MAGNETICS

®

Division of Spang & Company

Magnetic Cores
For Switching
Power Supplies
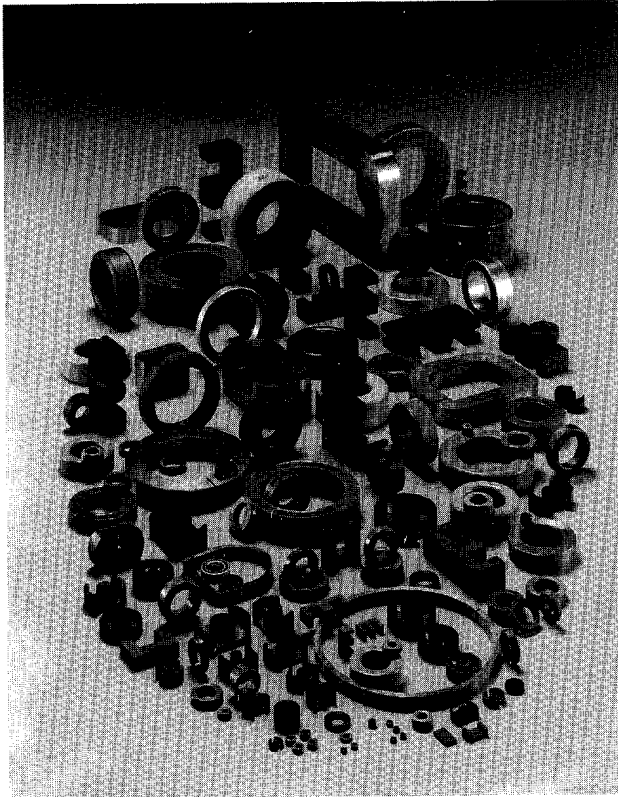
INTRODUCTION

Figure 1: A Multitude of Magnetic Cores.

The advantages of switching power supplies (SPS) are well documented. Various circuits used in these units have also been sufficiently noted in literature. Magnetic cores play an important role in SPS circuitry. They are made from a variety of raw materials, a range of manufacturing processes, and are available in a variety of geometries and sizes as shown in Figure 1.

Each material has its own unique properties. Therefore, the requirements for each application of a core in the power supply must be examined in light of the properties of available magnetic materials so that a proper core choice can be made.

This article describes the various magnetic materials used for cores in switching power supplies, their method of manufacture, and useful magnetic characteristics as related to major sections of the power supply.

Cores can be classified into three basic types: (1) tape wound cores, (2) powder cores, and (3) ferrites.

Additional core details on material descriptions and characteristics, plus sizes and specific design information, are available in the following MAGNETICS sources:

Ferrite Cores .... Catalog FC-601
Molypermalloy and High Flux Powder Cores .... Catalog MPP-400
KOOL MU Powder Cores ....……...... Catalog KMC-2.0
High Flux Powder Cores .... Catalog HF-PC-01
Tape Wound Cores .... Catalog TWC-500
Cut Cores ....….......... Catalog MCC- 100
Inductor Design Software for Powder Cores
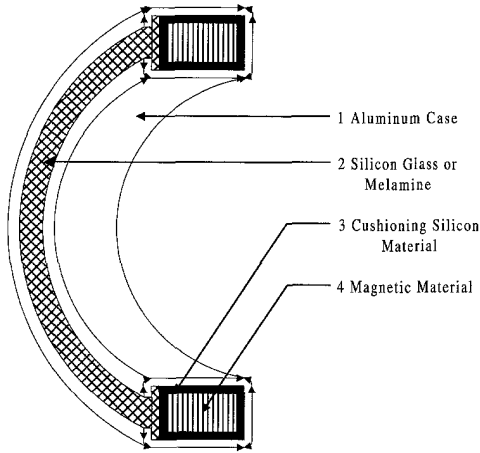Common Mode Inductor Design Software

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TAPE WOUND CORES

Figure 2: Cut-Away View of TWC.

Figure 2 shows a cutaway view of a typical tape wound core. The core is manufactured from a narrow strip of magnetic alloy, the thickness of which may vary from l/2 mil to 14 mils. The width ranges from l/8" to several inches. The metal strip is first slit to the desired width, covered with a thin coating of insulating material, and then wound on a mandrel, one wrap on top of the other, until a predetermined thickness has been reached. The last wrap is tack welded to the previous wrap to keep it from unwinding.

The core material is stressed during the winding operation and, therefore, loses some of its magnetic qualities. In order to restore these lost characteristics, the cores must be annealed in a hydrogen atmosphere furnace where the temperature is close to 1000°C.

Table 1: Magnetic Characteristics of Tape Wound Core Materials

Magnetic Material	Saturation Flux Density Kilogauss (B_m)	Curie Temperature °C (T_C)	Upper Frequency Limit*	
			Tape Thickness (in.)	Frequency
MAGNESIL ® (3% **SiFe**)	16.5	750	0.012 0.006 0.004 0.002	100 Hz 250 Hz 1 kHz 2 kHz
SUPERMENDUR	21	940	0.004 0.002	750 Hz 1.5 kHz
ORTHONOL ® (50% **Ni**)	15	500	0.004 0.002 0.001	1.5 kHz 4 kHz 8kHZ
PERMALLOY (80% **Ni**)	7.4	460	0.004 0.002 0.001 0.0005	4 kHz 10 kHz 20 kHz 40 kHz
AMORPHOUS 2605SC (iron-base)	15.5	370	0.001	20 kHz
AMORPHOUS 2605-S3 (iron-base)	14	370	0.001	100 kHz
AMORPHOUS 2714A (cobalt-base)	5.75	205	0.001	300 kHz

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

The exact temperature and cooling cycle vary for different materials and are quite critical in achieving the maximum magnetic characteristics.

The cores are then placed in protective containers with a small amount of silicon compound which cushions the core from shock or vibration that could easily degrade the core's magnetic characteristics. After testing, the cores are ready for shipping.

Common alloys used for tape wound cores are Magnesil®, Supermendur, Orthonol®, Permalloy and Metglas®. Table 1 shows comparative data for these materials. The last two columns in the chart show the various thicknesses of the material available and the recommended highest frequency for each thickness.

Magnesil, a silicon-iron compound, is primarily a low frequency material. It is the best choice for a core at 60 Hz due to the fact that it has the highest flux density of all of the above materials and is lowest in cost.

Supermendur, a 50% cobalt-based alloy, is specially processed to develop high squareness and high flux density. It is recommended for devices requiring extreme miniaturization and/or high-temperatures.

Orthonol, a 50%Ni — 50% Fe compound, has a lower flux density than Magnesil, but it has lower losses and can operate at higher frequencies. This can be seen by comparing the recommended frequencies for the equivalent thicknesses of materials. The maximum frequency for 2 mil Magnesil is 2 kHz while for Orthonol it is 4 kHz. Orthonol is also more expensive than Magnesil.

Permalloy, an 80% Ni — 20% Fe composition, has the lowest flux density of these first three materials. It is the highest frequency material. For example, 2 mil thick Permalloy can be used at 10 kHz.

Amorphous materials are available in 1 mil thickness. Cores are processed in the same manner as other tape cores. **Alloy 2605** is an iron-silicon alloy; made into a cut core form, it results in a higher energy storage capability than Permalloy. (Cut cores are made like tape cores, except they are rectangular in shape, cut into two pieces, with an air gap in between). **Alloy 2714A** is cobalt-based and has high permeability, high squareness, and low core losses. These characteristics make it useful for high frequency applications such as magnetic amplifiers in switching power supplies.

