Micro-Gapped Toroid

Ferrite Core Solutions Improve Power Supply Efficiency

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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, lightweight and efficient. To achieve these goals, power converters switching frequency has been increased up to1MHz. Unfortunately, conventional metallic core solutions exhibit high losses and/or low AL (nH/N^2 where N is the number of turns) at these frequencies.

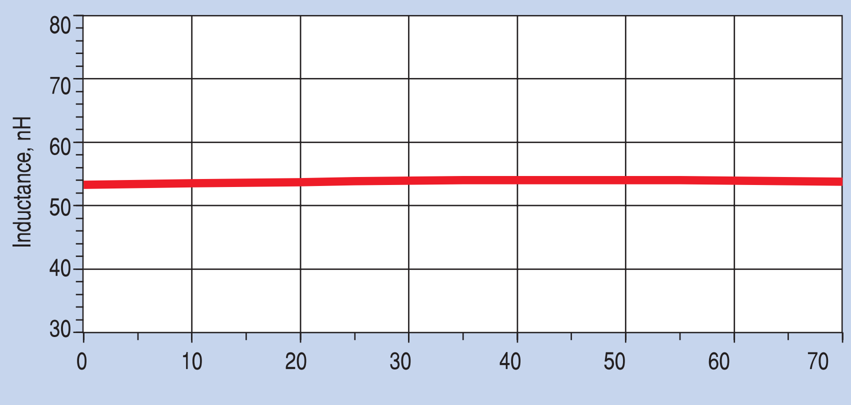

Figure 1. *Typical Temperature Performance.*

Ferrite toroids could be one solution, except that standard cores might saturate if 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 an 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 was the primary hang-up.

> Two new ferrite core families, the Micro-Gapped Toroid and Mini-Thick Bobbin, offer the advantages of lower losses than typical powder iron type cores, MHz operation, and resistance to saturation when there is a dc component.

The Micro-Gapped Toroid is only viable for Idc < 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 cause the structure to tower above the p. c. board. The Mini-Thick Bobbin is a single ferrite SMD component that is free of these shortcomings.

First, consider the Micro-Gapped Toroid shown in *Figure 2*. Its two toroid halves are 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.

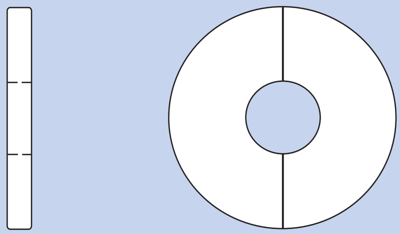

Figure 2. *Micro-Gapped Toroid.*

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 power applications at extreme temperatures.

Design Example

The objective is to design a filter choke for a 3V power supply. It must support 1A dc, 200% ripple of 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:

$$L = \frac{Z}{2\pi f} \tag{1}$$

Where:

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

Then:

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

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

$$\mu = \frac{L \times 10^{-9}}{2 \times N^2 \times h \times \ln\left(\frac{OD}{ID}\right)} \tag{3}$$

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

For a gapped toroid:

$$\mu = \frac{1}{\dfrac{1}{\mu_{mat} + \dfrac{gap}{\text{path length}}}} \tag{4}$$

For most power ferrites, μmat > 1000 over the temperature range of –55 to +150°C, yielding

$$gap = \frac{\text{path length}}{\mu_{mat}} \tag{5}$$

$$gap = \frac{\left(\frac{0.155 + 0.090}{2}\right) \times \pi}{132} = 0.003\text{-in., which is obtainable.}$$

Checking for the level of dc bias. Note: I = 2A, 200% X1

$$H = 0.4p\pi NI/\text{path length} = \frac{0.4\pi \times 25 \times 2}{\left(\frac{0.155 + 0.090}{2}\right) \times \pi \times 2.54} \tag{6}$$

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:

$$B_{ac} = \frac{6\left(\frac{1}{2.828}\right)}{4.44 \times f \times N \times A} \times 10^{+8} = \frac{\frac{6}{2.828} \times 10^{+8}}{4.44 \times 3 \times 10^5 \times 25 \times .007}$$

$$= 910 \tag{7}$$

Therefore, B_{ac} = 910 gauss for a total peak flux of B_{bias} + B_{ac} ≈ 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 = 50 and OD = 0.190-in., then:

$$H_2 = H_1 \times \frac{N_2}{N_1} \times \frac{\text{Path Length}_1}{\text{Path Length}_2} \tag{8}$$

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

$$\mu_{eff\ 2} = \mu_{eff\ 1} \times \frac{N_1^2}{N_2^2} \times \left(\frac{\ln\left(\frac{OD_1}{ID_1}\right)}{\ln\left(\frac{OD_2}{ID_2}\right)}\right) \tag{9}$$

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

$\mu_{eff\ 2}$ = 20 and the gap = 0.003 × 3132/20 = 0.020-in., which is also obtainable.

Checking gauss levels

$$B_{dc} = \mu H = 20 \times 112 = 2240 \text{ gauss}$$

$$B_{ac\,2} = B_{ac\,1} \times \frac{Area_1 \times N_1}{Area_2 \times N_2} \qquad (10)$$

$$B_{ac\,2} = \frac{900 \times (0.155 - 0.090) \times 25}{(0.190 - 0.090) \times 50}$$

$B_{ac2} \approx 300$ gauss for a total peak flux of 2540 gauss. This is an acceptable level and the 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.

