MAGNETICS®

Division of Spang & Company

A Critical Comparison of Ferrites with Other Magnetic Materials

MAGNETICS®
A Division of Spang and Company

Basic Differences-Composition and Structure

The difference in properties and performance of ferrites as compared with most other magnetic materials is due to the fact that the ferrites are oxide materials rather than metals. Ferromagnetism is derived from the unpaired electron spins in only a few metal atoms, these being iron, cobalt, nickel, manganese, and some rare earth elements. It is not surprising that the highest magnetic moments and therefore the highest saturation magnetizations are to be found in the metals themselves or in alloys of these metals. The oxides, on the other hand, suffer from a dilution effect of the large oxygen ions in the crystal lattice. In addition, the net moment resulting from ferromagnetic alignment of the atomic spins is reduced because a different, less efficient type of exchange mechanism is operative. The oxygen ions do serve a useful purpose, however, since they insulate the metal ions and, therefore, greatly increase the resistivity. This property makes the ferrite especially useful at higher frequencies. The purpose of this paper is to list the various considerations which enter into the choice of a material for a specific application and to contrast pertinent ferrite properties with those of bulk metal or powdered metal materials.

Material Considerations-Magnetic and Mechanical Properties

Saturation Magnetization

As mentioned previously, the highest saturation values are found in the metals and alloys. Thus, if high flux densities are required in high power applications, the bulk metals, iron, silicon-iron and cobalt-iron are unexcelled. Since the flux in maxwells ø = BA, where B = flux density in gausses and A = cross-sectional area in cm², obtaining high total flux in materials such as ferrites or permalloy powder cores can be accomplished only by increasing the cross-sectional area. Powdered iron has a fairly high saturation value, but exhibits low permeabilities.

Curie Temperatures

All magnetic materials lose their ferromagnetism at the Curie temperature. One overriding consideration for a magnetic material is that the Curie point of the material be well above the proposed operating temperatures. Table 1 lists the Curie Temperatures of the various materials. The Curie point depends only on composition and not on geometry. Even though some of the magnetic materials shown can be used at higher operating temperatures than others, very often the temperature limitations of the accessory items (wire insulation, potting or damping compound) can be more limiting; in this case, no practical advantage may be gained by the higher curie point materials.

Magnetic Losses

The magnetic losses in an A.C. application can be represented by the familiar Legg equation:

$$R_m = \mu f L(ef + aB_m + c)$$

where:

- R_m = total core loss in ohms
- e = eddy current coefficient
- a = hysteresis coefficient
- c = residual loss coefficient
- μ = magnetic permeability
- f = frequency in hertz
- L = inductance in henries
- B_m = maximum flux density in gausses

Eddy current losses will increase quite rapidly with frequency. In bulk metals, these high frequency losses can be reduced by reducing the thickness of the material perpendicular to the flux flow. This is accomplished by using thin gauge tapes or laminations or by powdering and insulating the particles. In ferrites, the same result is obtained by increasing the resistivity by many orders of magnitude. Thus, at the highest operating frequencies where further gauge or particle reduction is impractical, ferrites are the only available materials.

The hysteresis losses are proportional to the flux density and can be depicted as the area inside the hysteresis loop. High hysteresis losses are accompanied by the presence of unwanted harmonics. The nickel-iron (permalloy) alloys have low hysteresis losses and a great asset to the permalloy powder core is that these low losses are maintained with the accompanying reduction in eddy current losses.

The residual losses are not too well understood and perhaps represent an expression of our ignorance of the system. They apparently are tied in partially to absorption of energy from the system by gyromagnetic resonance.

A listing of the various losses in the materials under consideration is given in Table 1.

Permeability

Permeability is a function of composition and processing. The highest initial permeabilities (those measured at very low flux levels) are found in the nickel-iron alloys, particularly in supermalloy where the value is about 100,000. Powdered iron cores have low permeabilities (10-100) while permalloy powder cores are somewhat higher (15-550). Ferrites can be made over a wide range of permeabilities. The linear filter type permeabilities vary from 100-2000, while those used in power applications range from 3000-1 5,000. As the operating frequency increases, ferrites with lower permeabilities are used because these have distinctly lower losses in these regions. The permeabilities for a variety of materials are listed in Table 1.

Figure of Merit

A useful figure of merit for linear core materials is the µQ product. Values of this factor are tabulated in Table 1 . At frequencies of 100 KHz and above, the value for ferrites is considerably above all other materials.

