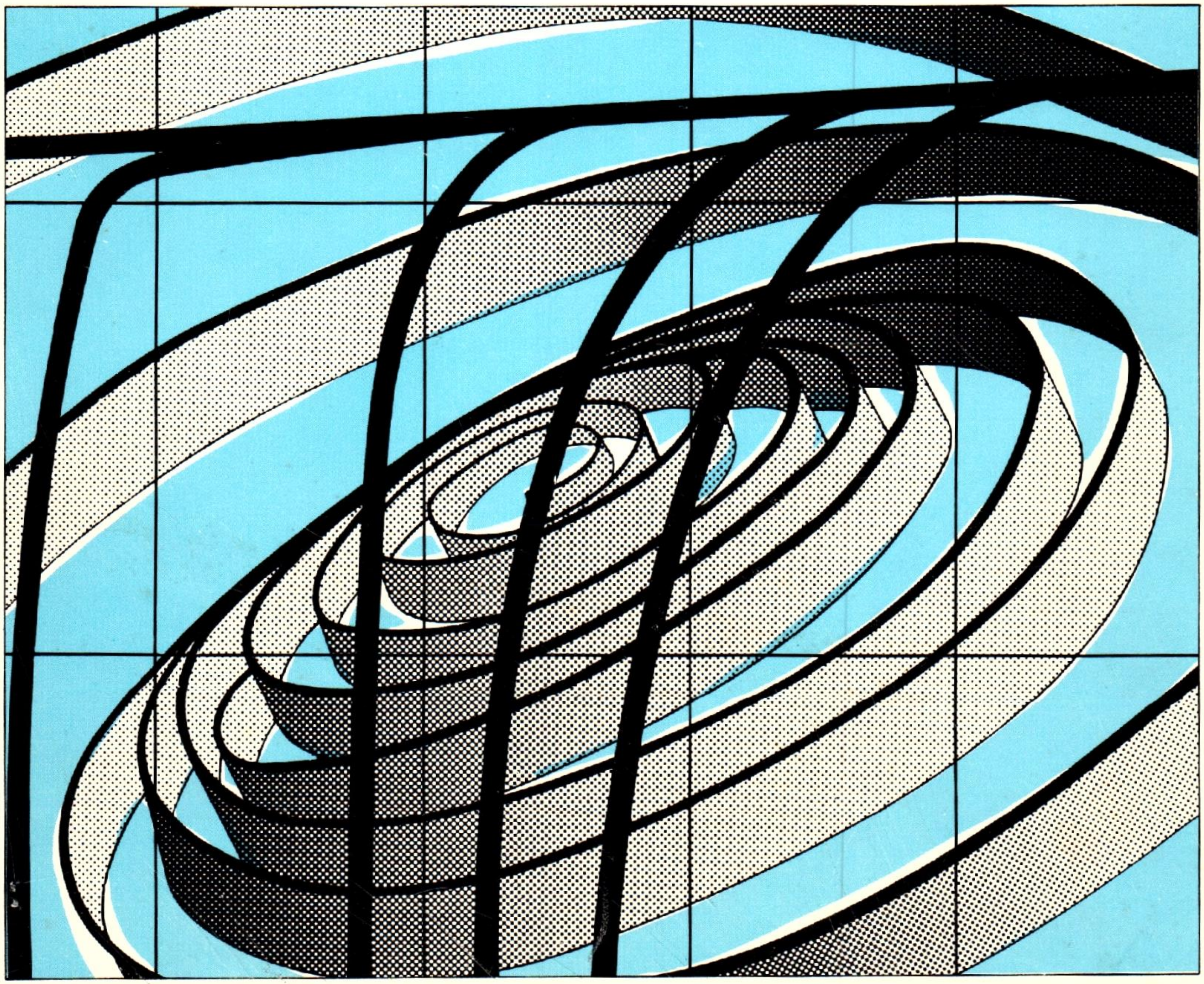
MAGNETIC
METALS

TAPE WOUND CORE DESIGN MANUAL



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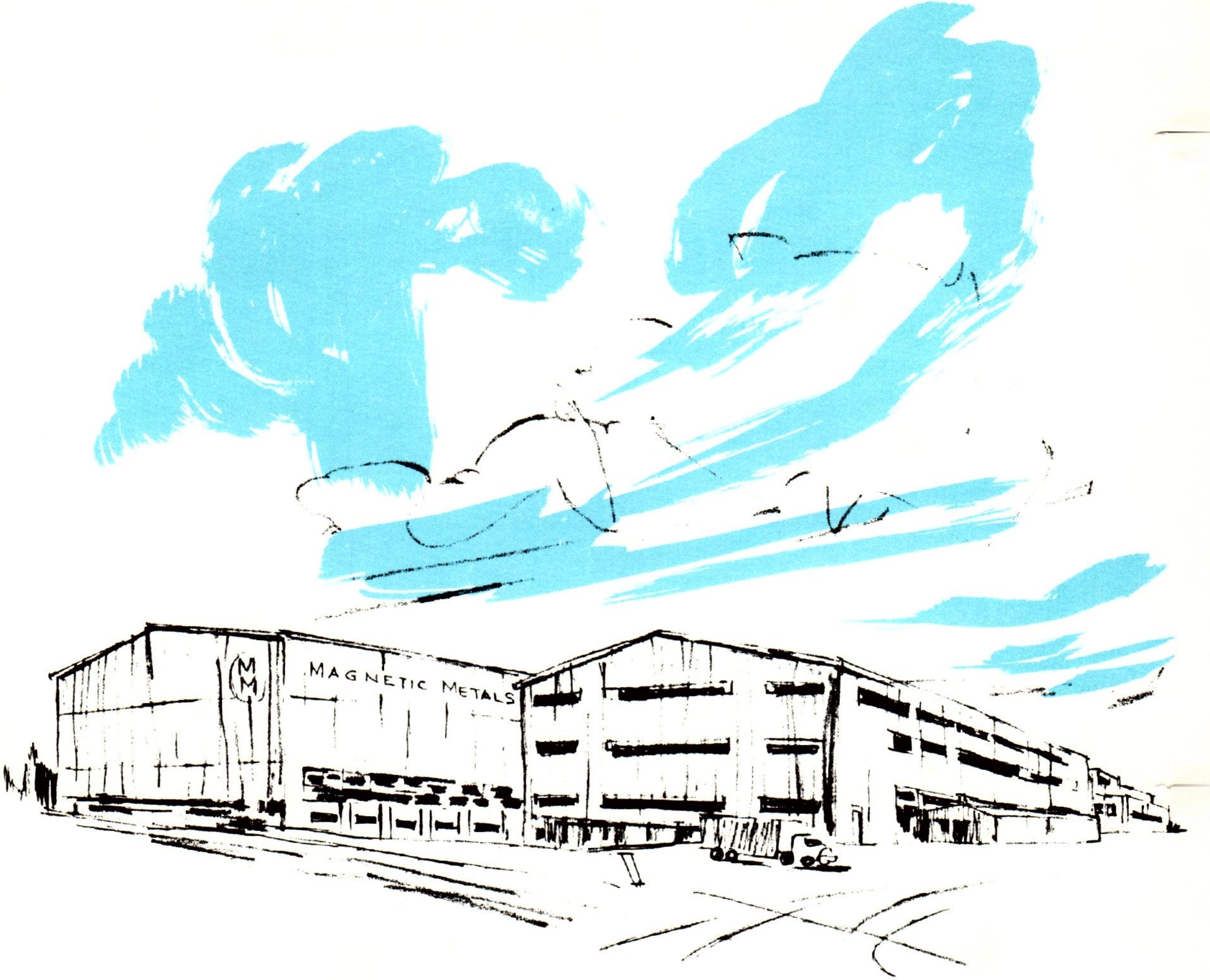

Magnetic Metals Company is one of the world's leading producers of electromagnetic cores, core parts and shielding for the electrical and electronics industries.

Shown above is our Camden, N.J., plant. On pages 2 and 3 are our Pennsauken, N.J., and Newport Beach, Calif., facilities. Magnetic Metals' has plants, warehouses and/or sales offices in all major manufacturing areas in the United States, Canada and Mexico.

Magnetic Metals' Research and Development and Engineering departments — responsible for a significant number of advances in today's electromagnetic technology — are headquartered in our Camden, N.J., plant. For technical assistance of any kind, the engineers and technicians who make up these departments are at your complete disposal.

In addition to this Tape Wound Core Design Manual, Magnetic Metals' Technical Information Library includes publications on Transformer Laminations, Motor Laminations, Electromagnetic Shielding, Photofabrication, Ferrite Toroid Cores and Ferrite Pot Cores.

Your Magnetic Metals representative will be pleased to provide any of these manuals for you.

The circuit diagrams and design information in this manual illustrate typical applications. Reasonable care has been taken in their preparation to insure technical correctness; however, no responsibility is assumed by Magnetic Metals Company for any consequences of their use.

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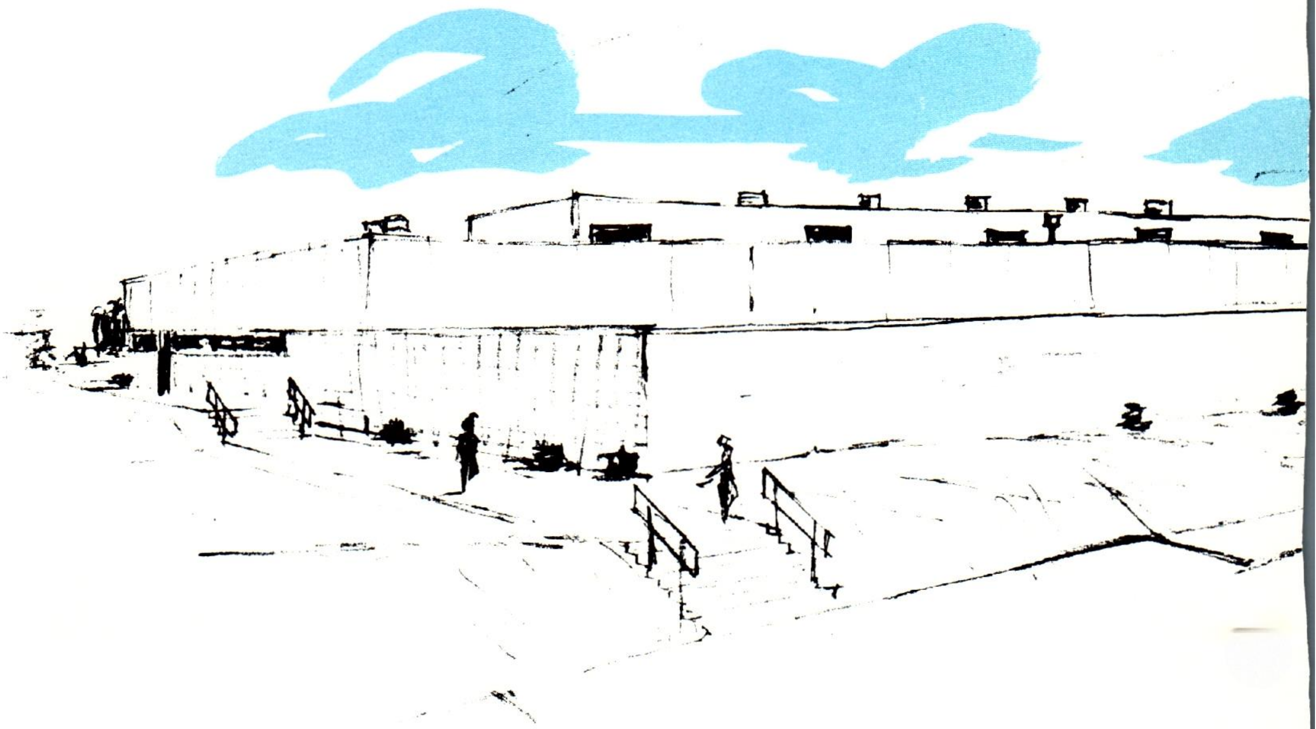
INTRODUCTION

We have developed this Manual to help make your job an easier one. In addition to complete ordering information and specifications for Magnetic Metals' comprehensive line of Tape Wound Cores, this book also offers meaningful discussions on the construction of Tape Wound Cores as well as their applications.
Also presented are typical hysteresis loops, CCFR control curves, magnetization curves and core loss curves.

The unique advantages of the Tape Wound Core configuration in magnetic circuitry permits the most efficient application of high permeability magnetic alloys.

This manual is designed as a total reference source for engineers involved in the application, specification and/or purchase of these cores.

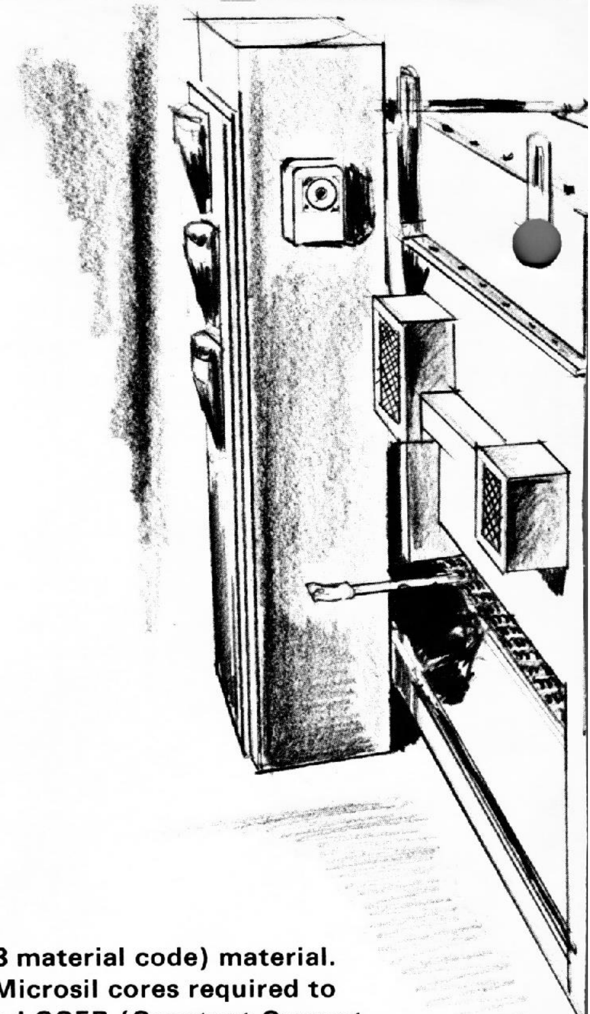


Originally published in early 1968, this updated edition of Magnetic Metals' Tape Wound Core Design Manual reflects recent technological advances in basic magnetic alloys, core casing, core testing and applications. It is intended to fill the design needs of both the more experienced engineer and the engineer new to Tape Wound Cores, their construction and application.

Concise application data — beginning on page 41 — includes Tape Wound Cores in signal transformers, coupling transformers, power transformers, current transformers, reactors, saturable reactors, saturable transformers, bi-stable magnetic amplifiers, magnetic inverter transformers, and others. A toroidal winding guide and a complete reference data section round out this manual which, we feel, is the most complete, most authoritative and most up-to-date publication of its kind.

Also provided — for quick reference — is a Tape Wound Core Design Chart which gives the designer instant access to the most commonly used design formulae, core dimensions and constants.

For personalized engineering assistance or further information on any Tape Wound Core or application discussed in this manual, call Magnetic Metals Company at (609) 964-7842.



ORDERING INFORMATION

How To Order Tape Wound Cores

Magnetic Metals' Precision Tape Wound Cores should be ordered by part number.

The part number of the tape wound core describes the core size, case type, material, and material thickness.

EXAMPLE: The part number 11-P-4602 designates a core with a 1" I.D. × 1.5" O.D. × .375" strip width (height), made from .002" thick Square 50 material in a plastic case.

11	P	46	02
Size code	Case code	Material code	Tape thickness code

Core Size

Tape wound core sizes and physical characteristics — designated by a two, three or four digit number — are tabulated on pages 8 through 10.

Case/Coating Codes

Available case and coating types are designated by a letter (Example P = Plastic) and are listed in Table I, Page 6. Epoxy coatings are designated by the code "E", "D", and "M".

Uncased cores using the "D" coating are guaranteed only to meet the core loss limits for Microsil (33 material code) material. Epoxy-coated Microsil cores required to meet guaranteed CCFR (Constant Current Flux Reset) limits and/or matching should be ordered with the "M" coating.

Material Code

Magnetic Metals has assigned code numbers to the various types of materials used in the manufacture of Tape Wound Cores. For example, the 80% nickel/iron alloy processed for maximum initial permeability — known as Permalloy, HyMu 80, etc. — has been assigned the material code number "80".

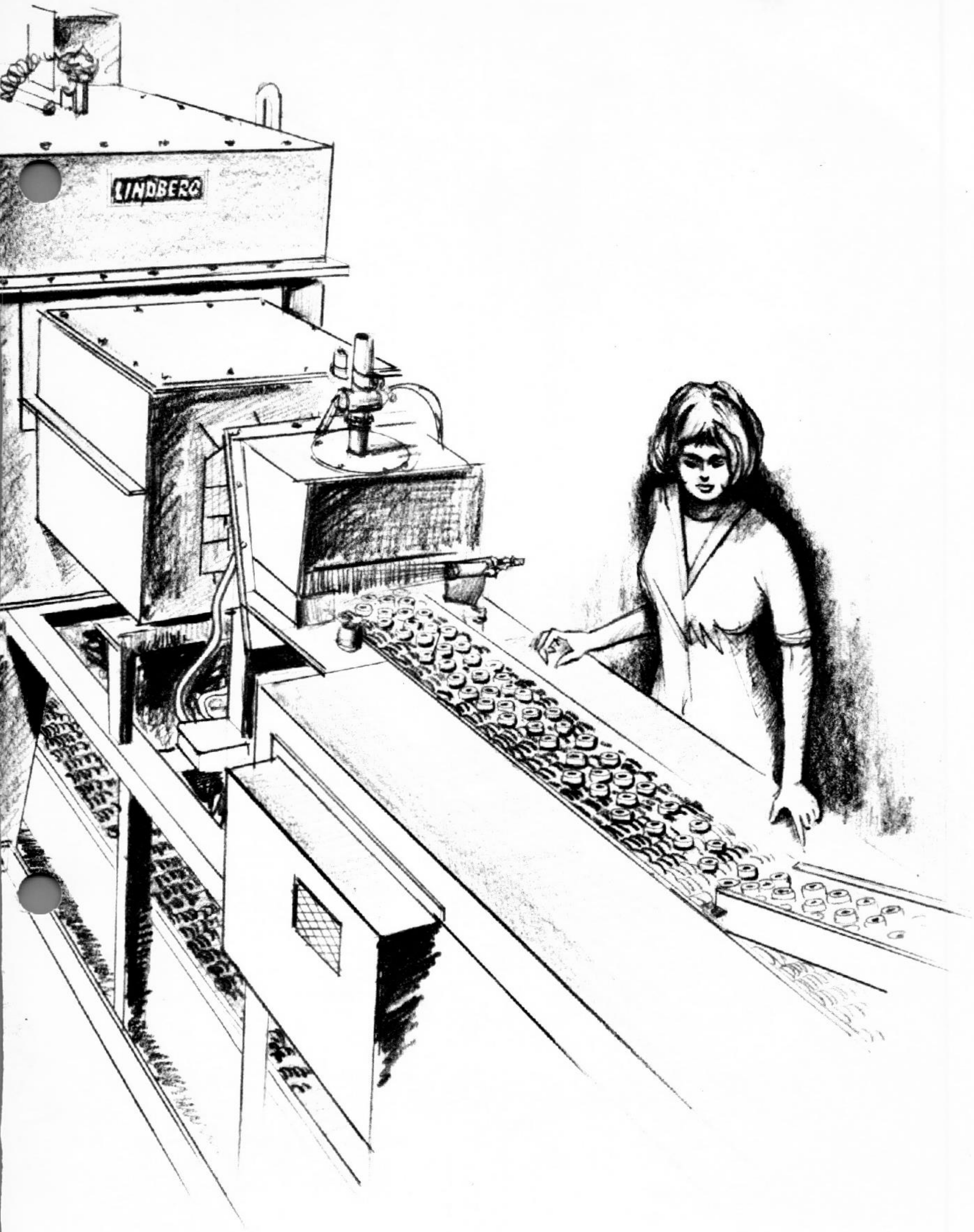
Within the range of available material types, the designation of each material has been narrowed to those listed on pages 12, through 14.

Table II, Page 6, presents Magnetic Metals material designations, and provides the code numbers to be used when ordering.

Tape Thickness Code

Materials used in the manufacture of Tape Wound Cores are supplied in thicknesses from .0005" through .014" for nickel alloys. Silicon alloys (Microsil) are available from .001 through .014.

Table IV, Page 7, indicates the available thicknesses and the ordering code.



Pulse Applications

Magnetic Metals has developed a special process whereby tape wound core pulse performance is optimized. To insure that cores intended for pulse applications are manufactured under this new process, the suffix "P" should be added to the standard core number, i.e., 11P4601-P. **Cores specially processed for pulse applications will not necessarily meet the low frequency CCFR limits published in this catalog.**

Table I — Case Types

Case/Coating Type	Case/Coating Codes	Maximum Coating Build-up (Inches)	Temperature Range For Continuous Operation (in Degrees Centigrade)	Max. Temp. (in Degrees Centigrade)	Breakdown Test Voltage
Aluminum	A	—	−65 to +170	200	—
Aluminum with Epoxy Coat	E	.010	−65 to +155	170	1000
Plastic	P	(1)—	−55 to +155	155	—
Sealed Plastic	S	(2)—	−65 to +105	130	—
Uncased/Epoxy Coat (Fluidized Bed)	D	(3)— (See Table VI.)	−65 to +155	170	1000
Uncased/Epoxy Coat (Painted)	M	(3) .020	−65 to +155	170	500
Uncased	U	—	—	—	—
Special	H	Specify	Specify	Specify	Specify

Notes: (1) Cases will be either Nylon (glass reinforced) or phenolic as available.

(2) Non-reinforced Nylon.

(3) Recommended for Microsil cores only. See page 4 .

Table II — Material Designations

Material Code	Material Description**	Magnetic Metals Designations	Trade Names of Similar Materials*
46	Grain oriented 50% Nickel/Iron alloy processed for maximum B-H loop squareness	Square 50	Hy-Ra "49"[1], Orthonol[2], Deltamax[3], Hipernik V[6]
81	80%Nickel/Iron/Molybdenum alloy processed for B-H loop squareness	Square 80	Square Permalloy Hy-Ra "80"[1]
87	Special 80% Nickel/Iron/Molybdenum alloy processed for maximum B-H loop squareness	SuperSquare 80	Exclusive to Magnetic Metals Company
107	High flux density vanadium/cobalt/iron alloy processed for maximum B-H Loop squareness	Supermendur	Supermendur[4]
33	Grain oriented silicon/iron alloy	Microsil	Silectron Z[4] Oriented T-S[5]
86	Special 80% Nickel/Iron/Molybdenum alloy processed for highest initial permeability and lowest H_o	Supermalloy	Supermalloy[4] Hymu "800"[1]
80	80% Nickel/Iron/Molybdenum alloy processed for high initial permeability	SuperPerm 80	4-79 Permalloy, HyMu "80"[1], Mu-metal[3], Hipernom[6]
49	Non-oriented 50% Nickel/Iron alloy processed for high initial permeability	SuperPerm 49	High Permeability "49"[1], 48-Ni[5], 4750[3]

*Trade Names of: 1—The Carpenter Steel Co. 2—Magnetics Div., Spang Industries, Inc. 3—Alleghany Ludlum Steel Corp. 4—Arnold Engineering Co. 5—Armco Steel Co. 6—Westinghouse

** Compositions shown are approximated. For exact materials' composition, See Table III.

Table III — Composition Of Alloys (Nominal)

Oriented Silicon Iron	50% Nickel/Iron alloy	Molybdenum Permalloy	Supermendur
Iron — 97% Silicon — 3%	Nickel — 50% Iron — 50%	Nickel — 80% Iron — 16% Molybdenum — 4%	Cobalt — 49% Iron — 49% Vanadium — 2%

Table IV — Tape Thickness Codes

Tape Thickness	Code
.0005″	005
.001″	01
.002″	02
.004″	04
.006″	06
.012″	12
.014″	14

Table V — Tolerance On Tape Wound Core Cases

Aluminum Cases			
Case I.D. or O.D.	**Tolerance**	**Case Height**	**Tolerance**
Up to 1.50″	±.005″	Up to 1.00″	+.010″ −.005″
1.51″ to 2.50″	±.008″		
2.51″ to 3.50″	±.012″	Over 1.00″	+.020″ −.005″
Over 3.50″	±.015″		

Table VI — Maximum Coating Thickness

Case Type	Core Height*	Thickness Per Side
Aluminum/Epoxy (E type)	All cores	.010″
Uncased/Epoxy (D type)	up to .50″	.010″—.030″
	.50″ up to 1.0″	.020″—.040″
	1.0″ up to 1.5″	.030″—.060″
	1.5″	.040″—.070″

*Where core buildup $\left(\frac{OD-ID}{2}\right)$ is greater than strip width, use the larger to determine coating thickness.

Table VII — Core Dimensions

	CORE DIMENSIONS IN			CASE DIMENSIONS IN						NET CORE AREA CM^2			MEAN PATH LENGTH		CASE WINDOW AREA IN^2		RATIO ID/OD	GR. CORE WEIGHT SQUARE 50*		PRODUCT Wa X Ca IN^4
				ID		OD		HT		.001	.002	.004 .006								
CORE SIZE	ID	OD	HT	Metal	Plastic	Metal	Plastic	Metal	Plastic	SF=.75	SF=.85	SF=.90	IN	CM	Metal	Plastic		Pounds	Grams	
433	.375	.438	.125	.310	.310	.513	.513	.197	.212	.01905	.0216	.0229	1.277	3.24	.0755	.076	.856	.00149	.680	.000297
343	.500	.563	.125	.435	.435	.637	.637	.197	.212	.01905	.0216	.0229	1.670	4.24	.1486	.149	.888	.00195	.889	.000585
356	.562	.625	.125	.498	.498	.700	.700	.197	.212	.01905	.0216	.0229	1.865	4.74	.1948	.194	.899	.00219	.992	.000767
482	.625	.688	.125	.560	.560	.762	.762	.197	.212	.01905	.0216	.0229	2.062	5.24	.246	.246	.908	.00242	1.098	.000970
431	.687	.750	.125	.622	.622	.825	.825	.197	.212	.01905	.0216	.0229	2.257	5.73	.304	.304	.916	.00265	1.202	.001197
38	.375	.500	.125	.312	.310	.563	.575	.197	.200	.0378	.0428	.0454	1.374	3.49	.0765	.076	.750	.00320	1.452	.000597
106	.438	.563	.125	.373	.375	.638	.630	.197	.205	.0378	.0428	.0454	1.572	3.99	.1093	.110	.778	.00366	1.661	.000854
47	.500	.625	.125	.473	.435	.688	.700	.197	.200	.0378	.0428	.0454	1.767	4.49	.1500	.149	.800	.00411	1.866	.001172
74	.625	.750	.125	.560	.570	.825	.820	.197	.195	.0378	.0428	.0454	2.160	5.49	.246	.255	.833	.00503	2.28	.001924
90	.750	.875	.125	.685	.665	.950	.945	.197	.195	.0378	.0428	.0454	2.553	6.48	.369	.347	.857	.00594	2.70	.00288
366	.875	1.000	.125	.810	.790	1.075	1.095	.197	.212	.0378	.0428	.0454	2.945	7.48	.515	.490	.875	.00686	3.11	.00403
153	1.000	1.125	.125	.935	.915	1.200	1.220	.197	.210	.0378	.0428	.0454	3.338	8.48	.687	.658	.889	.00777	3.53	.00536
2	.500	.750	.125	.435	.435	.825	.825	.197	.200	.0756	.0857	.0907	1.963	4.99	.1486	.149	.667	.00914	4.15	.00232
144	.625	.875	.125	.560	.560	.950	.950	.197	.200	.0756	.0857	.0907	2.356	5.98	.246	.246	.714	.01097	4.98	.00385
5	.650	.900	.125	.585	.575	.975	.985	.197	.200	.0756	.0857	.0907	2.435	6.18	.269	.260	.722	.01134	5.14	.00420
148	.750	1.000	.125	.685	.685	1.075	1.075	.197	.200	.0756	.0857	.0907	2.749	6.98	.369	.369	.750	.01280	5.81	.00576
483	.875	1.125	.125	.810	.790	1.200	1.220	.197	.212	.0756	.0857	.0907	3.142	7.98	.515	.490	.778	.01463	6.64	.00805
9	1.000	1.250	.125	.915	.920	1.340	1.342	.197	.200	.0756	.0857	.0907	3.534	8.98	.658	.665	.800	.01646	7.46	.01027
64	.500	.750	.250	.435	.420	.825	.840	.327	.330	.1512	.1714	.1815	1.963	4.99	.1486	.139	.667	.01829	8.29	.00464
67	.625	.875	.250	.570	.570	.945	.945	.327	.340	.1512	.1714	.1815	2.356	5.98	.255	.255	.714	.0219	9.95	.00797
79	.750	1.000	.250	.665	.670	1.085	1.093	.327	.330	.1512	.1714	.1815	2.749	6.98	.347	.353	.750	.0256	11.61	.01085
30	1.000	1.250	.250	.915	.920	1.340	1.343	.327	.330	.1512	.1714	.1815	3.534	8.98	.658	.665	.800	.0329	14.93	.0205
159	1.125	1.375	.250	1.060	1.040	1.450	1.470	.327	.342	.1512	.1714	.1815	3.927	9.97	.882	.849	.818	.0366	16.59	.0276
53	1.250	1.500	.250	1.170	1.170	1.570	1.570	.327	.320	.1512	.1714	.1815	4.320	10.97	1.075	1.075	.833	.0402	18.25	.0336
37	.625	1.000	.188	.570	.570	1.085	1.085	.265	.272	.1706	.1933	.205	2.553	6.48	.255	.255	.625	.0268	12.16	.00899
7	.750	1.125	.188	.665	.670	1.215	1.217	.265	.265	.1706	.1933	.205	2.945	7.48	.347	.353	.667	.0309	14.03	.01224
485	1.125	1.500	.188	1.060	1.040	1.575	1.595	.265	.280	.1706	.1933	.205	4.123	10.47	.882	.850	.750	.0433	19.65	.0311
489	1.625	2.000	.188	1.545	1.525	2.090	2.110	.265	.280	.1706	.1933	.205	5.694	14.46	1.875	1.827	.813	.0598	27.13	.0661
3	.625	1.000	.250	.570	.550	1.085	1.085	.327	.330	.227	.257	.272	2.553	6.48	.255	.238	.625	.0357	16.17	.01196
61	.750	1.125	.250	.665	.665	1.215	1.215	.327	.340	.227	.257	.272	2.945	7.48	.347	.347	.667	.0411	18.66	.01628
380	.875	1.250	.250	.810	.790	1.325	1.345	.327	.340	.227	.257	.272	3.338	8.48	.515	.490	.700	.0466	21.15	.0242
10	1.000	1.375	.250	.925	.920	1.455	1.468	.327	.330	.227	.257	.272	3.731	9.48	.672	.665	.727	.0521	23.64	.0315
16	1.625	2.000	.250	1.525	1.525	2.110	2.110	.327	.330	.227	.257	.272	5.694	14.46	1.827	1.827	.813	.0795	36.08	.0856
27	.750	1.000	.375	.665	.670	1.085	1.093	.452	.465	.227	.257	.272	2.749	6.98	.347	.353	.750	.0384	17.42	.01628
146	.625	1.125	.250	.560	.540	1.200	1.220	.327	.340	.302	.343	.363	2.749	6.98	.246	.229	.556	.0512	23.22	.01539
382	.750	1.250	.250	.685	.670	1.325	1.343	.327	.330	.302	.343	.363	3.142	7.98	.369	.353	.600	.0585	26.54	.0230
39	1.000	1.500	.250	.925	.920	1.570	1.592	.327	.330	.302	.343	.363	3.927	9.97	.672	.665	.667	.0731	33.18	.0420
13	1.250	1.750	.250	1.170	1.170	1.820	1.822	.327	.340	.302	.343	.363	4.712	11.97	1.075	1.075	.714	.0878	39.81	.0672
32	.625	1.000	.375	.570	.570	1.085	1.085	.452	.445	.340	.386	.408	2.553	6.48	.255	.255	.625	.0535	24.26	.01794
41	.750	1.125	.375	.665	.675	1.215	1.210	.452	.465	.340	.386	.408	2.945	7.48	.347	.358	.667	.0617	27.99	.0244

* For gross core weights of other materials, see table XIII, page 18.

Table VII — Core Dimensions (Cont.)

