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

In many applications designers need magnetic components with the ability to handle DC and still maintain an acceptable inductance. Other applications require the inductive device to exhibit low distortion and a stable value over temperature (Figure 1). In addition, the reduction in electronic device size, 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, power converters switching frequency has been increased up to1 MHz. Unfortunately, conventional metallic core solutions exhibit high losses and/or low A_L, nHy/N^2, at these frequencies. Ferrite toroids would be one solution, except standard cores might saturate when there is a DC component. Another possibility is formed cores, like RM types, but they are large and add cost. By combining the ability to gap a RM core with the shape of a toroid, the designer gets the best of both worlds: low ferrite losses, small size and resistance to DC saturation effects. This concept is the logic behind the Micro-Gapped Toroid. The ability to do this at an acceptable price is the primary hang-up.

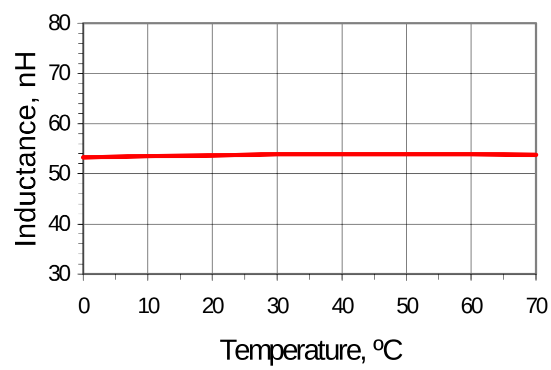

Figure 1 – Typical Temperature Performance

The Micro-Gapped Toroid is viable for $I_{dc} < 2A$. For $I_{dc} > 2A$, the open structure of a ferrite bobbin core is an acceptable solution. However, existing commercially available bobbin cores require support hardware.

Winding termination substrates add assembly cost, which is an additional failure point, and causes the structure to tower above the PC board. The Mini-Thick Bobbin is a single ferrite SMD component that is free of these shortcomings.

What is the Micro-Gapped Toroid?

First, consider the Micro-Gapped Toroid shown in Figure 2. It is two-toroid halves manufactured and glued together with a spacer material, creating two gaps, each of which is equal to one-half the total gap. This manufacturing process allows cost-effective fabrication of this structure, with tight control over its magnetic properties. Materials used in this assembly can operate at over 150°C ambient, making the Micro-Gapped Toroid suitable for harsh environment applications. This process allows for total gap sizes from 0.001-in. [0.025mm] to 0.024-in. [0.6mm]. The OD of the toroids range in size from 0.135-in. [3.4mm] to 0.500-in. [12.5mm]. The minimum ID is 0.090-in. [2.3mm] and a thickness of 0.020-in. [0.6mm] is easily produced. Effective permeabilities up to 500 are available with an associated A_L of 1500 nH/N^2. With the proper selection of core material the Micro-Gapped Toroid core can also be used for military and automotive power applications.

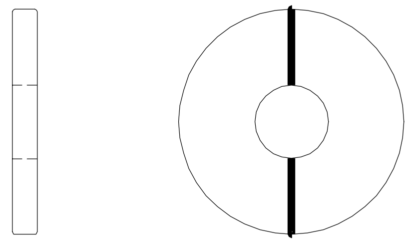

Figure 2 – The Micro-Gapped Toroid

Design Example

The objective is to design a filter choke for a 3V power supply. It must support 1A DC, 200% ripple of current and 6V peak-to-peak at a frequency of 300 kHz, over temperature range of -20°C to 80°C. Core height is restricted to less than or equal to 0.035-in.

