Question and Answers
by Gene Ferguson, W4FWG

ANTENNAS (OR IS IT ANTENNAE?) AND TRANSMISSION LINES

Part VI-B

NOTE: I request the editor of our newsletter to cause the two drawing sheets associated with this Part to be printed on separate sheets and attached to the back of our newsletter. This is to allow easy separation and access for reference to the various circuits as we discuss the topic and too, it will allow each of us to make a copy or two to keep as a handy reference for future use. I think and hope that you will find this worth retaining.

1. (Q) In Part VI-A, you spoke of long transmission lines, the reflected waves and analyzed how different terminations would cause the reflected waves to be different phases and amplitudes. Moreover, we got a presentation in the use of these different lengths and terminations for various types of circuits. You also promised to present additional information on this subject. Can you tell us of other uses for transmission lines as well?

(A) We can use transmission lines as component parts or total circuits, rather than utilizing discreet components. In many cases, circuits made of discreet components simply do not achieve the intended results due to their circuit's low "Q," their wide band pass characteristics and/or higher resistive losses. Let us review how we can use a shorted section of transmission line for capacitors or inductors and how we can use them in combination to achieve circuits with extremely high Q and narrow band pass. While this is a review for most of us, this different approach may make it easier for us to retain the info in our memory banks.

NOTE: At this juncture, we will depart from the Question and Answer format and go into the discussion mode. Please bear with us for the duration.

Please refer to the drawing sheet labeled "Sending End and Termination Impedance of Various Lengths of Transmission Lines" at the end of our newsletter and take a peek at Figure "A." While we discussed this is some detail in Part-6A, because of its use in everyday life, we want to expand a bit here. This drawing gives us a better picture than before. First, look at the extreme left side of the drawing. We have a symbol representing an Alternating Current (AC) generator. Actually, in our discussion of transmission lines, this is a RF generator. Without drawing this RF generator on each of the following sketched, assume that all such drawings will show the source on the left end and the termination on the extreme right of the drawing.

We see that Figure "A" is terminated (at the right end) in a short. Please note the waveform representations above the transmission line. The solid black wave line represents the "E" force line while the dashed wave line represents the "I" lines of force. The Impedance (Z) line is not shown, but for clarity, we can simply apply Ohm's Law to get the scaled Impedance all along the line, as a very heavy black line. We can use these "E" and "I" lines as in Ohm's Law calculations, power formulas or other applications. Notice that we always start our wave form representations at the terminated end. This is always the case in any reference book, not solely here. Note that in this instance, with a shorted termination, the Voltage (E) is low (near or equal to zero) while the Current (I) is at a maximum at the termination. Does this not represent what a short circuit with DC or AC flowing would approximate? Think about it: A

short will cause the maximum possible current to flow and we would measure the lowest possible voltage across a short. There is nothing mysterious about this study thus far – correct?

Take a quick glance down the page on the termination end of each drawing. Notice what happens to the E and I lines as the termination changes. Can't we relate each termination to and its waveform at that point to a DC circuit? Open circuit equates to a high voltage (E) and a low current (I), while a short will show a high current and a low voltage. .

Again, looking at the wave forms on Figure "A," starting at the shorted termination, follow the solid black line, the voltage or "E" line back to the left up to its maximum positive point. If we stop there and think about it, this point represents a quarter of a wavelength or 90 degrees back from the termination. If we move our generator to this 1/4 w*l* point, keeping the shorted termination, please note that the impedance at the generator will be the opposite of that at the termination. It would be very high, a high voltage divided by a low current = high Z. But if we continue tracing our E line back to the point where the voltage is once more at a minimum, we will have moved to a point exactly ½ w*l* from the termination or a one-half of a cycle (or Hertz), or 180 degrees. Now, if we move the generator to this point, the generator will see the same wave form as the termination, meaning that for a ½ *wl* of line, the generator and the termination will be equal, if the line impedance, generator and line are of the same impedance We covered this in Part-A, coming up with some Rules.

We should know by now, that if the same line is terminated in an open, the wave forms will be reversed, what is now the E line would be the I line. Of course, the termination and generator will be at a very low impedance.

One fact remains, whether the termination is an open or a short. On a ½ *wl* line, the generator end and the termination will see the SAME wave forms, the same phase and impedance.

