

Squeeze More Performance Out of Toroidal Inductors

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A new manufacturing technique allows for more turns per single layer of windings, enabling the engineer to design cooler, smaller and more EMI-resistant toroids.

Design engineers are under constant pressure to reduce component size while ensuring equal or greater performance. Most engineers would prefer to design with single-layer toroids due to their nearly ideal performance. The number of turns per single layer of traditionally wound toroidal inductors is limited by the core's inner diameter and how tightly you can pack the turns together. To increase inductance, a larger core or multiple layers of windings would normally be needed.

Rectangular wire, with its smaller width allowing more tightly packed turns, tends to twist and lie diagonally when wound. A new type of toroid has been developed that has its turns formed at sequential intervals. Using this method, many more turns can be placed in a single layer, thus increasing inductance without increasing core size. Other benefits include reducing the inductor size, lowering the temperature rise by using a larger diameter wire and reducing EMI noise (patent pending).

With toroidal inductors, there is an advantage to maintaining a single layer of windings. With a single-layer geometry, the inductor behaves closer to an ideal component

because of lower levels of parasitic capacitance. This can also lead to shorter design times.

Fig. 1a shows a schematic representation of the parasitic capacitance involved with a multiple-layer toroid. In addition to the turn-to-turn capacitance (interwinding capacitance) of each layer, there is also layer-to-layer capacitance (interlayer capacitance) and a very significant start/finish gap capacitance since there is no start/finish gap. This increases the total amount of parasitic capacitance by orders of magnitude. This high level of capacitance greatly reduces the impedance of the inductor at higher frequencies, allowing noise to pass more freely. And it reduces the effectiveness of the inductor as a filter element. It also lowers the self resonant frequency (SRF) and makes it extremely difficult to predict circuit performance.

Fig. 1b shows a schematic representation of the parasitic capacitance of a single-layer toroid. Note that the total parasitic capacitance is greatly reduced by the elimination of the interlayer capacitance and the substantial reduction of the start/finish gap capacitance since we now can incorporate an acceptable gap.

Fig. 2a shows a multiple-layer toroid with no gap, and

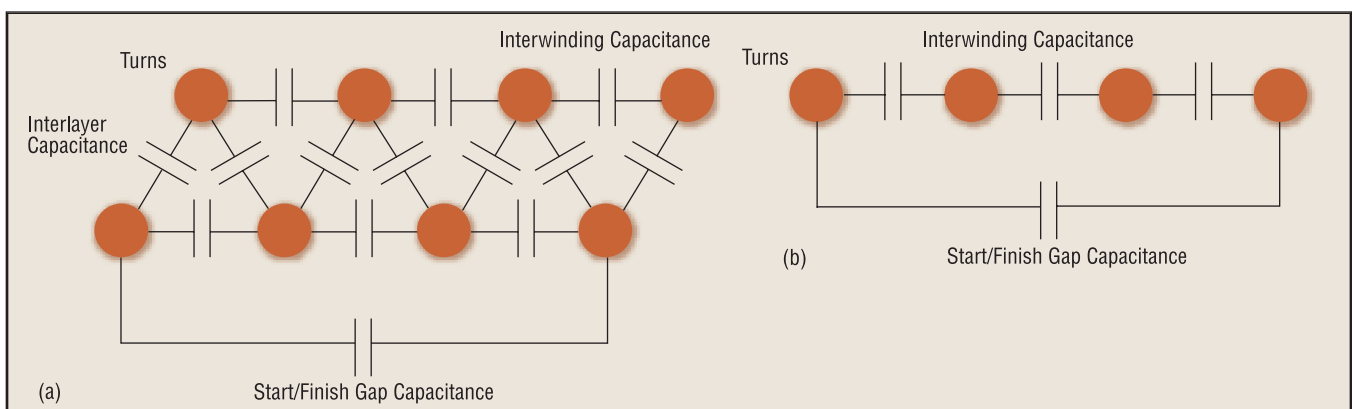


Fig. 1. An inductor having multiple layers of windings (a) exhibits much more parasitic capacitance than one with just a single winding layer (b).

