion.)

• • •

That just about wraps up a dual nav, dual com, glideslope, marker beacon, ADF, transponder and DME antenna design for the Quickie and Q-2. You may be interested to know that all the bits and pieces mentioned in this article are available from Radio Systems Technology in Grass Valley, California.

And I can't wait. I know somewhere, sometime I'm going to get a call from a Quickie builder who wants to know where to mount his satellite TV dish. I just know it! •


AN ANTENNA MOUNTED IN THE RIGHT CANARD CANNOT LOOK THROUGH EITHER PEOPLE OR METAL (ENGINE). THERE WOULD BE A LARGE NULL IN THIS ANTENNA'S PATTERN TO THE LEFT OF THE AIRCRAFT
PERSON
ENGINE
ANTENNA
REFLECTED SIGNAL
FIGURE 4
SCALE: NTS
APPROVED BY:
DRAWN BY OWJ
DATE: 17 MAR 82
REVISED
'QUICKIE ANTENNAS'
RADIO SYSTEMS TECHNOLOGY
GRASS VALLEY, CALIFORNIA 95945
DRAWING NUMBER
855-3061


A COMPLETE ANTENNA SYSTEM FOR THE QUICKIE. NOTE THAT THE ANTENNAS ARE COMPLETELY SEPARATE, AND THAT ANY OR ALL OF THE ANTENNAS MAY BE DELETED WITHOUT AFFECTING ANY OTHER ANTENNA.
#2 NAV
#2 COM
#2 GLIDESLOPE
TRANSP'DR
#1 COM
ADF SENSE
DME
ADF LOOP
#1 GLIDESLOPE
MKR BCN
#1 NAV
FIGURE 5
SCALE: NTS
APPROVED BY:
DRAWN BY OWJ
DATE: 17 MAR 82
REVISED
'QUICKIE ANTENNAS'
RADIO SYSTEMS TECHNOLOGY
GRASS VALLEY, CALIFORNIA 95945
DRAWING NUMBER
855-3062

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SEE FIG.5

## MKR BCN Antenna

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SEE FIG.5

## ADF

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SEE FIG.6

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SEE FIG.7

Mount the ground plane-radiating rod assembly to the FS120 bulkhead with the tip of the rod as reasonably close to the fuselage bottom (belly) as possible. Keep the rod as far away from the rudder cables as possible. If you are mounting two antennas (one DME and one transponder), then mount one to the forward face of the bulkhead and one to the aft face of the bulkhead, maintaining a minimum of 30 cm between the two antennas. Note that on the ground-plane side of the antennas, metal pieces (rudder cables, electrical cables, etc.) may be as close as you please, but on the radiating rod side, they should be as far away as possible. Brace the ground plane against vibration.

ADJUST ROD FOR 2.65 IN. BETWEEN GND PLANE AND TIP OF ROD.

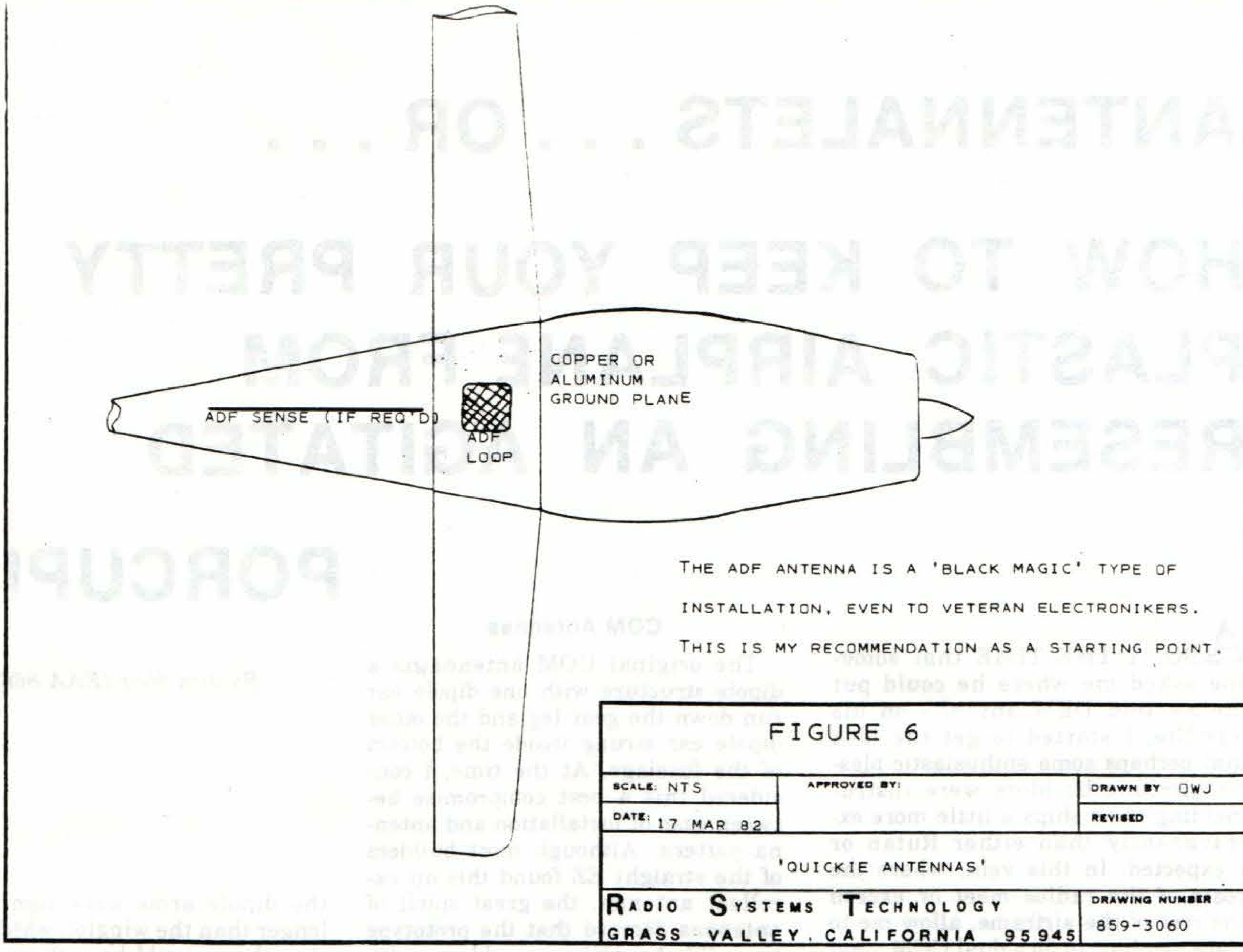
## Note: Health Hazard

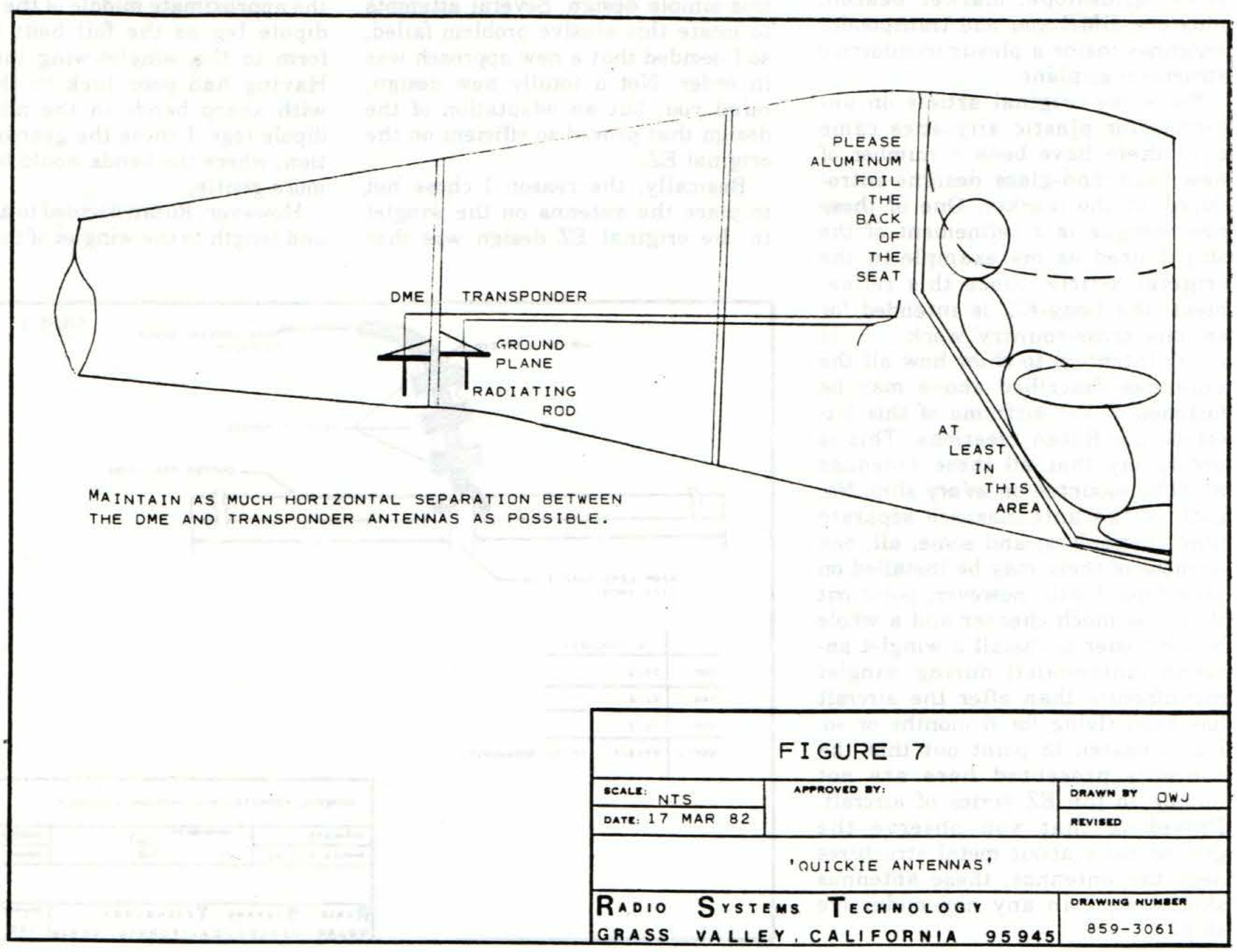
I have not as yet found any data on the health risks of running a 200-watt peak pulse microwave transmitter (i.e. transponder) less than two meters from a human. If I was building this airplane, I would put a sheet of aluminum foil on the backside of the seatback bulkhead — at least between what you might delicately call the "sensitive" portions of the body and the D-t antennas. Don't overdo. One micron aluminum is every bit as good as quarter-inch lead plate, and the old optical "if you can't see it, it won't zap you" theory is quite valid, but at least keep future generations in mind when building your setback bulkhead. (I refer you to your aviation medical examiner for a detailed discussion.)

• • •

That just about wraps up a dual nav, dual com, glideslope, marker beacon, ADF, transponder and DME antenna design for the Quickie and Q-2. You may be interested to know that all the bits and pieces mentioned in this article are available from Radio Systems Technology in Grass Valley, California.

And I can't wait. I know somewhere, sometime I'm going to get a call from a Quickie builder who wants to know where to mount his satellite TV dish. I just know it! •


COPPER OR
ALUMINUM
GROUND PLANE
ADF SENSE (IF REQ'D)
ADF
LOOP
THE ADF ANTENNA IS A 'BLACK MAGIC' TYPE OF
INSTALLATION, EVEN TO VETERAN ELECTRONIKERS.
THIS IS MY RECOMMENDATION AS A STARTING POINT.
FIGURE 6
SCALE: NTS
APPROVED BY:
DRAWN BY OWJ
DATE: 17 MAR 82
REVISED
'QUICKIE ANTENNAS'
RADIO SYSTEMS TECHNOLOGY
GRASS VALLEY, CALIFORNIA 95945
DRAWING NUMBER
859-3060


PLEASE
ALUMINUM
FOIL
THE
BACK
OF
THE
SEAT
DME
TRANSPONDER
GROUND
PLANE
RADIATING
ROD
AT
LEAST
IN
THIS
AREA
MAINTAIN AS MUCH HORIZONTAL SEPARATION BETWEEN
THE DME AND TRANSPONDER ANTENNAS AS POSSIBLE.
FIGURE 7
SCALE: NTS
APPROVED BY:
DRAWN BY OWJ
DATE: 17 MAR 82
REVISED
'QUICKIE ANTENNAS'
RADIO SYSTEMS TECHNOLOGY
GRASS VALLEY, CALIFORNIA 95945
DRAWING NUMBER
859-3061

# ANTENNALETS . . . OR . . .

# HOW TO KEEP YOUR PRETTY PLASTIC AIRPLANE FROM RESEMBLING AN AGITATED PORCUPINE

*By Jim Weir (EAA 86698)*

ABOUT THE TIME that someone asked me where he could put the **second** DEM antenna on his VariEze, I started to get the idea that perhaps some enthusiastic plastic airplane builders were instrumenting their ships a little more extravagantly than either Rutan or I expected. In this vein, where the costs of the radios meet or exceed the cost of the airframe, allow me to show you how to do a dual COM, dual NAV, glideslope, marker beacon, plus one DME and one transponder antennas inside a plastic (conductive structure) airplane.

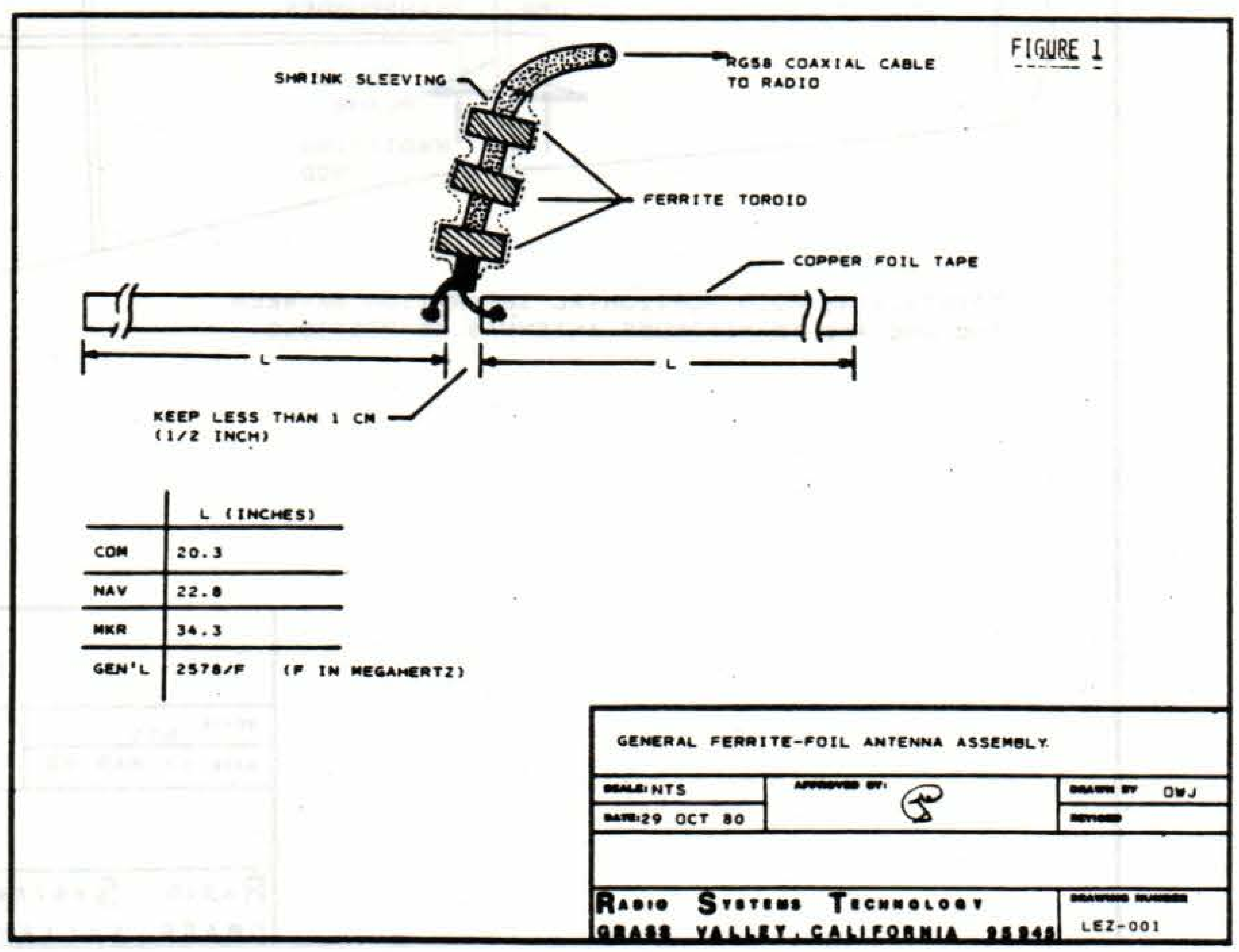
Since my original article on antennas for plastic airplanes came out,[1] there have been a number of new foam-and-glass designs introduced on the market. One of those new designs is a refinement of the ship I used as my example in the original article. Since this refinement, the Long-EZ, is intended for serious cross-country work . . . it is my intention to show how all the antennas described above may be fastened to the airframe of this latest of the Rutan creations. This is not to say that **all** these antennas **must** be mounted on **every** ship. No, each of the antennas are separate unto themselves, and some, all, one or more of them may be installed on your bird. I will, however, point out that it is much cheaper and a whole bunch easier to install a winglet antenna (antennalet) during winglet manufacture than after the aircraft has been flying for 6 months or so. I also hasten to point out that the concepts presented here are not unique to the EZ series of aircraft. Providing that you observe the ground rules about metal structures near the antennas, these antennas should work in any nonconductive ship.

### COM Antennas

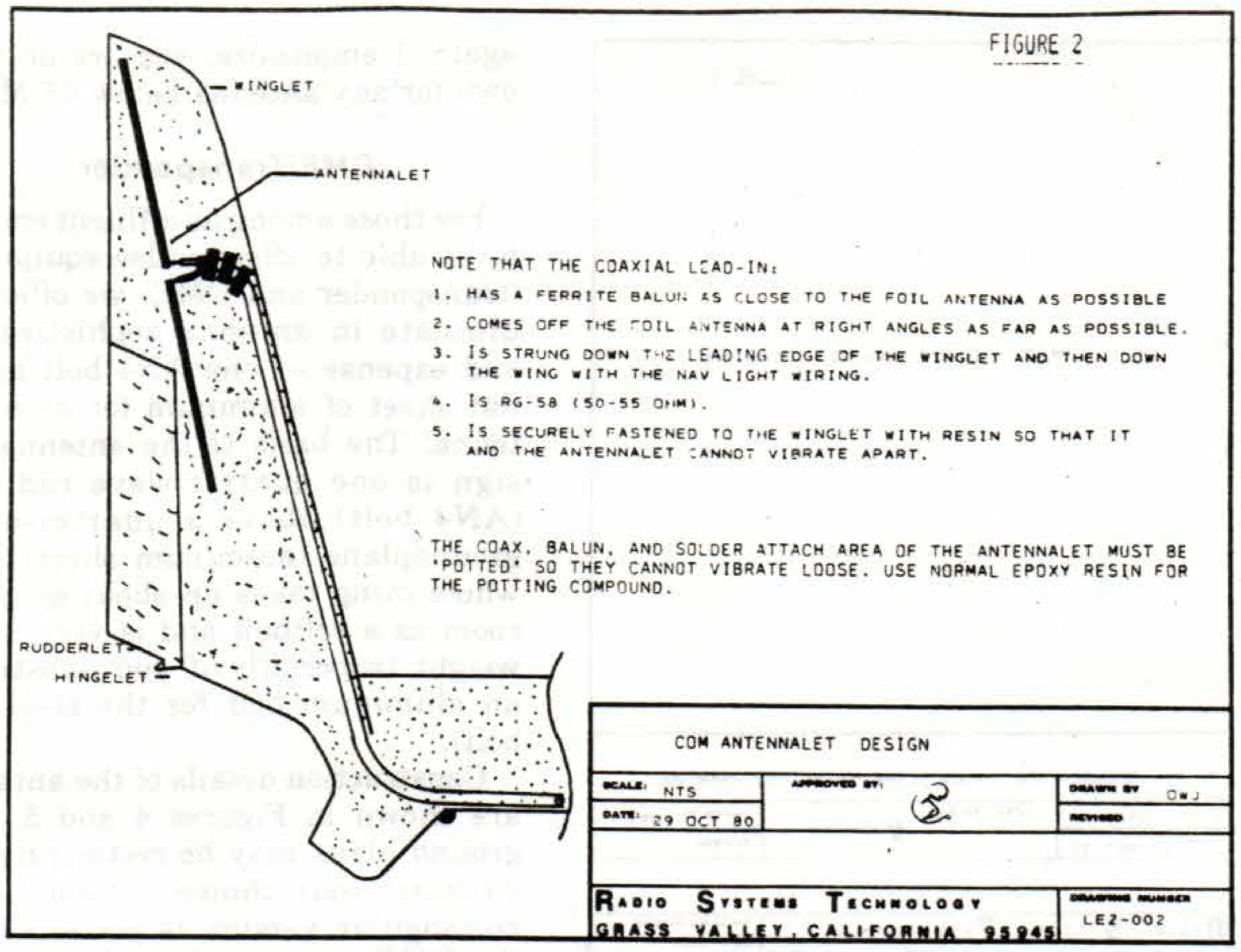
The original COM antenna was a dipole structure with one dipole ear run down the gear leg and the other dipole ear strung inside the bottom of the fuselage. At the time, I considered this a best compromise between ease of installation and antenna pattern. Although most builders of the straight EZ found this an excellent antenna, the great spirit of antennas decreed that the prototype Long-EZ should have problems with this simple design. Several attempts to locate this elusive problem failed, so I decided that a new approach was in order. Not a totally new design, mind you, but an adaptation of the design that proved so efficient on the original EZ.

Basically, the reason I chose not to place the antenna on the winglet in the original EZ design was that the dipole arms were significantly longer than the winglet, which meant that there would be a sharp bend in the approximate middle of the bottom dipole leg as the foil bent to conform to the winglet-wing interface. Having had poor luck in the past with sharp bends in the middle of dipole legs, I chose the gear-leg location, where the bends would be much more gentle.

However, Rutan decided to add area and length to the winglet of the Long-




| | L (INCHES) |
|---|---|
| COM | 20.3 |
| NAV | 22.8 |
| MKR | 34.3 |
| GEN'L | 2578/F (F IN MEGAHERTZ) |




EZ, so that now a full-length vertical dipole could be placed on the winglet with only one minor bend. Placing the COM antennalet in the winglet offers several advantages, not the least of which is getting that critical dipole tip area a ways away from metal engines, control cables and salt water sacks (passengers). One further advantage of antennalets is that a dual-COM setup may be easily installed by putting one COM antennalet in each of the two winglets.

Construction techniques for the COM antennalet shown in Figure 2 are basically the same as for the old gear-leg antenna. Once again, the most important detail is to keep the antenna **tips** away from the big pieces of metal. Also, it makes the antennalet work a whole bunch better if you locate the foil dipoles on the trailing edge of the winglet and run the coax and balun at right angles to the dipole as far forward as possible before bending the coax down the leading edge of the winglet, into the wing, and thence into the cabin. The coax may be run down the same path as the NAV light wire. Also, it is permissible to bend the bottom dipole ear slightly in order to miss the rudderlet. Please note further that improved measurement facilities here at RST have shown that the dipole elements should be slightly shorter (see Figure 1) for the dipole arms than presented in my earlier referenced article.

**NAV Antennas and Glideslope**

The only change that I am going to make on the NAV antenna located in the canard (antennard? cantenna?) is to shorten both dipole arms slightly as listed in Figure 1. The reason for this foreshortening (and likewise for the COM length reduction) is that we have obtained a 12 foot measuring mast at RST which reduces "earth effect" to a negligible quantity. The original work was done using 6' masts, and we had some ground-bounce effects that we could not account for. At any rate, install the NAV antenna into the canard in accordance with the drawings in the original article, but of a length as listed in Figure 1 of this report.

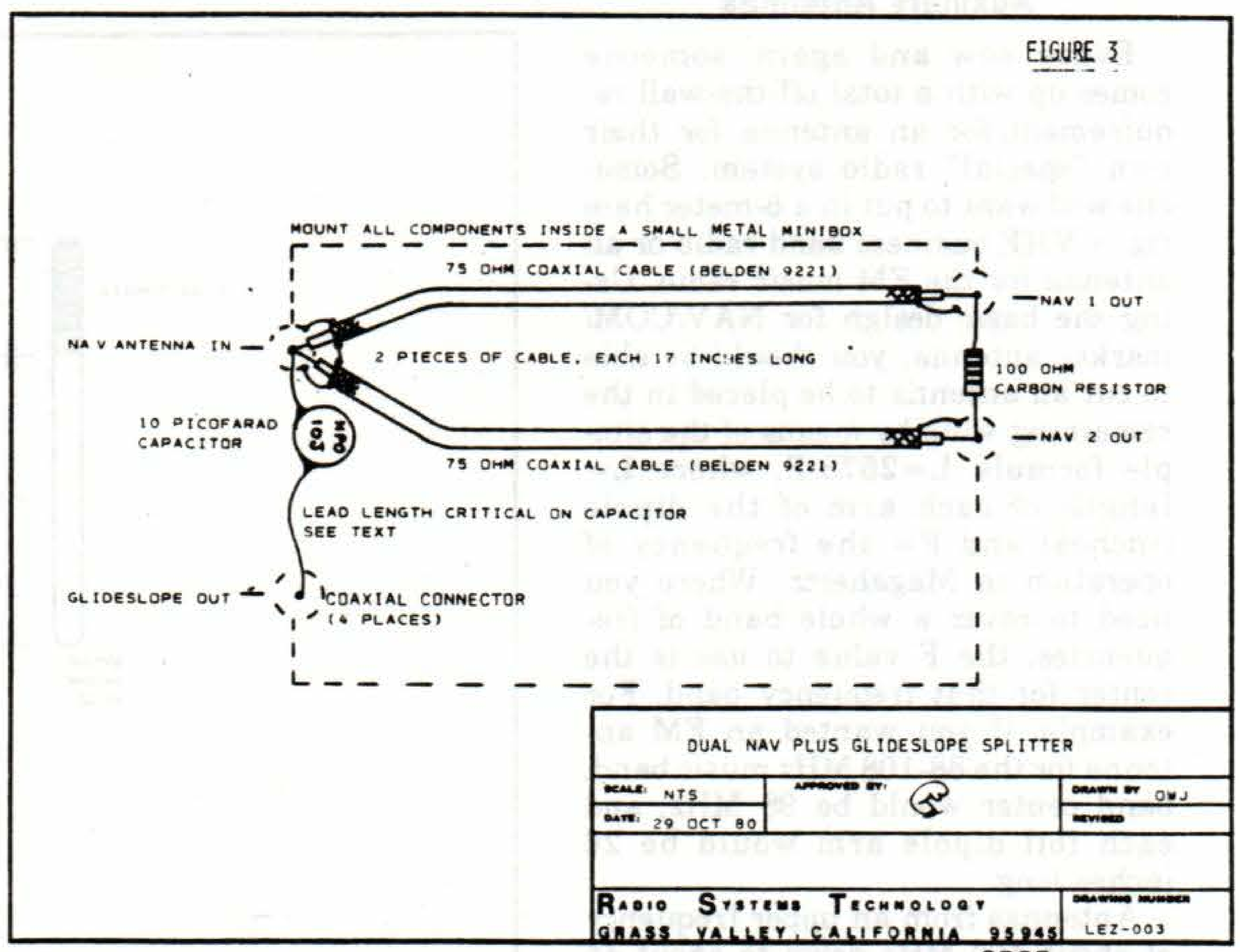
Getting a glideslope output, in addition to getting a second NAV antenna output, is done with what is called a hybrid splitter. The function of the splitter is to take the one signal from the canard NAV antenna, split it into two isolated NAV outputs, plus provide a glideslope output without interfering with the NAV outputs.

This splitter has been described several years ago in this and other magazines,[2 3] but the glideslope circuit has not been covered, so I will give a description of both circuits here.

The new splitter consists of two measured lengths of 75 ohM coaxial cable, plus one 100 ohM **carbon** resistor. If the 75 ohM cable has a polyethelyne dielectric (as opposed to teflon), the coax lengths should be about 17" long (each). The drawing, Figure 3, shows these cables as being straight. In fact, the 17" cables may be coiled up as tight as you please and stuffed into a very small box. Also in the drawing you can see the glideslope-coupling capacitor, a 10 picofarad NPO (or mica) capacitor with a total of one inch lead length. In this particular unit, you will notice that one lead of the capacitor is three-quarters of an inch long and the other lead is one quarter of an inch. So long as the total lead length is one inch (±0.2 inch), the glideslope circuit should work just fine.

