COMPONENTS DIVISION

TECHNICAL BULLETIN

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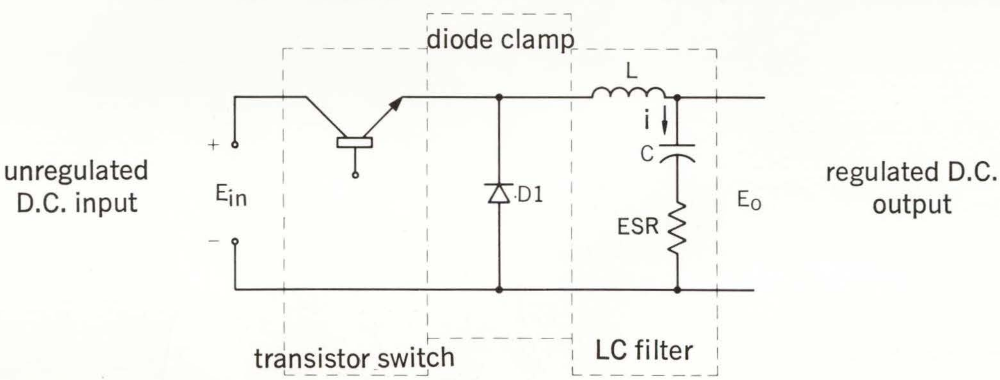
MAGNETICS®
A Division of Spang and Company

INDUCTOR DESIGN IN SWITCHING REGULATORS

Better efficiency, reduced size, and lower costs have combined to make the switching regulator a viable method for converting unfiltered D. C. input voltages into regulated D. C. outputs. This brochure describes the switching regulator and presents design information. In particular, MAGNETICS® Ferrite and Molypermalloy Powder cores used for the power inductor are highlighted.

DESCRIPTION



A typical circuit consists of three parts: transistor switch, diode clamp, and an LC filter. An unregulated D. C. voltage is applied to the transistor switch which usually operates at a frequency of 1 to 50 kilohertz. When the switch is ON, the input voltage, E_{in}, is applied to the LC filter, thus causing current through the inductor to increase; excess energy is stored in the inductor and capacitor to maintain output power during the OFF time of the switch. Regulation is obtained by adjusting the ON time, t_{on}, of the transistor switch, using a feedback system from the output. The result is a regulated D. C. output, expressed as:

$$E_{out} = E_{in}\, t_{on}\, f \qquad (1)$$

COMPONENT SELECTION

The switching system consists of a transistor and a feedback from the output of the regulator. Transistor selection involves two factors — (1) voltage ratings should be greater than the maximum input voltage, and (2) the frequency cut-off characteristics must be high compared to the actual switching frequency to insure efficient operation. The feedback circuits usually include operational amplifiers and comparators. Requirements for the diode clamp are identical to those of the transistor. The design of the LC filter stage is easily achieved. Given (1) maximum and minimum input voltage, (2) required output, (3) maximum allowable ripple voltage, (4) maximum and minimum load currents, and (5) the desired switching frequency, the values for the inductance and capacitance can be obtained. First, off-time (t_{off}) of the transistor is calculated.

$$t_{off} = (1 - E_{out}/E_{in\ max}) / f \qquad (2)$$

When E_{in} decreases to its minimum value,

$$f_{min} = (1 - E_{out}/E_{in\ min}) / t_{off} \qquad (3)$$

With these values, the required L and C can be calculated.

Allowing the peak to peak ripple current (Δi) through the inductor to be given by

$$\Delta i = 2 \cdot I_{o\ min} \qquad (4)$$

the inductance is calculated using

$$L = E_{out}\ t_{off} / \Delta i \qquad (5)$$

The value calculated for Δi is somewhat arbitrary and can be adjusted to obtain a practical value for the inductance.

The minimum capacitance is given by

$$C = \Delta i / 8 f_{min}\ \Delta e_o \qquad (6)$$

Finally, the maximum ESR of the capacitor is

$$ESR\ max = \Delta e_o / \Delta i \qquad (7)$$

INDUCTOR DESIGN

Two core materials are commonly used for the inductor in a switching regulator — Molypermalloy Powder and Ferrite. It is difficult to recommend one material over the other since the designer must take into consideration factors such as cost, volume, size and space limitations, and winding capabilities. Each material has advantages as described below.