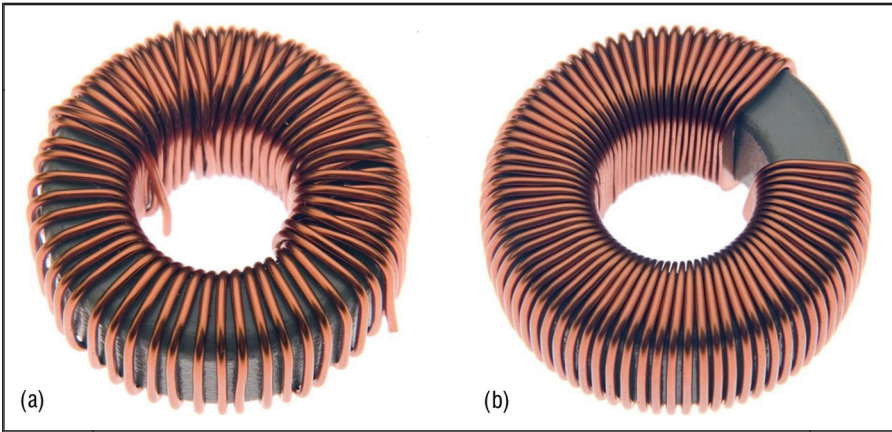


Fig. 2. A multiple-layer toroid with no start/finish gap (a) has significantly more parasitic capacitance than a single-layer toroid with a start/finish gap (b).

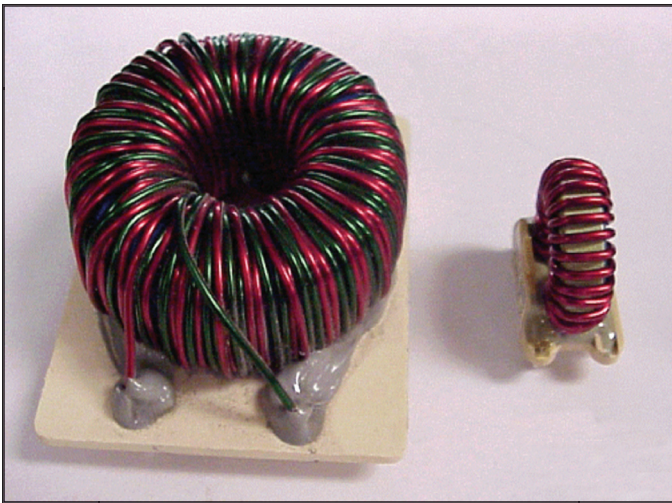


Fig. 3. The multiple-layer inductor (left) has so much parasitic capacitance that an additional inductor is needed as a filter (right) to eliminate noise that passes through the multiple-layer inductor. Together, both inductors consume a large amount of board space and add considerable size, weight and cost to the design.

Fig. 2b is a single-layer toroid with an acceptable gap.

An ideal inductor exhibits only inductance. Operation becomes much more complex with multiple layers of windings due to parasitic capacitance. Instead of designing with something close to ideal, the designer now has to take into account the increased level of capacitance and how it will affect the circuit performance. The SRF will be magnitudes-of-order lower with a multiple-layer toroid compared to a single-layer toroid. This can cause operational difficulties at higher frequencies, and because at these frequencies, the inductor is behaving more like a capacitor and less like an inductor.

For example, the SRF for the single-layer toroid of **Fig. 2b** is 37.6 MHz while it is only 2.5 MHz for the multiple-layer toroid in **Fig. 2a**. They have the same inductance, dc resistance (DCR) and core.

Fig. 3 shows an application where this technology has reduced the component count and freed up valuable board space. The PFC inductor on the left had multiple layers of

windings wound on the core. There was a size constraint, so a larger-size core was not an option. The only way to get the desired inductance on the required core was to go with multiple layers. However, this created the need for an additional inductor to filter out electrical noise that the first inductor passed through because of the high levels of parasitic capacitance (small inductor on the right). Also, an insufficient gap between the start and finish turns allowed additional noise to pass through the inductor, again creating a need for the additional inductor.

