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OPERATIONS AND MAINTENANCE MANUAL

FOR THE

RST-2802 ANTENNA KIT

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THE RST-2802
ANTENNA MANUAL

Edition: 06 Jan 2012

RST Engineering

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INTRODUCTION

In 1978, the Bellanca Aircraft Company (Alexandria MN -- the ABSOLUTELY COLDEST I've ever been in my life) asked me if it was possible to conceal the complete antenna system in the wood wings and fuselage of the Viking aircraft. Successful completion of that job brought me into contact with the brothers Rutan, Tom Jewett, Ken Rand, and that whole early bunch of brilliant designers that were starting to pour airplanes out of plastic bottles. We came up with a pretty slick formula to allow us to conceal a complete antenna system within the wings and fuselage of most popular plastic airplanes. (Not to disparage the woods ships like Falco -- Alfred and I came up with some pretty nifty designs there, too.)

The basic "ferrite toroid - copper tape" VHF antenna design has been installed on over ten thousand homebuilt airplanes over the last 15 years -- EZs, Quickies, Dragonflies, Falcos, Glassairs, RVs, and a whole bunch of others that you can see on the line at Oshkosh every year.

And, of course, the one that I will treasure for all time -- a wonderful one-time design for a gangly, goofy looking kluge called Voyager. A half-dozen of our antennas went around the world with that old crate and now hang (invisibly) in the Smithsonian. At least there WERE half a dozen when he started the takeoff roll, but he dumped two of my best designs into the Mojave desert when he ground the winglets into powder on the takeoff roll. Sigh. Anyway, if you ever get back to the Smithsonian and can look at the wingtips, you will see some RG-58 coax cable just hanging out the wingtips. I don't guarantee my antennas when they depart the airframe.

What we started out doing in the early 80s was supplying a kit for each airframe design -- the EZ had one, the Quickie had one, and so forth. What with manufacturers coming out with new designs literally each week, it became a logistics nightmare trying to keep up with engineering changes as we found out about them. What became even more of a nightmare (as we found out on the Quickie II) is that sometimes a designer would make seemingly insignificant changes in design that totally frapped our antennas. Case in point -- Quickie used fiberglass layups on the skin. Without us finding out about it, Q-II used carbon fiber and I guarantee you carbon fiber is a wonderful shield for antennas. So good in fact that you couldn't talk more than a couple of hundred feet on your airplane radio, and that just wasn't what we had in mind.

So we come down to how we do it today. This is a updated and enhanced rewrite of a whole bunch of articles that show you how we did it on various airplanes, and showing you how to use the ferrite toroids and copper tape that we have available for you. You then get to figure out for yourself just exactly on YOUR airframe where the best place for the antennas is.

For you manufacturers and designers -- tell you what I'm going to do. You send me a 3-view of your design and I'll mark it up showing you where I would put the antennas were it my airplane. If you want to install them in your prototype or if you have a builder willing to take a chance on a best-guess design (this is EXPERIMENTAL aircraft, remember?) and you want to fly it up (down?) to Grass Valley, I'll run it through the standard pattern range up here and give you a polar plot of how the antenna radiates. I can also give you a "standard" antenna plot of a regular whip antenna on a metal airplane so that you can evaluate your design against some sort of industry standard. It will be necessary to have a GPS installed in your prototype in order to run a constant distance on the pattern range. It will take a few hours to run a complete series of tests, so plan on spending a while. For the time being we are only able to do VHF COM, VHF NAV, and Marker Beacon tests. And please come in the late spring to early fall -- mucking around in the snow is the SECOND most favorite thing I do, right after everything else.

Jim Weir
VP Engineering, RST

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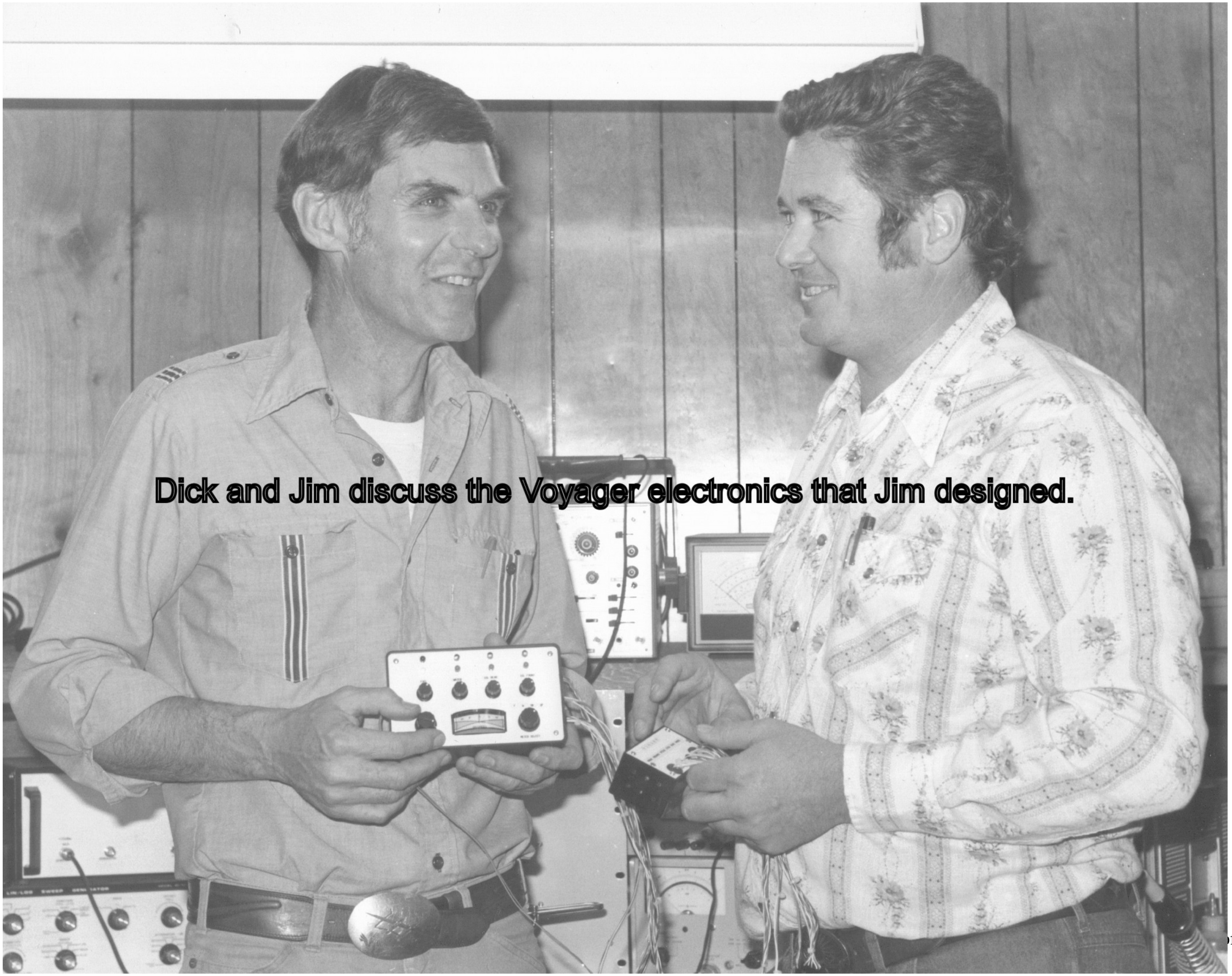
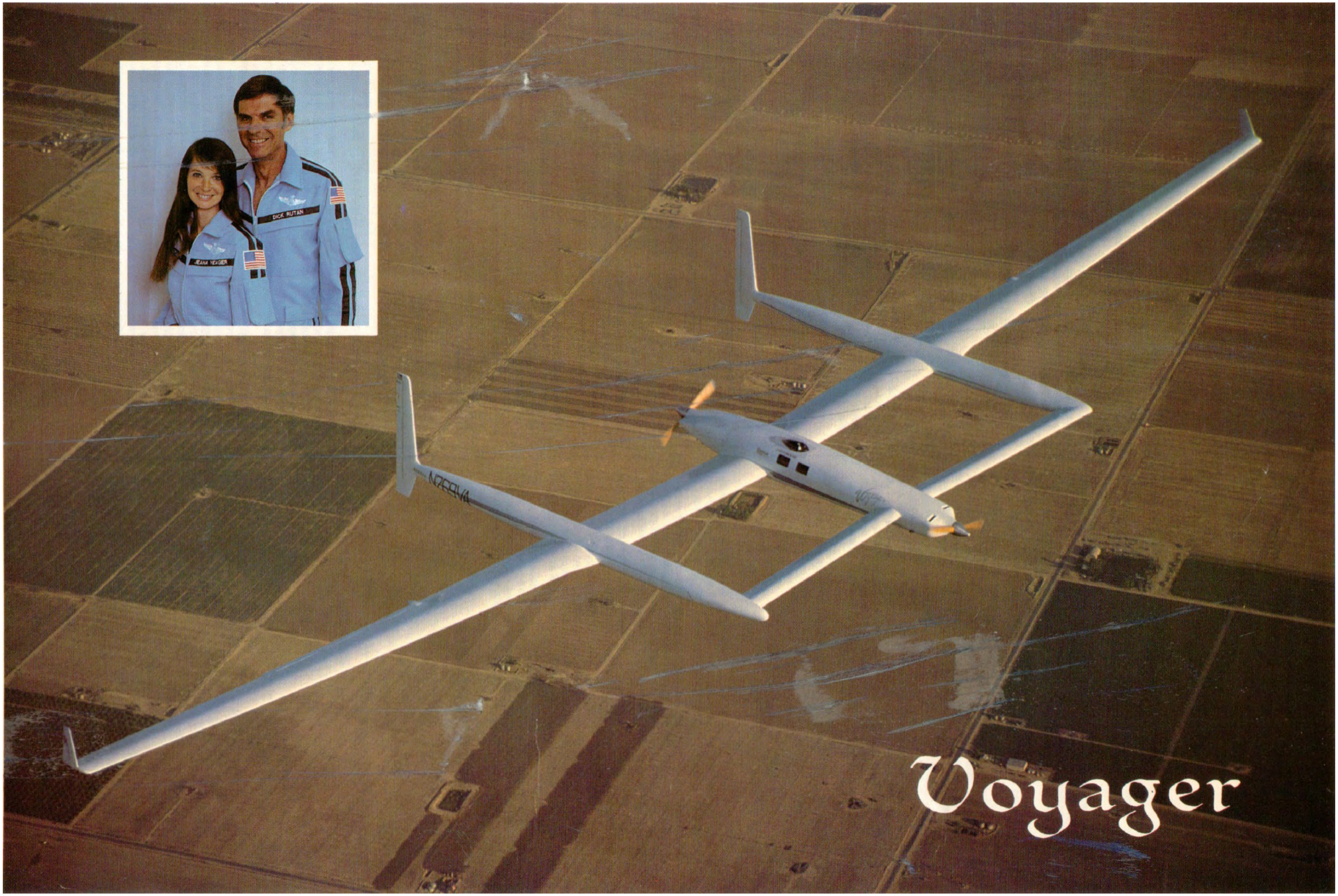


Dick and Jim discuss the Voyager electronics that Jim designed.


DICK RUTAN
JEANA YEAGER
N269VA
Voyager

GENERAL HIDDEN ANTENNA INSTALLATION

This section describes in general terms the installation of so-called “hidden” antenna systems on foam-fiberglass airplanes. While the same general principles hold on all types of radio-wave transparent construction (wood, wood/fabric, etc.) aircraft, we do NOT have any hard and fast rules about these other construction methods. Metal tube/fabric, carbon fiber, and all the rest of the construction methods are also not in our bag of tricks. Finally, ADF, GPS, CB, HF, and other antennas do not lend themselves well to general VHF/UHF techniques, and we do not have any further data on them.

