NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-697

Simplified Cut Core Inductor Design

Colonel W. T. McLyman

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JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
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PREFACE

The work described in this report was performed by the Guidance and Control Division of the Jet Propulsion Laboratory.

ACKNOWLEDGMENT

The author wishes to express his thanks to Dr. G. W. Wester for support in gathering data and his technical aid.

CONTENTS

FIGURES

LIST OF SYMBOLS

Ac	effective iron area, cm^2
Aw	wire area, cm^2
AWG	American wire gauge
Bac	alternating current flux density, teslas
Bdc	direct current flux density, teslas
Bm	operating flux density, teslas
ΔI	alternating current, amps
E	voltage (RMS)
Eng.	energy, watt seconds
f	frequency, Hz
F	fringing flux factor
H	magnetizing force ampturns/cm, (1 amp turn/cm = 0.79 oersted)
I	current (RMS)
J	current density amps/cm^2
K	window utilization factor
L	inductance, henry
lg	gap, cm
lm	magnetic path, cm
m	meters
μm	core material permeability
μo	absolute permeability $(4\pi \times 10^{-7})$
μr	relative permeability
N	turns
Φ	flux, webers
Wa	window area
W_{LOSS}	core loss, watts

*Symbols marked with a prime (such as H') are mks (meter kilogram second) units.

ABSTRACT

Although filter inductor designers have routinely tended to specify molypermalloy powder cores for use in high frequency power converters and pulse-width modulated switching regulators, there are significant advantages in specifying C cores and cut toroids fabricated from grain oriented silicon steels which should not be overlooked. Such steel cores can develop flux densities of 1.6 tesla, with useful linearity to 1.2 tesla, whereas molypermalloy cores carrying d.c. current have useful flux density capabilities only to about 0.3 tesla. The use of silicon steel cores thus makes it possible to design more compact cores, and therefore inductors of reduced volume, or conversely to provide greater load capacity in inductors of a given volume.

The convenient availability in the literature of molypermalloy core manufacturers of tables, nomographs and examples which have simplified the designer's task for such cores, is now matched by the availability in this paper of information which makes it possible to obtain quick and close approximations of significant parameters such as size, weight and temperature rise for silicon steel cores for breadboarding. Graphs, nomographs and tables are presented for this purpose, but more complete mathematical derivations of some of the important parameters are also included for a more rigorous treatment.

I. INTRODUCTION

Designers have routinely tended to specify molypermalloy powder cores for filter inductors used in high frequency power converters and pulse-width modulated (PWM) switching regulators because of the convenient availability (in the literature of the manufacturers of such core materials) of tables, nomographs and examples which simplify the design task. Such solutions do not necessarily result in inductors optimized for size and weight.

There are significant advantages in effecting such optimizations by use of C cores and cut toroids fabricated from grain-oriented silicon steel, despite such disadvantages as the need for banding material and the use of banding tools, and the need for gapping material, mounting brackets and winding mandrels. Grain-oriented silicon steels provide greater flexibility in design of high frequency inductors because the air gap can be adjusted to any desired width and because the relative permeability is high even at high dc flux density. Such steels can develop flux densities of 1.6 tesla, with useful linearity to 1.2 tesla. Molypermalloy cores carrying dc current have useful flux density capabilities only to about 0.3 tesla.

As shown in Figure 1 (page 10) molypermalloy powder cores operating with a dc bias of 0.3 tesla, have only about 80% of original inductance with very rapid falloff at higher densities. In contrast, the steel core has approximately four times the useful flux density capability while retaining 90% of original inductance at 1.2 tesla.

II. FUNDAMENTAL CONSIDERATIONS

The design of a linear reactor depends upon three inter-related factors.

1. Desired inductance
2. Direct current
3. Alternating current ΔI

With the required inductance established, the designer must determine the maximum values for Bdc and for Bac which will not produce magnetic saturation, and must make tradeoffs which will yield the highest inductance for a given volume. The core material which is chosen dictates the maximum flux density which can be tolerated for a given design. Magnetic saturation values for different core materials is shown in Table 1, below.

Table 1. Magnetic Material

Material Type		Flux Density (tesla)
Magnesil	3% Si, 97% Fe	1.6
Orthonal	50% Ni, 50% Fe	1.5
48 Alloy	48% Ni, 50% Fe	1.2
Permalloy	79% Ni, 17% Fe, 4% Mo	0.75

It will be remembered that maximum flux density depends upon Bdc + Bac in the manner shown in Figure 2 (page 11). It may be calculated for the inductor of Figure 3, however as follows:

$$\text{Bmax} = \text{Bdc} + \text{Bac} \quad \text{tesla}$$

$$\text{Bdc} = \frac{0.4\pi \text{NIdc} \times 10^{-4}}{\text{lg} + \frac{\text{lm}}{\mu\text{r}}} \text{ tesla} \tag{1}$$

$$\text{Bac} = \frac{0.4\pi \text{N}\frac{\Delta \text{I}}{2} \times 10^{-4}}{\text{lg} + \frac{\text{lm}}{\mu\text{r}}} \text{ tesla} \tag{2}$$

Combining Eqs. (1) and (2)

$$\text{Bmax} = \frac{0.4\pi \text{NIdc} \times 10^{-4}}{\text{lg} + \frac{\text{lm}}{\mu\text{r}}} + \frac{0.4\pi \text{N}\frac{\Delta \text{I}}{2} \times 10^{-4}}{\text{lg} + \frac{\text{lm}}{\mu\text{r}}}$$

$$\text{Bmax} = \frac{0.4\pi \text{N}(\text{Idc} + \frac{\Delta \text{I}}{2}) \times 10^{-4}}{\text{lg} + \frac{\text{lm}}{\mu\text{r}}} \text{ tesla} \tag{3}$$

The inductance of an iron-core inductor carrying dc and having an air gap may be expressed as:

$$L = \frac{0.4 \pi N^2 Ac \times 10^{-8}}{lg + \frac{lm}{\mu r}} \text{ henry} \tag{4}$$

Inductance is dependent on the effective length of the magnetic path which is the sum of the air gap width (lg) and the ratio of core mean length to relative permeability (lm/μr).

When the core air gap (lg) is large compared to relative permeability (im/μr), because of the high relative permeability (μr) variations in μr do not substantially affect the total effective magnetic path length or the inductance. The inductance equation then reduces to:

$$L = \frac{0.4 \pi N^2 Ac \times 10^{-8}}{lg} \text{ henry} \tag{5}$$

Final determination of the air gap requires consideration of the effect of fringing flux which is a function of gap dimension, the shape of the pole faces and the shape, size and location of the winding. Its net effect is to shorten the air gap.

Fringing flux decreases the total reluctance of the magnetic path and therefore increases the inductance to a value greater than that calculated from equation (5). Fringing flux is a larger percentage of the total for larger gaps. The increase of inductance due to fringing is

$$\frac{L'}{L} = \left(1 + \frac{lg}{\sqrt{Ac}} \log \epsilon \frac{2G}{lg}\right) \tag{6}$$

Equation (6) is plotted in Figure 3 (page 12). Because of fringing flux the inductance equation becomes:

$$L = \frac{0.4\pi N^2 AcF \times 10^{-8}}{lg} \text{ henry}$$

$$F = \frac{L'}{L} \quad (7)$$

Relative permeability may be calculated from the following expression:

$$\mu r = \frac{\mu m}{1 + \mu m \; lg/lm} \quad (8)$$

μm = core material permeability

Curves which have been plotted for values of lg/lm from 0 to 0.005, are shown in Figure 4 (page 13). The relative design permeability performance in a butt core joint structure for material permeabilities ranging from 100 to 1,000,000, are shown. Relative permeability variation as a function of core geometry is shown in the curves plotted in Figure 5 (page 14).

After establishing the required inductance and the dc bias current which will be encountered, core dimensions can be determined. This requires consideration of the energy handling capability which is controlled by the WaAc product of the available core window area Wa in cm^2 and the effective cross sectional area Ac of the core in cm^2. The energy handling capability of a core is derived from

$$\frac{LI^2}{2} = \text{Energy} \quad (9)$$

and

$$WaAc = \frac{2(Eng)}{Bm\ J\ K} \times 10^4 = cm^4 \quad (10)^*$$

*Derivation of equation (10) is shown in Appendix A.

in which: Bm = maximum flux density Bdc + Bac

(The ac flux density is usually very low, being on the order of 0.05 tesla.)

J = current density amps/cm^2

(A current density of 200 amp/cm^2 corresponds to 1000 cir. mil/amp.)

K = window utilization factor*

III. DESIGN EXAMPLE

For a typical design example, assume:

I. Inductance 0.015 henrys

II. dc current 2 amp.

III. ac current ΔI 0.1 amp

1. J = 400 amp/cm^2
2. Bm = 1.6 tesla
3. K = 0.4
4. f = 20KH_z

The order of procedure would then be as follows:

Step No. 1 — Calculate the energy involved from equation (9):

$$Eng = LI^2/2$$

$$Eng = 0.015\,(2.0)^2/2$$

$$Eng = 0.030 \text{ watt second}$$

Step No. 2 — Calculate the Wa Ac product from equation (10):

$$WaAc = \frac{2(Eng) \times 10^4}{Bm\,J\,K}\,cm^4$$

$$WaAc = \frac{2(0.030) \times 10^4}{(1.6)\,(400)\,(0.4)} = \frac{600}{256} = 2.34\ cm^4$$

---

*Derivation of the window utilization factor is shown in Appendix B.

A core which has a product area closest to the calculated value is the size AL-8 which is described in Table 10 (page 46). That size core has a WaAc product of 2.61 cm^4 (Ac = 0.807 effective cm^2 x Wa = 2.871 cm^2). (It should be remembered that the practical winding area of a bobbin is about 75% of the available Wa window area.)

Step No. 3 — Determine the wire size from:

$$\text{Wire size} = \frac{\text{Idc}}{\text{amp./cm}^2}$$

$$\text{Wire size} = \frac{2}{400} = 0.005\ \text{cm}^2\ \text{bare}$$

Select the wire size from Table 2 (page 21) as follows

wire size = 0.005 cm^2

AWG No. 20

0.005188 cm^2 bare

Step No. 4 — Calculate the number of turns

$$\text{Number of turns/cm}^2 = \frac{1}{\#20/\text{cm}^2} \times \text{K (fill factor)}$$

$$\text{Number of turns/cm}^2 = \frac{1}{0.005188} \times 0.40 = 77.10$$

Total number of turns = Wa x 77.10 = 221*

*The bobbin of a test specimen prepared in connection with this example was fully wound with 236 turns.

Step No. 5 — The air gap dimension is determined from equation (5) by solving for lg as follows:

$$lg = \frac{0.4\pi N^2 Ac \times 10^{-8}}{L}$$

$$lg = \frac{1.26\ (236)^2 (0.807) \times 10^{-8}}{(0.015)}$$

$$lg = 0.0377 \text{ cm}$$

Gap spacing is usually maintained by inserting Kraft paper. However this paper is available only in mil thicknesses. Since lg has been determined in cm, it is necessary to convert as follows:

$$\text{cm} \times 0.3937 = \text{mils (inch system)}$$

substituting values: $0.0377 \times 0.3937 = 0.0148$ inch

An available size of paper is the 7 mil sheet. Two thicknesses would therefore be used.

The effect of fringing flux* upon inductance can now be considered. As mentioned, the data shown in Figure 3 (page 12) was developed to show graphically the effect of gap length lg variation on fringing flux. In order to use this data, the ratio of lg to window length G must be determined. For the AL-8 size, Table 10 (page 46) shows a G value of 3.015 cm. Therefore:

$$\frac{lg}{G} = \frac{0.0377}{3.015} = 0.0125$$

and accordingly

$$\frac{G}{\sqrt{Ac}} = \frac{3.015}{0.898} = 3.36$$

The fringing flux factor F may be stated:

$$F = \frac{L'}{L} = 1.1$$

*Table 3 was developed to show how various gap lengths influence the fringing flux.

The recalculated number of turns can be determined by rewriting equation 7 as:

$$N = \sqrt{\frac{lg\ L}{0.4\pi AcF \times 10^{-8}}}$$

and by inserting the known values:

$$N = \sqrt{\frac{(0.0377)(0.015)}{(1.26)(0.807)(1.1) \times 10^{-8}}} = 225 \text{ turns}$$

(In a test sample made to prove out this example, the measured inductance was found to be 0.015 hy).

Step No. 6 — Calculate the ac and dc flux density from equation (3)

$$Bmax = \frac{0.4\pi N(Idc + \frac{\Delta I}{2}) \times 10^{-4}}{lg}$$

$$Bmax = \frac{(1.26)(225)(2 + 0.05) \times 10^{-4}}{(0.0377)}$$

$$Bmax = 1.53 \text{ tesla}$$

Step No. 7 — Calculate core loss. This may be determined from Figure 6 (page 15) in conjunction with equation (11), below:

$$Bac = \frac{0.4\pi N\frac{\Delta I}{2} \times 10^{-4}}{lg} \text{ tesla} \qquad (11)$$

Inserting values:

$$Bac = \frac{1.26(225)(0.05)10^{-4}}{(0.0377)} \text{ tesla}$$

$$Bac = 0.0374 \text{ tesla}$$

The ac core loss for this value can be found by reference to the nomograph shown in Figure 6 (page 15)* which is based upon solutions of the following expression for various operating frequencies:

$$W_{LOSS} = \frac{WATTS}{Kgm} \times W_t \times 10^{-3}$$

*Curves for core losses for other cores such as 4 mil silicon and 2 mil 50-50 nickel iron are shown in Figures 7 and 8 (pages 16 and 17).

W_t, the core weight, for the AL-8 size core is given in Table 10 (page 46) as 59.3 grams. Hence:

$$W_{LOSS} = 6 \times 59.3 \times 10^{-3} = 0.355 \text{ Watts}$$

Having executed the foregoing steps, the designer can quickly determine the size and weight of the fully wound inductor from the nomographs in Figure 9 (page 18), which compares $LI^2/2$ with Wa Ac, and in Figure 10A (page 19), which compares $LI^2/2$ with weight. These nomographs have been generated from the expression:

$$\text{Wa Ac} = \frac{2(\text{Eng}) \times 10^4}{\text{Bm J K}}$$

but are subject to the constraints:

$$\text{Bm} = 1.6\text{T}$$
$$\text{J} = 200 \text{ A/Cm}^2$$
$$\text{K} = 0.4$$

The nomograph in Figure 10B was generated from the Forty "C" core in this article to show how the weight increases with the Wa Ac product.

After core size has been determined approximately, it may be desirable to reshuffle the constraints somewhat in order to match the parameters of commercially available cores.

This completes the explanation of the example.

Much useful information which the designer needs can only be found in a scattered variety of texts and other literature. To make this information more conveniently available, helpful data has been gathered together and reproduced on the pages following those devoted to the example and its explanation (Tables 2-44, Figs. 1 - 58). The index has been prepared to make it possible for the designer to locate specific pertinent information more readily.

MOLYPERNALLOY POWDER CORES

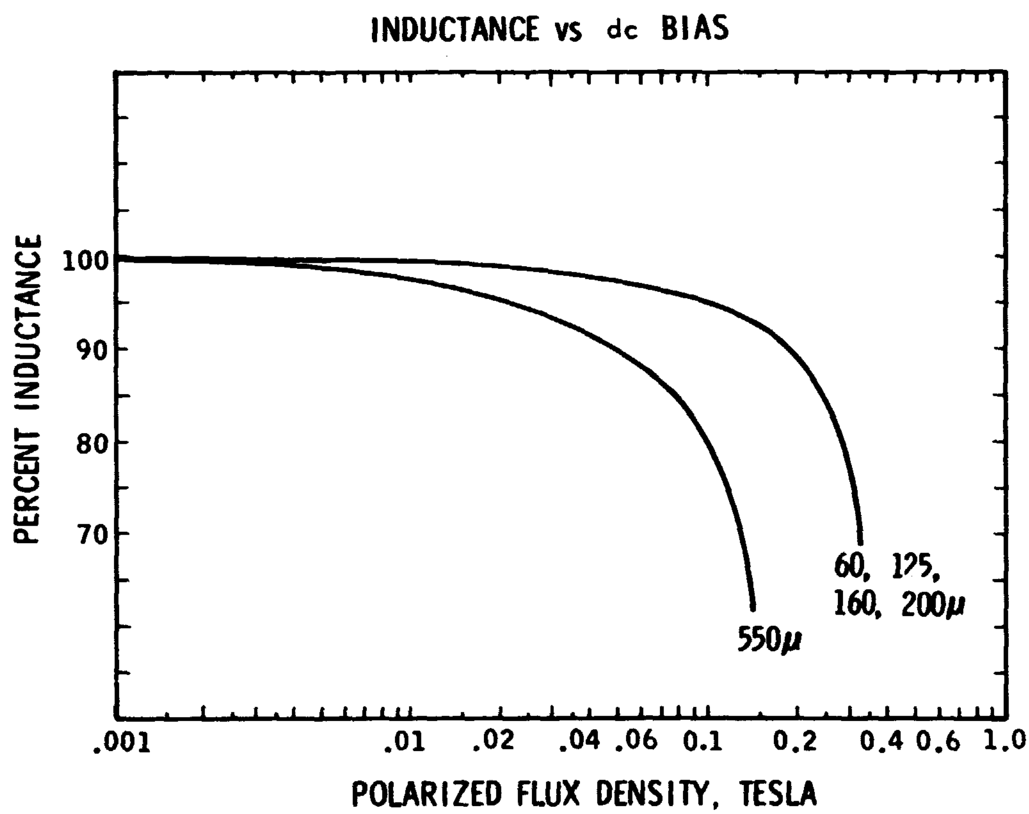


Figure 1. Inductance vs dc bias

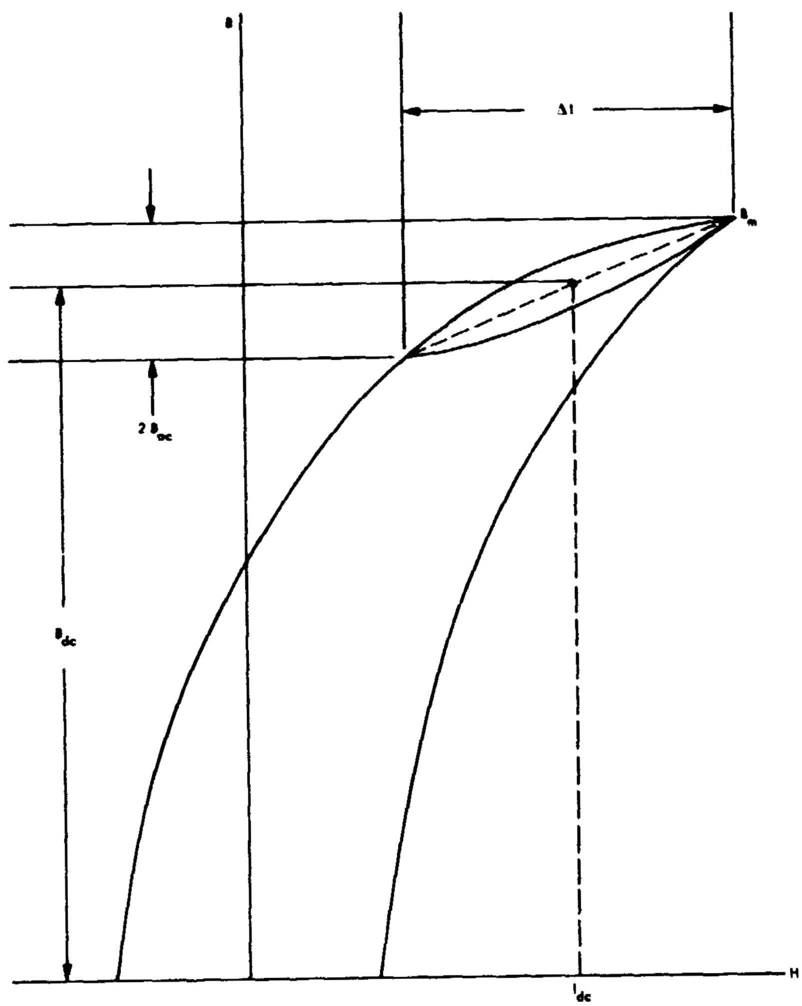


Figure 2. Flux Density Versus Idc + ΔI

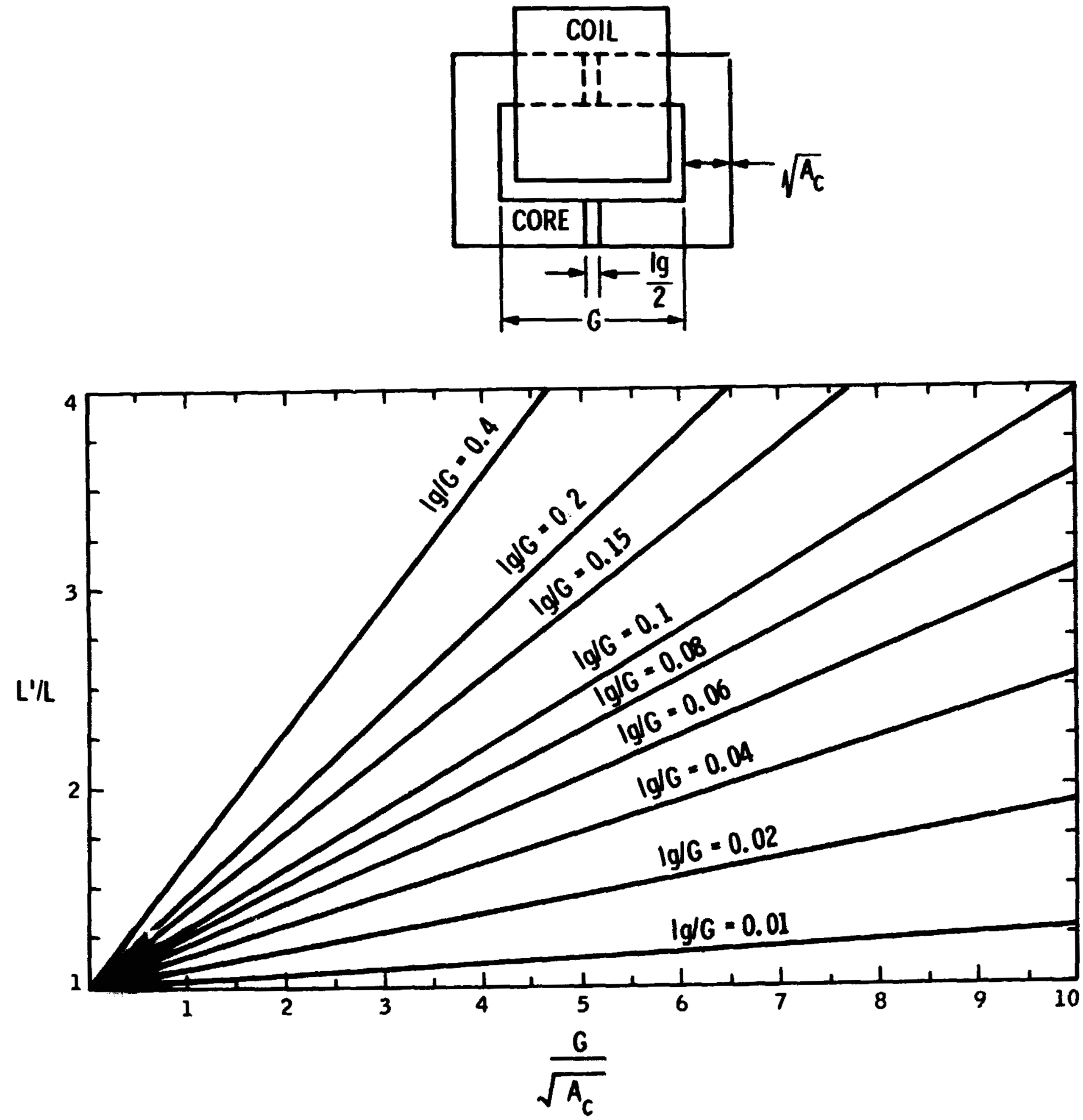


Figure 3. Increase of reactor inductance with flux fringing at the gap.

