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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-651

Design Parameters for Toroidal and Bobbin Magnetics

Colonel W. T. McLyman

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. Wester, and Mr. T. Koerner, of JPL, and Mr. R. Noah of Magnetic Inc. for support in gathering data and for their technical aid.

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LIST OF SYMBOLS

AWG	American wire gage
cir-mil	area of a circle whose diameter = 0.001 inches
ζ	zeta resistance correction factor for temperature
K_1	conductor area cm^2/wire area cm^2
K_2	wound area cm^2/usable window area cm^2
K_3	usable window area cm^2/window area cm^2
K	window utilization factor
Aw	wire area
Ac	iron area gross
lm	magnetic path
MLT	mean length turn
A_t	surface area of a transformer
μ	permeability
W_c	copper loss
W_I	iron loss
W_T	total loss
T	tesla 1 tesla = 1×10^{-4} gauss
R	resistance
I	current (RMS)
E	voltage (RMS)
B_m	operating flux density teslas
f	frequency Hz
Wa	window area
J	current density
P_o	output power
P_1	input power
P_T	total power
η	efficiency
L	inductance
ϕ	flux webers
μ_r	relative permeability
μ_o	absolute permeability ($4\pi \times 10^{-7}$)
H	magnitizing force ampturns/cm 1 amp turn/cm $\approx$ 0.79 oersted
m	meter

ABSTRACT

The adoption by NASA of the metric system for dimensioning to replace the long-used English units imposes a requirement on the U.S. transformer designer to convert from the familiar units to the less familiar metric equivalents. Material is presented to assist in that transition in the field of transformer design and fabrication. The conversion data makes it possible for the designer to obtain a fast and close approximation of significant parameters such as size, weight, and temperature rise. Nomographs are included to provide a close approximation for breadboarding purposes. For greater convenience, derivations of some of the parameters are also presented.

I. INTRODUCTION

The adoption by NASA of the metric system for dimensioning to replace the long-used English units imposes a requirement on the U. S. transformer designer to convert from the familiar units to the less familiar metric equivalents, Table 1. The following material is intended to assist in that transition in the field of transformer design and fabrication. The conversion data makes it possible for the designer to obtain a fast and close approximation of significant parameters such as size, weight, and temperature rise. For greater convenience, derivations of some of the parameters are also presented.

Table 1. Conversion Factors

To convert	Multiply By
Area	
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 1. (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	$2.8349 \quad 10^{1}$
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}

II. 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

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

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

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

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		Resistance	Heavy Synthetics								
				Area		Diameter		Turns-Per		Turns-Per		Weight
	$cm^2 10^{-3}$ (footnote b)	CIR-MIL[a]	$\frac{10^{-6}\,\Omega}{\text{cm at }20^{\circ}\text{C}}$	$cm^2 10^{-3}$	CIR-MIL[a]	cm	Inch[a]	cm	Inch[a]	cm^2	$Inch^2$	gm/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	4.36	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	0.1879
15	16.51	3260	104.3	18.37	3624	0.153	0.0602	6.77	16.6	32.66	210.6	0.1492
16	13.07	2581	131.8	14.73	2905	0.137	0.0539	7.32	18.6	40.73	262.7	0.1184
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	515.0	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	66260	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}.

III. TEMPERATURE CORRECTION FACTORS

The values shown in Fig. 1 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 = $\mu\Omega/\text{cm (at } 20^\circ\text{C)} \times \zeta$

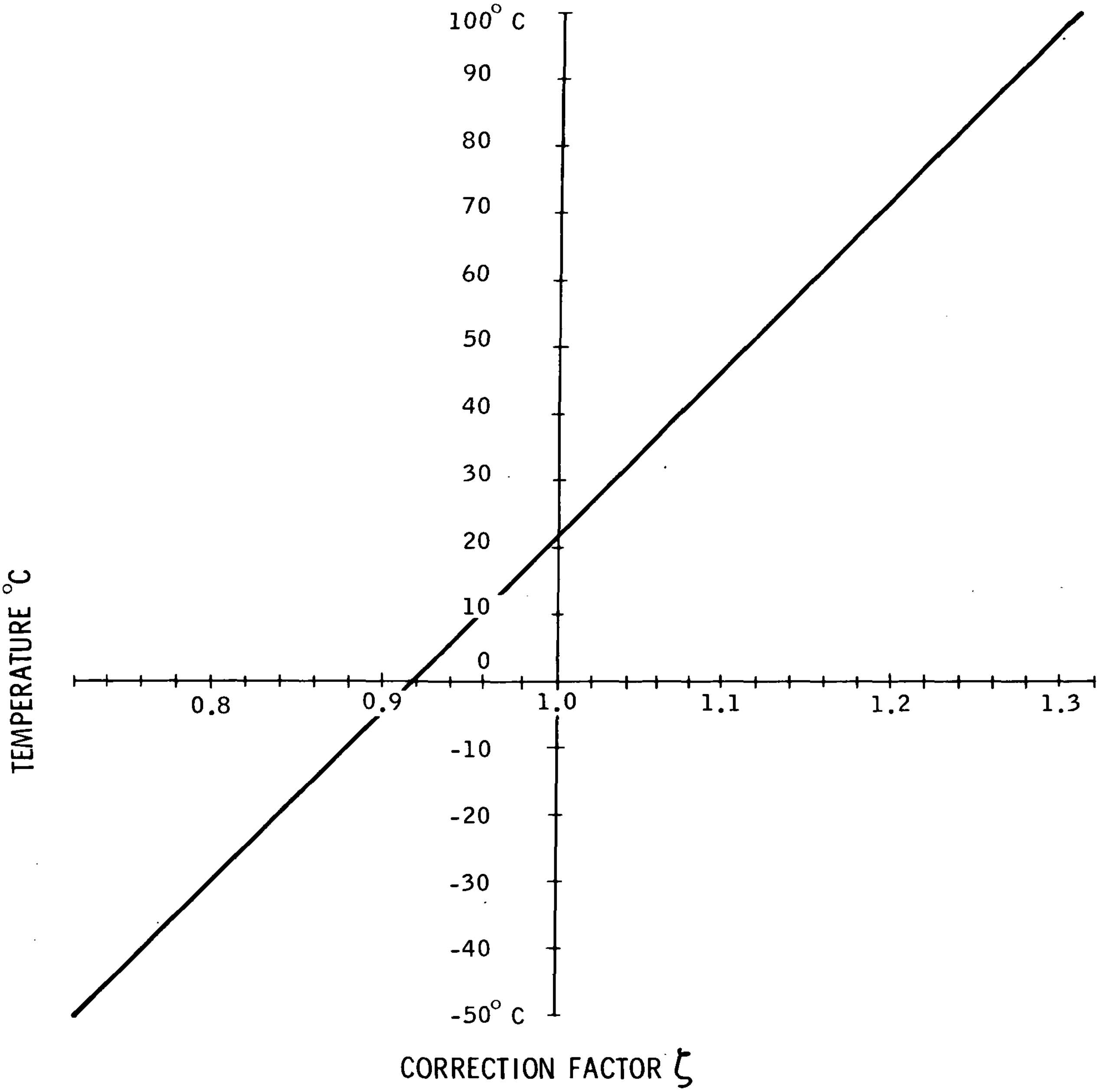


Fig. 1. Resistance Correction Factor (ζ, Zeta) for wire temperature between -50° and 100°C

IV. TOROIDAL FILL FACTORS

Figures 2, 3 and 4 have been devised to assist the engineer in optimizing the dimension of the window in the toroidal core. Available window area for winding turns is affected by:

(1) Minimum window diameter which may be safely wound

(2) Total space occupied by wire (copper and insulation)

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

conductor cm^2	=	copper cm^2
wire cm^2	=	copper cm^2 + insulation cm^2
wound cm^2	=	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
window area	=	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

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

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

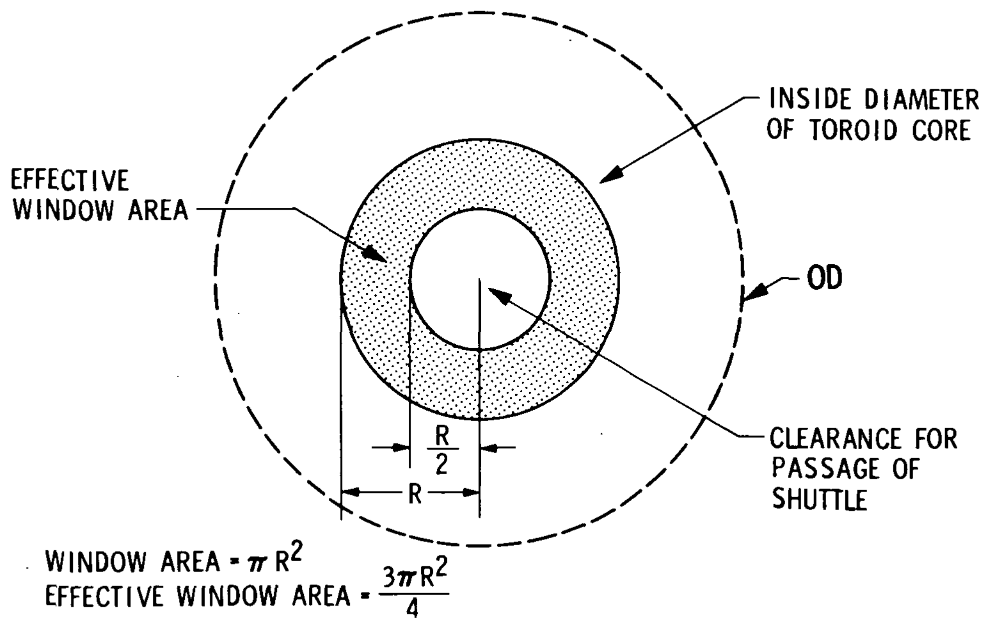
$$\text{AWG } 30 = \frac{0.5067 \text{ cm}}{0.6785 \text{ cm}} = 0.747$$

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

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.

Design Manual TWC-300 of MAGNETICS, Inc. indicates that random wound cores can be produced with fill factors as high as 0.7, but that progressive sector wound cores can be produced with fill factors of only up to 0.55. The charts of Figures 2, 3 and 4 are based upon fill factor ratios of 0.50, 0.60 and 0.70, respectively. 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 charts are based on the assumption that the inside diameter (ID) of the wound core is one-half that of the bare core, i.e. $K_3 = 0.75$ (to allow free passage of the shuttle).



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

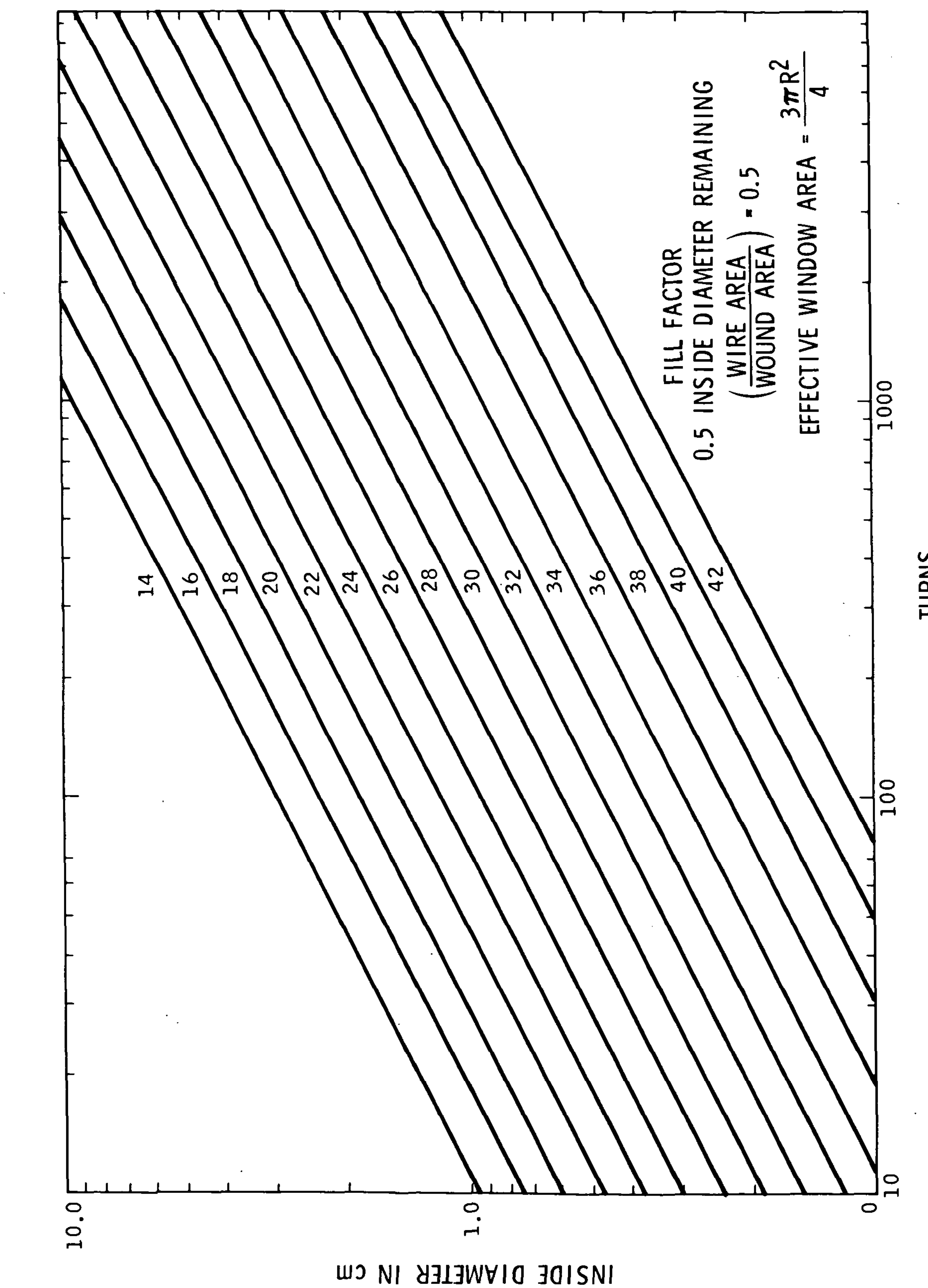


Fig. 2. Fill Factor 0.5

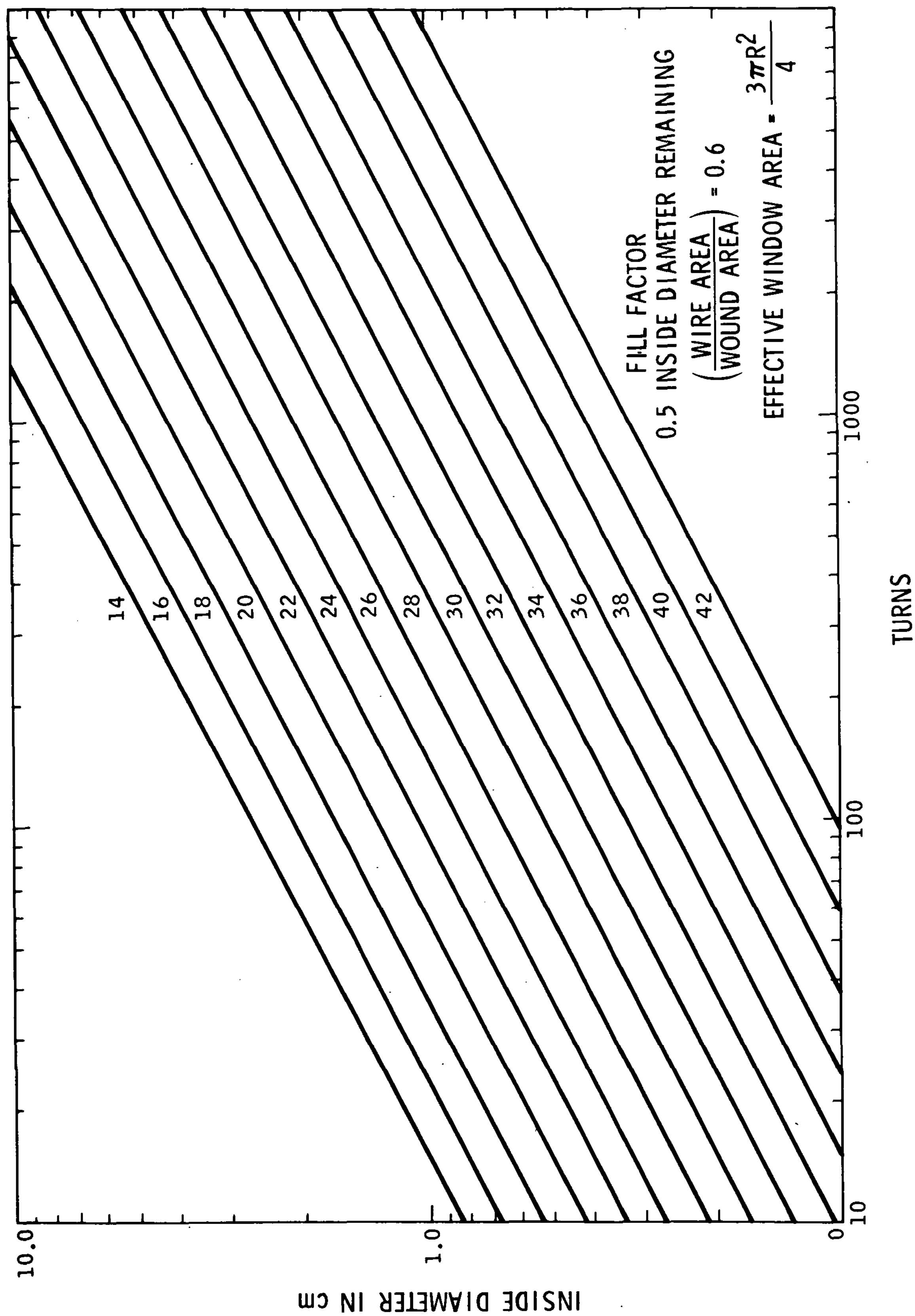


Fig. 3. Fill Factor 0.6

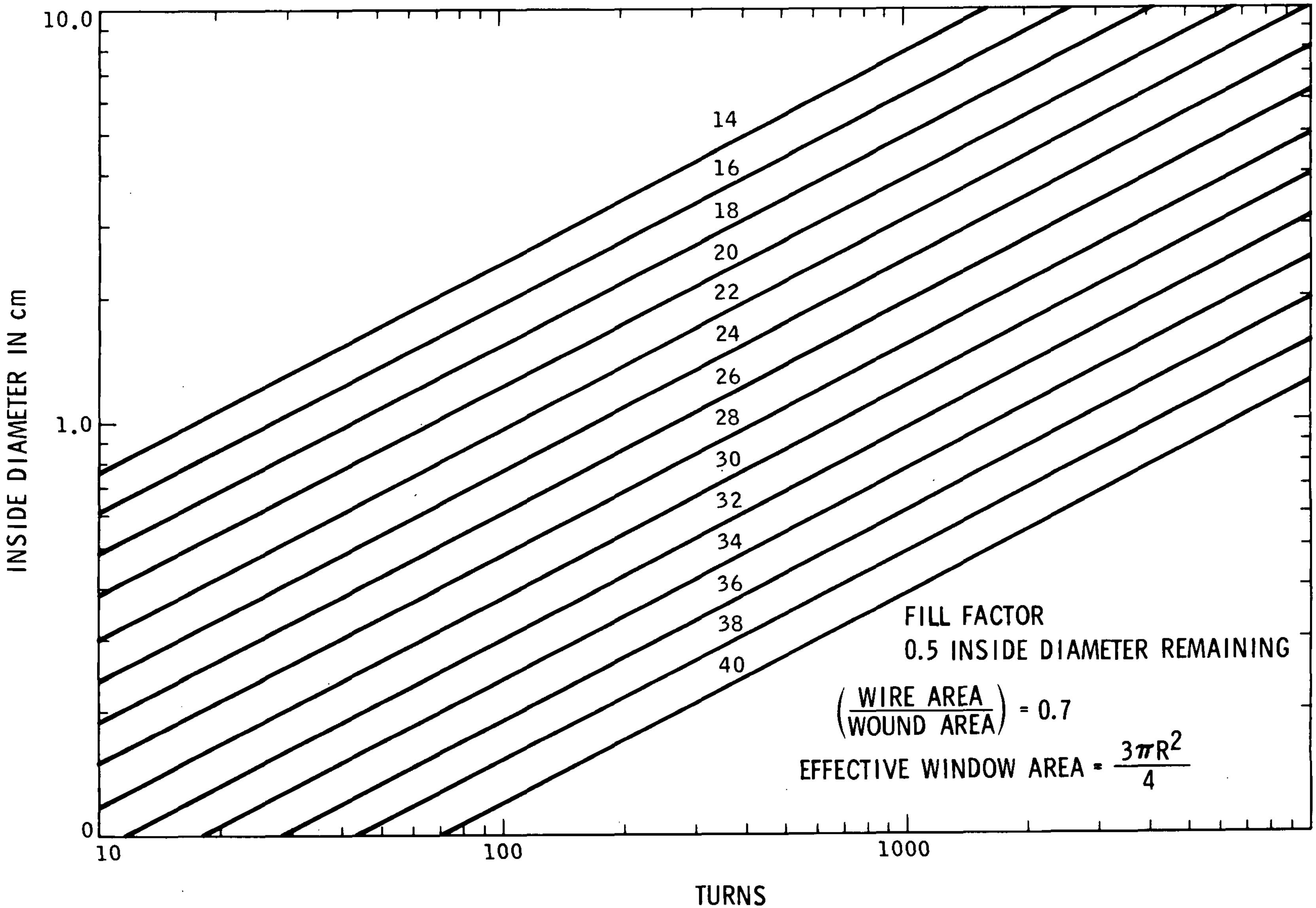


Fig. 4. Fill Factor 0.7

V. CORE SIZE SELECTION

Upon selecting the transformer core material and material thickness, the next step is to select the proper size core for a transformer with a given operating frequency and output power. The power handling capability of a transformer can be determined by its Wa Ac product where Wa is the available core window area in cm^2 and Ac is the core effective cross sectional area in cm^2.

The Wa Ac relationships are obtained by solving Faraday's Law in the following manner:

$$\text{Faraday's Law} = E = 4B_m \, Ac\, Nf \times 10^{-4} \text{ (square wave)}$$

$$E = 4.44B_m \, Ac\, Nf \times 10^{-4} \text{ (sine wave)}$$

E = applied voltage (rms)

B_m = flux density in teslas

Ac = core effective cross sectional area in cm^2

N = number of turns

f = frequency in Hz

Aw = bare wire area in cm^2

Wa = window area in cm^2

K = window utilization factor

I = current (rms)

J = current density

P_o = output power (total)

P_I = input power

P_T = total power

η = efficiency

Solving for

$$NAc = \frac{E \times 10^4}{4B_m f}$$

Window utilization factor

$$K = \frac{NAw}{Wa}$$

$$N = \frac{KWa}{Aw}$$

Multiply both sides by Ac

$$NAc = \frac{KWa\,Ac}{Aw} = \frac{E \times 10^4}{4B_m f}$$

Combining and solving for Wa Ac

$$\frac{KWa\,Ac}{Aw} = \frac{E \cdot \times 10^4}{4B_m f\,K}$$

$$Wa\,Ac = \frac{E\,Aw \times 10^4}{4B_m f\,K}$$

$$J = \frac{I}{Aw} = \frac{Amp}{cm^2}$$

$$\eta = \frac{P_o}{P_1}$$

$$P_I = E\,I$$

$$E\,Aw = \frac{EI}{J} = \frac{P_1}{J} = \frac{P_o}{J\eta}$$

$$Wa\,Ac\Big|_{total} = Wa\,Ac\Big|_{primary} + Wa\,Ac\Big|_{secondary}$$

$$Wa\,Ac\Big|_{total} = \frac{P_o}{J} \times \frac{10^4}{4B_m f K} + \frac{P_o\, 10^4}{4B_m f K J} = \frac{P_o\, 10^4}{4B_m f K J}(1/\eta + 1)$$

$$P_T = \frac{P_o}{\eta} + P_o$$

$$Wa\,Ac = \frac{P_T \times 10^4}{4B_m f KJ}$$

Window utilization factor K

$$\left.\begin{array}{l}\text{Lamination and Bobbin}\\ \text{Toroid 1/2 ID remaining}\\ \text{C Core and Bobbin}\end{array}\right\} \frac{Wa\,(eff)}{Wa} \times \text{Fill Factor} \times \frac{Aw\ Bare}{Aw\ Total} = 0.4$$

$$Wa\,Ac = \frac{P_T \times 10^4}{1.6 \times B_m f J} \text{ square ware}$$

$$Wa\,Ac = \frac{P_T \times 10^4}{1.77 \times B_m f J} \text{ sine wave}$$

The curve in Fig. 5 shows the required core Wa Ac product plotted against transformer output power for different frequency. The values held constant were:

B_m = 0.3T

J = 200 Amps/cm^2

$K = 0.40$

$\eta = 95\%$

These values were held constant so that one nomograph could be used with all materials and the Engineer could adjust B_m, J, K and η to fit the design. From the equation

$$Wa\ Ac = \frac{P_T \times 10^4}{1.6 \times B_m f J}$$

two nomographs were generated to compare output power

$$P_o = \frac{P_T}{(1/\eta + 1)}$$

with Wa Ac and P_o with weight. These nomographs were generated from the lamination and C core in the article. The nomograph in Fig. 5 compares P_o with Wa Ac, thus the size of the transformer can quickly be determined. The nomograph in Fig. 6 compares power with weight, thus the weight of a fully wound transformer can quickly be determined. These nomographs have the following constraints:

$B_m = 0.3T$

$J = 200\ A/cm^2$

$K = 0.4$

More than likely after the Wa Ac has been selected a slight reshuffle of the constraints is required to correspond to the actual core Wa Ac product.

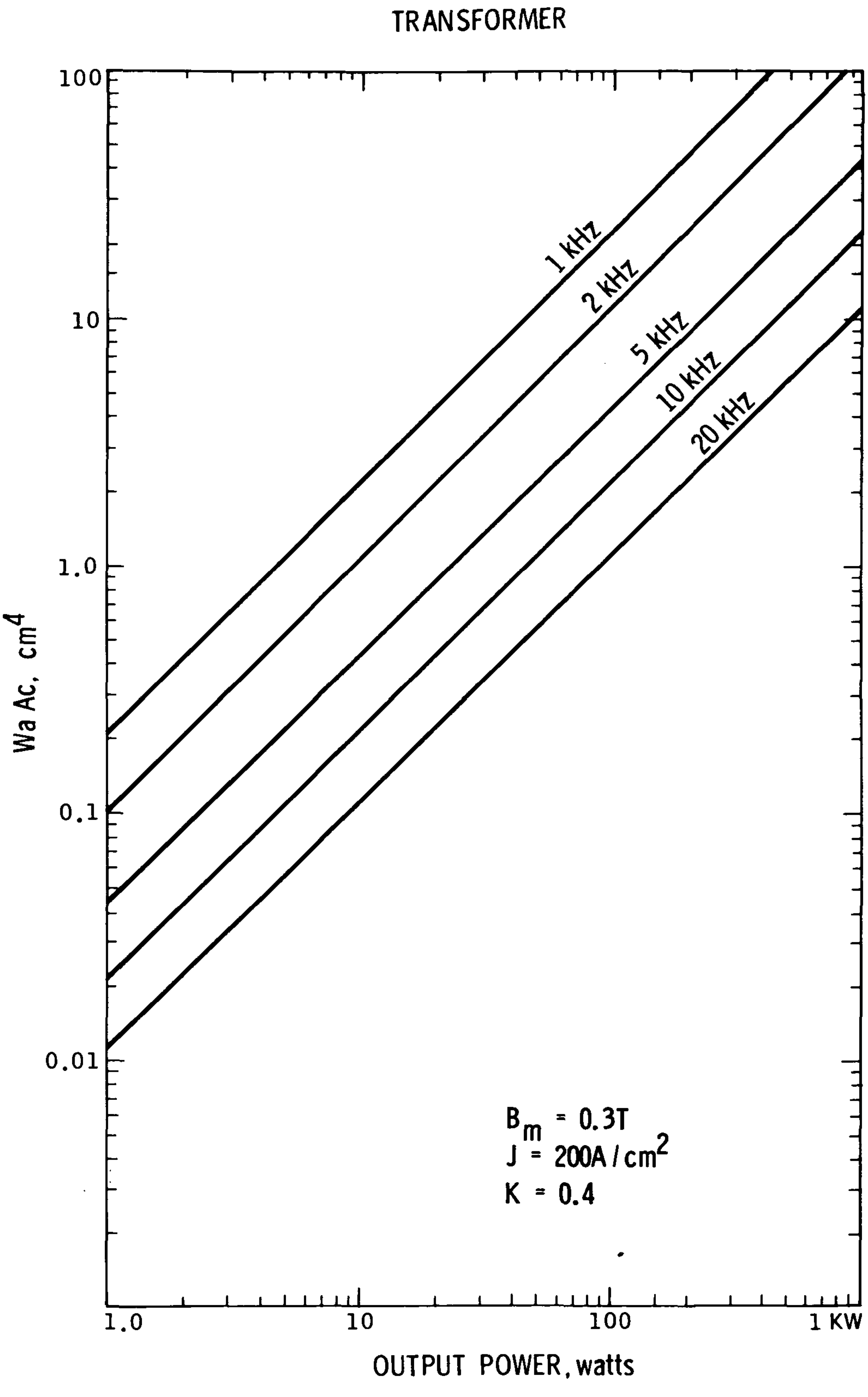


Fig. 5. Wa Ac versus Output Power

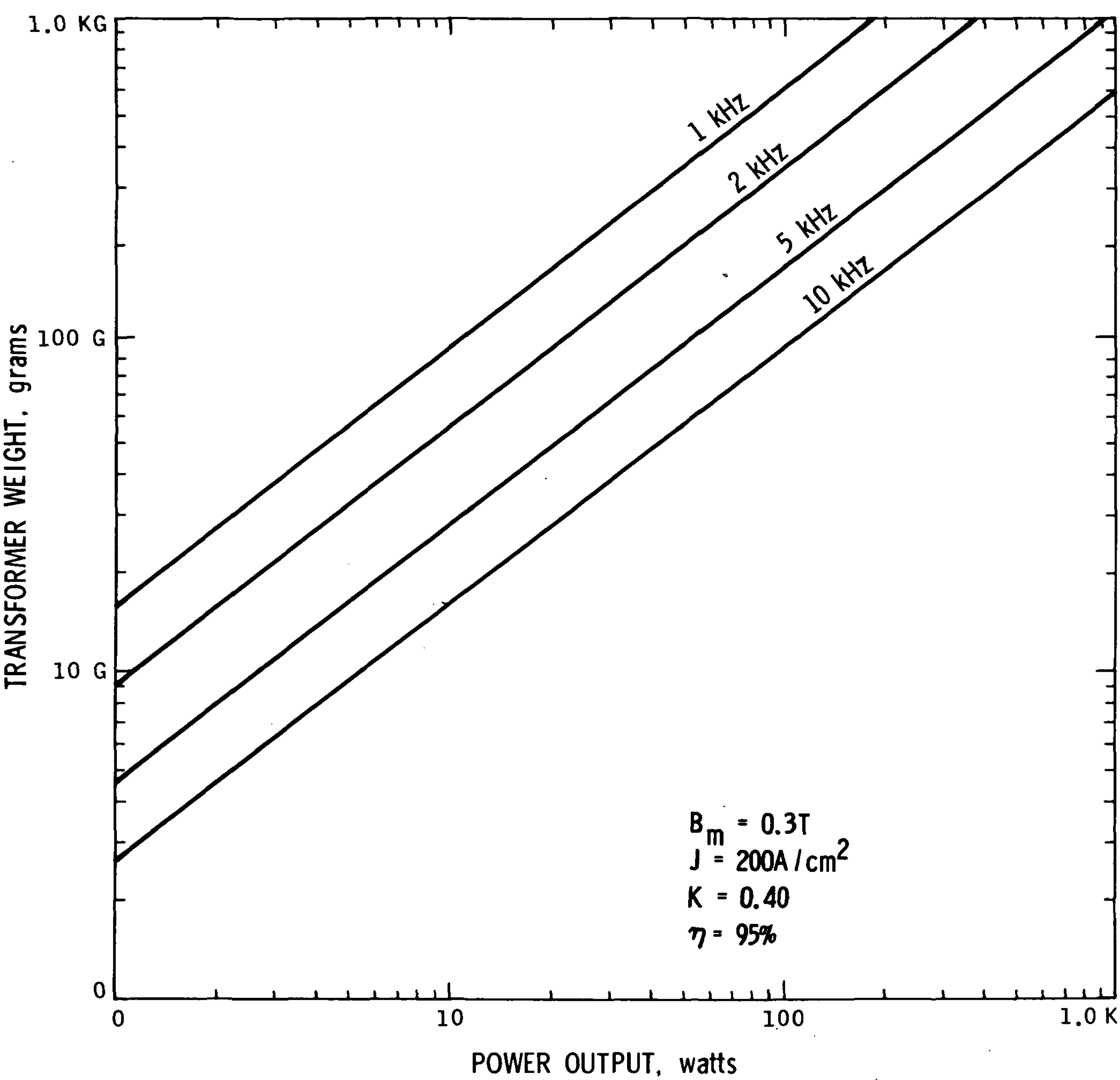


Fig. 6. Transformer Weight versus Power Output

VI. TOROID POWDER CORE SELECTION WITH dc CURRENT

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

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

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

$$\phi = B_m Ac'$$

$$B_m = \mu_r \mu_o H' = \frac{\mu_r \mu_o NI}{lm'}$$

$$\phi = \frac{\mu_r \mu_o NI Ac'}{lm'}$$

$$\frac{d\phi}{dI} = \frac{\mu_r \mu_o N Ac'}{lm'}$$

$$L = N\frac{d\phi}{dI} = \frac{\mu_r \mu_o N^2 Ac'}{lm'}$$

E = voltage, volts
L = inductance, henrys
I = current, amperes
N = number of turns
ϕ = flux, webers
B_m = flux density, teslas
Ac' = core cross section, $-m^2$
μ_r = relative permeability
μ_o = absolute permeability ($4\pi \times 10^{-7}$)
H' = magnetizing force, amp turns/m
lm' = magnetic path length, m
K = window utilization sector
Wa' = window area, m^2
J' = current density, amps/m^2
Eng = energy, watt seconds

$$\text{Energy} = \frac{1}{2}LI^2 = \frac{\mu_r \mu_o N^2 Ac'}{2lm'} I^2$$

If B_m is specified,

$$I = \frac{B_m lm'}{\mu_r \mu_o N}$$

$$Eng = \frac{\mu_r \mu_o N^2 Ac'}{2 lm'} \left(\frac{B_m lm'}{\mu_r \mu_o N} \right)^2 = \frac{B_m^2 \, lm' Ac'}{2 \mu_r \mu_o} \text{ watt seconds}$$

$$I = \frac{KWa'J'}{N} = \frac{B_m lm'}{\mu_r \mu_o N}$$

Solving for $\mu_r \mu_o$

$$\mu_r \mu_o = \frac{B_m lm'}{KWa'J'}$$

Substituting into the energy equation

$$Eng = \frac{B_m^2 \, lm'Ac'}{2} \cdot \frac{KWa'J'}{B_m lm'} = \frac{Wa'Ac'B_m J'K}{2}$$

let

Wa = window area, cm^2

Ac = core area, cm^2

J = current density, $amps/cm^2$

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

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

$J' = J \times 10^4$

Substituting into the energy equation

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

Solving for Wa Ac,

$$Wa \, Ac = \frac{2 \, (Eng)}{B_m JK} \times 10^4$$

let

lm = magnetic path length, cm

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

$$\mu_r = \frac{B_m lm \times 10^{-2}}{K\mu_o (Wa \times 10^{-4})(J \times 10^4)} = \frac{B_m lm \times 10^{-2}}{\mu_o \, Wa \, JK}$$

for $\mu_o = 4\pi \times 10^{-7}$

$$\mu_r = \frac{B_m lm \times 10^{-2}}{4\pi \times 10^{-7} \, Wa \, JK} = \frac{B_m lm \times 10^4}{0.4 \, Wa \, J \, K}$$

From the equation

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

two nomographs were generated to compare energy or $LI^2/2$ with Wa Ac and energy or $LI^2/2$ with weight. These nomographs were generated for 13 commonly used powder cores in this article. The nomograph in Fig. 7 compares $LI^2/2$ with Wa Ac, thus the size of an inductor can quickly be determined. The nomograph in Fig. 8 compares $LI^2/2$ with weight, thus the weight of a fully wound inductor can quickly be determined. These nomographs have the following constraints:

$B_m = 0.3$ T

$J = 200$ A/cm^2

$K = 0.4$

After the core size has been determined the next step is to pick the right permeability for that core size and that is done with the following equation:

$$\mu_r = \frac{B_m \, l \, m \times 10^4}{0.4\pi \, Wa \, J \, K}$$

More than likely after the permeability has been selected a slight reshuffle of the constraints to match the available core and permeability must be made.

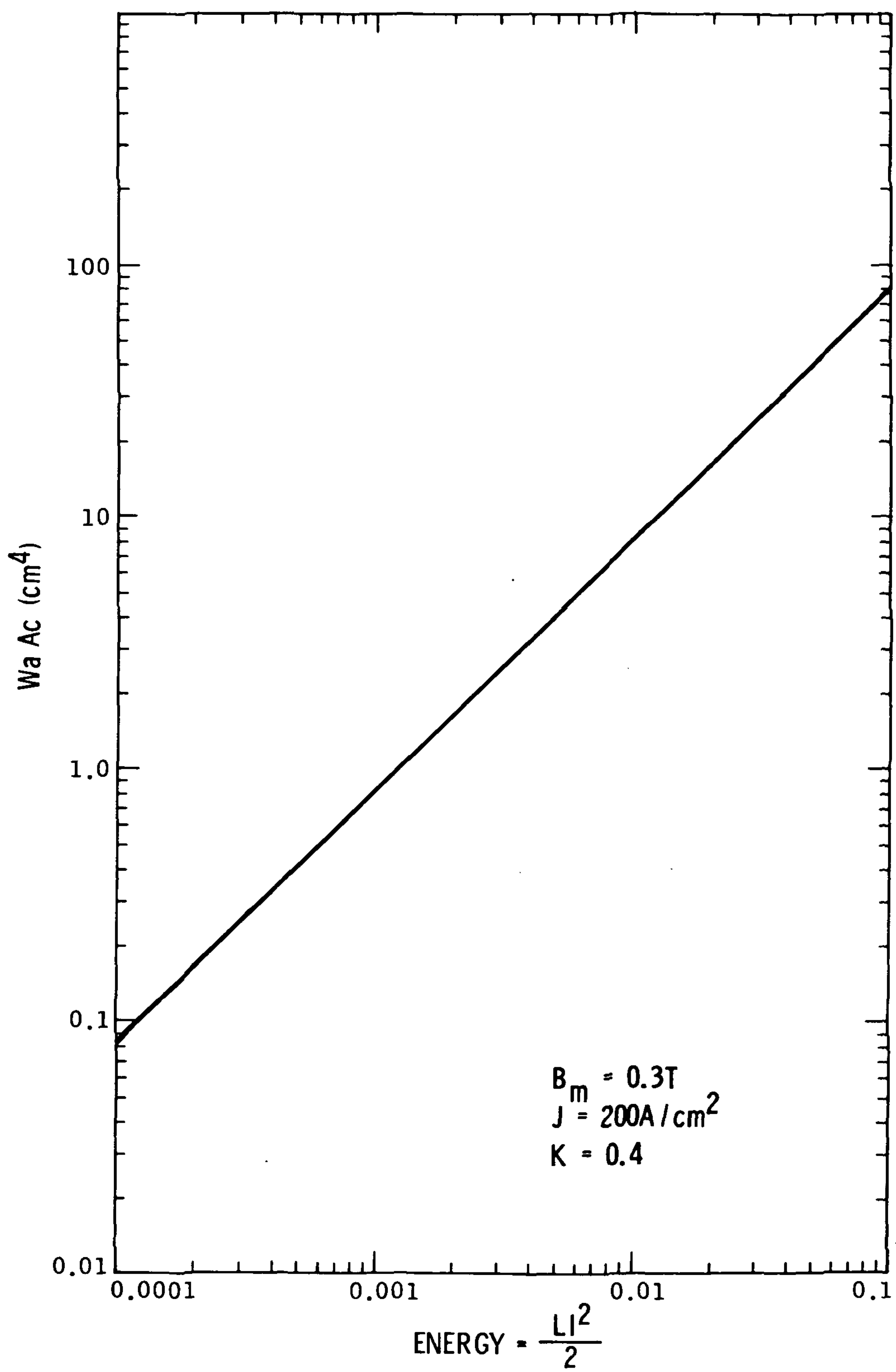


Fig. 7. Wa Ac versus $LI^2/2$

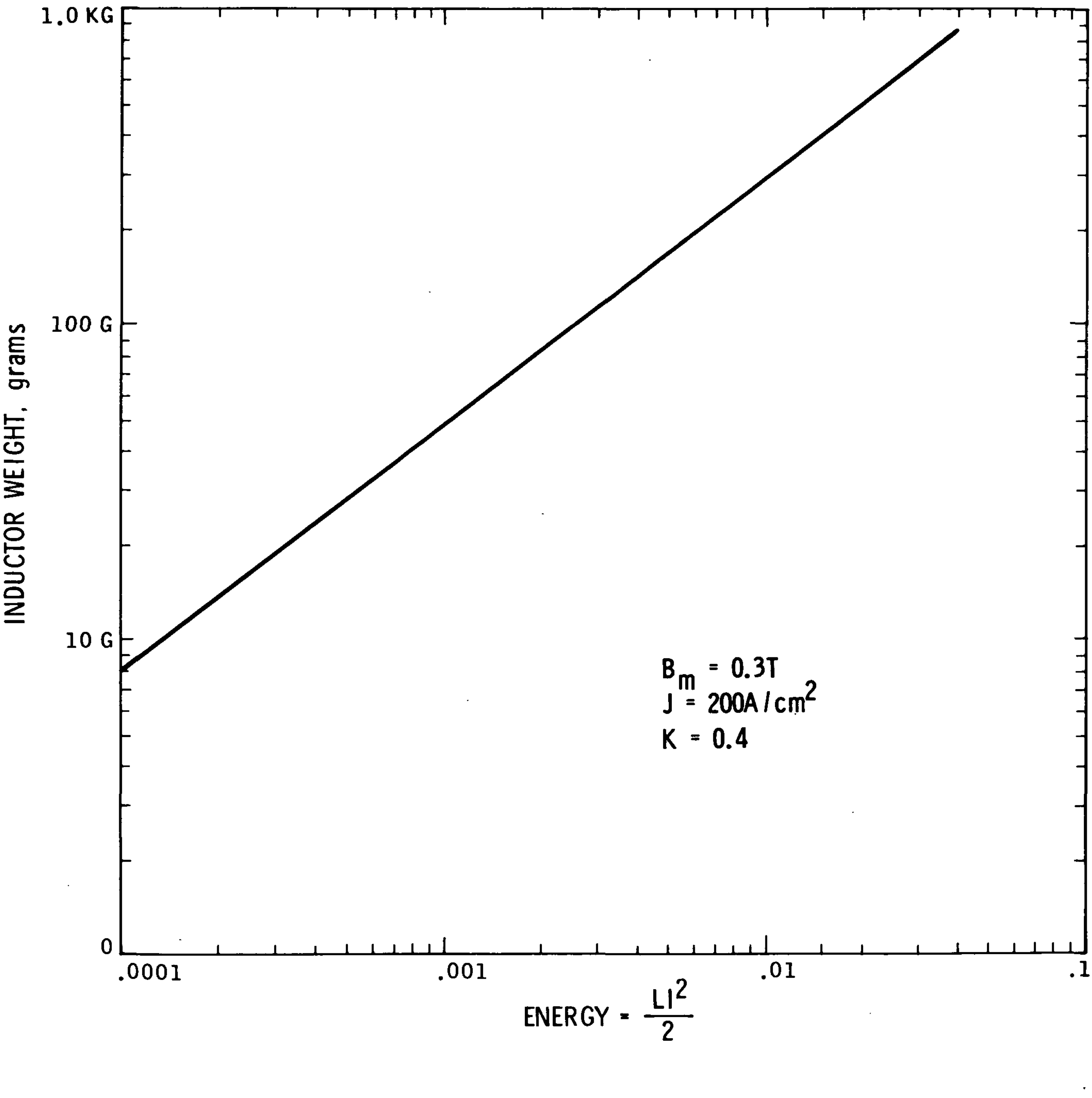


Fig. 8. Inductor Weight versus $LI^2/2$

VII. CALCULATION OF OUTSIDE DIAMETER OF WOUND TOROID

The outside diameter of the wound toroid, Fig. 9, (less the outside wrapper) may be calculated from (assuming one half of the ID remains after winding):

$$OD = \sqrt{D_2^2\,(3/4) + D_3^2}$$

where:

D = diameter

$A_1 = \pi\left(R_2^2 - R_1^2\right),\ A_1 = A_2$

Core window ID = $D_1 = 2R_1$, Core ID = $D_2 = 2R_2$, Core OD = $D_3 = 2R_3$

$\pi\left(R_2^2 - R_1^2\right) = \pi\left(R_4^2 - R_3^2\right),\ R_2^2 - R_1^2 = R_4^2 - R_3^2,\ R_1 = \dfrac{R_2}{2}$

$R_4^2 - R_3^2 = R_2^2 - \left(\dfrac{R_2}{2}\right)^2 = R_2^2\,(1 - 1/4),\ R_4^2 = R_2^2\,(3/4) + R_3^2$

$R_4 = \sqrt{R_2^2\,(3/4) + R_3^2}$

$OD = 2R_4$

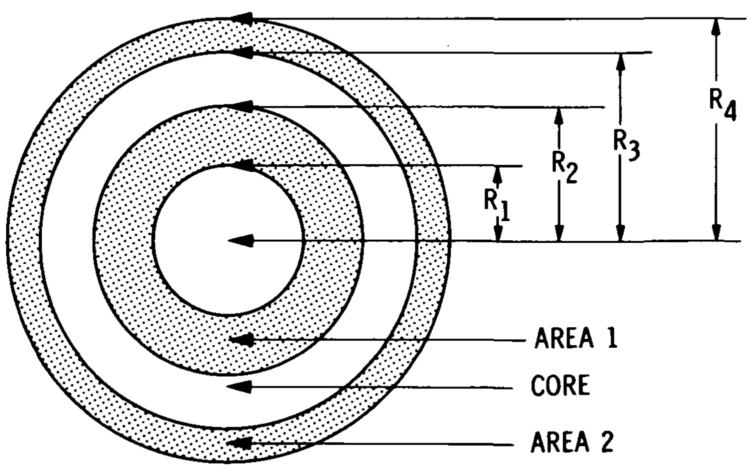


Fig. 9. Calculation of Outside Diameter of Wound Toroid

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VIII. MAGNETIC AND DIMENSIONAL SPECIFICATIONS FOR THIRTEEN COMMONLY USED MOLYPERMALLOY CORES

The following remarks apply to each of Tables 3 to 15, the data in which was compiled from Ref. 2.

