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Design Analysis of Step-down Multilayer Piezoelectric Transformer

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ABSTRACT

In this paper, 11 and 13 layered step-down piezoelectric transformers were fabricated and their electrical characteristics have been analyzed for AC-adapter When the voltage is applied to the driving piezoelectric vibrator polarized in the longitudinal direction, the output voltage is generated at the generating piezoelectric vibrator polarized in the thickness direction due to the piezoelectric effects. From the piezoelectric direct and converse effects, symbolic expressions between the electric inputs and outputs of the step-down piezoelectric transformer are derived with an equivalent circuit model With those expressions, load and frequency characteristics are discussed through the simulations. Output voltage and current from a 11-layered and a 13-layered piezoelectric transformers were measured under the different load and frequency conditions. First we measured resonant frequency from impedance curve and got equivalent impedance value of the piezoelectric transformer from admittance plot It was shown from experiments that output voltage increases and resonant frequency changes according to the various resistor loads Output current decreases inversely proportional to the change of loads Moreover, the measured output voltage and current are well matched with the simulated results obtained from the proposed equivalent circuit model Furthermore, a new step-down piezoelectric transformer has been suggested to increase the output power based on a simulation result having a driving piezoelectric vibrator polarized thickness direction

Keywords: step-down,piezoelectric transformer,analysis,simulation,multilayer

1. Introduction

Recently, compact size of electronic instrument with high power is requested in the electronic equipment These elements would however require small size, high efficiency, no electromagnetic noise of component One of the key solutions to this is piezoelectric transformer[1][2] It is a device that converts electrical energy to mechanical vibration and the mechanical stress to electrical output. It has many advantages compared with electromagnetic structure, high efficiency and relatively low electromagnetic noise[3][4].

From the original piezoeletric transformer proposed by C. A Rosen, theoretical and applicative studies were started by many researchers and one of them introduced a multilayer piezoelectric transformer[5]. Moreover, diverse forms of piezoelectric transformer were proposed with the issues of electromechanical characteristics of polarization and vibration direction[6]

In this paper, step-down Rosen type piezoelectric transformer is introduced for AC- adapter.

When voltage is applied to the driving piezoelectric vibrator polarized in the longitudinal direction, the output voltage is then detected at the generating piezoelectric vibrator polarized in the thickness direction due to the

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piezoelectric effects.

From the piezoelectric direct and converse effects, symbolic expression has been derived for step-down piezoelectric transformer with an equivalent circuit model. Load characteristics and frequency response are then discussed. Output voltage and current from a 11-layered and a 13-layered piezoelectric transformers were measured under the various conditions of loads and frequencies. Resonant frequency is then obtained from impedance curve and equivalent impedance of the transformer from admittance plot.

From the experiments, it is important to note that output voltage could increase and resonant frequency can be obtained according to the various resistor loads. Output current however decreases inversely proportional to the increase of load resistance. Furthermore, equivalent circuit model has been suggested for the simulation of output voltage and current, and their results are well matched with the experimental data.

2. The equivalent circuit model of step-down piezoelectric transformer

Fig. 1 shows the structure of Rosen type multilayer step-down piezoelectric transformer. When voltage is applied to the driving piezoelectric vibrator polarized in the longitudinal direction, the output voltage is then detected at the generating piezoelectric vibrator polarized in the thickness direction due to the piezoelectric effects.

We can draw an equivalent circuit model of the step-down piezoelectric transformer from Mason's equivalent circuit as shown in Fig. 2. We can analyze and simulate electrical characteristics of a step-down piezoelectric transformer based on Fig. 2.

