Pragmatic and Decisive Comparison of Magnetic Cores for Switching Mode Power Supply

Patel Himanshu K.
Lecturer (Instrumentation & Control Engineering)
Institute of technology
Nirma University
Ahmedabad-382481.Gujarat. INDIA
E-mail: hkpatel@hkpatel.com, Contact No.: - 09825291978

Abstract: Switching mode power supply is without doubt an important subassembly for any electronic equipment. With improvements in semiconductors & other circuit components, high frequencies are being utilized, sizes are being reduced and efficiencies are increasing in SMPS. Magnetic cores of various types play a key role in many of the components used in switched mode power supplies. Core material and geometries are a basic design consideration. Depending on the circuit requirements, degree of sophistication, manufacturing techniques, assembly equipments available and costs, the designer has a wide array of magnetic cores at his disposal.

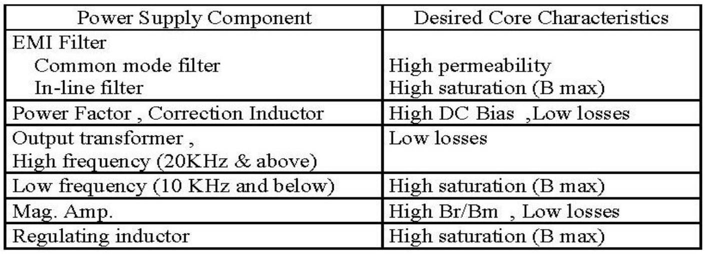
This paper discusses the merits and demerits of the various types of cores used in switching power supplies. A realistic and honest comparison of properties of available alternatives is suggested. Comparative analysis of various magnetic cores is presented for all the subassemblies of an SMPS.

INTRODUCTION:

The designer has a wide range of magnetic cores, to select the best option for his application. The list includes: Ferrite cores, Permalloy powder cores, Kool Mμ powder cores, 50 Ni/50 Fe powder cores, tape wound cores, cut cores, bobbin cores, laminations and powdered iron cores.

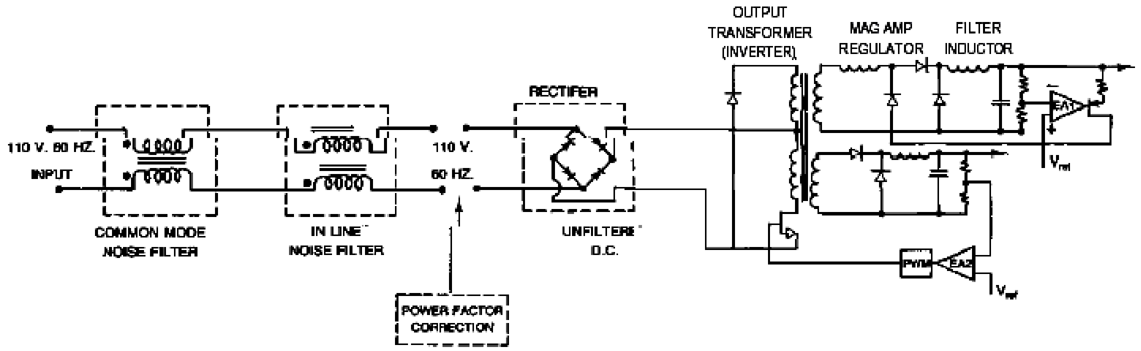
Making the right choice from this list is a real design challenge. An in depth comparison of these cores can certainly be a helping hand to the design engineer.

Figure 1 shows a typical block diagram of a switched mode power supply. Under each subassembly are listed the various types of magnetic cores and materials that can be used in these circuits. The design requirements for cores in each of the subassemblies are listed in Table 1.



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)

Table-1: Design requirements for cores in SMPS



Common Mode	**In Line**	**Power factor correction inductor**	**Output transformer**	**Mag amp regulator**	**Filter inductor**
1.Ferrite toroids 2.Ferrite shapes (Ungapped)	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	1.KOOL Mμ powder cores 2. Molypermalloy powder cores 3. 50 Ni- 50 Fe powder cores 4. Gapped ferrites 5. Powdered iron	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	1. Ni-Fe tape wound cores 2.Cobalt-base amorphous tape wound cores 3. Square loop ferrite toroids	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

Figure – 1: Block Diagram of SMPS.