**Marker Beacon**

Since I'm just as sure as shootin' that somewhere, someday, someone will get his plastic homebuilt blessed for IFR, we might just as well do the marker beacon design now. In essence, the marker beacon antenna that is placed in one wing instead of the canard (wing of your choice). The nice thing about marker beacon antennas is that you are dealing with high signal strengths and relatively non-critical receiver sensitivities. The



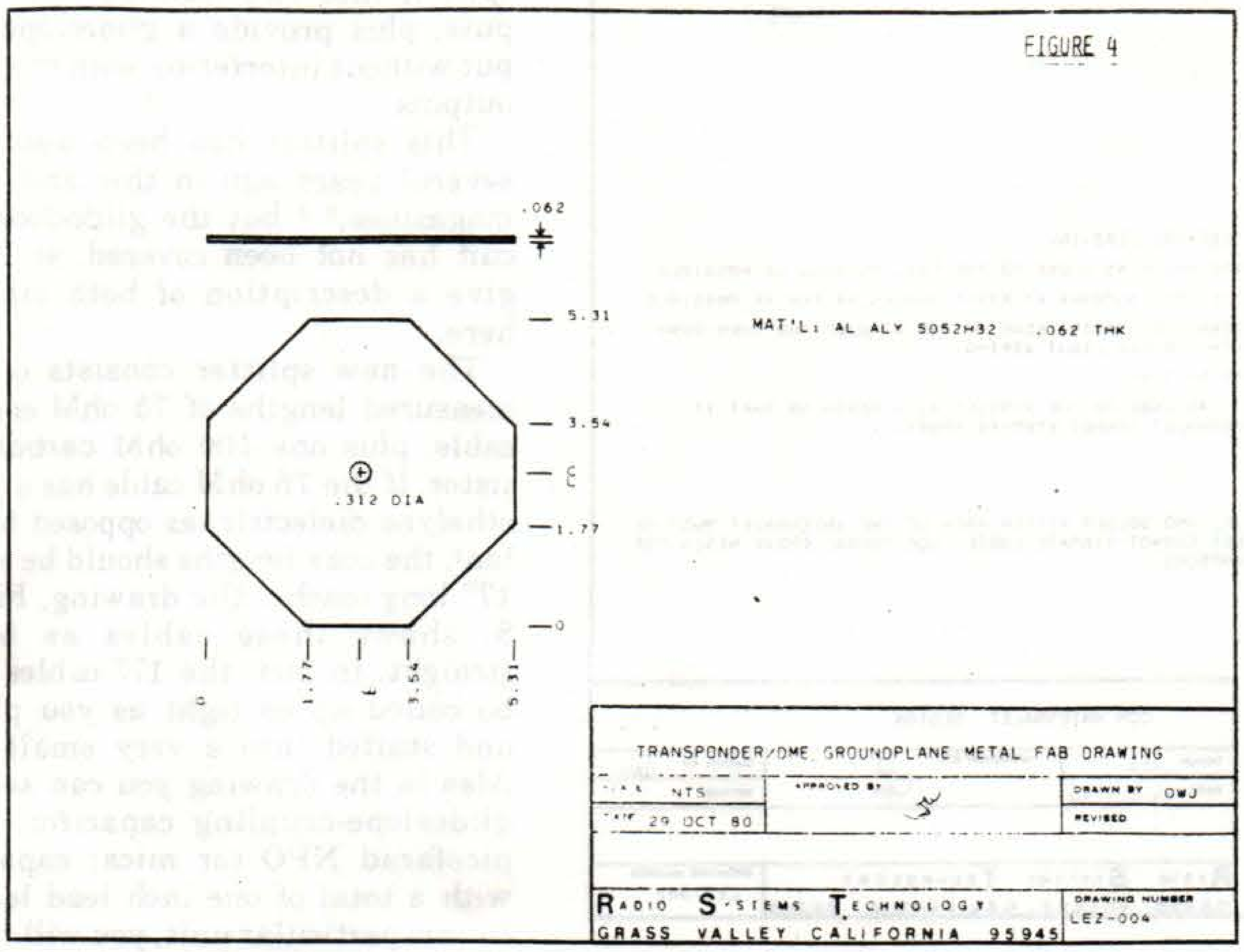


FIGURE 4

net effect is to make the antenna relatively immune to minor design compromises. If you have to put one antenna tip near the NAV light wiring, it won't really affect the antenna performance that much. If you need to bend the antenna sharply around a curved surface, again, no great problem. Even the cardinal sin of putting one tip near, say, an aluminum fuel tank will not completely destroy the usefulness of this antenna. The only effect you may see by compromising the marker antenna may be a small amount of range reduction or an instrument approach that picks up the marker further out when left of course than when right of course. Big deal.

### Auxiliary Antennas

Every now and again, someone comes up with a total off-the-wall requirement for an antenna for their own "special" radio system. Someone will want to put in a 6-meter ham rig, a VHF business band radio or an antenna for the FM music radio. Using the basic design for NAV/COM/marker antenna, you should be able to cut an antenna to be placed in the remaining wing by means of the simple formula L=2578/F, where L= length of each arm of the dipole (inches) and F= the frequency of operation in Magahertz. Where you need to cover a whole band of frequencies, the F value to use is the center for that frequency band. For example, if you wanted an FM antenna for the 88-108 MHz music band, band center would be 98 MHz, and each foil dipole arm would be 26 inches long.

Antennas from an upper frequency of about 400 MHz down to about 45 MHz may be handled in this manner. If your intention is to make a CB antenna for the 27MHz Garbage Band, a simple calculation will show that the dipole will be much longer than a single wing can accommodate. The only out you **may** have, if **you** wish to try it is to calculate the dipole lengths and serpentine the copper foil across the wing. Just think of it as a dipole doing S-turns along your wing and you've got the picture. I freely admit that I haven't tried it, I don't know if it will work or not, so you are pretty much on your own. One ploy that may be worth trying is a "helical" antenna, where the tape (or, actually wire, if you wish) is wound on a tubular form and inserted into a slot in the wing. Once again, I emphasize, you are on your own for any antenna below 45 MHz.

### DME/Transponder

For those among us affluent enough to be able to afford pulse equipment (transponder and DME) we offer the ultimate in antenna sophistication and expense — one AN4 bolt and a flat sheet of aluminum for each antenna! The basis of the antenna design is one quarter-wave radiator (AN4 bolt) above a quarter-wave groundplane (aluminum sheet). The whole thing takes up about as much room as a softball and is very lightweight (especially if you substitute an aluminum bolt for the steel AN bolt).

Construction details of the antenna are shown in Figures 4 and 5. The ground plane may be rectangular or circular, your choice, although the rectangular version is preferred for the DME because of bandwidth considerations. Bending the corners of the rectangle up for either mounting or clearance are O.K., as are trimming the sharp corners of the rectangle.

The mounting locations for the antenna on the fuselage are many. Beneath the pilot or co-pilot's seat assembly are excellent choices, as is the cavity adjacent to the landing gear legs. Once again, the only caveat is to keep any and all metal away from the radiating rod tip. However, anything **behind** the ground plane will not affect the rod. Just be sure that you mount the antenna with the rod pointing down. And, for those of you with more money than good sense, if you install both a DME **and** a transponder antenna, separate them horizontally by at least 24 inches.

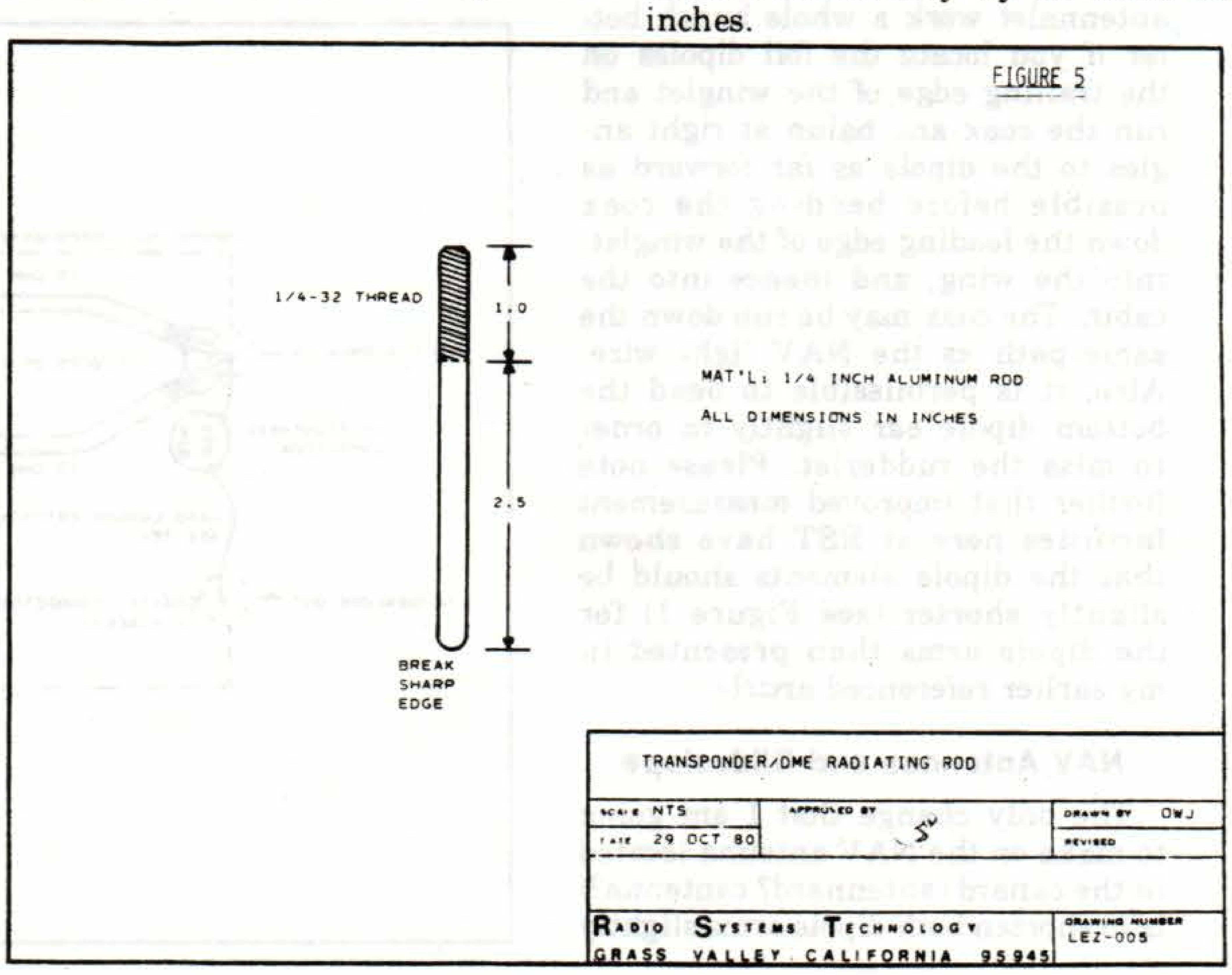
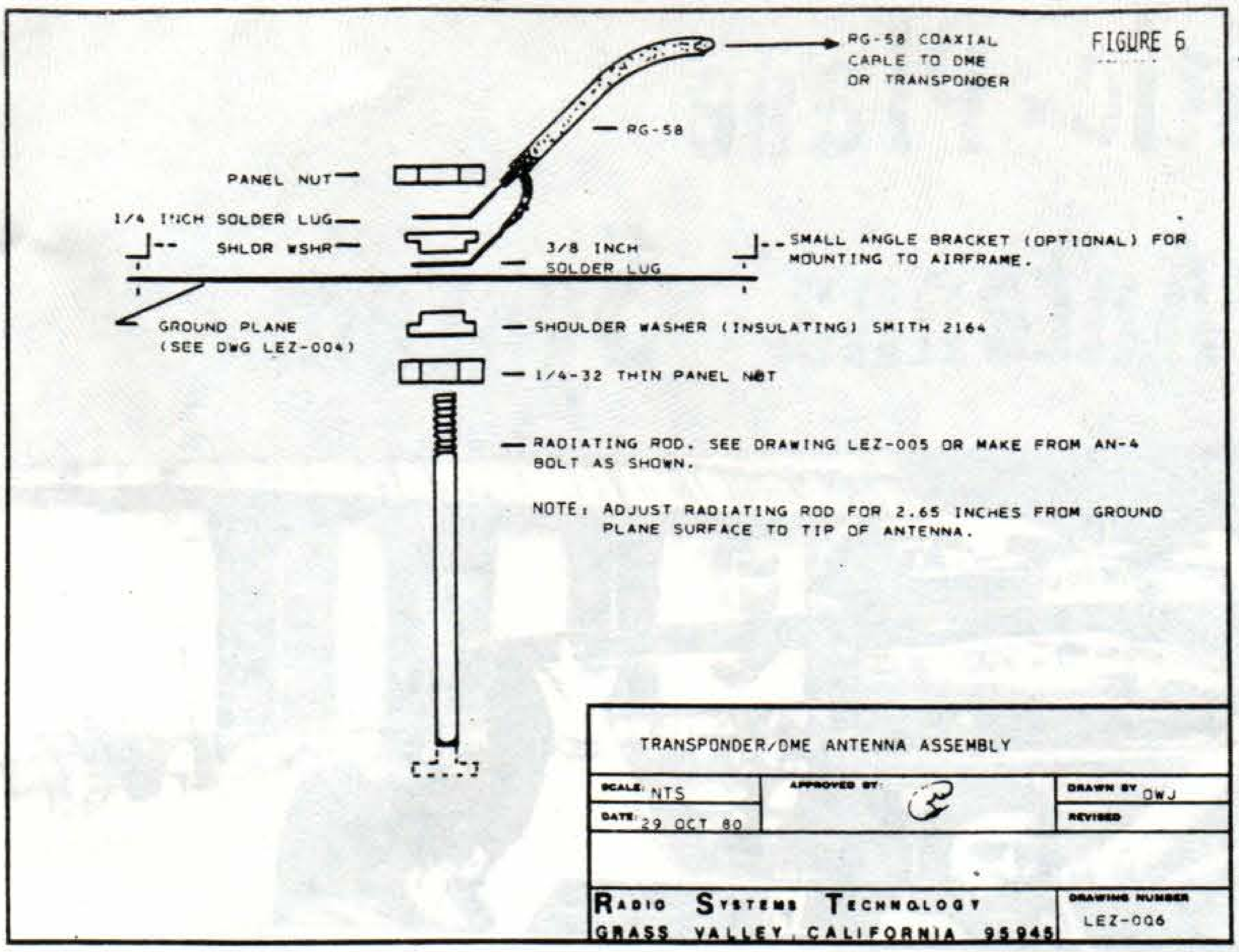


FIGURE 5




### Sources

Always the question comes up — where can I buy all the bits and pieces to make these fine antennas? The AN bolts and aluminum sheet you shouldn't have much trouble with, as they are standard aircraft hardware. And, although you can certainly purchase copper foil tape at almost any well-stocked office supply house or stained glass window shop, the foil tape, ferrite beads, cable connector, insulating washer and coax cable are all available from Radio Systems Technology, ~~10985 Grass Valley Ave., Grass Valley, CA 95945. Phone 916/272-2208. A complete NAV or COM foil antenna "kit" consisting of copper foil and ferrites is still only $5, with quick disconnects and longer foil pieces available at additional charge. Write or call RST and ask for a "Plastic Plane Antenna Price List"~~.

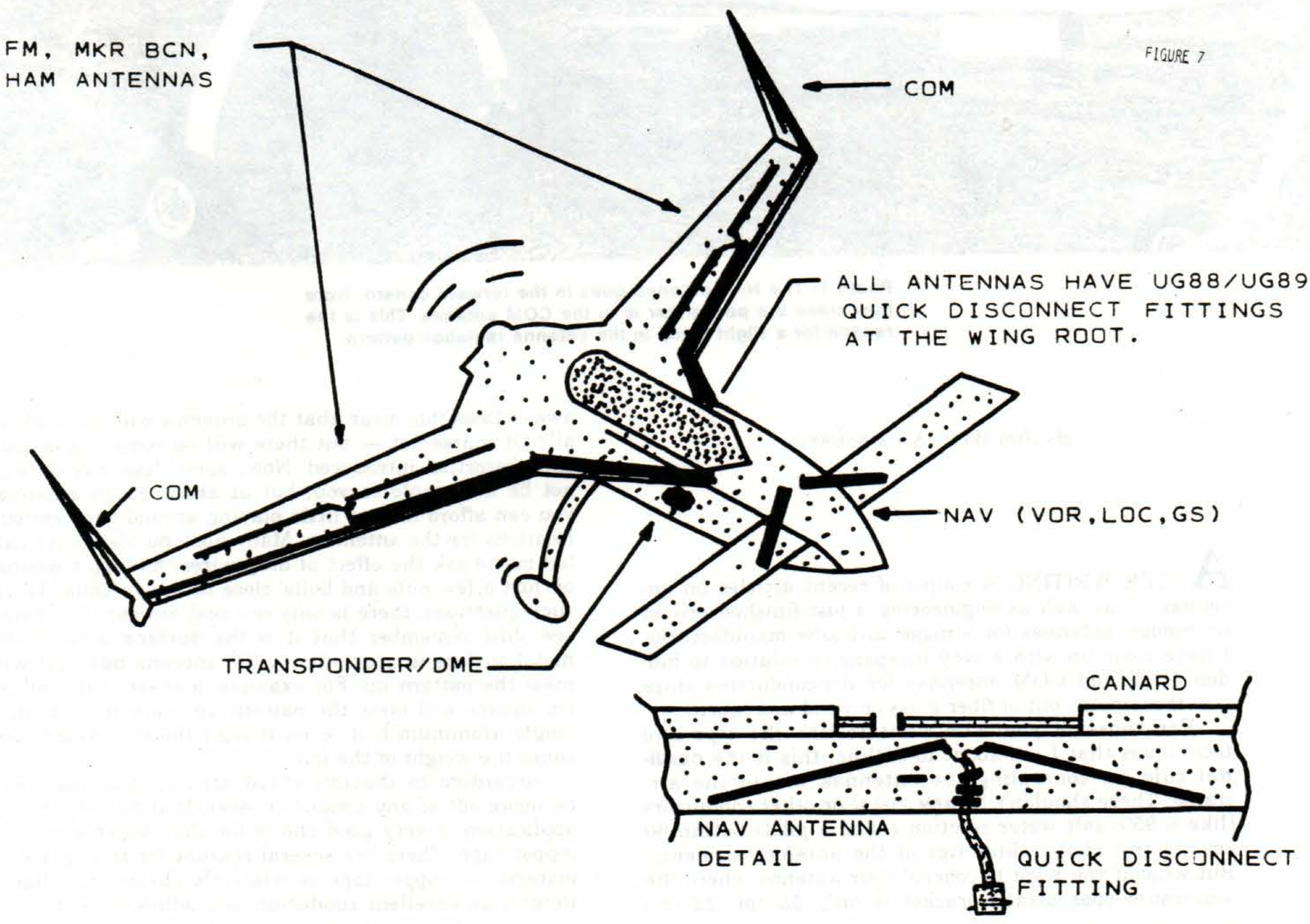
I would like to thank my research assistant Brian Flath (KA6CWO) for his invaluable aid in making the VSWR measurement and the Rutan clan for both installing and testing the prototype antennalets.

### References

1) The Plastic Plane $5 Antenna System, *SPORT AVIATION*, Jim Weir, May 1979, PP 45-48.

2) Economy Antennas, *SPORT AVIATION*, Jim Weir, October 1976, PP 71-78.

3) An N-Way Hybrid Power Divider, IRE Trans MTT, Ernest Wilkinson, January 1960, PP 116-118.



# The Plastic-Plane $5 Antenna System

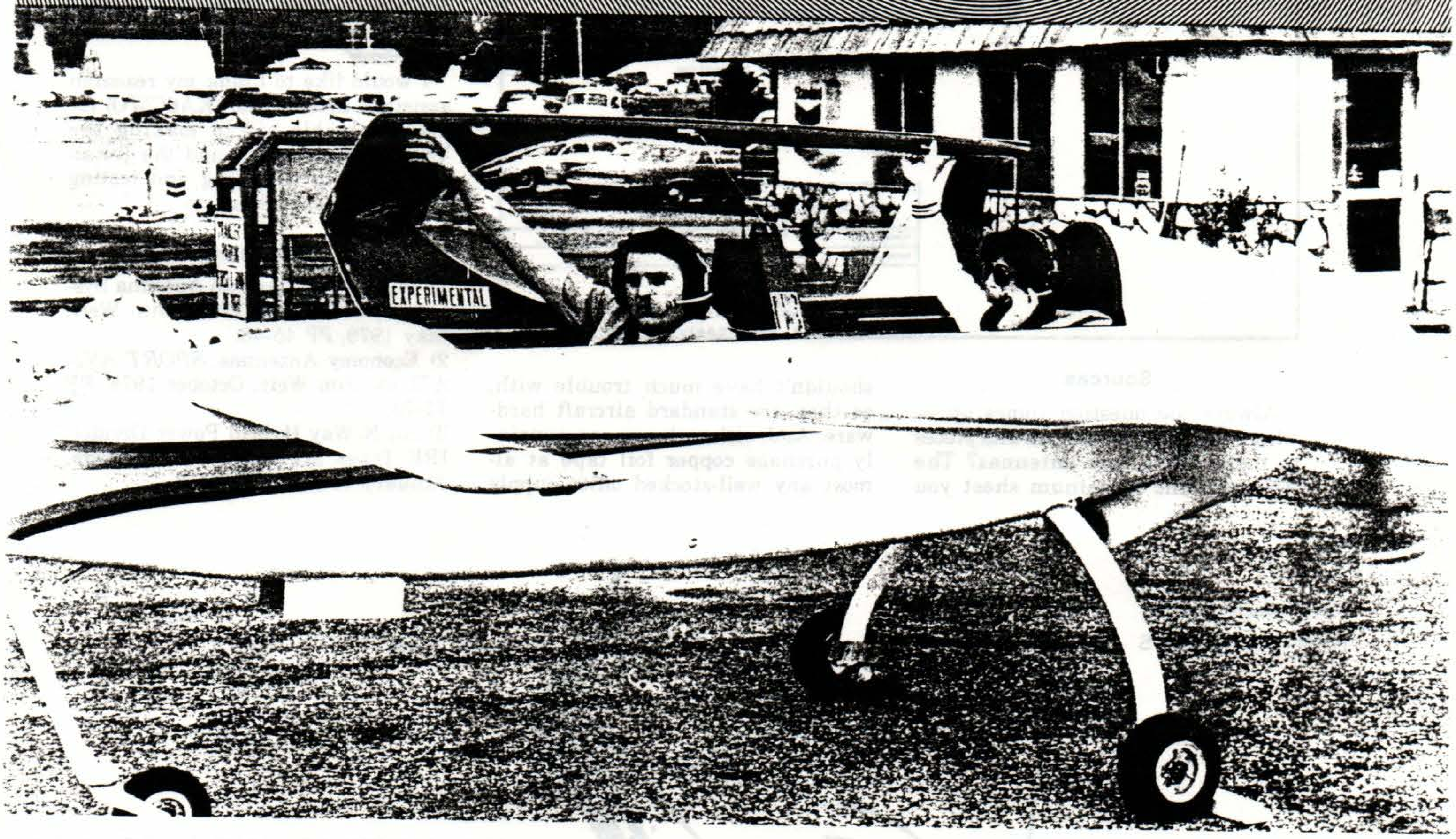



**Photo 1: The NAV antenna goes in the forward canard. Note how close the passenger is to the COM antenna. This is the reason for a slight bump in the antenna radiation pattern.**

*By Jim Weir (EAA 86698)*

AFTER WRITING A couple of recent articles on antennas,[1] [2] as well as engineering a just-finished project on hidden antennas for a major airframe manufacturer, I have come up with a very inexpensive solution to hidden NAV and COM antennas for nonconductive ships (i.e. those made out of fiber glass or wood and fabric).

For those of you who want to use the tips and techniques that I am about to outline, this is the **cardinal** rule for concealing the antennas within the airframe: There shouldn't be **any** metal or other conductors (like a 95% salt water solution called a pilot) within 60 cm (24 in.) of the outer tips of the antenna elements. But what if you want to conceal your antenna where the aluminum spar attach bracket is only 55 cm (22 in.) away? Does this mean that the antenna will not work at all? Of course not — but there will be some loss or pattern distortion introduced. Now, 'some' loss may or may not be acceptable to you, but at about $5 an antenna, you can afford to do a little playing around with various locations for the antennas. Many homebuilders have called me to ask the effect of drag wires, nav light wiring, or 'just a few nuts and bolts' close to the antenna. To all such questions, there is only one real answer: Try it and see. Just remember that it is the **surface area** of the metal surface in proximity to the antenna **tips** that will mess the pattern up. For example, a sheet of tin foil 50 cm square will mess the pattern up much more than a single aluminum bolt, even though the bolt weighs ten times the weight of the foil.

According to the referenced article,[1] antennas may be made out of any conductor, even brazing rod. In this application, a very good choice for the elements will be copper tape. There are several reasons for this choice of material — copper tape is relatively cheap, thin, lightweight, an excellent conductor, self adhesive, and (very important) readily available at any stained-glass window supply house.

One problem with plastic airplanes is that there is no large metal surface to act as a ground plane for the com antenna. This apparent drawback can be turned to our advantage by using a dipole for both COM and NAV — a separate dipole for each. The only trick is going to be getting the COM dipole as vertical as possible. Once we believed that COM antennas would not work at all if horizontally polarized (i.e. if the antenna is parallel to the earth's horizon), but since several brands of radio now use the horizontal NAV antenna for both NAV and COM reception, current thought is that, although vertical antennas are preferred for COM use, horizontal antennas will only be 'some' worse. Again, the famous 'some' principle. How much is some? Try it and see. Also, if one ear of the dipole is mounted horizontally, and the other ear vertical, you will get 'some' horizontal and 'some' vertical polarization to the antenna.

One thing we know for sure about dipoles — they **must** have a balun to operate. On this last antenna project, we found an absolutely spiffy broad-band balun that requires no tuning, no cutting, and is lightweight and (best of all) fairly cheap. Now, without going into a doctoral dissertation on the propagation of electromagnetic waves in high-permeability media, suffice it to say that a few ferrite beads slipped over the coax at the antenna makes a very good balun. These ferrite beads (actually doughnut coil toroids) are fairly cheap when purchased in large quantities. As a matter of fact, you should be able to make a NAV or COM antenna for about $3 worth of ferrite beads and another $2 worth of copper tape, wire, hardware and other small bits and pieces.

How long a piece of tape? If you make your antenna out of 1 cm (.5 in.) copper tape, the length chart shown in Figure 1 should let you cut your copper tape to the right length. This 1 cm width is not really critical either; widths from ½ to 2 cm should work quite well. Be cautious about widths less than ½ cm, though, as antenna bandwidth will begin to deteriorate rapidly as narrow tape is used.

Last, encasing the antenna in foam or covering it with a layer of resin does not seem to affect the operation at all. This suggests that the antenna may be buried within the wing or the canard of a plastic airplane and then glassed over. **Thin** coats of silver aluminum dope don't seem to have much affect on the pattern or radiation efficiency, either, so that you ought to be able to bury the antennas inside a toothpick and tissue paper airplane also. Just remember what I said about the 'some' effect of drag wires and aileron cables.

Now let's do a full-blown practical example. How about a complete NAV and COM antenna setup for the VariEze. (Yes, Brother Rutan has seen and blessed this article before I submitted it to be published.)

Since the NAV antenna is the easiest of the two to design, let's start out with that one first. After we get the hang of foil and ferrite antenna design, we can move on to the more difficult COM antenna.