MAGNETICS® Molypermalloy Powder cores have a distributed air gap structure, making them ideal for switching regulator applications. Their D. C. bias characteristics allow them to be used at high drive levels without saturating. They are available in 26 physical sizes (.140″ to 3.063″ O.D.) and 10 different permeabilities, described in Magnetics catalog MPP-303.

Ferrite E cores and pot cores offer the advantages of decreased cost and low core losses at high frequencies. For switching regulators, F or P materials are recommended because of their temperature and D. C. bias characteristics. By adding air gaps to these ferrite shapes, the cores can be used efficiently while avoiding saturation. Magnetics produces many sizes and shapes to suit a variety of needs. Hardware is also available for most parts. Detailed descriptions are covered in Magnetics catalog FC-305.

CORE SELECTION PROCEDURE

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 application must be known:
(1) Inductance required with DC bias,
(2) DC current.

For Molypermalloy Powder Cores:

1. Compute the product of LI^2 where:
   L = inductance required with DC bias (millihenries)

   I = maximum DC output current = I_o max + Δi
2. Locate the LI^2 value of the Core Selector Chart.

The Magnetics DC Bias Core Selector Chart on page 5 will quickly yield optimum permeability and smallest core size for switching regulator applications. This chart is based on a permeability reduction of less than 20% with DC bias and typical winding factors of 50%. Follow this coordinate to the intersection with the first core size that lies within the family of solid permeability lines. This core size is the smallest that can be used.

3. Any solid permeability line that passes through the intersection point of the LI^2 and core size coordinates, or crosses the LI^2 coordinate below this intersection point, may be used. Use the highest permeability indicated, as this choice will yield the lowest winding factor.

4. Inductance, core size and permeability are now known.

The nominal inductance (millihenries per thousand turns) can be obtained from the Inductance Table on Page 4 in catalog MPP 303. With this information, calculate the number of turns needed to obtain the required inductance (Use Scale A of Core Calculator).

5. Choose the correct wire size using the Wire Table in catalog MPP 303.

For Ferrite Pot Cores and E Cores:

1. Compute the product of LI^2 where:
   L = inductance required with DC bias (millihenries)

   I = maximum DC output current = I_o max + Δi

2. Locate the LI^2 value on the Ferrite Core Selector charts on pages 6 and 7. Follow this coordinate 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. If possible, it is advisable to use the standard gapped cores because of their availability. These are indicated by dotted lines on the charts and can be found in catalog FC305.

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. Choose the wire size from the wire table in Section 6 of catalog FC305 using 500 circular mils per amp.

DESIGN EXAMPLE

Choose a core for a switching regulator with the following requirements:

E_o	=	5 volts
Δe_o	=	.5 volts
$I_{o\ max}$	=	6 amps
$I_{o\ min}$	=	1 amp
$E_{in\ min}$	=	25 volts
$E_{in\ max}$	=	35 volts
f	=	20 KHz

1. Calculate the off-time and minimum switching, f_{min}, of the transistor switch using equations 2 and 3.

$t_{off} = (1 - 5/35)/20{,}000 = 4.3 \times 10^{-5}$

seconds and

$f_{min} = (1 - 5/25)/4.3 \times 10^{-5}$ seconds $= 18{,}700$ Hz.

2. Let the maximum ripple current, Δi, through the inductor be

$\Delta i = 2\ (1) = 2$ amperes

by equation 4.

3. Calculate L using equation 5.

$L = 5\ (4.3 \times 10^{-5})\ /2 = .107$ millihenries

4. Calculate C and ESR max using equations 6 and 7.

$C = 2/8\ (18700)\ (.5) = 26.7\ \mu$ farads

and ESR max $= .5/2 = .25$ ohms

5. The product of $LI^2 = (.107)\ (8)^2 = 6.9$ millijoules.

Molypermalloy Core Design

6. Following this coordinate, the first part number that falls within the solid line permeability family is 55548. (Note that part numbers in this chart are referenced to 125μ).

7. The intersection of the 6.9 coordinate and the 55548 size falls between the 26μ and 60μ curves. Only those permeability lines intersecting the LI^2 coordinate below the core intersection are usable.

8. Using the highest permeability indicated so as to yield the lowest winding factor, the 60μ core is chosen. The part number for a 55548 core in 60μ is 55071-A2.

