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A microprocessor controlled piezoelectric power converter

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Abstract- **Piezoelectric transformer (PT) for power conversion is receiving more and more attention because of its small thickness and high energy density. A major challenge of PT converter is the resonant characteristic of the PT that affects the performance of the whole converter. This paper presents a microprocessor controlled piezoelectric power converter system for Cold Cathode Fluorescent Lamp (CCFL) that can provide stable output around the resonant point of the PT. A micro-controller based control algorithm is introduced to provide frequency tracking. Experimental results are presented and illustrate that this system is suitable for such application.**

I. INTRODUCTION

Piezoelectric transformer for power conversion is receiving more and more attention. Its small thickness attracts many researchers to study and develop power converters based on it. Flynn [1] and Sanders calculated the limits on energy transfer for the Piezoelectric Transformer. The peak power density for a PZT-5H sample was calculated to be 330W/cm^3 at 100kHz. Lin [2] presented the principle, characteristic, application and different topology of Piezoelectric Transformer in details. The traditional Rosen Type PT or the new multi layer type piezoelectric transformers are generally considered outstanding to provide high voltage and high power density. The high power density and small thickness of piezoelectric transformer have also attracted researchers to study low voltage applications. Prieto, *et al.* [3] (2001) developed a topology suitable for PTs in DC/DC converters. It was operated at frequency around 500kHz and with input at 110Vac and output at 12Vdc, 8 watt. Recently Bove [4] and his group presented a new type piezoelectric transformer that produces 10-watt at 12Vdc output. More and more work on PT are being produced.

Generally speaking, there are two main directions for PT converter development nowadays. The first one is the Rosen type PT based step up converter which has good advantages for LCD backlight, since it is very thin for the portable device and there is no high voltage winding problems. The second direction is the low voltage output PT converter; this kind of converters is mainly the multi-layer piezoelectric transformer. However, the design, manufacturing and application techniques of multi-layer PT are still new compared with the mature Rosen type PT.

Piezoelectric transform has a number of drawbacks to overcome before it can become a popular power conversion component. A major issue is the variation of characteristics with operating conditions. The resonant characteristics of a piezoelectric transformer vary with the load and surrounding environment. This greatly increases the difficulty to control the PT converter. Once the piezoelectric transformer runs away from the resonant region, the performance of the PT will drop significantly. It will increase the PT dissipation and even reduce the life of the PT significantly. Moreover, the mechanical vibration characteristic of the PT makes the mounting and wiring challenge, which is not an issue at all in wire wound transformers.

This paper presents a microprocessor controlled piezoelectric CCFL converter. This microprocessor system controls a piezoelectric CCFL converter which select the correct resonant point for the PT to start and keep tracking the resonant point when the loading characteristic change, such as CCFL characteristic. A basic algorithm is designed to provide reliable output at keep tracking the resonant frequency. The microprocessor system is described and experimental results are presented.

II. BASIC PIEZOELECTRIC TRANSFORMER MODEL AND POWER CONVERSION CIRCUIT

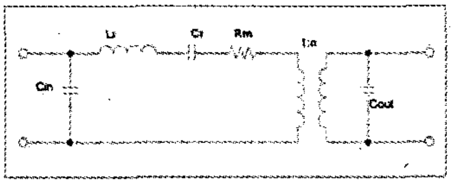

Figure 1. Conventional equivalent circuit model of piezoelectric transformer

Figure 1 shows a generic piezoelectric transformer model. Its operation is based on mechanical resonance of the structure whereby electrical energy is produced through exchange of mechanical energy. It is modeled by a resonant circuit. The parameters can be measured by an analyzer.

Figure 2 shows the measured gain characteristic of the PT which shows the resonant point of a 2Watts Rosen type PT to be used in our experiment. The characteristic shows several resonant peaks but one must confine operation to the highest peak in order to obtain the highest gain. However, the presences of multiple peaks make it difficult to control because the operating point may fall onto the wrong peak.

A good controller should have some intelligence to locate the operating point correctly and be able to keep it high on the characteristics. Hence, a narrow band and high-resolution frequency scanning mechanism is needed to ensure the system operates in the correct region.