The upper frequency limit for tape wound core materials is determined by the highest frequency at which a core will sustain only a moderate temperature rise when operated as a saturating transformer. If a large temperature rise is permitted, or if the core is to be operated at a flux density less than saturation, the frequency can be higher than that listed in the table.

It should be noted that for all these materials, the Curie temperature is quite high, a characteristic of most magnetic metals. Curie temperature is that temperature at which the material ceases to be magnetic. The Curie temperature of metals is higher than that of ferrites used for power applications.
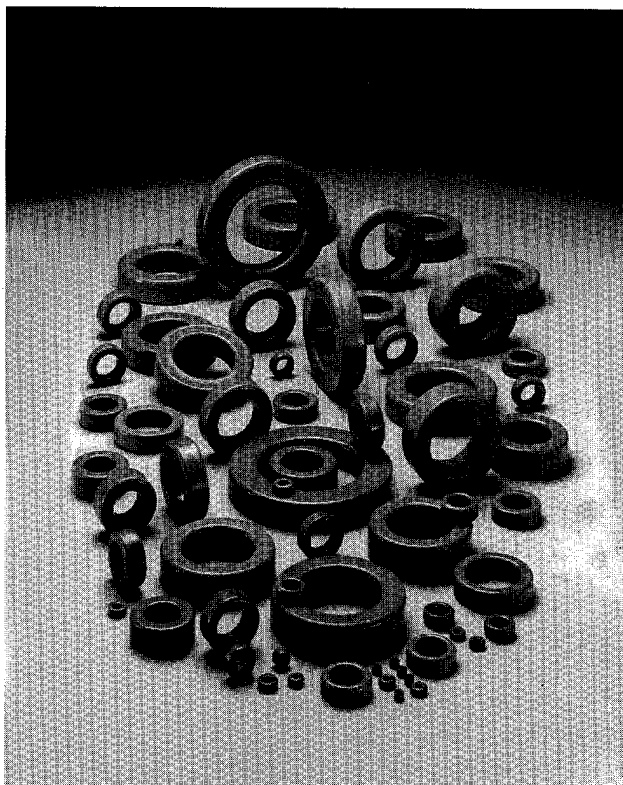
POWDER CORES

Powder cores are made in three varieties: (1) Molypermalloy, (2) High Flux, and (3) KOOL MU®. The manufacturing process is similar for all three types.

Figure 3 pictures some representative sizes of powder cores. An alloy material is first ground to a fine powder. The powder is mixed with an insulating material which separates each particle from the next, thus increasing resistivity. Next, the powder is pressed into toroidal shapes. The cores are annealed, painted, and then 100% tested for inductance.

Powder cores are manufactured with a large radius on both the inside and outside diameters to facilitate winding. The paint also makes winding easier because it has a low coefficient of friction and provides an extra margin of safety by insulating the wire from the core.

Figure 3: Typical Powder Cores.

Molypermalloy Powder (MPP) cores are made from a material similar to the Permalloy described previously for tape wound cores. MPP cores are made in ten different permeabilities ranging from 14 to 550. This is a far cry from the permeability of the virgin material - Permalloy metal - which has permeabilities ranging from 10,000 to 200,000 depending on the test conditions. The reduction in permeability is the result of separating the Permalloy particles with an insulating medium which provides the many air gaps distributed throughout the toroid. It is these air gaps that give the Permalloy powder their ability to withstand a dc field of up to several hundred oersteds before saturating. This is illustrated on page 4 in Figure 4, which is a series of graphs of permeability vs. dc bias. The permeability value is given as a percentage of the inductance with no dc.

MPP cores have extremely low losses and have a large energy storage capacity, making them excellent choices for chokes or power inductors at high frequency.

The inductance and permeability of each lot of cores is made to a nominal value with a ± 8% tolerance. The cores are 100% tested and placed into 2% categories. This enables the designer to arrange for cores other than nominal to be wound with a slightly different number of turns and thereby make inductors with nominal values of ± 2%.

High Flux powder cores are made from material similar to Orthonol(50Ni — 50Fe). They are called such because of a flux density higher than Permalloy. These cores have a higher energy storage capacity, which allows for a higher dc flow before saturating. They also result in a lower volume and weight component. High Flux cores have greater losses than Permalloy powder.
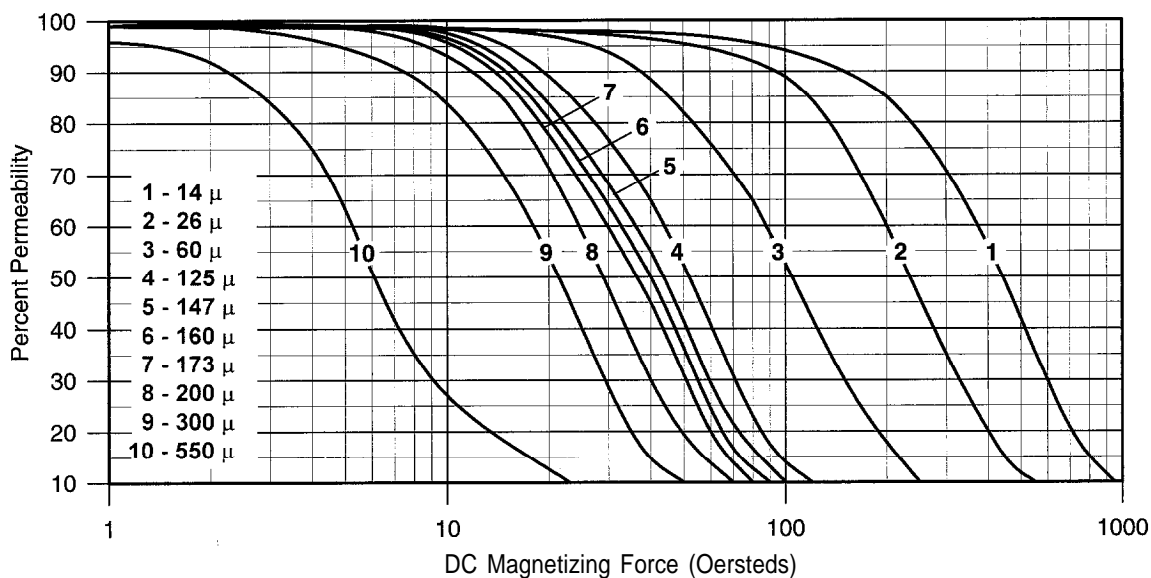
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Figure 4: Curves of Permeability vs. dc Bias for Permalloy Powder Cores.

Kool Mu powder cores are made from a ferrous alloy. The core losses are larger than MPP, but offer an economical advantage while at the same time providing large energy storage. Kool Mu core losses, however, are lower than iron powder cores. Where significant ripple may contribute to heat rise, Kool Mu cores are therefore better than iron powder. In some applications where heat rise can be tolerated, Kool Mu cores will offer a size reduction over iron powder in the same application. They are ideal for in-line noise filters where the inductor must support large ac voltages without core saturation occurring. Line filters can be smaller in size, requiring fewer turns than by using ferrite cores. The high flux density (10,000 gauss) and low core loss makes Kool Mu cores excellent for unidirectional drive applications such as pulse transformers and fly-back transformers. These cores are made in five permeabilities (26 through 125).