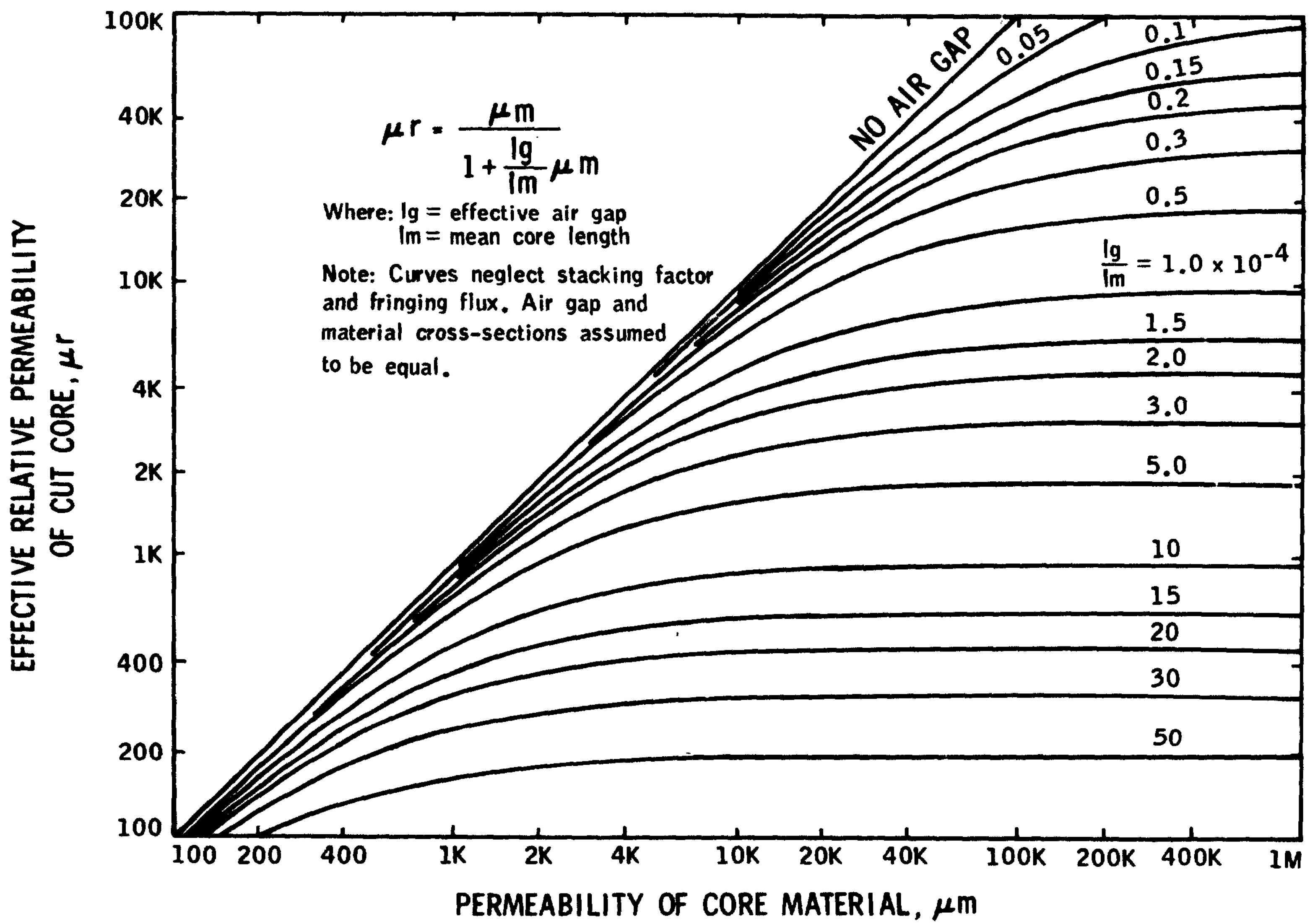


Figure 4. Effective Permeability of Cut Core vs Permeability of the Material

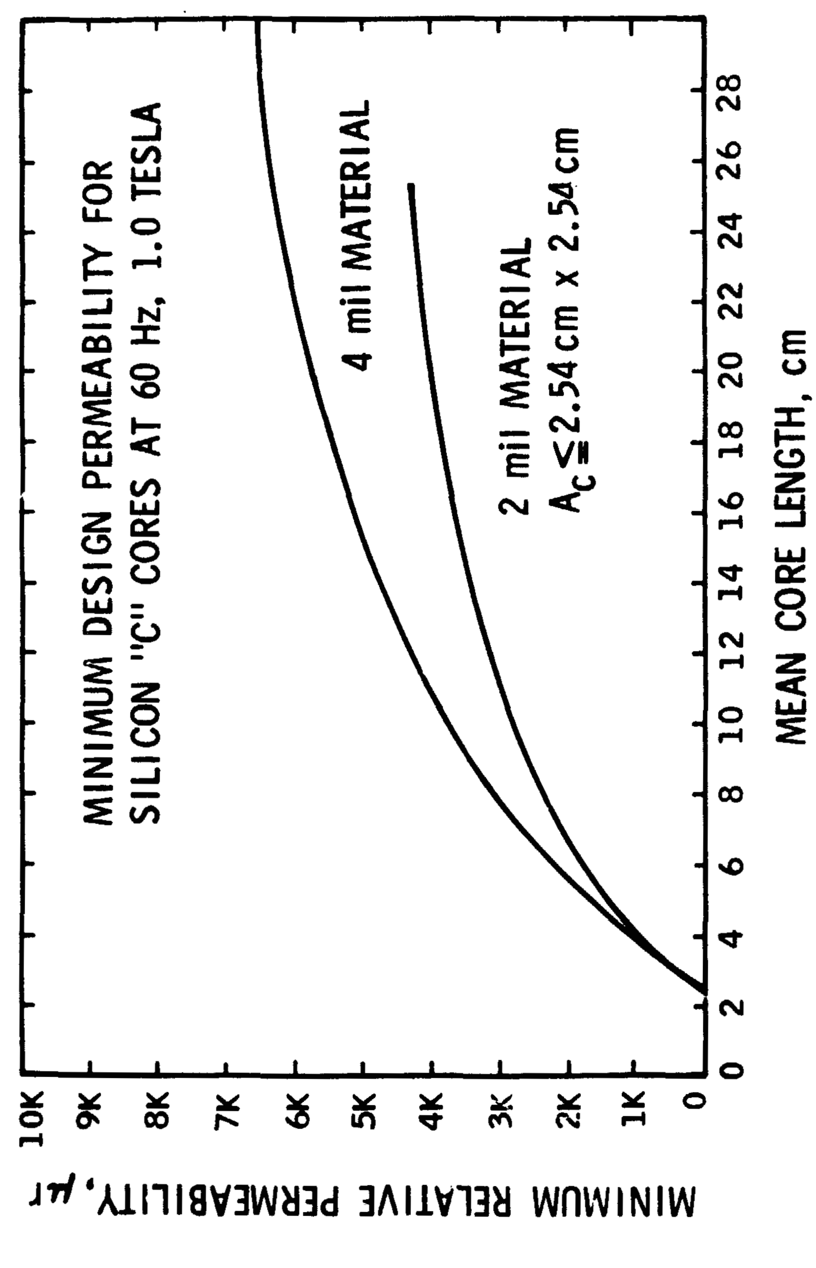


Figure 5. Minimum Design Permeability

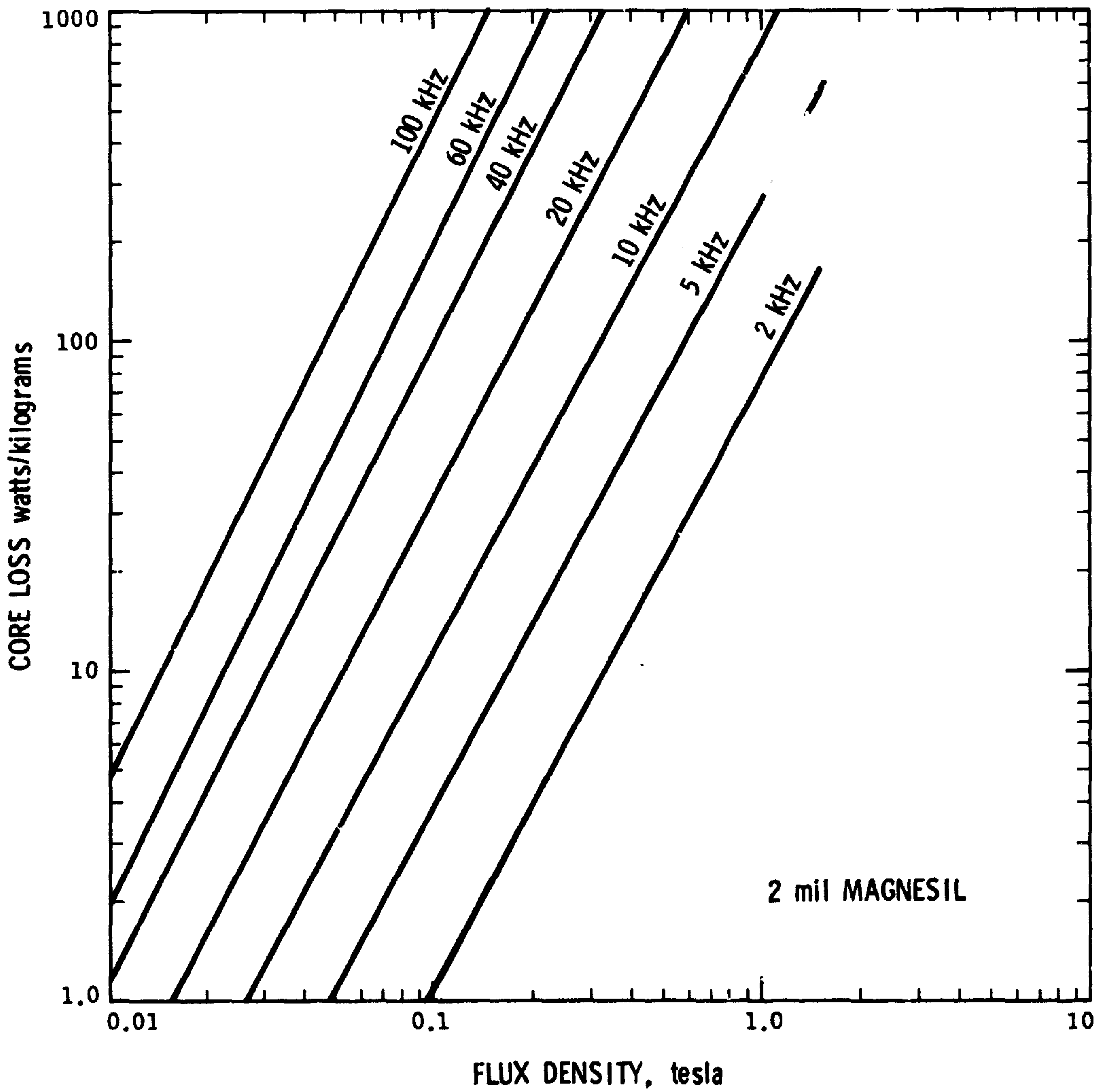


Figure 6. Design Curves Showing Maximum Core Loss for 2 mil Silicon "C" Cores

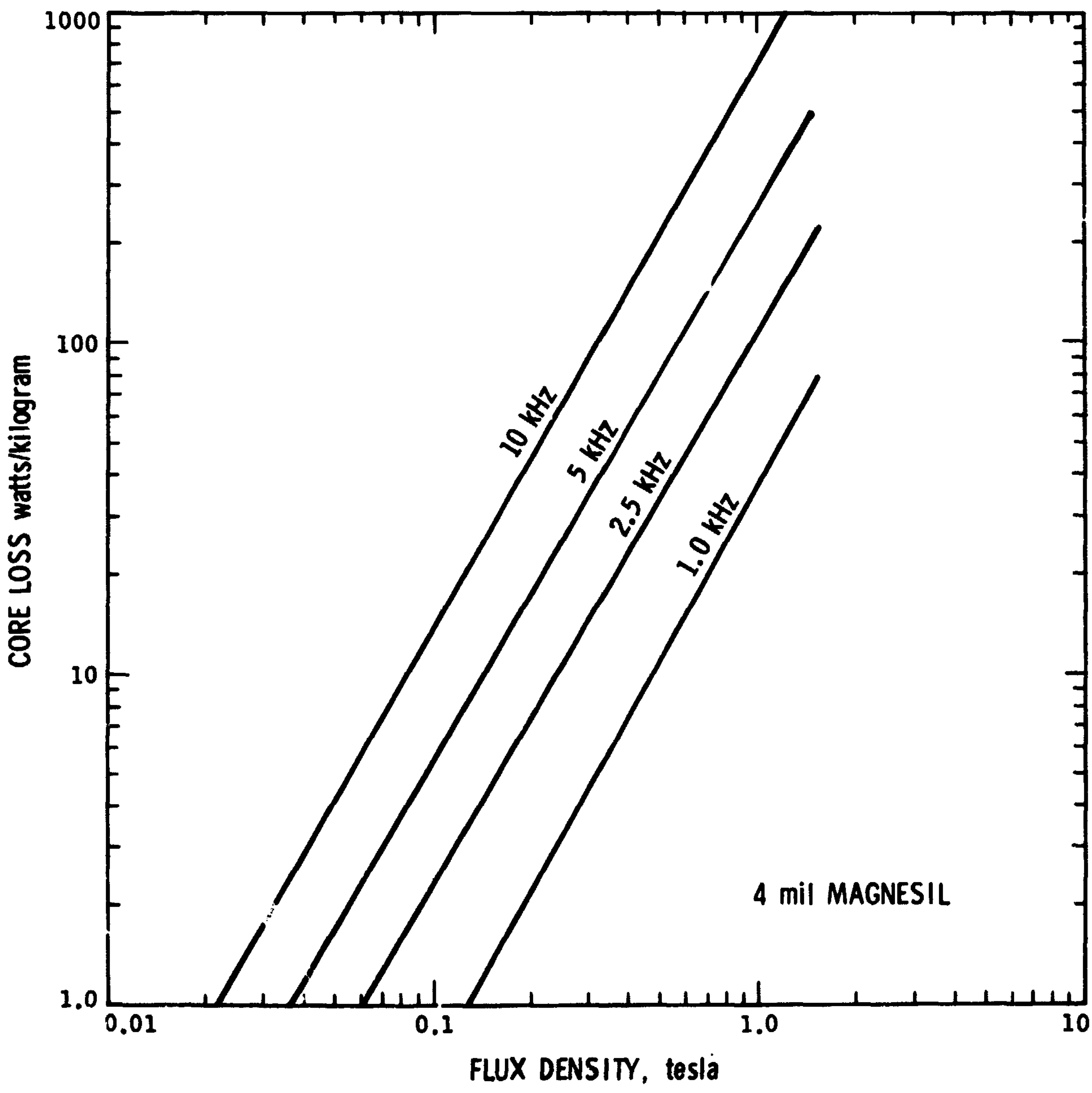


Figure 7. Design Curves Showing Maximum Core Loss for 4 mil Silicon "C" Cores

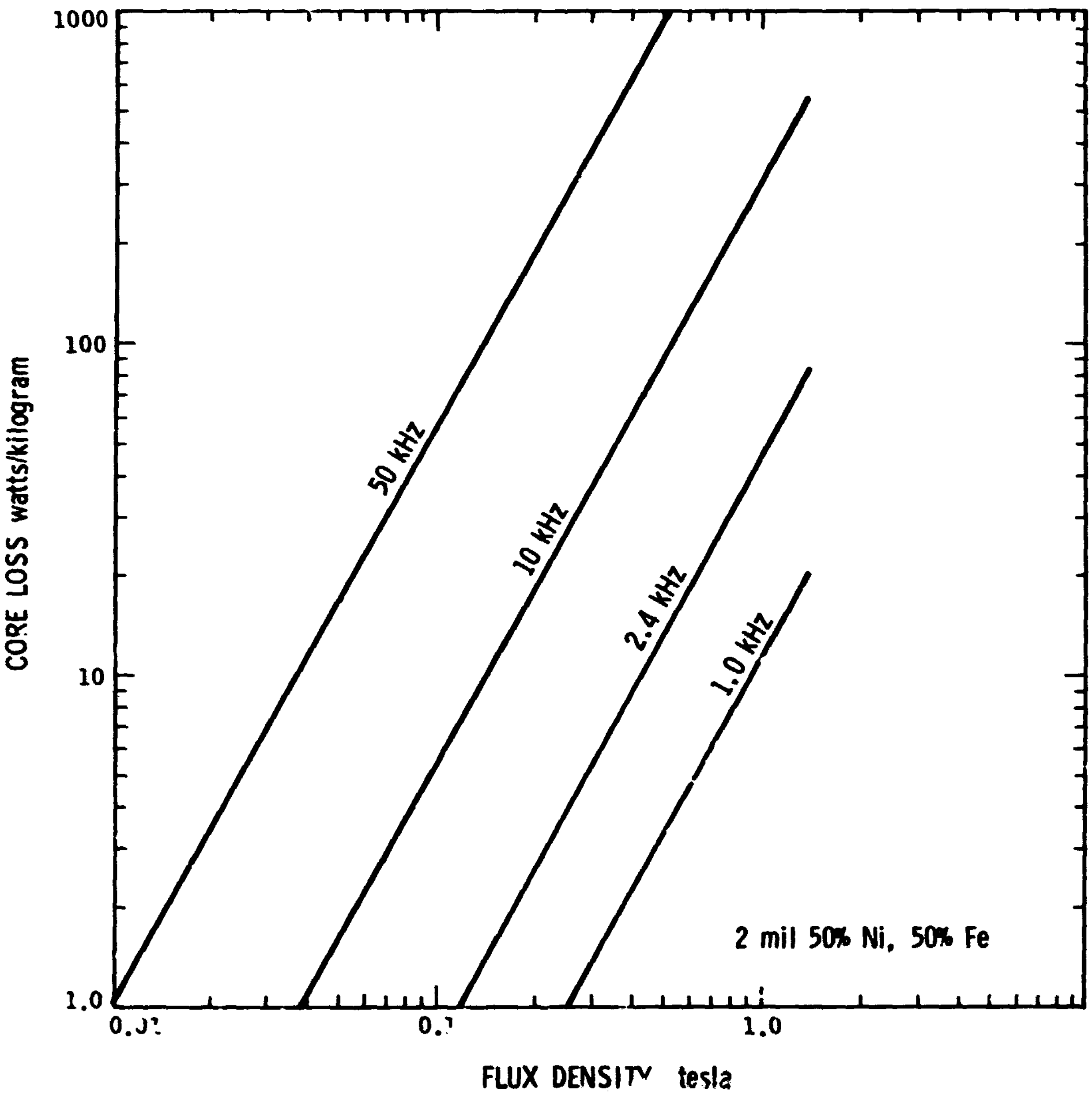


Figure 8. Design Curves Showing Maximum Core Loss for 2 mil 50-50 Ni-Fe

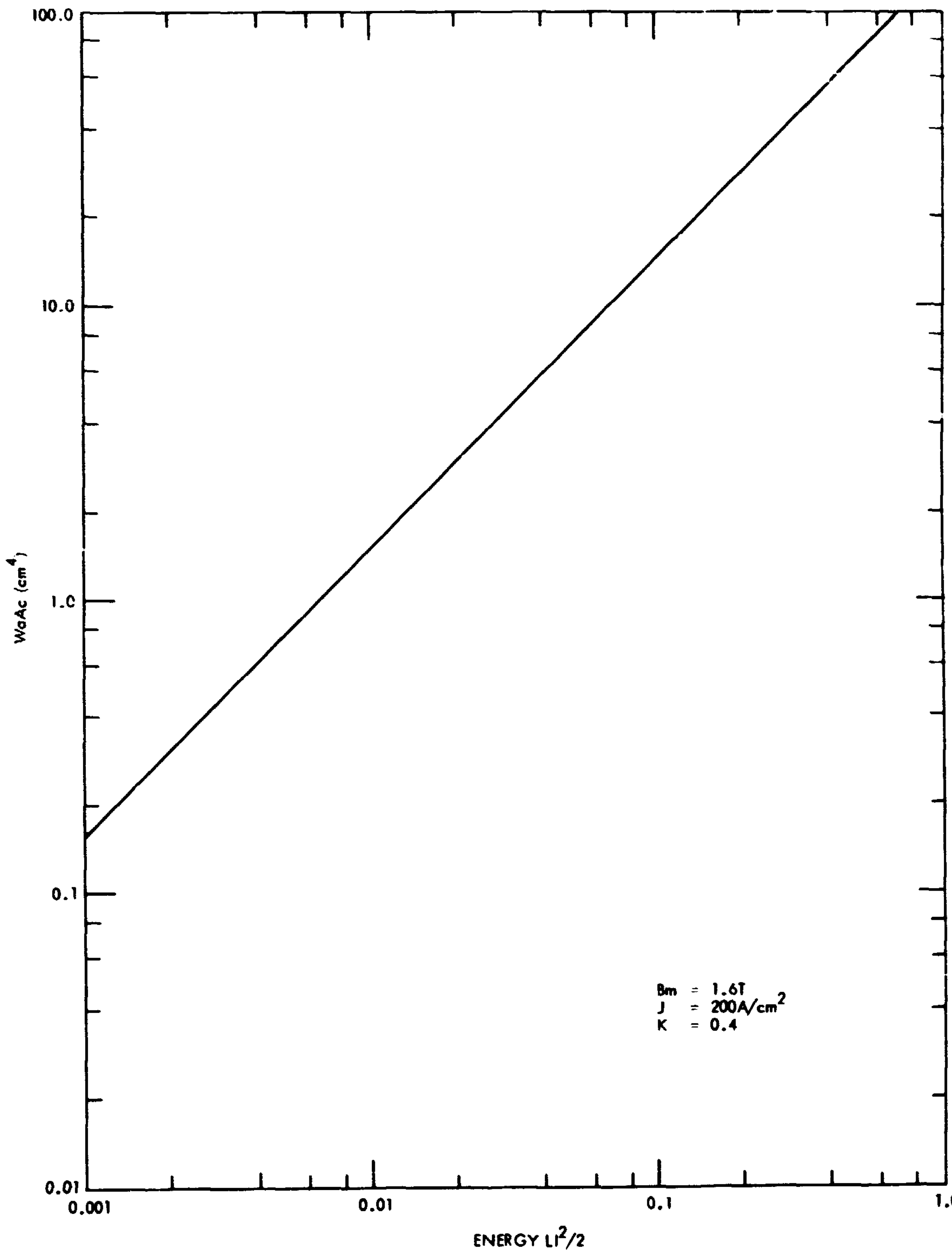


Fig. 9 . WaAc Product Versus Energy $LI^2/2$

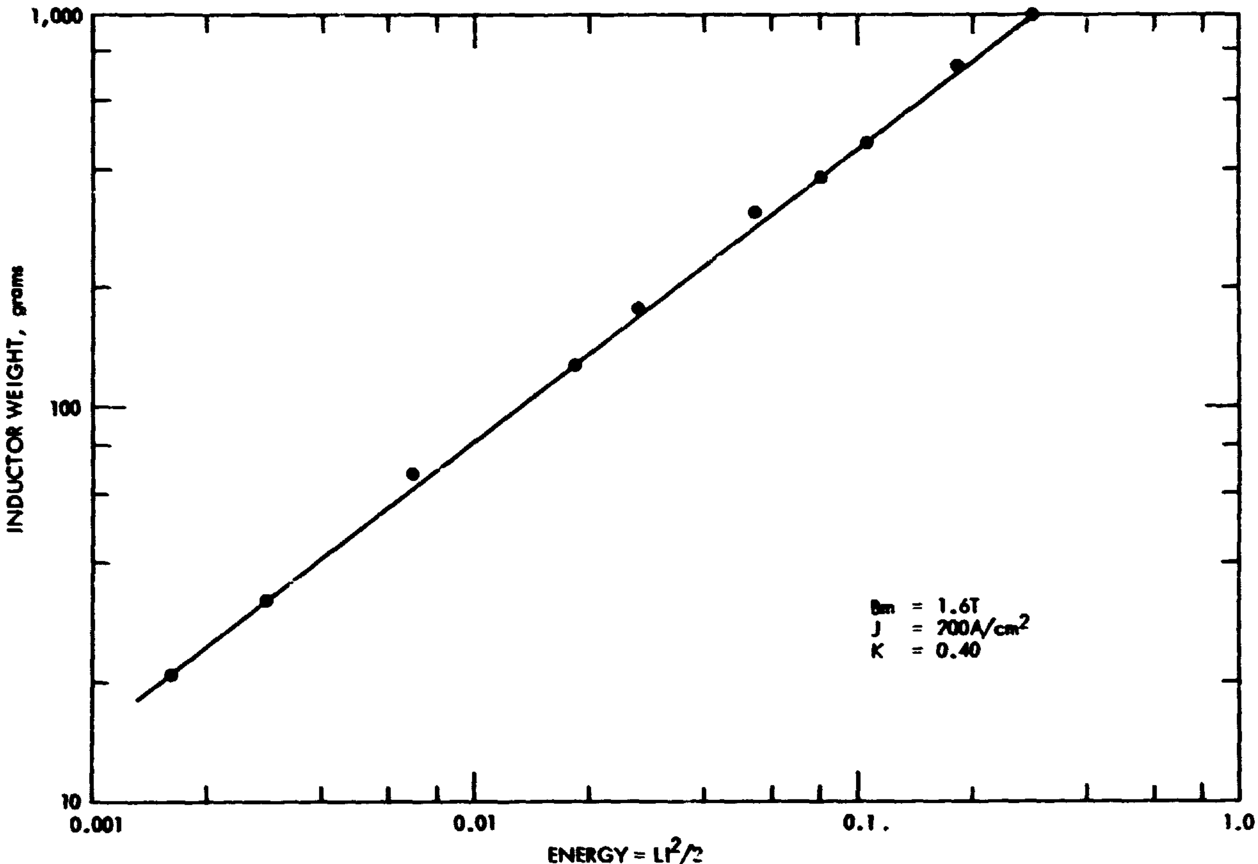


Fig. 10A. Inductor Weight Versus Energy $LI^2/2$

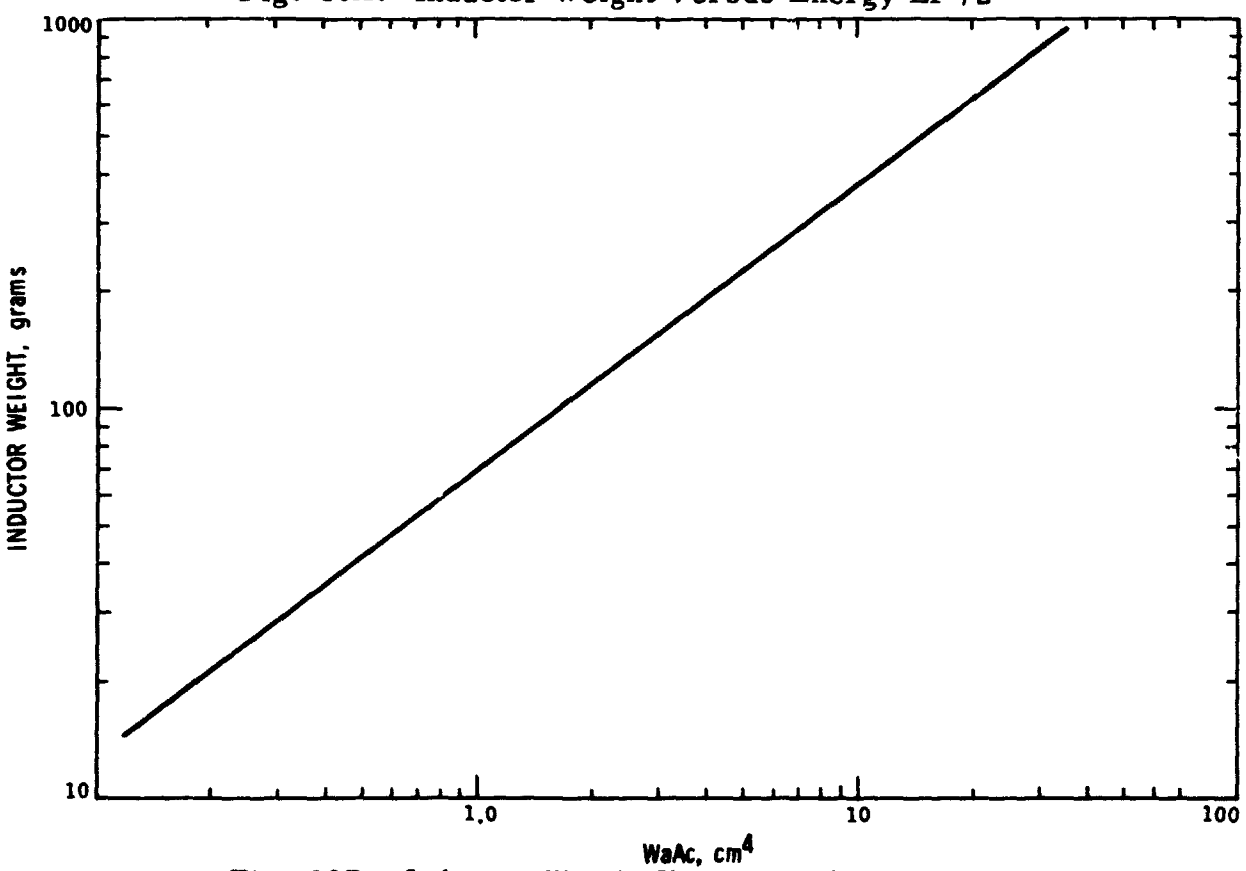


Fig. 10B. Inductor Weight Versus WaAc product

CONVERSION DATA FOR WIRE SIZES FROM #10 to #44

Columns A and B in Table 2 give the bare area in the commonly used circular mils notation and in the metric equivalent for each wire size. Column C gives the equivalent resistance in microhms/centimeter ($\mu\Omega$/cm or $10^{-6}\Omega$/cm.). Columns D to L relate to coated wires showing the effect of insulation on size and the number of turns and the total weight in grams/centimeter.

The total resistance for a given winding may be calculated by multiplying the MLT (mean length/turn) of the winding in centimeters, by the microhms/cm for the appropriate wire size, and the total number of turns. Thus

$$R = (MLT) \cdot \left(\frac{\mu\Omega}{cm}\right) \cdot (N)$$

The weight of the copper in a given winding may be calculated by multiplying the MLT by the grams/cm (column M) and by the total number of turns. Thus

$$wt = (MLT) \cdot \left(\frac{gm}{cm}\right) \cdot (N)$$

Turn per square inch and turns per square cm are based on 60% wire fill factor.

Table 2. Wire Table

Awg Wire Size	Bare Area: $cm^2 10^{-3}$ (footnote b)	Bare Area: CIR-MIL[a]	Resistance: $\frac{10^{-6}\,\Omega}{cm\ at\ 20°C}$	Heavy Synthetics Area: $cm^2 10^{-3}$	Heavy Synthetics Area: CIR-MIL[a]	Diameter: cm	Diameter: Inch[a]	Turns-Per: cm	Turns-Per: Inch[a]	Turns-Per: cm^2	Turns-Per: $Inch^2$	Weight: gr/cm
10	52.61	10384	32.70	55.9	11046	0.267	0.1051	3.87	9.5	10.73	69.20	0.468
11	41.68	8226	41.37	44.5	8798	0.238	0.0938	4.16	10.7	13.48	89.95	0.3750
12	33.08	6529	52.09	35.64	7022	0.213	0.0838	4.85	11.9	16.81	108.4	0.2977
13	26.26	5184	65.64	28.36	5610	0.190	0.0749	5.47	13.4	21.15	136.4	0.2367
14	20.82	4109	82.80	22.95	4556	0.171	0.0675	6.04	14.8	26.14	168.6	0.1874
15	16.51	3260	104.3	18.37	3624	0.153	0.0602	6.77	[illegible]	32.66	210.6	0.1442
16	13.07	2581	131.8	14.73	2905	0.137	0.0539	7.32	18.6	40.73	262.7	0.1154
17	10.39	2052	165.8	11.68	2323	0.122	0.0482	8.18	20.8	51.36	331.2	0.0943
18	8.228	1624	209.5	9.326	1857	0.109	0.0431	9.13	23.2	64.33	414.9	0.07472
19	6.531	1289	263.9	7.539	1490	0.0980	0.0386	10.19	25.9	79.85	515.2	0.05940
20	5.188	1024	332.3	6.065	1197	0.0879	0.0346	11.37	28.9	98.93	638.1	0.04726
21	4.116	812.3	418.9	4.837	954.8	0.0785	0.0309	12.75	32.4	124.0	799.8	0.03757
22	3.243	640.1	531.4	3.857	761.7	0.0701	0.0276	14.25	36.2	155.5	1003	0.02965
23	2.588	510.8	666.0	3.135	620.0	0.0632	0.0249	15.82	40.2	191.3	1234	0.02372
24	2.047	404.0	842.1	2.514	497.3	0.0566	0.0223	17.63	44.8	238.6	1539	0.01884
25	1.623	320.4	1062.0	2.002	396.0	0.0505	0.0199	19.80	50.3	299.7	1933	0.01498
26	1.280	252.8	1345.0	1.603	316.8	0.0452	0.0178	22.12	56.2	374.2	2414	0.01185
27	1.021	201.6	1687.6	1.313	259.2	0.0409	0.0161	24.44	62.1	456.9	2947	0.00945
28	0.8046	158.8	2142.7	1.0515	207.3	0.0366	0.0144	27.32	69.4	570.6	3680	0.00747
29	0.6470	127.7	2664.3	0.8548	169.0	0.0330	0.0130	30.27	76.9	701.9	4527	0.00602
30	0.5067	100.0	3402.2	0.6785	134.5	0.0294	0.0116	33.93	86.2	884.3	5703	0.00472
31	0.4013	79.21	4294.6	0.5596	110.2	0.0267	0.0105	37.48	95.2	1072	6914	0.00372
32	0.3242	64.00	5314.9	0.4559	90.25	0.0241	0.0095	41.45	105.3	1316	8488	0.00305
33	0.2554	50.41	6748.6	0.3662	72.25	0.0216	0.0085	46.33	117.7	1638	10565	0.00241
34	0.2011	39.69	8572.8	0.2863	56.25	0.0191	0.0075	52.48	133.3	2095	13512	0.00189
35	0.1589	31.36	10849	0.2268	44.89	0.0170	0.0067	58.77	149.3	2645	17060	0.00150
36	0.1266	25.00	13608	0.1813	36.00	0.0152	0.0060	65.62	166.7	3309	21343	0.00119
37	0.1026	20.25	16801	0.1538	30.25	0.0140	0.0055	71.57	181.8	3901	25161	0.000977
38	0.08107	16.00	21266	0.1207	24.01	0.0124	0.0049	80.35	204.1	4971	32062	0.000773
39	0.06207	12.25	27775	0.0932	18.49	0.0109	0.0043	91.57	232.6	6437	41518	0.000593
40	0.04869	9.61	35400	0.0723	14.44	0.0096	0.0038	103.6	263.2	8298	53522	0.000464
41	0.03972	7.84	43405	0.0584	11.56	0.00863	0.0034	115.7	294.1	10273	66210	0.000379
42	0.03166	6.25	54429	0.04558	9.00	0.00762	0.0030	131.2	333.3	13163	84901	0.000299
43	0.02452	4.84	70308	0.03683	7.29	0.00685	0.0027	145.8	370.4	16291	105076	0.000233
44	0.0202	4.00	85072	0.03165	6.25	0.00635	0.0025	157.4	400.0	18957	122272	0.000195
	A	B	C	D	E	F	G	H	I	J	K	L

[a] This data from REA Magnetic Wire Datalator (Ref. 1).

[b] This notation means the entry in the column must be multiplied by 10^{-3}.

TEMPERATURE CORRECTION FACTORS

The values shown in Fig. 11 are based upon a correction factor of 1.0 at 20°C. For other temperatures the effect upon wire resistance can be calculated by multiplying the resistance value for the wire size shown in column C of Table 2 by the appropriate correction factor shown on the graph. Thus, Corrected Resistance = $\mu\Omega$/cm (at 20°C) $\times \zeta$.

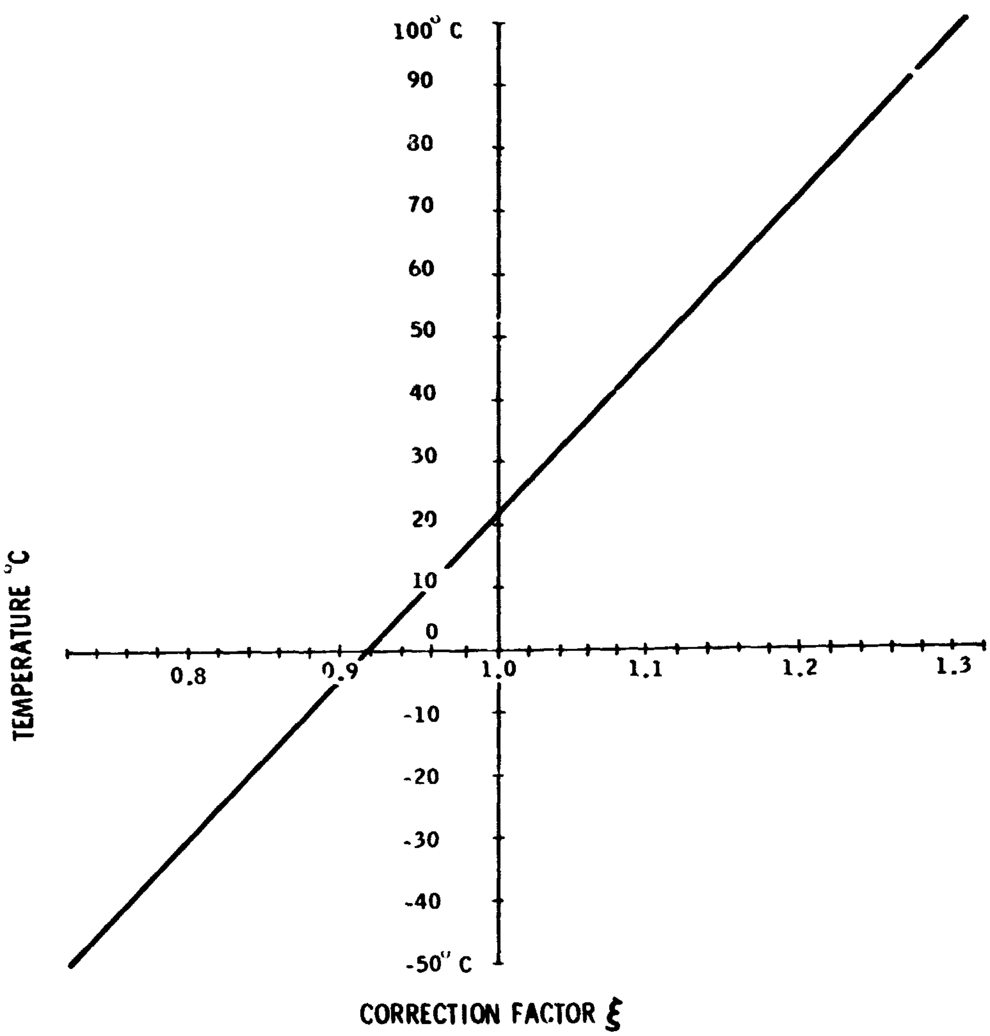


Fig. 11. Resistance Correction Factor (ζ, Zeta) for wire temperature between -50° and 100°C

Table 3. Calculated and measured inductance using various gap lengths.

Core	Ac (cm^2)	lm (cm)	N	lg (cm)	$G/\sqrt{Ac}$	L mh Calculate	L′ mh Measured	$F = \frac{L'}{L}$	lg/G
AL-8	0.806	10.66	236	0.0508	3.36	11.1	11.8	1.06	0.0168
AL 3	0.806	10.66	236	0.305	3.36	1.855	3.5	1.89	0.10
AL-124	0.716	8.4	76	0.101	3.00	0.473	0.673	1.42	0.04
AL-124	0.716	8.4	76	0.305	3.00	0.170	0.320	1.88	0.12
AL-18	1.257	14.34	320	0.457	3.502	3.54	6.63	1.87	0.116
AL-18	1.257	14.34	320	1.067	3.502	1.51	4.54	3.00	0.272
AL-22	3.58	17.2	74	0.711	2.598	0.347	0.665	1.92	0.144
AL-22	3.58	17.2	74	0.203	2.598	1.216	1.740	1.43	0.04

TEMPERATURE RISE VERSUS SURFACE AREA DISSIPATION DUE TO POWER LOSS, Figure 12

Power loss (core loss + winding loss) in the inductors produces a temperature rise which must be controlled to prevent damage or failure. Heat is dissipated from the inductor surfaces by a combination of radiation and convection and is dependent upon total exposed surface area. Dissipation is expressed in watts per square centimeter of surface area.

Temperature rise cannot be predicted with complete precision. Many different techniques are described in the literature for the computation temperature rise.

A method for temperature rise computation used by inductor designers is reasonably accurate for open core and coil construction. It is based on the assumptions that core and coil losses are lumped together and that this energy is dissipated through the concumferential area of the coil and core.

The nomograph of Fig. 12 (data obtained from Ref. 4) shows temperature rise versus power loss (core loss + copper loss) expressed in watts per square centimeter of surface area with heat transfer by combined radiation and convection.

The nomograph is based on heat transfer from a vertical surface by 45 percent convection and 55 percent radiation with an emissivity of 0.95 in a 25°C room at sea level. The heat loss from the upper side of a flat horizontal surface by convection is on the order of 15 to 20 percent more than than from the vertical surface. On the under side the heat loss depends on the area and conductivity of the surface.

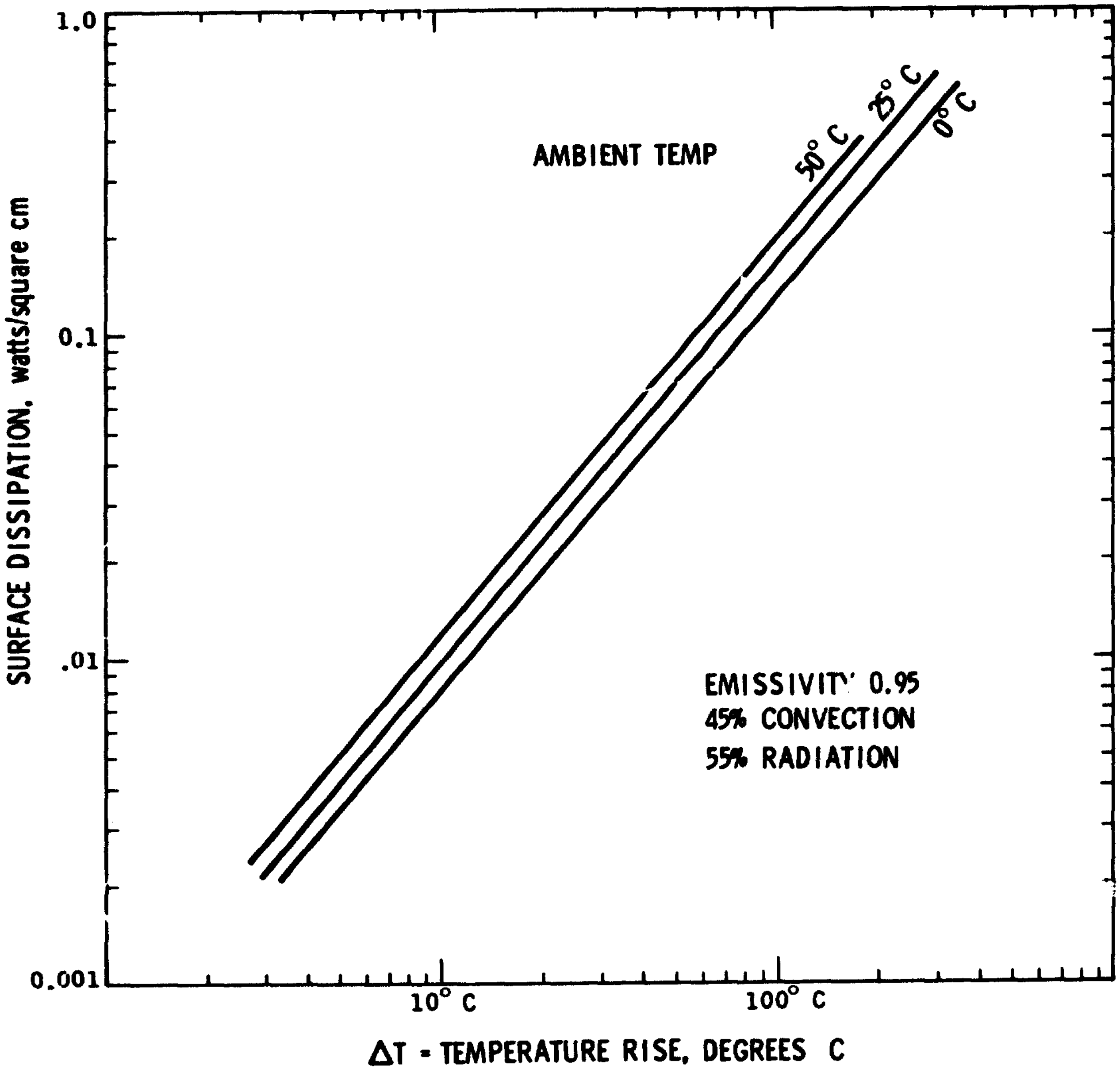


Fig. 12. Temperature Rise Versus Surface Dissipation

MAXIMUM PERMISSIBLE CURRENT DENSITY FOR A 25°C AND 50°C RISE

The curves shown in Fig. 13A is based upon a maximum permissible temperature of 25°C, with a surface dissipation of 0.03 watts/cm^2 and a 50°C rise with a surface dissipation of 0.07 watts/cm^2. The data is based upon an assumption that all the losses are copper. The surface areas have been calculated and are listed as A_t in the "C" core specification.

Power dissipated as heat in the Inductor is:

$$A_t(cm^2) \cdot watts/cm^2 = W_{(copper)}$$

Total number of turns

$$Wa(cm^2) \cdot N/cm^2 = N$$

Resistance of the winding

$$R = N \cdot \Omega/cm \cdot MLT$$

Current capability of the winding

$$W = I^2R$$

$$I = \sqrt{W_c/R}$$

Current density $I/cm^2 = I/\text{wire area } (cm^2)$

If the designer is designing with efficiency in mind Fig. 13B will be a useful aid. Knowing the total watts loss and maximum heat rise this nomograph will give the inductor surface area, knowing this area go back to Fig. 13A and pick out the current density of the wire.

The curve shown in Fig. 14 shows how the area increases with WaAc product. With the curves in Fig. 13A, B and the curve in Fig. 14 the designer will have a good idea for the current density.

The current densities are useful in picking out a first choice of wire size for a given current requirement but should not be regarded as final. Instead, the regulation, or other performance criteria should govern the final choice of wire size.

The surface area A_t for the C cores were computed from Fig. 15. Designation for terms are taken from tables of C cores in this text.

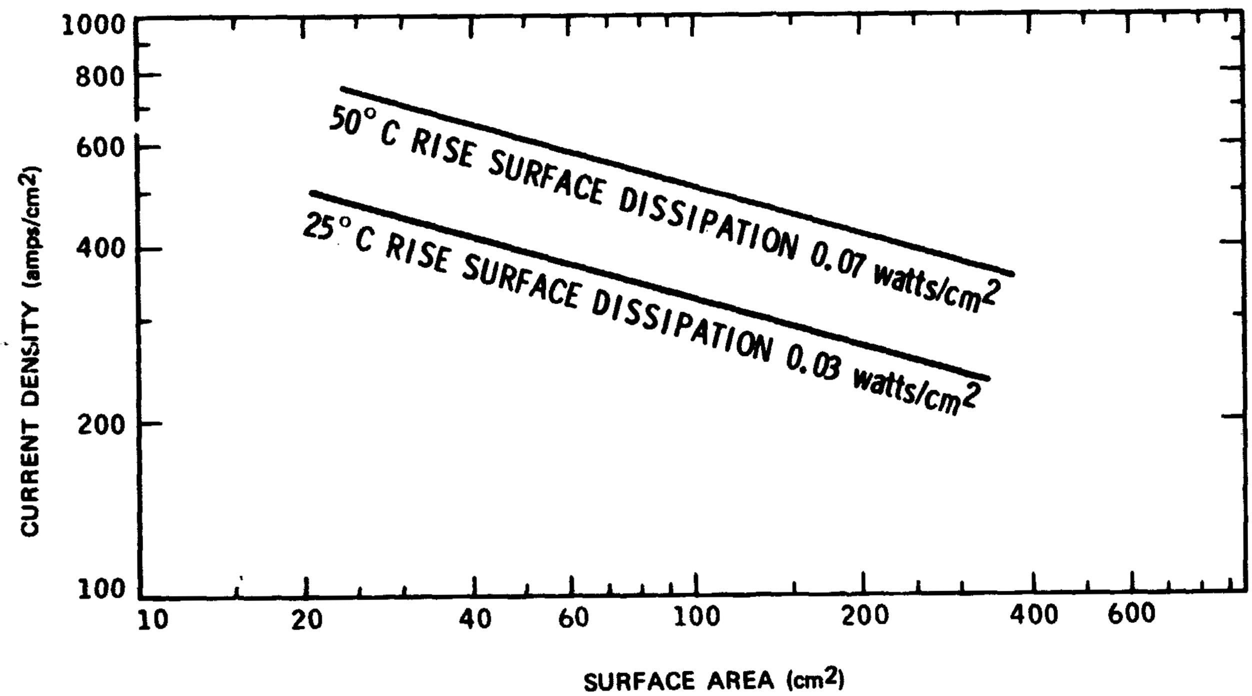


Fig. 13A. Current Density vs Surface Area for a 25° C and 50° C Rise

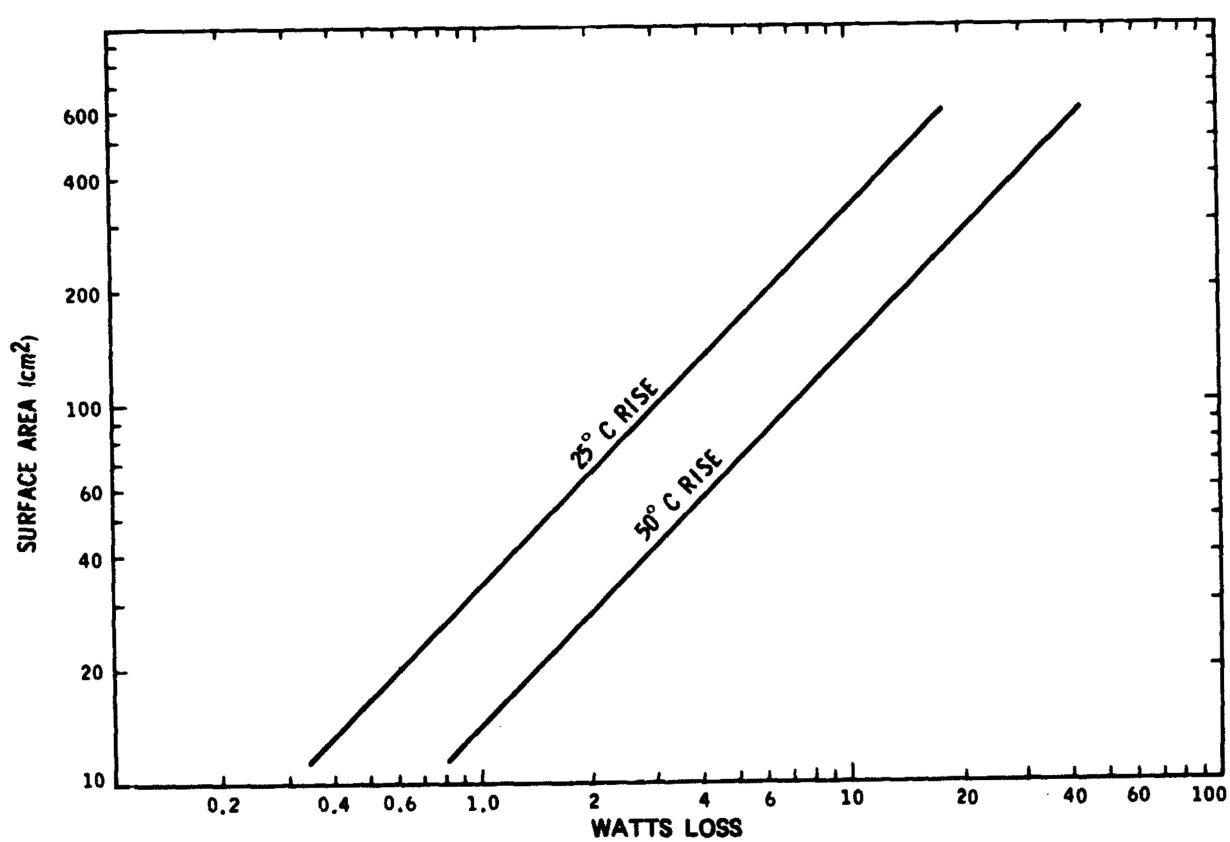


Fig. 13B. Surface Area vs Total Watt Loss for a 25° C and 50° Rise

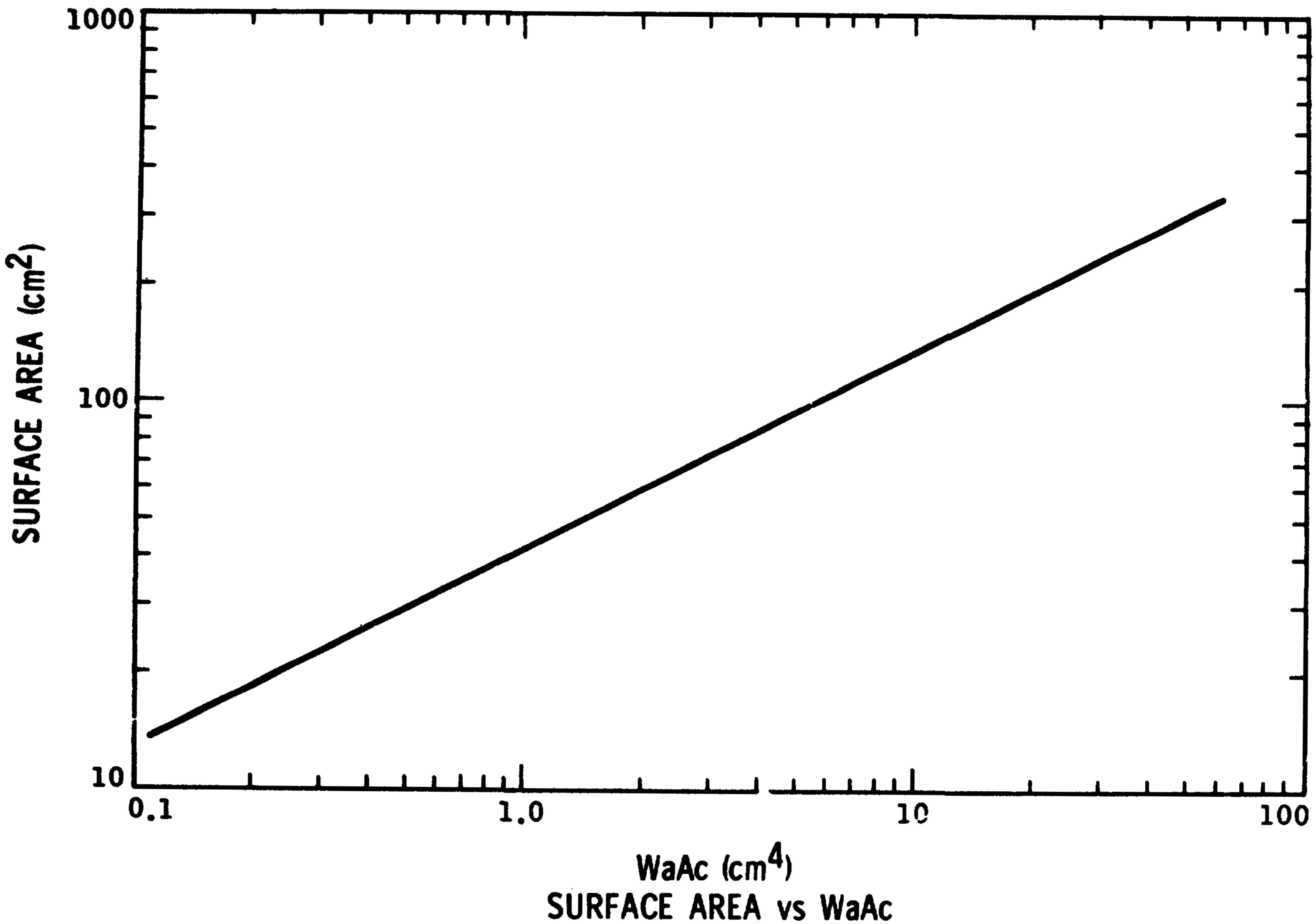
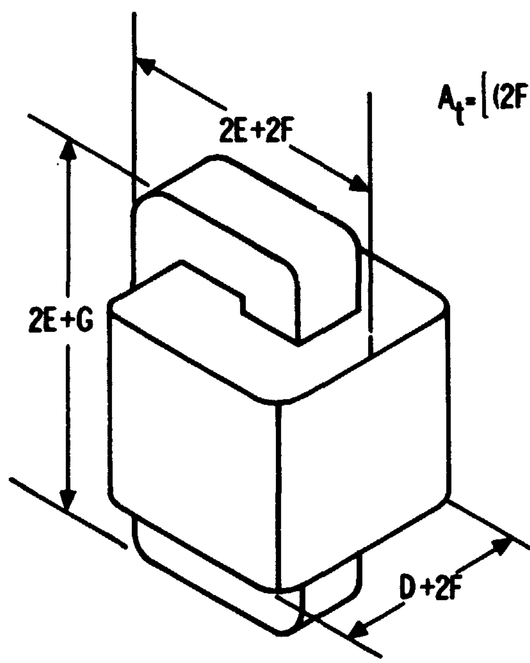
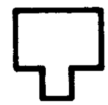


Fig. 14. Surface Area vs WaAc Product

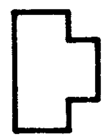


TOP



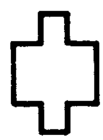
$$A_t = \left[(2F + D)(E + F)2 - 2EF\right] 2 +$$

SIDE



$$\left[(2E+G)(E+F)\,2 - 2EF\right] 2 +$$

FRONT



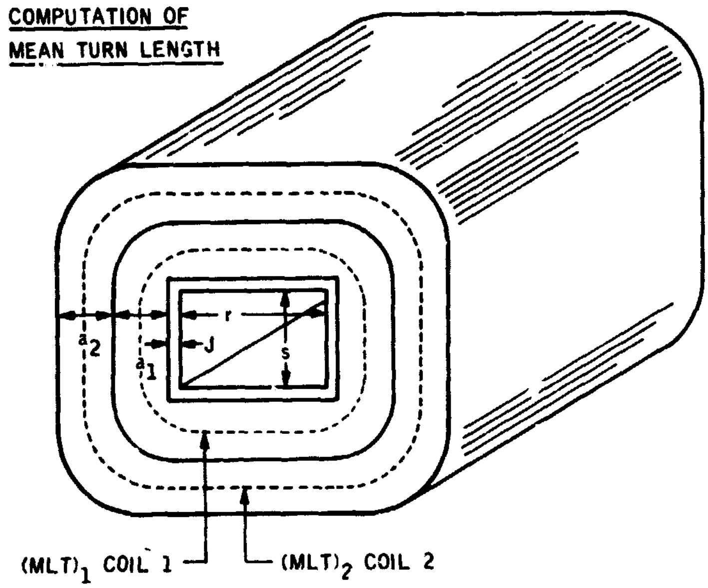
$$\left[(2E+G)(D+2F) - 4EF\right] 2 = \text{AREA}$$

REDUCES TO

$$A_t = 2\left\{ 2(E+F)\left[(D+2F) + (G+2E)\right] + (G+2E)(D+2F) - 8EF \right\}$$

"C" CORE SURFACE AREA (A_t)

Fig. 15. Surface Area of a "C" Core



$$(MLT)_1 = 2(r+2J) + 2(s+2J) + \pi a_1$$

$$(MLT)_2 = 2(r+2J) + 2(s+2J) + \pi(2a_1+a_2)$$

OR

$$(MLT)_2 = (MLT)_1 + \quad (a_1+a_2+2c)$$

OR

$$(MLT)_n = 2(r+2J) + 2(s+2J) + \pi\left[2(a_1+a_2+\ldots+a_{n-1}) + a_n\right]$$

WHERE:

a_1 = BUILD OF WINDING #1
a_2 = BUILD OF WINDING #2
a_n = BUILD OF WINDING #n
c = THICKNESS OF INSULATION BETWEEN a_1 & a_2