VHF COM, VHF NAV, MKR BCN, and other VHF-UHF aircraft antennas (including glideslope and amateur VHF/UHF bands) are made of copper foil elements, fed with RG-58 coaxial cable with 3 small ferrite toroids (“donuts” pronounced "TOW-royds") around the cable at the antenna end as shown in the drawings that accompany this book. This book also goes on to show that the only real difference between any of these ferrite-foil antennas is the length of the copper foil element itself. Please don’t fall for the old wive’s tale about the coax cable having to be some integral measure of a wavelength. Just make the cable run as short as reasonably possible to keep line loss at a minimum.

Generally, we try to keep COM antennas perpendicular to the earth’s surface (vertical polarization) and NAV antennas horizontal. Realizing that there are precious few vertical surfaces on most homebuilts means that you will have to compromise having two COM antennas that are in the optimum spot -- except for you lucky EZ drivers with the nifty bent wingtips. In both the horizontal and the vertical antennas, a little bending from true up or true horizontal is permissible to conform to the shape of the airframe. How much is permissible? Remember in the old Genave A-200 and Narco Escort 110 series of radios that the COM receiver ALWAYS worked on a horizontal antenna and that we got fairly decent reception even with a totally cross-polarized antenna. “How much” is always an experimental question, which is the name of the homebuilt airplane game. The only caveat is that the VHF NAV “VOR-LOC” antenna really needs to be truly horizontal for proper operation.

The copper foil and ferrites may be placed anywhere in or on the foam or fiberglass. You can put it on the surface, inside the glass on the foam surface, or imbedded in the foam -- absolutely no difference. However, no matter where you put the antenna, it is imperative that you have the solder joints where the coax attaches to the foil firmly potted so that when the airframe flexes that the solder joint will not break. One clever way I’ve seen to keep flexing from being a problem is where a shallow channel is milled into the foam, wax paper is put into the bottom of the channel, followed by the foil, followed by another layer of wax paper, and then microballoons or flox used to slurry over the whole shebang. That way the whole antenna floats in the structure and flexing the structure doesn’t do anything more than make the foil slide along the wax paper.

Speaking of flexing, we used to recommend the gear legs for vertical COM surfaces. About a year after this idea was published, some of our friends (including one Richard Rutan) reported to us that the antenna seemed to not be as good as it was just after installation. Upon further questioning, most of them admitted that the degradation was first noticed after a real belly-whopper of a landing (Rutan included). We deduced that the gear leg was flexing enough during a hard landing to actually break the foil. Once broken, the foil would never reattach itself and the antenna was rendered useless. The foil is strong, but not strong enough to survive a half-ton of airplane thumping along the runway. There are several ways to solve this problem. One is to run a wide, thin glass “soda straw” down the aft or forward part of the gear leg and slide the rolled-up copper foil into the straw. Fair the straw in to the gear leg and let the foil freely slide up and down inside the straw. Another way is to run a fairly hefty soft copper wire (say, a #14 or so stolen from a box of Romex house wire) down the surface of the foil and solder it the whole way down the foil strip. If the relatively thin foil breaks, it is no matter because the heavy wire ought to have enough stretch in it to remain attached. Then all the break in the foil matters is a microscopic gap (milli-inches) of wire, which means NOTHING to a VHF-UHF antenna.

Some general comments:

1. The coax cable ought to run at right angles away from the copper elements as far as reasonably possible before bending to go into the cabin.

2. Keep the foil TIPS away from large metal surfaces and wires to the extent possible, even if it means sacrificing perfect positioning or bending the elements around.

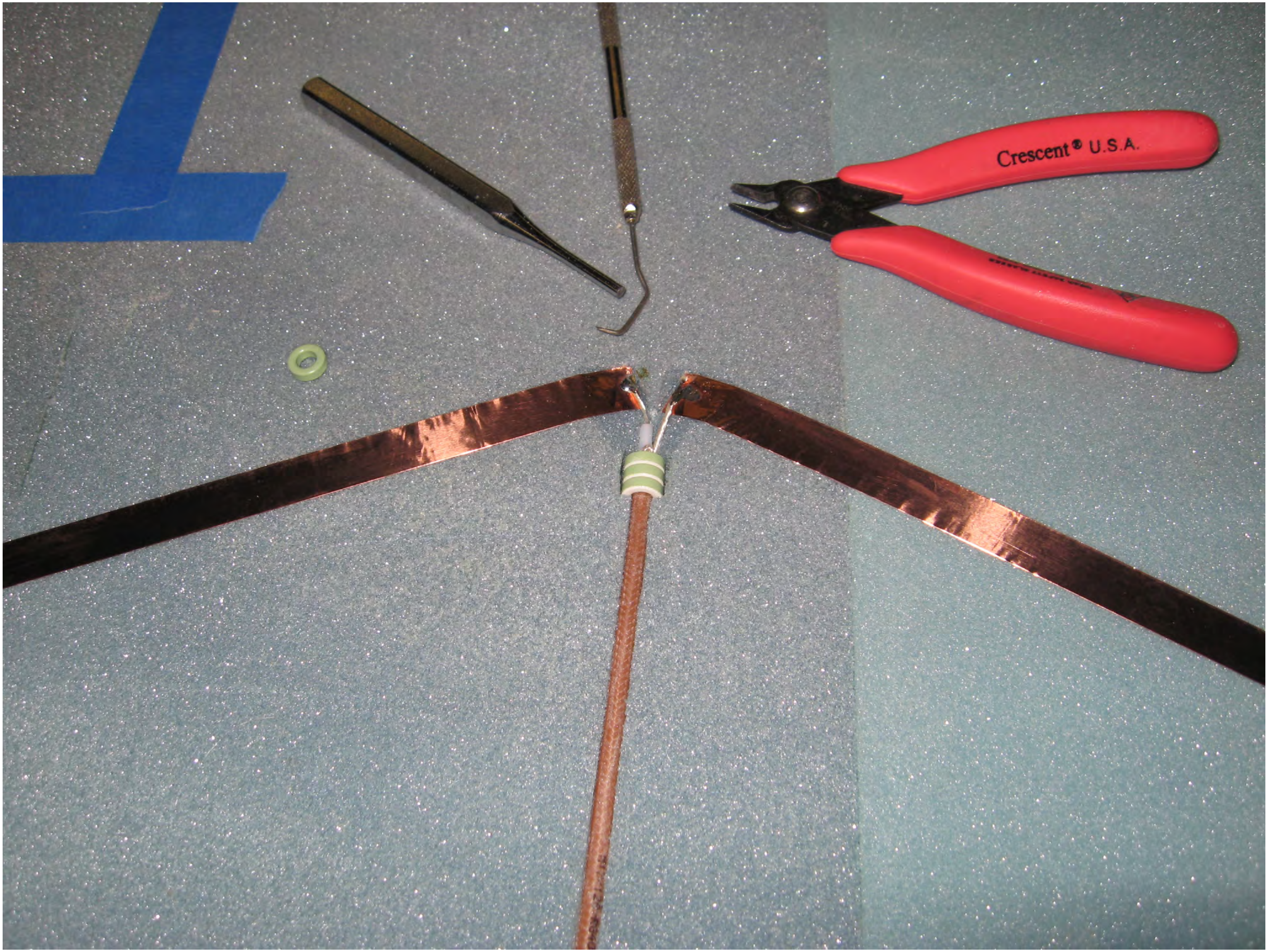
3. If you have the choice of which of the elements to connect the center conductor and braid of the coax to, connect the center conductor to the highest or furthest outboard of the two elements and the braid to the other element.

4. These antennas have worked in glass and fabric airplanes with almost every kind of paint and dope (including the aluminum coat used on fabric as a UV protectant) that we could find. A couple of times in the past few years there have been reports that there is a new German metallic paint (sorry, I don't know the brand) that makes ALL hidden antennas (not just ours) work poorly if at all. Anybody that has more information than this, if you would please let us know the how, why, and particulars of the process, we'll try and let the rest of the world in on the secret.

Transponder-DME antennas are made out of a flat aluminum shim stock called a "ground plane" and a little spaghetti-thick rod with a ball bearing on one end and a BNC connector on the other. The antenna should be installed with the ground plane horizontal with the earth's surface and the tip of the radiating rod pointed directly down. It does not matter how close to the fiberglass skin the rod tip comes, but it should be more than a foot (25 cm) or so away from any other conductor. When siting a transponder-dme antenna, just remember that if the fiberglass was transparent but that the ground station (center, tower, etc.) couldn't see the antenna because there was engine, people, or other conductors in the way, then the radio will NOT perform properly. Finally, be sure that there is some aluminum foil between the antenna rod and the sensitive parts of the crew's anatomy. See your medical examiner for a discussion of the microwave oven effect on the human body.

GPS antennas work quite well through fiberglass skin, but I caution you that we have NOT tried to mount a GPS antenna under fabric skin that has been coated with the aluminum pigment UV dope. Nor have we tried it under the aforementioned German paint. Write us and tell us your experiences with GPS antenna installations so that we can upgrade this little part of the book for your fellow builders.

Marker beacon antennas will work OK strung out horizontally along the wing as shown in several places in the attached article, but for really proper performance, they should be placed along the longitudinal axis of the airplane -- stretched fore to aft along the belly centerline. This will provide the best performance on actual ILS approaches, although the horizontal wing-mount has worked acceptably for lo these many years.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ANTENNAS ACCORDING TO JIM

by Jim Weir
VP Engineering, RST

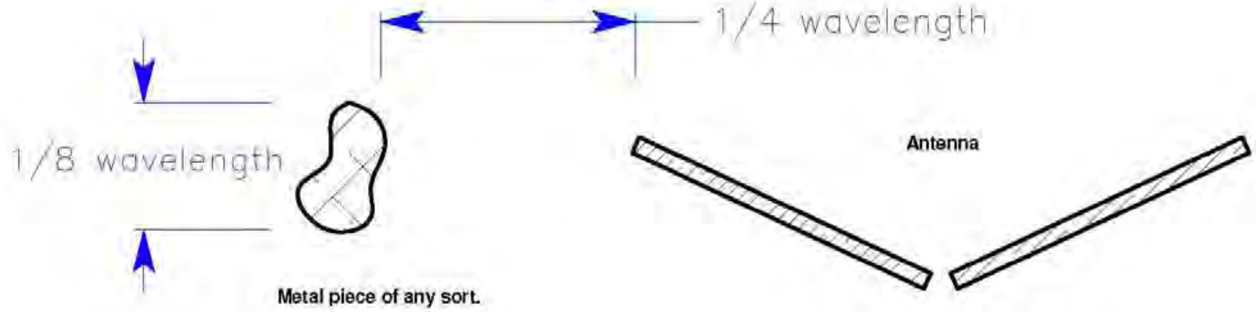
In the beginning was the silence, and Marconi bridged the waters with electricity, and the sound was heard throughout the land. It was heard, that is, if you had a big enough antenna. From the time that we first figured out how to send messages without wires, it became an art and a science how to throw those electronic waves into the ether and then catch them at the other end. From the days of the very early radio pioneers it was well understood that the ANTENNA was a fundamental component of the radio process.

It wasn't too many years after the first scribbled notes in the radio engineering notebook that we convinced ourselves that ANTENNAS WERE RECIPROCAL. That is, antennas don't care whether they are transmitting or receiving. What makes a good receiving antenna makes a good transmitting antenna and vice versa. The fundamental idea you must grasp is that there isn't any such thing as a "transmitter antenna" or a "receiver antenna" design that is better for one or the other. If she hears, she talks as well.

Airplanes present a particularly interesting set of problems in that size and shape become critical design limitations -- not many airplanes are capable of flying around with a 100 foot antenna mast strapped to the fuselage. Plastic airplanes (i.e. "composite" structures made of foam, glass cloth, and resin) present an even more interesting problem in that the plastic structure is, for the most part, transparent to radio waves. This means that if we are clever about it, we can hide the antennas underneath the glass skin and save all the drag that you expect when you hang an external antenna out into the breeze.

