Power Design

Ferrite is an ideal core material for transformers, inverters and inductors in the frequency range 20 kHz to 3 MHz, due to the combination of low core cost and low core losses. Ferrites may be used in the saturating mode for low power, low frequency operation (<50 watts and 10 kHz). Ferrite cores may also be used in flyback transformer designs, which offer low core cost, low circuit cost and high voltage capability. Powder cores (MPP, High Flux, Edge®, Kool Mµ®, Kool Mµ® MAX, Kool Mµ® H*f*, and XFLUX®) offer soft saturation, higher B_{max}, and superior temperature stability and are often the best choice for minimum size and robust performance in power choke, inductor, and flyback applications.

CORE GEOMETRIES

POT CORES

Pot cores, when assembled, nearly surround the wound bobbin. This aids in shielding the coil from pickup of EMI from outside sources. The pot core dimensions follow IEC standards so that there is interchangeability between manufacturers. Both plain and printed circuit bobbins are available, as are mounting and assembly hardware.

ROUND SLAB, DOUBLE SLAB & RM CORES

Slab-sided solid center post cores resemble pot cores, but have a section cut off on either side of the skirt. The additional openings allow larger wires to be accommodated and assist in removing heat from the assembly. RM cores are also similar to pot cores, but are designed to minimize board space, providing at least a 40% savings in mounting area. Printed circuit or plain bobbins are available. One-piece clamps permit simple assembly. Low profile is possible. The solid center post generates less core loss and minimizes heat buildup.

PQ CORES

PQ cores are designed specifically for switched mode power supplies. One result is an optimized ratio of volume to winding area and surface area, meaning that maximum inductance and winding area are possible with a minimum core size. The cores provide maximum power output with minimum assembled transformer weight and volume, in addition to taking up a minimum amount of area on the printed circuit board.

Assembly with printed circuit bobbins and one piece clamps is simplified. PQs provide a more uniform cross-sectional area, so they tend to operate with less pronounced hot spots than most other cores.

EC, ETD AND EER CORES

These shapes combine the benefits of E cores and pot cores. Like E cores, they have a wide opening on each side. This provides ample space for the large wires used for low output voltage switched mode power supplies. It also increases the flow of air which keeps the assembly cooler. The center leg is round, like that of the pot core. One of the advantages of the round center leg is that the winding has a shorter path length around it (11% shorter) than the wire around a square center leg with an equal area. This reduces the losses of the windings by 11% and enables the core to handle a higher output power. The round center leg eliminates the sharp bend in the wire that occurs with winding on a square center leg.

E, ER AND PLANAR E CORES

E cores offer the advantage of simple bobbin winding and ease of assembly. A wide variety of standard lamination-size, metric and DIN sizes are available. E cores are a low-cost choice in designs that do not require self-shielding. Planar cores are the best selection for low profile applications. Copper traces that are layered in the printed circuit board are the windings in most planar applications. This type of design provides superior thermal characteristics, economical assembly, low leakage inductance, and consistent performance.

EP CORES

EP cores are round center post cubical shapes which enclose the coil completely except for the printed circuit board terminals. The particular shape minimizes the effect of air gaps formed at mating surfaces in the magnetic path and provides a larger volume ratio to total space used. Shielding is excellent.

TOROIDS

Toroids are the least expensive ferrite shape. Available in a variety of sizes, outer diameters of 2.54 mm – 140 mm, toroids have good self-shielding properties. The fact that the core is a solid with no sections to assemble makes it a good choice if mechanical integrity is important in a high vibration environment. Toroid cores are available uncoated or with an epoxy, nylon or Parylene coating.

CORE MATERIALS

POWER

Magnetics R, P, F, T and L materials provide superior saturation, high temperature performance, low losses and product consistency.

T material is ideal for consistent performance over a wide temperature range. Applications for T include: Automotive, Electronic Lighting, Outdoor LCD Screens, Mobile Handheld Devices and AC adapters and chargers.

L material was formulated for high-frequency and high-temperature applications. L is designed for DC-DC converters, filters and power supplies that operate from 0.5 – 3.0 Mhz. Curie temperature is high for a ferrite material at 280°C.

R material is an economical, low-loss choice for a broad range of applications.

P material offers similar properties to R material, but is more readily available in some sizes.

F material is an established material with a relatively high permeability and 210°C Curie temperature.

Power Supplies, DC-DC Converters, Handheld Devices, High Power Control (gate drive) and EMI Filters are just a few of the applications that are typical for Magnetics ferrite power materials.

FILTER

Magnetics high permeability materials are engineered for optimum frequency and impedance performance in signal, choke and filter applications.

J and W materials offer high impedance for broadband transformers and are suitable for low-level power transformers.

J material is a medium perm, general-purpose material.

J's properties are well suited both for EMI/RFI filtering and broadband transformers.

W material has set the industry standard for high perm materials. In filter applications, W perm has 20-50% more impedance below 1 MHz than J perm.

