Ultrasound Brain Imaging System

Dec13-01
Michael McFarland
Zach Bertram
Jonathan Runchey
Maurio Mckay

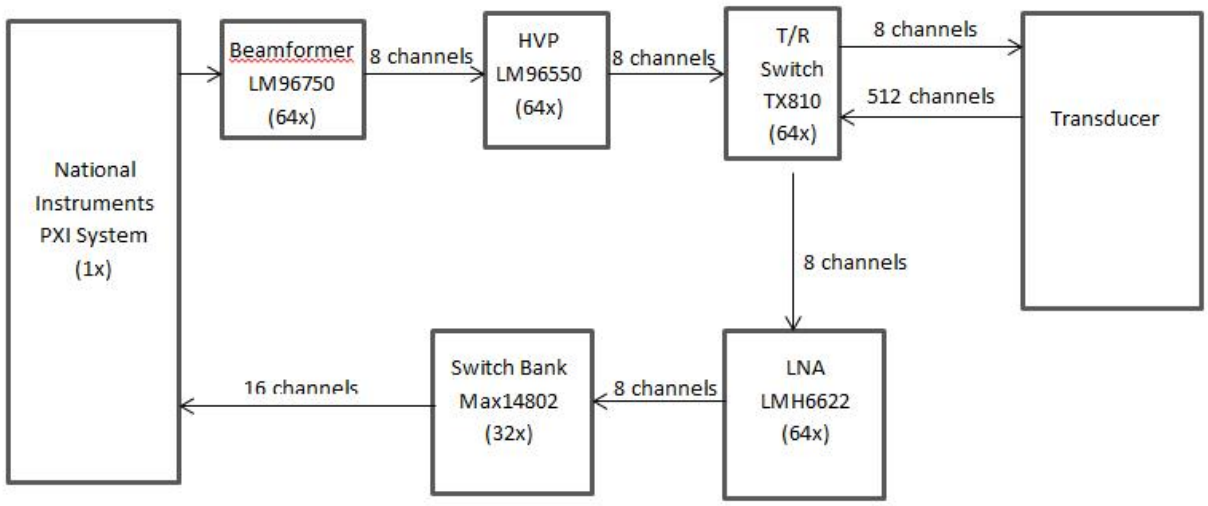
Client/Advisor:
Dr. Timothy Bigelow

Table of Contents

Problem Statement

The goal of this project is to design and build a revolutionary new pulse echo ultrasound system for brain imaging as a low cost alternative to fMRI. The project will use an existing 1.1 MHz ultrasound transducer with 512 elements. The phase and amplitude of each channel must be independently controlled. In addition, the data from each channel must be individually accessible. The circuit can be broken down into 2 stages. The first stage is a transmit stage while the second stage is a receive stage. A version of the transmit stage (~16 elements) has already been designed and placed on a PCB board by an earlier senior design team. The earlier team also designed a version of the receive stage. The students will be expected to review and test the existing transmit stage. They will then modify the design for the transmit and receive stage so that they can interface with a custom National Instruments DAQ system which will communicate with a pc for data acquisition and imaging. Success in the project will be demonstrated by functional hardware. Real-time imaging of the brain is beyond the scope of the project.

System Block Diagram



System description

Waveform Generator

The waveform generator generates digital samples of 1.1 MHz ultrasound pulses. A high-speed DAC will be used to convert the digital waveforms to the analog domain. In total, 512 individual signals will be generated by this functional block.

Beamformer

The beam former circuit works in concert with the high voltage pulse and our FPGA board from National Instruments. Its purpose is to send a control signal to each input channel of the high voltage pulser to configure the output channels to 1.1MHz and the proper delay.

High Voltage Amplifier

High voltage amplification of the generated pulses is necessary in order to provide enough energy to the ultrasound transducer (due to poor electrical to acoustic energy conversion within the transducer). A stronger signal means that there is less opportunity for signal loss while being transmitted. The maximum voltage that this component will generate is 50Vpp

Transmit/Receive Circuit

The transmit/receive circuit will transmit the amplified pulses to the ultrasound transducer. It will receive the reflected low voltage signals from the transducer and use them for the signal processing of the ultrasound. The transmit/receive circuit will also prevent high-voltage pulses from entering the receiver circuitry.

Low-Noise Amplifier

The low-noise amplifier will amplify the weak reflected signals that the transmit/receive circuit receives from the ultrasound transducer. It's placement after the receiver is to recover the low-power reflected ultrasonic signal in the presence of significant noise.

Variable-Gain Amplifier

A variable-gain amplifier is placed after the low-noise amplifier and is used to map the signal into the appropriate dynamic range for signal processing. Computerized control of this device will allow for the gain to be adjusted appropriately over time.

