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Design of a Pulse Generator Based on a Programmable System-on-Chip (PSoC) for Ultrasonic Applications

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Abstract**—**This paper describes the design of a pulse generator based on the Programmable System-on-Chip (PSoC) module. In this module, using programmable logic is possible to implement different pulses which are required for ultrasonic applications, either in a single channel or multiple channels. This module can operate with programmable frequencies from 3-74 MHz; its programming may be versatile covering a wide range of ultrasonic applications. It is ideal for low-power ultrasonic applications where PZT or PVDF transducers are used.

Keywords**—**Pulse generator, PVDF, Programmable System-on-Chip (PSoC), ultrasonic transducer.

I. Introduction

A pulse generator is a very important element in an ultrasonic system. It can operate in a continuous or pulsed mode depending on the application, with one channel for applications where only one single transducer is used or with multiple channels where piezoelectric transducer (PZT, PVDF) arrays are used. The most important parameters associated with a pulse generator are the operating and repetition frequency, sequential, simultaneous or burst mode and voltage amplitude of these electrical pulses. The particular type of use of the ultrasonic pulses depends on the specific application [2]-[4].

In ultrasonic systems for nondestructive testing narrow pulses (nanoseconds) may be required, with repetition frequencies within the KHz range, with one or multiple channels. Specific voltage supplies and current drivers are required for the proper excitation of the transducers [4]. Multiple channels to scan in ultrasound images and continuous /pulsed Doppler generators are used in ultrasonic systems for blood flow detection. In blood flow detection applications either in continuous or pulsed mode, pulses with appropriated operating frequencies for excitation of the piezoelectric transducers and pulses for demodulating the blood flow Doppler signals are required, demodulation can be homodyne, homodyne in quadrature or heterodyne [2], [3], [7].

Based on the above discussion, it is possible to conclude that any system requires of the generation of pulses in different ways depending on the specific application, [3], [4]. The proposed pulse generator in this application is able to generate pulses in a versatile manner for different ultrasonic applications using the Programmable System-on-Chip (PSoC) 5LP CY8C58LP USB module from Cypress Semiconductor Corporation [1].

PSoC is a programmable embedded System-on-Chip integrating a microcontroller core, also this kind of micro controllers contain a programmable hardware and software that could be set by its own Integrated Design Environment (IDE) that enables concurrent hardware and firmware editing, compiling and debugging the PSoC5LP system. The clock inside the PsoC has a programmable frequency from 3-74 MHz [1]. An advantage offered by the PSoC is its versatile pulse selection.

The pulse generator based on a PSoC module is suitable for use with PVDF transducer over a range of frequencies up to 35 MHz, the bandwidth range of a PVDF transducer can be from 0.001 Hz to 10 GHz, PVDF arrays are also desirable in non-destructive testing due to its flexibility. Unlike PZT transducers, PVDF transducers can be excited using voltages ranging from 1 to 30 V [5].

In the market there is a need for low-cost pulsers to excite transducer arrays. So in an attempt to provide a solution to this problem, this paper proposes to use the PSoC module as a pulse generator to excite PVDF transducer arrays because this platform can provide enough energy to excite polymeric transducers (5 volts at 25mA), this voltage is suitable for low power ultrasonic applications [5], [6].

Fig. 1 shows the different types of pulses most commonly used in ultrasonic applications. Fig. 1 (a) shows an excitation signal with fixed frequency and continuous mode. Fig. 1 (b) shows an excitation signal in pulse burst mode in which the repetition frequency and the number of cycles may be programmable for systems in pulsed mode. Fig. 1 (c) shows several channels with simultaneous excitation pulses for excitation of transducer arrays. Fig. 1 (d) shows multiple channels with shift pulse excitation for arrays with focusing applications. Fig. 1 (e) shows 2 channels with excitation in quadrature, in medical applications where bidirectional blood flow is detected, signals in quadrature are used for the demodulation of Doppler signals [2], [7]. The pulses can be generated independently or in combinations, such as simultaneous pulses and shift or burst.

