A Tri Band Antenna for 2 meters, 220 MHz, and 70cm Antenna Without Radials

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Twenty years ago a single band handie talkie would have been adequate for emergency use since almost all emergency activity was conducted on VHF. Today, that is not the case. In major metropolitan areas, both VHF and UHF are used for emergency communications organizations such as ARES/RACES. In some selected areas, even the UHF amateur band is full. This was the primary motivation for the dual band J-pole designed I presented in March 2003 of QST [1]. That article showed how to convert a single band VHF ½ wave J-pole shown in Figure 1 to also perform in the UHF -70 cm band with ½ wavelength performance. With that being a success, in Feb. of 2007 I introduced the DBJ-2, a portable roll up dual band J-pole [2]. My students and I have built over 10,000 for various RACES/ARES clubs and government agencies. One application I am particularly proud of is the use of the portable antenna kit among United States Forest Fire Fighters. The entire kit only weighs 7 ounces and can be erected in less than a minute. On average, it gives over 6dB of gain over a rubber duck. Since forest fires are indiscriminate of where they strike, coverage can be spotty when firefighters are deployed in rough terrain and 6dB of gain can be critical.

The motivation of all the above antennas come from inputs from users. The DBJ-1 began by having Howard N6MNV asking me whether it was possible to modify a single band J-pole to a true dual band J-pole. The roll up portable DBJ-2 was requested by ARES/RACES groups. One of my students suggested to offer the DBJ-2 as an emergency antenna kit which includes adapters for BNC, SMA and SMA female and a six feet extension cable. The DBJ-2 kits have been sent to major disaster throughout the world due to its light weight (7oz. including all accessories.) We would like to continue this tradition of continue improvement. So after the DBJ-2 what do users request?

One of the most often requested additions was whether it was possible to add 220 MHz to the DBJ-1. In the San Francisco Bay Area, 220 MHz has some FM voice channels but its most important contribution is packet radio. Packet, due to its modulation approach, causes interference on the band it operates. When packet is allocated to the 220 MHz band, the interference (especially on 2 meters) drops immensely.

Since the development of Outpost by Jim Oberhofer KN6PE, 220 MHz packet is not only popular in the Bay Area but has spread nationwide. For traffic passing, packet is far more efficient than voice. Thus, the most common request is for one antenna to cover 2 meters, 220 MHz and 70cm. This would simplify the need for multiple antennas during an emergency deployment. The 220 MHz band is not harmonically related to any other ham band. This makes matching difficult and construction of such an antenna is not obvious. Nevertheless, I accepted this challenge.

Requirements for an ARES/RACES Antenna

After interviewing multiple EC's (emergency coordinators) throughout the Bay Area, a summary of the desired specifications for a multi band 2 meter, 220 MHz, 70cm antenna was composed and is given below:

1. Must be easy to erect during an emergency. One piece construction desirable.
2. Low cost. Certainly far less than commercially available tri band antennas which retail in the $150 range.
3. Very reasonable performance
4. 5ft or so in length and radial free for durability.

Due to the success of the DBJ-1 and the inputs we received from users, maintaining the same form factor as the DBJ-1 was important. Since the DBJ-1 is deployed in emergencies, many users are not from a technical background so changing form factors (such as radials) should be avoided.

The problem can be stated in one sentence. Can the popular DBJ-1 dual band base antenna be adapted to also work at 220 MHz with minimal changes and no degradation of performance at 2 meters and 70cm?

Simply put, the goal here is to try to combine the DBJ-1 shown in Figure 2 with a 220 MHz J- pole shown in Figure 3.

Review of the Literature and Experimental Prototypes

Searching for a Tri-band VHF/UHF antenna using Google search or Bing did not yield much. One could always build a multi-band antenna with LC "band traps" which is commonly used in the 80-10 meter bands. Even at HF, experience builders of LC traps will only express to you how difficult it is to build good low loss stable traps. At VHF and UHF it is not practical even with access to sophisticated instrumentation such as an Agilent 8753D network analyzer. I leave the technique of LC traps at VHF/UHF for the professionals since my personal experience had limited success.

Going back to the basics, I search the literature and only came up with one Tri-Band (2 meter, 220 MHz and 70cm meter) antenna by J.L. Harris [3]. It was a stacked Tri-band J-pole antenna as shown in Figure 4. It is basically 3 parallel J-poles where the coax for each antenna is routed through the copper pipe and combined at the base.

My quest was to add 220 MHz to the DBJ-1 with minimum effort and still achieve ½ λ performance on all three bands. The antenna by Harris falls short of this goal. Certainly it is possible to obtain resonance on all three bands and with some careful adjustment even achieve reasonable SWR on all three bands. 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 odd harmonics and thus will experience low SWR at its 3^{rd}, 5^{th}, 7^{th}, etc. harmonic. The configuration shown in Figure 4 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. More important is that its elevation pattern will be maximum at 45^{o} leaving only about 25% of the RF energy in the horizontal plane as shown in Figure 10. This pattern is not optimized for terrestrial propagation.

To have an antenna operate only at its fundamental frequency will require some type of trap. This was accomplished in the DBJ-1 using a ¼ λ decoupling stub at UHF [1]. Without the decoupling stub at UHF, although the matching will be good, the radiation pattern will be not optimum as a vertically polarized antenna as shown in Figure 9.

Experimental Prototypes

For a tri band antenna, a good start was the dual band DBJ-1. The DBJ-1 starts out as an excellent configuration because it has true ½ wavelength performance on both VHF and UHF. Still the elusive question remained, how can one add 220 MHz to the DBJ-1 without affecting the VHF/UHF performance. The 220 MHz band is not harmonically related. Thus, there is no way of reusing the matching network used in the DBJ-1 to obtain resonance at 220 MHz.

