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Development of a Modular FPGA Based Digital Beamformer for PC Based Ultrasound Imaging System

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Abstract—**A digital transmit and receive beamformer for PC based ultrasound imaging was developed. This system consists of an analog front end, FPGA control board, ultrasound probe, and computer. Analog front end consists of programmable pulser and receiver circuit. The pulser circuit uses high voltage pulse generator to produce monocycle electrical pulses with the adjustable center frequency and amplitude up to 50 V. The receiver circuit uses a AD9272 chip, which is an 8-channel integrated analog front end module. Each of the 8 signal paths consists of a low noise amplifier (LNA), a digitally programmable variable gain amplifier (VGA), anti aliasing filter (AAF), and a 12-bit, 40 Mega Samples Per Second (MSPS) analog-to-digital converter (ADC). The probe is a 64 element linear probe which can produce pulses with center frequency of 3.5 MHz. The Xillinx Spartan 6 FPGA based beamformer consists of 8 channel transmit beamformer controller block and 8 channel receive beamformer blocks. The receive beamformer is composed with delay stage block, apodization blok, summation block, Hilber transform block, and envelope detection block. The implementation result shows that the system was able to process the RF signals.**

Keywords— **Ultrasound, digital beamformer, FPGA**

I. Introduction

Modern medical ultrasound scanners are used for imaging the internal structures of the body which are displayed in gray-scale B-mode images. Currently, it has become the most widely used medical imaging modality since it is safe, portable, inexpensive, non invasive, easy to use and display image in real time. Even as a mature technology, advances are still being made, ranging from improvement in transducer design, imaging hardware and new signal processing algorithm [1]

An ultrasoud image was produced by firing the internal target with focused ultrasound beam transmitted from ultrasound probe and using the same probe acquiring the echoes reflected from the internal target under investigation. Digital signal processing and scan conversion algorithms are used to process the RF data and produce the 2-D ultrasound image, respectively [1]

Digital beamformer has a vital role in ultrasound imaging system. It has two main functions: steering the transmitted ultrasound beam and defining a focal point within the target from which location of the returning echo is derived. The beamforming process needs a high delay time resolution to avoid the deteriorating effects of the delay quantization lobes on the image dynamic range and signal to noise ratio. However, to achieve a high timing resolution using over-sampling tehnique a huge data volume has to be acquired and processed in real time. It need high capacity storage. To avoide such problem, sampling process was just conducted above the Nyquist rate and interpolation was performed to achieve the required delay resolution.

This paper describes the progress that has been made in the design and construction of a prototype real-time FGPA-based digital beamformer for 64-channel 3.5 MHz linear arrays probe. The design of digital beamforming and how it was implemented on FPGA is described. Prior to the real application, simulated RF data were used to test the performance of the receive beamformer. The result shows that system be able to process RF signals and display the 2D image. Images from small targets were used to assess both axial and lateral resolutions of the system.

II. Methodology

The imaging hardware which consists of an 8 channel analog front end circuit were first designed and contructed to provide real experimetal data. Digital beamformer was designed and implemented on low cost Xillinx Spartan 6 development board of Opal Kelly [15]. The echo signals were acquired using 64-element 3.5 MHz ultrasound probe. A scan conversion algorithm was developed and implemented using Matlab for displaying the 2D ultrasound image.

A. Analog Front End

The analog front-end circuit consists of 5 boards: 8 channel programmable transmit beamformer board, 8 channel pulser board, 8 channel TX-RX board, 8 to 64 multiplexer and 64 to 8 demultiplexer HV switch board, 8 channel receiver board. The transmit beamformer, pulser, and TX-RX boards contains LM96570 Octal Digital Beamformer, LM96550 Octal High Voltage Pulser, LM96530 Octal Transmit/Receive Switch Chips of National

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Semiconductor, respectively. The receiver board incorporates the 8 channel AD9272 from Analog Device.

The programmable transmit beamformer board serves as the signal generator by outputting programmable digital pulse patterns. The LM96570 beamformer provides an 8-output channels designed to drive the positive and negative pulse control inputs of LM96550. Each channel launches an individually programmable pulse pattern with a maximum delay of 102.4μs in adjustable in increments of 2 ns. The length of a fired pulse pattern was set to 8 pulses and can be extended to 64 pulses. The pulse patterns and delay settings can be programmed into and read out from the individual channel controls via a four-wire serial interface [11].

