Thickness –Vibration –Mode Piezoelectric Transformer for Power Converter

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This paper presents a new sort of multilayer piezoelectric ceramic transformer for switching regulation power supplies. This piezoelectric transformer operate in the second thickness resonant vibration mode. Accordingly it's resonant frequency is higher than 1MHz. Because output power is low if input and output part of transformer are consisted of single layer, this research suggests a new method, which is consisted of both input and output part of transformer have 2-layered piezoelectric ceramics. The size of transformer is 20mm in width and length, and 1.4mm in thickness, respectively. To design a high efficient switching circuit of the transformer, internal circuit parameters were measured, and then we've calculated a parameter of inductor nd capacitor to design a driving circuit. We've used a MOSFET and it's driver circuit modified a clap oscillator circuit as the primary switching circuit.

Keywords : Piezoelectric transformer, Thickness vibration mode, Voltage gain, Driving circuit

1. INTRODUCTION

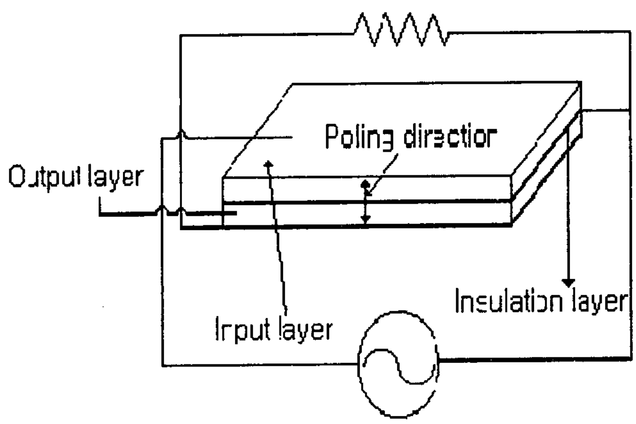
With the advance in electric and communication technology, there has been recently a great progress in miniature, lightweight and thin film electric equipment, for which miniaturization of power supply apparatus is required. The piezoelectric ceramic transformer that operated in the thickness vibration has recently attracted great interest, because it is to lead a great size reduction of power supply.

The piezoelectric ceramic transformer is a device that transmits electrical energy through mechanical vibration. Accordingly, power density of piezoelectric transformer is much larger than that of magnetic energy. Many sorts of piezoelectric transformer for high voltage have been studied since Rosen type was proposed as one operating in the length extensional vibration mode. But this type of transformers are not suitable for power conversion, because it operates only in the area of 200~300KHz and they have a high internal impedance that lead to power loss. Also, the conventional electromagnetic transformer are not to operate effectively because the increase of the switching frequency cause high core loss and copper loss. But the piezoelectric transformer, operating in thickness vibration mode, can be operated at high frequency and have high density of transfer power. So that at this paper, the $PbTiO_3$ piezoelectric transformers operating in thickness vibration mode, are made to use that piezoelectric material have the anisotropy(kt/kp) of large electromechanical coupling factors. But output power is low if input and output layer of transformer consists of single layer.

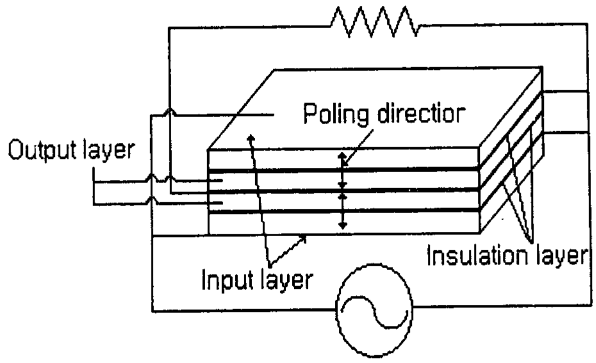
Therefore, to overcome this problem, this paper presents a new sort of piezoelectric transformer input and output layer consists of two piezoelectric ceramic layer. And for designing the high efficient switching circuit of the piezoelectric transformer, the internal circuit parameters were measured, then we calculate the inductor and the capacitor parameter and design the driving circuit. We use the MOSFET and it's gate driver circuit, which is modified clap oscillator circuit, as the primary switching circuit.

