# Electrical Charateristics of Step-down Piezoelectric Transformer

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**Abstract**

In this paper, we have explained electrical characteristics of a step-down Rosen type piezoelectric transformer for AC-adapter. When the electric voltage is applied to the driving piezoelectric vibrator polarized in the longitudinal direction, then 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 have derived with an equivalent circuit model. With the symbolic expressions, load and frequency characteristics have discussed through simulation. Output voltage and current from a 11-layered and a 13-layered piezoelectric transformers were measured under the various conditions of loads and frequencies. 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 has increased and resonant frequency has changed according to various resistor loads. Output current has decreased inversely proportional to changing of loads. Moreover, the measured values of output voltage and current are well agreed with the simulated values of the proposed equivalent circuit model.

## I. Introduction

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

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[4].

Moreover, diverse forms of piezoelectric transformer were proposed with the issues of electromechanical characteristics of polarization and vibration direction[5].

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 piezoelectric effects.

From the piezoelectric direct and converse effects, symbolic expression has been derived 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 transformer 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 results, it is important to note from experiments that output voltage could increase and resonant frequency is 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.

## II. The equvalent circuit model of step-down piezoelectric transformer

Fig. 1 shows the stucture 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.

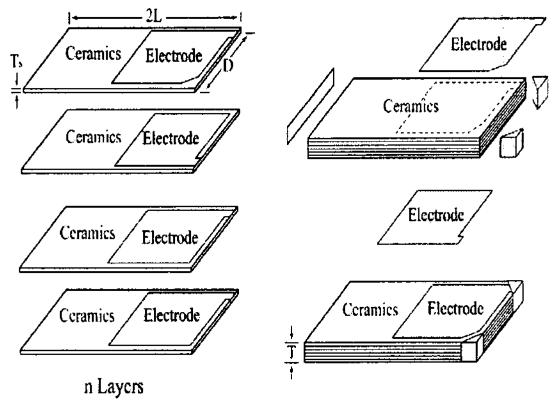


Fig. 1 The structure of a Rosen type multiplayer piezoelectric transformer

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 step-down piezoelectric transformer from Fig. 2.

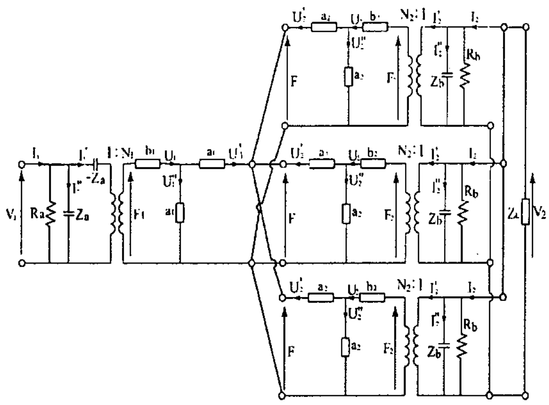

Fig. 2 Equivalent circuit model of a step-down piezoelectric transformer

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

$$a = Z_0 \tanh(\frac{\gamma L}{2})$$

$$b = \frac{Z_0}{\sinh(\gamma L)}$$

where $Z_0$, L and $\gamma$ 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). A 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,

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

$$C_{12} = -\frac{a_1^2 + 2a_1 b_1 + j2a_1 N_1^2 X_1}{a_1 N_1}$$

$$C_{21} = \frac{(R_a - jX_1)(a_1 + b_1) + N_1^2 X_1^2}{ja_1 N_1 R_a X_1}$$

$$C_{22} = \frac{(R_a - jX_1)(a_1^2 + 2a_1 b_1) + 2a_1 N_1^2 X_1^2}{ja_1 N_1 R_a X_1}$$

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

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

$$D_{11} = -\frac{2a_2 N_2^2 X_2^2 R_b + (2a_2 b_2 + a_2^2)(R_b - jX_2)}{ja_2 N_2 R_b X_2}$$

$$D_{12} = \frac{2a_2 N_2^2 X_2^2 R_b + (2a_2 b_2 + a_2^2)(R_b - jX_2 - jR_b X_2)}{ja_2 N_2 R_b X_2}$$

$$D_{21} = \frac{2a_2 N_2^2 X_2^2 R_b + (2a_2 b_2 + 2a_2^2)(R_b + jX_2)}{j2a_2^2 N_2 R_b X_2}$$

$$D_{22} = -\frac{2a_2 N_2^2 X_2^2 R_b + (2a_2 b_2 + 2a_2^2)(R_b - jX_2 - jR_b X_2)}{j2a_2^2 N_2 R_b X_2}$$