Fig. 16. Computation of Mean Turn Length

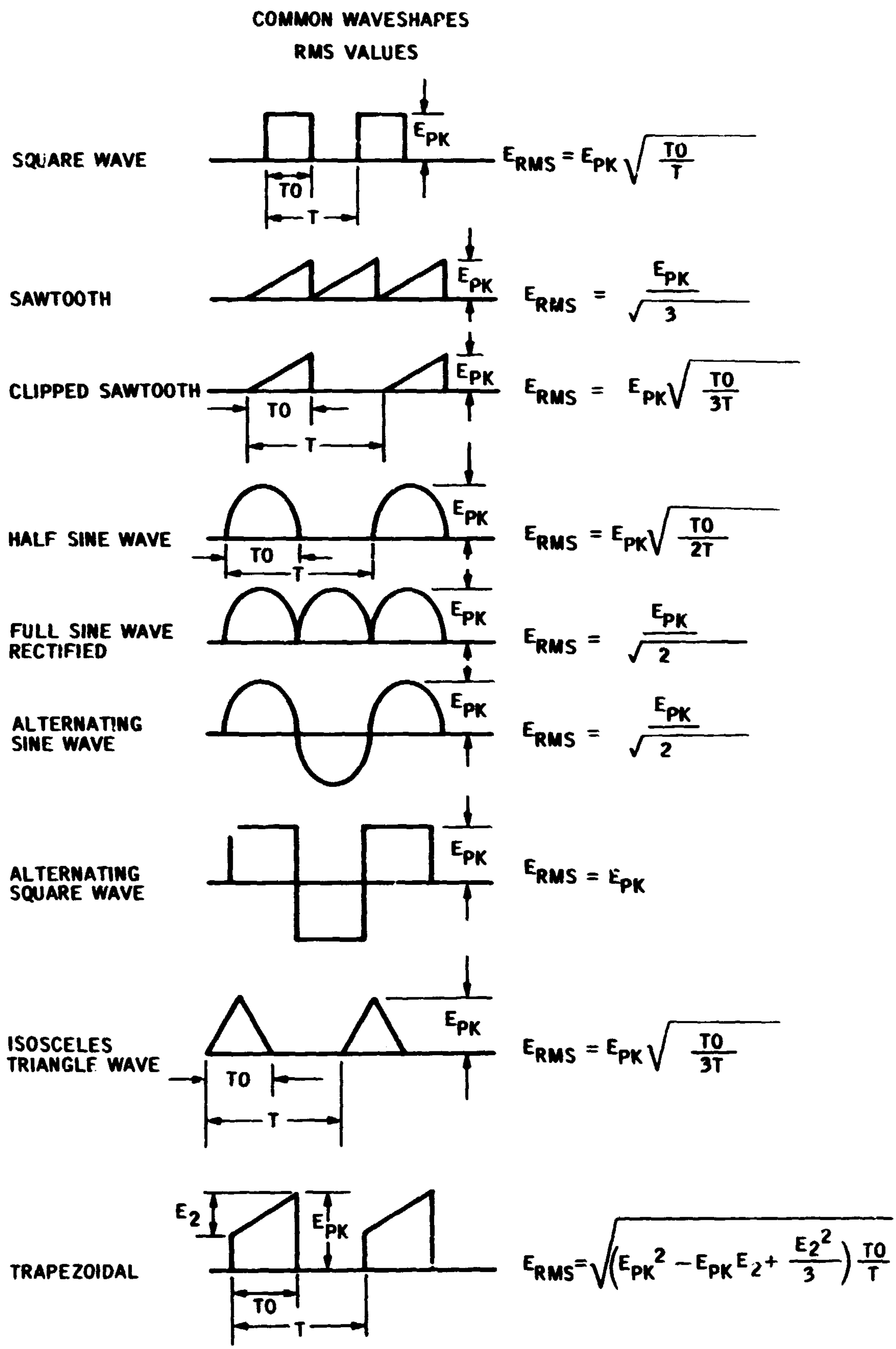


Fig. 17. Common Waveshapes RMS Values

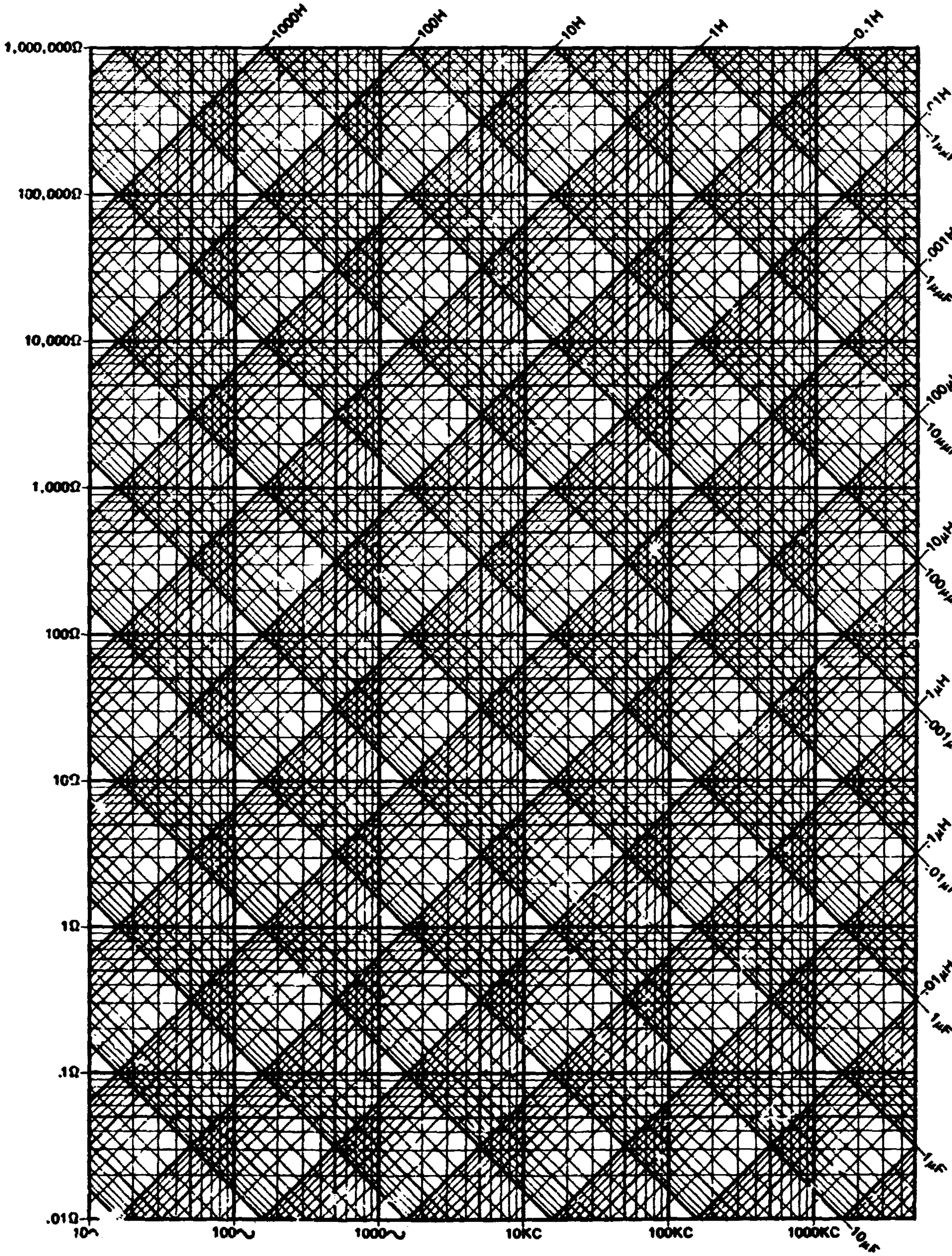


Fig. 18. Nomograph for Inductance, Capacitance, and Reactance

Table 4. Conversion Factors

Area	
To convert	**Multiply By**
Circular Mils to Square Inches	7.854×10^{-7}
Circular Mils to Square Mils	7.854×10^{-1}
Circular Mils to Square Millimeters	5.066×10^{-4}
Square Centimeters to Square Inches	1.55×10^{-1}
Square Feet to Square Meters	9.29×10^{-2}
Square Inches to Circular Mils	1.273×10^{6}
Square Inches to Square Centimeters	6.4516
Square Inches to Square Millimeters	6.4516×10^{2}
Square Inches to Square Mils	1.000×10^{6}
Square Meters to Square Feet	1.0764×10^{1}
Square Millimeters to Square Inches	1.55×10^{-3}
Square Millimeters to Circular Mils	1.973×10^{3}
Square Mils to Circular Mils	1.2732
Square Mils to Square Inches	1.00×10^{-6}
Length	
Centimeters to Inches	3.937×10^{-1}
Centimeters to Feet	3.281×10^{-2}
Feet to Centimeters	3.048×10^{1}
Feet to Meters	3.048×10^{-1}
Inches to Centimeters	2.54
Inches to Meters	2.54×10^{-2}
Inches to Millimeters	2.54×10^{1}
Inches to Mils	1.00×10^{3}
Kilometers to Miles	6.214×10^{-1}
Meters to Feet	3.2808
Meters to Inches	3.937×10^{1}
Meters to Yards	1.0936
Miles to Kilometers	1.6039

Table 4. (contd)

Length (contd)	
To convert	Multiply By
Millimeters to Inches	3.937×10^{-2}
Millimeters to Mils	3.937×10^{1}
Mils to Inches	1.00×10^{-3}
Mils to Millimeters	2.54×10^{-2}
Yards to Meters	9.144×10^{-1}
Weight (wt)	
Ounces to Pounds	6.25×10^{-2}
Ounces to Grams	2.8349×10^{1}
Pounds to Ounces	1.6×10^{1}
Pounds to Grams	4.5359×10^{2}
Grams to Ounces	3.527×10^{-2}
Grams to Pounds	2.205×10^{-3}

C CORE AND BOBBIN MAGNETIC AND DIMENSIONAL SPECIFICATION

A. Definitions for Tables 5 through 44.

Tables 5 through 44 show magnetic and dimensional specifications for forty C cores. Information given is listed by line as:

1 Manufacture and part number
2 Units
3 Ratio of the window area over the iron area
4 Product of the window area times the iron area
5 Window area Wa gross
6 Iron area Ac effective
7 Mean magnetic path length lm
8 Core weight of silicon steel multiplied by the stacking factor
9 Copper weight single bobbin
10 Mean length turn
11 Ratio of G dimension divided by the square root of the iron area (Ac)
12 Ratio of the Wa eff/Wa
13 Inductor overall surface area A_t
14-17 "C" core dimensions
18 Bobbin manufacturer and part number* **
19 Bobbin inside winding length**
20 Bobbin inside build**
21 Bobbin winding area length times build**
22 Bracket manufacturer and part number†

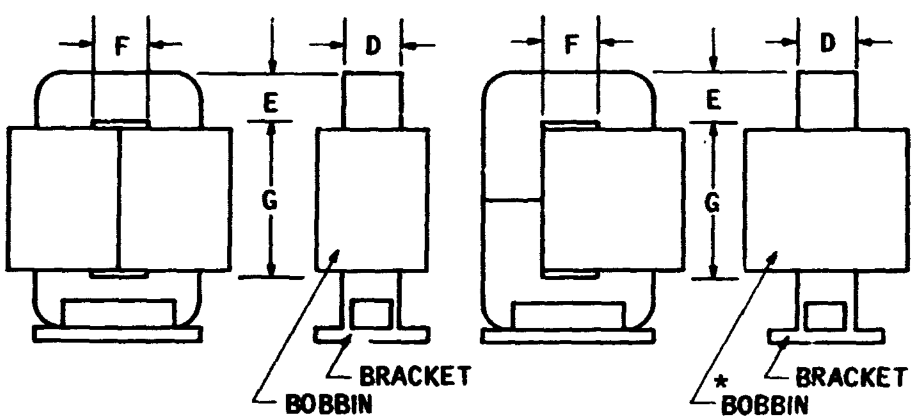
B. Nomographs for 40 C core sizes

Figures 19 through 58 are nomographs for 40 different "C" cores. The nomographs display resistance, number of turns, and wire size at a fill factor of K_2 = 0.60. These nomographs are included to provide a close approximation for breadboarding purposes.

*The first number in front of the part number indicates the number of bobbins.
**Dorco Electronics, 15533 Vermont Ave., Paramount, Calif. 90723.
†Hallmark Metals, 610 West Foothill Blvd., Glendora, Calif. 91740.

Table 5. "C" Core AL-2

"C" CORE	AL-2			
	ENGLISH		METRIC	
Wa/Ac			3.32	
Wa x Ac	0.0073	in^4	0.303	cm^4
Wa	0.156	in^2	1.006	cm^2
Ac (effective)	0.041	in^2	0.264	cm^2
lm	2.233	in	5.918	cm
CORE WT	0.027	lb	12.23	grams
COPPER WT	0.371	lb	16.87	grams
* MLT FULLWOUND	1.76	in	4.47	cm
$G/\sqrt{Ac}$			3.08	
Wa (effective) /Wa			0.835	
A_T	3.80	in^2	24.56	cm^2
D	0.250	in	0.635	cm
E	0.187	in	0.474	cm
F	0.250	in	0.635	cm
G	0.625	in	1.587	cm
BOBBIN	DORCO ELECTRONICS # 1-L-2			
LENGTH	0.580	in	1.473	cm
BUILD	0.225	in	0.571	cm
* Wa (effective)	0.130	in^2	0.841	cm^2
BRACKET	HALLMARK METALS # 04-010-03			



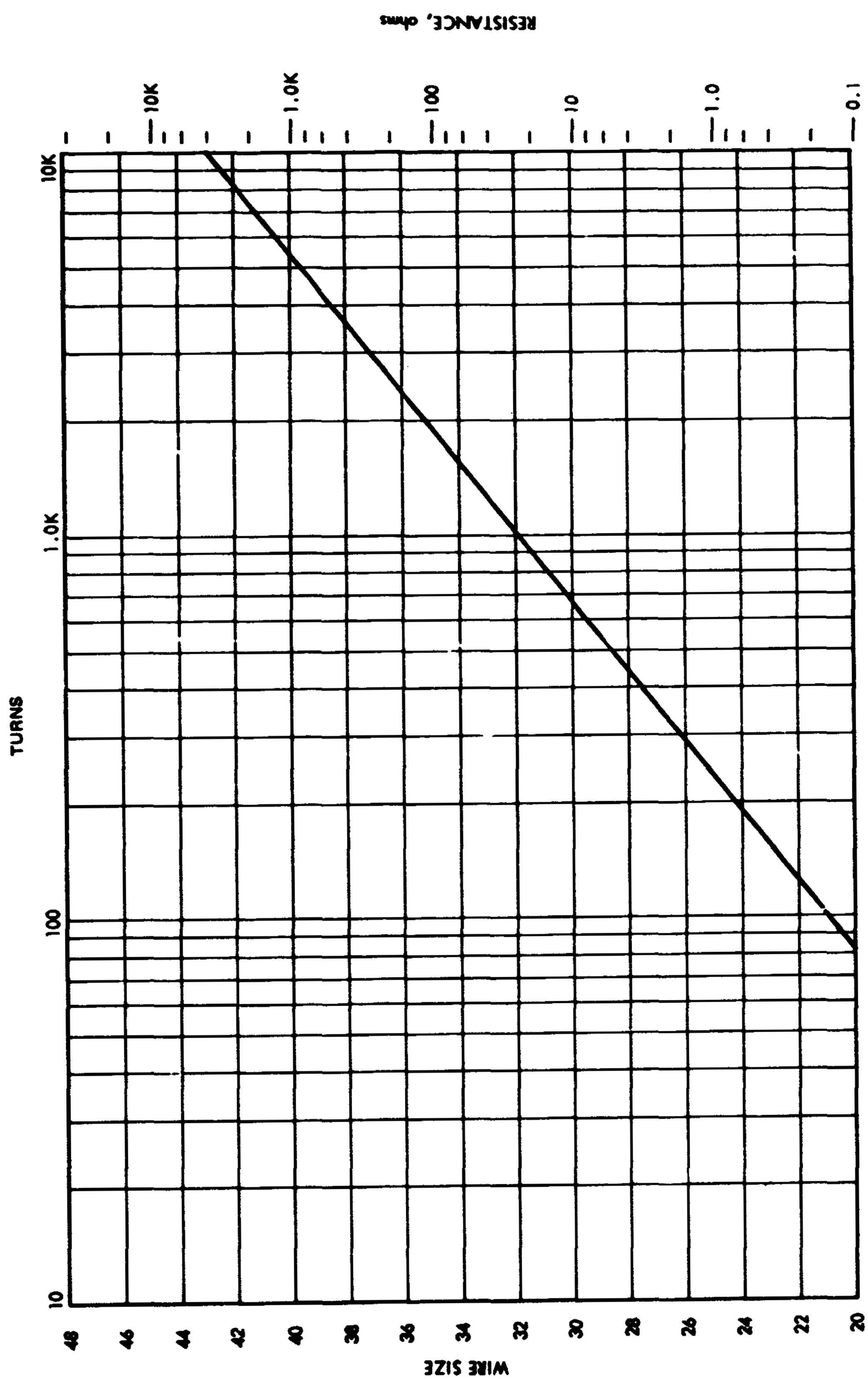
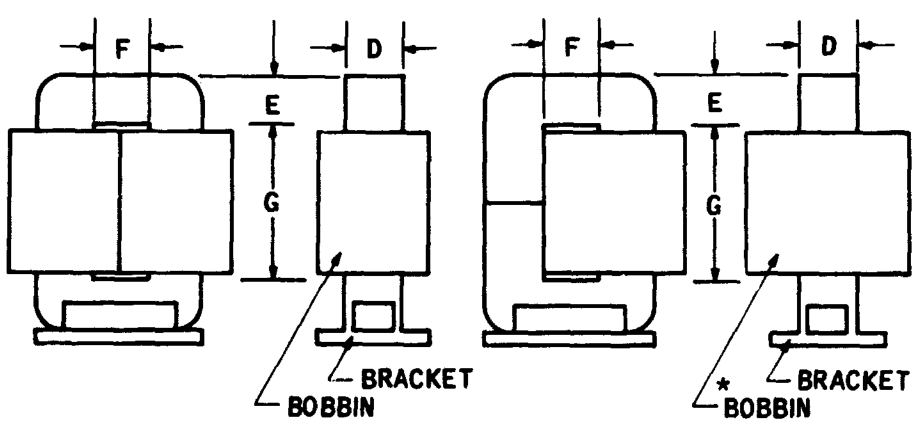


Figure 19. Nomograph for "C" core AL- 2

Table 6. "C" Core AL-3

"C" CORE	AL-3			
	ENGLISH		METRIC	
Wa/Ac			2.23	
Wa x Ac	0.0109	in^4	0.453	cm^4
Wa	0.156	in^2	1.006	cm^2
Ac (effective)	0.063	in^2	0.406	cm^2
lm	2.233	in	5.671	cm
CORE WT	0.035	lb	16.13	grams
COPPER WT	0.042	lb	19.25	grams
* MLT FULLWOUND	2.01	in	5.10	cm
$G/\sqrt{Ac}$			2.49	
Wa (effective) /Wa			0.835	
A_T	4.27	in^2	27.58	cm^2
D	0.375	in	0.952	cm
E	0.187	in	0.474	cm
F	0.250	in	0.635	cm
G	0.625	in	1.587	cm
BOBBIN	DORCO ELECTRONICS # 1-L-3			
LENGTH	0.580	in	1.473	cm
BUILD	0.225	in	0.571	cm
* Wa (effective)	0.130	in^2	0.841	cm^2
BRACKET	HALLMARK METALS # 06-010-03			



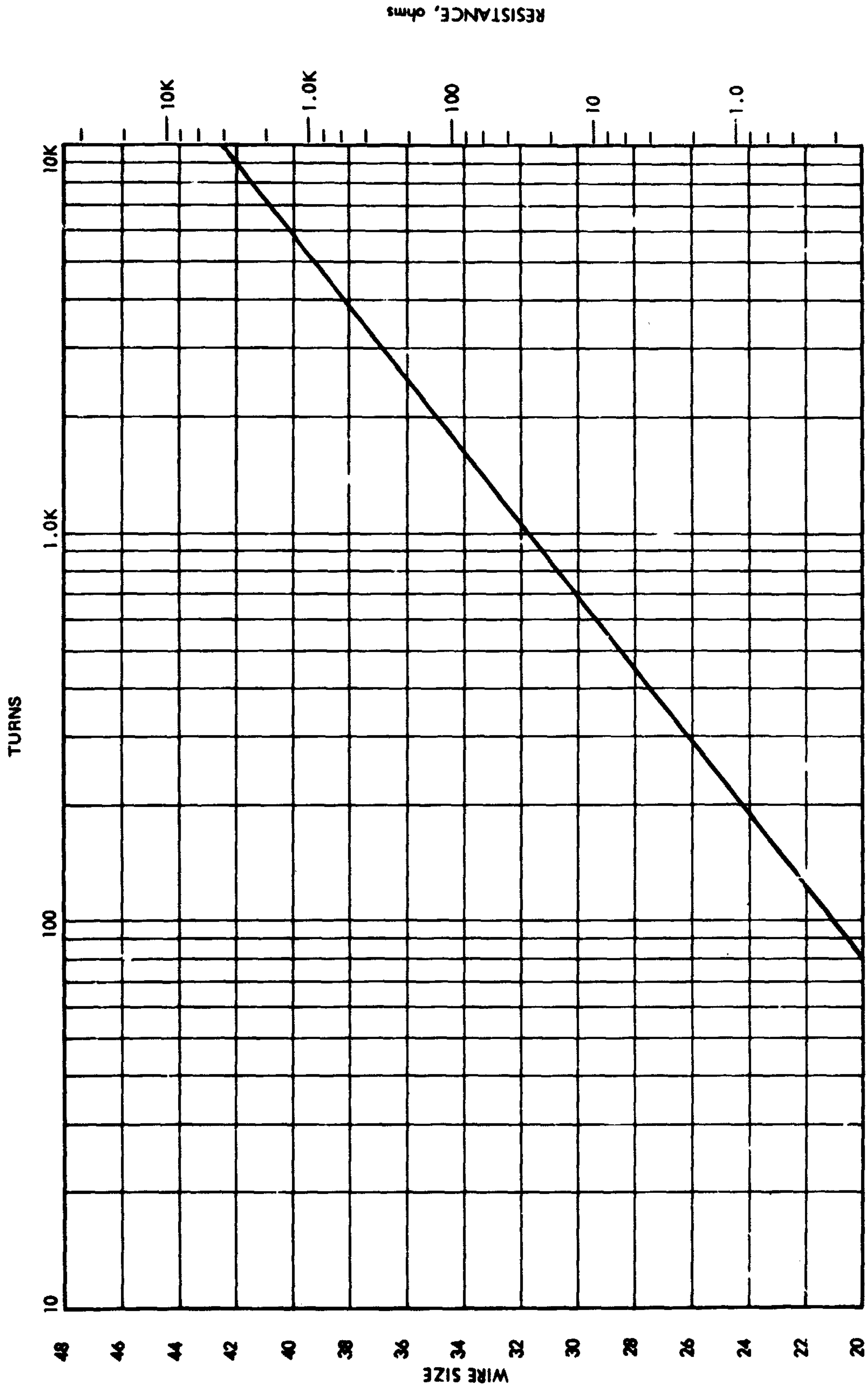
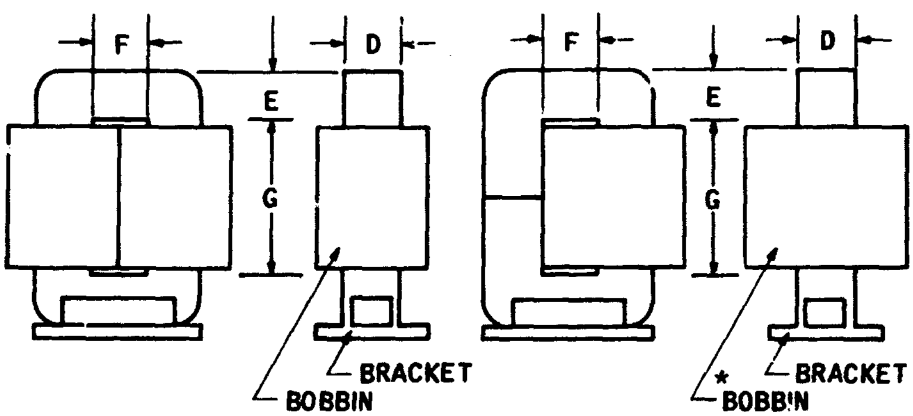


Figure 20. Nomograph for "C" core AL-3

Table 7. "C" Core AL-5

"C" CORE	AL-5			
	ENGLISH		METRIC	
Wa/Ac			2.33	
Wa x Ac	0.018	in^4	0.767	cm^4
Wa	0.219	in^2	1.423	cm^2
Ac (effective)	0.0836	in^2	0.539	cm^2
lm	2.933	in	7.45	cm
CORE WT	0.0596	lb	27.0	grams
COPPER WT	0.0643	lb	29.2	grams
* MLT FULLWOUND	2.13	in	5.42	cm
$G/\sqrt{Ac}$			3.026	
Wa (effective) /Wa			0.843	
A_T	5.90	in^2	38.1	cm^2
D	0.375	in	0.952	cm
E	0.250	in	0.635	cm
F	0.250	in	0.635	cm
G	0.875	in	2.22	cm
BOBBIN	DORCO ELECTRONICS # 1-L-5			
LENGTH	0.830	in	2.11	cm
BUILD	0.225	in	0.571	cm
* Wa (effective)	0.186	in^2	1.20	cm^2
BRACKET	HALLMARK METALS # 06-012-04			



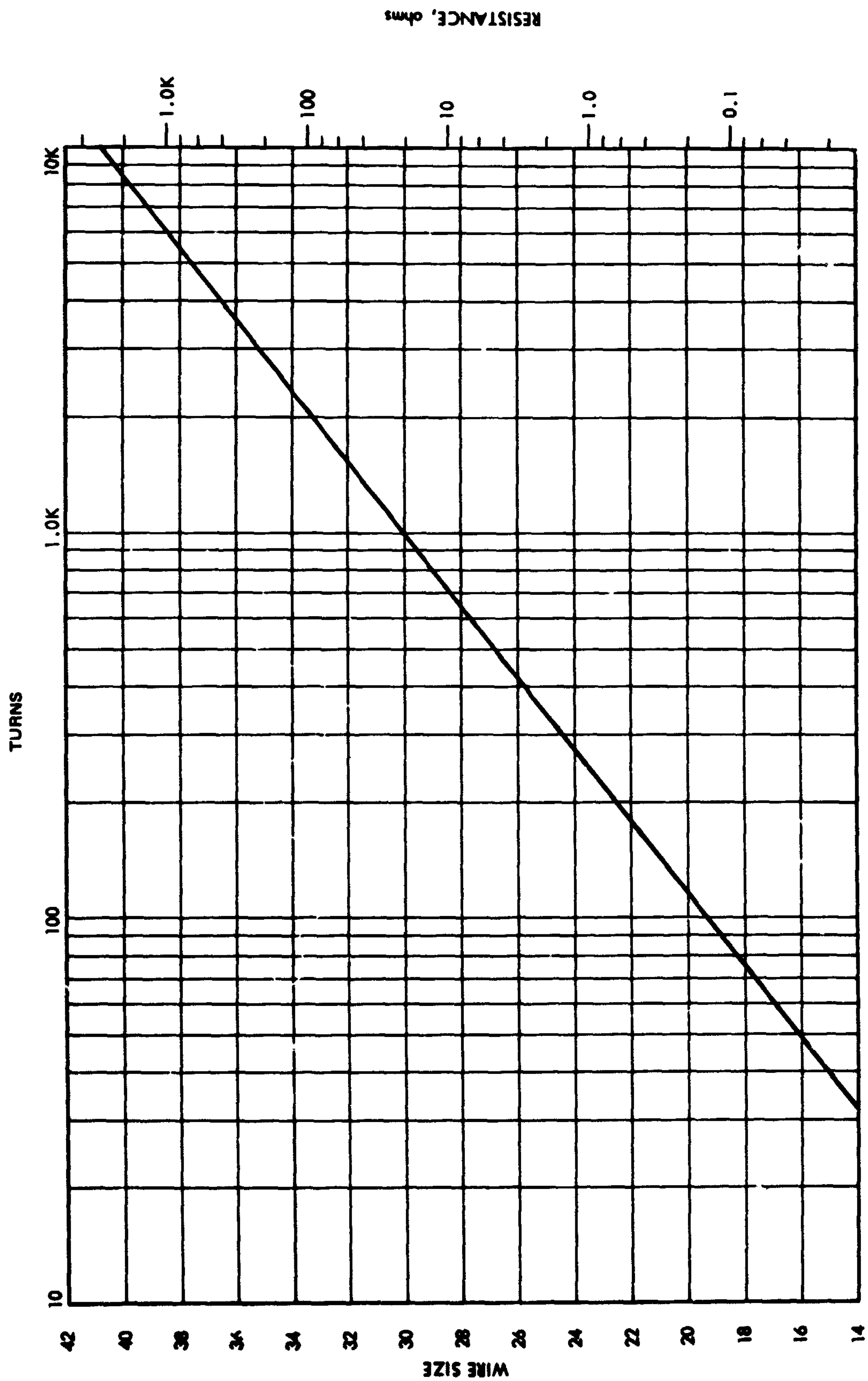
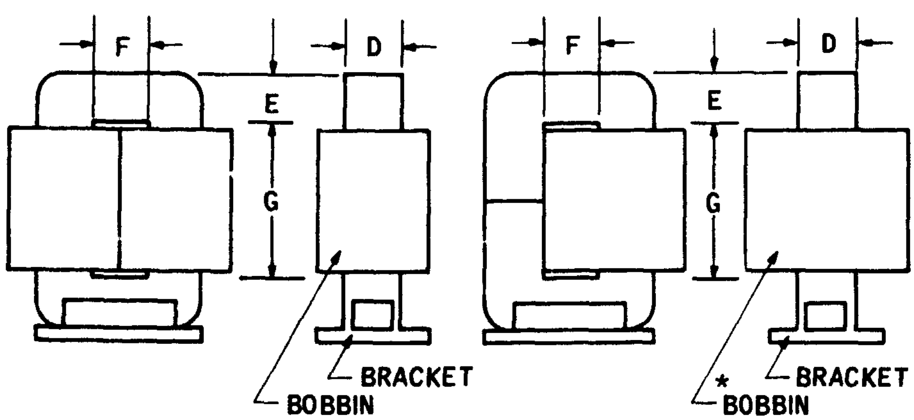


Figure 21. Nomograph for "C" core AL-5

Table 8. "C" Core AL-6

"C" CORE	AL-6	
	ENGLISH	METRIC
Wa/Ac		1.75
Wa x Ac	0.0206 in^4	0.857 cm^4
Wa	0.219 in^2	1.423 cm^2
Ac (effective)	0.111 in^2	0.716 cm^2
lm	2.933 in	7.45 cm
CORE WT	0.0809 lb	36.6 grams
COPPER WT	0.0719 lb	32.6 grams
* MLT FULLWOUND	2.38 in	6.06 cm
$G/\sqrt{Ac}$		2.63
Wa (effective) /Wa		0.843
A_T	6.50 in^2	41.9 cm^2
D	0.500 in	1.27 cm
E	0.250 in	0.635 cm
F	0.250 in	0.635 cm
G	0.875 in	2.22 cm
BOBBIN	DORCO ELECTRONICS # 1-L-6	
LENGTH	0.830 in	2.11 cm
BUILD	0.225 in	0.571 cm
* Wa (effective)	0.186 in^2	1.20 cm^2
BRACKET	HALLMARK METALS # 08-012-04	



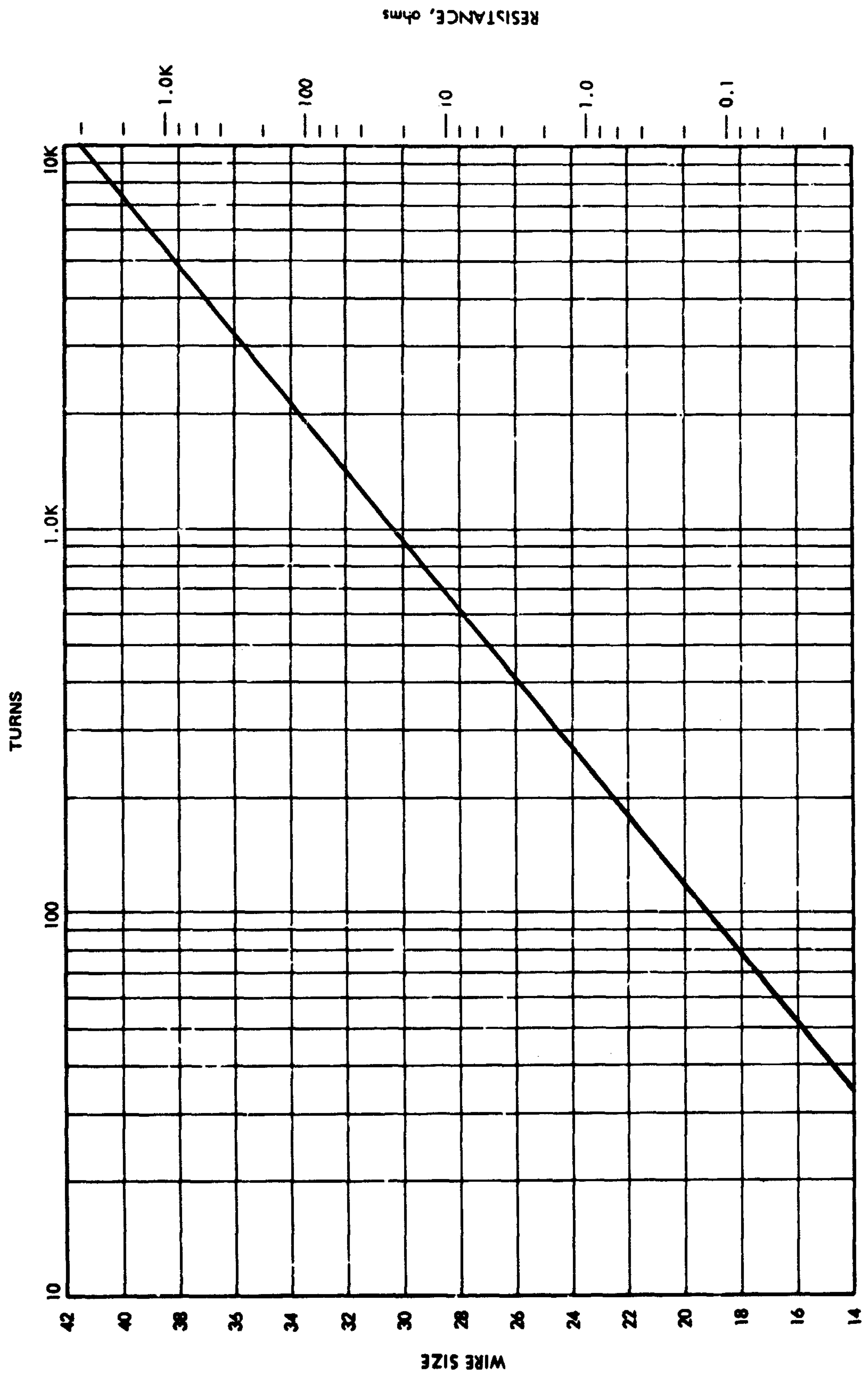
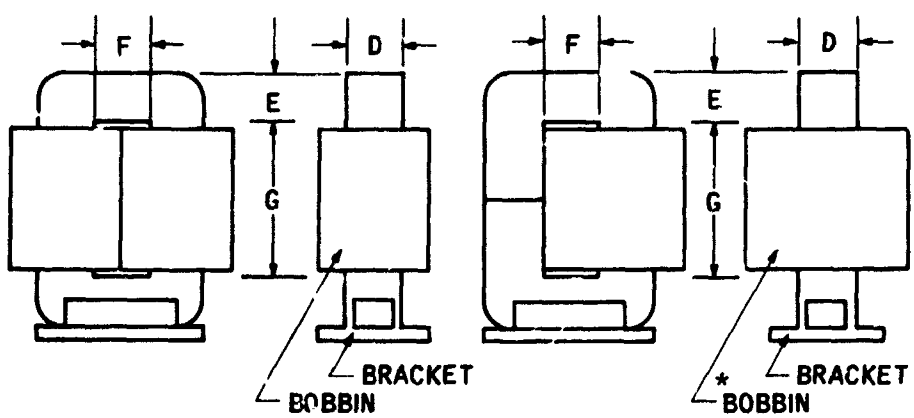


Figure 22. Nomograph for "C" core AL-6

Table 9. "C" Core AL-124

"C" CORE	AL-124			
	ENGLISH		METRIC	
Wa/Ac			2.50	
Wa x Ac	0.0391	in^4	1.626	cm^4
Wa	0.313	in^2	2.02	cm^2
Ac (effective)	0.111	in^2	0.716	cm^2
lm	3.308	in	8.40	cm
CORE WT	0.0916	lb	41.5	grams
COPPER WT	0.115	lb	52.13	grams
* MLT FULLWOUND	2.58	in	6.56	cm
$G/\sqrt{Ac}$			3.00	
Wa (effective) /Wa			0.876	
A_T	8.03	in^2	51.79	cm^2
D	0.500	in	1.27	cm
E	0.250	in	0.635	cm
F	0.313	in	0.795	cm
G	1.00	in	2.54	cm
BOBBIN	DORCO ELECTRONICS #		1-L-124	
LENGTH	0.955	in	2.425	cm
BUILD	0.288	in	0.731	cm
* Wa (effective)	0.275	in^2	1.77	cm^2
BRACKET	HALLMARK METALS #		08-013-04	



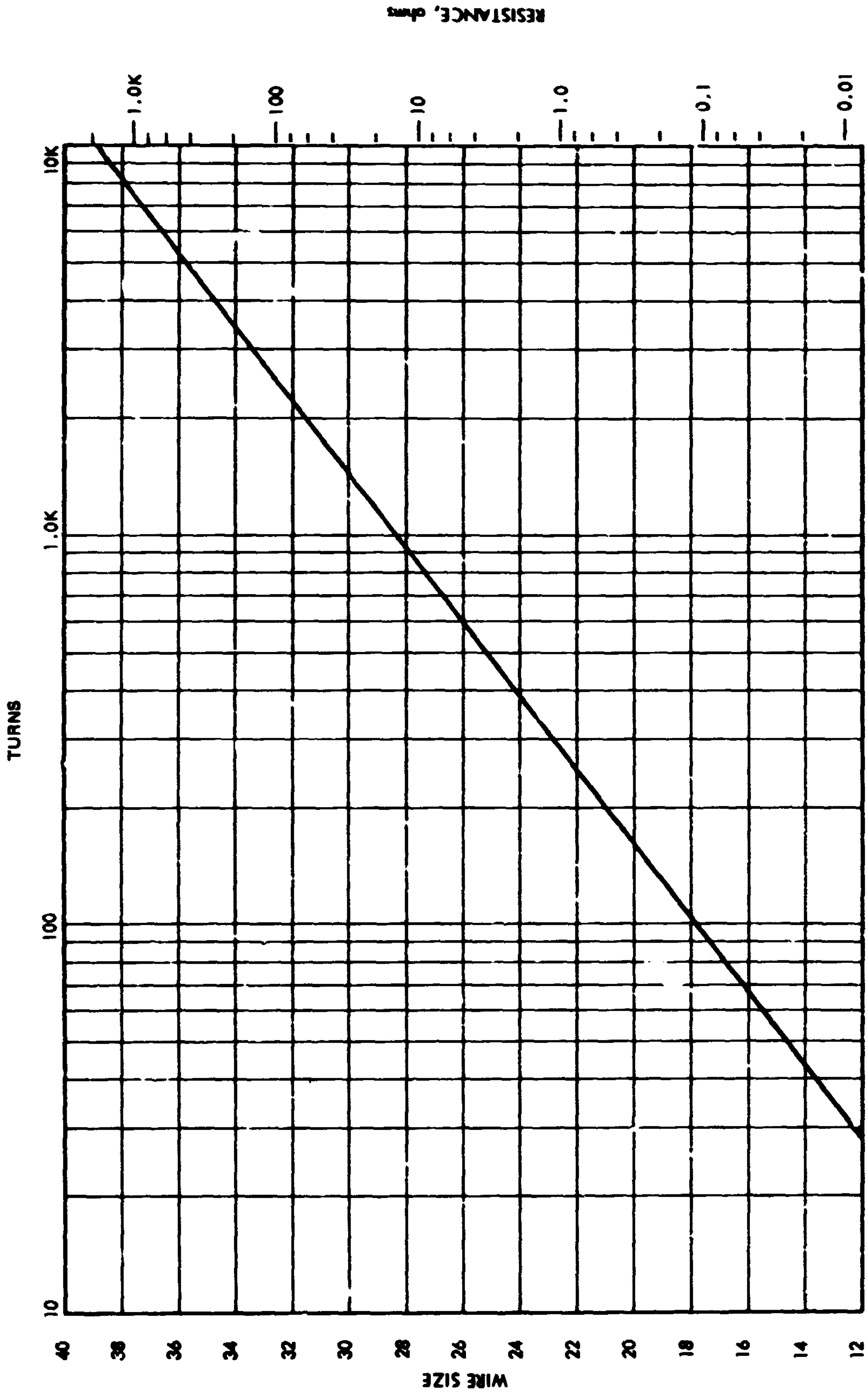
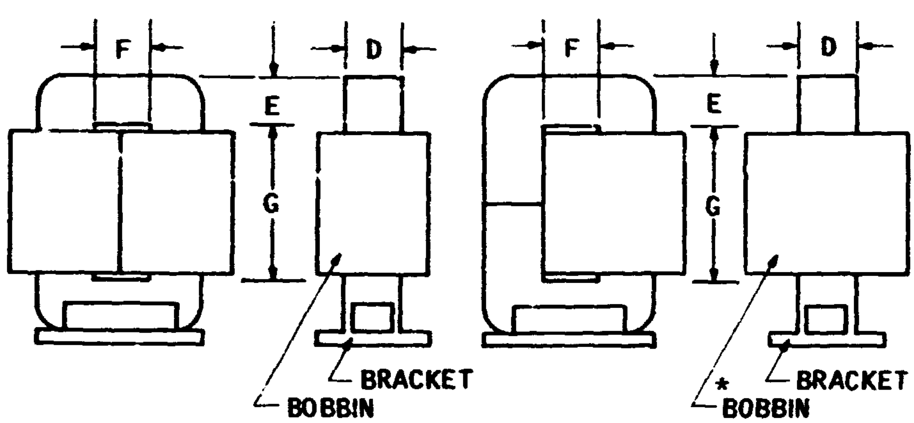


Figure 23. Nomograph for "C" core AL-124

Table 10. "C" Core AL-8

"C" CORE	AL-8			
	ENGLISH		METRIC	
Wa/Ac			3.16	
Wa x Ac	0.0628	in^4	2.612	cm^4
Wa	0.445	in^2	2.87	cm^2
Ac (effective)	0.125	in^2	0.806	cm^2
lm	4.198	in	10.66	cm
CORE WT	0.131	lb	59.3	grams
COPPER WT	0.180	lb	81.7	grams
* MLT FULLWOUND	2.77	in	7.06	cm
$G/\sqrt{Ac}$			3.36	
Wa (effective) /Wa			0.898	
A_T	11.29	in^2	72.8	cm^2
D	0.375	in	0.952	cm
E	0.375	in	0.952	cm
F	0.375	in	0.952	cm
G	1.187	in	3.015	cm
BOBBIN	DORCO ELECTRONICS #		1-L-8	
LENGTH	1.142	in	2.9	cm
BUILD	0.350	in	0.889	cm
* Wa (effective)	0.399	in^2	2.578	cm^2
BRACKET	HALLMARK METALS #		06-102-06	



