

Design Insulated Hybrid Transformer of Application for AC Adapters of Smart devices

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Abstract: Increasing strong demand for smaller insulated transformers, an ultra-small transformer has been developed by adopting an insulated hybrid structure with the size of W16.5 x L19.5 x H10.5 mm³, whose volume is 65 % smaller than conventional insulated transformers. Our new transformer has been improved in terms of noise reduction by 5-15 dB, power efficiency increase by 2 %, and production efficiency by 50 %. Relevant analyses are to be given.

Keywords: AC Adapter, Insulated transformer, Hybrid structure, Small size.

I. INTRODUCTION

With continuing worldwide popularity, smart devices such as phones, pads, watches, and glassed has become more sophisticated. Consequently, their batteries consume more electricity and the lifespan of these batteries have also become shorter. For the conveniences of users of smart device users carrying AC adapters, smaller and lighter powers are in strong demand, which highlights the importance of smaller charging AC adapters. To meet the strong demand of smaller and lighter AC adaptor, we have developed a new transformer for AC adaptors of smart devices by utilizing insulated hybrid structure.

Figure 1 shows a conventional 10W AC adapter board and its parts. The transformer is the thickest part, accounting for approximately 30% of the AC adapter board. Thus, the transformer is one major item in making these AC adapters slimmer. Present power of AC adapters for smart-phones and tablet PCs is in the range of 5W to 15W.

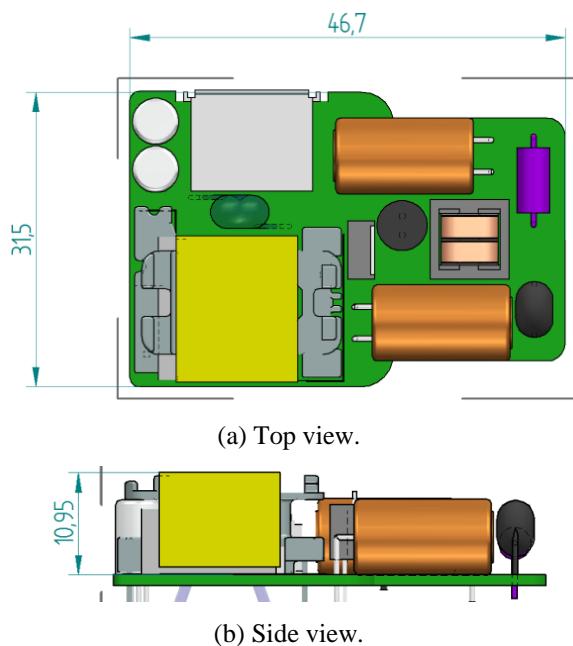


Fig.1. Conventional-type 10W AC Adapter.

We introduce an ultra-small transformer for 10W AC adapters which has an insulated hybrid structure. We have evaluated our new transformer in terms of volume, noise level, power and manufacturing efficiencies. We have compared features of the conventional transformer with those of the new one, which showed that hybrid-type wires without bobbin have higher circuit efficiency than the conventional one and its transformer is approximately 45% smaller. Our new transformer also meets the characteristics of EMI and allowed for a shorter manufacturing process of transformer, increasing the mass production efficiency by more than 50% than the conventional one.

II. CIRCUIT AND TRANSFORMER STRUCTURE

Figure 2 shows a block diagram of the AC adapter power supply. It is separated by an isolation power transformer.

Specifications for AC adapter power supply:

Input voltage : AC85~265V
Output voltage : 5Vdc
Output current : 0~2.0A
EMI specifications:
CISPR22,FCC_PART15,EN550022
Safety specifications :
EN60950/UL60950 AND IEC60950

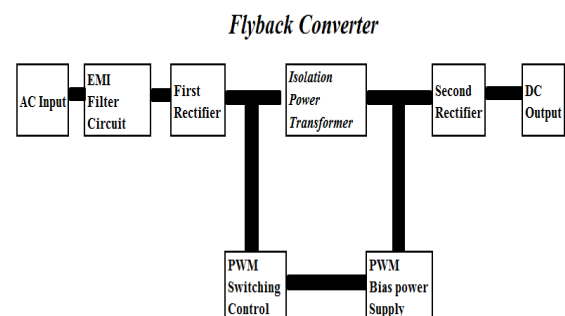


Fig.2. Block diagram of the AC adapter power supply. (PWM: Pulse Width Modulation).

