November 3rd, 2025

NANOMET™ - Soft Magnetic Material Evolves to Achieve Benchmark Power Conversion Performance

Soft Magnetic Materials Opportunities to Support Power Architecture Roadmap Trends

Increased power density within electronic inverter and converter technologies drives the development and roadmaps of all major component technologies. Faster switching speeds and frequencies demand new semiconductor technologies like GaN and SiC, but also require new magnetic materials to accompany the downsizing demand.

While BLDC motor inverters maintain switching frequencies in the lower double-digit KHz range other DC/DC conversion stages have significantly increased switching frequency. For the modern multiphase buck regulator, it is around 1MHz, and several hundred KHz in high voltage applications such as power factor correction or boost circuits. The ultimate benefit is scaling down application size and weight, while at a minimum, increasing efficiency and reducing losses. This trend is clearly seen for everyone using a notebook power supply when comparing the latest ones using GaN technology with those from 10 years ago. This continues across power conversion applications in industrial, commercial, and automotive environments and will continue to develop.

Inductor core losses are related to the mechanical core volume and increase with frequency and magnetic flux density. Downsizing components with traditional materials will increase the core losses and challenge thermal heat transfer. This demands expensive and intelligent thermal management systems, which leads to mechanical limitations and isolation issues. Magnetic core material represents today's biggest opportunity for breakthrough designs that meet efficiency and size requirements for next-generation power conversion circuits in all industries.

Figure 1 - Increasing power density in modern server applications

Soft Magnetic Materials: The Journey to Benchmark Performance Status

Having set the stage from the current market perspective, it is important to take the reader on a journey into that marketplace and demonstrate how the typical ferrite design space over the past twenty years is being challenged, matched, and exceeded by soft magnetic materials. Proven using benchmark measurement.

This paper describes the use of Soft Magnetic Material as a replacement for the typical ferrite solution. It identifies the material's use in a variety of different power applications via case studies and draws out the advantages in each example.

To set the scene for the journey, it is helpful to provide a snippet of history. NANOMET™ started as a national project in Japan to find an improved material with superior properties to overcome losses in conventional materials. In 2010, it was first introduced and trademarked by the TOKIN Corporation, which is part of the YAGEO Group today. NANOMET™ was considered for several different applications, including BLDC motor stator material and power inductors. Over the last 15 years, manufacturing processes were improved and ingredients optimized to form the material group available today.

To start the journey to benchmark status, a simple explanation of magnetic theory and identifying the challenges ferrite material has for the design engineer is necessary. Also, it is useful to note the plethora of losses that occur generally with magnetic designs.

The Ferrite Design Challenge stems from the non-linear B/H loop and the need to avoid ending up in saturation. An air gap is introduced as a solution into the magnetic circuit, and the design is tuned to cater for losses and magnetic flux spilling out, increasing EMI.

NANOMET™, a soft magnetic material, exhibits a B/H curve that, when compared with the ferrite air gap B/H loop it is the same but does not need the leaky air gap. The details of the material, its properties, and facets follow the theory. Armed with this knowledge, the reader is presented with 4 case studies of a variety of power applications, comprising Power Beads, TLVR, PCF, and Boost Inductor PCB mount Power Inductor 150nH, providing examples with low inductance & High Current Components, High Inductance & High Power Components, and PCB mounted.

Now you have an overview of the topic, let the detailed journey begin to benchmark performance status.

November 3rd, 2025

Understanding the Basics of Soft Magnetic Core Material and Losses

Permeability (μr) is directly linked to the inductance of a component design; it is a factor that is multiplied by the inductance of an air coil with the same shape and size. The value can be imagined as the effort needed to rotate a magnetic domain by an applied magnetic field. With increasing μ, the rotation ability becomes easier. This is shown in the B/H curve as the slope of B vs H. This slope can be adjusted using a physical air gap on the route of the magnetic flux, which tunes the component performance to sustain an application without saturation.

Magnetic saturation occurs when the rotation angle is in line with the magnetic field, and any increase in field strength will not add any more magnetic energy. The relation between the current flow creating the magnetic field strength and the magnetic flux created is nonlinear. This is shown in the B/H curve as limits on the vertical axis (Bsat). As a result, the inductance of the component will decrease, which is seen in datasheet diagrams as L → IDC but is of course also valid for alternating currents. Not only do RMS currents need to be considered, but also peak values, which should not trigger saturation.

Core loss is caused by rotating the magnetic domains quickly in an alternating magnetic field, which causes a kind of friction and results in heat generation. That loss is represented in the B/H curve as the area between the alternating hysteresis lines. One diagram shows all parameters visually, but only for a specific frequency. Raising the frequency increases the width of the hysteresis loop and ultimately the losses. As the dependence results in a geometric area increase, the losses influence is a square law rather than linear. A loss value is calculated using Steinmetz coefficients k, α, and β.

