A Truly Broadband, Efficient Low-Band Dipole

The Search for Ham Radio's "Holy Grail"

By

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My quest for the ham radio equivalent of the "holy grail" – a truly broadband 80 meter dipole – began in the spring of 2008, when I moved into my new QTH on five wooded acres in a semi-rural area. Finally free of restrictive covenants and neighbors who failed to see the beauty in amateur radio antennas, I dreamed of building, for the first time in my life, a reasonably competitive contest station. I eagerly looked forward to the contest mayhem on both phone and CW.

The station of my dreams would have two freestanding towers, one for the "run" rig and everyday DXing, and one for the "search and pounce" second rig. The tower for the "run" station was to have a four element SteppIR™, which would cover 20 through 6 meters, and a two element beam for 40 meters. For vertical polarization on 80 for the "run" rig, I designed and built a remotely tuned elevated ground plane that could be used anywhere in the band with an SWR very close to 1:1. A similarly designed, remotely tuned 160 meter inverted L ground plane was also erected. A horizontally polarized antenna would be needed for the "run" rig for good coverage on 80 meters, however, particularly for domestic contests such as the ARRL Sweepstakes and the Washington State Salmon Run. The second tower was to have a tribander, but wires would be needed for both 80 and 40 for the "S&P" rig as well. Since I intended to actively operate both phone and CW, both every day and in contests, I began to consider how I could construct horizontally polarized wires for 80 and 40 that would have a very low SWR in both modes.

While we own five acres, to maintain the pristine nature of the site and for maximum privacy, we had cleared only a relatively small area in the middle of the parcel for the house and yard (to include areas for the towers, where they would be somewhat hidden from the house). When it came time to lay out the low band dipoles, taking advantage of the tallest and most strategically located "antenna trees" for support, it surprisingly turned out that I did not have room for very many antennas (and that was before my XYL expressed her opinion on the subject!). It became obvious that the few wires that I could put up were going to have to do double duty, working well in both the CW and phone subbands, and thus my search for ham radio's "holy grail" – a truly broadband, but efficient, dipole – began. This article will chronicle my quest and the many valuable lessons that were learned along the way.

The Challenge of Bandwidth – How Serious A Problem Is It?

Like most hams, I knew from reading texts and journals, and from practical experience, that antennas have a finite 2:1 SWR bandwidth and that, on the lower frequency bands, that bandwidth is probably not sufficient to allow satisfactory operation over the entire band. Beyond that general knowledge, I had not previously given much thought to the bandwidth problem, however. I had always done what most of us do: cut the dipole using the formula we memorized to pass the license exam ($L_{Feet} = 468/F_{MHz}$), fed it directly with 50 ohm coaxial cable, hoisted it into the air as high as possible, "pruned and tuned" it as best as possible and then lived with the result, as unsatisfactory as that usually proved to be, especially on 80 meters.

Figure 1 shows SWR plots for dipoles made and fed in that typical fashion for all the HF bands, as modeled using *EZNEC* at three different heights above ground: 80, 60 and 35 feet. These graphs vividly depict the bandwidth problem on the lower frequencies, with the results varying significantly with antenna height.

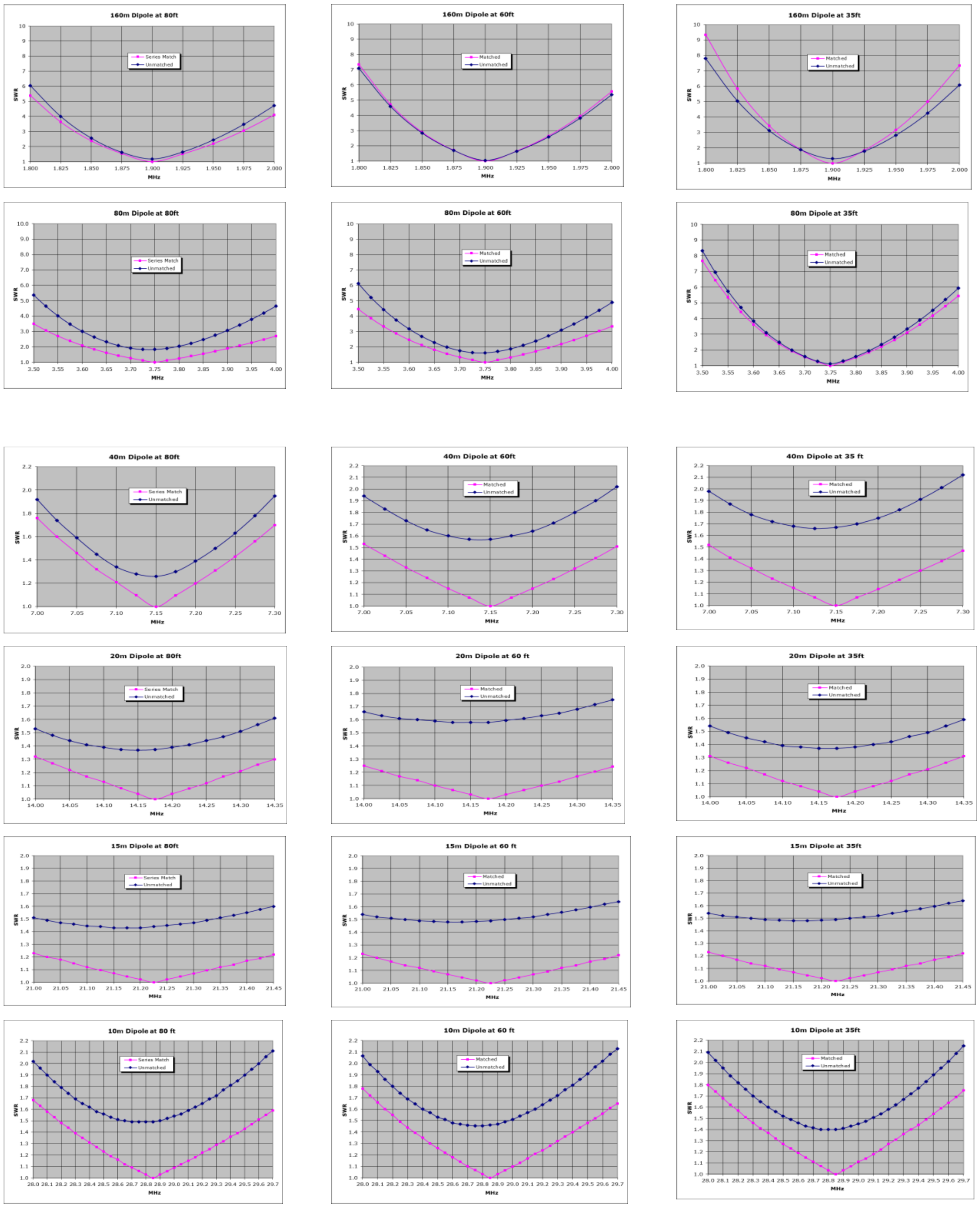

Fig 1. *EZNEC* models of dipoles from the standard formula, fed directly with 50 ohm coax (blue line) or series matched (purple line).

For example, an 80 meter dipole cut according to the formula, hung at 80 feet and directly fed with 50 ohm coax will exhibit a very poor "best case" SWR of 1.83:1 at resonance and has a 2:1 SWR bandwidth of a mere 125 kilohertz. Matching that typical dipole, which has a predicted impedance of 91.3 ohms, to the 50 ohm coax using a series match (discussed below) lowers the SWR at resonance to 1:1, but still the 2:1 SWR bandwidth is only 300 kilohertz – just 60% of the band. The 1.5:1 bandwidth of the series matched antenna at 80 feet is 175 kilohertz, or a mere 35% of the band. To meet my goals, at least two such antennas, and preferably three, would be needed on 80 meters, if they were erected at 80 feet above ground. At 60 feet, the typical dipole exhibits an SWR of 1.62 at resonance and has a 2:1 SWR bandwidth of 150 kilohertz. Matching the 60 foot antenna to its actual impedance of 80.78 ohms improves overall SWR but helps little with bandwidth. 2:1 SWR bandwidth is still only 250 kilohertz and 150 kilohertz for 1.5:1 bandwidth. At a height of thirty-five feet, the 80 meter dipole constructed according to the classic formula and directly fed with 50 ohm coax exhibits a better SWR of 1.1:1 at resonance, but has a 2:1 bandwidth of about 150 kilohertz and a 1.5:1 bandwidth of only 100 kilohertz. Series matching the 35 foot high antenna barely affects its bandwidth at all. An 80 meter dipole at that height is radiating most of its energy nearly straight up, so it is not an effective antenna for other than short range contacts, leaving aside how many such antennas it would take to cover the whole band satisfactorily.

The problem on 160 meters is even worse. While SWR at resonance is modeled to be 1.29 at 35 feet and 1.18 at 80 feet, 2:1 bandwidth is only 75 kilohertz or less at either height. On 40 meters, an unmatched antenna built in typical fashion is predicted to exhibit an SWR at resonance of 1.67 at 35 feet in height and 1.26 at 80 feet. A series matched 40 meter antenna at either 80 or 35 feet meets the 2:1 SWR bandwidth objective, but the goal of SWR at or below 1.5:1 across the whole band is not met if the antenna is erected at 80 feet. Series matched 20 and 15 meter dipoles at any height meet the 1.5:1 SWR goal across the band, with the plot on 15 meters being especially low across the band. However, on 10 meters, the 1.5:1 SWR goal is not met by a series matched dipole at any height. These *EZNEC* plots lead to the conclusion that the need for a broadband design is limited primarily to the lower frequency bands: 40, 80 and 160 meters, although there may be room for improvement on 20 and especially 10 meters, as well.