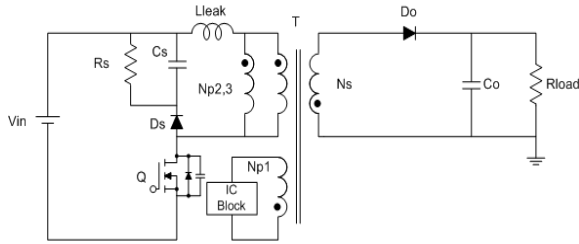


Fig.3. Flyback converter

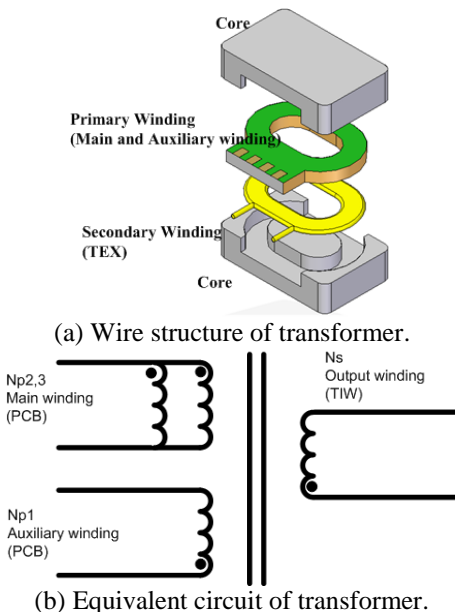
Figure 3 represents a Flyback converter with the leakage inductance concentrated in primary winding. In the moment in which the MOSFET(Q) in turned off, current in the primary winding will try to reach zero, but the leakage inductance makes that the current does not change so quickly. An over-voltage will appear in the leakage inductance. This operation model and its current are determined based on leakage inductance as shown below equation^[7-10].

$$I_p(s) = \frac{(V_g + nV_o - v_{ds}(t_3))C_{oss} + i_p(t_3)L_k C_{oss}s}{L_k C_{oss}s^2 + 1}$$

$$= \sqrt{\frac{C_{oss}}{L_k}} \frac{1}{s^2 + (\frac{1}{\sqrt{L_k C_{oss}}})^2} (V_g + nV_o - v_{ds}(t_3)) + \frac{i_p(t_3)s}{s^2 + (\frac{1}{\sqrt{L_k C_{oss}}})^2} \dots (1)$$

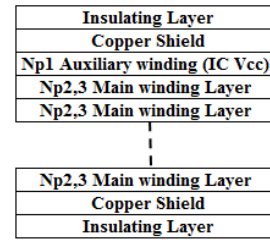
$$i_p(t) = (V_g + nV_o - v_{ds}(t_3)) \sqrt{\frac{C_{oss}}{L_k}} \sin\left(\frac{1}{\sqrt{L_k C_{oss}}} t\right) + i_p(t_3) \cos\left(\frac{1}{\sqrt{L_k C_{oss}}} t\right) \dots (2)$$

Figure 4 shows the drawing of transformer which has an insulated hybrid structure. This transformer does not require any bobbin unlike the conventional one. Np1 and Np2 of primary wires are made on multi-layered board and Ns1 made out of TIW is located on this board, which can be assembled into a transformer core. At this point, PCB needs to be shielded and the EMI level should go down in order to prevent EMI characteristics from being undermined. Since our new transformer does not require any bobbin, it can not only reduce the manufacturing processes by more than 50%, but also the volume of transformer.



(a) Wire structure of transformer.

(b) Equivalent circuit of transformer.

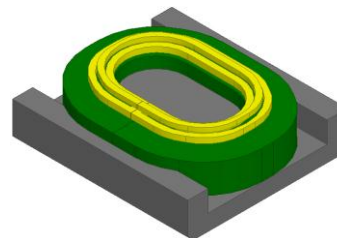


(c) Circuit structure of primary wires (Np1 and Np2,3).
Fig.4. The transformer structure with insulated hybrid structure.