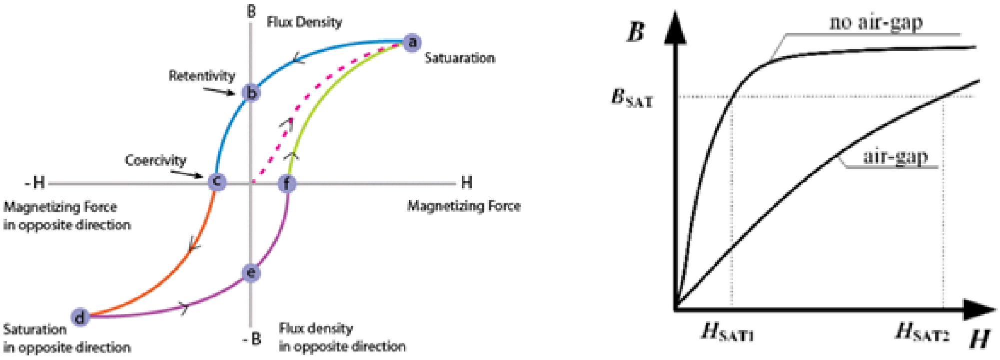


Figure 2 - Hysteresis curves with expressions

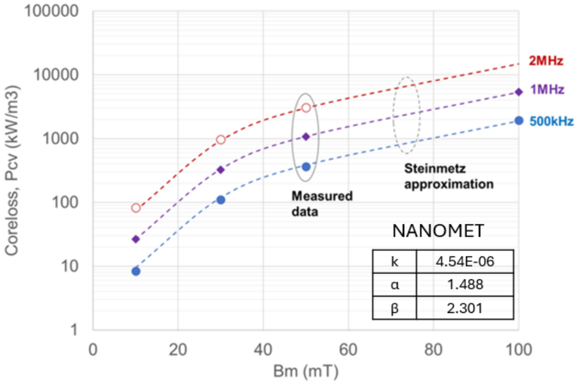


Figure 3 - NANOMET™ core loss vs. $Bm_{(f)}$

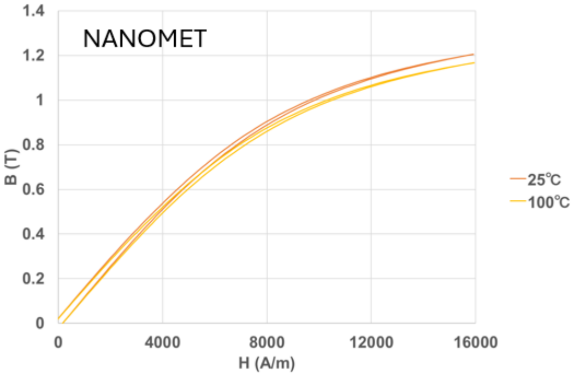


Figure 4 - NANOMET™ B/H curve

November 3rd, 2025

In addition to the pure core parameters, there are losses caused by the conductor/coil. DC losses caused by the resistance of copper, AC losses owing to the increased effective resistance from the skin effect, proximity losses caused by magnetic coupling between adjacent conductors in the coil, and fringing losses owing to fringing flux from the airgap intersecting the winding. For a given required inductance, proper component design and higher permeability material can be used to shorten the conductor and therefore reduce losses. Component designs can become more compressed with fewer windings or shorter conductors.

While conductor losses can be easily transferred to heat sinks or the mechanical framework via the PCB layout or available silicon-based thermal interface materials, core losses are more difficult to conduct thermally as the material itself does not have heat conduction properties like copper.

Soft Magnetic Material Properties that Overcome the Challenge

While modern ferrite-based materials have high flux density and low core losses, they lack saturation capability. To overcome the saturation issue, physical air gaps are required in the design, which causes a volume increase. In addition, ferrites have a hard saturation behavior that changes with temperature and demands increased volume to operate properly within application limits. Higher currents and high temperatures, even present for short times, need to be considered in the design. A material permeability of 900µ needs to be altered using an airgap, to around 100µ for practical use. This air gap and its leakage magnetic field cause additional EMI challenges and design compromises.

Typical metal composite inductors like the METCOM series enable downsizing for EMI applications as the current ripple is low and does not cause much core loss. For buck or boost applications and any other storage choke application, the core losses of this technology grow significantly owing to magnetic flux density and frequency. This limits their use. Over the last 20 years, these materials have seen many tuning iterations to provide significant improvements.

