A Top-Fed Vertical Antenna for 1.8 MHz — Plus 3

Mathematical analysis unlocks the secret behind this unusual antenna system.

By Carl Eichenauer,* W2QIP

Does your antenna act strangely at times? Does it resonate where it is not supposed to? Well, mine does. To understand why, I developed a BASIC computer program to "crunch" through various mathematical calculations. The program is listed in the Appendix. My "strange" installation consists of 80- and 40-meter inverted-Vs, fed from a single coaxial cable and mounted on a common support.

There is nothing unusual about this system; the approach is described in *The ARRL Antenna Book*.[1] The antenna shown in Fig. 1 provides satisfactory performance on 80, 40 and 15 meters. It also provides — strange as it may seem — effective radiation on 160 meters! No traps, switches or antenna matching networks are required to accomplish 4-band operation.

A certain amount of skepticism is in order at this point — in fact, I could not have been more surprised. After trying to tune the antenna on 160 m with the aid of a Transmatch, I eventually found that the system had a SWR of 1.2:1 on 1805 kHz with *no matching network* at all!

The following description and analysis of my antenna system should present ideas useful to other antenna builders. Those familiar with BASIC programming may eliminate many hours of number crunching on a calculator by using a program similar to mine.

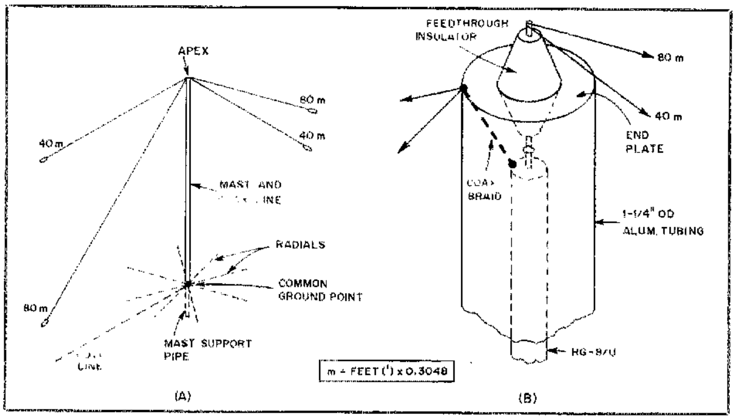

Fig. 1 — Physical details of the antenna system used by W2QIP. A shows the element and radial layout and B details the feed system.

Physical Details of System

A 34-foot wooden mast with a 12-foot aluminum-pole extension provides a center support for both antennas.[2] The 80- and 40-meter inverted-Vs are positioned roughly at right angles to each other. The lower ends are connected to convenient supports (such as trees, house corners or lamp posts) and the height above ground ranges from 6 to 20 feet. RG-8/U coaxial cable runs up the mast and through the center of the aluminum extension pole. A small aluminum plate covers the top end of the aluminum pole and a ceramic feedthrough insulator passes through the plate. The four antenna wires, in addition to an insulated guy wire, support the top of the antenna. The wooden mast is also guyed.

From the feed point, the coaxial line runs down the mast to ground level and then continues underground (at a depth of several inches) to the house, through the basement, and eventually reaches the operating position. Total line length is approximately 100 feet. The outer braid connects to the mast support at the point where the coaxial line goes underground. Bottom support for the mast consists of a 1-1/2 inch steel pipe driven into the earth to a depth of 10 feet. A set of eight wire radials ranging from 20 to 40 feet in length are buried to a depth of an inch or so and are connected to the coaxial-cable braid where it goes underground. This ground network turns out to be an important part of the 160-meter radiation system.

System Modeling

In an attempt to understand the mysterious antenna resonance at 160 meters, I investigated several analytic techniques. The technique that gave the closest agreement with measurements is based on principles set forth in Jordan's

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[1] Notes appear on page 27.