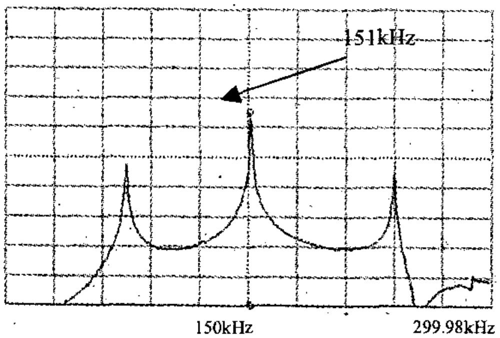

Figure 2. The typical PT gain characteristic measured by HP4194

Figures 3a&b shows a generic half bridge power conversion circuit using piezoelectric transformer. In fig. 3a an input matching network is sometimes employed shape the input waveform and reduce the current peak. It also provides soft switching. In order to get a balance between simple circuit design and good performance, a small low pass filter is used as the input-matching network. Figure 4 shows the filtered PT input voltage waveform.

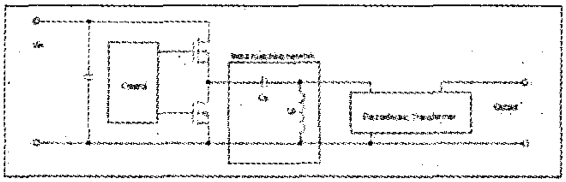

Figure 3a. Power conversion topology with an input matching network.

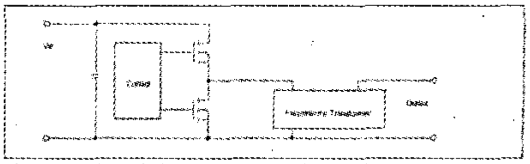

Figure 3b. Magnetic-less power conversion topology.

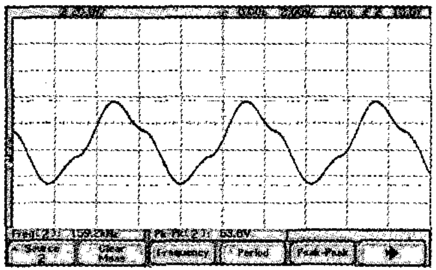

Figure 4. PT input voltage waveform.

III. A MICROPROCESSOR CONTROLLED SYSTEM

A microprocessor-controlled system is developed to control the piezoelectric power converter. A real time control algorithm is developed for the system.

Figure 6 shows the bock diagram of the system. An 8-bit resolution DAC is used to provide a fast and accurate control voltage. The voltage from the DAC is passed to a potential divider and added to the timing capacitor of the half bridge driver which has a RC oscillator. Hence, the potential divider parameters determine the span of frequency adjustment. However, the timing resistor of the half bridge driver determines the minimum switching frequency. This configuration omits the VCO generally needed for digital-frequency control. In fact, under this modification combines the function of VCO and half bridge driver and maximizes resolution under high frequency operation. Moreover, the span and the minimum setting can be changed easily by changing two resistors values only, so that the system can work with other piezoelectric transformers easily.

The high resolution frequency adjustment mechanism is a very important factor to control the piezoelectric transformer. As the resonant point of the PT is very sharp, the digital controlled frequency step must be fine enough to run on the resonant top without falling down. The CCFL experiment converter presented in this paper set a frequency band 15kHz around the resonant frequency with 8-bit resolution.

On the power switching stage, half-bridge configuration is used and matched with a low pass filter. A sensing circuit provides a low noise feedback voltage samples the output voltage of the converter. A low cost VCO converts the feedback voltage to a frequency feedback signal which can be read by the micro-controller. Figure 5 shows the good linearity of the feedback frequency. This mechanism provides high resolution feedback signal and avoids expensive high resolution AD converter.

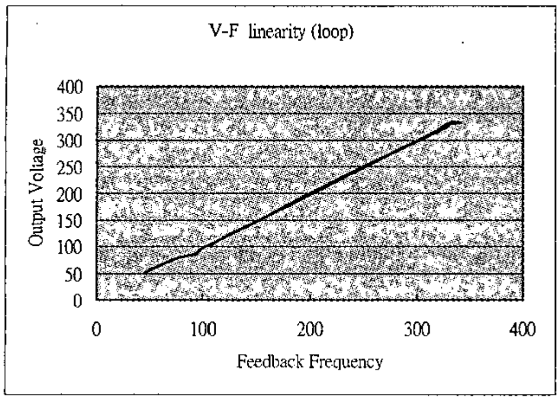

Figure 5. The linearity of the feedback frequency

A low cost MCS-51 micro-controller is used. The software inside the micro-controller continuously monitors the output and controls the DAC. The quality of the software greatly determines the performance of the converter. The other functions of the converter can be easily applied by a control signal and modify the program only without develop a circuit. In this system, the control hardware is minimized to one driving circuit and one feedback circuit only. All control functions are implemented by software. Hence, the merit of the micro-controller control can be enhanced that decrease the hardware cost and reduce the size.

