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2011 J. Phys.: Conf. Ser. 263 012010

(http://iopscience.iop.org/1742-6596/263/1/012010)

Journal of Physics: Conference Series **263** (2011) 012010 doi:10.1088/1742-6596/263/1/012010

A novel DC-DC convertor using LTCC technology for magnetic integration application

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Abstract. A compact DC-DC convertor is proposed and fabricated in multilayer ferrite substrate using LTCC technology. The spiral conductors are buried into the ferrite substrate with a multilayer 3-D structure to reduce the volume of convertor. The passive integration of magnetic components and surface circuitry are achieved in a whole substrate and the size of module can be reduced markedly. The whole height of module is only 3mm, 1/3 of the height of conventional modules. Testing results indicate that the performance of the module is excellent in Point-of-Load (POL) field. The step-down DC-DC converter converts input voltage of 5V to output voltage of 3.3V. It is confirmed that the maximum conversion efficiency of 93.2% is sufficient for actual DC-DC converter application. Such a compact DC-DC convertor provides a compact, low cost and high reliability approach for power supply and magnetic integration application.

1. Induction

The latest communication systems demand ever-greater functionality, higher performance, and lower cost in smaller and lighter formats. The power supply modules, especially DC-DC convertors, which cover significant space in the wireless communication terminals and systems [1-2]. To reduce the size and weight of DC-DC convertor is the key issue to achieve system miniaturization. Magnetics is the major bottleneck for achieving compact high power density DC-DC convertor [3-4]. Therefore, how to design a highly integrated DC-DC convertor has become a widespread interest around the world. In order to reduce the converter footprint and fully use the available space, 3D integration concepts are widely used in both areas, which design the magnetic component as a low-profile substrate [5].

There are some available integration technologies for multilayer integration applications, such as thin film technology, high-temperature co-fired ceramic (HTCC) technology, and low-temperature co-fired ceramic (LTCC) technology [6-7]. Particularly, the advantages of LTCC have motivated substantive research. In recent years, LTCC technologies are widely used for their superior advantages over other substrate technologies, such as three-dimensional (3-D) integration capabilities, small value of dielectric loss tangent and low cost for high-volume production [8]. Although LTCC technology

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has been widely adopted in RF and microwave electronics, using LTCC technology for power electronic applications is currently a relatively new area [9].

In this paper, a novel DC-DC convertor is proposed and fabricated in LTCC technology. In order to reduce the volume of the convertor, the spiral conductors are buried into the ferrite substrate. The passive integration of magnetic components and surface circuitry are achieved in a whole substrate and the size of module can be reduced markedly. Testing results indicate that the performance of the module is excellent in Point-of-Load field. The whole height of module is only 3mm which provides a compact, low cost and high reliability approach for power electronics application.

2. Structure design

Figure 1 shows a simplified functional diagram for a step-down DC-DC converter circuit. For this configuration, we would like to fabricate 2.6uH inductor, as circled in Fig. 1. In order to reduce the volume of the convertor, the spiral inductor was adopted as the basic design in the substrate to optimize the inductance as well as conductor resistance. Because it is difficult to design a higher density of turn number in toroidal inductor. On the other hand, it is possible to design a multilayer spiral inductor. Therefore, the spiral conductors are buried into the ferrite substrate to achieve a multilayer 3-D structure. Use of Ag conductor makes it possible to achieve low resistance of the inductor pattern. The thickness of conductor is 10um. To obtain an inductance of 2.6uH, the inductor are be computed as

$$L=\frac{\varphi}{I}=\frac{\int_S B_1 \mathrm{d}S_1}{I}+\frac{\int_S B_2 \mathrm{d}S_2}{I}=\frac{\mu_0\mu_r\int H_1 dS_1}{I}+\frac{\mu_0\int H_2 dS_2}{I} \tag{1}$$

where B_1 is the magnetic flux density, and H_1 is the magnetic field strength of the magnetic core, B_2 is the magnetic flux density, and H_2 is the magnetic field strength of the air [10].