This preliminary modeling was instructive in two respects. First, I learned why all those dipoles that I had tried to "prune and tune" over the years had not worked very well, often with poor SWR even at their point of resonance. When I was successful in getting the antennas fairly high up in the air, their feed point impedance was far from 50 ohms, with resulting high SWR. Secondly, I learned that, while matching the antennas properly improves their performance notably, it does little to improve bandwidth at the lower frequencies.

Ideas Considered But Rejected

Convinced by these *EZNEC* models that some special design would be needed to achieve my goals on 80 meters, I considered but ultimately rejected a number of alternatives. The most obvious was an antenna fed with ladder line (or coax) and a tuner. Had I chosen this path, such an antenna could have permitted even multiband operation. However, I have never been a fan of tuners. First, while they satisfy the rig's desire for a low SWR at its output, high SWR actually often exists on the transmission line, with resulting substantial losses, especially if coax is used for the line and if the line is a long one, as would be the case at my QTH. Secondly, and particularly if high power is in use, very high voltages can exist in the tuner with resulting danger of failure. Unless an automatic tuner is used, retuning is needed as frequency (and especially the subband of operation) changes. My goal was tuning free QSY within a subband and tuning free choice of modes as well. Ladder line is not aesthetically pleasing and can really get whipped around in a good wind.

One needs to insert a balun in the ladder line in order to run coax into the shack, a balun subject to those unknown but potentially high voltages mentioned above.

I do not want to start a “range war” on this issue. I know that many hams happily and very successfully employ tuners in their stations. Suffice it to say that, for my own reasons, *right or wrong*, I decided that use of a tuner was not for me.

I then went to the literature and found that there is no shortage of ideas for broadband low band antennas. Indeed, the ARRL’s *Antenna Book* devotes an entire chapter to the subject.[1] Similarly, the RSGB’S *Practical Wire Antennas*[2] and *Practical Wire Antennas 2*[3] offer suggested broadband configurations. The issue is addressed in Les Moxon’s *HF Antennas For All Locations*.[4] Various broadband designs can be found in the ARRL’s *Wire Antenna Classics*[5], *More Wire Antenna Classics*[6] and *Simple and Fun Antennas*.[7]

Without belaboring every suggested design, I studied and rejected them all for one or more reasons, to include that some were physical monstrosities, difficult to build or not likely to survive our Northwest winter windstorms, or were aesthetically displeasing, or “all of the above” (*e.g.*, the cage antenna), or their 2:1 SWR curve, while broader than a “normal” dipole, fell short of my goal of an antenna that had less than 2:1 SWR over the entire band and preferably less than 1.5:1 over the whole band. For example, the 2:1 SWR curve for the cage antenna on 80 meters is only 287 kHz, according to the *Antenna Book*.[8] The Double Bazooka antenna’s 2:1 bandwidth is only 14% greater than that of a simple dipole, according to the *Antenna Book*, which calls the antenna “controversial,”[9] probably because it has been questioned whether the antenna’s bandwidth comes at the expense of low efficiency.[10]

Stagger tuned dipoles offered promise, with a theoretical SWR of 1.9:1 across the entire 80 meter band.[11] However, to hope to achieve that result, it is necessary to “stagger” the dipoles not only in terms of their length, but by orienting them at right angles to one another. I spent a great deal of time constructing and erecting such a model, only to find that it did not work at all, at least on the first try The design never got a second chance when my XYL “asked” “*when is that giant spider web over the back yard coming down?*” I tried a “bow tie” or “fantail” version of the staggered dipole,[12] but it proved impossible to tune. Each time I modified the length of one wire, the tuning of the others was thrown off. It did not seem very mechanically sound, either, so eventually I gave up on that idea as well.

My First “Open Sleeve” Antenna Effort

Perusing the literature further, one antenna really caught my eye. It was an “open-sleeve folded dipole” designed by well known antenna authority Rudy Severns, N6LF, in the July, 1995 issue of *QST*.[13] Severns described an “open-sleeve” dipole as one having “additional conductors…added in close proximity to – but not connected to – a common single-wire dipole.” He theorized that, “[i]n addition to the fundamental resonance of the simple dipole, the added conductors create new resonances” increasing the antenna’s bandwidth or even potentially permitting multiband operation.

Severns’ design was a long, skinny rectangular “loop” in the fashion and shape of a classic folded dipole, with what he termed a “resonator wire” running down its middle, parallel to, but not connected to, the long top and bottom wires of the folded dipole. The horizontal wires of the folded dipole were 128 feet, 2 inches long and the vertical end wires were one foot in length. The “resonator wire” was 114 to 118 feet long and equally spaced from the ends and sides of the folded dipole. Severns modeled the antenna and found that it would have a feed point impedance of about 450 ohms, lending itself to being fed with a random length of 450 ohm ladder line to a 9:1 balun and then coax to the shack. The model of his antenna with a “resonator wire” of 118 feet in length resulted in a predicted SWR curve of less than 1.5:1 across the entire 80 meter band.

I was hooked and immediately began construction of N6LF's antenna. Very soon, I learned what I now call *W7ZZ's First Law of Antenna Experimentation*, one of many that I would master during my quest for the ham "holy grail": "*What sounds good in the journal article may well not work at all for you in your back yard."*

In fairness, Severns had hinted at this possibility in his article, noting that the antenna's "height above ground [and] ground effects are important and will affect the impedances and final dimensions." He noted that he "only had to adjust the center wire a bit to get the predicted performance" at *his* QTH. I can now attest that a journal author's definition of the term "a bit" may vary considerably from your own.

Close on the heels of the First Law, I quickly mastered the Second Law: "If it doesn't work in your back yard, you probably will not be able to figure out why, at least not without the help of other hams a lot smarter or more knowledgeable than you."

With the advantage of a lot of hindsight and considerable input from others smarter and more knowledgeable than I, here is what I did wrong, and my best guesses why N6LF's perfectly sound antenna design did not work for me and might not work for you either, should you try it.

First, I had a large spool of THHN insulated wire in the garage, so I used it to make the antenna. *Corollary One* to the *First Law* is that "*insulated wire and bare wire are not interchangeable when making antennas,*" as convenient or economical as it may seem to try. The insulation adds capacitance to the wire and therefore affects its electrical length. I knew that. I had just ignored it, assuming that a "broadband" antenna could tolerate some "fudging" in its construction without having a significant effect.

Secondly, I guessed at how high the antenna would be (and was off by quite a bit) and I had no idea of the conductivity of my soil, factors that Severns had pointed out were "important," as noted already. These three factors meant that I had no idea what the feed point impedance really was for my antenna as actually constructed, but experience soon proved it probably was not the 450 ohms modeled by N6LF. If the antenna impedance was not 450 ohms, then the ladder line was acting as a transformer, rather than merely as a transmission line, creating a different impedance at the balun than at the feed point of the antenna.[14] I later learned, much to my surprise, that 450 ohm ladder line is not really 450 ohms in impedance anyway. The ARRL's *TLW* software says that it is typically 405 ohms and testing with an antenna analyzer proved that the ladder line in use in my back yard was a bit lower still.

It was suggested to me that I vary the length of the ladder line to see if the antenna was affected. Sure enough, it was, indicating that the feed line was acting as part of the antenna or was interacting with it in some other, unknown way or, as mentioned, was acting as an impedance transformer in some unpredictable fashion. All of these variables of combined unknown effect were creating an unknowable impedance at the end of the ladder line that was then being divided by nine by the 9:1 balun, so it really came as no surprise that my first effort at N6LF's antenna was a complete disaster.

The Second Law Invoked: The Cry for Help Goes Out

As noted already, the quest for the "holy grail" had started in the spring of 2008. By the time that my model of N6LF's antenna proved to be a failure, it was December of 2009. Not wanting to give up on what appeared to be the most promising design I had found thus far, and having mastered the *Second Law*, I sent out a cry for help on one of the ham Internet reflectors, asking if anyone had modeled N6LF's antenna using *EZNEC*. At that time, my *EZNEC* modeling skills were not up to the task. Overnight, I received a reply from Terry Conboy, N6RY, with several models of the antenna with different “resonator wire” lengths and even a model of a wide spaced folded dipole with no “resonator wire.” Thus began a collaboration best characterized as professor/student – and a friendship – that has continued to the present day, with N6RY providing the technical expertise and W7ZZ tweaking N6RY’s various *EZNEC* designs by the trial and error method and then constructing and testing various prototypes in the back yard. Not long after we started exchanging ideas and models, N6RY proposed a “single open-sleeve dipole” model for consideration, and that has evolved into the antenna presented in this article.

