DESIGN MANUAL TWC 600

Tape Wound Cores

MAGNETICS®

Since 1949, MAGNETICS, a division of Spang & Company, has been a leading world supplier of precision, high permeability, magnetic components and materials to the electronics industry. Applications for these products range from simple chokes and transformers, used in telephone equipment, to sophisticated devices for aerospace electronics. Staffed with a high degree of technical talent, and having modern research facilities, MAGNETICS has followed a carefully charted course to find and fill specialized industrial needs, at the same time, pioneering in new designs, product developments, and innovations in manufacturing methods. Many of these developments have resulted in acceptance of MAGNETICS products as industry standards in tape wound cores, powder cores, and ferrite cores.

MAGNETICS®

Tape Wound Cores®

MAGNETICS TWC History

Although the groundwork for the formation of modern magnetic devices was laid by German military in World War I, it was after World War II that tape wound cores had their beginnings as electronics opened the way to new weapons systems. The Naval Ordnance Laboratory in Washington, DC turned its attention to facets of magnetism in devices where the vacuum tube had a serious drawback - fragility.

The Navy was constantly looking for a device with the vacuum tube's precise ability to control, but with none of its physical limitations. An old device, the magnetic amplifier, became the subject of a new study. Engineers and scientists assigned to this work began to dig deeply into the function the core plays, and particularly what could be done by using newer nickel-iron alloys. It was discovered that some alloys would reach saturation with very low magnetizing currents. This started the beginning of a new era for an old science - high permeability magnetics.

Magnetics was established in 1949 when the commercial market for high permeability magnetic materials was virtually non-existent and development in this field was just taking root. The new simplicity and reliability with which magnetic components could be used opened many doors in the field of electronics. Magnetics quickly was positioned as a leader in this field and has remained so ever since.

The first tape cores were used in applications where they were superior to the fragile vacuum tubes. Tape wound core applications grew rapidly because these new magnetic components performed far better due to environmental and operational advantages. They contained no parts to wear or burn out; and the effects of shock, vibration and temperature were small compared to other components. Tape cores also afforded the advantages of electrical isolation and signal mixing not easily obtainable from other electric parts.

Materials and Applications

Some of the magnetic devices in early applications have since been replaced by transistors and integrated circuits; however, a host of new applications and requirements for new core materials have emerged. Magnetic cores are often key parts of complicated electronic circuitry found in highly reliable airborne and space computers, telephone systems, radar installations, jet engine controls, power supplies and nuclear reactors.

Tape wound cores are made from high permeability magnetic strip alloys (.0005" to .014" thick) of nickel-iron (80% or 50% nickel), silicon-iron, cobalt-iron and various amorphous metals. They can be provided in protective cases or supplied epoxy encapsulated. Tape wound cores are produced as small as 0.375" in ID to more than 20" in OD, in over 1400 sizes.

Bobbin cores are miniature tape cores made from ultra-thin (.000125" to .001" thick) strip wound on non-magnetic stainless steel bobbins. Covered with protective caps and then epoxy coated, bobbin cores can be made as small as 0.050" in ID and with strip widths down to 0.032".

Vertical Integration

All components manufactured by Magnetics are process-controlled from processing of raw materials to producing finished cores. This total in-house capability, coupled with a "Zero Defects" Quality control process, assures the user that his high-tech applications will be performance guaranteed. In addition, unexcelled service includes expert applications engineering assistance, software package recommendations, and finished parts inventories to satisfy both prototyping and volume deliveries.

General Core Construction

From basic steel to finished core, strict quality control assures the ultimate in reliability as designs, specifications, and necessary tolerances are followed through production.

Basic Steel

The basic steel used is within $\pm$ 10% tolerance of nominal thickness. Particular attention is placed on physical selection of proper steel. Reasons for rejection of the basic steel in tape wound cores include poor physical characteristics, holes, pits, creases, blisters, wrinkles and poor magnetic properties such as low flux density and poor squareness ratio. Coil set and camber are held to a minimum to obtain optimum magnetic characteristics in the finished core. Each basic coil of raw material is identified with a coil number, thickness, material description, width, and weight. This identification is carried throughout the manufacturing process so that a complete history of every tape wound core is available.

Steel Evaluation

Each coil is tested for its basic properties by winding standard cores and processing them under various conditions to determine the optimum processing for that particular coil. The process specified for that coil becomes a part of the history which travels with that coil as it is made into production cores. It is your assurance that the ultimate in tight, guaranteed electrical limits will be obtained in the end product. In addition, the electrical data obtained on the basic coil evaluation is used for selection of special materials for special cores needed for critical applications where standard guaranteed limits are too wide.

Core Winding

All tape wound cores are wound to accurate dimensions, weights, and winding tensions to maintain uniformity in the finished product.

Annealing

Using automatic furnaces, all cores are annealed in a dry hydrogen atmosphere to remove strains and impurities from the tape. Critical time - temperature characteristics and cooling rates are accurately controlled. Temperatures corresponding to the evaluation of the basic steel as previously described are used.

Specifics of Core Construction

Protective Boxes

All tape wound cores made from nickel-iron materials are encased in a box to protect them from mechanical strains that affect magnetic properties. Silicon-iron cores are somewhat less affected, and may be obtained with or without protective boxes. An inert silicone cushioning or damping compound, whose amount is predetermined for each core size, is placed between the box and the core. This compound prevents movement of the core in the box and provides additional protection from external stresses.

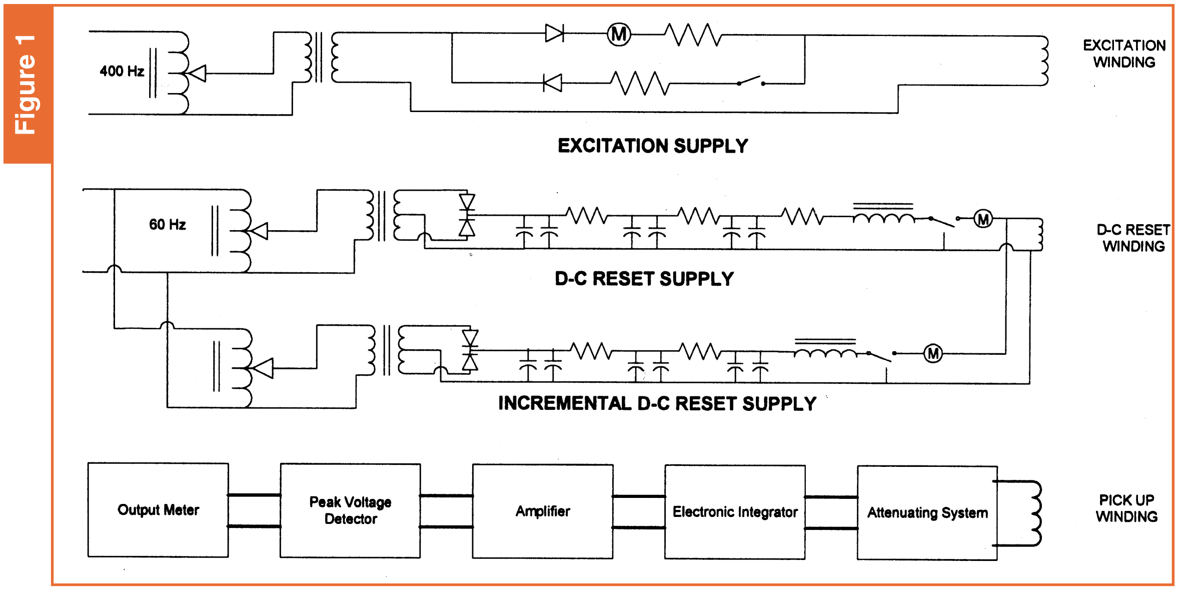
Boxes are either aluminum or phenolic, made to minimum dimensions (see Core Box Selection), but designed so that they are not strained by temperatures or by pressure from copper windings. Aluminum core boxes greatly minimize these dangers; the two types are uncoated and GVB (guaranteed voltage breakdown) painted. The guaranteed voltage breakdown finish seals the box and is capable of withstanding at least 1,000 Volts at 60 Hz between the copper windings and the bare case. It permits winding directly on the core without prior taping. GVB-coated cores are also checked for leaks and their ability to operate in high temperature environments.

Each core carries an **identifying number** (see "How to Order").

In addition, the job number is also stamped on the box.

This number indexes to a central quality control file that identifies:

1. **The basic coil of steel used in manufacturing the core**
2. **Heat-treating cycle**
3. **Date on which the core was manufactured**
4. **Number of cores manufactured in that lot**
5. **The electrical data for the lot**



Testing

Magnetics uses two testing methods for determining dynamic characteristics of tape wound cores. These methods include use of a Constant Current Flux Reset Tester and a Sine Current E-I Loop Tester, both of which are normally operated at a frequency of 400 Hertz. (Information regarding operation at other frequencies may be obtained by contacting the Magnetics Applications Engineering Department.)

The Constant Current Flux Reset test method has been chosen as a standard by the IEEE (Standards Paper #393) and by Magnetics because it measures parameters that are valuable in predicting core performance in many magnetic amplifier circuits.

Figure 1 above shows an operational diagram of the Constant Current Flux Reset Tester.

The excitation circuit provides a magnetizing force from a source of either half wave rectified current or full wave current, depending on the parameter to be measured.

The constant current or dc reset magnetizing force is supplied from a source of direct current to which an incremental direct current may be added.

Output of the core is integrated and measured in terms of the electrical output of an integrating system composed of an attenuator, electronic integrator, amplifier, peak voltage detector circuit, and an output meter or bridge balance system. The attenuating system compensates for core area so that flux density and output meter or dial readings are always proportional.

Measurements are made by applying proper excitation, with reset and pick up windings placed on the core. The core is excited by a sinusoidal full wave current adjusted to IEEE requirements. This drives the core around a major dynamic hysteresis loop from positive to negative saturation, and the flux density (B_m) is measured.

Next, the core is excited by the half wave (rectified) source, which drives the core into saturation during a half cycle. This permits the flux to return to the residual

Figure 2

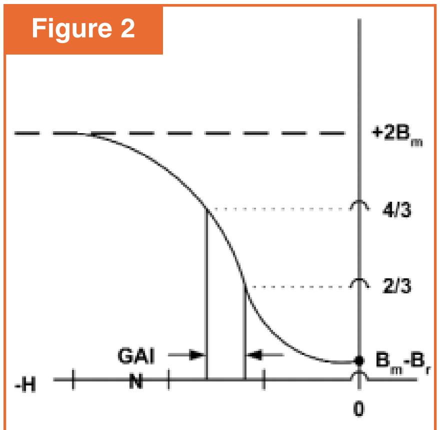
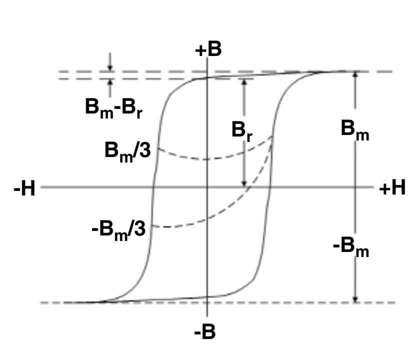


Figure 3



flux density (B_r) level during the “off” portion of the cycle. Output of the core is read as (B_m - B_r), providing an indication of the squareness of the core. From these values of B_m and B_m-B_r, the residual flux density (B_r) and the squareness ratio (B_r/B_m) can be computed.

When negative dc is applied to the reset winding with a positive ac half wave excitation (Figure 1), total flux change within the cycle will increase because the core is reset or driven down the back side of the hysteresis loop (Figure 2).

With the core being excited by a positive half wave source, only enough negative dc is introduced to reset the flux to a value equal to one-third of the saturation flux density. The reset magnetizing force required to accomplish this is an indication of loop width (H_1).

An increment of reset magnetizing force added to the initial reset force will further reset the flux from the flux density of B_m/3 to a flux density of -B_m/3. This incremental magnetizing force is a function of the slope of the linear portion of the dynamic hysteresis loop and is defined as Δ H.

Core gain can be determined from the formula (Δ B/Δ H) where delta B is the incremental flux reset. Standard measurements discussed above are summarized and illustrated in Figures 2 and 3 and are also fully covered in IEEE Standards Paper #393.

The supplementary dynamic testing method employed at Magnetics uses a Sine Current E-I Loop Tester that measures coercive force and peak differential permeability under sine current excitation.

E-I Loop Testing

By using synchronous switches, the following four patterns are displayed simultaneously on an oscilloscope:

PATTERN 1 - E-I loop of the core, with signals proportional to induced core voltage and magnetizing current being displayed on the vertical axis and horizontal axis respectively.

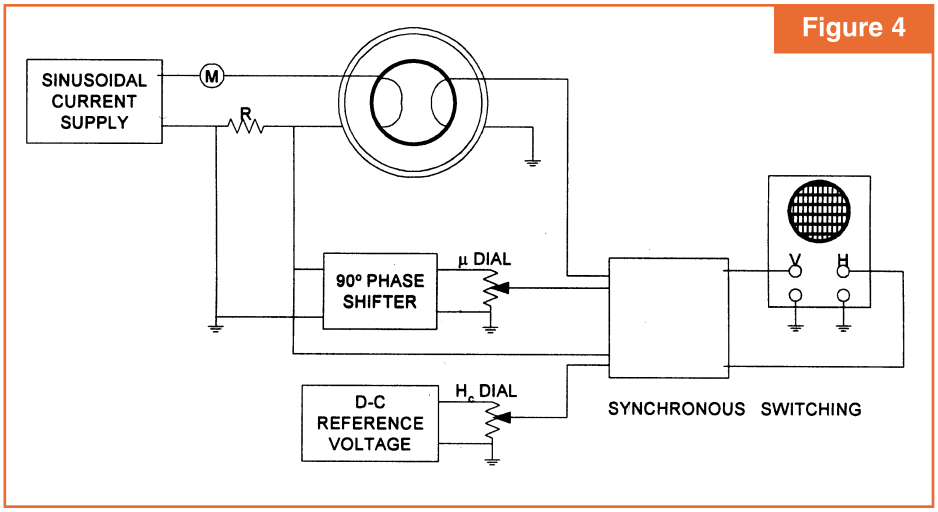
PATTERN 2 - An elliptical pattern which is a locus of constant permeability.

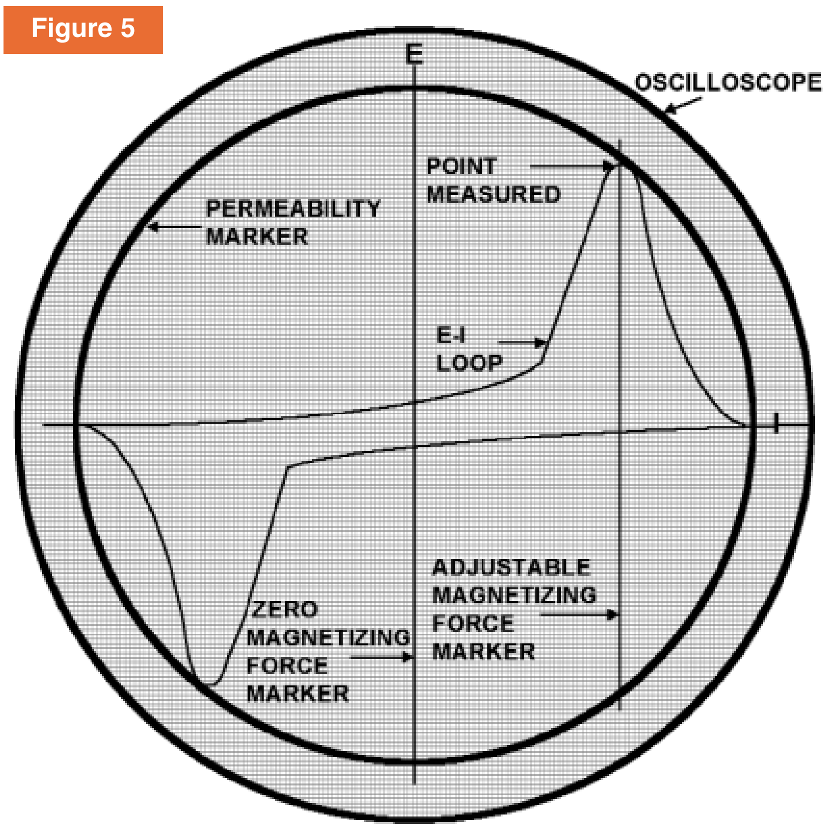
PATTERN 3 - A zero magnetizing force reference marker.

PATTERN 4 - An adjustable vertical magnetizing force line.

A test is made by exciting the core with a sinusoidal drive. Then, by means of precision potentiometers calibrated in units of permeability and magnetizing force, the position of patterns 2 and 4 are made to coincide with the peak of the E-I loop (Pattern 1). Peak differential permeability and coercive force are read from the potentiometer dials.

The excitation current includes rectifiers to provide both full wave and half wave sinusoidal current. By the use of an electronic integrator, it is therefore possible to measure B_m and B_m-B_r.





The residual flux density and the squareness ratio, B_r/B_m may be calculated from these measurements.

The simplified schematic drawing of a Sine Current E-I Loop Tester is shown in Figure 4. A summary of the measurements and an illustration of the patterns on the oscilloscope appear in Figure 5, and are also covered in IEEE Standards Paper #393.

Core Matching

The standard core matching method used by Magnetics consists of visual comparison of the 400 Hertz (although other test frequencies are possible) E-I loops of two cores displayed simultaneously on an oscilloscope.

Oscilloscope controls are adjusted so that one half of each of the E-I loops will occupy all of the screen. Only when the two loops coincide at all points to within five per cent of peak horizontal and vertical deflections are they shipped as a "five percent match."

Experience proves that this method results in the best possible match over the entire loop. It permits detection of odd wave forms not normally rejected by differential measure. While this matching method does not give numerical results, such results can be obtained on a standard test set on the basis of mutually acceptable limits.

Constant Current Flux Reset Matching

The supplementary core matching method used by Magnetics consists of matching the parameters obtained from the Constant Current Flux Reset Tester. Three of these characteristics (B_m, B_r/B_m, and H_1) are matched to within 5% while ΔH is matched to within 10%.

For very critical applications there is no substitute for matching completed **reactor assemblies.**

While this test will produce numerical or recorded results, cores matched with this method insure that only four distinct test points are being matched. Matching these four points does not insure that all other points on the hysteresis loops are matched to the same degree.

Since the performance of a core will be affected by any windings placed on it, Magnetics cannot guarantee the degree of match after winding.

For very critical applications there is no substitute for matching completed reactor assemblies.

Supermalloy Testing

Supermalloy tape wound cores are often used in applications requiring high initial permeabilities and low core losses over a wide range of frequencies. To insure proper operation in these applications, Magnetics performs an impedance permeability (μ_z) test on Supermalloy cores. Impedance permeability correlates well with the magnetizing currents flowing as a result of core losses and the inductive reactance of the wound cores. μ_z is equal to B/H where H is determined from the total magnetizing current and B is determined from the voltage induced in a pick-up winding on the core.

Magnetics' Supermalloy cores are manufactured to minimum μ_z limits for each material thickness. The μ_z test is performed at 20 gauss and at a high frequency where the core losses and the material permeability have an equal effect on the measured μ_z.

Special precautions should be taken to demagnetize Supermalloy cores before performing low level permeability tests. This insures that the core permeability is being measured at around the initial or "zero B" state and not around a B_r or remanence point.

DC Fluxmeter Testing

To help maintain constant high quality in core materials, Magnetics uses conventional fluxmeter methods of measuring magnetic parameters under static (dc) conditions. Although not a production test, this method is part of an established quality control procedure.

Parameters which can be determined from fluxmeter measurements are B_m, B_r, B_r,/B_m, H_c and for certain less square materials, initial and maximum permeability.

Because of its proven reliability, this test is used as a reference for other types of flux density measurement equipment.

Core Box Selection

Unboxed Cores
Encapsulated Cores
Non-Metallic Boxes
Aluminum Boxes
Aluminum Cases with GVB
Miniature Tape Wound Cores

Unboxed Cores

Because of the extreme sensitivity of nickel-iron cores to winding stresses and pressures, such cores are not available in an unboxed state. Magnesil cores are not as susceptible to these pressures and are available without boxes.

The advantages of an unboxed core are:

1. Maximum window area is available.
2. Where slight deterioration of properties after winding and potting can be tolerated, a slightly smaller package at somewhat lower cost is yielded.

Encapsulated Cores

Magnesil and cobalt-based amorphous cores (only) are available in encapsulated form. This protection is a tough, hard epoxy which adheres rigidly to the core, allowing the winder to wind directly over the core without prior taping. A smooth radius prevents wire insulation from being scraped.

The advantages of encapsulated cores are:

1. A minimum voltage breakdown of 1000 volts from core to winding is guaranteed.
2. The temperature rating of this finish is 125ºC (257ºF) in free air.
3. No taping is required on the core prior to winding.

Non-Metallic Boxes

For superior electrical properties, improved wearing qualities, and high strength, non-metallic boxes are widely used as protection for the core material against winding stresses and pressures. Tough and resilient, they come in two types: (1) where production quantities justify them, boxes may be made of molded glass-filled nylon, and (2) for low volume production quantities, phenolic fabrics are used. Both types meet a minimum 2000 volt breakdown requirement. The glass-filled nylon types can withstand temperatures to 200ºC without softening, while the phenolic materials will withstand temperatures up to 125ºC. The sizes that are tooled for glass-filled nylon are shown in the Core Size Table

Figure 6

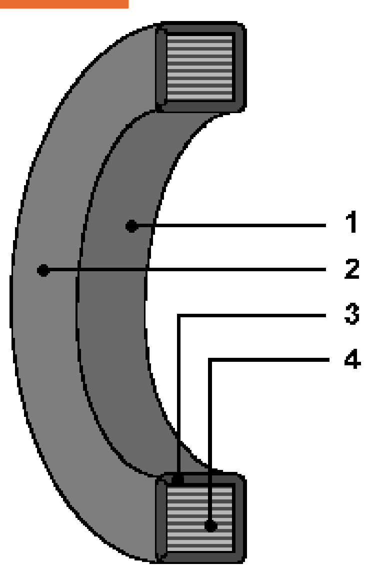


Figure 6 Non-Metallic Box Core Construction

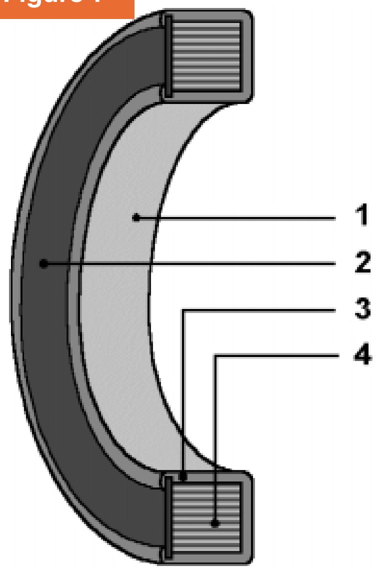
1. Nylon or Phenolic case, tough resilient, high electrical resistance.
2. Nylon or Phenolic insert, accurately cut, and pressure fitted for tight seal.
3. Inert cushioning, a high temperature silicone compound.
4. Magnetic materials, a selection of commercially available high permeability alloys.

Aluminum Boxes

Aluminum core boxes have great structural strength. A glass epoxy insert, to which the aluminum case is mechanically bonded, forms an airtight seal. These core boxes will withstand temperatures to 200ºC (392ºF), a critical factor in design of compact airborne equipment. Advantages of the aluminum box are:

1. Core boxes will withstand temperatures to 200ºC (392ºF). This is important to designing for extreme environmental conditions. See the “Magnetic Material Physical Properties” summary for core material temperature limits.
2. Magnetic properties will not be changed by coil winding. The strong aluminum construction will prevent any distortion of the core box, thus preserving the guaranteed magnetic properties of the core within.

Figure 7



3. Effects of vibration and shock are minimized because the tape is cushioned by an inert silicone compound.

Figure 7 Aluminum Box Core Construction

1. Aluminum case for greatest structural strength ever attained.
2. Silicone glass or malamine insert, to break electrical path around core.
3. Inert cushioning, a high temperature silicone compound.
4. Magnetic materials, a selection of commercially available high permeability nickel alloys.

Aluminum Box with GVB

This case is the same basic construction as the aluminum box, but in addition it has a thin, epoxy-type, protective coating surrounding the case. This finish adds no more than .015" to the OD, subtracts no more than .015" from the ID, nor adds more than .020" to the height.

Advantages of the GVB finish are:

1. A guaranteed 1,000 volts minimum breakdown from wire to case.
2. The finish will not cold flow under winding tensions. The case has a sufficiently tight seal for normal or low vacuum varnish impregnation. For high vacuum conditions and a guaranteed leak proof seal, contact the factory.
3. A GVB core permits direct winding of copper on the case without prior taping.
4. The coating will withstand temperatures as high as 200ºC and as low as -65ºC with an operating life of 20,000 hours. Applications include high performance aircraft and specialized shipboard use, as well as surface-to-air and air-to-air missiles. Storage does not affect GVB finish.
5. A GVB encased core is ideal in the majority of applications where rigid military specifications involve extreme environments under vibration or temperatures. For complete information on performance over extreme environmental conditions, contact Magnetics Applications Engineering Department.

Miniature Tape Wound Cores

All cores previously described are used primarily in circuits operating to 10 kHz and are available mainly in tape thicknesses from (.0005" to .004"), depending on inside diameter; certain ID's are also available in .00025" tape.

For higher frequency operation, miniature cores made from Orthonol or Permalloy 80 are available in thicknesses from .00025" to .001". These standard miniature cores may be coated with GVB to provide a hermetic seal and to guarantee a minimum voltage breakdown of 500 volts.

