CALIBRATING K TO NEC

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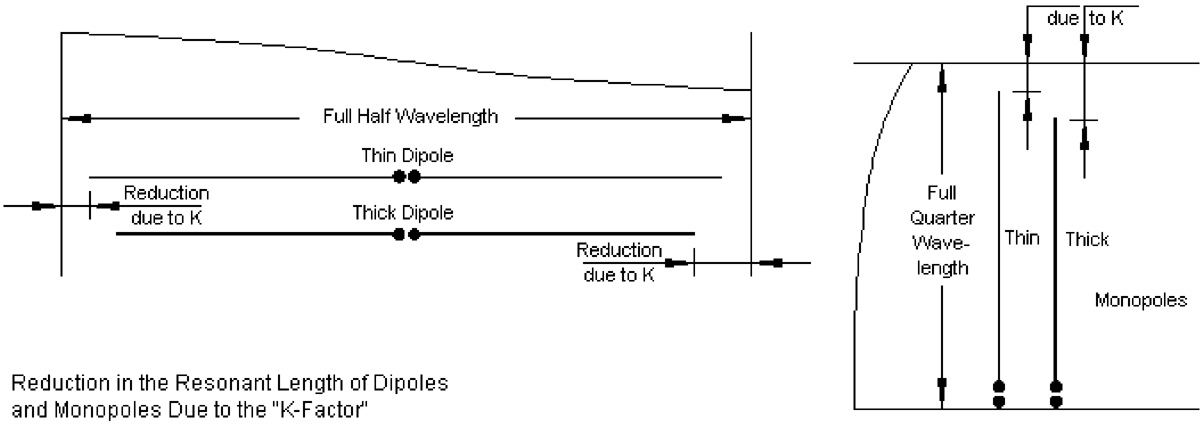
K is the factor by which one shortens the physical length of an antenna to achieve the correct electrical length. A half-wave dipole in free space or a vertical quarter-wave monopole over perfect ground will, at resonance, be physically shorter than a half or a quarter of a wavelength, respectively, as shown in **Figure 1**. The amount of shortening is regular; that is, it is a function of the antenna and not the surroundings (which will also have an affect upon the length of a resonant antenna). Nor does the shortening depend upon deformations, usually loops, at the ends of wire antennas, which simply add to the end effect.

Fig. 1



Reduction in the Resonant Length of Dipoles and Monopoles Due to the "K-Factor"

For most practical purposes, hams cut half-wavelength wire antennas to a length in feet approximating the constant 468 divided by the Frequency in MHz. This standard formulation has been in ARRL *Handbooks* since at least 1930. In 1947, the *Handbook* introduced a graph relating the ratio of the antenna element diameter and a half wavelength in free space to a multiplier K. K is always less than 1 and approximates the amount by which the antenna is shortened relative to a full half wavelength by virtue of its diameter. *Antenna Books* (through the mid-1990s) carried the graph continuously since 1949.

Unfortunately, the 1947 discussion refers to end effect only in terms of the additional system capacitance added by antenna end deformation.[1] In point of fact, deformation is an additional end effect. The value of K dependent upon antenna diameter is also an end effect to the degree that it is applicable only to the end quarter wavelength sections of a dipole, however many wavelengths long it may be. Likewise, it is applicable to the final quarter wavelength section of a vertical antenna over perfect ground, no matter how many wavelengths long the monopole might be. Other sections of such antennas (each a half wavelength for dipoles or a quarter wavelength for monopoles) will be roughly (but not exactly) a full half or quarter wavelength, respectively.

Explanations of the shortening effect are ordinarily traceable to accounts of the end capacitance of an antenna element, as if the end consisted of a spherical cap with the wire's radius.[2] Within the antenna-transmission-line analogy upon which classical mathematical treatments of antennas rest, the shortening effect is reducible for practical work a constant, often called K, corresponding to the diameter-to-half-wavelength ratio at the frequency of interest.[3]

Working values of K, the decimal multiplier used to account for regular end-effect shortening, ordinarily come from graphs of one or another sort. Such values often suffice for ordinary construction purposes, where other variables intervene in determining the final antenna element length. However, some calculations, especially those related to antenna modeling by method of moments techniques as implement in such programs as MININEC and NEC-2, may require more precise--or at least different--values for K than those provided by traditional graphical representations of K.

