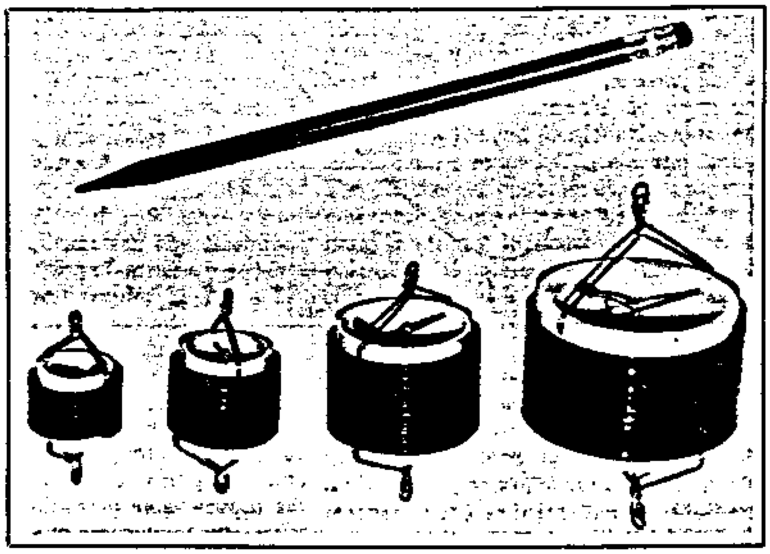
Optimizing Coaxial-Cable Traps

Effective high-reactance antenna traps provide good performance and increased effective bandwidth. Author Sommer supplies detailed data for coaxial-cable traps, along with design curves for two types of cable.



By Robert C. Sommer,* N4UU

The clever concept of using the same length of coaxial cable to form both the coil and the capacitor of a parallel-resonant antenna trap first appeared in an amateur publication in 1981.[1] Coaxial-cable antenna traps have been found to be broadband, inexpensive, easy to construct, stable with respect to temperature variations and capable of operating at surprisingly high levels of power. Furthermore, these traps can be made small and lightweight.[2,3]

This article shows an optimum diameter for such a trap, which permits a specified resonant frequency to be obtained with a minimum length of cable. Minimizing the length of cable not only reduces the cost, weight and the losses associated with the cable, but also achieves the maximum bandwidth over which the parallel-resonant impedance remains high. These are all desirable characteristics. The data for constructing optimized traps, for each of the HF bands, can be found in the figures.

Mathematical Background

Fig. 1 shows a cutaway view of a coaxial-cable antenna trap. Suppose the thickness of the cable (the outside diameter) is t inches, and that the cable is wound on a cylindrical form with an outside diameter of d inches, in order to produce a coil containing n turns. Assume the coil is close wound, with no spacing between the adjacent turns, so as to obtain the greatest inductance with a given number of turns. Assume, also, that one-half inch of shielded cable is used at each end of the coil as a pigtail to penetrate the coil form.[4] The total length of the shielded cable under those conditions is approximated closely by $\pi n(d + t) + 1$ inches. If the distributed capacitance of the cable is C_0 pF per foot, then the total capacitance of the cable is

$$C = \frac{C_0[\pi n(d + t) + 1]}{12}\ \text{pF} \qquad \text{(Eq. 1)}$$

Using the standard formula for inductance, the inductance of the coil formed by the coaxial cable can be expressed as

$$L = \frac{(d + t)^2 n^2}{18(d + t) + 40nt}\ \mu\text{H} \qquad \text{(Eq. 2)}$$

since the mean diameter of the coil is $d + t$ and the length of the close-wound coil is nt.[5] When the inner conductor at one end of the cable is connected to the braided shield at the other end of the cable, as shown in Fig. 1, a parallel-resonant circuit is formed. The resonant frequency is given by

$$f_0 = \frac{1000}{2\pi\sqrt{LC}}\ \text{MHz} \qquad \text{(Eq. 3)}$$

where L is expressed in microhenrys and C is expressed in picofarads. For any selected set of trap parameters (d, t, n and C_0), equations 1 and 2 are used to determine C and L, respectively, and equation 3 predicts the resonant frequency accurately.