(1) Total weight is core weight plus wire weight assuming AWG 20

(2) Maximum OD of wound core with residual hole = 1/2 ID

(3) MLT (mean length/turn), $K_2 \times K_3 = 0.6 \times 0.75 = 0.45$

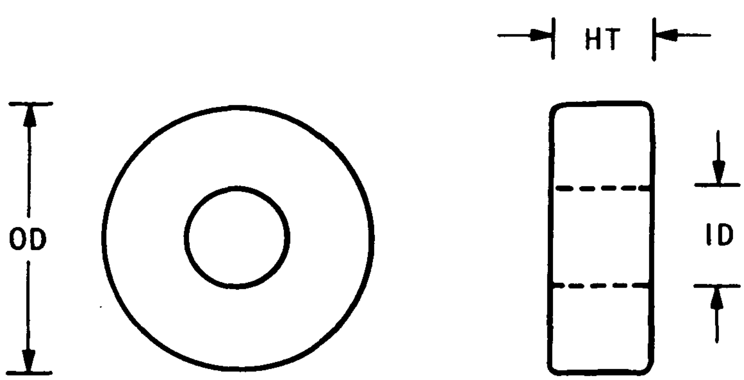
(4) Effective window area $Wa\ eff = 3\pi r^2/4$

(Data was computed with the aid of Refs. 2 to 4.)

Nomographs (Figs. 10 to 22) relate to the thirteen different core sizes. The nomographs show resistance, number of turns, inductance and wire size for a fill factor of 0.45 ($K_2 \times K_3$), and are based on a permeability of 60. To convert for other permeability values, the appropriate inductance multiplication factors listed should be used. The information appearing in the tables and on the figures, will enable the engineer to arrive at a close approximation for breadboarding purposes.

Table 3. Magnetic Inc 55051-A2, Arnold Engineering A-051027-2

	ENGLISH	METRIC
Wa/Ac		3.39
Wa x Ac	0.00104 in^4	0.0432 cm^4
OD	0.530 in	1.346 cm
ID	0.275 in	0.699 cm
HT	0.217 in	0.551 cm
Wa = WINDOW AREA	0.075×10^6 CIR-MIL	0.383 cm^2
Wa = EFFECTIVE	0.445 in^2	0.288 cm^2
Ac = CROSS SECTION	0.0175 in^2	0.113 cm^2
lm = PATH LENGTH	1.229 in	3.12 cm
CORE WEIGHT	0.0066 lb	3.0 grams
TOTAL WEIGHT	0.0106 lb	5.175 grams
WOUND OD MIN	0.581 in	1.475 cm
MLT	0.850 in	2.160 cm
A_t = SURFACE AREA	1.018 in^2	6.568 cm^2
PERMEABILITY		60
μ 125		2.08 x L @ μ 60
μ 160		2.67 x L @ μ 60
μ 200		3.33 x L @ μ 60
μ 550		9.17 x L @ μ 60



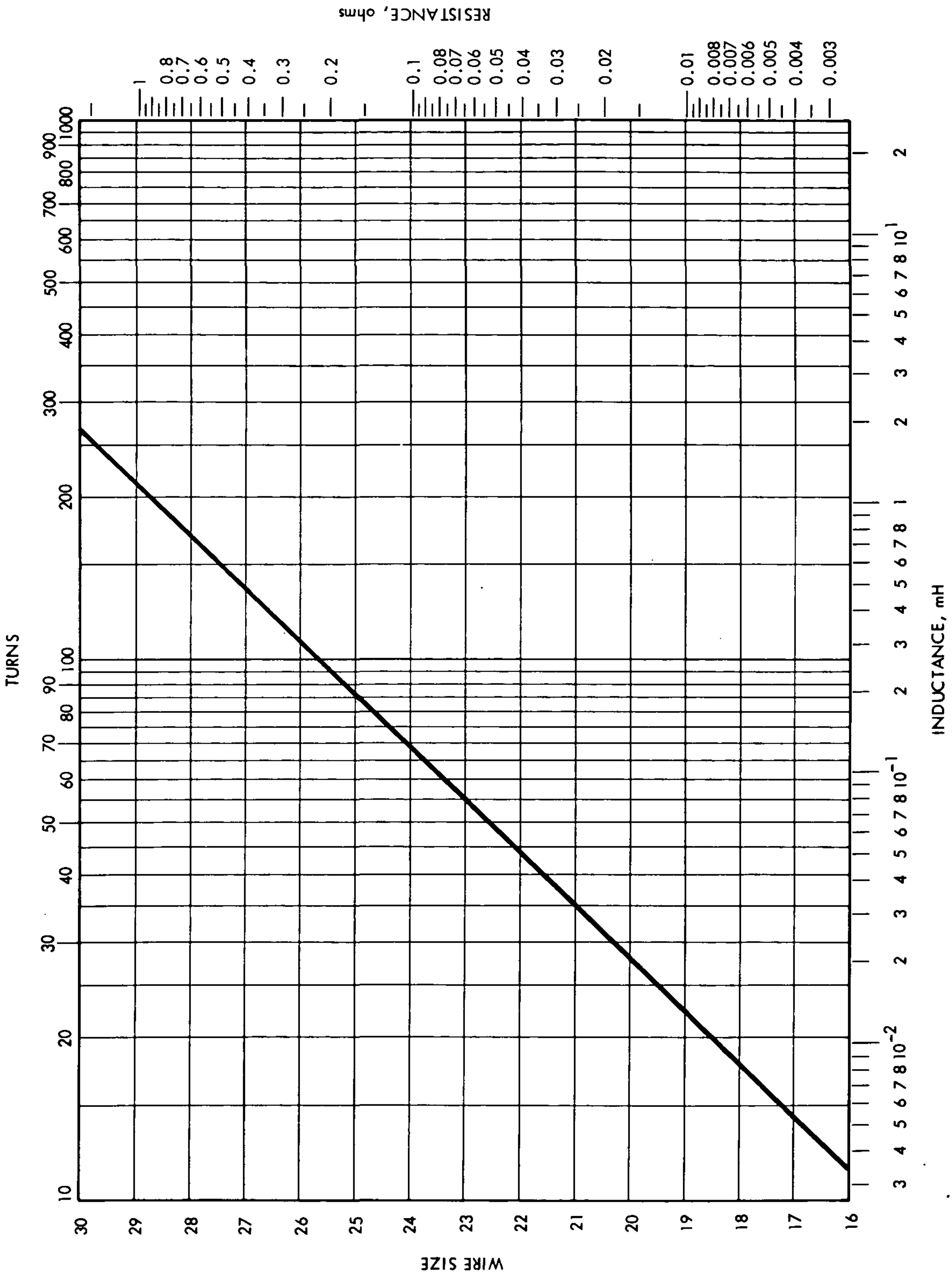
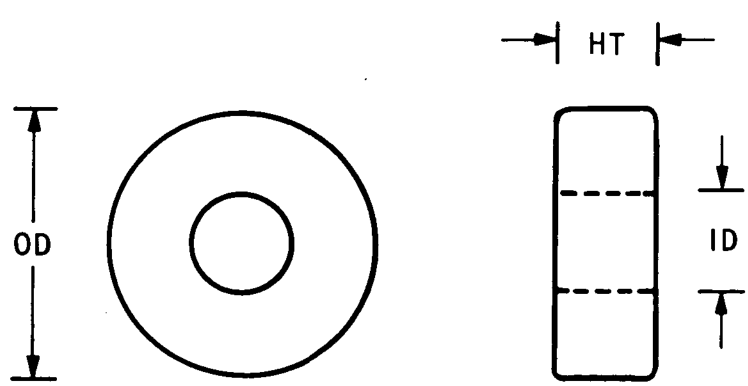


Fig. 10. Nomograph for Core 55051-A2

Table 4. Magnetic Inc 55121-A2, Arnold Engineering A-266036-2

	ENGLISH	METRIC
Wa/Ac		3.63
Wa x Ac	0.00336 in^4	0.139 cm^4
OD	0.680 in	1.740 cm
ID	0.375 in	0.953 cm
HT	0.280 in	0.711 cm
Wa = WINDOW AREA	0.141×10^6 CIR-MIL	0.713 cm^2
Wa = EFFECTIVE	0.0828 in^2	0.535 cm^2
Ac = CROSS SECTION	0.0304 in^2	0.196 cm^2
lm = PATH LENGTH	1.62 in	4.11 cm
CORE WEIGHT	0.0143 lb	6.50 grams
TOTAL WEIGHT	0.0257 lb	11.70 grams
WOUND OD MIN	0.753 in	1.925 cm
MLT	1.075 in	2.74 cm
A_t = SURFACE AREA	1.742 in^2	11.24 cm^2
PERMEABILITY		60
μ 125		2.08 x L @ μ 60
μ 160		2.67 x L @ μ 60
μ 200		3.33 x L @ μ 60
μ 550		9.17 x L @ μ 60



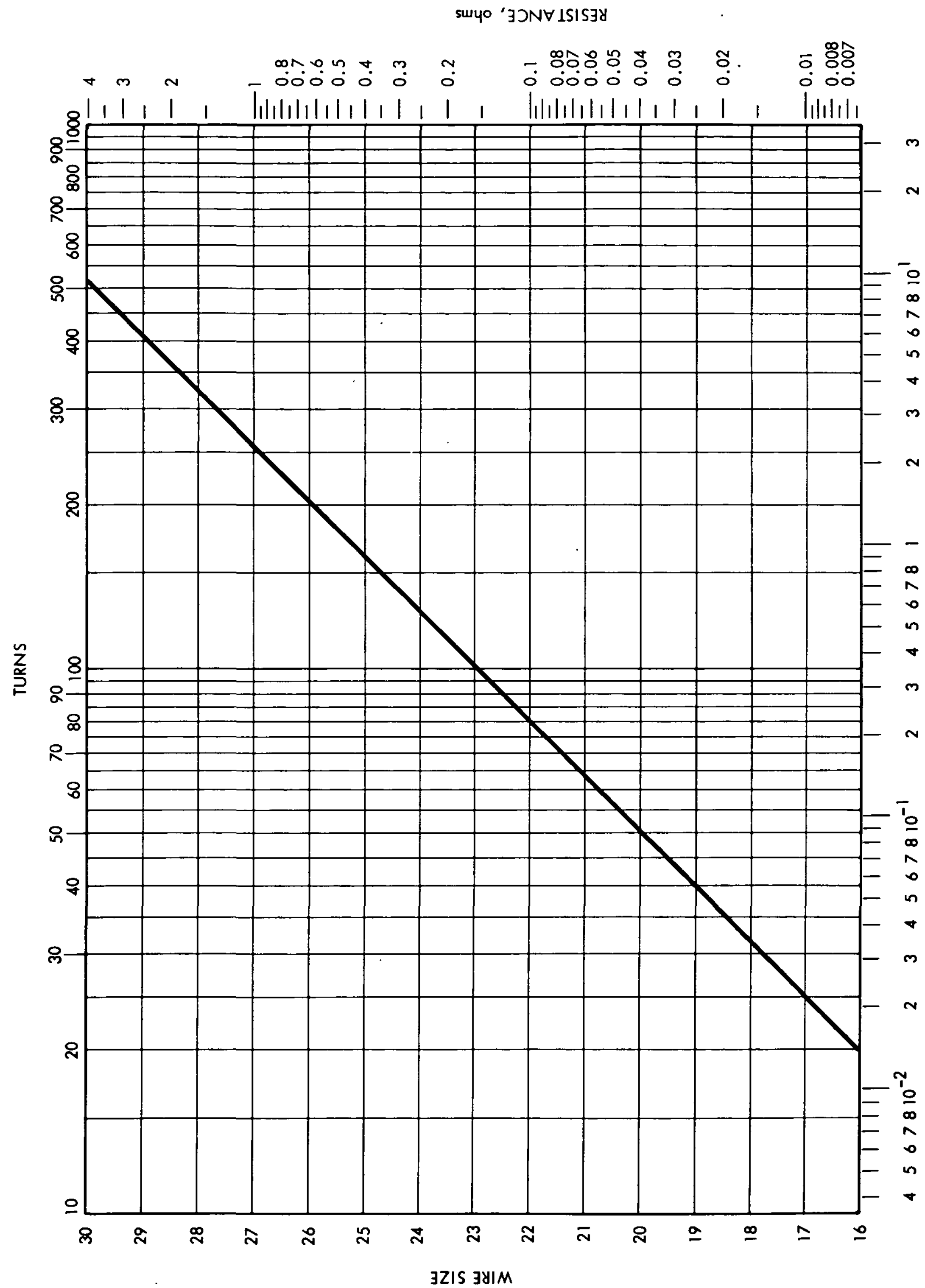
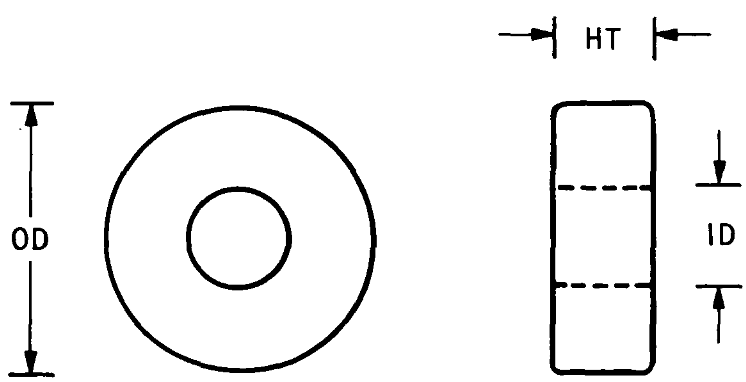


Fig. 11. Nomograph for Core 55121-A2

Table 5. Magnetic Inc 55848-A2, Arnold Engineering A-848032-2

	ENGLISH	METRIC
Wa/Ac		4.91
Wa x Ac	0.00636 in^4	0.264 cm^4
OD	0.830 in	2.11 cm
ID	0.475 in	1.21 cm
HT	0.280 in	0.711 cm
Wa = WINDOW AREA	0.23×10^6 CIR-MIL	1.14 cm^2
Wa = EFFECTIVE	0.13290 in^2	0.858 cm^2
Ac = CROSS SECTION	0.036 in^2	0.232 cm^2
lm = PATH LENGTH	2.01 in	5.09 cm
CORE WEIGHT	0.021 lb	9.6 grams
TOTAL WEIGHT	0.041 lb	18.6 grams
WOUND OD MIN	0.926 in	2.35 cm
MLT	1.166 in	2.97 cm
A_t = SURFACE AREA	2.431 in^2	15.69 cm^2
PERMEABILITY		60
μ 125		2.08 x L @ μ 60
μ 160		2.67 x L @ μ 60
μ 200		3.33 x L @ μ 60
μ 550		9.17 x L @ μ 60



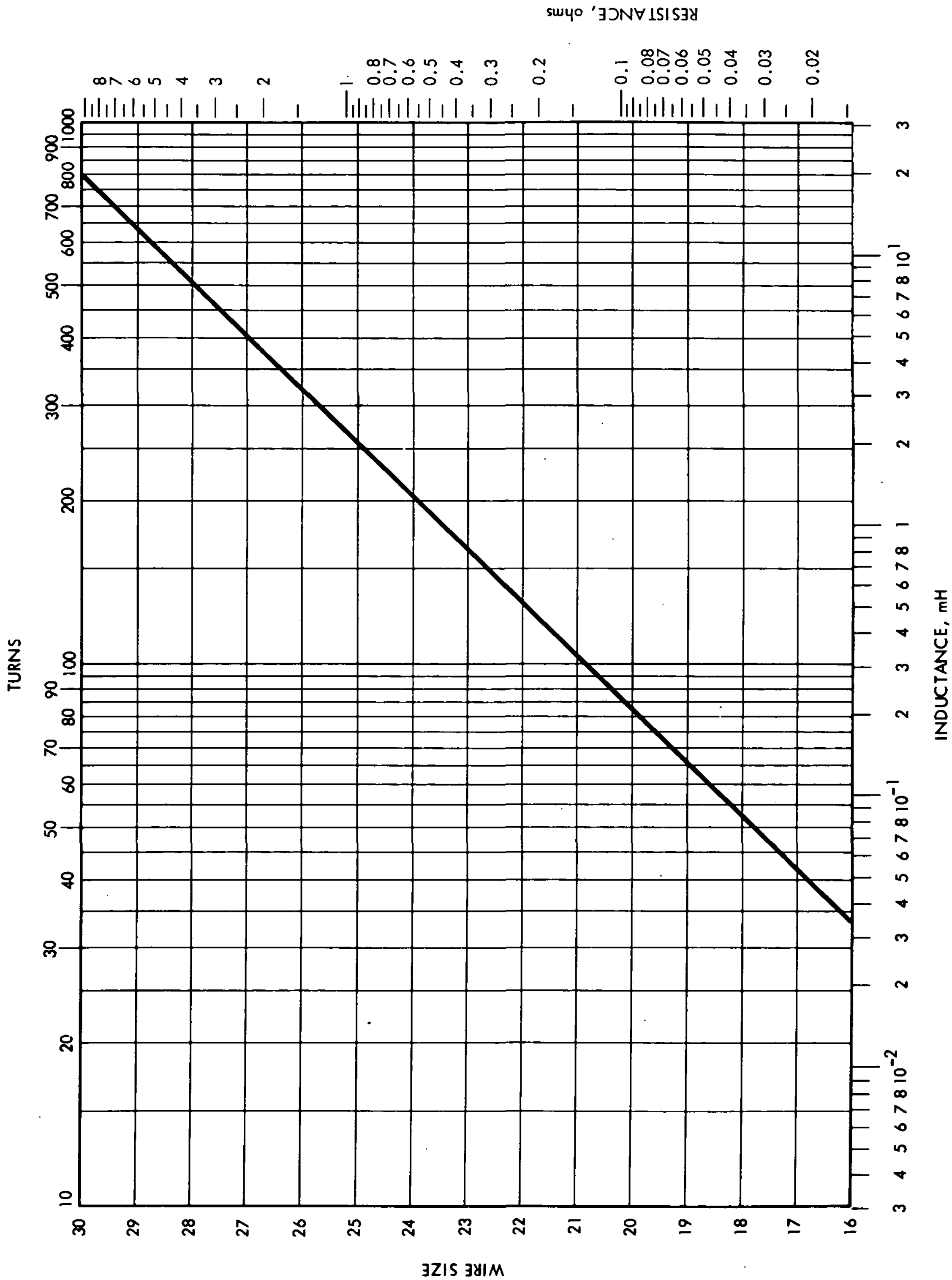
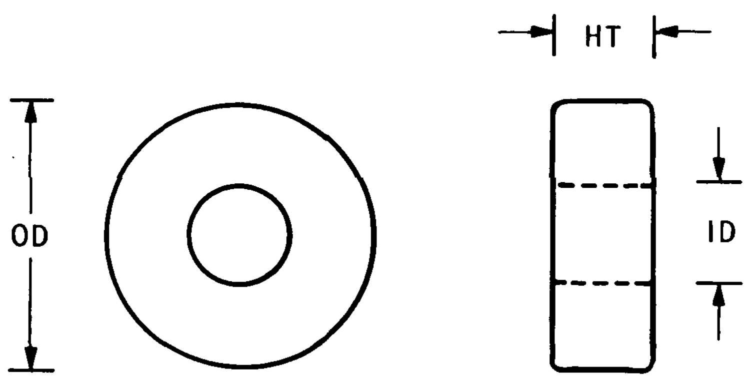


Fig. 12. Nomograph for Core 55848-A2

Table 6. Magnetic Inc 55059-A2, Arnold Engineering A-059043-2

	ENGLISH		METRIC	
Wa/Ac			4.30	
Wa x Ac	0.0713	in^4	0.460	cm^4
OD	0.930	in	2.36	cm
ID	0.527	in	1.339	cm
HT	0.330	in	0.838	cm
Wa = WINDOW AREA	0.28×10^6 CIR-MIL		1.407	cm^2
Wa = EFFECTIVE	0.164	in^2	1.056	cm^2
Ac = CROSS SECTION	0.0507	in^2	0.327	cm^2
lm = PATH LENGTH	2.23	in	5.67	cm
CORE WEIGHT	0.033	lb	15.0	grams
TOTAL WEIGHT	0.0716	lb	32.5	grams
WOUND OD MIN	1.035	in	2.63	cm
MLT	1.356	in	3.45	cm
A_t = SURFACE AREA	3.103	in^2	20.019	cm^2
PERMEABILITY			60	
μ 125			2.08 x L @ μ 60	
μ 160			2.67 x L @ μ 60	
μ 200			3.33 x L @ μ 60	
μ 550			9.17 x L @ μ 60	



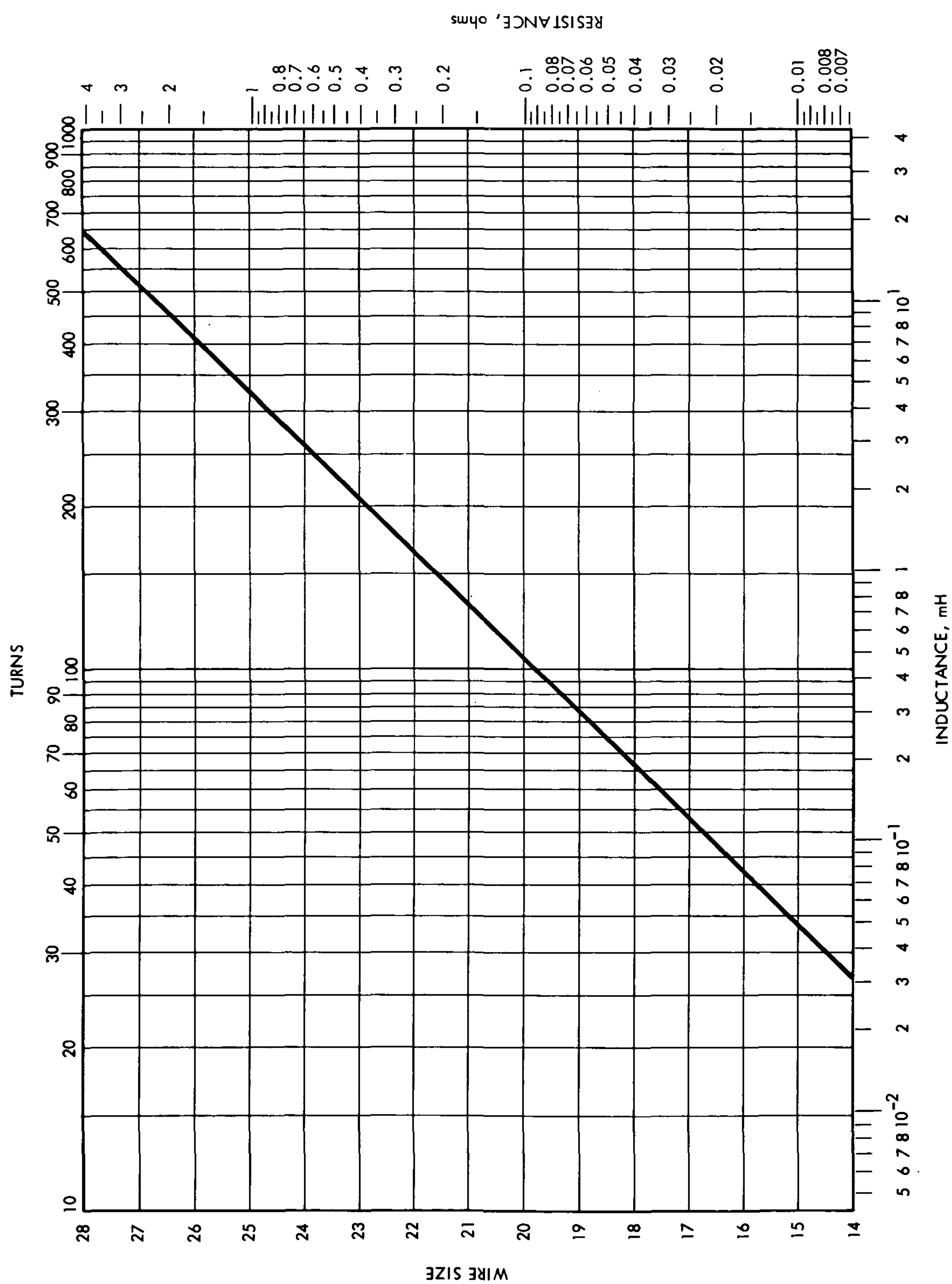
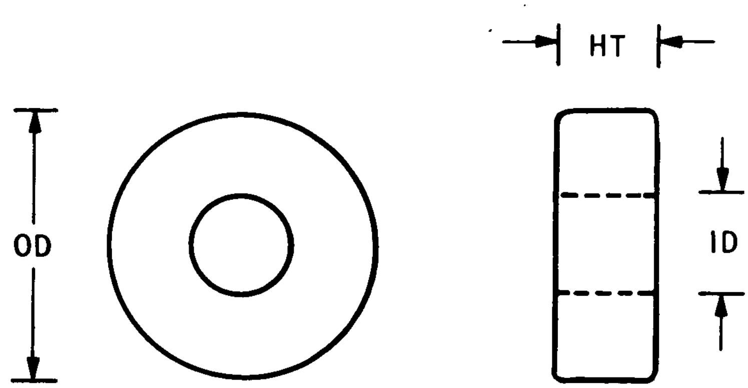


Fig. 13. Nomograph for Core 55059-A2

Table 7. Magnetic Inc 55894-A2, Arnold Engineering A-894075-2

	ENGLISH	METRIC
Wa/Ac		2.44
Wa x Ac	0.0239 in^4	0.997 cm^4
OD	1.090 in	2.77 cm
ID	0.555 in	1.41 cm
HT	0.472 in	1.20 cm
Wa = WINDOW AREA	0.31×10^6 CIR-MIL	1.561 cm^2
Wa = EFFECTIVE	0.1814 in^2	1.17 cm^2
Ac = CROSS SECTION	0.099 in^2	0.639 cm^2
lm = PATH LENGTH	2.50 in	6.35 cm
CORE WEIGHT	0.077 lb	35 grams
TOTAL WEIGHT	0.132 lb	59.7 grams
WOUND OD MIN	1.191 in	3.03 cm
MLT	1.81 in	4.61 cm
A_t = SURFACE AREA	3.103 in^2	20.019 cm^2
PERMEABILITY		60
μ 125		2.08 x L @ μ 60
μ 160		2.67 x L @ μ 60
μ 200		3.33 x L @ μ 60
μ 550		9.17 x L @ μ 60



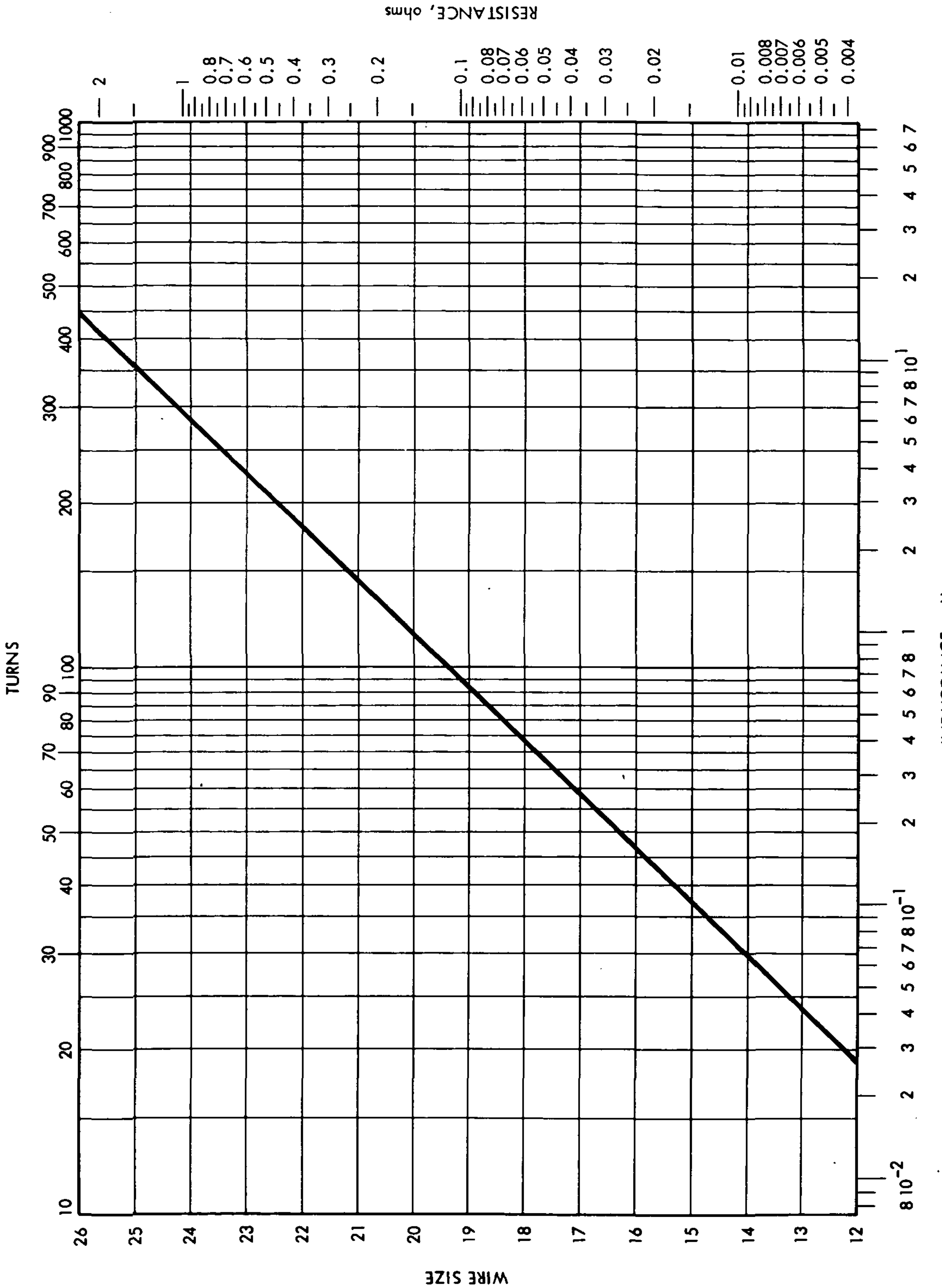
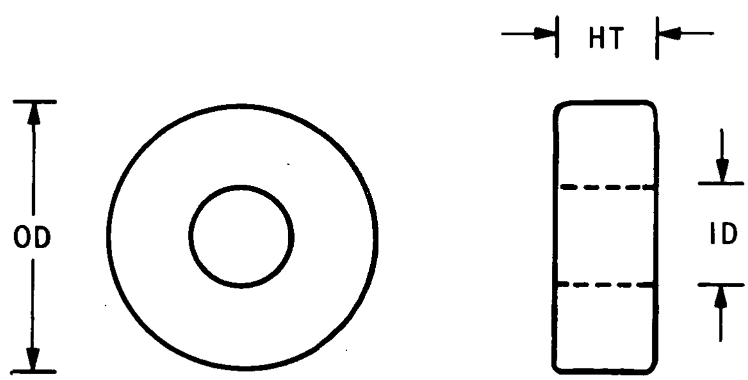


Fig. 14. Nomographs for Core 55894-A2

Table 8. Magnetic Inc 55071-A2, Arnold Engineering A-291061-2

	ENGLISH	METRIC
Wa/Ac		4.39
Wa x Ac	0.0468 in^4	1.95 cm^4
OD	1.332 in	3.38 cm
ID	0.760 in	1.93 cm
HT	0.457 in	1.16 cm
Wa = WINDOW AREA	0.58×10^6 CIR-MIL	2.93 cm^2
Wa = EFFECTIVE	0.340 in^2	2.1941 cm^2
Ac = CROSS SECTION	0.1032 in^2	0.666 cm^2
lm = PATH LENGTH	3.21 in	8.15 cm
CORE WEIGHT	0.101 lb	46 grams
TOTAL WEIGHT	0.198 lb	90 grams
WOUND OD MIN	1.486 in	3.77 cm
MLT	1.89 in	4.80 cm
A_t = SURFACE AREA	4.389 in^2	28.32 cm^2
PERMEABILITY		60
μ 125		2.08 x L @ μ 60
μ 160		2.67 x L @ μ 60
μ 200		3.33 x L @ μ 60
μ 550		9.17 x L @ μ 60



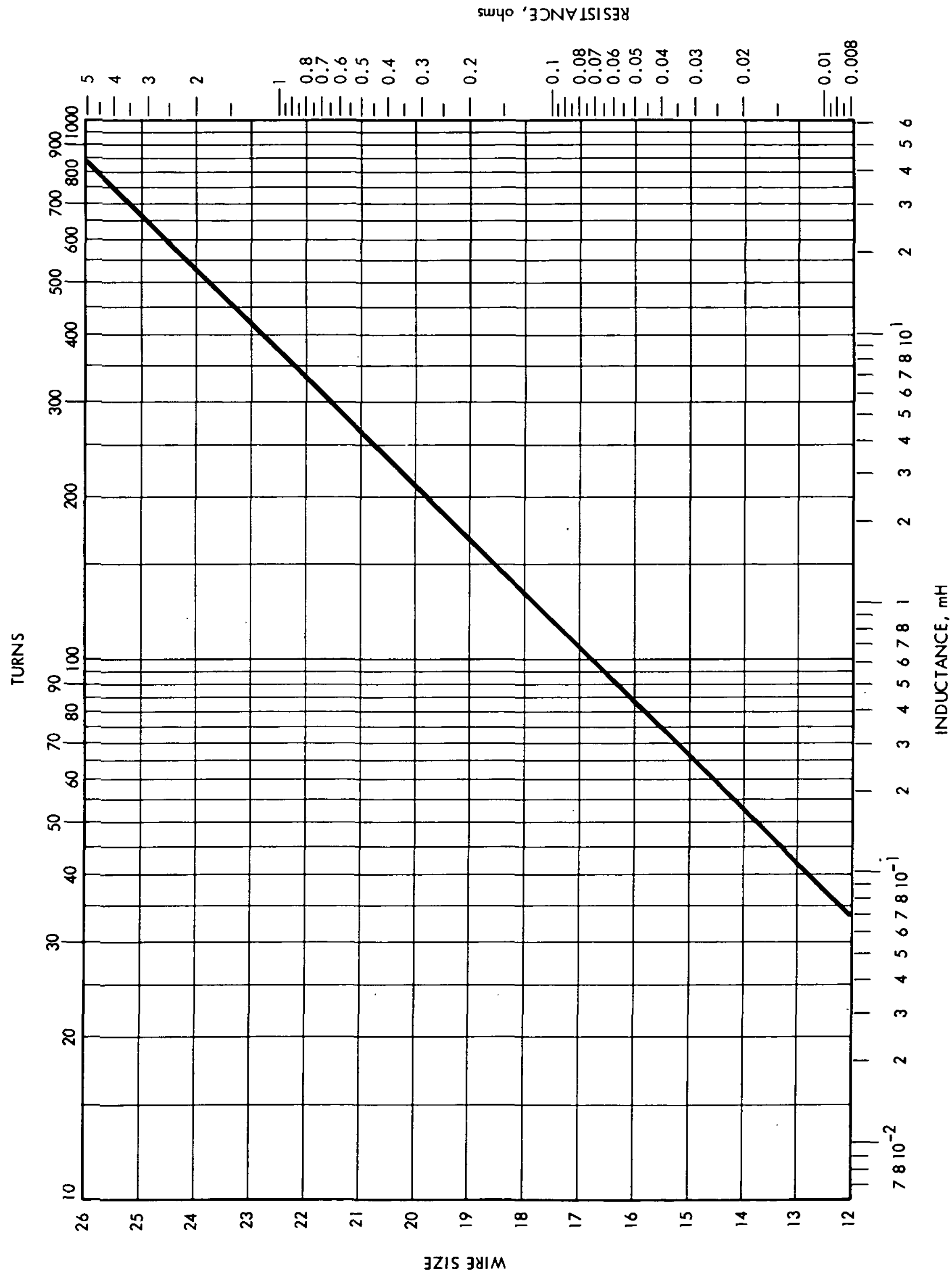
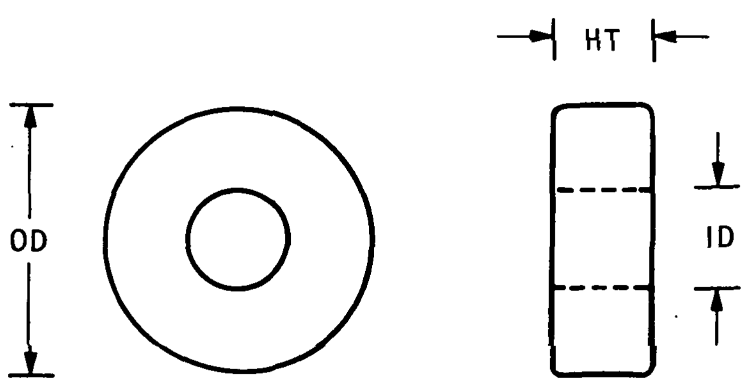


Fig. 15. Nomograph for Core 55071-A2

Table 9. Magnetic Inc 55586-A2, Arnold Engineering A-345038-2

	ENGLISH	METRIC
Wa/Ac		8.73
Wa x Ac	0.044 in^4	1.832 cm^4
OD	1.382 in	3.51 cm
ID	0.888 in	2.26 cm
HT	0.387 in	0.983 cm
Wa = WINDOW AREA	0.79×10^6 CIR-MIL	4.00 cm^2
Wa = EFFECTIVE	0.4644 in^2	3.009 cm^2
Ac = CROSS SECTION	0.0710 in^2	0.458 cm^2
lm = PATH LENGTH	3.53 in	8.95 cm
CORE WEIGHT	0.075 lb	34 grams
TOTAL WEIGHT	0.193 lb	87.4 grams
WOUND OD MIN	1.58 in	4.02 cm
MLT	1.70 in	4.32 cm
A_t = SURFACE AREA	6.305 in^2	40.68 cm^2
PERMEABILITY		60
μ 125		2.08 x L @ μ 60
μ 160		2.67 x L @ μ 60
μ 200		3.33 x L @ μ 60
μ 550		9.17 x L @ μ 60