M material is Magnetics' highest permeability material at 15,000µ. Applications for M include: EMI/RFI suppression filters, common mode chokes, signal processing, and broadband transformers.

LINEAR FILTERS AND SENSORS

Magnetics **C, E** and **V materials** offer excellent properties for low-level signal applications. These materials set the standard for high quality factor, long-term stability and precise and adjustable inductance. Applications for these materials include high Q filters, wideband transformers, pulse transformers and RLC tuned circuits.

Inductor Design

Ferrite E cores and pot cores offer the advantages of decreased cost and low core losses at high frequencies. For switching regulators, power materials are recommended because of their temperature and DC bias characteristics. By adding air gaps to these ferrite shapes, the cores can be used efficiently while avoiding saturation.

These core selection procedures simplify the design of inductors for switching regulator applications. One can determine the smallest core size, assuming a winding factor of 50% and wire current carrying capacity of 500 circular mils per ampere.

Only two parameters of the design applications must be known:
(a) Inductance required with DC bias
(b) DC current

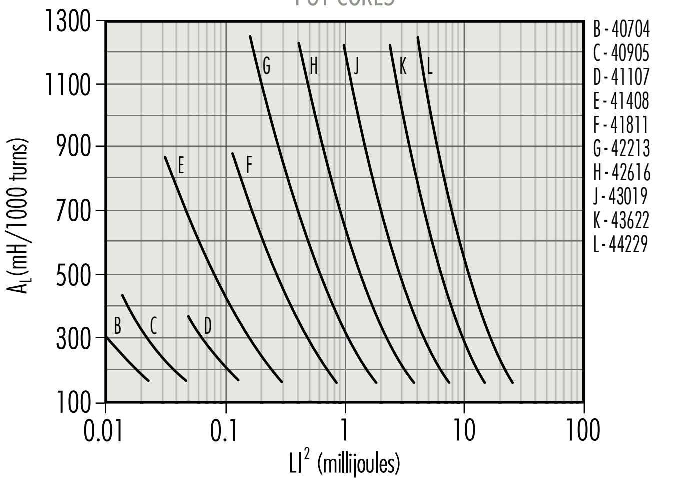
1. Compute the product of LI^2 where:
   L = inductance required with DC bias (millihenries)
   I = maximum DC output current + 1/2 AC Ripple
2. Locate the LI^2 value on the Ferrite Core Selector charts shown. Follow this coordinate up to the intersection with the first core size curve. Read the maximum nominal inductance, A_L, on the Y-axis. This represents the smallest core size and maximum A_L at which saturation will be avoided.
3. Any core size line that intersects the LI^2 coordinate represents a workable core for the inductor if the core's A_L value is less than the maximum value obtained on the chart.
4. Required inductance L, core size, and core nominal inductance (A_L) are known. Calculate the number of turns using

$$N = 10^3 \sqrt{\frac{L}{A_L}}$$

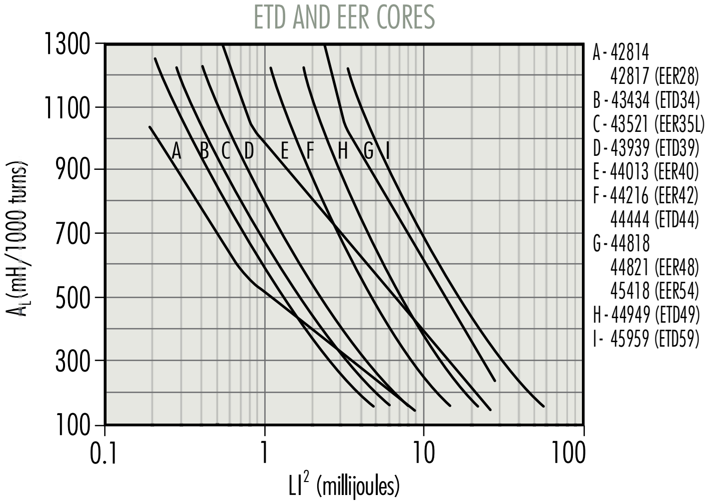
   where L is in millihenries.

5. Example: If I_{MAX} = 8 Amps; L, inductance required = 100 μHenries
   LI^2 = (0.100 mH) X (8^2 Amps) = 6.4 millijoules
6. There are many ferrite cores available that will support the energy required. Any core size that the LI^2 coordinate intersects can be used at the A_L value shown on the chart.
7. Some choices based upon an LI^2 value of 6.4 millijoules are:
   Pot core 43622 A_L = 400 Double Slab 43622 A_L = 250
   PQ core 43220 A_L = 300 E core 44317 A_L = 250
8. For the following A_L values the number of turns required is:
   A_L = 400, N = 16 A_L = 300, N = 19 A_L = 250, N = 20
   Make sure the wire size chosen will support the current and fit into the core set.