This hardware system provides a low cost, simple and reliable platform to control the piezoelectric transformer converter.

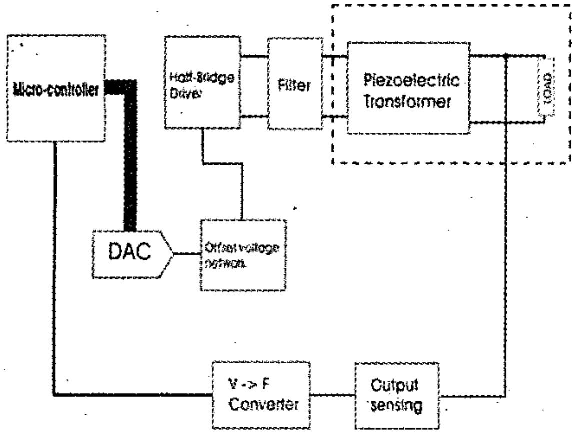

Figure 6. Block diagram of microprocessor based control circuit.

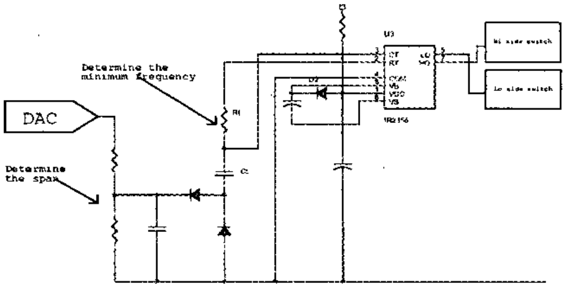

Figure 7. Circuit diagram of the frequency control mechanism.

IV. CONTROL ALGORITHM

Figures 8, 9& 10 show a full structure flow chart diagram of the control algorithm employed by the micro-controller in our experiment. Once the processor is started as shown in Figure 8, the program loads the default parameter of the program. It presets the left pointer start from zero and right pointer start from 255. It then enters the Maximum Gain Scanning (MGS) procedure that presented in Figure 9.

The main aim of MGS procedure is to find the resonant point at starting. The MGS procedure first monitors the gain of left pointer and then right, and then compare with each other. The program then let the left pointer go right continuously if the left pointer is smaller than right pointer gain and until it is larger than right pointer. If the case inverts, the right pointer is push to move left until the right pointer has larger gain than the left pointer. These steps will be looping accurately until the distance of pointer left and pointer right enter the preset stop distance as shown in Figure 11. On the assumption that the frequency steps resolution is high enough, the resonant peak is predicted to locate between or equal to the left and right pointers. Hence, the procedure output the mid point position of the left and right pointers and also output the feedback provides data to the main program and set this point to be the starting operation point.

The program will then analysis the result and decides if this point reliable and stable. If this point is reliable and stable, the program will go to the next command, otherwise the program will go back and run MGS procedure again until the stable resonant point is scanned out. This is an add-on function to the basic resonant tracking mechanism. This function aims to increase the reliability of the converter and provides auto recovery function.

After that, the program enters the Continuous Maximum Tracking (CMT) Procedure as shown in Figure 10 which maintains the converter working in maximum gain point. Inside the CMT procedure, the operating point move left one step to record the gain and then restore and move right one step to make another record. After comparing the two records, the program determines which direction to move and finally locked around the maximum point.

