Magnetics	Technical Note

Power Inductors 101

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Today, there are many sizes and types of inductors on the market for a variety of applications. This article will discuss power inductors, which can loosely be defined as any inductors that are designed to handle more than one amp of current.

Power inductors are typically used for energy storage in DC/DC converters or high current noise filter applications, including motor speed control, adjustable lighting, DC power conditioning, and more. Power inductors can be divided further into two groups - shielded and unshielded. Unshielded power inductors have an open magnetic circuit where the magnetic flux induced in the core by the current in the winding exits the core and extends through the air to the other side of the core where it completes the flux path. A simple solenoid inductor is a good example of an unshielded inductor. See Fig. 1.
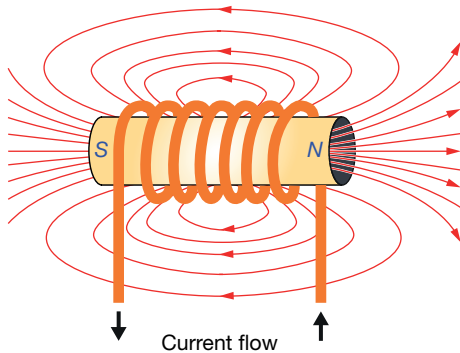

Current flow

Fig. 1 - An unshielded inductor allows magnetic flux to escape into the adjacent area

A shielded inductor is designed so that the magnetic flux never leaves the core, preventing flux from interfering with sensitive components that may be nearby. An example of a shielded inductor is a toroid. See Fig. 2.
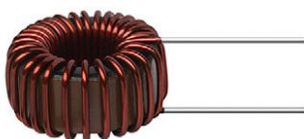

Fig. 2 - A toroidal configuration keeps most of the magnetic flux inside the core

Conventional inductor designs normally start with a core made out of soft magnetic material, such as ferrite or iron, that is wound with turns of insulated wire to achieve the desired inductance. Some examples of these common power inductors are shown in Fig. 3.

Fig. 3 - Examples of unshielded power inductors

Composite power inductor (CPI) construction differs from conventional magnetics since the assembly process is reversed. CPI construction starts with a pre-wound coil of wire that is welded or soldered into a lead frame. See Fig. 4.
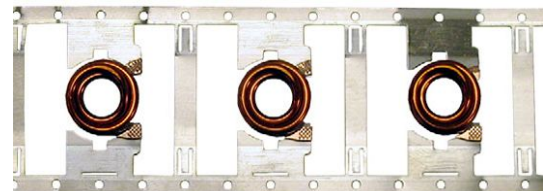

Fig. 4 - Pre-wound coils welded into a plated copper lead frame

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This assembly is placed in a steel die that is filled with powdered metal, insuring that the powder completely surrounds the coil. The powdered metal is then compressed by tooling from above and below at pressures in the range of 600 MPa to form a dense magnetic body around the coil. See Fig. 5 and Fig. 6.
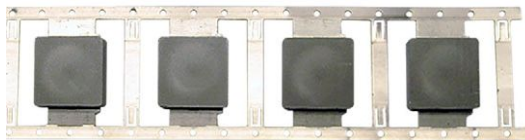

Fig. 5 - Iron powder pressed around coils

Fig. 6 - Finished composite inductors

The resulting CPI provides superior performance compared to conventional inductors. The most striking characteristic is the saturation curve. Most power inductor applications have a large component of DC current that flows through the inductor. As the current increases, the magnetic flux increases in the core and the effective magnetic permeability is reduced, causing an inductance drop. In ferrite materials, this drop is dramatic. The designer must insure that the current level in a ferrite inductor does not exceed the published saturation current or the circuit may fail due to the rapid drop in inductance.