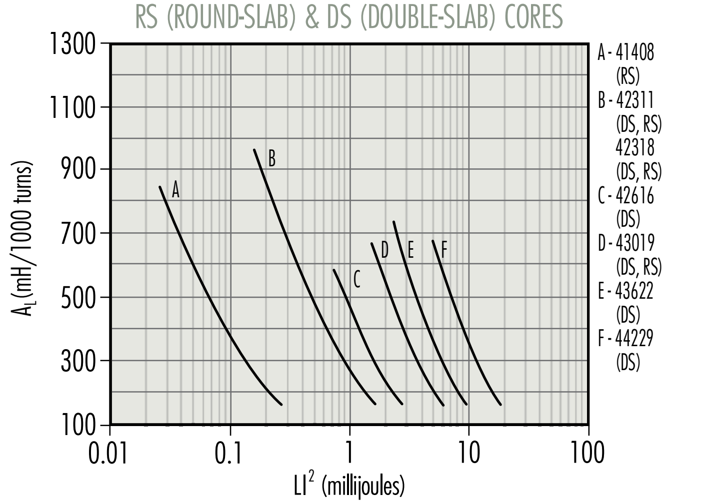
POT CORES



ETD AND EER CORES

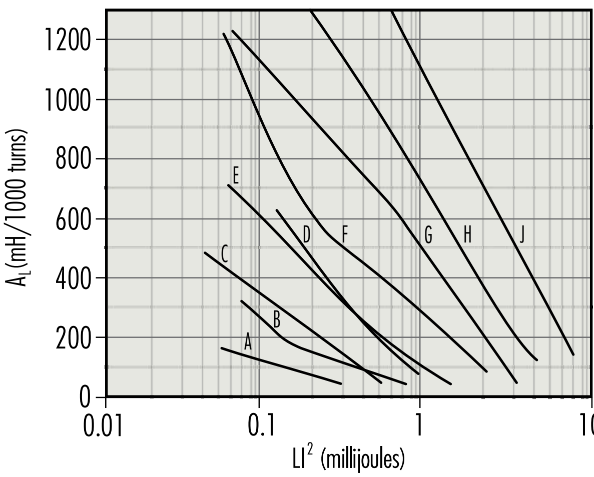


RS (ROUND-SLAB) & DS (DOUBLE-SLAB) CORES



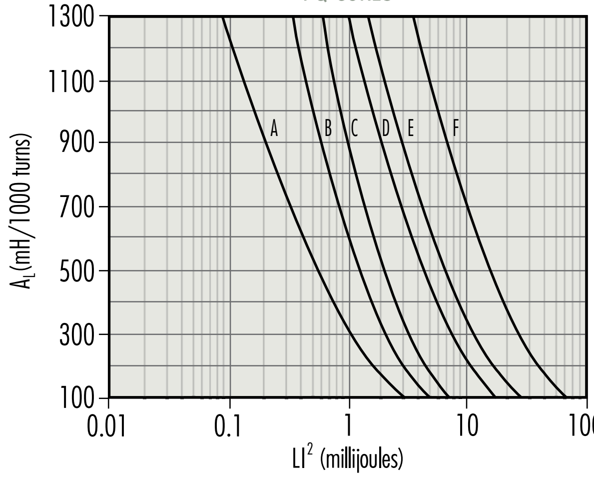
Inductor Design

RM AND EP CORES



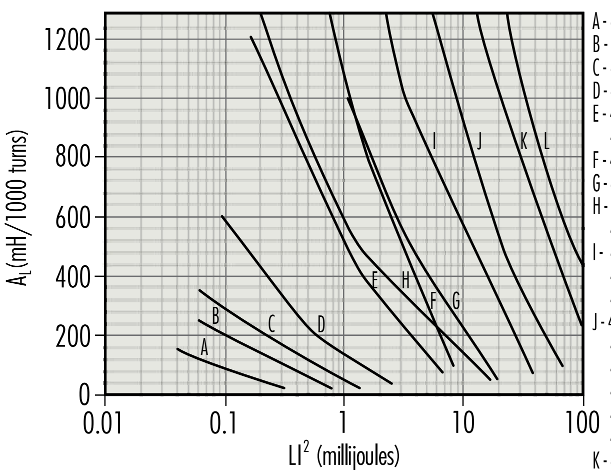
A - 40707 (EP7)
41010 (EP10)
41110 (RM4)
B - 41313 (EP13)
C - 41510 (RM5)
D - 41717 (EP17)
E - 41812 (RM6)
F - 42316 (RM8)
G - 42120 (EP20)
H - 42819 (RM10)
J - R43723 (RM12)