NANOMET™ is not just a variation of existing iron powder technologies but demands a completely new process to be invented to create a material with soft saturation behavior, temperature stability, low core losses, high permeability, and exceptional saturation behavior. While the manufacturing process has mechanical limitations, solutions for all major inductor applications have been created that lead to a benchmark component performance and minimal size. This enables smaller inductor designs with reduced copper resistance and benefits the overall loss equation.

Material	**Ferrites**	**Metal Composite**	**NANOMET™**
Composition	Mn-Zn	FeSiCr	FeSiBPCuCr
Process	Power mold sintering	Power mold curing	Hot mold
Permeability µ	900 (100 w/gap)	25	100
Bc(T)	0.5	1.2	1.3
µ vs T	Not stable	Stable	Stable
Core Loss	Low (relative loss:1)	High (relative loss:50)	Mid (relative loss:5)

Table 1 - Relation between different soft magnetic materials

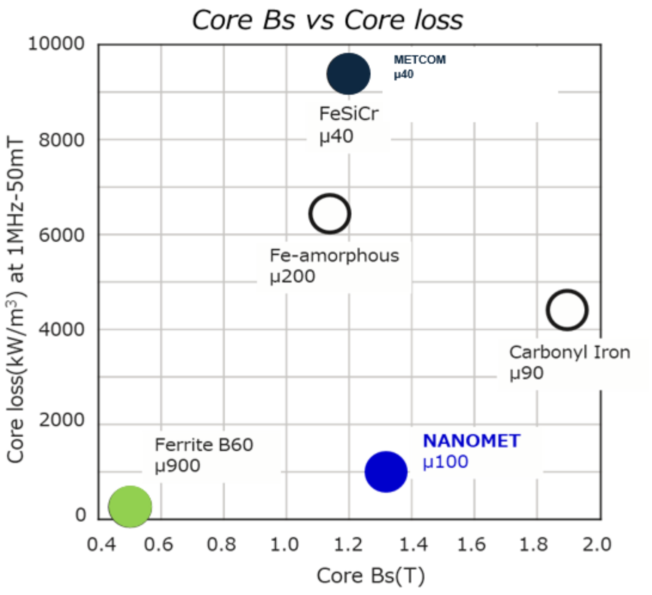


Figure 5 - Core loss vs magnetic saturation

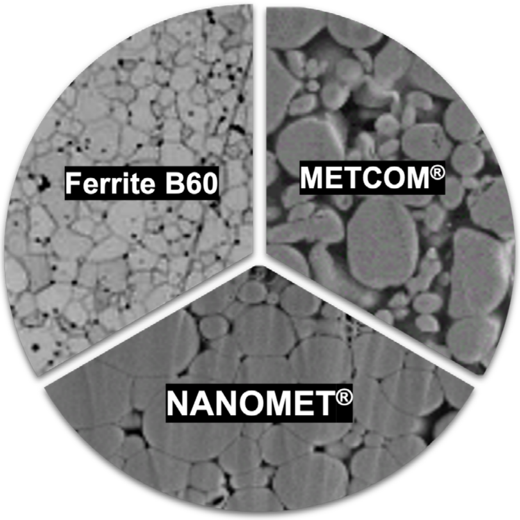


Figure 6 - Microscopic view/density

Every core material has process foundations that lead the way to mechanical inductor designs. While typical metal composite materials can be processed to form a core around a coil specifically for surface-mounted power inductors, the process for ferrites and NANOMET™ dictates forming a solid block shape first and assembling the coil afterwards. The process conditions of those materials require enormous pressure and heat that would soften electrical isolation materials and can cause deformation, which is called "Hot Press Molding" technology.

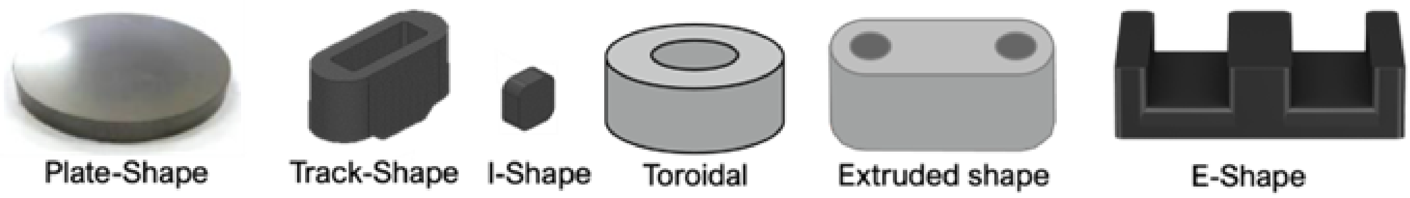


Figure 7 - Typical NANOMET™ core shapes used that can be manufactured

The Impact of an Air Gap in a Magnetic Core Structure

Metal composite and NANOMET™ inductors have a built-in airgap structure in the material that ensures each metal powder grain is coated with a Silicon shell, which represents the magnetic gap. Ferrite designs typically need to operate with an air gap to avoid saturation by applied current.

