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High Frequency Planar Transformer with Helical Winding Structure

Fu Wong and Junwei Lu

***Abstract*—A high frequency planar transformer with helical windings is proposed in this paper. This transformer combines the advantages of the planar magnetic core transformer and air core transformer. The experiment results show that the input impedance and the voltage ratio of this new transformer are much higher than its air core counterpart. The numerical result shows that the flux is evenly distributed and totally enclosed inside the planar ferrite. The electromagnetic interference (EMI), generated from the windings of transformer, is significantly reduced by using magnetic ferrite cores.**

***Index Terms*—Helical winding structure, high frequency transformer, planar transformer.**

I. Introduction

VARIOUS winding and magnetic core structures have been developed for high frequency transformer applications recent years [1]–[3]. Among them, the planar air core transformers and the planar magnetic core transformers are targeted by high frequency switching mode power supply designers. Both of them have their advantages and disadvantages for high frequency applications. The typical advantages for air core transformers are no core loss and low manufacturing cost. However drawbacks still exist for air core transformers due to the problems of EMI, low magnetic coupling coefficient and low input impedance. The planar magnetic core transformers using meander or spiral windings have problems of proximity effect and unbalance magnetic flux distribution. The proposed planar magnetic transformer with helical windings can significantly overcome some of these disadvantages while keeping their advantages. This paper will present an ideal planar transformer for low to medium power applications with very low manufacturing cost, low EMI and relatively high coupling coefficiency.

II. Structure of Planar Transformer

The proposed planar transformer consists of two pieces of planar magnetic ferrite and one double side printed circuit board (PCB), as shown in Fig. 1. The ferrite material is Philips soft ferrite −3F4. The dimension of planar ferrite is 32 mm × 20 mm × 3 mm. The double side PCB with thickness of 0.2 mm forms an air core transformer with vertically helical windings.

The primary winding and secondary winding are looped by connecting the strip lines at each end through the upper layer and bottom layer of the PCB vertically, as shown in Figs. 1 and 2. The plat-through technique is used to connect the strip lines between the upper layer and the bottom layer of the PCB to form a complete helical loop of primary and secondary windings.

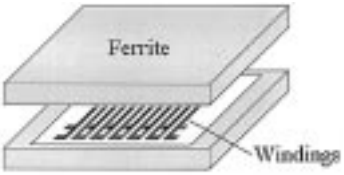

Fig. 1. Overall structure of the proposed planar transformer.

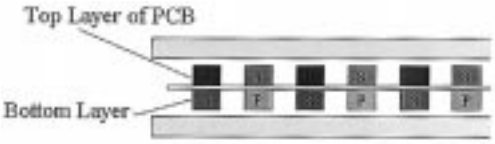

Fig. 2. Part of the cross section of helical windings.

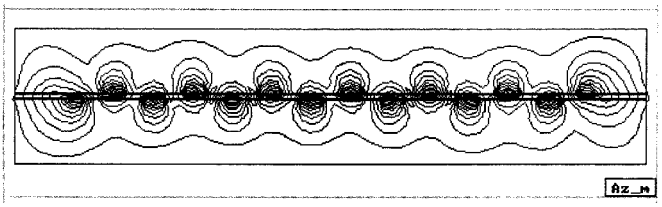

Fig. 3. The numerical simulation of magnetic flux distribution in HF transformer.

Two pieces of planar magnetic ferrite place together to wedge planar helical windings and to make a planar transformer. This planar transformer with such structure can significantly increase the magnetizing impedance and reduce the EMI generated by the planar helical winding (when it was used as an air core transformer). All the flux generated by the coils is enclosed inside the two pieces of ferrite. The primary winding and the secondary winding are separated from each other to minimize the proximity effect and further to reduce the eddy current density inside the windings [4]–[6].

III. Flux Distribution

Operating at a frequency of 1 MHz, the magnetic flux distribution of the transformer shows that the magnetic flux is evenly distributed around each primary winding and induces the emf in the secondary winding, shown in Fig. 3. The problem of unbalance magnetic flux distribution is much less than the meander type and the spiral coil of planar transformers [1], [5]. Two pieces of ferrite enclose all the magnetic flux

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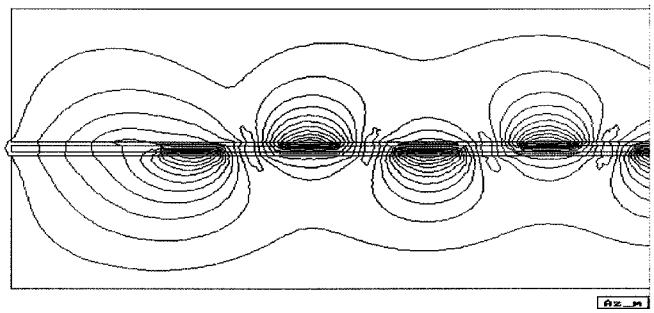

Fig. 4. Flux distribution of first four pairs of winding.