Calibrating K to NEC-2

The widespread use of antenna modeling programs, such as NEC-2 and MININEC, suggests an alternative method of calculating both K and the length of antennas. It is possible to correlate values of K with NEC models, to separate end effects from material and other uniform effects upon antenna elements, and then to calculate predictively, with good accuracy relative to NEC-2, the length of single- and multiple-quarter and half wavelength antenna elements. A small GW Basic program suffices for the calculations, once the calibration is accomplished.

The methods described here produce accurate results in terms of NEC-2 models for finding K and the length of antenna elements up to 7 quarter and half wavelengths for the frequency range of 3 to 30 MHz and selected antenna materials ranging from #18 AWG copper wire through 2" aluminum tubing. Limitations on that accuracy will be described at each stage of the program development.

Let us call K_T the total antenna shortening factor, K_M the portion of the shortening factor attributable to material losses and any other factor uniformly affecting every increment of length along the antenna, and K_E the end effect or the shortening factor applicable to the end quarter wavelength of a vertical over perfect ground or the end quarter wavelengths of a dipole in free space. The technique for calculating K_T requires the selection of an element diameter and the derivation of values of K_T for two frequencies, F_L and F_H, at the lower and upper limits of a range of frequency interest. HF antenna work, for example, may be interested in the range of 3 to 30 MHz. For any selected element diameter, K_T will vary regularly across the range from K_L to K_H, where K_L will, of course, be the larger value at the lower frequency limit.

Deriving K_L and K_H from antenna models requires the construction of a suitable basic antenna model, for example, a quarter-wave vertical over perfect ground. For a selected element diameter, the antenna is resonated. Technically, resonance is a condition at which the antenna (or, in this case, the model) shows only resistive impedance, with the reactance equal to zero. In modeling practice, anything close to zero is of little practical consequence for a real wire antenna. In this case, however, reactance must be nulled to some arbitrarily small value. For purposes of correlating equations and modeling results, I have used a reactance less than $\pm 0.01\,\Omega$ as sufficiently precise to permit calculation to 4 significant figures. Again, in practice, this degree of precision is spurious, but the aim here is the correlation of two calculational schemes, and the added precision is useful in tracing curves unambiguously.

Variation of Resonance in NEC-2 for a Sample Quarter-Wavelength Antenna

Number of Segments	**Variation in jX from Standard in Ohms**	**Resonant Length of Antenna in inches**
5	-0.180	958.202 @ -0.001 Ω jX
10	-0.057	958.066 @ -0.001
15	-0.023	958.030 @ -0.001
20	-0.009	958.015 @ -0.000
* 25	-0.001	958.004 @ -0.001
30	-0.008	958.012 @ +0.001
35	-0.019	958.013 @ +0.001

* Standard: #10 AWG Copper wire quarter-wavelength vertical over perfect ground at 25 segments per quarter wavelength

Table 1. Variation of resonance in NEC-2 for a sample quarter-wavelength antenna of #10 AWG copper wire at 3 MHz.

The choice of NEC-2 implementations may affect the consistency of modeling results. In addition, the selection of the number of segments per quarter wavelength will also affect the results, since the calculated feedpoint impedance will vary slightly with the number of segments per unit of antenna length. **Table 1** shows a representative sample of the variation in question at 3 MHz using #10 copper wire. Let us use 25 segments per quarter wavelength as the standard, resonating the quarter wavelength antenna to ±0.001 Ω jX. The second column shows the reactance variation as the number of segments is varied, while the third column shows the length of the antenna if resonated within the same limits as the standard. The figure of 25 segments per quarter wavelength was selected because results converged within ±0.01 Ω jX between 20 and 30 segments per quarter wavelength.

