MODIFICATION TO MININEC FOR THE ANALYSIS OF WIRE ANTENNAS WITH SMALL RADIUS TO WAVELENGTH RATIOS

Todd D. Poston
Stephen W. Kershner
Kershner and Wright
5730 General Washington Drive
Alexandria, Virginia 22312

MININEC is a useful and compact method of moments antenna program, but MININEC does not give reasonable values for the input reactance of very thin wires at low frequencies. This problem greatly restricts the use of MININEC in the design and analysis of vlf and lf antennas. A modification to the program which eliminates this restriction is discussed. The modification consists of treating both the source and observation segments as filaments and only considering the wire radius when computing the self-impedance. A listing of the changed computer code is included.

I. INTRODUCTION

MININEC is a method of moments microcomputer program, written in BASIC, that analyzes thin-wire antennas [Julian et al., 1982]. This compact code is based on a modified Galerkin procedure that was described by D. R. Wilton to solve an integral equation for the electric field [Li et al., 1983; Wilton, 1981]. With proper modeling, MININEC can solve accurately for the current and impedance on most arbitrarily oriented wires.

However, the input reactance given by MININEC for an electrically short, thin monopole begins to diverge from the expected value for wire radii less than approximately $10^{-5}\lambda$, where λ is the wavelength. This limitation in the program is evident in Fig. 1, which displays the input reactance X_a calculated by MININEC and the expected values for a 90.5 m monopole at 150 kHz for $10^{-7} < a/\lambda < 10^{-4}$ where a is the wire radius. The expected value is the input reactance for a short vertical radiator given by the equation

$$X_a = -Z_o \cot \frac{2\pi h}{\lambda} \text{ ohms} \quad . \tag{1}$$

The characteristic impedance Z_o is given by

$$Z_o = 60 \left[\ln \left(\frac{h}{a}\right) - 1\right] \text{ ohms} \quad , \tag{2}$$

which fits experimentally measured values, where h is the height of the radiator [Jasik, 1961]. The above expression is approximately the same as the more complicated expression for the input reactance given by the induced emf method, using a sinusoidal current distribution [Jordan and Balmain, 1968]. The exact a/λ value where MININEC is no longer valid depends on the particular microcomputer, whether double precision variables are being used, and the number of segments chosen. This limitation prevents MININEC from being used to design vlf and lf antennas that use wires with small radius to wavelength ratios.

A modification to the program has been developed which replaces the code for integral psi with code that treats the current as a filament on the wire axis. This change has resulted in reactances that differ by less than 1 percent from the values given by Eq. (1) and that are in excellent agreement with the experimental values for both a monopole and a top-loaded monopole. This is a fix which allows MININEC to be used to analyze vlf and lf antennas.

II. MODIFICATION AND VERIFICATION

MININEC is based on the assumptions that the wire radius is very small in comparison to a wavelength and that the radius is small with respect to the segment length so that there will be no azimuthal component of the current [Julian et al.]. Evidently, from Fig. 1, the assumption on a/λ is overpowered by a computational error for values less than approximately 10^{-5}.

In order to determine the vector and scalar potentials from a current carrying wire, MININEC evaluates an integral psi given by

$$\psi_{m,u,v} = \int_{s_u}^{s_v} k(s_m - s')ds' \quad , \tag{3}$$

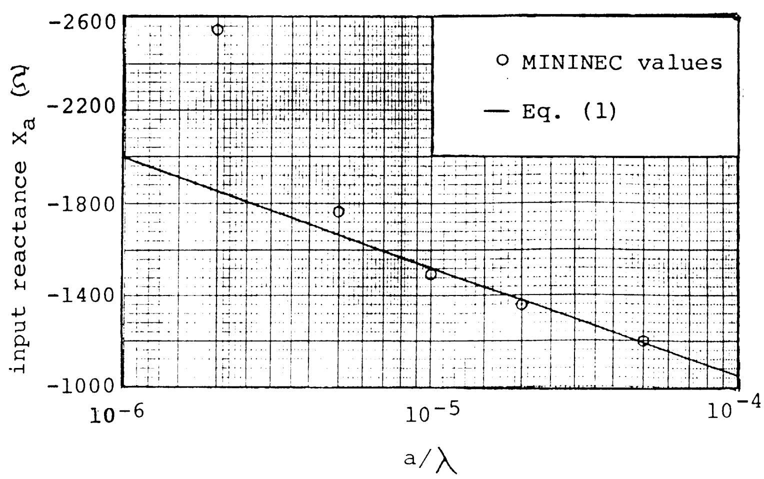

Figure 1. Input reactances from MININEC for a 90.5 m monopole divided into five segments at 150 kHz.

