New Ferrite Core Solutions for Single Ended Power Supplies

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Abstract

The growth of portable electronic equipment has created the opportunity for new inductive components for power conversion. SEPIC, flyback, buck and boost inverters require low cost components that can operate efficiently at frequencies up to 1 MHz. To realize these components, two new ferrite core families, The Micro-Gapped Toroid and The Mini-Thick Bobbin, were developed. These cores offer the advantage of ferrite core losses and resistance to saturation with DC present. The following is an over view of the properties and design considerations of these components.

Introduction

There are several areas in electronic devices where one needs magnetic components that have the capability to handle DC and still maintain an acceptable inductance. Other applications require that the inductive device exhibit low distortion and not vary in value over temperature (figure 1).

The constant reduction in size of electronic devices, including cellular telephones and computers, has put demands on designers to create power supplies that are small, light weight and efficient. To achieve these goals, the operating frequency of the power converters, battery voltage to circuit levels or the power management circuits located next to a processor, have been increased to 1 MHz. The conventional inductive solutions that are currently available exhibit high losses and/or low A_L.

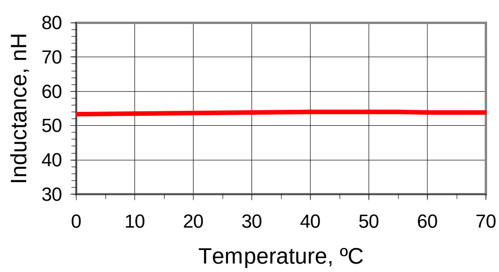

Figure 1 – Typical Temperature Performance

Ferrite toroids would be a solution except that standard cores will saturate with the DC. Formed cores, like RM type, are large and add cost. If you were able to combine the gap of the RM cores with the shape of a toroid, you would have the best of all worlds: the low losses associated with ferrite, small size and resistance to DC saturation effects. This concept is the logic behind the Micro-Gapped Toroid. The variable is to do this at an acceptable price. However, this solution is only viable for Idc < 2 amps.

For Idc > 2 amps, the open structure of a ferrite bobbin core represents an acceptable solution. However, existing commercially available bobbin cores require support hardware. Winding termination substrates add assembly cost, an additional failure point, and causes the structure to tower above the printed circuit board. The Mini-Thick Bobbin is a single ferrite SMD component that is free of these shortcomings.

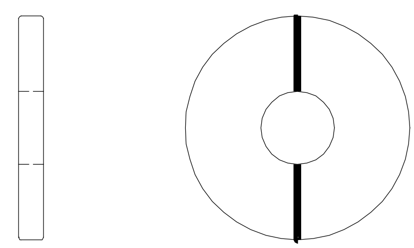

Figure 2 – The Micro-Gapped Toroid

What is the Micro-Gapped Toroid?

The easiest way to describe the Micro-Gapped Toroid is to examine the schematic that is shown in figure 2. Two toroid halves are manufactured and glued together with a spacer material to create two gaps each equal to ½ the total gap. The manufacturing process developed at Ceramic Magnetics allows us to fabricate this structure in a cost-effective manner with tight control over magnetic properties. The materials used in this assembly will operate at ambient temperatures over 150°C, making the Micro-Gapped Toroid suitable for military and automotive applications.

This process allows for total gap sizes from 0.001" [0.025mm] to 0.024" [0.6mm]. The OD of the toroids range in size from 0.135" [3.4mm] to 0.500" [12.5mm]. The minimum ID is 0.090" [2.3mm] and thicknesses of 0.020" [0.6mm] are easily produced. Effective permeabilities up to 500 are available with an associated A_L of 1500 nHy per turn. With the proper selection of core material the Micro-Gapped Toroid core can also be used for power applications at extreme temperatures.

Design Example

Our objective is to design a core for a filter choke in a 3 volt power supply. It must support 1 amp DC, 200% ripple of 6 volts peak to peak at a frequency of 300 kHz, over temperature range of -20°C to 80°C. The height of the core is restricted to less than or equal to 0.035".