9. The 55071-A2 core has a nominal inductance of 61 mH/1000T. The number of turns needed without DC bias is 42.

10. Using 500 circular mils/amp, this gives a wire size of 14.

A 55071-A2 core with 42 turns of #14 wire meets the design requirements.

Ferrite Core Design

6. Due to the many shapes available in ferrites, there can be several choices for the selection. Any core size that the LI^2 coordinate intersects can be used if the maximum A_L is not exceeded. Following the LI^2 coordinate, the choices are:

(a)	45224 EC 52 core,	A_L 315
(b)	45015 E core,	A_L 250
(c)	44229 solid center post core,	A_L 315
(d)	43622 pot core,	A_L 400
(e)	43230 PQ core,	A_L 250

7. Given the A_L, the number of turns needed for the required inductance is:

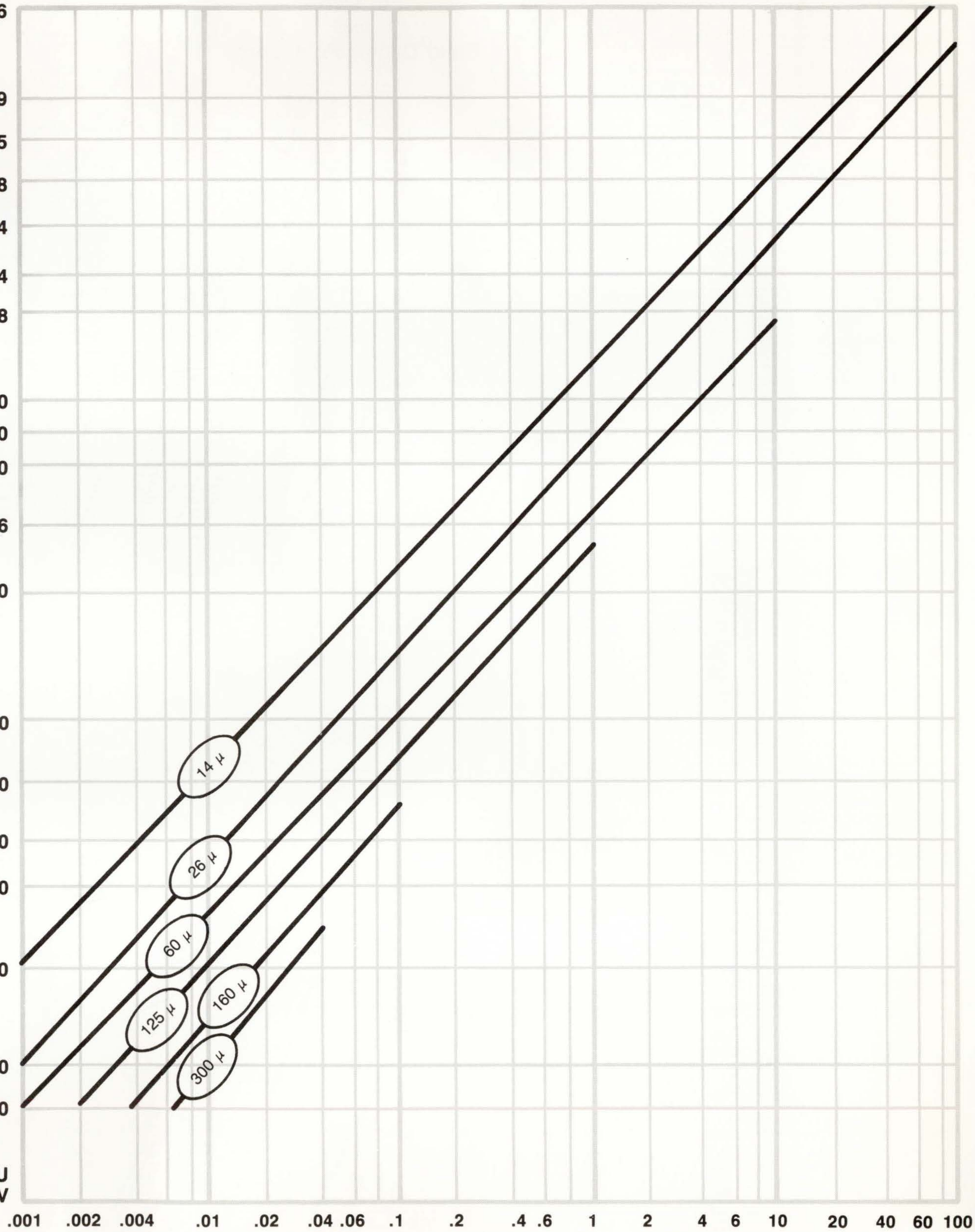
A_L	Turns
250	21
315	19
400	17

8. Use #14 wire.

MOLY PERMALLOY DC BIAS CORE SELECTOR CHART

See Page*	H/NI	Part No. (125μ)
82	.063	55866
80	.088	55109
78	.099	55715
74	.117	55438
72	.128	55254
70	.140	55324
66	.154	55548
64	.198	55930
62	.214	55350
60	.221	55310
58	.247	55206
56	.306	55120
54	.402	55050
52	.467	55130
50	.530	55040
46	.577	55280
44	.704	55030
42	.924	55270
38	.924	55020

