Wire Antennas for Limited Space (Part One of a Series)

Build Your Score with a few dB Here and There Bill, N6ZFO, has a nice piece in the Sweepstakes Handbook showing the statistical relationship between the strength of our signals and our Sweepstakes score. His analysis shows that each 1 dB improvement is good for a 2.6% increase in our score. Making three 1 dB improvements is good for nearly 8%. Those improvements may come from a power amp, a more efficient antenna tuner, a better antenna, a better ground system, or any combination thereof. The difference between a 1.5kW power amp and 1 kW is 1.7 dB and at least $1.5K. Often that 1.7 dB can be obtained for a few hundred dollars and a few hours invested in the antenna system!

Many of our members have limited space for antennas, but we don't need to let that prevent us from having fun in contests. That was certainly the story of my life until I moved to the Santa Cruz Mountains two years ago. While still in Chicago, I found some good solutions to the space problem, and, thanks to some research, two good reasons to avoid multiband dipoles fed with twinlead (like the G5RV and various windoms). This series presenting various "how to" antenna ideas is intended to help us think about how we can pick up those relatively inexpensive extra dB, and have more fun.

Why not multiband with twinlead? Two good reasons. First, the commonly used "window" lines may have low loss when they're dry, but N7WS showed (in ARRL Antenna Compendium #6) that losses soar (much higher than coax) when they're wet. Second, any imbalance in the antenna will cause common mode current that couples noise from the feedline to the antenna (and transmitted RF to your shack). The only cure is a very good common mode choke at the feedpoint. To build a good one that will handle high power and kill the noise, it must be wound with coax, not twinlead. Since most contest activity occurs during our rainy season, because virtually all ham antennas are unbalanced by their surroundings, and because most of us live around lots of HF noise sources, mutltband wires fed with twinlead look a lot better on paper than in practice.

So lets look at three much better solutions.

1) Fit more bands into the same space with a "fan" dipole. It's nothing more than two or more dipoles connected to the same feedpoint. Each behaves as a classic dipole. Feed it with coax and a good coaxial choke at the feedpoint. A 20/15/10M dipole fits into 35 ft of space.

2) Use a loaded dipole to cover 80 and 40 meters. Barry, KU3X, operating as Hypower Antenna Company, builds some very nice limited space antennas using loading coils that act as traps on the next highest band. His 2B4080L is a great solution for 40M and 75/80M meters, and is only 90 ft long. The loading coils are self resonant on 40 with their own capacitance and a are each a quarter wave from the feedpoint (33 ft), and, so they act as end insulators on that band. On the other side of each loading coil is another 10 ft or so of wire that combines with the loading coils to resonate on 75/80M. This was my only antenna for160/80/40M in Chicago, and it worked very well. (More later about how I made it work on 160).

3) Build a top-loaded (Tee) vertical or inverted L for 80 and 160 meters. Antennas can be loaded with series inductance near the feedpoint or along their length, or with capacitance at their ends. The capacitive approach is generally much more efficient (that is, more radiated power, less loss). The inverted L is one form of this antenna, the Tee is another. The vertical portion has the highest current so it does the most radiating; its radiation is at a low vertical angle, which makes this a good DX antenna. The top section brings it to resonance (making it a better match to the transmitter) and may also contribute some high angle radiation. With a Tee vertical, radiation from the opposing halves of the top section cancel each other. This antenna needs radials (or at least some form of counterpoise) to be efficient. We'll talk more about this antenna and radials later.

Building Fan Dipoles is easy. I build wire antennas using either #10 copper (for very long antennas that must withstand considerable stress) or #12 THHN (house wire). For a fan, I use #10 for the longest element, #12 (or even #14) for the shorter ones. A center insulator should be easy, but it isn't, simply because there's more junk for sale than good stuff. The one that The Wireman sells looks to me like the best of a bad lot. The Alpha Delta might be good, but I'm concerned about how waterproof it is. For end insulators, I like the squarish PVC egg insulators or medium sized porcelain eggs.

Spacers are easy to fabricate from ½-inch PVC conduit (the UV-resistant type). Cut it into short pieces (about 8 inches for two-wires, about 15 inches for three). Drill 3/16-inch holes about 3/4 inch from each end, and another at the center of the 3-wire spacers, for the wires to pass through. A 20/15/10 fan needs six 3-wire spacers – a pair each side of center, a pair at the ends of the 10M elements, and a pair at the ends of the 15M elements. An 80/40 fan needs at least 12 spacers.

