Packaging Compatible Micromagnetic Devices Using Screen Printed Polymer/Ferrite Composites

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Abstract

In this paper, an approach to realize fully integrated microinductors and microtransformers is investigated. These integrated inductors and transformers are composed of electroplated fine copper coils and polymer filled magnetically soft ferrites (NiZn and MnZn), in which fine ferrite particles are added to a polyimide matrix to form a composite. The electrical resistivity of the fabricated NiZn and MnZn ferrite composites are approximately 1 Mohm-cm and 0.01 Mohm-cm, respectively. The MnZn ferrite composite has higher saturation flux density ($B_s = 0.43$ T) and relative permeability than the NiZn ferrite composite ($B_s = 0.28$ T). Using these magnetic composite materials and screen-printing techniques, four different integrated inductor and transformer geometries are designed, fabricated, tested, and compared. A two layer vertically stacked spiral microinductor with 50 µm height has a specific inductance of 15 µH/cm², and a quality factor of 15 at 10 MHz, and a dc resistance of 2.1 ohms. Sandwich type spiral microinductors have specific inductance of 6.5 µH/cm², quality factor of 17 at 10 MHz, and dc resistance of 1.3 ohms. Sandwich type spiral microtransformers have the best gain characteristics of the four geometries investigated (1.5dB loss for a nominal 1:1 turns ratio device at 25 MHz). The magnetic shielding performance of the ferrite composite material is also investigated. Spiral coils shielded by screen printed ferrite composite had stray magnetic field emissions reduced by up to 75% when compared to their unshielded counterparts of identical geometry.

Key words:

Integrated Microinductors and Microtransformers, Screen Printing, Electroplating, Magnetic Composite, Soft Ferrites (NiZn and MnZn), Shielding, and Electronic Packaging.

1. Introduction

There are a large number of passive components used in consumer electronic products such as VCRs, camcorders, television tuners, and other communication devices. Therefore, much research has been performed to realize miniaturized electronic products that have low profile, high efficiency, high packaging density, and low cost (reducing assembly cost and mass production through batch fabrication). For realizing these new electronic products, a large number of passive components currently used in electronic products should be scaled down and integrated.

Advances in microelectronics fabrication and packaging fabrication technology have enabled a variety of approaches to integrate passive components such as capacitors and resistors. Although there has been some research into integrated inductors and transformers based on sputtered and electroplated magnetic alloy films, integrated magnetic components are not as well developed as resistors and capacitors. Integrated magnetic components should also have compatible fabrication sequences with other passives in order to be co-integrated and form highly integrated systems. For realizing these integrated inductors and transformers operating at high frequencies, lithographically patterned and electroplated fine copper coils and
screen printed NiZn and MnZn ferrite composites are investigated.

The NiZn and MnZn ferrites are widely used as core materials for high frequency inductors and transformers. Since they have higher resistivity than alloy-based magnetic materials, eddy current losses which can be large at high frequency in metal-core inductors are reduced. In order to create integrated magnetic devices (that is, no hybrid device-to-package assembly) based on this material, it is usually necessary to undergo a high temperature process. Screen printable ferrite magnetic pastes are commercially available and used for microwave devices and low power applications. However, the temperature of firing these pastes, 750-950 °C, is incompatible with other processing steps to fabricate integrated inductors and transformers using polymeric materials. In some applications, reduction of the ferrite deposition temperature to maintain co-integration with other devices is of interest.

Much research has been performed regarding the deposition of ferrite films at low temperatures, such as using spin spray coating, electroplating, RF sputtering, and magnetron sputtering. However, these methods have relatively low deposition rates and usually produce thinner films than required. Thicker films are often necessary to achieve high inductance, quality factor, saturation current, and other good performance characteristics in integrated inductors and transformers. The purpose of this study is to investigate fabrication techniques to create packaging compatible integrated magnetic components based on thicker ferrite film materials deposited at temperatures lower than the firing temperature of ferrite pastes.

