A Tri-Band Antenna without Radials for 2 Meters, 1.25 Meters, and 70 Centimeters

An innovative revision of a design the author originally published in *QST* in 2003.

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Twenty years ago, a single-band handheld transceiver would have been adequate for most emergency activities, because they were conducted on VHF. Today, both VHF and UHF are used for emergency communications by organizations such as ARES and RACES. In some areas, even the UHF amateur band is full. This was the primary motivation for introducing the DBJ-1 dual-band J-pole and the DBJ-2 roll-up portable version.[1, 2] Edison, WB6IQN, and his students have built thousands of these over the last 10 years for various ARES/RACES clubs and government agencies.

[Edison Fong, WB6IQN, photo]

An often-repeated request was whether the 1.25-meter band could be added to the DBJ-1. In the San Francisco Bay Area, 1.25 meters has some FM voice channels, but its most important use is for packet radio.

Since the development of Outpost Packet Message Manager by Jim Oberhofer, KN6PE, 1.25-meter packet is not only popular in the Bay Area, but has spread nationwide.[3] Thus, one antenna that covers 2 meters, 1.25 meters, and 70 centimeters would be very desirable. This would simplify the need for multiple antennas during an emergency deployment. The 1.25-meter band is not harmonically related to any other ham band, and thus, its antenna dimensions for that band are not related to those in the 2-meter or 70-centimeter band. This makes impedance matching difficult, and the construction of such an antenna is not obvious.

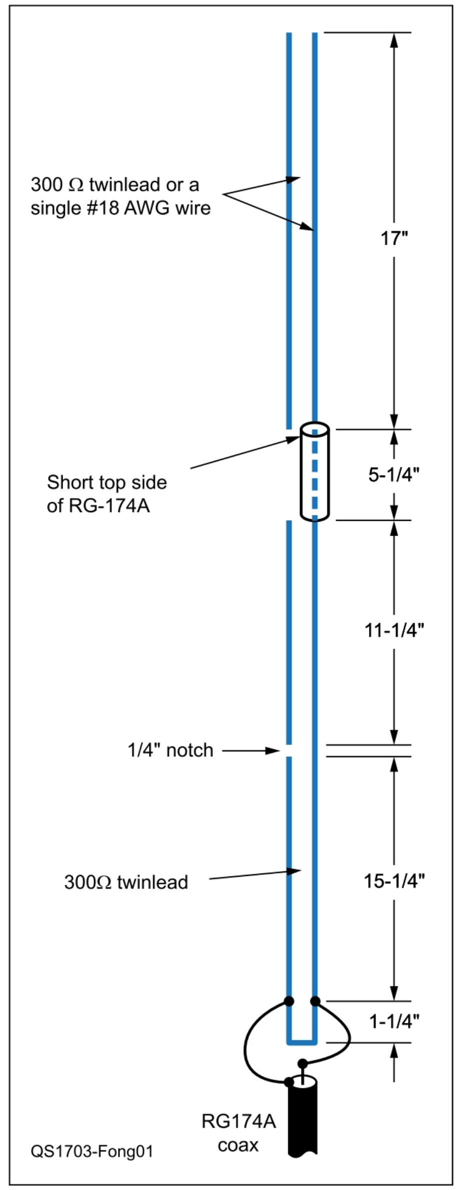

Figure 1 — The original DBJ-1 dual-band J-pole shows the approximate dimensions used when the antenna is inserted into a ¾-inch OD Class 200 PVC pipe.