We hit briefly in earlier Parts about using short sections of transmission lines for discrete components. In Part-A we got into some detail about the long, one wavelength, ½ and ¼ wavelength lines and what the reflected waves would look like and even what some of them could be utilized for. Now, we will look at some shorter sections as well and see how they can and are used to our advantage.

Figure "B" shows us a 1/8 wavelength of line terminated in an open. We can see that it can be used as a capacitor, since a capacitor has the same characteristics when an RF signal is applied. Due to its short length, it is difficult to see that the current leads the voltage as it does across a capacitor, but close analysis will show the proper phase shift. *If a 1/8 wl of transmission line, terminated in an open equals a capacitor (rather large) wouldn't it stand that a section of line less than 1/8 wl would represent a capacitor of smaller value?*

See how simple? And you thought all this was going to be difficult!!

Now, drop down to Figure "C." This 1/8 wavelength line terminated in a short as is the ½ wavelength shown in Figure "A." At the termination end, the wave forms start the same as in Figure "A." Once again, follow the solid black line back to the left until it peaks at the source point. What happens on a transmission line that is equal to 1/8 wavelength? Well, the impedance reverses. So, with a short at the termination with its maximum "I" and minimum "E" lines, the source will see the partial reversal, or a maximum voltage (E) and a minimum

current (I), a somewhat HIGH IMPEDENCE. This type circuit can be used as an inductor. ***If a very short section of line, less than 1/8 wl is used, it will become proportionally smaller in size – a smaller inductor.***

Just below Figure "C" is shown how we can connect a 1/8 *wl* open section, which appears as a capacitor, to a 1/8 shorted section and obtain a ¼ *wl* line, that looks like an inductor or coil and we have a Parallel Resonate circuit. So, a shorted 1/4 *wl* line can be used as a Parallel Resonate circuit as shown in Figure "D."

In Figure "E" we see a ¼ wavelength line terminated in an open and used as a Series Resonate circuit. Since we hit on these applications in Part-6A, we'll not elaborate more at this time.

This then bring us to some practical applications of this theory and study.

As stated earlier, a 1/8 *wl* (or shorter) may be used as a capacitor. A one inch section of 300 ohm feed line cut with bared ends just long enough to solder to the circuit will approximate 5 mmfd, a very small capacitor.

One-half, one-quarter and one-eighth *wl* stubs are utilized frequently in various (many) applications. One comes readily to mind, that of a "J" Pole antenna designed for both, the 2 meter and the 440 band. A little background theory may be wise at this point, however.

Please refer to our Attachment sheet labeled "Building a 2 Band J-Pole Antenna."

As a reminder, the stated lengths shown in most antenna circuits shown in various publications are for reference only. Many variables can and do enter into the design and actual construction of antennas, but we'll attempt to cover most of these altering factors!!!

An important fact to remember: Any transmission line will have a *VELOSITY FACTOR*, which means that RF energy travels more slowly through a wire than in free space. Different types of wire and insulating media causes different speeds through it. This velocity factor (VF) is a percentage of the speed in which RF energy will travel though a conductor or pair of conductors as compared to the speed it would travel in free space - on that particular piece of conductor or conductors. While the formula for a half-wave antenna; 468/Frequency in MHz is OK for a wire antennas, it assumes a bare wire, not-insulated, and it takes into account the end effect. Therefore it is invalid as a formula to determine wavelength for transmission lines. For calculations of transmission lines, we need to revert back to the actual wavelength in free space multiplied by the VF of that particular line. Our basic formula for *wl* is 984/F(MHz) times VF. This will give us a transmission line section somewhat shorter in free space.

984/F(MHz) for one full wavelength (in Feet) in Free Space.
984/F(MHz) times VF for computing the length of transmission lines
468/F(MHz) for computing ½ wavelength antenna length (with uncovered conductor).

Remember too, that when we enclose any antenna in any type of cover or shield, we alter the VF of that antenna. For example, when we encase a J-Pole antenna in a PVC pipe or tube, the design frequency is now shifted somewhat due to the additional slowing of the energy along that antenna. Unfortunately, we never know the velocity factor of such enclosures – different manufacturers of PVC pipes may use different manufacturing materials and procedures so each will be different. This applies, to a lesser degree, to some cable manufacturers who may

slightly alter the standard VF to a degree sufficient to throw our calculations off a bit. The insulating material within a cable will also alter the VF, so we need to know what that particular manufacturer states that the VF of that particular cable really is.

