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Chapter 28

Antenna System Troubleshooting

Even with commercial equipment, there is not a single amateur who, at some time, has not introduced an error into the antenna system either during installation or use. Similarly, of course, nothing remains faultless forever and those are the subjects of this chapter — finding the errors and faults. The first section of the chapter is directed at the beginner, providing a structured process to hunt for and find the problem. It is adapted from the Wireless Institute of Australia *Amateur Radio* magazine's excellent series of "Foundation Corner" articles for new hams. It was originally written by Ted Thrift, VK2ARA, and Ross Pittard, VK3CE. The second section of the chapter is more detailed and assumes more technical background on the part of the reader. It is adapted from material written by Tom Schiller, N6BT, as part of his book *Array of Light*, *3rd Edition* (**www.n6bt.com**).

The goal of this chapter is not to provide an exhaustive procedure that can be followed "cookbook-style" to troubleshoot any antenna or antenna system. There are just too many variables and configurations for that to be possible. Rather, this chapter suggest systematic approaches and general guidelines to apply in order to find problems. Once problems are identified, the solution is usually obvious and even trivial.

Anyone with experience in maintaining or building systems of more than a few parts — whether related to Amateur Radio or not — will recognize the value of a systematic approach to troubleshooting. The underlying lesson in this material is that carefully analyzing a problem with a step-by-step approach pays off in effective troubleshooting, saving time and expense. This is true for antennas, transceivers, computer systems — any sort of technology. Whether the reader is just getting on the air or has a lifetime of experience, there is something for everyone in this chapter.

The final section of this chapter is more about maintenance than troubleshooting but the two are so closely linked that the information will be helpful. It is another adaptation from the WIA *Amateur Radio* "Foundation Corner" columns, this one written by Ross Pittard, VK3CE, and Geoff Emery, VK4ZPP.

28.1 ANTENNA SYSTEM TROUBLESHOOTING FOR BEGINNERS

So you can no longer hear anything and you think your antenna system is faulty. It is very likely that it is, or at least some part of it is faulty. To repair the fault, we first have to find it. To do this we have to treat your antenna system in exactly the same way as fault finding inside a radio. After all, it is an electrical circuit and if not completely correct, will not work in the way that you expect. The process described in the rest of this section can be adapted to most simple antenna systems similar to that shown in **Figure 28.1**.

Start with an inventory of the antenna system. Any of these can be the cause of your problem:

- The support poles and ropes
- The antenna insulators
- The antenna elements
- The feed point or balun
- The feed line
- The entry point to the shack
- The jumper cable to the radio

A *jumper cable* (also called a *patch cable*) is a short piece of coaxial cable with RF connectors on each end. It is used to connect two pieces of equipment together. The discussion below assumes that you have a coaxial feed line to the antenna.

Determine the characteristics of the antenna you are troubleshooting:

- Is it a balanced half-wave dipole?
- Is it an off-center-fed (OCF) dipole?
- Is it a multiband antenna, for example, a G5RV?
- What is the primary band it is designed for?

Consider the characteristics of the radio as well:

- Does it have a built in antenna tuner or do you use an add-on antenna tuner?
- Can you transmit a carrier signal on any band?
- Can you adjust the power level of the carrier?

During the following sequence of testing, be alert for mistaken or loose connections, loose or disconnected power and control cables, wires touching each other that shouldn't be, and so forth. Your main system components may be just fine but not connected properly. This is *very* common!

If you haven't started one yet, this is a great time to start your "shack notebook" in which you record how your station is built. This is where you write down test results, color codes of control cables, modifications to equipment, dates of installation, etc. This information can be a huge time-saver in the future when you are troubleshooting or designing an addition to the station. A spiral-bound or composition book of graph paper is the best option, but a loose-leaf binder works well, too. Remember to put the date on each page as you make an entry.

28.1.1 BEFORE TESTING

If your radio has a built in auto tuner it has by now attempted to match your antenna system, faults and all. You may have also tried other bands to see if you can get "something" to work. To find the fault we must test the system *on the primary band for which it was designed*. Keep this in mind when you start testing.

Test Equipment

In addition to your radio, you will need at least the following items.

- A suitable power/SWR meter.
- A volt-ohm meter to check continuity of cables and wires.
- A suitable 50-Ω dummy load.
- At least two tested and known-good 50-Ω jumper cables.

28.1.2 INITIAL TESTING

This is to ensure that both your radio and your test equipment are working correctly.

1) Remove the antenna coax and connect your test jumper cable.

2) Connect the other end of the jumper cable to your power/SWR meter.

3) Connect your dummy load to the power/SWR meter.

4) Set the power range on the meter to a high scale to prevent overload.

5) Set the radio to the antenna's primary band and engage the auto tuner to tune to the 50-Ω dummy load.

6) Set your radio to CW, AM or FM.

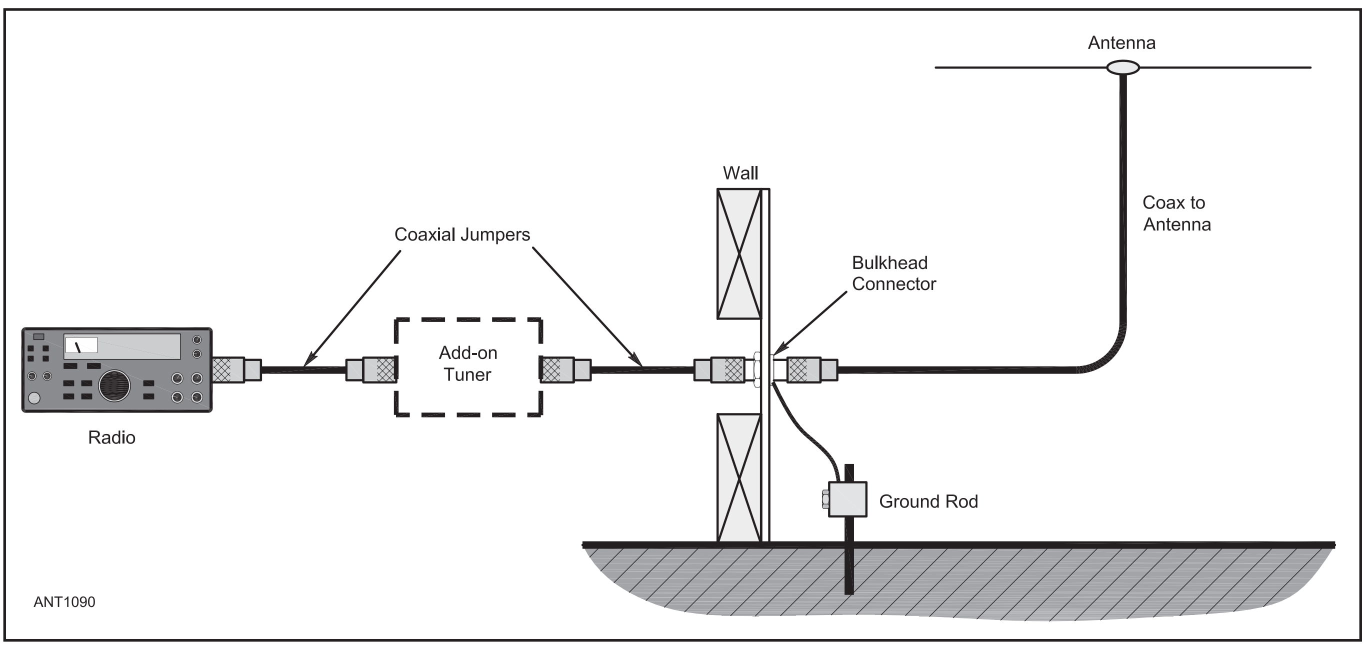

Figure 28.1 — A typical simple antenna system. If the transceiver does not have a built-in auto tuner, an external add-on tuner may be included in the system. It is good practice for the antenna cable to enter the shack through a connector on a grounded wall panel. This bulkhead connector is often a lightning arrestor, as well. Coax jumpers connect the various pieces of equipment together.