All three powder core types are offered in the same physical sizes.
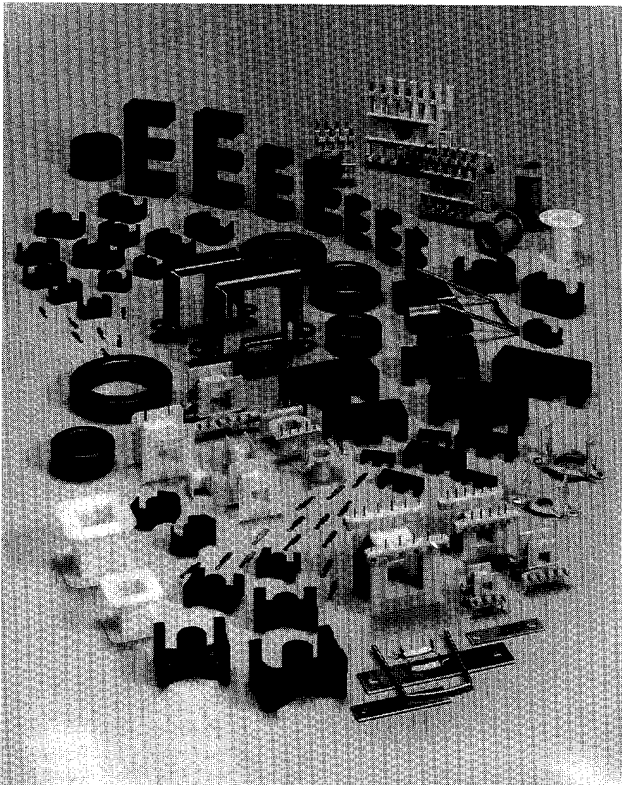
FERRITE CORES

Figure 5: Typical Ferrite Cores and Hardware

Figure 5 shows a large variety of some ferrite core shapes and sizes that are available. Ferrites are manufactured differently from the previously discussed materials. Raw material are oxides of various metals such as iron, manganese, and zinc. Oxides normally act as insulators and, therefore, ferrites have higher resistivity than magnetic alloys, permitting them to function at much higher frequencies, even to the megahertz region.

The raw materials are mixed and fired in a presintering kiln. They are then broken up into uniform particles, and pressed into one of the many shapes desired. The "green" cores are fired in another atmosphere-controlled sintering kiln.

Since sintered cores are a hard ceramic, further processing has to be done with diamond grinding wheels. Mated cores such as pot cores and E, U, and I cores must have their mating surfaces ground to minimize the air gap. Toroids are finished in a tumbler where the sharp edges of the toroids are removed.

Ferrite Materials

The electrical characteristics of ferrites are different from powder cores or metal strip cores. Table 2 lists seven different ferrite core materials and their electrical characteristics. Flux density and initial permeability are lower than in magnetic alloy materials. F, P, R and K materials are mostly used in electronic power transformers. The difference is in the core losses. F material has its lowest core losses at room temperature; P and R material core losses decrease as temperature increases, with the low point for P at about 70° C and a low point for R at about 90° C. K material is designed for low core losses at frequencies above 20 kHz. J, W and H materials are used in e.m.i. filter applications where high permeability is a desirable characteristic.

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Table 2: Various Ferrite Materials and Characteristics

Material Code	Flux Density	Initial Perm	Application	Curie Temp. °C
R	5,000	2,300	Transformers Inductors	> 230
K	4,600	1,500	"	> 230
P	5,000	2,500	"	> 230
F	4,900	3,000	"	> 250
J	4,300	5,000	EMI Filters Broadband xfmrs.	> 140
W	4,300	10,000	"	> 125
H	4,200	15,000	"	> 120

Ferrite Core Shapes

Ferrite cores are made in a variety of shapes and sizes. Each shape has definite advantages that make it the best core to use in certain situations. Table 3 lists popular ferrite shapes available today and their comparative ratings under different considerations. As noted in the chart, selection depends on many factors, and there is no one correct answer for all situations; in most cases, the choice is a compromise.

TABLE 3
FERRITE CORE COMPARATIVE GEOMETRY CONSIDERATIONS

	Pot Core	Double Slab Core	E Core	Ec, ETD Cores	PQ Core	EP Core	Toroid
Core Cost	high	high	low	medium	high	medium	very low
Bobbin Cost	low	low	low	medium	high	high	none
Winding Cost	low	low	low	low	low	low	high
Winding flexibility	good	good	excellent	excellent	good	good	fair
Assembly	simple	simple	simple	medium	simple	simple	none
Mounting Flexibility**	good	good	good	fair	fair	good	poor
Heat Dissipation	poor	good	excellent	good	good	poor	good
Shielding	excellent	good	poor	poor	fair	excellent	good

** Hardware is required for clamping core halves together and mounting assembled core on a circuit board or chassis
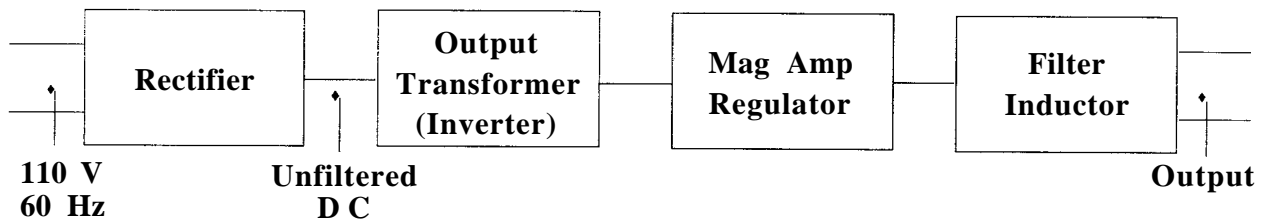
THE SWITCHING POWER SUPPLY

Figure 6: Block Diagram of a Switching Power Supply.

Figure 6 is a block diagram of a typical switching power supply. It shows a 60 Hz line voltage input which is rectified. This dc is converted into a high frequency square wave or high frequency pulses in the inverter section. These are then rectified to provide a dc output at a voltage different than the input because of the turns ratio of the transformer. This switching power supply requires cores for the high frequency transformer, sometimes a core for a driver section, and possibly a core for a current transformer.

Figure 7 shows a schematic of a switching flyback regulator which is a typical companion to the inverter. The input is unregulated dc which is chopped into pulses by a switching transistor.
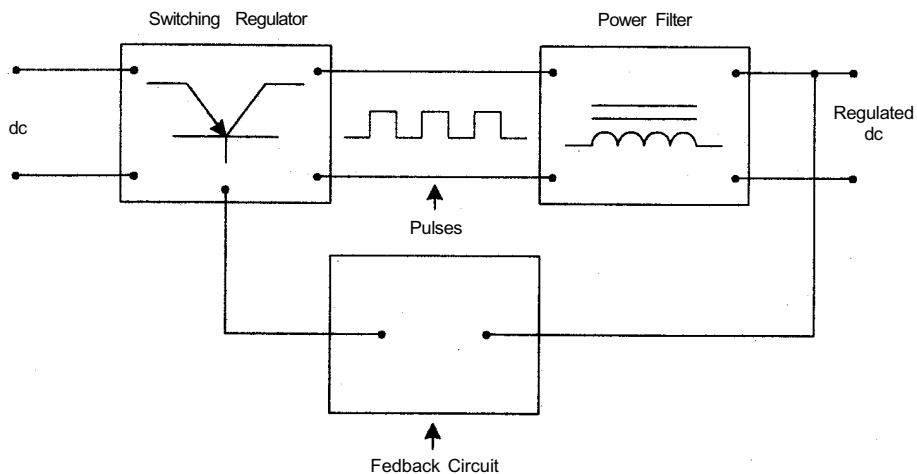

Figure 7: Schematic of a Switching Regulator.

