Magnetic Cores for Switching Power Supplies

Magnetics offers one-stop shopping for magnetic cores in a multitude of materials, sizes, and shapes.

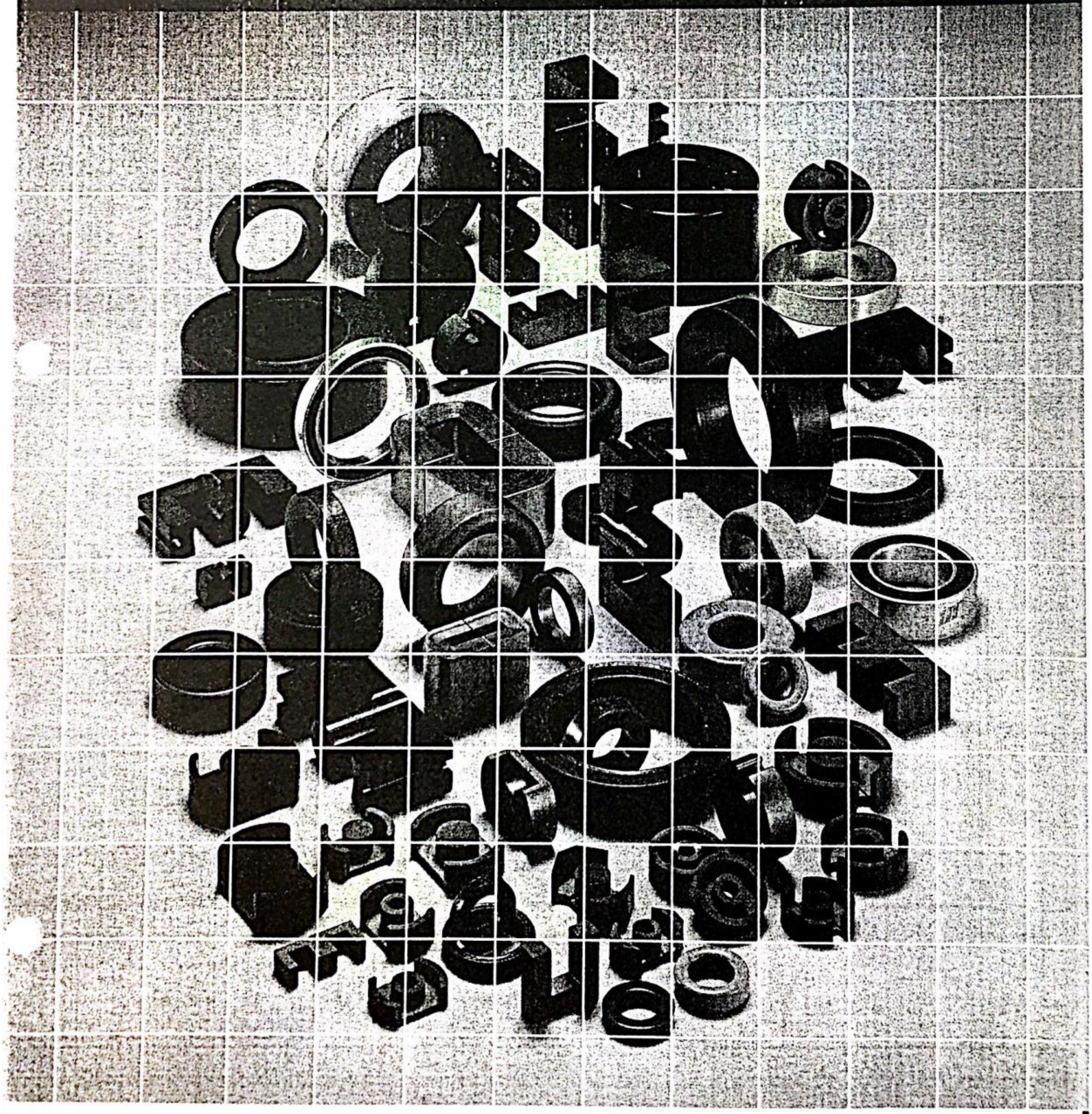
Complete in-process capability, from raw materials to finished parts, assures you a wide selection of quality cores that meet the exacting specifications of components used in switching power supplies: (1) ferrites, tape cores, and nickel cut cores for the output transformer; (2) ferrites, powder cores and cut cores for the regulator inductor; (3) ferrites and powder cores for filters; and (4) miniature tape cores and saturable cores for the drive transformer.