7) Adjust output power to minimum.

8) Press (PTT) and adjust output power to (say) 5-10 W.

9) Check that the power indication in the radio and the power/SWR meter are similar.

You have now set a benchmark with known output into a 50-Ω load. *This is an important step*. Do not change any settings on your radio until all tests are completed and the faults fixed.

28.1.3 ANTENNA SYSTEM TESTING

Your Second Test

Here is where we start to eliminate possible causes of your problems. Start by simplifying your antenna system. Remove any extra equipment (switches, filters, etc) between the radio and the antenna, reducing your antenna system to a single connection similar to that in Figure 28.1.

It is likely that you have some kind of receptacle or bulkhead connector (such as a UG-363 adaptor or Amphenol 83-1F) where your antenna coax enters the shack. From there you have a jumper cable to your radio. We test this next.

1) Remove the test jumper cable from the radio to the power/SWR meter.

2) Connect your normal jumper cable from the radio to the power/SWR meter.

3) Press (PTT) and observe the power reading. It should be exactly the same as step 8, above. If not, your jumper cable is faulty or not suitable.

Test and Fix

First, perform a continuity check of the inner and outer conductors of the jumper cable. Then check the cable insulation — there should be no continuity from the inner to outer conductor. Check that the pins on each PL-259 plug are correctly soldered and fit firmly in the SO-239 receptacles. Look for markings on the jacket of the cable to ensure that it is a 50-Ω cable. *If you find a fault and fix it, retest steps 1-3 above*.

Your Third Test

Here is another elimination step. It is very common to have bulkhead connectors that are also lightning arrestors. These are not totally fool-proof and can fail due to a lightning hit or moisture. Even non-arrestor connectors fail from moisture or other reasons. We do need to test this connector. If you do not have any connectors between the antenna and your transceiver, skip this test and proceed to the fourth test below.

1) Disconnect the coax to the antenna from the bulkhead connector.

2) Using your "now tested OK" jumper cable, perform a dc test (continuity test) on the connector using the following steps.

3) Connect the jumper cable to the connector on the inside.

4) Test the insulation from inner to outer conductor using a high resistance scale. If the connector is also a lightning arrestor, test the inner conductor to earth ground (should be an open circuit) then test the outer conductor to earth ground (should be a short circuit or very low resistance).

5) The easiest way to test continuity of the connector is to connect your 50-Ω dummy load to the outside of the connector. Look for 50 Ω from the inner to outer conductor.

6) Using two jumper cables and the power/SWR meter, apply power from your transmitter to the dummy load on the outside of the connector.

7) Power should be the same as when you tested your jumper lead.

8) SWR must be no higher than 1.1:1 or the connector is faulty at RF.

Before the Fourth Test

When are we going to test the antenna? Very soon but since it does not work we need to perform a visual inspection. Assuming you have some kind of wire antenna, you need to lower it and in the process, inspect and ensure that:

- On the insulators at each end, there is no possibility of contact between the antenna wire and the supporting wire/ropes.
- If there are any splices in the wire elements, they are well crimped or soldered.
- At the center insulator, there is no possibility of contact between the element wires.
- At the balun or coax connection the element connections are soldered or firmly connected.
  - If it is a center-fed dipole it should be a 1:1 choke balun.
  - If it is an OCF dipole, it should be a 4:1 or 6:1 balun.

Cut away the waterproofing around the coax termination and inspect for water damage. If the connector is discolored or corroded it will need to be cleaned if not replaced and the cable checked as well.

Similar steps apply if you have a Yagi or vertical antenna.

Your Fourth Test

Now we are going to carefully test the main antenna coax cable *and* its connectors. First some dc tests, then we can RF test.

1) With the coax disconnected from the antenna *and* bulkhead connector (or radio), test continuity overall of the inner conductor, then the outer conductor. Test the insulation from the inner to outer conductor on the highest scale.

2) Connect the 50-Ω dummy load to the antenna end of the main coax. At the radio end, measure resistance from the inner to outer conductor. You should see close to 50 Ω.

3) Reconnect the bulkhead connector or radio end of the main coax. You should now have connected in sequence; radio, jumper, power/SWR meter, jumper, bulkhead/wall connector, main coax and dummy load as in **Figure 28.2**.

4) Press PTT and note the power reading: It should be very close to your preset 5 or 10 W. Check SWR; it should be no higher than 1.1:1. Be very wary of seeing no reflected power at all. This could mean that the coax is so lossy that reflected power is unreadable. One more test will determine this.

5) Relocate the power/SWR meter from the shack to the

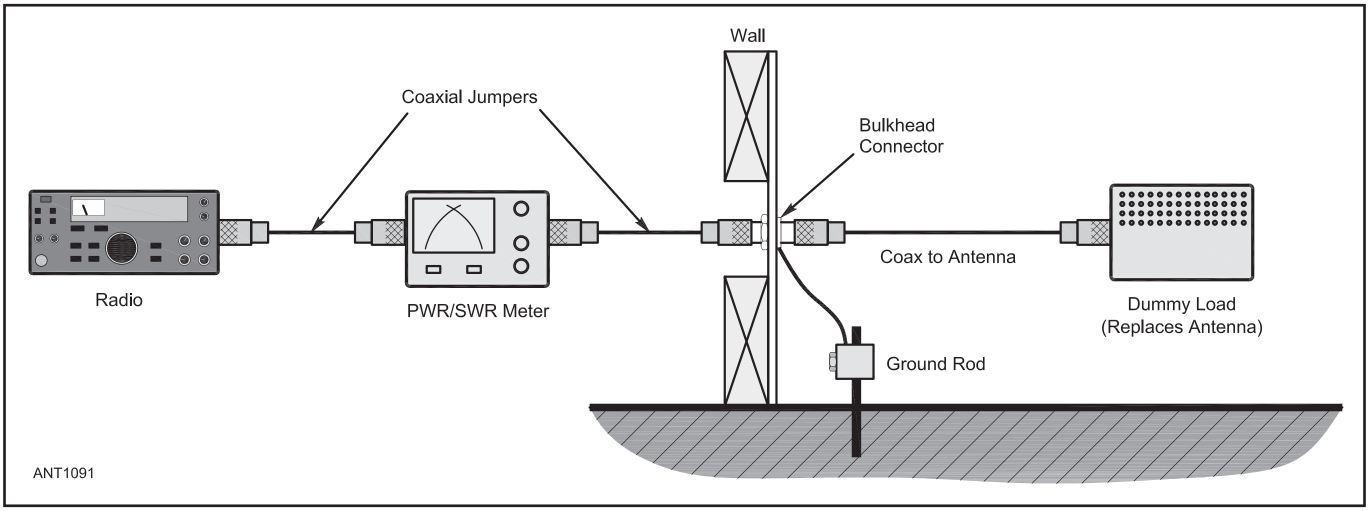

Figure 28.2 — Test setup to check SWR with the antenna replaced by a dummy load.

antenna end of your main coax but put it where it can be seen. The sequence is now: radio, jumper, bulkhead/wall connector, main coax, power/SWR meter, dummy load as in Figure 28.3.

