Large Kool Mµ® Core Shapes

TECHNICAL BULLETIN

Ideal for high current inductors, large Kool Mµ geometries (E cores, Toroids, 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 applications of high current inductors are Uninterruptible Power Supplies (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 steel 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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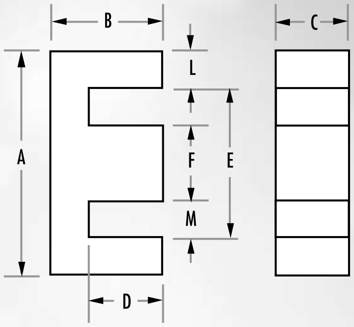
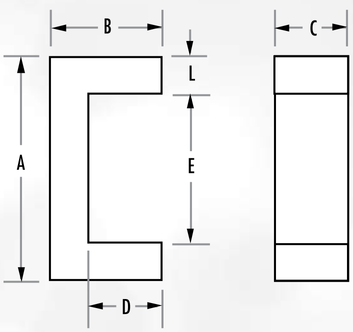
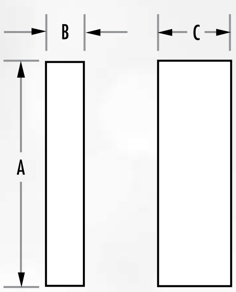


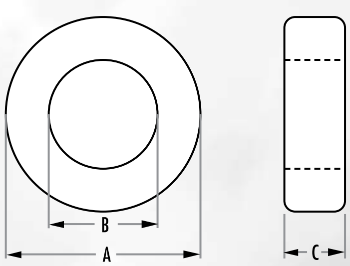
E CORES



U CORES



BLOCKS



TOROIDS

TABLE 1 — DIMENSIONS (mm)

	TYPE	A	B	C	D	E	F	L	M
E CORES	**E5528** ***DIN 55/21***	54.9	27.6	20.6	18.5	37.5	16.8	8.4	10.2
	E5530 ***DIN 55/25***	54.9	27.6	24.6	18.5	37.5	16.8	8.4	10.2
	E6527 ***Metric E65***	65.1	32.5	27.0	22.1	44.2	19.7	10.0	12.0
	E7228 ***F11***	72.4	27.9	19.1	17.7	52.6	19.1	9.5	16.8
	E8020 ***Metric E80***	80.0	38.1	19.8	28.1	59.3	19.8	9.9	19.8
	LE114	114.0	46.2	34.9	28.9	79.8	34.9	17.1	22.5
	LE114HT26	114.0	46.2	26.19	28.9	79.8	34.9	17.1	22.5
See Figure 8	**LE130**	130.3	32.5	53.9	22.2	108.4	20.0	10.0	44.2
See Figure 8	**LE160**	160.0	38.1	39.6	28.1	138.4	19.8	9.9	59.3
U CORES	**U5527**	54.9	27.6	16.3	16.8	33.8		10.5	
	U5529	54.9	27.6	23.2	16.8	33.0		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	
	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	22.4	22.7	49.3		15.4	
BLOCKS	**B4741**	47.5	41.0	27.5					
	B5030	50.5	30.3	15.0					
	B5528	54.86	57.56	20.6					
	B6030	60.0	30.0	15.0					
	B8030	80.5	30.3	20.0					
TOROIDS	**77191**	58.0	25.6	16.1					
	77111	58.0	34.7	14.9					
	77615	62.9	31.7	25.9					
	77735	75.0	44.4	35.9					
	77868	78.9	48.2	13.9					
	77908	78.9	48.2	17.1					
	77102	103.0	55.7	17.9					
	77337	134.0	77.1	26.8					
	77165	166.5	101.0	33.1					

