PULSE ECHO ULTRASOUND SYSTEM DESIGN

By: Dec1204

Member Information

- Client and Faculty Advisor Information
  - Dr. Timothy Bigelow, bigelow@iastate.edu
- Student Team Information
  - Jon Driggs – Team Leader
  - Francis Ferrer – Team Leader
  - Allen Kellar – Communications
  - Amairani Tapia – Communications
  - Justin Batcheler – Web Designer
  - Richard Page – Web Designer

Brain Imaging Technology

- fMRI – Functional Magnetic Resonance Imaging
  - Uses changes in blood oxygen levels to detect areas of brain activity
  - Is effective, but expensive to implement

- Pulse Echo Ultrasound
  - Transmits and receives ultrasonic pulses through a transducer
  - Is effective and less expensive, but requires complex hardware

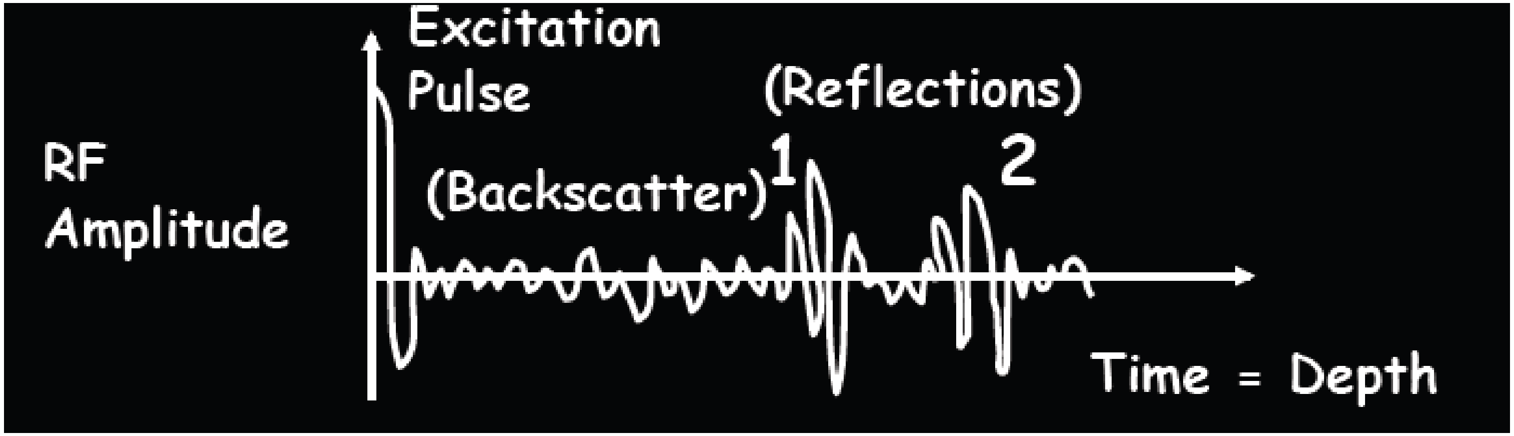
Pulse Echo Ultrasound

- A pulse signal, or excitation signal, is transmitted through the transducer
- The acoustic signal is reflected back to the probe once it reaches boundaries between tissues
- The amount of delay between transmitting a pulse and receiving a pulse indicates the depth of tissue

Pulse Echo Ultrasound

- Illustration of Pulse Echo Ultrasound TX and RX

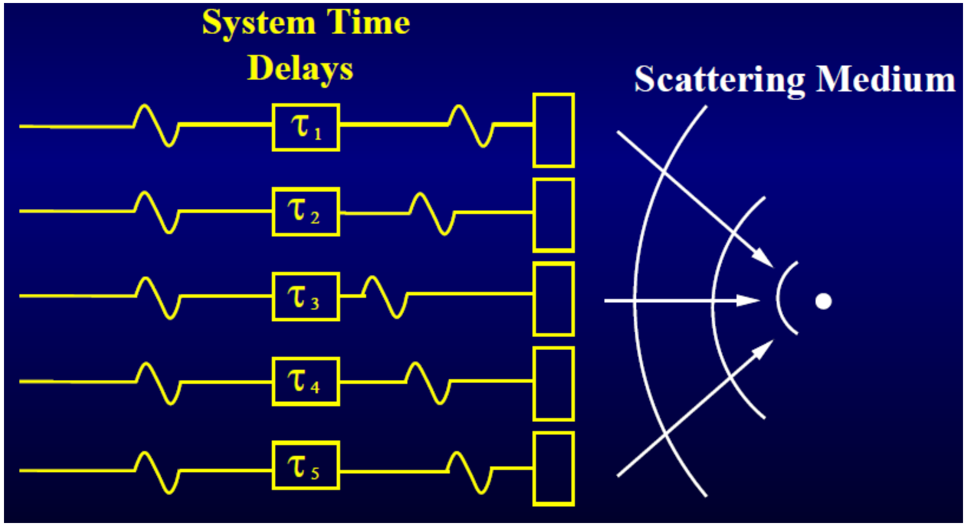
- Reflected signals can be used to form an image based upon their time delay



[REF] Yao Wang, "Medical Imaging", 2009, http://eeweb.poly.edu/~yao/EL5823/MI_Ultrasound2_2012_turnbull.pdf

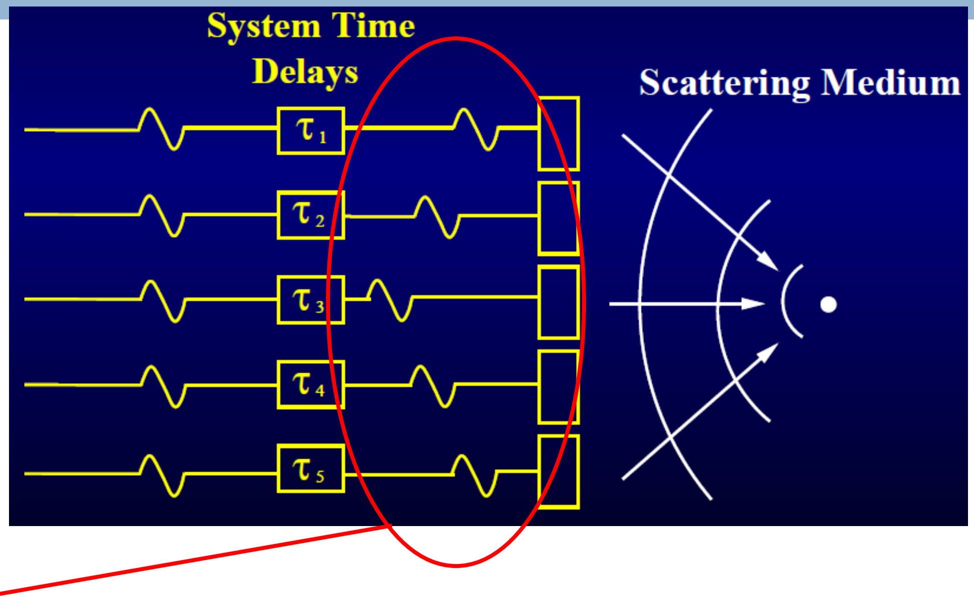
Problem Statement

- Produce a low-cost Pulse Echo Ultrasound System
- System sends and receives pulses through 128 elements of a transducer
  - Phase and amplitude are controlled
- Recovered signals can be processed to form an image