6) Press PTT and note power reading: it should be at least 75% of your preset 5 or 10 W. If much less, the coax is lossy and should be replaced.

7) Check SWR and it should be no higher than 1.1:1.

8) If you do replace the main coax, repeat all of steps 1 to 7 above.

We are nearly done. Reapply the waterproofing to the connection of coax to balun, or at least some temporary tape. (If it now works you will get so busy you may forget to finish it all!) Pull your antenna back up into position, taking care not to put *any* stress on the coax cable. We are going to test the SWR on the primary band *without* the help of the tuner in the radio.

The Final Test

Initially we are going to test without the tuner engaged, so we can see how well the antenna is working on the main band that it was designed for. It is only on this band that we can make any adjustments to the length of the wire elements. Before we start adjusting we need to know which direction to go, so we will test the high end, middle and low end of the band.

Connect the power/SWR meter between the radio and the bulkhead connector or between the radio and the coax to the antenna. *Remember that we are now going to be testing "On Air" so we need to consider others and ask if the frequency is in use*. (You can also use an SWR analyzer as described in the **Antenna and Transmission Line Measurements** chapter.)

Assuming that the main band is 40 meters, tune the radio to, say, 7250 kHz (near the top of the band) and find a quiet spot. Check/ask if the frequency is in use. If it is not,

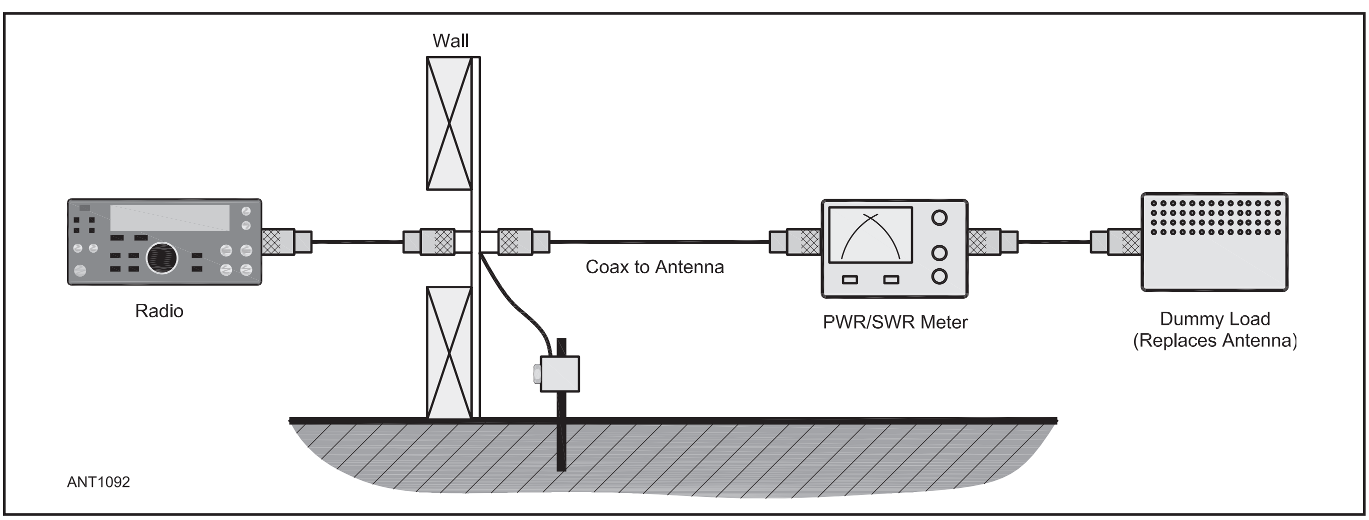

Figure 28.3 — Test setup to check if the main coax is lossy.

announce, "[Your call] testing."

- Set carrier power to a low value such as 10 W.
- Set SWR meter calibrate control to near maximum and increase power just enough to be able to set the calibration reading to full-scale.
- Return the meter to read SWR and write down the reading.

Now tune the radio to the middle of the band and find a quiet spot. Repeat the test procedure using an appropriate mode. Repeat near the bottom of the band.

Compare the three SWR readings and decide if the antenna is long (SWR too high at the high end of the band) or short (SWR too high at the low end of the band), or if no adjustment is required. Note that if all SWR readings are 1.5:1 or lower, very little will be gained by adjusting the length. If SWR is uniformly high everywhere in the band, the antenna itself is at fault.

If the antenna SWR measurements are acceptable, it is now time to let the radio and auto tuner operate. If you use an add-on antenna tuner, you'll need to make sure that the jumper between it and the radio is good as described previously, then reinstall it between the radio and antenna. The following paragraph assumes the auto tuner is internal to the radio.

Remove the power/SWR meter from the antenna feed line so that the antenna is connected directly to the radio through the bulkhead connector and jumper. Engage the auto tuner and let it set up on a convenient frequency. Set the output power control to about 75-80% of maximum, then find a clear frequency as before and initiate the auto tuner operation as instructed for your radio. Since you have confirmed your antenna system presents a reasonable SWR to the radio, your tuner should operate normally and you can resume operating! If the tuner does not operate properly, there may be excessive RF current on the feed line's outer surface. Add a choke balun at the output of the radio or antenna tuner and try again. (See the **Transmission Line System Techniques** chapter.) If the tuner still doesn't work, you may have a defective tuner.

If the antenna SWR measurements indicate an antenna fault, the exact troubleshooting sequence will depend on the type of antenna. Remember to write everything down in case you need to contact the manufacturer or ask for other help. Start with a visual inspection of the entire antenna looking for loose or corroded elements and joints. Perform a continuity check of all coils, clamps, and capacitors. Wiggle the various pieces while making measurements to look for intermittent connections. If nothing is obviously wrong, try disassembling the antenna, cleaning the various metal-to-metal surfaces using a nonferrous, nonabrasive synthetic cleaning pad such as a Scotch-Brite pad, then reassemble (checking for proper dimensions and orientation of parts) and test. If this fails to restore normal operation, you should contact the manufacturer's customer service department or ask for help from your local club.

28.2 GUIDELINES FOR ANTENNA SYSTEM TROUBLESHOOTING

The antenna is an electrical device implemented via a mechanical construction; therefore, if it is built properly, it should "work" (especially for production units). There are five general categories of problems:

- Test measurements
- Mechanical
- Proximity
- Feed system
- Misunderstandings

Guidelines for dealing with and approaching each type of problem are presented in the following sections. They will be used in subsequent sections in different ways to address different types of problems. Think of them as a kind of toolbox for troubleshooting. Many of them assume you are testing some type of Yagi or other beam antenna but the general guidelines apply to all types of antennas

It is important to remember this simple rule for adjustments and troubleshooting: Do the simplest and easiest adjustment or correction *first*, and only *one* at a time.

