

New Materials Permit Inductors to Keep Pace with Smaller Systems

Inductors of all types — whether discrete, chip, bead or coil — are trying to keep pace with the demands of modern power-supply designs by using diverse forms and materials, such as thin films, ferrites and ceramics.

COIL INDUCTORS generally are used in power supplies and electric home appliances where large currents and high voltages are involved. Chip inductors, however, are aimed mostly at mobile phones and portable consumer electronic products where lower voltages and currents are required, and small size is critical. Bead inductors are used in both applications. Recently, switching-regulator power supplies have been coming down in size, and smaller-size inductors also are becoming an important issue. Here, inductor low profile is the name of the game.

Unfortunately, the dearth of such high-frequency inductors has been an impediment to co-packaging inductors with such supplies, particularly inductors that can work with low-current buck regulators. That is beginning to change. Many modern buck converters co-package low-profile inductors within the same housing. These supplies come from companies Enpirion Technologies, Micrel Semiconductor, Linear Technology and Fuji Device Technology, to name a few. They co-package either their own inductors or ones from other suppliers.

The newest low-profile inductor is the wire-wound

BRL3225 series from Taiyo Yuden USA. Designed for switch-mode dc-dc converters in hand-held consumer electronics products, they measure just 32 mm × 2.5 mm × 1.7 mm. They range in inductance values from 1 μH to 100 μH, dc resistance values from 0.043 Ω to 2.5 Ω and saturation currents from 2400 mA to 270 mA maximum.

Vishay Intertechnology has introduced its IHLP low-profile high-current inductor in a 2020 case size (5.18 mm × 5.49 mm × 2.00 mm). Featuring a frequency range of up to 1 MHz, it has an inductance range from 0.10 μH to 10 μH, a saturation current range of 2 A to 25 A, typical dc resistance from 2.7 mΩ to 169.3 mΩ (2.9 mΩ to 18.2 mΩ maximum) and an operating temperature range of 55°C to 125°C.

BI Technologies' TT Electronics' compact surface-mount power inductor, the HM69T, measures 7.4 mm × 7.2 mm × 5.0 mm (Fig. 1a). It includes inductance values of 90 nH, 100 nH and 150 nH with rated dc currents of 57 A, 52 A and 27 A, respectively (up to 200 nH and 75 A for the S version). Typical dc resistance is 0.298 mΩ ±3%, and the operating temperature range is -40°C to 125 °C. The firm also expanded its molded inductor family with miniature and custom surface-mount devices, the latest being the HM72A series with dimensions of 6 mm × 6 mm × 1.6 mm. Made of a pressed powdered iron alloy core, they operate over a range of 300 kHz to 1 MHz, with inductance values ranging from 100 nH to 33 μH and current saturation levels of up to 80 A. The operating temperature range is -40°C to 155°C (Fig. 1b).

Both monolithic (LQM series) and wire-wound (QH series) inductors with low profiles and high-current carrying

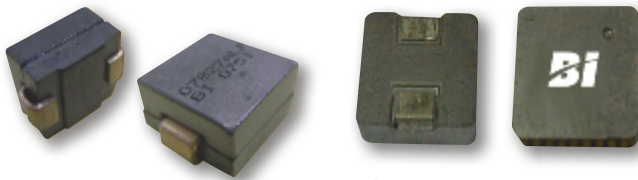


Fig. 1a. The HM69S surface-mount power inductor from BI Technologies' TT Electronics with dimensions of 7.4 mm × 7.2 mm × 5.0 mm comes with inductance values of up to 200 nH and 75 A.