Optimum Trap Parameters

As described above, it is easy to determine f_0 once the parameters of the trap have been selected. In practice, however, a value of f_0 is selected, and then the parameters are determined in order to

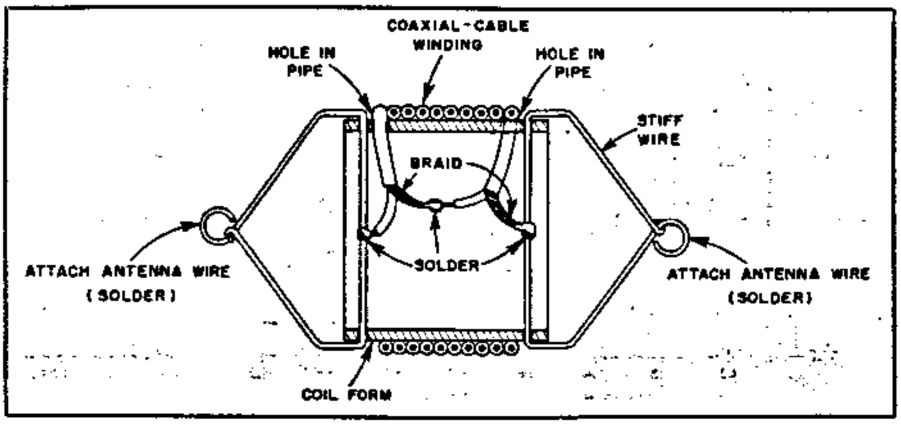


Fig. 1 — Cutaway view of a coaxial-cable antenna trap built on PVC tubing.

[1]Notes appear on page 42.

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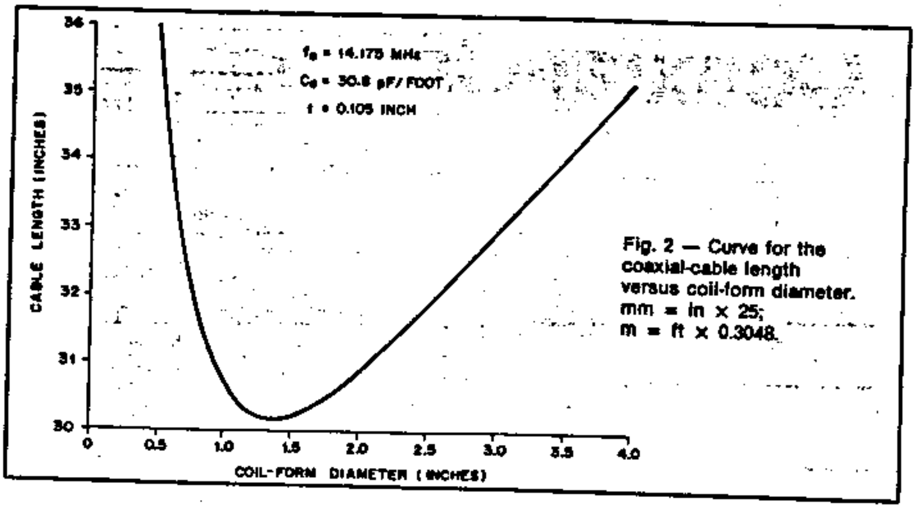


Fig. 2 — Curve for the coaxial-cable length versus coil-form diameter. mm = in × 25; m = ft × 0.3048.

achieve the selected value of f_o. This can be accomplished by placing the right members of equations 1 and 2 into equation 3 and performing some algebraic manipulations to arrive at the cubic equation

$$a_3n^3 + a_2n^2 + a_1n + a_o = 0 \quad \text{(Eq. 4)}$$

where

$a_o = -216{,}000{,}000\ (d + t)$
$a_1 = -480{,}000{,}000\ t$
$a_2 = (2\pi f_o)^2\ (d + t)^2\ C_o$
$a_3 = (2\pi f_o)^2\ (d + t)^3 \pi\ C_o$

