160/80/75-Meter Broad-Band Inverted — V Antenna

BY JAMES L. LAWSON,* W2PV

For some years the author has been greatly interested in DX, principally on the "easy" bands (40 through 10 meters), but also on 75 and 80 meters, and more recently on 160 meters as well. On 75 and 80 meters a square array of $\lambda/4$ verticals has been in use for 4 years, where phasing has permitted directional "beams" to be used. This system has been quite effective for reception, but probably due to grounding inefficiencies has not been really satisfactory for transmitting. On 160 meters a low (height about 30 feet) bent dipole has been in use, and even at that height many DX countries have been worked. Nevertheless, the author wished to improve both the (transmitting) effectiveness on 75 and 80 meters and the total 160-meter effectiveness. To this end he has designed and constructed a high inverted-V dual-band antenna; *high* to improve the effective low-angle radiation from the antenna and *inverted V* to accommodate all antennas on only one high support. The design criteria also included the hope of covering the entire 75/80 meter band with no tuning adjustments. The initial choice of the inverted V was also influenced by the idea that horizontal polarization from a sufficiently high antenna over ordinary ground[1] – and especially over poor ground – might be superior to vertical polarization. A horizontal dipole might be the logical best choice; however the dipole requires two expensive supports rather than just one for the inverted V. In any case, the inverted V appeared to be a good initial candidate for both 160 and 75/80 meters. The support required was a guyed tower 110 feet high and this was constructed in a relatively standard way using Rohn No. 45 sections and 3/16-inch stainless-steel guy wires broken up by insulators every 27 feet to avoid not only all resonances at the lower frequencies, but for all amateur bands which might be activated by nearby antenna systems.

Antenna Bandwidth

The bandwidth of an antenna has been defined in many ways, and it is necessary here to make clear a proper definition of bandwidth and just how it can be measured. A simple antenna radiating element can be thought of as a single resonant circuit containing lumped equivalent capacitance, C (element to ground), inductance, L (element to ground), and resistance, R (effective radiation and loss resistance). The effective Q of the circuit $L\omega_0/R$, where ω_0 is $2\pi f_0$ and f_0 is the resonant frequency of the antenna, would be a normal "electrical" parameter of bandwidth. The *total* electrical bandwidth, B_e (the bandwidth between frequencies where the reactance is equal in magnitude to the resistance) would be simply: $B_e = f_0/Q$. Unfortunately this "electrical" bandwidth is not the most useful definition of antenna bandwidth. It has become customary to cite antenna bandwidth, B, as the frequency band within which the voltage standing wave ratio, or SWR, remains under 2 to 1. This latter is a measurable property of an antenna system[2] and has become an acceptable standard for tolerable loads on linear amplifiers. Although transmission line losses would ordinarily not rise significantly with even higher SWRs, an SWR of 2 or less is a conservatively low figure for satisfactory transmission. I wish to emphasize here that for an SWR of 2 from a *practical* point of view the increased losses in the coupling and transmission system are generally negligible; even the indicated reflected power of 11 percent (at an SWR of 2) is *not* lost but in effect is rereflected into additional forward power at the driving point (linear amplifier coupling network). For these reasons, I will use B, the frequency interval between SWR equals 2 points, as the definition of bandwidth. In the event that an antenna is matched at the resonant point (an SWR of 1), B is simply related to B_e and in fact is just: $B=0.7\,B_e$.

The bandwidth requirement for 160-meter transmission in this area of the northeast USA is quite nominal; for DX purposes it is only 25 kHz (1800 to 1825 kHz). To be sure, the next 25 kHz is permitted, but at lower power only, and is therefore not particularly useful for transmitting to DX stations. In any case 50 kHz is an adequate antenna bandwidth. It should be noted that for

A great deal of mystery seems to have surrounded the electrical properties of the inverted-V antenna since it was popularized some years ago. Here, W2PV offers his analysis of how the system operates, and shows how to construct a practical two-band version of this effective antenna.

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*2532 Troy Rd., Schenectady, NY, 12309.

