“Now that it’s built, where do I put the antennas?”

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Antenna placement is a problem we experience daily. The rabbit ears on the TV are able to pull in a signal, but if I move them a little, the picture would get much better. The FM rock station starts to fizz and pop when the car stops, but clears up when the car moves just a couple of feet. The building, overpass, the nearby hilltops all have an impact on the quality of your Cell phone or the number of bars. Your GPS system is lost inside a building. All of these are antenna placement issues. If you want clear radio reception in your car, don’t drive into a parking garage.

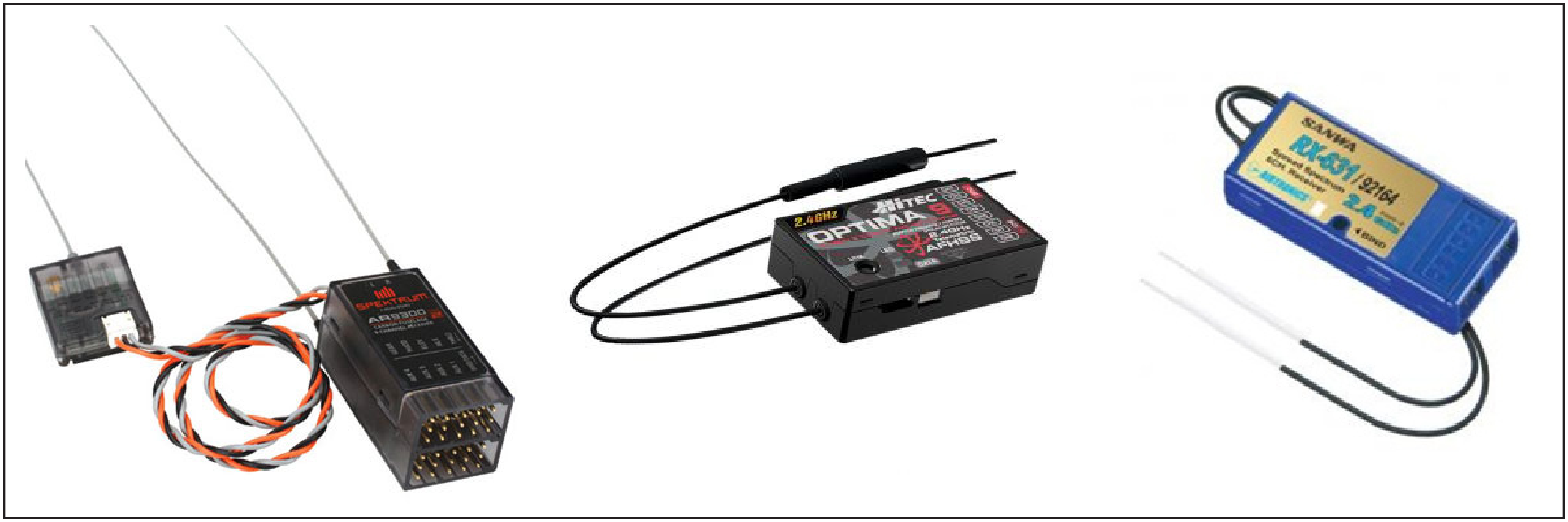
Unfortunately, like the car driving into a parking garage, aircraft are moving which means the quality of the signal at the receiving antenna is constantly changing.

When carbon/Kevlar weave fabrics were first used in fuselages, no one was ready for the problems it caused 72 MHz antennas. A bunch of solutions appeared, none of them pretty. The most common was a 36 inch long antenna dangling from the tail and swinging in the wind. In the end, it became the accepted method of antenna placement. No matter what you called it, it was an ugly compromise.

Years later, 2.4 GHz came along and changed the antenna rules again. A 2.4 GHz antenna is very short so dangling them out the end of the fuselage was no longer an option. Fortunately, as long as the aircraft is built with materials transparent to a 2.4 GHz signal you can place the antenna anywhere inside the aircraft. Materials like fiberglass, wood, Styrofoam and plastic are “transparent” to the 2.4 GHz signal.