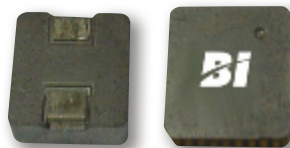


Fig. 1b. BI Technologies' latest molded inductor family member with dimensions of 6.0 mm × 6.0 mm × 1.6 mm, the HM72A, features inductance values ranging from 100 nH to 33 μH and current saturation levels of up to 80 A. (Source: BI Technologies TT Electronics)

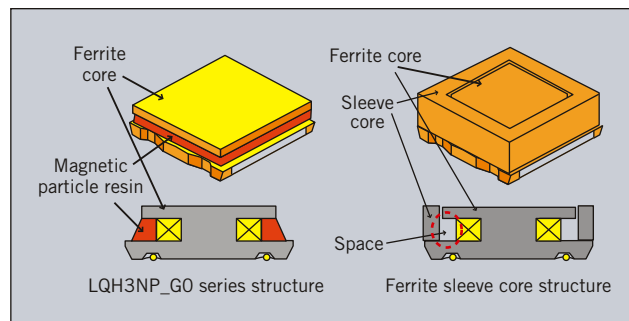


Fig. 2. Murata's LQ3NP_G0 series power inductor for dc-dc converters of small mobile equipment employs a closed magnetic path structure using magnetic particle resins. (Source: Murata Manufacturing Co. Ltd.)

capability are offered by Murata Manufacturing. The monolithic series includes inductors with profiles of 0.85 mm, 0.5 mm, 1.1 mm and 0.5 mm, with respective inductance ranges of 0.47 μH to 4.7 μH , 0.47 μH to 2.2 μH , 1.0 μH to 3.3 μH , and 0.47 μH to 2.2 μH . Respective rated currents are 1.2 A, 1.1 A, 1.5 A and 0.8 A.

Wire-wound types include the LHQ3NP_G0 with a low profile of 0.9 mm (a 3-mm \times 3-mm case), an inductance range of 1.0 μH to 250 μH , 1.525 A of rated current and 0.11 Ω of dc resistance. This inductor is made by a closed magnetic path structure using particle resin (Fig. 2).

Würth Electronics Midcom offers high-current and high-temperature surface-mount inductors. The WE-HC/WE-HCA series has inductance values from 0.11 μH to 150 μH in a footprint ranging from 7 mm \times 7 mm to 13 mm \times 13 mm. The inductors operate from -40°C to 155°C. The WE-HCFT line of high-current through-hole inductors features values from 10 μH to 15 μH , measures 22 mm \times 17 mm \times 11.5 mm and operates from -40°C to 125°C.

Wire-wound inductors are products of an old technology that has recently witnessed an important advance. "This is the first one since the invention of the Litz wire," said Weyman Lundquist, president of West Coast Magnetics, which has

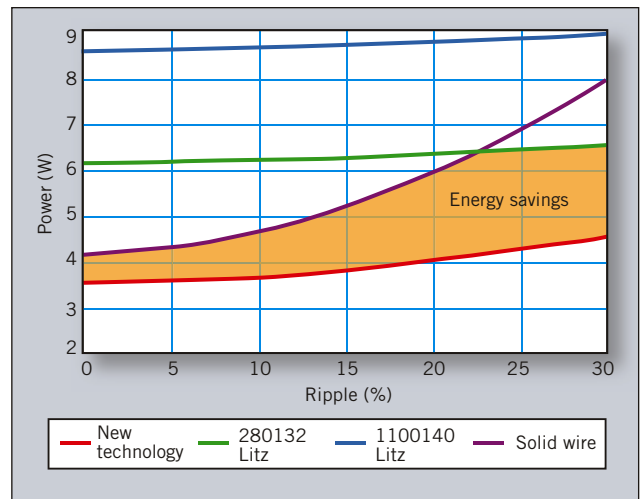


Fig 3. In tests performed on a 90- μH 40-A inductor with a ripple current at 25 kHz, it has been shown that a new magnetic inductor technology developed at Dartmouth College substantially outperforms conventional solid- and Litz-wire wound inductors using the same core geometry and number of wire turns. Total winding losses for this example were 17% to 35% lower than for both solid- and Litz-wire designs over a ripple range from 0% to 30%. The technology has been exclusively licensed by West Coast Magnetics. (Source: West Coast Magnetics)



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exclusively licensed this technology advance from Dartmouth College's Thayer School of Engineering where it was invented, enabling low ac and dc resistance inductor products. It combines the low dc resistance properties of a foil-wound inductor with the low ac resistance of a Litz wire.

