Pulse-Echo Ultrasound Brain Imaging

Design Document

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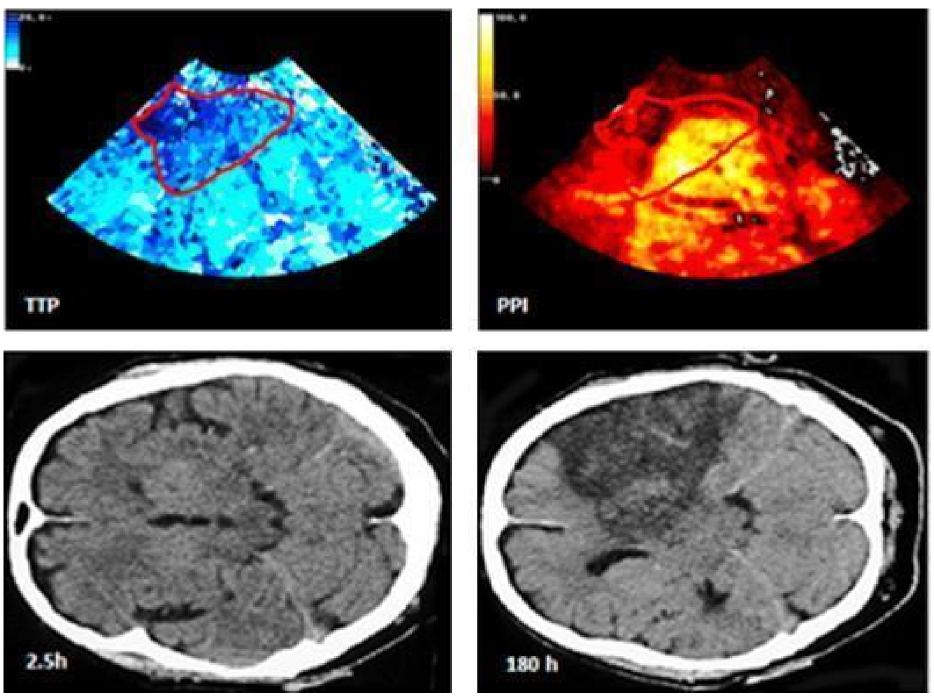

http://www.sciencedirect.com/science/article/pii/S2211968X12000484

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Executive Summary

The goal of this project is to expand upon a previous group's design for a pulse echo ultrasound system for brain imaging, which could be used as a low cost alternative to fMRI. The following report will contain the design for a transmission circuit and a receive circuit for the ultrasound system. The transmit circuit will be able to send high voltage pulses (+/-50V) over 512 channels to a transducer. The receive circuit will then receive the signals from the transducer and amplify them before sending them to a computer interface.

System Requirements

Our goal is to design and build a transmit circuit capable of sending +/-50V pulses over 512 channels to send to a 512 element transducer our client has previously bought. The circuit should then be capable of receiving low voltage pulses back from the transducer and amplifying them to send to the National Instruments DAQ system. To reduce costs our client wants us to demultiplex the signal from 512 channels to 128 channels before sending it to the National Instruments system.