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book.[3] He points out that while lumped-constant circuit elements can be used to model an antenna system over a narrow band of frequencies, transmission-line simulation of the antenna elements is a more accurate approach when analyzing an antenna over a broad frequency range.

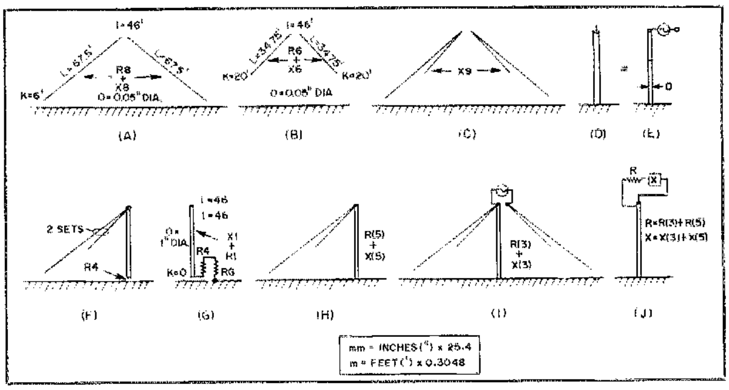

Fig. 2 — Step-by-step development for the mathematical model of the antenna. See text for details.

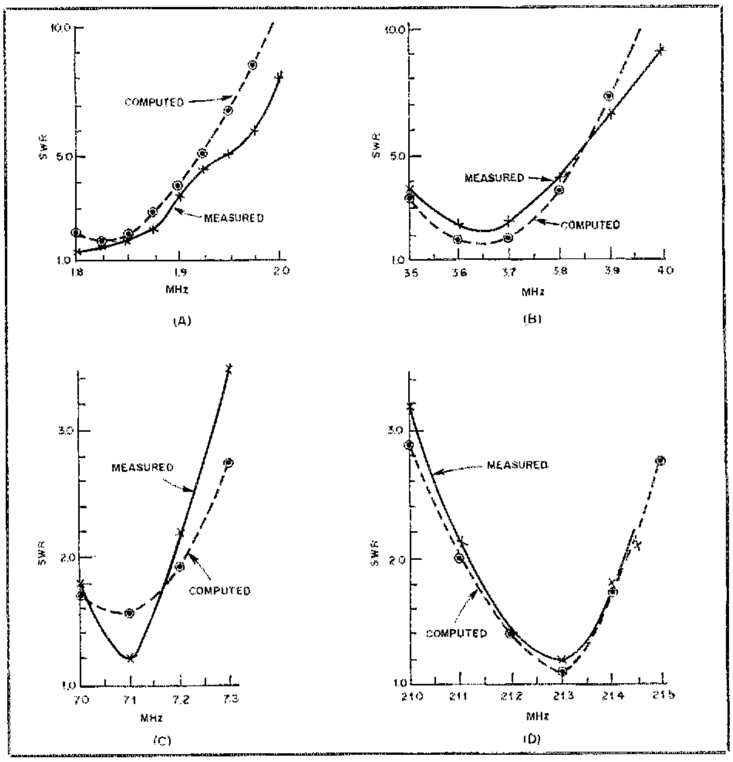

Fig. 3 — Measured and calculated SWR curves for the antenna on (A) 160 meters, (B) 80 meters, (C) 40 meters and (D) 15 meters.

The following 10 steps and the BASIC program outline the analysis of my antenna system. Each step is based either on transmission-line or radiation-resistance formulas. In each case, the formulas are functions of frequency.

The six conductors represented in Fig. 2 consist of two 80-meter dipole halves, two 40-meter dipole halves, and the center conductor and braid of the coaxial feed line. For the purpose of mathematical modeling, we will first assume that the six antenna conductors are suspended in free space.

