New Power Ferrite for Low Losses at High Frequency

L material is a new low loss MnZn power ferrite with a permeability of 900 which is specially designed for the frequency range 0.5 to 3MHz. The usage of low-loss high-frequency power ferrite enables downsizing of the inductive components, and increases the throughput power density in switched mode power supplies. **Dirk Huisman, Technical Director Europe, Magnetics, Eindhoven, Netherlands**

Power conversion is one of the major application areas for ferrites. Very often, this conversion is realised by switched mode power supplies (SMPS). In a SMPS, power is converted to different voltage and current levels dependent on what is required by the end application. Although numerous converter types and topologies exist, they all have the same basic magnetic components in their circuitry; inductors and/or transformers.

A feedback-control of the ratio of the output voltage and input voltage defines the on- and off-time of a MOSFET (which is the switching frequency), causing the periodical change of the flux-density amplitude (B) through the inductors and/or transformers.

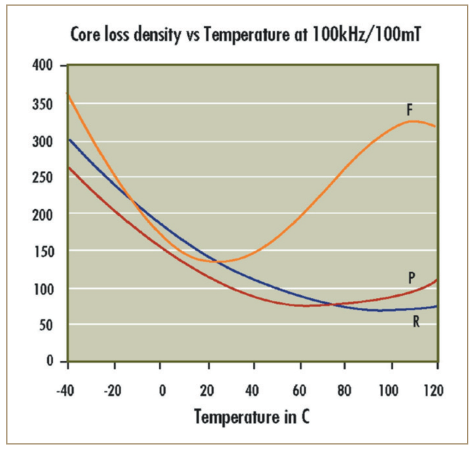
An ongoing trend over the last decades is the increase in switching frequencies. This results in higher throughput power densities for the magnetic cores, which can be used for downsizing core shapes, to effect further miniaturisation of the circuitries. In addition to miniaturisation, another benefit may be the lower level of power loss dissipation in the cores, resulting in lower temperature rises.

Four types of power ferrites

Magnetics has three well-established power ferrites in its product range for frequencies up to 500kHz. Over the years these materials, R (permeability μ ≈ 2300), P (μ ≈2500) and F (μ ≈ 3000) ferrites, have had substantial improvements in their power loss properties. Figure 1 shows the loss density of these ferrites over a temperature range till 120°C at conditions of 100kHz and 100mT.

Most power ferrites show loss minima between 70 and 100°C, which reflects in most cases the operating temperature. For lower operating temperatures, the recommendation is to use ferrites like the F material, where the temperature loss dip is shifted to around 25°C. Each type of power ferrite shows its own specific variation of losses in relation to temperature (T), frequency (f) and flux density (B).

Figure 1: Core loss density for R,P and F ferrites



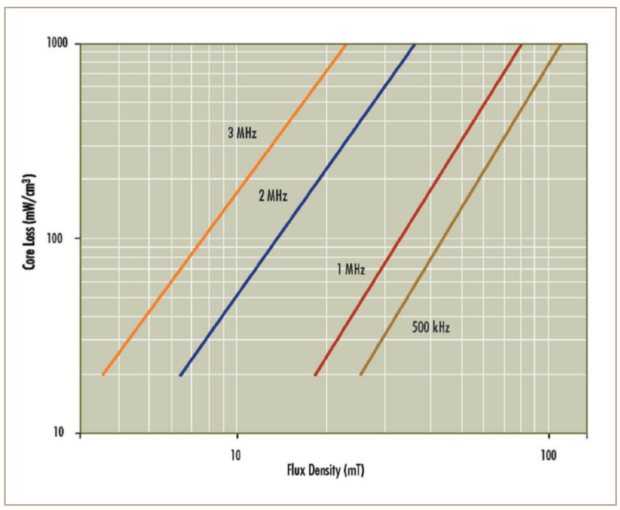


Figure 2: L material losses versus flux density at several frequencies at 100°C

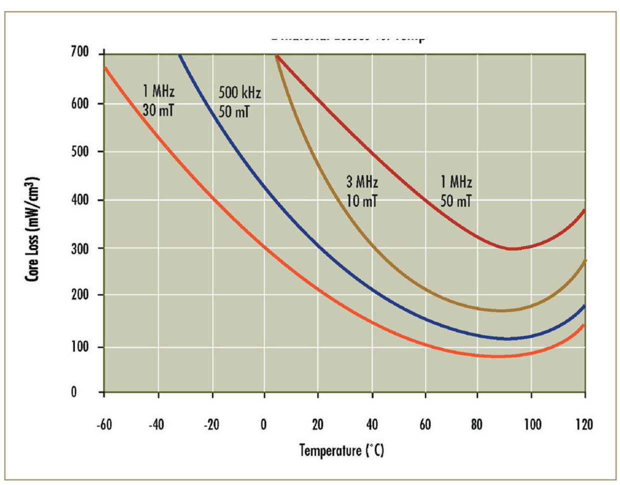


Figure 3: L material losses versus T on several combinations of frequency and flux density