Let's break airplanes down into two categories -- "metal" airplanes and "plastic" airplanes. When I say a "metal" airplane, I am including not only those aircraft with metal skins, but fabric or wood airplanes with steel tube fuselages, airplanes with wood wings but metal flying wires, aileron cables, and other large ironmongery structures inside the wing, and other airplane types with "large" pieces of metal imbedded into the structure. To fit the bill of a "plastic" airplane (and wood rib / fabric cover "toothpicks and tissue paper" airplanes), I have a rule of thumb to use:

If there is a piece of metal more than an eighth of a wavelength long within a quarter wavelength of the "plastic plane" antenna design, the antenna performance will be degraded



METAL SEPARATION FROM ANTENNA		
Scale: NTS	Approved by: Jim Weir	Drawn by: owj
Date: 3 Jun 96		Rev:A
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.Let us examine this little rule and see if we can make some sense out of it.

A “piece of metal” can be a spar cap strip, a flying wire, a control cable, a large hinge, a landing gear leg, and other like objects. It does NOT necessarily have to be sheet metal. It also includes any kind of a conductor like carbon fiber cloth OR a human being (remember, underneath our skins we are just a 90% salt water sack).

Strangely enough, it does NOT include aluminum pigmented UV dopes used as the undercoat to a color coat on fabric. For whatever molecular reason, the little tiny particles of aluminum seem to be separated by a thin layer of dope and do not upset internal antennas. What WILL upset the antenna are some varieties of metallic paints -- and as yet, nobody has done a thorough analysis of brands and colors. What has been reported to me is that there is one unidentified brand of German paint that has bollixed up some internal antennas, but at this time I cannot get anybody to tell me what brand and what color(s) are messing up the works.

An “eighth of a wavelength” is calculated as 1475/f , where the result is inches and f is the frequency in Megahertz. For example, if we concern ourselves with the aircraft COM band centered at 127 MHz, then we don’t want metal objects bigger than 1475/127 = 12 inches within a quarter wave of the antenna. This is 12” in ANY dimension; a 12” piece of #18 wire is just about as bad as a 12” square of aluminum sheeting.

A “quarter wavelength” is calculated as 2950/f, so in the example above, we don’t want that 12+” object within 24” of the antenna.

What is “degraded”? Several things degrade when you get metal around the antenna. First, it detunes the antenna so that you do not have the same frequency response you expected. Second, it puts little bumps and holes in the antenna radiation pattern so that you may be loud and clear in some directions and can’t be heard at all in other directions. How much can we “degrade” an antenna and still expect reasonable performance? That is sort of like asking how big a hole we can have in our pistons and still have the engine run. We’d prefer not to have any, but if we have a tiny pinhole, it will probably run OK. When we get dime sized holes, it isn’t going to run so awfully good at all. It is all a matter of how far from perfect you are willing to accept, and that is YOUR call.

One last comment and we’ll get on with the designs. With the classic dipole “rabbit ears” design, metal close to the center of the antenna where the ears come together has practically zero effect. Metal out at the tips of the ears has a tremendous effect. If you are trying to use a plastic plane design in a ship with metal, keep the metal parts away from the tips of the ears and you shouldn’t have much trouble. If you are having trouble visualizing this, just look at any VOR antenna on a single engine Cessna. See how the center of the antenna is right in the middle of a big patch of (vertical stabilizer) metal? But how the tips are kept as far away as possible from the metal?

In the designs that follow, we are going to be vitally concerned with three main questions -- how long do we make the antenna, how fat do we make the antenna, and what do we make the antenna out of?

WAVELENGTH

Almost without exception, antennas are made some fraction of a wavelength long. The formula for wavelength is 11800/f where the wavelength will be given in inches and f is the frequency in MHz. For example, if we want to know the wavelength of the LAX VOR on 113.6 MHz. we simply take 11800, divide it by 113.6, and up pops the answer 103.9 inches. Think of it this way. The VOR signal (and in fact, all radio waves) travel at the speed of light. If you've got 113.6 million of them per second coming off the VOR antenna, each one travels a distance measured by dividing the speed of light by the rate at which they come off the antenna. The speed of light is 11800 million inches per second. Dividing 11800 million by 113.6 million comes up with (gee whiz) the same answer we got before -- 103.9 inches.

Mostly we want fractions of a wavelength. We can get there two ways. Say, just for ornery sake, we want to know what a quarter-wavelength is at 113.6 MHz.. We can get there two ways. One is to calculate a whole wavelength (103.9") and divide that by four, coming up with around 26 inches. The other way is to first divide 11800 by four, giving us 2950. Then divide 2950 by 113.6 and we come up with the same answer, 26 inches

.BANDWIDTH

I am frequently asked, "Why can't I just take a hairfine wire and glue it to the canopy. Won't that work for an antenna?" The answer is yes, it WILL work as an antenna. But only at one very precise frequency. When we need to cover a whole BAND of frequencies, then the concept of antenna "fatness" comes into play. Without going into a long song and dance about standing waves and reflection coefficients, suffice it to say that the FATTER the antenna elements, the BROADER the bandwidth. Fortunately for we airplane drivers, an antenna doesn't have to be fat in all three dimensions. As a matter of fact, thin metal tape will work almost exactly as well as a solid rod of the same diameter.

There is a measurement called "aspect ratio" which is calculated by taking the length of one of the antenna "ears" and dividing it by the antenna width. For example, a VHF navigation band dipole antenna (yes, we are getting a little ahead of ourselves here) comprised of two 22½" long ears made out of half-inch wide copper tape would have an aspect ratio of (22.5/0.5) around 45. The rule of thumb is that the CENTER FREQUENCY for which the antenna is designed multiplied by SIX and then divided by the ASPECT RATIO will be the approximate bandwidth of the antenna. So, for our VHF nav band antenna centered at 113 MHz. with an aspect ratio of 45, the bandwidth should be somewhere around (113 * 6)/45, or around 15 MHz. This means that the antenna will be "good" (a purely subjective word) from around 105 MHz. to around 120 MHz.. Do you want more bandwidth? Just use wider tape.

Without getting into the fine details, it is also true that making an antenna FATTER will also reduce its length a small amount. An antenna made up of #40 wire (approximately the diameter of the hair of the small yak, not to be confused with the large yak) might be 24 inches long to resonate at a particular frequency. An antenna made of ½" copper tape might be 22½" long to resonate at the same frequency. Unfortunately, there is no rule of thumb I can give other than a quarter-wave antenna is at LEAST 5% shorter than a calculated quarter wave, and the rest is measurement and experience.

Dipole Width Versus Bandwidth

Scale: nts	Approved by: *Jim Weir*	Drawn by: owj
Date: 3 Jun 96		Rev: A
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ANTENNA MATERIALS

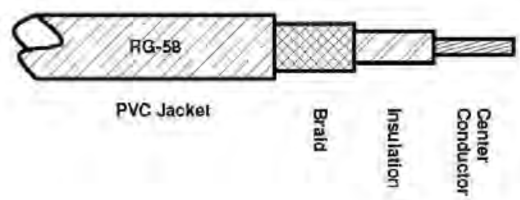
Don't ever ask a theoretical physicist what to use for making the very best antenna. He will tell you that solid silver is the very best way to go. For those of us without 6-digit incomes, though, copper is very, very close to silver as a good antenna material. As a matter of fact, copper tape has come to be used almost universally as a plastic plane antenna element. Metal ships, too, use copper tape for antenna elements, but wrap it in a fiberglass rod to keep it from fluttering about in the breeze. Yep, cut one of those pretty white fiberglass "COM" antennas in half and the odds are that you will find a piece of copper tape curled up inside.

Almost any metal will serve as a decent antenna element, but some of them are better for our purposes than others. As we said above, copper (especially the tape) works quite well and has one distinct advantage over other metals -- you can solder directly to copper using plain old radio rosin core solder. Stainless steel works pretty well for antennas that need some mechanical rigidity, but soldering to stainless is an art most of us can't master. And, stainless is heavy. Aluminum (and aluminum tubing) work well as lightweight antenna elements, but aluminum will corrode over time leaving your antenna useless. Plain old iron and steel rust too badly and are too heavy for consideration. One other type of element that I've used over the years when I had to have a quick-and-dirty antenna prototype is the thinwall brass tubing that you can get at the airplane model store. I'd probably never do a production design using brass tubing, but for a simple, cheap, solderable antenna element, brass (and brass' cousin -- brazing rod) is easy to work with.

Equally as important as what to use for an antenna element is what to use for an insulator. That is, what kinds of things can we cover or pot the antenna (and/or cable) with that won't mess up the quality of the antenna. Fiberglass cloth is excellent, as are almost all resins I've been able to test. Silicone sealant ("RTV") of the clear variety. The colored varieties are PROBABLY ok, but I've never used them. Thinwall white PVC waterpipe if you are going to put the antenna INSIDE the PVC, or thin and thickwall if you are going to tape the antenna to the outside of the PVC. The gray PVC and black ABS plumbing pipe have had mixed reviews -- I haven't had any problem with them, but some folks I talk to on the Internet say that they've experienced some difficulties. Dry, varnished or sealed wood. Almost any kind of clear plastic (polystyrene, nylon, etc.) or synthetic fabric (Stits, dacron, etc.). Like I said above, the aluminum ultraviolet dope doesn't seem to be a problem, but metallic paint on the fabric has given some folks trouble and other folks it hasn't bothered. Plain old colored and white enamel and "epoxy" (polyurethane, etc.) paints aren't a problem.

COAXIAL CABLE

Somehow that signal from your new antenna design has got to be piped to the antenna jack on your radio. That "piping" is universally through a special type of shielded wire called "coaxial cable", or more commonly, "coax". Coax comes in many varieties, but the most common types around the house are 72 ohm (Ω) and 50Ω. 72Ω is fine for TV and stereo work, but it will NOT perform properly in an aircraft radio installation. You need to use 50Ω cable for aircraft antenna work. It may be tempting to use that leftover roll of cable you wired the TV antenna with, but I assure you that when your brand new Belchfire takes to the skies and the VOR needles start to wander and the tower calls you garbled and unreadable, you will NOT be pleased about ripping that 72Ω stuff out by the roots and replacing it with the right coax.



Coaxial Cable Nomenclature

Scale: NTS	Approved by: Jim Weir	Drawn by: OWJ
Date: 6 Jun 96		Rev: A
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By far and away, the most popular cable for aircraft use is good old RG-58 cable. Don't be misled into thinking that RG-59, since it looks and feels so much like RG-58, is the same stuff. RG-58 is 50Ω cable; RG-59 is 72Ω cable. (McShack sells them both.) There is also some misinformation out there about the relative merits of RG-58 (about a quarter of an inch in diameter) versus RG-8 (about half an inch in diameter). They are both 50Ω cables and both rated for the same frequency ranges. The argument is that Uncle Johnny's aunt's boyfriend hooked his CB up with RG-8 and now can talk to Alaska any time of the day or night. Only if said boyfriend also put a 10 kW linear amplifier on at the same time would I believe even a part of this cockamamie story, and even then wouldn't believe the whole thing. I'll say it one last final time: for anything below 1000 MHz. or so, RG-58 is the cable of choice. (For transponder runs longer than ten feet or so, most transponder manufacturers specify the kind of coax they want you to use. It is usually an RG-213 type cable for those long runs.)

