Radio Installations In Ultralights and Homebuilts

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With the cost of handheld VHF radios coming down many of us are now installing portable transceivers in our airplanes. These installations have met with varying degrees of success and I know many pilots who are very frustrated with the poor quality of reception after spending hundreds of dollars and hours of installation time.

In this article I will go over some of the basics and try to give you a picture of where the problems are and suggest solutions to these problems. There are two fundamental concerns that need to be addressed. These will lead into secondary concerns as we proceed. Right off the bat, I must emphasize that getting the most out of your radio installation is an art rather than a science. I cannot give you a set of procedures to follow that will produce the same results in every case. In addressing these problems I will give you suggested solutions, and as you implement these solutions you will find that some are very effective and others aren't. Each installation will be different. It is a matter of trying one thing after another until the results are acceptable to you for the use to which you will put your radio.

The first concern is that we want to maximize the capabilities of the radio that we purchased by providing it with the most efficient transmission and reception facility that our pocket book and imagination will allow. What I am talking about here is the antenna "system". Any radio is useless without the proper antenna system. Notice I said antenna system. There is much more to installing an antenna than simply connecting it to the radio. A poorly installed antenna can easily reduce the radio's efficiency by 50%. This may not matter, or even be noticeable, when you are only 2 miles away from the station you are communicating with, but at 40 miles it can mean the difference between communicating and not communicating.

By tuning our antenna system to peak performance, our radio will be able to get most of its transmit power out into the air, thus sending our signal as far as possible and it will also be able to receive desired incoming signals as strongly as possible.

The second concern is that we want to minimize the reception of background signals or noise that make it difficult to understand the desired signal. We usually call this noise RF interference (RF standing for Radio Frequency). We are constantly being bombarded by RF radiation from thousands of different sources. What we are concerned with is radiation that is at the same frequency, or in the same frequency range, that we are using. In the case of VHF radios we are using frequencies in the range of 118 to 135 Mhz.

We have no control over RF interference from sources outside of our airplane. But we can control, or try to control, the RF interference that is radiating from sources within our airplane. As we all know, the major source of this interference is from the ignition system of our engine. I will discuss ways of minimizing this radiation. By doing so we will improve the signal-to-noise ratio of the received signal and make listening to someone else's transmissions a whole lot easier. Generally speaking, attacking this problem improves our reception but does nothing for our transmission. When we come to it, I will point out one case where transmissions will benefit.

Antenna Installation

The installation of the "antenna system" is a very important part of the overall radio installation in your airplane. Your radio talks to the outside world through its antenna, so let's see how we can give your radio a fighting chance.

The first thing we need to do is understand the relationship between frequency and wavelength. We are going to "tune" our antenna to work best at the radio frequency we have chosen to operate at. These principles are the same no matter what kind of radio we are using. They apply equally to VHF and CB radios; transmitters, receivers and transceivers.

The frequency that our VHF transceivers operate at is in the range of 118 to 135 Mhz (million cycles per second). This is the frequency of the carrier signal onto which our voice signal is modulated. Even though our radio will operate over a range of frequencies, we will have to choose just one to tuned the antenna to. Most VHF antennas are tuned to 121 Mhz. This is approximately mid-way in the most-used range of channels. A channel is simply a discrete frequency setting. VHF radios have channel increments of .05 Mhz or .025 Mhz, depending on vintage. We will tuned our antenna to 121.00 Mhz.

In order to do this we have to calculate the wavelength of the radio waves at this frequency. The wavelength of any wave is equal to the velocity of propagation of the wave divided by the frequency (w=v/f). The velocity of propagation is simply the speed of light. After all, light is electromagnetic radiation just like our radio waves are. This is approximately equal to 300,000,000 meters per second. Therefore, the wavelength at 121.00 Mhz is:

300,000,000 mps / 121,000,000 cps = 2.5 meters

Now that we know this, what do we do?

Well, to start with we need the antenna. We can either make our own or buy one. The antenna is nothing more than a conducting rod or wire of the correct length. The ideal antenna length is 1/2 of one wavelength. The antenna will pick up many millions of radio waves of different frequencies that strike it all the time. What we want it to do is pick up the frequency we are interested in better than any others. By making it exactly 1/2 wavelength the antenna will resonate at the frequency we want, thereby picking up the desired frequency best. On an airplane, 1/2 of 2.5 meters (1.25 meters) is a bit long. By using a proper ground plane we can achieve almost the same results by making the antenna only 1/4 wavelength (I will explain how this works shortly). The difference in amplitude of the signal received is small and the antenna is much easier to handle, so normally we will make our antennas 1/4 wavelength in length. The important thing is to make the length as close to 1/4 wavelength as possible. In our case that is 0.625 meters (1.91 feet or 1'-10 & 15/16").