Thus, one selects parameters d, t, f_o and C_o, computes the coefficients a_o, a_1, a_2 and a_3, and then solves equation 4 to find the proper value of n. Once n is determined, the total length of shielded coaxial cable required can be calculated from

$$\ell = \pi n(d + t) + 1 \text{ inches} \quad \text{(Eq. 5)}$$

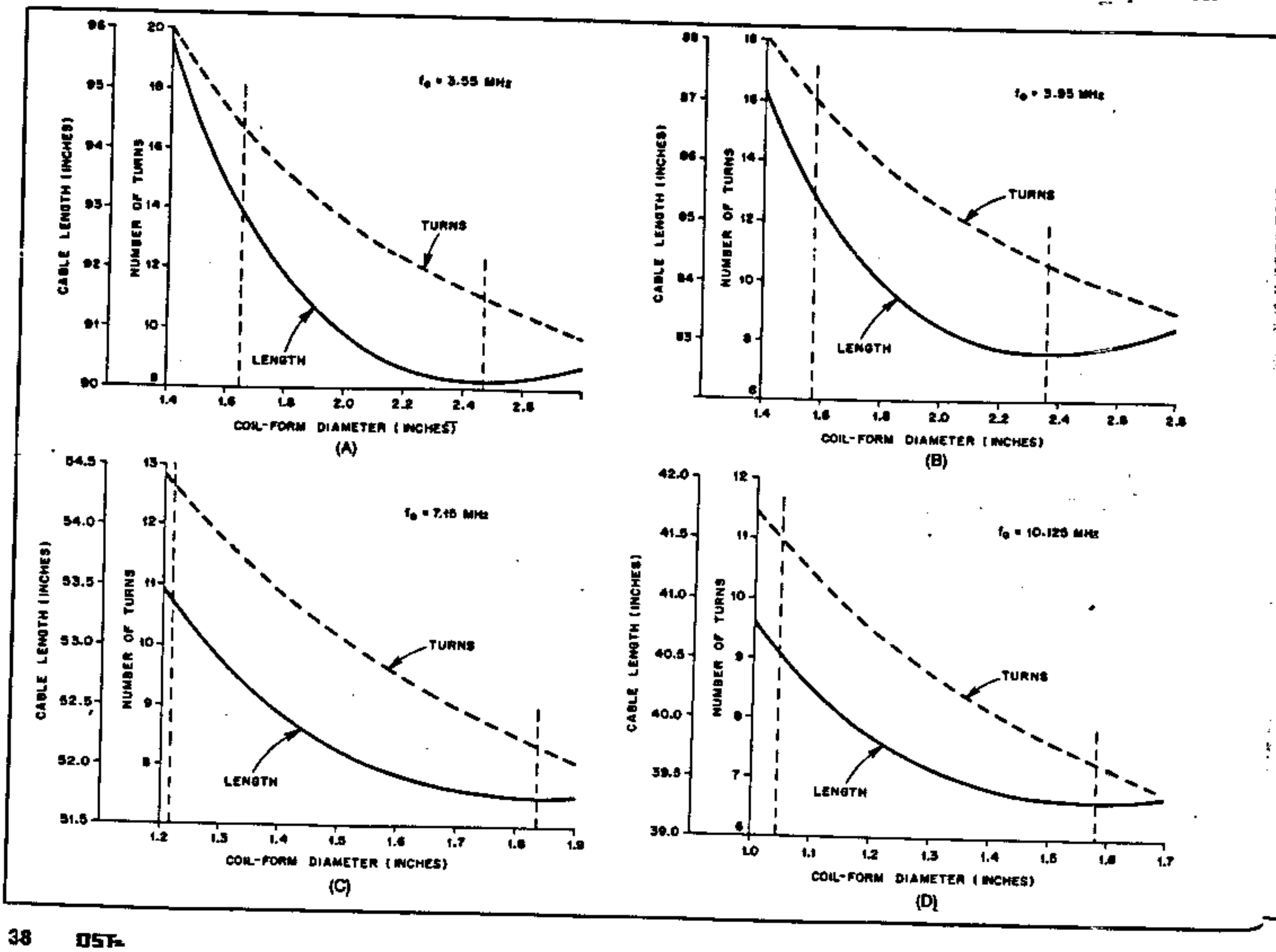
Using miniature RG-174/U cable and f_o = 14.175 MHz as an example, equations 4 and 5 were evaluated for several different values of d, and the results (which show the required cable length, ℓ, as a function of the outside diameter of the coil form, d) are presented in Fig. 2. It is interesting that there is a minimum length of cable that permits resonance to be achieved at the selected resonant frequency. Here an optimized trap is defined as that which requires a minimum length of cable in order to achieve resonance at a specified frequency. Consequently, Fig. 2 shows that a trap that is resonant in the 20-meter band and made with RG-174/U cable, will be optimized if the cable is wound on a form that is 1.4 inches in diameter.