Enthused about the “open-sleeve” concept, and noting that N6LF’s article claimed that it was “an idea that’s been around since W[orld] W[ar] II,” I conducted some research of the literature. The earliest article that I could find was in the August, 1983 issue of *CQ* magazine.[15] It was mostly theoretical in nature but the author, WBØDGF, concluded: “I feel as though I have discovered an entirely new and exciting antenna. In a way it is new to the amateur community. Why, in over 30 years of experience, no amateur has put its simplicity and broadband capabilities to work, I do not know.” A very brief reference to a three-band open-sleeved dipole was found, authored by antenna guru Bill Orr, W6SAI [SK], in the February, 1995 issue of *CQ*.[16] Orr noted that the 17th Edition of the ARRL *Antenna Book* had a “good write up” on the antenna. Looking in the 21st edition, which I own, sure enough I found a section authored by WBØDGF on the theoretical aspects of the open-sleeve antenna.[17] However, my search concluded that there was a complete absence in the literature of practical advice on how to model or build this antenna (other than N6LF’s version), and that finding prompted the writing of this article.

How to Model the Single Open-Sleeve Broadband Dipole

Recall W7ZZ’s *First Law of Antenna Experimentation*. While dimensions will be offered in this article for 80, 40 and 20 meter versions of this antenna that have been modeled by the authors using *EZNEC*, built and tested by W7ZZ with excellent results, and used successfully on the air, if you build them in your back yard, they may not work well, or at all, especially if your antenna as constructed or your antenna height or ground conditions differ from the design or the conditions at W7ZZ.

Indeed, it must be confessed that W7ZZ modeled and built a prototype 10 meter version of the single open-sleeve dipole using an early working design which, despite several attempts, refused to perform as modeled and, so far, neither W7ZZ nor N6RY has been able to figure out exactly why (recall the *Second Law*). The 160 meter version of the antenna has only been modeled using *EZNEC*; it has not been built or tested by the authors. For these reasons, it is important that you be able to model this antenna for yourself. This maximizes the likelihood that your antenna will perform as expected at your QTH and, if not, that you (or, recalling the *Second Law*, others smarter or more knowledgeable than you) will be able to figure out why, so that the second try will succeed.

As shown in Figure 2, the basic design of N6RY’s single open-sleeve antenna is the ultimate in simplicity. The lower wire is a classic dipole, fed at its center. At some distance above the dipole, centered on it and parallel to it, is a shorter wire that is not physically connected to the dipole or transmission line in any way. Severns termed this the “resonator wire” because his 80 meter model appeared to him to have two points of resonance, obviously caused by the presence of the second wire. All of our models exhibit double “dips” in SWR (much less pronounced on other bands than the 160 and 80 meter versions), which are affected by the resonance of this additional wire and its spacing from the dipole. However, we prefer the term "parasitic" to refer to this wire, that clearly is affecting the dipole's performance in some fashion but is not in physical contact with it.

While the actual antenna consists of three pieces of wire (the two halves of the dipole and the parasitic wire), it should be modeled in *EZNEC* using four wires as shown in Figure 2, three for the dipole and one for the parasitic wire. Due to the manner with which *NEC* deals with parallel wires in close proximity to one another, it is important for both the middle *EZNEC* wire of the dipole and the parasitic wire to be of the *same length* and the *same number of EZNEC segments*.

You will find that this also makes tinkering with the model, to make it suitable for your installation (height, ground, wire size, etc.), very easy. For example, one can lengthen or shorten the dipole, without having to change the length of the parasitic wire in the model, just by adding to or subtracting from the "outboard" *EZNEC* wires of the dipole. Conversely, one can shorten or lengthen the parasitic wire without changing the entire length of the dipole (unless you choose to do so): just change the length of the parasitic and center dipole wires equally, leaving the outermost coordinates of the dipole unchanged. After you have done this a few times, it will be second nature to you.

So that the *EZNEC* source can be placed in the middle of the dipole, one must use an odd number of segments for the dipole's center *EZNEC* wire. We used 99 segments for the center wire, so that the source would be on the fiftieth, middle segment. The more segments that are used in the model, the more accurate it will be (provided that no segment is shorter than 0.001 wavelength).[18] Some of our models use eight *EZNEC* wires: a very short segment in the middle of the dipole and two "inboard" wires in lieu of the single 99 segment wire in the four-wire version, with the parasitic wire likewise consisting of three wires rather than one. As long as the three center wires of the dipole and the three wires of the parasitic wire are of the same lengths and the same number of segments with respect to one another, the end result is the same. Figure 2 illustrates the simpler design, which is neither better nor worse than the eight-wire model.

The antenna is modeled in only two planes: the X and Z axis, with no Y component at all. It is convenient to center both wires at the intersection of the X and Z axes. This makes it easy to lay out the design on the axes and to troubleshoot the coordinates of each wire if there is a problem, since the coordinates of wire points to the right of the Y axis are the same as those to the left, other than their polarity. This is illustrated in Figure 2. A good starting point for the overall lengths of both wires is to model the parasitic wire for the top of the band and the dipole for the bottom. The usual formula can be used: $L_{Feet} = 468/F_{MHz}$. Because we planned to build our antenna using #12 bare copper wire, we used a slightly different formula: $L_{Feet} = 474/F_{MHz}$. Since there is going to be some trial and error experimentation with regard to wire lengths anyway, either formula will give you a good place to start.

EZNEC models for all of the antennas described in this article, at three different heights above ground, are also available as a downloadable ZIP file from the *ARRL Antenna Book, 23rd Edition's* website.

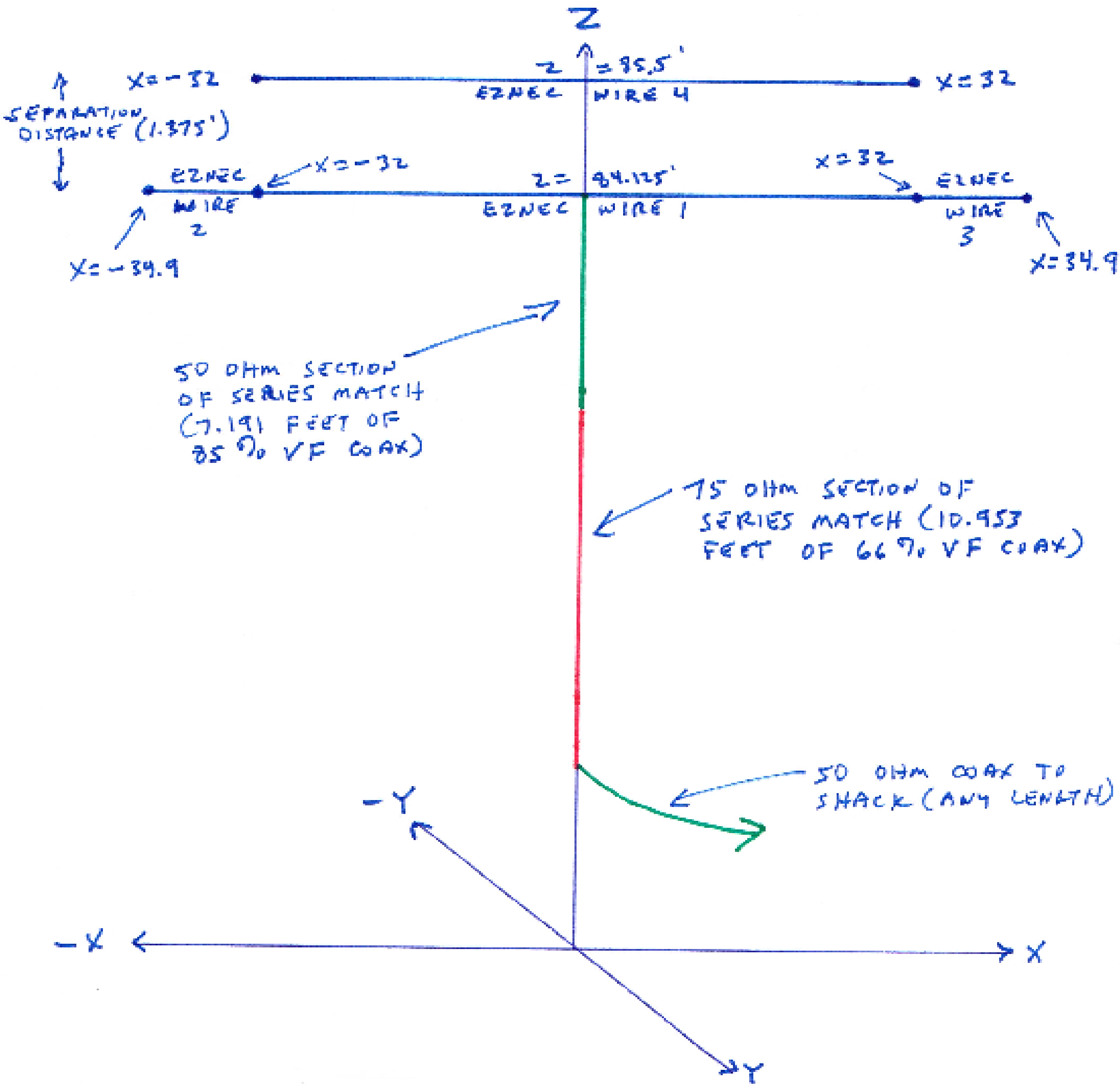

Figure 2. Typical *EZNEC* model for the broadband dipole (not to scale). The dimensions shown are for a 40 meter antenna at about 85 feet and are taken from Table 1. Wires 1 and 4 of the *EZNEC* model should always be the same length and consist of the same odd number of segments. An odd number is used so that the feed point will be at the center of the antenna. Wires 2 and 3 should always be the same length and the same number of segments. The separation distance between the two wires is the difference in their Z height. When the antenna is constructed, a choke will be placed at the feed point or at an electrical one-half wavelength (or multiple of an electrical half wavelength) from the feed point (see text). Table 1 gives suggested lengths and separation distances for 160, 80, 40, 20 and 10 meter versions of the antenna. *EZNEC* wires 1, 2 and 3 are the "dipole" wire and *EZNEC* wire 4 is the "parasitic" wire referred to in Table 1.

