Comparative Analysis of Driving Inverters for the Piezo-Electric Transformer

Yoichi ISHIZUKA[1], Souichirou SHIMOKAWA[1], Fujio KUROKAWA[1], Hirofumi MATSUO[1], Kengo KIMURA[2] and Nanjo AOIKE[2]

[1] Department of Electrical and Electronic Engineering, Faculty of Engineering, Nagasaki University,
1-14 Bunkyo-machi Nagasaki-shi, Nagasaki, 852-8521 Japan
Tel. +81-95-847-1111(2670), Fax.: +81-95-846-7379

[2] Sanken Electric Co., Ltd.
3-6-3 Kitano, Niiza-shi, Saitama-ken, 352-8666 Japan
e-mail : isy2@net.nagsaki-u.ac.jp

Abstract: Comparative analysis of driving inverters for piezo-electric transformer (PT) is performed and the suitable drive circuit for portable devices such as personal digital assistants (PDA) is chosen with the experiment in this paper. As a result, a single-switch inverter with a small two winding reactor is chosen, and then the advantages of this method are clarified. It is also confirmed that the driving inverter with this method enables to realize a stabilized AC 400V output and 82% power efficiency from DC 3V input under the conditions of the variations of load current or input voltage from the experiments.

Keyword: Piezo-electric Transformer, Back-Light System, Single-Switch Driving Circuits, Control Method

1. Introduction

A piezo-electric transformer (PT) has superior characteristics such as compact size, thinness, high voltage gain, high power density and so on.

This great device is usually applied for the driving inverters of the back-light system of cold cathode fluorescent lamp (CCFL) for liquid crystal displays (LCD) of notebook PC or personal digital assistants (PDA) because of the features mentioned above.

A requirement of the driving inverter in practical use is a high voltage gain, that is, several hundreds of AC output voltage is obtained from several DC input voltage. In this case, the output frequency of the inverter is set as the lamp frequency of CCFL.

Therefore, in the total thinking, the driving inverter for PT requires the features such as compact-size, lightweight, high voltage gain, high power efficient and low harmonic distortion of output voltage. In addition, it is required to design the circuit adapted to the resonant characteristic of PT.

The purpose of this research is to compare some common driving inverters for PT, theoretically and experimentally that has not been discussed enough in the past. The best driving inverter is selected which satisfies the requirements and is suitable to the backlight system.

2. Comparative Analysis of Driving Inverter

2.1 Piezo-Electric Transformer

Figure 1 shows a picture of Rosen-type structure PT used in the experiment. The highest voltage gain is 81 and largest power efficiency is 91% at near 57kHz. Fig. 2 (a) and (b) show the frequency characteristics of voltage gain and power efficiency of only the PT, respectively. It is confirmed that the resonant frequency is about 57kHz.

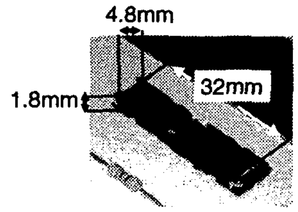
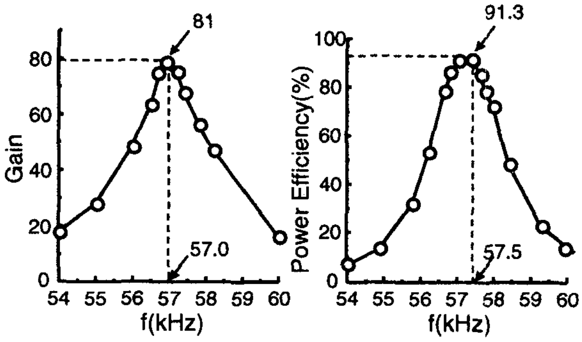


Fig.1 The piezo-electronic transformer.



(a)Voltage Gain (b) Power Efficiency

Fig. 2 Voltage gain and power efficiency versus frequency.