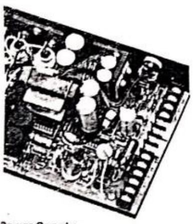
This brochure discusses the advantages and disadvantages of the various types of cores used in switching power supplies. A number of design articles are referenced in addition to a listing of other useful Magnetics literature.

For the most complete line of magnetic cores, come to Magnetics.

MAGNETICS ®

Division of Spang & Company





Power Supply
of RO Associates

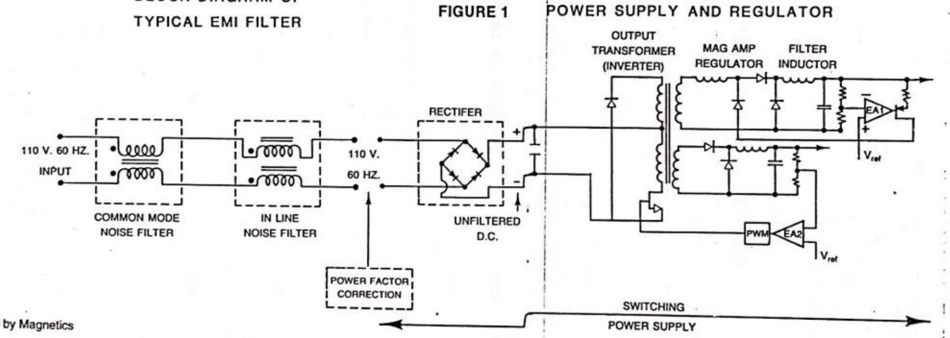
Power Supply Component	Desired Core Characteristics
EMI Filter Common mode filter In-line filter	 High permeability High saturation (B max)
Power Factor Correction Inductor	High DC Bias Low losses
Output transformer High frequency (20KHz & above)	 Low losses
Low frequency (10 KHz and below)	High saturation (B max)
Mag Amp	High Br/Bm Low losses
Regulating inductor	High saturation (B max)

relatively low saturation levels; therefore, for a given flux density, a larger core cross-section is needed. This added core area increases copper losses (AC and DC); however, at 20 KHz and higher, the reduction in core loss obtained when using a ferrite is

BLOCK DIAGRAM OF TYPICAL EMI FILTER

FIGURE 1

BLOCK DIAGRAM OF TYPICAL SWITCHING POWER SUPPLY AND REGULATOR



Items listed in **Bold** are offered by Magnetics

Common Mode
1. **Ferrite toroids**
2. **Ferrite shapes (Ungapped)**

In Line
1. **Molypermalloy powder cores**
2. **50 Ni- 50 Fe powder cores**
3. **Gapped ferrites**
4. Powdered iron
5. Si-Fe laminations
6. **KOOL Mμ powder cores**

Power factor correction inductor
1. **KOOL Mμ powder cores**
2. **Molypermalloy powder cores**
3. **50 Ni- 50 Fe powder cores**
4. **Gapped ferrites**
5. Powdered iron

Output transformer
1. **Ferrites**
   (a) **pot cores**
   (b) **shapes**
   (c) **toroids**
2. **Ni-Fe tape wound cores**
3. Amorphous tape wound cores
4. **Cut Cores**
   (a) **Ni-Fe**
   (b) **Amorphous**
5. **Ni-Fe laminations**

Mag amp regulator
1. **Ni-Fe tape wound cores**
2. Cobalt-base amorphous tape wound cores
3. Square loop ferrite toroids