An air gap allows the magnetic field to leak through the whole design and can cause EMI challenges. The field leakage also causes fringing losses to structures close to the winding. In high-power designs, this can introduce a significant amount of heat in the conductor.

With some core designs, even metal composite or NANOMET™ component structures require minimal airgaps to increase the saturation capability or cater for the required mechanical conditions that the application demands and the core assembly process dictates.

In any case, the gap is smaller with iron-based silicon-coated materials, and the impact of EMI emission and fringing losses is much less.

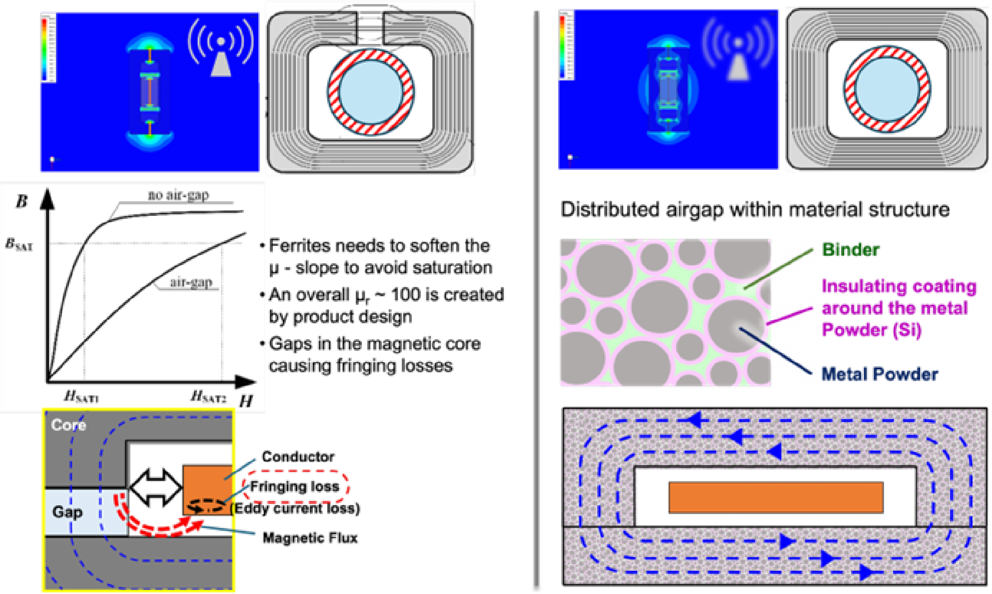


Figure 8 - Influence of airgaps in power inductor designs

Having covered most of the basics to understand the challenges of soft magnetic materials we now focus on NANOMET™ applications that solve demanding requirements or ones not even possible without its use.

Figure 9 - Examples of component shapes

Power Application Impact of NANOMET™ - Case Studies

#1 - Power Beads/Low Inductance & High Current Components

Multiphase buck regulator power modules on demanding server boards generate more than 100A individually and need to be close to GPUs/CPUs for efficiency. As an example, the AMD MI300 board currently in production shows a typical setup (Source: https://youtu.be/8Ve5SAFPYZ8).