Unfortunately, a 2.4 GHz signal is extremely poor at “bending” around materials that are not transparent. Things that can conduct an electrical current, like metal and carbon fiber reflect or block the signal. Your body and other items with a high water content, actually absorb the signal. Because of 2.4’s inability to “bend” around them, situations occur where the signal cannot be seen by the receiver. All of the 2.4 GHz systems have to deal with this issue. Fancy signal processing, antenna with cool names or more powerful signal amplifiers cannot “cheat” this law of nature.

Kit manufactures were caught off guard again. There was no way to install a 2.4 GHz antenna in some of these carbon fuselages. Some tried whiskers with varying degrees of success. It didn’t take



1. Contemporary 2.4 GHz receivers, all with multiple antennae. The Spektrum 9300 on the left has a satellite receiver as well.

long for model makers to start building "2.4 GHz ready" fuselages that replaced the carbon in the nose of fuselages with fiberglass/epoxy. Nonetheless, because of the cramped space inside many sailplanes, antenna placement is still difficult.

Diversity and Redundancy

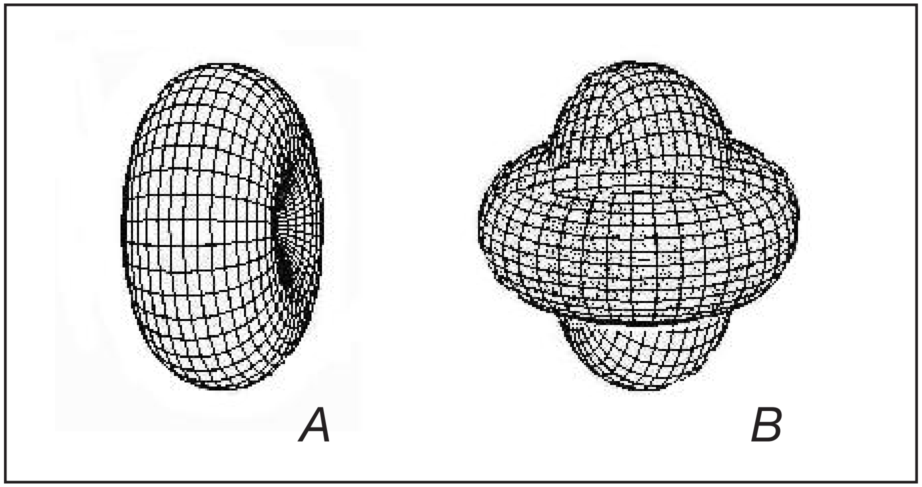
Antenna placement became more flexible when some of the 2.4 GHz manufactures started providing receivers with longer, multiple antennas. Internet chatter (by individuals, not brand representatives) concerning the reasoning behind two antennas was interesting to follow. One camp insists that their system is so good that it does not need a second antenna. The other camp claiming that two are always better than one. Today, nearly all the manufactures include a second antenna on their more expensive receivers. (See #1 above.)

But, no 2.4 GHz receiver actually "needs" more than one antenna. There is a lot of poor information (a combination of misinformation and speculation) on line concerning redundant receivers and antenna diversity. There is nothing complicated about the concepts. Frankly, both are just a little common sense.

(See #2, next page.) The first diagram (A) is an example of the "donut" reception pattern of a single antenna running through the middle of the donut. As you can see, when the antenna is pointed at the transmitter, there may be tremendous signal loss.

The second diagram (B) demonstrates a second antenna placed at a 90 degree angle to the first. The resulting reception pattern is known as antenna "diversity." The diagram should tell you everything you need to know. There is no magic here. 2.4 GHz does not "need" a second antenna, but it sure can't hurt to have one.

Some receivers, like the Spektrum 9300 in #1 above, have a second satellite receiver. This is known as receiver redundancy. We already have examples of redundancy in some RC applications.