[1] Chief Signal Officer, Pentagon, Washington, 25, D.C., "Radiation from Antennas in the 2-to 30-Megacycle Band," *Radio Propagation Unit Technical Report* No. 2, July 1947, pp. 1-281.

[2] Author's Note: Almost all amateurs have an SWR meter available, but unfortunately have an unwarranted optimism on their reliability or accuracy. It is not uncommon for different SWR meters to indicate anywhere from 1.4 to 4 when the actual SWR is 2. This is chiefly caused by the (uncalibrated or variable) power calibration of the meter for both forward-and reverse-crystal detectors.

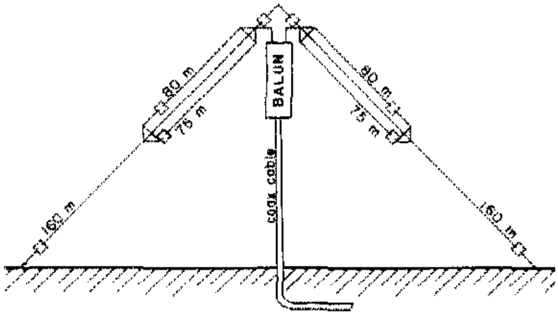

Fig. 1 — The initial two-band system described in the text.

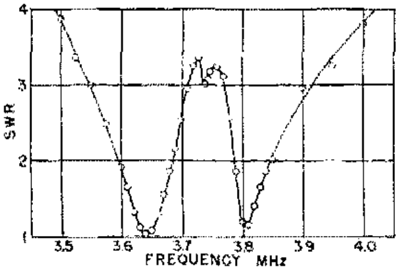

Fig. 2 — The 80-meter SWR curve for the system shown in Fig. 1.

reception such an antenna is quite satisfactory even a long way from resonance (e.g., 250 kHz) as the incoming noise level is so high that it will override receiver noise even with very large antenna reactance. Thus the *signal-to-noise* ratio will be *unchanged even over a very wide band. For 75 and* 80 meters it is desirable to have the full 500 kHz (3500 to 4000) available for transmission and, of course, reception. This is a very difficult matter to arrange without any tuning adjustments because of the large ratio of bandwidth to center frequency desired. Nevertheless, this has been virtually obtained in the design to be described later.

A Parallel-Wire 75/80/160-Meter Antenna System

One of the first attractive ideas was a trapped-wire system for the (three) desired band segments in much the way trapped-multiband dipoles have been used in the past. However the trap to separate 75 and 80 might be difficult and would not likely to be well behaved over the entire band.[3] Furthermore the simultaneous use of multiple-wire parallel antennas has been common and it was decided to try such an arrangement as shown in Fig. 1.

A single long wire would work as the 160-meter resonator and two appropriately trimmed parallel wires would serve as the 75- and 80-meter resonators. It was expected (see later discussion) that the bandwidth of 75- and 80-meter wires would individually be about 200 kHz, and that the combination might behave like two coupled circuits to produce a double-humped broadband (perhaps 500 kHz) circuit. This turned out not to be the case, as will be described. The antenna was strung as in Fig. 1 with the 75- and 80-meter wires on opposite sides of the 160-meter wire and separated from it by about one foot. The entire assembly was fed through a 1:1 balun. After construction it turned out quite easy to find the resonant frequencies of the three elements and to trim them to arrive at any desired frequency. It became immediately apparent that, although the resonance of the 160-meter wire behaved about as expected, the individual resonances of the two shorter wires were much sharper than either expected or desired. A typical SWR run for the 3.5 to 4.0 MHz band is shown in Fig. 2. As can be seen the 75/80 meter performance was of the correct qualitative behavior, but much too narrow in bandwidth. This sort of undesirable performance has also recently been reported[4], and as we shall soon see, is inherent for parallel-wire systems of this general type.