Design Charts

Equations 4 and 5 were used to generate the design charts that are shown in Fig. 3, which pertains to RG-174/U cable, and Fig. 4, which pertains to RG-58/U cable. The nominal cable parameters used in these calculations were

RG-174/U: t = 0.105 inch,
C_o = 30.8 pF/foot
RG-58/U: t = 0.200 inch,
C_o = 28.5 pF/foot

Each chart shows the length of the cable and the number of turns required for



resonance in one of the HF amateur bands through a narrow range of diameters for the coil form. The dashed vertical line at the right indicates the precise value of d that minimizes ℓ. This point is found by using differential calculus and solving a fifth-order equation.

The results show that an optimized coaxial-cable trap is characterized by a coil configuration in which the length of the coil, nt, is equal to 0.450 times the mean diameter of the coil, d + t. This causes the two terms in the denominator of equation 2 to be equal. The dashed vertical line at the left indicates that value of d that gives rise to a square coil configuration, in which the length and diameter of the coil are equal. Generally, square coils exhibit a relatively high Q. It is probably unwise to choose a diameter less than that of the square coil configuration.

To maximize the trap performance, the diameter of the coil form should be such that the length of the cable is minimized. Since this might not always be possible because the proper size of material is not available, a smaller diameter should be acceptable; but a diameter larger than that, which gives rise to a square coil should be selected. In all cases, the range of diameters between the optimum and square configurations is broad enough that suitable material should be available.

Design Examples

Suppose a 15-meter trap is going to be made from RG-174/U coaxial cable. From the dashed vertical lines in Fig. 3F it is apparent that the diameter of the coil form should be greater than 0.75 inch, with a diameter of 1.14 inches being optimum. A local hardware store should have ¾-inch polyvinyl chloride (PVC) tubing that has an outside diameter of 1.10 inches (close to the optimum diameter). Fig. 3F shows that with a coil-form diameter of 1.10 inches, the trap will require 22 inches of cable, wound into a 5½-turn coil.

As a second example, suppose a 20-meter trap is going to be made from RG-58/U coaxial cable. From the dashed vertical lines in Fig. 4E, it is apparent that the diameter of the coil form should be greater than 1.3 inches, with a diameter of 2 inches being optimum. In this case, a piece of 1¼-inch PVC pipe that has an outside diameter of 1.68 inches serves nicely. Fig. 4E shows that the trap will require 35½ inches of cable, wound into a 5¼-turn coil.

As a final example, consider the design of a 75-meter trap that is to be made of RG-174/U and will be resonant at 3.825 MHz. Since the 75/80 meter band is relatively broad, two design charts are presented: one for f_0 = 3.55 MHz, which can be used accurately for the lowest 100 kHz of the band, and one for f_0 = 3.95 MHz, which can be used accurately for the highest 100 kHz of the band. Refer to Fig. 3A. It is clear that the optimum diameter of the coil form for the low end of the band is about 2.47 inches, and, from Fig. 3B, that the optimum diameter for the coil form for use near the high end of the band is about 2.36 inches. In this case, a pair of PVC pipe couplings with an outside diameter of 2.25 inches were used to make a pair of traps for use in a 75/160 meter inverted-V antenna.