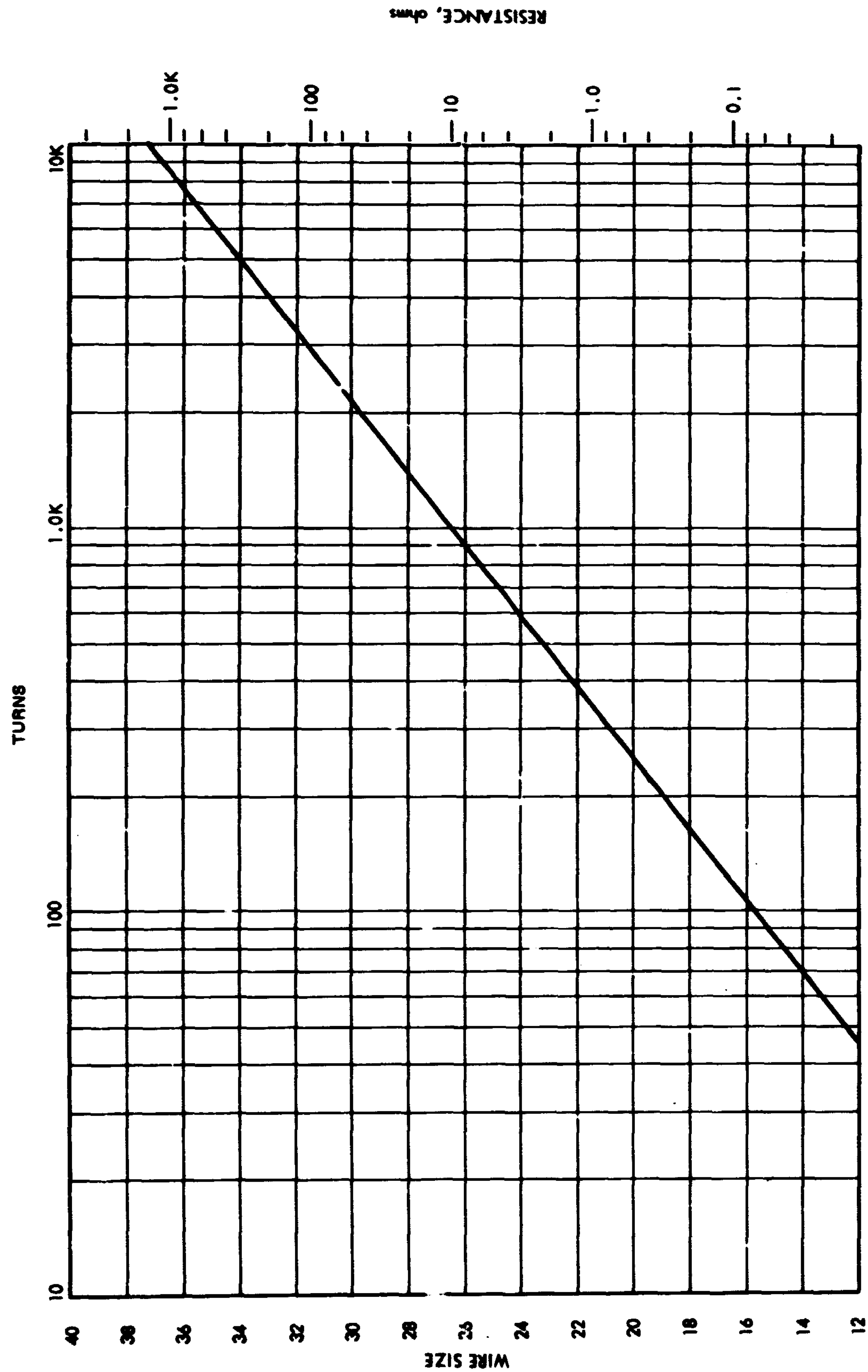
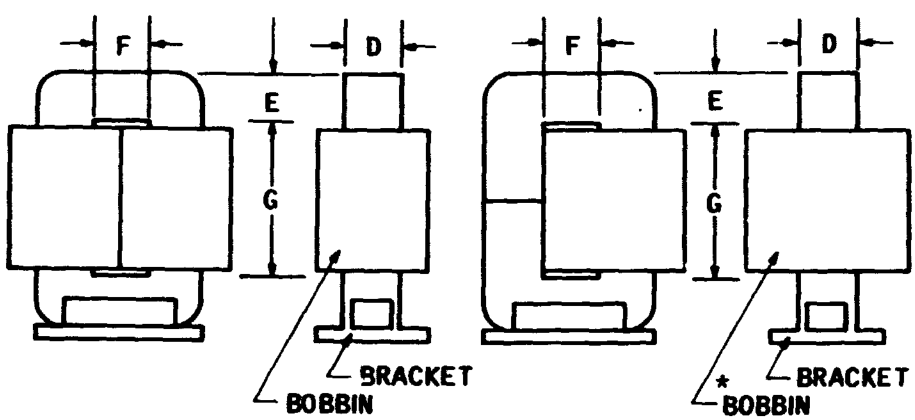


Figure 24. Nomograph for "C" core AL-8

Table 11. "C" Core AL-9

"C" CORE	AL-9			
	ENGLISH		METRIC	
Wa/Ac			2.37	
Wa x Ac	0.0837	in^4	3.48	cm^4
Wa	0.445	in^2	2.870	cm^2
Ac (effective)	0.167	in^2	1.077	cm^2
lm	4.198	in	10.66	cm
CORE WT	0.175	lb	79.3	grams
COPPER WT	0.196	lb	89.0	grams
* MLT FULLWOUND	3.02	in	7.69	cm
$G/\sqrt{Ac}$			2.90	
Wa (effective) /Wa			0.898	
A_T	12.15	in^2	78.39	cm^2
D	0.500	in	1.27	cm
E	0.375	in	0.952	cm
F	0.375	in	0.952	cm
G	1.187	in	3.015	cm
BOBBIN	DORCO ELECTRONICS #		1-L-9	
LENGTH	1.142	in	2.90	cm
BUILD	0.350	in	0.889	cm
* Wa (effective)	0.399	in^2	2.578	cm^2
BRACKET	HALLMARK METALS #		08-102-06	



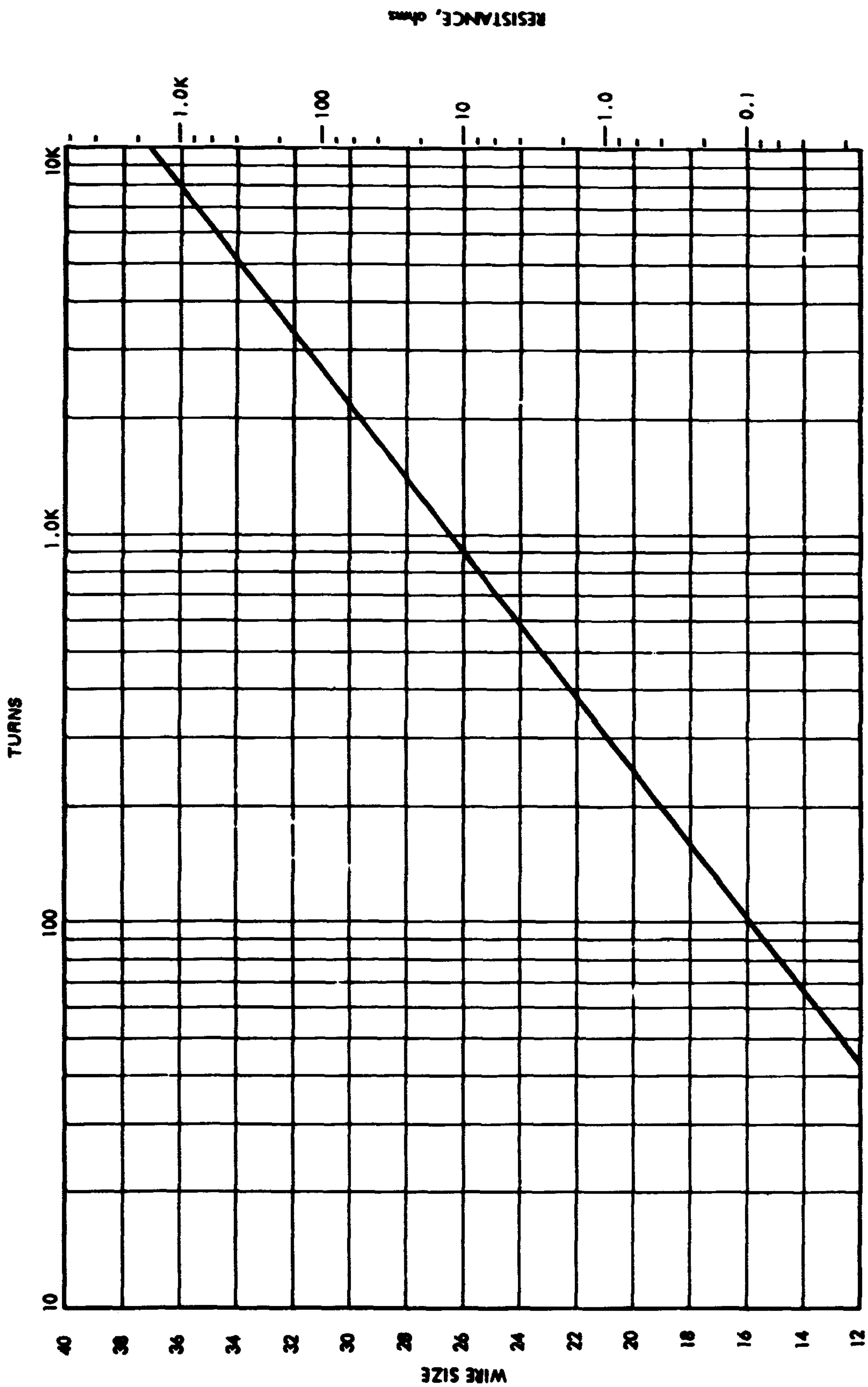
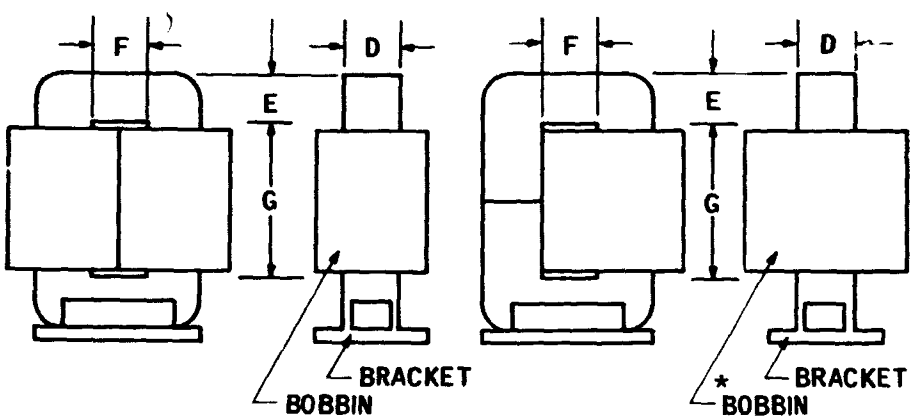


Figure 25. Nomograph for "C" core AL-9

Table 12. "C" Core AL-10

"C" CORE	AL-10			
	ENGLISH		METRIC	
Wa/Ac			1.90	
Wa x Ac	0.104	in^4	4.326	cm^4
Wa	0.445	in^2	2.870	cm^2
Ac (effective)	0.208	in^2	1.342	cm^2
lm	4.198	in	10.66	cm
CORE WT	0.216	lb	97.8	grams
COPPER WT	0.213	lb	96.4	grams
* MLT FULLWOUND	3.27	in	8.33	cm
$G/\sqrt{Ac}$			2.603	
Wa (effective) /Wa			0.898	
A_T	13.01	in^2	83.9	cm^2
D	0.625	in	1.587	cm
E	0.375	in	0.952	cm
F	0.375	in	0.952	cm
G	1.187	in	3.015	cm
BOBBIN	DORCO ELECTRONICS # 1-L-10			
LENGTH	1.142	in	2.90	cm
BUILD	0.350	in	0.889	cm
* Wa (effective)	0.399	in^2	2.578	cm^2
BRACKET	HALLMARK METALS # 010-102-06			



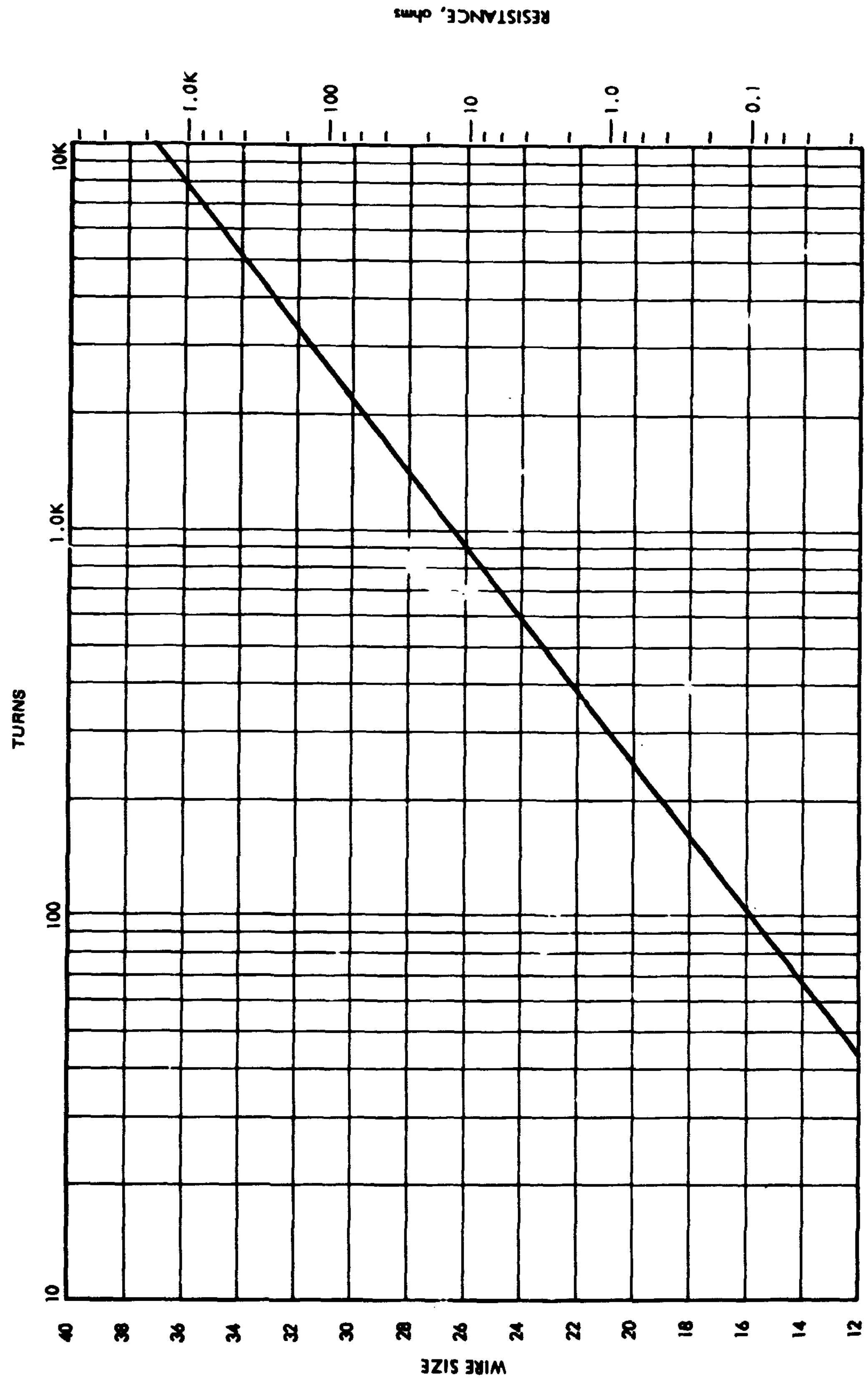
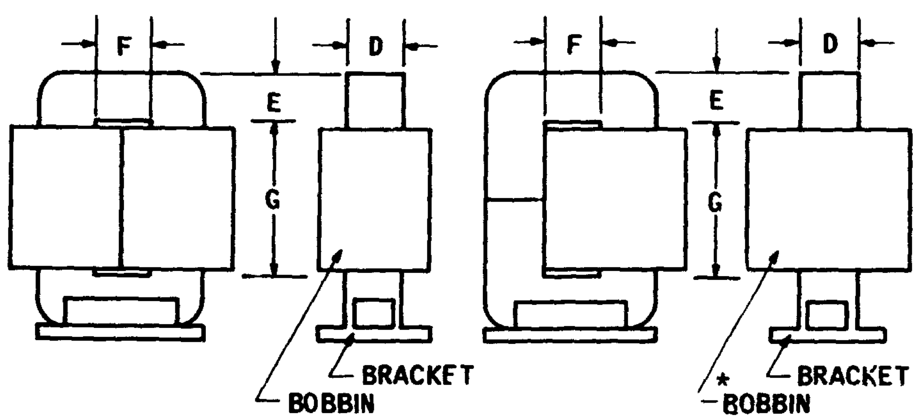


Figure 26. Nomograph for "C" core AL-10

Table 13. "C" Core AL-12

"C" CORE	AL-12	
	ENGLISH	METRIC
Wa/Ac		2.57
Wa x Ac	0.123 in^4	5.117 cm^4
Wa	0.563 in^2	3.63 cm^2
Ac (effective)	0.195 in^2	1.26 cm^2
lm	4.523 in	11.5 cm
CORE WT	0.217 lb	98.3 grams
COPPER WT	0.295 lb	133.7 grams
* MLT FULLWOUND	3.54 in	9.00 cm
$G/\sqrt{Ac}$		2.55
Wa (effective) /Wa		0.911
A_T	15.61 in^2	100.7 cm^2
D	0.500 in	1.27 cm
E	0.437 in	1.11 cm
F	0.500 in	1.27 cm
G	1.125 in	2.857 cm
BOBBIN	DORCO ELECTRONICS # 1-L-12	
LENGTH	1.08 in	2.74 cm
BUILD	0.475 in	1.21 cm
* Wa (effective)	0.513 in^2	3.31 cm^2
BRACKET	HALLMARK METALS # 08-106-07	



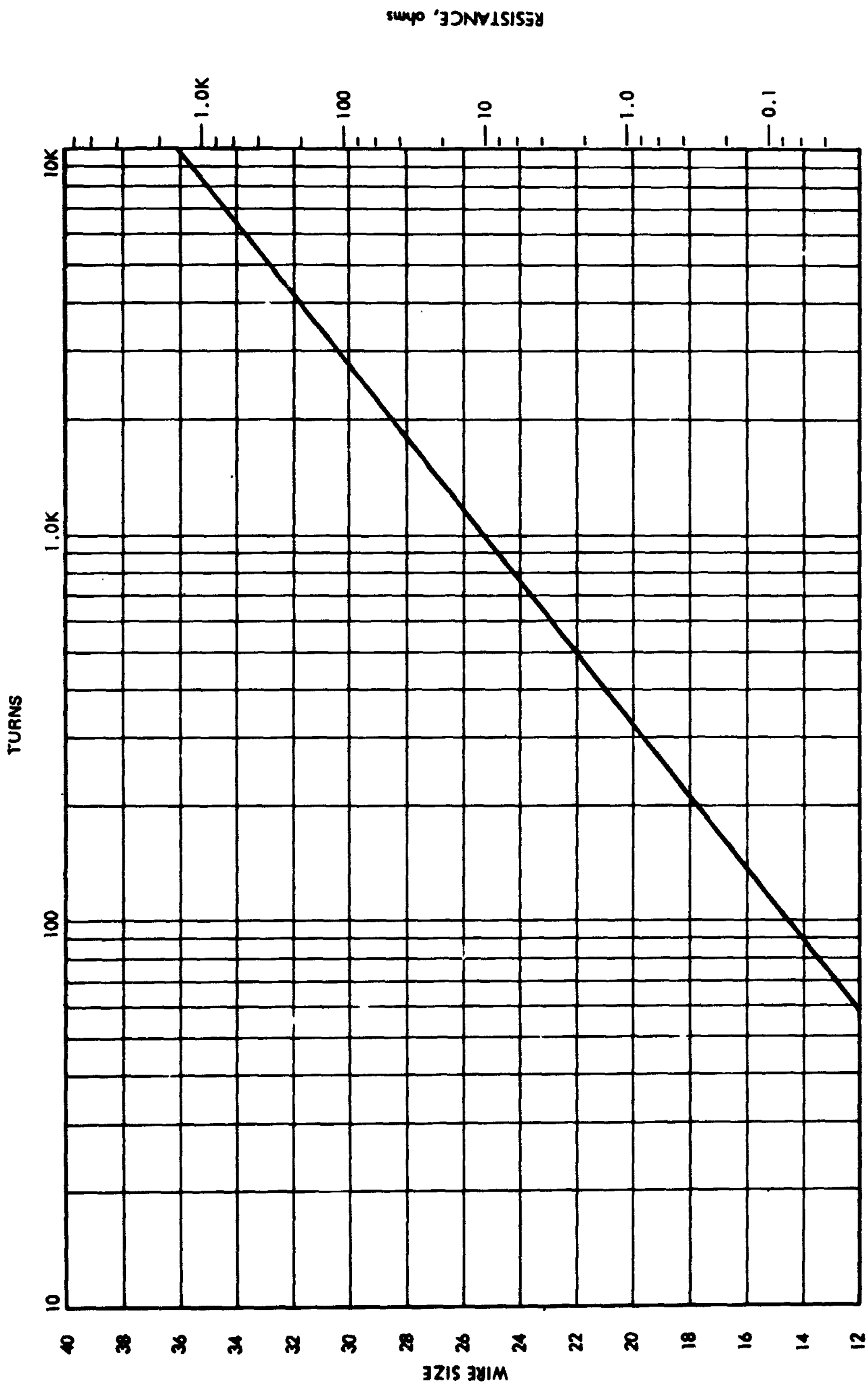
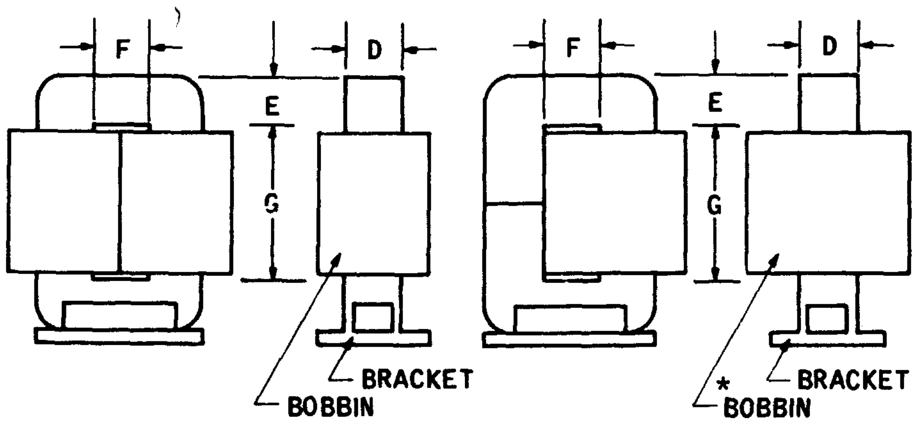


Figure 27. Nomograph for "C" core AL-12

Table 14. "C" Core AL-135

"C" CORE	AL-135			
	ENGLISH		METRIC	
Wa/Ac			2.89	
Wa x Ac	0.139	in^4	5.78	cm^4
Wa	0.633	in^2	4.083	cm^2
Ac (effective)	0.195	in^2	1.26	cm^2
lm	4.648	in	11.8	cm
CORE WT	0.223	lb	101	grams
COPPER WT	0.312	lb	159	grams
* MLT FULLWOUND	3.74	in	9.50	cm
$G/\sqrt{Ac}$			2.55	
Wa (effective) /Wa			0.915	
A_T	17.04	in^2	110	cm^2
D	0.500	in	1.27	cm
E	0.437	in	1.11	cm
F	0.562	in	1.43	cm
G	1.125	in	2.857	cm
BOBBIN	DORCO ELECTRONICS #		1-L-135	
LENGTH	1.08	in	2.74	cm
BUILD	0.537	in	1.36	cm
* Wa (effective)	0.579	in^2	3.74	cm^2
BRACKET	HALLMARK METALS #		08-107-07	



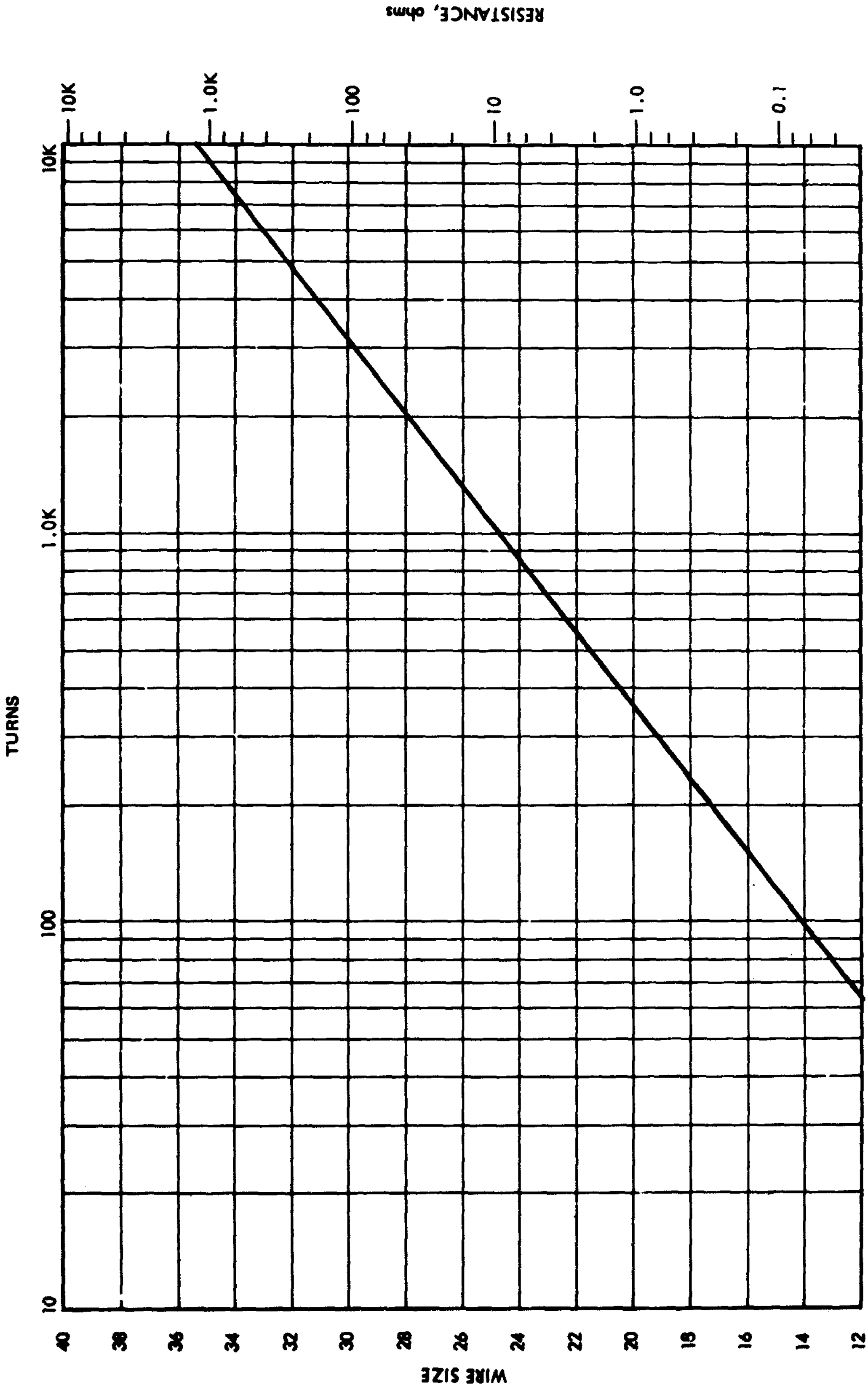
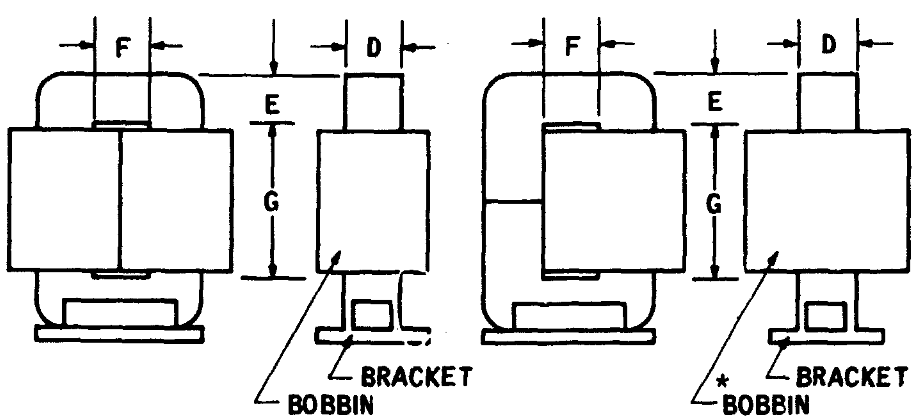


Figure 28. Nomograph for "C" core AL-135

Table 15. "C" Core AL-78

"C" CORE	AL-78			
	ENGLISH		METRIC	
Wa/Ac			3.00	
Wa x Ac	0.165	in^4	6.86	cm^4
Wa	0.703	in^2	4.53	cm^2
Ac (effective)	0.208	in^2	1.34	cm^2
lm	5.891	in	14.96	cm
CORE WT	0.311	lb	141	grams
COPPER WT	0.331	lb	150	grams
* MLT FULLWOUND	3.21	in	8.15	cm
$G/\sqrt{Ac}$			4.93	
Wa (effective) /Wa			0.905	
A_T	16.99	in^2	109.6	cm^2
D	0.750	in	1.91	cm
E	0.313	in	0.795	cm
F	0.313	in	0.795	cm
G	2.250	in	5.715	cm
BOBBIN	DORCO ELECTRONICS #		1-L-78	
LENGTH	2.205	in	5.60	cm
BUILD	0.288	in	0.731	cm
* Wa (effective)	0.635	in^2	4.10	cm^2
BRACKET	HALLMARK METALS #		012-015-05	



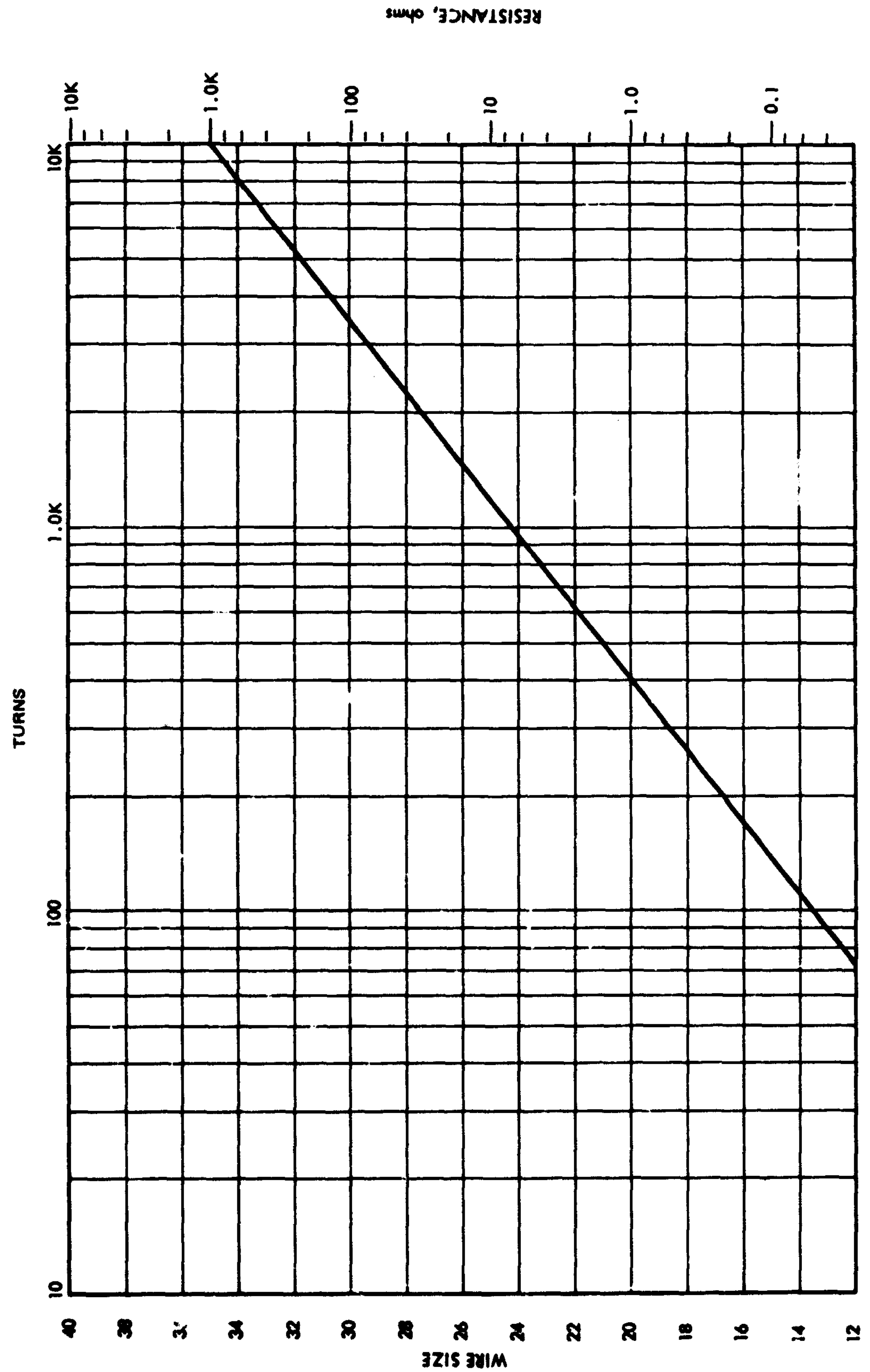
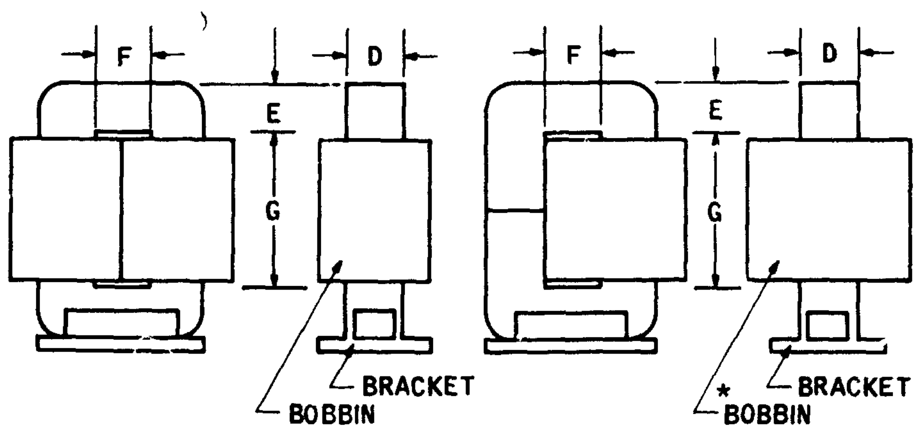


Figure 29. Nomograph for "C" core AL-78

Table 16. "C" Core AL-18

"C" CORE	AL-18			
	ENGLISH		METRIC	
Wa/Ac			5.08	
Wa x Ac	0.214	in^4	8.03	cm^4
Wa	0.977	in^2	6.389	cm^2
Ac (effective)	0.194	in^2	1.257	cm^2
lm	5.648	in	14.34	cm
CORE WT	0.271	lb	123	grams
COPPER WT	0.575	lb	260	grams
* MLT FULLWOUND	2.95	in	7.51	cm
$G/\sqrt{Ac}$			3.502	
Wa (effective) /Wa			0.890	
A_T	21.93	in^2	141.50	cm^2
D	0.500	in	1.27	cm
E	0.437	in	1.111	cm
F	0.625	in	1.587	cm
G	1.562	in	3.927	cm
BOBBIN	DORCO ELECTRONICS #		1-L-18	
LENGTH	1.497	in	3.802	cm
BUILD	0.590	in	1.498	cm
* Wa (effective)	0.880	in^2	5.697	cm^2
BRACKET	HALLMARK METALS #		08-108-07	



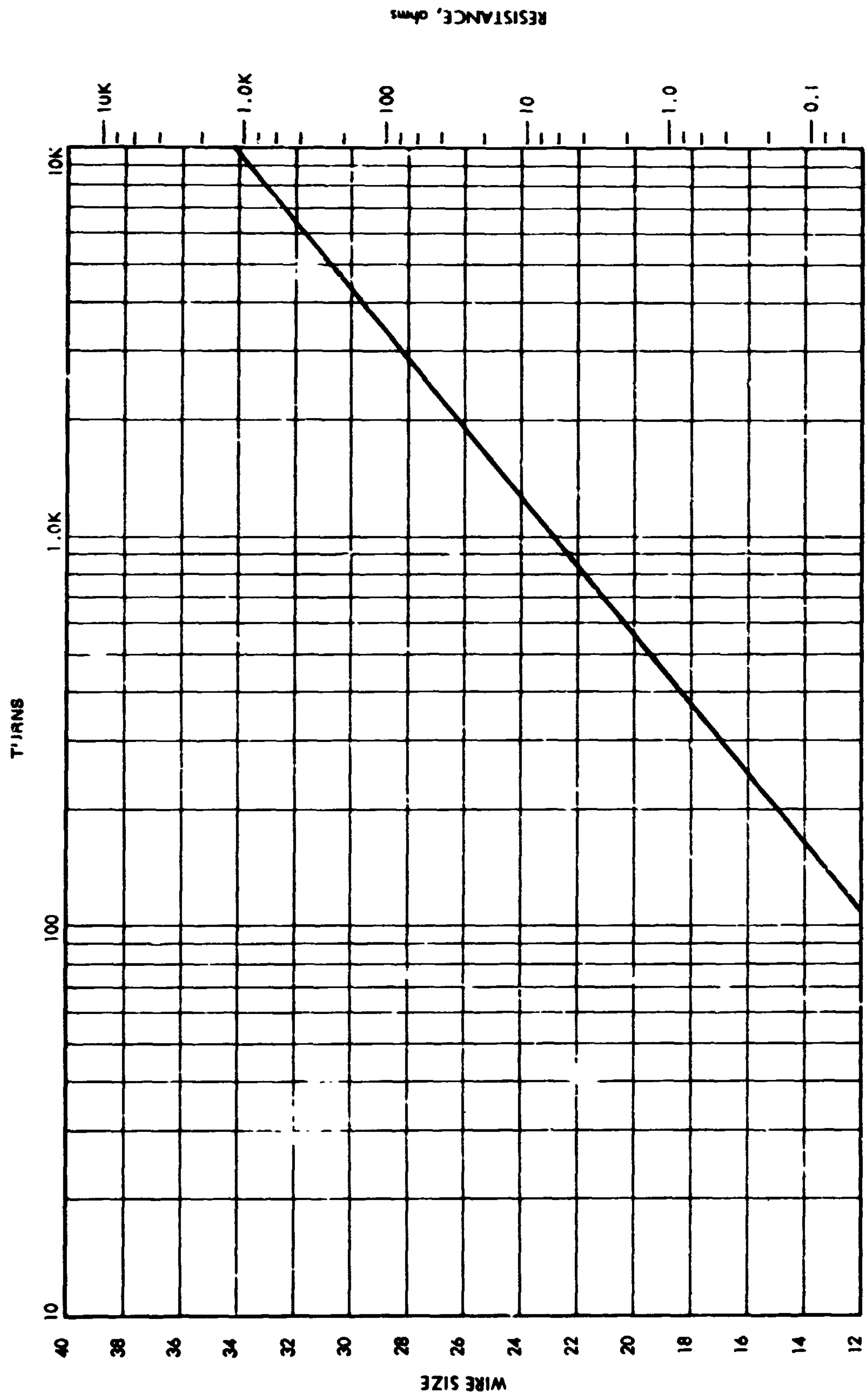
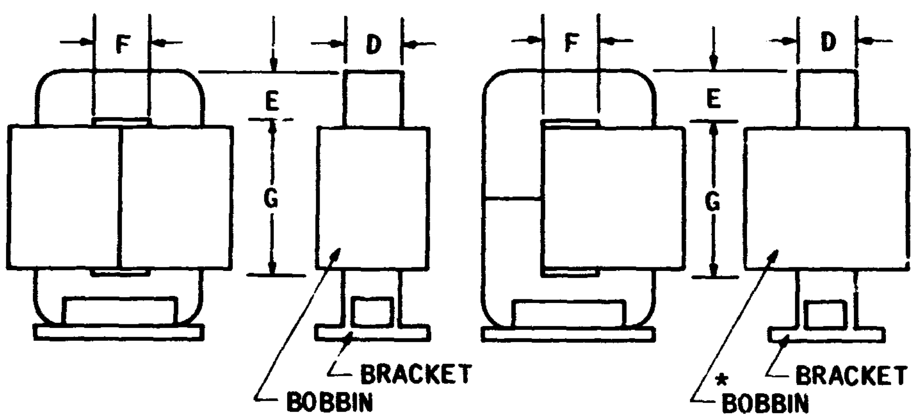


Figure 30. Nomograph for "C" core AL-18

Table 17. "C" Core AL-15

"C" CORE	AL-15	
	ENGLISH	METRIC
Wa/Ac		2.50
Wa x Ac	0.245 in^4	10.2 cm^4
Wa	0.781 in^2	5.037 cm^2
Ac (effective)	0.279 in^2	1.80 cm^2
lm	5.588 in	14.2 cm
CORE WT	0.388 lb	176 grams
COPPER WT	0.448 lb	203 grams
* MLT FULLWOUND	3.97 in	10.08 cm
$G/\sqrt{Ac}$		2.96
Wa (effective) /Wa		0.891
A_T	21.07 in^2	135.9 cm^2
D	0.625 in	1.587 cm
E	0.500 in	1.27 cm
F	0.500 in	1.27 cm
G	1.562 in	3.967 cm
BOBBIN	DORCO ELECTRONICS # 1-L-15	
LENGTH	1.497 in	3.80 cm
BUILD	0.465 in	1.18 cm
* Wa (effective)	0.696 in^2	4.49 cm^2
BRACKET	HALLMARK METALS # 010-108-08	