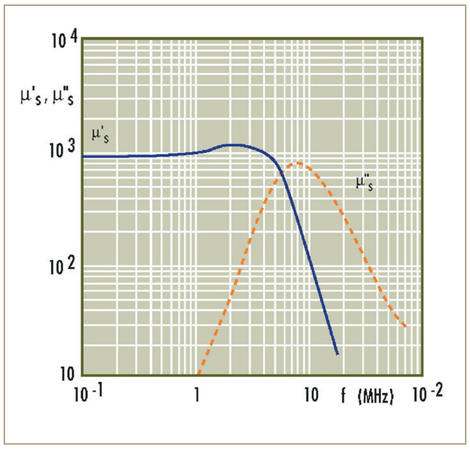


Figure 4: Real and complex permeability

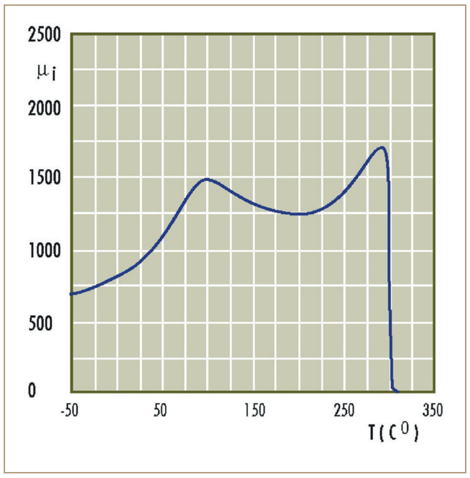


Figure 5: Permeability versus temperature

To make the range of power ferrites more complete by covering the usable frequencies up to 3MHz, the L material for transformer and inductor applications from 500kHz to 3MHz has been developed. Within this range, AC core losses are minimised and the loss versus temperature curve exhibits its minimum at a suitable elevated temperature (70 to 100°C). In addition, the Curie temperature is quite high (>300°C), so that saturation (B_{max}) is good across a wide temperature range.

The loss characteristics, as shown in Figures 2 and 3, are typical for a 42206 toroid size, with (OD/ID/H) of 22.1, 13.7 and 6.35mm. They have been measured on sintered, non-ground toroids, not subjected to any stresses. Specific core loss data will usually differ from these numbers due to influence of geometry, size, and processing operations like grinding and coating. Figure 4 shows that the real permeability rolls of till 50% of its initial value at 6MHz, and Figure 5 shows the permeability over temperature. In Table 1, the maximum level of core loss density is given for uncoated and coated toriods, and core shapes, like planars and PQs at 1MHz/30mT and 3MHz/10mT and 100°C.

Table 1: Core loss limits on toroids and shapes

Core Loss Limits Cores up to 30 mm	1 MHz, 30mT (300G), 100°C	3 MHz, 10mT (100G), 100°C
UNCOATED TOROIDS	175 mW/cm^3 Max	300 mW/cm^3 Max (Ref Only)
COATED TOROIDS	230 mW/cm^3 Max	400 mW/cm^3 Max (Ref Only)
SHAPES	230 mW/cm^3 Max	400 mW/cm^3 Max (Ref Only)

Comparison of performance

To facilitate the design of power inductors and transformers a core loss equation can be used for which fit parameters have to been determined. Such an equation, which is very suited for computer programming purposes, makes it possible to calculate on each condition of f, B and T the power loss density for these power ferrites. The equation is shown in Table 2, and the parameters have been determined for the material loss