CORE SIZE	CORE DIMENSIONS IN			CASE DIMENSIONS IN						NET CORE AREA CM^2			MEAN PATH LENGTH		CASE WINDOW AREA IN^2		RATIO ID/OD	GR. CORE WEIGHT SQUARE 50*		PRODUCT Wa X Ca IN^4
	ID	OD	HT	ID Metal	ID Plastic	OD Metal	OD Plastic	HT Metal	HT Plastic	.001 SF = .75	.002 SF = .85	.004 .006 SF = .90	IN	CM	Metal	Plastic		Pounds	Grams	
28	.875	1.250	.375	.800	.795	1.340	1.343	.452	.465	**.340**	**.386**	**.408**	3.338	**8.48**	.503	.496	.700	.0699	31.72	.0353
44	1.000	1.375	.375	.925	.925	1.455	1.455	.452	.445	**.340**	**.386**	**.408**	3.731	**9.48**	.672	.672	.727	.0782	35.46	.0473
12	1.125	1.500	.375	1.050	1.050	1.570	1.570	.452	.445	**.340**	**.386**	**.408**	4.123	**10.47**	.866	.866	.750	.0864	39.19	.0609
486	1.375	1.750	.375	1.295	1.275	1.840	1.860	.452	.467	**.340**	**.386**	**.408**	4.909	**12.47**	1.317	1.277	.786	.1029	46.65	.0926
6	.650	1.150	.375	.585	.585	1.240	1.240	.452	.455	**.454**	**.514**	**.544**	2.827	**7.18**	.269	.269	.565	.0790	35.83	.0252
52	.750	1.250	.375	.665	.665	1.340	1.335	.452	.455	**.454**	**.514**	**.544**	3.142	**7.98**	.347	.347	.600	.0878	39.81	.0326
484	.875	1.375	.375	.810	.790	1.450	1.470	.452	.467	**.454**	**.514**	**.544**	3.534	**8.98**	.515	.490	.636	.0987	44.79	.0483
11	1.000	1.500	.375	.925	.920	1.570	1.593	.452	.465	**.454**	**.514**	**.544**	3.927	**9.97**	.672	.665	.667	.1097	49.76	.0630
87	1.250	1.750	.375	1.170	1.170	1.820	1.822	.452	.445	**.454**	**.514**	**.544**	4.712	**11.97**	1.075	1.075	.714	.1317	59.72	.1008
42	1.500	2.000	.375	1.400	1.400	2.110	2.110	.452	.455	**.454**	**.514**	**.544**	5.498	**13.96**	1.539	1.539	.750	.1536	69.67	.1443
362	.750	1.250	.500	.685	.665	1.350	1.345	.607	.630	**.605**	**.685**	**.726**	3.142	**7.98**	.369	.347	.600	.1170	53.08	.0461
62	1.000	1.500	.500	.925	.920	1.570	1.593	.607	.610	**.605**	**.685**	**.726**	3.927	**9.97**	.672	.665	.667	.1463	66.35	.0840
29	1.250	1.750	.500	1.050	1.035	1.705	1.725	.607	.610	**.605**	**.685**	**.726**	4.712	**11.97**	1.075	1.057	.692	.1609	72.99	.1082
85	1.125	1.625	.500	1.170	1.160	1.820	1.850	.607	.610	**.605**	**.685**	**.726**	4.320	**10.97**	.866	.841	.714	.1755	79.62	.1344
487	1.375	1.875	.500	1.295	1.275	1.965	1.985	.607	.631	**.605**	**.685**	**.726**	5.105	**12.97**	1.317	1.277	.733	.1902	86.26	.1646
14	1.500	2.000	.500	1.400	1.400	2.110	2.110	.607	.620	**.605**	**.685**	**.726**	5.498	**13.96**	1.539	1.539	.750	.205	92.89	.1924
84	1.750	2.250	.500	1.650	1.650	2.350	2.350	.607	.600	**.605**	**.685**	**.726**	6.283	**15.96**	2.138	2.138	.778	.234	106.16	.267
17	2.000	2.500	.500	1.860	1.860	2.652	2.652	.607	.610	**.605**	**.685**	**.726**	7.069	**17.95**	2.717	2.717	.800	.263	119.43	.340
18	2.500	3.000	.500	2.360	2.360	3.152	3.152	.607	.620	**.605**	**.685**	**.726**	8.639	**21.94**	4.373	4.374	.833	.322	145.97	.547
151	.750	1.500	.375	.685	.665	1.575	1.595	.452	.475	**.680**	**.771**	**.817**	3.534	**8.98**	.369	.347	.500	.1481	67.18	.0518
75	1.250	2.000	.375	1.170	1.160	2.110	2.110	.452	.465	**.680**	**.771**	**.817**	5.105	**12.97**	1.075	1.057	.625	.214	97.04	.1512
243	2.000	2.750	.375	1.910	1.890	2.850	2.870	.452	.485	**.680**	**.771**	**.817**	7.461	**18.95**	2.865	2.806	.727	.313	141.83	.403
385	3.000	3.750	.375	2.900	2.880	3.860	3.880	.452	.467	**.680**	**.771**	**.817**	10.603	**26.93**	6.605	6.514	.800	.444	201.54	.929
125	1.000	1.750	.500	.920	.900	1.840	1.860	.607	.610	**.907**	**1.028**	**1.089**	4.320	**10.97**	.665	.636	.571	.241	109.48	.1246
60	1.250	2.000	.500	1.170	1.170	2.110	2.110	.607	.620	**.907**	**1.028**	**1.089**	5.105	**12.97**	1.075	1.075	.625	.285	129.39	.202
488	1.500	2.250	.500	1.420	1.400	2.340	2.360	.607	.631	**.907**	**1.028**	**1.089**	5.890	**14.96**	1.584	1.539	.667	.329	149.29	.297
490	1.625	2.375	.500	1.535	1.515	2.475	2.495	.607	.631	**.907**	**1.028**	**1.089**	6.283	**15.96**	1.851	1.803	.684	.351	159.24	.347
83	1.750	2.500	.500	1.650	1.650	2.600	2.600	.607	.600	**.907**	**1.028**	**1.089**	6.676	**16.96**	2.138	2.138	.700	.373	169.20	.401
493	1.875	2.625	.500	1.785	1.765	2.725	2.745	.607	.631	**.907**	**1.028**	**1.089**	7.069	**17.95**	2.502	2.447	.714	.395	179.15	.469
475	2.250	3.000	.500	2.160	2.140	3.100	3.120	.607	.631	**.907**	**1.028**	**1.089**	8.247	**20.95**	3.664	3.597	.750	.461	209.01	.687
498	2.500	3.250	.500	2.400	2.380	3.360	3.380	.607	.631	**.907**	**1.028**	**1.089**	9.032	**22.94**	4.524	4.449	.769	.505	228.91	.848
381	1.250	2.250	.500	1.170	1.150	2.340	2.360	.607	.631	**1.210**	**1.371**	**1.452**	5.498	**13.96**	1.075	1.039	.556	.410	185.78	.269
15	1.500	2.500	.500	1.400	1.395	2.600	2.615	.607	.610	**1.210**	**1.371**	**1.452**	6.283	**15.96**	1.539	1.528	.600	.468	212.33	.385
335	1.750	2.750	.500	1.660	1.640	2.850	2.870	.607	.631	**1.210**	**1.371**	**1.452**	7.069	**17.95**	2.164	2.112	.636	.527	238.87	.541
76	2.000	3.000	.500	1.910	1.895	3.100	3.115	.607	.610	**1.210**	**1.371**	**1.452**	7.854	**19.95**	2.865	2.820	.667	.585	265.41	.716
19	2.500	3.500	.500	2.313	2.380	3.688	3.630	.607	.610	**1.210**	**1.371**	**1.452**	9.425	**23.94**	4.202	4.449	.714	.702	318.49	1.050
334	1.000	1.500	1.000	.935	.915	1.575	1.595	1.135	1.112	**1.210**	**1.371**	**1.452**	3.927	**9.97**	.687	.658	.667	.293	132.70	.1717
55	1.250	1.750	1.000	1.170	1.170	1.820	1.822	1.135	1.105	**1.210**	**1.371**	**1.452**	4.712	**11.97**	1.075	1.075	.714	.351	159.24	.269
95	1.500	2.000	1.000	1.400	1.400	2.110	2.110	1.135	1.110	**1.210**	**1.371**	**1.452**	5.498	**13.96**	1.539	1.539	.750	.410	185.78	.385
128	1.750	2.250	1.000	1.670	1.650	2.340	2.360	1.135	1.110	**1.210**	**1.371**	**1.452**	6.283	**15.96**	2.190	2.138	.778	.468	212.33	.548

* For gross core weights of other materials, see table XIII, page 18.

Table VII — Core Dimensions (Cont.)

CORE SIZE	CORE DIMENSIONS IN			CASE DIMENSIONS IN ID		OD		HT		NET CORE AREA CM^2			MEAN PATH LENGTH		CASE WINDOW AREA IN^2		RATIO ID/OD	GR. CORE WEIGHT SQUARE 50*		PRODUCT Wa X Ca IN^4
	ID	OD	HT	Metal	Plastic	Metal	Plastic	Metal	Plastic	.001 SF=.75	.002 SF=.85	.004 .006 SF=.90	IN	CM	Metal	Plastic		Pounds	Grams	
59	2.000	2.500	1.000	1.860	1.890	2.652	2.620	1.135	1.152	**1.210**	**1.371**	**1.452**	7.069	**17.95**	2.717	2.806	.800	.527	238.87	.679
225	2.500	3.000	1.000	2.410	2.390	3.100	3.120	1.135	1.120	**1.210**	**1.371**	**1.452**	8.639	**21.94**	4.562	4.486	.833	.644	291.95	1.140
164	1.250	2.000	1.000	1.170	1.150	2.090	2.110	1.135	1.110	**1.815**	**2.056**	**2.177**	5.105	**12.97**	1.075	1.039	.625	.570	258.77	.403
168	1.500	2.250	1.000	1.420	1.400	2.340	2.360	1.135	1.110	**1.815**	**2.056**	**2.177**	5.890	**14.96**	1.584	1.5	.667	.658	298.58	.594
491	1.625	2.375	1.000	1.545	1.515	2.465	2.495	1.135	1.162	**1.815**	**2.056**	**2.177**	6.283	**15.96**	1.875	1.803	.684	.702	318.49	.703
494	2.000	2.750	1.000	1.910	1.890	2.850	2.870	1.135	1.162	**1.815**	**2.056**	**2.177**	7.461	**18.95**	2.865	2.806	.727	.834	378.20	1.074
340	1.250	2.250	1.000	1.170	1.150	2.340	2.280	1.135	1.162	**2.419**	**2.742**	**2.903**	5.498	**13.96**	1.075	1.039	.556	.819	371.57	.538
169	1.500	2.500	1.000	1.410	1.390	2.600	2.620	1.135	1.120	**2.419**	**2.742**	**2.903**	6.283	**15.96**	1.561	1.517	.600	.936	424.65	.781
97	1.750	2.750	1.000	1.650	1.650	2.850	2.850	1.135	1.120	**2.419**	**2.742**	**2.903**	7.069	**17.95**	2.138	2.138	.636	1.053	477.73	1.069
58	2.000	3.000	1.000	1.860	1.860	3.152	3.152	1.135	1.198	**2.419**	**2.742**	**2.903**	7.854	**19.95**	2.717	2.717	.667	1.170	530.81	1.359
20	2.500	3.500	1.000	2.313	2.313	3.688	3.688	1.135	1.188	**2.419**	**2.742**	**2.903**	9.425	**23.94**	4.202	4.202	.714	1.404	636.98	2.101
199	3.000	4.000	1.000	2.900	2.880	4.110	4.130	1.135	1.130	**2.419**	**2.742**	**2.903**	10.996	**27.93**	6.605	6.514	.750	1.638	743.14	3.303
492	1.750	3.000	1.000	1.660	1.640	3.100	3.120	1.135	1.162	**3.024**	**3.427**	**3.629**	7.461	**18.95**	2.164	2.112	.583	1.390	630.34	1.353
495	2.000	3.250	1.000	1.900	1.880	3.360	3.380	1.135	1.162	**3.024**	**3.427**	**3.629**	8.247	**20.95**	2.835	2.776	.615	1.536	696.69	1.772
496	2.250	3.500	1.000	2.150	2.130	3.610	3.630	1.135	1.162	**3.024**	**3.427**	**3.629**	9.032	**22.94**	3.630	3.563	.643	1.682	763.04	2.269
133	1.750	2.750	1.500	1.650	1.650	2.850	2.850	1.685	1.688	**3.629**	**4.113**	**4.355**	7.069	**17.95**	2.138	2.138	.636	1.580	716.60	1.604
441	2.000	3.000	1.500	1.910	1.890	3.100	3.120	1.635	1.662	**3.629**	**4.113**	**4.355**	7.854	**19.95**	2.865	2.821	.667	1.755	796.22	2.149
200	3.000	4.000	1.500	2.900	2.880	4.110	4.130	1.685	1.640	**3.629**	**4.113**	**4.355**	10.996	**27.93**	6.605	6.514	.750	2.458	1114.71	4.954
22	2.500	3.750	1.500	2.313	2.313	3.938	3.938	1.685	1.688	**4.536**	**5.141**	**5.444**	9.817	**24.94**	4.202	4.202	.667	2.743	1244.09	3.939
23	3.250	4.500	1.500	3.062	3.062	4.688	4.688	1.685	1.688	**4.536**	**5.141**	**5.444**	12.174	**30.92**	7.364	7.364	.722	3.401	1542.68	6.904
185	2.000	3.500	1.500	1.900	1.880	3.610	3.630	1.685	1.640	**5.444**	**6.169**	**6.532**	8.639	**21.94**	2.835	2.776	.571	2.896	1313.76	3.190
201	3.000	4.500	1.500	2.870	2.880	4.640	4.630	1.685	1.640	**5.444**	**6.169**	**6.532**	11.781	**29.92**	6.469	6.514	.667	3.950	1791.49	7.278
203	3.250	4.750	1.500	3.120	3.100	4.890	4.910	1.685	1.660	**5.444**	**6.169**	**6.532**	12.566	**31.92**	7.645	7.548	.684	4.213	1910.93	8.601
442	3.500	5.000	1.500	3.370	3.350	5.140	5.160	1.635	1.662	**5.444**	**6.169**	**6.532**	13.352	**33.91**	8.920	8.814	.700	4.476	2030.36	10.035
211	4.500	6.000	1.500	4.370	4.350	6.140	6.160	1.685	1.660	**5.444**	**6.169**	**6.532**	16.493	**41.89**	14.999	14.862	.750	5.529	2508.09	16.873
497	2.250	3.500	2.000	2.150	2.130	3.610	3.630	2.195	2.182	**6.048**	**6.855**	**7.258**	9.032	**22.94**	3.630	3.563	.643	3.643	1526.09	4.538
499	3.000	4.250	2.000	2.870	2.850	4.390	4.410	2.195	2.182	**6.048**	**6.855**	**7.258**	11.388	**28.93**	6.469	6.379	.706	4.242	1924.20	8.087
24	3.250	4.500	2.000	3.062	3.062	4.688	4.688	2.195	2.188	**6.048**	**6.855**	**7.258**	12.174	**30.92**	7.364	7.364	.722	4.535	2056.90	9.205
25	4.000	5.250	2.000	3.813	3.813	5.438	5.438	2.195	2.188	**6.048**	**6.855**	**7.258**	14.530	**36.91**	11.419	11.419	.762	5.412	2455.01	14.274
190	2.250	4.000	1.500	2.150	2.130	4.110	4.130	1.685	1.640	**6.351**	**7.198**	**7.621**	9.817	**24.94**	3.630	3.563	.563	3.840	1741.73	4.765
500	3.000	4.750	1.500	2.870	2.850	4.890	4.910	1.635	1.662	**6.351**	**7.198**	**7.621**	12.174	**30.92**	6.469	6.379	.632	4.761	2159.75	8.491
77	3.250	5.000	1.500	3.062	3.062	5.188	5.188	1.685	1.688	**6.351**	**7.198**	**7.621**	12.959	**32.92**	7.364	7.364	.650	5.069	2299.08	9.665
501	3.250	5.250	1.500	3.120	3.100	5.390	5.410	1.635	1.662	**7.258**	**8.226**	**8.710**	13.352	**33.91**	7.645	7.598	.619	5.968	2707.15	11.468
502	4.000	6.000	1.500	3.870	3.850	6.140	6.160	1.635	1.662	**7.258**	**8.226**	**8.710**	15.708	**39.90**	11.763	11.642	.667	7.021	3184.88	17.644
26	4.500	6.500	1.500	4.313	4.312	6.688	6.688	1.685	1.688	**7.258**	**8.226**	**8.710**	17.279	**43.89**	14.610	14.603	.692	7.724	3503.37	21.915
202	3.000	5.000	2.000	2.870	2.850	5.140	5.160	2.195	2.170	**9.677**	**10.968**	**11.613**	12.566	**31.92**	6.469	6.379	.600	7.490	3397.20	12.938
78	4.000	6.000	2.000	3.813	3.813	6.188	6.188	2.195	2.188	**9.677**	**10.968**	**11.613**	15.708	**39.90**	11.419	11.419	.667	9.362	4246.50	22.838
503	4.000	6.500	2.000	3.840	3.820	6.670	6.690	2.195	2.182	**12.097**	**13.710**	**14.516**	16.493	**41.89**	11.581	11.461	.615	12.288	5573.54	28.953
504	4.500	7.000	2.000	4.340	4.320	7.170	7.190	2.195	2.182	**12.097**	**13.710**	**14.516**	18.064	**45.88**	14.793	14.657	.643	13.458.	6104.35	36.984

*For gross core weights of other materials, see table XIII, page 18.

TAPE WOUND CORE CONSTRUCTION

Tape wound cores are fabricated on specially-designed machines which wind insulated tape onto a mandrel under controlled tension. This control helps to provide an extremely uniform cross-section.

The wound cores are then annealed in a controlled environment to stress-relieve the material and to develop the required magnetic characteristics previously determined by careful raw material evaluation and selection.

Annealed cores are sensitive to mechanical strain in varying degrees depending upon the alloy. These strains cause changes in the magnetic characteristics of the material which may severely alter the performance of the finished core. To prevent these changes from taking place, the annealed tape cores are housed within cases which protect them from the strains of electrical winding and other external disturbances. (see Figure 1.)

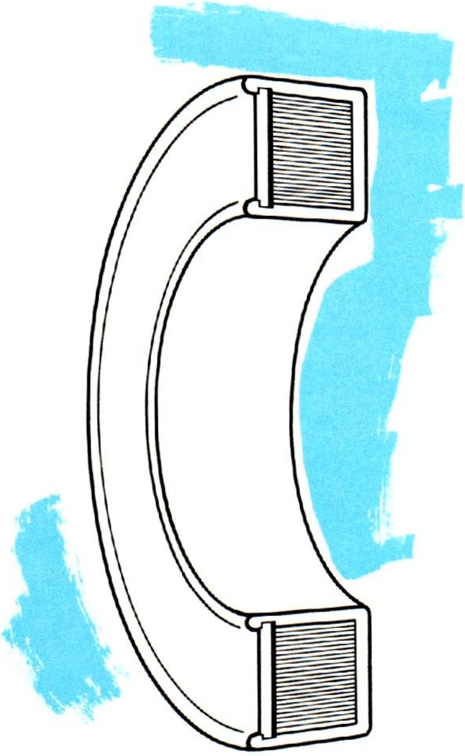
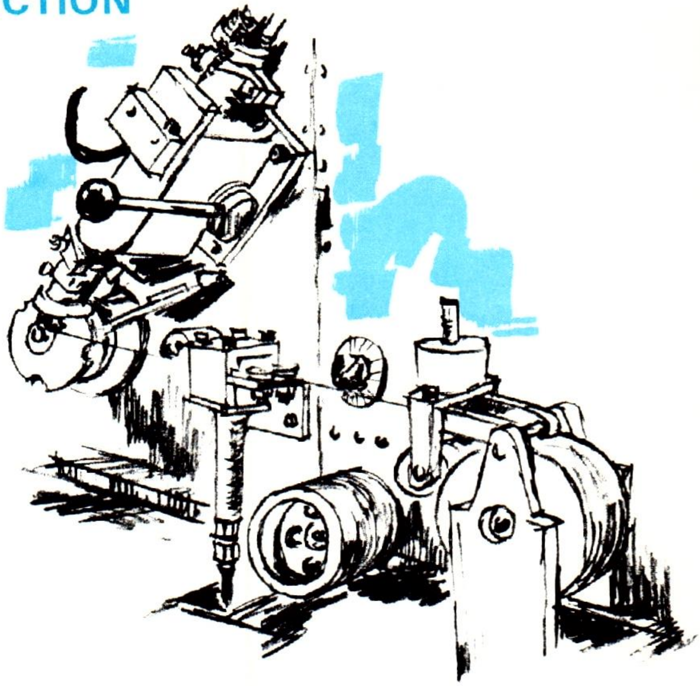


FIGURE 1 — Cut-away view of an aluminum-cased tape wound core.



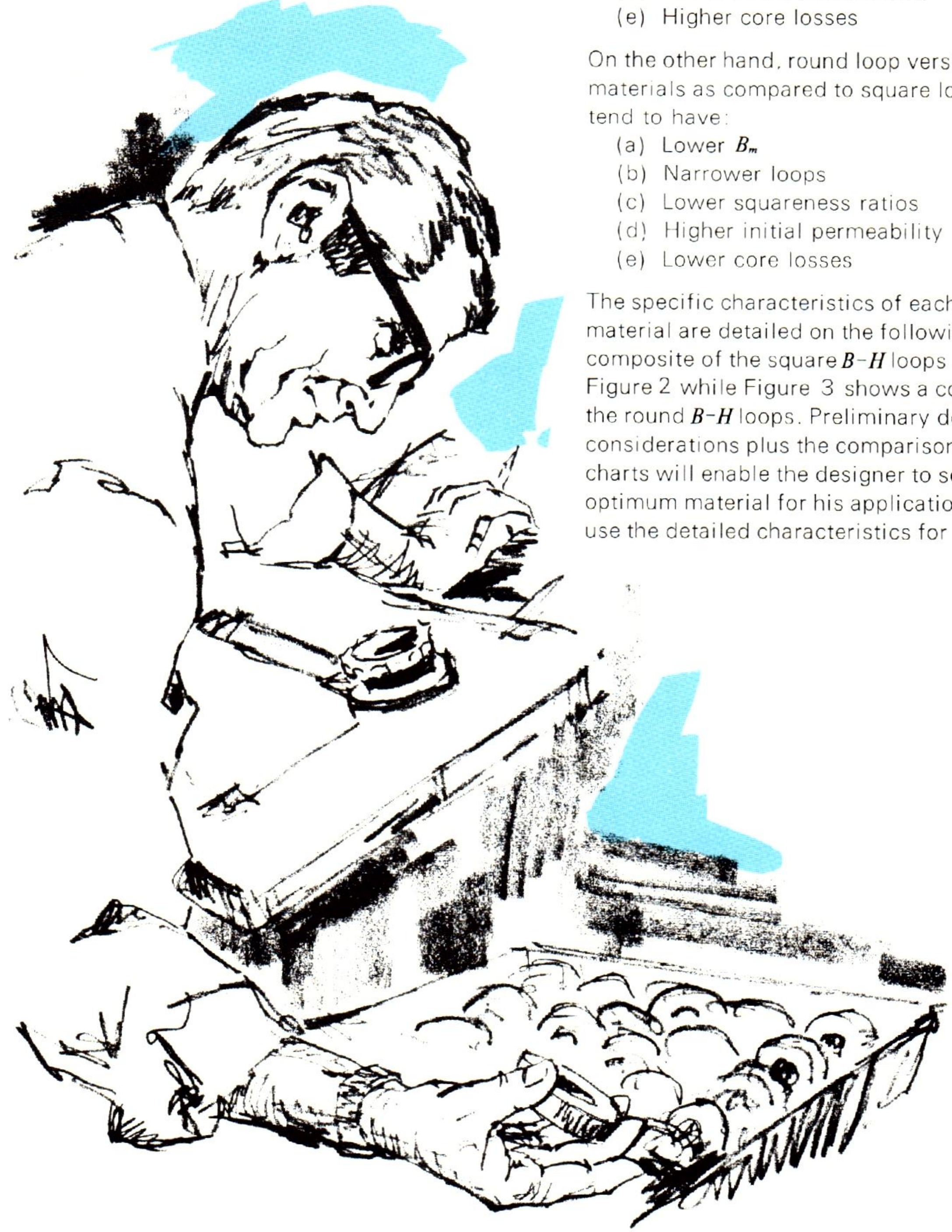
The cases are fabricated of various materials depending upon the intended application: Plastics, such as phenolic, nylon, glass reinforced nylon and Metals, such as aluminum, brass, etc., are used.

A damping medium fills the space between the core and the case to minimize the motion of the core within the case, thus reducing the possibility of change in electrical characteristics under shock and vibration.

The non-metallic cases (glass-filled nylon, phenolic, nylon) provide protection and are the most widely used.(This is because they fill the need of most environmental conditions to which the cores will be subjected.) The glass-filled nylon case has proven superior to the phenolic case because of its greater strength. Aluminum cases provide greater environmental protection and this quality can be further enhanced by the application of an epoxy finish over the case.

MATERIALS FOR TAPE WOUND CORES

The magnetic materials used for tape wound cores are generally classified in two broad categories: (1) "Square Loop", (2) "Round Loop". This reference is made to the relative shape of the plot of B (flux density) versus H (magnetizing force), or B–H loop.



For a given basic material, square loop versions tend to have:

(a) Higher maximum flux capabilities (B_m)
(b) Wider loops (greater H_c-loop width at zero flux)
(c) Higher squareness ratios (ratio of residual flux at zero H to maximum flux at specified maximum magnetizing force, or B_r/B_m).
(d) Lower initial permeability
(e) Higher core losses

On the other hand, round loop versions of materials as compared to square loop materials tend to have:

(a) Lower B_m
(b) Narrower loops
(c) Lower squareness ratios
(d) Higher initial permeability
(e) Lower core losses

The specific characteristics of each available material are detailed on the following pages. A composite of the square B–H loops is shown in Figure 2 while Figure 3 shows a composite of the round B–H loops. Preliminary design considerations plus the comparison curves and charts will enable the designer to select the optimum material for his application, and then use the detailed characteristics for final design.

Square Loop Materials

See Table II, Page 6, for Comparison of specific characteristics.

SuperSquare 80 — 80% Ni/Fe/Mo represents a major advance in the processing of electrical alloy steels. Produced by sophisticated metallurgical techniques SuperSquare 80 (a Magnetic Metals exclusive) offers the designer a magnetic material of unusual uniformity. In comparison to Square 80 (or any of its equivalents) SuperSquare 80 offers higher maximum flux density, higher gain and a higher squareness ratio with only a very slight increase in coercive force. One noteworthy feature of this material is the remarkable uniformity of the cores produced. These cores have half the spread of typical magnetic electrical characteristics normally encountered with Square 80. This material can be made to provide a high degree of thermal stability for certain pre-selected magnetic characteristics. When thermal stability is a requirement, complete specifications should be reviewed with Magnetic Metals engineering department. This material can be made with different permeability vs temperature characteristics providing positive, zero, or negative temperature coefficients.

Square 80 — 80% Ni/Fe/Mo — is a relatively low coercive force, lower flux level material. It offers reasonably good squareness and high gain. Core losses are quite low. Applications include low power, high frequency or high efficiency inverter transformers, low level and high frequency magnetic amplifiers, magnetic modulators, and pulse transformers.

Square 50 — 50% Ni/Fe alloy. (grain oriented). It offers the highest squareness ratio (lowest saturated reactance) and very high gain. This material has significantly high B_m while core losses are low enough to consider its use in higher frequency applications than the silicon steels. Applications include bi-stable switching devices, inverter transformers, high performance power magnetic amplifiers, linear current transformers, timing devices, driver transformers, and wherever an extremely square loop material, manufactured to close tolerance, is required.

Microsil — 97% Fe/Si — Oriented Silicon Iron Alloy. This material is generally used for high power, relatively low frequency applications in high performance power transformers, saturable reactors, inverter transformers, magnetic amplifiers (power), current transformers, output transformers, etc. This is the least expensive of the square loop materials, and has high maximum flux. The Squareness ratio is lower than for Square 50. The core losses are higher while gain is significantly lower.

Supermendur — 49% Co/49% Fe/Va. This is the highest flux density material available in tape wound cores. Applications include power transformers, power magnetic amplifiers, inverters, and wherever size and weight are a major design consideration. Gain is lower than that of silicon steel.

Round Loop Materials

See Table II, Page 6, for comparison of specific characteristics.

Supermalloy — 80% Ni/Fe/Mo. This is a special 80% nickel-iron alloy processed for exceptionally high initial permeability. Applications include very low level signal transformers, low level and high frequency magnetic pre-amplifiers, high value inductors which have no superimposed direct currents and precision current transformers.

SuperPerm 80 — 80% Ni/Fe/Mo. This material offers very high permeability and low magnetizing force. The initial permeability is also quite high. Applications include low level signal transformers, magnetic modulators, sensitive magnetic amplifiers, linear current transformers and high frequency applications. This material can be made with different permeability vs. temperature characteristics providing positive, zero, or negative temperature coefficients.

SuperPerm 49 — 50% Ni/Fe Alloy. This material has characteristics that fall between Silicon Steel and 80% Ni/Fe/Mo. It provides the designer with high initial permeability as well as a high maximum flux. Applications include current transformers, proportioning reactors, high quality and wide frequency response transformers and medium power magnetic amplifiers.

COMPOSITE HYSTERESIS CURVES

Square Loop Materials
400 Hertz ac Excitation with Sine Current

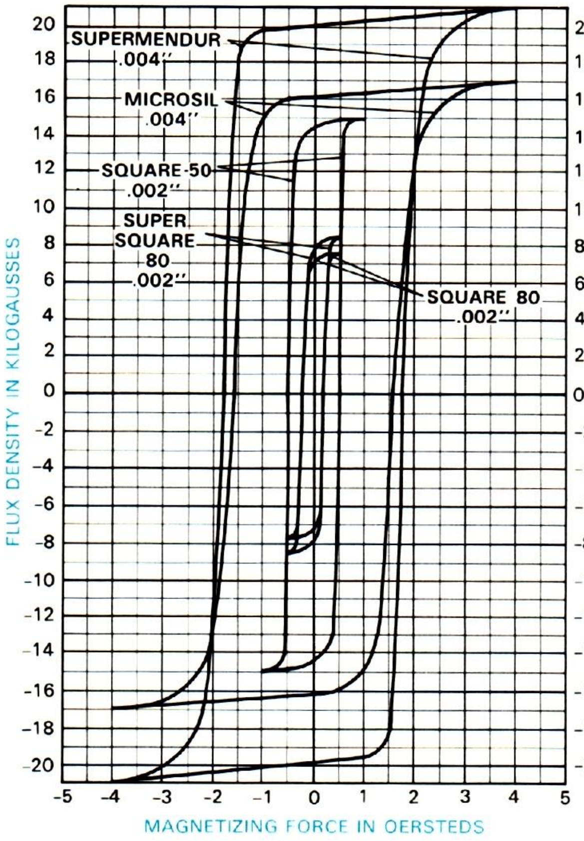


FIGURE 2.

Round Loop Materials
400 Hertz ac Excitation with Sine Current

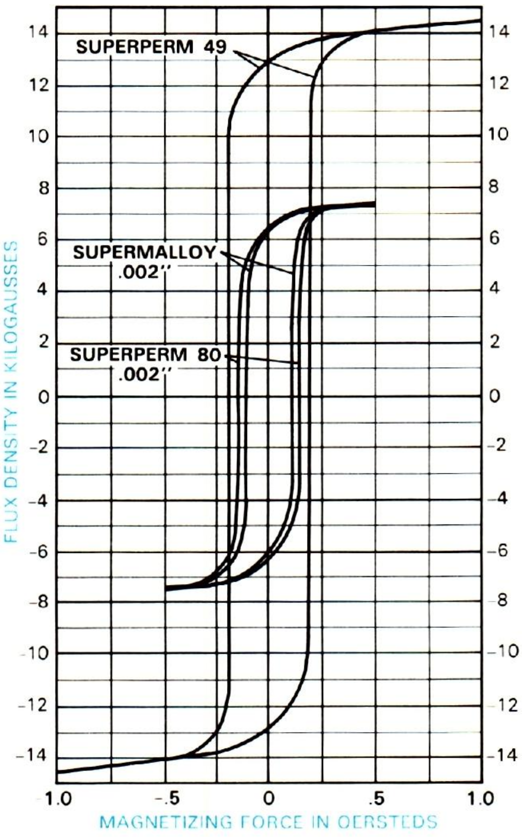
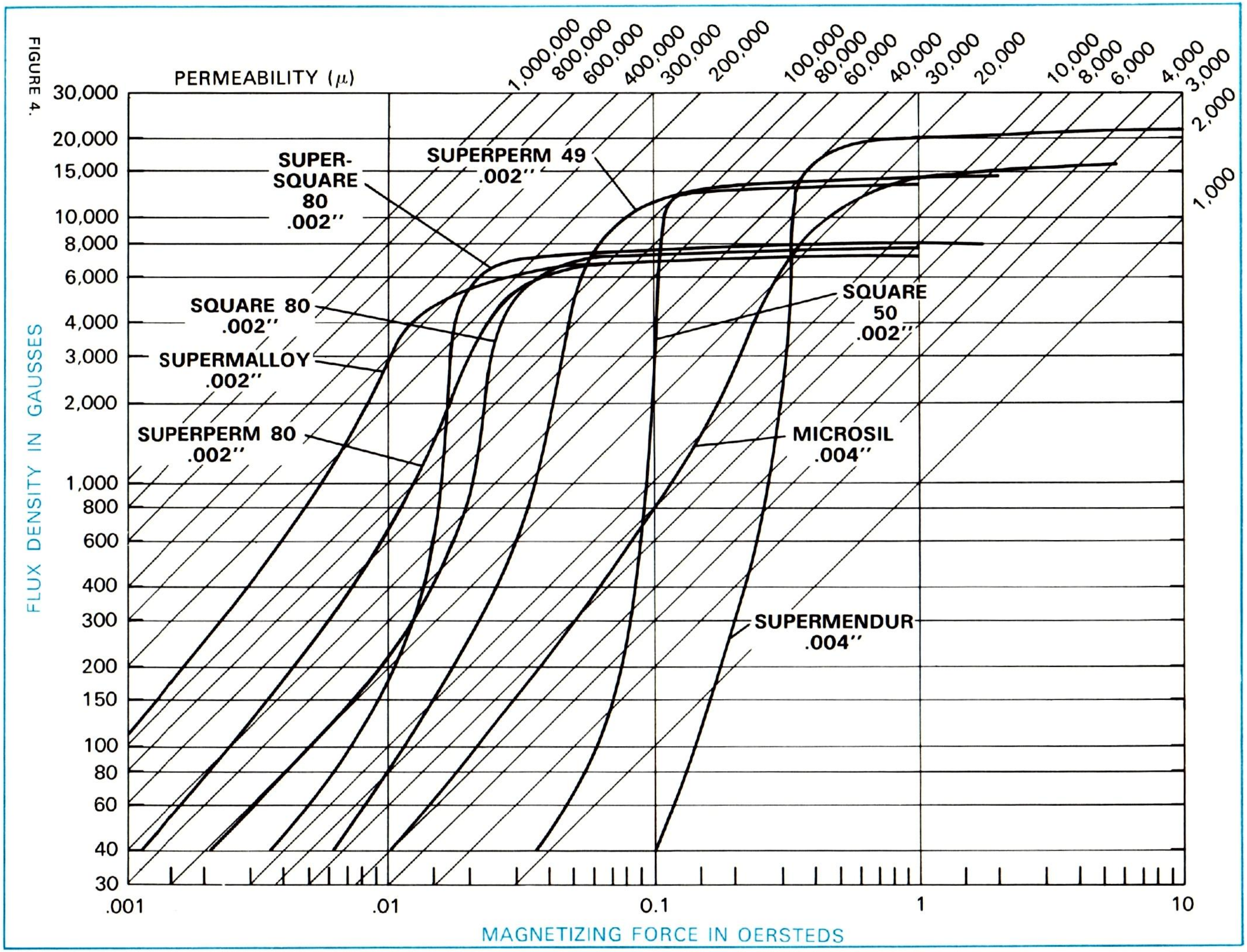


FIGURE 3.