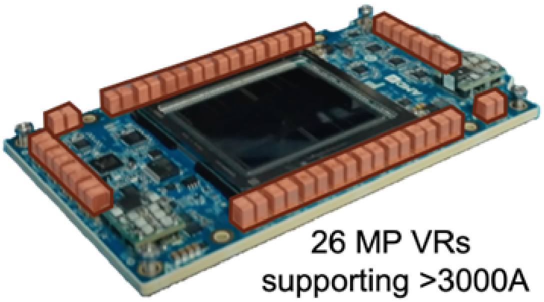


Figure 10 - AMD MI300 server board

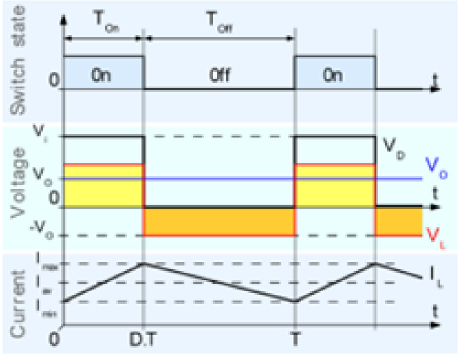
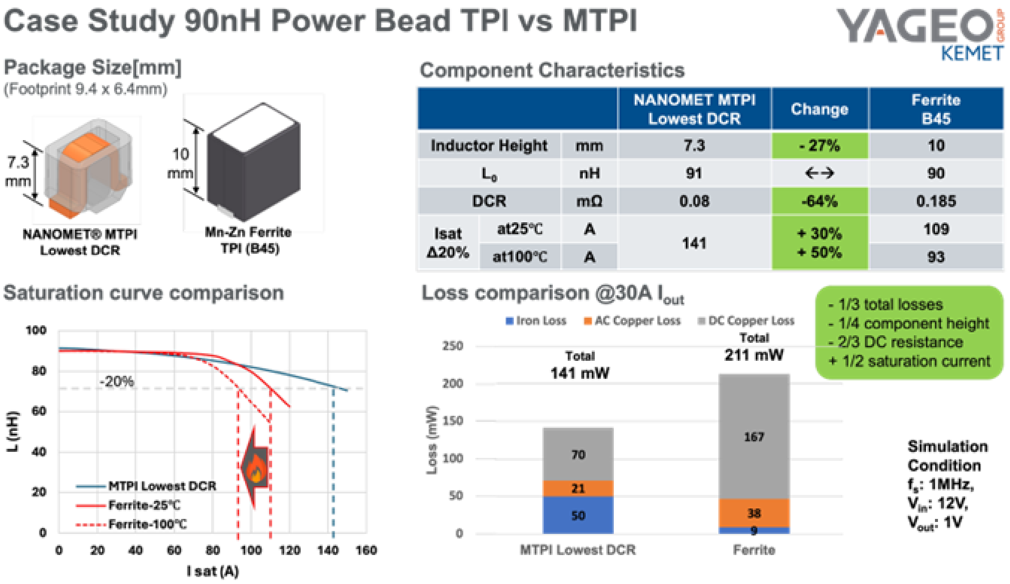


Figure 11 - Buck VR functional diagram



Case Study 90nH Power Bead TPI vs MTPI

Package Size[mm]
(Footprint 9.4 x 6.4mm)

Component Characteristics

			NANOMET MTPI Lowest DCR	Change	Ferrite B45
Inductor Height		mm	7.3	- 27%	10
L_0		nH	91	←→	90
DCR		mΩ	0.08	-64%	0.185
Isat Δ20%	at25℃	A	141	+ 30% + 50%	109
	at100℃	A			93

Saturation curve comparison

Loss comparison @30A I_{out}

- 1/3 total losses
- 1/4 component height
- 2/3 DC resistance
+ 1/2 saturation current

Simulation Condition
f_s: 1MHz,
V_{in}: 12V,
V_{out}: 1V

Figure 12 - Performance overview 90nH power inductor ferrite vs. NANOMET™

Even at medium load conditions, it is remarkable that the smaller component has significantly improved key performance properties like copper resistance and saturation capability, and cuts the overall losses by 33%. Even with higher load currents, the DC copper losses will further dominate, and NANOMET™ further improves the situation. Even when the core or iron losses in total, @30A, are higher (50mW vs. 9mW), the shorter conductor compensates for the total losses, with lower AC and DC resistance values. Since a physical air gap is not needed, the benchmark component emits less EMI because there is less leakage of magnetic field.

November 3rd, 2025

Power Application Impact of NANOMET™ - Case Studies

#2 - TLVR/Low Inductance & High Current Components

To overcome load transient events when high-power CPUs & GPUs start, various countermeasures are implemented so the output voltage does not drop below the minimum specified operating voltage of the semiconductor devices. A typical buck regulator can achieve ~200A/ms while a TLVR-based buck regulator achieves up to ~1000A/ms at the cost of efficiency.

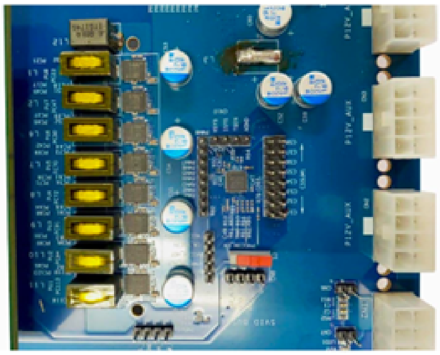


Figure 13 - Article #A-0041 Rev. 1.0 (MPS)