Expected Bandwidth For a Single Wire

At this point it may be helpful to calculate the expected bandwidth of a single-wire inverted V for 75 and 80 meters. Such a calculation can be easily made (approximately) by approaching the problem in either of two ways. The first is to consider the antenna wire leg ($l = \lambda/4$) as one conductor of a transmission line (with the ground as the other conductor). The input reactance, Z_i, of this open circuited length of line l is given simply by the low loss transmission line equations i.e.,

$$Z_i = jZ_o \cot 2\pi l/\lambda = -jZ_o \cot\theta$$

where $Z_o = 138 \log_{10} (4h/d)$ ohms h = average antenna height over ground d = diameter of the antenna wire in the same units Z_o, the characteristic impedance of the line, is typically several hundred ohms; indeed for $h = 70$ feet and $d = 0.064$ (No. 14 wire), $Z_o = 650$ ohms. Z_i is zero if $l = \lambda/4$ (at the resonante frequency), but at other frequencies near resonance:

where $\theta \neq \pi/2$, $Z_i = jZ_o (\theta - \pi/2) = jZ_o \Delta\theta$

Remembering that the total bandwidth, B, is 0.7 times the frequency interval between points where the reactance is equal to the radiation resistance of the antenna leg (here taken as 25 ohms or one half the resistance of the entire inverted V) we obtain:

$B = 1.4 \times f_o \times 2\Delta\theta/\pi = 1.4 \times f_o \times 2 \times 25/(\pi \times 650) = 140$ *kHz at a center frequency of 3.8 MHz.*

This transmission-line model is convenient and simple; however, it is certainly not completely valid. For example, in a transmission line the E field is orthogonal to the conductors: such is not the case here where at the antenna open end a spreading E field occurs. Nevertheless the model should give qualitatively the right answer and probably a reasonable approximation to the quantitative answer.

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[3] *Bob Polansky, W6JKR, "Low-band Converted-Vee Antenna," Ham Radio,* December 1969, pp. 18-21.

[4] E.H. Conklin, K6KA, "Antenna Systems for 80 and 40 Meters," *Ham Radio,* February 1970, pp. 55-63.

Another estimate can be made using a lumped constant model of the antenna leg. The *capacitance* of the antenna to ground can be obtained from standard formula[5] (in this approximation the voltage carrying outer half of the wire only is used) from which, in conjunction with the 25-ohm radiation resistance, the Q can be calculated, from which B is obtained:

$C = 0.24l/\log_{10}(2l/d)$ picofarads = 58 pF

$Q = 1/(\omega RC) = 28$

$B = 1.4 \times f_o/Q = 185$ *kHz at a center frequency of 3.75 MHz*

This model of the antenna is approximate because the antenna is really a distributed system; however, again, it should give a reasonable approximation to the expected bandwidth, B. An advantage of this approach is that one can also quickly estimate the effect of multiwire cages on the bandwidth using the electrostatic formula for C.[5] This shows that one can about double the bandwidth using several wires whose spacing is perhaps two feet.

These estimates show that the expected bandwidth of a 75- or 80-meter resonant wire inverted-V antenna should be perhaps 200 kHz, and in fact, such bandwidths are commonly cited for such antennas. However, the results shown in Fig. 2 show much narrower resonances, and this fact prompted an investigation into the behavior of the parallel-wire system.

Behavior of Parallel-Wire Antennas

Consider first just two wires, the long 160-meter wire and the shorter 75-meter wire as shown in Fig. 3. It is convenient first to ignore the mutual coupling between wires and also, for the time being, the radiation (resistance) effects. Let us consider the currents and voltages on the wires, each being regarded as a transmission line of high characteristic impedance, say, 650 ohms to ground. Let us now excite the antenna system by injecting a current, I, at its center (or driving point), at a frequency (and wavelength) which resonates with the shorter wire (say 75 meters). The ends of each line are open circuited, hence zero current points. We shall use the well-known property of transmission lines equating the product of Z_o and the current at any point, iZ_o, to the voltage, e, at a point one-quarter wavelength away. Thus for the antenna wires, e is zero a quarter wave back from the open (zero current) ends. This makes the voltage zero at the driving point due to the shorter wire, but also zero at about the center of the longer wire *and* also at its center (about one-quarter wavelength away) it must be zero everywhere along the wire, and by the same simple theorem on transmission lines referred to above, the current on the long wire must also be zero everywhere. This reasoning shows that a system of wires of various resonant lengths driven at the resonant frequency of a given wire will show no reactive voltages or currents except solely on the resonant wire.