Typical Core Characteristics

Typical Micro-Gapped Toroid 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-in. [25μm] of parylene-C coating to withstand a minimum dielectric breakdown of 1.00kV. However, the most important characteristic of the micro-gapped toroid is its ability to handle a high dc current as shown in *Figure 4*.

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.

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 core windings can be wrapped around the termination tabs and soldered directly to the p.c. 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 tradi-

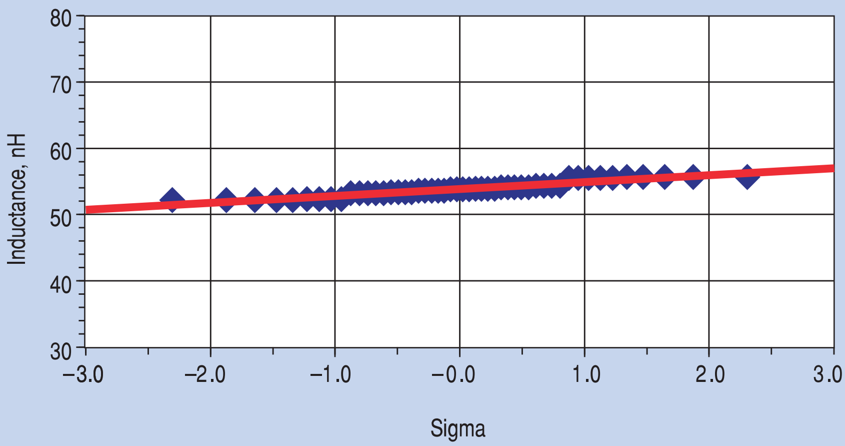

Figure 3. *Typical AL distribution.*

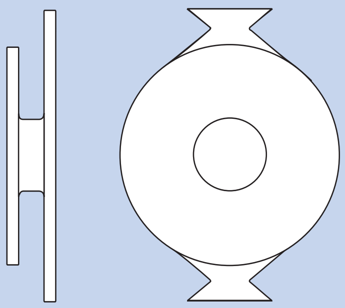

Figure 5. *The Mini-Thick Bobbin.*

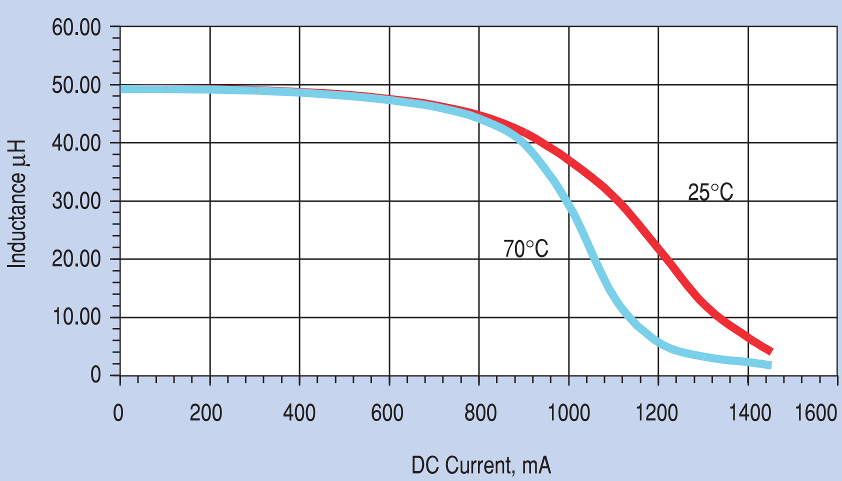

Figure 4. *Incremental inductance vs. DC bias.*

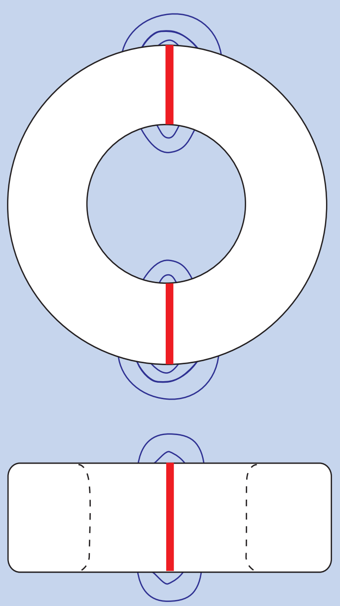

Figure 6. *Micro-Gapped Toroid Fringe flux.*

tional manufacturing techniques of pressing and machining. Because the core is formed by injection molding, 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 p.c. 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 or plastic shield may be necessary.

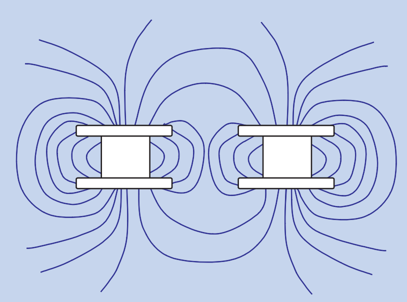

Figure 7. *Coupling Bobbins.*

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