Antenna & Transmatch Evaluation

Field Manual

Official Guide for the Strange Antenna Challenge

By Erik E. Weaver, NØEW (Edition:1.3) $15.00 USD

Introduction

Thank you for investing your time reading this KØS field manual. If you are relatively new to amateur radio I suggest you read each chapter. Information presented in earlier chapters may not be repeated. If you are planning to take part in one of the KØS contests, or are looking for an introduction to antennas or transmatches ("antenna tuners"), you should find this field manual useful.

The KØS Strange Antenna Challenge idea developed as I read Kurt N. Sterba's "Aerials" books. Kurt can be brutally honest, but I've found he is nearly always right when discussing antenna and feedline theory, and I find his writing style both entertaining and informative. I highly recommend his books (available from www.wr6wr.com) and his monthly article in "World Radio" magazine.

We can learn many things using ("flying") strange things as antennas, such as umbrellas, loadlocks, ladders, fences, folding chairs or painting easels. It is also a lot of fun, as is hearing "you're antenna is a *whaaat*?"

One learned skill is effectively using our antenna tuner. Believe me, once you can achieve a tune and fully load your transceiver into a pair of folding chairs, or a dog cage, you will find you can <u>easily</u> tune up any "normal" style antenna such as a dipole or loop. This is the best way I know to learn how to use your antenna tuner.

Another practical skill is learning to fly a wide variety of strange antennas. After all, if you are trying to get your station back on the air following a tornado or hurricane it will be far easier if you know you only need to find two pieces of metal – you will be back on the air handling traffic while other stations are forlornly trying to re-rig their broken towers!

Have a great time, share your enthusiasm with others, including the press, and I'll look for you on the air during the next KØS event! Visit www.n0ew.org/k0s/ for KØS rules. The rest of my web site has additional information, presentations and kits. If you have any questions, suggestions, or corrections, please contact me at: erik@n0ew.org

Sincere regards & 73,

Erik E. Weaver, NØEW
May 2004, Springfield, MO

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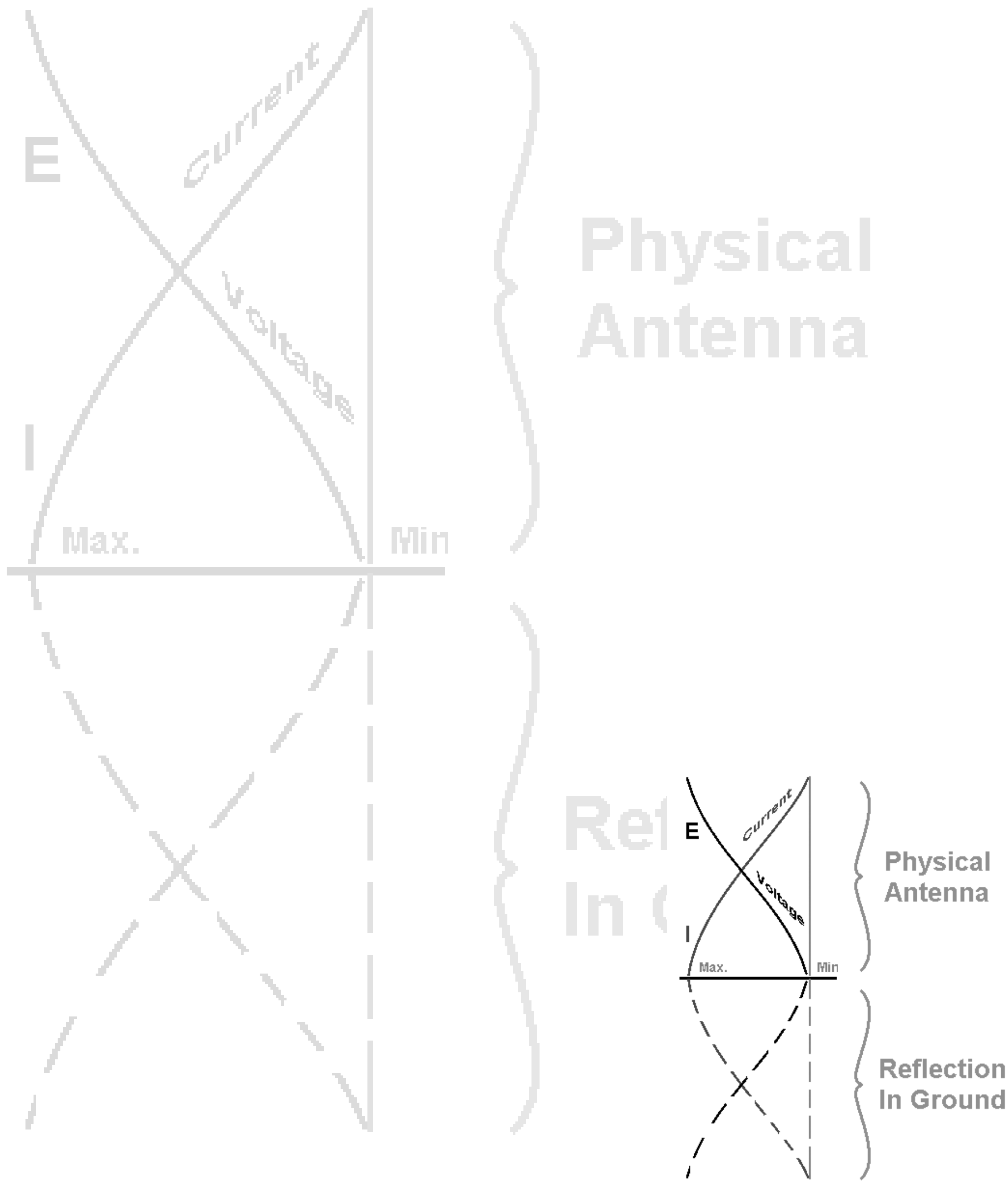
Chapter I

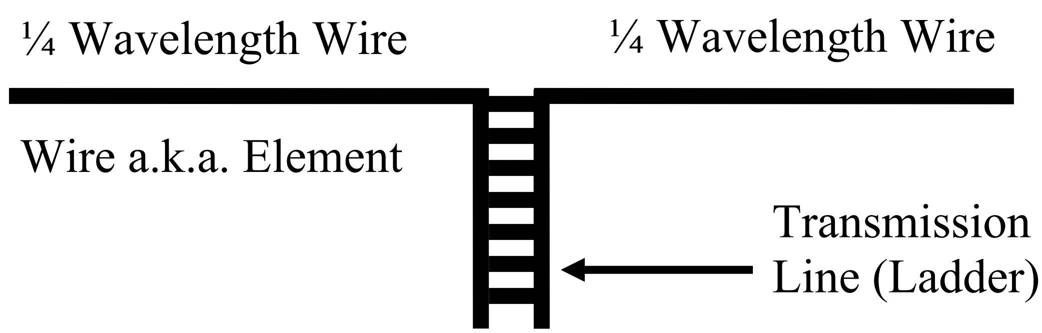
Antenna Basics

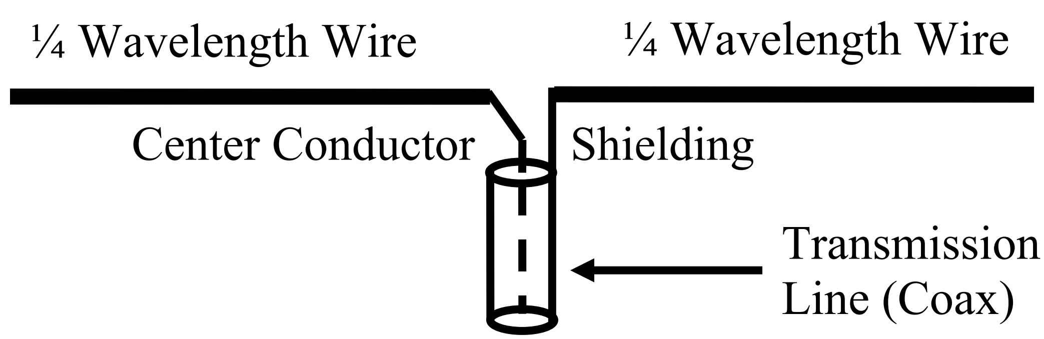


Dipole Antenna Fundamentals

The dipole antenna is the most basic form of antenna. This is our beginning point. A dipole antenna is constructed from two equal lengths of conductive material – usually wire. This wire may be bare, insulated, solid, weave, or stranded. The "wire" can even be metal tubing instead of wire – this is most common when constructing beam antennas. However, in all cases it must be constructed of electrically conductive material (I've even read an article in which an amateur radio operator discussed using tubes filled with salt water as his radiating elements).

A dipole is considered to be a "balanced" antenna because neither wire is attached to your station ground – it is ground independent. Two equal lengths of wire are separated from one another by a small insulator and extend away from one another for ¼ wavelength in opposite directions. These wires are suspended some height above the earth (they may also be hung in your attic, etc.).





The center insulator is usually a piece of plastic, but any non-conductive material will work. Choose a material that will not become saturated by water during a rain storm or you will defeat the purpose of the insulator (by allowing the two antenna elements (wires) to short together). The insulator in the center that separates the two ¼ wavelength wires is required.

An optional insulator is normally placed at the far end of each wire. These additional insulators serve two functions: they provide a convenient connection point for the rope or string that suports our antennas, and it discourages voltage discharges from leaving the end of the wire and possibly causing a fire or other damage. Voltage discharges from the ends of any antenna wire (or "element") is why you should always keep the ends of all antennas away from people and flammable objects – maintain at least two feet distance between the end of your antenna wire and any other object, and at least 10-feet above the earth so people will not grab the wire while you are transmitting.

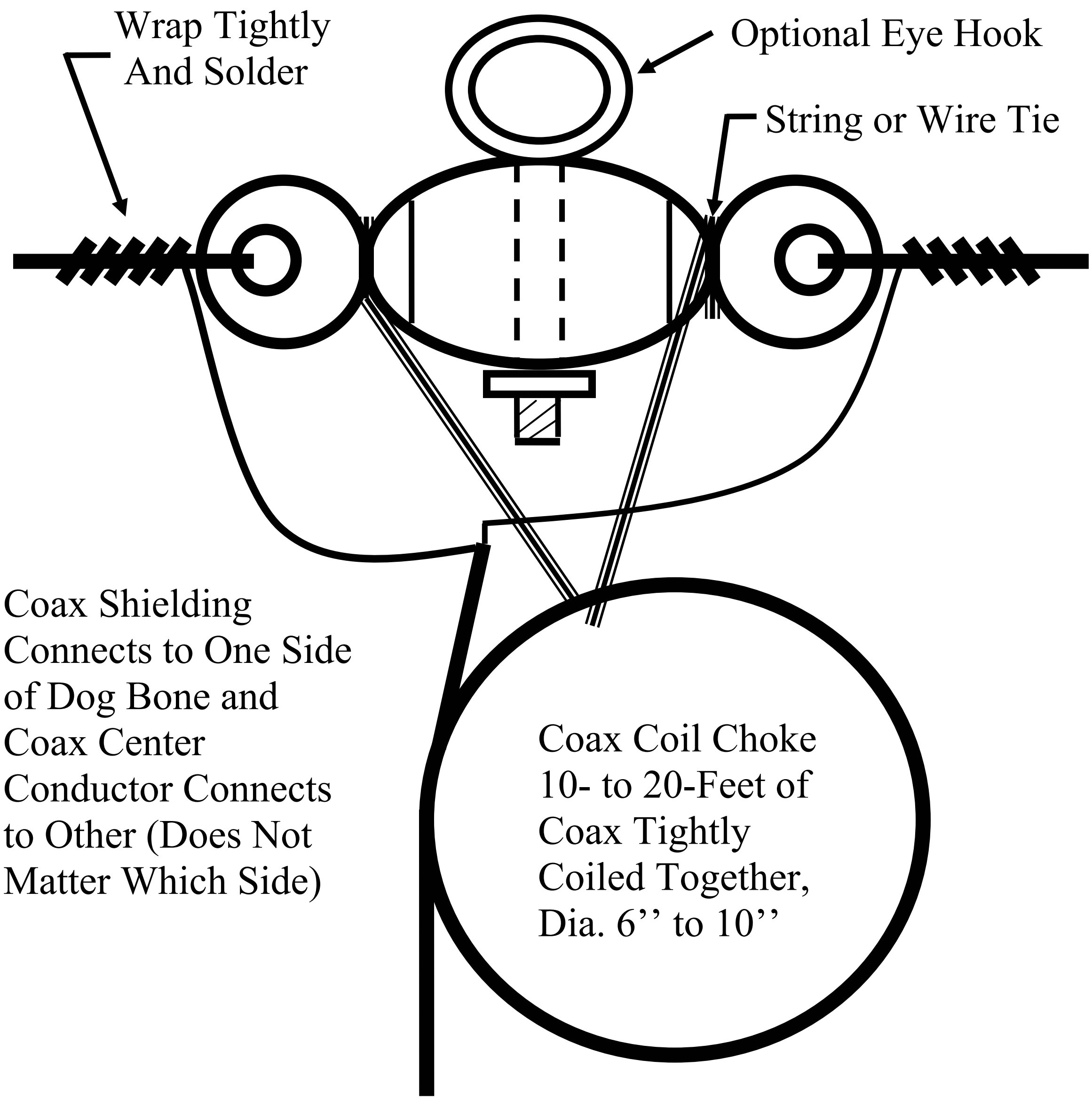
One very common insulator is called a "dog bone." These are normally made of plastic or porcelain, are several inches long, and have one hole at each end. Your antenna wire is inserted through one hole, and your supporting rope is inserted through the other hole. Some have an eye hook running through the middle section of the dog bone to facilitate it supporting the center of a dipole antenna.
Dog bones sporting an eye hook normally serve as the center insulator of a dipole so the antenna elements (wires) extend from it in both directions (see diagram).

After inserting your antenna wire through one hole in the dog bone insulator continue to thread enough antenna wire through so you may tightly wrap the free end back around the antenna wire 5 to 10 times. Leave a small loop of wire through the dog bone so it has a little freedom of movement. Next solder the wrapped wire to the antenna wire (I normally use # 14 stranded hard drawn copper). This should secure your dog bone to the end of the antenna for many years[1].

If you are always going to feed this antenna with the same transmission line you should also solder those wires to your antenna elements. If you plan to change transmission line, or want the option to easily do so, you instead need to permanently attach a SO-239 (SOcket) to the dog bone for coax, or some type of mounting lugs for ladder line. In either case the electrical connection to the antenna wires be must well made, the assembly should be weather proofed, and the weight of the transmission line should be supported by the center insulator. Neither the antenna nor transmission line wires should bear the weight of the line – they will too easily break. Keep water from entering the coax and rust-proof nuts, bolts, etc.

When you measure the length of your antenna wire you should measure to the most extreme extension of the loop that runs through the hole in the dog bone. The excess wire you tightly wrapped around the antenna wire to secure the dog bone is not taken into account. (Tight tolerances are critical for UHF/VHF, but less so for HF.)

Dog Bone Insulator



Calculating ¼ Wavelength

One calculation that will repeatedly occur during your amateur radio studies and antenna projects involves determining various lengths of antenna elements (such as the two ¼ wavelength wires in your dipole), ground radials (which are part of a vertical antenna), or transmission line.

I prefer to begin with the actual number of meters in a given measurement (such as an antenna element) and then convert this from meters into feet. My calculation method is a little more cumbersome than some other formulas you may find elsewhere, but it has the advantage of allowing you to convert any needed metric measurements into their corresponding number of feet. I use a calculator, if you are using scrap paper or doing the calculations in your head you may prefer to memorize a variety of the shortcut formulas (like a loop antenna requires the wire to be 1005/(f MHz) long (in feet), or a ¼ wavelength dipole antenna element is 234/(f MHz) long (in feet)). You may or may not like my method – use whatever works best for you.

The basic formula is[2]: **300 / frequency in MHz = meters**.

Let's walk through an example. For our example we want to determine the length of a ¼ wavelength at 7.2 MHz.

300 divided by 7.2 MHz = 41.67 meters

Now we need to convert this into feet. There are approximately 39.37 inches in one meter, and there are 12 inches in one foot. Therefore:

41.67 times 39.37 = 1640.55 inches.
1640.55 divided by 12 = 136.71 feet.

Therefore, one full wavelength at a frequency of 7.2 MHz is approximately 136.71 feet. We now divide this by 4 to find the length of each ¼ wavelength element (our typical dipole antenna wires).

136.71 / 4 = 34.18 feet.

Each ¼ wavelength element is a little over 34 feet. But how do we determine how many inches are in 0.18 of one foot? Simply multiply this number by 12 (inches) and that will give us the number of inches equal to 0.18 of one foot.

12 * 0.18 = 2.16 inches.

Our final answer is ¼ wavelength at 7.2 MHz is equal to 34 feet and 2.16 inches.

What about that fraction of one inch? (The 0.16 inch.)

Normally you don't need to be this accurate. Either you are going to add about one foot of extra wire to each antenna element and then slowly trim off excess antenna wire until you achieve "resonance," or you will use an antenna tuner and don't need to be accurate to fractions of an inch (or even fractions of one foot for that matter).

However, it is important each wire of the dipole is the same length.

Still want to find 0.16 of one inch? One quarter inch is 0.25; it is less than this. One eighth inch is 0.125, so it is somewhere between 1/8 and ¼ of an inch. How accurately can you cut a wire? If you can accurately cut your wire to 0.16 of an inch, will you be able to maintain this accuracy as you attach each end of the wire to the insulators (used to suspend the antenna)?

If we still want to know, this is how I'd determine how many 1/8 inch units is represented by 0.16 of one foot (but remember, this is unnecessary).

8 times 0.16 = 1.28, of 1/8th inch units.

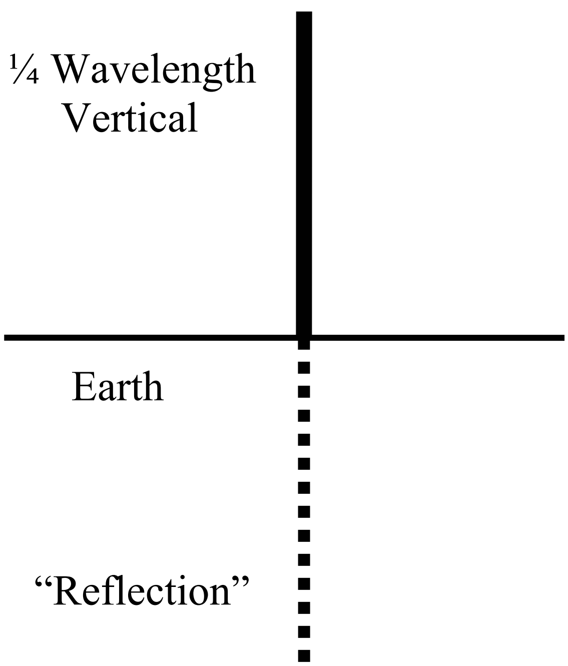
This is one full 1/8th inch and 0.28 of the next 1/8th inch. Or just a tiny bit more than 1 ¼ eights of an inch. Measure 34 feet, 2 inches, one full 1/8 inch, and then a "couple hairs" past ¼ of the distance to the next 1/8 inch mark.

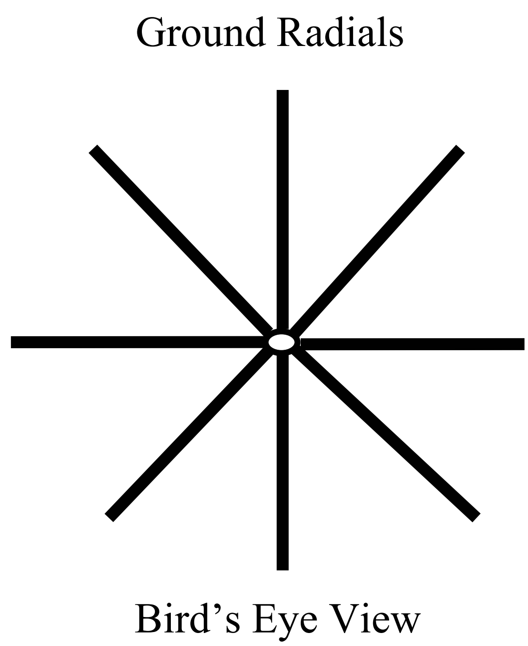
If you wanted to know how many 1/16^{ths} of an inch were equal to 0.16 of one foot, use the number "16" in place of the number "8" above. This holds true for any fraction of an inch, 1/32, 1/64, etc.

16 * 0.16 = 2.56, of 1/16th inch units.

Vertical Antenna Fundamentals

You can think of a vertical antenna as a dipole antenna stood vertically on end. Now push it into the earth until the feedpoint is located at the surface of the earth. One antenna element now extends ¼ wavelength upwards; the other is buried (sometimes called a "mirror" or "reflection") and almost entirely useless to us as an antenna because the earth is not a very good "RF reflector." In fact, it is usually a much better "RF sponge." We overcome the poor RF quality of the "buried" element by spreading out wires along the surface of the earth. These wires provide a much better conductive surface for our RF current to traverse (and "more wires is more better"). In terms of balance, a vertical antenna is "unbalanced" because one element is connected to your station ground (typically the ground plane radials & coax shield).





There two types of vertical antenna. One elevates the "RF reflecting wires" above the earth (these wires are then usually called a "ground plane" or "counterpoise"), and the other places these wires on the surface of the earth (the wires are now called "ground radials" or "radials"). When elevated, a common rule of thumb is to have at least two of these wires measure ¼ wavelength on each band you intend to operate[3]. When on the earth, or buried just below the surface, length is much less important. It is then important to concentrate more wire close to the feed point, and none need be longer than 40% of a wavelength at the lowest frequency. But, as the number of ground radials is reduced, this total length is less important. If you use 32 radials you have passed the point of diminishing returns: each time you now double the number of wires in the ground plane, you will get less improvement than the previous time you doubled their number. But improvement adds quickly up to 32.

The importance of the ground radials, or ground plane, can not be stressed too much. They make up the 2nd half of the vertical antenna. **For your antenna to work well you need <u>both</u> halves!**

Do not bury your ground radials more than one inch below the surface of the earth. As I said, the earth is not a good reflector, but it is fairly good at absorbing RF. If you bury your radials too deeply they will not work (they become ground rods). It is common to simply lay the radial wires directly on the earth. You can pin them down with bent wires. Once the grass grows over them they'll usually stay in place.

You may also spread out rolls of chicken wire or fencing wire on the ground, just be certain to make a solid electrical connection to each piece of metal serving as part of your ground plane and connect these to your station ground. The diameter of the ground radials does not really matter. If I were using them on the ground I'd want them thick enough they would not rust apart for many years. If they were elevated above the earth I'd want them thick enough to take the weight of ice during the winter and to stand up to the wind during storms. These wires may be insulated or bare wire, solid or stranded. If for temporary use, any metal can suffice.

If you are using coax to feed your vertical antenna, connect the coax shielding to the ground plane system and connect the center conductor to the vertical element. If you are feeding it with balanced line (ladder line) it does not matter which wire is connected where.

Your vertical element must be insulated from the earth. There are three basic ways of accomplishing this task. Temporary antennas often have a wire simply hung from a tree branch. For more permanent installations you may dig a hole and set a wooden or plastic (such as PVC) pole in the earth. The pole may be tall enough to affix a wire to (or suspend the wire inside the pole), or the pole itself may be made of metal and attached to a short wooden post driven into the earth.

The important points to remember are: (1) insulate the vertical element from the earth and your ground radials; and (2) get as much metal as you can spread out on the surface of the earth below the vertical element, and in as many compass directions as possible (a huge sheet of copper would great, but very expensive).

Height

With a dipole antenna it is important to get the center (called the "feedpoint," where your transmission line connects to the antenna wire) up as high as possible above planet earth to achieve the greatest distance for your radio transmissions[4]. This will give you the best chances to talk to fellow amateur radio operators in other countries and continents (called working "DX" – think "Distance").

If you want to work other stations within a few hundred miles of your location, it is better to position your feedpoint at a height of approximately 15% to 20% of a wavelength above the earth. This is called a Near Vertical Incidence Skywave, or "NVIS" antenna (pronounced "NEV-iss").

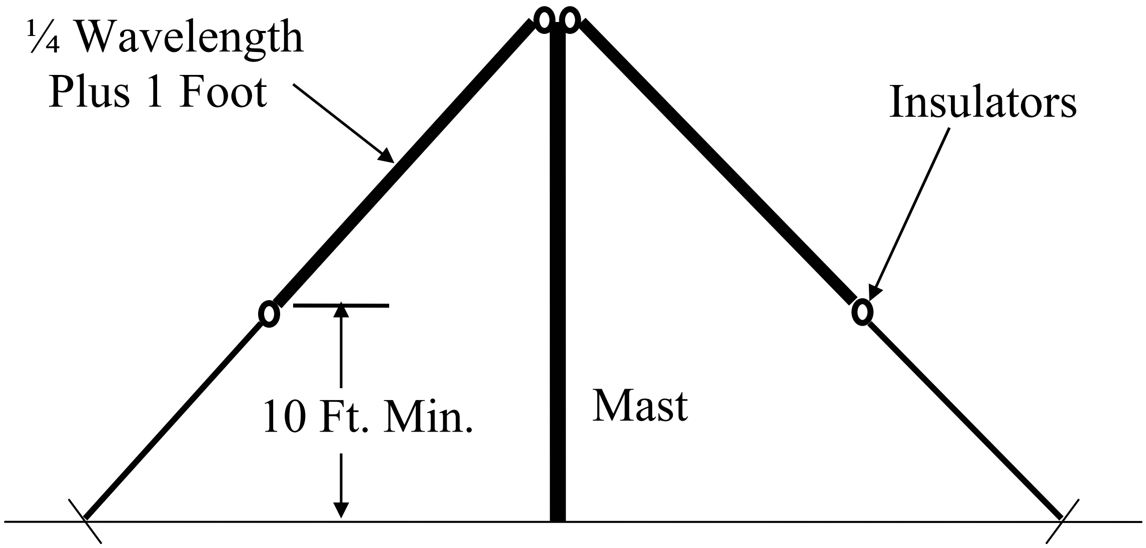
The best bands for NVIS communications are usually 40- through 80-meters. There are many variables to be considered, but one of these bands will generally perform well for short distance, or regional, communications. The time of day will determine which ban performs better. As radio frequency increases, and as the angle approaches 90-degrees, radio waves tend to cut through the atmosphere.

As you can see, there really is not a single answer to "what is the best antenna height?" Your answer depends upon where you want the best opportunities to make contacts. Generally speaking, if you want to talk to other countries, get your dipole antenna up high. If you want to speak to others around your state, keep the antenna around 0.20 of a wavelength above the earth. (300 / 7.2 MHz * 39.37 /12 = 136.7 feet * 0.20 = 27.34 = 27 ft. 4 in.).

You should be aware the majority of your effective RF radiation (your radio signal) will (usually) be generated at your feedpoint. By comparison much less of your effective signal is radiated off the ends of your wire. This, along with the fact that raising one pole or mast high above the earth is easier than raising two or three, is why the so-called "inverted vee" is so popular.

Get your feedpoint as high as possible and you can simply stake down the ends of your dipole using rope (or string) and tent stakes. When doing this add about one foot to each wire of your dipole and if possible keep the ends of the antenna wire ten feet above the earth. There are two reasons for this: to keep people away from the antenna elements while you are transmitting and to reduce the amount of RF

(Radio Frequency) energy the earth absorbs. This second point is not quite as important because most of the effective RF radiation will take place at the feedpoint, not the ends of your antenna (this is true when the individual antenna wires are a multiple of ¼ wavelength of the frequency you are operating – when your antenna wires are ½ wavelength long, the opposite is true).



Inverted Vee Dipole Antenna

The angle between your antenna elements should be no closer together than 90-degrees; 120-degrees is better. The ideal orientation of the antenna elements is parallel to the earth (180-degrees) but that is obviously no longer an "inverted" vee.

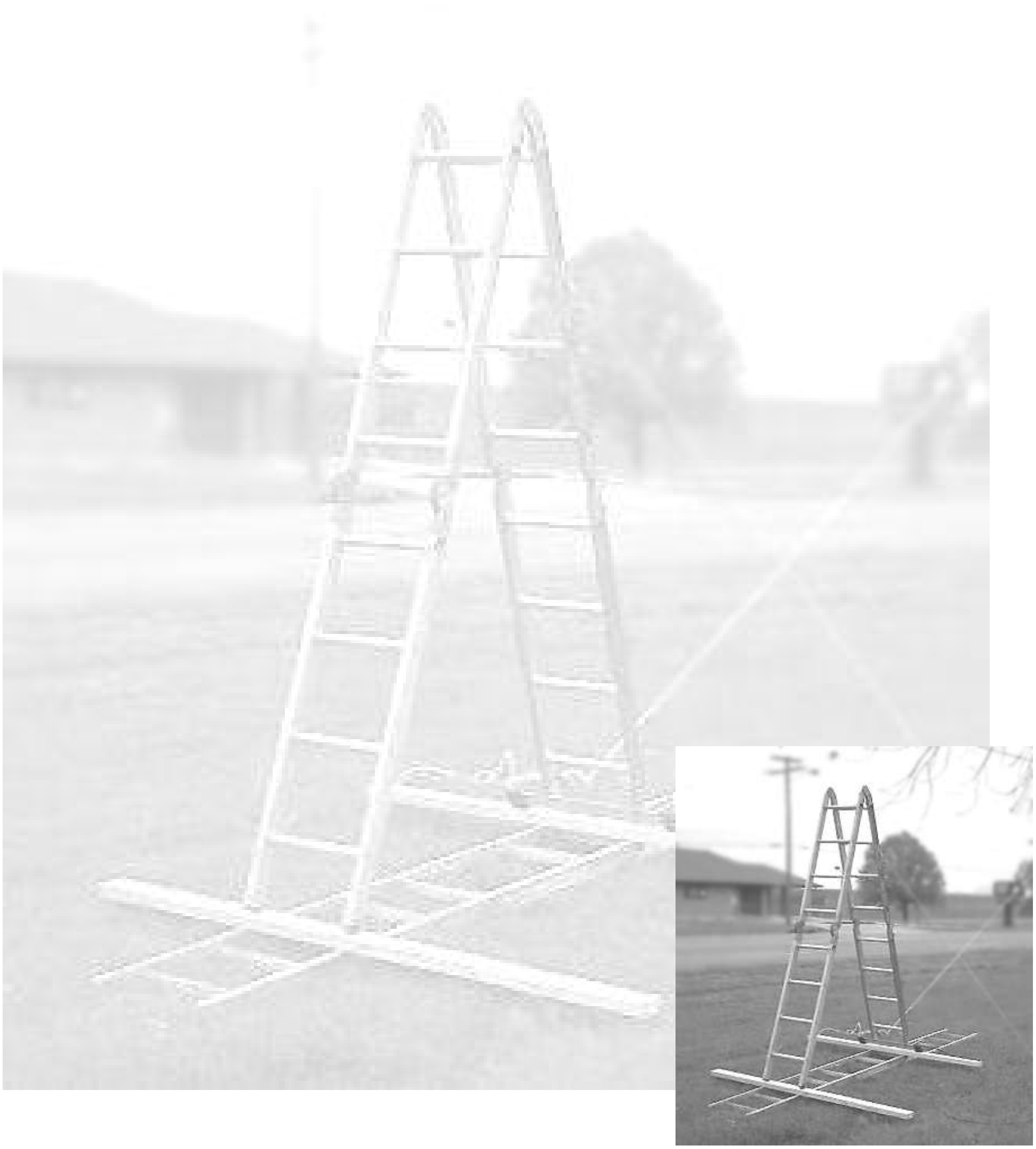
Do not worry too much about height. Do what you can, but many people have made numerous overseas contacts with antennas that are technically NVIS antennas. Think about it. On 80-meters, say 3.963 MHz, what is a ¼ wavelength?

(That's right – a pop quiz!)

Your answer is a little over 62 feet. This is technically still a NVIS antenna on 80-meters. To have an antenna a full wavelength above the ground for this band you need to be at nearly 250 feet height. A tower that high needs to be cleared by the FAA and requires lights so planes do not crash into it. There simply are not many people with towers this tall. Heights of 30- to 40-feet above the earth are much more common. Even most towers are only 50- to 100-feet tall.

Chapter II

Strange Antenna Examples



Coax Choke[5]

One of the most important things we can do when experimenting with strange antennas is attempt to isolate the strange antenna from unknown effects. The better we realize this goal, the more our test measurements and contacts with other amateurs will reflect only the strengths and weaknesses of the strange antenna we are attempting to evaluate. To this end, one of the things we should try to do is keep the RF energy we send to the antenna, in the antenna system, and prevent it from radiating off the outside of the coax shielding.

Wrapping 10- to 20-feet of coax into a tight coil is an easy and inexpensive way to help assure the RF radiating from your strange antenna is actually coming from the strange antenna and not off the outside of the feedline (10-feet, 7 turns is a good start). Note the images showing the kind of coax choke I normally take with me to the field. You can see they are not perfect, but they certainly are not a random scramble of wire! Each coil of coax is pressed tightly against the turn both before and after it. You do not want the first turn touching the last turn because this has the effect of skipping all the coils between the two (well, it may not be that bad of an error, but I think you get my point – you are working against the other coils).

If you are feeding your strange antenna with balanced line (ladder line) really all you need do is keep it separated from other objects (this includes planet earth) by a minimum of a couple of its widths. Also use a balun or transmatch before you hook it to your transceiver (if you are using a tube radio, you may not need a transmatch, but we will not discuss vacuum tube radios).

Altoid’s Breakout Box

Note the Altoid’s mint box in the previous images. There is a SO-239 mounted in the top of the mint can along with a pair of 5-way binding posts (both may be purchased at Radio Shack or Mouser.com). This quickly allows me to “breakout” (connect) my coax to a pair of wires. I then hose clamp these two short “breakout” wires to whatever metallic item I am about to fly as an antenna.

My mint box has been filled with silicone, although this is not necessary. A small metal project box from Radio Shack or Ten-Tec could also be used in place of the mint can. Use whatever box/enclosure you have on hand, but I recommend it is metal so stray RF is contained inside the enclosure.

You could simply free enough of the center conductor and braid to reach your strange antenna and then use a hose clamp to directly connect the coax to the antenna. Be certain the center conductor remains insulated from the shielding. Remember to coil up the coax near the feedpoint so you have a coax choke in place.

You don’t have to use a hose clamp to attach your feedline to your strange antenna. You can use clamps, or even tap and drill a hole for a screw and washer, although that is more effort than I’d recommend for playing with experimental antennas. Of course, you may try to fly a bridge or grain silo and need to use a more substantial connector than a hose clamp to obtain a good electrical connection. Try a clamp.

The key is you need the ability to easily pass an electrical current to your strange antenna from your transmission line. You want very little resistance between your feedline and the metal of your strange antenna. Any means of attaching your transmission line to your antenna accomplishing this goal is satisfactory.

Vertical

One of the most important things to remember when you are setting up a strange <u>vertical</u> antenna is it requires a ground plane (or ground radials) of some kind. The loadlock vertical shown next uses the metal chain link fence as its ground plane. This is where the coax shielding is connected. (This fence measures about 20-feet along each of two sides, set at 90-degrees to one another – the vertical is set up roughly in the middle of one of these sides). The metal loadlock serves as the vertical element, and this is where the coax center conductor is connected. The step ladder shown in the picture is fiberglass and not electrically part of the antenna – it is only used for physical support.

The Altoid's mint "breakout box" is attached to the coax choke as previously shown. There are two # 14 insulated wires (approximately 10- to 14-inches long) leading from the breakout box (from the binding posts).

One wire of the breakout box is tightly attached to the base of the loadlock and the other wire is tightly attached to the horizontal railing of the fence. Both are held in place with a metal hose clamp. No paint was removed from the loadlock, nor was either surface sanded, or in any way prepared. The hose clamps were tightened by hand-screwdriver with the #14 wire pressed between the hose clamp and fence (or loadlock).

This method of attaching the coax to the "strange" antennas was used for all the strange antennas discussed in this field manual. I have found it provides an adequate electrical connection. It is quite simple to attach and easy to adjust. (K.I.S.S.)

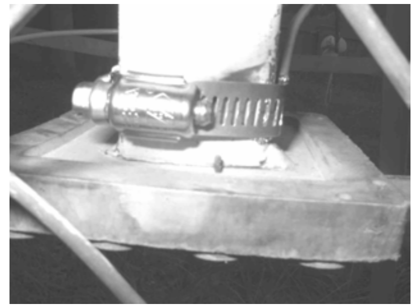
I normally just attach the hose clamps at some convenient point, and run the feedline through a transmatch before going to the transceiver. So far this has always worked fine. I use a MFJ antenna tuner that has a variable "roller" inductor inside along with two air variable capacitors, designed to handle 300-watts of transmitted power – I transmit at 100-watts.

What if you can not achieve a match? Try moving the hose clamps. Think of a Windom antenna[6] match – exact placement of the wire along the antenna element can alter the impedance seen by the transmatch / transceiver. Sometimes you only need to find a slightly better place to feed your strange antenna to make it work.

Another quick and easy solution is to add, or subtract, about 20-feet of coax between the antenna and the transmatch (specifically you want ¼ electrical wavelength). This may change the impedance the transmatch "sees" and sometimes this alters the impedance enough the transmatch will be able to tune the antenna.

Note the "breakout" wire sandwiched between the hose clamp and fence rail (and loadlock). In these images the hose clamp has been loosened somewhat. Previous to loosening them there was no visible gap between the hose clamp and the metal to which is pressed the wire.

The A-frame ladder antenna shown on the title page to this chapter is also a vertical antenna. The ladder bent into the "A" is fed by the center conductor from a length of coax and the other ladder is lying in the grass and has the coax metal shielding attached to it. There are two pieces of 2x4 separating the two ladders from one another – this is an important point, the two halves of vertical antennas must be insulated from one another (this is also true of dipole antennas). In this configuration the "A" ladder is the primary radiating antenna element and the ladder laying on the ground is the "mirror" half of the vertical antenna, also called its ground radial, or ground plane.



Another point one should be aware of is how to attach the feedline wires (either directly off the coax, or via the breakout box) to smaller or more delicate items, such as chicken wire, or a metal measuring tape, which will crush if you apply too much pressure.

Looking closely at the image of the tape measure dipole on the roof one can see the white dog bone insulator that is cradled in the curve of the metal measuring tape. The wire from the Altoid's breakout box is sandwiched between the metal tape and the dog bone with our ubiquitous hose clamp tightly pressing the wire against the metal tape.

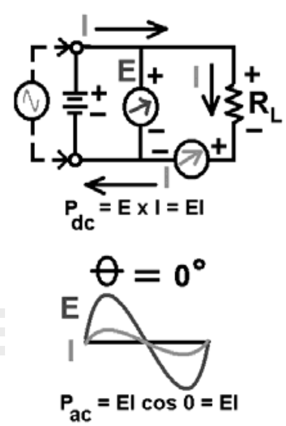
Dipole

The biggest difference in making a dipole verses a vertical antenna is both sides of the feedline wires need to be attached to virtually identical items. A pair of shopping carts is a famous example, but a pair of metal folding chairs, or aluminum ladders may also be set up as "balanced" antennas. Another big difference between a dipole and vertical antenna is the dipole does not need a set of ground planes or radials to operate properly. This is because it operates independent of ground.

However, each side of the dipole must be insulated from the other side. The two metal folding chairs are dipole elements and can not touch one another.

Chapter III

Antenna Tuner Theory[7] – Introduction



Do You Need an Antenna Tuner (Transmatch)?

This is perhaps the single most important question facing amateur radio in the 21st century! (*Well, maybe not quite* <u>*that*</u> *important.*)

The answer is “it depends,” which is generally my answer to any question involving amateur radio. This is such a diverse hobby & service that pat answers are far and few between (such as you should <u>never</u> set up an antenna or tower that may fall across an electrical power line).

With regard to the KØS Strange Antenna Challenge the answer is usually, "Yes!" However, at your mobile or home station the answer becomes increasingly unclear. Let’s take each of these situations in turn.