What do we need to make a good NAV antenna? Well, from the length charts we see that the first thing we need are two 61 cm (24 in.) lengths of copper tape, or a total tip-to-tip length of 122 cm. Also, the antenna elements need to be laid in as horizontal a surface as possible. Where do we have a horizontal fiber glass or foam surface about a meter and a quarter (4 ft.) long? How about the canard? Sure, why not. The only conductor close by is the pilot's feet, and even there, they will be at the low-sensitivity center of the antenna if we string the dipoles equally onto each side of the canard. If the copper tapes are stuck to the foam before the glass

DIPOLE LENGTHS (EACH ELEMENT) FOR THE NAV AND COM ANTENNAS

| | LENGTH CM | LENGTH IN |
|---|---|---|
| NAV | 61.2 | 24.1 |
| 360 COM | 54.6 | 21.5 |
| 90 COM | 56.6 | 22.3 |

FIGURE 1

FIGURE 2

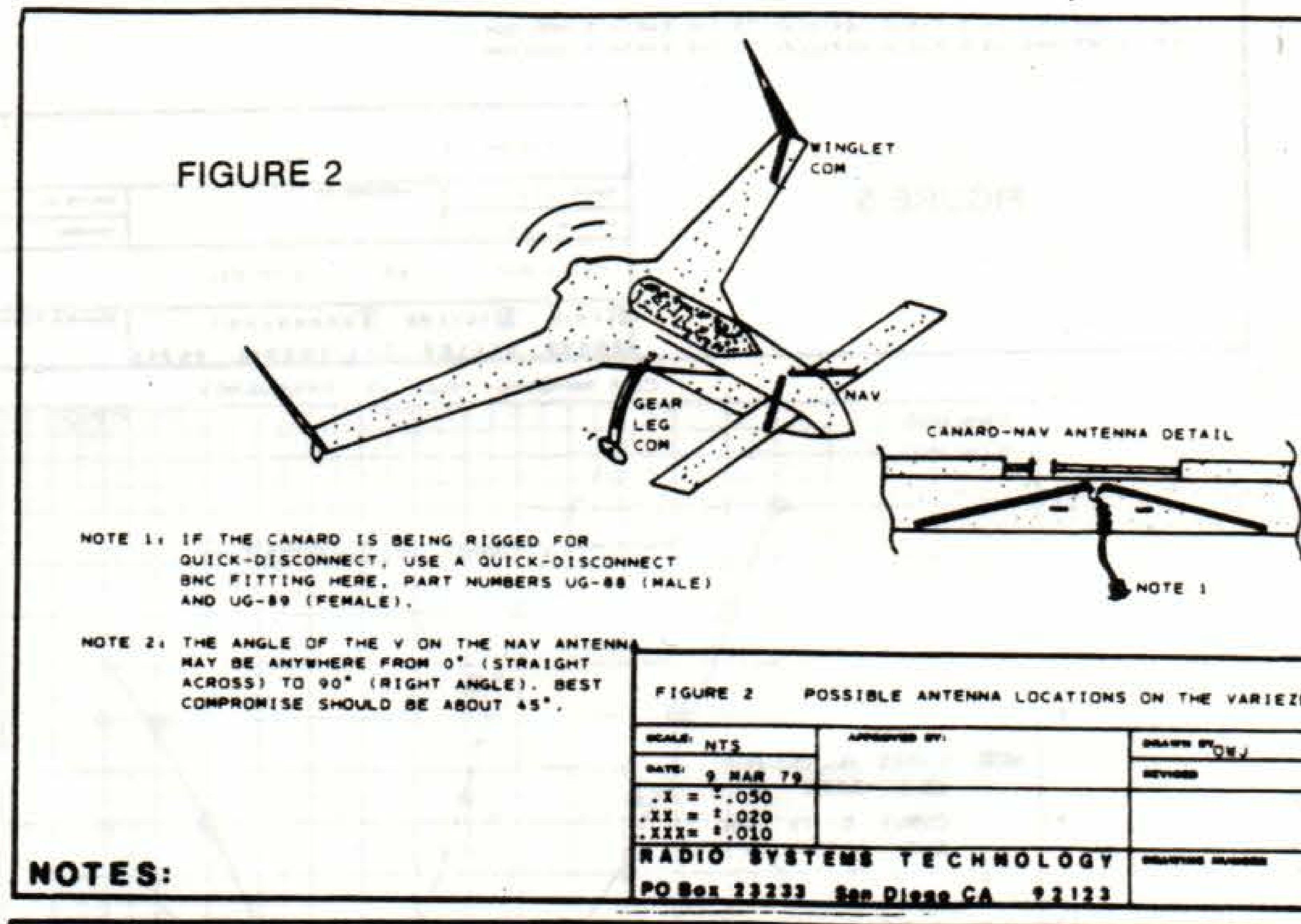
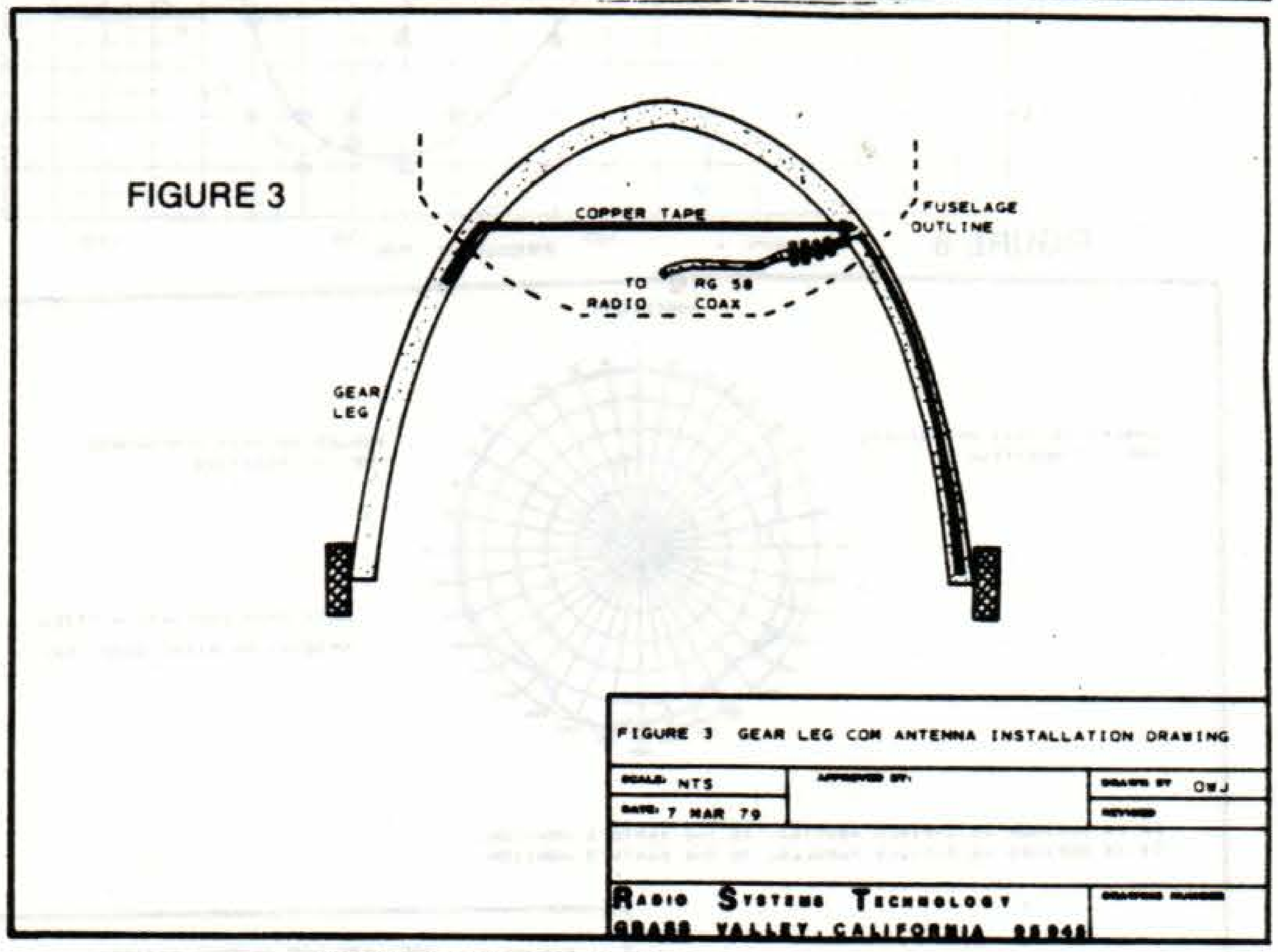



FIGURE 3



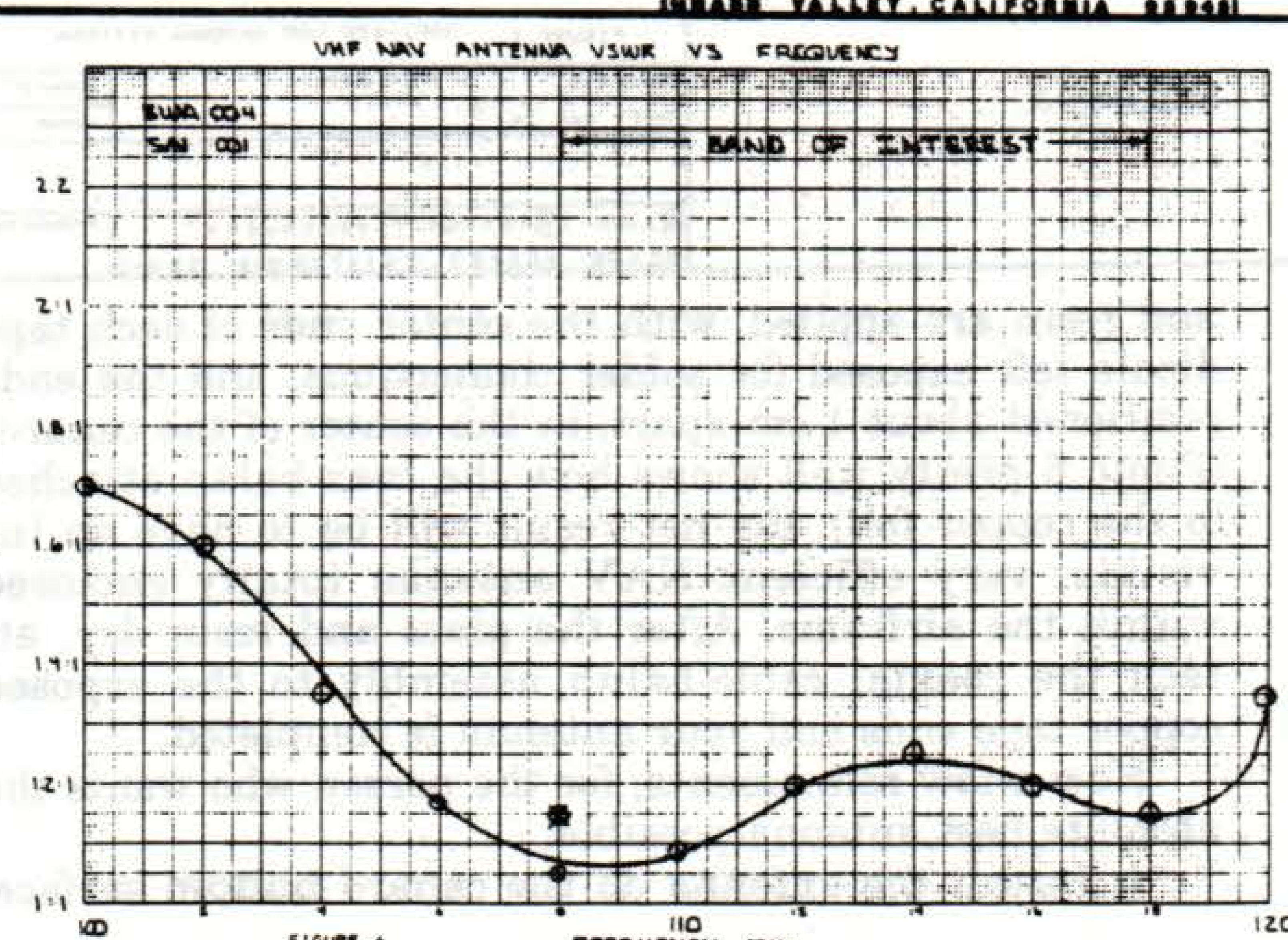



FIGURE 4

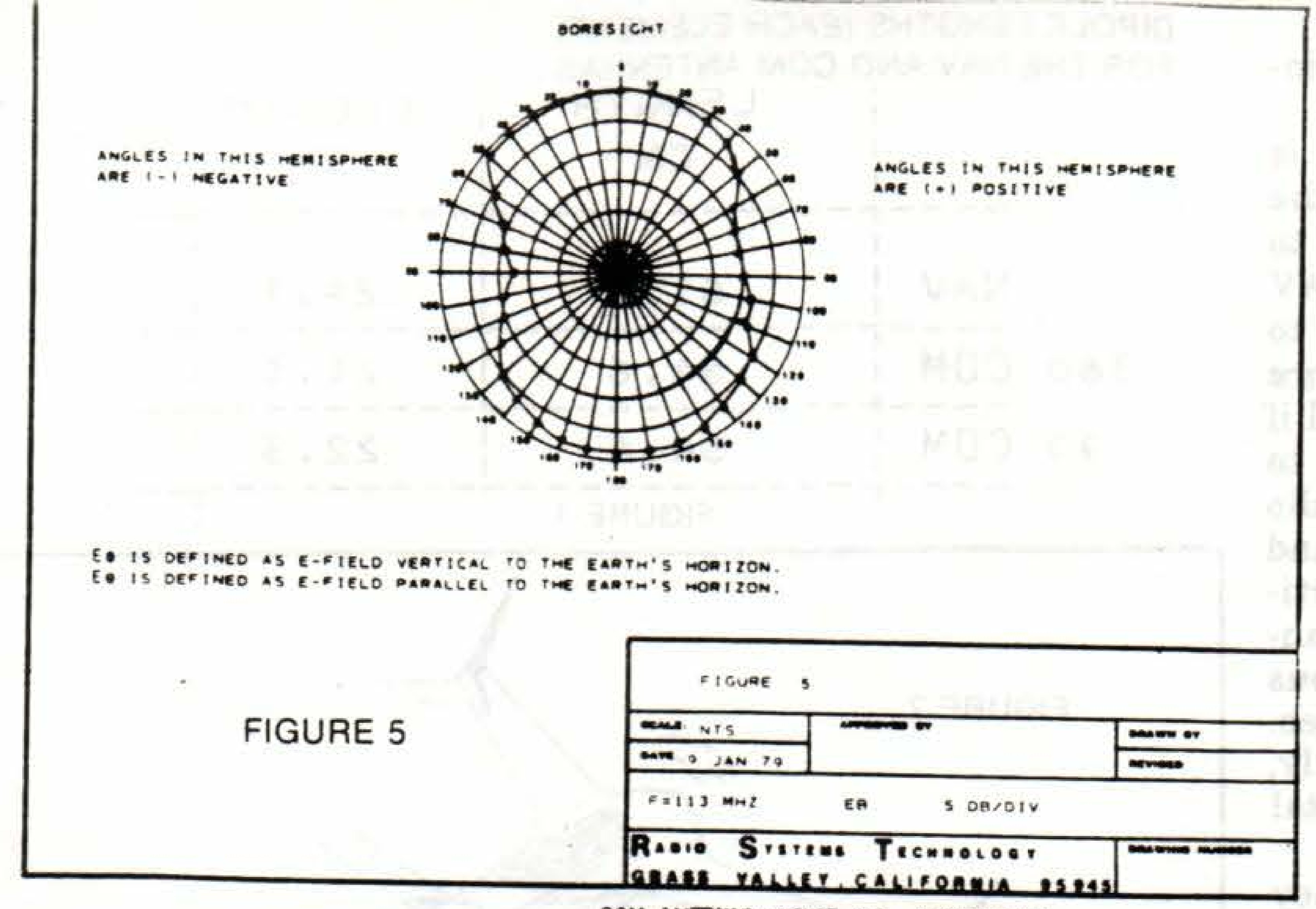



FIGURE 5

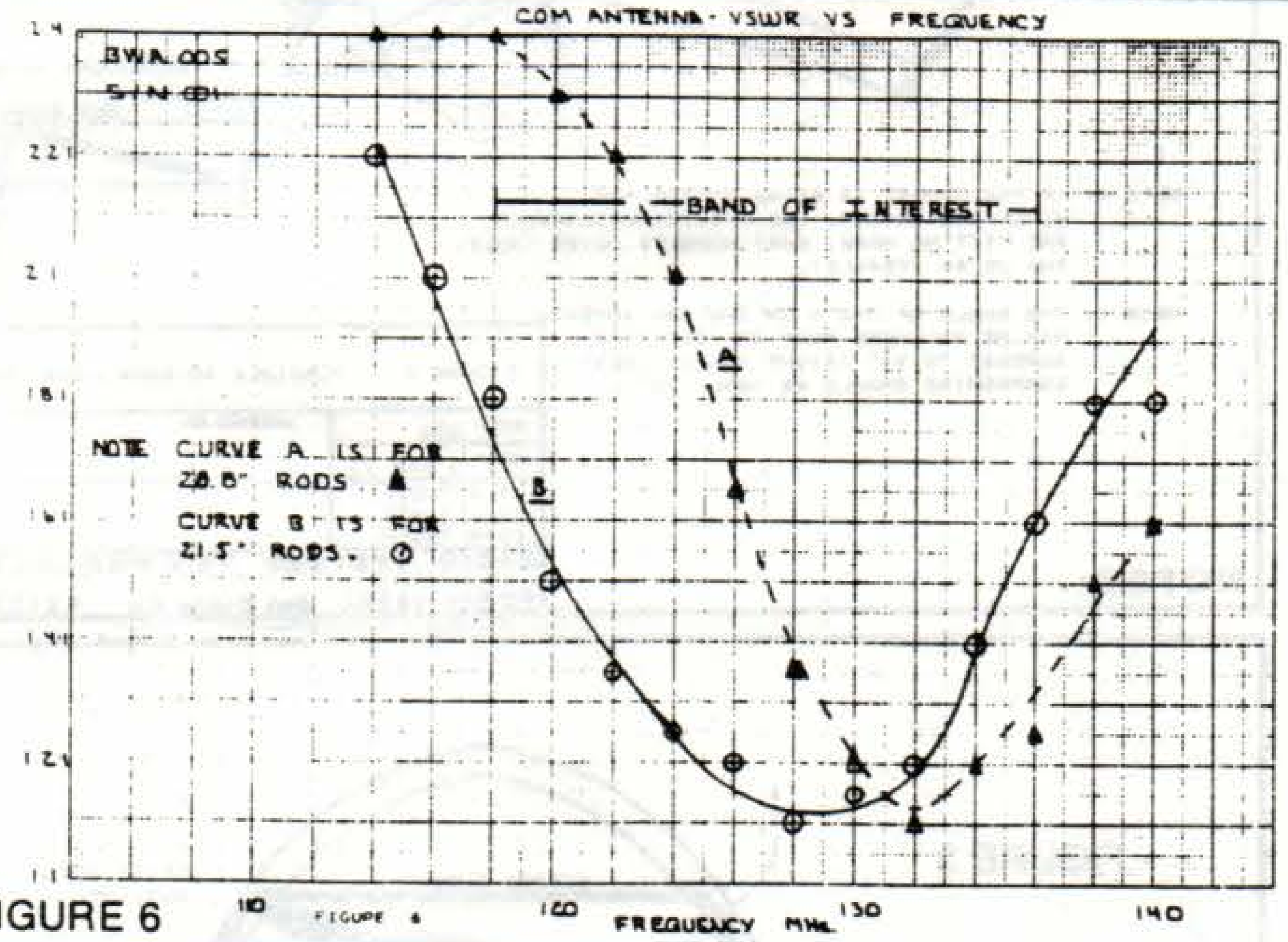



FIGURE 6

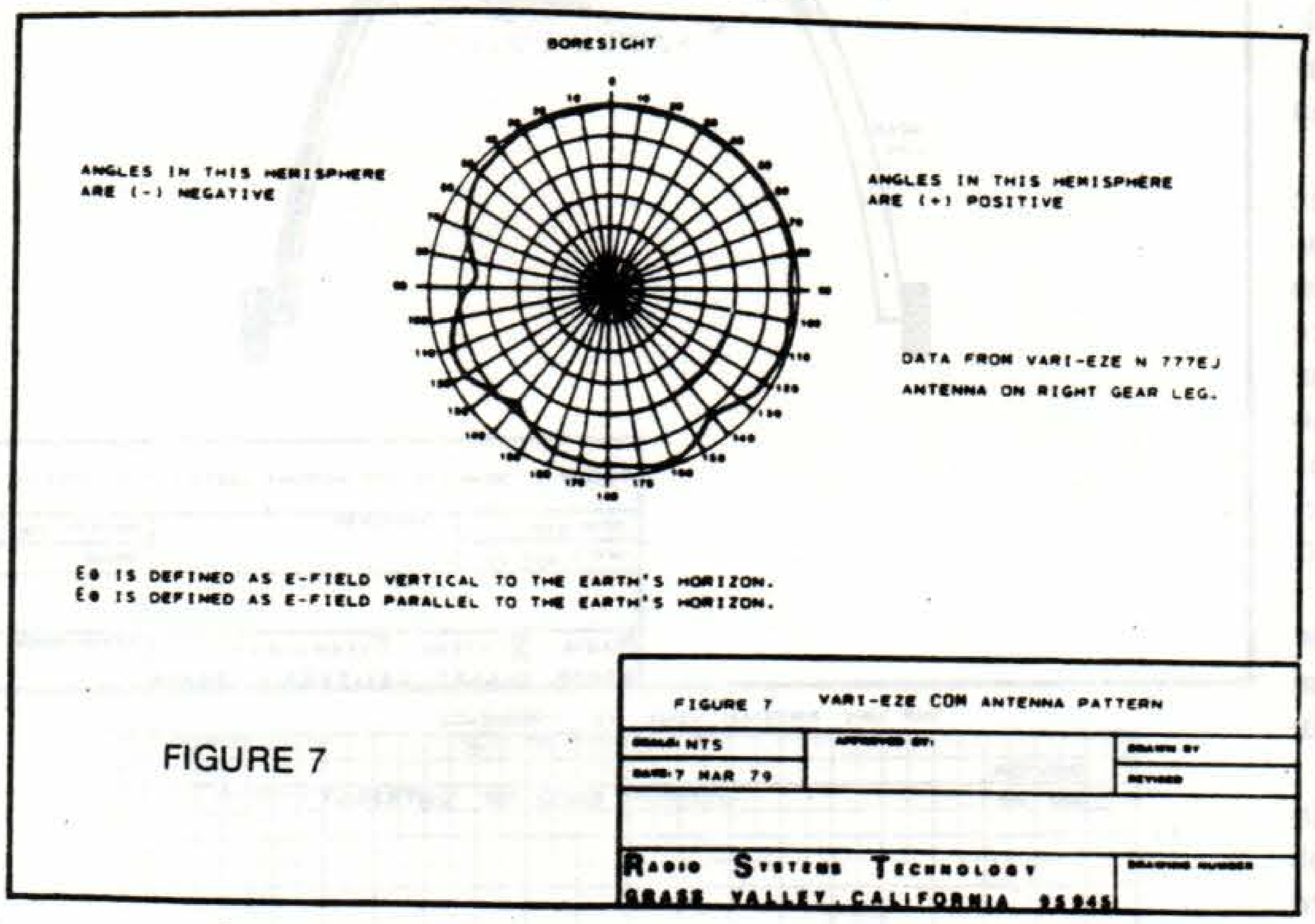



FIGURE 7

and resin are applied, with the center ends of each tape dipole left exposed for solder connections, and the ends positioned about 1 cm apart, in the center of the canard, (Photo 6 pretty well shows how the coax-balun attaches to the copper foil), the net result will be to have an invisible, very efficient NAV antenna totally enclosed within the airframe. After the glass and resin dry, attach the coaxial cable-balun assembly to the exposed copper tape ends and your antenna is completed.

Now a few refinements, for the person who wants the absolute best antenna possible:

1. Install the antenna on the canard **bottom** surface. This is done for two reasons; first, ground reception will be measurably better, and second, any 'tape line' will not be readily visible after the color coat finish is applied.

2. Instead of installing the dipole elements straight out, put them kitty-corner across the canard in a V-shape with the open end of the V pointed forward. Again, there are two good reasons for this: first, it eliminates a rather sharp null off the ends of the dipole, and second, it 'aims' the antenna **slightly** forward for maximum off-the-nose reception.

3. (And this one is for the **real** purist) Rout out a 1 cm (.5 in.) groove .06 mm (.0025 in.) deep in the canard foam as a recess for the tape so that there is no tape line in the glass finish — as though you could see a .06 mm bump anyway!

Now for the COM antenna — and this isn't going to be quite as easy to position as the NAV antenna. The whole darn airplane isn't much more than 2 meters tall; where are we going to find a vertical surface 10 cm tall for the COM dipole?

Basically, we are going to have to compromise and make the best of a bad situation. One solution is to run one of the dipole elements vertically up the winglet and the other element horizontally along the wing surface at the base of the winglet. Then hollow out a 5 mm tube down the center of the wing foam for the coax. String the coaxial cable down this hole, connect the coax center conductor to the vertical dipole and the braid to the horizontal dipole. Then fair the balun and the solder connections into the foam. Note that once the glass and resin go on, the only way to get at the antenna for repair is to destroy the winglet. However, if you are after dual-com capability (in an EZ?), this is the only method whereby you can get two vertical antennas, one in each winglet. And, as I stated before, this antenna will give 'some' vertical and 'some' horizontal polarization.

Although the winglet is a perfectly good (electrical) place for the COM antenna, I think that ease of repair considerations alone should force the choice of another location. I personally think that the gear legs are the best compromise choice. There are several reasons for this opinion, and most of them have to do with ease of installation and servicing. With the dipoles on the gear legs, the center attach solder joints are accessible through the fuselage center section. (I know, I know, you and I have never made a bad joint, but we've both got this friend Ernie who epoxied up his airplane and then tried out his nav lights . . .).

At any rate, one copper tape dipole should be run down the right gear leg with about 2 cm (1 in.) of the tape extending into the fuselage center section. Solder the coax center conductor to this tape. Solder the braid to the remaining piece of copper tape and run this tape on as direct a line as possible out the center section and down the left gear leg. A color coat of resin over the copper tape completes the antenna.

Of course, there are refinements to this COM antenna for the exceptionally discriminating craftsman:

1. The best position on the gear leg for the tape is the leading edge of the fiber glass. Wrap the tape around the leg and fair into place with resin.

2. Cut a small block of foam to support the copper tape in the fuselage center section. This will keep the tape from vibrating and eventually splitting.

3. The right and left gear leg dipoles may be interchanged, if it is easier for you to wire it this way, so long as the coax center conductor is attached to the dipole leg with the maximum vertical extent.

Since our labs here at Radio Systems Technology uses quantities of these toroids, and we also have a fair stock of copper tape, we will be happy to supply our fellow EAAers. ~~with four toroids* and 120 cm of 1 cm copper tape for $5. This amount of material, plus your RG-58 coaxial cable, will allow you to make one NAV or COM antenna. Just ask for a ferrite foil antenna kit. (Radio Systems Technology, 10985 Grass Valley Ave., Grass Valley, CA 95945, telephone 916/272-2203.)~~

Figures 4, 5, 6 and 7 show test results obtained with antennas constructed and installed in accordance with the data contained in this article. Figure 4 shows the VSWR or 'goodness' of the NAV antenna, with 1:1 being theoretically perfect and 2:1 being very acceptable performance. The antenna appears to have less than 1.3:1 across the nav band. Figure 5 shows the radiation pattern of the same antenna installed in the aircraft. Here you can clearly see the small 'null' holes in the pattern off the left and right wing tips due to dipole end-on effect. Had we not bent the ears into a V, the nulls would have been so deep as to make the pattern into a figure 8.

Figures 6 and 7 show the VSWR and pattern of a COM dipole attached to the right gear leg. The area of slightly reduced gain to the port side is the probable result of engine (metal) cowling and copilot (salt water) effects on the dipole arms, reducing the gain in those areas. This amount of pattern distortion is well within reason.

I would like to thank Ed Hamlin, who graciously tried out our screwball ideas in his beautiful VariEze N777EJ, and who also flew the pattern measurement test; Burt and Dick Rutan for their guidance, assistance and kind words; and my research associate Larry Pitts for his help in making and testing these antennas.

### FOOTNOTES

1. 'Economy Antennas' or 'What To Do With Leftover Brazing Rod', *SPORT AVIATION*, Jim Weir, October 1976, page 71-78.
2. 'Understanding Aircraft Antennas', Private Pilot Magazine, Jim Weir, October 1978, page 36-39.

### REFERENCES

1. 'The Microwave Engineer's Handbook', Horizon House, 1965.
2. 'Communications System Engineering Handbook', Hamsher, McGraw-Hill, 1967.
3. 'Reference Data For Radio Engineers', ITT, 4th Edition.
4. 'Radio Amateur's Handbook', ARRL, 1972.


**Photo 2: It is possible to put most of the COM antenna in this winglet, but it would be impossible to repair.**

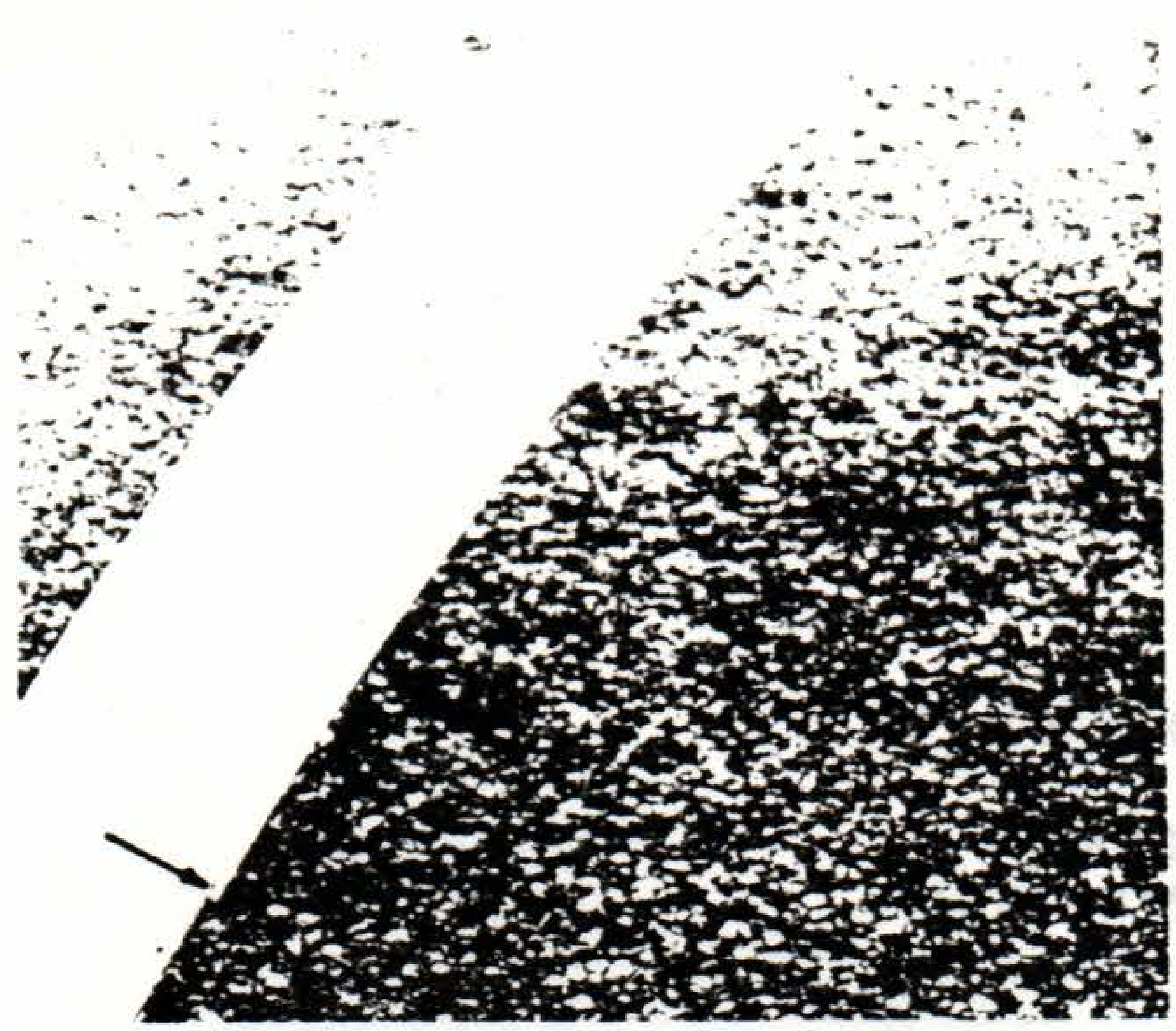


**Photo 3: A COM antenna running down the forward edge of the right gear leg. Ed did such a fine job of fairing it in that it is hard to see.**

