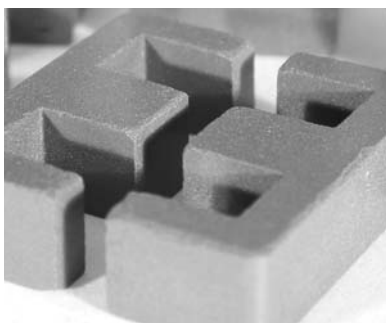




## Large Kool M $\mu$ <sup>®</sup> Core Shapes



### TECHNICAL BULLETIN

Ideal for high current inductors, large Kool M $\mu$  geometries (E cores, U Cores and Blocks) offer all the advantages of Kool M $\mu$  material, low core loss, excellent performance over temperature, near zero magnetostriction and soft saturation. Typical examples of high current inductors are Uninterruptible Power Supply (including transformerless UPS), large PFC chokes, traction and inverters for renewable energy (solar/wind/fuel cell conversion).

Available in various sizes (see Table 1), Kool M $\mu$  shapes compare favorably with gapped ferrites, powdered iron and silicon iron cores. In addition, for very large core requirements, these large shapes can be configured and bonded into a number of custom designs.

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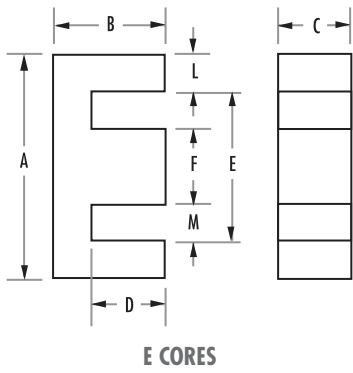
**TOLL-FREE: 1 800 245 3984**  
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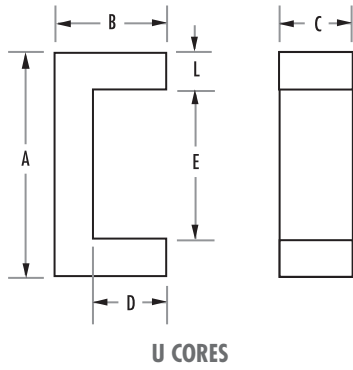
**MAGNETICS HONG KONG**  
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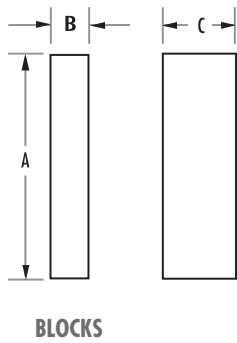
**EMAIL: [ASIASALES@SPANG.COM](mailto:ASIASALES@SPANG.COM)**



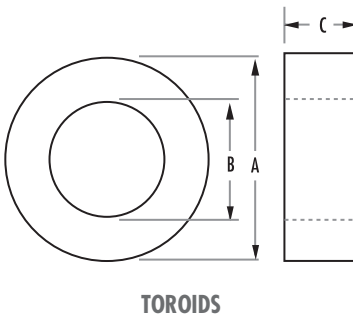
E CORES



U CORES



BLOCKS



TOROIDS

## DIMENSIONS (mm)

TABLE 1

E CORES	TYPE	A	B	C	D	E	F	L	M
	<b>E5528</b> DIN 55/21	54.9	27.6	20.6	18.5	37.5	16.8	8.4	10.3
	<b>E5530</b> DIN 55/25	54.9	27.6	24.6	18.5	37.5	16.8	8.4	10.3
	<b>E6527</b> Metric E65	65.1	32.5	27.0	22.2	44.2	19.7	10.0	12.1
	<b>E7228</b> F11	72.4	27.9	19.1	17.8	52.6	19.1	9.5	16.9
	<b>E8020</b> Metric E80	80.0	38.1	19.8	28.1	59.3	19.8	9.9	19.8
	<b>LE130</b>	130.0	32.5	54.0	22.2	108.4	20.0	10.0	44.2
	<b>LE145</b>	145.0	27.9	38.2	17.8	124.2	19.0	9.5	52.6
	<b>LE160</b>	160.0	38.1	39.6	28.1	138.4	19.8	9.9	59.3
U CORES	TYPE	A	B	C	D	E	L		
	<b>U5527</b>	54.9	27.6	16.3	17.0	33.9	10.5		
	<b>U5529</b>	54.9	27.6	23.2	17.0	33.9	10.5		
	<b>U6527</b>	65.1	32.5	27.0	22.2	44.2	10.0		
	<b>U6533</b>	65.1	32.5	20.0	20.0	40.1	12.5		
	<b>U7228</b>	72.4	27.9	19.1	17.8	52.6	9.5		
	<b>U7236</b>	72.4	35.6	20.9	21.7	44.6	13.9		
	<b>U8020</b>	80.0	38.1	19.8	28.1	59.3	9.9		
	<b>U8038</b>	80.0	38.1	23.0	22.7	49.3	15.4		
BLOCKS	TYPE	A	B	C					
	<b>B4741</b>	47.5	41.0	27.5					
	<b>B5528</b>	54.9	27.6	20.6					
	<b>B6030</b>	60.0	30.0	15.0					
TOROIDS	TYPE	A	B	C					
	<b>77111</b>	58.0	34.7	14.9					
	<b>77191</b>	58.0	25.6	16.1					
	<b>77908</b>	78.9	48.2	17.0					