KØS Strange Antenna Challenge

You will be flying nearly anything under the sun that is metal or capable of carrying an electrical current. Few, if any, of these will happen to match the impedance of your feedline and transceiver. I won’t go so far as to say it is “impossible,” but let me confidently state you will be able to see impossible from where your are rigging your strange antennas! <u>Plan to use some type of transmatch</u>. This may be a spare coil and capacitor, or it may be a 1.5 KW tuner – it doesn’t matter whether you buy, build or borrow the device, but you should have one, or be prepared to spend a very long day transmitting on very few antennas. However, if you are prepared to spend time with an antenna analyzer (or similar equipment) I am certain you will be able to find a few things that you can fly “in the nude” so to speak (Windom antenna[8] style matching).

Mobile Station

Now we must define our needs. What frequencies do you wish to work? How much money are you willing to spend? If you are only working 2-meters, 440, or similar bands, the question is easily answered: get a ¼ wave or 5/8 wave antenna and be done with it – you still need to decide whether to use a magnetic mount or drill holes in your vehicle. Even if I were going to permanently mount my antennas (drill holes) I’d use mag-mounts long enough to be certain I like the placement of my antenna(s).

HF is the next step. How many frequencies? Are you using a screwdriver or similar style antenna? If you are only working a small number of frequencies, or you only work one frequency 95% of the time you may just want to cut an antenna for that band and forgo any tuner. There are antenna supports that will allow the use of up to three antennas by using different tips angling off in slightly different directions. A screwdriver antenna will also allow you to forgo the need of a tuner. These are becoming quite popular, but are somewhat expensive.

On the other hand, you may have no idea what frequencies you want to use. In this case, provided you don't wish to spend the money to purchase a 6- to 80-meter screwdriver, you may just mount a 102-inch stainless steel whip antenna and use a transmatch to tune it.

If you go this route you need to decide whether to use a manual or automatic tuner. Most people will use an auto-tuner. This is much safer! Perhaps if you are only going to change frequencies when stopped you might consider a manual tuner, but even then I'd recommend the auto-tuner – it is too tempting to change frequencies while driving. **If you can operate your transceiver while driving, make certain you can obtain a good impedance match <u>while keeping your eyes on the road</u>**.

Home Station

At a home station we still need to know what frequencies you wish to work, and we still need to know how much money you are willing to spend. But we need to answer other important questions, such as how much room do you have in which to erect antennas and/or towers, can these be permanent or semi-permanent installations, or are you renting (visiting) and will take them down after each use?

If you are going to put up a small number of antennas to work most of all of the amateur radio bands you will want (need) to use a tuner. If you have the space to put up an antenna for each band you will work you may not need a tuner (some bands may be combined on the same antenna, so one antenna is not required per band). If you are using a vacuum tube transceiver you will be able to match a wider range of antennas than if you are using a newer transistor based transceiver. This is because: (1) transistors are more likely to be damaged by excessive voltage, and (2) vacuum tube radios normally have a matching ("tank") circuit built into them.

Most of us are using the newer transistor based radios, and most of us wish to work more than one or two bands. As the number of bands we wish to work increase, the more likely we are to find a use (need) for a transmatch (antenna tuner). Which bands you wish to work also has some affect upon your choices. If you are only interested in the higher frequencies your antennas will be smaller and therefore it will be easier to find room for them in your yard or attic. If you are interested in the lower frequencies (40- through 160-meters) much more of your yard will be taken up by antennas. Not many of us have room to erect a 160-meter dipole for example (300/1.8*39.37/12/2= 250- to 275-feet (and ideally the height above the earth would be the same or greater – *ya, right! If you have THAT antenna farm you don't need my advice!*)).

This is one of the reasons I expect most amateurs will want a transmatch – most of us simply do not have enough yard to put up one antenna for each band (or two, if you really want to get good coverage). This means our antennas need to work double, triple, or even all-band duty!

What is a simple explanation of what an antenna tuner does?

A properly adjusted transmatch ensures energy exchanges between your antenna and transceiver conduct the maximum amount of RF energy, by reducing lost or unusable RF energy. Physically this is achieved inside your transmatch by the specific position of variable capacitors (plates) and variable inductors (coils). Once the transmatch has been properly adjusted, the transceiver will "see" its designed impedance (usually 50-Ohms) as it "looks" down the transmission line towards the antenna, and at the same time the antenna will "see" its designed impedance as it "looks" down the transmission line toward the transceiver. Both conditions must occur simultaneously. At this point a conjugate match has been achieved and all energy transmitted by your transceiver will be radiated by the antenna (except for transmission line loss)[9].

Great. Is there a <u>simpler</u> explanation!?

No.

Just kidding! But first we have to come to some understanding about the terms "impedance" and "reactance." Once you understand these two terms you should adequately understand the above description.

<u>Impedance may be thought of as the rate at which energy is transferred from one part of a system to another part of the system. You may also think of it as the resistance to alternating current</u>. Impedance = Z = (V / I). Another formula expressing impedance is: Z = R ± jX (where Z = impedance; X = reactance).

Reactance is sometimes confusing. I think this is partly because it has been referred to as "imaginary" energy. How can something imaginary affect our radio transmissions? It can't, of course. However, reactance is NOT IMAGINARY, the energy is very real! It can be measured, therefore it exists. The reason it is called "imaginary" is due to the appearance of its mathematical expression.

<u>Reactance is energy that provides no useful work</u>, which is to say it does not help our antenna to radiate a RF signal. It may be thought of as a kind of "loop" of energy. You might picture it as an eddy swirling in a river – a leaf (a portion of our RF signal) caught in this eddy just spins in circles, instead of being carried down the river to the ocean (our RF signal radiating outward into the atmosphere). Capacitive reactance (X_C) is caught up in an electrostatic field. Inductive reactance (X_L) is caught up in a magnetic field. As the AC current alternates the reactive energy is passed from one field to another, and back again (our "eddy").

Further explaining reactance becomes more complex. We have to introduce phase and vectors. The mathematical expression for impedance, including the term for reactance (X) is: $Z = R \pm jX$. Solving this equation provides the answer to how much of our RF energy leaving our transmitter is radiated from our antenna. We will return to this point, but let's first consider our antenna system as a whole….

Our basic antenna system is comprised of three parts: (1) transceiver; (2) transmission line; and (3) antenna. Each of these parts operates at some specific "impedance." Our goal, of course, is to radiate as much of our transceiver's energy into the atmosphere as possible. For this to occur, each part of the antenna system must operate at the same impedance (voltage/current = V/I).

Modern transceivers operate at 50-Ohms impedance. This means as they "look" into the transmission line toward the antenna they need to "see" 50-Ohms impedance in order to transmit at full power. If they see either larger or smaller impedance they will reduce their power output[10].

At the opposite end of our antenna system is our antenna. For the antenna to absorb all of the energy delivered to it, this energy must arrive at the specific value of impedance for which the antenna is designed to operate. This value of impedance is affected by a number of things, including height above earth, diameter of the antenna elements, and nearby objects.

Connecting the two ends of our antenna system (transceiver and antenna) is the transmission line. This will be either coax or ladder line. Common impedance values of coax are 50- and 75-Ohms, and 300- and 450-Ohms for ladder line. Transmission line impedance is affected by such things as the diameter of the conductor (wire / shielding), spacing of the conductors (two wires for ladder line; one wire and one shielding for coax), and the composition of the dielectric material (what insulates one conductor from the other).

Sometimes transmission line is referred to as an impedance “transformer.” We will not discuss this in great detail, but if you think of various impedance values as corresponding diameters of pipe, you can imagine how the pressure under which water travels along these pipes is affected by the pipe diameter. Don’t take this comparison too literally. All I want you to grasp is as your RF signal travels along a transmission line, if there are various sections of the path made up of different impedance values, the “rate” at which the RF travels is affected by the conduit through which it is traveling.

What are our “givens” and “variables” in our antenna system?

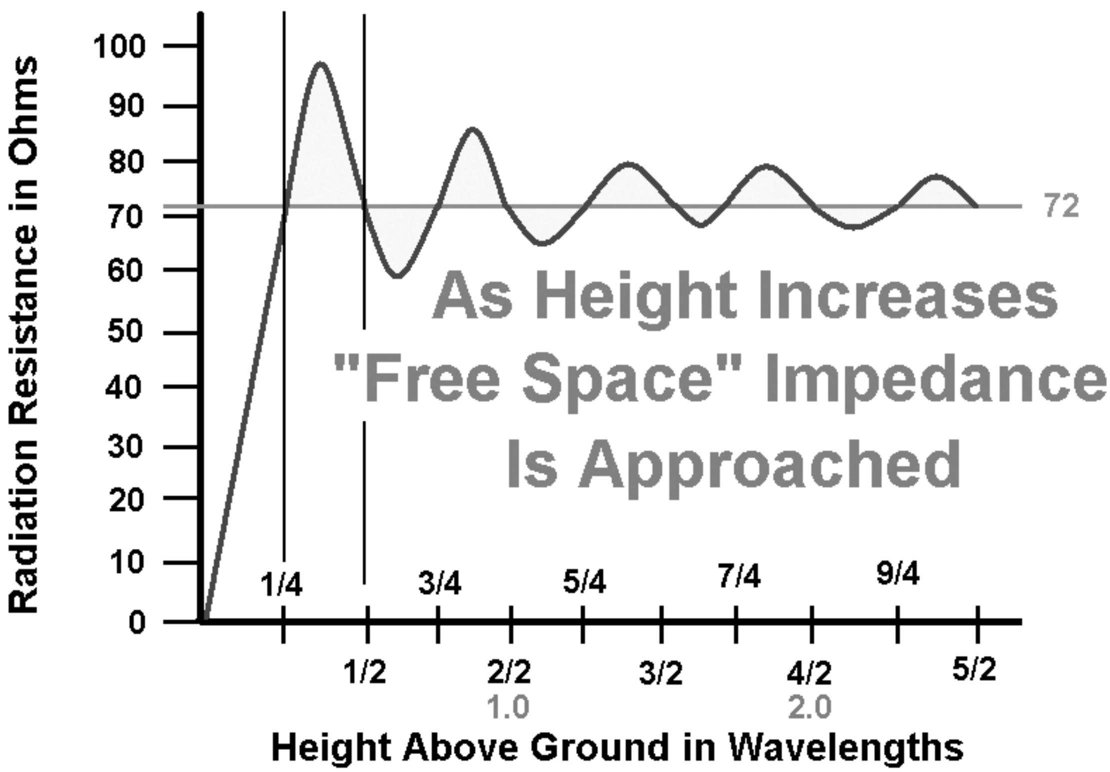
We know ideally each part of the antenna system would operate at the same impedance. We know our transceiver operates at 50-Ohms and this can not be changed. This leaves us two variables with which to work: the antenna and the transmission line.

I mentioned a number of things that affected the antenna’s impedance: height above the earth, diameter of the elements, and nearby objects. Nearby objects are difficult to qualify, but the general rule is: don’t have them nearby! Set up your antenna as distant from other objects as possible. When feasible, position two antennas at 90° to one another[11] (this reduces their mutual affects upon one another – recall they are an alternating current system). The diameter of your elements is fixed once you have constructed the antenna, and your choices are usually based upon construction and support needs. Use metal wires or pipes.

This leaves us with height above the earth. Other than ensuring (as well as possible) you have maintained maximum clearance for your antenna, height is the only variable easily changed. Height applies most directly to dipoles, beams, and elevated verticals. Earth-mounted verticals are affected by the relationship between the length of their vertical element and the ground radials extending along the earth (just as dipole elements are insulated from one another, the vertical element of all vertical antennas is insulated from their ground radials).

Examine the following graphics:

Dipole Height Affects Impedance[12]



The vertical scale is the impedance of our dipole at its feedpoint (in the center of the two ¼ wavelength elements), also called radiation resistance. The scale along the bottom of the graphic is the height of our dipole above the earth measured in fractions of a wavelength (this allows you to use this chart for all amateur bands).

Note the horizontal line at 72-Ohms. A dipole radiating RF energy in outer space will have an impedance at its feedpoint of roughly 72- to 73-Ohms. You can easily see the first ¼ wavelength above the earth creates the largest variation in feedpoint impedance. The higher we raise the antenna above the earth the closer it approaches the feedpoint impedance of a dipole in outer space (this is logical – if we raise the antenna high enough, it will be in outer space).

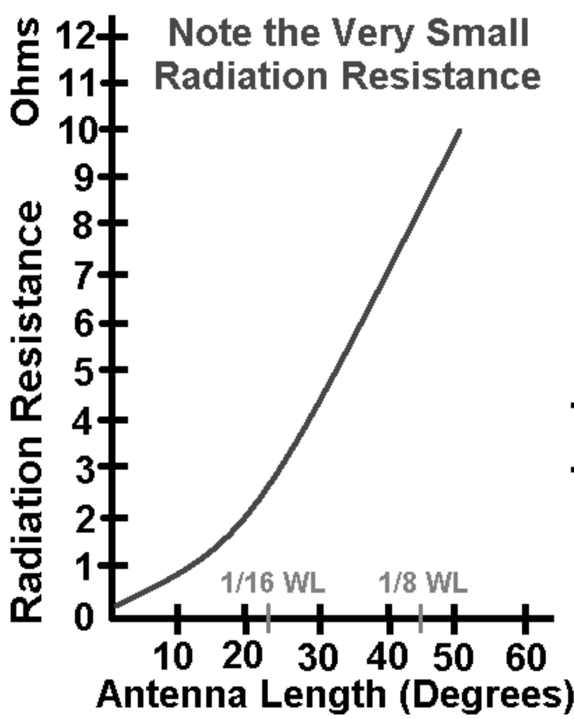
The next graphic charts a number of characteristics of earth-mounted vertical antennas. The horizontal scale is in fractions of a wavelength and also in degrees of a wavelength (180˚ = ½ wavelength; 90˚ = ¼ wavelength; etc.). The vertical scales are broken into two different views (left/right), and several different measurements.

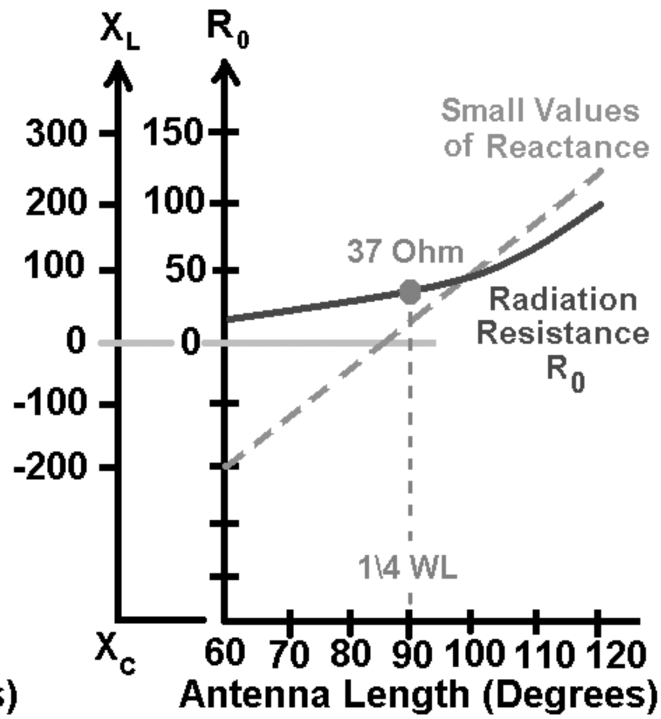
The left half of the graphic plots points that are under 60˚ of a wavelength, and the right side plot points above 60˚ of a wavelength.

The left side shows "radiation resistance" measured in Ohms on the vertical scale. We will not discuss this at length, but it shows us very short vertical antennas (relative to fractions of a wavelength) are not very efficient – in other words, the amount of RF energy radiated is small. This is because much of the RF is absorbed by the earth. A very short vertical antenna is a "compromise" antenna.

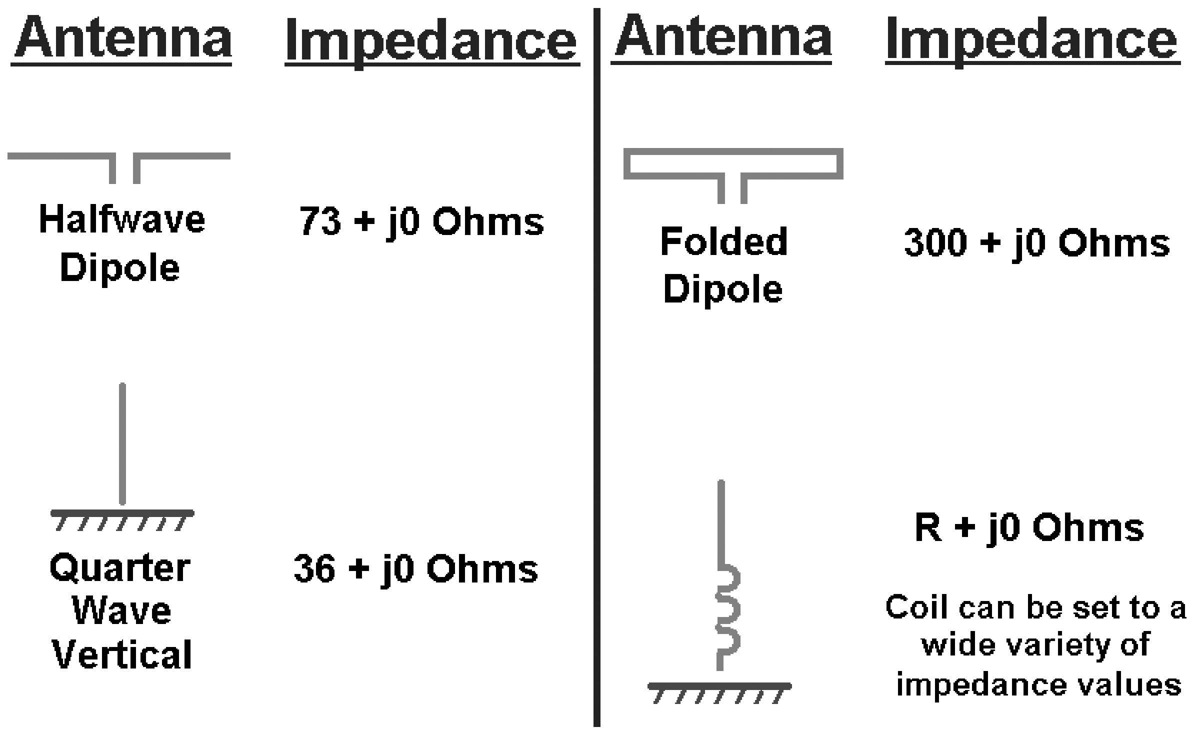
The right side shows feedpoint resistance (R_0) and reactance (X, where X_L is inductive reactance and X_C is capacitive reactance). The point plotted shows us a vertical antenna ¼ wavelength in element length (vertical height) will have a feedpoint impedance of 37-Ohms, and the reactance will be very small, or even non-existent. You can see that increasing our vertical element length to 100˚ brings us quite close to 50-Ohms impedance, but that we would then have about +100 Ohms in inductive reactance.

Vertical Length Affects Impedance[13]





The next graphic will provide a quick overview of a number of common antennas and their nominal feedpoint impedance values[14]:



Each of the above basic antennas has a different feedpoint impedance for which reactance is zero. Feedpoint point impedance is the impedance the transmission line must deliver to the antenna for the antenna to radiate all of the energy delivered to it – if the transmission line provides either a greater or lesser amount of impedance the antenna will not be able to absorb all the energy.

Energy not absorbed by an antenna is reflected back toward the transceiver[15]. This gives birth to the standing wave ratio, the infamous SWR, of which many are mortally afraid.

I do not recommend you spend much time worrying about SWR[16]. Instead, focus upon the impedance values at each point of your antenna system. If you adequately match the impedance at the connection points (junctions) of your antenna system, the SWR will take care of itself. In other words, **deal with the illness (impedance mismatch) not the symptom (SWR)**.

To make a long story short – if that is still possible….

Use a transmatch (aka "tuner") if…

…you want to feed your antenna with ladder line, which has extremely low loss.

Ladder line experiences very little RF loss but its impedance is quite a bit higher than your transceiver. You will need a tuner to match this difference in impedance.

…you want to use one antenna on multiple bands.

For an antenna to be naturally resonant at a given frequency it must be a specific length. As the antenna length changes (longer or shorter), or as we operate a different frequencies (higher or lower), we experience an impedance mismatch between the antenna and transceiver. A tuner will correct this mismatch.

If the antenna is cut to the EXACT length for a given frequency, reactance is zero. If the antenna is too long, inductive reactance is present (X_L). If the antenna is too short, capacitive reactance is present (X_C).

Changing frequency adds reactance: (1) Higher frequency = electrically longer antenna = inductive reactance (X_L) is added to the antenna; (2) Lowering frequency = electrically shorter antenna = capacitive reactance (X_C) is added to the antenna.

…your antenna's natural range of resonance is too small to cover the band.

An example may be the 10-meter band, which is quite wide, from 28.0 MHz to 29.7 MHz. You may find your antenna is only able to cover a portion of this band while maintaining an acceptable impedance match. Using an antenna tuner will allow you to work this entire band.

Do <u>not</u> use a transmatch if…

…SWR is 1.5 or less across the frequencies you wish to operate.

Most modern transceiver will operate at full power with this small amount of impedance mismatch. You simply do not need an antenna tuner.

…you wish to reduce RFI to neighboring TVs, phone lines, etc.

Using an antenna tuner will result in more effective RF radiation from the antenna. It is unlikely the transmission line is radiating more RF than the antenna proper, and certainly this will be true once you have matched the antenna with a tuner.

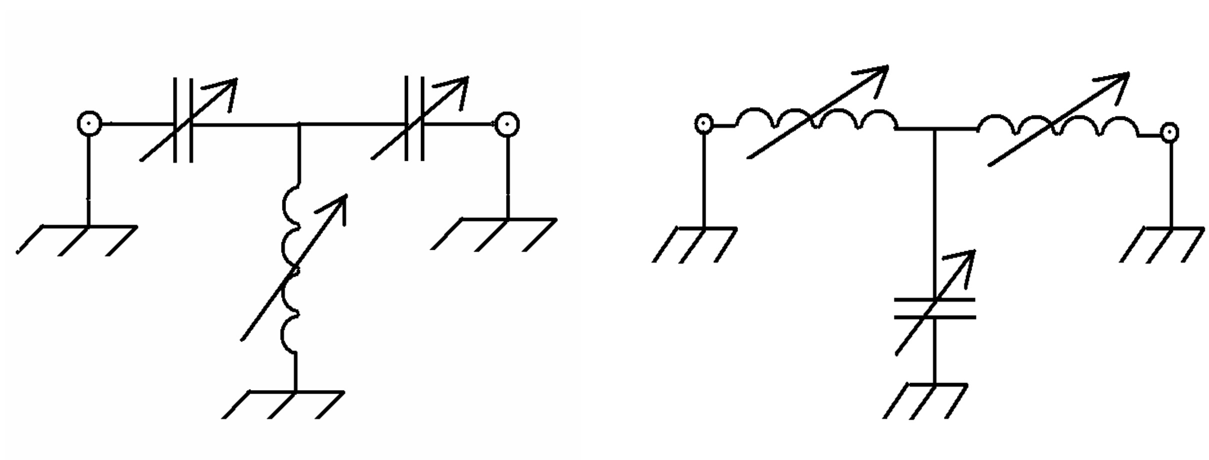
…you have a large impedance mismatch above HF frequencies.

Losses will be very great at UHF and higher frequencies. A better approach is to use a better antenna system without inherent impedance mismatches.

Now that we have discussed whether or not you may need an antenna tuner, let's take a closer look at the internal workings of a tuner.

C-L-C

The most common transmatch design is the C-L-C. This means there are two capacitors (C) in series between your antenna and transceiver, with an inductor (L) placed between these two capacitors going to ground (same as your station ground). These are very popular because they have such a great ability to match a wide range of impedance values between the antenna and the transceiver.



The second most common design is the L-C-L. As you may guess, this has two inductors in series between the antenna and transceiver, with a capacitor going to ground. The biggest advantage of this design is it suppresses frequency harmonics. However, today's modern transceivers have so little harmonic emissions this is no longer a significant advantage.

Variable inductors cost more than variable capacitors. Higher cost and no longer needing the benefit of harmonic suppression have led to the C-L-C transmatch eclipsing the L-C-L as the most popular transmatch design.

Common to All Antenna Tuners

All antenna tuners ("transmatches") have a number of things in common, which is expected since all are designed to perform the same basic function, namely to:
(1) cancel reactance; (2) provide a purely resistive match ("load") into which the transceiver may transmit (the "load" is your antenna).

All transmatches will be constructed of variable capacitors and inductors (coils). I've always seen air variable capacitors used. The inductor may either be a variable type or a tapped type.

If the inductor is variable you will have a knob allowing you to select any inductor position between its minimum and maximum value. If you have a tapped inductor you will have a limited number of settings from which to select (normally via a rotary switch). A variable inductor is preferred because you can always obtain an optimum match. If you have a tapped inductor you will have to determine the "best" switch position available, but this may or may not allow you to obtain an optimum setting. The best switch setting may still be sufficient to allow a successful match, but it may not allow you to achieve a perfect 1:1 SWR match (fortunately perfect SWR is not a requirement to produce a functional match).

By altering the relative positions of the internal components of your transmatch, you vary the "complex impedance" (meaning a combination of both pure resistance and reactance) found on both sides of your transmatch. This is the "tuning" process. Once you have found a workable combination of the variable capacitors and inductor, any reactance in the antenna system will be eliminated and the transmitter will "see" 50-Ohms pure resistance (as it "looks" into the transmission line toward the antenna), and the antenna will "see" (as it "looks" into the transmission line toward the transmitter) whatever Ohms pure resistance it needs to efficiently operate (this value (Ohms) depends on a number of conditions, including height above the earth, distance to other objects, length of antenna elements, amount of reflected power, etc.). The better of two close settings produces greater RF output, which is why an inline output ammeter is recommended[17].

Perhaps the most misunderstood part of an antenna system is reactance.

As you may recall reactance is sometimes called “imaginary”power, but don’t let this fool you: reactance is very real. It can be measured. Remember it is power that performs no useful work – it is just being stored, then returned; stored & returned.

We naturally desire all our transmitted energy to provide useful work – RF energy radiating from our antenna (or being received by it, which is the same thing really as far as the antenna system is concerned, it only differs in the direction of energy flow). To achieve maximum useful work we must eliminate reactance.

Why is reactance called “imaginary” if it’s real energy? Look at the following formula:

$$Z = R + jX$$

This is saying impedance (“Z”) is equal to resistance (“R”) plus reactance (“jX”). Mathemagicians use the lower case “i” and sometimes “j” to represent what they call imaginary numbers (I've been told this is where the term “imaginary” is born). The "j-operator" is there to remind us that term refers to the "phase angle."

Now let’s spend a little time with the above formula. This describes the condition of our antenna system, and how well we “solve” this formula in the real world has a direct affect upon the effectiveness of our antenna, be it “strange” or “normal.”

To begin with, the “+ jX” part of the formula may refer to either a positive (inductive reactance = $+X_L$) or a negative (capacitive reactance = $-X_C$) amount of reactance. If you prefer, you may think of it as taking one of two forms:

$$Z = R + jX$$
$$Z = R - jX$$

Another way of stating the same thing:

$Z = R + (+jX)$ = Resistance plus a positive (+) reactance.
$Z = R + (-jX)$ = Resistance plus a negative (–) reactance.

Subtraction is actually adding a negative number. This is what the above spells out for us. We are always adding some value of reactance to our antenna system, yet what we are adding may be a positive or negative number. Looking at it this way, we see that impedance (Z) is equal to some amount of real resistance (R) measured in Ohms, plus either positive reactance or plus negative reactance. The "X" represents the amount, or magnitude, of the reactance present, and is also measured in Ohms.

For example, if we know we have 500 Ohms reactance, we still need to know if it is positive or negative (it is either "+j500" Ohms, or it is "–j500" Ohms). The X is the "500" in this example. It will be either positive or negative, but can never be both.

Resistance (R) represents real resistance, and is sometimes also called "radiation resistance" when we are speaking about an antenna, where R represents our RF signal's effective radiation into the atmosphere. There is always a small amount of resistance in all conductors, which results in a very small amount of loss in the form of heat. The formula for "radiation resistance" is a little more complicated: $(I^2(R_{Ohmic}+R_{Dielectric}+R_{Radiation}))$. This shows there are several types of "resistance" (R), and all of them must be accounted for to fully define your effective RF radiation.

Let's try an example to clarify these points.

Imagine we have an antenna and have connected a meter to the antenna feedpoint (where our transmission line connects to the antenna). This meter reads "70 Ohms, +j200 Ohms." This tells us the antenna feedpoint has an impedance of 70 Ohms real resistance, and positive 200 Ohms reactance (the "imaginary" part doing no useful work – just energy caught in a loop or "eddy").

If we just connect to this antenna with a piece of coax, there is 200 Ohms of reactance present, which means some of our RF energy will fail to provide the useful and desired work of radiating our RF signal, and will instead be caught up in an "eddy" simply being handed back and forth – in short, doing a lot of nothing!

If we are using a modern transistor-based transceiver (as opposed to a vacuum tube-based design) either the transceiver will be damaged, or its self-protection circuit will cut in and reduce the power output (so it will not damage itself). This is because the excess reactance is not allowing the transmitter to "see" something close to the pure 50-Ohms impedance it was designed to push power into. Only when the transmitter "sees" impedance close to it's designed value (of 50-Ohms pure resistance and zero reactance), will we be able to transmit at full power. (Properly adjusting our antenna tuner allows this to take place.)

We remove the undesirable reactance by introducing into the antenna exactly the same magnitude (the “X”) of reactance, but of opposite “sign” so they cancel one another out, leaving only pure resistance.

Since the antenna shows us “70 Ohms, +j200 Ohms” we will add into the antenna “–j200” (negative 200 Ohms reactance). This has the following effect:

70 Ohms Resistance + j200 Ohms Reactance
plus – j200 Ohms Reactance
70 Ohms Resistance, and ZERO Ohms Reactance.

We are left with 70 Ohms pure resistance. All reactance has been cancelled. There is no longer any “imaginary” energy caught in loops in our antenna system. This frees all our energy to provide us with useful work, which in our case is radiating a RF signal from our antenna.

Now we just have to change the 70 Ohms resistance into 50 Ohms resistance and our transceiver will be able to fully transmit it full power into the antenna.

Our transmatch accomplishes both these tasks at the same time (provided it is properly “tuned,” and the mismatch between the antenna and transceiver falls within the tuner’s ability to correct). We will not explore the exact methods this transformation takes place inside the antenna tuner. It would take a short book to properly explain (“Reflections II” by W2DU is a good starting point).

Conjugate Match

The term “conjugate match” describes the condition our antenna system experiences when a proper match has been obtained with our antenna tuner. This tells us: once one junction of the antenna system has obtained a proper match (zero reactance at the desired impedance), all antenna system junctions experience this match (the same "impedance").

> “The term ‘conjugate match’ identifies a condition where the impedances on opposite sides of a junction have identical resistive components, and reactive components, if any, that are equal in magnitude but opposite in sign…. When a conjugate match is

> accomplished at any of the junctions in a system, all reactances in the system are canceled, *including any reactance in the load*. This reactance cancellation establishes resonance in the entire system, and the generator delivers its maximum available power to the load."
>
> M. Walter Maxwell, W2DU, "Reflections II" Page 17-2

Italics are Maxwell's (who designed antenna systems for NASA, among his many notable qualifications). "Reflections II" should be considered required reading, but it is difficult to digest. I suggest trying the first few chapters. Then lay it down for a few months and try again after studying other books. Repeat as required.

By "load" Maxwell means our antenna. By "generator" he means our transmitter. When your antenna tuner achieves a proper match (a conjugate match) your antenna is in fact "tuned" and resonant (Maxwell defines resonance[18] as the lack of reactance, or zero reactance).

Sound too good to be true?

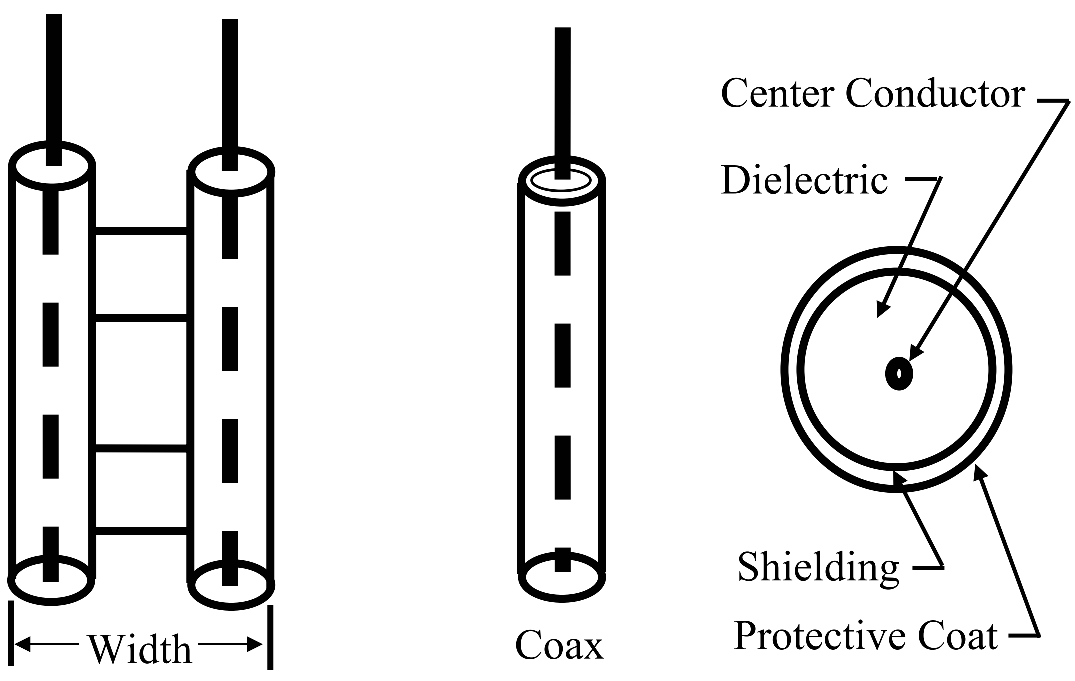
We haven't yet addressed your transmission line. In cases where there was originally a large mismatch between the antenna and transceiver, or where very lossy transmission line is being used, we have another factor to consider: transmission line loss[19], also known as line attenuation. If this loss is too great even with a perfectly matched antenna system our RF signal may not be very strong.

Transmission Line

Transmission line is used to connect each piece of your antenna system to the other components of your antenna system. It is used to connect your radio ("transceiver", because it both transmits and receives) to your antenna, and any equipment you may have between these two, such as an antenna tuner ("transmatch") or a SWR ("Standing Wave Ratio") meter. There are two basic types of transmission line: ladder line and coax cable, each of which has multiple sub-types.

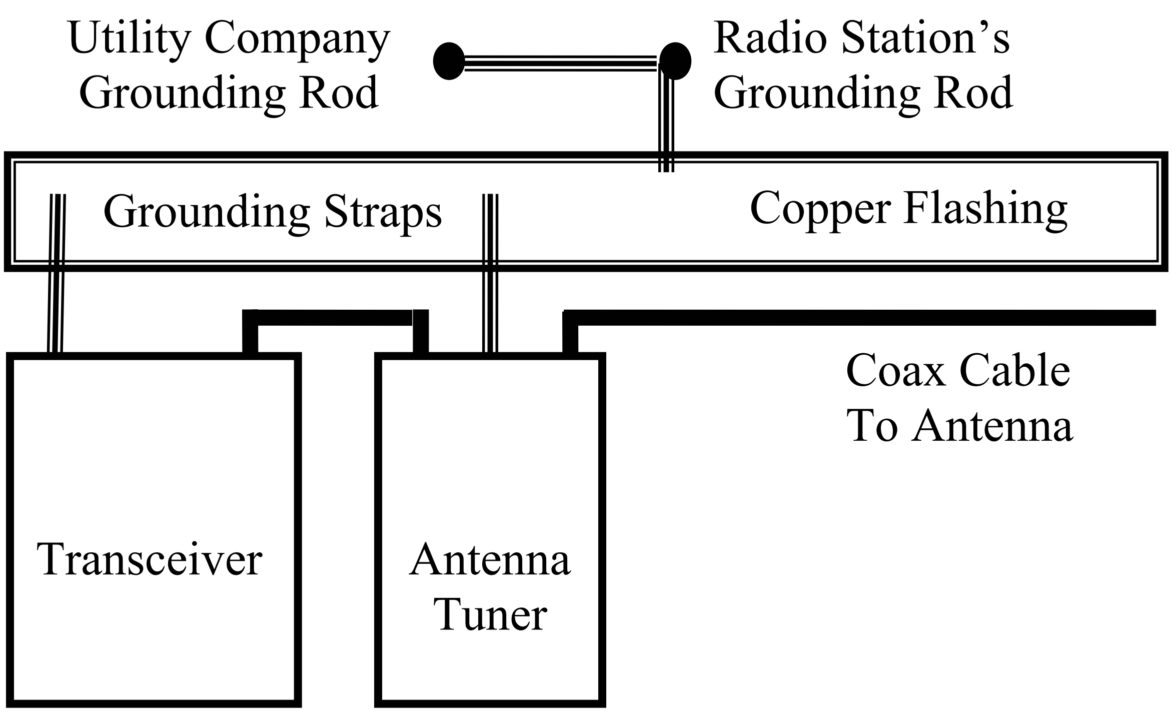
Ladder line is also commonly called window line or twinlead. It is also called "balanced" line because it operates independent of your station ground. It requires a "balun" to connect to modern transceivers. Provided the two conductors are kept a constant distance from one another, and are separated from metal objects by a distance equal to one or two widths (or greater: see diagram), the energy radiating outward will cancel out. This means ladder line radiates very little wasted energy. Even if there is high SWR on the line there will be very little loss in your RF transmission. This ability to deliver nearly all of the transmitted RF energy to its destination is one of the largest advantages gained when properly using ladder line. Normally it is not shielded.

Coaxial cable is simply called coax. It is coaxial in its design, meaning it is constructed of concentric layers of metal insulated from one another by a material called a "dielectric." In the very center is a wire (the "center conductor") which is surrounded by a comparatively thick layer of dielectric insulation, surrounded by a layer of metal, called the shielding or braid. This shielding may be a single layer of metal or multiple layers of metal. The most common is braided copper. A fairl common shielding is the combination of foil and braid. The shielding is covered by a thin layer of insulated material which may be treated to offer additional protection against weathering or underground burial. The purpose of this outermost cover is to protect the rest of the coax from rain, sunlight, etc., but it does not stop RF energy from radiating in any meaningful way.



Coax is <u>un</u>balanced. It <u>does</u> require a connection to your station RF ground (not to be confused with your home's electrical ground from your utility company). The metal shielding inside your coax maintains a connection with the body of the coax connector (PLug, PL-259), and this electrical connection is maintained with the metal case of your antenna tuner and transceiver. This effectively connects your coax shielding to the same ground that is shared by all your station equipment. All your station equipment should be connected to ground by a common “bonding” strap, or copper foil/flashing, which then connects to a grounded rod in the earth, which is in turn connected to your home’s electrical utility company ground.

The coax’s metal shielding is its only means of conserving your transmitted energy until such time as it is delivered to your antenna. Were this metal layer to be damaged your RF signal would “leak” from the coax. If the shielding is entirely removed your coax would effectively radiate as if it were a single antenna wire.



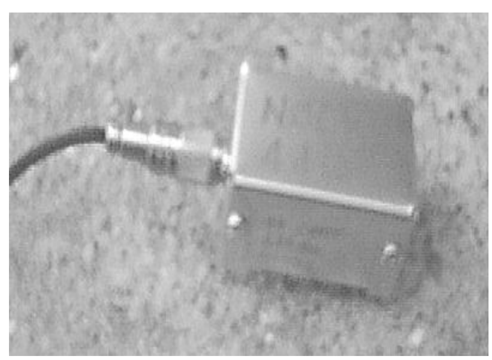
Coax is designed to offer two paths for your RF signal to follow: along the center conductor and along the <u>inside</u> of the metal shielding. If RF is allowed to flow along the <u>outside</u> of your metal shielding you have provided a third, undesirable, path for your RF. Your coax will now radiate as an antenna. (Which is why you should use either a balun or coax choke near your antenna’s feedpoint – <u>especially</u> if you are using a “strange” antenna). RF may also enter your shack.