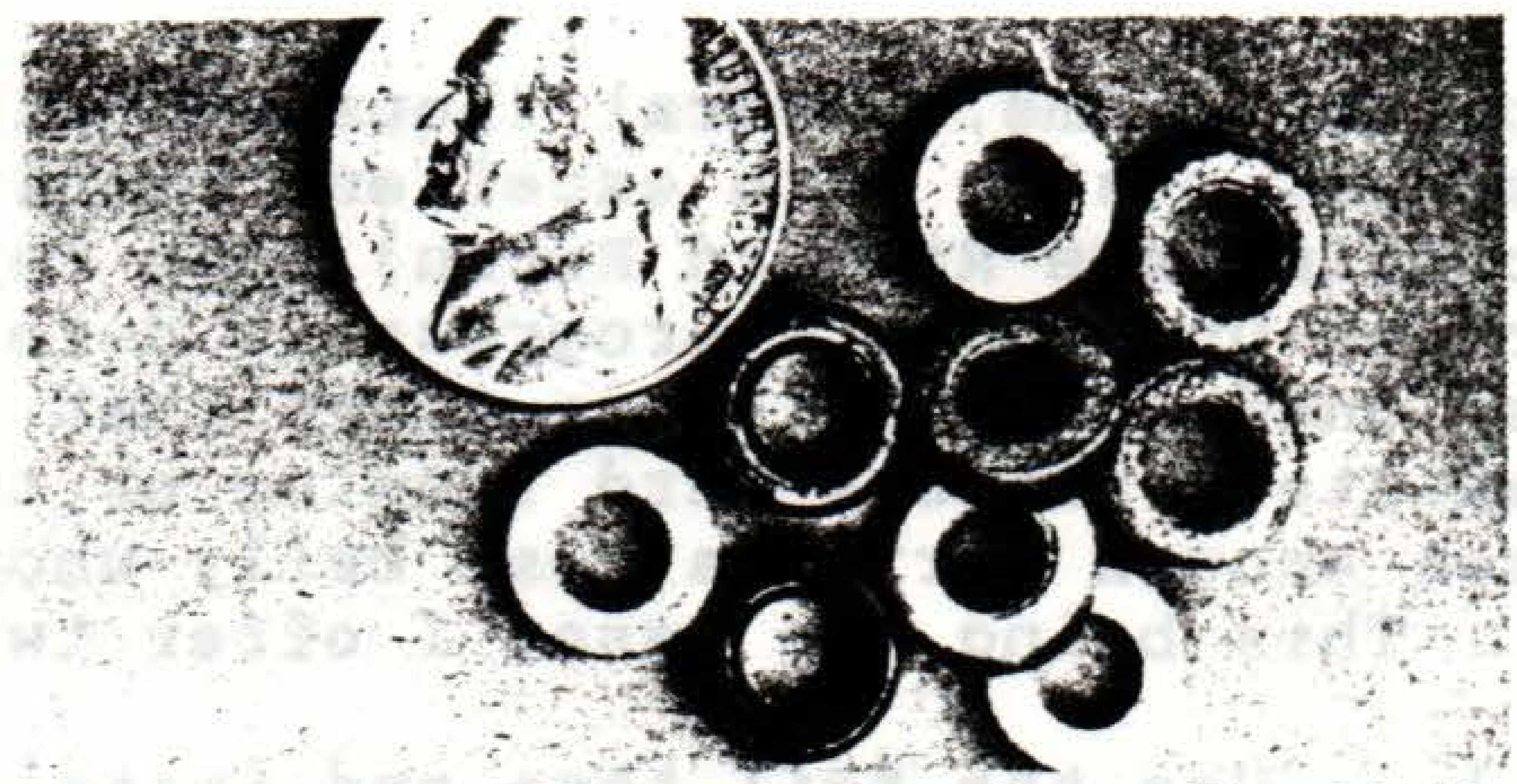


**Photo 4: Enough toroids to make two antennas. The nickel is for comparative size.**

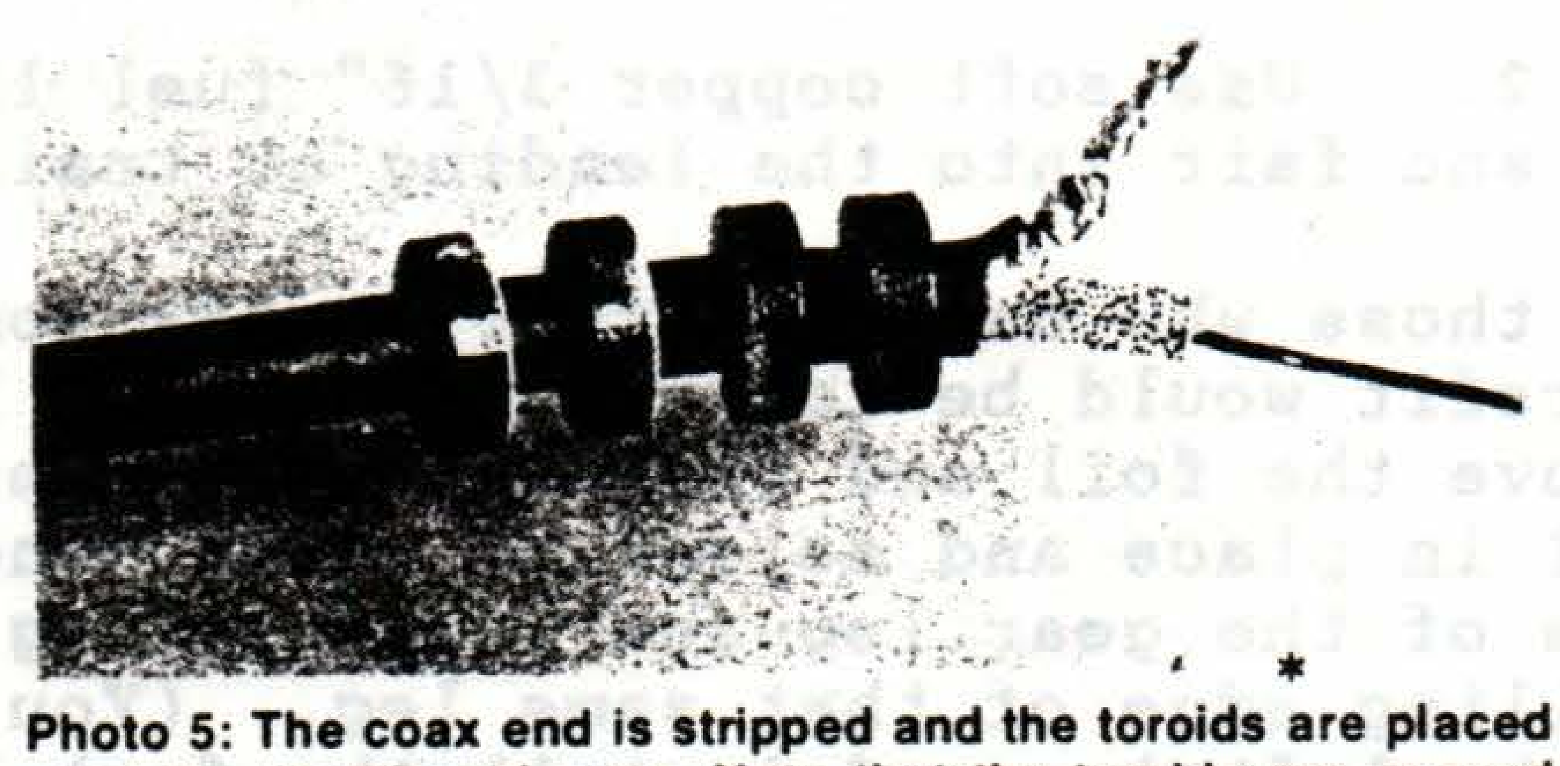


**Photo 5: The coax end is stripped and the toroids are placed over the unstripped coax. Note that the toroids are spaced about a toroid width apart.**

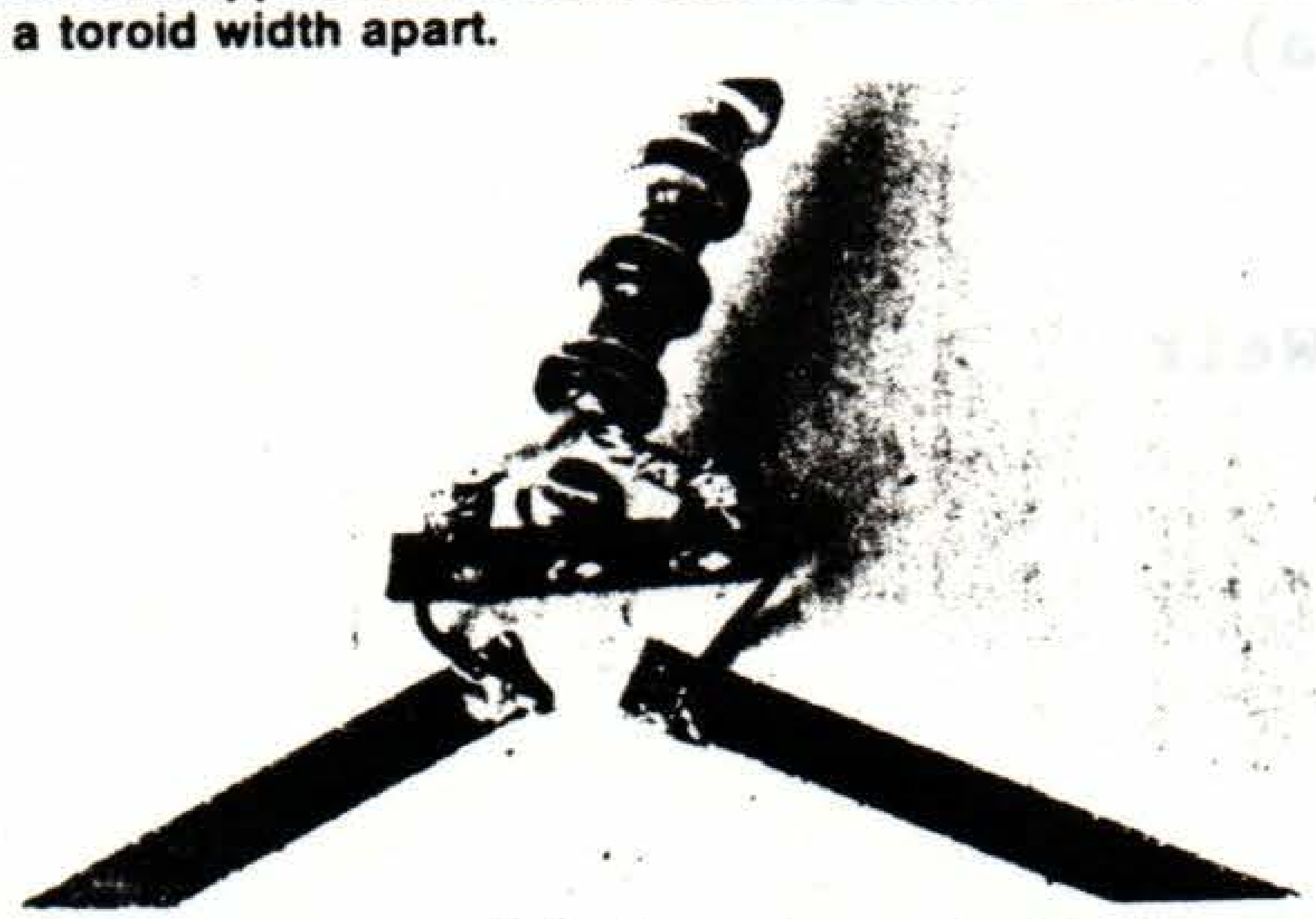


**Photo 6: The two copper foil elements attached to the coax by means of short wires to the coax terminal strip. The toroids may be epoxied into place, or you may use shrink sleeving as I did.**



*THREE TOROIDS ARE ALL THAT ARE NECESSARY.

15 Dec 81

**ADDENDUM**
**(RST/82703)**

In mid-1979, I wrote the first article specifically concerned with plastic-plane antennas (Sport Aviation, May 1978, pp. 45-59)

Since that time, several thousand builders have used these foil-ferrite antennas, mostly with excellent results. However, a few builders (including one Richard Rutan) have reported that the COM antenna on the gear leg undergoes a progressive deterioration over time. When questioned, most builders admit that the problems began to occur immediately after a hard landing or two. My theory is that the gear leg flexes enough during a real belly-whopper that the copper tape breaks in two. This being the case, I offer two suggestions:

1. Use the foil tape and install the antenna in the winglet. If the winglet ever flexes, you've got more problems than worrying about your COM antenna.

2. Use soft copper 3/16" fuel line for the antenna elements, and fair into the leading or trailing edge of the gear leg.

For those who have had foil separation on their gear legs, the ideal retrofit would be to scrape the gear leg down to the foil and either remove the foil and install the copper fuel line, or leave the broken foil in place and solder the fuel line to the foil on, say, the leading edge of the gear leg and retrofitting the new antenna on, say the trailing edge of that same leg. (You may, though, leave the broken foil on the left leg and install the fuel line on the right leg and vice versa).

Jim Weir

# Understanding Aircraft Antennas

## A Primer for Care and Feeding of Airplane Bristles

**by JIM WEIR**

REPRINTED FROM PRIVATE PILOT

THAT CRAZY kite-flier named Franklin (Ben, late of Philadelphia) proved it: If you don't have antennas outside your airplane, you are not going to talk to anybody. Of course, brother Ben could not have foreseen today's Wichita Wonderplanes flitting about the skies, but he *did* prove once and for all that electromagnetic energy (or "phoric elektricitee," as he called it) cannot escape from a metal enclosure. So, if your airplane is made out of metal, even if it has a steel tube fuselage, you will need to hang the antenna out in the breeze for it to do any good at all. And, yes, for those of you building your plastic airplanes, you *can* bury the antennas inside the foam.[1]

Just exactly what is an antenna, anyway. Well, back in grad school, they taught us that an antenna was "a conductive structure so arranged as to launch an electromagnetic field into the impedance of free space and/or provide an effective aperture," ... horse puckey! Keep it simple: An antenna is a piece of metal used to capture and launch radio signals. From this definition comes an amazing idea called the Reciprocity Theorem, which states that:

*A good receiving antenna makes a good transmitting antenna, and vice versa. An antenna does not distinguish between transmitting and receiving.*

Now, to blithely breeze through a full semester's antenna design course in two sentences, here it is: 1) The best antenna compromise is an antenna which is a quarter wave is given as 4=2953/f, where m/4 is a quarter wavelength in inches, and f is the antenna resonant frequency in MegaHertz. 2) The fatter you make the antenna, the wider will be the frequency band over which the antenna will be useful.

To bring the above two sentences closer to home, look at Photo 1. The "bent wire" com antenna shown is a quarter-wave (23-inch) long, and therefore resonant about 122.5 MHz. This antenna was intended to be used on the old 90-channel radios, so it was cut to the center of the 118-127 MHz, 90-channel com band, which is 122.5 MHz. The antenna shown in Photo 2 is nothing more than a slightly shorter, slightly larger in diameter version of the same antenna, *fatter* because it is designed to cover a broader bandwidth for the 360-channel radios (118-136 MHz) and *shorter* because the center of the 118-136 MHz band is slightly higher in frequency (127 MHz vs. 122.5 MHz). Remember, the higher the frequency, the shorter the antenna and the broader the bandwidth, the bigger around the antenna.

Now, there are a half-dozen companies in the business of making antennas as well as a good half-dozen articles written on how to home-brew your own antennas (and, again, I refer you to ref. 1). However, the thrust of this dissertation will focus on how you, the pilot, can recognize which of these bristly rascals is the com antenna, the nav, the marker, the transponder and the DME antennas as well as recognize conditions that may make the antenna perform less than optimum.

Let's start with those antennas (or antennas, for the English major) of which there is at least one example on almost every aircraft — the com antenna. As we have seen above, com antennas can be as shown in Photo 1 (the "bent-wire," 90-channel) or Photo 2 (the broadband 360-channel whip). Spending a grand-and-a-half on your shiny new 360 navcom and trying to save ten bucks by using the old bent wire antenna is like renting the fanciest tuxedo in town and going to the ball barefoot. Another style of broadband com antenna is the blade or "shark's fin" antenna shown in Photo 3. The performance of the blade, though, is only about 5% better than the standard broadband whip, though it weighs twice as much, has double the drag and is triple the cost. In all, then, my choice of antenna for broadband com use is the classic $30 broadband whip. Let's investigate this whip a bit to see how it can be used most effectively.

First, let's investigate the construction of this antenna. The base generally is die-cast aluminum into which a thin, hollow fiberglass tube is press-fitted and epoxied into place. A solid strip of copper is inserted into this fiberglass rod and soldered to a BNC connector which is then screwed into the threads cast into the base. What we have, then, is a relatively flat, wide antenna element inside a waterproof tube. The tube then is filled with a lightweight, waterproof foam, and a weatherproofing cap is epoxied onto the top of the rod. The whole works is given a coat of white epoxy paint, tested and put in a box for shipment.

These antennas may be installed onto metal or fabric airplanes, but there are several areas of concern that you may wish to observe in either installation or servicing. In metal ships, there will be no problem with ground planes, but in fabric or steel-rod fuselage aircraft a ground plane must be installed for proper operation. This ground plane is best made with a 24-inch radius circle of plumber's flashing copper, but aluminum foil will work almost as well. If a 24-inch radius circle cannot be fitted into the airframe, 24-inch strips extending radially from the base of the antenna will work almost as well; the more strips the better, but not less than three.

In either case, metal or fabric, the epoxy paint on the antenna base must be cut through by the (supplied) mounting lockwashers so that there is good electrical contact between the antenna base, through the screws, to the ground plane. (Note: There should be an insulating weatherproofing neoprene rubber pad installed between the antenna base and the aircraft skin.)

Also, the radiation pattern of the antenna resembles a doughnut slipped over the antenna rod. Note that there is a "hole" in the radiation straight up and straight down. This is why, when flying directly over a tower or FSS transmitter, the sound sometimes becomes garbled and distorted; the ground transmitter is in the hole of your antenna pattern. This theoretical perfectly circular pattern may be upset (sometimes totally destroyed) by the presence of metallic objects nearer than one-quarter wavelength (about 24 inches) to the tip area of the antenna. Other antennas, airframe structures, landing gear, propellers or people near the antenna will distort the pattern. If you are installing dual com antennas, be sure they are at least 24-inches apart.

The last comment I wish to make regarding com antennas is that each com transceiver must have its own antenna. Do not attempt to connect two transceivers to a single antenna without the use of a specially designed device called a com circular, or the most common name, "towel-bar" antenna. What the towel-bar gives you, for only about quadruple the price of a rabbit ear, is a relatively circular pattern, as opposed to the more cardioid pattern of the rabbit-ear, plus a great coat of white epoxy paint. What the towel-bar does *not* give you is a total range increase. The antenna pattern of the towel-bar is perfectly circular in all directions, while the V antenna, as we saw above, has a strong lobe in the forward direction and a weak lobe in the rear. So, what the towel-bar giveth in one direction, it taketh away in another.

The next most common antenna is the marker beacon antenna. Like the VOR, the marker beacon signal is transmitted with horizontal polarization, so that a horizontal antenna will be necessary.

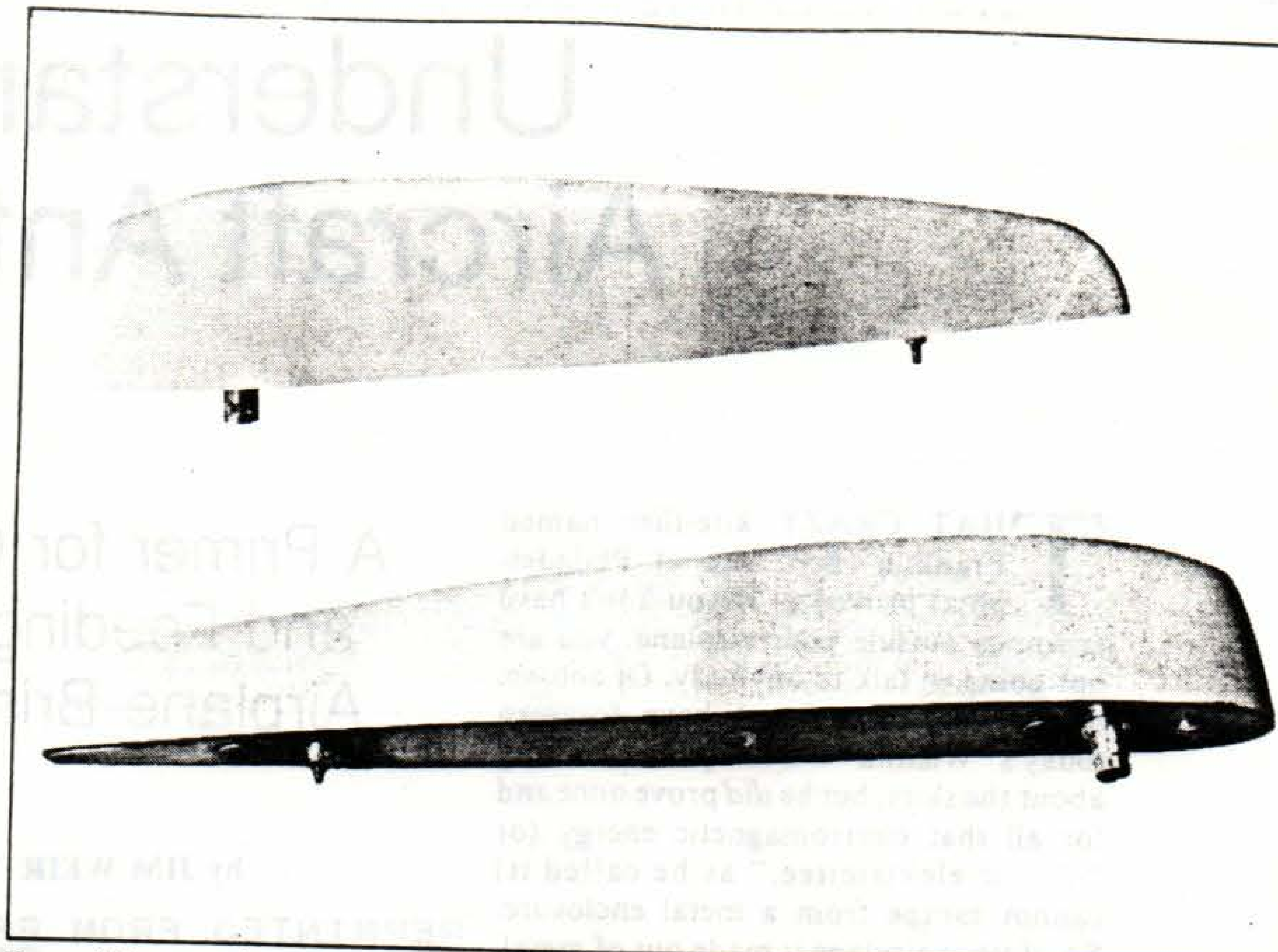
The most common marker antenna is the bent-wire, quarter-wave sled "J" shown in the photo. This antenna is usually always mounted on the belly, with the antenna running horizontally fore-to-aft. Because the marker beacon operates at 75 MHz, the sled antenna ought to be about 39 inches long. At the front, the antenna is directly grounded to the airframe, and is supported about six inches from the skin at the back by a fiber insulator. The center conductor of the coax attaches to the antenna through an insulator and sliding clip. The antenna is tuned by sliding the clip back and forth until the point of maximum sensitivity is found.



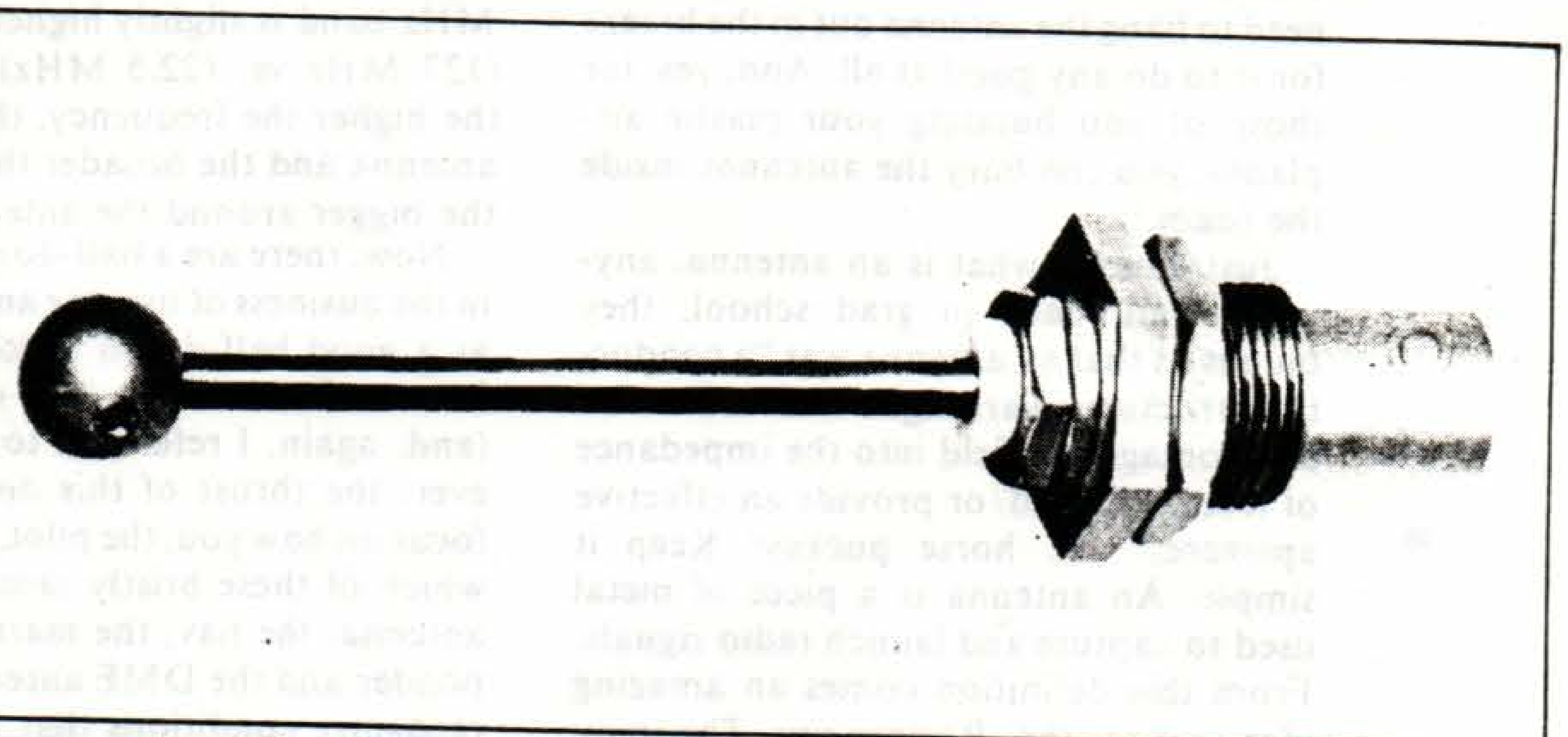
Another style of marker antenna is also on the market; the "boat" antenna, as shown in the photos, is ten times *less* sensitive, twice as hard to tune, costs triple and has more drag than a bent-wire sled. But, it surely looks pretty. (If you get the idea by now I do not like expensive antennas, you've been doing your homework.) About the best thing I can say for the boat is that it is less likely to ice up and break off.

Then there's the transponder antenna. Because the transponder works on only two relatively close-spaced frequencies, a quarter-wave vertical whip made out of ⅛-inch stainless rod soldered to a modified BNC connecter will work adequately. Because the transponder frequencies are 1060 and 1090 MHz, the whip will actually be a short stub about 2.7 inches long. This stub will be mounted on the belly, preferably as far from the landing gear and marker antenna as possible.

The DME antenna is the one place in the airplane that I will squander enough bucks to buy a good blade antenna. Although spending $40 for a blade as opposed to $10 for a stub hurts me in my most tender spot — the pocketbook — this is one place where the theory of false economy prevails. Although the DME band and the transponder frequencies are



**Two of the new boat-type antennas for marker beacons.**

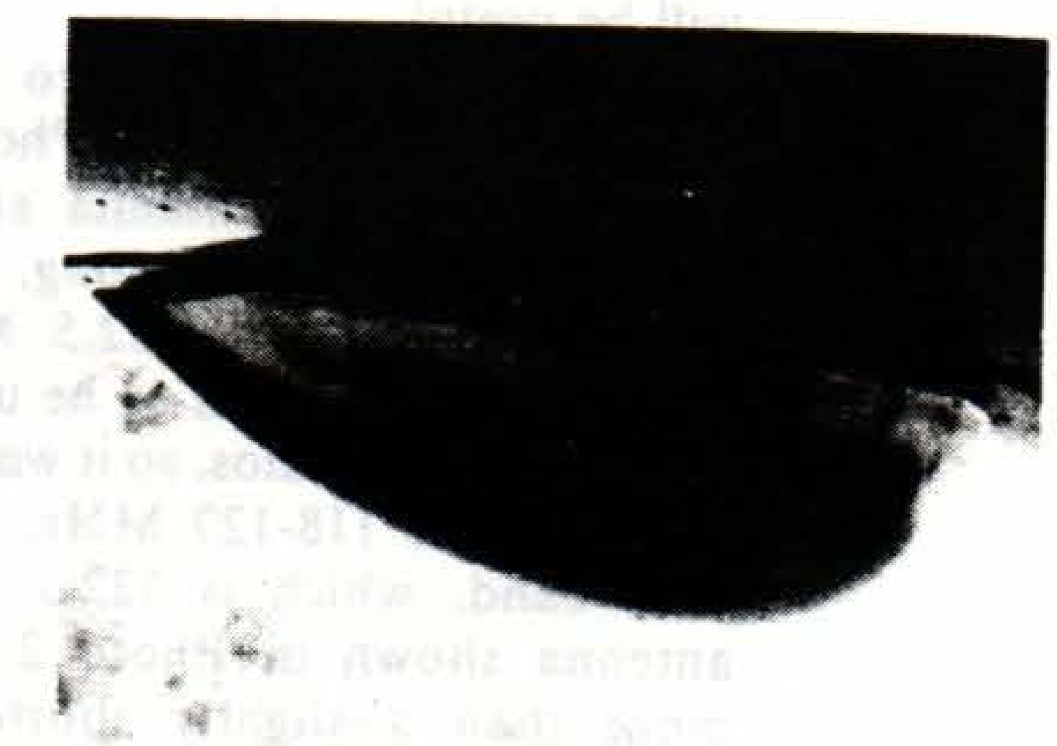


**Transponder stub — keep it clean!**


**A com antenna diplexer that allows one communications antenna to serve two communications transceivers.**

**Semi-broadband DME stub antenna.**


**Nav splitter takes the signal from one rabbit-ear antenna and splits it for two VOR-LOC receivers plus a glideslope receiver.**



**A belly-mounted ADF antenna hump.**

virtually identical, the DME has to cover the entire 950-1225 MHz band, and for this reason, I recommend the more costly blade. (Note: If you believe your DME antenna is bad, the easy test is to swap DME and transponder antenna leads. If DME reception improves, you can bet the DME blade is bad.) The DME blade is also mounted on the belly, as far away as reasonably possible (preferably over 24-inches) from the transponder and marker antennas.