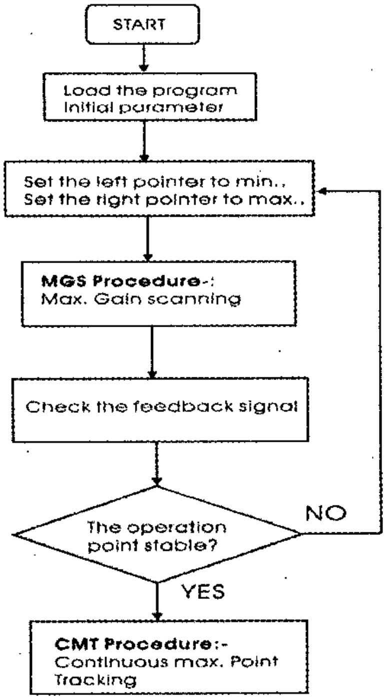

Figure 8. Flow chart of the main program

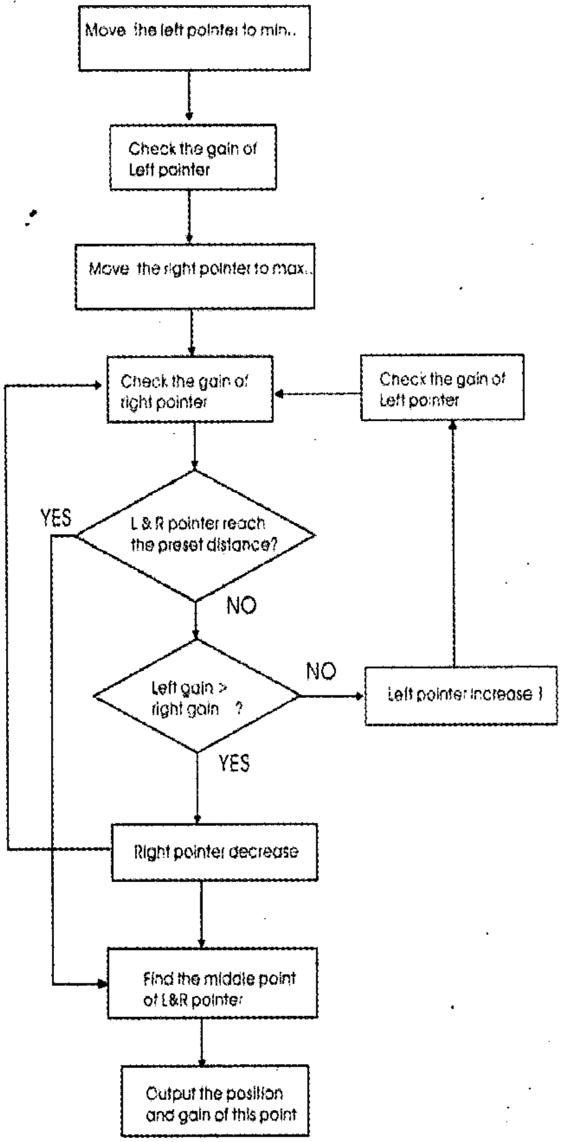

Figure 9. Flow chart of the Maximum Gain Scanning (MGS) Procedure.

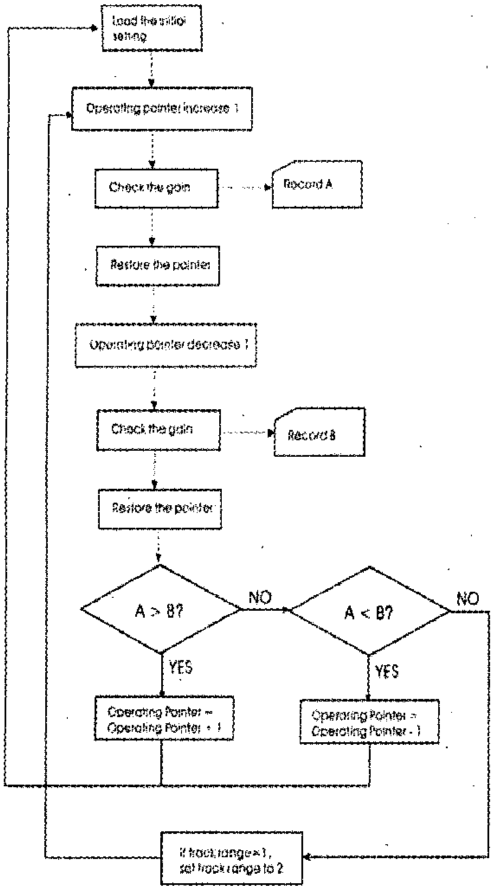

Figure 10. Flow chart of the Continuous Maximum Tracking (CMT) Procedure.