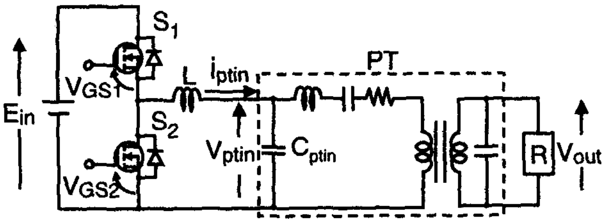
2.2 Driving Inverters for the Piezo-Electric Transformer

The driving inverters for Rosen-type structure of PT, which are a half-bridge type with two switches and two boost types with a single switch, are discussed in this research.

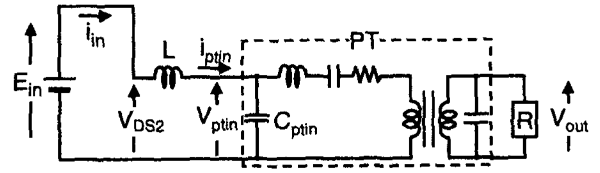
Figure 3 shows a main circuit and equivalent circuits of each state of a half-bridge type inverter with two switches. Fig. 4 shows a main circuit and equivalent circuits of a single switch inverter with a conventional single winding reactor. Fig. 5 shows a main circuit and equivalent circuits of a single switch inverter with a small two winding reactor. In Figs. 3, 4 and 5, the dotted line area shows an equivalent electrical circuit model of PT[1] and R is load.

For circuit analysis, let us define the equivalent circuits of the inverter corresponding to the on and off conditions of the switch.

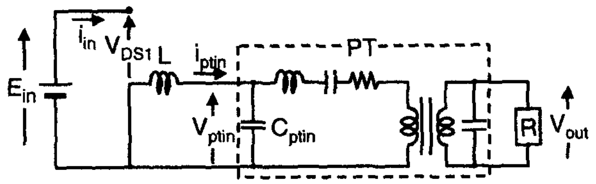
A half-bridge type inverter with two switches is composed of two switches S_1 and S_2 driven complementarily and a single winding reactor L for the resonance as shown in Fig. 3(a).



(a) Main circuit

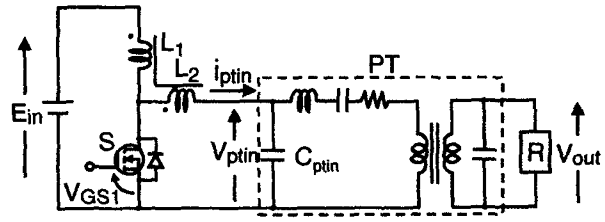


(b) State I

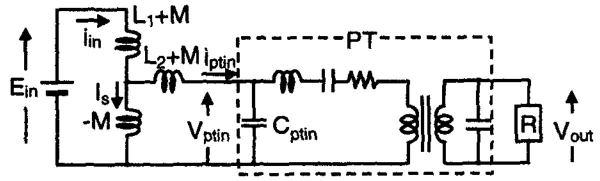


(c) State II

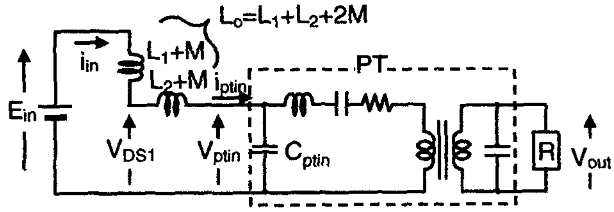
Fig.3 A half-bridge type with two switches inverter.