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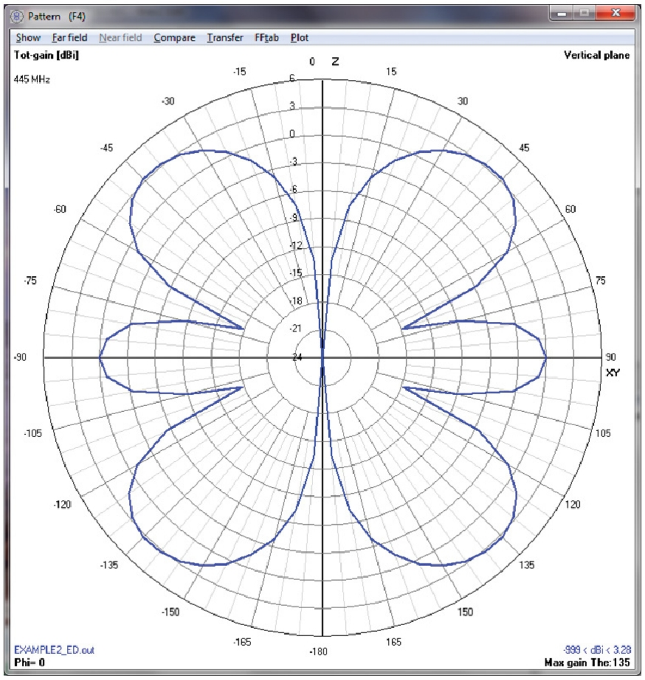

Figure 2 — A vertical half-wave dipole resonating on its third harmonic places a fraction of its energy in the horizontal lobes.

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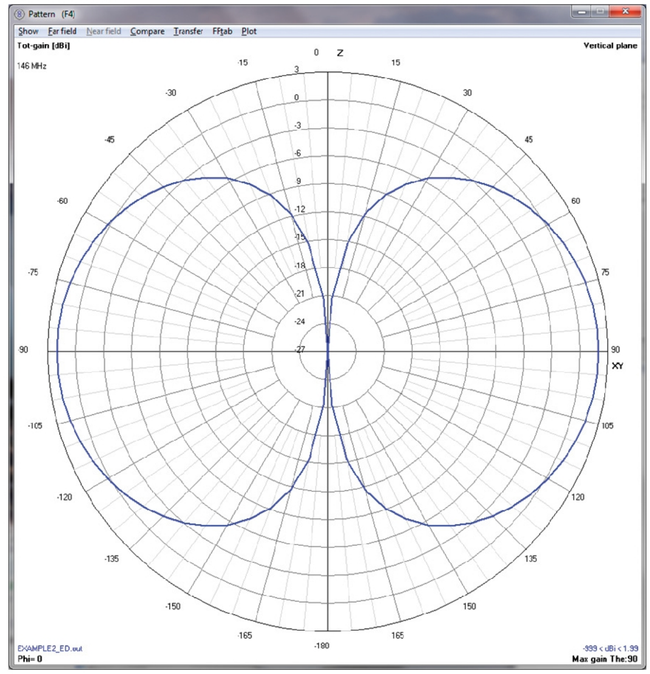

Figure 3 — A vertical half-wave dipole pattern has its maximum energy on the horizon.

If you already own a dual-band DBJ-1, this article will explain how to include the 1.25-meter band by adding some wire, a longer piece of RG-174 lead-in coax, and replacing the 5-foot section of PVC pipe with a 6-foot piece. After maybe an hour's worth of work, you will have a TBJ-1 — a tri-band J-pole — as shown next to Tessa Fong, KJ6QXM, in the lead photo.

Requirements for an ARES/RACES Antenna

Interviews with multiple emergency coordinators, including American Red Cross and FEMA personnel throughout the country, resulted in a summary list of desired characteristics for a multi-band 2-meter, 1.25-meter, 70-centimeter antenna.

- The antenna must be easy to erect during an emergency, and should be of durable one-piece construction, free of radials.
- It should be no more than about 6 feet in length.
- It must be low cost; certainly far less cost than commercially available tri-band antennas that retail in the $180 range.
- Performance should be comparable to that of a dipole, and it should operate from a single feed line.

Because of the success of the DBJ-1, and the input we received from its users, maintaining the same form factor as the DBJ-1 was important. This also makes it easier for folks who already own a DBJ-1 and wish to add 1.25 meters. The DBJ-1 is deployed in emergencies, where users often do not have a technical background, so changing form factor was to be avoided. In summary, the antenna must be easy to deploy, rugged, low-cost, and it must perform well.