Filter inductor
1. **Molypermalloy powder cores**
2. **50 Ni- 50 Fe powder cores**
3. **Gapped ferrites**
4. **Powdered iron**
5. **Cut Cores**
6. Si-Fe laminations
7. **KOOL Mμ powder cores**

Table 2 — Core Material Considerations

	Flux Density	Initial Perm.	Frequency* Range	Max. op. Temp.	Core Losses	Core Cost	Winding Cost	Temp. Stability	Mounting Flexibility
Ferrite Toroids MAGNETICS™ J Mat'l W Mat'l H Mat'l	4300 4300 4200	5000 10,000 15,000	to > MHz	100°C	lowest	low	high	fair	fair
Ferrite Shapes K Mat'l R Mat'l P Mat'l F Mat'l	4600 5000 5100 4700	1500 2300 2700 3000	to 2MHz to 200kHz to 100kHz to 100kHz	125°C 125°C 125°C 125°C	(1) (2) (3)	(see Table 3 below for geometry considerations)			
MPP Cores	7000	14-550	< 1MHz	200°C	low	high	high	good	fair
50 Ni-50 Fe Powder Cores	15,000	60-200	< 1MHz	200°C	low	high	high	good	fair
KOOL Mμ® Powder Cores	11,000	60-125	< 1MHz	200°C	low	low	high	good	fair
Powdered Iron	9000	22-90	< 1MHz	200°C	high	lowest	high	fair	fair
Silicon-Fe Laminations	16,000	4000	< 1000Hz	300°C	highest	low	low	fair	good
Ni/Fe Tape Cores Ni/Fe Bobbin Cores	7,000 to 15,000	to 100,000	to 100kHZ	200°C	low to medium	high	high	good	fair
Amorphous Tape Cores (iron-base)	16,000	10,000	to 500kHz	150°C	low	high	high	good	fair
Amorphous Tape Cores (cobalt-base)	5,000	to 100,000	to 500kHz	100°C	low	high	high	good	fair
Si-Fe Tape Cores	16,000	4000	<1000Hz	300°C	highest	medium	high	good	fair
Ni-Fe Cut Cores	15,000	15,000	to 100kHz	150°C	medium	high	low	good	fair

*Frequency depends on adjusting operating flux density to levels that keep core losses to acceptable limits.
(1) Core losses decrease up to 100°C
(2) Core losses decrease up to 70°C, remain low to 100°C
(3) Low core losses at lower temperatures

Table 3 — Ferrite Core Comparative Geometry Considerations

	Core Cost	Bobbin Cost	Winding Cost	Winding Flexibility	Assembly	Mounting Flexibility**	Heat Dissipation	Shielding
Pot Core	high	low	low	good	simple	good	poor	excellent
Slab-sided Core	high	low	low	good	simple	good	good	good
E Core	low	low	low	excellent	simple	good	excellent	poor
EC Core	medium	medium	low	excellent	medium	fair	good	poor
Toroid	very low	none	high	fair	none	poor	good	good
PQ Core	high	high	low	good	simple	fair	good	fair

**Hardware is required for clamping core halves together and mounting assembled core on a circuit board or chassis.

Table 4 — Output Transformers

	Advantages	Disadvantages
Ferrites* (a) Pot Cores	1. Shielding excellent 2. Bobbin winding (inexpensive) 3. Hardware availability good 4. Mounting and assembly easy 5. Low loss materials available 6. Printed circuit mounting available 7. Can be gapped for specific inductance	1. Size limitation 2. Heat confined 3. More expensive than other ferrites 4. Cannot handle large conductors

***See Table 3 on characteristics of various shapes.

Table 4 (Output Transformers continued)