When making on-air comparisons, select signals that are at the "margin" and not pushing your receiver well over S9 where it can be difficult to measure differences of a few dB. Terrain has a lot to do with performance as well. If you are comparing with large stations, keep in mind that station location was probably selected carefully and the antennas were placed exactly where they should be for optimum performance on the property.

Remember the Law of Conservation of Energy: Energy can neither be created, nor destroyed. Therefore, the *sum* of all the energies in a system (an antenna system) is a constant. From the perspective of transmitting, we start with so many watts and the energy will go somewhere, either emitted from the antenna and on its way to the destination, or dissipated as heat due to loss.

If you increase your antenna efficiency, you will expand your performance envelope, and thus be able to hear *and* work more stations, providing more enjoyment from radio. If you increase only your transmit power, you will expand your "transmit envelope," but you won't be able to hear any better!

28.2.1 TEST MEASUREMENTS

A. Test the antenna at a minimum height of 15-20 feet. (See **Figure 28.4**) This will move the antenna far enough away from the ground (which acts to add capacitance to the antenna) and enable meaningful measurements. Use sawhorses *only* for construction purposes.

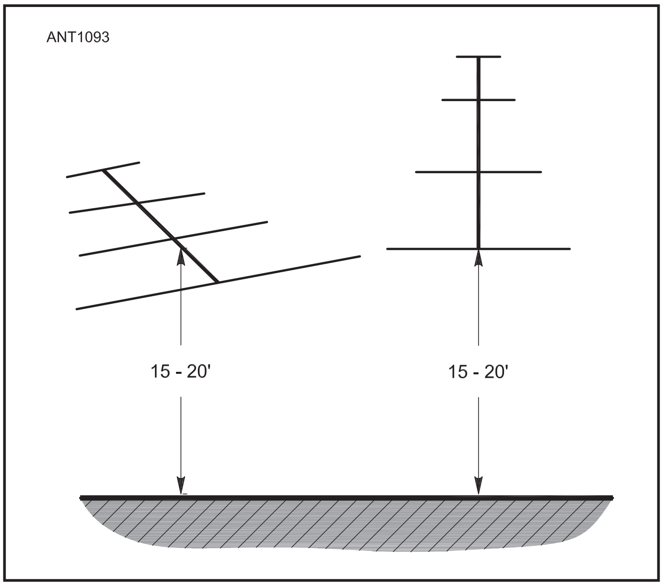

Figure 28.4 — When testing a Yagi or quad antenna, make sure it is at least 15 to 20 feet above ground. If oriented vertically, the reflector should be the closest to ground. Performance will still change as the antenna is raised.

- A minimum height of 15-20 feet above ground does not mean 5 feet above a 10-15 foot high roof, it means above ground with nothing in between.
- Antenna resonant frequency will shift upward as it is raised.
- Feed point impedance will change with a change in height and this applies to both horizontal and vertical antennas.
- Some antennas are more sensitive to proximity to ground than others.
- Some antennas are more sensitive to nearby conductive objects (i.e. other antennas) than others.

B. Aiming the antenna upward with the reflector on the ground might coincide with some measurements on rare occasions, but there are no guarantees with this method. The reflector is literally touching a large capacitor (earth) and the driven element is very close, too. Raise the antenna at least 15-20 feet off the ground.

C. When using a hand-held SWR analyzer you are looking for the dip in SWR, not where the impedance or resistance meter indicates 50 Ω. ("Dip" = frequency of lowest SWR value, or lowest swing on the meter.) On the MFJ-259/269 series, the left-hand meter (SWR) is the one you want to watch, not the right-hand meter (IMPEDANCE).

D. Check for nearby broadcast transmitters. The small amount of power used by the hand-held metering devices is no match for several thousand watts. The front-ends of the devices are broadband and will receive this out-of-band broadcast energy and "assume" it is reflected energy. This will manifest itself as the meter never showing a low SWR — sometimes as low as 1.3:1 or higher than 5:1 — all the while the antenna is actually matched properly. The broadcast transmitter will change its power and direction at sunset/sunrise, making daytime and nighttime measurements different. If the signal is from an AM transmitter, you may see the meters move with the programming audio amplitude.

E. Does the SWR and frequency of lowest dip change when the coax length is changed? If so, the balun might be faulty, as in not isolating the load from the coax feed line. Additionally. with an added length of coax and its associated small (hopefully small) amount of loss:

- The value of SWR is expected to be lower with the additional coax and,
- The width of the SWR curve is expected to be wider with the additional coax *when measured at the transmitter end of the coax*.

F. Be sure you are watching for the right dip, as some antennas can have a secondary resonance (another "dip"). It is quite possible to see a Yagi reflector's resonant frequency, or some other dip caused by interaction with adjacent antennas.

28.2.2 MECHANICAL

A. Are the dimensions correct? Production units should match the documentation (within reason). When using tubing elements, measure each *exposed* element section during assembly and the element *half-length* (the total length of each half of the element) after assembly. Measuring the entire length is sometimes tricky depending on the center attachment to the boom on Yagis, as the element can bow, or the tape might not lie flat along the tubing sections. Self-designed units might have a taper error.

B. Making the average taper diameter larger will make the equivalent electrical element longer. This makes the antenna act as if the physical element is too long.

C. Making the average taper diameter smaller will make the equivalent electrical element shorter. This makes the antenna act as if the physical element is too short.

D. If the element is a mono-taper (tubing element is the same for the entire length), larger diameter elements will be physically shorter than smaller diameter mono-taper elements to give the same electrical performance at the same frequency.

E. The type of mounting of the element to the boom affects the element length, whether it is attached directly to the boom, or insulated from the boom. Incorrect mounting/mounting plate allocation will upset the antenna tuning:

- A mounting plate 4 × 8 inches has an equivalent diameter of approximately 2.5 inches and 4 inches in length for each element half.
- A mounting plate that is 3 × 6 inches has an equivalent diameter of about 1.8 inches and a length of 3 inches for each element half.
- The mounting plate equivalent will be the first section in a model of the element half.

F. In a Yagi, if the elements are designed to be touching, are the elements touching the boom in the correct locations?

G. In a Yagi, if the elements are designed to be insulated, are the elements insulated from the boom in the correct locations?

H. The center of hairpin matching devices (i.e. on a Yagi) can be grounded to the boom.

I. The boom is "neutral," but it is still a conductor! The center of a dipole element is also "neutral" and can be touched while tuning without affecting the reading. With a hairpin match, the center of the hairpin can also be touched while tuning and touching the whole hairpin might not affect the readings much at all.

J. Tests have shown that in installations with several Yagis on a common mast, insulating the elements from the boom can reduce interaction between the individual antennas.

K. Sufficient spacing between Yagis on a common mast is critical to not lose gain and F/B. Even 10 foot spacing between a 20 meter monoband Yagi and a 15 meter Yagi can significantly reduce the gain on 15 (sometimes by 50%), plus almost completely eliminating the F/B on 15.

L. The higher frequency Yagi in a common stack is the one that will be affected by the lower frequency Yagi(s). If a stack of 20, 15 and 10 meter Yagis (20 being the lowest on the mast — which is the correct stacking sequence), the 15 will be affected by the 20, the 10 will be affected by the 15 and possibly also by the 20.

28.2.3 PROXIMITY

A. What else is nearby (roof, wires, guy lines, gutters)? If it can conduct at all, it can and probably will couple to the antenna!

