Simulation and Design of Applied Electromagnetic Systems
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The film transformer

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Abstract

In order to realize the ultra light and small power supplies, we propose here a film shape transformer. This new transformer is constructed by the chemical etching processes. Experimental works show that this film transformer takes about 98 percent coupling factor over 500kHz and operates over 95 percent efficiency at 1.5MHz.

1. INTRODUCTION

With the developments of modern electronic devices such as the book size computer, word processor and codeless telephone, it is essentially required to reduce the size and weight of their electric power supplies. In order to design small and compact electric power supplies, it is required to reduce the size of magnetic devices, e.g. reactor and transformer. One of ways to reduce the size of a magnetic device is to employ high frequency excitation [1,2]. In such a high frequency exciting condition, a serious problem is that the major performance of the device is dominated by the frequency characteristics of the core magnetic materials. To overcome this difficulty, new magnetic materials typically represented by amorphous magnetic material have been exploited and utilized [3,4]. Nevertheless, it is difficult to avoid an essential increase of iron loss in accordance with the rise of operating frequency. Another solution of this problem is to exploit a coreless transformer. Previously, we have succeeded in realizing the coreless transformer with high efficiency and demonstrated its usefulness for the DC to DC converters [5,6].

In the present paper, an ultimate thin and light weight high frequency transformer named the film transformer is proposed. This new transformer is composed of the lamination of thin film conductors. Each of the films is constructed by the chemical etching processes. Basic operating principle is the skin effects similar to those of our previously exploited coreless transformer [5]. This fact was confirmed by comparing their frequency characteristics. Depending on the load conditions, efficiency of the film transformer reaches over the 95%. Thus, we experimentally verify that our film transformer is applicable to the practical power supplies.

2. THE FILM TRANSFORMERS

2.1 Principle

Figure 1(a) shows a typical core type conventional transformer which utilizes the magnetic flux linking the conductors wound around the magnetic core. On the other side, our film transformer utilizes the magnetic flux enclosing the current carrying conductors as shown in Fig.1(b). This basic operating principle is the same as those of the twisted coils transformer [1]. However, in order to couple the primary and secondary circuits in a flat surface, we arrange both of the primary and secondary coils in a circular, rectangular or L shape with proper separations.

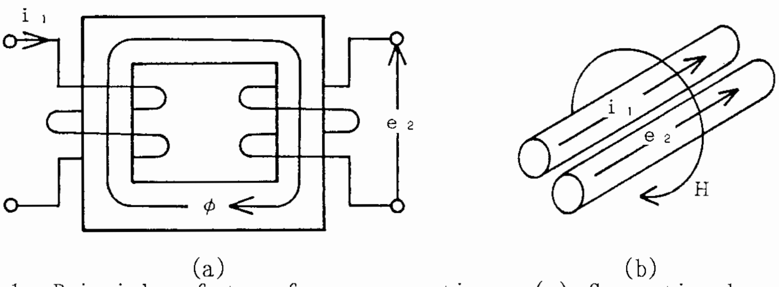


Figure 1. Principle of transformer operation. (a) Conventional core type transformer, and (b) new type transformer.

Figure 2(a) shows a film transformer whose primary and secondary coils are arranged in a coaxially circular shape. When alternating current is flowing through the primary coil, the magnetic flux starts from the center to outer on the top surface and returns from outer to center on the under surface of coaxially circular arranged coils or viceversa. This magnetic flux essentially induces a voltage in a secondary coil because the secondary coil is arranged in a coaxially circular shape on a film base common to primary and secondary coils.

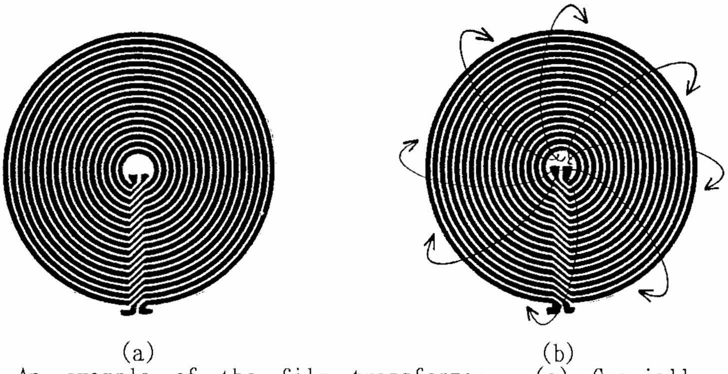


Figure 2. An example of the film transformer. (a) Coaxially circular arranged coils, and (b) a state of magnetic flux flow.

2.2 Practical considerations

In order to realize the film transformer for practical use, at least, three points should be taken into account the design of film transformer.

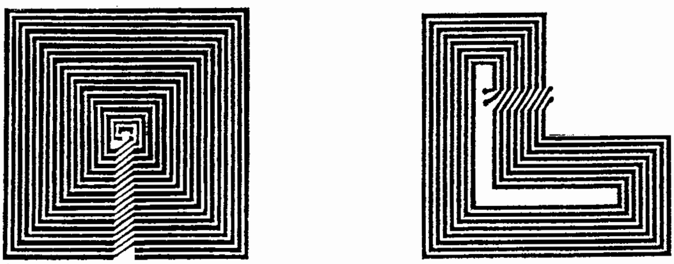
The first is concerning with the terminal arrangement of the primary and secondary coils. It is desirable to install their terminals at the outside of film. Let us consider the coil arrangement shown in Fig.2(a), then it can be observed that one of the primary terminals locates at the outside and the other locates at the center of the film base. This means that connection to the electric source should be done crossing over the transformer coils. This condition is the same about secondary connection. To remove this fault, the coaxial circular arranged coils having symmetrical pattern to those of Fig. 2(a) is so laminated as to coincide with the direction of magnetic flux flow, and connected their terminals at the center. Thus, it is possible to install both of the primary and secondary terminals at the outside of film.

