Breakthrough in Power Magnetics Materials

By Powerinductors.net

With the advancements in Gallium Nitride (GaN) and Silicon Carbide (SiC) materials in the last 5-10 years there has been renewed interest in advancements in magnetic materials for power inductors and transformers. The last few years at the Applied Power Electronics Conference and Exposition (APEC) there have been more intense discussions regarding the future of power magnetics materials.

Incremental Improvements in Magnetics Core Materials

The ferrite and powdered core manufacturers have been making incremental improvements to their various materials in the last few decades. The saturation flux densities of ferrite materials have increased and core losses for both ferrite materials and powdered core materials have been reduced in general. Figure 1. compares the core losses for 3C90 ferrite (released in early 90's) with various ferrite materials released up until 2014. The graph clearly shows the incremental reduction in core loss from 3C90 to 3C98. However, even with these improvements design engineers are always asking for further improvements in core materials.

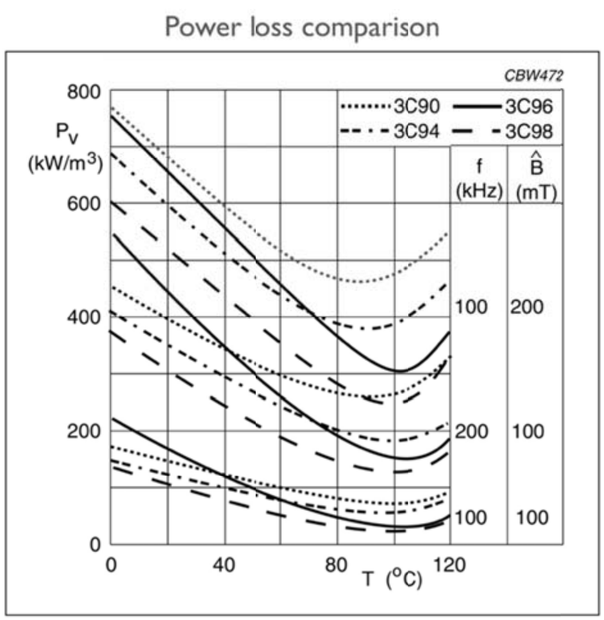

Figure 1. Core losses from Ferroxcube 3C96-3C98 Brochure

For some time now, design engineers desired the soft saturation characteristics of a powdered core, but with the core losses closer to those of a power ferrite material. Design engineers presently either have to use ferrite cores with a large gap, litz wire, and implement construction methods to deal with the fringing flux losses or use powdered cores and deal with the high core losses.   Some have used hybrid solutions where they used one ferrite E core half and one powdered E core half, but those have been in the minority.

New MAGMENT Core Material

In 2016 MAGMENT (MAGnetic ceMENT) introduced a novel core material that has the highly desired combination of soft saturation characteristics of powdered core material and an almost 60% reduction in core losses when compared to SiFe powdered core materials. This material is a patented concrete with magnetizable particles embedded in a cement matrix manufactured in a pressureless process. Furthermore, the magnetizable particles are actually recycled ferrite with carefully selected characteristics. The features of this MAGMENT material are:

- Permeability in the same range as powder core materials
- High DC-bias capability
- Saturation reached only at very high fields
- Very low core losses
- Very high thermal conductivity to efficiently dissipate heat
- Concrete-like mechanical robustness in a very broad temperature range

MAGMENT's first released material has a permeability of 40 and is designated as MC40. The material details are shown in Figure 2. MAGMENT in 26 (MC26) and 60 (MC60) permeabilities are being developed now and will be released later in 2017.