Ferrite	f (kHz)	k	x	y	a	b	c	d	e
R	<100	1.476*10-7	1.43	2.85	2.67	-0.0342	1.75*10-4	0	0
	100-500	1.571*10-7	1.64	2.68	,,	,,	,,	,,	,,
	>500	5.574*10-7	1.84	2.2	,,	,,	,,	,,	,,
P	<100	3.011*10-7	1.36	2.86	1.92	-0.0277	1.91*10-4	0	0
	100-500	2.497*10-7	1.63	2.62	,,	,,	,,	,,	,,
	>500	6.122*10-7	3.47	2.54	,,	,,	,,	,,	,,
F	<10	1.567*10-6	1.06	2.85	1.44	-0.0261	4.51*10-4	1.82*10-6	-2.56*10-8
	10-100	3.432*10-7	1.72	2.66	,,	,,	,,	,,	,,
	100-500	2.501*10-7	1.66	2.68	,,	,,	,,	,,	,,
	>500	3.314*10-7	1.88	2.29	,,	,,	,,	,,	,,
L	500-1000	1.133*10-8	1.94	2.78	6.15	-0.104	5.25*10-4	0	0
	1000-3000	1.465*10-11	3.06	2.51	3.64	-0.0716	4.52*10-4	,,	,,

Table 2: Fit constants to calculate core loss density with the form $P = k f^x B^y (a + bT + cT^2 + dT^3 + eT^4)$
Notes: 1) In this core loss equation, the flux density B is the amplitude flux density (so half top-top) of a sinusoidal flux density wave form, the flux density B should be used in the units of mT
2) The frequency should be used in kHz, and the temperatures in °C
3) The fit constants are representing material losses, measured on typical toroid size; 42206, not subjected to any stresses as caused e.g. by grinding, coating

characteristics for the R, P, F and the new L material.

The core loss equation is given by the following equation:

$$P = k\, f^x\, B^y * (a + bT + cT^2 + dT^3 + eT^4)$$

The term between brackets with the fit constants a, b, c, d and e, describes the losses in relation to the temperature. This part equals '1' on the temperatures where the materials are showing their minimum losses. This is for the F and P ferrite at 25 and 80°C respectively and for the R and L ferrite at 100°C. At these temperatures, the loss equation simplifies to:

$$P = k\, f^x\, B^y$$

When comparing the performance of L material with R, P and F ferrite materials, one can consider the material performance factor (the product of flux density B times frequency f). This product (f x B) is directly proportional to the throughput power that a ferrite core can handle. Curves for this performance factor (f x B) versus frequency can be easily constructed by using the fit constants from the simplified core loss equation above.

Isolating B and multiplying both sides with f one can write:

$$(f*B) = (P/k)^{(1/y)}\, f^{(1-x/y)}$$

This equation with the fit constants c, x and y as published in Table 1 for the several frequency ranges, can now we used to construct the (f*B) curves in Figure 6. Some smoothing is used at the frequency points were the set of constants for material are changing. The curves are constructed for a core loss density (P) of 500mW/cm^3. From the curves it can be seen that for the low frequencies the differences in performance are not so large, because saturation limitation plays a role. For higher frequencies the differences increase, and a tremendous step in the throughput power handling capability can be made by using the new L material in the higher frequency range. From the curve, it can also be seen that the optimum frequency for the L material is at 1MHz.

L material is an excellent solution when circuits like DC/DC converters and high frequency filters are designed for frequencies up into the MHz range. The material is offered in a wide variety of core shapes and sizes up to 30mm including planars, PQs toroids and other shapes. Larger sizes are also available for special applications.

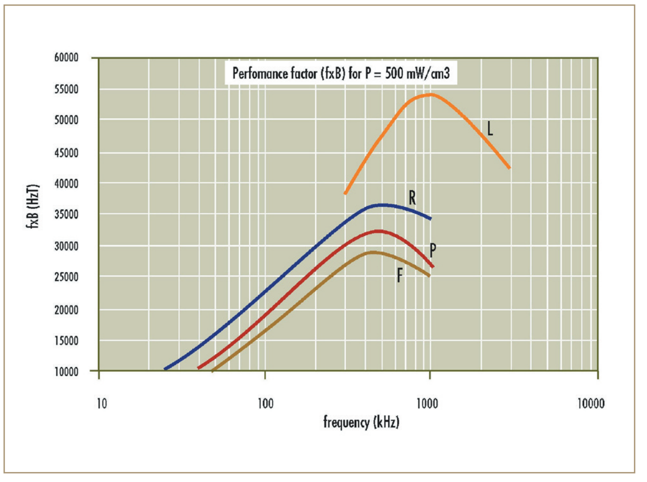


Figure 6: Comparison of material performance factors