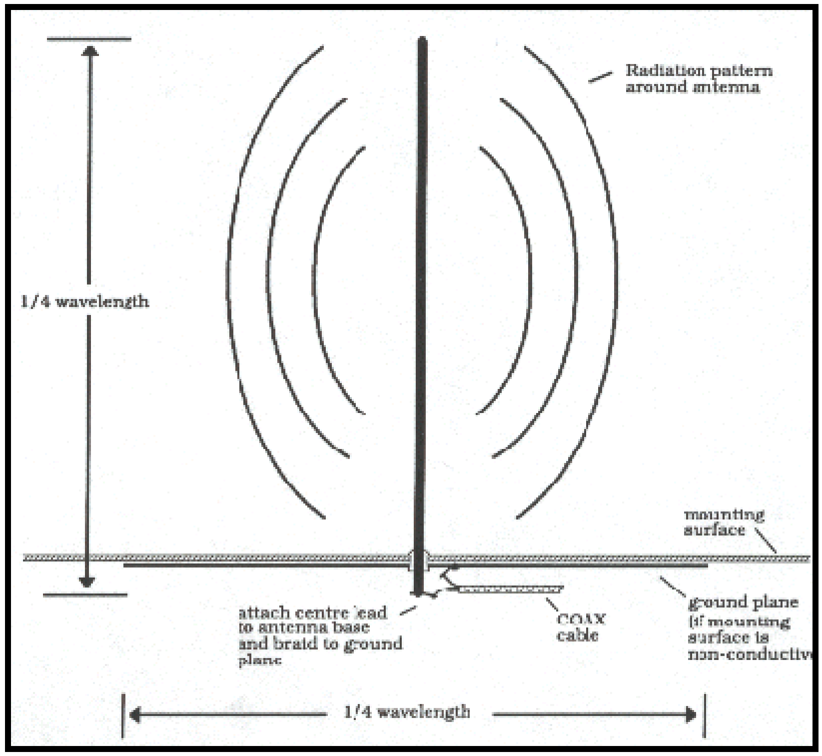

Figure 1

If you wish to make your own, select a suitably weather impervious conducting rod, stainless steel or brass, and cut it to 0.625 meters. From an electronics parts store you can pick up an insulated mount so that you can mount it to the airframe without an electrical connection to the surrounding surface. Drill and tap a small hole in the base of the rod and attach a solder lug with a machine screw. Our lead-in cable can then be soldered to this lug. Personally, I just bought an antenna for $75.00 from a local aircraft parts supplier. They can be ordered from catalogue shops for about the same price.

Before drilling a hole and mounting the antenna we need to consider location and a ground plane. The ground plane is a conductive reflecting surface, ideally metal, at the base of the antenna, but insulated from it. The electromagnetic signal which strikes the antenna gets converted to an electrical signal conducted by the antenna. The ground plane gives us a reference ground for this electrical signal. If you think back to your basic electricity in high school, you will remember that in order to measure a voltage difference you must measure between two points. Usually a "hot"contact and a ground. It's the same basic principle here. A metal ground plane will also reflect the electromagnetic radiation which hits it. This has the effect of doubling the length of the antenna to 1/2 wavelength. That's why we can get away with only a 1/4 wavelength antenna. To understand how this works, visualize a mirror lying horizontally and a stick extending vertically up from the mirror. When you look at it you can see the reflection of the stick in the mirror, as well as the stick itself, such that the stick actually looks twice as long as it really is. The light waves are acting in the same way that radios waves will act when we have our antenna positioned vertically over the ground plane.