Having said all that, I know of no means other than direction communications with the specific manufacturer of ordinary 300 ohm ribbon type wire to determine its VF. However, my experience has shown that most have a velocity factor of between .80 and .90, so I use the mean average of .85 to do my calculations. The best we can do is start with a piece too long, then, as one professor told my class, calculate it closely, then use our diagonals to 'tune' it. This is why we hams are so important to the world - we got diagonals!!!

The J-pole antenna is basically a ½ *wl* radiator atop a ¼ wave shorted stub. Since this is an antenna as opposed to an ordinary transmission line, we shall compute all parts using our antenna formula for a one-half *wl* section and work from there. In these discussions, we will be using and referring to 300 ohm lead-in as our construction material as show in the uppermost sketch on the referenced sheet.

Using our formula to calculate the length needed for the lower 1/4 *wl* shorted stub section, we calculate this to be: 468/144 = 3.25 feet times 12 to convert to inches = 39 inches (½ *wl*). We divide this by 2 to get our desired 1/4 wavelength section which equals 19.5. Multiply this by our assumed VF of .85 and we come up with a length of 16.58 inches. This is 'Right On' with the drawing.

The upper part is simply an end fed ½ wl dipole added to this lower ¼ shorted stub. The upper part, being a ½ *wl* section is computed to be 39 inches. If we apply our assumed VF to this, we would get 33.15 inches, which is considerably shorter than reality. Why? A number of factors enter into this equation. First, a section of the insulating material is removed at the NOTCH area, thereby changing the total VF. Secondly, this is no longer transmission line with opposing currents flowing in the two conductors; it is now an antenna. This changes the VF. Then too, the second conductor, while not physically connected to anything, actually does become a part of the radiating element since it is both, capacitively and inductively connected to the active wire in this section. So, these variables all come to play, making it nearly impossible to compute the VF, but it will be approaching .95 to .98. For this upper section, it is best to forget the VF, compute using the ½ *wl* antenna formula 486/H (MHz) where we have determined it to be 39 inches; then WE GET THE ANALYZER AND DIAGONALS and adjust for the lowest SWR. But look, we are very close already, if we use our estimated VF of .96 we'll derive a length of 37.44 inches, close enough to have a fully functional antenna. But, to get it "JUST RIGHT," we need to do our "trimming" from the 39" length.

Looking at the uppermost drawing on our attached sheet labeled "Building a 2 Band J-Pole Antenna," we see our computed antenna; but this is really a 'tried and proven' design that has been in use for many years I've built many; I am using one now, modified slightly, hung on the wall in the shack. In summary, starting at the bottom of this sketch we see the ¼ *wl* section of transmission line, terminated at lower end in a short, the two conductors, trimmed of insulation and firmly soldered together. Then we simply add a ½ *wl* conductor of some sorts above this stub. Incidentally, I've used a solid conductor in place of the twin lead above the stub, replaced it with copper tubing, all have worked great with the same formulation.

When we insert this antenna assembly into a PVC pipe, the VF may be altered a bit and some adjustment necessary. Often, the notches cut in the twin lead, the 'shorted-on-one-end' sections, the necessary construction materials (wood stick, PVC pipe) combine to give us a VF somewhere near 85 percent, but it will work OK as designed, maybe the base frequency will be shifted slightly. Again, the Antenna Analyzer and diagonals should be utilized to accurately adjust the lengths for the lowest SWR.

AN OFTEN OVERLOOKED POINT IS THAT SMALL SECTION AT THE EXTREME BOTTOM, THE SHORTED SECTION END OF THE SHORTED STUB. **This seems insignificant if this transmission line is made of 300 ohm line, but ½ the width of the stub section should be included in the computed length for greater accuracy. In some designs, this may be in inches, not a small fraction of an inch as in our 300 ohm line.**

Know too, that the solder blobs where we attach cable to the transmitter will decrease the distance between the two conductors slightly and will alter the VF as well as the SWR, as will the insertion of the antenna into a PVC pipe. So, our calculated length will usually be a bit longer than the real world finished product. And this is good, as it leaves us some extra material for 'trimming.'

Working up from this lower shorted termination stub section, where the impedance (Z) would be very near zero, to the top of this section only, which would have a rather high Z; we know that at some point along this conductor or pair of conductors, we can find a point whose impedance is equal to that of our feed line, in this case, a cable. The RG-174 cable has an impedance of 50 ohms and a VF of 66%, or as generally stated, simply .66. The point along our 300 ohm cable from the shorted end to where the Z= 50 ohms is approximately 1-1/4 inches as shown on the drawing.