## MAGNETIC DATA

TABLE 2

E CORES	TYPE	$A_L$ nH/TURN <sup>2</sup> (±8%)		$V_e$ (mm <sup>3</sup> )	$W_A$ (mm <sup>2</sup> )	PART NUMBER	
		26 $\mu$	$A_e$ (mm <sup>2</sup> )				
	<b>E5528</b>	116	350	123	43,100	381	<b>00K5528E026</b>
	<b>E5530</b>	138	417	123	51,400	381	<b>00K5530E026</b>
	<b>E6527</b>	162	540	147	79,400	537	<b>00K6527E026</b>
	<b>E7228</b>	130	368	137	50,300	602	<b>00K7228E026</b>
	<b>E8020</b>	103	389	185	72,100	1,110	<b>00K8020E026</b>
	<b>LE130</b>	254	1080	219	237,000	1,960	<b>00K130LE026</b>
	<b>LE145</b>	190	736	210	155,000	1,870	<b>00K145LE026</b>
	<b>LE160</b>	180	778	273	212,000	3,330	<b>00K160LE026</b>
U CORES	TYPE	26 $\mu$	$A_e$ (mm <sup>2</sup> )	$I_e$ (mm)	$V_e$ (mm <sup>3</sup> )	$W_A$ (mm <sup>2</sup> )	PART NUMBER
	<b>U5527</b>	67	172	168	28,896	921	<b>00K5527U026</b>
	<b>U5529</b>	85	244	168	40,992	921	<b>00K5529U026</b>
	<b>U6527</b>	89	270	219	59,100	1,630	<b>00K6527U026</b>
	<b>U6533</b>	82	250	199	49,750	1,284	<b>00K6533U026</b>
	<b>U7228</b>	74	184	210	38,600	1,540	<b>00K7228U026</b>
	<b>U7236</b>	87	290	219	63,510	1,545	<b>00K7236U026</b>
	<b>U8020</b>	64	195	273	53,200	2,740	<b>00K8020U026</b>
	<b>U8038</b>	97	354	237	83,898	1,793	<b>00K8038U026</b>
BLOCKS	TYPE	26 $\mu$	$A_e$ (mm <sup>2</sup> )	$I_e$ (mm)	$V_e$ (mm <sup>3</sup> )	$W_A$ (mm <sup>2</sup> )	PART NUMBER
	<b>B4741</b>	N/A	*	*	53,600	*	<b>00K4741B026</b>
	<b>B5528</b>	N/A	*	*	31,200	*	<b>00K5528B026</b>
	<b>B6030</b>	N/A	*	*	27,000	*	<b>00K6030B026</b>
TOROIDS	TYPE	26 $\mu$	$A_e$ (mm <sup>2</sup> )	$I_e$ (mm)	$V_e$ (mm <sup>3</sup> )	$W_A$ (mm <sup>2</sup> )	PART NUMBER
	<b>77111</b>	33	144	143	20,600	948	<b>0077111A7</b>
	<b>77191</b>	60	229	125	28,600	514	<b>0077191A7</b>
	<b>77908</b>	37	227	200	45,300	1,800	<b>0077908A7</b>

\*Dependent on design configurations. Contact Magnetics Application Engineering for assistance.

