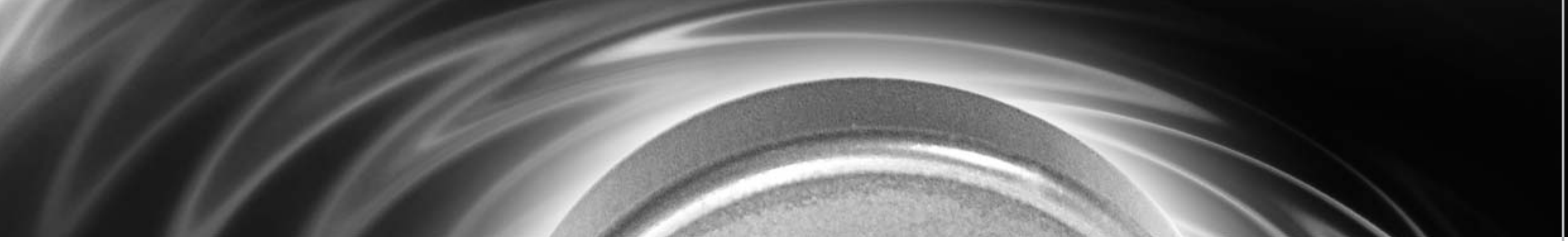
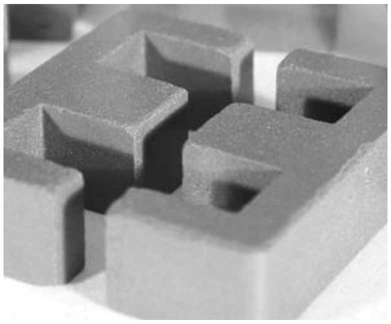


Large Kool Mμ® Core Shapes



TECHNICAL BULLETIN

Ideal for high current inductors, large Kool Mμ geometries (E cores, U Cores and Blocks) offer all the advantages of Kool Mμ 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 Mμ 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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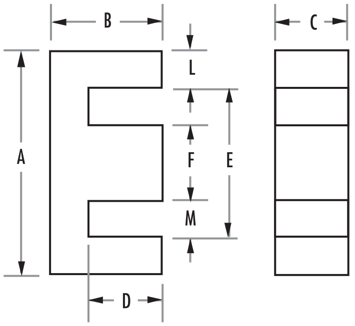
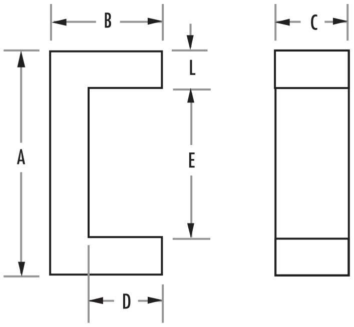
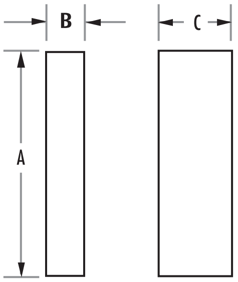


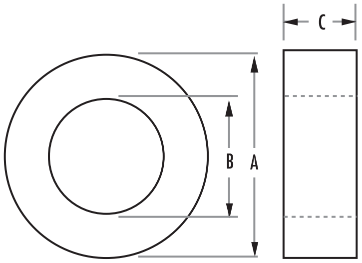
E CORES



U CORES



BLOCKS



TOROIDS

DIMENSIONS (mm)

TABLE 1

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

MAGNETIC DATA

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

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

MATERIALS AND DC BIAS

Large Kool Mµ cores are available in three permeabilities, 26µ, 40µ, and 60µ. The magnetic data for each 26µ 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 Mµ 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.