Functional

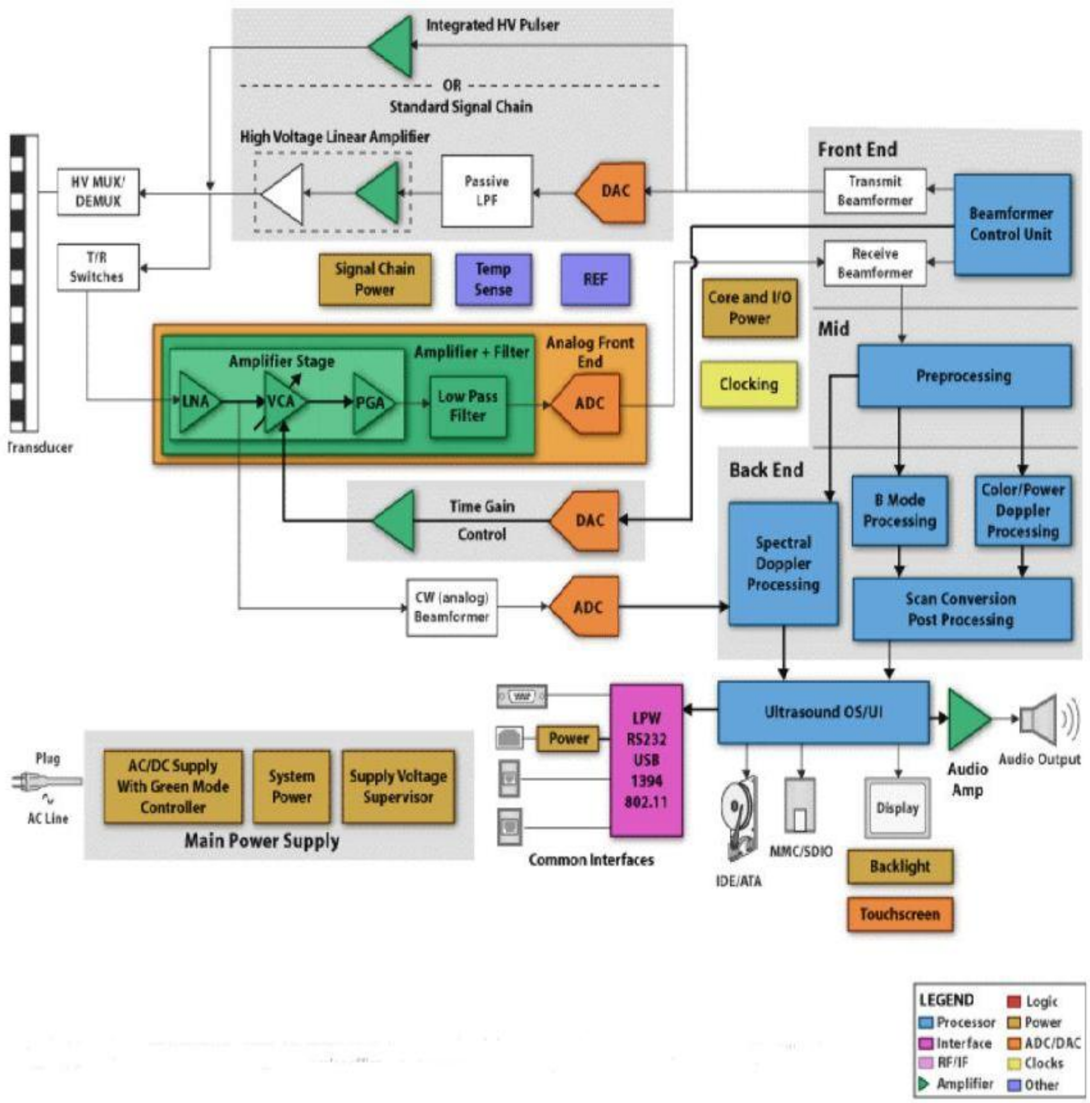
- Transmit 512 channels at 1.5 MHz
- Receive 128 channels
- Generate +/- 50 V bipolar pulses
- Protection for the receive circuitry
- Variable gain for differing imaging depths

Non-functional

- Maximum 60 in^2 boards (to reduce cost)
- Circuitry housing
- Spacing optimization in complete machine to maintain accessibility

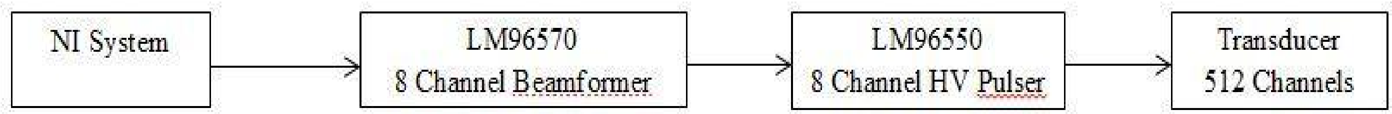
System Overview

We have divided our current design into three separate parts; transmit circuit, receive circuit, and the computer interface. The transmit and receive circuit are based on research from a previous group and suggested ultrasound hardware provided on the Texas Instruments website. A block diagram of the suggested Texas Instruments design can be seen below:



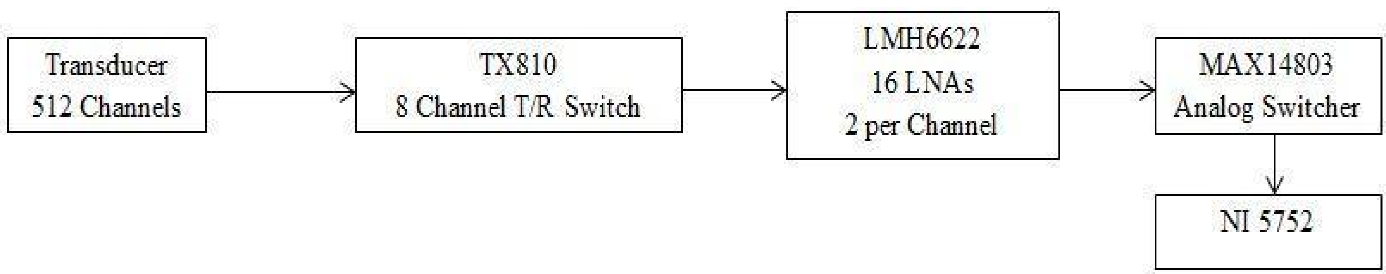
Transmit Circuit:

The transmit circuit will be responsible for sending +/-50V pulses to the transducer, using the LM96570 (beamformer) and LM96550(high voltage pulser). The control of the beamformer, and thusly the entire transmit circuit, is delegated to a National Instruments system specifically designed for use in ultrasound. The previous group's design used high voltage pulsers, which were controlled by being connected directly to a computer interface and needed 18 control bits to be able to send pulses over 8 channels. To help keep costs down we decided to go with Texas Instrument's suggestion of using the LM series combination of the LM96570 and LM96550. The extra addition of the beamformer IC allows us to control the pulser using a serial interface, which reduces the required control bits from 18 down to 9. Below is a block diagram representation of the transmit circuit:



Receive Circuit:

