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MODELER'S NOTES

Gerald J. Burke

For this issue of Modeler's Notes we have a contribution from Ralph Holland, VK1BRH, on NEC results for the feedpoint reactance of monopoles. This will be followed by an update of NEC subjects from the last issue and a do-it-yourself change to NEC to reduce the solution time for large matrices.

Holland's results show good agreement in feedpoint reactance between NEC and the simple formula attributed to Howe. I do not have access to references [1] and [2] that Holland cites, but it would be interesting to trace the history of the bicone approximations for dipole or monopole capacitance. R.E. Collin, in *Antennas and Radiowave Propagation,* McGraw-Hill, 1985, gives the form of Holland's equation (8) derived from the biconical transmission line analysis of Schelkunoff, *Advanced Antenna Theory.* Collin says that it is "not very accurate but does provide a useful estimate." In the earlier book *Antennas, Theory and Practice* by Schelkunoff and Friis, Wiley, 1951, page 305, the form of Holland's equation (9) (Howe's form) is obtained for the antenna capacitance by including the effect of the wire ends on the charge distribution. Holland's results show that the end effect is worth including at zero cost in complexity. Of course Schelkunoff's and Howe's equation do not take account of the source gap width, and NEC does so in a "fuzzy" sense, so the agreement would no doubt be different for thicker wires.

Anyone who has comments on material covered here, suggestions or observations on using NEC or other modeling codes or can submit an article on EM modeling topics is encouraged to submit them to:

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Any contributions will be very welcome, and thanks to Ralph Holland for his results on input reactance.

Validation of NEC2 and Z_o by feedpoint reactance of monopoles.

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Abstract

It is a well known fact, in practical circles, that the reactance of a short linear radiator is related to its static or low–frequency capacitance. This relationship holds true for lengths up to 1/20 of a wavelength [1]. This capacitance can be used to determine the average characteristic impedance of that radiator and to validate the performance of NEC [3].

Introduction

Short radiators can be considered as a uniform transmission line with little or no losses per unit length [1] – ie the propagation constant is nearly pure imaginary and the characteristic impedance is nearly pure real. For such cases, the transmission line formula [1][2][4][5] can be simplified with the relationship between the input impedance, characteristic impedance and length given by:

$$X_i = -Z_o\cot(\beta h) \qquad \{h \text{ height}, \beta \cong 2\pi/\lambda\} \qquad (1)$$

When βh is small ($h <= \lambda/20$) equation 1.0 can be approximated by:

$$X_i \cong -Z_o/\beta h \qquad (2)$$

The characteristic impedance is also related to the inductance and capacitance per unit length by the following equation [2]:

$$Z_o = R_o(1-(\alpha/\beta)j) \qquad \{\alpha \text{ is the attenuation constant}\}$$

$$\cong R_o \qquad \{\text{when } \alpha \text{ is small}\} \qquad (3)$$

$$R_o = \sqrt{(L/C)} \qquad \{L\ \text{Hm}^{-1}, C\ \text{Fm}^{-1}\} \qquad (4)$$

The capacitance C and inductance L (both per unit length) [1] are also related to the intrinsic properties of the media in which the object is located. The relationship for free–space is:

$$LC = \mu_o\varepsilon_o \quad = 1/c^2 \qquad \{c = \text{speed of light}\} \qquad (5)$$

Equation 5 and equation 4 can be combined to arrive at:

$$C = 1/(cR_o) \quad \cong 3{,}335.6\text{x}10^{-12}/R_o \quad \{C=\text{Fm}^{-1}\} \qquad (6)$$

Capacitive reactance is given by the familiar formula:

$$X_c = -1/(\omega C_o) \qquad \{C_o \text{ in Farads}, \omega = 2\pi f, f \text{ in Hz}\} \qquad (7)$$

Several formulae have been provided by various authors to arrive at the characteristic impedance of monopole radiators. There is some contention about which formula to use to determine Z_o; this is complicated by the fact that the characteristic impedance of a linear element is not uniform across its length.

Schelkunoff [1] states, from biconical dipole theory, that for a monopole:

$$R_o = (\zeta/2\pi)[\ln(2h/a)-1] \qquad \{\zeta = \sqrt{(\mu_o/\varepsilon_o)} \cong 377\} \qquad (8)$$

While Howe [1] states for a monopole that:

$$R_o = (\zeta/2\pi)[\ln(h/a)-1] \qquad (9)$$

Verification

NEC–81 [3] was used to simulate the feed–point reactance X_i for various vertical dipoles in free–space. The corresponding X_i were divided by two to relate them to monopoles over ideal ground. (Recall that the impedance of a monopole of length h fed against a perfect ground is half that of a dipole of total length 2h.) The negative X_i were transformed to the equivalent capacitances by equation 7.