B. Does the SWR change when the antenna is rotated? If so, this indicates interaction. Note that in some combinations of antennas, there can be destructive interaction even if the SWR does not change. Computer models can be useful here.

C. What is within ¼ wavelength of the antenna? Imagine a sphere (like a big ball) with the antenna in question at the center of the sphere, with the following as a radius, depending on frequency. Think in three dimensions like a sphere — up and down and front and rear as in **Figure 28.5**.

160 meters = 140 foot *radius* for ¼ wavelength
80 meters = 70 foot *radius*
40 meters = 35 foot *radius*
20 meters = 18 foot *radius*
15 meters = 12 foot *radius*
10 meters = 9 foot *radius*

D. Interaction occurs whether or not you are transmitting on the adjacent antennas. When receiving, it simply is not as apparent as when transmitting.

E. Wire antennas under a Yagi can easily affect it. This includes inverted V dipoles for the low bands and multiband dipoles. The wire antennas are typically for lower frequency band(s) and will not be affected by the Yagi(s), as the Yagis are used for the higher bands.

F. Are the higher frequency antennas (Yagis) above the lower frequency ones in the stack? Is there adequate distance between the various antennas? Remember, anything within ¼ wavelength in any direction is a potential problem. Careful modeling might not necessarily indicate the interaction in found in the actual installation. Cross polarization between VHF antennas and HF Yagis on the same mast is OK.

G. An 80 meter rotatable dipole should be parallel to nearby Yagi boom(s) so that it is essentially transparent. Other antennas that could interfere *might be able* to be positioned at right angles. Orienting the 80 meter dipole parallel to the boom also makes the installation more neutral in the wind. Most Yagis have more wind load from the elements than from the boom which tends to make them "hunt" in the wind. Adding area to the boom can, therefore, help the installation be more manageable in the wind.

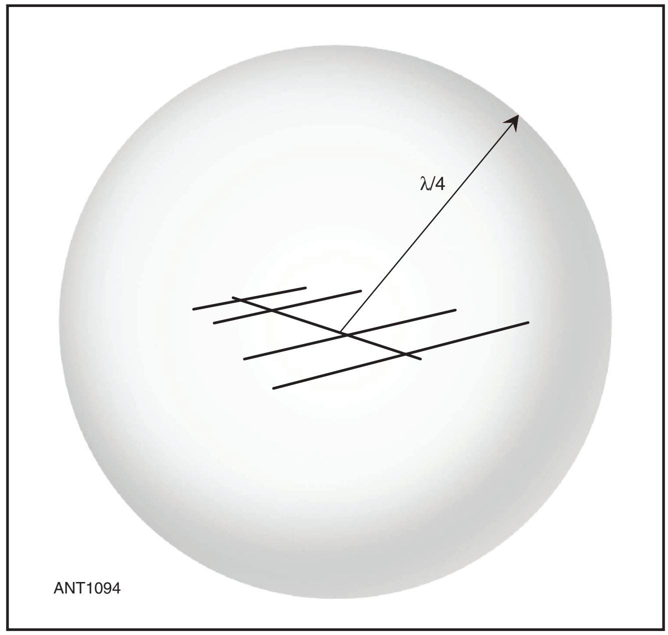

Figure 28.5 — Any conductive material within λ/4 that has a medium to low impedance at the frequency of operation has the potential of interacting with the antenna.

28.2.4 FEED SYSTEM

The feed system includes:

- the feed line
- switching mechanisms
- pigtails from the feed point on the antenna to the main feed line or switch
- all feed lines inside the radio room

The feed system is the *entire connection* between the radio and the feed point of the antenna.

A. Is the feed line (coax) known to be good? (Start with the easiest first.) Is there water in the coax? This can give strange readings, even frequency-dependent ones. If there is any question, swap the feed line for a known good one and test again.

B. Are the connectors installed properly? Has a connector been stressed (pulled)? Is the rotation loop done properly to not stress the coax? Is it an old existing loop or a new one? Usually it's alright if new. Type N connectors (especially the older type) are prone to having the center conductor pull out due to the weight of the coax pulling down on the connector. Connectors are easy to do, using the right technique.

C. Is there a "barrel" connector (a PL-258 dual-SO-239 adapter) in the feed line *anywhere*? Has a new or different barrel been inserted? These are a common failure point, even with new barrels. The failures range from micro-bridges across the face of the barrel shorting out the center and shield, to resistance between the two ends of the barrel. Have the new barrels been tested in a known feed system? Always test them before installing. Use only quality RF adapters as these are common system failure points.

D. Is the coax intact and not frayed such that the shield can come into contact with anything? This can cause intermittent problems as the coax shield touches the tower, such as on rotation loops and coax on telescoping towers.

E. Is the tuner OFF on the radio? This is often overlooked when adding a new antenna.

F. Are there any new devices in the line? It might be a good idea to remove everything but the essential items when troubleshooting.

G. Is there a remote antenna switch? Swap to another port.

H. Are there band-pass or low-pass filters in the line? Filters can become defective, causing strange SWR readings.

28.2.5 MISUNDERSTANDINGS

The antenna can be working properly but there may be a misunderstanding of the anticipated readings versus the actual readings. There can also be discrepancies between the observed "performance" (i.e. F/B ratio) and the specification(s). Having an open mind here is a great asset and will aid in understanding and resolving the situation. "Open mind" means no preconceived ideas or bias, which is sometimes difficult. Remember that we are working toward a solution to improve performance. Common misunderstandings:

A. "A low SWR means the antenna has gain." No, it only means it is matched to the feed line. Remember that a dummy load also has low SWR.

B. "A high SWR means the antenna does not have gain." No, it only means it is not matched or is fed improperly.

C. "An SWR that does not go to 1:1 is a serious problem." No, as long as your rig can tune it, use it. Reflected power is not totally lost. As long as the feed line loss is acceptable, SWR does not need to be 1:1. (See the **Transmission Lines** chapter for more information on matched line loss with varying SWR.)

D. "My antenna has a great pattern, so it must have a lot of gain." No, these two antenna aspects are not necessarily related. The Beverage receiving antenna has an excellent pattern, but its gain is about –20 dBd.

E. "Once the antenna is up, it will stay there forever." An antenna is an electrical device implemented via a mechanical structure. Mechanical devices require periodic maintenance, just like your car.

28.3 ANALYZING AN ANTENNA PROBLEM

Having a specific sequence of steps to take for a systematic resolution of installation questions will make the process easier with less frustration. It will also provide a learning environment and future projects will run smoother and be enjoyable, as the prospect of a higher performance envelope is anticipated!

The following typical debugging sequence is divided into five parts. Each one uses the guidelines to address a specific aspect of the resolution process. Not all the steps will be used each time a new antenna is installed; however, reading through them will be beneficial.

The length of this material and the steps noted should not deter anyone from reading — installation difficulties are usually simple to resolve.

28.3.1 PART 1 — SWR

A. The usual reason for debugging is that the SWR is not as expected. This is the only measurement that can be reliably made by the majority of people.

- If the SWR is showing high values (4:1 or higher), do not attempt any adjustment of the antenna before *first* certifying the feed system is correct.
- High values like this are so far away from the expected values that they essentially eliminate the antenna from being the current problem.

B. Remove all devices in the feed system to eliminate possible components with problems, such as low pass filters (especially if 10 meter SWR readings are not as expected); therefore, we want to work as directly as possible with the antenna in a good location.