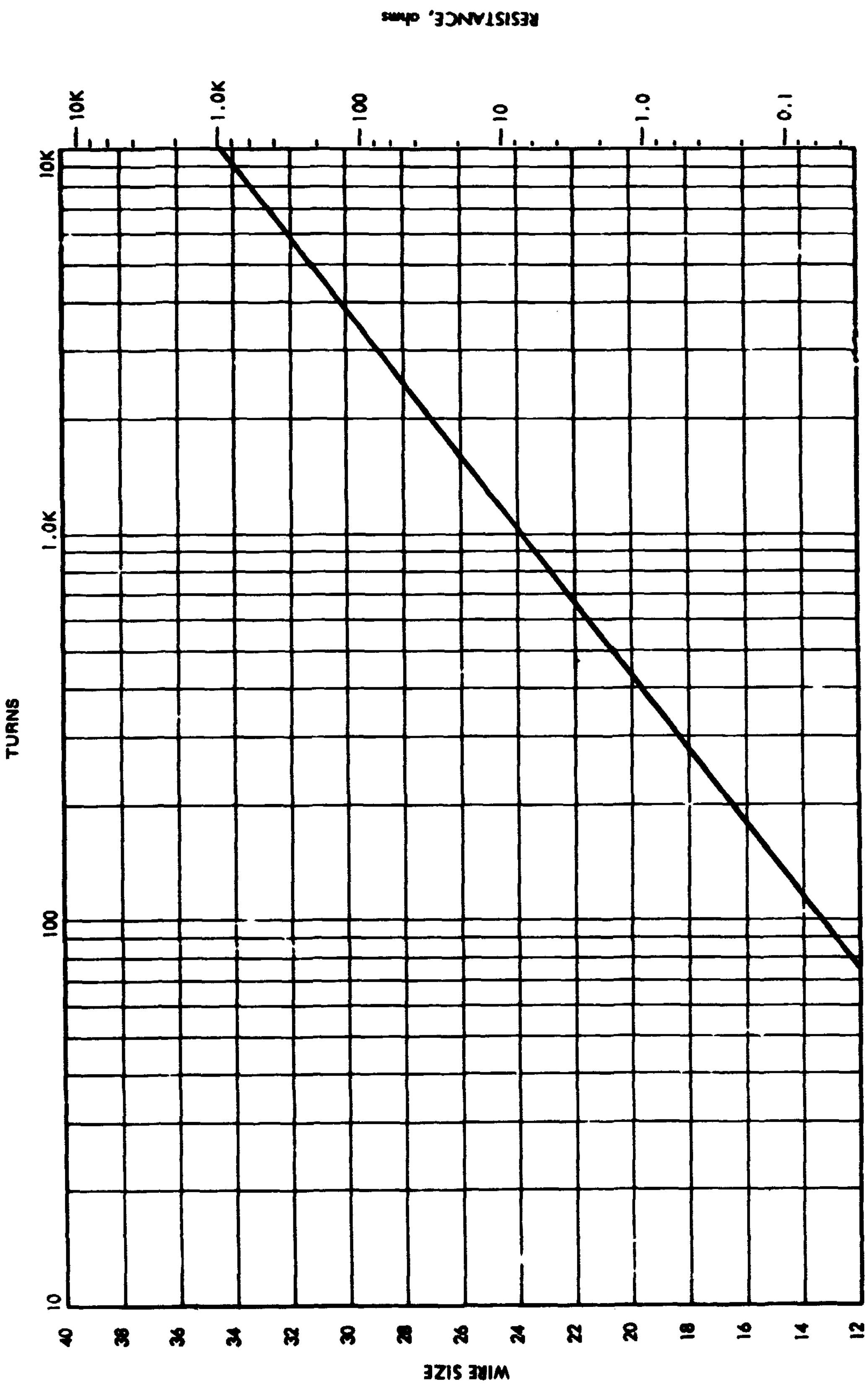
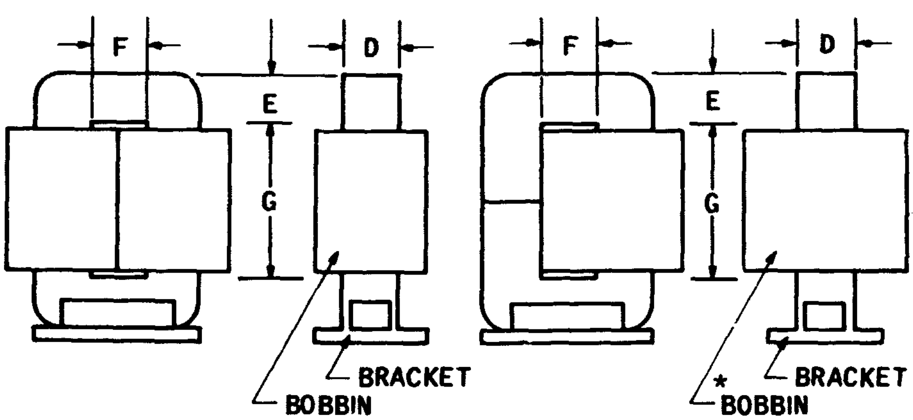


Figure 31. Nomograph for "C" core AL-15

Table 18. "C" Core AL-16

"C" CORE	AL-16			
	ENGLISH		METRIC	
Wa/Ac			2.08	
Wa x Ac	0.293	in^4	12.2	cm^4
Wa	0.781	in^2	5.037	cm^2
Ac (effective)	0.334	in^2	2.15	cm^2
lm	5.588	in	14.2	cm
CORE WT	0.462	lb	209	grams
COPPER WT	0.476	lb	216	grams
* MLT FULLWOUND	4.22	in	10.72	cm
$G/\sqrt{Ac}$			2.70	
Wa (effective) /Wa			0.891	
A_T	22.21	in^2	143.3	cm^2
D	0.750	in	1.905	cm
E	0.500	in	1.27	cm
F	0.500	in	1.27	cm
G	1.562	in	3.967	cm
BOBBIN	DORCO ELECTRONICS #		1-L-16	
LENGTH	1.497	in	3.80	cm
BUILD	0.465	in	1.18	cm
* Wa (effective)	0.696	in^2	4.49	cm^2
BRACKET	HALLMARK METAL		012-108-08	



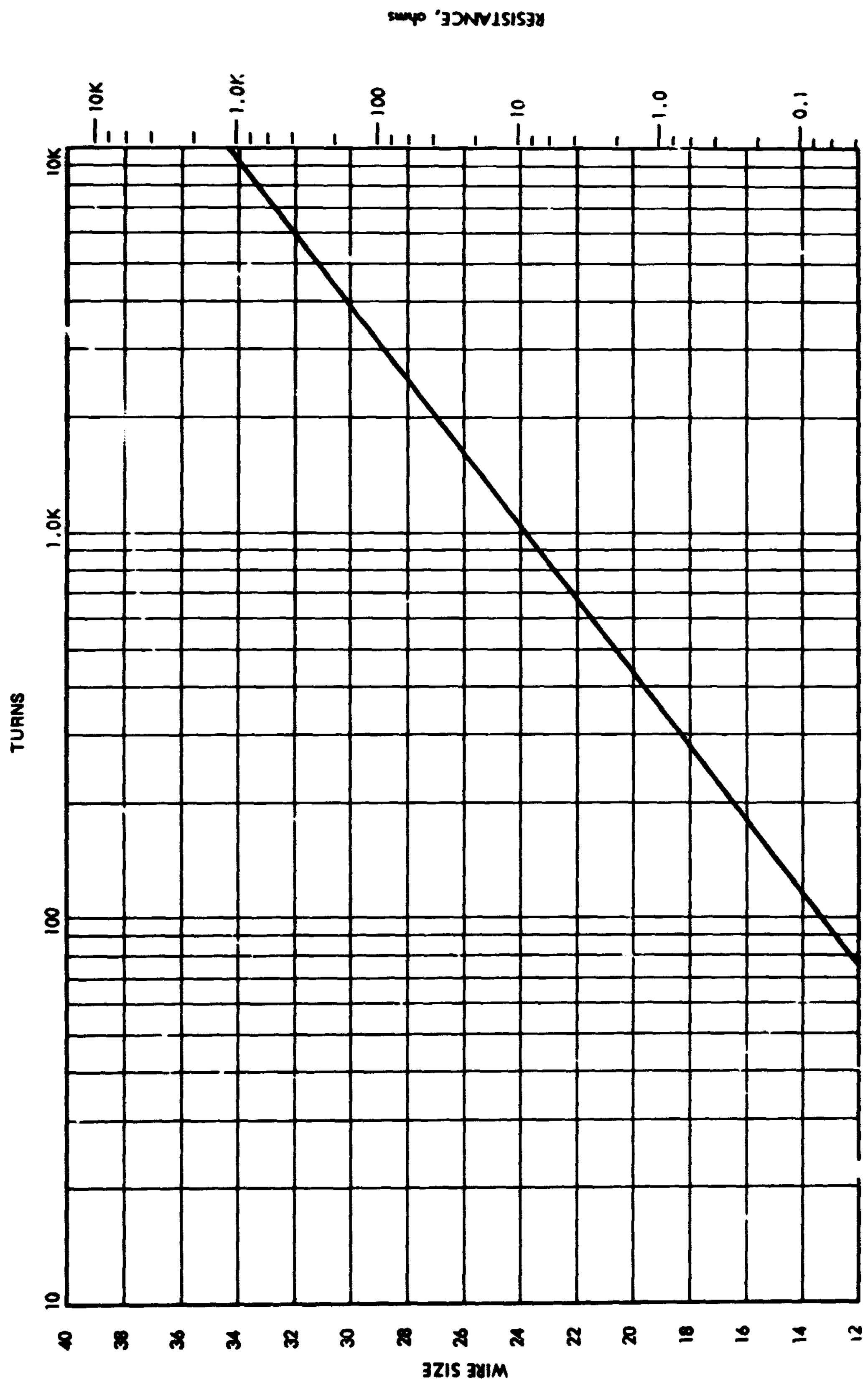
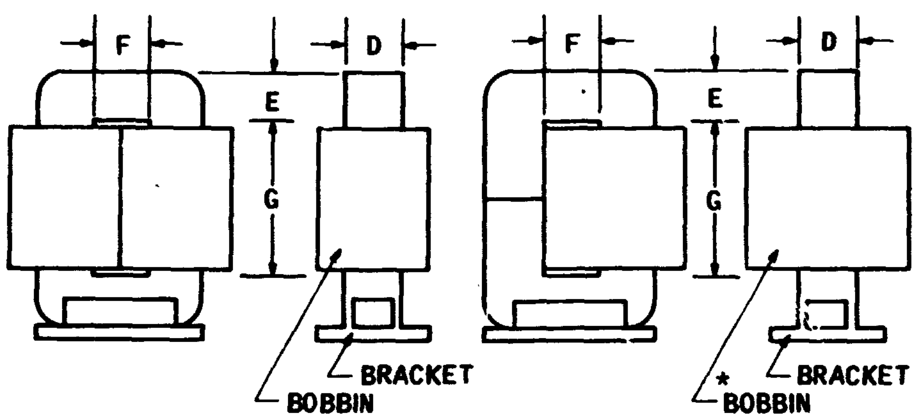


Figure 32. Nomograph for "C" core AL-16

Table 19. "C" Core AL-17

"C" CORE	AL-17			
	ENGLISH		METRIC	
Wa/Ac			1.56	
Wa x Ac	0.39	in^4	16.2	cm^4
Wa	0.781	in^2	5.037	cm^2
Ac (effective)	0.445	in^2	2.870	cm^2
lm	5.588	in	14.2	cm
CORE WT	0.617	lb	279	grams
COPPER WT	0.533	lb	241	grams
* MLT FULLWOUND	4.72	in	11.99	cm
$G/\sqrt{Ac}$			2.342	
Wa (effective) /Wa			0.891	
A_T	24.5	in^2	158	cm^2
D	1.000	in	2.54	cm
E	0.500	in	1.27	cm
F	0.500	in	1.27	cm
G	1.562	in	3.967	cm
BOBBIN	DORCO ELECTRONICS # 1-L-17			
LENGTH	1.497	in	3.80	cm
BUILD	0.465	in	1.18	cm
* Wa (effective)	0.696	in^2	4.49	cm^2
BRACKET	HALLMARK METALS # 10-108-08			



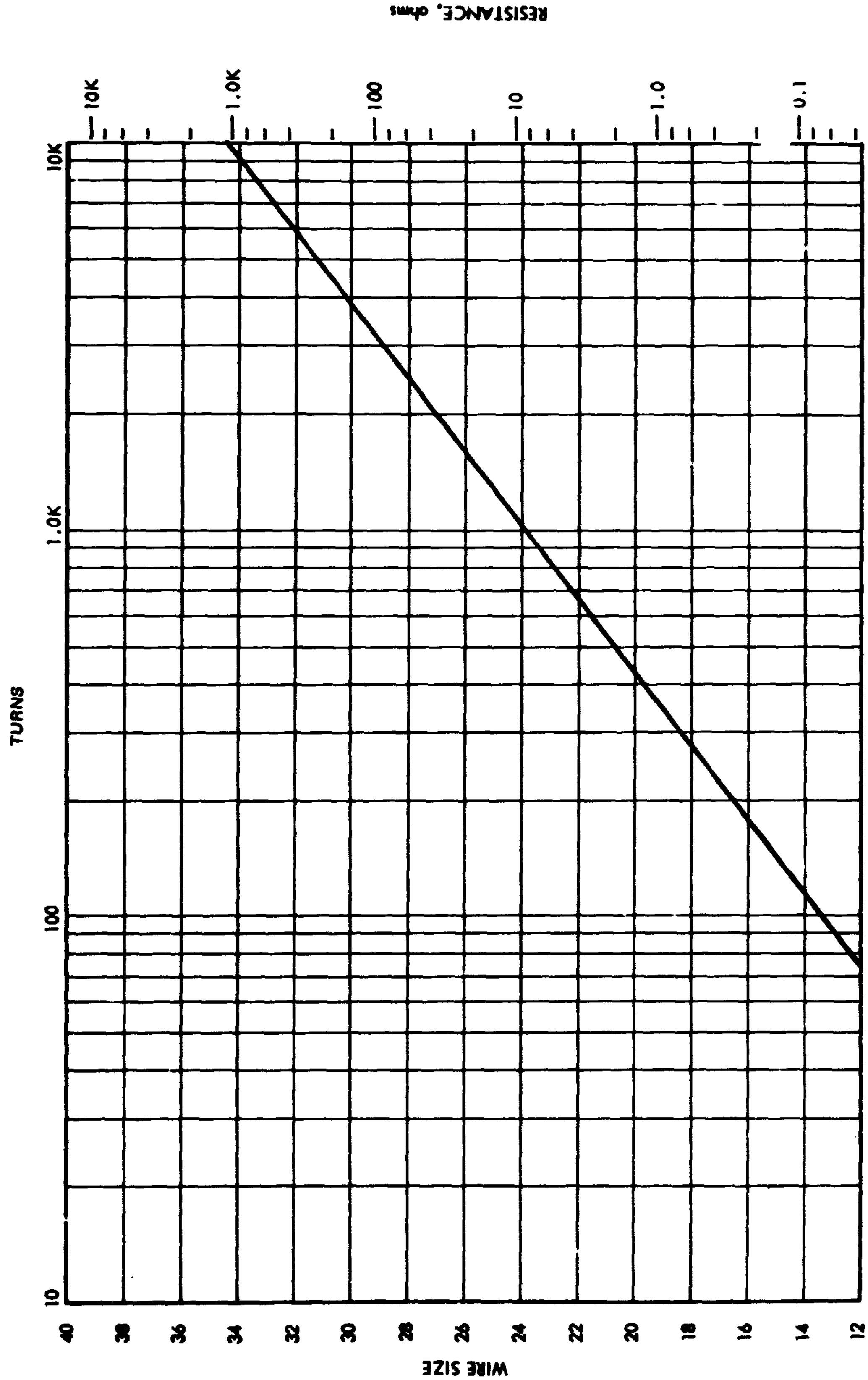
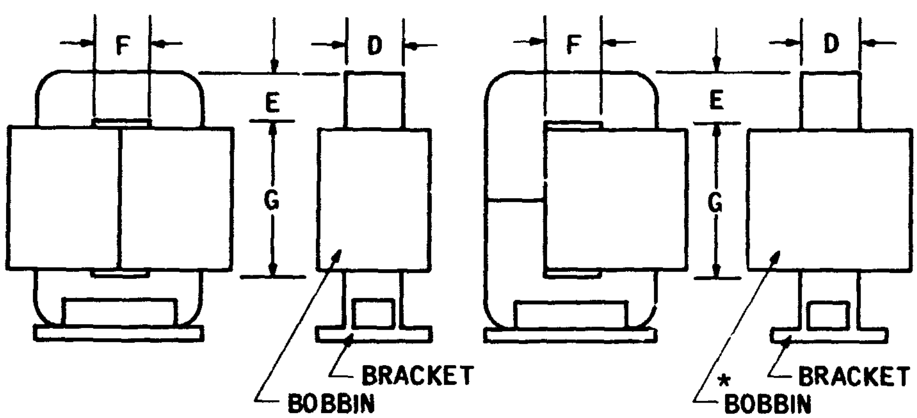


Figure 33. Nomograph for "C" core AL-17

Table 20. "C" Core AL-19

"C" CORE	AL-19			
	ENGLISH		METRIC	
Wa/Ac			1.95	
Wa x Ac	0.489	in^4	20.3	cm^4
Wa	0.977	in^2	6.30	cm^2
Ac (effective)	0.445	in^2	2.87	cm^2
lm	5.838	in	14.8	cm
CORE WT	0.644	lb	292	grams
COPPER WT	0.731	lb	332	grams
* MLT FULLWOUND	5.11	in	12.98	cm
$G/\sqrt{Ac}$			2.34	
Wa (effective) /Wa			0.903	
A_T	28.2	in^2	182	cm^2
D	1.000	in	2.54	cm
E	0.500	in	1.27	cm
F	0.625	in	1.587	cm
G	1.562	in	3.967	cm
BOBBIN	DORCO ELECTRONICS # 1-L-19			
LENGTH	1.497	in	3.80	cm
BUILD	0.590	in	1.498	cm
* Wa (effective)	0.883	in^2	5.69	cm^2
BRACKET	HALLMARK METALS # 10-110-08			



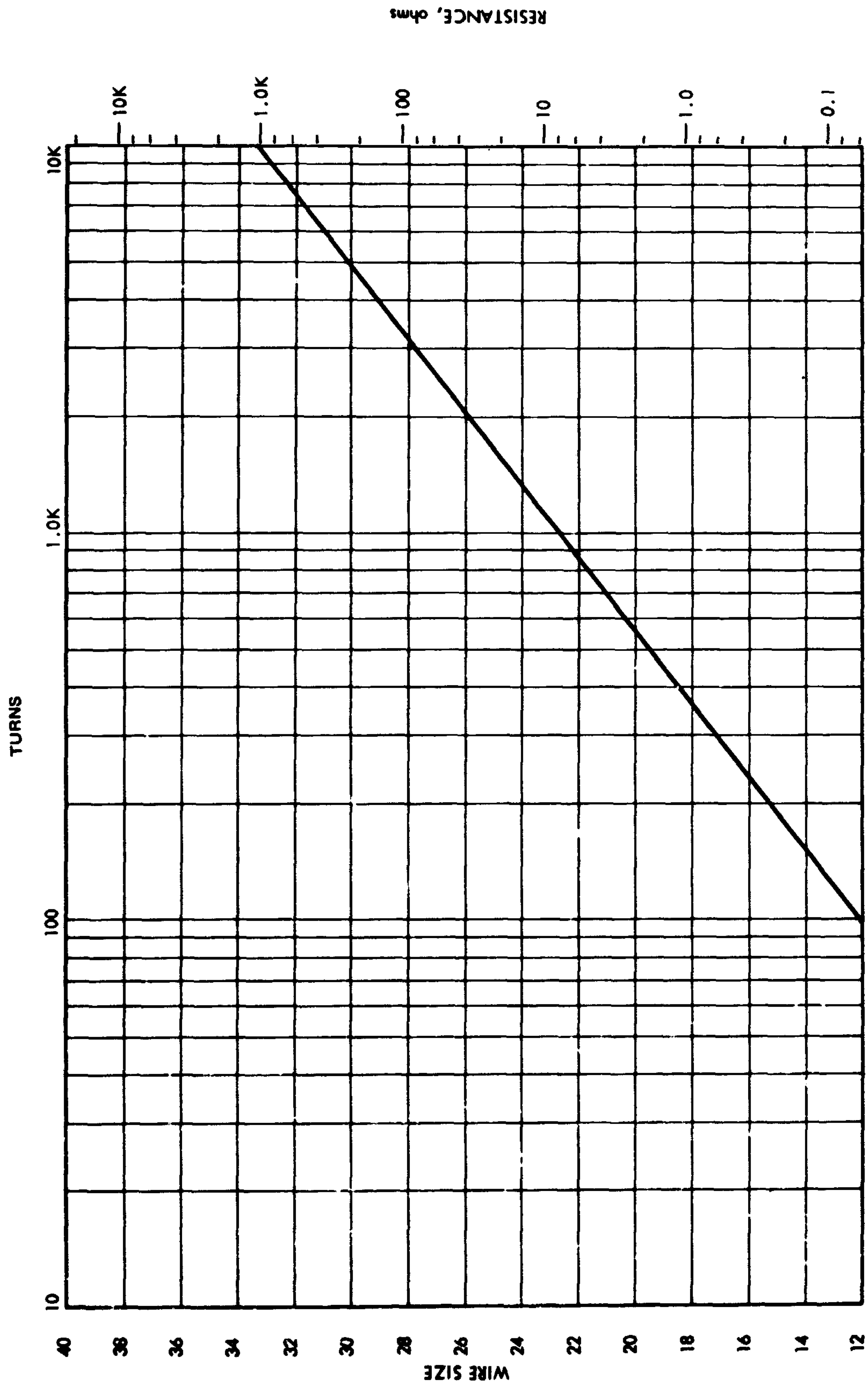
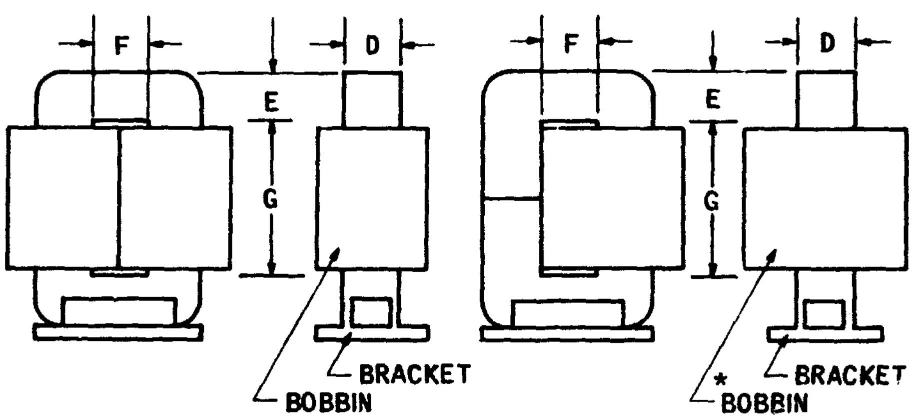


Figure 34. Nomograph for "C" core AL-19

Table 21. "C" Core AL-20

"C" CORE	AL-20			
	ENGLISH		METRIC	
Wa/Ac			1.56	
Wa x Ac	0.611	in^4	25.4	cm^4
Wa	0.977	in^2	6.30	cm^2
Ac (effective)	0.556	in^2	3.58	cm^2
lm	6.228	in	15.8	cm
CORE WT	0.859	lb	389	grams
COPPER WT	0.767	lb	348	grams
* MLT FULLWOUND	5.36	in	13.62	cm
$G/\sqrt{Ac}$			2.09	
Wa (effective) /Wa			0.903	
A_T	31.7	in^2	205	cm^2
D	1.000	in	2.54	cm
E	0.625	in	1.587	cm
F	0.625	in	1.587	cm
G	1.562	in	3.967	cm
BOBBIN	DORCO ELECTRONICS # 1-L-20			
LENGTH	1.497	in	3.80	cm
BUILD	0.590	in	1.498	cm
* Wa (effective)	0.883	in^2	5.69	cm^2
BRACKET	HALLMARK METALS # 10-114-010			



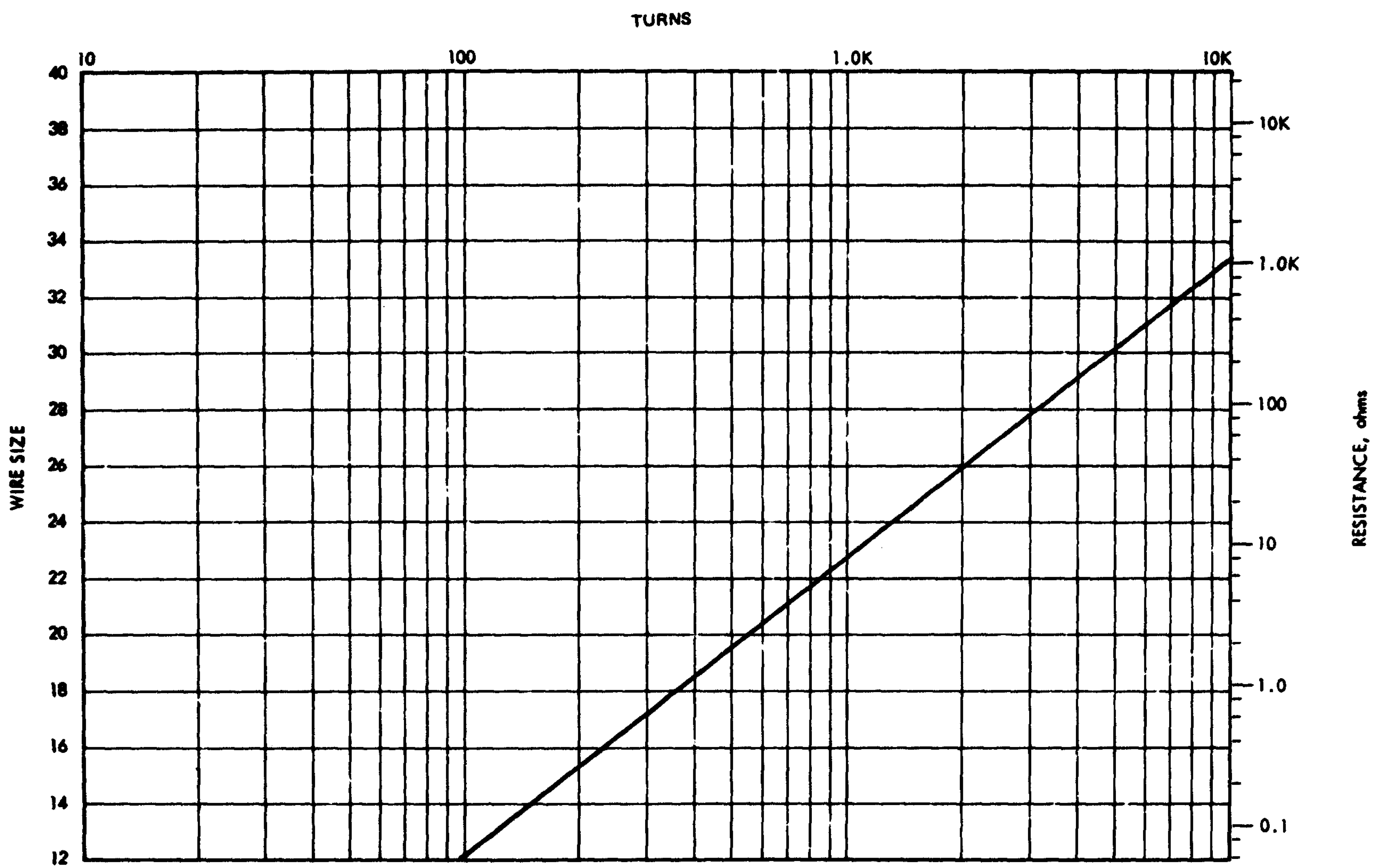
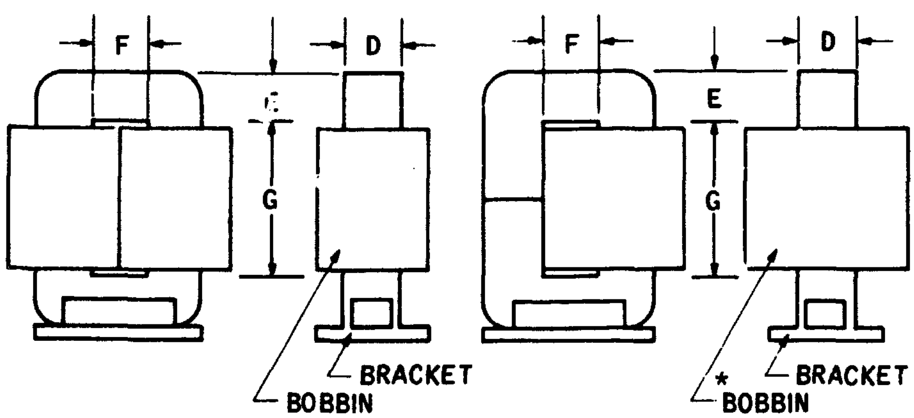


Figure 35. Nomograph for "C" core AL-20

Table 22. "C" Core AL-22

"C" CORE	AL-22			
	ENGLISH		METRIC	
Wa/Ac			1.94	
Wa x Ac	0.757	in^4	31.5	cm^4
Wa	1.21	in^2	7.804	cm^2
Ac (effective)	0.556	in^2	3.58	cm^2
lm	6.978	in	17.2	cm
CORE WT	0.961	lb	435	grams
COPPER WT	0.961	lb	435	grams
* MLT FULLWOUND	5.36	in	13.62	cm
$G/\sqrt{Ac}$			2.598	
Wa (effective) /Wa			0.912	
A_T	35.3	in^2	228	cm^2
D	1.000	in	2.54	cm
E	0.625	in	1.587	cm
F	0.625	in	1.587	cm
G	1.937	in	4.92	cm
BOBBIN	DORCO ELECTRONICS # 1-L-22			
LENGTH	1.872	in	4.75	cm
BUILD	0.590	in	1.498	cm
* Wa (effective)	1.10	in^2	7.12	cm^2
BRACKET	HALLMARK METALS # 10-114-010			



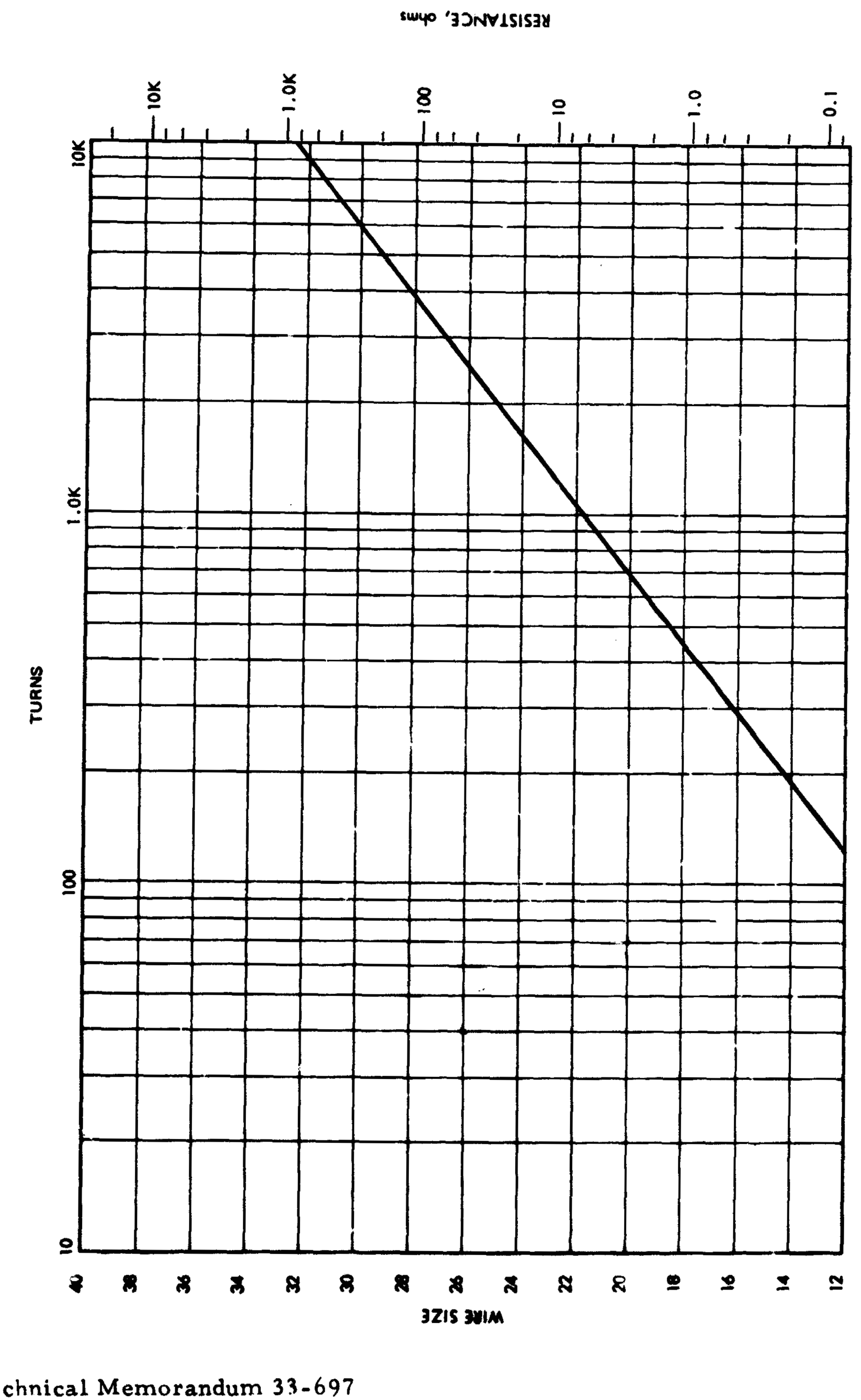
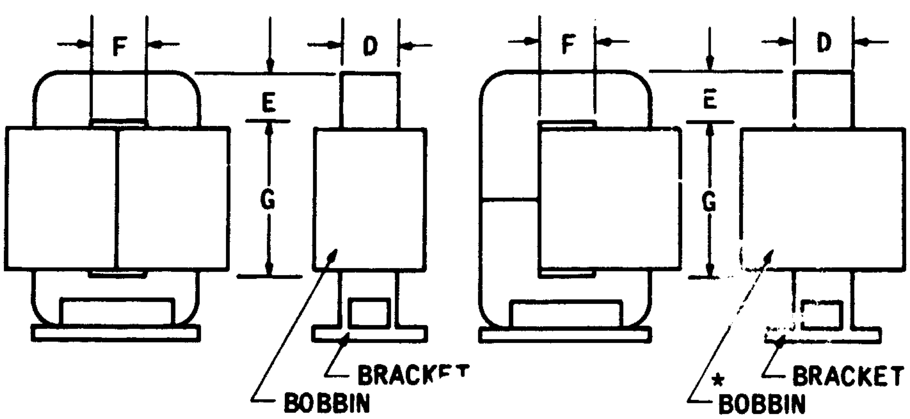


Figure 36. Nomograph for "C" core AL-22

Table 23. "C" Core AL-23

"C" CORE	AL-23	
	ENGLISH	METRIC
Wa/Ac		1.55
Wa x Ac	0.946 in^4	34.96 cm^4
Wa	1.21 in^2	7.804 cm^2
Ac (effective)	0.695 in^2	4.48 cm^2
lm	6.978 in	17.2 cm
CORE WT	1.203 lb	545 grams
COPPER WT	1.056 lb	479 grams
* MLT FULLWOUND	5.86 in	14.89 cm
$G/\sqrt{Ac}$		2.32
Wa (effective) /Wa		0.912
A_T	38.1 in^2	246 cm^2
D	1.250 in	3.175 cm
E	0.625 in	1.587 cm
F	0.625 in	1.587 cm
G	1.937 in	4.92 cm
BOBBIN	DORCO ELECTRONICS # 1-L-23	
LENGTH	1.872 in	4.75 cm
BUILD	0.590 in	1.498 cm
* Wa (effective)	1.10 in^2	7.12 cm^2
BRACKET	HALLMARK METALS # 14-114-010	



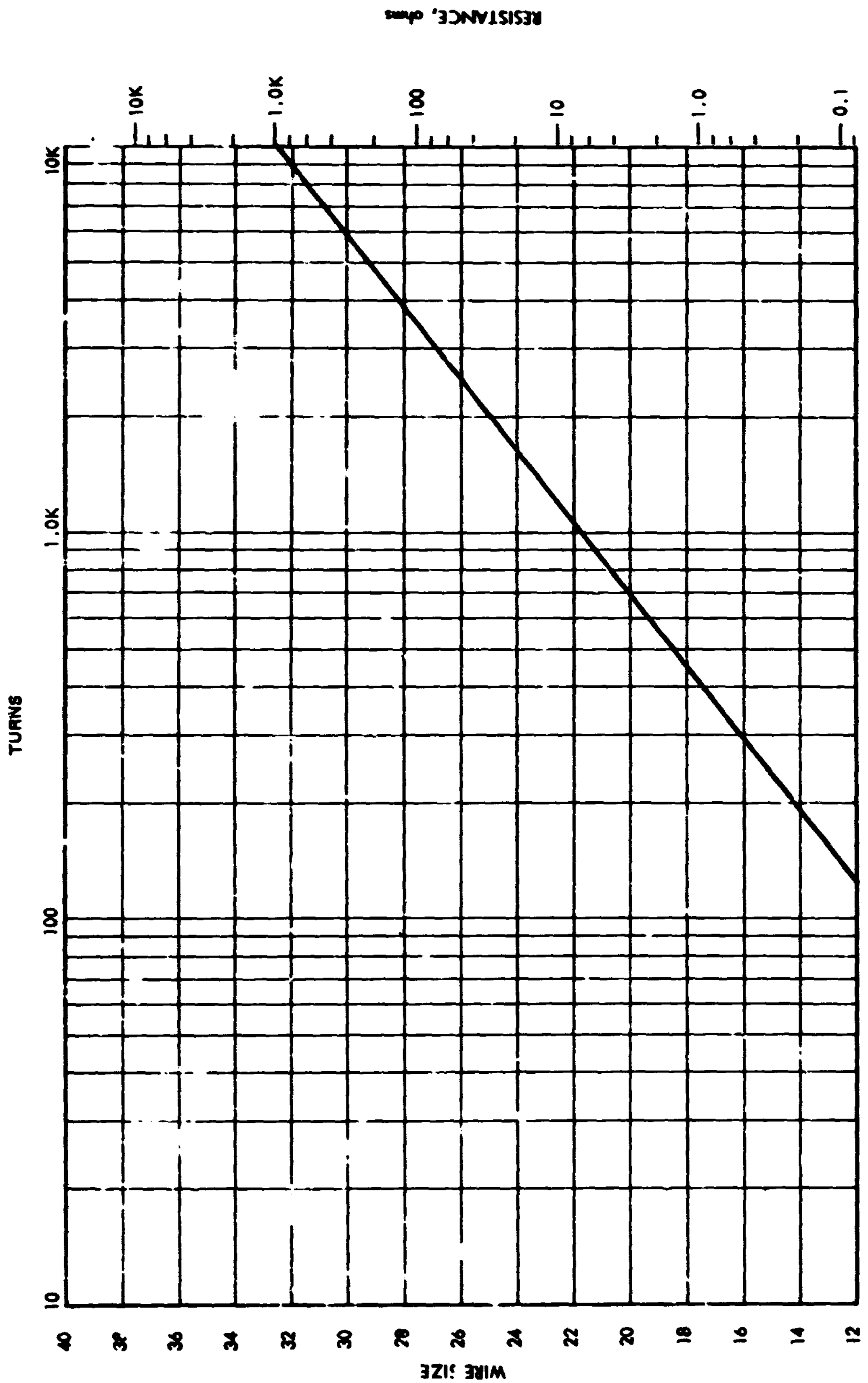
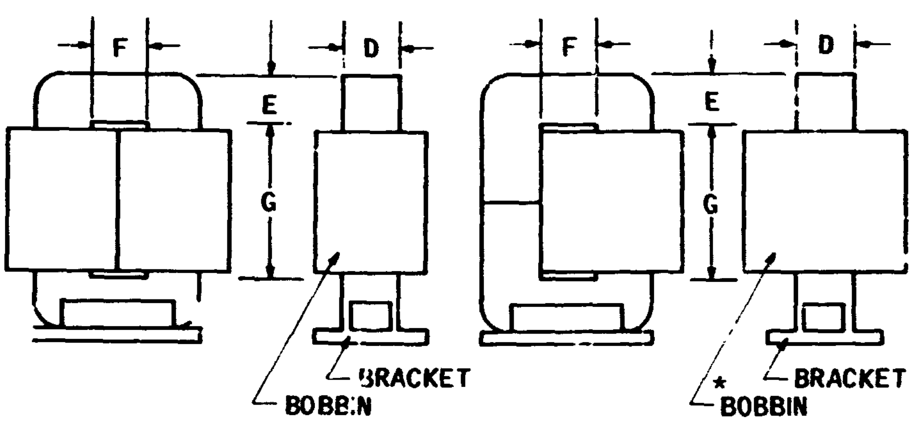


Figure 37. Nomograph for "C" core AL-23

Table 24. "C" Core AL-24

"C" CORE	AL-24			
	ENGLISH		METRIC	
Wa/Ac			2.77	
Wa x Ac	1.08	in^4	44.93	cm^4
Wa	1.73	in^2	11.16	cm^2
Ac (effective)	0.556	in^2	3.58	cm^2
lm	7.871	in	20.0	cm
CORE WT	1.086	lb	492	grams
COPPER WT	1.501	lb	680	grams
* MLT FULLWOUND	5.75	in	14.62	cm
$G/\sqrt{Ac}$			3.10	
Wa (effective) /Wa			0.929	
A_T	43.6	in^2	281.6	cm^2
D	1.000	in	2.54	cm
E	0.625	in	1.587	cm
F	0.750	in	1.905	cm
G	2.313	in	5.875	cm
BOBBIN	DORCO ELECTRONICS # 1-L-24			
LENGTH	2.248	in	5.709	cm
BUILD	0.715	in	1.816	cm
* Wa (effective)	1.607	in^2	10.37	cm^2
BRACKET	HALLMARK METALS # 10-200-010			



