# The Micro-Gapped Toroid
# A New Magnetic Component

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**Abstract:** The magnetic components available for designing inductive devices for use in portable equipment, power management or linear inductors, has been limited to either formed ferrite or powder iron cores. The use of chip inductors is limited by low inductance and energy storage. Ferrite toroids would be a solution except cores will saturate with DC present or exhibit non linear properties. The Micro-Gapped Toroid offers a compromise to these concerns. Resistance to DC effects, linear operation, high $A_l$, efficient energy storage and adaptable to surface mount devices.

### I. Introduction

There are several areas in electronic devices where one needs a magnetic component that has the capability to handle DC and still maintain acceptable inductance. Other applications require the inductive device exhibit low distortion and not vary in value over temperature.

The constant reduction in size of electronic devices, cell phones 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 convertors, battery voltage to circuit levels or power management circuits located next to a processor, has been increased to N x 100 kHz, $1 < N < 10$. With N increasing to 10, the conventional inductive devices, powder iron, MMP, Kool μ and Metglass cores have higher losses or become more costly.

Ferrites cores would be a solution except standard toroids will saturate with the DC and formed cores like RM type are large and add cost. If you could combine the gap of the RM cores with a toroid you would have the best of all worlds. Low losses associated with ferrite, small size and resistance to DC saturation effects. This is the logic behind the Micro-Gapped Toroid. The variable is to do this at an acceptable price.

Another area of interest is data rates over the Internet. ISDN circuits have a low level DC present and ADSL has a requirement for linear inductive components. Most of the solutions can be implemented with standard formed ferrite cores. However, there will be areas where space is key, PCMCIA devices or laptop computers, and the Micro-Gapped Toroid is a solution.

### II. What is the Micro-Gapped Toroid?

The easiest way to describe the structure of the Micro-Gapped Toroid is shown in figure 1. Two half toroids are created by cutting a toroid in half 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 allow 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.

The process allows for total gap sizes from 0.001" (0.025mm) to 0.020" (0.500mm) in toroids with OD's of 0.135" (3.4mm) to 0.500" (12.5mm). Thicknesses of 0.025" (0.600 mm) are easily produced. Effective permeabilities to 500 are available with associated $A_l$ of 1500 nHy/turn. With proper selection of core material the Micro-Gapped Toroid core can be used for power applications, signal transformers where a DC bias is present, linear inductors and temperature stable high frequency (100 Mhz) high Q inductors.

### III. Design Example

Design a core for a filter choke in a power supply, 3 volts, to support 1 amps DC, 200% ripple of 6 volts peak to peak, Frequency of 300 kHz, over temperature range of -20°C to 80°C

Calculate $L = Z / 2\pi f$
Where $Z = 10 * \text{load} = 10 * 3 / 2 = 15\ \Omega$

Then $L = 8\ \mu\text{Hy}$

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

and N = 25

then $\mu = 8 / (2*625* 0.035*2.54* \ln (155/90))*1000$

$\mu = 132$

If we use a gapped toroid where

$\mu_{eff} = 1 * ( 1/\mu_{mat} + \text{gap} / \text{path length} )^{-1}$

For most power $\mu_{mat} > 1000$ over the temperature range yielding gap = path length / $\mu$

$= (0.155 + 0.090)*\pi / 2*132$

gap = 0.003"

This size gap is obtainable.

Checking for level of bias.

H = .4πNI/path length

H = 64 oersteds

with $\mu = 132$

Then $B = \mu * H = 8500$ gauss bias

with a ripple of 6 volts peak to peak, assume sine wave

then $B_{ac} = 6 * (1/2.828) / 4.44fNA*10^{-8}$

giving $B_{ac} = 870$ gauss

for a total flux peak

$B_{bias} + B_{ac} = 9370$ gauss

This will be sufficient to saturate the material at any temperature, therefore adjust the design by

1. Increase turns
2. Increase OD
3. Cannot adjust height, space

Let turns = 50 or a 100% increase

Let OD = 0.190

then $H = 64 * 2 * 245 / 280 = 110$

$\mu_{eff} = 110 * 625 / 2500 * \ln(155/90)/\ln(190/90)$

$\mu_{eff} = 20$

gap = 0.003 * 132 / 20 = 0.020"

This is an obtainable gap

Checking gauss levels

$B_{dc} = \mu * H$

$= 20 * 110 = 2200$ gauss

$B_{ac} = 870*(.155 - .09)*25 /(.19 - .09)*50$

$B_{ac} = 720$ gauss

This is an acceptable level and core is producible.