COMPOSITE dc MAGNETIZATION CURVES

FIGURE 4.



LIMITS OF PERFORMANCE OF MATERIALS

Table VIII — Test Conditions Applicable to CCFR Limits

Performance Designation	Frequency (Hertz)	Peak Excitation (Oersteds)		ΔB_1 for Measurement of H_1 (Gausses)	ΔB_2 for Measurement of H_2 or $\Delta H = H_2 - H_1$ (Gausses)
		For B_M and B_R/B_M	For H_1 and ΔH		
SuperSquare 80	400	0.5	1.0	5,000	10,000
Square 80	400	0.5	1.0	5,000	10,000
Square 50	400	1.0	2.0	10,000	20,000
Microsil (.004 inches and thinner)	400	3.0	6.0	10,000	20,000
Microsil (.012 inches thick)	60	3.0	6.0	10,000	20,000
Supermendur	400	3.5	7.0	14,000	28,000

For Test circuit see page 38. For test procedure refer to Institute of Electrical and Electronics Engineers No. 106.

Table IX — Stacking Factors — Standard Values for Test Limits

Tape Thickness (Inches)	.001	.002	.004	.005	.006
Stacking Factor (Percent)	75	85	90	50	90

Table X — 400 Hz Constant Current Flux Reset Test Limits

See Table XI for values of ΔH.

Performance Designation	Thickness (Inches)	B_M (Gausses*)	B_M-B_R (Gausses)	H_1 (Oersteds)
SuperSquare 80	.001	7200-8400	600-1250	.038-.052
	.002	7200-8400	725-1350	.034-.048
	.004	7200-8400	750-1400	.040-.054
Square 80	.001	6800-8200	560-1500	.025-.052
	.002	6800-8200	700-1600	.023-.045
	.004	6800-8200	770-1800	.025-.050
	.006	6800-8200	850-2000	.028-.055
Square 50	.001	14,000-15,500	140-1000	.15-.25
	.002	14,000-15,500	140-1050	.15-.25
	.004	14,000-15,500	140-1150	.18-.30
	.006	14,000-15,500	140-1200	.21-.40
Microsil	.002	15,000-18,000	900-2500	.45-.70
	.004	15,000-18,000	1200-3500	.30-.60
	.012	15,000-18,000	1200-4000	.08-.35**
Supermendur	.002	20,000-22,000	1000-2000	.55-.75
	.004	20,000-22,000	1000-2000	.50-.70

* To convert gausses into webers per square meter for SI units, multiply by 10^{-4}.

** at 60 Hz

Table XI — Maximum Values of Δ H by ID/OD Ratio

Performance Designation	Tape Thickness (Inches)	Maximum ΔH (Oersteds) at 400 Hertz				
		ID/OD Ratio				
		.600-.649	.650-.699	.700-.749	.750-.799	800 or Greater
SuperSquare 80	.001	.0100	.0090	.0085	.0080	.0070
	.002	.0100	.0090	.0085	.0080	.0070
	.004	.0150	.0140	.0135	.0130	.0120
Square 80	.001	.0130	.0120	.0110	.0100	.0085
	.002	.0130	.0120	.0110	.0100	.0090
	.004	.0228	.0195	.0172	.0150	.0130
	.006	.0285	.0260	.0235	.0210	.0180
Square 50	.001	.0435	.0390	.0360	.0330	.0300
	.002	.0475	.0450	.0400	.0375	.0320
	.004	.0563	.0525	.0488	.0450	.0430
	.006	.0650	.0600	.0550	.0550	.0450
Microsil	.002	.1420	.1380	.1340	.1300	.1250
	.004	.1530	.1460	.1390	.1320	.1250
	.012*	.072 *	.067 *	.062 *	.057 *	.055 *
Supermendur	.002	.1200	.1100	.1000	.0900	.0800
	.004	.1000	.0920	.0850	.0780	.0700

* at 60 Hertz

Table XII — Permeability Test Limits — Round Loop Materials

Performance Designation	Frequency (Hertz)	Induction (Gausses)	Thickness (Inches)	Minimum Permeability (Impedance Measurement)
Supermalloy	100	20	.001	55,000
			.002	55,000
			.004	55,000
SuperPerm 80	60	40	.001	26,000
			.002	30,000
			.004	35,000
			.006	35,000
SuperPerm 49	60	40	.001	4,500
			.002	5,000
			.004	5,000
			.006	5,000

Table XIII — Gross Core Weight Conversion Table

(To obtain core weights for other materials, multiply by the factors below.)*

Designation	Factor	Designation	Factor	Designation	Factor
SuperSquare 80	1.059	Microsil	0.927	Supermally	1.059
Square 80	1.059	Supermendur	0.988	SuperPerm 49	1.000
Square 50	1.000			SuperPerm 80	1.059

* For gross core weights see table XII

Wire Table

Wire Size AWG	Diameter With Heavy Insulation (Inches)	Area Circular Mils Nominal	Resistance Ohms Per 1000 Ft.	Weight Pounds Per 1000 Ft.	Layer Winding Turns Per Inch	Random Winding Turns Per Inch$_2$	Machine Minimum Wound I.D. (Inches)	Maximum Turns For Case I.D. of	
								0.5 In.	1.0 In.
8	.132	16510	.628	50.4	6	42	2.000	—	—
9	.118	13090	.793	40.0	7	57	1.750	—	—
10	.106	10380	.999	31.7	8	75	1.500	—	—
11	.094	8230	1.26	25.2	9	95	1.250	—	—
12	.084	6530	1.59	20.1	11	130	1.000	—	—
13	.075	5190	2.00	15.9	12	159	.875	—	—
14	.067	4110	2.52	12.6	13	193	.875	—	—
15	.060	3260	3.18	10.0	15	248	.875	—	—
16	.054	2580	4.02	7.95	17	316	.750	—	120
17	.048	2050	5.05	6.32	19	394	.750	—	180
18	.043	1620	6.39	5.02	21	487	.750	—	260
19	.039	1290	8.05	3.99	23	596	.500	60	360
20	.035	1020	10.13	3.16	26	792	.500	80	450
21	.031	812	12.77	2.51	29	982	.500	90	560
22	.028	640	16.20	1.99	32	1210	.438	120	680
23	.025	510	20.30	1.59	36	1260	.438	150	850
24	.022	404	25.67	1.26	40	1550	.313	180	1040
25	.020	320	32.37	1.01	45	1940	.313	250	1310
26	.018	253	41.02	.799	50	2700	.300	310	1560
27	.016	202	51.44	.634	55	3550	.300	370	1870
28	.014	159	65.31	.504	62	4180	.300	470	2500
29	.013	128	81.21	.401	68	5160	.300	620	3250
30	.012	100.0	103.7	.318	77	6560	.250	750	4000
31	.011	79.2	130.9	.254	85	8090	.250	920	5050
32	.010	64.0	162.0	.202	94	10000	.250	1250	6870
33	.009	50.4	205.7	.161	105	12500	.250	1510	8740
34	.008	39.7	261.3	.127	119	16250	.218	1920	10620
35	.007	31.4	330.7	.101	133	20600	.218	2440	13120
36	.0060	25.0	414.8	.0803	145	25000	.218	2930	16250
37	.0055	20.2	512.1	.0641	161	30900	.218	3500	19370
38	.0049	16.0	648.2	.0509	181	39300	.218	4300	23750
39	.0043	12.2	846.6	.0403	205	51500	.218	5300	30000
40	.0038	9.61	1079	.0319	226	72000	.218	7450	42500
41	.0034	7.84	1323	.0252	250	89800	.218	9950	58120
42	.0030	6.25	1659	.0199	283	116500	.218	12600	72500
43	.0027	4.84	2143	.0159	315	143000	.187	14900	85000
44	.0025	4.00	2593	.0127	340	168500	.187	17400	100000

DATAPAC

For use primarily in prototype and research and development projects, Magnetic Metals offers the designer a new concept in packaging of Tape Wound Cores. Called "Datapac," the new package allows Tape Wound Cores to be blister-packed individually with detachable permanent data records.

The "Datapac" is intended to aid the designer in the analysis of prototype designs. Presented on the permanent-record "Datapac" card is CCFR data including B_m, B_m-B_r, H, and ΔH. With this new package, it is virtually impossible for cores and their pertinent data to become separated.

Magnetic Metals will also provide similar hysteresis data for up to 10 pieces in standard production orders.

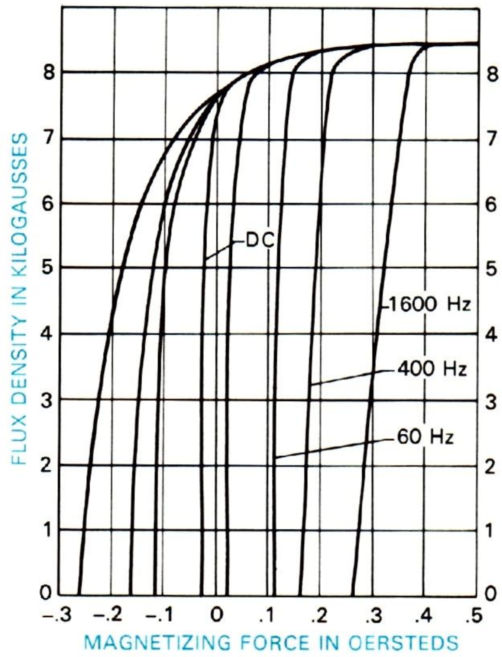
Sample "Datapacs" can be obtained free of charge direct from Magnetic Metals.

CHARACTERISTICS OF STANDARD CORE MATERIALS

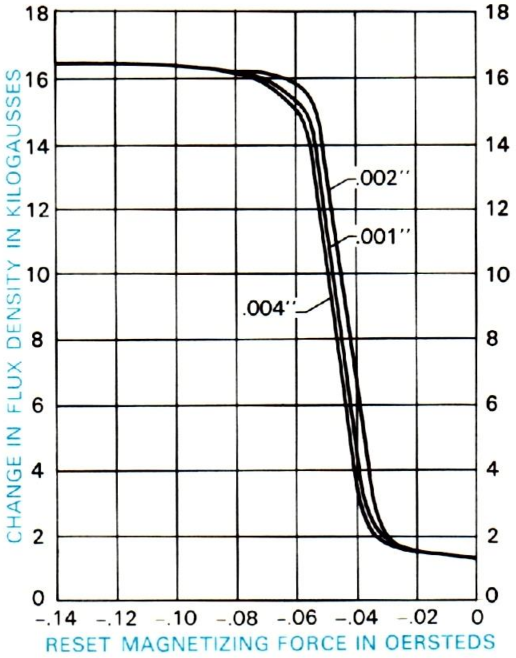
SUPERSQUARE 80

80% Ni/Fe/Mo

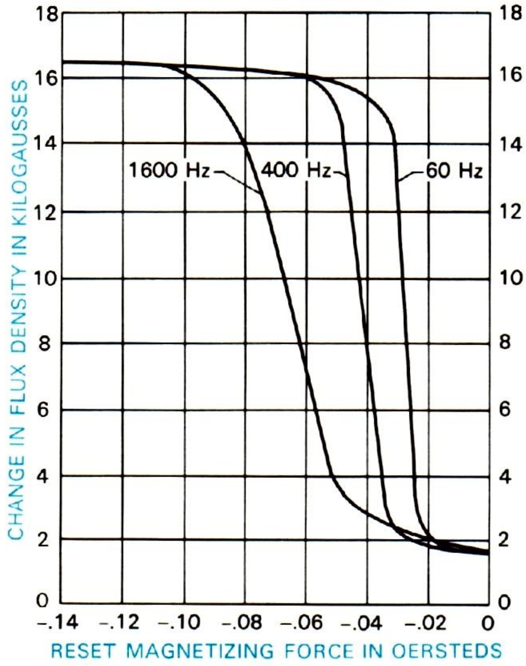
TYPICAL HYSTERESIS LOOPS
.002″ SUPERSQUARE 80
Upper Two Quadrants ac Excitation With Sine Current



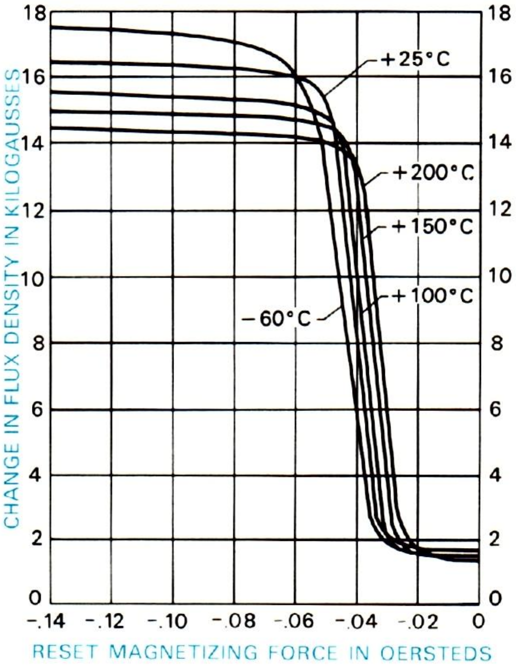
TYPICAL CCFR CONTROL CURVES
SUPERSQUARE 80
Variation With Thickness



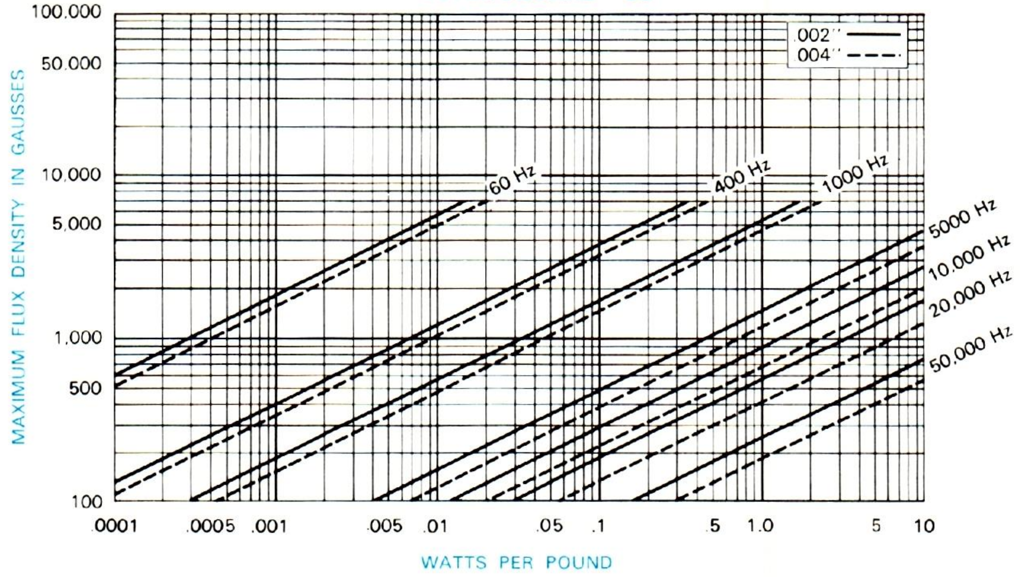
TYPICAL CCFR CONTROL CURVES
.002″ SUPERSQUARE 80
Variation With Frequency



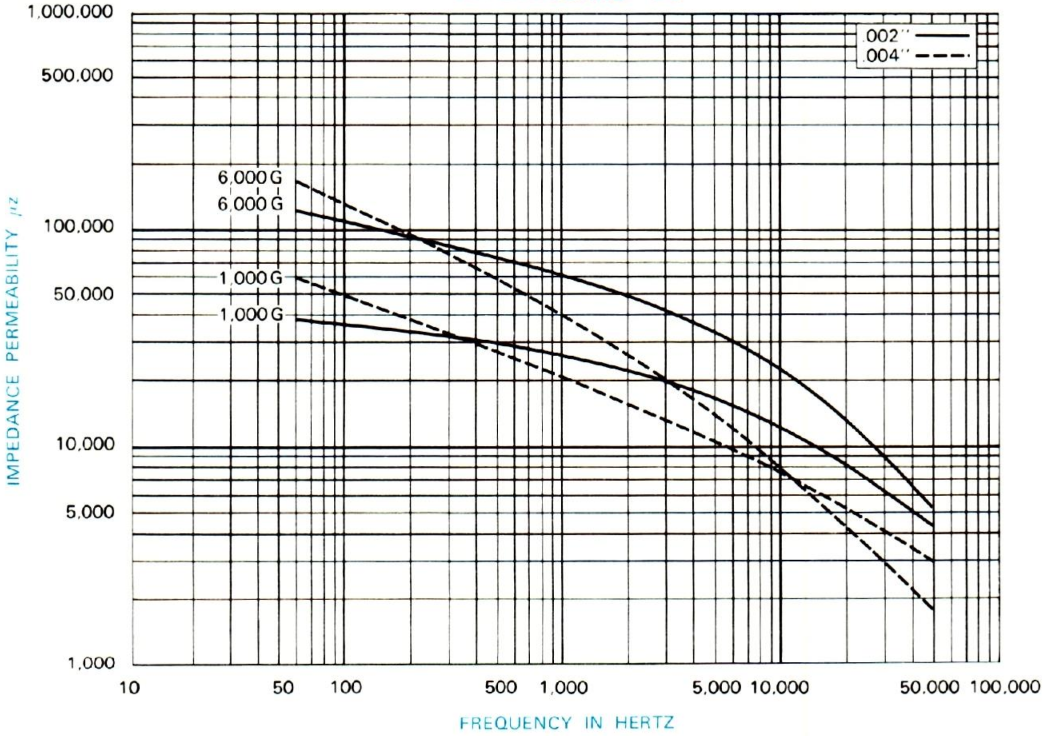
TYPICAL CCFR CONTROL CURVES
.002″ SUPERSQUARE 80
Variation With Temperature



TYPICAL CORE LOSS CURVES
SUPERSQUARE 80



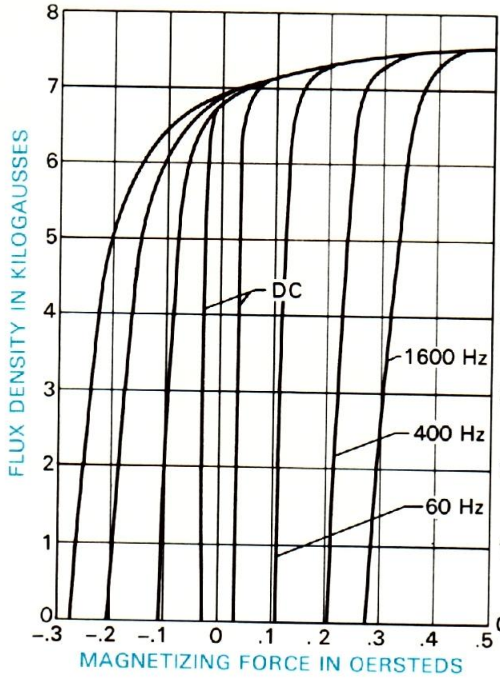
TYPICAL IMPEDANCE PERMEABILITY CURVES
SUPERSQUARE 80



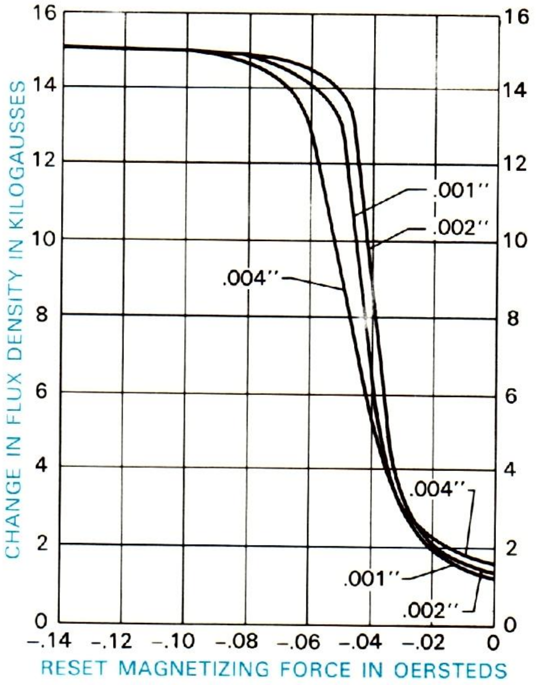
SQUARE 80

80% Ni/Fe/Mo

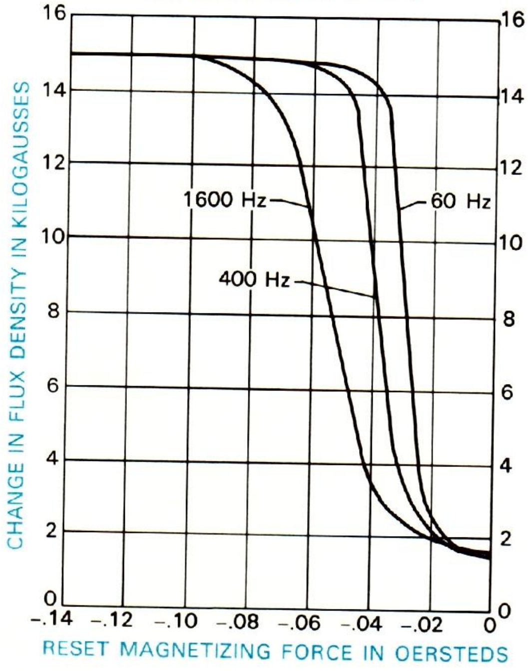
TYPICAL HYSTERESIS LOOPS
.002″ SQUARE 80
Upper Two Quadrants ac Excitation With Sine Current



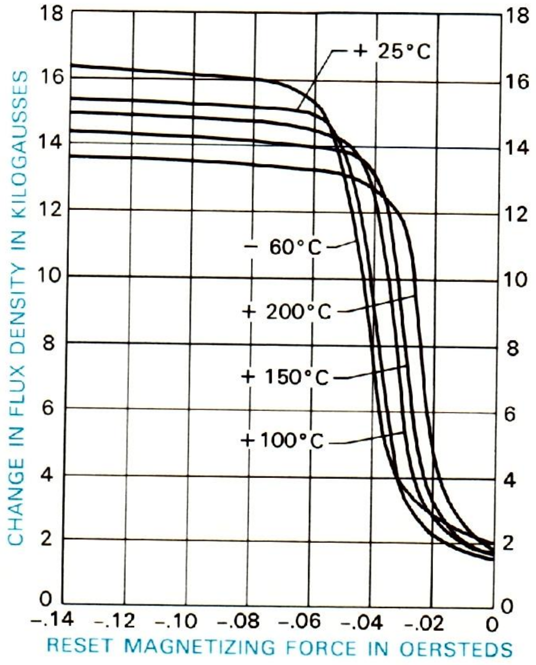
TYPICAL CCFR CONTROL CURVES
SQUARE 80
Variation With Thickness



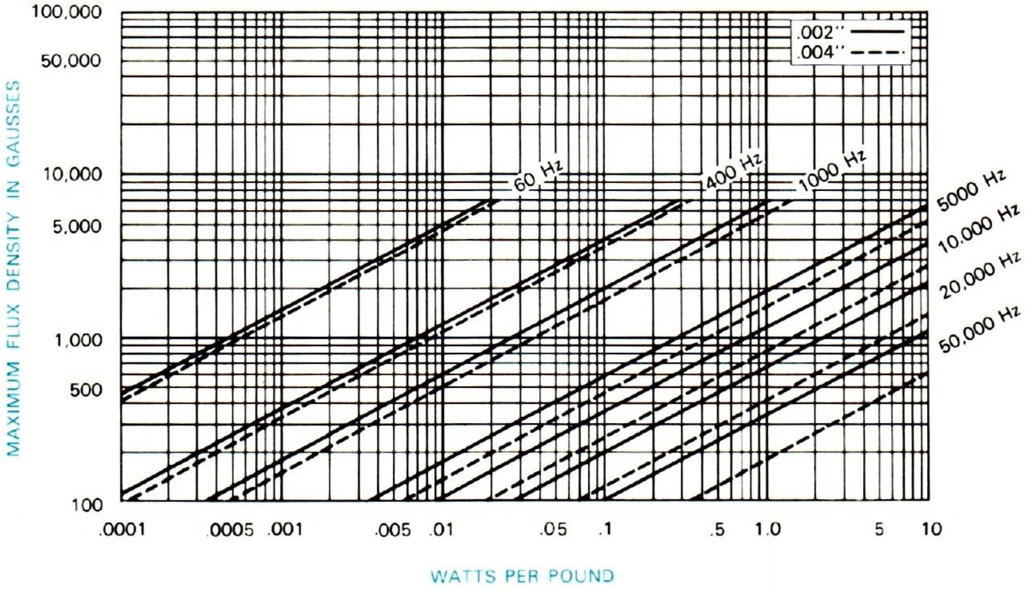
TYPICAL CCFR CONTROL CURVES
.002″ SQUARE 80
Variation With Frequency



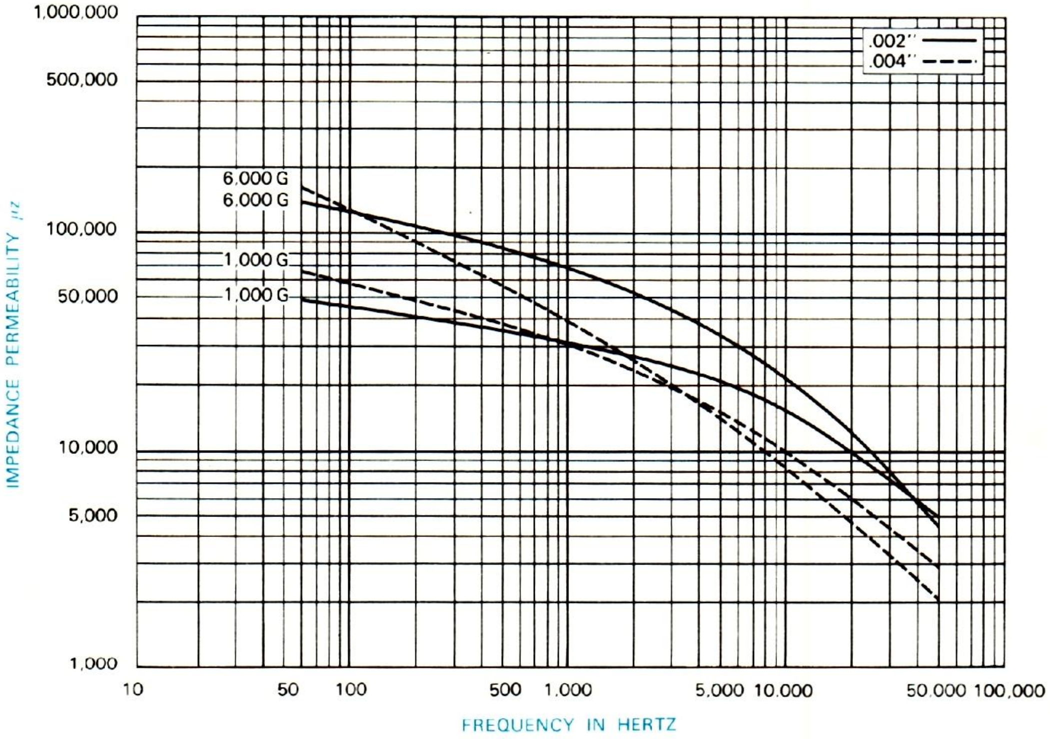
TYPICAL CCFR CONTROL CURVES
.002″ SQUARE 80
Variation With Temperature



TYPICAL CORE LOSS CURVES
SQUARE 80



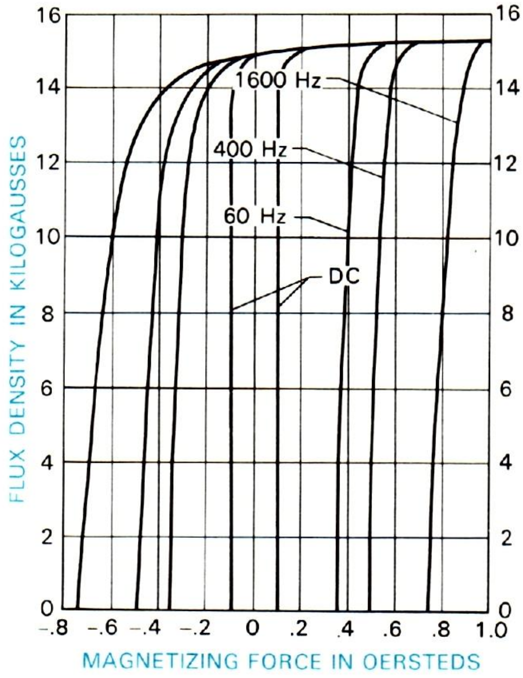
TYPICAL IMPEDANCE PERMEABILITY CURVES
SQUARE 80



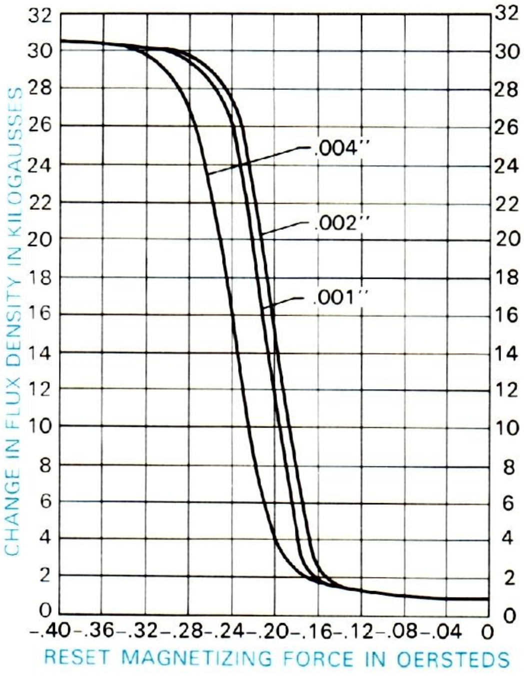
SQUARE 50

Oriented 50% Ni/Fe

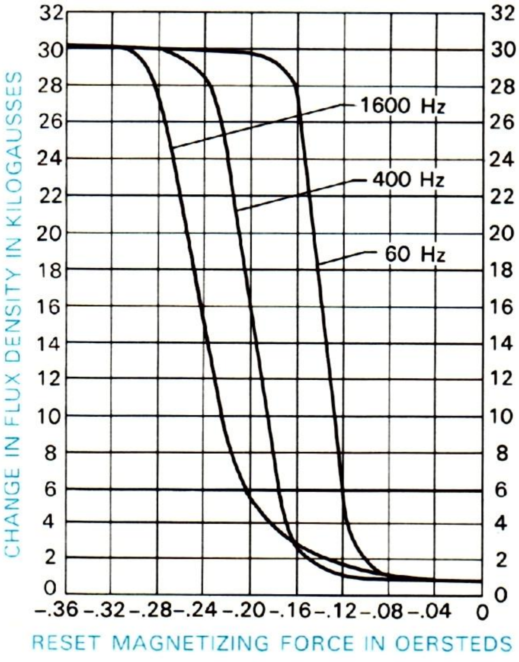
TYPICAL HYSTERESIS LOOPS
.002″ SQUARE 50
Upper Two Quadrants ac Excitation With Sine Current



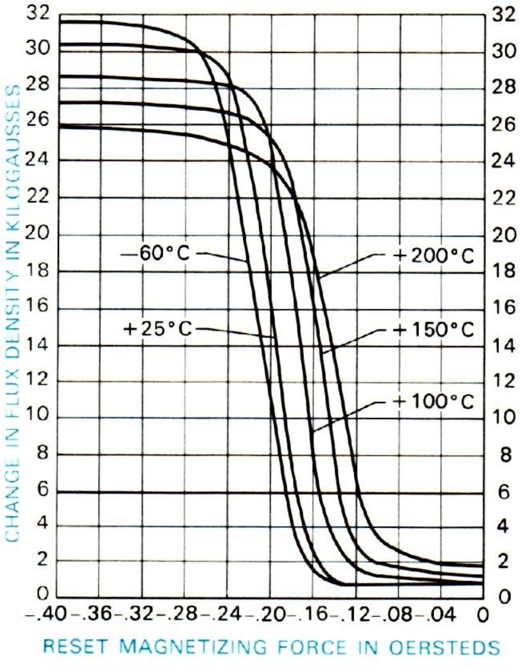
TYPICAL CCFR CONTROL CURVES
SQUARE 50
Variation With Thickness



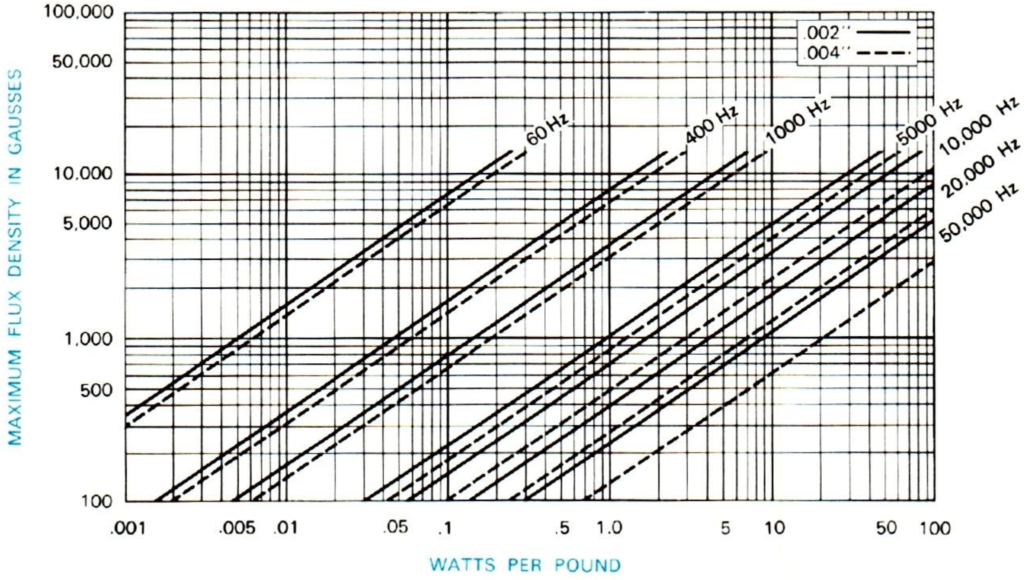
TYPICAL CCFR CONTROL CURVES
.002″ SQUARE 50
Variation With Frequency