Figure 1 shows the input capacitance (Co) for various antenna lengths h (with a constant radius of $1.22\text{x}10^{-3}$m) versus frequency. Note how the curves are linear at the lower frequencies as suggested by equation 2.

Figure 2 shows the variation of capacitance per metre (C) with height (h) and radius(a) for short monopoles operating in the linear reactance region where $h <= \lambda/20$. Both NEC2 results and Schelkunoff's formula are plotted. NEC2 shows a relatively good correspondence with the Schelkunoff theory. However, if Howe's formula is used to determine C, it will correspond even better to the NEC2 results for small h/a. Equation 7, and the monopole length was used to reduced NEC2 data to C, while equation 6 was used to convert Ro derived from Howe or Shelkunoff to C.

Figure 3 plots the differences between the NEC2 results and the two formulae. A simple modification has been applied to Howe's formula to minimize differences.

Conclusion

Such good correspondence between base reactance and the derived Z_o means that NEC2 is reasonably accurate in determining the reactive component of short radiators.

The correspondence between the derived Z_o and Howe's formula over a large range is also validation of Howe's work. This suggests that Z_o calculations for short antenna loading etc. should employ Howe's formula rather than Schelkunoff's.

References

[1] H. Paul Williams, "Antenna Theory and Design Volume II", Sir Isaac Pitman and Sons Ltd., Second Edition 1966, p42–55.

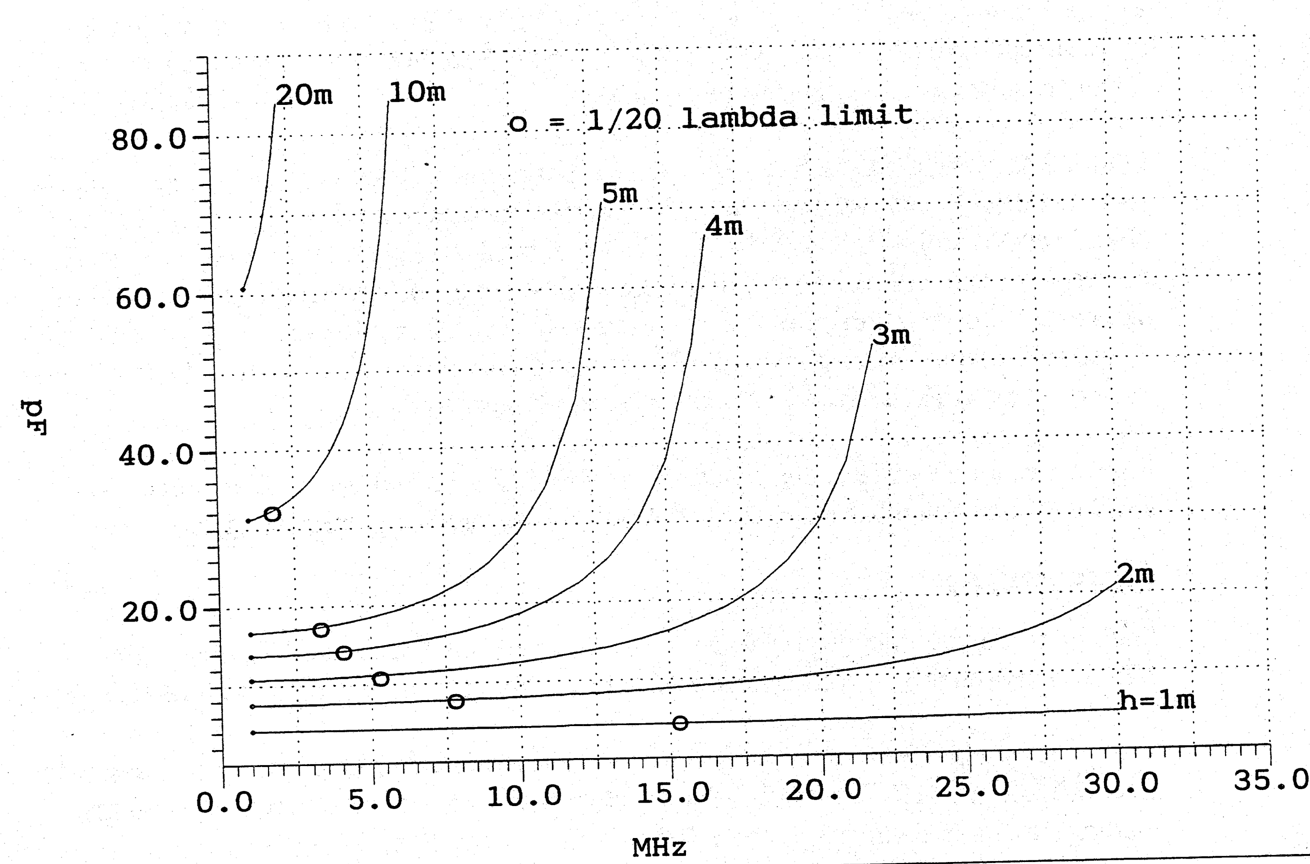
[2] H. Paul Williams, "Antenna Theory and Design Volume I", Sir Isaac Pitman and Sons Ltd, Second Edition 1966, p107–113.