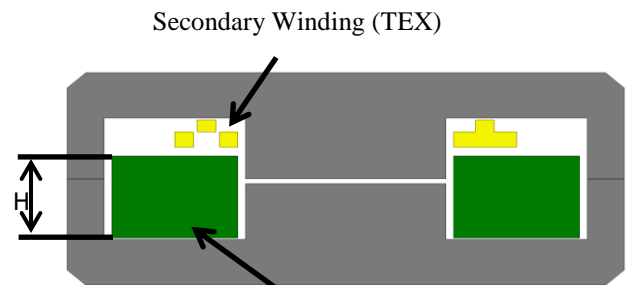
III. ANALYSIS OF THE TRANSFORMER WITH HYBRID INSULATED STRUCTURE

A. Leakage Inductance

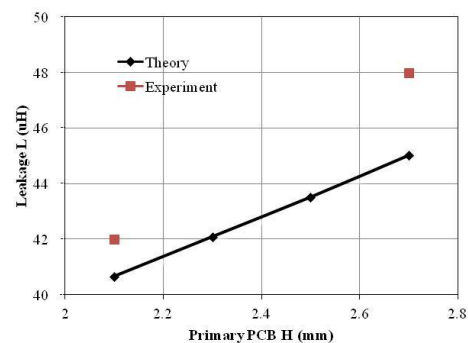
As AC adapters have a flyback converter-type circuit system, transformer inductance has a big impact on voltage surge and efficiency. The conventional one has small leakage inductance as primary and secondary wires have the interleaved structure (sandwich type)^[1-5].



(a) 3D view of new type.



Secondary Winding (TEX)
Primary Winding (PCB)
(b) 2D side view of the new type.



(c) The connection between primary PCB height and leakage L of Np2 and Ns1.

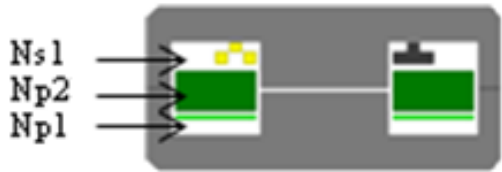
Fig.5. Characteristics of leakage L of insulated hybrid-type transformer.

It is found that our new type is more likely to increase leakage inductance because its primary wires board is made separately from the secondary ones. Factors affecting the leakage inductance of our new type are the length between primary wires board and secondary one as well as the thickness of primary wires board.

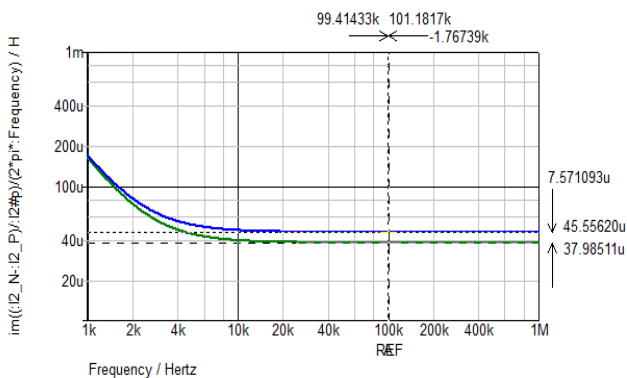
Magnetic field interpretation offers a clear explanation on the connection between the thickness of primary board and leakage inductance. Figure 6 shows the views of our new transformer and the comparative values of leakage inductance. Figures 6(a) and 6(b) are the wire structures of different models(A and B) and results of magnetic field interpretation. Primary wires are installed on PCB using Np1-3 and TIW wires are covered with secondary ones. A thin primary PCB tends to decrease leakage inductance as shown in Fig. 6(c). The test results on 2.1mm and 2.7mm boards have produced a maximum of 7% differences from analysis. It appears that sample transformers produce a difference in leakage inductance, which seems to be caused by a difference in simulation models and the shape of second wires. This difference of 7% does not seem to have an effect on evaluating transformer properties.



(a) Type-A wires structure.



(b) Type-B wires structure.



(c) Analysis results of leakage inductance of Type-A and Type-B.

Fig.6. Characteristics of leakage inductance by wire type.

Our new transformer consists of three wires, two primary wires and one secondary wire. As for flyback converter, leakage inductance of primary main wires (Np2) and secondary wires (Ns) have a connection with Vds voltage surge of main FET and secondary rectification diode surge. The characteristics of leakage inductance are considered to be strongly affected by the location of each wire when a PCB is made of secondary wires. Figure 6 shows characteristics of leakage inductance by wire location.

Leakage inductance of Type B has decreased by 7.6uH compared to that of Type-A. Such interpretation output has been applied to optimize the new transformer and generate leakage inductance up to the level of the conventional one.

