Scalable Low cost Ultrasound Beam former

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Abstract

Medical ultrasound machines are one of the most sophisticated signal processing machines in use today. Ultrasound beam former is designed by handful number of companies in the world because of technical complexity involved. We are designing ultrasound beam former which is highly modular, scalable and reusable. Many companies currently using brought out modules of ultrasound beam former which are very expensive. The beam former designed in-house which is less expensive will give cost benefits to our customers.

Keywords: *Ultrasound Medical Imaging****,*** *Ultrasound Beam Former****,*** *B-Mode Image****,*** *High Speed Digital Design, Modular Design, Scalable Architecture, Transducer element, Beam.***.**

1. Introduction

Real-time ultrasound imaging systems are important tools in practice. Medical ultrasound machines are one of the most complex signal processing machines in use today. Heart of the ultrasound imaging systems is a beam former. Beam forming or spatial filtering is a signal processing method used in sensor arrays for directional signal transmission or reception. Beam former generates intended ultrasound signals; to capture echo and performs signal conditioning. This signal is then used for image processing to display final output on screen.

2. Ultrasound Imaging Basics

Creation of an ultrasound image is achieved in three steps

1) Producing a sound wave
2) Receiving the Echoes
3) Constructing image from Received echoes.

Medical Ultrasound transducer is an array of piezoelectric crystals. Individual transducer elements are called as ‘channels’. Group of channels, excited together forms a beam. To achieve sharp images, the sound output of transducer needs to be focused at the point of interest. In ultrasound imaging, sound from a beam is focused at a point by adjusting delay between transmissions of pulses from each channel. This method is shown in figure 1. As shown in figure, the transducer elements, are placed linearly on a plane in such a way that sound from each of the channel reaches the focus point at the same time and thus achieving the intended focus.

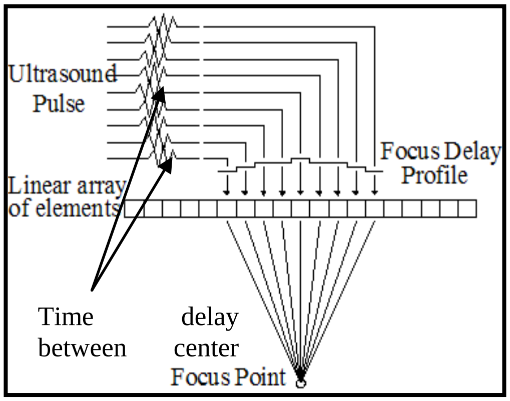

Figure 1: Focusing of a sound wave using delay

In the figure 1, pulses shown are the electrical signals used to generate sound beam. Displacement of each signal shows relative time delay between different channels.

The transmitted pulse gets reflected by tissues and organs in human body and resulting echoes are received by the transducer. The output of ultrasound is a grayscale image which is derived from intensity of received echoes. Low echo voltage represents dark area and high echo voltage is shown as bright region on the screen. This relation is shown in figure 2.

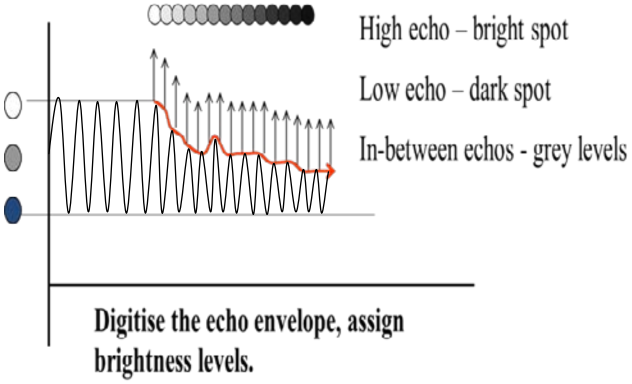

Figure 2: Representing echo levels

Output from multiple beams is required to produce a single static image. The multiple beams are generated by all elements in transducer array by sliding window method. Thus each beam produced captures data from different area. To form the image ultrasound machine needs to determine the direction of the echo, what is the strength the echo was and how much long it took the echo to be received from when the sound pulse was transmitted. Once the ultrasound beam former calculates these three things, it can locate in the image which pixel to light up and to what intensity. The combined output of all beams is shown as a frame represented in figure 3 below. From the Frame the Black(dark) areas are 'filled' by interpolation of data linearly received from adjoining beams. Output from multiple such frames is used to generate video signal.