1) Fig. 2A shows the two 80-meter antenna elements. Each wire can be analyzed as a sloping transmission line in which one conductor is a combination of the earth and antenna radial system. Inspection of the actual antenna shows that the input end of the line (I) is 46 feet high, the output end (K) is 6 feet high and the output load impedance is infinite. This information along with wire diameter and frequency-of-operation data is placed into an appropriate formula and the reactance looking into each half of the antenna (X8) is calculated. Next, the same data is used in a different formula to calculate the radiation resistance looking into the two elements acting as a dipole. One-half of this value is assigned to each element (R8). The key electrical properties of these two "radiating transmission lines" are now defined.

2) The same procedure used in step 1 is used to calculate R6 and X6.

3) Next, the 40- and 80-meter elements are connected together and their total reactance is calculated. This value (X9) is simple — the parallel value of X6 and X8 (Fig. 2C).

4) Fig. 2D represents the analysis of the coaxial line. Since the bottom end is connected to ground, only the 46-foot section shown is relevant to the model. Furthermore, since the line is open-circuited at the top end (for the moment), nothing but a source of voltage appears at the upper end (assuming, of course, that the signal generator is turned on and that it can operate into an infinite-impedance load).

5) As an alternative equivalent, the transmission line can be represented by a solid conductor whose diameter is equal to the O.D. of the transmission-line outer braid (Fig. 2E). The voltage from the transmitter is represented simply by a two-terminal sine-wave generator with one terminal connected to the vertical conductor and one terminal open circuited (for the moment).

6) Next, the two sets of conductors from step 2C are "connected" to the vertical conductor top. From the reactance of this combination, X9, the equivalent electrical length (in degrees) of the elements can be determined for any given frequency. The vertical conductor electrical length (in degrees) is calculated from the physical length. These two sections form a top-loaded vertical antenna. By "lifting" the bottom connection off ground, the base radiation resistance of the top-loaded vertical can be determined (Fig. 2F).

7) An unfortunate fact of nature must be accounted for — no ground system is perfect. Therefore, a resistor (RG, the ground loss) is inserted in series with the radiation resistance of the vertical, as

shown in Fig. 2G. Consider the 46-foot vertical section as another transmission line in which the input end is at 46 feet above ground and the output end is terminated in a resistor of value R1 + RG. This information, along with the vertical-section outside diameter and operating frequency is used to determine the values of X1 and R1, the reactive and resistive components of the vertical transmission line.

8) In Fig. 2H one set of sloping elements is reattached. Now, the series equivalent value for the whole system is calculated.

9) In Fig. 2I one terminal of a sine-wave generator is attached to the vertical element and the set of wires and the other set of sloping wires is connected to the other terminal of the generator. This allows the equivalent series reactance and resistance for the complete set of wires to be calculated.

10) Fig. 2J displays the equivalent result of the modeling. The resistances and reactances of steps 8 and 9 are added together to give the effective input impedance for the complete antenna system. Since this representation is broadband in nature, the system SWR can be checked at any frequency by "sweeping" the signal source!

Calculated vs. Measured Results

An SWR meter at the transmitter end of the transmission line was used for SWR measurements in all cases except one; because SWR values from below the 160-meter band were desired, a home-made RX bridge was employed.

Fig. 3 shows the measured and calculated SWR curves. Resonance occurs near the bottom edge of the 160-meter band. Fortunately, virtually all of my operation on 160 is cw. For operation higher in the band, the computer program showed that lowering the height of the apex by a foot or two should provide satisfactory performance.

Note that the calculated SWR is consistently higher than the measured values. This characteristic can be modified by selection of the value of ground resistance used in the calculations. In the case shown, a value of 5 ohms has been arbitrarily selected. If a lower value is used, the lowest calculated SWR coincides almost exactly with the lowest measured value, but the off-resonance SWR rises at a more rapid rate than the measured values. This simply points out the fact that the model is representative, but not exact. In defense of the model, it should be pointed out that SWR measurements are seldom exact either!

The SWR curves for the other bands present few surprises. Over the years, similarly installed dipoles and inverted Vs have produced essentially the same response characteristics.

