Proceedings of Symposium on Ultrasonic Electronics, Vol. 32 (2011) pp. 535-536
8-10 November, 2011

High Voltage Staircase Drive Circuit for Triggered HIFU Treatment

トリガーハイフのための高電圧階段波出力回路

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1. Introduction

A High Intensity Focused Ultrasound (HIFU) treatment has gotten a lot of attention to treat a tumor because of its noninvasiveness and less damage to nomal tissues than surgical treatment. Ultrasound, transmitted from outside the body, coagulates a tumor at the focal point by its energy.

It is a common practice for an ultrasound system to drive a piezoelectric transducer to generate ultrasound waves. For a high accuracy and time efficiency of the treatment, an array transducer with a number of elements is used. To drive each element, an inexpensive, low power-dissipation and compact circuit is required. A staircase voltage drive circuit which can eliminate the third and fifth harmonics, satisfies such requirements.[1]

Triggered HIFU treatment is a method of coagulating a large region in a short time by utilizing cavitation cloud. In treggered HIFU, two kinds of ultrasound waves, called “trigger pulses” and “heating waves”, which have different amplitudes and possibly focused at different foci, are used. The triggering pulses have extremely high intensity to generate cavitation cloud and to enhance the following long-burst heating waves with moderate intensity. The driving circuit for triggered HIFU must switch the output voltage amplitudes quickly because the typical lifetime of a cavitation cloud is several tens of milliseconds.

2. Methods

Circuits used in this study are shown in **Fig.1** and **Fig.2**.

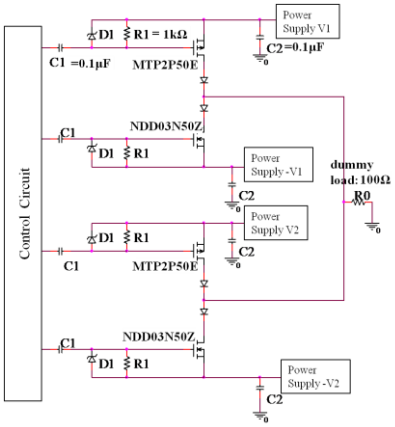

Fig.1. Circuit diagram of staircase voltage driver

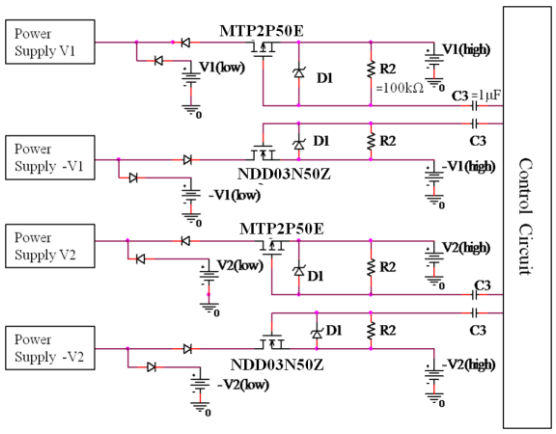

Fig.2. Circuit diagram of voltage switching circuit

The staircase voltage drive circuit, shown in Fig.1 for an element is designed for operation at a frequency in a MHz range. This circuit consists of four MOSFETs, working as switches, and DC power supplies. The gates of power p-MOSFETs (MTP2P50E, ON Semiconductor) and n-MOSFETs (NDD03N50Z, ON Semiconductor) are driven by bipolar pulses generated by control circuit consisting of an FPGA and MOS drivers (Dual Power MOSFET Drivers, MAX626s, Maxim Integrated Products).When one MOSFET is turn on, the voltage level of the connected DC power supply is output. The staircase voltage waveform was adjusted to eliminate the third and fifth harmonics. The driving frequency can be changed by controlling the duty of every pulse. A diodes put in series with the drain of each MOSFET is for circuit protection. When both p-MOSFETs (or n-MOSFETs) are turned on at the same time. To ensure this function at high frequency, a silicon carbide Schottky diode (CSD01060A, Cree Inc) was selected.