2. CONSTRUCTION AND OPERATING OF PIEZOELECTRIC CONVERTER

Figure 1 shows the construction of piezoelectric transformer operating in thickness extensional vibration mode. It is 20mm in width and length and 1.4mm in thickness, respectively. And the 0.1mm insulation layer is set between the input and output layer to electrically isolate them, and the input and output layers are alternately polarized toward the opposite direction of thickness. Figure 1(a) shows the construction of two layer. And we made the construction of four layers for output power elevation of the piezoelectric transformer as figure 1(b). In order to induce mechanical vibration, AC resonant frequency voltage must be applied to the input part of the piezoelectric transformer. The mechanical vibration is propagated to the output part, which generates AC voltage. Thickness directed resonance is the best means to elevate transfer efficiency. The second resonant mode has such good effects as widest resonant frequency band and low impedance. This merits are illustrated by the figure 2, which shows the vibration displacement and stress distribution of the thickness extensional vibration mode. Fig. 2(a) shows the half-wavelength resonance of the first resonant mode, in which the input and output layers expand and contract simultaneously. The generated charge quantity changes in proportion to the stress value in the piezoelectric materials. Thus, Fig. 2(a) shows the maximum stress to the insulation layer.



(a) Two layer construction of piezoelectric transformer



(b) Four layer construction of piezoelectric transformer

Fig. 1. Piezoelectric ceramic transformer construction.

When the piezoelectric transformer is operated by the second resonant mode, the input and output layers expand and contract alternately, and the stress is maximized at the middle of each layer.

And we made the driving circuit for switching power converter. Fig 3 shows the switching circuit on primary side and rectifying circuit on secondary side are indispensable. To design a high efficient switching circuit of the transformer, internal circuit parameters were measured, and than we've calculated a parameter of inductor and capacitor to design a driving circuit. We've used a MOSFET and it's gate driver circuit modified a clap oscillator circuit as the primary switching circuit. The MOSFET switches turn on and off alternately as the resonant frequency. Figure 4 show the waveforms of MOSFET, input voltage and output voltage at load resistance 50[Ω].

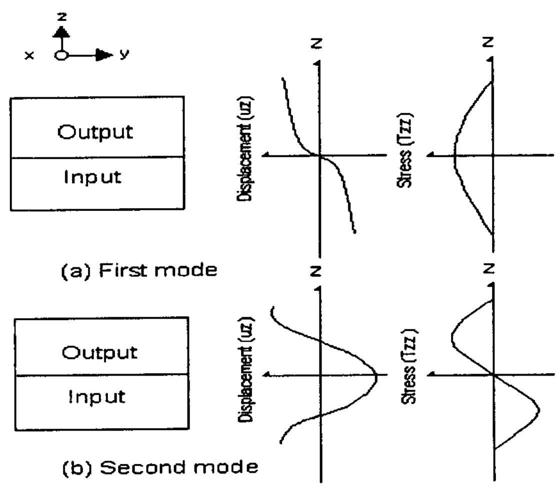


Fig. 2. Displacement and stress distribution of piezoelectric transformer.

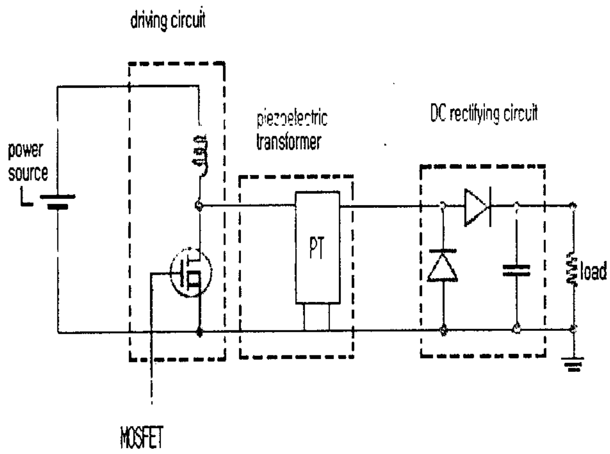
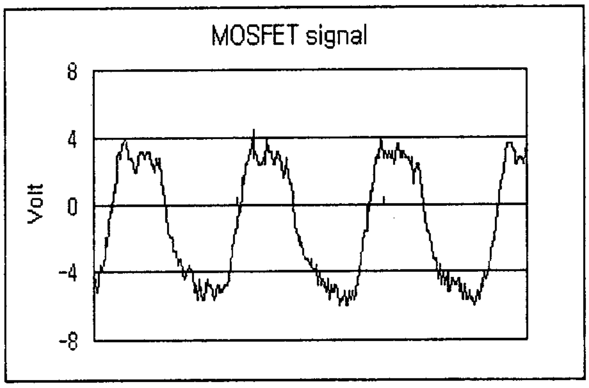
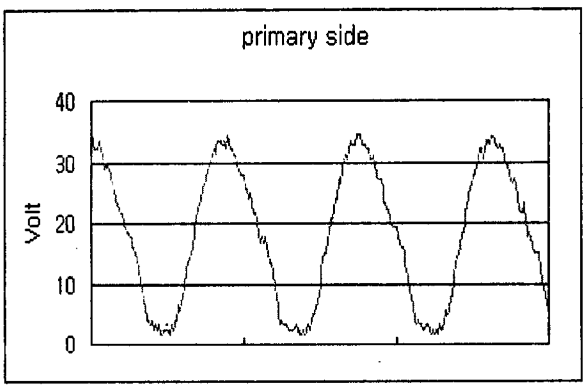