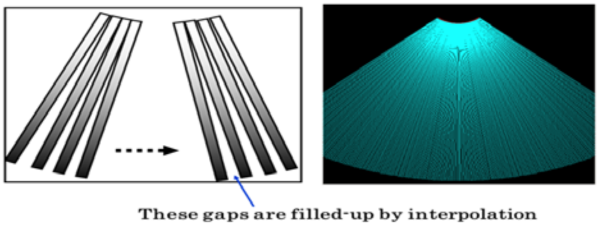

Figure 3: Multiple beams forming a frame

3. Beam-Former applications

1. Automotive industry.
2. Ultrasound medical imaging.
3. Defense.

4. System Requirements

SL.No	Industry	Focal Length	Accuracy
1	Automotive	1 to 4 meters	Medium
2	Medical	4.5 to 23 cm	High
3	Defense	Kilometers	Medium

Table 1: Ultrasound requirements

Medical ultrasound signals use frequencies between 1MHz to 15MHz.Ultrasound signals suffer attenuation of 0.3dB/cm/MHz. This translates into three main requirements – First, high transmit pulse voltage so that received echoes are having sufficient signal levels to get detected. Transmit voltage for an ultrasound beam-former is between 100 Vpp (Volts peak to peak) and 150 Vpp. Second, high input gain; voltage of echo signal received is typically between 10µV to 10mV. Third, high SNR (Signal to Noise Ratio) & very low noise figure for amplifiers.

High speed ADC with minimum sampling rate of eight times signal frequency and 12 bits resolution is required. Minimum eight channel 128 elements transducer is required. An eight channel beam former will generate beam by exciting eight piezoelectric crystals at a time. Thus eight parallel ADCs will be required to capture data from each of the channel. This gives data rate close to 5Gbps for a 25 frames per second, 128 elements, eight channel beam former with 7.68MHz sound frequency.

The pitch (distance between centers of two piezoelectric crystals) of ultrasound transducer is as low as 0.3mm. Focusing distances are in range of 3 cm to 15 cm. With these considerations minimum delay required to achieve ten focal points between given distance is 0.8 ns (nano seconds).

Receive echoes from focal points close to the surface, require a little amplification. This region is referred to as the near field. But echoes recieved from points(focal pt) deep in the body, are extremely weak and must be amplified by a factors of 1,000 or more. This area or region is referred to as the far field. The operation of controlling gain in synchronization with distance of signal is called as TGC (Time Gain Compensation) as distance travelled by sound wave is function of time.

5. Design

5.1 Block Diagram

To achieve modularity and scalability the beam former is divided into two sections – Analog board and Digital board. Analog board is again divided into two sub sections- Transmitter and Receiver. As each of the design section is designed to be independent of rest of the system, analog board can be used for any high speed, low voltage application by interfacing it with suitable control signals. Similarly Digital board can be used as a independent data capture board.