On a conventional airplane the skin is usually aluminum which provides a natural ground plane. With ultralights or homebuilts the skin is usually fabric, maybe with some fiberglass or wood in spots. On some ultralights there is no skin (except on the wings - we hope). So select a suitable hard-surface location. If you don't have one, you will have to make one between tubes. On my airplane I have a fiberglass turtle-deck running the full length of the fuselage, which is perfect. Once you select the location, make a ground plane out of lightweight aluminum or a fine mesh. Make the ground plane at least 1/4 wavelength in diameter. It doesn't have to be round as long as it is at least this large. Fasten it to the underside of the hard surface with glue and drill a hole through the hard surface and the ground plane large enough to accommodate the insulated base of the antenna, then mount the antenna through this hole (see Figure 1).

I've put the cart before the horse here since we haven't selected the ideal location yet. Here's how to do this, and hopefully you will find a hard surface right where the ideal location is! First, we want the antenna to be as far away from the engine as possible. This is because we want to put some distance between our"ears" and the major source of RF interference in the airplane. If your engine is in front the best location will be on the back part of the fuselage. If your engine is a mid-ship pusher, you may be better off locating it at the front of the inter-wing gap or on the nose, if you have a cowling (see Figure 2). The antenna must be vertical for best reception and transmission. Note the radiation pattern in Figure 1. If the antenna were horizontal you can see that reception from forward and aft of the airplane would not be good. In the vertical orientation we will not have good reception from directly below, but this is not important since, if our target station is directly below us, it would only be a few hundred feet away!

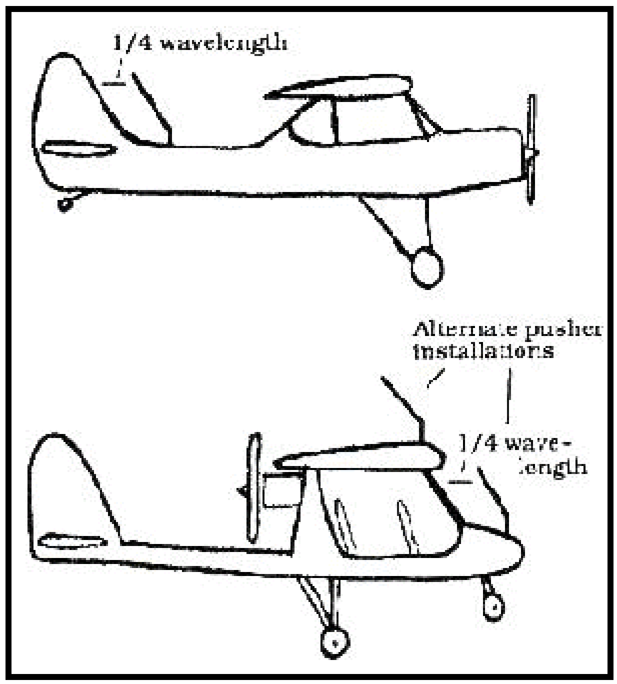

Figure 2

Commercially available antennas are generally bent backwards at about 30 degrees to the vertical. This reduces drag and also prevents the antenna from bending under the air blast. If you are making your own, bend the rod about 3 inches above the mount. Do not bend it more than about 30 degrees. (This also makes your airplane look pretty hot!)

The next consideration is the vertical stabilizer if we are locating the antenna on the aft fuselage. The antenna should be at least 1/4 wavelength in front of the vertical stab (.0625 meters).This will reduce the width of the "shadow" cast by the stabilizer from the rear and also will reduce reflections from the vertical stab. Remember what happens when your TV antenna picks upreflections? That's right, you get ghosting. The same thing can happen with audio signals which results in a blurred reception. Now that you have finally selected the ideal location, go ahead and drill that hole.

But we're not finished yet. Now we need to get the signal from the antenna to the radio. We do this with a length of Coaxial cable. Not just any Coax cable! It must have the correct characteristic impedance to match the radio input impedance. I won't go into explaining impedance, it will suffice to say that most radios have an input impedance of 50 ohms (consult your manual to verify this). The correct Coax to use is called RG58 which has a characteristic impedance of 50 ohms. If you were to use the wrong one, for example75 ohm Coax which is used for TV's, you would have an impedance mismatch between your lead-in cable and your radio. This would result in attenuation (reduction) and distortion of the signal. Source the right one. Next, cut it to the correct length. The lead-in cable must be in increments of 1/2 wavelength (1.25 meters). If 1.25 meters is too short to reach from your antenna to your radio,then make the cable 2.5 meters long. This should be long enough, but if not make it 3.75 meters, etc. Got the picture?