RG-58 comes in two varieties -- solid copper center conductor and stranded tinned copper center conductor. My vote is for the solid conductor for a couple of good reasons. First, it is less lossy than the stranded. Second, it is a lot easier to work with, especially when putting on connectors. Third, it is less expensive. I use the stranded when the cable is going to be continually flexed, day in and day out. If, for example, you were taking your canard off your airplane on a daily basis and flexing the cable back and forth about a dozen times every time you removed the canard, I just MIGHT use the stranded. However, if you are like 99.99% of the rest of us and only moving the cable around when working on the airplane, my overwhelming choice is the solid center conductor.

I'll also try and clear up another popular misconception. The length of the coaxial cable between radio and antenna does NOT have to be any particular length. It does NOT have to be a multiple of a quarter or half wavelength. Please do not listen to the old wives' tale about somebody cutting the cable to a magic length and making the radio work better. If cutting cables to some magic length makes things work better, then something is wrong with the antenna or with the radio.

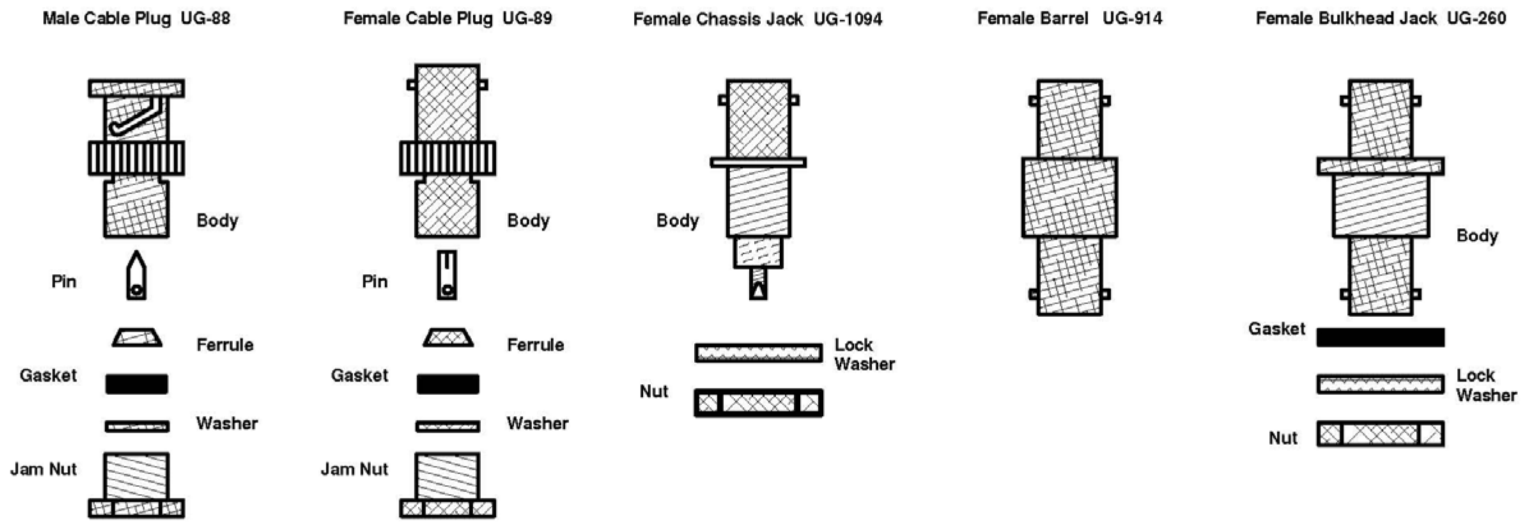
Finally, where do you get RG-58 without having to buy it in thousand foot spools or pay a buck a foot for it? Just between us chickens (hush, now) the stuff you buy from the "McShack" store and the stuff I buy from my friendly local industrial wire supply is the same quality cable. Just be sure you buy from the BULK roll and not the prepackaged stuff out on the main floor. They keep this bulk roll in the back room; go back and make sure they are cutting it from the bulk spool. We used to carry it in 100 foot lengths cut from our 1000 foot spool, but we ran some tests on both the "McShack" stuff and our "high quality" coax and couldn't tell any difference.
The only real failures we have had with this design was when we tried gluing them onto the EZ gear legs. It seems that some EZ drivers tend to plant their machines firmly when alighting back on Earth (hello, Dick Rutan) and the copper tape was stretched well beyond its elastic limit, snapping it in two. So now we recommend several locations for dipole antennas on plastic airplanes:

CONNECTORS

When the coax needs to be separated from the antenna (say, for example, like a removable canard with the VOR antenna inside the canard), then we use coaxial connectors to do the quick-disconnect job. Without doubt, the most popular connector to use below 2 GHz. is the BNC series. For whatever reason, the TNC series became popular for GPS units, but from a radio engineering point of view BNC is every bit as good and half the price.

Why BNC and not some other connector? Well, BNC is what is called a “constant impedance” connector -- it is just a metallic extension of the 50Ω coax. BNC is weatherproof and watertight. Finally, BNC is relatively light and mechanically strong. It is just that perfect blend that comes along every now and again -- sort of like the DC-3. Not very fast, not very sexy, but it will be around long after the pocket-rockets are in the scrapyard.

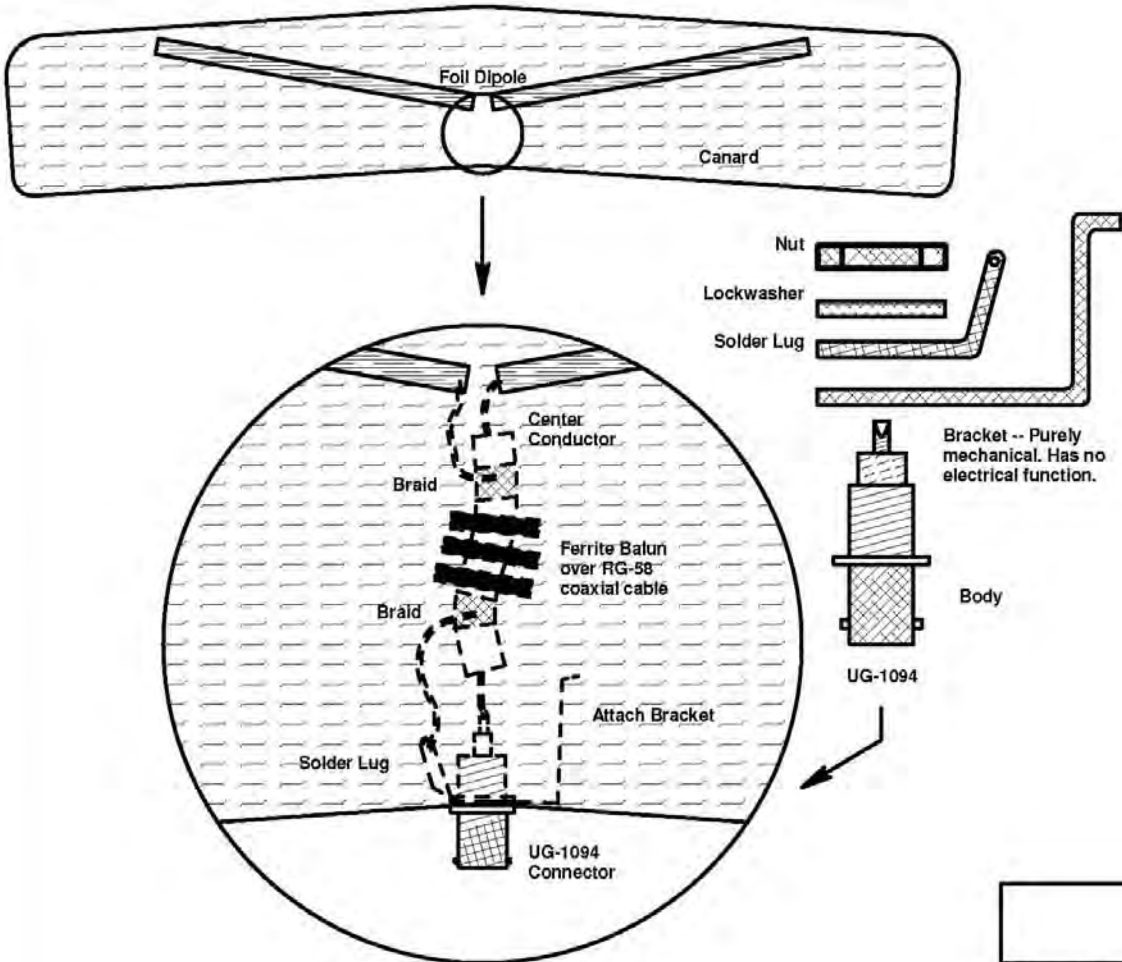
However, there comes a point in time when you want to break the cable in the middle and have what is called a "quick disconnect". This is done quite simply by using a male (UG-88) on one end of the cable and a female (UG-89) on the other end of the cable. Another way of doing it is by using male (UG-88) connectors on both ends of the cable, and a double female --called a UG-914 FEMALE BARREL -- in between the two (no snickering, those of you with dirty minds).   If the cable break is going to go through a skin (like a wing root) or a firewall, there is a water and weatherproof bulkhead version of the UG-914 called a UG-260. RST carries all of these varieties of the connector in stock should you need a supplier.



BNC Connectors

Scale: 1:1 apx.	Approved by: Jim Weir	Drawn by: owj
Date: 3 Jun 96		Rev: A
RST Engineering 13249 Grass Valley Ave Grass Valley CA 95945 916/272-2203 (voice & fax) rst-engr@oro.net		Drawing # 802-8916

There has also been some question about how to fasten a connector to a part of the airplane rather than just leaving it dangling in space. Once again, the BNC family comes to the rescue in the form of a small lightweight panel-mount connector (UG-1094) . The 1094 is the connector of choice when you are embedding the connector into the body of the airplane. For example, the COZY folks wanted a good way to be able to disconnect the VOR antenna in the canard. We came up with an easy solution involving one UG-1094, a thin piece of aluminum, a solder lug, and some RTV or microslurry. It would be just as easy to have used a thin piece of plastic for the aluminum, but during the soldering lug attaching problem, I was worried that the heat conducted by the connector body would have melted the plastic. Hence the design as you see it on the next page.

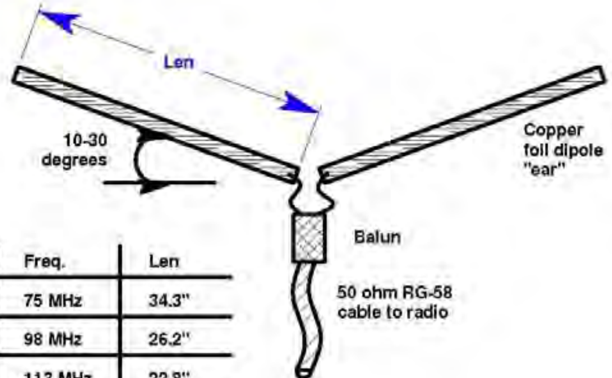


Canard Quick Disconnect		
Scale: NTS	Approved by: Jim Weir	Drawn by: OWJ
Date: 6 Jun 96		Rev: A
RST Engineering 13249 Grass Valley Ave Grass Valley CA 95945 916/272-2203 (voice & fax) rst-engr@oro.net		Drawing # 802-8904

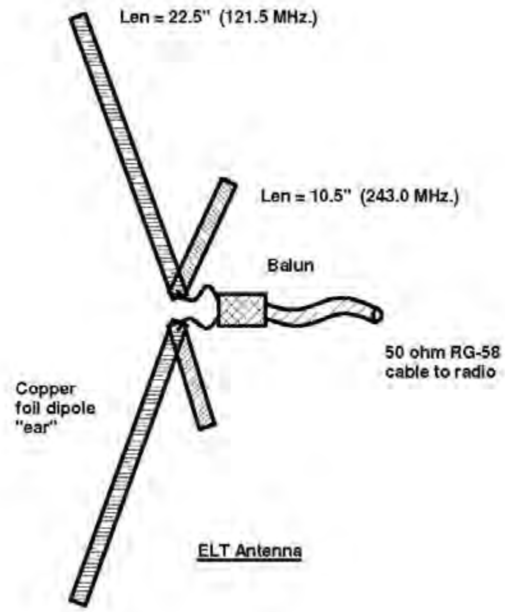
PLASTIC PLANE DESIGNS

The universal plastic plane VHF antenna has got to be the plain old copper tape dipole. Bonehead simple, difficult to foul up, cheap to make, and very adaptable to bending around, over, and under parts of the airframe. This antenna has been used by everybody from the first prototype of the EZ (Rutan and I hadn't met when he did the Viggen) through Voyager to some stuff that still isn't out of the Skunk Works.