PQ CORES



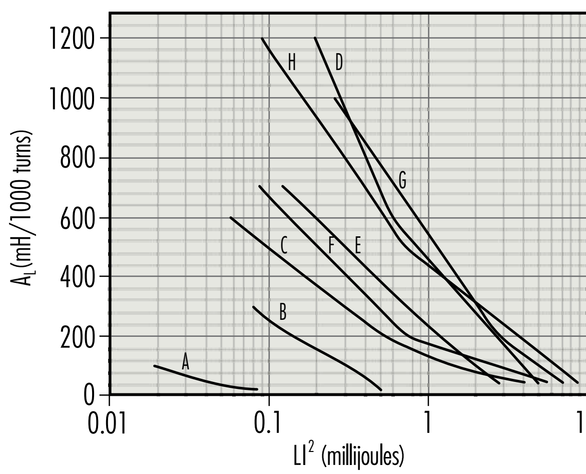
A - 42016
42020
B - 42614
C - 42610
42620
42625
43214
D - 43220
43230
E - 43535
44040
F - 45050

LAMINATION SIZE E CORES



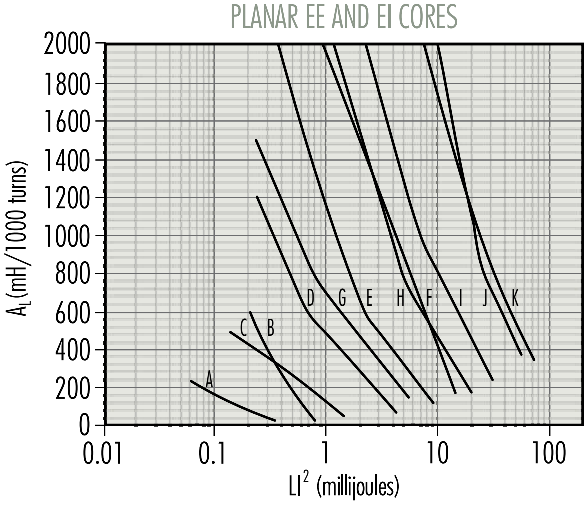
A - 41203
B - 41707
C - 41808
D - 42510
E - 43009
43515
F - 44317
G - 44033
H - 44011
44016
I - 44020
44022
44721
J - 45528
45530
47228
48020
45724
46016
K - 46527
47133
L - 49928

E CORES



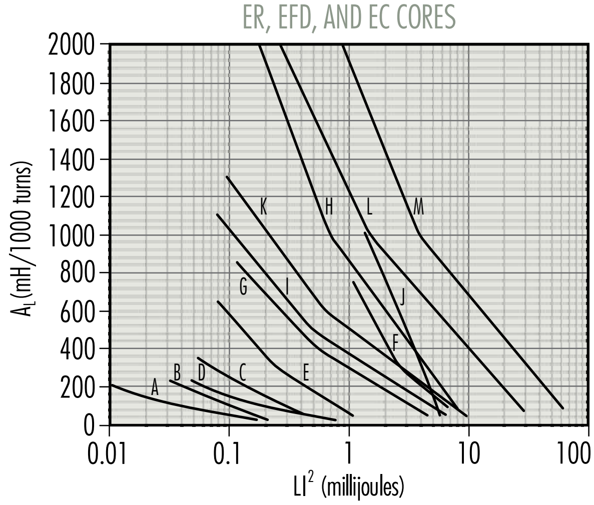
A - 40904
B - 41205
C - 42513
42515
D - 42520
42530
E - 41810
F - 43007
G - 42526
H - 42530
43520

PLANAR EE AND EI CORES



A - 41425 (EE, EI)
41434 (EE, EI)
B - 41805 (EE, EI)
C - 42107 (EE, EI)
D - 42216 (EE, EI)
E - 43208 (EE, EI)
43616 (EE, EI)
F - 43808 (EE, EI)
G - 44008 (EE, EI)
H - 44308 (EE, EI)
44310 (EE, EI)
I - 45810 (EE, EI)
J - 46410 (EE, EI)
K - 49938 (EE)

