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Article

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Examination of high Q factor multilayer chip inductor applied magnetic flux path control technology

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Abstract

Inductors used for power supplies can be miniaturized by increasing the frequency. However, as the frequency increases, the loss in the inductor increases, which hinders the improvement of efficiency. This study suggests a flux path control technology as a method for reducing inductor loss. Herein, we investigate high Q value chip inductors with magnetic flux path control technology. By applying magnetic flux path control technology, the Q value was improved by 35% in comparison with conventional multilayer chip inductors.

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Keywords: Multilayer chip inductor; Magnetic flux path control technology; Q factor; Skin effect; Proximity effect

1. Introduction

In small electronic devices such as smartphones, stacked chip inductors are used ubiquitously, and their numbers only continue to increase with the advancement of small electronic devices [1]. This demand is attributed to the circuit configuration accompanying the multiband, multifunctional, and high-functionalization of the radio frequency (RF) circuit in small mobile devices or small electronic devices like notebook computers. The numbers of parts to be mounted has hence increased, and the loss generated in each part greatly affects the efficiency of the entire compact electronic device. Inductors used in RF circuits must have high Q values. There are two main types of chip inductors that use ferrite or ceramic sealing materials. Inductors using ferrite have higher Q values up to around 10 MHz than those using ceramic. However, in the region of 10 MHz or higher, the iron loss in ferrite chip inductors increases, and the Q value becomes smaller than that of ceramic chip inductors [2]. Therefore, in the high frequency band, a laminated ceramic chip inductor is preferred. However, the Q value of laminated ceramic chip inductors is still small (about 10) at 100 MHz [3]. In addition, a flat wire is employed for the chip inductor, which causes the skin effect to appear more prominently than that using a round wire. Furthermore, since the multilayer chip

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Nomenclature

MPC magnetic flux path control technology

inductor is very narrow between the winding layers, the alternating current (AC) resistance caused by the proximity effect is large. Current research focuses on devising the optimal position of the via and thickness of the winding for the high Q value technology of the chip inductor [4,5]. However, these prior works do not consider changing the winding structure itself. Therefore, we propose a magnetic flux path control technology (MPC) that reduces the AC resistance caused by the skin effect and proximity effect by loading magnetic materials and improves the inductance [6,7]. Herein, we analyze the magnetic field of a multilayer chip inductor to which MPC is applied and describe its impedance characteristics. We report a reduction in AC resistance and improvement in the Q value at the frequency of 100 MHz.

The points to be considered herein are as follows:

- (1) Conventional chip inductor structure and
- (2) Characteristic comparison between chip inductors with applied MPC and conventional chip inductors

2. Structure and impedance characteristics of conventional chip inductors

Fig. 1 shows the structure of a conventional chip inductor. The edge width of the exterior long side is 1.07 mm, whereas the exterior short side is 0.55 mm. Meanwhile, the coil long side is 0.62 mm, coil short side is 0.32 mm, conductor width is 0.06 mm, and conductor thickness is 0.012 mm. The number of turns (N) is 3.25, and a rectangular coil is used. The thickness between layers is 0.012 mm, and the layers are connected by a via with a diameter of 0.06 mm. Also, ceramic is used as the sealing material.

