Powder Core Shapes

TECHNICAL BULLETIN

Kool Mµ® Shapes

Ideal for high current inductors, 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 applications of high current inductors are Uninterruptible Power Supplies (including transformerless UPS), large Power Factor Correction (PFC) chokes, traction, and inverters for renewable energy (solar/wind/fuel cell conversion).

XFLUX® Shapes

E Cores and Blocks are also available in XFLUX material, which is ideal for low and medium frequency inductors and chokes. XFLUX is characterized by its high saturation (1.6 Tesla), which is advantageous in applications where inductance under load is critical. These applications include inverters for alternative energy, PFC boost designs, and UPS.

Available in various sizes (see Table 1, page 2), Kool Mµ and XFLUX 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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Dimensions

TABLE 1

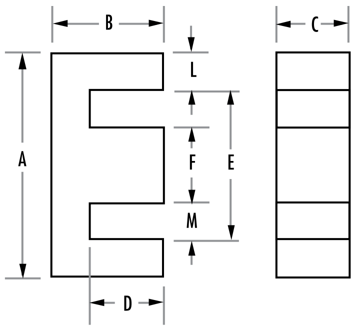
E CORES		A	B	C	D(min)	E(min)	F	L(nom)	M(min)
1808E *EI-187*	mm	19.3±0.305	8.10±0.178	4.78±0.152	5.53	13.9	4.78±0.127	2.39	4.64
2510E *E-2425*	mm	25.4±0.381	9.53±0.178	6.35±0.102	6.22	18.7	6.35±0.127	3.18	6.24
3007E *DIN 30/7*	mm	30.10±0.457	15.0±0.229	7.06±0.152	9.55	19.8	6.96±0.203	5.11	6.32
3515E *EI-375*	mm	34.54±0.508	14.2±0.229	9.35±0.178	9.60	25.2	9.32±0.203	4.45	7.87
4017E *EE 42/11*	mm	42.85±0.635	21.1±0.305	10.8±0.254	14.9	30.30	11.9±0.254	5.94	9.27
4020E *DIN 42/15*	mm	42.85±0.635	21.1±0.330	15.4±0.254	14.9	30.35	11.9±0.254	5.94	9.27
4022E *DIN 42/20*	mm	42.85±0.635	21.1±0.330	20.0±0.254	14.9	30.35	11.9±0.254	5.94	9.27
4317E *EI-21*	mm	40.87±0.610	16.5±0.279	12.5±0.178	10.3	28.32	12.5±0.300	6.05	7.87
5528E *DIN 55/21*	mm	54.86±0.813	27.56±0.406	20.6±0.381	18.5	37.49	16.8±0.381	8.38	10.2
5530E *DIN 55/25*	mm	54.86±0.813	27.56±0.406	24.6±0.381	18.5	37.49	16.8±0.381	8.38	10.2
6527E *Metric E65*	mm	65.15±1.27	32.51±0.381	27.00±0.406	22.1	44.19	19.7±0.356	10.0	12.0
7228E *F11*	mm	72.39±1.09	27.94±0.508	19.1±0.381	17.7	52.62	19.1±0.381	9.53	16.8
8020E *Metric E80*	mm	80.01±1.19	38.10±0.635	19.8±0.381	28.01	59.28	19.8±0.381	9.91	19.8
8024E	mm	80.01±1.19	24.05±0.635	29.72±0.381	14.02	59.28	19.8±0.381	9.91	19.8
8044E	mm	80.01±1.19	44.58±0.635	19.8±0.381	34.36	59.28	19.8±0.381	9.91	19.8
114LE	mm	114.3±0.762	46.18±0.381	34.93±0.381	28.60	79.50	35.10±0.381	17.2	22.1
130LE	mm	130.3±3.81	32.51±0.305	53.85±1.27	22.1	108.4	20.0±0.762	10.0	44.22
160LE	mm	160.0±2.54	38.10±0.635	39.62±1.27	28.14	138.2	19.8±0.762	9.91	59.28