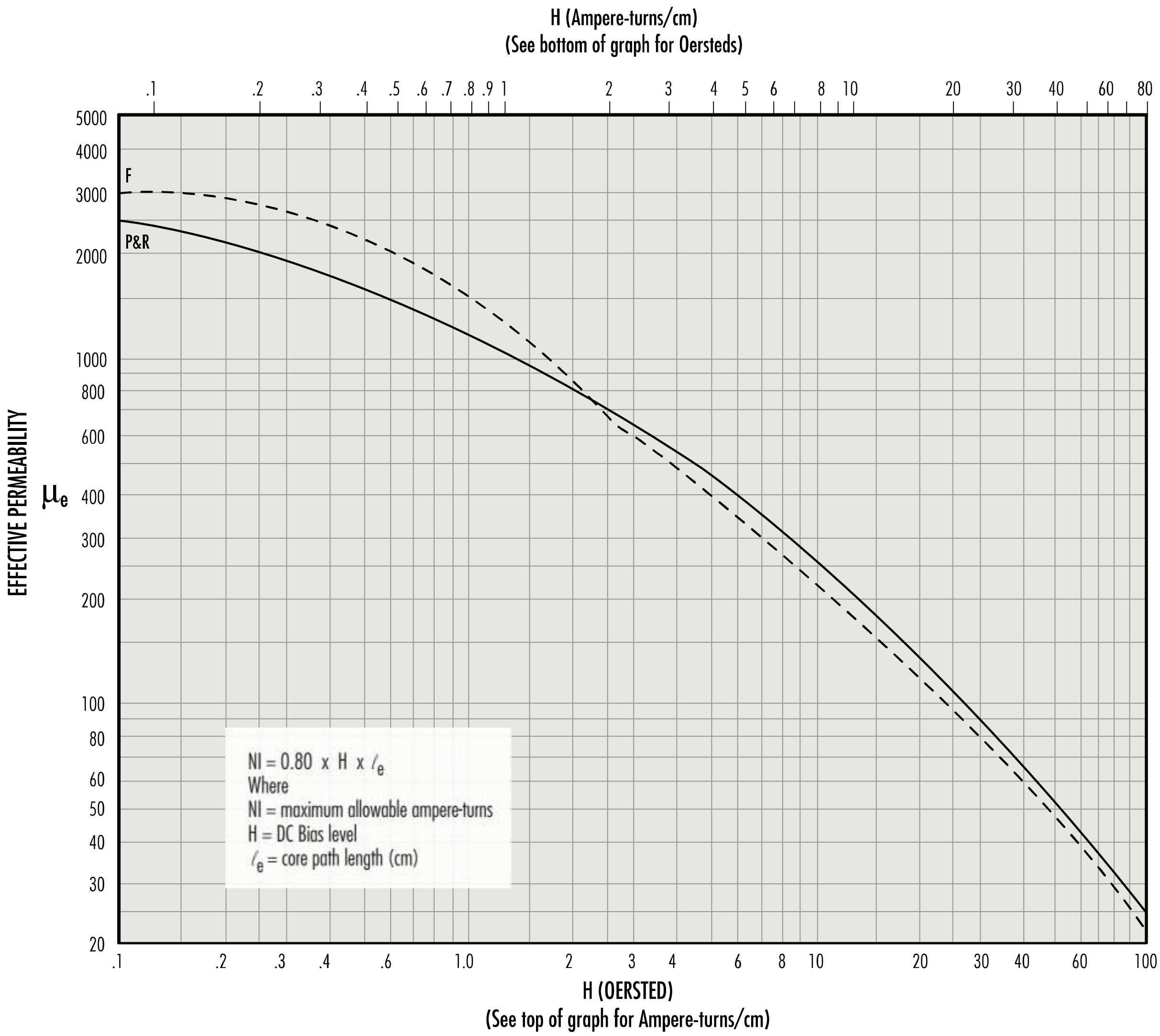
ER, EFD, AND EC CORES



A - 41009 (EFD)
B - 40906 (ER)
41126 (ER)
41212 (EFD)
C - 41308
41426 (ER)
D - 41515 (EFD)
E - 41826 (ER)
F - 42517
42521 (ER)
G - 42313 (ER)
42523 (EFD)
H - 43021 (ER)
44119 (EC)
I - 42014 (ER)
43030 (EFD)
J - 43225 (ER)
K - 43517 (EC)
L - 45224 (EC)
M - 47035 (EC)

Inductor Design

DC BIAS DATA — FOR GAPPED APPLICATIONS



The above curves are limit curves, up to which *effective permeability* remains constant. They show the maximum allowable DC bias, in ampere-turns, without a reduction in inductance. Beyond this level (see insert), inductance drops rapidly.

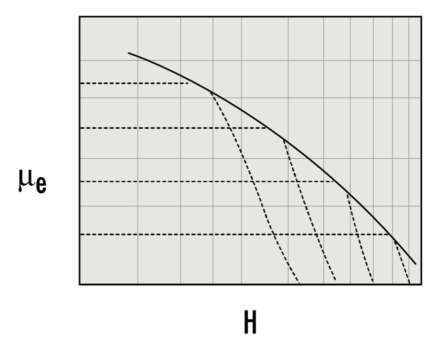
Example: How many ampere-turns can be supported by an R42213A315 pot core without a reduction in inductance value?
$\ell_e = 3.12$ cm $\mu_e = 125$

Maximum allowable H = 25 Oersted (from the graph above)
NI (maximum) = $0.80 \times H \times \ell_e$ = 62.4 ampere-turns
or (Using top scale, maximum allowable H = 20 A·T/cm.)
NI (maximum) = A·T/cm x ℓ_e
= 20 x 3.12
= 62.4 A·T

$$\mu_e = \frac{A_L \bullet \ell_e}{4\pi A_e}$$

$$\frac{1}{\mu_e} = \frac{1}{\mu_i} + \frac{\ell_g}{\ell_e}$$

A_e = effective cross sectional area (cm^2)
A_L = inductance/1,000 turns (mH)
μ_i = initial permeability
ℓ_g = gap length (cm)



Inductance falls off rapidly above the limit curve. The dashed lines illustrate the μ_e curve for individual gapped core sets.