	Advantages	Disadvantages
(b) E Cores	1. Simple low cost winding 2. Heat dissipated readily 3. Mounting hardware simple 4. Can mount in different directions 5. Printed circuit board mounting available 6. Assembly is simple 7. Cores are inexpensive 8. Large wires can be accommodated 9. Low profile available 10. Low loss materials available 11. Can be gapped for specific inductance	1. Shielding is minimal
(c) EC Cores	1. Round center leg provides shorter path length for windings, saving wire and reducing losses 2. Core can handle more power 3. Round center leg prevents bends in wire 4. Can accommodate large wires 5. Printed circuit mounting available 6. Mounting hardware available 7. Low loss materials available 8. Can be gapped for specific inductance	1. Shielding low 2. More costly than E core 3. Takes up more space
(d) Slab-sided solid center post cores	1. Solid round center leg provides less core loss 2. Easy and large exits for large conductors 3. Standard hardware available 4. Assembly simple 5. Low profile is possible 6. Low loss materials available 7. Can be gapped for specific inductance	1. Shielding medium
(e) PQ Cores	1. Optimum ratio of volume to winding area 2. Minimum core size for given design 3. Minimum assembled size for a given design 4. Minimum PC board area 5. Easy assembly 6. Printed circuit bobbin available 7. Cores operate cooler 8. Low loss materials available 9. Can be gapped for specific inductance	1. More expensive than E Cores
(f) Toroids	1. No radiating flux 2. No accessories required 3. Low loss materials available 4. Cores can be gapped for specific inductance 5. Cores have a large radius to prevent sharp bends in wires 6. Cores can be painted with protective insulation to prevent shorting core to windings 7. Cores are inexpensive 8. High input impedance	1. Toroidal winding equipment necessary 2. Subjected to external stray fields 3. Cores are prone to saturate if excitation is unbalanced
Ni-Fe Tape Cores	1. High flux density at lower frequencies 2. Size can be small for a given power 3. Wide temperature range (to 200°C) 4. Can handle high power 5. Unlimited range of sizes 6. Can be gapped 7. High input impedance	1. Frequency limitation at high flux density (up to 20 KHz) 2. More expensive than ferrites 3. Need toroidal winding equipment 4. Cores are prone to saturate if excitation is unbalanced
Ni-Fe Cut Cores	1. Same as Ni-Fe tape wound cores 2. Easy to wind and assemble 3. Will not saturate easily due to gapping	1. More expensive than Ni-Fe tape cores

Table 4 (Output Transformers continued)

	Advantages	Disadvantages
Amorphous Tape Wound Cores	1. High flux density 2. Size can be small for a given power 3. Wide temperature range (to 150°C) 4. Can handle high power 5. Extremely low core losses 6. Frequency range to 100 KHz 7. Unlimited range of sizes 8. Can be gapped	1. More expensive than ferrites 2. Need toroidal winding equipment
Amorphous Cut Cores	1. Same as amorphous tape cores 2. Easy to wind and assemble 3. Will not saturate easily due to gapping	1. More expensive than amorphous tape cores
Ni-Fe laminations	1. High flux at lower frequencies 2. Easy to wind — bobbins available 3. Size can be small 4. Can handle high power 5. Wide temperature range (to 200°C) 6. Can be gapped	1. Must preassemble stack 2. Assembly cost higher 3. Frequency limitation at high flux density