The only real failures we have had with this design was when we tried gluing them onto the EZ gear legs. It seems that some EZ drivers tend to plant their machines firmly when alighting back on Earth (hello, Dick Rutan) and the copper tape was stretched well beyond its elastic limit, snapping it in two. So now we recommend several locations for dipole antennas on plastic airplanes:

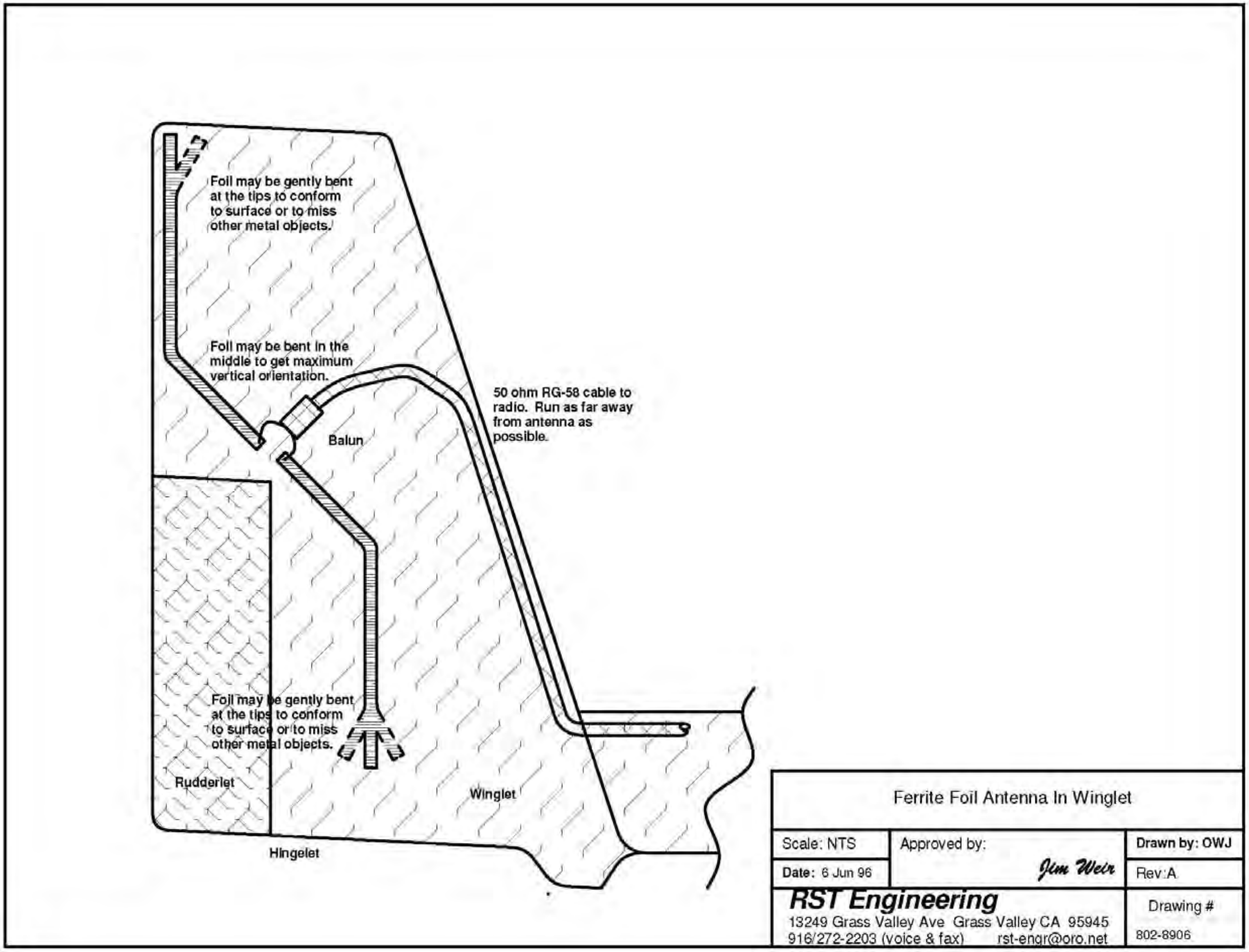


Service	Freq.	Len
Marker Beacon	75 MHz	34.3"
FM Music Radio	98 MHz	26.2"
VOR/LOC	113 MHz	22.8"
VHF COM	127 MHz	20.3"
Amateur 2m	146 MHz	17.7"
Glideslope	345 MHz	7.5"
General	F in MHz.	2575 / F

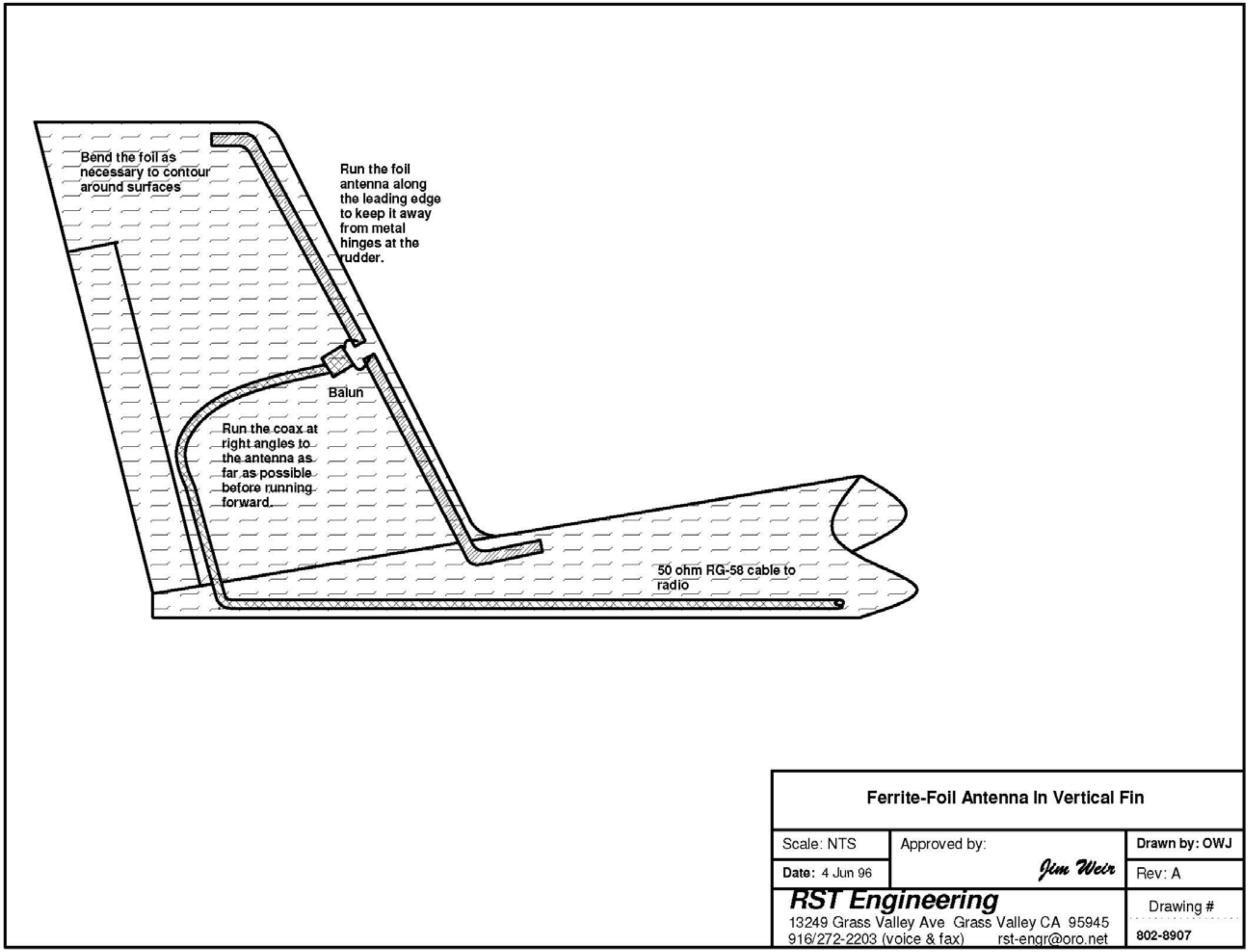


Ferrite-Foil Antenna Dimensions		
Scale: NTS	Approved by: Jim Weir	Drawn by: OWJ
Date: 3 Jun 98		Rev: B
RST Engineering 13249 Grass Valley Ave Grass Valley CA 95945 916/272-2203 tech@rst-engr.com		Drawing # 802-8905

1. In the winglet vertical for COM antennas.



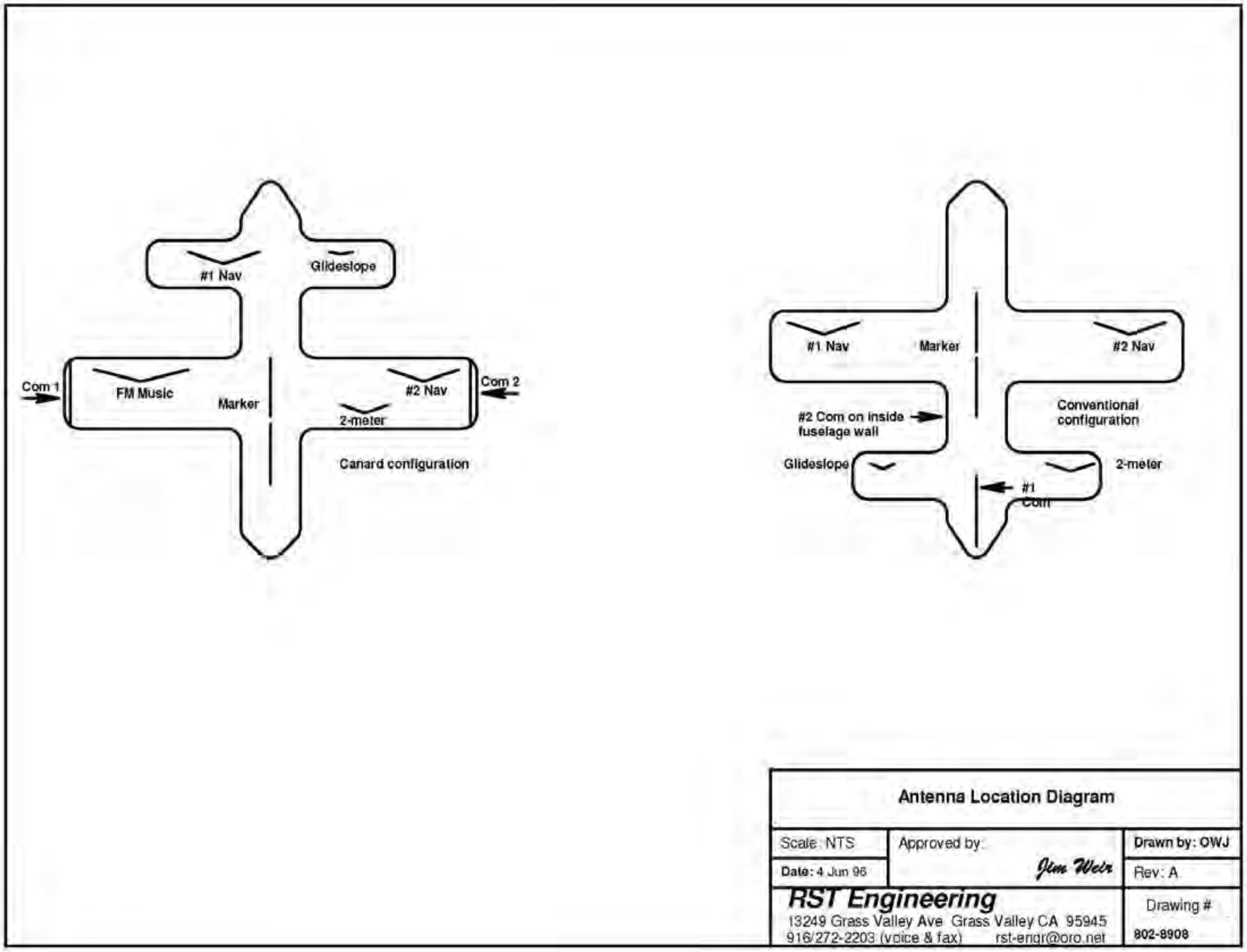
2. In the vertical fin (for non-winglet airplanes) for COM antennas.



