Stub Matching: A Review

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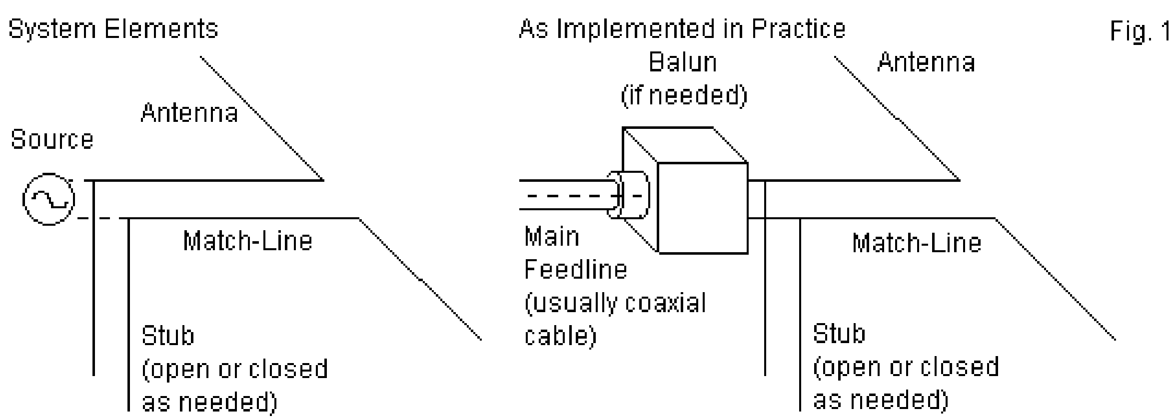
As long as hams wish to use or experiment with antennas like the Extended Double Zepp and others that present complex feedpoint impedances, stub matching will remain one alternative method of matching the antenna to a 50-Ω feedline. Most discussions of stub matching in amateur radio handbooks, however, appear almost wholly in qualitative terms. The purpose of this discussion it to convert that discussion into quantitative terms. The original notes for this analysis appeared as an appendix to an article in the last century: "Modeling and Understanding Small Beams: Part 3: "The EDZ Family of Antennas," *Communications Quarterly* (Fall, 1995), pp. 53-71. A number of inquiries about the semi-hidden location of the notes have come my way, prompting me to redo the article and to give it a place of its own. In the process, I have clarified a few steps in the procedure and added some notes on testing the results with antenna-modeling software.

There are a number of engineering texts that treat stub matching from the perspective of the most basic transmission-line properties. One such text is Reed and Ware, *Communications Circuits*, which devotes 32 pages to the subject. Fred Griffee, N4FG, has been treating these and other sources of matching circuit analysis in a series of articles for *antenneX*. We need not undertake such a long journey in order to arrive at a procedure that will allow us simply to calculate the requisite values for the match line and the stub. We shall proceed by reviewing the basic concept of stub matching, presenting the basic equations for calculating the elements of a stub-matching network, and finally using a simple BASIC implementation of those equations to solve a couple of exemplary problems.

The Stub-Matching System

Most amateur radio antenna manuals give the simple equations for calculating the reactance of both shorted and open transmission line stubs. However, these treatments regularly omit similar equations for calculating the length of the line between the antenna and the stub-feedline junction. So let's begin again.



Basic Elements of the Match-Line and Stub Matching System

The left portion of **Fig. 1** shows the basic structure of a typical stub-matching system. It consists of the antenna with its complex feedpoint impedance, a length of matching-feedline (the Line) leading to the critical junction, a reactive Stub, and the source. The source ordinarily has the same impedance as the main feedline connecting the ultimate energy source to the junction of the line and the stub. Therefore, we may redraw the circuit as shown on the right in **Fig. 1**. In this sketch, we have added an optional balun plus the main feedline (the Feed) leading to the power source, ordinarily a transmitter or transceiver. The functions of the antenna and the main feedline are well-known, but the functions of the other two elements require brief comment.

The matching-feedline operates as an impedance transformer. When there is a complex antenna feedpoint impedance or a mismatch between the antenna impedance and the matching-feedline impedance, the overall impedance, as well as the resistive and reactive components of that impedance, will vary along the line. These values are normally given as series values. If the line type (that is, its characteristic impedance or Z_O) is properly chosen, at some point along the line, the resistive component of the impedance will be of such a value that its corresponding parallel equivalent value will equal the characteristic impedance of the main feedline. This point defines the correct length of matching feedline to use.