Our goal was to add 1.25-meter coverage to the DBJ-1 with minimum effort and still achieve half-wave dipole performance on all three bands.

Could the popular DBJ-1 dual-band base antenna (shown in Figure 1) be adapted to also work at 1.25 meters, with minimal changes and no degradation of performance at 2 meters and 70 centimeters? The answer is "yes" — and with only an additional cost of about $3 worth of materials, if you already own a DBJ-1. You can build the complete antenna for under $5.

Review of the Literature

Searching the literature, we found a tri-band (2-meter, 1.25-meter, and 70-centimeter) antenna by John Harris, WD4KGD.[4] It was a stacked tri-band J-pole antenna — essentially three J-poles, where the coax for each antenna is routed through the copper pipe and combined at the base.

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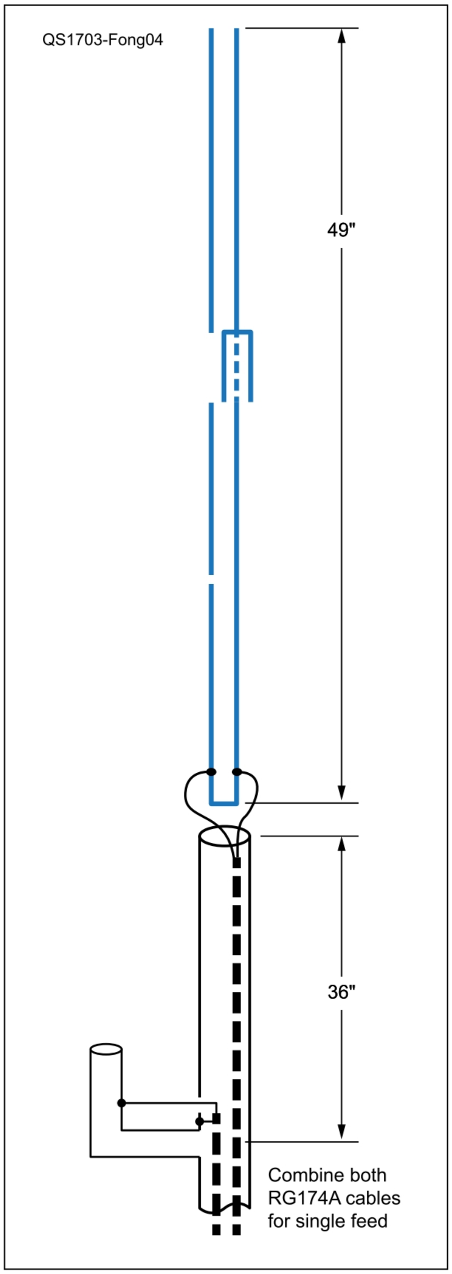

Figure 4 — The DBJ-1 dual-band J-pole stacked on top of a 1.25-meter band J-pole.

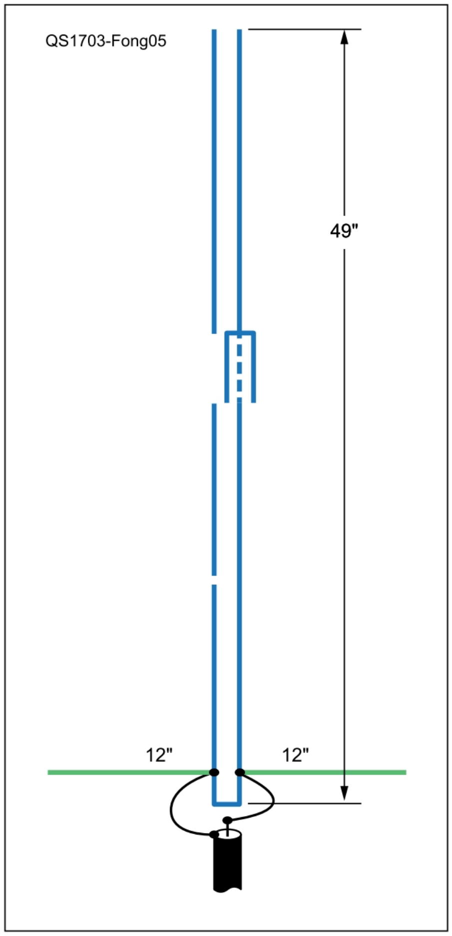

Figure 5 — The DBJ-1 dual-band J-pole with a 1.25-meter band dipole fed in parallel.