The length (in familiar units) of a quarter-wavelength of a radio wave in free space at a given frequency accords with the familiar equations,

$$L_{(ft)} = 245.8928 / F_{(MHz)} \text{ or } L_{(in)} = 2950.7136 / F_{(MHz)} \qquad \mathbf{1}$$

where $L_{(ft)}$ is the quarter wavelength in feet, $L_{(in)}$ is the length in inches, and $F_{(MHz)}$ is the frequency in MHz. Constants are based on the value of the speed of electromagnetic radiation used in implementations of NEC-2. Calculation of the length of a half wavelength of a radio wave in free space would use numeric constants exactly twice the values in (1).

Models of resonant real antennas composed of elements, ordinarily with a circular cross section of measurable dimension, will be shorter. The shortening factor, K_T, for single quarter wavelength verticals over perfect ground is simply

$$K_T = L_{(Model)} / L_{(Ideal)} \qquad \mathbf{2}$$

where $L_{(Model)}$ is the resonant length of the modeled antenna and $L_{(Ideal)}$ is the length of the ideal antenna calculated in equation (1). Apart from any other method of obtaining a value for K_T, we can always find a value for K_T at a specific frequency for a specific antenna element material in this manner. Since modeled antennas ordinarily specify the material from which the antenna is constructed, K_T includes the combined effects of both end effects and of material effects.

Resonating antenna models to a suitable degree of precision can be a tedious task, especially if one surveys numerous materials at many frequencies. There is an alternative. First, for a given antenna element material, derive from the modeling program values of K_H and K_L at the frequency extremes of the range of interest. Then, for any specific frequency within the range F_H and F_L, corresponding to the limiting values K_H and K_L, calculate K as follows:

$$K_T = K_H + [(\log \frac{F_H}{F})^{EE} \bullet (K_L - K_H)] \tag{3}$$

where K_T is the antenna shortening factor, K_H is the value of K of a given diameter element at its highest frequency, K_L is the value of K of a given diameter antenna element at its lowest frequency, F_H is the highest frequency (for K_H), F_L is the lowest frequency (for K_L), and F is any frequency in the range of interest.

The exponent, EE, also varies with frequency.

$$EE = .0333[(F/3) - 1] + .61 \tag{4}$$

for the frequency range 3 to 30 MHz. The value of EE is approximately linear from 3 to 30 MHz. It ranges from 0.61 to 0.91. Equation (4) simply calculates proportional parts for the value of the exponent.

The values of K_T returned by the equations are quite precise, relative to NEC-2 models of quarter-wavelength monopoles over perfect ground, using 25 segments and brought to resonance. The maximum variance from values derived from the models is about 0.03% with the largest diameter materials, and closer with all other antenna element sizes. This variance sets the practical limits of accuracy of this calibration scheme in terms of element diameters.

K_M, K_E, and Long Antennas

Separating the factors K_M and K_E from the overall value of K_T is straightforward. By choosing resonated antennas of multiple quarter wavelengths, one may derive another set of values for the overall shortening effect. Let us distinguish the two values of K_T by calling the quarter wave value K_{QW} and the multi-quarter wave value K_{TQ}. Let us also assume that the end effect appears only on the last quarter wavelength section, while the material effect appears on every quarter wavelength section. We may now derive the values of K_M and K_E by solving the resultant simultaneous equations, which reduce to the following (where n is the number of quarter wavelengths in the longer antenna):

$$K_E = \frac{(n-1) K_{QW} L_{(Ideal)}}{K_{TQ}(n L_{(Ideal)}) - K_{QW} L_{(Ideal)}} \tag{5}$$

and

$$K_M = \frac{K_{QW}}{K_E} \qquad \mathbf{6}$$

We may now use these values of K_M and K_E to calculate the lengths of multiple quarter-wavelength antennas (where n is the number of quarter wavelengths):

$$L = (n - 1)\, K_M\, L_{(Ideal)} + K_E\, K_M\, L_{(Ideal)} \qquad \mathbf{7}$$

The length, L, will be in units of choice, usually dependent upon the choice of units for the length of the modeled antennas at 3 and 30 MHz.