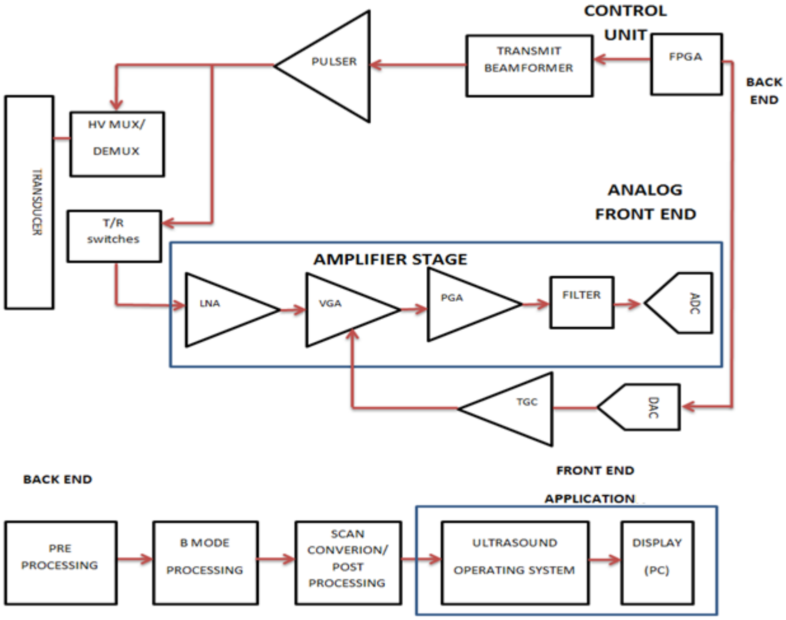

Figure 4: ULTRASOUND BEAM-ORMER

5.2 Analog Board

Analog board is designed to be used as eight channel beam former device. The analog board has complete circuit required for generation and reception of ultrasound signals. However, control signal for Analog Board is provided digital board. Power supply required for operation of each board is derived on the same board.

5.2.1 Transmitter Section

When initiating a scan, a pulse is generated with the help of Transmit Beam former. Transmit beam former is an IC which will generate logic level ultrasound signals with required delay between channels to achieve desired focus point. Transmitted pulse is amplified to 100 Vpp with the help of HV (High Voltage) pulser. The beam former presented here uses 128 elements transducer with 8 channel capacity operating at 7.68MHz.Thus to reduce hardware – the 8 channel output of HV pulsar is connected with 128 elements of transducer using high voltage MUX-DEMUX.

5.2.2 Receiver Section

After transmit, the transducers immediately switch into receive mode. The echoes will be in the range of 10uV-10mV.

The beam former project uses integrated eight channel LNA, VGA (Variable Gain Amplifier), TGC (Time Gain Compensation), LPF (Low Pass Filter) and ADC. The LNA has gain of 21.3dB which can be digitally controlled. Additional cascaded VGA (Variable Gain Amplifier) has maximum gain of 30dB, which also can be digitally controlled. To achieve different gain required for near field and far field signal a TGC is achieved by controlling attenuation of voltage control attenuator by using DAC. The DAC is controlled by FPGA.

LPF is required between VGA and ADC as an anti-aliasing filter and to limit the noise bandwidth. ADC is 12 bit pipeline ADC operated at 61.44 MHz with serial LVDS output.

5.3. Digital board

Digital board consists of FPGA, USB 2.0 controller with 8051 microcontroller. Digital board is designed to interface 2 eight channel analog boards. Thus same digital board can be used for eight channel or 16 channel beam former. Same architecture can be scaled up to form a 32 or 64 channel beam former with a little modifications.

At power up digital board will be programmed by front end application over USB. This approach reduces on board memory requirements. FPGA is the main processing block of the design. FPGA captures output from ADCs, generate real-time control signals for analog board and processes captured data and transmit it over USB to front end for generating image.