In this equvalent model, F and U are the force and the particle velocity on the surface of the vibrator.. Z_E^{LC} is the clamped impedance, N the ideal transformer turn-ratio. and a and b are

$$a = Z_0 \tanh(\frac{\gamma L}{2}), \quad b = \frac{Z_0}{\sinh(\gamma L)}$$

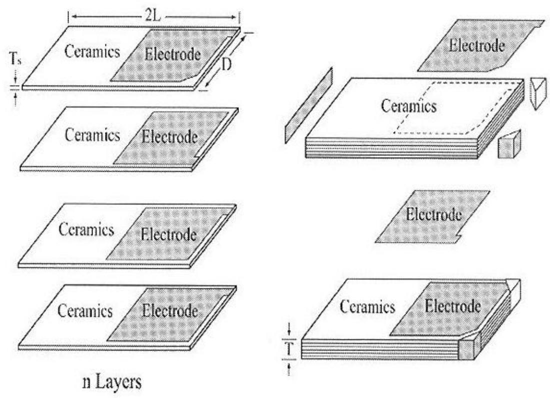

Fig. 1. The structure of a Rosen type multiplayer piezoelectric transformer.

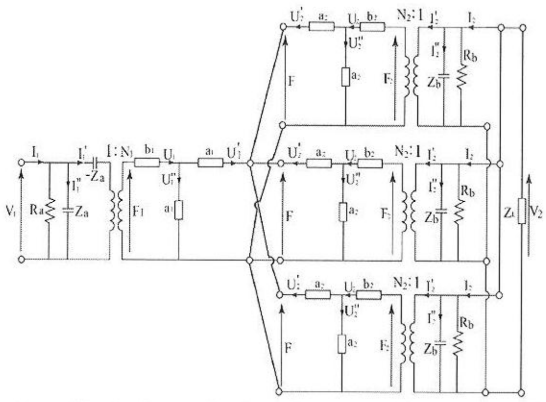

Fig. 2. Equivalent circuit of a step-down piezoelectric transformer.

where Z_0, L and γ are the mechanical characteristic impedance, half-length of the vibrator and the propagation constant, respectively.

From Fig. 2, the electromechanical equations between the electric input V_1, I_1, F(force), U(particle velocity) can be derived as (1). Also the electromechanical equations between the electric output V_2, I_2 and mechanical input F and U can be derived as (2).

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} C_{11} C_{12} \\ C_{21} C_{22} \end{bmatrix} \begin{bmatrix} F \\ U \end{bmatrix} \quad (1)$$

C_{11}, C_{12}, C_{21}, C_{22} in the equations are as follow,

$$C_{11} = \frac{a_1 + b_1 + jN_1^2 X_1}{a_1 N_1}$$

$$C_{12} = -\frac{a_1^2 + 2a_1b_1 + j2a_1N_1^2X_1}{a_1N_1}$$

$$C_{21} = \frac{(R_a - jX_1)(a_1 + b_1) + N_1^2X_1^2}{ja_1N_1R_aX_1}$$

$$C_{22} = \frac{(R_a - jX_1)(a_1^2 + 2a_1b_1) + 2a_1N_1^2X_1^2}{ja_1N_1R_aX_1}$$

$$\begin{bmatrix} F \\ U \end{bmatrix} = \begin{bmatrix} D_{11} D_{12} \\ D_{21} D_{22} \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} \quad (2)$$

D_{11}, D_{12}, D_{21}, D_{22} in the equations can be

$$D_{11} = -\frac{2a_2N_2^2X_2^2R_b + (2a_2b_2 + a_2^2)(R_b - jX_2)}{ja_2N_2R_bX_2}$$

$$D_{12} = \frac{2a_2N_2^2X_2^2R_b + (2a_2b_2 + a_2^2)(R_b - jX_2 - jR_bX_2)}{ja_2N_2R_bX_2}$$

$$D_{21} = \frac{2a_2N_2^2X_2^2R_b + (2a_2b_2 + 2a_2^2)(R_b + jX_2)}{j2a_2^2N_2R_bX_2}$$

$$D_{22} = -\frac{2a_2N_2^2X_2^2R_b + (2a_2b_2 + 2a_2^2)(R_b - jX_2 - jR_bX_2)}{j2a_2^2N_2R_bX_2}$$

From the equation (1) and equation (2), electrical input-output equation of step-down piezielectric transformer can be derived as (3), (4)