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

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

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

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

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

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

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

**Ⅲ.Experimental results and simulations**

To analysis electrical characteristics, we have to know measured and calculated resonant frequency value 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, $\rho$ 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 length of 11-layered and 13-layered piezoelectric trasformer are 35[㎜] and 41.6[㎜], respectively

From the equation (5), resonant frequency is caculated that 11-layered is 88.7[㎑] and 13-layered is 74.5[㎑]. And from impedance curve, resonant frequency is measured that 11-layered is 89.4[㎑] and 13-layered is 74.6[㎑].

Output voltage and current from a 11-layered and a 13-layered piezoelectric transformer were measured under the various conditions of loads and frequencies. Using the equation 4, we simulated the characteristics with matlab.

Fig. 5 shows experimental results of output voltage under the load resisrances of 10[Ω]~1[kΩ] and various driving frequencies when input voltage is 100[Vp-p] from a 11-layered piezoelectric transformer. The simulation results of the 11-layer piezoelectric transformer is Fig. 4.

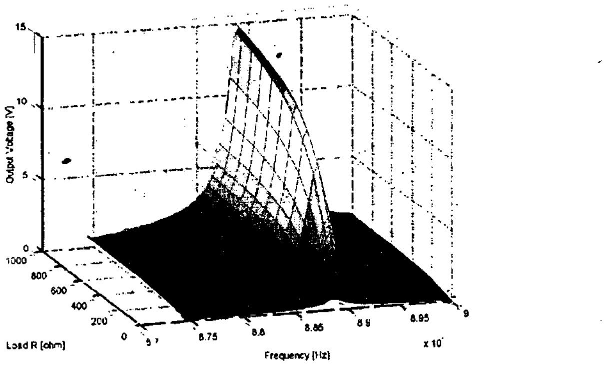


Fig.3 Output voltage characteristics of a 11-layered piezoelectric transformer (simulation)

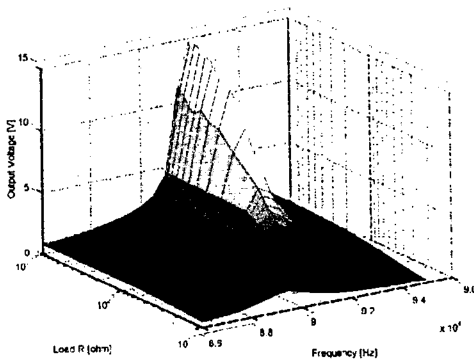


Fig.4 Output voltage characteristics of a 11-layered piezoelectric transformer (experiment)

Fig. 5 is the experimental results of output voltage under the same condition from a 13-layered piezoelectric transformer. The simulation results of the 13-layered piezoelectric transformer is Fig. 6.

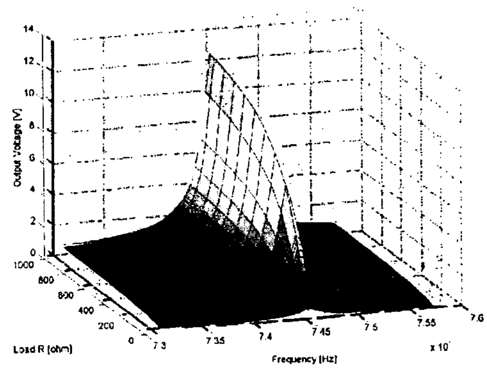


Fig.5 Output voltage characteristics of a 13-layered piezoelectric transformer (simulation)

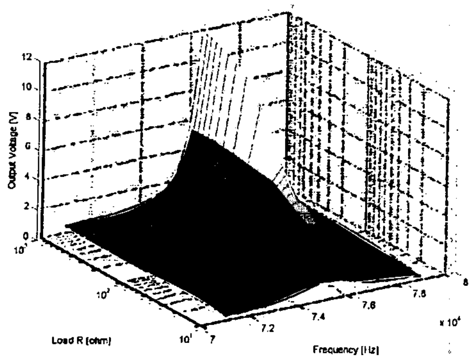


Fig.6 Output voltage characteristics of a 13-layered piezoelectric transformer (experiment)

Fig. 7, Fig. 8 show the simulation and experimental results of output current under the load resisrances of 10[Ω]~ 100[] and various driving frequencies when input voltage is 100[Vp-p] from a 11-layered piezoelectric transformer.