[3] G.J.Burke and A.J. Poggio, "Numerical Electromagnetics code (NEC–81)", UCID–18834, Lawerence Livermore National Laboratory, "CA, 1981.

[4] John D. Kraus, "Antennas", McGraw–Hill Book Company, Second Edition, 1988.

[5] Simon Ramo, John R. Whinnery, Theodore Van Duzer, "Fields and Waves in Communication Electronics", John Wiley and Sons Inc, Third Edition 1994, p248–249.

Fig 1 NEC2 monopole Co for h and f (a=1.22mm)



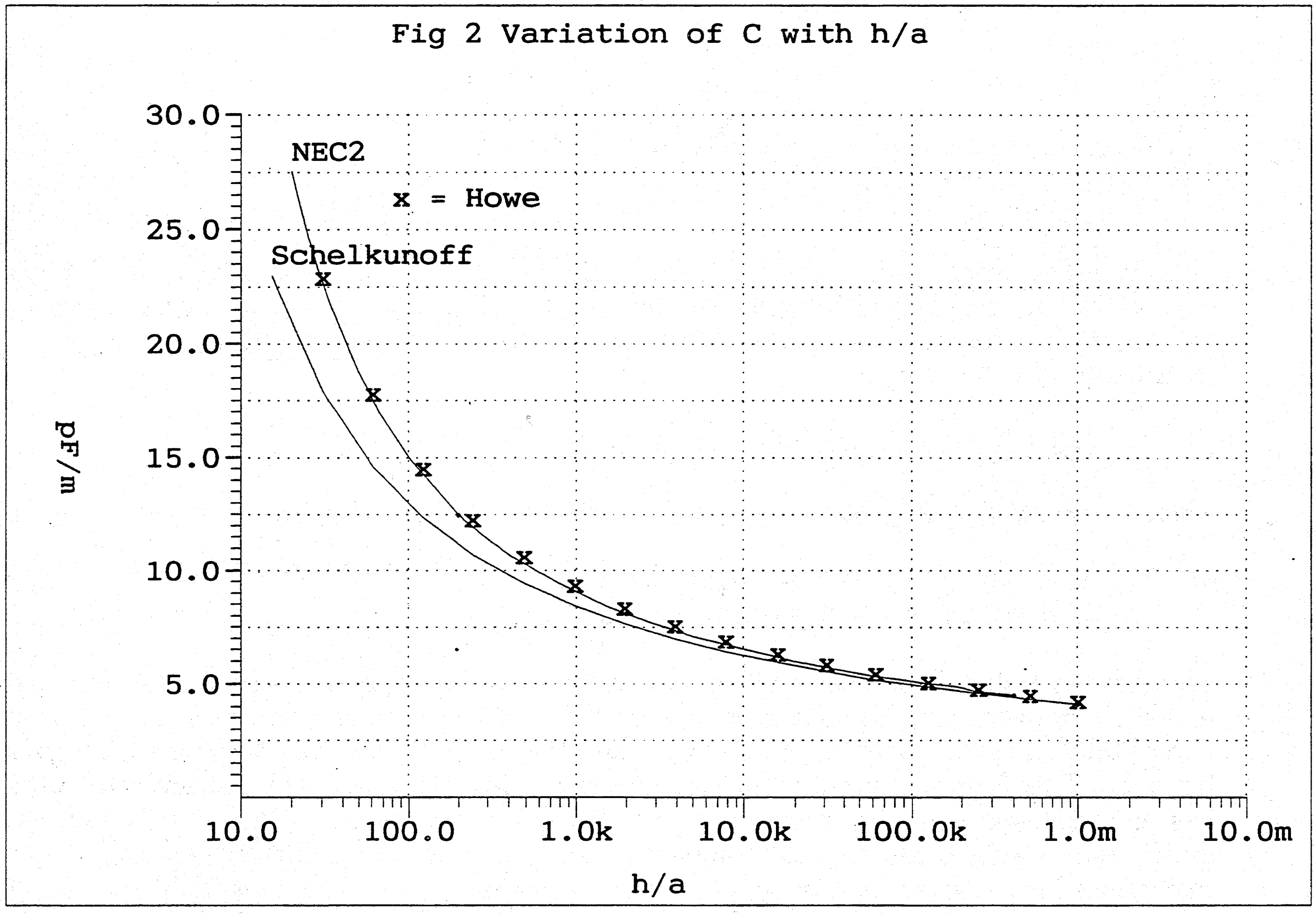


Fig 2 Variation of C with h/a
NEC2
x = Howe
Schelkunoff
30.0
25.0
20.0
15.0
10.0
5.0
pF/m
10.0
100.0
1.0k
10.0k
100.0k
1.0m
10.0m
h/a