Miniature tape wound cores, available in a wide range of standard flux capacities, are very useful for operating frequencies up to 500 kHz. Perhaps the greatest advantage of these parts is that their size is much smaller than that obtained in boxed cores.

Magnetics has soft magnetic core materials available for all applications of saturating and high sensitivity magnetic circuits. These materials are especially selected and processed to meet exacting magnetic circuit requirements, and are manufactured to tight guaranteed tolerances according to IEEE test procedures or other common industry test methods.

Description and Uses of Available

Magnesil

(MATERIAL CODE “K”)

This material is a grain-oriented 3% silicon-iron alloy available in .001”, .002”, .004” and .012” thicknesses. It is processed and annealed to develop high Squareness and low core loss. It is usually used in high quality toroidal power transformers, current transformers and high power saturable reactors and magnetic amplifiers.

It exhibits high saturation flux density with high squareness but has comparatively high coercive force and core loss. With its high Curie temperature, it is quite useful in magnetic devices, which are to be exposed to temperatures between 200ºC and 500ºC. At higher temperatures, flux density, however, must be reduced. Also, at higher temperatures, unboxed cores only should be used due to box temperature limitations.

Square Orthonol

(MATERIAL CODE “A”)

This material is a grain-oriented 50% nickel-iron alloy available in thicknesses of .0005”, .001 “, .002”, .004” and .014” for tape wound cores, and .00025 “ and .0005” thicknesses for bobbin cores. It is manufactured to meet exacting circuit requirements for very high squareness and high core gain, and is usually used in saturable reactors, high gain magnetic amplifiers, bistable switching devices, and power inverter-converter applications. Other applications such as time delays, flux counters and transductors demanding extremely square hysteresis loops require selection of Square Orthonol.

48 Alloy

(MATERIAL CODE “H”)

This material, a 50% nickel-iron alloy, has a round B-H loop and is available in .002”, .004” and .014” thicknesses. It exhibits lower Saturation Flux Density, Squareness, Coercive Force, and core gain than the Orthonol types. However, when used in proportioning magnetic amplifiers, it eliminates the possibilities of triggering. It is useful in devices requiring lower coercive force and low losses such as special transformers, saturable reactors, and proportioning magnetic amplifiers.

Square Permalloy 80

(MATERIAL CODE “D”)

This material is a non-oriented 80% nickel-iron alloy available in .0005”, .001 “, .002”, .004” and .014” thicknesses for tape wound cores and .000125”, .00025” and .0005” thicknesses for bobbin cores. It is manufactured to meet the high Squareness, and high core gain requirements of magnetic preamplifiers and modulators. It is especially useful in converters and inverters where high voltage at low power levels are required, but where circuit losses must be kept to a minimum. Square Permalloy 80 has a Saturation Flux Density approximately 1/2 that of the Orthonol’s, but has Coercive Force values 1/5 to 1/7 that of the 50% oriented nickel-iron alloys. Core gain for Square Permalloy 80 is higher by approximately 1.7 times the core gain of Orthonol.

Round Permalloy 80

(MATERIAL CODE “R”)

This material is a non-oriented 80% nickel-iron alloy available in thicknesses of

Soft Magnetic Materials

.001”, .002” and .004”. It is processed to develop high Initial Permeability and low Coercive Force. It has lower Squareness and core gain than the Square type, as these characteristics are sacrificed to produce the high Initial Permeability and low Coercive Force properties. This material is especially useful in designing highly sensitive input and inter-stage transformers where signals are extremely low and dc currents are not present. It is also useful in current transformers where losses must be kept to a minimum and high accuracy is a necessity. The initial permeability of this material is usually between 20,000 and 50,000 with Coercive Force values about 70% that of Square Permalloy 80.

Supermalloy

(MATERIAL CODE “F”)
This material is a highly refined and specially processed 80% nickel-iron alloy available in .0005”, .001”, .002” and .004” thicknesses. It is manufactured to develop the ultimate in high Initial Permeability and low losses. Initial permeability ranges from 60,000 to 100,000 while the Coercive Force is about 1/3 that of Square Permalloy 80. This material is very useful in ultra-sensitive transformers, especially pulse transformers, and ultra-sensitive magnetic amplifiers where extremely low loss is mandatory.

Supermendur

(MATERIAL CODE “S”)
This material, available in small quantity by special order, is a highly refined 50% cobalt-iron alloy, available in .002” and .004” thicknesses. It is specially processed and annealed to develop high Squareness and high Saturation Flux Density. Supermendur serves well in devices requiring extreme miniaturization and high operating temperatures. It can be used in the same types of applications as Magnesil; however, due to its higher Flux Density (approximately 21,000 gausses), reduction in core size and weight may be accomplished. It has the highest Curie temperature of any of the available square loop alloys, so it will find applications in high temperature work.

Amorphous-E (Cobalt-based)

(MATERIAL CODE “E”)
Amorphous-E, a cobalt-based alloy, has low losses, very high permeability, high squareness and low Coercive Force. These characteristics make the alloy most ideal for SMPS applications such as magnetic amplifiers, semiconductor noise suppressors and high frequency transformers. It also finds use in high sensitivity matching transformers and ultra-sensitive current transformers. This alloy has near-zero magnetostriction, high corrosion resistance and a high insensitivity to mechanical stress.

Amorphous-C (Iron-based)

(MATERIAL CODE “C”)
With exceptionally low core losses and very high squareness, Amorphous-C is a perfect fit for a wide variety of applications, including saturable reactors, pulsed power designs, and high efficiency power transformers. Because of its low loss characteristics, Amorphous-C™ is a premier material for high frequency power applications, where high core losses rule out the use of less efficient alloys such as grain-oriented silicon iron.

MATERIAL CODES

Magnesil
K

Square Orthonol
A

48 Alloy
H

Square Permalloy 80
D

Round Permalloy 80
R

Supermalloy
F

Supermendur
S

Amorphous-E
E

Amorphous-C
C

Physical Properties

MATERIALS COMPARISON

Table 1 TYPICAL PROPERTIES OF MAGNETIC ALLOYS

PROPERTY	3% Si-Fe Alloys	50% Ni-Fe Alloys	80% Ni-Fe Alloys	50% Co-Fe Alloys	Fe-Based Amorph.	Co-Based Amorph. (Atomic %)
% Iron	97	50	17	49	91	4
% Nickel	....	50	79	....	....	1
% Cobalt	....	....	....	....	....	66
% Silicon	3	....	....	....	5	15
% Molybdenum	....	....	4	....	....	....
% Other	....	....	....	2 V	3 B	14 B
Density (gms/cm3)	7.65	8.2	8.7	8.2	7.3	7.59
Melting Point (ºC)	1475	1425	1425	1480	1100	1000
Curie Temperature (ºC)	750	500	460	940	390	205*
Specific Heat (Cal./ºCgm)	0.12	0.12	0.118	0.118	0.13	0.13
Resistivity (μΩ-cm)	50	45	57	26	120	140
CTE ($x10^{-6}$/ºC)	12	5.8	12.9	9.9	5.0	12.7
Rockwell Hardness	B-84	B-90	B-95	B-98	C-69	C-69

** Effective continuous operating temperature 90°C.*

Table 2 MAGNETIC CHARACTERISTICS COMPARISON*

Mat'l Code	Material Type	Flux Density		Br/Bm	Coercive Force			
					DC		400 Hertz CCFR **	
		(kG)	(Teslas)		Oersteds	A/M	Oersteds	A/M
A	Square Orthonol	14.2 - 15.8	1.42 - 1.58	.94 up	.1 - .2	7.9 - 15.9	.15 - .25	11.9 -19.9
C	Amorphous-C	14.5 - 16.0	1.45 - 1.60	.85 up	.025 - .075	2.0 - 6.0	.04 - .100	3.18 - 7.96
D	Square Permalloy 80	6.6 - 8.2	.66 - .82	.80 up	.02 - .04	1.6 - 3.2	.022 - .044	1.75 - 3.50
E	Amorphous-E	5.0 - 6.5	.5 - .65	.90 up	.008 - .02	.64 - 3.2	.01 - .025	.79 - 2.0
F	Supermalloy	6.5 - 8.2	.65 - .82	.40 - .70	.003 - .008	.24 - .64	.004 - .015	.32 - 1.19
H	48 Alloy	11.5 - 14.0	1.15 - 1.40	.80 - .92	.05 - .15	4.0 - 12.0	.08 - .15	6.4 - 12.0
K	Magnesil	15.0 - 18.0	1.5 - 1.8	.85 up	.4 - .6	31.8 - 47.8	.45 - .65	35.8 - 51.7
R	Round Permalloy 80	6.6 - 8.2	.66 - .82	.45 - .75	.008 - .02	.64 - 1.6	.008 - .026	.64 - 2.07
S	Supermendur	19.0 - 22.0	1.9 - 2.2	.90 up	.15 - .35	12.0 - 27.9	.50 - .70	39.8 - 55.7

** The values listed are typical of 0.002" thick materials of the types shown. For guaranteed characteristics on all thicknesses of alloys available, contact Magnetics Applications Engineering Department.*

*** 400 Hertz CCFR Coercive Force is defined as the H1 reset characteristic described by the Constant Current Flux Reset Test Method in IEEE Std. #393.*

**** Gain is the 400 Hertz core Gain described by the Constant Current Flux Reset Test Method per IEEE Std. #393 for cores with ID/OD of 0.75 to 0.80.*

Magnetics manufactures “Performance Proved” tape wound cores using the high permeability alloys shown below. Each core is coded by a part number, which describes it in detail. Knowing the code will simplify purchasing.

A typical number is:

01	51	029	- 2	A
(1)	(2)	(3)	(4)	(5)
Match Code	Box	Size	Thickness	Material Type

Core matching is available (see Core matching section on pg. 8)

Matching codes are: 01 - singles; 02 - pairs; 03 - triples; 04 - quads

How to Order Tape Wound Cores

1. Core matching is available (see Core matching section on pg. 8)
   Matching codes are: 01 - singles; 02 - pairs; 03 - triples; 04 - quads
2. 50 series are cores in non-metallic boxes
   51 series are cores in aluminum boxes
   52 series are cores in aluminum boxes with GVB finish
   53 series unboxed cores are Magnesil only
   54 series are encapsulated cores
   56 series (ring lamination cores) are in nylon boxes
3. Size listings shown in Magnetics literature may show non-metallic boxes, such as 50029. To order any other type of box, just change the first two digits. For example, aluminum is 51029; aluminum with GVB is 52029, and unboxed is 53029. See the core selection table for size listings of available cores (page 62).
4. Following the basic series number is another number, which describes the tape thickness in mils.
   Thickness codes are: 5 - 1/2 mil; 1 - 1 mil; 2 - 2 mil; 4 - 4 mil
   8 - 12 mil; 7 - 14 mil (for Ring Cores only)
5. The final letter describes the desired magnetic material (see Table 3).

Magnetics has available a line of miniature stainless steel bobbin cores for use in high frequency magnetic amplifiers. These cores are recommended for use in applications whose operating frequency is between 2 kHz and 500 kHz. Each miniature core is coded by a part number, which describes it:

01	80 531	0	D	MA
(1)	(2)	(3)	(4)	(5)
Match Code	Bobbin Core	Thickness	Material	Spec. Code

Core matching is available (see Core matching section on pg. 8)

Matching codes are: 01 - singles; 02 - pairs; 03 - triples; 04 - quads

How to Order Miniature Tape Wound Cores

1. Core matching is available (see Core matching section on pg. 8)
   Matching codes are: 01 - singles; 02 - pairs; 03 - triples; 04 - quads
2. 80500 to 80999 are cores on stainless steel bobbins.
3. Number preceding the letter is tape thickness in mils.
   Thickness codes are: 9 - 1/8 mil; 0 - 1/4 mil; 5 - 1/2 mil; 1 - 1 mil
4. Single letter code describes the material.
   A = Orthonol D = Permalloy 80
5. Double letter designation following the material code is the standard high frequency magnetic amplifier core code. These characters can alternatively represent a “Special Specification” code, identifying non-standard expectations.

Table 3 MATERIAL CROSS REFERENCE AND AVAILABLE TAPE THICKNESSES

Square Orthonol®	A	0.0005” 0.001” 0.002” 0.004” 0.014”	Orthonik Deltamax Hipernik V 49 Square Mu
Square Permalloy 80	D	0.0005” 0.001” 0.002” 0.004” 0.014”	Square Mu 79 Super Square Mu 79 Hy Ra 80 4-79 Permalloy Square Permalloy
Round Permalloy 80	R	same as “D” material	Hy Mu 80 Mo-permalloy
48 Alloy	H	0.002” 0.004” 0.014”	Carpenter 49 Allegheny 4750 Hipernik 49 Alloy
Supermalloy	F	0.0005” 0.001” 0.002” 0.004”	Supermalloy
Magnesil®	K	0.001” 0.002” 0.004” 0.012”	Silectron Microsil Hypersil Supersil
Supermendur	S	0.002” 0.004”	Supermendur
Amorphous-C	C	0.001	Metglas® Alloy 2605S2
Amorphous-E	E	0.001”	Metglas® Alloy 2714A

Transformer Design

Core Selection

The following procedure is useful for selecting a core and designing a transformer using tape wound cores. This discussion is for general applications at frequencies between 60Hz and 300kHz.

Transformer Design Software is available at www.mag-inc.com.

1.1 From the circuit requirements determine the following transformer specifications:

f = operating frequency (Hz)
V_p = primary voltage (V_{rms})
I_p = primary current (A)

1.2 From the wire chart (page 58), select the wire size to handle the primary current I_p in 1.1 above and note the wire area (Aw) in cm^2.

1.3 From the materials chart below, select the material and tape thickness corresponding to the operating frequency. The upper frequency limit column in the chart is based on the material being used at or near its saturation flux density. The material can be used at higher frequencies than those noted here by operating it at a flux density less than its saturation value.
If the transformer is the saturating type, the flux density used must be its saturation value. This is the number shown on the chart below but might have to be modified because of the operating temperature (see material data curves, starting on page 49). If the transformer is the more common non-saturating type, the flux density is usually reduced to 90% or less of the saturation value.

An additional requirement on selecting the operating flux density for the non-saturating transformer is to limit the core losses and the resulting temperature rise in the core. This is accomplished by selecting a flux density that produces core losses between 5 and 25 watts per pound depending on the ratio of the weight of magnetic material to the outside surface area. Large cores that weigh 5 to 10 pounds usually have a high weight ratio and limit the core loss to 5 watts per pound. Smaller cores weighing as little as 10 grams will have a low weight ratio and can operate at a core loss of 25 watts per pound and higher.

1.4 Using the above considerations, select the operating flux density (B) and solve the following equation for W_aA_c (area product):

$W_aA_c = (A_w V_p \times 10^8)/(4 B_m K f)$
Use the values as noted above for A_w, E_p, B_m, and f.
W_a = winding area of core (cm^2)
A_c = effective core cross sectional area (cm^2)
K = winding factor

Factor K is 0.20 for a common two winding transformer. If the transformer is for a self-saturating Royer or Jensen type inverter (such as in Figures 8 and 9), use K = 0.15 to allow for the space required for the switching windings. Factor 4 in the denominator is used for square wave excitation. For sine wave excitations, this factor should be changed to 4.44.

For a transformer core that meets the above conditions, select one with a W_aA_c value greater than the solution of equation (1). W_aA_c values for Magnetics tape wound cores are listed in the Core Size and Selection Table beginning on page 52.

Table 4. Magnetic Characteristics of Tape Wound Core Materials

Magnetic Material	Saturation Flux Density (kG)	Curie Temp (°C)	Upper Frequency Limit*	
			Tape Thickness (in)	Frequency
Magnesil (3% SiFe)	16.5	750	.012 .006 .004 .002	100 Hz 250 Hz 1 kHz 2 kHz
Supermendur (49% Co)	22	940	.004 .002	400 Hz 1 kHz
Orthonol (50% Ni)	15	500	.004 .002 .001	1.5 kHz 4 kHz 8 kHz
Permalloy (80% Ni)	7.4	460	.004 .002 .001 .0005	4 kHz 10 kHz 20 kHz 40 kHz
Amorphous-C	14.5	390	.001	25 kHz
Amorphous-E	5.75	205	.001	300 kHz

**Frequency limit is based on material being used at a flux density close to saturation. A higher frequency is usable with lower flux densities – see text.*

Transformer Design

2.1 From the Core Size and Selection Table, note the cross sectional area (A_c) of the selected core and tape thickness. Use this value in the following equation and solve for the number of primary turns (N_p).

$N_p = (E_p x 10^8)/(4\ B_m\ f\ A_c)$

Magnetizing Current

2.2 Many transformer designs will require a limit on magnetizing current (I_m). To find the value of current for the above design, determine the material core loss in watts per pound from the Core Loss Curves (beginning on page 44). The weight of the core selected can be calculated using the information immediately below this table (Note 4). Multiply the material core loss in watts per pound by the core weight to find the core loss in watts.

For toroidal (uncut) geometries, core loss closely approximates Volt-Amperes (VA) and can be substituted for it ($VA = P_{CL}$). Magnetizing current (I_m) is calculated using the following equation:

$I_m = VA/E_p$

Transistor Invertor Applications

The transistor inverter/converter made its appearance in 1955, but did not become popular until the 1970's. Since then, its usage has exploded into a new industry of power conversion equipment.

Figure 8 shows an original, but still in use, self-saturating (Royer Inverter) circuit. It is also known as a multivibrator or oscillator because one transistor conducts current while the opposite one does not; then the reverse occurs. The transformer core saturates in each half cycle, causing each transistor to switch on or off as the case may be.

Figure 9 shows a modification to this circuit (known as a Jensen circuit). It differs from Figure 8 mainly because it has two transformers. Here, transformer T1 saturates, causing the switching of the transistor, while T2 does not.

There are many other circuits now being used. However, these two circuits are still popular for frequencies up to 20kHz using tape wound cores for military applications. Above 20kHz the applications are often commercial, using ferrite cores.

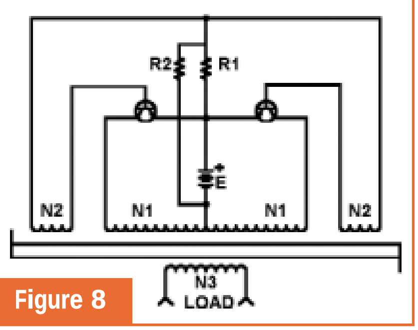


Figure 8

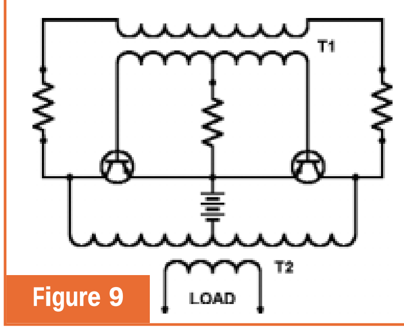


Figure 9

The transistors in Figure 8 operate as switches and serve the same function as the switch contacts of a mechanical vibrator. The energy required to operate the transistors as switches is supplied by feedback windings, N2, to the bases of the transistors. The magnetic core of the transformer is utilized fully in that flux is driven to positive and negative saturation on alternate half cycles and induces, in all windings, an alternating square wave voltage. This square wave may be delivered to the load directly or rectified (full wave) to dc at a voltage higher (or lower) than battery voltage depending upon the turns ratio N3/N1.

The voltage spike on the leading edge of each pulse is produced by the inductive kickback of a switch opening an inductive circuit, in this case a transistor turning off. This voltage pulse generated by one transistor turning off is the means by which the other transistor is turned on; hence it serves a useful purpose.

If this pulse is too high, however, there is danger of damaging the transistors. For this reason, it is desirable to use magnetic materials having a rectangular hysteresis loop so that, at saturation, the windings exhibit low inductance and little kickback. Because of the gain of the transistors, there is usually no problem in the kickback being too small, whereas it can be disastrous to the transistors when the pulse is excessively large.

Transistor Design Factors

Transistor Selection

1. The maximum voltage rating of the transistor must be at least twice the battery voltage. When one transistor is on, the transistor that is off must block the battery voltage plus the induced battery voltage in the primary winding as well as the transient spike which, at light loads, may be as high as battery voltage. The addition of a buffer capacitor may be desirable if, at any time, the converter is to operate unloaded.

2. To maximize the efficiency of a power converter under load, the transistor should switch the maximum voltage possible. Because of junction heating, there is a maximum collector current which can be switched and which is independent of the supply voltage. Therefore, with a given collector current, the power output will increase directly with increased supply voltage.

   Assuming circuit losses (core, copper, and transistor) are fixed, then the efficiency under load, is increased with increasing supply voltage.

   Improved efficiency also results with the use of transistors having high current gain since the driving power feed back to the base must be supplied from the source through primary windings N1. It is necessary to provide a current limiting resistor R1 in the base circuit, but the I2R losses in this resistance should be small to achieve high efficiencies. Hence, the N1/N2 ratio should be as high as possible, yet N2 must be adequate to provide sufficient voltage and current to saturate the transistor at high collector currents.

3. The frequency cut-off characteristics of the transistor must be high compared to the actual switching frequency. If the transistor cannot switch rapidly between the states of saturation and cut-off, excessive junction heating will result. Therefore, the frequency cut-off characteristics of the transistor should be from five to ten times the frequency of oscillation. When the transistor characteristic is ten times the frequency of the multi-vibrator, the output wave form would be more nearly a square wave than if the frequency were only five times that of the multivibrator.

Magnetic Core Characteristics

The choice of core material for converter design can be simplified by considering three ranges of materials:

(a) 50% Ni-Fe grain oriented (Orthonol), for frequency range of 50 Hz to 10kHz
(b) 79% Ni-Fe (Permalloy) or iron-based amorphous (Amorphous-C) for frequency range of 5kHz to 50kHz
(c) Amorphous-E for frequency range of 25kHz to 250kHz

Orthonol has a high maximum flux density with low losses; Permalloy 80 has about half the maximum flux density of Orthonol, but much lower losses (only one tenth the losses of Orthonol).

To the converter designer, this means that in most power applications where a given voltage and frequency are required, the best choice is either Orthonol or iron-based Amorphous-C. By choosing the higher flux density material, less iron and copper are required; thus, smallest size and best efficiency are achieved. Efficiency is high because the core losses are small compared to the high output power achievable.

It is interesting to note that high efficiencies can be attained at high audio frequencies because as frequency is increased, the core size is decreased; the increased core losses are offset by the reduction in core volume as the frequency goes up.

On the other hand, when the converter design calls for a voltage at low power levels and where high efficiencies are desired under light load conditions, or when operating frequency is above 10kHz, Permalloy 80 and Amorphous-C should be considered.

When the frequency approaches 50kHz and higher, Amorphous-E is preferred because of its lower core losses, even though its flux density is lower than those of the other two materials.

Often these topologies are designed for portable use where high efficiencies at light loads are desired to conserve battery power. For this type of application, core losses may be greater than the power delivered to the load unless cores having extremely low losses are used, hence, the choice of a core material having the lowest losses.

The effects of windings on circuit characteristics should be considered by the converter designer for either (a) too few windings, or (b) excessive windings. An appreciation of this can direct the designer to the selection of an appropriate core size for a particular application.

The circuit of Figure 8 operates as a magnetic-coupled multivibrator where switching is initiated by core saturation. The change in impedance of the core from its unsaturated to saturated state produces a rapid increase in collector current. At the same time, the induced voltage-supplying base current is reduced, producing a rapid turn-off of the transistor. Thus, for proper operation, there must be a significant change in the impedance of the core as it proceeds into saturation. For this reason, there must be a sufficient number of turns on the core to produce this change in impedance. Primary windings N1 should be ten turns or greater, and N2 should be five turns or greater to insure proper circuit operation.

An excessive number of turns can result in an apparent increase in magnetizing current due to interwinding capacitance. Winding capacitance is further evidenced by ringing or spurious oscillations which are produced when the core is excited with a square wave input; some of this effect can be reduced by progressive sector winding, but it is best to limit windings to a maximum of about 2,500 turns. An optimum design resulting in minimum core and winding cost (based on keeping output turns below 2,500) can result in an economical and efficient unit.

When simple DC/DC conversion is required and the operating frequency is not specified, a higher operating frequency implies a smaller unit. However, in many cases, increasing the frequency will dictate the need for a more expensive material. Most often, either the size or cost is specified, and a compromise between the two must be made.

To design a transformer for either a Royer or a Jensen type circuit, the steps starting on page 19 can be followed, keeping in mind the preceding remarks on materials and winding techniques.

References

1. Mogen, Donald C. - "Operation of a Saturable Core Square Wave Oscillator" Proceedings National Conference on Aeronautical Electronics, May 1956 (Copies may be obtained from Honeywell Transistor Division, Minneapolis, Minnesota).
2. Bright, Pittman, Rogers - "Transistors as On-Off Switches in Saturable-Core Circuits" Electrical manufacturing, December 1954.
3. Stoner, Donald L. - "Transistors" C.Q., March 1958 pp 75-79.
4. Sommerfield, E.H. - "The New Look in DC-DC Power Conversion" C.Q., March 1958, pp 36 following.

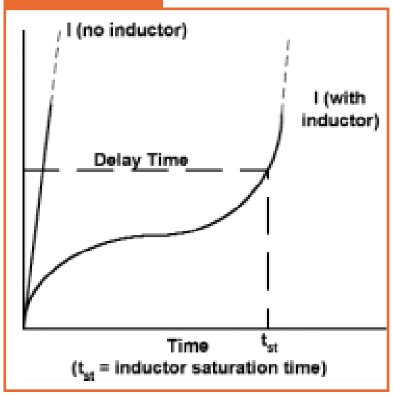
Thyristor Protection

Toroidal tape wound cores are ideal for thyristor protection immediately after switching on or switching off the device. The function the core plays is to delay the voltage to the thyristor and hence adjust the current so that it gradually increases. After the current through the thyristor reaches a safe level, the core saturates and is effectively out of the circuit (see Figures 10 and 11).