Coincidentally, the lengths of these coupling units were perfect. Figs. 3A and 3B show that, with a diameter of 2.25 inches, 12 turns are required for resonance at 3.55 MHz, and 11 turns are required for resonance at 3.95 MHz. Since the desired resonant frequency is near the high end of the band, 11¼ turns was chosen. Equation 5 shows that the required length of cable is about 84¼ inches. Since it is much easier to shorten a length of coaxial cable than

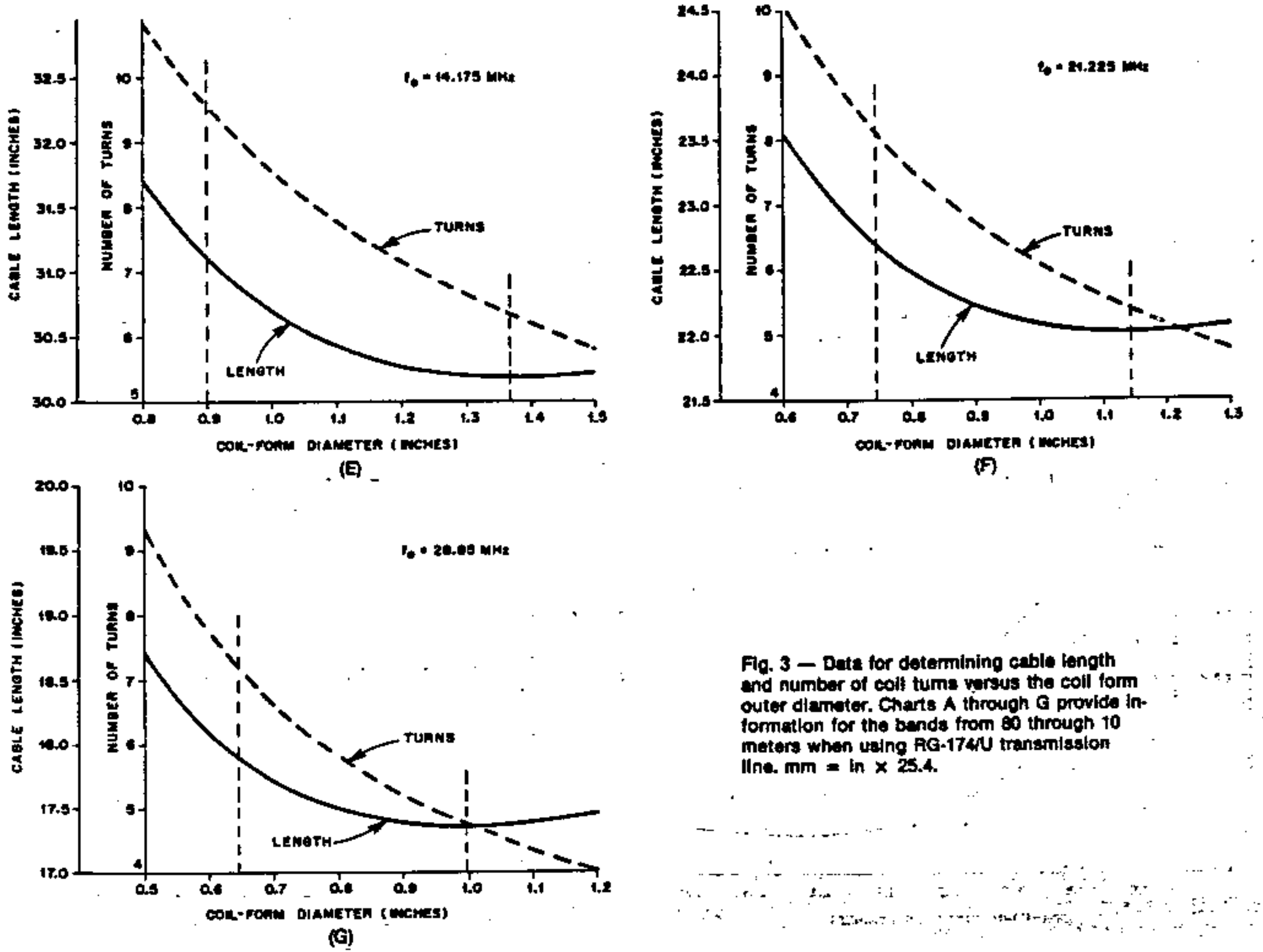


Fig. 3 — Data for determining cable length and number of coil turns versus the coil form outer diameter. Charts A through G provide information for the bands from 80 through 10 meters when using RG-174/U transmission line. mm = in × 25.4.

to lengthen it, these traps were wound initially using 86-inch lengths of cable, and the ends were then shortened slightly in order to raise the resonant frequency to 3.825 MHz.