Finally, you have to terminate the lead-in cable. Most radios use a BNC type connector for the antenna input. This can be obtained from the same place you got your RG58 wire. Terminate the radio-end with this connector. At the antenna end, solder the inner conductor of the Coax to the solder lug at the base of the antenna. Attach the braid of the Coax to the groundplane. This is most easily done by soldering the braid to another lug and attaching the lug to the groundplane with a small bolt and nut. If you bought a more expensive antenna than the $75.00 one I did, it may come with a BNC connector at the base. If so, you simply have to terminate the antenna-end with a BNC connector as well. A good termination is important, so don't do a sloppy soldering job or a sloppy crimping job on the BNC. A bad connection will result in reflections and attenuation.

If you follow all these rules you will have an ideal antenna installation. Locating an antenna severalhundred, or thousand, feet above the earth is far less than ideal. But, if we are going to fly our airplanes, we have to make the bestof it. Remember what I said, each of these steps will result in a little better reception or transmission of the signal. It may be hard to tell the effect of any one step, but the accumulated effect of all these steps will make a significantdifference to the distance over which you can communicate.

RF Shielding

Once you have tuned you antenna, your radio is transmitting its signal and receiving the desired incoming signal as well as it can. There is one more serious problem that we have to attend to, however, if we are going to get the most out of our radio installation.

This problem is RF (radio frequency) interference from the ignition system in our airplane. First I will explain why an engine generates RF radiation, then I will discuss how to suppress it.

In a typical two cycle ignition system there is a magnet embedded in the flywheel and a coil of wire mounted next to the flywheel for each ignition circuit (spark plug). As the flywheel turns and the magnet approaches "it's" coil, an electric current is gradually built up in the primary circuit (see Figure 4). The primary circuit includes the points and the primary side of the ignition coil or transformer. As this current gradually builds so does a magnetic field in the ignition coil. As this magnetic field builds a voltage is also built up on the secondary side of the coil (the spark plug side). The voltage reached is proportional to the rate of change of the magnetic field. At exactly the right moment, as determined by ignition timing, the points open and the current suddenly stops flowing in the primary circuit. Without a current to sustain it the magnetic field in the ignition coil suddenly collapses. This sudden collapse induces a very high voltage in the secondary side of the coil and causes a spark to jump across the gap in the sparkplug. This in turn results in a very sudden and high current flow in the secondary circuit.

It is this very sudden and brief current flow through the secondary circuit and the spark jumping the gap that generates the RF radiation. The spark plug wire, coil and spark plug itself are acting as an antenna to radiate this energy. Because the secondary side is the high voltage side of the circuit, it radiates most of the energy. However, the sudden collapse of the current in the primary circuit will also cause some radiation from all of the elements in this circuit. This will include the wires between the ignition coil and the flywheel coil as well as the "kill switch" wires.

The radiation from the secondary circuit is of very high energy for a very short duration. It is omni-directional and chromatic in nature, so we know it is going to hit our antenna, and we can be sure that some of the radiation will be on the frequency our radio is tuned to. The result is a very short blip in our earphones. A 2 cylinder, 2 cycle engine turning at 5500 RPM is going to generate 183 of these "blips" per second. Add these up and instead of hearing a "blip" we hear a continuous "buzz".

Because this radiation is chromatic (covering all frequencies), it will actually dissipate rapidly and therefore will not travel very far. At a hundred meters or so away from the engine we would hardly notice it. This means that it will only interfere with the incoming, received signal and will not affect the transmitted signal. The station we are transmitting to will not "hear" our engine interference at all. So you don't have to be embarrassed thinking that the receiving station can detect your poor shielding job, only you can hear it.

Now that we know were it is coming from, how do we get rid of it? As with antenna tuning, we will start at the point of greatest benefit and continuing making smaller and smaller improvements until we are satisfied with the results. The majority of RF radiation comes directly from the secondary circuit which includes the spark plug, spark plug wire and ignition coil. The single biggest improvement comes from installing resistor spark plug caps. These have a resistor built right into the cap. On Rotax engines the resistor should be about 5000 ohms. My Rotax 532 came with them already installed. The brand is NGK and the part number is LB05EZ. If you are not sure if you have them or not, take an ohm meter and measure the resistance through the cap. It should be 5000 ohms + or- 10%. These caps can be obtained from a Rotax dealer or most motorcycle shops. If you have a different engine, check the manual or the manufacturer for the recommended resistor size.