In addition, the parameters of inductor can be optimized through Electromagnetic calculation and simulation based on the computing formula of inductance. Figure 2 shows the simulation model of the multilayer inductor, which W is the line width of the conductor, D is the thickness of the ferrite substrate, and S (the sum of A, B and C) is the length of the conductor. After calculation and simulation, the line width of 0.75 mm, the thickness of 1.4 mm, and the length of 11.75mm are obtained. The LTCC inductor has no saturation and exhibits high inductance value. Then, switching loss of converters could be largely reduced for very low current ripple. Moreover, an inductor fabricated using LTCC technology is used as a substrate where the traces are printed and devices mounted on top of the substrate. In this way, the passive integration of magnetic components and surface circuitry are achieved in a whole substrate and the size of module can be reduced remarkably.

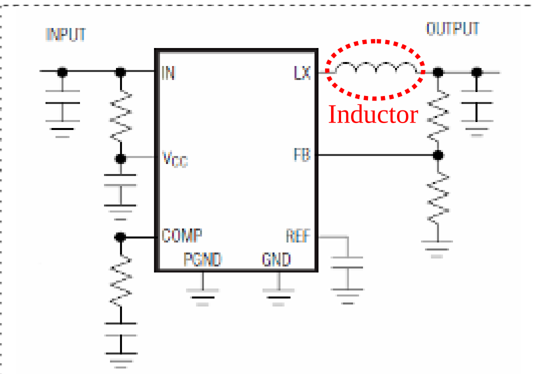

Figure 1. The functional diagram of the convertor

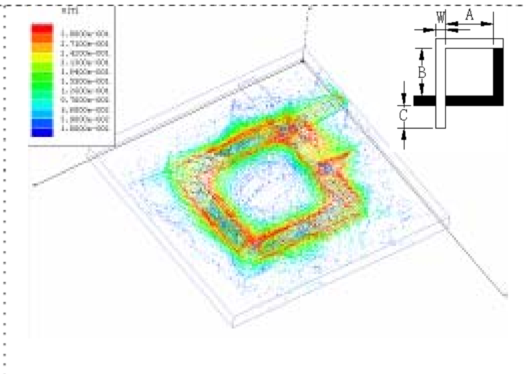

Figure 2. The simulation model of the multilayer inductor

3. Experimental process

Based on the proposed schema and 3-D multilayer structure, a DC/DC convertor was fabricated using the LTCC process, as shown in Fig. 3. The initial permeability and Q factor of the LTCC ferrite green tape (casting with PPT-LSF400 powders) are 450 and 90.

First, the ferrite green tap is cut and via holes are punched. Vias for conduction between layers and wiring patterns are screen printed on the green sheet using conductive paste. Many layers of these printed green sheets are arranged in layers, then heat and pressure is applied to laminate them (the organic resin in the green sheets acts as glue for bonding the layers during lamination). By firing the conductor metal and ceramic together while driving off organic binder in them, the DC/DC convertor in a multilayer ceramic substrate can be obtained. The measured metal's thickness of the conductor is about 10 micrometer.

Based upon the above experimental process, the sintering profile, as shown in Fig. 4, were modified in order to eliminate inner stress in the multilayer substrate. The profile has a lower temperature rising rate about 3 ℃ per minute in the range of room temperature to 280 ℃, 280 ℃ to 450 ℃, and reaches the peak temperature of 900 ℃, lasting for 0.5 h. With a properly controlled process, we can achieve excellent performance to meet desired specifications.