Ordinarily, at the junction of the matching-feedline and the main feedline, there will also be a reactive component to the overall impedance. Although usually given as a series value, it too has a corresponding equivalent parallel value. A reactance of the opposite type but of the same magnitude will compensate for the junction reactance. In this exercise, the compensating reactance will be composed of a feedline stub, even though lumped components (capacitors or inductors) are also usable with somewhat greater losses in some instances. Compensating for the parallel reactance will leave a parallel resistance equal to the main feedline. With the reactance compensated, the resulting series resistance value will be the same value, thus effecting a match to the main feedline.

Notice that the compensating stub (open-circuited or short-circuited) is connected in parallel, that is, across the line. We shall only deal with this case, since the norm in HF practice is to use a parallel transmission line for the match line between the antenna and the junction. However, in purely coaxial cable system, the compensating reactance is often applied in series with the line, usually by breaking the braid only and using anoth length of coaxial cable for the stub.

Calculating the Matching-Feedline and Stub Lengths

Often left to graphical analysis (such as a Smith Chart) along with some miscellaneous calculations, the calculation of match-line and stub systems can be direct. With the advent of home computers and various comuter languages, the reputed tediousness of the calculations is no longer a hindrance. Indeed, a simple computer program is faster than most graphical methods (some of which have been computerized). Although the programming of the calculations originally appeared in GW Basic, Fred Griffee has updated the program into a windows executable.

The process begins by understanding that along a match-line, we are seeking the point at which the parallel-equivalent value of the series resistance is equal to the characteristic impedance of the main feedline (or, ultimately, of the source resistive impedance). Associated with these values is a value of series reactance and its parallel equivalent. If we call the series resistance and reactance the target values, then we define R_T and X_T. Let Z_F be the characteristic impedance of the main feedline (or of the source). Then, using the series-to-parallel resistance conversion equation,

$$Z_F = \frac{R_T^2 + X_T^2}{R_T} \qquad \textbf{(1)}$$

Solving for X_T^2, we get

$$X_T^2 = Z_F R_T - R_T^2 \qquad \textbf{(2)}$$

Before using equation (2), we must calculate the reflection coefficient, ρ, (actually its square) of the antenna-to-match-line system. Let the match-line characteristic impedance be Z_M. Then, using the antenna feedpoint impedance, $R_L \pm jX_L$, we can calculate.

$$\rho^2 = \frac{(R_L - Z_M)^2 + X_L^2}{(R_L + Z_M)^2 + X_L^2} \qquad \textbf{(3)}$$

Using this figure for ρ, we can then calculate the value of series resistance at the point in the line defined by equation (2), using that equation to remove reactance values from the calculation of R_T: The use of equation (2) lets us combine it with equation (3) and rearrange the terms to arrive at equation (4). This equation is one key to the procedure, since it reduces the calculation of the target resistive component of the impedance to being a function of the impedances of the match line (Z_M), the main feedline (Z_F), along with the value of ρ^2.

$$R_T = \frac{Z_M^2(1 - \rho^2)}{Z_F(\rho^2 - 1) + 2Z_M(\rho^2 + 1)} \qquad \textbf{(4)}$$

The target value of reactance is, of course, the square root of equation (2).

The equation, in various forms, for calculating the impedance, Z_{in}, anywhere along a transmission line back from a load, Z_L, is well published in literature available to radio amateurs.[2] That equation can be rewritten as separate equations for R_{in} and X_{in}, which will be more useful for present purposes. We shall use equations for lossless lines for three reasons. First, the lengths of line involved--all well under a wavelength--have losses far less significant than other potential error factors that enter the use of matching stubs. Second, for most types of transmission line, the most imprecise figure is the velocity factor of the line to be used, and most hams do not have access to laboratory grade measuring equipment to bring experimental determination of that figure under 5%. Third, physically replicating a calculated antenna, especially one with a significant reactive component at the feedpoint, usually results in departures from calculated values. Nevertheless, a calculation of the anticipated matching line and stub lengths will do much better than put one in the ball park: it will allow one to make a close play at the plate.