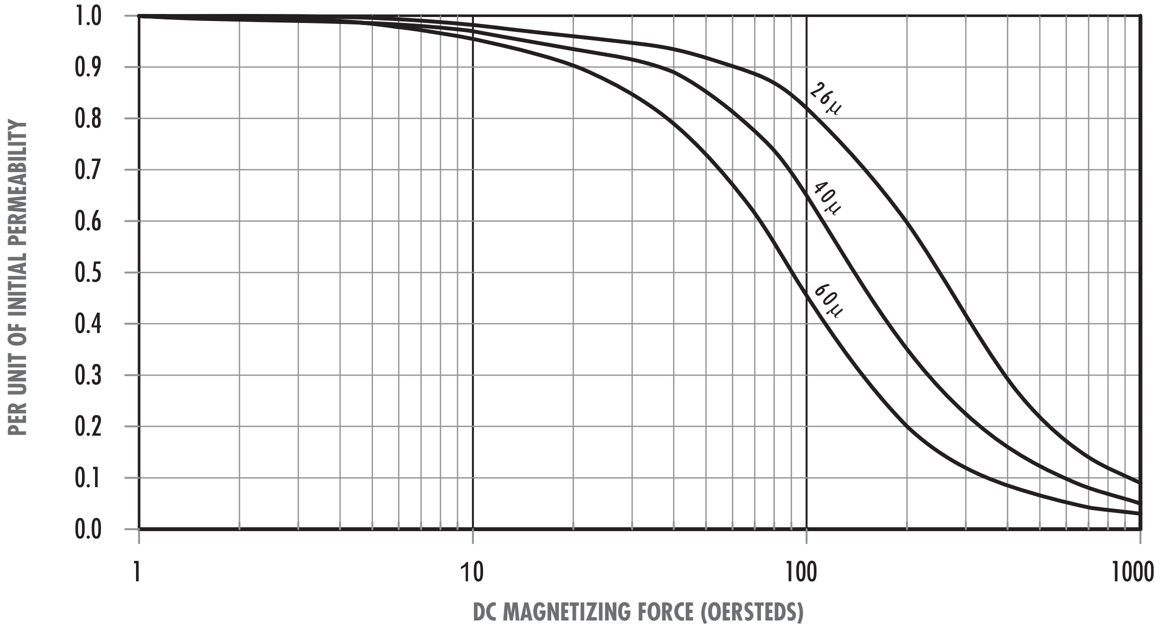


FIGURE 1

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.

$$L = \frac{.4\,\pi\,\mu\,N^2\,A_e\,10^{-6}}{l_e}$$

where:
L = inductance in mH
µ = core permeability
N = number of turns
A_e = effective cross section in mm2
l_e = core magnetic path length in mm

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 Mµ 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 Mµ E cores or an E core assembly.

Kool Mµ 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 Mµ 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 Mµ E Cores”.

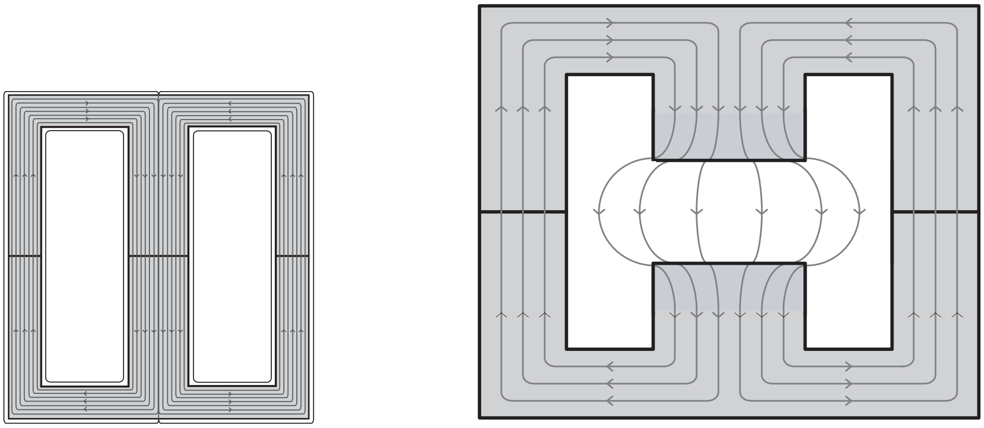
COMPARISON TO GAPPED FERRITE

Although high grade ferrite core losses are lower than Kool Mμ 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 Mμ cores. Gapped ferrites typically have a ±3% tolerance on inductance compared to Kool Mμ's ±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.