2. Geometrical Design Issues for Micromagnetic Devices

Integrated inductors and transformers operating in the MHz frequency range should have desirable characteristics such as high inductance, quality factor, saturation current, and low resistance. Integrated inductors can be designed with differing geometries such as spiral, meander, and bar type. A bar type geometry in which the magnetic core is wrapped by conductor lines has short conductor lines resulting in low resistance, but has complex fabrication sequences. Spiral type inductors are commonly used due to their simple geometries and simple fabrication sequences. However, these devices usually require large areas in order to achieve high inductance and a high quality factor due to the area required for multiple conductor turns. To avoid this problem, conductor lines can be stacked vertically, and each layer of conductor line can be connected using a via. In addition, magnetic cores are necessary to achieve a high inductance value and a high quality factor.

NiZn and MnZn ferrites are appropriate core materials at higher frequencies due to their high resistivity and low dielectric constant. Polymer filled NiZn and MnZn ferrites are also used as shielding materials at high frequency, which is desirable since integrated inductors and transformers, which may be in closer proximity to other components than hybrid assembled devices, need to be shielded to reduce electromagnetic interference (EMI) during high frequency operation. Finally, integrated inductors should have compatible fabrication sequences with integrated capacitors and resistors to be used as integrated passives for multichip modules.

In order to achieve the above mentioned conditions, four different inductor and transformer designs are fabricated, tested, and compared. Figure 1 shows the cross sectional view of the proposed spiral type integrated magnetic devices. The first inductors and transformers are sandwiched spiral type inductors and transformers with ferrite composite cores, in which polymer filled ferrites are applied at the bottom, top, and (to allow ease of fabrication) between conductor lines using screen printing as shown in Figure 1-(b). The second inductor and transformer geometries are two layer vertically stacked spiral type devices, in which a spiral type layer with multiple conductor turns is vertically stacked and connected through a central via as shown in Figures 1-(c), (d). Inductors of both types with and without polymer filled ferrite cores were fabricated to assess the effect of the ferrite on inductor and transformer performance. The third and fourth types of inductors and transformers are bar type devices, in which electroplated copper conductor lines wrap the screen printed ferrite composite core; both open core and closed core devices of this type have been fabricated.

Figure 1. Comparison of cross-sectional views of integrated magnetic devices: (a) single layer spiral type inductor; (b) sandwiched spiral type inductor with ferrite composite core; (c) two layer vertically stacked spiral type inductor with air core; (d) two layer vertically stacked spiral type inductor with ferrite composite core.
3. Fabrication Process

3.1. Fabrication of Sandwiched Spiral Type and Meander Type Inductors and Transformers with Ferrite Composite Cores

Figure 2 shows a brief fabrication sequence for sandwich type spiral inductors and transformers. The design and fabrication sequence for the transformer is identical to the inductor except for the different design of the conductor lines. The process started with a glass substrate. Fabricated ferrite composite materials (polymer filled ferrite) are composed of ferrite powder (both NiZn and MnZn formulations) and polyimide binder as described in Reference14, and were deposited on the substrate by screen printing. The screen printed magnetic material was cured either in a convection oven in air at 200 °C for 10 hours; or in a furnace in nitrogen at 300 °C for 1 hour. Chromium/copper/chromium layers were deposited to form a seed layer for electroplating using electron-beam evaporation. Thick photoresist was coated, and molds were formed. After removing the top chromium layer, copper was electroplated into the photoresist molds to form the spiral conductors, and the molds were removed. The seed layer was wet etched to isolate the conductor lines. Polymer filled ferrite was screen printed on the top of electroplated copper conductor lines and between the conductor lines, and cured to remove the solvents.

Figure 3. Photomicrographs of sandwiched spiral type microinductors and microtransformers with ferrite composite core: (a) microinductor (dimension: 2.6mm x 2.6mm x 70µm); (b) microtransformer (dimension: 2.6mm x 2.6mm x 70µm).

3.2. Fabrication of Two Layer Vertically Stacked Spiral Type Inductors and Transformers with and without Ferrite Composite

As shown in Figure 4, the fabrication of these devices also began with a glass substrate. Chromium/copper/chromium layers were deposited to form a seed layer for electroplating using electron-beam evaporation. The mesh-type seed layer was patterned to form a conductor network to be removed after serving as the seed layer for plating of the conductor and via. Polyimide (Dupont PI2611) was spun on the top of the mesh type seed layer to construct electroplating molds for the lower spiral conductor lines. Two coats were made to obtain 20 µm thick polyimide molds. After coating, the polyimide was cured as described above. An aluminum layer (0.2 µm thick) was deposited on top of the cured polyimide as a hard mask for dry etching. Molds for lower conductor lines were patterned and etched using a plasma etcher until the seed layer was exposed. After etching the aluminum hard mask and the top chromium of the seed layer, the molds were filled with electroplated copper using standard electroplating techniques.