*Catalog MPP-303U or MPP-303V

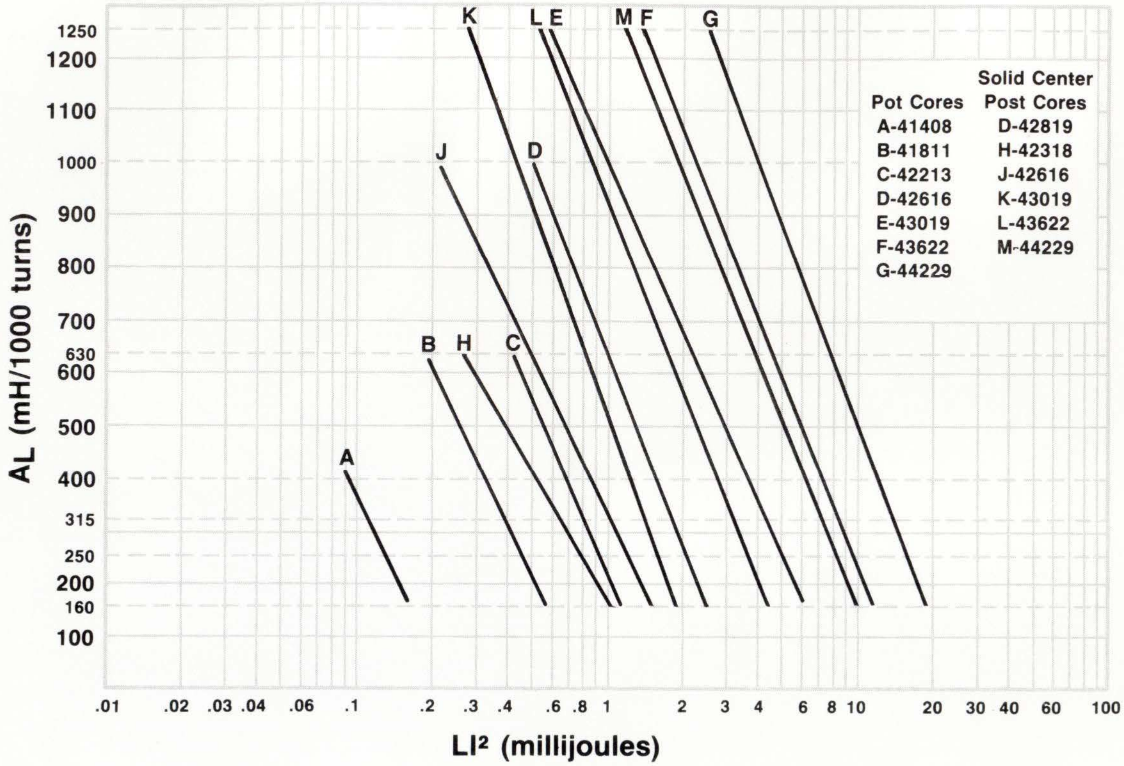


$L\,I^2$

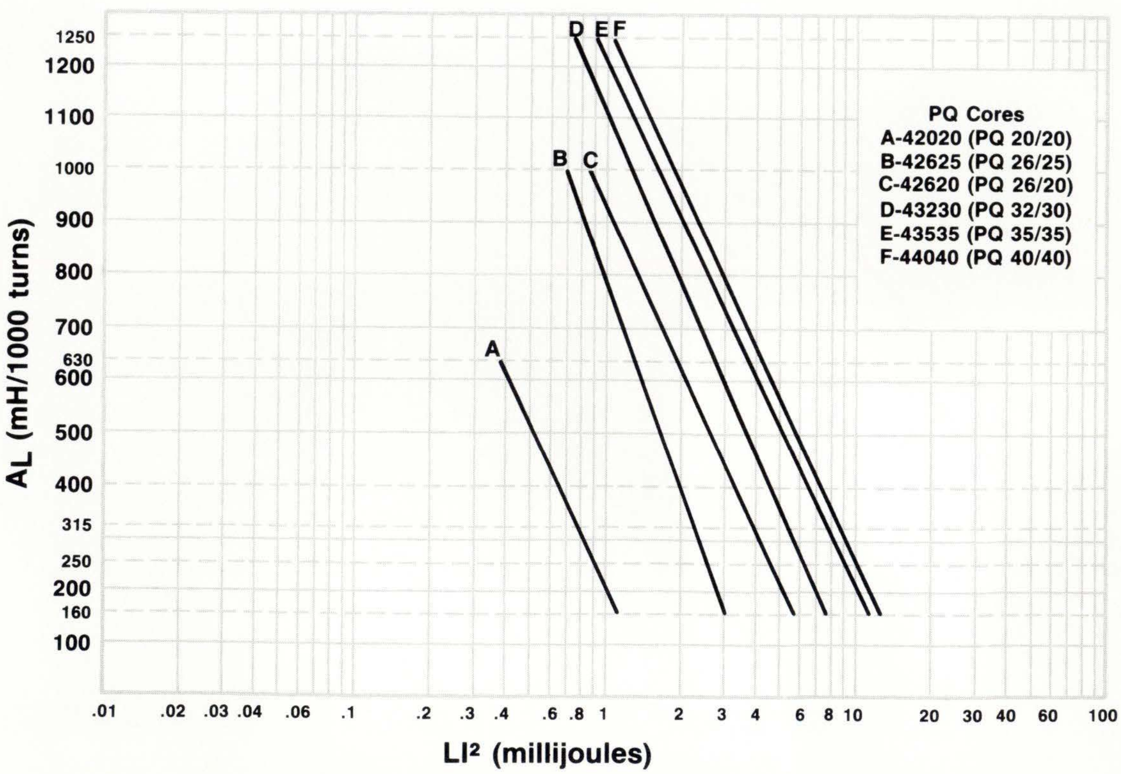
L = Inductance with DC bias (mh) **I = DC current (amperes)**