## MATERIALS AND DC BIAS

Large Kool M $\mu$  cores are available in three permeabilities, 26 $\mu$ , 40 $\mu$ , and 60 $\mu$ . The magnetic data for each 26 $\mu$  core is shown on Table 2, page 2. The most critical parameter of a switching regulator inductor material is its ability to provide inductance, or permeability, under DC bias. The chart below (Figure 1) shows the reduction of permeability as a function of DC bias. The distributed air gap of Kool M $\mu$  results in a soft inductance versus DC bias curve. In most applications, this swinging inductance is desirable since it improves efficiency, decreases the volume needed and accommodates a wide operating range. With a fixed current requirement, the soft inductance versus DC bias curve provides added protection against overload conditions.

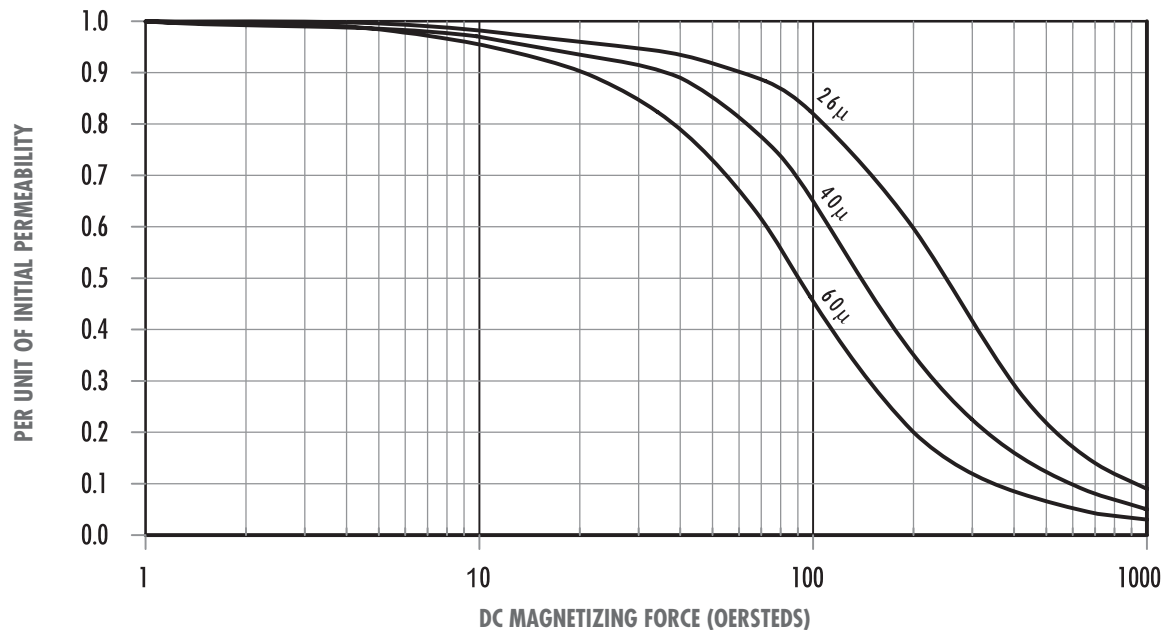


FIGURE 1

## LEAKAGE FLUX

Leakage Flux occurs when some of the magnetic field is not contained within the core structure. All transformers and inductors have some amount of leakage flux. In low permeability material the effect is that measured inductance is higher than the inductance calculated using the core parameters (see the equation below). The increase in measured inductance compared with calculated inductance, due to leakage, is strongly affected by the number of turns and the coil design.

$$L = \frac{.4 \pi \mu N^2 A_e 10^{-6}}{l_e} \quad \text{where: } \begin{array}{l} L = \text{inductance in mH} \\ \mu = \text{core permeability} \\ N = \text{number of turns} \\ A_e = \text{effective cross section in mm}^2 \\ l_e = \text{core magnetic path length in mm} \end{array}$$

Core dimensions also affect leakage flux. In the case of an E core, a core with a longer winding length will have less leakage than a core with a shorter winding length. Also, a core with less winding build will have more leakage than a core with more winding build. Magnetics Kool M $\mu$  E cores are tested for inductance factor ( $A_L$ ) with full, 100 turn coils.

## EXTERNAL LEAKAGE FIELD

Core shape affects the external leakage field. The E core shape, where most of the core surrounds the winding, has a greater external leakage field than the toroidal shape, where the winding surrounds the core. The external leakage field of the E core shape must be considered when using Kool M $\mu$  E cores or an E core assembly.

Kool M $\mu$  E cores should not be assembled with metallic brackets since the leakage flux may cause eddy current heating in the brackets. The leakage field must be considered when laying out the circuit board. Components susceptible to a stray magnetic field should be spaced away from the Kool M $\mu$  E core. For more information on this subject contact Magnetics Applications Engineering Group for a copy of a white paper, "Leakage Flux Considerations on Kool M $\mu$  E Cores".

