Low-Temp Co-Fired Magnetic Tape Yields High Benefits

By **George Slama**, Midcom Inc., Watertown, SD

Low-temperature co-fired ceramic (LTCC) ferrite, combined with screen printable silver conductor and low permeability dielectric produce small, low power, low profile transformers with no wire or discrete core.

Although their size is smaller and frequency requirements are higher, the transformer's basic wire wound technology hasn't changed much since Michael Faraday's discovery in 1831. Today's smallest transformers use hand-wound toroidal cores in a process that has eluded complete automation. Extensive use of manual labor is only temporary because it is masked by very low cost overseas labor. The parts themselves are fragile and must be mounted into headers or encapsulated to be handled by placement equipment. Additionally, consistency in a manual process is always hard to maintain.

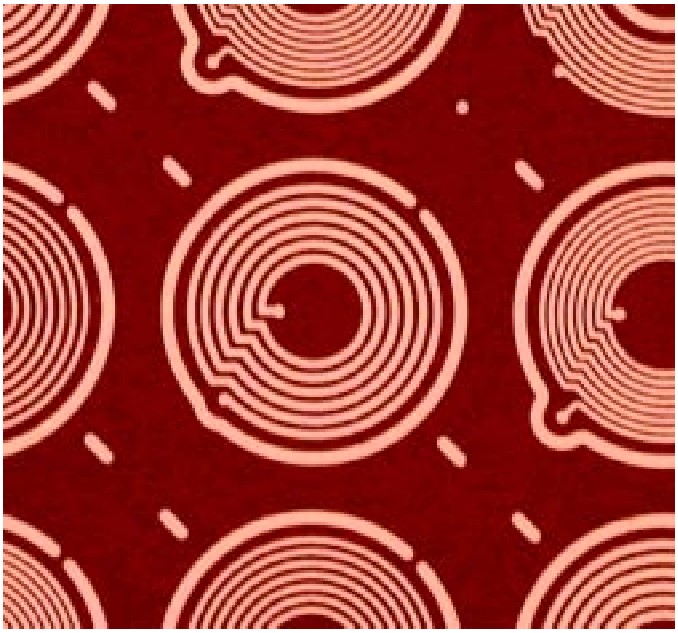

Fig. 1. *Close up of 0.006-in. wide conductor pattern printed on a sheet of ferrite tape.*

A new approach to transformer production is to use low-temperature co-fired ceramic (LTCC) ferrite. LTCC is a well-established process that has been in use for many years in the microelectronics packaging industry. It's similar to the thick film hybrid process employed for mutlilayer ceramic capacitors and chip inductors. The process for building transformers uses a ferrite-based green tape prepared from a slurry of ceramic oxides, plasticizers, binders, and solvents. The slurry is cast onto a mylar carrier film moving under a knife-edge, the height of which determines the tape thickness. Air drying the slurry removes the solvent and allows the formation of the tape—which is only a few thousandths of an inch thick. [1]

The tape is then cut into sheets that become the individual layers of an assembly, called a "stack." A single sheet may be large enough to contain a matrix of hundreds of transformers similar to IC wafers. The sheets are punched with a series of holes for both tooling alignment and for via interconnections between layers. Vias are then filled with a conductive material using a stencil and screening process. The next step is to print conductive patterns on each sheet that represent the windings and interconnecting traces using a process similar to silk screening (**Fig. 1**). The final printing applies a low permeability material to selected areas. The sheets are then aligned and stacked together. High-pressure pressing melds all the layers into a solid mass.

The matrix of transformers is then singulated into individual pieces. Next, they are fired in a furnace following a precise and carefully controlled temperature profile. Peak temperatures are in excess of 800°C. The firing process burns off the organic binders and plastisizers, and then sinters the layers and printings into a solid monolithic structure, physically bonding the particles together. Unless there are special termination requirements, the parts are complete and ready for testing, packaging, and shipment.

Design Considerations

Transformer design using LTCC ferrite tape presents several challenges to the traditional ways of thinking and designing magnetics. First, the windings are embedded in ferrite. This is like using magnetically shielded wire and results in nontraditional flux paths[2].

