Here's some plain speaking, non-formularized aspects of antenna life as seen through the eyes of W0AGD. John Magnusson of Telex/Hy-Gain eases us into the antenna season with some very sound and easy to understand advice.

Improving Antenna Performance

BY JOHN E. MAGNUSSON*, W0AGD

It is about that time of year again to take a look at the antenna system to see how well it weathered the winter. It's also a good time to get rid of some of the problems that were revealed during the past season's operating activity. This will be especially true if you were lucky enough to find a new v.s.w.r. bridge under the Christmas tree and made a few simple measurements since then. Inspection might indicate why the antenna isn't doing too well or perhaps any better than the reports you've been receiving confirm.

Whether you build your own antenna from scratch, using the *Handbook*, or assemble a commercially designed antenna; the overall performance *can be easily improved upon*. It will, however, require an established procedure to follow and some accurate documentation to determine where to start and which direction to go in to make the indicated improvements.

Very often the dimensions obtained by your own calculations, or those furnished with a commercial product, are influenced to a great extent by the variables that appear at each installation site. These effects on the antenna must be compensated for by minor changes in the original dimensions. Unfortunately, the state-of-the-art is not at the level at which you can buy a 50 ohm 1000 watt antenna, just as you can buy a power resistor or a similar component. Every antenna installation is influenced by one or more of the following conditions, and these must be taken into consideration:

*5329 Gladstone St., Lincoln, NE 68504

A. The physical height of the antenna.
B. The soil conditions below the antenna.
C. The type of support structure used.
D. The proximity effect of nearby objects.
E. The quality of feedline, balun.

The height above ground is not necessarily the number of feet from the antenna top to the earth below. Soil conditions, water tables, and soil conductivity determine the true height of any antenna. This explains the different loading characteristics experienced with amateur equipment between dry and wet seasons. These variations can be eliminated to a large degree by installing a ground radial system below the antenna, whether it is a beam or a dipole.

The support structure used to install a beam or support a dipole will have a measurable effect on the overall antenna performance. This is more noticeable with guyed towers than with self-supporting towers. To eliminate the pyramid effect of the guys extending from the ground anchors to the top of the tower, strain insulators should be installed to "break" the guys. After the guys have been broken by strain insulators into non-resonant lengths, each guy section should be checked with a neon indicator to determine if there is any r.f. energy absorption.

Finally, there is the proximity effect of nearby objects over which you have little or no control. If you're fortunate enough to live on an acre or so and have a large clear area available for the installation of a self-supporting tower and antenna, or a vertical antenna with adequate ground plane, proximity effect is reduced to a minimum, unless, of course, you install so many antennas that it looks like an aluminum orchard, and the proximity effect of one antenna affects the other.

A house with an abundance of electrical wiring, conduit, plumbing, vents and duct work, and siding, will have a noticeable detuning effect on a ground mounted vertical antenna installed near the house or a beam antenna mounted near the roof on a short roof mount.

Most of us are not fortunate enough to have an unlimited amount of real estate. Therefore, prior to installing any antenna some consideration must be made as to the proximity effect of the house, trees, power lines, fences, or whatever else exists within the primary field of the antenna. In the case of ground mounted vertical antennas, whenever possible, the distance from the vertical to the nearest object should be ¼ wavelength at the lowest frequency. By the same token, a beam antenna should not be installed less than ½ wavelength above ground at the lowest operating frequency. Contrary to what you may have read in the past, when installing more than one antenna on a common mast, a minimum separation of 10 feet should be provided between each antenna. Ideally, the electrically largest antenna should be at the greatest height.

Let's consider only two antennas on a common mast as an example. If you have a 4 element full sized 20 meter beam, and a 6 element 10 meter beam,