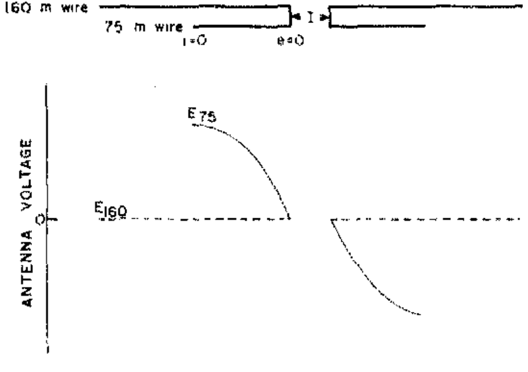

Fig. 3 – Currents and voltages on the two parallel wires. See text.

Field Relationships

We come now to an important concept in the formation of a radiated wave by a wire element, namely that the resonant current largely appearing at the driving end produces an external magnetic field, which must be directly related to the H field of the radiated wave, whereas the *electric* field, generated by the electrostatic field largely at the open end of the wire is directly related to the E field of the radiated wave. Since E and H are necessarily related to the impedance of free space so must the effective electrostatic field of the antenna be related to its driving current. Note now that if the two antenna wires are reasonably close together in terms of wavelength, the *current* will appear only in the driven resonant element, but the effective *electric field* is made up of not only that from the voltage, E, appearing on the current-carrying wire, but from the voltages on all the other wires (each carrying zero voltage and hence field). Thus, in order to radiate, the resonant wire (75 meters) carrying a given (central) current, I, must simply exhibit a sufficiently large end voltage, E_{75} to make up for the *screening* effect of the adjacent ground potential wires. In the case of *two* antenna wires the electric field is made up about equally by the field of the resonating element, and the nonresonating (zero field) element. This shows that the resonating element must have *twice* the voltage to generate the correct electric field as it would have without the second (screening) conductor. To state it more generally, with n parallel elements, the reactive voltage appearing on the resonating element is n times as large as it would have been without the presence of the other adjacent wires. Since the *bandwidth*, using a given radiation resistance, is inversely proportional to the magnitude of the reactive currents it also follows that the bandwidth of an element is reduced by a factor of n due to the presence of the other wires which screen the electric field.

Now that this principle is understood, it becomes easy to see that *short* elements are all effectively screened by longer elements, but the reverse is *not* true. The electric field of an excited long element will not be screened effectively by a

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[5] "Radio Formulae," *Handbook of Chemistry and Physics*, Chemical Rubber Publishing Company, 37th edition 1955, pp. 2964, 2965.

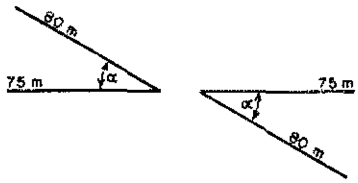

Fig. 4 — A plan view of two wires for the 80/75-meter band.

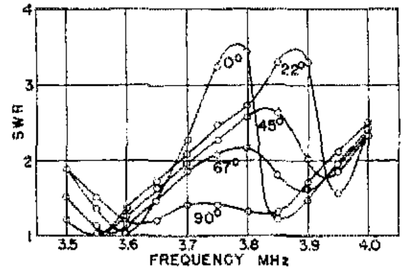

Fig. 5 — A series of SWR curves at different degrees of separation for the two antennas shown in Fig. 4. Note particularly the curve for 90 degrees of separation.

much shorter element, since its main field comes from its unscreened end. Measurements made on the 160-meter resonance of the antenna shown in Fig. 1 showed its bandwidth to be about 70 kHz, or essentially what was expected "theoretically." Furthermore the bandwidths of the individual 75- and 80- meter resonances are about 75 MHz or perhaps 1/3 of the originally "expected" values, but note that with the three wires present due to *screening it really should be narrowed by a factor* of 3. Also the shortest wire (75 meters) is narrowed most of all just as we now qualitatively expect.