In the DBJ-1 shown in Figure 2, the input feedpoint uses the same tap point for both VHF and UHF. This is possible because UHF is the 3rd harmonic of VHF. The UHF radiating element is 12 inches up from the ¼ λ VHF matching stub followed by a ¼ wave UHF decoupling stub. The UHF decoupling stub is a 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 ½ λ pattern at both VHF and UHF. This has become a standard for both the ham and commercial industry for a simple effective dual band antenna [1]. This was a great start, but what options does one have if one desired to add 220MHz operation to the DBJ-1?

One technique to achieve 220 MHz resonance was to stack a 220 MHz J-pole constructed with ½ inch copper pipe onto the DBJ-1 as shown in Figure 5. RG174a is slipped through the ½ inch copper pipe to connect to the DBJ-1. However, the total length of the antenna becomes 8 ft which is prohibitively too long and is not practical. A prototype of this configuration was constructed and sure enough it work. Although functional, its esthetics, physical construction, and cost did not meet the original requirements.

Quickly running out of ideals, it dawn on me that I could just construct a 220 MHz horizontal dipole at the feedpoint of the DBJ-1 as shown in Figure 6. That worked and the prototypes I build certainly had good resonance. Only one problem, the 220 MHz antenna was horizontally polarized. Also, it would look like radials which did not meet the original specifications. But this was a good learning experience. It worked and it was something to move forward on. I then attempted to bend the elements to a vertical direction. As soon as the 220 MHz ¼ λ elements start approaching a vertical position, the SWR rises to unacceptable levels. This is because the elements start coupling to the VHF ¼ λ stub and coax shield and contributes a capacitive term. I quickly figured how I could remedy the horizontal polarization problem. Convert the horizontal dipole into a loop antenna to give vertical polarization characteristics as shown in Figure 7. Step by step I was getting closer to my ideal antenna. The only obstacle was to come up with a configuration where everything could be placed inside a piece of ¾ inch pvc pipe as in the DBJ-1 and also maintain vertical polarization.

After much though, I thought about coiling a vertical wire ¼ λ (about 12 inches) for 220 MHz, around the bottom of the matching stub of the DBJ-1 and for the ground resonate section, coil an equivalent piece around the RG174 lead in. This configuration is shown Figure. 8. This is the configuration of which we have applied for a patent [4].

With some minimum adjustments, this worked great. One could fine tune the resonance by compressing or expanding the coils to fine tune the resonance. So how would one build this? The great thing here is that each band is tuned separately with almost NO interaction.

Construction details –
The antenna is built around the DBJ-1 dual band j-pole. Details of this construction is covered in March QST [1]. One starts out with this configuration. This is basically a 2 meter J-pole constructed from 300 ohm twinlead and then with a UHF decoupling stub to achieve full ½ wave performance both at VHF and UHF.

The following is a brief review of the construction of the antenna, more details can be found in [1]. Referring to Figure 2, the first step is to start with a 300 ohm twinlead of about 28 inches in length. Short the bottom. At about 1 ¼ inch up from the short, tap off the 50Ω ohm point with RG174a. Cut a ¼ notch about 15 ¼ inch from the 50 ohm tap. The leaves about 11 ¼ inches for the UHF ½ λ element.

At this point, measure the SWR and trim the notch for 445 MHz. Next add the ¼ λ RG174a decoupling stub. Start with about 4 ½ inches with a short at the top. Solder the open bottom end to the top of the UHF ½ λ section (11 ¼" section). Measure the SWR. Trim the stub 1/8" at a time until the resonant frequency is back to 445 MHz.

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

For the 220 MHz addition, cut out two pieces of 12 inch #16 solid wire. This is for the construction of the vertical 220 MHz dipole. Construct the 220 MHz coils by using ½ inch pvc pipe as the coil form. Slip piece through the ¼ λ stub and other piece through the RG174 lead in coax. Solder the coils to the center conductor and the other to the braided shield. A photo is shown of the 220 MHz coils wrapped around the twinlead and coax in Figure 8.

Measured Results
The SWR on all three bands was very acceptable. Everyone will tell you that SWR measurements are very inconsistent. I couldn't agree with that more. First measuring

SWR at UHF from one of the “ham” SWR analyzer can be troublesome. I have found at resonance they are quite accurate. This is because they all use a bridge configuration of some type. The bridge is driven with an I and Q signal and if the load is close to 50 ohms, the data matches well with our Agilent 8753D in our lab. However, as we deviate from 50 ohms, the inaccuracy quickly increases. This happens as you move away from the resonant frequency. Since one does not calibrate out the length of the coaxial cable at the point of test, as in a true network analyzer, it cannot be accurate. For example, without calibration at UHF, a 4 ½ inch open stub will read a short. Similarly a short will read an open. Thus at UHF even the slightest piece of coax will throw off the measurements if one is not at resonance.

The simplest way to make accurate measurements at VHF and UHF is with an in line directional coupler such as the BIRD 43. The measurements shown in Figure 11 were performed on a BIRD 43 being driven with 10 watts. At both 2 meters and 220 MHz SWR is below 1.4 to 1, even at band edges. At UHF, it below 1.5 to 1 from 441-450 MHz. This is typically more than adequate since repeater input frequencies at UHF are in the 445-450 MHz range.

Conclusions - Presented here is a novel base station antenna which covers the VHF (2 meter), 220 MHz, and UHF amateur band. It is easy to construct with materials costing in the $10 range. Matching is excellent on all three bands and can be tuned independently. This antenna meets the demands set by ARES/RACES group for ruggedness, easy deployment, and performance. It requires no radials, is totally weather protected, and only 5 ½ feet tall.

References

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