TABLE 2 — MAGNETIC DATA

	TYPE	A_L nH/Turn^2 (±8%) 26µ	A_e (mm^2)	l_e (mm)	V_e (mm^3)	W_A (mm^2)	PART NUMBER
E CORES	**E5528**	116	350	123	43,100	381	**00K5528E026**
	E5530	138	417	123	51,300	381	**00K5530E026**
	E6527	162	540	147	79,400	537	**00K6527E026**
	E7228	130	368	137	50,400	602	**00K7228E026**
	E8020	103	389	185	72,000	1,110	**00K8020E026**
	LE114	235	1220	215	262,000	1,300	**00K114LE026**
	LE114HT26	182	914	215	197,000	1,300	**00K114LE026HT26**
See Figure 8	**LE130**	254	1080	219	237,000	1,960	**00K130LE026**
See Figure 8	**LE160**	180	778	273	212,000	3,330	**00K160LE026**
U CORES	**U5527**	67	172	168	28,900	921	**00K5527U026**
	U5529	85	244	168	41,000	921	**00K5529U026**
	U6527	89	270	219	59,100	1,630	**00K6527U026**
	U6533	82	250	199	49,800	1,284	**00K6533U026**
	U7236	87	290	219	63,500	1,545	**00K7236U026**
	U8020	64	195	273	53,200	2,740	**00K8020U026**
	U8038	97	354	237	83,900	1,793	**00K8038U026**
BLOCKS	**B4741**	N/A	*	*	53,600	*	**00K4741B026**
	B5030	N/A	*	*	23,000	*	**00K5030B026**
	B5528	N/A	*	*	31,200	*	**00K5528B026**
	B6030	N/A	*	*	27,000	*	**00K6030B026**
	B8030	N/A	*	*	48,800	*	**00K8030B026**
TOROIDS	**77191**	60	229	125	28,600	514	**0077191A7**
	77111	33	144	143	20,700	948	**0077111A7**
	77615	82	360	144	51,800	789	**0077615A7**
	77735	88	497	184	91,400	1,550	**0077735A7**
	77868	30	176	196	34,500	1,820	**0077868A7**
	77908	37	221	196	43,400	1,820	**0077908A7**
	77102	48	358	243	86,900	2,470	**0077102A7**
	77337	68	678	324	220,000	4,710	**0077337A7**
	77165	78	987	412	407,000	8,030	**0077165A7**

*Dependent on design configurations. Contact Magnetics Sales Engineers for assistance.

MATERIALS AND DC BIAS

Large Kool Mµ® cores are available in four permeabilities, 14µ, 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.

PERMEABILITY VS. DC BIAS

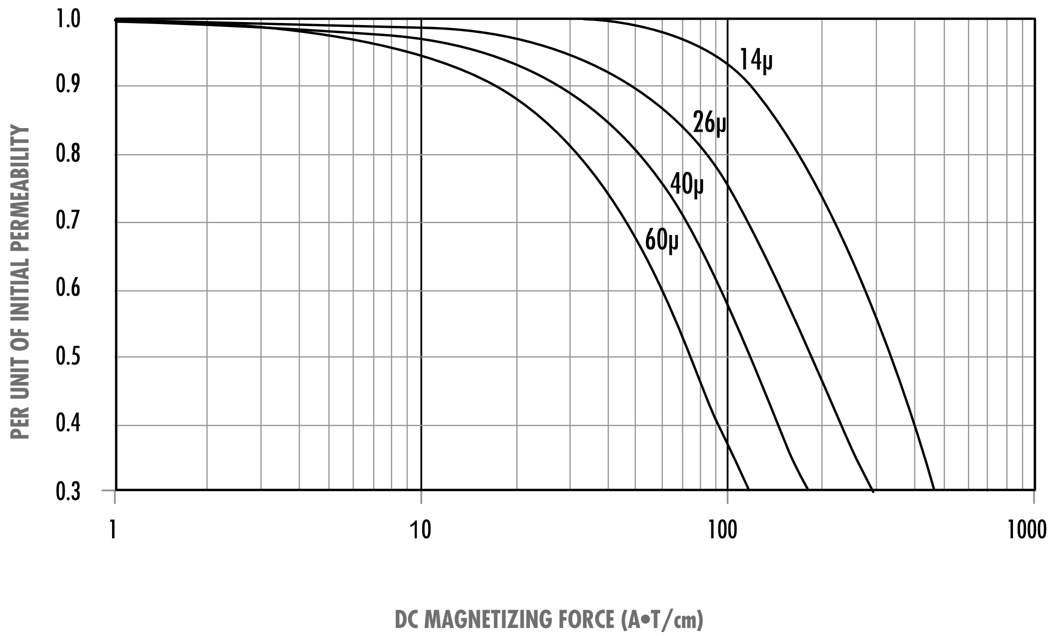


FIGURE 1

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 mm^2
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 visit Magnetics' website to download the white paper, "Leakage Flux Considerations on Kool Mµ E Cores."

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.

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.