Fig. 9, Fig. 10 show the simulation and experimental characteristics of output voltage under the same condition from a 13-layer piezoelectric transformer.

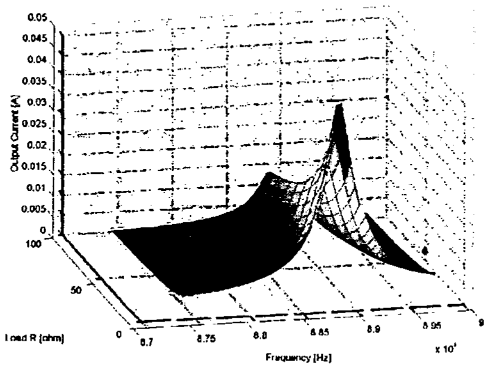


Fig. 7 Output current characteristics of a 11-layered piezoelectric transformer (simulation)

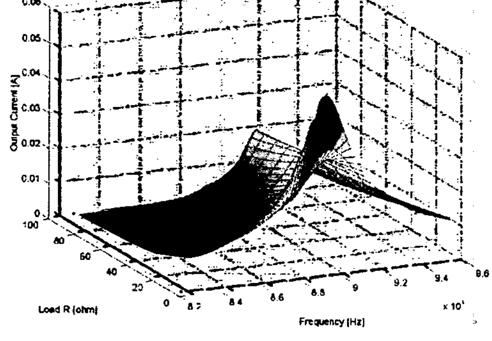


Fig. 8 Output current characteristics of a 11-layered piezoelectric transformer (experiment)

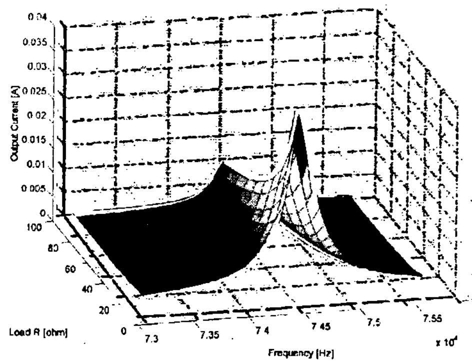


Fig. 9 Output current characteristics of a 13-layered piezoelectric transformer (simulation)

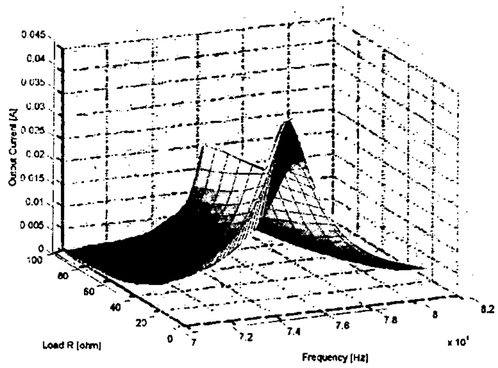


Fig. 10 Output current characteristics of a 13-layered piezoelectric transformer (experiment)

## Ⅳ. Conclusions

In this paper, we have analyzed electrical charateristics of 11-layered and 13-layered step-down multilayer piezoelectric transformers and have compared with simulation. We have compared resonant frequency measured from impedance curve with that caculated from symbolic expression. We have mesured and analyzed output voltage and currenrt under the various condition of loads and frequencies.

Resonant frequency has shifted according to variation of the load .

Output voltage is 1.64[Vp-p] from a 11-layer piezoelectric transformer and 1.31[Vp-p] from a 13-layered piezoelectric transformer under input voltage 100[Vp-p], load 10[Ω]. As the load resistance increase, output voltage has increased and unchanged under load over 200[Ω] from 11-layer piezoelectric transformer and under load over 100[Ω] from 13-layered piezoelectric transformer.

Output current has decreased inversely proportional to change of loads. It is 50.5[mA] from a 11-layered piezoelectric transformer and 41.5[mA] from a 13-layered piezoelectric transformer under input voltage 100[Vp-p], load 10[Ω], According to increasing the load, output current has decreased rapidly. Under load over 100[Ω], output current is 1 ~ 3[㎃], irregularly.

Measured values of output voltage and current has well agreed with simulated values of the proposed equivalent circuit model.

For the next time, we have to study to increase output current for AC-adapter

**Referennces**


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