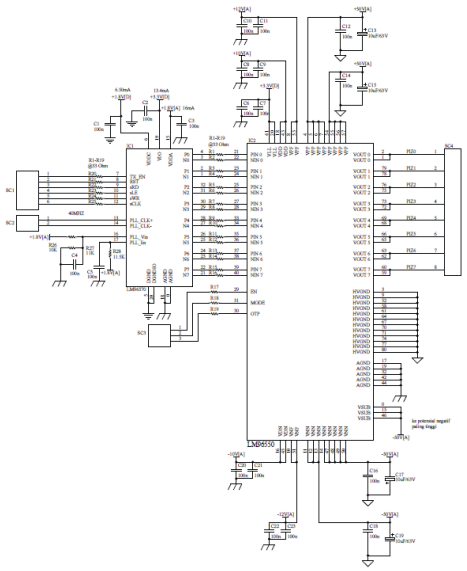

Figure 1. Transmit beamformer and pulser circuit

The programmed pulse patterns are sent out by activating the transmit signal TX_EN. Upon a rising edge of the transmit signal TX_EN, the delay counter of each channel starts counting according to the programmable delay profile. When the counter reaches the 17-bit programmed delay value, the programmed pulse pattern is sent out continuously at the programmed frequency until it reaches the length of the pulse pattern. These output pulse patterns then drive the inputs of the high voltage pulser, LM96550.

The LM96550 pulser board contains eight high-voltage pulser with integrated diodes generating ±50V bipolar pulses with peak currents of up to 2A and pulse rates of up to 15 MHz. The LM96550 has an input buffer at its logic interface. It is powered by VLL (2.5 to 5 Volt) and controlled by EN. When EN is set to HI, and the channel inputs PIN n or NIN n is HI will result in a positive or negative pulse at the channel's output pin [12]. The pulser outputs drive both the inputs of the LM96530 T/R switch board. Fig. 1 shows the transmit beamformer and pulser circuitry.

The LM96530 TX/RX board is triggered by 8, 5-volt, rising edge signals. The signals pass through 8 1-of-8 HV demultiplexers (Supertex HV2301, Supertex inc.) so that 8 adjacent elements are chosen. Triggered by these rising-edge signals, the pulser circuit generates a 50 volt impulse of 10 ns duration for each chosen element. Immediately following the transmitter/receiver (T/R) switch, 8 8-to-1 multiplexers are used to select the corresponding activated element out of 64 elements. The multiplexer and demultiplexers are controlled by the same control signal to maintain the synchronization. In LM96530 chip, a voltage clamping was installed. It is to protect the following circuit. The LM96530 TX-RX switchs as shown in Fig. 2 are directly connected to transducer elements and receiver board. Since, a transducer element has the dual functions of transmitting and receiving ultrasound energy. During the transmitting phase, high voltage pulses are applied to the ceramic elements. A typical transmit/receive (T/R) switch, LM96530, can consist of four high voltage diodes in a bridge configuration. Although the diodes ideally block transmit pulses from the sensitive receiver input, diode characteristics are not ideal, and the resulting leakage transients imposed on the inputs can be problematic [13].

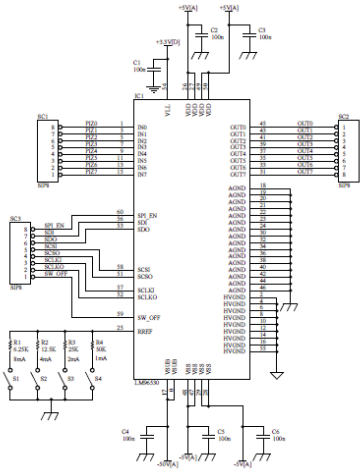

Figure 2. TX/RX switch circuit

The receiver board incorporates 8 channel AD9272 chip from Analog Device. Echo signals from chosen elements enters the AD9272 input channells. Each channel contains both TGC signal path and a CW Doppler signal path. Common to both signal path, the LNA provides user-adjustable input impedance termination. The CW Doppler path includes a transconductance amplifier and a crosspoint