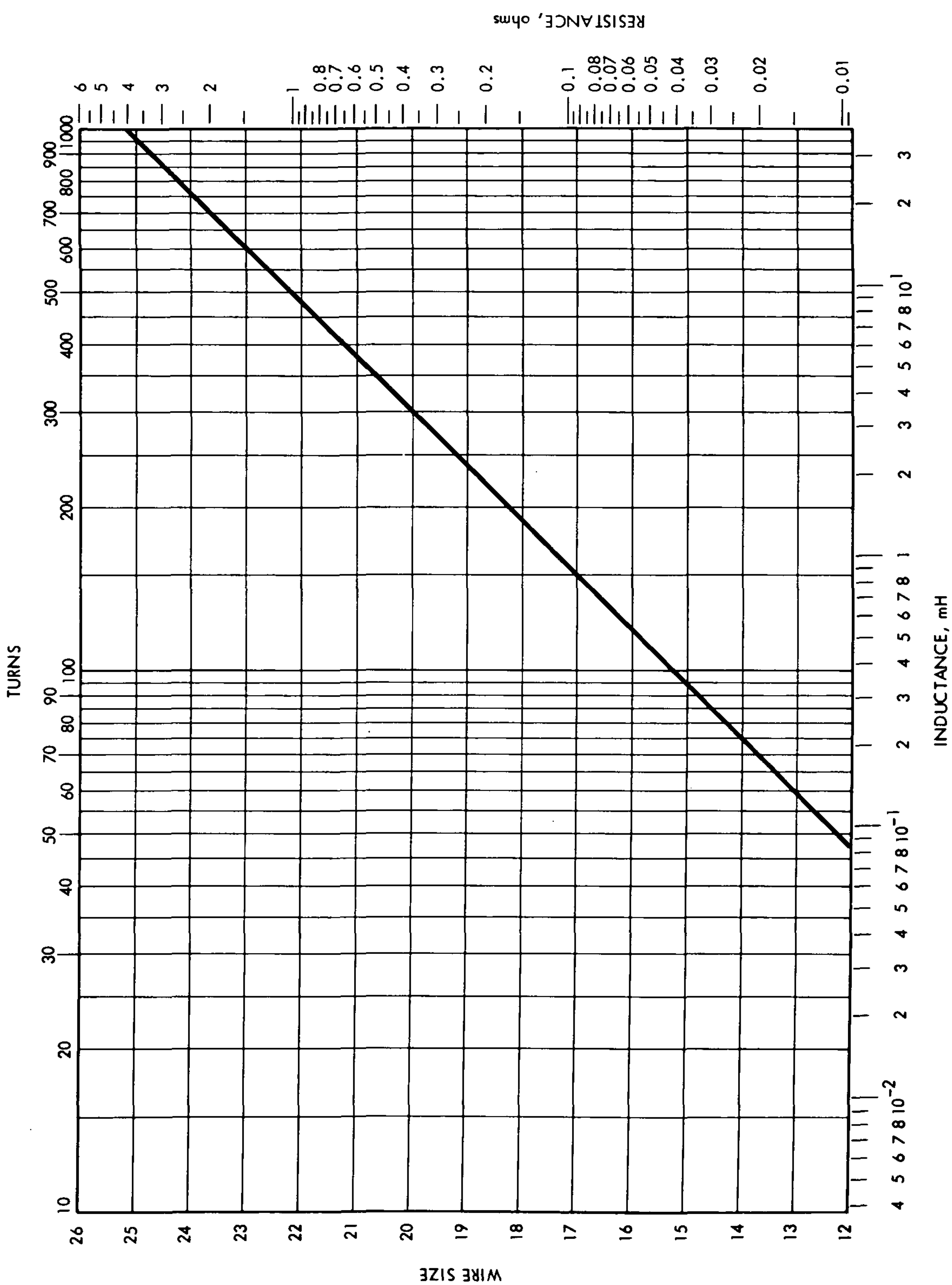
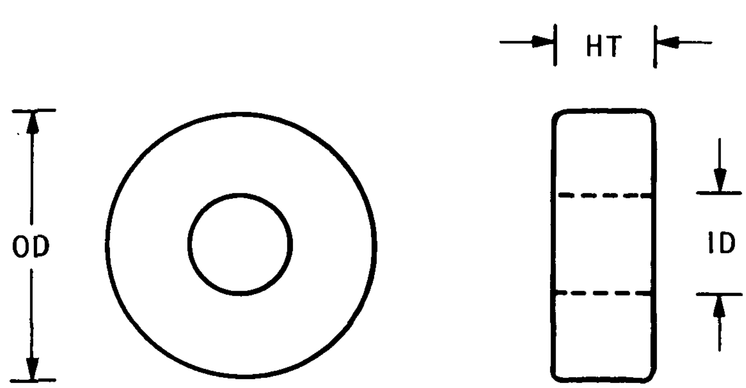


Fig 16. Nomograph for Core 55586-A2

Table 10. Magnetic Inc 55076-A2, Arnold Engineering A-076056-2

	ENGLISH		METRIC	
Wa/Ac			5.43	
Wa x Ac	0.0586	in^4	2.44	cm^4
OD	1.44	in	3.66	cm
ID	0.848	in	2.15	cm
HT	0.444	in	1.128	cm
Wa = WINDOW AREA	0.72×10^6	CIR-MIL	3.64	cm^2
Wa = EFFECTIVE	0.424	in^2	2.723	cm^2
Ac = CROSS SECTION	0.1039	in^2	0.670	cm^2
lm = PATH LENGTH	3.54	in	8.98	cm
CORE WEIGHT	0.112	lb	51	grams
TOTAL WEIGHT	0.239	lb	108.4	grams
WOUND OD MIN	1.62	in	4.11	cm
MLT	1.91	in	4.88	cm
A_t = SURFACE AREA	7.271	in^2	46.91	cm^2
PERMEABILITY			60	
μ 125			2.08 x L @ μ 60	
μ 160			2.67 x L @ μ 60	
μ 200			3.33 x L @ μ 60	
μ 550			9.17 x L @ μ 60	



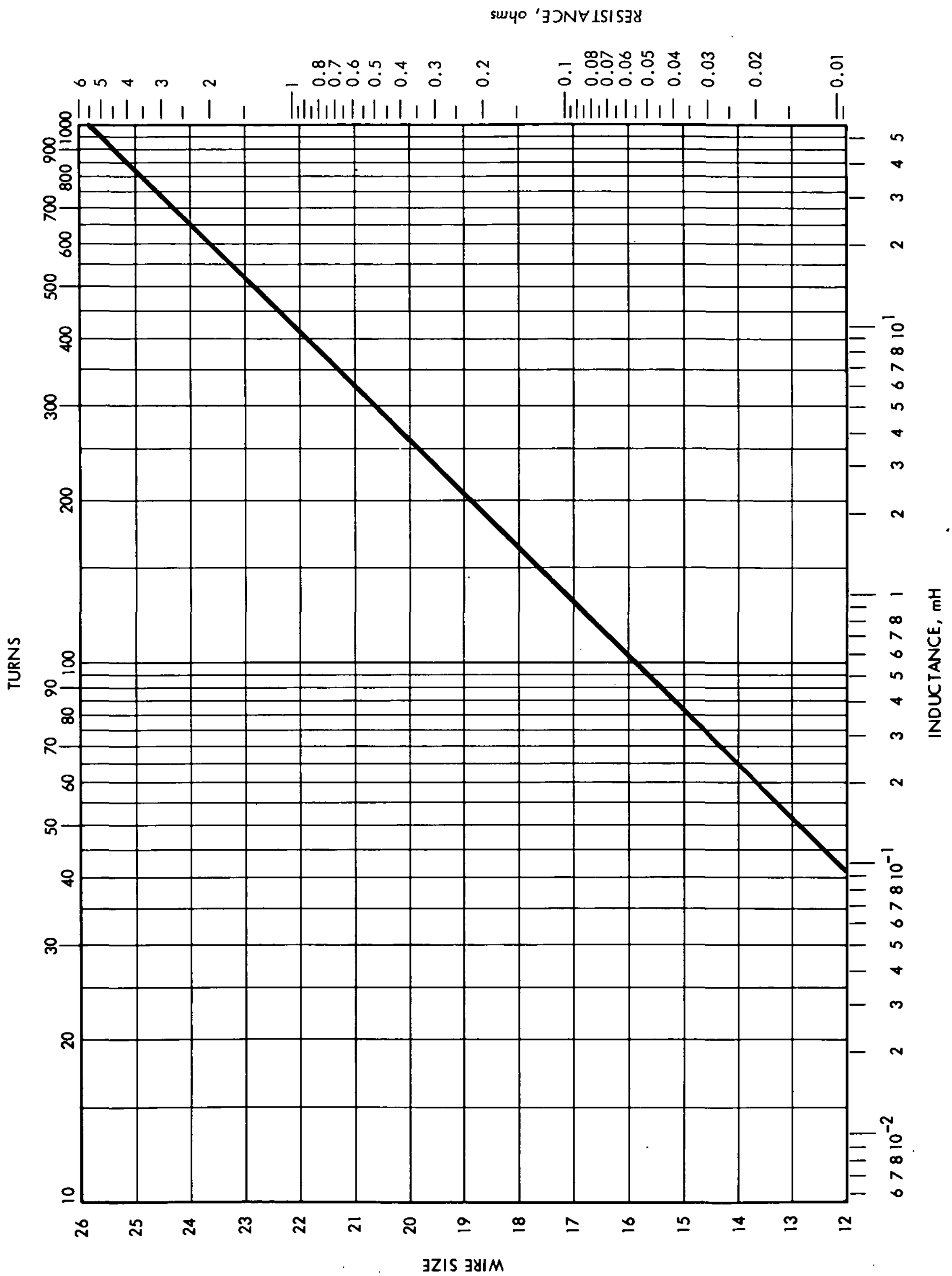
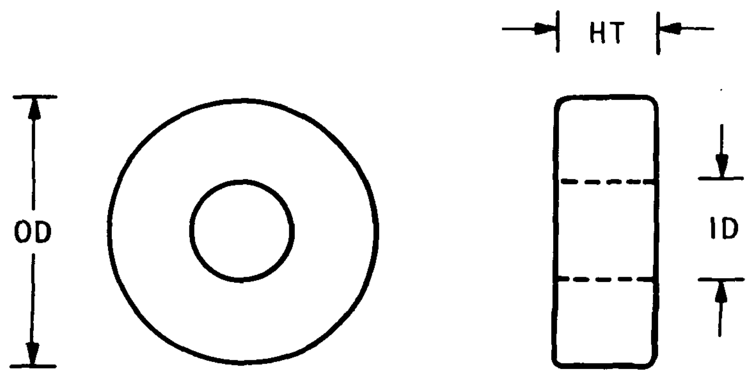


Fig. 17. Nomograph for Core 55076-A2

Table 11. Magnetic Inc 55083-A2, Arnold Engineering A-083081-2

	ENGLISH	METRIC
Wa/Ac		4.02
Wa x Ac	0.108 in^4	4.53 cm^4
OD	1.602 in	4.07 cm
ID	0.918 in	2.33 cm
HT	0.605 in	1.54 cm
Wa = WINDOW AREA	0.84×10^6 CIR-MIL	4.27 cm^2
Wa = EFFECTIVE	0.496 in^2	3.198 cm^2
Ac = CROSS SECTION	0.164 in^2	1.06 cm^2
lm = PATH LENGTH	3.88 in	9.84 cm
CORE WEIGHT	0.198 lb	90 grams
TOTAL WEIGHT	0.388 lb	176 grams
WOUND OD MIN	1.79 in	4.54 cm
MLT	2.36 in	6.07 cm
A_t = SURFACE AREA	9.46 in^2	61.05 cm^2
PERMEABILITY		60
μ 125		2.08 x L @ μ 60
μ 160		2.67 x L @ μ 60
μ 200		3.33 x L @ μ 60
μ 550		9.17 x L @ μ 60



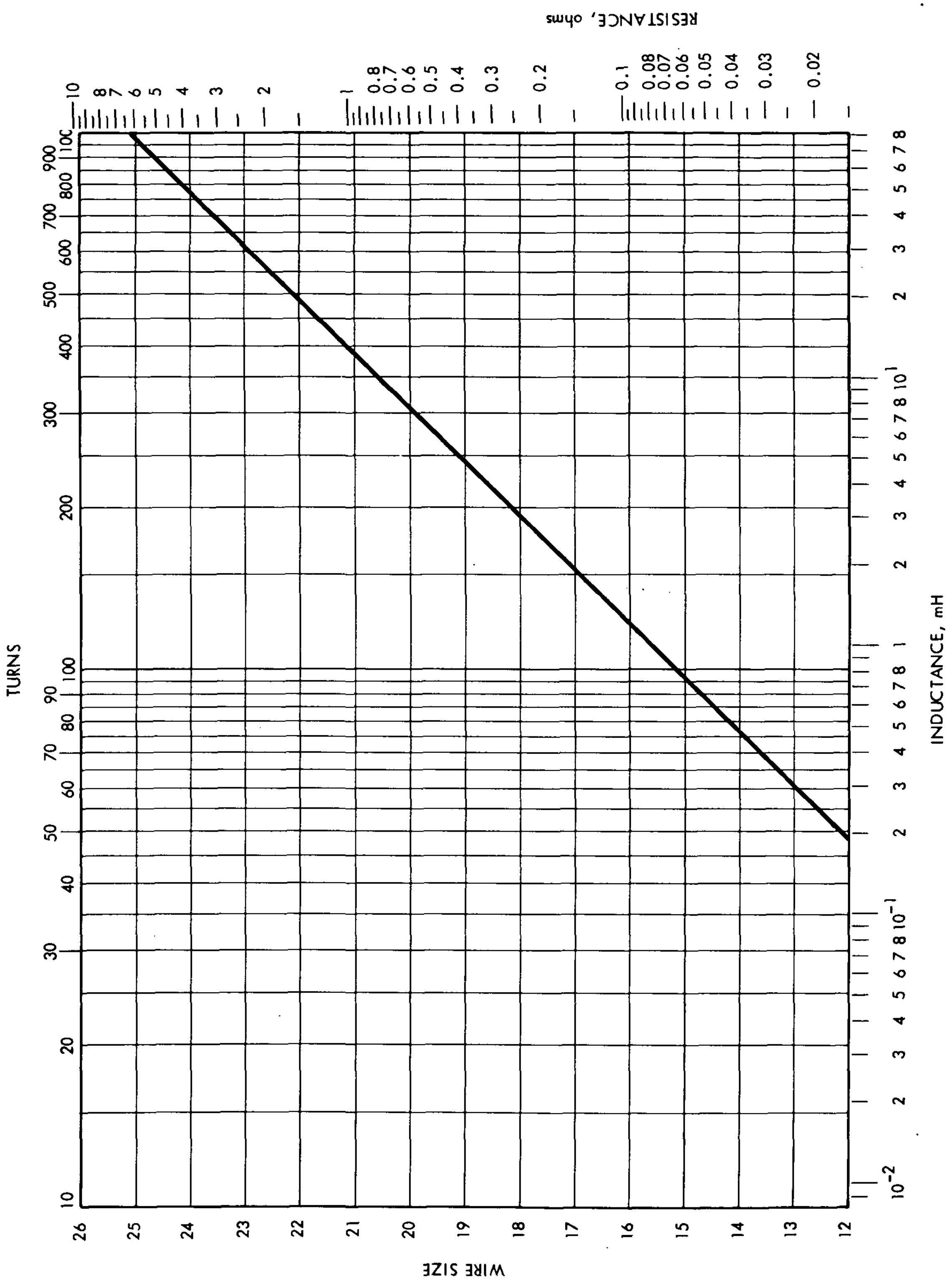
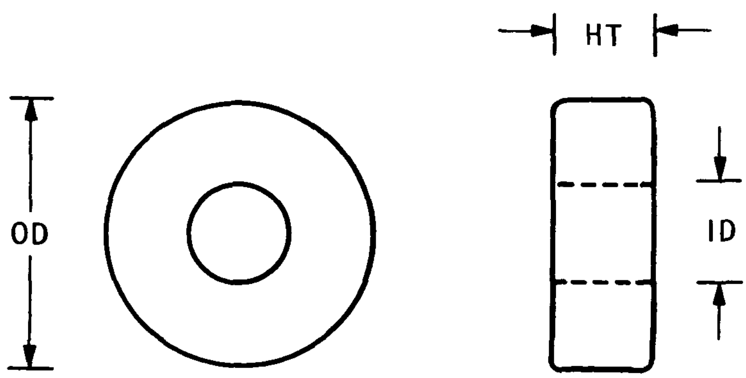


Fig. 18. Nomograph for Core 55083-A2

Table 12. Magnetic Inc 55439-A2, Arnold Engineering A-759135-2

	ENGLISH		METRIC	
Wa/Ac			2.19	
Wa x Ac	0.200	in^4	8.33	cm^4
OD	1.875	in	4.76	cm
ID	0.918	in	2.33	cm
HT	0.745	in	1.89	cm
Wa = WINDOW AREA	0.84×10^6	CIR-MIL	4.27	cm^2
Wa = EFFECTIVE	0.496	in^2	3.198	cm^2
Ac = CROSS SECTION	0.302	in^2	1.95	cm^2
lm = PATH LENGTH	4.23	in	10.74	cm
CORE WEIGHT	0.346	lb	180	grams
TOTAL WEIGHT	0.641	lb	291	grams
WOUND OD MIN	2.04	in	5.17	cm
MLT	3.00	in	7.62	cm
A_t = SURFACE AREA	12.30	in^2	79.37	cm^2
PERMEABILITY			60	
μ 125			2.08 x L @ μ 60	
μ 160			2.67 x L @ μ 60	
μ 200			3.33 x L @ μ 60	
μ 550			9.17 x L @ μ 60	



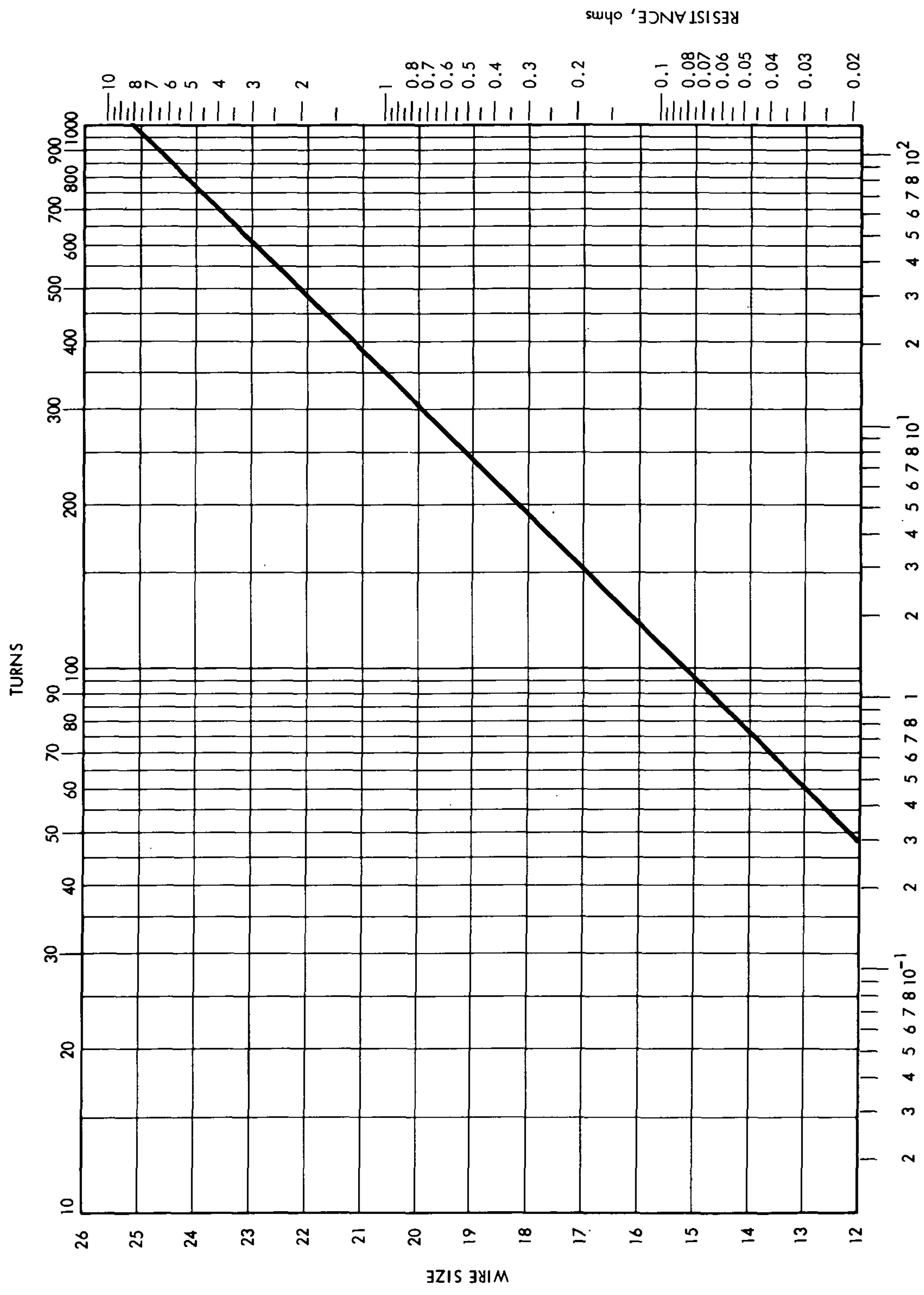
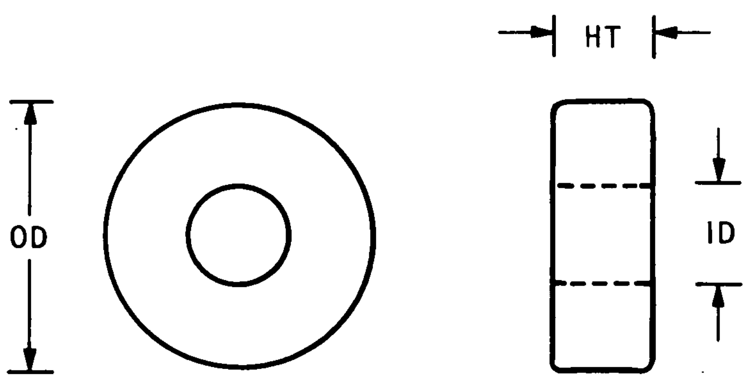


Fig. 19. Nomograph for Core 55439-A2

Table 13. Magnetic Inc 55090-A2, Arnold Engineering A-090086-2

	ENGLISH	METRIC
Wa/Ac		4.63
Wa x Ac	0.194 in^4	8.06 cm^4
OD	1.875 in	4.76 cm
ID	1.098 in	2.79 cm
HT	0.635 in	1.61 cm
Wa = WINDOW AREA	1.21×10^6 CIR-MIL	6.11 cm^2
Wa = EFFECTIVE	0.710 in^2	4.58 cm^2
Ac = CROSS SECTION	0.205 in^2	1.32 cm^2
lm = PATH LENGTH	4.58 in	11.62 cm
CORE WEIGHT	0.286 lb	130 grams
TOTAL WEIGHT	0.588 lb	267 grams
WOUND OD MIN	2.10 in	5.34 cm
MLT	2.62 in	6.66 cm
A_t = SURFACE AREA	12.64 in^2	81.58 cm^2
PERMEABILITY		60
μ 125		2.08 x L @ μ 60
μ 160		2.67 x L @ μ 60
μ 200		3.33 x L @ μ 60
μ 550		9.17 x L @ μ 60



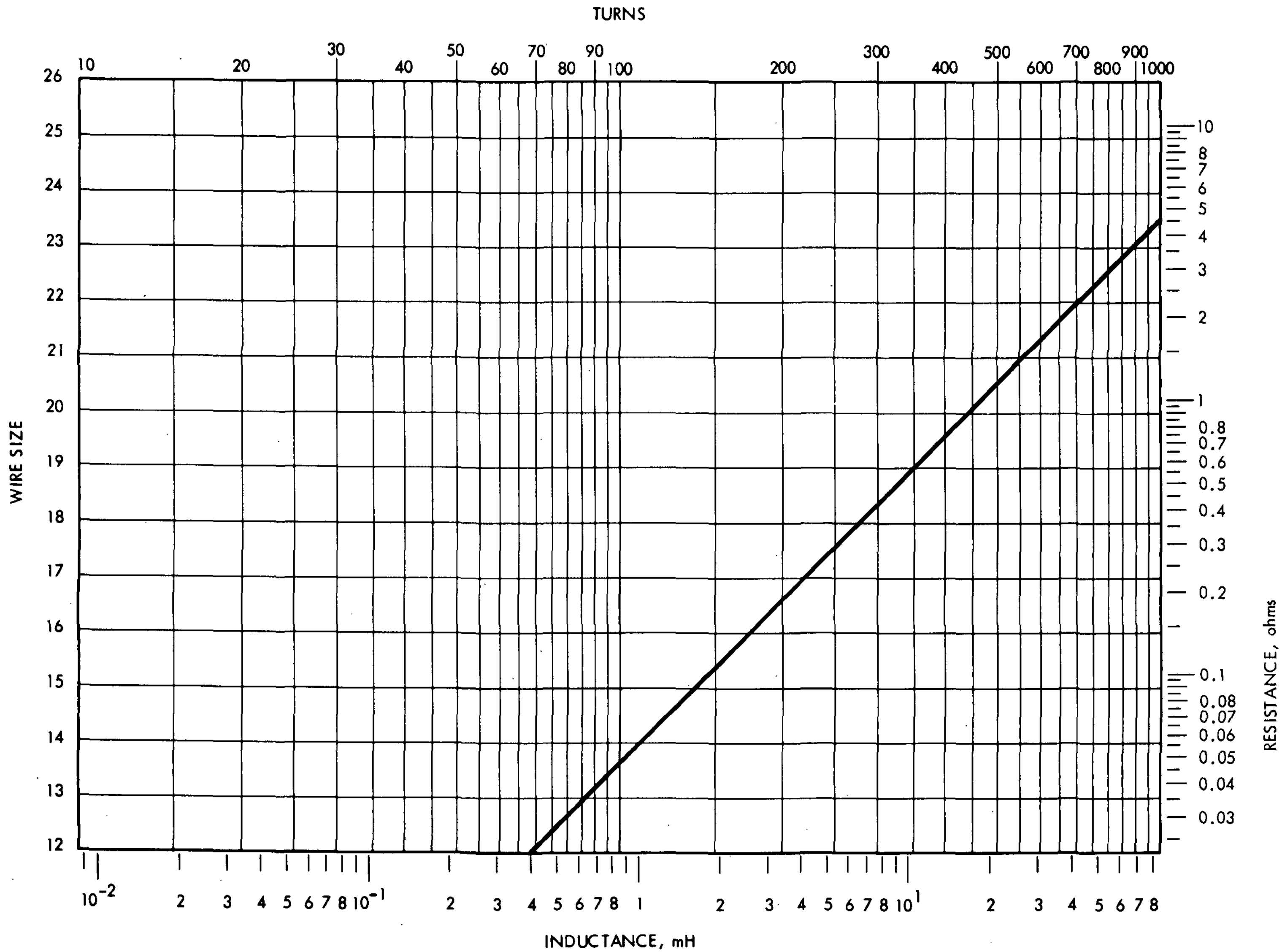
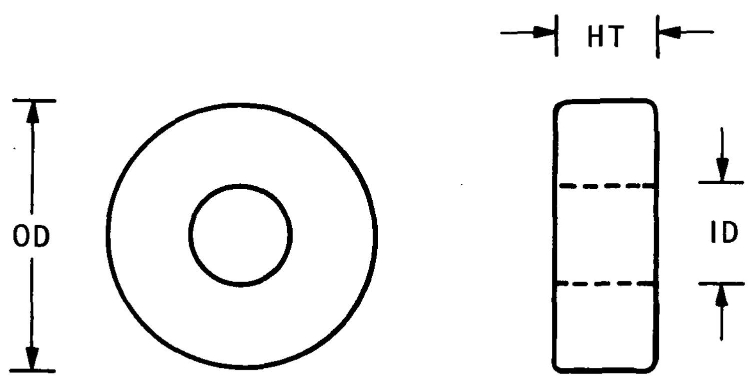


Fig. 20. Nomograph for Core 55090-A2

Table 14. Magnetic Inc 55716-A2, Arnold Engineering A-106073-2

	ENGLISH		METRIC	
Wa/Ac			6.06	
Wa x Ac	0.224	in^4	9.32	cm^4
OD	2.035	in	5.17	cm
ID	1.218	in	3.09	cm
HT	0.565	in	1.435	cm
Wa = WINDOW AREA	1.48×10^6	CIR-MIL	7.52	cm^2
Wa = EFFECTIVE	0.874	in^2	5.62	cm^2
Ac = CROSS SECTION	0.192	in^2	1.24	cm^2
lm = PATH LENGTH	5.02	in	12.73	cm
CORE WEIGHT	0.298	lb	135	grams
TOTAL WEIGHT	0.652	lb	296	grams
WOUND OD MIN	2.29	in	5.82	cm
MLT	2.55	in	6.50	cm
A_t = SURFACE AREA	14.15	in^2	91.32	cm^2
PERMEABILITY			60	
μ 125			2.08 x L @ μ 60	
μ 160			2.67 x L @ μ 60	
μ 200			3.33 x L @ μ 60	
μ 550			9.17 x L @ μ 60	



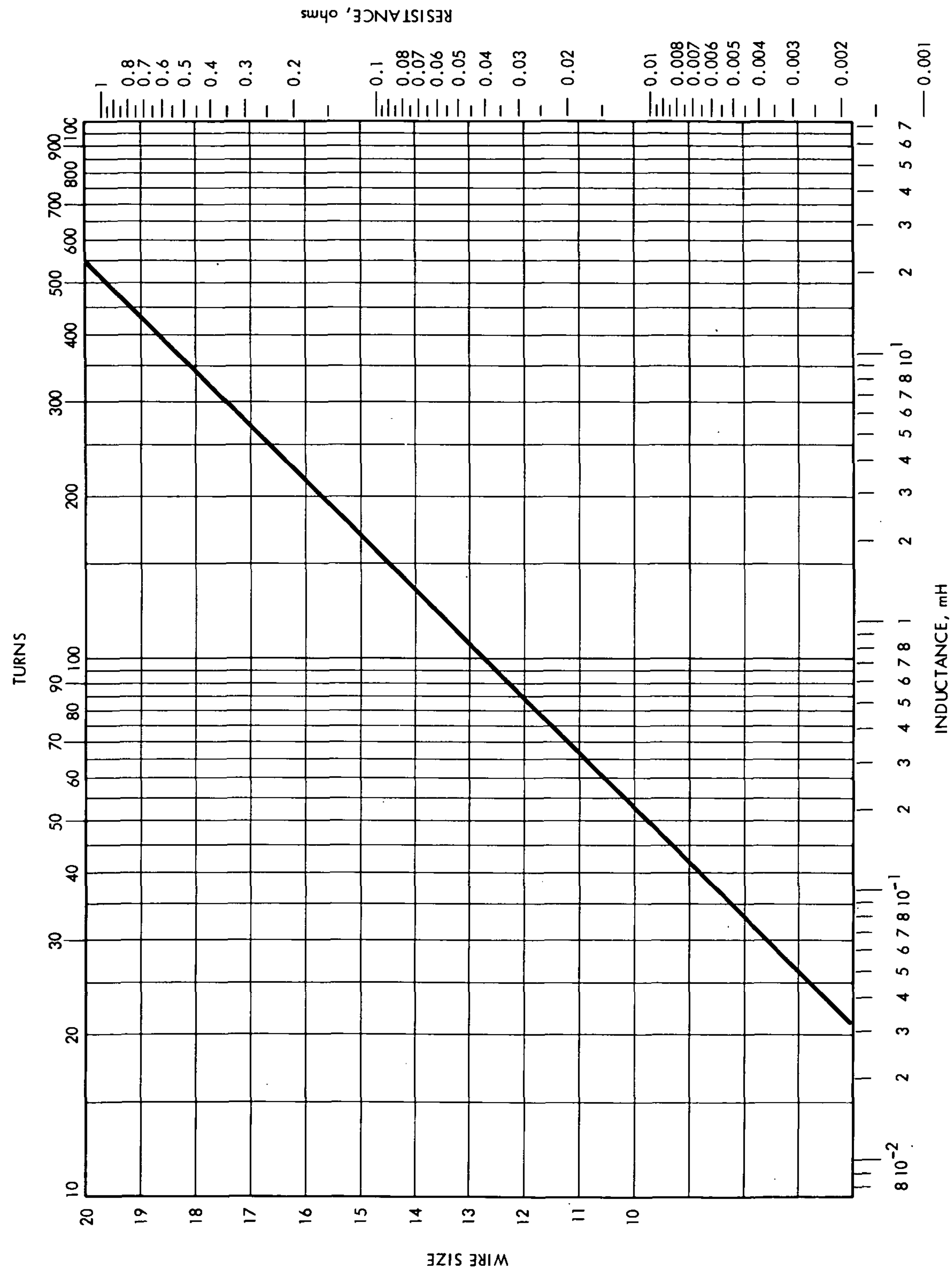
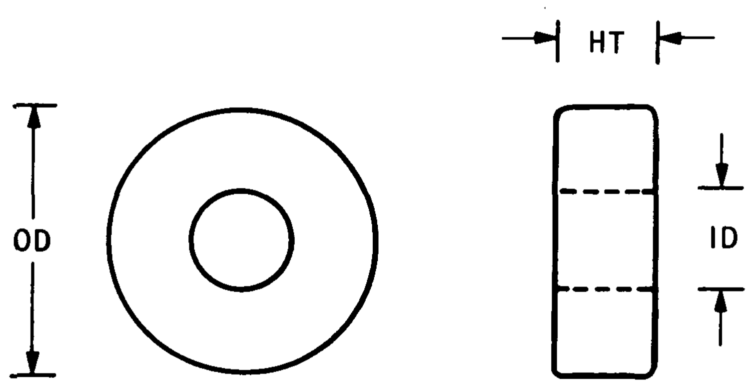


Fig. 21. Nomograph for Core 55716-A2

Table 15. Magnetic Inc 55110-A2, Arnold Engineering A-488075-2

	ENGLISH	METRIC
Wa/Ac		6.58
Wa x Ac	0.328 in^4	13.65 cm^4
OD	2.285 in	5.8 cm
ID	1.368 in	3.47 cm
HT	0.585 in	1.486 cm
Wa = WINDOW AREA	1.87×10^6 CIR-MIL	9.48 cm^2
Wa = EFFECTIVE	1.1023 in^2	7.093 cm^2
Ac = CROSS SECTION	0.223 in^2	1.44 cm^2
lm = PATH LENGTH	5.63 in	14.30 cm
CORE WEIGHT	0.385 lb	175 grams
TOTAL WEIGHT	0.864 lb	392 grams
WOUND OD MIN	2.57 in	6.53 cm
MLT	2.75 in	7.00 cm
A_t = SURFACE AREA	17.42 in^2	112.4 cm^2
PERMEABILITY		60
μ 125		2.08 x L @ μ 60
μ 160		2.67 x L @ μ 60
μ 200		3.33 x L @ μ 60
μ 550		9.17 x L @ μ 60



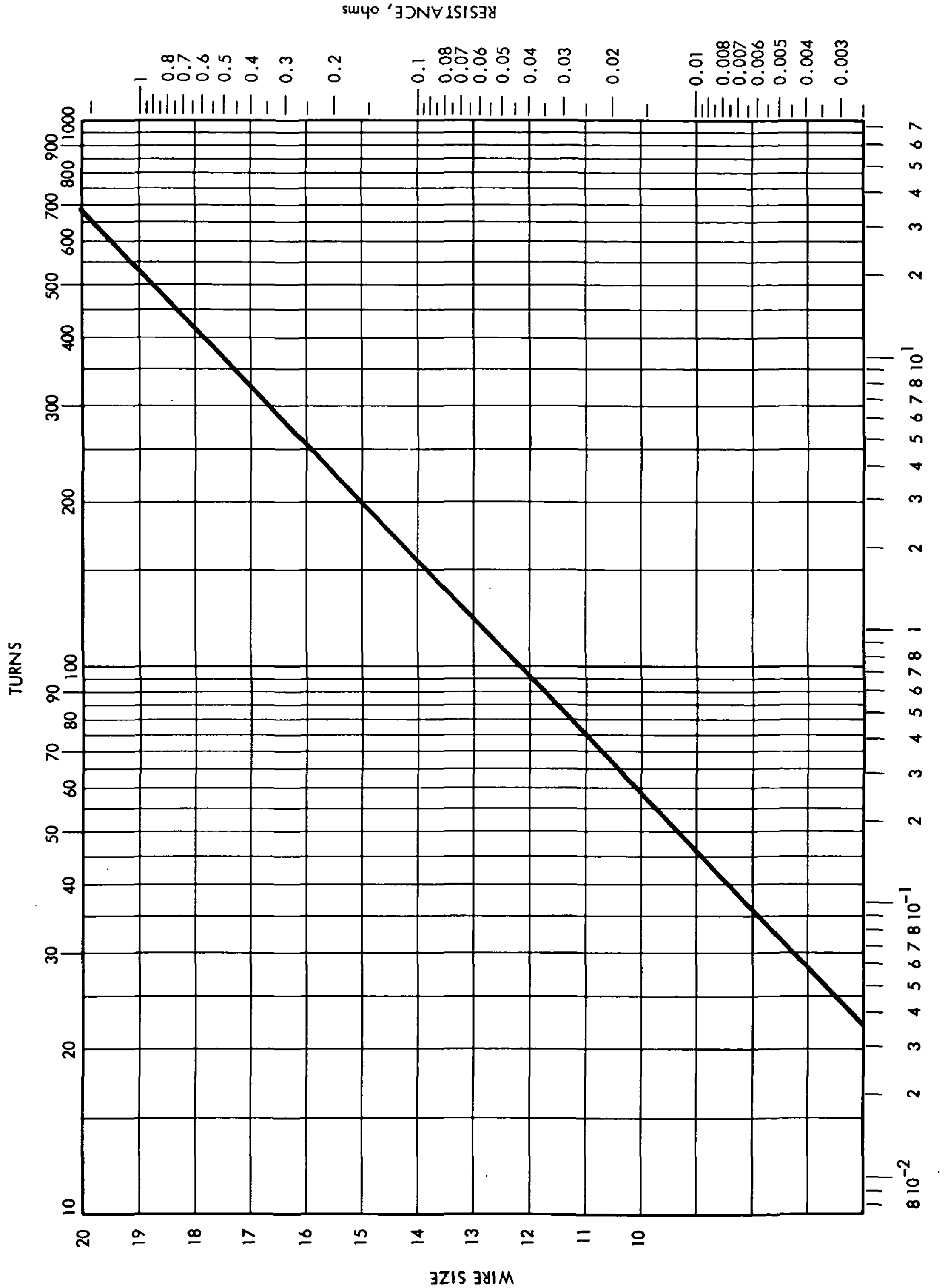


Fig. 22. Nomograph for Core 55110-A2

IX. CORE LOSS FOR MOLYPERMALLOY POWDER CORES

Figure 23 depicts core loss curves for molypermalloy powder cores. These curves were obtained from Magnetics Inc., and are believed to be more typical curves for 60μ to 200μ than the data previously published in its catalog. Many catalogs state core loss in ohms per millihenry. Here it is expressed in milliwatts per gram.

TYPICAL CURVES OF 60, 125, 160, 200 μ

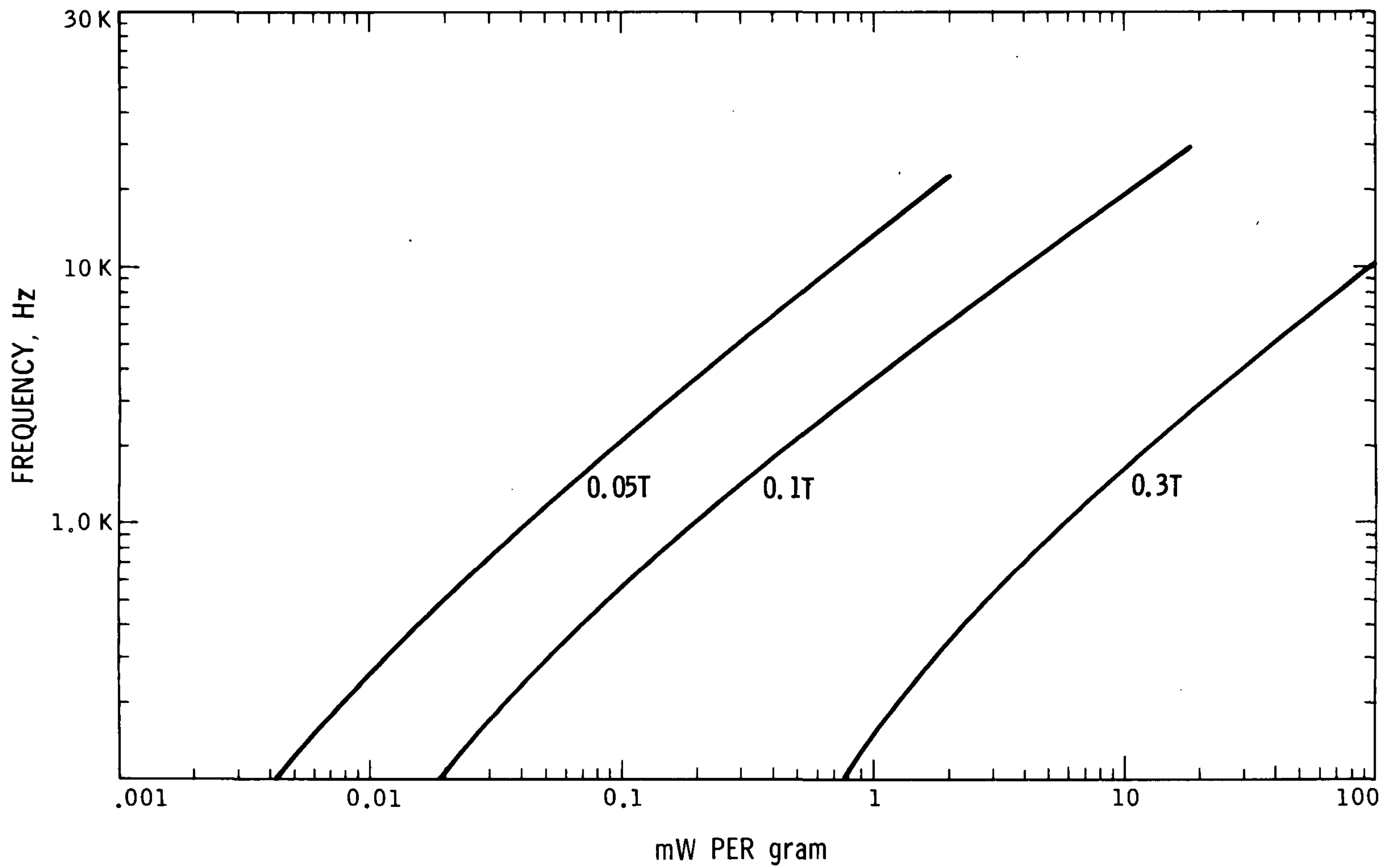


Fig. 23. Core Loss Versus Frequency at 0.05T, 0.1T, and 0.5T

X. POWDER CORE (PERMEABILITY VERSUS dc BIAS)

Figure 24 shows inductance change versus dc bias for 60, 125 and 200 permeability materials.