B. EMI characteristics of AC adapters by transformer structure

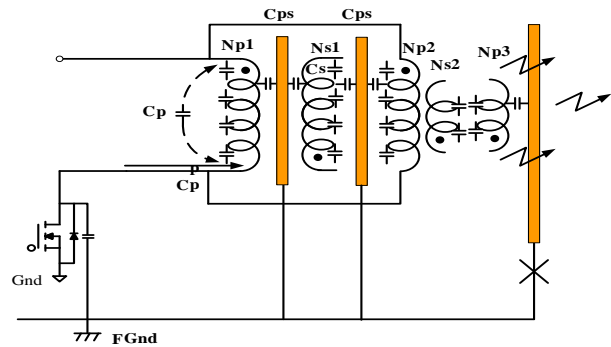
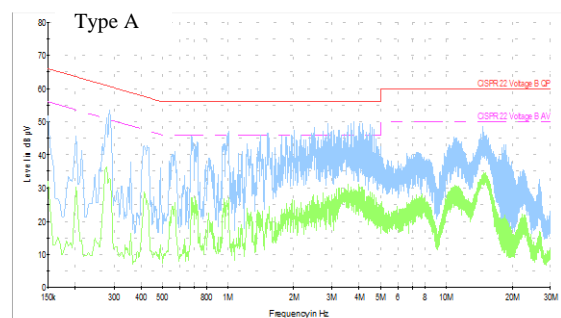
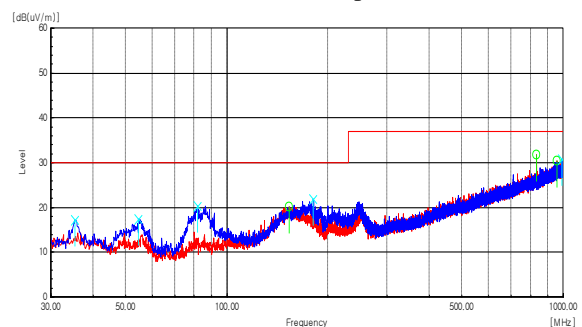


Fig.7. Internal noise path of transformer.

Since AC adapters should meet the requirement of EMI characteristics of CISPR22, FCC_PART15 and EN550022, we have tested noise levels. Figure 6 shows internal noise path of transformer. Transformer has two kinds of parasitic capacitance which are Cp, Cs, Np1, Np2, Ns1 as well as Np1, Ns1, Cps. Parasitic capacitance makes a path to deliver noise to the primary side^[6]. As figure 5(a) shows, copper shield is installed on PCB to decrease parasitic capacitance and increase impedance of noise path. Figures 8 and 9 show the test results on EMI characteristics of AC adapters when the conventional and new type was installed. Conducted noise of the new type decreased by a maximum of 5dB compared to the conventional-type. Radiated noise went down up to 15dB in 70MHz.

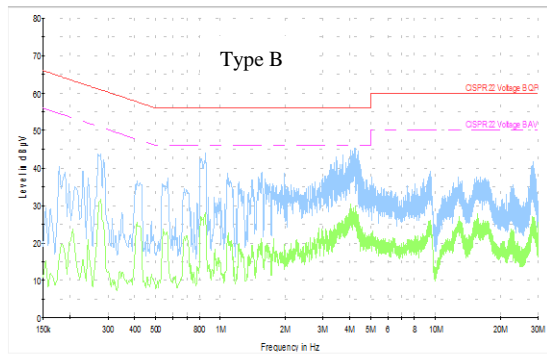


(a) Conducted noise spectrum.

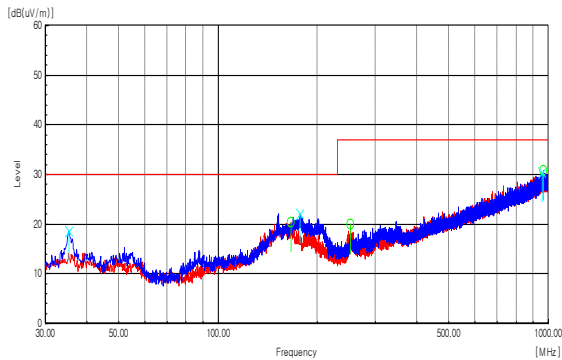


(b) Radiated Noise.

Fig.8. EMI characteristics of AC adapters with the conventional-type transformer.



(a) Conducted noise spectrum.



(b) Radiated Noise.

Fig.9. EMI characteristics of AC adapters with the original-type transformer.

C. Characteristics of power efficiency when mounted on AC adapters

Figure 10 shows the outside view of new and conventional type transformers. New type is approximately 45% smaller than the conventional one. The whole view of AC adaptor with new transformer is shown in the figure 10. The height of the new transformer mounted on the PCB decreased up to 7.0 mm compared to 10.95 mm of the conventional-type, which comes out to be reduced approximately by 25% of the entire height.