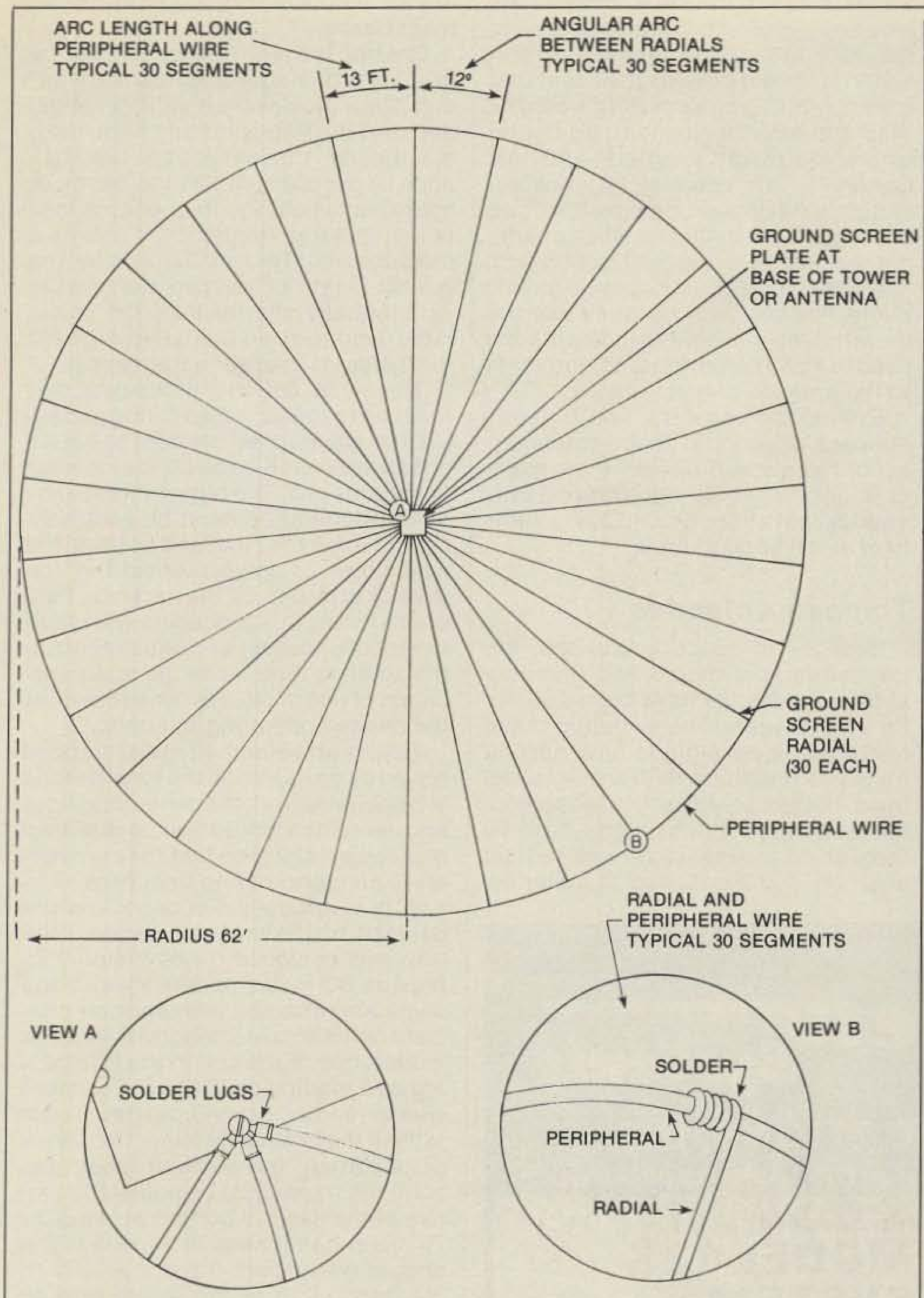

Fig. 1– A radial system typical of those used in commercial broadcasting.

no problem. You can place the 20 meter beam at the top of the tower, and the 10 meter beam 8 to 10 feet above it. Even though the 20 meter beam will look like a large ground plane under the 10 meter beam, it is no challenge to have 8 to 10 feet of separation, which fortunately is a ¼ wavelength, or greater on 10 meters. The 10 meter beam would perform fine. However, what if you had a 40 meter beam and 10 feet above it the 20 meter beam? This would be almost the same as installing the 20 meter beam on a clothesline pole.

Antenna Bandwidth

Every monoband antenna is actually a one frequency device. We do, however, have the advantage of being able to operate over a limited range of about 2% to 3% between the 2 to 1 v.s.w.r. limits normally considered acceptable. The exception is when provisions have been made in the antenna driven element to substantially increase its diameter, or number, which will increase its bandwidth. The conical monopole is a good example of a broad-band radiator. The basic conical monopole will provide a four octave bandwidth, or 4:1 frequency range, because of the ratio of its diameter to overall length. The discone antenna is another example of the same technique used to provide broad-band operation. Table I has been prepared for your convenience in making v.s.w.r. measurements and is based on 2% of the operating frequency. (It has been my experience that you seldom obtain greater than 2% bandwidth between the 2:1 limits.) As all of the amateur bands are harmonically related to each other, it would be normal to expect twice the bandwidth on a 40 meter antenna as compared to an 80 or 75 meter antenna, and twice the bandwidth on 20 meters as compared to a 40 meter antenna. A great deal is being done to make a good broadband h.f. amateur antenna for each band, including some work started at Collins Radio Company over 20 years ago. Presently you will find multiple driven elements and log-yagi's, to mention a few. We can look for additional work to become evident as the demand for greater bandwidth and the freedom to operate in both the c.w. and phone portions of the bands is increased by the end users.