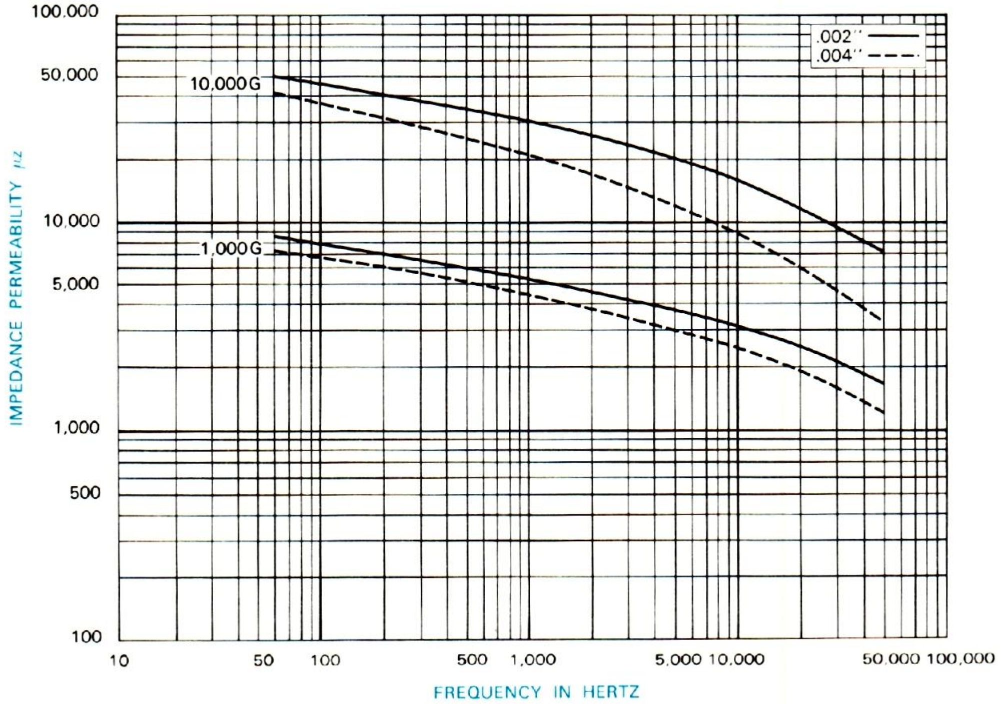
TYPICAL CCFR CONTROL CURVES
.002″ SQUARE 50
Variation With Temperature



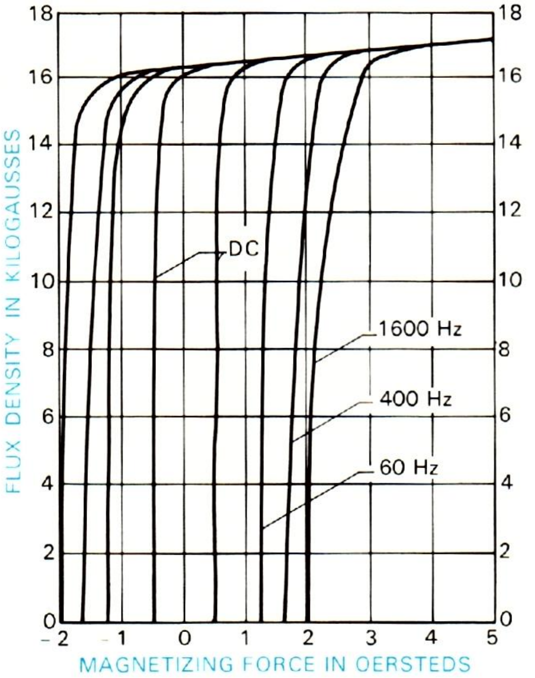
TYPICAL CORE LOSS CURVES
SQUARE 50



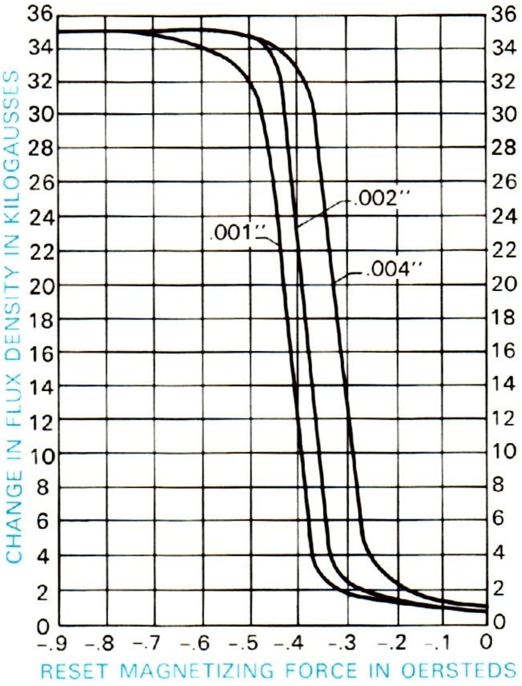
TYPICAL IMPEDANCE PERMEABILITY CURVES
SQUARE 50



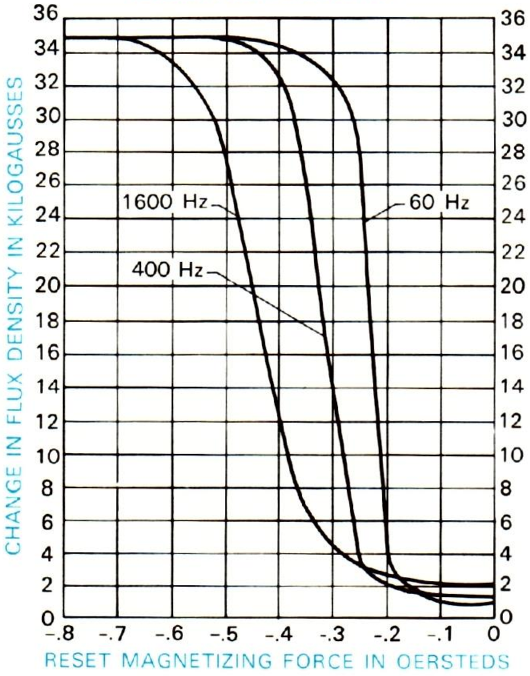
TYPICAL HYSTERESIS LOOPS
.004″ MICROSIL
Upper Two Quadrants ac Excitation With Sine Current



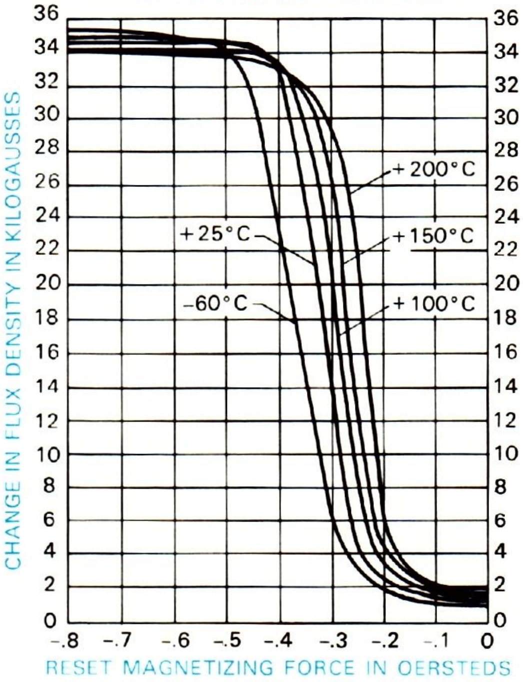
TYPICAL CCFR CONTROL CURVES
MICROSIL
Variation With Thickness



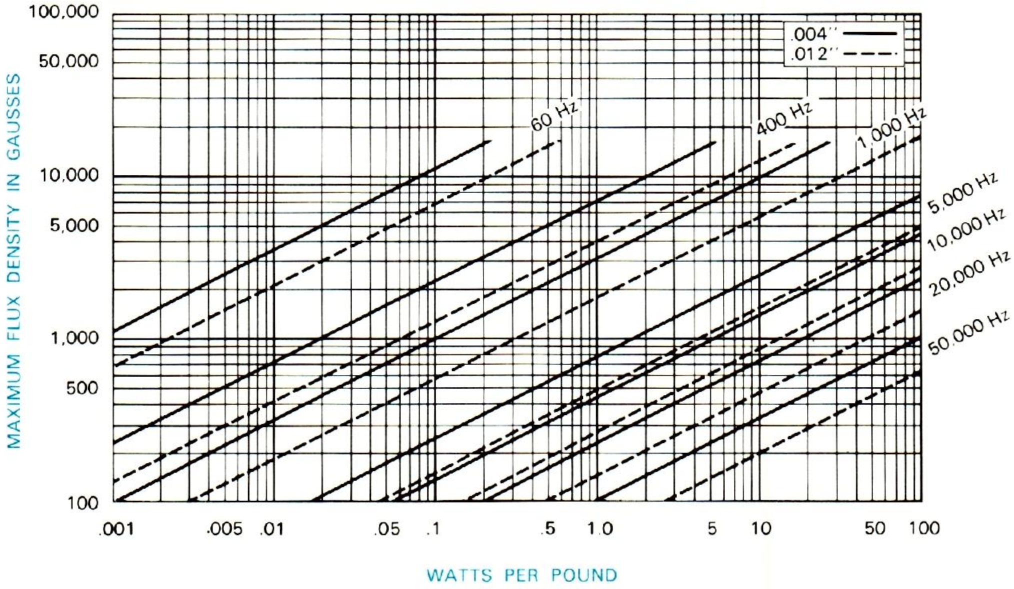
TYPICAL CCFR CONTROL CURVES
.004″ MICROSIL
Variation With Frequency



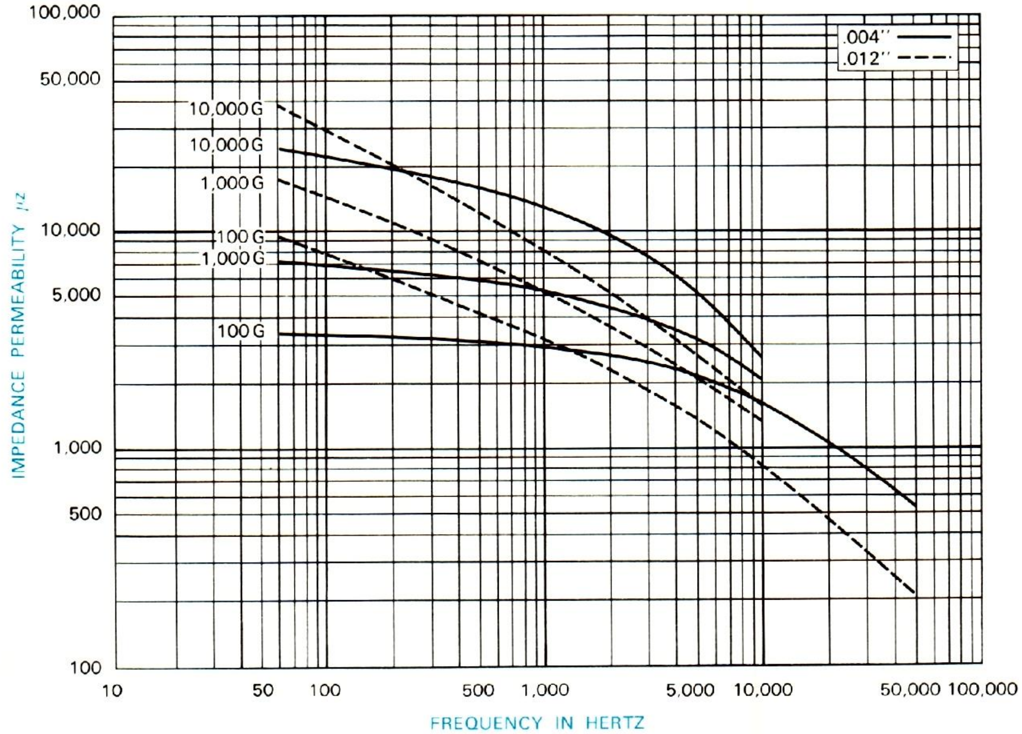
TYPICAL CCFR CONTROL CURVES
.004″ MICROSIL
Variation With Temperature



TYPICAL CORE LOSS CURVES
MICROSIL



TYPICAL IMPEDANCE PERMEABILITY CURVES
MICROSIL

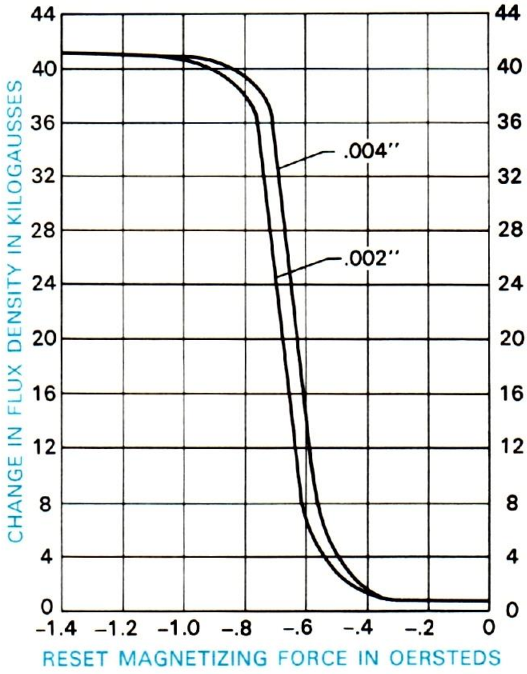


SUPERMENDUR

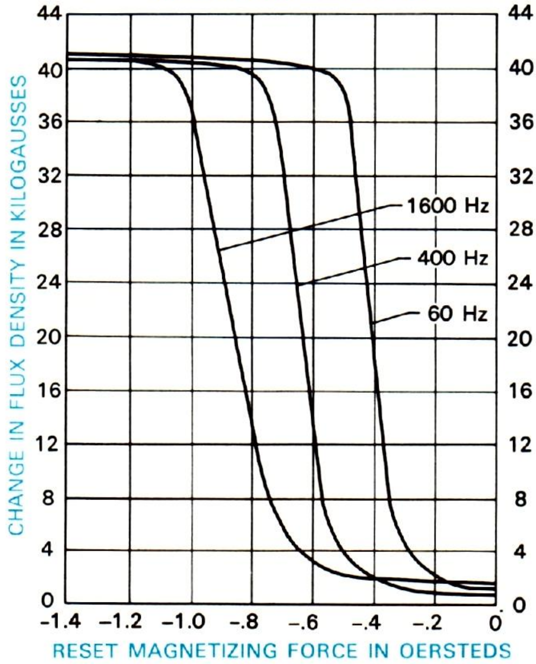
Special 49% Cobalt, 49% Iron, 2% Vanadium

TYPICAL HYSTERESIS LOOPS .004″ SUPERMENDUR Upper Two Quadrants ac Excitation With Sine Current

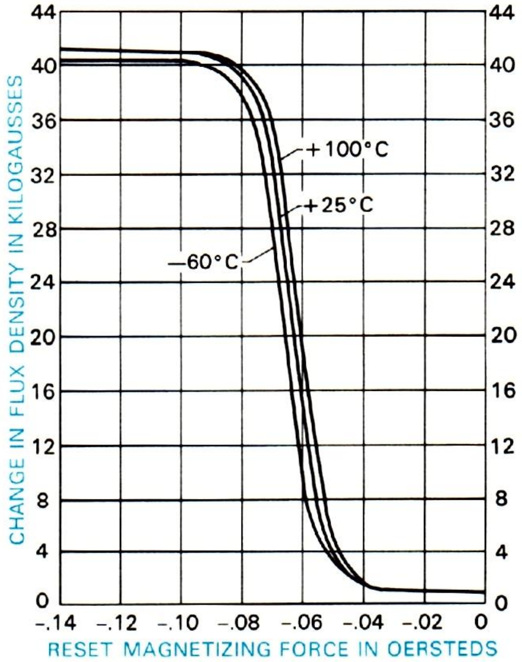
TYPICAL CCFR CONTROL CURVES SUPERMENDUR Variation With Thickness



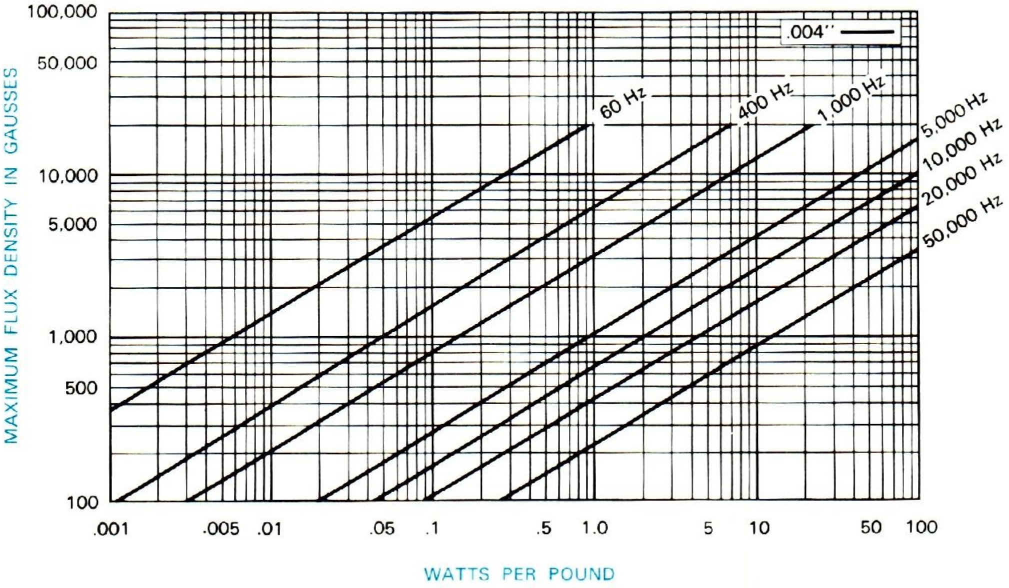
TYPICAL CCFR CONTROL CURVES .004″ SUPERMENDUR Variation With Frequency



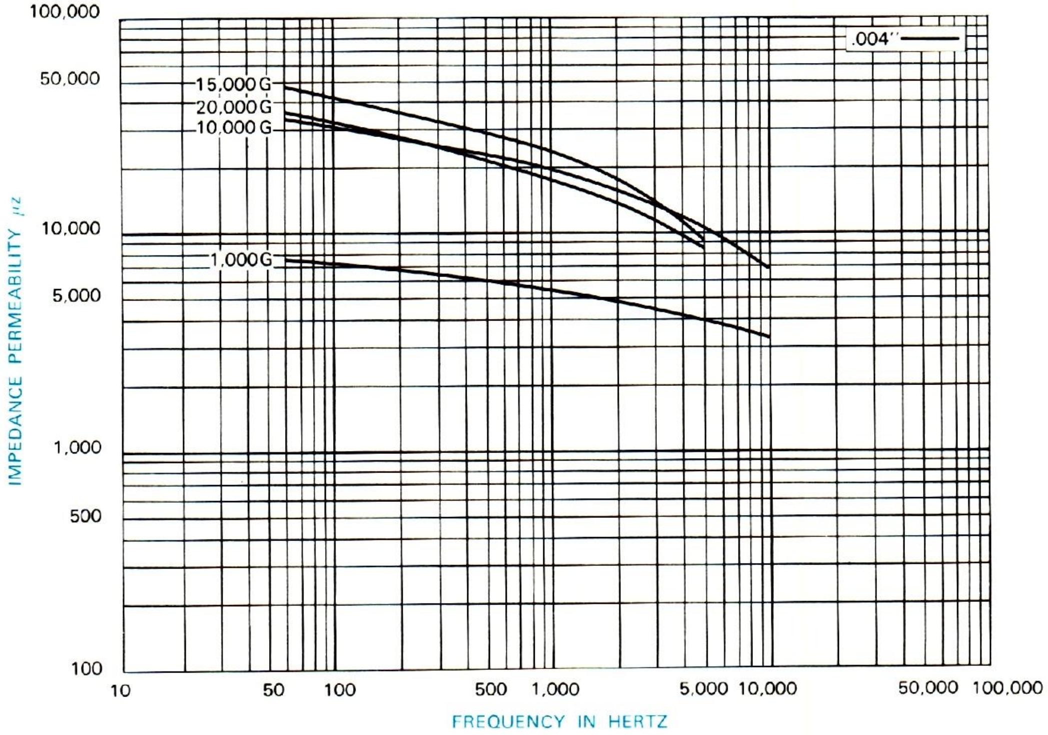
TYPICAL CCFR CONTROL CURVES .004″ SUPERMENDUR Variation With Temperature

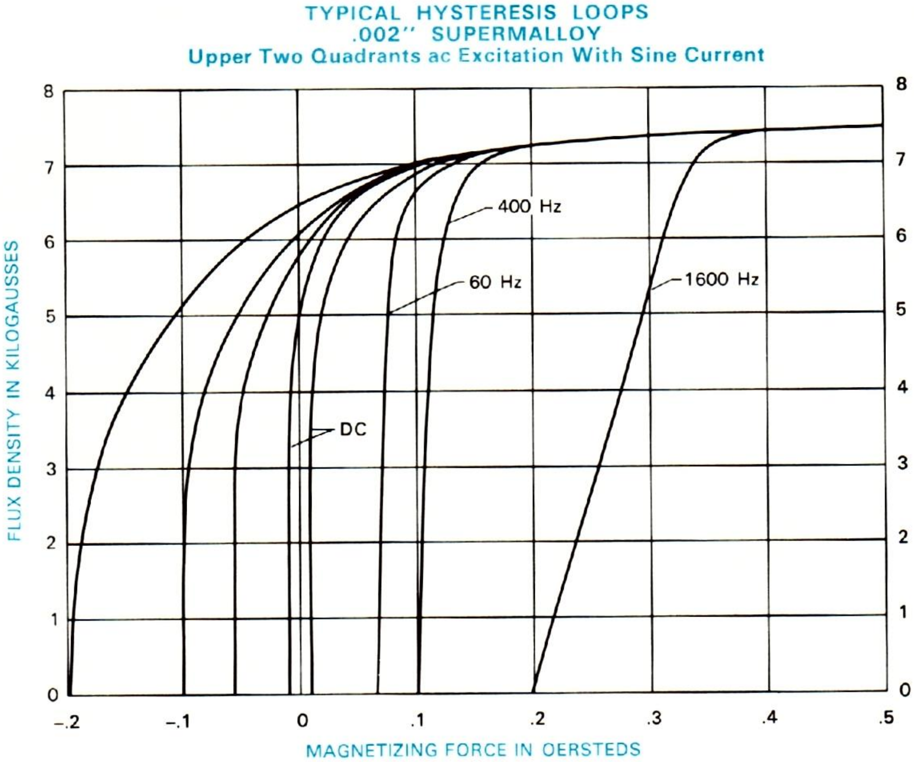


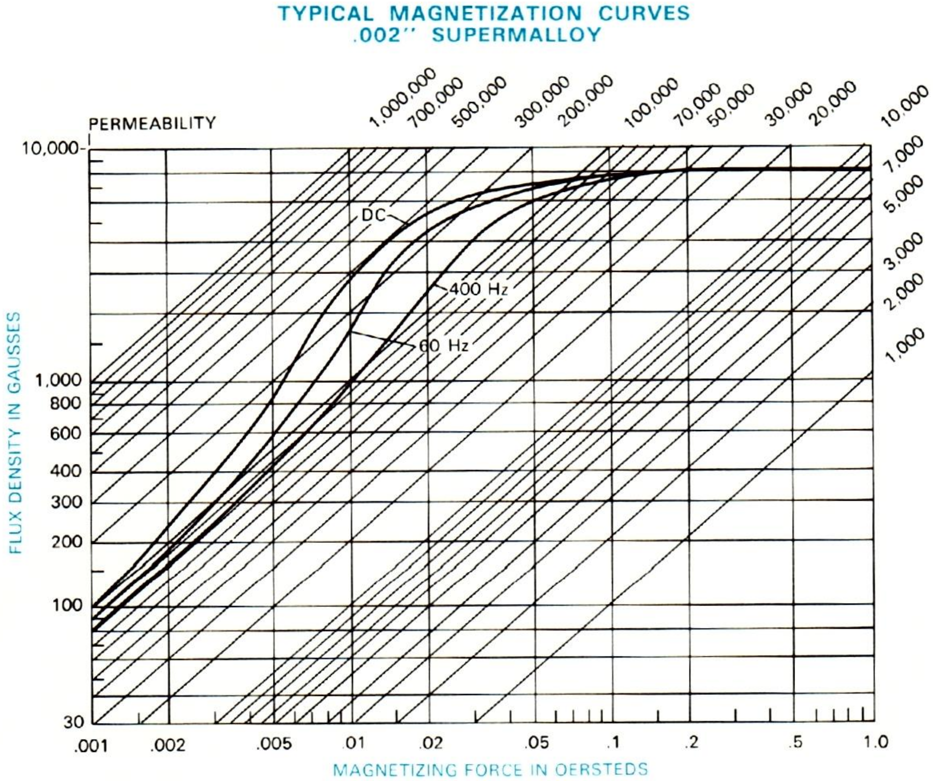
TYPICAL CORE LOSS CURVES
SUPERMENDUR



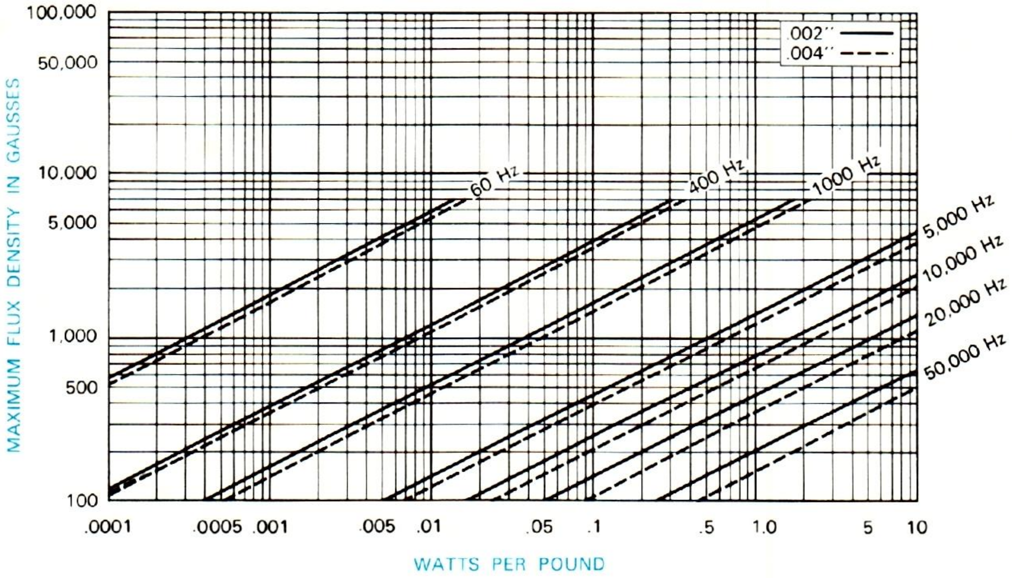
TYPICAL IMPEDANCE PERMEABILITY CURVES
SUPERMENDUR



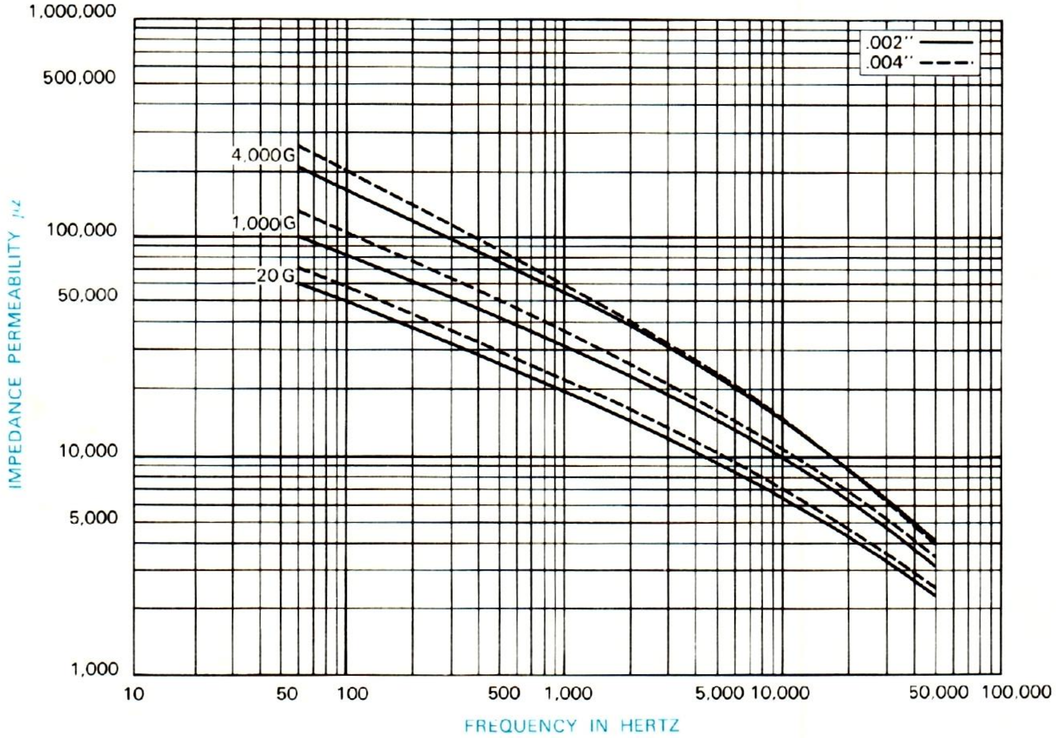

TYPICAL HYSTERESIS LOOPS
.002″ SUPERMALLOY
Upper Two Quadrants ac Excitation With Sine Current
FLUX DENSITY IN KILOGAUSSES
0
1
2
3
4
5
6
7
8
MAGNETIZING FORCE IN OERSTEDS
−.2
−.1
0
.1
.2
.3
.4
.5
DC
60 Hz
400 Hz
1600 Hz


TYPICAL MAGNETIZATION CURVES
.002″ SUPERMALLOY
PERMEABILITY
1,000,000
700,000
500,000
300,000
200,000
100,000
70,000
50,000
30,000
20,000
10,000
7,000
5,000
3,000
2,000
1,000
FLUX DENSITY IN GAUSSES
10,000
1,000
800
600
400
300
200
100
30
MAGNETIZING FORCE IN OERSTEDS
.001
.002
.005
.01
.02
.05
.1
.2
.5
1.0
DC
400 Hz
60 Hz

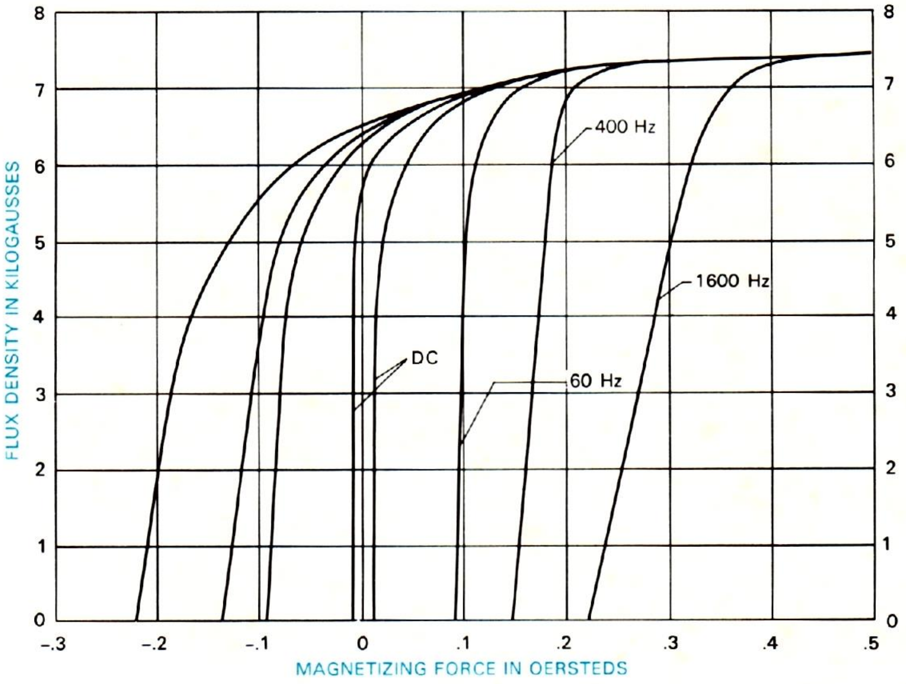
TYPICAL CORE LOSS CURVES
SUPERMALLOY



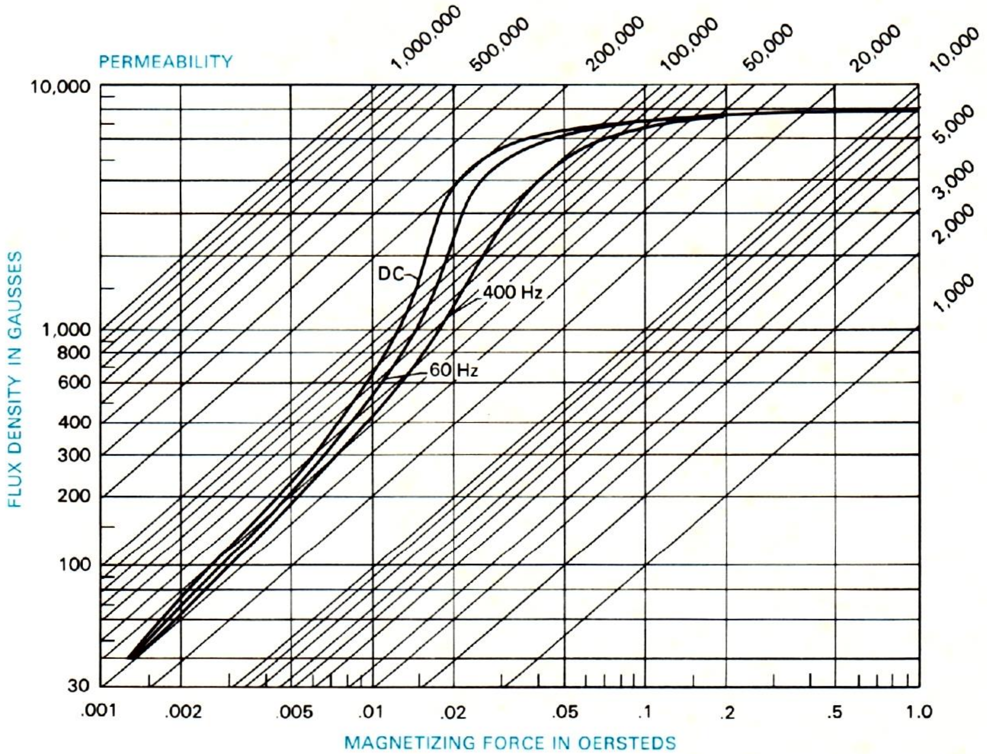
TYPICAL IMPEDANCE PERMEABILITY CURVES
SUPERMALLOY