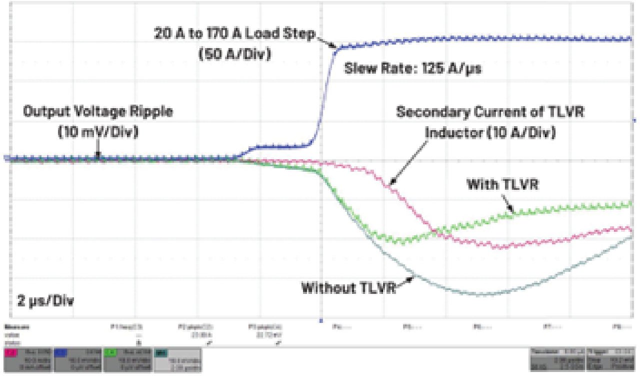
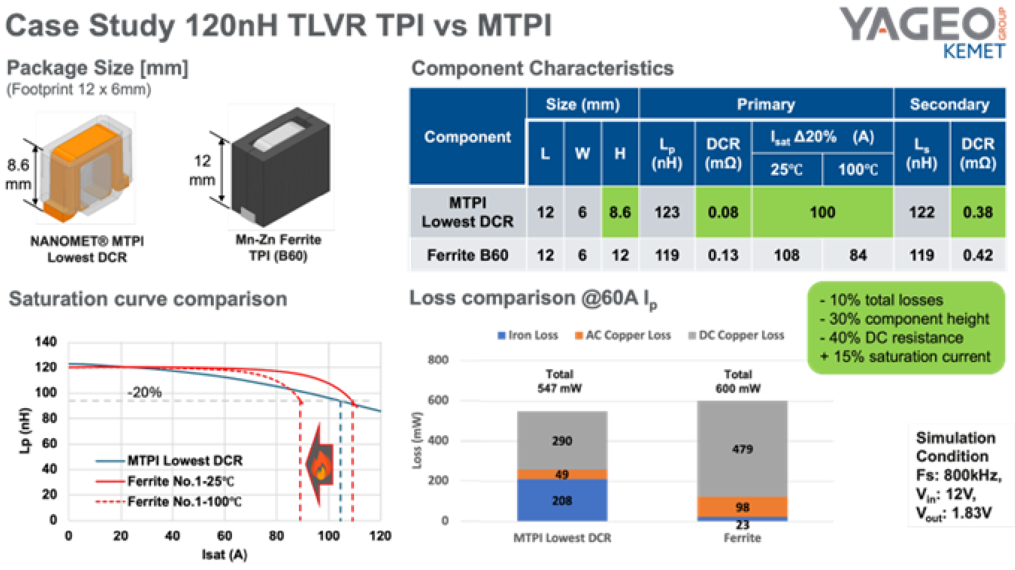


Figure 14 - Vol 57, No 1 - Feb 2023 (Analog Devices)



Case Study 120nH TLVR TPI vs MTPI

Package Size [mm]
(Footprint 12 x 6mm)

Component Characteristics

Component	Size (mm)			Primary				Secondary	
	L	W	H	L_p (nH)	DCR (mΩ)	I_{sat} Δ20% (A) 25℃	I_{sat} Δ20% (A) 100℃	L_s (nH)	DCR (mΩ)
MTPI Lowest DCR	12	6	8.6	123	0.08	100		122	0.38
Ferrite B60	12	6	12	119	0.13	108	84	119	0.42

Saturation curve comparison

Loss comparison @60A I_p

- 10% total losses
- 30% component height
- 40% DC resistance
+ 15% saturation current

Simulation
Condition
Fs: 800kHz,
V_{in}: 12V,
V_{out}: 1.83V

Figure 15 - Performance overview 120nH TLVR ferrite vs. NANOMET™

Even at medium load conditions, it is remarkable that a 30% smaller component with the same footprint achieves better performance in all key categories. Even when the core losses of NANOMET™ are higher against the ferrite material, the total component loss is lower. With increasing load current, the copper losses will further dominate the total losses. Since a physical air gap is not needed, there is less leakage of the magnetic field emitted from the inductor, producing less EMI. The amount of energy carried over from the secondary to the primary circuit when a load step occurs is also related to the coupling factor, which is higher without an airgap.

Power Application Impact of NANOMET™ - Case Studies

#3 – PFC or Boost Inductor/High Inductance & High-Power Component

High voltage power applications operate with lower switching frequency, but boundaries are being broken and are fast reaching the 200KHz range. Either to align phase angles of AC power supply or boost output voltage levels, a high-performance inductor is needed. Component downsizing is essential to decrease mechanical space and weight.