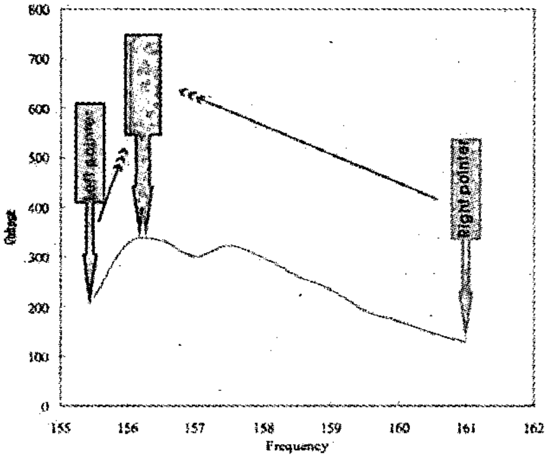

Figure 11. Movement of left and right pointer under the MGS procedure.

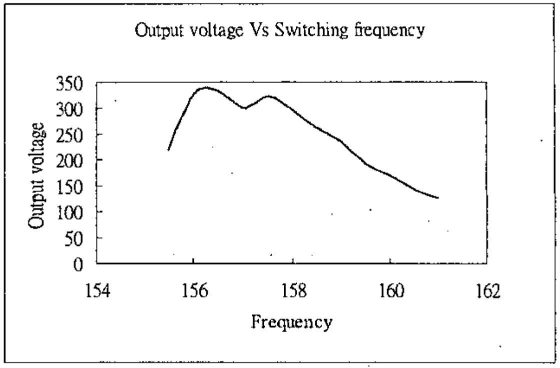

Figure 12. PT converter output characteristic under different switching frequency when loading a cold cathode fluorescent lamp.

Figure 12 shows the PT output characteristics with a CCFL load. The multi peak characteristic is caused by the impedance change of the lamp. This also indicates the movement of resonant point as shown in Figure 13. The control algorithm mentioned above is able to find the resonant point even under the multi peak gain characteristic. The MGS procedure is able to cover a large frequency range and select the maximum point accurately. However, the CMT procedure is limited by the speed of load change. Fortunately loads for PT application is usually smooth and stable.

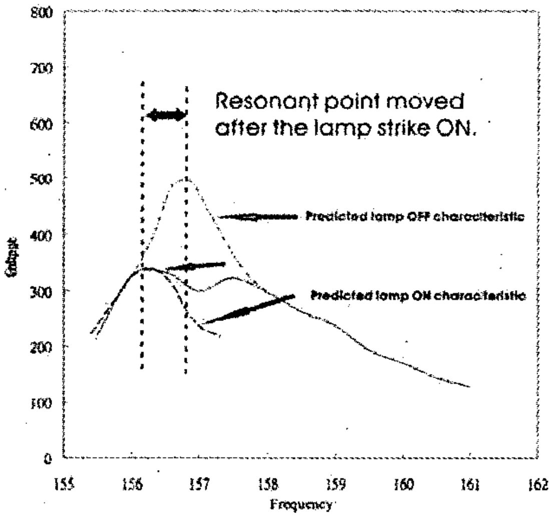

Figure 13. The change of load impedance makes the resonant point move.

V. EXPERIMENTAL RESULTS

Figure 14 shows the set up is small and thin that installed with a 2W Rosen type PT. Figure 15 and 16 show the results obtained from the experimental set up. The input voltage to the converter is 26Vdc and 30Vdc. The load is a CCFL.

Sine wave is produced across the CCFL load and the RMS value is measured by the CRO as well. The frequency measured by the CRO shows the resonant frequency is tracked by the microprocessor and the tracking is maintained smoothly.

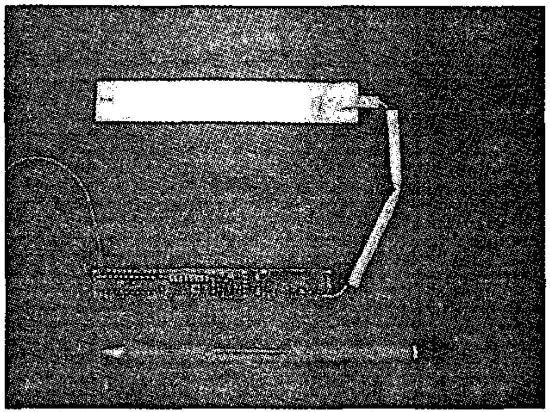

Figure 14. Finished microprocessor controlled PT CCFL converter.