Tuning Information

My experience shows that traps constructed with close adherence to the data in Figs. 3 and 4 are usually resonant within one percent of the design frequency. Small variations in C_o and t do occur from one batch of cable to another, and among cables produced by different manufacturers. Stray capacitance can also become significant at the higher frequencies. In order to compensate for such variations, and to provide for the fine adjustment of resonant frequency to a favored segment of the band, some suggestions for tuning are presented next.

The values of ℓ and n, which are read from the design charts, will leave a half-inch pigtail of *shielded* cable at each end of the coil. One should start with an extra inch or two of cable that has been dressed to make the connections. If some additional length of shielded cable is left inside the coil form, the capacitance is increased; consequently, the resonant frequency will be lowered. This sensitivity of the resonant frequency to the length of the cable has been computed, and is given in Table 1 in units of kilohertz reduction in f_o per inch of additional coaxial cable.

To achieve resonance near 7.050 MHz with RG-174/U, for example, Table 1 shows that an additional 1-inch length of coaxial cable inside the coil form will lower the f_o by about 66 to 68 kHz. An additional 1½ inches will lower it by about 100 kHz, thereby dropping the f_o from 7.150 to 7.050 MHz. To raise the resonant frequency, the coaxial cable inside the coil form can be dressed back in order to reduce the capacitance, and the turns on the coil can be spread slightly to reduce the inductance.

Bandwidth

The useful bandwidth of a trap is that over which the parallel-resonant impedance

Table 1

Electrical Characteristics of Coaxial Cable Antenna Traps

	RG-174/U				RG-58/U			
	Minimum Length		Square Coil		Minimum Length		Square Coil	
Freq. (MHz)	*Sensitivity (kHz/inch)*	*Reactance (ohms)*	*Sensitivity (kHz/inch)*	*Reactance (ohms)*	*Sensitivity (kHz/inch)*	*Reactance (ohms)*	*Sensitivity (kHz/inch)*	*Reactance (ohms)*
3.550	19.5	193.8	18.9	187.9	16.7	178.7	16.1	172.7
3.950	23.6	189.6	22.9	183.8	20.2	174.8	19.5	168.9
7.150	68.1	167.7	66.1	162.6	58.3	154.7	56.2	149.1
10.125	126.4	155.8	122.6	151.1	108.2	143.8	104.3	138.4
14.175	229.2	145.0	222.5	140.6	196.6	133.9	189.0	128.7
21.225	466.2	132.7	452.7	128.7	400.9	122.7	384.5	117.6
28.850	796.2	123.8	773.7	120.2	686.2	114.7	656.7	109.6