In designing for operation at high dc currents, it is desirable to choose a core permeability which will result in maximum inductance at peak current.

$$H = \frac{NI}{lm}$$

H = magnetizing force ampturns/cm

N = number of turns

I = peak currents (Amperes)

lm = mean magnetic path (cm)

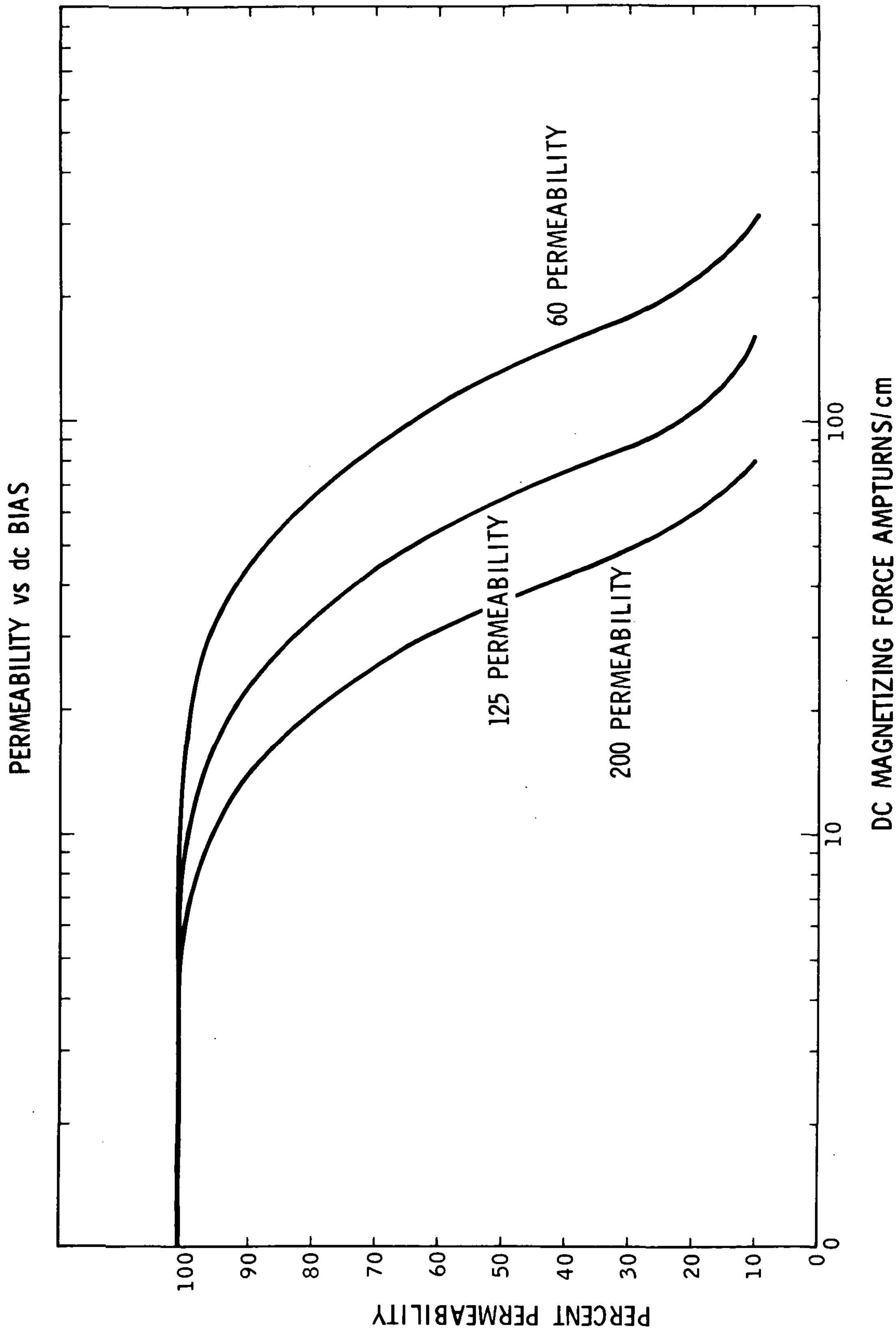


Fig. 24. Permeability vs dc Bias

XI. LAMINATION, C CORE AND BOBBIN MAGNETIC AND DIMENSIONAL SPECIFICATIONS

A. Definitions for Tables 16 through 41.

Tables 16 through 41 show magnetic and dimensional specifications for eleven EE, EI laminations and C cores. Information given is listed by line as:

1 Manufacturer and part number

2 Units

3 Window area Wa divided by iron area Ac

4 Iron area Ac times the window area Wa

5 Iron area Ac

6 Window area Wa

7 Mean magnetic path length lm

8 Core weight of silicon steel with unity stacking factor. For the appropriate weight multiply the solid weight by the stacking factor and density factor.

Stacking Factor

Thickness	Butt Jointed	Interleaved 1 x 1
0.004	0.90	0.80
0.006	0.90	0.85
0.014	0.95	0.90
0.018	0.95	0.90

	Density Factor
3% Silicon	7.64 gm/cc = 1.00
48% Nickel	8.25 gm/cc = 1.08
80% Nickel	8.74 gm/cc = 1.14

9 Weight = copper fully wound

10 MLT Fullwound = single winding on bobbin

11 MLT 1st half = First of two windings wound with equal area

12 MLT 2nd half = Second of two windings wound with equal area

13 Transformer overall surface area A_t

14-19 Lamination dimensions

20 Bobbin Manufacturer and part number

21 Bobbin inside winding length

22 Bobbin inside build

23 Bobbin winding area length x build

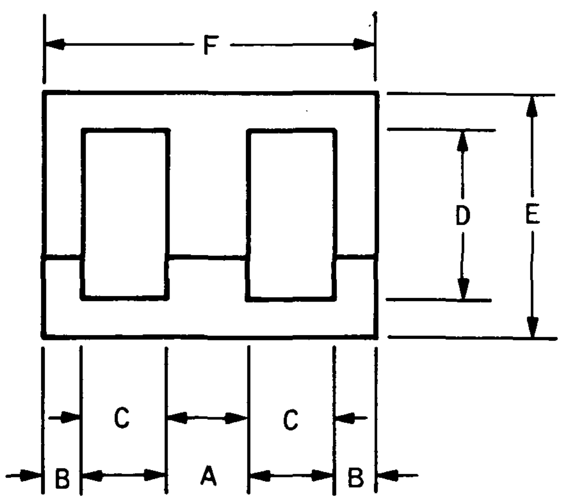
B. Nomographs for 11 Laminations and 15 C Core Sizes

Figures 25 through 50 are nomographs for 11 different laminations and 15 C cores sizes. 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.

*Per bobbin

Table 16. Lamination EE-30-31

	ENGLISH		METRIC	
Wa/Ac	3.00		3.00	
Wa x Ac	0.000213	in^4	0.00964	cm^4
Ac	0.00879	in^2	0.0567	cm^2
Wa	0.0264	in^2	0.1701	cm^2
lm	0.938	in	2.381	cm
CORE wt SOLID	0.00224	lb	1.02	grams
COPPER wt	0.002	lb	0.88	grams
MLT FULLWOUND	0.677	in	1.72	cm
MLT 1st HALF	0.568	in	1.44	cm
MLT 2nd HALF	0.785	in	1.99	cm
A_T	0.6374	in^2	4.11	cm^2
A	0.094	in	0.239	cm
B	0.047	in	0.119	cm
C	0.094	in	0.239	cm
D	0.281	in	0.714	cm
E	0.375	in	0.953	cm
F	0.375	in	0.953	cm
BOBBIN	NY-GLASS # NY-1			
LENGTH	0.230	in	0.584	cm
BUILD	0.069	in	0.175	cm
AREA	0.0159	in^2	0.102	cm^2



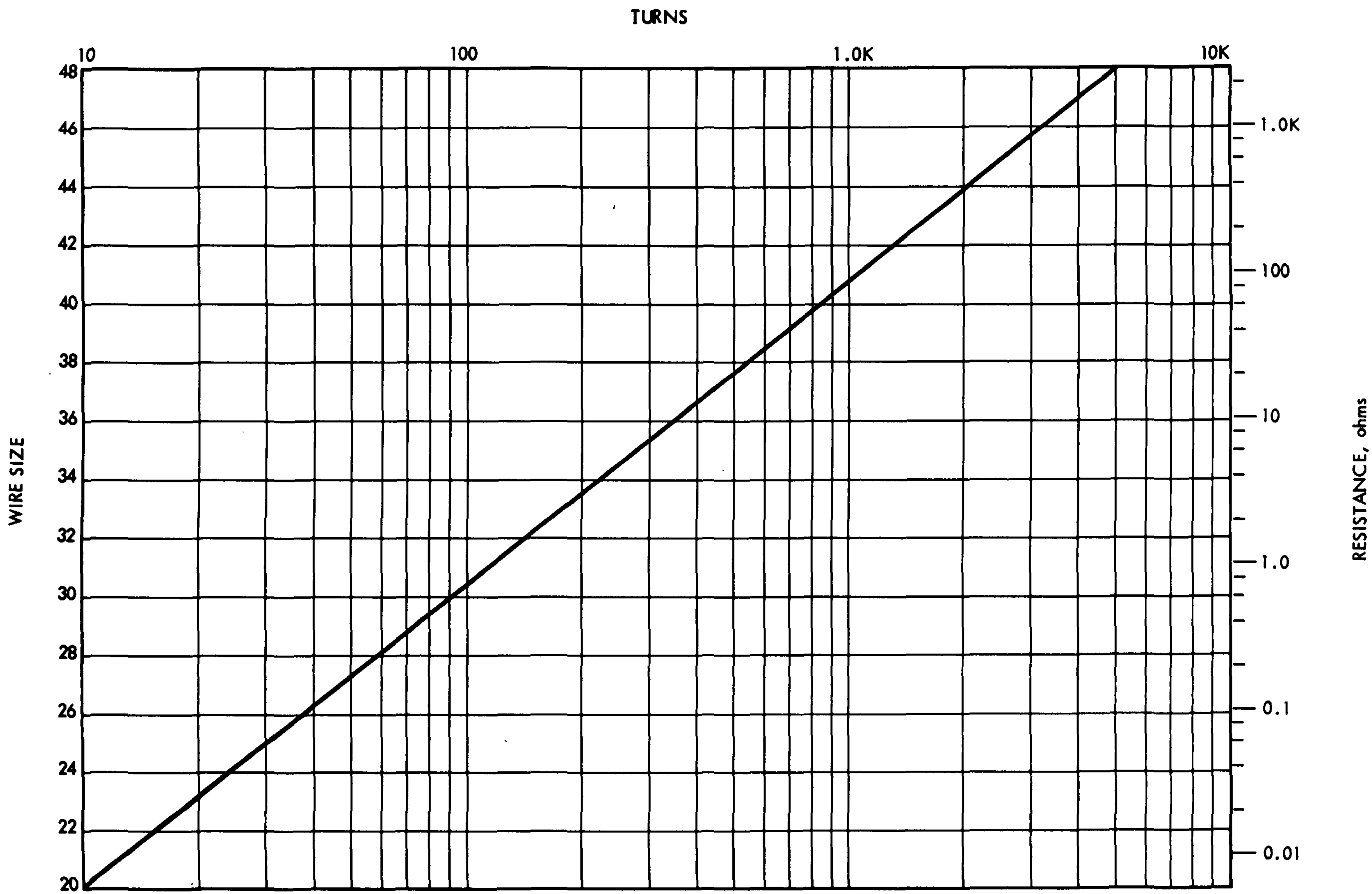
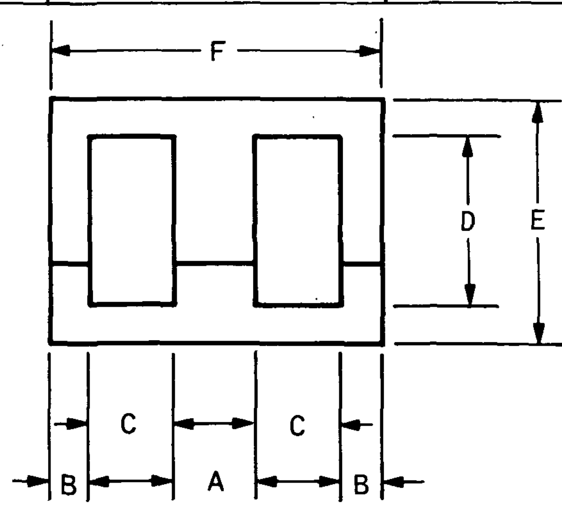


Fig. 25. Nomograph for Lamination EE-30-31

Table 17. Lamination EE-28-29

	ENGLISH	METRIC
Wa/Ac	2.52	2.52
Wa x Ac	0.00061 in^4	0.0258 cm^4
Ac	0.0156 in^2	0.101 cm^2
Wa	0.0391 in^2	0.256 cm^2
lm	1.125 in	2.858 cm
CORE wt SOLID	0.00482 lb	2.19 grams
COPPER wt	0.004 lb	1.85 grams
MLT FULLWOUND	0.892 in	2.265 cm
MLT 1st HALF	0.740 in	1.879 cm
MLT 2nd HALF	1.045 in	2.654 cm
A_T	1.027 in^2	6.625 cm^2
A	0.125 in	0.318 cm
B	0.062 in	0.157 cm
C	0.125 in	0.318 cm
D	0.312 in	0.792 cm
E	0.438 in	1.113 cm
F	0.500 in	1.270 cm
BOBBIN	NY-GLASS #NY-2	
LENGTH	0.269 in	0.673 cm
BUILD	0.097 in	0.246 cm
AREA	0.026 in^2	0.168 cm^2



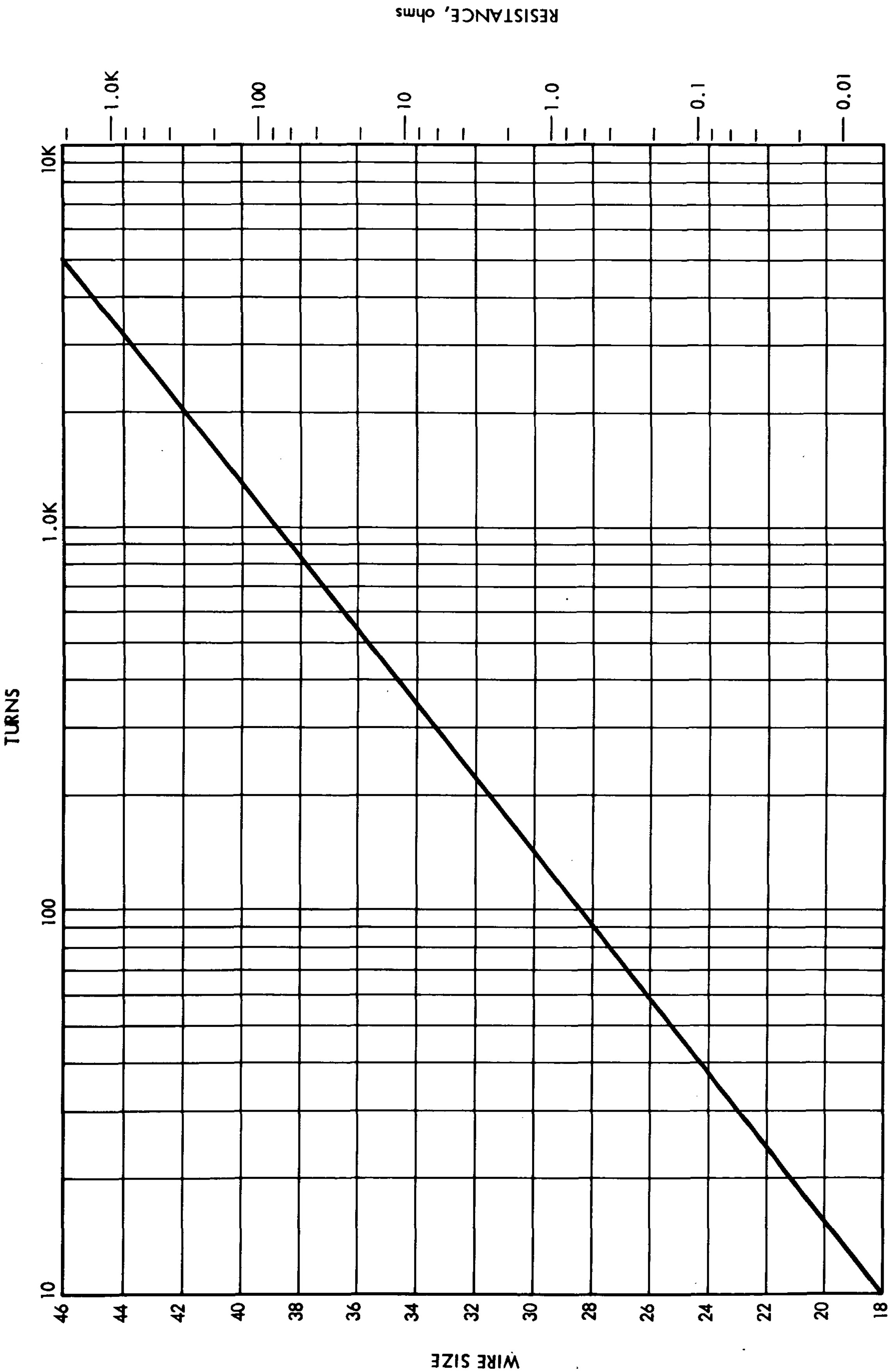
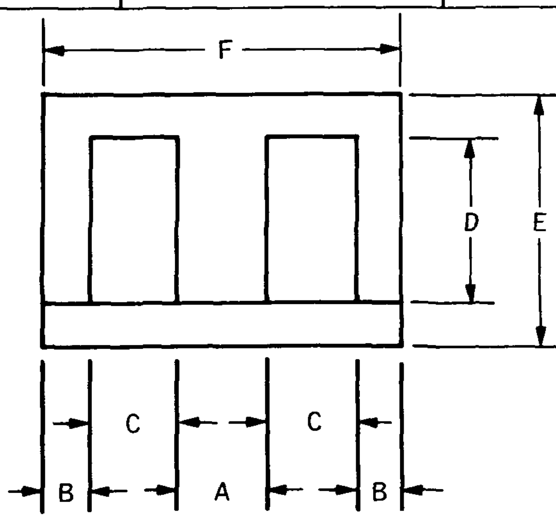


Fig. 26. Nomograph for Lamination EE-28-29

Table 18. Lamination EI-187

	ENGLISH		METRIC	
Wa/Ac	2.33		2.33	
Wa x Ac	0.00288	in^4	0.120	cm^4
Ac	0.0352	in^2	0.227	cm^2
Wa	0.0820	in^2	0.529	cm^2
lm	1.625	in	4.128	cm
CORE wt SOLID	0.156	lb	7.09	grams
COPPER wt	0.0136	lb	6.20	grams
MLT FULLWOUND	1.34	in	3.40	cm
MLT 1st HALF	1.11	in	2.82	cm
MLT 2nd HALF	1.57	in	3.99	cm
A_T	2.270	in^2	14.65	cm^2
A	0.188	in	0.478	cm
B	0.094	in	0.239	cm
C	0.188	in	0.478	cm
D	0.438	in	1.113	cm
E	0.625	in	1.588	cm
F	0.750	in	1.905	cm
BOBBIN	NY-GLASS # NY-4			
LENGTH	0.375	in	0.953	cm
BUILD	0.147	in	0.373	cm
AREA	0.0551	in^2	0.355	cm^2



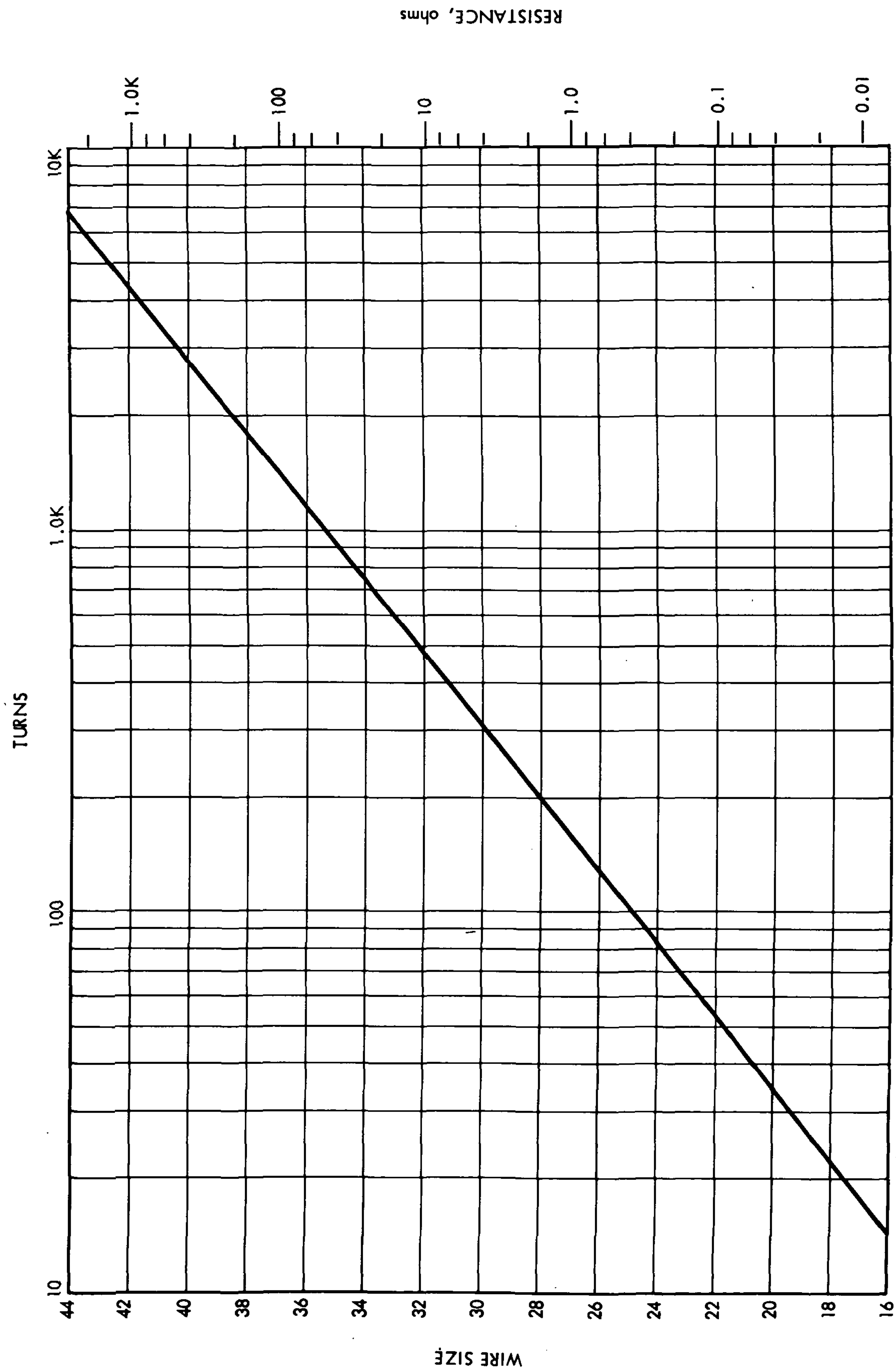
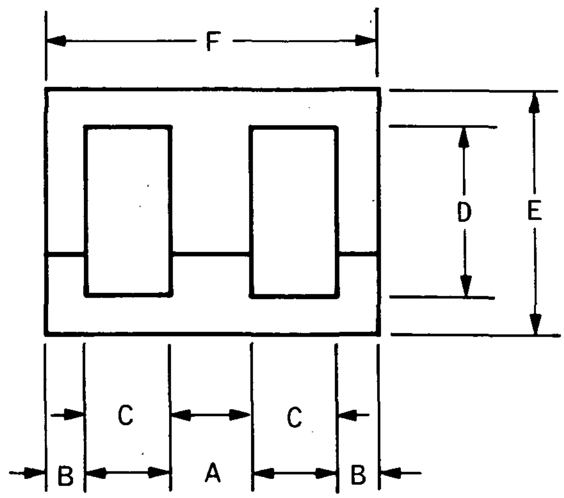


Fig. 27. Nomograph for Lamination EI-187

Table 19. Lamination EE-24-25

	ENGLISH	METRIC
Wa/Ac	2.00	2.00
Wa x Ac	0.00781 in^4	0.325 cm^4
Ac	0.0625 in^2	0.403 cm^2
Wa	0.125 in^2	0.806 cm^2
lm	2.00 in	5.08 cm
CORE wt SOLID	0.0342 lb	15.50 grams
COPPER wt	0.0254 lb	11.5 grams
MLT FULLWOUND	1.800 in	4.57 cm
MLT 1st HALF	1.470 in	3.73 cm
MLT 2nd HALF	2.130 in	5.41 cm
A_T	3.30 in^2	21.3 cm^2
A	0.25 in	0.635 cm
B	0.125 in	0.318 cm
C	0.250 in	0.635 cm
D	0.500 in	0.127 cm
E	0.750 in	1.905 cm
F	1.000 in	2.540 cm
BOBBIN	NY-GLASS # NY-6	
LENGTH	0.415 in	1.054 cm
BUILD	0.210 in	0.533 cm
AREA	0.0872 in^2	0.5624 cm^2



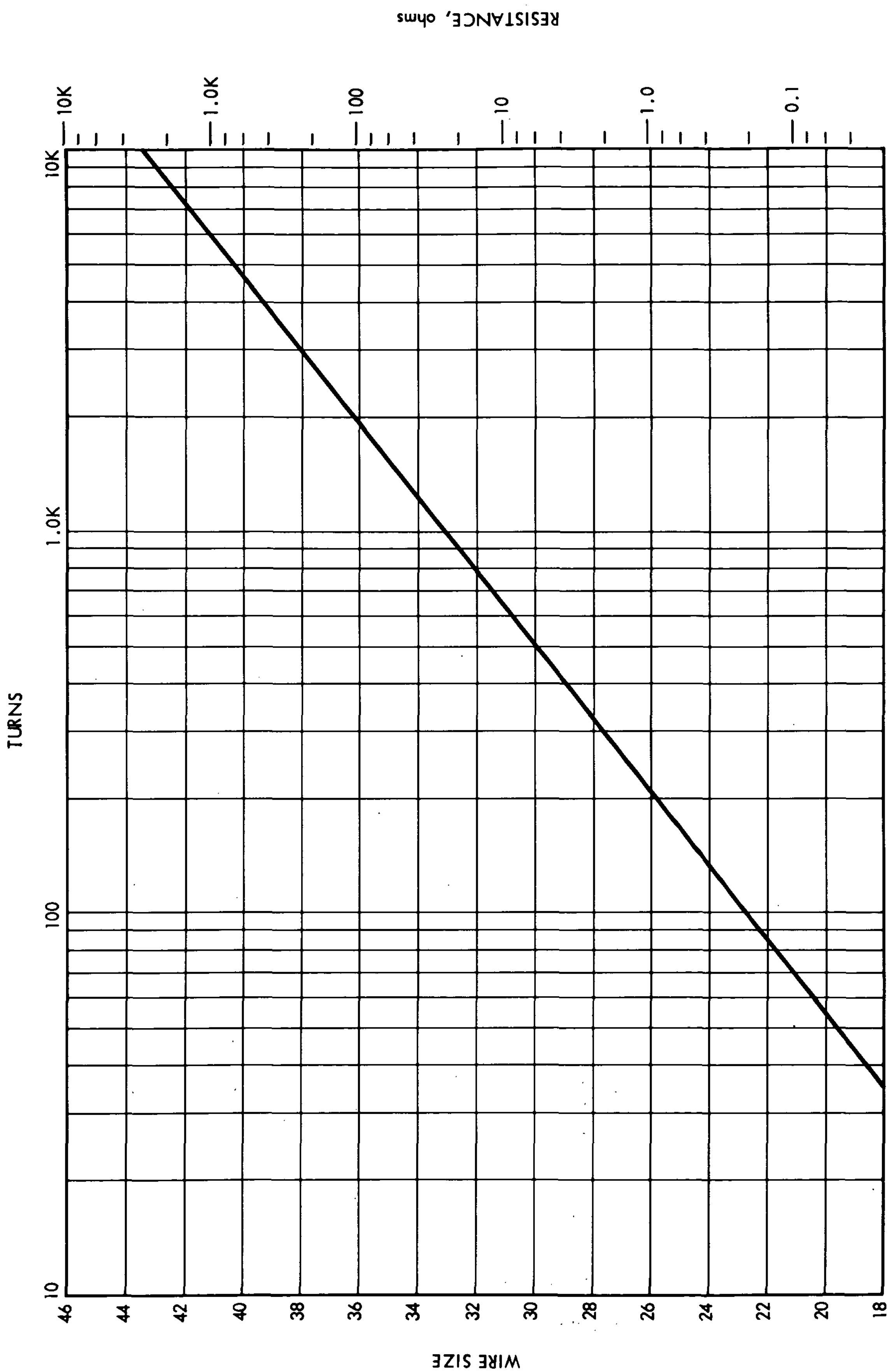
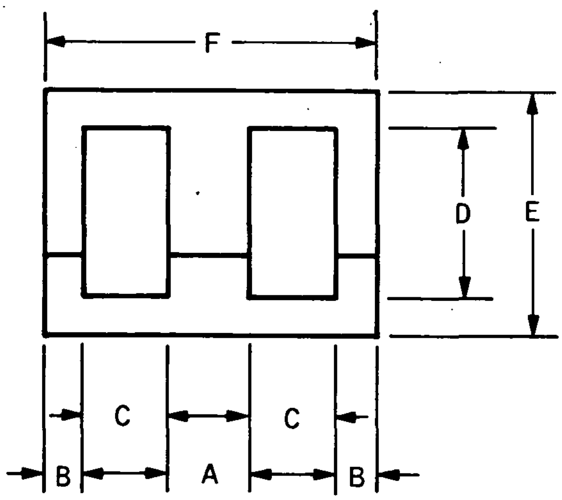


Fig. 28. Nomograph for Lamination EE-24-25

Table 20. Lamination EE-26-27

	ENGLISH	METRIC
Wa/Ac	1.22	1.22
Wa x Ac	0.0242 in^4	1.005 cm^4
Ac	0.141 in^2	0.907 cm^2
Wa	0.172 in^2	1.109 cm^2
lm	2.63 in	6.66 cm
CORE wt SOLID	0.101 lb	45.8 grams
COPPER wt	0.0507 lb	23 grams
MLT FULLWOUND	2.32 in	5.89 cm
MLT 1st HALF	1.99 in	5.05 cm
MLT 2nd HALF	2.65 in	6.73 cm
A_T	6.295 in^2	40.6 cm^2
A	0.375 in	0.953 cm
B	0.188 in	0.478 cm
C	0.250 in	0.635 cm
D	0.688 in	1.748 cm
E	1.062 in	2.697 cm
F	1.250 in	3.18 cm
BOBBIN	NY-GLASS # NY-8	
LENGTH	0.605 in	1.537 cm
BUILD	0.210 in	0.533 cm
AREA	0.127 in^2	0.819 cm^2



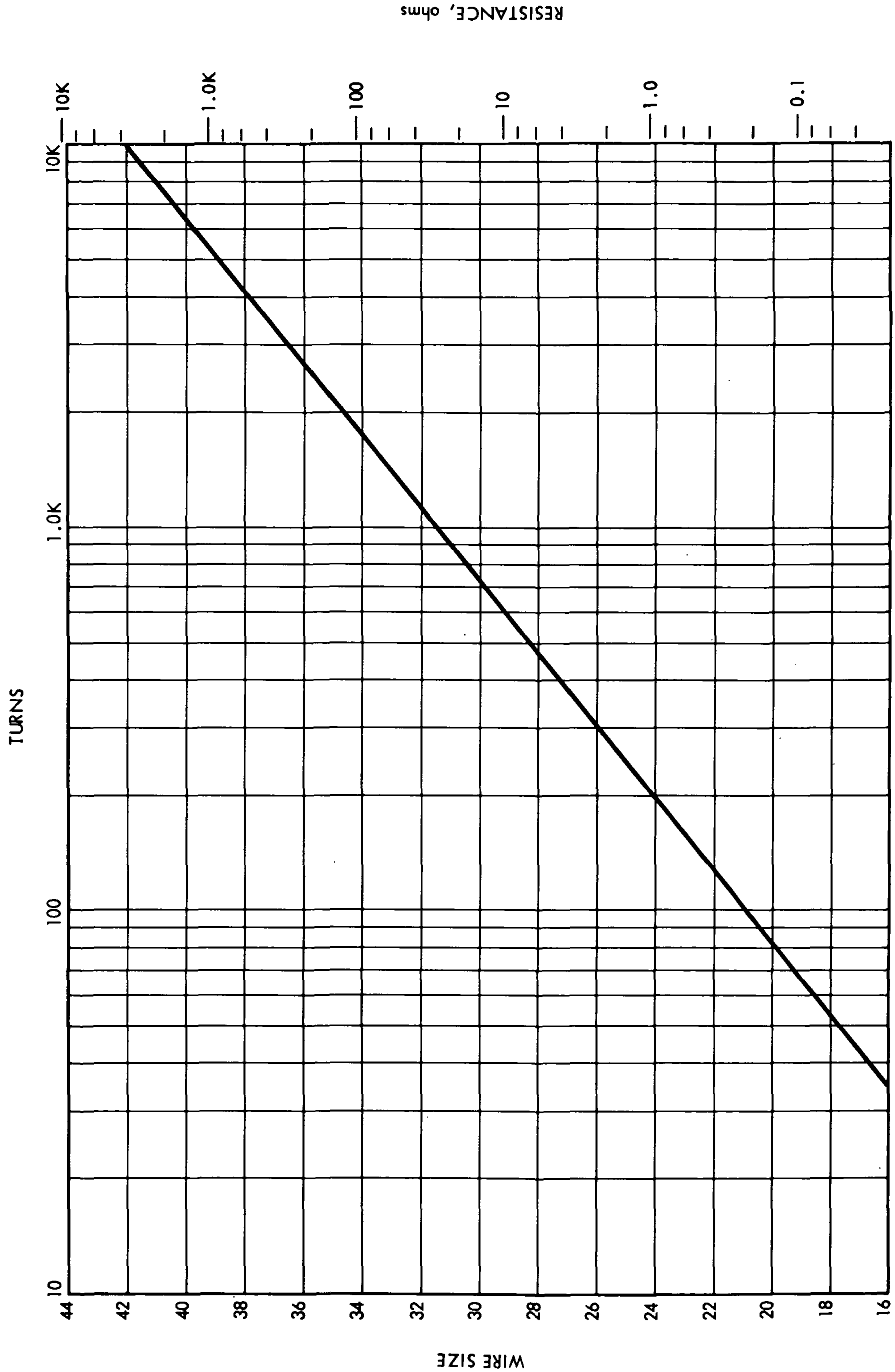
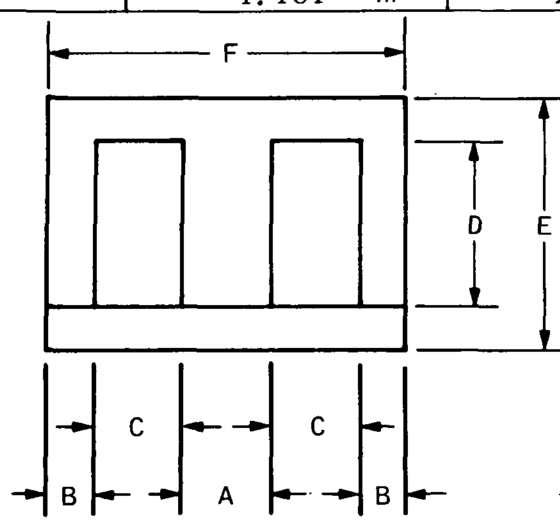


Fig. 29. Nomograph for Lamination EE-26-27

Table 21. Lamination EI-375

	ENGLISH		METRIC	
Wa/Ac	1.66		1.66	
Wa x Ac	0.0327	in^4	1.374	cm^4
Ac	0.14	in^2	0.91	cm^2
Wa	0.234	in^2	1.51	cm^2
lm	2.88	in	7.30	cm
CORE wt SOLID	0.110	lb	49.7	grams
COPPER wt	0.0772	lb	35.0	grams
MLT FULLWOUND	2.515	in	6.39	cm
MLT 1st HALF	2.087	in	5.30	cm
MLT 2nd HALF	2.94	in	7.47	cm
A_T	7.390	in^2	47.68	cm^2
A	0.375	in	0.953	cm
B	0.188	in	0.478	cm
C	0.312	in	0.792	cm
D	0.750	in	1.905	cm
E	1.125	in	2.858	cm
F	1.375	in	3.493	cm
BOBBIN	NY-GLASS # NY-7			
LENGTH	0.665	in	1.689	cm
BUILD	0.272	in	0.691	cm
AREA	1.181	in^2	1.1674	cm^2



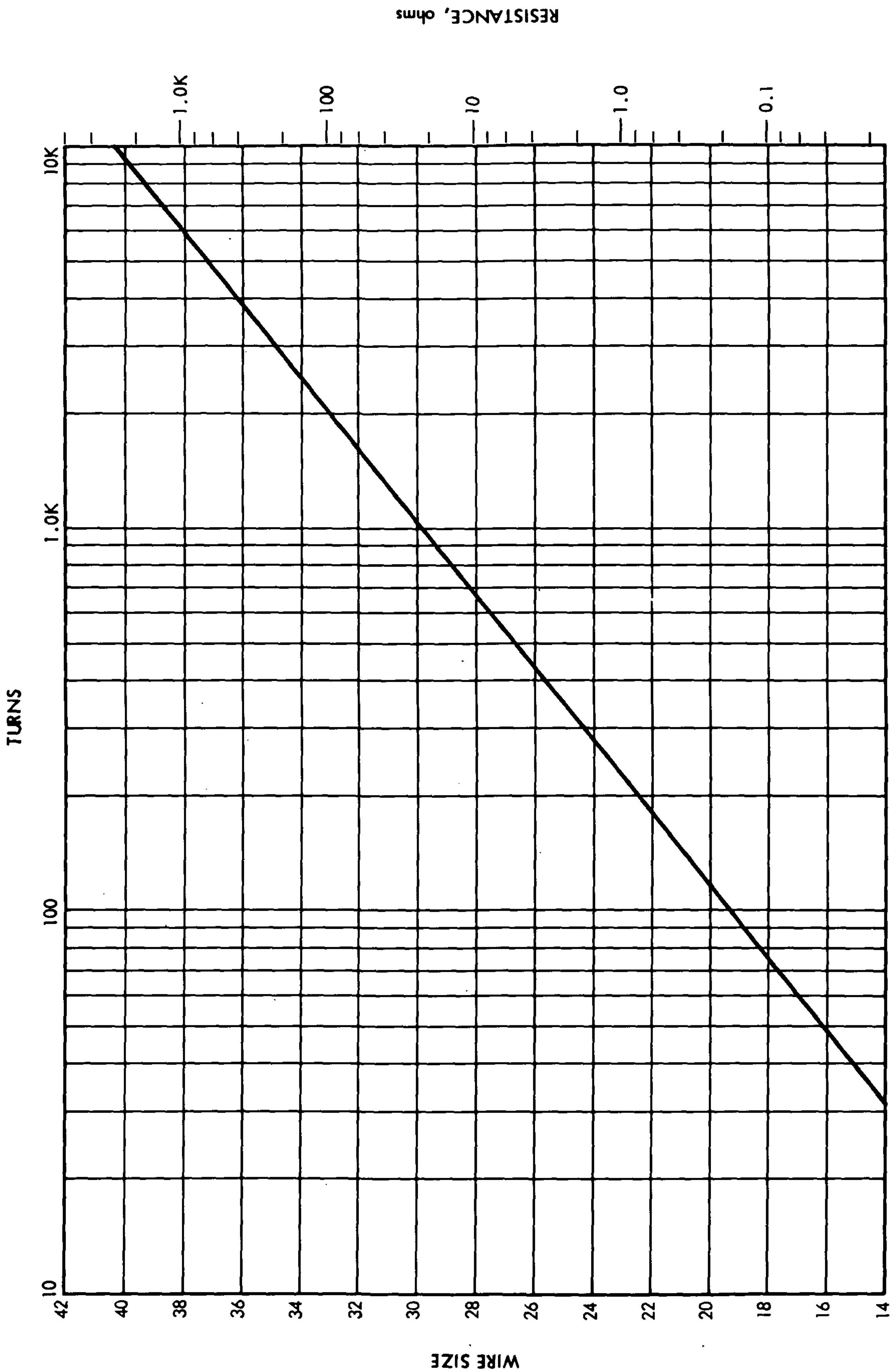
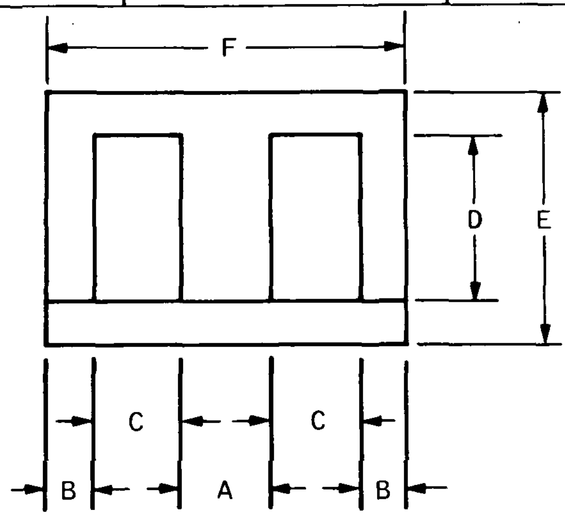


Fig. 30. Nomograph for Lamination EI-375

Table 22. Lamination EI-50

	ENGLISH		METRIC	
Wa/Ac	0.750		0.750	
Wa x Ac	0.047	in^4	1.95	cm^4
Ac	0.250	in^2	1.61	cm^2
Wa	0.188	in^2	1.21	cm^2
lm	3.00	in	7.62	cm
CORE wt SOLID	0.203	lb	92.0	grams
COPPER wt	0.0617	lb	28.0	grams
MLT FULLWOUND	2.82	in	7.15	cm
MLT 1st HALF	2.50	in	6.36	cm
MLT 2nd HALF	3.13	in	7.95	cm
A_T	8.93	in^2	57.6	cm^2
A	0.500	in	1.27	cm
B	0.250	in	0.635	cm
C	0.250	in	0.635	cm
D	0.750	in	1.91	cm
E	1.25	in	3.18	cm
F	1.50	in	3.81	cm
BOBBIN	NY-GLASS # NY-44			
LENGTH	0.661	in	1.68	cm
BUILD	0.200	in	0.508	cm
AREA	0.132	in^2	0.852	cm^2