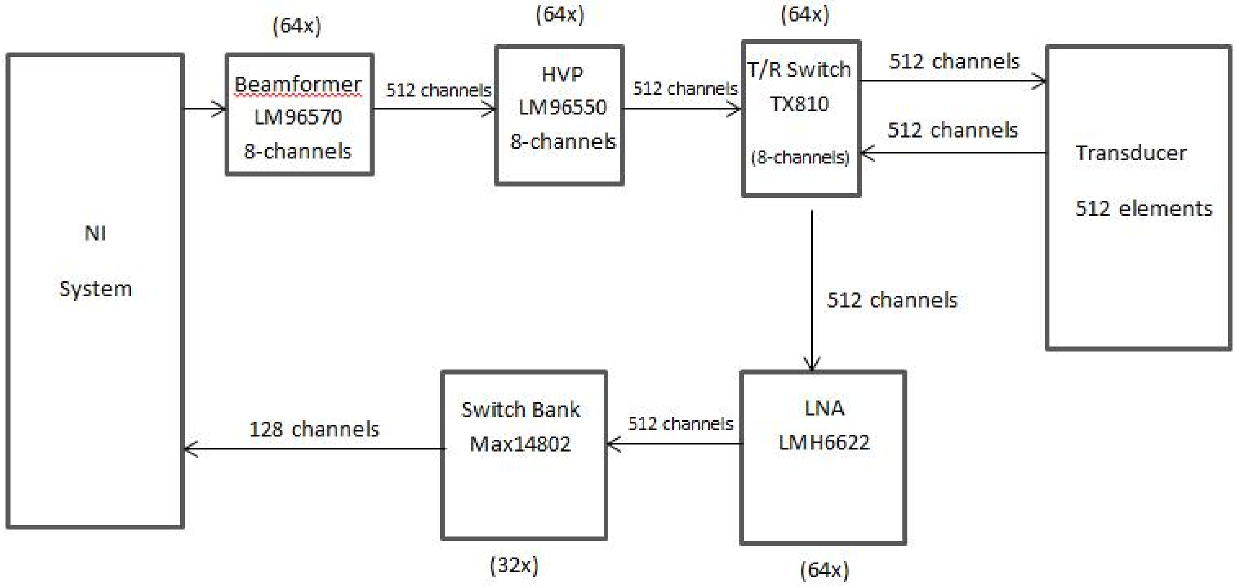
The receive circuit will be responsible for receiving the low voltage signals sent back by the transducer. The receive circuit will amplify and demultiplex the signal down to 128-channels (from 512 channels) before sending the information back to the computer interface. The receive circuit contains the TX810(T/R switch), the LMH6622 (Low Noise Amplifier or LNA), and the MAX14803 (analog switcher). The TX810 is responsible for protecting the receive circuitry from the high voltage pulses from the transmit circuit, by limiting its output voltage to $2V_{pp}$. The low noise amplifier stage of the receive circuit is responsible for amplifying the low-voltage signal received back from the transducer, before it is sent to the analog switches. The analog switches are responsible for demultiplexing the signal from 512 channels to 128 channels. Below is a block diagram representation of the receive circuit:



Computer Interface:

To control our circuit we are going to be using a National Instruments PXI system which will be capable of sending control signals to our transmit and receive circuit. The National Instruments PXI system will contain the NI-5752 module, which contains a variable gain amplifier and analog to digital converter.

Overall System Block Diagram:



Detailed System Design

Transducer

The transducer is the part of the system that will come in contact with the patient. It is able to receive a high voltage pulse which it then converts into an ultrasonic pulse at a pre-determined frequency. The ultrasonic pulse is then sent into the body and the reflected pulses are captured by the transducer and converted into electrical signals that can be processed to form images. We will be using a 512 element transducer in our design.

Computer Interface System

We will be using the National Instruments PXI System to receive the signals back from the transducer and to control our high voltage pulser. The PXI system has a modular design which allows us to different boards based on our needs. Our team will use the NI PXI-7813R Virtex-II 3M Gate R Series Digital RIO Module to send control signals to the Beamformer. For the receive circuit we will be using the NI 5752 board.

NI PXI-7813R:

Parameter	Specification	Required Specification
Digital Control Signals	160 bits (will need 2)	320 bits (64*5)

NI-5752:

Parameter	Specification	Required Specification
Receive Channels	32 channels (we will need 4)	128 channels

Beamformer

The Beamformer connects directly to the high voltage pulser and reduces the amount of digital signals needed to control the high voltage pulser from 18 to 9 channels.

We will be using the Texas Instruments LM96570 Transmit Beamformer. It offers eight output P and N channels at an individual delay from .78 ns to 102.4 μs at a max pulse rate of 80 MHz. The National Instruments PXI system will send five control bits to the Beamformer which will then interpret these control bits and send the appropriate signal to the high voltage pulser to create a high voltage pulse over each of the 8 channels.