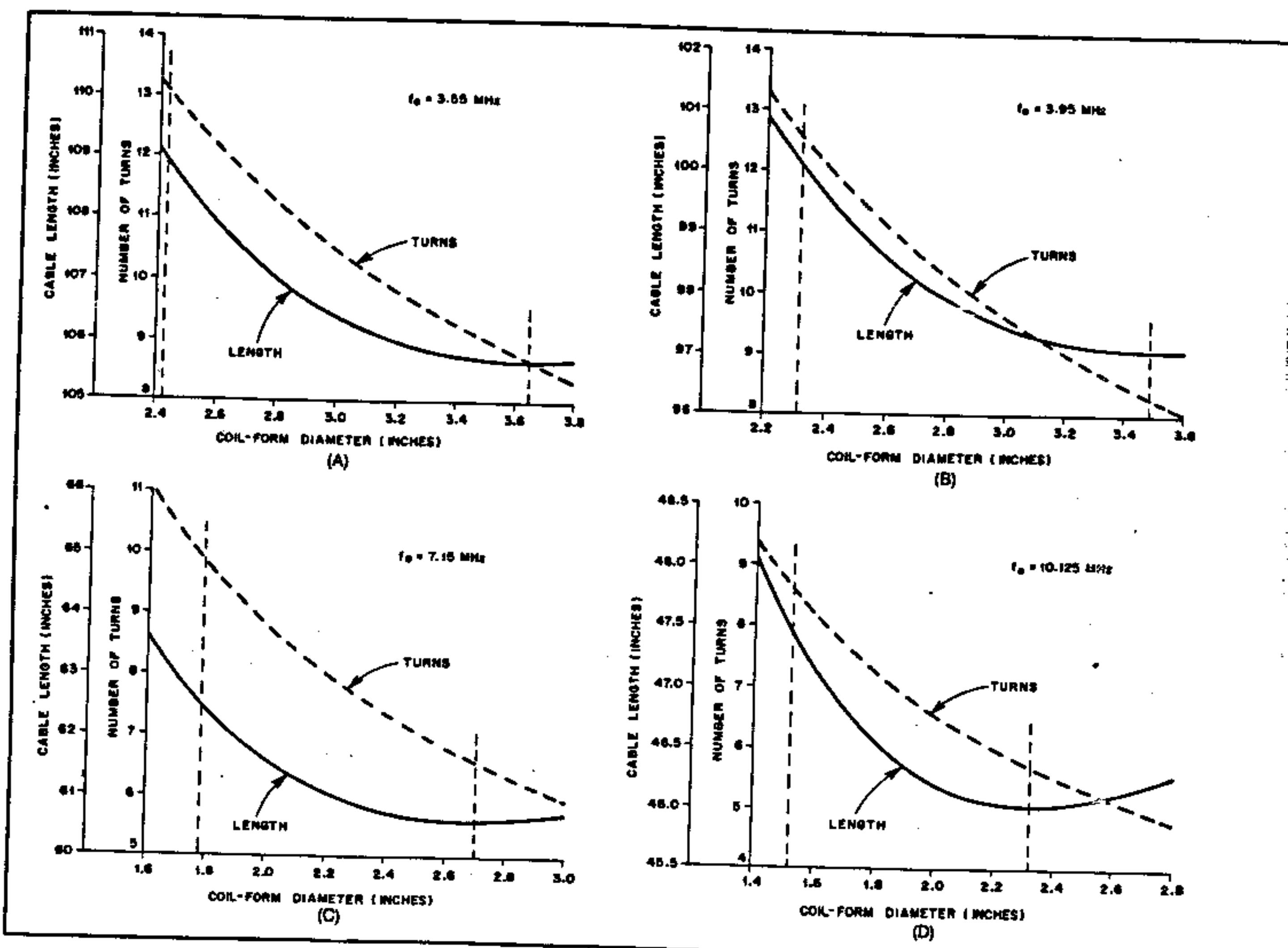


Table 2
Characteristics of Some Miniature Traps Using RG-174/U Coax

Resonant Band (meters)	*Coil Form Diameter (inches)*	*Number of Turns (n)*	*Total Weight (ounces)*
75	2.250	11.25	2.7
40	1.500	10.00	1.2
20	1.100	7.75	0.9
10	0.875	5.25	0.5

remains high enough to isolate or trap the outer sections of the antenna. Ignoring losses, it can be shown easily that the impedance of a parallel-resonant circuit can be expressed as

$$Z(f) = -j \frac{X_o}{(f/f_o) - (f_o/f)} \quad \text{(Eq. 6)}$$

where X_o is the reactance of each element (both C and L) at the resonant frequency, f_o; and f is the operating frequency. It can be seen that Z(f) is proportional to X_o. Consequently, a large value of X_o should provide a relatively large operational bandwidth.

The minimum length of cable is equivalent to the maximum X_o. The values for reactance shown in Table 1 are the values of X_o for coaxial cable traps. Based on these data, traps made from RG-174/U have a slightly greater *operational* bandwidth than those made with RG-58/U. In either case, the optimized traps will have the greatest operational bandwidth.

Construction Techniques

The construction technique described by Carter (illustrated in Fig. 1) provides lightweight traps when made with RG-174/U.[4] A "family" of traps for use in dipoles made by the author are shown on the first page of this article. Their characteristics are summarized in Table 2. Alternative configurations for dipole traps were described by DeMaw and by Johns, who also considers the construction of coaxial-cable traps for use in vertical and rotary-beam antennas. In all cases, the design charts and other data given in this article are applicable.