FERRITE DC BIAS CORE SELECTOR CHARTS

Pot Cores and Solid Center Post Cores

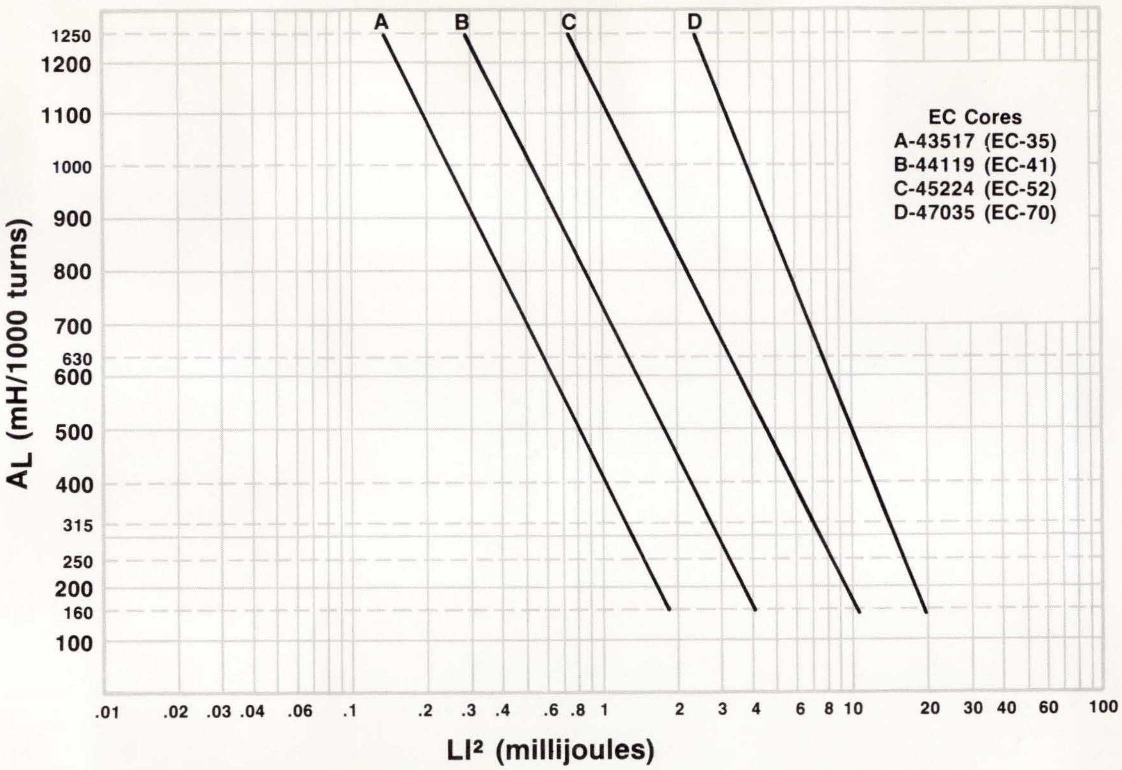


PQ Cores