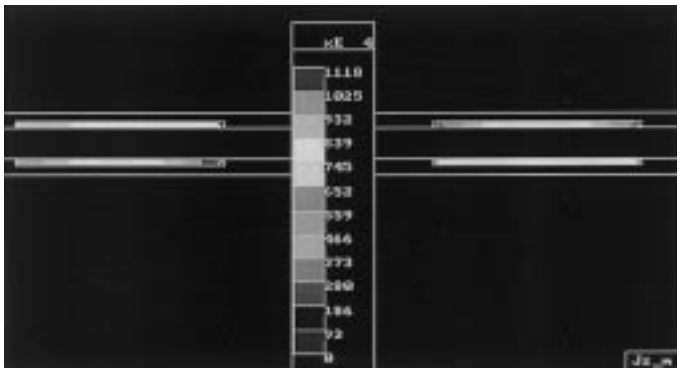

Fig. 5. Eddy Current Distribution for the first two pairs of windings.

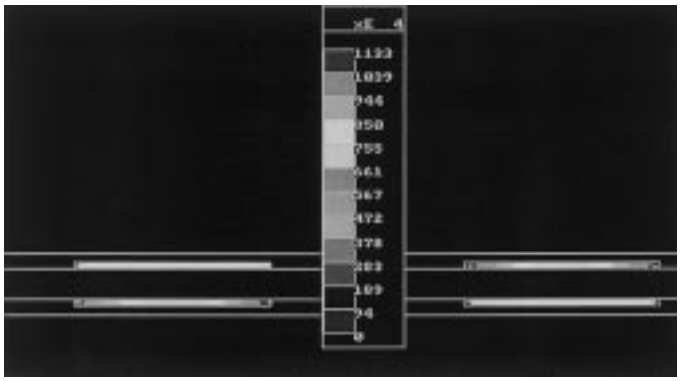

Fig. 6. Eddy current distribution for the middle two pairs of windings.

inside the transformer, which increases magnetic coupling and input impedance, and reduces EMI as produced by an air core transformer.

Fig. 4 shows that the details of the flux distribution of the first four pairs of winding of the transformer. The magnetic flux distribution of each pair of windings are very similar, except the pair of winding at the ends. Every strip line of the secondary winding is evenly induced by the adjacant primary lines.

IV. Eddy Current Analysis

The eddy current distribution inside the transformer windings will effect the leakage inductance and the overall performance of the HF transformer. The eddy current distribution of the helical printed circuit winding of the planar transformer operating at 1 MHz was simulated by BEM-based eddy-current solver [7]. The numerical results are listed in Figs. 5–7. From these three figures, the eddy current distributions are found that they are very similar in each two pair of windings. The eddy current is

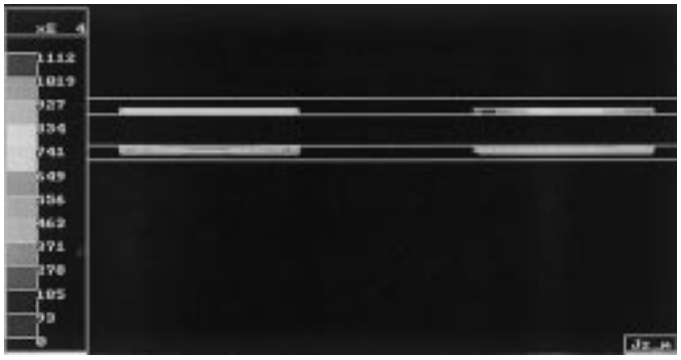

Fig. 7. Eddy current distribution for the last two pairs of windings.

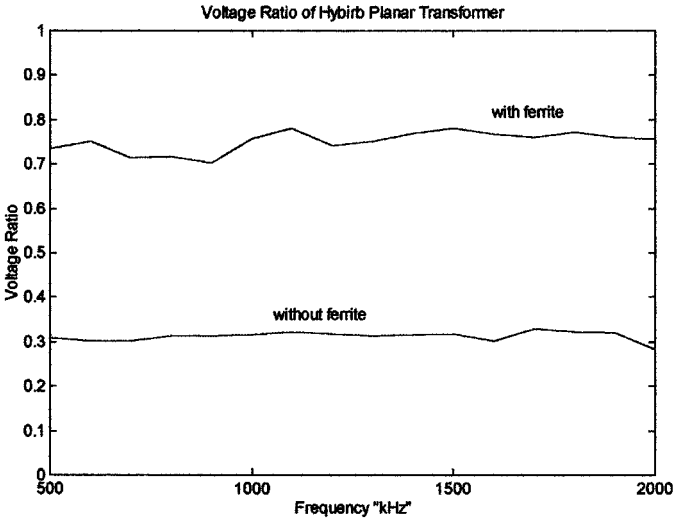

Fig. 8. The comparison of voltage ratio of the planar transformers with and without ferrite.