Table 5—Inductors

	Advantages	Disadvantages
Molypermalloy Powder Cores	1. Distributed air gap 2. Cores do not saturate easily 3. Permeability vs. DC bias remains high 4. Cores have a good radius and are painted with a protective insulation 5. Large energy storage capacity 6. Good temperature stability 7. No accessories required 8. Can wind few turns by hand inexpensively	1. More expensive than ferrites 2. Toroidal winding equipment necessary for large number of turns
50 Ni-50 Fe Powder Cores	1. Same as MPP cores 2. Cores have a higher B_{max}-support large AC voltages without saturation occurring 3. Filters can be made smaller in size, requiring fewer turns than molypermalloy or ferrite 4. Large energy storage capacity — larger than MPP, powdered iron, or ferrites	1. Same as MPP cores
Kool Mμ Powder Cores	1. Same as MPP cores and 50 Ni-50 Fe powder cores 2. Cost between powdered iron and MPP 3. Core losses significantly lower than powdered iron	1. Toroidal winding equipment necessary for large number of turns
Gapped Ferrites (pot cores, shapes)	1. Cores are easy to gap 2. Gapped cores will not saturate easily 3. Winding is simplified, inexpensive	1. Cores require accessories such as bobbins, clamps
(toroids)	1. Cores can be gapped, won't saturate 2. No accessories required 3. Cores have large radius to prevent sharp bends in wires 4. Cores can be painted with protective insulation to prevent shorting core to windings 5. Cores are inexpensive	1. Toroidal winding equipment necessary 2. Subjected to external stray fields
Powdered Iron	1. Low cost 2. Large energy storage capacity	1. Losses are HIGHER than powdered cores or ferrites 2. Takes up more space
Silicon Laminations	1. Winding is easy 2. Assembly is simple 3. Energy storage capacity is large 4. Inexpensive	1. Must preassemble stack 2. Losses are highest of all material types

Table 6 — FILTERS

— Common Mode —

	Advantages	Disadvantages
Ferrite Toroids	1. High permeability (up to 10,000) provides high impedance to unwanted signals 2. Cores have a large radius to prevent sharp bends in wires 3. Cores can be painted with a protective insulation to prevent shorting core to windings 4. Cores are inexpensive	1. Toroidal winding equipment necessary
Ferrite Shapes (Ungapped)	1. Winding is simplified 2. High insulation is possible 3. High permeability materials	1. More expensive than toroid 2. Required accessories such as bobbin, possibly clamp 3. Lower effective permeability than toroids
	— In Line —	
Molypermalloy Powder Cores	1. Cores do not saturate easily 2. Cores have a good radius and are painted with a protective insulation 3. No accessories required 4. Good temperature stability	1. Toroidal winding equipment required 2. More expensive than ferrites
50 Ni-50 Fe Powder Cores	1. Same as MPP cores 2. Cores have a higher B_{max}—support large AC voltages without saturations occurring 3. Filters can be made smaller in size, requiring fewer turns than molypermalloy or ferrite	1. Same as MPP cores
Kool Mμ Powder Cores	1. Same as MPP cores 2. Core losses lower than the powdered iron 3. Cost between powdered iron and MPP cores 4. B_{max} is between MPP and 50 Ni-50 Fe	1. Toroidal winding equipment required
Gapped Ferrites (pot cores, shapes)	1. Cores are easy to gap 2. Gapped cores will not saturate easily 3. Winding is simplified	1. Cores require accessories such as bobbins, clamps
(toroids)	1. Cores can be gapped, won't saturate 2. No accessories required 3. Cores have a large radius to prevent sharp bends in wires 4. Cores can be painted with protective insulation to prevent shorting core to windings 5. Cores are inexpensive	1. Toroidal winding equipment is necessary 2. Subject to external radiation
Powdered Iron	1. Low cost 2. Relatively high flux density	1. Losses are higher than powdered cores or ferrites
Silicon Laminations	1. Winding is easy 2. Inexpensive 3. High flux density	1. Must preassemble stack 2. Losses are highest of all types

Additional Literature Available from Magnetics

Powder Cores (Moly Permalloy)
MAGNETICS ® Moly Permalloy Powder (MPP) cores have a distributed air gap structure, making them ideal for switching regulator applications since their DC bias characteristics allow them to be used at high drive levels without saturating. Composed of 80% nickel, balance iron and molybdenum, they are available in 26 physical sizes (.140" to 3" O.D.) and 10 different permeabilities (14 to 550). **MPP-400**

Powder Cores (High Flux)
MAGNETICS ® high flux (HF) powder cores are also distributed air gap cores made from a 50% nickel- 50% iron alloy powder. HF cores have a saturation flux density of 15,000 gausses as compared to 7,000 gausses for standard MPP cores or 4500 gausses for ferrites. The core loss of HF powder cores is significantly lower than powdered iron cores. **HFC-01**

(Continued)