Since we wish the matching line to yield a resistive impedance component that correlates with the characteristic impedance of the main feedline, we may begin with the formula that appeared in the *ARRL Handbook* in the 80s and early 90s.[3]

$$R_{in} = \frac{R_L(1+\tan^2 \ell_r)}{(1-\frac{X_L}{Z_O}\tan \ell_r)^2 + (\frac{R_L}{Z_O}\tan \ell_r)^2} \tag{5}$$

where R_L is the resistive component of the antenna impedance, X_L is the reactive component of the antenna impedance, Z_O is the characteristic impedance of the matching section transmission line, and R_{in} is the resistive component of the impedance at a distance ℓ_r from the antenna along the line. In this exercise, R_{in} is precisely our target value of resistance, R_T. For our purposes, we shall assume that ℓ_r is in radians, although in general, it might also be in degrees relative to a wavelength at the frequency of interest for the antenna.

The matching line length calculation simply requires us to solve equation (5) for ℓ_r and to convert that length in radians into degrees and feet. A rewrite of equation (5) yields a quadratic:

$$\tan^2 \ell_r (\frac{X_L^2}{Z_O^2} + \frac{R_L^2}{Z_O^2} - \frac{R_L}{R_{in}}) - \tan \ell_r \, 2\frac{X_L}{Z_O} + 1 - \frac{R_L}{R_{in}} = 0 \tag{6}$$

Solving for ℓ_r, we obtain

$$\ell_r = \arctan \frac{\frac{X_L}{Z_O} \pm \sqrt{\frac{X_L^2}{Z_O^2} - (\frac{X_L^2}{Z_O^2} + \frac{R_L^2}{Z_O^2} - \frac{R_L}{R_{in}})(1 - \frac{R_L}{R_{in}})}}{(\frac{X_L^2}{Z_O^2} + \frac{R_L^2}{Z_O^2} - \frac{R_L}{R_{in}})} \tag{7}$$

Note that there are two solutions, since for every 180° of line length (under mismatch conditions), there will be two points at which the resistive component of the impedance has the same value.

The limiting case is where the value under the radical in equation (7) goes to less than zero. This condition indicates that, with the combination of line impedance values chosen for the antenna impedance values measured or derived from a modeling program, the resistive component never reaches the chosen main feed line characteristic impedance. The solution to this problem is usually to select a different transmission line for the matching line section.

Equation (7) returns two lengths in terms of radians along a wavelength. We can convert these lengths to a more familiar measurement in degrees by the equation

$$\ell_d = \frac{180\,\ell_r}{\pi} \tag{8}$$

where ℓ_r is the length in radians and ℓ_d is the length in degrees. Transformation of these lengths into feet involves the equation

$$L_f = \frac{\ell_d \, VF}{0.366 \, f_{MHz}} \tag{9}$$

where L_f is the required length in feet, f_{MHz} is the frequency of interest in MHz for the antenna, and VF is the velocity factor of the matching section transmission line.

Using the value of ℓ_r, we may calculate the remnant reactance by using the *Handbook* formula for X_{in}:

$$X_{in} = \frac{X_L(1 - \tan^2 \ell_r) + (Z_O - \frac{R_L^2 + X_L^2}{Z_O}) \tan \ell_r}{(1 - \frac{X_L}{Z_O} \tan \ell_r)^2 + (\frac{R_L}{Z_O} \tan \ell_r)^2} \tag{10}$$

where all of the variables have the same meaning as in equation (7). Applying equation (10) to the two lengths resulting from equation (7) will yield opposing values of reactance. We may choose to match either with a stub. Alternatively, we may calculate the reactance values directly from the square root of equation (2), assigning the signs this way: the reactance associated with the shorter line length will have the sign of the reactance at the antenna feedpoint.

For the stub calculations, we shall first convert the reactance into a parallel value to facilitate mechanical connections for the stub.

$$X_p = \frac{R_s^2 + X_s^2}{X_s} \tag{11}$$

where R_s is the main feedline characteristic impedance (or the ultimate source resistive impedance), X_s is the calculated input remnant reactance, and X_p is the equivalent parallel reactance which the stub is to compensate.