The benefits of Kool Mμ include soft saturation, Kool Mμ are designed to exploit the controlled, partial roll-off in the material; they have more than twice the capacity of ferrite; flux capacity stays relatively constant with temperature; Kool Mμ is inherently fault-tolerant and fringing losses do not occur with Kool Mμ (refer to side bar).

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.

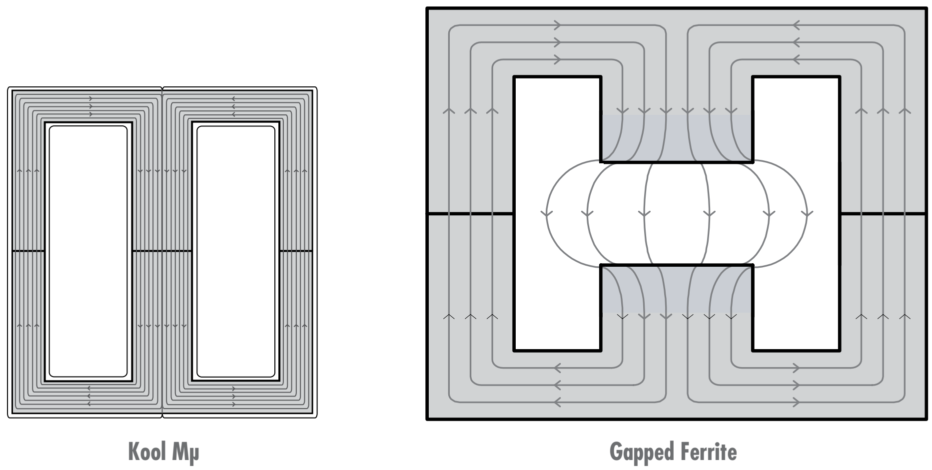


FIGURE 2

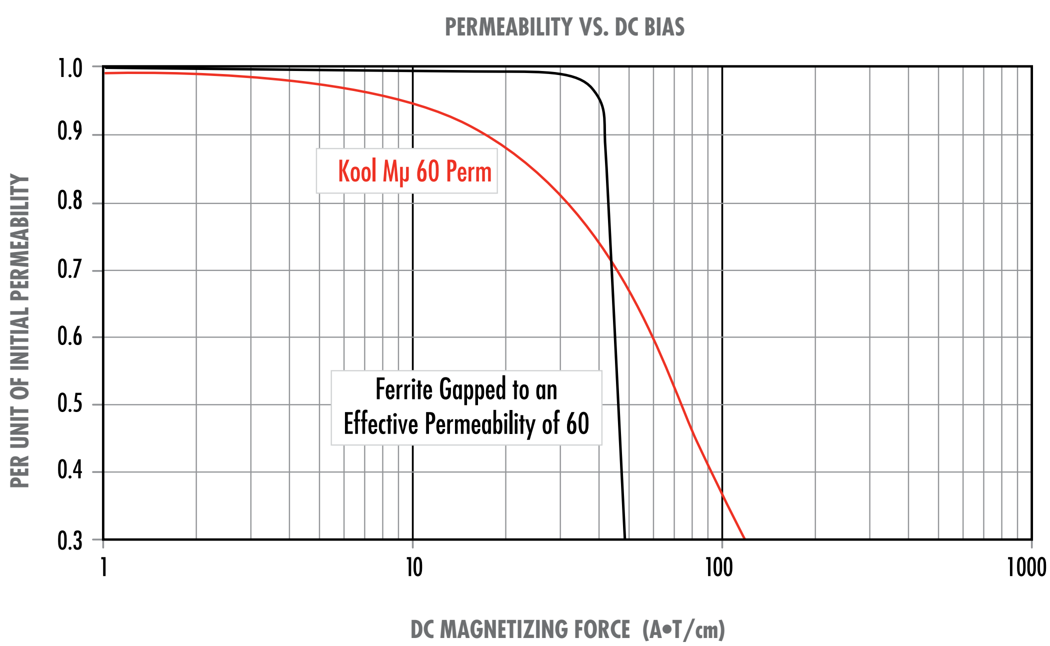


FIGURE 3

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 coated Kool Mμ toroids are rated for 200°C continuous operation. Uncoated Kool Mμ geometries can theoretically be used up to the Curie temperature of the Kool Mμ material, which is 500°C.

COMPARISON TO POWDERED IRON

Kool Mμ advantages include core losses lower than powdered iron (Figure 4), near zero magnetostriction, and no thermal aging (see sidebar).

