A High-Speed High-Voltage Bipolar Pulser for Medical Ultrasonic Imaging Applications

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***Abstract*-- This study proposes a high-speed high-voltage bipolar pulser for medical ultrasonic imaging applications. The designed pulser adopts high-speed level shifters and high-voltage push-pull output stages and can generate 200-Vpp (±100V) output pulses with rising and falling times of 18.2 ns and 18 ns, respectively, under a 1-KΩ resistance parallel with a 220-pF capacitance load. The measured second harmonic distortion (HD2) of the transmitted signal is about -40 dBc. The proposed pulser is suitable for medical ultrasonic imaging with low second harmonic sideband signals.**

I. INTRODUCTION

Medical ultrasonic imaging is one of the modern non-destructive and non-radiative testing methods for examining and diagnosing patients. Fig. 1 shows a block diagram of a typical ultrasound system composed of a pulse generator (pulser), a HV multiplexer (HV MUX), a T/R switch, a low noise amplifier (LNA), a variable-gain amplifier (VGA), an analog-to-digital converter (ADC), and a digital signal processor [1]. A high-speed, high-voltage pulser is one of the most important components for multichannel, portable, and compact ultrasound scanners [2-4]. Design of the high voltage excitation devices for medical ultrasound transducers is generally required to support the high voltage (>50Vpp) output pulses with the capability of switching faster than several tenth MHz frequency at the cost of minimal power consumption.

In previous works, high-voltage pulses implemented using discrete components for ultrasound imaging systems have demonstrated excellent performance [2-3]. In order to achieve a high-speed and compact multichannel device, a single-chip high slew-rate bipolar pulser is strongly required [5-7]. Unipolar pulse generators, because of their simple and accurate implementation, are still widely used in medical ultrasound applications [2, 4]. However, to achieve a higher sensitivity and for Doppler signal acquisition, a high performance, bipolar pulser is necessary. Conventional off-the-shelf pulse generators generally operate below 10 MHz switching frequency and are difficult to provide a high slew-rate current for diverse transducers with different resonance frequencies. Moreover, because the pulse generator drives the transducer array with high voltages, voltage level shifters are required in the pulse generator to shift the low-voltage control signal levels to high-voltage levels. In this study, we present a single-chip solution of ultra-high slew-rate high-voltage pulser architecture for applications of compact ultrasound scanners.

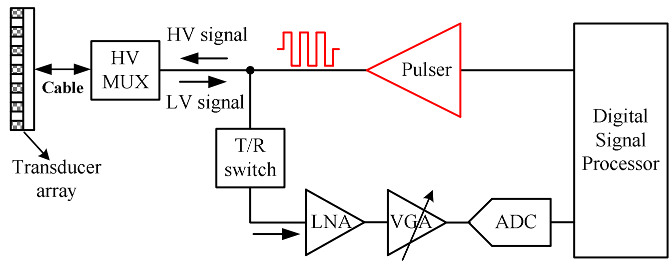

Fig. 1. Block diagram of a typical ultrasound imaging system.

II. PROPOSED ARCHITECTURE

Fig. 2 shows the proposed architecture of the high-speed high-voltage bipolar pulser, which mainly consists of two input buffers, two level shifters (#1-#2), a dead time generator, two pre-drivers, and two power transistors (MP1-MP2). The control signals, IN_P and IN_N, are composed of a series of pulses. One of the pulses of the input control signals is half-period delay from those of the other one. When the level of IN_P is high, MN1 turns off and MP1 turns on. MP1 drives the output to a high voltage level VDDH (100V). The power transistor MN1 pulls down the output to a low voltage level VSSL (-100V) when the level of IN_N is high. The low and high voltage levels of the input control signals are 0 V and 5 V, respectively. To avoid the short circuit at the output of MP1 and MN1, a dead time generator is added in the circuit. Level shifters #1 and #2 boost the low and high voltage levels of the outputs of the dead time generator from 95V to 100V and from -100V to -95V, respectively.

During the stable state, both the levels of IN_P and IN_N are low and the output is returned to zero voltage level by MP2 or MN2. To achieve a fast zero return and avoid a ringing at the output during the stable state, a return-to-zero circuit is added in the pulser. The return-to-zero circuit is composed of a return-to-zero controller, a level shifter (#3), a delay circuit, two pre-drivers, two power transistors (MP2-MN2), and two diodes (D1-D2). The return-to-zero controller turns on MP2 and MN2. MP2 and MN2 drive the output to zero voltage level. Two diodes, D1 and D2, are inserted between the output and MP2-MN2, respectively, to prevent from turning off MP2 and MN2 during the transient state. Because of the large capacitance loads at the gates of MP1-MP2 and MN1-MN2, four pre-drivers are used to drive these power transistors. In order to reduce the pin numbers of pulser ICs, a built-in voltage generator circuit which can generate intermediate voltages is also included in this chip.