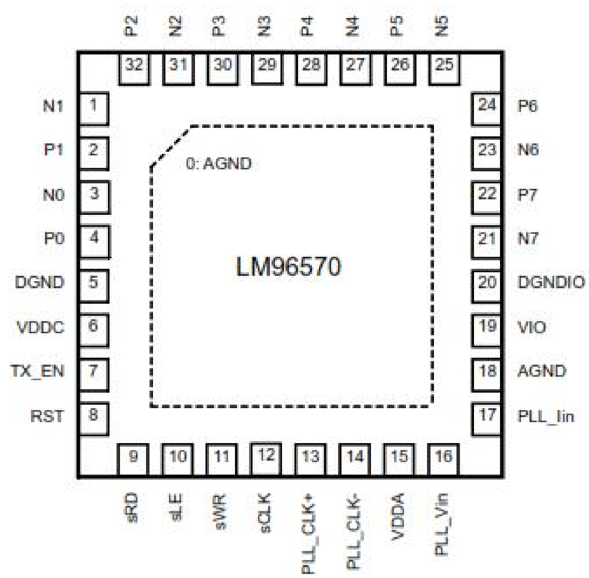


Figure 1 LM 96570 Pin layout

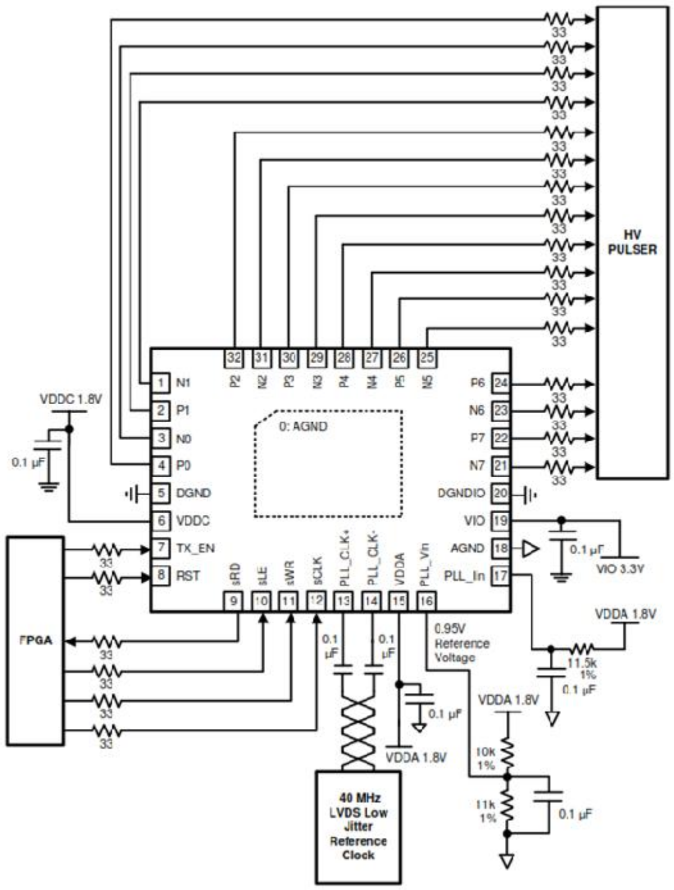


Figure 2 Reference Circuit

High Voltage Pulser

The High Voltage Pulser is the component of our system that will generate the excitations of the transducer. These excitations will be in the form of both positive and negative square pulses. It will be controlled by the LM96570 Beamformer.

We will be using the Texas Instruments LM96550 Ultrasound Transmit Pulser. As you may notice in the following table, we desire 512 channels of operation, but the LM96550 supplies only 8. Therefore, we will be using 64 pulsers in conjunction with one another to achieve the desired 512 channels.

Parameter	LM96550 Specification	Required Specification
Voltage Output	+/- 50 V	+/- 50 V
Frequency Range	Up to 15 MHz	1.5 MHz
Number of Channels	8	512 (8x64)
Switching Delay Time	32 ns	Less than 167 ns