Reversing the signs of the reactances gives the values that must be returned by appropriate compensating stubs. The length of a shorted stub, when the desired reactance is known, is given by

$$\ell_S = \mathit{arctan} \frac{X_{in}}{Z_O} \tag{12}$$

and the length of a corresponding open stub is given by

$$\ell_O = \mathit{arccot} \frac{X_{in}}{Z_O} \tag{13}$$

where X_{in} is the desired reactance, Z_O is the characteristic impedance of the transmission line used for the stub, and ℓ_S and ℓ_O are the lengths of shorted and open stubs, respectively. Since the values of ℓ_S and ℓ_O are in radians, they can be converted into feet by the same means used to convert the length of the matching line.

The final step is to select the best combination of matching line and stub for the proposed antenna. Ordinarily--for least loss and mechanical simplicity--the combination with the shortest combined length of matching line and stub is the most desirable option.

A Simple Utility BASIC Program for Stub Matching

The calculations for a stub-matching system lend themselves to a simple utility program in BASIC or almost any other language. **Fig. 2** gives the listing for my own program, replete with my personal programming quirks. Lines 10-130 set up the input values for the calculation. Lines 140 through 170 calculate the target resistance value along the match-line. Lines 180-440 calculate the length of the matching-line section and the series resistance and reactance values at that point. The equations is broken down into components to precalculate repetitive parts. Line 200 catches the case where the value under the radical is less than zero. Lines 360-410 calculate the reactance for each of the solutions to equation (7), once more with the relevant equation broken down into segments or normalized. (These lines also recalculate the input resistance of the matching line; I put this in while setting up the program as a check and never took it out, since it involves only a few extra lines. The technique is useful for error catching during the program writing process. However, using R_T and X_T and bypassing these steps would shorten the program somewhat.)

The results of the calculations so far can be recorded on paper by a program pause and a <Print Screen> command. Since two screens of material will fit on one piece of paper, do not <Form Feed> at this time. Lines 450-710 calculate the required parallel reactive components and the stub values that will compensate for them, two values for each line length. A second <Print Screen> will combine this information with the input values for a complete record. A sample double screen printout appears in **Fig. 3**. The antenna is a 10-meter (28.5 MHz) Extended Double Zepp with a 450-Ω stub match system for a 50-Ω feedline, where the EDZ models a feedpoint impedance of 141-j694 Ω. Option A is 5.0' with a shorted stub of 1.2' or an open stub of 9.4', and option B is 5.5' with a shorted stub of 15.2' or an open stub of 7.0'. Option A and a shorted stub provide the mechanically simplest system to implement. You can truncate the decimals in the results almost anywhere, since in most cases, results to the nearest Ohm and tenth of a foot will be close enough to permit antenna system adjustment.