So what have we here? Well, as I see it (others may not offer this explanation, as I've never seen it explained in this manner), the upper section of a J-pole is plain and simply a ½ wl dipole, vertically mounted, end-fed at the lower end, not directly by a cable, but by and through a near perfect insulator. The bottom ¼ wl stub does several things for us. One is that the feed line (cable) is attached near the shorted end. The insulating feature of the stub then isolates this ground (and the feed line on the other wire) from the radiating element, the upper ½ wl dipole. In so doing, the lower ¼ stub becomes an impedance matching transformer, raising the 50 ohm feed line impedance to a high value to match the impedance of the upper ½ wl section, which is an end fed dipole from a high impedance source. The upper end, the radiator, being end-fed, with no cable attached at either the center of the dipole, nor at the end (remember the ¼ stub is also an insulator), makes for a clean radiation pattern with no shading or energy loss due to a feed line in close proximity. Sure makes sense to me! I see nothing complicated about this arrangement at all.

This theory is proven by comparing the radiation pattern to that of a vertically mounted dipole, also end fed at the correct impedance, except the J-pole is a bit better!

Notice that a ¼ of an inch of one wire is removed at the NOTCH, leaving the remaining conductor to run the full length of the antenna. This then leaves the upper ½ wavelength section nearly isolated but for the one conductor. The relative high Z of the lower section feeds the upper section at this high Z point. We know from our earlier study that what is present on one end of a ½ *wl* section is present at the other end, so we have a high Z at the open end of our

antenna. Doesn't an ordinary ½ *wl*, center fed dipole exhibit the same characteristics? The other conductor in the twin lead, the one that was cut for the Notch, actually becomes a part of the radiator, being inductively and capacitively coupled, increasing its bandwidth somewhat. Bandwidth, but not gain, can be improved if we shorted the two conductors at the top and/or lower end. I often short the upper end to make an excellent 'hanging' point with a small nail or push pin, or in the encasement into a PVC pipe, a small wooden dowel.

We should mention the RG-174 cable. It is cut to a length of 20 inches which is about ¼ *wl* at this band. Ideally, it should leave the antenna at a 90 degree juncture, but mostly, this section serves, in this case, to be a convenient length to insert BELOW the antenna, within the same PVC pipe, making this extended section a good mounting area; allowing a ready mount for the antenna. We should only place mounting brackets on the lower 12 inches of the 20 inch pipe extension however, to avoid interfering with our antenna radiation.

This just about wraps up the construction details, except for its insertion into a UV resistant PVC pipe of sufficient diameter to house the antenna. A means must be provided the support the assembly within the pipe, keeping it rigidly in place. I have mine installed on a wall inside the shack without being in a pipe, but have constructed a number, mostly for marine use and for use on autos and vans. I normally glue two or more small diameter wooden dowels together, end-to-end, carefully aligning them into a straight continuous piece, allowing the glue to fully dry/set, then keeping the piece in a really low humidity area for a couple of days, shellac it with a couple of coats and allowing this to dry overnight. I then start at the very bottom, taping the 20 inch cable to the stick, leaving about one inch of the connector end free to attach the female chassis connector to the lower end cap, then tape the stub firmly and continue to complete the antenna, taping it about every 4 or 5 inches along the way as a section is completed. A few pieces of high quality tape will firmly hold the assembly in place as we push it into our PVC, adding the end caps to hold it in place. With end caps, the bottom cap modified to accept the matching cable connector, we will have us an ordinary, but well constructed J-pole – cheap - and as good as most. Let us talk about this type of antenna a bit before we get into our 2 band unit.

This basic J-pole antenna will work both the 2 meter and the 440 band, the antenna accepting the third harmonic, not the fundamental frequency for 440. This leaves a lot to be desired; the radiation pattern is somewhat scattered when the third harmonic is used, actually gives a wide area coverage on 440, but the 90 degree radiation normally exhibited by a vertically mounted dipole is considerable less than desired. For that reason, an attempt to make the J-pole tune to both bands on its fundamental frequency was achieved by Ed Fong, WN8IQN, a Phd and Senior Member of IEEE. An article about this antenna appeared in the QST, February 2003 and is copyrighted by ARRL. I am taking the liberty of describing the DBJ-1: A VHF-UHF DUAL BAND J-POLE ANTENNA as a guide to walk through the theory and construction of such an antenna. I give all the credit to these original sources.