**ADVANTAGES OF KOOL  $\mu$  COMPARED WITH GAPPED FERRITE SOLUTIONS ARE:**

- **Soft Saturation:** Ferrite must be designed in the safe flat area of the roll-off curve. Powder cores like Kool  $\mu$  are designed to exploit the controlled, partial roll-off in the material (Figure 3).
- **Flux Capacity:** With more than twice the flux capacity of ferrite, at a typical 50% roll-off design point, this can result in a 35% reduction in core size.
- **Temperature:** Flux capacity of ferrites decreases with temperature while Kool  $\mu$  stays relatively constant.
- **Fault-tolerance:** The soft saturation curve makes the Kool  $\mu$  design inherently fault-tolerant, whereas gapped ferrite is not.
- **Fringing Losses:** Do not occur with Kool  $\mu$ ; can be excessive with gapped ferrites.

## COMPARISON TO GAPPED FERRITE

Although high grade ferrite core losses are lower than Kool  $\mu$  core losses, ferrite often requires low effective permeability to prevent saturation at high current levels. Ferrite, with its high initial permeability, requires a relatively large air gap to get a low effective permeability. This large air gap results in gap loss, a complex problem which is often overlooked when comparing material loss curves. Simply put, gap loss can drastically increase total losses due to fringing flux around the air gap (Figure 2). The fringing flux intersects the copper windings, creating excessive eddy currents in the wire.

Gapped ferrite cores do have advantages over Kool  $\mu$  cores. Gapped ferrites typically have a  $\pm 3\%$  tolerance on inductance compared to Kool  $\mu$ 's  $\pm 8\%$ . Gapped ferrites are available in a wider selection of sizes and shapes. Since ferrite material can have a higher gapped effective permeability it is well suited for relatively low bias applications, such as feed forward transformers and low biased inductors.