One must also tell *EZNEC* the type of wire that will be used in the antenna's construction. As just mentioned, and for reasons that will be explained as the construction of the antenna is discussed below, we used #12 bare copper wire. Wire size and type are input directly into *EZNEC*, which "translates" the wire size to the dimension actually used by the underlying *NEC* software. While *EZNEC* can model insulated wire, we strongly discourage you from trying it. Doing so almost certainly introduces a "wild card" into the process and may very well cause an antenna that looks fine in the model to fail to perform once constructed, due to variations in insulation material from one brand of wire to the next.

A *very* important variable is the distance above ground of the entire antenna. It is strongly suggested that this be actually measured before the antenna is constructed, so that your model matches the actual height at which the antenna will hang above ground. To do this, shoot lines over your two supporting trees and pull them to the ground. Tie them together and attach a tag line where the two lines meet. Pull the two lines and the tag line up in the air until taut. Tie a knot in the tag line at ground level and then pull down the ropes. Take off the tag line and measure its length to the knot – that will be the height above ground that should be entered in the model for the parasitic wire, as explained further below. Leave the two lines over the trees, so you'll be set to pull up the antenna at the modeled height once it is built.

The separation distance between the parasitic wire and the dipole is a matter for trial and error experimentation using *EZNEC*, as are the actual lengths of the two wires. In *EZNEC*, the separation distance is modeled by placing the parasitic wire and the dipoles at different heights on the Z axis. If the dipole is at 80 feet and the parasitic wire is at 81 feet, for example, the separation distance between them is one foot. Good starting separation distances are 29 inches on 160 meters, 17 inches on 80, 14 inches on 40, 6 inches on 20 and 5 inches on 10 meters. You will note that we skipped 15 meters. That is because, as mentioned previously, a series matched dipole on 15 meters offers such a low SWR across the entire band (about 1.2:1 or less, as shown in Figure 1) that fashioning a broadband antenna is simply unnecessary on that band.

Another important variable is the type of ground and conductivity at your site. Due to conditions at W7ZZ, we modeled the antenna using "Real/High Accuracy" ground described in *EZNEC* as "Average, Pastoral, Heavy Clay." Differing choices for the ground description will affect the model. *EZNEC*'s help files describe the various ground types available in the program.

For a given wire size and type, ground type and height above ground of the dipole, there are a seemingly infinite number of combinations of dipole length, parasitic wire length and wire separation. As you try to improve your model from the starting dimensions and data, it is very important to keep a log of which variable(s) you last changed and, if the resulting SWR curve is better than the last, print it out and note all of its associated *EZNEC* coordinates and settings before experimenting further. This is *W7ZZ's Third Law of Antenna Experimentation*: *"If you fail to record all the EZNEC coordinates and settings associated with that nearly perfect model, you will modify it in the hope of making it better still, and then be unable to replicate the near perfect model later on, losing it forever."* I learned the *Third Law* the hard way. Indeed, being something of a slow learner, I learned it the hard way over and over again.

At this point, your model will have no transmission line. Place the *EZNEC* Source in the middle of the dipole. By default, *EZNEC* plots SWR of models at a load impedance of 50 ohms, but the program allows you to select a different load impedance called "Alt SWR Z_0." Set *EZNEC*'s "Alt SWR Z_0" to 100 ohms. This is purely arbitrary, but one has to start somewhere. Tell *EZNEC* to run an SWR sweep of the entire band using fairly small frequency steps and, when the plot appears, make sure that *EZNEC* was indeed using the Alt SWR Z_0 of 100 ohms and not 50 ohms, to which the program may have defaulted. Observe or print out the plot. Increase or decrease the Alt SWR Z_0 impedance and run another SWR plot. If the new plot comes closer to low SWR across the band than before, continue increasing or decreasing Alt SWR Z_0 and repeat the process.

After a number of tries, if your best plot has not yet exhibited results that you deem satisfactory in terms of low SWR across the entire band, then tinker with the length of the dipole *and/or* the length of the parasitic wire (remembering that the center portion(s) of the dipole in the model must match the parasitic wire in length and number of segments) *and/or* the separation distance, and then start the process all over again. It is wise to experiment with only one variable at a time but, whether you experiment with one or several, keep the *Third Law* at the forefront of your mind as you do so. While the trial and error system works well – if a bit tedious! – you can automate the process by putting *AutoEZ*, a *Microsoft Excel*^{TM} application developed by Dan Maguire, AC6LA, to work. The lengths of the wires, wire separation and other variables can be input into *AutoEZ* and the program will optimize for best SWR.[19]

It should be noted that the Alt SWR Z_0 that you are experimenting with is *not the impedance of the antenna at the center of the dipole*. It is an *arbitrary* impedance that, for the design being tested, happens to produce a result *over the whole band* that is desirable: very low SWR at as many frequencies within the band as possible. Indeed, the most desirable SWR plot over the whole band probably will not show a perfect 1:1 match anywhere in the band. When W7ZZ modeled, built and erected his prototype antennas, the SWR plots for which are shown in this article (Figure 3 below), W7ZZ set Alt SWR Z_0 to the actual Source impedance of the antenna as reported by *EZNEC* and that impedance was then series matched to 50 ohm coax. While W7ZZ's antennas worked well and accomplished our broadband goals (and indeed the 80 meter prototype is still in use at W7ZZ's QTH today), further modeling by N6RY has shown that the best results are obtained when Alt SWR Z_0 is selected empirically, by trial and error, to the impedance that produces the best (lowest) SWR plot over the whole band, *regardless of the actual impedance of the antenna*. Again, the best plot probably will not show a perfect 1:1 SWR anywhere in the band. Don't worry about that: SWR of 1:1 at some point in the band is not our goal. Our goal is the lowest *overall* SWR over the *entire* band.

The Alt SWR Z_0 for My Model is Other Than 50 Ohms. Now What Do I Do?

Rest assured that the Alt SWR Z_0 impedance that produces the best SWR plot for your model is almost certainly not going to be 50 ohms. Your task now is to match your unique Alt SWR Z_0 impedance to 50 ohm coax. There are two ways to do this: using a quarter wave transformer (often called a "Q section")[20] or a series section transformer. As luck would have it, the Alt SWR Z_0 that produced the best SWR plot for our prototype model of the 80 meter single open-sleeve dipole at the desired height of 80 feet was very close to 112.5 ohms.

N6RY pointed out that an impedance of 112.5 ohms was perfect for matching to 50 ohm coax by inserting an electrical quarter wave section of 75 ohm coax between the feed point of the antenna and the 50 ohm line running to the shack. A quick search in the literature and on the Internet revealed that 75 ohm RG11U has a velocity factor of 66%, which I verified with an antenna analyzer for the RG11U that I purchased from a local supplier. It was a simple matter thereafter to calculate the physical length of an electrical quarter wave of RG11U. The formula for a full wavelength in free space, expressed in feet, at 3.75 MHz is 984/3.75, so a quarter wave is (984/3.75)/4. Since RG11U's velocity factor is 66%, the physical length of an electrical quarter wavelength is ((984/3.75)/4)*(.66) feet. That length of RG11U at the feed point of the antenna matched the antenna to the 50 ohm coax running to the shack very well.

Remember the *First Law*. While our 80 meter model was perfect for use of a quarter wave matching section, yours may not, and may require use of the series section method of impedance matching described below.

Indeed, the Alt SWR Z_0 determined empirically for our 40 and 20 meter prototypes at 80 feet could not be transformed to 50 ohms by the simple quarter wave 75 ohm section that worked for the 80 meter antenna. Accordingly, N6RY suggested that a series section transformer be employed. Simply stated, a series section transformer consists of two lengths of coaxial cable in series with the feed line and the antenna. The first, 50 ohm cable, is attached to the feed point of the antenna at one end and to a section of 75 ohm cable at the other. The other end of the 75 ohm section is then connected to the 50 ohm line running to the shack.

One must take into account the velocity factors for the coax you employ in each section since they vary with the manufacturer. Some very heavy math is required to calculate the necessary lengths of the two coax sections, which is described in detail in *The ARRL Antenna Book*[21]. N6RY came to the rescue, creating an *Excel* spreadsheet that performed all the calculations. You can use the series match calculator authored by W8WWV that can be found on the Internet[22]. All that is required is inputting the frequency (the middle of the band), the desired Alt SWR Z_0 impedance (enter as purely resistive, with no reactive component) and the velocity factors of the two coax sections you intend to use. Belden 9913f was used for 50 ohm cable at W7ZZ and its velocity factor is 85% according to the manufacturer. You will enter the velocity factor for your brand of coax. As noted above, RG11U generally has a velocity factor of 66%.