I do not recommend inserting resistors into the spark plug wire itself (automotive shops have these) because this adds another point of possible bad connections and failure to the circuit. We don't need anymore potential for ignition failure than we already have!

The resistance will reduce the current flow and increase the duration which results in lower radiated energy. If you do not exceed the recommended resistor size it will not affect the potency of the spark.

This should reduce the noise in your earphones by about 50%. A boon to communications and longer lasting eardrums. This, however, will probably not be satisfactory. The next step is to start shielding. A shield is a metal conductor placed between the radiating antenna, in this case the ignition circuit, and the receiving antenna. This shield will absorb the unwanted radiation and, if it is grounded properly, it will drain the energy away to ground.

To start with, the metal structure of the airplane will provide some shielding, particularly if you have a metal firewall between the engine and your antenna. To make sure this is effective we must have a good ground connection between the engine and the airframe. You might think you already have one but don't forget that the engine is probably mounted on rubber lord mounts. So install a 16 or 18 AWG ground wire between a point on the engine and a bolt on the airframe. I use one of the bolts mounting a coil to the engine and a non-structural bolt on the airframe. Terminate the wire with proper spade or ring terminals to insure a trouble free connection. Do not use a structural bolt because even very minute currents in this conductor can produce galvanic corrosive action under humid or wet conditions.

The next step to improved listening is to shield the main source of radiation, which is the spark plug. The easiest and most effective way to do this is simply to purchase spark plug shields. These are made by several spark plug manufacturers and are available from many 2-cycle engine dealers. I have Bosh caps and shields on mine. This step should reduce the ignition noise to a trickle.

To test the results so far, sit in your airplane and tune the radio to the local tower frequency. Listen for chatter from air traffic, not the tower. Because you're not in the air you won't receive the tower well at all. Set the volume and squelch for normal listening and then start your engine. If the engine interference is strong enough to break the squelch, you still have a major problem, but it shouldn't be. Wait for more chatter from air traffic and pay attention to the background engine noise while you are receiving a transmission. Now rev your engine up and listen again. Decide whether the noise level is acceptable or not. If it is not then try more shielding, as follows. The next most beneficial step is to shield the ignition coils. The secondary side of the coil contains a lot of wire which is part of the spark plug circuit. The best material to use here is a thin copper sheet. This may be hard to obtain, so aluminum will do. You will have to design this yourself since the location and orientation of the coil(s) varies from engine to engine. The idea is to make a box around the coil that will stop RF radiation from propagating away from the coil. It is not necessary to carry this around between the coil and the engine since the engine will stop any radiation in that direction. Bend the copper or aluminum into shape leaving two or more tabs that you can drill holes in to mount the box, using the coil mounting bolts. This will also provide the necessary electrical grounding contact to the engine. Cut out a slot or hole through which the spark plug wire and primary circuit wires can pass. Be sure to smooth all edges that might wear through the wires. After doing this you may want to do another test to decide whether or not to carry on.

The next step in shielding is to attack the primary circuit elements. This consists of shielding the wires between the coil(s)and the entrance to the bell housing. Also included in this is shielding the kill switch wires which run to the cockpit. The wires to the bell housing can be shielded using expandable tinned copper braid. Remember to solder a ground wire to both ends of the shield and attach them to a convenient bolt on the engine. Rather then run a shield over the kill switch wires, it is easier to replace them with a two-conductor shielded cable. The cable will have a drain wire running through it, in contact with the shield, which is used to ground the shield at both ends of the cable. One end on the engine and the other on the airframe.

You have now done all you can to come between the RF radiation from your ignition system and your antenna. You should now find the level of interference quite acceptable. There are, however, two more things to keep in mind when hooking up the radio. There are two cables connected to your radio that we have thus far ignored. These are the push-to-talk switch cable and the headset cable. Both must be made with shielded wire with the shield properly grounded through the connector into the radio. If not, they will pick up what little radiation is left floating around and "pipe" it directly into the radio. Because th RF is being piped into the radio it will not only cause reception interference but this is the case where it can also interfere with your transmissions. If you buy a PTO switch it should come with shielded wire, but if you make your own, watch out for this.

I started this article with the statement that installing your radio is an art rather than a science. All I can suggest is to try these steps in order of importance, as they are presented. Stop when you are satisfied with the results.

Good communication is the key to success!