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Thick Film Ni-Ferrite Inductors

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Abstract. Ni-ferrite inductors were realized in thick film multilayer technology on Al_2O_3 substrate using Pd/Ag conductive paste, Al_2O_3 dielectric paste and Ni-ferrite paste. Three different constructions of square spiral inductors were printed, fired and measured: "simple" spiral, "reverse" spiral and "outer" spiral. While "simple" spiral contains one conductive layer, the other two types have two conductive layers. Additional magnetic thick layers were placed on the bottom and the top of inductor constructions. Inductors were measured on the network analyzer in the HF range (up to $\times 100\text{MHz}$). An original CAD, based on well known method of current images, was developed to predict and explain the experimental results. Obtained results indicate the possibility of using thick film spiral inductors in the HF range for the same application as the chip inductors, but except the fact that this type of inductors could be used as a discrete hybrid component, it could be directly incorporated in the hybrid circuits (such as filters etc.).

1. INTRODUCTION

Miniaturization and integration of magnetic components are an important part in miniaturizing electronic devices in high frequency range. A few papers have been heard on the integration of inductors. Firstly inductors have been realized by thin film technology. For an experimental demonstration of the feasibility of building such a thin film coil using IC techniques, it was constructed a coil on a glass (SiO_2) or Si substrate. Next it has proposed the planar inductors, which are miniature inductors with magnetic layers, planar coils and insulators, and fabricated by thin film and photo etching technique [1]. The lower Mo-permalloy magnetic film is deposited by dc sputtering on a glass substrate. SiO insulation film and copper film on thin chromium film are deposited by vacuum evaporation. Then, coil is formed by photo etching. After forming the coil, SiO insulation film and Mo-permalloy magnetic film is deposited by vacuum evaporation. Similar technique was used for the realization of planar inductors in paper [2]. Recently, the planar microtransformers were fabricated by a dry process technique [3]. The substrate was 2-in Si wafer with a $10\text{-}\mu\text{m}$ -thick SiO_2 layer. CoZrRe amorphous magnetic layer was deposited by ion beam sputtering, and magnetic layers were defined by argon ion beams etching. In reference [4], as a magnetic layer was used amorphous CoZrNb layer. Amorphous magnetic materials have been used to overcome a serious problem that the performance of the device is dominated by the frequency characteristics of the core magnetic materials. Common conclusion from these investigations was: for further improvement, we must devise to make the film thicker. Achieving higher frequency operation and higher inductances with the same surface area would require thicker magnetic films. Because, in our research, a series possible types of thick film planar inductors with Ni-ferrite layer have been evaluated. Using Ni-ferrite has practical significance for two reasons: first, in obtaining a minimum parasitic capacitance and second, this feature is important for stable high-frequency performance.

2. SIMULATION AND EXPERIMENTAL RESULTS

Planar inductors were realized in thick film multilayer technology on Al_2O_3 substrate using Pd/Ag conductive paste, Al_2O_3 dielectric paste and Ni-ferrite paste. Ni-ferrite powder with average grain size less than $0.9\mu\text{m}$ was used for the ferrite paste preparation. Ferrite paste was printed on Al_2O_3 substrate and fired $850^\circ\text{C}/10\text{min}$. Design parameters have been obtained for a few types of square planar conductors geometry: "simple" spiral, "reverse" spiral and "outer" spiral. While "simple" spiral contains one conductive layer, the other two types have two conductive layers. At "reverse" spiral inductor is one square coil under other square coil and between them is insulator layer. "Outer" spiral inductor is same construction as in [4] but here is realized in thick film technology. These inductors are denoted as ind.1, ind.4 and ind.6, respectively. Ind.2 and ind.3 are "simple" spiral with one magnetic layer and in magnetic sandwich. Ind.5 and ind.7 are "reverse" and "outer" square spiral in magnetic sandwich. All designed inductors have same area $0.9\times 0.9\text{ cm}^2$, same number of turns ($z=4$) and same dimensions: l_{line} = width of the conductor = $300\text{ }\mu\text{m}$, length of the smallest segment = 2.4 mm and step of increased length of segment =

600 μm . Model for the computer simulation is based on analytical analysis and presents an original CAD for design of planar inductive components. This paper gives more complex and accurate analysis than our earlier work [5]. In earlier work, the real N-turn square spiral inductor was replaced with a set of concentric squares, each carrying a current I. In this paper, the real N-turn square spiral inductor is replaced with a set of straight conductors which have unequal lengths. Thick film inductors have conductors with rectangular cross-section because in our calculation is used the concept of cross-section geometric and arithmetic mean distances, GMD and AMD, respectively, as in ref. [6,7].