Powder Cores (Kool Mμ)
MAGNETICS® Kool Mμ® powder cores are distributed air gap cores made from a ferrous alloy powder. In high frequency applications, core losses of powdered iron cores can be a major factor in contributing to undesirable temperature rises. KOOL Mμ cores are ideal because their losses are significantly less, resulting in lower temperature rises. Available in sizes .140" to 1.84" O.D. **KMC-02, KMC-S1**

Ferrite Cores
A comprehensive catalog on pot cores, toroids, E, U, and I cores, RM and RS cores, EP cores **FC-601**
Critical Comparison of Ferrites with other Magnetic Materials **CG-01-A**

Tape Wound Cores
Tape wound cores and made from high permeability alloys of nickel-iron, grain oriented silicon-iron and cobalt-iron. They are available in over 1,000 standard and special sizes for a wide range of frequency applications. Tape thicknesses range from 1/2 mil through 14 mils. Commonly used sizes are in stock for immediate shipment. Amorphous alloys present low loss and interesting characteristics ideal for switched mode power supplies at frequencies to 500 kHz. **TWC-400**

Mag Amp Tape Wound Cores
Nickel-iron and amorphous cobalt-base alloys present low core losses and square B-H loops for mag amp regulation in switched mode power supplies at frequencies to 500 kHz. **TWC-400**

Bobbin Cores
Bobbin cores are miniature tape cores manufactured from ultra-thin tape (.000125" to .001" thick), and are available in widths from .032" to .25". Wound on non-magnetic stainless steel bobbins, core diameters are available down to .050" or less. **BCC 1-1**

Cut Cores
MAGNETICS® cut cores are ideal for applications in which low core loss is desired and core saturation is undesirable. These cut cores are offered in a choice of soft magnetic materials including Orthonol® (50 nickel-50 iron) alloy, Permalloy 80 (80 nickel- 20 iron), & supermendur. **MCC-100**

General Information
"Inductor Design in Switching Regulators." An 8 page bulletin on the core selection and design procedure for power inductors **SR-1**
Power Transformer and Inductor Design **TID-100**
How to Select the Proper Core for Saturating Transformers **TWC-S2**
Inverter Transformer Core Design and Material Selection **TWC-S3**

Design Software
Common Mode Filter Inductor Design **CMF-2.1**
Power Inductor Design **PDR-2.3**
Nickel-Iron Laminations **LRC-2.2**

Useful Design Articles

The following reference articles are quite informative in the design of switched mode power supplies:

Gerald L. Fawney, Inductors: MPP Toroids with DC Bias, Power Conversion International, September, 1982
Phillip E. Thibodeau, The Switcher Transformer: Designing it in One Try for Switching Power Supplies, Electronic Design, September 1, 1980
Slobodan Cuk, Basics of Switched-Mode Power Conversion: Topologies, Magnetics, and Control, Power Conversion International, July/August 1981 Part 1, October 1981 Part 2
Robert Miller, Dr. A. Kusko, Thorleif Knutrud, Inductor Designs Easily Perform Delay and Switching Functions, EDN, February 5, 1977
Tomm V. Aldridge, Richard M. Haas, Designing the Soft Induc-
Clement A. Berard, Switching Power Supplies for Satellite Radiation Environments, Solid-State Power Conversion, September/October 1977
R.J. Haver, Switched Mode Power Supplies—Highlighting A 5-V, 40-A Inverter Design, Application Note AN-737, Motorola Semiconductor Products Inc.
R.J. Haver, A New Approach to Switching Regulators, Application Note AN-719, Motorola Semiconductor Products Inc.
Jagdish Chopra, Squeeze More from Power Supplies, Electronic Design 14, July 5, 1974
Jade Alberkrack, A Cost-Effective Approach to a 400 Watt Off-Line Switchmode Power Supply, Power Conversion International, July/August 1981
Rihei Hiramatsu, Koosuke Harada, Tamotsu Ninomiya

Table 1 — Properties of Soft Magnetic Materials

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