With CPIs, the iron particles have a thin insulation layer to form an air gap that causes the saturation to be gradual, predictable, and almost linear. See Fig. 7.
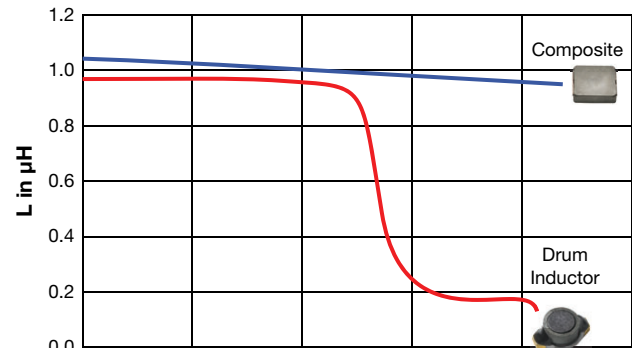

Fig. 7 - Comparison of saturation curves for a composite inductor vs a ferrite inductor with a similar footprint and inductance

This insulation layer also insures that each tiny metal particle stays electrically insulated from its neighbor, reducing the incidents of eddy currents and enabling high quality CPIs to operate in DC/DC converters up to 5 MHz without excessive core loss. CPIs can handle current spikes many times their rated current without hard saturation, making CPIs the configuration of choice where there may be regular current surges and inductance drop cannot be tolerated.

In addition to improved saturation over ferrite inductors, CPIs have excellent inductance stability and saturation stability over temperature. Composite inductor inductance and saturation performance will vary as little as 2 % over the operating range of -55 °C to 155 °C.

CPI technology is also highly scalable. Currently, footprint sizes range from 3 mm by 3 mm up to 22 mm by 22 mm. Profiles are available for the smaller sizes below 1.0 mm. Inductance ranges from 0.1 µH to 150 µH. Very large composite inductors can handle over 100 A of steady state current.

There are many CPI suppliers and their inductors are not all created equally. There are three basic types of metal powders used to build CPIs.

The first type of metal powder is pure iron. The advantage of pure iron is that it can be made into very small particles in the range of 4 µm by a sophisticated and expensive chemical process. These small particles provide the lowest core losses at high frequencies because they limit the iron volume in which the eddy currents can circulate. The small particles also provide the best saturation since there are literally billions of insulated iron particles in each CPI, all with a minute air gap. The disadvantage of the small particles is that the multitude of air gaps provides a lower effective magnetic permeability, thus reducing the inductance that can be achieved in a given package size. CPIs made with these high purity small particles have the highest DCR for a given inductance, but many times have lower total losses because core losses are minimized by the small particles.

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The second type of metal powder is iron alloy powder. With iron alloys, powder particles can be made through a process called atomization where the molten alloy is forced through a nozzle along with an inert gas similar to an aerosol spray to make fine particles that cool into the alloy powder. This is a very cost-effective way to make metal powder, but it can only produce particle sizes cost-effectively down to about 10 μm, where the eddy current losses are up to six times higher than 4 μm particles because eddy currents increase with particle size squared.

To make atomized iron useful for CPIs, silicon is typically added to the iron, which increases the internal resistivity of the larger iron powder particle. This higher particle resistance reduces eddy currents and lowers core loss, but the losses are still greater than that of pure iron with smaller particles. The larger particle size of the iron alloy creates higher overall permeability and the CPI will require fewer turns to achieve target inductance, yielding a lower DCR than the pure iron CPIs. However, the lower DCR may not compensate for the higher core losses, especially at higher frequencies.

The third type of metal powders are also alloys, but tend to be a bit more complicated. These alloys are made from proprietary blends of iron and other metals and provide high temperature operation (155 °C and above) and lower core losses than silicon alloys. These specialty alloys provide an improvement in one or more characteristics of the inductor such as core loss, temperature stability, or saturation, but most often compromise another. The good news is the designer has choices and can choose the performance that is most suited to their application.

Most manufacturers of CPIs don't reveal the material types, so design engineers have to determine the performance for themselves, and a simple one-to-one comparison of a parameter such as DCR may not result in the best choice of composite inductor. Here are some hints on determining which material is being offered. See Table 1.

1. Observe the heat rating current and 20 % saturation current from the datasheet. (Note: Some manufacturers publish 30 % saturation numbers to make their inductors look better). If the 20 % saturation current is significantly higher than the heat rating current (30 % to 50 % or more), then the composite inductor is made from high purity, small iron particles. Use this type of inductor where high frequency performance is important, such as when operating in the 800 kHz to 5 MHz range. Maximum temperature for this material is limited to 125 °C.