STUB

```
10 'file STUB.BAS
20 CLS:COLOR 11,1,3:CLS
30 PRINT"                    General Solutions for Stub Matching,": PRINT"             given Antenna R & X plus
Line, Stub, & Feed Zo":PRINT"                         L. B. Cebik, W4RNL":PRINT
40 PRINT"For any antenna load R and X, this program finds the Line and Stub length neededto match
any feedline Zo, if a match is possible with the proposed Line, Stub, and Feed Zo values.":PRINT
50 INPUT"Enter Antenna Load Resistance in Ohms        ",RL
60 INPUT"Enter Antenna Load Reactance in Ohms         ",XL
70 INPUT"Enter Frequency (in MHz)                     ",FQ
80 INPUT"Enter Zo of Line (from antenna to stub)      ",ZL
90 INPUT"Enter Velocity Factor of Line (as decimal)   ",VFL
100 INPUT"Enter Zo of Feed (from stub junction to rig) ",ZF
110 INPUT"Enter Velocity Factor of Feed                ",VFF
120 INPUT"Enter Zo of Stub (from line-feed junction)   ",ZS
130 INPUT"Enter Velocity Factor of Stub                ",VFS
140 RLS=(RL*RL):XLS=(XL*XL):ZLS=(ZL*ZL):RIS=(RI*RI)
150 RHOS=(((RL-ZL)*(RL-ZL))+XLS)/(((RL+ZL)*(RL+ZL))+XLS)
160 RT=((ZL*ZL)*(1-RHOS))/((ZF*(RHOS-1))+((2*ZL)*(RHOS+1))):RI=RT
170 'IF (ZF*RT)-(RT*RT)<0 THEN 350 ELSE XT=SQR((ZF*RT)-(RT*RT))
180 A=(XLS/ZLS)+(RLS/ZLS)-(RL/RI):B=2*(XL/ZL):C=1-(RL/RI)
190 IF A=0 THEN A=1E-08
200 NUM=((B*B)-(4*(A*C))):IF NUM<0 THEN 350
210 TLP=(B+SQR((B*B)-(4*(A*C))))/(2*A)
220 TLM=(B-SQR((B*B)-(4*(A*C))))/(2*A)
230 LP=ATN(TLP):LM=ATN(TLM)
240 PI=3.141592654#
250 LPD=(LP*180)/PI:LMD=LM*180/PI
260 IF LPD<0 THEN LPD=180+LPD
270 IF LMD<0 THEN LMD=180+LMD
280 LPF=(LPD*VFL)/(.3660131*FQ):LMF=(LMD*VFL)/(.3660131*FQ)
290 PRINT"Possible line lengths are A. ";LPF;"feet and B. ";LMF;"feet."
300 LR=LP:GOTO 360
310 RIA=RI:XIA=XI:PRINT"For Line length A., Rs=  ";RI;"Ohms and Xs=  ";XI;"Ohms."
320 LR=LM:GOTO 360
330 RIB=RI:XIB=XI:PRINT"For Line length B., Rs=  ";RI;"Ohms and Xs=  ";XI;"Ohms."
340 GOTO 440
350 IF NUM<0 THEN PRINT"There are no possible solutions with this combination of of antenna
impedance  and line impedance.":GOTO 710
360 IF RL=0 THEN RL=1E-08
370 RA=RL/ZL:XA=XL/ZL:T=TAN(LR):TS=T*T
380 DA=(1-(XA*T))*(1-(XA*T)):DB=(RA*T)*(RA*T):DN=DA+DB
390 RS=RA*RA:XS=XA*XA
400 RN=RA*(1+TS):XK=XA*(1-TS)
410 XM=((1-RS)-XS)*T:XN=XK+XM:RZ=RN/DN:XZ=XN/DN:RI=ZL*RZ:XI=ZL*XZ
420 IF LR=LP THEN GOTO 310
430 IF LR=LM THEN GOTO 330
440 PRINT"For a record of these calculations, press <Print Screen>."
450 PRINT:PRINT"Press <C> to continue."
460 I$=INKEY$:IF I$="c" OR I$="C" THEN GOTO 470 ELSE 460
470 CLS:PRINT:PRINT"Stub Calculations:":PRINT
480 PRINT"Option A: Rs= ";RIA;" and Xs= ";XIA;" Ohms
490 XPA=((RIA*RIA)+(XIA*XIA))/XIA:XCOMPA=(-1*XPA)
500 PRINT"The required parallel stub reactance to compensate is ";XCOMPA;"Ohms."
510 LRL=ATN(XCOMPA/ZS):LDL=(ABS(LRL)*180)/PI
520 IF XCOMPA<0 THEN LDL=180-LDL
530 LFL=(LDL*VFS)/(.3660131*FQ)
540 LRC=ATN(ZS/XCOMPA):LDC=(ABS(LRC)*180)/PI
550 IF XCOMPA>0 THEN LDC=180-LDC
560 LFC=(LDC*VFS)/(.3660131*FQ)
570 PRINT:PRINT"The required SHORTED STUB length is ";LDL;"degrees or ";LFL;"feet.
580 PRINT"The required OPEN STUB length is ";LDC;"degrees or ";LFC;"feet.
590 PRINT:PRINT:PRINT"Option B: Rs= ";RIB;" and Xs= ";XIB;" Ohms
600 XPB=((RIB*RIB)+(XIB*XIB))/XIB:XCOMPB=(-1*XPB)
610 PRINT"The required parallel stub reactance to compensate is ";XCOMPB;"Ohms."
620 LRL=ATN(XCOMPB/ZS):LDL=(ABS(LRL)*180)/PI
630 IF XCOMPB<0 THEN LDL=180-LDL
640 LFL=(LDL*VFS)/(.3660131*FQ)
650 LRC=ATN(ZS/XCOMPB):LDC=(ABS(LRC)*180)/PI
660 IF XCOMPB>0 THEN LDC=180-LDC
670 LFC=(LDC*VFS)/(.3660131*FQ)
680 PRINT:PRINT"The required SHORTED STUB length is ";LDL;"degrees or ";LFL;"feet.
690 PRINT"The required OPEN STUB length is ";LDC;"degrees or ";LFC;"feet.
700 PRINT:PRINT"Press < Print Screen > to complete the record of calculations."
710 PRINT:PRINT"For another run, press <A>; to quit, press <Q>."
720 I$=INKEY$:IF I$="a" OR I$="A" THEN 10 ELSE IF I$="Q" OR I$="q" THEN 730 ELSE 720
730 RUN "C:\basic\menu.bas"
```