U CORES*		A	B	C	D	E	L
3112U	mm	31.24±0.51	11.2±0.26	12.1±0.39	2.54	14.2	8.26
4110U	mm	40.64±0.51	11.2±0.51	9.53±0.39	2.54	23.6	8.38
4111U	mm	40.64±0.51	11.2±0.26	12.1±0.39	2.54	23.6	8.38
4119U	mm	40.64±0.51	11.2±0.26	19.1±0.39	2.54	23.6	8.38
5527U	mm	54.86±0.64	27.56±0.51	16.3±0.39	16.7	33.78	10.5
5529U	mm	54.86±0.64	27.56±0.51	23.2±0.39	16.5	33.02	10.5
6527U	mm	65.15±1.4	32.51±0.31	27.00±0.41	22.1	44.22	10.0
6533U	mm	65.15±1.4	32.51±0.31	20.0±0.41	19.6	39.24	12.5
7236U	mm	72.39±0.89	35.56±0.64	20.9±0.39	21.3	43.68	13.9
8020U	mm	80.01±0.89	38.10±0.64	19.8±0.39	28.14	59.28	9.91
8038U	mm	80.01±0.89	38.10±0.64	23.0±0.39	22.4	49.27	15.4

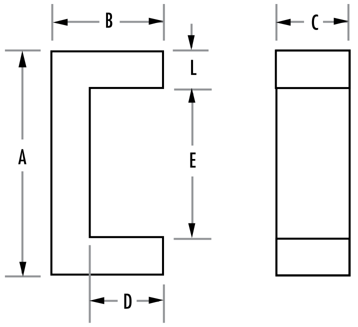
BLOCKS		A	B	C
4741B	mm	47.50±0.61	41.00±0.51	27.51±0.41
5030B	mm	50.50±0.51	30.30±0.30	15.0±0.26
5528B	mm	54.86±0.64	27.56±0.41	20.6±0.39
6030B	mm	60.00±0.51	30.00±0.25	15.0±0.25
7020B	mm	70.5±0.51	20.3±0.25	20.0±0.25
7030B	mm	70.5±0.5	30.3±0.25	20.0±0.2
8030B	mm	80.49±0.51	30.30±0.51	20.00±0.21
9541B	mm	95.00±0.61	41.00±0.51	27.51±0.41

*U Cores currently available in Kool Mμ only. Contact Magnetics for XFlux availability.

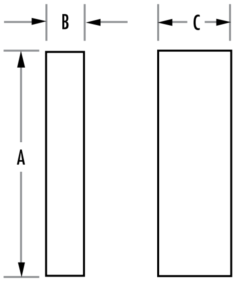
Dimension Drawings



E CORES



U CORES



BLOCKS

Magnetic Data

TABLE 2

E CORES	A_L nH/T^2 ± 8%				Path Length l_e (mm)	Cross Section A_e (mm^2)	Volume V_e (mm^3)
	26µ	40µ	60µ	90µ			
1808E	26	35	48	69	40.1	22.8	914
2510E	39	52	70	100	48.5	38.5	1,870
3007E	33	46	71	92	65.6	60.1	3,940
3515E	56	75	102	146	69.4	84.0	5,830
4017E	56	76	105	151	98.4	128	12,600
4020E	80	108	150	217	98.4	183	18,000
4022E	104	140	194	281	98.4	237	23,300
4317E	88	119	163	234	77.5	152	11,800
5528E	116	157	219	322	123	350	43,100
5530E	138	187	261	382	123	417	51,300
6527E	162	230	300	-	147	540	79,400
7228E	130	173	235	-	137	368	50,400
8020E	103	145	190	-	185	389	72,000
8024E	200	275	370	-	131.4	600	78,840
8044E	91	113	170	-	208	389	80,900
114LE	235	335	445	-	215	1,220	262,000
130LE	254	-	-	-	219	1,080	237,000
160LE	180	-	-	-	273	778	212,000