2. If the heat rating current is approximately equal to the 20 % saturation current, the metal powder is most likely an alloy or a blend of powders. These CPIs are best used in DC/DC converters below 800 kHz and for high current noise filters. Operating temperature is often limited to 125 °C for these materials.

3. If the operating temperature rating is 155 °C or greater, it is likely this material is a specialty alloy. Use these CPIs for DC/DC converters up to 1 MHz and for high current noise filters and where elevated operating temperatures above 125 °C are required.

COMPARISON OF VISHAY IHLP (COMPOSITE INDUCTOR) MATERIALS IN A 12 V TO 5 V BUCK CONVERTER WITH 2.9 A RIPPLE AT 300 kHz AND 1 MHz SWITCHING FREQUENCIES						
	VISHAY IHLP MATERIAL	DCR (mΩ)	RATED CURRENT (A)	20 % SATURATION CURRENT (A)	TOTAL LOSSES (mW) BUCK CONVERTER	MAX. TEMP. (°C)
300 kHz 2.9 A Ripple 3.3 μH	-01/-A1	28	6.0	13.5	2.10	125
	-11/-1A	25	7.0	6.5	**2.00**	125
	-51/-5A	26	8.3	6.8	2.30	155
1 MHz 2.9 A Ripple 1.0 μH	-01/-A1	9	11.0	22.0	**0.92**	125
	-11/-1A	7.6	12.5	9.5	0.96	125
	-51/-5A	7.9	12.0	13.0	1.00	155

Note
- At 1 MHz, the lowest DCR material does not provide the best combined total loss

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Even armed with the information above, it may be difficult to choose the best CPI for an application. Some manufactures have dedicated web tools specific to their product to aid the designer in the correct choice. See Fig. 8.

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IHLP® INDUCTOR LOSS CALCULATOR TOOL

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Choose Calculator Type
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Choose Available Series
IHLP-2525CZ-01 ▾

IHLP-2525CZ-01 - 1 Buck µH Ind. Loss Calculator

Ratings		
Inductance	1	µH
25º C DC Res	0.009	Ohms
Isat	22	Amps
I(Heat)	11	Amps

Inputs: Enter data into yellow fields

Outputs

Select Inductance:

0.1 µH	○
0.15 µH	○
0.2 µH	○
0.22 µH	○
0.33 µH	○
0.47 µH	○
0.68 µH	○
0.82 µH	○
1 µH	●
1.5 µH	○
2.2 µH	○
3.3 µH	○
4.7 µH	○
6.8 µH	○
8.2 µH	○
10 µH	○

Input	Value	Unit	Output	Value	Unit
Frequency =	1000000	Hz	ET_{ckt}	2.92	V-usec
I_{ind} =	7	Amps	F(eff)	653886.5	Hertz
Ambient Temp =	50	ºC	Res	0.011254	Ohms
Volts In =	12	Volts	I_{max}	8.46	Amps
Volts Out =	5	Volts	I_{min}	5.54	Amps
V_{SW} =	0.025	Volts	I_{ripple}	2.92	Amps
V_D =	0.025	Volts	Duty	0.42	
			P_{core}	0.233	Watts
ET_{100} =	0.68	V-usec	P_{dc}	0.551	Watts
B_{pk} =	429.5	G	P_{ac}	0.144	Watts
A	0.270 Inch	6.86 mm	P_{tot}	0.929	Watts
B	0.255 Inch	6.47 mm	Temp. Coeff.	31.8	ºC/W
C	0.118 Inch	3.0 mm	Temp Rise	29.6	ºC
			Comp Temp	79.6	ºC
Reference Cost	1.0		Compared to IHLP-2525CZ-01		

Inductor Current (One Cycle)

Time (µSec)

Warning Messages:

Notes May Be Added Here:

Fig. 8 - Vishay's online core loss calculator gives the designer an opportunity to compare various sizes, values, and materials of Vishay's IHLP composite inductors to provide the best solution for size and performance in buck, boost, and buck-boost DC/DC converters

In summary, composite inductors can be the best choice for power if there is a need for performance and small size. Composite inductors provide the best saturation, temperature stability, and smallest shielded package for power inductors in the range of 0.47 µH to 150 µH.

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