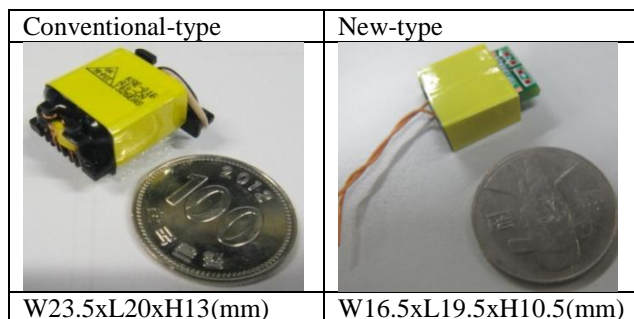
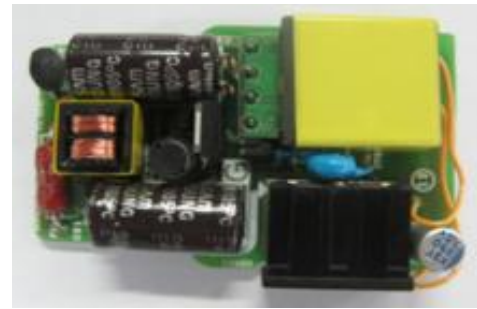
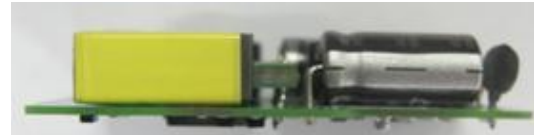


Fig. 10. The outside views and sizes of new and conventional transformers.



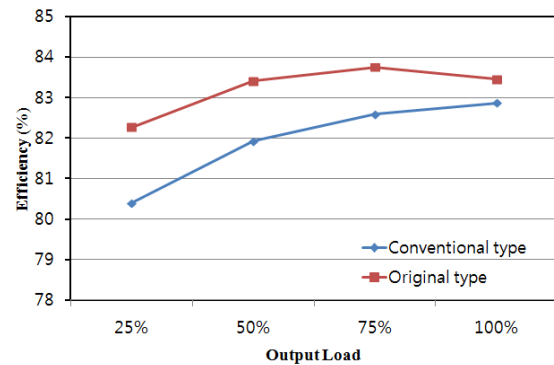
(a) Top view of AC adapter board.



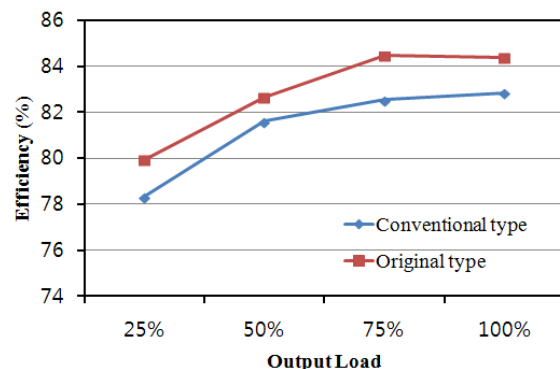
(b) Side view of AC adapter board.

Fig. 11. Outside view of the new transformer mounted on AC adapter.

Figure 12 shows efficiency characteristic of AC adapter power supply. The new-type is more effective than the conventional one by 2% at most.



(a) Efficiency characteristics of input voltage AC115V.



(b) Efficiency characteristics of input voltage AC230V.
Fig.12 Characteristics of power efficiency of AC adapter.

IV. CONCLUSION

For the AC adaptors of smart devices, an ultra-small transformer has been developed by adopting an insulated hybrid structure with the size of W16.5 x L19.5 x H10.5 mm³, whose volume is 65 % smaller than conventional insulated transformers. Electrical features, structure and

EMI characteristics of the new transformer have been characterized by simulation and relevant tests. It also compared power efficiency and EMI characteristics of each conventional and original transformer when they are mounted on AC adapters with the key findings as the following:

1. The size of the original-type transformer is approximately 65% smaller than the conventional one.
2. Conducted noise of the original-type transformer decreased up to 5dB and radiated noise up to 15dB compared to the conventional-type one.
3. Power efficiency of AC adapter went up by 2%
4. The original-type transformer drove up production efficiency by 50%.

Our new insulated hybrid-type transformer is expected to be further applied to not only 10 WAC adapters but also other products.

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BIOGRAPHIES



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Xinlan Li, received her B.S from the University of Science and Technology Liaoning, Liaoning, China, in 2004, and her M.S and Ph. Dr from Gyeongsang National University, Gyeongnam, Korea in 2008 and 2012, respectively, where she

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