C. Isolate the feed system as the first step.

- Place a 50-Ω dummy load at the antenna end of the coax feed line.
- Measure the SWR of the coax feed line at the transmitter end (dummy load at the other).
- If you measure anything other than a low SWR (1.2:1 or less), the coax should be changed and/or;
  – If you see a significant drop in power through the coax (use a wattmeter), the coax should be replaced.
  – If the coax is good, proceed to the next steps.

D. Is the antenna at a reasonable height above ground?

- 15-20 feet above ground and roof.
- If not, place it as high as possible and watch for proximity effects.

E. Does the SWR change as it is rotated?

- What else is on the mast?
- Are there any wire antennas nearby?
- What it is rotating above or below to cause a change in measurement?

F. Are the element lengths correct?

G. Are the elements in the proper location?

H. If a hand-held test unit is used, is there a broadcast transmitter within several miles? This is very important on 160, 80/75 or 40 meter antennas.

28.3.2 PART 2 — FEED SYSTEM AND ANTENNA ASSEMBLY

A. Stay calm.

B. Do the easiest thing(s) first.

C. If a simple change was made (i.e. moved an element a few inches), the problem is most often in the feed system.

D. Swap the coax, even if it takes some effort.

E. Try to remove the parts of the antenna feed system one at a time to isolate the culprit.

F. Be sure to track the correct dip in SWR readings.

G. On production antennas, most problems are identified by checking for:

- Element length and tuning (and location on the boom, but extremely rare).
- A local broadcast transmitter affecting the readings — use your transmitter and its SWR meter.
- Antenna mounted properly; clear of proximity issues, including conductive guy wires.
- Correct feed line and matching system adjusted properly.

28.3.3 PART 3 — KEEPING RECORDS

A. Keep sequential notes of each step taken.

- A legal pad or notebook is excellent — number the steps and each page.
- Write down what was done and then write down the observed result.
- Underline the amount of a change and use a + or – sign, or say "longer" or "shorter."

B. If you make a change, do only one item at a time.

- If you change more than one item, you will not know what caused the observed change.
- If nothing appeared to change and more than one item was changed, it is possible that the items changed countered the effect(s) of each other.
- Changing more than one item at a time makes it *impossible* to track.

C. Write on your notepad the initial observation(s) and the conditions, such as height and proximity.

- This increases your situational awareness and it will provide a documented starting point.

28.3.4 PART 4 — HOME-MADE ANTENNAS

A. For noncommercial, home-brew, or "one-off" antennas:

- Follow same procedures for production units.
- Element tapering needs to be verified.
- Element mountings might not be properly accounted for (i.e. insulating boots when using old Hy-Gain mounts for a new design)
- Matching techniques might not be working as expected. Check directly at the feed point without the matching device in place.
  - – A hairpin will step up the impedance and might just move it to the high side of 50 Ω, making adjustment (down) to 50 Ω impossible.
  - – If the design is a "forward stagger" type, the forward Yagi needs to be shorted across the feed point (i.e. hairpin); otherwise, the driver will have an open or shorted coaxial stub (the pigtail feeding it) attached across it.

B. Keeping a design notebook, with as much detail as possible using the same note-taking procedure as described earlier is invaluable.

28.3.5 PART 5 — ON-AIR OBSERVATIONS

A. F/B is less than expected.

- Antenna height affects F/B, so does the angle being used. Refer to typical plots to acquaint yourself with these issues.
- F/B specification might be too ambitious. Some specifications are given as peak values, available only across a narrow frequency range (if not tuned properly, might be out of band).
- How much to expect?
  - – A 2-element full-size parasitic Yagi will be around 12-16 dB and A 2-element shortened, loaded Yagi can be >20 dB if tuned properly.
  - – A 3-element full-size Yagi "naturally" wants to be around 20 dB.
- Stacked Yagis on one mast (for example, 20-15-10 meters) can greatly affect the F/B.
- Rotator clamps not secure, mast slipping.
- Antenna attachment might not be secure, even with the clamps tight, and the antenna is slipping on the mast (typical with hard steel masts).

B. How much gain (redistribution of the constant energy) to expect? **Table 28.1** lists real-life, reasonable, verifiable figures for full-size 20 meter antennas, with gain specified as dB compared to a full size dipole at the same height, same location:

These figures are increased by 2.14 dB when comparing to the isotropic source (4.5 dB + 2.14 = 6.64 dBi); and if ground reflection gain is also included (i.e. at 1 wavelength above ground), add another 5.8 dB. Using both

Table 28.1
Expected Performance Values of Full-Size Antennas

Gain (dBd)	*Antenna Type*	*Full Size Boom Length (20 meter antenna)*
0	Dipole	Reference*
4.5	2 element	10' boom
5.5	3 element	20' boom
6.5	4 element	30' boom
7.5	5/6 element	42' boom
8.5	7 element	60' boom
9.5	8 element	80' boom
10.5	9 element	105' boom
12.5	12 element	175' boom
14.5	20 element	330' boom

*The Reference is a dipole is in the exact same location as the Yagi, such as over ground) of these, the 5.5 dB figure for a 3-element Yagi becomes 13.44 dBi. Whichever the case, the reference must be specified; otherwise, you know nothing about the antenna.

C. Does not seem to be competitive or crack pileups.

- Not aimed in the right direction (being off 30 degrees can be a lot).
- Gain specification in error or loss in the antenna system.
- Coax, switches, antenna tuning, antenna components, radial system.
- Could it be a problem with the operator?

28.3.6 TROUBLESHOOTING HIGH SWR IN YAGI ANTENNAS

This section applies mainly to Yagi antennas; however, it should be useful for other types as well. There are additional sections for other types of antennas.

One thought to keep in mind when tuning a Yagi is that in a Yagi, the primary purpose of the driver (driven element) is to excite the array. The driver tuning has very little to do with the gain and pattern, although the spacing between the driver and adjacent elements is quite important to the Yagi design. In a 2-element Yagi, the driver location does impact the gain and pattern, because it sets the boom length; however, the parasitic element (either a reflector or director) is the primary "controller."

To locate the problem of a high SWR, we need a scope of reasonableness. We need to keep our mind open to locate where the problem is and where the problem is not. Let us say we have just put up a commercially produced Yagi antenna and it has a high SWR at the rig end of the coax. The first thing that comes to mind is that it is the antenna. Perhaps it is, but we need to follow a plan.

Let us say our rig, with the example new antenna, is showing an SWR of 3:1. If the antenna is the culprit, it means the feed line is seeing a load (antenna feed point) that is not close to the characteristic impedance of the coax. In simple form, if the coax is 50 Ω, a 3:1 SWR means the antenna feed point impedance is either 150 Ω or 17 Ω. The feed point impedance of a Yagi can be as low as 17 Ω, but not as high as 150 Ω; therefore, we need to make a choice and we choose that the feed point is 17 Ω. We need to consider there might be an impedance transformation device at the feed point, but this device most likely will never transform the feed point to as high as 150 Ω for an expected 50-Ω feed.

There are times when the feed point will be intentionally transformed high. Band-specific 4:1 coaxial baluns can reduce even harmonics. These baluns require the Yagi feed point to be four times the impedance of the coax, or 200 Ω. This is accomplished using a hairpin across the Yagi feed point. The circuit is: 50-Ω coax up the tower, mast and out to the driver, through the 4:1 coaxial balun and attached to the feed point, which also has the hairpin across the feed point. Back to our example with a 3:1 SWR.