Squareness

The squareness ratio is defined as the ratio of Br to Bm and is especially important in memory and switching core applications. Magnesium-manganese ferrites can be produced with extremely high squareness ratios. While some metal tape and bobbin cores possess similar high ratios, their higher cost and difficulty in miniaturization made the ferrites the material of choice in large scale memory applications in early computer models. Thin magnetic film memories, which may be considered bulk metals, have become increasingly important, and along with semiconductor, disk, tape and bubble memories, have replaced the old core memories. The importance of this phase is emphasized by the fact that the market value for computer magnetics is now greater in dollars to that of the power materials market. It is interesting to note that disk media and bubble materials are ferrite type oxides.

Brittleness

One drawback to the ferrite core as compared with metal cores is its brittleness. Being ceramic in nature, care must be exercised in the handling of these cores. Powder cores are also somewhat brittle and similar precautions are required. Although metal tape cores are not brittle, (except amorphous metal cores), they nevertheless are sensitive to strain and mechanical shock, especially in the high permeability materials. Consequently, tape wound cores are often embedded in a damping compound which prevents the transfer of strain or shock to the cores.

Hardness

Ferrites are very hard materials as compared with the other materials under consideration. This property is especially useful in applications in which wear is a factor. Consequently, ferrite material is being used extensively in magnetic recorder head applications.

Geometry Considerations

Formability

The three types of materials- bulk metal, powdered metal and ferrite - are produced by widely varying techniques and consequently the available geometries also vary.

- **Bulk metals -** These are produced mostly by standard metallurgical process involving melting followed by hot and cold rolling. The sheet material produced is either slit and wound into tape or bobbin cores or punched into laminations. Photoetching, a new method of forming small complex parts, avoids costly tooling, and produces stress-free parts.

- **Powdered Iron and permalloy -** These materials are always die-pressed into toroids or slugs, molypermalloy usually in toroids and powdered iron into slugs.

- **Ferrites** - Because ferrites are produced by a ceramic technique, they can be made in a large number of shapes. Unlike the bulk metals, they can be molded directly, and unlike the powdered permalloy, they can be machined and ground to close tolerances after firing. Various forming processes for ferrites include die pressing, extrusion, hydrostatic pressing and hot pressing. The available shapes include toroids, E-I cores, U-I cores, pot cores, rods, tubes, beads and blocks.

Tunability

An exact inductance is required in certain L-C circuits. If the shape of the inductor is toroidal, the inductance can be trimmed only by the addition or removal of turns, a time consuming and costly procedure. If a ferrite pot core is used, the tuning can be accomplished by means of a screw-type trimmer core which changes the effective air gap of the core. Threaded rods of powdered iron or ferrite materials are used extensively as tuning elements in slug tuned inductors.

Winding Considerations

Winding turns on a toroid involves specialized equipment and the process involves winding each core separately in a relatively time consuming operation. The bobbins used in ferrite pot cores can be wound many at a time on a rather simple machine. This ease of winding constitutes an important advantage for ferrite pot cores.

Magnetic Shielding

If magnetic components are relatively close in a circuit, the fields produced by one component may affect the performance of other cores. One solution is to increase the space between components. This increases the overall size of the system. Another is to use a magnetic shield which increases weight and size. A ferrite pot core is inherently self-shielding by nature of the enclosed magnetic circuit.

Inductance Stability Considerations

Temperature Stability

In telecommunications circuitry (tuned L-C filters), the maintenance of a near-constant inductance as a function of temperature and time is most critical. One method of achieving this stability is by the insertion of an air gap. The gap may be distributed as in powder cores or localized as in gapped ferrite pot cores. Gapping also results in a reduction in the effective permeability but often this is not a serious limitation. In gapped ferrite cores, the temperature coefficient (T.C.) can be linear to match a capacitor with an equal but opposite T.C. (polystyrene) or relatively flat if a flat T.C. capacitor (silver-mica) is used.