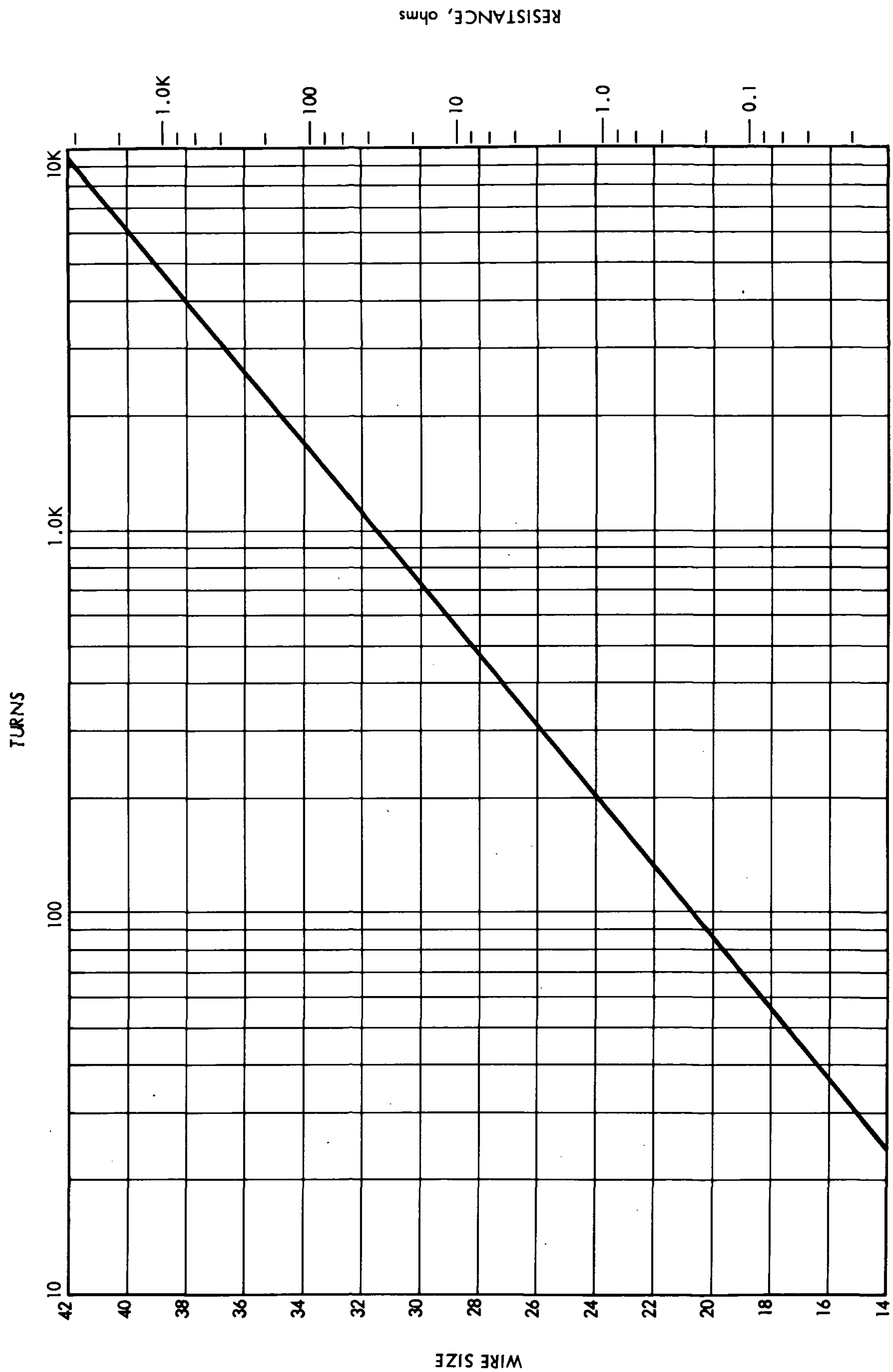
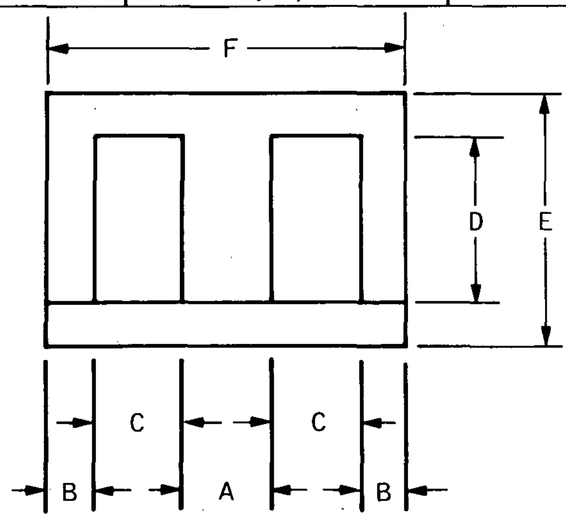


Fig. 31. Nomograph for Lamination EI-50

Table 23. Lamination EI-21

	ENGLISH		METRIC	
Wa/Ac	1.02		1.02	
Wa x Ac	0.0635	in^4	2.64	cm^4
Ac	0.25	in^2	1.61	cm^2
Wa	0.254	in^2	1.64	cm^2
lm	3.25	in	8.255	cm
CORE wt SOLID	0.219	lb	99.3	grams
COPPER wt	0.090	lb	41	grams
MLT FULLWOUND	3.01	in	7.92	cm
MLT 1st HALF	2.60	in	6.59	cm
MLT 2nd HALF	3.43	in	8.71	cm
A_T	10.2	in^2	66.0	cm^2
A	0.500	in	1.27	cm
B	0.250	in	0.635	cm
C	0.312	in	0.792	cm
D	0.812	in	2.06	cm
E	1.31	in	3.33	cm
F	1.63	in	4.13	cm
BOBBIN	NY-GLASS # NY-9			
LENGTH	0.726	in	1.84	cm
BUILD	0.265	in	0.673	cm
AREA	0.192	in^2	1.240	cm^2



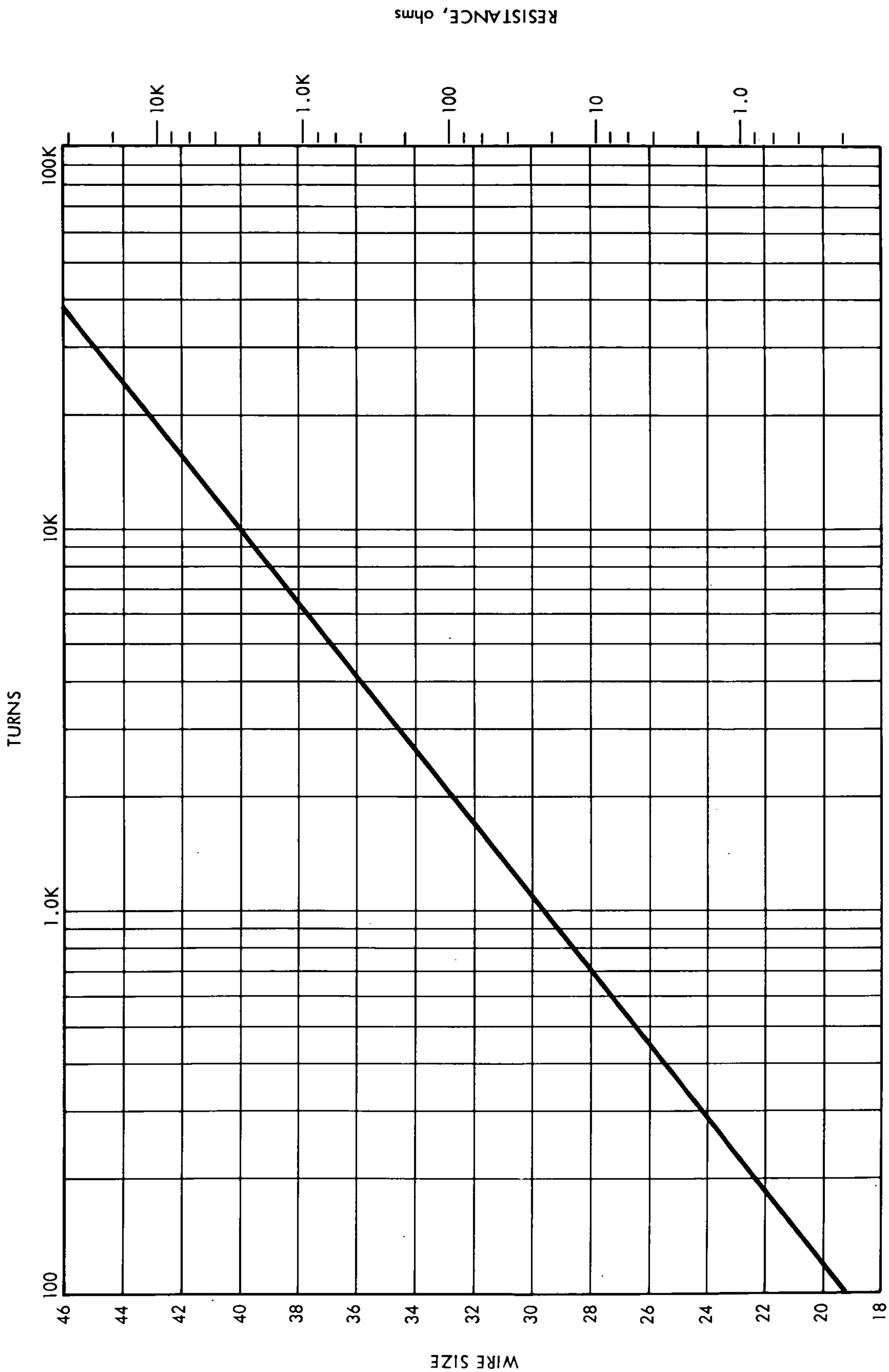
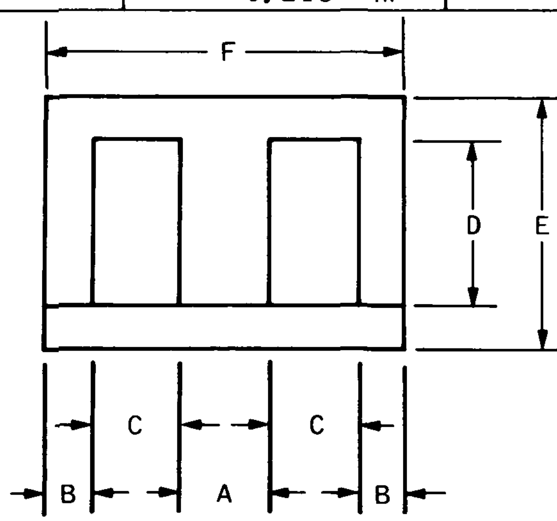


Fig. 32. Nomograph for Lamination EI-21

Table 24. Lamination EI-625

	ENGLISH		METRIC	
Wa/Ac	0.750		0.750	
Wa x Ac	0.115	in^4	4.76	cm^4
Ac	0.391	in^2	2.52	cm^2
Wa	0.293	in^2	1.89	cm^2
lm	3.75	in	9.53	cm
CORE wt SOLID	0.395	lb	179	grams
COPPER wt	0.154	lb	70	grams
MLT FULLWOUND	3.39	in	8.60	cm
MLT 1st HALF	3.04	in	7.29	cm
MLT 2nd HALF	3.73	in	9.48	cm
A_T	13.9	in^2	89.6	cm^2
A	0.625	in	1.59	cm
B	0.312	in	0.792	cm
C	0.312	in	0.792	cm
D	0.938	in	2.38	cm
E	1.56	in	3.97	cm
F	1.88	in	4.76	cm
BOBBIN	NY-GLASS # NY-10			
LENGTH	0.841	in	2.14	cm
BUILD	0.260	in	0.660	cm
AREA	0.218	in^2	1.41	cm^2



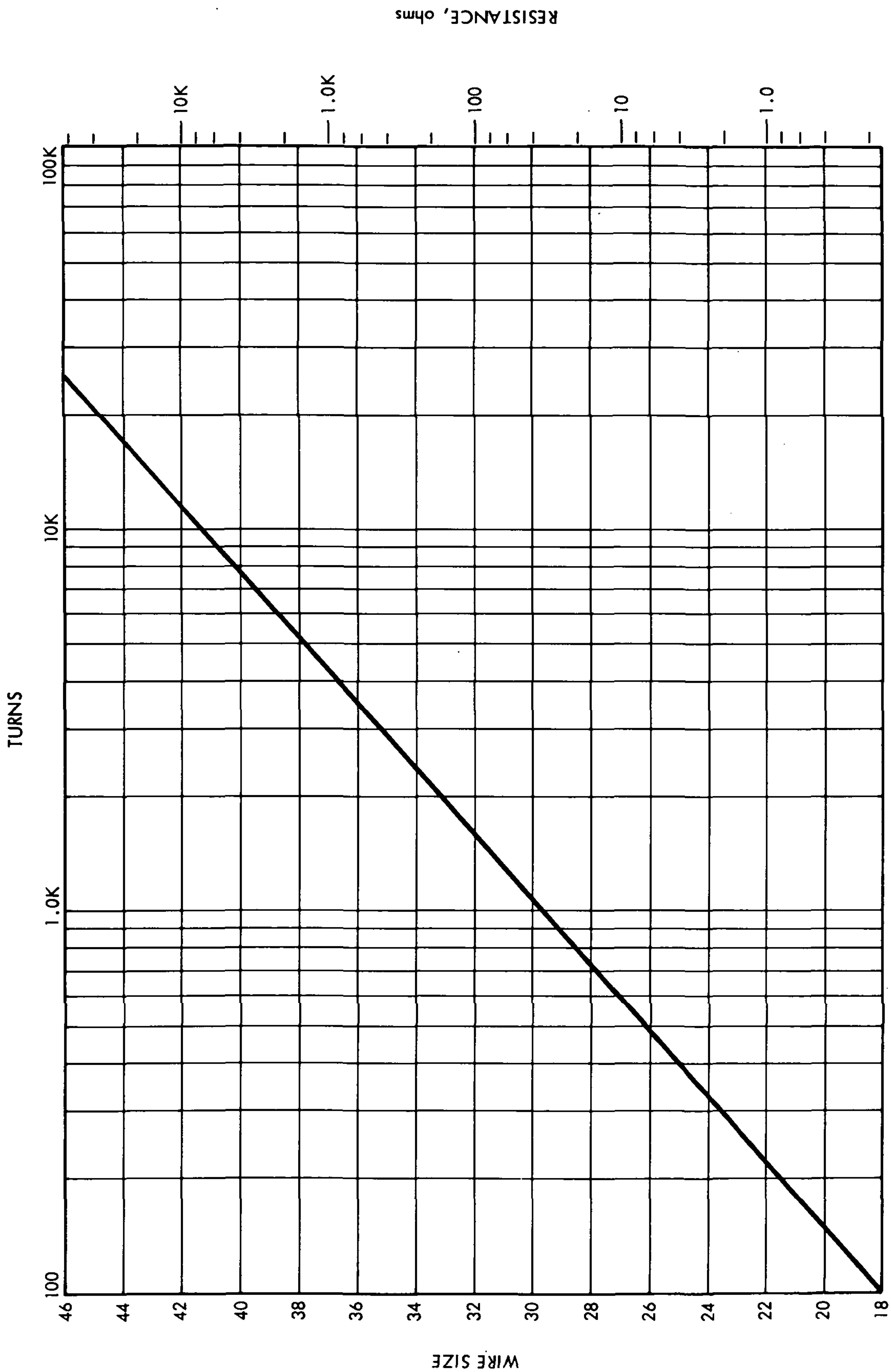
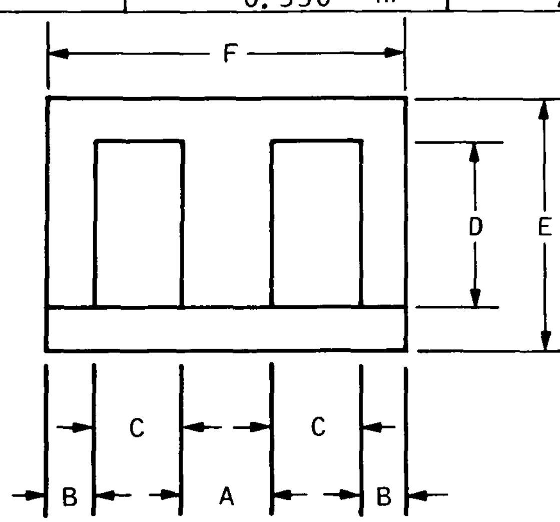


Fig. 33. Nomograph for Lamination EI-625

Table 25. Lamination EI-75

	ENGLISH		METRIC	
Wa/Ac	0.750		0.750	
Wa x Ac	0.237	in^4	9.87	cm^4
Ac	0.563	in^2	3.63	cm^2
Wa	0.422	in^2	2.72	cm^2
lm	4.50	in	11.4	cm
CORE wt SOLID	0.688	lb	312	grams
COPPER wt	0.232	lb	105	grams
MLT FULLWOUND	4.21	in	10.7	cm
MLT 1st HALF	3.71	in	9.41	cm
MLT 2nd HALF	4.72	in	12.0	cm
A_T	20.1	in^2	130	cm^2
A	0.750	in	1.91	cm
B	0.375	in	0.952	cm
C	0.375	in	0.952	cm
D	1.125	in	2.86	cm
E	1.875	in	4.76	cm
F	2.25	in	5.72	cm
BOBBIN	NY-GLASS # NY-11			
LENGTH	1.02	in	2.59	cm
BUILD	0.322	in	0.838	cm
AREA	0.330	in^2	2.13	cm^2



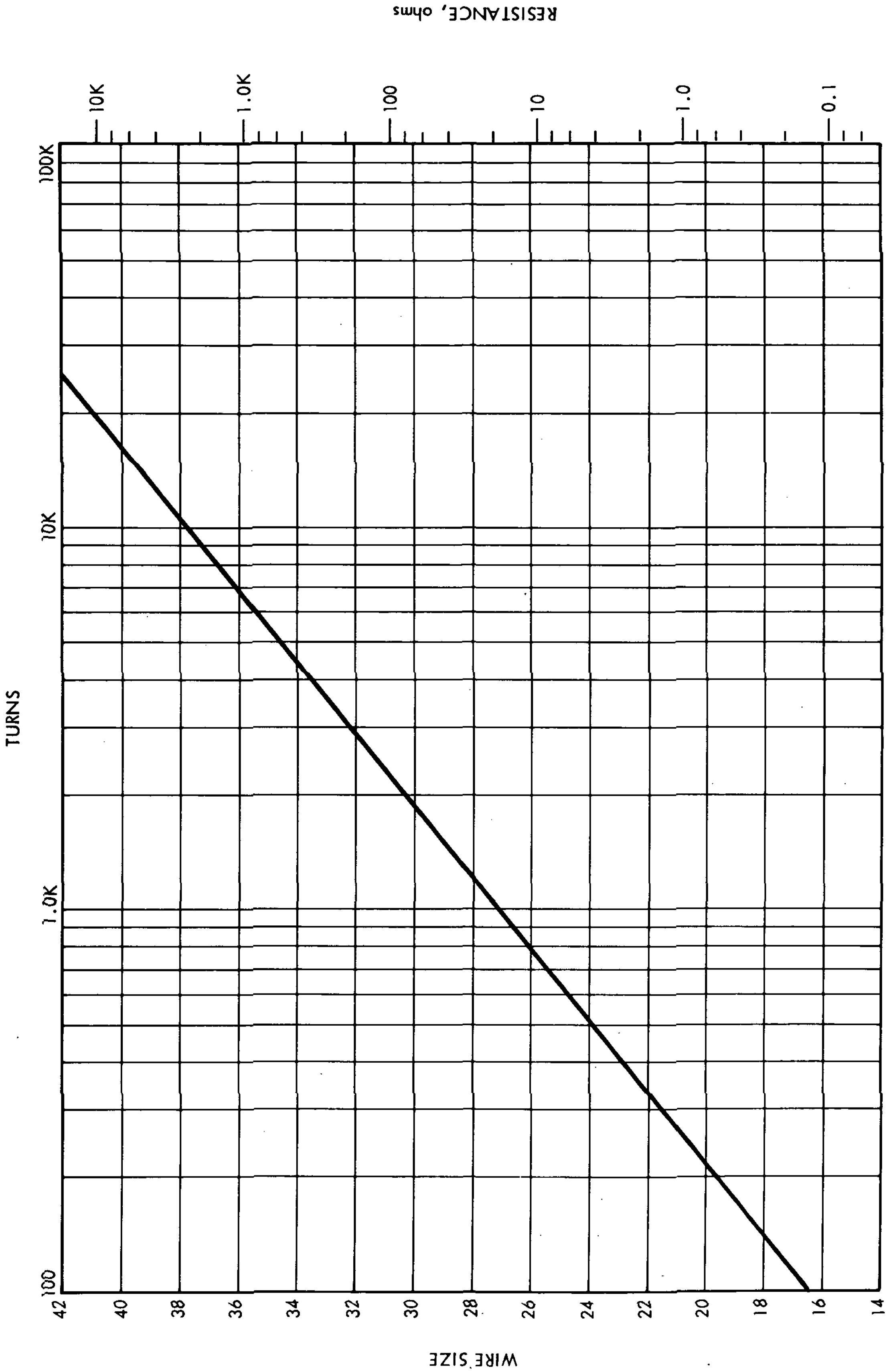
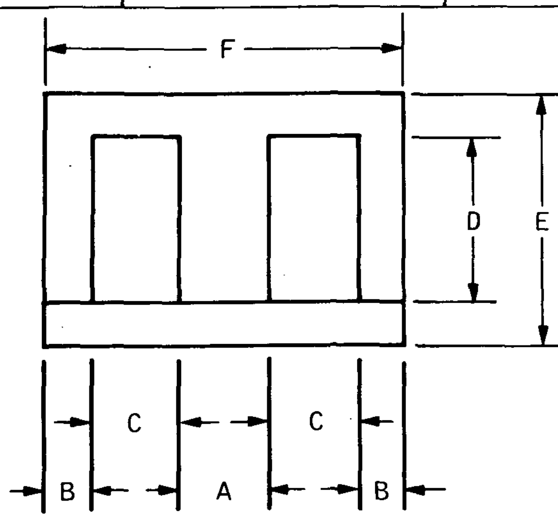


Fig. 34. Nomograph for Lamination EI-75

Table 26. Lamination EI-87

	ENGLISH		METRIC	
Wa/Ac	0.750		0.750	
Wa x Ac	0.439	in^4	18.3	cm^4
Ac	0.766	in^2	4.94	cm^2
Wa	0.574	in^2	3.71	cm^2
lm	5.25	in	13.3	cm
CORE wt SOLID	1.06	lb	481	grams
COPPER wt	0.375	lb	170	grams
MLT FULLWOUND	4.92	in	12.5	cm
MLT 1st HALF	4.32	in	11.0	cm
MLT 2nd HALF	5.52	in	14.0	cm
A_T	27.3	in^2	176	cm^2
A	0.875	in	2.22	cm
B	0.438	in	1.112	cm
C	0.438	in	1.112	cm
D	1.312	in	3.332	cm
E	2.188	in	5.557	cm
F	2.625	in	6.667	cm
BOBBIN	NY-GLASS # NY-12			
LENGTH	1.21	in	3.073	cm
BUILD	0.383	in	0.973	cm
AREA	0.464	in^2	2.993	cm^2



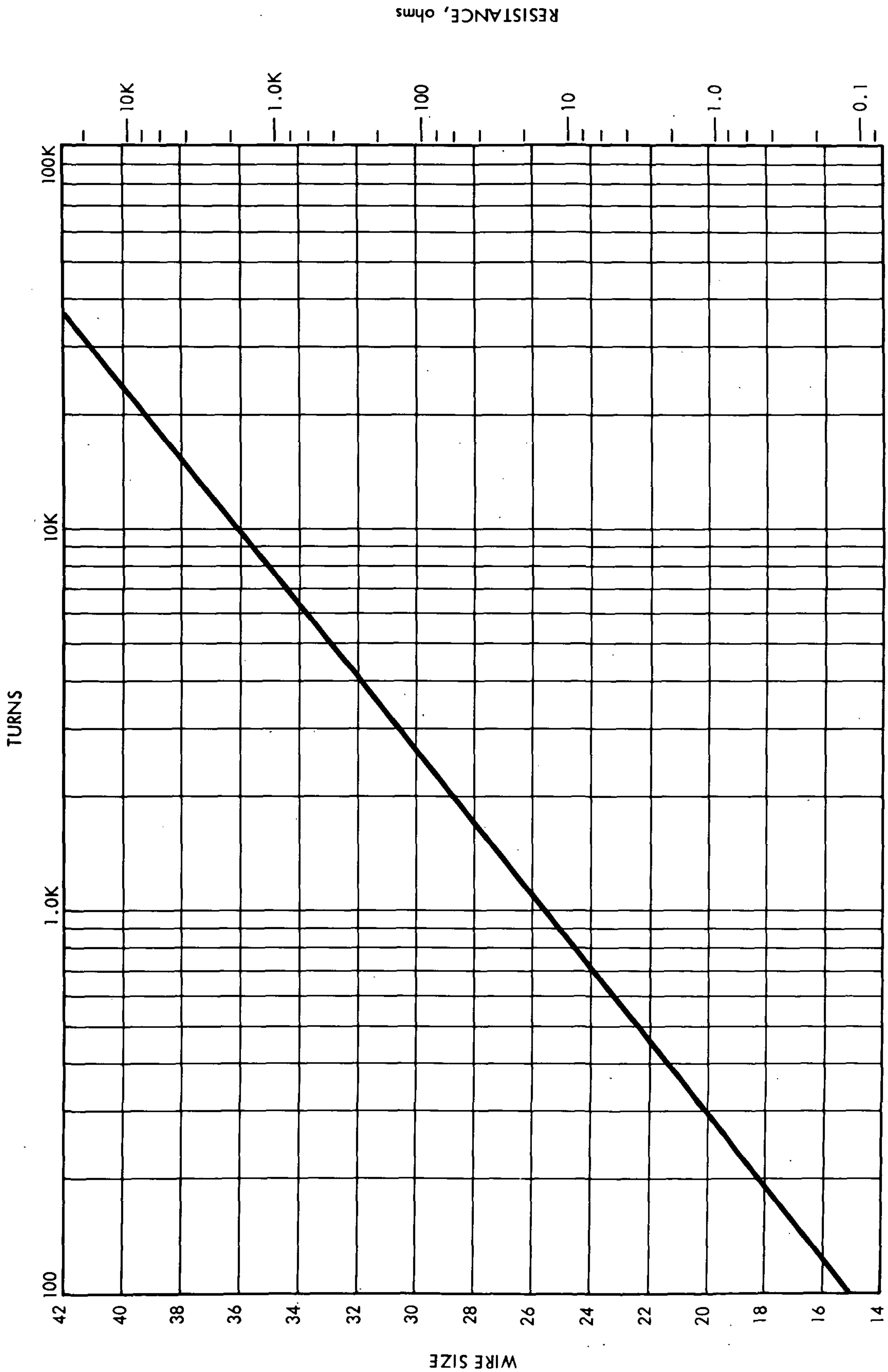
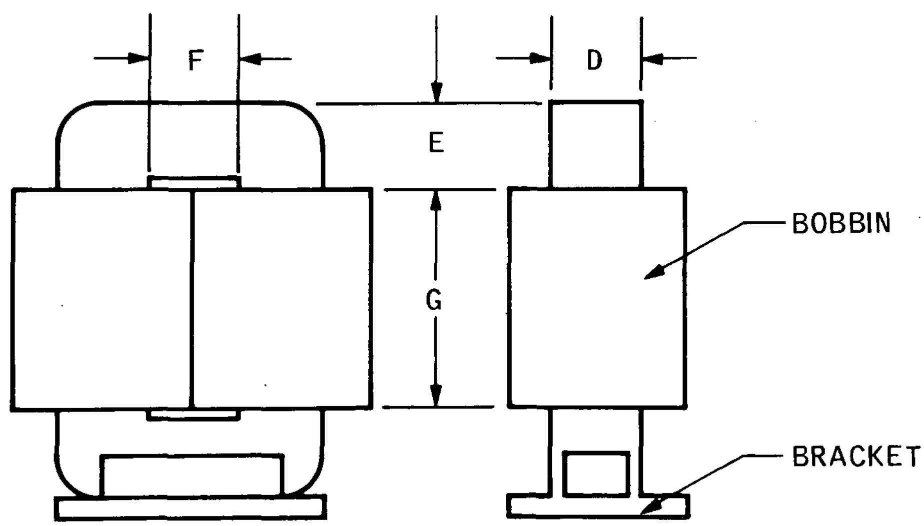


Fig. 35. Nomograph for Lamination EI-87

Table 27. "C" Core Magnetic Inc MC 0001

	ENGLISH		METRIC	
Wa/Ac			4.09	
Wa x Ac	0.004	in^4	0.161	cm^4
Ac	0.031	in^2	0.20	cm^2
Wa	0.125	in^2	0.806	cm^2
lm	1.86	in	4.72	cm
CORE wt SOLID	0.016	lb	7.28	grams
COPPER wt	0.015	lb	6.6	grams
MLT FULLWOUND	1.27	in	3.23	cm
MLT 1st HALF	1.11	in	2.82	cm
MLT 2nd HALF	1.43	in	3.63	cm
A_T	2.375	in^2	15.32	cm^2
D	0.25	in	0.635	cm
E	0.125	in	0.317	cm
F	0.25	in	0.635	cm
G	0.50	in	1.270	cm
BOBBIN	DORCO ELECTRONICS # 12767			
LENGTH	0.43	in	1.092	cm
BUILD	0.10	in	0.254	cm
AREA	0.043	in^2	0.277	cm^2
BRACKET	HALLMARK METALS # 04-008-02			



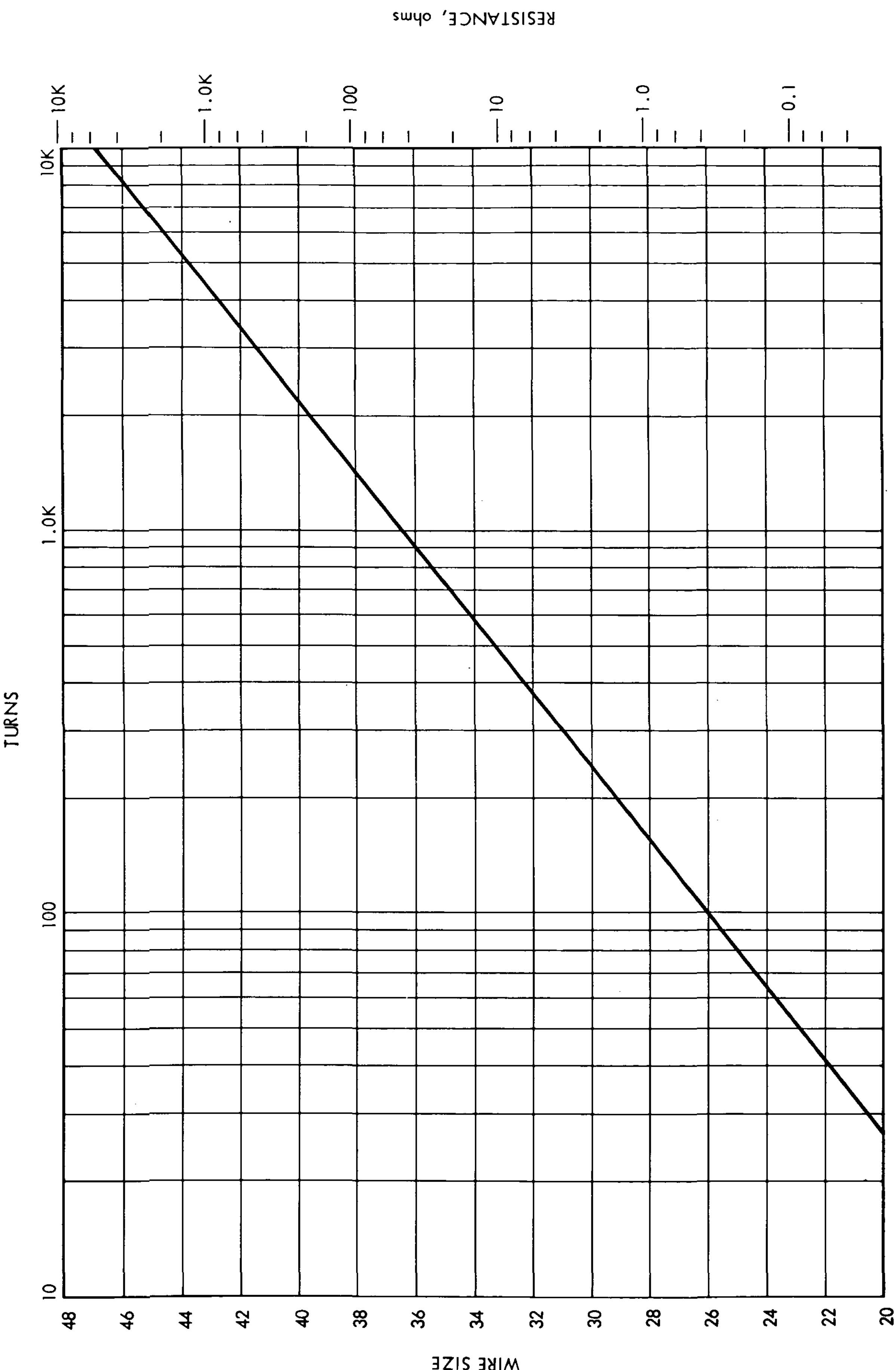
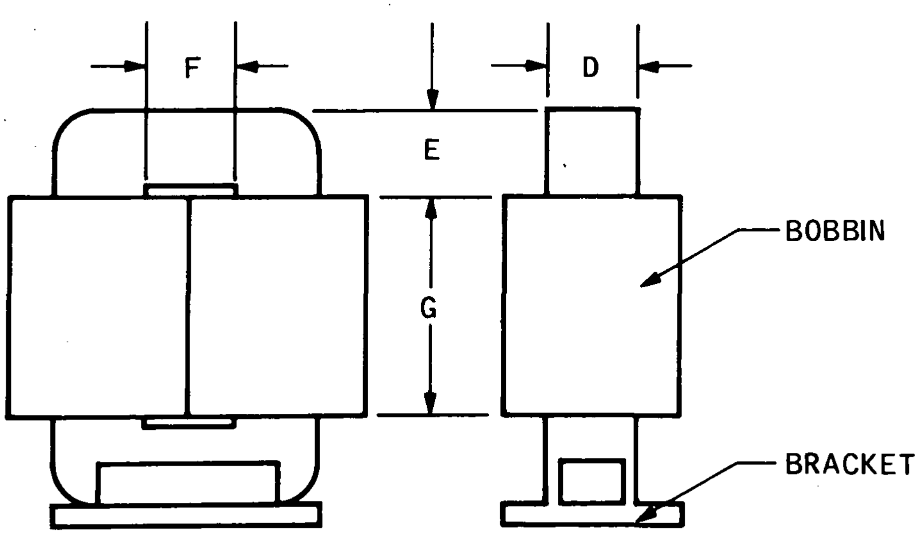


Fig. 36. Nomograph for "C" Core MC 0001

Table 28. "C" Core Magnetic Inc MC 0002

	ENGLISH		METRIC	
Wa/Ac			3.66	
Wa x Ac	0.00733	in^4	0.305	cm^4
Ac	0.047	in^2	0.303	cm^2
Wa	0.156	in^2	1.006	cm^2
lm	2.293	in	5.82	cm
CORE wt SOLID	0.0296	lb	13.45	grams
COPPER wt	0.0207	lb	9.4	grams
MLT FULLWOUND	1.39	in	3.53	cm
MLT 1st HALF	1.24	in	3.15	cm
MLT 2nd HALF	1.55	in	3.94	cm
A_T	3.25	in^2	20.96	cm^2
D	0.25	in	0.635	cm
E	0.187	in	0.476	cm
F	0.25	in	0.635	cm
G	0.625	in	1.588	cm
BOBBIN	DORCO ELECTRONICS # 12768			
LENGTH	0.560	in	1.42	cm
BUILD	0.100	in	0.254	cm
AREA	0.056	in^2	0.361	cm^2
BRACKET	HALLMARK METALS # 04-010-03			



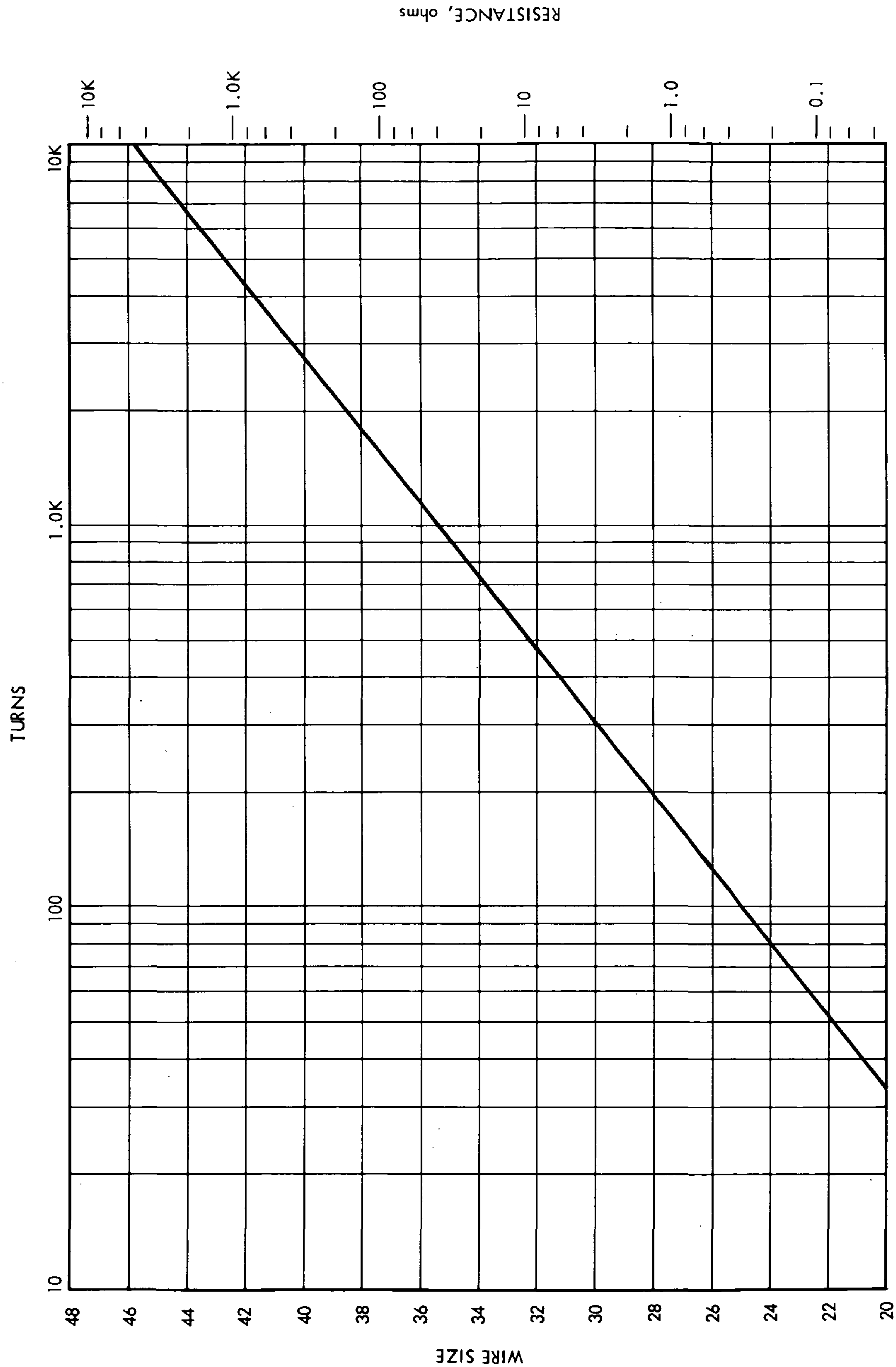
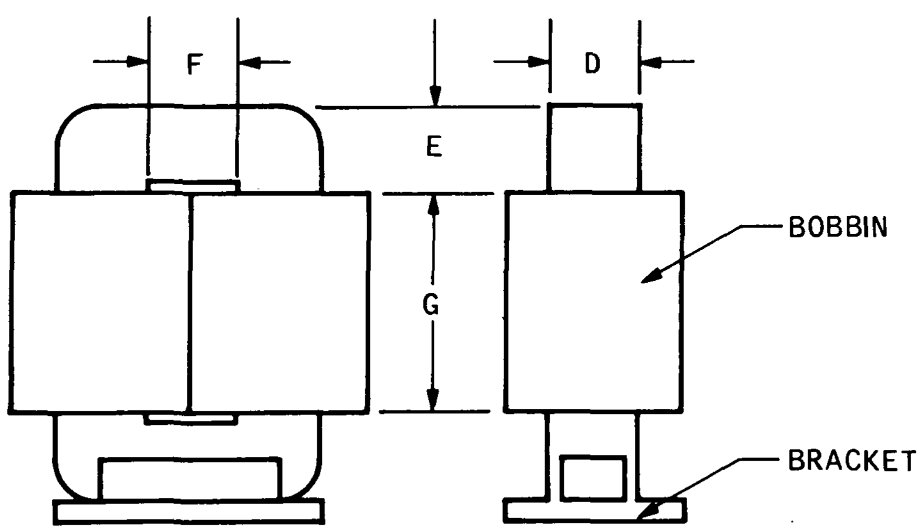


Fig. 37. Nomograph for "C" Core MC 0002

Table 29. "C" Core Magnetic Inc MC 0004

	ENGLISH		METRIC	
Wa/Ac			3.58	
Wa x Ac	0.014	in^4	0.574	cm^4
Ac	0.063	in^2	0.406	cm^2
Wa	0.219	in^2	1.413	cm^2
lm	2.975	in	7.55	cm
CORE wt SOLID	0.0513	lb	22.27	grams
COPPER wt	0.0282	lb	12.8	grams
MLT FULLWOUND	1.52	in	3.86	cm
MLT 1st HALF	1.38	in	3.51	cm
MLT 2nd HALF	1.65	in	4.19	cm
A_T	4.625	in^2	29.8	cm^2
D	0.25	in	0.635	cm
E	0.25	in	0.635	cm
F	0.25	in	0.635	cm
G	0.875	in	2.222	cm
BOBBIN	DORCO ELECTRONICS # 12769			
LENGTH	0.800	in	2.032	cm
BUILD	0.087	in	0.221	cm
AREA	0.0696	in^2	0.449	cm^2
BRACKET	HALLMARK METALS #04-012-04			