The glideslope antenna, if it is separate, can take many shapes. One is a center-fed folded dipole U, a horizontal blade or batwing structure, or, as Cessna has recently introduced an inside-the-windshield plastic-foil assembly. In any event, the antenna is generally a small (8 inches across), dipole rabbit-ear of some sort. Because the glideslope signal is horizontally polarized and usually is quite strong, the usual location for the glideslope antenna is on top of the forward cabin, inside the nose cap (for twins) or inside the windshield on a plexiglass mount.

Because the glideslope frequency is so harmonically related to the nav frequencies (i.e.. the glideslope frequencies are approximately third harmonics of the nav frequencies), and because the glideslope frequencies are quite strong *and* horizontally polarized it is very possible to use a three-way coupler on the nav antenna and employ the ¾ properties of this antenna to split off the glideslope signal with no great loss of range.

The ADF is the only radio in the airplane that needs two antennas — sense and loop antennas. The sense antenna usually is a long wire antenna about six feet long running from the top forward section of the cabin to a spring attached to the top of the fin.

The loop antenna comes in several forms. One old-style antenna gives the airplane the appearance of being a hunchback. More modern loops are small rectangular boxes mounted on the outside of the fuselage. By comparing the signals supplied by the loop and sense antennas, the direction finding function is done, and the balance between loop and sense signals is quite delicate. Please note that making the sense antenna longer will not increase the receiver's range, but will instead completely upset the loop-sense balance.

There are a couple of exceptions to the above general comments on ADF antennas and both involve hiding the sense antenna somehow. One particularly widespread method is to combine the marker beacon and sense antennas. If your airplane has this combination, look for an exceptionally long (say 50-60 inches) sled-type marker antenna with a small coil in series with the wire about 39 inches from the front end of the antenna. Another way hides the sense antenna inside the loop antenna housing. Although some early models of sense-in-loop antennas were numb (i.e., insensitive), their manufacturers have come out with amplifying matching boxes that increase the sensitivity to just about normal.

So much for the antennas themselves — how about their care and feeding? First, I make it a practice to see that antennas are never painted when the rest of the airplane gets a new coat. Although this probably stems from the days that white paint had a high lead content, and thus would short out the antenna if it were painted, today's white paint has a high level of titanium dioxide, or other heavy metal oxide, and as such will do only minor dielectric loading of the antenna. This will show up as a bandpass shift toward a lower frequency range. Although the shift is minor, it still upsets me in an engineering sense to have spent so much money on a good antenna and then compromise the design.

My solution is to remove the antennas during painting and give them a good coat of epoxy white, making sure that any insulator is masked during the painting. Of course, you may use colored paint with this procedure (masking the insulator), but using colored paints with metallic salts will do a great job of shorting it out if the whole antenna is painted.

Perhaps the greatest problem you will ever have with your DME or transponder will be keeping the belly grime off the antennas. Not only does the grime look bad, but it is comprised of almost pure carbon particles in oil, both fairly good conductors. If a transponder pulse, say, comes down the cable to a grimy antenna, it will be reflected (bounced back) down the coax line and arrive back at the transponder output stage just in time to heat up the output tube. Given a few thousand pulses over a few minutes time, this can heat up the output stage to the point of destroying the (rather expensive) output devices. Even if all the power is not reflected back, enough will be reflected back to cause Center to report your transponder as "weak" or "no signal received," not in radar contact, resume normal navigation and position reports." As if IFR wasn't enough fun already, you get to go back to the 1940s method of flying in the soup! Solution — carry a wiping rag and on your checklist right after "lamp and fuse inspection" put down "wipe belly antennas clean."

That's all for this time. Next, we'll take a crack at converting one of those "mil-spec" military headsets that strangely keep appearing on the civilian market to civilian aircraft radio use. 'Til then, keep those cards and letters coming in — especially that great fan of mine in Tijuana who sends his postcards in plain brown envelopes! —*Old Weird Jim*

[1] "Economy Antennas, or what to do with leftover brazing rod," *Sport Aviation*, October 1976. [redacted]2.

# ECONOMY ANTENNAS
# or
# WHAT TO DO WITH LEFTOVER BRAZING ROD

RADIO SYSTEMS TECHNOLOGY

*By Jim Weir (EAA 86698)*

DURING THE DESIGN of a line of inexpensive kit avionics, I have come into contact with a great number of pilots who are as Scotch as I am when it comes to buying an item we can make ourselves. Since the predominant bellyache seems to be the high cost of antennas, I have given two forums at Oshkosh ('75 & '76) on the subject of homebrew antennas. This article is a general condensation of those forum notes for those members who have not attended a recent Convention.

Let's lay down a few ground rules for using this article productively. First, just as the Grand Canyon was dug by a Scotsman who dropped a nickel down a gopher hole, so will this article zero in on the most economical way to do a job. If you want to gold-plate the thing when you are done or mill the antenna from solid platinum, have at it. I prefer to make the eagle squeak. Second, I offer no proof for my equations. If you want to dig deeper, the references at the end of the article will guide you on your way. Third, since (I hope) some of you will be keeping this article for a while, and since the metric system of measurement will be predominant in this country in a couple of years, measurements are given primarily in metric, with English measurements in parentheses (inches). Last, I freely admit that I've never installed an antenna into a plastic airplane. The antennas in this article intended for use with nonconductive structures (plastic airplanes) are those which work on a laboratory test basis only. I welcome comments on the results of these antennas in actual use.

## WHAT DOES AN ANTENNA DO AND WHY

Ask an antenna engineer what an antenna is and you'll get an answer that starts like, "It's a conductive device designed to launch an electromagnetic field into the impedance of free space and provide an effective aperture ..." And so on. Boiling this down to something my simple mind can understand, find that!

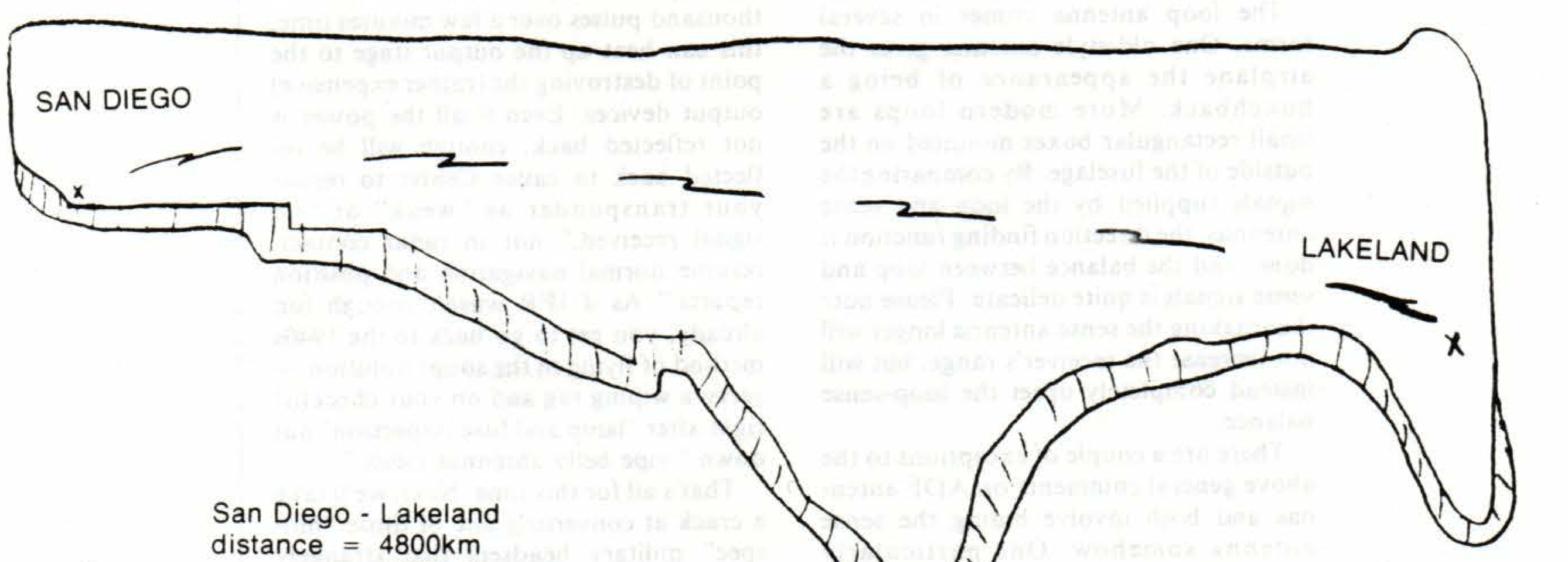
An antenna is a structure designed to either capture or launch radio waves.

From this definition, I find an amazingly simple fact called the Reciprocity Theorem, which states that:

A good receiving antenna makes a good transmitting antenna, and vice versa. An antenna does not distinguish between transmitting and receiving.

What we really need to do now is learn some simple characteristics of these radio waves we will be using our antenna to transmit and receive. Perhaps the most important characteristic to comprehend is the direct conversion between frequency and wavelength.

Einstein proved (at least to **my** satisfaction) that radio waves travel 300,000,000 meters per second (186,000 miles per second) in a vacuum. Thus, no matter whether the waves are standard broadcast, television, aircraft communications or navigation, they all travel at the




San Diego - Lakeland
distance = 4800km
(= 3000mi)

time = distance/rate
= $4800/3\times10^5$
(= 3000/186,000)
= .016 sec

**FIGURE 1 — RADIO WAVE SPEED**

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P/N 82706

rate of 3 x $10^8$ meters/second (1.86 x $10^5$ miles/second) in a vacuum (and, as we shall see shortly, also in air). To illustrate my point, a wave transmitted by a radio station in Lakeland, Florida (home of the Sun 'n Fun EAA winter fly-in) would arrive in my lab in San Diego (home of Radio Systems Technology) .016 second later.

Now, what distinguishes one signal wave from another is the frequency of oscillation of the wave. If the wave vibrates 118 million times per second, we say that the wave has a frequency of 118 million hertz or 118 Megahertz (118 MHz).

Finally, we can ask ourselves, if the wave, no matter its frequency, travels 3 x $10^8$ m/sec., and if the wave vibrates at some frequency "f", how far does the wave travel during one vibration? A little algebra shows that this distance (called **one wavelength**) is:

wavelength (meters in air) = 300/f(MHz)
(inches in air) = 11,800/f(MHz)

So, a wave on frequency 122.8 MHz travels

300/122.8 = 2.44 meters
(11,800/122.8 = 96.1 inches)

during one vibration, and is said to have a **wavelength** of 2.44 meters (96.1 inches).

Wonderful, you say, but so what. Why on earth do I care how far a wave travels during one oscillation? Well, it so turns out that antennas are made a specific fraction of a wavelength long. All you need is the frequency of the wave you are using and you will be able to construct an antenna directly from the wavelength. As a matter of fact, most common antennas are made ¼ wavelength long.

¼ wavelength (in air) = 75/f(MHz) meters
or
(¼ wavelength (in air) = 2953/(MHz) inches)

So far, we have only discussed radio waves travelling in air. If the waves are forced to travel through some other insulator, the waves slow up and bunch together thus **shortening** the wavelength. How much they are shortened depends entirely on an electrical property of the insulator called **dielectric constant** ($\epsilon$). This **dielectric constant** is always greater than 1, and a perfect vacuum has a dielectric constant equal to 1. Some common insulators and dielectric constants are listed below:

Air = 1.008 (1.0 for all practical purposes)
Window Glass = 7.8
Polyethelyne = 2.3
Polytetrafluoroethelyne (Teflon) =2.1

Now, we may never have occasion to work with window glass in our airplanes, but we most certainly will be working with coaxial cable made from polyethelyne or Teflon dielectrics. The formula for wavelength and quarter wavelength in dielectric material is:

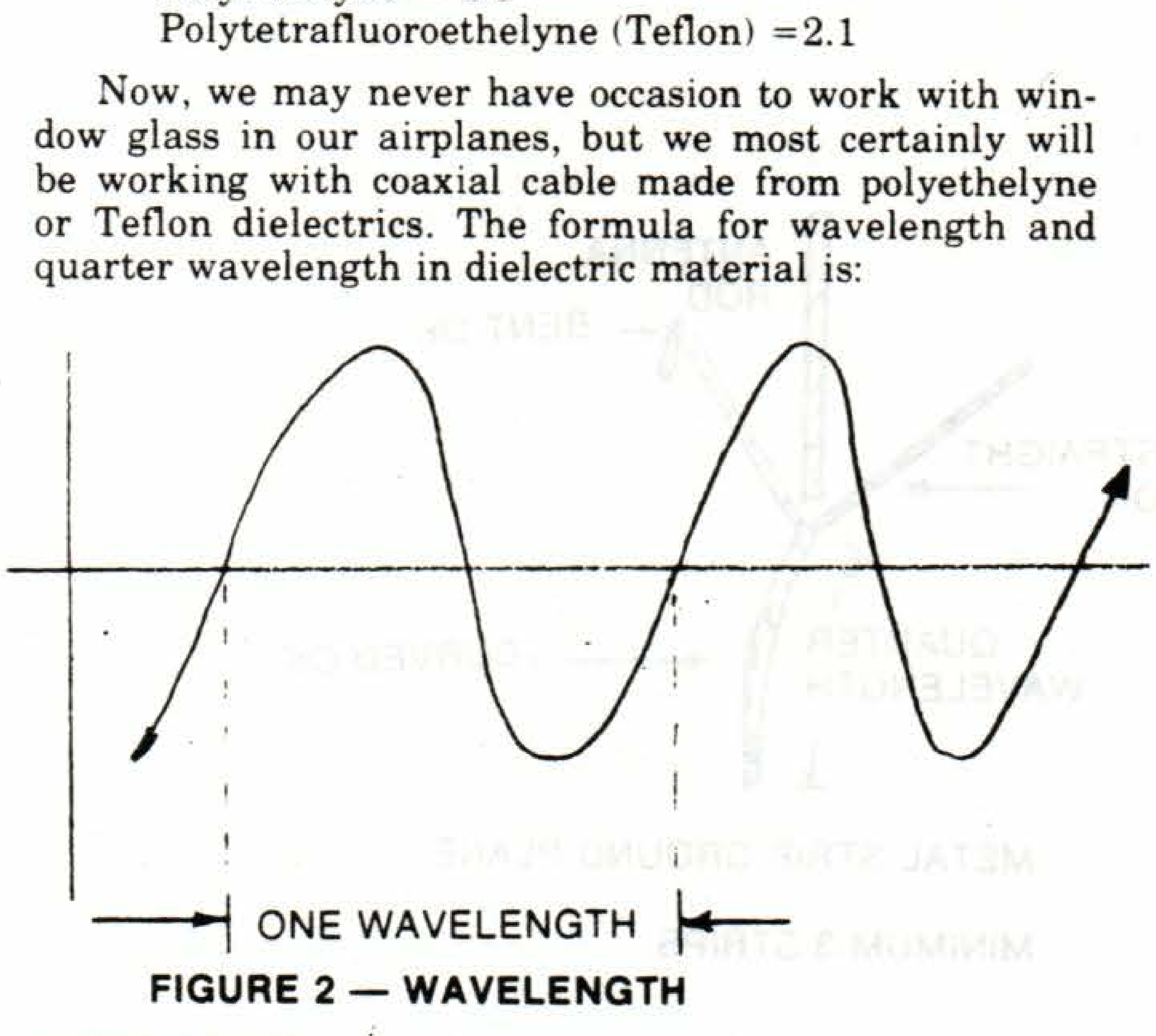



**FIGURE 2 — WAVELENGTH**

$$\text{wavelength} = \frac{300}{f(\text{MHz})\sqrt{\epsilon}} \text{ meters (in dielectric)}$$

$$(\text{wavelength} = \frac{11{,}800}{f(\text{MHz})\sqrt{\epsilon}} \text{ inches) (in dielectric)}$$

$$\tfrac{1}{4} \text{ wavelength} = \frac{75}{f(\text{MHz})\sqrt{\epsilon}} \text{ meters (in dielectric)}$$

$$(\tfrac{1}{4} \text{ wavelength} = \frac{2953}{f(\text{MHz})\sqrt{\epsilon}} \text{ inches) (in dielectric)}$$

For example, if we wish to know how long a ¼ wavelength at 122.8 MHz in Teflon cable is, we can calculate

$$\tfrac{1}{4} \text{ wavelength} = \frac{75}{122.8\sqrt{2.1}} = .42 \text{ meters}$$
(= 16.6 inches)

## COAXIAL CABLE
### How to Pipe Radio Wave Energy Between Antenna and Transceiver

Although we haven't begun to describe our antennas yet, somehow we've got to figure a way to transfer the radio signals between the antenna and the transceiver. The only real way to do this is by means of a special type of wire called "coaxial cable". As the figure shows, coaxial cable is comprised of a center wire conductor, a tube of dielectric insulator covering the center conductor and a braided wire sheath over the dielectric. (The outer plastic sheath is strictly for weather protection and has no electrical effect on the cable.) It is also true that the cable has a property called "RF Characteristic Impedance" which changes as a function of the center conductor outer diameter to the braided sheath inner diameter. (For the technical reader,

$$Z_0 = \frac{138}{\sqrt{\epsilon}} \log_{10} \frac{D}{d})$$

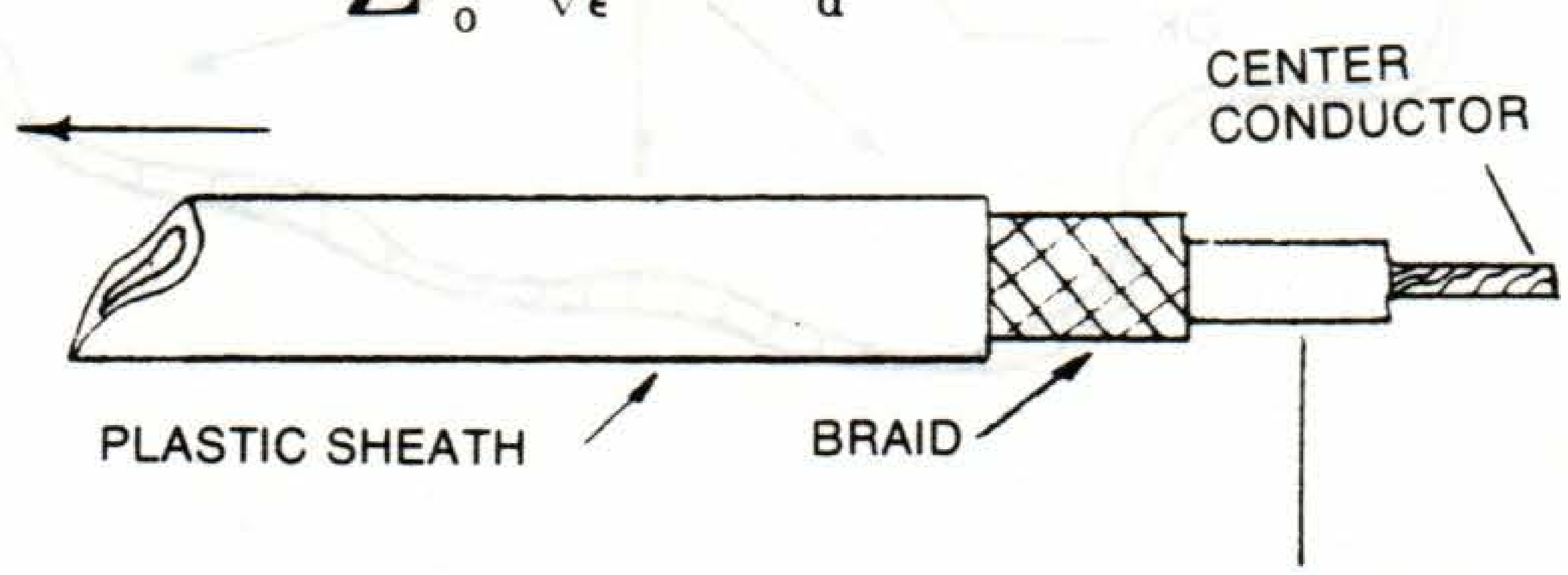



**FIGURE 3 — COAX CABLE CONSTRUCTION**

For aircraft use, all cabling is done with 50 ohm cable. (NOTE — This does **not** mean an ohmmeter will read 50 ohms when measuring the cable. Impedance (ohms) has a much different meaning than resistance (ohms).) The most common types of RF coaxial cable are listed

| Cable Number | o.d. | loss at 120 MHz for 3 meter (10') run | dielectric | weight for 3 meter (10') run |
|---|---|---|---|---|
| RG 8 | 1.0 cm (.4") | 5% | $\epsilon = 2.3$ | 450g (1.0 lb) |
| RG 58 | 0.5 cm (.2") | 11% | $\epsilon = 2.3$ | 125g ( .3 lb) |
| RG 174 | 0.25 cm (.1") | 18% | $\epsilon = 2.3$ | 45g ( .1 lb) |

One relatively important property of coaxial cable is that a piece of cable ¼ wavelength long has the property of **impedance inversion**. Briefly, this property allows a ¼ wavelength piece of cable **open circuited** at one end to appear as a **short circuit** at the other end. Similarly, a piece of coax ¼ wavelength long **short circuited** at one end will appear as an **open** circuit at the opposite end. This property will allow us to make a variety of devices, among them a **balun** to be used with dipole antennas.

## COMMUNICATIONS ANTENNAS

The function of the com antenna is twofold. First, it must transmit our aircraft transceiver signal to the ground station and second, it must receive the ground station signal and route it to the transceiver. Fortunately, the Reciprocity Theorem says that we can use the same antenna for receiving **and** transmitting. (Switching circuits inside the transceiver activated by the PTT button on the microphone switch the coax from the antenna to either transmitter or receiver within the transceiver.)

What we must do is decide how to mount the antenna onto the airframe. The primary consideration for the location is the **polarization** of the radio wave desired. Almost all ground communications is done with what is called **vertical polarization**, so the aircraft antenna should also have vertical polarization for best reception. What constitutes vertical polarization is simply that the antenna rod be mounted vertically with respect to the **earth's** surface. Now, we all know that the rod on the airplane will only be vertical **if** it is mounted on a top or bottom surface of the aircraft **and** if the airplane isn't performing a climb, turn or bank. (In a 45° bank, the polarization is neither vertical nor horizontal, but an unhappy cross between the two.) However, during aerobatic maneuvers, the last thing I want to do is talk to the ground, so a location on a top or bottom surface of the aircraft will be the best choice. However, mounting an antenna on the bottom (belly) presents a couple of problems. First is the fact that the landing gear will block (shadow effect) radiation for some angles of aircraft position. Second, in retractable gear aircraft, the antenna will land before the airplane in a wheels-up landing. If the antenna is bolted to frame as it should be, a great deal of destruction to the skin in the area of the attach points will be done. I've really never seen an acceptable belly-mount com antenna installation.

All things considered, the top of the fuselage as close to the c.g. will be the best compromise. In cabin aircraft, this will be very close to directly above the pilot's head. In canopy aircraft, just forward or aft of canopy travel will be best.

Another consideration for antenna location (except for totally fiber-glass aircraft) is the fact that a **ground plane** of metal must extend from the base of the antenna **horizontally** as far as possible. Now, the ground plane doesn't have to be solid (although solid is preferable), but steel tubes make a good ground plane, as do strips of metal (aluminum foil or copper tape) cut ¼ wave-

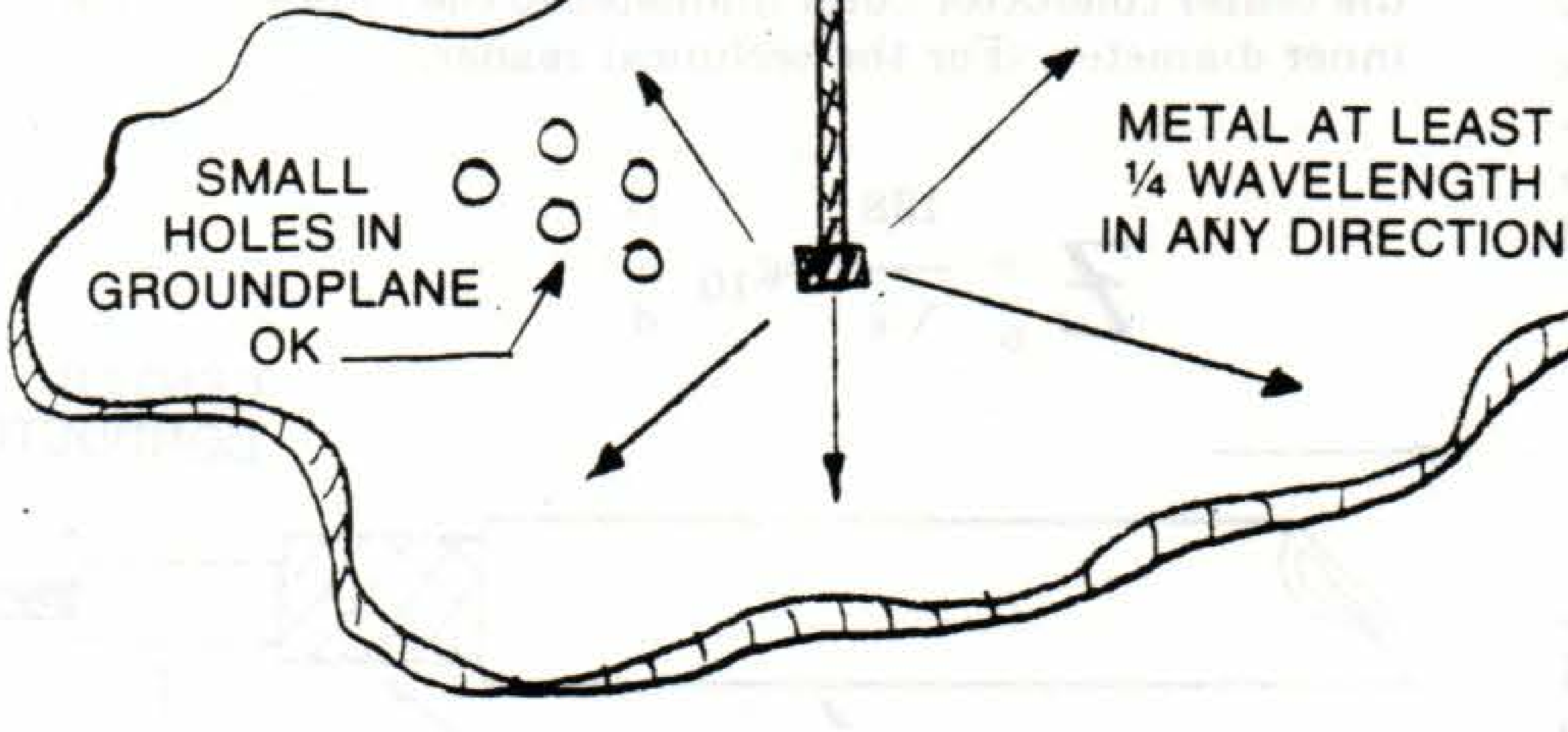
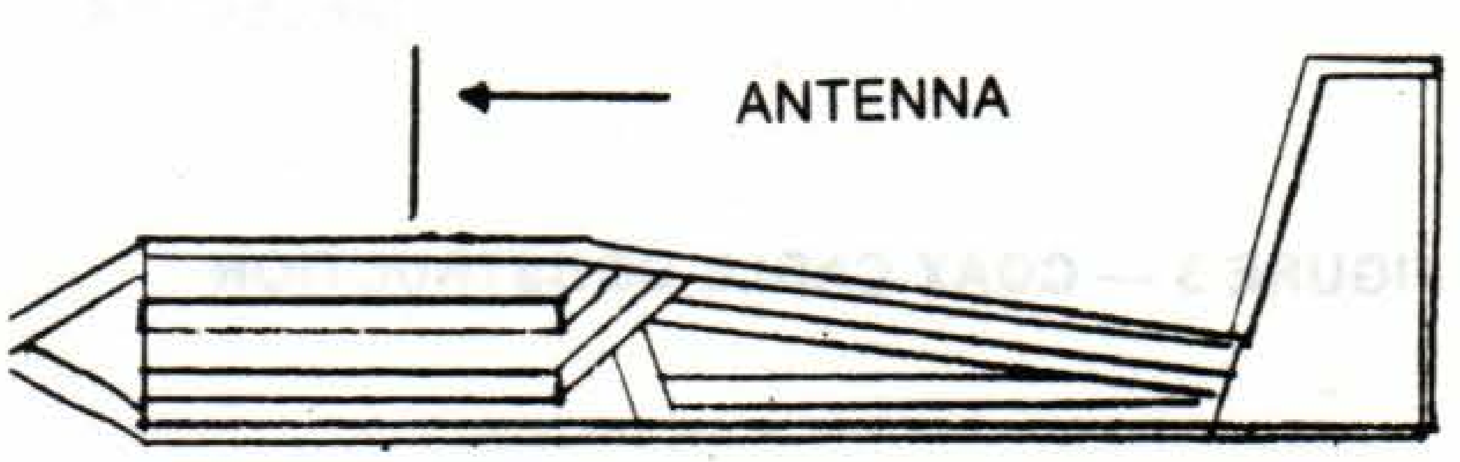
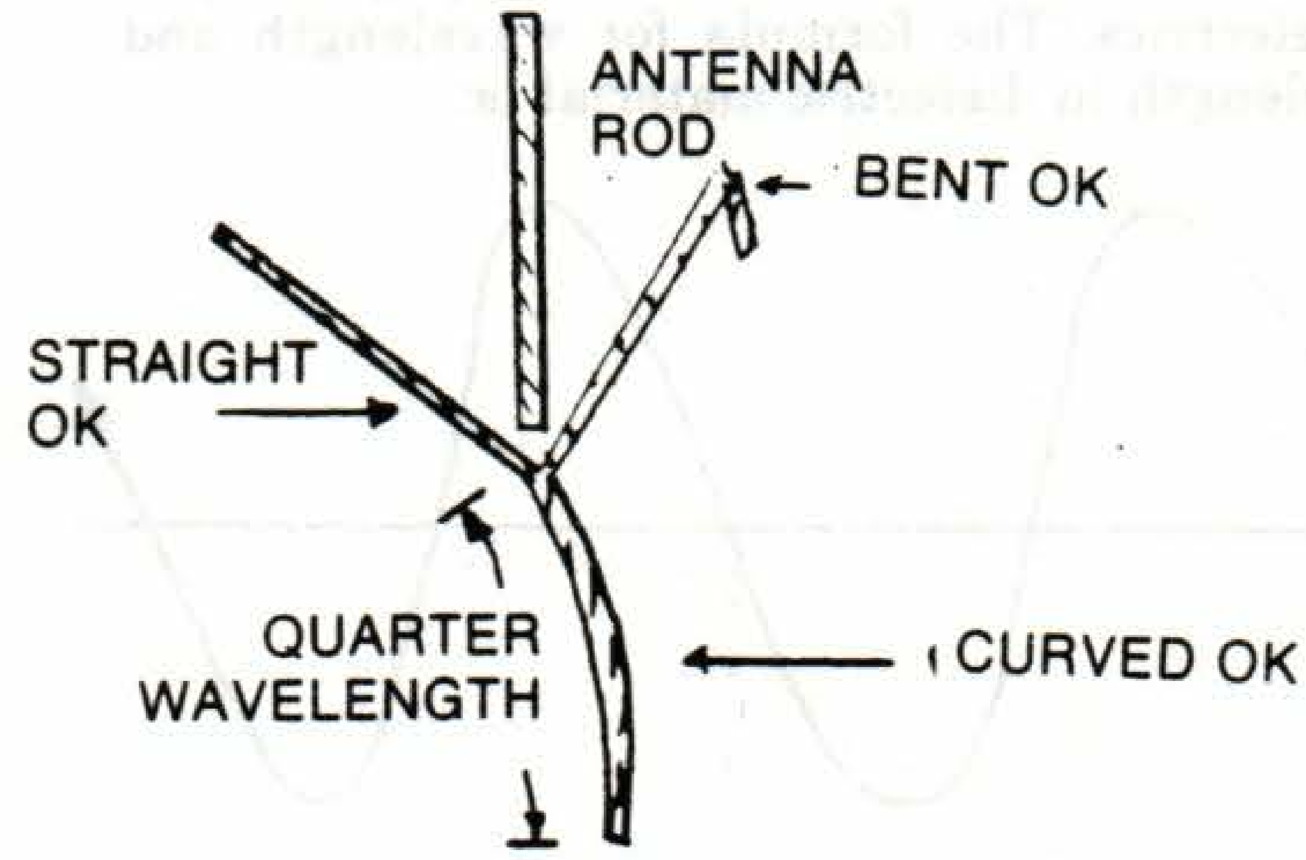



**FIGURE 4**
**(GROUND PLANES)**




ALUMINUM/STEEL TUBE STRUCTURE




METAL STRIP GROUND PLANE

MINIMUM 3 STRIPS

length long and attached to the antenna coax braid **immediately** at the base of the antenna. (Aluminum foil must be soldered or prevented from corrosion at the attach points.) Poor ground planes cause more antenna installation troubles than any other cause.