U CORES*	A_L nH/T^2 ± 8%				Path Length l_e (mm)	Cross Section A_e (mm^2)	Volume V_e (mm^3)
	26µ	40µ	60µ	90µ			
3112U	-	92	111	179	65.6	101	6,630
4110U	-	56	78	109	85.2	80	6,820
4111U	-	72	95	138	85.2	101	8,600
4119U	-	110	151	218	85.2	159	13,600
5527U	67	-	-	-	168	172	28,900
5529U	85	-	-	-	168	244	41,000
6527U	89	-	-	-	219	270	59,100
6533U	82	-	-	-	199	250	49,800
7236U	87	-	-	-	219	290	63,500
8020U	64	-	-	-	273	195	53,200
8038U	97	-	-	-	237	354	83,900

BLOCKS	A_L nH/T^2 ± 8%	Path Length l_e (mm)	Cross Section A_e (mm^2)	Volume V_e (mm^3)
4741B	**	**	**	53,600
5030B	**	**	**	23,000
5528B	**	**	**	31,200
6030B	**	**	**	27,000
7020B	**	**	**	28,600
7030B	**	**	**	42,800
8030B	**	**	**	48,800
9541B	**	**	**	107,200

* U Cores currently available in Kool Mµ only. Contact Magnetics for XFLUX availability.

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

Materials & DC Bias

The most critical parameter of a switching regulator inductor material is its ability to provide inductance or maintain permeability under DC Bias. The Permeability vs. DC Bias chart (Figure 1) shows the reduction of permeability as a function of DC Bias for Kool Mµ material. The distributed air gap of powder cores results in a more gradual drop in inductance with increased DC Bias. 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 also provides added protection against overload conditions.

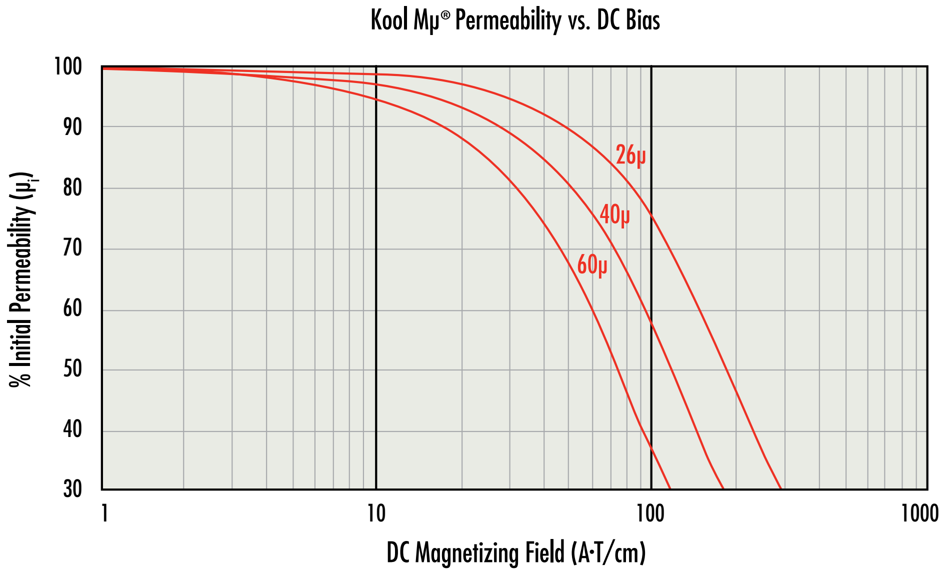


FIGURE 1

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 an idealized core with no leakage flux, inductance is calculated via the following:

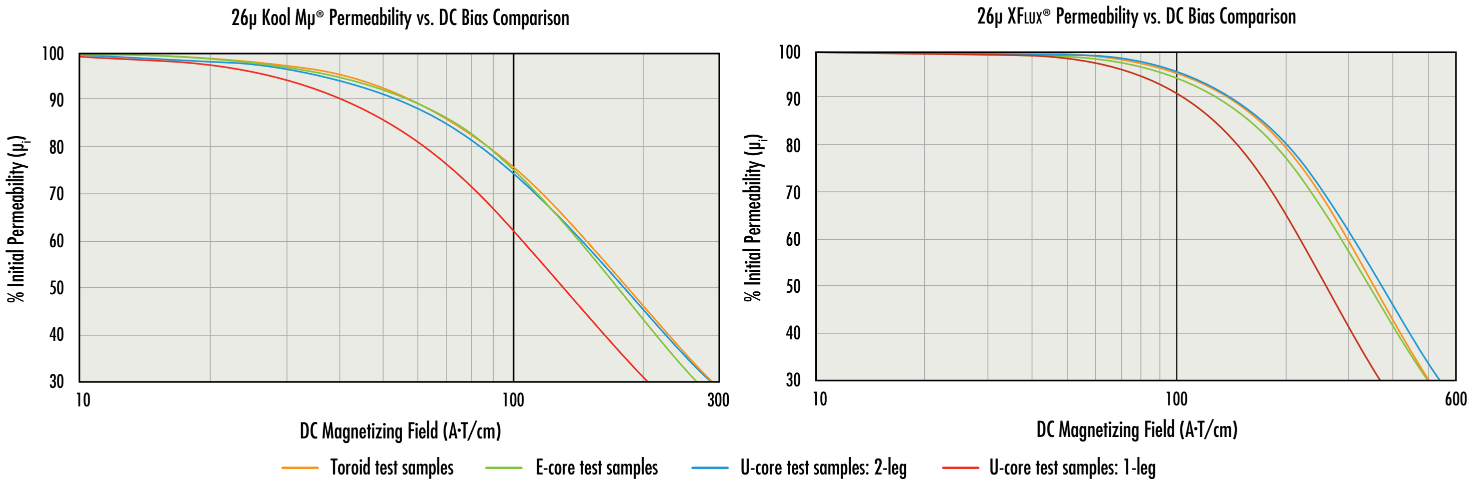
$$L = \frac{.4\,\pi\,\mu\,N^2\,A_e\,10^{-6}}{l_e}$$

L = inductance in mH
µ = core permeability
N = number of turns

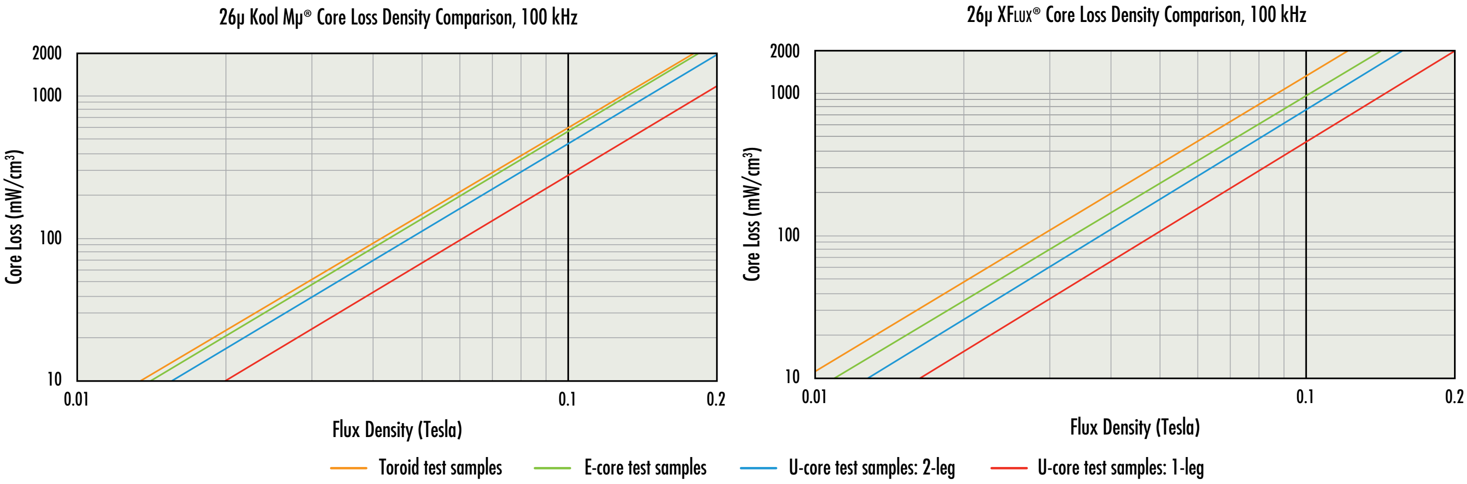
A_e = effective cross section in mm^2
l_e = core magnetic path length in mm