The solution to this problem is a single-layer toroid whose core size and inductance remain the same as the original inductor (**Fig. 4**). Engineers were able to apply the same amount of turns used in the multiple-layer design to only a single layer. The result is only one layer of windings with a sufficient start/finish gap, which negates the need for a second inductor. The component count, weight and required board space were all reduced without compromising inductance. Circuit performance was improved due to the increased predictability of the inductor.

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Fig. 4. This single-layer toroid has the same core size and inductance as the combined inductances of those in Fig. 3, but it takes up much less board space, is easier to design and is less expensive.

New Forming Technology

In a traditionally wound toroid, the maximum number of turns per layer is limited by the inner diameter of the core, where the turns of wire make contact (Fig. 5a). The inductor wound with the new forming technology allows many more turns per layer (Fig. 5b). This is due to the wire being formed at specific intervals to allow for more densely packed windings. The complete turn is not formed, as rectangular wire is, because of the tendency for the wire to then twist and lie down, making it extremely difficult to wind. The windings at the outer diameter of the inductor are circular, covering more of the core than rectangular wire would. This improves radiated EMI characteristics. Approximately 70% more turns can be wound on a given layer, yielding an approximate increase in inductance by a factor of three.

While maintaining the same core size and wire gage, many additional turns of windings can be wound in a single layer. This is a benefit when the available board space is limited and fixed, and additional inductance is required. Fig. 6a shows an inductor wound with the new forming process, and Fig. 6b shows a traditionally wound inductor. Without increasing core size, the inductance was increased from 30.3 μH to 83.2 μH , for an increase in inductance by a factor of 2.75.

The increase in the number of turns will boost the DCR, thus increasing the temperature rise. If the added DCR causes too high a temperature rise, a heavier gage wire can be used to equalize the DCR while still increasing the inductance by a factor of 1.86 μH to 56.4 μH .

As an example, Fig. 7 shows a common-mode inductor wound with this new forming technology. Fig. 8 shows a graph that compares the impedance/frequency

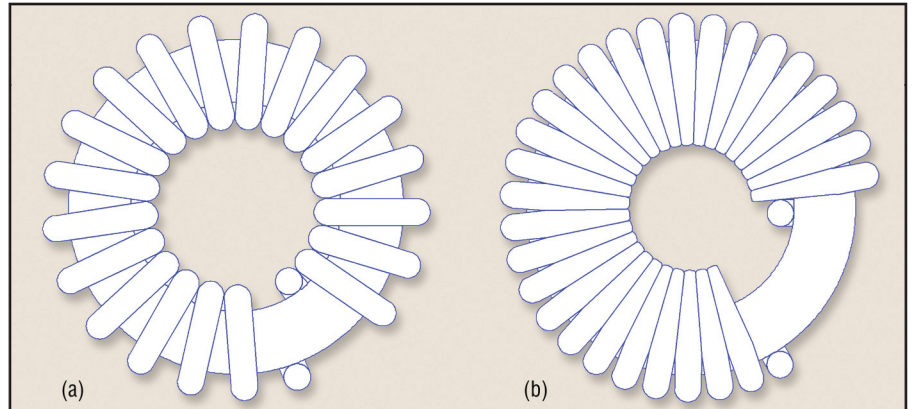


Fig. 5. A conventionally wound toroid (a) cannot be wound as tightly as one using the new wire-forming technology (b). Up to three times more inductance can be obtained with the new technology using the same size core.