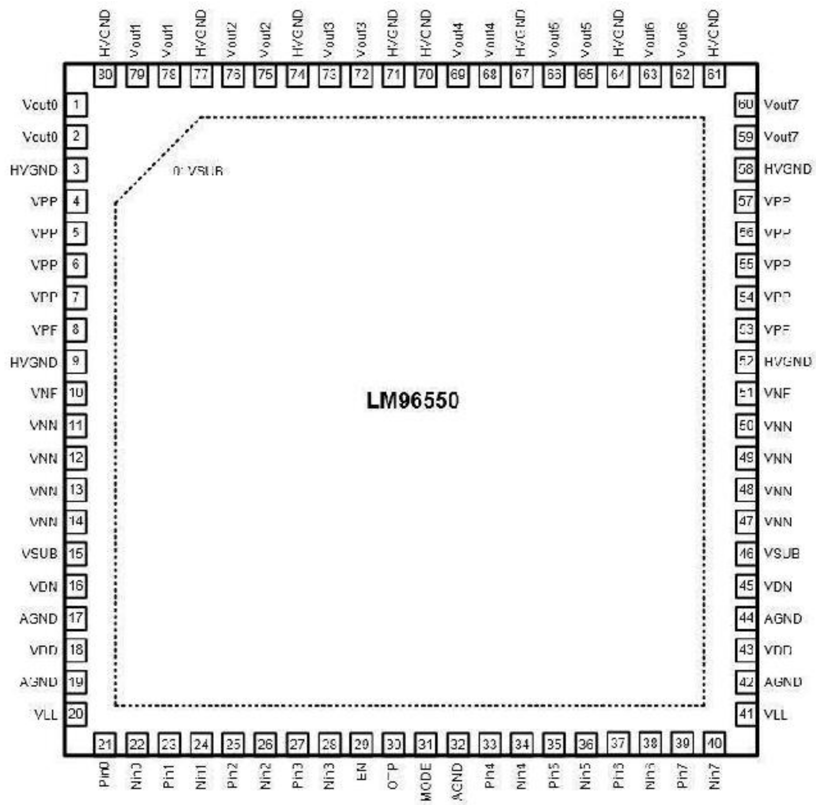


Figure 3 LM96550 Pin Layout

The pulser will only operate when the EN pin is driven HI. If the pulser is enabled, driving PIN or NIN HI will generate a positive or negative pulse, respectively, at Vout. Vout will be pulled to the positive supply (VPP) or the negative supply (VNN) by power MOSFETs. If both PIN and NIN are LO the output Vout will be pulled to GND (0 V). It is important to never drive both PIN and NIN HI as this will cause damage to the circuit. The following figure is a block diagram of a single channel of the pulser.

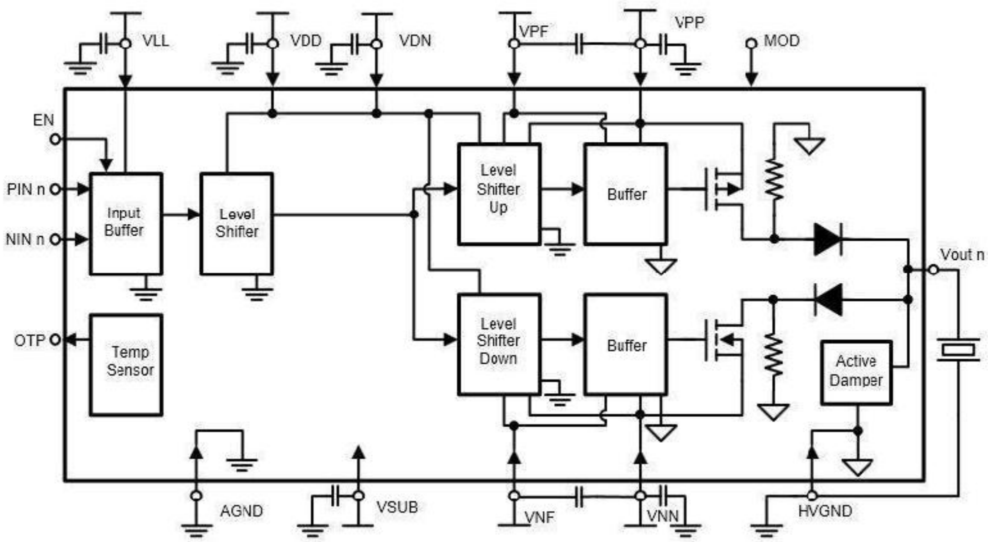


Figure 4 Block diagram of single LM96550 channel

T/R Switch

The T/R switch will act as an interface between the transmit and the receive sides of our system. It will allow high-voltage signals from the High Voltage Pulser to be passed to the transducer in the transmit stage, while limiting the output voltage to the receive stage to only 2Vpp Thus, the T/R switch's primary purpose is to act as a buffer between the system's Low Noise Amplifier and the High Voltage Pulser as the Low Noise Amplifier can be permanently damaged by high voltages.

We will be using the Texas Instruments TX810 part in our system. The TX810 supports 8 channels and has three digital control bits (B1, B2, and B3) that determine its biasing current; increasing the biasing current decreases the switch's impedance. Some properties of the system may be optimized by introducing different values of load inductance and resistance, but this may also lower the system's sensitivity. We will determine what values we will use once sufficient testing has taken place.