In low permeability materials the effect of leakage flux is that measured inductance is higher than the inductance calculated using the equation shown above. The increase in measured inductance compared with calculated inductance, due to leakage, is strongly affected by the number of turns as well as by the coil design and geometry. These effects can also extend to DC Bias performance and core loss.

Effects on performance under DC Bias can be seen in the sample tests shown below. U-core inductors wound on only one leg show a marked decrease in performance compared to the same cores with windings distributed over 2-legs, which yields performance comparable to E-cores and toroids.



Effects on core loss can also be seen in the sample tests shown below. U-cores wound on only one leg have a noticeable decrease in core loss, followed by the same U-cores wound on two legs, then E-cores, then toroids.



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, and 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- or 200-turn coils. U-core inductance factors are listed for 1-leg windings.

External Leakage Field

The external leakage field must be considered when using an E core, U core, or block assembly as core shape affects the leakage flux. Powder core shapes (E cores, U cores, and blocks), where most of the core surrounds the winding, have a greater external leakage field than the toroidal shape, where the winding surrounds the core.

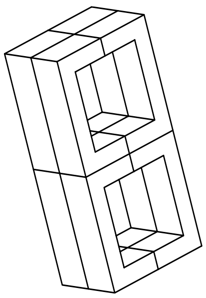
E cores, U cores, and blocks should not be assembled with metallic brackets since the leakage flux may cause eddy current heating in the brackets. The leakage field must be considered when laying out the circuit board. Components susceptible to a stray magnetic field should be spaced away from the core. For more information on this subject, visit Magnetics' website to download the white paper, "Leakage Flux Considerations on Kool Mμ E Cores."

Special Designs & Assembly Considerations

Many applications require a custom assembly or even a custom core. The material properties of powder cores and the flexibility of these geometries make them ideal for custom assemblies.

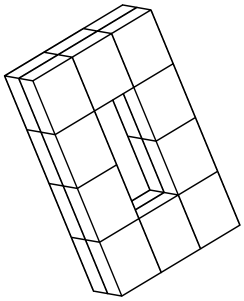
Discrete air gaps between powder core blocks are not generally needed because the air gap is inherent in the material. At the same time, extremely smooth mating surfaces (such as are employed with ferrites) are not required because the small incidental gap between blocks does not add appreciable extra 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 powder core surfaces are rougher and more porous. Cores may require a double application of adhesive to ensure a strong bond.



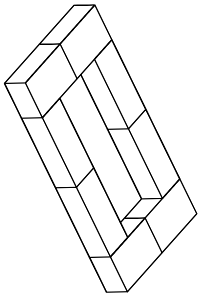
**QUANTITY OF 8
6527U CORES
STACKED TO MAKE
(1) 130LE SET**

A_L = 254±8% (26μ)



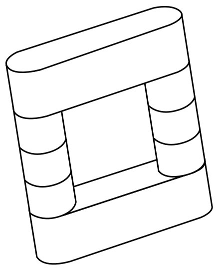
**QUANTITY OF 20
4741B BLOCKS**

A_L = 189±8% (26μ)



**QUANTITY OF 8
6030B BLOCKS**

A_L = 32±8% (26μ)



**CYLINDER AND
ROUNDED BLOCK
ASSEMBLY**

Contact Magnetics for
more information.