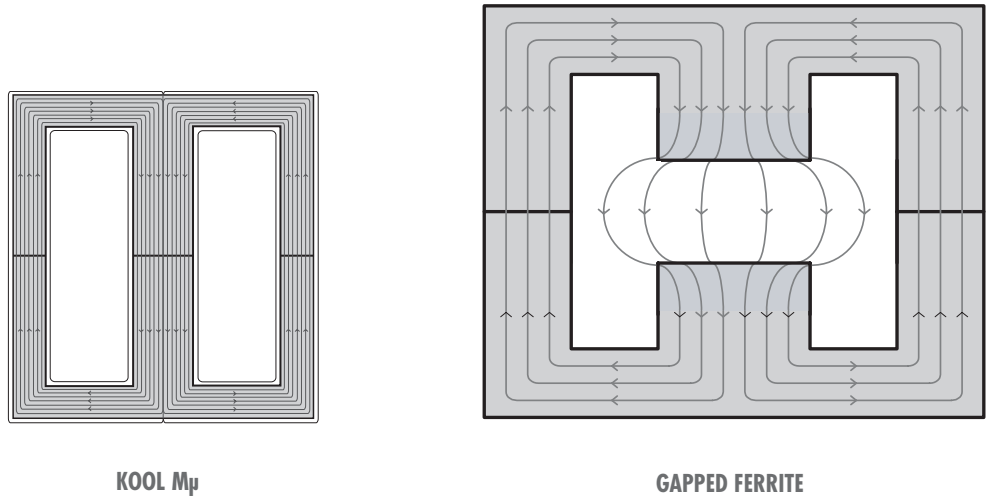


FIGURE 2

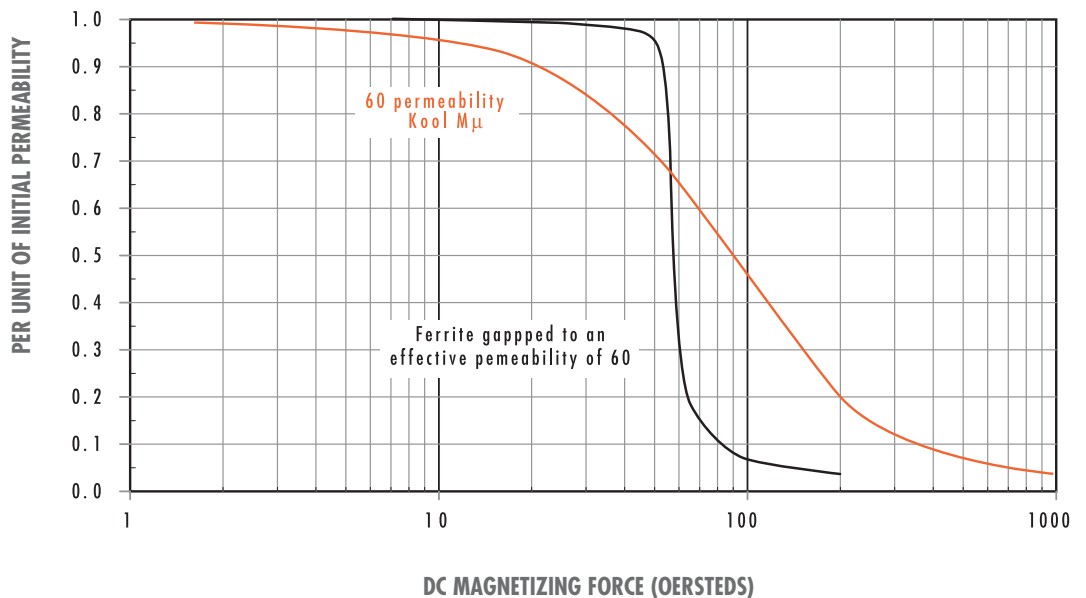


FIGURE 3

**ADVANTAGES OF KOOL M $\mu$  COMPARED WITH POWDERED IRON SOLUTIONS ARE:**

- **Core Losses:** Kool M $\mu$  offers lower core losses than powdered iron (Figure 4).
- **Near Zero Magnetostriction:** Kool M $\mu$  is ideal for eliminating audible frequency noise in filter inductors.
- **No Thermal Aging:** Kool M $\mu$  is manufactured without the use of organic binders. There is no thermal aging whatsoever in Kool M $\mu$ . All Kool M $\mu$  cores are rated for 200°C continuous operation.

## COMPARISON TO POWDERED IRON

Kool M $\mu$ , (Al, Si, Fe composition) offers similar DC bias characteristics when compared to powdered iron (pure Fe composition), see Figure 5. In addition to withstanding a DC bias, switching regulator inductors see some AC current, typically at 10 kHz to 300 kHz. This AC current produces a high frequency magnetic field, which creates core losses and causes the core to heat up. This effect is lessened with Kool M $\mu$ ; therefore inductors are more efficient and run cooler.