If the aircraft is being fitted with dual **com** transceivers, two antennas must be provided. It is sufficient isolation if these antennas are mounted at least ¼ wavelength apart.

The last consideration is antenna tip spacing. If your aircraft is of unusual design where there is a large amount of metal above the fuselage (say an aircraft with a superstructure mounted engine), the tip of the antenna **must** be kept at least ¼ wavelength away from the metal of the superstructure. The same restriction goes for antennas mounted forward of the cockpit on the cowling where there is a metal windshield brace. Keep the antenna tip away from any metal structure.

Now, at last we can start to talk about the antenna itself. Really, there are only three questions we need to ask about the antenna rod itself: How long do we make it, how fat do we make it and what do we make it out of.

The first question is relatively simple to answer — we make it 5% shorter than a ¼ wavelength in air. (The 5% foreshortening is what we highly sophisticated engineering types call a "fudge factor".) The ¼ wavelength should be calculated for the center of the band of frequencies you are interested in. For instance, if your transceiver covers 118 - 123 MHz, you would cut your antenna for a frequency of $\frac{118+123}{2}$ = 120.5 MHz.

Similarly, a "90 channel" covering 118 - 127 MHz would cut to a center frequency of 122.5 MHz. A "360 channel" radio would have an antenna cut for 127 MHz. Let's do the calculation for the "90 channel" (122.5 MHz) case:

$$\text{antenna rod length} = \tfrac{1}{4}\text{ wavelength } (.95)$$
$$= \left(\frac{75}{122.5}\right)(.95) = .58 \text{ meter}$$
$$= \left(\frac{2953}{122.5}\right)(.95) = (22.9 \text{ inch})$$

The second question — how fat do we make the antenna — is a compromise between aerodynamics and antenna bandwidth. The fatter the antenna, the broader a bandwidth will be covered, and also the greater the drag. However, if a given bandwidth **must** be covered, we make the antenna that fat and accept the drag penalty. (Yes, yes, the antenna **can** be streamlined by making the rod oval-up to about a 3:1 width ratio without affecting these equations.) To cover a given bandwidth, the rod **must** have the following thickness:

$$\text{rod diameter (mm)} = \frac{\text{Bandwidth (MHz)}}{2} \text{ mm}$$

$$\text{(rod diameter (inches)} = \frac{\text{Bandwidth (MHz)}}{50} \text{ inches)}$$

(These values for aircraft band COM service only.)

For example, if we wish to cover the 90 channel COM band (as above), the antenna must be at least

$$\text{rod diameter (mm)} = \frac{127\text{-}118}{2} = 4.5 \text{ mm}$$

$$\text{(rod diameter (inches)} = \frac{127\text{-}118}{50} = .18\text{")}$$

On the other hand, to cover the full 360 channel com band, the diameters are:

$$\text{rod diameter (mm)} = \frac{136\text{-}118}{2} = 9.0 \text{ mm}$$

$$\text{(rod diameter (inches)} = \frac{136\text{-}118}{50} = .35 \text{ inch)}$$

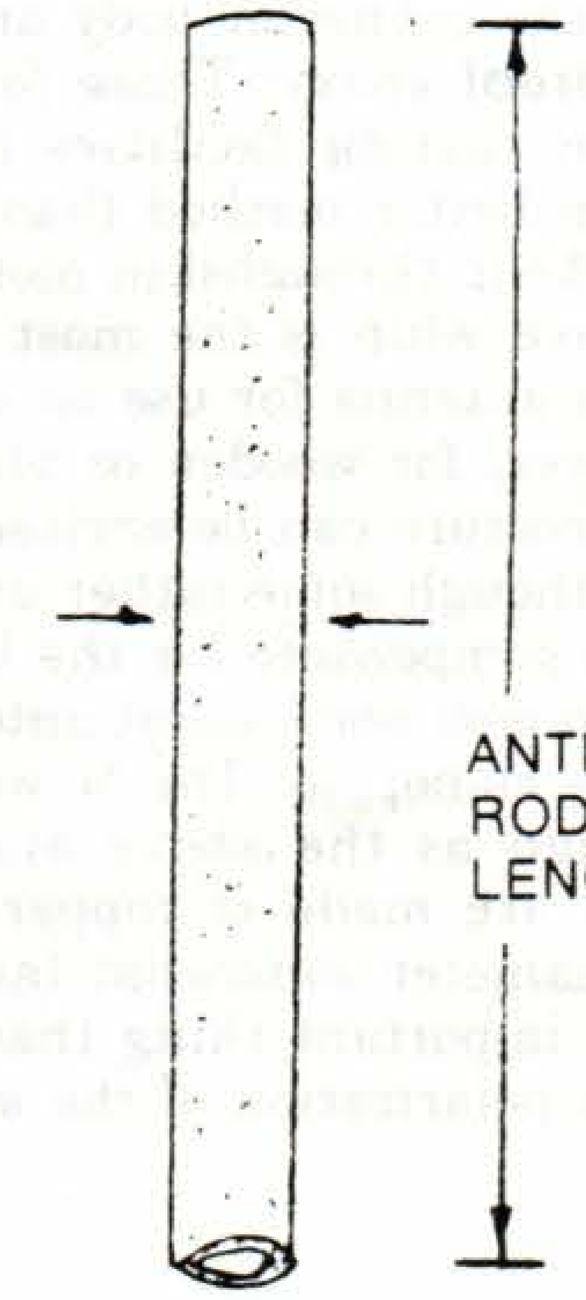



FIGURE 5

Now, these values are quite conservative, so that if only 4 mm (or 5/32") rod were available for the 90 channel rod, it would still provide acceptable performance. However, 3 mm (⅛") rod would probably suffer noticeable degredation at the band edges.

Also, the rod may be tapered approximately 20% for aerodynamics and looks without serious problems.

Now for the question of the day — what do you make the antenna rod out of? The antenna engineer has a stock answer to that question — solid silver rod works best. Sure it does, if you're working on a government contract. For those of us working out of our own pockets, we'll compromise the ideal situation a bit.

Agreed, silver is best. However, copper runs a very close second, and is quite readily available. Next comes aluminum, which is hard to solder, but very cheap and plentiful. Then gold (and if you can afford gold antenna rods, why are you reading this article?). At the bottom of our acceptable list comes brass, which is solderable and cheap, cheap, cheap in the form of brazing rods.

Also, a little known fact is that the antenna signal is all contained within .005 mm (2/10000") of the surface of the antenna rod. Thin tubing works just as well as solid rod for antennas. In particular, fiber-glass rods with copper plating or copper braid on the outside work well and are strong and light. Aluminum tubing also works well. However, **any** corrosion on the surface of the antenna will **drastically** affect operation (i.e. then the top .005 mm of the rod is crud and crud makes a lousy antenna) so that a coat of **non-lead-based** paint or epoxy dip of your bright, shiny antenna rod should keep it operating well for many years. Silver-plating aluminum or brass tubing, then epoxy dipping the tube makes one of the finest antenna rods available.

The main mechanical problem with aircraft antennas is how to keep the fool things from blowing off in the wind. To be more specific, how do you keep the antenna rod secure against windblast, insulated from the metal skin of the aircraft, yet provide a point to attach the center conductor of the coax to the base of the antenna. The simple solution to the problem is to mount the antenna rod into a male coaxial connector, then mount the female connector onto the chassis skin. Presto, a watertight, vibration-proof, insulated feedthrough! Point of information: don't use the "CB" style PL259/SO239 series connector as they are not waterproof. The "BNC" series is good for rod diameters up to 5 mm (3/16"). Above this diameter, series "N" connectors will do up to 12 mm (0.5") rod diameters. Both can be had with waterproof gasketing. Fill the connector body around the rod with a dense, **waterproof** epoxy. Those fortunate souls among us with resin casting facilities can probably come up with an even better method than this for providing a waterproof, cheap throughskin mount.

The vertical ¼ wave whip is the most common and best drag/performance antenna for use on metal or tube & fabric ships. However, for wooden or plastic aircraft, the entire antenna structure can be enclosed within the airframe structure, although some rather unique "tricks" must be performed to compensate for the loss of a good ground plane. The cheapest and easiest antenna to make is the so-called sleeve monopole. The ¼ wave radiation rod is the same design as the above discussion. The quarter-wave sleeves are made of copper gasline tubing with an inside diameter somewhat larger than the o.d. of the coax. One important thing that must be remembered is that the polarization of the antenna is de-

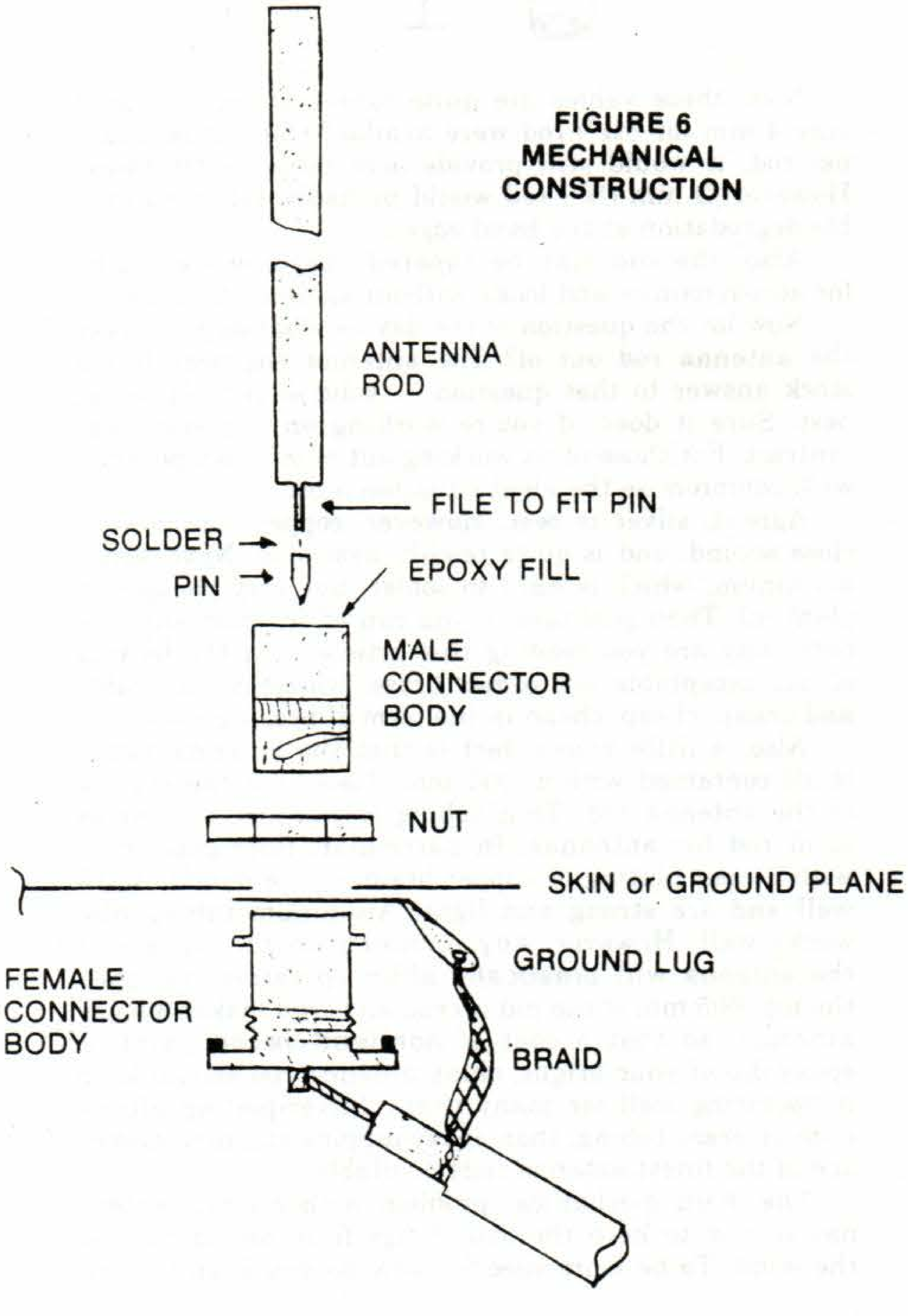



**FIGURE 6**
**MECHANICAL CONSTRUCTION**

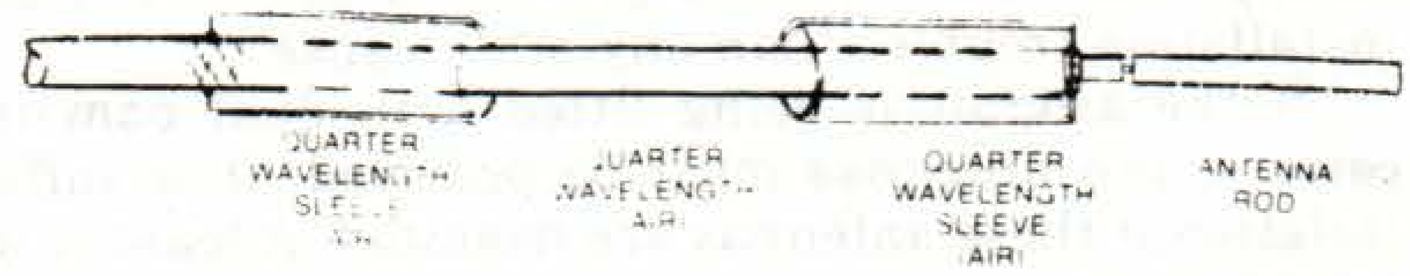



**FIGURE 7 — SLEEVE MONOPOLE**

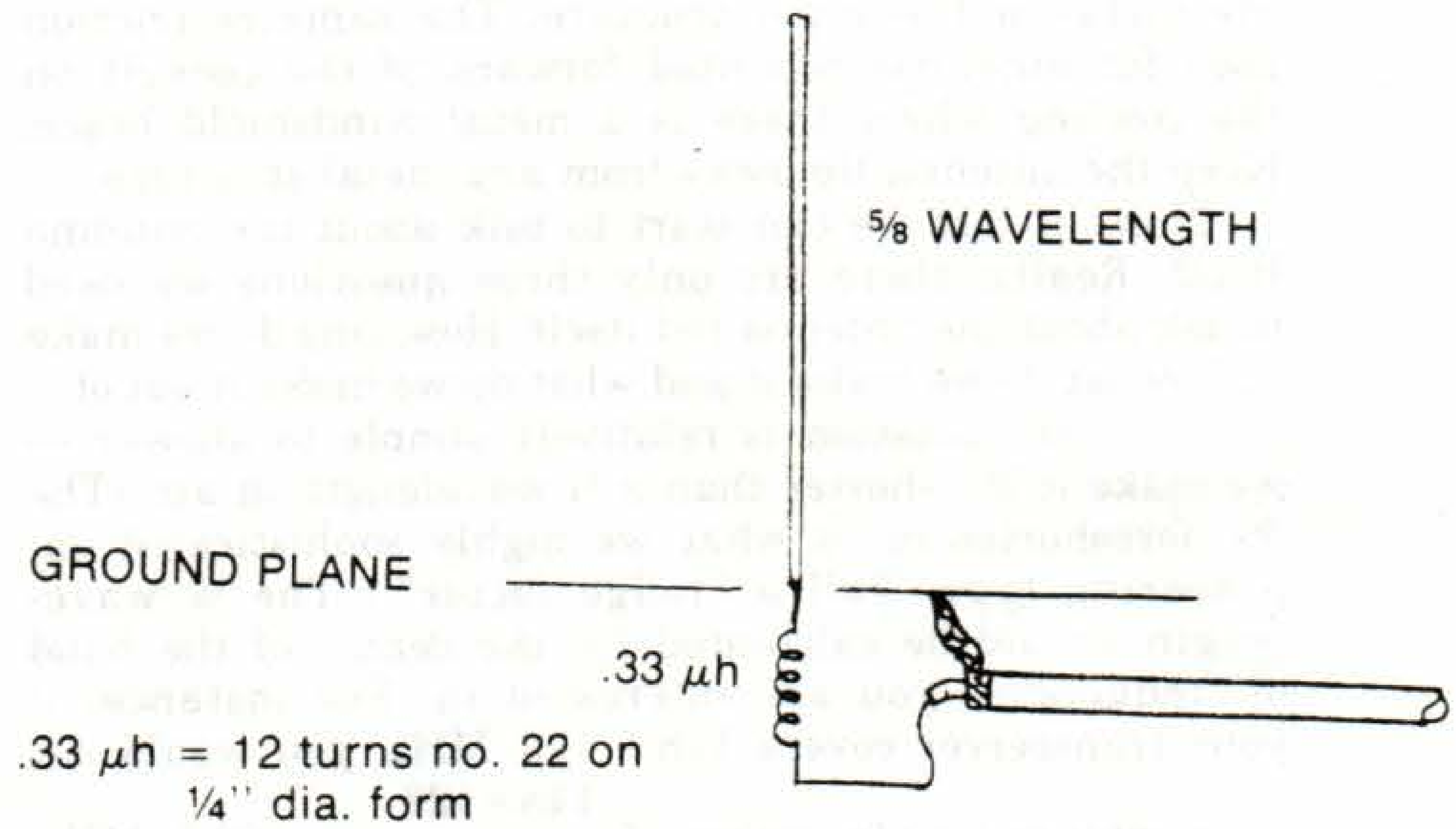



**FIGURE 8 — ⅝ WAVELENGTH**

termined by the positioning of the radiation rod **and** the ¼ wave sleeves (especially the sleeve closest to the rod). Don't lay the rod horizontal in the wing and expect vertical polarization.

For base-station use, drag and mechanical size are not as important as they are in aircraft design. Now, the ¼ wavelength rod has a "radiation pattern" that strongly resembles a doughnut slipped over the rod. A great deal of power is wasted radiating straight down and straight up. What we would like to do is squeeze the doughnut to resemble a pancake and achieve more range due to the modified antenna pattern. (IMPORTANT: Antenna "gain" is only achieved by reducing the radiation to some locations and increasing the radiation in that exact amount in the desired location.) At any rate, the pattern of a ⅝ wavelength antenna strongly resembles a "squashed doughnut" with maximum radiation aimed at the horizon. Unfortunately, the ⅝ wave antenna does not look like our desired 50 ohm impedance, so the antenna needs some tuning at the base. The figure shows a .33uh loading coil at the base of the antenna. This load tuning of the antenna further restricts the bandwidth of the antenna to approximately ½ the value obtained in the ¼ wave case. Another way of saying this is that the ⅝ wave antenna needs to be twice as fat as the ¼ wave antenna for a given bandwidth. The ground-plane radials may be a solid sheet (as a quonset hangar roof) or the above-mentioned ¼ wave rods, strips or aluminum foil.

**NAVIGATION ANTENNAS**

There are two differences between COM and NAV antennas. First, they are cut to a center frequency of 113 MHz, and second, they are **horizontally** polarized. Any of the antennas mentioned above, lengthened and laid horizontally, will make a serviceable NAV antenna. There are certain problems however, in using a ground-plane antenna in the NAV configuration. If the antenna is mounted on the **left** side of the fuselage, reception to the **right** will be almost nil and vice versa. In metal and tube and fabric aircraft, balancing the antenna to receive horizontal waves equally from all directions is most often done by means of a set of "rabbit ears" mounted in a horizontal plane. Once again, the "ears" are made ¼ wavelength long (each). (Don't forget the 5% fudge factor.) The rod length for 113 MHz is:

antenna is the tip of the vertical fin, although plastic and wood aircraft have used copper tape and/or buried rods in the wing. The important thing is to keep the rods within 1 cm (½") or so at the center. The bend, or "sweep" should aim FORWARD for best reception and REARWARD for best streamlining on fin-mounted antennas. Do whichever is more important to you. Mechanically, the rods can be clamped to a piece of bakelite, formica, fiber-glass or what-have-you. At this laboratory, we use cutoff scraps of p.c. board to good advantage.

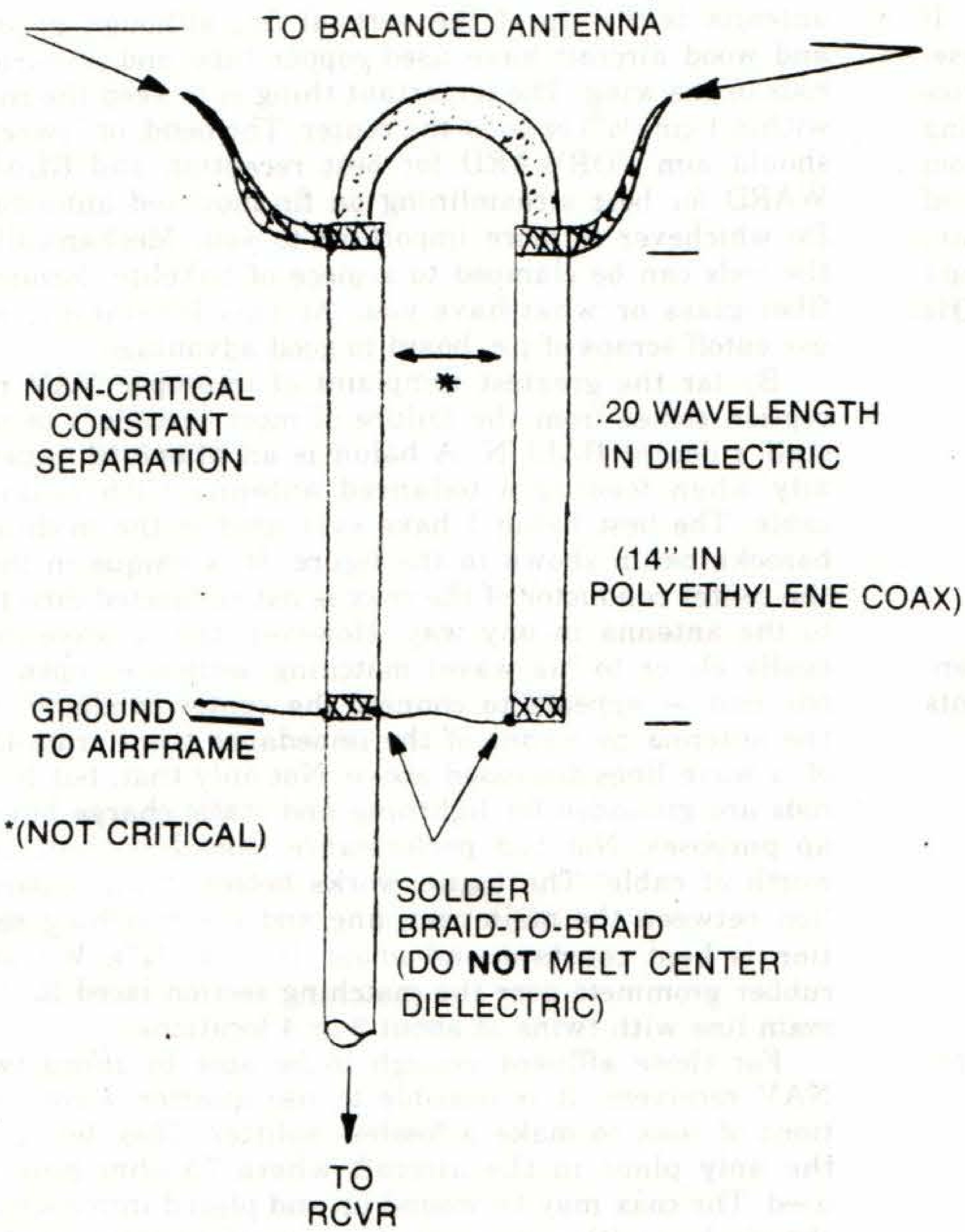



**FIGURE 10**
**BALUN**

ber greater than 1. Thus, if the antenna has an input impedance of 100 ohms, the VSWR is 100/50 = 2:1. If the antenna impedance were 33 ohms, the VSWR would be 50/33 = 1.5:1.

The question then becomes — how good of an antenna do we need? Good engineering practice allows the VSWR to be 1.5 - 1.8 to 1 for transmit (COM) and 3 - 4 to 1 for receive (NAV) functions. This allows (1.8:1) the input impedance to vary from 28 ohms to 90 ohms for transmit antennas and from 12 ohms to 200 ohms for 4:1 NAV antennas.

The simplest way to measure VSWR is with a VSWR bridge, RF signal generator, and sensitive DC voltmeter. Of course a swept band RF generator, oscilloscope and logarithmic detector and amplifier make the job a lot easier if a great deal of antenna work is to be done. (Some chapters buy a couple of hundred dollars worth of gear and rent them out for a couple of bucks a day to the membership.) The VSWR bridge has got to be homemade, as the least expensive commercial unit is over a hundred dollars. The cost to home-brew the bridge is less than $5. Calibrate the bridge with short lead carbon resistors (i.e. 100 ohms = 2:1, 150 ohms = 3:1, etc.).

When you measure the antenna, the bridge should be as close as possible to the antenna. Long coax runs between bridge and antenna will produce erroneous results. Try to get the bridge within 15 cm. (6") of the antenna. If necessary, make the coax run long between oscillator and bridge rather than bridge and antenna.

The antenna itself should be clear of all metal objects (fences, buildings, etc.) by at least 20 meters (50 feet) and should be mounted in position on the aircraft. Before attaching the oscillator to the antenna or bridge, pick a frequency where no interference will occur.

## CONCLUSION

In conclusion, let's review briefly the important items in this article. Com antennas should be vertical, fat and hollow. Keep the top of the antenna away from metal. Nav antennas should be horizontal, medium slender and swept. Keep the ends of the antenna away from metal and use a balun. Measurements can be made as cheaply or as expensively as you wish. The accuracy of the measurements is not that much better with expensive test equipment.