### IV. Modeling Effective μ and Fringe Effects

We are attempting to develop a method to predict the effective μ of the Micro-Gapped Toroid by generating a series of graphs and fitting measured results to the following mathematical model.

Given the basic equation for inductance,

$$L = 2 N^2 \mu_{eff} h \ln (OD/ID) * 10^{-9} \quad (1)$$

where L is in Henry's

N = turns

h, OD and ID are in cm.

If a Micro-Gapped Toroid inductance is measured, then the effective μ can be calculated by

$$\mu_{eff(measured)} = L(measured)/2N^2h \ln (OD/ID)* 10^{-9} \quad (2)$$

If we assume the area of the gap is effected by fringe fields, F, as follows

$$A_{core} = F * A_{gap} \quad (3)$$

then if $\mu_{eff}$ is defined as

$$\mu_{eff(calculated)} = [ (1/F)*(l_g/l_c) + (1/\mu_m)*((l_c-l_g)/l_c)]^{-1} \quad (4)$$

where $l_c = (OD + ID)*\pi/2 \quad (5)$

setting equation (1) equal to (4) and solving for fringe factor, F, we get

$$F = (l_g/l_c)*[( (2 N^2 h \ln (OD/ID) * 10^{-9})/L(measured) ) - (l_c-l_g)/( l_c*\mu_m)]^{-1} \quad (6)$$

Measurements were made on two different Micro-Gapped Toroids where the gap was held constant and the length, h, was adjusted between 0.16" and 0.016" by grinding. The average results for ten cores of each size are presented in Table 1.

Micro-Gapped Toroid 1. OD = 0.216, ID = 0.12, Thickness = variable, gap = 0.003

Micro-Gapped Toroid 2. OD = 0.175, ID = 0.09, Thickness = variable, gap = 0.003

Table 1

Inductance Average Variations in Thickness

| Thickness | $L_1$ μH | $L_2$ μH |
|---|---|---|
| 0.160 | 849 | 740 |
| 0.082 | 438 | 397 |
| 0.040 | 233 | 205 |
| 0.032 | 184 | 163 |
| 0.021 | 132 | 115 |
| 0.016 | 104 | 91 |

If there were no contribution of fringe fields to the measured inductance then dividing the inductance by the thickness should yield a constant. The results are shown in Table 2.

Table 2
Normalize L / Thickness

| Thickness | $L_{core\ 1}/T$ | $L_{core2}/T$ |
|---|---|---|
| 0.160 | 5310 | 4625 |
| 0.082 | 5345 | 4845 |
| 0.040 | 5830 | 5180 |
| 0.031 | 5945 | 5260 |
| 0.021 | 6275 | 5490 |
| 0.016 | 6520 | 5680 |

Yielding a fringe factor shown in Table 3

Table 3

| Thickness | $L_{core\ 1}/T$ | $L_{core2}/T$ |
|---|---|---|
| 0.160 | 0.472 | 0.411 |
| 0.082 | 0.241 | 0.218 |
| 0.040 | 0.127 | 0.113 |
| 0.031 | 0.100 | 0.089 |
| 0.021 | 0.072 | 0.063 |
| 0.016 | 0.057 | 0.049 |

Ceramic Magnetics is currently characterizing several more Micro-Gapped Toroid samples with different OD/ID ratios and gap variations. When this study is completed the data will be presented on our web page, cmi_ferrite.com. It is the objective of this study to predict the fringe factor, F, to allow for more complete model of the Micro-Gapped Toroid to assist in designing functional devices.