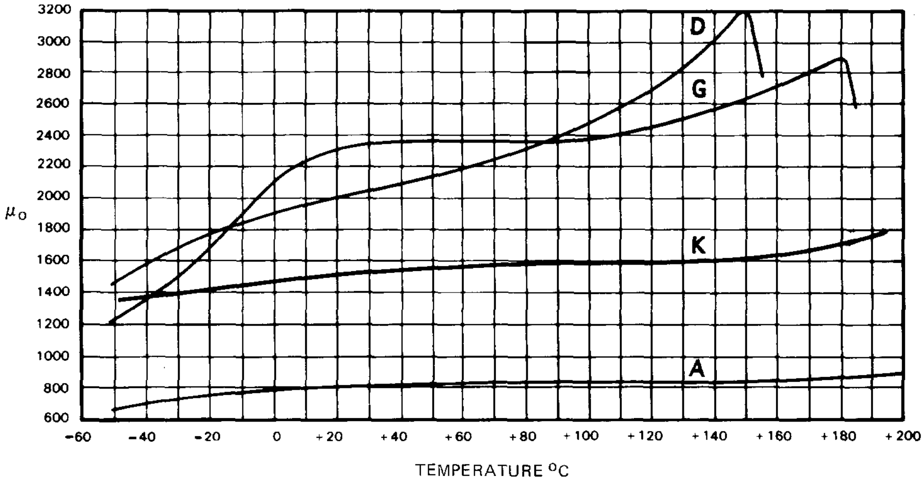
$$T.C. = \frac{\Delta L}{L \Delta T}$$

where ΔL and ΔT are corresponding changes in inductance and temperature and L is inductance at a standard temperature.

Figure 1 illustrates the temperature characteristics of several ferrite materials.

As pointed out, the use of an air gap greatly increases the temperature stability. The powder core toroid and ferrite pot core are thus used to good advantage. In the powder core, the T.C. is built into the toroid, whereas in the pot core, the T.C. can be varied by changing the gap. However, in the latter, the effective permeability and therefore the inductance of the core is changed. By choice of the proper size core with the proper gap, the optimum inductance and T.C. can be obtained.

Figure 1 — Ferrite Toroids
Initial Permeability (μo) Vs. Temperature



Permeability VS. AC Flux Density

It is often desirable to have a minimum change in permeability with AC excitation. Here again, the air gap in either permalloy powder cores or ferrites can be used to advantage. Figures 2, 3 and 4 show the relative change in inductance for a ferrite toroid, ferrite pot core, and permalloy powder toroid.