[REF] Mark L. Palmeri, "Ultrasound Beamforming and Image Formation, 2007

Problem Statement

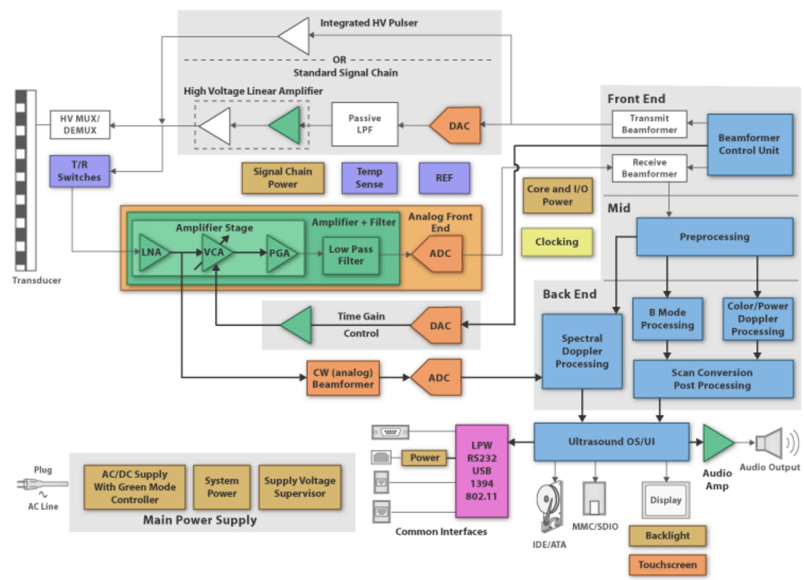


- Different delays allow for the transducer to focus energy on a specific point
  - Allows for more power to be transmitted to a specific region of interest, more power is reflected back that can be processed

Approach

- Researched approaches used by industry and used design resources and ASICS created by semiconductor companies (Texas Instruments, Maxim)

- Utilized contacts professors in the department had to obtain some components for the system

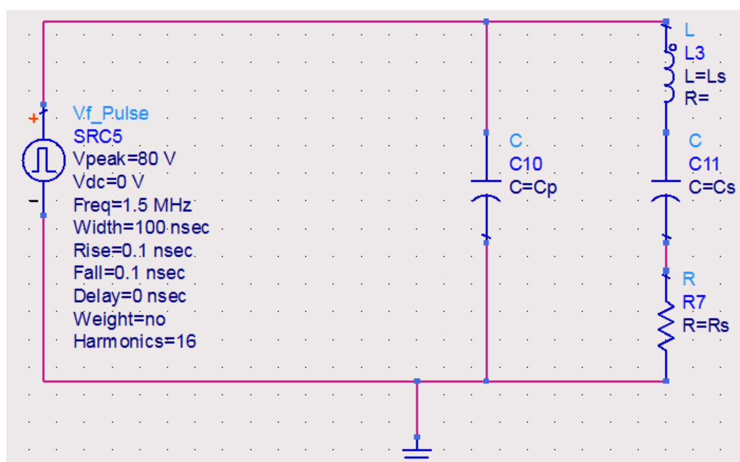


Design – Functional Requirements

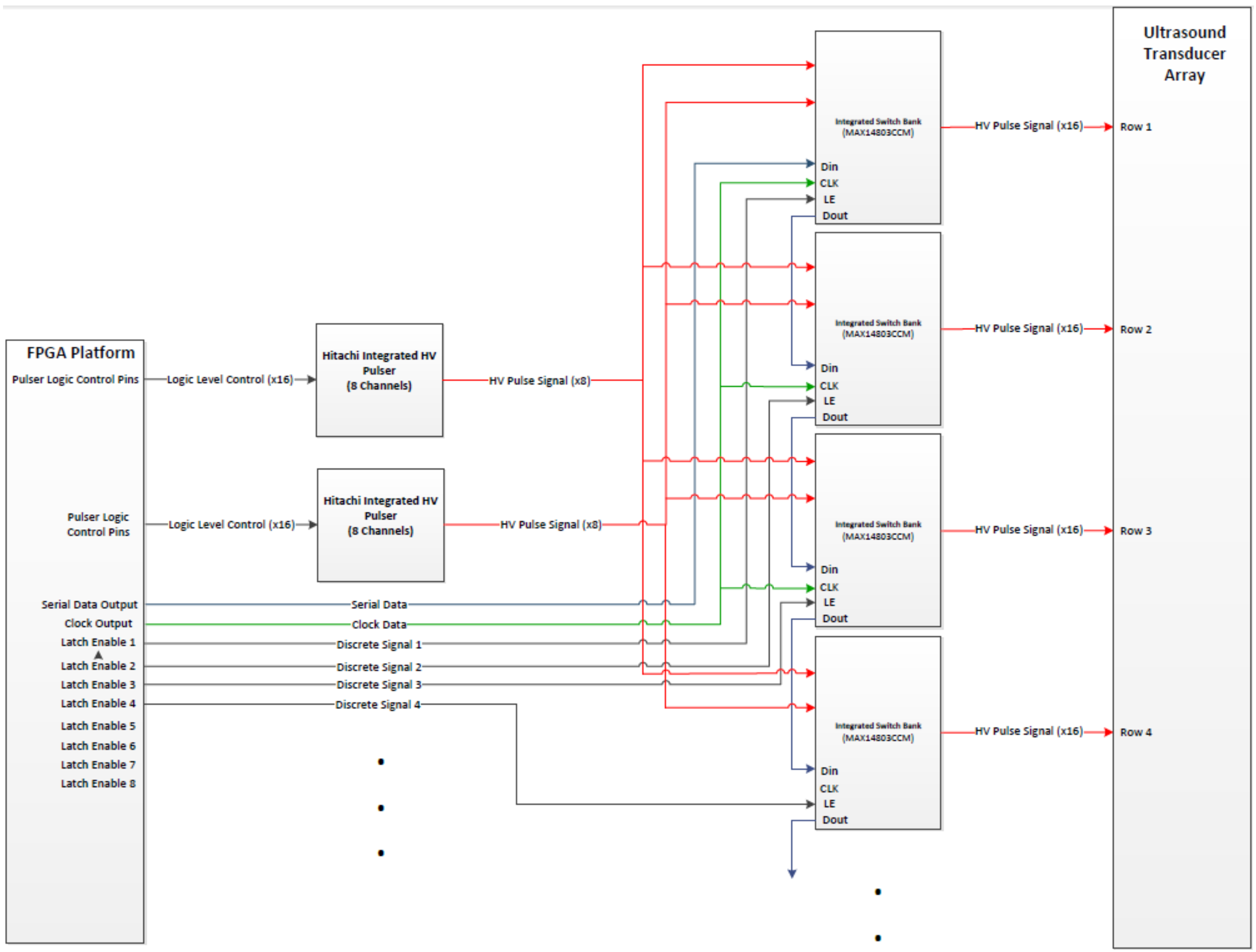
- Waveform Generator must be controlled by a simple user interface provided by an FPGA development board
- Generated pulse delay must be controllable from 10ns to 20 us
- Pulse amplitude must be controllable from 0V to 80V
- Individually control a linear array of 128 elements
- Recover reflected pulses through receiver circuitry

Meeting Technical Requirements

- **Phase Control:** Utilize a 200 MHz oscillator to drive counter circuits for each channel
- **Amplitude Control:** Utilize the impedance of the transducer to filter a PWM signal

