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Staircase Voltage MOSFET Driver Circuit for Therapeutic Ultrasound

治療用超音波発生のための MOSFET 階段駆動回路

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1. Introduction

HIFU(High Intensity Focused Ultrasound) is attracting interests as a new method to treat a tumor. A HIFU systems needs to transmit higher power than ultrasound imaging systems. Using a piezoelectric transducer is a common practice to generate ultrasound waves. An important component of such ultrasound systems is high voltage drivers used to excite the transducer, typically consisting of a number of array elements. The demands for the driver circuit are high-voltage, high-power drive capability, compactness, and safety as a medical tool. We created a new type of MOSFET switching circuit for therapeutic ultrasound on the basis of staircases voltage drive concept. The staircase drive can significantly decrease the harmonic than the conventional square-wave drive. Because it does not require a resonant circuit to improve the electrical efficiency, the drive frequency can be freely changed and the total size of the drive circuit can be smaller. The experimental results with a prototype driver circuit as well as the results from circuit simulation are discussed.

2. Circuit Description

The principle of the operation of the staircase voltage MOSFET drive circuit is described. **Fig. 1** shows a shematic diagram of the staircase voltage MOSFET drive circuit. The circuit was triggered by bipolar pulses genarated by the control circuit, consisting of a TTL counter, a FPGA, and MAX626s (Maxim Integrated Products, Inc. Dual Power MOSFET Drivers) [1]. Here, R0 is a dummy load whose value was chosen to be 50 Ω in the experiment. A diode is put in series with each drain of the MOSFET's. **Fig. 2** shows the signals to drive each gate of the MOSFET's, and **Fig .3** shows the output voltage waveform obtained by circuit simulation with PSpice. Even when either of both n-MOSFET's (FDP5N50[2]) or both p-MOSFET's (FQP3P50 [3]) are turned on, the drain current flows through only one of them, owing to the function of the diode in series with the drain. Staircase voltage is thereby formed by a relatively simple complementary MOSFET circuit with a relatively simple gate drive signals. A prototype circuit was made on the basis of this design.

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3. Result and Discussion

Fig. 4 shows the output voltage from the prototype circuit in an actual operating condition at a frequency of 1 MHz. The voltage applied to each source of the MOSFET's was 40V, 20V, -20V, and