2. Antenna reception patterns.

3. Above, no redundancy. 4. Below, redundant system.

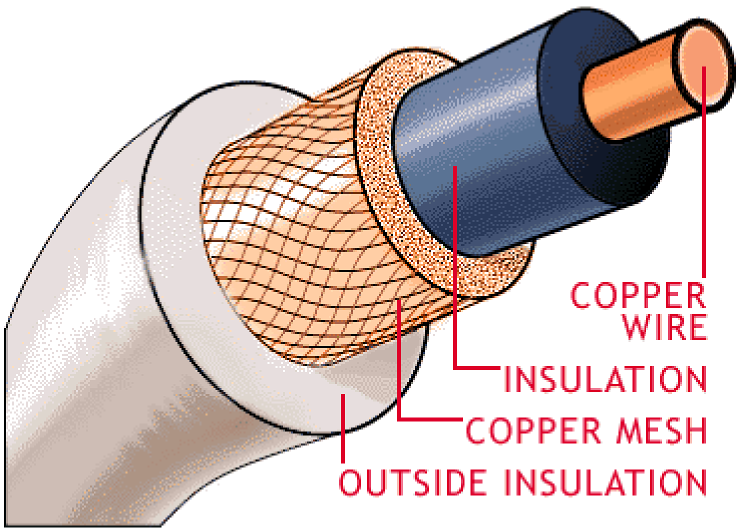
Larger RC aircraft with a backup battery have redundant electrical systems. Aircraft with two engines have redundant power systems.

Another example of redundancy is easily demonstrated with bridge design. Image #3 shows a bridge without redundancy. Remove a single leg and the bridge fails. When non-redundant systems fail, they fail catastrophically. The second bridge, #4, is an example of redundancy in the bridge supports. You can remove a leg or several sections of the bridge and the bridge continues to perform its task. Like the bridge in #3, 2.4 GHz does not “need” a second receiver. Like the bridge in #4, it can’t hurt. Similar to antenna diversity, there is no magic.

Combine antenna diversity with receiver redundancy and you have the best of both worlds. If your system allows for receiver redundancy you might as well use it.

Antenna Construction

With 2.4 GHz, the demands placed on antenna construction have also changed. A 72 MHz antenna could be made from just about any electrical conducting material as long as it was over



5. Co-axial cable construction.

two feet long. 2.4 GHz antennas are a different animal and are only 31 millimeters long. Today's longer 2.4 GHz antennas use a co-axial cable that allows you to move the antenna (the final 31 mm) away from the receiver.

Co-axial cable has a core wire surrounded by an insulator and a wire mesh jacket. (See #5 above) The wire mesh jacket shields the internal wire from radio signals. To work as a 2.4 GHz antenna, the final 31 mm of the wire mesh jacket have been stripped off the co-axial cable. This is the portion of the co-axial cable that actually "sees" the signal. You can shorten or lengthen the cable as long as the unshielded portion of the antenna remains 31 mm long. ***Do not*** clip off any of the unshielded portion of the antenna. If you do, it will significantly reduce the antenna sensitivity, reducing its range.

A radio signal will weaken as it travels from the unshielded 31 mm, down the core wire to the receiver. Obviously, you want to keep this loss to a minimum. Generally, the smaller the wire and the longer the length, the greater the signal loss. Signal loss also occurs at connectors, both crimped and soldered. A kink in a co-axial cable can significantly contribute to signal loss.

One of the factors that determine the quality of a co-axial cable is the distance between the center wire and the outer shielding. Imagine the center core wire traveling down the center tube from a paper towel roll. As long as the tube is keep straight, the tube maintains a common diameter and the imaginary wire running up the middle maintains a common distance from the shielding. Now bend the tube until it kinks and the tube flattens at that location. The distance between the inner core wire and the outer shielding is significantly reduced. A kink causing this sudden loss of thickness will increase signal loss of the antenna at that location.