The invention works by displacing the ac eddy currents to defined locations inside any copper foil winding, which effectively neutralizes the loss-causing eddy current effects inside the windings. This effect is created by shaping the copper winding around the field created by a gap in the magnetic core path. (Gaps in the magnetic core are commonly used in this class of inductor.)

When this technique is employed, the foil winding retains the very low dc resistance typical of this class of winding, and also has very low ac resistance. Typically, the total loss is lower than what is achievable with a Litz-wire winding. The resulting combination of low ac and low dc copper losses makes for a more efficient inductor (Fig. 3).

NEWER THIN MATERIALS

Toshiba Materials is ready to offer flexible ultrathin inductors using special magnetic materials (Fig. 4). These structures are 5 mm × 5 mm and 0.3 mm thick, are adjustable from 0.1 mm to 0.4 mm thick and have high Q values of more than 25 at 10 MHz. The inductors feature stable characteristics against a large current of greater than 1 A.

One of the most advanced such inductors is from Enpirion Technologies, which has already produced low-profile inductors made with a copper spiral sandwiched between two ferrite cores. The company's EP5352Q/5362Q (500 mA/600 mA) inductors feature a low profile of just 1.1 mm within a 4-mm × 5-mm QFN20 package. These can operate at 5 MHz and feature input and output voltage ranges of 2.4 Vdc to 5.5 Vdc and 0.8 Vdc to 3.3 Vdc, respectively.

Enpirion has gone one step further by producing low-profile MEMS inductors as part of its EN5366Q dc-dc converter at the first International Workshop on Power Supply on Chip (PwrSoC) last year in Cork, Ireland. With an output voltage of 1.2 V, power density for this product is 532 W/in.³ (0.032 W/mm³). Output currents of 6 A, representing current density of 444 A/in.³ (0.027 A/mm³), were achieved. All of this was done within a 10-mm × 12-mm × 1.85-mm package. Key to the dc-dc converter's performance is a MEMS inductor that sits atop the switching electronics (Fig. 5).

At this same workshop, Fuji Device Technology displayed its FB6831J dc-dc converter using a conventional inductor with respectable performance levels.

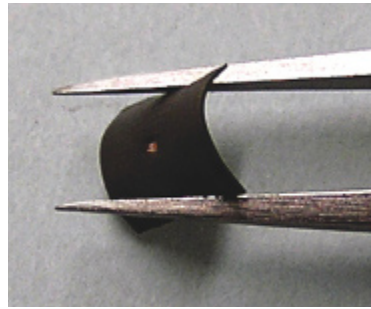


Fig. 4. Using amorphous materials, Toshiba is ready to offer flexible ultra-thin 0.3-mm × 5-mm × 5-mm inductors. They feature high Q values of more than 25 at 10 MHz against a large current of over 1 A. (Source: Toshiba Materials Co. Ltd.)

Although it had smaller dimensions of 2.40 mm × 2.95 mm × 1.00 mm than the Enpirion unit, it had a higher current-density rating of about 0.070 A/mm³ versus about 290 A/mm³, but a lower output-current rating of about 0.5 A versus 6 A.

The goal of PwrSoC '08 was to address the issue of developing next-generation, miniaturized switched-mode power supply product formats for use in future mobile phones, portable electronics and high-performance computing platforms. These multicomponent products can also be referred to as power supply-in-package (PSiP) systems.

At that workshop, scientists from the Power Electronics Research Laboratory at University College, Cork, Ireland, demonstrated a 20-MHz, 0.5-A micro-inductor with a monolithic MOSFET and driver power-train IC operating in the 15-MHz to 65-MHz range. Efficiency levels as high as 95% can be achieved within a footprint of 3 mm³ at 100 MHz.

The MEMS approach to making inductors has proven valuable for high-performance dc-dc converter and RF mobile communications with portable devices, where space is at a premium. Much of the work on MEMS inductors has been demonstrated successfully in the lab. Introducing them to the mass market cost-effectively has been more challenging.