(a) Main circuit

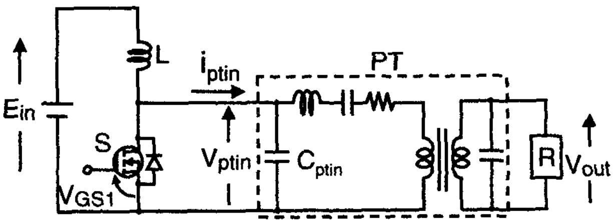


(b) State I

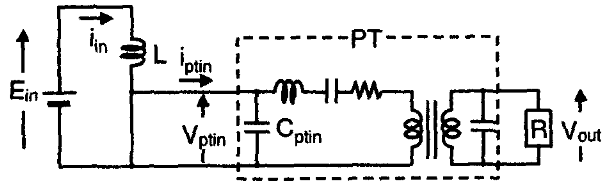


(c) State II

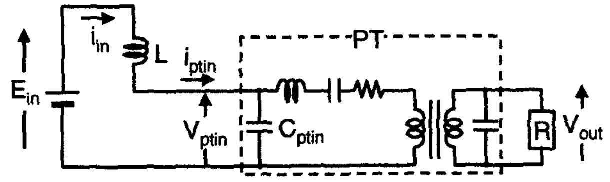
Fig. 5 A single switch inverter with a small two winding reactor.



(a) Main circuit



(b) State I



(c) State II

Fig. 4 A single-switch inverter with a conventional single winding reactor.

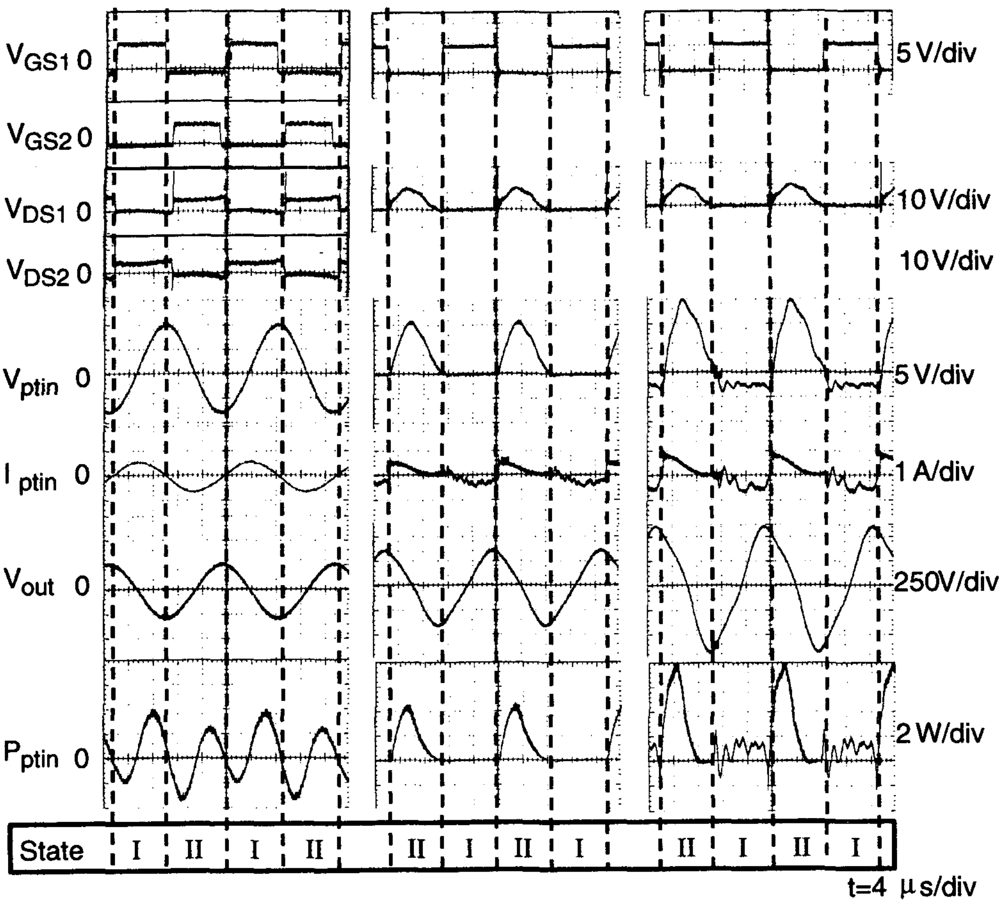
In state I in Fig. 3(b), S_1 is on and S_2 is off. Alternatively, in State II in Fig. 3(c), S_1 is off and S_2 is on. A state that both switches are off can be ignored for a simple discussion