One coat of polyimide was spin-cast and cured to isolate the lower conductor lines and the upper conductor lines. A via hole was patterned on a sputtered aluminum hard mask and etched through the polyimide layer using plasma etcher. The via hole was filled with plated copper. A copper/chromium seed layer was deposited, and molds for the upper conductor lines were formed using thick photoresist. The molds were filled with electroplated copper and removed. After removing the seed layer, a polyimide passivation layer was coated and cured to protect the top conductor lines from oxidation. The polyimide was optionally masked and etched to the bottom layer. The bottom mesh seed layer was then wet etched. Polymer filled ferrite was screen printed on the dry etched core mold and hardcured. After the completion of fabrication, samples were tested.
Figure 5 shows two layers vertically stacked spiral type microinductor and microtransformer with polymer filled ferrite core, respectively. Figure 6 shows scanning electron micrographs of two layer vertically stacked spiral type microinductor and microtransformer with ferrite composite core, respectively. The top view, screen printed magnetic core, a via interconnection, lower and upper conductor lines, and a bonding pad to test the device are clearly distinguished.

Figure 5. Photomicrographs of two layer vertically stacked spiral type microinductors and microtransformers with ferrite composite core: (a) microinductor (dimension: 2mm x 2mm x 50µm); (b) microtransformer (dimension: 3mm x 3mm x 50µm).

Figure 6. Scanning electron micrographs of upper and lower layer conductor lines, via interconnection, ferrite core, and bonding pad for two layer vertically stacked spiral type microinductors and microtransformers with ferrite core: (a) microinductor; (b) microtransformer.

3.3. Fabrication of Bar Type Inductors and Transformers with Ferrite Composite Cores

Figure 7 shows a brief fabrication sequence. The mesh-type seed layer was formed on the substrate. PI2611 was spun on the top of the patterned seed layer and cured. An aluminum hard mask was used to etch out the polyimide in order to form electroplating molds for solenoid-type lower conductor lines (20 µm thick). The molds were filled with electroplated copper and a ferrite composite was screen printed through the patterned (open and closed bar shape) mask and cured. Polyimide was applied to isolate the lower conductor lines and the upper conductor lines. Via holes were formed by plasma etching and filled with electroplated copper.
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Figure 7. Fabrication sequences for bar-type microinductors and microtransformers with a screen printed ferrite core: (a) patterning of mesh-type seed layer and forming of electroplating molds of lower conductor lines; (b) electroplating of lower conductors and removal of photoresist molds; (c) screen printing of polymer filled ferrites; (d) curing of ferrite composite and coating of insulator; (e) via conductor plating; (f) upper conductor plating; (g) removal of polyimide and mesh-type seed layer.

After depositing the seed layer, molds for the upper conductor lines were formed using thick photoresist and filled with electroplated copper. After removing the photoresist molds and the seed layer, a polyimide passivation layer was coated and cured to passivate the top conductor lines. The polyimide was optionally masked and etched to the bottom. The bottom mesh-type seed layer was wet etched. Figure 8 shows the photomicrographs of integrated bar type microinductors and microtransformers with polymer filled ferrite core. As shown in the Figures, the screen printed polymer filled ferrite core is wrapped by plated copper coils.

Figure 8. Photomicrographs of bar type microinductors and microtransformers with polymer filled ferrite cores (dimension: 1mm x 4mm x 0.13mm): (a) integrated microinductor (closed magnetic circuit); (b) integrated microtransformer (closed magnetic circuit).

4. Experimental Results and Discussion

Electrical properties of the fabricated samples were measured using a Philips PM 2525 multimeter and a Keithley 3322 LCZ meter. The electrical resistivity of the polymer-filled NiZn ferrite composite was approximately 1 Mohm-cm and that of polymer-filled MnZn ferrite was approximately 0.01 Mohm-cm. The composite materials show negligible electrical conductivity, which is desirable for high frequency magnetic devices; thus, eddy current losses can be neglected. Magnetic properties of screen printed composite materials were characterized using a Lake Shore vibrating sample magnetometer. The measured sample shows that the MnZn ferrite composite material has higher saturation flux density ($B_s = 0.43 \, \text{T}$) and relative permeability than NiZn ferrite composite material ($B_s = 0.28 \, \text{T}$) as shown in Figure 9.