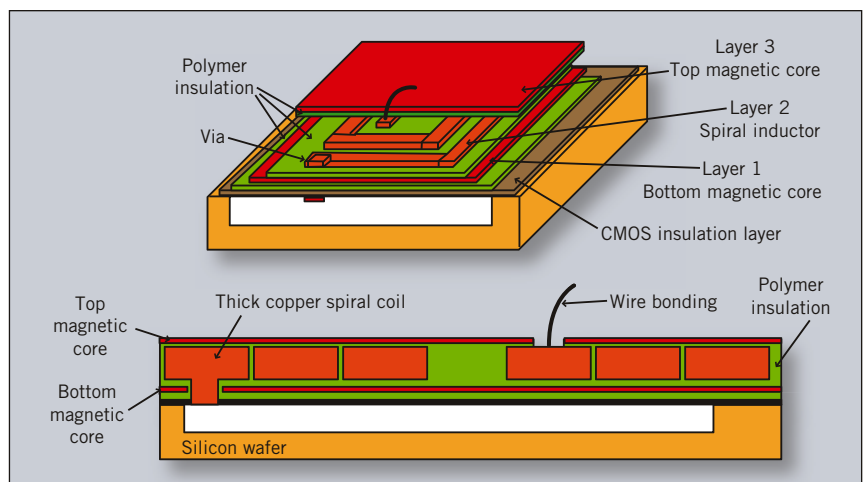


Fig. 5. Key to Enpirion Technologies' EN5366Q dc-dc converter's ability within a 10-mm × 12-mm × 1.85-mm package is a low-profile MEMS inductor that sits atop the switching electronics. With an output voltage of 1.2 V, power density is 532 W/in.³ (0.032 W/mm³). Output current is 6 A, representing current density of 444 A/in.³ (0.027 A/mm³). (Source: Enpirion Technologies.)

One effort was at the Georgia Institute of Technology aimed at making low-power inductors with minimized eddy current losses for use in high power-density compact switching converters. It resulted in the development of an automated electroplating system for fabricating thick magnetic cores compromising a large number of submicron laminates without human operator intervention. Inductors with high inductance values, quality factors and power-handling capability were realized. A miniature dc-dc converter with power conversion efficiency of 10 W was demonstrated (Figs. 6a and 6b).

Scientists at the IBM T. J. Watson Researcher Center demonstrated that high-performance thick copper inductors can be made on-chip using conventional photolithographic means. They also demonstrated that using MEMS inductors yielded higher performance levels.

They began by using 4- μm -thick copper spirals with a 4- μm -thick copper underpass on a high-resistivity substrate (75 $\Omega\text{-cm}$) to reduce ohmic losses. The underpass is connected to the spirals with a 4- μm -high copper via, which lowers the spiral-to-underpass capacitance. For further lowering the capacitive losses, another 6.1- μm -thick interlayer dielectric separates the underpass from the substrate. A peak Q of 26.6 at 3.8 GHz and a resonant frequency of 18 GHz was achieved.

In the second method, one-mask CMOS-compatible micro-machining scheme was used to eliminate substrate losses. It completely removes the silicon substrate from directly below

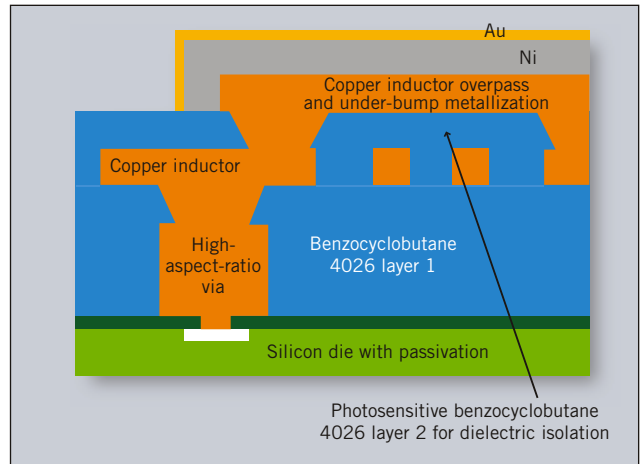


Fig. 7. High-aspect-ratio vias are employed by IMEC for connecting an inductor on-chip to copper pads using wafer-level packaging. (Source: IMEC)

the inductors. The result was a more impressive peak Q of 52.8 at 8.2 GHz and a resonant frequency of 27 GHz.