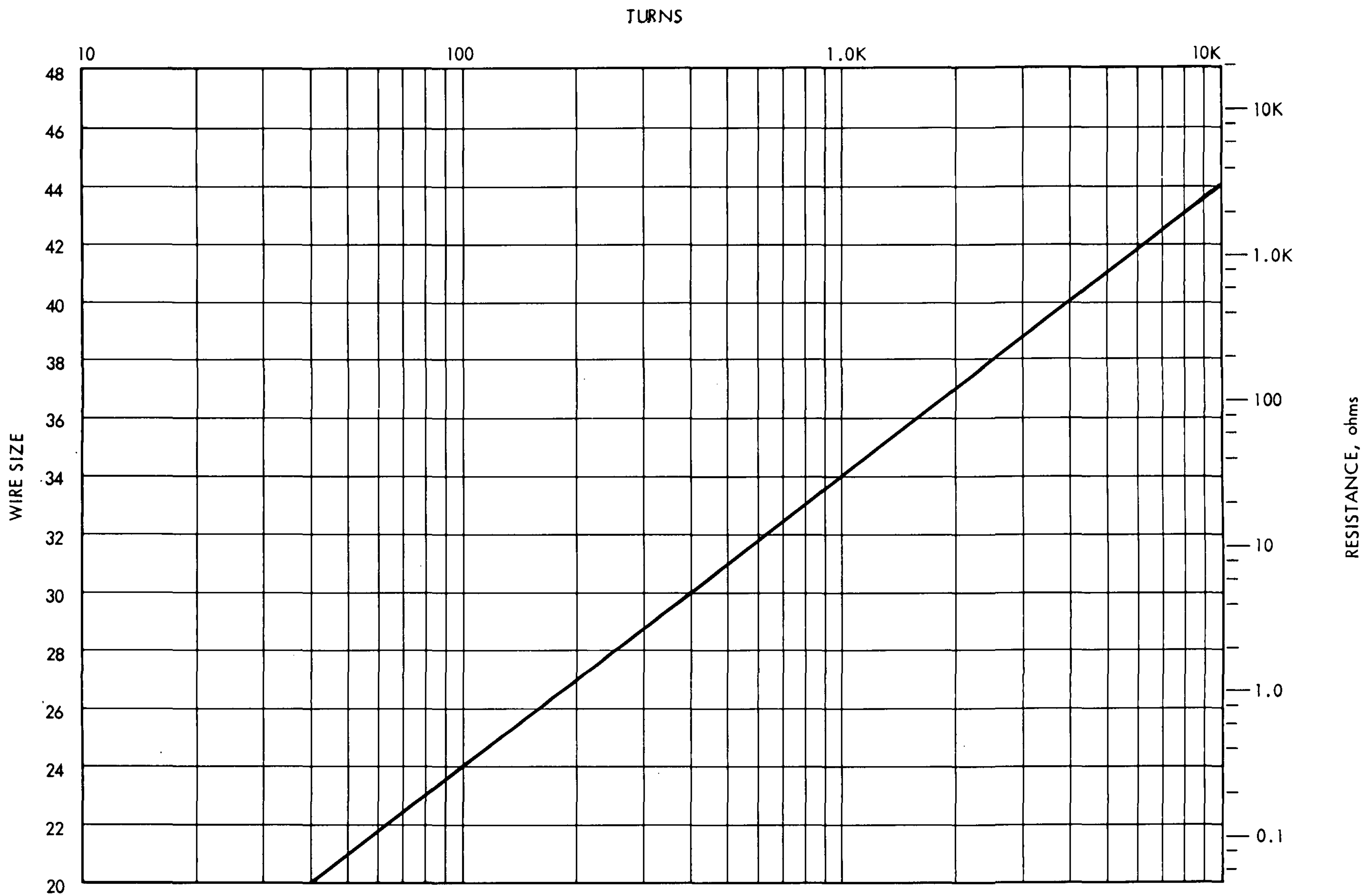
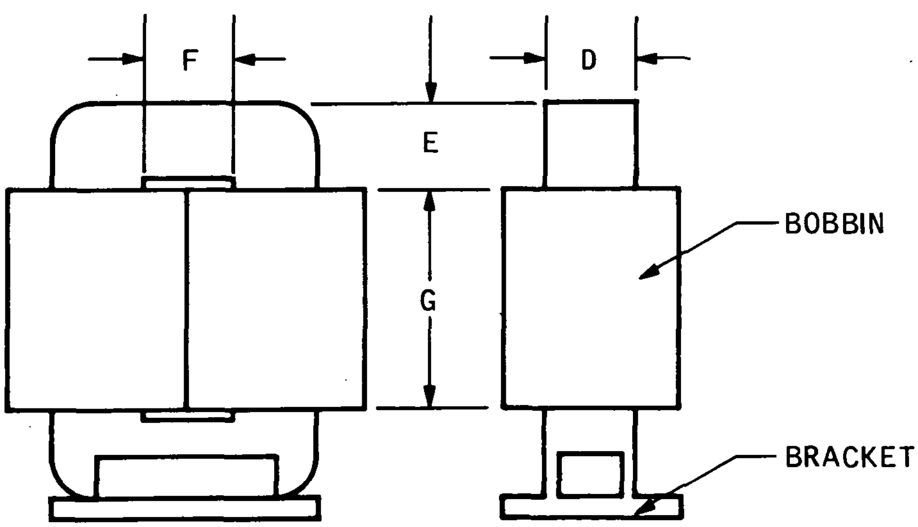


Fig. 38. Nomograph for "C" Core MC 0004

Table 30. "C" Core Magnetic Inc MC 8400

	ENGLISH		METRIC	
Wa/Ac			5.37	
Wa x Ac	0.021	in^4	0.893	cm^4
Ac	0.062	in^2	0.403	cm^2
Wa	0.344	in^2	2.217	cm^2
lm	3.98	in	10.09	cm
CORE wt SOLID	0.0686	lb	31.14	grams
COPPER wt	0.057	lb	26	grams
MLT FULLWOUND	1.52	in	3.86	cm
MLT 1st HALF	1.38	in	3.51	cm
MLT 2nd HALF	1.65	in	4.19	cm
A_T	6.125	in^2	39.5	cm^2
D	0.25	in	0.635	cm
E	0.25	in	0.635	cm
F	0.25	in	0.635	cm
G	1.375	in	3.493	cm
BOBBIN	DORCO ELECTRONICS # 12770			
LENGTH	1.310	in	3.33	cm
BUILD	0.087	in	0.221	cm
AREA	0.114	in^2	0.735	cm^2
BRACKET	HALLMARK METALS #04-012-04			



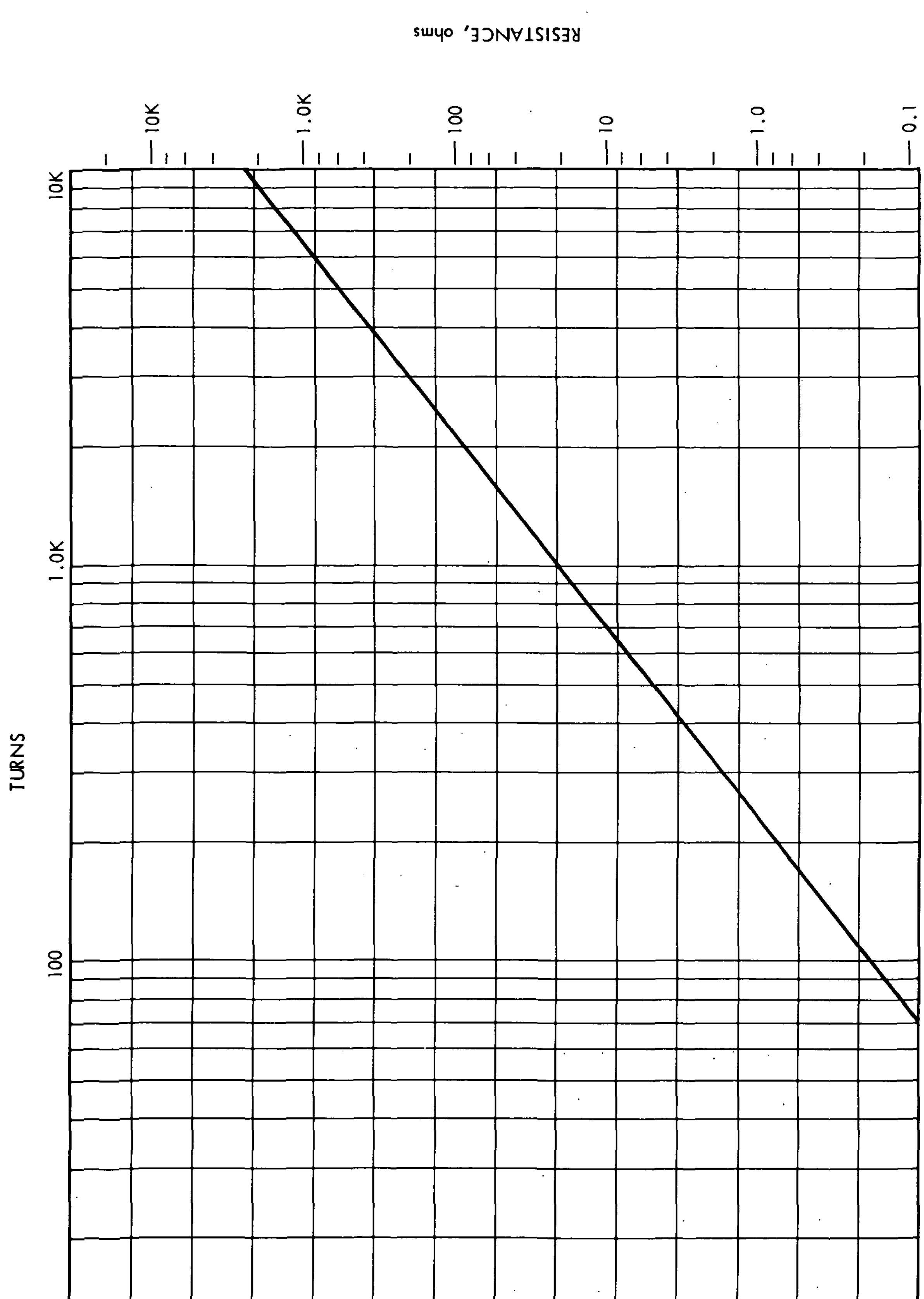
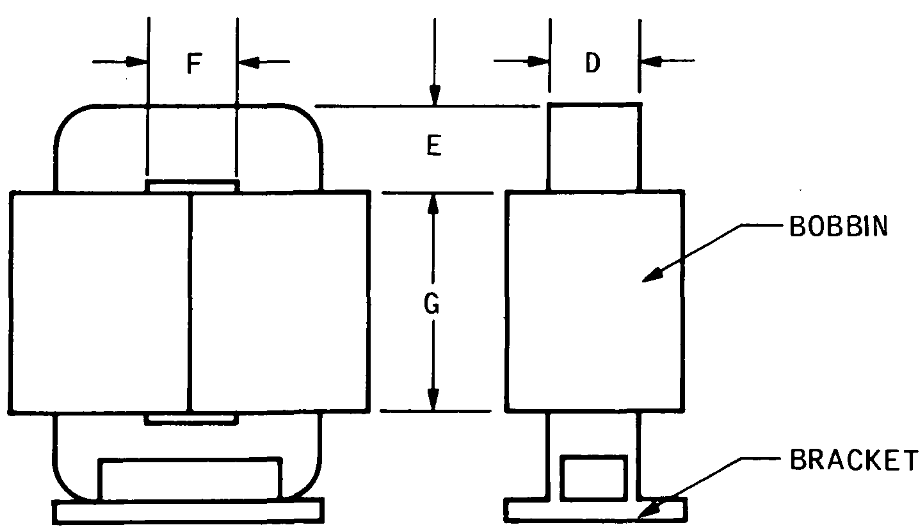


Fig. 39. Nomograph for "C" Core MC 8400

Table 31. "C" Core Magnetic Inc MC 1200

	ENGLISH	METRIC
Wa/Ac		3.98
Wa x Ac	0.035 in^4	1.467 cm^4
Ac	0.094 in^2	0.606 cm^2
Wa	0.375 in^2	2.419 cm^2
lm	3.475 in	8.83 cm
CORE wt SOLID	0.090 lb	40.8 grams
COPPER wt	0.088 lb	40. grams
MLT FULLWOUND	1.97 in	5.00 cm
MLT 1st HALF	1.73 in	4.39 cm
MLT 2nd HALF	2.21 in	5.61 cm
A_T	7.125 in^2	45.95 cm^2
D	0.375 in	0.953 cm
E	0.250 in	0.635 cm
F	0.375 in	0.953 cm
G	1.00 in	2.54 cm
BOBBIN	DORCO ELECTRONICS # 12771	
LENGTH	0.920 in	2.34 cm
BUILD	0.152 in	0.386 cm
AREA	0.140 in^2	0.902 cm^2
BRACKET	HALLMARK METALS # 06-014-04	



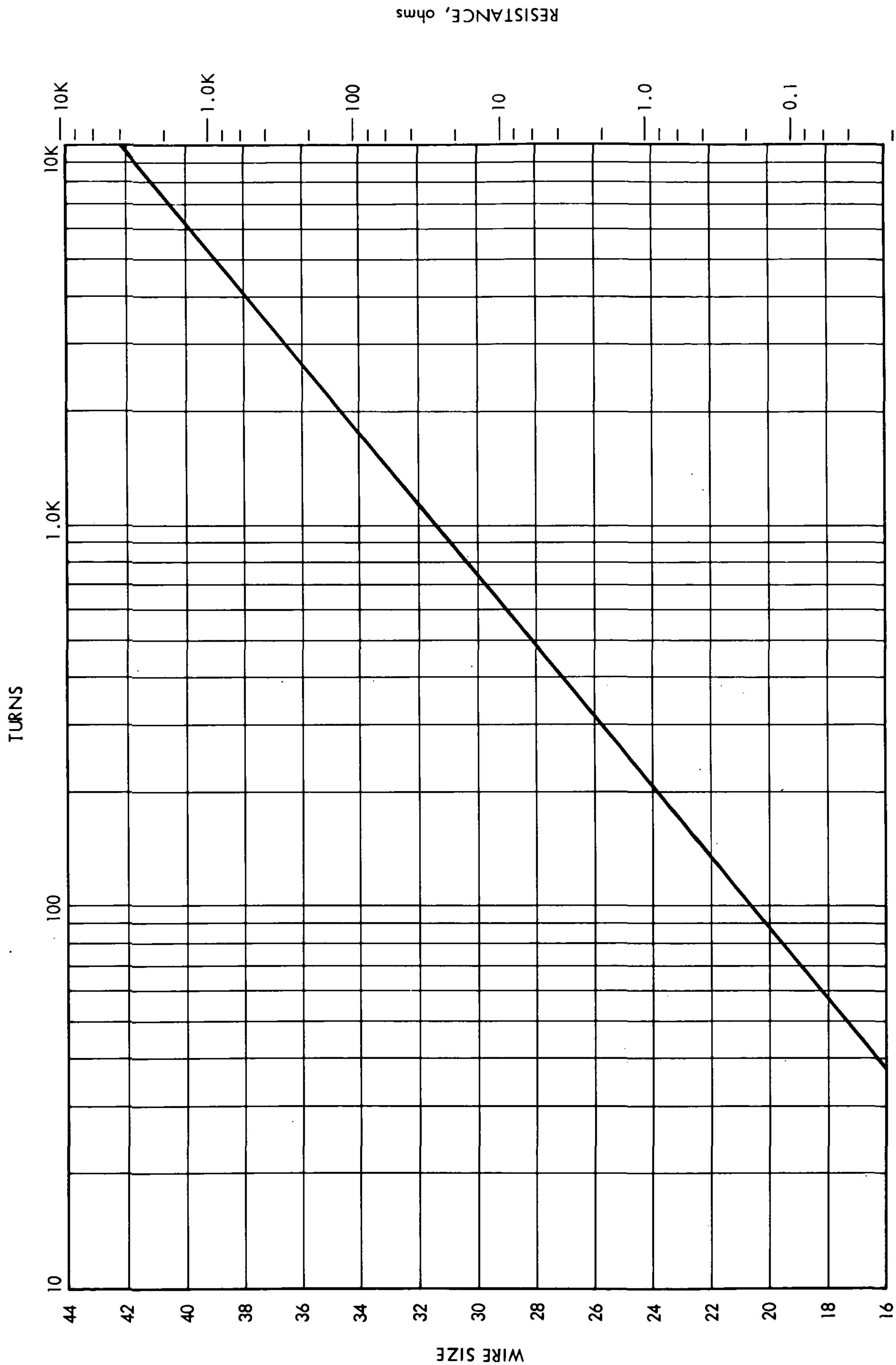
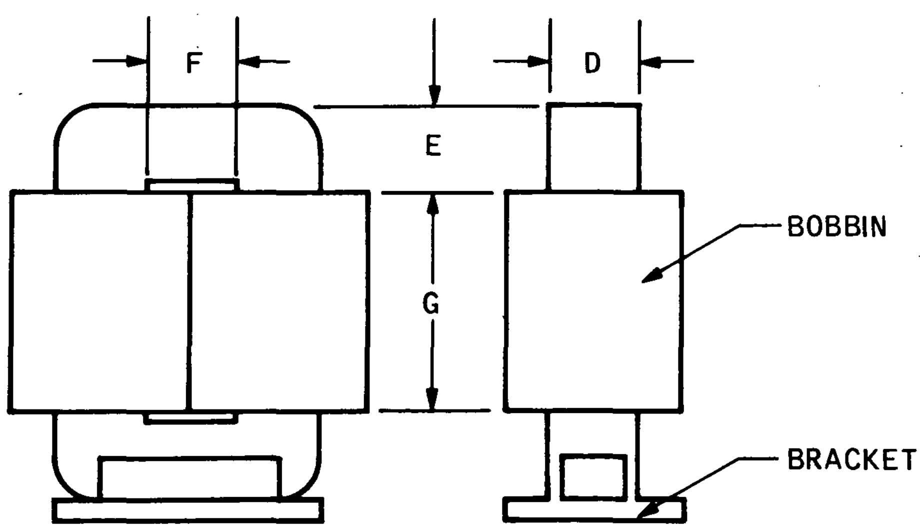


Fig. 40. Nomograph for "C" Core MC 1200

Table 32. "C" Core Magnetic Inc MC 4400

	ENGLISH		METRIC	
Wa/Ac			3.96	
Wa x Ac	0.062	in^4	2.600	cm^4
Ac	0.125	in^2	0.806	cm^2
Wa	0.500	in^2	3.225	cm^2
lm	3.725	in	9.46	cm
CORE wt SOLID	0.128	lb	58.3	grams
COPPER wt	0.14	lb	65	grams
MLT FULLWOUND	2.42	in	6.15	cm
MLT 1st HALF	2.10	in	5.33	cm
MLT 2nd HALF	2.74	in	6.96	cm
A_T	9.50	in^2	61.27	cm^2
D	0.50	in	1.27	cm
E	0.25	in	0.635	cm
F	0.50	in	1.27	cm
G	1.00	in	2.54	cm
BOBBIN	DORCO ELECTRONICS # 12772			
LENGTH	0.910	in	2.31	cm
BUILD	0.202	in	0.513	cm
AREA	0.184	in^2	1.186	cm^2
BRACKET	HALLMARK METALS # 08-100-04			



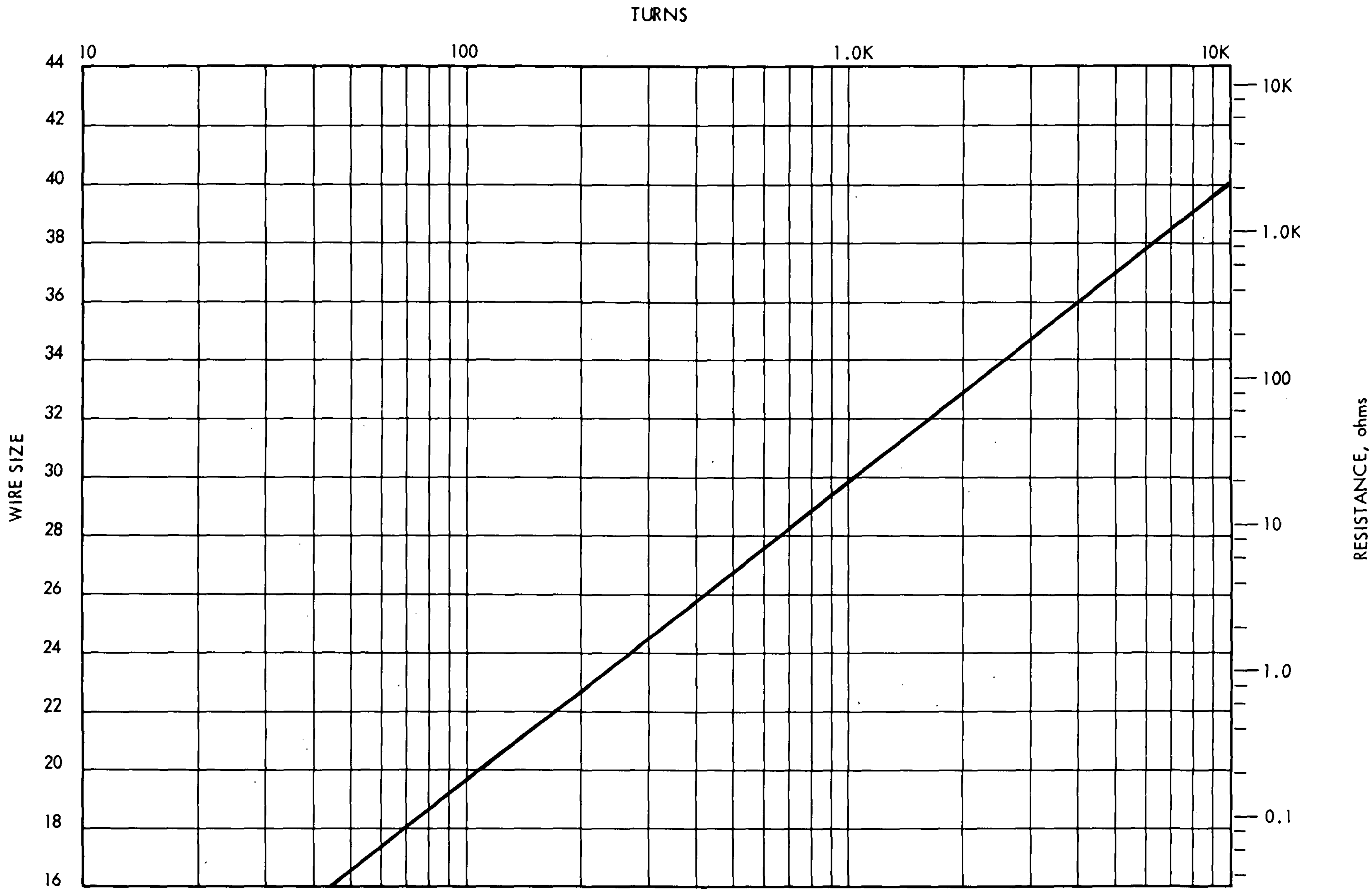
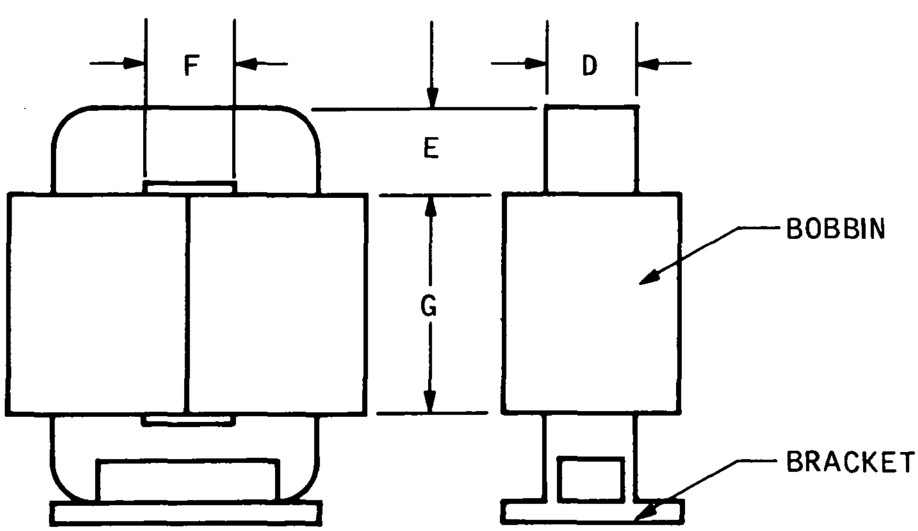


Fig. 41. Nomograph for "C" Core MC 4400

Table 33. "C" Core Magnetic Inc MC 2300

	ENGLISH		METRIC	
Wa/Ac			6.97	
Wa x Ac	0.109	in^4	4.55	cm^4
Ac	0.125	in^2	0.806	cm^2
Wa	0.875	in^2	5.643	cm^2
lm	5.23	in	13.27	cm
CORE wt SOLID	0.180	lb	81.8	grams
COPPER wt	0.255	lb	116	grams
MLT FULLWOUND	2.42	in	6.15	cm
MLT 1st HALF	2.10	in	5.33	cm
MLT 2nd HALF	2.74	in	6.96	cm
A_T	13.25	in^2	85.46	cm^2
D	0.50	in	1.27	cm
E	0.25	in	0.635	cm
F	0.50	in	1.27	cm
G	1.75	in	4.45	cm
BOBBIN	DORCO ELECTRONICS # 12773			
LENGTH	1.660	in	4.22	cm
BUILD	0.202	in	0.513	cm
AREA	0.335	in^2	2.16	cm^2
BRACKET	HALLMARK METALS # 08-100-04			



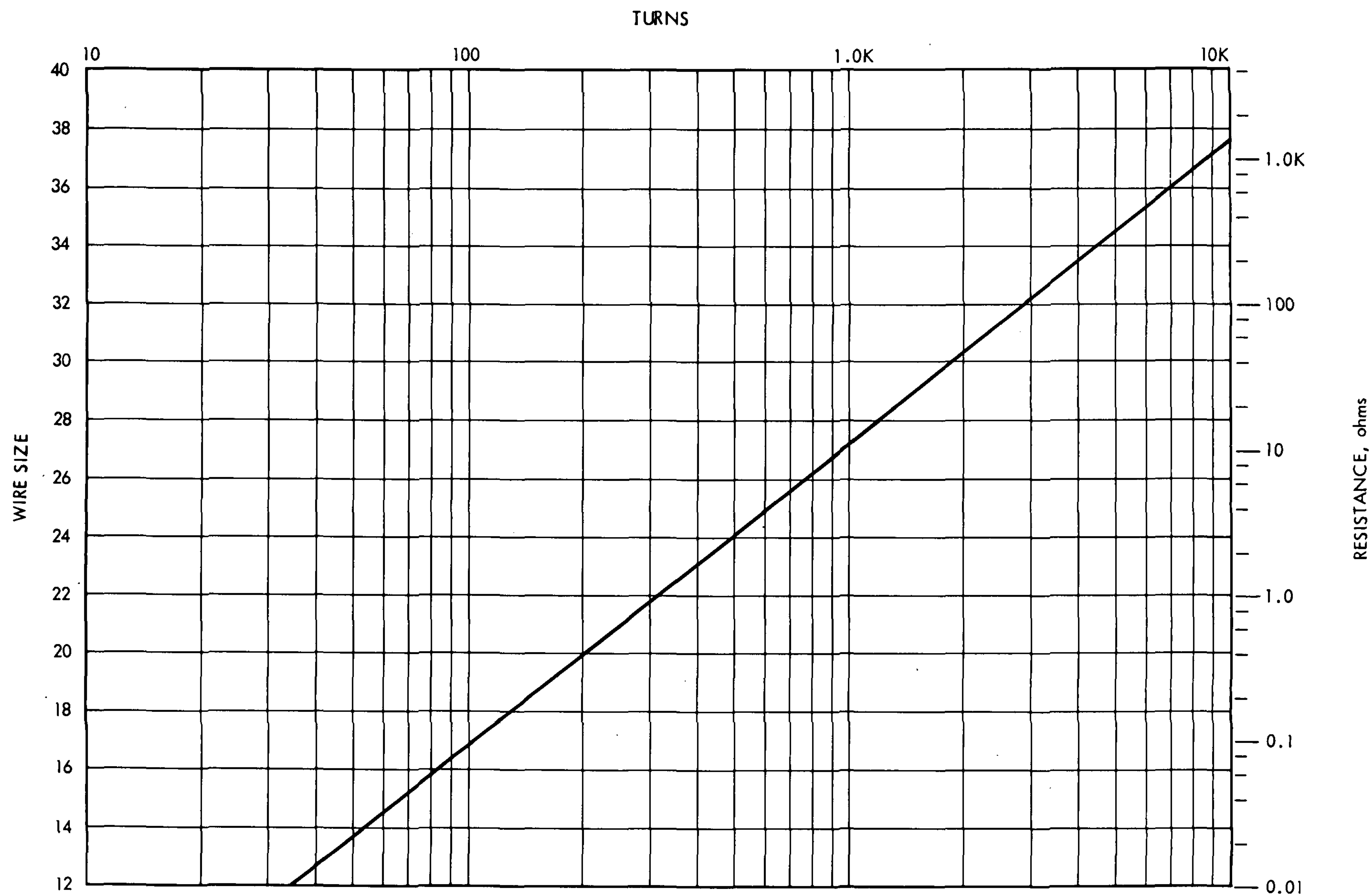
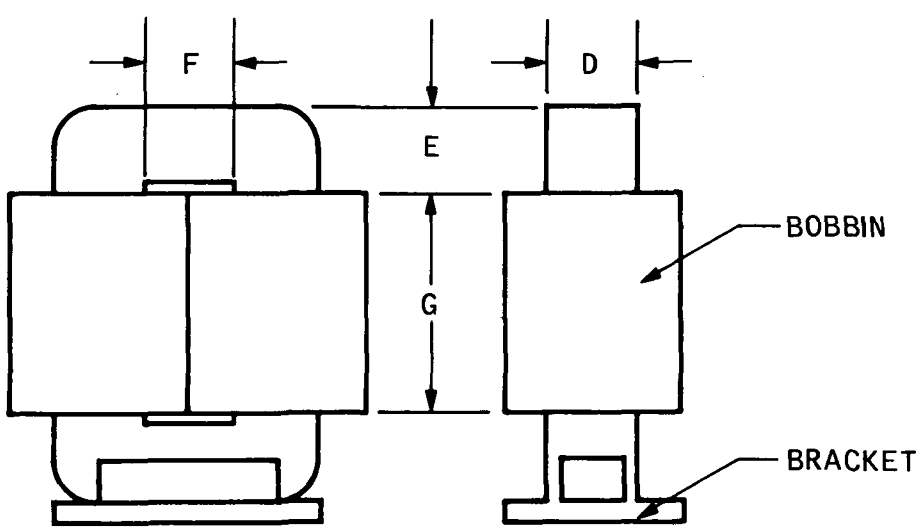


Fig. 42. Nomograph for "C" Core MC 2300

Table 34. "C" Core Magnetic Inc MC 1300

	ENGLISH		METRIC	
Wa/Ac			4.15	
Wa x Ac	0.146	in^4	6.1	cm^4
Ac	0.187	in^2	1.21	cm^2
Wa	0.781	in^2	5.04	cm^2
lm	5.57	in	14.16	cm
CORE wt SOLID	0.288	lb	130	grams
COPPER wt	0.242	lb	110	grams
MLT FULLWOUND	2.67	in	6.78	cm
MLT 1st HALF	2.35	in	5.97	cm
MLT 2nd HALF	2.99	in	7.59	cm
A_T	16.23	in^2	104.7	cm^2
D	0.375	in	0.952	cm
E	0.50	in	1.27	cm
F	0.50	in	1.27	cm
G	1.562	in	3.97	cm
BOBBIN	DORCO ELECTRONICS # 12774			
LENGTH	1.470	in	3.73	cm
BUILD	0.202	in	0.513	cm
AREA	0.297	in^2	1.915	cm^2
BRACKET	HALLMARK METALS # 06-108-08			



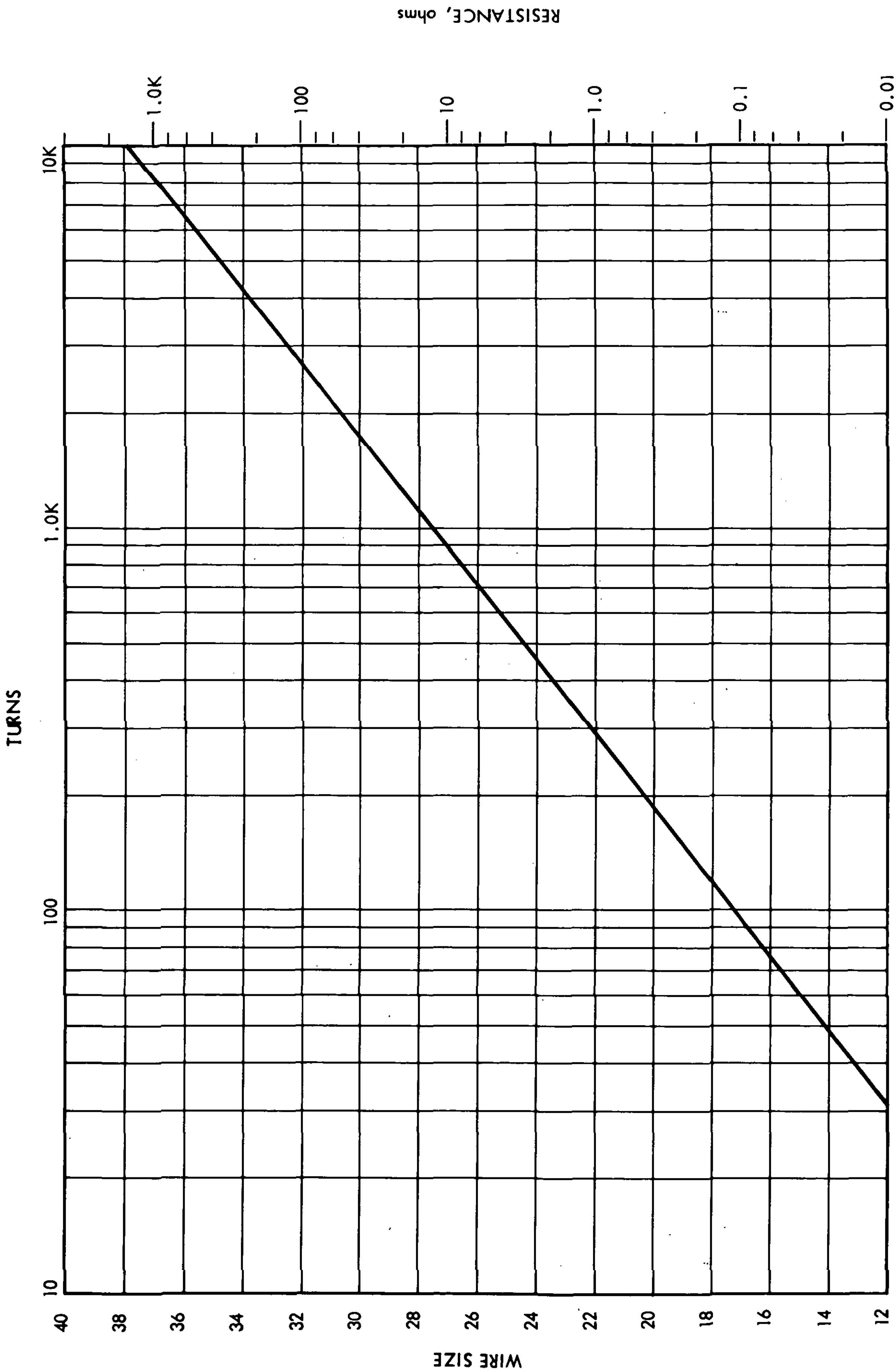
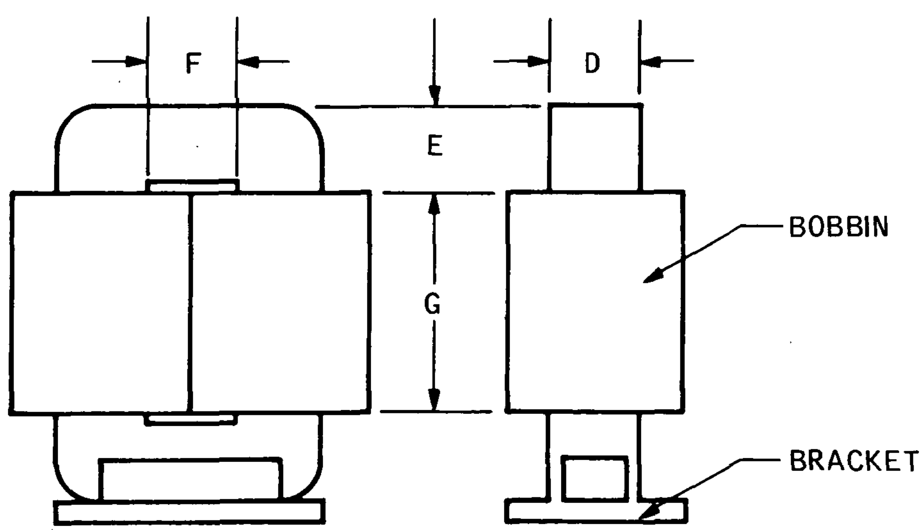


Fig. 43. Nomograph for "C" Core MC 1300

Table 35. "C" Core Magnetic Inc MC 0014

	ENGLISH		METRIC	
Wa/Ac			3.12	
Wa x Ac	0.195	in^4	8.11	cm^4
Ac	0.250	in^2	1.61	cm^2
Wa	0.781	in^2	5.04	cm^2
lm	5.574	in	14.2	cm
CORE wt SOLID	0.384	lb	174.0	grams
COPPER wt	0.264	lb	120	grams
MLT FULLWOUND	2.92	in	7.42	cm
MLT 1st HALF	2.60	in	6.60	cm
MLT 2nd HALF	3.24	in	8.23	cm
A_T	17.37	in^2	112.0	cm^2
D	0.50	in	1.27	cm
E	0.50	in	1.27	cm
F	0.50	in	1.27	cm
G	1.562	in	3.97	cm
BOBBIN	DORCO ELECTRONICS # 12775			
LENGTH	1.470	in	3.73	cm
BUILD	0.202	in	0.513	cm
AREA	0.297	in^2	1.915	cm^2
BRACKET	HALLMARK METALS # 08-108-08			



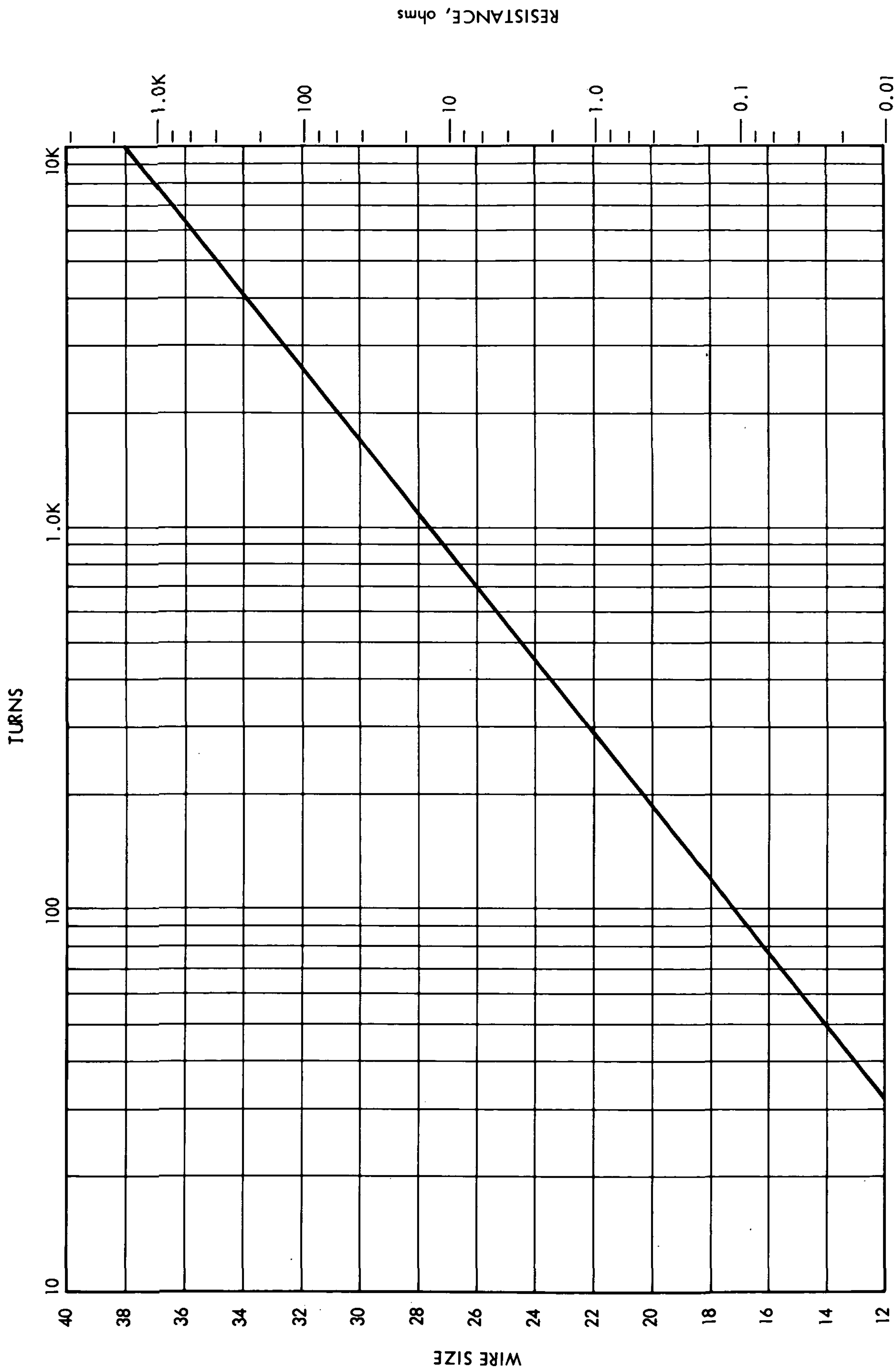
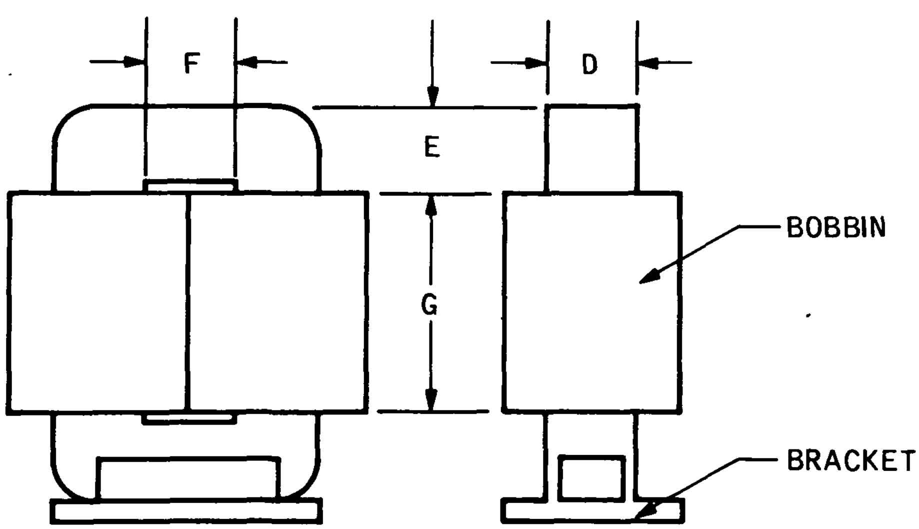