These pulses pass through a power filter stage that generates a dc voltage lower in value than the input. Regulation is achieved with the feedback circuit which causes the transistor to shorten or lengthen the pulses, thus holding the output voltage constant under varying loads.

Figure 8 shows an EMI filter section, another companion to the inverter. It contains cores for both a common mode filter and an in-line filter.
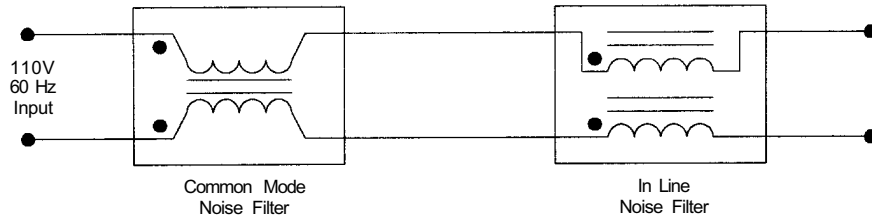
Figure 8: Schematic of an EMI Filter.

These filters are often needed to (1) keep noise generated by the inverter from passing into the power lines and (2) keep noise from coming through the power line to the power supply.

The Power Transformer

The circuit in Figure 6 can be the two-transistor type known as a push-pull or bridge circuit or a single transistor type known as the flyback or forward converter.

Cores used for the transformer in Figure 6 can be made from a variety of shapes, sizes and materials. Core selection and final transformer design are complicated. They depend on the type of circuit, frequency of operation, output power required, ambient temperature, duty cycle and many others.

Transformer core material selection is mainly among ferrites, powder cores, or strip materials. Strip materials are usually used at frequencies between 60 Hz and 20 kHz because they have the highest flux density of available materials, thus resulting in the smallest transformers. Above 20 kHz, ferrites are preferred due to low core losses and availability in a variety of geometric shapes. However, at frequencies around 20 kHz, where both are usable, the application determines the material to be used. Where high reliability is a requirement or wide temperature variations exist, strip cores are preferred. In applications where low cost is a main concern, ferrites are dominant. Powder cores can be used from low frequencies up to 300 kHz; however, they are limited to circuits requiring gapped structures such as flybacks or buck-boost converters.

As inverter frequency increases, core losses dominate the design. The transformer, instead of being designed to utilize the maximum flux density of the core, is designed to keep core losses at a minimum. At 20 kHz, most transformers, whether they use ferrites or tape wound cores, are designed to operate around 2 kG to keep the losses at a reasonable level.

Transformer cores for flyback circuits require an air gap in the core so that they do not saturate from the dc current flowing in their windings. Tape wound and ferrite cores can also be provided with air gaps. Toroidal powder cores are most commonly used because they offer a distributed-type air gap. The frequency of the application will dictate the selection of either tape wound cores or ferrites as described previously, while powder cores will operate at frequencies up to 300 kHz and beyond.

Figure 6 also shows a small inductor in series with the secondary of the main transformer. This core is used as a current transformer for measuring the output of the unit or for detecting differences in the output leads due to transistor unbalances. Ferrite toroids are most often used for these transformers.

At this same location, transformers are often used to control the output currents. Here, ferrite toroids can be used, but more often small tape wound cores are used in a mag-amp circuit.

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The Switching Regulator

The switching regulator, Figure 7, includes a power inductor. Because of the large dc current through its windings, the core must have a large air gap to keep it from saturating. Cores used here are gapped ferrite cores or powder cores.

In the waveform of the current, because there is usually only a small ripple, the ac flux swing in the core is small. Therefore, iron powder cores and silicon laminations may also be used. They are least expensive of the above-mentioned cores but have much higher core losses; thus, care must be taken in design of such units to avoid inductor overheating and possible damage to other components.

Another innovation in power inductor design is the use of swing chokes. In some switching regulator and flyback designs, it is desirable at low output currents to keep the current from going in a negative direction. Therefore, it is useful at low dc to have a higher inductance which can be later reduced at high dc.

The EMI Filter

In Figure 8 (EMI filters), the cores used for the common mode filter are mainly high permeability toroids. Here, the cores are wound either bifilar, using both of the line current wires, or two identical windings on opposing sides of a toroid. In this way the flux created by each line current cancels the flux from the other line so the high line current does not saturate the core. Because of this arrangement, any unwanted noise that attempts to flow out of the power supply through both input leads in the same phase and same direction will be attenuated by the high impedance of the core. Ferrite toroids in permeabilities of 5,000 (J Material), 10,000 (W material), and 15,000 (H material) are popular because of their high permeability or impedance characteristics.

In-line filters are necessary to eliminate noises that are in phase with the line currents. Heavy line currents flowing through the windings of these filters tend to saturate the core. Therefore, the cores must be gapped; preferred types are ferrites and powder cores.

TRANSFORMER DESIGN

Since ferrites are more common in today's market, this presentation concentrates on ferrite cores in various designs and frequencies. Powder core designs are discussed briefly.

Transformer Equations

Transformer core selection is usually done by solving two (2) equations simultaneously:

Equation (1): $E = 4BNfA_C x10^{-8}$

where   E = Primary voltage across N turns (volts)

B = Peak flux density in the core (gauss)

N = Number of turns

f = Frequency (Hz)

A_C = Effective cross sectional area of the core (cm²)
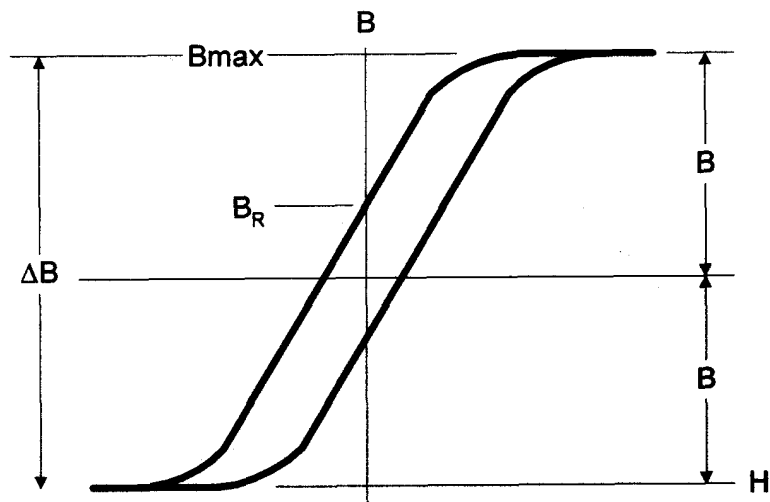
Figure 10: Hysteresis Loop

Note: B in Equation (1) is the usable flux value as indicated in the Hysteresis Loop of Figure 10. Actual ΔB is twice the B value; Equation (1) has this factored in.

