Ferrite and Powder Core Materials for Power Inductors

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Understanding the Effect of Core Materials

Power inductors come in all shapes and sizes and are made from a variety of core materials. For example, the Coilcraft SLC series uses a gapped ferrite core, whereas the MLC series uses a powder core. The MVR series is offered in two different materials (the MVRT uses ferrite and the MVRC uses powder).

Why the need for options? What is the difference?

The difference in core material usually comes down to one fairly simple trade-off between core loss and core saturation. This paper discusses the typical core differences and offers some guidelines for inductor choice.

Core Saturation

All soft magnetic materials require an air gap in the core material in order to withstand the current without core saturation that is required for power applications. Ferrite materials are gapped by creating a space in the core magnetic flux path. These gaps are achieved by grinding the gap in a one-piece core or placing a non-magnetic spacer between halves of assembled cores. On the other hand, powder cores such as powdered iron, have by their very nature miniature air gaps distributed throughout the material. It is typically not necessary to add an actual air gap or space in powder cores.

The physical difference in the way the air gap is accomplished helps explain the performance difference. It is easy to imagine that in the powder cores the distribution of a large number of tiny air gaps do not all saturate at exactly the same flux level (applied current), whereas in the ferrite core air gap, saturation does happen in a much more all-at-once fashion.

The result is that powder cores have a more gradual saturation characteristic than ferrite. Figure 1 demonstrates the difference. The curves illustrate how the 0.36 µH MVRT (ferrite) and 0.36 µH MVRC (powder core) inductors saturate. The MVRT (blue curve) stays flat longer, but then drops off more abruptly than the MVRC (red curve). These inductors have exactly the same winding and core size, differing only in the core material. If the peak inductor current is less than 20 A the ferrite core is likely to be the preferred choice, whereas the powdered iron core would be preferred at higher peak currents. This is an especially important characteristic in late generation VRM/VRD power supplies with high transient current requirements where inductor current is likely to spike well above the typical operating waveform.

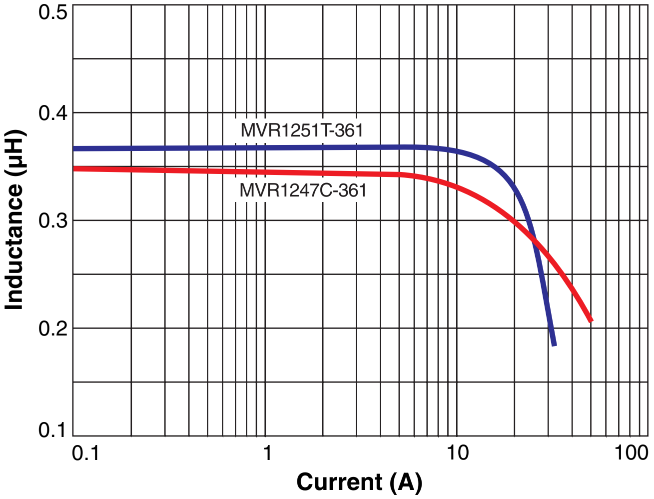

Figure 1. Comparison of L vs I for powered iron and ferrite

Core Loss

At first glance, core loss would also seem be a relatively simple characteristic that could be considered as a trade-off against core saturation. For example, consider the following core loss information for three popular core material types.

Material Type	**Core Loss at 200 mT, 100 kHz**
TDK PC 95 (ferrite)[1]	350 mW/cm^3
Magnetics Kool Mu (ferrous alloy powder)[2]	4000 mW/cm^3
Micrometals 52 (powdered iron)[3]	>10,000 mW/cm^3

The vast (order of magnitude) difference in core loss between different core material types certainly suggests that ferrite would be a preferred material to powder cores. If core loss alone were considered, that would certainly be true.

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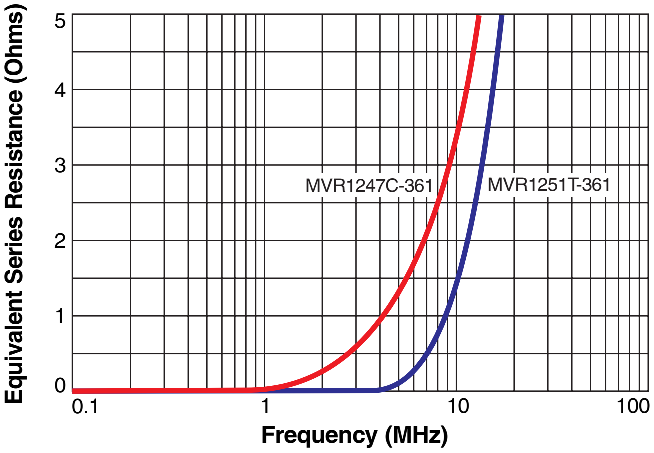
[1] www.component.tdk.com
[2] www.mag-inc.com
[3] www.micrometals.com

Other factors influence the apparent core loss beyond the material properties. Fringing flux loss for example, occurs in the area around the discreet gap in ferrite cores, which makes winding and air gap placement considerations in addition to the choice of material and gap size.

ESR

In order to predict inductor performance it is helpful to have one figure of merit that includes all the losses, regardless of their physical cause. One useful tool is the Equivalent Series Resistance (ESR), which can be measured directly and includes the effective ac and dc resistances of an inductor.

Consider the following ESR curves for the same two MVR series inductors shown above.



Frequency	MVR1251T-361	MVR1247C-361
DC	0.0009	0.0009
500 kHz	0.017	0.035
1 MHz	0.028	0.097
5 MHz	0.183	1.19

Figure 2. Comparison of ESR for powdered iron and ferrite

The curves indicate that the total loss does not differ as much as the core loss alone would indicate. For example, the core loss at 100 kHz is vastly different (100×), but the overall ESR shows the parts indistinguishable. The fact that the curve is still flat at that point indicates that the DCR is the dominant loss mechanism for these inductors in that range. At 1 MHz to 5 MHz, a popular range for today's converters, the ESR is substantially higher for the powdered iron core compared to the ferrite.