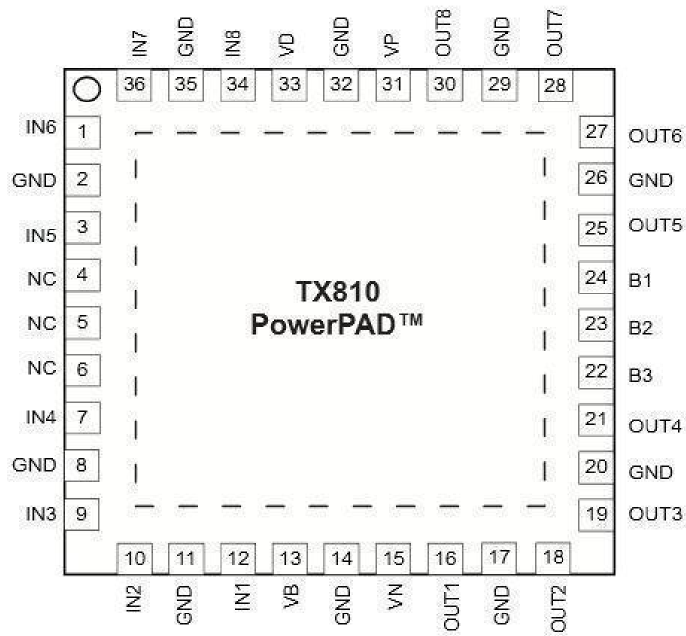


Figure 5 TX810 Pin Layout

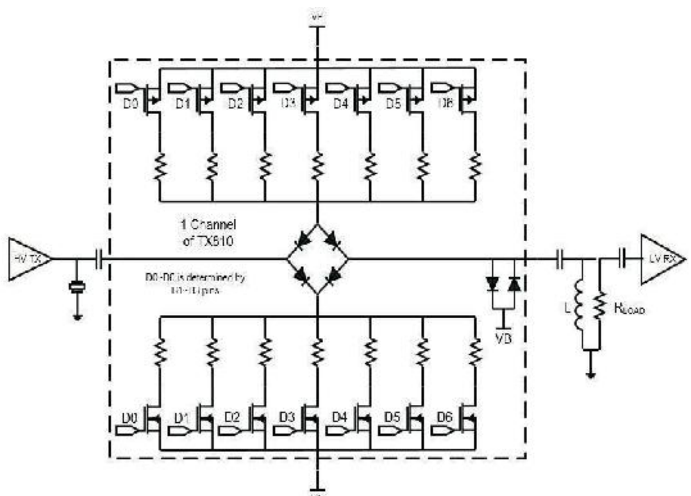


Figure 6 Block diagram of single TX810 channel

Low Noise Amplifier

The low noise amplifier amplifies the heavily attenuated, reflected signals from the transducer which have been transmitted through the T/R switch (TX810) such that the signals can be sampled and processed for imaging.

For the low noise amplifier we chose to go with the LMH6622 from Texas Instruments. For our design our client estimated we would need to have 40dB worth of gain before sending the receive signal to the NI-5752 device. He was also looking for a 3dB bandwidth around

10MHz to accomplish this we decided to go with two LMH6622 amplifiers in series. The reason for this was so that we could reach the required gain of 40dB and still have a 3dB bandwidth for each amplifier of at least 10 MHz.

Parameter	LMH6622 Specifications	Required Specification
LNA Gain	N/A	40dB
3dB Bandwidth	N/A	10MHz
Gaind Bandwidth	120MHz	N/A

Switch Bank

In order to reduce how many NI 5752 boards we would need to buy, we decided to use Max14802 switch banks to multiplex our receive signal from 512 channels down to 128 channels.

Parameter:	MAX14802 Specifications:	Desired Value:
Number of Available Switches	16 integrated SPST switches	An integrated array of 16-32 switches
Serial Interface	Each device features a 20 MHz serial interface that operates at 5V. Serial interfaces between devices can be daisy-chained for simplified control. “Latch Enable” pins control whether the devices retains its currently programmed state or loads a new state in.	The device will feature an interface that will allow for each switch to be controlled individually.

Board Break Down

To save money our group plans on limiting ourselves to 60 in^2 for all printed circuit board designs. The reason for this is that senior design groups at Iowa State receive a discount on printed circuit boards under 60 in^2. To accomplish this task we plan on dividing our circuit up into two separate groups as follows:

Transmit/Receive Boards:

The transmit/receive boards are responsible for transmitting the high voltage pulses to the transducer, and also receiving back the low voltage signal from the transducer. After receiving the low voltage signal from the transducer the circuit will amplify the low voltage signal before sending the amplified signal to the switch board. Below is a breakdown of how many parts will be needed for each 16 channel board.

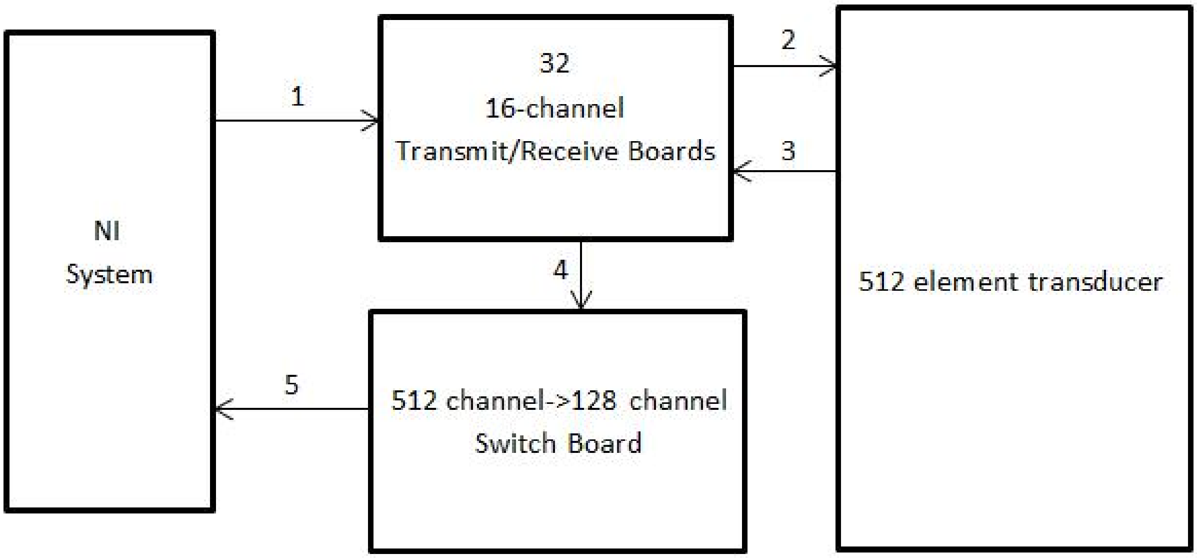
Device	Number of Devices per Board; 32 Boards Total
LM96550	2
LM96570	2
TX810	2
LMH6622	16

Switch Boards:

The switch board will be responsible for de-multiplexing the signal down to 128 channels before sending the signal to the NI-5752 modules.