Equation (2): $\qquad KW_A = A_W N$

where $\qquad\qquad$ K = Winding Factor

$\qquad\qquad\qquad$ W_A = Core winding area

$\qquad\qquad\qquad$ A_W = Cross section of wire to be used (circular mils)

$\qquad\qquad\qquad$ N = Number of turns

Solving equation (1) and (2) results in

Equation (3) $\qquad$ $W_A A_C = \dfrac{A_W E x 10^8}{4BKf}$

$W_A A_C$ is a factor that indicates power handling capacity in magnetic cores. Equation (3) allows one to select a core size regardless of operating conditions.
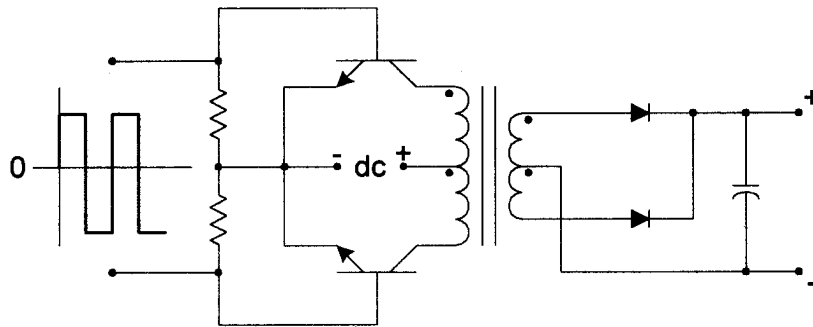
Push-Pull Circuit

Figure 11: Typical Push-Pull SPS Circuit.

A typical push-pull circuit is shown in Figure 11. The input signal is the output of an IC network, or clock, which switches the transistors alternately ON and OFF. High frequency square waves on the transistor output are subsequently rectified producing dc.
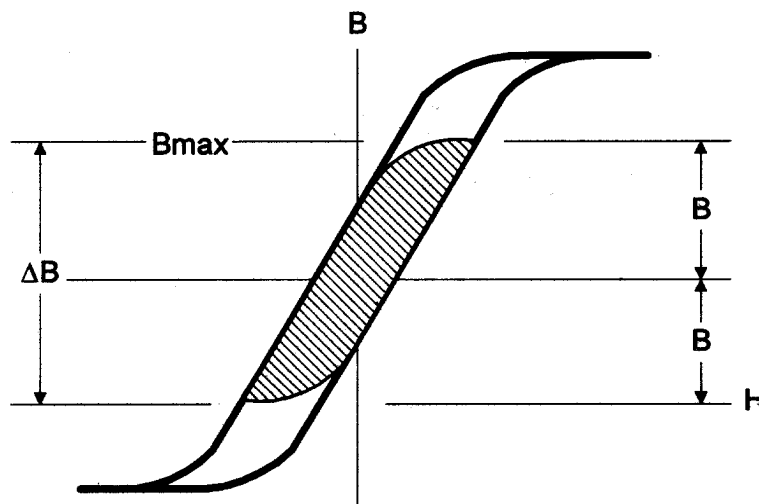

Figure 12: Hysteresis Loop of Magnetic Core in Push-Pull Circuit

For ferrite transformers at 20 kHz, it is common practice to apply equation (3) using flux density (B) levels of 2 kG maximum. This is illustrated by the shaded area of the Hysteresis Loop in Figure 12.

This B level is chosen because the limiting factor in selecting a core at this frequency is core loss. At 20 kHz, if the transformer is designed for a flux density close to saturation (as done for lower frequency designs), the core will develop an excessive temperature rise. Therefore, the lower operating flux density of 2 kG will usually limit the core losses, thus allowing a modest temperature rise in the core.

Above 20 kHz, core losses increase greatly. To design the SPS for higher frequencies, it is necessary to operate the core flux levels lower than 2 kG. Figure 13 shows the reduction in flux levels for **MAGNETICS** power materials necessary to maintain constant core losses at various frequencies in order to limit temperature rise. The figures are based on limiting core loss density to 100 mW/cm³, a figure that would keep the temperature rise at approximately 40°C for **medium sized cores.**
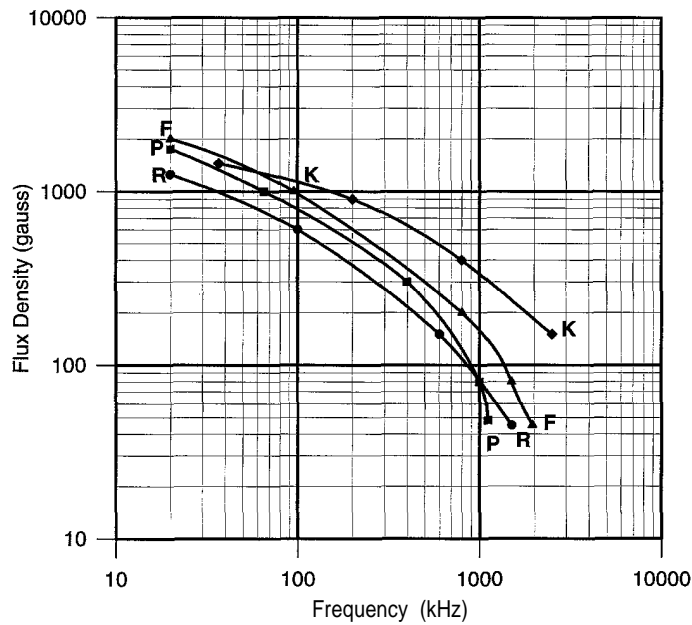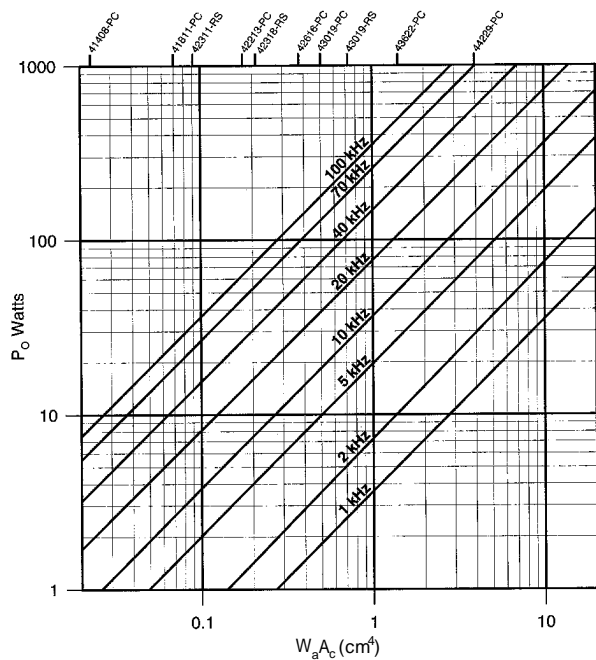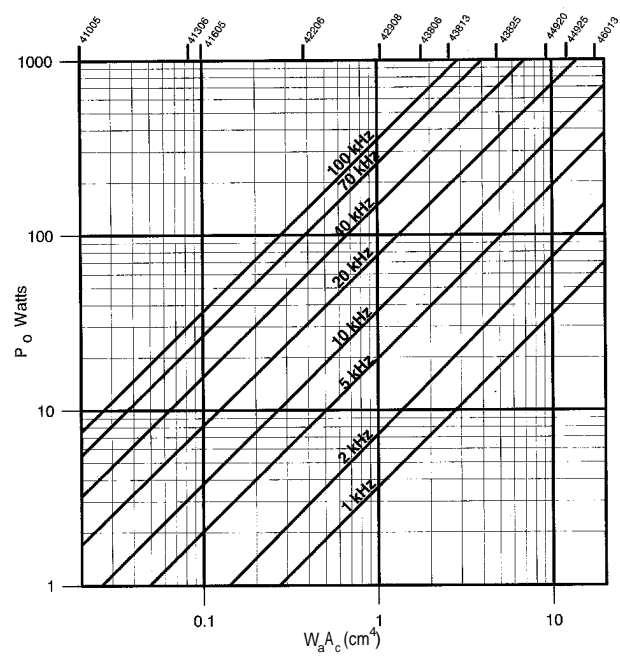