Conclusions

If you wonder whether this antenna really works, I must confess that it has not been responsible for a 160-meter DXCC award. However, in a recent ARRL 160-meter contest it was used with a QRP rig running three watts input. Over a three-hour period 50 stations in 22 states were worked. If nothing else, this should prove that the system does radiate on 1.8 MHz!

Appendix

The BASIC program listed below was developed on a Timex/Sinclair 1000® computer with 16K of RAM. [The program will run on the 2K T/S 1000 if the REM statements are removed from the program. — Ed.] The program follows the analysis algorithm presented in the text. Readers familiar with BASIC programming should have no trouble in adapting the program to any BASIC-equipped machine.

```
#L:-(

10 REM FILE NAME IS ANTENNA2
20 FOR F=1.8 TO 2.0 STEP .025
30 LET P=3.1415927
40 DIMR(10)
50 DIMX(10)
60 REM 80 M.SLOPER REL.TO GND.
70 LET L=[illegible]
80 LET Q=.05
90 LET T=46
100 LET K=5
110 LET D=(I+K)/2
120 LET R4=0
130 LET X4=-1E6
140 GOSUB 400
150 LET X8=X5
160 LET R8=.01215*(ABS(1-COS(ATN(B)))*180/P)↑2
170 REM 40 M.SLOPER REL.TO GND.
180 LET L=34.75
190 LET Q=.05
200 LET I=46
210 LET K=20
220 LET D=(I+K)/2
230 LET R4=0
240 LET X4=-1E6
250 GOSUB 400
260 LET X6=X5
270 LET R6=.01215*(ABS(1-COS(ATN(B)))*180/P)↑2
280 REM VERTICAL REL.TO GND.
290 LET L=46
300 LET Q=1
310 LET I=46
320 LET K=0
330 LET D=(I+K)/2
340 LET X4=0
350 LET R4=0
360 GOSUB 400
370 LET R1=R5
380 LET X1=X5
390 GOTO 550
400 REM Z SUBROUTINE
410 LET B=TAN(2*P*L*F/984)
420 IF X4=0 GOTO 450
430 LET Z0=60*LOG(48*D/Q)
440 GOTO 510
450 LET Z0=60*(LOG(24*L/Q)-1)
460 LET X9=X8*X6/(X8+X6)
470 LET B1=ATN(Z0/ABS(X9/2))
480 LET B2=ATN(B)
490 LET R4=.01215*(ABS(COS(B1)-COS(B1+B2))*180/P)↑2
500 LET R4=R4+5
510 LET R3=R4/Z0
520 LET X3=X4/Z0
530 GOSUB 900
540 RETURN
550 REM PAR.R1 AND X1 VALUES
560 LET R=(R1↑2+X1↑2)/R1
570 LET X=(R1↑2+X1↑2)/X1
580 REM PAR.EQUIV.OF 80 SLOPER
590 LET R(6)=(R8↑2+X8↑2)/R8
600 LET X(6)=(R8↑2+X8↑2)/X8
610 REM PAR.EQUIV.OF 40 SLOPER
620 LET R(1)=(R6↑2+X6↑2)/R6
630 LET X(1)=(R6↑2+X6↑2)/X6
640 REM PAR.EQUIV.OF 80&40 SLOPERS
650 LET R(2)=R(6)*R(1)/(R(6)+R(1))
660 LET X(2)=X(6)*X(1)/(X(6)+X(1))
670 REM SER.EQUIV.OF 80&40 SLOPERS
680 LET R(3)=X(2)/(X(2)/R(2)+R(2)/X(2))
690 LET X(3)=R(2)/(X(2)/R(2)+R(2)/X(2))
700 REM PAR.EQUIV.OF80&40 SLOPERS+VERT.
710 LET R(4)=R(2)*R/(R(2)+R)