Initial permeability	25°C	μ_i		**40 ± 10%**
Flux density @ H=25 kA/m (314 Oe)	25°C	B_{max}	[mT]	**450**
	100°C	B_{max}	[mT]	**390**
Coercitive field strength	25°C	H_c	[A/m]	**270**
Curie-Temperature		T_c	[°C]	**> 210**
Resistivity	DC	ρ	[Ω m]	**20**
Density		γ	[kg/m³]	**3750**
Relative loss factor	@1 MHz	$\tan\delta/\mu i$	$[10^{-3}]$	**< 0.5**
Relative temperature coefficient	-40°C...150°C	α_F	$[10^{-6}/K]$	**< 50**
Hysteresis material constant	10kHz	η_B	$[10^{-6}/mT]$	**< 3**
DC-Bias (percent permeability change)	@4 kA/m (50 Oe)	μ_{rev}/μ_i		**55%**
	@8kA/m (100 Oe)	μ_{rev}/μ_i		**33%**
Realtive core losses	@ 50kHz, 100mT	P_V	[kW/m³]	**300**
Specific heat		c_p	[J/kg K]	**700**
Thermal conductivity		λ	[W/mK]	**3**
Young's modulus		E_c	[MPa]	**25000**
Compressive strength		f_c	[MPa]	**>50**
Tensile strength		f_t	[MPa]	**2**
Linear expansion coefficient		$\Delta l/l$	$[10^{-6}/K]$	**12**

Figure 2. Technical Data for MAGMENT MC40 material grade

For further information on the MAGMENT MC40 material refer to the full datasheet

MAGMENT not only created a material with soft saturation characteristics and lower core losses, but the MAGMENT material allows for the reduction of manufacturing costs and therefore, overall power inductor costs. Traditionally large power inductor designs are wound around a large powdered toroid or on a bobbin with E cores then inserted in to the wound bobbin. In other words, the winding follows the core geometry. For some larger power designs, the finished inductor is then placed in an aluminum case for optimal heat dissipation and encapsulated with an epoxy that has some thermally conductive capabilities. This is especially done with inductors that will be exposed to harsh environments.

On the contrary, when using MAGMENT material the appropriate air coil is designed, along with the appropriate Aluminum box, and then the MAGMENT material is simply poured over the air coil that is centered in the Aluminum box. This ensures a complete magnetic filling of the available volume within the housing yielding maximum performance and cooling. With a MAGMENT design the core geometry follows the winding. As compared to the conventional manufacturing of winding around cores and sealing with a potting material, the flowability of MAGMENT materials allow for simple “wind and magnetic pour” process, which goes along with absolute shape and size flexibility. This allows to both tailor components to minimize material utilization and to any given space constraints by a special magnetic design algorithm yielding lowest cost as compared to any other inductive technology. See figure 3 for an example of a MAGMENT power inductor. The design algorithm can minimize either cost or total losses.

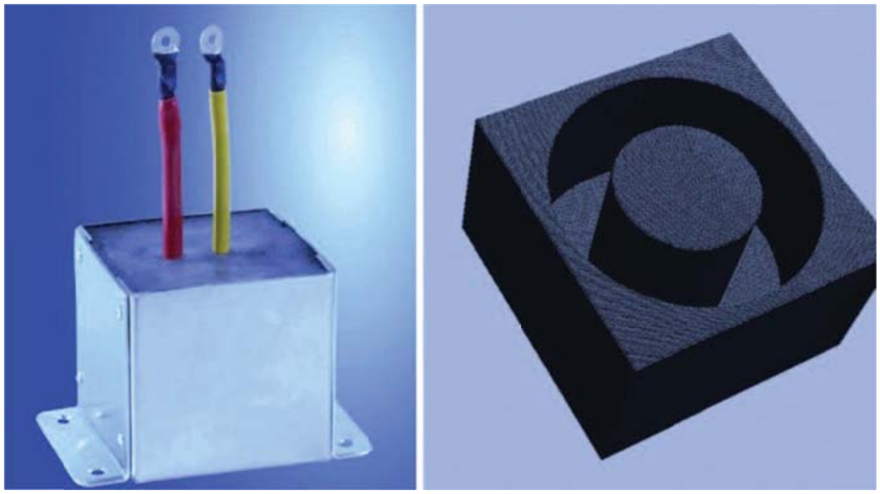

Figure 3. MAGMENT inductor (left) depicting its magnetic material shape (right)

With this proprietary design algorithm MAGMENT optimizes the electrical design and core geometry which results in the typical inductance vs. current curve shown in figure 4.