Transducer

The transducer, otherwise known as the probe, is the component in the system that has contact with the body. The basic function of the transducer is to receive an electrical pulse and convert it into an acoustic vibration at a pre-determined frequency. Ultrasonic pulses reflected off of the body are captured by the transducer and converted into electrical signals that can be processed to form images.

Functional requirements

Table 1 - Resource Requirement Descriptions

System Component:	Requirement Description:
Waveform Generator	The waveform generator will be capable of controlling the pulser IC in order to produce high-voltage signals. Each output must be individually controllable in order to implement a phased-array system.
Waveform Generator	**PXI-NI PXI-7811R Specifications:** 160 Digital I/O lines

	At speeds up to 40MHz
Beamformer	The beamformer needs to be able to easily interface with the LM96550(high voltage pulser) and NI-PXI-7811R module
Beamformer	**LM96570 Specifications:** The LM96570 is the part recommended by Texas Instruments to use in conjunction with the LM96550 high voltage pulser. Provides 16 logic outputs to control the high voltage pulser. Controllable by 5 digital input channels.
High Voltage Pulser	**High Voltage Pulser Requirements:** Bipolar output voltage: +/-50V Operating Frequency: 1MHz Number of Channels: 4-32 channels Switching delay time: Less than 167ns
High Voltage Pulser	We will use the LM96550 in our design.
High Voltage Pulser	**LM96550 Operating Specifications:** Bipolar output voltage limit: +/-50V Frequency range of operation: 1 MHz-25 MHz Number of channels: 8 Switching delay time: 24 ns
T/R Circuit	The T/R circuit shall function as protection against high-voltage transients for the receiver. However, the T/R circuit shall allow high-voltage transmitted signals to propagate to the Ultrasound Transducer. The T/R circuit shall only allow a signal with

	maximum amplitude of X V to enter the receiver circuit.
T/R Circuit	We will be using the TX810 to meet these requirements.
Low Noise Amplifier	Required Specification: Gain: ~100V/V Input Voltage Noise: ~<10nV/sqrt(Hz)
Low Noise Amplifier	**LMH6622 Specifications:** GBW: 320MHz Input Voltage Noise: 1.6nV/sqrt(Hz)
Analog Front End	The Analog Front End should contain a variable gain amplifier with an adjustable gain and an ADC that produces LVDS data at the output.
Analog Front End	**PXI-NI5752 Module Specification:** 32 analog Input channels 16 digital I/O channels Variable Gain range of -5dB to 30dB 12-bit ADC
Transducer	Operates in the 1.5 MHz frequency range
Transducer	Linear array with 512 elements

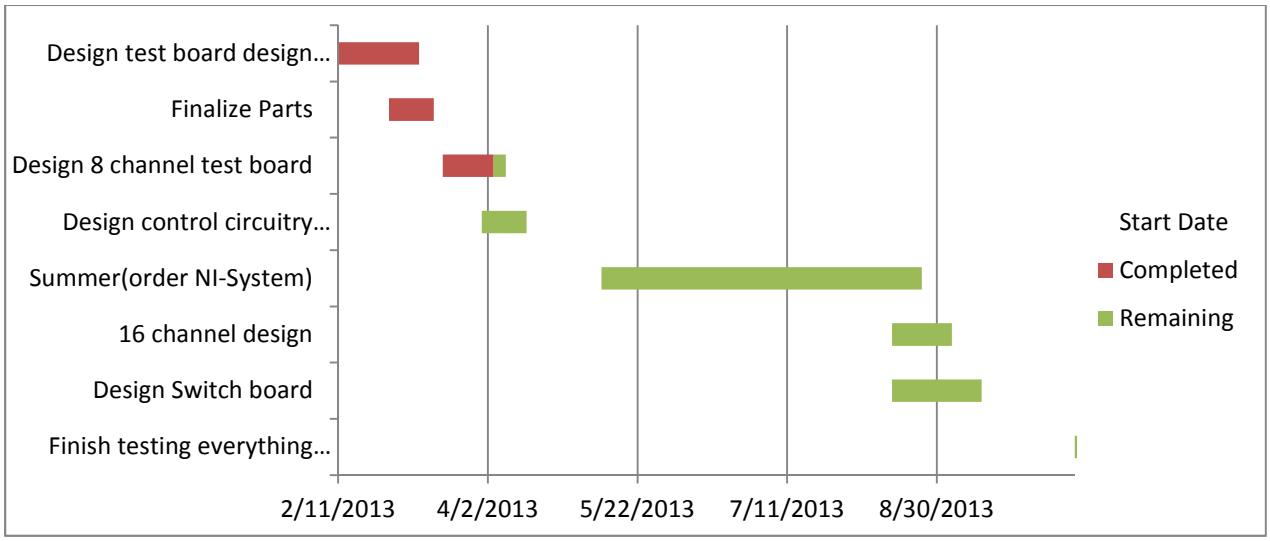
Non-functional requirements

For our ultrasound system we will try to fit our design on 60in^2 double sided boards, to take advantage of the student discount. This means we will have to split up our final design into smaller 16-channel circuits. From there, connecting the boards in an effective yet aesthetically pleasing way for the users, will be one of the end goals.