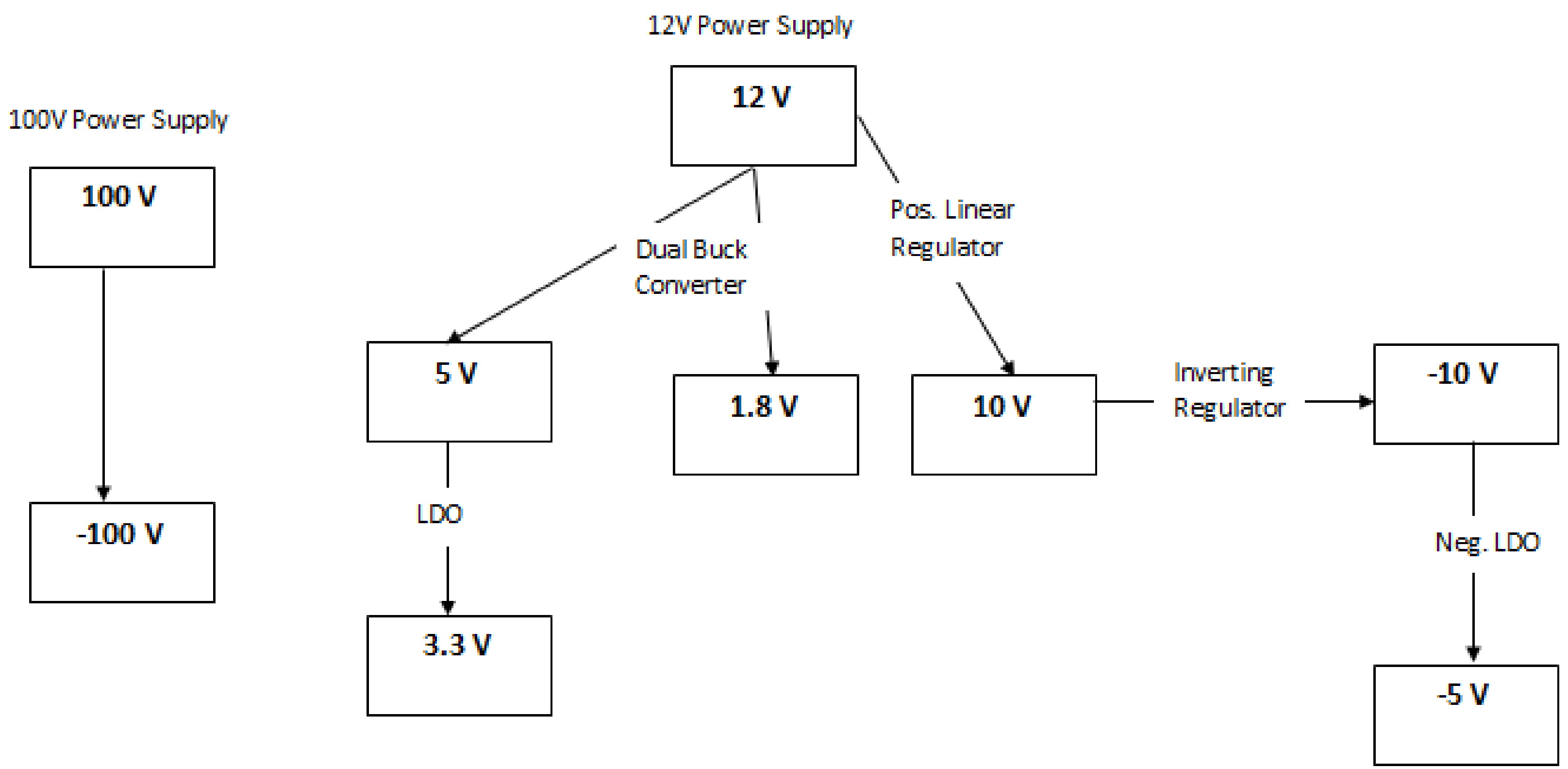


Design – Block Diagram



Power Electronics

- Power Regulation



Dual Buck Converter Design

$$D_{min} \approx \frac{V_{OUT} + V_{FD}}{V_{IN(max)} + V_{FD}}$$

$$D_{5V,min} = \frac{5V + 0.5V}{12V + 0.5V} = 44\%$$

$$L_{min} \approx \frac{V_{IN(max)} - V_{OUT}}{I_{LRIP(max)}} \times D_{min} \times \frac{1}{f_{SW}}$$

$$L_{5V,min} = \frac{12V - 5V}{600mA} \times 44\% \times \frac{1}{600kHz} = 12.8\mu H$$

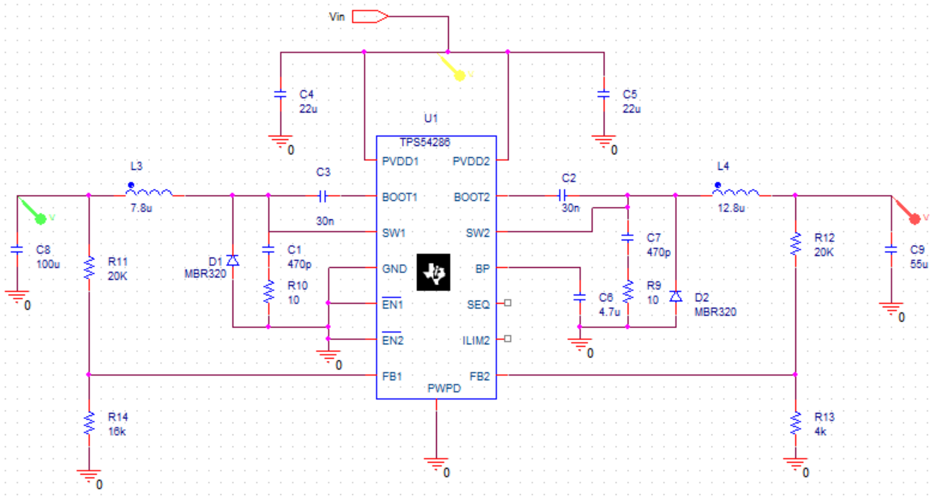
$$C_{OUT} = \frac{1}{4 \times \pi^2 \times (f_{RES})^2 \times L}$$

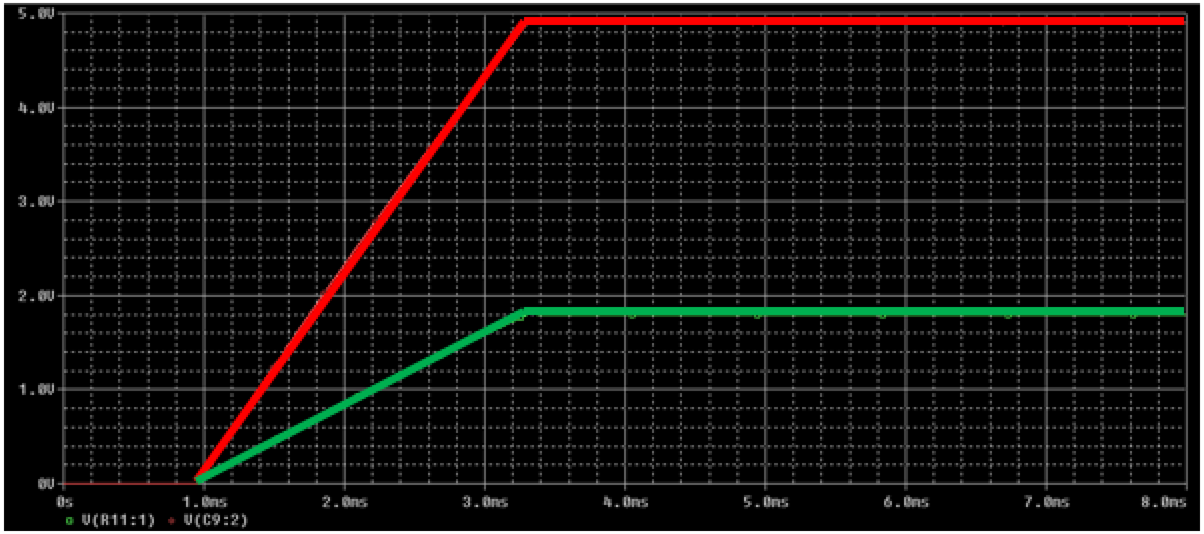
$$C_{5V,OUT} = \frac{1}{4 \times \pi^2 \times 6000Hz^2 \times 12.8\mu H} = 55\mu F$$