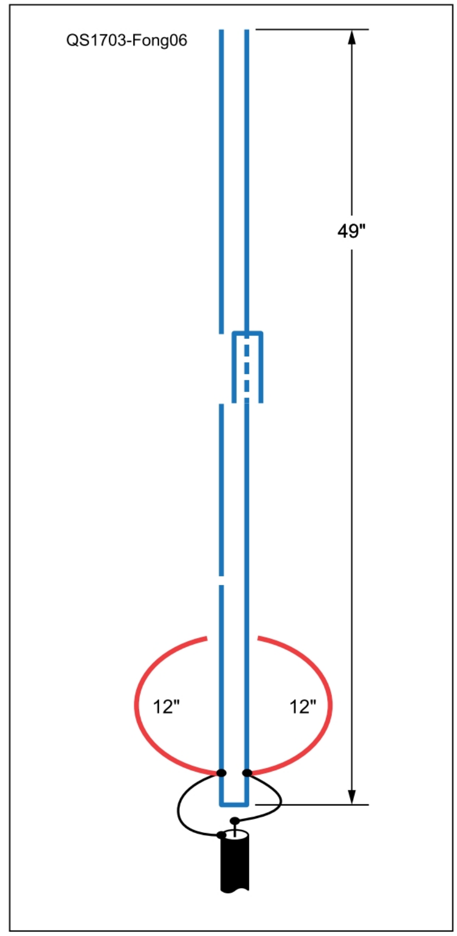

Figure 6 — The DBJ-1 dual-band J-pole with a 1.25-meter band loop antenna fed in parallel.

The Harris antenna fell short of this goal. Certainly, it is possible to obtain resonances on all three bands and, with some careful adjustments, even achieve reasonable SWR on all three bands with the Harris configuration. An experienced antenna designer will notice that this configuration suffers from the same drawback of using a 2-meter VHF antenna at UHF. All conventional antenna configurations resonate at harmonics, and thus can experience low SWR at odd integer harmonics. The Harris configuration is no exception. The VHF portion will also present a low impedance at UHF. This will be in parallel with the UHF section and thus present a lower impedance than desired. We also found that matching was difficult to achieve at UHF because the distance of the J portion of the antenna is limited by the right-angle elbows and T connectors in ½-inch copper pipe. With standard copper pipe fittings, the minimum distance is about 2¼ inches (independent of band), which does not result in a good transmission line at UHF, where a quarter wavelength is 6 inches.

More importantly, the elevation pattern at UHF will have a maximum at 45 degrees above the horizon, leaving only about 25% of the RF energy in the horizontal plane, as seen in Figure 2. This pattern is not optimized for terrestrial propagation. The goal is to achieve a vertical dipole pattern on all bands, as shown in Figure 3.

Experimental Prototypes

In the DBJ-1 shown in Figure 1, the input feed point uses the same tap point for both VHF and UHF. This is possible because UHF is the third harmonic of VHF. The UHF radiating element is the 11¼-inch length above the quarter-wave VHF matching stub, followed by a quarter-wave UHF decoupling stub. The UHF decoupling stub is shorted at the top, which transforms to an open at UHF at the bottom of the stub, and thus decouples the remainder of the antenna at UHF. The stub is not active at VHF. This configuration gives a good vertical half-wave dipole pattern at both VHF and UHF (see Figure 3). At this point, we searched for options to add 1.25-meter operation to the DBJ-1.

