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# Creation of Multiple Cavitation Clouds by Phased Array Transducer Driven with Staircase Voltage

アレイトランスデューサの階段型電圧駆動によるマルチキャビテーション生成

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## 1. Introduction

HIFU(High Intensity Focused Ultrasound) has gotten a lot of attention as minimally invasive therapeutic modality. An important component to piesoelectrically generate high intensity ultrasound is a high voltage driver used to excite the transducer. When it consists of number of piezoelectric array elements, a driver with multiple inputs and outputs is needed. Demand for such an array-transducer driver is a high drive voltage, compactness, and a low level of odd harmonics. We have created a new type of MOSFET switching circuit for therapeutic ultrasound on the basis of staircase voltage drive concept (**Fig.1**), which can significantly decrease the harmonics than square wave drive. A typical thickness-mode transducer is piezoelectrically active not only at the fundamental, but also at the odd-harmonic frequencies. Therefore, the odd harmonic components in the electric driving signal have to be reduced for suppressing harmonic ultrasound components, which may potentially induce unwanted therapeutic effects.[1, 2]

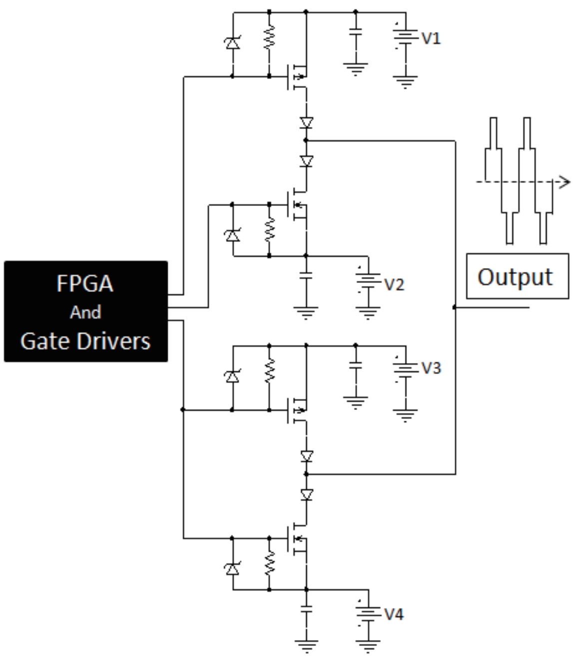


Fig.1. Staircase Voltage MOSFET Driver Schematic (1ch)

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An array transducer has many advantages over a single element transducer, in electronic displacement of the focal zone and dynamic formation of complex pressure field distributions.
In this study, we demonstrate fast electronic displacement of focus by an array transducer driven by an 8 chennel staircase voltage driver under the control of FPGA. Cavitation clouds were created at three positions by electronically changing focal distance, which were observed using a high-speed camera.

## 2. Materials and Methods

**Fig.2** shows the experimental system. The focal distance is changed by the phase of staircase voltage of each annular element, which is controlled by the turn-on and turn-off timings of each one of four MOSFETs used in combination. These timings are represented by a one bit digital output from an FPGA (Spartan-3A starter kit) every 7.5 ns. This corresponds to a minimum phase step of 2.7 deg at 1.0 MHz, which is sufficiently small for focal pattern generation. To control 8 channels, 24 FPGA outputs in total are needed. An 8-track 16-sector array transducer (Imasonic) with a central frequency of 1.0 MHz, an outer and inner diameter of 100 and 36 mm, respectively, and a radius of curvature and geometric focusing length of 100 mm was used. Each 16 elements on the same annular ring were electrically combined to form an annular ring array.