where

$$k(s_m - s') = \frac{1}{2\pi} \int_{-\pi}^{\pi} \frac{e^{-jkr_m}}{r_m} d\phi \quad , \tag{4}$$

$$r_m = [(s_m - s')^2 + 4a^2 \sin^2 \frac{\phi}{2}]^{1/2} \quad , \tag{5}$$

s_m is the observation point, s_v and s_u are the upper and lower end points, respectively, of the source segment and a is the wire radius. Equation (3) results in an elliptical integral of the first kind due to a singularity at $r_m = 0$. Since the wires are very thin in terms of wavelength when MININEC becomes unreliable, the current and charge densities are approximated by filaments of current and charge on the wire axis following Harrington. Thus, the double integral is simplified to a single integral [Harrington, 1981]

$$\psi(m,n) = \frac{1}{4\pi\Delta 1_n} \int_{\Delta 1_n} \frac{e^{-jkR_m}}{R_m} dl \quad , \tag{6}$$

where the distance between the source segment and observation point is

$$R_m = \begin{cases} [\rho_m^2 + (z-z_m)^2]^{1/2} & m \neq n \\ (a^2 + z^2)^{1/2} & m = n \end{cases} \quad , \tag{7}$$

$\Delta 1_n$ is the length of the source segment, n is the center of source segment, m is the observation point, ρ_m is the horizontal distance between m and n, z_m is the vertical distance between z and m, and z is the vertical coordinate along the source. The integral can be approximated by expanding e^{-jkR_m} with a Maclaurin series to two terms. For m=n, this approximation yields

$$\psi(m,n) \approx \frac{1}{2\pi\Delta 1_n} \ln \left(\frac{\Delta 1_n}{a}\right) - j\frac{k}{4\pi} \quad , \tag{8}$$

For m≠n, use the crudest approximation with R_m constant so that

$$\psi(m,n) \approx \frac{e^{-jkR_m}}{4\pi R_m} \quad .$$

This simplifying modification was incorporated into MININEC by changes to the two subroutines in lines 20-890 [Li et al., 1983]. Primarily, most of the elliptical integration subroutine was deleted (specifically lines 70-220). The remaining integral is still performed numerically with the Gaussian quadrature subroutine. In addition, other statements had to be changed in order to adapt this modification into the program without changing the variables. These changes included the deletion of the variable I6 in lines 650 and 860, and the square of the wire radius A2 is no longer necessary in line 730. Also, lines 281-288 were inserted to treat the m=n case, including when a half segment is being calculated, and two lines (60 and 785) were added to direct the program to the proper lines based on the value of distance D. The modified subroutines of an IBP Personal Computer version of MININEC are listed in the Appendix.

Figure 2 displays the results of the modified MININEC along with the same expected values of input reactance. The agreement is within 1 percent for $10^{-7} < a/\lambda < 10^{-4}$.

This modified MININEC was also used to determine the input impedance at 50 kHz of a 192 m top-loaded monopole with six radial wires. The tower was divided into five segments, and the radial wires were each divided into three segments. The tower had a radius of 0.48 m and the six top radials each had a radius of 0.0127 m ($a/\lambda \approx 2\times10^{-6}$) which gave an input reactance of 0.621 - j625 ohms, or within 3 percent of the value obtained from experimental data (0.636 - j609 ohms) [Devaney et al., 1966].

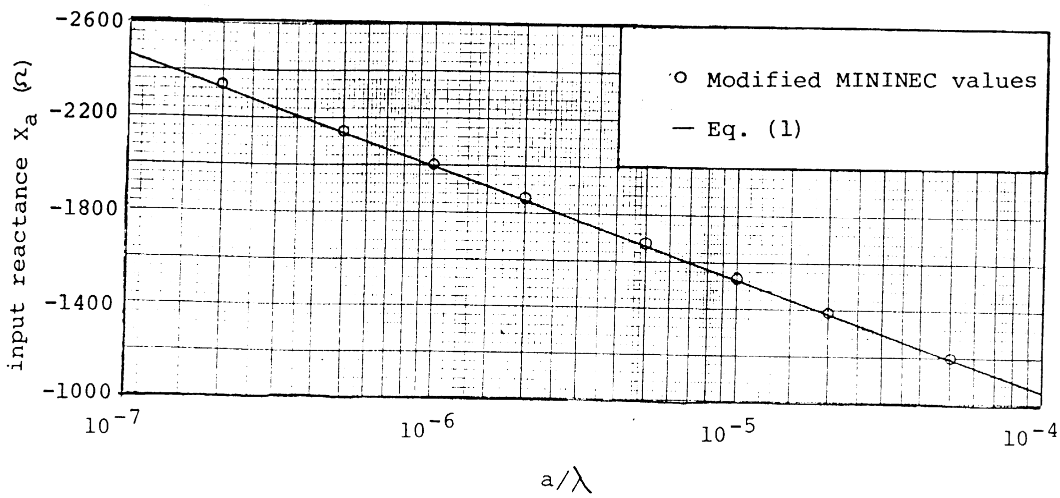

Figure 2. Input reactances from modified MININEC compared to expected values for a 90.5 m monopole divided into five segments at 150 kHz.