The Corrupted Packet

Now that we have some basics down, lets shift back to the antennas in my aircraft. All of this data was collected from "2.4 GHz ready" fuselages and does not discuss antennas that exit the aircraft such as whiskers. I have permanently installed data loggers in each of my sailplanes and have kept notes of what works best. The data logger works because of the nature of digital communications.

Today's digital data is not sent in a continuous coherent stream. It is broken into "packets." The transmitter is only sending packets about 10 percent of the time. Yes, there are gaps between the packets. In addition, some of the packets may not be received or might be corrupted. In a direct sequencing system, corrupted packets are typically caused by something blanketing the antenna. The data logger records these corrupted packets as "fades." Recording corrupted packets for an individual antenna is useful in determining best antenna placement.

Unfortunately, this technique does not work with true frequency hopping systems. In addition to corrupted packets from a blanketed antenna, when a frequency hopping system hops to a channel that is already occupied, the packet is assumed to be corrupted and will be rejected. Because frequency hopping systems reject these packets as part of their interference avoidance architecture, it is impossible to tell if the packet loss is from a blanketed antenna or a signal collision during a hop. If the 2.4 GHz spectrum is crowed, the packets rejected from signal collisions may be very high compared to packets lost from antenna blanketing. The short version is that the data here would not help in antenna location.

The wireless transmission systems used by all the RC manufactures expect to have corrupted data packets. So many packets are transmitted in a very short period of time that random missing packets have no impact on the quality of the data stream necessary for flying RC aircraft. Because of the nature of the data stream required for RC, human reflexes and a bunch of other stuff, random corrupted or missing packets will not be noticed by the pilot in the field. If you are flying on 2.4 GHz now, you are suffering from corrupted packets and don't even know it.

In an effort to combat corrupted packets, every manufacturer sends redundant multiple copies of the same packet to provide the most coherent data stream possible (another example of redundancy). If the system rejects a packet, the duplicates will usually make up for it. Keep in mind that if the packets quit coming (transmitter died or you flew your aircraft behind a metal building) or a large number of simultaneous packets are lost or corrupted (antenna shielded by carbon or a big metal engine block) you might have issues.

In addition to reducing the impact of random corrupted packets by sending redundant packets, the significance of lost data packets is further reduced with antenna diversity and receiver redundancy. With proper antenna placement, a corrupted data packet received by antenna A may not be corrupted on antenna B. The impact is reduced again when receiver A may receive a corrupted packet, but receiver B does not.

The benefit of diversity and redundancy is demonstrated by the data logger. The data logger records corrupted packets as "fades" for each antenna. If all of the antennas suffer a fade at the same time, the data logger records it as a "frame loss." It is not unusual to have hundreds of fades in a flight and no frame losses. Diversity and redundancy work.

Before some of you start jumping off a cliff, a corrupted data packet will not cause your servos to imitate a Mexican jumping bean. Corrupted packets are simply rejected at the front end of the receiver and never make it to the servo amplifier. The receiver just holds the control surface in the last position until a new uncorrupted packet is received. Therefore, they have no impact on servo movement. ***Corrupted packets cannot cause an un-commanded servo movement in a 2.4 GHz system.***

The short version is that every 2.4 GHz system will have corrupted data packets. A perfect data stream is impossible; but at the same time, a perfect data stream is not required.

Antenna Location

By comparing the number of corrupted packets before and after antenna relocation, the best location and attitude of an antenna can be found. Record the information from different antenna locations, repeat the results in several different aircraft and a picture begins to develop. Share the information with others that can confirm the results in their aircraft and the picture becomes more clear.

Surprisingly, little thought is given to antenna placement when today's pilots assemble their airplane. Typically, where to install the antennas is left until the very end. And then the thought process is often limited to, "Ah, I'll just cram it in there." Unfortunately, the data indicates that haphazard antenna placement will significantly increase the number of fades.

To minimize corrupted packets, design your antenna placement with the following five rules in mind.