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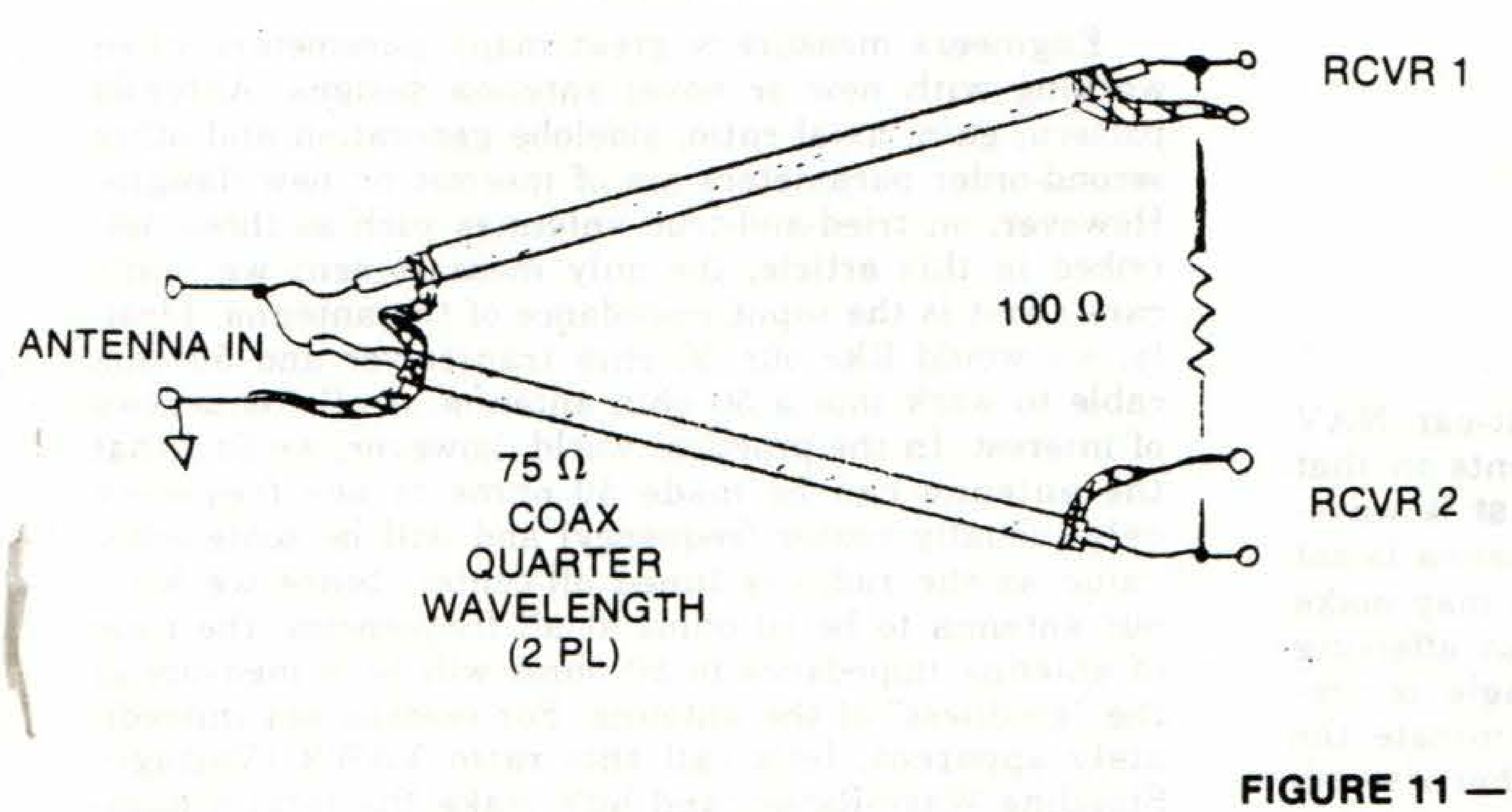



**FIGURE 11 — SPLITTER**

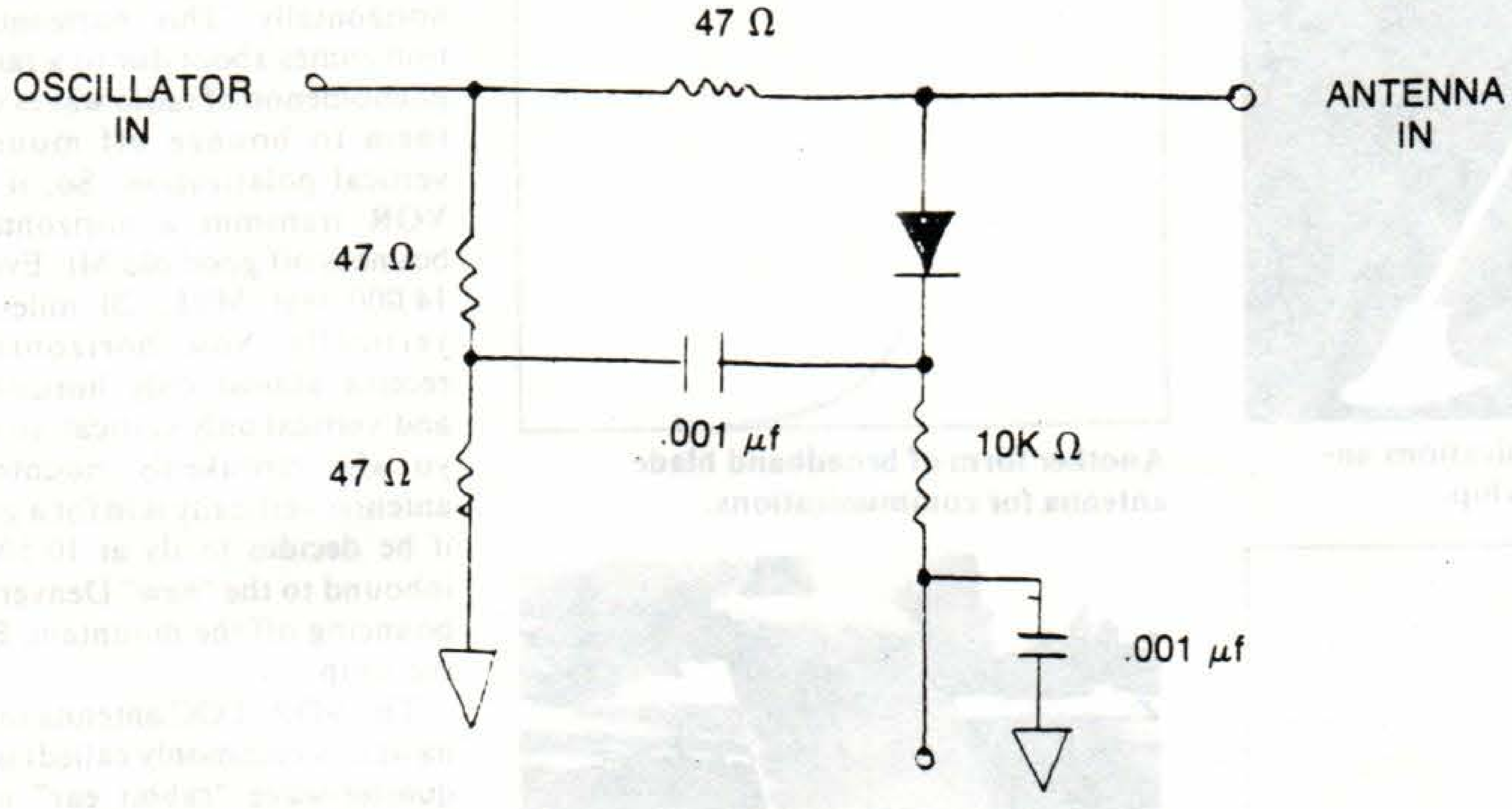



**FIGURE 12 — VSWR BRIDGE**

# LORAN ANTENNAS FOR PLASTIC AIRPLANES

*By Jim Weir (EAA 86698)*

LOng RAnge Navigation. LORAN. As one of the speakers at the Oshkosh '83 forums said, "LORAN is the hottest thing since new love". I can't debate it; I agree, LORAN (specifically, LORAN-C) has VOR and DME navigation beat by a country mile. Now, that's a country NAUTICAL mile, mind you, since LORAN is primarily a boater's system, but we airplane folks have found a way to latch on to this system and make it work for us. Indeed, some manufacturers are actually producing LORAN units intended for use only in aircraft (see Fig. 1).

Since LORAN started out life as a marine navaid, there are certain terms that the handbooks (Ref. 1, Ref. 2) use that are quite foreign to our vocabulary. LOP's, hyperbolic positions, cycle slippage, and master-slave chain selection are as confusing to the new user as VOR, marker beacon, reciprocal bearings, and TO-FROM ambiguity are to the new pilot. This article, though, will not attempt to make you an "instant expert" on using LORAN. That will come in an article to be published next spring. Instead, this article will provide guidance to those of you attempting to use LORAN in your plastic airplanes like the E-Z, CO-Z, Quickie, Dragonfly, and all the other "composite" aircraft.

First, let's examine why LORAN on boats works so well. For one thing, boats can have a vertical whip antenna 5 or 10 feet high, and the more VERTICAL extent to the antenna, the more range you will get from your LORAN. For another thing (and every bit as important as a long vertical antenna), boats have underneath them a horizontal ground plane some 8000 miles in radius (shaped like a ball, spins on its axis every 24 hours, get the idea?). Yep, boats are a near perfect platform for a LORAN antenna because of their long vertical antennas and near-perfect literal ground plane.

Now we come to airplanes. But, heck, even a metal airplane isn't too bad. A short (24") vertical antenna above a metal ship that extends 5 or 10 times that length in most directions will perform very well, if not perfectly, on LORAN. In metal ships, too, virtually all cables, engine grounds, shield wires, and ignition grounds are bonded to the conductive airframe.


Fig. 1

As opposed to plastic airplanes, there is no ground plane to speak of. Cables may or may not be common to the ground of the electrical system, which may or may not be bonded to the engine, which may or may not . . . What we find is that our good old VHF antenna (Ref. 3), which couldn't have cared less about large ground planes and bonding, but was very critical in length, is being replaced by an antenna that is very demanding of a large ground plane and a long antenna, but doesn't care the length of antenna or ground plane — the bigger the better.

The only problem is that the antenna element must be VERTICAL. Those of you following this series of articles must be aware by now that vertical space for antennas is at a premium. (It is NOT true that Rutan designed the Long-EZ so I could get a COM antenna in each winglet, but I DO wish the Delta Dyke people would have talked to me for a while . . .) At any rate, you all know that a COM antenna needs to be vertical and about 42" long. In the EZ, that takes up a winglet; in the Quickie series, that pretty well fills the vertical fin. Falco and Barracuda drivers have filled the vertical fin, also. The bottom line is this: decide BEFORE you build the plane what is most important to you. I've said it time and time again: An airplane is an inherently lousy antenna platform. An Atlas missile — a hot air balloon — THOSE are good antenna platforms. An airplane is a series of compromises. You want maximum COM range? Put the COM antenna in the best vertical spot on the airframe. You want maximum LORAN range? Then to heck with COM, put the LORAN antenna in the best vertical spot. You want both? Go buy a sailboat.

What doesn't work? Loops. Together with the fine folks at II-Morrow (Ref. 4) who kindly whispered into my ears the secrets of LORAN, and who then loaned me the unit shown in Figure 1, I investigated LORAN antennas for a solid month. Loop antennas, which I originally thought would be the answer to the aviation LORAN antenna problem, came out a big zero. I tried linear wound, pi-wound, scramble wound, and bifilar wound; single, double parallel, cross, T, and X; unamplified, amplified, sigma, delta, and switched modes; ferrite, air, and iron core, and most combinations of the above. The results were strikingly similar, and not at all unexpected once I became privy to a LORAN secret: phase means a lot. Thus a vertical wire antenna, which is phase insensitive, will perform well for any direction of flight, while a loop antenna will give superb results in some directions and absolute garbage in others. This was not unexpected; others have noted similar results (Ref. 5).

What that leaves us, then, is a vertical wire antenna, which is coupled to the coax and coupled to the ground plane DIRECTLY at the base of the antenna by an "antenna matching coupler" sold WITH the LORAN by the manufacturer. Do NOT try to use an ADF coupler or "brand-new-surplus" coupler — the manufacturer has optimized this coupler for his particular radio. The problem is that the coupler is a metal box about the size of two cigarette packages stacked end-to-end. If you put the wire antenna in, say, the winglet of an EZ, where do you mount the coupler within about

6" of the antenna while still providing access to the coupler for service? Fortunately, that's not my problem. Their answers are given in an appendix to this article.

My problem is this: How do I give you an internal LORAN antenna design for your plastic airplane that will perform fairly well, be easy to install, and cost next to nothing? (Shortly after that, I will invent the 150 hp $200 engine and get Jim Bede to give an Oshkosh forum.) In all sincerity, though, here is how I might proceed with two aircraft antenna designs: the Long-EZ and the Quickie. Please note that individual designs for your airframe are much better handled by your designer using the principles outlined in this article than by calling us; your designer has much more detailed information than we could ever hope to collect.

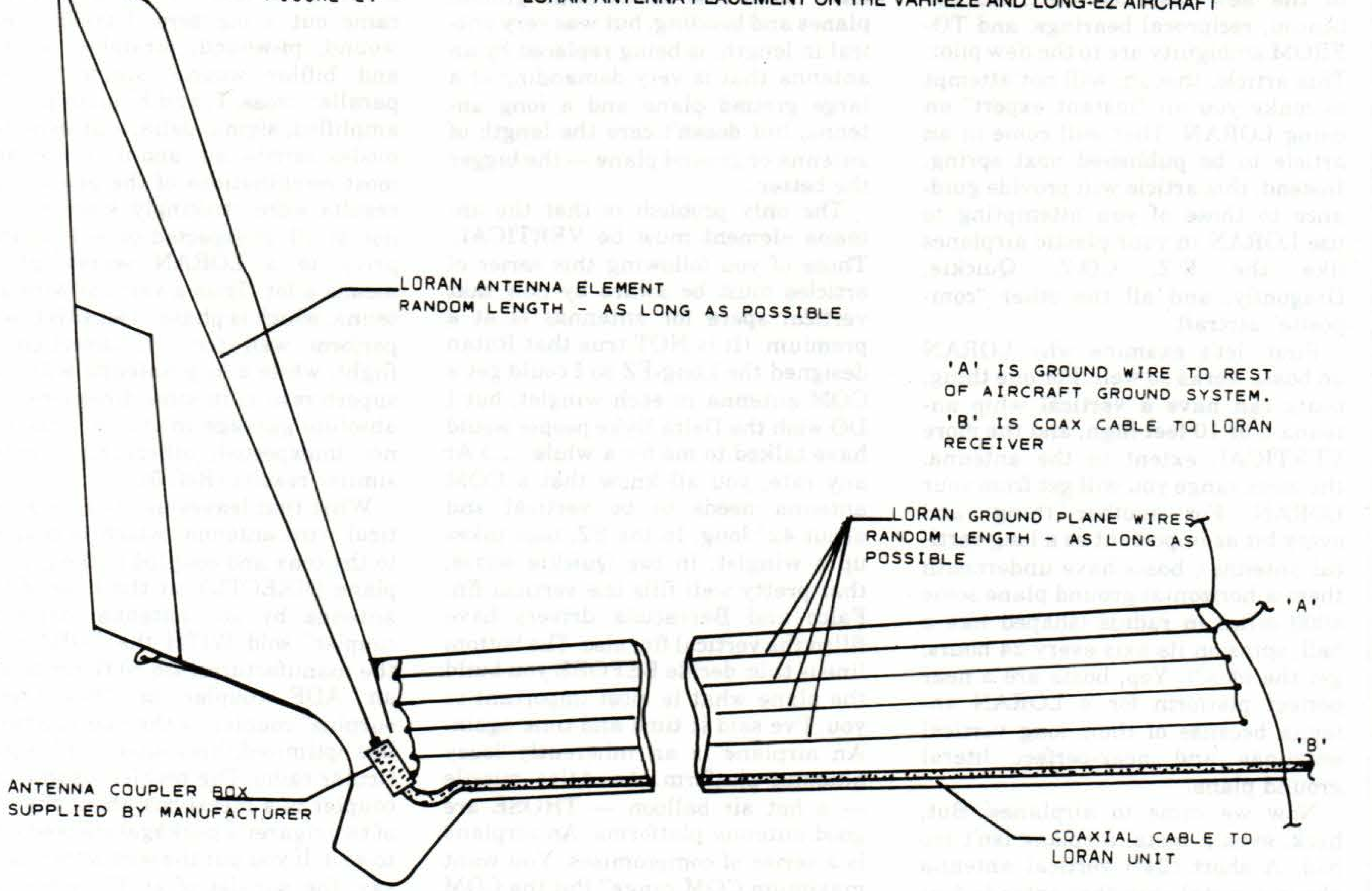
The VariEze (or Long-EZ) design: This design is rather easy, made so by the fact that Burt and Mike have left us TWO fairly long vertical surfaces called winglets. One of these winglets (say, for argument, the left winglet) will contain the COM antenna as designed years ago (Ref. 3) with no changes. The right wing and winglet will undergo significant electrical modification. First, the antenna element itself is a very ordinary unsophisticated length of wire. Wire. Copper, steel, brass, or silver; skinny, fat, wide, or narrow; mil-spec triple plated multiple stranded or a bent coat hanger. Wire. Of any size, shape, material, or origin. Wire. The only critical thing is to put the wire as long vertically as possible. In the EZ, this means wire strung from the bottom of the winglet to the top.

At the bottom of the winglet goes the antenna coupler, as close to the base of the antenna as possible, in accordance with the LORAN manufacturer's instructions and Mike's comments in the appendix.

Now comes the magic. Watch closely now. On the right wing foam, prior to glassing, lay lengths of wire from winglet to wing root, the full span of the wing, 4 on top of the wing, and 4 on the bottom of the wing, equally spaced around the wing. Wire size is not important, nor is wire material; the important thing is that all 8 wires run full-span from winglet to wing root. Dip the wire in epoxy and lay it on the foam (straightness is not necessarily an asset). Allow the first wire to dry, then dip the second wire in epoxy and lay it on the foam to dry. Keep this up until all 8 wires are epoxied onto the foam. The purist, of course, will take an X-Acto knife and open up a micro-thin trench in the foam, lay the wire in the trench, and flox over. This class of person, though, will also gold-plate his rocker box covers, and usually wins the "best workmanship" award at fly-ins. My kind of builder.

I'll bet you thought you were through. Hah. Now the real work starts. First, solder or wire from the winglet end of wire #1 to wire #2, from wire #2 to wire #3, and so on until all 8 wires are bonded together. Then run a SHORT common wire from this junction to the antenna coupler. Then, at the wing root end, solder a wire similarly from wire 1 . . . to wire 8, and then a wire from this junction to the LORAN chassis. Listen up, now, because this is the important part: make sure EVERY control cable, EVERY metal mass, EVERY coax shield, in short EVERY piece of metal over 1" square on the ship is bonded to electrical neutral (or airframe ground, or chassis common, or whatever term you choose), and then to the LORAN chassis. Make an ohmmeter check. Surprise yourself. Find that your aileron

FIGURE 2. LORAN ANTENNA PLACEMENT ON THE VARI-EZE AND LONG-EZ AIRCRAFT



cables lose their conductivity in a hard right bank. Find that your engine is common to absolutely nothing. AND THEN DO SOMETHING ABOUT IT! See Figure 2.

It is necessary, it is ABSOLUTELY necessary, that all major metal structures are common to each other. Not only does it prevent noise, it extends the ground plane, and thus the range.

Speaking of noise, any spark-type noise from the voltage regulator, strobes, or other arc souce will drive your LORAN up the wall. As you will come to see in my spring article, LORAN depends upon decoding a low-frequency noise-sensitive pulse in the midst of a bunch of crackles and pops (lightning, man-made arcs and sparks, and airframe noises) and other LORAN pulses. In particular, newfangled digital gadgets like clocks, fuel flow analyzers, digital OMNI heads, digital tachometers, thermometers, and the like, may cause your LORAN to come down with a case of the shivering fits. I recommend: A. A sparkless voltage regulator (see these pages for a home-built design, coming shortly); B. A shielded ignition system, including magneto filters; C. Bonding EVERYTHING (and I really can't emphasize this enough) together with triple-ought (000) size wire if necessary; D. A frank discussion with your digital gadget people as to how to keep his digital trash out of your LORAN.

Quickie folks, you don't have it quite so easy. The COM antenna in your airplane is in the vertical fin, and there just isn't anywhere else to put the LORAN antenna. This is going to necessitate what is called in my field an "engineering compromise" (in other circles called "hammer, weld, file, and paint to match"). The gist of the compromise is this: leave the VHF COM antenna on the leading edge of the vertical fin as designed (Ref. 6). Then run a hair-fine LORAN wire antenna (say, #22-26 or so) along the AFT edge of the vertical fin, terminating at the matching box in the fuselage aft section. Run ground plane wires along the fuselage as shown in Figure 3, and reread the admonitions above on grounding everything in the airplane to a common point. Everything.

What have we done here? First of all, we have violated the sanctity of "24 inches from the COM metal to any metal" rule. Yep, we've put that little LORAN rascal right in the field of the COM antenna. The net effect of putting this LORAN antenna in the field of the COM antenna will cause an aft null in the COM antenna's pattern, but the null will be so narrow (5 degrees or so) and so shallow (say, 15 dB) that it will not materially affect the COM transceiver's performance. The further away you keep the LORAN wire from the com antenna, the narrower and shallower the null will be.

Second, we have sniggled both antennas which need verticality into one surface, with one antenna having minimal interference and the other antenna with no measurable effects at all.

Here, then, is a nutshell version of my recommendations for LORAN antennas in plastic airplanes:

1. Keep them vertical and as tall as possible.
2. Keep them close — within an inch or two — to the antenna coupler.
3. Provide a ground plane (or long strips of wire approximating a ground plane) as large as possible.
4. Bond all metal pieces of the airplane together.
5. Take extraordinary measures to prevent spark-type interference from reaching the LORAN antenna.

[redacted]

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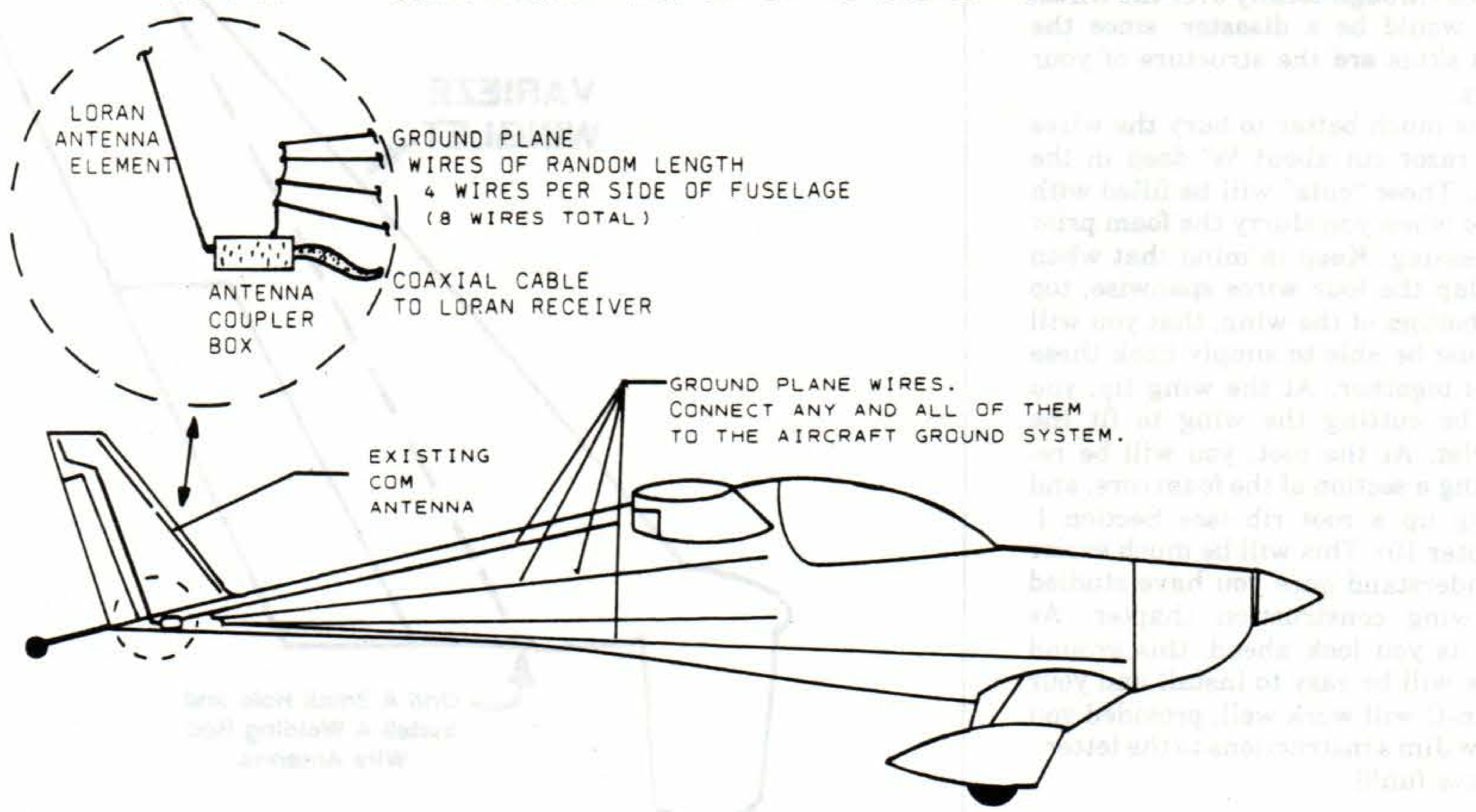
FIGURE 3. LORAN ANTENNA PLACEMENT ON THE QUICKIE AND QII SERIES OF AIRCRAFT



**Appendix**
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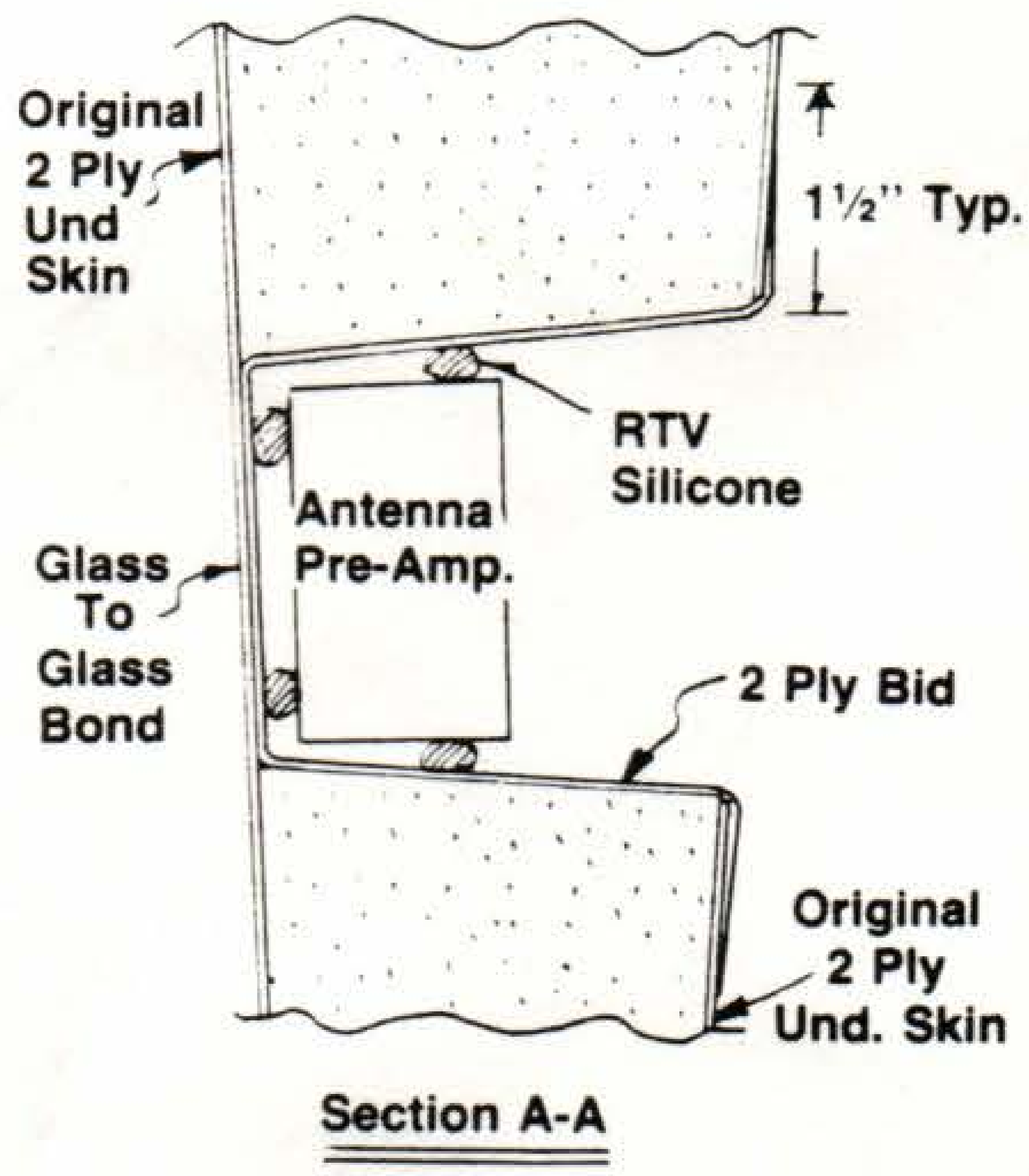
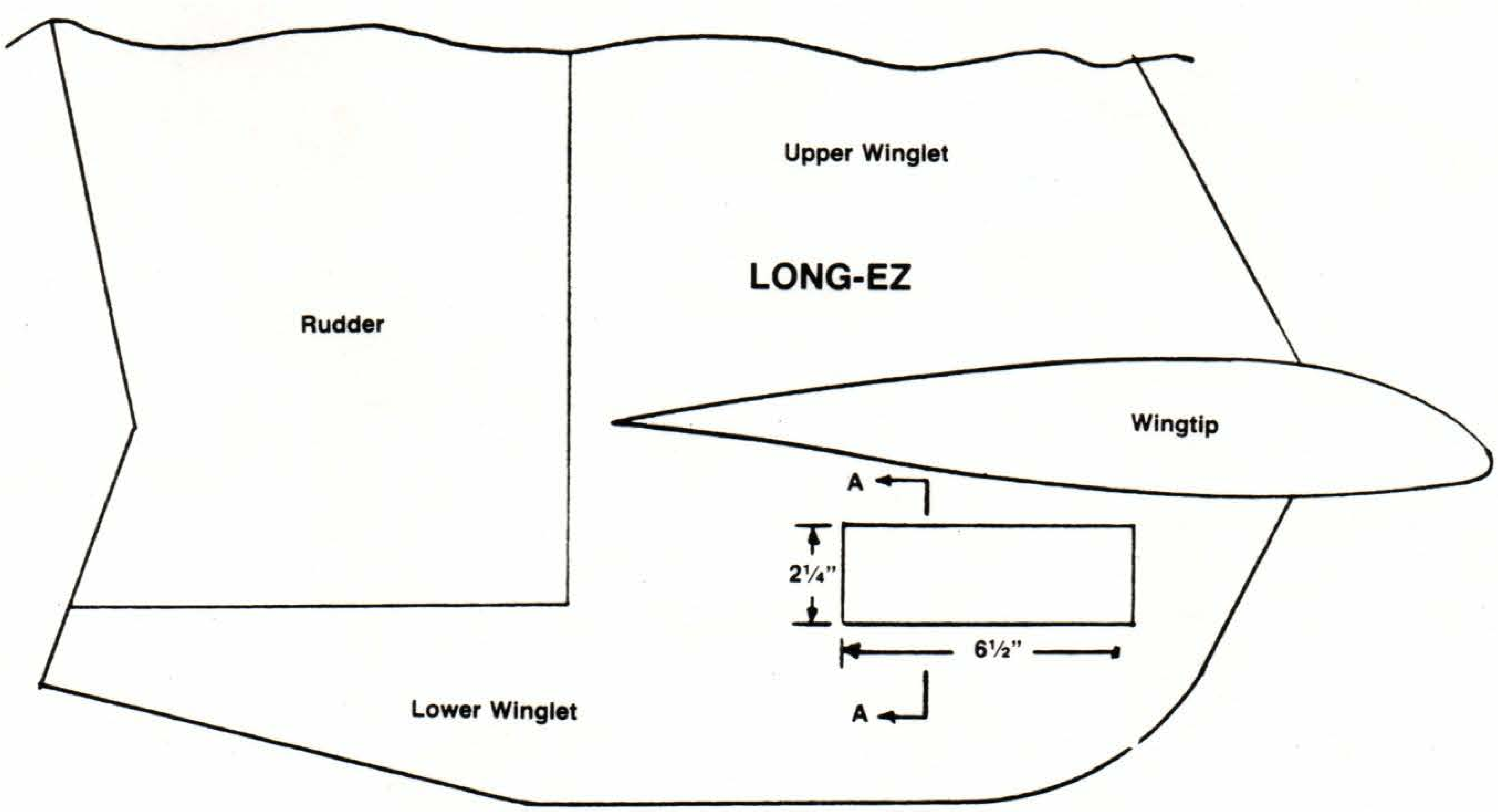



Mounting the antenna preamp in the lower winglet in a Long-EZ.