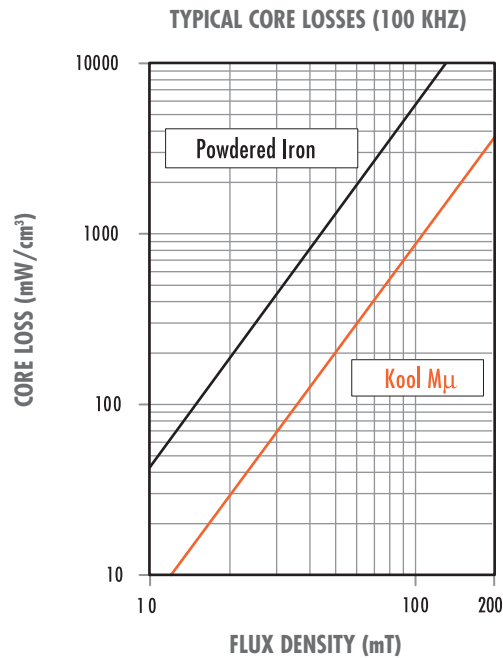


FIGURE 4

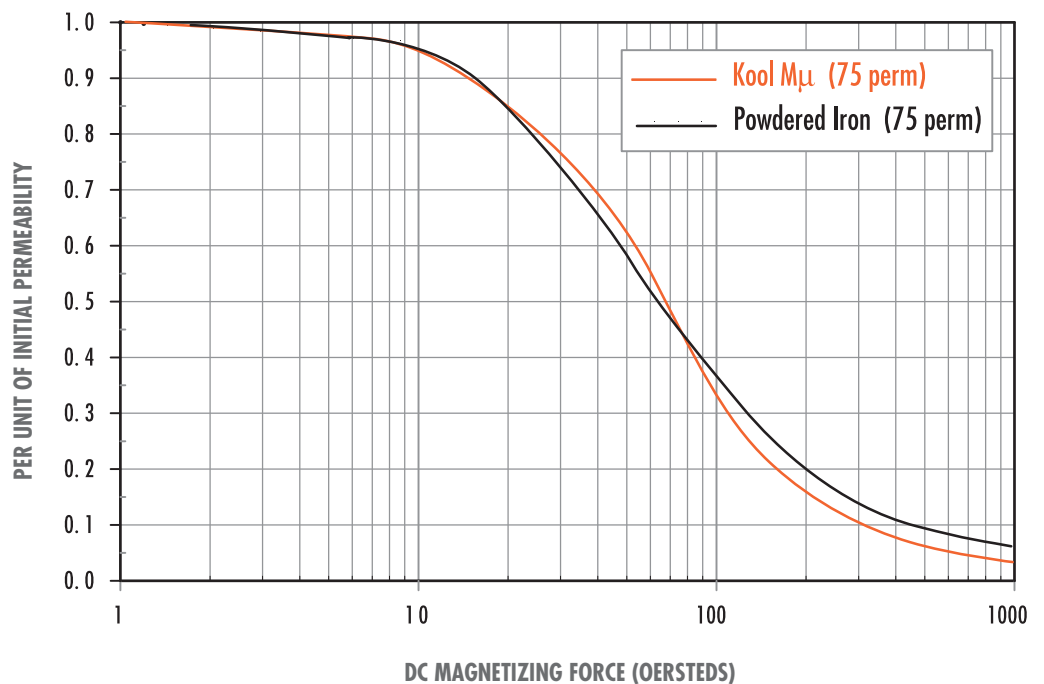


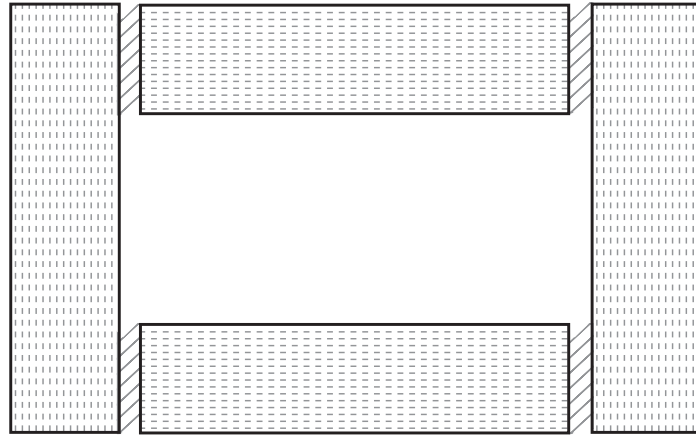
FIGURE 5

**ADVANTAGES OF KOOL M $\mu$  COMPARED WITH SILICON IRON SOLUTIONS ARE:**

- **Soft Saturation:** Silicon blocks have discrete gaps, unlike the distributed gaps of Kool M $\mu$ , so the onset of saturation with increasing current is much sharper. Kool M $\mu$  can be designed deep into the saturation curve, resulting in smaller inductors.
- **Core Losses:** Kool M $\mu$  is much lower in core losses than the silicon steel laminations. The difference generally becomes more dramatic as the frequency increases (Figure 7).
- **Temperature Stability:** The epoxies used in silicon steel assembly are not generally rated for 200°C operation as Kool M $\mu$  is.
- **Cost:** Kool M $\mu$  cores have a lower cost than similar size silicon steel blocks.

## COMPARISON TO SILICON STEEL

One approach to realizing large inductors is to utilize special grades of silicon iron laminations, often in a block or bar geometry, see Figure 6. The silicon iron has the advantage of higher saturation flux density. Kool M $\mu$  shapes (E cores, U cores and blocks) can also be configured for large inductor applications. See Special Designs section on page 8. Although silicon iron has the advantage of higher saturation flux density, Kool M $\mu$  offers the following benefits; soft saturation, significantly lower core losses, temperature stability and lower cost.