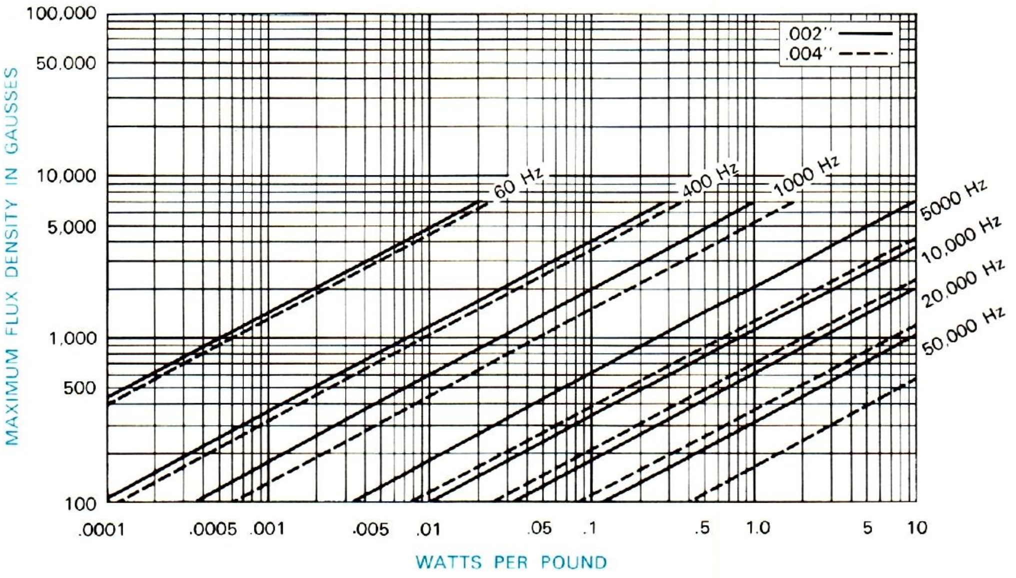
TYPICAL HYSTERESIS LOOPS
.002" SUPERPERM 80
Upper Two Quadrants ac Excitation With Sine Current



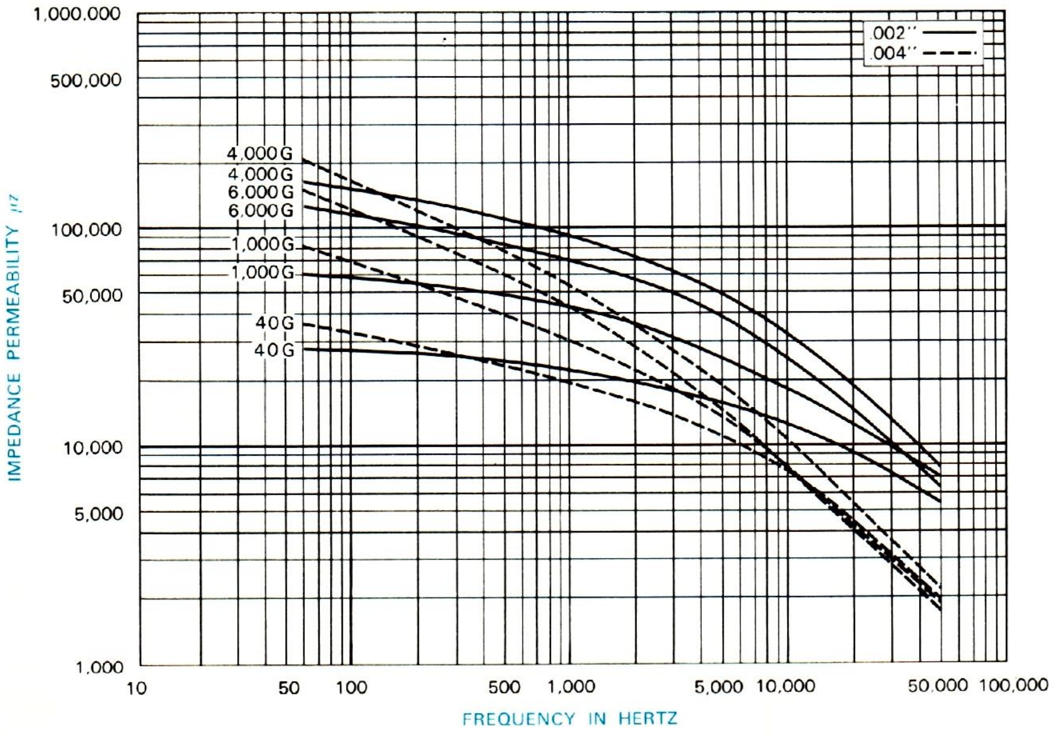
TYPICAL MAGNETIZATION CURVES
.002" SUPERPERM 80



TYPICAL CORE LOSS CURVES
SUPERPERM 80



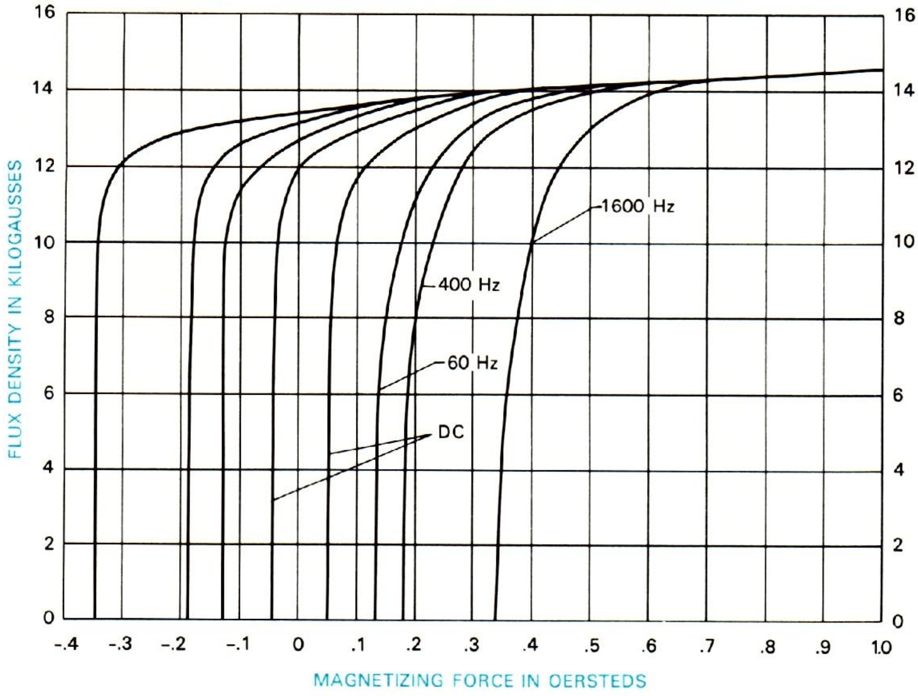
TYPICAL IMPEDANCE PERMEABILITY CURVES
SUPERPERM 80



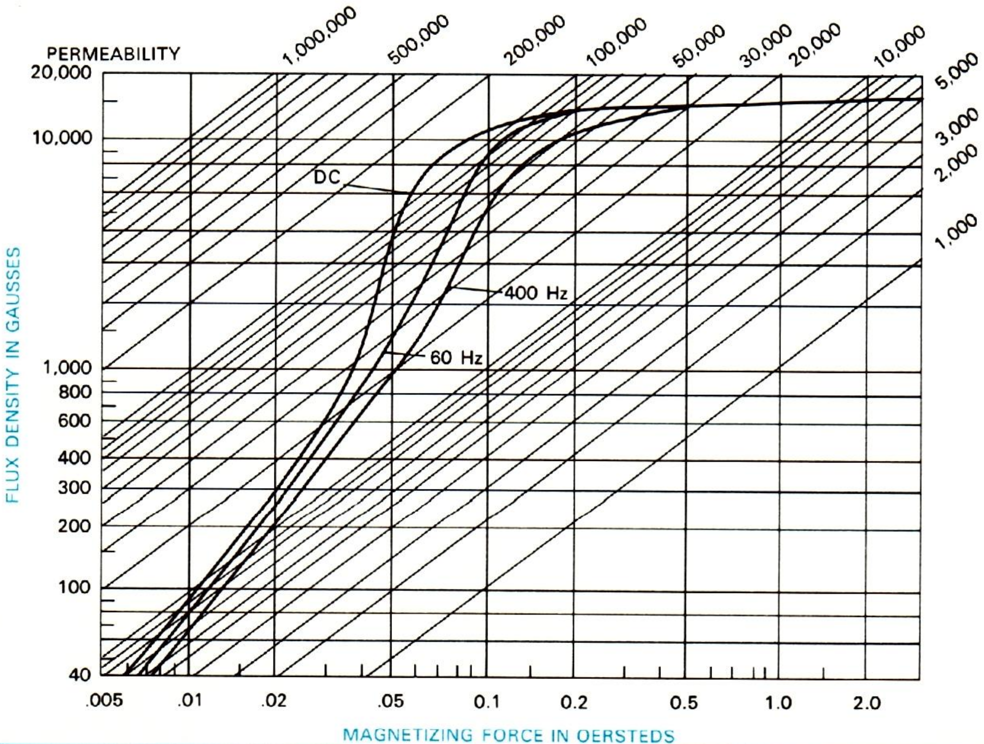
SUPERPERM 49

50% Ni/Fe

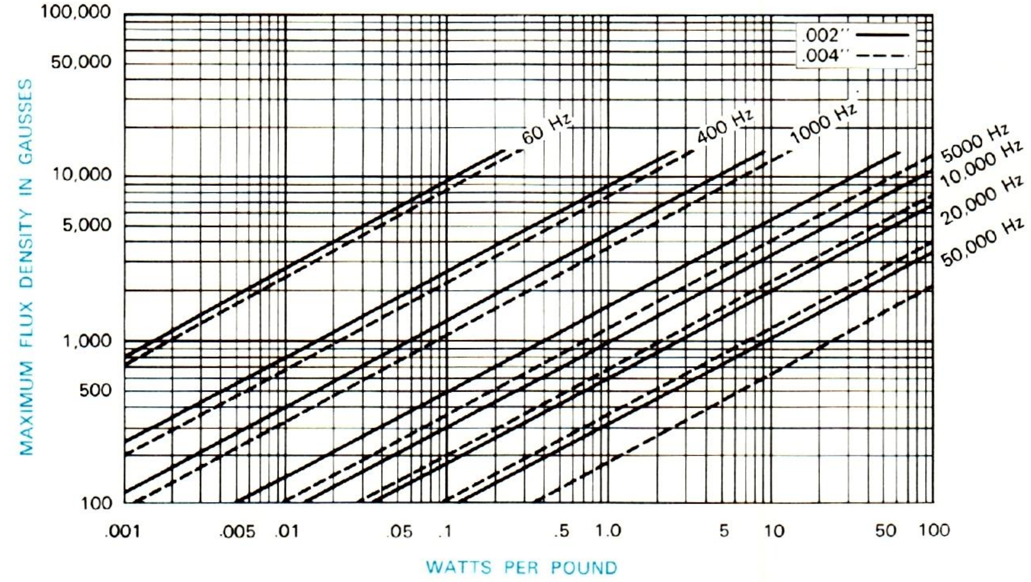
TYPICAL HYSTERESIS LOOPS
.002″ SUPERPERM 49
Upper Two Quadrants ac Excitation With Sine Current



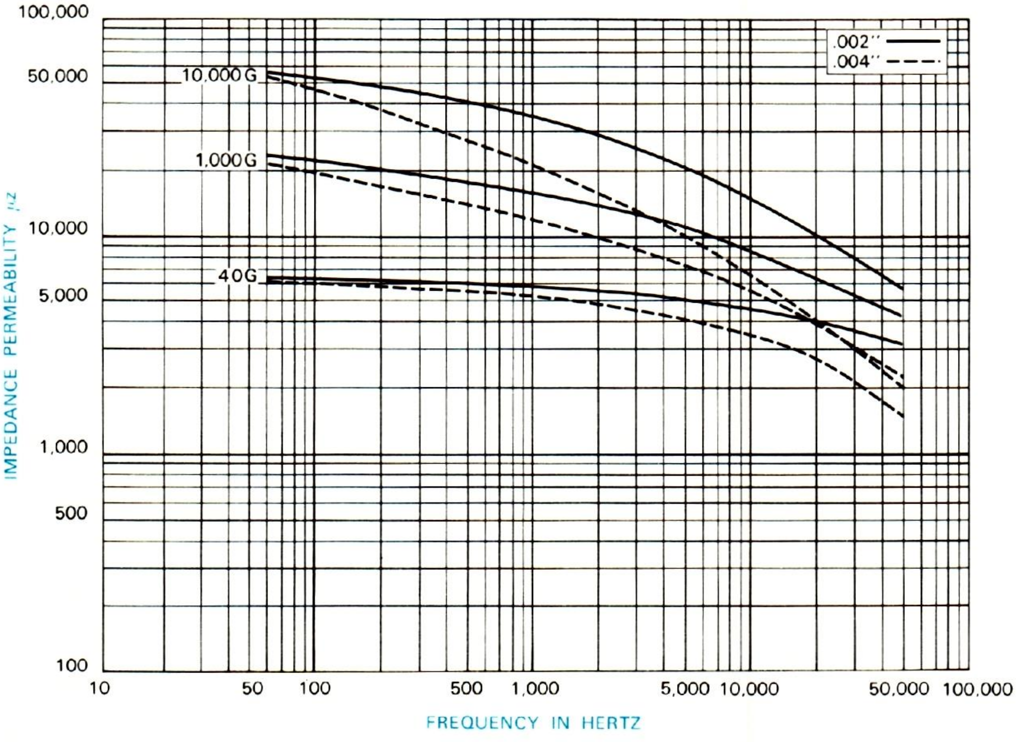
TYPICAL MAGNETIZATION CURVES
.002″ SUPERPERM 49



TYPICAL CORE LOSS CURVES
SUPERPERM 49



TYPICAL IMPEDANCE PERMEABILITY CURVES
SUPERPERM 49



TAPE WOUND CORE CONFIGURATION

The tape wound core approaches the perfect magnetic circuit configuration. A review of the physical and magnetic characteristics of the toroidal shape reveals many features which contribute to this near-perfect circuit.

The effective air gap in the magnetic path is so small that it can be considered non-existent. This minimizes losses, fringing, leakage, distortion, and decreases the magnetizing force necessary to produce a given flux within the material. Figure 5 illustrates the leakage flux phenomenon in comparison to conventional "E" laminations and "cut cores."

In a toroidal core and coil assembly, the entire magnetic path is contained within the electrical winding, further minimizing leakage flux and increasing winding-to-winding coupling. Figure 6 illustrates this effect in comparison to the lamination and the cut core.

The tape wound core configuration also provides a good degree of self-shielding from external magnetic fields. The single, uniform, magnetic path causes any entering magnetic field to split into two and induce equal but opposite voltages in the two halves of a uniformly distributed winding. Thus, there tends to be no voltage apparently induced in the total winding. This effect can be achieved somewhat in a cut core, by splitting the windings into two halves, with one half on each leg. However, the areas in which this technique can be applied is minimal, because of the cost consideration. Figure 7 illustrates this self-shielding effect in comparison to the lamination and cut core.

Tape wound cores generate a small flux in the axial direction. This leakage flux can be contained by ring laminations assembled to the top and bottom of the core.

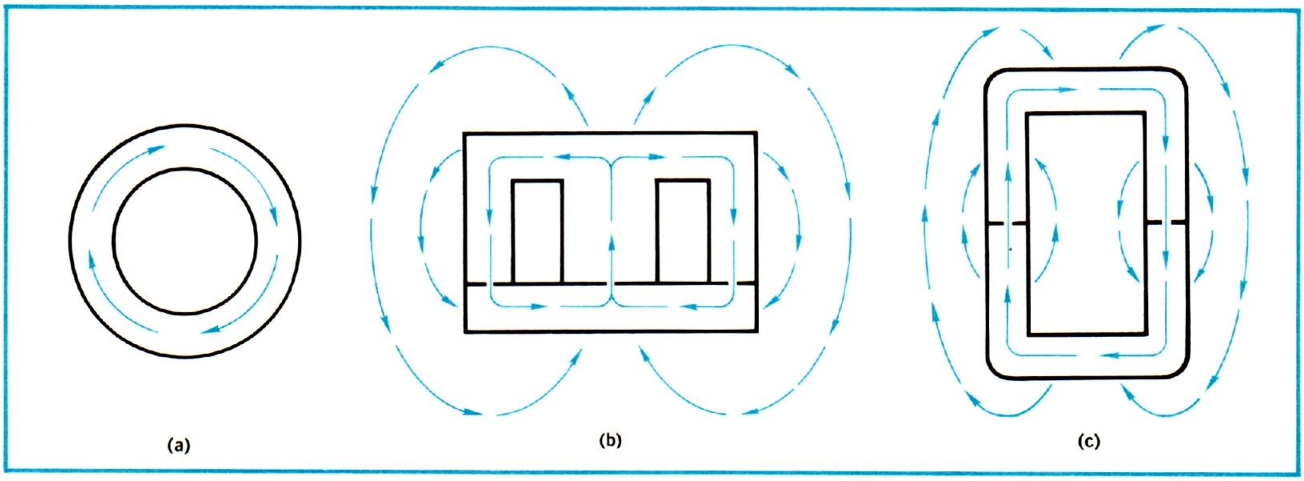


FIGURE 5 — Magnetic and leakage paths of (a) Toroidal Core; (b) stack of E-1 Laminations; (c) Cut Core. This shows the low leakage flux characteristics of a Toroid.

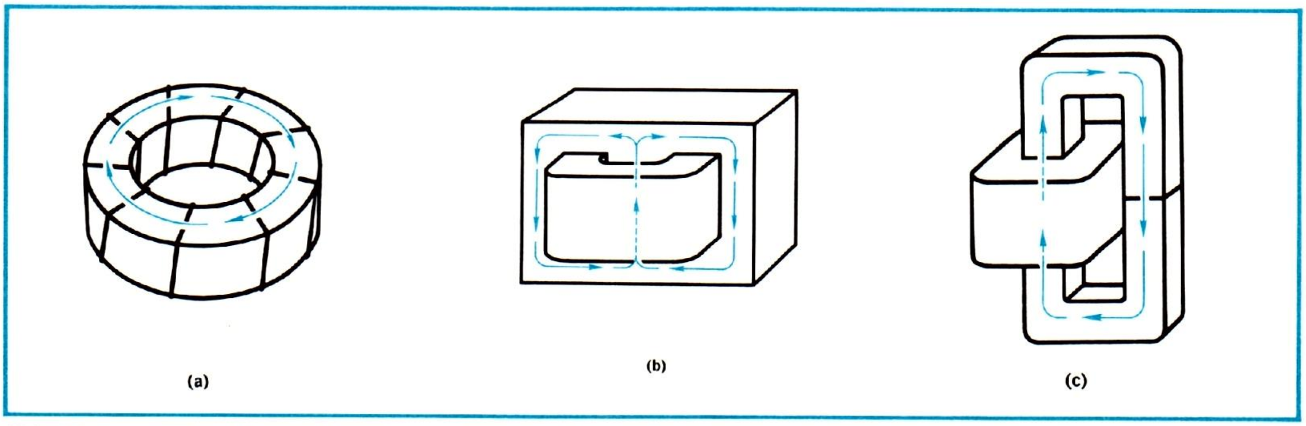


FIGURE 6 — Toroidal Core (a) contains the magnetic flux path within the winding as compared to shell-type Laminated Core (b) and Cut Core (c), where paths are completed outside the winding.

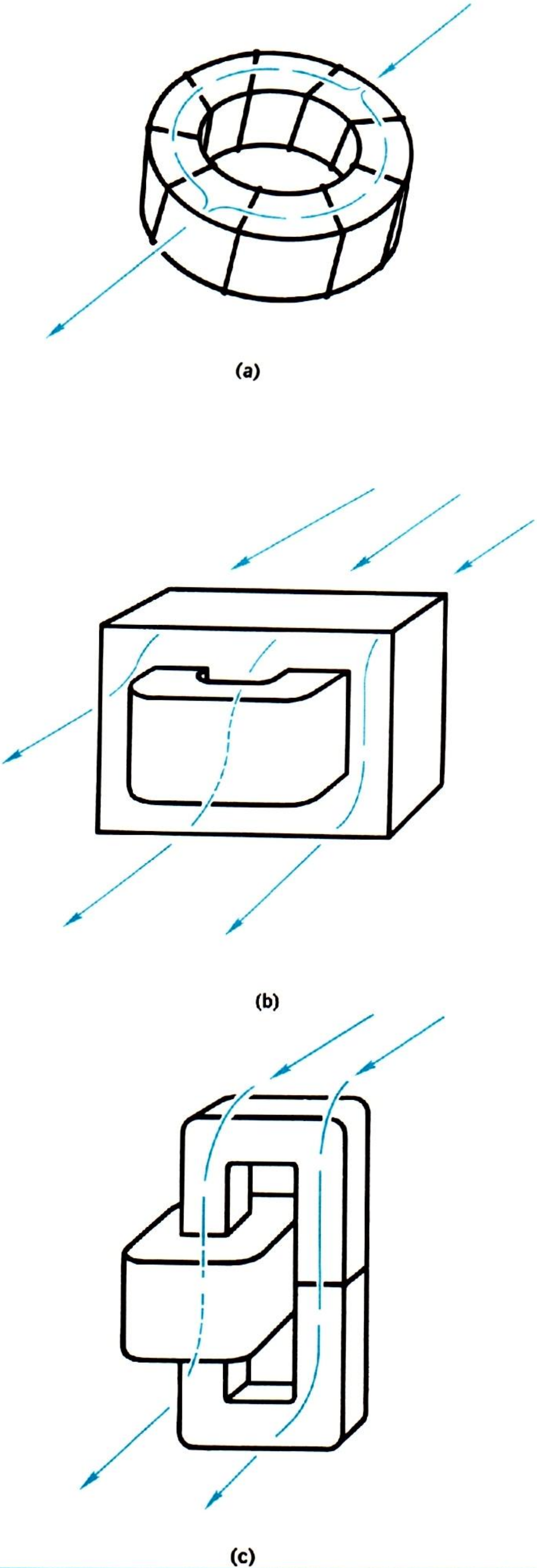


FIGURE 7 — Stray field divides equally in Toroid (a), passes through coils/cores in random fashion in Laminated Core (b) and Cut Core (c).

More complete shielding of any configuration is achieved through the use of Magnetic Metals' Shieldmu, an extremely versatile and convenient shielding material. Magnetic Metals also offers a complete facility for the drawing and fabricating of any type shielding enclosure. Contact the Camden office or your Magnetic Metals Sales Representative for more details on Shieldmu and fabricated and drawn shields. (See Magnetic Metals' Electromagnetic Shielding Design Manual.)

The stamped ring core and the DU lamination are other useful magnetic circuit configurations. Many engineers design around stamped ring cores to achieve superior stability and other special properties. Cores of DU laminations possess many of the advantages seen in the toroidal structure.

TAPE WOUND CORE TESTING

Constant Current Flux Reset Test

The Constant Current Flux Reset (CCFR) test is widely used to evaluate core performance for magnetic amplifier use. The test is described in IEEE Standard Paper No. 106. The ac excitation is usually specified at 400 hertz, but frequencies between 60 and 6000 hertz may also be specified. The test circuit is shown in Figure 8.

With zero dc control current and full wave ac sine current excitation (diode shorted), the current in "*R*" is set to a specified value sufficient to give maximum flux change. The flux change develops a voltage in winding "*O*" which is indicated by the integrating flux voltmeter.

Insertion of the diode in the ac excitation circuit (switch open) changes the current to half sine wave and the core flux then varies between B_m and B_r, the residual flux level. The flux voltmeter now indicates $B_m - B_r$.

Adjusting the dc level in winding "D" resets the flux from B_r to other values as shown in the B-H loops, drawn in Figure 9. Plotting flux change against reset magnetizing force gives a

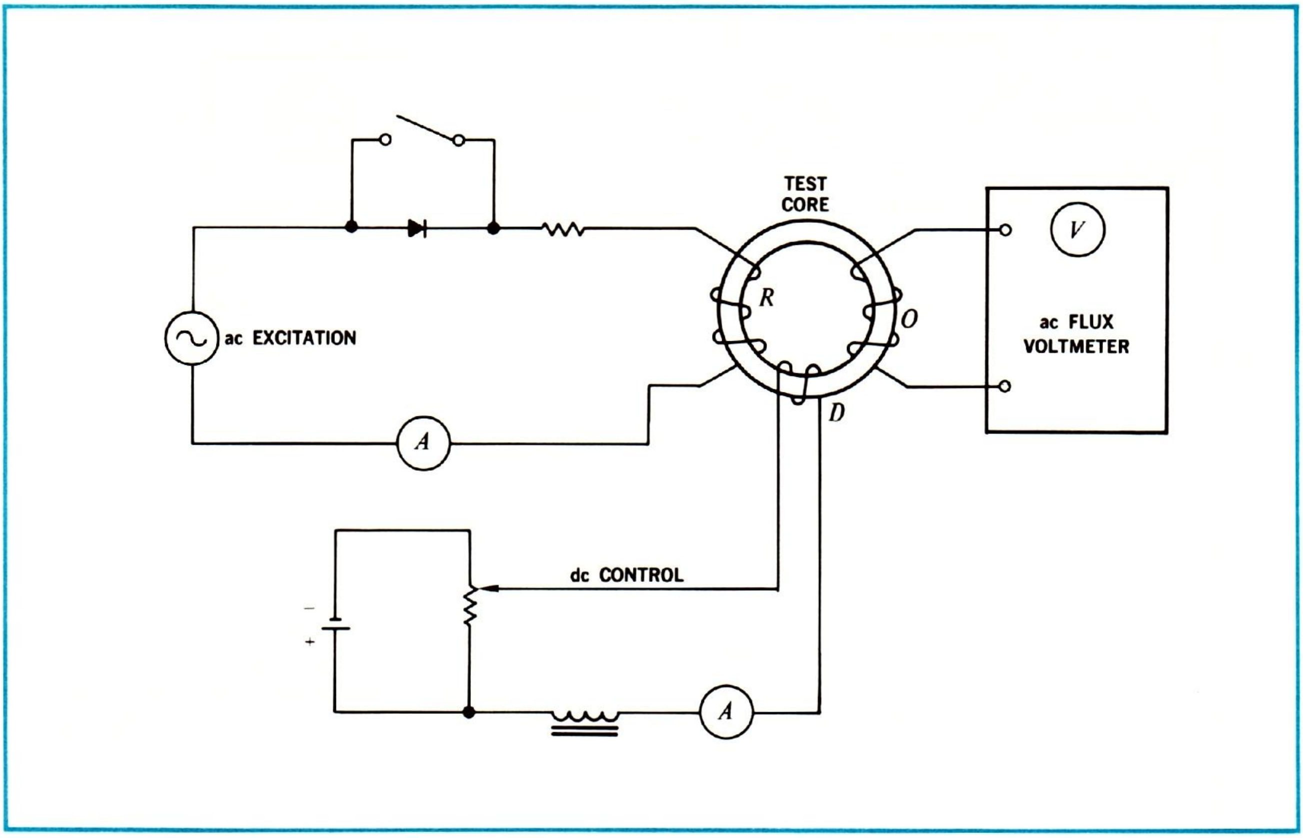


FIGURE 8 — Basic constant current flux (CCFR) test circuit.

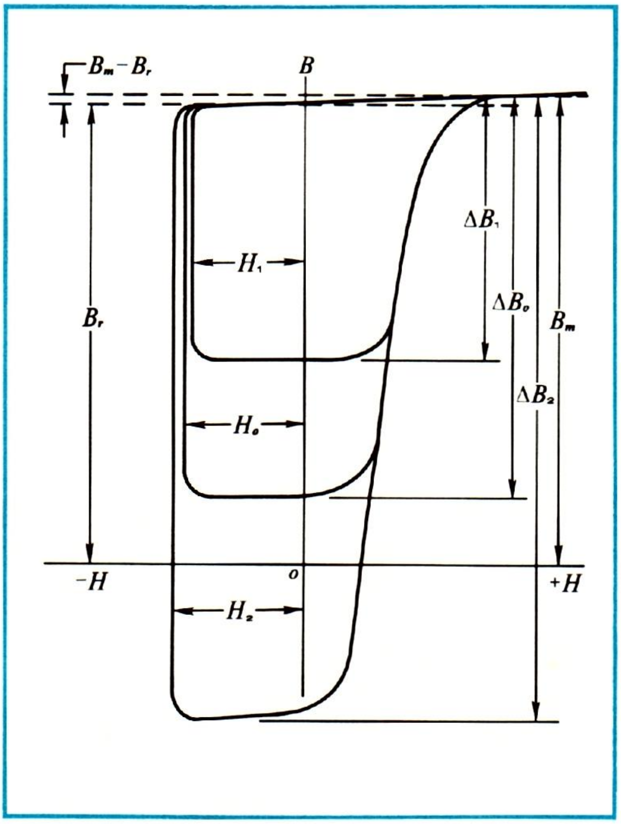


FIGURE 9 — CCFR hysteresis loops.

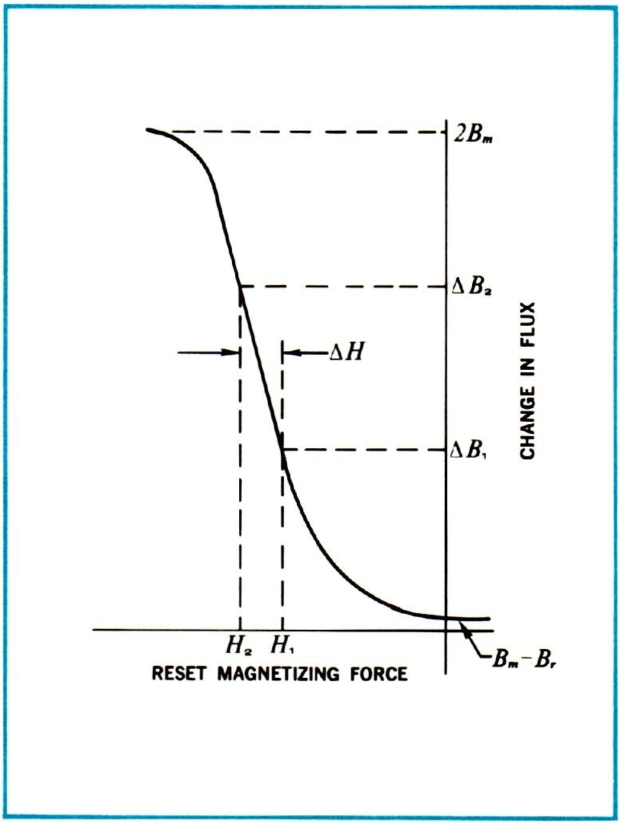


FIGURE 10 — CCFR transfer curve.

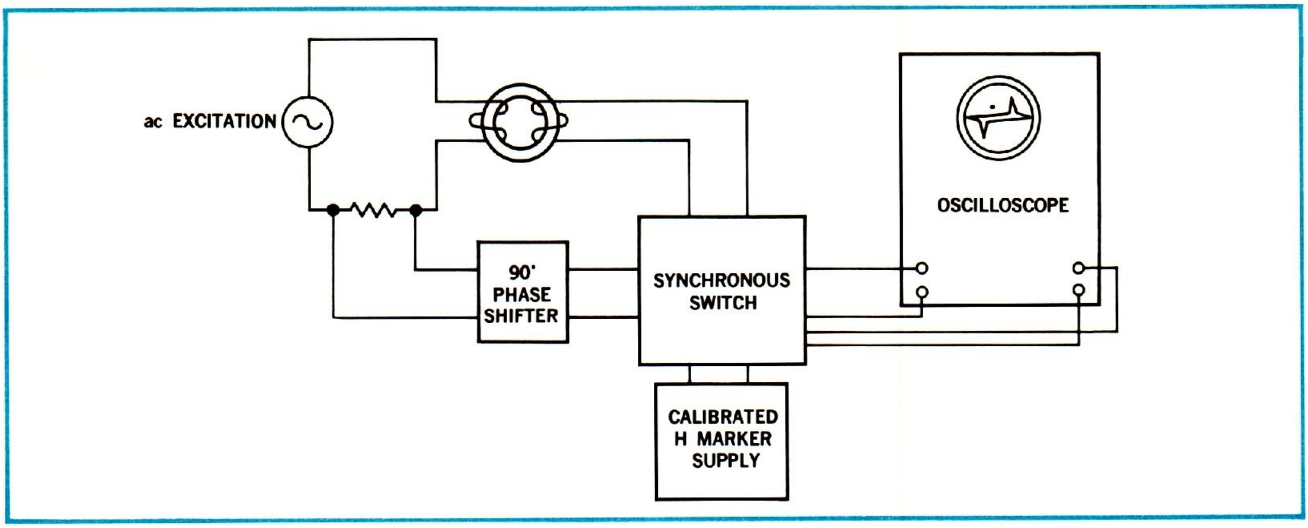


FIGURE 11 — Basic sine current test circuit.

curve as shown in Figure 10. Standard test data are determined by reading H_1, the reset magnetizing force required to obtain a flux change of ΔB. This is approximately one-third of $2B_m$. ΔH is the additional magnetizing force required for an additional one-third flux change. The ratio of $\Delta B_2 - \Delta B_1$ to ΔH is expressed in kilogausses per oersted; the inverse of this is referred to as the "gain".

Sine Current Test

The Sine Current Test (sometimes referred to as the E-I Loop Test) has also been standardized by IEEE Standards Paper #106.

