ELECTROMAGNETIC ANALYSIS OF THE THIN FILM TRANSFORMER

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ABSTRACT

In this paper, we propose a thin film transformer for small electronic devices. The primary and secondary coils of the film transformer are arranged coaxially on one layer and multiply laminated. The operation principle of the transformer is based on the skin effect and the mutual effect between the coils at high frequency. We apply the integral equation method to analyze this transformer. Using the model, we evaluate the electromagnetic field and calculate the lumped circuit parameters, i.e. inductance and resistance, which are compared with experimental values. A fairly good agreement is obtained.

1. INTRODUCTION

With the developments of modern electronic devices such as the notebook computer, word processor and cordless telephone, it is essential to reduce the size and weight of their electric power supplies.

In this paper, a thin and light weight high frequency transformer which we call a film transformer is proposed. This new transformer is composed of the lamination of thin film conductors. Each film is constructed by the chemical etching processes. The operating principle is based on the skin effect and mutual effect between coils [1-2]. To design and improve the film transformer characteristics, it is essential to analyze its electromagnetic phenomena and parameters. Both the primary and secondary coils of our film transformer are arranged coaxially on the one layer and multiply laminated. Because of these coaxially arranged coils, the magnetic field of the transformer can be modeled with axisymmetric assumption. Since the operation principle of the transformer is based on the skin effect, the development of a computational model that takes into account the skin effect is extremely important. Applying the numerical methods, e.g. the finite element method (FEM) and boundary element method (BEM) to this problem leads to results with good accuracy. Particularly, some calculation methods for voltage-source problems that consider the current distributions in conductors are very useful tools for the design of magnetic devices [3-8]. These methods have been used to various voltage-source problems but have not always produced acceptably accurate solution. In the present, we applied a method to obtain more exact current distributions in thin film conductors of the transformer. This method uses Fredholm integral equation of the second kind about the electric field intensity. To demonstrate the advantages of the method, using a vector potential expression, we calculate the magnetic field, impedance and ratio of transformation of the thin film transformer for various frequencies under the open and short secondary circuit conditions. The results obtained show good agreement with experimental results.

2. FILM TRANSFORMER

A. *Construction.*

Some constructive shapes of the thin film transformer are shown in Fig. 1. This transformer is composed of two layers primary and secondary coils. Connections between layers of separate coils are serial. Figure 2 shows the sizes of the separate turns and the distances between them. This transformer may be composed of two, four or more layers.

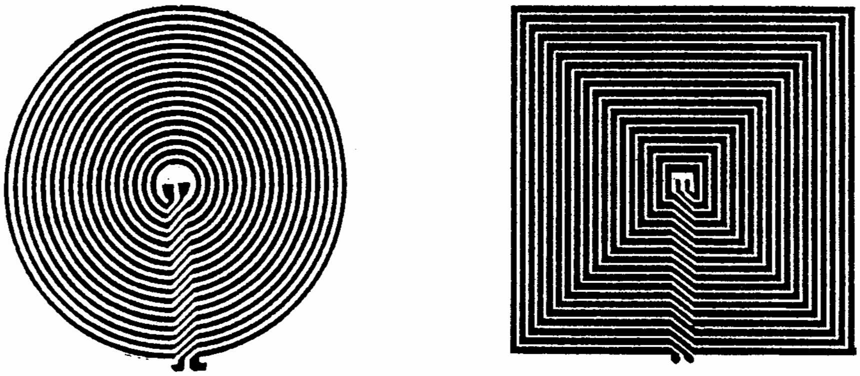
B. *Method of analysis*

When an electromagnetic system is composed of n parallel coaxial conductors and each conductor is fed by a voltage u_i, we constrain a system of integral equations

$$\dot{E}_i(Q) + j\lambda \sum_{l=1}^{n} \int_{S_l} \sigma_l(M)\dot{E}_l(M)\sqrt{\frac{\rho_M}{\rho_Q}} f(k)dS_l = \frac{\dot{u}_i}{2\pi\rho_Q}, \qquad i=1,\dots,n \qquad (1)$$

where $\lambda = \frac{\omega\mu_0}{2\pi}$ is the characteristic parameter of the integral equations.

The function u_i is constant over the conductor cross-section. The conductivity σ is inside the integrals. Obviously, for inhomogeneous conductors, the conductivity may be a function of position. Integrating the system of equations (1) over the conductor section S_i, the system of integral equations for an electromagnetic system consisting of conductors with current excitation is as follows



(a) (b)

Fig. 1 Thin film transformer.

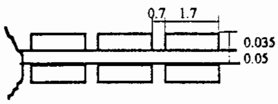


Fig. 2. The sizes of the turns (unit in mm).

$$\dot{E}_i(Q) + j\lambda \sum_{l=1}^{n} \int_{S_l} \sigma_l \dot{E}_l(M) \sqrt{\frac{\rho_M}{\rho_Q}} \left[f(k) - \frac{1}{2\pi a_i \sqrt{\rho_Q}} \int_{S_i} \sigma_i \frac{f(k)}{\sqrt{\rho_Q}} dS_i \right] dS_l = -\frac{\dot{I}_i}{2\pi\rho_Q a_i} \qquad (2)$$

where $a_i = \int_{S_i} \frac{\sigma_i}{2\pi\rho_Q} dS_i$ and i=1,..., n.