SILICON STEEL BLOCK CONFIGURATION

FIGURE 6

### CORE LOSS COMPARISON

#### 26 PERMEABILITY KOOL M $\mu$ VS. SILICON STEEL LAMINATION

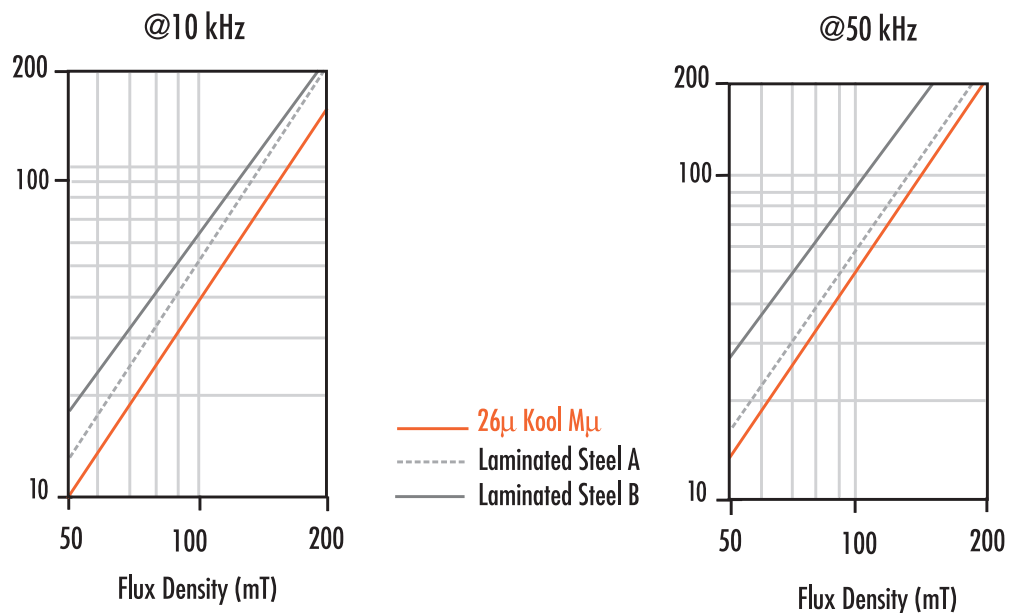


FIGURE 7

## CORE SELECTION

Only two parameters of the design application must be known: inductance required with DC bias, and the DC current. Use the following procedure to determine the core size and number of turns.

1. Compute the product of  $LI^2$ , where: L = inductance required with DC bias (mH) I = DC current (amperes).
2. Locate the  $LI^2$  value on the Core Selector Table (Table 3).
3. Inductance and core size are now known. Calculate the number of turns by using the following procedure:
  - a) The nominal inductance ( $A_L$  in  $nH/T^2$ ) for the core is obtained from Table 2. Determine the minimum nominal inductance by using the worst-case negative tolerance (-8%). With this information, calculate the number of turns needed to obtain the required inductance in mH by using:  $N = (L \times 10^6 / A_L)^{1/2}$ .
  - b) Calculate the bias in oersteds from:  $H = \frac{4 \pi NI}{l_e}$  (with  $l_e$  in mm).
  - c) From the Permeability vs. DC bias curve, determine the roll-off in per unit of initial permeability for the calculated bias level.
  - d) Increase the number of turns by dividing the initial number of turns (from step 3a) by the per unit value of initial permeability. This will yield an inductance close to the required value. A final iteration of turns may be necessary.
4. Choose a wire or foil size and verify that the window fill that results is manufacturable. Duty cycles below 100% allow smaller wire sizes and lower winding factors, but do not allow smaller core sizes.

CORE SELECTOR TABLE

TABLE 3

TYPE	$LI^2$
<b>E CORES</b>	
<b>E5528</b>	100-400
<b>E5530</b>	150-500
<b>E6527</b>	300-900
<b>E7228</b>	300-800
<b>E8020</b>	400-1200
<b>LE130</b>	3100-6300
<b>LE145</b>	2100-4300
<b>LE160</b>	4600-7700

TYPE	$LI^2$
<b>U CORES</b>	
<b>U5527</b>	300-650
<b>U5529</b>	350-800
<b>U6527</b>	1000-2700
<b>U6533</b>	500-1300
<b>U7228</b>	800-1700
<b>U7236</b>	800-1800
<b>U8020</b>	1500-2800
<b>U8038</b>	1000-2300
<b>TOROIDS</b>	
<b>77111</b>	100-300
<b>77191</b>	70-300
<b>77908</b>	300-800

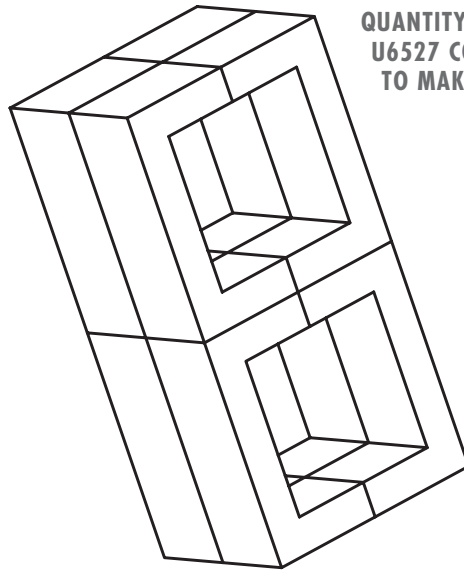
The above table is based on a winding factor of 60% and an AC current which is small relative to the DC current. The table is based on the nominal inductance of the chosen core size and a permeability of 26.