Coax comes in a wide quality range. Higher quality coax offers greater RF signal retention (low RF loss) as your RF signal travels between your transmitter and your antenna. While experiencing high SWR, coax does allow additional losses to add up. This loss can be substantial. This is one reason coax is a better choice when relatively low SWR will be experienced on the transmission line, or the run is very short, and ladder line is a better choice when high SWR will be experienced on the transmission line, or when the run is very long (greater than 100 to 150 feet).

Standing Wave Ratio (SWR)

SWR is a ratio of the amount of RF energy flowing from your transceiver to your antenna, and the amount of RF energy flowing from your antenna back toward your transceiver[20]. However, the calculation is not as simple as dividing one value by the other. You will also find SWR called VSWR and occasionally ISWR. Don't worry about this – they all provide the same ratio (or SWR measurement). "V"SWR measures the voltage component of your RF signal whereas "I"SWR measures the current component. Most amateur radio operators measure voltage, but both are equally accurate for our purposes.

Any RF energy not absorbed by your antenna is "reflected" back towards your transceiver. This is where the terms "forward" and "reflected" power are born. (Forward power is also known as "incident" power[21].) When an antenna is operating well, the amount of reflected power is very low, and sometimes even zero, although even with modern transceivers it is not necessary to obtain a perfect 1:1 SWR (zero reflected power equals a perfect 1:1 SWR).



Low SWR is obviously not the only, nor even the most important, consideration when trying to deliver a solid RF signal over a great distance. Consider a dummy load. This is one or more non-inductive resistors designed to absorb RF energy at 50-Ohms impedance. The result is a perfect 1:1 SWR and no effective RF radiation going into the atmosphere. Perfect SWR – horrible antenna! (Use carbon composition or metal foil resistors if you make your own dummy load.)

Another famous example of "low SWR for the wrong reason"[22] is a vertical antenna using just the earth as its "ground radials." You can measure a near-perfect 1:1 SWR, but have almost all of your RF energy being absorbed into the earth. This is another case of a great looking SWR, and a horrible antenna! In this case, to fix the problem of almost zero effective radiation you need to install a number of ground radials. Now RF will radiate from the antenna, but you can expect the SWR to leap to perhaps 2:1. But which performs as the better antenna?

Low SWR, in the absence of other details, is not a very good measure of an antenna system[23]. You need more information to qualify the SWR measurement. Low SWR may indicate either a "good" or "bad" antenna.

One of the perennial arguments heard in amateur radio is whether one should measure SWR at the antenna or the transceiver. As with most things the best answer, although not very useful in and of itself, is "it depends." Those arguing for placing the SWR meter at the antenna, point out this it the only place the antenna's SWR may be exactly measured. Those arguing for placing the SWR meter near your operating station point out that unless there is a very large amount of loss in your transmission line a meaningful measurement of SWR may be made at your operating station, and it is certainly more convenient to place the meter at this location. It is also more affordable to place the SWR meter at the operating station because you can read its value directly. Remote placement of the SWR meter (at the antenna) requires a means of sending the reading to your operating station.

In my opinion is it is usually adequate to place the SWR meter at your operating station. This is both more affordable and more flexible. However, one must be aware this results in a lower measured SWR than truly exists at the antenna. This is not necessarily bad, but it is prudent to use high quality coax, or balanced line, and know how much RF power is being lost between your antenna and SWR meter. Once you know how much power is being lost in the transmission line you will be able to accurately determine the SWR at your station.

Always remember SWR by itself is meaningless – you must also know how much power is lost in your transmission line, and how effectively your antenna is radiating. Using a field strength meter to actually measure your RF radiation is the only way to determine with certainty the effectiveness of your antenna system. Plans are readily available for building your own, and MFJ sells an affordable model if you just want to buy one.

RF energy lost while traveling along the transmission line is called line attenuation[24]. All reputable manufacturers publish this data. All coax and ladder line experience line attenuation. Power that is reflected experiences this loss three times – once on the way toward the antenna, again on its return trip back to the transceiver, and a third time after it re-reflects off the transmitter and returns toward the antenna[25]. This is why high SWR becomes a significant problem with long runs of coax or when the transmission line allows high line attenuation (high RF loss)[26].

If you use balanced line (ladder line) you do not need to worry very much about additional transmission line loss because it will be very, very small when the ladder line is properly routed. This is one of the reasons a very useful and popular antenna is a 135-foot center fed dipole (fed with ladder line, which is connected in the center of this 135-foot dipole, with each half insulated form the other). When this dipole is connected to a transmatch you will be able to match a very wide range of frequencies. If I had to pick a single simple antenna, this would be my choice[27].

(If I had a larger yard and could deal with the additional supports, I would select a loop antenna at least 40-feet high, fed with ladder line and connected to a transmatch in my shack.)

When using coax it is a good idea to use as little as possible, but don't take this to extremes – there is nothing wrong with keeping 10 feet or so additional length in your shack so you can easily rearrange your equipment.

Coax Choke and Baluns

If your antenna is almost perfectly matched to your transmission line you may not need a balun or coax choke. On the other hand little harm is done by using them, especially the coax choke (because it will not overheat). If you are planning to use your antenna on more than one band it is likely you will need a balun or choke.

Your goal when transmitting is for your antenna to radiate as much of the energy your transceiver creates as possible. One of the easiest ways we can help insure this takes place is keeping the RF energy in the antenna, as opposed to allowing it run down the outside of the coax shielding. This is one of the primary reasons for using a balun or coax choke. Properly sized, either of these devices will prohibit your RF energy from flowing onto the outside of your coax shielding. Should RF reach the outside of your shielding it will radiate as if it were another antenna element. When using a balanced transmission line stray RF is not a concern, unless you are feeding a beam or using shielded balanced line.

When using coax your RF signal will travel along the center conductor and along the inside of your metal shielding. However, if your RF travels along the outside of your metal shielding you have a problem![28]

Yes, it seems strange at first blush, but your coax's metal shielding is thick enough your RF signal will not penetrate from one side of the shielding to the other[29], unless it is damaged. The only way for RF to get to the outside of the shielding is through a cut in the cable or to escape from the antenna at the feedpoint and flow along the outside of the shielding. This is almost always undesirable. (Please note that we are not considering the line attenuation of the coax at this time, which all coax has, and may be thought of as a small amount of RF "leaking" from the coax.)

A number of problems may occur when RF energy escapes along the outside of the coax metal shielding. You may experience RF interference[30] in your shack, or in the neighbors TV, a RF "burn" when you touch your equipment or microphone, poor audio, problems with your CW (Morse code) keyer, or a disrupted front-to-back ratio in your beam antenna.

I normally use a balun or coax choke. When using balanced transmission line (ladder line, twinlead, window line, etc.) do not attempt to coil it into a choke – it will not work. I certainly recommend you at least use a coax choke (also simply called a choke) with any coax-fed antenna to stop your precious RF energy from spilling down the outside of your coax shielding.

You can purchase a balun of the type needed or you can quickly wrap a coax choke to perform the same function using 10- to 20-feet of coax you may already have on hand. If you are new to amateur radio it is unlikely you wish to make a balun, but you can easily make a coax choke!

If you have a copy of the "ARRL Antenna Book" look up the coax choke chart[31]. Failing this simply coil up your coax in a tight stack and tape it together. You want each turn of coax to contact the turn before and after it as much as possible, but not to contact any other turns. Keep the diameter at least 15 times the outside diameter (OD) of the coax's width. As a rule of thumb make the coax at least 6 inches across for HF (10-meter band through 160-meter band) and at least 3 inches across for VHF/UHF (6-meters and 2-meters for example).

Baluns are actually a small family of devices: balun, balbal, or unun. These all refer to the whether you desire to move between balanced (ladder line) to unbalanced (coax) transmission line (bal-un), between balanced and balanced line (bal-bal), or between unbalanced and unbalanced line (un-un). I will usually refer to all of these with the generic term “balun.”

The most common baluns are 1:1 (one to one) and 4:1. Baluns are a form of transformer, either changing voltage or current by a given ratio. For most amateur radio uses the current balun performs better[32]. Baluns may be made to provide other ratios but for most uses you will only need concern yourself with the two mentioned above. One reason for this is a 4:1 balun will heat up more slowly than a 9:1 balun (as an example). Once a balun overheats, it fails to work, and may be damaged requiring repair or replacement.

There are two basic types of balun. One is made by wrapping wires through a doughnut shaped ferrite core and the other is made by threading your coax through 50 ferrite beads, called the W2DU balun[33]. The only word of caution when buying a W2DU balun is to be certain the seller has not used too few beads. There are many knock-off companies that sell a so-called W2DU balun, but with 25 or fewer beads. This will not work as it should. (Read “Reflections II” by W2DU.)

If you transmit too much RF energy through a balun its ferrite core may become overheated, which may lead to it becoming “saturated” and failing to work[34]. This will not happen with your coax choke because its core is simply air and much more difficult to overheat, if not impossible (although it is possible to melt the coax if you are transmitting at very high power and using coax not rated for that power).

One of the purposes of the KØS contest & special event is to discover the effectiveness of everyday items as antenna elements. For this reason you should use a balun or coax choke near the feedpoint of your strange antenna. It is one of the best ways to help ensure your RF radiation actually takes place from the strange antenna, and not your feedline.

If you are matching impedances that are greatly different (more than 2:1 or 3:1) on each side of the connection point, you certainly will benefit from using a balun, but not necessarily the coax choke. Whereas both the balun and choke are effective at halting stray RF energy from flowing along the outside of your transmission line, they behave differently when the goal is matching impedance. A rolled up coil of coax will do nothing to transform the impedance from one end of the coax coil to the next. It may however, change the “phase.” This is sometimes called a “coax balun” and used to feed some beam antennas[35] (not discussed in this manual).

(Allow me to digress briefly. If you are not experimenting with an antenna or joining in a KØS contest, you may sometimes find this “leaking” RF to be a benefit. Perhaps you are trying to regain communications following a hurricane in Florida. All you care about is getting a signal on the air and to relay traffic. You could care less whether the RF radiates from your antenna wires, from the coax, or from a dog cage. You may be feeding a couple of metal railings on the second story from the first floor and not using a coax choke. This could result in some RF radiating from the coax, which will add some vertically polarized RF to the horizontal RF from the railings. If you are able to pass emergency messages it doesn’t matter whether the RF is “poor” or “great” – the RF just needs to work!)

Impedance

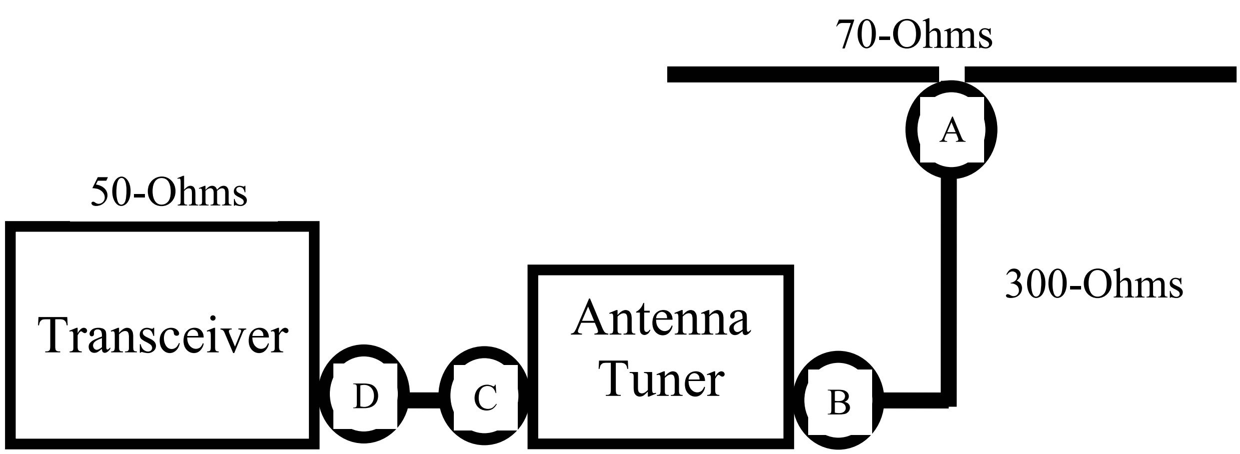
Impedance[36] is resistance to an alternating current (ac) circuit. It may also be thought of as the rate at which energy is transferred from one part of a system to another. In antenna systems we want all our components and transmission line to operate at the same impedance. When they all operate at the same impedance the maximum amount of energy is transferred from one part of the system to the next.

However, we often have to make adjustments because many antennas do not naturally operate at 50-Ohms impedance, whereas most modern transceivers are designed to load only into a 50-Ohms impedance. Other concerns include long lengths of the transmission line, or when we wish to use a single dipole across multiple amateur radio bands – for these reasons we may desire to feed the antenna with balanced transmission line. In any of these cases we must do something to help bring any impedance not designed to be 50-Ohms, to become equal to 50-Ohms (or nearly so) by the time it reaches the transceiver. This is the only condition under which our transceiver will output its full power (this is not true of “tube” transceivers, but we will not discuss "tube rigs" in this manual).

Our most efficient transmission line is balanced line, and the most commonly found of these are ladder lines operating at either 300-Ohms or 450-Ohms. A fairly common situation is having a dipole high enough above the earth that its feedpoint impedance is close to 70-Ohms, and feed it with 300-Ohm ladder line. The other end of the transmission line (also called “feedline”) is connected to a transmatch (“tuner”) that is equipped with a 4:1 balun. How well will this work?

Our goal is to match each component of our antenna system to the next with as little loss of RF signal as possible, to feed our antenna RF energy at the rate it is designed to accept RF energy, and to allow the transceiver to output its transmitted RF signal at 50-Ohms impedance. Furthermore, we want there to be zero net reactance in the system. Using two baluns (current transformers), "A" and "B" in the diagram (strictly speaking "A" is a "bal-bal," and "B" is a "bal-un"), and a transmatch will allow this antenna system to work quite well.

Recall that impedance is the rate at which energy is transferred from one part of a system to another and lowest loss takes place when both sides of the transferal point operate at the same impedance (measured in Ohms). There are always at least three components in our antenna system: transceiver, transmission line, and antenna. There may also be an antenna tuner located between the transceiver and antenna. Therefore we have a minimum of two connection points (energy transferal terminals), and will have four connection points when a tuner is added.



The connection points "C" and "D" are the simplest – they both desire a 50-Ohm impedance so we just connect them with any high quality 50-Ohm coax cable, such as RG-8X, RG-213, or even RG-58 (it is such a short run, under two feet, that the greater line attenuation (loss) of the RG-58 vs. the RG-8X will be insignificant).

Connection points "A" and "B" present a larger challenge. "A" is where the antenna connects to the feedline, and "B" is where the feedline enters the tuner.

Point "A" will be a 4:1 balun (specifically a "bal-bal"). This will reduce the 300-Ohm impedance of the ladder line by a factor of four as it moves from the feedline to the antenna (300 / 4 = 75-Ohms, which is very close to the 70-Ohms impedance the antenna wishes to “see” as it is being fed our RF energy). RF energy moving from the antenna to the feedline (when we are listening to other stations) will be increased by a factor of four, once again providing a very close match to our transmission line (70 * 4 = 280-Ohms).

Point “B” is an internal balun inside the antenna tuner (yes, a true “bal-un”!) transforming our RF signal at a 4:1 ratio. The transformation figures will be very similar to what takes place at the antenna feedpoint.

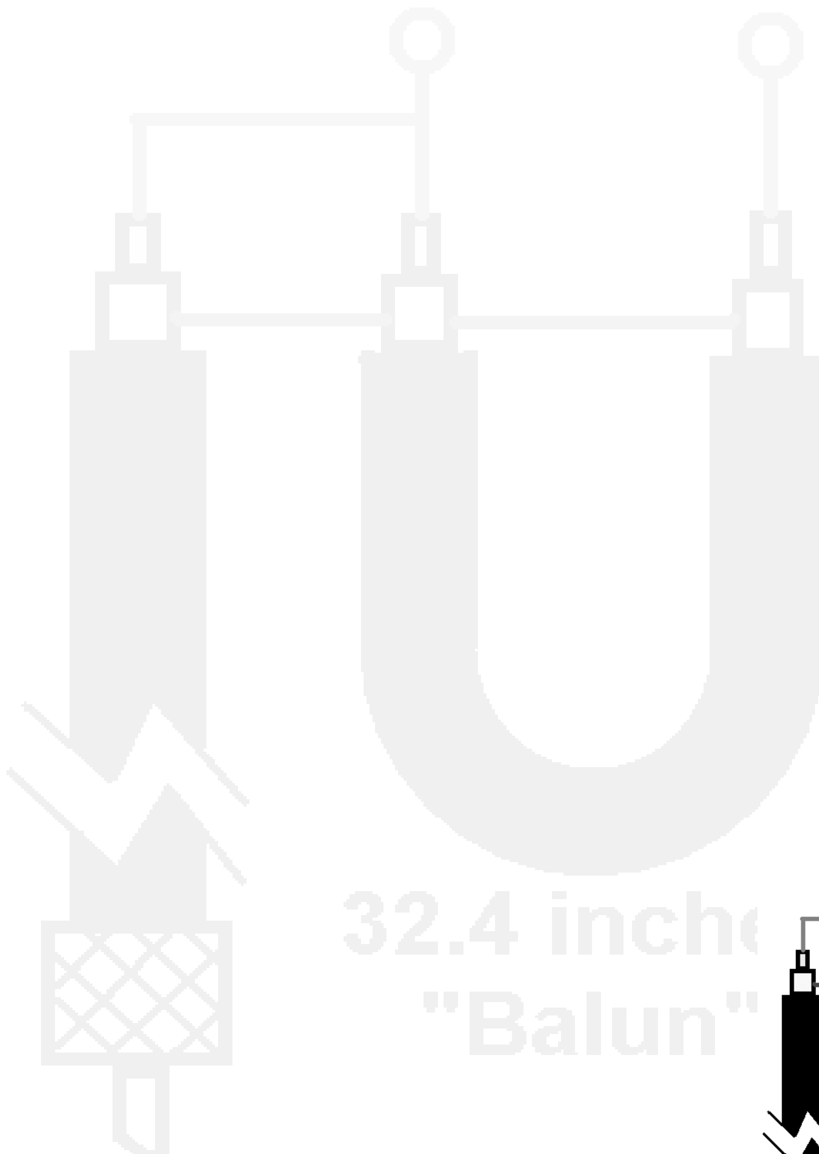
The transmatch is delivered a 50-Ohm RF signal from the transceiver when we transmit, which if the transmatch is placed in “by-pass” mode (meaning it does nothing but pass the RF signal directly through its 4:1 internal balun without affecting the signal in any other way), will multiply our 50-Ohm signal by a factor of four (50 * 4 = 200-Ohms which is an adequate match in most cases).

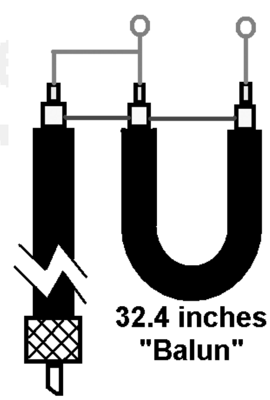
In reverse, when we are receiving a signal from another station, the 280-Ohm received RF signal will be reduced by a factor of four (280 / 4 = 70-Ohms) which is a good match.

You will note for this example we left the transmatch in “by-pass” mode. Effectively, we are not using the transmatch at all. It could have as easily been replaced by a 4:1 balun. If we were to actually make use of the transmatch, we would be able to remove all net system reactance and also produce a near-perfect 50-Ohm load into which the transceiver could operate.

Chapter IV

Using Transmission Line





USING BALANCED LINE

Balanced line[37] (ladder line) must remain distant from other objects, including the earth, and especially metal and magnetic objects. Keep it at least two inches away from other objects, and further is better. The reason balanced line has such low loss is the electromagnetic fields of the two conductors effectively cancel one another out (referring only to line loss, not transmitting RF from your transceiver to your antenna). If you place an object against, or too close to, balanced line it becomes unbalanced line (coax is also unbalanced line). Once the ladder line becomes unbalanced it will begin to radiate RF as if it were an antenna, because it does not have a metallic shielding surrounding its center conductor.

Properly terminating balanced line is important. You first need to know if you are going to connect to a balanced or unbalanced terminal (sometimes called a "load," which may be an antenna, tuner, or dummy load). A balanced terminal will not have a connection to your station ground. An unbalanced terminal will include an electrical connection to your station ground.

Dipole and loop antennas are balanced loads, so you can simply connect your ladder line to the antenna wires. Your ladder line will remain balanced until it reaches your antenna feedpoint, where each of its wires will head off in different directions. That causes them to become unbalanced, and since they are not enclosed by metal (as with coax cable) they will radiate as if they are an antenna (as in this case they are designed to be).

You may also place a "bal-bal" at the antenna feedpoint. This will adjust the impedance (rate of energy transferal) between the dipole or loop antenna and balanced line so they are closer in value to one another. Is this required? In a word "no" it is often not "required," but it may be desirable. You need to determine the impedance the antenna needs to "see" (as it "looks" down the transmission line toward the transceiver) at its feedpoint connection with the ladder line in order to work most efficiently. This depends upon a number of things, such as wire diameter and spacing, height above the earth, and the effect of nearby objects.

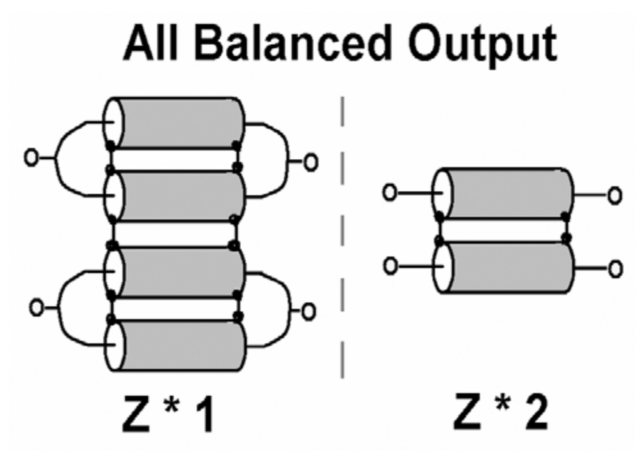
We are not going to explore these affects in this manual. However, if you have an antenna tuner on the other end of your balanced line, you won't require a balbal at the antenna feedpoint – you may consider it optional. If you are <u>not</u> using a tuner on the other end of your balanced line you will need to study this topic in greater detail. You will at least require a balun where your balanced line enters the transceiver (if you are using a balanced to balanced tuner, or a "tube" transceiver this may not be true).

If you are connecting (terminating) your balanced line to an antenna tuner, find out if your antenna has an internal 4:1 balun. Many do. If not, you will need to obtain an external balun. Check your tuner's manual. It is likely there are binding posts on the back of your tuner. Each wire of the balanced line will connect to a separate binding post and then a short "jumper" wire will connect one of these posts to a third binding post. This is a fairly common arrangement.

Connecting your balanced line to a single coax transmission line will require a balun. It will have some type of mounting hardware (screws, solder lugs, etc.) for the balanced line to enter the balun, and it will have a means of connecting coax to the balun. Most likely the coax will connect to a SO-239.

What if you wish to penetrate a wall with your balanced line? Shielded balanced line is available. You may use this as one solution. Another solution is to run coax cable through the wall and then directly connect your balanced line to the coax[38]. RG-62 has an impedance of 93-Ohms, and RG-63 is 125-Ohm coax. There are a number of ways to connect the coax and balanced line, and each results in a different impedance (one reference is found in "The ARRL Antenna Book").

In the diagram "Z" means "impedance." Using the connections shown on the right side, RG-63 results in an impedance of 125-Ohms * 2 = 250-Ohms, which is a good match for 300-Ohm ladder line. It is important to note the shielding of the coax is connected together on each end. The coax shielding at your station end of the coax connect to your station ground (or to the tuner's ground, which is in turn grounded). The shielding outside the wall is not connected to anything (but still connect each coax shielding to the other coax shielding). The balanced line's wires are connected directly to the center conductors of the coax, one wire of the balanced line connects to one center conductor wire from one piece of coax, and the remaining wires are connected in the same manner to the other piece of coax. Keep all the coax close together so their lengths remain the same (failure to do so may result in "phasing" errors, but this will not be discussed in this field manual).



USING COAX

Coax may be placed against other objects, coiled on the floor, and otherwise pretty much just left lying wherever you drop it and still work fine. This is one of the major benefits of using coax. Coax being used outdoors does need to be weather-proofed so water does not enter through the connectors or antenna junction. You do need to be aware of what is called line loss or “attenuation.” This is the amount of RF energy “leaking” from (actually heating) the coax and the amount of this loss varies with frequency. Determine what frequencies you wish to operate and refer to the manufacturer’s data to find the amount of loss[39]. This is normally listed in decibels (dB) per 100 feet at a specific frequency.

Recall that a 3 dB change is a factor of 2, and a 10 dB change is a factor of 10. If your coax will have a 3 dB loss at the frequency you intend to operate, half of your transmitted power will be lost heating the coax. At 10 dB the lost RF energy represents the majority of your signal. Decibel measurements are valid for any power comparisons, not just transmission lines.[40]

On the other extreme, if you can reduce your loss to under 1 dB the party to whom you are speaking will never be able to hear the difference[41]. For that matter, most people will not hear a 2 dB change, and many have trouble hearing a 3 dB change. Calculate all your losses (measured in dB) and try to keep them to 3 dB or less. If you can do this, your antenna system is operating very well. On the other hand, it is not the end of the world if you miss this mark. Many people have made DX contacts with much higher than 3 dB loss in their antenna system. Do what you can to minimize antenna system losses and then get on your radio and operate!

Connecting coax is pretty straightforward. There are numerous explanations located on the Internet or in most of the reference books listed in Chapter VI that will show you how to solder the connectors to the coax[42]. This is the only tricky part.

It <u>is</u> recommended you solder the connections. If you plan to use the coax outside, in a mobile, or portable environment this is very important. (Use solid dielectric in mobile installations.) Failure to solder the connections can lead to the shield braiding becoming partially broken which may cause interference in your RF signal because the broken ends make intermittent contact. Water may also more easily get inside your coax cable and this will allow the shielding and center conductor to short together, which is undesirable.

Anytime you solder, use high heat so you can quickly bring the metals being soldered to a temperature that will melt the solder. This allows you to get “on and off” quickly. The longer you apply heat to the connector the more likely you are to damage the coax or the connector. It may be counter-intuitive, but it is true: lower heat applied longer is more likely to cause damage. You should not have to apply heat to the connector more than a minute or two to make a proper connection. I generally do not solder more than two “holes” on one connector without letting it cool somewhat (when applying connectors to each end of a piece of coax I alternate ends after soldering each hole).

You should first place your soldering iron against the object with greater mass, heat it up and then move the soldering iron into contact with the object having smaller mass. The idea is to bring them both to the solder’s melting temperature at the same time. When applying solder, place it against the metal on the side opposite your iron’s tip. If it melts you know all the metal is hot enough[43]. I find using thinner solder is easier to work with, such a 0.033 inch diameter.

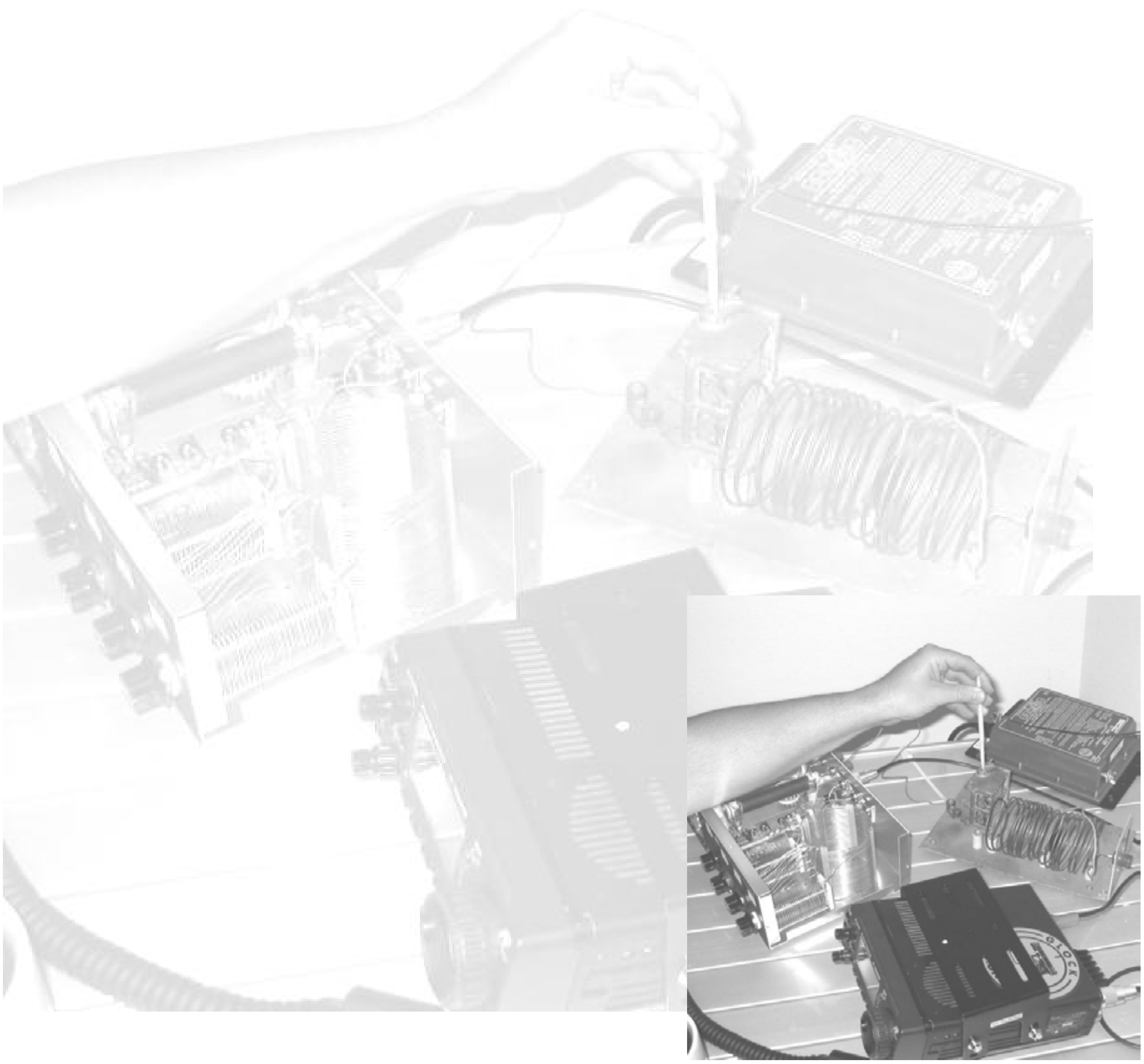
Only use electronic grade solder. Do not use plumber’s solder because its acid content is too high. This may not be terribly important soldering a PL-259, but if you forget and use the high acid solder on an electronic kit (field strength meter, PSK-31 interface, antenna tuner, etc.) it will eat away all the connections. To my knowledge this error is never covered under warranty. The device will be destroyed and not even worth repairing because new connections will separate all the time once the process of breaking down has begun.

Once you have soldered the appropriate connectors to the ends of your coax it is simply a matter of pushing the ends together and tightening the connection. The types of connections used most often in amateur radio use are the UHF and BNC connectors. Type “N” connectors are also found sometimes, and SMA connectors are becoming fairly common on newer HTs (handheld transmitters).

UHF connectors are the most common. You will commonly use the plug (PL-259) and the socket (SO-239). There are also a variety of connectors for splicing pieces of coax together, such as connectors with a SO-239 on each end, or with a PL-259 one each end. Other common connectors allow you to interconnect between BNC, UHF, and N type connectors. Don’t worry about how many of these connectors you use. The loss is very small. If you find you have more than 20 of them on one length of transmission line you might reconsider.

Chapter V

Manual Antenna Tuners – Basic Operation[44]



Importance of Maintaining Log

Achieving a better understanding your antenna tuner (“transmatch”) begins with keeping a log of its use. This is especially useful when you are using it with the same antennas over and over.

Taking accurate notes will allow you to easily determine approximate settings the next time you use that antenna and tuner on or close to a frequency you have previously tuned. After a fairly short period of time you will develop a general feeling for how your antenna and tuner work together, and it will become increasingly easier to quickly obtain good matches. If you pay any attention at all while tuning your antenna this will happen naturally, but if you maintain a log of the pertinent information you will learn this much faster. You will also have a permanent record of successful tunings. If you don’t use that antenna / tuner for a long time, and forget the proper settings, these records will enable you to simply pick up where you left off. Furthermore, these notes would allow others using your equipment to quickly find a successful tune.

Each time you tune a given antenna, make a notation in your station log of at least the following information (this assumes you are using a C-L-C tuner, which is the most common style – if you are using a different style transmatch then adjust your notes accordingly):

Transceiver information:	
Model	(Icom-746)
Frequency	(3.963)
TX Power	(100 watts)
Mode	(SSB)
Antenna information:	
Name	(Skywire loop)
Height	(40-feet)
Feedline	(450-Ohm ladder line)
Feedpoint	(Two-feet south of NW corner of loop)
Transmatch settings:	
Inductor	(H, or perhaps “68” if a roller inductor)
Antenna capacitor	(2.5)
Transceiver capacitor	(3)

Note any unusual circumstances, or conditions.

Tuning Known Antennas

If you have been maintaining your tuning log, this begins by simply looking up the nearest tune you have made with this antenna and tuner, and then adjusting the tuner settings to the positions in your log.

However, there is always the possibility that something may have changed since the last time you used this antenna and tuner. For this reason you always want to start your tuning procedure at low power. By low power I mean 5- to 10-watts of transmitted power on RTTY, CW, or AM mode. If you can transmit your call sign at low power with the expected forward and reflected power (or SWR) readings, go ahead and increase your power. I would suggest you increase your transmitting power in no greater intervals than 10-watts steps.

The only difference between tuning a known and unknown antenna is the starting point for a "known" antenna is different – go ahead and start the tuning process discussed for "Tuning Unknown Antennas" except use your recorded values as your starting point.

Perhaps you are at Field Day and have never actually used this antenna and tuner together. You can often take a "shortcut" and estimate the proper tuning point based upon your past experience. This is another occasion when having a written log will make the comparisons to past antennas easier.

Tuning Unknown Antennas

CHANGE TRANSMATCH SETTINGS SLOWLY. This is by far the most common error I have seen people make when using a manual antenna tuner.

The first rule of tuning an antenna is the same as the first rule of being a good mate, student, negotiator, salesman, or amateur radio operator: **listen first**.

1. Adjust your volume and squelch so you hear enough white noise (static) that you will be able to distinguish when it become noticeably louder or quieter.
2. Set your capacitors to their middle value (often "5").

3. Set your inductor to its minimum number of turns (open the case and observe where the coil (inductor) is shorted at each extreme of its adjustment device – **you want to try to find a successful tune using the fewest number of turns** because the inductor will cause increasing loss of RF power as you increase the number of turns used to achieve a good tuning point).
4. Slowly increase the number of turns included in the tuning circuit while listening for the white noise to increase. Note points where the noise is the loudest. Select the loudest point that uses the fewest number of turns on the inductor.
5. SLOWLY adjust the antenna (tuner output) capacitor in one direction and then the next. Listen for one direction to result in louder white noise. Remember to make these adjustments slowly. When you have found a setting with noticeably louder static stop there.
6. Repeat the previous step with the other capacitor adjustment knob. You are again listening for the white noise to get louder. Louder means a better match is being found because the circuit you are adjusting is receiving better. Antennas work as well receiving as when transmitting.
7. What if you don't hear any change? First of all, did you really move slowly? Generally the capacitors are much more sensitive than the inductor and you can easily move right past a good setting and never know it.
8. If this still doesn't help, make sure the volume and squelch are set so you can easily hear a change in the static. Sometimes it can be too loud to easily hear this change and other times it can be too quiet.
9. Still no luck? Try setting one of the capacitors slightly in one direction and leave it there – "fixed" (either way is the same at this point) and then try adjusting the other capacitor. If this doesn't help, try the other direction as being "fixed." If that doesn't help, switch capacitors (set the one you were adjusting to a fixed position and adjust the one you had set to a fixed position), and repeat this process.
10. Still not getting anywhere? Now try the inductor in the next-best position and repeat the capacitor adjustments as described above.

Following the above steps should allow you to achieve a 2:1 or better SWR just by listening closely. Now that you are "in the ballpark" you can apply a small amount of transmitted power (5- to 10-watts) while watching your meters.... Listen!!!
If you do not hear anyone on frequency, announce your call sign while observing your meters. Did you in fact see either a SWR of 2:1 or less, or see very little reflected power? If the preceding steps have been done correctly that is what you saw. If this is not what you saw (cringe!) go back to step #1 and try again.

Assuming your "ballpark" tune is working, you are now ready to fine tune.

If you have a SWR meter you are looking for it to dip towards a 1:1 setting. Remember to make all adjustments very slowly, because you can easily breeze right past the optimum set point and never see a needle dip!

If you have a forward and reflected power meter (or numerical reading on your transceiver), watch for low reflected power or high forward power. I prefer to watch my reflected power and find a combination of the inductor settings and the capacitor settings that result in very little reflected power. You always want minimal reflected power – zero is best. The maximum forward power naturally varies with the transceiver's output setting. (DO NOT ADJUST AN INDUCTOR WHILE TRANSMITTING – although to be honest, I personally adjust my variable inductors when I am transmitting only 5- to 40-watts, but I NEVER adjust a tapped inductor when transmitting.)

I have often noticed once I am close to achieving a good tune my final "finesse" adjustments of my capacitors are made in opposite directions. These adjustments may be <u>extremely</u> small! For example, if I turn my output capacitor (where my antenna connects to the tuner) slightly to the right and see a small drop in reflected power, I often see a further reduction in reflected power when I make a slight turn to the left with the input capacitor (where the transceiver connects to the tuner).

Once I have reduced the reflected power as much as it appears is likely to occur AND it is showing a SWR under 2:1, and preferably pretty close to 1:1 if not dead-on 1:1, I then increase my transmitted power to about 30-watts. Again listen and if you do not hear anyone announce your call sign.

You should see the forward power jump higher than before but the reflected power hardly changing. The meters we amateurs normally have do show some difference in sensitivity between high and low power settings. This is a cost factor of manufacturing high quality meters. If we had more expensive and more accurate meters we should NOT see any change in the SWR as we increase power.

If you did see a large increase in forward (transmitted) power and a very little increase in reflected power (or almost no change in your SWR value), go ahead and increase your power to 80 to 100 watts, and repeat the above. You should be able to step up your transmitted power without any significant changes in SWR or reflected power until you arrive at your desired power output. When the antenna is properly tuned the SWR will not change based upon power output.

If you do see significant changes in SWR (or reflected power) while increasing power there is something wrong. It could be anything from simply needing to obtain a somewhat better match with the tuner's adjustments (inductor and capacitors), the antenna may be outside that tuner's ability to find a match, or the antenna may have partially fallen to the ground. Your transmission line may also be in need of repair or repositioning, especially if it is ladder line.

I recall I once had a "sloop" antenna (loop antenna cantered somewhat to the west: slope + loop = sloop) that was acting very strangely. One day it would tune up fine and the next it would either not tune at all, or it would not take full TX power, or it would hold a tune for a period of time and then "snap," fall out of tune. These same symptoms had two different cures at two different times. On one occasion one end of the sloop had fallen from the tree and was laying on the ground. I couldn't see this until the sun came up. On the other occasion, which was by far the more difficult to figure out, it dawned on me that after the ladder line entered the shack it was laying across a lead crystal ashtray! Since I always disconnect my antennas when I'm done and connect them to ground, sometimes when I hooked it up to the tuner it contacted the ashtray (trouble!) and other times it remained several inches distant from the offending ashtray (easy to tune).

THIS IS HARDER TO EXPLAIN, THAN TO DO! Really!

Remember to make your setting changes very, very slowly. Remember that the adjustments you make while only listening follow the same procedure as the adjustments you make while transmitting.