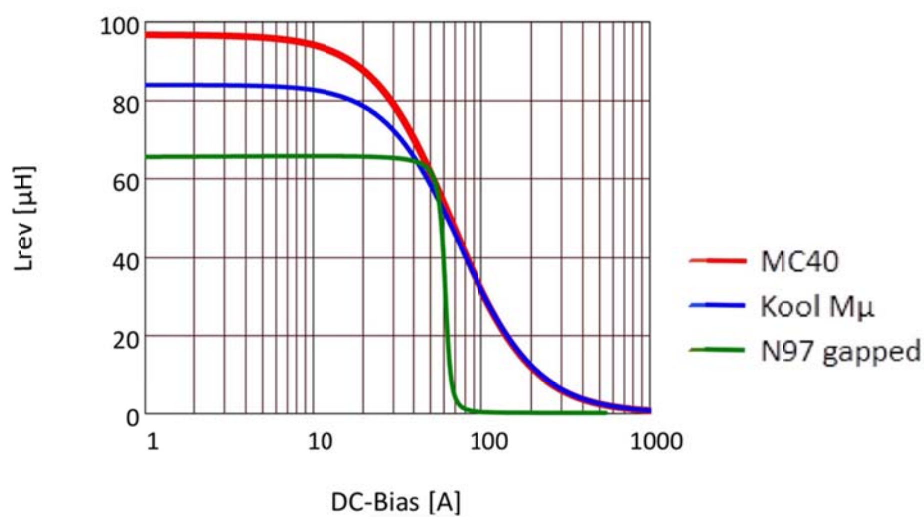

Figure 4. Inductance vs. Current of geometry optimized MAGMENT inductor

Comparing a Traditional Power Inductor to a MAGMENT Power Inductor

A customer approached MAGMENT with the traditional inductor shown in Figure 5. It used a SiFe 40µ toroid with an inductance of 34 µH @ 30A peak. This inductor had the following mechanical dimensions: 45 mm x 45 mm x 28 mm and the customer requested a MAGMENT inductor with the same mechanical dimensions, less overall losses, and a reduced cost.

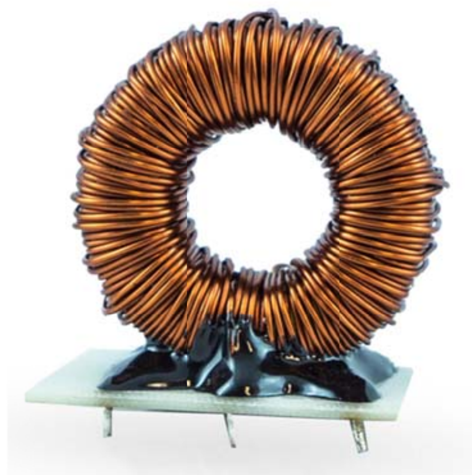

Figure 5. Traditional inductor using SiFe 40µ – 34µH @ 30Apeak

Additional data on the traditional inductor the customer provided is shown in Table 1.

								LOSSES [W]				WEIGHT [g]	
	µ	N	le [mm]	Ae [mm²]	DCR [mOhm]	ACR [mOhm] @ 75 kHz	B [mT]	Core	DCR LOSSES	ACR LOSSES	Total	Core	Copper
Traditional Inductor	40	34	81.5	67.2	10	566	45	1.20	4.49	0.41	6.10	39	50

Table 1. Technical data for Traditional inductor using SiFe 40µ.

The MAGMENT design team used the proprietary design algorithm mentioned earlier and developed a MAGMENT inductor very similar to the one shown in Figure 6. The final MAGMENT inductor met the requested mechanical dimensions of 45 mm x 45 mm x 28 mm and had an almost 18% reduction in overall losses. Equally as important, the MAGMENT inductor is approximately 25% less in cost.

Figure 6. Typical MAGMENT inductor using MC40 40µ

Table 2 compares the MAGMENT inductor to the traditional inductor in detail.   One of the first things to note is that the turns of the MAGMENT inductor are reduced by almost 60% and this is possible because of the large core area of the MAGMENT inductor. Consequently, the flux density of a MAGMENT inductor was reduced by 74%. This is possible because as mentioned earlier with a MAGMENT design the core geometry follows the winding. Finally, the core loss of the MAGMENT inductor is only 0.06 W while the traditional inductor had 1.20 W of core loss. This large reduction in core loss in the MAGMENT inductor results in the almost 18% reduction in overall losses.