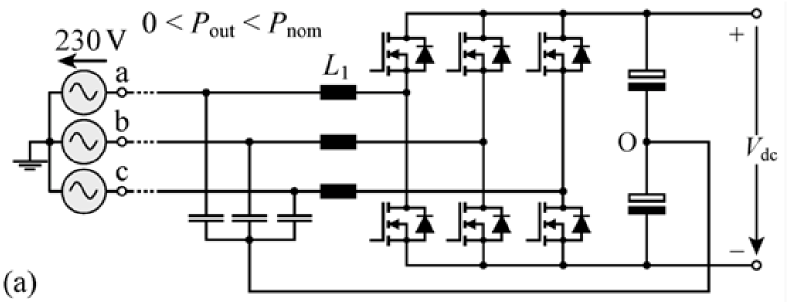
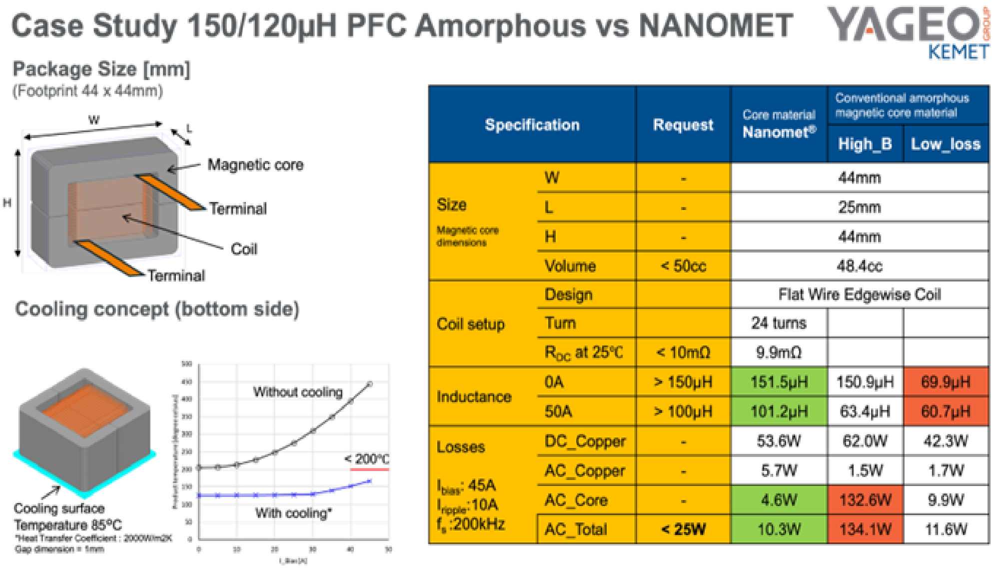


Figure 16 - Typical 3 phase PFC circuit



Case Study 150/120µH PFC Amorphous vs NANOMET

Package Size [mm]
(Footprint 44 x 44mm)

Cooling concept (bottom side)

Specification		Request	Core material Nanomet®	Conventional amorphous magnetic core material	
				High_B	Low_loss
Size Magnetic core dimensions	W	-	44mm		
	L	-	25mm		
	H	-	44mm		
	Volume	< 50cc	48.4cc		
Coil setup	Design		Flat Wire Edgewise Coil		
	Turn		24 turns		
	R_{DC} at 25℃	< 10mΩ	9.9mΩ		
Inductance	0A	> 150µH	151.5µH	150.9µH	69.9µH
	50A	> 100µH	101.2µH	63.4µH	60.7µH
Losses I_{bias}: 45A I_{ripple}:10A f_s :200kHz	DC_Copper	-	53.6W	62.0W	42.3W
	AC_Copper	-	5.7W	1.5W	1.7W
	AC_Core	-	4.6W	132.6W	9.9W
	AC_Total	**< 25W**	10.3W	134.1W	11.6W

Figure 17 - Performance comparison of PFC choke application 22kW miniaturized

When mechanical space and weight are not of concern, amorphous soft magnetic materials trimmed for low losses/high flux cores can be used in PFC choke applications, as the trend is for ever-increasing switching frequencies. High B amorphous materials can be used for lower switching frequencies and would reach the target size requirements.

Once a small component size, low core losses, and high switching frequencies are demanded, there is no alternative but to use NANOMET™; however, a heat transfer mechanism is required to conduct the winding losses to a dedicated heat sink.

Power Application Impact of NANOMET™ - Case Studies

#4 – PCB mount Power Inductor 150nH

Output inductors of multiple VR applications demand small, powerful components; downsizing only works by touching inductors. A quick view of a PCB shows lots of inductors for local power conversion and supporting the CPUs and GPUs.