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} K_{11} K_{12} \\ K_{21} K_{22} \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} \quad (3)$$

$$K_{11} = C_{11}D_{11} + C_{12}D_{21}$$
$$K_{12} = C_{11}D_{12} + C_{12}D_{22}$$
$$K_{21} = C_{21}D_{11} + C_{22}D_{21}$$
$$K_{22} = C_{21}D_{12} + C_{22}D_{22}$$

$$\begin{bmatrix} V_2 \\ I_2 \end{bmatrix} = \frac{1}{K_{11}K_{22} - K_{12}K_{21}} \begin{bmatrix} K_{22} - K_{12} \\ -K_{21} K_{11} \end{bmatrix} \begin{bmatrix} V_1 \\ I_1 \end{bmatrix} \quad (4)$$

3. Experimental results and simulations

In this experiment, commercially available compound was used to fabricate the devices To analysis electrical characteristics, we have to know measured and calculated resonant frequency values of the step-down piezoelectric transformer The resonant frequency is expressed as equation (5)

$$f_r = \frac{1}{L\sqrt{\rho s_{11}^E}} \quad (5)$$

In this equation, ρ is the density of piezoelectric transformer and S_{11}^E is elastic compliance when electric field(E) is constant. L is the length of the piezoelectric transformer. The lengths of 11-layered and 13-layered piezoelectric transformers are 35[㎜] and 41 6[㎜], respectively. The thicknesses of 11-layered and 13-layered are 1 70[mm] and 1.88[mm]. From equation (5), resonant frequency is calculated to be 88 7[㎑] for 11-layered and 74.5[㎑] for 13-layered From the impedance curve, resonant frequency is measured of 89 4[㎑] for 11-layered device and 74.6[㎑] for 13-layered. Output voltage and current from a 11-layered and a 13-layered piezoelectric transformers were measured under the various conditions of loads and frequencies. Using equation 4, output voltage characteristics of a 11-layered piezoelectric transformer is simulated shown in Fig. 3 to compare the result with that obtained from the experimental data shown in Fig. 4 and they show good agreement

Fig. 5 shows experimental results of output voltage under the load resistances of 10[Ω]~1[kΩ] and various driving frequencies when input voltage is 100[Vp-p] from a 11-layered piezoelectric transformer

Fig 6 represents the experimental results of output voltage for 13-layered device under the same condition with 11-layered device

Fig 7 and Fig 8 show good agreement of the simulation with the experiment of output current for 11-layered piezoelectric transformer under the load resistances of 10~100[Ω] with various driving frequencies when input voltage is 100[Vp-p].

Fig. 9 and Fig. 10 represent the simulation and experimental characteristics of output voltage for 13-layered piezoelectric transformer with a reliable tendency.

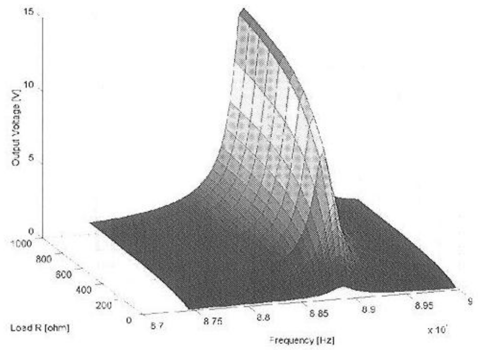

Fig. 3. Output voltage characteristics of a 11-layered piezoelectric transformer (simulation).

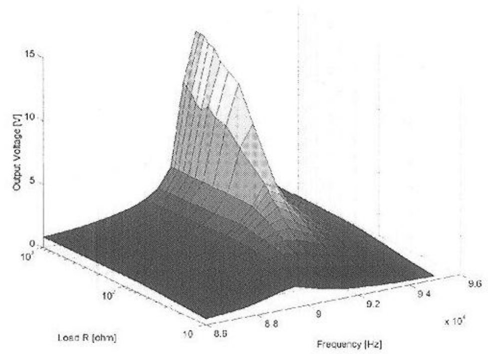

Fig. 4. Output voltage characteristics of a 11-layered piezoelectric transformer (experiment).