If a square wave voltage pulse V needs to be delayed for a length of time, t, the following equation can be used to determine core size: $NA_c = (100\ Vt)/\Delta B$

where: V = Peak voltage in Volts
t = Delay time in µsec
N = Number of turns
A_c = Effective core cross sectional area in cm^2
ΔB = Change in flux density in Gauss

Figure 10



Turns are kept very low, and in most cases only one turn is used. If a larger volt-time capacity is required, a taller core can be used or cores can be stacked together and one turn applied to the stack.

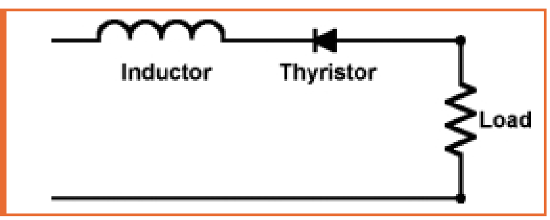
Since the waveform is unipolar, round loop materials can be used because they have the largest flux swing from remanence to saturation (B_m-B_r). For instance, Supermalloy has a B_m-B_r value of approximately 2000 Gauss.

To get a larger flux swing, a reset winding can be used so the core switches from remanence of one polarity to saturation of the opposite polarity. If a reset winding is used, Orthonol (or A material) is recommended. A flux swing of 25000 Gauss can be used for Orthonol.

Prior to saturation, the core presents an inductance and adjusts the current waveform according to Ampere's law: $I = (l_e \Delta H)/N$

where: I = Current in Amperes
l_e = Magnetic path length in cm
ΔH = Change in magnetizing force in Oersteds
N = Number of turns

Figure 11



Current Transformer Applications

For optimum current transformer operation, the following conditions should be met:

1

Constant load impedance.

2

Zero leakage flux.

3

Zero exciting current.

4

Infinite flux density

Current transformers fall into a general category known as instrument transformers. Their main purpose is to produce, from the primary current, a proportional secondary current that can easily be measured or used to control various circuits.

As shown in Figure 12, the primary winding is connected in series with the source current to be measured. The secondary winding is normally connected to a meter, relay, or a burden resistor to develop a low level voltage that is amplified for control purposes.

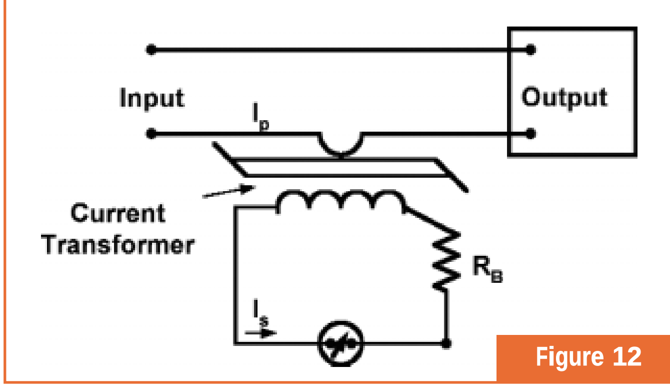


Figure 12

The first condition, constant load impedance, is usually met in all current transformer applications. It should also be pointed out that the load impedance is usually kept as low as possible, since an increase in load impedance increases the core flux, which thereby increases the exciting current.

Both the magnetic core material and the physical winding configuration influence the second condition, zero leakage flux. With high permeability cores and proper winding techniques, this condition can be approximated and the errors are small. The most satisfactory cores for current transformers are toroids with both the primary and secondary windings encircling the entire core. This affords very close coupling to the core and links both windings, thus achieving negligible leakage flux.

The third condition, zero exciting current, is never fully achieved. There will always be some exciting current, but it can be minimized by use of larger and/or more expensive cores.

The fourth condition of infinite flux density is also never achieved. The use of larger cores will allow approaching this condition at greater core cost and more required space.

Current transformer designs normally involve trade-offs on accuracy, size and cost. Although square loop materials can be used near saturation if minimum size is required, most current transformers use round loop materials such as Magnesil, 48 Alloy, or Supermalloy. These types of materials typically have higher initial permeability than their square-loop counterparts, which allows them to have better efficiency and larger range of use with respect to frequency. The materials are usually operated at less than 50% saturation flux density in order to obtain good current transformer accuracy.

The basic theory of a current transformer is the same as for any other iron-core types. There are, however, subtle differences that change the design procedures and core selection method to be used. The primary is normally a single turn (or at least a small number of turns) while the secondary has a large number of turns; a turns ratio of 1000 or more is common.

For best results, the secondary should be evenly spaced completely around the core.

Accuracy

A high turns ratio generally causes a high leakage inductance. This causes the secondary output to be less than that predicted from the primary voltage times the turns ratio ($E_p \times N_s/N_p = E_s$), resulting in an output error. High permeability materials in toroidal shapes afford close core coupling and link both windings to minimize leakage flux. Coupling is increased if the primary winding has several turns; however, satisfactory results can be obtained with only a single turn. For best results, the secondary should be evenly spaced completely around the core.

The exciting current determines the maximum accuracy that can be achieved with a current transformer. Exciting current may be defined as the portion of primary current that satisfies the hysteresis and eddy current losses of the core. This becomes a second source of error because the secondary current is proportional to the primary current minus the exciting current. The secondary current is, therefore, not an exact measure of the primary current, and the magnitude of this error is directly proportional to the ratio of magnetizing current to the primary current. High permeability and low core loss materials in toroidal shapes are recommended to reduce errors due to leakage flux and high magnetizing currents.

These improved accuracies result from increased permeabilities that lower the magnetizing current and are based on using toroids and manufacturing techniques to reduce leakage flux.

Material Selection

Material selection for a current transformer depends on the operating frequency, accuracy and desired cost. If accuracy is not important, the material and thickness of the steel strip can follow guidelines from Table 4 on page 17. The chart does not include ferrites; however, and they must be considered for frequencies over 20kHz. This discussion does not include them.

At power frequencies of 60 and 400Hz, the chart indicates the uses of silicon steel where a typical accuracy of a current transformer is from 1% to 5%. 48 Alloy improves the accuracy to 0.5%. Further improvement results from Permalloy or Supermalloy materials, where accuracies of 0.1% and less are typical. These improved accuracies result from increased permeabilities that lower the magnetizing current and are based on using toroids and manufacturing techniques to reduce leakage flux.

$E_S = I_S \times R_B$
$I_p = I_S \times N_S/N_p$
$I_p = I_S \times N_S$
$W_a = (A_{C\mu} \times N_S)/K$

Transformer Design

The design of a current transformer begins by examining the load requirements. The burden (R_B) on the transformer determines the resistance and current for maximum output. The load current, which is the secondary current (I_S), coupled with the load resistance (R_B), determines the transformer's secondary voltage (E_S):

$$E_S = I_S \times R_B$$

The primary current (I_p) is the current to be measured or controlled. Therefore, the ratio of primary to secondary currents is inversely proportional to the turns ratio:

$$I_p = I_S \times N_S/N_p$$

In most cases, a single turn primary is used; hence the primary current is equal to:

$$I_p = I_S \times N_S$$

Using the value of secondary current (I_S) and the Wire Table (page 58), the wire size and its cross sectional area ($A_{C\mu}$) should be determined. The winding area required for the secondary is:

$$W_a = (A_{C\mu} \times N_S)/K$$

K, the winding factor, is a function of the empty space between wires, and insulation on the wires and between layers. A winding factor of 0.2 is conservative, but will usually result in a finished transformer utilizing a nearly full winding area. It also accounts for having both a secondary and primary winding. The value of K may have to be reduced if high voltages are being used (more insulation between windings and, therefore, more winding area will be needed). From the last equation, the magnetic core to be used can be selected from the Core Selection Chart on page 52.

$B = (E_S \times 10^8)/(4.44\, N_S\, f\, A_c)$

Saturation

Using the secondary voltage (E_S) and the number of turns in the secondary winding (N_S) in the transformer equation, the flux density in the core can be determined as follows:

$$B = (E_S \times 10^8)/(4.44\, N_S\, f\, A_c)$$

where: B = flux density in Gauss
f = frequency in Hertz
A_c = effective core area in cm^2

Flux density from this equation should be checked to see if it is less than the maximum flux density of the material that was chosen. If not, a core with a larger cross section (keeping the same or larger winding area) must be selected and checked for saturation. Conversely, if the calculated flux density is much less than the maximum of the material selected, a core with a smaller cross section can possibly be used (although at a less efficient accuracy).

Magnetizing current I_m is calculated from: $I_m = VA/E_p$

Magnetizing Current

To check the accuracy of the current transformer design, it is necessary to calculate the amount of the magnetizing current. Using the calculated flux density (B), primary voltage (E_p) from $E_p = E_s \times N_p/N_s$, and core material, determine the material core loss in watts per pound from the Core Loss Curves.

Core weights are calculated from information below the Core Size and Selection Tables. Multiply the material core loss (W/lb) by the core weight to find the core loss (P_{CL}) in watts.

Core loss closely approximates VA (Volt-Ampere capacity) of the material and can be substituted for it ($VA = P_{CL}$). Magnetizing current I_m is calculated from:

$$I_m = VA/E_p$$

This value of I_m, divided by the total primary current multiplied by 100 is a measure of the accuracy of the transformer in percentage points; the lower the number, the more accurate is the transformer.

The Best Material Choice

The best choice of core materials for current transformers is based on two factors: (1) accuracy and (2) size. It may be necessary to compromise on these two factors to reach the optimum design.

On current transformers used to measure small currents, size and cost are small, and Supermalloy is the best choice due to its better inherent accuracy.

On current transformers used to measure large currents (≥100A), size and cost become appreciable, and Supermalloy is not generally used except for extremely demanding applications. In the majority of high current applications, Magnesil is usually chosen because of its lower cost.

The following study was made to compare the results obtained from the various core materials available, when used in typical current transformer applications. To show a true comparison of core materials, the following assumptions were made:

Material Comparisons

1. **Core Configuration** – A toroid core structure will be used since this is the optimum core configuration for current transformers. It affords essentially a zero air gap structure, which minimizes leakage flux.
2. **Turns Ratio** – The same turns ratio and wire size will be used for all materials.
3. **Core Material** – Typical magnetic characteristics will be used for Supermalloy, 48 Alloy, and Magnesil cores.
4. **Core Size** – The core size will be different for each material. The ID and OD will be held constant because of their effect on exciting current. The width of the tape (height of the core) will be varied to compensate for the different flux densities of the three materials. For all materials, the ratio of flux density used to maximum flux density will be kept constant.

The accuracy calculated in each case is based on the exciting current of the core. It is not to be assumed that this is the ultimate accuracy that could be obtained, but rather that this is a comparative accuracy of the various core materials. The major factors contributing to error of a current transformer are: (1) leakage flux, (2) I^2R losses in windings, and (3) core losses.

The error due to leakage flux is negligible in most current transformers made of toroidal cores with proper winding methods.

The copper losses can be made quite small by proper design of core size and wire size. The exciting current can be compensated for by adjusting the turns ratio. The actual expected accuracy is therefore better than that shown in the table comparison below.

Summary

From the previous discussion, the main core requirements for current transformer applications can be summarized as follows:

1. The core configuration should provide a closed magnetic path on which the windings can be placed, with close coupling to minimize leakage flux: ideally a toroid.

2. The core material should have high permeability, low-loss characteristics to minimize the effects of exciting current.

3. The core should have a high usable flux density to minimize the size of the core.

Table 5. Comparison of the effect of core materials on a 200/2 Ampere 400 Hertz Current Transformer

	.004" MAGNESIL	.002" 48 ALLOY	.002" SUPERMALLOY
INPUT	200 AMP/1 TURN	200 AMP/1 TURN	200 AMP/1 TURN
OUTPUT	2 AMP/100 TURNS	2 AMP/100 TURNS	2 AMP/100 TURNS
BURDEN	5 OHMS	5 OHMS	5 OHMS
RATED VA	20 VA	20 VA	20 VA
CORE	50252-4K	50252-2H	50088-2F
CORE SIZE (in)	1.50 x 2.25 x 0.50	1.50 x 2.25 x 0.50	1.50 x 2.25 x 1.00
EXCITING CURRENT	2.75 AMPS	0.97 AMP	0.18 AMP
ACCURACY	1.4%	0.5%	0.1%
COST RATIO	1.0	2.2	4.5

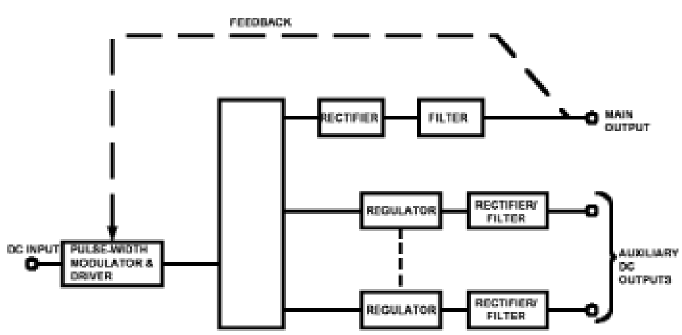
Output Regulators

FOR SWITCHED-MODE POWER CONVERTERS

A popular and effective application of Square Permalloy 80 and Amorphous-E tape wound cores occurs in multiple-output switched-mode power supplies. By using such a square-loop core to provide a controllable delay at the leading edge of the pulses at the secondary of the transformer, one or more outputs can be independently and precisely regulated without the losses inherent in linear regulators or the complexity of conventional switching regulators. In cases where the load currents of the subordinate outputs are high (in excess of one or two Amps), the advantages of the saturable-core regulators become more and more significant. Figure 13 shows the block diagram of a typical multi-output supply of this type, while Figure 14 illustrates the regulation scheme.

Multiple-output switched-mode power supply

Figure 13

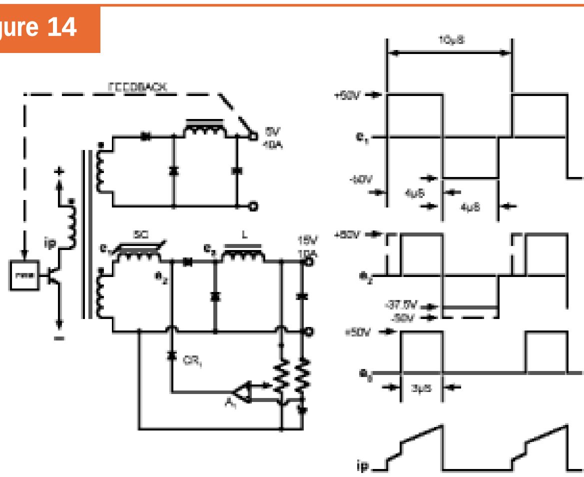


For simplicity of this example a forward converter topology is shown, but the technique is equally useful in flyback and push-pull converters. Typical waveforms are shown in Figure 14. In the pulse width modulator (PWM), the primary pulse width is controlled by sensing the 5V output, comparing it to a reference, and using the error signal to adjust the pulse duration. If there were no saturable core (SC) in the circuit, the 15V output would be "semi-regulated," since the primary control loop would provide line regulation. However, the output would vary with load and temperature.

To produce 15V dc at the output, the average value of the rectified waveform applied to the input inductor L must be 15V. Given the pulse height of 50V and a repetition period of 10 µs, the required width of the positive pulse at e_2 must be:

PW = (15V/50V) x 10µs = 3µs

Figure 14



Regulation scheme.

Because the input pulse (e_1) is 4 µs wide, the saturable core must delay the leading edge by 1 µs. Since the amplitude of the pulse is 50V, we can say that the core must "withstand" 50V x 1µs, or 50 volt-microseconds. To accomplish this, the core is reset by this amount during each alternate half cycle. The waveform at e_2 illustrates this. As the input to the core swings negative, diode CR1 conducts and allows the error amplifier A_1 to "clamp" the output side of the core at -37.5V. The result is that the core is subjected to a reverse voltage of 50V - 37.5V for a duration of 4µs, producing a reset of:

$$\Lambda = 12.5V \times 4\mu s = 50V\mu s$$

(Λ = withstand)

As the output varies, the error amplifier will alter this value to ensure that the output is regulated at 15 V dc in spite of changes in the rectifier voltage drops, etc. The waveform of the primary current (i_p) shows the increase in current when the core saturates and begins to deliver current to the output inductor. This has an incidental bonus: the primary switching transistor has already turned on and saturated, and hence the 15V output does not contribute to turn-on switching losses in the transistor.

The design of the saturable reactor requires

3 steps:

1 - Determine Λ, the withstand volt-seconds to delay the leading edge of the pulse and achieve the required output voltage.

Here, the designer must decide whether the output must be capable of independent 'shutdown' (for short-circuit protection or turn-off from an external logic signal), or simply regulation at a fixed value.

Withstand = Excluded Pulse Area = Λ = V x t
where: V = pulse amplitude
t = delay at leading edge

Case 1 – Shutdown: The required withstand is simply the area under the entire positive input pulse. In the circuit of Figure 14, it would be 50V x 4μs = 200 Volt- microseconds.

Case 2 - Regulation only: Assuming that the output inductor has been designed for continuous conduction, the reactor must only reduce the input pulse width enough to furnish the required average value (equal to the dc output voltage) at the input of the filter inductor.

In both cases, one must allow "headroom" to accommodate load transients. This comment relates to the choice of turns on the secondary winding of the transformer that feeds the regulator, which must precede the calculation of the volt-seconds that the reactor must support. For example, one might design for a control range of ±20% to allow the pulse width to increase or decrease by 20% when the load current steps up or down. To allow the pulse width to increase, the input pulse width must be 20% greater than the nominal pulse at the output of the reactor. Depending on the operating frequency and core used, one must allow an additional margin due to the rise time of current in the core after it saturates. This is typically on the order of one microsecond. This implies that the secondary voltage be at least 20% higher than it would be to produce the desired output voltage if the saturable reactor were not present. To allow the pulse width to decrease, the reactor must withstand additional volt-seconds to reduce the pulse width 20% below the nominal value.

In the circuit of Figure 14, a "regulation only" design would require a withstand of
Λ = 50V x 1μs + 20%, or 60Vμs

2 - Choose the core.

There are two popular methods of determining the size of the required core. Each results in a minimum area product, W_aA_c, to provide the necessary withstand and accommodate the wire size (which determines the temperature rise). One method begins with the desired temperature rise and power to be handled (withstood), the core geometry, and the fill factor. The other requires an initial choice of the wire size, which must be estimated based on intuition about the ultimate temperature rise. Although the latter is admittedly pragmatic, it is popular because of its simplicity.

In the latter method, the steps are as follows:

A. Pick the wire size, based on the current. A reasonable value is 400 Amps (rms) per cm^2 of conductor for a temperature rise of 30 to 40 degrees C in core sizes of 0.5 to 1 inch OD. This yields A_w, the cross-sectional area of one conductor.

B. Choose a core material, to determine the saturation flux density, B_m. In this application, Square Permalloy 80 is a good choice, since it has low coercive force and a very square BH loop. Its B_m is approximately 7000 gauss (Amorphous-E would offer a B_m value of about 5500 Gauss).

C. Choose the fill factor K, using 0.3 to 0.5, with the lower values for higher power applications.

D. Calculate W_aA_c (product of cross section A_c and window area W_a, both in cm^2) as follows:

$$W_aA_c = (A_w \Lambda \text{ x}108)/(2 B_m K)$$

E. Select a core from the Core Size and Selection Tables beginning on page 52 or from the Mag Amp Core Data Table on page 33 with at least this area product. In doing so, the tape thickness must be chosen, and the values in the W_aA_c column must be modified according to Note 2 at the bottom of the page. Tape thicknesses of 0.0005 and 0.001 inch are recommended for frequencies up to 100 KHz, with the thinner tapes found in the bobbin-wound core cata log preferred at higher frequencies.

In the circuit of Figure 14, the current during conduction of the core is 10A, and the duty ratio is 15/50, or 0.3. Thus the rms current is $\sqrt{(10^2 \text{ x } 0.3)}$, or 5.5A. An appropriate wire size is AWG #16, since its cross-sectional area, A_w, is .0152 cm^2 Again, using the "regulation only" case, W_aA_c is as follows:

$$W_aA_c = (.0152 \text{ x } 60 \text{ x}10\text{-}6 \text{ x}108)/(2 \text{ x } 7000 \text{ x } 0.1) = 0.0652$$

Note that a fill factor of 0.1 has been used since the wire size is relatively large. Since the converter frequency is 100 kHz, a tape thickness of .0005" is perhaps a wise choice. In consulting the core data table, the column of W_aA_c figures must be altered by a factor of approximately .013/.022 (the typical ratio of the cross sectional areas of cores with 0.0005" and 0.002" tape thicknesses), according to Note 2 at the bottom of the page. The most convenient way to do this is to alter the value of the desired W_aA_c, and then find the appropriate core in the table. Using this approach, the listed value must be at least .0.0652 x (.022/.013), or 0.1103. Two logical candidates are the 50374 and 50063 cores, whose W_aA_c values are 0.137 and 0.132, respectively.

For the purpose of this example the 50063 core is chosen. Its effective core cross-sectional area, A_c, is .050 cm^2 and its mean length of magnetic path, l_e, is 5.98 cm. These values are noted for future use.

3. Determine the number of turns.

The number of turns is determined by the withstand, L, to produce the desired output of the regulator:

$$N = (\Lambda \text{ x}108)/(2 B_m A_c) \text{ turns}$$

where: Λ = withstand, in volt-seconds
B_m = saturation flux density, in Gauss
A_c = core cross-sectional area, in cm^2

The control circuit can now be designed. In doing so, it is helpful to estimate the current required to reset the core and thus calculate the average control current based on the duty ratio of the resetting (negative portion) of the input pulse. The current is related to the magnetizing force as follows:

$$I_m = (0.794 \times H \times l_e)/N$$

where: **H = magnetizing force, in Oersteds**

l_e = magnetic path length, in cm

H is not simply the dc coercive force, but rather the value corresponding to the flux swing and frequency, as given in the Material BH Loops (for high frequency, see page 48). Note the "loop widening effect" as the coercive force increases with frequency.

Again, using the circuit of Figure 14 and the chosen core, the required number of turns is:

$$N = (60 \times 10^{-6} \times 10^{8})/(2 \times 7000 \times 0.050) = 8.57 \text{ turns}$$

= (round off to 9 turns)

To estimate H, a simple way is to use data supplied in curves for core loss (W/lb), which reflects the widening of the loop. For Square Permalloy 80, this formula can be applied:

$$H = (0.6 \times 10^{6} \times W/lb)/(B_m \times f)$$

(If using Amorphous-E material, the formula is:

$$H = (0.525 \times 10^{6} \times W/lb)/(B_m \times f)\ )$$

Completing the above example, the core loss for 0.0005" thick Square Permalloy is 250 W/lb at 100kHz.

$$H = (0.6 \times 10^{6} \times 250)/(7000 \times 105)$$

Thus, the magnetizing current will have a typical value of:

$$I_m = (0.794 \times 0.214 \times 5.98)/9 = 0.11 \text{ A}$$

Alternative control circuit.

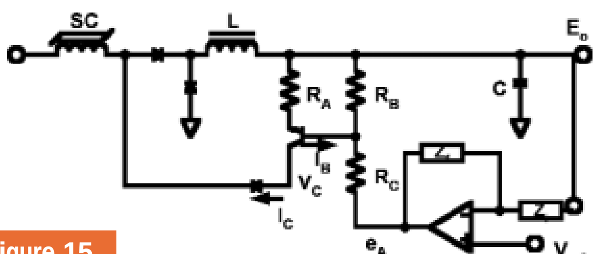


Figure 15

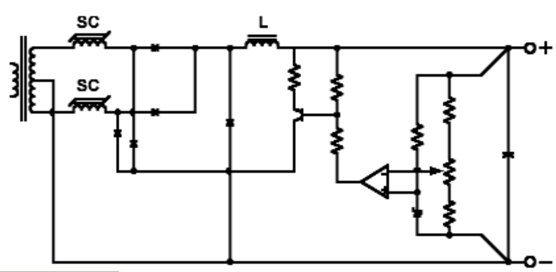


Figure 16 **Full-wave saturable core regulator**

An alternative control circuit is given in Figure 15. It has several notable features:

1. The resetting control current is derived from the output, providing a "preload" - a means of preventing the magnetizing current of the reactor from raising the output voltage at zero load.

2. The core is reset from a current source, rather than a voltage source. This has been shown by Middlebrook [2] to minimize the phase shift of the control transfer function. In this circuit, R_A degenerates the transconductance of the transistor, making the transfer function more independent of the transistor. R_B and R_C simply shift the level of the amplifier's output, which is unnecessary if the amplifier is powered from a voltage higher than the output.

3. The compensating networks, Z_f and Z_i, can be designed using techniques for conventional buck-derived regulators.

Note, however, that this circuit actually has two feedback loops - one through the error amplifier, and one directly from the output through R_A and the transistor.

Full-wave outputs can be handled in the same manner as the forward converter discussed earlier. The circuit of Figure 16 illustrates this application.

Finally, it is sometimes useful to be able to translate the voltage required to reset the core, change its level, or trade voltage for current. In these cases, a second winding can be placed on the core, with a larger or smaller number of turns than the power-handling winding, and with its end opposite the control transistor being returned to a convenient bias voltage. For example, a control winding with less turns will exhibit less voltage swing but will require more control current than the main winding.