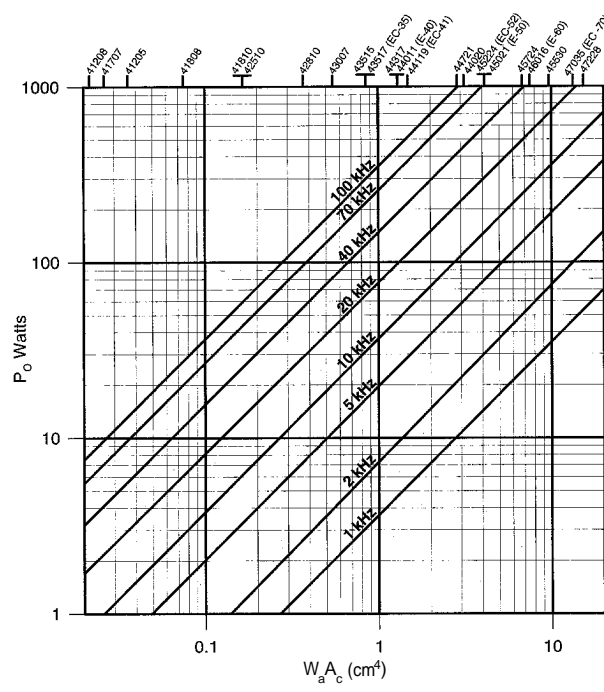**Figure 13:** Flux Density vs. Frequency.

To simplify core selection without using equation (3) and under the limiting conditions noted above, graphs shown in Figure 14 can be used.
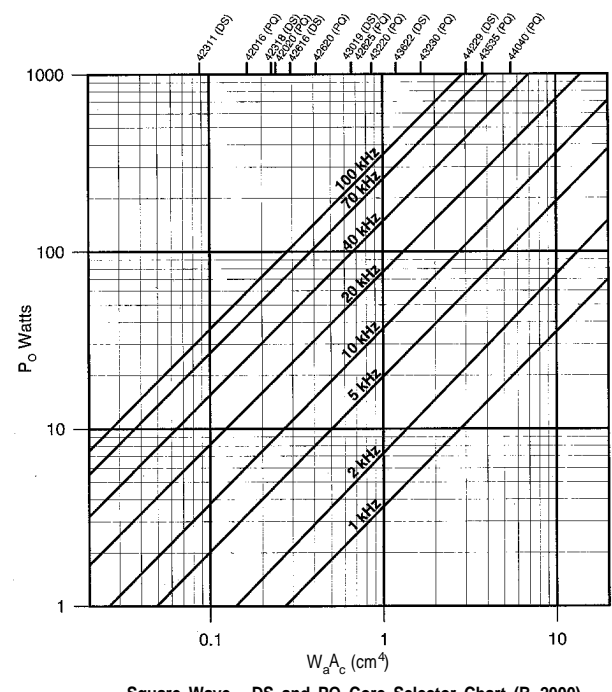

Square Wave - Pot, RS Core Selector Chart (B=2000)

Square Wave - Toroid Core Selector Chart (B=2000)

Square Wave -E and EC Core Selector Chart (B=2000)

Square Wave - DS and PQ Core Selector Chart (B=2000)

Figure 14: P_0 vs. $W_a A_c$

The graphs in Figure 14 show the output power vs. core size at various frequencies. Core selection is made by determining the amount of output power required. Using one of the charts in Figure 14, find the intersection of the output power and the operating frequency line; the vertical projection of this point indicates the core to be used. If the vertical projection of the point is between two cores, choose the larger one. If, for example, a ferrite pot core is needed for a transformer output power of 20 watts at 20 kHz, the above procedure indicates that the correct pot core is between a 423 18-UG and a 42616-UG size. In this example, the larger core (42616-UG) would be the better selection.

Above 20 kHz, this procedure is changed as follows. First note the intersection of the horizontal line representing the desired output power and the frequency of operation. The vertical line through this intersection intersects the horizontal axis which lists the appropriate $W_A A_C$. This factor is based on operating at B=±2kG and must be increased inversely in proportion to the decreased flux density recommended for the operating frequency (see Figure 13). Using the newly selected $W_A A_C$ factor on the graph, the vertical line through this point indicates the core to be used in this design.

In the example above (output of 20 watts), if the core is to operate at 50 kHz, the graph indicates a pot core with a $W_A A_C$ of 0.023×10^6 circular mils cm². Figure 13, however, shows that the flux density at 50 kHz must be reduced to 1300 gauss. Therefore, the ratio

$\dfrac{W_A A_C \text{ at } 20 \text{ kHz}}{W_A A_C \text{ at } 50 \text{ kHz}} = \dfrac{2000}{1300} = 1.54.$ The new $W_A A_C$ at 50 kHz must be $0.023 \times 10^6 \times 1.54$ or 0.035×10^6.

From the graph, the larger $W_A A_C$ value dictates a 42213-UG pot core.
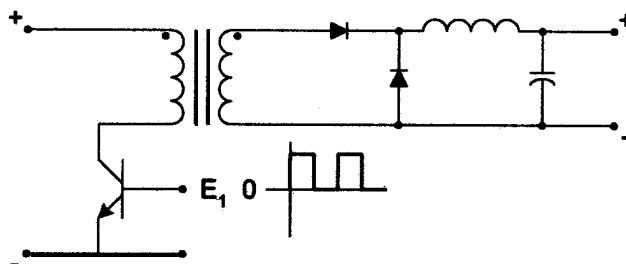
Feed Forward Circuit

Figure 15: Typical Feed Forward SPS Circuit.

In the feed forward circuit shown in Figure 15, the transformer operates in the first quadrant of the Hysteresis Loop. Unipolar pulses applied to the semiconductor device cause the transformer core to be driven from its B_R value toward saturation. When the pulses are reduced to zero, the core returns to its B_R value. In order to maintain a high efficiency, the primary inductance is kept high to reduce magnetizing current and lower wire losses. This means the core should have a zero or minimal air gap.

For ferrites used in this circuit, ΔB (or B max) is typically 2400 gauss or B (as applied to Equation 3) is ± 1200 gauss as shown in Figure 16. In the push-pull circuit, it was recommended that the peak flux density in the core should not exceed B=±2000 gauss in order to keep core losses small. Because of the constraints of the Hysteresis Loop, the core in the feed forward circuit should not exceed a peak value of B=±1200 gauss.
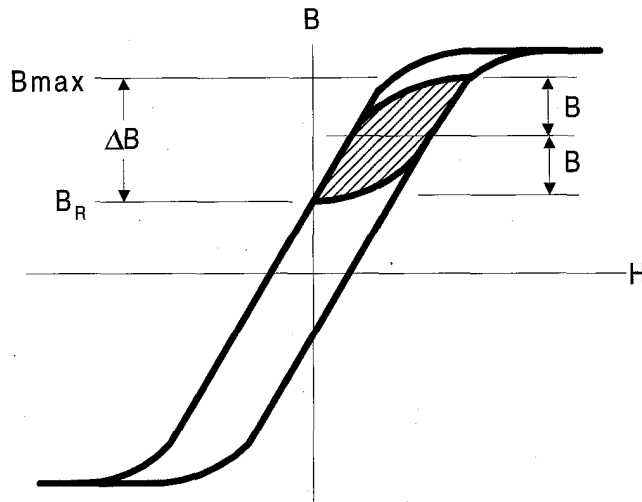
Figure 16: Hysteresis Loop for Magnetic Core in Feed Forward Circuit.