Dipoles in free space will be exactly twice the length of the corresponding verticals over perfect ground.[4] Values of K_T, K_E, and K_M will be the same, but the value of $L_{(ideal)}$ will be twice the value used for quarter wavelength antennas in (7). Alternatively, one may recast the equations to reflect preferred basic antennas and units of measure.

The initial choice of n, the number of wavelengths in the longer antenna upon which the calculation of K_E and K_M are based in (5) and (6), will influence the direction of error in the final calculation of long antennas. If n is small, for example, 3, then calculated values of antennas with more quarter or half wavelengths will be short. If n is large, say, 7, then calculated values of antennas with fewer quarter or half wavelengths will be long. Using each of these values of n and checking antennas with 5 quarter or half wavelengths yields errors under 0.05% using either technique, relative to NEC-2 models.

K_M reflects predominantly material loss affects on antennas, which are in part dependent upon the surface area (and hence, the diameter) of the element. However, figures derived from modeled values for lossless elements show a residual value for K_M, which appears to increase with antenna element diameter. However, the amount by which the lossless K_M is less than 1.0 is very small. Consequently, the source of the residual K_M cannot be definitively traced to antenna factors. Nor can it be definitely ascribed either to the limits of the modeling program or to the limits of this calculation scheme.

Those unfamiliar with the variation of length with various other antenna properties may find a surprise in **Table 2**. The table lists the calculated lengths (confirmed by NEC-2 models) of 7-half-wavelength dipoles in free space for common copper wire and aluminum sizes. Although it is unlikely that anyone will build such an antenna from 2" aluminum tubing, the list of values is instructive with respect to the interaction of material losses and end effect upon antenna length. Note that the modeled antenna length increases with the copper wire size and even with the first two sizes of aluminum. Although the table has intentionally used a frequency where the length variation curve is most dramatic, a similar, if lesser, variation occurs throughout the HF region.

Sample Calculated Lengths of 7 Half-Wavelength Dipoles at 3 MHz

Antenna element diameter in inches		Length in feet of a 7-Half-Wavelength Dipole
Copper Wire antennas:		
#18:	0.0403	1141.48
#16:	0.0508	1141.76
#14:	0.0641	1141.94
#12:	0.0808	1142.07
#10:	0.1019	1142.14
Aluminum antennas:		
	0.125	1141.83
	0.25	1141.89
	0.5	1141.67
	0.75	1141.43
	1.0	1141.24
	1.25	1141.03
	1.5	1140.88
	1.75	1140.71
	2.00	1140.58

Table 2. Sample calculated lengths of 7-half-wavelength dipoles at 3 MHz.

The GW Basic Program

The attached utility program in GW Basic provides values of K_T, K_M, and K_E in the frequency range 3 to 30 MHz for a selection of common amateur antenna materials ranging from #18 AWG wire to 2" diameter tubing. In addition, the program provides the lengths of dipole antennas in free space from 1 to 7 half wavelengths long. (Vertical antennas over perfect ground will be exactly half the lengths of the dipoles for a number of quarter wavelengths equal to the number of half wavelengths in the corresponding dipole.) The program makes use of equations (1) to (7) above. Key to the program is the development of limiting values of resonant antenna lengths from NEC models at 3 and 30 MHz for each material. For the sake of linear programming, the limiting values appear in the program listing twice, a set within the calculation FOR-NEXT loops for each of the output options.

Program output is a pair of tables, each for 14 antenna materials. If a particular material is missing from the list, the user can easily modify one or more of the information lines to include it. Or, one can interpolate with quite reasonable accuracy values for intermediate materials. Option A lists the lengths of short to long dipoles. Option B lists values of K_T, K_M, and K_E for each material. For reference (and because screen space was available), corresponding quarter-wave monopole (over perfect ground) and half-wavelength dipole (in free space) lengths are given for each material. For wire smaller than #18, the longest given length will very likely suffice for all antenna construction purposes.

