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Letter

Splitting Conductors of Coils on PCB for AC-resistance Reduction

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This letter proposes a method to suppress copper loss due to the skin and proximity effect (AC-resistance) by splitting the conductors of a coil on a printed circuit board (PCB) into some traces and swapping them at the corner of the coil. The proposed structure for the coil is characterized as having no via, which results in an increase in cost and copper loss. The simulation results demonstrate that in the proposed coil comprising 12 corners (12c coil), splitting a conductor into three traces, the resistance is suppressed by 16.7% compared with a spiral coil, and the quality factor is improved by 11.0%. Practical experiments on the prototype of the 12c coil further revealed improvements in the resistance and quality factor by 19.7% and 18.8%, respectively.

Keywords : Skin effect, Proximity effect, Spiral coil, Printed circuit board (PCB)

1. Introduction

Coils built on printed circuit boards (PCBs) have been used for transformers and inductors because they have the advantages of downsizing and consistency for mounting components on the PCBs [1–2]. However, copper loss caused by the skin and proximity effect (AC-resistance) is increased at high-frequency regions. In order to suppress AC-resistance, some configurations of the PCB trace like a litz wire have been proposed [3–4]. However, the realization of such a structure requires a lot of vias, which may lead to increased length of the winding, DC-resistance, and complexity in implementation.

This letter proposes a new structure of coils that suppress AC-resistance compared to a conventional spiral coil without vias and the increase in length of the winding.

2. Proposed structure of coils without vias

Figure 1 shows the proposed coil structure. Fig. 1 (a) is the top view of the proposed coil. The shape of the coil is the polygon. In Fig. 1, the coil has 12 corners (12c). Fig. 1 (b) provides an enlarged view of the coil. A winding of the coil is divided into some traces and interchanged at the corner of the coil. Each divided trace is arranged on separate layers, so this structure does not need vias.

In order to verify the effectiveness of the proposed coil, it is compared with a conventional spiral coil. Figure 2 is the cross-sectional area of a winding of the coils. The cross-sectional area of each winding of coils is the same. The parameters of the coils under consideration are listed in Table 1.

3. Evaluation of the proposed coil

3.1 Simulation results Figure 3 shows the frequency characteristics of the spiral and proposed coil by the Finite Element Method (FEM). In this simulation, three types of proposed coils are considered. The proposed coil effectively suppresses the increase of AC-resistance. Furthermore, comparing the resistance values of the

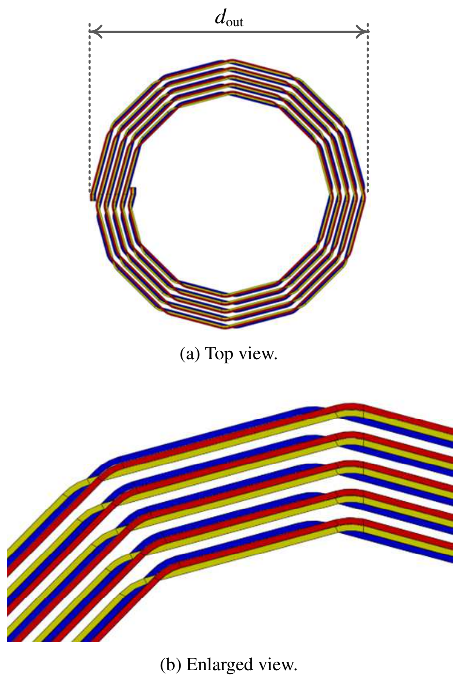

Fig. 1. Proposed coil structure.

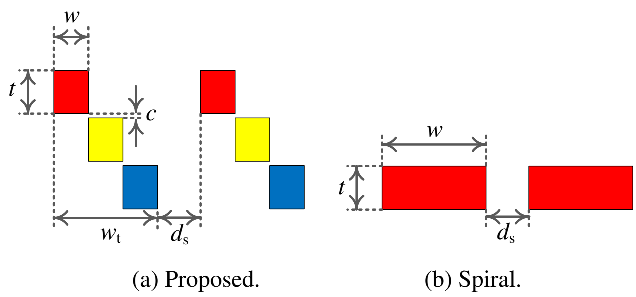

Fig. 2. The cross-sectional area of the spiral and proposed coils.

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Table 1. Parameters of spiral and proposed coils.