Core selection for a feed forward circuit is similar to the push-pull circuit except that B for Equation 3 is now limited to ± 1200 gauss. If the charts in Figure 14 are used, $W_A A_C$ is selected from the appropriate graph and increased by the ratio of $\frac{2000}{1200} = 1.67$, or by 67%.

If the transformer operating temperature is above 75°C, the value of B will be further reduced. Figure 17 shows the variation of ΔB with temperature. Therefore, the recommended ΔB value of 2400 (B=±1200) gauss has to be reduced, the amount depending on the final projected temperature rise of the device.

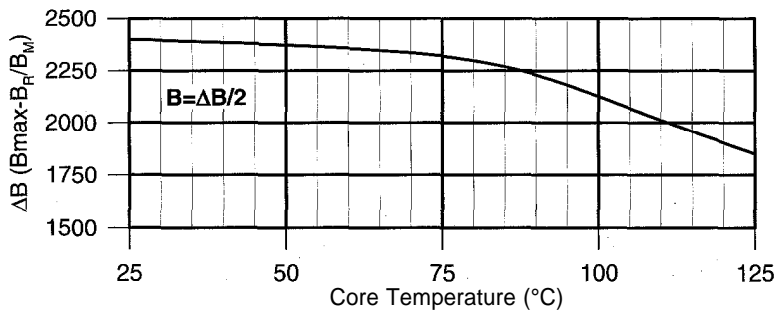**Figure 17:** Recommended ΔB at higher temperatures.

The value of ΔB remains virtually unchanged over a large frequency range above 20 kHz. However, at some frequency, the adjusted value of B, as shown in Figure 13, will become less than the B determined by the above temperature considerations (Figure 17). Above this frequency, the B used to select a core will be the value obtained from Figure 13.
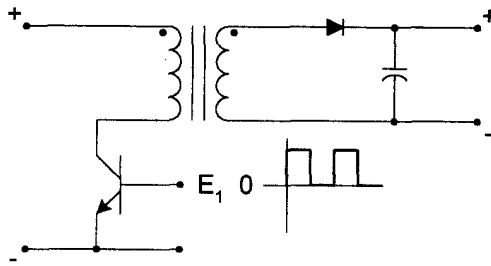
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Fly Back Circuit

Figure 18: Typical Flyback Regulator Circuit.
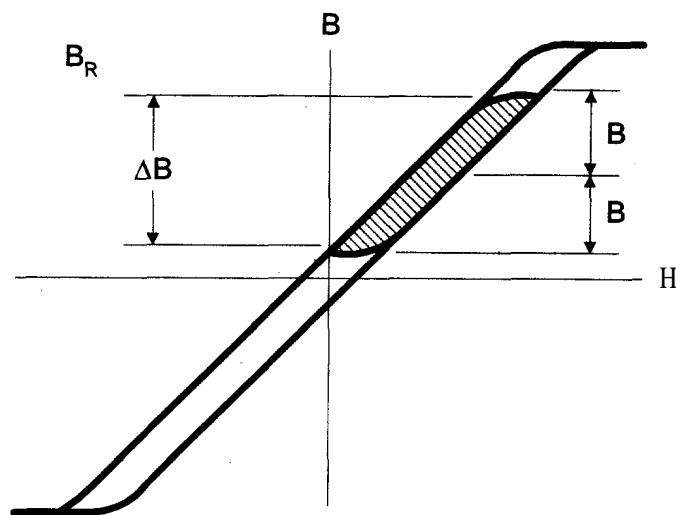

Figure 19: Hysteresis Loop of Magnetic Core in Flyback Circuit.

A typical schematic is shown in Figure 18. Unipolar pulses cause dc to flow through the core winding, moving the flux in the core from B_R towards saturation. When the pulses go to zero, the flux travels back to B_R as in feed forward design. However, the difference between the feed forward and the flyback circuit is that the flyback requires the transformer to act as an energy storage unit. The core must not saturate and is usually a gapped structure.

In most designs, the air gap is large; therefore, B_R is small as noted on the Hysteresis Loop in Figure 22 and can be considered zero. The maximum flux density available is approximately 3600. This means ΔB is 3600 or $B = \pm 1800$ gauss. Core selection for this circuit can also be done using Equation 3 or the charts in Figure 14 as previously described. The B value in Equation 3 is ± 1800 gauss at 20 kHz and is used until a higher frequency (Figure 13) dictates a lower B is required.

Another requirement is that the core must be able to store the energy needed by the secondary winding. Since this could result in a different core size, it is necessary to review both requirements and then select the larger core. Energy storage is determined from:

$$ES = 1/2 \, LI^2 \qquad\qquad \text{Equation (4)}$$

where ES is energy storage (joules)

L is inductance required at maximum current (henries)

I is maximum dc (amperes)

Ferrite core selection with this information can be done from a Hanna curve. Using current and inductance values, a core and air gap can be determined. **MAGNETICS** also provides a series of curves of LI^2 vs. A_L for gapped cores, making the core and air gap selection much easier.

Other ideal cores for the flyback circuit are Molypermalloy Powder (MPP) and Kool Mu cores. Available in toroids, they are pregapped in that a distributed type air gap exists. Ideal for military applications because of their high curie temperature, they are also used in commercial applications. This is especially true where low profile units are required and EMI emissions in the transformer must be minimized.

MPP and Kool Mu core selection for the flyback transformer depends on energy storage required and is accomplished in a manner similar to ferrite cores. **MAGNETICS** publishes curves of LI^2 vs. core size. A suitable core for the transformer can be selected from these curves.

MPP and Kool Mu cores are usable as energy storage devices up to 300 kHz without an undue temperature rise. They are usable beyond this frequency but at reduced flux densities.

Core Losses

Because of the high power levels being used for transformers at 20 kHz and above, and the fact that core losses are the limiting design factor, it becomes important to consider the core losses at the operating temperature of the unit. In optimizing the design, it is good practice to design the transformer to operate at temperatures higher than ambient. The core losses of many earlier ferrites increase with temperature while newer materials' losses decrease, as typified by the curves in Figure 20.
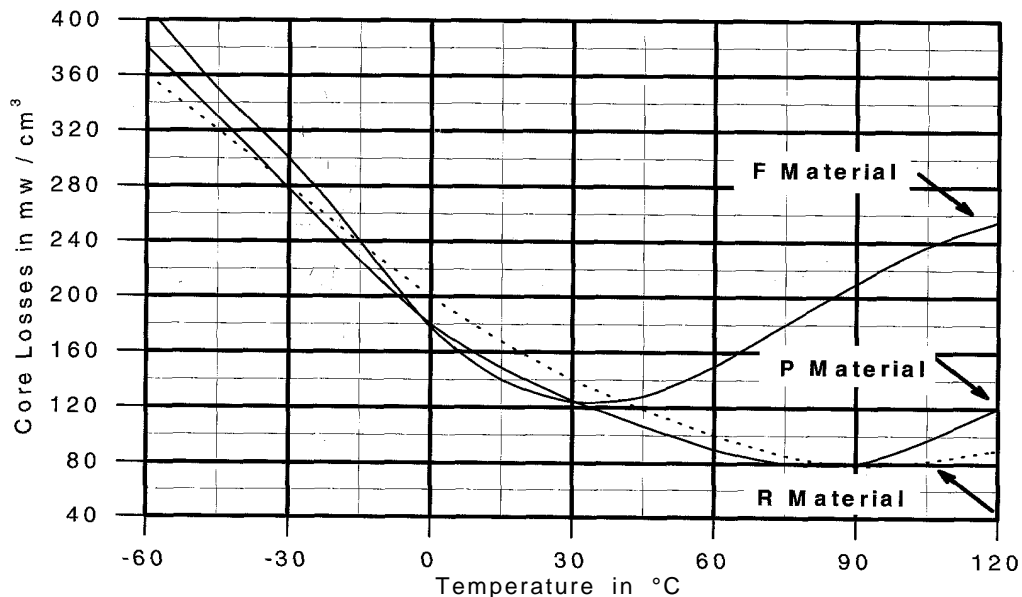

Figure 20: Core Losses vs. Temperature for Ferrite Materials.