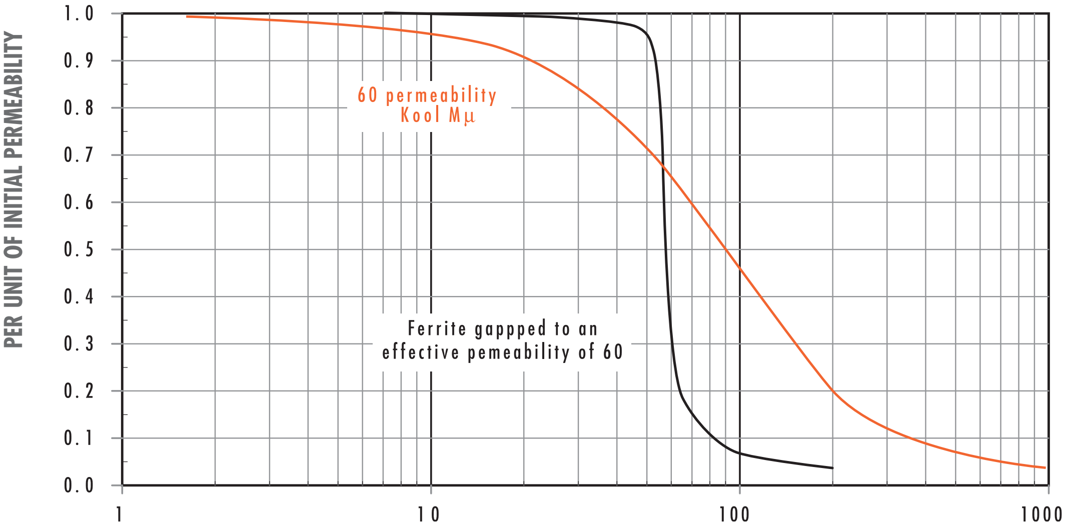
ADVANTAGES OF KOOL Mμ COMPARED WITH GAPPED FERRITE SOLUTIONS ARE:

- **Soft Saturation:** Ferrite must be designed in the safe flat area of the roll-off curve. Powder cores like Kool Mμ 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 Mμ stays relatively constant.
- **Fault-tolerance:** The soft saturation curve makes the Kool Mμ design inherently fault-tolerant, whereas gapped ferrite is not.
- **Fringing Losses:** Do not occur with Kool Mμ: can be excessive with gapped ferrites.


KOOL Mμ

GAPPED FERRITE

FIGURE 2



DC MAGNETIZING FORCE (OERSTEDS)

FIGURE 3

ADVANTAGES OF KOOL Mμ COMPARED WITH POWDERED IRON SOLUTIONS ARE:

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

COMPARISON TO POWDERED IRON

Kool Mμ, (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 Mμ; therefore inductors are more efficient and run cooler.