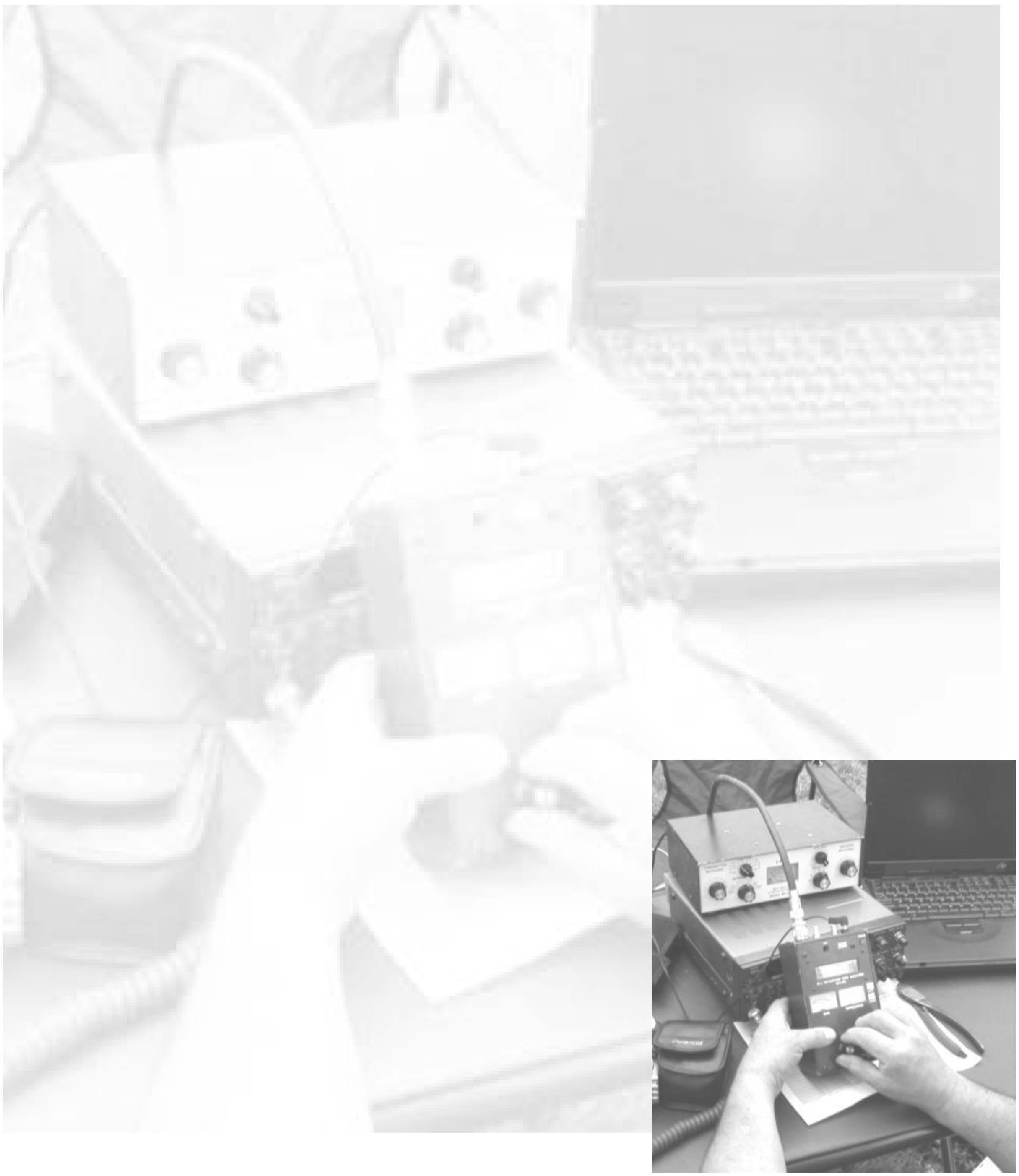
Usually you find your best setting with the capacitors set for maximum values (fully meshed) and the inductor at its minimum value.

If you ever see smoke, or smell smoke, STOP! All electronic devices are powered by smoke, and if you let the smoke out they will no longer work!

NEVER PLACE ANTENNAS WHERE THEY MAY COME INTO CONTACT WITH POWER LINES SHOULD THE ANTENNA FALL!

Chapter VI

Field Notes



Sample Charts and Graphs

The following charts display antenna measurements taken May 2004 with my MFJ Antenna Analyzer. I measured three antennas from 160-meters through 6-meters. The "normal" antennas were a 10-meter vertical antenna (Solarcon A-99), and a homemade 2-meter copper j-pole (which I also measured on 2-meters). The "strange" antenna was a loadlock dipole about 6-feet above the earth. The vertical was 25-feet above the earth and the j-pole was about 15-feet above the earth. All use a coax choke balun. Blanks of the charts are included in this field manual, as well as a few I did not use, some of which have a blank axis for you to scale.

All measurements were taken by connecting the antenna analyzer to the coax feeding the respective antennas and reading the analyzer values from the LCD screen for each measurement point. The vertical had 35-feet of RG-58 coax between the measurement point and the antenna feedpoint, the j-pole had roughly 25-feet of RG-58, and the loadlock dipole had 20-feet of RG-8.

Let's start by looking at the 2-meter copper j-pole. If you'll look at the "2-Meter SWR Chart" you will see that it should perform reasonably well. The highest SWR in the 2-meter band is 1.3:1, and it is resonant at 145.07, with nearly zero reactance (Xs = 4). The top half of the chart is where the SWR was plotted, and the bottom half is where Ohms was plotted, with notations made as to the corresponding value of reactance. All in all, a pretty decent antenna for 2-meters, which is good because this is its designed frequency! But how would it measure up on 80-meters?

The next page shows the "40:1 SWR Chart" in which the SWR has been plotted from 160-meters through 6-meters. This chart allows SWR up to 40:1 to be plotted. Along the 5:1 row you will note there are a number of rectangles. These correspond to the approximate location of each amateur radio band 160- through 6-meters. These are not meant to be extremely accurate, they are merely to provide a reference point across the horizontal axis, which displays 1- through 54-MHz.

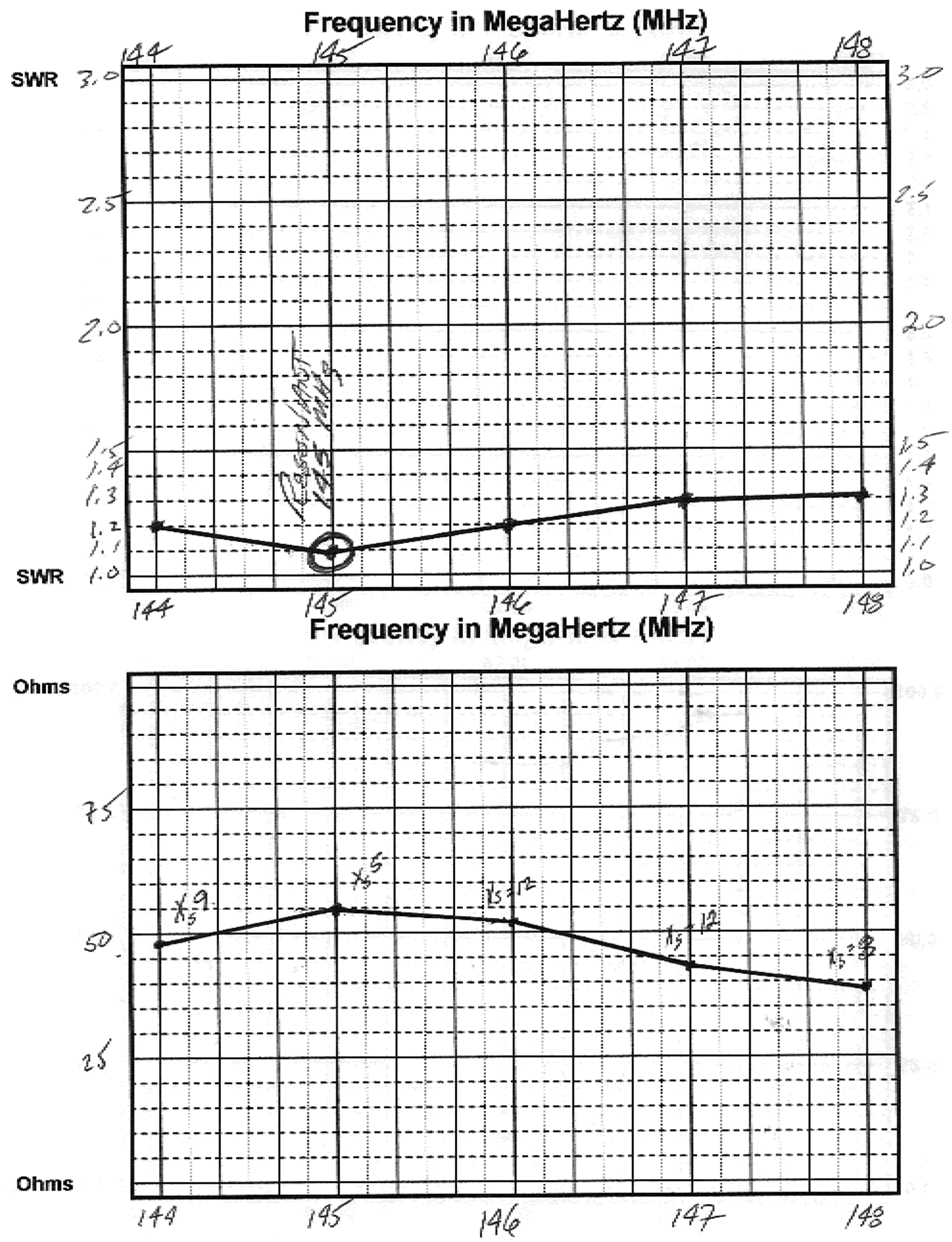
The third chart, "Series Resistance & Series Reactance Table" allows you to quickly build a table of SWR, series resistance (Rs) and series reactance (Xs). There are also columns for parallel resistance and reactance. One way to use this table would be to complete an initial measurement on all bands, and then either plot specific bands of interest or measure specific bands more accurately. In any case, this table provides an easy way to view your overall antenna performance.

2-Meter SWR Chart

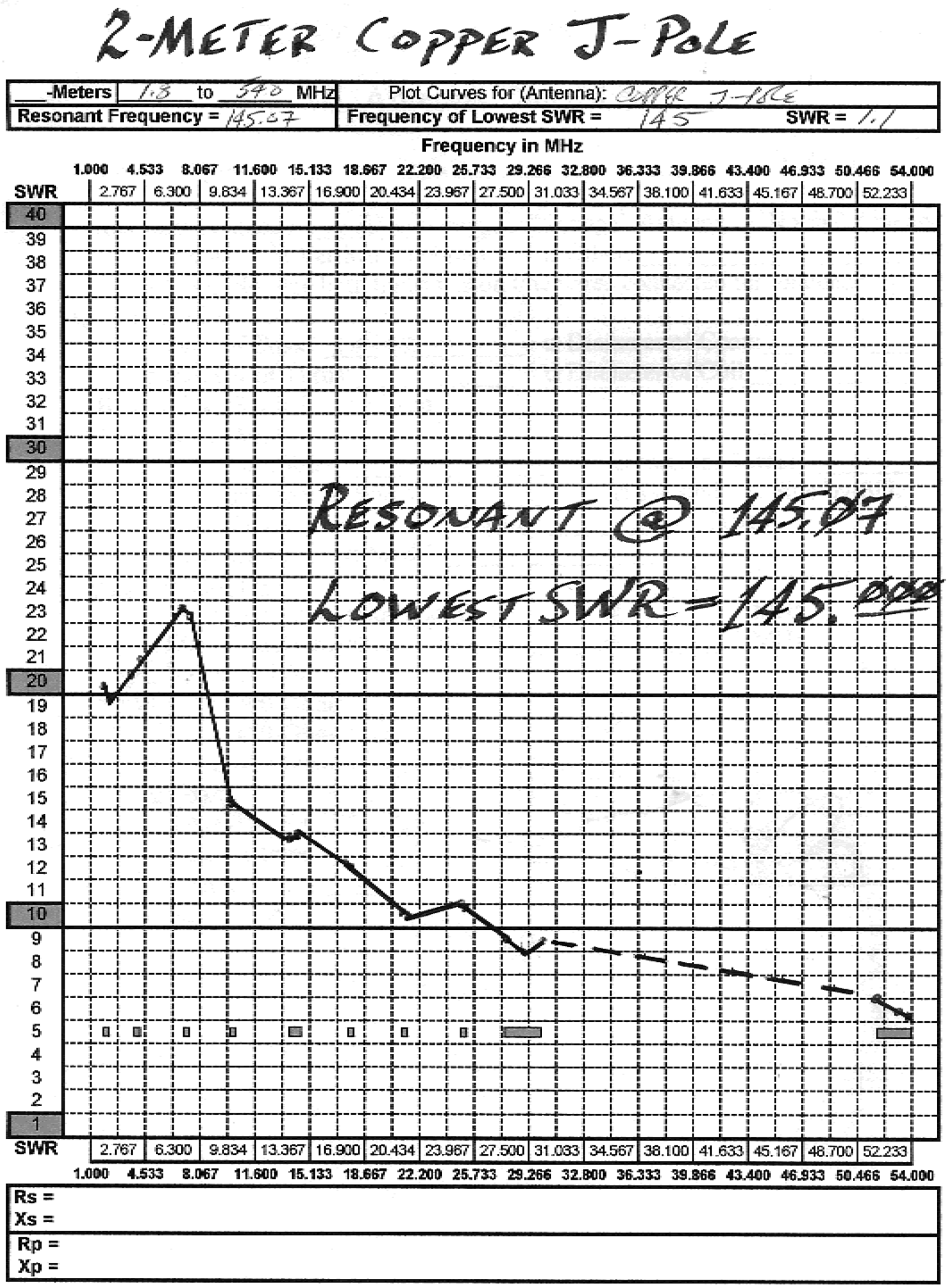
2-METER COPPER J-POLE

RESONATE @ 145.07 = X_s 4

2-Meters	144 to 148 MHz	Plot Curves for (Antenna): Copper J-Pole



40:1 SWR Chart



Series Resistance & Series Reactance Table

2-METER COPPER J-POLE

Table for SWR, Series & Parallel Resistance & Reactance
Use this table to obtain an overview of the antenna's SWR, resistance and reactance

Antenna Description Copper J-Pole, Mounted @ ≈15 ft Height

Note	Band	Frequency	SWR	Series Resistance Rs	Series Reactance Xs	Parallel Resistance Rp	Parallel Reactance Xp
	160	1.800	20.2	2	33		
	"	2.000	19.9	2	38		
	80	3.500	20.9	8	105		
	"	4.000	21.5	16	169		
	40	7.000	23.8	3	67		
	"	7.300	23.3	2	55		
*est →	30	10.120	15.2	2	3*		
≈1/10 WL	20	14.000	13.9	33	162		
	"	14.350	14.0	73	248		
	17	18.068	12.8	4	34		
	"	18.168	12.7	4	32		
	15	21.000	10.7	4	16		
	"	21.450	10.6	5	24		
≈1/6 WL	12	24.890	11.0	406	365		
	"	24.990	10.9	487	344		
	10	28.000	9.8	6	38		
	"	28.850	9.1	6	21		
≈1/5 WL	"	29.700	9.4	4	7		
≈1/3rd WL	6	50.000	7.0	6	9		
	"	52.000	6.5	10	24		
	"	54.000	6.2	35	90		
	2m	145.00	1.1	55	5		

SKETCH of ANTENNA:

We've seen the SWR curve of the 2-meter copper j-pole across all amateur bands from 160-meter up through 2-meters. Obviously, this is an extremely short antenna on 160-meters, and the SWR plot reflects this poor natural performance. 12- and 20-meters were especially poor. This is not to say a successful tune couldn't be achieved (it could) and contacts made. Remember that people have made contacts with many strange antennas, from light bulbs, to umbrellas, to folding chairs.

What about the 10-meter vertical? How will it compare with the 2-meter j-pole?

Looking at the "40:1 SWR Chart" for the 10-meter vertical we can immediately see it likely will perform much better than the 2-meter j-pole on the HF amateur bands. This is no surprise since it has been constructed to be resonant on the 10-meter band (the Solarcon A-99 is actually an 11-meter antenna that had about 6- to 7-inches cut off the top to tune it to the 10-meter band). In fact it has a very good SWR curve on several amateur bands.

The second 10-meter chart the "5:1 SWR Chart," affords a closer comparison between the 40:1 and 5:1 SWR charts near the antenna's resonance. At a glance we can see a large frequency range is less than 3:1, from 18.6 to 41.7 MHz. On the surface this would seem to be very easy to match with a transmatch. If we extend our interest to the 5:1 bandwith (frequency range) we find we may expect to easily match a very large range from 54-MHz all the way down to the 13.3 MHz. <u>Of course this is only SWR. There is more to achieving a successful and useful match. Certainly the amount of reactance present in the antenna is very important</u>.

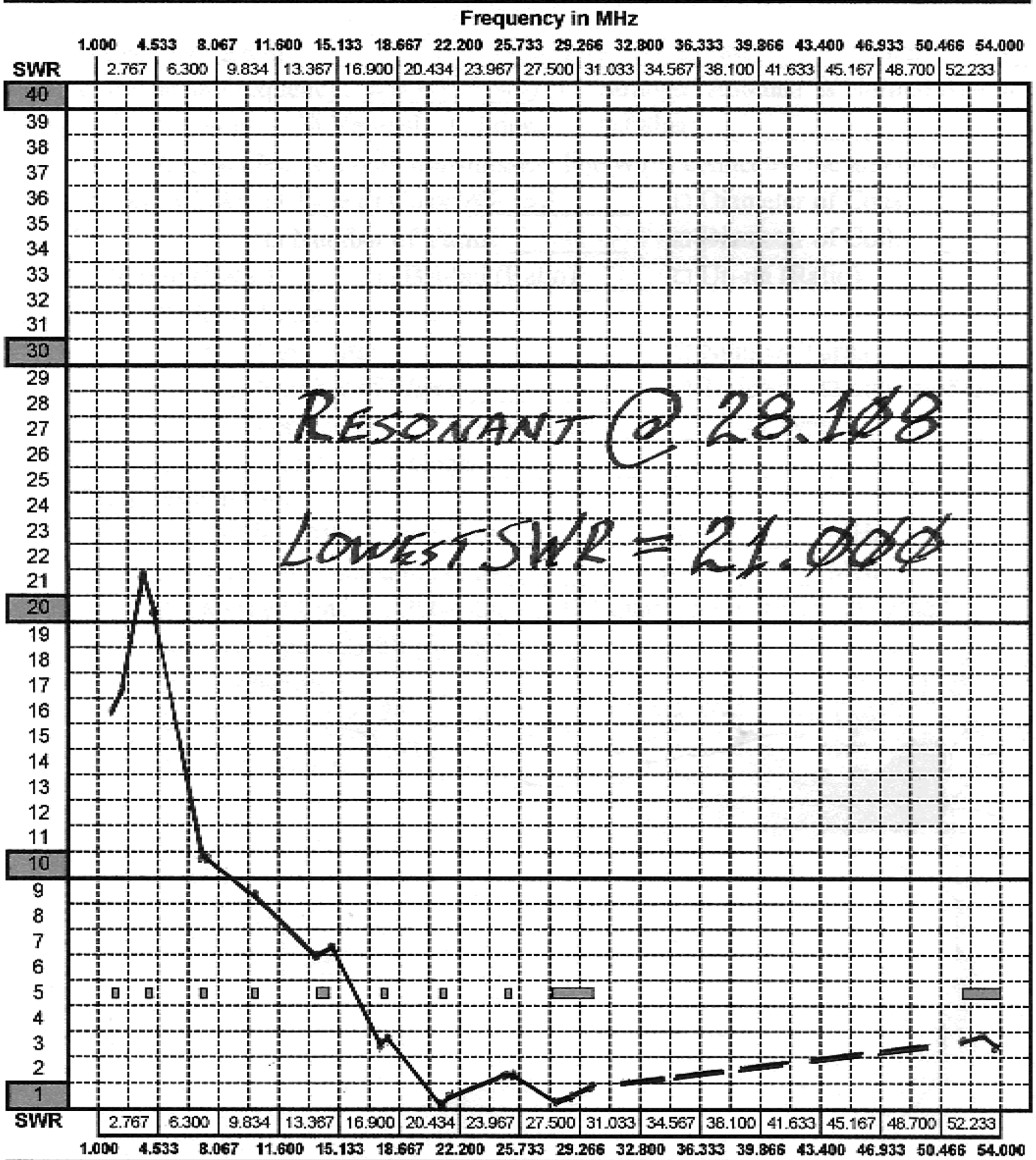
The next charts will allow us to study reactance. First let's take a quick overview. For this we take a look at the "Series Resistance & Series Reactance Table." Scanning down the "Xs" (series reactance) column, we see that 6- to 17-meters has relatively moderate amounts of reactance, but at 20-meters reactance increases dramatically. This confirms our SWR observation that 54- to 13-MHz should be a good frequency range to work this antenna (with a tuner). We also see the series resistance (Rs) for these ranges are in the useful range (naturally enough – recall that we are looking inside the 5:1 SWR bandwidth for a 10-meter antenna). This is followed by three charts showing band-specific SWR / Ohm plots. Notes have been made with regard to measured reactance values. Reactance is very important.

As you look through the blank charts supplied with this field manual you will note several are without a labeled axis. These are supplied so you may adjust them to any value of Ohms, SWR, or reactance needed.

40:1 SWR Chart

10-METER VERTICAL @ 25 FT. HT.

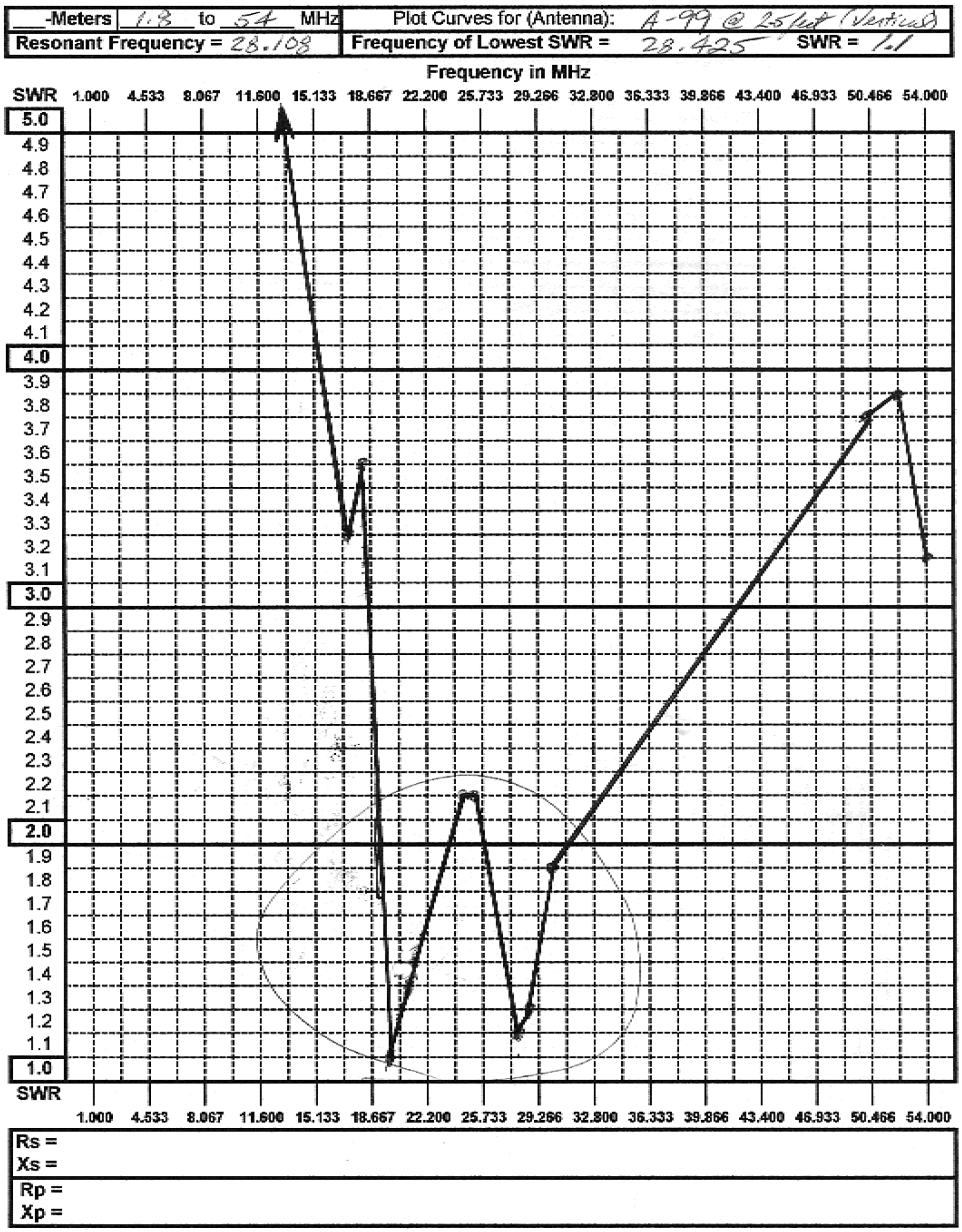
___-Meters 1.8 to 54.0 MHz	Plot Curves for (Antenna): A-99 VERTICAL
Resonant Frequency = 28.108	Frequency of Lowest SWR = 21.000 SWR = 1.1



Rs =
Xs =
Rp =
Xp =

5:1 SWR Chart

10-METER VERTICAL



Series Resistance & Series Reactance Table

1Ø-METER VERTICAL

Table for SWR, Series & Parallel Resistance & Reactance

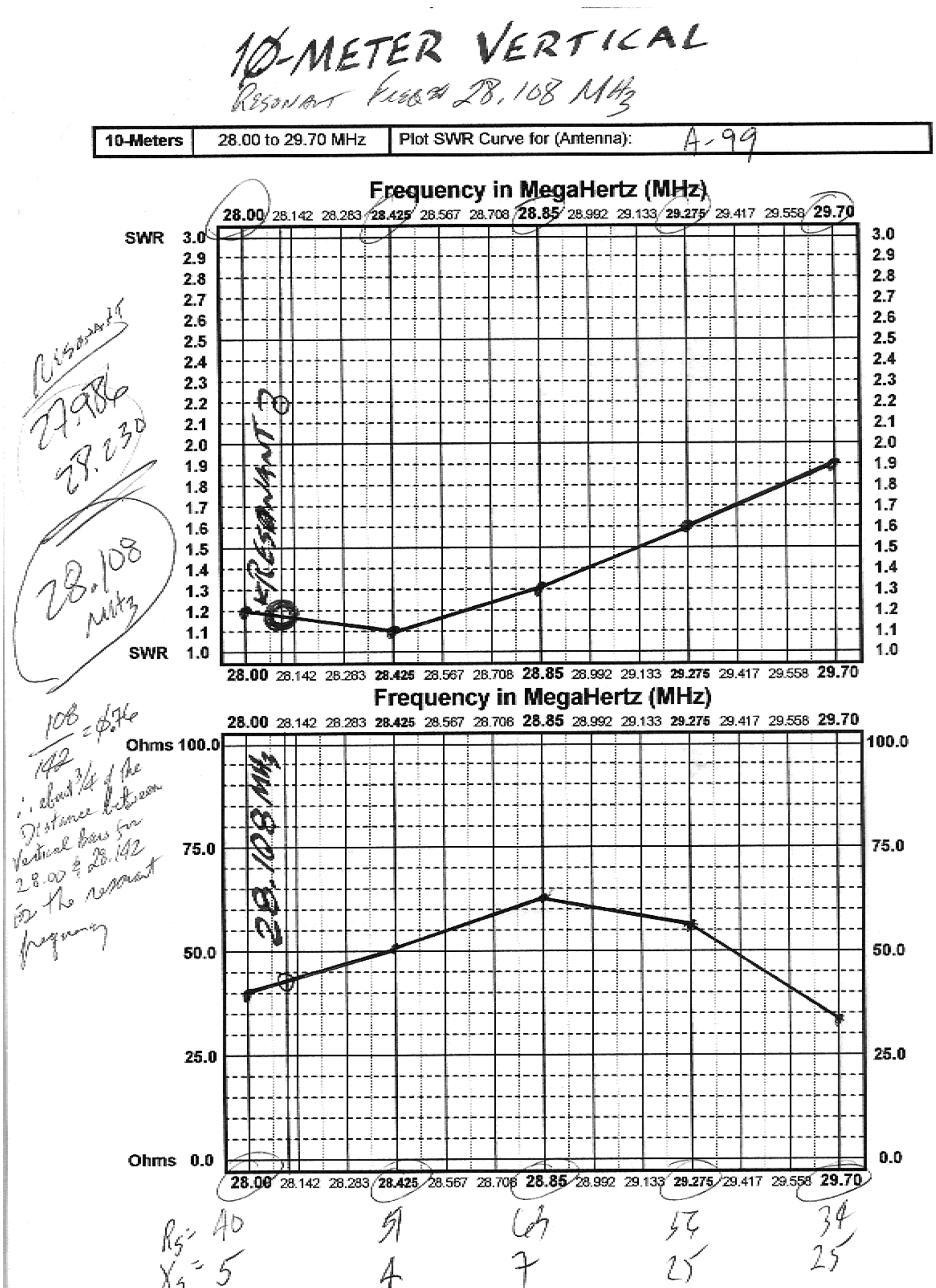
Use this table to obtain an overview of the antenna's SWR, resistance and reactance

Antenna Description A-99 Vertical @ 25 foot Feedpoint

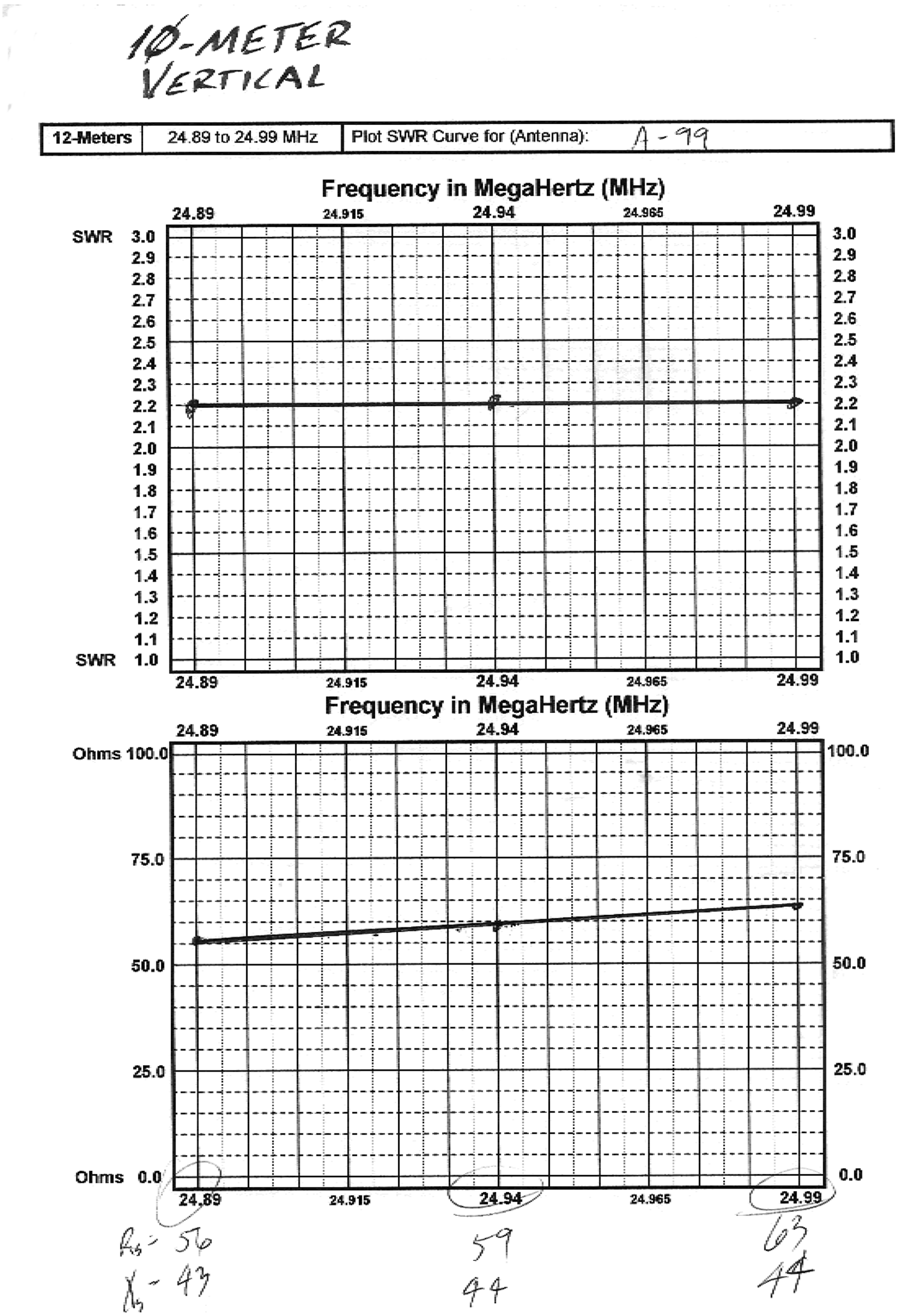
Band	Frequency	SWR	Series Resistance Rs	Series Reactance Xs	Parallel Resistance Rp	Parallel Reactance Xp
160	1.800	16.6	8	85		
"	2.000	17.2	11	112		
80	3.500	21.9	8	114		
"	4.000	20.4	4	60		
40	7.000	10.9	8	54		
"	7.300	109	13	77		
30	10.120	9.4	16 *	30 *		
20	14.000	7.0	53	131		
"	14.350	7.2	205	213		
17	18.068	3.3	52	64		
"	18.168	3.6	45	59		
15	21.000	1.1	57	8		
"	21.450	1.4	74	Ø		
12	24.890	2.2	56	43		
"	24.990	2.2	63	44		
10	28.000	1.2	40	5		
"	28.850	1.3	63	7		
"	29.700	1.9	34	25		
6	50.000	3.8	200	Ø		
"	52.000	3.9	16	32		
"	54.000	3.2	19	21		

SKETCH of ANTENNA:

10-Meter Charts



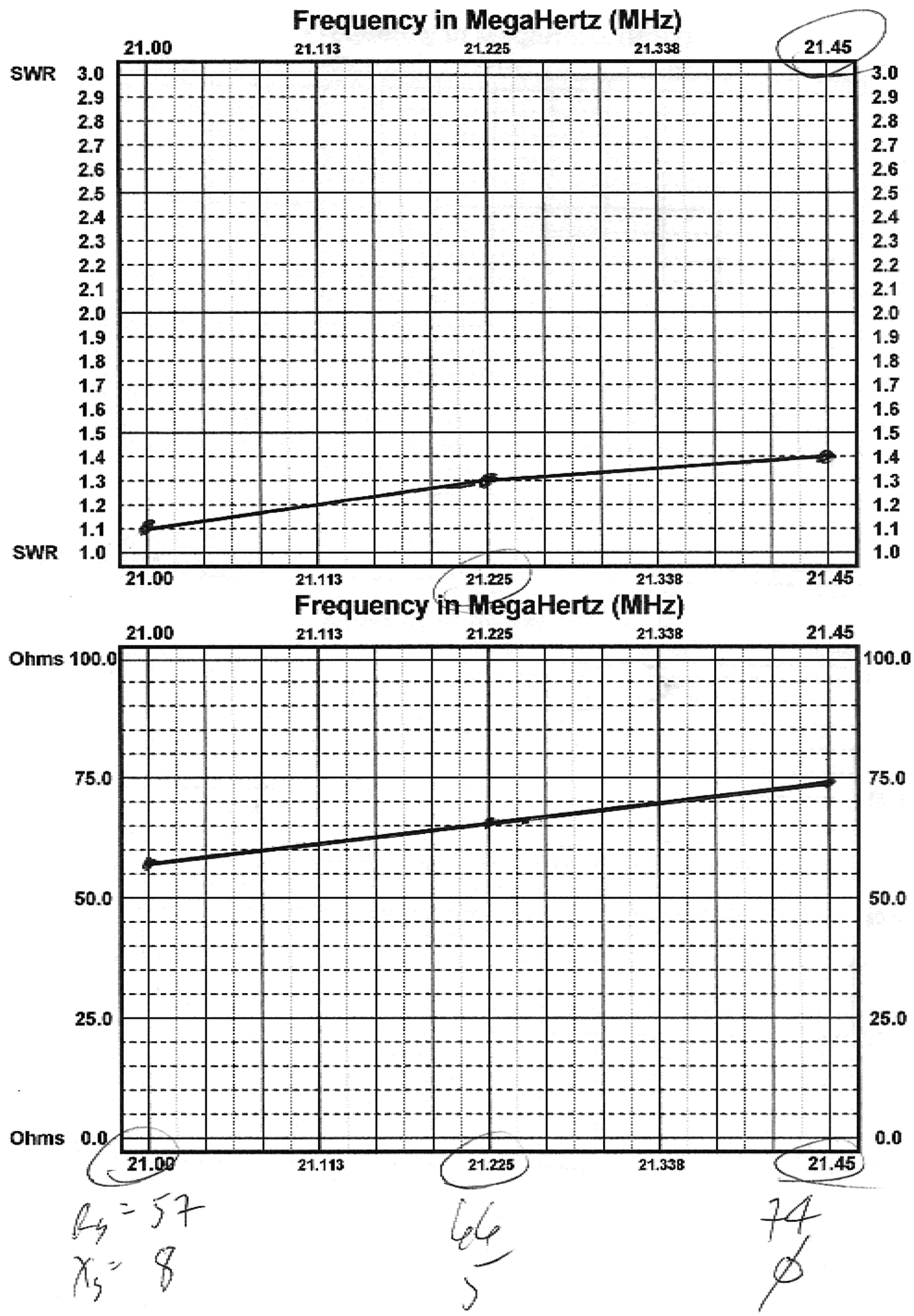
12-Meter Charts



15-Meter Charts

10-METER VERTICAL

15-Meters	21.00 to 21.45 MHz	Plot SWR Curve for (Antenna): A-99



Another interesting chart was produced from an Excel spreadsheet. I was curious about the reactance on the 10-meter vertical antenna, so I measured reactance from 1.75-MHz through a little above 54-MHz. I noted series reactance maximum and minimum values, and the corresponding frequency and series resistance at these points. The chart entitled "10-Meter Vertical: Xs, with Rs" displays the results of these measurements.