By applying some additional sections of the transmission lines to the basic J-Pole as we have just discussed, he was able to make the ordinary J-Pole antenna into a true 2 band antenna.

Take a look at the second (lower) antenna to the left on our drawing sheet.

Note that the lower section remains unchanged from the original unit. This still serves the same as before for the 2 meter band, but serves to pass the 420 – 450 MHz band as well.

Thinking back to our just discussed Transmission Line Theory, we can see that for 440 MHz, we really have a 3/4 *wl* lower shorted stub section attached to a 1/2 *wl* (at 430 MHz) line terminated in an open on both ends section of line; the 420-450 MHz radiating element. It should be noted here that the lower section, being 3/4 *wl* at UHF, works fine for UHF. ***Remember the ½ wl part of this ¾ wavelength section serves only as a transmission line for the remaining ¼ wavelength section and if we recall, both ends of a ½ wavelength section offer the same Impedance. There IS a small penalty to pay however, since there is about 0.3 db loss in the ½ wl section of his ¾ length of 300 ohm line, resulting in a very, very slight lowering of the output signal on UHF.***

Above the lower, shorted section, you will note some major changes from the first (upper) drawing, two sections as opposed to one. As before, starting at the very bottom, the 1/4 *wl* stub acts the same as before for 2 meters, but appears close to a ¾ *wl* resonator, resonating on the third harmonic of the 440 MHz band. Just above this shorted termination line, we see a new radiating element cut to a length of 11-1/4 inches (plus the ¼ inch at the first or lower Notch). This is now our UHF ½ *wl* radiating element, plain and simple. It will resonate on the fundamental frequency of 420-450 MHz. Using our formula, we would expect this section to be 12.76 inches without considering the VF. So, it is reasonable to believe the total of 11-1/2 inches for this radiation section to be accurate, considering the VF of the twin lead plus the added PVC. It would really matter little if this 300 ohm section, the UHF radiating section, were replaced with a single heavy gauge wire, cut to the proper length figured in the 468/f(MHz) formula and disregarding any VF. I've use 5/16 inch copper tubing on a couple. Running the reflected wave for this combination, we can see a near perfect match from this lower section to the 11-1/4 inch section (actually 11-1/2 as the ¼ inch conductor at the notch area is part of our radiator. This makes for a complete UHF J-pole. ***The added 5-1/4 inch section of RG-174 cable acts as we would expect a ¼ wl shorted on the terminated end to act. It acts as an insulator, offering a high impedance to the lower 11-1/2 inch section, our UHF radiator, while blocking any energy from entering the upper 17 inch section.*** **Too, is should be noted that, with only only one of the conductors of this section of RG-174 cable being actively connected, the outer shield being open on one end, the VF of .66 for this type of cable no longer applies, but will increase considerably and its actual length must be determined by experimentation. It is safe to assume that the VF is now somewhere near .80.**

Our upper radiating element looks a lot different now, however. To couple the 2 meter energy to the uppermost radiating element, we use a short section of 50 ohm cable (inthis case, RG-174) shorted on one end, the upper end. Here is where we put our recently learned theory to work. This short section of cable appears as a ¼ *wl* line for 430, but as a 1/8 wl section for 2 meters, both being terminated at one end (the upper end). This is an insulator for UHF, isolates the lower part completely from the upper part on UHF. As far as UHF is concerned, there is no upper section, but being near an 1/8th *wl* for 2 meters, it acts only as a small inductor. If we recall, a 1/8 *wl* line, shorted on one end acts like an inductor. If a line is slightly shorter than a 1/8 wl, shorted section, the size of the inductor will be smaller. Therefore, the cable section can be considered as a small inductor for 2 meters (part of the radiator) and an open circuit for UHF. Thus, by applying some of the Transmission Line theory, we have a 2 band antenna, each band operating on its fundamental frequency. I should add, this is true with any compromised antenna; it is not perfect, but good enough. If properly constructed, this unit should show a SWR no greater than 1.3:1 on either band; good enough for any of our needs.

See, I told you that all this was simple!!

I will be happy to assist anyone wishing to construct either of these antennas. It would be difficult to write all the steps into this Part. If help is needed, just ask.