3. On the gear leg curled up inside of a "soda straw" faired onto the front or rear of the leg so that the antenna can flex inside the straw on landing for COM antennas.

4. In the wing (or canard) horizontal for nav antennas, glideslope antennas, fm music radio antennas, and most other auxiliary antennas.

5. In the belly longitudinally for marker beacon antennas.



These antennas are made out of copper tape a little shorter than a quarter wave on each “ear” of the dipole and with a slight angle between the ears -- somewhere between 15 and 30 degrees off of 180º. Any smaller angle than this and we start to get the famous “hole in the donut” effect where there is a big null or hole in reception off the tips of the antenna. This isn’t a good idea in either nav or comm, so I recommend an angle (*) between the ears of the antenna in these cases.

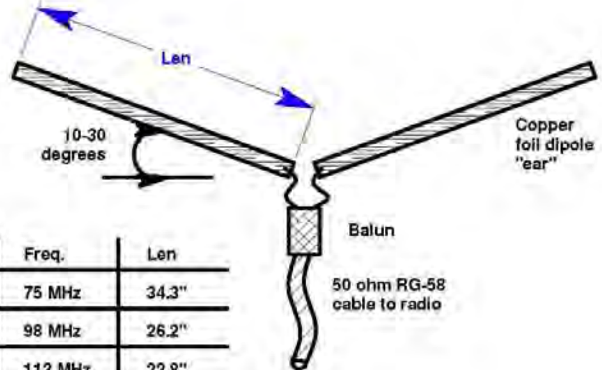
In the case of the marker antenna, we WANT a big hole fore and aft in the pattern, so the antenna should be laid out straight with no bends.

(*) One trick you can use if you don’t have room for a V-shaped antenna is to run the antenna straight and then bend the last 20-30% of the antenna at right angles both forward or both aft to achieve the same effect as the whole antenna being bent.

6. One very special case of antenna that we haven't yet talked about are ELT antennas. This is kind of a specialized case of the VHF com antenna, but there are a couple of things that make it a little more difficult than just the plain old copper dipole antenna.

In the first place, we hope we never get to use the antenna. On the other hand, if we DO need to use the antenna, it is probably the most important antenna on the airplane. For this reason, it needs to be firmly attached to what you suspect will be the largest fiberglass piece of the wreckage. A lot of folks are using the back seat or bulkhead area between the rear seat passenger and the aft fuselage. Some folks are using leftover space in the wing. Wherever it goes, remember two things. One, the antenna does you no good if the coax between the ELT and the antenna breaks. Locate the ELT as near as reasonably possible to the antenna. Two, since we can't guarantee the final orientation of the pieces, whether you make the antenna horizontal or vertical makes not a whit of difference. I prefer vertical, but it is not as important to make this antenna vertical as it is to make the com antennas vertical.

In the second place, this antenna needs to cover two widely separated frequencies – 121.5 MHz. and 243.0 MHz. The easiest way to do this is with a double-V antenna as shown on the next page. Just don't forget the little toroids to make sure that all the power the ELT has goes into the antenna and not reflected back down the coax. The angle between the V isn't critical; it can be anywhere between 30 and 90 degrees. Just keep the short and the long antenna elements on "opposite" sides of the antenna, but even these elements should have an angle between them as shown.



Service	Freq.	Len
Marker Beacon	75 MHz	34.3"
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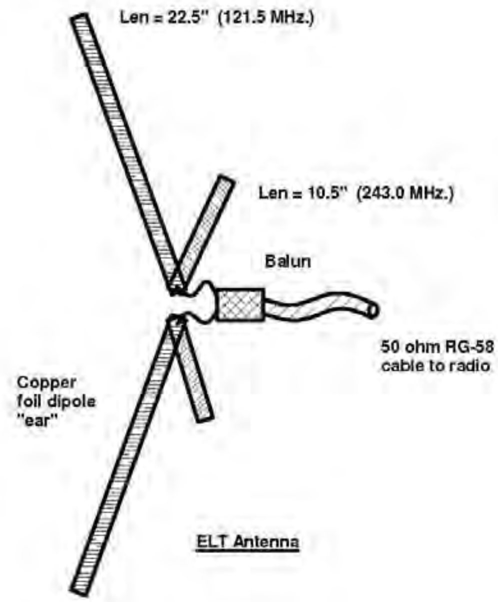
General	F in MHz.	2575 / F



Ferrite-Foil Antenna Dimensions

Scale: NTS	Approved by: *Jim Weir*	**Drawn by:** OWJ
Date: 3 Jun 98		Rev: B
RST Engineering 13249 Grass Valley Ave Grass Valley CA 95945 916/272-2203 tech@rst-engr.com		Drawing # 802-8905

There are other antennas that we use on aircraft -- transponder, DME, GPS, and Loran, just to name a few. While there are some tips and techniques that I can share with you, these radios come with their own antennas that you need to know how to mount in your airplane.

1. Under the seat cushions or in the strake vertically on a thin metal (”pie plate”) horizontal ground plane for transponder and DME antennas. The most common transponder/DME antenna supplied with your radio will undoubtedly be a little silver rod with a silver b-b on one end and a BNC panel mount connector on the other end. If you are going to conceal this antenna in the belly or in the strake, this is EVERY BIT as good an antenna as the little aerodynamic blade, just not quite as pretty (and concealed, what’s the difference?).

The MOST IMPORTANT thing to provide the antenna is a good ground plane. This is nothing more than a piece of metal (thickness absolutely not important) cut so that one of the principal dimensions is 5½” and with a 3/8" hole in the center to mount the antenna rod and connector. If you are making it a circular groundplane, then the diameter should be 5½”. If you are making a rectangular groundplane, then each side should be about 4½” long so that the 5½” dimension is in between the 4½” sides and the 6½” hypotenuse of the square. If you want to make it octagonal or hexagonal or pentagonal or any shape you want, have at it. Just remember that it should be roughly symmetric about the center antenna rod.

This antenna should be mounted so that the antenna rod is vertical to the earth’s surface and with the tip of the rod pointing down at the earth. It is certainly permissible to bolt or solder small tabs on the ground plane to attach it to the airplane’s structure, and it is also permissible to drill small holes in the ground plane for the same reason.

If you have a large expanse of metal in the airplane, will this work for a ground plane? Yes, most certainly. If it is many times the 5½” dimension then you rapidly get to the point of diminishing returns. What you want to avoid is a ground plane TWICE or FOUR times the 5½” dimension, as you now have a halfwave groundplane that isn’t any good at all. In short, if it isn’t 5½” then it should be at least 16.5” in all dimensions.

Just one aeromedical fact of life for your contemplation. Just like you wouldn’t stick your fanny in a microwave oven, neither should you needlessly expose yourself to airborne microwave radiation. If your body can “see” the radiating rod of this antenna (even though there may be fiberglass or other plastic in the way), you owe it to yourself to shield yourself from this antenna. The cheapest, easiest, and lightest weight way I know of is to put an aluminum foil sheet between your body (or the most sensitive parts thereof) and this antenna. This may take the form of aluminum foil glued to the back of the seats or to fiberglass bulkheads or small aluminum foil “deflector plates” strategically located between the crew compartment and the antenna.

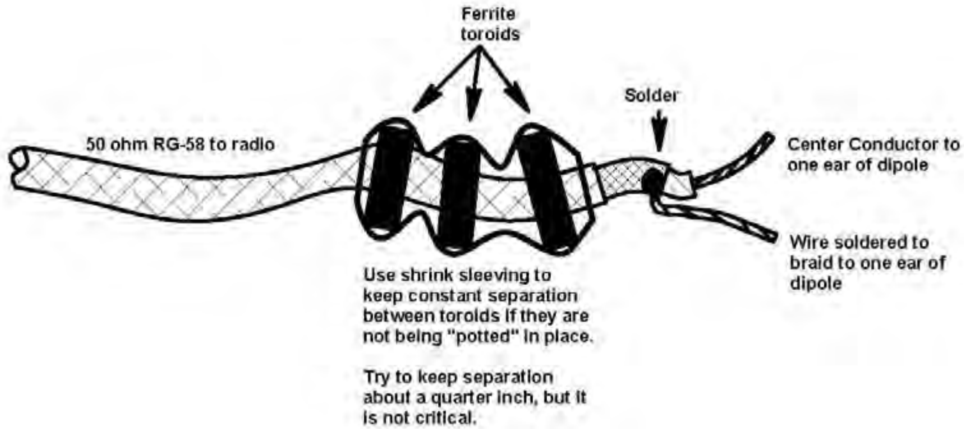
2. Likewise, GPS antennas come from the manufacturer of the GPS. Most GPS antennas are self-contained and do not need a separate ground plane. If your antenna does require a ground plane, a square of thin metal 1¾” on a side (or odd multiples -- 3, 5, 7, etc.) will work for both the 1.227 GHz. hi-resolution and 1.575 GHz. regular accuracy modes.

BALUNS AND SPLITTERS

This is probably as good a place as any to talk about baluns and splitters. These little devils are the simplest things to design and yet the most misunderstood part of the entire antenna system.

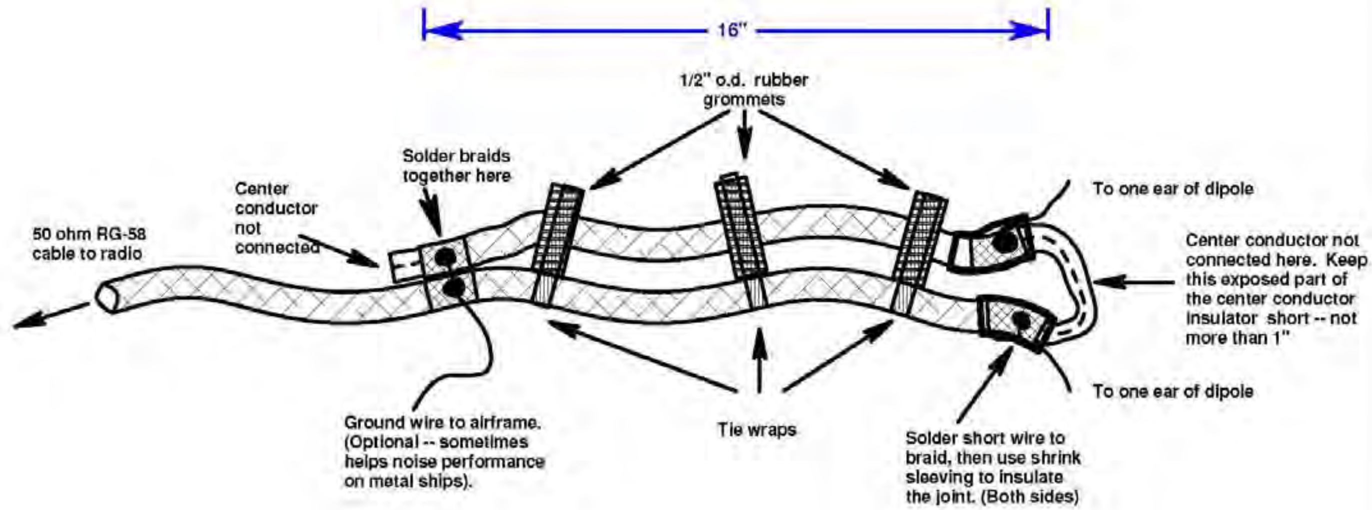
1. A BALUN (rhymes with Alan) takes a BALanced dipole antenna and matches it to UNbalanced coaxial cable. Now it is certainly possible (and I've done it myself from time to time) to connect the coax cable directly to the dipole antenna, center conductor of the coax to one arm of the dipole and braid of the coax to the other arm of the dipole and just let the reflected power worry about itself. You see, the only reason for a balun is to keep reflected power from traveling down the outside of the coax braid and radiating or reflecting into the rest of the airplane's electrical system along the way. There are several good ways to make a balun, but in airplane work (especially plastic airplane work) two ways predominate -- ferrite bead baluns and coaxial baluns. Each has their good points and their bad points.