Vertical Antennas

The vertical antenna is technically a monopole because it is one-half of a dipole antenna. The monopole works against the automobile body in mobile operation, against ground when it is ground mounted, or against a radial system when roof mounted. The car body, the ground, or the radials make up the other half of the antenna. Therefore, they are an important consideration in obtaining the optimum performance from the vertical. Most verticals will give adequate results working against average ground regardless of the soil conditions. Nevertheless, the efficiency of the antenna can be improved upon by improving the soil conditions.

Soil Conditions

The actual ground conductivity of the soil has been of primary concern to the broadcast industry for decades, since the a.m. broadcast band primarily uses vertically polarized monopole antennas. In addition to soil conductivity measurements, the broadcasting vertical antenna is usually located in a low, wet area whenever possible. This is not because a marsh or swamp is the cheapest piece of real estate available, but rather it is because they're interested in the most efficient ground system that can be provided. In addition to the selection of a good site, a large number of radials are installed at the base of the broadcast vertical antenna to supplement the existing soil conditions. Fig. 1 is an example of a radial system. The reason for the ground plane, or radial system, is to improve the efficiency of the vertical radiator. The efficiency can be easily visualized as follows. If you have a 60% efficient radial system, then it stands to reason that for every 100 watts fed into the feedline for the vertical antenna, 60 watts will reach the radiator itself, and the other 40 watts will be lost in the ground system, accomplishing nothing more than making life miserable for the earth worms. The greater the number of radials installed, the more efficient the ground plane becomes, and subsequently the percentage of power radiated by the vertical radiator increases. The optimum ground plane would have a total of 120 radials, or one radial every three degrees around the base of the antenna. This is impractical or impossible for most installations. However, it helps point out the importance of the radial system for a vertical antenna, and may help explain the common evaluation of the vertical antenna, which says: "A vertical antenna is one that operates equally as poorly in all directions at the same time."

To give additional credibility to this long-established comment, take a look at the actual soil conductivity measurements throughout the continental United States. The soil conductivity throughout the United States varies from a low of 0.5 millimhos to a maximum of 30 millimhos. That in itself is a 60:1 variation, and would tend to confirm the first impression that amateurs in some parts of the country are really fortunate to be located on top of a 30 millimhos soil condition. However, when you compare that to the 5000 millimhos reading of salt water, it should be easy to accept that a good radial ground system would be time and effort well spent, no matter where you install a vertical antenna. Generally, all commercial amateur verticals have been designed to give acceptable performance when operating against existing soil conditions. The installation of a substantial ground plane, however, will certainly improve its efficiency, even if it indicates the need to make some minor adjustments to the antenna dimensions.

Even in the case of a horizontal dipole or a directional beam antenna, a set of radials at the base of the tower or under the dipole will assure a constant height above ground over a variety of weather conditions.

Trapped Antennas

Because of space limitations, the trapped vertical, dipole, and directional beam antennas have been popular for over 20 years. The evolution of the trap made it possible to have several bands of operation with a single element. In the case of vertical antennas, the trap made it possible to have 80 through 10 meters in a single vertical antenna, and 20, 15, and 10 meter operation with a single two or three element beam.

The trap is a relatively simple device in theory. It is a parallel resonant circuit that provides an infinite impedance at the trap operating frequency, electrically disconnecting the balance of the element. On the bands of operation where the frequency is lower than the trap frequency, it acts as a loading coil. This explains why the overall length of trapped elements is substantially shorter than the calculated length of an unloaded element for the same operating frequency.

There's a definite procedure that must be followed in measuring and adjusting any trapped element to obtain proper operation on all bands inherent to the antenna. The highest frequency band of operation must be established first, then the next, and so on all the way down to lowest operating frequency provided by the antenna. Failure to follow this procedure will result in a lot of unnecessary adjustments to the antenna later on as the additional bands of operation are "fine-tuned" at the desired operating frequency.