Stacking J-poles

One technique to achieve 1.25-meter resonance was to stack the DBJ-1 on top of a 1.25-meter J-pole constructed with ½-inch copper pipe (see Figure 4). RG-174A is slipped through the ½-inch copper pipe to connect to the DBJ-1. The total length of the antenna becomes 8 feet, which is prohibitively too long for our purpose, and is not practical. We constructed a prototype of this configuration and, although it functioned, its aesthetics, the difficulty of construction, and cost did not meet the original requirements.

A Dipole Fed in Parallel

We thought that we could just construct a 1.25-meter horizontal dipole at the feed point of the DBJ-1, as shown in Figure 5. That method worked, and the prototypes we built certainly had good resonances. The significant problem was that this 1.25-meter antenna was horizontally polarized. Also, it would protrude like radials, which did not meet the original specifications. While this idea did work, it was time to move on.

We attempted to bend the elements to a vertical direction. As soon as the 1.25-meter quarter-wavelength elements started to approach a vertical position, the SWR rose to unacceptable levels. This is because the elements coupled strongly to the VHF stub and coax shield.

The 1.25-meter band is not harmonically related to any other ham band, and thus its antenna dimensions for that band are not related to those in the 2-meter or 70-centimeter band.

A Nearly Vertical Loop Fed in Parallel

We also attempted to bend the horizontal dipole into a nearly vertical loop antenna (see Figure 6) to try to achieve vertical polarization characteristics. We were getting closer to the ideal antenna. The obstacle to overcome was to find a configuration where everything could be placed inside of the ¾-inch PVC pipe, as in the DBJ-1 while maintaining the vertical polarization.

Evolution to the Helical Dipole

A simplified drawing of the evolved solution is shown in Figure 7. Starting with a DBJ-1 antenna, we wound one of the 12-inch-long ,1.25-meter band dipole elements (seen in Figure 5) into a helical dipole element upward around the bottom of the matching stub of the DBJ-1. We then wound a corresponding helical dipole element around the RG-174A coax lead. In essence, we constructed a vertically polarized normal-mode helical dipole that is resonant in the 1.25-meter band, and fed it in parallel with the same coax that feeds the rest of the DBJ-1 antenna. [Because the helix winding diameter is a small fraction of a wavelength, this helix — like the "rubber ducky" on a handheld transceiver — radiates a vertical polarization in the direction *normal* or broadside to its vertical axis. — *Ed.*] The completed antenna mounted on the roof is shown in the lead photo with Tessa Fong, KJ6QXM, standing next to it.

You can fine-tune the resonance by compressing or expanding the helix windings. The great thing here is that each band is tuned separately with almost no interaction.

Constructing the Tri-Band J-Pole

The tri-band J-pole antenna is built around the DBJ-1 dual-band J-pole (see Note 1). This antenna is a 2-meter J-pole constructed from 300 Ω twin-lead that then utilizes a UHF decoupling stub to achieve half-wave dipole performance on both VHF and UHF. The following is a brief review of the