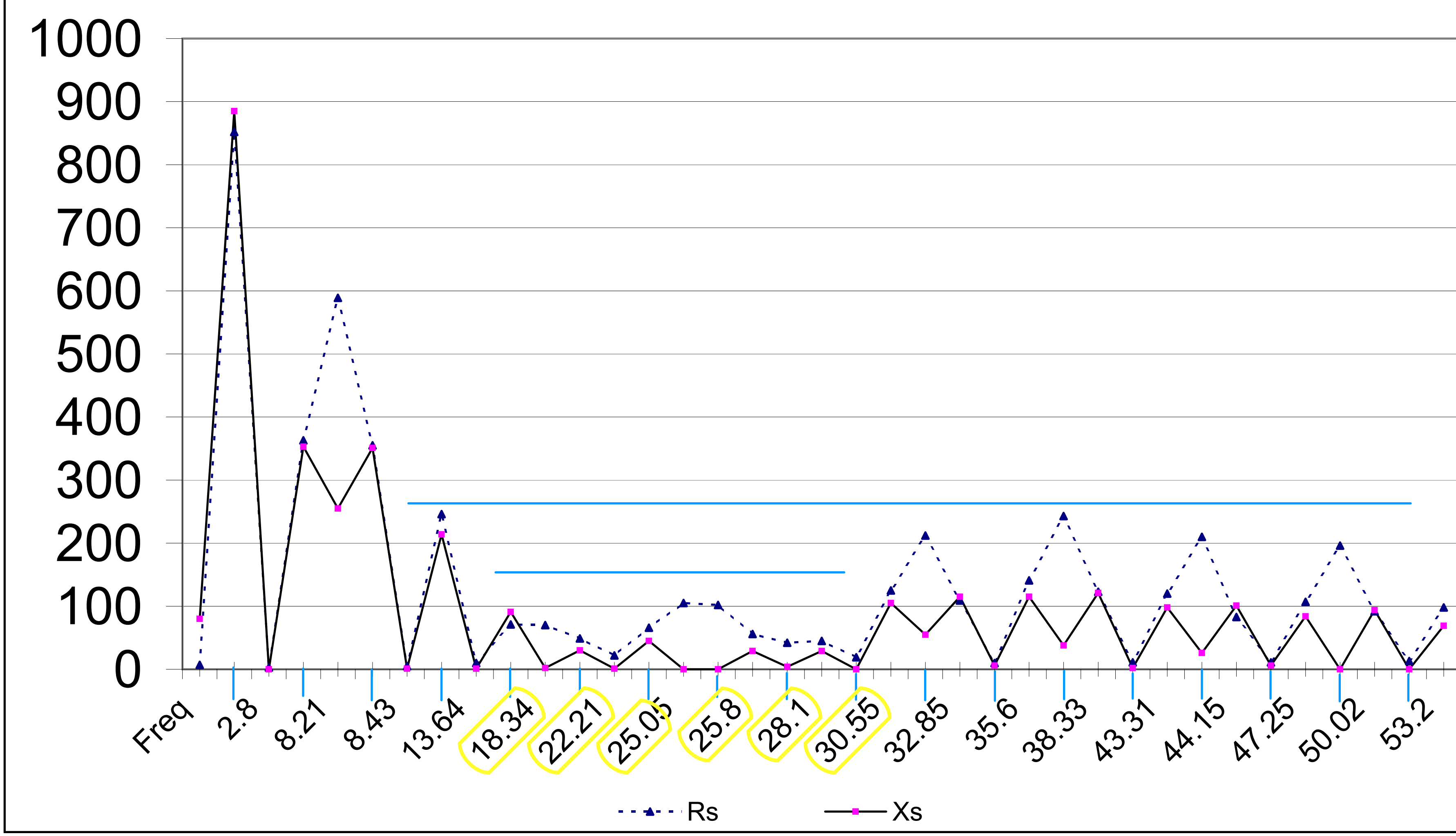
You can see three basic "heights" to the mutual plots. Between 14- and 30-MHz we find the lowest levels of both series resistance and reactance. This will be the easiest frequency range to achieve a successful tune. In fact, I know from experience that a number of these ranges do not require a transmatch. Next we see peaks ranging up to the "200" level, which corresponds to our 5:1 SWR bandwidth. Outside this range the values become considerably greater, and achieving a successful tuning match will become more difficult. At these frequencies (roughly below 10-MHz) our transmatch will have to match both a large amount of reactance as well as a much larger impedance mismatch.

This is not to say we will not be able to match the lower frequencies, only that the transmatch will have to work harder to do so. We will have less efficiency at these frequencies. There is no "free lunch" and the more extreme matching conditions your tuner has to deal with, the less effective RF radiation you can expect to gain when you do obtain a match. This is because your antenna system has to work harder – the transmatch itself is matching increasingly large mismatches and the transmission line is carrying increasingly larger mismatches (higher SWR). Both are less efficient conditions to operate as compared to a naturally resonant antenna, which means incurred losses are greater (especially in any coax with high SWR).

Now we come to the fun part! Why load up a 2-meter j-pole on 80-meters when you can use a loadlock dipole!? (Loadlocks are large, adjustable metal posts placed inside trailers hauled by "big trucks" to keep the loads stable.) Care to guess whether this will prove to be an effective antenna? Examine the next few charts and see what you think, and why. This is the same process you will go through when setting up your own "strange" antennas.

First, I want to introduce you to the "Antenna Data Sheet." This one-page document will standardize recording the basic data of your antennas. You can use this as an annual diagnostic of your antennas (which you have been doing, right?) or as a database of antenna configurations. At the very bottom are three charting areas. On this one you see a quick sketch of the dipole and a note as to its orientation.

10-Meter Vertical: Xs, with Rs



Antenna Data Sheet

LOADLOCK DIPOLE

Antenna Date Sheet

Name of Antenna: Loadlock Dipole (LLDP) Date: 5-3-04

☒ Resonant Frequency: 19.224 MHz ☒ Height @ Feedpoint: 5'-9 1/2"

☒ "Strange" Antenna ~~☐ Normal Antenna~~

☒ Dipole ~~☐ Vertical ☐ Loop ☐ Other:~~

☒ Yes ☐ No Are both transmission line wires connected the antenna?

☒ Coax Choke: ☐ Type of Coax: RG-8/U ☐ Diameter of Coax: 1/2"

☐ Number of Turns: 7 ☐ Diameter of Coil: 7"

~~☐ Bal-un (Ratio)____ ☐ Bal-bal (Ratio)____ ☐ Un-un (Ratio)____~~

~~☐ Home Made~~

~~☐ Size Wire:____~~ ☐ Number Turns:____

~~☐ Number of Wires:____ ☐ Twisted ☐ Side-by-Side~~

~~☐ Ferrite Core ☐ Company:____ ☐ Type:____~~

~~☐ Commercial ☐ Model:____~~

Transmission Line:

☐ Published Attenuation (Loss)____ @ ____ MHz

☐ Measured Attenuation (Loss)____ @ ____ MHz

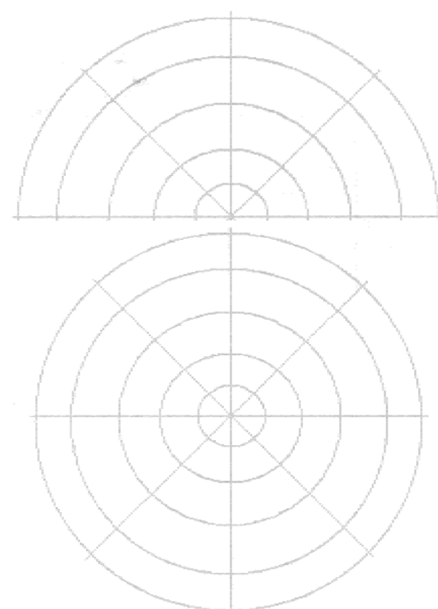
~~☐ Balanced Line ☐ 300-Ohm ☐ 450-Ohm ☐ 600-Ohm ☐ Other____~~

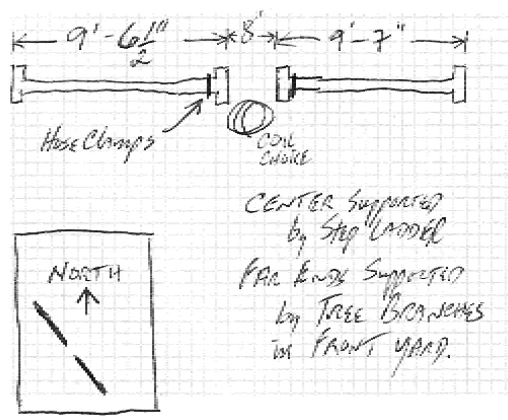
☒ Coax Type (RG-8): RG8-U

☒ Manufacturer: JSC Wire & Cable

☒ Length: 20 ft ☐ Age: 4 yrs

☒ Compass Orientation: NW-SE





The next charts are the 40:1 SWR, 5:1 SWR, series resistance & reactance, and the 17-Meter SWR / Ohms for the loadlock dipole. Given this was never designed to be an antenna, I find its SWR curves to be remarkably similar to the 2- and 10-meter "normal" antennas. True, it is more erratic and goes off even the 40:1 chart on the low bands, but this seems pretty good for two chunks of metal just six feet off the ground! It is naturally resonant between 17- and 15-meters (19.244 MHz).

At 18.1 MHz a ¼ wavelength (WL) is a little over 13 ½ feet. Each leg of the loadlock dipole measured nearly 9'–7" which is (9.6/13.6) 71% of the "proper" ¼ WL for 17-meters (too short). This may partly explain the reactance on this band. You can see the series resistance is just about perfect for a direct coax feed (51- to 52-Ohms). Only the excess reactance needs to be eliminated by a transmatch and this will load up fine for our transceiver.

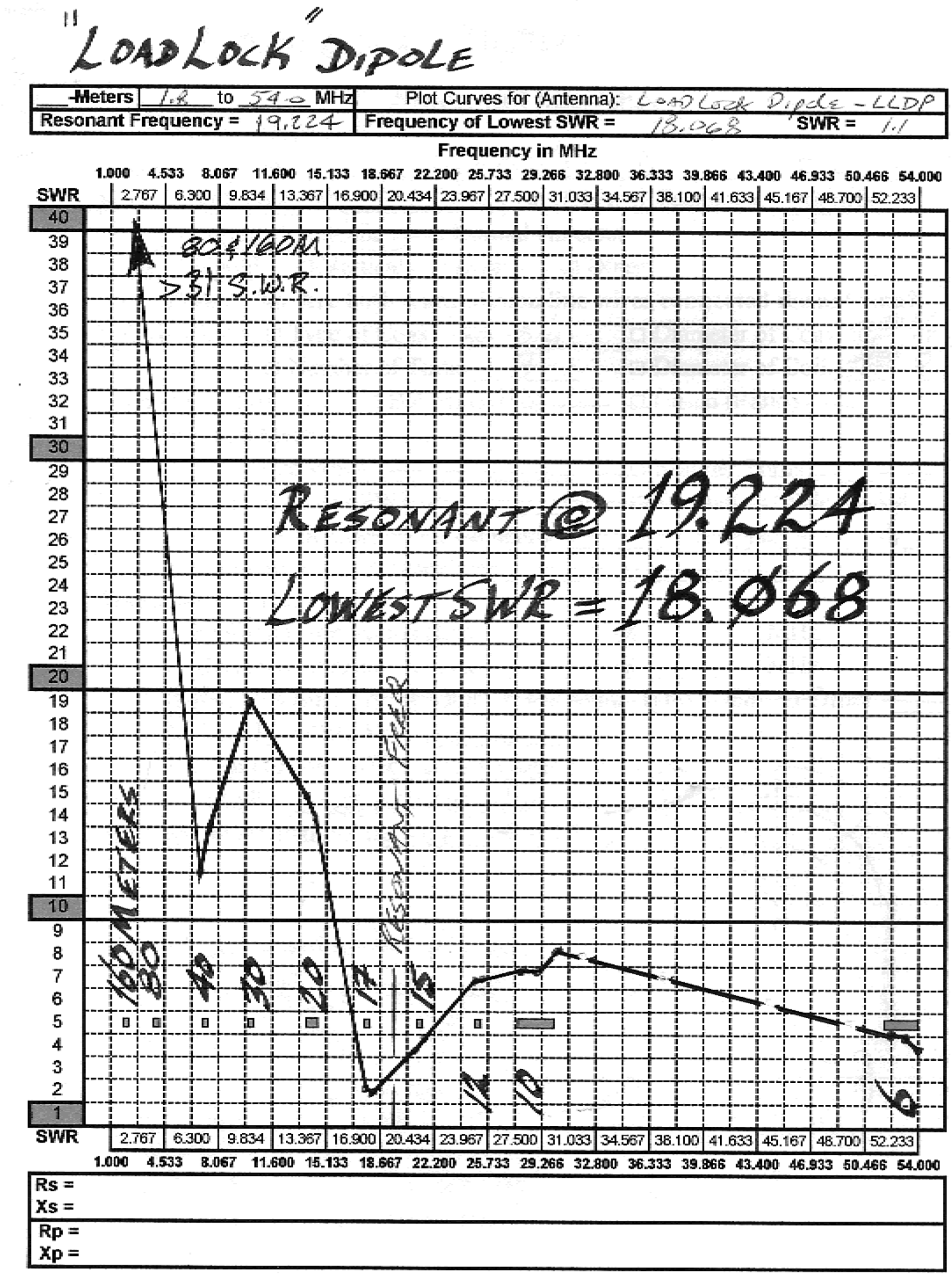
Looking at the "Series Resistance & Series Reactance Table" we can see both 17- and 15-meters will be fairly easy to tune – they are less than 4:1 SWR and the reactance is not too great (all between 34- and 90-Ohms). While I expect we can tune up these loadlocks across most of the amateur bands, I would expect to obtain a fairly good signal on 17- and 15-meters. You will note that at 6-meters we have another opportunity to obtain a decent match. At 52-MHz our loadlock dipole is almost exactly a full wavelength (300/52*39.37/12= 18.93 feet; 9.6*2= 19.2 feet). Both the Ohms and reactance are a little high, but depending upon the matching range of your tuner, you may be able to "fly" this on 6-meters. Certainly the lower end of 6-meters should be an obtainable match.

These are the measurements I review when trying to determine whether a given antenna has a reasonable chance of performing well. The process is quite a bit easier with "normal" antennas because you have access to volumes of published data and tested antennas. With "strange" antennas you have to either experiment more or take a little more caution with your pre-test set up by carefully measuring SWR, resistance, and reactance.

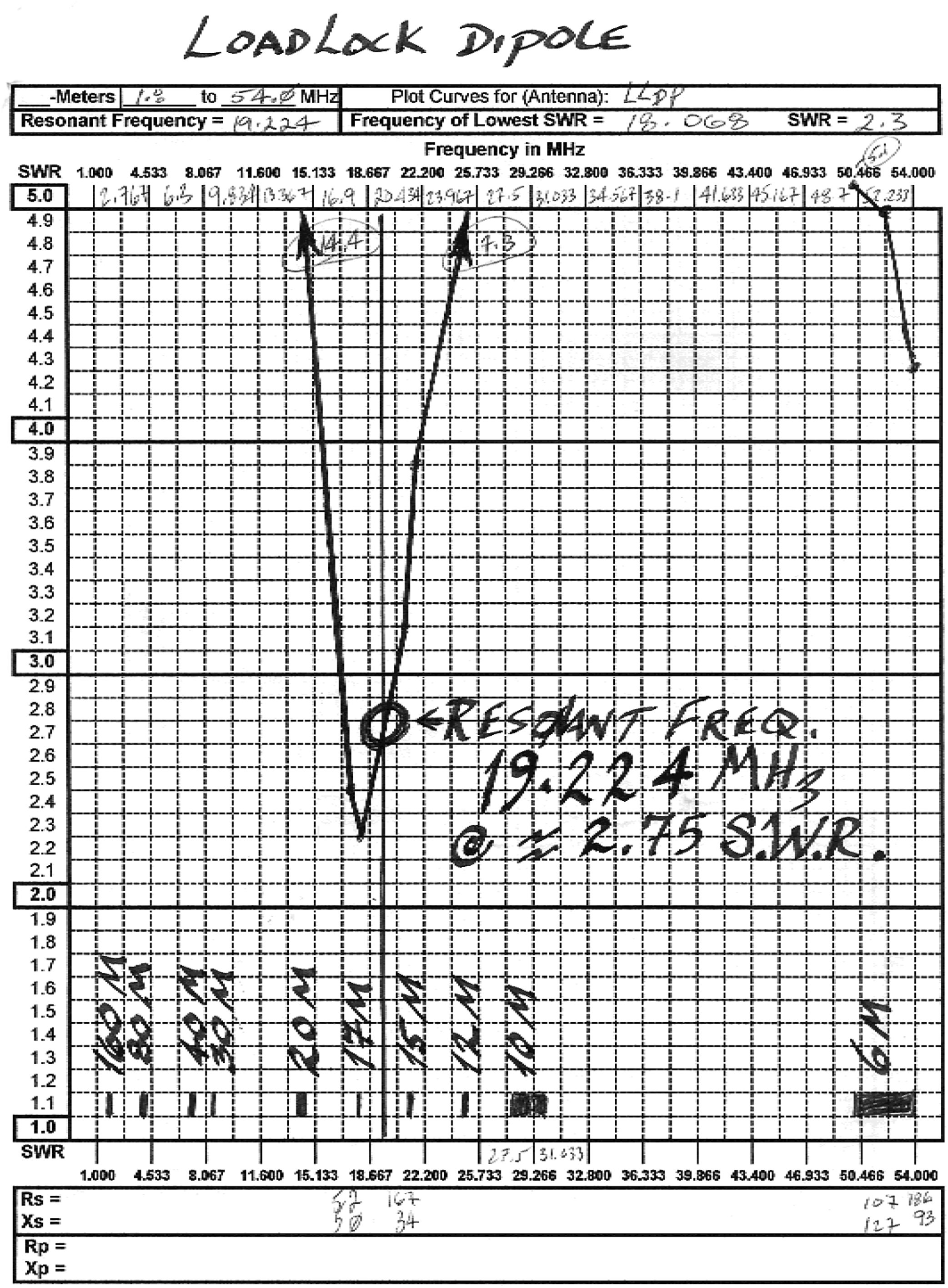
If you will make copies of the provided charts (they are also available in PDF format on my website) and use them each time you set up an antenna, either normal or strange, you will quickly begin to get a feel for what works well as an antenna, and what requires more effort for less return (less RF radiation).

<u>The bottom line is this</u>: If it is metal and you can match it with your antenna tuner, you <u>will</u> radiate a signal. If you spend a little time playing with attachment points, height, and transmission line issues, you will create many fine "strange" antennas!

40:1 SWR Chart



5:1 SWR Chart


LOADLOCK DIPOLE
-Meters 1.8 to 54.0 MHz
Plot Curves for (Antenna): LLDP
Resonant Frequency = 19.224
Frequency of Lowest SWR = 18.068
SWR = 2.3
Frequency in MHz
SWR
1.000 4.533 8.067 11.600 15.133 18.667 22.200 25.733 29.266 32.800 36.333 39.866 43.400 46.933 50.466 54.000
5.0 4.9 4.8 4.7 4.6 4.5 4.4 4.3 4.2 4.1 4.0 3.9 3.8 3.7 3.6 3.5 3.4 3.3 3.2 3.1 3.0 2.9 2.8 2.7 2.6 2.5 2.4 2.3 2.2 2.1 2.0 1.9 1.8 1.7 1.6 1.5 1.4 1.3 1.2 1.1 1.0
RESONANT FREQ.
19.224 MHz
@ ≈ 2.75 S.W.R.
160M 80M 40M 30M 20M 17M 15M 12M 10M 6M
Rs =
Xs =
Rp =
Xp =

Series Resistance & Series Reactance Table

LoadLock Dipole

Table for SWR, Series & Parallel Resistance & Reactance

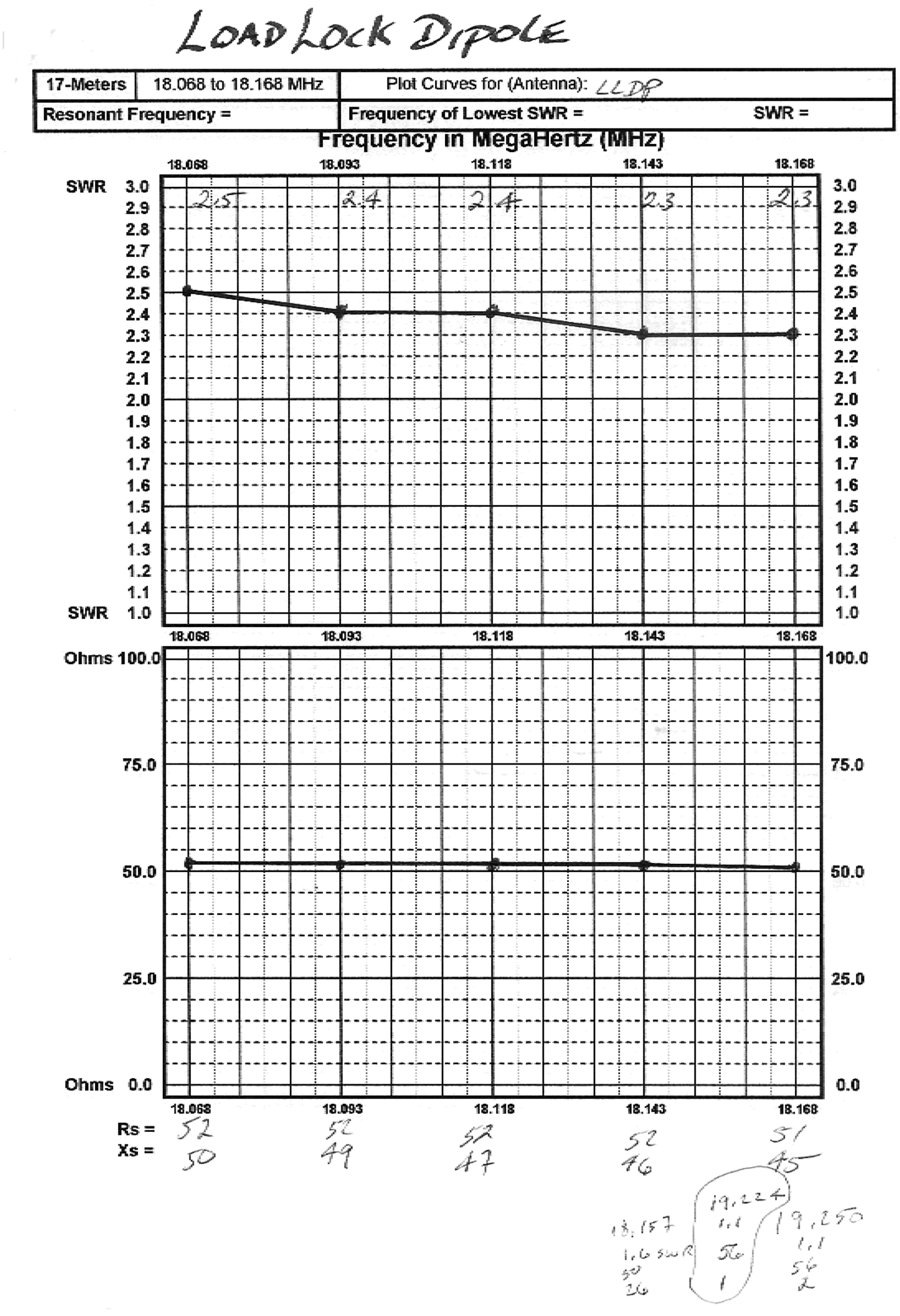
Use this table to obtain an overview of the antenna's SWR, resistance and reactance

Antenna Description LoadLock Dipole (LLDP) 5/3/04

Band	Frequency	SWR	Series Resistance Rs	Series Reactance Xs	Parallel Resistance Rp	Parallel Reactance Xp
160	1.800	>31	Ø	177		
"	2.000	>31	Ø	156		
80	3.500	>31	1	77		
"	4.000	>31	1	63		
40	7.000	12.0	4	24		
"	7.300	14.0	3	19		
30	10.120	19.5	2	16		
20	14.000	15.4	12	109		
"	14.350	14.4	20	133		
17	18.068	2.5	52	50		
"	18.168	2.3	51	45		
15	21.000	3.2	167	34		
"	21.450	3.9	165	88		
12	24.890	7.3	10	44		
"	24.990	7.4	9	42		
10	28.000	7.9	5	4		
"	28.850	7.9	5	7		
"	29.700	8.7	4	17		
6	50.000	5.1	25	67		
"	52.000	5.0	107	127		
"	54.000	4.3	186	93		

SKETCH of ANTENNA:

17-Meter SWR / Ohms Chart



Troubleshooting

Troubleshooting is a process of elimination to discover the cause of an error in your communication and antenna system. The basic approach is to continually narrow the components in which a potential problem may reside until you have found the faulty item. Intermittent problems are the most difficult. There are times when an intermittent problem is not a malfunctioning piece of equipment but instead a piece of equipment that is occasionally "positioned" so as to fail.

An example from my own shack was an intermittent problem tuning a specific antenna to work a traffic net. Some days it would all work well, and I was able to quickly tune my station and take part in the net. At other times I was able to achieve a tune, but it would soon fail, or fail when I increased to full power (100-watts). Occasionally it was such a great problem I was unable to achieve a stable tune.

It finally dawned on me what the problem was… My ladder line entering the shack was routed very close to a lead crystal ashtray. Sometimes I positioned this balanced line too close to the ashtray, and other times it was sufficiently distance so there were no problems. Very obvious once you see the problem, but it was hard to recognize as I looked around the shack and at the antenna and feedline searching for the cause of my woes!

Begin by dividing your transmitter and antenna system into logical groupings:

1. Software (if digital mode)
2. Interconnects
3. Power Supply and Cords
4. Transceiver
5. Transmatch
6. Transmission Line
7. Antenna

You will now test each logical group for either defects or to eliminate every part of your antenna system that is "down stream" as working properly. The whole idea is to chunk your antenna system into digestible sizes and figure our which of the above logical groups contains the source of your systems trouble. Please note that we refer to an antenna "system" – you must think of your RF signals entire path as your "antenna system" beginning with the power supply and ending at the antenna.

Required Information to Troubleshoot Your Antenna

Begin by placing your transmatch in "by-pass" mode. You only want to observe the SWR of the antenna and feedline. If you have other pieces of equipment inline between your antenna and transceiver you may need to remove them as well, and perhaps even test this equipment independently of your antenna system (equipment does malfunction – it is possible the "antenna" problem is the inline SWR meter, for example).

Once you have removed extraneous equipment from the antenna system to be tested (the antenna system should only be comprised of the transceiver, transmission line and the antenna for this test) you will proceed to plot SWR curves for all bands:

1. Plot a SWR curve for each band, for each antenna displaying problems.
2. Plot SWR points at least at both ends and the middle of each band.
3. Use as little transmitted power as possible.

What if all bands perform poorly?

Replace the antenna with a dummy load and perform the above tests one more time. The SWR curves should be nearly 1:1 across all frequencies. If this is NOT the case, replace the transmission line and then re-test the antenna system. You should now see nearly 1:1 SWR across all frequencies (transceiver is operating at 50-Ohms, the coax is 50-Ohms, and the dummy load is operating at 50-Ohms). If even this second test fails, test your dummy load, SWR meter, and transmitter with different test equipment. Either the second batch of coax is also bad, or one of these other pieces of equipment is malfunctioning.

Using Your Antenna Analyzer

This is not an attempt to provide an exhaustive review of the test options found in the popular MFJ Antenna Analyzer. Rather, we will introduce a few of the basic yet useful tests one may make with this device to help determine the health of your antenna system.

The accuracy of the MFJ device is not high when compared to commercial or scientific grade equipment, however its cost is far less (around the $300 mark). If you require extreme accuracy be prepared to spend thousands of dollars. While those of us who tend toward the anal may cringe at the idea, we amateurs do not often require extreme accuracy in our measurements: +/– 10% is often sufficient. This may seem like a large variance; sometimes our measurement's margin of error is only 2% to 3% – just don't worry too much about the precision of our meters.

When you first turn on your MFJ antenna analyzer it will by default expect to measure 50-Ohms. This may be user-defined in the advanced modes. This allows the nominal Ohms to be varied to include nearly all impedances we amateurs may expect to measure.

If you have the newer model (it includes both UHF and VHF) be certain the manual button selecting the highest frequency range is OFF before you power up the device. After turning on the device it will test the voltage. You should watch this to be certain it is between 11- and 18-volts. However, I no longer use mine once the voltage drops below 13.0 vdc because the device becomes VERY INACCURATE well before it's low-voltage warning is displayed.

Most of the functions we will discuss appear in the very first screen displayed immediately following its self-test. The LCD screen will show you:

1. Frequency of measurement;
2. SWR;
3. Series resistance; and
4. Series reactance.

The first of these, frequency of measurement, simply tells us what frequency the antenna analyzer is measuring. This is user-selectable by the two knobs toward the bottom of the meter. The knob on the right is used to select one of several wide range of frequencies, and the knob on the left is used to select specific frequencies within the wider selection.

I once asked a MFJ technician if it mattered whether one measured a given frequency, 4.000 MHz for example, with the wide range knob assigned to the range displaying 4.000 MHz, or if one could also measure it accurately from the neighboring wide range setting. (If this sounds confusing, it will become clear once you begin using the device.) The answer is it does NOT matter. I have since measured a variety of things from both wide range selection settings and found this to be true.

A point of caution – be careful as you rotate the frequency knob. You do NOT want to rotate this past the point where you feel resistance. Doing so may damage the device.

Frequency of Measurement

In the upper left hand corner of the LCD screen you will see the frequency you are measuring. This is used to "dial in" the meter to the specific frequency you desire to measure. The remaining displays are directly correlated to this frequency.

SWR

The SWR appears in the upper right hand corner of the LCD display. Record this number for your SWR measurement.

Ohms

This will be displayed at the lower left, and titled "Rs," which stands for Series Resistance. If you enter the advanced modes, you can also display the parallel resistance of what is being measured.

Reactance

This will appear on the lower right of the display, and is entitled "Xs," which stands for Series Reactance. This too may be set to display parallel reactance in the advanced modes. There is no indication as to whether we are looking at capacitive or inductive reactance however.

Resonance Frequency

To determine an antenna's resonate frequency, observe the reactance (Xs) while you are (slowly) moving the knob at the bottom left. When the Xs equals zero, or as close to zero as you can measure, you will have found the antenna's resonate frequency. Note this is not always where the lowest SWR occurs.

Cable Loss

To find the cable loss display you will have to push the “mode” button. Once you are in this mode you are ready to measure the amount of RF loss (attenuation) the coax will experience at whatever frequency you have selected (again, view the upper left hand corner of the LCD display).

There are a number of other functions this device is handy for including finding the distance from the meter to a fault in the coax. This is a very handy device, and well worth the $300 if you are interested in antenna design, building your own antenna tuner, or similar activities.

Using Other Test Equipment

There are a variety of simple tests that the average amateur may make to help determine the status of their antenna system parameters. The following pages will outline a few tests, some of which are appropriate for taking to the field when you experiment with your “strange” antennas. First we will describe the test equipment and outline its uses. Then we will examine some tests we may wish to conduct.

Field Strength Meter

Field strength meters measure the actual RF radiation from your antenna. For this reason they provide the ultimate documentation for whether a given change in your antenna system is for the better or worse. There are two types of field strength meters. One is a “relative” meter and the other is a “calibrated” meter.

The relative field strength meter is the most common version and is a device you can easily build yourself. (It is in fact a pretty good early “homebrew” project if such things interest you.) The only energy available to deflect its meter is whatever RF energy it receives from its environment. Our goal is to measure the RF energy radiating from our antenna system with this device and then make some change to our antenna system and re-read the meter. We determine the success of our change by comparing the relative meter change (greater of lesser) to our expected results (which depend upon our test, sometimes we expect a greater amount of RF radiation and at other times we expect to find less RF radiation being measured).

The calibrated field strength meter has an internal tuned circuit (often called an "oscillator"). This mysterious tuned circuit is an inductor and capacitor that "oscillate" – they are tuned to some specific frequency (derived from a specific setting of the inductor and capacitor). This oscillation is then compared to the RF energy measured from your antenna (or any other source of RF radiation reaching the field strength meter) and is displayed for evaluation. Since the measured RF energy is compared to its own internal "benchmark," you should obtain measured readings that are directly comparable to one another at all times.

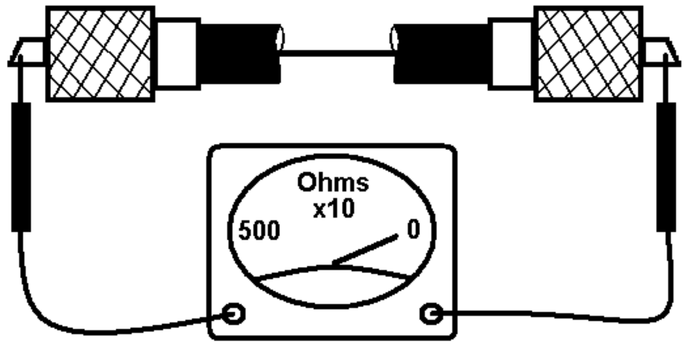
You always need to study your environment to ascertain whether the measured RF energy is truly coming solely from your antenna system. This is true of all field strength meters. You also need to be aware there are two fields generated (or radiated) from our antenna systems: the "near" field and the "far" field. We won't discuss these but you can refer to "The ARRL Antenna Book" and/or "The ARRL Handbook" to learn more about the differences in these fields. For now, just pay special attention to conducting all tests consistently.

VOM

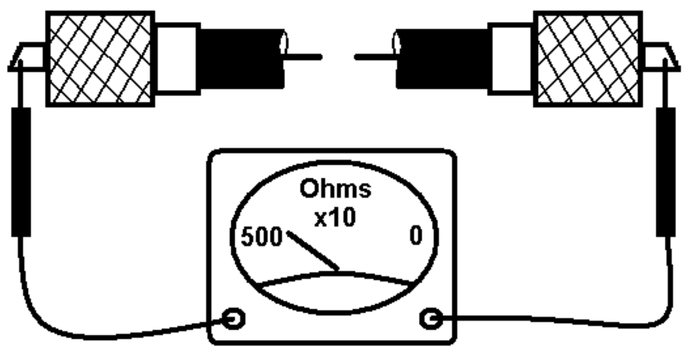
The Volt-Ohm Meter (VOM) is perhaps the most basic piece of test equipment. You use this meter to measure Volts, or Ohms. VOMs come in digital and analog styles. Either will work for most amateur applications however one or the other is sometimes preferred for specific types of measurements, so you may wish to pick up one of each. Some VOMs will also measure the values of inductors and capacitors, which can be handy. Sometimes you can find these on sale for just a few dollars. You may wish to pick some of these up for use in various projects, or tossing in your spare toolbox. Radio Shack and other stores have a good selection of VOMs at reasonable prices. Fluke makes some of the best VOMs you will find anywhere.

Uses range from simple continuity tests (checking for a short or open circuit) to verifying actual values of resistance or voltage. They are useful when testing connectors you have mounted on coax, making electronic kits, and verifying individual electronic components and circuits are working properly.

When you have finished soldering your PL-259s on each end of your coax you should test for continuity. Place the VOM on a very small resistance setting (such as (“R x1” or “R x10”) and touch the leads together and observe the meter (some VOMs require this to “zero” the meter, others do not require this step). You should see a very small amount of resistance. Now hold one lead (either one) to the center pin of one PL-259, and then touch the other lead to the other PL-259’s center conductor. You should see the a meter reading very similar to when you touched the leads together. If you see a similar reading it means there is very little resistance between the two PL-259’s, and this is good because it means the wire connecting the two center pins is intact (versus broken or “open”).



Good - "Closed"



Bad - "Open"

While keeping the first lead in place change the second lead to the metal body of the second PL-239. You want to see a completely different reading on your meter indicating an “open” circuit exists (the first PL-259’s center conductor is <u>not</u> in contact with (“shorted” to) the shield braiding).

You can also test individual components, such as a 15K (15,000) resistor by holding each lead of the meter to separate leads of the resistor. In this case you will want the meter set to close to “R x1,000.” If you were to leave the meter’s setting in the position discussed above (R x10) the resistor would read as an open circuit because its value is too high for the VOM to measure properly at the too low multiplier (x10 versus x1,000).

Dummy Load

These are typically metal enclosures of some kind with a coax socket connector (SO-239) connected to an internal resistor. Some are filled with oil, some are air cooled. All of them are designed to absorb RF energy and convert it to heat.

Inside you will find one or more non-inductive resistors (not wire wound; use either carbon composition or metal foil). Usually these operate at 50-Ohms impedance. The impedance of the dummy should match your transmission line and transmission source (transceiver) impedance. If not, you will need to make some additional calculations, or obtain a dummy load designed to operate at the appropriate impedance ("Ohms" value).

The maximum wattage you can transmit into a dummy load is determined by how quickly it can dissipate heat. This is directly related to both input (transmitted) power and length of the transmission. For example, a dummy load may be rated to dissipate 300-watts if transmitted into it for less than 30-seconds, and have an unlimited duration of transmission time if under 20-watts are transmitted into the dummy load.

A dummy load is typically very affordable. Most amateurs consider it a "must have" item. It is very useful when troubleshooting. Sometimes you will use it to simply verify the problem exists in the antenna or not, and at other times you will transmit a signal into the dummy load so you can obtain a useful reading on another piece of equipment. This is also a very easy piece of equipment to make yourself, and is a good beginning project.

Wattmeter

Wattmeters are very useful. They can be stand-alone devices or built-in meters found in a variety of amateur radio equipment. Prices range from very cheap to very expensive, and accuracy generally follows price. Good deals may often be found at local hamfests (flea markets for amateur radio operators) or on eBay.

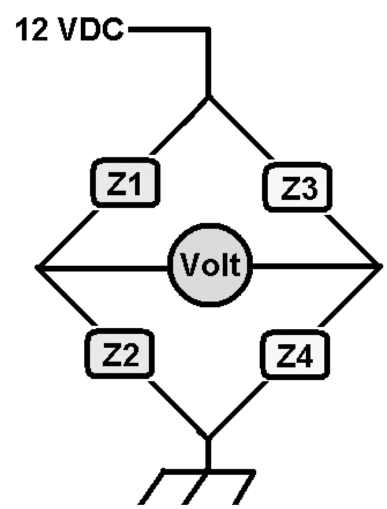
One of the most popular wattmeters for amateur radio use is the Model 43, manufactured by Bird. This is a highly recommended piece of equipment. The basic meter can be purchased from $100 to $350. It requires "plugs" or "elements" to be plugged into the front of the meter which determine the effective power level and frequency range the meter is able to measure. These elements generally cost between $75 and $100 for the amateur HF bands (2 through 30 MHz). Higher frequency elements, such as those in the microwave bands, cost more. The elements are very delicate and if you drop them they may need to be recalibrated, or replaced.

Antenna Current Probe

This device measures the electromagnetic field generated by an antenna, length of wire, or transmission line. It is useful during antenna design, for determining if RF current is escaping your transmission line, and useful for determining if your balun is working properly. In some cases you can use a field strength meter in its place. Some antenna analyzers also replace many of its uses.

Noise Bridge

This is a useful device for determining an unknown resistance and sometimes an unknown reactance, depending upon how the internal components are designed. A noise bridge that measures both resistance and reactance is useful to determine antenna impedance, feedline length, values of resistance, inductance & capacitance, and the frequency of a tuned circuit.



There are practical reasons for understanding how a noise bridge works. The underlying concept behind its construction will be seen over and over again in the course of your amateur radio studies.
A noise bridge works by measuring known values and comparing these to one unknown value and one variable value. First, assume all resistors are identical: Z1, Z2, Z3, and Z4 are 100-Ohm resistors. The voltage at the junction of Z1 and Z2 will be the same as the voltage at the junction of Z3 and Z4, and this is considered a “balanced” condition, and in this condition the voltage will read zero. This is because Z1 and Z2 taken together, are equal to Z3 and Z4 taken together – they are “balanced.”

If we now change Z4 to a 50-Ohm resistor we have created an "unbalanced" condition and the voltage meter will no longer read zero. We can determine the value of Z4 by adjusting a variable resistor (Z3). When the volt meter once again reads "zero" whatever the value of the variable resistor, this will equal the value of the unknown resistor.

When constructing our own noise bridge we will insert multiple resistors in Z4's position. After inserting each new, and known, resistor we will adjust the variable resistor until the volt meter reads zero. Once it reads zero, we mark the location of the variable resistor's knob (which either has a mark or pointer on it) on the meter's enclosure, and in this manner continue to calibrate our noise bridge for whatever range of resistors we wish to be able to measure in the future.

Most noise bridges are designed to be used with your transceiver providing a user-selected frequency (providing the "noise") to allow us to find an unknown reactance and resistance. These noise bridges have two adjustable dials, with calibration marks, both resistance and reactance. We calibrate reactance in a manner similar to resistance, as described above. The useful range of most noise bridges is generally limited to:

Resistance values from 0 to 250-Ohms
Reactance values from 0 to 300-Ohms

If the meter "jumps" rather than smoothly changing value, suspect the battery voltage is too low (change or recharge). A noise bridge may also be used to tune a transmatch without transmitting a signal.

Coax Test – SWR Meter

Goal: Determine if a length of coax is damaged.

Equipment: SWR meter; dummy load.

Overview: If the transceiver, coax, and dummy load are all designed to operate at 50-Ohms, when a suitable transmission is sent through the SWR meter and coax to the dummy load, the SWR meter's reading will provide an indication of the quality of the coax – whether it is "good," qualified by if the characteristic impedance (Z_0) of the coax is still close to its manufactured value of 50-Ohms.