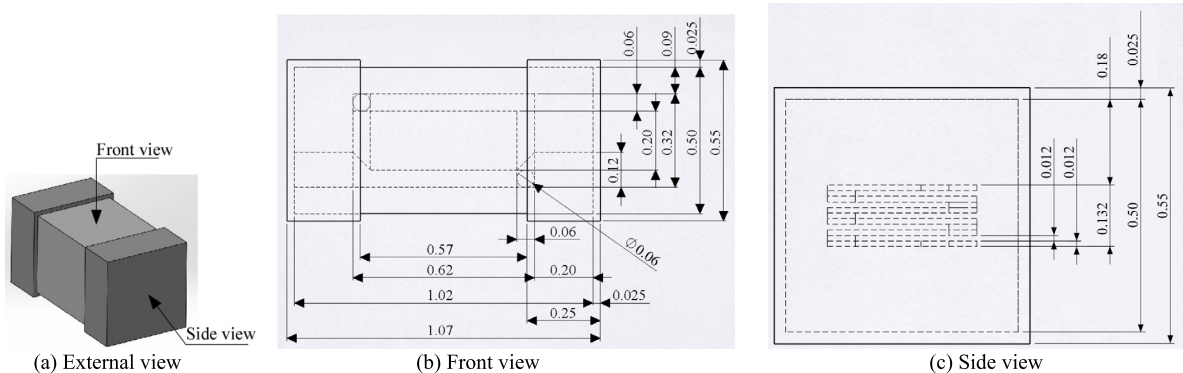


Fig. 1. Structure of chip inductor (unit: mm).

Fig. 2 demonstrates the impedance characteristics of a conventional chip inductor. An impedance analyzer (KEY SHIGHT E4990A) was used to measure the impedance characteristics when the measurement frequency was changed from 1 to 100 MHz.

Fig. 2(a) exhibits the resistance, which is 251.7 m Ω at frequency (f) = 100 MHz, while Fig. 2(b) represents inductance and measures 5.4 nH at f = 100 MHz. Fig. 2(c) displays the Q value, which is 13.5 at f = 100 MHz.

Also, in Fig. 2(a)–(c), disturbance occurs in the measured waveform in the frequency range of f = 80 – 100 MHz, which is influenced by the range switching of the impedance analyzer.

3. Analysis model and conditions

Fig. 3 displays a simplified analysis model (hereinafter called “comparative example”) for performing calculations in a two-dimensional cylindrical coordinate system based on the structure of Fig. 2. The model was manufactured so that the winding length equals 1.54 mm, which is the length of the winding in Fig. 2.

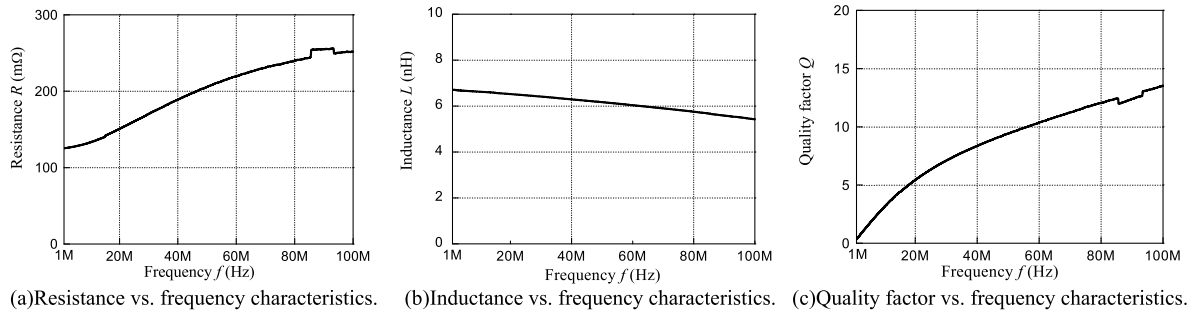


Fig. 2. Impedance characteristics of chip inductor.

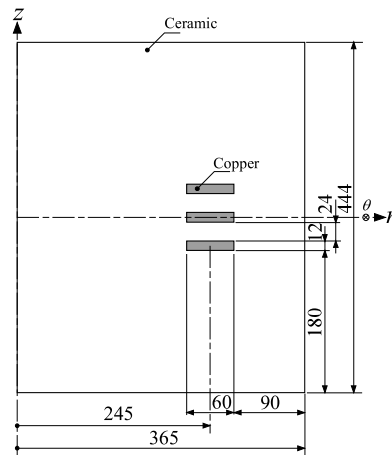


Fig. 3. Analysis model of conventional chip inductor (Comparative example) (unit: mm).