The lengths of the two sections so calculated are then entered as transmission lines 1 and 2 in the model, the *EZNEC* Source is moved to the end of the 75 ohm line (where it joins the 50 ohm coax running to the shack) and the model is complete. Running a new SWR plot, with *EZNEC* now set to read SWR to a 50 ohm load rather than the Alt SWR Z_0 impedance, should produce a curve nearly identical to the one with no transmission line and with *EZNEC* plotting SWR for the Alt SWR Z_0 impedance. All that has been done with the series section is to match the 50 ohm coax going to the shack to the Alt SWR Z_0 impedance for your modeled antenna.

There are limitations with regard to the source impedance that can be matched using a series match made of 50 and 75 ohm cable sections. The Alt SWR Z_0 impedance to be matched by the typical series match should not exceed 112.5 ohms (112.5 ohms being a special case, as already mentioned, in which the first 50 ohm section is of zero length and the second, 75 ohm section, is an electrical quarter-wavelength – as a practical matter, the matching circuit consists only of a quarter wave section of 75 ohm line).

If your desired Alt SWR Z_0 exceeds 112.5 ohms, tinker with the wire lengths and/or separation distance to find a new Alt SWR Z_0 that is below 112.5 ohms yet produces as good a result. However, if your best model uses an Alt SWR Z_0 of greater than 112.5 ohms, then two series section matching circuits in series with one another can be used to match the higher impedance to 50 ohm line. Using the series match calculator, use 75 ohm line from the antenna feed point to the second section, rather than 50 ohm, and use 50 ohm cable for the second section, rather than 75 ohm. The calculator will then state lengths for each section that, in series, will match the Alt SWR Z_0 impedance of greater than 112.5 ohms to a 75 ohm load.

Next, undertake a second series match calculation using 75 ohms as the impedance to be matched and 50 ohms as the desired matched impedance. This section will consist of the typical 50 ohm line in series with 75 ohm line, which will be connected to the 50 ohm line running to the shack. Since this double series matching circuit has two 50 ohm sections back to back, it will end up being constructed as 75 ohm line from the antenna to a single section of 50 ohm line which will be connected to another 75 ohm section terminating at the 50 ohm coax leading to the shack. While this double series match circuit will work for Alt SWR Z_0 impedances above 112.5 ohms, usually the better choice is to target an impedance lower than that, so that either a quarter wave 75 ohm line or a single 50/75 ohm series section match may be employed.

It Doesn't Work as Advertised. Now What Do I Do?

Recall the *First Law*. It applies to those who write journal articles as well as to those who read them! W7ZZ's first prototype of the 80 meter antenna, erected at 80 feet in height, exhibited an actual SWR curve somewhat similar to the *EZNEC* prediction but, overall, SWR was unacceptably worse, especially at the high end of the band. N6RY theorized that the antenna might be affected by common mode current on the outside of the coax. To test that theory, he modeled the antenna with an extra wire, parallel to the feed line, to represent the outer braid acting as a conductor. Sure enough, this model's SWR plot closely resembled how the W7ZZ prototype of the antenna was behaving in real life.

N6RY suggested addition of a balun or choke on the feed line to suppress common mode currents on the braid. A choke was utilized, which will be described below as construction of the antenna is discussed, which greatly improved the antenna's performance, bringing it nearly in line with the *EZNEC* model. The "actual" SWR curves for the 80 meter prototype antenna as shown in Figure 3 are with that choke in place. *EZNEC* predicted SWR of 1.39:1 or below from 3.5 to 3.975 MHz, with most of the band exhibiting SWR of 1.3:1 or less, rising from 3.975 MHz to a worst case SWR of 1.65:1 at 4.0 MHz. In actual use, W7ZZ's prototype antenna exhibits SWR of 1.5:1 or better over essentially the entire 80 meter band, with most of the band having SWR of less than 1.4:1, and an absolute worst case SWR of about 1.65:1 at 4.0 MHz.

Enthused at the success achieved with the 80 meter prototype, test versions of models for 40 and 20 meters were also built by W7ZZ. All were erected at 80 feet. A choke was placed at the feed point for the 40 meter antenna. Since the 20 meter antenna was intended for only temporary use, no choke was used for it. Figure 3 shows how these antennas performed in W7ZZ's back yard as compared with their *EZNEC* models. W7ZZ's 80, 40 and 20 meter prototypes were designed by matching the load to the actual antenna impedance at resonance, rather than to an Alt SWR Z_0 determined empirically as recommended in this article. Therefore, W7ZZ's antennas, while a great improvement over a typical impedance matched dipole and other broadband antennas in the literature, do not reflect the much better performance that one should expect from the most current design.

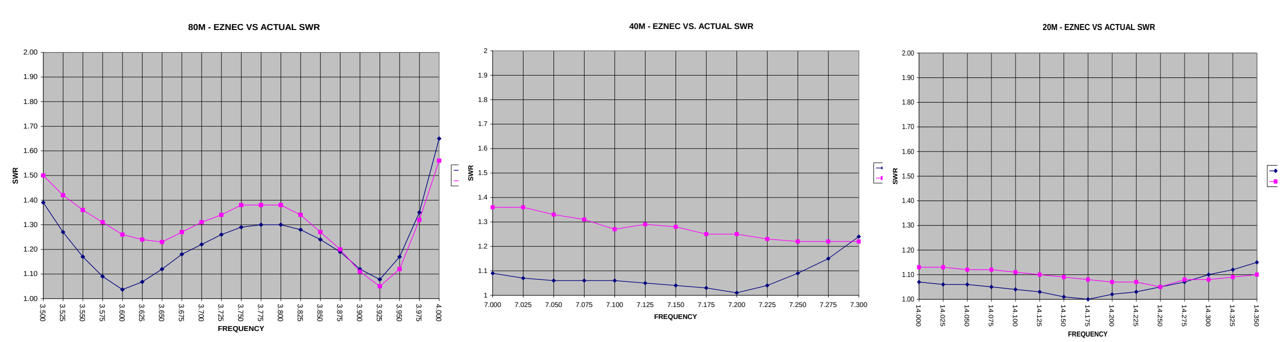

Figure 3. Predicted (blue) and Actual (purple) SWR Plots for the Prototype Antennas. Performance was sufficiently satisfactory that the 80 meter prototype is still in use by W7ZZ.

Figure 4 presents *EZNEC* predicted SWR plots for 160, 80, 40, 20 and 10 meter antennas at several heights above ground, all as modeled using the method described in this article. Table 1 provides the dimensions of all of these antennas for construction purposes.

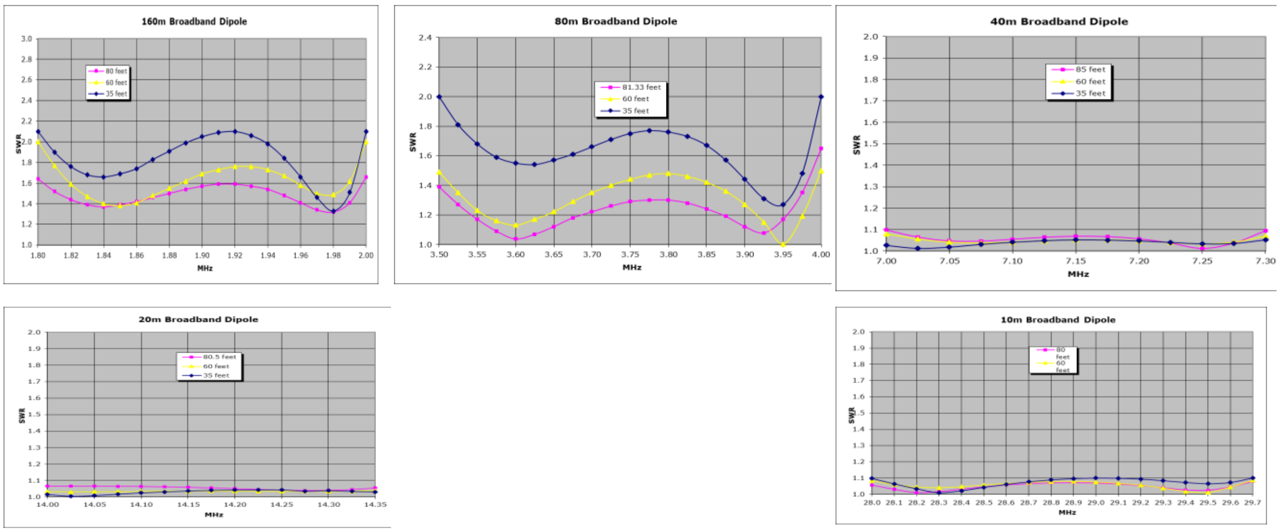

Figure 4. 160, 80, 40, 20 and 10 meter EZNEC predicted SWR plots for the broadband dipole at 80, 60 and 35 feet.

Examining the predicted SWR plots for these antennas, it is clear that the series-section-matched, single open-sleeve dipole offers hams a fairly simple antenna that can be used with very low SWR over the entire bandwidth of all the HF bands. It is especially useful for 80 and 40 meters. While building antennas based on our models should offer you excellent results, we encourage you to master the design process outlined in this article, and strongly encourage you to further experiment using the open-sleeve concept. We certainly do not wish to suggest that our designs are the best that can be achieved.

They Look Good on Paper, But Do They Work?