In a traditional transformer, the magnetic path is well defined by the core shape, its size, and cross-sectional area. Windings are well defined and completely separate from the core. Normally, the windings are formed on a coil former and then the core is placed around them. With LTCC ferrite tape, the windings and core are fully integrated. In the traditional transformer, the air, insulation, and windings around the coil have much higher reluctance to the flux than the core; hence the flux concentrates in the core. This core magnetic path encompasses the entire winding, aiding in effective coupling. According to Faraday's law, the voltage induced in a loop or loops of wire (coil turns) is related to the amount of flux passing through the interior of the loop (**Fig. 2**)[3]. In a traditional transformer, the flux is directed to pass through the turns by the core—for example, the center leg of an E-core. In the LTCC transformer, the core is intimate with the windings and thus a low reluctance path is available right next to the conductor. Since flux will seek the path of least reluctance, it may not pass through the other turns of the winding. Flux that does not couple by passing through the other winding turns is lost and is referred to as leakage inductance.

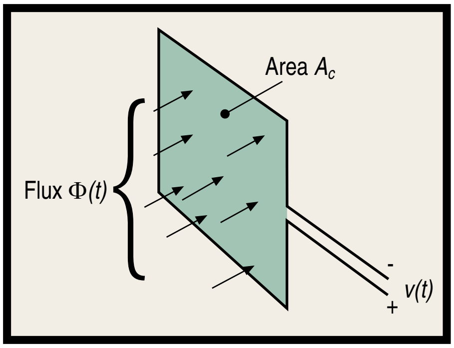

Fig. 2. *The voltage v(t) induced in a loop of wire is related by Faraday's law to the derivative of the total flux Φ(t) passing through the interior of the loop.*

Typically, you can solve this problem by adding a lower permeability material between the windings on the layers of ferrite tape to help direct the magnetic flux to increase coupling [4]. Introduction of low permeability material helps direct and control the flux paths around the coil so more flux passes through the winding turns.

General winding considerations are conductor width, thickness, and

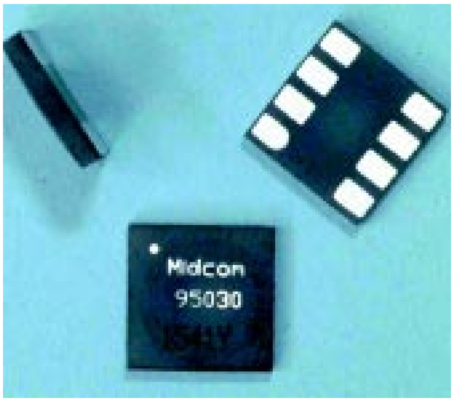

Fig. 3. *Low-power transformers series. Units are only 0.3 in. x 0.3 in. x .060 in.*

spacing between turns and windings. Several geometries exist for positioning coil turns relative to each other. Parasitic capacitance can be a problem due to the high aspect ratio of the winding width-to-thickness, if they are stacked on top of each other, which can limit high-frequency response. Leakage inductance is higher because of reduced coupling, causing overshoots on fast waveforms and a lower power transfer efficiency. Most performance requirements can be met by trading off a gain in one parameter against a decrease in another.

A unique feature of using LTCC ferrite is that the form factor is very flexible. There are no predefined coil forms or core shapes. The transformer shape can be adjusted to meet the needs of the application. Terminations can be positioned and sized on any of the six surfaces to make the best use of available area.

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Material Development

One key to the success of this process is the selection and development of materials that provide the desired properties and fire together to produce dense, flat and crack-free parts. Nickel-Zinc (NiZn) ferrite was chosen because if its high resistivity and low sintering temperature. High resistivity reduces eddy current losses at high operating frequencies. Also, the ferrite's high resistivity can withstand a sufficiently high voltage that it provides galvanic isolation. Currently, relative permeability is limited to about 500 because of the temperature limits imposed by the type of conductor material used. An important point to mention is that although the units are sintered at more than 800°C, the ferrite Curie temperature is only 120°C.

Low winding resistance is important to achieve high power transfer efficiency through reduced dc winding resistance losses. This requires use of high conductivity metals such as silver, copper, and gold. Gold's cost generally rules it out. The required inert atmosphere for firing copper raises its manufacturing cost, makes the organic burnout more difficult, and adversely affects the properties of ferrite, so it's rarely used. That leaves silver as the usual choice for LTCC applications[5]. Differently blended pastes are used for via filling, internal conductors, and external solderable terminations.

Third, a very low permeability material is needed to help direct the flux paths within the structure and to enhance the dielectric properties of the ferrite tape. These materials must not only meet their individual design requirements, but also be compatible to being fired together without losing their properties or contaminating each other—a feat more easily said than done.

Application

The resulting transformers can be used for power applications under 1W that require galvanic isolation. Typical applications include isolated power for sensors, RS-232 or 485 circuits, data acquisition—and even digitally-interfaced modems.