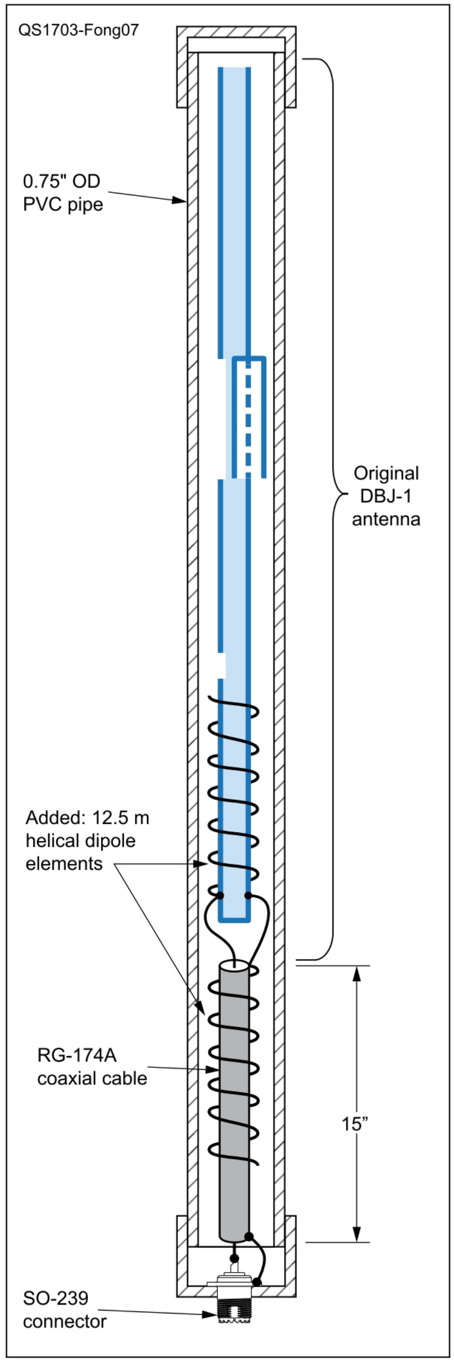

Figure 7 — The tri-band antenna is based on the DBJ-1 antenna, with added helical dipole elements (not drawn to scale). It measures 5½ feet, and fits inside a 6-foot length of ¾-inch, 200 psi PVC pipe.

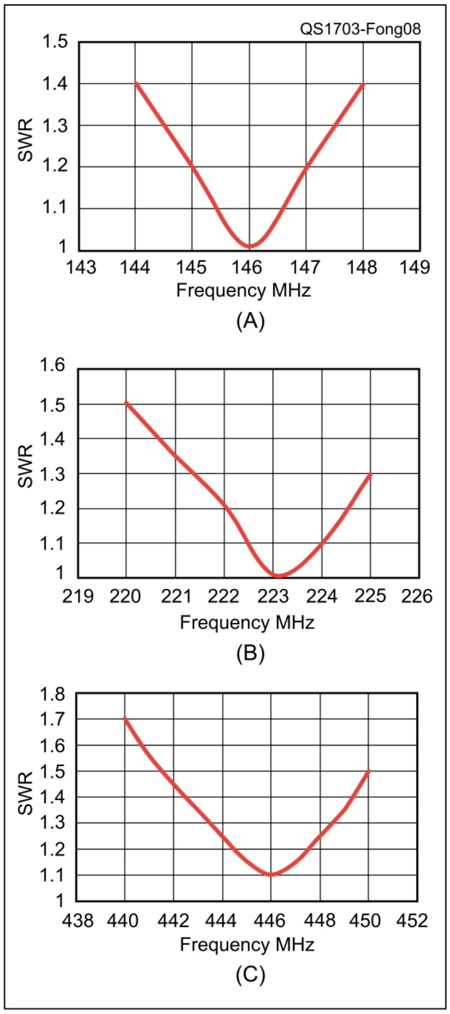

Figure 8 — SWR measurements on 2 meters, 1.25 meters, and 70 centimeters are all within acceptable limits.

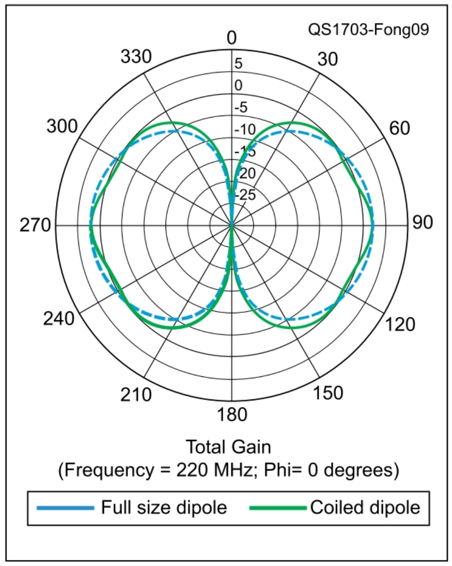

Figure 9 — A simulation of an ideal dipole at 220 MHz compared with the pattern of a helical dipole that has 12 feet of #14 AWG coated wire (mimics RG-174A coax) passing through the center of the helical dipole.

construction of that antenna. Referring to Figure 1, start with a 28-inch length of 300 Ω twinlead. We used JSC 1320-1000S ladder line, which we bought in bulk from Ham Radio Outlet.