$$R13 = \frac{V_{FB} \times R12}{V_{OUT1} - V_{FB}}$$

- R12 = 20kΩ
- R13 = 3.83kΩ
- Vout = 5V
- Vfb = 0.8V

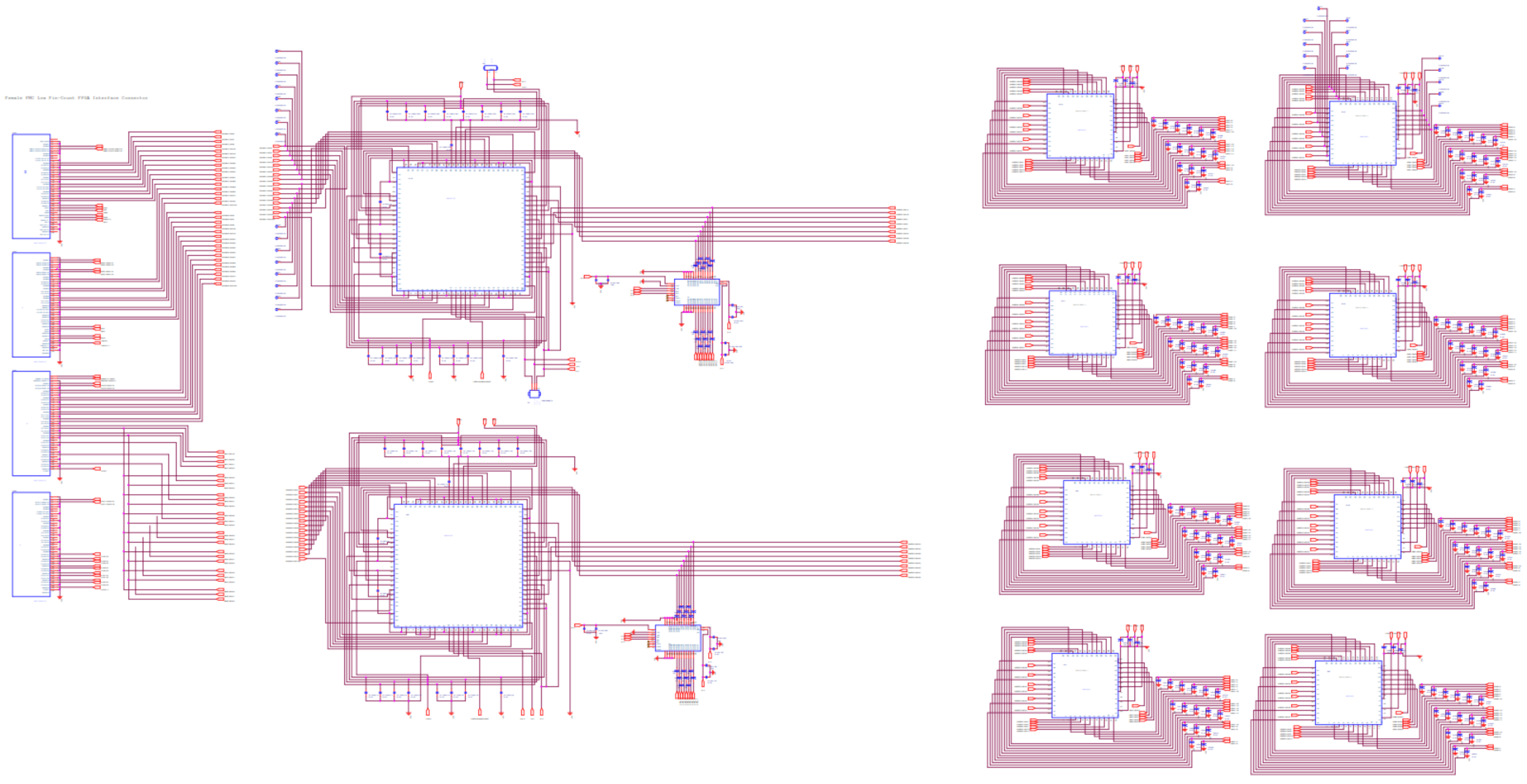
Dual Buck Converter





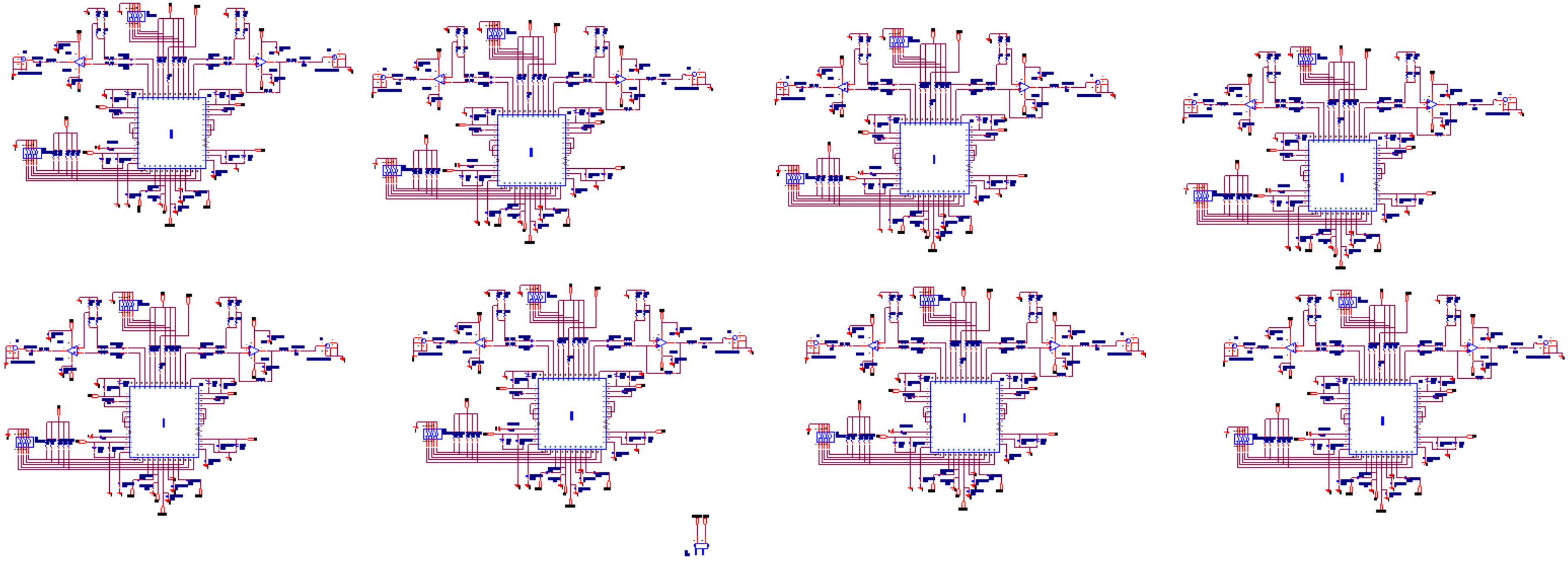