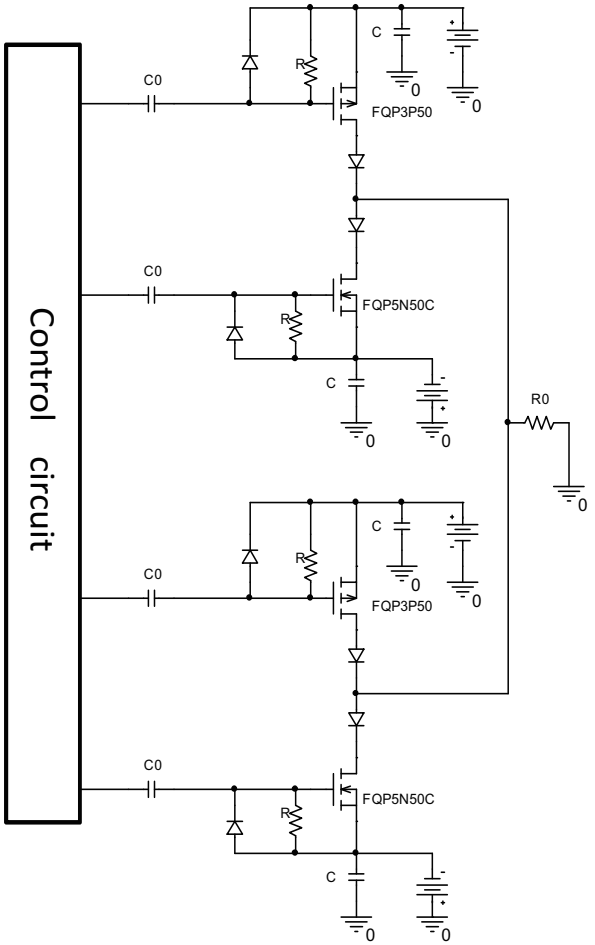

Fig.1 Staircase Voltage MOSFET Driver Circuit

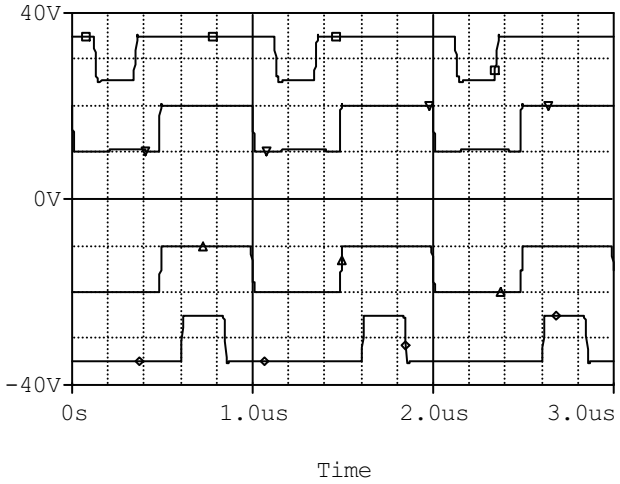

Fig.2 Gate input signal

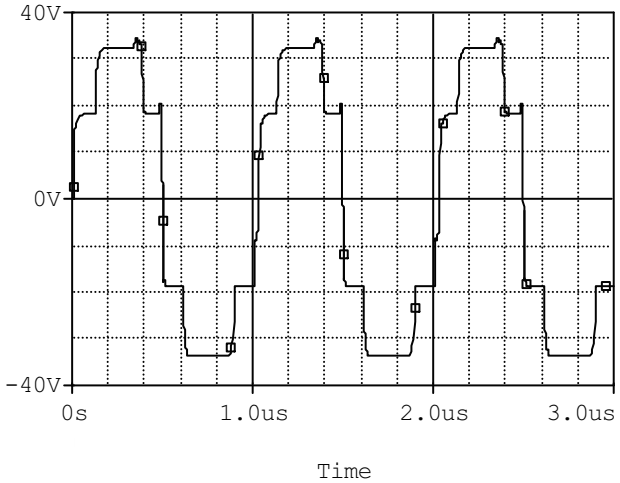

Fig.3 Output voltage

-40V, respectively. Because the delay in the operation of FQP3P50 is larger than FDP5N50, the ascending and descending waveforms are not symmetrical. The ringing waveforms may have been due to the circuit itself and the voltage probe. **Fig. 5** shows the spectrum of the output voltage in Fig. 4. The higher harmonic components contained in square waves should be reduced by using the staircase waves instead. The amplitudes of the third and fifth harmonics contained in square waves were reduced by approximately 20 dB. It resulted in the amplitudes of all harmonic components 30 dB less than the fundamental except for the seventh and ninth harmonics. Considering the band-pass character of a piezoelectric transdcucer the amplitude level of the seventh and ninth harmonics will not practically cause any problem. Because the breakdown voltages of FQP3P50 and FDP5N50 are higher than 400 V, this circuit will be able to produce electric power needed for HIFU operation.

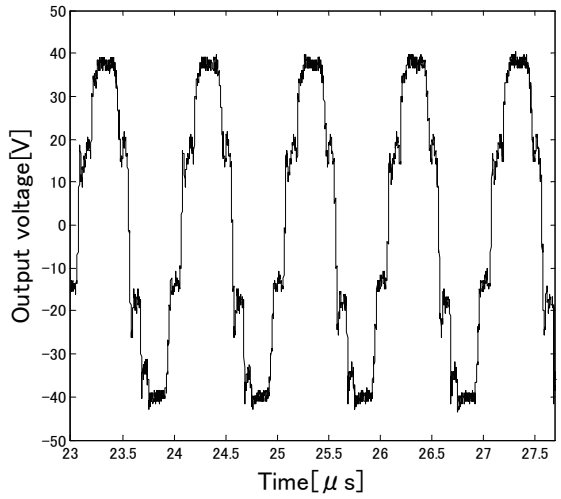

Fig.4 Output voltage

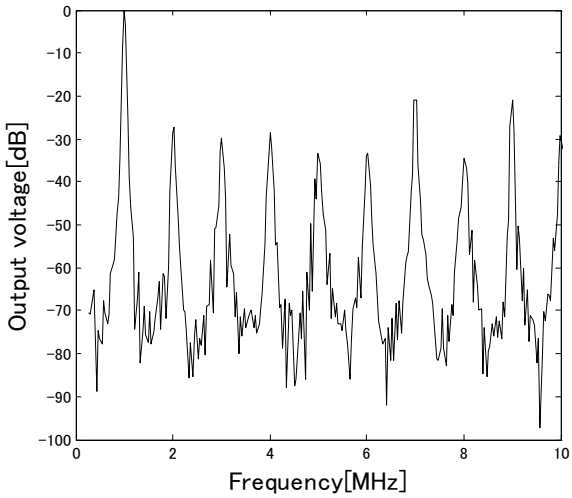

Fig.5 Output voltage Spectrum

4. Conclusions

We proposed a novel staircase voltage drive circuit using complementary MOSFET's for a HIFU system. Its operation was checked with circuit simulation and then a prototype circuit was made and tested. The higher harmonic components of the output signal was significantly reduced in comparison with square waves, eliminating the need of additional resonant circuits, which has been making the overall bulky and less flexible in operation.

References

1.MAX626 Dual Power MOSFET Drivers, Application Hints Maxim Integrated Products.
2.FDP5N50 500V N-Channel MOSFET, UniFET™ applicationnote:FairchildSemiconductor, 2007 .
3.FQP3P50 500V P-channel MOSFET, QFET ® application note: Fairchild Semiconductor ,2000.