A series of transformers (**Fig. 3**, on page 33) have been developed for low power switching applications in the 250 kHz to 2 MHz range. These include turns ratios from 1:0.5 to 1:4, all with split primary and secondary windings, allowing for series, parallel or center tapped connections.

Part No.	Turns Ratio	VµS Rating	Primary DCR Ω±10% at 20˚C	Secondary DCR Ω ±10% at 20˚C	Primary Inductance µH ±10%	Secondary Inductance µH ±10%	Leakage Inductance µH Nominal
95026	1:1	4.5	0.9	0.9	23.6	23.6	2.9
95027	1:2	4.5	0.9	1.5	18.7	72.6	1.9
95028	1:3	4.5	0.9	6.7	20.4	183.3	1.8
95029	1:4	4.5	0.9	12.3	21.9	342.1	1.7
95030	1:0.5	9.0	6.1	0.9	97.9	24.3	9.2
95031	1:1	9.0	6.1	6.3	103.0	103.6	6.8
95032	1:1.5	9.0	6.1	6.8	86.8	193.8	5.1
95033	1:2	9.0	6.1	12.5	92.2	356.5	4.6

Table 1. *Low-power series transformer specifications. Notes: (1) Terminals 2-3, 6-7 joined; (2) Inductance at 500 MHz, 0.5V$_{rms}$; and (3) Dielectric rating: 250 Vac.*

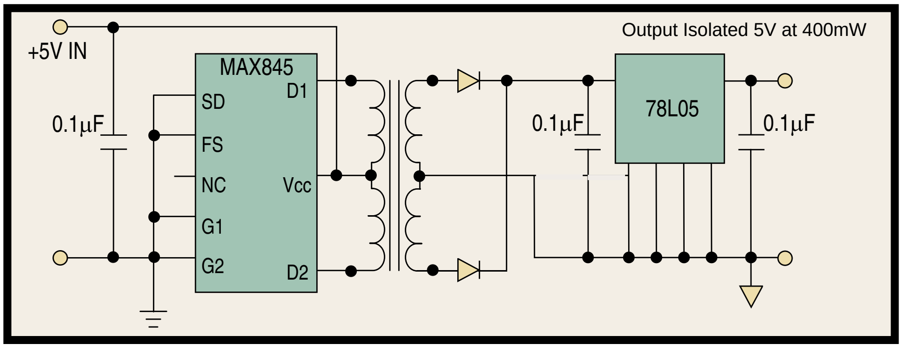

Fig. 4. *Power supply using the Maxim MAX845 IC with a Midcom 95032 transformer.*

Part No.	LS µH ±20% 100 kHz, 0.1V$_{rms}$	I_{SAT} (A)	I_{rms} (A)	DC Res. Ω ±20% at 20˚C
95034	0.47	1.50	3.6	0.040
95035	0.68	1.39	2.7	0.080
95036	0.82	1.14	2.4	0.098
95037	1.0	0.96	2.2	0.116
95038	1.2	0.83	2.1	0.134
95039	1.5	0.74	2.0	0.152
95040	1.8	0.66	1.8	0.169
95041	2.2	0.50	1.6	0.223
95042	2.7	0.39	1.8	0.169
95043	3.3	0.36	1.8	0.187
95044	4.7	0.30	1.6	0.223

Table 2. *2520 SMT inductor specifications. Notes: (1) I_{SAT}: DC current where L_S drops ~10% from no dc; and (2) I_{rms}: dc current to raise part 40°C.*

Table 1 lists the values currently available. **Fig. 4** is a typical circuit using the Maxim MAX845 isolated transformer driver IC [6]. In this figure, the circuit provides more than 400mW of regulated, isolated power using a minimum of components and all under 2 mm.

A series of low profile (<1 mm) inductors are under development to bridge the gap between drum core inductors and chip inductors. **Table 2** outlines typical properties.

Future

The future holds many opportunities for discrete low power transformers along with the ability to create modules containing groups of components built into a single package. With LTCC, this can include not just transformers and inductors, but capacitors, resistors, and any necessary interconnections.

The ability to use tapes optimized for particular functions (i.e., high permitivity for capacitors, high permeability for transformers) in the same structure opens opportunities to further reduce component count, size, and cost. **PETech**

References

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2. *J. Bielawski, G.A. Slama, A.H. Feingold, C.Y.D.Huang, M.R. Heinz, R.L. Wahlers, "Low Profile Transformers Using Low Temperature Co-Fired Magnetic Tape", Proceedings of the IMAPS 2002 Telecom Hardware Solutions Conference.*
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6. *MAX845 Data sheet, Maxim Integrated Products.*