## V. Typical Core Characteristics

The following is a typical data sheet for a Micro-Gapped Toroid. Shown on this data sheet are the following:
Figure 1. Mechanical Dimensions and Gap.
Figure 2. Typical Properties and Part Number
Figure 3. Inductance versus Temperature.
Figure 4. Inductance versus Temperature with Bias
Figure 5. Normal Inductance Distribution

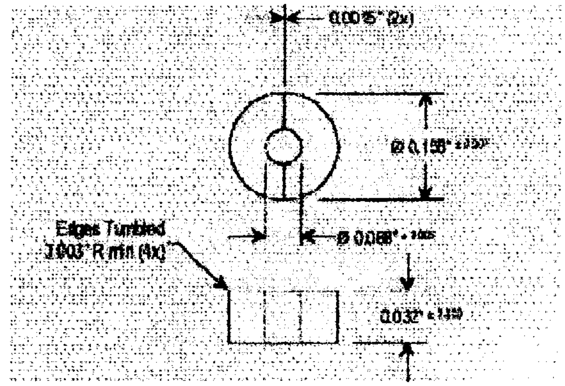


**Figure 1. Mechanical Dimensions and Gap**

Description: GT150803TC/003/CB200
CMI Part Number: 080511-01

*Electrical Specifications*
AL = 13nH ± 25%
Tested at 0 to 70°C, 100kHz, 20mV
OCL = 7.0μH minimum
Tested at 25°C, 100kHz, 20mV,
500mA DC bias, 30 turns

*Physical Specifications*
Coat with Parylene-C (0.001") to withstand a minimum dielectric breakdown of 1.00kV DC

**Figure 2. Typical Properties and Part Number**

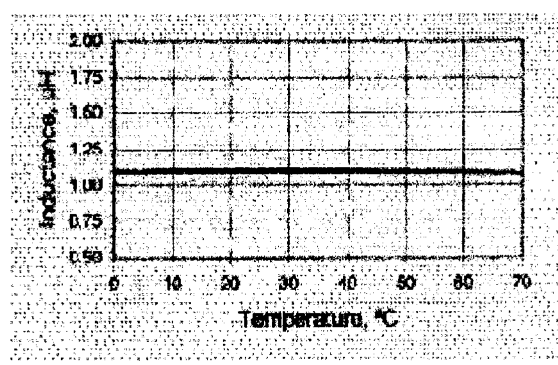


**Figure 3. Inductance versus Temperature**

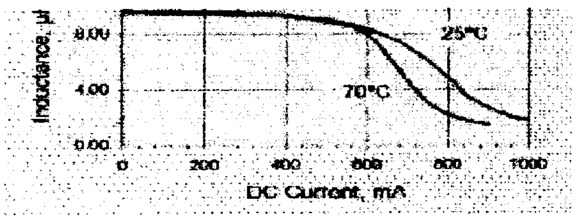


**Figure 4. Inductance versus Temperature with Bias**

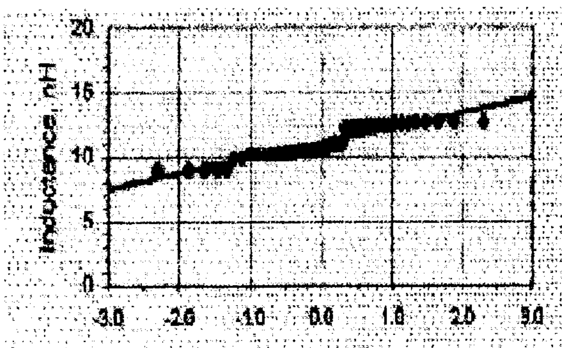


**Figure 5. Normal Inductance Distribution**

## VI. 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 convertors, 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. In addition cores can be made where the primary and secondary are isolated from each other with a barrier and support standoff voltages greater than 7500 volts applied directly to the ferrite. With parylene and normal magnet wire coatings, standoff voltages greater than 10,000 volts can be supported.

## VII. Conclusion

A new magnetic component, the Micro-Gapped Toroid, has been developed by Ceramic Magnetics. This component offers the designer the power loss advantages of ferrite materials compared to typical powder iron type cores. It is a device which will operate into the megahertz frequency range with efficient core losses, as a linear inductor or for RF temperature stable inductors. It will offer the designer a high energy storage device suitable for surface mount devices.

Because of the high inductance factors achievable the designer will be able to reduce turns lowing manufacturing cost. The variations possible with this device will allow easy integration into surface mount requirements.

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