We now have an antenna that meets our broadband objectives. The question remains, is this antenna efficient as well? Antenna efficiency is the fraction of power that is applied to the antenna that the antenna actually radiates. The rest of the power is lost as heat in lossy parts of the antenna structure. System losses can also include the effects of ground, feed line and matching network losses. Discussing this broadband dipole project with a cynical ham friend of mine, he noted that a dummy load is very broadbanded, but it is about as inefficient a radiator as one can find. He pointed out that we will have designed a truly noteworthy and useful antenna only if it is *both* broadbanded *and* efficient.

Band	Height (feet)	Dipole Length (feet) (lower wire)	Parasitic Length (feet) (upper wire)	Separation (inches)	Alt SWR Z_0 Ohms	50 Ohm Series Match Length (feet)	75 Ohm Series Match Length (feet)
160	80	262	237.8	30	112.5	n/a	85.834
	60	260	239.26	24	95	22.127	48.956
	35	262	240.53	24	90	25.683	43.36
80	81.833	136	119	10	112.5	n/a	43.277
	60	134	118.3	24	112.5	n/a	43.277
	35	133.59	119.37	18	112.5	n/a	43.277
40	85.5	69.8	64	16.5	88	7.191	10.953
	60	70.9	63.9	8	85	7.734	10.116
	35	69.98	62.84	18	112.5	n/a	22.7
20	80.5	35.7	32.1	6	98	2.663	7.044
	60	35.6	31.8	6	97	2.766	6.88
	35	35.6	32.2	6	80	4.352	4.414
10	80	17.46	15.46	5	93	1.553	3.075
	60	17.44	15.456	5	95	1.457	3.224
	35	17.5	15.57	5	85	1.916	2.507

Table 1. Dimensions for 160, 80, 40, 20 and 10 meter versions of the antenna at 80, 60 and 35 foot elevations. The coax lengths for the series match assume an 85% velocity factor for the 50 ohm coax and a 66% velocity factor for the 75 ohm coax. If you use coax with a different velocity factor, you will need to recompute the lengths. Similarly, the EZNEC model assumed the use of #12 bare copper wire and "Real/High Accuracy" ground described as "Average, Pastoral, Heavy Clay."

N6RY has calculated and plotted the wire losses for our broadband dipole and those plots, for antennas modeled at a height of 80 feet, are presented in Figure 5. The plots are limited to wire losses, on the theory that we are comparing our design to a simple dipole that would be hung over the same type of ground and that would also be fed with coax and matched with a similar series section match to achieve the lowest SWR. In other words, the only real difference between the two types of antenna is the existence of the parasitic wire in the broadband dipole and whatever losses its presence introduces.

Examining the wire loss plots in Figure 5, each exhibits very low loss over most of the band, with loss increasing near the top of the band. This is worst on 160 meters, where the wire loss is -0.2 dB from 1.8 to about 1.94 MHz, rising thereafter to -0.37 dB at 1.975 MHz and peaking at -0.64 dB at the top of the band. (Losses are given as negative values of dB – *Ed.*) Of course, the performance of the 160 meter version of the antenna is also the worst of them all, with SWR hovering at plus or minus 1.5:1 over the whole band whereas, on the other bands, such an SWR was the worst case. On 80 meters, wire loss is a low -0.1 dB from 3.5 to 3.8 MHz, rising to -0.23 dB at 3.95 MHz and a worst case -0.34 dB at the top of the band. On 40 meters, the worst case loss is -0.15 dB. On 20 and 10 meters, wire loss is negligible: less than -0.1 dB across the whole band. Studying the wire loss at the top end of each band, N6RY concluded that greatly higher currents flow in the parasitic wire at the top end of the band, presumably resulting in the noted losses. Overall, however, even at their worst, losses in this antenna design are minimal and clearly acceptable to achieve the benefits of very low SWR over an entire band.

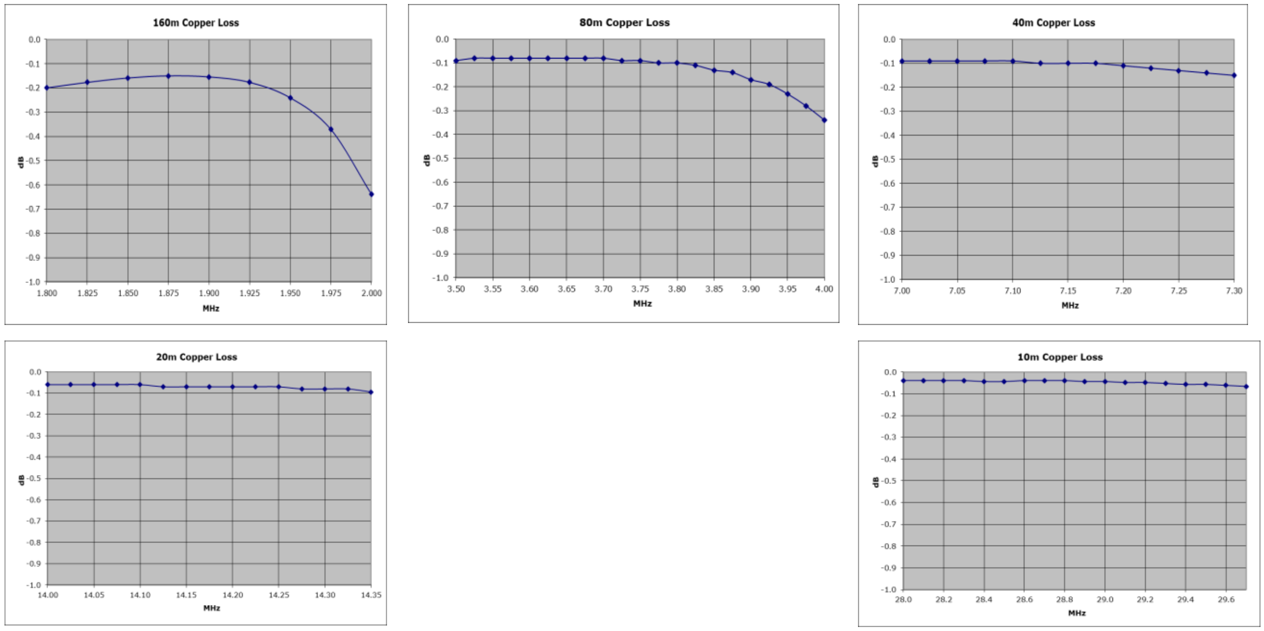

Figure 5. The broadband design is very efficient. Losses are minimal compared to a "normal" dipole.

Theory is great, but how do these antennas play in real life? The 80 meter version has performed as one would expect for such an antenna at the 80 foot height at which it has been erected at W7ZZ's QTH. It certainly is nice to know that I could work CW tonight and phone tomorrow night on the same antenna, without giving the change in frequency a second thought. On 40 and 20, the antennas at 80 feet have been superior performers. In just a few hours of operation in the ARRL Phone DX Contest, with 100 watts to the prototype antennas, stations from as far away as Chile and Asiatic Russia were in the log on 20 meters, mostly on the first call. On 40 meters, stations from South America, Central America, the Caribbean, Europe, Japan and Asia all were in the log on the first or second call. These antennas play very well indeed.

We Did It! The Ham "Holy Grail" Is In Hand

While the quest was a long and tortuous one, extending unbelievably over a period of nearly four years of intermittent work on the project, it is clear that the ham radio "holy grail" is in hand. Hams can now build a truly broadband and efficient, relatively simple dipole-like antenna that performs equally as well in the CW and phone portions of the band. Indeed, this antenna will outperform any existing dipole that you have up in the air now over most of the band, and should equal it at least, even in the narrow band segment that your antenna effectively now covers with reasonable SWR. These antennas should perform as well and maybe better than your existing antennas that are being matched in the shack with a tuner, and the minimal wire losses in these antennas may be less than the loss now being suffered due to high SWR on the feed line between your tuner's output and your antenna's feed point. And, did I mention – you won't need that tuner any more!

However, what has been truly amazing is not the successful designing and building of this broadband dipole, but the knowledge that I have gained along the way of antenna design, antenna modeling, transmission lines, impedance matching, common mode currents, baluns and chokes and their usefulness, ground effects, the effect of antenna height on performance, antenna efficiency, antenna construction and the like, some of which has been touched on above. Even if the antenna design had ultimately been a failure, pursuing the ham "holy grail" would have been a very worthwhile endeavor indeed.

Construction of the Series-Matched, Single Open-sleeve Broadband Dipole

Construction presented several challenges:

(1) The shorter parasitic wire is the one on top. Were it the other way around, the lower wire could just be "hung" from the upper.

(2) The two wires must be separated from one another by a specific distance and that separation distance is an important part of the model and therefore should be as constant as feasible over the length of the antenna. Both wires need to remain reasonably taut for this to occur and some kind of non-conducting spacers must be employed.

(3) A way must be found for the parasitic wire to stay centered on the dipole below it, despite the fact that the parasitic wire is not connected in any way to the dipole or feed line (or anything else, at least in the model).

(4) An early test version of the antenna revealed that it has a tendency to twist while being pulled up into the air, particularly before the weight of the coax helps to stabilize it, and a lot of antenna is part way into the air before the coax in the middle leaves the ground. Depending upon the distance between spacers and the manner by which the antenna was attached to the support ropes, the ends wanted to twist even when it was fully in the air. N6LF encountered this problem with his antenna as well and tried to solve it by inserting fishing swivels between the antenna support ropes and the antenna itself and by hanging fishing weights from the bottom wire to weight it in the proper orientation. A better solution than that was needed.