Figure 11 indicates this basic test circuit which produces, on an oscilloscope, a visual display of the voltage (E) versus the current (I) used to produce the change in flux. Figure 12 shows this display in detail.

The previously calibrated dials of Figure 11 are adjusted to have the peak of the E-I loop (sometimes referred to as the "Butterfly" loop) intersect the permeability ellipse and the coercive force marker. Peak differential permeability (μ_p) and coercive force (H_c) are then read directly from the dials.

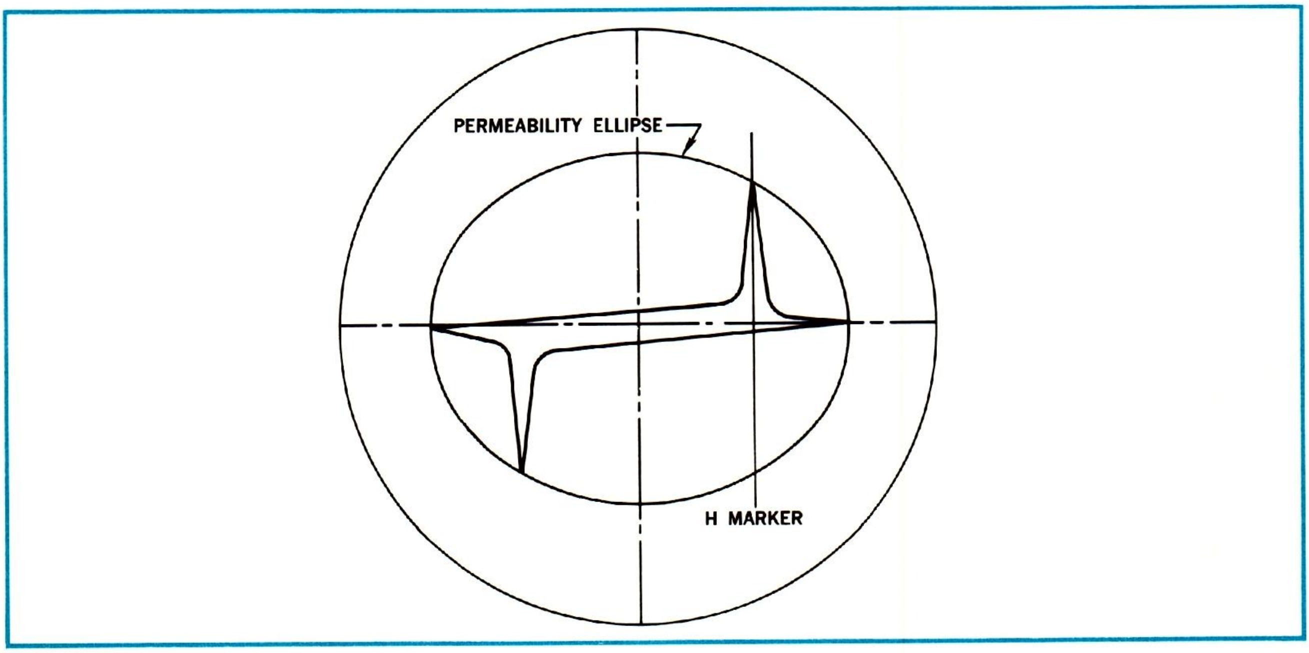


FIGURE 12 — Sine current E-I loop display.

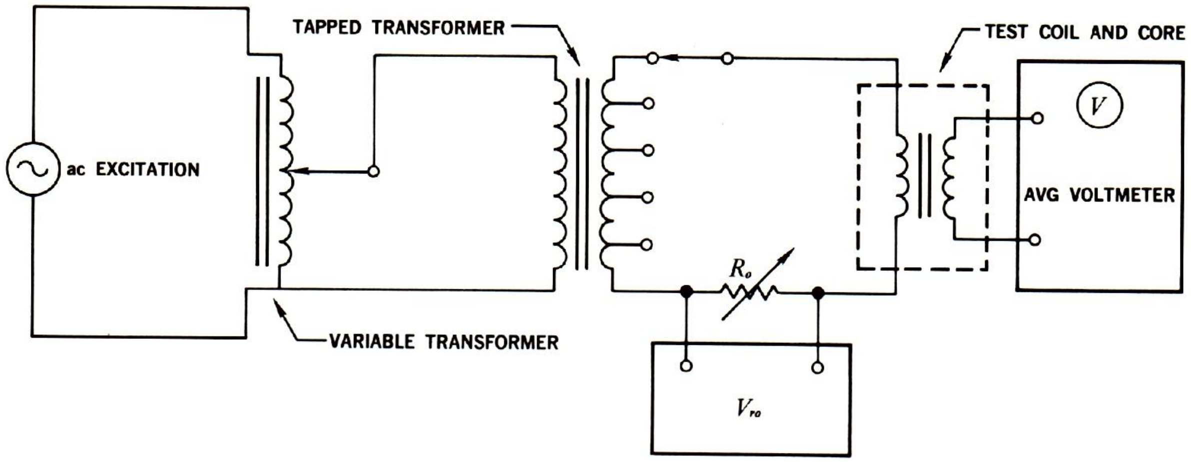


FIGURE 13 — Basic ac permeability test circuit.

ac Permeability

Since the permeability of all magnetic materials varies with flux or excitation level and frequency, it is customary to specify the flux level and test frequency when measuring permeability.

Of most interest is the initial permeability, usually measured at 40 gausses, 60 hertz. Generally, the initial permeability of a core is an indication of the type of permeability characteristics that can be expected at other levels. For low inductions a test procedure similar to that outlined in ASTMA-346-64 is employed. See Figure 13. The usual test conditions are shown in Table XII for round loop materials. (See page 18.)

Other Tests

Depending upon the specific requirements and application, additional tests such as dc ballistic, Dynamic Hysteresis Loop, Pulse, etc., are available as required.

Core Matching

Most cores are matched by the E-I loop or the CCFR method. In the E-I loop method, loops are displayed simultaneously on an oscilloscope and compared point by point. In the CCFR method, cores are matched according to their values of B_m, H_1 (usually within 5%) and ΔH (within 10%). For general purposes, the E-I loop method provides more critical matching because it compares cores over the entire loop, whereas the CCFR method checks only four points. However, where gain must be closely matched, the CCFR technique is preferred.

Where close matching is critical to the performance of a component it is suggested that matching be verified after addition of the copper wire winding. This test of the wound assembly matches its resistances, capacitances and possible effects of winding strain.

APPLICATIONS OF TAPE WOUND CORES

Signal Transformers

Most signal transformers have rather low level, continuously varying voltages applied to the primary — and they have relatively high impedance loads on the secondary. For such applications, it is necessary that the primary have a high open circuit inductance, (OCL), low resistance, low core loss, and low phase shift — all of which are inter-related. In most closed loop servo systems where many signals may be added together, low phase shift of each signal is a pre-requisite to insure low quadrature nulls. And where the transformer is operated over a wide frequency range, attention must be given to minimizing inter/intra winding capacitance.

Since the impressed primary voltage is usually low, the core flux will also be quite low . . . and the transformer will normally have a primary inductance directly proportional to the initial permeability of the core. A comparison of initial permeability between toroidal tape wound cores, and laminations, regardless of the material, will indicate that the toroidal shape is the only logical choice for a signal or input transformer. This is especially true if additional consideration is given to the natural shielding abilities of the toroid. Using SuperPerm 80 or Supermalloy, it is not unusual to obtain a low level inductance of as much as a thousand henries on a core as small as ½" × ¾" × ⅛" high. (This is our size 2).

Design Notes

a. Make certain the primary turns are sufficient to limit the maximum flux (for the maximum anticipated primary voltage, at the minimum anticipated frequency) to less than the B_m of the selected core material.

$$B_m = \frac{10^8 E_p}{4.44 A N_p f}$$

Both the values of B_m and the magnetizing force required are plotted for each material on pages 20 through 35.

b. In designing very high inductance primaries be certain to check for self resonance, especially in higher frequency applications, and wind for minimum capacitances.

c. The core loss may also be an important factor in determining the component performance in the circuit. It is conveniently determined from the core loss curves for round loop materials shown on pages 30 through 35.

d. Use SuperPerm 80 or Supermalloy.

e. For improved performances, low level signal transformers should be shielded with Shieldmu, Magnetic Metals magnetic foil tape.

Example: The following indicates the sequence used when designing a signal transformer to couple a 10000 ohm amplifier input impedance to a signal chain having a reflected impedance of 100,000 ohms with the transformer operating at 400 Hz, with a maximum of 10 volts applied to the primary.

$$\text{Impedance Ratio} = \frac{\text{PRI}}{\text{SEC}} = \frac{100{,}000}{10{,}000} = 10{:}1$$

$$\text{Turns Ratio} = \sqrt{\frac{Z_p}{Z_s}} = \sqrt{10} = 3.16$$

Assume transformer open circuit impedance is 8 times reflected load;

$$Z_t = 8(100{,}000) = 800{,}000$$

$$OCL = \text{Open Circuit Inductance}$$

$$OCL = \frac{800{,}000}{2\pi f} = \frac{800{,}000}{2512}$$

$$OCL = 318 \text{ hy} - \text{Primary Inductance}$$

Experience shows that high inductances (over 20 henries) require large numbers of turns or large core area — either case normally resulting in relatively low flux densities.

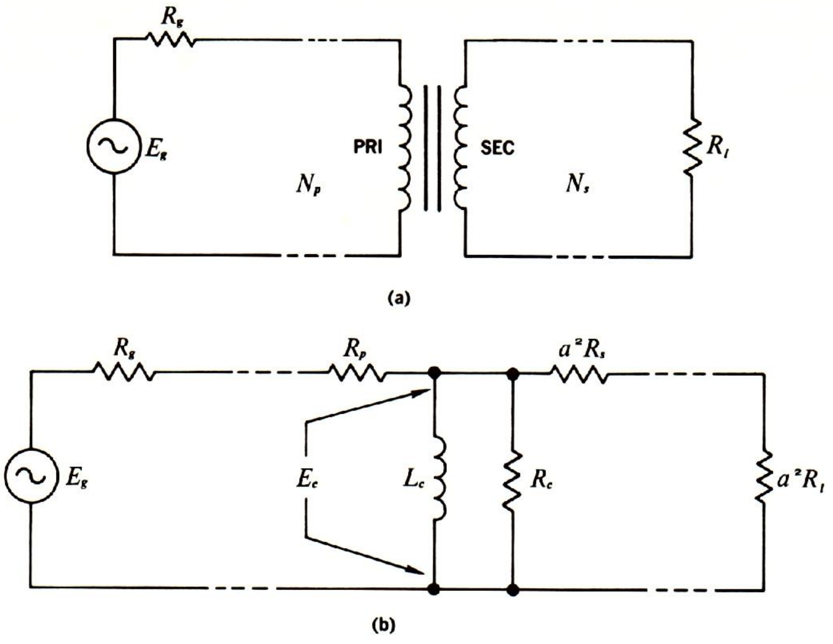
Therefore, assume initial permeability as the minimum permeability — and a Magnetic Metals size 2 core in Supermalloy.

$$318 = \frac{.4(3.14)(.0907)60{,}000 N_p^2}{4.99 \times 10^8}$$

$$N_p^2 = .232 \times 10^7$$

$$N_p = 1.52 \times 10^3 = 1520\text{T} - \text{Primary T}$$

$$N_s = \frac{1520}{3.16} = 482 \text{ T}$$



$a = \frac{N_p}{N_s}$ Alternate calculation of R_c: $R_c = \frac{E_c^2}{P_s W}$

FIGURE 14 — Signal Transformer. (a) Basic circuit diagram, (b) Equivalent circuit.

Total turns 2002 — use #36 wire for primary and secondary.

$$B_m = \frac{10^8(10)}{4.44(.0907)(1520)(400)} = 4080 \text{ gausses}$$

Therefore, core will not saturate.

The circuits and other applicable equations are indicated in Figure 14.

Coupling Transformers

Coupling, or interstage transformers, very often carry a dc component of current in the primary and/or the secondary. Unless the dc component is quite low, or the dc currents balance out (as in a push-pull circuit) and stay balanced out . . . or unless the transformer is decoupled from the dc, the tape wound core will find limited application for coupling transformers. The relatively low dc magnetizing force saturates the core, reducing the permeability, hence the inductance, to a very low value. This may introduce considerable distortion, especially if the transformer is driven from a high impedance source.

Where it is desirable to maintain the toroidal shape, it may be possible to utilize 80% Ni/Fe/Mo powder cores which have a fixed equivalent air gap enabling a considerably larger dc component to be applied to the transformer. Laminations of course, are used where dc is encountered. By varying the lamination size, shape, and especially the air gap, any dc can be accommodated.

Magnetic Metals offers the most complete range of lamination sizes, shapes and materials described in separate bulletins.

The circuit and equations of the coupling transformer are the same as the signal transformer (Figure 14) with the dc component.

Design Notes

a. Make certain the dc flux level is well below the B_m for the selected material when superimposed upon the maximum anticipated ac flux level. Curves on pages 20 through 35 for each material include magnetization curves showing the relationship between B_m and the magnetizing force.

b. Try 50% Ni/Fe alloy (Round 50) or oriented silicon iron alloy (Microsil) for tape wound core design.
c. Investigate Filtoroids or laminations.

Example: The design of the coupling transformer (carrying dc) is the same as the signal transformer. All calculations are the same. The only difference will be the value of permeability (μ) used in the formula for inductance. This permeability (incremental permeability) will normally be lower due to the dc component of excitation.

Power Transformers

Power transformers operate from a low source impedance, i.e., power line, generator, etc., and provide power at any voltage level required. Since most systems designers consider power transformers nothing more than sophisticated voltage dividers and necessary evils, it is incumbent upon the transformer designer to minimize size and weight, while maintaining high efficiency and low heat rise. Utilizing oriented silicon iron alloy with extremely high maximum flux capabilities (16 + Kilogausses), it is possible by straight-forward toroidal design, to reduce size and weight by as much as 20% when compared to cut core designs. In each case, the reduction in size does not sacrifice performance. In fact, a well-designed toroidal power transformer will not only be smaller in size . . . but it will also actually have lower losses and regulation.

Supermendur or Vanadium Permendur will reduce size still further though at an increase in core cost.

The size of a power transformer is generally proportioned to the square root of the power supplied, for a given frequency. A few trial designs will provide the designer with a guide to core size.

Design Notes

a. Design power transformers to work at the highest B_m possible for the maximum anticipated primary voltage, and the minimum anticipated frequency, but keep in mind the limits of temperature rise and distortion. Curves on pages 20 through 35, for each material include magnetizing curves showing flux density versus magnetization force and core loss curves for a number of frequencies.
b. Lowest winding resistance (regulation) is achieved on cores with square cross sections. High current density in the wire should be utilized within the limits of allowable regulation and heat rise.
c. Heavy current windings should be placed closest to the core, with the wire size decreasing with subsequent windings. Heavy wire windings (heavier than AWG #22) can be layer wound. After calculating the number of turns on the first layer, the number of turns possible on each succeeding layer decreases by six.
d. Investigate the use of auto-transformer design to help reduce size and weight.
e. Use oriented silicon iron alloy (Microsil) or Vanadium Permendur; select thickness for core loss, frequency, etc.
f. Three-phase transformers: Although three-phase power may be transformed with three single-phase toroidal transformers, there is no convenient way to design a single three-phase transformer unit using toroidal cores. Three-phase lamination shapes are available for these applications — see Magnetic Metals' lamination catalog for specific data.

Example: An airborne power transformer is required to provide isolated 115 volts at 1 ampere, and 26 volts at 0.25 amperes. Excitation is 115 volts, 400 Hz. A Magnetic Metals size 75 core, in .004 Microsil (grain oriented silicon steel) should be adequate.

$$N_p = \frac{115(10^8)}{4.44(400)(.817)(15000)} = 530\text{ T}$$

$$N_{s_1} = 530(1.03) = 547\text{T}$$

(allowing for 3% regulation)

$$N_{s_2} = \frac{530}{115}(26)(1.03) = 124\text{T}$$

$$I_p = \frac{115(1) + 26(.25)}{115} = 1.06\text{ amp}$$

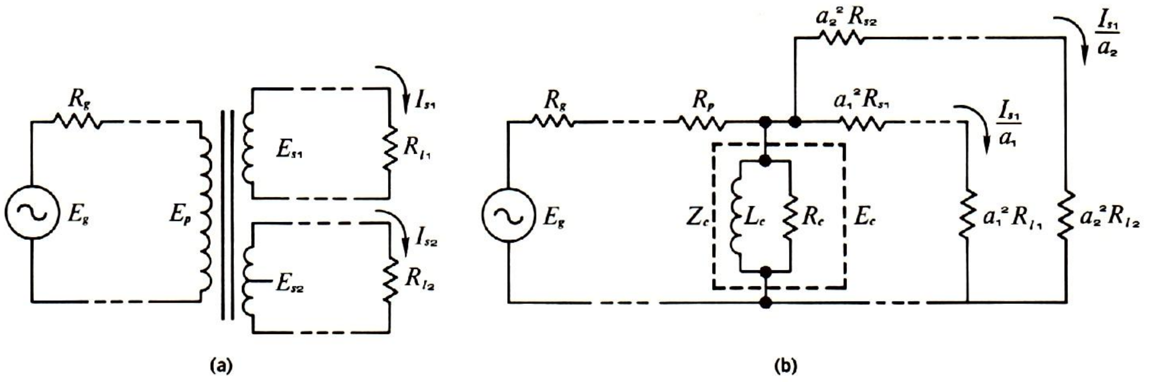
use #22 wire

$$I_{s_1} = 1.0\text{ amp}$$

use #22 wire

$$I_{s_2} = .250\text{ amp}$$

use #27 wire



$$a = \frac{N_p}{N_s} \qquad Z_c = \frac{E_c^2}{P_z W} \qquad R_c = \frac{E_c^2}{P_s W} \qquad N_p = \frac{E_g \times 10^8}{4.44 B_m A f} \qquad N_s = \frac{E_s}{E_g} \times N_p$$

FIGURE 15 — Power Transformer. (a) Basic circuit diagram. (b) Equivalent circuit with formulas for primary and secondary turns and magnetizing current impedance. See page 62 for list of symbols used.

The required turns in these wire sizes will fit, provided the two #22 wire windings are placed on first, then the #27 wire winding.

The circuits and applicable equations are indicated in Figure 15.

The calculation of secondary turns, N_s, assumes that E_s is the open circuit voltage. The voltage drops in both primary and secondary windings, because of load current flow, will require an adjustment of the turns to obtain the desired terminal voltage.

Current Transformers

Current transformers are often used with a one-turn primary winding to monitor the current in a power lead. Multiturn secondaries then provide a reduced current for metering or system functions. However, a few applications require current step-up with the greater number of turns on the primary winding.

In current transformer design, the core characteristics must be carefully selected, because excitation current essentially subtracts from the metered current and affects the ratio and phase-angle of the output current. If the values of L_c and R_c in Figure 16b are too small because the permeability of the core material is low and the core loss is high, only a part of the current aI_p will flow in the output load R_l. This will be particularly important for low current values if the core permeability drops greatly at low flux levels.

Ideally, then, for applications requiring accurate current ratios over a large range of currents, a core should have high initial permeability and low core losses. 80% Ni/Fe/Mo meets all these requirements. If the current range is limited, size, cost, and some very high current applications may call for oriented silicon iron alloy or 50% Ni/Fe alloy.

Design Notes

a. Initially assume an ideal transformer with the exact turns/current ratio. The toroidal configuration virtually eliminates errors due to leakage flux. Some errors may be compensated for by adjusting the secondary turns.

b. The secondary resistance is a part of the burden; there is some advantage in keeping it small.

c. Calculate the core cross-sectional area required to generate a voltage in the secondary circuit:

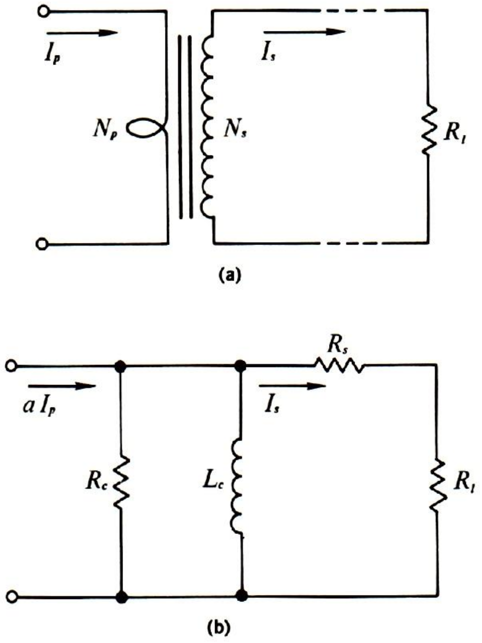
$$A = \frac{I_s(R_s + R_1)10^8}{4.44 N_s f B_m}$$

The value of B_m may be as high as the level which gives maximum permeability or higher provided the excitation currents as calculated below do not disturb the current ratio or phase-angle beyond acceptable limits. The inductance is calculated from

$$L_c = \frac{0.4\,\pi N^2 A}{10^8\, l\, \mu\, L}$$

The value of the equivalent resistance R_c which disipates the core loss is calculated from

$$R_c = \frac{(IR_s)^2}{P}$$



$$a = \frac{N_p}{N_s}$$

when $R_c >> R_s + R_l$

$2\ \ fL_c >> R_s + R_l$

then

$$I_s = aI_p$$

or

$$I_p N_p = I_s N_s$$

Alternate calculation of R_c:

$$R_c = \frac{I_s^2 (R_s + R_l)^2}{P_s W}$$

FIGURE 16 — Current Transformer. (a) Basic circuit. (b) Equivalent circuit (referred to secondary).

Core loss curves on pages 30 through 35 for round loop materials. The values must be selected to agree with the proposed frequency of operation and ac flux levels.

d. Use Supermalloy, SuperPerm 80, or SuperPerm 49.

Example: Assume a one turn primary carries 10 amperes, 60 Hz. and the current transformer must provide 0.1 amperes through a 1.0 ohm load. (Assume secondary resistance is negligible): Turns Ratio 100:1 For grain oriented silicon steel (Microsil) core

$$\textbf{Area of Core} = \frac{0.1(10)10^8}{4.44(100)(60)(10{,}000)} = .375\ \text{cm}^2$$

use Magnetic Metals size 39 core.

Estimating the effect of the core inductance and core loss

$$L_c = \frac{.4(3.14)(100^2)(.385)(80{,}000)}{10^8(9.97)} = .388\text{hy}$$

$$X_c = .388(377) = 162\ \text{ohms}$$

R$_c$, estimated from core loss at 10,000 gausses:

$$\textbf{Core Loss} = .1\,w/\#(.07\#) = .0071\text{W}$$

$$\frac{E^2}{R} = .1w = \frac{.1(1.0)^2}{2}$$

$$R_c = \frac{.1}{.002} = 50\ \text{ohms}$$

Therefore, the shunting effect of L_c and R_c are small enough to have little effect on the current ratio — something under 2% — which can be compensated for by two additional turns on the secondary.

The circuits and applicable equations are indicated in Figure 16.

Reactors

Reactors (Inductors) generally are single winding devices having relatively high inductances and relatively low resistances. A toroidal core provides the maximum inductance per unit volume as compared to any other configuration. However, where direct current is encountered, the negligible air gap of the toroid is not sufficient to prevent saturation. This occurs for relatively low levels of direct current excitation. Further, the "Q" of the tape wound toroid is relatively low. For high "Q" application, the 80% Ni/Fe/Mo powder cores, described in a separate engineering bulletin, are recommended.

Design Notes

a. Make certain that the dc components of the excitation are below the maximum for the material being considered.

b. After designing the inductor check that the maximum ac voltage or current will not cause saturation, especially in tuned circuits.

c. Use SuperPerm 80 or SuperPerm 49.

Saturable Reactors

Saturable Reactors are inductors whose reactance is a function of a variable dc supplied to a winding which is electrically isolated from the reactor winding. While in theory, it would only take two windings to achieve this effect (Figure 17a), the voltage induced in the dc control winding would usually upset the control circuit. Hence the circuit of Figure 17b is utilized. Note that there is a mutual cancellation of the fundamental frequency component in the center leg. This eliminates the above mentioned objection. In actual practice, however, a harmonic voltage is usually found to be induced in the control winding. The voltage appears to be generated by a very high impedance source and the circulating current is normally low.

In practice, the saturable reactor is used as a variable source impedance. The applied ac source voltage is divided between the reactor and the load, depending upon the degree of saturation supplied by the control winding. In certain reactor applications square loop materials produce wave forms which show a "firing angle" similar to the output of a thyratron or silicon-controlled rectifier with ac excitation. For low excitations, round loop materials will provide an output wave similar to the source, varying only in magnitude (and perhaps phase angle) but exhibiting no firing angle. See Figure 18.

Saturable reactors, requiring no circuit components other than the core and coil, have been built to control power from milliwatts to kilowatts.

Design Notes

a. Each core (leg) is designed to absorb ½ the maximum applied ac excitation.
b. The output voltage of the saturable reactor, at zero signal is the core's excitation current multiplied by the load impedance.
c. The response time of the saturable reactor is the classic L/R (inductance/resistance) ratio of the control circuit. However, due to the continuous variation of the permeability, it is best calculated on an average basis.
d. For power applications use silicon iron alloy (Microsil).
e. The toroidal configuration of a saturable reactor consists of the load windings placed on individual cores. The cores are then stacked together so that the control winding can be wound over a pair of cores.

Example: A saturable reactor is to operate from 115 volts, 60 Hz, and furnish maximum possible voltage to a lamp of 1000 watts, by means of a 10 ma dc control.

The maximum possible output voltage would be obtained from a core material having the lowest saturated permeability, i.e., highest squareness ratio. This would suggest Square 50 alloy. However, for the mundane task of light dimming, this would be uneconomical. The next most logical choice would be Microsil.

Each core must be capable of 57.5 volts at approximately 10 amperes. This requires #12 wire, which in turn requires the use of a winding shuttle of almost one inch in diameter. The core selected must therefore have a much larger I.D. than this to allow for the winding. Use a Magnetic Metals' size 21 core.

$$N = \frac{57.5(10^8)}{4.44(60)(15000)(4.78)} = 302\text{T}$$

(#12 wire on each of two cores)

Since this size wire can be layer wound, the first layer on this (cased) core will have 80 turns, and require 5 layers. The build-up is 10 × (.084) or .84 inches; leaving an I.D. of 2.313 – .84 or approximately 1.4 inches.

Complete saturation of this material occurs at approximately 3.0 oersteds, or 6.06 N_i/inch. Control turns required:

$$\frac{6.06(9.82)}{.01} = 5950 \text{ Turns}$$

#30 wire placed over the stacked cores containing 302 T each of #12 wire.

Saturable Transformer

A very popular version of the saturable reactor is the saturable transformer, often used in servo systems with two-phase ac servo-motors; hence a phase reversible connection of the reactors is used. Unlike the reactor, whose output is limited to the line voltage, the saturable transformer, having primary and secondary windings, can produce virtually any output voltage required regardless of the excitation voltage. Figure 19 shows the circuit diagram. With zero dc or with equal currents through the control windings, the impedances, and hence the voltage drops across the reactors, are equal.

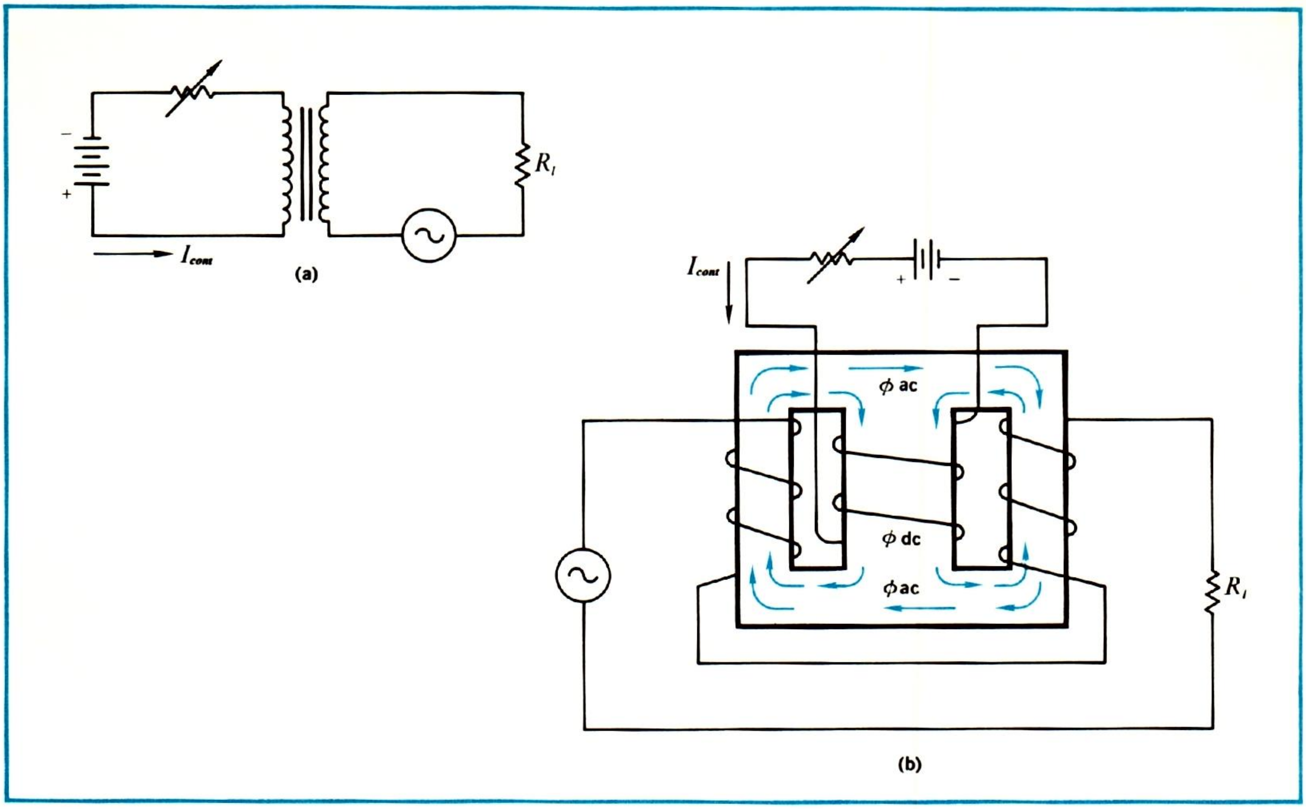


FIGURE 17 — Saturable Reactors. (a) Two winding reactor; (b) Three-legged reactor.

The sum of the induced secondary voltages, because they are connected in phase opposition, will be a low harmonic voltage. The increase of dc through one reactor control winding causes its primary winding impedance, i.e., voltage drop to decrease with a corresponding increase in voltage drop across the other reactor primary. There will now be a difference in the opposing induced secondary voltages, with a net output of a particular phase. The reversal of the signal condition reverses the phase of the output. Best linear performance is obtained when the steady state direct currents through the control windings are equal to each other and equal to one-half the reactor saturating current. These control windings can be driven by transistor, vacuum tube or magnetic amplifier demodulators/discriminators, or any other source of differential dc.

A variation of the saturable reactor/transformer circuit for servomotor applications is shown in Figure 20. This circuit utilizes the basic saturable reactor. However, the power windings are connected in a bridge fashion. The operation of the circuit is self-evident. This type of reactor provides a lower phase shift vs. amplitude characteristic than the transformer type, but is

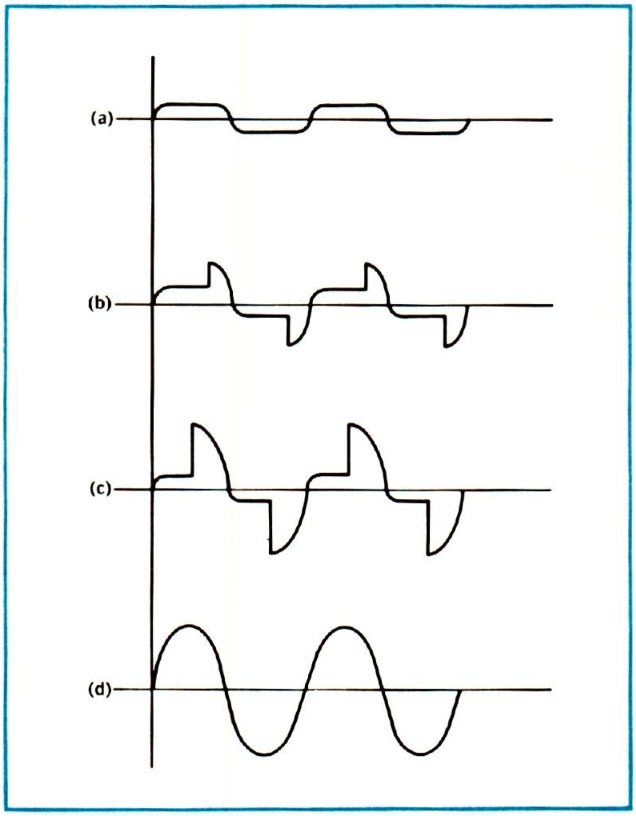


FIGURE 18 — Output of saturable reactor. (a) Cutoff; (b) Low output; (c) Half output; (d) Full output.

limited to operating at whatever excitation voltage is available. Unlike the true saturable reactor, each leg of the bridge reactor must be capable of absorbing almost the entire line voltage, rather than half of the line voltage.

Design Notes

a. The saturable transformer can control large amounts of power and is an amplifier as well.

b. The toroidal configuration of the saturable transformer consists of the power windings (primary and secondary) placed on individual cores. The cores are then stacked together so that the control winding can be wound over the pair of cores.

c. Use Microsil or Square 50.

Example: The dc control and ac primary windings are designed in the same manner as the saturable reactor. Allowance must be made, however, for the space the secondary windings will occupy. The secondary turns are calculated based upon primary/secondary voltage, but increased by a factor which compensates for the lack of complete saturation of the material. For Microsil (silicon steel) this factor may be 1.25-1.33 depending upon the specific design. For Square 50 this may be 1.15-1.25 depending upon the design.