Current Mode Control

Another configuration of control circuitry is shown in Figure 17. It is equally useful for half-wave and full-wave applications, but is shown here in the half-wave case for simplicity. This circuit is particularly advantageous when independent current limiting (of the mag amp output) is desired. Unlike the current-limiting methods of the past, where the output of an overcurrent detector op amp or comparator was “ORed” with the error amplifier output, this method “embeds” the current monitoring function in the feedback loop. Thus, it is always active and provides exceptionally smooth transitions as the output is loaded beyond the current limit and then returned to normal load conditions.

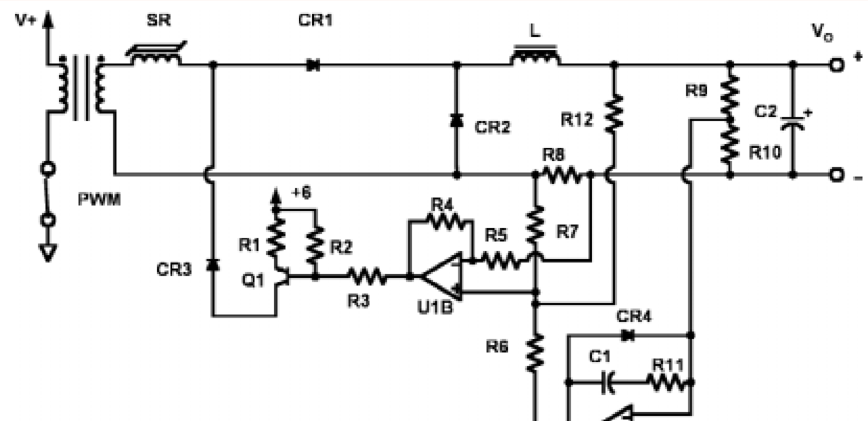


Figure 17 Mag amp regulator with current mode control

Amplifier U1B is the current error amplifier, whose input circuit is comprised of resistors R6, R7, and R12. The output of U1A is the most important input to this network, since it is a result of the output voltage error. The output voltage, Vo, is also introduced (via R12) for bias and to shape the current foldback characteristics, if desired. Resistor R8 samples the regulator’s output current, and the resultant voltage is applied to the error amplifier through resistor R7. Resistors R4 and R5 determine the gain of the amplifier; gain = (R4 + R5)/R5.

To visualize the operation of this circuit, first assume that the output of U1A is stationary during a change in the current. An increase in current causes an increase in the voltage drop across R8. Since the regulator output is treated as the arbitrary ground reference, this increase in current is evidenced by a downward voltage swing at the junction of R7 and R8. This is amplified without inversion by U1B and applied to the mag amp reset transistor, Q1, through R3. The increase in reset current decreases the pulse width at the output of the mag amp and thus opposes the increase in current that was sensed by R8.

The voltage feedback loop begins with R9, the input resistor for the voltage error amplifier, U1A. Biasing resistor R10 is not part of the transient response analysis, since its voltage doesn't change (the inverting input of U1A is a virtual ground and remains stationary). Resistor R11 and capacitor C1 form the feedback network of U1A, making it an integrator with a zero at the frequency where C1's reactance equals R11. The output of U1A is then applied through R6 to the other amplifier, U1B, which amplifies it and applies it to the reset transistor. An increase in the output voltage, Vo, is inverted by amplifier U1A and ultimately increases the mag amp's reset current supplied by Q1. This corrects the perturbation.

Diode CR4 limits the positive voltage swing at the output of U1A. Since U1's output voltage is the "reference" for the current limiter, the clamping action of CR4 determines the maximum output current.

The design philosophy is to have the current-mode feedback determine the phase shift at the unity-gain crossover frequency, since its maximum is 90 degrees. The two feedback paths combine to a vector sum, and thus the dominant one will determine the phase shift. It is recommended that the current-mode loop cross the unity-gain axis at around one-tenth the switching frequency, and the voltage-mode feedback cross over at least two or three octaves below the current-mode loop. References 4 and 5 describe the design of mag amp output regulators in more detail.

Circuits using these square-loop cores have appeared in power converters operating at frequencies up to 1 MHZ [3]. Not only can they perform output regulation, but also they can be used in the primary circuits to control the frequency of the converter. Applications are practically limitless in the hands of the designer with imagination and a firm concept of these interesting "volt-second" components.

References

1. Colonel William T. McLyman, Transformer and Inductor Design Handbook, Dekker, New York, 1978.
2. R.D. Middlebrook, "Describing Function Properties of a Magnetic Pulse-Width Modulator," *IEEE Power Electronics Specialists Conference,* 1972 record, pp 21-35.
3. R. Hiramatsu and C. E. Mullett, "Using Saturable Reactor Control in 500 KHz Converter Design," *Proceedings of the Tenth National Solid-State Power Conversion Conference, Powercon 10 record,* pp. F-2.1-F.2.10.
4. R.M. Tedder, "Limitations of the Magamp Regulator and an Improved Magamp Choke De- sign Procedure," *Powertechnics,* November and December, 1988.
5. C. Jamerson, "Calculation of Magnetic Amplifier Post Regulator Voltage Control Loop Parameters," *Proceedings of the Second International High Frequency Conference,* pp. 222-234, Washington, D.C., April, 1987.
6. D.Y. Chen, J. Lee, and C. Jamerson, "A Simple Model Predicts Small-Signal Control Loop Behavior of Magamp Post Regulator," *Proceedings of 1988 High Frequency Power Conversion International,* pp. 69-84, San Diego, CA, May, 1988.

Table 6. High Frequency Magnetic Amplifier Cores

Part Number		Core Dimension ID	OD	Ht	Case Dimensions ID min	OD max	Ht max	Path Length (cm)	Core Area (cm^2)	P_{fe} (W) 50kHz 2kG(max)	$W_a(cm^2)$	W_aA_c (cm^4)
50B10-5D	in	0.650	0.900	0.125	0.580	0.970	0.200	6.18	0.051	0.118	1.76	0.0897
-1D	mm	16.5	22.9	3.18	14.7	24.6	5.08		0.076	0.220		0.1340
-1E									0.076	0.092		0.1340
50B11-5D	in	0.500	0.625	0.125	0.430	0.695	0.200	4.49	0.025	0.044	0.984	0.0243
-1D	mm	12.7	15.9	3.18	10.9	17.6	5.08		0.038	0.083		0.0375
-1E									0.038	0.034		0.0375
50B12-5D	in	0.375	0.500	0.125	0.305	0.570	0.200	3.49	0.025	0.035	0.500	0.0127
-1D	mm	9.53	12.7	3.18	7.75	14.5	5.08		0.038	0.066		0.0193
-1E									0.038	0.027		0.0193
50B45-5D	in	0.500	0.750	0.250	0.430	0.820	0.325	4.99	0.101	0.194	0.984	0.0725
-1D	mm	12.7	19.1	6.35	10.9	20.8	8.26		0.151	0.363		0.1080
1E									0.151	0.149		0.1080
50B66-5D	in	0.500	0.750	0.125	0.439	0.820	0.200	4.99	0.050	0.097	0.984	0.0360
-1D	mm	12.7	19.1	3.18	10.9	20.8	5.08		0.076	0.182		0.0548
-1E									0.076	0.075		0.0548

Testing Mag Amp Cores

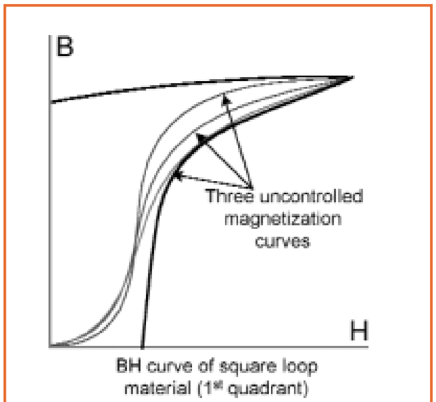


Figure 18

A common pitfall on testing square loop tape wound cores is to measure the inductance or A_L value. Although this a common measurement for ferrite and powder core materials, which are round loop materials, it is not a valid measurement for square loop materials like Square Permalloy, Orthonol, and Amorphous-E alloys. Although an inductance measurement can be obtained on a square loop material, it does not give any indication of the functional magnetic properties.

Additionally, the inductance measurement of the square loop material is not repeatable. This is due to the remanence of the core (B_r). Any measurement leaves the core at some B_r value rather than at the origin (see Figure 18). Factors such as application and removal of a dc bias field, proximity to a permanent magnet, and partial demagnetization (among other causes) results in a very unreliable and unrepeatable measurement. Furthermore square loop materials are processed to control saturation (B_m), coercive force (H_c) as well as B_r. Square loop materials are not processed to control the initial magnetization curve, which yields the inductance (reference Figure 18).

For square loop materials, including mag amp cores, a test of the core's saturation level is far more useful. The test set-up shown in Figure 19 is commonly used to measure a core's saturation level. The core is typically wound with 10 turns (for both drive and secondary) and tested as follows:

- The core is driven to a flux level that is approximately half of its saturation flux density, B_1. For Permalloy this would be 3700 Gauss, Orthonol would be 7500 Gauss, and Amorphous-E would be 2500 Gauss. The corresponding measured voltage, V_1, is calculated by:

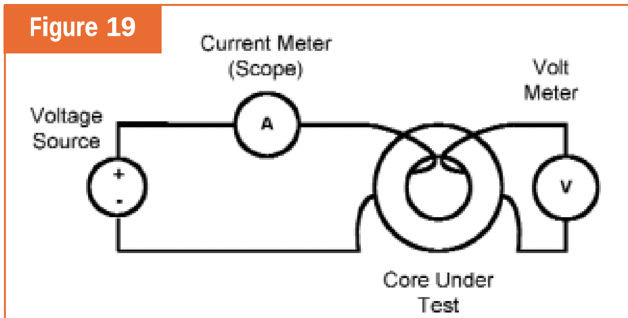
  $$V_{rms} = 4.44 \times B_1 \times A_e \times N \times f \times 10^{-8}$$

  B1 in Gauss
  Ae is the effective area of the core in cm²
  N is turns
  f is frequency in Hertz

- With the voltage still at a level corresponding to half of the cores saturation level, the peak current or I_1 is observed on an oscilloscope.

- The voltage is then increased while the current waveform on the scope increase to I_2. The core is considered to be entering saturation when $I_2 = 3I_1$, and the voltage at which I_2 occurs is recorded as V_2. The above equation is then rearranged to solve for B_2, which is the core's saturation flux density.

Figure 19



Cores for Pulse Compression

A growing field of applications for tape wound cores involves pulse compression techniques to increase peak current levels while still delivering a constant energy to the load (often a laser system). These compression requirements often arise as a means to reduce the stress imparted to the main power switch (reference Figure 20a) due to excessive peak current flowing through it. By compressing the current waveform downstream of the switch, lower peak currents are 'seen' by it, yet the necessarily high peak current can still be delivered to the laser load.

Figure 18 shows a circuit comprised of a switch, 2 capacitors, and an inductor. After C1 is charged from input voltage V_{max}, the switch is closed. This action dumps C1's collected energy into the LC circuit made up from L and C2, and sets up a current waveform with a sinusoidal shape, as shown. The frequency (and therefore the width) of this half sine wave is determined by the relative values of L and C1 plus C2. Therefore careful choice of component values will narrow the current pulse while increasing its peak value (because total energy in the system will remain constant).

Figure 20b details a three-stage compression circuit. The current pulse rises in peak amplitude after each stage, but has its duration shortened. Depending on the particular circuit configuration, the voltage waveform (and V_{max}) can either be amplified (and compressed) in a similar manner to I_{peak}, or might simply have its duration compressed while retaining the same peak value. Although energy transfer tends to be more efficient if V_{max} remains unchanged through each stage (because raising Vmax implies different capacitor values and therefore poor power matching from one stage to the next), many designers opt to increase V_{max} so that progressively smaller capacitors may be used at each stage further downstream of the switch (for fixed charge on all capacitors, higher voltage implies smaller capacitance). Figure 20b shows pulse compression with progressively smaller capacitor values.

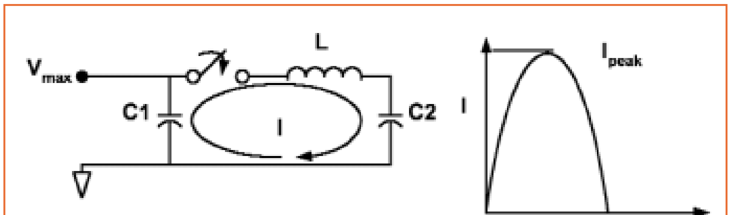


Figure 20a

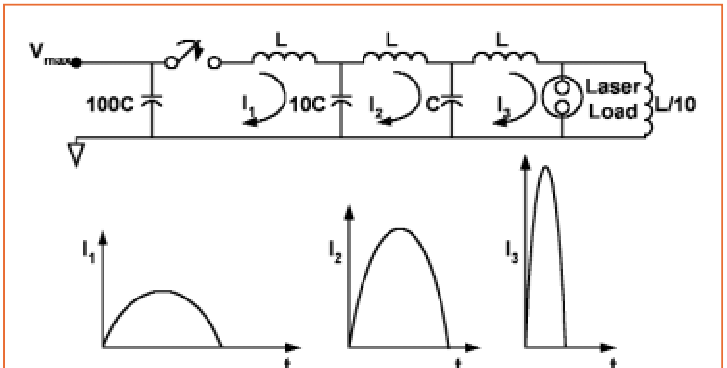


Figure 20b

Note that while each stage has a decreasing capacitor value, the voltage across it will be twice that of its neighbor upstream.

In the case of Figure 20a, each inductor core is actually used as a saturating inductor. That is, when the capacitor to the left of it is fully charged, the energy from that capacitor is dumped into the inductor. As the inductor stores more and more energy, it eventually saturates, allowing its energy to cascade into the next capacitor downstream, and so on.

Core Material Considerations

The ideal core material for these types of saturating inductors should be processed to have:

1. **High saturation flux density**
2. **Low losses**
3. **Very high interlaminary insulation**
4. **Very low magnetostriction**

High saturation flux density allows the core size to be kept to a minimum or, more importantly, to allow high voltages to be developed across each inductor just prior to its saturation. Faraday's law may be rearranged into the following form:

$$V = (N \times A_c \times \Delta B)/(100 \times \Delta t)$$

where: V = Voltage across inductor (V)
N = Inductor turns
A_c = Effective core cross sectional area (cm^2)
ΔB = Total flux swing in core (G)
Δt = Voltage pulse duration (μsec)

Therefore if the core is biased to its $-B_R$ point (negative remanence) and is allowed to proceed to positive saturation ($+B_{sat}$), then a very square BH-loop, high B_{sat} material is desirable. Orthonol (A material), with a saturation flux density of over 14kG and squareness ratio of more than 94% is ideal for this application, and will yield a flux excursion of over 27kG.

Core losses develop more readily in the inductor material as frequency increases (or equivalently as the pulse width shortens). Of course better efficiency will be obtained by using material with the lowest possible core loss. This criterion may be satisfied in one of two ways. First, the core material thickness may be decreased by going to thinner and thinner foils to wind the core. For example, Orthonol can be processed to strip thicknesses as low as .0005”. The ‘price’ to be paid for this advantage is a smaller effective core area for a given overall core size, because the stacking factor is smaller for thinner tapes (i.e., less of the core area is actual magnetic material, and more is insulation between wraps and open space between layers). A second tactic to reduce core losses is to simply choose a more efficient material, such as Permalloy 80 (D material). Although the core should be less lossy, Permalloy has saturation flux density and squareness values significantly lower than those of Orthonol, and as such will only yield a flux swing of about 12kG.

Because the peak voltage levels in pulse compression designs can be exceptionally high, and because this naturally implies very large flux swings, the potential exists for breakdowns and shorts between the individual wraps of material that comprises the core. If we examine the above equation with an eye toward the voltage stress put between layers of tape, this becomes apparent. As an example, consider a case using .001” thick, 2” wide (area equal to 0.0129 cm_2) Orthonol tape for the core structure, and flux swing of 27kG. If the pulse width is 0.2µs (a typical value), then the voltage from one wrap to the next can be up to 17.4 Volts. Considering that typical insulation layers may accommodate 2-3 V before they break down, this is a true concern. Magnetics has developed strip-coating methods that can apply our interlaminary insulation to provide far in excess of this value. Additionally, if the interlaminary voltage becomes too large for a practical design, several smaller-height cores may be stacked with insulating washers between them as opposed to one solid core. This strategy reduces the interlaminary voltage, as the total voltage is then divided evenly across the stacked smaller height cores.

The last requirement, low magnetostriction, may seem to be a minor concern, as this phenomenon (which causes magnetic materials to expand and contract as they are excited) typically manifests as a nuisance noise or buzzing if the core is operated at an audible frequency. However, is the excitation signal is very large and the pulse width very small, this effect can actually impart a large amount of mechanical stress to the core. In other words, as the voltage peak ‘hits’ the core, the material will suddenly (and in some cases violently) react by expanding quickly. The most noticeable consequence of the magnetostrictive effect is lower efficiency as the core material is stressed and damaged. Other second order effects may cause the interlaminary insulation to break down prematurely as is it stressed and damaged by core movement. Orthonol and Permalloy 80 (and in fact most NiFe alloys) are both exceptionally low magnetostriction materials, and therefore are both appropriate candidates to overcome this design constraint.

Combining all of the above requirements into one over-reaching material choice is generally not possible, as each design requirement is generally satisfied at the expense of one (or more) of the others. However, industry designs tend to consider very thin (0.0005”) foils of Orthonol, with Permalloy being considered for even lower loss designs.

References

1. W.C. Nunnaly, “Magnetic Switches and Circuits,” Los Alamos National Laboratory, 1982.

Figure 21.

Typical DC Hysteresis Loops for 48 Alloy and Orthonol

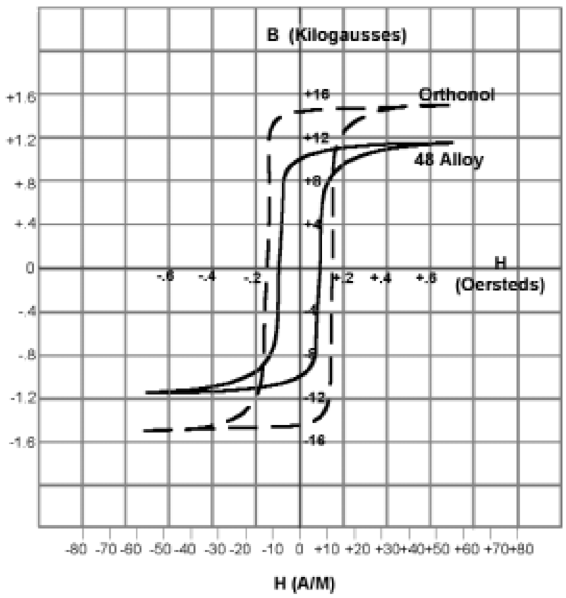


Figure 22.

Typical DC Hysteresis Loops for Square Permalloy 80 and Supermalloy

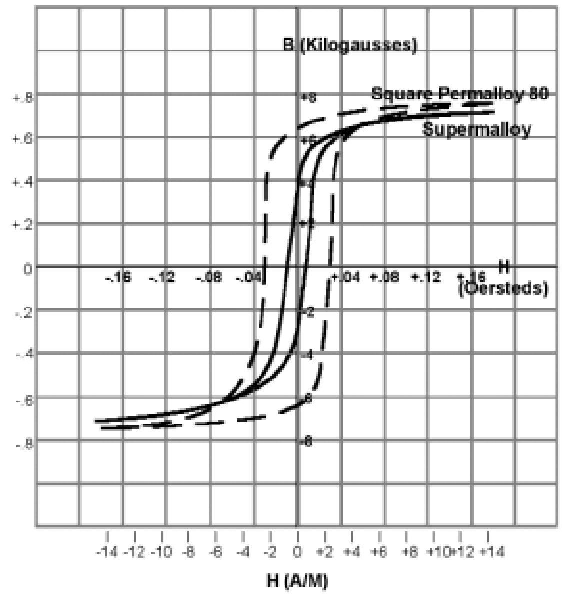


Figure 23.

Typical DC Hysteresis Loops for Magnesil and Supermendur

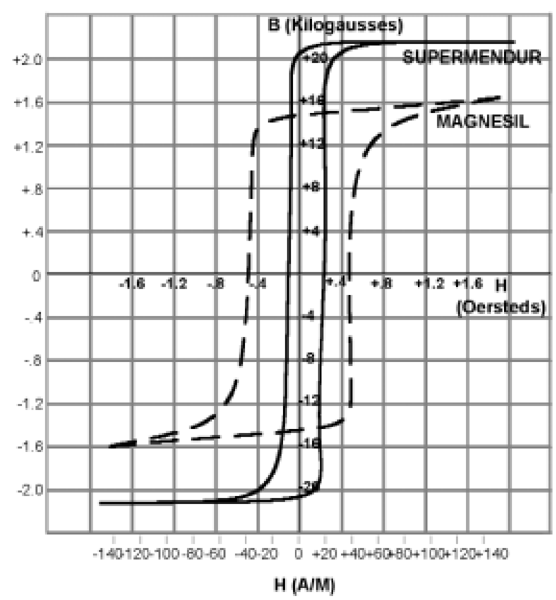


Figure 24.

Typical Hysteresis Loops for 2 mil Orthonol

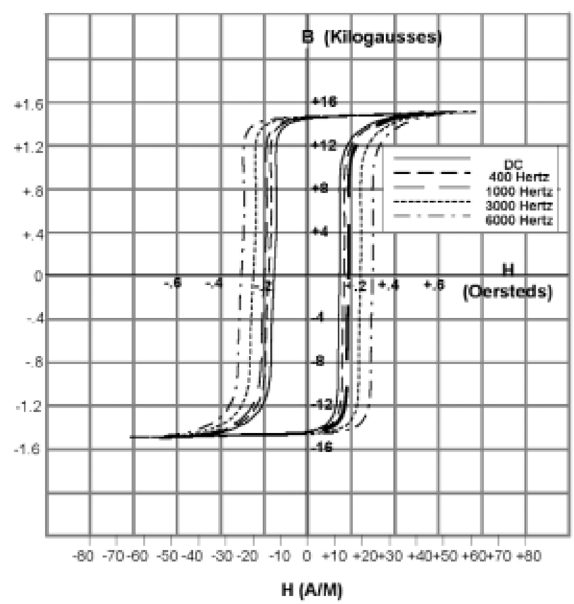


Figure 25.

Hysteresis Loops for 1/2 mil Square Permalloy 80

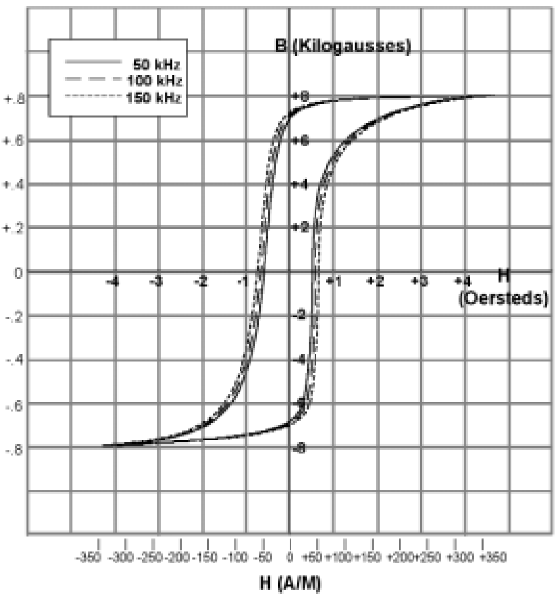


Figure 26.

Hysteresis Loops for 2 mil Square Permalloy 80

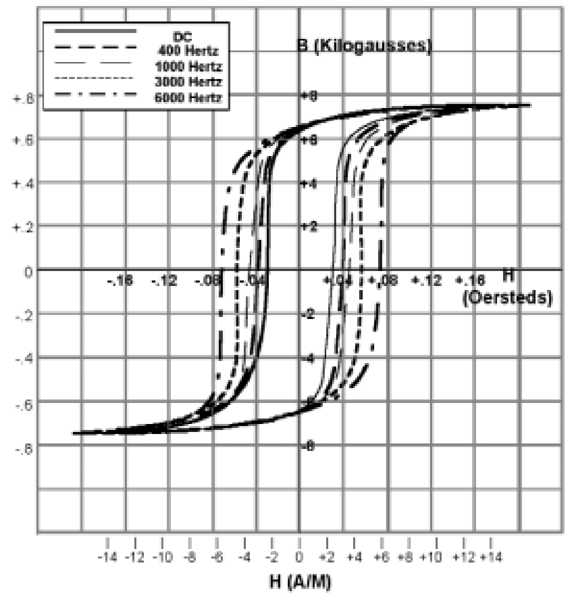


Figure 27.

Hysteresis Loops for 1 mil Square Permalloy 80

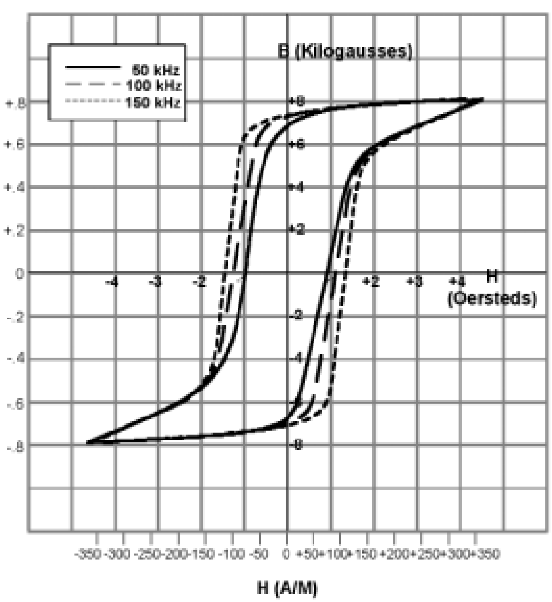


Figure 28.