Device	Number of Devices per Board; 4 Boards Total
Max1402	8

Below is a block diagram demonstrating the interconnections between boards:



Challenges Encountered

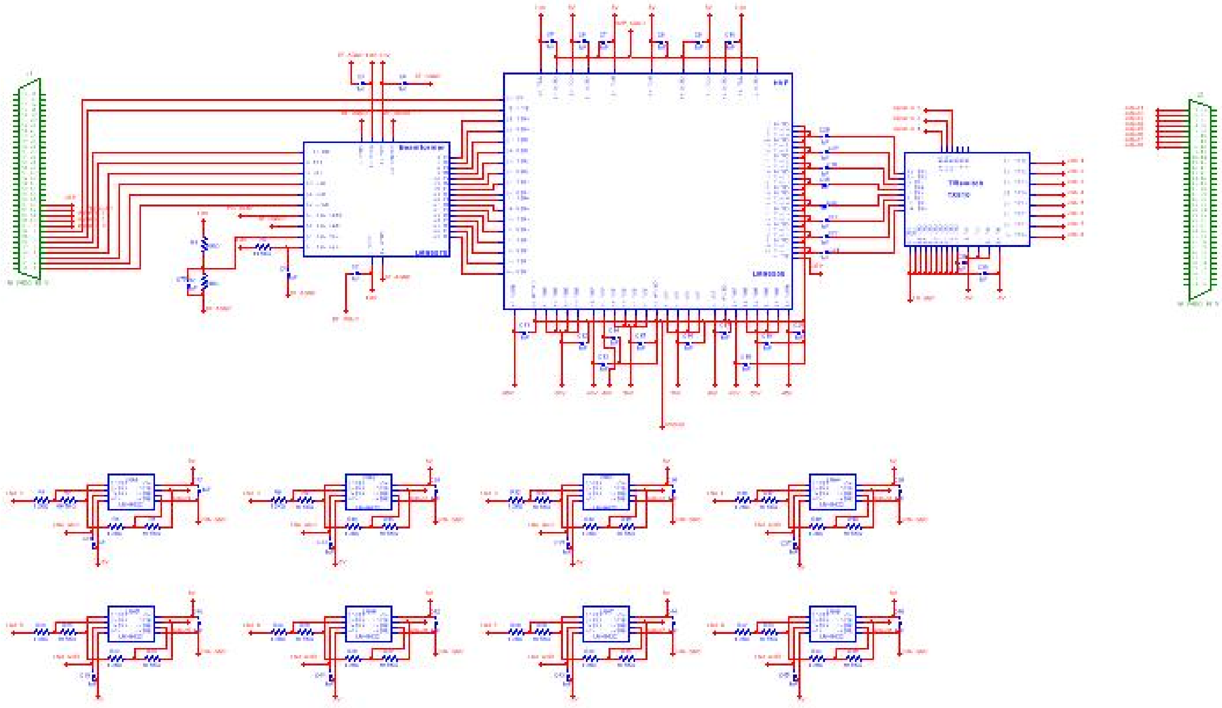
- Learning Ultiboard/Multisim
  - None of our group members had previous experience with Multisim, Ultiboard, or PCB design in general.
- Understanding the previous group's work
  - We are continuing a previous senior design team's work, and therefore had to put in a large amount of effort to understand their work and design. We also had to change a fair amount of their design in order to comply with updated requirements.
- Finalizing our part set
  - We also spent a large amount of time in choosing our parts. Initially we changed our high voltage pulser from a Hitachi part that the previous group had chosen to the current TI part, and ultimately, we chose an entirely new series of (TI) parts.