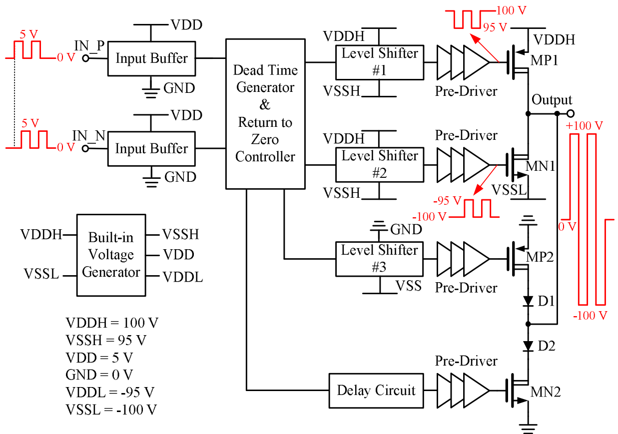

Fig. 2. Proposed architecture of the integrated bipolar pulse generator.

III. EXPERIMENTAL RESULTS

The designed integrated pulser has been implemented in 0.5-μm 2P4M SOI high-voltage technology. Fig. 3 shows the chip photograph of the designed pulser with the core size of 4000 μm × 1585 μm. Fig. 4 shows the photo of the test board with the packaged pulser. Fig. 5 shows the measured results of the input signals and the output waveform of the pulser under a 1-KΩ resistance parallel with a 220-pF capacitance load. The input signals (IN1 and IN2) are 2-MHz square waveforms. The peak-to-peak value of the output waveform is 200V (±100V). The measured rising and falling times are 18.2 ns and 18 ns, respectively. The measured second harmonic distortion (HD2) of the transmitted signal is -40 dBc. Table I summaries the overall performance and comparisons.

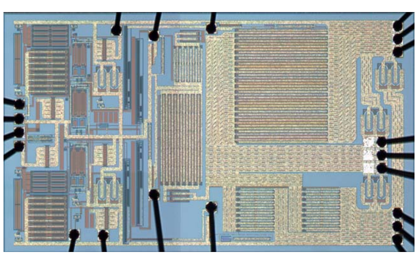

Fig. 3. Chip micrograph of the designed pulser.

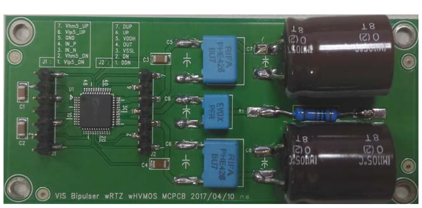

Fig. 4. Photo of the test board with the packaged pulser.

IV. CONCLUSION

This paper has presented a high-speed high-voltage bipolar pulser. The designed pulser can produce 200 Vpp output pulses with rising and falling times of 18.2 ns and 18 ns, respectively, under a 1-KΩ resistance parallel with a 220-pF capacitance load. The HD2 of the transmitted signal is -40 dBc. The measured results show that the proposed pulse generator is applicable for ultrasonic imaging systems.

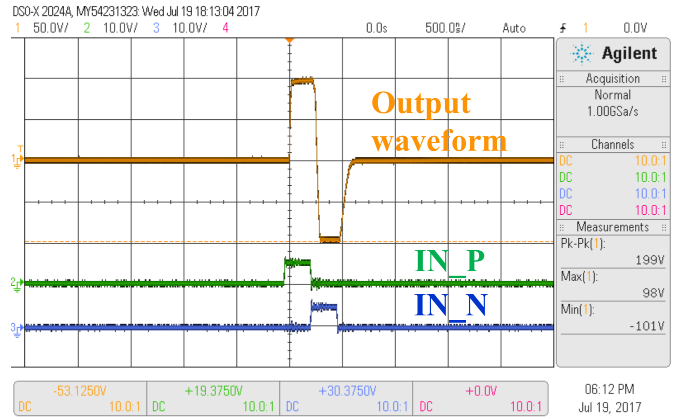

Fig. 5. Measured input signals and output waveform of the proposed pulser under a 1-KΩ resistance parallel with a 220-pF capacitance load.

TABLE I
PERFORMANCE SUMMARY

	This work	Maxim [5]	TI [6]	Supertex [7]
Output voltage	0 to ±100V	0 to ±100V	0 to ±50V	0 to ±70V
Frequency	Up to 20MHz	Up to 10MHz	Up to 15MHz	Up to 20MHz
Peak Current	2 A	2 A	2 A	2 A
Rising time	18.2 ns	21 ns	18 ns	15 ns
Falling time	18 ns	21 ns	18 ns	15 ns
Slew rate	4.4KV/μs (220pF// 1KΩ)	3.8KV/μs (240pF// 1KΩ)	2.2KV/μs (330pF// 100Ω)	3.7KV/μs (330pF// 2.5kΩ)
HD2	-40 dBc	-43 dBc	-40 dBc	-40 dBc

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