The analysis model with applied MPC to Fig. 4 is shown. In Fig. 4(a), the magnetic material was loaded in a cap shape to the winding. In Fig. 4(b), a magnetic material, in addition to the one in Fig. 4(a), was loaded on the lower portion of the top conductor and the top portion of the bottom conductor to suppress the proximity effect. In Fig. 4(c), in addition to that in Fig. 4(b), a magnetic body is loaded like a top plate on top of top conductor and the bottom of bottom conductor to increase the inductance. Further, the structures t and w of the magnetic substance were used as parameters. The analysis conditions are listed in Table 1. For analysis, Maxwell Ver. 19 of ANSYS, Inc. was used. The analysis method consists of two-dimensional AC magnetic field analysis. The analysis model is an axisymmetric model in which the zr plane is rotated in the θ direction with the z axis of the model,

Table 1. Analysis conditions.

Item	Software	Analysis method	Solution	Mesh size	Frequency	Current	Dimension	Material
Contents	ANSYS Maxwell Ver.19	Two-dimensional AC magnetic field analysis	FEM	Copper: 1.5 μm Magnetic material: 1.5 μm ceramic: Automatic Air: Automatic	$f = 100 \text{ MHz}$	$I = 0.5 \text{ A}$	$t = 5, 7, 10 \mu\text{m}$ $w = 5, 10, 15 \mu\text{m}$	Copper: ($\rho = 1.72 \times 10^{-8} \Omega\text{m}$, $\mu_r' = 1, \mu_r'' = 0$) Magnetic material: ($\mu_r' = 6, \mu_r'' = 0.1$) ceramic: ($\rho = \infty \Omega\text{m}$, $\mu_r' = 1, \mu_r'' = 0$) Air: ($\rho = \infty \Omega\text{m}$, $\mu_r' = 1, \mu_r'' = 0$)

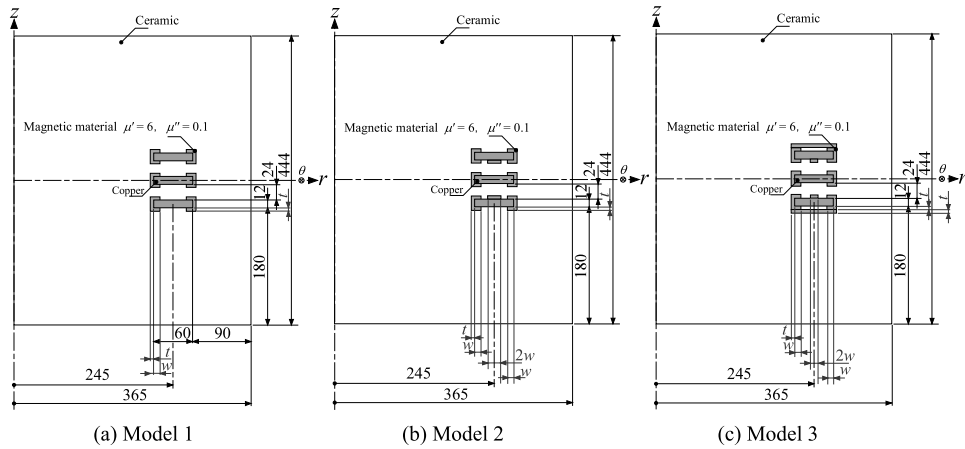


Fig. 4. Analysis model of chip inductor with MPC (unit: mm).