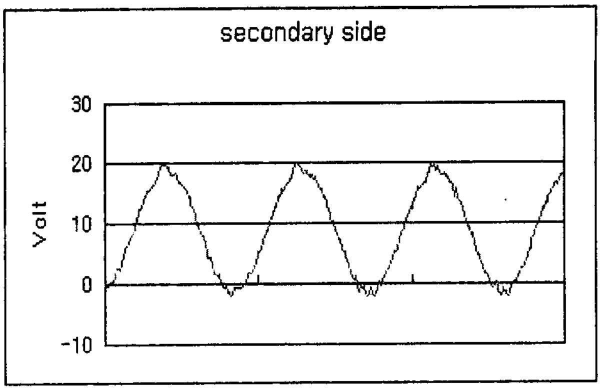
Fig. 3. Driving circuit of piezoelectric transformer.



(a) MOSFET signal



(b) Input voltage of PT



(c) Output voltage of PT

Fig. 4. Input and output waveform of piezoelectric transformer.

3. RESULTS AND DISCUSSION

The piezoelectric transformer can be analyzed by using the lumped-constant equivalent circuit for simulation. Fig. 5 shows the equivalent circuit of piezoelectric transformer. Since each of input and output layers consists of one piezoelectric layer, Mason's equivalent circuit is applicable.

This equivalent circuit is the Rosen type of piezoelectric transformer. Though it is somewhat problematic to be applied to the piezoelectric transformer of thickness vibration mode, it was proved that with the input and output layers consisting of one layer Mason's equivalent circuit is applicable because admittance characteristics of the piezoelectric transformer is similar to the equivalent circuit of the Rosen type. Voltage gain was calculated from the input and output voltage, V_{in} and V_{out} by Eq. (1)

$$\text{Gain} = V_{out}/V_{in} \tag{1}$$

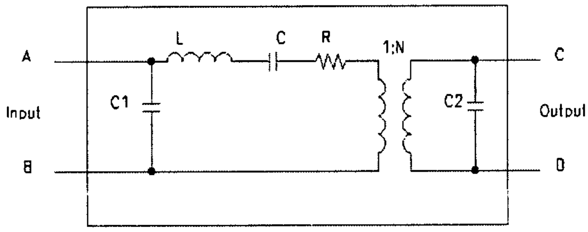
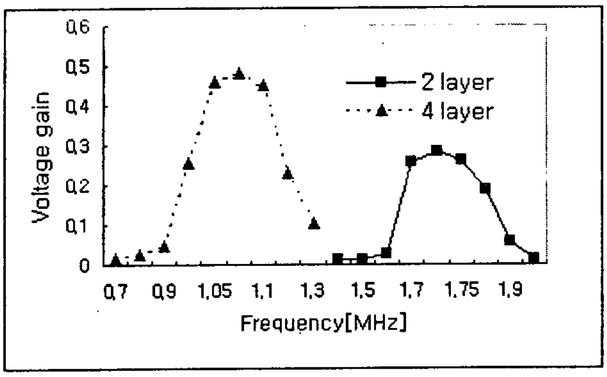
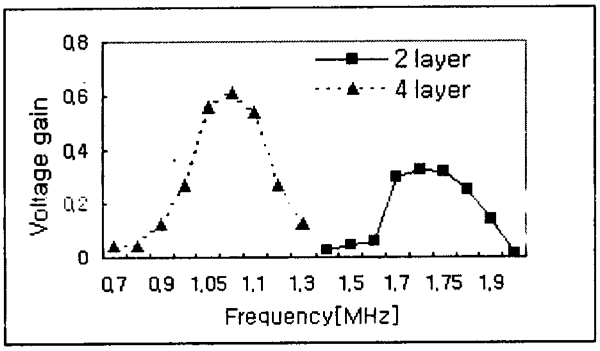


Fig. 5. Equivalent circuit of piezoelectric ceramic Transformer.

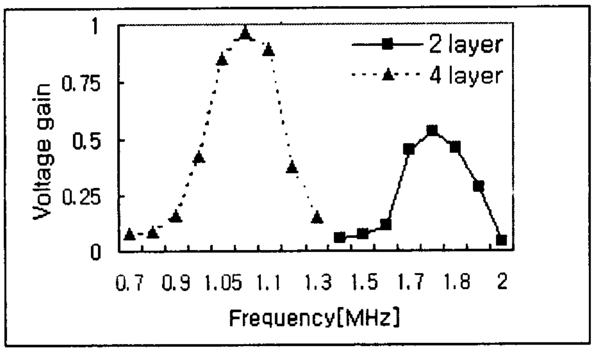
Fig. 6 shows the voltage gains from the measurement with three different resistances 30, 50 and 100[Ω]. There were differences in voltage gains between the four layer and two layer.