TABLE I
COMPARISON OF VOLRAGE RATIO OF PLANAR TRANSFORMERS

Transformer	In this paper	Type I in [1]	Type II in [1]	In [2]
Voltage ratio $_{(max)}$	0.8 (<2MHz)	0.5 (<2MHz)	0.4 (<2MHz)	0.6 @1MHz

evenly distributed in the whole winding of the HF transformer. It agrees with the flux distribution mentioned in above section. The maximum eddy current flows around the two sides of the strip lines of the secondary winding, because of the magnetic fields generated by the current flowing the strip line [4].

V. Voltage Ratio and Input Impedance

The voltage ratio of the transformer has been measured and plotted for the frequency range between 500 kHz to 2 MHz as shown in Fig. 8. The voltage ratio of the transformer with ferrite is double of the voltage ratio of the transformer without ferrite. The voltage ratio in this frequency range is close to 0.8. It is quite higher comparing with the voltage ratio of an air core planar transformer. The voltage ratio is also better comparing with the planar transformers with spiral winding at this frequency range [1], [2]. They are listed in Table I.

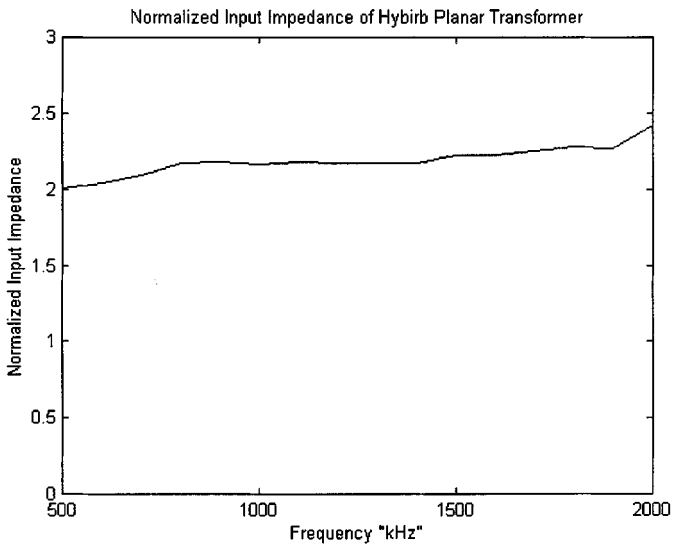

Fig. 9. The normalized input impedance.

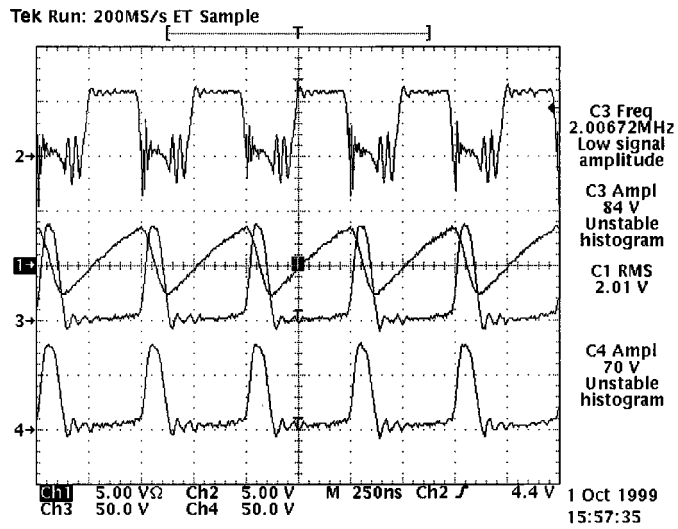

Fig. 10. Switching waveforms of the testing planar transformer.

The input impedance normalized with its air core counterpart is shown in Fig. 9. The input impedance of the transformer with magnetic ferrite is twice of the input impedance of the transformer without the ferrite materials. The input impedance keeps increasing form "2" at 500 kHz to "2.4" at 2 MHz, due to the increasing of the permeability of the ferrite material at that frequency range.

VI. Experimental Results with the Load

The planar transformer with helical winding structure has been tested with the load, using single switch forward switching resonate converter configuration. Fig. 10 shows the switching waveforms of the testing transformer. The waveform at the top of Fig. 10 is measured between the gate and the source of the switching MOSFET. Channel 3 is the waveform of V_{DS} of the MOSFET. The output from the secondary winding of the testing transformer is monitored by channel 4. The current flowing through the primary winding is indicated by channel 1. The peak to peak voltage ratio is 0.83 with load of 100 Ω at 2 MHz. For the resonant period is less than 150 ns, the switching frequency can be further increased.

VII. Conclusions

The HF planar transformer with helical winding structure has been fabricated and investigated. Both experimental results and numerical simulation results have shown that the planar transformer performed excellent at frequency range between 500 kHz to 2 MHz. The magnetic flux distribution described the characteristic of low electromagnetic interference of the proposed HF planar transformer. The planar transformer also has advantages of the evenly distributed eddy current and the relatively higher input impedance. The manufacturing cost is much lower than the cost of traditional HF transformers. It improves significantly the ratio of the performance/cost of the HF transformer design. It is an ideal type of switching transformer for high frequency, low to medium power applications.

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