Verticals and dipoles over real ground, of course, will vary in resonant length according to ground conditions and (for dipoles) height above ground. **Table 3** lists the modeled resonant lengths for an aluminum 0.5"-diameter dipole at 28.5 MHz, in 4' increments from 16' to 36' above medium ground. This same type of data has often been shown as the variation in resistance and reactance of a fixed length dipole as the height is increased. Displaying it as "effective K_T" is simply another useful perspective on the data.[5]

Values of "Effective K_T" for Dipoles Over Real Ground

Height in Feet	**Resonant Antenna Length in Feet**	**Effective K_T**	**Feedpoint Resistance in Ohms**
Free Space	16.46	.9535	72.0
16	16.64	.9640	74.9
20	16.48	.9546	63.4
24	16.34	.9465	68.3
28	16.42	.9509	77.3
32	16.54	.9582	76.3
36	16.52	.9567	68.9

Notes:

1. All lengths and feedpoint resistances are rounded for ease of reading. Antenna lengths were varied until resonance (±0.01 Ω reactance) was achieved.
2. Feedpoint resistance is listed to demonstrate the absence of a simple direct correlation with antenna length or K_T.

Table 3. The effective K_T of a 0.5"-diameter dipole over real ground at heights from less than 0.5 wavelength to greater than 1 wavelength.

Fortunately for antenna builders, these basic antennas exhibit acceptably low reactances across a reasonably wide frequency range. Hence, a knowledge of precise values of K_T is not needed for successful antenna building. However, for some investigations, the values of K_T yielded by the utility program may prove useful in sorting promising from unpromising formulations of experimental or modeling trends.

The goal of this project is neither to supplant traditional graphical representations of K nor to force upon antenna constructors an unnecessary level of precision. As noted earlier, the functions of the level of precision used in the development of the Basic program were to trace value curves accurately and to compare values produced by the modeling and the calibrated computational scheme. For most wire antennas with loops at the ends, the traditional 5% total end effect reduction will continue to perform adequately for real antennas amid the host of surrounding objects within which we raise them.

For many, this program may be only a curiosity, especially in view of the fact that it does not itself evaluate the accuracy of NEC-2 models relative to real antennas. However, it can shorten the trial and error time required to zero in on resonant antenna models of various lengths. In the absence of a modeling program such as NEC-2, the Basic program yields equally usable resonant antenna lengths for free space or over perfect ground, as may be apt. Moreover, it gives some further insight into antenna length as a combined function of end effects and material losses. The user may modify the frequency range and the selection of materials used in the program. Indeed, the program reference values can be calibrated to any present or future version or implementation of NEC. Finally, the program may also serve as one kernel within a larger program within which values of K, the antenna-shortening factor, may play a significant role.

NOTES

1. See *The Radio Amateur's Handbook*, 24th Ed. (West Hartford: ARRL, 1947), pp. 194-195. I am indebted to Michael Tracy, KC1SX, of the ARRL Technical Information Service, who added his efforts to my own in the search for the source of the *Handbook* graph. Nothing in *QST* or other League publications has shown itself. If anyone has knowledge of an authoritative source for the graph, I would appreciate correspondence or e-mail.

2. See, for example, the treatment of end "caps" in S. A. Schelkunoff, *Electromagnetic Waves* (New York: Van Nostrand, 1943), p. 465. At best, one can draw some inferences from sources such as this, but they do not show the definitive development of the *Handbook* graph. See note 1. The designation of the shortening factor as "K" is also problematic in connection with transmission-line analogy calculations, which often use K to designate the characteristic impedance of a biconical antenna, and sometimes of its cylindrical counterparts.

3. For information on experimental work refining the antenna shortening factor, see John S. Belrose, "VLF, LF, and MF Antennas," in *The Handbook of Antenna Design*, Vol. 2, ed. Rudge, Milne, Oliver, and Knight (London: Peter Peregrinus, 1983), pp. 564-65.

4. The exactitude is a function of the manner in which NEC calculates vertical antennas over perfect ground.

5. All models were constructed on EZNEC 1.06, available from Roy Lewallen, W7EL. Although the work could have been done on virtually any version of NEC-2, the wire dimension manipulation features of EZNEC made it especially apt to the reiterative nature of this task. I recommend that, if the attached program is to be used regularly in conjunction with a version of NEC, then the program should be calibrated for the specific version of NEC used by confirming the values of, or developing replacement values for, lines 200-330 and 580-710 of the program.