Impedance transformation devices (matching circuits) are used to step up the feed point impedance to match the feed line (some matching circuits step down the impedance, but almost all used in Yagi antennas step up the feed point impedance). If the Yagi feed point impedance is 17 Ω, a hairpin (inductive reactance across the feed point) can be used to increase the feed point to match the 50-Ω feed line. So, if the Yagi really has 17-Ω feed point impedance and there is a hairpin-matching device, one might want to be sure the hairpin is properly attached and adjusted (if there is an adjustment). An important piece of information is to know the untransformed feed point impedance.

Yagis can be designed with a very low feed point impedance, but most production antennas are not. In our example, let us assume the feed point impedance is in the range of 35 Ω. Now what do we do?

The Yagi, without a hairpin, would have a SWR of about 1.4:1, derived by dividing the characteristic impedance of the coax by the feed point: 50 / 35 = 1.4. Therefore, if we remove the impedance transformation device and measure the driven element directly (at a reasonable test height above ground), we should see an SWR of about 1.4:1. If we do, we can eliminate the Yagi as the cause of the 3:1 SWR we saw at the rig end of the coax feed line. This means the problem is elsewhere, so we can go to the common section below.

28.3.7 TROUBLESHOOTING HIGH SWR IN NON-YAGI ANTENNAS

Full-size dipole antennas will not have a matching device, because their impedance is usually between 45 and 90 Ω, depending on the shape and height above ground. The lower values will be for dipoles that are inverted Vs with the ends not far from the ground. If you have a high SWR on one of these antennas, it is almost sure to be in the feed system.

You should check all the components from the antenna to the rig. This includes the balun (rare to have a problem here), connectors, coax and all equipment in the line, such as SWR meter, antenna switch, etc.

There can be several reasons for a higher than expected SWR. What "a higher than expected SWR" means is that the SWR exceeds the specification by a large margin, such as 2:1, when a 1.3:1 is expected. A difference of a few tenths should not be a serious concern. We are addressing a more major difference. Let us continue the example above for a purchased antenna. If the antenna is one that has been in production, then it is reasonable to expect the antenna to meet the specifications. If the antenna does not meet the specifications, then try the following step first, then move to the longer list below:

Remove the driver element from the array (Yagi), place it on a wooden stepladder. Measure the element to be certain it is built properly, with the correct dimensions. Check the SWR. If the SWR remains at 3:1, the problem is not in the antenna. It must be in the delivery system, because the driver is a dipole and it will not be 3:1 under any circumstances. A dipole's feed point impedance can be between 40 to 90 Ω, depending on its height above ground, which translates into an SWR of not more than 1.8:1. If the SWR is noticeably higher, then the delivery system is suspect and must be checked. This consists of the rig, amplifier, tuner(s), antenna selector(s), all metering equipment (SWR/power meter), all coax lines and connections.

The usual questions to move through the process are:

1) Is the tuner in the line? Many times, a tuner has been left in with settings that cause the rig's SWR indicator to read improperly.

2) Is the SWR/power meter battery powered? A low battery can cause erratic readings.

3) How sure are you that the coax connections are properly made? How good are the solder joints?

4) Is there water in the coax?

5) Is there an RF choke or balun being used to decouple the coax feed line from the antenna?

If the problem is still not solved, here is the longer list:

1) Remember that an antenna is an electrical design implemented in a mechanical structure; therefore, be sure all joints are mechanically secure, making a solid connection.

2) Remember that an antenna is simply an airborne conductor. There is no "magic"!

3) Be sure the new antenna is at a reasonable test height. Having a Yagi antenna a few feet above ground, such as on sawhorses, will not provide much useful information. An antenna covering 20 through 10 meters should be in the clear about 12 feet above ground, preferably higher. A 40 meter dipole or Yagi can be effectively tested down to 15 feet, but will probably shift upward in frequency as the antenna is raised to its final height. The ground contributes a very large amount of capacitance!

4) Aiming a Yagi upward at the sky with the reflector laying on the ground is also not a good idea. The reflector is very closely coupled to the ground and it will not be properly tuned. If the reflector can be raised several feet above the ground (a quarter wave is perfect), the entire antenna can be accurately tuned. Of course, it might be easier to raise the whole antenna horizontally 12-15 feet.

5) Check the dimensions of the assembled antenna to ensure they are reasonably close to the drawings. Unless a particular design is extremely sensitive, a difference of an inch on 20 meter elements should not cause a serious SWR change.

6) Check for other antennas within proximity to the new antenna. Antennas that are related to the new one are of particular interest. A few guidelines are provided in **Table 28.2**. "New Antenna" refers to the one just put up and assumes it is a horizontal design."Watch These" means other antennas that can be influencing the new one. "Coupling Distance" is the distance that the new antenna can effectively couple through the air to another antenna. The coupling distance implies distance to the closest point between the antennas.

7) If the new antenna is a horizontal type, a vertical antenna within near proximity will not usually cause any problems. The anticipated isolation between horizontal and vertical polarization is 20 dB and this is sufficient to isolate the antennas from causing harmful interference, or sufficient influence as to cause a high SWR on either antenna.

Table 28.2
Potential Interactions

New Antenna	*Watch These*	*Coupling Distance (ft)*
40 meters	80, 160 meters	35
20 meters	20, 40, 80 meters	18
15 meters	20, 40 meters	12
10 meters	15, 20, 80 meters	10

8) There are some new SWR meters on the market that make antenna adjustments and testing quite easy. These instruments provide a direct SWR readout, along with the frequency. At least one can display a graph of the SWR curve. If one of the new SWR meters is being utilized, caution should be observed. These instruments send out a low level signal to the antenna under test then sense the reflected power, computing the return loss and the resulting SWR at that point on the feed line. The SWR indicated is the SWR at that point on the line, not necessarily at the actual feed point.

The difficulty using these instruments arises when there is RF energy in the area from sources other than from the antenna under test. Some are so sensitive that a SWR reading of 1:1 on the instrument is not possible. The stray RF energy does not have to be near the frequency being tested, as the front end of the instruments are basically untuned and, therefore, very wide.

During the day, AM broadcast stations can dramatically influence these instruments. At dusk, most AM stations reduce their power and redirect the antenna patterns; however, the redirected energy might just now be in the direction of the antenna under test, whereas during the day the energy was directed somewhere else and was not noticed.

AM broadcast harmonics can be a problem up through 40 meters; maybe higher harmonics are multiples of the operating (fundamental) frequency, such as 1200 kHz (AM band) with harmonics at 2400 kHz and 3600 kHz. Although the harmonics are greatly reduced by the filters at the AM transmitter, reducing a harmonic from a 50 kW transmitter so that it is insignificant compared to the reflected power from a 5 mW signal from one of these SWR devices is a tough order.

Any of these instruments can be used as long as one is aware of this possible problem. Using a transmitter at a few watts will be the most accurate, as the energy from other sources will be substantially less than that of the transmitter.

9) If the antenna is physically correct and the antenna is commercially made, then the problem must be due to other conductors or antennas within close proximity, the match, or feed system. The feed system includes the balun or RF choke and the feed line. The feed line has connectors. Some feed lines purchased pre-made use connectors that are only crimped. Some amateurs believe they should be soldered.