Typical Hysteresis Loops for Amorphous-E

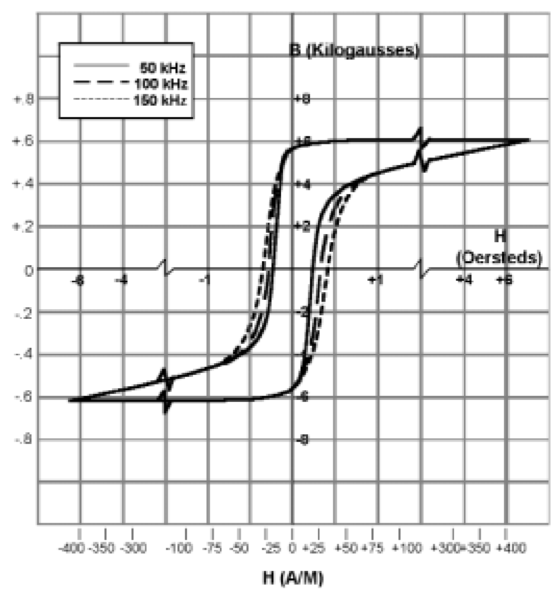


Figure 29.

Permeability versus Flux Density for Permalloy Materials

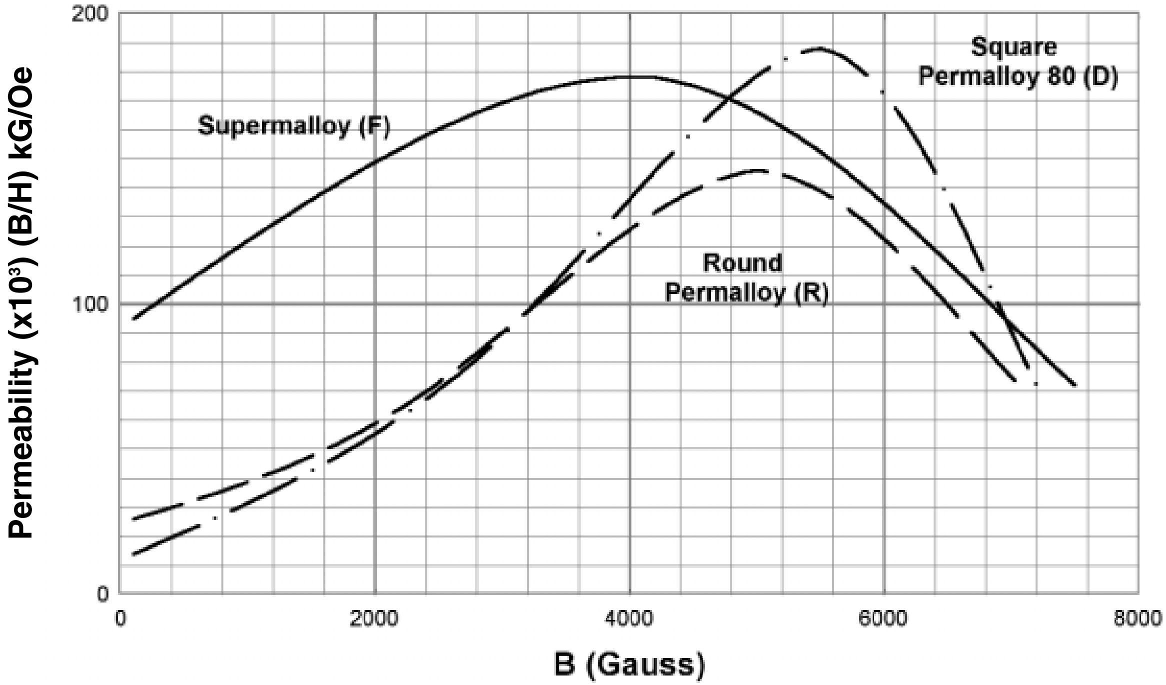


Figure 30.

Typical Variation of Flux Density with Temperature

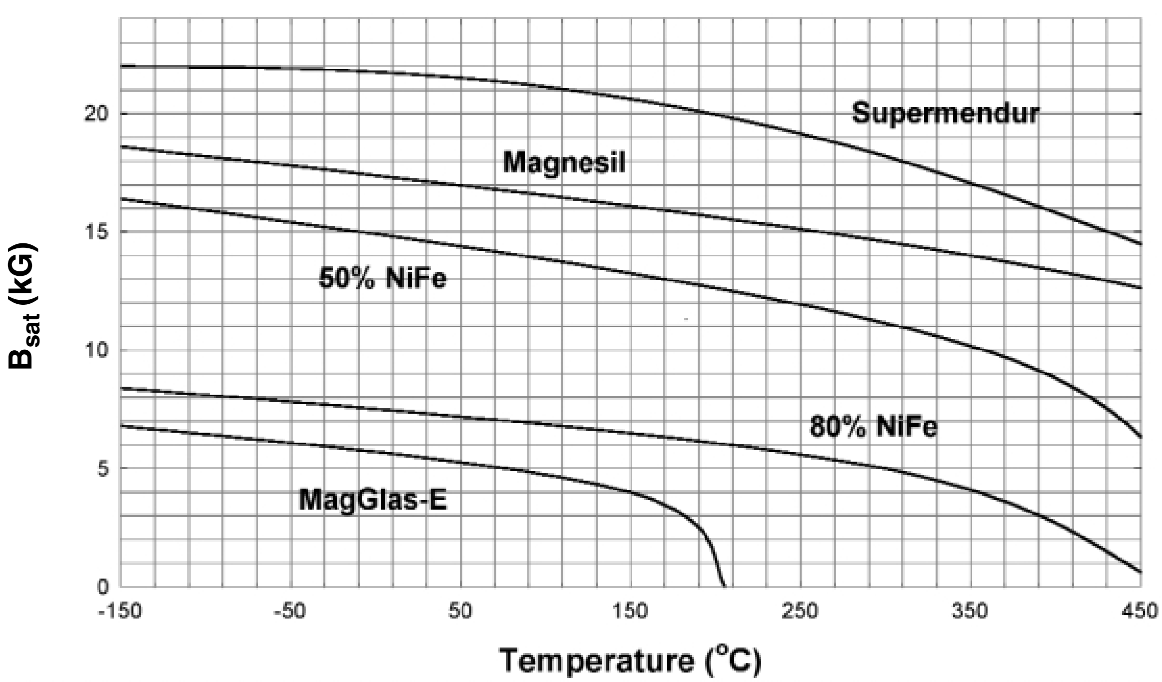


Figure 31. **Typical Variation of Flux Density with Temperature for Orthonol**

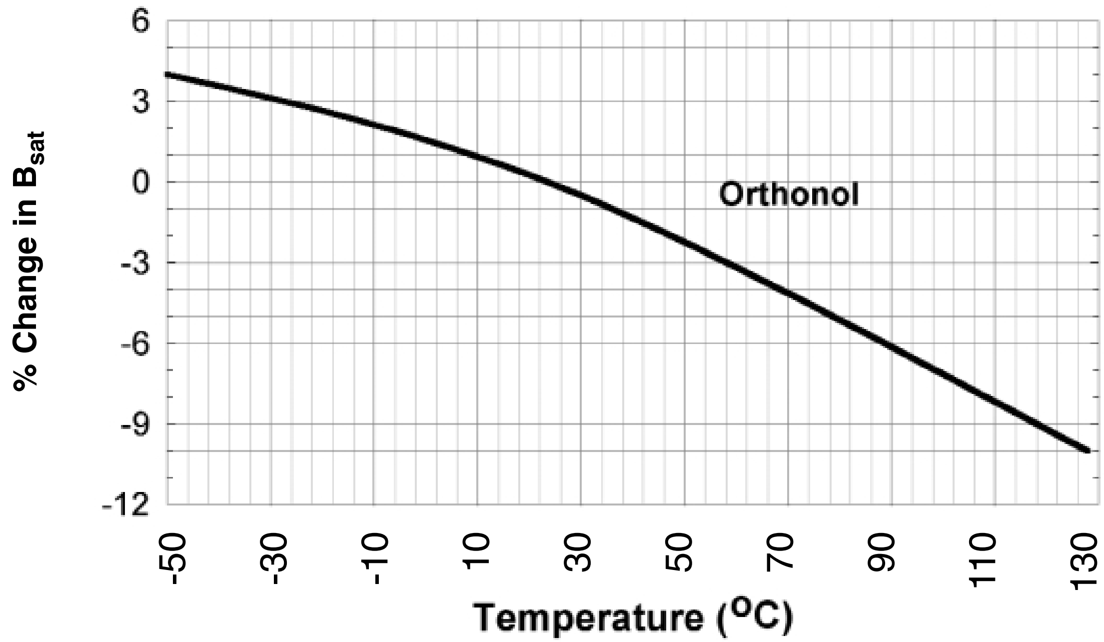


Figure 32. **Typical Variation of Flux Density with Temperature for Square Permalloy and Amorphous-E**

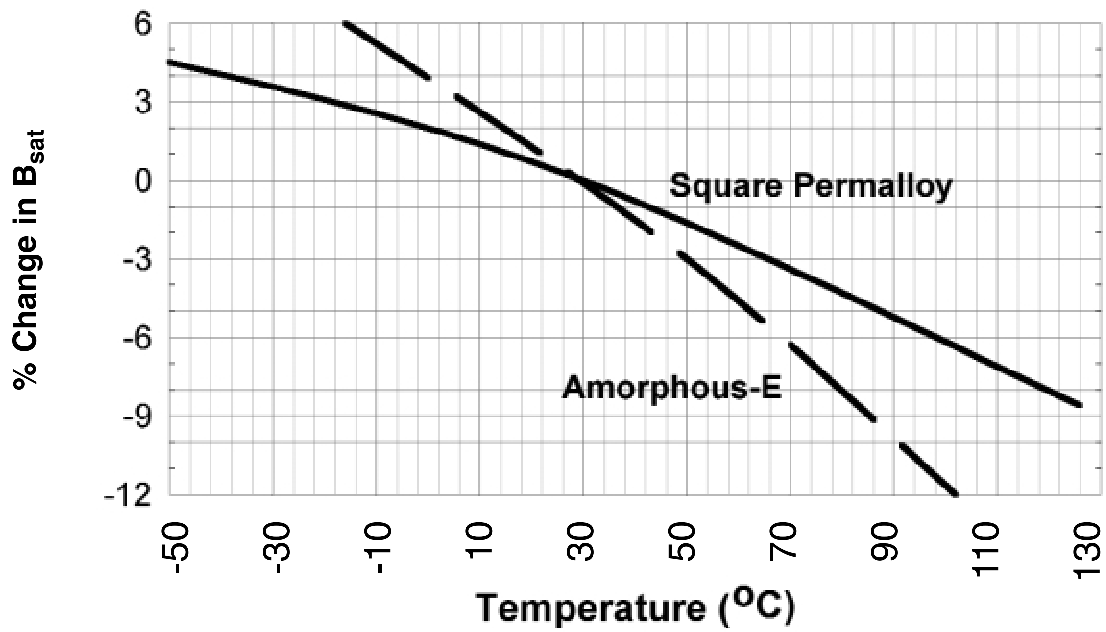


Figure 33. Typical Variation of Squareness Ratio with Temperature for Orthonol

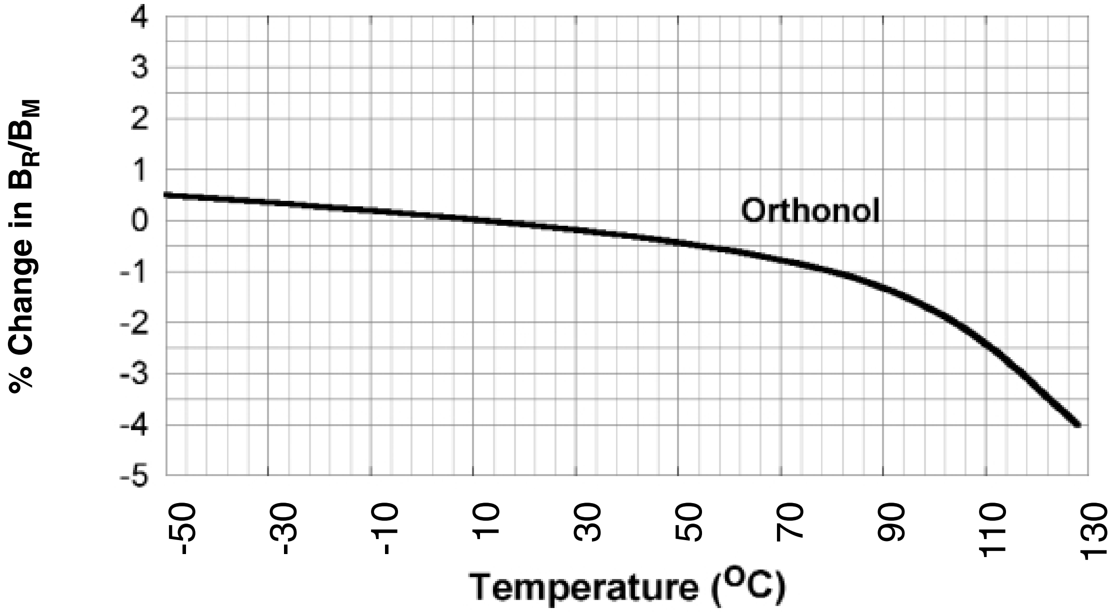


Figure 34. Typical Variation of Squareness Ratio with Temperature for Square Permalloy

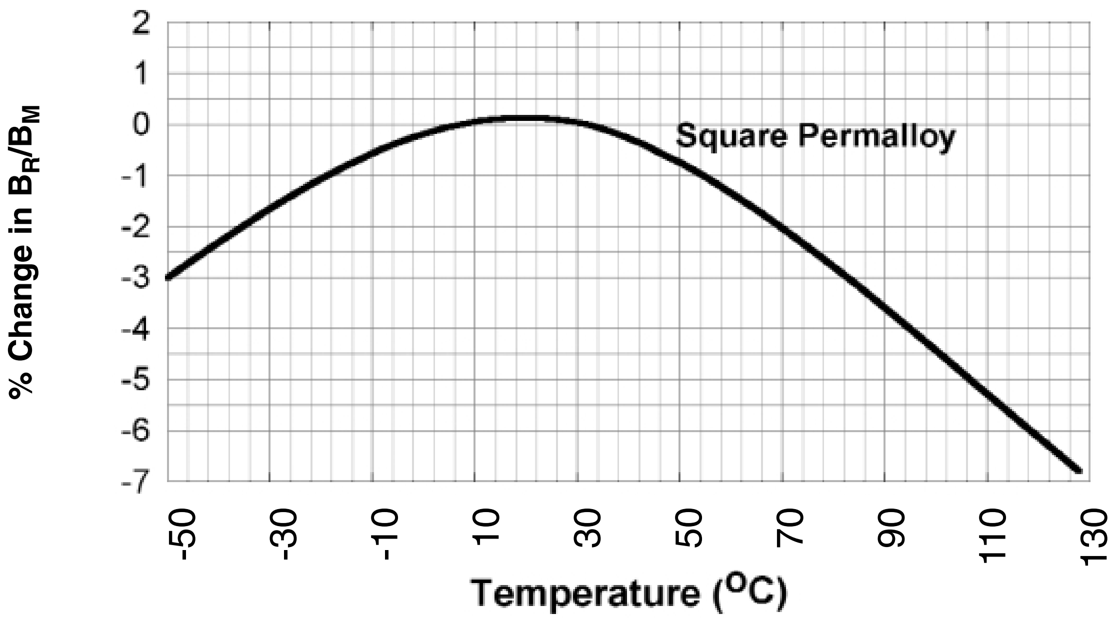


Figure 35. Typical Variation of H1 with Temperature for Orthonol

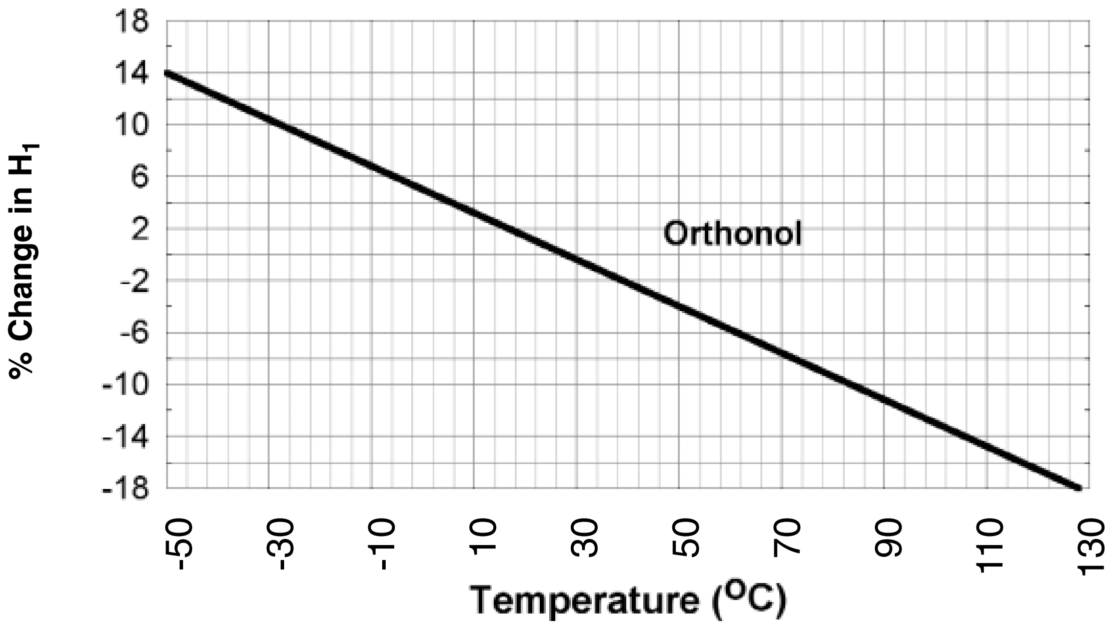
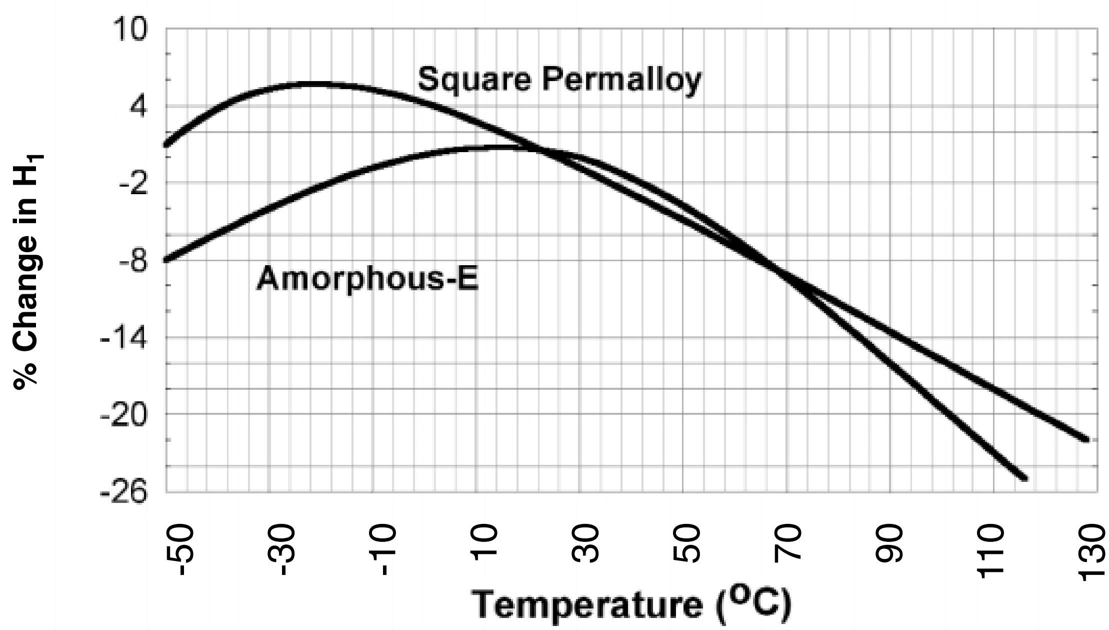


Figure 36. Typical Variation of H1 with Temperature for Square Permalloy and Amorphous-E



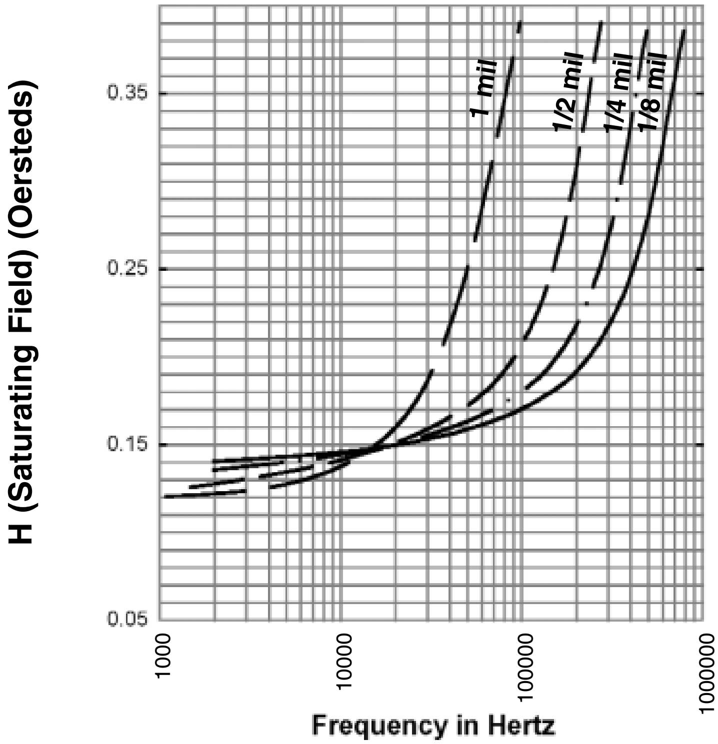


Figure 37.

Average MMF Required to Saturate Permalloy 80 Versus Frequency (Square Wave Current)

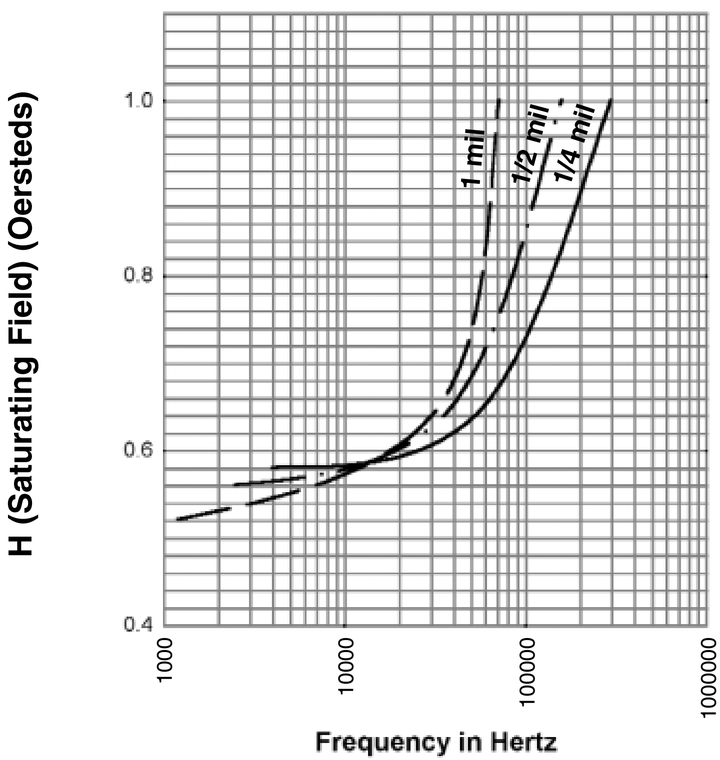


Figure 38.