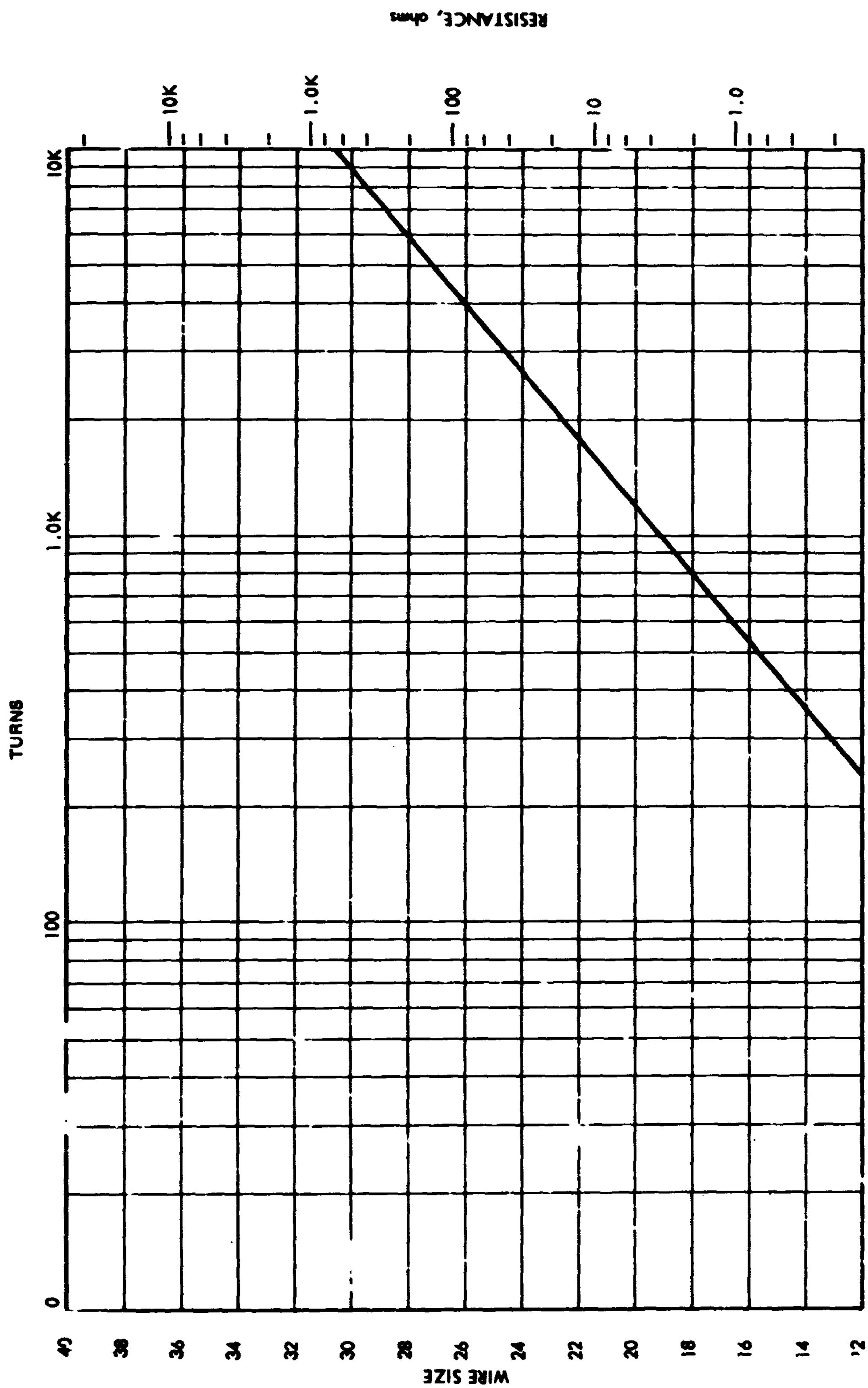
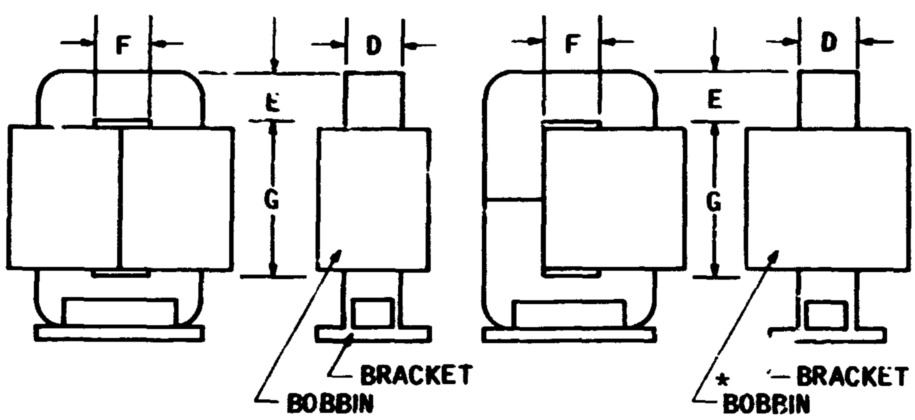


Figure 38. Nomograph for "C" core AL-24

Table 25. "C" Core AH-121

"C" CORE	AH-121			
	ENGLISH		METRIC	
Wa/Ac			2.65	
Wa x Ac	0.00588	in^4	0.250	cm^4
Wa	0.125	in^2	0.806	cm^2
Ac (effective)	0.042	in^2	0.270	cm^2
lm	1.78	in	4.520	cm
CORE WT	0.020	lb	9.06	grams
COPPER WT	0.031	lb	14.21	grams
* MLT FULLWOUND	1.88	in	4.79	cm
$G/\sqrt{Ac}$			2.40	
Wa (effective) /Wa			0.820	
A_T	3.25	in^2	20.96	cm^2
D	0.375	in	0.952	cm
E	0.125	in	0.317	cm
F	0.250	in	0.635	cm
G	0.500	in	1.250	cm
BOBBIN	DORCO ELECTRONICS # 1-H-121			
LENGTH	0.455	in	1.156	cm
BUILD	0.225	in	0.572	cm
* Wa (effective)	0.102	in^2	0.661	cm^2
BRACKET	HALLMARK METALS # 06-008-02			



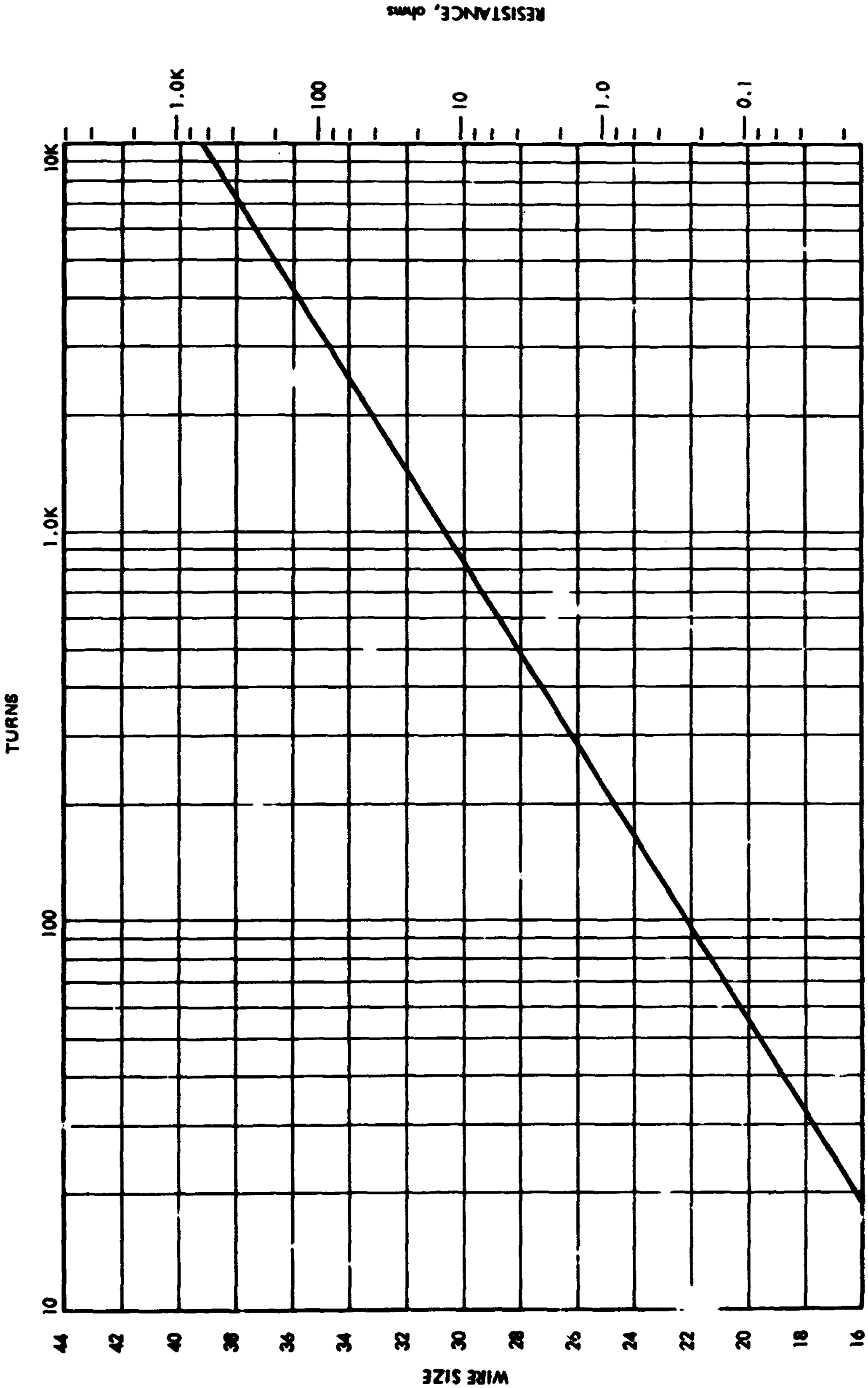
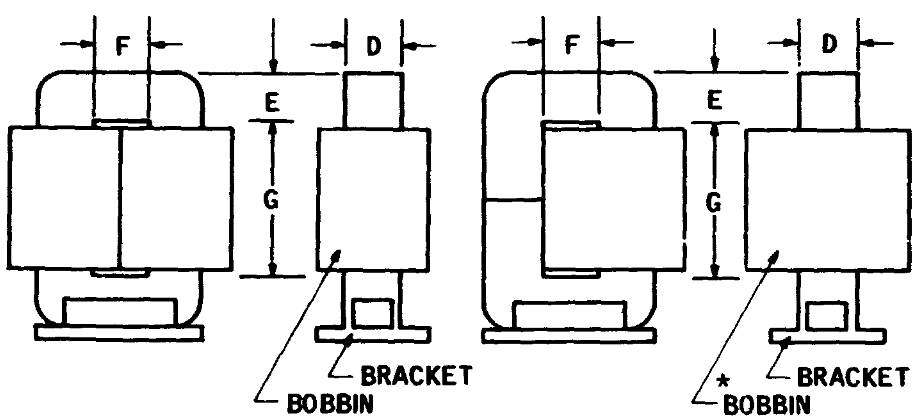


Figure 39. Nomograph for "C" core AH-121

Table 26. "C" Core AH-231

"C" CORE	AH-231			
	ENGLISH		METRIC	
Wa/Ac			2.19	
Wa x Ac	0.0109	in^4	0.45	cm^4
Wa	0.156	in^2	1.006	cm^2
Ac (effective)	0.064	in^2	0.412	cm^2
lm	2.23	in	5.66	cm
CORE WT	0.039	lb	17.66	grams
COPPER WT	0.042	lb	19.28	grams
* MLT FULLWOUND	2.01	in	5.10	cm
$G/\sqrt{Ac}$			2.48	
Wa (effective) /Wa			0.836	
A_T	4.27	in^2	27.58	cm^2
D	0.375	in	0.952	cm
E	0.187	in	0.476	cm
F	0.250	in	0.635	cm
G	0.625	in	1.587	cm
BOBBIN	DORCO ELECTRONICS # 1-H-231			
LENGTH	0.580	in	1.473	cm
BUILD	0.225	in	0.571	cm
* Wa (effective)	0.130	in^2	0.842	cm^2
BRACKET	HALLMARK METALS # 06-010-03			



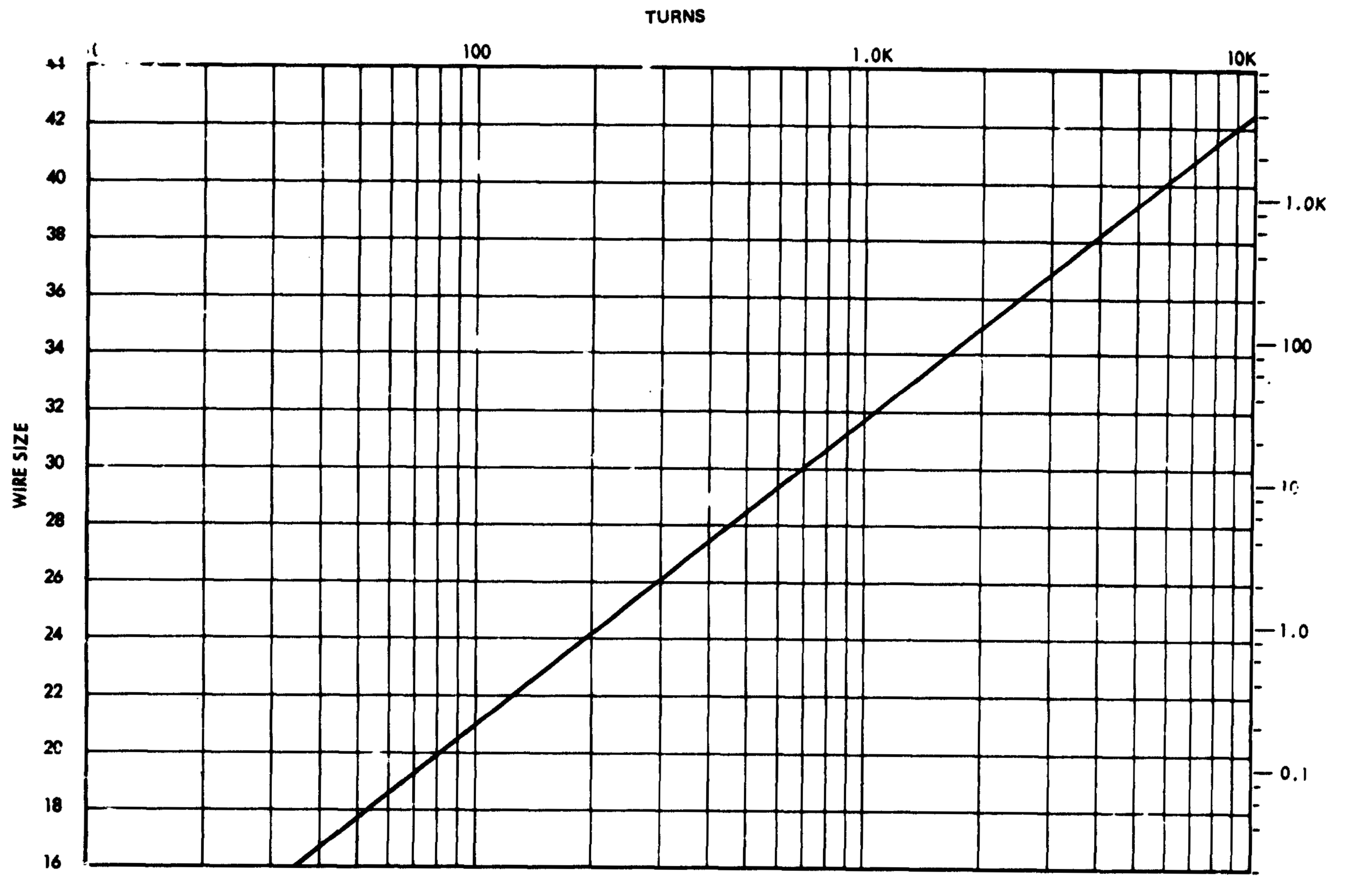
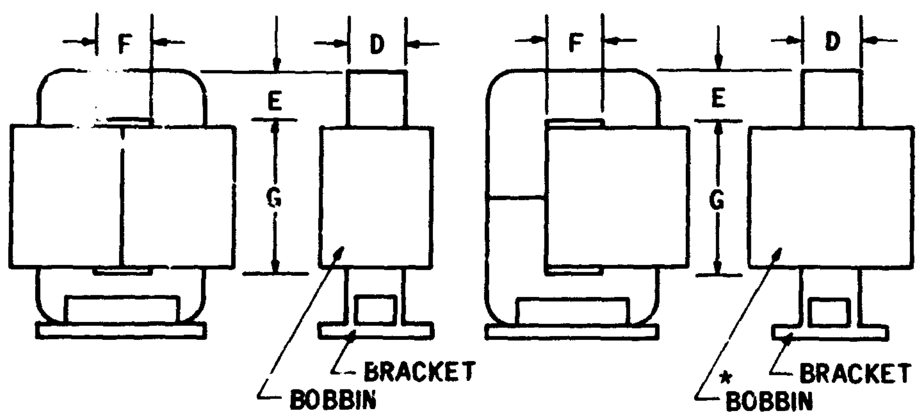


Figure 40. Nomograph for "C" core AH-231

Table 27. "C" Core AH-99

"C" CORE	AH-99			
	ENGLISH		METRIC	
Wa/Ac			3.81	
Wa x Ac	0.0257	in^4	1.06	cm^4
Wa	0.313	in^2	2.02	cm^2
Ac (effective)	0.074	in^2	0.477	cm^2
lm	3.20	in	8.12	cm
CORE WT	0.065	lb	29.44	grams
COPPER WT	0.101	lb	45.90	grams
* MLT FULLWOUND	2.27	in	5.77	cm
$G/\sqrt{Ac}$			3.68	
Wa (effective) /Wa			0.877	
A_T	6.97	in^2	44.97	cm^2
D	0.375	in	0.952	cm
E	0.219	in	0.556	cm
F	0.313	in	0.794	cm
G	1.00	in	2.54	cm
BOBBIN	DORCO ELECTRONICS # 1-H-99			
LENGTH	0.955	in	2.423	cm
BUILD	0.288	in	0.732	cm
* Wa (effective)	0.275	in^2	1.772	cm^2
BRACKET	HALLMARK METALS # 06-012-04			



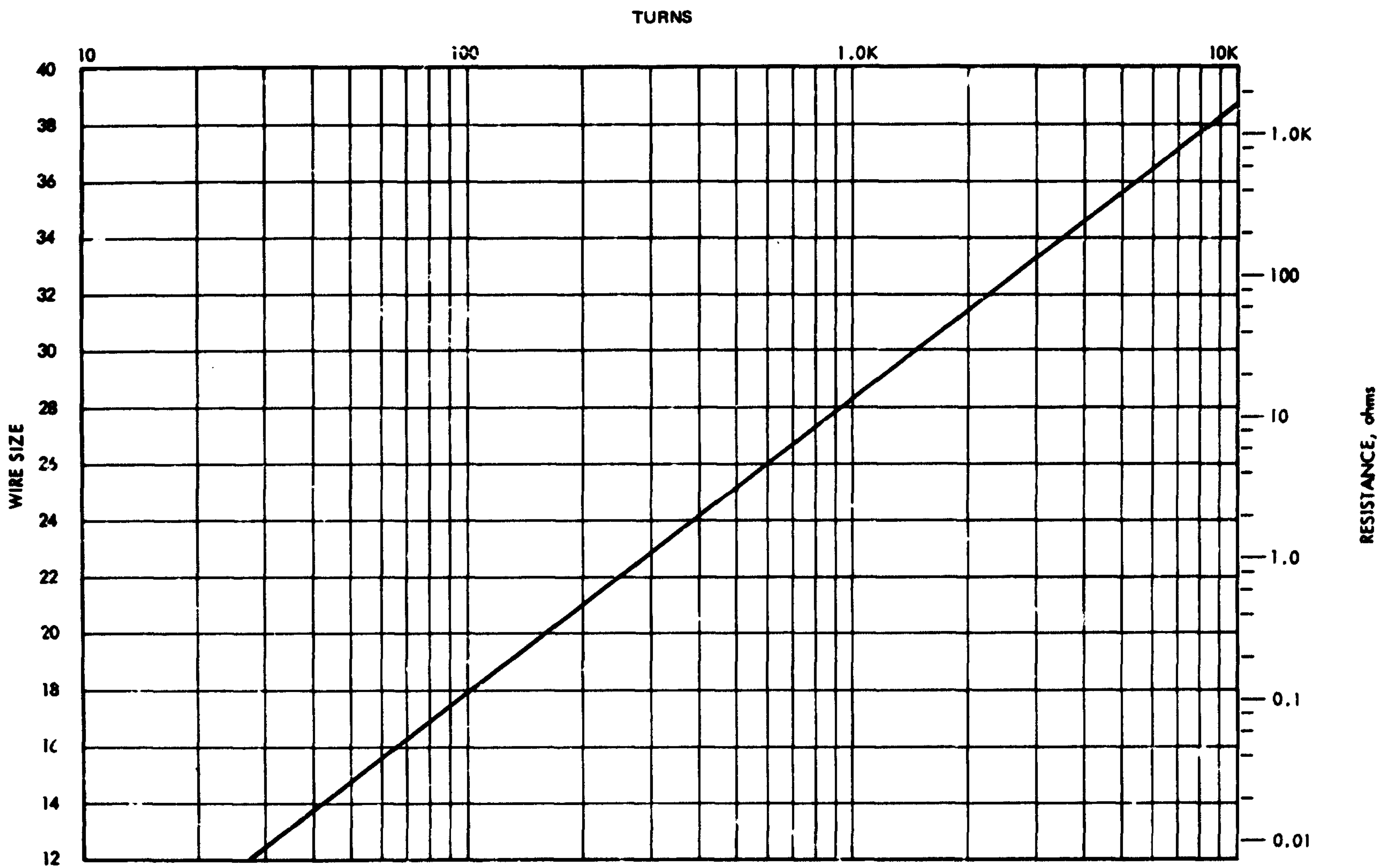
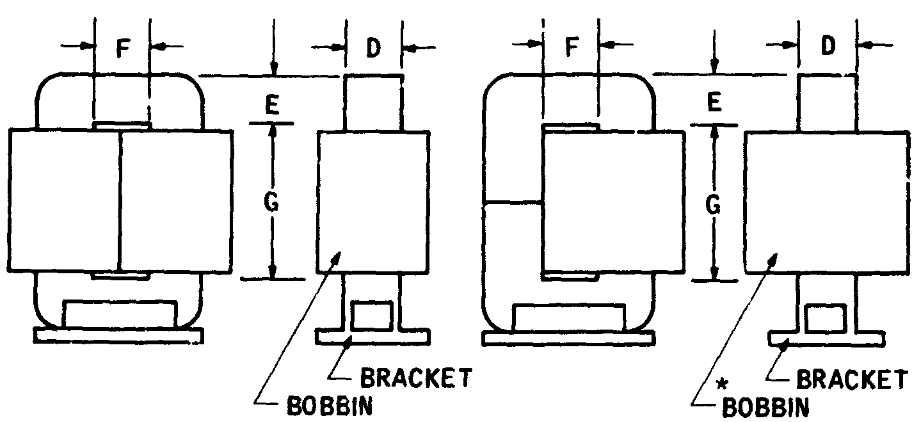


Figure 41. Nomograph for "C" core AH-99

Table 28. "C" Core AH-115

"C" CORE	AH-115			
	ENGLISH		METRIC	
Wa/Ac			3.98	
Wa x Ac	0.0353	in^4	1.46	cm^4
Wa	0.313	in^2	2.02	cm^2
Ac (effective)	0.085	in^2	0.546	cm^2
lm	3.42	in	8.68	cm
CORE WT	0.080	lb	36.24	grams
COPPER WT	0.104	lb	47.17	grams
* MLT FULLWOUND	2.33	in	5.93	cm
$G/\sqrt{Ac}$			3.45	
Wa (effective) /Wa			0.877	
A_T	7.38	in^2	47.62	cm^2
D	0.375	in	0.952	cm
E	0.250	in	0.635	cm
F	0.313	in	0.795	cm
G	1.00	in	2.54	cm
BOBBIN	DORCO ELECTRONICS # 1-H-115			
LENGTH	0.955	in	2.423	cm
BUILD	0.288	in	0.731	cm
* Wa (effective)	0.275	in^2	1.772	cm^2
BRACKET	HALLMARK METALS # 06-014-04			



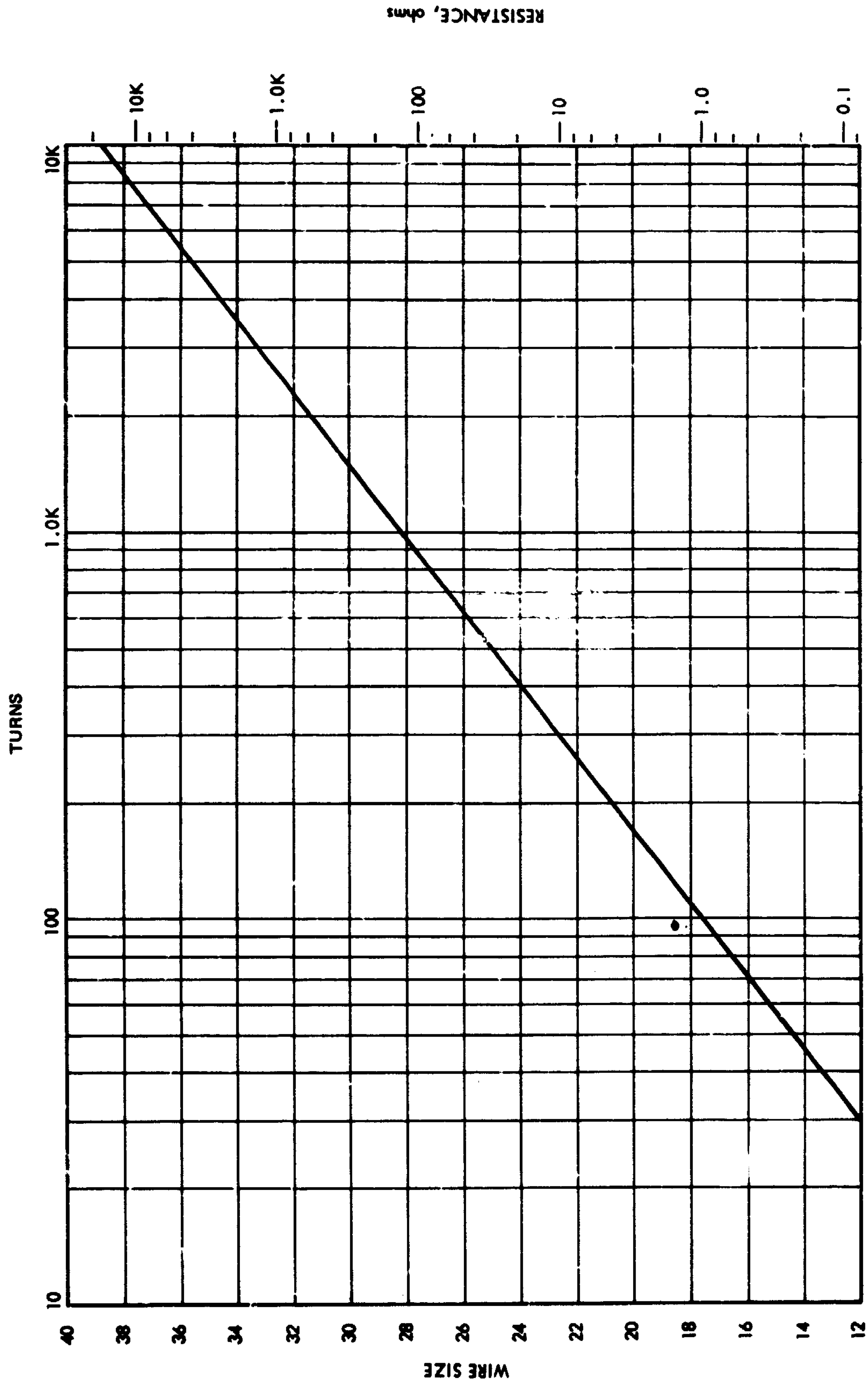
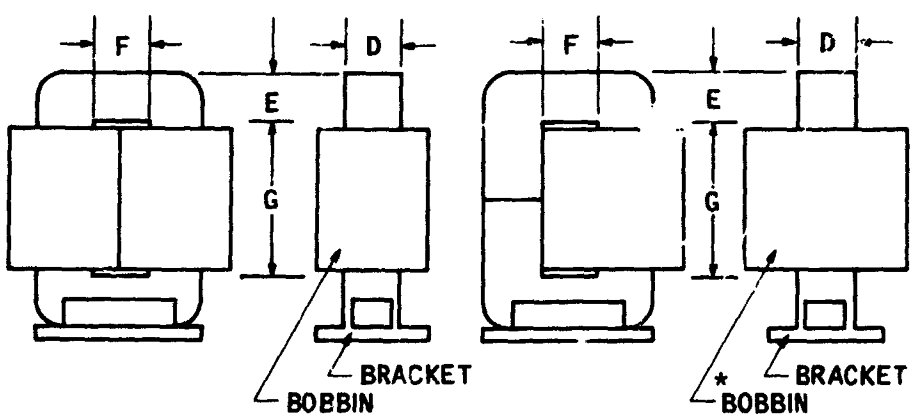


Figure 42. Nomograph for "C" core AH-115

Table 29. "C" Core AH-126

"C" CORE	AH-126			
	ENGLISH		METRIC	
Wa/Ac			3.20	
Wa x Ac	0.0439	in^4	1.82	cm^4
Wa	0.375	in^2	2.419	cm^2
Ac (effective)	0.105	in^2	0.679	cm^2
lm	3.62	in	9.19	cm
CORE WT	0.106	lb	48.0	grams
COPPER WT	0.144	lb	65.2	grams
* MLT FULLWOUND	2.65	in	6.74	cm
$G/\sqrt{Ac}$			3.09	
Wa (effective) /Wa			0.890	
A_T	9.35	in^2	60.30	cm^2
D	0.375	in	0.952	cm
E	0.313	in	0.794	cm
F	0.375	in	0.952	cm
G	1.00	in	2.54	cm
BOBBIN	DORCO ELECTRONICS # 1-H-126			
LENGTH	0.955	in	2.425	cm
BUILD	0.350	in	0.889	cm
* Wa (effective)	0.334	in^2	2.155	cm^2
BRACKET	HALLMARK METALS # 06-100-05			



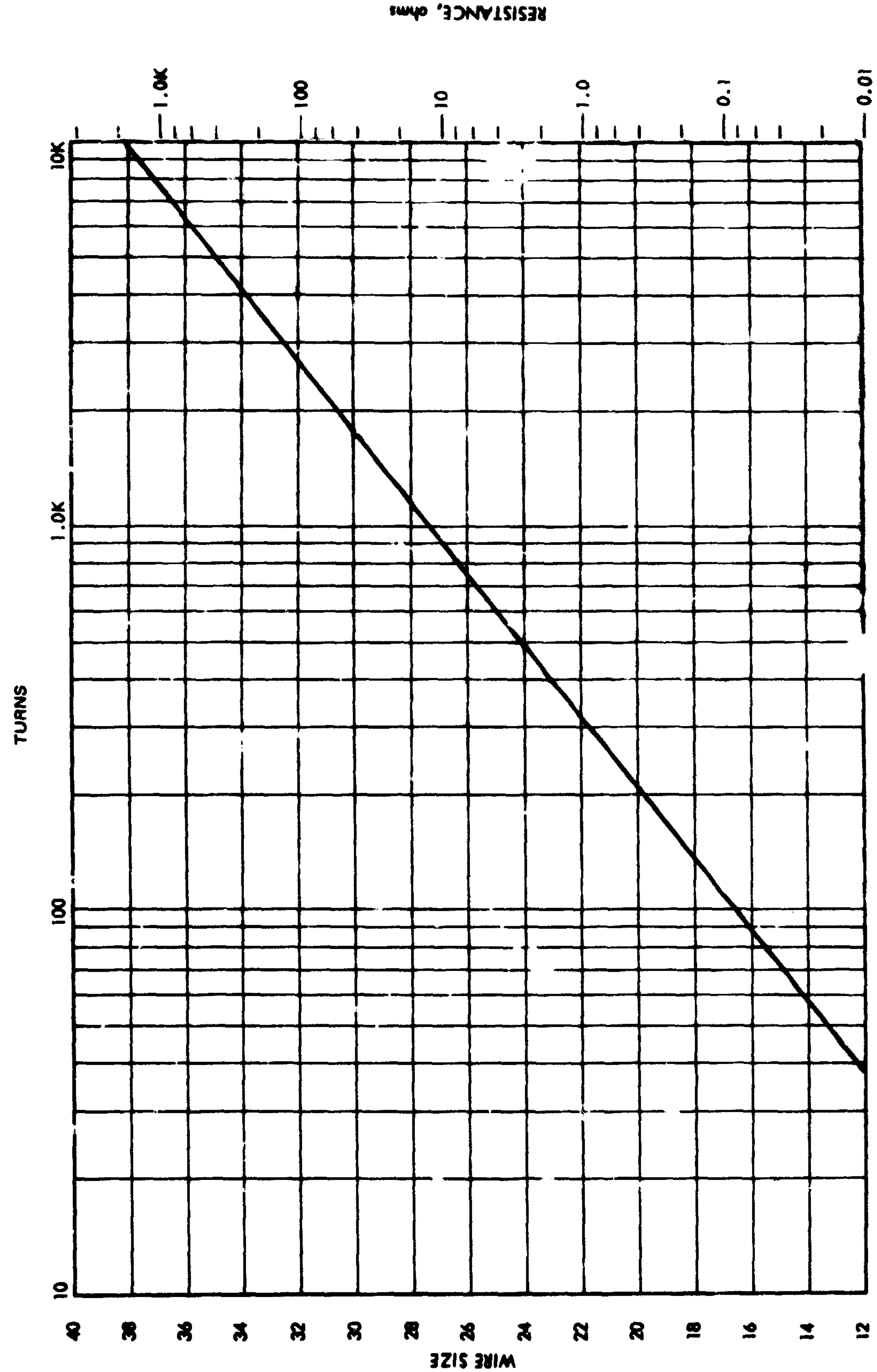
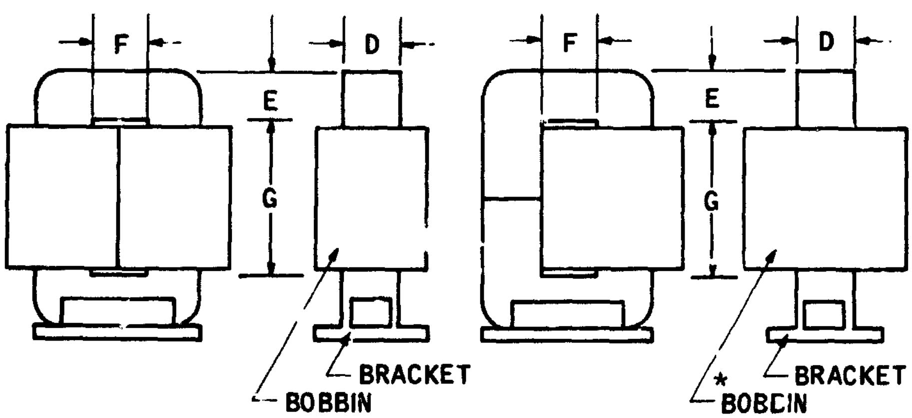


Figure 43. Nomograph for "C" core AH-126

Table 30. "C" Core AH-382

"C" CORE	AH-382			
	ENGLISH		METRIC	
Wa/Ac			2.40	
Wa x Ac	0.0585	in^4	2.43	cm^4
Wa	0.375	in^2	[illegible]	cm^2
Ac (effective)	0.140	in^2	0.905	cm^2
lm	3.42	in	8.68	cm
CORE WT	0.133	lb	60.25	grams
COPPER WT	0.164	lb	74.4	grams
• MLT FULLWOUND	3.02	in	7.69	cm
$G/\sqrt{Ac}$			2.67	
Wa (effective) /Wa			0.890	
A_T	9.81	in^2	63.29	cm^2
D	0.625	in	1.587	cm
E	0.250	in	0.635	cm
F	0.375	in	0.952	cm
G	1.00	in	2.54	cm
BOBBIN	DORCO ELECTRONICS #		1-H-382	
LENGTH	0.955	in	2.425	cm
BUILD	0.350	in	0.889	cm
* Wa (effective)	0.334	in^2	2.155	cm^2
BRACKET	HALLMARK METALS #		010-014-04	



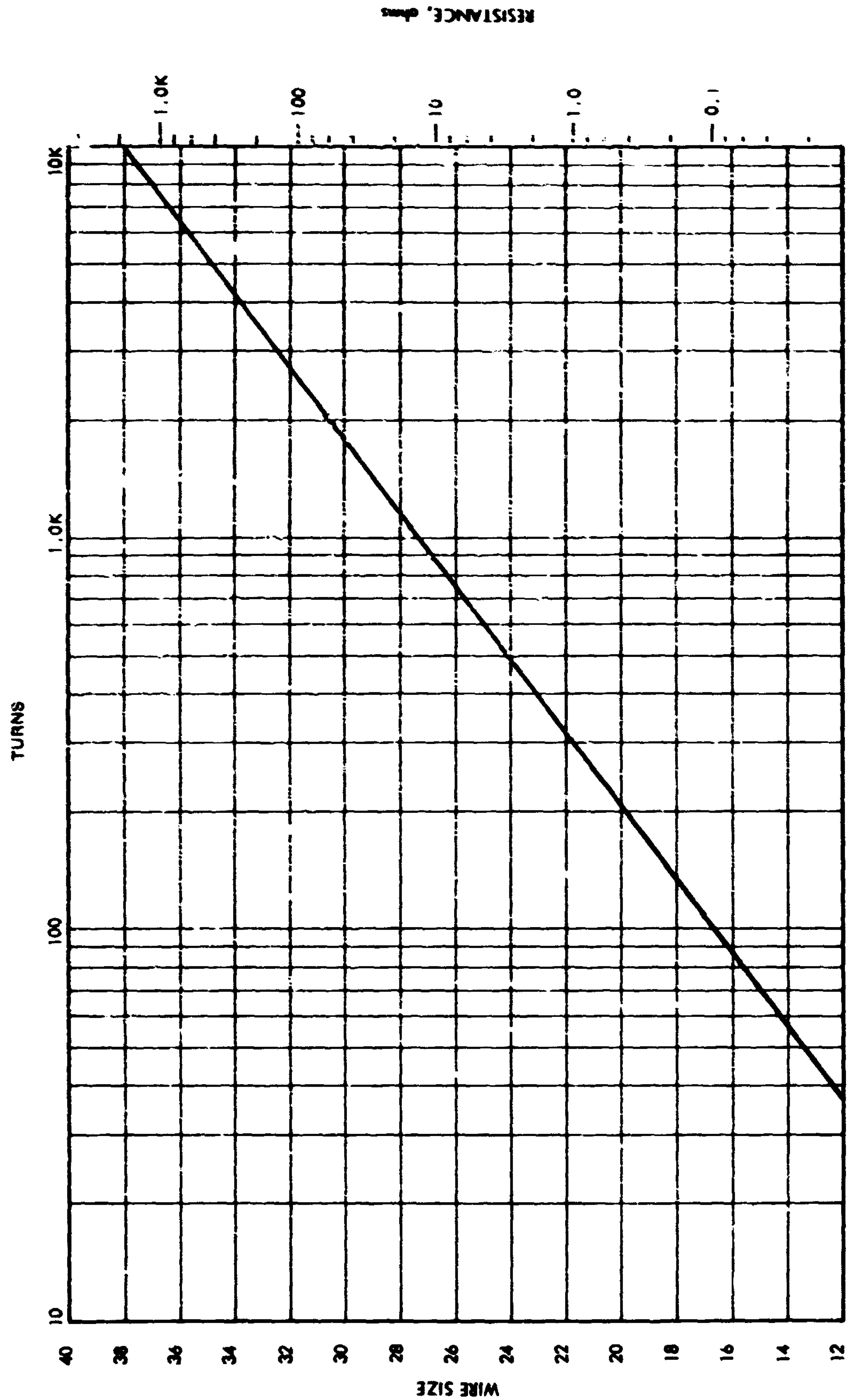
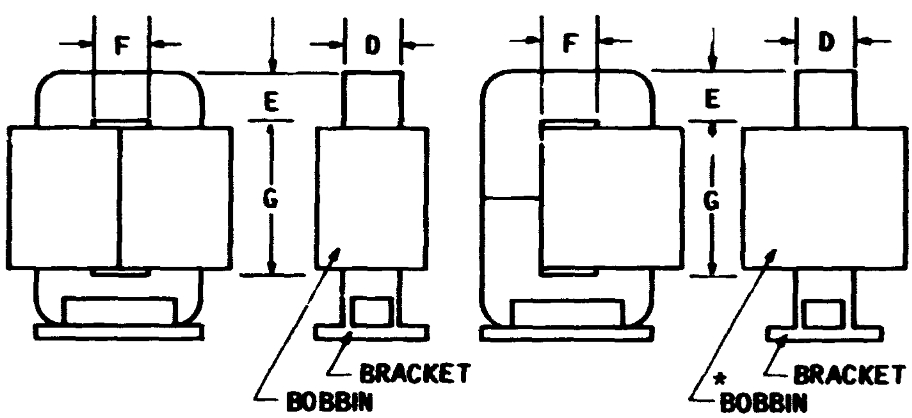


Figure 44. Nomograph for "C" core AH-382

C-2

Table 31. "C" Core AH-1

"C" CORE	AH-1			
	ENGLISH		METRIC	
Wa/Ac			4.50	
Wa x Ac	0.0704	in^4	2.92	cm^4
Wa	0.563	in^2	3.63	cm^2
Ac (effective)	0.113	in^2	0.726	cm^2
lm	3.92	in	9.95	cm
CORE WT	0.122	lb	55.26	grams
COPPER WT	0.264	lb	119.6	grams
* MLT FULLWOUND	3.17	in	8.05	cm
$G/\sqrt{Ac}$			3.36	
Wa (effective) /Wa			0.911	
A_T	12.25	in^2	79.01	cm^2
D	0.500	in	1.270	cm
E	0.250	in	0.635	cm
F	0.500	in	1.270	cm
G	1.125	in	2.857	cm
BOBBIN	DORCO ELECTRONICS # 1-H-1			
LENGTH	1.080	in	2.74	cm
BUILD	0.475	in	1.21	cm
* Wa (effective)	0.513	in^2	3.31	cm^2
BRACKET	HALLMARK METALS # 08-100-04			



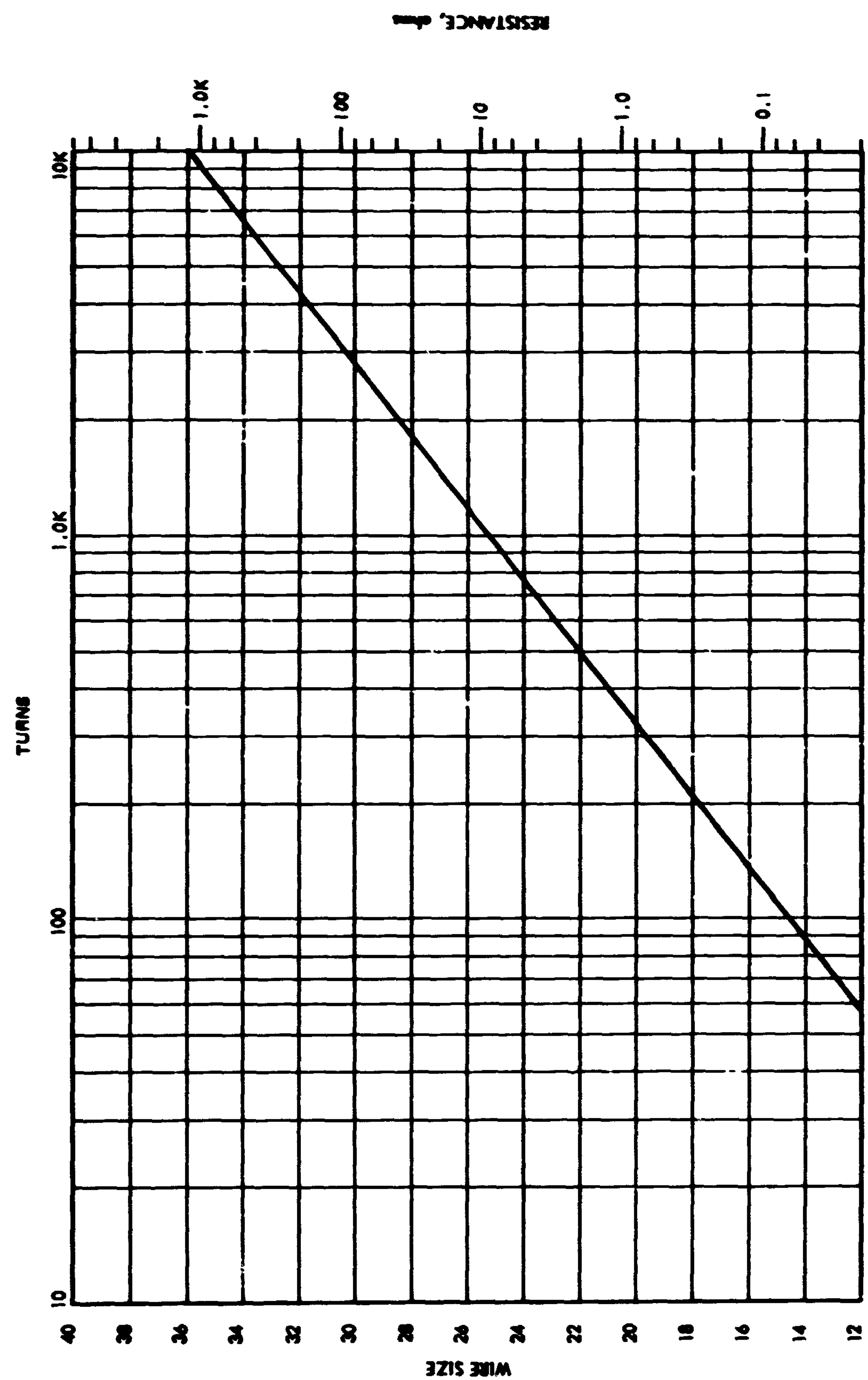
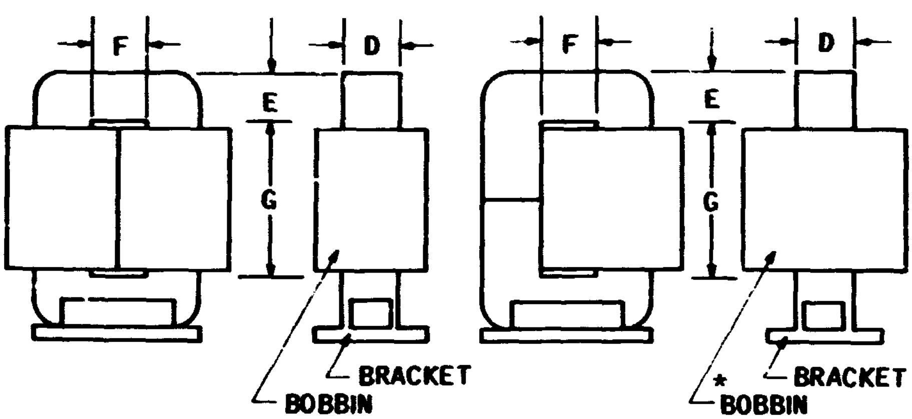