Single switch inverters are composed of one main switch S and a single winding reactor L in Fig. 4. In Fig. 5, small two windings of reactors L_1 and L_2 have a loose coupling. A state that S is on in Figs. 4(a) and 5(a), State I appears as shown in Fig. 4(b) and Fig. 5(b), respectively. Alternatively, State II that S is off is shown in Fig. 4(c) and Fig. 5(c), respectively. In Fig. 5, $L_o=L_1+L_2+2M$. M is a mutual inductance.

2.3 Experimental Results

To compare these driving inverters, let us confirm the waveform of each part of the circuits by experiment. Experimental conditions are as follows: E_{in}=DC3V and R=100kΩ as input power source and load, respectively. In this case, a battery and CCFL are assumed to be employed. The value of the reactor L in Figs. 3 and 4 is 64μH, which is determined from the resonant frequency of PT and input capacitance C_{ptin}. In Fig. 5, L_o is determined from the resonant frequency of PT and C_{ptin}. Consequently, the values of two winding reactor L_1 and L_2 in Fig. 5 are 16.1μH and 15.8μH, respectively.

Figs. 6(a), (b) and (c) show the observed waveforms of the gate signals V_{GS1} and V_{GS2}, the drain-source voltage of the each switch V_{DS1} and V_{DS2}, the input voltage of PT V_{ptin}, the input current of PT I_{ptin}, the output voltage V_{out} and the input power P_{ptin} in three driving inverters shown in Figs 3, 4 and 5, respectively. In addition, the state numbers are indicated at the bottom.



(a) PT inverter shown in Fig. 3 (b) PT inverter shown in Fig. 4 (c) PT inverter shown in Fig. 5

Fig. 6 Waveforms of each driving inverter for PT.

For an efficient driving of PT, it is ideal to supply the input voltage V_{ptin} and current I_{ptin} which has only resonance frequency component because of the resonant characteristic of PT. From this reason, it is apparent that the significant points for driving of PT is the waveforms and amplitude of the input voltage V_{ptin} and current I_{ptin} of PT.

In Fig. 6(a), V_{ptin} and I_{ptin} represent the full-resonant waveforms whose frequency is 57kHz which almost equal to the resonant frequency of PT. The waveforms are very suitable for the input of PT cause of the resonant characteristics of it. However, the minus power is occurred by phase difference between V_{ptin} and I_{ptin} as shown in P_{ptin}. It can be seen that a part of minus power was lost with parasitic resistance or on-resistance of switches, which becomes energy loss. The power efficiency is 68.5% and the voltage gain is 62.8.

In Fig. 6(b), V_{ptin} and I_{ptin} represent the half-resonant waveforms whose frequency is 57kHz which almost equal to the resonant frequency of PT. The half-resonant waveforms have a little of high harmonics and the harmonic components will be lost in PT cause of the resonant characteristic of PT. However, the most of the input power of PT is plus that means all of input power is supplied to PT as shown in P_{ptin}. Therefore, the power efficiency is 89.5% and the voltage gain is 86.4.

In Fig. 6(c), the coupling of L_1 and L_2 boosts the input voltage of PT. A resonance is occurred with the reactor and large input capacitance C_{pd1} of PT. The waveform of each part is similar to that in Fig. 6(b). It can be seen that two winding reactor L_1 and L_2 boosts V_{ptin}. The peak value of V_{DS} is about 10V same as the other driving inverters. The power efficiency is 82.6% and the voltage gain is 131.