10) A balun should have its leads as short as possible, usually about 2½ inches. An RF choke balun should be wound on a cylinder (solenoidal) to be most effective. (See the **Transmission Line System Techniques** chapter.)

11) The split portion attached to the feed point needs to be waterproofed so that water will not wick down inside the coax. If there are guy wires, they should be broken up with insulators into nonresonant lengths, or use nonconductive guy cable.

12) If the coax feed line is old, it is possibly contaminated.

The contamination comes from the jacket of the coax contaminating the interior dielectric.

13) The coax might also have water inside. This can happen when the end is split (i.e. such as for an RF choke or pigtail connection) and the water wicks up the braid and goes inside the coax cable. Water can also find a path on the inner dielectric and flow inside the coax cable. Air-dielectric coax is especially sensitive and vulnerable to water. It has even been suggested that water can condense inside coaxial cable with an air dielectric. An air-dielectric cable is one that uses air, rather than a solid material for the space between the center conductor and the shield.

The above information pertains to antennas you design and build as well, except that the actual SWR specification will probably not be readily known but it will be anticipated. Keep in mind that a vast majority of Yagi designs have an impedance of less than 50 Ω at the feed point. It is rare to find any that are even in the 40+ Ω range. Some go as low as 10 Ω. This means the SWR can be as high as 5:1 without a matching circuit.

28.3.8 YAGI FEED POINT IMPEDANCE NOTES

Most Yagi designs are in the high teens to mid 20-Ω range and the unmatched SWR will be a maximum of 2.5:1 for a 20-Ω feed point (assuming no reactance). The matching systems usually utilized (hairpin, gamma, T) are step-up circuits, which means the matching circuit raises feed point impedance. The feed point can be transformed to values above 50 Ω, even as high at 200 Ω if a 4:1 balun is desired to be used (50-Ω coax × 4 = 200 Ω).

Please note that transformed impedance is not the same as "native" impedance, meaning untransformed. An antenna that has a native impedance of 10 Ω will have the same current flowing in it when the feed point is transformed to 50 Ω to match the coax feed line's characteristic impedance of 50 Ω.

A "dual-driven" 2-element driver design with crossed-over feed straps between the driver elements is a way of transforming the feed point impedance to a higher value, such as 200 Ω. The "native" feed point impedance of that antenna will be much lower, possibly even way below 50 Ω.

28.4 REFURBISHING ALUMINUM ANTENNAS

Whether passed on by another amateur, recovered from the local recycling shop, grabbed as a bargain at a swap meet or just needing to do maintenance, the average amateur often has to bring up to scratch antennas that are the worse for wear.

Two of the most detrimental factors to aluminum are the results of electrolysis caused by poor choice of connectors and the chemistry of the air. Salt near the coast or industrial/automotive particulates can, when mixed with the normal moisture content, eat away at the shiny aluminum. If allowed to progress far enough, the mechanical integrity of the structure is impaired beyond simple repair.

The first procedure is to inspect the antenna. Look for the dreaded white oxide powder around connectors and joints. This points the way to the areas that need particular attention. Next is to try and remove the connector hardware which may be seized beyond recovery. This is particularly the case where steel plated with cadmium or zinc/galvanized hardware has been used. Before struggling with wrenches and screwdrivers, spray the area with penetrating oil such as Kroil or other modern preparations. These are more effective than some of the older preparations such as WD40 and CRC-556.

If the items release, you have had a win. If not then you have to find a suitable method of removal. Sometimes, heating the area with a blowtorch may cause sufficient expansion for the frozen joint to be loosened. Clamps may be cut free using a cutting wheel on a high speed grinding tool — before cutting into the underlying aluminum, try leverage with a small bladed screwdriver and hopefully you will be able to break the metal along the cut without bruising or deformation of the aluminum. Even an old fashioned hacksaw with a fine toothed blade might be suitable in making the cut.

Metal threads that are frozen because of corrosion can be a great frustration. This can be made more difficult if they pass through plastic insulators, as trying to grind the heads off will melt the plastic. A method that has been found helpful is to drill though the head of the metal thread with a sharp drill slightly smaller in diameter than the shank. The hole only needs to be slightly deeper than the depth of the head. Then use a drill slightly smaller than the diameter of the head to remove the head. This method generates less heat from friction than most other methods and is particularly easy to use on PoziDriv or Phillips head hardware as the drill is automatically centered.

Having disassembled the antenna, it is necessary to further inspect its condition and repair and/or treat areas that are damaged. Areas of oxidation need to be removed by abrasion. This can generally be done using a kitchen plastic scouring pad such as Scotch-Brite, if the oxidation is superficial. The advantage of using the plastic pad is that it does not impregnate the surfaces with metal particles of dissimilar metal which will only cause further corrosion later on.

If the pitting is deep, it may be necessary to remove the damaged area and insert a suitable sleeve just to restore mechanical strength. Pitted areas can sometimes be cleaned and an internal sleeve of PVC or similar used but remember to ensure balance if the element or boom section is undamaged on the opposite end. Remember that crystallization occurs in aluminum subjected to constant vibration, a lesson learned from the aircraft industry but obvious in aluminum antennas mounted in windy sites.

If the metal has to be cut, it must be joined to be electrically continuous and particularly at VHF and UHF, the outside diameter must be maintained to keep the tuning characteristics within specification. For this reason, internal sleeves are usually preferable with use of aluminum pop rivets that have aluminum mandrels. Some bargain rivets use steel mandrels and in the right conditions you will have a loose fastening, a nonconductive joint and a noisy antenna.

Once the various components have been cleaned and mended they are ready for reassembly. Replace the hardware with stainless steel and use nylon insert (Nylok) nuts that remain tight without deforming the tubing. Worm drive stainless steel hose clamps are used but not the ones with plain steel worm drives. Boom clamps using U-bolts are expensive items and a wire brush can be used on the threads to remove any rust, followed with a light spray of aluminum-based paint and replacing the washers and nuts with bright steel ones which are then also painted. If possible, after assembly, a further coat of paint is applied to keep the moisture from these components.

Remember that UV light causes many wire jackets to degrade and so any pigtails, whether insulated or not, benefit from having heat shrink tubing applied.

All swaged joints should be cleaned to bright metal on the mating surfaces, remembering the RF skin effect. Use a thin coating of anti-oxidation compound at all metal-to-metal joints as described in the section on Corrosion in the chapter **Building Antenna Systems and Towers**.

On the exterior, if there are concerns of moisture ingress, clean the surface of any contaminants and apply neutral-cure silicone sealant or cover with butyl rubber self-vulcanizing tape. See the section on Waterproofing in the chapter **Building Antenna Systems and Towers**. Do not be tempted to use hot melt glue on external applications as it deteriorates rapidly from UV radiation.

Although there are warnings about painting antennas, particularly where there is evidence of pitting or scratching on the surface a light spray of aluminum-based paint provides added protection against additional damage. The point is that you are not painting a rusty hulk and brushing paint on thickly but lightly coating the surfaces and paint runs will not occur to cause insulation of parts of your antenna.

It is probably wise to have a progressive program of inspection and maintenance of all antenna systems. Birds find our structures good perches, wind can bend things and moisture which is trapped can all cause damage. At least every couple of years is a good program. Look after your antennas and they will serve you well and long.