Comparison to Gapped Ferrite

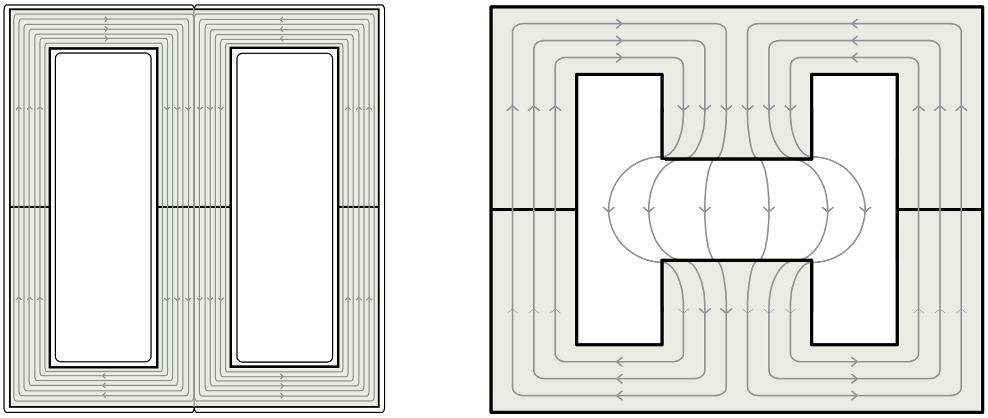
Advantages of Powder Cores compared with Gapped Ferrite are:

- **Soft Saturation:** Ferrites must be designed in the safe flat area of the roll-off curve. Powder cores 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 50% inductance roll-off, powder cores can provide a reduction in required core size of up to 35%.
- **Temperature:** Flux capacity of ferrites decreases with temperature while powder cores stay relatively constant.
- **Fault-tolerance:** Powder core designs are inherently fault-tolerant with soft saturation curves, whereas gapped ferrite is not.
- **Fringing Losses:** Do not occur with powder cores; can be excessive with gapped ferrites.

Although high grade ferrite core losses are lower than powder 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 achieve a low effective permeability. This large air gap results in gap loss, a complex problem which is often overlooked when comparing material loss curves. 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 soft-saturation characteristics of powder cores are designed to exploit the controlled, partial roll-off of permeability in the material, while having more than twice the flux capacity of a ferrite. This slow roll-off also has the added benefit of improved fault tolerance. Additionally, flux capacity in powder cores stays relatively constant with temperature in comparison to ferrite materials.

Gapped ferrite cores do have advantages over powder cores. Gapped ferrites typically have a ±3% tolerance on inductance compared to most powder cores' ±8%. Gapped ferrites are available in a wider selection of 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.