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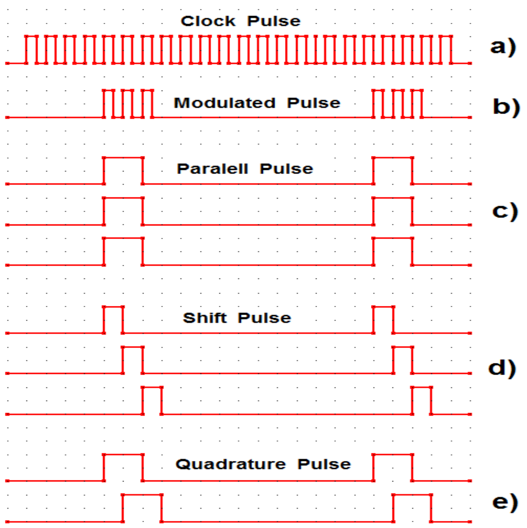

Fig. 1 Excitation pulses for an ultrasonic system, (a) fix frequency, (b) pulse bursts, (c) simultaneous channels, parallel pulses, (d) sequential channels, shift pulses, (e) quadrature pulses

II. Methodology

The proposed pulse generator was implemented in a PSoC-5LP module, which has programmable logic hardware [1]; this hardware allows to program different types of pulses as shown in Fig. 1.

The output pulses generated by the PSoC-5LP module are displayed and acquired with a digital oscilloscope.

The sequence of ultrasonic pulses generated by the PSoC module can be performed simultaneously on multiple channels, or with shifts with programmable time delays via software from one channel to another. It is possible to generate pulse burst and/or implement a frequency sweep by choosing a clock and a counter to generate a frequency divisor. It is also possible to program independent channels with tone bursts with the operating frequencies of the ultrasonic transducers, and to generate a tone burst for multiple channels with simultaneous pulses or shift pulses.

To evaluate the pulse generator, excitation pulses were generated to excite the PVDF Shielded Piezo transducer (Measurement Specialties SDT1-28K model) [5]. The connection schematic diagram is shown in Fig. 2.

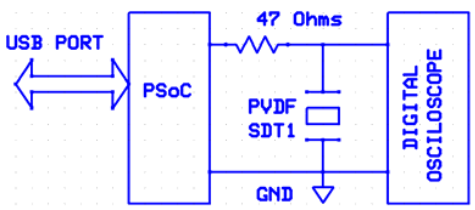

Fig. 2 Schematic diagram of the frequency sweep applied to the PVDF SDT1-28K transducer

Using the circuit shown in Fig. 2, a frequency sweep was performed in the range of 100 kHz to 35 MHz, exciting the PVDF transducer SDT1-28K, in order to obtain its frequency response.

Evaluation tests were performed to the programmable pulse generator; the block diagram of the experimental setup is shown in Fig. 3.

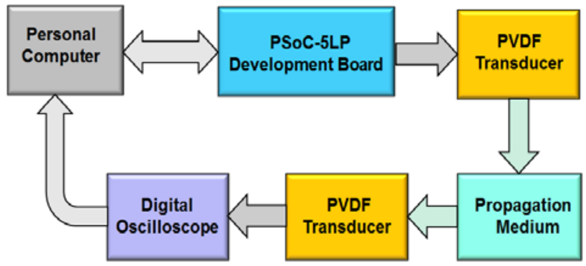

Fig. 3 Block diagram of the experimental setup.

Two experiments were implemented, in both experiments a glass container full of water was used, two PVDF SDT1-28K transducers were submerged in water, one of these transducers was used as transmitter and the other as receiver as shown in Figs. 4 and 5.

Fig. 4 shows experiment number one; here both transducers were submerged in water, with a 30 mm gap between them without any obstacle.

Fig. 5 shows experiment number two, in this experiment the two transducers were submerged in water and between them an acrylic bar (21 mm wide, 270 mm long and 5mm thick) was used as an obstacle.

Tests described above were performed to evaluate the pulse generator. The acoustic parameters of the materials employed in the experiments are shown in Table I.

TABLE I
Acoustic Parameters

Material	Longitudinal Velocity [mm/s]	Transversal Velocity [mm/s]	ZL [MRay]
Acrylic	2.75		3.26
Water at 25°C	1.4967	2.4	1.494
PVDF	2.2		3.8

III. Results

To validate the performance of the pulse generator based on a PSoC-5LP module, different pulses were programmed and the results were acquired with a digital oscilloscope, as shown in Fig. 6, where it is possible to see the pulse generation with a single channel or multiple channels, in a continuous or pulsed way through a repetition frequency and a tone burst.

Fig. 7 shows the results when using the PSoC-5LP module to implement a frequency sweep from 100 kHz to 35 MHz applied to the PVDF SDT1-28K transducer. In this graph is clearly seen that the natural vibration frequency in the thickness mode of the PVDF transducer is near to 24 MHz.