Program Listing for STUB.BAS

Fig. 2

General Solutions for Stub Matching,
given Antenna R & X plus Line, Stub, and Feed Zo
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For any antenna load R and X, this program finds the Line and Stub length needed to match any feedline Zo, if a match is possible with the proposed Line, Stub, and Feed Zo values.

Enter Antenna Load Resistance in Ohms	141.36
Enter Antenna Load Reactance in Ohms	-693.56
Enter Frequency (in Mhz)	28.5
Enter Zo of Line (from antenna to stub)	450
Enter Velocity Factor of Line (as decimal)	.95
Enter Zo of Feed (from stub junction to rig)	50
Enter Velocity Factor of Feed	.66
Enter Zo of Stub (from line-feed junction)	450
Enter Velocity Factor of Stub	.95

Possible lines lengths are A. 5.038553 feet and B. 5.485493 feet.
For line length A., Rs= 41.10245 Ohms and Xs= -19.12316 Ohms.
For line length B., Rs= 41.10246 Ohms and Xs= 19.12327 Ohms.
For a record of these calculations, press <Print Screen>.

Press <c> to continue.

Stub Calculations

Option A: Rs= 41.10245 Ohms and Xs= -19.12316 Ohms.
The required parallel stub reactance to compensate is 107.4669 Ohms.

The required SHORTED STUB length is 13.43154 degrees or 1.223229 feet.
The required OPEN STUB length is 103.4315 degrees or 9.419658 feet.

Option B: Rs= 41.10246 Ohms and Xs= 19.12327 Ohms.

The required SHORTED STUB length is 166.5685 degrees or 15.16963 feet.
The required OPEN STUB length is 76.56851 degrees or 6.973203 feet.

Press <Print Screen> to complete the record of calculations.

For another run, press <A>; to quit, press <Q>.

Typical Output Sheet from STUB.BAS — Fig. 3

One caution is necessary with the use of calculating programs. Unlike graphical solutions, calculating programs give no feel for the sharpness or broadness of the results, that is, how small physical variations from the calculations will affect the adjustments. In general, the higher the ratio of reactance to resistance at the antenna feedpoint, the sharper the curve. In these cases, small physical variations may require extensive adjustment of the calculated lengths.

Recent *ARRL Handbooks* have presented an interesting 12-meter EDZ cut to a length that provides a feedpoint impedance of 142-j555 Ω.[4] With 450-Ω transmission line (VF=.95), both options yield 5'5" of matching line with negligible reactance, obviating the need for a stub. The impedance presented by the matching line to the coax is 55 Ω. In fact, using the program with a feedline impedance of 50 Ω produces a "no possible solution message." The lesson is that before giving up on a combination, try raising or lowering the feedline impedance by 10% to see if a solution emerges. The resulting SWR on the coax will be well within limits. However, K7KGP's antenna is quite unusual, and exact reproduction or scaling for other bands may require extensive on-site adjustment.

These examples only sample the use of a utility program in making matching-section calculations. The limits of stub matching are far wider than these examples. Of course, modeling the results on NEC with transmission-line capabilities permits all calculations to be verified.

A Sample EZNEC Verification of the Calculations

You may fairly easily estimate the anticipated feedpoint impedance of any antenna by modeling it in NEC or MININEC. The example in **Fig. 3** is an extended double Zepp, which is simply a wire about 1.25 wavelengths long and center-fed. The upper portion of **Fig. 4** shows the wire set-up in EZNEC for the EDZ alone. This version of the antenna model gives us the feedpoint impedance which we shall use as an input to the program or the series of calculations. The model is based on a much later version of the program than the one from which the sample in **Fig. 3** was derived. However, the feedpoint impedance is within a few tenths of an Ohm for both the resistive and the reactive components. In fact, you should expect differences of this order if you use a version of the NEC program that differs from the one used by the original modeler. As well, you may see slight differences in reported values if you change the compiled Fortran for the core that you use.