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As mentioned earlier, core losses dominate the considerations in designing high frequency transformers. Table 4 summarizes a comparison of core losses of several available materials at a flux density of 2000 gauss and frequency of 25 kHz. It should be noted that core losses for Permalloy tape wound cores compare favorably with other materials but they are more expensive in these thin gauges.

Table 4: Core Loss in mW/cm³ for Various Magnetic Core Materials
Test Conditions: B=2,000 gauss and f=25 kHz.

Ferrite "P" (Room Temperature)	105
Ferrite "P" (80°C)	75
Ferrite "R" (Room Temperature)	140
Ferrite "R" (100°C)	70
1 mil Permalloy	144
1/2 mil Permalloy	111
Metglas 2605SC	366
Metglas 2714A	36

POWER INDUCTOR DESIGN

In order to design a power inductor, one must know the inductance required and the peak current flowing in the coil. If the ac component of the current is small, it can be neglected, and the peak current Will be the maximum dc. If the ac is considerable, calculate its peak value and add it to the dc value to get the peak current in the coil.

For power inductors, **MAGNETICS** has formulated charts that help to Select either a ferrite core and its required gap or a permalloy powder core. See Figures 22(a) and 22(b) (page 19). To use these charts, first calculate LI^2 (mh x amps²), then use the charts to make the core selection.

Detailed design procedures and examples using these graphs for inductor designs can be found in **MAGNETICS** Catalog SR-1.
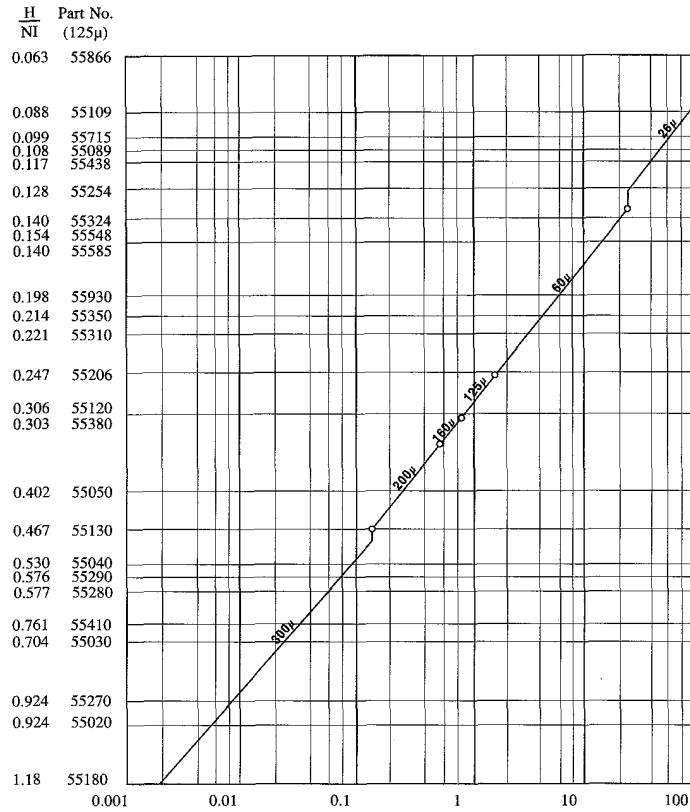
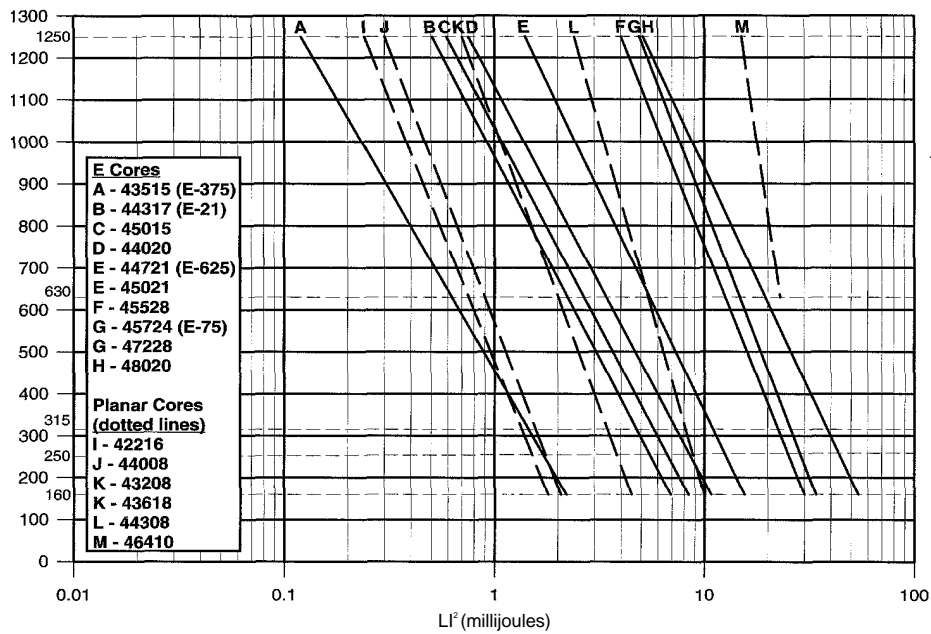**Figure 22(a):** Molypermalloy dc Bias Core Selector Chart.

H/NI	Part No. (125μ)
0.063	55866
0.088	55109
0.099	55715
0.108	55089
0.117	55438
0.128	55254
0.140	55324
0.154	55548
0.140	55585
0.198	55930
0.214	55350
0.221	55310
0.247	55206
0.306	55120
0.303	55380
0.402	55050
0.467	55130
0.530	55040
0.576	55290
0.577	55280
0.761	55410
0.704	55030
0.924	55270
0.924	55020
1.18	55180

E Cores
A - 43515 (E-375)
B - 44317 (E-21)
C - 45015
D - 44020
E - 44721 (E-625)
E - 45021
F - 45528
G - 45724 (E-75)
G - 47228
H - 48020

Planar Cores
(dotted lines)
I - 42216
J - 44008
K - 43208
K - 43618
L - 44308
M - 46410

LI^2 (millijoules)

Figure 22(b): Ferrite dc Bias Core Selector Chart.
A family of these graphs appears in Magnetics Ferrite Catalog FC-601

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Conclusion

Choice of material, shape and size of cores used in switching power supplies can be complicated. This presentation is intended to give engineers sufficient background information to at least guide them into the right ballpark for selecting the most cost-effective magnetic core for a particular design. Additional details can be found in the MAGNETICS literature and software referred to in the text or in the introduction.

A fully-staffed application engineering department is always available for individual consultation in addition to a qualified sales force to give undivided attention to providing product service such as prototype samples and production quantities.

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