1. Place the antenna (the last 31 mm) in an area where it will not be blocked by carbon, batteries, electrical wires or metal or carbon pushrods.

2. Electrically isolate the antenna from all other wires, metal or carbon.

3. Orientate the antenna to achieve antenna diversity.

4. If antennas are too close, something blocking one antenna may also block the other. Install diverse antennas as far apart as possible.

5. Do not kink any antenna cables.

If you are a sailplane guy, you are probably thinking, “How are you gonna achieve all that in a lawn dart fuselage?” It’s a good question. By using the plastic tubes that come with the Spektrum 9300 receiver (or some other RF transparent tube), you can satisfy all five design rules.

The effect of the tubes on fade count was discovered accidently. Because the receiver is usually the last item squashed into the fuselage, antennas are kinked, pulled, stretched and wrapped around servo wires and batteries. It isn’t pretty. I realized that by installing the tubes before the servo tray and battery are installed, the antenna would wind up where I want it, not where I forced to stuff it. Later, simply slide the antenna into the tube just before the receiver is rammed into place. A little time prepping and installing the tubes makes the final installation easy.

There is something more about the tubes. I wish I knew why it happens. Simply placing the antenna inside the tubes results in a reduction of fades no matter where you place the tube inside the fuselage. (This is true in messy sailplane installations where antenna are rubbing the inside of the fuse, servos and the wiring harness, and may not have the same impact where the install has much more room.)

Now take the advantage of the tube and improve it again by installing the tubes in a way that each of the design rules are satisfied. After installing four tubes in a way that satisfied all five of the rules, the fade count on a ten minute flight dropped from the mid to high three figures to the low double or single digits. Although this reduction in fades seems high, there was no change in the frame losses. It was at zero before and stayed that way. The pilot did not notice any change.

Even though the system functioned the same, personally, I want as few fades as possible in my aircraft.

The Installation

Image #6 is the antennas install in a new Tragi 801 also known as the “Cluster.” The red and blue indicate the antenna tube. The red portion is the last 31 mm of the antenna, the part that “sees” the signal. All five of the design rules are satisfied.