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.

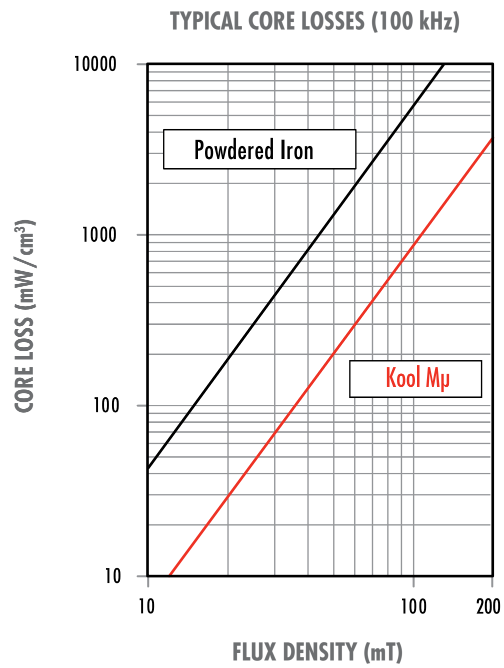


FIGURE 4

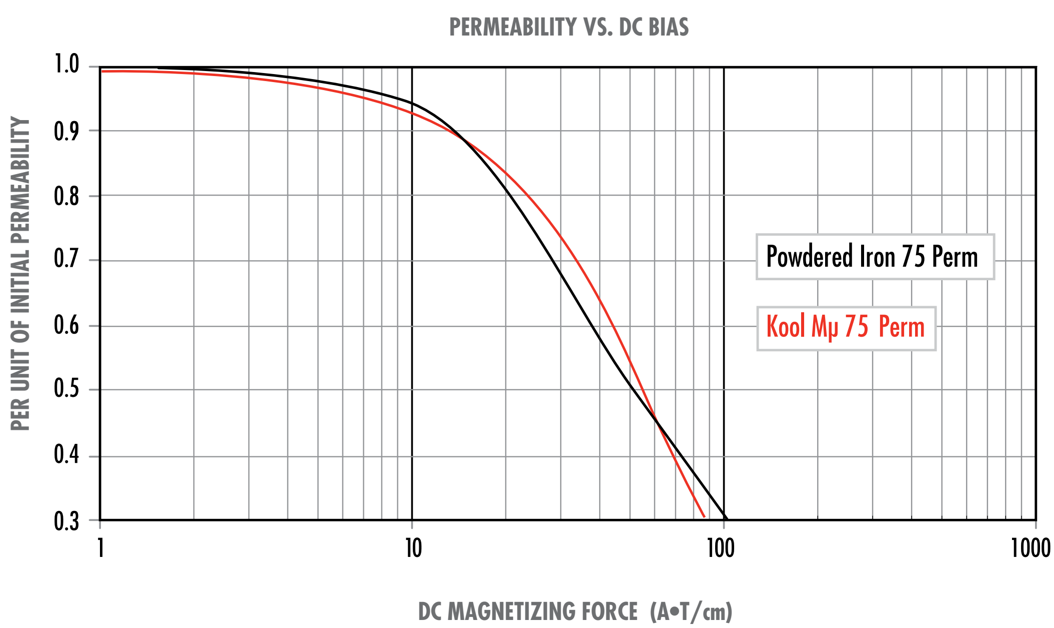


FIGURE 5

ADVANTAGES OF KOOL Mµ® COMPARED WITH SILICON STEEL 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).
- **Cost:** Kool Mµ cores have a lower cost than similar size silicon steel blocks.

COMPARISON TO SILICON STEEL

Kool Mµ offers the benefits of soft saturation, significantly lower core losses, good temperature stability and a lower cost than similar size silicon steel blocks (refer to side bar). Kool Mµ shapes (E cores, U cores and blocks) can be configured for large inductor applications. See Special Designs section on page 8.

In comparison, the silicon steel has the advantage of high saturation flux density. Using special grades of silicon steel laminations, in a block or bar geometry, is one approach to realizing large inductors, see Figure 6.