A ferrite bead balun is nothing more than a one-turn inductor inside a ferrite toroid (pronounce TOW-royed) core. All we are trying to do is to use those little ferrites (which are a special grade of powdered iron mixed in a glue that separates the little grains of iron from one another) to strip off any reflected power from the antenna before it can get into the electrical system. Generally we use three beads for a VHF antenna. The first bead will take off 90% of the reflected signal, the second bead will take off 90% of the last 10% (a 99% reduction) and the third bead will take off 90% of the last 1% that is left, giving us somewhere around a 99.9% perfect balun. And, since the ferrites aren't "tuned" the balun will be "good" across the entire aircraft band so that we don't have to worry about the balun not being tuned properly.



Ferrite Balun Construction		
Scale: NTS	Approved by: Jim Weir	Drawn by: OWJ
Date: 4 Jun 96		Rev:A
RST Engineering 13249 Grass Valley Ave Grass Valley CA 95945 916/272-2203 (voice & fax) rst-engr@oro.net		Drawing # 802-8909

There is another way to make a balun, and that is out of the same coaxial cable that you use for running the antenna to the radio. This, though, is a tuned balun, and will generally be "good" over a more limited range of frequencies than the ferrite balun. The up side is that it is cheap and easy to make. If space and weight are not a problem, then the coax balun may do your job for you. Note that with the coaxial balun that the center conductor of the coax does NOT connect to ANYTHING at the antenna end, only to the connector going to the radio at the panel end. This may seem strange, and if I go into the properties of quarter-wave transmission line transformers here, we will be reading until next Oshkosh. Trust me, the center conductor is only connected at the radio end.



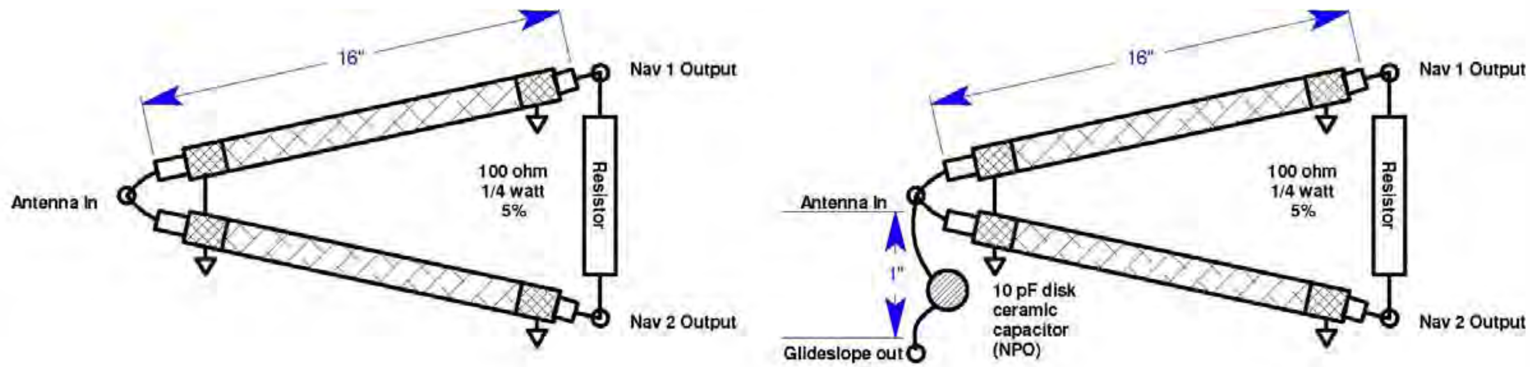
Coaxial Balun Assembly		
Scale: NTS	Approved by: Jim Weir	**Drawn by: OWJ**
Date: 5 Jun 96		Rev:A
RST Engineering 13249 Grass Valley Ave Grass Valley CA 95945 916/272-2203 (voice & fax) rst-engr@oro.net		Drawing # 802-8910

2. A SPLITTER is a trick little device that lets us run two VOR/LOC receivers (note clearly that I said **<u>receivers</u>**) from one antenna. Of course, nothing is for nothing, and the tradeoff is a loss of about 30% of the range of the receiver. That is, if one receiver is connected to your antenna directly and has a range of (let's say) 100 miles, then with a splitter on that antenna cable the range of the receiver is reduced to 70 miles. It does NOT matter whether or not the second radio is connected, working, broken, or even in the airplane. The splitter itself has an inherent split-the-power-equally loss of 30% and that is just as theoretically good as we can get. The good news is that there is nothing you can do with one of the outputs that will affect the other output in the least. There is no known defect in the #2 receiver that will cause any noticeable changes in the #1 receiver's operation, and vice versa.

This little gem was first proposed by a pretty smart engineer by the name of Wilkinson, and for that reason, you may hear it referred to as a "Wilkinson hybrid" or "Wilkinson splitter". At the risk of having the word spread that "Jim said it is OK to use 70Ω cable in the airplane", I will say that inside this coupler box is the ONLY place in the airplane that 70Ω cable should be used. 50Ω cable will NOT give the proper split, will destroy the isolation between the receivers, and in general, gum up the works. On the other hand, the cable to the antenna from the splitter and the cables from the splitter to the radios MUST be 50Ω for the system to work properly

It is also true that the VOR antenna and balun can be pressed into service as a glideslope antenna. It turns out that a quarter wave antenna and a 3/4 wave antenna have many of the same desirable characteristics. Since the glideslope band is almost precisely 3 times the frequency of the VOR band, a 1/4 wave VOR antenna is a 3/4 wave glideslope antenna. Coupling the glideslope signal from the VOR antenna is accomplished with a simple series resonant circuit -- and if you work the physical layout right, it only takes one component to do this. You see, the leads of a capacitor have some inherent self-inductance (about 20 nanohenries per inch). If you make the capacitor value resonate with the lead inductance, you have a series resonant circuit using only one component, a capacitor. In particular, if you use a 10 pF capacitor with one inch of lead length, it will form a series resonant circuit smack in the middle of the glideslope band. How to neatly make the capacitor have one inch leads? Put the antenna input jack and the glideslope output jack an inch apart. Then a 10 pF capacitor stretched between these two will couple almost all the glideslope signal from the antenna to the glideslope output with practically zero loss to the VOR signal going into the rest of the splitter.

Finally, it is possible to split off the marker beacon signal from the VOR antenna, but it isn't quite as simple as just a capacitor. RST Engineering is working on this project and we hope to be able to publish our findings in our forum at Oshkosh next year. It will involve some fairly sophisticated amplification and some moderately expensive filtering, but it will also eliminate having to construct or buy a separate marker antenna. Not only that, but a foil marker antenna is LONG (78" tip to tip) and won't fit in a lot of the smaller ships.



Antenna Splitter		
Scale: NTS	Approved by: Jim Weir	Drawn by: OWJ
Date: 7 Jun 96		Rev: A
RST Engineering 13249 Grass Valley Ave Grass Valley CA 95945 916/272-2203 (voice & fax) rst-engr@oro.net		Drawing # 802-8911

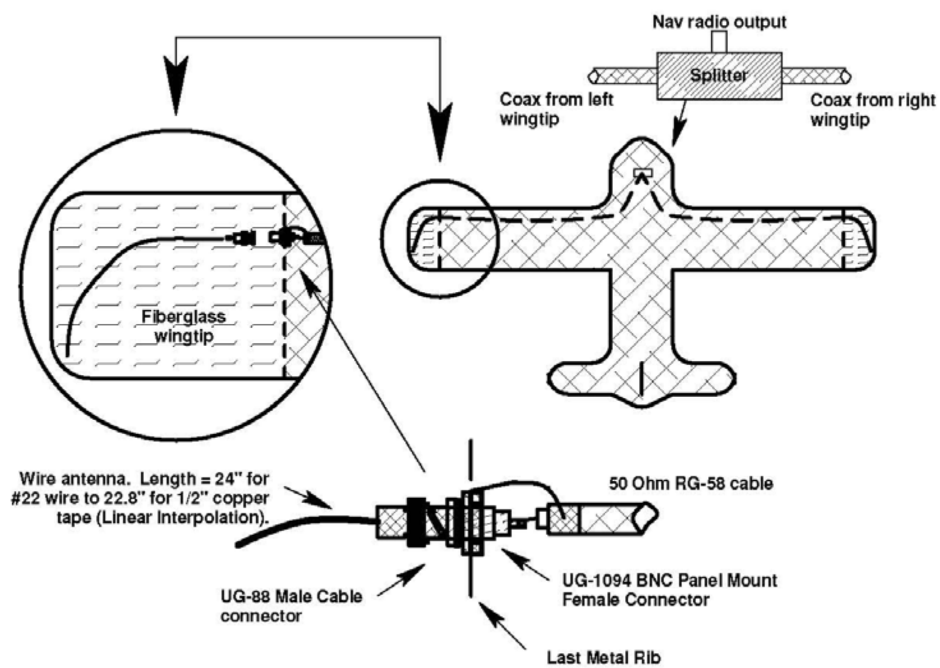
METAL PLANE DESIGNS

Metal plane designs can be used to try and hide internal antennas on both all-metal skin aircraft and steel tube and fabric aircraft. In both cases the trick is the same -- get enough of a plastic or fabric “window” so that the antenna can look outside of the ship to “see” the ground station that you are trying to communicate with. Some of the places we have hidden antennas on metal ships have been in the plastic wingtips, in the plastic dorsal fin structure, and in the plastic rudder tips. In all cases the procedure has been the same -- use the metal skin or tube as a ground plane and put a quarter-wave monopole above this ground plane.

Tube and fabric folks -- please understand this basic principle: A cagework of steel tubes is every bit as good a radio shield as a solid-skinned airplane. You CANNOT put an antenna inside of a metal-tube structure and expect even mediocre performance. You MUST use the tricks that we are about to develop for metal planes even though to the eye your airplane is 90% fabric.

1. COM antennas can be hidden in any vertical area where a 22” piece of wire or tape can be bent around as nearly vertical as possible. Remember, though, that the more metal you get near the TIP of the antenna the less it will act as an antenna. Some places clever designers have hidden the antenna have been in the dorsal fin fairing and in “droopy” wingtip plastic housings. In a droopy wingtip, put the tip of the antenna as nearly vertical to the earth’s surface as you can get it.