Program Listing

```
10 REM     file "KNEC.BAS"
20 COLOR 11,1,3:CLS:X$=STRING$(79,32)
25 REM     Option selection page
30 LOCATE 1,16:PRINT"Calculation of K, the Antenna Shortening Factor,":LOCATE
        2,18:PRINT"and Vertical and Horizontal Antenna Lengths":LOCATE 3,30:PRINT"L. B.
        Cebik, W4RNL":PRINT
40 PRINT " This program calculates values of the antenna shortening factor and antenna
lengths, including quarter-wave verticals over perfect ground, half-wavelength dipoles in free
space, and long wire vertical and horizontal antennas. The"
50 PRINT " frequency limits are 3 to 30 MHz. All dimensions are calibrated to NEC-2
antenna models. Available materials are AWG #18 to AWG #10 copper wire and aluminum rod
or tubing from 0.125 to 2.0 inch diameters.":PRINT
60 PRINT " Select one of the following two options:":PRINT:PRINT " <A> A table of antenna
lengths from 1 to 7 half wavelengths.":PRINT
70 PRINT " <B> A table of values of K, along with the lengths of quarter-wavelength
        vertical and half-wavelength horizontal antennas."
80 Z$=INKEY$:IF Z$="a" OR Z$="A" THEN 90 ELSE IF Z$="b" OR Z$="B" THEN 470 ELSE 80
85 REM     Option A calculations
90 CLS:LOCATE 1,8:PRINT "Tables of Horizontal Antenna Lengths from 1 to 7 Half
        Wavelengths":PRINT:VV$="###.##":WW$="####.##":YY$=STRING$(3,32)
100 PRINT " AWG Wire sizes are copper; decimal wire diameters are aluminum. Quarter-wave
        vertical antennas over perfect ground are 1/2 the values shown where Xn = the number
        of quarter wavelengths.
110 LOCATE 6,1:INPUT " Enter the frequency of interest in MHz ",F
120 IF F<3 OR F>30 THEN LOCATE 6,1:PRINT X$:GOTO 500
130 WLF=983.5712/F
140 LOCATE 6,1:PRINT X$:LOCATE 6,1:PRINT" Frequency:";F;"MHz";:LOCATE
        6,58:PRINT"Wavelength: ";:PRINT USING "###.##";WLF;:PRINT" ft"
150 LOCATE 7,25:PRINT "Number of half-wavelengths; Length in feet"
160 PRINT " Wire size";:PRINT YY$;:PRINT "  X 1    X 2    X 3    X 4    X 5    X 6    X7"
170 FOR A=1 TO 14
180 IF A=1 THEN 200 ELSE IF A=2 THEN 210 ELSE IF A=3 THEN 220 ELSE IF A=4 THEN 230
        ELSE IF A=5 THEN 240 ELSE IF A=6 THEN 250 ELSE IF A=7 THEN 260 ELSE IF A=8
        THEN 270 ELSE 190
190 IF A=9 THEN 280 ELSE IF A=10 THEN 290 ELSE IF A=11 THEN 300 ELSE IF A=12 THEN
        310 ELSE IF A=13 THEN 320 ELSE IF A=14 THEN 330
200 W$=" #18-0.0403":LQL=959.435:LQH=95.335:LTL=6848.87:LTH=684.82:GOTO 340
210 W$=" #16-0.0508":LQL=959.183:LQH=95.252:LTL=6850.53:LTH=684.8:GOTO 340