Figure 45. Nomograph for "C" core AH-1

Table 32. "C" Core AH-40

"C" CORE	AH-40	
	ENGLISH	METRIC
Wa/Ac		5.24
Wa x Ac	0.0820 in^4	3.41 cm^4
Wa	0.656 in^2	4.23 cm^2
Ac (effective)	0.113 in^2	0.726 cm^2
lm	4.30 in	10.92 cm
CORE WT	0.134 lb	60.70 grams
COPPER WT	0.309 lb	140.2 grams
• MLT FULLWOUND	3.17 in	8.05 cm
$G/\sqrt{Ac}$		3.91
Wa (effective) /Wa		0.917
A_T	13.37 in^2	86.28 cm^2
D	0.500 in	1.270 cm
E	0.250 in	0.635 cm
F	0.500 in	1.270 cm
G	1.313 in	3.334 cm
BOBBIN	DORCO ELECTRONICS # 1-H-40	
LENGTH	1.268 in	3.22 cm
BUILD	0.475 in	1.206 cm
* Wa (effective)	0.602 in^2	3.88 cm^2
BRACKET	HALLMARK METALS # 08-100-04	



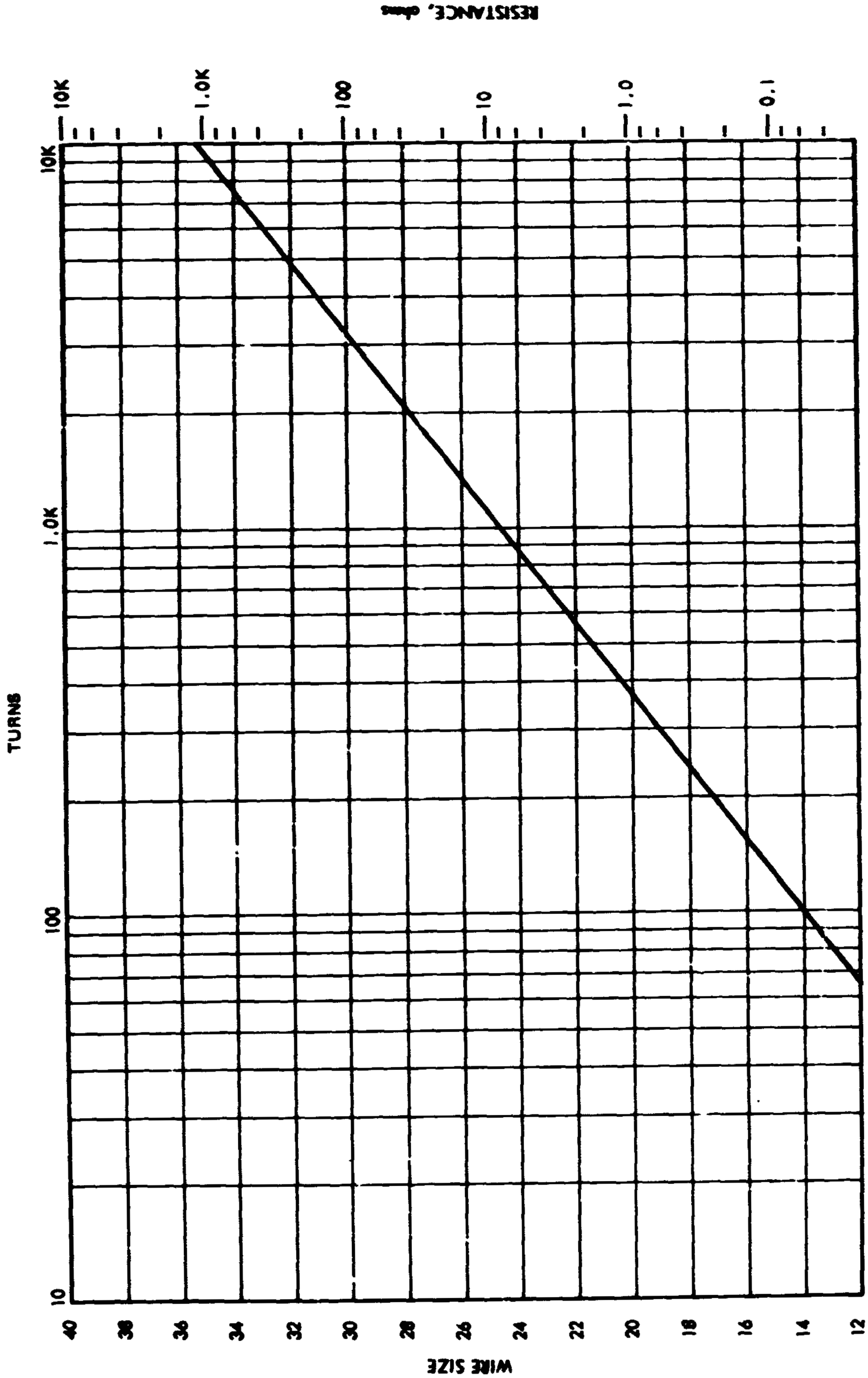
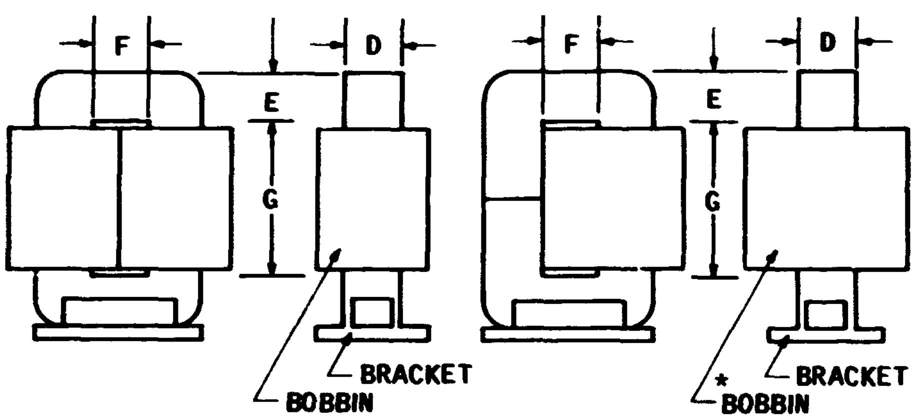


Figure 46. Nomograph for "C" core AH-40

Table 33. "C" Core AH-41

"C" CORE	AH-41			
	ENGLISH		METRIC	
Wa/Ac			4.20	
Wa x Ac	0.102	in^4	4.24	cm^4
Wa	0.656	in^2	4.23	cm^2
Ac (effective)	0.140	in^2	0.906	cm^2
lm	4.30	in	10.92	cm
CORE WT	0.167	lb	75.65	grams
COPPER WT	0.334	lb	151.37	grams
• MLT FULLWOUND	3.42	in	8.69	cm
$G/\sqrt{Ac}$			3.50	
Wa (effective) /Wa			0.917	
A_T	14.20	in^2	91.59	cm^2
D	0.625	in	1.587	cm
E	0.250	in	0.635	cm
F	0.500	in	1.270	cm
G	1.313	in	3.334	cm
BOBBIN	DORCO ELECTRONICS #		1-H41	
LENGTH	1.268	in	3.22	cm
BUILD	0.475	in	1.206	cm
* Wa (effective)	0.602	in^2	3.88	cm^2
BRACKET	HALLMARK METALS #		010-100-04	



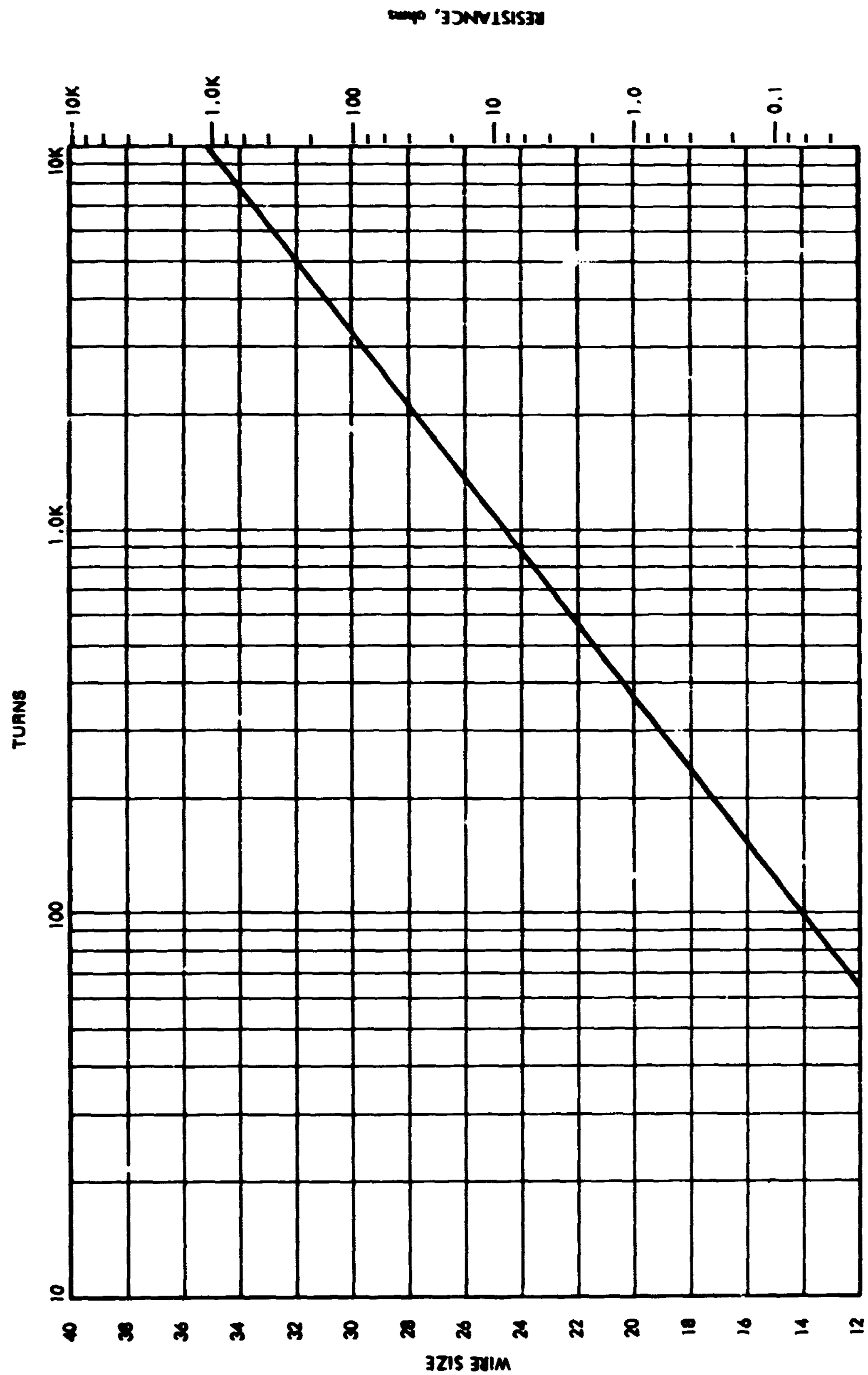
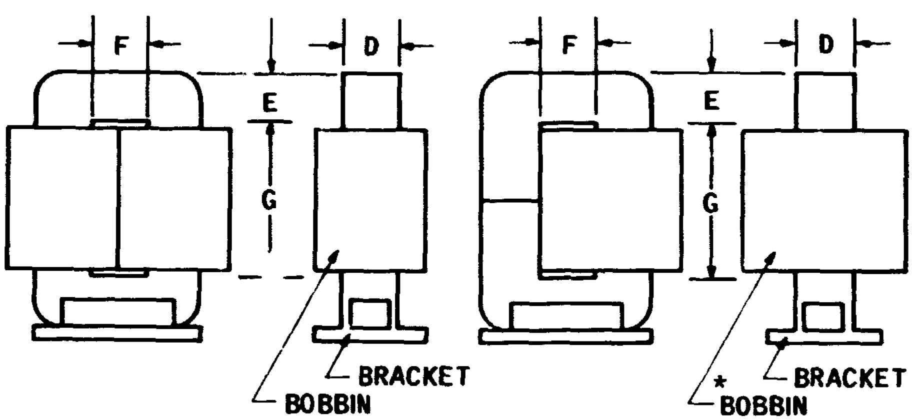


Figure 47. Nomograph for "C" core AH-41

Table 34. "C" Core AH-42

"C" CORE	AH-42			
	ENGLISH		METRIC	
Wa/Ac			4.20	
Wa x Ac	0.123	in^4	5.11	cm^4
Wa	0.656	in^2	4.23	cm^2
Ac (effective)	0.169	in^2	1.091	cm^2
lm	4.3	in	10.92	cm
CORE WT	0.201	lb	91.05	grams
COPPER WT	0.353	lb	160.25	grams
* MLT FULLWOUND	3.62	in	9.20	cm
$G/\sqrt{Ac}$			3.19	
Wa (effective) /Wa			0.917	
A_T	15.03	in^2	96.97	cm^2
D	0.750	in	1.905	cm
E	0.250	in	0.635	cm
F	0.500	in	1.270	cm
G	1.313	in	3.334	cm
BOBBIN	DORCO ELECTRONICS # 1-H-42			
LENGTH	1.268	in	3.22	cm
BUILD	0.475	in	1.206	cm
* Wa (effective)	0.602	in^2	3.88	cm^2
BRACKET	HALLMARK METALS # 012-100-04			



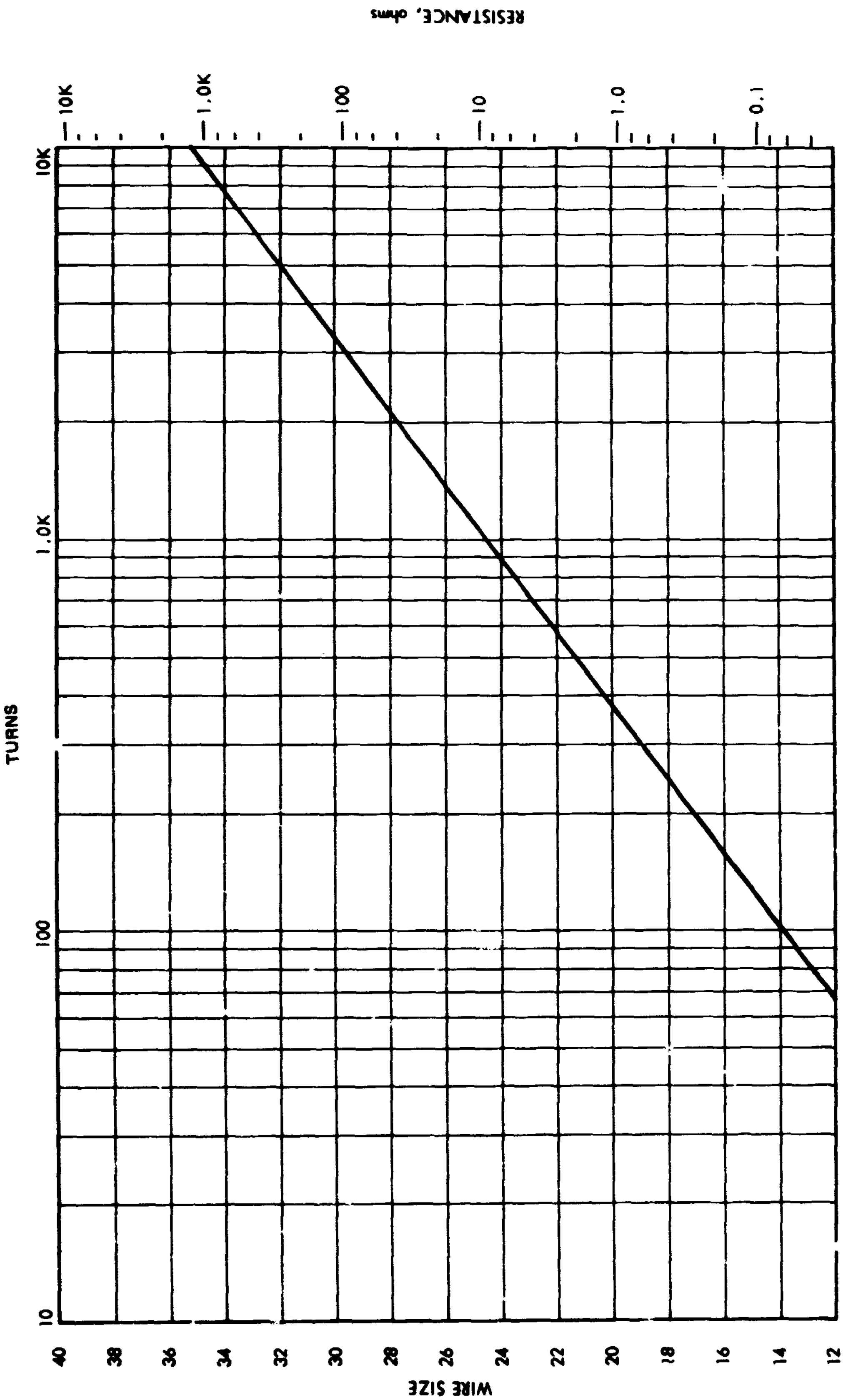
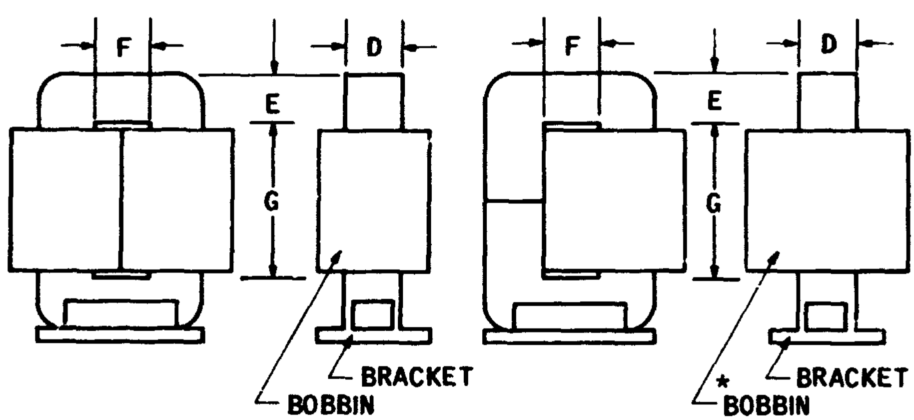


Figure 48. Nomograph for "C" core AH-42

Table 35. "C" Core AH-310

"C" CORE	AH-310			
	ENGLISH		METRIC	
Wa/Ac			2.00	
Wa x Ac	0.158	in^4	6.57	cm^4
Wa	0.563	in^2	3.63	cm^2
Ac (effective)	0.253	in^2	1.631	cm^2
lm	4.32	in	10.97	cm
CORE WT	0.303	lb	137.5	grams
COPPER WT	0.326	lb	148.0	grams
* MLT FULLWOUND	3.92	in	9.96	cm
$G/\sqrt{Ac}$			2.24	
Wa (effective) /Wa			0.911	
A_T	16.25	in^2	104.8	cm^2
D	0.750	in	1.905	cm
E	0.375	in	0.952	cm
F	0.500	in	1.270	cm
G	1.125	in	2.857	cm
BOBBIN	DORCO ELECTRONICS # 1-H-310			
LENGTH	1.080	in	2.74	cm
BUILD	0.475	in	1.21	cm
* Wa (effective)	0.513	in^2	3.31	cm^2
BRACKET	HALLMARK METALS # 012-104-06			



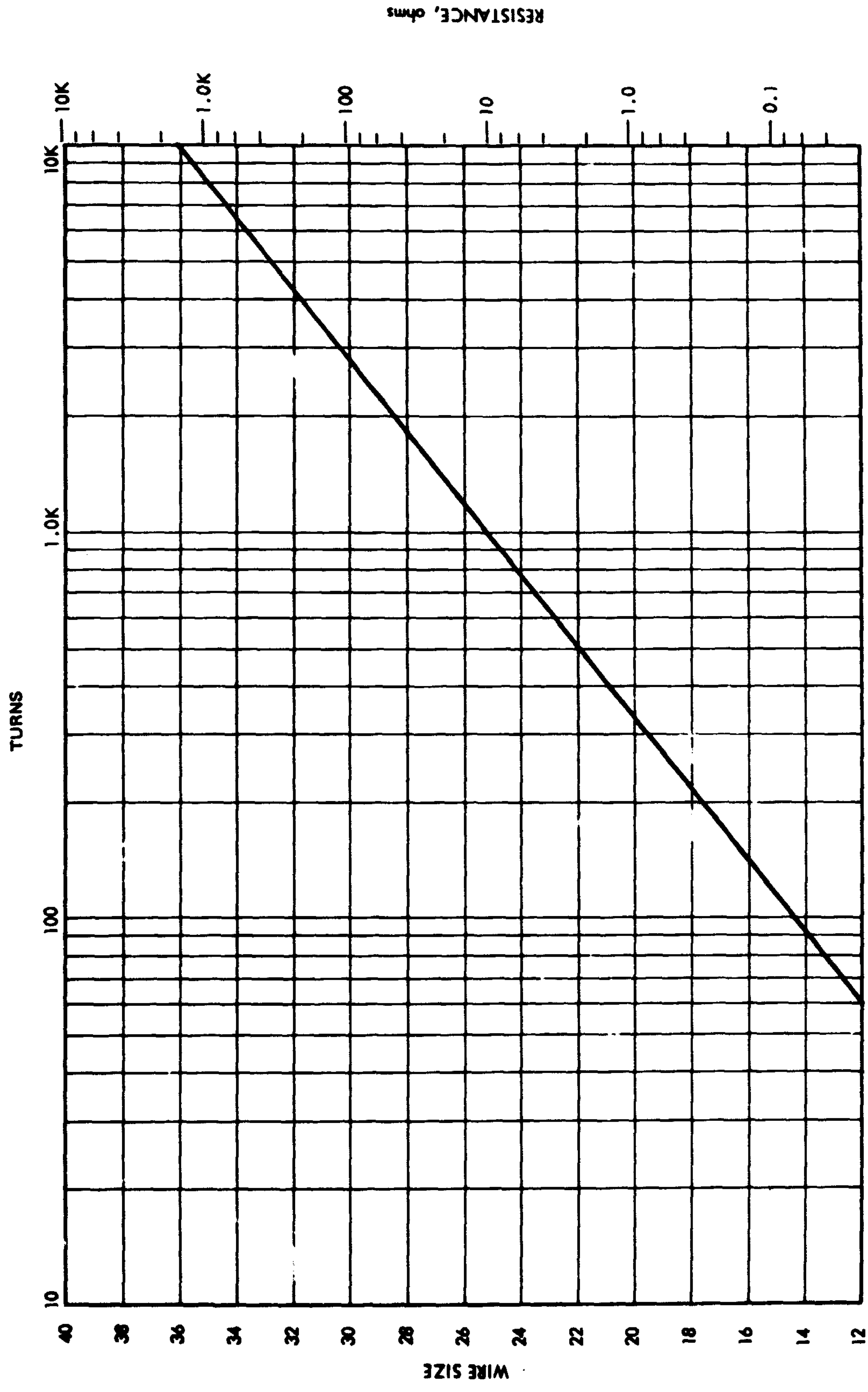
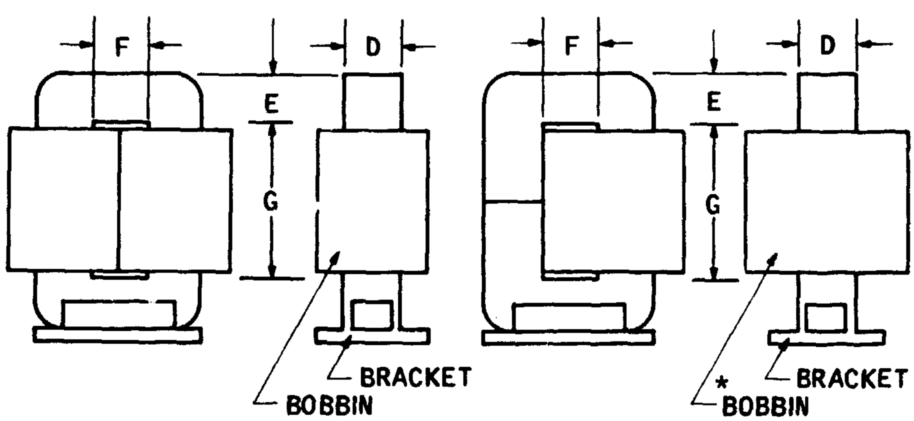


Figure 49. Nomograph for "C" core AH-310

Table 36. "C" Core AH-49

"C" CORE	AH-49			
	ENGLISH		METRIC	
Wa/Ac			10.3′	
Wa x Ac	0.205	in^4	8.52	cm^4
Wa	1.45	in^2	9.35	cm^2
Ac (effective)	0.127	in^2	0.818	cm^2
lm	6.44	in	16.35	cm
CORE WT	0.225	lb	101.9	grams
COPPER WT	0.880	lb	399.3	grams
* MLT FULLWOUND	3.95	in	10.05	cm
$G/\sqrt{Ac}$			5.44	
Wa (effective) /Wa			0.946	
A_T	26.10	in^2	168.4	cm^2
D	0.375	in	0.952	cm
E	0.375	in	0.952	cm
F	0.750	in	1.905	cm
G	1.937	in	4.921	cm
BOBBIN	DORCO ELECTRONICS # 1-H-49			
LENGTH	1.892	in	4.80	cm
BUILD	0.725	in	1.84	cm
* Wa (effective)	1.371	in^2	8.85	cm^2
BRACKET	HALLMARK METALS # 06-108-06			



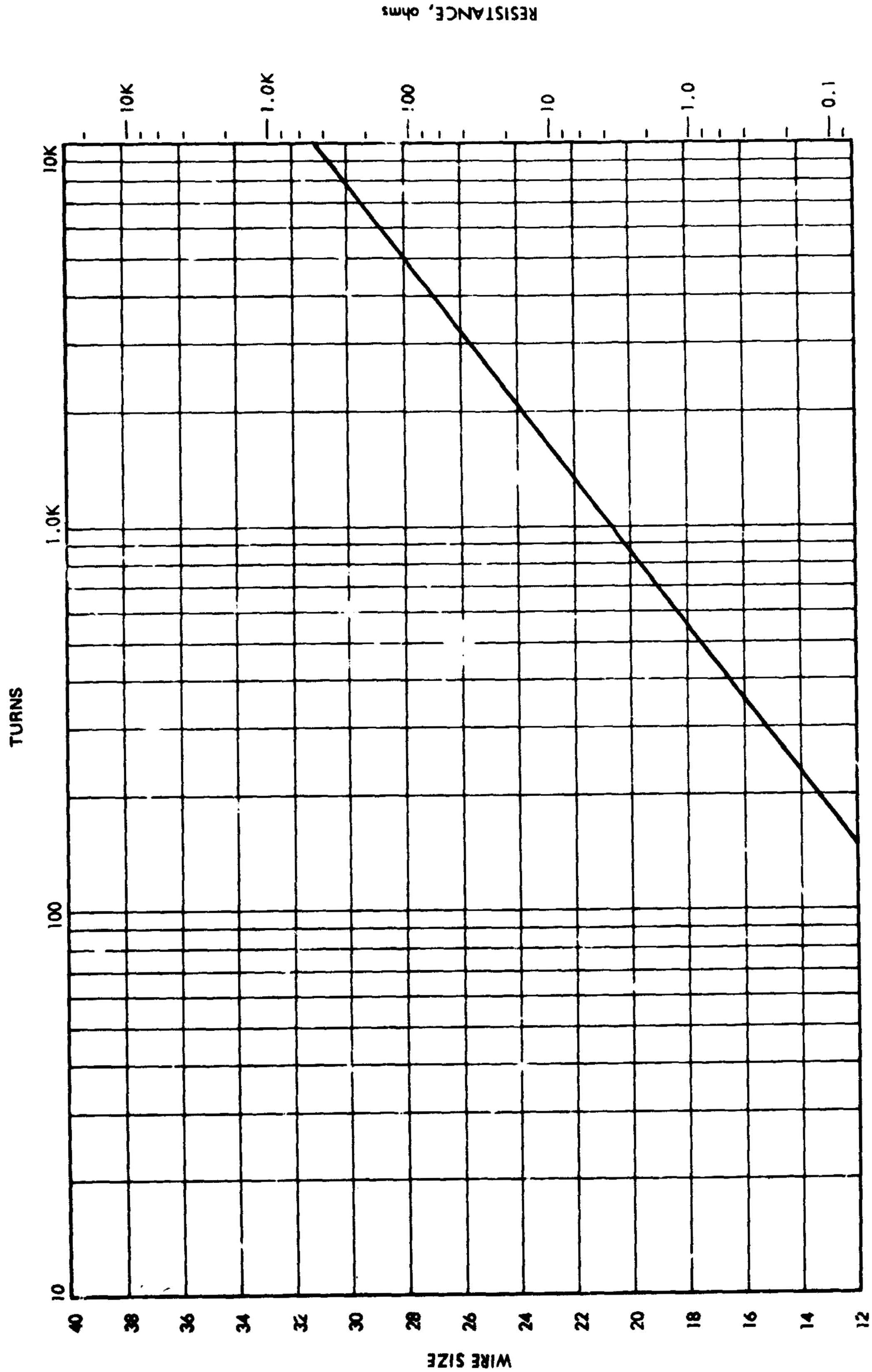
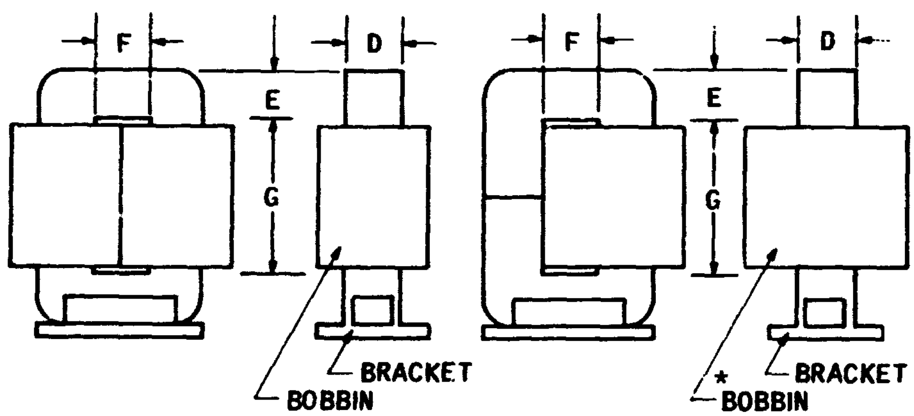


Figure 50. Nomograph for "C" core AH-49

Table 37. "C" Core AH-48

"C" CORE	AH-48			
	ENGLISH		METRIC	
Wa/Ac			3.12	
Wa x Ac	0.306	in^4	12.73	cm^4
Wa	0.977	in^2	6.30	cm^2
Ac (effective)	0.282	in^2	1.[illegible]17	cm^2
lm	5.25	in	13.33	cm
CORE WT	0.406	lb	183.9	grams
COPPER WT	0.693	lb	314	grams
* MLT FULLWOUND	4.69	in	11.91	cm
$G/\sqrt{Ac}$			2.94	
Wa (effective) /Wa			0.933	
A_T	23.36	in^2	150.7	cm^2
D	1.00	in	2.54	cm
E	0.313	in	0.794	cm
F	0.625	in	1.587	cm
G	1.562	in	3.968	cm
BOBBIN	DORCO ELECTRONICS #		1-H-48	
LENGTH	1.520	in	3.86	cm
BUILD	0.600	in	1.52	cm
* Wa (effective)	0.912	in^2	5.88	cm^2
BRACKET	HALLMARK METALS #		10-104-05	



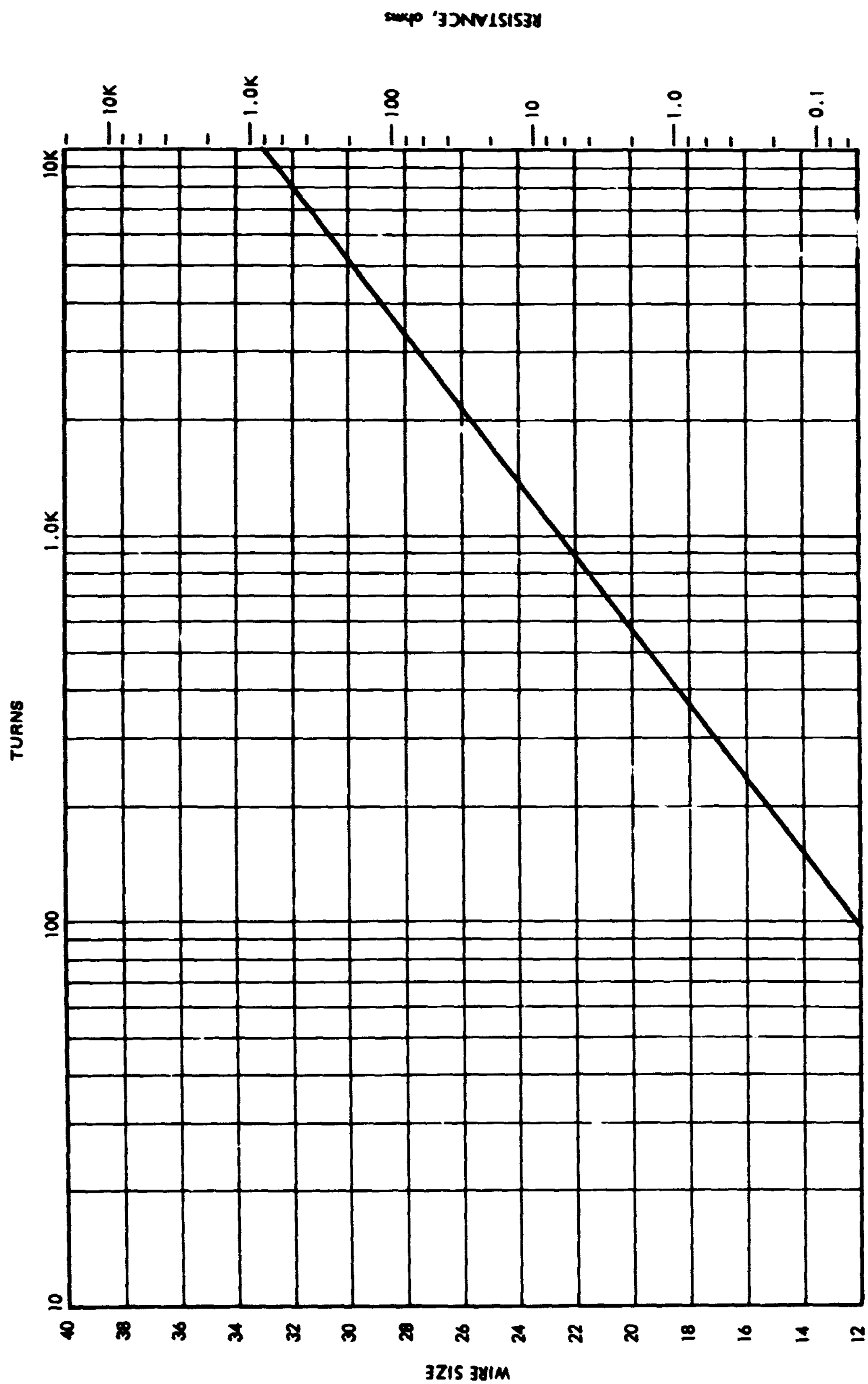
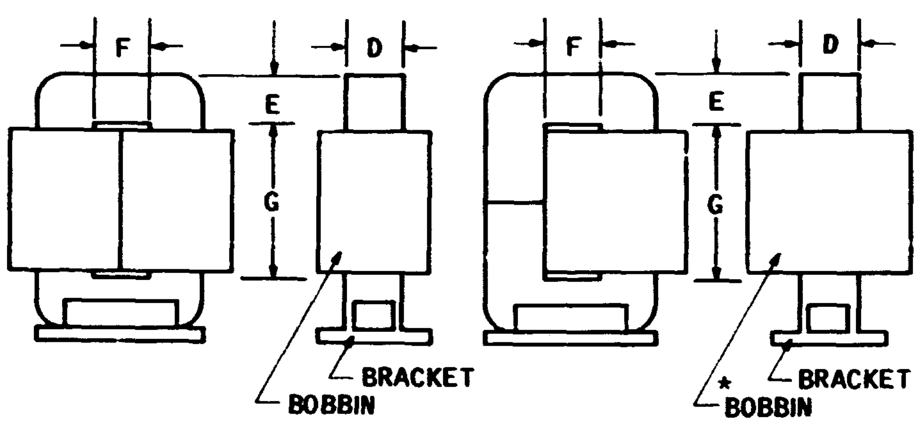


Figure 51. Nomograph for "C" core AH-48

Table 38. "C" Core AH-52

"C" CORE	AH-52			
	ENGLISH		METRIC	
Wa/Ac			5.17	
Wa x Ac	0.408	in^4	16.97	cm^4
Wa	1.45	in^2	9.35	cm^2
Ac (effective)	0.253	in^2	1.631	cm^2
lm	6.44	in	16.35	cm
CORE WT	0.450	lb	203.8	grams
COPPER WT	0.839	lb	380.3	grams
* MLT FULLWOUND	4.70	in	11.95	cm
$G/\sqrt{Ac}$			3.11	
Wa (effective) /Wa			0.945	
A_T	26.4	in^2	170.5	cm^2
D	0.750	in	1.905	cm
E	0.375	in	0.952	cm
F	0.750	in	1.905	cm
G	1.937	in	4.921	cm
BOBBIN	DORCO ELECTRONICS # 1-H-52			
LENGTH	1.892	in	4.805	cm
BUILD	0.725	in	1.84	cm
* Wa (effective)	1.371	in^2	8.84	cm^2
BRACKET	HALLMARK METALS # 012-108-06			



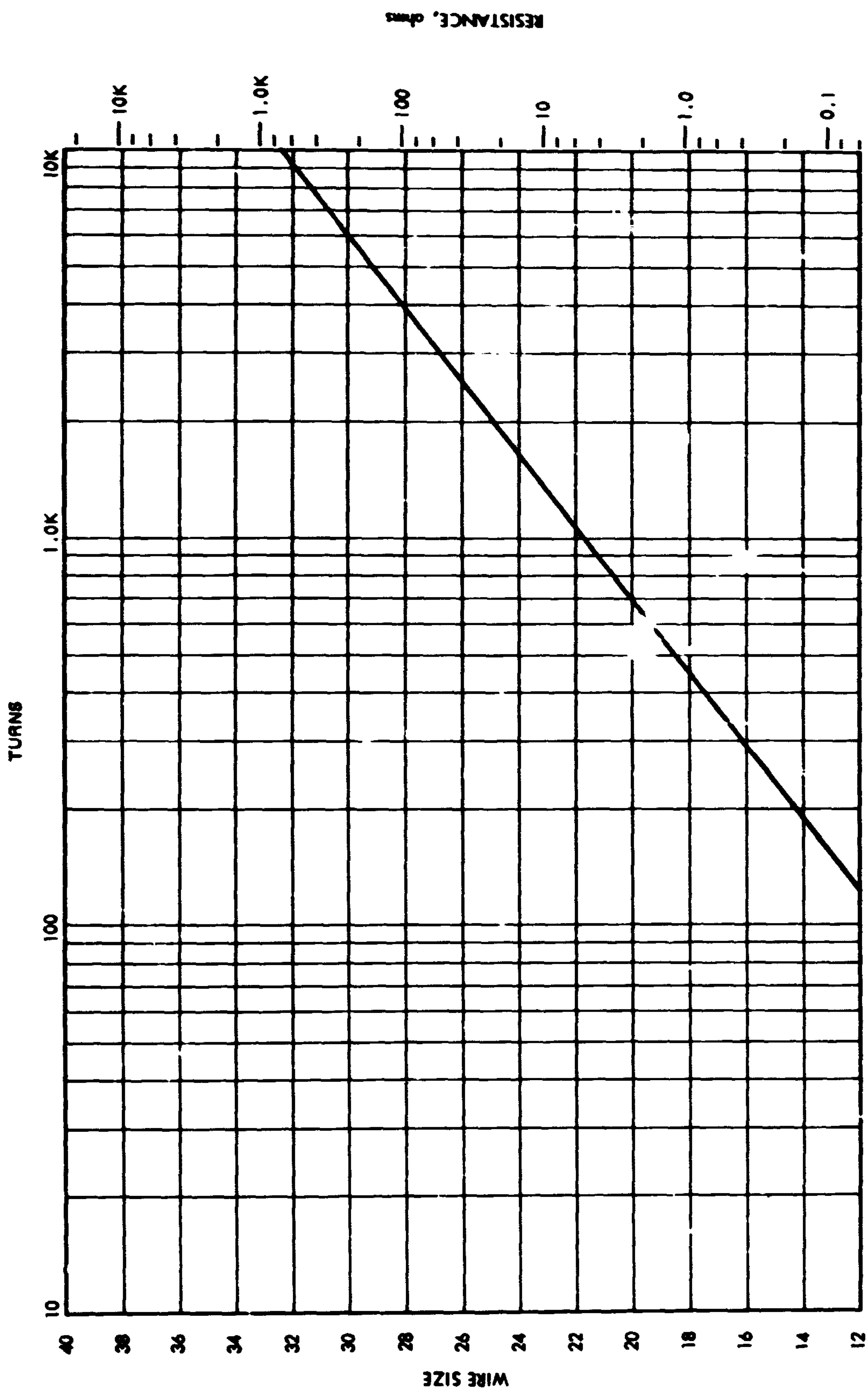
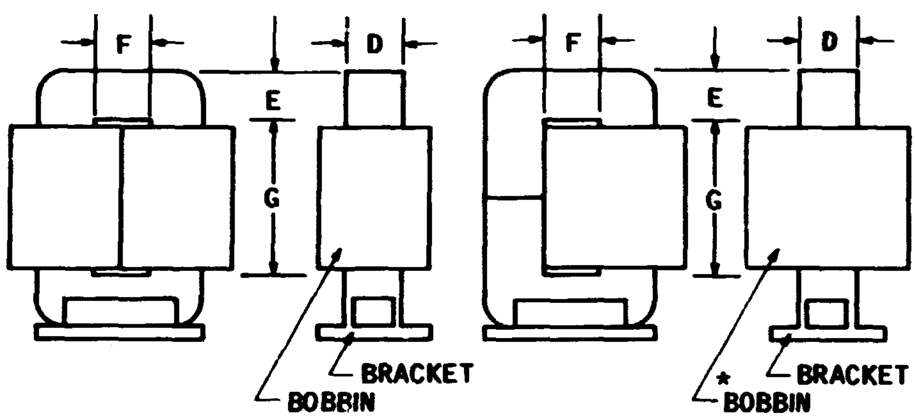