The bar type ferrite inductors fabricated in this case had relatively poor electrical characteristics compared with their spiral counterparts; thus, electrical characterization focused on the spiral inductors. The spiral type inductors are distinguished as shown in Table 1. The inductance, Q-factor, and gain-phase characteristics of the fabricated inductors and transformers were measured by a Hewlett-Packard impedance/gain-phase analyzer 4194A. The measured dc resistance of the type B sandwich spiral inductor was approximately 2.41 ohms, while its dc resistance as estimated from geometry and bulk copper resistivity was approximately 2.38 ohms. The evaluated value and the measured value were well matched. However, there is some discrepancy in the measured and evaluated dc resistance of the vertically stacked two layer spiral inductors, types C
and D. As an example, the measured dc resistance of the type C inductor was 2.85 ohms, while its evaluated value was approximately 2.56 ohms. This discrepancy could be due to the metal via contact used to connect the upper and lower spiral conductor lines.

Table 1. Designed parameters of screen printed spiral-type inductors.

<table>
<thead>
<tr>
<th>Type</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>sandwich and spiral type</td>
<td>sandwich and spiral type</td>
<td>Vertically stacked two layer spiral type</td>
<td>Vertically stacked two layer spiral type</td>
</tr>
<tr>
<td>Conductor (µm) (width, thickness, and spacing)</td>
<td>30, 20, 50</td>
<td>40, 20, 40</td>
<td>30, 20, 30</td>
<td>20, 20, 20</td>
</tr>
<tr>
<td>Magnetic core</td>
<td>NiZn ferrite</td>
<td>NiZn ferrite</td>
<td>NiZn ferrite</td>
<td>NiZn ferrite</td>
</tr>
<tr>
<td>Number of windings</td>
<td>13</td>
<td>13</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>Dimension (mm)</td>
<td>2.6 x 2.6 x 0.07 (h)</td>
<td>2.6 x 2.6 x 0.07 (h)</td>
<td>2 x 2 x 0.05 (h)</td>
<td>2 x 2 x 0.05 (h)</td>
</tr>
</tbody>
</table>

Figures 10 and 11 show the inductance and Q-factor characteristics of single layer planar spiral inductors with air cores and sandwich type spiral inductors with polymer filled ferrite cores as a function of frequency. As shown in Figures 10 and 11, the inductors incorporating polymer filled ferrite have a higher inductance and quality factor than the corresponding air core inductors. The increase of the width of the conductor and the decrease of the spacing between the conductor lines produces higher inductance and quality factor. Figures 12 and 13 show the inductance and Q-factor characteristics of the vertically stacked two layer spiral coil inductors with and without polymer filled ferrite core as a function of frequency and also verifies the good performance of integrated inductors with polymer filled ferrite core. As shown in Figures 12 and 13, the lower resistance of the coil produced a higher quality factor. The measured Q-factor is high (15-17 at 15 MHz), and due to the material properties, higher Q-factors at higher frequencies are expected. Ferrite powders with better magnetic properties than those used are expected to yield even more favorable results.

As shown in Figure 14, the integrated inductors and transformers incorporating MnZn ferrite composite have higher inductance than the corresponding NiZn ferrite composite devices, corresponding to the B-H characteristics of the tested core materials. Figure 15 shows gain-phase characteristics of integrated sandwich-type spiral coil micromachined transformers with and without composite magnetic materials. The composite-based microtransformers have higher gain characteristics than micromachined transformers without composite. The reduced leakage flux due to the applied ferrite composite on the top and bottom of conductor lines may increase coupling factor between the primary and the secondary coils, even though composite material between the conductor lines is non-optimal from
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Figure 12. Comparison of inductance and Q-factor as a function of frequency for type C inductors.

a leakage flux point of view. Vertically stacked two layer spiral coil microtransformers which have the same geometry and different magnetic cores, (polymer filled ferrite core and air core) have similar characteristics of gain and phase. The inductances of the primary and the secondary coils in two layer spiral transformers ranged from 350 to 550 nH. The primary inductance is slightly higher than the secondary inductance corresponding to the ratio, 1.17 : 1, of the primary winding to the secondary winding.