Kool Mμ

Gapped Ferrite

FIGURE 2

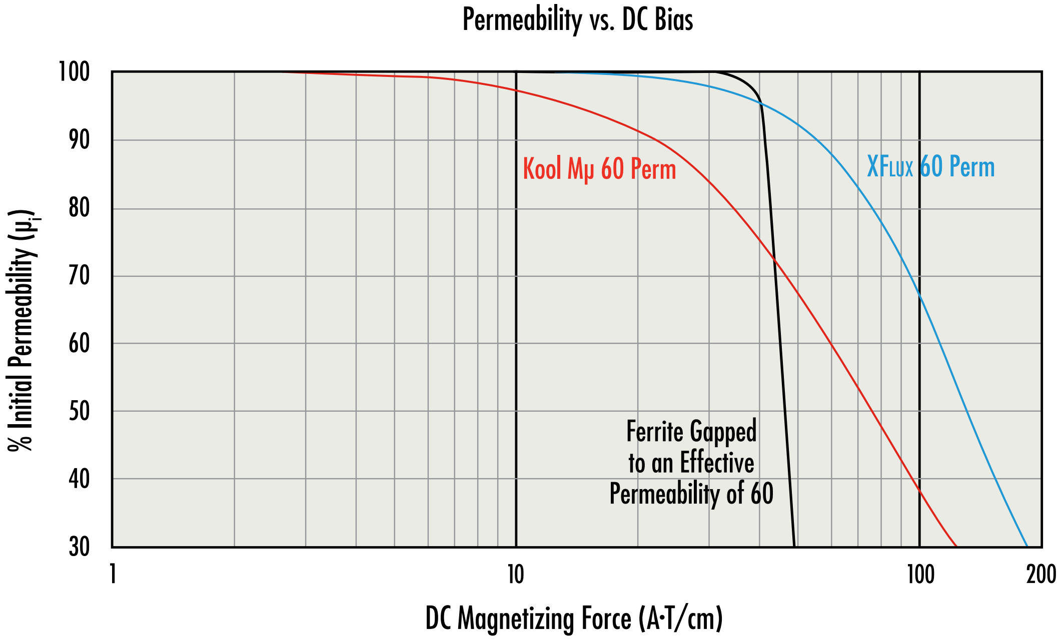


FIGURE 3

Comparison to Powdered Iron

Advantages Of Powder Cores Compared With Powdered Iron Solutions are:

- **Core Losses:** Magnetics powder cores offer 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**: Magnetics powder core materials are manufactured without the use of organic binders, so there is no thermal aging. All coated Kool Mμ and XFLUX toroids are rated for 200°C continuous operation. Uncoated geometries can theoretically be used up to the Curie temperature, which is 500°C for Kool Mμ and 700°C for XFLUX.

Kool Mμ material offers significantly lower core losses than powdered iron (see Figure 4), near zero magnetostriction, and no thermal aging.

Alloy powder cores offer 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 increases core temperature. This effect is lessened with Kool Mμ, making inductors more efficient and cooler.