Testing

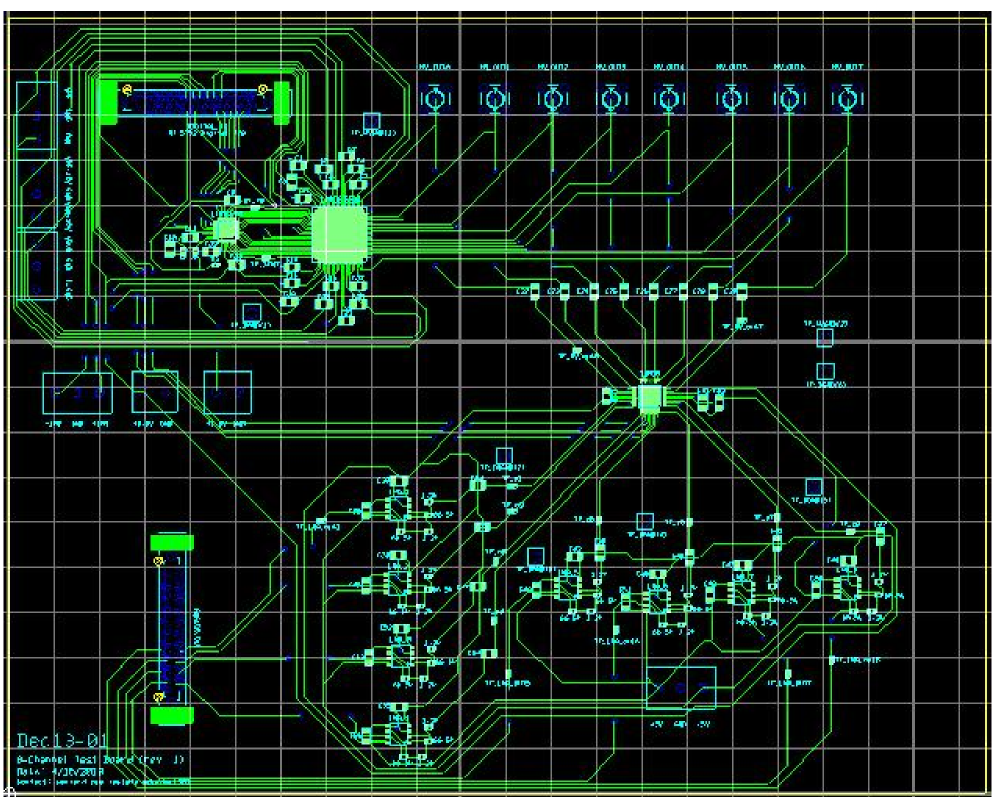
First Semester Test Plan

For our first testing phase our group plans on designing and ordering an 8-channel test board containing the LM96570, LM96550, TX810, and eight LMH6622 chips. During the first phase of testing we want to show that we can both send and receive a signal using our planned chip set.

We also want to make sure our circuit is compatible with the National Instruments system our client plans to order. Thus, we have designed our circuit to connect directly to the National Instruments system. Below is a schematic of the circuit we plan to test:



Below is the PCB design of our 8-channel test board:



Below is the I/O configuration of the test board:

Input (NI-5752)	Pin Name
DI 0	BF sRD
DI 1	HV_OTP
DO 0	NC
DO 1	BF_TX_EN
DO 2	NC
DO 3	BF_RST
DO 4	NC
DO 5	BF_sLE
DO 6	HV_MODE
DO 7	BF_sWR
DO 8	HV_EN
DO 9	BF_sCLK
DO 10	T/R_B1
DO 11	NC
DO 12	T/R_B2
DO 13	NC
DO 14	T/R_B3
DO 15	BF_PLL_CLK+

Output (NI-5752)	Pin Name
AI 0+	LNA4
AI 1+	LNA5
AI 2+	LNA3
AI 3+	LNA6
AI 4+	LNA2
AI 5+	LNA7
AI 6+	LNA1
AI 7+	LNA8
AI 8+	NC
AI 9+	NC
AI 10+	NC
AI 11+	NC
AI 12+	NC
AI 13+	NC
AI 14+	NC
AI 15+	NC

Budget

This semester we had a senior design budget of $1000. The majority of our budget was used to purchase the parts needed for our 8-channel test board. Below is a breakdown of where our money was spent:

date purchased	part	part number	quanity	unit price	extended price
4/8/2013	10kohm resistor	P10KGCT-ND	10	0.1	1
4/8/2013	11kohm resistor	P11KGCT-ND	10	0.1	1
4/8/2013	11.5kohm resistor	P11.5KHCT-ND	10	0.1	1
4/8/2013	sma connector	ACX1231-ND	15	3.87	58.05
4/8/2013	High Voltage Pulser	LM96550	5	30.25	151.25
4/8/2013	Beamformer	LM96570SQX/NOPB	5	9.91	49.55
4/12/2013	female connector to transducer	1003-1647-ND	1	265.5	265.5
4/12/2013	VHDCI Connector, 68-Pin, Vertical, PWB Through Hole Mount	780389-01	2	21	42
4/12/2013	1.2kohm resistor	P1.2KGCT-ND	50	0.0092	0.46
4/12/2013	66.5kohm resistor	P66.5KHCT-ND	50	0.0138	0.69
4/18/2013	PCB		1	33	33
4/26/2013	10kohm resistor	P10KGCT-ND	40	0.1	4
4/26/2013	15kohm resistor	P15KGCT-ND	20	0.1	2
4/26/2013	20kohm resistor	P20KGCT-ND	20	0.1	2
4/26/2013	30kohm resistor	P75KGCT-ND	30	0.1	3
4/26/2013	100kohm resistor	P100KGCT-ND	10	0.1	1
4/26/2013	150kohm resistor	P150KGCT-ND	30	0.1	3
4/26/2013	200kohm resistor	P200KGCT-ND	10	0.1	1
4/26/2013	zener diode	NZX2V1B,133-ND	16	0.2	3.2
	total				622.7