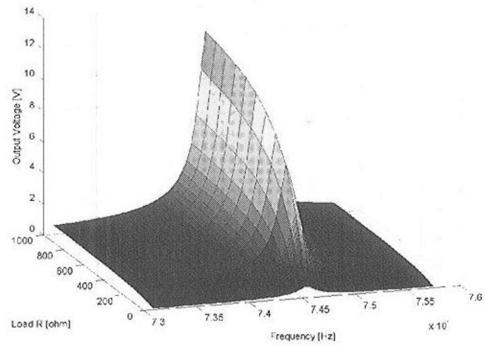

Fig. 5. Output voltage characteristics of a 13-layered piezoelectric transformer (simulation).

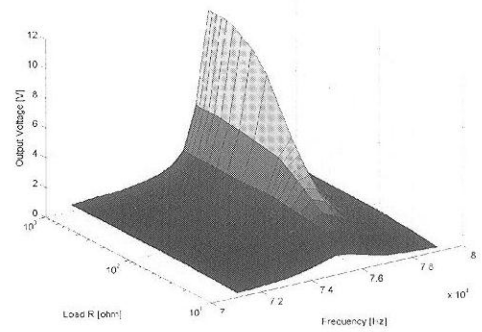

Fig. 6. Output voltage characteristics of a 13-layered piezoelectric transformer (experiment).

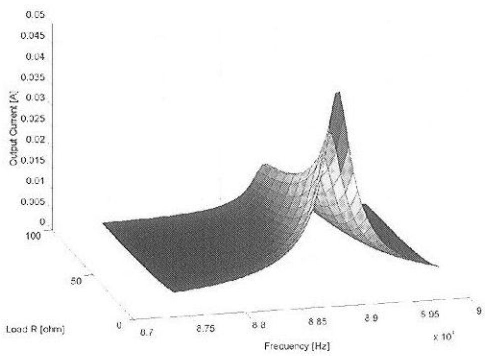

Fig. 7. Output current characteristics of a 11-layered piezoelectric transformer (simulation).

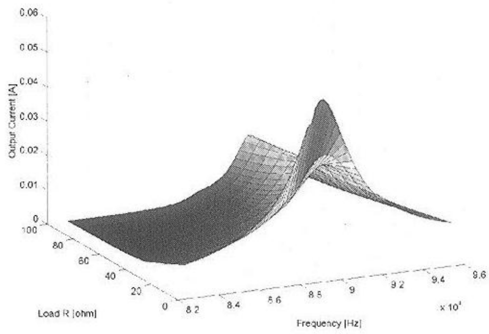

Fig. 8. Output current characteristics of a 11-layered piezoelectric transformer (experiment).

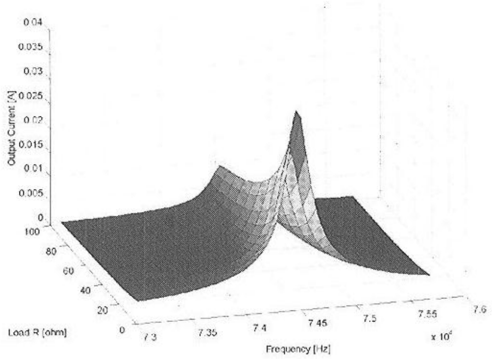

Fig. 9. Output current characteristics of a 13-layered piezoelectric transformer (simulation).

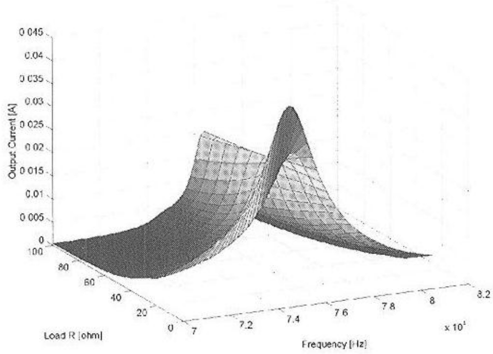

Fig. 10. Output current characteristics of a 13-layered piezoelectric transformer (experiment).