	Spiral	Proposed
Number of turn	N: 5	N: 5
Outer diameter [mm]	d_{out}: 60	d_{out}: 60
Trace width [mm]	w: 1.2	w: 0.4
Total trace width [mm]	-	w_t: 1.2
Trace thickness [mm]	t: 0.5	t: 0.5
Clearance [mm]	-	c: 0.01
Space of windings [mm]	d_s: 0.5	d_s: 0.5

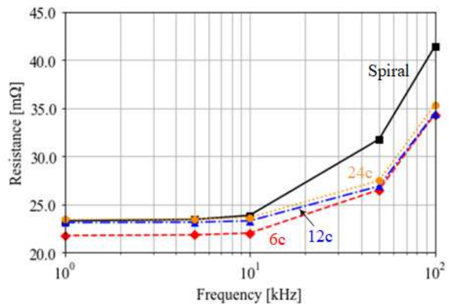

Fig. 3. FEM result of frequency characteristics of resistance.

Table 2. FEM results at 100 kHz.

	Spiral	6c	12c	24c
Equivalent series resistance [mΩ]	R_s: 41.4	R_s: 34.4	R_s: 34.5	R_s: 35.3
Inductance [μH]	L: 2.16	L: 1.76	L: 2.00	L: 2.05
Quality factor	Q: 32.8	Q: 32.2	Q: 36.4	Q: 36.4

proposed coil with 6 corners (6c), 12c, and 24 corners (12c, 24c) shapes, it is evident that the 12c and 24c shapes more effectively suppress AC-resistance.

Table 2 shows the characteristics of the spiral and proposed coil at 100 kHz by FEM. As the outer diameter of the spiral coil is equal to the circumscribed circle of the proposed coils, the length of windings of the spiral one is longer than that of the proposed coils. Consequently, the resistance and inductance of the spiral coil are larger because of the difference in winding length. Moreover, as the number of corners in the polygon increases, approaching a circle, the difference in length decreases. The proposed 12c and 24c coil improves the quality factor by 11.0% compared to the spiral one. However, the optimal splitting numbers depend on the shapes of the PCB coils. So, an optimal design method has not been established.

3.2 Experimental results Figure 4 shows prototypes of the spiral and proposed 12c coil with the common parameters listed in Table 1 for AC-resistance evaluation. The equivalent series

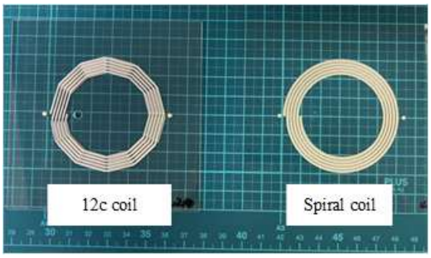

Fig. 4. Prototypes of spiral and 12c coil.

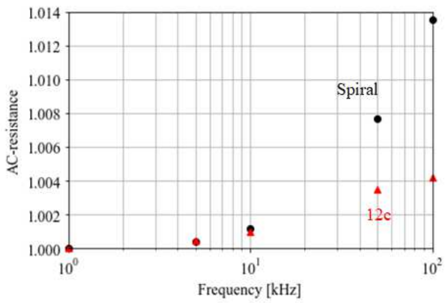

Fig. 5. Experimental result of frequency characteristics of resistance.

Table 3. Experimental results at 100 kHz.

	Spiral	12c
Equivalent series resistance [mΩ]	R_s: 502	R_s: 403
Inductance [μH]	L: 2.34	L: 2.23
Quality factor	Q: 2.93	Q: 3.48

resistance and inductance of these coils are measured by the LCR meter (Hioki, IM3533).

Figure 5 shows the frequency characteristic of the AC-resistance of the coils. Each AC-resistance value is obtained by dividing an equivalent series resistance measured with the LCR meter by the resistance at 1 kHz. From Fig. 5, the proposed 12c coil effectively suppresses the increase of AC-resistance at high frequencies.

Table 3 shows the characteristics of the prototypes of the spiral and proposed coil at 100 kHz. The 12c coil achieves a reduction in equivalent series resistance of 19.7% compared to the spiral one. The inductance of each coil is almost the same. The 12c coil improves the quality factor by 18.8% compared to the spiral one.

4. Conclusion

This letter proposes a new coil structure formed on PCBs to suppress the AC-resistance compared to the spiral one. The proposed structure involves splitting the winding into some traces constituting the coil in the width direction and shaping the coil into a polygon. Simulation results demonstrate that by employing the 12c coil shape and dividing the winding into three traces, the proposed approach achieves a resistance reduction of 16.7% and improves the quality factor by 11.0%, as confirmed by FEM. Practical experiments have revealed that the prototype of the 12c coil improves equivalent series resistance by 19.7% and the quality factor by 18.8%.

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