6. Results

6.1 MATLAB

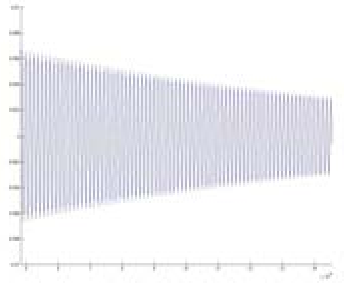

Fig 5 Received damped signal from single channel

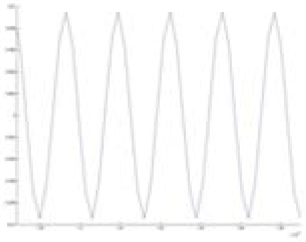

Fig 6:Gain compensation signal from single channel

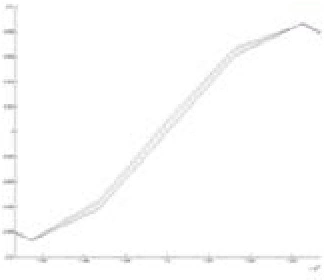

Fig 7: Received signal from channel 1 to 4

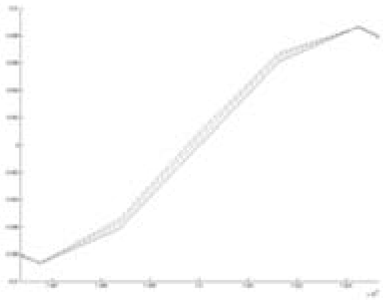

Fig 8:Received signal from channel 5 to 8

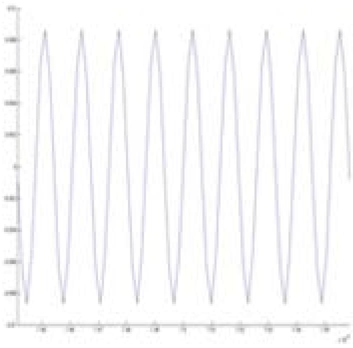

Fig 9:Additional of 8 channel signal to form a single beam

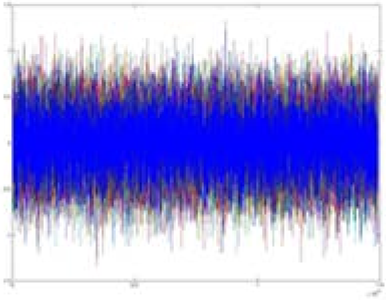

Fig 10:Addtion of noise signals from 8 channel

6.2 Test results of Beam former

Fig 11: TX_BEAMFORMER with 330us Delay

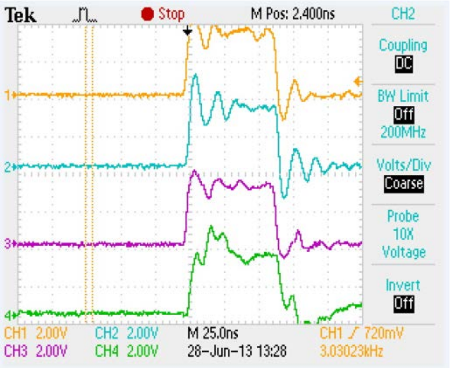

Fig 12: 4 Channel Outputs of TX_BEAMFORMER

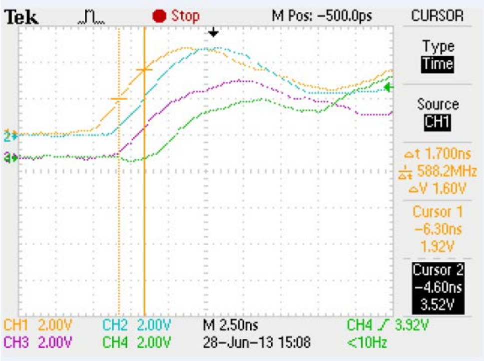

Fig 13: Delays Between Channel 1 and Channel 2 is 1.62ns

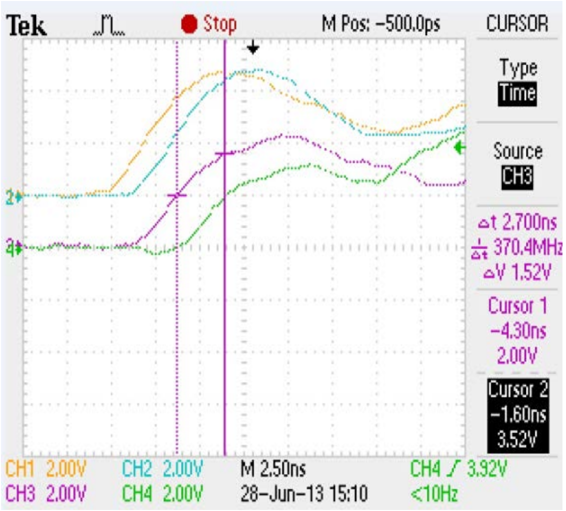