From these results, it is clarified that a single switch inverter with a small two winding reactor can realize the highest voltage gain which is enough for the driving for CCFL with the low drain-source voltage stress of the switch. In addition, the power efficiency of the single switch type inverter is superior to the two switches type inverter because the power factor of P_{ptin} in the single switch type inverter is higher than that of the two switches type one.

3. Control Method

In this section, the effective control method for a single switch inverter with a small two winding reactor are discussed.

The frequency control of the switch is the most effective for output voltage regulation because the voltage gain is largely changed with the switching frequency control by the resonant characteristic of PT. However, the off term of the switch needs to be equal to the half period of the resonance as shown in V_{DS1} in Fig. 6(c) to realize the soft-switching at all time. Therefore, the pulse frequency modulation (PFM) with fixed off term as shown in Fig. 7 is effective to control the driving inverter[2].

Figs.8 and 9 show the regulation characteristics of the amplitude of the output voltage V_{out} for the variation of the input voltage V_{in} and the load R, respectively. The range of the variation of V_{in} and R are assumed from 2.6V to 3V and from 80kΩ to 120kΩ, respectively.

From the results, the proposed control method can realize the regulation of the amplitude of V_{out} about 400V within 1% error. The power efficiency is kept over 82% for -20% variation of the input voltage and +/- 20% variations of the load.

4.Conclusion

Comparative analysis of driving inverters for PT is performed. As a result, it is revealed that a single switch inverter with a small two winding reactor is effective for portable devices such as PDA by the experiment. This driving inverter of PT is most appropriate because of compact-size, lightweight, high voltage gain and high power efficient for backlight systems of LCD of PDA. Also, using the battery as an input power source, this driving inverter enables to realize a stabilized AC 400V output and 82% power efficiency for –20% variation of the rated input voltage of 3V and +/-20% variation of the load with the rated resistance of 100kΩ.

Reference

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[2] T. Oyama, S. Shimokawa, Y. Ishizuka, F. Kurokawa, H. Matsuo, K. Kimura and N. Aoike, "Comparison of Single-Switch Driving Circuits for Piezoelectric Transformer Used in the Back-Light System," Techinal Report of IEICE. EE2002-15, pp.83-88, 2002.

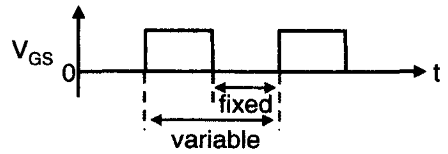

Fig. 7 The pulse frequency modulation (PFM) with fixed off term.

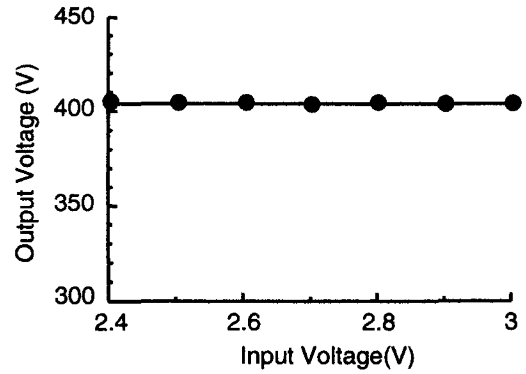

Fig. 8 Regulation characteristic of the output voltage E_O for the variation of the input voltage V_{in}.

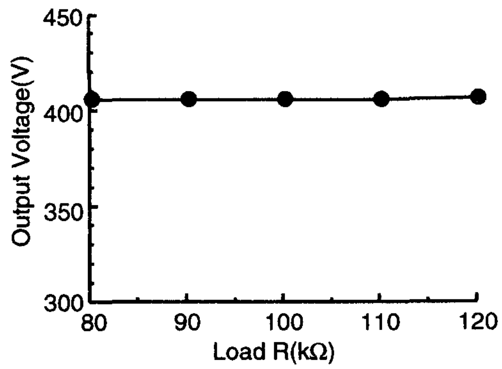

Fig. 9 Regulation characteristic of the output voltage E_O for the variation of the load R.