Layout the proposed receptacle on the inboard surface of the **lower** winglet under the wing. This receptacle will need to be at least 2¼" x 6½" and should be oriented horizontally. Mark the dimensions of the receptacle with a felt tip pen. Cut through the inboard skin, using a hacksaw blade or modeller's Zona saw. Use a screw driver blade or wood chisel to pry the rectangular piece of skin off the foam. Now carefully dig out all of the foam until you are through to the outboard skin. Use a sharp knife and a Dremel. Sand the sides of the rectangular receptacle smooth, and sand the inside of the outboard skin (bottom of the receptacle). Round the edges of the receptacle to about a ¼" radius, and thoroughly sand the skin for 1½" all around. Slurry the foam sides of the receptacle and layup 2 plies of BID @ 45° into the receptacle such that you get a good glass layup that ties the inboard skin to the outboard skin of the lower winglet. The first ply should lap onto the inboard skin about 1½" all around. The second ply should lap about 1". Peel ply the edges of the glass to get a smooth transition.

The pre-amp can be mounted inside the receptacle, the simplest method, and a very adequate one, would be to "glue" the pre-amp into the receptacle with 3 or 4 "blobs" of RTV silicone. The antenna coax cable from the Loran-C receiver, should come down the "conduit" previously hotwired into the wing cores, and plus into the pre-amp. The other end of the pre-amp should have the antenna "wire" plugged directly into it. A suitable door or cover should be installed over the pre-amp to protect it from the elements. This can be a custom fabricated glass laminate, held on with 6 #6 flush screws and buried nut plates, similar to the nose door over the battery. Just as good would be an appropriately shaped piece of .016 "glued" over the pre-amp with RTV silicone.

For a VariEze, the pre-amp could probably be installed in the lower winglet. It will depend on the size and shape you made your lower winglet. An option would be to dig a "hole" into the end of the wing at the leading edge. Do **not** cut into any of the major structure that attaches the upper winglet to the wing. This "hole" should be sanded smooth and glassed with 2 plies of BID. Again, the pre-amp can be mounted with a few "blobs" of RTV silicone. Getting the

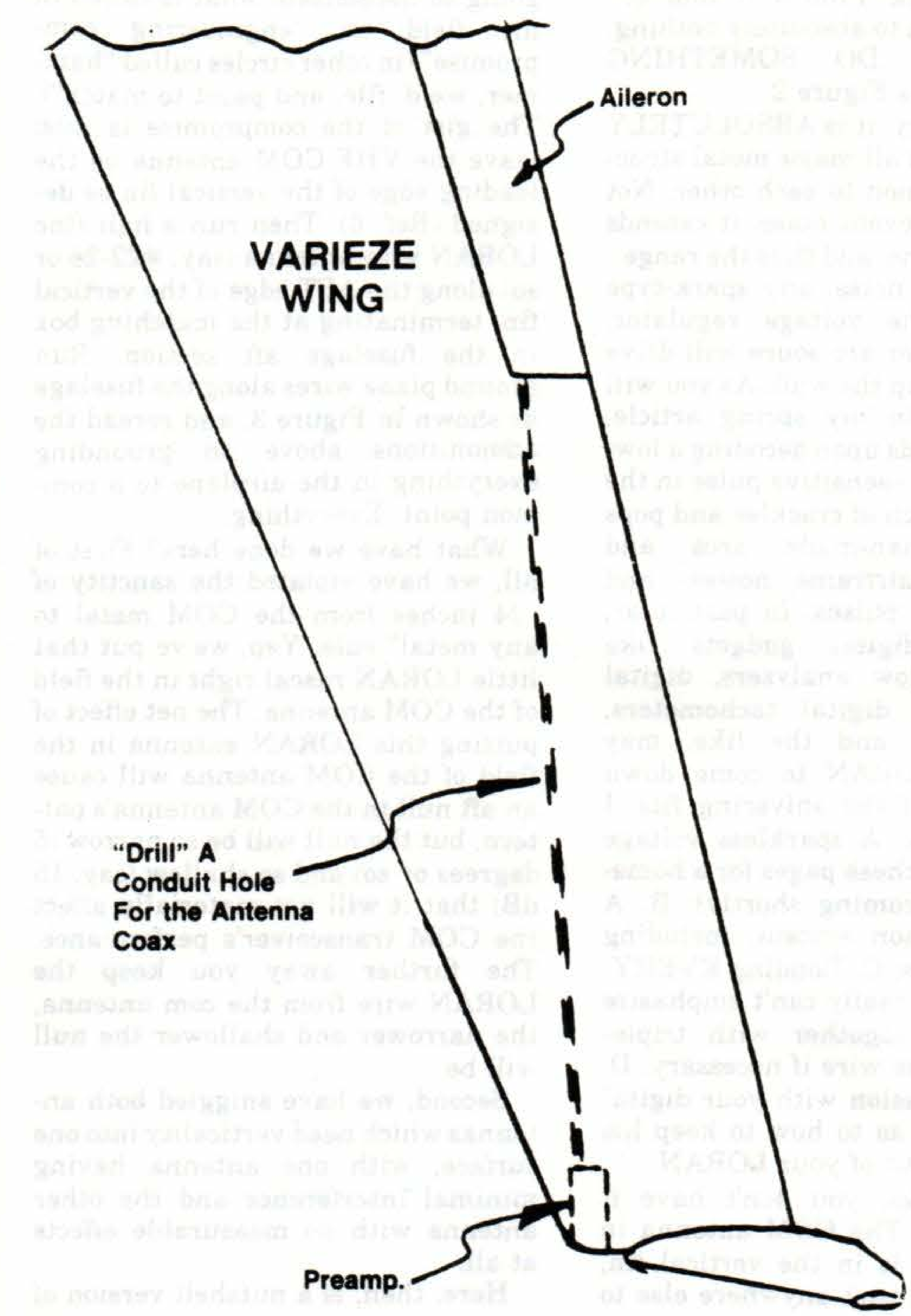


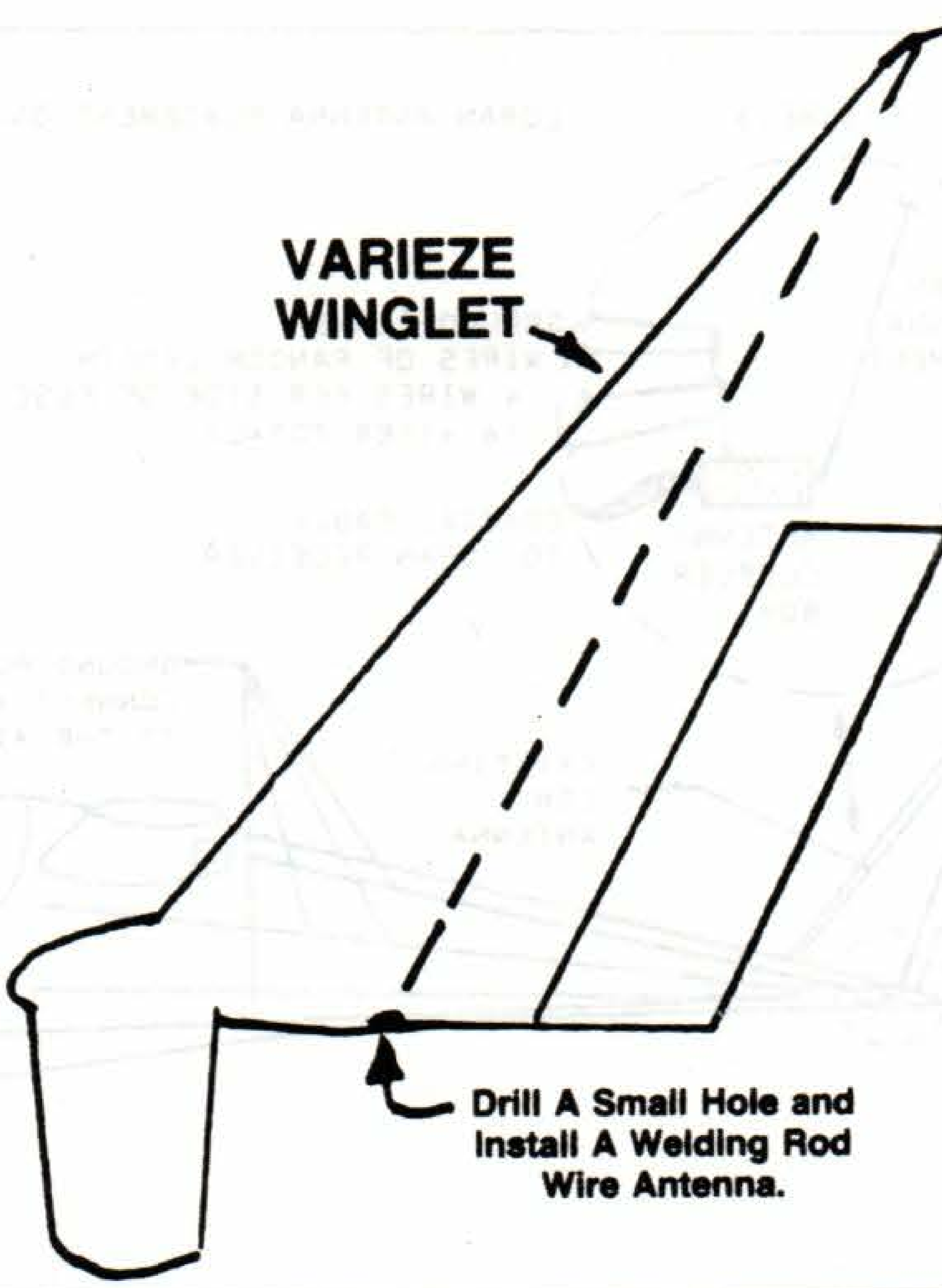
coaxial antenna cable to the pre-amp in an already completed VariEze is not quite so simple. A suggestion would be to run the cable along the leading edge of the aileron spar out to the outboard tip of the aileron, then through the foam core to the pre-amp. It is possible to "drill" a hole from the outboard forward corner of the aileron cutout, to the wingtip, using a piece of 5/16" OD x .035 wall steel tubing for a drill. You will need a piece about seven feet long. The "cutting" end should be serrated with a hacksaw. Chuck this tube drill in your electric drill and carefully align the drill to start in the outboard corner of the aileron cutout, and come out in the area of the leading edge of the wing tip. It sounds difficult, but you will be surprised how easy it is to do. Run the coax antenna cable through this hole, and connect it to the appropriate end of the pre-amp. The antenna itself is connected to the other end, and should be a piece of 1/16" or 3/32" welding rod. Stainless might be best to prevent corrosion. This wire can be sharpened on one end, and pushed up through a small hole into the upper winglet foam core until it reaches the top of the winglet. You want the longest antenna possible.

The "ground plane" that Jim has described in this article, should be built by burying the wires in razor cuts in the foam, rather than by glueing the wires to the surface as suggested. Wires glued to the surface of the foam would cause "bumps" in the glass skins, which in turn could cause the structural glass skins to be sanded through locally over the wires. This would be a disaster, since the glass skins **are** the structure of your wings.

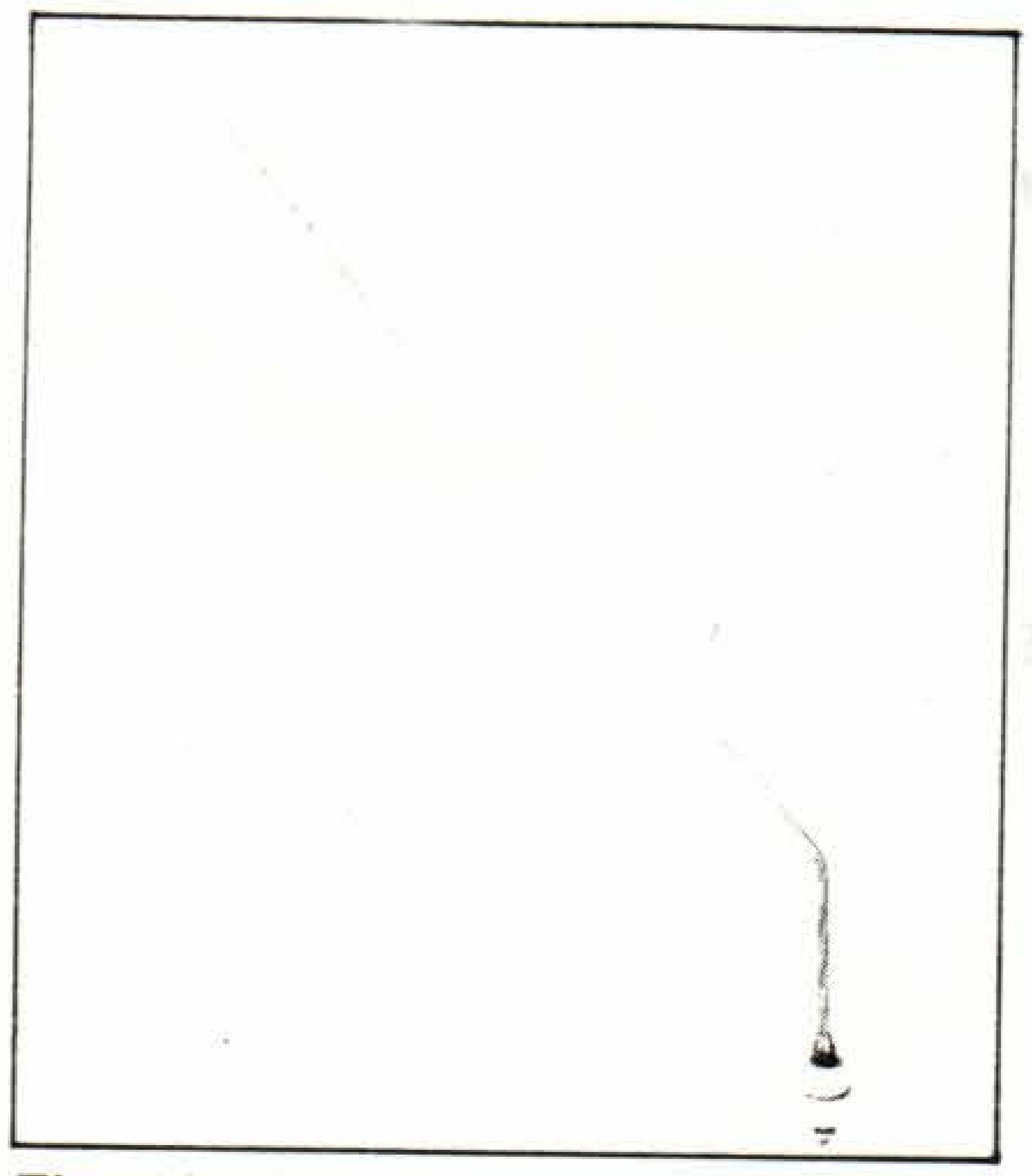
It is much better to bury the wires in a razor cut about 1/8" deep in the foam. These "cuts" will be filled with micro when you slurry the foam prior to glassing. Keep in mind that when you lap the four wires spanwise, top and bottom of the wing, that you will not just be able to simply hook these wires together. At the wing tip, you will be cutting the wing to fit the winglet. At the root, you will be removing a section of the foam core, and laying up a root rib (see Section I, Chapter 19). This will be much easier to understand once you have studied the wing construction chapter. As long as you look ahead, this ground plane will be easy to install and your Loran-C will work well, provided you follow Jim's instructions to the letter.

Have fun!!!

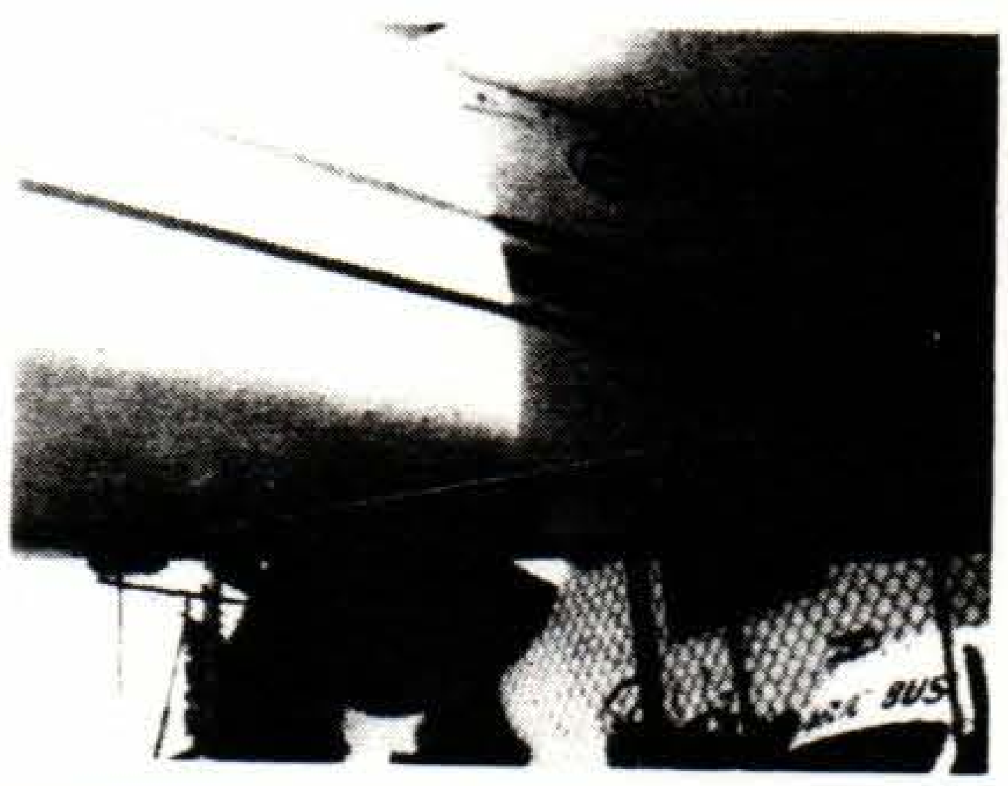


**One of the best communications antennas, the broadband whip.**

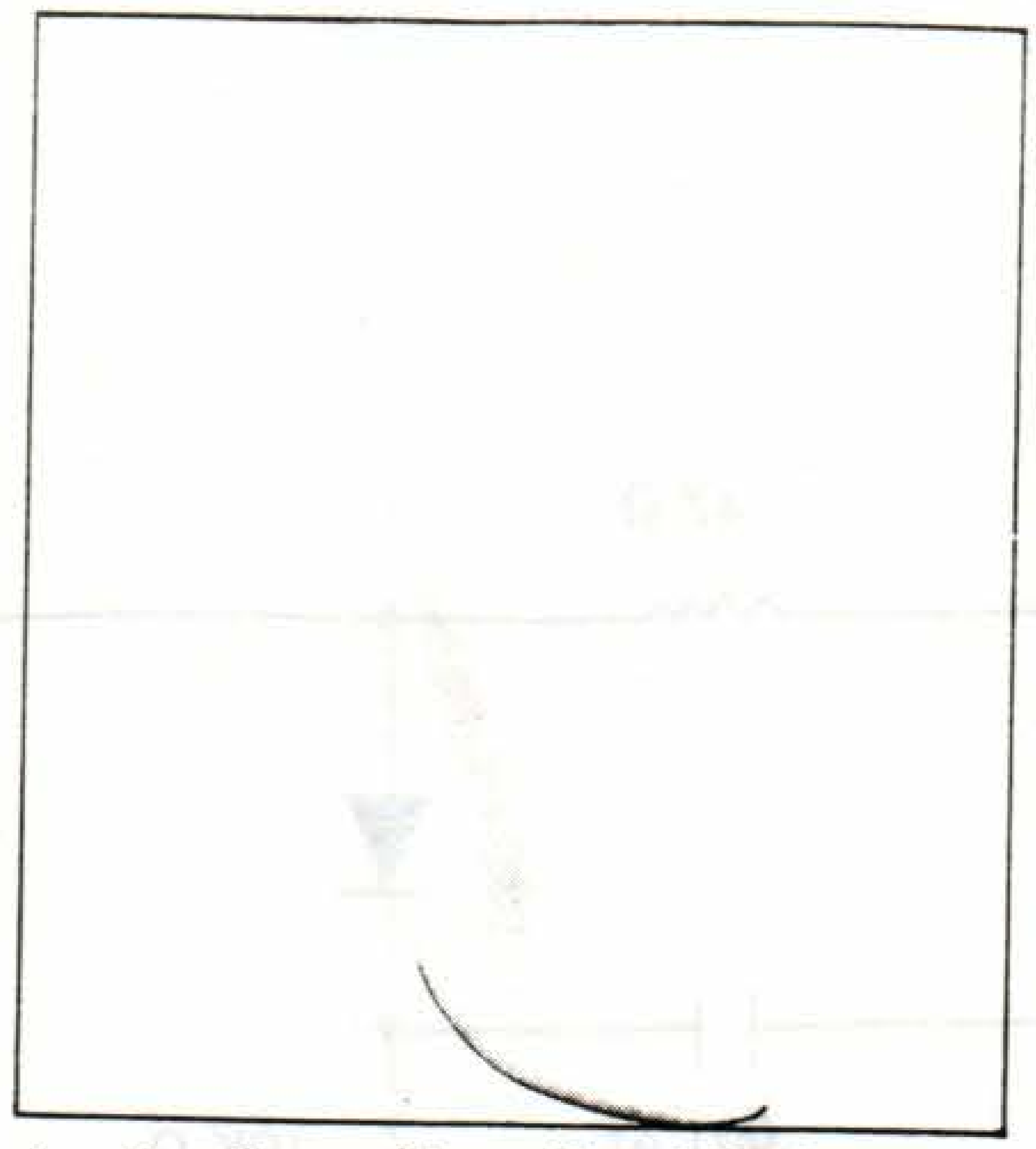


**The old reliable bent-wire communications whip.**

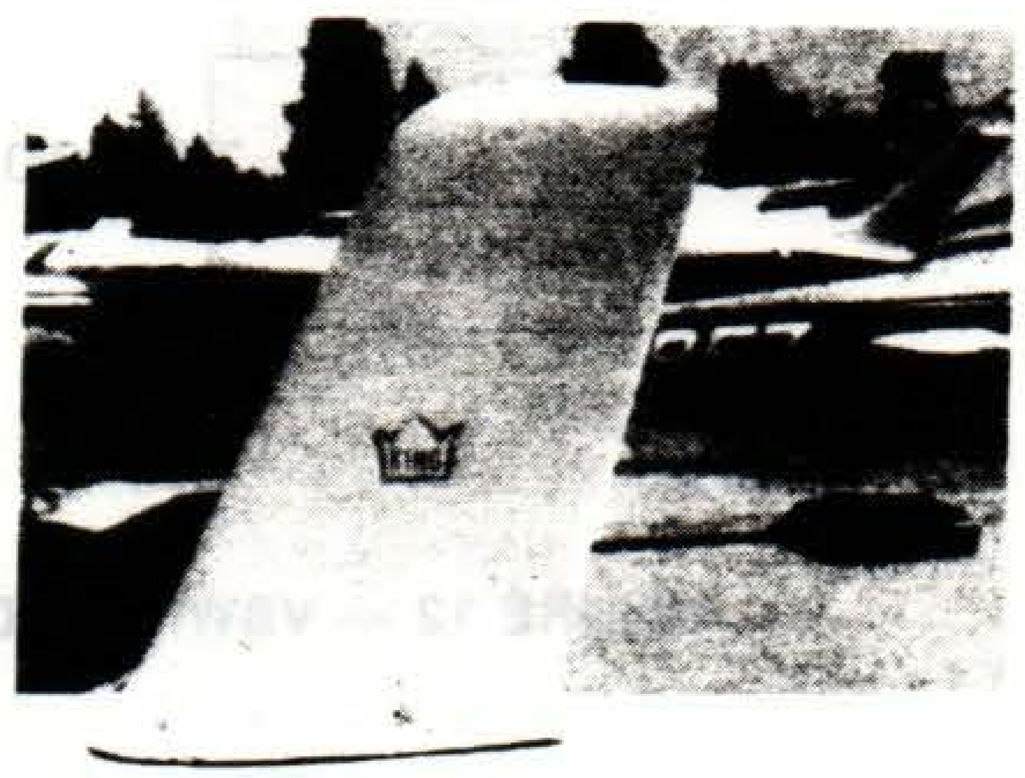


**Backward-leaning VOR antenna under the tail of an Ercoupe.**

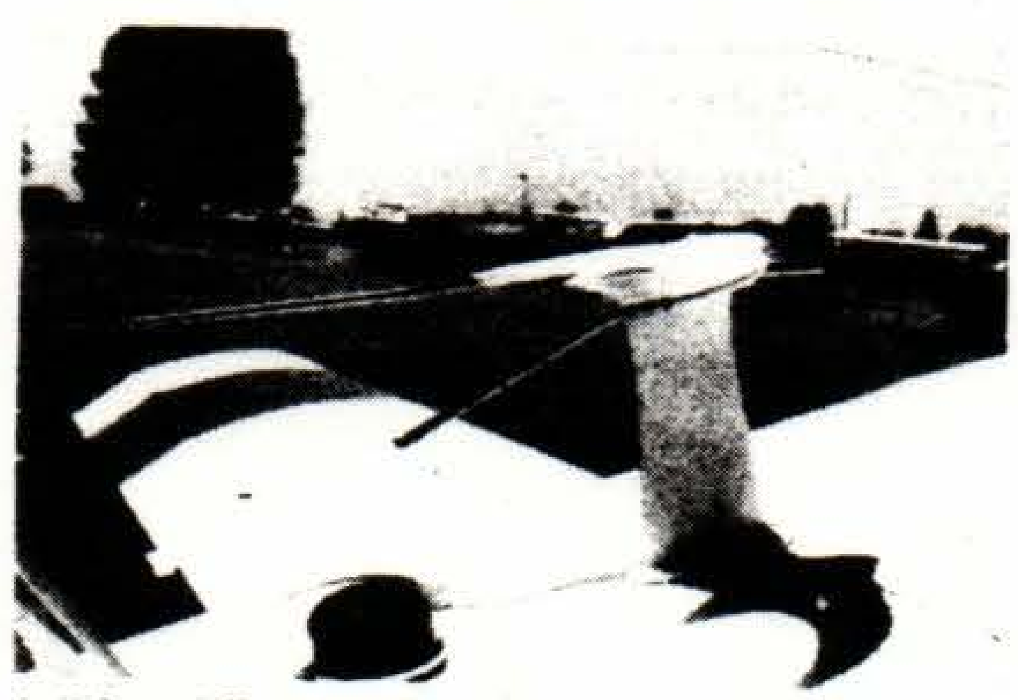
**A blade version of the towel-bar VOR antenna.**



**Another form of broadband blade antenna for communications.**



**Yet another broadband blade antenna.**



**A "do-all" antenna: the bent-back rods are the VOR antenna, the blade is the communications antenna, and the forward-leaning rods are the glideslope antenna.**

**Classic sled runner type of marker beacon antenna.**

diplexer (see photo) which is designed to disable one of the transceivers when the other transceiver is in the transmit mode.

In contrast to com antennas, which should be mounted vertically, VOR LOC antennas, which receive both omni and localizer signals, *must* be mounted horizontally. This horizontal polarization comes about due to a rather peculiar phenomenon of radio waves which causes them to bounce off mountains with vertical polarization. So, if the Denver VOR transmits a horizontal signal, it bounces off good old Mt. Evans (altitude 14,000 feet MSL, 20 miles southwest) vertically. Now, horizontal antennas receive almost only horizontal signals, and vertical only vertical, so the poor yo-yo who mistakenly mounted his omni antenna vertically is in for a great surprise if he decides to fly at 10,500 and track inbound to the "new" Denver omni signal bouncing off the mountain. Especially in the soup.

The VOR/LOC antenna (or nav antenna as it is commonly called) is generally a quarter-wave "rabbit ear" mounted on top of the vertical fin and bent either forward or aft at a 45° angle. Note that the rods are horizontal with respect to the earth's surface, as opposed to the vertically pointing com antenna. The best *reception* will occur in the direction of the bend of the element ears, but they *look* better if pointed off. Unfortunately, most pilots are concerned with what is in front of them, not aft, so it becomes the old engineering vs. styling argument that is generally decided by the sales group. Go count the Wichita Wonders — 99% of them have the antennas pointing aft!

The rabbit-ear antenna is what is called a balanced antenna, but the coaxial cable that connects it to the radio is unbalanced wire. Between the antenna and the coax, a matching network called a balun (for *bal*anced-*un*balance) must be installed for the antenna to work properly. This does not have to be a very sophisticated device — the most common (and also efficient and cheap) balun is made with about 25¢ worth of coaxial cable and a half hour's work.

Some older aircraft have been retrofitted with the VOR antenna far aft on the belly underneath the horizontal stabilizer. I rank these installations right up there with airbags and income tax! I've been asked time and time again to 'tweak my radio up for better reception' by these folks who have perfectly good radios, but who do not have a ghost of a chance for good nav operation. The tips of the VOR antenna must be kept *at least* 24 inches away from any metal surface, and the higher you get the antenna away from the airframe the better!

There is a new nav antenna on the market that is being purchased by the same folks who can afford to buy the marginally better but far more expensive com blade antennas. This antenna goes by many names: balanced loop, halo,