Schematics – Pulse Echo Ultrasound

- Transmit

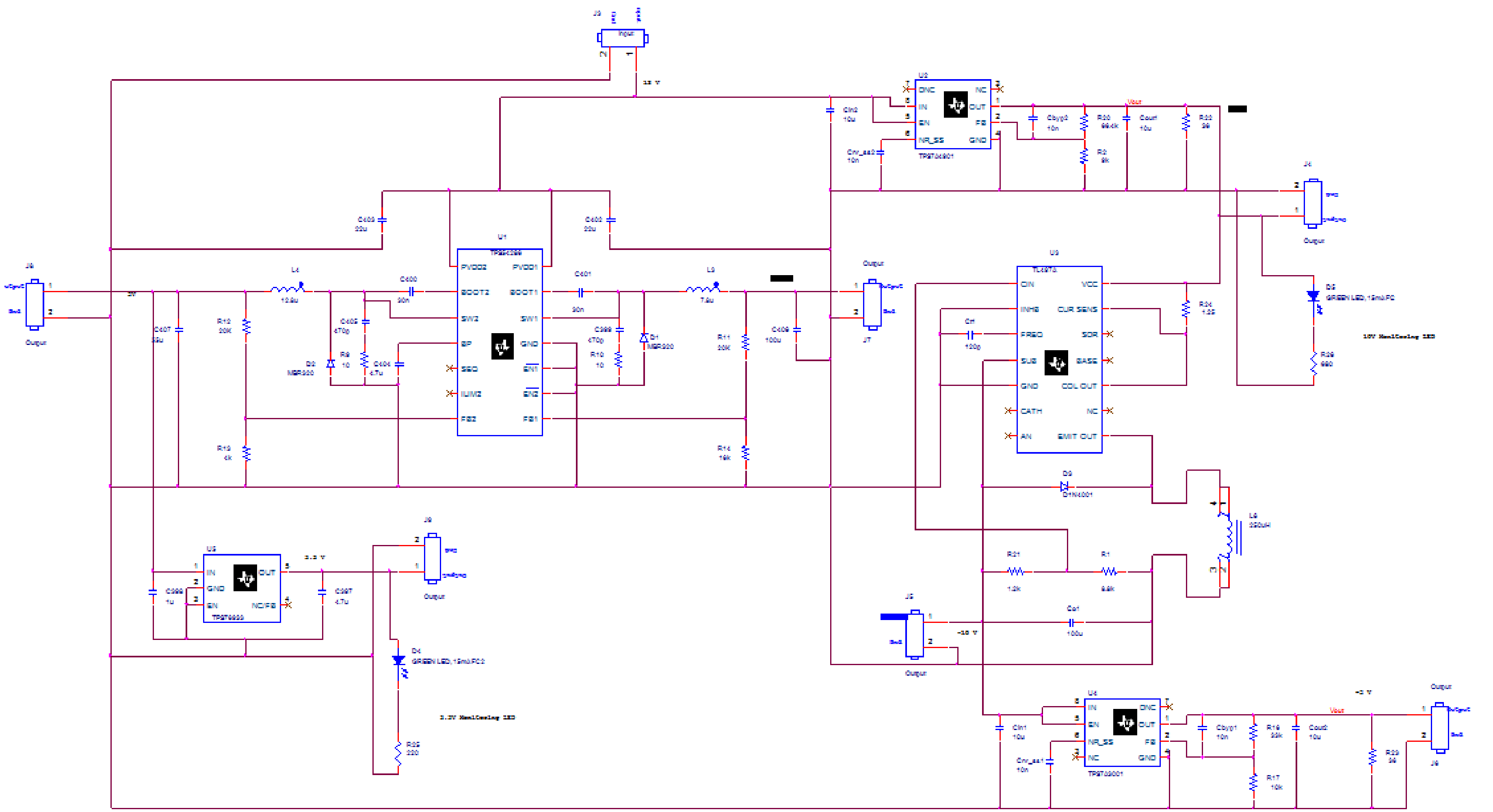


Schematics – Pulse Echo Ultrasound

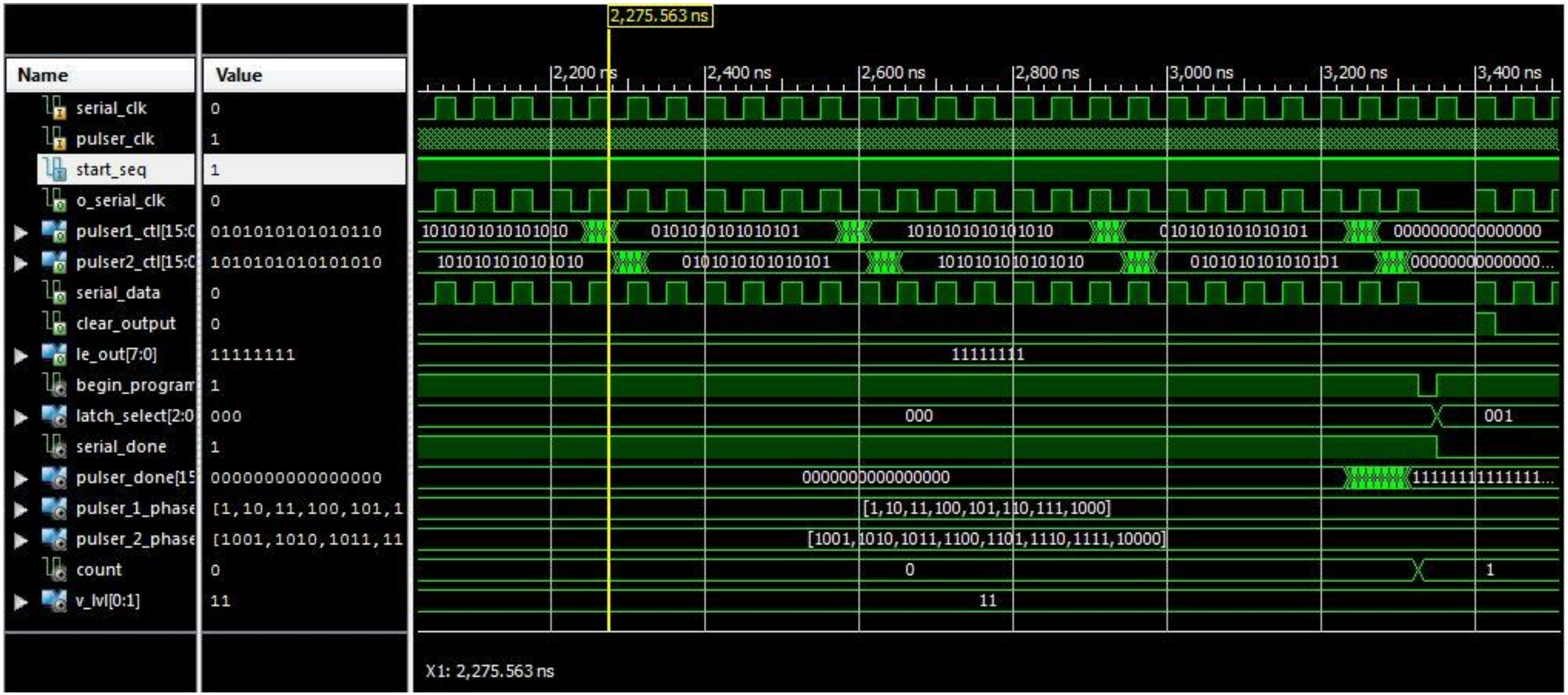
- Receive



Schematics – Power Electronics