2. NAV antennas can be hidden in any horizontal surface where a 24” piece of wire or tape can be bent around as nearly horizontal as possible. Here, though, we are going to have to employ a little trickery to make the system work properly. If you put a whip antenna in just one wingtip, the reception to the side of the airplane without the antenna will be poor. For a nav antenna where you may want to cross-check your position with VORs on both sides of the airplane, or where you may be shooting a LOC approach in a crab, just using one whip would not be a good idea. Yet just putting a whip in each wingtip and joining them together under the panel with a T-connector isn’t the way to solve the problem either. You will have to use a HYBRID ADDER (which is nothing more than a plain old VOR/LOC splitter run “backwards” with the normal “outputs” connected one to each whip antenna coax) and absolutely equal (1” or 2 cm) lengths of coax cable coming from each wingtip whip to the adder. You can then use a second splitter in the normal way from the adder to split this added signal for two VOR/LOC receivers and a glide slope if you wish.

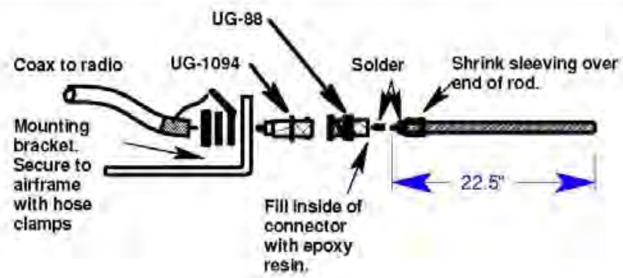


Wingtip VHF NAV Antenna		
Scale: NTS	Approved by: Jim Weir	Drawn by: OWJ
Date: 6 Jun 96		Rev: A
RST Engineering 13249 Grass Valley Ave Grass Valley CA 95945 916/272-2203 (voice & fax) rst-engr@oro.net		Drawing # 802-8912

There is a second class of metal airplane antenna designs, and that is where you really don't care about hiding the antenna, all you want to do is make a simple, cheap antenna that will work over a limited band of frequencies. Typically, an ultralight that wants an external antenna for a handheld transceiver falls into this category. There will also be times when a larger aircraft wants to hang an "experimental" antenna onto the airframe without a lot of drilling and sawing of metalwork. Herewith one idea for this class of antenna.

The radiating rod for this antenna can be made out of anything you want. The only caution is that somehow you will have to solder a small metal pin about the size of a #2 x ¼" screw onto the element to get it into the connector. In particular, I have used ⅛" brass brazing rod for this use and it performs remarkably well. Remember, though, that the thinner the rod you use, the narrower the bandwidth of the antenna. ⅛" diameter rod will cover the lower 5 MHz of the VHF COM band quite well -- from 118 through 123 MHz.; for most light aircraft uses, these are the common frequencies that you will need.

This antenna needs a ground plane, and the easiest way to get a ground plane in an ultralight or that class of airplane is to use worm clamps to attach the mounting bracket to the largest assemblage of metal sheet or tubing on the airplane. If the ground plane is SYMMETRIC (i.e. the ground plane metal is fairly equally distributed around the antenna) then the antenna pattern will be equally good from all directions. If the ground plane is all on one side of the antenna, then that will be the direction of best reception.



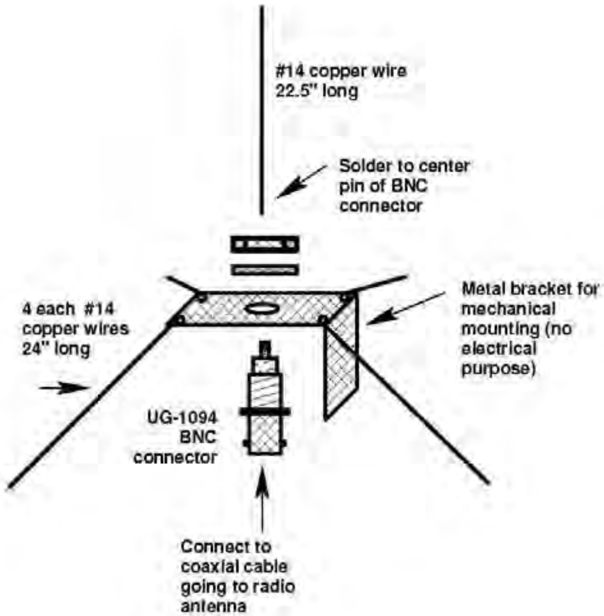
Quick And Easy Com Antenna		
Scale:NTS	Approved by: Jim Weir	Drawn by: OWJ
Date: 6 Jun 96		RevA:
RST Engineering 13249 Grass Valley Ave Grass Valley CA 95945 916/272-2203 (voice & fax) rst-engr@oro.net		Drawing # 802-8913

BASE STATION ANTENNAS

In most articles on “aircraft antennas”, there is a noticeable lack of the second half of the equation -- the ground station antenna that the airplane is going to talk to. Herewith two ideas for a ground station antenna, one for an “emergency cobble-up” antenna that can be made in five minutes using plain old Romex wire, a small scrap of PC board material or copper gutter flashing, and a BNC connector. The other one is for a quite elegant copper water pipe “plumber’s delight” base station antenna called a J-pole. Both antennas will serve their intended purpose quite nicely -- I have used the “Romex ranger” on search and rescue missions where I had to be packed an on the road in half an hour and then throw the antenna up into a tree with string and such at the other end of the journey. I have also made half a dozen J-poles for some of my friends that wanted a home antenna that looked like a professional antenna but at a tenth of the price. Both antennas have their place in our antenna arsenal.

1. The “Romex ranger” is nothing more than 5 pieces of #14 copper wire that you can get by cutting 2 lengths of house wire (14-2 w/g) 24” long, stripping all four insulated wires to make the four ground plane radials, using one of the bare copper Romex ground wires for the radiating rod, and discarding the sixth (bare) wire.

Drill a 3/8" hole in the 1” square copper p.c. board scrap or copper flashing scrap and mount a BNC panel mount connector (UG-1094) in the hole. Drill 0.062” holes near the 4 corners of the scrap (wiggle the drill around to open the hole up a few thousandths past 0.062” or use a slightly larger drill). Hook the ground plane bare wires through these four holes and solder each ground wire to the copper where it passes through the hole. Note: if you are REALLY in a hurry, you can eliminate the drilling of the holes and simply solder the wire to the copper, but the mechanical reliability won’t be quite as good. Now solder the radiating copper wire to the center pin of the BNC connector. Connect a coax cable between this BNC connector and your radio, and you are on the air.



Ground Station "Romex Ranger" Com Antenna		
Scale: NTS	Approved by:	Drawn by: OWJ
Date: 6 Jun 96	Jim Weir	Rev: A
RST Engineering 13249 Grass Valley Ave Grass Valley CA 95945 916/272-2203 (voice & fax) rst-engr@oro.net		Drawing # 802-8914

2. The J-pole is a little more trouble to construct, but I've been witness to it surviving 90 mile an hour winds, snow, rain, and all the rest of it without missing a beat. And, it can be firmly bolted to an antenna mast or a roof eave for a truly professional looking installation.

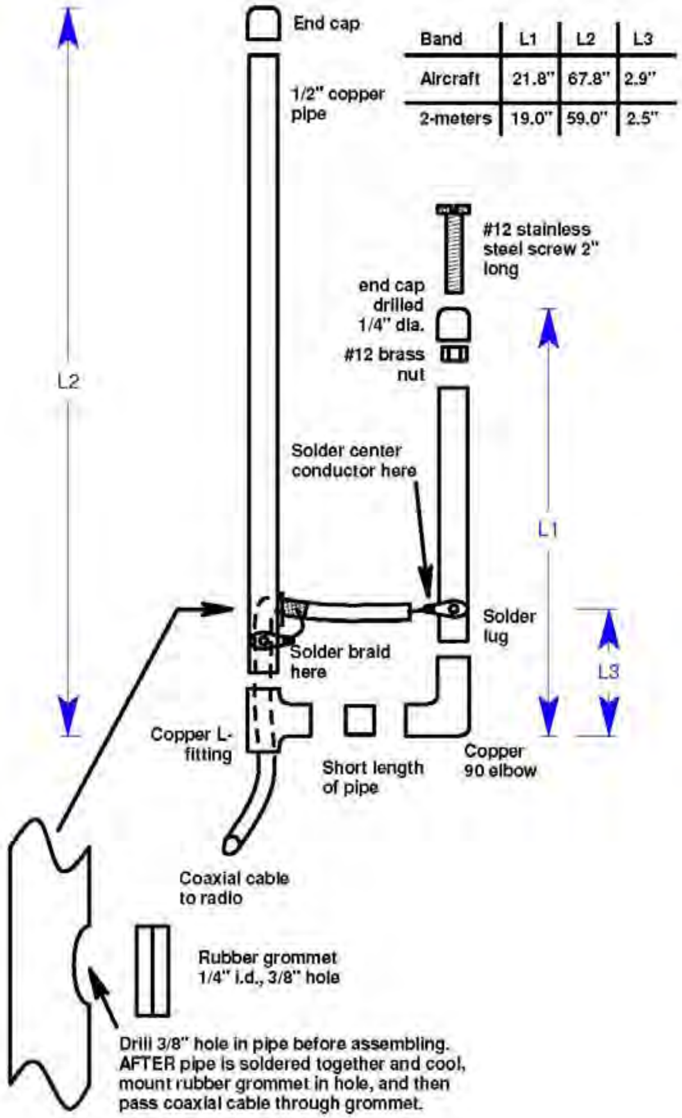
For this antenna you will need ½" copper water pipe, a ½" copper tee, and a ½" copper elbow. You will also need some small hardware (a #12 stainless steel screw, two #12 brass nuts, a rubber grommet, and a couple of solder lugs) and a BNC connector if you want to be able to disconnect the antenna from the lead-in coax cable. To make the antenna perform at the absolute peak of performance, you will also need an inline power meter or VHF standing-wave bridge (NOT a CB bridge).

This antenna will be one of the very few places in electronics that I will recommend the use of plumber's flux and even then, only where the copper pipe and fittings are being soldered together. It is also one of the only places where I recommend the use of a propane torch for putting things together -- but NOT around the coax cable.

One of the tricks of assembling this antenna is to drill the one end cap as shown, butter the brass #12 nut with enough flux to insure that the solder will make good electrical contact between the nut and the end cap, tighten nut inside the end cap with the stainless screw on the outside of the end cap, and then solder the assembly together. We use a stainless screw here because the solder will not adhere to the screw, but will solder the brass nut firmly to the copper end cap and thence to the copper pipe. The stainless screw will then be used to tune the length of the copper pipe exactly to your operating frequency.

The drawings only show that a copper tee is used at the bottom of the antenna. If you want to make a little mini-mast, simply solder on a piece (length not critical) of copper pipe onto the bottom of the tee and get the J-pole a little higher up in the air for better range. The bottom pipe can be bolted or clamped to anything without upsetting the antenna tuning.

Band	L1	L2	L3
Aircraft	21.8"	67.8"	2.9"
2-meters	19.0"	59.0"	2.5"



J-Pole Base Station Antenna

Scale: NTS	Approved by: *Jim Weir*	Drawn by: OWJ
Date: 6 Jun 96		Rev: A
RST Engineering 13249 Grass Valley Ave Grass Valley CA 95945 916/272-2203 (voice & fax) rst-engr@oro.net		Drawing # 802-8915

There is one other type of base station antenna we haven't talked about, and this is called a base matched halfwave dipole. It is a foil dipole mounted on a small wooden dowel and covered with a piece of PVC water pipe. The trick of this dipole is to get the coax cable to come out of the bottom of the water pipe without coupling to the bottom half of the dipole and at the same time to make the outer shell of the coax electrically "cold" so that you can mount the pipe to a metal antenna mast. The parts and plans for this antenna are sold as the RST-8710 vertical matched dipole Sorta-Kit.

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MORE INFORMATION

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