First, calculate:

$$L = \frac{Z}{2\pi f} \qquad (1)$$

Where:

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

Then:

$$L = \frac{15}{2\pi \times 300 \times 10^3} = 8\mu H \qquad (2)$$

Assuming a core size with OD = 0.155-in., ID = 0.090-in., h = 0.035-in., and N (no. turns) = 25:

$$\mu_{eff} = \frac{L \times 10^9}{2 \times N^2 \times h \times \ln\left(\frac{OD}{ID}\right)}$$

$$\mu_{eff} = \frac{8}{2 \times 625 \times 0.035 \times 2.54 \times \ln\left(\frac{155}{90}\right)} \times 1000 = 132$$

For a gapped toroid:

$$\mu_{eff} = \frac{1}{\left[\frac{1}{\mu_{mat}} + \frac{gap}{path\ length}\right]} \qquad (3)$$

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

$$gap = \frac{path\ length}{\mu_{eff}} \qquad (4)$$

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

gap = 0.003-in., which is obtainable.

Checking for the level of DC bias. Note: I = 2 amps, 200% x I

H = 0.4πNI/path length

$$H = \frac{0.4\pi \times 25 \times 2}{\left(\frac{0.155 + 0.090}{2}\right) \times \pi \times 2.54} \qquad (5)$$

H = 64 oersteds

With μ = 132, then B = μH ≈ 8500 gauss (B_{bias}) and with 6V peak-to-peak ripple (assuming a sine wave) then:

$$B_{ac} = \frac{E_{RMS}}{4.44 \times f \times N \times A} \times 10^{+8} \qquad (6)$$

$$B_{ac} = \frac{\frac{6}{2.828} \times 10^{+8}}{4.44 \times 3 \times 10^5 \times 25 \times .007} = 910\ gauss$$

Therefore, B_{ac} = 910 gauss for a total peak flux of $B_{bias} + B_{ac} \approx 9400$ 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 $turns_2$ = 50 and OD_2 = 0.190-in., then:

$$H_2 = H_1 \times \frac{N_2}{N_1} \times \frac{Path\ Length_1}{Path\ Length_2}$$

$$H_2 = 64 \times 2 \times \frac{245}{280} \approx 112 \quad \text{Oersteds}$$

$$\mu_{eff\,2} = \mu_{eff\,1} \times \frac{N_1^2}{N_2^2} \times \left(\frac{\ln\left(\frac{OD_1}{ID_1}\right)}{\ln\left(\frac{OD_2}{ID_2}\right)} \right) \qquad (8)$$

$$\mu_{eff\,2} = 112 \times \left(\frac{625}{2500} \right) \times \left(\frac{\ln\left(\frac{155}{90}\right)}{\ln\left(\frac{190}{90}\right)} \right)$$

:$_{eff2}$ = 20 and the gap = 0.003×132 / 20 = 0.020-in., which is also obtainable.

Checking gauss levels

B_{dc} = :$_{eff2}$$H_2$ = 20×112 = 2240 gauss

$$B_{ac2} = B_{ac1} \times \frac{Area_1 \times N_1}{Area_2 \times N_2} \qquad (9)$$

$$B_{ac2} = \frac{900 \times (0.155 - 0.090) \times 25}{(0.190 - 0.090) \times 50}$$

B_{ac2} ≈ 300 gauss, for a total peak flux of 2540 gauss. This is an acceptable level and the core can be manufactured.

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

The Micro-Gapped Toroid tolerances are typically ±0.005” or less 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-in. [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.

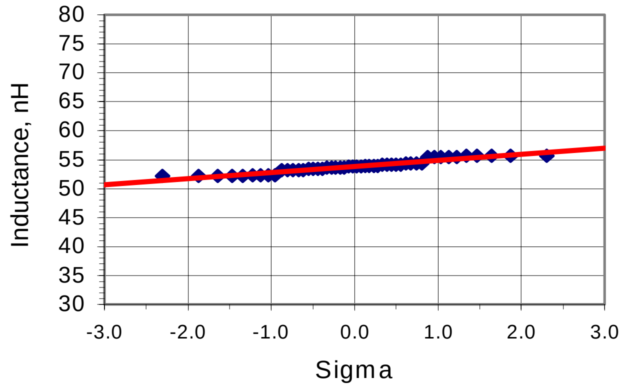

Figure 3 – Typical AL Distribution

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 2,000V can be supported.