Conduct Test:

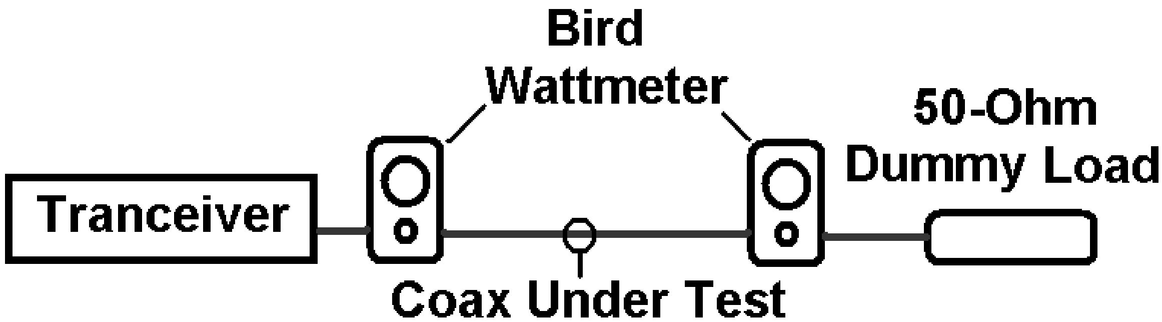
1. Connect your transceiver to a SWR meter with a short piece of 50-Ohm coax (no more than one- to two-feet).
2. Connect the SWR meter to one end of the 50-Ohm coax to be tested.
3. Connect a 50-Ohm dummy load to the opposite end of the coax.
4. Transmit with as little power as will deflect the SWR meter's needle, using AM, RTTY, or CW mode.
5. Record the SWR reading:
    a. The SWR meter should read 1:1;
    b. If the reading is more than 1.2:1 or 1.3:1 either the meter is damaged, or the coax is damaged (no longer has a Z_0 equal to its designed Z_0).

Coax Test – Bird Wattmeter

Goal: Determine decibel (dB) loss of coax.

Equipment: Transceiver; Wattmeter(s); dummy load.

Overview: A RF signal will be transmitted through a length of coax, two wattmeters, and into a dummy load. Comparing the power present in the coax near the transmitter, to that near the dummy load will allow a calculation to be made, the results of which will be compared to the manufacturer's loss data for that coax.



Conduct Test:

1. Connect transceiver to wattmeter with small amount of 50-Ohm coax.
2. Connect length of 50-Ohm coax to be tested to first wattmeter and to a second wattmeter (or measure twice by moving the wattmeter if you only have one wattmeter).
3. Connect second wattmeter (or length of coax to be tested if only one wattmeter) to dummy load.
4. Transmit with the minimal amount of power to deflect the SWR meter's needle in AM, CW, or RTTY mode.
5. Read your meter's manual:
    a. Some require that you first measure forward power, then reflected power – some operate in the opposite manner;
    b. Some require you calculate the SWR:
        i. $r = \sqrt{\dfrac{\text{(REFLECTED POWER)}}{\text{(FORWARD POWER)}}}$
        [Reflected divided by Forward, then find the square root]
        ii. SWR = (1 + r) / (1 – r)
    c. Note your measured forward & reflected powers, or calculated SWR
6. Results of Wattmeter Test:
    a. Loss (in dB) = 10 * (log P1/P2) * (coax length/100)
    b. Where:
        i. P1 is the forward power output at the transmitter;
        ii. P2 is the forward power read at the far end of the coax;
        iii. The "100" is used because we are assuming the published coax loss figures are for 100 feet of coax – if a different number of feet is being used in your published data, change this number accordingly.
    c. Look up the coax's new loss value.
    d. Compare this to the measured loss value.

    e. **<u>If loss is greater than 1.0 dB over its loss when new, consider replacing the coax</u>**.
7. An example:
    a. You have measured 50 feet of RG-58 coax cable at 3.7 MHz. You measure 8 watts at the dummy load and 11 watts at the transmitter.
    b. New RG-58 loss is 0.7 dB per 100 feet of coax at 3.7 MHz.
    c. Loss (in dB) = 10*(log(11/8))*(100/50)
       = 2.8 dB; 2.8 >> 0.7

    Therefore coax is bad because 2.8 is much larger than 0.7.

Measuring Transmatch Losses

<u>Goal</u>: Determine amount of loss incurred inside your transmatch.

<u>Equipment</u>: Transceiver; Bird wattmeter (or other accurate wattmeter); transmatch; and 50-Ohm dummy load.

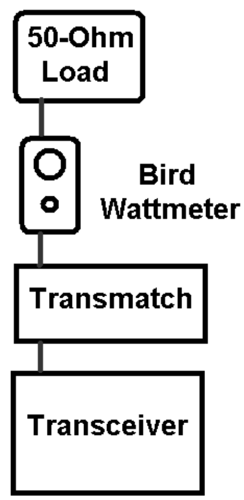
<u>Overview</u>: Your transmatch will be tuned to a series of frequencies. At each frequency your transceiver will transmit a RF signal through the transmatch, through a Bird wattmeter, and into a 50-Ohm dummy load. At each frequency the power output will be measured twice – once through the tuned transmatch and once by-passing the transmatch. By comparing the RF power on the output side of the transmatch in "by-pass" to the RF power measured in the same location after a transmatch has achieved a successful tune, we will be able to calculate the power difference, and from this the amount of loss of RF power loss in the tuned transmatch (in dB).

<u>Conduct Test</u>:
1. Connect your transceiver to your transmatch using a small amount of 50-Ohm coax.
2. Connect your transmatch to your Bird wattmeter using a small amount of 50-Ohm coax.
3. Connect your Bird wattmeter to your 50-Ohm dummy load.
4. Transmit with as little power as possible to obtain a needle deflection on your Bird wattmeter, using AM, RTTY, or CW mode.
5. Adjust your transmatch for minimal SWR.
6. Record the forward power displayed on the Bird wattmeter.

7. Set your transmatch to "by-pass" (none of the tuning circuits are being used; it is as if you do not even have the transmatch inserted between the wattmeter and the transmitter).
8. Record the forward power displayed on your Bird wattmeter.
9. Repeat this process for a variety of frequencies (you can expect losses to change somewhat with frequency).
10. Calculate change in forward power in decibel (dB):
    a. (Forward Power in By-Pass) / (Forward Power When Tuned)
    b. Take the "log" of the above ratio
    c. Multiply by 10 = Loss in decibels (dB)
11. For Example:
    a. 5.0 / 4.2 = 1.1904762
    b. log 1.190 = 0.0755
    c. 10 * (0.0755) = 0.755 = 0.75 dB loss

<u>Sample Transmatch Losses</u>:

Freq.	By-Pass Watts	Thru-Tuner Watts	Loss (dB)
1.80	5.0	4.2	.76 dB
3.75	5.5	5.0	.41
7.25	5.2	5.0	.17
10.12	5.2	5.0	.17
14.23	4.4	4.0	.41
18.13	5.5	5.5	.41
21.30	4.6	4.6	0.00
24.95	4.4	4.2	.20
28.70	4.2	4.0	.21



Losses Due To Long Coax Run

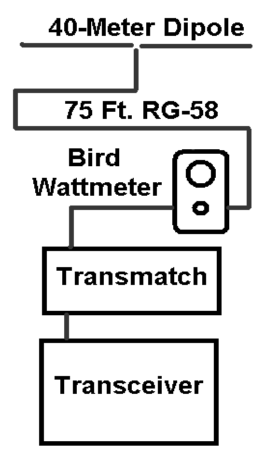
<u>Goal</u>: Determine coax loss over a long run.

<u>Equipment</u>: Transceiver; transmatch; Bird wattmeter; long length of coax; and an antenna, or dummy load.

<u>Overview</u>:

Sample Coax Losses[45]:

Freq.	SWR	Thru-Tuner Loss	Total Loss
1.9			
3.7			
7.2			
10.1			
14.2			
18.1			
21.4			
24.9			
28.6			



Measuring Transceiver Power Output

Goal: Determine actual amperage flowing as the transceiver output at maximum transmitted power.

Equipment: VOM and/or Antenna Analyzer; Transceiver; Bird wattmeter; and 50-Ohm dummy load.

Overview: You will connect your transceiver to a Bird wattmeter with a short length of 50-Ohm coax, and connect the wattmeter to a 50-Ohm dummy load with a short piece of 50-Ohm coax. You will transmit at full power into the dummy load and record the forward power registered by the wattmeter. From this you will calculate the amperage flowing in the coax as it leaves the transmitter.

Conduct Test:

1. Use an accurate VOM and/or Antenna Analyzer to measure your 50-Ohm dummy load to ensure it is in fact a 50-Ohm non-inductive load.
2. Using short lengths of 50-Ohm coax connect your transceiver to a Bird wattmeter and in turn to a 50-Ohm dummy load.
3. Transmit in AM, RTTY, or CW mode at full power.
4. Record the forward power registered by your Bird wattmeter.
5. Amperage flowing from the transceiver is determined by solving for I:
    a. $I = \sqrt{(\text{Watts} / \text{Resistance})}$
    b. $I = \sqrt{(\text{Watts} / \text{50-Ohms})}$
    c. I = Current (measured in amps) flowing from transceiver.

Transceiver

One of the easiest ways to limit the scope of potential problems is to use your dummy load. Connect a 50-Ohm dummy load to your transceiver output and transmit at low-power:

> Does the transmitter output match the selected amount of output?
> Is the SWR 1:1, or very close?
> Are the noted problems still occurring or have they disappeared?

If successful, increase power output and repeat the above steps.

Transceiver Test Results:

Since the transceiver & dummy load both operate at 50-Ohms impedance, if the above tests fail:

Either the transceiver is operating improperly, or
The dummy load is damaged

Replace the dummy load with a second dummy load or test a second transceiver into the first dummy load, and re-test as above. If you find the dummy load is operating properly, you have eliminated the antenna, and any feedline between where you placed the dummy load and the antenna. The problem is taking place somewhere between the dummy load and transceiver, or perhaps one of the peripherals connected to your transceiver (laptop, etc.).

Transmission Line

Test your transmission line before testing the antenna. Most problems seem to be related to the transmission line in some way. Loose connectors and/or poorly soldered connections seem to be the most common causes.

However even “new” transmission line can fail, and sometimes only at selected frequencies. There a few simple tests you can apply to your transmission line using only a VOM and wattmeter for testing equipment. Let’s take a look at these tests.

VOM Test:

This will not prove the transmission line is good, but it can eliminate an open or shorted line as the problem, and is a good place to begin your transmission line analysis because is to simple and fast. It also identifies the number one reason is antenna system failures: connector problems.

Begin by zeroing your VOM by shorting the leads together and zeroing the meter. Some digital meters do not require this – check your VOM’s manual.

Check for Shorted Coax:

Shorted coax can cause high SWR. First disconnect the feedline from the antenna because some antennas will show as a "short" all the time (a j-pole is one example). In these cases you can only determine if the coax has shorted by disconnecting it from the antenna.

1. Disconnect the feedline from the antenna.
2. Set the VOM to R = 1,000, or R = 10,000.
3. Connect one lead to the center pin of the coax, and the shield of the feedline connector (the "spinny-get-tight" part) is connected to the other VOM lead (which lead connects where, does not matter).
4. Is the Coax Shorted?
    a. Verify the far end of the coax is NOT connected to anything.
    b. **Resistance should read high, close to its maximum reading** (showing an open circuit).
    c. A reading less than full scale may indicate:
        i. Short between shielding & center conductor; or
        ii. Water in the coax (causing a short).
5. Is the Coax Open?
    a. Short one end of the coax together.
        i. 'Gater-clip' the center connector to shield ring (braiding).
        ii. Construct a SO-239 with the shield & center shorted together.
    b. Set the VOM to its lower R setting (R x1).
    c. Re-zero meter & test coax as before (if needed, or uncertain).
    d. **The VOM should read close to zero**.
        i. If it reads a high value, either the coax shielding or coax center conductor is an open circuit (has a break in it).
        ii. Check the connectors first:
            1. If they are solder type, re-heat & re-solder;
            2. If this fails, cut off the connector & re-test;
        iii. If the test now passes, replace the connectors.
        iv. If this still fails (with no connectors placed on the coax), the coax has a break in it and must be replaced.

The Best Test:

It is possible the coax may pass the above tests, yet fail when operating at radio frequencies (RF), or even just at specific frequencies. For these reasons you may wish to perform a better test on the coax using a dummy load, some kind of power meter, and of course a transceiver.

1. At the far end of the coax connect a 50-Ohm dummy load (in place of the antenna).
2. Using short length of 50-Ohm coax connect your transceiver to a power meter of some kind (noise bridge, wattmeter, or SWR meter).
3. Connect the coax to be tested between the meter and dummy load (it too needs to be 50-Ohm).
4. Following the manufacturer's instructions, use the meter to test the coax on several bands. You are watching for any unusual behavior or readings. There were a number of coax tests described above, to which you may wish to refer.

Test Coax with Noise Bridge

Goal: Measure feedpoint resistance and reactance, and determine the characteristic impedance of the coax, and compare this to its designed value to discover if the coax should be replaced.

Equipment: Noise bridge; transceiver;

Overview: A noise bridge allows you to determine both the pure resistance and reactance present at the point where you insert the noise bridge in your antenna system. We will now use it to determine if a length of coax remains close to its manufactured characteristic impedance.

Conduct Test:

1. Connect the transceiver to the noise bridge with a short piece of 50-Ohm coax at the point of the antenna system you wish to test.
2. Connect the unknown coax to be tested to the "Unknown" terminal of the noise bridge.
3. Check your noise bridge's instructions to determine whether is has its own internal dummy load of it you will require attaching a dummy load.
4. Conduct the test:
    a. Set the transceiver to the frequency for which you wish to test the coax (you should test the coax on a number of bands, not just a single band).

b. Adjust the noise bridge for “null.”
c. Read the “Resistance” and “Reactance” from the calibrated dials.
d. The resistance should be 50-Ohms and the reactance zero (or very close to these values), otherwise replace the coax.

RF Losses Due to High SWR

When high SWR exists on your transmission line RF energy is reflected between the source (transceiver) and the load (antenna). Each trip a fraction of this energy is lost as heat in the coax. Additional line losses quickly increase due to this heating of the coax. However, with balanced transmission line additional SWR losses are very small and are often negligible.

High SWR losses may be cured in a number of way:

1. Replace the coax cable with balanced transmission line (ladder line).
2. Replace high-loss coax with low-loss coax:
    a. This will only help if the SWR loss is not too great.
    b. All coax incurs greater line loss than balanced line.
3. Obtain a proper impedance match in the antenna system:
    a. Use a transmatch;
    b. Design, and use on the antenna a smaller frequency range.

Chapter VII

Further Reading

Books and Magazines

"The ARRL Antenna Book"
"The ARRL Handbook"
These are both very helpful reference books.

"Reflections II" Maxwell, W2DU
This is a great book. Expect to "elephant eat" this one!

"Practical Antenna Handbook" J. Carr
As the title suggests, this is a very practical book. Good both as a starting point as well as a desk reference.

"Wirebook IV" P. Jones, N8UG
This offers a lot of good advice. Its main focus is antenna wire, transmission line, and connectors.

"Heil Ham Radio Handbook" B. Heil, K9EID
Many topics are discussed in this book – filled with good advice.

"Near Vertical Incidence Skywave Communications" Fiedler and Farmer
This is the best NVIS book I've found.

"Troubleshooting Antennas and Feedlines" Tyrrell, W1TF
I found the discussion regarding the use of test equipment especially interesting. I have found this to be a useful guide.

"Easy-Up Antennas" E. Noll, W3FQJ
Filled with easy yet effective methods to get those antennas up!

"QST" Magazine (free with ARRL membership)
I view QST as providing ideas that we need to develop on our own. Seldom is enough information provided to complete the projects featured, but they certainly give us some good ideas to pursue. Remember to watch out for the "April Fools" article each April!

Web Sites

www.n0ew.org

Well, I'm biased, this is my web site, sometimes lovingly called the "incredible stick page!"

www.arrl.org

This is the largest association for amateur radio, The American Radio Relay League.

www.wr6wr.com

Home of "World Radio" and Kurt N. Sterba!

www.cebik.com

Filled with information about antennas!

www.cablexperts.com/cfdocs/tech_data.cfm#attenuation
www.k1ttt.net/technote/coaxloss.html#tables
www.davisrf.com/ham1/coax.htm
www.radioworks.com/ccoax.html

Coax loss data

www.thewireman.com
www.cablexperts.com
www. mfjenterprises.com
www.hamradio.com

Good places to fill your amateur radio needs!

www.ac6v.com
www.w8ji.com

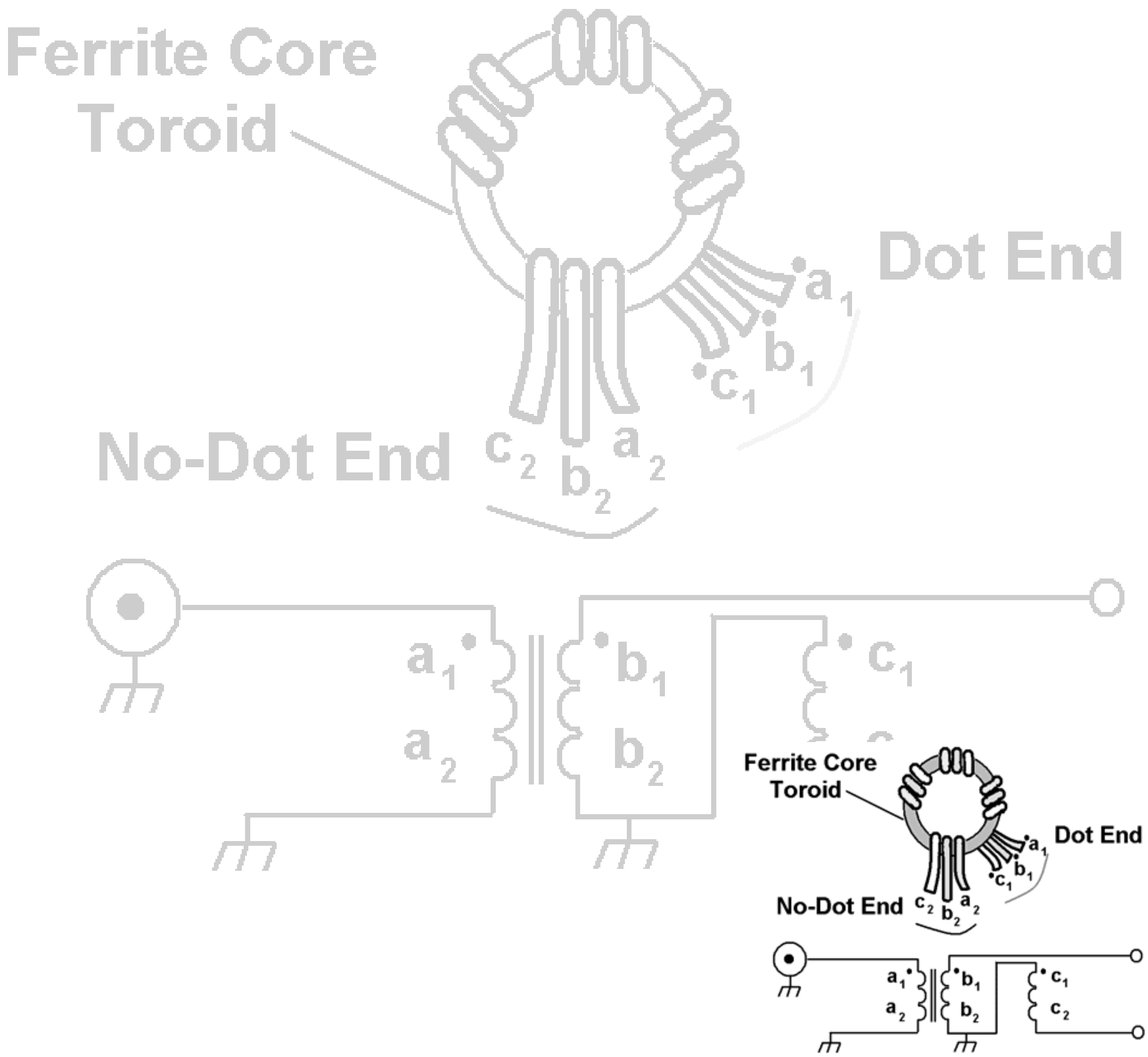
Interesting information.

ww2.netnitco.net/users/wt9w/Toroids.html

Winding toroids.

Appendix A

Selected Terms & End Notes



Selected Terms:

aka – "also known as"

antenna tuner – A device that matches impedance between your transceiver and antenna; aka "transmatch," or simply "tuner"

capacitor – See "variable capacitor"

dielectric material – This is the insulating material separating the conductors in our transmission line.

impedance – Impedance may be thought of as the rate at which energy is transferred from one part of a system to another part of the system. You may also think of it as the resistance to alternating current. Impedance = Z = (V / I). Another formula expressing impedance is: $Z = R \pm jX$ (where Z = impedance; X = reactance).

inductor – See "variable inductor"

reactance – This is the resistance to alternating current. It may be thought of as energy caught up in a "loop" because it is energy that performs no useful work. Reactive energy is very real (NOT imaginary) but it does not help our RF signal to radiate into the atmosphere. Capacitive reactance (X_C) is caught up in an electrostatic field. Inductive reactance (X_L) is caught up in an inductive (magnetic) field. As the AC current alternates the reactive energy is passed from one field to another, and back again.

RF – "Radio Frequcncy" – in this manual this nearly always refers to electromagnetic energy being radiated from our antenna or carried between our antenna and transceiver.

roller inductor – This is a coil of wire that has a piece of metal connected to ground that moves along the coil (or sometimes the coil moves along this piece of metal), the position of which is user-selectable by a slide or crank. Many prefer this style because any value of inductance may be selected (within the coil's designed range of inductance).

tapped coil – This is a coil of wire with a number of additional wires soldered to its turns at various points. These wires are user-selectable by a switch of some type. Once the switch is placed in a given position the wire selected shorts the inductor to ground, which effectively alters the number of turns of the coil in the circuit. This alters the amount of inductance. Only inductance values corresponding to these tapped points may be selected.

transmatch – A device that matches impedance between your transceiver and antenna; aka “antenna tuner,” or simply “tuner”

transmission line – This is the electrical conductor that carries the electromagnetic signal (RF) between your transceiver and antenna. There are two basic types: coax and balanced line.

transceiver – A radio that both transmits and receives: trans-ceiver.

tuner – A device that matches impedance between your transceiver and antenna; aka “transmatch,” or “antenna tuner”

variable capacitor – These are metal plates built in two sets that mesh together without touching. One set is allowed to rotate and the other set is fixed in position. When they are completely meshed together the capacitance value is at maximum. The gap between the pieces of metal has a great impact upon the maximum amount of energy they can handle without being damaged.

variable inductor – These are coils of metal, almost always wire. Spacing between the turns of wire (called “turns per inch”) and the diameter of the wire affects the maximum amount of energy they can handle without being damaged. Fewer turns results in lower inductance, and as the number of turns increases so does the inductance of the coil. There are two primary types: “tapped coil” and “roller inductor.” Refer to those terms for a description of each.

Reference Material:

"The ARRL Handbook, for Radio Communications 2003" 80th Edition,
American Radio Relay League (ARRL), www.arrl.org, ISBN 0-87259-192-1
"The ARRL Antenna Book" 19th Edition,
American Radio Relay League (ARRL), www.arrl.org, ISBN 0-87259-504-7
"Discover Physics"
Benjamin Crowell, Ph.D.
Light and Matter, www.lightandmatter.com, ISBN 0-9704670-8-7
"Heil Ham Radio Handbook"
Bob Heil, K9EID, www.heilsound.com, Melco Publishing
"Practical Antenna Handbook" 4th Edition,
Joseph Carr, TAB Electronics, ISBN 0-07-137435-3
"Reflections II, Transmission Lines and Antennas"
M. Walter Maxwell, W2DU,
Worldradio Books, www.wr6wr.com, ISBN 0-9705206-0-3
"Troubleshooting Antennas and Feedlines"
Ralph Tyrrell, W1TF,
MFJ Publishing, www.mfjenterprises.com
"Understanding, Building, and Using Baluns and Ununs"
Jerry Sevick, Ph.D., W2FMI
CQ Communications, Inc., ISBN 0-943016-24-X
"Wirebook IV" The Wireman, Inc., www.thewireman.com, Press Jones, N8UG

End Notes:

Full publishing information for each cited reference is found above. Individual end notes are formatted in the following manner: End note number; Subject statement; Partial title of the reference(s) listed above, with Chapter and/or Page number(s).

[1] Soldering Antenna Wires: “Heil Ham Radio Handbook” Pg. 48; “Wirebook IV” Pg. 7.9

[2] Wavelength of Specific Frequency: “The ARRL Antenna Book” 23-1

[3] Ground Radials: “Reflections II” Pgs. 5-6, 5-7, NOT Resonant; 0.4 WL optimal length.

[4] Optimal Height of Vertical Antenna: “Reflections II” Pg. 20-15, Maximum horizontal radiation from a vertical antenna occurs at 0.64 WL height.

[5] Coax Choke and Baluns: “The ARRL Antenna Book” Pgs. 6-9, 26-21, 26-22 to 26-25; “Practical Antenna Handbook” Pgs. 471-477; “Reflections II” Chapter 21; “Wireman IV” Pgs. 9.1 - 9.13

[6] Windom Antenna: “The ARRL Antenna Book” Pgs. 7-5, 9-5; “Practical Antenna Handbook” Pgs. 209-210

[7] Introduction to Transmatch Theory: “The ARRL Handbook” Chapter 6, 22.55 – 22.65; “Reflections II” Chapters 3-4, 7-9, 13-14, 16-17, 24

[8] Windom Antenna: “The ARRL Antenna Book” Pg. 7-5, 9-5; “Practical Antenna Handbook” Pgs. 209-210

[9] My Antenna Tuner Really Does Tune My Antenna: “Reflections II” Chapter 7, Pg. 13-3

[10] Transistor-Based Transceivers, DO Lose Reflected Power: “Reflections II” Pg. 13-4

[11] Mutual Coupling: “The ARRL Antenna Book” Pg. 8-12

[12] Height vs. Feedpoint Impedance of Dipole Antenna: “Practical Antenna Handbook” Pg. 145; “The ARRL Antenna Book” Pgs. 2-2, 3-2 Fig. 1

[13] Height vs. Feedpoint Impedance of Vertical Antenna: “The ARRL Antenna Book” Pg. 3-2 Fig. 1; “Practical Antenna Handbook” Pg. 184-185

[14] Nominal Feedpoint Impedances: “Practical Antenna Handbook” 141-156, 173-189; “The ARRL Antenna Book” 6-1 through 6-10, 26-8

[15] Reflected Wave: Reflected Energy DOES Re-Reflect Toward Antenna: “Reflections II” Pg. 1-9

[16] SWR up to 3:1, 4:1 and often 5:1 can NOT be heard on opposite end: “Reflections II” Pg. 1-4

[17] Ammeter Inline with Transmatch: “Reflections II” Pg. 7-10, Sec. 7.4, Max. ammeter output = max. C + min. L

[18] “American Heritage Dictionary” – ‘resonance’: The increase in amplitude of oscillation of an electric or mechanical system exposed to a periodic force whose frequency is equal to or very close to the natural frequency of the system.

[19] SWR – Remains on Line After Conjugate Match & At 4:1 SWR Additional Line Loss is Roughly Equal to Line Attenuation: “Reflections II” Pg. 6-16

[20] How Waves Travel Along Transmission Line: “Reflections II” Pgs. 3-2 through 3-8

[21] Incident means ‘original’: "Discover Physics" Pg. 30

[22] Low SWR for the Wrong Reasons: “Reflections II” Chapter 5

[23] SWR is a Two Variable Function: “Reflections II” Pgs. 1-3, Sec. 1.2

[24] Transmission Line Attenuation: “The ARRL Antenna Book” 24-1; “The ARRL Handbook” 19.5, 19.6

[25] Re-reflected Power: “Reflections II” Pg. 5-11, Sec. 5-7

[26] Additional Line Loss Due to SWR: “The ARRL Antenna Book” Book 24-9; “Reflections II” 4-9, 6-6, 6-8; “Reflections II” Except for line attenuation all power is radiated by the antenna: 5-11, 6-3, 6-5, 17-2, 17-4

[27] “Reflections II”: Ch. 20, multi-band antennas; 20-1, SWR increases much more quickly in trapped dipole vs. basic dipole; 20-8, balanced-fed random length dipole (min. 1/4 WL at lowest freq.), with tuner

[28] Baluns: “Reflections II” 20-11, Reduce RF in the Shack & Eliminate RF Flowing on Outside of Coax Shielding; Chapter 21

[29] Skin Effect: “The ARRL Handbook” 10.12

[30] RF Interference (RFI, TVI): “The ARRL Handbook” Chapter 28, 30.30; “Practical Antenna Handbook” 573

[31] Coax Choke Chart: “The ARRL Antenna Book” 26-21

[32] Current Balun vs. Voltage Balun: “The ARRL Antenna Book” Pg. 26-25; “Understanding, Building, and Using Baluns and Ununs” Pg. 35; “Wireman IV” Pg. 9.5

[33] W2DU Balun: “The ARRL Antenna Book” 26-22; “Reflections II” 21-6; “Understanding… Baluns and Ununs” 36, 41, 54, 56, 86-87, 113; “Wireman IV” 9.3, 9.7

[34] Ferrite Core Balun, Saturation and Coax Choke: “The ARRL Antenna Book” Pgs. 6-9, 26-21; “The ARRL Handbook” 6.49; “Reflections II” 21-10; “Understanding… Baluns and Ununs” 29, 33, 34, 41, 43, 47, 111-113

[35] 180-Degree Phase Shift Coax Balun for Beam Antenna: “The ARRL Antenna Book” Pgs. 18-6, 26-24; “The ARRL Handbook” Pg. 19.15; “Practical Antenna Handbook” Pgs. 465-466

[36] "...impedance contains reactance when the voltage and current are not in phase.": “Reflections II” Pg. 9-13

[37] Balanced and Unbalanced Transmission Line: “Practical Antenna Handbook” Pg. 208

[38] Coax as Balanced Line (pg. 48): “The ARRL Antenna Book” Pg. 24-21; “Wirebook IV” Pgs. 6.5-6.6

[39] Nominal Characteristics of Common Transmission Lines (pg. 49): “The ARRL Handbook” Pg. 19.2; “Wirebook IV” Pg. 2.27

[40] Decibel (dB) Power Loss Comparison (pg. 49): “The ARRL Antenna Book” Pg. 2-9; “The ARRL Handbook” Pg. 4.17; “Heil Handbook” Pg. 77

[41] Power Reduction of 1 dB "just barely" Heard by Receiving Station (pg. 49): “Reflections II” Pg. 6-16

[42] Soldering Coax Connections (pg. 49): “Wirebook IV” Pgs. 3.5 – 3.23

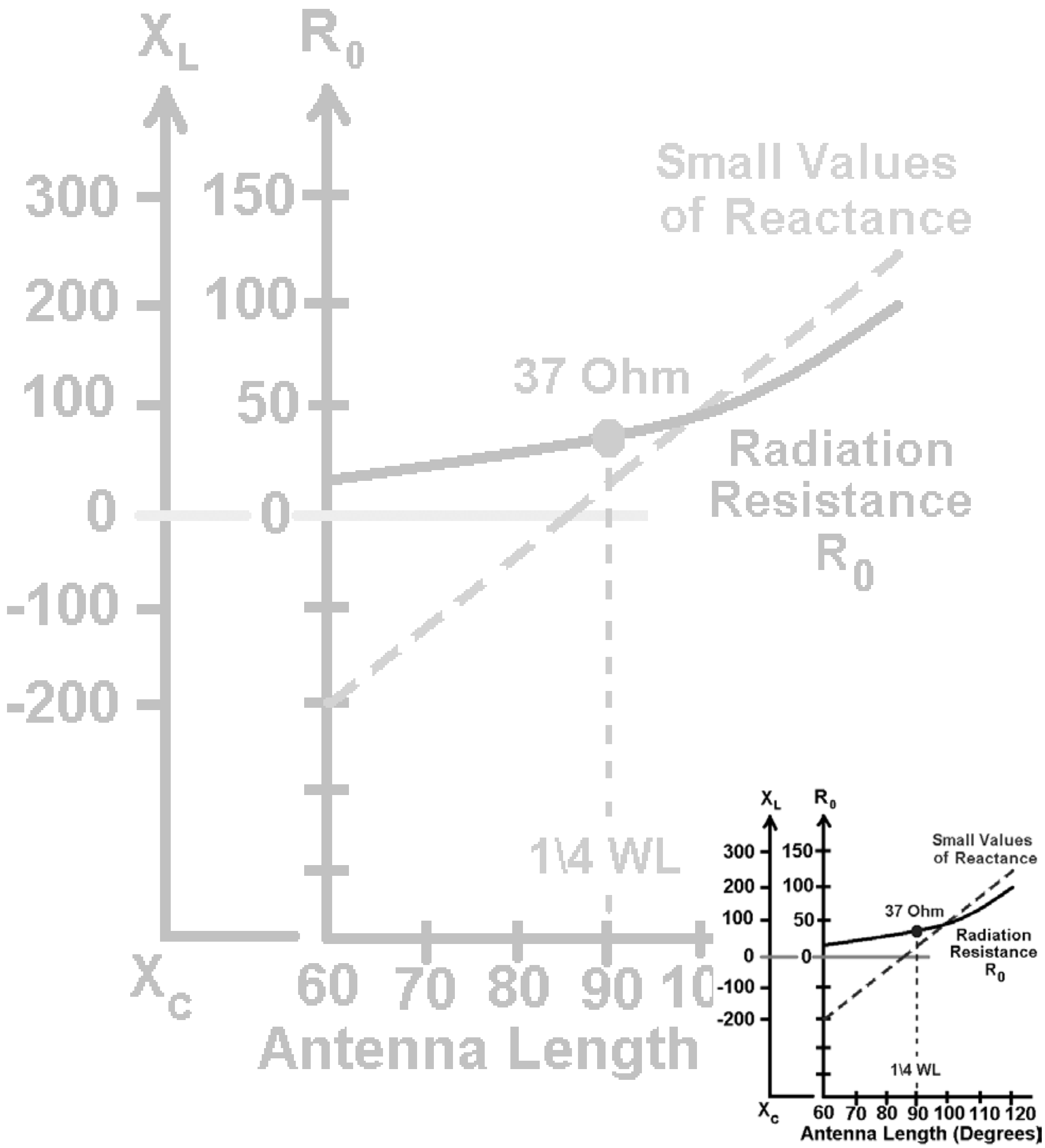
[43] Soldering Tricks (pg. 50): “Heil Handbook” Pgs. 117-120

[44] You may wish to read a variety of online manuals: http://www.mfjenterprises.com/manuals.php

[45] “Troubleshooting Antennas and Feedlines”: 5-2

Appendix B

Blank Data Sheets & Charts



Manual Transmatch Log

Transceiver:____
Antenna information:
Name:____________ Type:______________ Height:_____________
Feedline:__________ Feedpoint:__________ Balun/Choke:_________

Transceiver		TX	Tuned Meter Readings			C-L-C Tuner Setting*			
Freq.	Mode	Power	SWR	Forw	Refl	C-TX	Induct	C-Ant	Notes

* If L-C-L type tuner, use “Inductor_Transceiver / Capacitor / Inductor_Antenna.”