Transformer Design

Magnetics offers two methods to select a ferrite core for a power application.

CORE SELECTION BY POWER HANDLING CAPACITY

The Power Chart characterizes the power handling capacity of each ferrite core based upon the frequency of operation, the circuit topology, the flux level selected, and the amount of power required by the circuit. If these four specifics are known, the core can be selected from the Power Chart on page 68.

CORE SELECTION BY WaAc PRODUCT

The power handling capacity of a transformer core can also be determined by its WaAc product, where Wa is the available core window area, and Ac is the effective core cross-sectional area. Using the equation shown below, calculate the WaAc product and then use the Area Product Distribution (WaAc) Chart to select the appropriate core.

$$WaAc = \frac{P_o D_{cma}}{K_t B_{max} f}$$

WaAc = Product of window area and core area (cm^4)

P_o = Power Out (watts)

D_{cma} = Current Density (cir. mils/amp) Current density can be selected depending upon the amount of heat rise allowed. 750 cir. mils/amp is conservative; 500 cir. mils is aggressive.

B_{max} = Flux Density (gauss) selected based upon frequency of operation. Above 20 kHz, core losses increase. To operate ferrite cores at higher frequencies, it is necessary to operate the core flux levels lower than ± 2 kG. The Flux Density vs. Frequency chart shows the reduction in flux levels required to maintain 100 mW/cm^3 core losses at various frequencies, with a maximum temperature rise of 25°C for a typical power material, Magnetics P material.

A_c = Core area in cm^2

f = frequency (hertz)

K_t = Topology constant (for a space factor of 0.4)

V = Voltage

I_p = Primary current

I_s = Secondary current

N_p = Number of turns on the primary

N_S = Number of turns on the secondary

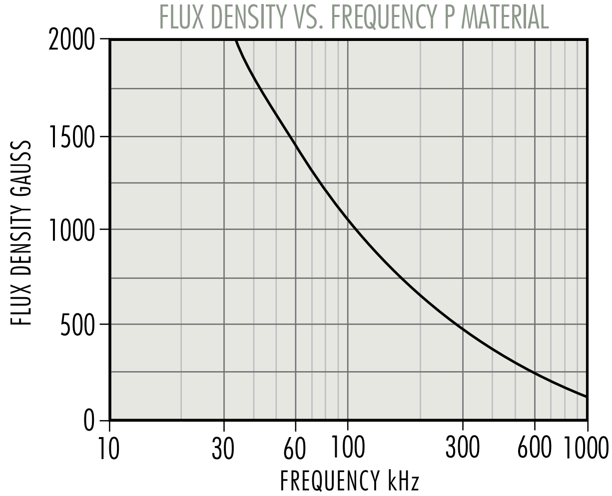
TOPOLOGY CONSTANTS K_t

Forward converter = 0.0005
Half-bridge = 0.0014
Flyback = 0.00033 (single winding)
Push-Pull = 0.001
Full-bridge = 0.0014
Flyback = 0.00025 (multiple winding)

For individual cores, WaAc is listed in this catalog under "Magnetic Data."

The WaAc formula was obtained from derivations in Chapter 7 of A. I. Pressman's book, "Switching Power Supply Design. Choice of B_{max} at various frequencies, D_{cma} and alternative transformer temperature rise calculations are also discussed in Chapter 7 of the Pressman book.

FLUX DENSITY VS. FREQUENCY P MATERIAL



Once a core is chosen, the calculation of primary and secondary turns and wire size is readily accomplished.

$$N_p = \frac{V_p \times 10^8}{4BA_c f} \qquad N_s = \frac{V_s}{V_p} N_p$$

$$I_p = \frac{P_{in}}{V_{in}} \qquad I_s = \frac{P_{out}}{V_{out}}$$

$KWa = N_p A_{wp} + N_s A_{ws}$
Where
A_{wp} = primary wire area A_{ws} = secondary wire area
Assume K = .4 for toroids; .6 for pot cores and E-U-I cores
Assume $N_p A_{wp}$ = 1.1 $N_s A_{ws}$ to allow for losses and feedback winding

$$\text{efficiency } e = \frac{P_{out}}{P_{in}} = \frac{P_{out}}{P_{out} + \text{wire losses} + \text{core losses}}$$

$$\text{Voltage Regulation } (\%) = \frac{V_{no\ load} - V_{full\ load}}{V_{full\ load}} \times 100$$