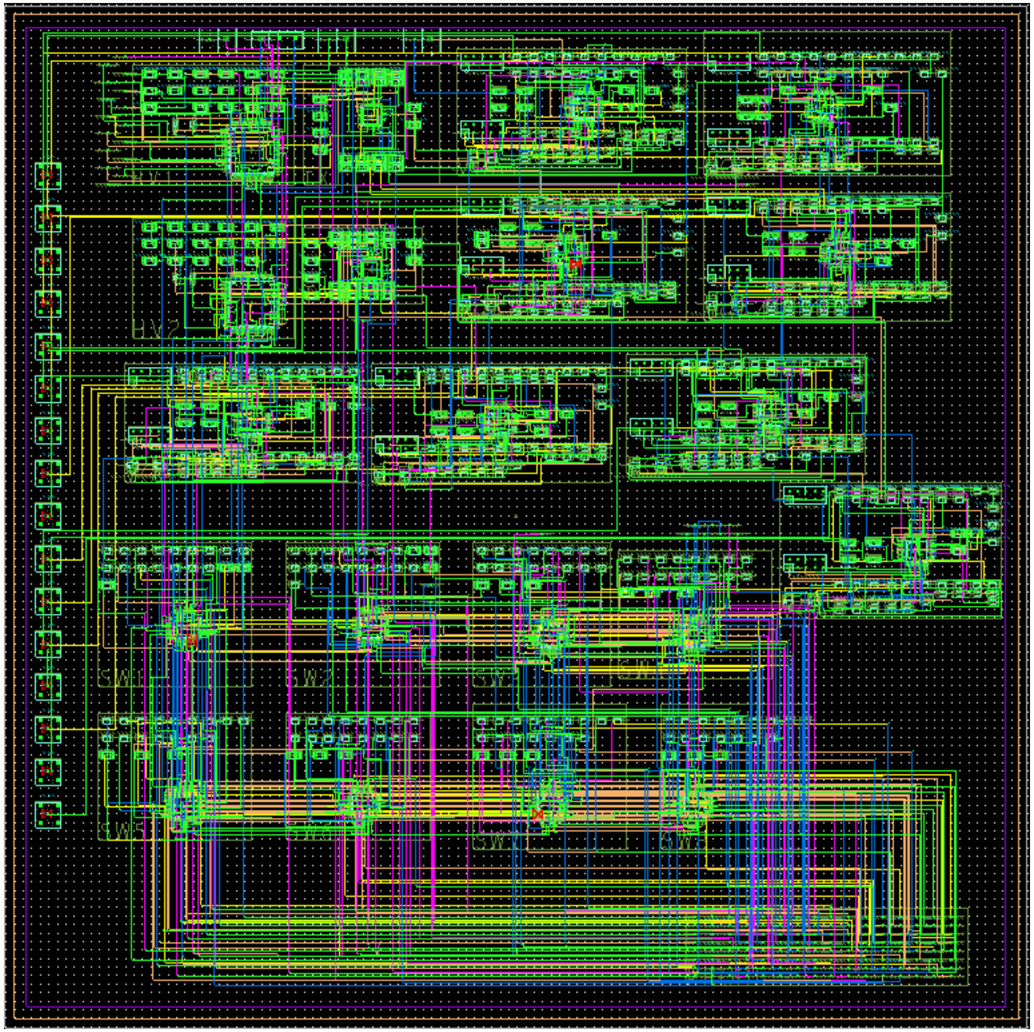


FPGA Results



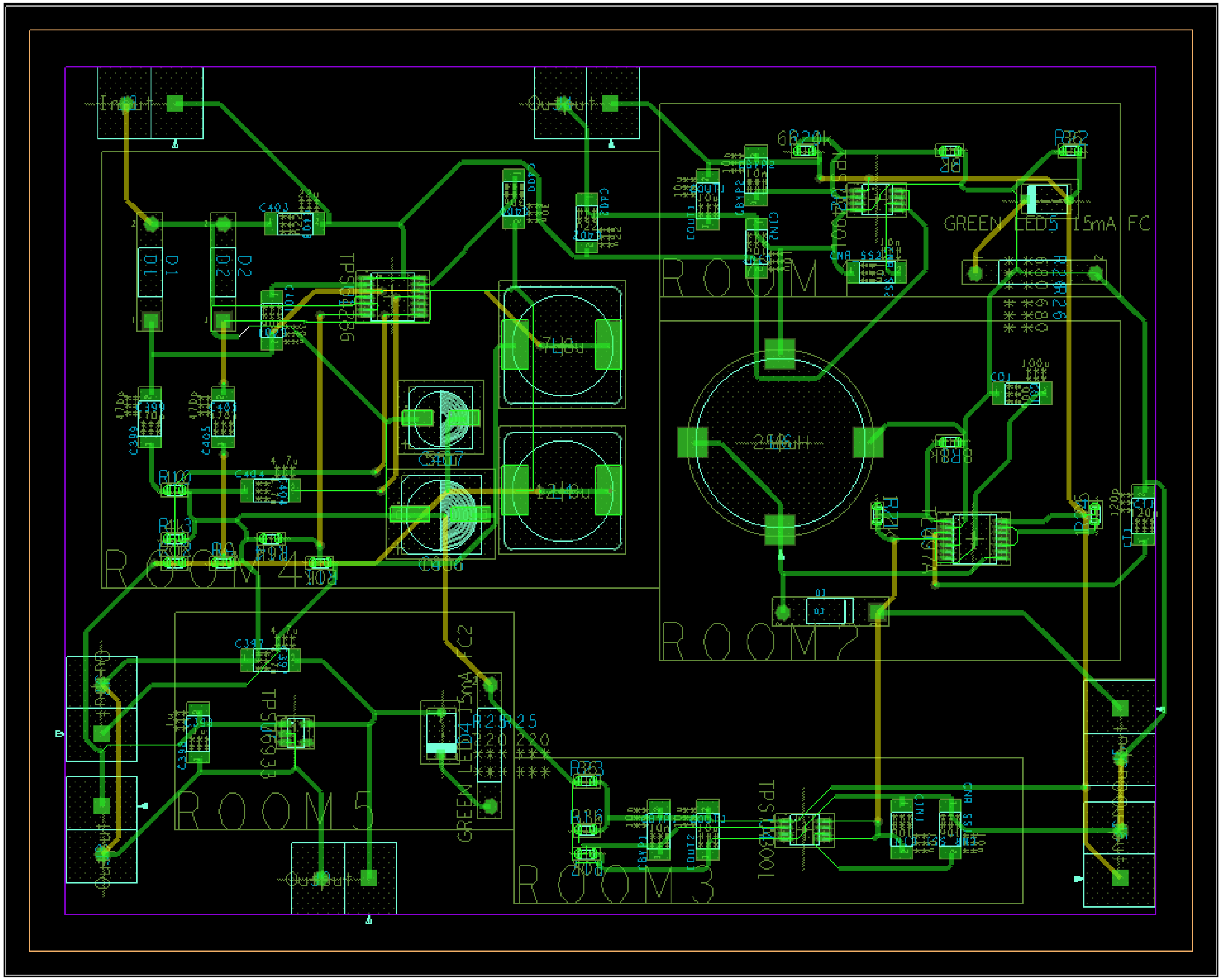
- Designed a state machine to control transmitter hardware with strict timing requirements