New work on high-permeability core materials for embeddable inductors in flexible organic substrates also shows promise. Researchers at Hong Kong's University of Science and Technology developed a high permeability dual-phase nickel zinc ferrite (NZF) core fabricated using a low temperature sol-gel. Crystalline NZF powder was added to the sol-gel precursor of NZF. The solution was deposited onto the substrates as thin films and heat-treated at different temperatures.

Results showed that adding NZF powder induced low temperature transformation of the sol-gel NZF phase to high permeability phase at 250°C, which is about 350°C lower than the transformation temperature for pure NZF sol-gel films. Electrical measurements of dual-phase NZF cored 2-layered spiral inductors showed the inductance increased by three times compared to inductors without the dual-phase NZF cores.

Researchers at Belgium's IMEC developed an economical method of making high-Q inductor on-chip. They used mask-aligner lithography and wafer-level packaging, making interconnect copper lines and chip space dimensions suitably small so as to be economically practical (Fig. 7).

Reportedly, they have worked out the lithographic solutions for printing the isolating layer and via and the inductor metal. This process allows further down-scaling, eventually matching on-chip pad dimensions. The technology has resulted in a low-cost fabrication process that yields high-performance devices with a quality factor of more than 30. **Ⓞ**

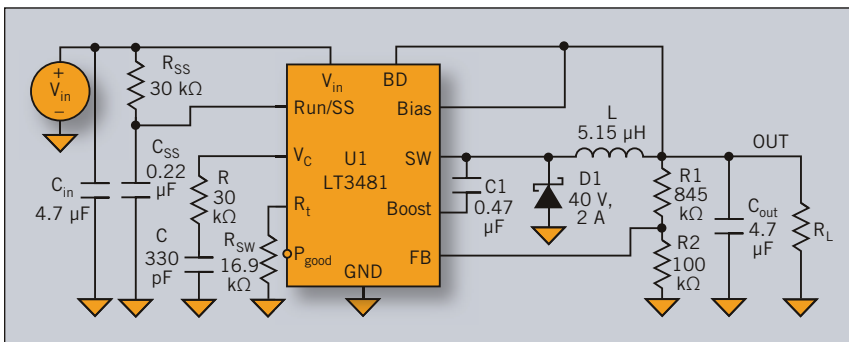


Fig. 6a. (Above) This dc-dc buck converter, operating at 2 MHz, uses MEMS laminated power inductors.

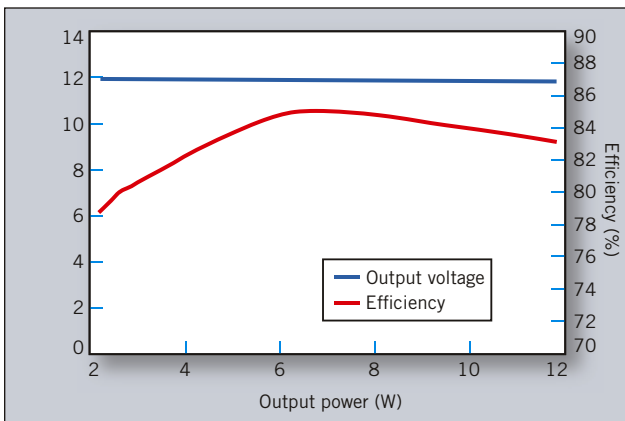


Fig. 6b. (Left) The buck converter's performance shows a steady 12-Vdc output with an efficiency range of approximately 78% to 84% over an output power range of 2 W to 12 W. (Source: Georgia Institute of Technology)