Taking an 80 and 40 meter trapped dipole as an example, the length of the element wire from the center insulator and feedline connection to the trap must be established first for the desired 40 meter operating frequency. (The trap is electrically disconnecting the balance of the element because the trap was designed for 40 meters.) To provide 80 meter operation with the same antenna, the element now consists of the 40 meter length of wire, the inductance of the coil in the trap (acting as a loading coil), and the element wire extending beyond the trap. To establish the desired 80 meter frequency of operation, the element length beyond the traps must be adjusted to arrive at the desired portion of the 80 or 75 meter band. Keep in mind that you should not expect more than 2% to 3% bandwidth in the single wire dipole antenna, which doesn't give you much freedom in moving up and down the band as seen in Table I.

In an all-band trapped vertical, the distance from the base to the first trap must be adjusted initially to establish proper operation on 10 meters. Next the distance between the first trap (10 meters) and the second trap (15 meters) would be adjusted to establish 15 meter operation, followed by the same procedure for 20, 40, and finally 80 or 75 meters. Ignoring the 10 and 15 meter performance of the antenna and establishing the overall length of the vertical radiator for optimum performance on 80 or 75 meters is a waste of time. Any dimensional change made between the base and the first trap at a later date will automatically change the overall length of the entire radia-

Table I

80 and 75 Meters
3.6 MHz × 2% = 72 kHz
3.7 MHz × 2% = 74 kHz
3.8 MHz × 2% = 76 kHz
3.9 MHz × 2% = 78 kHz
40 Meters
7.0 MHz × 2% = 140 kHz
7.1 MHz × 2% = 142 kHz
7.2 MHz × 2% = 144 kHz
7.3 MHz × 2% = 146 kHz
20 Meters
14.1 MHz × 2% = 282 kHz
14.2 MHz × 2% = 284 kHz
14.3 MHz × 2% = 286 kHz
15 Meters
21.1 MHz × 2% = 422 kHz
21.2 MHz × 2% = 424 kHz
21.3 MHz × 2% = 426 kHz
21.4 MHz × 2% = 428 kHz
10 Meters
28.2 MHz × 2% = 564 kHz
28.4 MHz × 2% = 568 kHz
28.6 MHz × 2% = 572 kHz
28.8 MHz × 2% = 576 kHz
29.0 MHz × 2% = 580 kHz
29.2 MHz × 2% = 584 kHz
29.4 MHz × 2% = 588 kHz
29.6 MHz × 2% = 592 kHz
6 Meters
52.0 MHz × 2% = 1.04 MHz
2 Meters
146 MHz × 2% = 2.92 MHz

Table I– Bandwidth based on 2% of operating frequency.

tor, thereby influencing *all* bands of operation. The same is also true of a trapped beam antenna element, as it too must be set up for 10 meter operation first, followed by 15 meter operation, and finally the extension beyond the traps to obtain the desired 20 meter operating frequency. As outlined earlier, no two installations are the same because of all of the factors that influence the operation of the antenna. The dimensions that you obtain either by your own calculations, or that are provided in the assembly instructions, *basically only get you into the ball park*. To arrive at the desired center operating frequency on each band of operation requires you to "fine-tune" the antenna as indicated by additional measurements using a v.s.w.r. bridge. Increasing or decreasing the original dimensions to compensate for the installation site will adjust the antenna to the desired operating frequency on each band and give you the best performance possible.

A dipole antenna is basically a series resonant circuit made up of the inductance of the antenna element and the capacitance from the element to ground. The impedance of the dipole is a function of height above ground and may vary from a few ohms to a value in excess of 100 ohms. Very few 80 meter dipoles are actually 72 ohms, as most of the 80 meter antennas are seldom over 35 to 40 feet off the ground. Therefore, the input impedance would be closer to 50 ohms than 72 ohms.

With the exception of the vertical antenna, which is fed against ground, the feedpoint of the dipole or directional antenna should be fed with a balanced voltage unless provisions have been made in the antenna to allow the driven element to be fed with an unbalanced voltage. With the invention of the pi-network, the pi-L section, unbalanced coaxial feedline, coaxial rotary joints, low-pass filters and co-axial relays, the use of an r.f. coil made from coax cable, or a balun, is needed to transform the unbalanced voltage of the equipment output to the balanced voltage of the antenna element.