Fig. 44. Nomograph for "C" Core MC 0014

Table 36. "C" Core Magnetic Inc MC 1030

	ENGLISH		METRIC	
Wa/Ac			3.28	
Wa x Ac	0.26	in^4	10.93	cm^4
Ac	0.281	in^2	1.81	cm^2
Wa	0.937	in^2	6.04	cm^2
lm	5.34	in	13.5	cm
CORE wt SOLID	0.415	lb	188	grams
COPPER wt	0.434	lb	197	grams
MLT FULLWOUND	3.39	in	8.61	cm
MLT 1st HALF	2.98	in	7.57	cm
MLT 2nd HALF	3.80	in	9.65	cm
A_T	18.81	in^2	121.3	cm^2
D	0.750	in	1.905	cm
E	0.375	in	0.952	cm
F	0.625	in	1.587	cm
G	1.500	in	3.81	cm
BOBBIN	DORCO ELECTRONICS # 12776			
LENGTH	1.470	in	3.73	cm
BUILD	0.260	in	0.660	cm
AREA	0.382	in^2	2.46	cm^2
BRACKET	HALLMARK METALS # 012-106-06			



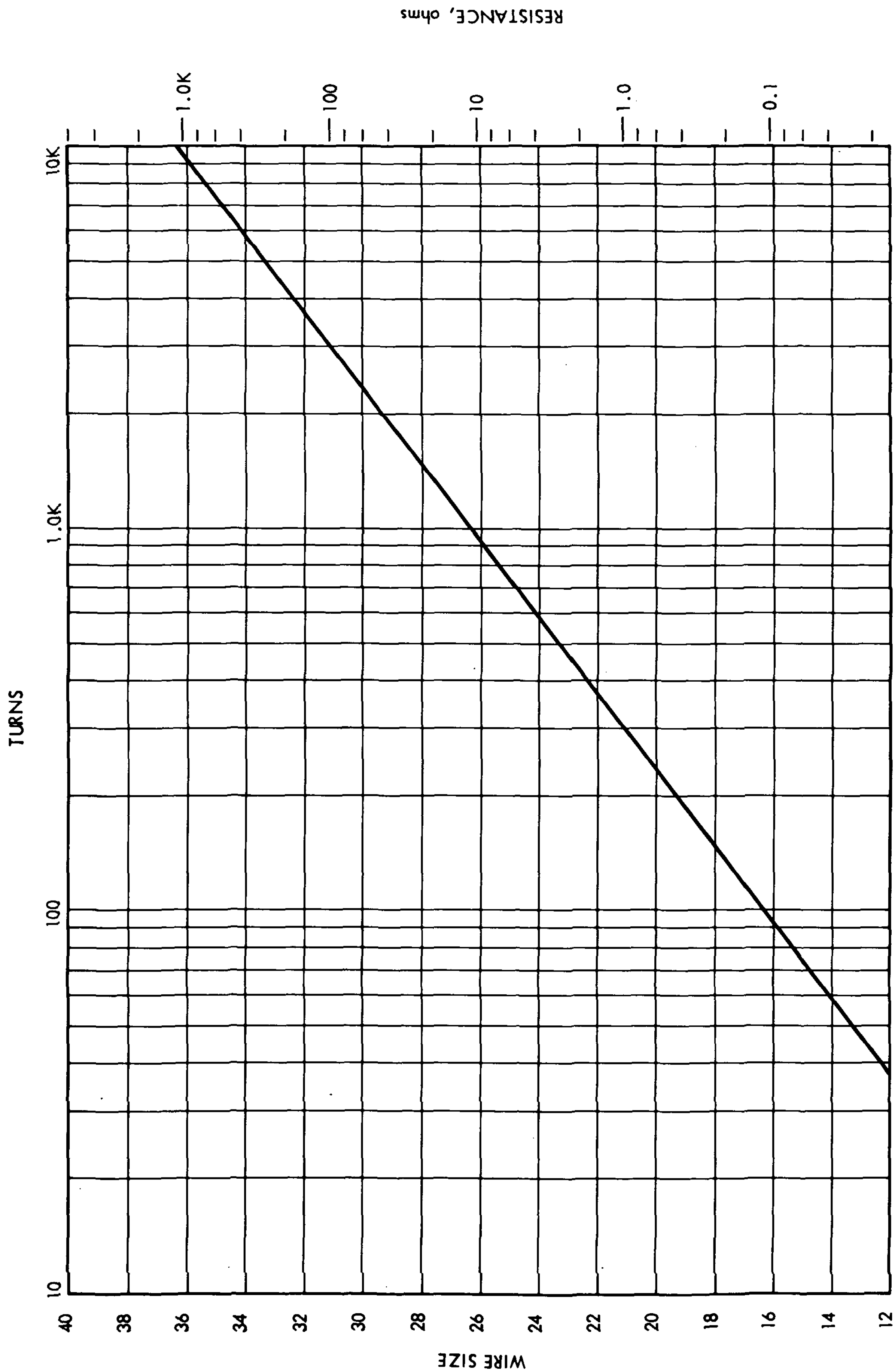
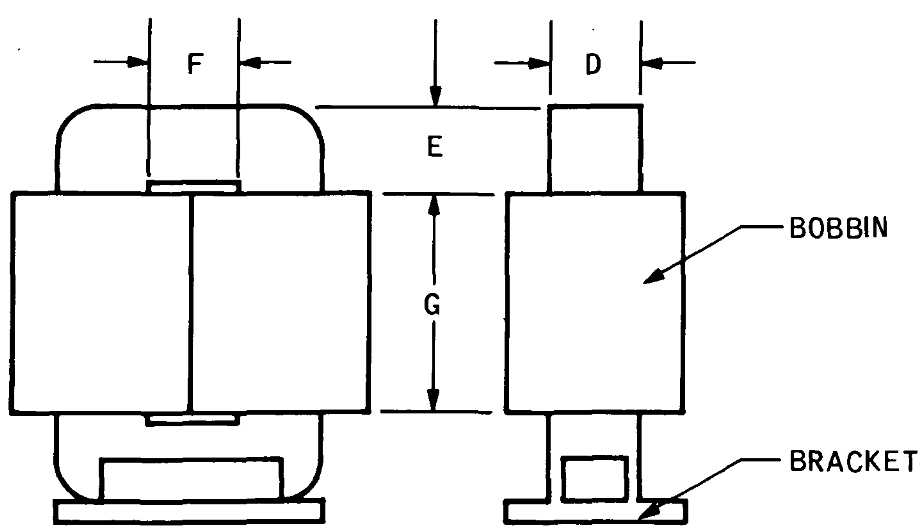


Fig. 45. Nomograph for "C" Core MC 1030

Table 37. "C" Core Magnetic Inc MC 1000

	ENGLISH		METRIC	
Wa/Ac			3.11	
Wa x Ac	0.474	in^4	19.68	cm^4
Ac	0.3906	in^2	2.517	cm^2
Wa	1.210	in^2	7.82	cm^2
lm	6.25	in	15.9	cm
CORE wt SOLID	0.674	lb	306	grams
COPPER wt	0.414	lb	188	grams
MLT FULLWOUND	3.99	in	10.13	cm
MLT 1st HALF	3.59	in	9.12	cm
MLT 2nd HALF	4.39	in	11.15	cm
A_T	24.52	in^2	158.2	cm^2
D	1.00	in	2.54	cm
E	0.3906	in	0.991	cm
F	0.625	in	1.59	cm
G	1.937	in	4.92	cm
BOBBIN	DORCO ELECTRONICS # 12777			
LENGTH	1.846	in	4.68	cm
BUILD	0.255	in	0.647	cm
AREA	0.470	in^2	3.04	cm^2
BRACKET	HALLMARK METALS # 10-107-06			



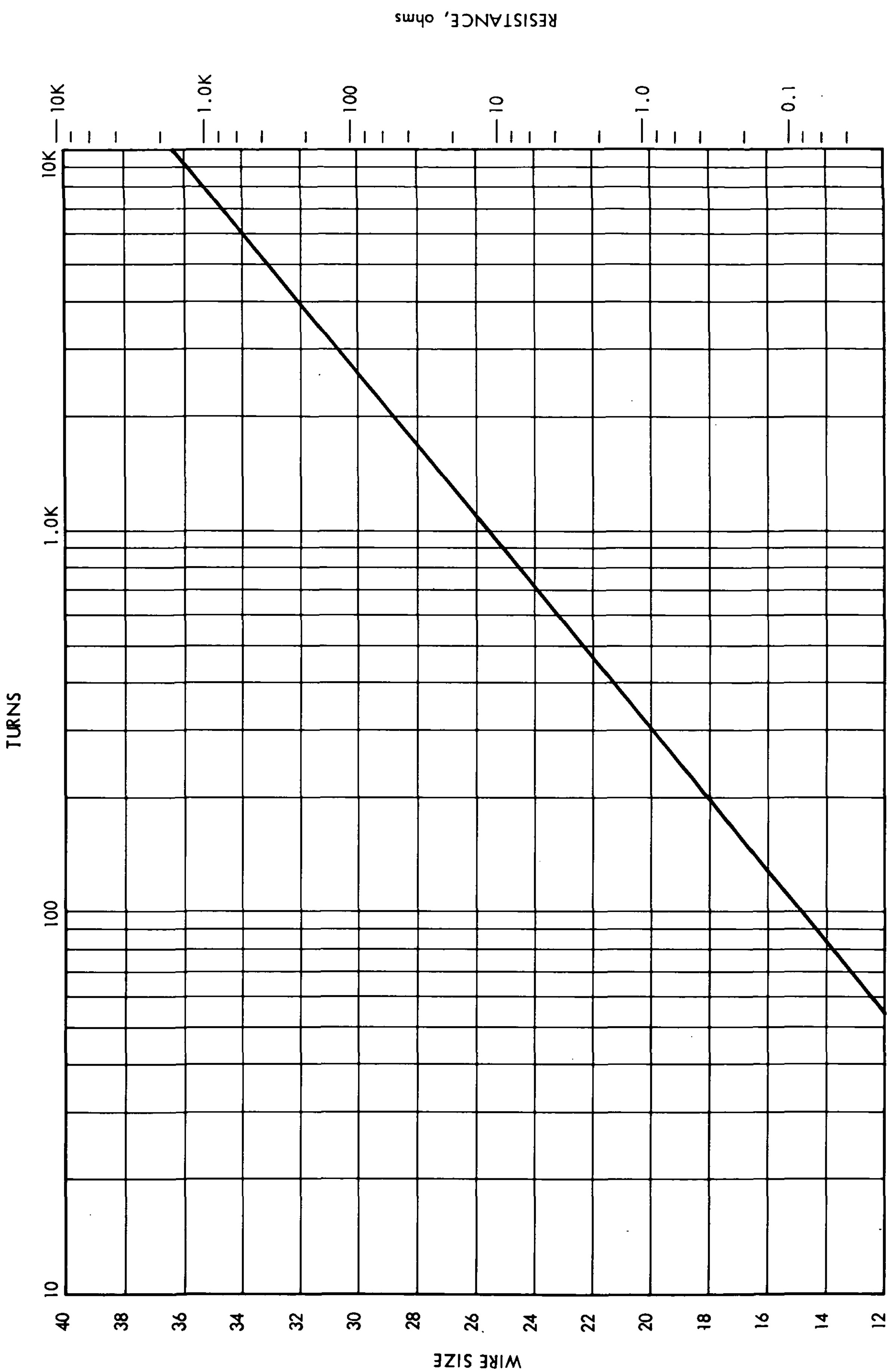
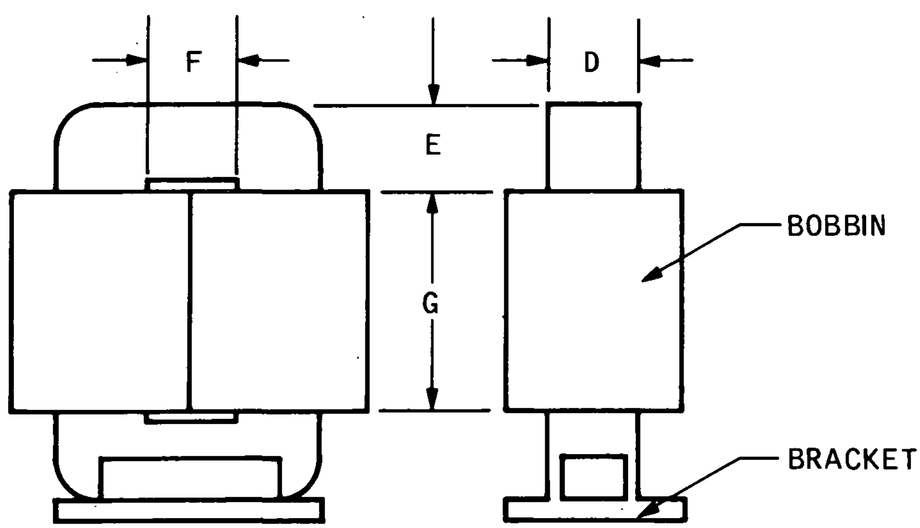


Fig. 46. Nomograph for "C" Core MC 1000

Table 38. "C" Core Magnetic Inc MC 1610

	ENGLISH		METRIC	
Wa/Ac			9.0	
Wa x Ac	0.563	in^4	23.39	cm^4
Ac	0.250	in^2	1.61	cm^2
Wa	2.250	in^2	14.51	cm^2
lm	7.46	in	18.95	cm
CORE wt SOLID	0.515	lb	233	grams
COPPER wt	1.38	lb	626	grams
MLT FULLWOUND	4.48	in	11.38	cm
MLT 1st HALF	3.38	in	8.58	cm
MLT 2nd HALF	5.58	in	14.17	cm
A_T	40	in^2	258	cm^2
D	0.50	in	1.27	cm
E	0.50	in	1.27	cm
F	1.50	in	3.81	cm
G	1.50	in	3.81	cm
BOBBIN	DORCO ELECTRONICS # 12778			
LENGTH	1.41	in	3.58	cm
BUILD	0.70	in	1.78	cm
AREA	0.987	in^2	6.37	cm^2
BRACKET	HALLMARK METALS # 08-208-08			



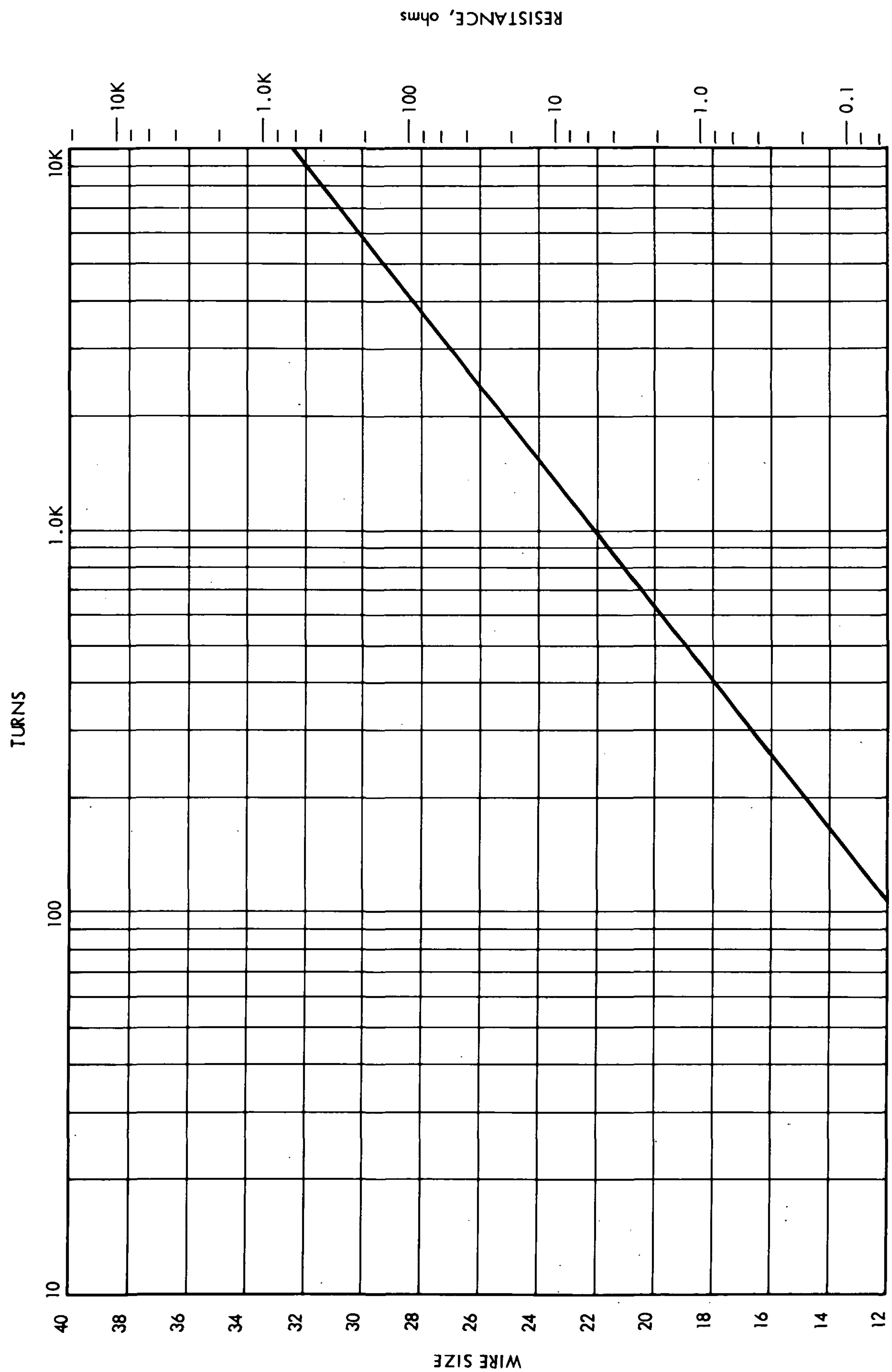
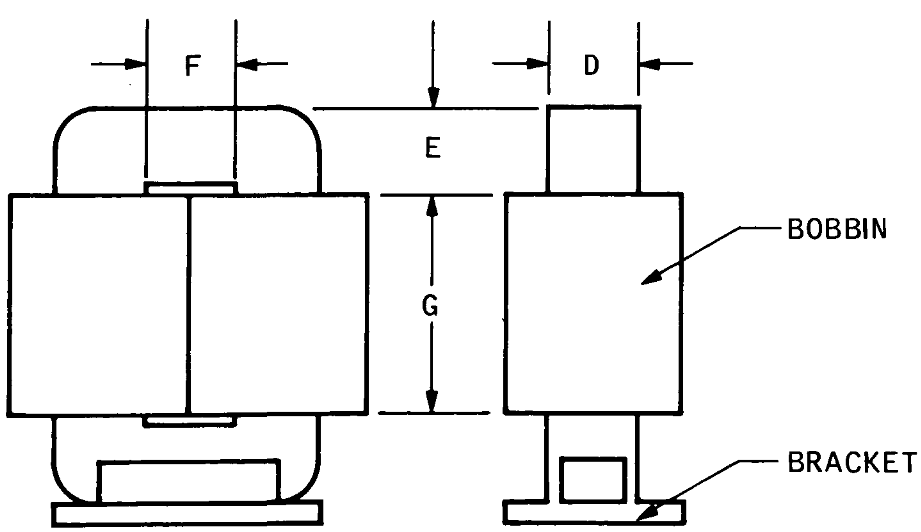


Fig. 47. Nomograph for "C" Core MC 1610

Table 39. "C" Core Magnetic Inc MC 2000

	ENGLISH	METRIC
Wa/Ac		6.22
Wa x Ac	0.947 in^4	39.36 cm^4
Ac	0.3906 in^2	2.52 cm^2
Wa	2.42 in^2	15.62 cm^2
lm	7.5 in	19.07 cm
CORE wt SOLID	0.808 lb	366 grams
COPPER wt	1.64 lb	744 grams
MLT FULLWOUND	5.02 in	12.75 cm
MLT 1st HALF	4.11 in	10.44 cm
MLT 2nd HALF	5.91 in	15.01 cm
A_T	40.9 in^2	264 cm^2
D	1.00 in	2.54 cm
E	0.3906 in	0.992 cm
F	1.25 in	3.175 cm
G	1.937 in	4.92 cm
BOBBIN	DORCO ELECTRONICS # 12779	
LENGTH	1.845 in	4.69 cm
BUILD	0.575 in	1.46 cm
AREA	1.061 in^2	6.84 cm^2
BRACKET	HALLMARK METALS # 10-202-07	



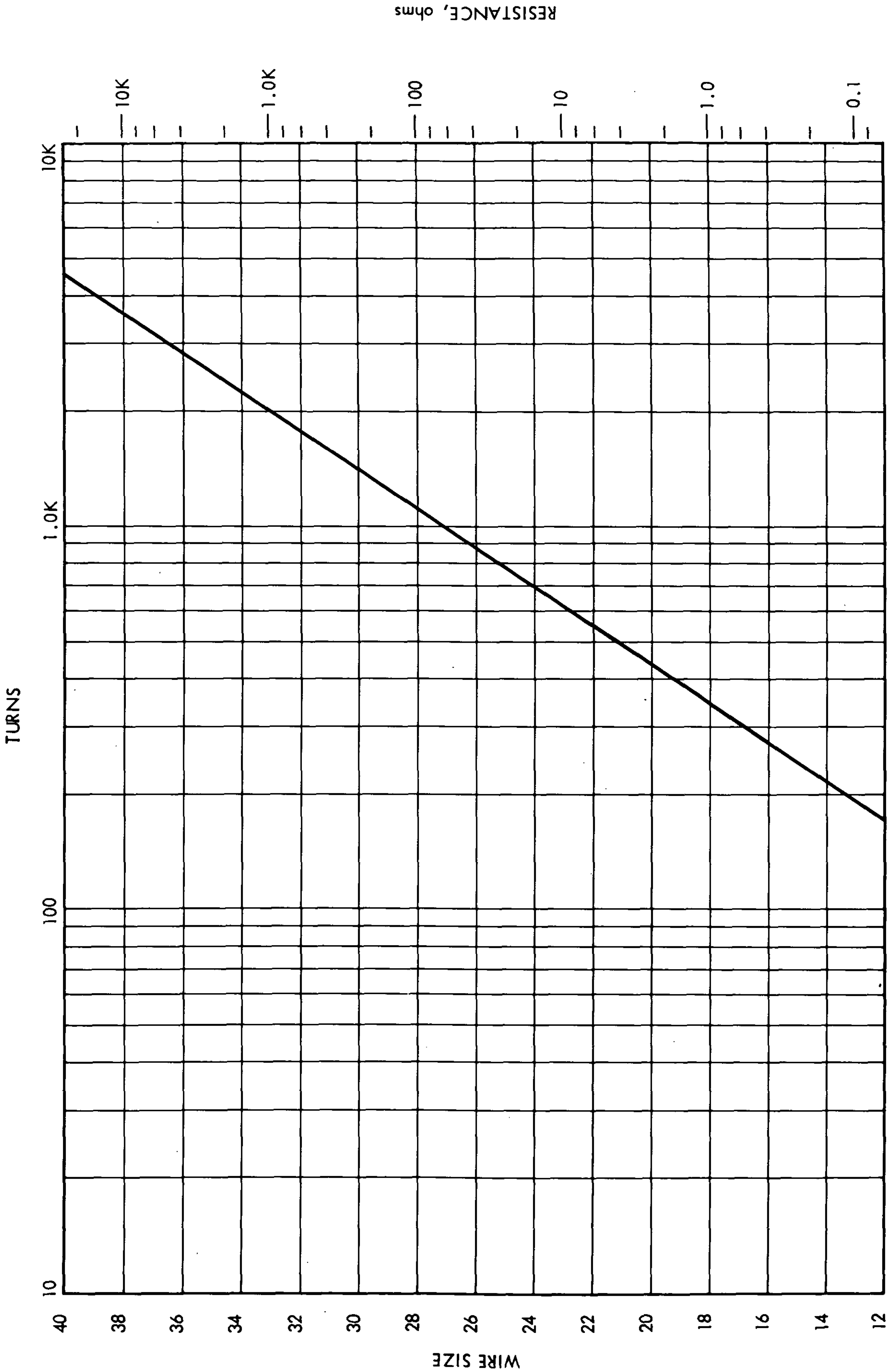
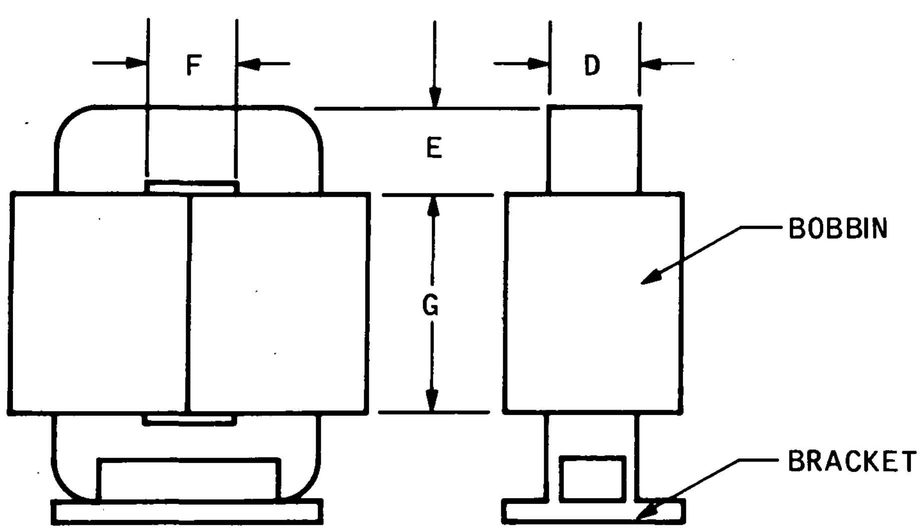


Fig. 48. Nomograph for "C" Core MC 2000

Table 40. "C" Core Magnetic Inc MC 6800

	ENGLISH		METRIC	
Wa/Ac			3.08	
Wa x Ac	0.976	in^4	40.65	cm^4
Ac	0.563	in^2	3.63	cm^2
Wa	1.734	in^2	11.20	cm^2
lm	7.21	in	18.31	cm
CORE wt SOLID	1.105	lb	501	grams
COPPER wt	1.25	lb	568	grams
MLT FULLWOUND	5.18	in	13.16	cm
MLT 1st HALF	4.68	in	11.88	cm
MLT 2nd HALF	5.69	in	14.45	cm
A_T	35.43	in^2	228.5	cm^2
D	1.50	in	3.81	cm
E	0.375	in	0.952	cm
F	0.750	in	1.905	cm
G	2.312	in	5.873	cm
BOBBIN	DORCO ELECTRONICS #12780			
LENGTH	2.222	in	5.64	cm
BUILD	0.322	in	0.818	cm
AREA	0.715	in^2	4.61	cm^2
BRACKET	HALLMARK METALS # 18-108-06			



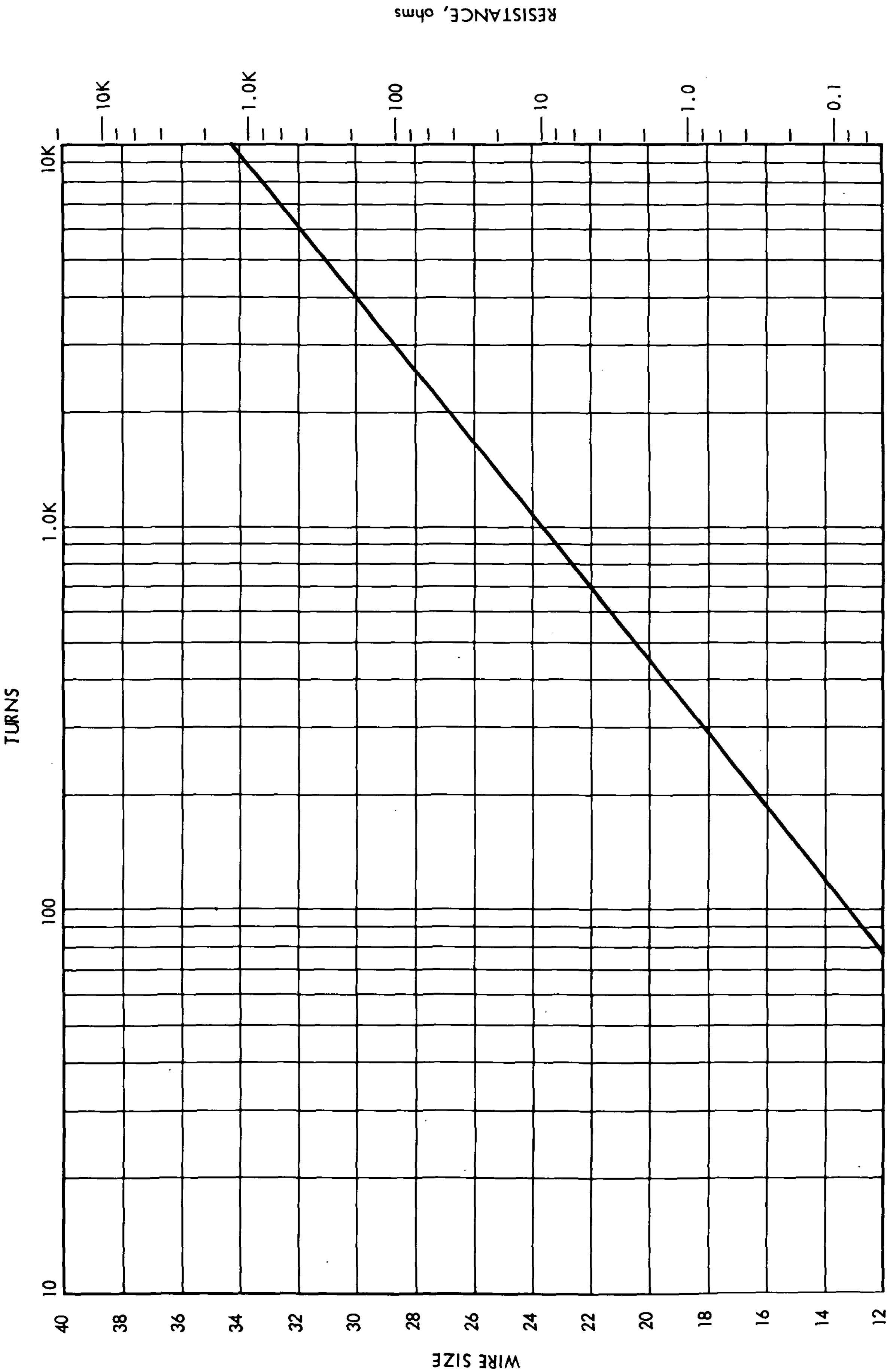
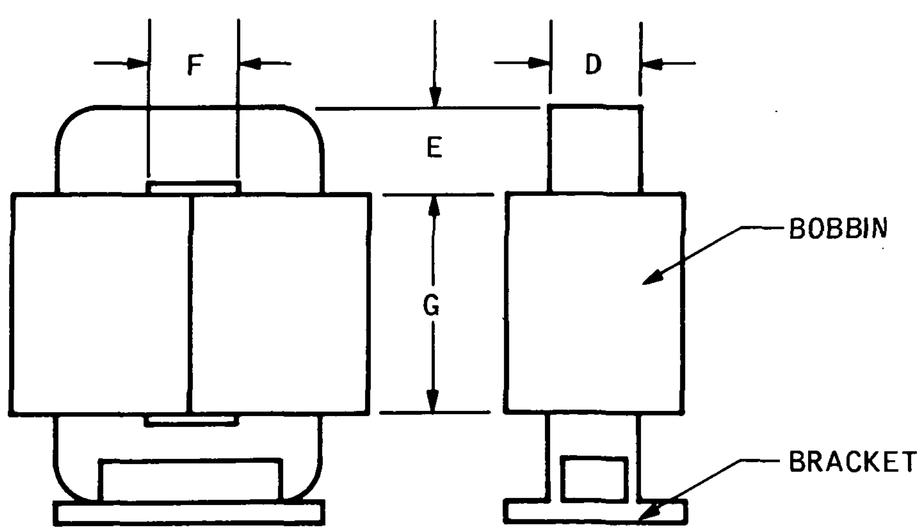


Fig. 49. Nomograph for "C" Core MC 6800

Table 41. "C" Core Magnetic Inc MC 1620

	ENGLISH		METRIC	
Wa/Ac			5.44	
Wa x Ac	1.72	in^4	71.73	cm^4
Ac	0.562	in^2	3.625	cm^2
Wa	3.063	in^2	19.76	cm^2
lm	9.175	in	23.3	cm
CORE wt SOLID	1.42	lb	646	grams
COPPER wt	2.47	lb	1120	grams
MLT FULLWOUND	5.9	in	14.99	cm
MLT 1st HALF	4.61	in	11.71	cm
MLT 2nd HALF	7.19	in	18.26	cm
A_T	63.25	in^2	408	cm^2
D	0.750	in	1.905	cm
E	0.750	in	1.905	cm
F	1.750	in	4.45	cm
G	1.750	in	4.45	cm
BOBBIN	DORCO ELECTRONICS # 12781			
LENGTH	1.630	in	4.14	cm
BUILD	0.820	in	2.08	cm
AREA	1.34	in^2	8.62	cm^2
BRACKET	HALLMARK METALS #012-304-012			



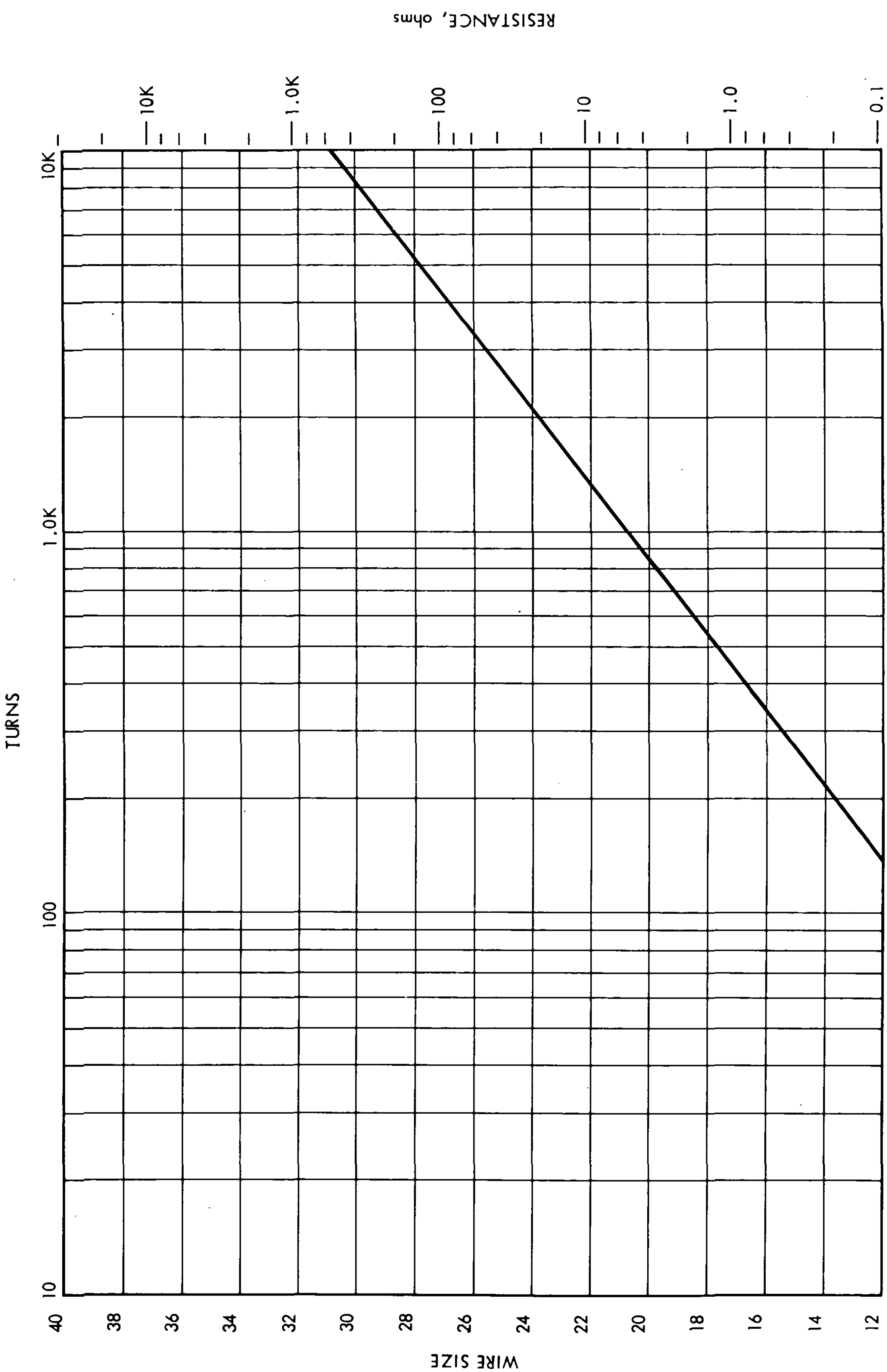


Fig. 50. Nomograph for "C" Core MC 1620

XII. TEMPERATURE RISE VERSUS SURFACE AREA DISSIPATION DUE TO POWER LOSS, Figure 51:

Power loss (core loss + winding loss) in a transformer produces a temperature rise which must be controlled to prevent damage or failure. Heat is dissipated from the transformer 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 in a transformer winding cannot be predicted with complete precision. Many different techniques are described in the literature for the computation of transformer temperature rise.

A method for temperature rise computation used by transformer 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 circumferential area of the coil and core.

The nomograph of Fig. 51 (data obtained from Ref. 5) 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 from the vertical surface. On the under side the heat loss depends on the area and conductivity of the surface.

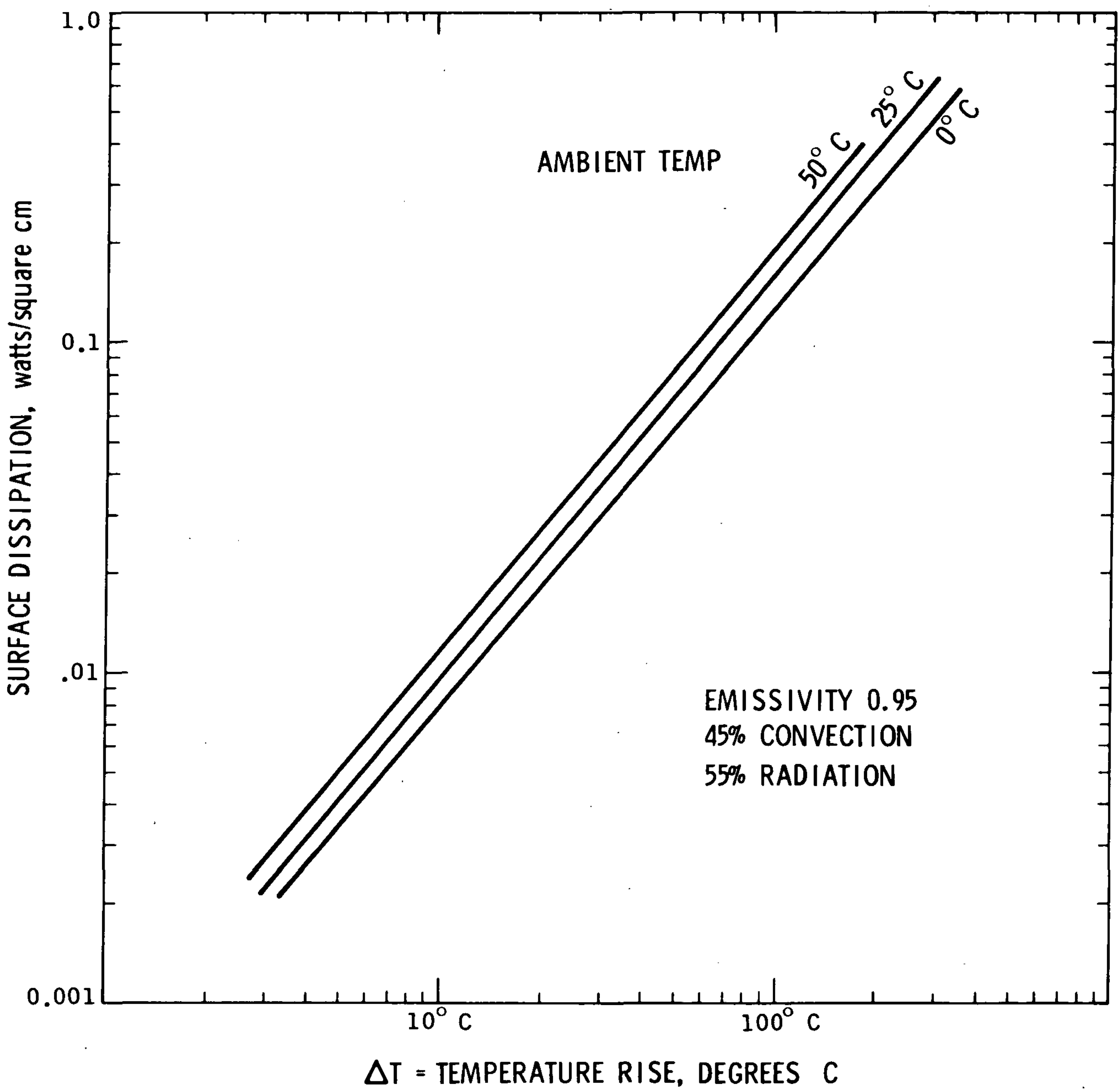


Fig. 51. Temperature Rise Versus Surface Dissipation

XIII. MAXIMUM PERMISSIBLE CURRENT DENSITY FOR 50°C RISE, Figures 52, 53 and 54

The curves shown are based upon a maximum permissible temperature rise of 50°C, with a surface dissipation of 0.07 watts/cm^2. Maximum efficiency is achieved when the iron power loss and the copper power loss are equal. The data are based upon an assumption of 50% iron and 50% copper power losses. Surface areas for toroidal cores, laminations, and C cores have been calculated. Power dissipated as heat in the transformer is:

$$A_t(\text{cm}^2) \cdot 0.07 \text{ Watts/cm}^2 = W_T$$

$$W_c = W_I = W_T/2$$

$$Wa(\text{cm}^2) \cdot T/\text{cm}^2 = T$$

$$R = T \cdot \Omega/\text{cm} \cdot \text{MLT}$$

$$W_c = I^2 R$$

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

W_c = Copper Loss

W_I = Iron Loss

W_T = Total Loss

T = Turns #(for a given wire size)

T/cm^2 = Table 1 (K) for a given wire size

Wa = Window Area

$$\text{Current Density } I/\text{cm}^2 = I/\text{Wire Area (cm}^2)$$

These 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 toroids, laminations, and C cores were computed from Figs. 55, 56 and 57. Designation for terms are taken from tables of toroids, laminations, and C cores in this text.