Antenna Data Sheet

Name of Antenna:____ Date:________

□ Resonant Frequency:_____________ □ Height @ Feedpoint:______________

□ "Strange" Antenna □ Normal Antenna

□ Dipole □ Vertical □ Loop □ Other:______________________

□ **Yes** □ **No Are both transmission line wires connected the antenna?**

□ Coax Choke: □ Type of Coax:____________ □ Diameter of Coax:_________

□ Number of Turns:_________ □ Diameter of Coil:__________

□ Bal-un (Ratio)_____ □ Bal-bal (Ratio)_____ □ Un-un (Ratio)_____

□ Home Made

□ Size Wire:________________ □ Number Turns:_________

□ Number of Wires:__________ □ Twisted □ Side-by-Side

□ Ferrite Core □ Company:__________ □ Type:____________

□ Commercial □ Model:_____________________________

Transmission Line:

□ Published Attenuation (Loss)_________ @ _________ MHz

□ Measured Attenuation (Loss)_________ @ _________ MHz

□ Balanced Line □ 300-Ohm □ 450-Ohm □ 600-Ohm □ Other_______

□ Coax Type (RG-8):_____________

□ Manufacturer:_________________

□ Length:__________ □ Age:______

□ Compass Orientation:________________

Power Comparisons (in decibels (dB))

Description	Forward RF Power (Watts)	Reflected RF Power	(Forward) ÷ (Reflected)	"Log" Function	x10 (ANSWER)
					dB
					dB
					dB
					dB
					dB
					dB
					dB
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					dB
					dB
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					dB
					dB
					dB
					dB
					dB
					dB

___-Meters	_______ to _______ MHz	Plot Curves for (Antenna):	
Resonant Frequency =		**Frequency of Lowest SWR =**	**SWR =**

Frequency in MHz

1.000 4.533 8.067 11.600 15.133 18.667 22.200 25.733 29.266 32.800 36.333 39.866 43.400 46.933 50.466 54.000

2.767 | 6.300 | 9.834 | 13.367 | 16.900 | 20.434 | 23.967 | 27.500 | 31.033 | 34.567 | 38.100 | 41.633 | 45.167 | 48.700 | 52.233

2.767 | 6.300 | 9.834 | 13.367 | 16.900 | 20.434 | 23.967 | 27.500 | 31.033 | 34.567 | 38.100 | 41.633 | 45.167 | 48.700 | 52.233

1.000 4.533 8.067 11.600 15.133 18.667 22.200 25.733 29.266 32.800 36.333 39.866 43.400 46.933 50.466 54.000

Rs =
Xs =

Rp =
Xp =

___-Meters ________ to ________ MHz | Plot Curves for (Antenna):

Resonant Frequency = | **Frequency of Lowest SWR =** **SWR =**

Frequency in MHz

1.000 4.533 8.067 11.600 15.133 18.667 22.200 25.733 29.266 32.800 36.333 39.866 43.400 46.933 50.466 54.000

SWR 2.767 | 6.300 | 9.834 | 13.367 | 16.900 | 20.434 | 23.967 | 27.500 | 31.033 | 34.567 | 38.100 | 41.633 | 45.167 | 48.700 | 52.233

40
39
38
37
36
35
34
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32
31
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28
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1

SWR 2.767 | 6.300 | 9.834 | 13.367 | 16.900 | 20.434 | 23.967 | 27.500 | 31.033 | 34.567 | 38.100 | 41.633 | 45.167 | 48.700 | 52.233

1.000 4.533 8.067 11.600 15.133 18.667 22.200 25.733 29.266 32.800 36.333 39.866 43.400 46.933 50.466 54.000

Rs =
Xs =

Rp =
Xp =

___-Meters ________ to ________ MHz | Plot Curves for (Antenna):

Resonant Frequency = | Frequency of Lowest SWR = | SWR =

Frequency in MHz

SWR 1.000 4.533 8.067 11.600 15.133 18.667 22.200 25.733 29.266 32.800 36.333 39.866 43.400 46.933 50.466 54.000

2.767 6.300 9.834 13.367 16.900 20.434 23.967 27.500 31.033 34.567 38.100 41.633 45.167 48.700 52.233

5.0
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2.0
1.9
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1.5
1.4
1.3
1.2
1.1
1.0

SWR 2.767 6.300 9.834 13.367 16.900 20.434 23.967 27.500 31.033 34.567 38.100 41.633 45.167 48.700 52.233

1.000 4.533 8.067 11.600 15.133 18.667 22.200 25.733 29.266 32.800 36.333 39.866 43.400 46.933 50.466 54.000

Rs =
Xs =

Rp =
Xp =

Table for SWR, Series & Parallel Resistance & Reactance

Use this table to obtain an overview of the antenna's SWR, resistance and reactance

Antenna Description

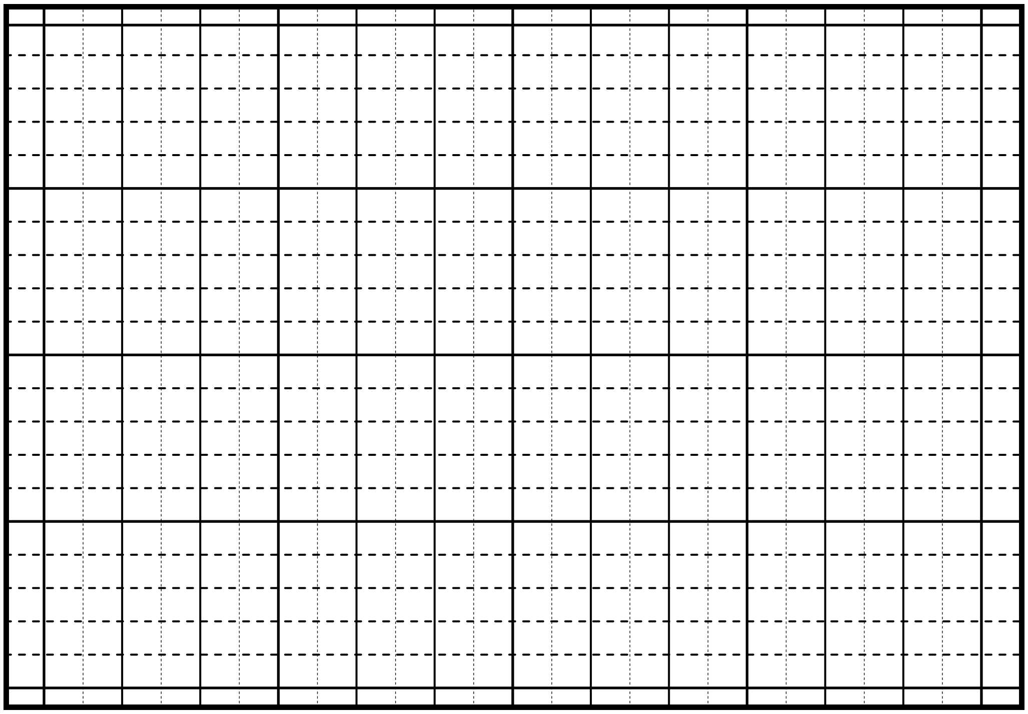
Band	Frequency	SWR	Series Resistance Rs	Series Reactance Xs	Parallel Resistance Rp	Parallel Reactance Xp
160	1.800					
"	2.000					
80	3.500					
"	4.000					
40	7.000					
"	7.300					
30	10.120					
20	14.000					
"	14.350					
17	18.068					
"	18.168					
15	21.000					
"	21.450					
12	24.890					
"	24.990					
10	28.000					
"	28.850					
"	29.700					
6	50.000					
"	52.000					
"	54.000					

SKETCH of ANTENNA:

___-Meters ________ to ________ MHz	Plot Curves for (Antenna):
Resonant Frequency =	**Frequency of Lowest SWR =** **SWR =**

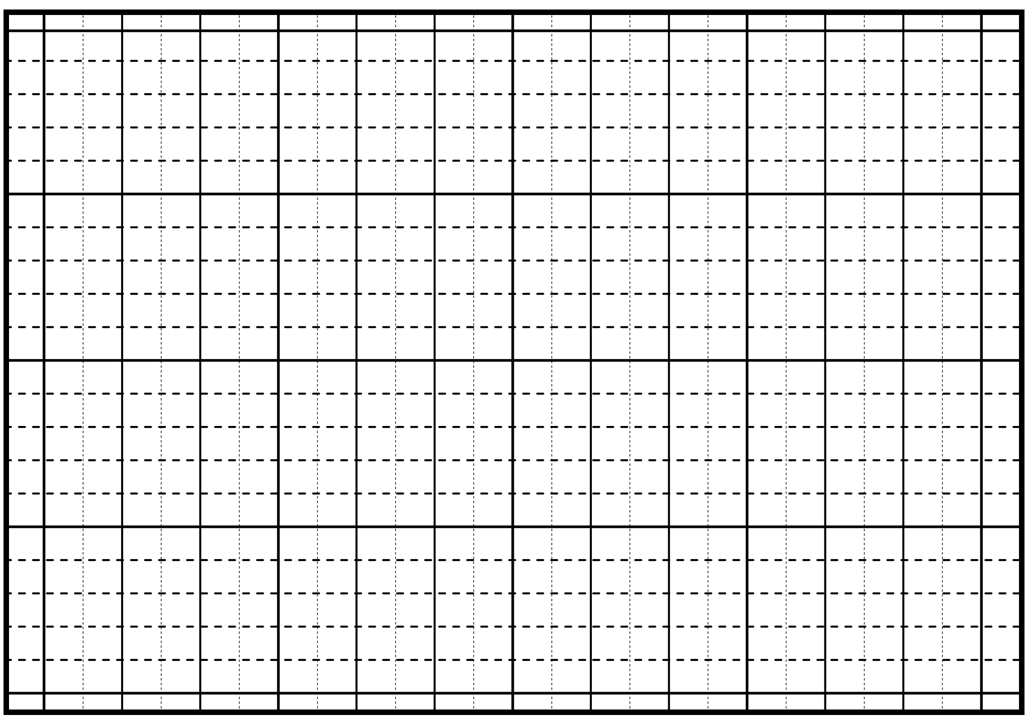
Frequency in MegaHertz (MHz)

SWR



SWR

Ohms

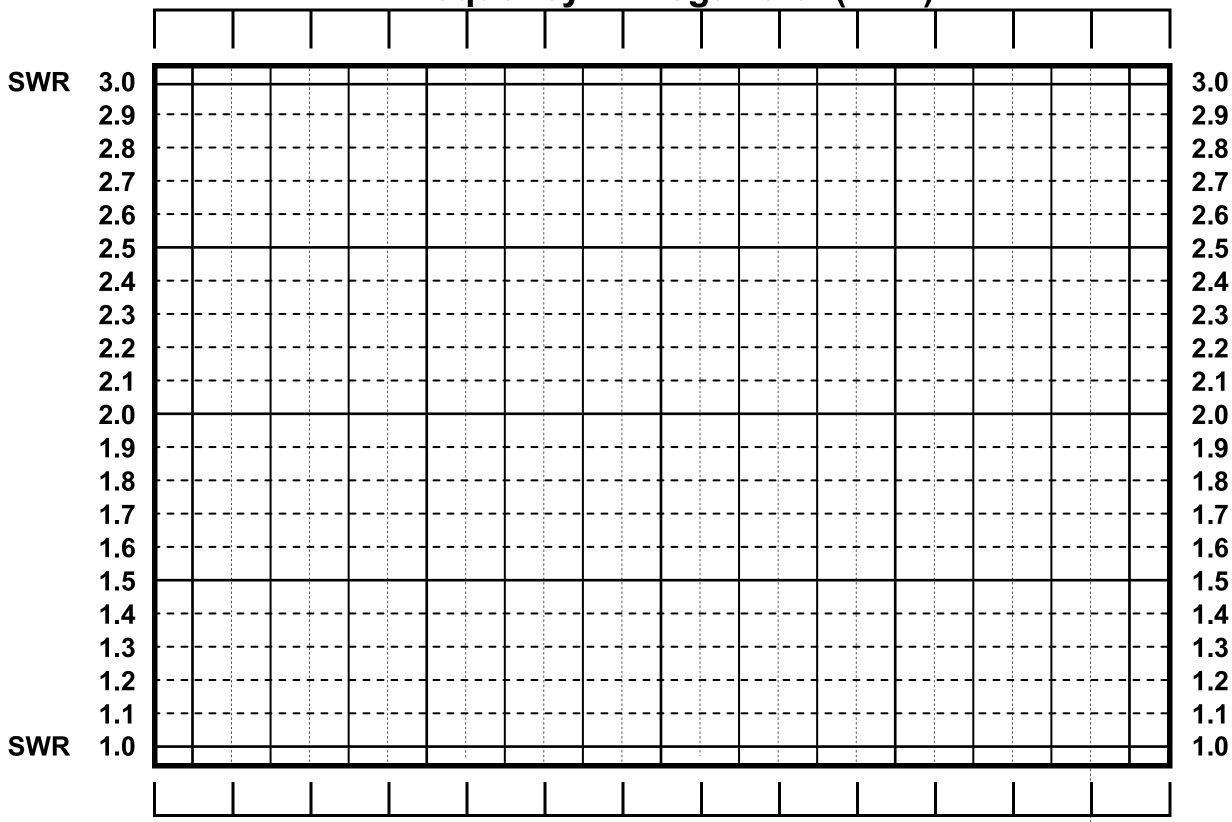


Ohms

Rs =
Xs =

		Plot Curves for (Antenna):
Resonant Frequency =		**Frequency of Lowest SWR =** **SWR =**

Frequency in MegaHertz (MHz)



50.00			**51.00**			**52.00**			**53.00**			**54.00**	☐ **6-M**
28.00	28.142	28.283	**28.425**	28.567	28.708	**28.85**	28.992	29.133	**29.275**	29.417	29.558	**29.70**	☐ **10-M**
24.89			**24.915**			**24.94**			**24.965**			**24.99**	☐ **12-M**
21.00			**21.113**			**21.225**			**21.338**			**21.45**	☐ **15-M**
18.068			**18.093**			**18.118**			**18.143**			**18.168**	☐ **17-M**
14.00			**14.088**			**14.175**			**14.263**			**14.35**	☐ **20-M**
10.10			**10.113**			**10.125**			**10.138**			**10.15**	☐ **30-M**
7.00			**7.075**			**7.15**			**7.225**			**7.30**	☐ **40-M**
3.50			**3.625**			**3.75**			**3.875**			**4.00**	☐ **80-M**
1.80			**1.85**			**1.90**			**1.95**			**2.00**	☐ **160-M**

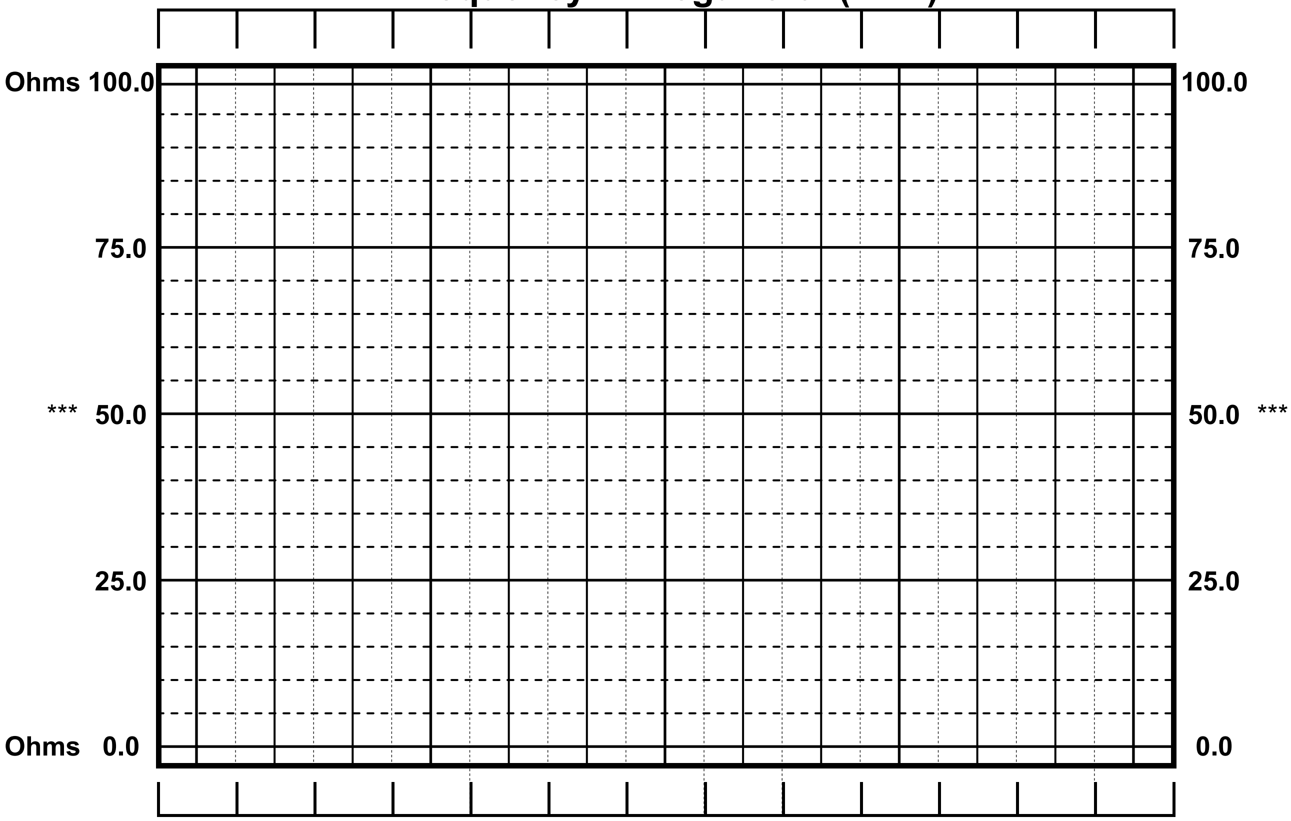
Rs =
Xs =

Check the amateur band for which the above SWR plot applies. This form is supplied to make field notes easier. You may wish to note reactance values beside the plot-points.

NOTES:

		Plot Curves for (Antenna):	
Resonant Frequency =		**Frequency of Lowest SWR =**	**SWR =**

Frequency in MegaHertz (MHz)



50.00			**51.00**			**52.00**			**53.00**			**54.00**	☐	**6-M**
28.00	28.142	28.283	**28.425**	28.567	28.708	**28.85**	28.992	29.133	**29.275**	29.417	29.558	**29.70**	☐	**10-M**
24.89			**24.915**			**24.94**			**24.965**			**24.99**	☐	**12-M**
21.00			**21.113**			**21.225**			**21.338**			**21.45**	☐	**15-M**
18.068			**18.093**			**18.118**			**18.143**			**18.168**	☐	**17-M**
14.00			**14.088**			**14.175**			**14.263**			**14.35**	☐	**20-M**
10.10			**10.113**			**10.125**			**10.138**			**10.15**	☐	**30-M**
7.00			**7.075**			**7.15**			**7.225**			**7.30**	☐	**40-M**
3.50			**3.625**			**3.75**			**3.875**			**4.00**	☐	**80-M**
1.80			**1.85**			**1.90**			**1.95**			**2.00**	☐	**160-M**

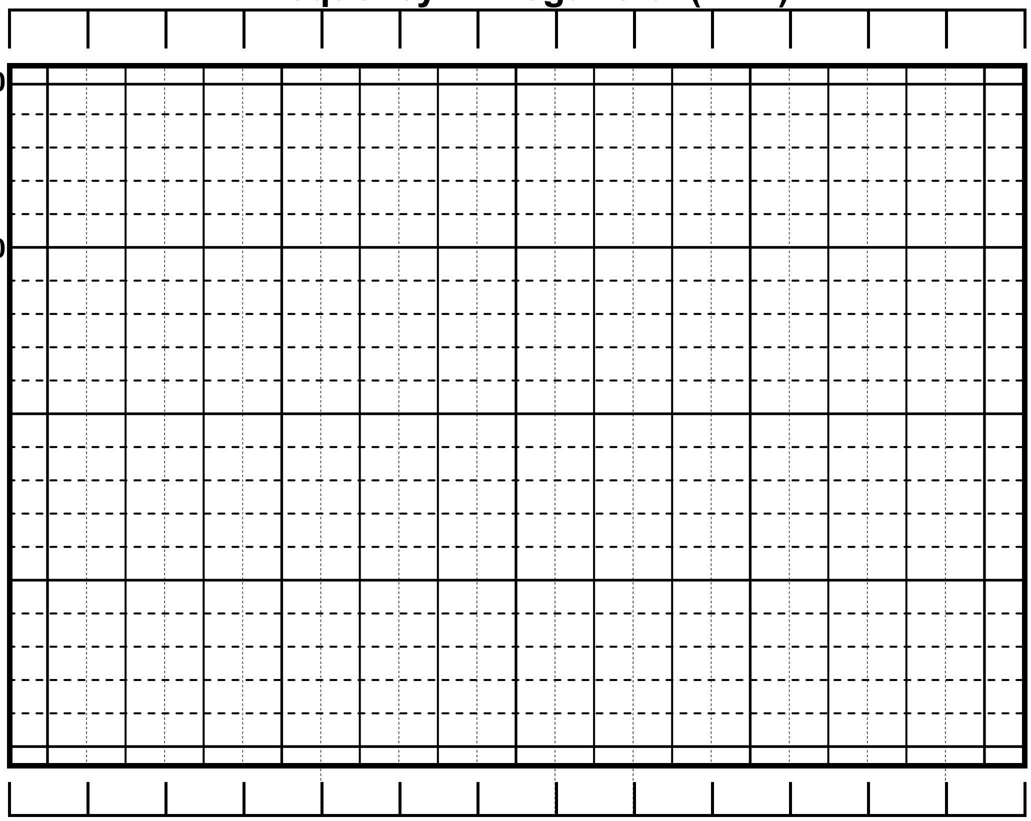
Rs =
Xs =

Check the amateur band for which the above SWR plot applies. This form is supplied to make field notes easier. You may wish to note reactance values beside the plot-points.

NOTES:

		Plot Curves for (Antenna):	
Resonant Frequency =		**Frequency of Lowest SWR =**	**SWR =**

Frequency in MegaHertz (MHz)



50.00			**51.00**			**52.00**			**53.00**			**54.00**	☐	**6-M**
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24.89			**24.915**			**24.94**			**24.965**			**24.99**	☐	**12-M**
21.00			**21.113**			**21.225**			**21.338**			**21.45**	☐	**15-M**
18.068			**18.093**			**18.118**			**18.143**			**18.168**	☐	**17-M**
14.00			**14.088**			**14.175**			**14.263**			**14.35**	☐	**20-M**
10.10			**10.113**			**10.125**			**10.138**			**10.15**	☐	**30-M**
7.00			**7.075**			**7.15**			**7.225**			**7.30**	☐	**40-M**
3.50			**3.625**			**3.75**			**3.875**			**4.00**	☐	**80-M**
1.80			**1.85**			**1.90**			**1.95**			**2.00**	☐	**160-M**

Rs =

Xs =

Check the amateur band for which the above SWR plot applies. This form is supplied to make field notes easier. You may wish to note reactance values beside the plot-points.

NOTES:

		Plot Curves for (Antenna):
Resonant Frequency =		**Frequency of Lowest SWR =** **SWR =**

Frequency in MegaHertz (MHz)

Ohms

*** ***

Ohms

50.00			**51.00**			**52.00**			**53.00**			**54.00**	**6-M**
28.00	28.142	28.283	**28.425**	28.567	28.708	**28.85**	28.992	29.133	**29.275**	29.417	29.558	**29.70**	**10-M**
24.89			**24.915**			**24.94**			**24.965**			**24.99**	**12-M**
21.00			**21.113**			**21.225**			**21.338**			**21.45**	**15-M**
18.068			**18.093**			**18.118**			**18.143**			**18.168**	**17-M**
14.00			**14.088**			**14.175**			**14.263**			**14.35**	**20-M**
10.10			**10.113**			**10.125**			**10.138**			**10.15**	**30-M**
7.00			**7.075**			**7.15**			**7.225**			**7.30**	**40-M**
3.50			**3.625**			**3.75**			**3.875**			**4.00**	**80-M**
1.80			**1.85**			**1.90**			**1.95**			**2.00**	**160-M**

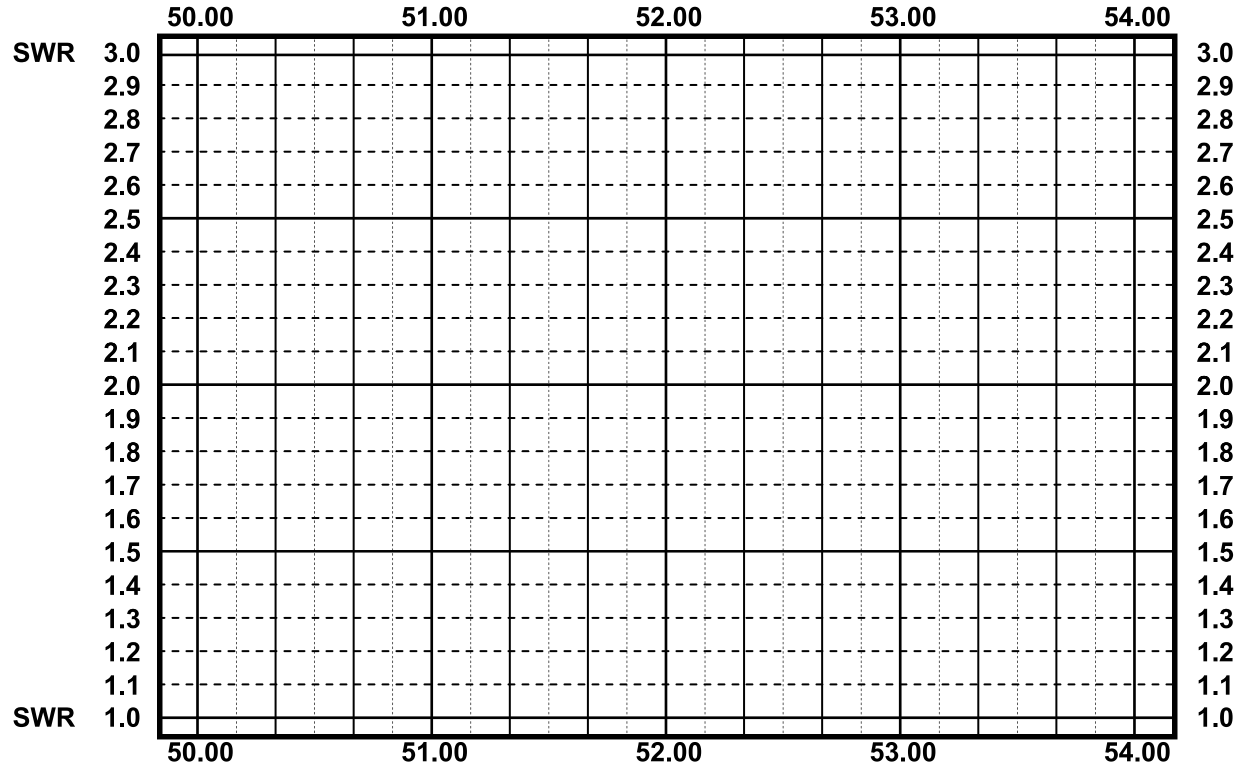
Rs =
Xs =

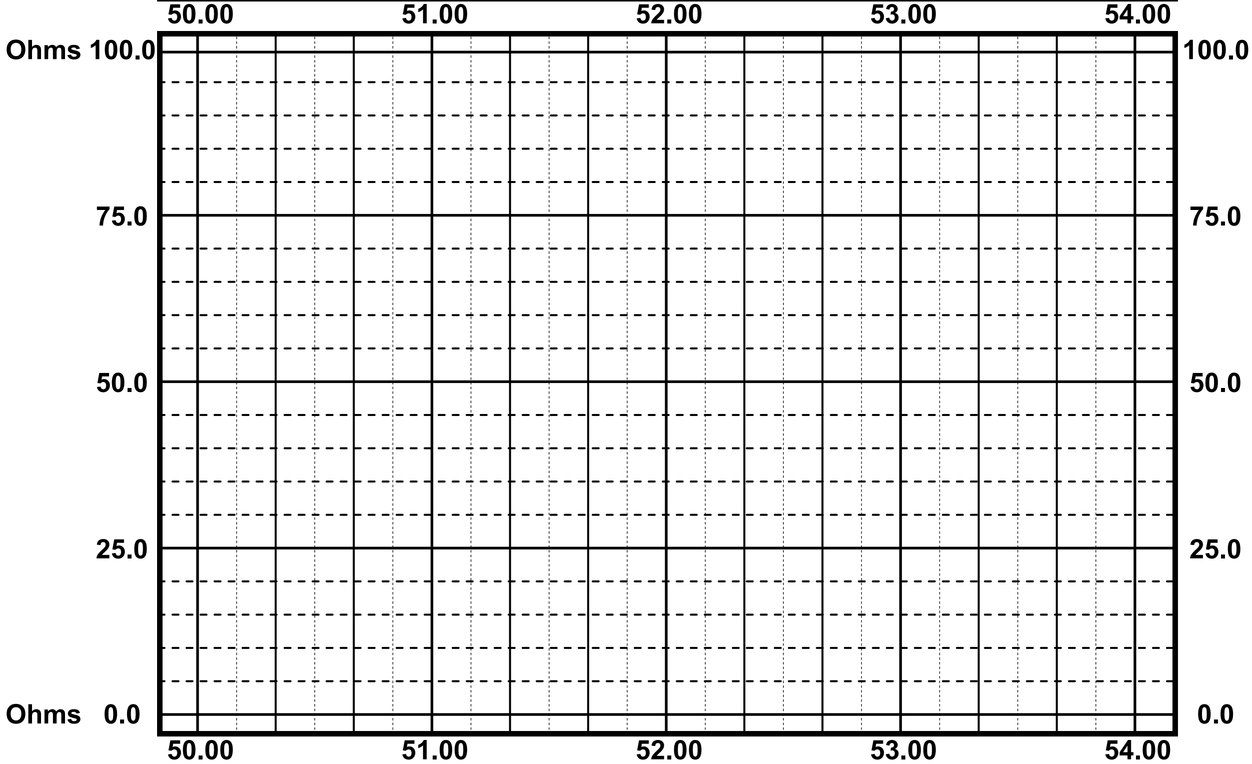
Check the amateur band for which the above SWR plot applies. This form is supplied to make field notes easier. You may wish to note reactance values beside the plot-points.

NOTES:

6-Meters	50.00 to 54.00 MHz	Plot Curves for (Antenna):	
Resonant Frequency =		Frequency of Lowest SWR =	SWR =

Frequency in MegaHertz (MHz)

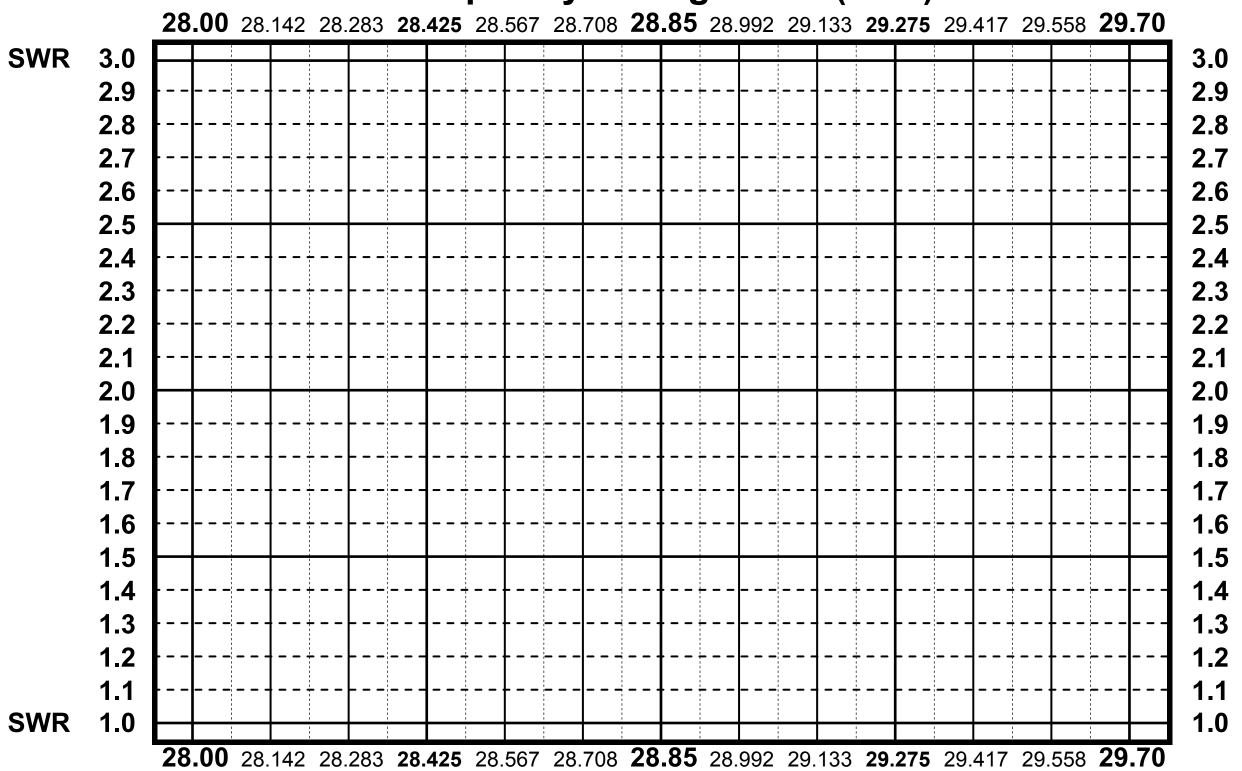


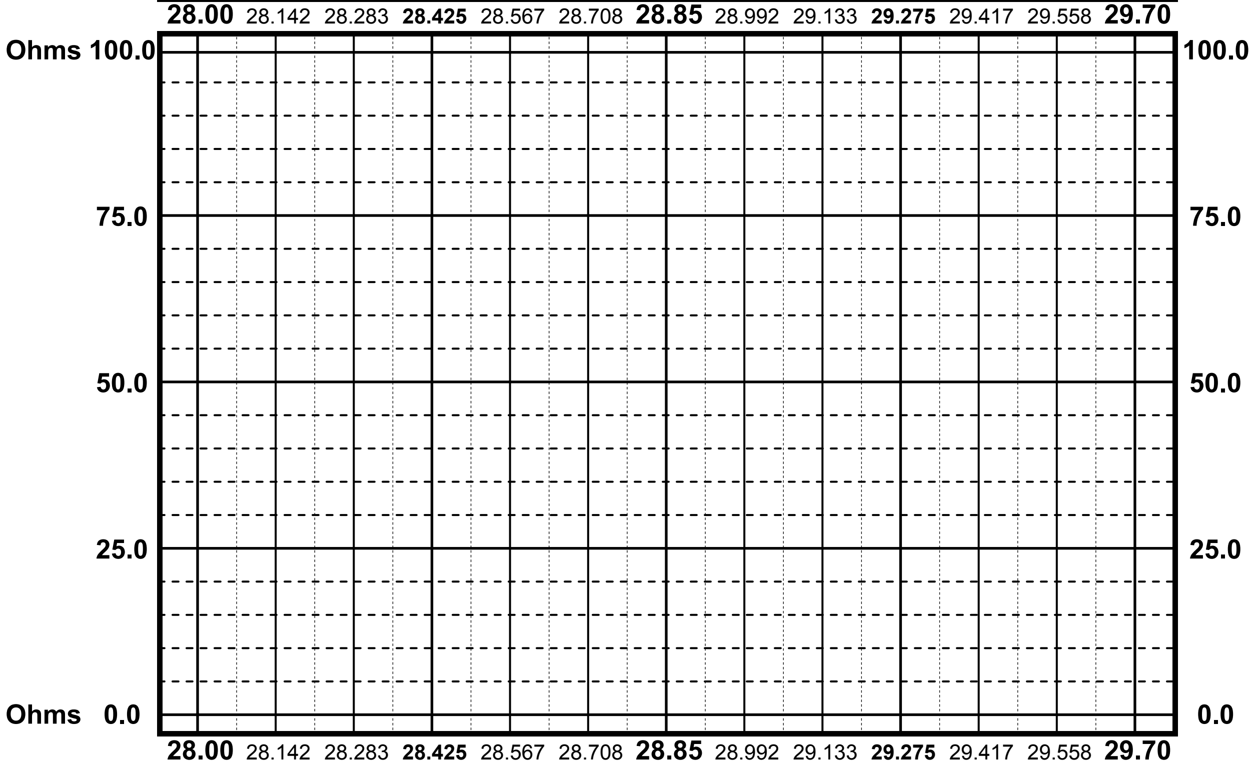


Rs =
Xs =

10-Meters	28.00 to 29.70 MHz	Plot Curves for (Antenna):	
Resonant Frequency =		Frequency of Lowest SWR =	SWR =

Frequency in MegaHertz (MHz)

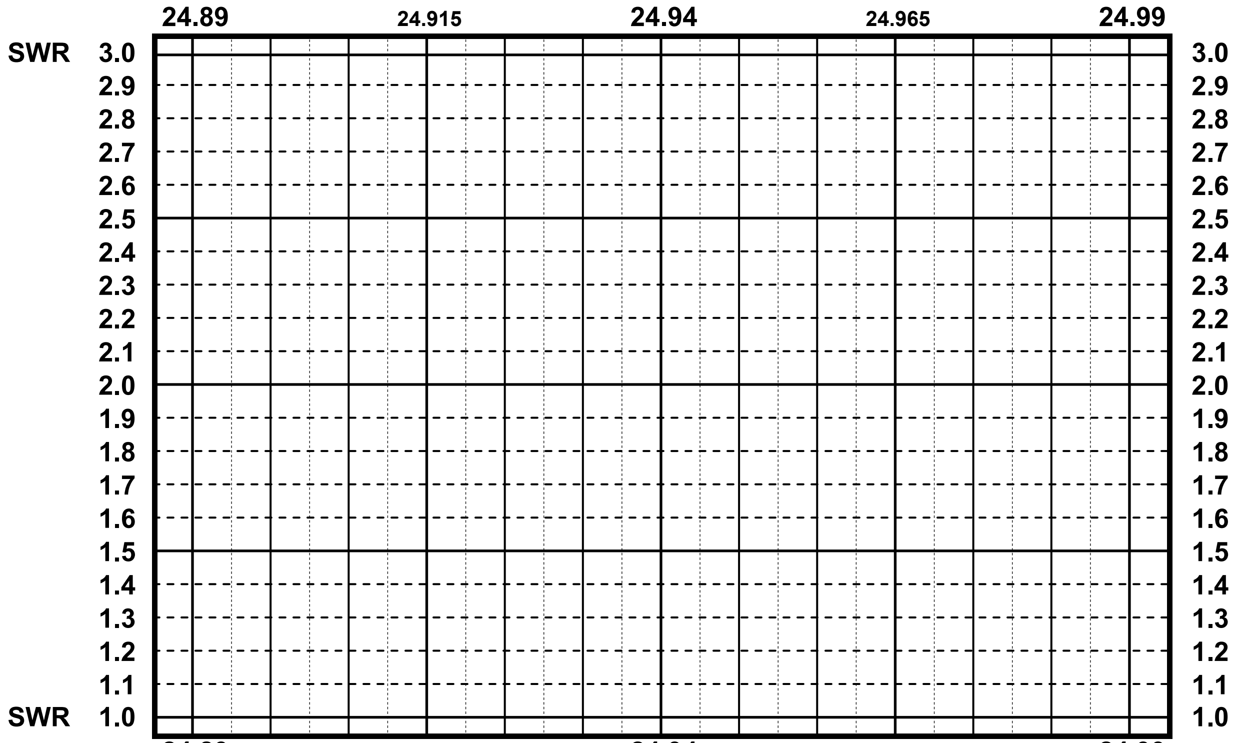


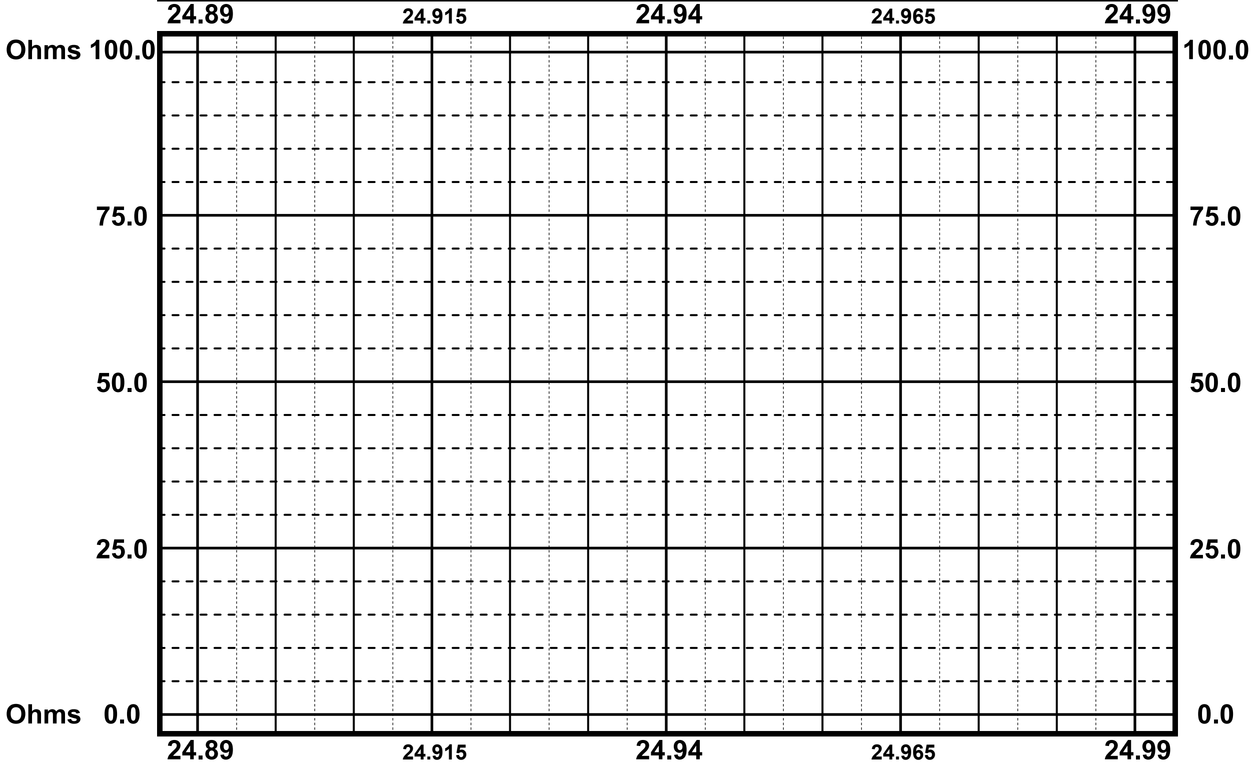


Rs =
Xs =

12-Meters	24.89 to 24.99 MHz	Plot Curves for (Antenna):	
Resonant Frequency =		Frequency of Lowest SWR =	SWR =

Frequency in MegaHertz (MHz)