We are now in position to improve the antenna of Fig. 1; the simplest technique is to separate the wires by fanning them out at an angle. A plan view of such an antenna for 2 wires for 75/80 meters is shown in Fig. 4.

This antenna was constructed; its erection and measurements provided an interesting Saturday project. A series of SWR-frequency curves were taken for different fan angles α and are shown in Fig. 5. The curve for α = 0 (parallel wires) is different from that shown in Fig. 2 because the omission of the (screening) 160-meter wire broadened each resonance appreciably (as we now expect). As the wires are fanned out, resonant frequencies are somewhat spread due to changes in mutual and capacitance coupling effects in the wires. A steady improvement in behavior can be seen with increasing fan angles all the way to 90 degrees, where the curve now shows a very well-behaved double resonance shape exactly like that originally desired. Note the requirement to go *all the way* to 90 degrees for most effective performance. Actually at 90 degrees *three* important things occur: first there is no electric screening left due to orthogonal fields, second there is no mutual coupling effect due to orthogonal wires, and third – something which has not been mentioned up to this time – excitation of the system at a frequency exactly in between the two wire resonant frequencies results in good (radiated wave) radiation resistance. (In the parallel-wire case such excitation largely causes a high circulating current between the wires with little or no radiation.) These experiments suggest a good reason why orthogonal 2 band (such as 80/40 meter) inverted Vs have been used and seem to work *quite well, and they also suggest a good* possibility for the 75/80/160-meter system originally proposed.

Broadband 75/80/160-Meter Design

It appears that wherever two resonances are expected to be highly interactive (say within a single band to be covered) an orthogonal wire system is highly desirable. In the coverage of the frequencies desired, this indicates that the 75-and 80-meter wires be orthogonal. The question remains as to the best place to add the 160-meter wire to provide least screening of the 75/80 complex; this clearly would be at an angle of 45 degrees (just in between the orthogonal set). A plan view of this arrangement is shown in Fig. 6.

Measurements indicated that the screening effect is indeed tolerably small, i.e., the bandwidth of the 75/80 combination was narrowed only about 10 percent by the addition of the 160-meter

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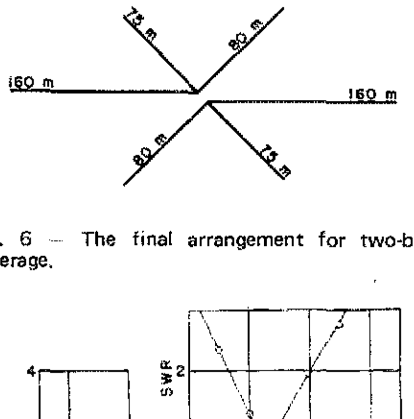

Fig. 6 — The final arrangement for two-band coverage.

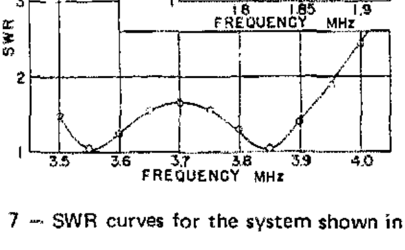

Fig. 7 — SWR curves for the system shown in Fig. 6.