(5) Finally, the lower frequency versions of the antenna are fairly heavy due to the weight of the numerous spacers, the amount of wire being used and the weight of the coax hanging from the center point. The design and construction techniques presented below solved all of these problems. The 80 meter prototype of the antenna has been in the air in W7ZZ's back yard, strung between tall trees that sway wildly in high winds, through several seasons and all kinds of foul weather, without incident.

The easiest way to start to build the antenna is to find two trees that are separated from one another by a distance longer than the antenna and stretch what will become a catenary rope between them, at chest to neck level. If you can do this between the trees that will actually be used to support the antenna, that is ideal, because then the antenna will not have to be moved to its point of erection but will already be there, and even properly aligned. I was able to do this with the 80 meter prototype but had to carry the 40 meter version from its point of construction to where it would be hauled into the air, because there was dense vegetation between the support trees that prevented me from building it there. That took three people to accomplish, one on each end and one in the middle. I wish I had that on film. We looked like a bizarre Chinese New Year's dragon as we trudged through the back yard with the antenna swaying between us. Note that I have suggested that the catenary rope be stretched at a height between chest and head level. It is going to take quite some time to assemble this antenna, so you do not want to be doing it while half stooped over. I wish that I had learned that lesson sooner than I did.

Figure 6. Center spacer, flanked by two others, as described in the text. A commercial center insulator hangs from the center spacer.

Next, calculate the distance you want to use between spacers and, with that information, the total number of spacers that will be required. I chose to put a spacer exactly in the center and then two more, only a few inches from it, one on either side. This was to allow me to attach the center insulator to the center spacer, so that it would be supported by it, but have the other spacers nearby to maintain the separation distance at this point of stress, and also to eliminate twisting at the center while the antenna was being raised. The three center spacers and the method I used to attach the center insulator to the center spacer are shown in Figure 6. My dipole length for the prototype 80 meter antenna was 136 feet long or 68 feet on a side, so I placed my spacers four feet apart, starting from the center.

For this purpose, I ignored the spacers that were only a few inches from the center and started my measurements from dead center. This gave me 17 intervals of 4 feet, requiring 17 spacers, plus the spacer closest to the center for a total of 18 spacers per side. Adding the center spacer, a total of 37 were required for the 80 meter antenna. This has worked well and so a spacer distance of 48 inches would be a good place for you to start for your 80 meter antenna, although your actual spacer distance will vary somewhat with the final length of your model. My trial and error testing established that consistent wire separation could not be maintained with a spacer separation distance much longer than four feet. While a shorter separation distance would be better for that purpose, it increases the weight of the antenna unnecessarily. For my 40 meter antenna, I used a spacer distance of 42 inches, but this time I started measuring from the spacers close to center. The measurements just worked out for me that way. 23 spacers were required in total. My 20 meter antenna required 13 spacers at an interval between them of about 43 inches. My 20 meter version was intended only as a temporary antenna, largely to further test the broadband design, so I was much less fussy with its construction than I was with my 80 and 40 meter versions, which I intended to keep up permanently.

The spacers themselves are made from one-half inch PVC pipe glued into a PVC end cap. I calculated the length of the pipe to be cut for each spacer as follows:

(a) the separation distance between the wires, plus

(b) the length that would be inserted into the cap (three-quarters of an inch), plus

(c) an arbitrary one-quarter inch for the parasitic wire to be below the bottom of the cap, plus

(d) an arbitrary one-quarter inch for the dipole wire to be above the bottom of the PVC pipe.

Since my 80 meter separation distance was 10 inches, I cut each piece of PVC pipe to a length of 11.25 inches accordingly.

I then prepared the caps by drilling a small hole dead center in each one. I screwed an appropriately sized screw eye into each PVC cap. The size of the screw eyes varied with the size of catenary rope that I intended to use for each antenna. I used “550 parachute cord” to support the 20 meter antenna, so small screw eyes were used for it. For the much longer and heavier 80 and 40 meter antennas, I used five-sixteenths line, so a larger screw eye was required to pass that size rope. After screwing in the screw eyes, the PVC caps and pieces of pipe were glued together.

Next, I constructed a crude cardboard template to mark where the holes would be drilled for the wires on the PVC pipe. Since the parasitic wire was to be that arbitrary one-quarter inch below the bottom of the PVC cap, I made a small hole in my cardboard one-quarter inch from its top and a second hole 10 inches below that, establishing my separation distance. I then placed the template on the PVC pipe, butting its top against the bottom of the cap, and marked the pipe with a marker through the two holes in the template. When all the spacers were so marked, I drilled holes just a hair larger than the #12 gauge wire that I intended to use at the places I had marked.

Since one of the problems we will need to deal with is movement of the spacers, especially while the antenna is being raised, it is strongly recommended that the holes drilled for the wires be only very slightly wider than the wire to be used. This will make construction of the antenna more difficult, since it will be harder to pass the wire through the holes over the distance of the antenna, but in the long run this is worth the extra effort. For purely aesthetic reasons, I spray painted all my spacers black. I thought that might make the antennas less conspicuous under most weather conditions. I might well be wrong in that regard – I haven't compared the painted spacers in the air against unpainted ones.

Having prepared the spacers, I then untied one end of the catenary rope and fed it through the screw eyes of all the spacers. The catenary rope was then re-tied and the spacers spread out into their approximate positions.

An important issue to be solved is how to keep the spacers in their proper locations, both at the top, where the catenary rope passes through the screw eye, but also at the bottom. As early versions of the antenna were hoisted into the air, it was noted that some of the spacers would move laterally at the bottom, such that the spacer would end up at an angle, rather than perpendicular, to the catenary rope when the rope was pulled taut. This was unacceptable because it affected the wire separation distance at that point. It also looked funny, with most of the spacers nicely perpendicular to the catenary rope and then some at odd, varying angles.

To keep the screw eyes from moving on the catenary rope, they were held in place using short pieces of soft aluminum picture hanging wire wrapped around the rope, over and around the screw eye and then around the rope on the other side. This can be seen in Figure 7. Once the entire antenna was built, the bottoms of the spacers were held in place by wrapping electrical tape around the dipole wire on either side of each spacer. This was very tedious and time consuming. Having given this method further thought, one might try injecting some glue in the space between the dipole wire and the spacer using a glue gun. The spacers will not move at the bottom once the antenna is in the air, so all that needs to be accomplished is to keep the bottom of the spacer from moving laterally while the antenna is being pulled up.

Once all the spacers are wired to the catenary rope so that they will not move around, untie the catenary rope. Measure one spacer separation distance from each end spacer and tie a loop into the catenary rope at that point. The reason for this will be explained below. Re-tighten the catenary rope.

Figure 7.

Figure 8.

I used #12 bare solid copper wire for the antenna. This choice was made for several reasons. First, I had a 1200-foot spool in the garage that I had purchased some time before at a good price at a "big box" hardware store. Knowing that I was going to be building several of these antennas, I knew that a great deal of wire would be needed and this was an easy source and already paid for, before the price of copper wire had shot sky high.

Secondly, while solid copper wire is soft and stretches under load, my use of a catenary rope would eliminate the problem of the wire stretching. While the antenna's wires would be taut, they would not be under tension as would a normal dipole wire supporting its own weight, the weight of the coax and absorbing the stress of swaying trees trying to tear it apart, if attached to support ropes at its end. All of the stress for my antenna, supported by a catenary rope, would be taken by the rope; the antenna would just hang underneath, relatively stress free. Finally, the softness of the wire and the fact that it was solid, rather than stranded, appealed to me as I thought about having to feed it through numerous small holes in the spacers over substantial lengths.

The next step is to feed the parasitic wire through the upper spacer holes. It is very important that the center point of the parasitic wire ends up in the middle of the center spacer. While I did not do this, with hindsight, I would suggest fixing the center point in place by wrapping and soldering a piece of small gauge wire around the parasitic wire and around the spacer, trapping the parasitic wire in place. I used wrapped electrical tape on each side of the center spacer for this purpose.

Depending upon the layout of the spacers, on some prototypes I used spacers for my end insulators. On some versions, spacers ended up very close to a normal end insulator, even butting up against it in some cases. Upon further reflection, it is recommended that spacers not be used as end insulators and that they be kept some distance from the actual end insulator, to minimize the possibility of additional capacitive loading from the spacer at a high voltage point of the antenna. This might be especially important at frequencies above 40 meters.

Having terminated the parasitic wire with an end insulator, drill holes as necessary in the remaining spacers, such that you can run line from the insulator through any remaining spacers to the loop that you created earlier. I used "550 parachute cord" for this purpose with all models of the antenna, in part because it is fairly elastic. Having done this on both ends, tighten each rope passing through the loops, until the parasitic wire is taut for its entire length, again making sure that it is centered on the center spacer.