The V.S.W.R. Measurement

The v.s.w.r. bridge is one of the most useful accessories you can possess. It allows you to determine which direction any antenna should be adjusted in to have the minimum v.s.w.r. on the portion of the band where you need optimum performance. Three simple measurements, even though they are made at the equipment end of the coaxial cable, will indicate whether or not the antenna favors a frequency lower or a frequency higher than the desired operating point. From this information it's a simple matter of making a small adjustment in the overall length of the element to move the minimum v.s.w.r. to the center of the desired operating range. The only word of caution is that any v.s.w.r. measuring device, regardless of the initial cost, is only as accurate as the isolation provided in the unit between the reflected and forward power readings. Getting overly concerned about a 2:1 v.s.w.r. reading is not a legitimate reason for alarm. A 2:1 v.s.w.r. measurement represents a loss of 0.38 dB when using 100 feet of coax at 30 MHz, and the loss is less at lower frequencies. Big deal! It takes almost 10 times that amount of loss to detect a noticeable change in the signal at the other end of the contact. However, some of the newer solid state equipment on the market today will not handle a mismatch in excess of 2.5:1, and *does* require reduction of the v.s.w.r. below 2:1 as terminated at the equipment.

Granted, you can install a line flattener, antenna tuner, or similar device at the equipment end of the coaxial cable. While this doesn't accomplish anything to improve the performance of the antenna, it does satisfy the requirements of some equipment and psychologically satisfies one's desire to have a low v.s.w.r. meter reading. The same is true of attempts to cut the length of the coax cable so as to use the transformation effect of the cable itself to match the impedance of the antenna to the equipment. The subject of coaxial cables is a complete article in itself.

In most cases, the newly installed antenna can be measured and a v.s.w.r. curve established by making three measurements at the equipment end of the cable. After all, you are only interested in knowing if the antenna favors the low end or the high end of the band. There's no need to concern yourself with the design engineers approach whereby the antenna is measured through a ½ wave line section and rotated back to the input terminals using a Smith Chart. This cannot be done with a v.s.w.r. bridge or equipment commonly available to a majority of amateurs. Now let's get onto the business of finding out what the installation looks like.

Initial Measurements Of Your Antenna

In the comfort of your own shack using Table I make a measurement with your v.s.w.r. bridge at the desired operating frequency, another measurement 2% lower in frequency, and a final measurement 2% higher in frequency. From these three measurements you will determine if the original dimension must be *lengthened to lower* the frequency of the antenna, or if it must be *shortened to raise* the frequency of the antenna.

On a 20-15 or 10 meter antenna shorten or lengthen the element one inch and make another set of v.s.w.r. measurements to see how many kHz a one-inch change represents for your particular installation.

1. On a beam, which is a half-wave element, this would be one inch on both halves of the driven element.
2. On a vertical, which is a quarter-wave element, it would be one inch on the dimension outlined.

After you have determined the amount of change the initial adjustment provided, another change in the same dimensions should put you on, or very close to, the exact center frequency desired.

Example: The antenna appears to be resonant 350 kHz lower than desired. A one-inch dimensional change caused a 150 kHz change in the resonant frequency within 50 kHz of the desired frequency, close enough for all practical purposes, unless you are willing to make another adjustment.

On an 80 or 40 meter antenna, a one-inch dimensional change isn't going to produce a very noticeable improvement in the antenna. It is too small a percentage of the overall element length to be effective. The dimensional change should be two or three inches, depending upon how far the frequency must be changed. This change will produce a reference as to how many kHz the antenna changed as a function of the adjustment made. From this information it is possible to make the next adjustment and obtain the desired center operating frequency.

If your v.s.w.r. bridge must be set to a calibration point in the forward position before reading the v.s.w.r., the bridge should be recalibrated prior to each measurement, even if the measurements are only 100 kHz to 200 kHz apart. If you do not recalibrate the v.s.w.r. bridge each time, you destroy the accuracy you are attempting to maintain between each measurement.

Another consideration is the useful frequency range of the v.s.w.r. bridge itself. If it was designed for h.f. only, 3 to 30 MHz, it cannot be used to determine how well a 6 or 2 meter antenna is matched to the feedline. The marketplace has an abundance of v.s.w.r. bridges for 27 MHz; however, some of these may be inadequate at 3 to 14 MHz.

No attempt has been made to express theoretical or mathematical calculations regarding an antenna. Basically it's the application of the simplest approach to the improvement of an antenna system by the use of an inexpensive accessory and measurements that can be made in the comfort of the ham shack. This approach, plus a minimum amount of documentation as to the progress being made with each dimensional change, makes it possible to obtain the maximum performance from any antenna installation. It is time well spent. It is also a far less expensive approach to improving the entire system as compared to a substantial investment in additional power to compensate for the inefficiency of the existing antenna installation.