220 W$=" #14-0.0641":LQL=958.885:LQH=95.154:LTL=6851.67:LTH=684.768:GOTO 340
230 W$=" #12-0.0808":LQL=958.478:LQH=95.04799:LTL=6852.43:LTH=684.699:GOTO 340
240 W$=" #10-0.1019":LQL=958.001:LQH=94.931:LTL=6852.81:LTH=684.618:GOTO 340
250 W$=" 0.125 in. ":LQL=957.22:LQH=94.807:LTL=6850.95:LTH=684.45:GOTO 340
260 W$=" 0.25 in.  ":LQL=955.36:LQH=94.35:LTL=6851.31:LTH=684.082:GOTO 340
270 W$=" 0.50 in.  ":LQL=952.85:LQH=93.734:LTL=6850.05:LTH=683.55:GOTO 340
280 W$=" 0.75 in.  ":LQL=951.03:LQH=93.275:LTL=6848.59:LTH=683.144:GOTO 340
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290 W$=" 1.00 in.  ":LQL=949.58:LQH=92.898:LTL=6847.46:LTH=682.82:GOTO 340
300 W$=" 1.25 in.  ":LQL=948.31:LQH=92.575:LTL=6846.2:LTH=682.555:GOTO 340
310 W$=" 1.50 in.  ":LQL=947.22:LQH=92.292:LTL=6845.25:LTH=682.332:GOTO 340
320 W$=" 1.75 in.  ":LQL=946.22:LQH=92.038:LTL=6844.28:LTH=682.14:GOTO 340
330 W$=" 2.00 in.  ":LQL=945.3:LQH=91.81199:LTL=6843.45:LTH=681.983:GOTO 340
340  Q=2950.7136#:LQW=Q/F:LQWH=Q/30:LQWL=Q/3:KQH=LQH/LQWH:KQL=LQL/LQWL:
      KTH=LTH/(3*LQWH):KTL=LTL/(3*LQWL)
350 EE=(((F/3)-1)*.0333333)+.61:KQW=KQH+((.4343*LOG(30/F))^EE)*(KQL-KQH)
360 KTQ=KTH+((.4343*LOG(30/F))^EE)*(KTL-KTH)
370 LQ=KQW*LQW:LT=KTQ*(3*LQW):KE=(6*LQ)/(LT-LQ):KM=KQW/KE:PRINT W$;:PRINT
YY$;
380 FOR B=1 TO 7
390 BB=B-1:LD=(2*LQW)/12:LL=((BB*LD)*KM)+(KQW*LD)
400 IF B<6 THEN PRINT USING VV$;LL;:PRINT YY$;
410 IF B>5 AND B<7 THEN PRINT USING WW$;LL;:PRINT YY$;
420 IF B=7 THEN PRINT USING WW$;LL
430 NEXT
440 NEXT
450 PRINT:PRINT "  <Print Screen> for hard copy";YY$;YY$;"<A>nother run, <V>alues of K, or
      <Q>uit";
460 Z$=INKEY$:IF Z$="a" OR Z$="A" THEN 90 ELSE IF Z$="v" OR Z$="V" THEN 470 ELSE IF
      Z$="Q" OR Z$="q" THEN 810 ELSE 460
465 REM              Option B Calculation
470 CLS:LOCATE 1,16:PRINT "Calculation of K, the Antenna Shortening Factor"
480 LOCATE 3,1:PRINT" KT is the total shortening factor. KM is the shortening factor due to
      element   material. KE is the shortening factor due to end effect.  Values calibrated to"
490 LOCATE 5,1:PRINT" NEC-2 models for 3-30 MHz.  AWG sizes are copper; decimal sizes are
      aluminum."
500 LOCATE 7,1:INPUT " Enter the frequency of interest in MHz      ",F
510 IF F<3 OR F>30 THEN LOCATE 7,1:PRINT X$:GOTO 500
520 WLF=983.5712/F
530 LOCATE 7,1:PRINT X$:LOCATE 7,1:PRINT" Freq:";F;"MHz";:LOCATE
              7,20:PRINT"Wavelength:";:PRINT USING "###.##";WLF;:PRINT" ft":LOCATE
      7,48:PRINT"1/4-WL Vertical";:LOCATE 7,65:PRINT"1/2-WL Dipole"