Predicted results were verified by measurements in HF range (up to $\times 100$ MHz), on network analyzer. Experimental results for ind.1, ind.7 and ind.6 are summarized in Table 1, which also shows the predicted values of L. The last row shows percentage difference between the predicted and the observed value of L. The agreement is generally very good. The experimental values of inductance and operating frequencies for all designed inductors are shown in Table 2. The value of inductance of ind.2 shows enhancement inductance of "simple" spiral on account of additional magnetic layer. The values of inductance of ind.3, ind.5 and ind.7 show enhancement inductance of "simple", "reverse" and "outer" spiral in magnetic sandwich. In many applications are required a large value inductance on as possible as smaller area, that is very important relation inductance-area. This relation for three different square spiral is given on Fig.1 and it is best for "outer" spiral.

Table 1. Comparison of measured and calculated values of inductance of inductors without magnetic layers.

	f [MHz]	ind. 1	ind. 4	ind. 6
Measured L [nH]	1	118,9	29,9	418,4
	10	119,9	32,7	415,5
	50	114,1	32,6	567,8
	100	117,4	33,8	< 0
	200	143,6	42,7	< 0
Calculated L [nH]	400	233,2	< 0	< 0
		115,5	30,2	415
Difference (%)		1.7	3	0,5

Table 2. Measured values of inductance of fabricated inductors and range of operating frequencies.

Type of inductor	Inductance L [nH]	freq. range [MHz]
ind. 1	118.4	< 200
ind. 2	127.2	< 100
ind. 3	152.6	< 100
ind. 4	31.9	< 100
ind. 5	64.5	< 50
ind. 6	416.9	< 50
ind. 7	522.2	< 50

Figure 1. Calculated inductance by cm^2 as a function of a width of conductor, $t_{\text{line}} = \text{rez}$, for: a) "simple" spiral, "outer" spiral, c) "reverse" spiral inductor.

3. CONCLUSION

A method of analysis and computer program have been applied to investigation of the characteristics of thick film inductor. The results of the inductor analysis have correlated well with experimental results. The typical specifications of the best inductor are as follows: $9 \times 9 \text{ mm}^2$ in size, inductance of 0.5 μH constant up to 50 MHz, and a quality factor of 10 at 50 MHz. The thick film inductor implemented as an integral part imbedded in the interconnections of a multichip module can play a role as an inductive component in realizing modules such as filters, sensors, dc/dc converters and similar devices.

References

- [1] K. Kawabe, H. Koyama, K. Shirae, "Planar inductor", IEEE Trans. on Mag., vol.20, no.5, 1984, pp. 1804-1806.
- [2] O.Oshiro, H.Tsujimoto, K. Shirae, "A novel miniature planar inductor", IEEE Trans. on Mag., vol. 23, no.5, 1987, 3759-61.
- [3] M. Mino, T. Yachi, A. Tago, K. Yanagisawa, K. Sakakibara, "A new planar microtransformer for use in micro switching converters", IEEE Trans. on Mag., vol. 28, no. 4, 1992, pp. 1969-1972.
- [4] T. Sato, H. Tomita, A. Sawabe, T. Inoue, T. Mizoguchi, M. Sahashi, "Magnetic thin film inductor and its application to a MHz switching dc-dc converter", IEEE Trans. on Mag., vol. 30, no. 2, 1994, pp. 217-233.
- [5] S. M. Jenci, O. S. Aleksić, Lj. D. Živanov, D. I. Raković, "Analysis and optimization of planar thick film Ni-ferrite inductor", Proc. of ISEF '95, Thessaloniki, 1995, pp. 155-158.
- [6] H. W. Grover, "Inductance Calculations", Dover Publication, 1946.
- [7] H.M.Greenhouse, "Design of planar rectangular microelectronic inductors", IEEE Trans. on Parts, Hybrids and Packing, vol. 2, no. 2, 1974, pp. 101-109.