If a core is chosen for use with a large AC current relative to any DC current, such as a flyback inductor, a slightly larger size may be necessary. This will assist in reducing the operating flux density of the AC current that generates core losses.

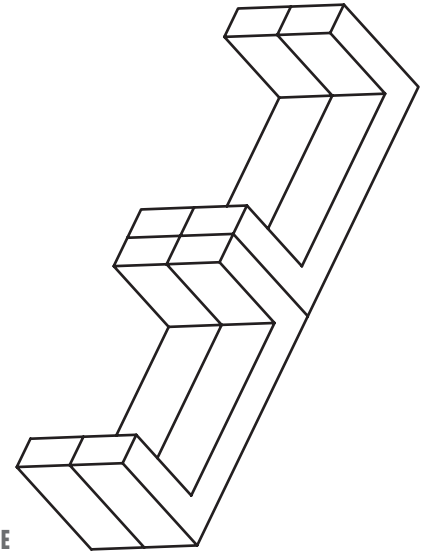
## SPECIAL DESIGNS

Many applications require a custom assembly or even a custom core. The material properties of Kool  $\mu$ , and the flexibility of these geometries make the core ideal for custom assembly.

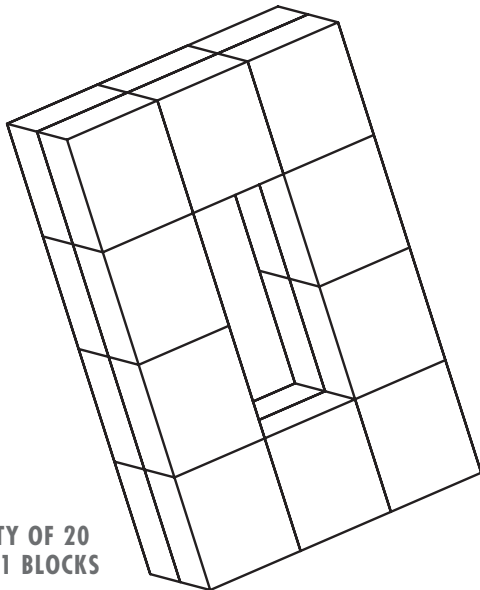
FIGURE 8



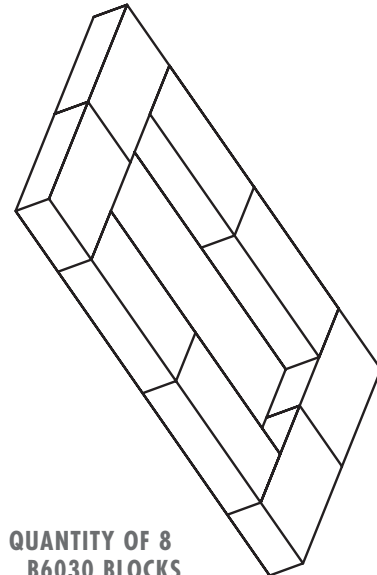
QUANTITY OF 8  
U6527 CORES STACKED  
TO MAKE (1) LE130 SET



QUANTITY OF 4  
U8020 CORES CONFIGURED  
TO MAKE (1) LE160 PIECE



QUANTITY OF 20  
B4741 BLOCKS



QUANTITY OF 8  
B6030 BLOCKS

## ASSEMBLY CONSIDERATIONS

Discrete air gaps between Kool  $\mu$  blocks are not generally needed because the air gap is inherent in the material. At the same time, extremely smooth mating surfaces (such as are employed with ferrites) are not required because the small incidental gap between blocks does not add appreciable extra gap and does not reduce inductance significantly.

The adhesives used for assembling blocks generally need to be thicker than those commonly used for ferrite assemblies, since the Kool  $\mu$  surface is rougher and more porous. Magnetics has seen good results with Bondmaster<sup>®</sup> ESP 309. Cores may require a double application of adhesive to allow for the porosity in the surface of the Kool  $\mu$  blocks.