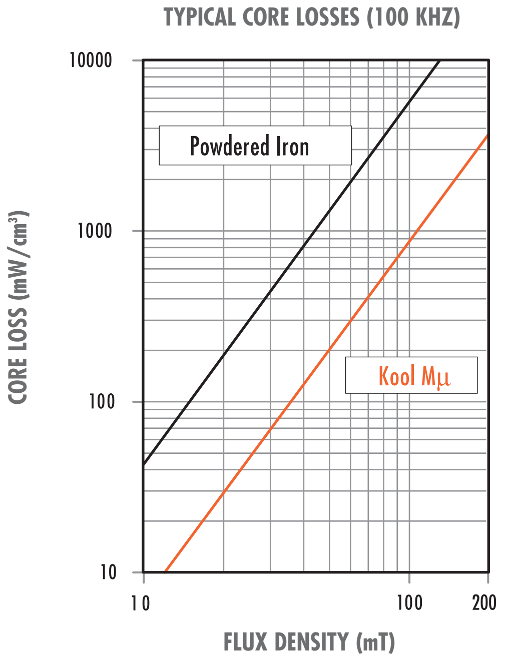


FIGURE 4

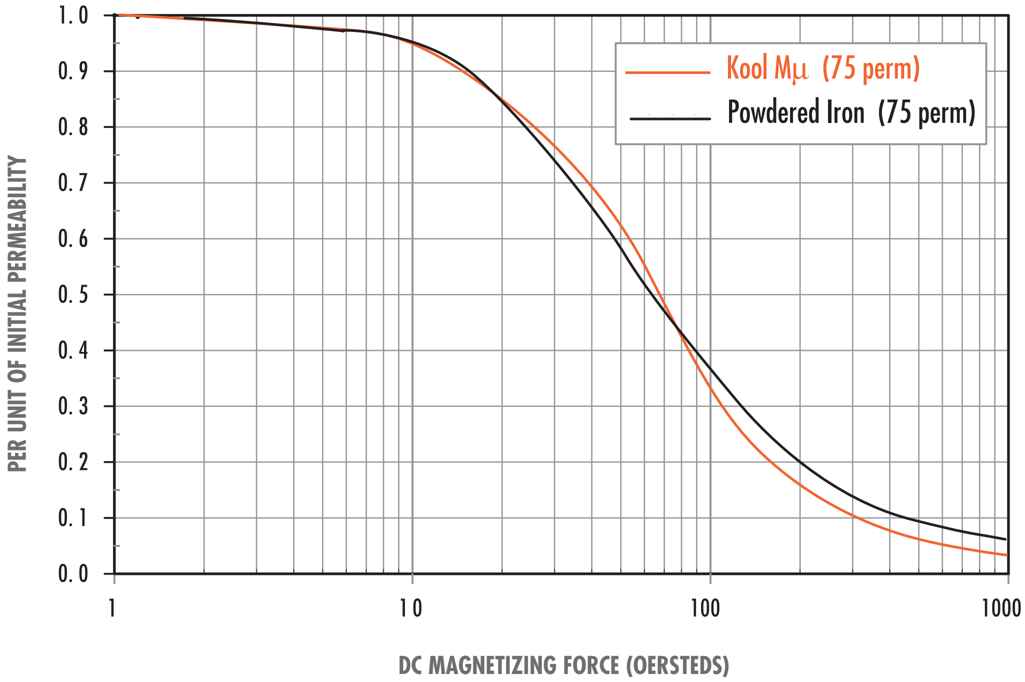


FIGURE 5

ADVANTAGES OF KOOL Mµ COMPARED WITH SILICON IRON SOLUTIONS ARE:

- **Soft Saturation**: Silicon blocks have discrete gaps, unlike the distributed gaps of Kool Mµ, so the onset of saturation with increasing current is much sharper. Kool Mµ can be designed deep into the saturation curve, resulting in smaller inductors.

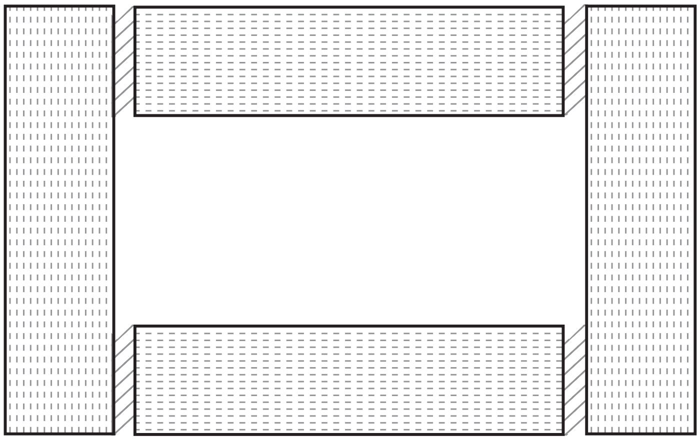
- **Core Losses**: Kool Mµ is much lower in core losses than the silicon steel laminations. The difference generally becomes more dramatic as the frequency increases (Figure 7).

- **Temperature Stability**: The epoxies used in silicon steel assembly are not generally rated for 200°C operation as Kool Mµ is.

- **Cost**: Kool Mµ 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 Mµ 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 Mµ 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 Mµ VS. SILICON STEEL LAMINATION

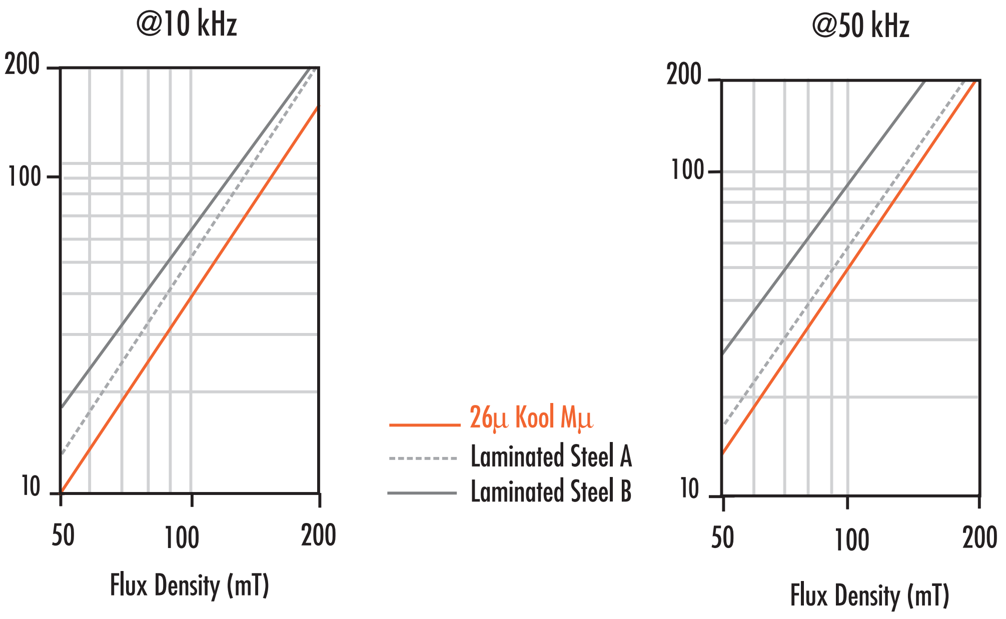


FIGURE 7

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
E CORES	
E5528	100-400
E5530	150-500
E6527	300-900
E7228	300-800
E8020	400-1200
LE130	3100-6300
LE145	2100-4300
LE160	4600-7700