1. The antennas are not blocked.

2. The tube electrically isolates the antenna from all wires.

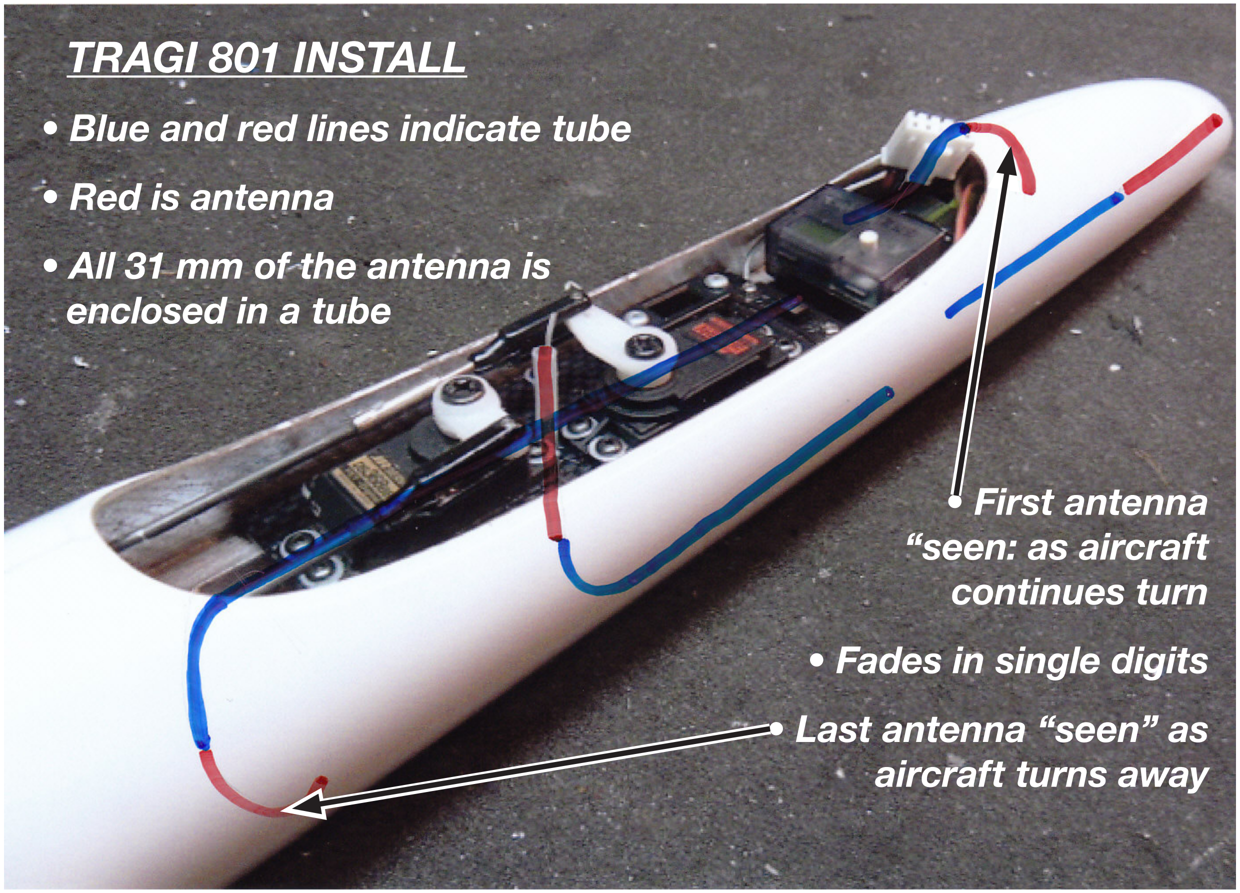
3. The antenna orientation is diverse.

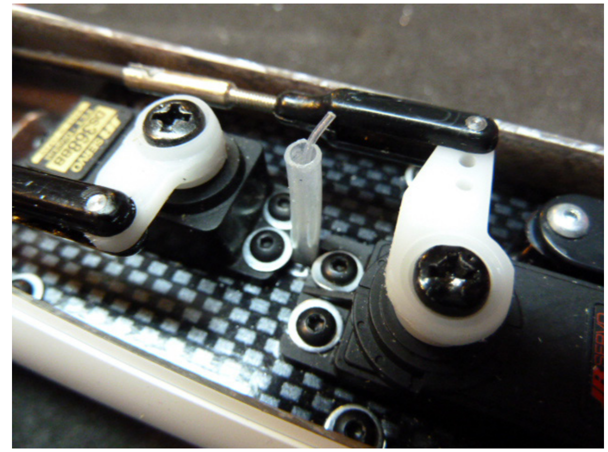
4. The antennas are as far apart as possible.

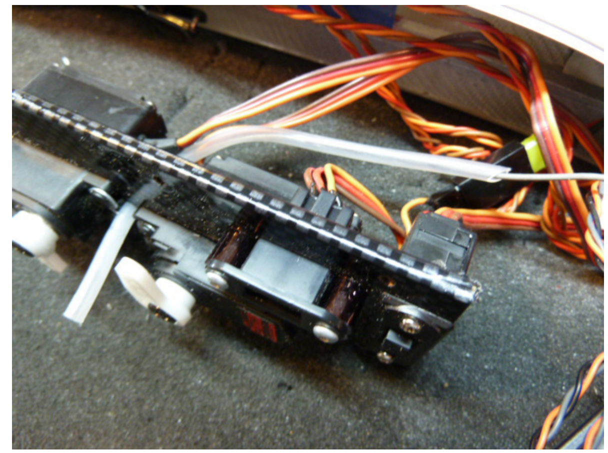
5. None of the antenna cables are kinked.