The correct choice of core materials will optimize power supply performance. In metal ferromagnetic materials, eddy current losses increase rapidly with frequency and are controlled by using thin laminations, thin-gauge strips of material, or by powdering and insulating metallic particles used to produce the core. Practical and theoretical factors limit the effectiveness of this approach. Ferrite materials have one paramount advantage — very high electrical resistivity, which means that eddy current losses are much lower than metals.

As operating frequencies increase, ferrites become a practical and useful magnetic material since ferromagnetic types cannot be made progressively thinner or smaller to reduce eddy current losses to acceptable levels.

While ferrites do provide low core losses at higher frequencies, they have, as previously mentioned, 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 greater that the subsequent increase in copper losses. Additionally, fewer turns are needed at higher frequencies to support a given voltage; hence, the copper losses are kept down.

For the lower range of power and switcher frequencies, nickel-alloy ferromagnetic cores have relatively high electrical resistivity; laminated, or strip wound cores fabricated from thin strip, can be effective up to the 20 KHz range (or higher if designed and operated at low flux density levels).

Tables 2 and 3 summarize the various types of cores with respect to materials and shape Characteristics. These tables provide a basis for magnetic core selection. The correct choice of core depends on circuit requirements such as frequency, power level, circuit configuration, and environmental conditions. These tables will be assisting us in choosing the optimum core for your application.

The advantages and disadvantages of the various types of core materials and geometries in transformers, inductors, and filters are reviewed in Tables 4, 5, and 6.

Table- 2: Core Material considerations

	Flux density	**Initial Perm.**	**Frequency* Range**	**Max. op. Temp.**	**Core losses**	**Core costs**	**Winding cost**	**Temp. Stability**	**Mounting flexibility**
Ferrite Toroids			To>MHz	100°C	Lowest	Low	High	Fair	fair
J Material	4300	5000							
W Material	4300	10000							
H Material	4200	15000							
Ferrite Shapes						(see Table 3 below for geometry considerations)			
K Material	4600	1500	To 2MHz	125°C					
R Material	5000	2300	To200MHz	125°C	(1)				
P Material	5100	2700	To100KHz	125°C	(2)				
F Material	4700	3000	To100KHz	125°C	(3)				
MPP Cores	7000	14-550	<1MHz	200°C	Low	High	High	Good	fair
50 Ni-50 Fe Powder Cores	15000	60-200	<1MHz	200°C	Low	High	High	Good	fair
KOOL Mμ Powder Cores	11000	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	16000	4000	<1000Hz	300°C	Highest	Low	Low	Fair	good
Ni/Fe Tape Cores Ni/Fe Bobbin Cores	7000 to 15000	To 100,000	To 100KHz	200°C	Low to medium	High	High	Good	fair
Amorphous	16000	10000	To 500KHz	150°C	Low	High	High	Good	fair

Tape Cores (iron-base)									
Amorphous Tape Cores (cobalt-base)	5000	To 100,000	To 500KHz	100°C	Low	High	High	Good	fair
Si-Fe Tape Cores	16000	4000	<1000Hz	300°C	Highest	Medium	High	Good	fair
Ni-Fe Cut Cores	15000	15000	To 100KHz	150°C	Medium	High	low	Good	fair

(1) Core losses decrease up to 100ºC (2) Core losses decrease up to 70ºC, remain low to 100ºC (3) Low core losses at lower temperatures

Table 3 — Ferrite Core Comparative Geometry Considerations

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

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
(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	1. Shielding low 2. More costly than E core 3. Takes up more space

	6. Mounting hardware available 7. Low loss materials available 8. Can be gapped for specific inductance	
(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 4. 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
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 Bmax-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. Toroidal winding equipment necessary for large number of turns
(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 2. powdered cores or ferrites 3. 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

	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
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 Bmax—support large AC voltages without saturations occurring 3. Filters can be made smaller in size, requiring fewer turns than mlypermalloy 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. Bmax 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

Conclusion:

The assertive comparison of magnetic cores presented in this paper can be a powerful design tool for the designer. The correct choice of core materials will optimize power supply performance.