(a) 30[Ω]



(b) 50[Ω]



(c) 100[Ω]

Fig. 6. Voltage gain according to frequency.

As shown in fig. 6, the voltage gain of the four layer transformer was twice as much as that of the two layer one, which is assumed to have resulted from the increase of the charge by doubling the pole area of the piezoelectric ceramic layers. The output voltage, one of the most problematic aspects of the piezoelectric transformer, can be considerably increased by this newly designed model, which, if used on the DC-DC converter, could be of very wide application. The differences of the resonance frequency band between the two models were resulted from the disparity in the thickness of each layer made in the manufacturing process.

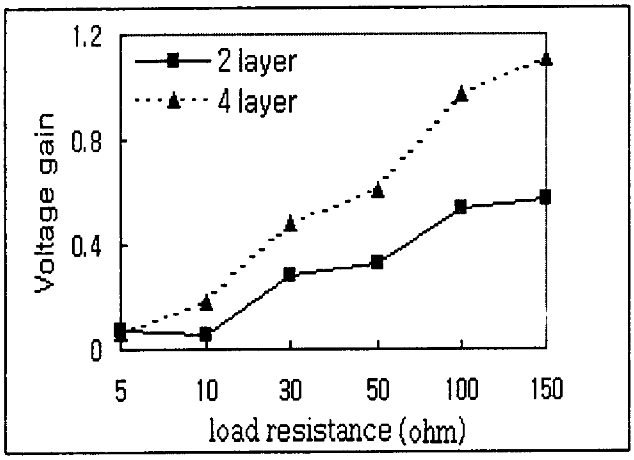


Fig. 7. Maximum voltage gain according to loading resistance.

Table. 1. Resonance frequency and maximum voltage gain according to load resistance

Load [Ω]	2 layer		4layer	
	Voltage gain	Resonance frequency [MHz]	Voltage gain	Resonance frequency [MHz]
5	0.07	1.71	0.068	1.063
10	0.055	1.72	0.185	1.070
30	0.282	1.72	0.482	1.072
50	0.326	1.73	0.612	1.073
100	0.532	1.75	0.97	1.077

The curves in Fig. 7, indicating the increment of maximum voltage gain measured at each resonance frequency according to the changes of load resistance, shows that the four layered ceramics has more voltage gain than the two layer one. The maximum voltage gains and the resonance frequencies according to each load resistance are figured out in Table 1.

4. CONCLUSION

The results from an experiment on the newly designed piezoelectric transformer for a switching power supply are as follows:

1) The input and output voltage draws a sine curve in the driving circuit designed for the piezoelectric transformer.
2) The voltage gain of the four layer piezoelectric transformer is twice as high as that of the two layer one.

The major object of this experiment was to prove the applicability of a driving circuit designed for the piezoelectric transformer and to obtain its higher output voltage in the case of our using multi-layered ceramic materials the data also showed that designing the feedback control circuit, and the. piezoelectric ceramic transformer could have wide application.

REFERENCES

[1] O. Ohnishi, H. Kishie, A. Iwamoto, Y. Sasaki, T. Zaitsu, and T. Inoue, "Piezoelectric ceramic transformer operating in thickness extensional vibration mode for power supply", *IEEE Ultrasonic Symposium Proc.*, pp. 483-488, 1992.

[2] T. Zaitsu, T. Inoue, O. Ohnishi, A. Iwamoto, "2MHz power converter with piezoelectric ceramic transformer", *IEEE INTELEC Proc.*, pp. 430-437, 1992.

[3] S. Kawashima, O. Ohnishi, H. Hakamata, S. Tagami, A. Fukuoka, T. Inoue, and S. Hirose, "Third order longitudinal mode piezoelectric ceramic transformer and its application to high-voltage power inverter", *IEEE International Ultrasonic Symposium Proc.*, Nov. 1994.

[4] J. I. Hong, H. J. Yoo, S. H. Yoon, H. K. Yoon, W. N. Jang and Y. C. Park, "Structural and Electrical Porperties of $PbTiO_3$ System as a Function of MnO_2 Addition", *KIEE*, Vol. 44, No. 11. pp. 1488-1493, 1995.

[5] J. H. Yoo, J. I. Hong, S. H. Lee, I. H. Lim, S. J. Kim, "Voltage Gain Characteristics of Piezoelectric Transformer Operating in Second Thickness Extensional Vibration Mode", *KIEEME*, Vol. 11, No. 10, pp.855-860, 1998.