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	µ	N	le [mm]	Ae [mm²]	DCR [mOhm]	ACR [mOhm] @ 75 kHz	B [mT]	Core	DCR LOSSES	ACR LOSSES	Total	Core	Copper
Traditional Inductor	40	34	81.5	67.2	10	566	45	1.20	4.49	0.41	6.10	39	50
MAGMENT Inductor	40	14	102	602	10	685	12	0.06	4.49	0.49	5.05	176	31

Table 2. Traditional inductor and MAGMENT inductor comparison – 34uH @ 30Apeak

The inductance vs. current graph in figure 7 clearly shows that the performance of the MAGMENT inductor at peak current is equivalent to the traditional inductor.

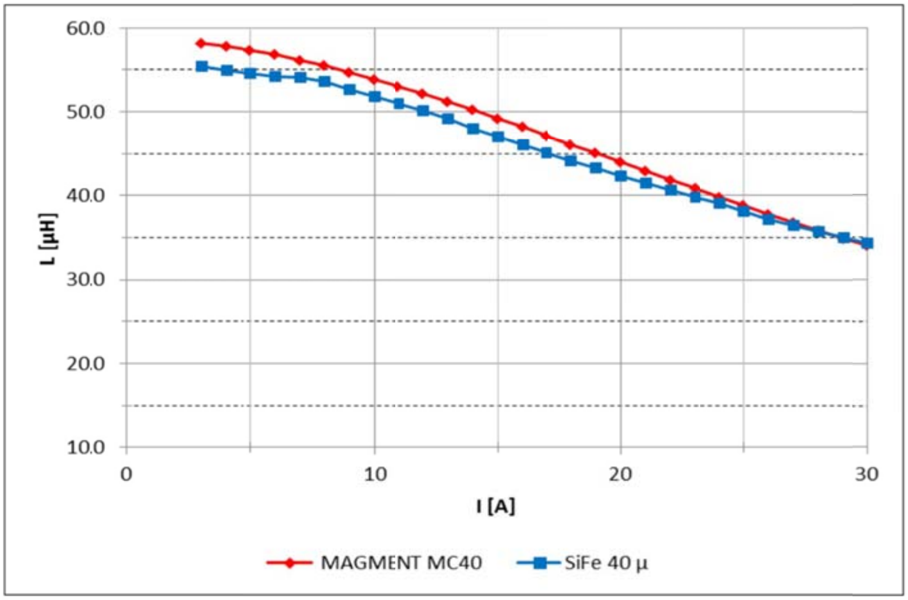

Figure 7. Inductance vs. Current comparison of MAGMENT and Traditional Inductor

Further Analysis

While reviewing table 2 it is evident that this particular MAGMENT inductor will weigh more as a result of the MC40 material which weighs more when compared to the SiFe material. In the above comparison, if the size of the inductor was not a constraint then the losses of the MAGMENT inductor could be further reduced. It is important to note that since a MAGMENT inductor generally will have more surface area than a traditional inductor the MAGMENT inductor can have higher DCR and yet have less measured temperature rise. In this comparison the traditional inductor has a calculated thermal resistance of 24.6^{o}C/W which results in calculated temperature rise of 150^{o}C. On the contrary, the MAGMENT inductor has a calculated thermal resistance of 7.3^{o}C/W which results in a calculated temperature rise of 37 ^{o}C. MAGMENT inductors tested by customers in their application circuit have shown the benefits of the larger surface area and resulting reduced temperature rise.

Conclusion

The proprietary magnetic design algorithm is a powerful tool that the MAGMENT design team utilizes to completely optimize MAGMENT inductors for all types of applications. Future application notes will discuss total losses further and the magnetic design algorithm in more detail. The MAGMENT material is a magnetic material that is revolutionary and as mentioned in beginning of this application note has the following features:

- Permeability in the same range as powder core materials
- High DC-bias capability
- Saturation reached only at very high fields
- Very low core losses
- Very high thermal conductivity to efficiently dissipate heat
- Concrete-like mechanical robustness in a very broad temperature range
- In general, lower costs when compared to equivalent traditional inductors.