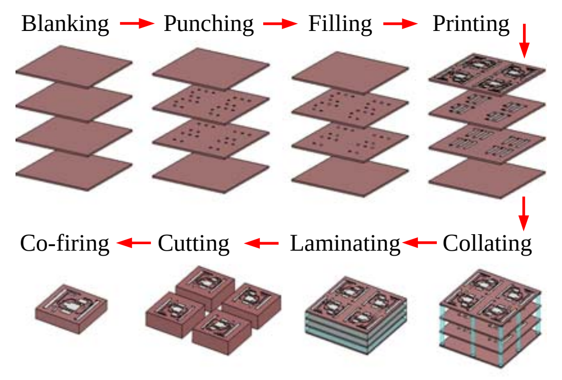

Figure 3. The fabricated process of the LTCC DC/DC convertor

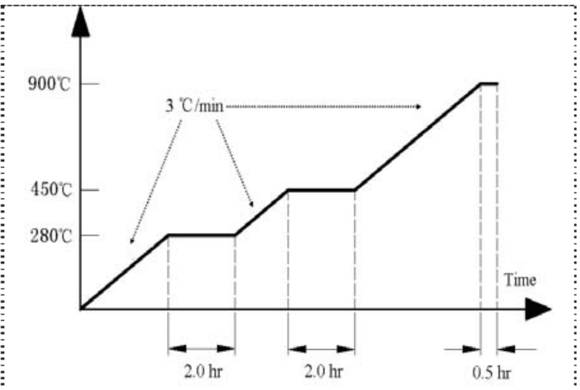

Figure 4. The sintering profile during the co-firing process

4. Experimental results

After the analysis and optimization of experimental process, the designed multilayered buck DC/DC convertor is fabricated and measured. Measurement results indicate that the performance of the module is excellent in POL field. The step-down DC-DC converter converts input voltage of 5V to output voltage (V_o) of 3.3V. Maximum output ripple (V_{pp}) of 24mV, output power (P_o) of 5W and output regulation of less than 1% are achieved to meet the design specifications. Conversion efficiency of the DC-DC converter was calculated by the ratio of input power to output power.

Table 1. The testing result of the DC-DC converter

Testing Points	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9
P_o (W)	1.4	1.6	1.9	2.3	2.9	3.8	4.5	4.8	5.0
V_{pp} (mV)	14.1	14.2	15.1	15.8	17.0	19.2	22.8	23.7	24.0
Efficiency (%)	92.3	93.2	92.7	91.6	91.0	92.8	91.8	90.2	90.2

Table 1 shows the measurement results of the DC-DC converter. It is confirmed that the maximum conversion efficiency of 93.2% is sufficient for actual DC-DC converter application. Figure 5 shows the samples of the convertor. The convertor with integrated inductor substrate has dimensions

10mm×10mm×3.0mm. The whole height of module is only 3.0mm, 1/3 of the height of traditional modules. It is feasible to achieve miniaturization power supply modules by magnetic integration utilize LTCC technology.

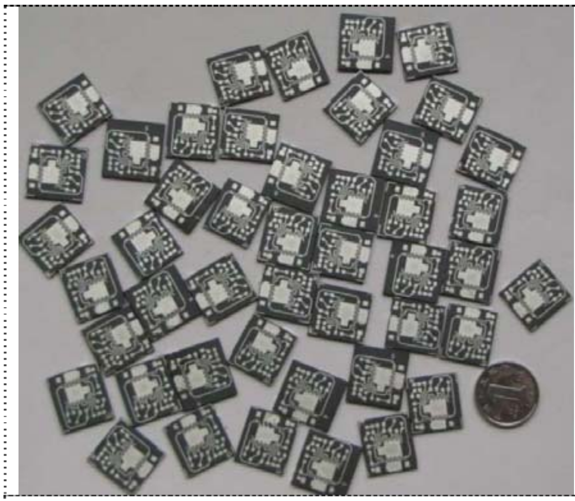

Figure 5. The samples of the convertors

5. Conclusions

This paper proposes a novel DC-DC convertor with the spiral conductor is buried into the ferrite substrate. The convertor is fabricated in multilayer ferrite substrate using LTCC technology. Testing results indicate that the performance of the module is excellent. The step-down DC-DC converter converts input voltage of 5V to output voltage of 3.3V. It is confirmed that the maximum conversion efficiency of 93.2% is sufficient for actual DC-DC converter application. Furthermore, the height of the DC/DC convertor with integrated inductor substrate is only 3mm, 1/3 of the height of traditional modules. The DC-DC convertor provides a low cost and high reliability approach for magnetic integration application

6. Acknowledgment

The authors wish to thank the Fundamental Research Funds for the Central Universities (Grant No. ZYGX2009J091), Sichuan Provincial Fundamental Research of China (Grant No. 2008JY0057) for financial support.

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