Instead of restricting the analysis at the comparison of magnetic cores efforts are made to provide the insight by extending the comparison for various core geometries.

All the critical parameters are considered in the comparative analysis to enable the designer for the optimization of the core for desired application.

The designs of transformers, inductors and filters in SMPS can be optimized with the help of tables presented.

References:

[1] Gerald L. Fawney, Inductors: MPP Toroids with DC Bias, Power Conversion International September, 1982.

[2] Phillip E. Thibodeau, The Switcher Transformer: Designing it in One Try for Switching Power Supplies, Electronic Design, September 1, 1980.

[3] Slobodan Cuk, Basics of Switched-Mode Power Conversion: Topologies, Magnetics, and Control, Power Conversion International, July/August 1981 Part 1, October 1981 Part 2.

[4] Robert Miller, Dr. A. Kusko, Thorleif Knutrud, Inductor Designs Easily Perform Delay and Switching Functions, EDN, February 5, 1977.

[5] Tomm V. Aldridge, Richard M. Haas, Designing the Soft Inductor, a New Component for Use in Switching Converters, Solid-State Power Conversion, March/April 1979.

[6] Unitrode Corp. Switching Regulator Design Guide, Bulletin No. U-68.

[7] Colonel William T. McClyman, Transformer & Inductor Design Handbook, Marcel Dekker, Inc.

[8] Neil Kepple, High Power Flyback Switching Regulators, Solid-State Power Conversion,January/February 1978.

[9] Dan Chen, Harry Owen, and Thomas Wilson, Designing of Energy Storage Reactors for Single Winding Constant-Frequency DC to DC Converters Operating in the Discontinuous Reactor Current Mode, 1980 Intermag Proceedings.

[10] Abraham Pressman, Switching & Linear Power Supply Power Converter Design, Hayden Publishing Co.

[11] Eugene R. Hnatek, Choose Switching Regulators for Your Computer Power-Supply Design, Electronic Design 6, March 15, 1975.

[12] Clement A. Berard, Switching Power Supplies for Satellite Radiation Environments, Solid-State Power Conversion, September/October 1977.

[13] R.J. Haver, Switched Mode Power Supplies-Highlighting A 5-V, 40-A Inverter Design,Application Note AN-737, Motorola Semiconductor Products Inc.

[14] R.J. Haver, A New Approach to Switching Regulators, Application Note AN-719, Motorola Semiconductor Products Inc.

[15] Jagdish Chopra, Squeeze More from Power Supplies, Electronic Design 14, July 5, 1974

[16] Jade Alberkrack, A Cost-Effective Approach to a 400W Off-Line Switchmode Power Supply, Power Conversion International, July/August 1981.

[17] Rihei Hiramatsu, Koosuke Harada, Tamotsu Ninomiya, Switch Mode Converter Using High-Frequency Magnetic Amplifier, International Telecommunications Energy Conference, Washington, D.C. Nov. 26-29, 1979.

[18] Lloyd Dixon, Raoji Patel, Designers' Guide to:Switching Regulators, Part 1,2,3, EDN, October20, November5, November 20, 1974.

[19] Tom Gross, A Little Understanding Improves Switching-Inductor Designs, EDN, June 20, 1979.

[20] Stephen Hayes, P.E., Selecting Cores for Inductors Used to Store Energy, Power Conversion International, November/ December 1981.

[21] A. Paul Brokaw, Start-Up Transients in Switching Regulators and Input Filters, Solid-State Power Conversion, September/ October, 1976.

[22] Ferdinand C. Geerlings, SMPS Power Inductor and Transformer Design, Power Conversion International, November/ December, 1979.