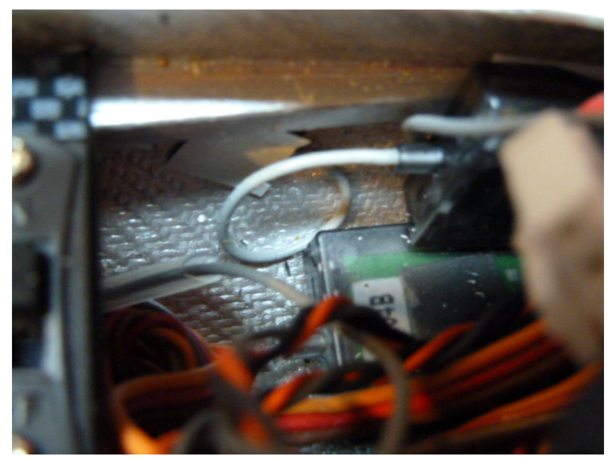
The planning for this install started with looking at the aircraft in flight. If you want to put all the antennas in the nose, start by figuring out what is the last portion of the nose of the fuselage you see as the aircraft turns away just before it is blanked by the wing. Then determine what is the first part of the fuse you see as the nose appears from behind the wing. (This same analysis works for any type or aircraft.) The antenna in the bottom of the fuse just ahead of the wing is the last seen. The antenna in the top of the fuse just ahead of the canopy is the first. These two antennas get the most attention in my installation.

This aircraft uses a 2100mAh LiFe battery so the space ahead of the battery was open and became the location of the third antenna. The last antenna was at 90 degrees to the one in the nose and was mounted between the servos. (See #7 and #8, next page.)