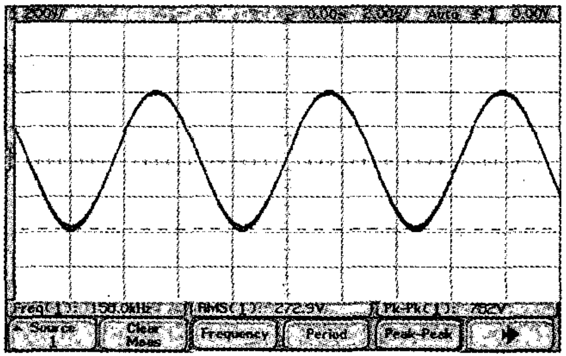

Figure 15. Output voltage waveform for 26V input.

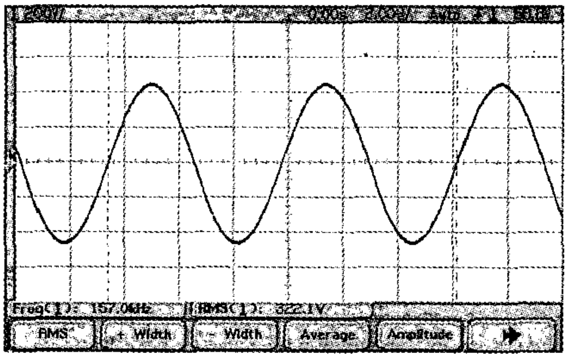

Figure 16. Output voltage waveform for 30V input.

VI. CONCLUSIONS

Piezoelectric transformer is an attractive component for power conversion because of its small thickness. A major drawback of the piezoelectric transformer is the sensitivity of its resonant characteristics to operation conditions. In this project a microprocessor system is designed and a versatile control algorithm is presented to provide stable operation of a piezoelectric power converter. Experimental results are presented and illustrates that this system is suitable for such application.

REFERENCES

[1] Anita M. Flynn and Seth R. Sanders, "Fundamental Limits on Energy Transfer and Circuit Considerations for Piezoelectric Transformers", IEEE Transaction on power electronics, vol 17, no 1, 2002.

[2] Chih-yi Lin, "Design and Analysis of Piezoelectric Transformer Converters" Ph.D Dissertation, Electrical engineering Dept., Virginia Polytechnic Institute and State University, 1997

[3] M. J. Prieto, J. Diaz, J. A. Martin, F. Nuno, "A Very simple DC/DC Converter Using Piezoelectric Transformer", Universidad de Oviedo – Area de Tecnologia Electronica, Spain, 2000.

[4] Torsten Bove, Wanda Wolny, Erling Ringgaard, Klaus Breboel, "New Type of Piezoelectric Transformer with Very High Power Density", Denmark, IEEE 2001.

[5] J.Navas, T.Bove, J.A.Cobos, F.Nuno, K.Brebol, "Miniaturised Battery Charger using Piezoelectric Transformers", ESPRIT project (TRAMST 25644), 2001.

[6] M.Sanz, P.Alou, R.Prieto, J.A.Cobos and J.Uceda, "Comparison of different alternatives to drive Piezoelectric Transformers", Universidad Politecnica de Madrid, ESPIRIT project #25644, 2002.

[7] Weiping Zhang, Weixing Huang, Dan Y.Chen and Fred C.Lee, "Characterization of Nonlinear Internal Resistance of a Power Piezoelectric Transformer", Virginia Polytechnic Institute and State University, 2001.

[8] Gregory Ivensky, Svetlana Bronstein, and Sam Ben-Yaakov, "Analysis and Design of a Piezoelectric Transformer AC/DC Converter in a Low Voltage Application", Power Electronics Laboratory, Ben-Gurion University of the Negev, IEEE 2002.

[9] R.Prieto, M.Sanz, J.A.Cobos, P.Alou, O.Garcia and J.Uceda, "Design Considerations of Multi-Layer Piezoelectric Transformers", Universidad Politecnia de Madrid, IEEE 2001.