It is suggested that a commercial dipole center insulator be used, the kind that accepts a PL259 coaxial cable connector or otherwise attaches to the coax feed line. Depending upon the center insulator employed, as you measure the dipole halves, you will need to take into account whatever wire length the insulator has from the PL259 to the point at which each dipole half will attach to the insulator. Often, this is wire braid several inches in length. *That braid (or other wire material) acts as part of the length of the dipole and therefore needs to be taken into account as one measures the dipole halves.*

I shortened the center spacer so that the center insulator, when attached to it, would be in line with the dipole wire. I then drilled holes in the center spacer to attach the center insulator to it, using large wire ties run through the spacer holes and the attachment hole of the insulator. This is shown in Figure 8. Once the center insulator is in place, feed each half of the dipole through the bottom spacer holes and terminate each dipole wire with an antenna insulator, remembering to adjust your spacers so that there is some distance between the insulators and the closest spacer, to avoid capacitive end loading, as mentioned above. Pull the dipole taut using the same method as described for the parasitic wire. The method by which both the parasitic and dipole wires are attached to the loops in the catenary wire is shown in Figure 9.

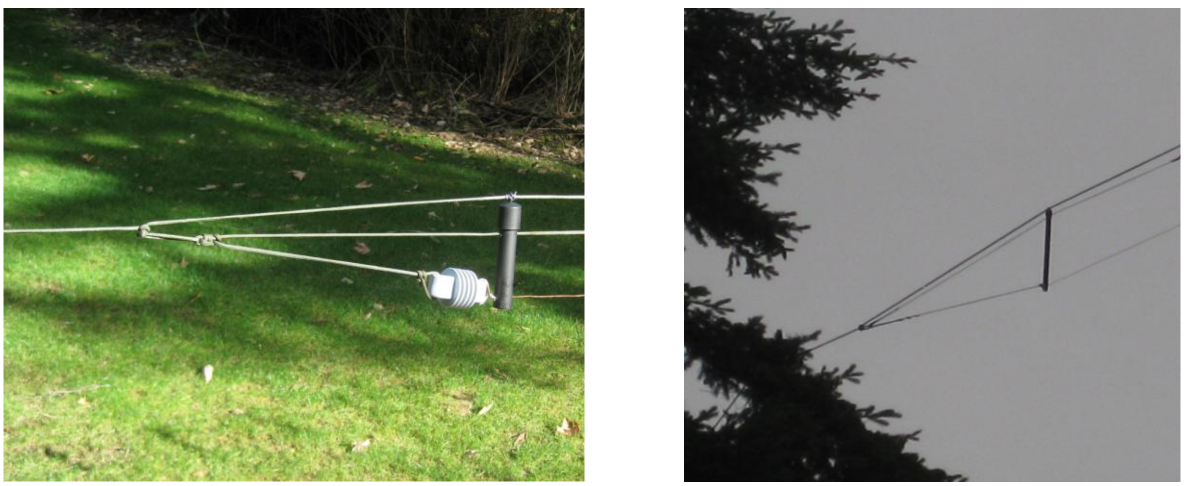

Figure 9. Detail of how both the parasitic wire and dipole are held taut by lines passed through remaining spacers to a loop in the catenary rope located about one spacer separation distance from the end of the dipole. As mentioned in the text, it would be better to keep the spacers away from the end insulators to avoid capacitive end loading, especially on the higher frequencies. This photograph is of a prototype 10 meter antenna. The photograph on the right is of W7ZZ's 40 meter dipole at 80 feet. For that prototype, a spacer was used as the end insulator for the dipole, which is why only one insulator is seen in the photo (for the parasitic wire).

The next step is to make the matching section. If this is a single length of 75 ohm line (a Q section), this is very straightforward. Just put a PL259 on each end of the correctly calculated length of RG11U (remembering that the length will be determined by the velocity factor of the line being used, usually 66%), attach one end to the center insulator and the other to 50 ohm line running to the shack, using a barrel connector between them.

If a series section match is being used, you will need to prepare two lengths of coax, one for the 50 ohm section and the second for the 75 ohm section. Again, in calculating the lengths of the section using the series match calculator to be found online, be sure to enter the correct velocity factor for each type of coax that you will be using. The dimensions shown in this article presume that Belden 9913f 50 ohm coax is used, as it was at W7ZZ's QTH, with a velocity factor of 85%. Before cutting the 50 ohm coax to the needed length, consider that it will be connected to the next section, of 75 ohm coax, by a barrel connector. Therefore, the length of the barrel connector, presumed to be 50 ohms in impedance, must be taken into account as if it were part of the 50 ohm section. For this reason, *the 50 ohm coax piece that you make will be shorter than calculated by the length of one barrel connector*. The 75 ohm line is cut to the calculated length because the barrel connector at its end is deemed to be part of the 50 ohm line running to the shack.

As discussed above, testing of the prototype antennas established that use of a choke or balun to suppress common mode currents on the feed line was essential if the antenna was to perform as modeled by *EZNEC*. At W7ZZ, a choke designed by W1HIS and presented in an article found online[23], made by passing coax in a circular shape through two groupings of four ferrite toroids each, was used.

Placement of the choke raised two questions: (1) Could the coax wound through the toroids be the coax that is used to make the 50 ohm section of the series section match, and (2) can the choke be located someplace other than the feed point, since it is quite heavy? N6RY advised that the 50 ohm coax serving as part of the series section match could be used for the choke since the choke affects only currents flowing on the *outside* of the braid (the common mode currents). The RF flowing to the antenna is flowing on the *inside* of the braid, which is unaffected by the choke.

As for location of the choke, N6RY pointed out that, if a transmission line is an electrical one-half wave in length, the impedance is the same at each end, regardless of the impedance of the line itself, and that impedance will repeat every electrical one-half wave. A discussion of this principle can be found in the *Antenna Book*.[23] This meant that the choke could be wound on the feed line at any electrical one-half wavelength from the actual feed point and its high impedance effect would be present at the feed point, just as if the choke had physically been placed right there.

While this solved the problem of extra weight at the feed point, another problem was created: how was I to calculate an electrical one-half wavelength for the outside of the braid of both the matching section coax and the 50 ohm line running from the matching section to the shack, since to do that I would need to know the velocity factor for the outside of the braid? I was unable to find information on this question, despite a diligent search. Common sense told me that the velocity factor of the outside of the braid would not be the same as published by the manufacturer for the center conductor and inside of the braid, since the outside dielectric is thin in comparison with the center dielectric and it is the presence of the dielectric that is primarily responsible for slowing down the flow of energy that would otherwise be at the speed of light.

Not knowing what velocity factor to use, I did something very unscientific: I guessed. Theorizing that, if my Belden 9913f coax had a velocity factor of 85%, the velocity factor of the outside of the braid would be higher, I guessed at 95% and just assumed that it was the same for the 75 ohm coax that was part of the line as well. I have since found an article on line that suggests that my guess was a good one.[25] In any event, the guess was good enough, because the choke on the W7ZZ 80 meter antenna (shown in Figure 10) brought its SWR plot from marginally acceptable over the most of the band to very satisfactory and nearly as predicted by *EZNEC* over the whole band.

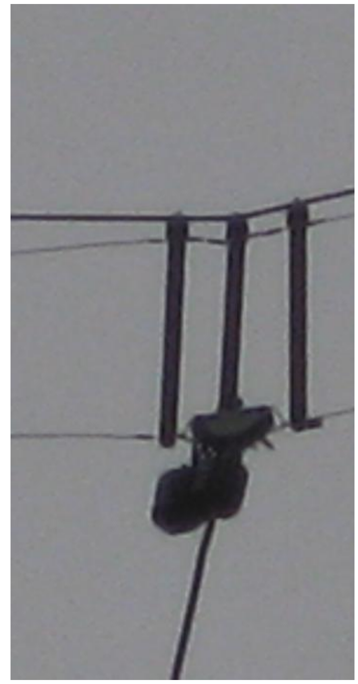

Figure 10. On the left, the choke installed an electrical half-wave from the feed point of the 80 meter prototype. The pieces of wood shown in the photograph are to prevent chafing of the coax by tree bark. On the right, the choke installed at the feed point of the 40 meter prototype. A choke is necessary to prevent current from flowing on the coax braid, which prevents the antenna from achieving its predicted excellent SWR across the whole band.

It is very helpful if three people can participate in raising the antenna into the air. Two pull on the support ropes simultaneously, so both sides of the antenna rise in unison, while the third person ensures that the antenna does not twist as it is lifted up and then makes sure that the coax doesn't kink as the antenna rises.

Having now built several of these antennas and having hoisted them up and down multiple times for testing purposes and improvements in design, I can attest that they are not as difficult to build as it may sound from reading the above. If you are going to build antennas for more than one band, I would suggest starting with the highest frequency, which would be the shortest antenna, to master the tricks of the trade, so that the longer versions will go together more speedily. Of course, I started with the 80 meter version, again proving that I am a master of doing things the hard way.

Well, now you know how to both design and build the "holy grail" of ham antennas, a truly broadband, efficient low band dipole. Figures 11 and 12 are photographs of the prototype antennas in the air. Play with the models suggested in this article to design the antenna that will work best at your location, give one a try and enjoy the freedom to operate in either the CW or phone portions of the low bands anytime that you want with a very acceptable SWR – perhaps better than you experience now in only a limited portion of the band – and without a tuner. While we encourage you to model your own antenna for best results, if you don't have *EZNEC* or if you haven't mastered it, copying one of our models at the height closest to the expected height at your location should give results close to our predictions. And, as we said before, we encourage you to further experiment with the open-sleeve design concept. You may well improve upon our designs or think of potential new applications for the design concept beyond the simple broadband dipole presented in this article.

Figure 11.

Figure 12.

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