as shown in Figs 3, 4. The winding is an edgewise coil with $N = 3$ and has an outer diameter of $275 \mu\text{m}$, copper foil pattern width of $60 \mu\text{m}$, copper foil pattern thickness of $12 \mu\text{m}$, and copper foil pattern width of $24 \mu\text{m}$. The characteristics of the magnetic material were measured at a frequency of 100 MHz of the oxidized carbonyl-iron and epoxy composite core [8]. Resistance (R) and inductance (L) were analyzed assuming that the current (I) was 0.5 A and $f = 100 \text{ MHz}$. Also, Q was calculated using the following equation:

$$Q = \frac{\omega L}{R} \quad (1)$$

4. Analysis result

4.1. Impedance characteristics depending on the size of magnetic material

Fig. 5 illustrates the impedance characteristics when the dimensions t and w of the magnetic substance are changed for the Model 3 in which the Q value is the highest. From the analytical results of the resistance value shown in Fig. 5(a), when $t = 7 \mu\text{m}$ or less, the resistance is lower for all values of w compared to those of the chip inductor without MPC. In particular, the resistance reduction effect is remarkable when w was 0.1 to 0.2 times the width of the conductor, i.e., when w was between 5 and $10 \mu\text{m}$. Also, at $t = 10 \mu\text{m}$ and $w = 15 \mu\text{m}$, the resistance increases compared to the resistance of the chip inductor without MPC. This effect may be attributed to the fact that an increase in the iron loss of the loaded magnetic body was larger than that of the copper loss reduced by

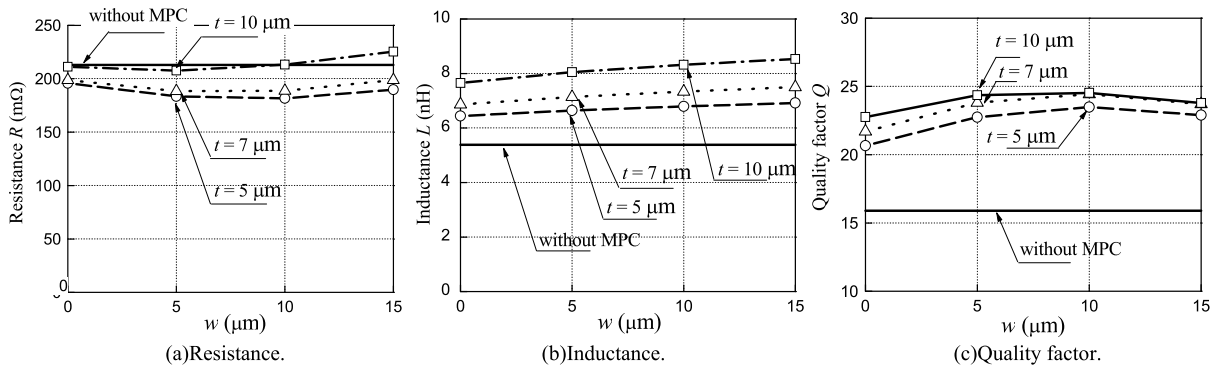


Fig. 5. Impedance characteristics depending on the dimensions of the magnetic body with parameters t and w ($I = 0.5 \text{ A}$, $f = 100 \text{ MHz}$) (Model 3).

loading the magnetic body. The results regarding inductance are given in Fig. 5(b). With an increase in w and t , the inductance increases compared to that of the chip inductor without MPC. This result is likely caused by an increase in the loading amount of the magnetic material with the increase of w and t . The results concerning the Q value are presented in Fig. 5(c), where the Q value is maximum for each value of t when w is $10\ \mu\text{m}$ and when t and w are both $10\ \mu\text{m}$. Also, the Q value was improved compared to that of the inductor without MPC in any of the w and t values.

4.2. Impedance characteristics depending on loading position of magnetic material

Fig. 6 displays various characteristics in a comparative example where MPC is not applied and each model where MPC is applied. Furthermore, Fig. 6 exhibits the values when the Q value is the highest when t and w are changed.