Wires

Wire Create Edit Other — Fig. 4 — EDZ Alone

Coord Entry Mode Preserve Connections Show Wire Insulation

No.	End 1				End 2				Diameter	Segs
	X (in)	Y (in)	Z (in)	Conn	X (in)	Y (in)	Z (in)	Conn	(in)	
1	-262	0	0		262	0	0		0.071	59

Wires

Wire Create Edit Other — EDZ with Junction Wire

Coord Entry Mode Preserve Connections Show Wire Insulation

No.	End 1				End 2				Diameter	Segs
	X (ft)	Y (ft)	Z (ft)	Conn	X (ft)	Y (ft)	Z (ft)	Conn	(in)	
1	-21.8333	0	0		21.8333	0	0		0.071	59
2	-0.05	0	-5.0386		0.05	0	-5.0386		0.01	1

The lower portion of **Fig. 4** shows the antenna-wire set-up to test the calculated results under option A in **Fig. 3**. The short, thin second wire is positioned away from the main wire by the exact length of the match line: 5.0386'. **Fig. 5** shows the shorted stub and the open stub versions of the matching system. In both cases, the top transmission line uses the actual distance between the wires in **Fig. 4**. The characteristic impedance and velocity factor are the values specified in **Fig. 3**. The second line shows either a shorted stub or an open stub with the length, characteristic impedance, and velocity factor values used in the original calculation. In both of these models, of course, we moved the source from the main antenna wire to the junction wire (wire 2) in the lower version of the wire table.

Transmission Lines

Trans Line Edit Fig. 5 Option A with Shorted Stub

Transmission Lines

No.	End 1 Specified Pos.		End 1 Act	End 2 Specified Pos.		End 2 Act	Length	Z0	VF	Rev/Norm
	Wire #	% From E1	% From E1	Wire #	% From E1	% From E1	(ft)	(ohms)		
1	1	50	50	2	50	50	Actual dist	450	0.95	N
2	2	50	50	Short ckt			1.2232	450	0.95	N
*										

Transmission Lines

Trans Line Edit Option A with Open Stub

Transmission Lines

No.	End 1 Specified Pos.		End 1 Act	End 2 Specified Pos.		End 2 Act	Length	Z0	VF	Rev/Norm
	Wire #	% From E1	% From E1	Wire #	% From E1	% From E1	(ft)	(ohms)		
1	1	50	50	2	50	50	Actual dist	450	0.95	N
2	2	50	50	Open ckt			9.4197	450	0.95	N
*										

The shorted-stub version of the antenna reports a modeled feedpoint or source impedance of 49.95 - j0.30 Ω. The open-stub version reports an impedance of 49.93 - j0.91 Ω. Given the tiny variation between the feedpoint impedance of this new model and the original from 10 years ago, we obtain good confirmation of the calculations.

The models in this exercise are in free-space. Since feedpoint impedance values vary with the height of the antenna above ground, modeling the proposed antenna in its actual operating environment is advisable for the most useful results. This advice is especially pertinent to antennas of the type for which the match-line and stub matching system is most apt, that is, antennas with a feedpoint having a significant reactive component and a moderately high to high resistive component.

Lossless lines are a very good approximation of actual performance of the match-line and stub system. Using option A with a shorted stub, the total line length for both the match-line and stub is under 0.18 wavelength, a very short run for parallel transmission line. Indeed, manufacturing variations between the listed and the actual velocity factor are more likely than losses to require field adjustment of the system.

This exercise has shown that we can in a very straightforward way calculate the required values for a match-line and stub matching system when we use a parallel compensating stub. The equations are amenable to encapsulation in any convenient sort of computer program for ease of use. The availability of such programs transform the technique from a mystery to a highly usable matching system for some antenna and feedline combinations.

Notes

1 See Reed and Ware, *Communications Circuits*, 3rd Ed. (Wiley, 1962), pp. 210-242.

2 See, for example, Terman, *Radio Engineer's Handbook*, p. 186, or Kuecken, *Exploring Antennas and Transmission Lines by Personal Computer*, pp. 180-181.

3 See, for example, p. 16-2 of the 1987 *ARRL Handbook* for a normalized version of the equation or p. 16-3 of the 1992 *ARRL Handbook* for a non-normalized version.

3 See, for example, the 1992 *ARRL Handbook*, p. 33-11.