SILICON STEEL BLOCK CONFIGURATION

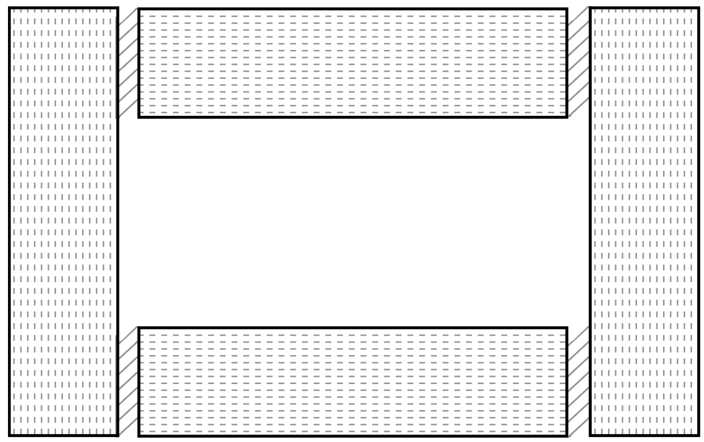


FIGURE 6

CORE LOSS COMPARISON
26 PERMEABILITY Kool Mµ VS. SILICON STEEL LAMINATION

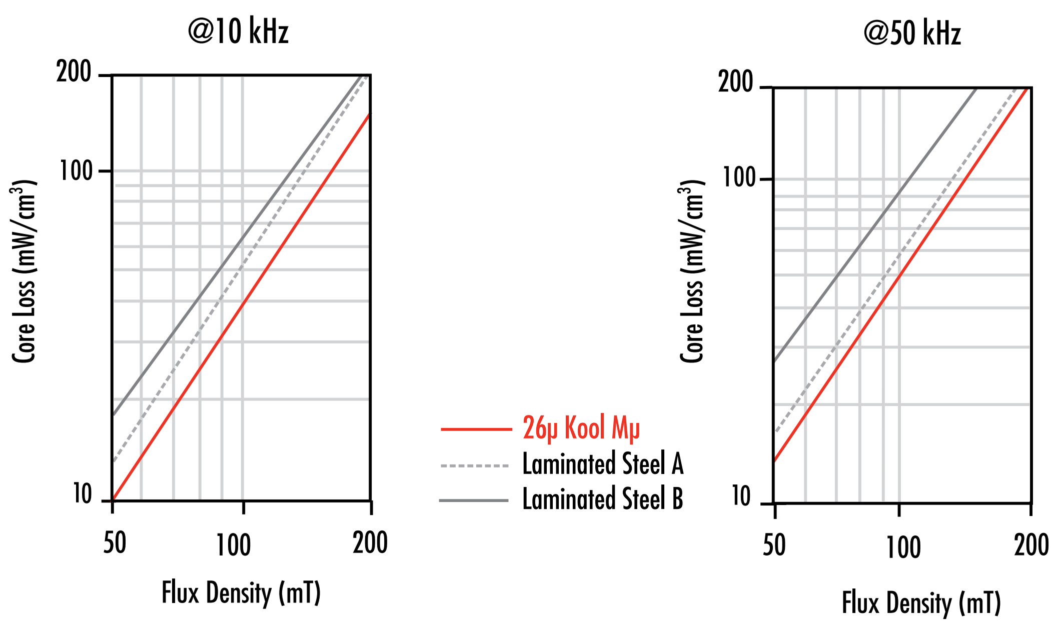


FIGURE 7

CORE SELECTION

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

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 A•T/cm from: $H = \dfrac{NI}{l_e}$ (with l_e in cm).

   c) From the Permeability vs. DC bias curve (Figure 1), 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.

TABLE 3

E CORES	LI^2
E5528	50-150
E5530	75-150
E6527	150-350
E8020	300-500
LE114	500-1600
LE114HT26	350-1300
LE130	1150-3500
LE160	1500-4500

TOROIDS	LI^2
77191	50-100
77111	50-100
77615	150-225
77735	250-550
77868	100-250
77908	125-325
77102	250-650
77337	650-2250
77165	1250-4250

U CORES	LI^2
U5527	150-450
U5529	225-550
U6527	400-1200
U6533	300-850
U7228	350-1100
U7236	350-1100
U8020	450-1500
U8038	500-1600

BLOCKS	#BLOCKS	LI^2
4741B	8	1225-3000
4741B	16	1450-6000
4741B	24	3670-9000
8030B	4	940-1110
8030B	6	1450-4080

The above table is based on a winding factor of 60% (40% for toroids) 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. The current carrying capacity of the wire is 600 A/cm^2.