The circuit to switch the amplitude of staircase voltage, shown in Fig.2, is designed for operation in a frequency of kHz range. When the MOSFET for switching amplitude is turned off, the voltage level of the DC power supply is switched from high to low (e.g. from V1 (high) to V1 (low)). When it is turned on, it operates oppositely. The voltage level of the DC power

supply, connected to the source of MOSFET, shown in Fig.1, can thereby be changed.

3. Results and Discussion

Fig.3 shows the output voltage from the circuits in Figs.1 and 2 for 200 μs at an operating frequency of 1 MHz. The voltage waveform of triggering pulse is shown in **Fig.4**, where the voltages applied to each source of MOSFETs in Fig.2 were 200 V, -200 V, 80 V, and -80 V for the trigger pulse, and 50 V, -50 V, 20 V, and -20 V for the heating waves.

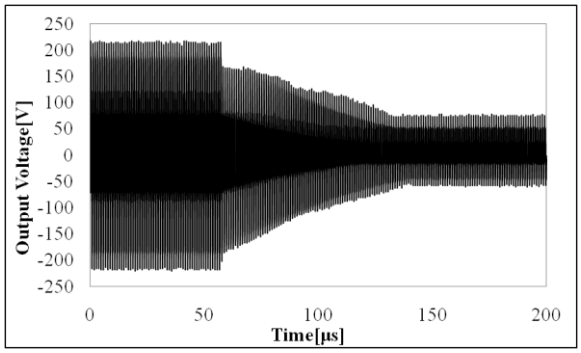

Fig.3.Amplitude switched output voltage waveform

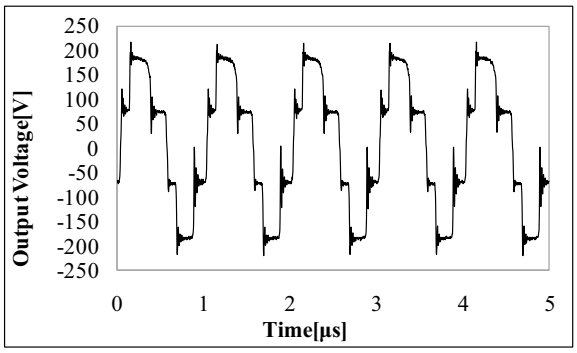

Fig.4.Staircase voltage waveform at higher amplitude(±V1(high)=±200 V,±V2(high)=80 V)

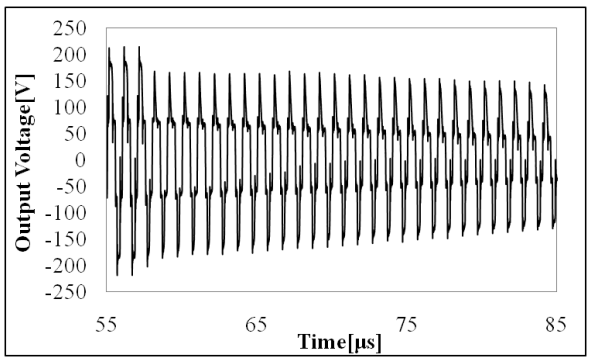

Fig.5.Output voltage during amplitude switching

As shown in Fig.3, the amplitude can be switched from the trigger pulse to the heating wave within 100 μs, which is shorter than the typical lifetime of a cavitation cloud by orders of magnitude and short enough for the triggered HIFU application. This amplitude switching time is mainly determined by the products of C2 and MOSFET's on-resistance, which about 80 μs. Therefore, even faster switching is possible by choosing a smaller capacitance for C2.

In the triggered HIFU application [2], the duration of the trigger pulse can be more than 1 ms at 400 Vpp and that of the heating waves can be more than 20 s at 100 Vpp. It was confirmed that the developed circuit can operate at 600 Vpp for 100 ms.

4. Conclusion

A stair case voltage drive circuit for triggered HIFU treatment, which can change the output voltage from an extremely high level for generating cavitation clouds to a moderate level for heating tissues within a time orders of magnitude shorter than the lifetime of a cavitation cloud, was successfully developed.

Acknowledgment

This research is granted by the Japan Society for the Promotion of Science (JSPS) through the "Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST Program)", initiated by the Council for Science and Technology Policy (CSTP).

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