Relative Change of Inductance With AC Flux Level for Toroids and Pot Cores

Figure 2 — Ferrite Toroid

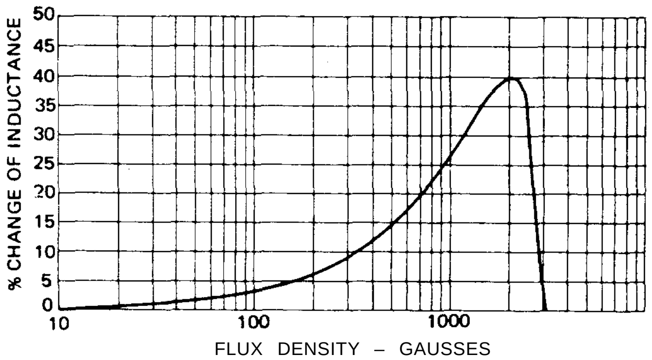


Figure 3 — Ferrite Pot Core

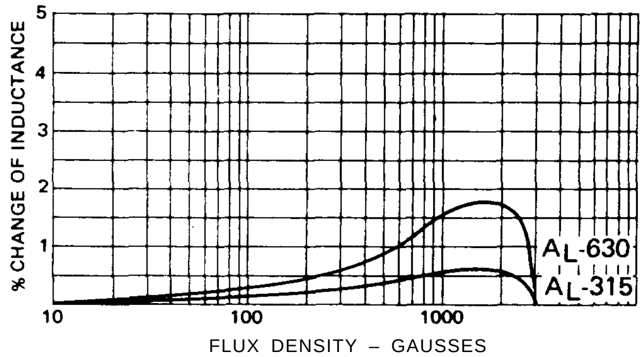


Figure 4 — Permalloy Powder Toroid

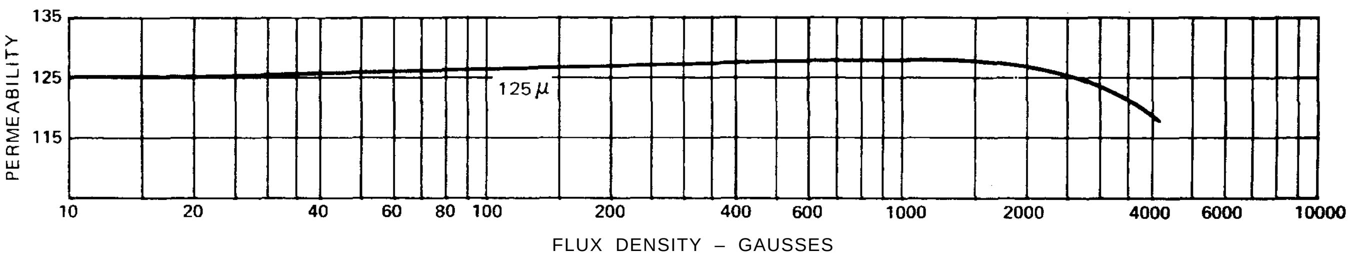
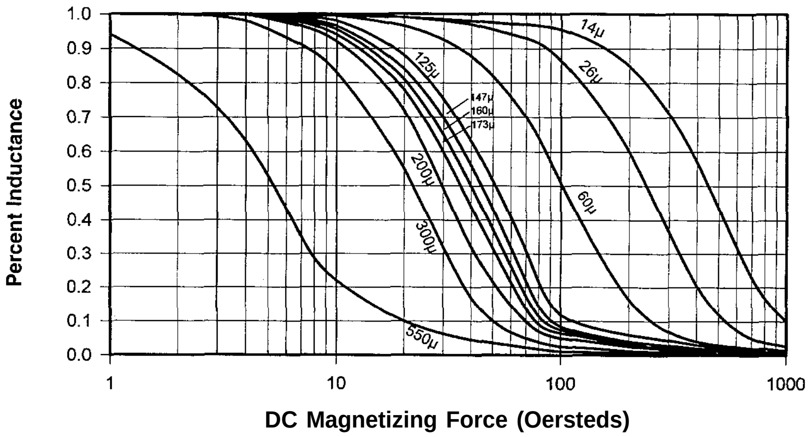


Figure 5

Inductance VS. DC Bias, Permalloy Powder Cores



Permeability VS. DC Bias

Often an AC circuit has a superimposed DC bias conditon. Minimum variation of permeability with DC is desirable. Powder cores are especially resistant to these changes. Figures 5, 6, and 7 show typical variations of µ with DC bias for permalloy, high flux and Kool Mµ® powder toroids. Gapped ferrite pot cores show a similar effect, shown in Figure 8.

Permeability VS. Time

In most magnetic materials there is a slight decrease in permeability with time after the material is demagnetized or after it is first produced. This effect is known as disaccommodation. In non-linear applications this effect is not too important. However, in low flux level circuits where a constant inductance is required, the effect must be considered. The effect is pronounced in low permeability materials and is negligible for high permeability materials. However, the effect can be minimized greatly by reduction of the effective permeability by insertion of an air gap. Thus in powder cores, the change of permeability due to this effect is less than . 1%. In ferrite pot cores, the localized gap reduces the effect in proportion to the effective permeability compared with the toroidal permeability. Since the effect is logarithmic, most of the decrease occurs in the first few days after firing. If some aging of the cores occurs before usage, the change of inductance due to time will be negligible.