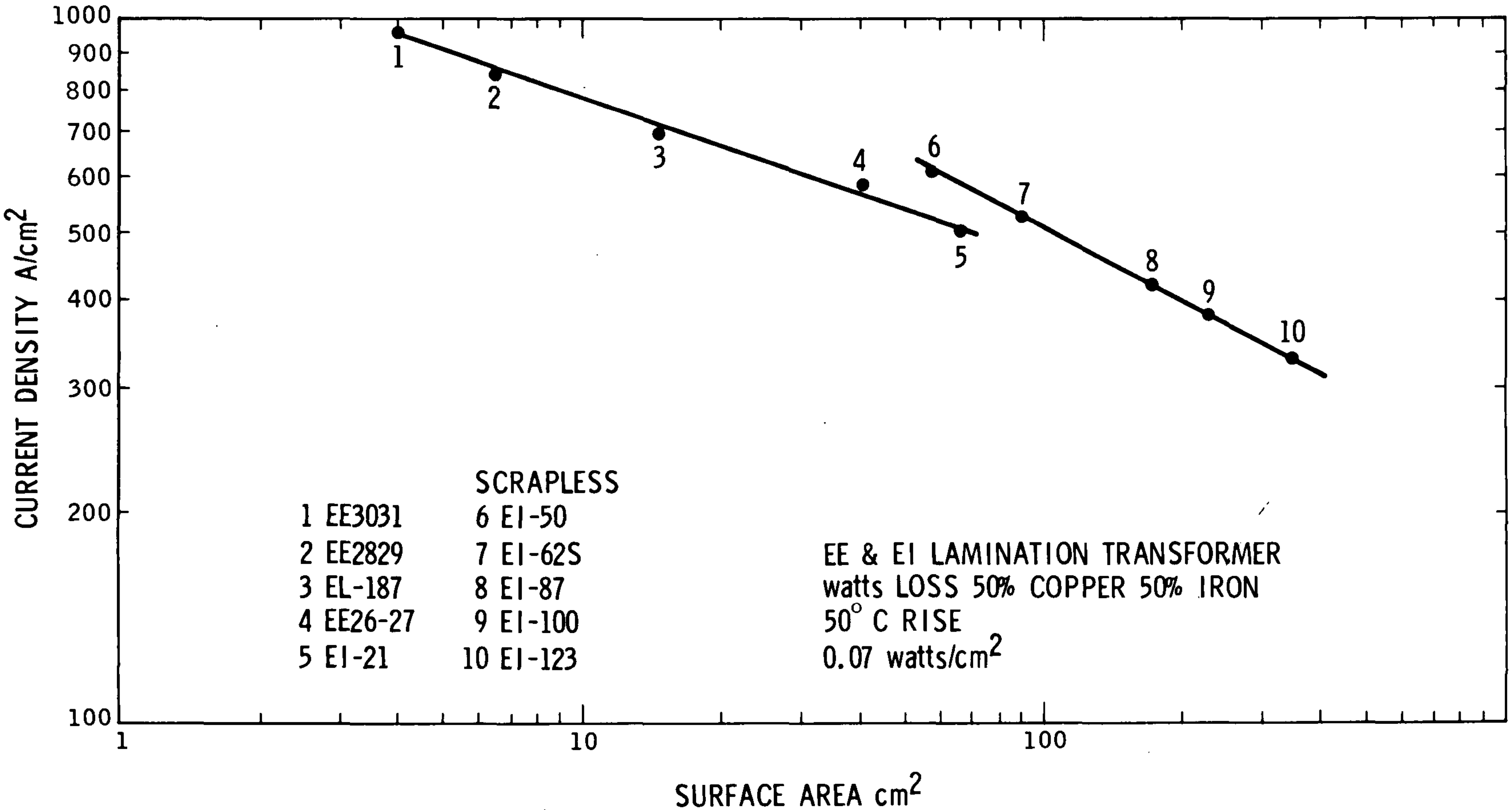


Fig. 52. Current Density vs Surface Area for a 50°C Rise (Lamination)

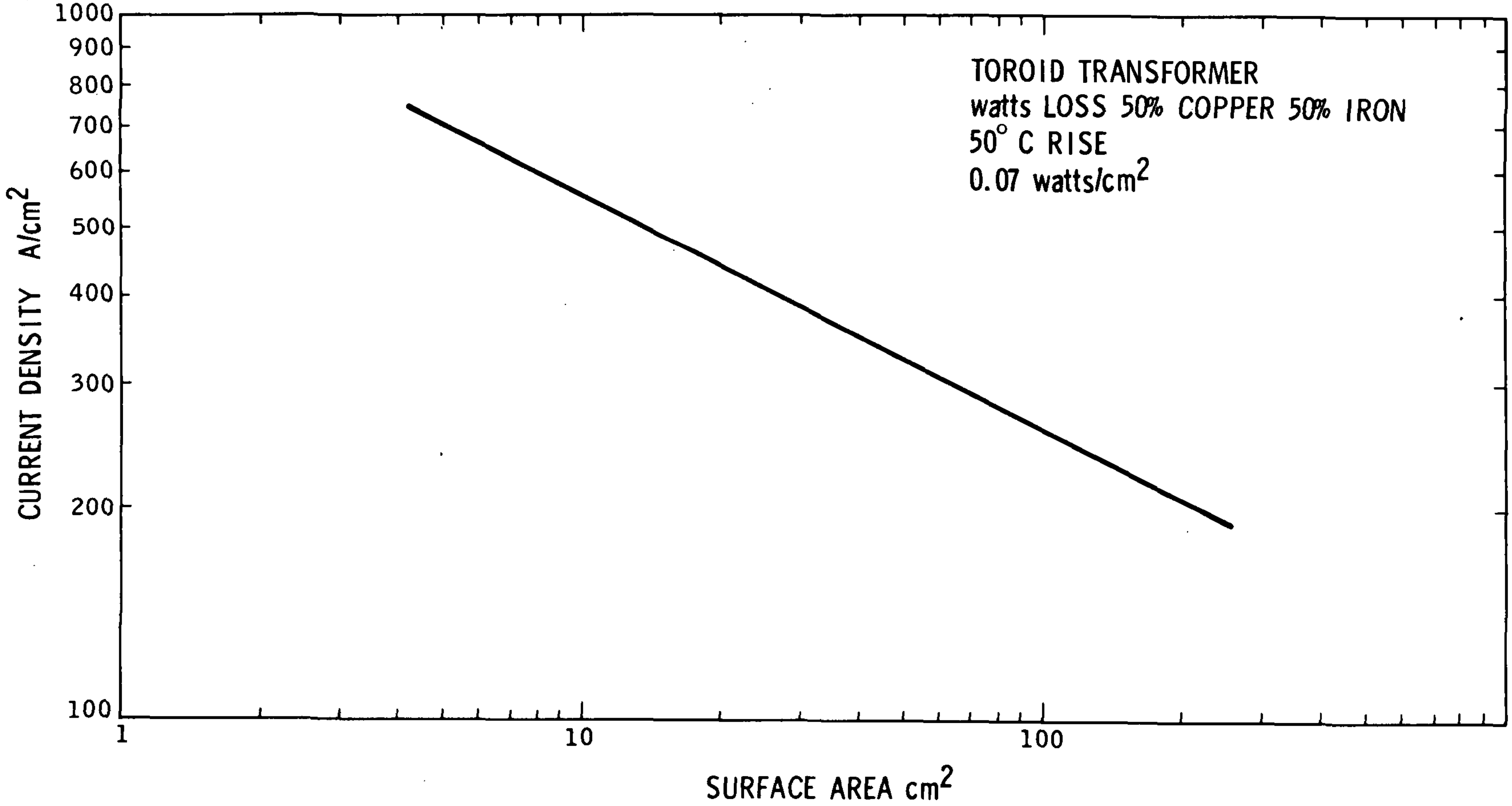


Fig. 53. Current Density vs Surface Area for a 50° C Rise (Toroid)

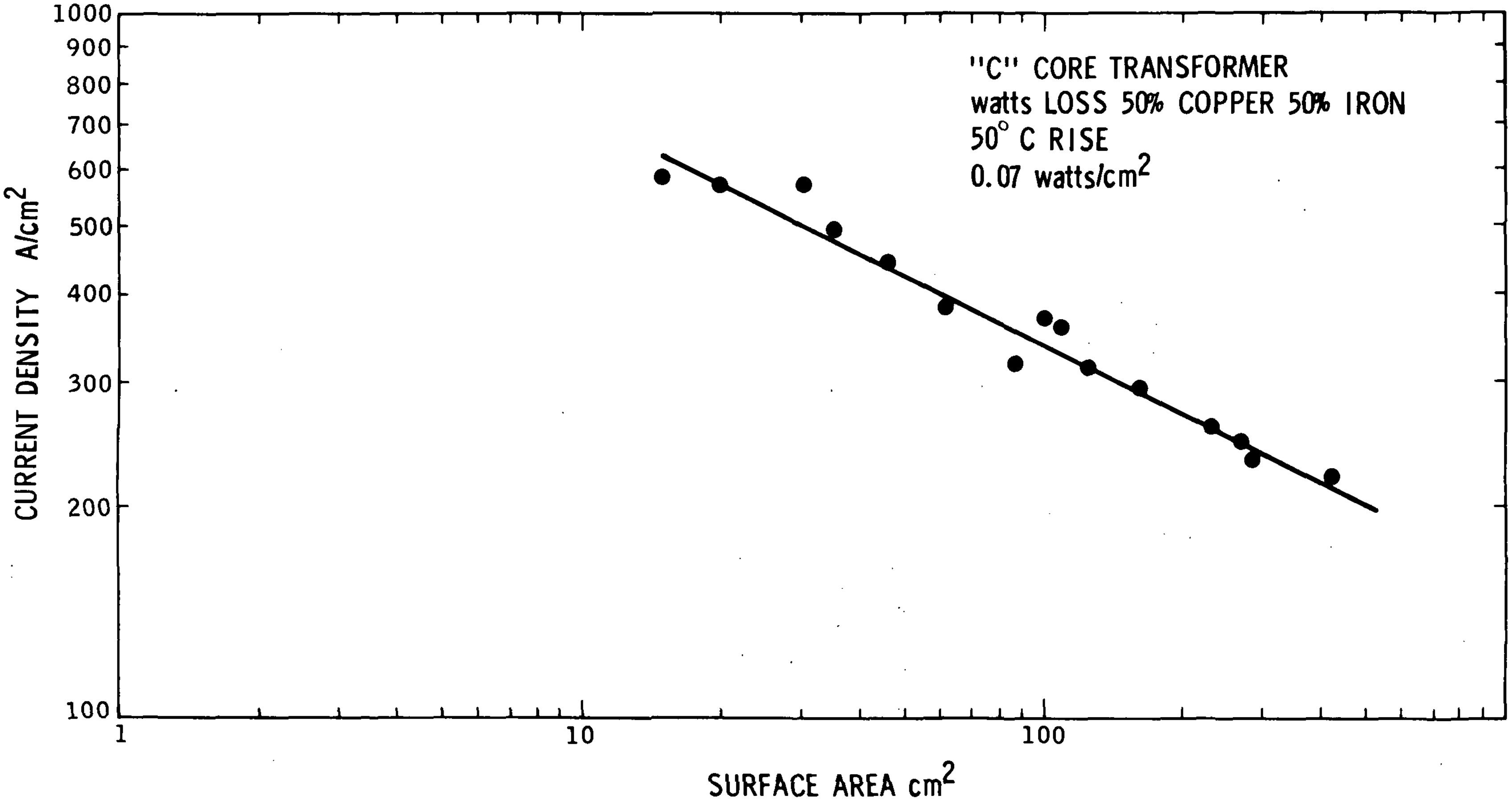
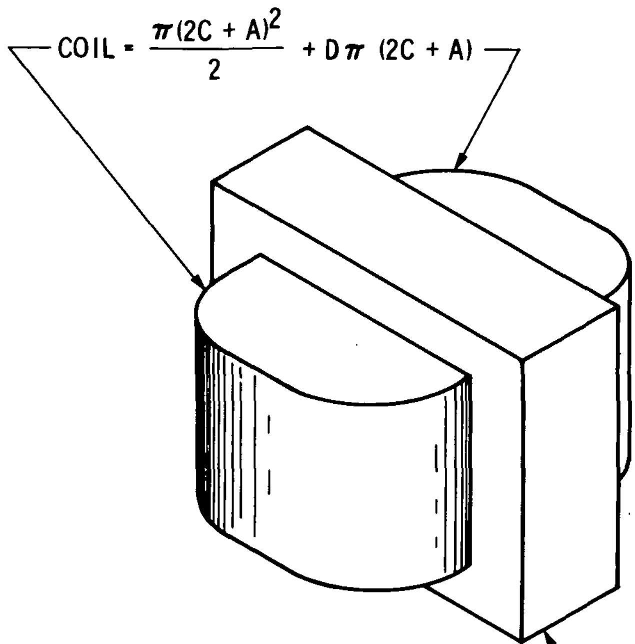


Fig. 54. Current Density vs Surface Area for a 50° C Rise (C Cores)



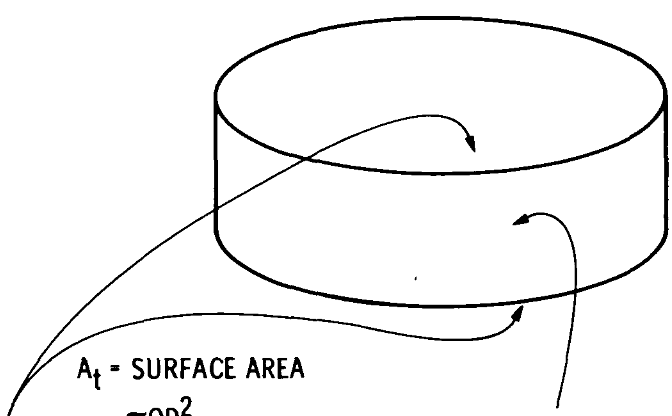
A_t = SURFACE AREA

A_t LAMINATION = 2 (FE + SF + SE - DA - 2DC)

S = BUILD

$$A_t = \frac{\pi(2C + A)^2}{2} + D\,\pi\,(2C + A) + 2\,(FE + SF + SE - DA - 2DC)$$

Fig. 55. Lamination A_t

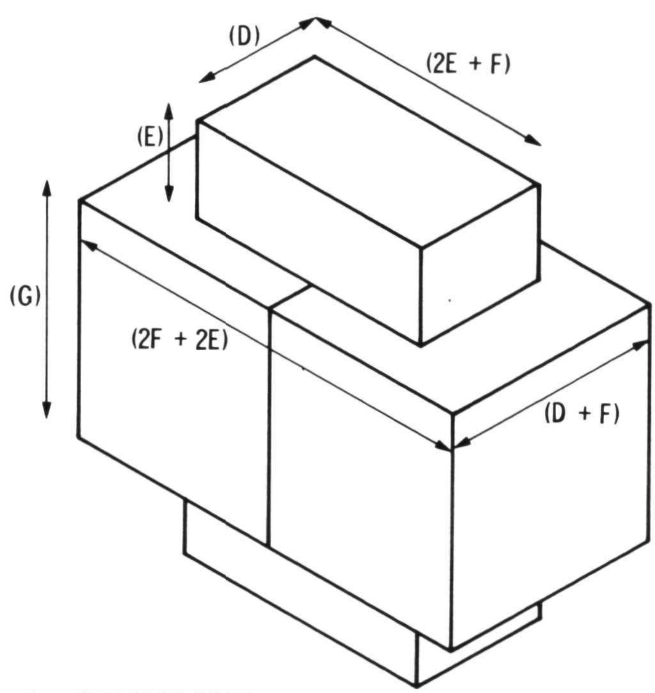


A_t = SURFACE AREA

$$A_t = \frac{\pi OD^2_{WOUND}}{2} + \pi\, OD_{WOUND} \times (HT_{CORE} + OD_{WOUND} - OD_{CORE})$$

Fig. 56. Toroid A_t

"C" CORE



A_t = SURFACE AREA

$A_t = 4E\ (2E+F) + (ED)\ 4 + 2\ (D+F)\ (G) + 2\ (2F+2E)\ (G) + 2\ (D+F)\ (2F+2E)$

Fig. 57. C Core A_t

XIV. PERMEABILITY AND AIR GAP

The permeability of a magnetic core is decreased by inserting an air gap. Inserting an air gap causes the magnetization curve to "shear over." The size of air gap can be varied by different stacking methods.

Normal Permeability (μ)* is the slope of a line drawn through the tips of a hysteresis loop formed at a specified value of H or B, as shown in Fig. 58. For the maximum flux density B_m, the normal permeability is:

$$\mu = \frac{B_m}{H}$$

*This is not to be confused with $\mu\Delta$ or μ_d per manufacturer's data (Ref. 6).

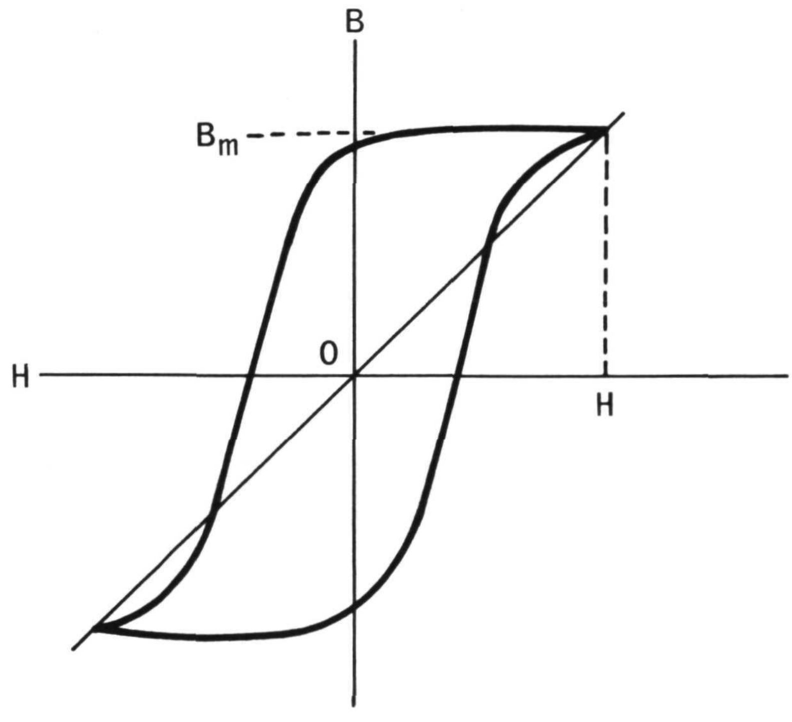


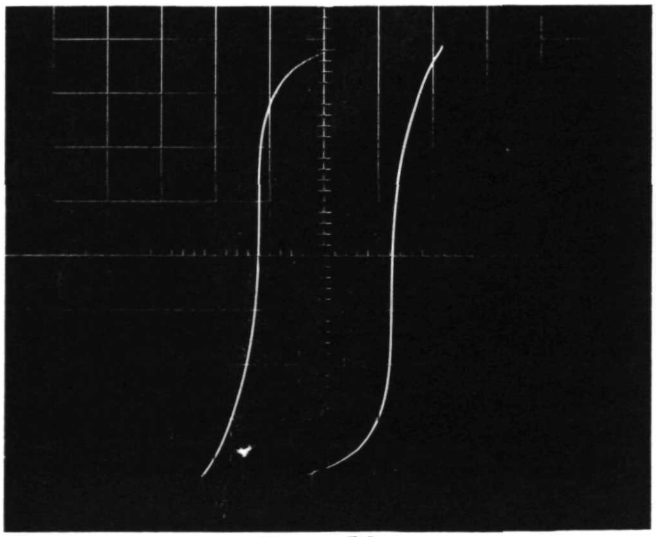
Fig. 58. Hysteresis Loop

Eight coils were wound to show different stacking methods and its effect on relative air gap.

Stacking method:	1 x 1
	5 x 5
	15 x 15
	32 x 32
	BUTT
	BUTT 25 μm Kraft
	BUTT 50 μm Kraft
	$\frac{1}{2}$ 1 x 1 & $\frac{1}{2}$ BUTT

Figures 59 through 66 show how the stacking method can influence the permeability. The lamination used and test condition:

Size	El-375
Material	Permalloy 80
Thickness	0.006
Area	0.91 cm^2
Flux density	0.1T/cm
lm	7.3 cm
Turns	70
Frequency	2.4 kHz



10 ma/cm horiz.
Stack 1 x 1

Fig. 59

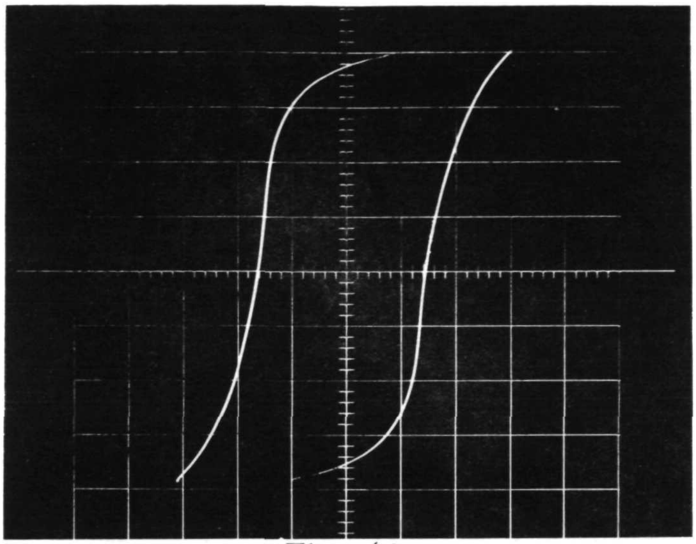


Fig. 60

10 ma/cm horiz
Stack 5 x 5

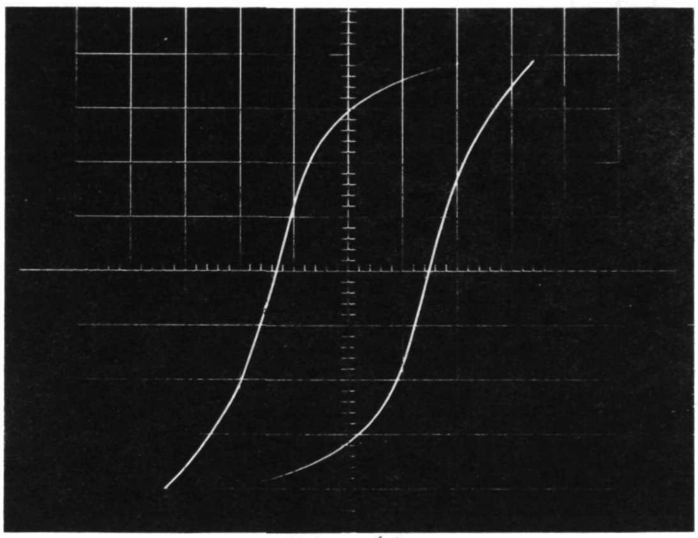


Fig. 61

20 ma/cm horiz
Stack 15 x 15

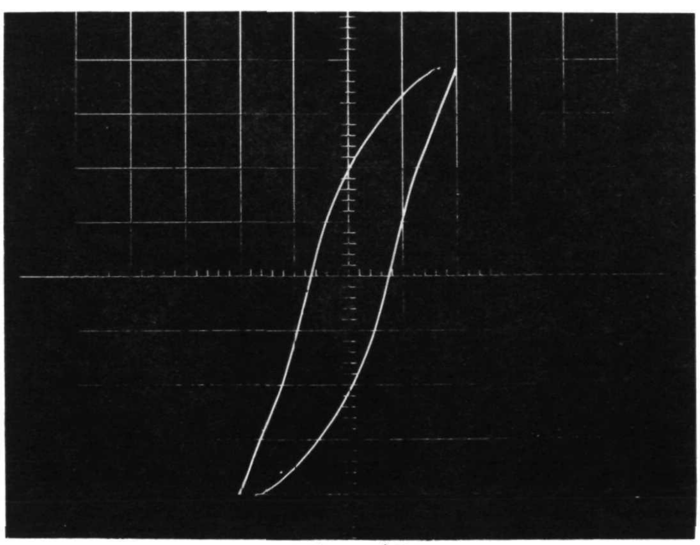


Fig. 62

50 ma/cm horiz
Stack 32 x 32

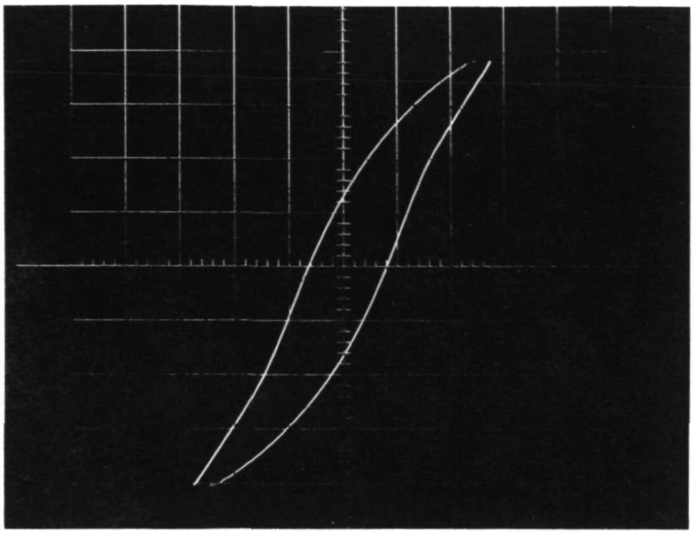


Fig. 63

50 ma/cm horiz
Butt Stack

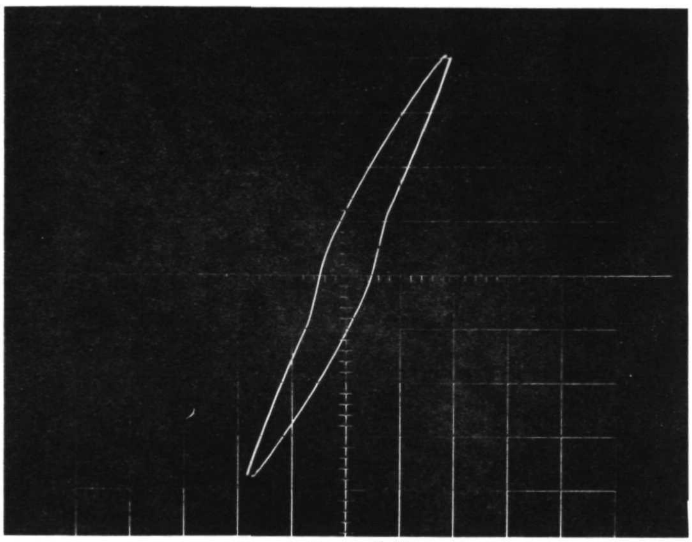


Fig. 64

200 ma/cm horiz
Butt Stack
25 μm gap

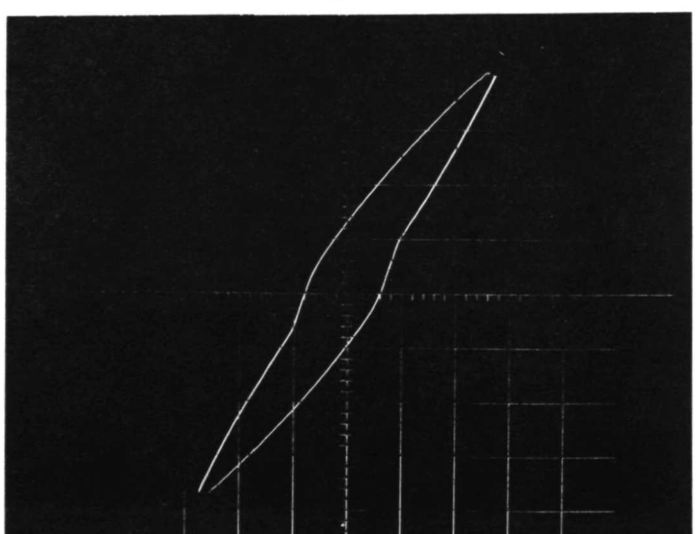
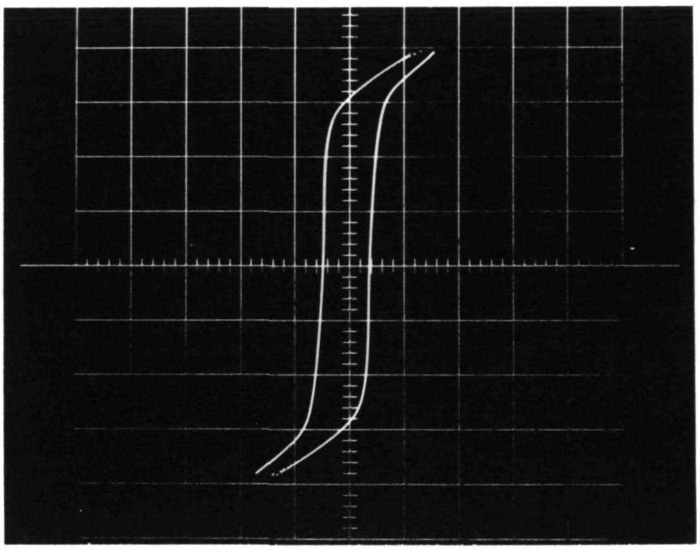


Fig. 65

200 ma/cm horiz
Butt Stack
50 μm gap



50 ma/cm

Stack

$\frac{1}{2}$ 1 x 1 & $\frac{1}{2}$ BUTT

Fig. 66

XV. ENGINEERING AIDS

Figures 67, 68, 69 and Table 42 have been inserted for use as engineering aids. The nomagraph shown in Figure 67 is for Inductance, Capacitance, and Reactance. Figure 68 can be used to compute the mean turn length and its derivation. Figure 69 compares core loss of four different magnetic materials. These curves show core loss as a function of flux density and frequency. Table 42 is a list of the AIEE preferred tape wound toroidal cores tabulated with metric dimensions.

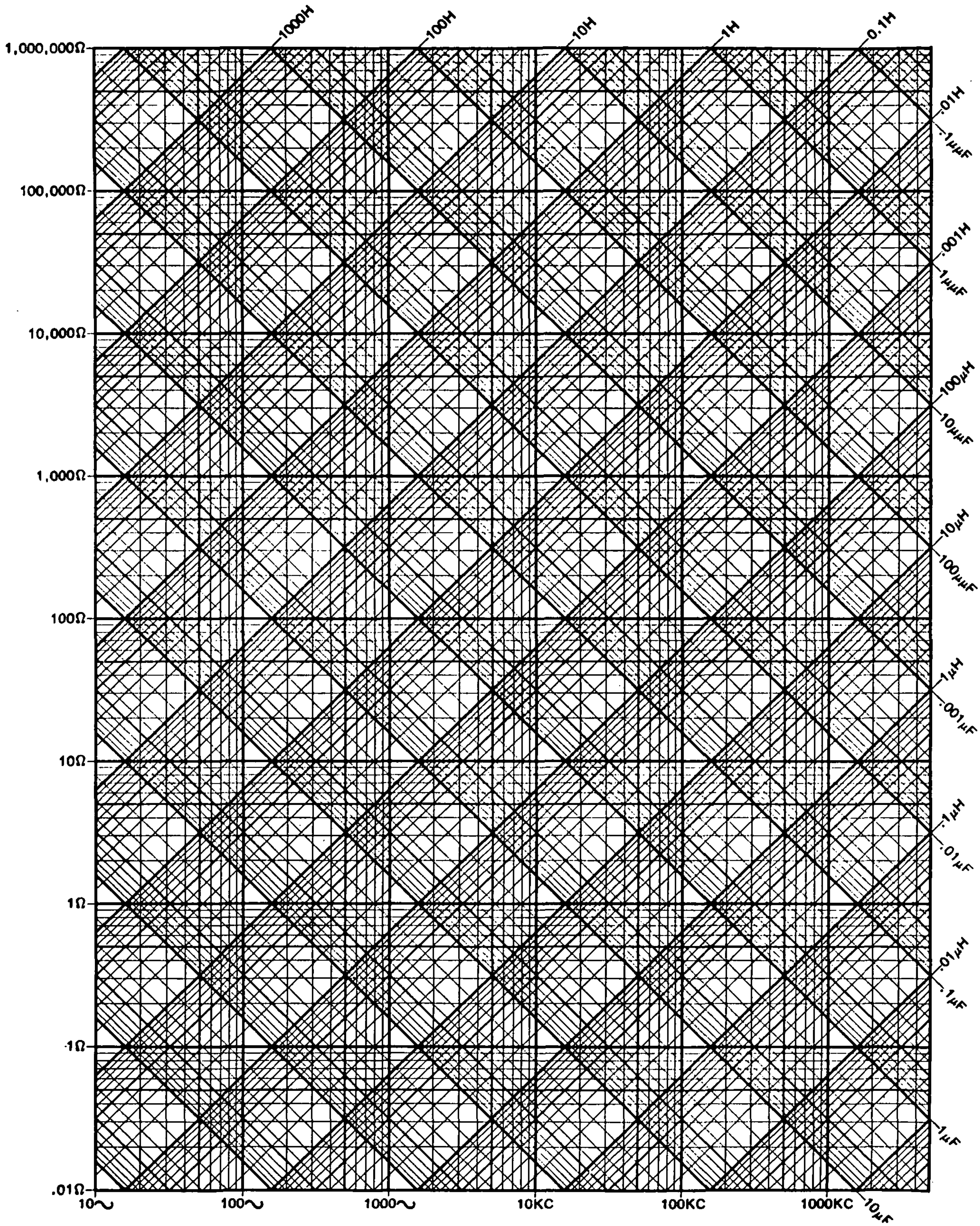
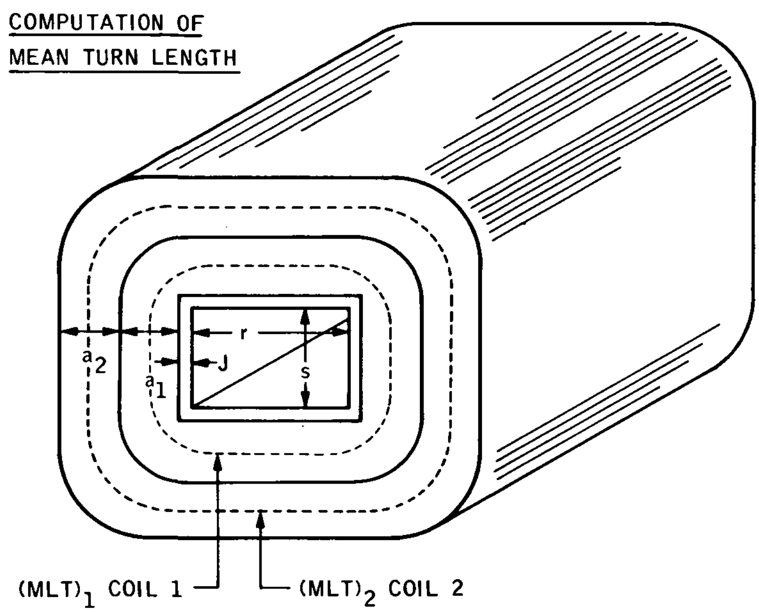


Fig. 67. Nomograph for Inductance, Capacitance, and Reactance



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

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

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. 68. Computation of Mean Turn Length

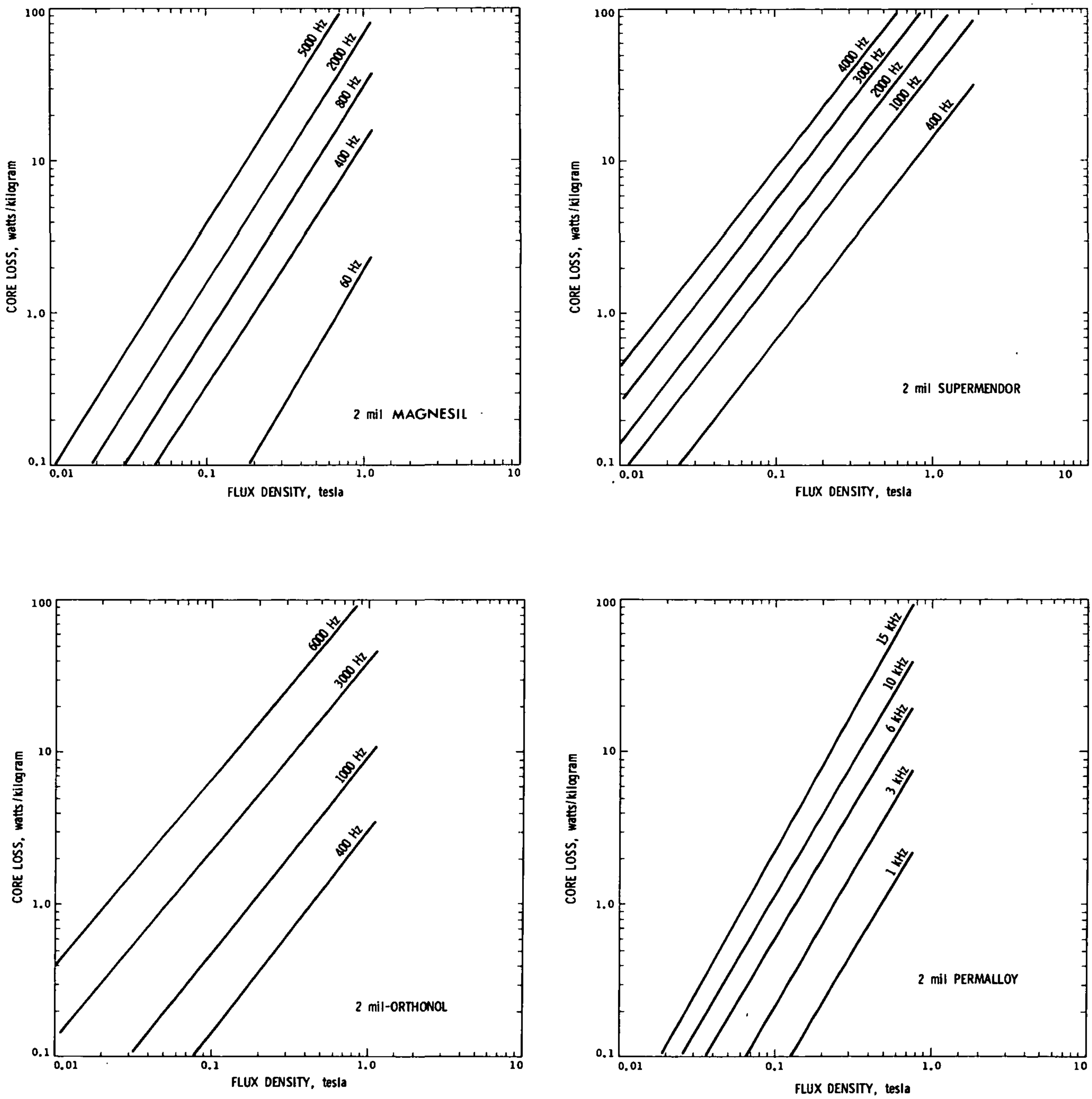


Fig. 69. Silicone, Cobalt, and Nickel Iron Core Loss Curves

Table 42. A.I.E.E. - Preferred Tape Wound Toroidal Cores

Mag Inc	Arnold	(1) $Ac(cm^2)$	$Wa(cm^2)$	(2) ID(cm)	OD(cm)	Height (cm)	lm(cm)	Core wt (grams)	$Ac \times Wa(cm^4)$
52056	8T8043	0.043	0.877	1.057	1.801	0.643	4.49	1.67	0.0377
52000	8T5340	0.086	0.794	1.006	2.169	0.643	4.99	3.73	0.0682
52076	8T5958	0.193	1.38	1.323	2.804	0.803	6.48	10.9	0.266
52007	8T5651	0.257	1.38	1.323	2.804	0.960	6.19	14.5	0.355
52002	8T5515	0.086	1.51	1.387	2.550	0.643	6.98	4.62	0.129
52061	8T5502	0.171	2.11	1.641	2.804	0.960	7.48	10.4	0.361
52106	8T5504	0.193	2.11	1.641	3.122	0.803	8.98	12.6	0.407
52011	8T4168	0.086	4.07	2.276	3.439	0.643	8.98	6.71	0.350
52004	8T7699	0.171	4.07	2.276	3.439	0.960	9.43	13.4	0.696
52029	8T4635	0.257	4.16	2.301	3.731	0.973	9.97	21.2	1.069
52032	8T5800	0.343	4.07	2.276	4.074	0.973	9.97	29.8	1.396
52026	8T5233	0.514	4.07	2.276	4.074	1.290	9.97	44.7	2.092
52038	8T6847	0.686	4.07	2.276	4.074	1.608	11.96	59.6	2.79
52030	8T5387	0.343	6.65	2.911	4.709	0.973	11.96	35.8	2.28
52035	8T7441	0.686	6.65	2.911	4.709	1.608	11.96	65.6	4.56
52425	8T5772	0.771	6.65	2.911	5.344	1.290	12.96	87.2	5.13
52001	8T5320	1.371	9.45	3.470	6.690	1.679	15.95	191	12.95
52018	8T4179	0.257	11.7	3.863	5.344	0.973	14.46	32.4	3.00
52017	8T4178	0.686	17.6	4.740	6.690	1.679	17.95	107	12.07
52103	8T6110	1.371	17.6	4.740	7.960	1.679	19.94	238	24.12
52022	8T8027	2.742	17.6	4.740	7.960	2.949	19.94	477	48.25
52031	8T4180	0.686	28.4	6.010	7.960	1.679	21.93	131	19.48
52128	8T6100	1.371	28.4	6.010	9.230	1.679	23.93	286	38.93
52042	8T5468	2.742	28.4	6.010	9.230	2.949	23.93	572	77.87
52100	8T5690	5.142	28.4	6.010	9.865	4.219	24.93	1117	146.03
52081	8T5737	5.142	49.2	7.915	11.770	4.219	30.91	1386	253
52427	8T9259	7.198	49.2	7.915	13.040	4.219	32.90	2065	354
52112	8T5611	6.855	75.7	9.820	13.675	5.489	36.89	2205	519
52426	8T9260	10.968	75.7	9.820	15.580	5.489	39.88	3814	830

(1) Cross-sectional area calculated for 2 mil (0.002 in.) material

(2) Dimensions listed are sizes of aluminum boxed cores (not coated)

REFERENCES

1. Magnetic Wire Datalator. REA Magnetic Wire Co., Inc., Fort Wayne, Ind., 1958.
2. Molypermalloy Powder Cores. Catalog MPP-303S, Magnetic, Inc., Butler, Pa.
3. Design Manual Featuring Tape Wound Cores. Design Manual TWC-300, Magnetic, Inc., Butler, Pa., 1962.
4. MPP Cores. Catalog PC-104E, Arnold Engineering, Marengo, Ill., 1972.
5. Blume, L. F., Transformer Engineering. John Wiley & Sons, Inc., New York, N. Y., 1938.
6. Lee, R., Electronic Transformers and Circuits. Second Edition. John Wiley & Sons, New York, N. Y., 1958.

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