720 LET X(4)=X(2)*X/(X(2)+X)
730 REM SER.EQUIV.OF 80&40 SLOPERS+VERT.
740 LET R(5)=X(4)/(R(4)/X(4)+X(4)/R(4))
750 LET X(5)=R(4)/(R(4)/X(4)+X(4)/R(4))
760 REM SER.VALUES FOR ANTENNA
770 LET R1=R(5)+R(3)
780 LET X1=X(5)+X(3)
790 REM REFLECTION COEF.
800 LET V1=SQR((R1-50)↑2+X1↑2)
810 LET V2=SQR((R1+50)↑2+X1↑2)
820 LET V=V1/V2
830 REM  VSWR
840 LET V=(1+V)/(1-V)
850 PRINT"F=";F;" X=";X1
860 PRINT"R=";R1;" VSWR=";V
870 PRINT
880 NEXT F
890 STOP
900 REM LINE R AND X SUBROUTINE
910 LET C=(1-X3*B)↑2+(R3*B)↑2
920 LET R=R3*(1+B↑2)/C
930 LET X=(X3*(1-B↑2)+B*(1-R3↑2-X3↑2))/C
940 LET R5=R*Z0
950 LET X5=X*Z0
960 RETURN
970 END
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```
*RUN


F=  1.8  X= -36.79183
R=  77.75574  VSWR=  2.060922

F=  1.825  X= -16.213753
R=  86.00515  VSWR=  1.743639

F= 1.85  X=  21.77462
R= 95.5599  VSWR=  2.046966

F=  1.875  X=  54.04112
R=  106.7074  VSWR=  2.791916

F=  1.9  X=  88.23508
R=  119.8171  VSWR=  3.855286

F=  1.925  X=  123.0536
R=  135.3697  VSWR=  5.124723

F= 1.95  X= 164.247
R=  153.9985  VSWR=  6.782116

F=  1.975  X=  207.8211
R=  174.5483  VSWR=  8.590436

F=  2  X=  254.7821
R=  204.1618  VSWR= 10.5928


ready
*20 FOR F=3.5 TO 4.0 STEP .1
*RUN


F=  3.5  X=-73.5251
R=  66.48304  VSWR=  2.415184

F=  3.6  X=  -14.44687
R=  74.61266  VSWR=  1.751711

F=  3.7  X=  36.76289
R= 77.5977  VSWR=  1.887677

F=  3.8  X=  81.99717
R=  75.59361  VSWR= 3.56362

F=  3.9  X= 144.457
R=  77.41974  VSWR=  7.297825

F=  4  X= 210.934
R=  80.79132  VSWR=  13.17314


ready
*20 FOR F=7.0 TO 7.3 STEP .1
*RUN


F=  7  X=  -44.09847
R=  75.65639  VSWR=  1.722581

F=  7.1  X= 4.48773
R=  73.68868  VSWR=  1.582331

F=  7.2  X=  31.80422
R=  73.99452  VSWR=  1.905327

F=  7.3  X=  60.01251
R=  76.04982  VSWR=  2.763779


ready
*20 FOR F=21 TO 21.5 STEP .1
*RUN


F=  21  X=  -52.86379
R=  48.20148  VSWR=  2.854866

F= 21.1  X=-34.9547
R=  49.26755  VSWR=  1.994922

F= 21.2  X= -17.06762
R=  49.21908  VSWR=  1.408788

F= 21.3  X= 2.17015
R=  45.08509  VSWR=  1.119743

F= 21.4  X=  24.11262
R= 40.9635  VSWR= 1.75343

F= 21.5  X=  45.62159
R=  39.40734  VSWR=  2.750102
```

Notes

[1] G. Hall, Ed., *The ARRL Antenna Book*, 14th ed. (Newington: ARRL, 1982), chapter 8.

[2] m = ft × 0.3048; mm = in. × 25.4.

[3] Jordan, *Electromagnetic Waves and Radiating Systems* (Englewood Cliffs, NJ: Prentice-Hall, 1950), chapter 13.