The second is concerning with the transformer ratio. As described in the reference [1], the transformer ratio of this type transformer depends on the length of coils, i.e. a transformer ratio corresponds to those of the primary and secondary coils length. If a primary coil is longer than those of secondary, then lower voltage can be obtained at the secondary circuit but leakage flux of the primary coil is essentially increased. Even though a large number of laminations is required, this fault can be removed by changing the circuit connection. For example, let us consider a pair of film transformer. If two primary coils are connected in series and two secondary coils are connected in parallel, then it possible to get a half of primary impressed voltage at the secondary terminals.

The third is concerning with the improvement of coupling factor. Because of an edge effect at the outer side, the magnetic flux does not flow ideally as shown in Fig.2(b) but it may take the closed paths penetrating the base films. Namely, the magnetic flux flow normal to the film surface is caused by the edge effect at the outer side. Obviously, this bypassing magnetic flux makes the coupling factor lower. One of the solutions of this problem is to increase the number of laminations.

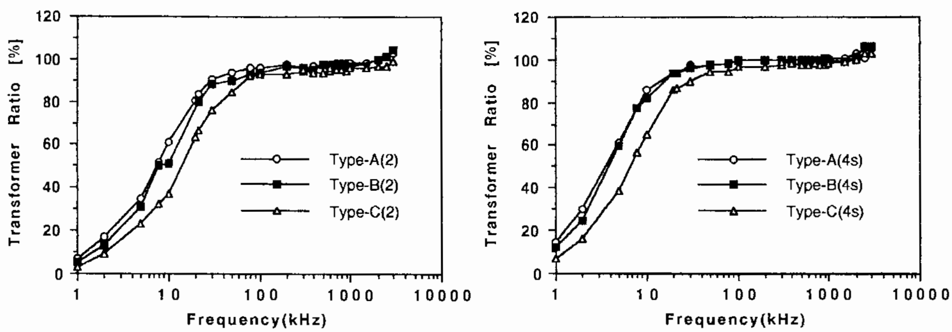
2.3 Experimental

We made the three types of trial film transformers by the chemical etching processes. One is the coaxially circular coil pattern shown in Fig.2(a) and the others are shown in Fig.3.



(a) (b)

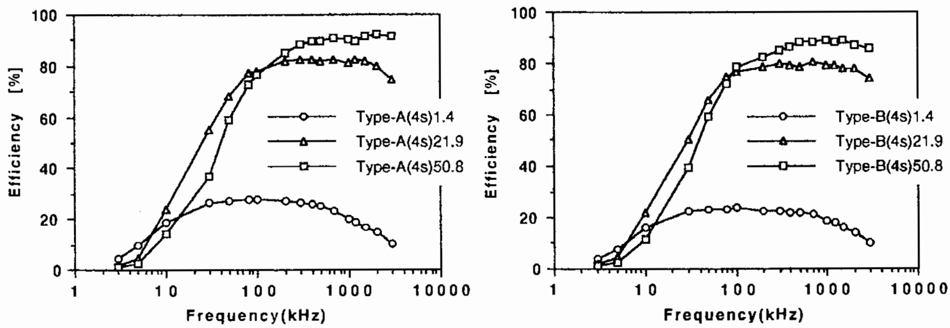
Figure 3. The trial film transformer patterns. (a) Coaxially square arranged coils, and (b) coaxially L shape arranged coils.



(a) (b)

Figure 4. The frequency characteristic of the transformer ratio, which corresponds to the coupling factor at high frequency. (a) Two layers, and (b) four layers (series connected). Types A, B and C are the circular, rectangular and L shape film transformers, respectively.

Figure 4 shows the frequency characteristic of the transformer ratio, which corresponds to the coupling factor at high frequency. In this figure, 4(a) shows a transformer ratio of the film transformers composed of a series connected two films. On the other side, Fig.4(b) show a transformer ratio of the film transformers composed of a series connected four films. The difference between them suggests that the frequency characteristic of the coupling factor can be improved by increasing the number of film lamination.



(a) (b)

Figure 5. The frequency characteristics of efficiency. (a) Four layers series connected circular shape film transformer, (b) four layers series connected rectangular shape film transformer. 1.4, 21.9 and 50.8 denote the load resistance value in Ohm.

Figure 5 shows the frequency characteristics of efficiency. The results in Fig.5 suggest that it is possible to realize highly efficient film transformers even though the load and operating frequency conditions are limited. Also, Fig. 5 shows that the optimum operating frequency depends on the load resistance value, and it moves to a higher frequency in accordance with the larger load resistance value. This tendency is similar to the results in the Ref.[5]. Also, the frequency characteristic of transformer ratio in Fig. 4 is similar to those of the Ref.[5]. These similarities suggest that the basic operating principle of film transformers is the skin effects.

3. CONCLUSION

In the present paper, an ultimate thin and light weight high frequency transformer has been proposed. Depending on the load conditions, efficiency of the film transformer reaches over the 95%. Thus, we have experimentally verified that our film transformer is applicable to the practical power supplies.

4. REFERENCES

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