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

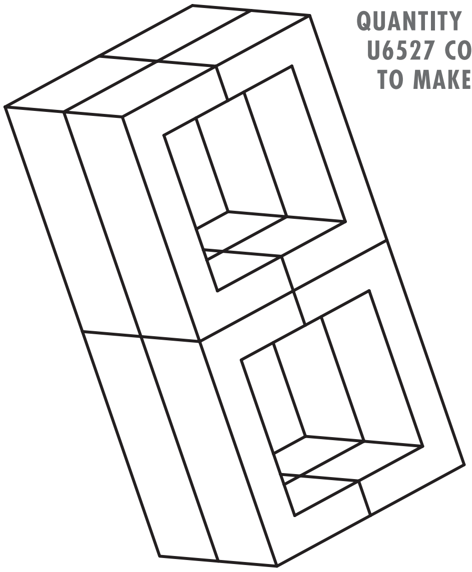
The above table is based on a winding factor of 60% and an AC current which is small relative to the DC current. The table is based on the nominal inductance of the chosen core size and a permeability of 26.

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.

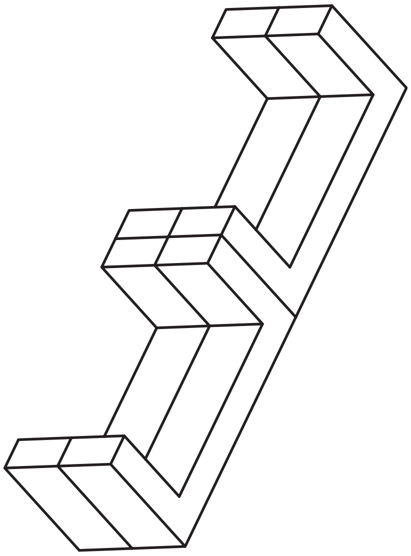
SPECIAL DESIGNS

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

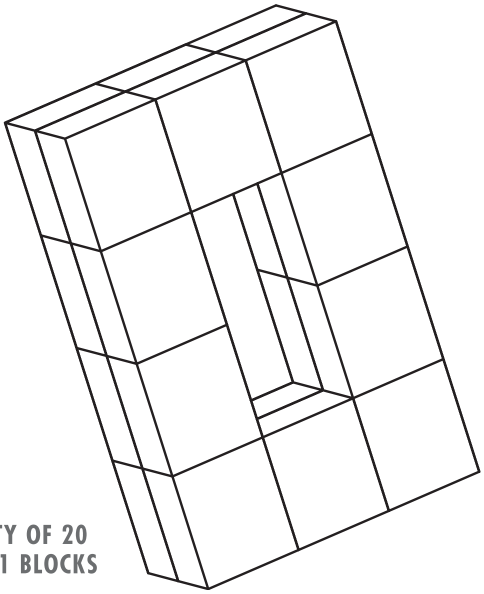
FIGURE 8



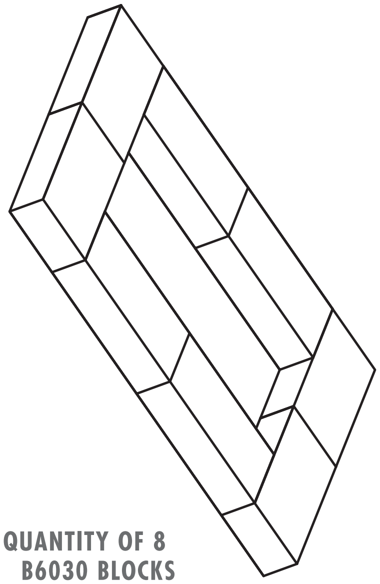
QUANTITY OF 8
U6527 CORES STACKED
TO MAKE (1) LE130 SET



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 Mµ 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 Mµ surface is rougher and more porous. Magnetics has seen good results with Bondmaster® ESP 309. Cores may require a double application of adhesive to allow for the porosity in the surface of the Kool Mµ blocks.