540 LOCATE 8,2:PRINT"Wire Size":LOCATE 8,20:PRINT"KT":LOCATE
      8,30:PRINT"KM":LOCATE 8,40:PRINT"KE":LOCATE 8,52:PRINT"L (ft)":LOCATE
      8,67:PRINT"L (ft)"
550 FOR A=1 TO 14
560 IF A=1 THEN 580 ELSE IF A=2 THEN 590 ELSE IF A=3 THEN 600 ELSE IF A=4 THEN 610
      ELSE IF A=5 THEN 620 ELSE IF A=6 THEN 630 ELSE IF A=7 THEN 640 ELSE IF A=8
      THEN 650 ELSE 570
570 IF A=9 THEN 660 ELSE IF A=10 THEN 670 ELSE IF A=11 THEN 680 ELSE IF A=12 THEN
      690 ELSE IF A=13 THEN 700 ELSE IF A=14 THEN 710
580 W$=" #18-0.0403":LQL=959.435:LQH=95.335:LTL=6848.87:LTH=684.82:GOTO 720
590 W$=" #16-0.0508":LQL=959.183:LQH=95.252:LTL=6850.53:LTH=684.8:GOTO 720
600 W$=" #14-0.0641":LQL=958.885:LQH=95.154:LTL=6851.67:LTH=684.768:GOTO 720
610 W$=" #12-0.0808":LQL=958.478:LQH=95.04799:LTL=6852.43:LTH=684.699:GOTO 720
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620 W$=" #10-0.1019":LQL=958.001:LQH=94.931:LTL=6852.81:LTH=684.618:GOTO 720
630 W$=" 0.125 in. ":LQL=957.22:LQH=94.807:LTL=6850.95:LTH=684.45:GOTO 720
640 W$=" 0.25 in.  ":LQL=955.36:LQH=94.35:LTL=6851.31:LTH=684.082:GOTO 720
650 W$=" 0.50 in.  ":LQL=952.85:LQH=93.734:LTL=6850.05:LTH=683.55:GOTO 720
660 W$=" 0.75 in.  ":LQL=951.03:LQH=93.275:LTL=6848.59:LTH=683.144:GOTO 720
670 W$=" 1.00 in.  ":LQL=949.58:LQH=92.898:LTL=6847.46:LTH=682.82:GOTO 720
680 W$=" 1.25 in.  ":LQL=948.31:LQH=92.575:LTL=6846.2:LTH=682.555:GOTO 720
690 W$=" 1.50 in.  ":LQL=947.22:LQH=92.292:LTL=6845.25:LTH=682.332:GOTO 720
700 W$=" 1.75 in.  ":LQL=946.22:LQH=92.038:LTL=6844.28:LTH=682.14:GOTO 720
710 W$=" 2.00 in.  ":LQL=945.3:LQH=91.81199:LTL=6843.45:LTH=681.983:GOTO 720
720 Q=2950.7136#:LQW=Q/F:LQWH=Q/30:LQWL=Q/3:KQH=LQH/LQWH:KQL=LQL/LQWL:
      KTH=LTH/(3*LQWH):KTL=LTL/(3*LQWL)
730 EE=(((F/3)-1)*.0333333)+.61:KQW=KQH+((.4343*LOG(30/F))^EE)*(KQL-KQH)
740 KTQ=KTH+((.4343*LOG(30/F))^EE)*(KTL-KTH)
750 LQ=KQW*LQW:LT=KTQ*(3*LQW):KE=(6*LQ)/(LT-LQ):KM=KQW/KE:IF KM>.9999 THEN
      KM=.9999
760 V=KQW*(245.8928/F):D=V*2:Y$=STRING$(5,32):V$=STRING$(9,32):U$=".####":
T$="###.##":S$=STRING$(6,32)
770 PRINT W$;:PRINT S$;:PRINT USING U$;KQW;:PRINT Y$;:PRINT USING U$;KM;:PRINT
Y$;:PRINT USING U$;KE;:PRINT V$;:PRINT USING T$;V;:PRINT V$;:PRINT USING T$;D
780 NEXT
790 PRINT:PRINT "  <Print Screen> for hard copy";V$;"<A>nother run, <W>ire lengths, or
<Q>uit";
800 Z$=INKEY$:IF Z$="a" OR Z$="A" THEN 470 ELSE IF Z$="Q" OR Z$="q" THEN 810 ELSE
      IF Z$="w" OR Z$="W" THEN 90 ELSE 800
810 END
```