Using the ESR

Even knowing the ESR of an inductor alone does not answer the question of how much loss there will be in any given application. Much still depends on the wave shape, for example.

Example 1.

Assume a converter is needed to provide an output of 3.3 V at 20 A (66 Watts). The ESRs at 500 kHz are as follows:

ESR for MVR1247C-361 = 0.035

ESR for MVR1251T-361 = 0.017

Since a buck converter inductor current average is equal to the dc load current, we might try to calculate the loss by $I^2R = I^2 \times ESR$. By this method we can calculate the loss for each inductor.

Power Loss for MVR1247C-361 = 14 W

Power Loss for MVR1251T-361 = 6.8 W

Based on this simple example it would seem that a designer might not choose to use either of these inductors. The powdered iron part would have losses of about 21% of the output power, and even the ferrite part about half of that. However, we have not properly considered the waveshape of the inductor current. Performance will (probably) be much better than the ESR curve might predict. Figure 3 shows a very simplified version of a possible buck converter waveform.

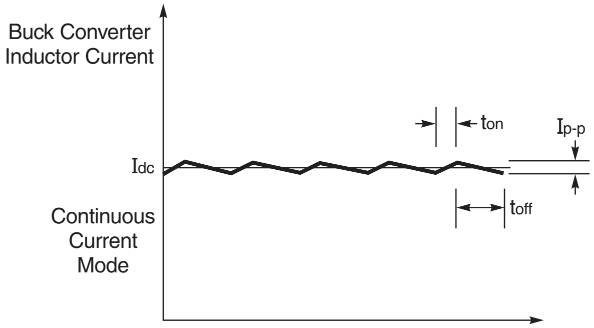


Figure 3. Ideal Converter Waveform with Small Ripple Current

In this case it is assumed that the inductor current is continuous and that the ripple current is relatively small compared to the average current. Let's assume that the ripple current peak-peak is about 10% of the average current. From the example, this means:

Idc = 20 A
Ip-p = 2 A

In order to predict the inductor losses correctly, the high frequency loss and the low frequency loss are individually calculated and then combined. The low frequency loss is calculated by I^2R, where R is the DCR, and I is the rms value of the dc load and the ripple current combined. For both parts under consideration, the DCR is approximately 0.0009 Ohms.

Low Frequency Power Loss for MVR1247C-361 = 0.36 W

Low Frequency Power Loss for MVR1251T-361 = 0.36 W

To get the total loss, we must add the high frequency loss, which also is I^2R, but in this case the R is the ESR and the I is the rms value of the ripple current only, which for this example is approximately 1.15 Arms.

High Frequency Power Loss for MVR1247C-361 = 0.046 W

High Frequency Power Loss for MVR1251T-361 = 0.022 W

Adding the low and high frequency losses together:

Total Power Loss for MVR1247C-361 = 0.36 + 0.046 = 0.406 W

Total Power Loss for MVR1251T-361 = 0.36 + 0.022 = 0.382 W

In this case we can see that the DCR loss still dominates the inductor loss and the total loss for each choice would be less than 1% of the output power.

This predicted loss is greater than DCR loss, but is not nearly the 7 W to 14 W originally predicted by multiplying the ESR by the entire load current. Our conclusion then, is that the inductor loss must be calculated by a combination of the DCR and ACR, and for a continuous current mode converter in which the ripple current is small compared to the load current, the losses will be reasonable.

If we reconsider the same example at 5 MHz, we find the total inductor losses to be:

Total Power Loss for MVR1247C-361 = 1.9 W

Total Power Loss for MVR1251T-361 = 0.6 W

At this frequency the ac losses are now quite significant and dominate the overall inductor loss.

Example 2.

For comparison, we should consider the case of the discontinuous current in which ripple current is the maximum as in the waveform in Figure 4. In this case ripple current is the same magnitude as the dc or load current. It is clear that the loss due to ESR will be much more significant. If we continue the previous example with a ripple current of 20 Ap-p, we would predict total losses at 500 kHz as follows.

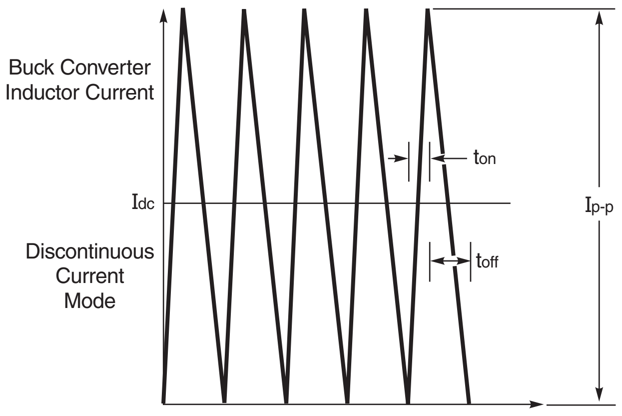


Figure 4. Ideal Converter Waveform with Large Ripple Current

Total Power Loss for MVR1247C-361 = 5.0 W

Total Power Loss for MVR1251T-361 = 2.6 W

These losses are about 7 to twelve times higher than the losses at the same frequency for the example with 10% ripple. Fortunately most converters operate with significantly less than 100% ripple current most of the time.

Conclusions

This paper started with a discussion about what seemed like a simple question:

Ferrite or Powder?

In order to answer that question, we must consider not only the core material choice, but how the core performance compares to winding loss and how the inductors perform with typical converter waveforms.