Average MMF Required to Saturate Orthonol Versus Frequency (Square Wave Current)

Core Loss Curves

Figure 39. 2 mil 48 Alloy

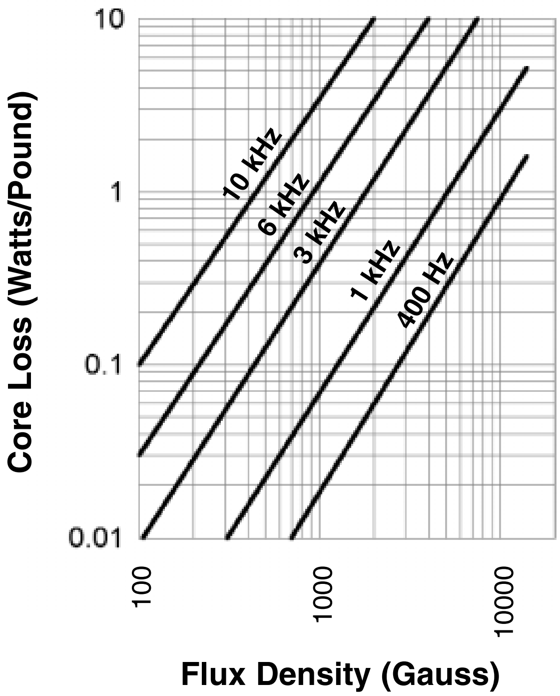


Figure 40. 2 mil Orthonol

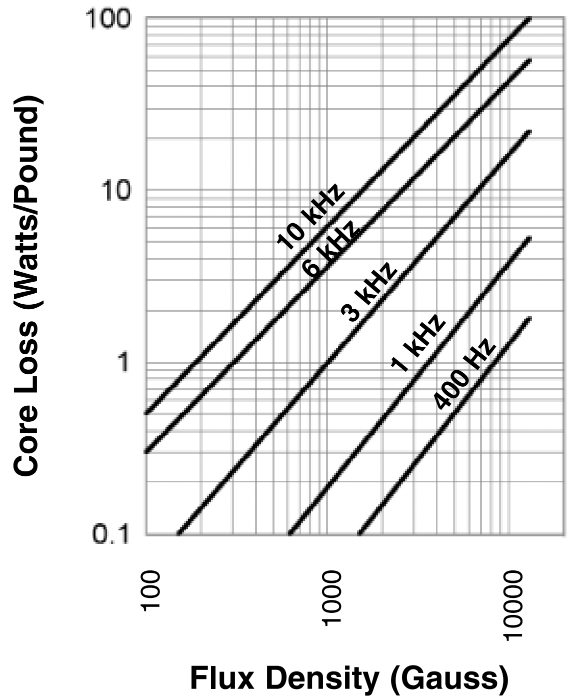


Figure 41. 1 mil Orthonol

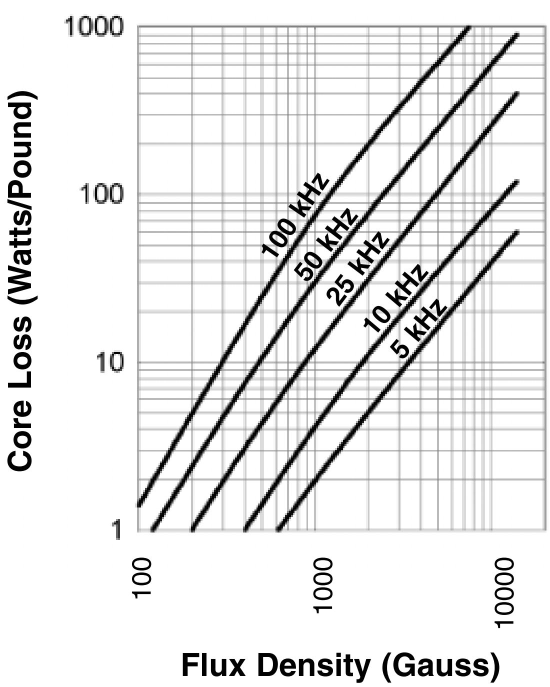


Figure 42. 1/2 mil Orthonol

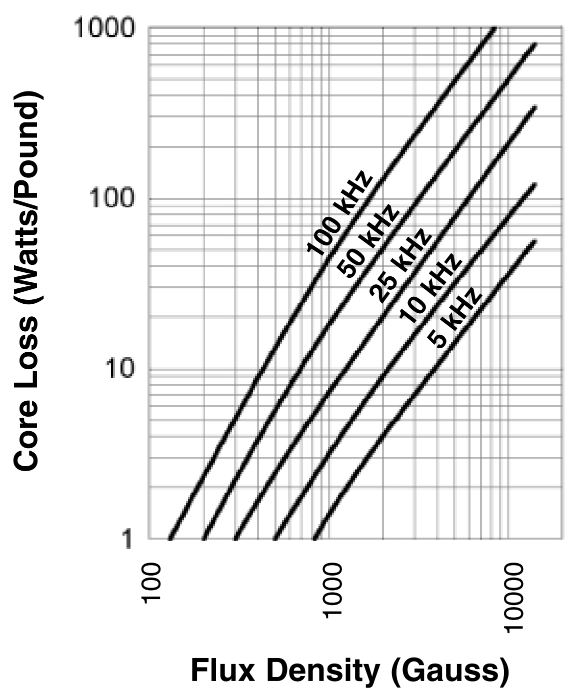


Figure 43. **2 mil Sq. Permalloy**

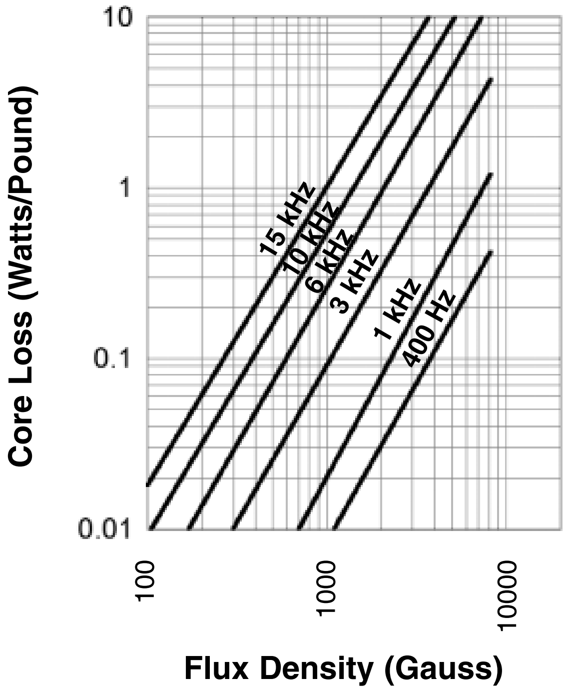


Figure 44. **1 mil Sq. Permalloy**

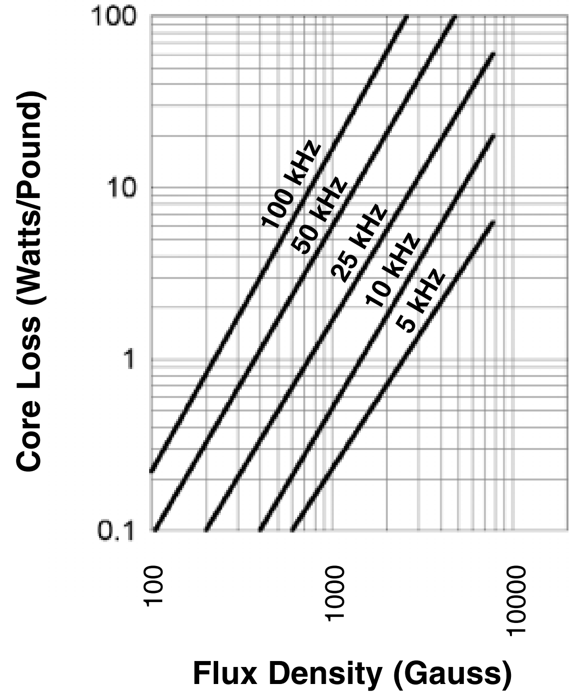


Figure 45. **1/2 mil Sq. Permalloy**

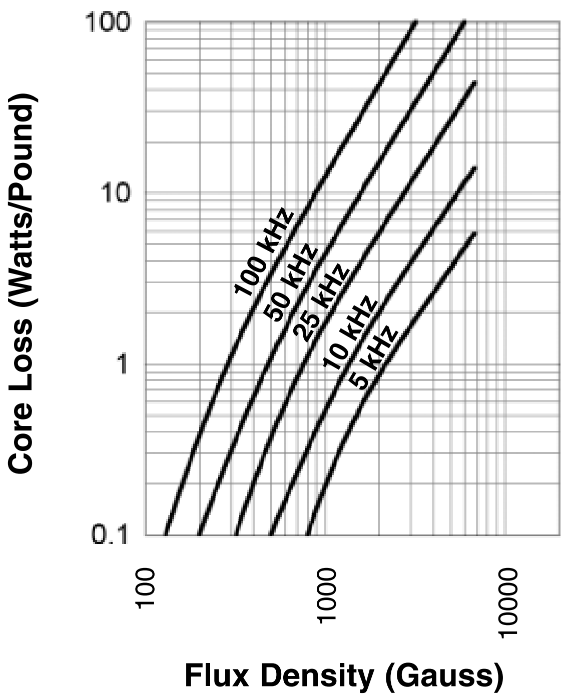


Figure 46. **2 mil Supermalloy**

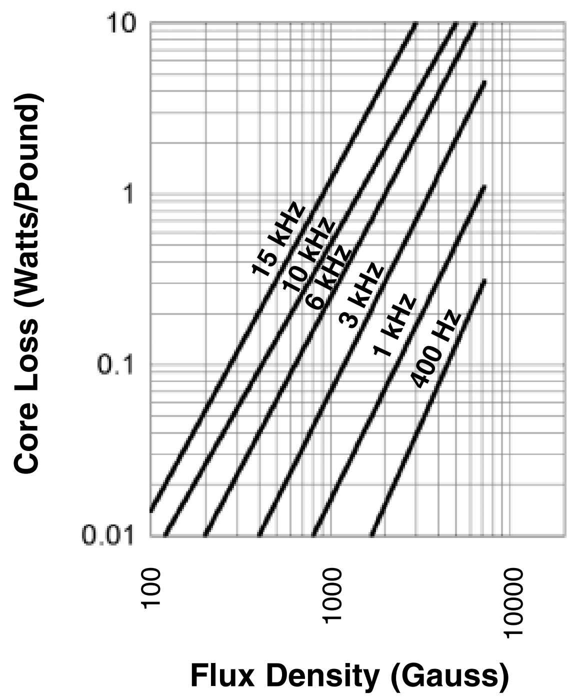


Figure 47. 1 mil Supermalloy

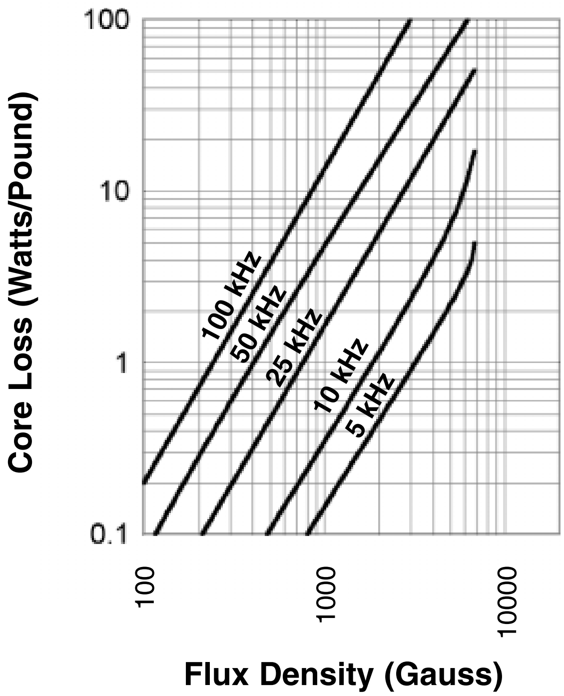


Figure 48. 1/2 mil Supermalloy

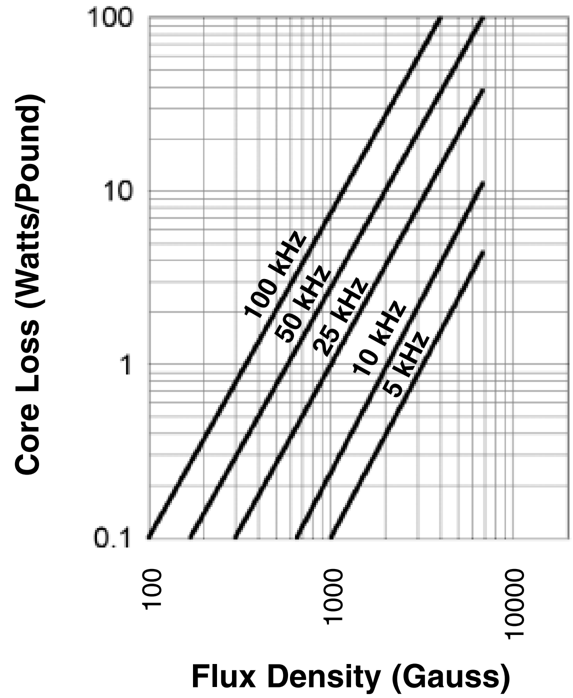


Figure 49. 4 mil Magnesil

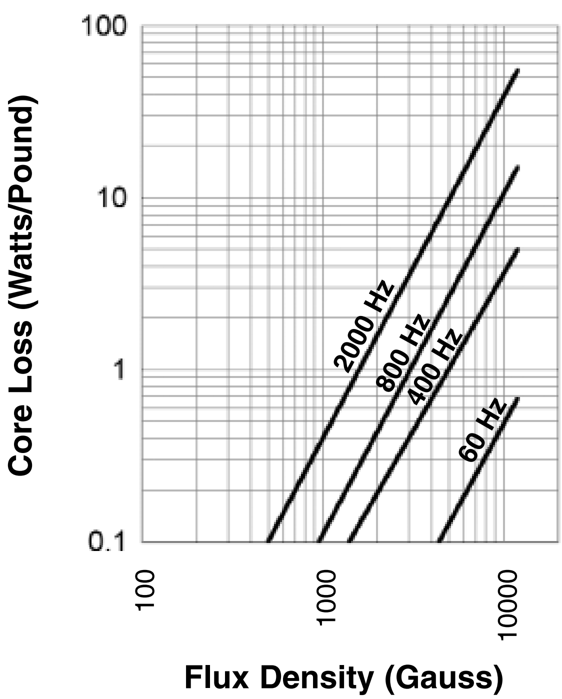


Figure 50. 2 mil Magnesil

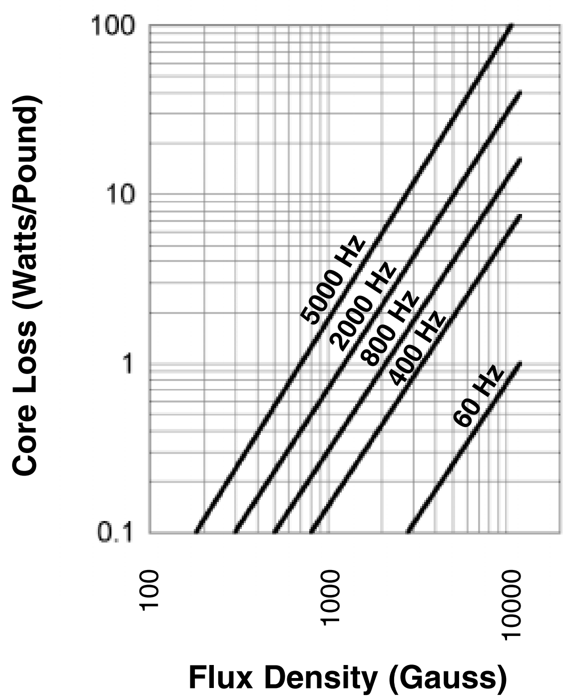


Figure 51. 4 mil Supermendur

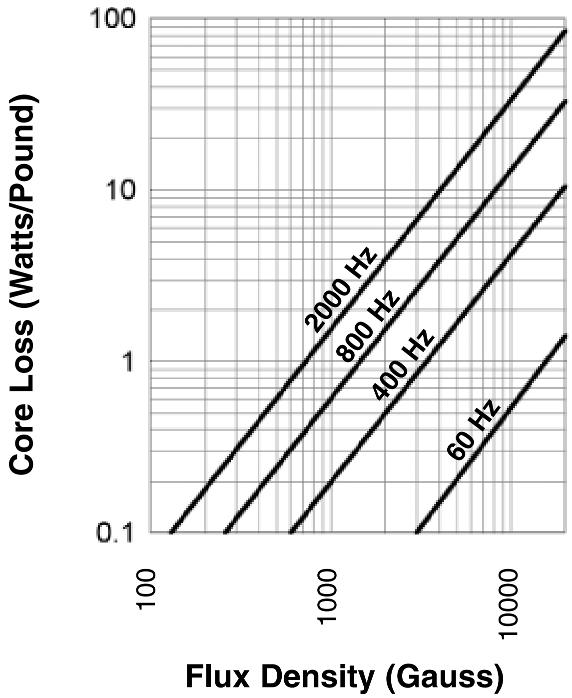


Figure 52. 2 mil Supermendur

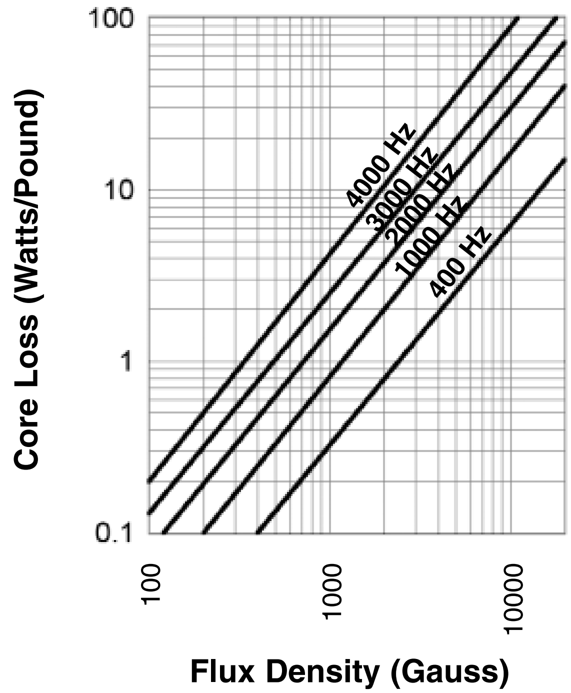


Figure 53 Amorphous-C

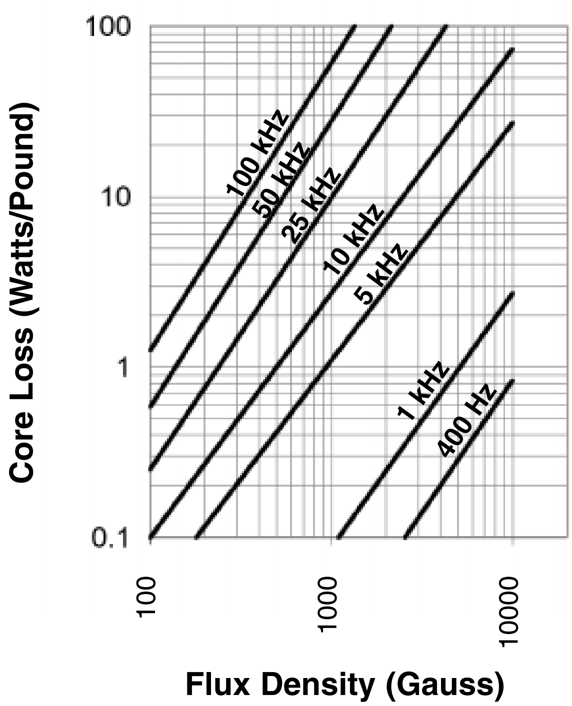


Figure 54 Amorphous-E

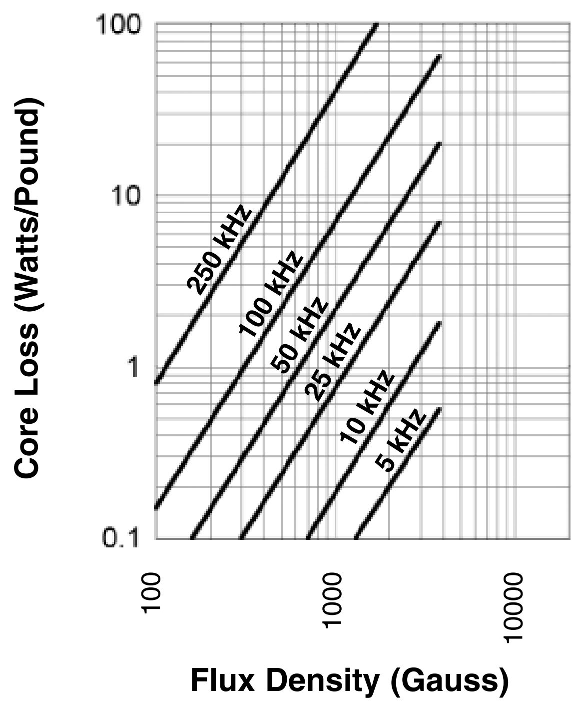


Figure 55. Typical Impedance Permeability, 48 Alloy

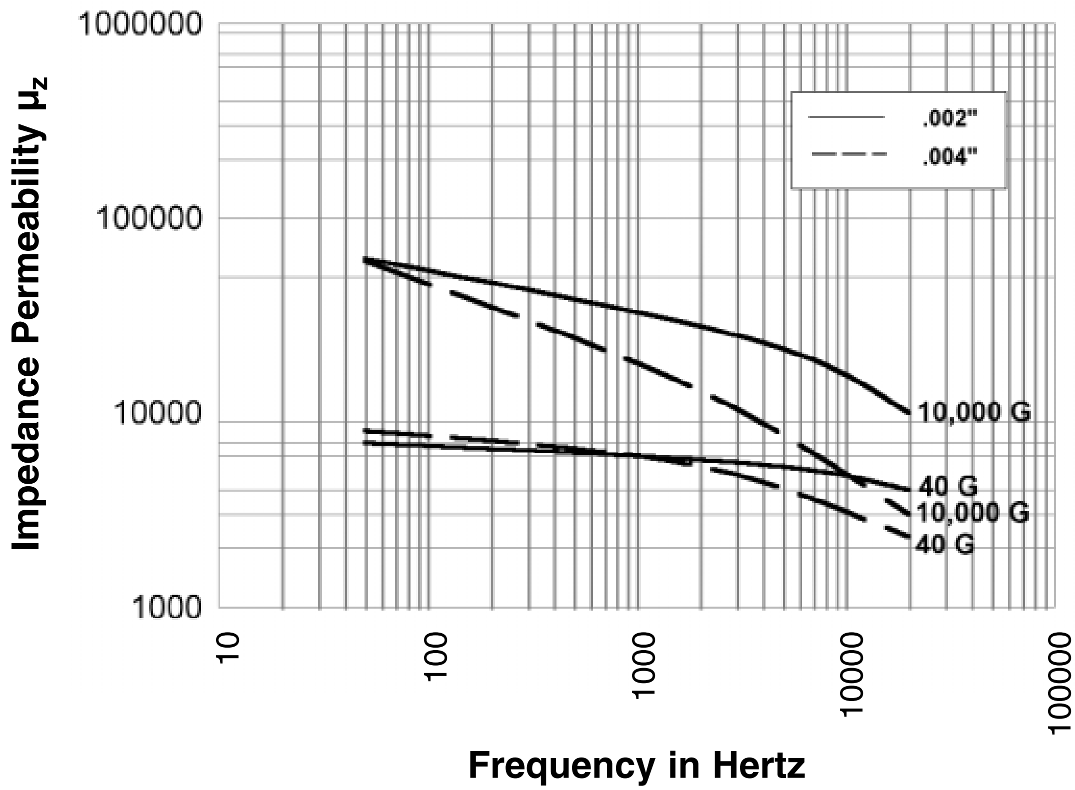


Figure 56. Typical Impedance Permeability, Orthonol

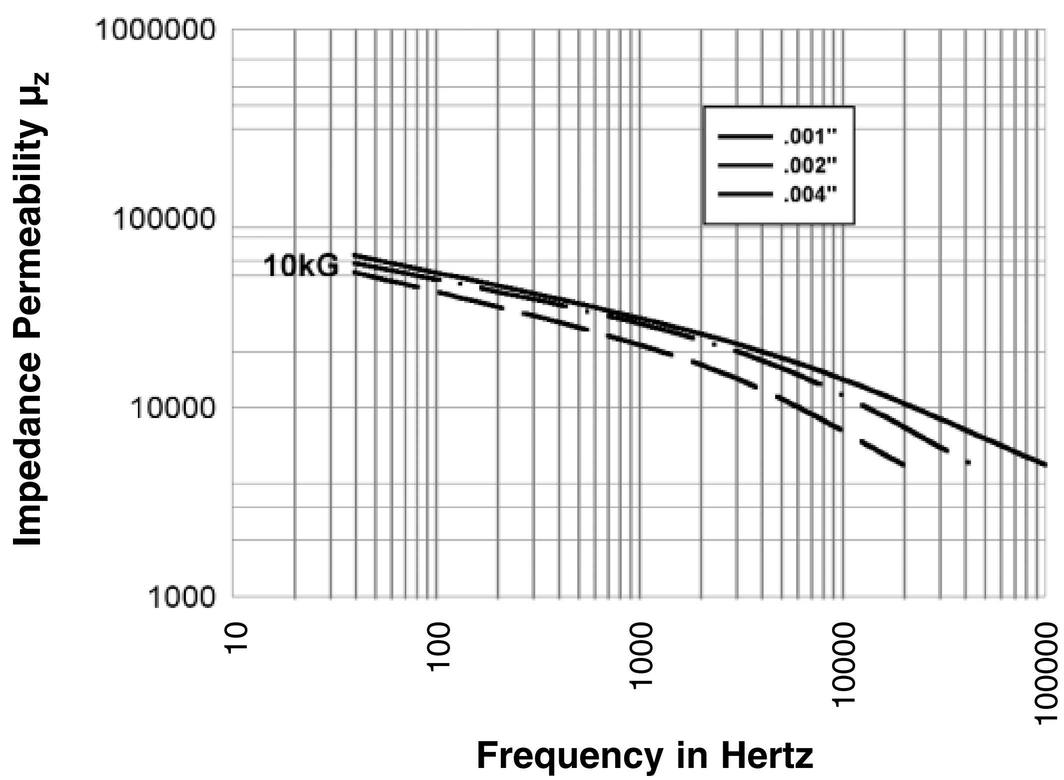


Figure 57. **Typical Impedance Permeability, Square Permalloy 80**

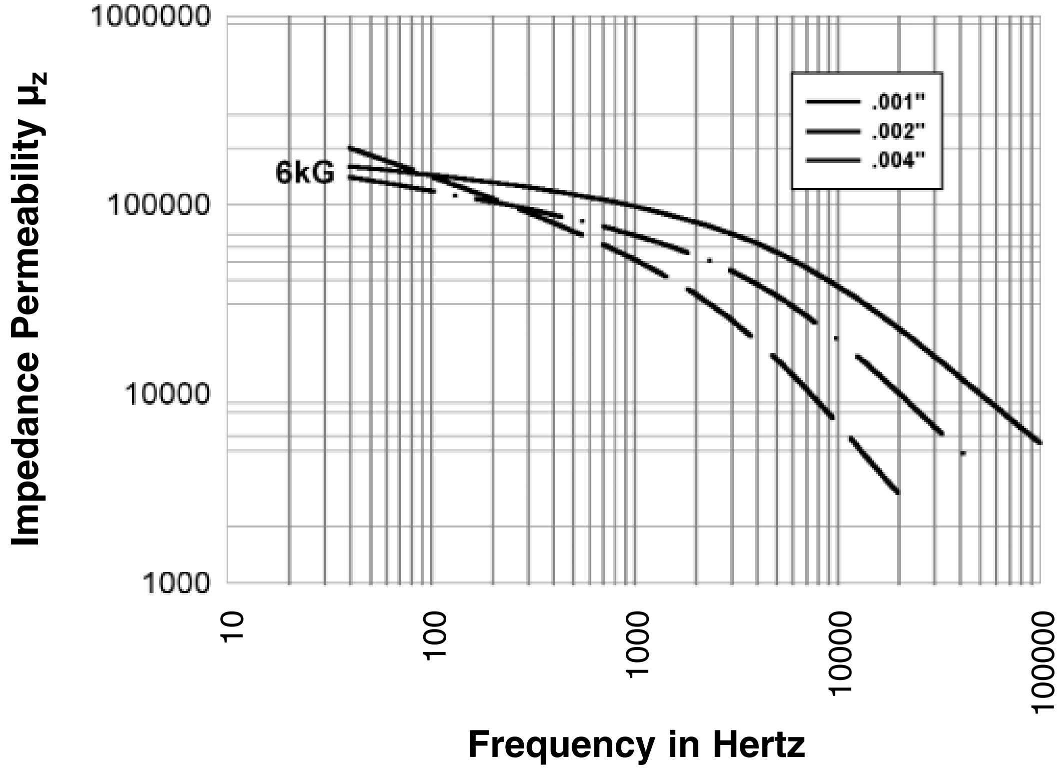


Figure 58. **Typical Impedance Permeability, Supermalloy**

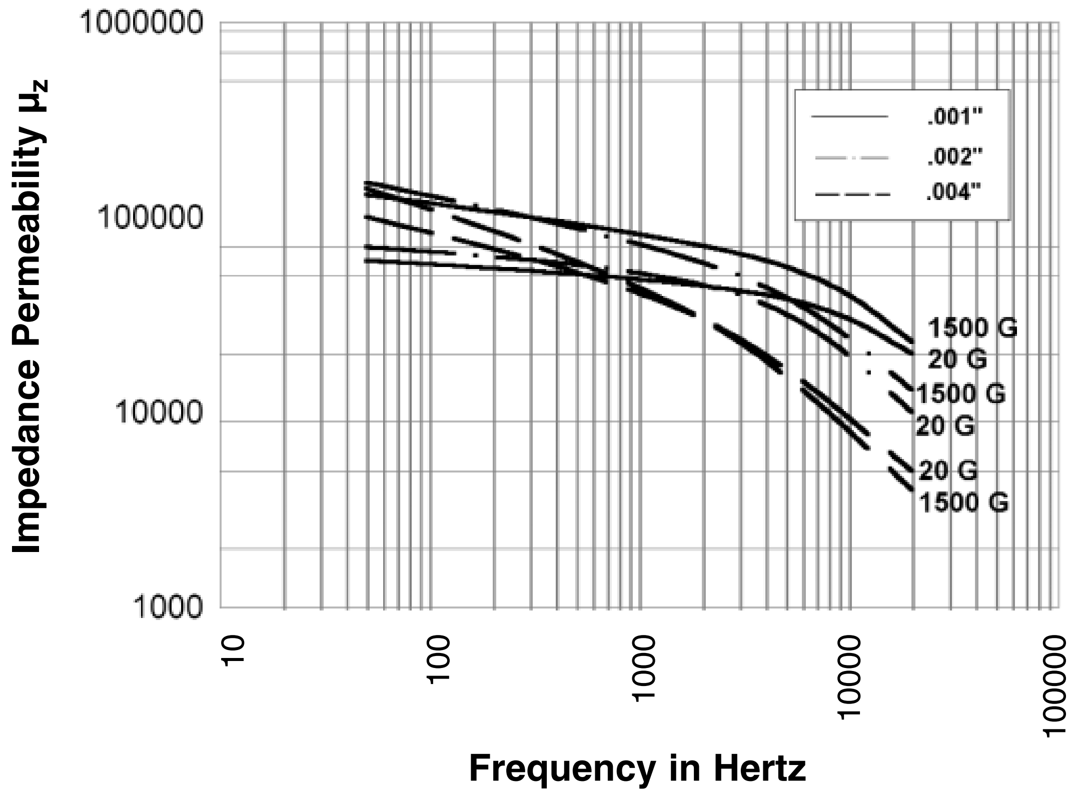


Figure 59. **Typical Impedance Permeability, Magnesil**

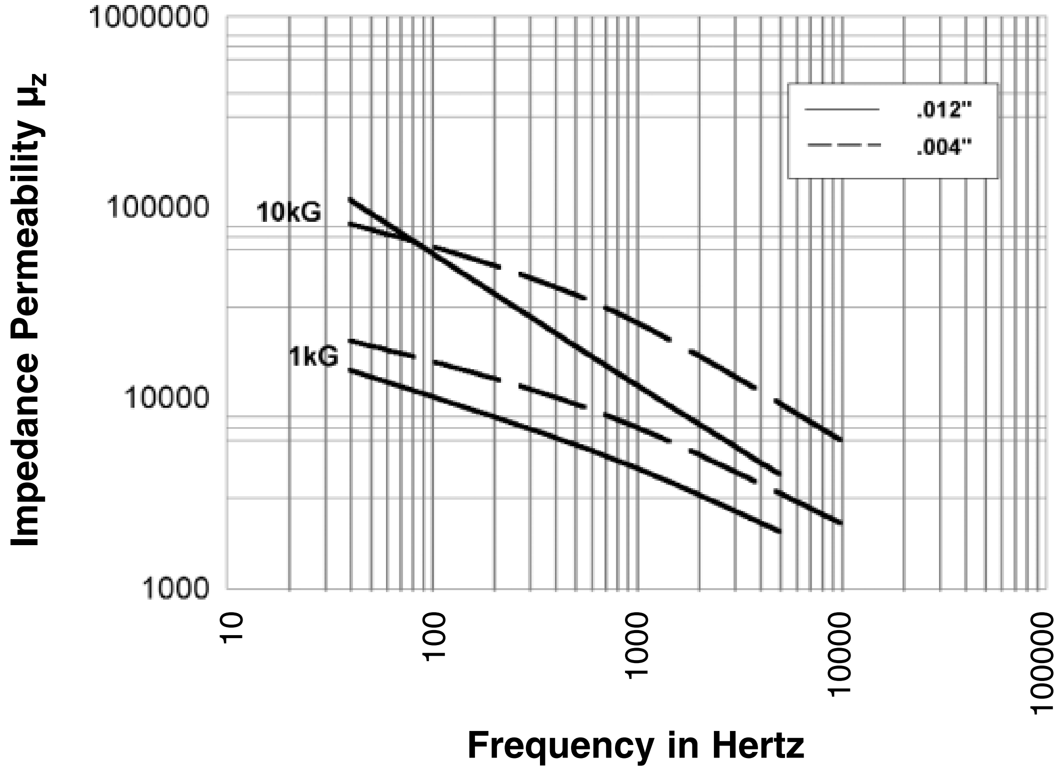


Figure 60. **Typical Impedance Permeability, Supermendur**

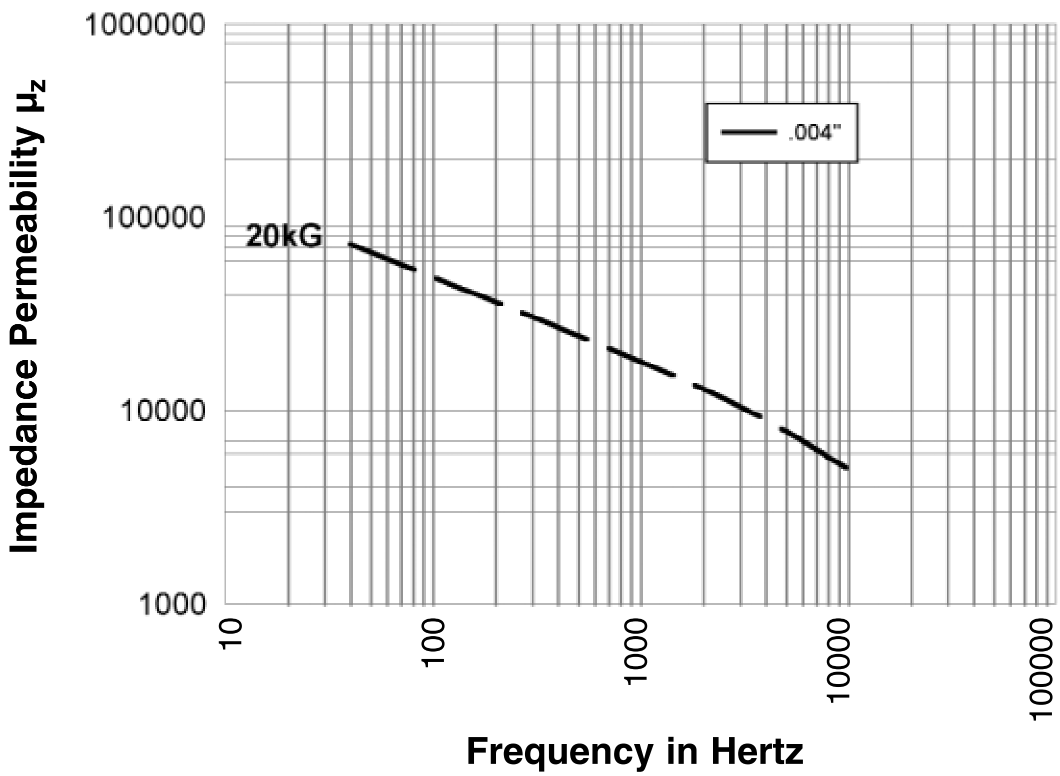


Figure 61. **Typical Impedance Permeability, Amorphous-C**

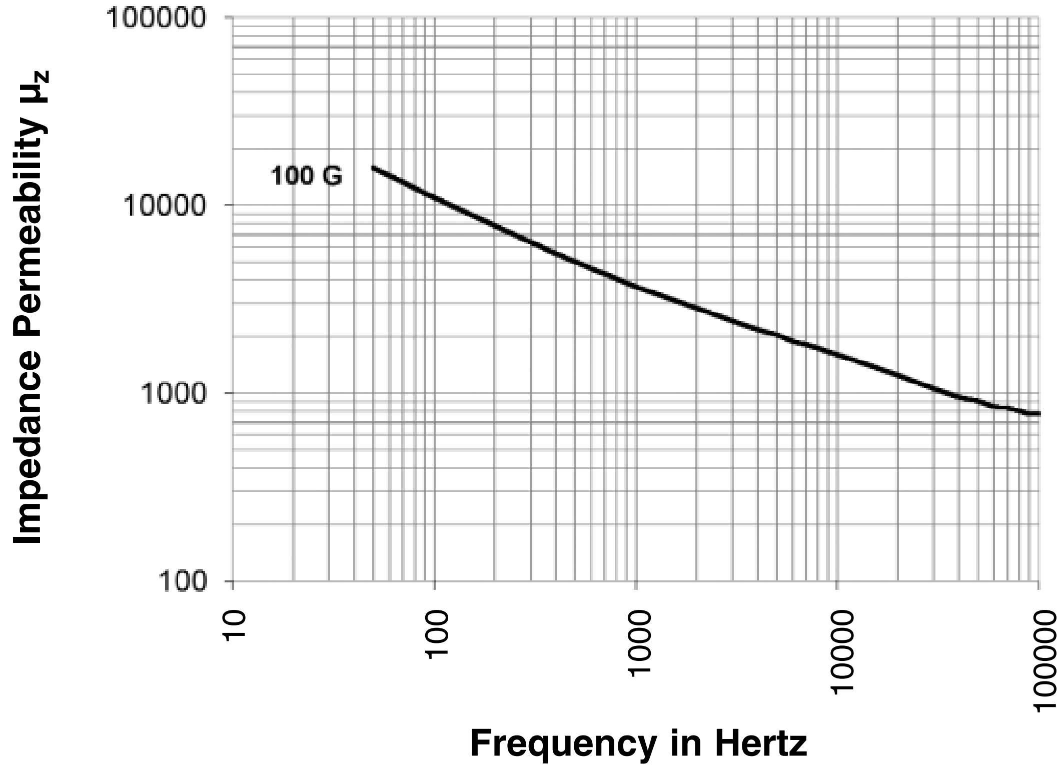
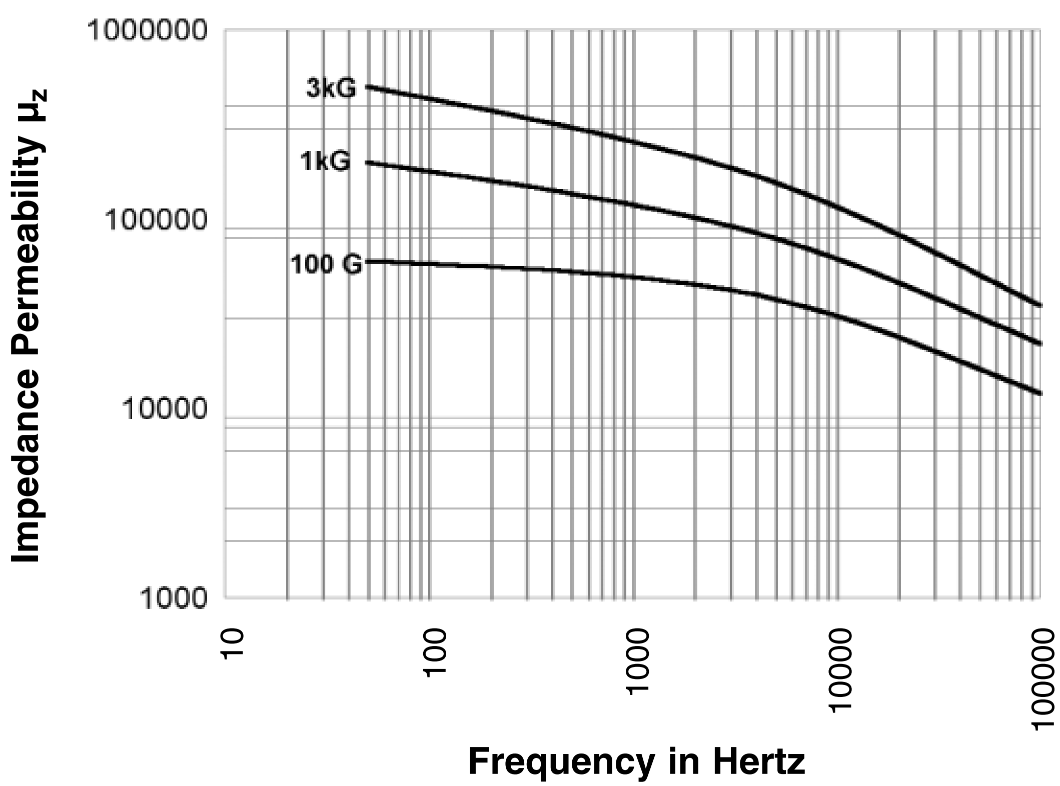


Figure 62. **Typical Impedance Permeability, Amorphous-E**



Core Sizes and Selection Tables

Table 7. Magnetics Tape Wound Core Sizes

Core Part Number		Nominal Core Dimensions			Case Dimensions			Path Length	Window Area	Effective Core Area (cm^2)					W_aA_c
		I.D.	O.D.	HT.	I.D. Min	O.D. Max	HT. Max	cm	cm^2	0.0005	0.001	0.002	0.004	0.012 & 0.014	cm^4
50402	in	0.375	0.438	0.125	0.306	0.509	0.199	3.250	0.456	0.013	0.019	0.022	N/A	N/A	0.010
	mm	9.5	11.1	3.2	7.8	12.9	5.0								
50107	in	0.500	0.563	0.125	0.432	0.632	0.199	4.240	0.916	0.013	0.019	0.022	0.023	N/A	0.020
	mm	12.7	14.3	3.2	11.0	16.0	5.0								
50356	in	0.687	0.750	0.125	0.618	0.819	0.197	5.730	1.914	0.013	0.019	0.022	0.023	N/A	0.041
	mm	17.	19.0	3.2	15.7	20.8	5.0								
50153	in	0.375	0.500	0.125	0.313	0.569	0.199	3.490	0.456	0.025	0.038	0.043	N/A	N/A	0.020
	mm	9.5	12.7	3.2	8.0	14.4	5.0								
50154	in	0.438	0.563	0.125	0.369	0.632	0.199	3.990	0.673	0.025	0.038	0.043	N/A	N/A	0.030
	mm	11.1	14.3	3.2	9.4	16.0	5.0								
50056	in	0.500	0.625	0.125	0.431	0.694	0.199	4.490	0.916	0.025	0.038	0.043	0.045	N/A	0.041
	mm	12.7	15.9	3.2	10.9	17.6	5.0								
50057	in	0.625	0.750	0.125	0.556	0.819	0.199	5.480	1.534	0.025	0.038	0.043	0.045	N/A	0.066
	mm	15.9	19.0	3.2	14.1	20.8	5.0								
50155	in	0.438	0.563	0.250	0.369	0.632	0.324	3.990	0.724	0.050	0.076	0.086	N/A	N/A	0.061
	mm	11.1	14.3	6.4	9.4	16.0	8.2								
50000	in	0.500	0.750	0.125	0.431	0.819	0.199	4.990	0.916	0.050	0.076	0.086	0.091	N/A	0.081
	mm	12.7	19.0	3.2	10.9	20.8	5.0								
50002	in	0.650	0.900	0.125	0.581	0.969	0.199	5.980	1.676	0.050	0.076	0.086	0.091	N/A	0.142
	mm	16.5	22.9	3.2	14.8	24.6	5.0								
50011	in	1.000	1.250	0.125	0.921	1.329	0.209	8.970	4.238	0.050	0.076	0.086	0.091	N/A	0.365
	mm	25.4	31.8	3.2	23.4	33.8	5.3								
50748	in	2.500	2.750	0.125	2.389	2.869	0.247	20.940	29.407	0.050	0.076	0.086	0.091	N/A	2.527
	mm	63.5	69.9	3.2	60.7	72.9	6.3								
50176	in	0.500	0.750	0.250	0.431	0.819	0.324	4.990	0.916	0.101	0.151	0.171	0.182	N/A	0.157
	mm	12.7	19.0	6.4	10.9	20.8	8.2								
50033	in	0.625	0.875	0.250	0.556	0.944	0.324	5.980	1.534	0.101	0.151	0.171	0.182	N/A	0.263
	mm	15.9	22.2	6.4	14.1	24.0	8.2								
50061	in	0.750	1.000	0.250	0.671	1.079	0.334	6.980	2.273	0.101	0.151	0.171	0.182	N/A	0.390
	mm	19.0	25.4	6.4	17.0	27.4	8.5								
50004	in	1.000	1.250	0.250	0.921	1.329	0.334	8.970	4.238	0.101	0.151	0.171	0.182	N/A	0.724
	mm	25.4	31.8	6.4	23.4	33.8	8.5								
50076	in	0.625	1.000	0.188	0.546	1.079	0.272	6.480	1.478	0.113	0.171	0.193	0.205	N/A	0.284
	mm	15.9	25.4	4.8	13.9	27.4	6.9								
50106	in	0.750	1.125	0.188	0.671	1.204	0.272	7.480	2.273	0.113	0.171	0.193	0.205	N/A	0.441
	mm	19.0	28.6	4.8	17.0	30.6	6.9								
50296	in	0.600	0.900	0.250	0.531	0.969	0.324	5.980	1.478	0.121	0.182	0.206	N/A	N/A	0.304
	mm	15.2	22.9	6.4	13.5	24.6	8.2								
50323	in	2.500	2.800	0.250	2.329	2.971	0.410	21.140	29.407	0.121	0.182	0.206	0.218	N/A	6.056
	mm	63.5	71.1	6.4	59.2	75.5	10.4								
50007	in	0.625	1.000	0.250	0.546	1.079	0.334	6.480	1.478	0.151	0.227	0.257	0.272	N/A	0.380
	mm	15.9	25.4	6.4	13.9	27.4	8.5								
50084	in	0.750	1.125	0.250	0.671	1.204	0.329	7.480	2.273	0.151	0.227	0.257	0.272	N/A	0.582
	mm	19.0	28.6	6.4	17.0	30.6	8.4								