Figure 13. Comparison of inductance and Q-factor as a function of frequency for type D inductors.

If the fabricated transformer is symmetrically wound, the coupling coefficient K is defined as:

\[ K = \frac{M}{\sqrt{L_1 L_2}} = \frac{1}{1 + \frac{l_P}{P_m}} \]  

(1)

where M is the mutual inductance, \( L_1 \) is the primary inductance, \( L_2 \) is the secondary inductance, \( P_l \) is the permeance of the leakage flux path, and \( P_m \) is the permeance of the mutual flux path. Lower leakage flux produces higher coupling in the fabricated transformer.

Figure 14. Comparison of inductance of sandwiched spiral type microtransformers with dimension 2.6mm x 2.6mm x 70µm and 12 turns.

Figure 15. Comparison of gain of sandwiched spiral type microtransformers (dimension 2.6mm x 2.6mm x 70µm; primary coil turns are 7 turns, and secondary coil turns are 6 turns).
In the fabricated sandwiched spiral-type transformer, simulation was performed to obtain the coupling factor based on the measured gain characteristics and the measured parameters. The values of $L_i$ and $L_o$ in Figure 16 were experimentally measured to be 0.23 µH and 0.21 µH, respectively; the values of $R_i$ and $R_o$ were also experimentally measured to be 1.2 ohms and 1.04 ohms, respectively. $C_{1}$, $C_{2}$, and $C_{12}$ were estimated as 10, 10, and 12 pF, respectively. Based on these values of the circuit of Figure 16, a series of PSPICE simulations were performed as a function of frequency in which the coupling factor was parametrically varied. The simulation with the coupling factor, 0.85, was found to be the closest match to the data based on initial gain values and low-frequency slope; thus, this value was chosen as an estimate of the coupling factor. In the fabricated two layer spiral-type transformer, the simulation was also performed in the same fashion to obtain the coupling factor based on the measured gain characteristics and the measured parameters. In this case, the measured values are: $L_1$ is 0.38 µH, $R_1$ is 1.31 ohms, $L_2$ is 0.34 µH, $R_2$ is 1.18 ohms; the estimated values are: $C_1$ is 13 pF, $C_2$ is 13 pF, and $C_{12}$ is 15 pF, respectively. The simulated coupling factor was approximately 0.78.

Figure 16. Equivalent circuit of planar integrated transformer: $L_1$ and $R_1$ are the self-inductance; $M$ is the mutual inductance; $L_2$ and $R_2$ are coil resistance; $C_1$, $C_2$ and $C_{12}$ are the stray capacitance, respectively.

Integrated inductors need to have high DC saturation current, especially for power converter applications, since the inductors should maintain a constant inductance even when high currents flow through the inductor. As an example, the DC current is proportional to the load current when the integrated inductors are applied to switched DC/DC boost converters. Figure 17 shows that the integrated polymer filled ferrite inductor has saturation current, $I_{80} = 280$ mA comparable to that of an electroplated iron-core integrated inductor$^{11}$. As shown in Table 2, the two layer vertically stacked spiral inductor with 50 µm height has the largest inductance (15 µH/cm² at 10 MHz) and dc resistance (2.1 ohms). The smallest inductance (1.2 µH/cm² at 10 MHz) and dc resistance (0.35 ohms) are achieved in the fabricated bar type microinductor with a closed magnetic core, Table 2. Meander-type devices have a negative mutual inductance which contribute to low total inductance due to the opposite current directions of two adjacent conductor lines, while spiral-type devices have a positive mutual inductance which contribute to high total inductance due to the same current directions of two adjacent conductor lines. Some theoretical analyses have been performed on planar spiral inductors without magnetic materials$^{15}$, on magnetic substrates$^{16}$, and between magnetic sheets$^{17}$. However, the analysis of planar spiral inductors with magnetic materials has been done with the assumptions of linear magnetic characteristics of the magnetic materials. These equations also do not directly apply to the structures fabricated in this work due to additional leakage paths in these structures that are a result of an attempt to ease fabrication complexity. To predict the exact behavior of the planar inductors, some modeling tools incorporating nonlinear magnetic characteristics should be developed. As shown in Table 3, a sandwich type spiral transformer has the best gain characteristics and the lowest resonant frequency (27 MHz), a sandwich type meander transformer has the worst gain characteristics, and a closed bar type transformer has the highest resonant frequency (38 MHz). The turn ratio of the primary winding to the secondary winding of fabricated transformers is approximately 1. These integrated magnetic devices have a high current capability (up to 2 A steady DC current) and are suitable for power applications.