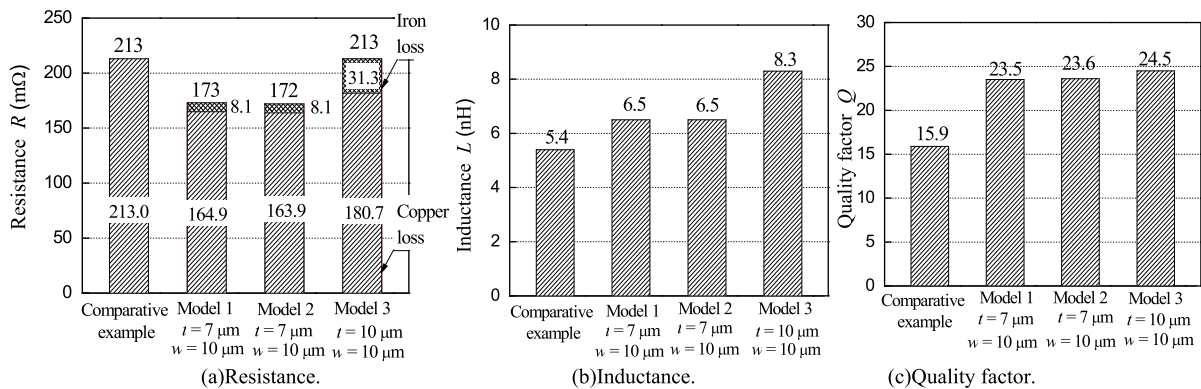


Fig. 6. Impedance characteristics of chip inductor ($I = 0.5\ \text{A}$, $f = 100\ \text{MHz}$).

Fig. 6(a) illustrates resistance, R . In this case, Model 2 exhibits the most R -value reduction of 19.2 %, i.e., $213 - 172\ \text{m}\Omega$ compared with the comparative example without MPC. Concurrently, Fig. 6(b) depicts the inductance, L . The largest increase in L of 53.7 % occurs in Model 3, i.e., $5.4 - 8.3\ \text{nH}$, compared to the comparative example without MPC. Fig. 6(c) gives the Q value. In this case, Model 3 offers the most improved Q value, with a 35 % increase, i.e., from 15.9 to 24.5, compared with the comparative example without MPC. The analysis was performed with w set to 5, 10, and $15\ \mu\text{m}$, and t set to 5, 7, and $10\ \mu\text{m}$. Models 1 and 2 have the highest Q value when w and t are 10 and $7\ \mu\text{m}$, respectively. Yet, Model 3 has the highest Q value when both t and w are $10\ \mu\text{m}$.

Based on these results, loading the magnetic material as in Model 3 produces the most significantly increased inductance and improved Q value.

5. Conclusion

The contents described herein are as follows:

(1) Impedance characteristics depending on the size of the magnetic material.

In Model 3, analyses were performed to confirm the influence of the magnetic substance's dimension parameters, t and w , on the impedance characteristics of the chip inductor. When $t = 7\ \mu\text{m}$ or less, the resistance was reduced compared to that of a chip inductor without MPC for all values of w . The Q value is maximum for each value of t when w is $10\ \mu\text{m}$ and when t and w are both $10\ \mu\text{m}$. Also, for all values of w and t , the Q value was improved compared to that of the inductor without MPC.

(2) Impedance characteristics depending on the loading position of the magnetic material.

To confirm the impedance characteristics depending on the magnetic material loading position of the chip inductor to which MPC is applied, analyses of three comparative examples where MPC is not applied were conducted. The resistance reduced most in Model 2 (19.2 %), i.e., from 213 to $172\ \text{m}\Omega$, compared to the comparative example. The inductance increased most in Model 3 (53.7 %), i.e., from 5.4 to $8.3\ \text{nH}$, compared with the comparative example. The Q value improved the most in Model 3 (35 %), i.e., from 15.9 to 24.5, compared with the comparative example.

Based on the above results, resistance can be reduced, inductance can be increased, and Q value can be improved by loading the magnetic body at the appropriate position, demonstrated in Model 3, and applying the flux path control technology.

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