Figure 6

Inductance VS. DC Bias Curves, High Flux Powder Cores

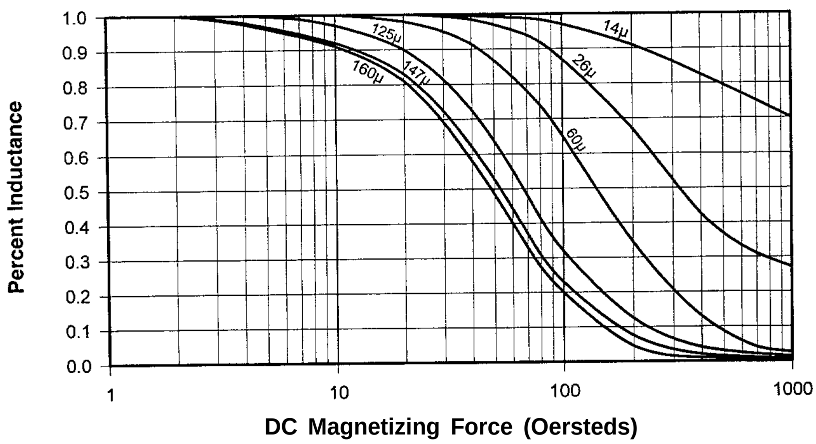


Figure 7

Inductance VS. DC Bias Curves, Kool Mµ Powder Cores

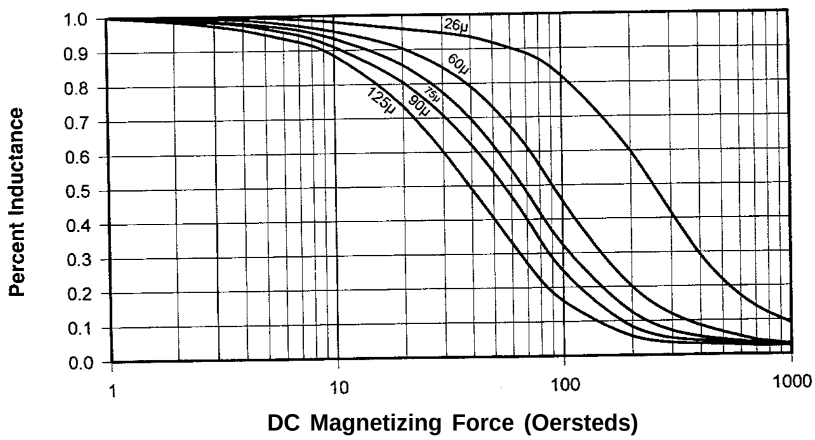
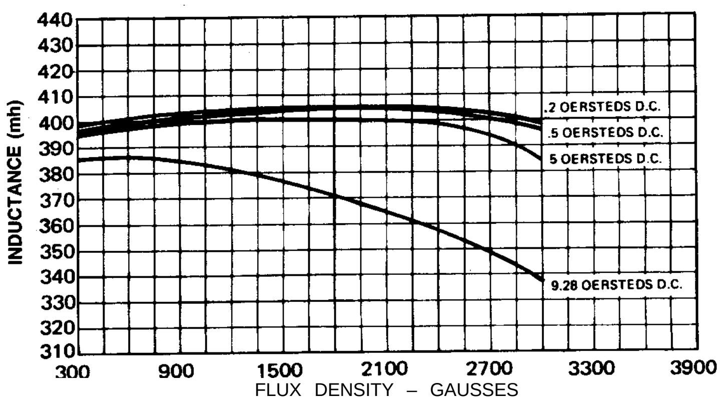


Figure 8

Inductance VS. DC Bias for A Ferrite Pot Core



Application Considerations-
Ferrite Advantages and Disadvantages

Application	Advantages	Disadvantages
Low Frequency (<1KHz) **High Flux Applications** Generators Motors Power Transformers	• Ease of forming shapes allows possible use in inexpensive, high loss applications such as relays, small motors.	• Flux density low • Relative cost high • Limited size of parts
Medium Frequency (1-100 KHz) **Non-Linear High Flux Applications** Flyback Transformers Deflection Yokes Inverters Wide Band Transformers Recording Heads Pulse Transformers Memory Cores	• Cost much lower than Nickel-Iron alloys, especially thin tapes • Moderately high permeabilities available • Low losses, especially in upper half of this range • Inherent shielding in pot cores • Good wear resistance • Easily adapted to mass production	• Flux density lower than Nickel-Iron alloys • Permeabilities lower than Nickel-Iron alloys • Curie Temperature fairly low • Good mating surface necessary for high inductance • Smaller flux change than bobbin cores
Medium Frequency (1-100 KHz) **Low Flux, Linear Applications** Loading Coils Filter Cores Tuned Inductors Wide Band Transformers Antenna Rods	• Permeabilities higher than powdered iron or Permalloy cores • Gapped pot cores provide: 1. Adjustability 2. Stability - temperature, time, A. C. flux density, D.C. bias 3. Self-shielding • µQ Products higher than other materials • Wide choice of Inductance and Temperature Coefficient	• Low Curie point • Need precision grinding of air gap • Brittleness • Mounting hardware needed
Higher Frequencies (>200 KHz) **Low Flux, Linear Applications** Filters Inductors Tuning Slugs	• Low losses (especially eddy current) • Ferrites, powdered iron and moly-permalloy can operate at higher frequencies • Medium frequency advantages apply	• Permeability decreases with frequency • Medium frequency disadvantages apply • Poor heat transfer
Microwave frequencies (>500 MHz)	• Low dielectric losses • Good gyromagnetic properties • Only bulk materials available	