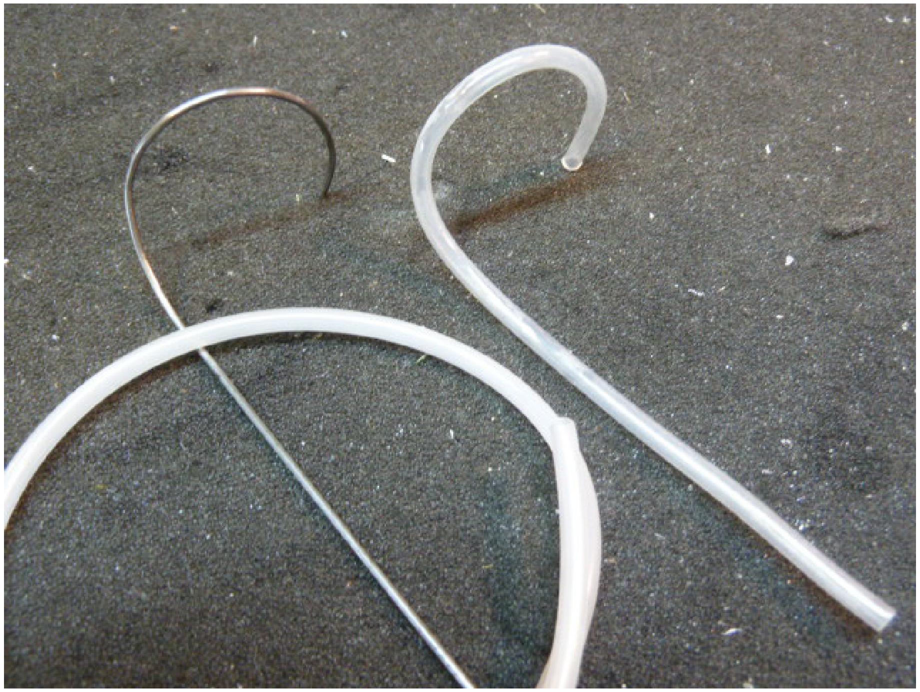




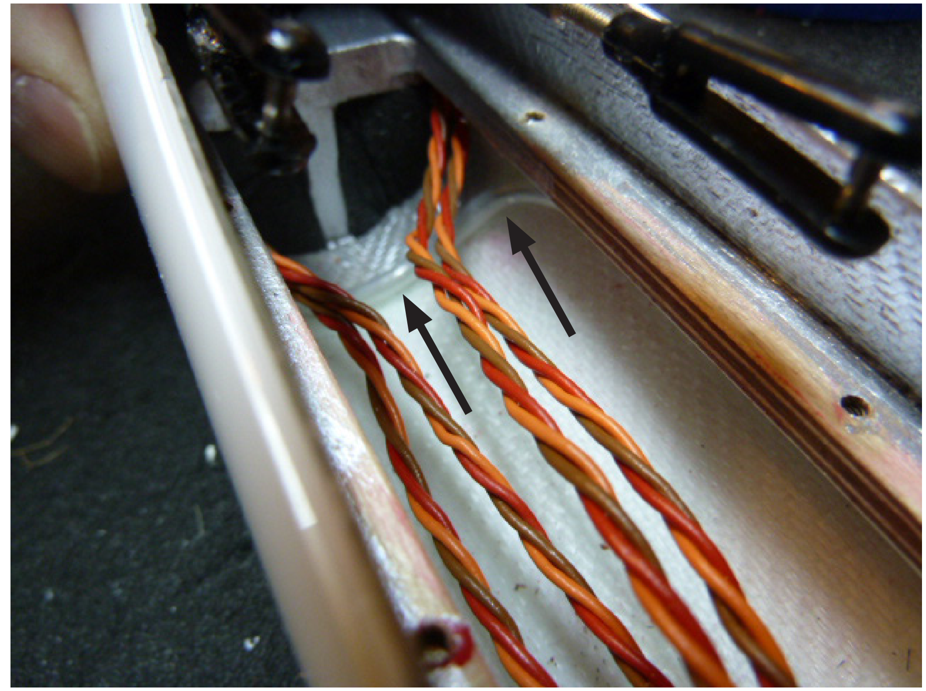
6. Above, Tragi 800 install. 7., 8, and 9. From top on right, showing tube installations.

As you can see, some of the tube shapes are fairly complicated. Fortunately, it is simple to pre-shape the tubes by sliding them over a bent piece of piano wire, heating the tube up, cool it in water and then slide the tube off the wire. (See #10, next page.) Cooling in the water is VERY important. The water provides a lubricant so the tube slides off the wire more easily. You wind up with a compound curved tube that fits and only need to be tack glued in place. Make sure you rough up the outside of the tube or wrap masking tape around the tube where you expect to use glue.

The tube in #9, right, and #11, next page, runs under the edge of the servo tray and then down and over the bottom of the fuselage. A similar tube was formed for the



10. Tube shaping.



11. Curved antenna tube under servo tray.

antenna that curves around the upper fuselage just ahead of the canopy. Notice how there are no kinks in the antenna wire because of the tube.

As you can see, planning where to place the tubes has to be done long before cramming the receiver into the fuselage. The result is a much better installation and in the case of 2.4 GHz, fewer corrupted packets.

In Closing

I have seen installations of all the 2.4 GHz brands. In one, the antennas were wire tied to the wiring harness (I was dumbfounded), in another they were wrapped around the receiver and held in place with a rubber band (I was speechless.), and in many, the antenna is just stuffed into all the other wires (You have got to be kidding me!). Amazingly, they worked OK. I think it just shows how well the 2.4 GHz systems work even when the pilot tries to kill his aircraft with a poor installation. Although sloppy installations seem to work, do you really want to decrease your signal strength, reduce your sensitivity and limit your range?

This exercise confirms that lost packets at a particular antenna (fades) are covered by the second antenna in nearly every case. A typical flight results in many fades on an individual antenna but in few or no frame losses at the receiver. In addition, the number of fades can be further reduced with good antenna placement. The fewer fades, the less likely you will have a frame loss.

Try this in your own aircraft and let me know what you think. Send me an email at duworm@aol.com.