Short the bottom of the twinlead. At about 1.25 inches up from the short, tap off the 50 Ω point with RG-174A coax cable. That cable should be longer than about 15 inches. Cut a ¼-inch notch about 15.25 inches from the 50 Ω tap point. The leaves about 11¼ inches above the notch for the UHF half-wave element.

Insert the antenna in a 6-foot long, ¾-inch diameter 200 psi PVC pipe, and measure the SWR. Trim the notch every ⅛ inch until you achieve resonance at 445 MHz. Next, add the quarter-wave RG-174A decoupling stub. Start with about 5.25 inches with a short at the top. Solder the bottom end center conductor lead — shown by a dashed line in Figure 1 — to the top of the 11¼-inch UHF half-wave section. Measure the SWR. Trim the coaxial stub every ⅛ inch until resonance is achieved at 445 MHz. Again, remember to insert the antenna back into the PVC pipe before measuring the SWR. Although the thin-wall, 200 psi PVC pipe does not cause any measurable loss, it does slow down the speed of the signal (the velocity factor is less than one), which causes the resonant frequency to go down 1 to 2% after being inserted into the PVC pipe.

The last step to making the DBJ-1 is to add the 2-meter section. This is a 17-inch piece of #18 AWG wire or twinlead (either will work). Trim this for resonance at 146 MHz.

Adding the 1.25-Meter Helical Dipole

For the 1.25-meter addition, cut out two 12-inch pieces of #18 AWG solid copper wire. Construct the 1.25-meter band helices by using a ½-inch diameter dowel rod as the coil form. Wind this for seven turns. Slip one piece through the quarter-wave VHF stub and the other piece through the RG-174A lead-in coax. Add the 1.25-meter top helix element wrapped around the twinlead, and the bottom helix wrapped around the RG-174A coax feed line. Solder the upper helix to the center conductor and the lower helix to the braided shield of the coax. We wound the helical dipole elements in the same direction. Figure 7 shows the added helices and the elements of the DBJ-1 antenna-fed with a 15-inch length of RG-174A coax cable that is attached to an SO-239 connector at the bottom of the assembly.

Tuning on the 1.25-meter band is straightforward. Spread the helices to about 8 inches and measure the resonant frequency with an SWR meter. To reduce the resonant frequency, spread the coils. Similarly, compress the coils to raise the resonant frequency.

Measured Results

From my experience, measuring the SWR at UHF with consistent results is difficult, but we have found that, near resonance, most ham instruments are quite accurate. The simplest way to make accurate and consistent measurements at VHF and UHF is with an in-line directional coupler such as Bird Technologies Model 43 Directional Wattmeter. The measurements shown in Figure 8 were performed with such an instrument, driven with 10 W. The SWR on all three bands was very acceptable. At 2 meters (see Figure 8A) and 1.25 meters (see Figure 8B), SWR is below 1.4 to 1, even at band edges. At UHF (see Figure 8C), the SWR is less than 1.5 to 1 from 441 to 450 MHz. This is typically more than adequate, because repeater input frequencies at UHF are in the 445 to 450 MHz range.

The bandwidth of the 1.25-meter section is reduced about 30% compared to a vertical half-wave dipole because the elements are physically shortened in the helical dipole configuration. The SWR is below 1.5 to 1 throughout the 222 to 225 MHz band (see Figure 8B).

We could not find a simple method for modeling helical dipoles using *EZNEC*, and resorted to *FEKO*, a more advanced antenna simulator.[5]

In essence, we constructed a vertically polarized normal-mode helical dipole that was resonant in the 1.25-meter band, and fed it in parallel with the same coax that feeds the rest of the DBJ-1 antenna.