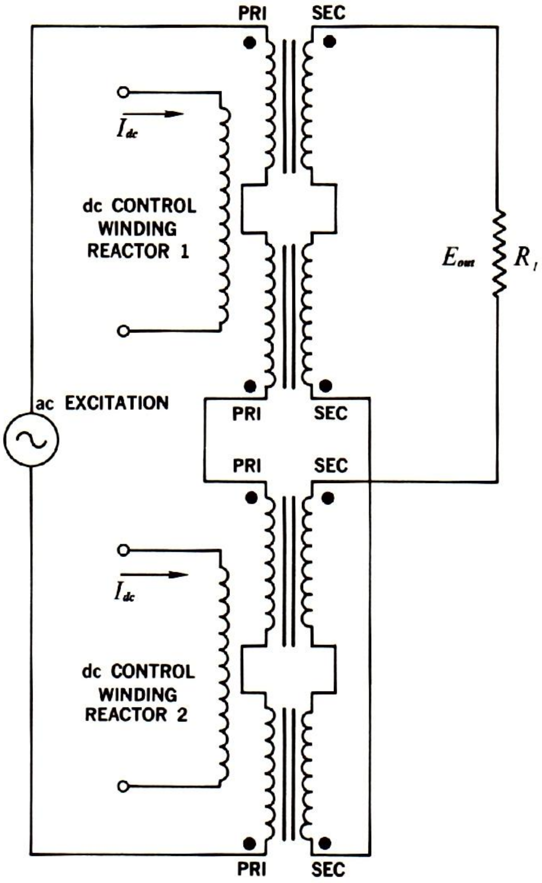


FIGURE 19 — Saturable transformer circuit.

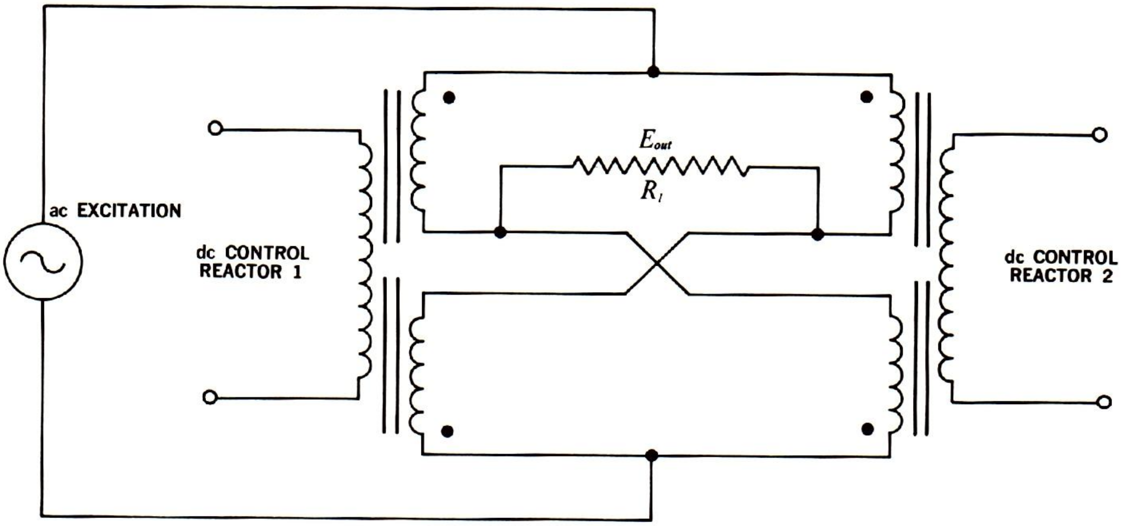


FIGURE 20 — Saturable reactor bridge.

Self-Saturating Magnetic Amplifiers

An extension of the saturable reactor is the self-saturating magnetic amplifier. By proper placement of the saturable reactor power or gate windings into conventional rectifier circuits, i.e., bridge, center tapped, etc., undirectional currents will flow through these windings, which at some level will cause self-saturation. Upon applying only ac power to the circuit, the self-saturating magnetic amplifier will provide full output as shown in Figure 21a with zero control current.

Under this condition, the application of control ampere turns reduces the amplifier output. To correct for this inverse relationship, bias current is supplied to cut off the output as shown in Figure 21b. The minimum current value is determined by the excitation current required by the core. Now, an increase in control current gives an increase in output. This is true for both positive and negative signals as in Figure 21b. However, the gain for positive signals is much greater than that for negative signals. The amplifier gain depends upon core material and very high gains are obtained only in toroidal core assemblies.

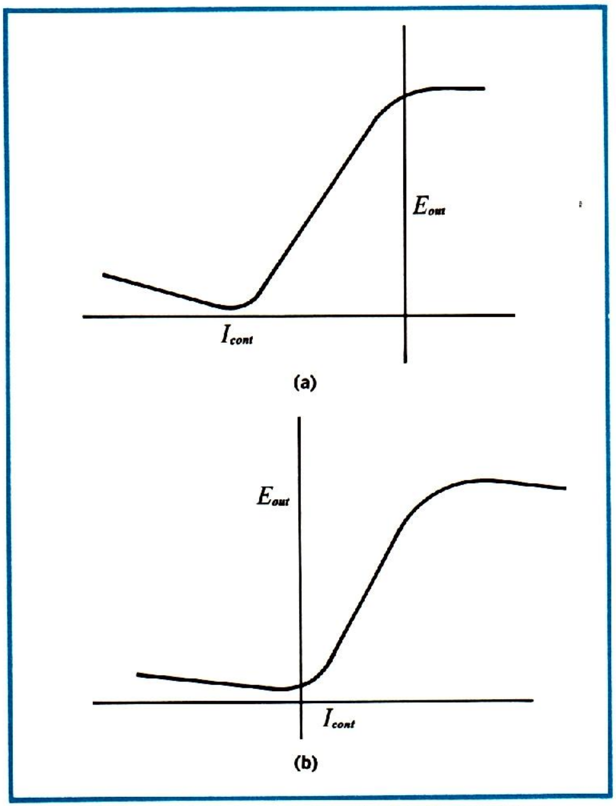


FIGURE 21 — (a) Unbiased output of self-saturating magnetic amplifier; (b) Amplifier biased to cut-off.

The time constant of a self-saturating magnetic amplifier to respond to a step change in input signal, is a function of the control circuits L/R (Inductance/Resistance) ratio.

For the calculation of time constant, all commonly coupled windings are included and are considered additive; this includes bias and feedback windings as well as all control windings. An approximation of the time constant of a self-saturating magnetic amplifier is indicated below. Several variations of the equation are published whereby some of the constants are changed for the different circuit configurations. The differences are relatively small if only one basic formula is used. Even though the physical feedback winding is used in the calculation of time constant, the effect of the feedback itself is not included in this equation and must be taken into consideration when determining the overall response time of an amplifier which has a feedback circuit.

$$T = \frac{.1}{2N_p}\left(\frac{.75E_p}{NI}\right)\left(\frac{N_1}{R_1}^2 + \frac{N_2}{R_2}^2 + \cdots\right) + .6$$

in cycles.

N_p = Gate turns; E_p = Gate voltage; NI = Full control ampere-turns required to change magnetic amplifier from cut-off to full "on".

N = number of turns of a winding, bias, feedback, and control windings.

R = resistance of the winding plus the resistance of the circuit of which it is a part, i.e., bias, feedback, and control windings.

Figure 22 indicates several types of self-saturating magnetic amplifiers.

Design Notes

a. As in the saturable reactor, a gate winding is wound on each of two cores. The cores are then stacked together so that the control, bias, and feedback windings can be wound over the pair of cores.

b. Gate: The ac power windings are designed to support the full line voltage. Wire size is similar to that of the secondary of a dc power supply transformer.

c. Control: The control winding is usually designed to provide full saturation of the core with the available dc signal. It is not good practice to have a high ac voltage applied to the gate circuit and to saturate the core only partially with the maximum available signal, in anticipation of increasing system gain without additional stages. A review of the drift characteristics in relationship to the maximum output will reveal that the relative system drift will be appreciable with a design of this type.

d. Bias: The bias winding is designed to provide sufficient ampere-turns to cut off the amplifier for zero control signal. The turns are determined by the voltage and current capabilities of the available dc supply. Since the time constant of the amplifier is affected by the time constant of the bias winding as well as of the control winding and of all other common windings, it is good practice to keep the number of turns on the bias winding as small as possible.

e. Feedback: Negative feedback is used to linearize and stabilize the output. Positive feedback is used to increase the output even to the point of instability to create a bi-stable operating condition. Here

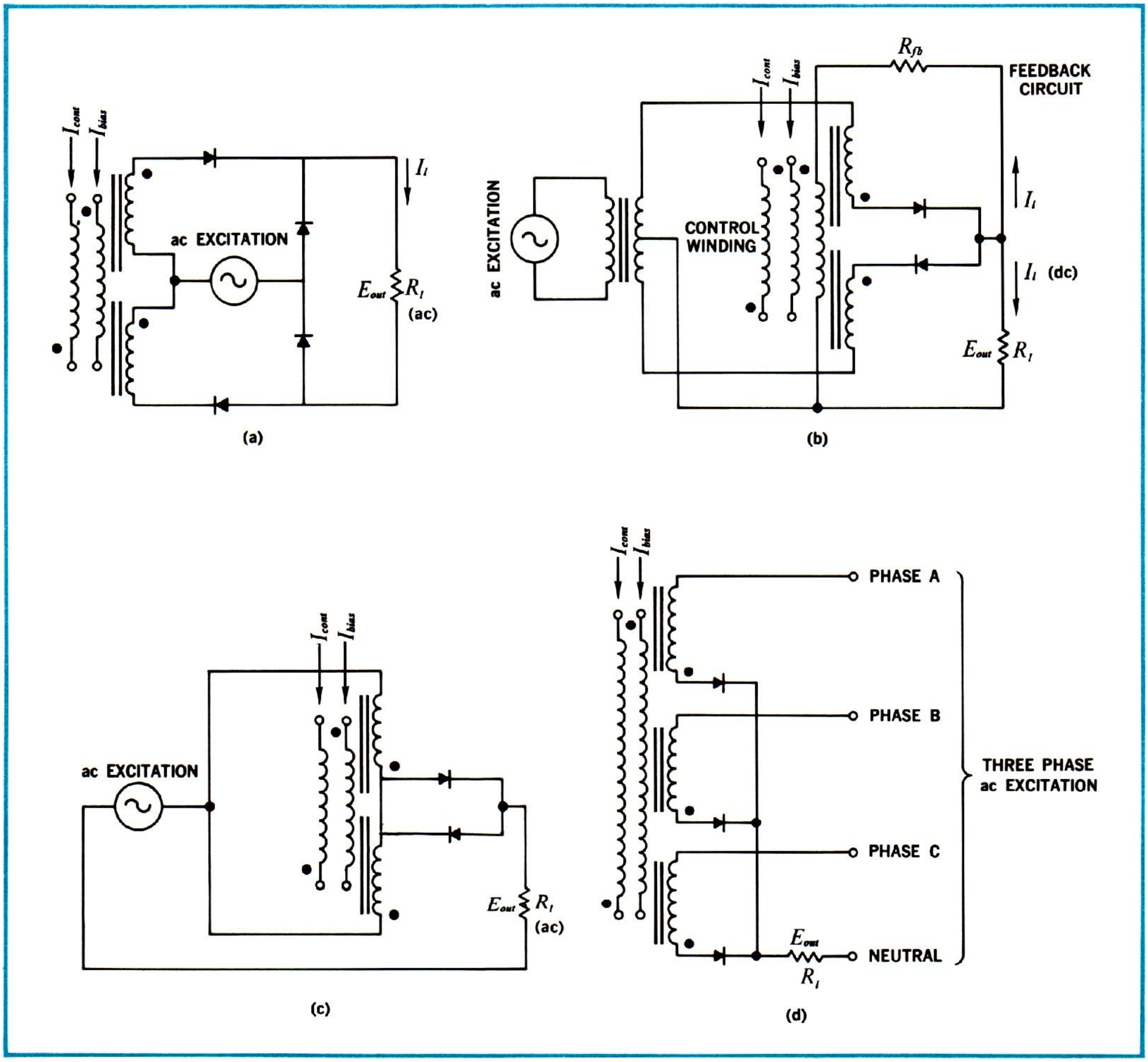


FIGURE 22 — Several types of self-saturating magnetic amplifiers. (a) Full wave amplifier with dc output; (b) Center-tapped amplifier with feedback (dc output); (c) Doubler-connected amplifier with ac output; (d) Three-phase half-wave amplifier with dc output.

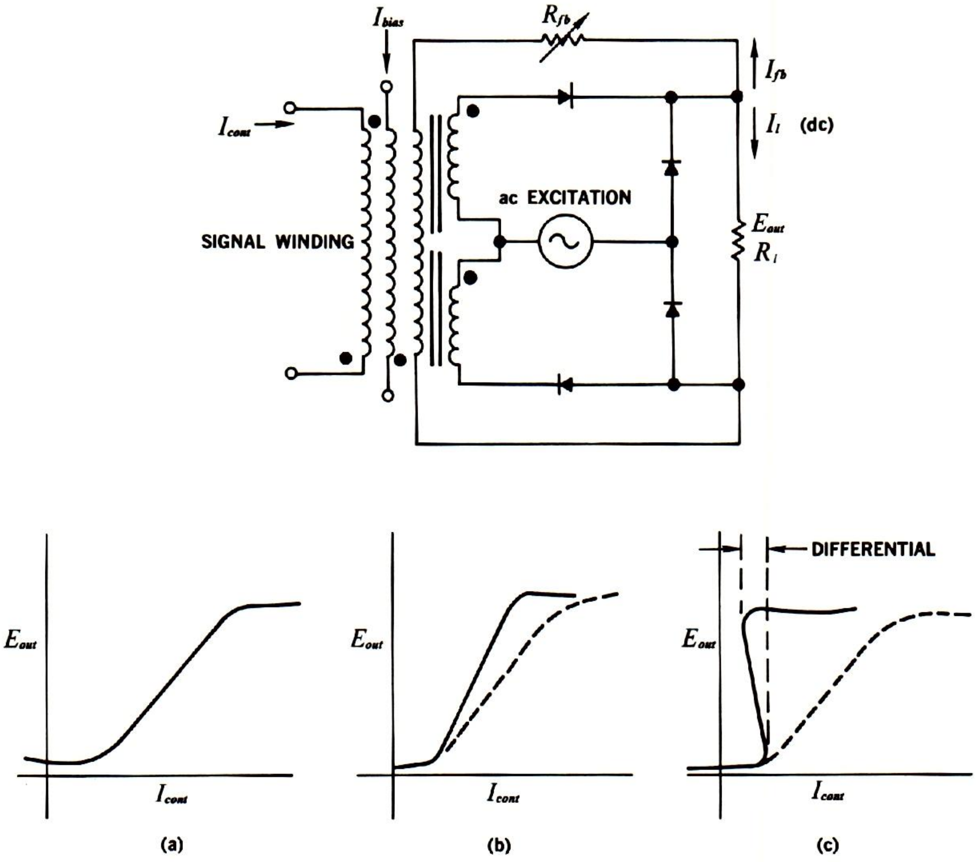


FIGURE 23 — Bi-Stable (positive feedback) magnetic amplifier with (a) No feedback; (b) Some feedback; (c) Excess feedback.

again, the number of turns should be kept low.

f. The available signal determines the selection of the core material. Oriented silicon iron alloy (Microsil) is used for high level signals (tens of milliamperes and up) while Molybdenum Permalloy (Square 80) is used for low level signals (microamperes). The other materials fill in the range depending upon power rating, response time, cost, etc.

g. Extremely high gains are possible with magnetic amplifiers. When using large numbers of control turns, especially in low level amplifiers, wind the control winding for minimum capacitance, using progressive or sector winding.

Example: This type of amplifier is designed in the same manner as the saturable reactor, except that each ac power (gate) winding must be capable of absorbing the entire line voltage.

Bi-Stable Magnetic Amplifiers

In the operation of relays, solenoids, etc., it is often desirable to provide a specific on-off switching function from a continuously varying signal source. By providing excessive positive current feedback in a self-saturating magnetic amplifier circuit, such a magnetic amplifier switch can be produced. Figure 23 shows a typical bridge magnetic amplifier with positive feedback current controlled by a variable resistor. Figure 23a shows the normal transfer curve without any positive feedback; Figure 23c shows a high amount of positive feedback — note the negative slope. The difference between the on and off points (full output and cut-off) can be made extremely small — sometimes as small as a few microamperes of control current.

Design Notes

a. The available signal determines the selection of the core material. Supermalloy or Super Square 80 for lowest levels, oriented silicon iron alloy, Microsil for highest levels.

b. When operating into an inductive load, the core may trigger full on for very low or even no signal. This may be overcome by using a core material having a less square B-H loop. It is also possible to mask the inductance with capacitors, discharge rectifiers, etc.

c. Response time is increased by the positive feedback factor; decreased by the negative feedback factor.

d. The characteristic switch points will move left or right directly with the decrease and increase of the bias supply voltage; the differential will increase or decrease directly with changes in ac excitation.

Example: This type of amplifier is designed in the same manner as the saturable reactor, except that each ac power (gate) winding must be capable of absorbing the entire line voltage.

Push-Pull, Self-Saturating Magnetic Amplifiers

In many control systems a bi-directional dc output is required for the operation of generator fields, motors, hydraulic valves, etc. If the load to be driven by the amplifier is center-tapped or otherwise split into two halves (see Figure 24), then the amplifier merely consists of two matched unidirectional magnetic amplifiers, each with a separate output, but sharing a common bias and signal.

If, however, the load is a two terminal device, through which current direction has to be reversed, then the special circuit, including ballast resistors, shown in Figure 25, must be used. It should be pointed out however, that this circuit is wasteful of power. The amplifiers must be capable of delivering six times the useful load power. By referring to Figure 25, and assuming that one half the amplifier is providing

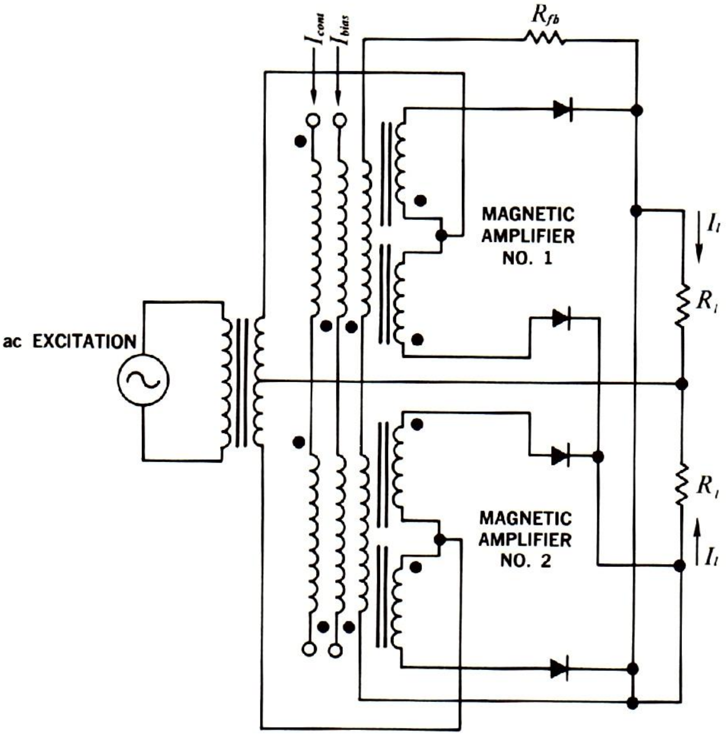


FIGURE 24 — Push-pull magnetic amplifier with center-tapped load.

full output while the other is cut off, it may be seen that the ballast resistor (which usually equals the load impedance for optimum power transfer) across the cutoff magnetic amplifier, appears in series with the load. This requires the conducting amplifier to produce twice the required load voltage. With twice the load voltage also appearing across the ballast resistor of the conducting amplifier, thereby, dissipating four times the load power, the total of six times the usual power becomes evident. In many applications, however, the load is inductive in nature and the ballast resistors help decrease the time constant of the load itself. Due to the large transformer-like thermal capacity of the magnetic amplifier, these types of push-pull applications have been used for loads in the kilowatt range. Utilizing negative feedback around both amplifiers, drift characteristics have been reduced below most system requirements. With proper selection of rectifiers for current carrying capabilities, momentary overloads have little effect upon the longevity of these devices.

Example: This type of amplifier is designed in the same manner as the saturable reactor, except that each ac power (gate) winding must be capable of absorbing the entire line voltage.

Magnetic Modulators

The magnetic modulator is basically a very sensitive saturable reactor/transformer device for converting low level (micro-ampere) dc signals into proportional ac voltages. Generally the incoming signal is supplied from a two terminal source rather than a differential source as described for the saturable transformer. This requires an additional dc bias winding to establish a reference sense for reversing the phase of the output. Figure 26 indicates several types of magnetic modulator circuits.

Toroidal magnetic modulators will generally provide better stability and higher gain than a

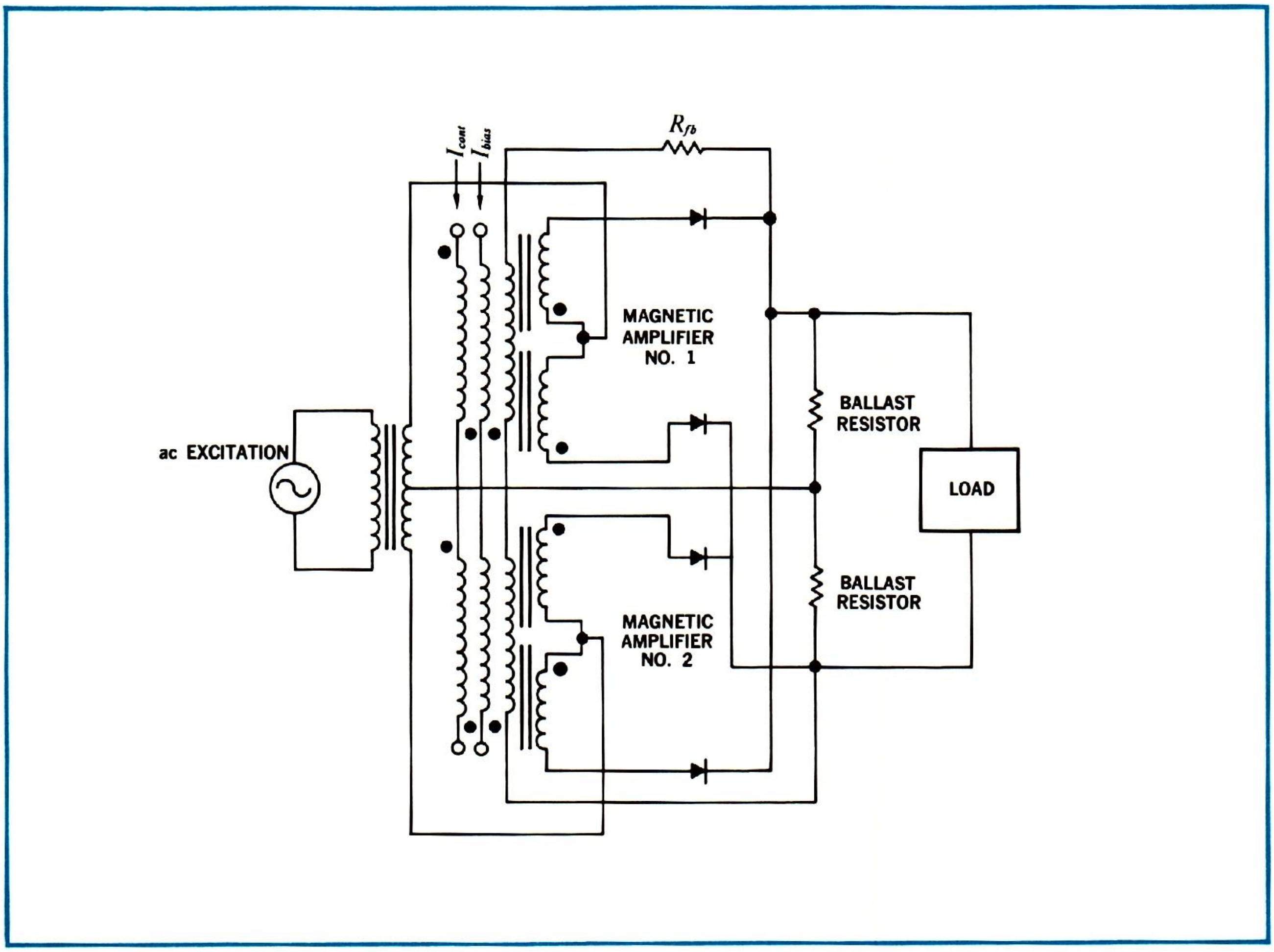


FIGURE 25 — Push-pull magnetic amplifier with two terminal load.

laminated version. This is primarily due to the lack of effective air gap, which, aside from requiring additional magnetizing force from the signal source, also tends to change with temperature, aging, physical stress, etc.

Since a magnetic modulator is a pair of variable inductors which are balanced about a null point with the signal intentionally upsetting this balance, any other disturbance which also causes a change in balance will also produce an unwanted output. Additional systems benefits include lower nulls and less phase shift. Hysteresis is also considerably less.

Design Notes

a. Use SuperPerm 80 or Supermalloy at low inductions.

b. For lowest nulls make certain to specify uniform distribution of all windings; also match finished reactors after temperature cycling between the specified limits.

Example: This type of amplifier is designed in the same manner as the saturable reactor, except that each ac power (gate) winding must be capable of absorbing the entire line voltage.

High-Speed Reset Magnetic Amplifiers

An interesting development in magnetic amplifiers is the reset type which overcomes the slower response of the self-saturating type. The basic circuit of this single core device is indicated in Figure 27. By virtue of the

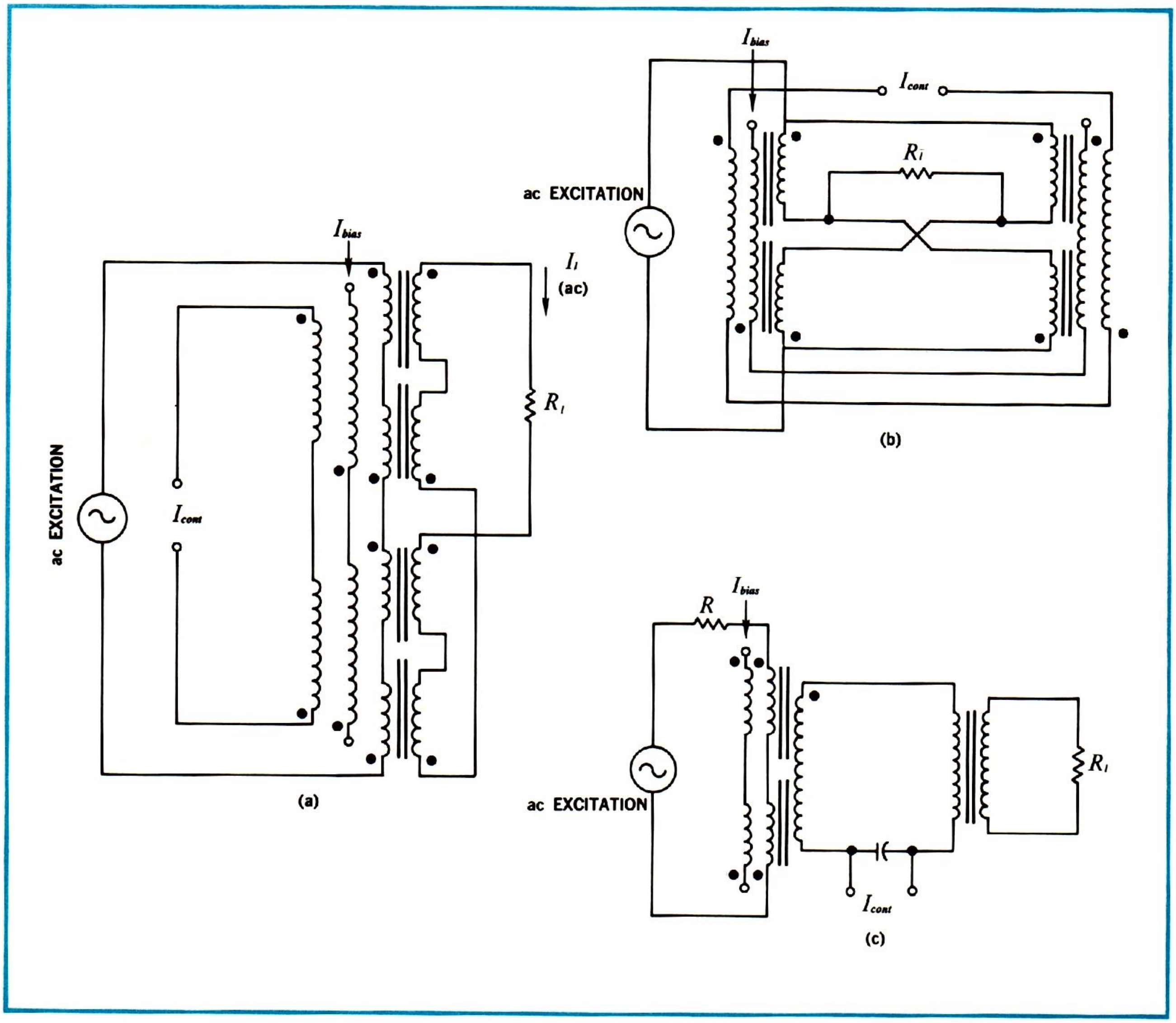


FIGURE 26 — Basic magnetic modulator circuit. (a) Saturable Transformer; (b) Saturable Bridge; (c) "Lear" Circuit.

rectifier in the gate circuit, the application of ac power will cause self-saturation with the half rectified wave appearing across the load R. By increasing the reset voltage from zero and noting the reset rectifier/winding polarity relative to the gate circuit, it will be noted that the MMF applied is opposite to that produced by the gate circuit — although on the alternate half cycle of ac excitation. Therefore, the reset circuit "resets" the core's flux level every other half cycle (without the usual L/R delay). This establishes a new flux level from which the gate circuit will start. If the reset MMF is sufficient to reset the core from $+B_r$ to $-B_r$, a properly designed gate circuit will be "cut off" and only the core's exciting current will be present in the load.

Under these conditions, consider the introduction of a signal voltage of the polarity indicated. This will reduce the net voltage of the reset circuit with a decrease in the amount of reset MMF available. The core will no longer be reset to $-B_r$ but to some lesser value, permitting the gate circuit to conduct or fire when the flux change is complete and the core saturates. The firing angle in the gate circuit will increase to 180° as the signal voltage increases to equal the reset voltage. The signal voltage can be ac, usually transformer coupled into the reset circuit — the transformer being driven by a transistor or other type of amplifier. Since the operation of single core, high-speed amplifier devices is similar to a transformer, (although the alternating voltage is applied to two windings rather than one), the response is a function of the carrier frequency, which can be assumed to be approximated by f/2 for the 3 db. point.

A dual (differential output), highly stable amplifier for the operation of high performance hydraulic valves, and other differentially operated devices, is indicated in Figure 28.

Design Notes

a. Use oriented 50% Ni/Fe alloy (Square 50 for best performance.

b. Gate turns are determined as for the primary of a transformer. Reset turns are also determined in the same manner for cut-off conditions. For a quiescent firing angle, the turns on the reset winding are reduced proportionately.

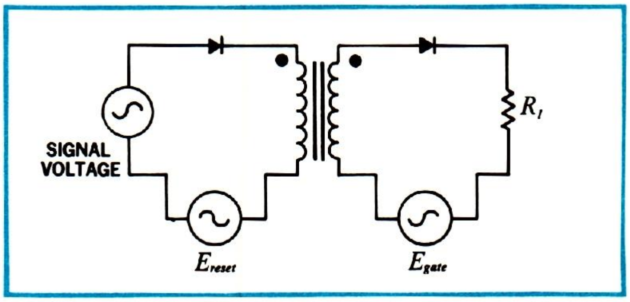


FIGURE 27 — Basic high speed reset circuit.

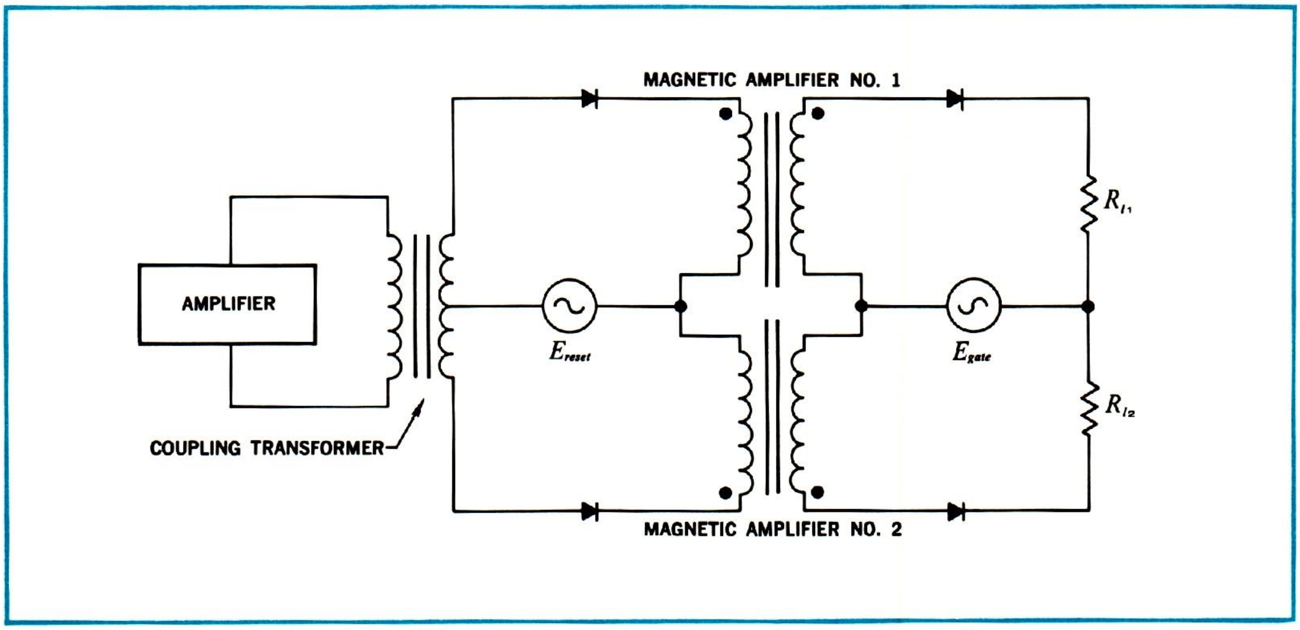


FIGURE 28 — Push-pull (differential dc) servo amplifier using reset amplifiers.