Ease of access for repair and diagnostics is a problem we are looking to fix as we create our circuits. By making sure things are organized and arranged in logical working order we can

ensure that future engineers who need to fix the boards will be able to easily to replace the parts or build replacement boards for broken parts.

Work Plan



Deliverables

First Semester

An eight channel test board that can interface with the National Instruments system our client plans to order.

Second Semester

A working high frequency pulser that is able to send on 512 channels and receive on 128 channels at ~1.1 MHz. The final version of the system will be put into a case to hold the transmit and receive boards that upon completion of the project will no longer need user interaction.

Accompanying the completed physical machine will be documentation of the project, including data sheets and layouts for all parts of the machine. A detailed write up will be provided for future engineers who wish to modify or elaborate on our design. We will also include a detailed instruction manual for the end user. This will contain information on hazardous operating conditions and the limitations for the hardware will be included.

Risk management

If we are unable to obtain the test board by the end of the spring semester, our progress in the fall semester could be delayed. Before we can buy the PXI system from National Instruments our client needs to make sure that our design will be able to properly interface with the National Instruments system. It is a priority that this gets done before summer break as it could take up to 10 weeks to receive the PXI system, which we will need next semester to test our future designs.

When we get the test board and begin soldering there may be some risks inherent to the process. A resource that could be used to avoid this is an oven to solder the components on the

board. Another resource is that one of the group members had attended a soldering seminar where he had to do some surface mount soldering.

Standards

The best source on industry standard for Ultrasounds was in the Code of Federal Regulations under section number 21 CFR 1050.10. It firsts explains all the definitions that are needed to understand the material and then goes into some performance requirements. I have listed the requirements that apply to us below:

1. A means shall be incorporated to indicate the magnitudes of the temporal-average ultrasonic power and the temporal-average effective intensity when emission is of continuous-wave waveform.
2. A means shall be incorporated to enable the duration of emission of ultrasonic radiation for treatment to be preset and such means shall terminate emission at the end of the preset time. Means shall also be incorporated to enable termination of emission at any time. Means shall be incorporated to indicate the magnitude of the duration of emission.
3. A means shall be incorporated for indicating the magnitudes of pulse duration and pulse repetition rate of the emitted ultrasonic radiation, if there are operation controls for varying these quantities.
4. A means shall be incorporated to provide a clear, distinct, and readily understood visual indicator when and only when electrical energy of appropriate ultrasonic frequency is being applied to the ultrasonic transducer.

The next sub index of this section describes where and how labels should be fixed to the ultrasound. All of the controls need to have a label explaining what each control does and how to use it. The waveform generator must also have a label fixed on it. The specifications for labels are listed below:

> Labels required by this paragraph shall be permanently affixed to or inscribed on the ultrasonic therapy product; they shall be legible and clearly visible. If the size, configuration, or design of the ultrasonic therapy product would preclude compliance with the requirements of this paragraph, the Director, Center for Devices and Radiological Health, may approve alternate means of providing such labels.

The last part of this section explains what information must be explained by the manufacturer of the ultrasound. It is listed below:

1. Adequate instructions concerning assembly, operation, safe use, any safety procedures and precautions that may be necessary regarding the use of ultrasonic radiation, and a schedule of maintenance necessary to keep the equipment in compliance with this section.
2. Adequate description of the spatial distribution of the ultrasonic radiation field and the orientation of the field with respect to the applicator. This will include a textual discussion with diagrams, plots, or photographs representative of the beam pattern.
3. Adequate description, as appropriate to the product, of the uncertainties in magnitude expressed in terms of percentage error, of the ultrasonic frequency effective radiating area, and, where applicable, the ratio of the temporal-maximum effective intensity to the

temporal-average effective intensity, pulse duration, pulse repetition rate, focal area, and focal length.

4 A listing of controls, adjustments, and procedures for operation and maintenance, including the warning "Caution—use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous exposure to ultrasonic energy."

These standards produced by the federal government ensure that the ultrasound is used properly.

Assigned Tasks:

Zach Bertram	Webmaster/PCB design
Michael McFarland	Leader/PCB design
Jonathan Runchey	Communication/Multisim
Maurio Mckay	Communication/Document Writing

Client/Faculty Advisor Information

Dr. Timothy Bigelow, bigelow@iastat.edu
2113 Coover Hall, Iowa State University