Typical Power Handling Chart

Power in Watts				Pot, RS, DS	E Cores	RM, PQ, EP	UU, UI, UR	ETD, EER, EC	EFD, Planar	Toroid
20 kHz	50 kHz	100 kHz	250 kHz							
2	3	4	7	41811 RS DS PC	41205 EE 41707 EE	41313 EP 41812 RM 41912 RM			42107 EE 41805 EE	40907 TC 41406 TC 41303 TC 41435 TC 41304 TC 41206 TC 41506 TC 41407 TC 41405 TC 41305 TC
5	8	11	21	41814 PC 42311 RS DS HS	41808 EE	41717 EP 42013 RM 42016 PQ 42610 PQ			42019 EFD 42216 EI 42214 EI 43208 EI	41306 TC 41607 TC 41450 TC 41410 TC 41605 TC 41610 TC 41606 TC
12	18	27	52		41810 EE 42510 EE	42316 RM				
13	20	29	56	42213 PC		42614 PQ				
15	22	32	62	42318 RS DS HS					42214 EE	
18	28	40	78			42020 PQ			42523 EFD	
19	30	42	83	42616 RS DS HS	42513 EE 42515 EI	42120 EP 43214 PQ	42515 UI		42216 EE 43618 EI 42217 EE 44008 EI	42106 TC 41809 TC
26	42	58	113						43208 EE	42206 TC
28	45	63	122		42520 EE				43030 EFD	
30	49	67	131	42616 RS PC		42620 PQ				42109 TC
33	53	74	144		42515 EE	42819 RM				42207 TC
40	61	90	175		42526 EE 43007 EE					42506 TC
42	70	94	183	43019 HS		42625 PQ			43618 EE	
48	75	108	210	42823 PC 43019 RS DS PC	43009 EE		42512 UU 42515 UU	42929 ETD	44008 EE	42507 TC
60	97	135	262		42530 EE 43515 EE	43220 PQ		43517 EC	43808 EI	42212 TC
70	110	157	306	43622 DS HS		43723 RM	42220 UU 42530 UU	42814 EER 42817 EER 43434 ETD		42508 TC 42908 TC 42712 TC
105	160	235	460	43622 RS	44011 EE 44317 EE				44308 EI 44310 EI	
120	195	270	525	43622 PC		43230 PQ			43808 EE	43806 TC
130	205	290	570		43520 EE	44230 RM		44119 EC	43809 EE	
150	240	337	656		44016 EE 44020 EI			43521 EER 43939 ETD	44308 EE	43113 TC 42915 TC
200	310	450	875						44310 EE	43610 TC

Typical Power Handling Chart

Power in Watts				Pot, RS, DS	E Cores	RM, PQ, EP	UU, UI, UR	ETD, EER, EC	EFD, Planar	Toroid
20 kHz	50 kHz	100 kHz	250 kHz							
220	350	495	962		44721 EE		44119 UR			
230	350	550	1073	44229 RS DS		43535 PQ	44121 UR	44013 EER		
260	400	585	1137							43813 TC
280	430	630	1225	44229 PC	44020 EE			44216 EER		
300	450	675	1312					44444 ETD 44818 EER 45224 EC	45810 EI	43615TC
340	550	765	1487		44033 EE		44125 UR			
360	580	810	1575		44022 EE	44040 PQ		45418 EER		43620 TC
410	650	922	1793		44033 EE 45724 EE		44130 UR	44821 EER 44949 ETD	46410 EI	44416 TC 44419 TC 43825 TC
550	800	1237	2406		46016 EE					44015 TC 44715 TC
650	1000	1462	2843			45050 PQ			45810 EE	
700	1100	1575	3062		45528 EE		45716 UR	45454 ETD	46410 EE	44920 TC 44916 TC
900	1500	2000	3900		45530 EE					44925 TC
1000	1600	2250	4375	43428 UG	47228 EE 46022 EE		45917 UR	45959 ETD 47035 EC		46013 TC 46113 TC
1600	2600	3700	7215				46420 UR			44932 TC 46019 TC
2000	3000	4500	8750		46527 EE 47133 EE 48020 EE					46325 TC 46326 TC 47313 TC
2800	4200	6500	12675				49316 UI 49316 UU		49938 EE	48613 TC 48626 TC 47325 TC 49715 TC 48619 TC 49718 TC 48625 TC
11700	19000	26500	51500		49928 EE		49330 UU 49332 UU 49920 UU 49925 UI 49925 UU			49725 TC 49740 TC

Ferrite Core selection listed by typical Power Handling Capabilities (Chart is for Power Ferrite Materials, F, P, R, L and T, Push-Pull Square wave operation)

Wattage values shown above are for push-pull converter design. De-rate by a factor of 3 or 4 for flyback. De-rate by a factor of 2 for feed-forward converter.
Example: For a feed-forward converter to be used at 300 watts select a core that is rated at 600 watts based on the converter topology.