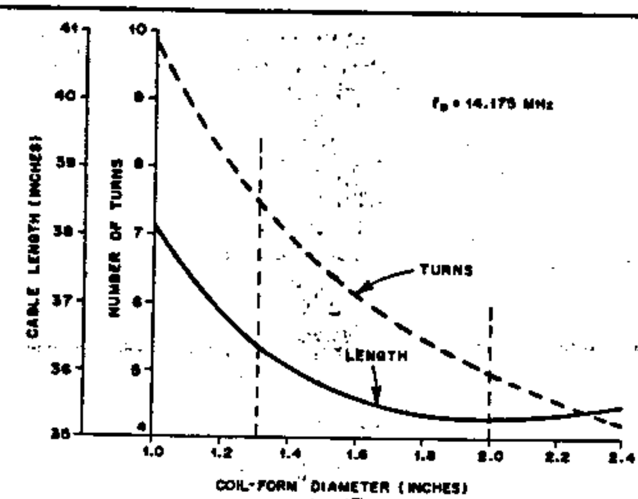
Power Ratings

Coaxial-cable antenna traps are able to operate at surprisingly high levels of power. An inverted-V antenna for operation on the 40/80/160-meter bands was constructed with miniature traps made with RG-174/U, similar to those shown on the first page of this article. There were no problems when operating at 1 kW average input power on 40 and 80 meters. Subsequent operation at 1.4 kW *output* power on 160-meter CW produced the complete failure of one of the 80-meter traps. This was caused by excessive heating, which brought about an internal short circuit between the inner and outer conductors of the coaxial cable. The remaining traps show signs of overheating, but did maintain their electrical integrity.

Based on this experience it appears that miniature coaxial-cable antenna traps made with RG-174/U can be used safely if the average power to the antenna is approximately 500 watts or less. For higher levels of power the larger traps made with RG-58/U should be employed.

Acknowledgments

I wish to acknowledge the assistance pro-



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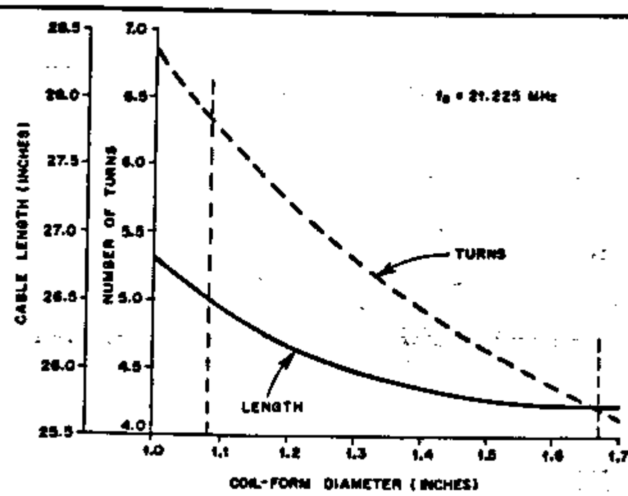

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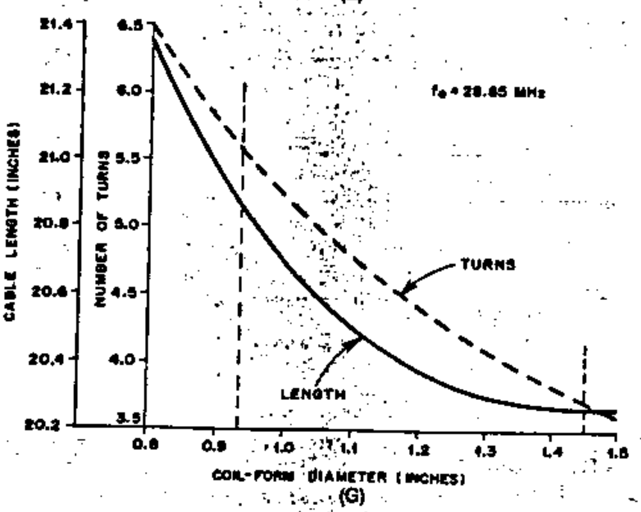

(G)

Fig. 4 — The same information provided in Fig. 3, but for traps made from RG-58/U coaxial cable. mm = in x 25.4.