From the comparison, output voltage is 1.64[Vp-p] for 11-layer piezoelectric transformer and 1.31[Vp-p] for 13-layered piezoelectric transformer under input voltage of 100[Vp-p] and load of 10[Ω]. As the load resistance increases, output voltage also increases and almost unchangeable under the load over 200[Ω] for 11-layered and the load over 100[Ω] in case of 13-layered piezoelectric transformer.

Output current decreases inversely proportional to the load variation. It is 50.5[mA] for a 11-layered and 41.5[mA] for 13-layered under the input voltage of 100[Vp-p] and load of 10[Ω]. According to the increase of the load, output current decreases rapidly. Under the load over 100[Ω], output current ranges from 1to 3[mA], irregularly.

From the results, output power is about 0.3[W] at the steady state. The output power of the general Rosen type step-down piezoelectric transformer is comparatively small for the real application. We therefore suggest a new step-down piezoelectric transformer for the possible work. That has a driving piezoelectric vibrator polarized thickness direction shown in Fig. 11 to show a new type of structure.

Fig. 12 and Fig. 13 depict both the simulation results of output voltage and current for new step-down piezoelectric transformer. The output power was calculated within a range of 0.9[W].

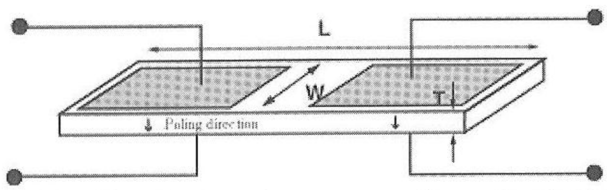

Fig. 11. The structure of a new step-down piezoelectric transformer.

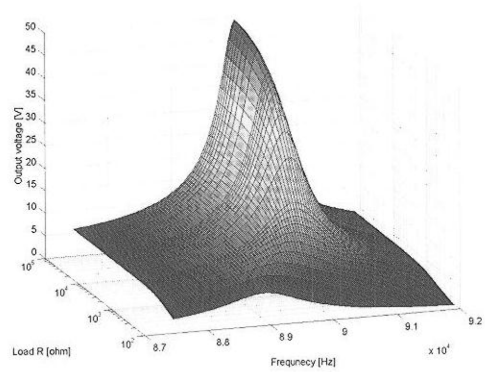

Fig. 12. Output voltage characteristics of a anew type step-downed piezoelectric transformer (simulation).

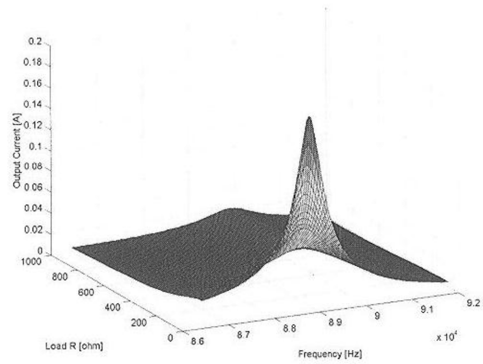

Fig. 13. Output current characteristics of a new type piezoelectric transformer (simulation).

4. Conclusions

In this paper, we have designed and analyzed the electrical characteristics of 11-layered and 13-layered step-down multilayer piezoelectric transformers. Symbolic expressions from the equivalent circuit are derived and simulated to compare with the experimental data. Resonant frequency measured from the impedance curve was also compared with the data calculated from a symbolic expression. Output voltage and current are also theoretically derived from the proposed equivalent circuit model and compared with the experimental data with a good agreement under the various conditions of loads and frequencies. It is found that resonant frequency has then shifted according to the variation of loads. But this step-down piezoelectric transformer output power is small for AC-adapter.

Finally a new type of step-down piezoelectric transformer is proposed to obtain a high power to implement in the real applications with the simulation results of output voltage and current

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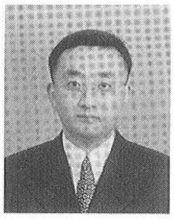

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