Note: Assuming core loss to be approximately 100 mW/cm^3, B Levels used in this chart are:
@ 20 kHz - 200 mT, 2000 gauss; @ 50 kHz - 130 mT, 1300 gauss; @ 100 kHz - 90 mT, 900 gauss; @ 250 kHz - 70 mT, 700 gauss

Area Product Distribution (WaAc) Chart

WaAc (cm^4)	RS, DS, HS	E	EC, EER, EFD, ETD	EP, RM	ER	Planar	Pot	PQ	TC	U, UR
<0.001									40200 TC 40301 TC 40502 TC	
0.001									40401 TC 40402 TC 40503 TC 40601 TC	
0.002		40904 EE					40704 UG			
0.003					40906 EE		40905 UG		40603 TC	
0.004			41009 EFD		41126 EE					
0.005				40707 EP						
0.006					41308 EI		41107 UG			
0.008						41434 EI			40705 TC	
0.01			41212 EFD	41010 EP 41110 RM	41308 EE 41426 EE	41425 EE	41109 UG		41003 TC	41106 UI
0.02	41408 RS DS HS	41203 EE	41515 EFD	41510 RM		41434 EE	41408 UG		41005 TC	41106 UU
0.03		41205 EE 41707 EE		41313 EP	41826 EE	42107 EI 41805 EI			40907 TC	
0.04						41805 EI			41303 TC 41435 TC	
0.05	41811 HS			41812 RM	42313 EE				41206 TC 41304 TC 41405 TC 41407 TC 41506 TC	
0.06				41717 EP 41912 RM		42107 EE	41410 UG		41305 TC	
0.07	41811 RS DS				42014 EI	42107 EE 41805 EE	41811 UG	42610 UG	41306 TC 41406 TC	
0.08	42311 DS HS	41808EE			42517EI				41450TC	
0.09			42019 EFD				41814 UG			
0.1	42311 RS	41810 EE			42014 EE	42216 EI			41605 TC	
0.2	42318 RS DS HS	42510 EE 42515 EI	42523 EFD	42013 RM 42120 EP 42316 RM	42517 EE 43021 EI	42214 EI	42213 UG	42016 UG 42020 UG 42614 UG	41606 TC 41607 TC 41410 TC 41610 TC	
0.3	42616 RS DS HS	42513 EE	43030 EFD		42521 EE 43225 EE	43618 EI 42216 EE 42214 EE		43214 UG	41809 TC 42106 TC	42515 UI
0.4		42526 EE		42819 RM		42217 EE 43208 EI 44008 EI	42616 UG	42620 UG	42109 TC 42206 TC	
0.5		42520 EE 43007 EE	42814 EER		43021 EE				42207 TC	
0.6	43019 DS HS	42515 EE 43009 EE				43618 EE	42823 UG	42625 UG		42220 UU 42515 UU
0.7	43019 RS	42530 EE	42929 EFD 42817 EER			43208 EE	43019 UG		42507 TC	
0.8			43517 EC			44008 EE		43220 UG	42506 TC 42212 TC	42512 UU
0.9						43808 EI			42508 TC	

Area Product Distribution (WaAc) Chart

WaAc (cm^4)	RS, DS, HS	E	EC, EER, EFD, ETD	EP, RM	ER	Planar	Pot	PQ	TC	U, UR
<1	43622 RS DS HS	43515 EE 44011 EE 44020 EI	43434 ETD	43723 RM		44308 EI			42712 TC 42908 TC	42530 UU
2		44016 EE 44317 EE 43520 EE	43521 EER 43939 ETD 44013 EER 44119 EC	44230 RM		44310 EI 43808 EE	43622 UG	43230 UG	42915 TC 43113 TC 43806 TC	
3	44229 RS DS	44721 EE	44216 EER 44818 EER			43809 EE 44308 EE		43535 UG	43610 TC 43813 TC	44119 UR 44121 UR
4		44020 EE 44022 EE	44444 ETD 44821 EER 45224 EC 45418 EER			44310 EE	44229 UG		43615 TC	44125 UR
5						45810 EI		44040 UG	43620 TC 44416 TC	44130 UR
6		44033 EE 46016 EE	44949 ETD			46410 EI			44419 TC	
7		45724 EE							43825 TC 44015 TC	
8						45810 EE		45050 UG	44715 TC	
9			45454 ETD						44920 TC	45716 UR
10		45528 EE								
11						46410 EE			44916 TC	
12		45530 EE								
13			47035 EC						44925 TC	
14			45959 ETD							45917 UR
15		47228 EE								
16									46013 TC 46113 TC	
21		46022 EE							44932 TC	
22										46420 UU
23		47133 EE					43428 UG			
24		46527 EE								
25									46019 TC 47313 TC	
34		48020 EE							46325 TC 46326 TC	
46									48613 TC	49316 UI
51						49938 EE			47325 TC	
61										49925 UI
70									48619 TC	
91		49928 EE							48625 TC 48626 TC 49715 TC	49316 UU
106									49718 TC	
121										49925 UU
171									49725 TC	
286										49920 UU
372									49740 TC	