Hi-Speed Reset (Cont.)

Example: A half wave reset amplifier must be controlled from cut-off to full output by a 6.0 volt, 400 Hz signal. The output is to be 115 volts, 400 Hz, half wave into 100 ohms. Use Magnetic Metals size 11 core in Square 50 material.

$$RWT = \text{Reset Winding Turns}$$

$$RWT = \frac{6(10^8)}{4.44(400)(15000)(.544)} = 42\text{T}$$

$$\text{Gate Winding Turns} = \frac{115}{6}\left(42\right) = 805\text{T}$$

$$I_{gate} = \frac{115(.707)}{100} = .81 \text{ amp}$$

use #23 wire.

Core requires 0.2 oersteds for reset (from curves)

$$0.2 \text{ Oersteds} = .404\, N_i/\text{inch} = 1.61\, N_i$$

$$I_{reset} = \frac{1.61}{42} = .038 \text{ ma}$$

use #35 wire.

Inverter Transformers

The application of solid state inverters to convert dc voltages to ac voltages at almost any frequency and level desired and to other dc voltages (the dc transformer) has been expanding. While designing a workable inverter is fairly straightforward, the design of the transformer must be considered carefully in order to maintain consistency of production and performance. The basic inverter circuit indicated in Figure 29 is fairly well described in the literature, but the detailed design and construction of the transformer is not as readily available.

Generally, the core material for the inverter transformer is selected for maximum flux density and maximum squareness. Cores with higher flux capabilities enable smaller transformers to be built. Maximum squareness is by far the more important characteristic. This, of course, must be tempered by the operating frequency, allowable temperature rise, maximum power output, as well as cost considerations.

A lack of good B-H loop squareness will result in spikes being generated on the output of the square wave. Theoretically, when the core is saturated, there is no flux change; however, in actual practice, due to imperfect saturation where the squareness ratio is less than 1.0, there is an unwanted flux change. This change, in addition to other possible causes, will generate a spike which, even though of short duration, will cause heating of the transistor junction. This effect is minimized considerably with a square loop material such as Square 50. Considering the foregoing, then, the ideal inverter transformer would have a high squareness ratio (B_r/B_m), low core loss, and high flux capabilities such as the aforementioned Square 50.

Referring to Figure 29, a high power version of this circuit, operating at 60 hertz, would require a rather large and costly core. The two transformer circuit of Figure 30 overcomes this by utilizing a considerably smaller core of ideal characteristics (one whose size is determined by the power required by the base circuit of the transistors) for the saturating/feedback transformer, and a low cost (i.e., Microsil) nonsaturating power output transformer. This not only reduces the overall cost, but contributes to improved power losses and temperature rise.

Of equal importance to core selection is winding technique. Ideally, the two halves of the center tapped collector windings and the feedback winding should be wound simultaneously to maximize the coupling coefficients. An asymmetrical winding technique, with resultant loose coupling, will produce spikes on the output waves. These spikes indicate improper switching which will cause additional heating of the transistor junction. A more practical method of winding would be to spiral one half of the collector winding over the full periphery of the core, and then place the other half of the collector winding in between the turns of this spiral. The feedback winding should be wound in a similar manner. If the center tapped collector windings consist of many layers, then the simultaneous winding of the collector and feedback windings should be considered. As a minimum condition, the feedback winding must be directly next to the collector winding and should be wound in one 360° sweep.

Some special consideration must be given to the output winding. On the assumption that the dc supply is a low voltage, the turns on the primary and the feedback windings will be relatively small. However, output conditions may require many secondary turns. A large number of turns (the number depending upon the frequency of operation) can develop large inter/intra-winding capacitances, resulting in "ringing" or damped oscillations being superimposed upon the square wave output. It is recommended that the total number of turns be kept as small as practical by using a larger core area. But where a larger number of turns is unavoidable, they should be placed upon the core using a progressive or sector winding method.

The selection of the output transistors is determined by the maximum emitter-to-collector voltage rating which should be something more than twice the supply voltage, the maximum collector current for the specified environmental conditions, and the gain. In the saturated region, it may be expected that the transistor gain is considerably lower than in the linear region. On high current transistors, this gain may be only slightly over 10. The gain determines the amount of feedback or base current required. Inadequate base drive for the maximum load will cause the transistors to overheat and, possibly to burn out.

The square wave produced by a typical inverter is satisfactory for power applications such as light, heat, motors, etc. However, it may be desirable to obtain refinements of the wave shape where a system must operate on both sine wave generators and inverters, or the equipment is sensitive to the peak value of the applied voltage. Several avenues are open. There is the brute force filter, consisting of series and parallel resonant elements. For high power applications, the size and cost of large filter components become prohibitive. Other types of classic and hybrid filters can be used, but the low impedance of the source must be considered in the filter design. See Figure 31.

The peak to average ratio of a sine wave may be simulated as shown in Figure 32a. A square wave is generated with a peak value equal to the peak value of the sine wave to be duplicated. By inserting a saturating inductor in series with the output line, the output will look as in Figure 32c, if the inductor is designed to absorb about 30% of the generated voltage. This will provide a peak/average (or peak/rms) voltage ratio of a sine wave.

Another technique is to apply the output of the square wave inverter to a harmonic corrected constant voltage transformer. Assuming frequency remains fairly constant, a corrected wave shape and a degree of voltage regulation will be obtained. On certain models of these transformers, it is necessary to disconnect the feedback winding which introduces part of the input wave into the output. This may increase the distortion.

Design Notes

a. The turns required for each half of the collector winding are calculated in a manner

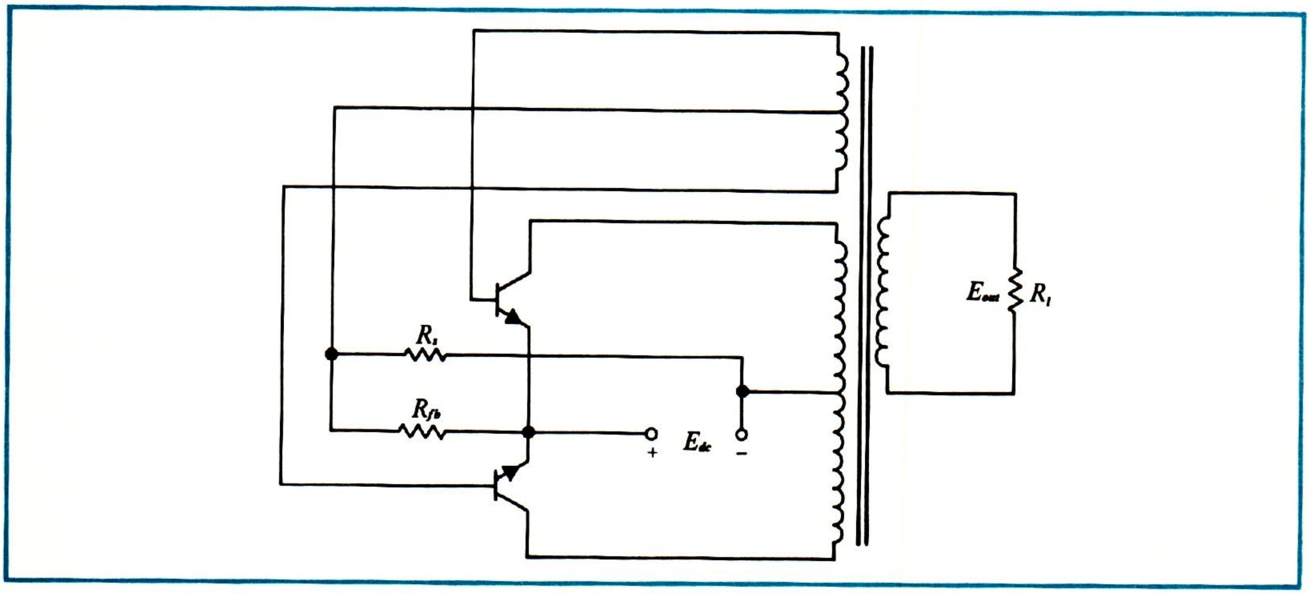


FIGURE 29 — Conventional square wave inverter circuit.

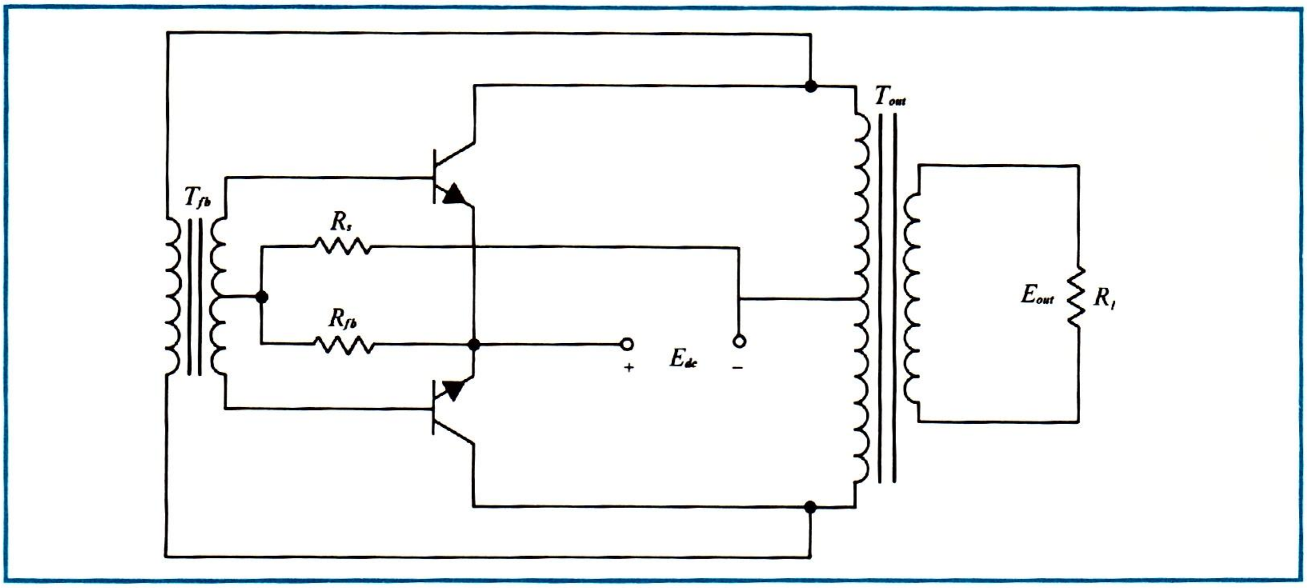


FIGURE 30 — Two-transformer square wave circuit.

similar to that of an ordinary transformer. The only difference is the change of the factor 4.44 to 4.0, since it is the average of the induced voltage rather than the RMS value of a sine voltage which is considered:

$$N = \frac{10^8 E_{dc}}{4 f A (B_m)}$$

b. The turns required for the feedback winding are determined by the base/emitter voltage and the voltage required by the base resistor which limits base current.

c. Wire sizes are determined in the conventional manner but the collector circuit must supply the power to the base and feedback circuit in addition to supplying the load power.

d. For high power inverters, consider the two-transformer type. For inverters with highly reactive loads which may upset the feedback/switching circuit, an isolated oscillator driving a power output stage, such as shown in Figure 33, can be employed.

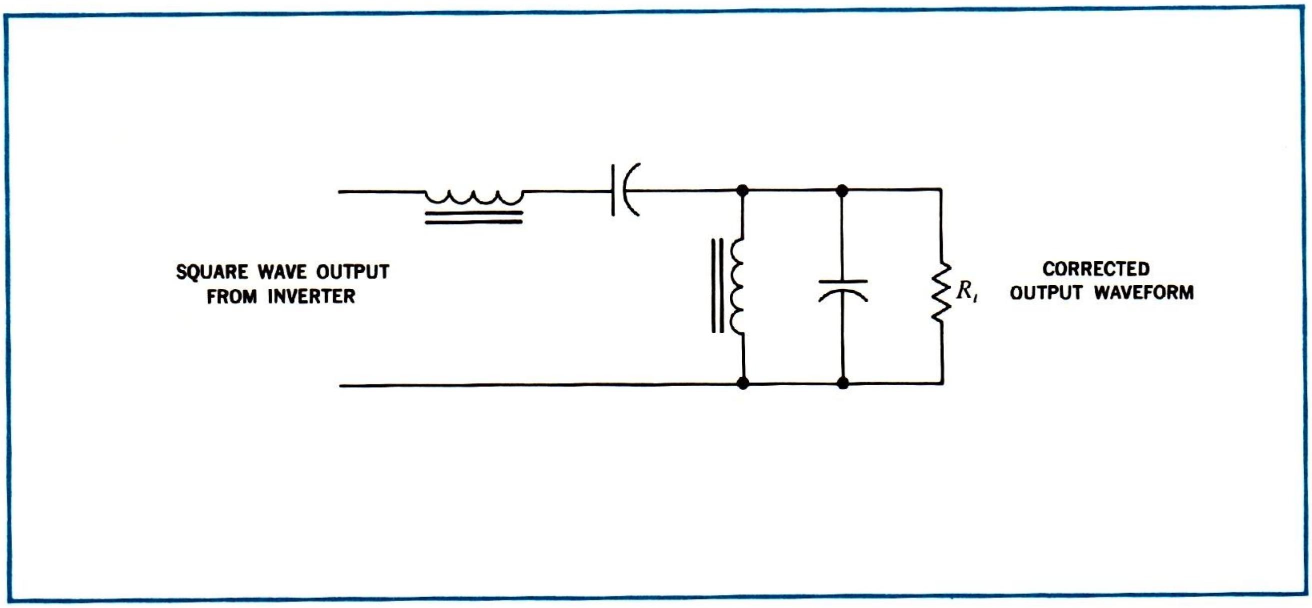


FIGURE 31 — Brute force filtering of square wave.

e. For applications where supply voltages are higher than available transistor ratings, consider the circuit of Figure 34. The voltage impressed across each emitter/collector equals twice the source voltage divided by the number of pairs of transistors.

f. For higher frequencies, thinner tapes must be used. By referring to the core loss curves, an optimum tape material and thickness can be selected for every application.

Example: To design an inverter transformer to operate from a 12 volt storage battery, utilizing germanium power transistors, and provide an output of 115 volts, 60 Hz at 100 watts to power small appliances, use Magnetic Metals' core size 58.

$$N_p = \frac{12(10^8)}{4(60)(15000)(3.08)} = 108T$$

108 Turns each half of primary — total 216 T

$$I_p = .707\left(\frac{100}{12}\right) = 5.9 \text{ amp}$$

use #15 wire

Layer winding #15 on size 58 core requires 4 layers or build-up of approx. 0.50'' total.

$$I_{sec} = \frac{100}{115} = .87 \text{ amp}$$

use # 23 wire

$$N_{sec} = \frac{115}{12}(108) = 1032T$$

use #23 wire

Assuming a 1.0 volt base drop and 1.0 amp base drive plus a 3 ohm base limiting resistor,

$$E_{fb} = 4.0 \text{ volts}$$

$$N_{fb} = \frac{108}{12}(4) = 36T$$

use #22 wire each half, or 72 turns total.

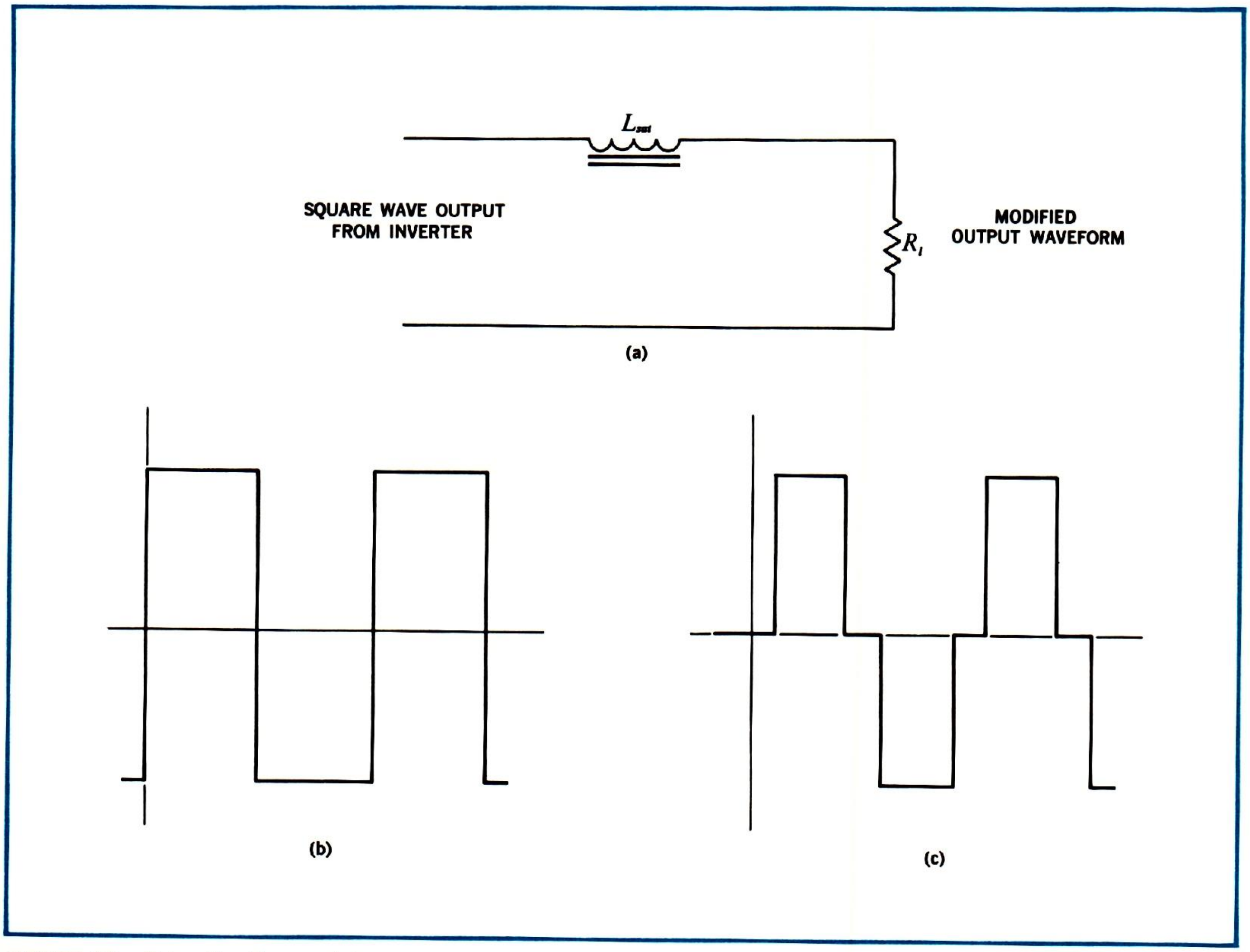


FIGURE 32 — Saturating Reactor (a) converts square wave (b) into wave form (c) having a peak to average ratio of a sine wave.

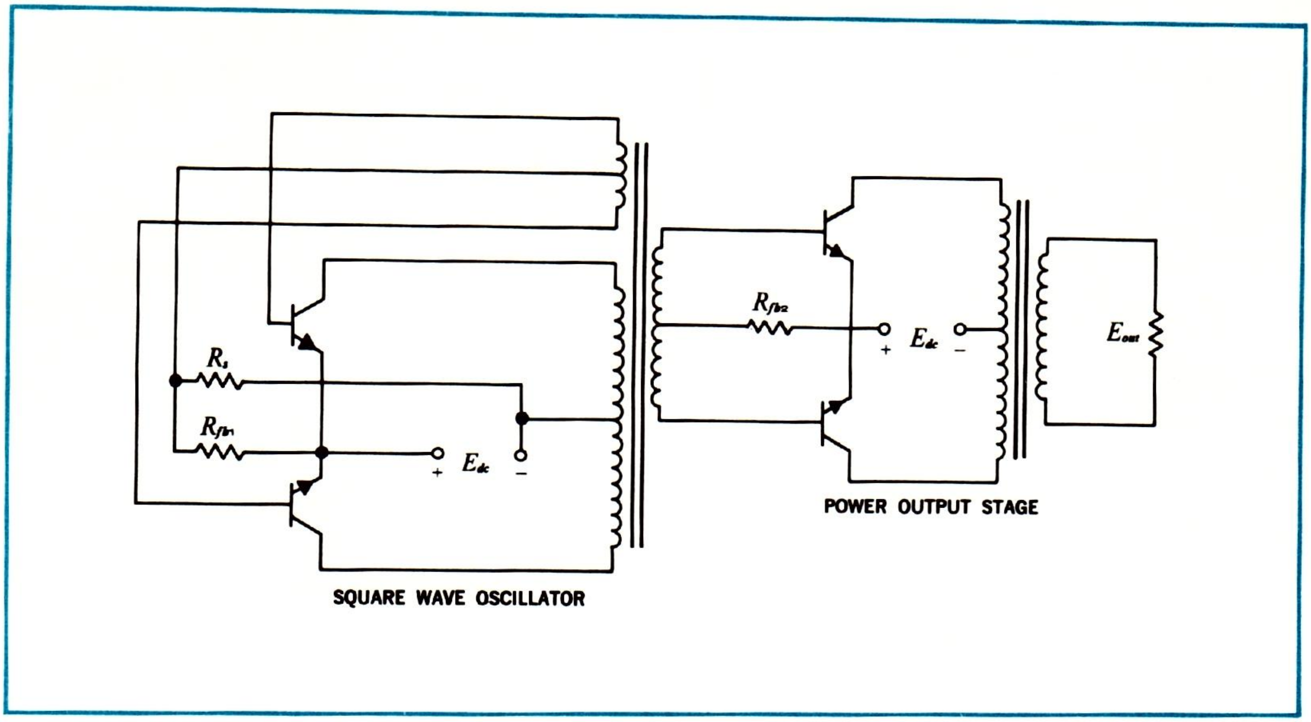


FIGURE 33 — Square wave inverter using isolated square wave oscillator and power output stage.

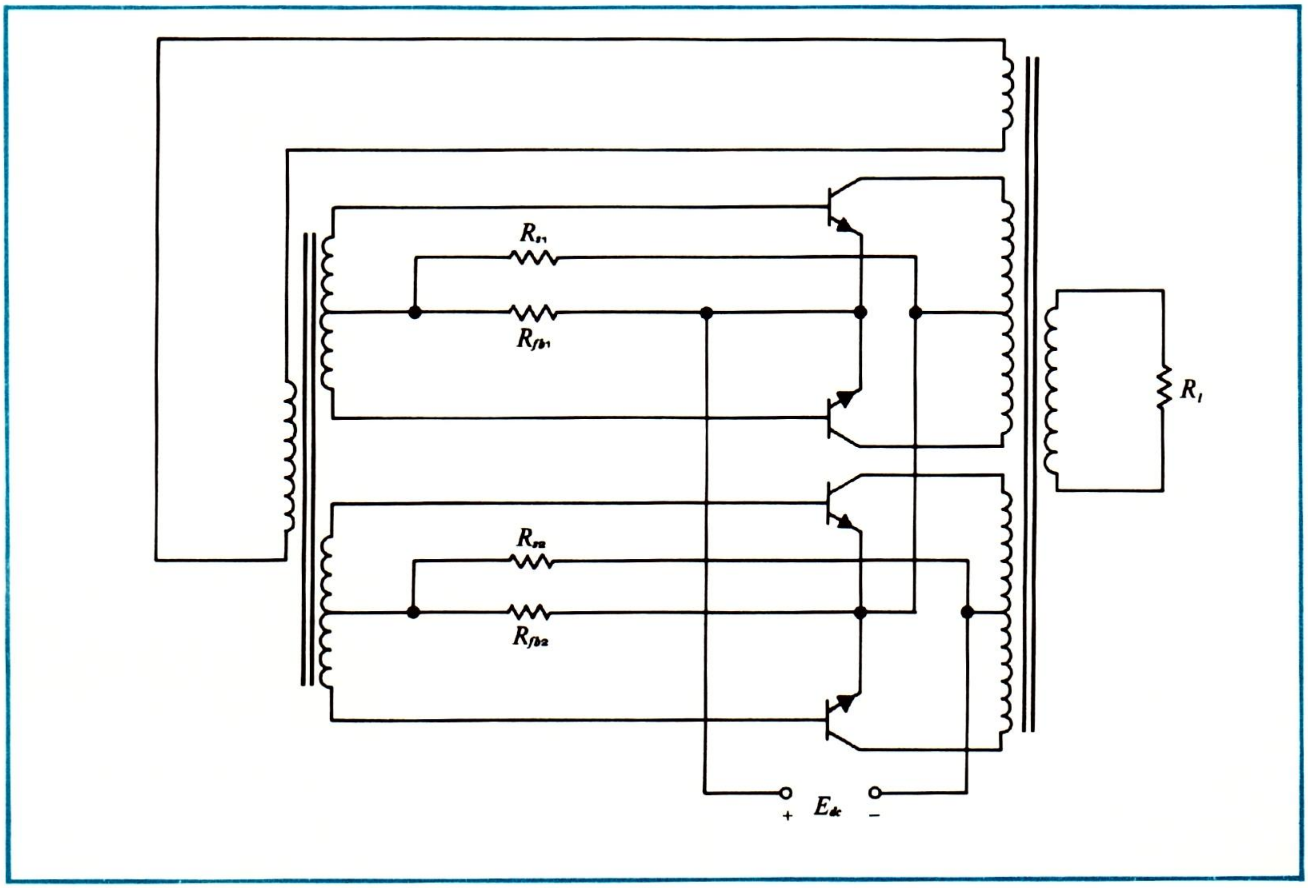


FIGURE 34 — Square wave inverter for supply voltage (E_{dc}) higher than transistor rating V_{ec}.

GLOSSARY

AMPERE'S LAW: Defines the relationship between a magnetizing force and current. It is commonly written as $H = \frac{.4\pi NI}{l}$ where H is the magnetizing force in oersteds, N is the number of turns, I is the current through N, turns, and l is magnetic path length of core.

B_r: See Residual Flux Density.

B_m: See Maximum Flux Density.

CCFR: Constant Current Flux Reset Test for core materials. This is described in IEEE 106, "Test Procedure for Toroidal Magnetic Amplifier Cores."

COERCIVE FORCE: (H_c) The value of magnetizing force required to reduce the flux density to zero.

ΔH : The change in excitation (CCFR) required to change a core's magnetic flux density from approximately 1/3 B_m to 2/3 B_m.

FARADAY'S LAW: Defines the relationship of voltage and flux as

$$e = \frac{Nd\phi}{dt}\left(10^{-8}\right)$$

For sinusoidal voltage conditions, it is written

$$E_{rms} = 4.44 B_m A_c f N (10^{-8})$$

where E_{rms} is the voltage applied, B_m is the maximum flux density in the material in gausses, A_c is the effective core cross-sectional area in square centimeters, f is the frequency of applied voltage in hertz, and N is the number of turns to which E_{rms} is applied.

GAIN: For CCFR tests, the ratio of change in flux for a change in excitation, expressed in gausses per oersted.

GAUSS: Unit of magnetic induction in the cgs electromagnetic system of units. One gauss equals one maxwell per square centimeter.

H_1: The excitation (CCFR) required to establish a flux level of approximately 1/3 B_m.

MAGNETIC FLUX or TOTAL FLUX: The product of the magnetic induction, B, and the cross-sectional area, when the magnetic induction is assumed to be uniformly distributed and normal to the plane of cross-section.

MAGNETOMOTIVE FORCE (MMF). The force, produced usually by a current-carrying coil, which produces a magnetic flux in a magnetic circuit.

MAXIMUM FLUX DENSITY: B_m, the maximum value of magnetic induction at the peak excitation.

MAXWELL: Unit of magnetic flux in the cgs electromagnetic system of units. One maxwell equals 10^{-8} webers.

OERSTED: Unit of magnetizing force in the cgs electromagnetic system of units. One oersted equals a magnetomotive force of one gilbert per centimeter of path length, or 79.6 ampere-turns per meter.

PERMEABILITY, ac : (μ ac) Ratio of the changes in magnetic induction to changes in magnetizing force (B to H).

RESIDUAL FLUX DENSITY: (B_r) The value of magnetic induction that remains in a magnetic circuit when the magnetomotive force is reduced to zero.

SATURATION: Magnetic flux level beyond which, theoretically, an increase in excitation will produce no further increase in flux. In practice, the flux will increase an insignificant amount for very large changes in excitation.

SQUARENESS RATIO: (B_r/B_m) Ratio of residual flux density to maximum flux density.

STACKING FACTOR: Ratio of the actual core material cross-sectional area to the gross core cross-sectional area.

WINDING FACTOR: (K) Ratio of the total area of copper wire in the center hole of a toroid to the window area of the toroid.

WINDOW AREA: (W_a) Area of hole of a core.

LIST OF SYMBOLS USED IN FORMULAE AND CIRCUIT DIAGRAMS

A — Cross-sectional area of magnetic flux path, in cm^2.

a — Turns ratio.

B_m — Maximum flux density in core, in gausses.

E_{out} — Output voltage.

E_c — Induced primary voltage.

E_g — Source voltage in volts, rms.

E_s — Open circuit voltage in a secondary winding. Actual output voltage is determined by calculation of voltage drops in each winding.

f — Frequency of applied voltage E_g, in hertz.

I_{bias} — Bias current.

I_{cont} — Control current.

I_{dc} — Direct current.

I_{fb} — Feedback current.

I_l — Load current.

I_p — Primary current in amperes.

I_s — Secondary current in amperes.

l — Length of magnetic path, in cm.

L_c — Inductance of the core and primary winding.

L_{sat} — Saturating inductor.

μ — Permeability.

N_p — Number of primary turns.

N_s — Number of secondary turns.

P_s — Specific core loss in watts per pound.

P_z — Specific apparent power in volt-amperes per pound.

ϕ **ac** — ac flux.

ϕ **dc** — dc flux.

R_c — Equivalent core loss resistance.

R_{fb} — Feedback resistance.

R_g — Resistance of a signal source.

R_l — Load resistance (or burden).

R_p — Resistance of primary winding.

R_s — Resistance of secondary winding.

T_{fb} — Feedback transformer.

T_{out} — Output transformer.

W — Weight of core in pounds.

Z_c — Equivalent exciting current impedance.

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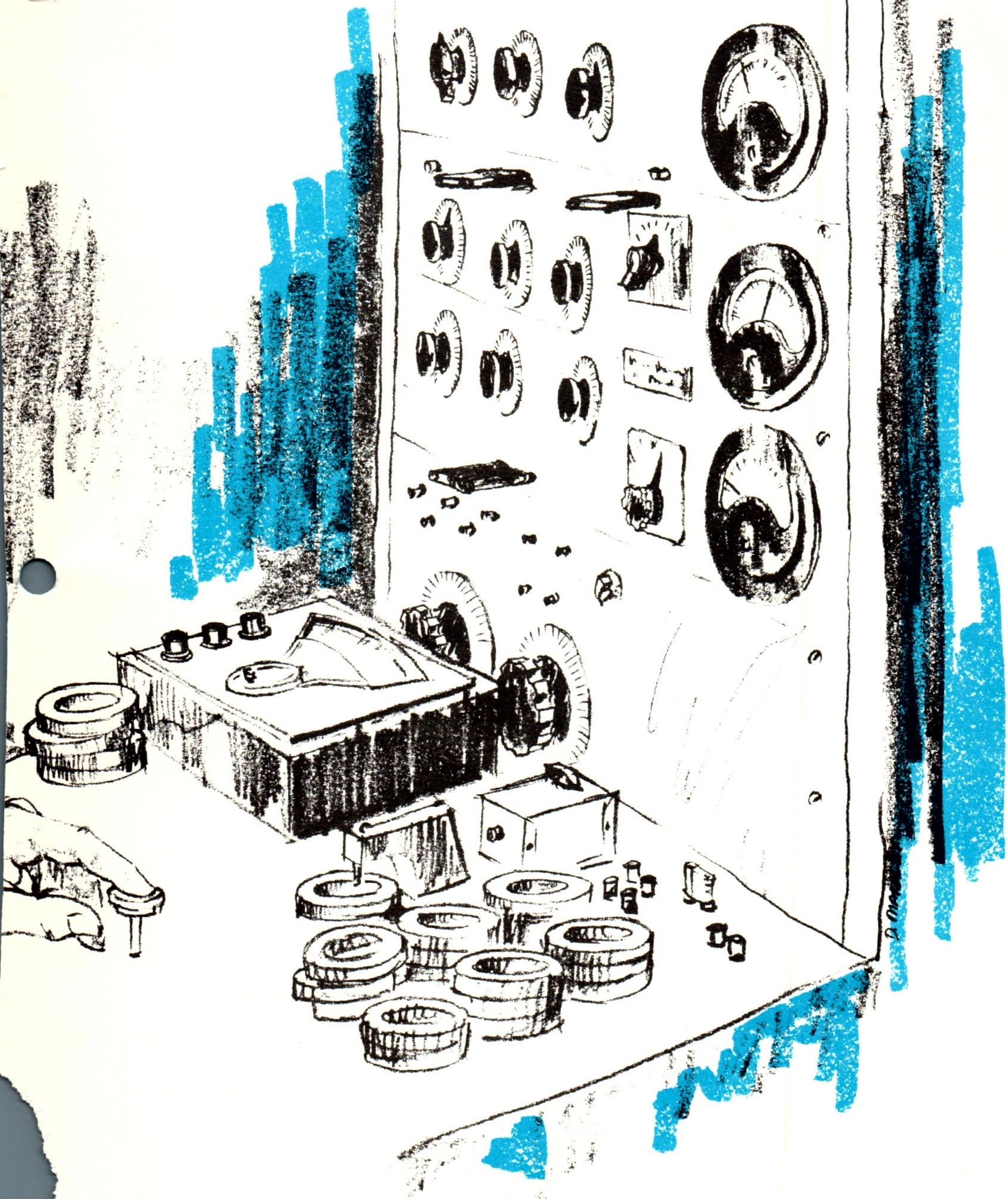

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MAGNETIC METALS COMPANY
CAMDEN, NEW JERSEY

MANUFACTURING FACILITIES

Camden, New Jersey 08101/(609) 964-7842

Pennsauken, New Jersey 08110/(609) 964-7842

Chicago
Elk Grove Village, Illinois 60007/(312) 437-7440

California
Newport Beach, California 92663/(714) 545-9413

Canada
Brantford, Ontario, (519) 753-8675

Mexico
Mexico City, 5/47-17-17

C1-171-20M

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