Solving Eqs.(1) or (2), it is possible to determine the current distribution in the conductor due to the axisymmetric electromagnetic field. If the current distribution is known, then the different electromagnetic field characteristics are easily evaluated by means of the vector potential expression. Thus, the electromagnetic field calculation of such electromagnetic systems is reduced to a set of Fredholm integral equations of the second kind while the system is excited by the constant voltage or current source.

A computer program has been developed to realize the analysis method and to investigate the characteristics of the thin film transformer.

C. Results and discussion

The method and computer program, presented above, are applied to analyze the thin film transformer, shown in Fig. 1.

For thin fiilm transformer in Fig. 1, the computed results of the inductance and the resistance together with experimental ones for the various frequencies are shown in Fig.3-6. By considering this results, it is obvious that the coil's inductance decreases and the

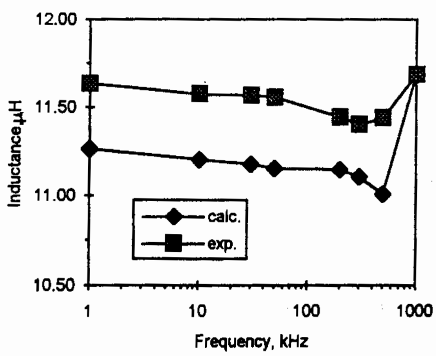


Fig. 3. Coil Inductance vs. Frequency.
(film transformer, shown in Fig. 1a)

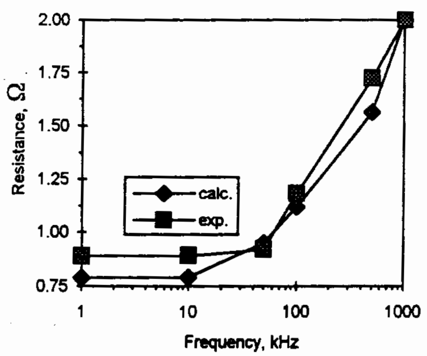


Fig. 4. Coil Resistance vs. Frequency.
(film transformer, shown in Fig. 1a)

resistance increases due to the skin effect when the exciting frequency is raised up. The inductance and resistance increase significantly near the 1MHz. Figure 6 shows the computed results concerning the change of internal inductance as a function of frequency for thin film transformer shown in Fig. 1a. Because of the skin effect, it decreases when the frequency increases and it begins to increase near 1MHz. The

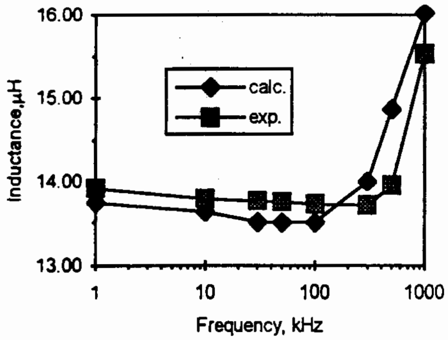


Fig. 5. Coil Inductance vs. Frequency.
(film transformer, shown in Fig. 1b)

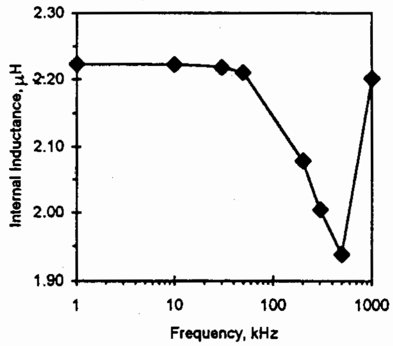


Fig. 6. Internal Inductance vs. Frequency.
(film transformer, shown in Fig. 1a)

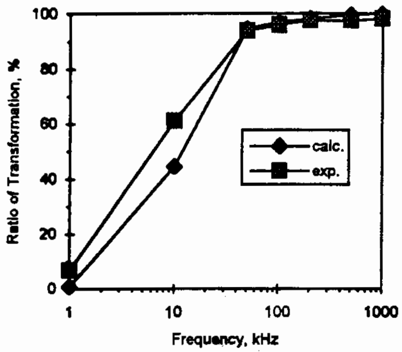


Fig. 7 Ratio of transformation vs. Frequency
(film transformer, shown in Fig. 1a)