Figure 52. Nomograph for "C" core AH-52

Table 39. "C" Core AH-10

"C" CORE	AH-10			
	ENGLISH		METRIC	
Wa/Ac			1.78	
Wa x Ac	0.534	in^4	22.21	cm^4
Wa	0.977	in^2	6.30	cm^2
Ac (effective)	0.492	in^2	3.175	cm^2
lm	6.23	in	15.82	cm
CORE WT	0.846	lb	383	grams
COPPER WT	0.724	lb	328	grams
* MLT FULLWOUND	5.09	in	12.94	cm
$G/\sqrt{Ac}$			2.23	
Wa (effective) /Wa			0.396	
A_T	30.38	in^2	196	cm^2
D	0.875	in	2.222	cm
E	0.625	in	1.587	cm
F	0.625	in	1.587	cm
G	1.562	in	3.968	cm
BOBBIN	DORCO ELECTRONICS # 1-H-10			
LENGTH	1.497	in	3.80	cm
BUILD	0.585	in	1.485	cm
* Wa (effective)	0.875	in^2	5.65	cm^2
BRACKET	HALLMARK METALS # 014-114-010			



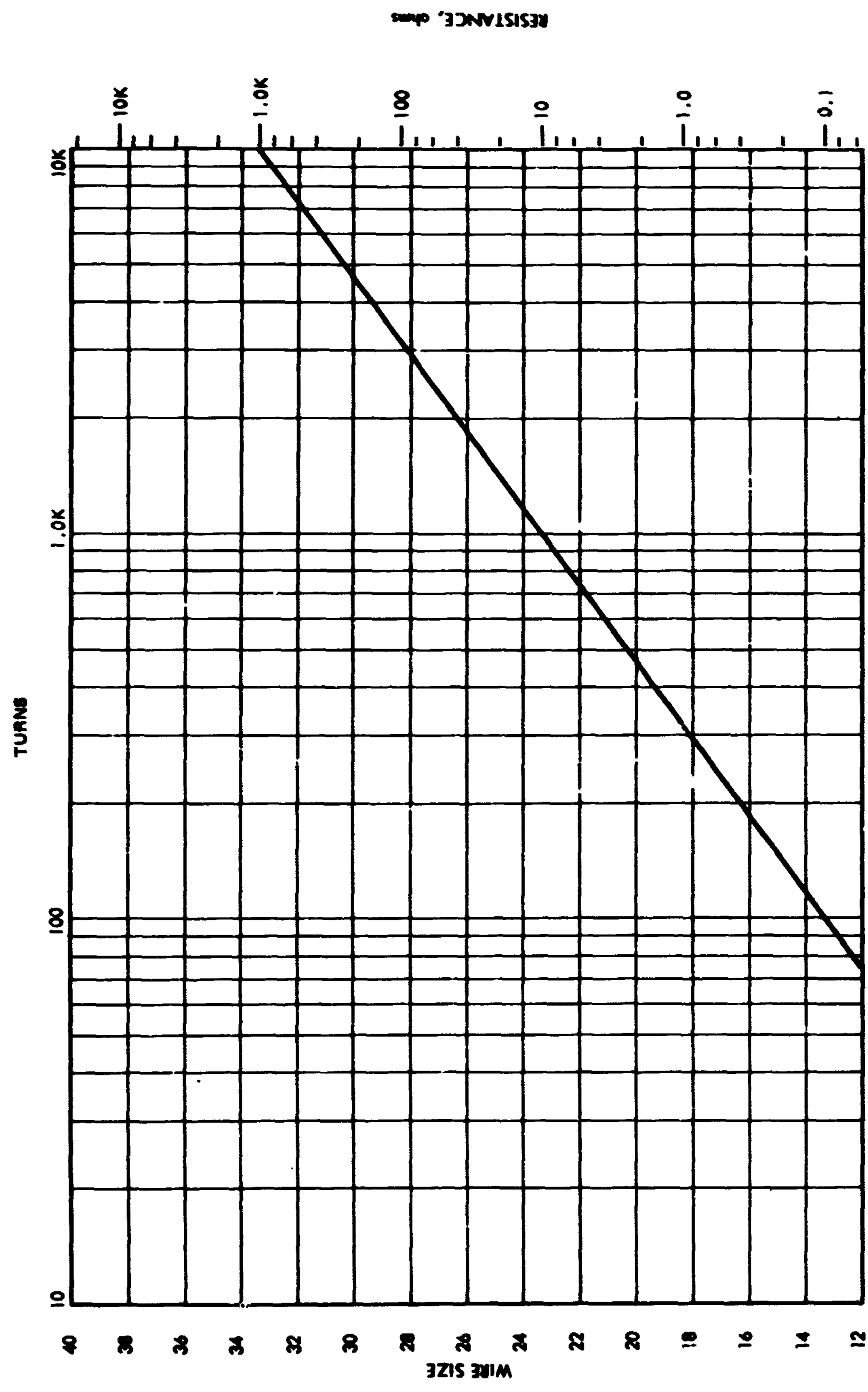
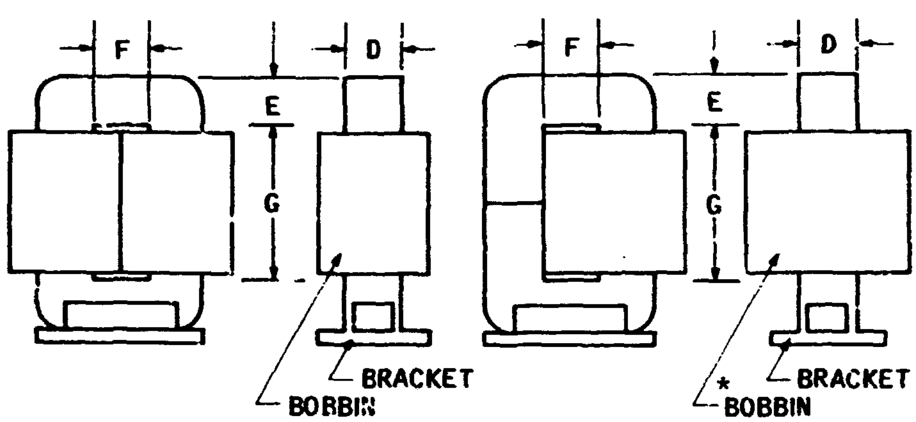


Figure 53. Nomograph for "C" core AH-10

Table 40. "C" Core AH-20

"C" CORE	AH-20			
	ENGLISH		METRIC	
Wa/Ac			4.41	
Wa x Ac	0.678	in^4	28.20	cm^4
Wa	1.73	in^2	11.12	cm^2
Ac (effective)	0.352	in^2	2.270	cm^2
lm	6.89	in	17.50	cm
CORE WT	0.668	lb	302	grams
COPPER WT	1.47	lb	667	grams
* MLT FULLWOUND	5.65	in	14.35	cm
$G/\sqrt{Ac}$			3.91	
Wa (effective) /Wa			0.93?	
A_T	36.6	in^2	236	cm^2
D	1.25	in	3.175	cm
E	0.313	in	0.794	cm
F	0.750	in	1.905	cm
G	2.313	in	5.87	cm
BOBBIN	DORCO ELECTRONICS # 1-H-20			
LENGTH	2.247	in	5.707	cm
BUILD	0.715	in	1.816	cm
* Wa (effective)	1.606	in^2	10.36	cm^2
BRACKET	HALLMARK METALS # 14-106-05			



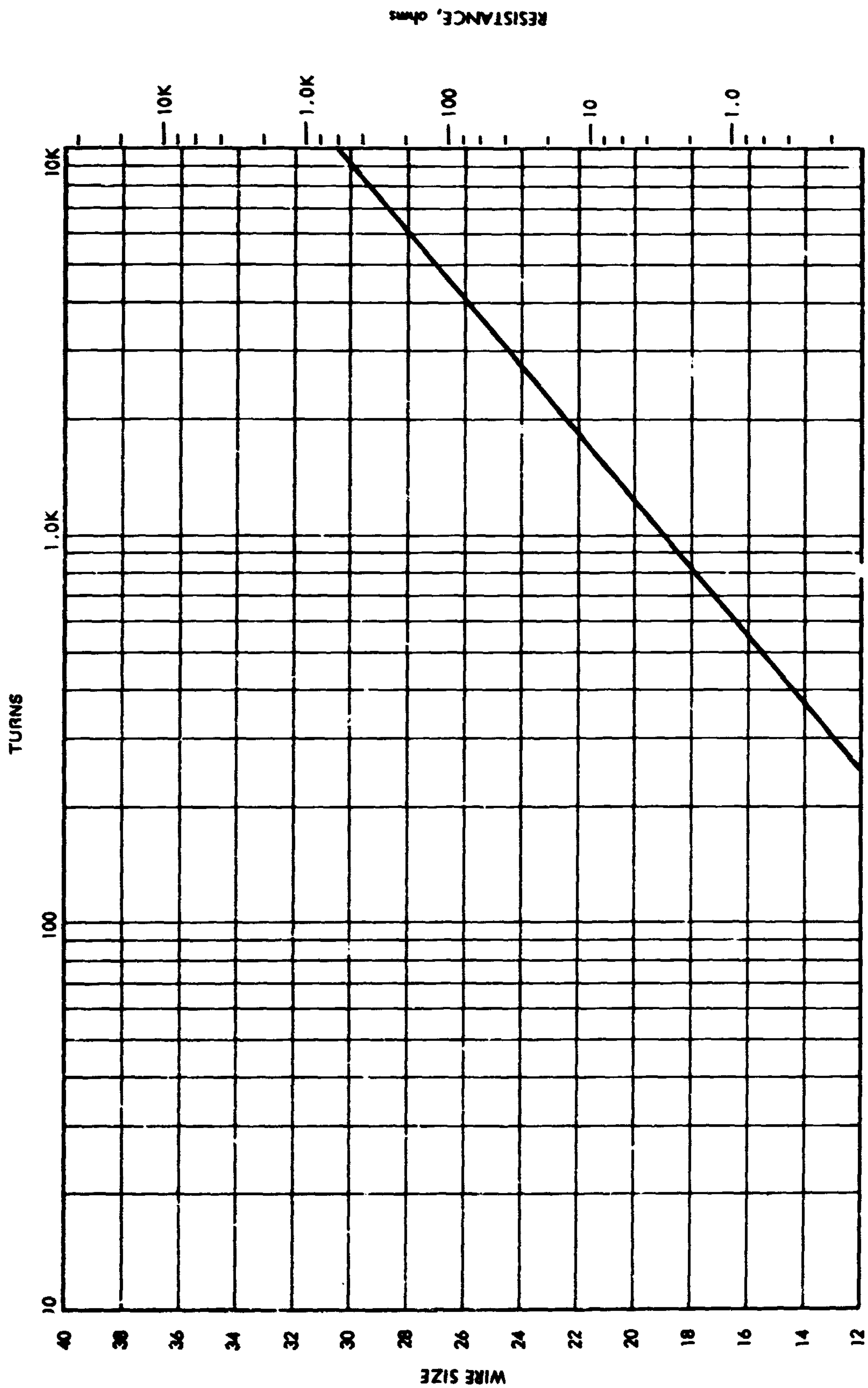
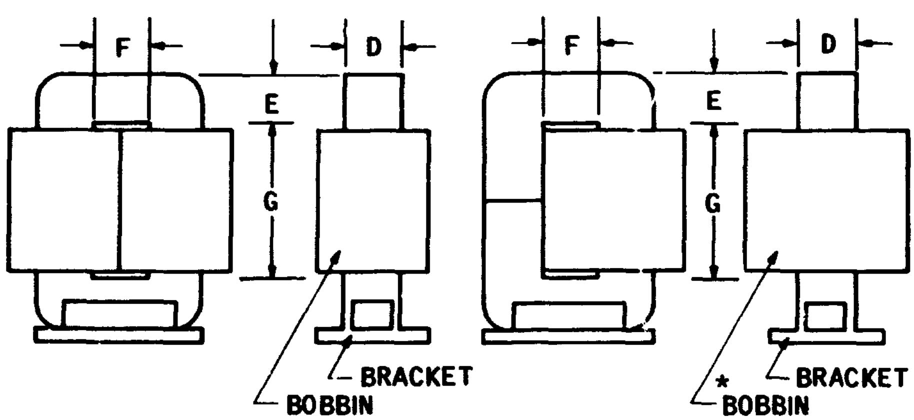


Figure 54. Nomograph for "C" core AH-20

Table 41. "C" Core AH-15

"C" CORE	AH-15			
	ENGLISH		METRIC	
Wa/Ac			1.93	
Wa x Ac	0.756	in^4	31.46	cm^4
Wa	1.21	in^2	7.80	cm^2
Ac (effective)	0.563	in^2	3.63	cm^2
lm	6.98	in	17.72	cm
CORE WT	1.082	lb	490	grams
COPPER WT	0.960	lb	435	grams
* MLT FULLWOUND	5.36	in	13.62	cm
$G/\sqrt{Ac}$			2.58	
Wa (effective) /Wa			0.913	
A_T	35.3	in^2	227	cm^2
D	1.00	in	2.54	cm
E	0.625	in	1.587	cm
F	0.625	in	1.587	cm
G	1.937	in	4.921	cm
BOBBIN	DORCO ELECTRONICS # 1-H-15			
LENGTH	1.872	in	4.75	cm
BUILD	0.590	in	1.498	cm
* Wa (effective)	1.104	in^2	7.123	cm^2
BRACKET	HALLMARK METALS # 10-114-010			



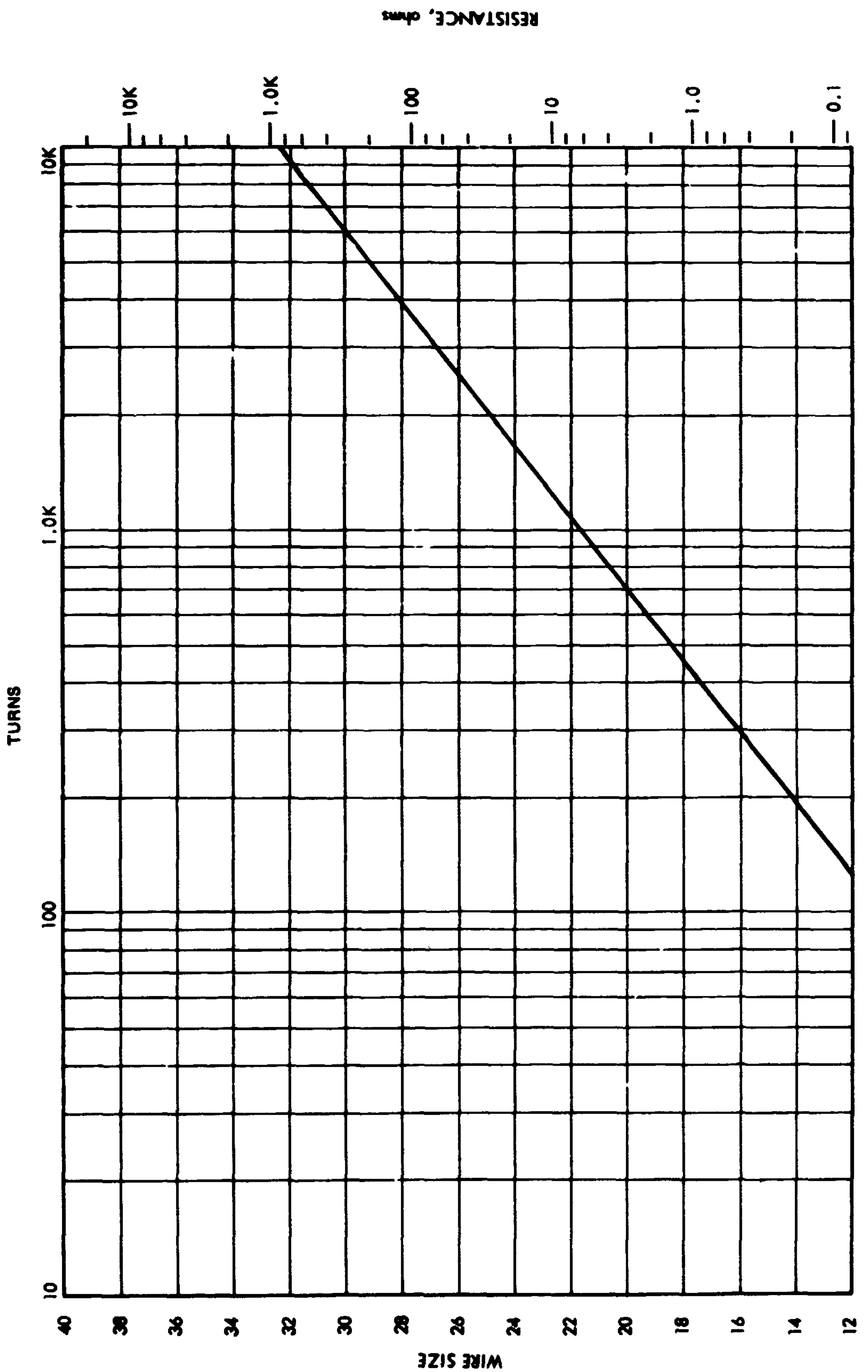
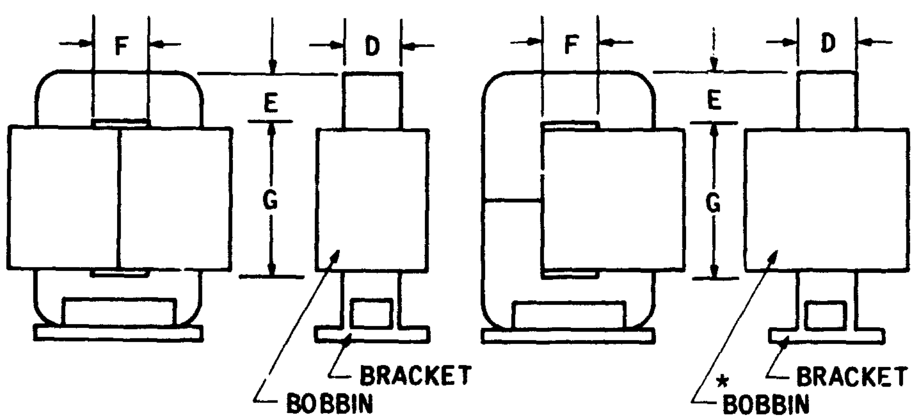


Figure 55. Nomograph for "C" core AH-15

Table 42. "C" Core AH-16

"C" CORE	AH-16			
	ENGLISH		METRIC	
Wa/Ac			1.72	
Wa x Ac	0.851	in^4	35.4	cm^4
Wa	1.21	in^2	7.80	cm^2
Ac (effective)	0.633	in^2	4.08	cm^2
lm	6.98	in	17.72	cm
CORE WT	1.219	lb	552	grams
COPPER WT	1.005	lb	455	grams
* MLT FULLWOUND	5.61	in	14.25	cm
$G/\sqrt{Ac}$			2.09	
Wa (effective) /Wa			0.913	
A_T	36.7	in^2	237	cm^2
D	1.125	in	2.858	cm
E	0.625	in	1.587	cm
F	0.625	in	1.587	cm
G	1.937	in	4.21	cm
BOBBIN	DORCO ELECTRONICS # 1-H-16			
LENGTH	1.872	in	4.75	cm
BUILD	0.590	in	1.498	cm
* Wa (effective)	1.104	in^2	7.123	cm^2
BRACKET	HALLMARK METALS # 12-114-010			



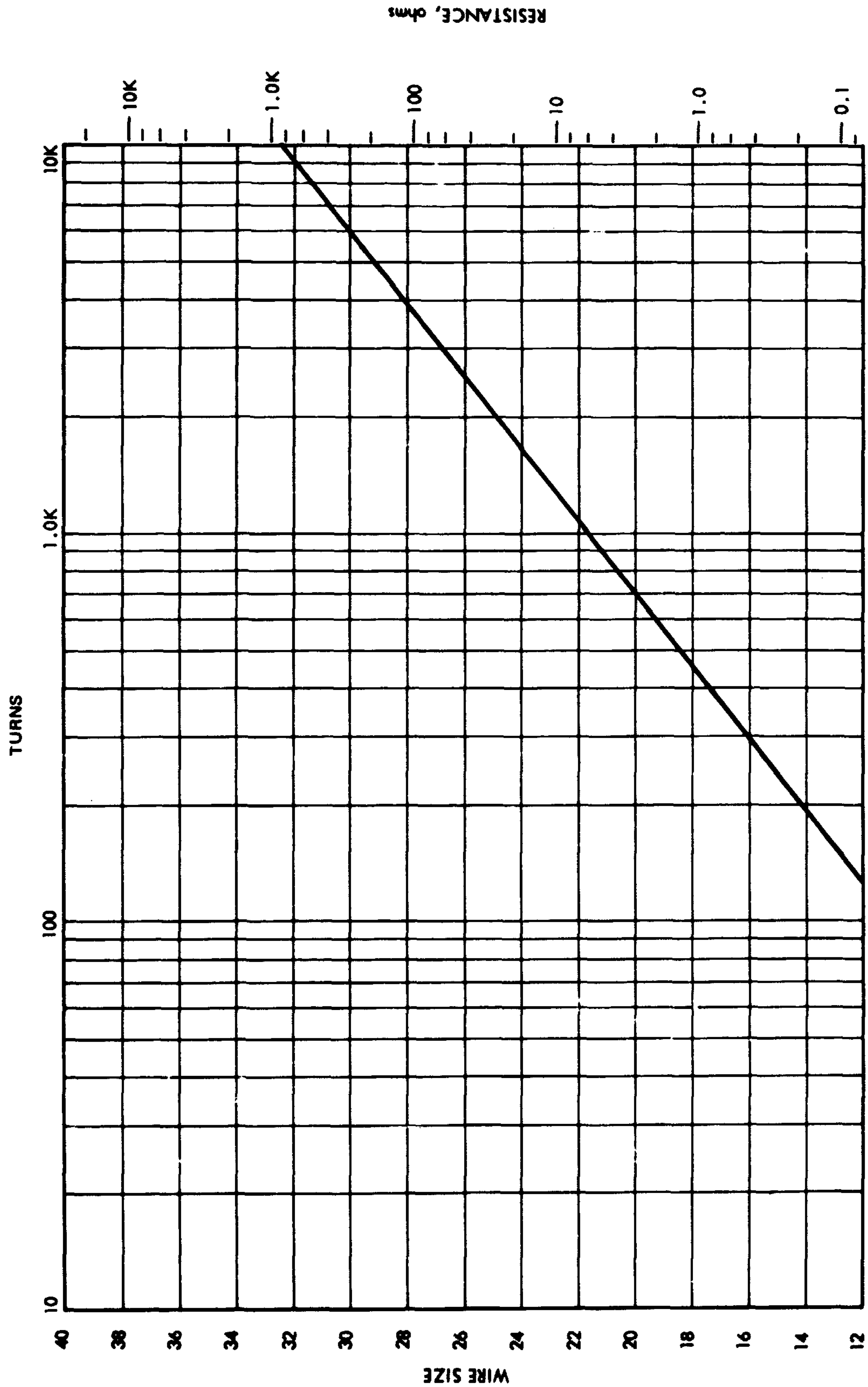
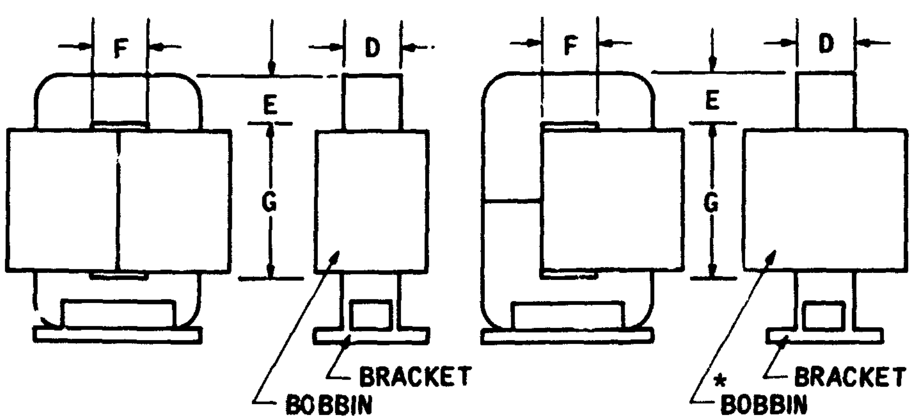


Figure 56. Nomograph for "C" core AH-16

Table 43. "C" Core AH-18

"C" CORE	AH-18			
	ENGLISH		METRIC	
Wa/Ac			1.55	
Wa x Ac	0.942	in^4	[illegible].35	cm^4
Wa	1.21	in^2	[illegible].90	cm^2
Ac (effective)	0.703	in^2	[illegible]3	cm^2
lm	6.93	in	17.60	cm
CORE WT	1.353	lb	613	grams
COPPER WT	1.050	lb	476	grams
* MLT FULLWOUND	5.86	in	14.89	cm
$G/\sqrt{Ac}$			2.31	
Wa (effective) /Wa			0.913	
A_T	38.1	in^2	246	cm^2
D	1.25	in	[illegible].175	cm
E	0.625	in	1.587	cm
F	0.625	in	1.587	cm
G	1.937	in	4.921	cm
BOBBIN	DORCO ELECTRONICS # 1-H-18			
LENGTH	1.872	in	4.75	cm
BUILD	0.590	in	1.498	cm
* Wa (effective)	1.104	in^2	7.123	cm^2
BRACKET	HALLMARK METALS # 14-114-010			



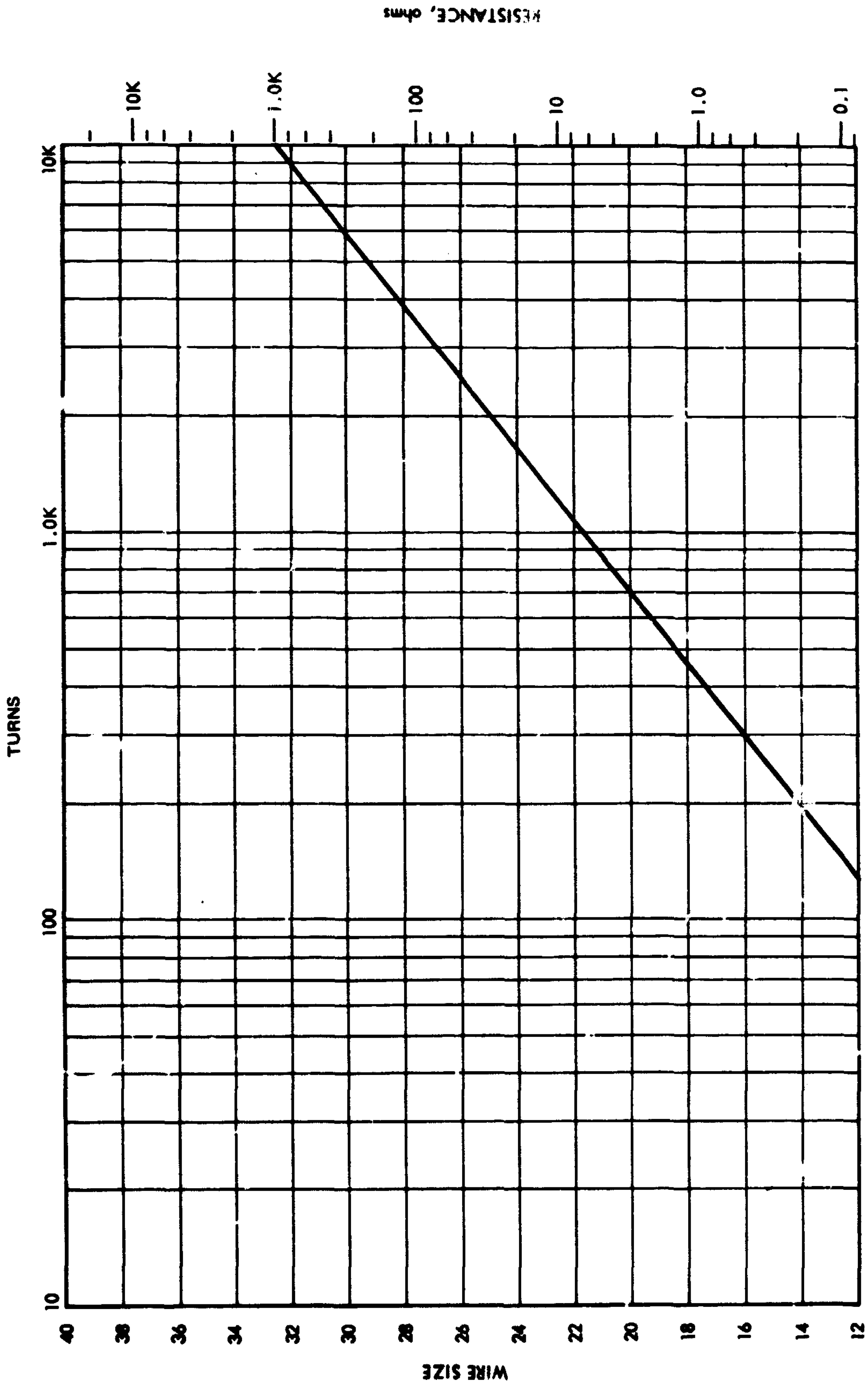
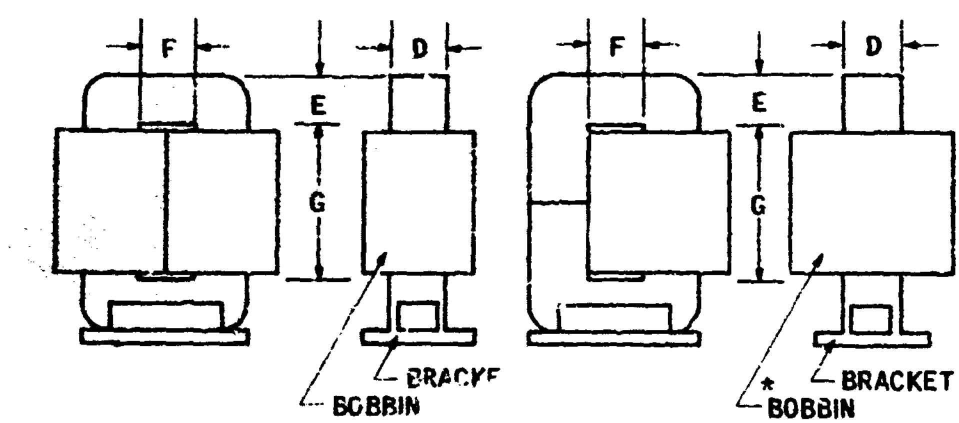


Figure 57. Nomograph for "C" core AH-18

Table 44. "C" Core AH-412

"C" CORE	AH-412			
	ENGLISH		METRIC	
Wa/Ac			2.35	
Wa x Ac	1.038	in^4	43.2	cm^4
Wa	1.56	in^2	10.06	cm^2
Ac (effective)	0.598	in^2	3.85	cm^2
lm	7.70	in	19.55	cm
CORE WT	1.222	lb	553	grams
COPPER WT	1.322	lb	599	grams
* MLT FULLWOUND	5.67	in	14.41	cm
$G/\sqrt{Ac}$			3.25	
Wa (effective) /Wa			0.921	
A_T	40.5	in^2	261	cm^2
D	1.25	in	3.175	cm
E	0.531	in	1.349	cm
F	0.625	in	1.587	cm
G	2.500	in	6.350	cm
BOBBIN	DORCO ELECTRONICS # 1-H-412			
LENGTH	2.435	in	6.18	cm
BUILD	0.593	in	1.498	cm
* Wa (effective)	1.44	in^2	9.266	cm^2
BRACKET	HALLMARK METALS # 14-111-09			



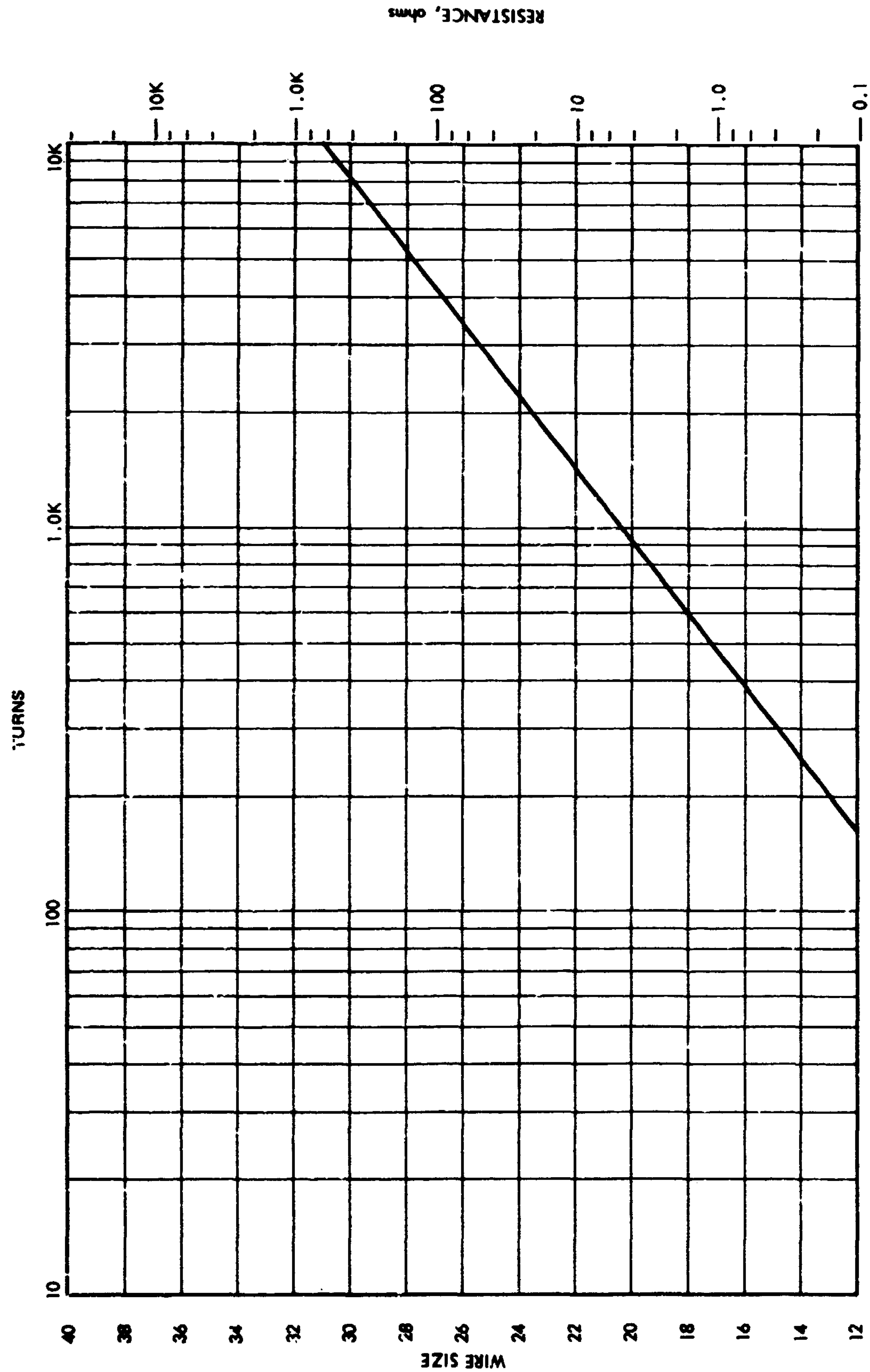


Figure 58. Nomograph for "C" core AH-412

APPENDIX A

LINEAR REACTOR DESIGN WITH AN IRON CORE

After calculating the inductance and dc current, select the proper size core with a given $LI^2/2$. The energy handling capability of an inductor can be determined by its WaAc product where, Wa is the available core window area in cm^2 and Ac is the core effective cross sectional area cm^2. The WaAc relationship is obtained by solving E = LdI/dt as follows:

$$E = L\frac{dI}{dt} = N\frac{d\phi}{dt}$$

$$L = N\frac{d\phi}{dI}$$

$$\phi = BmAc'$$

$$Bm = \frac{\mu oNI}{lg' + \frac{lm'}{\mu r}}$$

$$\phi = \frac{\mu oNI\,Ac'}{lg' + \frac{lm'}{\mu r}}$$

$$\frac{d\phi}{dI} = \frac{\mu oN\,Ac'}{lg' + \frac{lm'}{\mu r}}$$

$$L = N\frac{d\phi}{dI} = \frac{\mu oN^2\,Ac'}{lg' + \frac{lm'}{\mu r}}$$

$$\text{Energy} = \frac{1}{2}LI^2 = \frac{\mu o\,N^2Ac'I^2}{2\left(lg' + \frac{lm'}{\mu r}\right)}$$

If Bm is specified,

$$I = \frac{Bm\left(lg' + \frac{lm'}{\mu r}\right)}{\mu o N}$$

$$Eng = \frac{\mu o N^2 Ac'}{2\left(lg' + \frac{lm'}{\mu r}\right)} \left(\frac{Bm\left(lg' + \frac{lm'}{\mu r}\right)}{\mu o N}\right)^2$$

$$Eng = \frac{Bm^2\left(lg' + \frac{lm'}{\mu r}\right)Ac'}{2\mu o}$$

$$I = \frac{KWa'J'}{N} = \frac{\left(Bm(lg' + \frac{lm'}{\mu r})\right)}{\mu o N}$$

Solving for $(lg' + lm'/\mu r)$

$$\left(lg' + \frac{lm'}{\mu r}\right) = \frac{\mu o K Wa' J'}{Bm}$$

Substituting into the energy equation

$$Eng = \frac{Bm^2 \left(\frac{\mu o K Wa' J'}{Bm}\right) Ac'}{2\mu o}$$

$$Eng = \frac{Bm^2 Ac'}{2\mu o} \times \frac{\mu o K Wa' J'}{Bm}$$

$$Eng = \frac{Bm K Wa' Ac' J'}{2}$$

let

Wa = window area, cm^2

Ac = core area, cm^2

J = current density, amps/cm^2

H = magnetizing force, amp turn/cm

lg = air gap, cm

lm = magnetic path length, cm

$Wa' = Wa \times 10^{-4}$

$Ac' = Ac \times 10^{-4}$

$J' = J \times 10^{4}$

$lm' = lm \times 10^{-2}$

$lg' = lg \times 10^{-2}$

$H' = H \times 10^{2}$

Substituting into the energy equation

$$Eng = \frac{Wa\, Ac\, Bm\, JK}{2} \times 10^{-4}$$

Solving for WaAc

$$WaAc = \frac{2(Eng)}{Bm\, JK} \times 10^{4}$$

APPENDIX B

WINDOW UTILIZATION FACTOR

The fraction of the available window space which will be occupied by the copper may be calculated from

$$K = \frac{\text{conductor cm}^2}{\text{wire cm}^2} \times \frac{\text{wound cm}^2}{\text{usable window cm}^2} \times \frac{\text{usable window cm}^2}{\text{window cm}^2}$$

where

$$\text{conductor cm}^2 = \text{copper cm}^2$$

$$\text{wire cm}^2 = \text{copper cm}^2 + \text{insulation cm}^2$$

$$\text{wound cm}^2 = \text{number of turns x wire area of one turn}$$

usable window cm^2 = available window area minus residual area which results from the particular winding technique used

$$\text{window area} = \text{available window cm}^2$$

The term

$$\frac{\text{conductor cm}^2}{\text{wire cm}^2} \; (= K_1)$$

is dependent upon wire size. Typical values which may be calculated from the data of Table 2, Columns A and D are

$$\text{AWG } 10 = \frac{52.61 \text{ cm}}{55.90 \text{ cm}} = 0.941$$

$$\text{AWG } 20 = \frac{5.188 \text{ cm}}{6.065 \text{ cm}} = 0.855$$

$$AWG\ 30 = \frac{0.5067\ cm}{0.6785\ cm} = 0.747$$

$$AWG\ 40 = \frac{0.04869\ cm}{0.0723\ \ cm} = 0.673$$

The term

$$\frac{\text{wound cm}^2}{\text{usable window cm}^2} (= K_2)$$

is the fill factor for the usable window area. It can be shown theoretically that for circular cross-section wire wound on a flat form that the ratio of wire cm^2 to the area required for the turns can never be greater than 0.91. In practice, the actual maximum value is dependent upon the tightness of winding, variations in insulation thickness, and wire lay. Consequently, the fill factor is always less than the theoretical maximum

As a typical working value for copper wire with a heavy synthetic film insulation, a ratio of 0.60 may be used safely.

The term usable window cm^2/window cm^2 (K_3) defines how much of the available window space may actually be used for the winding. The winding area available to the designer depends on the bobbin configuration. A single bobbin design offers an effective Wa between 0.835 to 0.929 while a two bobbin configuration offers an effective Wa between 0.687 to 0.372. A good value to use for both configurations is (K_3) = 0.75.

A typical value for the copper fraction in the window area is about 0.40. For example for AWG 20 wire, $K_1 \times K_2 \times K_3 = 0.855 \times 0.60 \times 0.75 = 0.385$.

$$0.4 = \underset{K_1}{\frac{\text{Aw Bare}}{\text{Aw Total}}} \times \underset{K_2}{\text{Fill Factor}} \times \underset{K_3}{\frac{\text{Wa(eff)}}{\text{Wa}}}$$

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