PCB Layout – Pulse Echo Ultrasound



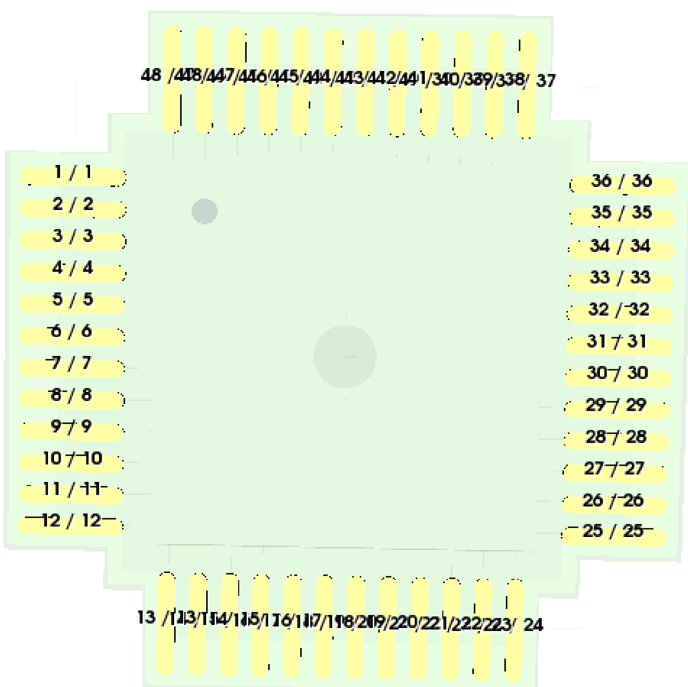
PCB Layout – Connector Board

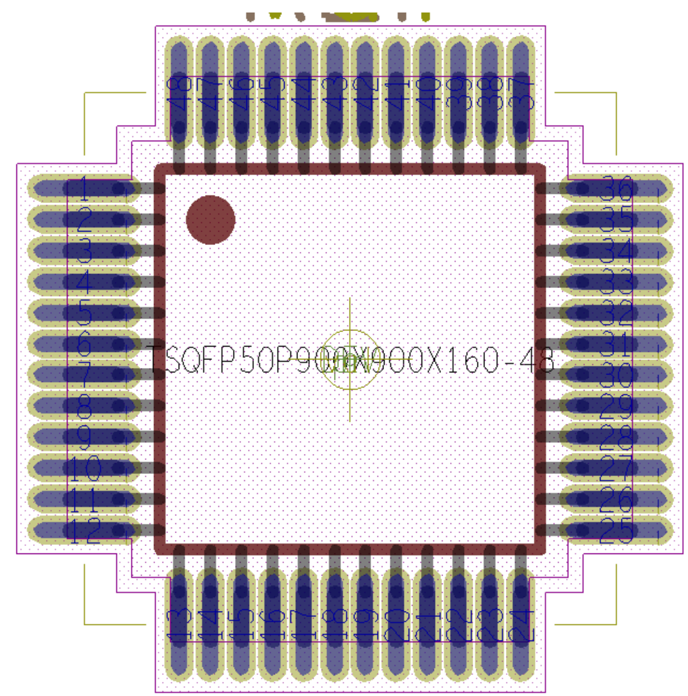
PCB Layout – Power Electronics



PCB – Footprints & Padstacks

- Switch Bank MAX140803CCM
  - Footprint
  - Padstack



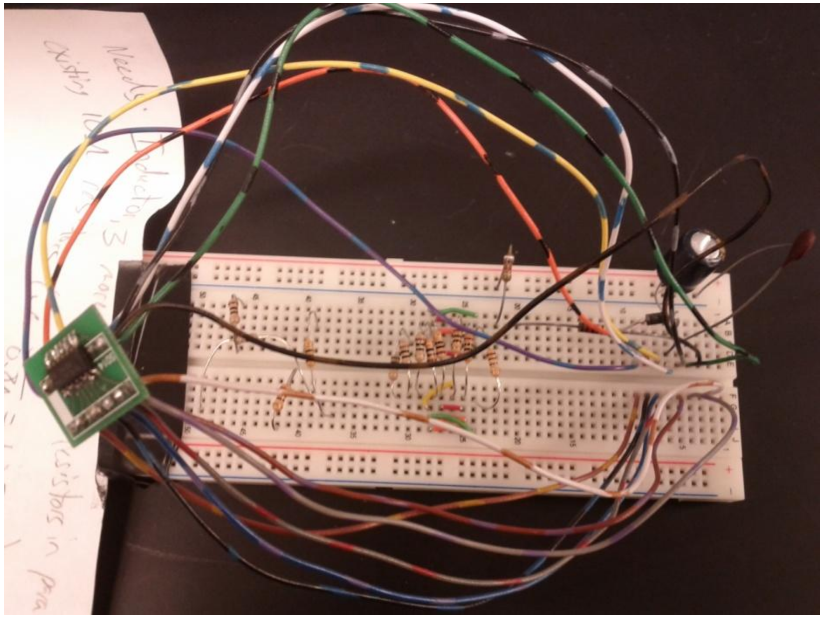


Testing

- Integrated circuits were originally tested in PSPICE if the models were available
- Most devices do not have PSPICE models
- Tested the physical ICs on a breadboard based off the PSPICE schematics
- Provided verification of schematics