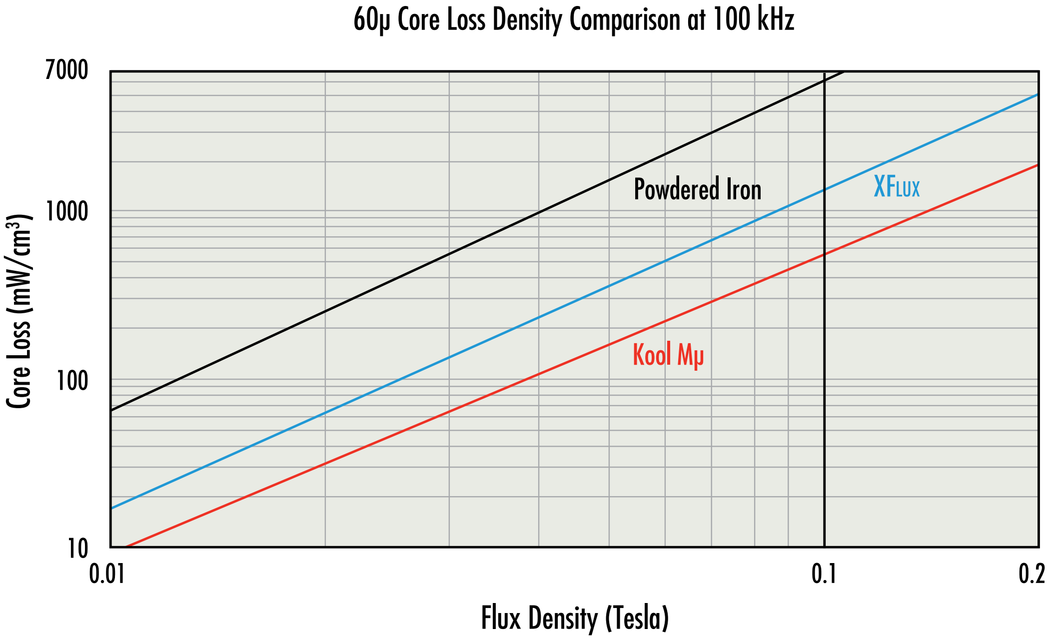


FIGURE 4

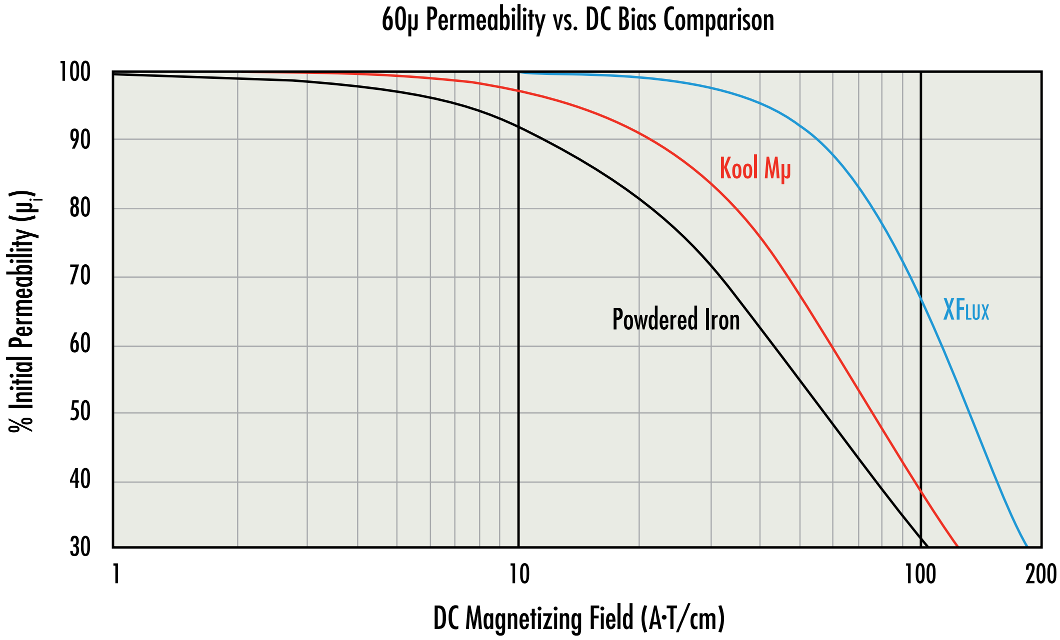


FIGURE 5

Comparison to Silicon Steel

Advantages of Powder Cores compared with Silicon Steel are:

- **Soft Saturation:** Silicon blocks have discrete gaps, unlike the distributed gaps of powder cores, so the onset of saturation with increasing current is much sharper.
- **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.
- **Cost:** Kool Mµ cores have a lower cost than similar sized silicon steel blocks.

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. Powder cores can be designed deep into the saturation curve, resulting in smaller inductors. Powder core shapes (E cores, U cores and blocks) can also be configured for large inductor applications.

In comparison, 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

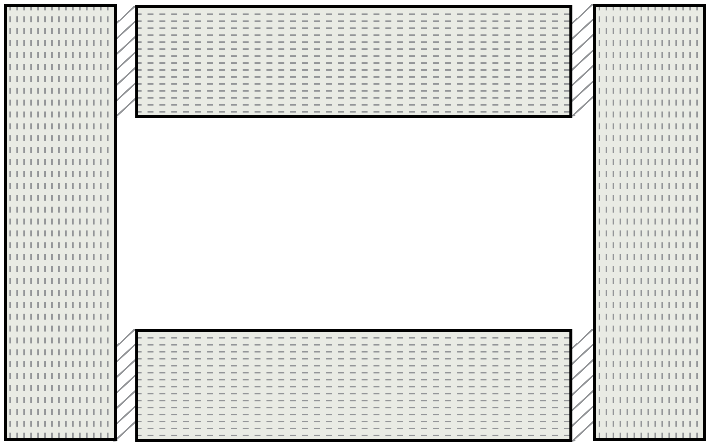


FIGURE 6

Core 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 using Magnetics 2017 Powder Core Catalog pgs. 26-27
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: $H = \frac{NI}{l_e}$ (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.

The LI^2 values listed in Powder Core Catalog are based on a winding factor of 60% (40% for toroids) and an AC current which is small relative to the DC current. LI^2 values are 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.