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Low Voltage Power Supply Using Step-Down Piezoelectric Transformer

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A low voltage power supply was developed with a step-down piezoelectric transformer (PT), capable of supplying up to 4 A at an output voltage of 2 V, where the efficiency was estimated to be better than 80 %. The PT was 15 by 15 by 5 mm in size and composed of two layers at the primary and of 40 layers at the secondary. A new PT is manufactured with an improved process to have a reduced internal-loss and a higher Q value to deliver more than 5 A. The power supply has been studied extensively without an inductance in the driving circuitry and identified the issues to overcome.

Summary

The piezo-electric transformer (PT) converts the mechanical vibration to the electric power. The output side is made of lamination of multiple sheets, and by adding the electrodes in series, a step-up, i.e., low current-high voltage, and by adding in parallel, a step-down, i.e., high current-low voltage, power converters can be realized. The PT is made of ceramics and metal electrodes that are not affected by magnetic field, thus the power supply has a potential to be operated in a strong magnetic field. Isolation of the input and the output is easily realizable. A low voltage power supply using a step-down PT has been implemented.

The PT has intrinsic resonance frequencies. The sinusoidal voltage frequency supplied at the input of the PT is converted in a voltage at the output. The input to output voltage ratio shows a resonance as a function of the driving frequency. The dependence of the voltage conversion on the driving frequency is utilized for stabilizing the voltage against the change of load.

For driving a load, matching of the output impedance with the load is critical to attain the maximum efficiency. With the output capacitance of the PT, C_d2, and the carrier frequency, f, the optimal resistance R_op is defined as

R_op = 1/(wC_d2) where w = 2πf.

In a step-down transformer with an output capacity of 2 V and 4 A, the output capacitance to match the load becomes a few microfarads for the carrier frequency being around 100 kHz. Such a large output capacitance is an issue in manufacturing the PT.

A step-down PT was fabricated in a size of 15 mm by 15 mm by 5 mm and composed of two layers at the primary and of 40 layers at the secondary. The PT has capability to deliver more than 10 A at an output of 2 V if the PT functions ideally. In reality the output current was limited to about 4 A as the PT became too hot because of the internal loss. A new PT is fabricated by scrutinizing the manufacturing process to reduce the internal loss and to have a higher Q value in resonance and better performance in overall. The low voltage power supply using the new PT is to deliver more than 5 A at an efficiency better than 80 % at an output voltage of 2 V.

The output voltage is stabilized by a feedback circuitry. The feedback loop includes error-correction amplifiers, FET's and a control IC for a full-bridge phase-shift switching of the FET's. The full-bridge phase-shift switching realizes a flexible control over the frequency in driving the PT. The error-correction amplifier detects the deviation of the output voltage from a reference voltage and supplies error-correction signal to the control IC. The error signal changes the timing of the signals driving the gate of the FET's and modifies the duty ratio of the driving pulse, thus modifying the amplitude of the carrier. The error-correction signal also changes the switching frequency of the control IC, thus shifting the frequency of the carrier.

A conventional drive circuitry of the PT includes an inductance to make a sinusoidal carrier. Driving the PT without an inductance has been studied extensively. Resonance frequency of the PT is composed of a fundamental and overtone modes. While the conventional driving with an inductance activates the fundamental mode exclusively, the driving without an inductance activates the fundamental and the overtone modes simultaneously. The existence of the overtone modes seems to be causing difficulty in the feedback to stabilize the output voltage. Ratio of the fundamental and the overtone modes depend on the carrier frequency and a choice of the frequency with an improved feedback circuitry may lead to a solution.

Author: UNNO, Yoshinobu (KEK)

Co-authors: KATSUNO, Masafumi (NEC TOKIN Corporation); IMORI, Masatoshi (The University of Tokyo); JINNOUCHI, Osamu (Tokyo Institute of Technology); IMADA, Satoru (NF Corporation); KISHIDA, Takuya (Tokyo Institute of Technology); KANADA, Yasumasa (The University of Tokyo)

Presenter: UNNO, Yoshinobu (KEK)

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