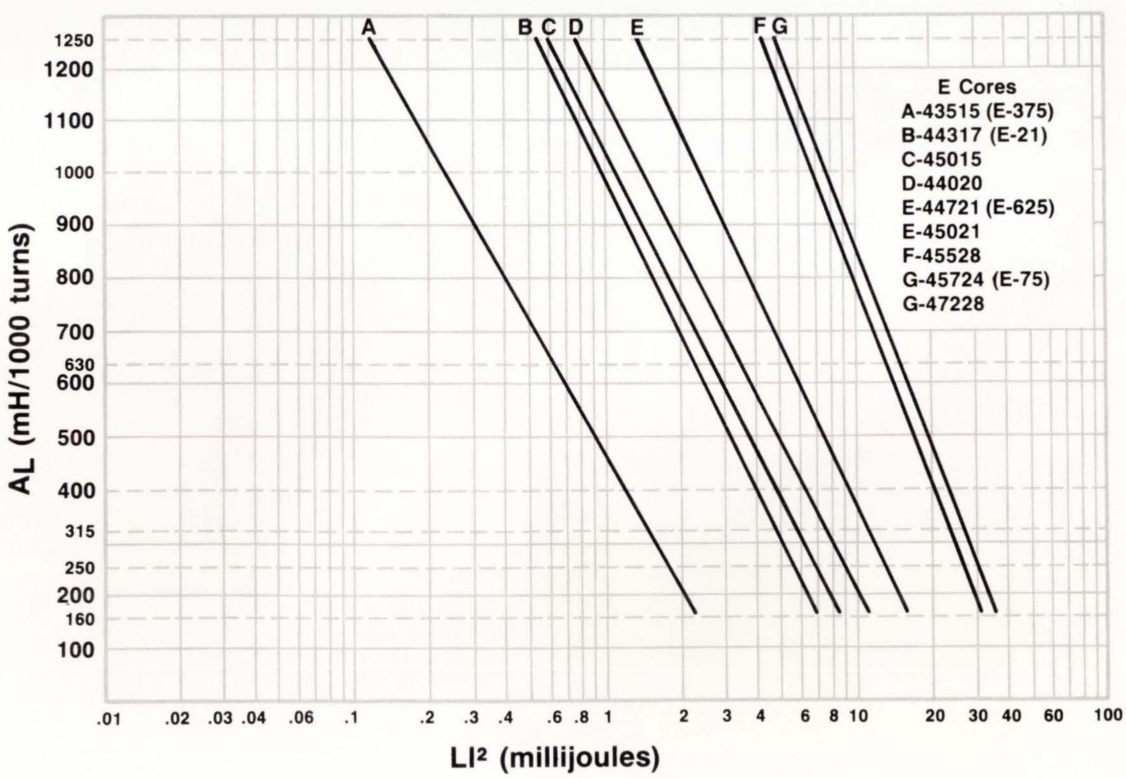


FERRITE DC BIAS CORE SELECTOR CHARTS

EC Cores



E Cores



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