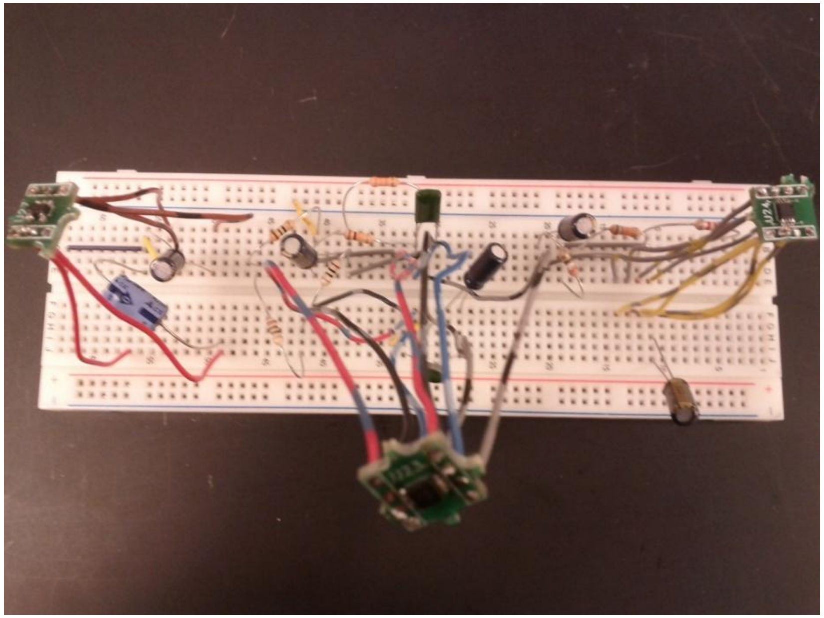
Testing - Power Electronics

Inverting Regulator



- Could not test due to a lack of a breadboard inductor

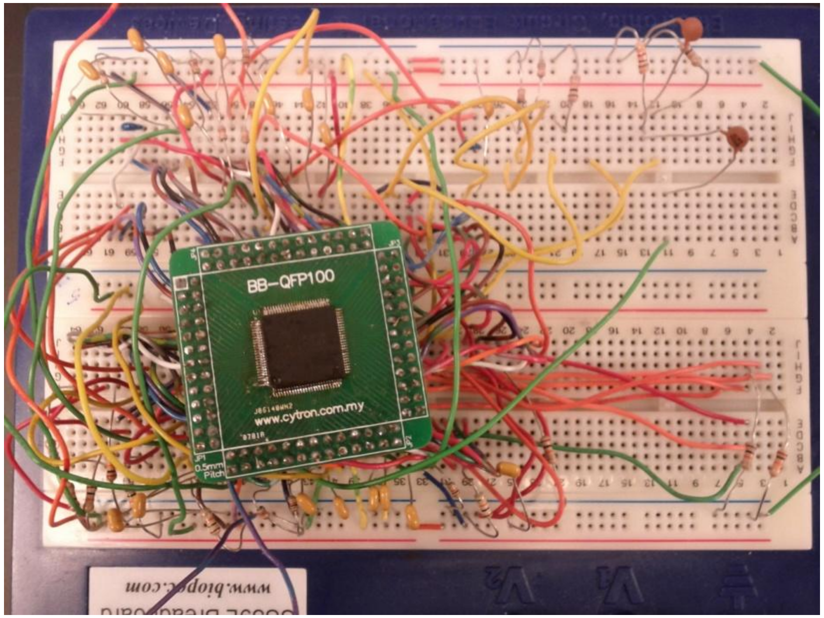
Linear Regulators

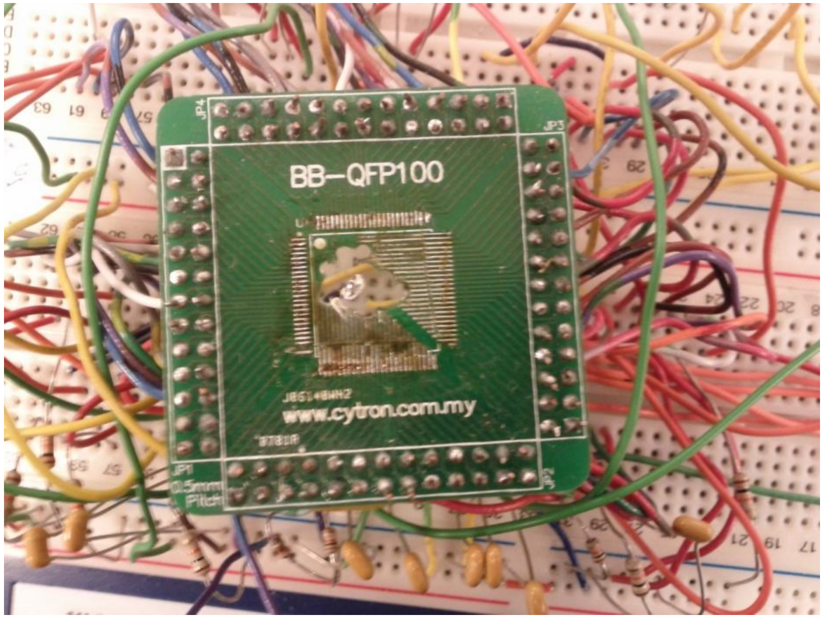


- Positive, Negative, and 3.3 linear regulators performed to spec

Testing - Pulser

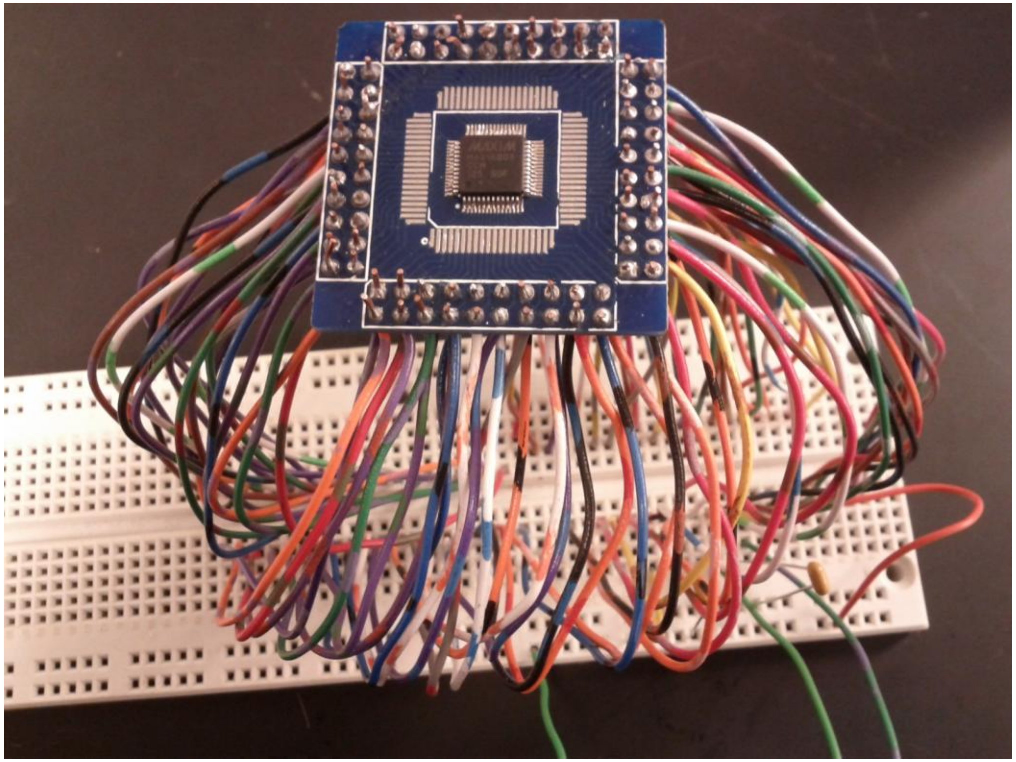
- Breadboard Pulser IC
  - Testing the proper circuit setup to run the IC
  - Unable to test further due to destruction of wafer





Testing - Switch Bank

- Breadboard Switch Bank IC
  - Tested to see if channels can be opened and closed



Challenges

- Working backwards
- Limited FPGA Experience
- Limited PCB Layout Experience
- Bread boarding and testing of ICs
  - Pulser
  - Switch Bank
  - Power Electronics

Recent Changes

- Final PCB Product was too expensive
  - Cost for 6-layer board is ~$1000
- Designed a 16-channel version of our final product
  - Estimated cost ~$500
- Acquired additional funding November 28th
  - Went back to original design

Cost Estimates – Testing and Final Product

Part:	Part Description:	Cost:
ML605 Evaluation Kit	XLINX FPGA Board	$1,800
FMC XM101 LVDS QSE Mezzanine Card	FPGA breakout board for LVDS pins with QSE Connectors	$700
AFE5808EVM	Analog Front End Analog to Digital Converter Evaluation Board	$299 x 6= $1,794.00
TSW1250EVM	Analysis system	$650.00
TX810	Transmit/Receive Switch	$11.16 x 10 = $111.60
HDL6V5581	HV Pulser	$0
MAX14803CCM	High-Voltage Switch Bank	$26.91 x 14 = $376.74
Ultrasound Probe		$15,000.00
Power Electronics	Regulators and Converters	$320.19
Resistors, Capacitors, Inductors		$173.86
Connectors	Transducer and Mezzanine card connectors	$264.03
PCB Fabrication		$1000
Total Cost		$22,190.42

Remaining Work

- Final PCB product is currently being fabricated
- Solutions developed will continue to be used
- Focus on leaving documentation for future work
- Future development of design
  - Direct control of 512 ultrasound elements

Questions?