First calculate

$$L = \frac{Z}{2\pi f}$$

Where

$$Z = 10 \cdot load = 10 \cdot \frac{3}{2} = 15\Omega$$

Then

$$L = 8\mu Hy$$

If we make the following assumption for core size, OD = 0.155", ID = 0.090", h = 0.035"

and let N = 25, then

$$\mu = \frac{8}{2 \cdot 625 \cdot 0.035 \cdot 2.54 \cdot \ln\left(\frac{155}{90}\right)} \cdot 1000$$

$$\mu = 132$$

For a gapped toroid

$$\mu = \frac{1}{\frac{1}{\mu_{mat}} + \frac{gap}{path\ length}}$$

For most power ferrites, $\mu_{mat} > 1000$ over the temperature range of -55 to +150°C, yielding

$$gap = \frac{path\ length}{\mu_{mat}}$$

$$gap = \frac{\left(\frac{0.155 + 0.090}{2}\right) \cdot \pi}{132}$$

$$gap = 0.003"$$

This size gap is obtainable.

Checking for the level of DC bias.

$$H = .4\pi NI/\text{path length}$$

$$H = 64 \text{ oersteds}$$

with $\mu = 132$, then $B = \mu \cdot H = 8500$ gauss. Biased and with a ripple of 6 volts peak to peak (assume sine wave) then,

$$B_{ac} = \frac{6 \cdot \left(\frac{1}{2.828}\right)}{4.44 \cdot f \cdot N \cdot A} \cdot 10^{-8}$$

giving B_{ac} = 870 gauss for a total peak flux of $B_{bias} + B_{ac}$ = 9370 gauss

Unfortunately, this flux level will be sufficient to saturate the ferrite material at any temperature. Therefore, we must adjust the design by increasing the number of turns and/or increasing the OD.

If turns = 50 and OD = 0.190 then

$$H = 64 \cdot 2 \cdot \frac{245}{280} = 110$$

$$\mu_{eff} = 110 \cdot \left(\frac{625}{2500}\right) \cdot \left(\frac{\ln\left(\frac{155}{90}\right)}{\ln\left(\frac{190}{90}\right)}\right)$$

μ_{eff} = 20 and the gap = 0.003 · 132 / 20 = 0.020"

This gap is also obtainable.

Checking gauss levels

$$B_{dc} = \mu \cdot H$$
$$= 20 \cdot 110 = 2200 \text{ gauss}$$

$$B_{ac} = \frac{870 \cdot (0.155 - 0.090) \cdot 25}{(0.190 - 0.090) \cdot 50}$$

B_{ac} = 720 gauss for a total peak flux of 2920 gauss. This is an acceptable level and core is producible.

The importance of this simple design is to demonstrate that all the mechanical properties, can be adjusted to satisfy the requirements of a design without tooling cost.

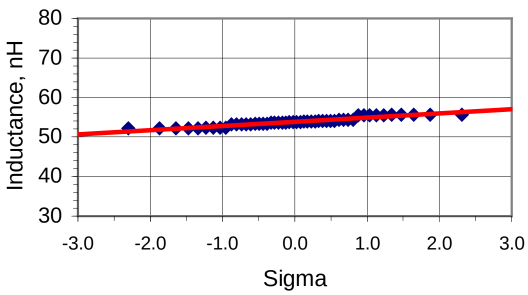

Figure 3 – Typical A_L distribution

Typical Core Characteristics

The micro-gapped toroid is specified like any other pressed ferrite core. Typical dimensional tolerances are ± 2% of the given dimension. The tolerance of the gap is reflected in the A_L specification. As a result of the gap, the A_L distribution is very tight (figure 3). The cores are also always provided with 0.001" [25µm] of parylene-C coating to withstand a minimum dielectric breakdown of 1.00 kV. However, the most important characteristic of the micro-gapped toroid is its ability to handle a high DC current as shown in figure 4.