Table 1 — Properties of Soft Magnetic Materials

Material	Initial Perm. μ_o	B_{max} Kilogausses	Loss Coefficients e x 10^6	Loss Coefficients a x 10^3	Loss Coefficients c x 10^3	Curie Temp. °C	Resistivity (ohm-cm)	μ_oQ at 100 kHz	Operating Frequencies
Fe	250	22	-	-	-	770	10×10^{-6}	-	60-1000 Hz
Si-Fe (unoriented)	400	20	870	120	75	740	50×10^{-6}	-	60-1000 Hz
Si-Fe (oriented)	1500	20	-	-	-	740	50×10^{-6}	-	60-1000Hz
50-50 Ni Fe (grain-oriented)	2000	16	-	-	-	360	40×10^{-6}	-	60-1000Hz
79 Permalloy	12,000 to 100,000	8 to 11	173	-	-	450	55×10^{-6}	8000 to 12,000	1 kHz-75kHz
AMORPHOUS Alloy B	3000	15-16	-	-	-	370	135×10^{-6}	-	to 250 kHz
AMORPHOUS Alloy E	20,000	5-6.5	-	-	-	205	140×10^{-6}	-	to 250 kHz
Permalloypowder	14 to 550	3	.01 to .04	.002	.05 to .1	450	1.	10,000	10 kHz-1 MHz
High Flux powder	14 to 160	15	-	-	-	360	-	-	10 kHz to 1 MHz
Kool Mu®powder	26 to 125	10	-	-	-	740	-	-	to 10 MHz
Iron powder	5 to 80	10	.002 to .04	,002 to .4	.2 to 1.4	770	10^4	2000 to 30,000	100 kHz-100 MHz
Ferrite-MnZn	750 to 15,000	3 to 5	.001	.002	.01	100 to 300	10 to 100	100,000 to 500,000	10 kHz-2 MHz
Ferrite-NiZn	10 to 1500	3 to 5	-	-	-	150 to 450	10^6	30,000	200 kHz-100MHz
Co-Fe 50%	800	24	-	-	-	980	70×10^{-6}	-	-

Listed below are catalogs and brochures where additional details and design information on the products manufactured by Magnetics are available. Some can be obtained on our website. Otherwise, write, phone or e-mail us to request a copy. (See back cover for contact information).

Tape Wound Core Literature

TWC-500	Design Manual
TWC-S1	Fundamentals of Tape Wound Core Design
TWC-S2	How to Select the Proper Core for Saturating Transformers
TWC-S3	Inverter Transformer Core Design and Material Selection
TWC-S5	Composite Core
SR-4	Mag Amp Cores and Materials

Powder Core Literature

MPP-400	Design Manual, MPP Cores
HFC-1.0	High Flux Cores
HFD-1.0	High Flux Cores Diskette
MPP-Q1	Q Curves for Molypermalloy Powder Cores
KMC-2.0	Kool Mu Cores
KMD-2.0	Kool Mu Cores Diskette
KMC-S1	Kool Mu Application Notes
KMC-E1	Kool Mu E Cores
CG-03	Cores For Flybacks
PCD-2.3	Magnetics Inductor Design Software

Nickel-Iron, Supermendur, & Amorphous Cut Core Literature

MCC-100T	Design Manual

Bobbin Core Literature

BCC-1.1	Design Manual
BCD-1.1	Design Manual Diskette

Ferrite Literature

FC-601	Design Manual
FC-S1	Ferrite Material Selection Guide
FC-S2	EMI/RFI Common Mode Filters
FC-S3	Q Curves
FC-S4	Step Gap E Cores Swing Chokes
FC-S5	Common Mode Inductors for EMI
FC-S6	Planar Core Design and Use - Technical Papers
FC-S7	Curve Fit Equations for Ferrite Materials
FC-S8	Designing with Planar Ferrite Cores
CG-01	A Critical Comparison of Ferrites with other Magnetic Materials
CMF-2.1	Common Mode Filter Inductor Design Software
CAD-1.3	CLIP ART Diskette

General Information

CG-04	Testing Magnetic Cores
CG-05	Frequently-Asked Questions About Magnetic Materials
TID-100	Power Transformer and Inductor Design
SR-1A	Inductor Design in Switching Regulators
PS-01	Cores for SMPS
PS-02	Magnetic Cores for Switching Power Supplies
APB-2	All Products Bulletin
HED-01	Cores for Hall Effect Devices

MAGNETICS®

Division of Spang & Company

HOME OFFICE AND FACTORY
P.O. Box 391
Butler, PA 16003
FAX: 724-282-6955
Phone: 724-282-8282
1-800-245-3984
e-mail: magnetics@spang.com
www.mag-inc.com

MPP Powder Cores • High Flux Powder Cores

KOOL MU® Powder Cores

Tape Wound Cores • Bobbin Cores

Ferrite Cores

Custom Components

Printed in USA • CG-01 1H