I would be remiss if we didn't discuss the total length of the 2 meter radiating element, all that above the 1/4 *wl* stub at the bottom. The 2 meter radiator consists of everything above the shorted ¼ *wl* stub. The 11-1/4 section plus the very small inductor plus the 17 inch upper portion plus the 1/4 inch at the notch, all combine to be the 2 meter antenna. If we really get down and do our math, we can see that it is a bit shorter than our formula derived length would indicate, even considering the VF it were known. This shortened length is due to the fact that the inductor near the center acts like a loading coil and adds inductance (length) to our radiator. Think of a HF mobile with its antenna mounted on it with a loading coil near the center. Same, same.

In our ham activity, we see and need many more applications of these shortened sections of transmission lines. I hope this series of articles has enlightened us enough to now understand their operation and better envision any device using them.

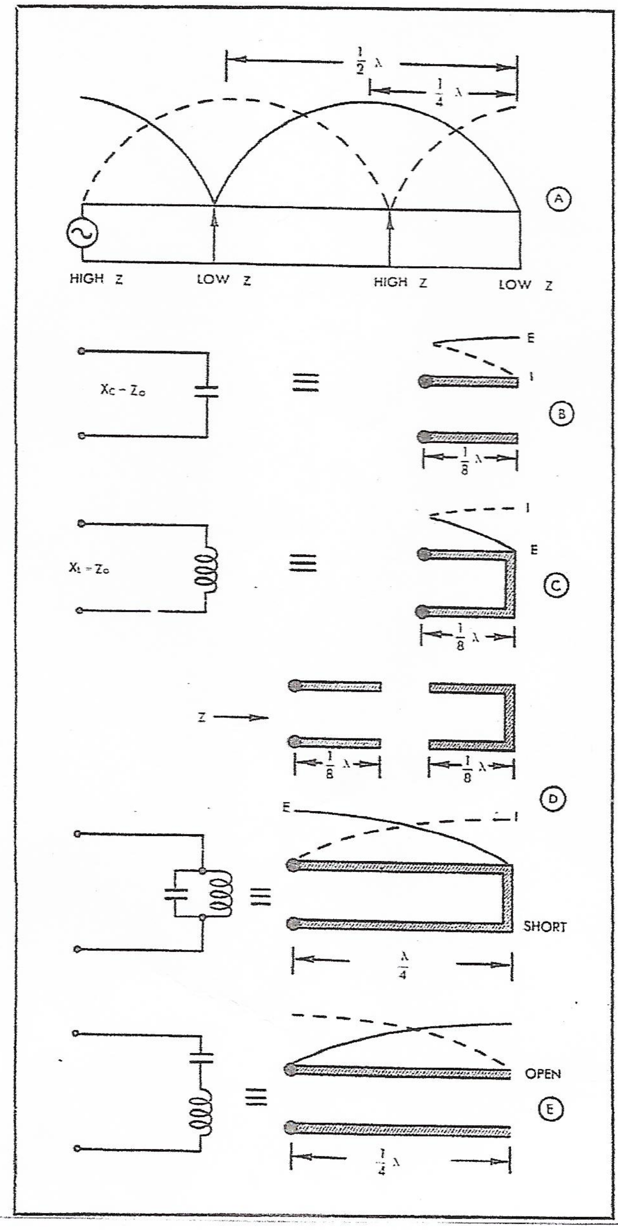
Soon, I hope to provide you a modification of the antenna that appeared in the earlier Newsletter, the one submitted by Bill Adams, a J-Pole made of ½ copper pipe. It is my desire to modify it in such a manner as to allow it to work both bands by making a simple mod or two, costing less than $15.00.

WARNING: The 300 ohm antennas just described should work great for power inputs up to but not to exceed 55-60 watts. If higher power is to be used, the RG-174 cable needs to be replaced with a higher rated cable, but remember the VF will most likely be different in another cable, so we would need to change the lengths accordingly.

Thanks for enduring this very long discussion. I realize it is a lot of reading and I appreciate your indulgence.

Oh, one last change. In my Part 1 of this series, I stated that any vertical antenna would work better with radials added. I should have stated that any vertical antenna that is 'end fed.' Obviously, a vertical dipole, center-fed may suffer with radials attached. I never actually ran tests on a J-Pole with radials, but a highly trained acquaintance of mine did and confirmed an improvement by adding radials bent downward to 30 degrees, but not at 45 degrees. His measurements included true Field Strength readings at 100 meters and at the 3 mile point over unobstructed terrain. Sorry about the goof!!!

Sending End and Termination Impedances of Various Lengths of Transmission Lines



Building a 2 Band J-Pole Antenna