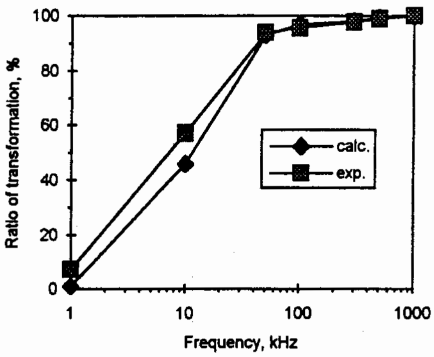
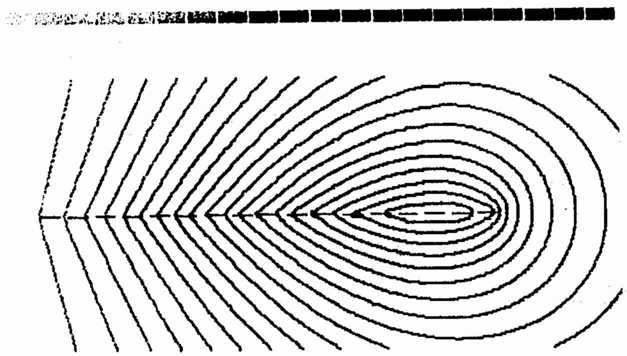
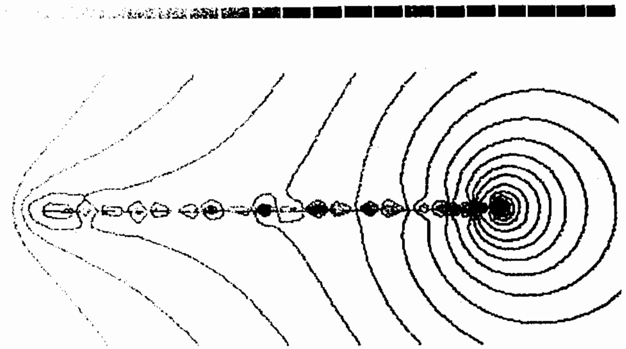


Fig. 8 Ratio of transformation vs. Frequency
(film transformer, shown in Fig. 1b)

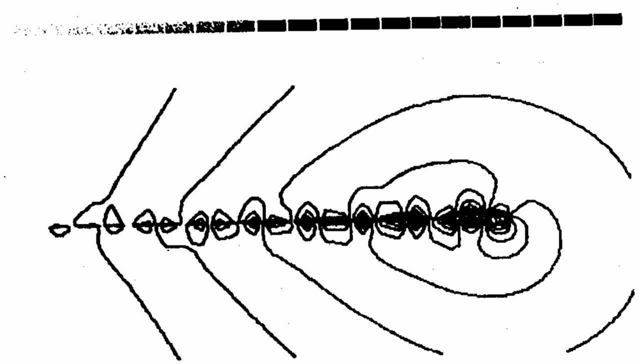
phenomenon occurred near 1MHz may be due to an edge effect of the films which, in turn, causes a significant change of the magnetic field distribution (see Fig. 9b). The results obtained from calculations coincide well with experiments.



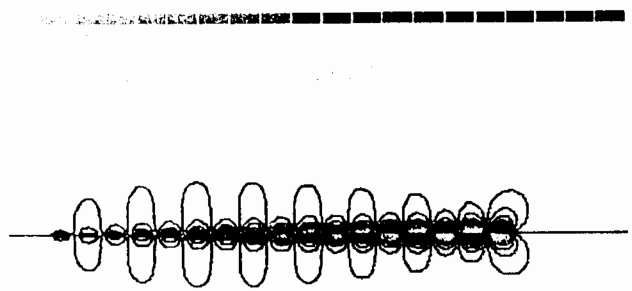
(a) Two layer film transformer with open secondary circuit at 1kHz frequency.



(b) Two layer film transformer with open secondary circuit at 1MHz frequency.



(c) Two layer film transformer with short secondary circuit at 100kHz frequency.



(d) Four layer film transformer with short secondary circuit at 100kHz frequency.

Fig. 9. Magnetic field distribution of the thin film transformer.

Figures 7 and 8 show the computed ratio of transformation together with the experimental one. Clearly, when the frequency is increased, the induced voltage in the secondary coil simultaneously increases. After 50kHz, the ratio of transformation exceeds 90%. Again the calculated values agree well with the measured values.

Figures 9a-d show the magnetic field distributions under the secondary open and short circuited conditions for two types of the film transformer at different frequencies. In Fig. 9a the applied frequency is 1kHz, in Figs.9c,d - 100kHz and in Fig. 9b - 1MHz. Figures 9a-b concern the modes with open secondary circuit, and Figs. 9c-d - those with short secondary circuit. The results in Figs. 9a-c are for the two layer film transformer. Also, the results in Figs. 9d is for the four layer one. The magnetic field distribution is quite different in the modes and conditions, that are considered. The difference between the low and high frequencies is that the magnetic field is concentrated nearer to the coils in the high frequency case, especially when the transformer is composed of a large number of layers. The magnetic field distribution at 1MHz frequency significantly changes because of the edge effect of the film transformer.

3. CONCLUSION

We have proposed a thin and light weight high frequency transformer and its analysis method based on the integral formulation. This film transformer demonstrates high efficiency and ratio of transformation. A method of analysis and computer program has been applied to investigate the characteristics of thin film transformer. The results obtained for the transformer analysis have correlated well with experimental results. Thus, it has been shown that the thin film transformer is quite convenient for constructing of compact power supplies and the applied method for its analysis can be successively used to design such electromagnetic system composed of coaxial parallel conductors with a high-frequency voltage supply.

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