I use copper split bolt connectors from McMaster Carr to hold the spacers in place on the antenna. Part number 6921K56 is the smallest one they sell, $1.80 each in boxes of 25. I also use these connectors to tie the elements together at the center insulator. I use eyelets sold by The Wireman on each wire where it mechanically lashes to the center insulator, then loop it back to the point where I connect it electrically.

When building the antenna, I cut all the wires for the elements at least 24 inches long, using part of the extra length for mechanical termination at the center insulator and some to go through the end insulator and wrap back on itself. I trim each element for length to be about 5% long before raising it the first time, then again once I've had the rig up in the air and checked it (either with an analyzer or an SWR bridge). I determine element lengths based on modeling in W7EL's EZNEC.

Assembling the fan: I build the longest element first, putting the needed spacers on each half of the antenna, connecting both elements at the center insulator, then temporarily tying off each end through the egg insulator. Then I temporarily hang the antenna between two supports about 5 ft or so off the ground where I can work on it, and build the other elements of the fan. First I string all the elements through the spacers and temporarily tie the spacers in place with the split-bolt connectors. Next, I terminate all the elements at the center insulator, again using one or more split bolts. Then I add a piece of UV-resistant rope between the spacer at the end of the 15M element and the spacer at the end of the 10M element, and pull it tight. This tends to give the antenna better mechanical stability. At this point, the antenna should be pretty well put together, but I let it sit for a week or so under tension to settle in place mechanically.

After that settling period, I tighten up the rigging at the center insulator, the spacers, and the ends, trimming each element so that it's a few percent long. Then I screw the split-bolt connectors down nice and tight, lash them to the spacers using UV-resistant tie-wraps, and tape that lashing with Scotch 88 (for more UV protection). Now the antenna is ready to fly.

Trimming for length: Horizontal antennas interact with surrounding objects, including the earth. Before final trimming to length, any antenna should be rigged to its intended operating position and checked for resonance, then lowered and trimmed if needed. In general, proximity to ground lowers the resonant frequency by a few percent.

Rigging the Antenna:

- I use either marine pulleys (West Marine is a good source) or pulleys sold by a B&B Small Engine, a supply house in Capitola that caters to tree climbers.
- I use the 5/16-inch UV-resistant rope sold by DX Engineering (and others) to hang my wires high in trees that get a lot of wind and can sway a lot. The smaller 3/16-inch version is fine for smaller antennas strung between fixed supports. Be careful

about this rope in conditions where it will rub and abraid – I've had expensive failures when this rope could rub against a limb or tower element.

- It's long been good practice to use a weight on one end of a rope or wire suspended between trees to allow the rig to adjust to wind whip (the word "sway" is far too mild mannered to describe what happens in a real storm). Some hams use old window weights, others use plastic bottles or buckets filled with sand. I use 6.5 gal drinking water containers from the local hardware store. Filled with water they're about 60#. I fill them with sand (about 95#).
- Within the limits of most city lots, and most terrain, higher is better. I fight for every foot of height I can get. On 80 and 40, every five feet or so of additional height, <u>especially for the center of the antenna</u>, increases low angle radiation, making us a bit louder on the east coast or working DX.
- Avoid the Braided copper antenna wire. I've used a bunch of it, both bare and insulated, and regretted it each time (on at least three occasions, with considerable cost to re-rig the antennas that fell apart). It simply does not stand up to stress.

Electrical considerations:

- Insulated wire is electrically longer than bare copper – that is, an antenna made with insulated wire must be about 2% shorter than a bare copper wire to hit the same resonant frequency.
- Combining dipoles into a fan narrows the SWR bandwidth of the higher frequency dipoles by about 50%. There is no loss of bandwidth for the longest dipole.
- A low fan dipole for 80/40 meters is a good match to 50 ohms, but a high 80/40 fan is closer to 75 ohms. A fan dipole for 20/15/10 meters is a good match to 50 ohms whether its low or high.
- All of the above are predicted by NEC modeling and I have confirmed them with my real antennas.
- Don't play cheap with coax on a long feedline. The difference between 150 ft of RG59 and RG11 (or between RG58 and RG8) is 1-2 dB over the width of most ham bands, VSWR taken into account. My 80/40 fans both load well on 30M and 17M; and since I'm feeding them with RG11, they're pretty efficient on those bands too.