50029	in	1.000	1.375	0.250	0.901	1.474	0.354	9.470	4.438	0.151	0.227	0.257	0.272	N/A	1.089
	mm	25.4	34.9	6.4	22.9	37.4	9.0								

Core Part Number		Nominal Core Dimensions			Case Dimensions			Path Length cm	Window Area cm^2	Effective Core Area (cm^2)					W_aA_c cm^4
		I.D.	O.D.	HT.	I.D. Min	O.D. Max	HT. Max			0.0005	0.001	0.002	0.004	0.012 & 0.014	
50168	in	0.750	1.000	0.375	0.671	1.079	0.459	6.980	2.273	0.151	0.227	0.257	0.272	N/A	0.582
	mm	19.0	25.4	9.5	17.0	27.4	11.6								
50032	in	1.000	1.500	0.250	0.901	1.599	0.354	9.970	4.238	0.202	0.303	0.343	0.363	N/A	1.453
	mm	25.4	38.1	6.4	22.9	40.6	9.0								
50030	in	1.250	1.750	0.250	1.149	1.851	0.357	11.960	6.815	0.202	0.303	0.343	0.363	N/A	2.239
	mm	31.8	44.4	6.4	29.2	47.0	9.1								
50391	in	1.000	1.250	0.500	0.906	1.344	0.599	8.970	4.435	0.202	0.303	0.343	0.363	N/A	1.519
	mm	25.4	31.8	12.7	23.0	34.1	15.2								
50094	in	0.625	1.000	0.375	0.546	1.079	0.459	6.480	1.534	0.224	0.340	0.386	0.408	N/A	0.592
	mm	15.9	25.4	9.5	13.9	27.4	11.6								
50034	in	0.750	1.125	0.375	0.671	1.204	0.459	7.480	2.273	0.224	0.340	0.386	0.408	N/A	0.876
	mm	19.0	28.6	9.5	17.0	30.6	11.6								
50181	in	0.875	1.250	0.375	0.796	1.329	0.459	8.470	3.160	0.224	0.340	0.386	0.408	N/A	1.220
	mm	22.2	31.8	9.5	20.2	33.8	11.6								
50504	in	1.125	1.500	0.375	1.036	1.599	0.479	10.470	5.478	0.224	0.340	0.386	0.408	N/A	2.116
	mm	28.6	38.1	9.5	26.3	40.6	12.2								
50133	in	0.650	1.150	0.375	0.571	1.229	0.459	7.180	1.676	0.299	0.454	0.514	0.545	N/A	0.861
	mm	16.5	29.2	9.5	14.5	31.2	11.6								
50188	in	0.750	1.250	0.375	0.671	1.329	0.459	7.980	2.238	0.299	0.454	0.514	0.545	N/A	1.149
	mm	19.0	31.8	9.5	17.0	33.8	11.6								
50383	in	0.875	1.375	0.375	0.776	1.474	0.479	8.970	3.160	0.299	0.454	0.514	0.545	N/A	1.625
	mm	22.2	34.9	9.5	19.7	37.4	12.2								
50026	in	1.000	1.500	0.375	0.901	1.599	0.479	9.970	4.238	0.299	0.454	0.514	0.545	N/A	2.177
	mm	25.4	38.1	9.5	22.9	40.6	12.2								
50038	in	1.000	1.500	0.500	0.901	1.599	0.604	9.970	4.238	0.398	0.605	0.689	0.726	N/A	2.906
	mm	25.4	38.1	12.7	22.9	40.6	15.3								
50035	in	1.250	1.750	0.500	1.149	1.851	0.607	11.960	6.815	0.398	0.605	0.689	0.726	N/A	4.673
	mm	31.8	44.4	12.7	29.2	47.0	15.4								
50055	in	1.500	2.000	0.500	1.401	2.099	0.604	13.960	9.924	0.398	0.605	0.689	0.726	0.766	6.810
	mm	38.1	50.8	12.7	35.6	53.3	15.3								
50345	in	1.750	2.250	0.500	1.619	2.381	0.627	15.950	13.787	0.398	0.605	0.689	0.726	0.766	9.458
	mm	44.4	57.2	12.7	41.1	60.5	15.9								
50017	in	2.000	2.500	0.500	1.869	2.631	0.627	17.950	18.182	0.398	0.605	0.689	0.726	0.766	12.471
	mm	50.8	63.5	12.7	47.5	66.8	15.9								
50425	in	1.250	2.000	0.375	1.134	2.116	0.492	12.960	6.815	0.448	0.681	0.771	0.817	N/A	5.256
	mm	31.80	50.8	9.5	28.8	53.7	12.5								
50555	in	1.250	2.250	0.500	1.119	2.381	0.627	13.960	6.699	0.796	1.210	1.371	1.452	N/A	9.185
	mm	31.8	57.1	12.7	28.4	60.5	15.9								
50001	in	1.500	2.500	0.500	1.369	2.631	0.627	15.950	9.640	0.796	1.210	1.371	1.452	1.532	13.215
	mm	38.1	63.5	12.7	34.8	66.8	15.9								
50103	in	2.000	3.000	0.500	1.869	3.131	0.627	19.940	17.894	0.796	1.210	1.371	1.452	1.532	24.531
	mm	50.8	76.2	12.7	47.5	79.5	15.9								
50128	in	2.5	3.5	0.500	2.369	3.631	0.627	23.930	28.678	0.796	1.210	1.371	1.452	1.532	39.316
	mm	63.5	88.8	12.7	60.2	92.2	15.9								
50451	in	1.000	1.500	1.000	0.891	1.609	1.104	9.970	4.238	0.796	1.210	1.371	1.452	N/A	5.813
	mm	25.4	38.1	25.4	22.6	40.9	28.0								
50040	in	1.500	2.000	1.000	1.401	2.099	1.104	13.960	9.853	0.796	1.210	1.371	1.452	N/A	13.509
	mm	38.1	50.8	25.4	35.6	53.3	28.0								
50042	in	2.500	3.500	1.000	2.334	3.666	1.144	23.930	28.678	1.590	2.420	2.742	2.903	3.065	78.637
	mm	63.5	88.9	25.4	59.3	93.1	29.0								
50120	in	2.000	3.250	1.000	1.869	3.381	1.127	20.940	18.086	1.990	3.024	3.428	3.629	3.831	61.999
	mm	50.8	82.6	25.4	47.5	85.9	28.6								

Notes:

1. Dimensions for boxed cores refer to 50000-series (Nylon-boxed) parts. Epoxy Encapsulated dimensional tolerances follow in Table 8. Please consult Magnetics' Applications Engineering Department for dimensions of other case types.
2. W_aA_c figure refers to "Area Product", a figure of merit for the power-handling capability of cores. This is the product of the core's effective area and its winding area. The values in this table are calculated using the effective area of cores manufactured from .002" thick material.
3. Please consult Magnetics Sales or Applications Engineering Department for core sizes not listed above.
4. Core weight can be calculated (in pounds) using:

Weight = l_e x A_c x K, where

K = 0.0192 for Permalloy (80% Nickel) materials
0.0181 for Supermendur, Orthonol, and 48 Alloy
0.0169 for Magnesil
0.0161 for Amorphous-C
0.0167 for Amorphous-E

Table 8. Dimensional Guarantees for Encapsulated Cores

	HEIGHT	ID	OD
***OD ≤ 0.650"**	+0.050"	-0.065"	+0.065"
0.650" < OD < 1.500"	+0.070"	-0.100"	+0.100"
1.500" < OD	+0.100"	-0.125"	+0.125"

Final core dimensions are obtained by adding the noted tolerance to OD and Height dimensions and subtracting it from the ID dimension. For instance, a bare core with ID = 0.750", OD = 1.250", and Ht = 0.250" would have encapsulated dimensional limits of ID = 0.650" minimum, OD = 1.350" maximum, and Height = 0.320" maximum.