Figure 17. Comparison of saturation current of two layer vertically stacked spiral type microinductors with and without ferrite composite material measured at 10kHz frequency.

<table>
<thead>
<tr>
<th>Geometries of fabricated microinductors</th>
<th>Inductance (µH/cm² at 10MHz)</th>
<th>Q-factor at 10 MHz</th>
<th>dc resistance (ohms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>bar type with open magnetic core</td>
<td>2.1</td>
<td>5</td>
<td>0.65</td>
</tr>
<tr>
<td>bar type with closed magnetic core</td>
<td>1.25</td>
<td>7</td>
<td>0.31</td>
</tr>
<tr>
<td>meander type with sandwich type magnetic core</td>
<td>5</td>
<td>8</td>
<td>1.15</td>
</tr>
<tr>
<td>spiral type with sandwich type magnetic core</td>
<td>6.5</td>
<td>17</td>
<td>1.3</td>
</tr>
<tr>
<td>two layer vertically stacked spiral type and open magnetic core</td>
<td>15</td>
<td>15</td>
<td>2.1</td>
</tr>
</tbody>
</table>
Table 3. Comparison of gain and resonant frequency of integrated transformers with differing geometries.

<table>
<thead>
<tr>
<th>Geometries of fabricated microtransformers (the ratio of turns 1:1)</th>
<th>Gain characteristics (dB at 25 MHz)</th>
<th>Resonant frequency (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>bar type with open magnetic core</td>
<td>-11.5</td>
<td>33</td>
</tr>
<tr>
<td>bar type with closed magnetic core</td>
<td>-10</td>
<td>38</td>
</tr>
<tr>
<td>meander type with sandwich type magnetic core</td>
<td>-13</td>
<td>31</td>
</tr>
<tr>
<td>spiral type with sandwich type magnetic core</td>
<td>-1.25</td>
<td>27</td>
</tr>
<tr>
<td>two layer vertically stacked spiral type and open magnetic core</td>
<td>-3.5</td>
<td>29</td>
</tr>
</tbody>
</table>

The fabricated sandwich type spiral inductor with polymer filled ferrite was tested to determine whether the fabricated ferrite composite materials have the EMI shielding effect using an HP RFL 912 Gauss Meter. After applying dc current into the fabricated inductors using an HP E3614A power supply, the Hall probe tip connected to the Gauss meter was placed in contact with the fabricated planar inductors to measure the induced flux. Due to the centrally-located bonding pad, it was necessary in both the shielded and unshielded cases to displace the probe tip to cover only half of the inductor to have access to the central pad; however, since the appropriate comparison between shielded and unshielded inductors was relative, this displacement should have no effect on estimated shielding performance. Figure 18 shows the difference of the induced flux between the shielded and the unshielded planar coils. The shielded planar coils have about 75% of the shielding effect compared to the unshielded devices. However, the shielding effect of the ferrite composite material may be higher than the measured value, since the fabricated planar coils was not shielded well because of the difficulty of alignment of the screen-printer and one of the testing pads of the planar spiral coil was placed in the center of the device without shielding.

5. Conclusions

Several integrated inductors and transformers have been presented using electroplated copper coils and screen printed soft NiZn and MnZn ferrite magnetic composites. These screen printed inductors and transformers have the strong advantages of ease of fabrication, a variety of promising geometries, batch fabrication, low eddy current loss, and compatible fabrication sequences with other integrated passive components such as resistors and capacitors. The presented screen printed ferrite magnetic composite did not require high temperature processing such as sintering and firing. In addition, sandwich type spiral inductors and transformers are automatically EMI shielded by encapsulating the plated copper coils with polymer-filled magnetic ferrites. Among the presented integrated inductors and transformers, the screen printed sandwich type inductors and transformers have highest quality factor and coupling factor, while the two layer vertically stacked spiral microinductors have the highest inductance. The magnetic composite materials can also be used as shielding materials at high frequency due to their EMI shielding effect.

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References


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