<u>Top-Loaded End Fed Wire for 80 and 160</u> My first 160M antenna was completely improvised. I was in Chicago, had that loaded 80/40 dipole up in the air (fed with RG59 and a "string of beads" choke balun) and wanted to work 160. The first thing I tried was end-feeding it against that wrought iron fence. It worked – sort of – but fried the choke balun with 100 watts in a contest weekend. The next step was to replace the coax with some vintage 75 ohm Belden KW twinlead (a lucky hamfest purchase) and get rid of the choke balun. That antenna worked even better – I managed to work the lower 48 states with 100 watts and a lot of persistence.

Note that this antenna was FAR from ideal. The shack was on the 2^{nd} floor, about 25 ft under one end of the dipole. There was 75 ft of feedline (which became the antenna), which ran horizontally for about 45 ft before rising 25 ft to the center of the horizontal wire. There were also two wires running down to the fence (the counterpoise). While we might call them "ground" wires, they carried antenna current, so they were part of the antenna (and their radiation contributed to the total).

<u>Vertical Antennas, Radials, and Efficiency</u>

Radial systems (or counterpoises) don't need to be perfect to work, but the closer they are to ideal, the better the efficiency. First, let's clarify the difference between elevated radials and radials that are in/on the ground.

Elevated radials should be resonant (one quarter wave), and have the advantage that only four radials are as good as 40-60 radials on the ground. Sounds great – BUT to be elevated, they must be at least 1/10 wavelength above ground. That's 25 ft on 80M, 50 ft on 160M. Few of us can build elevated radial systems for these bands.

Radials in/on the ground do not need to be any certain length. There are several simple "rules of thumb." 1) More copper is better. 2) Copper close to the feedpoint matters a lot more than copper far from the feedpoint. That is, if we have a limited length of wire, it's better to have more short radials than a few long ones. 3) Symmetry of the radial system is good, but not crucial. If you can't run radials in some directions (for example, there's a driveway or building in the way), run more radials in the directions where you can.

An improvised counterpoise can be used in place of (or in addition to) a radial system. In Chicago, I used a big wrought iron fence that ran around the front of my property, with a few wire radials added. My friend KK9H uses the power system ground and the aluminum ducts of the HVAC system in his house as a counterpoise. He doesn't have a big signal, but I've worked him three times on 160 from here in Santa Cruz!

When I moved to Santa Cruz, I brought along that loaded 80/40 dipole, with the 75 ft of twinlead attached, and it was the first antenna I hung here. It was up about 75 ft, and it worked very well, but I wanted more. So I got pulleys installed at about 110 ft in a redwood and at 75 ft in a madrone, and strung ropes between them to rig a taller Tee vertical – this one is about 86 ft. Does it work any better? I've done the math, which is summarized in Table 1 below. The taller antenna gives me more radiation resistance, which should improve the efficiency by 0.25dB.

Radials improve the efficiency of the antenna. Without radials, antenna current would flow in the earth, which is pretty lossy. With radials, more of the current flows in them, reducing the loss. Think of the antenna as a series circuit consisting of Rr (radiation resistance), Rw (wire resistance), and Rg (the loss of the ground system). Because the same current flows through the series circuit, the efficiency is Rr / (Rr + Rw + Rg). So the key to efficiency is to make Rr large while making Rw and Rg small. 70 ft of #12 wire is about 1Ω (with skin effect). From the ARRL Antenna Book, we learn that 16 radials as short as 0.1λ will yield about 11Ω; 32 yields Rg = 9Ω; and 64 radials should bring Rg down to about 7 ohms. Table 1 shows that that isn't a big improvement for a lot of copper! While I haven't seen data, my guess is that four λ/8 radials would probably yield an Rg of 20 ohms.

It should be noted that what I've presented here is a simplified analysis, and the ARRL Antenna Book includes a far more detailed one by Rudy Severns, N6LF. In it, he shows how and why ground losses increase with short antennas, in some cases more than predicted by the simpler analysis.

Antenna Dimensions (ft)			Efficiency for Rg+Rw		
Vertical	Horizontal	Rr (Ω)	8Ω	12Ω	20Ω
70 ft	81 ft	21.7	-1.36 dB	-1.91 dB	-2.84 dB
80 ft	64.5 ft	25.9	-1.17 dB	-1.65 dB	-2.49 dB
85 ft	57 ft	27.8	-1.1 dB	-1.56 dB	-2.35 dB
90 ft	49.7 ft	29.6	-1.04 dB	-1.48 dB	-2.2 dB

Table 1 – Dimensions and Losses in a Tee Vertical