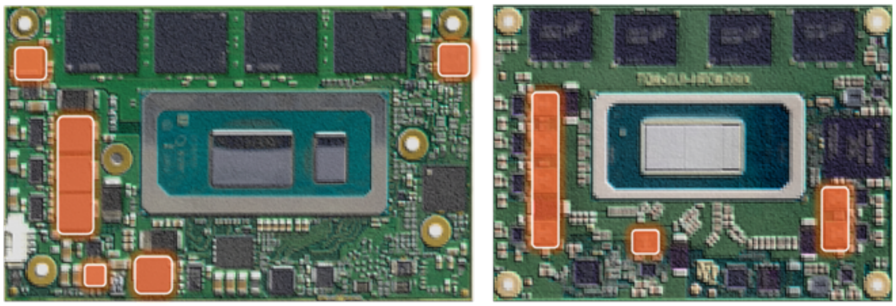
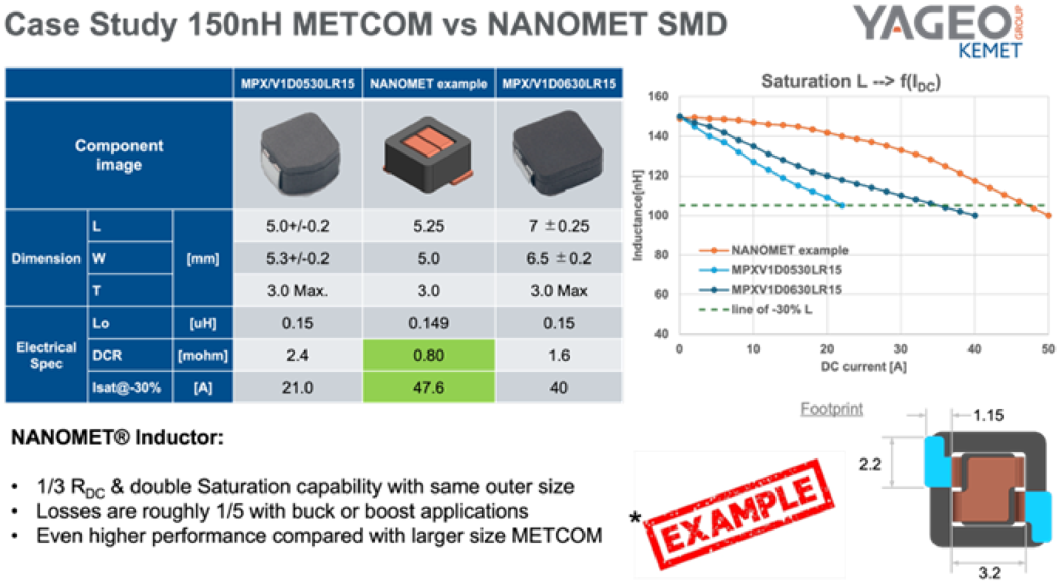


Figure 18 - Typical distribution of power inductors on modern embedded PCBs



Case Study 150nH METCOM vs NANOMET SMD

			MPX/V1D0530LR15	NANOMET example	MPX/V1D0630LR15
Component image					
Dimension	L	[mm]	5.0+/-0.2	5.25	7 ±0.25
	W		5.3+/-0.2	5.0	6.5 ±0.2
	T		3.0 Max.	3.0	3.0 Max
Electrical Spec	Lo	[uH]	0.15	0.149	0.15
	DCR	[mohm]	2.4	0.80	1.6
	Isat@-30%	[A]	21.0	47.6	40

NANOMET® Inductor:

- 1/3 R_{DC} & double Saturation capability with same outer size
- Losses are roughly 1/5 with buck or boost applications
- Even higher performance compared with larger size METCOM

Figure 19 - Performance comparison METCOM to NANOMET™ SMD Power Inductor

The example does not include the core losses, as this is not critical, but it shows visibly that the material is very stable against DC currents in such a small size. The core losses will be only 20% per the same volume and the copper losses decrease as well.

November 3rd, 2025

Power Benchmark Status and the Future

The journey so far has shown the reader that NANOMET™ has the same B/H loop property as the ferrite solution. Hence, simpler air gap-free designs compared to its ferrite counterparts. All aspects of losses are considered, and while for particular losses, NANOMET™ exceeds the ferrite design when total losses are analyzed, NANOMET™ wins and often by some margin.

It is remarkable that NANOMET™ is favorable in all benchmarks and thus has become of age in a variety of different applications. The future looks bright for NANOMET™ as it suits a broad application design space and has a strong roadmap potential for further material development addressing increased frequency ranges and optimized core losses.

A YAGEO engineering team is currently working on solutions to overcome the challenges to integrate a coil structure and produce molded types of inductors. Satisfying another area of the design marketplace.

While a breakthrough technology like NANOMET™ crosses design boundaries and is in mass production under strict quality procedures, there is still room for improvement. Lessons learned when moving to mass production allow for even greater property adjustment and material optimization. For each design, a perfect material becomes available to benchmark in another benchmark use case.

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