III. CONCLUSIONS

A quick modification to MININEC has been presented that allows the program to analyze vlf and lf antennas. The adapted program yields reasonable values for the input reactance of wires with very small radius to wavelength ratios, without introducing significant error in the resistance values. This alteration could be implemented as an option in the program instead of replacing the valid code for larger wires. Also, the modification could be included in a change that allows for antennas with both relatively large and small radius wires to be analyzed.

IV. ACKNOWLEDGMENTS

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V. REFERENCES

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APPENDIX: LISTING OF MODIFIED MININEC SUBROUTINES

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20 X3=T*D(P4)
30 Y3=T*F(P4)
40 Z3=F*T*G(P4)*F0
50 D=SQR(D0-F3*(X3*X2+Y3*Y2+Z3*Z2)+X3*X3+Y3*Y3+Z3*Z3)
60 IF D<1 THEN RETURN
230 B1=D*W
240 T3=T3+COS(B1)/D
250 T4=T4-SIN(B1)/D
260 RETURN
270 P1=1
280 F0=1
281 IF K=1 AND P3-P2=1 AND P1=(P3+P2)/2 THEN GOTO 282 ELSE GOTO 285
282 T1=2*LOG(S(P4)/A(P4))
283 T2=-(W*S(P4))
284 GOTO 880
285 IF I=J AND K=1 AND P3-P2=.5 AND 1-P1/INT(P1)=0  THEN GOTO 286 ELSE GOTO 290
286 T1=LOG(S(P4)/A(P4))
287 T2=-(W*S(P4)/2)
288 GOTO 880
290 IF C(J,1)=-C(J,2) THEN F0=SGN(C(J,P1))
300 F3=2*SGN(C(J,P1))
310 IF P1-INT(P1)=H0 GOTO 440
320 I4=INT(P1+1)
330 I5=INT(P1)
340 X1=(X(I4)+X(I5))/2
350 Y1=(Y(I4)+Y(I5))/2
360 Z1=(Z(I4)+Z(I5))/2
370 X2=X1-X(P2)
380 Y2=Y1-Y(P2)
390 Z2=Z1-Z(P2)*F
400 X3=X1-X(P3)
410 Y3=Y1-Y(P3)
420 Z3=Z1-Z(P3)*F
430 GOTO 530
440 I4=INT(P2+1)
450 IF P2-INT(P2)=H0 THEN I4=P2
460 I5=INT(P2)
470 X2=X(P1)-(X(I4)+X(I5))/2
480 Y2=Y(P1)-(Y(I4)+Y(I5))/2
490 Z2=Z(P1)-F*(Z(I4)+Z(I5))/2
500 X3=X(P1)-X(INT(P3))
510 Y3=Y(P1)-Y(INT(P3))
520 Z3=Z(P1)-F*Z(INT(P3))
530 D0=X2*X2+Y2*Y2+Z2*Z2
540 D3=X3*X3+Y3*Y3+Z3*Z3
550 S4=(P3-P2)*S(P4)
560 F2=1
570 N3=7
580 T1=H0
590 T2=T1
600 T=S(P4)+.001*A(P4)
610 A2=A(P4)*A(P4)
620 IF SQR(D3)+SQR(D0)>T GOTO 680
630 I6=16*A(P4)/S(P4)
640 IF P1-INT(P1)>0 THEN F2=2
660 IF P1-INT(P1)>0 THEN S4=S(P4)/2
670 GOTO 720
680 T=SQR(D0)/ABS(S4)
690 IF T>3 THEN N3=3
700 IF T>5 THEN N3=1
710 I6=H0
720 I5=N3*2
730 D0=D0
740 L=N3
750 T3=H0
760 T4=T3
770 T=S4*(Q(L)+.5)
780 GOSUB 20
785 IF D<1 THEN GOTO 282
790 T=S4*(.5-Q(L))
800 GOSUB 20
810 L=L+1
820 T1=T1+Q(L)*T3
830 T2=T2+Q(L)*T4
840 L=L+1
850 IF L<I5 GOTO 750
860 T1=F2*T1*S4
870 T2=F2*T2*S4
880 RETURN
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