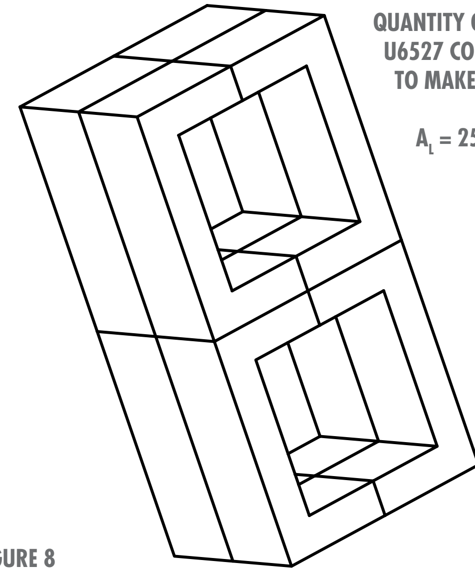
If a core is chosen for use with a large AC current relative to any DC current, such as a flyback inductor, a slightly larger size may be necessary. This will assist in reducing the operating flux density of the AC current that generates core losses.

LI^2 values only apply when the blocks are assembled into a structure.

For additional assistance refer to the inductor design software on Magnetics website.

SPECIAL DESIGNS

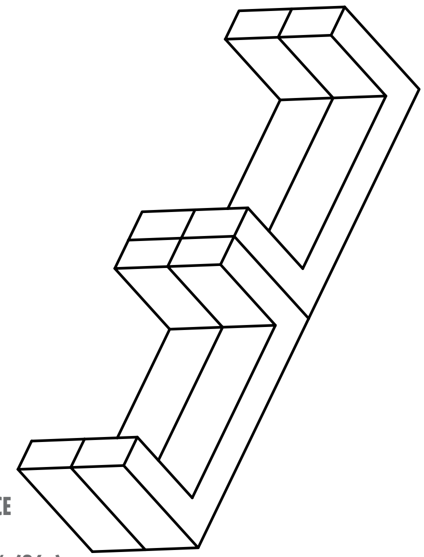
Many applications require a custom assembly or even a custom core. The material properties of Kool Mµ®, and the flexibility of these geometries make the core ideal for custom assembly.



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

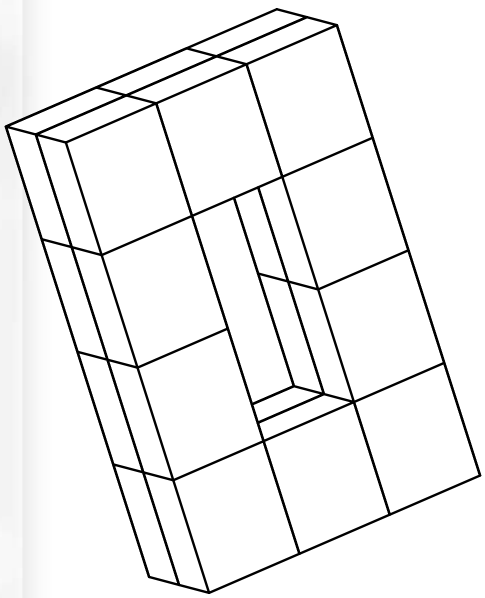
A_L = 254±8% (26µ)

FIGURE 8



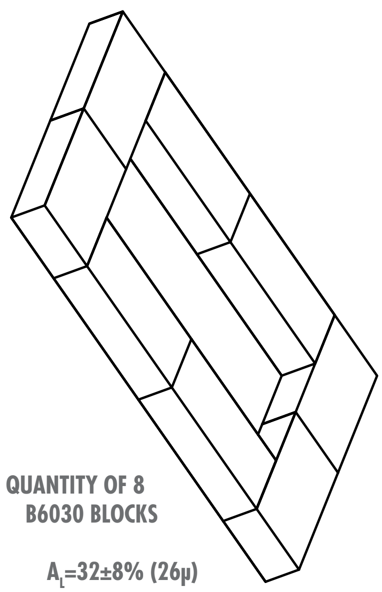
QUANTITY OF 4
U8020 CORES CONFIGURED
TO MAKE (1) LE160 PIECE

A_L = 180±8% (26µ)



QUANTITY OF 20
B4741 BLOCKS

A_L=189±8% (26µ)



QUANTITY OF 8
B6030 BLOCKS

A_L=32±8% (26µ)

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 Loctite® ESP-109. Cores may require a double application of adhesive to allow for the porosity in the surface of the Kool Mµ blocks.