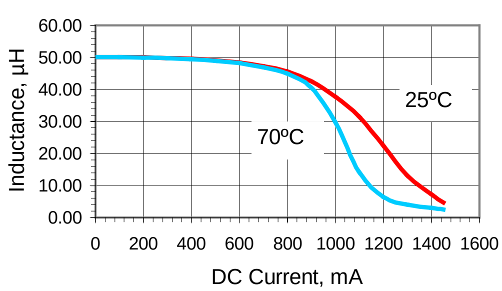

Figure 4 – Incremental inductance vs. DC bias

Applications and Variations of Core Shape

The Micro-Gapped Toroid has ideal characteristics for use in battery operated equipment, power management circuits, distributed or localized power inverters, signal inductors with a DC component, linear inductors and high frequency temperature stable devices. With variations to the core shape, devices as small as 3.5mm x 2.5mm x 0.5mm can be made. With the addition of parylene and magnet wire coatings, standoff voltages of greater than 2,000 volts can be supported.

The Mini-Thick Bobbin Solution

The Mini-Thick Bobbin (figure 5) is a core that allows for wire termination directly on the core. It is available in heights as small as 0.080" [2mm] with typical A_L values of 50 nHy per turn. The core windings can be wrapped around the termination tabs and soldered directly to the PCB. This reduces overall cost and assembly time of adding mounting hardware. These cores are produced by an injection molding process and are fully sintered to obtain normal ferrite properties. This forming process allows additions of features that are not obtainable by the traditional manufacturing techniques of pressing and machining. Because the core is formed by injection molding, the finished core is free of nano-cracks caused by the grinding operations that are needed to form currently available bobbin cores.

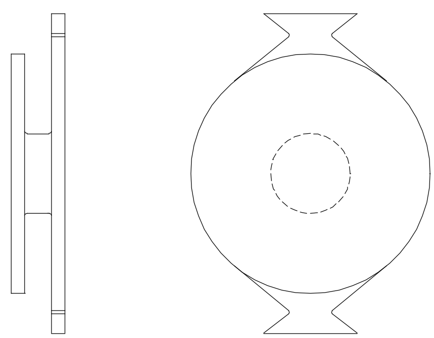

Figure 5 – The Mini-Thick Bobbin

EMC Issues

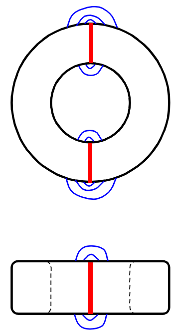

Figure 6 – Micro-Gapped Toroid Fringe flux

Since the Micro-Gapped Toroid has two discreet gaps, there is a fringe flux that can couple into circuit traces on the PCB and cause EMC issues (figure 6). This fringe field around the gap area will cause the calculated effective permeability to be understated by up to 20%.

The Mini-Thick Bobbin is an open magnetic structure that needs to be analyzed for EMC problems. If two cores are placed adjacent to each other they will couple and variations in inductance will occur (figure 7). The location and polarity of winding must be considered. The addition of a ferrite or plastic shield may be necessary.

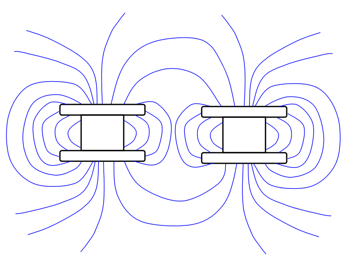

Figure 7 – Coupling Bobbins

Conclusion

Two new magnetic components, the Micro-Gapped Toroid and Mini-Thick Bobbin, have been developed by Ceramic Magnetics. These components offer designer engineers the power loss advantages of ferrite materials, compared to typical powder iron type cores, operation into the megahertz frequency range with efficient core losses with a DC bias present. They are also high energy storage devices suitable for surface mounting. In addition, both solutions offer a significant cost advantage.