Limits for small (OD<0.650") have been specified to accommodate permanent winding bushings to maintain roundness and concentricity. Note that some 0.002" and 0.004" thick cores can be coated without the need for a winding bushing, and therefore may have tighter dimensional tolerances. Consult Magnetics Applications Engineering if the above dimensional adders are prohibitive.

Table 9. Miniature Tape Wound Core Sizes

Core Part Number		Case Dimensions			Mean Length (cm)	Window Area cm²	Permalloy 80 Flux Capacity (Maxwells)				Orthonol Flux Capacity (Maxwells)		
		I.D. Min	O.D. Max	HT. Max			1/8	1/4	1/2	1 mil	1/4	1/2	1 mil
80512-(*)MA	in.	.097	.225	.120	1.20	.0506	30	50	80	100	100	160	200
	mm.	2.41	5.72	2.67			(.002)	(.0033)	(.0053)	(.0066)	(.0033)	(.0053)	(.0066)
80550-(*)MA	in.	.128	.255	.120	1.45	.0860	30	50	80	100	100	160	200
	mm.	3.18	6.48	2.67			(.002)	(.0033)	(.0053)	(.0066)	(.0033)	(.0053)	(.0066)
80505-(*)MA	in.	.160	.290	.120	1.70	.137	30	50	80	100	100	160	200
	mm.	4.06	7.37	2.67			(.002)	(.0033)	(.0053)	(.0066)	(.0033)	(.0053)	(.0066)
80512-(*)MA	in.	.222	.350	.120	2.20	.255	30	50	80	100	100	160	200
	mm.	5.59	8.89	2.67			(.002)	(.0033)	(.0053)	(.0066)	(.0033)	(.0053)	(.0066)
80529-(*)MA	in.	.097	.225	.185	1.20	.0506	60	100	160	200	200	320	400
	mm.	2.41	5.72	4.45			(.004)	(.0066)	(.0105)	(.0132)	(.0066)	(.0105)	(.0132)
80544-(*)MA	in.	.125	.255	.185	1.45	.0860	60	100	160	200	200	320	400
	mm.	3.18	6.48	4.45			(.004)	(.0066)	(.0105)	(.0132)	(.0066)	(.0105)	(.0132)
80523-(*)MA	in.	.160	.290	.185	1.70	.137	60	100	160	200	200	320	400
	mm.	4.06	7.37	4.45			(.004)	(.0066)	(.0105)	(.0132)	(.0066)	(.0105)	(.0132)
80530-(*)MA	in.	.222	.350	.185	2.20	.255	60	100	160	200	200	320	400
	mm.	5.59	8.89	4.45			(.004)	(.0066)	(.0105)	(.0132)	(.0066)	(.0105)	(.0132)
80524-(*)MA	in.	.285	.415	.185	2.70	.425	60	100	160	200	200	320	400
	mm.	7.24	10.54	4.45			(.004)	(.0066)	(.0105)	(.0132)	(.0066)	(.0105)	(.0132)
80531-(*)MA	in.	.345	.480	.185	3.20	.620	60	100	160	200	200	320	400
	mm.	8.76	12.19	4.45			(.004)	(.0066)	(.0105)	(.0132)	(.0066)	(.0105)	(.0132)
80608-(*)MA	in.	.405	.540	.185	3.70	.850	60	100	160	200	200	320	400
	mm.	10.29	13.72	4.45			(.004)	(.0066)	(.0105)	(.0132)	(.0066)	(.0105)	(.0132)
80609-(*)MA	in.	.470	.605	.185	4.20	1.14	60	100	160	200	200	320	400
	mm.	11.94	15.37	4.45			(.004)	(.0066)	(.0105)	(.0132)	(.0066)	(.0105)	(.0132)
80558-(*)MA	in.	.222	.385	.185	2.30	.255	90	150	240	300	300	480	600
	mm.	5.59	9.78	4.45			(.006)	(.010)	(.016)	(.0198)	(.010)	(.016)	(.0198)
80581-(*)MA	in.	.285	.445	.185	2.80	.425	90	150	240	300	300	480	600
	mm.	7.24	11.30	4.45			(.006)	(.010)	(.016)	(.0198)	(.010)	(.016)	(.0198)
80610-(*)MA	in.	.345	.505	.185	3.39	.620	90	150	240	300	300	480	600
	mm.	8.76	12.83	4.45			(.006)	(.010)	(.016)	(.0198)	(.010)	(.016)	(.0198)
80611-(*)MA	in.	.220	.415	.185	2.40	.255	120	200	320	400	400	640	800
	mm.	5.59	10.54	4.45			(.008)	(.0133)	(.021)	(.0264)	(.0133)	(.021)	(.0264)
80598-(*)MA	in.	.285	.480	.185	2.90	.425	120	200	320	400	400	640	800
	mm.	7.24	12.19	4.45			(.008)	(.0133)	(.021)	(.0264)	(.0133)	(.021)	(.0264)
80516-(*)MA	in.	.345	.540	.185	3.40	.620	120	200	320	400	400	640	800
	mm.	8.76	13.72	4.45			(.008)	(.0133)	(.021)	(.0264)	(.0133)	(.021)	(.0264)
80612-(*)MA	in.	.405	.605	.185	3.90	.850	120	200	320	400	400	640	800
	mm.	10.29	15.37	4.45			(.008)	(.0133)	(.021)	(.0264)	(.0133)	(.021)	(.0264)
80588-(*)MA	in.	.470	.665	.185	4.40	1.14	120	200	320	400	400	640	800
	mm.	11.94	16.89	4.45			(.008)	(.0133)	(.021)	(.0264)	(.0133)	(.021)	(.0264)
80613-(*)MA	in.	.285	.510	.185	3.00	.425	150	250	400	500	500	800	1000
	mm.	7.24	12.95	4.45			(.010)	(.0165)	(.0265)	(.033)	(.0165)	(.0265)	(.033)
80606-(*)MA	in.	.345	.570	.185	3.50	.620	150	250	400	500	500	800	1000
	mm.	8.76	14.48	4.45			(.010)	(.0165)	(.0265)	(.033)	(.0165)	(.0265)	(.033)
80614-(*)MA	in.	.405	.630	.185	4.00	.850	150	250	400	500	500	800	1000
	mm.	10.29	16.00	4.45			(.010)	(.0165)	(.0265)	(.033)	(.0165)	(.0265)	(.033)
80615-(*)MA	in.	.470	.695	.185	4.50	1.14	150	250	400	500	500	800	1000
	mm.	11.94	17.65	4.45			(.010)	(.0165)	(.0265)	(.033)	(.0165)	(.0265)	(.033)

Core Part Number		Case Dimensions			Mean Length (cm)	Window Area cm²	Permalloy 80 Flux Capacity (Maxwells)				Orthonol Flux Capacity (Maxwells)		
		I.D. Min	O.D. Max	HT. Max			1/8	1/4	1/2	1 mil	1/4	1/2	1 mil
80560-(*)MA	in.	.217	.385	.320	2.30	.245	180	300	480	600	600	960	1200
	mm.	5.46	9.78	7.87			(.012)	(.020)	(.032)	(.0395)	(.020)	(.032)	(.0395)
80539-(*)MA	in.	.280	.445	.320	2.80	.410	180	300	480	600	600	960	1200
	mm.	7.11	11.30	7.87			(.012)	(.020)	(.032)	(.0395)	(.020)	(.032)	(.0395)
80517-(*)MA	in.	.342	.510	.320	3.30	.602	180	300	480	600	600	960	1200
	mm.	8.64	12.95	7.87			(.012)	(.020)	(.032)	(.0395)	(.020)	(.032)	(.0395)
80616-(*)MA	in.	.400	.570	.320	3.80	.830	180	300	480	600	600	960	1200
	mm.	10.16	14.48	7.87			(.012)	(.020)	(.032)	(.0395)	(.020)	(.032)	(.0395)
80617-(*)MA	in.	.465	.630	.320	4.30	1.12	180	300	480	600	600	960	1200
	mm.	11.81	16.00	7.87			(.012)	(.020)	(.032)	(.0395)	(.020)	(.032)	(.0395)
80600-(*)MA	in.	.280	.480	.320	2.90	.410	240	400	640	800	800	1280	1600
	mm.	7.11	12.19	7.87			(.016)	(.0265)	(.042)	(.053)	(.0265)	(.042)	(.053)
80618-(*)MA	in.	.340	.540	.320	3.40	.602	240	400	640	800	800	1280	1600
	mm.	8.64	13.72	7.87			(.016)	(.0265)	(.042)	(.053)	(.0265)	(.042)	(.053)
80619-(*)MA	in.	.400	.605	.320	3.90	.830	240	400	640	800	800	1280	1600
	mm.	10.16	15.37	7.87			(.016)	(.0265)	(.042)	(.053)	(.0265)	(.042)	(.053)
80525-(*)MA	in.	.465	.665	.320	4.40	1.12	240	400	640	800	800	1280	1600
	mm.	11.81	16.89	7.87			(.016)	(.0265)	(.042)	(.053)	(.0265)	(.042)	(.053)

** Add material type and thickness code when ordering (see page 15)   ( ) Effective cross sectional area shown in cm²*

Magnetics Ring Cores

As referenced under How to Order (page 15), Magnetics maintains a series of ring lamination cores featuring high permeability Permalloy material punched into rings (from .014" thick material) that are stacked within a glass filled nylon core box. Because the core material is stamped rather than wound, consistency can be obtained with respect to uniform cross-sectional area around the core's path length and very high low frequency permeability. While these cores routinely find use in high precision current-sensing schemes (such as Ground Fault Circuit Interrupts, or GFCI's), they are useful in any of a variety of applications requiring the highest possible permeability and consistency at relatively low to moderate frequency ranges.

The following table details sizes currently available.

Table 10. Magnetics Ring Core Sizes

Part Number	No. of Rings	Core Dimension			Case Dimensions			Path Length (cm)	Core Area (cm^2)
		ID	OD	Ht	ID min	OD max	Ht max		
56822-7D	4	0.348 in	0.480 in	0.056 in	0.291 in	0.539 in	0.118 in	3.304	0.024
		8.8 mm	12.2 mm	1.4 mm	7.4 mm	13.7 mm	3.0 mm		
56037-7D	7	0.305 in	0.405 in	0.098 in	0.255 in	0.462 in	0.165 in	2.833	0.032
		7.7 mm	10.3 mm	2.5 mm	6.5 mm	11.7 mm	4.2 mm		
56054-7D	6	0.438 in	0.562 in	0.084 in	0.369 in	0.632 in	0.153 in	3.990	0.034
		11.1 mm	14.3 mm	2.1 mm	9.4 mm	16.1 mm	3.9 mm		
56154-7D	9	0.438 in	0.562 in	0.126 in	0.369 in	0.632 in	0.199 in	3.990	0.050
		11.1 mm	14.3 mm	3.2 mm	9.4 mm	16.1 mm	5.1 mm		
56153-7D	9	0.375 in	0.500 in	0.126 in	0.313 in	0.569 in	0.199 in	3.491	0.051
		9.5 mm	12.7 mm	3.2 mm	8.0 mm	14.5 mm	5.1 mm		
56000-7D	9	0.500 in	0.750 in	0.126 in	0.431 in	0.819 in	0.199 in	4.987	0.102
		12.7 mm	19.0 mm	3.2 mm	10.9 mm	20.8 mm	5.1 mm		
56106-7D	14	0.750 in	1.125 in	0.196 in	0.671 in	1.204 in	0.272 in	7.481	0.237
		19.0 mm	28.6 mm	5.0 mm	17.0 mm	30.6 mm	6.9 mm		
56392-7D	14	1.125 in	1.500 in	0.196 in	1.036 in	1.599 in	0.292 in	10.47	0.237
		28.6 mm	38.1 mm	5.0 mm	26.3 mm	40.6 mm	7.4 mm		
56055-7D	36	1.625 in	2.000 in	0.504 in	1.401 in	2.099 in	0.604 in	14.46	0.610
		41.3 mm	50.8 mm	12.8mm	35.6 mm	53.3 mm	15.3 mm		

Wire Table

AWG Wire Size	Resistance W / meter (x.305, W/ft)	Wire OD(cm) Hvy Bld	Wire Area Circ. Mils	Wire Area sq.cm. (x0.001)	Current Capacity, Amps (by columns of amps / sq.cm.) 200	400	600	800
8	.00207	.334	18,000	91.2	16.5	33.0	49.5	66.0
9	.00259	.298	14,350	72.7	13.1	26.2	39.3	52.4
10	.00328	.267	11,500	58.2	10.4	20.8	31.2	41.6
11	.00413	.238	9,160	46.4	8.23	16.4	24.6	32.8
12	.00522	.213	7,310	37.0	6.53	13.1	19.6	26.1
13	.00656	.1902	5,850	29.6	5.18	10.4	15.5	20.8
14	.00827	.1714	4,680	23.7	4.11	8.22	12.3	16.4
15	.01043	.1529	3,760	19.1	3.26	6.52	9.78	13.0
16	.01319	.1369	3,000	15.2	2.58	5.16	7.74	10.3
17	.01657	.1224	2,420	12.2	2.05	4.10	6.15	8.20
18	.0210	.1095	1,940	9.83	1.62	3.25	4.88	6.50
19	.0264	.0980	1,560	7.91	1.29	2.58	3.87	5.16
20	.0332	.0879	1,250	6.34	1.02	2.05	3.08	4.10
21	.0420	.0785	1,000	5.07	.812	1.63	2.44	3.25
22	.0531	.0701	810	4.11	.640	1.28	1.92	2.56
23	.0666	.0632	650	3.29	.511	1.02	1.53	2.04
24	.0843	.0566	525	2.66	.404	.808	1.21	1.62
25	.1063	.0505	425	2.15	.320	.61	.962	1.28
26	.1345	.0452	340	1.72	.253	.506	.759	1.01
27	.1686	.0409	270	1.37	.202	.403	.604	.806
28	.0653	.0366	220	1.11	.159	.318	.477	.636
29	.266	.0330	180	.912	.128	.255	.382	.510
30	.341	.0295	144	.730	.100	.200	.300	.400
31	.430	.0267	117	.593	.0792	.158	.237	.316
32	.531	.0241	96.0	.487	.0640	.128	.192	.256
33	.676	.0216	77.4	.392	.0504	.101	.152	.202
34	.856	.01905	60.8	.308	.0397	.0794	.119	.159
35	1.086	.01702	49.0	.248	.0314	.0627	.0940	.125
36	1.362	.01524	39.7	.201	.0250	.0500	.0750	.100
37	1.680	.01397	32.5	.165	.0203	.0405	.0608	.0810
38	2.13	.01245	26.0	.132	.0160	.0320	.0480	.0640
39	2.78	.01092	20.2	.102	.0123	.0245	.0368	.0490
40	3.51	.00965	16.0	.081	.00961	.0192	.0288	.0384
41	4.33	.00864	13.0	.066	.00785	.0157	.0236	.0314
42	5.45	.00762	10.2	.052	.00625	.0125	.0188	.0250
43	7.02	.00686	8.40	.043	.00484	.00968	.0145	.0194
44	8.50	.00635	7.30	.037	.00400	.00800	.0120	.0160
45	10.99	.00546	5.30	.027	.00309	.00618	.00927	.0124
46	13.81	.00498	4.40	.022	.00248	.00496	.00744	.00992
47	17.36	.00452	3.60	.018	.00194	.00388	.00582	.00776
48	22.1	.00394	2.90	.015	.00175	.00350	.00525	.00700
49	27.6	.00353	2.25	.011	.00150	.00300	.00450	.00600
50	34.7	.00325	1.96	.010	.00098	.00195	.00292	.00390

MPP, High Flux, and Kool Mμ® Powder Cores

Powder cores are excellent as low loss inductors for switched-mode power supplies, switching regulators, and noise filters. Most core types can be shipped immediately from stock.

Molypermalloy powder cores (MPP) are available in ten permeabilities ranging from 14 through 550, and have guaranteed inductance limits of ±8%. Insulation on the cores is a high dielectric strength finish not affected by normal potting compounds and waxes. Thirty sizes include ID's from 0.070" (1.78mm) to 1.938" (49.2mm) and OD's from 0.140" (3.56mm) to 3.063" (77.8mm). Standard cores include either temperature stabilized (as wide as -65°C +125°C for stable operation) or standard stabilization.

High Flux powder cores have a much higher energy storage capacity than MPP cores and are available in six permeabilities from 14 through 160. High Flux cores are available in sizes identical to MPP cores.

Kool Mμ powder cores have a higher energy storage capacity than MPP cores and are available in five permeabilities from 26 through 125. Kool Mμ toroids are available in sizes identical to MPP cores, and this material is also available in a number of E-Core sizes. Permeability for Kool Mμ E-Cores is from 26 to 90, and sizes are tooled ranging from the EF12.6 to the Metric E80 size.

MPPTHINZ® are extremely low height (<lmm) self shielded power inductor cores, allowing finished inductor heights in the 1.5mm to 2mm range. THINZ come in 5 sizes with ODs ranging from 0.120" trough 0.310" and four permeabilities, 125μ, 160μ, 200μ, and 250μ.

FOR FURTHER INFORMATION VIEW POWDER CORES DESIGN MANUAL AT www.mag-inc.com.

APPLICATIONS:

- Inductors for high Q
- Low loss filter circuits
- Loading Coils
- Transformers
- Chokes and Inductors

Ferrite Cores

Ferrite Cores are manufactured for a wide variety of applications. Magnetics has developed and produces the leading MnZn ferrite materials for power transformers, power inductors, wideband transformers, common mode chokes, and many other applications. In addition to offering the leading materials, other advantages of ferrites from Magnetics include: the full range of standard planar E and I cores; rapid prototyping capability for new development; the widest range of toroid sizes in power and high permeability materials; standard gapping to precise inductance or mechanical dimension; wide range of coil former and assembly hardware available; and superior toroid coatings available in several options.

POWER:
Four low loss materials are engineered for optimum frequency and temperature performance in power applications. Magnetic' materials provide superior saturation, high temperature performance, low losses, product consistency.

SHAPES: E cores, Planar E cores, ETD, EC, U cores, I cores, PQ, Planar PQ, RM, Toroids (2mm to 86mm), Pot cores, RS (round-slab), DS (double slab), EP, Special Shapes.

APPLICATIONS: Telecomm Power Supplies, Computer Power Supplies, Commercial Power Supplies, Consumer Power Supplies, Automotive, DC-DC Converters, Telecomm Data Interfaces, Impedance Matching Transformers, Handheld Devices, High power control (gate drive), Computer Servers, Distributed Power (DC-DC), EMI Filters, Aerospace, Medical.

HIGH PERMEABILITY:
Three high permeability materials (5000µ, 10000µ and 15000µ) are engineered for optimum frequency and impedance performance in signal, choke and filter applications. Magnetics' materials provide superior loss factor, frequency response, temperature performance, and product consistency.

SHAPES: Toroids (2 mm to 86 mm), E cores, U cores, RM, Pot cores, RS (round-slab), DS (double slab), EP, Special Shapes.

APPLICATIONS: Common Mode Chokes, EMI Filters, Other Filters, Current Sensors, Telecomm Data Interfaces, Impedance matching interfaces, Handheld devices, Spike Suppression, Gate Drive Transformers

LOW LEVEL / SPECIAL MATERIALS:
A number of special materials are engineered for specific performance results, including frequency response, temperature factor, Curie temperature, permeability across temperature for GFCI and telecomm performance, and loss factor. Magnetics' materials provide outstanding performance, customization options, and superior product consistency.

SHAPES: E cores, Planar E cores, ETD, EC, U cores, I cores, PQ, Planar PQ, RM, Toroids (2mm to 86mm), Pot cores, RS (round-slab), DS (double slab), EP, Special Shapes.

APPLICATIONS: EMI Filters, Current sensors, Chokes, Tuned Filters, Data interfaces, Special temperature requirements, Other Special Requirements.

FOR FURTHER INFORMATION WRITE FOR CATALOG FC-601.

SHAPES:

- Pot cores
- Toroids
- E, I, U Cores
- Planar
- EP, PQ, EFD
- Other Shapes

APPLICATIONS:

- Transformers
- Inductors
- Filters
- Common-mode chokes
- Data communications interfaces
- Delay Lines, etc.

Cut Cores

SUPERMENDUR C-cores and E-cores are used in power transformers at frequencies up to 1500 Hz where minimum weight and size are required.

PERMALLOY 80 C-cores are ideal for the output transformer of high frequency, high power inverters. The low core loss of these cores makes them suitable up to 5000 gauss, at frequencies up to 25 kHz. Other uses: high power pulse transformers, high frequency inductors, and low loss current transformers.

ORTHONOL® C-cores have a saturation flux density of 15,000 gauss, and a core loss approximately one-half that of a silicon-iron C-core of the same material thickness. These cores are suitable for power transformers operating at flux densities to 10,000 gauss, and frequencies to 8 kHz.

AMORPHOUS-C C-Cores have superior high—frequency losses and a relatively high saturation flux density value of at least 14,500 gauss. This material may to used to produce cores for high efficiency power transformers as well as gapped energy storage inductors.

FOR FURTHER INFORMATION VISIT www.mag-inc.com.

Custom Components

MAGNETICS offers unique capabilities in the design and manufacture of specialized components fabricated from magnetic materials in many sizes and shapes. Standard catalog items can be modified, as needed, to fit your requirements. Or wholly new parts can be made from blocks of magnetic material.

Prototype cores can be produced for a variety of purposes, including special space or form factor constraints, non-standard electrical requirements, special fixturing considerations, and planar ferrite development.

For customer components, contact MAGNETICS' Applications Engineering, and let MAGNETICS help meet your special requirements.

Rapid Prototyping Service

MAGNETICS' world-class materials offer unique and powerful advantages to almost any application. An even greater competitive edge can be gained through innovations in new core shapes and custom geometries, and MAGNETICS is poised to help. Our Rapid Prototyping Service can quickly make a wide variety of core shapes in ferrite, MPP, High Flux, or Kool Mu®. The time between receipt of your drawing and delivery of the parts to you is usually less than 10 days. This quick turnaround time results in a shorter design period, which gets your product to market faster. Plus, our application engineers may be able to provide design assistance that could lead to a lower piece price. To learn more about how our Rapid Prototyping Service can help you shorten your design cycle, contact a MAGNETICS Application Engineer.