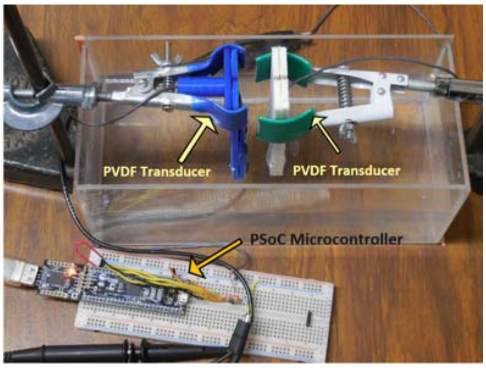

Fig. 4 Experimental setup without obstacle.

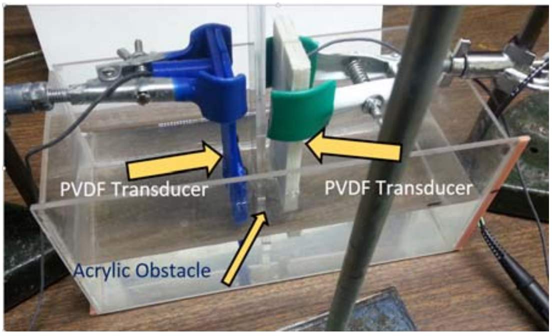

Fig. 5 Experimental setup with obstacle

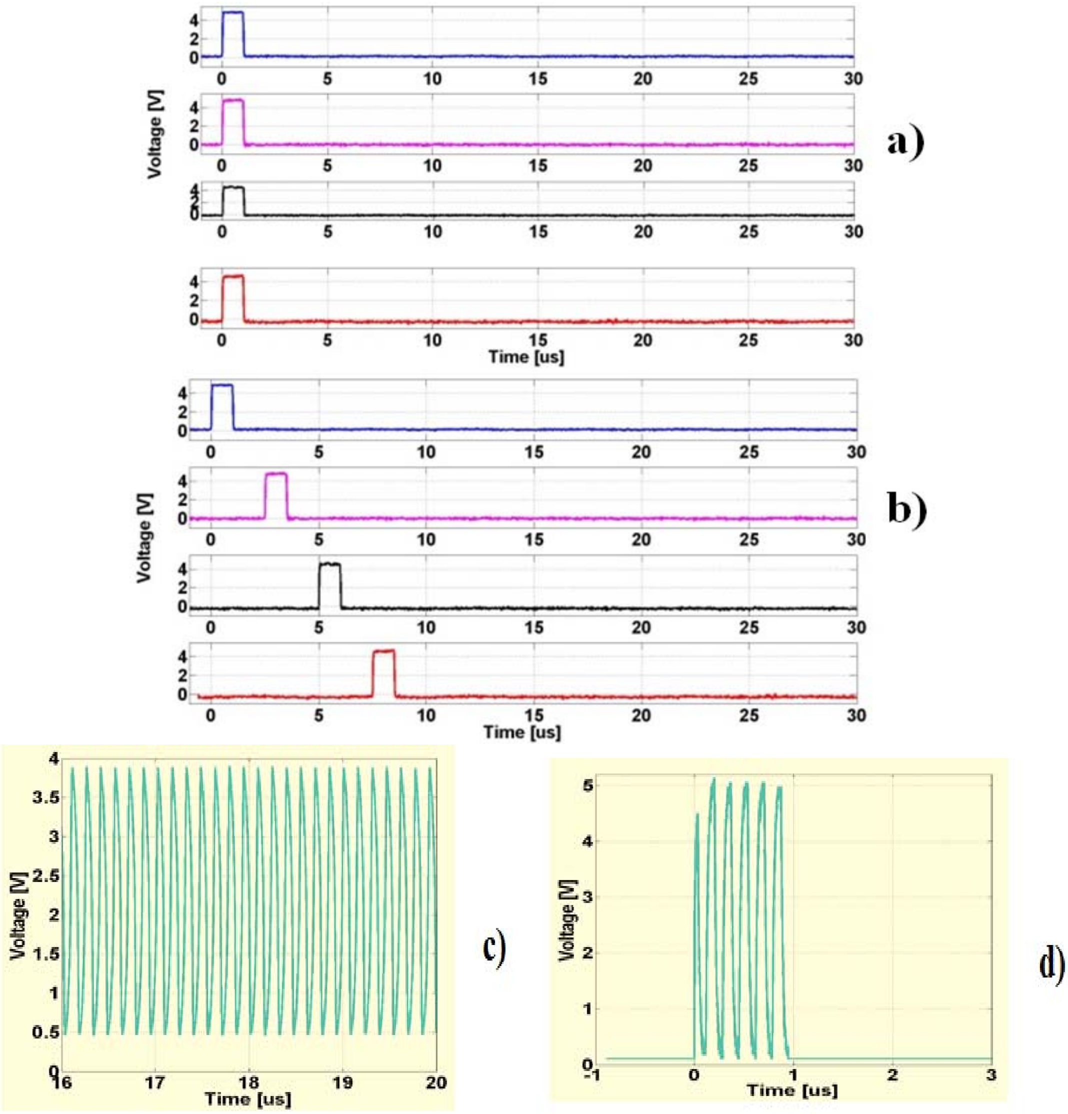

Fig. 6 Excitation pulses, (a) simultaneous mode, (b) sequential mode, (c) continuous pulses, (d) tone burst

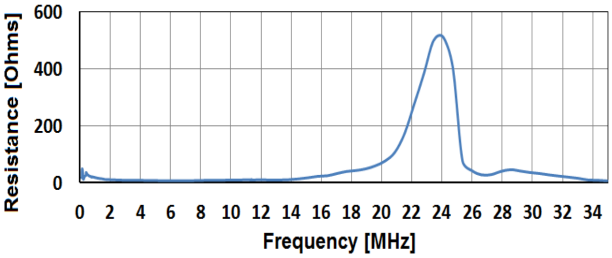

Fig. 7 Frequency response from 100 kHz to 35 MHz to the PVDF SDT1-28K transducer

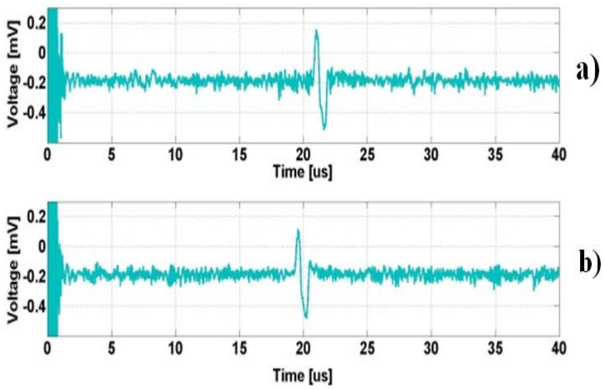

Fig. 8 Echoes from the SDT1-28K PVDF transducer, (a) echo without obstacle, (b) echo with obstacle

Fig. 8 shows the results of the experiments shown in Figs. 4 and 5, using as a transmitter and receiver PVDF Shelded Piezo sensor transducers (Measurement Specialties SDT1-28K model).

As shown in Fig. 8, it is evident that when an obstacle between the transmitter and receiver is interposed, due to the fact that the material of the obstacle has a higher propagation velocity than the medium, the resulting echo will have a different propagation velocity in the time domain. In this case (with obstacle) the echo is advanced relative to the echo only in water, because the propagation velocity of the object under test is higher than that of water (see Table I).

IV. Conclusions

A pulse generator for ultrasonic applications was implemented using a microcontroller PSoC-5LP module, which generates pulses in a versatile mode.

As already mentioned in the methodology section, it is possible to conclude that the sequence of ultrasonic pulses generated by the PSoC microcontroller can be performed simultaneously on multiple channels, or with shifts with programmable time delays via software from one channel to another. It is possible to generate pulse burst and/or performing a frequency sweep. It is also possible to program independent channels with tone bursts with the operating frequencies from the ultrasonic transducers, and apply a tone burst for multiple channels with simultaneous pulses or shift pulses.

The advantage of the pulse generator implemented using the PSoC-5LP module with respect to commercial generators is its versatility, as it can operate programmable frequencies from 3-74 MHz, which covers a wide range of ultrasonic applications, it is ideal for low power ultrasonic applications, since the output voltage is 5V (25mA), for applications requiring more power additional voltage power supply and current drivers are required.

Experimental results show the great potential for low power applications and it is very versatile to excite PVDF transducers either as transmitters, receivers or arrays.

Acknowledgment

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