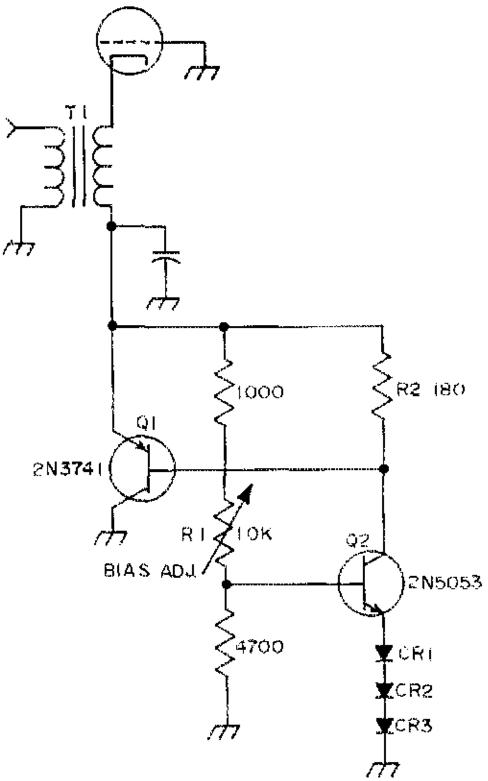

Fig. 3 — Shunt regulator circuit for biasing sweep-tube linear amplifiers. See text for parts not listed below. CR1 — CR3 incl. — Silicon power-supply diodes, such as 1N3194.

power transistors such as the 2N173 could be used. With changes in the divider network, the regulator may be operated at higher voltages. With R1 changed to 0.1 megohm and R2 increased to 2200 ohms, the regulator performed nicely in the 50-volt region, making it a candidate for use with a Class AB1 6146 amplifier. If several cathode-driven sweep *tubes are to be run in parallel, idle current* equalization[4] may be achieved with separate shunt regulators and a multifilar cathode rf choke. — *Mike Rigik, W7THL, and Wes Hayward, W7ZOI, Device Development, Tektronix, Inc., Beaverton, OR 97005.*

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wire. Trimming the lengths of all elements to their best values was quite easy; in this case the wire elements were shortened by folding back and securing with a small electrician's "bug." The final SWR curves are shown in Fig. 7 and show excellent characteristics: bandwidths of 70 kHz for 160 meters, and 500 kHz for 75 and 80 meters.

Antenna Performance

Performance of the antenna system has been quite satisfactory. On 160 meters DX contacts have been made easily, and from comparative reports received, the author feels that performance is just about what was hoped for and expected. On 75 and 80 meters the expected good transmitting performance seems to have been realized. Reception of many DX stations has also been quite good, but there are many instances where a vertical antenna array is quite a bit better, i.e., when the DX station is partly obscured in local QRM (such as VE stations) on 75 meters. In actual fact it has been quite desirable to have *both* the vertical array and the inverted V antennas available so that the best choice for DX reception could be made experimentally.

Summary

1. It has been shown that orthogonal inverted-V antennas make an excellent dual-band system and provide good broadbanding for 75 and 80 meters.
2. A 75/80-meter inverted V has been built which efficiently covers the entire (500 kHz) band with no tuning adjustments.
3. Antennas should preferably be mounted away from (grounded) metal conductors such as towers or other non resonant antenna wires which tend to screen the electric field. Antenna *performance* at resonance is not especially hurt by screening, but its *bandwidth* is seriously reduced.

Gimmicks and Gadgets

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can be adjusted to give the appropriate output level.

Most of the component values are not critical, except the *RC* products which determine timing. Since the frequency is low, almost any bipolar transistors can be used. Npn types are shown, but pnp will work with opposite polarity. The beta rating should be at least twice R3/R4, to insure saturation.

[EDITOR'S NOTE: The unit shown in the photograph was assembled and tested in the ARRL Lab. A 220-ohm resistor was used to simulate the relay coil resistance. The transistors were 2N3860. C1 was 25 µF. We were interested in seeing how much range of pitch could be obtained, and changing the value of C2 and C3 was most productive in this respect.

It was found that frequencies from about 600 to 1800 Hz could be produced, but as the frequency was made higher than obtainable with the constants given in Fig. 1 it was necessary to reduce the collector voltage in order to maintain oscillation. This was done by changing the value of R8, a component not used in the circuit supplied by WA5FTP. If a separate source of voltage for the whistle is used, the voltage itself can be varied, but if the car battery is used, R8 may have to be adjusted to drop the collector voltage to something around 6, for oscillation frequencies much over about 1000 Hz. We got up to about 1800 Hz with C2 and C3 having been reduced to .02 µF.]

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[4] DeMaw, "Some Ground Rules for Sweep-Tube Linear-Amplifier Design," *QST*, July, 1968.