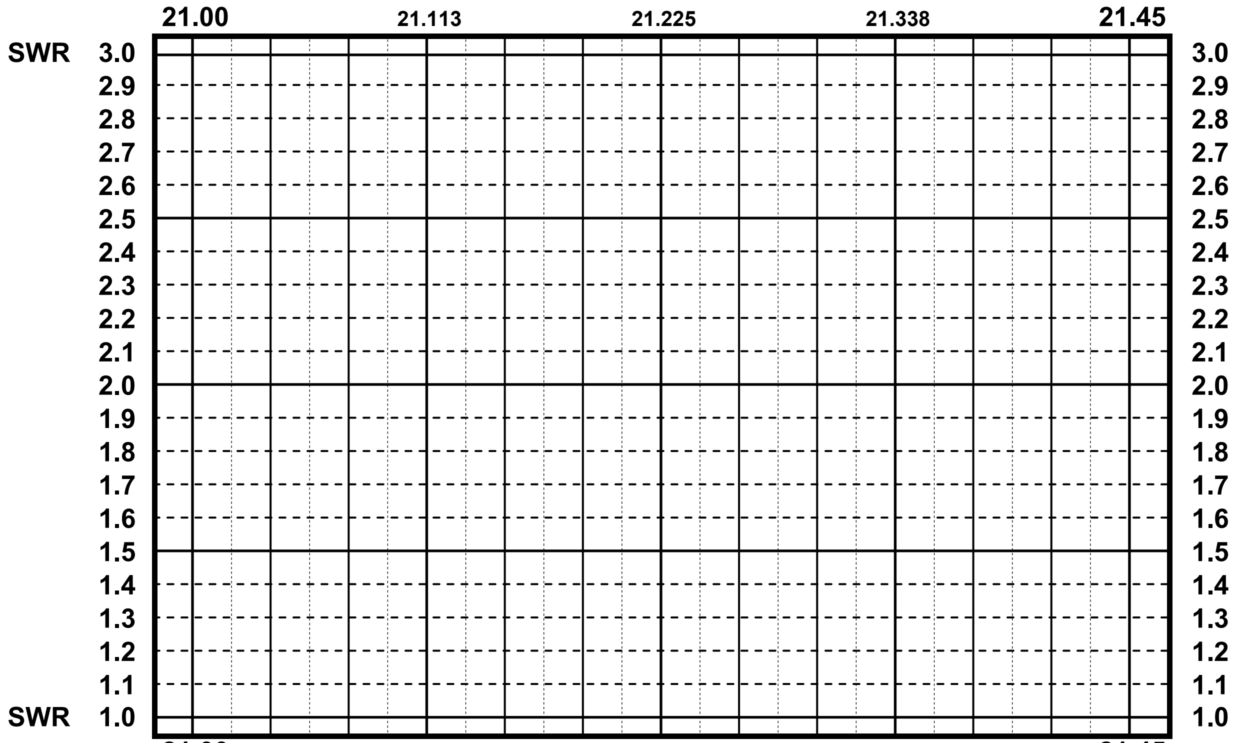


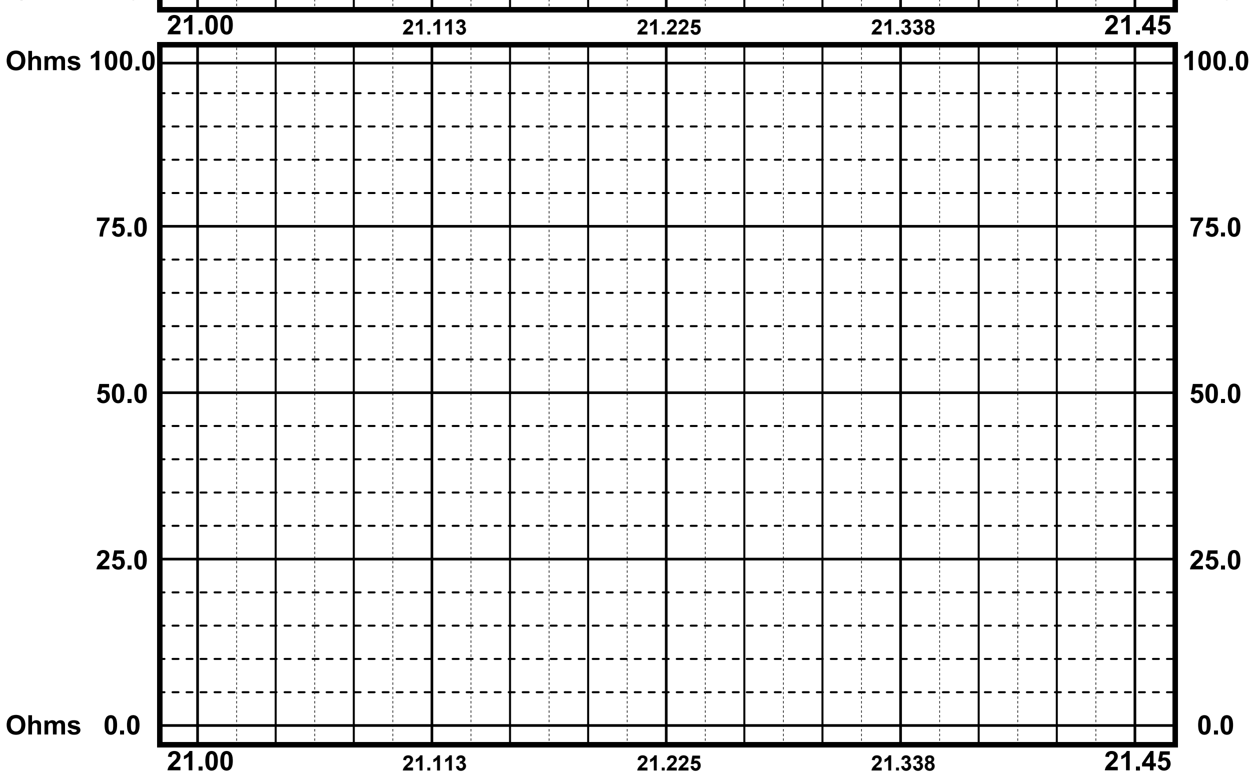


Rs =
Xs =

15-Meters	21.00 to 21.45 MHz	Plot Curves for (Antenna):	
Resonant Frequency =		**Frequency of Lowest SWR =**	**SWR =**

Frequency in MegaHertz (MHz)





Rs =
Xs =

17-Meters	18.068 to 18.168 MHz	Plot Curves for (Antenna):	
Resonant Frequency =		**Frequency of Lowest SWR =**	**SWR =**

Frequency in MegaHertz (MHz)

18.068 18.093 18.118 18.143 18.168

SWR 3.0 | **3.0**
2.9 | **2.9**
2.8 | **2.8**
2.7 | **2.7**
2.6 | **2.6**
2.5 | **2.5**
2.4 | **2.4**
2.3 | **2.3**
2.2 | **2.2**
2.1 | **2.1**
2.0 | **2.0**
1.9 | **1.9**
1.8 | **1.8**
1.7 | **1.7**
1.6 | **1.6**
1.5 | **1.5**
1.4 | **1.4**
1.3 | **1.3**
1.2 | **1.2**
1.1 | **1.1**
SWR 1.0 | **1.0**

18.068 18.093 18.118 18.143 18.168

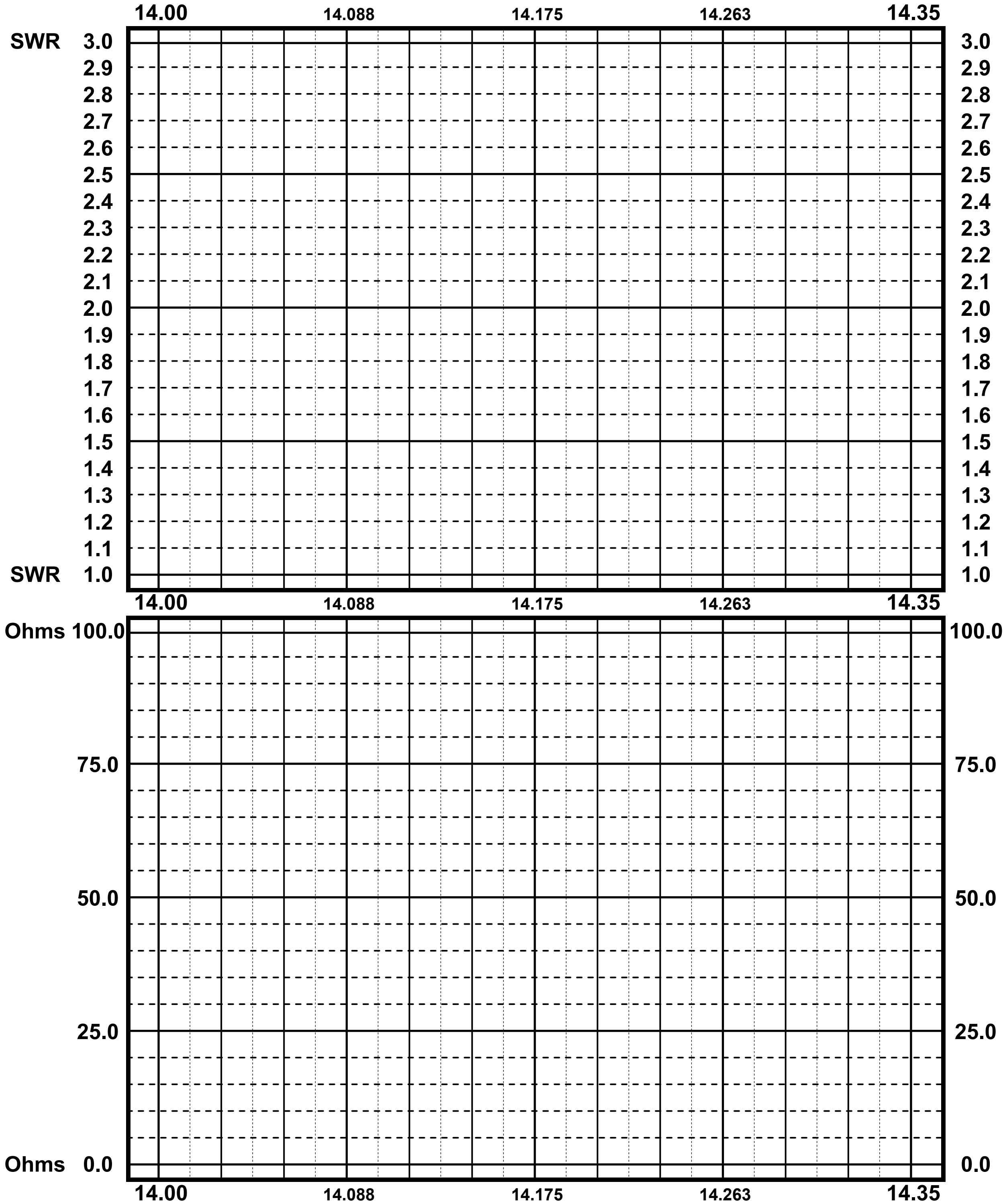
Ohms 100.0 | **100.0**
75.0 | **75.0**
50.0 | **50.0**
25.0 | **25.0**
Ohms 0.0 | **0.0**

18.068 18.093 18.118 18.143 18.168

Rs =
Xs =

20-Meters	14.00 to 14.35 MHz	Plot Curves for (Antenna):	
Resonant Frequency =		Frequency of Lowest SWR =	SWR =

Frequency in MegaHertz (MHz)



Rs =
Xs =

30-Meters	10.10 to 10.15 MHz	Plot Curves for (Antenna):	
Resonant Frequency =		**Frequency of Lowest SWR =**	**SWR =**

Frequency in MegaHertz (MHz)

10.10 **10.113** **10.125** **10.138** **10.15**

SWR 3.0 **2.9** **2.8** **2.7** **2.6** **2.5** **2.4** **2.3** **2.2** **2.1** **2.0** **1.9** **1.8** **1.7** **1.6** **1.5** **1.4** **1.3** **1.2** **1.1** **SWR 1.0**

3.0 **2.9** **2.8** **2.7** **2.6** **2.5** **2.4** **2.3** **2.2** **2.1** **2.0** **1.9** **1.8** **1.7** **1.6** **1.5** **1.4** **1.3** **1.2** **1.1** **1.0**

10.10 **10.113** **10.125** **10.138** **10.15**

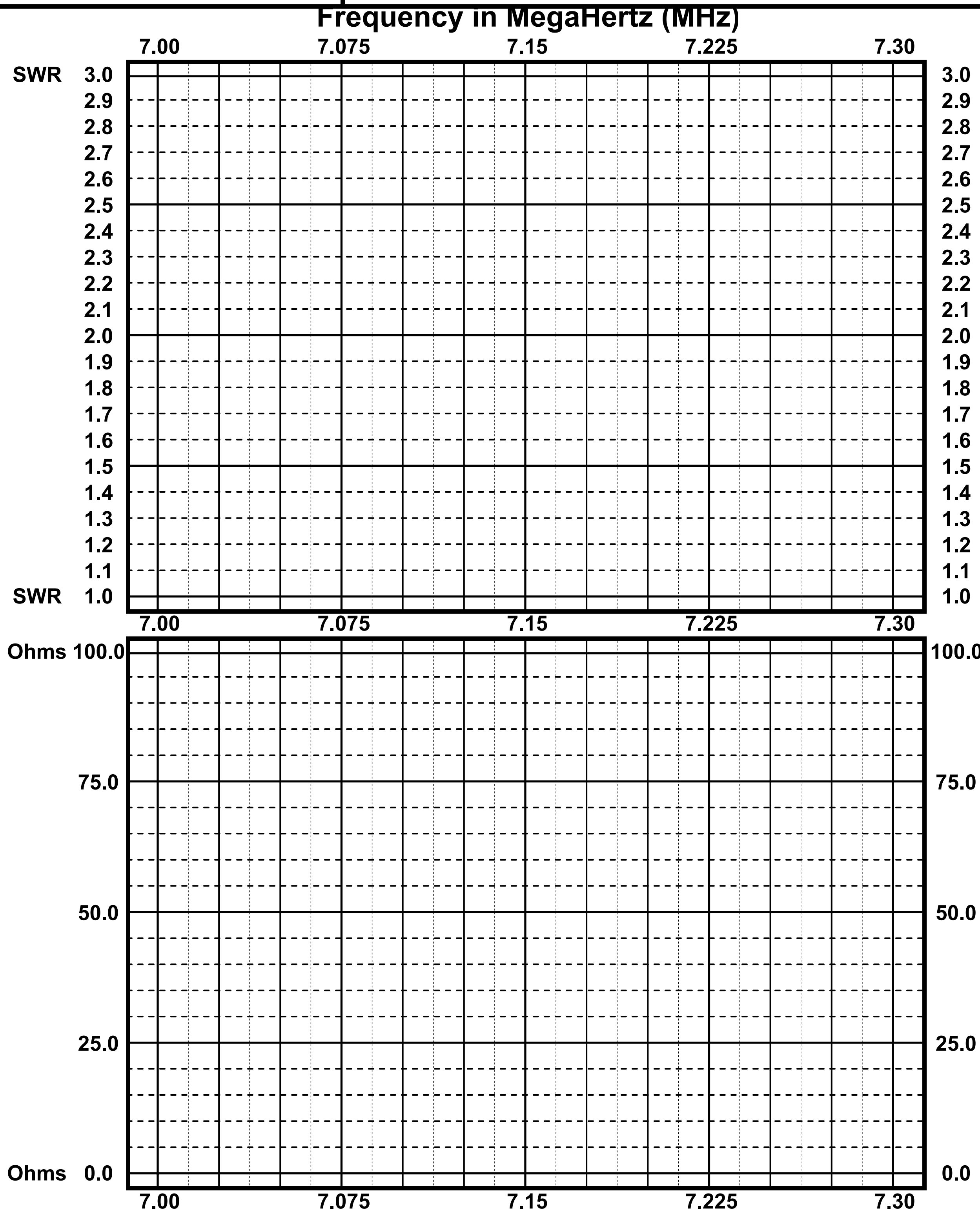
Ohms 100.0 **75.0** **50.0** **25.0** **Ohms 0.0**

100.0 **75.0** **50.0** **25.0** **0.0**

10.10 **10.113** **10.125** **10.138** **10.15**

Rs =
Xs =

40-Meters	7.0 to 7.3 MHz	Plot Curves for (Antenna):	
Resonant Frequency =		**Frequency of Lowest SWR =**	**SWR =**

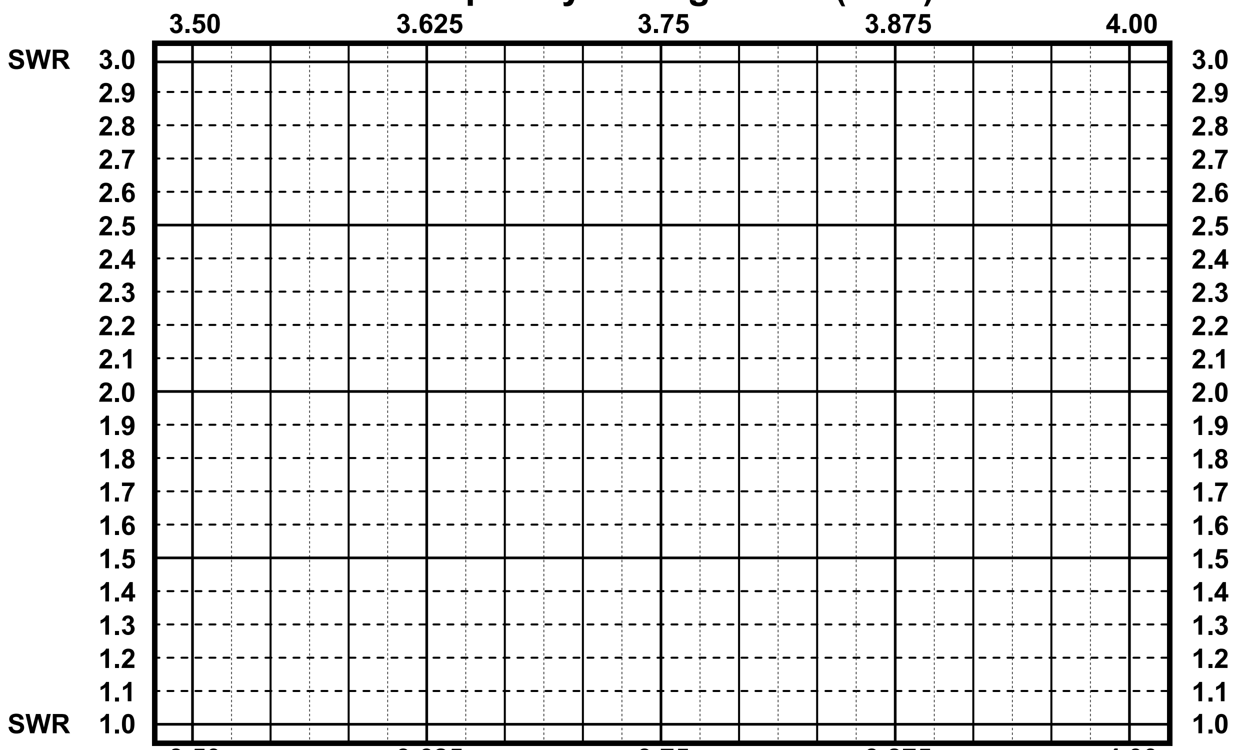


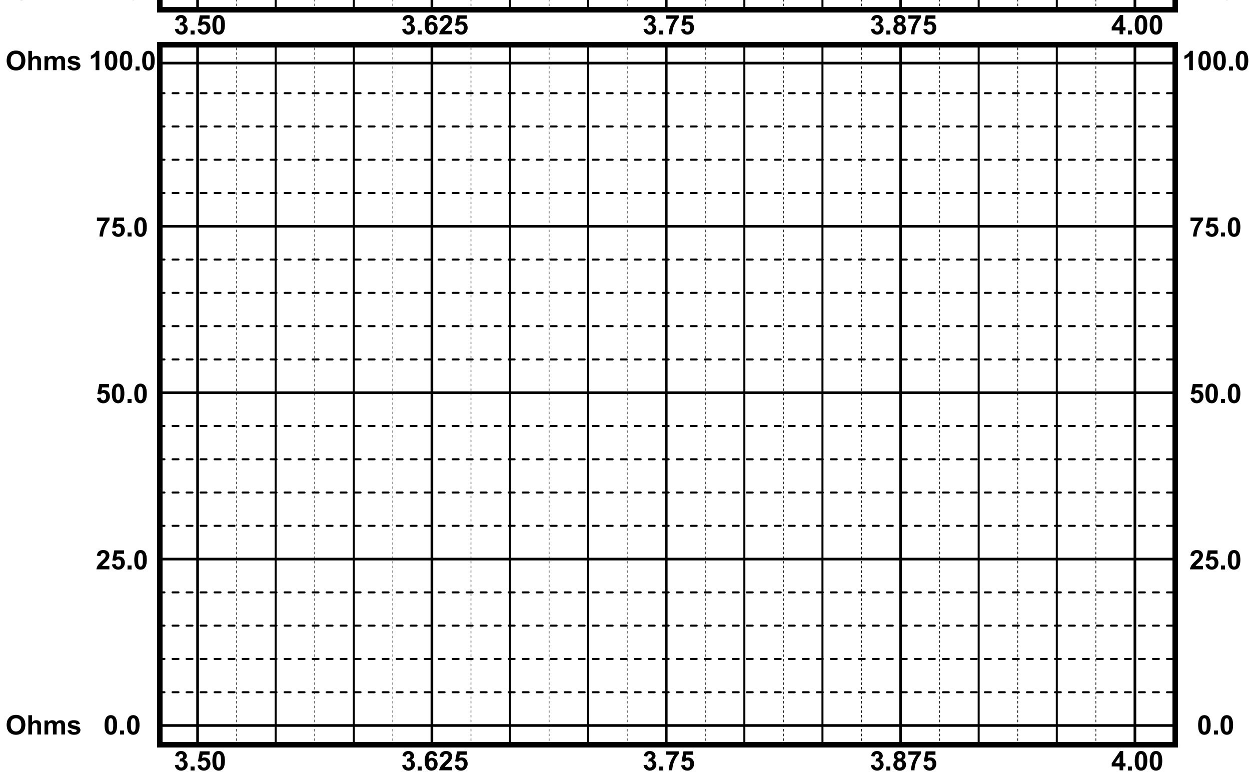
Rs =

Xs =

80-Meters	3.5 to 4.0 MHz	Plot Curves for (Antenna):	
Resonant Frequency =		Frequency of Lowest SWR =	SWR =

Frequency in MegaHertz (MHz)

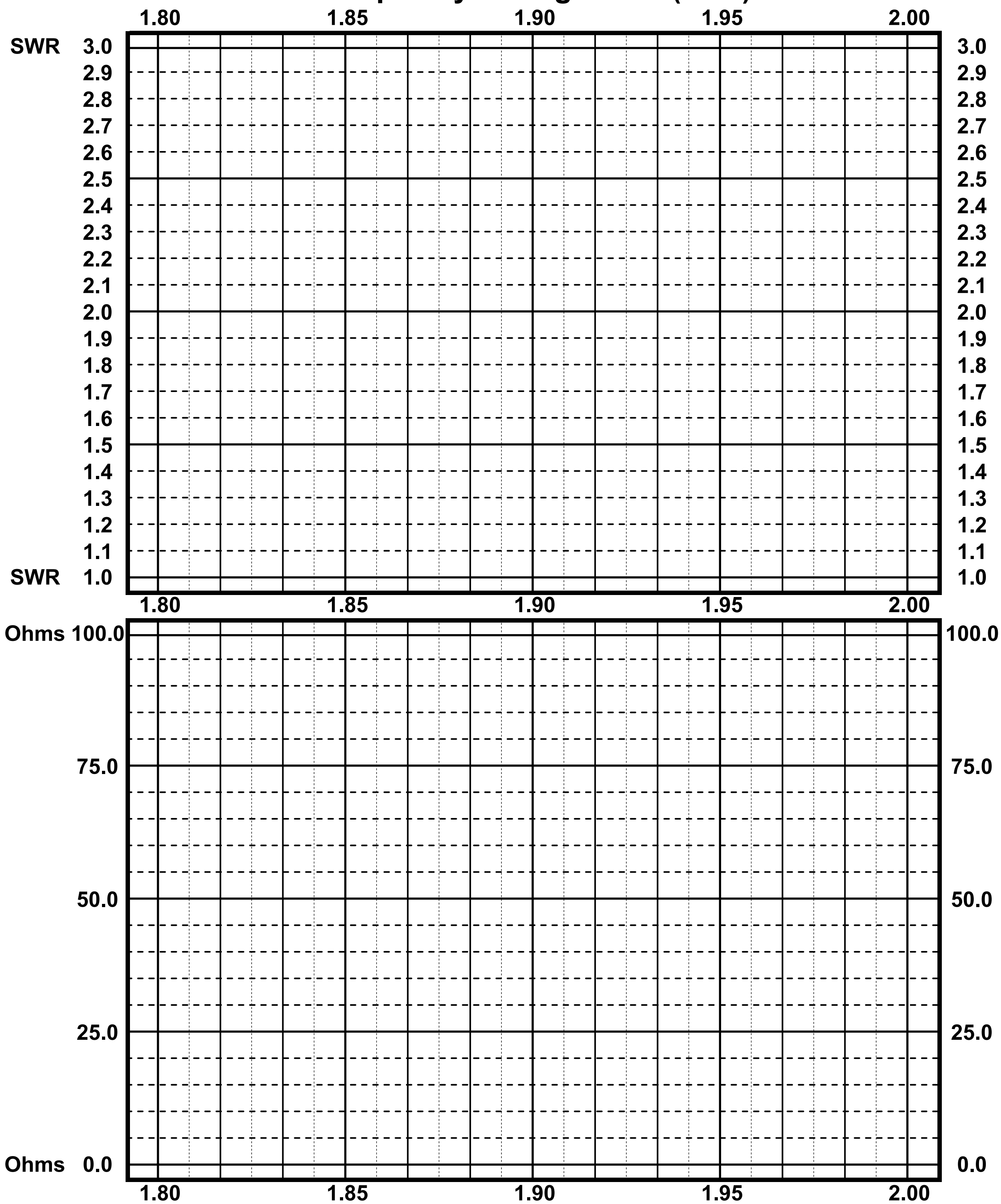




Rs =
Xs =

160-Meters	1.8 to 2.0 MHz	Plot Curves for (Antenna):	
Resonant Frequency =		Frequency of Lowest SWR =	SWR =

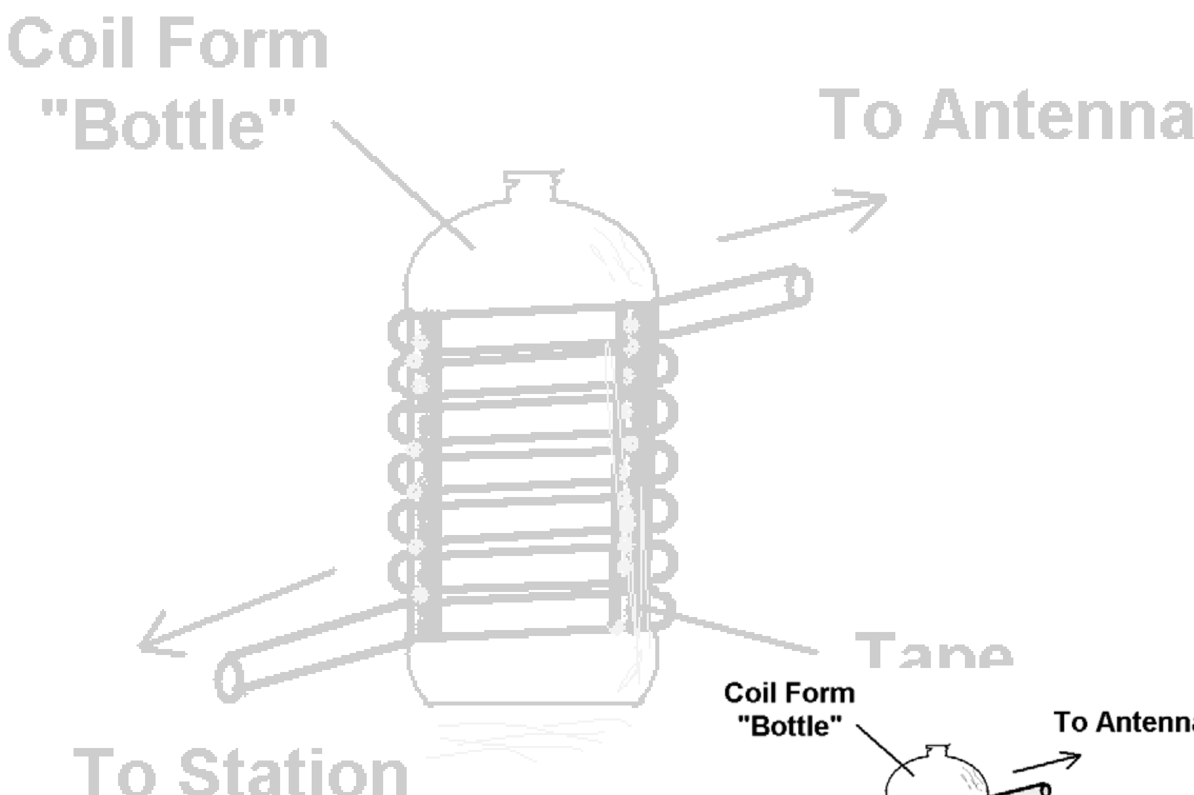
Frequency in MegaHertz (MHz)

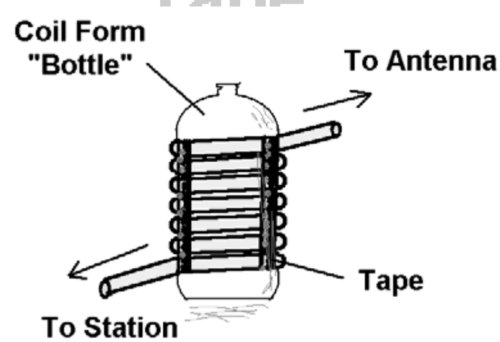


Rs =
Xs =

Appendix C

Quick Reference Guide





Meters to Feet Calculations:

Notes:

WL = wavelength
MHz = MegaHertz

¼ WL = 234 / (Frequency in MHz) = Dipole or Radial ¼ WL in Feet

½ WL = 468 / (Frequency in MHz) = Dipole or Radial ½ WL in Feet

Full WL (for Loop) = 1005 / (Frequency in MHz) = Loop, 1.0 WL in Feet

Erik's method of converting any number of meters into Feet & Inches:

(300 / (Frequency in MHz)) * (39.37 / 12) = Feet & Decimal Inches

To convert decimal inches into full inches and decimal fraction of an inch:

(12 * (Decimal Inches)) = Full Number of Inches & Decimal Inch

To convert decimal portion of remain one inch:

(N * (Decimal Inch)) = Fraction of One Inch & Decimal Remainder

Where "N" is the fraction of an inch you desire (N= "8" for 1/8 inch)

Calculating SWR:

$$r = \sqrt{\frac{\text{(REFLECTED POWER)}}{\text{(FORWARD POWER)}}}$$

[Reflected divided by Forward; then find the square root]

SWR = (1 + r) / (1 – r)

Calculating changes of power (such as RF loss or gain):

Loss (in dB) = 10 * (log P1/P2)

or

Gain (in dB) = 10 * (log P1/P2)

Note that if you are measuring a length of coax for line loss, if your manufacturer's data sheet measured a different number of feet of coax than you measured, you will have to multiply your results by the ratio of this difference.

Coax Coil Choke:

10- to 20-feet of coax
Diameter at least 15 times the OD of the coax width
Keep each turn tightly pressed against the turn before and after
Do NOT use a metal form (unless you remove it)

Antenna Fundamentals:

Dipole:

- Each leg is ¼ wavelength
  - 234 / (f MHz)
- No "ground" connection
- Connection with transmission line:
  - Coax connections – connection placements don't matter
  - Ladder line connections – connection placements don't matter

Vertical:

- Vertical height is ¼ wavelength
  - 234 / (f MHz)
- Requires a GOOD ground connection
  - Radial wires, 4- to 16-radials performs very well
  - Any number is better than none!
- Connection with transmission line:
  - Vertical to center conductor of coax
  - Ground to coax shielding
  - Ladder line connections – connection placements don't matter

Loop:

- 1005 / (f MHz) on lowest band (smallest frequency)
- Connection with transmission line:
  - Coax connections – connection placements don't matter
  - Ladder line connections – connection placements don't matter

Reactance:

If the antenna is cut to the EXACT length for a given frequency, reactance is zero.
If the antenna is too long, inductive reactance is present (X_L).
If the antenna is too short, capacitive reactance is present (X_C).

Changing frequency also adds reactance:
Higher frequency = electrically longer antenna = inductive reactance (X_L) is added to the antenna;
Lowering frequency = electrically shorter antenna = capacitive reactance (X_C) is added to the antenna.

Decibel (dB) Power Loss / Gain:

Change in Power			Decibel Change
x1	1 ÷ 1 = 1,	(log operation) * 10 =	0.00 (no change)
x2	2 ÷ 1 = 2,	(log operation) * 10 =	3.01 (double power)
x3	3 ÷ 1 = 3,	(log operation) * 10 =	4.77
x4	4 ÷ 1 = 4,	(log operation) * 10 =	6.02
x5	5 ÷ 1 = 5,	(log operation) * 10 =	6.99
x6	6 ÷ 1 = 6,	(log operation) * 10 =	7.78
x7	7 ÷ 1 = 7,	(log operation) * 10 =	8.45
x8	8 ÷ 1 = 8,	(log operation) * 10 =	9.03
x9	9 ÷ 1 = 9,	(log operation) * 10 =	9.54
x10	10 ÷ 1 = 10,	(log operation) * 10 =	10.00 (ten times power)

Change in Power			Decibel Change
x-1	1 ÷ 1 = 1.000,	(log operation) * 10 =	0.00 (no change)
x-2	1 ÷ 2 = 0.500,	(log operation) * 10 =	-3.01 (half power)
x-3	1 ÷ 3 = 0.333,	(log operation) * 10 =	-4.77
x-4	1 ÷ 4 = 0.250,	(log operation) * 10 =	-6.02
x-5	1 ÷ 5 = 0.200,	(log operation) * 10 =	-6.99
x-6	1 ÷ 6 = 0.167,	(log operation) * 10 =	-7.78
x-7	1 ÷ 7 = 0.143,	(log operation) * 10 =	-8.45
x-8	1 ÷ 8 = 0.125,	(log operation) * 10 =	-9.03
x-9	1 ÷ 9 = 0.111,	(log operation) * 10 =	-9.54
x-10	1 ÷ 10 = 0.100,	(log operation) * 10 =	-10.00 (ten times less)

<u>Giving RS(T) Signal Reports</u>

How are you heard? How do you easily yet meaningfully report how well you are hearing to another station? *(Please, specifically note the key word: "hearing" – we'll return to this point shortly.)* For phone (voice) operators, two numbers are given in a signal report. The first indicates "Readability" and the second indicates "Strength." CW operators provide a third number, and sometimes a brief post script.

<u>It is important to remember this is a QUALITIVE (subjective) opinion, not a QUANTATIVE measure of some number on a meter</u>. RS(T) reports have nothing to do with any meter on your transceiver. The only important quality provided in a RS(T) report is YOUR OPINION of how well you are hearing the other station at your location.

<u>The first number ("R") ranks "Readability." It is scaled from 1 through 5</u>.

"**Readability**" represents our opinion of our ability to distinguish the other station's signal. It might be compared to enunciation, and I often think of this in terms of how many words I understand. Getting every word said? That's a "5." Missing only an occasional word yet easily able to understand what is being communicated? That's a "4" – you can't give a "5" because they are not "perfectly readable." Difficult to discern what is being conveyed? That's a "3" because only with considerable effort do you figure out what they are saying. A "2" is barely discernible. You get a word here and there but a casual conversation is impossible. In an emergency you could work information back and forth, but you'd much rather have another station relay the information between your two stations. A "1" can not be given because that means they are unreadable.

<u>The second number ("S") ranks "Strength." It is scaled from 1 through 9</u>.

"**Strength**" has nothing to do with how many words you are hearing. Strength has to do with how well their radio signal is coming through your speakers <u>to your ears</u>. It is like the difference between a whisper and a shout. Sometimes you can hear every word another station is saying, yet they may be very weak (whispering). The opposite may also be true: they may be difficult to understand, but have a strong signal, so you can hear the bits and pieces of what they are saying quite easily, but parts are missing or garbled. Can you sit back in your easy chair and easily hear their words? (Whether you understand them or not.) That is likely an "8" or "9" signal strength. Perhaps a "7." Leaning forward and cupping your ear? Sounds like a "1," "2," or "3" signal strength to me! But remember, these are subjective values – what I consider a "3" you might consider a "1." This will happen and is perfectly acceptable.

You may find there is seemingly a rather large gap between these report values. With practice you will develop you own opinions as how to decrypt these gray areas. Any honest attempt to constrain your reports to the RS(T) system is better than distorting a subjective quality report to provide a meaningless (to others) S-meter reading from your transceiver. Your meters are only relative to your equipment, and not anyone else's. No "S-meter" value standard exists. It has been tried, but manufacturers can not agree upon an industry standard. Adding to the difficulty is the wide range of user-defined signal modifiers, such as gain and pre-amps, which may also affect the perceived strength of received signals.

"**Tone**" is traditionally used for CW. There is some debate concerning how a meaningful signal report system may be developed for digital modes. Those interested in these topics should refer to the ARRL and other sources.

The ARRL has a web page outlining these points along with other useful information, such as UTC conversion and phonetics:

http://www.arrl.org/FandES/field/forms/fsd220.html

I find periodically reviewing the descriptions of the various report figures useful in that it allows me to more closely report heard signals within the established parameters to which we are expected to adhere.

RS(T) System

Readability

1–Unreadable.
2–Barely readable, occasional words distinguishable.
3–Readable with considerable difficulty.
4–Readable with practically no difficulty.
5–Perfectly readable.

Signal Strength

1–Faint signals, barely perceptible.
2–Very weak signals.
3–Weak signals.
4–Fair signals.
5–Fairly good signals.
6–Good signals.
7–Moderately strong signals.
8–Strong signals.
9–Extremely strong signals.

Tone

1–Sixty cycle ac or less, very rough and broad.
2–Very rough ac, very harsh and broad.
3–Rough ac tone, rectified but not filtered.
4–Rough note, some trace of filtering.
5–Filtered rectified ac but strongly ripple-modulated.
6–Filtered tone, definite trace of ripple modulation.
7–Near pure tone, trace of ripple modulation.
8–Near perfect tone, slight trace of modulation.
9–Perfect tone, no trace of ripple or modulation of any kind.
X–If the signal has the characteristic steadiness of crystal control.
C–If there is a chirp.
K–If there is a click.

Words in voice procedure

Over – I have finished talking and I am listening for your reply. Short for "Over to you."
Out (or Clear) – I have finished talking to you and do not expect a reply.
Roger – Information received.
Copy – I understand what you just said (after receiving information).
Wilco – Will Comply (after receiving new directions).

Note: "Over and out" is an incorrect combination, since the two statements contradict each other. "Roger" was the U.S. military designation for the letter R (as in received) from 1927 to 1957.

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I am hopeful clubs and individuals benefit from this information and that your interest and involvement in KØS contests grow. ***This is tons of fun!***

I respectfully request an e-mail with details if you use any of the information in here, or sponsor your own "strange antenna" activities in your area. If you post information on a web site please include a link back to my web site. Comments or suggestions may be E-mailed to:

erik@n0ew.org

If you found this information useful, or just like the "cut of my jib," feel free to send me a few bucks to help support the cost of developing and keeping available the various online resources. This is not required – think of this along the lines of "shareware."

Here are a few of the areas of my web site in which you may find useful or interesting information (CaSe SenSiTive):

http://www.n0ew.org/book/
http://www.n0ew.org/projects/
http://www.n0ew.org/smarc/presentations/
http://www.n0ew.org/smarc/SMARCalling/

Printed and bound copies of this "KØS Field Manual" are available.
In 2004 this was $15 USD. Contact me for an updated price quote.

* * *

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"You're using whaaaat as an antenna!?"

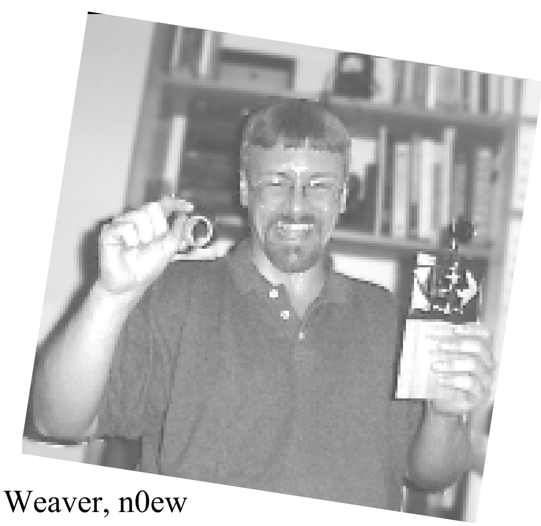
After reading Kurt N. Sterba's books I was inspired to sponsor a special event celebrating "Strange Antennas" such as those discussed by Krusty Kurt. Many of my fellow hams were also intrigued by the imaginative possibilities, and the first Strange Antenna Challenge was born. Years later this enthusiasm continues!

The core idea is quite simple: Assemble make-shift antennas using anything except wire and pipe, make multiple contacts with distant stations, and trade a fair amount of information regarding each others antenna and station so the effectiveness of each "Strange Antenna" may be evaluated.

This process of discovery holds a number of interesting and redeeming values, ranging from discovering what everyday items may be pressed into service as antennas, learning to use a transmatch very well, demonstrating the flexibility and creativity of ham radio, and of course having a really great time with friends!

In 2003, the first KØS special event was organized as a club function located in Springfield, MO. As years pass, increasing numbers of radio amateurs set up their own "satellite" contest stations and enter the fray with other amateurs interested in playing with these fun, exciting, and of course, "strange" antennas!

This "KØS Field Manual" serves as an amateur radio operator's introduction to antenna and transmatch (antenna tuner) design and operation. Included are troubleshooting and evaluation advice, as well as examples and discussion of a wide variety of antennas, transmission lines, transmatches, and test equipment. Blank charts of all documentation aids I have developed are also included.



Have fun & 73
Erik n0ew