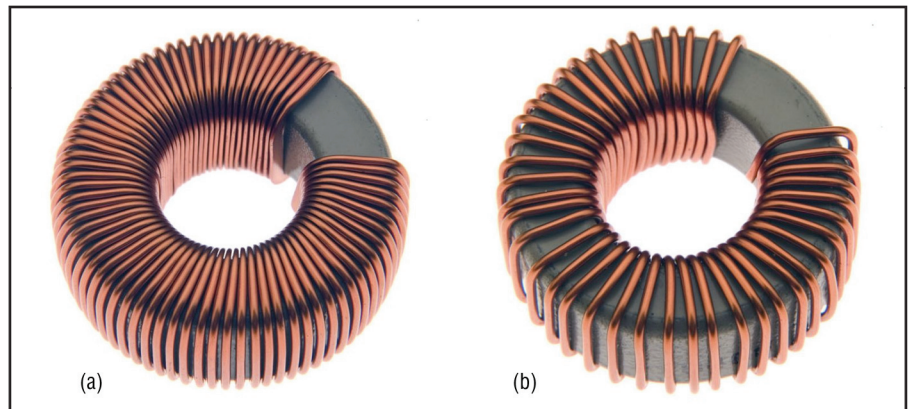


Fig. 6. These toroids illustrate how much more compactly a toroid using the new wire-forming technology (a) can be wound compared to a conventionally wound toroid (b).



Fig. 7. The new wire-forming technology allows a common-mode inductor to be wound easily on a single toroid with gaps.

characteristics between a traditionally wound common-mode inductor and a formed common-mode inductor, keeping the core and fill factor constant. The number of turns increased from 18 to 25. As can be seen in the graph, the formed inductor exhibits greater impedance, making it more effective at blocking unwanted high-frequency noise. While maintaining inductance, the core outer diameter can be reduced up to 15%, the height reduced up to 31%, the volume reduced up to 50% and the weight reduced up to 46%. This translates into a savings of board space, reduces the minimum height requirement and decreases the weight. This is an extremely useful benefit in space/height/weight-critical applications.

For the same core size and inductance, a larger diameter wire can be used to reduce DCR and temperature rise up to 60%. This is ideal for situations where the inductor is running too warm and there is insufficient board space to increase the core size. Many times, multiple layers of windings and insufficient start/finish gaps pass unacceptable levels of EMI, both conducted and radiated. While maintaining core size and

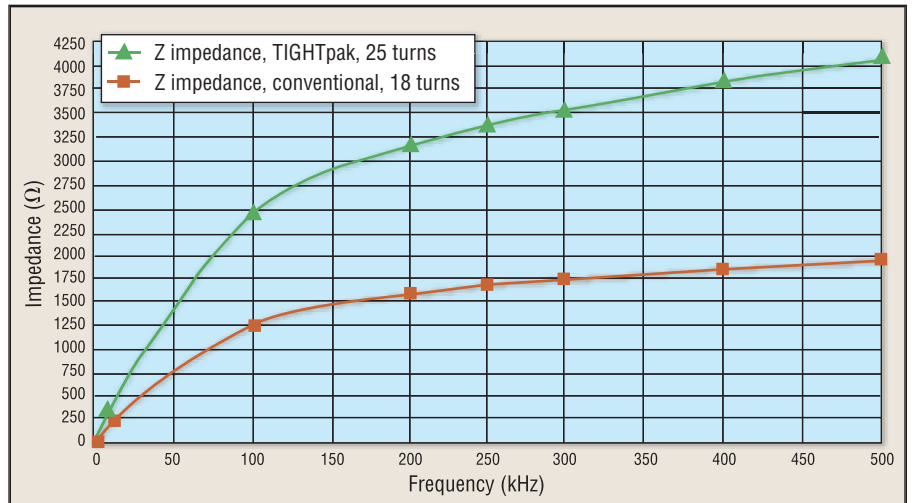


Fig. 8. The inductor of Fig. 7 exhibits much greater impedance over frequency than a conventionally wound type, enabling it to be more effective as a high-frequency filter.

inductance, the number of turns per layer can be increased to eliminate multiple layers or to provide a sufficient start/finish gap. This can reduce EMI to acceptable levels.

Maintaining a single-layer geometry allows the engineer to design with parts that are closer to ideal than multiple-layer toroids. Both the parasitic capacitance and resistance are minimized. This simplifies the design effort and shortens the design cycle.

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