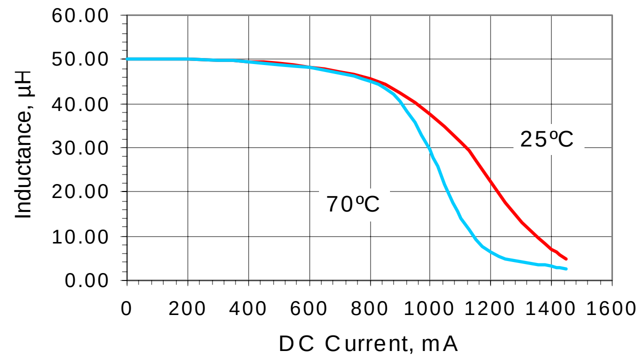

Figure 4 - Incremental Inductance vs. DC Bias

The Mini-Thick Bobbin

The Mini-Thick Bobbin (Figure 5) is a core that allows wire termination directly on it. It is available in heights as small as 0.080-in. [2mm] with typical A_L values of 50nH per turn. The inductor windings can be wrapped around the termination tabs and soldered directly to the PC board. 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 the addition of features that are not obtainable by the traditional manufacturing techniques of pressing

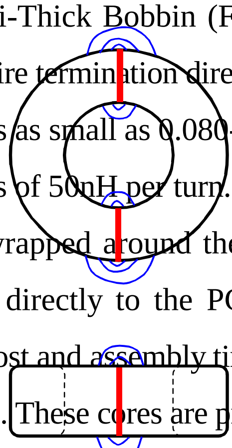

Figure 6 – Micro-Gapped Toroid Fringe flux

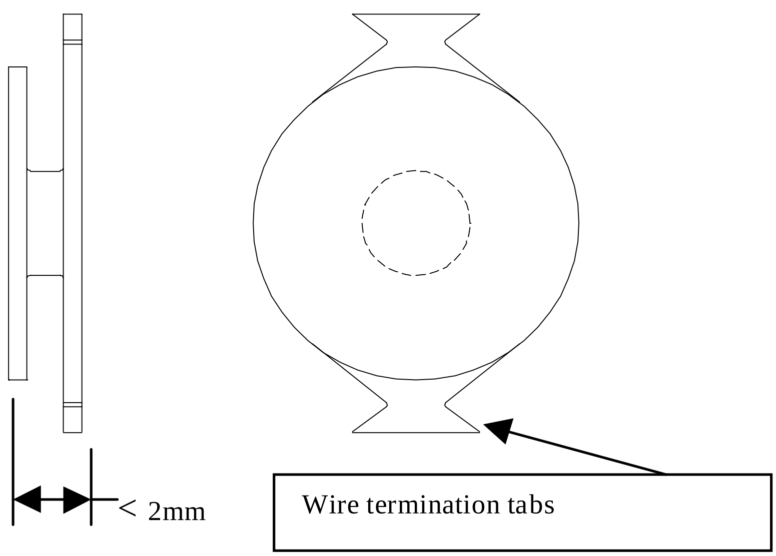

Figure 5 – The Mini-Thick Bobbin

and machining. Because injection molding forms the core, the finished core is free of nano-cracks induced by the grinding operations that are needed to form currently available bobbin cores.

The Micro-Gapped Toroid has two discreet gaps, so there is a fringe flux that can couple into circuit traces on the PC board and cause EMI (Figure 6). This fringe field around the gap area causes the calculated effective permeability to be understated by up to 20%.

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

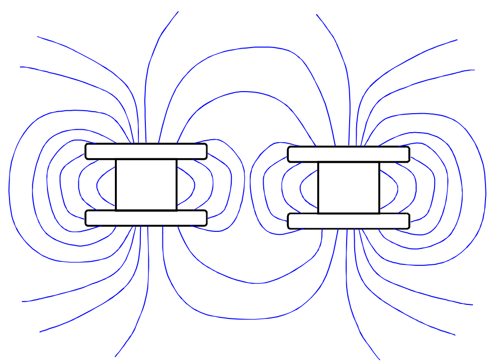

Figure 7 – Coupling Bobbins

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.