Keith Synder, KI6BDR, and Dr. Steve Stearns, K6OIK, of the Northrop Grumman Electromagnetic Systems Laboratory in San Jose, California, assisted in the modeling. A *FEKO* simulation of the vertical radiation pattern of the 1.25-meter portion of the antenna is shown in comparison with the pattern of an ideal dipole in Figure 9. In this simulation, there is a 12-foot length of #14 AWG insulated wire inserted through the center axis of the helical dipole. The #14 AWG wire mimics RG-174 coax because it is virtually the same diameter with plastic insulation. The difference between the vertical plane patterns of two antennas is negligible. There is some vertical distortion, but it is inconsequential.

Conclusions

The TBJ-1 antenna is a novel, vertically polarized base station antenna that covers the 2-meter, 1.25-meter, and 70-centimeter amateur bands. The antenna requires no radials, is totally weather-protected, and is less than 6 feet tall. With some basic tools, it can be constructed with materials that cost under $5. If one already owns a DBJ-1, the cost to add the 1.25-meter band is about $2 of wiring, including a longer piece of RG-174A lead-in coax, a 6-foot piece of ¾-inch PVC pipe, and about an hour of time. Matching is excellent on all three bands, and the bands can be tuned independently. This antenna meets the requirements set by ARES/RACES for low cost, ruggedness, easy deployment, and good performance.

Ed's students will gladly build you a working tri-band antenna. E-mail Ed at **edison_fong@hotmail.com** for details.

Notice:

An application for a US patent on this tri-band antenna is currently pending. Individual hams and/or clubs are free to construct the TBJ-1 antenna, royalty free, on an individual and non-commercial basis, according to the plans and details in this QST *article. — Edison Fong, WB6IQN.*

Notes

[1]E. Fong, WB6IQN, "The DBJ-1: A VHF-UHF Dual-Band J-Pole," *QST*, Feb. 2003, pp. 38 – 40.

[2]E. Fong, WB6IQN, "The DBJ-2; A Portable VHF-UHF Roll-up J-Pole Antenna for Public Service," *QST*, Mar. 2007, pp. 38 – 40.

[3]J. Oberhofer, KN6PE, Outpost Packet Message Manager, Version 3, **www.outpostpm.org**.

[4]J. L. Harris, WD4KGD, "A VHF/UHF 3-Band Mobile Antenna," *QST*, Feb. 1980, pp. 16 – 17.

[5]*FEKO* (FEidberechnun fur Kiper mit Obeflache)

Ed Fong, WB6IQN, was first licensed in 1968 as WN6IQN and now holds an Amateur Extra class license. He obtained his BSEE and MSEE degrees from the University of California at Berkeley, and his Ph.D. from the University of San Francisco. A senior member of the IEEE, he has 12 patents and over 40 published papers and books in the field communications and integrated circuit design. He is currently employed by the University of California, Santa Cruz as an instructor, teaching graduate classes in RF design and high-speed interfaces. In his 35-year career, he has done work for Stanford University, National Semiconductor, Advanced Micro Devices, and numerous startup companies in the Silicon Valley. You can reach Ed by e-mail at **edison_fong@hotmail.com**.

Tessa Fong, KJ6QXM, was first licensed in 2001, when she was in middle school. She is a member of the Cathay Amateur Radio Club and serves as its activities director, which includes responsibilities for organizing its annual ARRL Field Day and its famous Christmas party. She is one of the net controllers for the club's weekly net. Tessa is a member of SARES (Sunnyvale Amateur Radio Emergency Services) and participates in its EOC radio checks. She is a second-year engineering student in the Honors Program at Boise State University.

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Strays

QST Congratulates...

Charles "Buc" Fitch, W2IPI, of Avon, Connecticut, who received an "Outstanding Member" award from Chapter 14 of the Society of Broadcast Engineers last December. He has been a member for more than 30 years and a mentor to engineers throughout Connecticut. In the accompanying photo, Buc (right) is being presented the award by Chapter 14 chairperson Fred Krampits. [John Ramsey, photo]