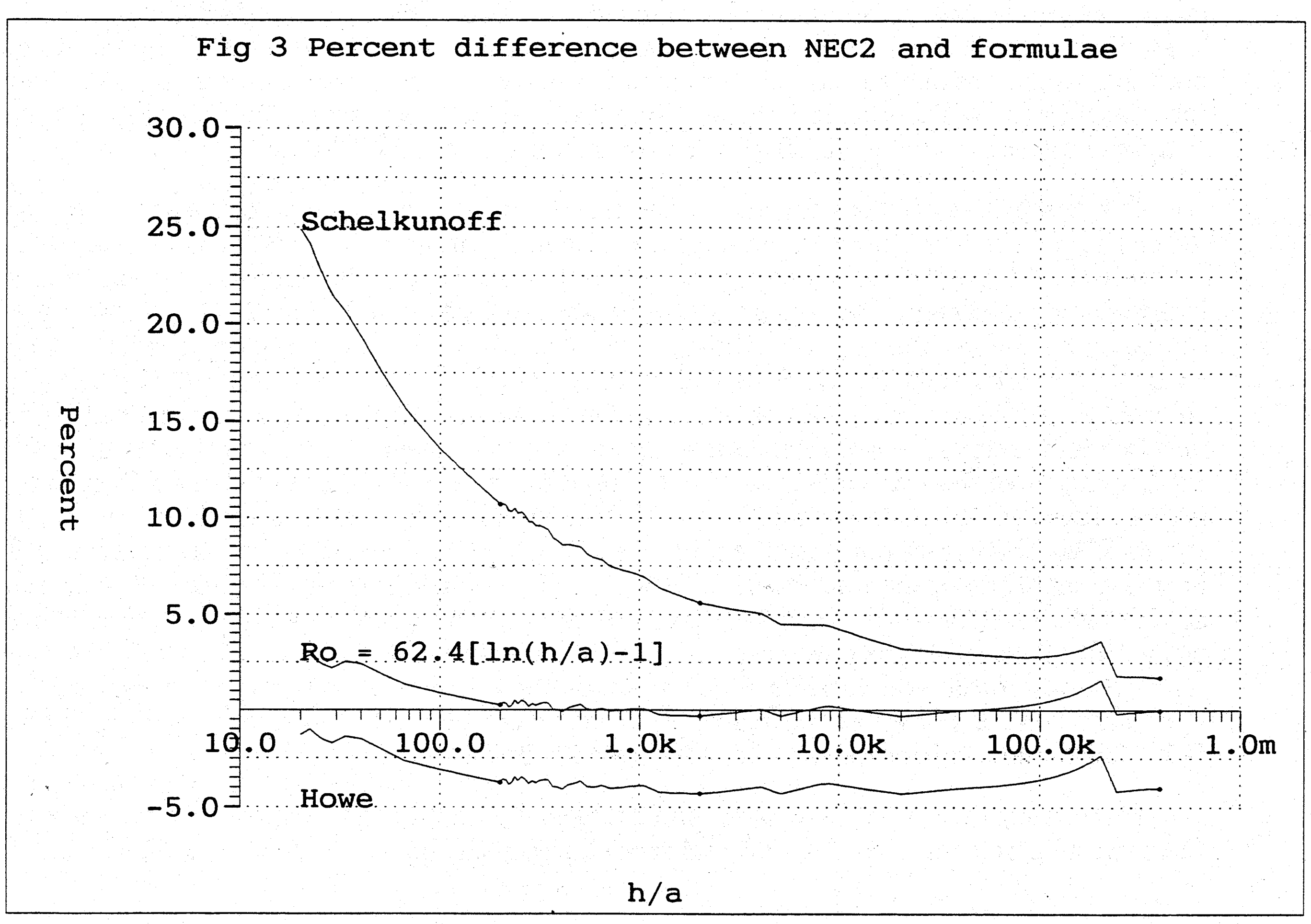


Fig 3 Percent difference between NEC2 and formulae
Schelkunoff
Ro = 62.4[ln(h/a)-1]
Howe
30.0
25.0
20.0
15.0
10.0
5.0
-5.0
Percent
10.0
100.0
1.0k
10.0k
100.0k
1.0m
h/a