Fig 14: Delays Between Channel 3 and Channel 4 =2.43ns

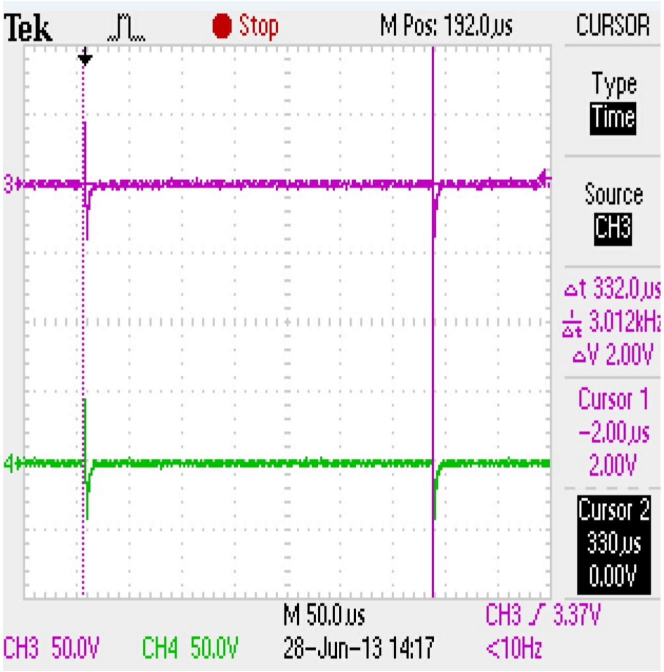

Fig 15: PULSER 2 Channel Output with 330us Delay

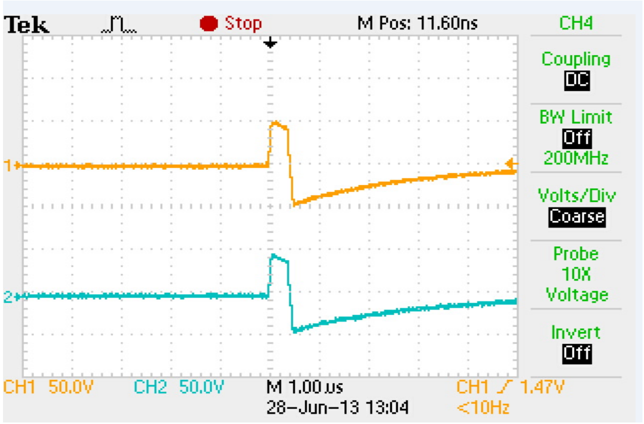

Fig 16: PULSER 2 Channel Output

7 .Hardware setup

Fig 17:Hardware Build for the beamformer

8.Outputs

Fig 18:Image of the object scanned

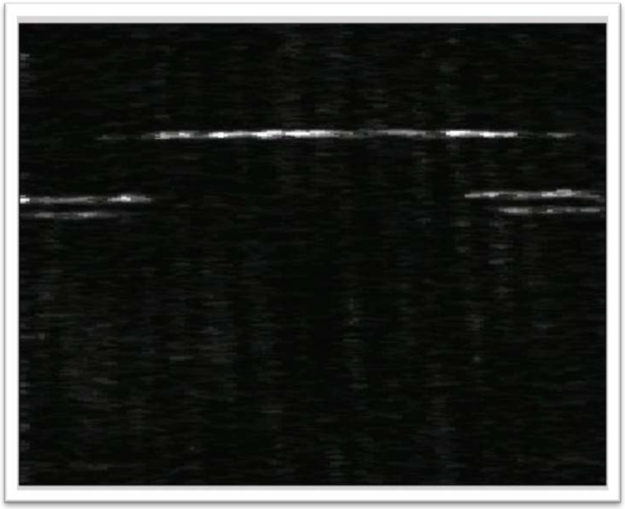

Fig 19:Ultrasound Image of the Fig 18 object (scanned from top view)

9. Conclusions

- The beam former design discussed in the paper is an excellent example of a scalable approach of design .Current design is of an eight channel beam former which can be used as 16/32/64 channel device with little modification
- The beam former design is modular. Analog Board and digital board can be used separately as continuous ultrasound data generator and ultrasound data accusation unit respectively

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