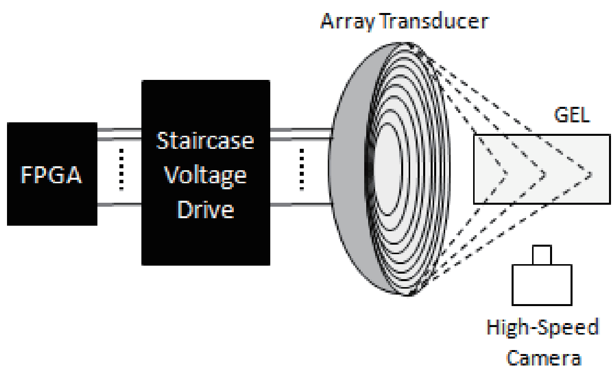


Fig.2　Experimental system

A poly acryl-amide gel containing 1% of BSA (Bovine Serum Albumin) was submerged in degassed water (DO 30~40%) and exposed to HIFU pulses generated by the stair case drive voltage of about 250 Vp-p. The focal distance was changed every 100 µs sequentially among 90, 100, and 110 mm. This cycle was repeated 10 times. The behavior of multiple cavitation clouds created by the exposure was observed by a high-speed camera (Vision research, Phantom V7.3).

## 3. Result

Cavitation clouds created and maintained by the exposure sequence around the three focal spots were successfully observed by the high-speed camera. The clouds were vibrating synchronously to the scanning cycle like blinking.

**Fig.3** shows the difference images between before and right after exposure at 100, 200 and 300 µs from the start. At 100, 200 and 300 µs, creation of a cavitation cloud at the focal distance of 90, 100, 110 mm, respectively, are seen. **Fig.4** is the difference image between before and right after all exposures finished at 3 ms. Cavitation clouds are distributed around all three focal points.

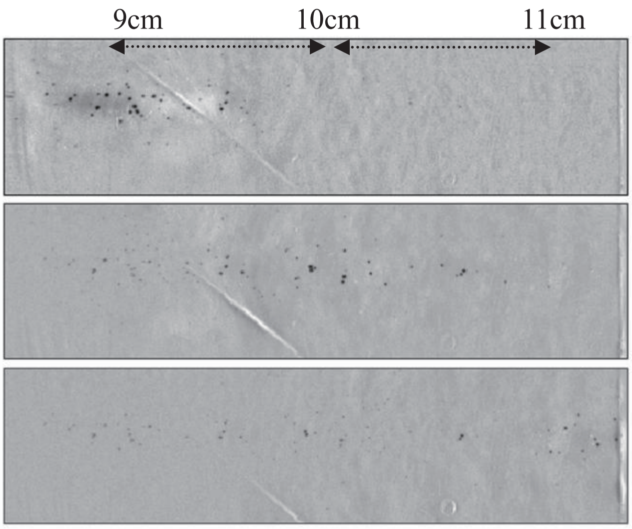


Fig.3. Difference images between before and right after exposure.
(top : 100 µs, middle : 200µs, bottom : 300µs)

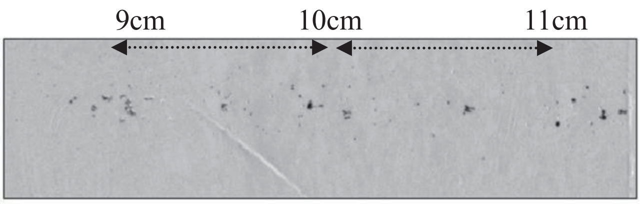


Fig.4. Difference images between before and right after all exposures (3ms)

## 4. Discussion

Because the life of a cavitation cloud is relatively short, fast scanning of the focal point is necessary in order to create and maintain multiple of them. The fastness in the electronic control of the developed staircase voltage drive system was well demonstrated by the experimental results shown in Fig.3. In each one of the three focal zones, there was an interval time of 200 µs between exposures, which was proved to be short enough to maintain the created cloud of cavitation. Much more number of clouds of cavitation may be created and maintained by this type of exposure sequence.

The cavitation cloud at 100 µs was thicker than those at 200 and 300 µs, probably because the ultrasonic intensity at the focal distance of 90 mm was significantly higher than those at 100 and 110 mm. The cloud thickness seems to have been equalized by repeating the exposure cycle as seen in Fig. 4.

The developed driver system seems to have a potential to be applied to “Triggered HIFU”, in which cavitation clouds are created and maintained by extremely high intensity triggering pulses and enhance the heating effect of subsequent CW ultrasound.[3]

## 4. Conclusion

A multi-channel stair case voltage driver under FPGA control was developed. In combination with an array transducer, its fastness in the electronic scanning of a high-intensity focus was well demonstrated by creating and maintaining multiple clouds of cavitation, which were observed with a high speed camera in a transparent tissue mimicking gel.

## Acknowledgment

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