BME 464: ULTRASOUND

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Transmitter and Receiver

Transmitter
The transmitter is used to send a strong pulse to the transducer (Aerotech 2.25MHz /.5" Ultrasonic Contact Type Transducer), causing the piezoelectric disk to quickly deflect and send an ultrasound pulse. A 15V DC input charges the 0.1uF capacitor, releasing its charge as the NMOS transistor (Taiwan Semiconductor 2N7000K) is turned on. The NMOS is turned by a 200ns signal every cycle, provided by the FPGA of the controller. The 3.3V signal is passed through a 1:2 transformer to be able to turn on the NMOS. The signal is then amplified through a 1:5 transformer before being sent to the transducer. An example of the transmitter waveform is shown below.

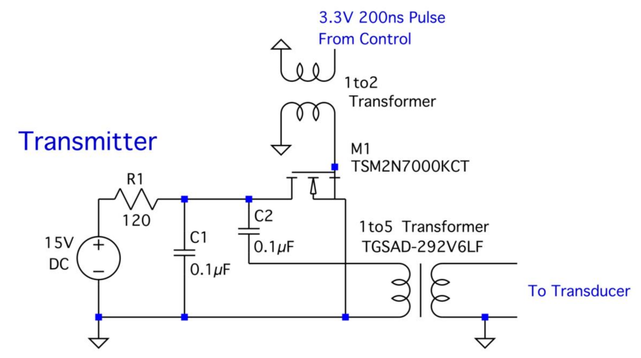

Figure 3: Transmitter schematic

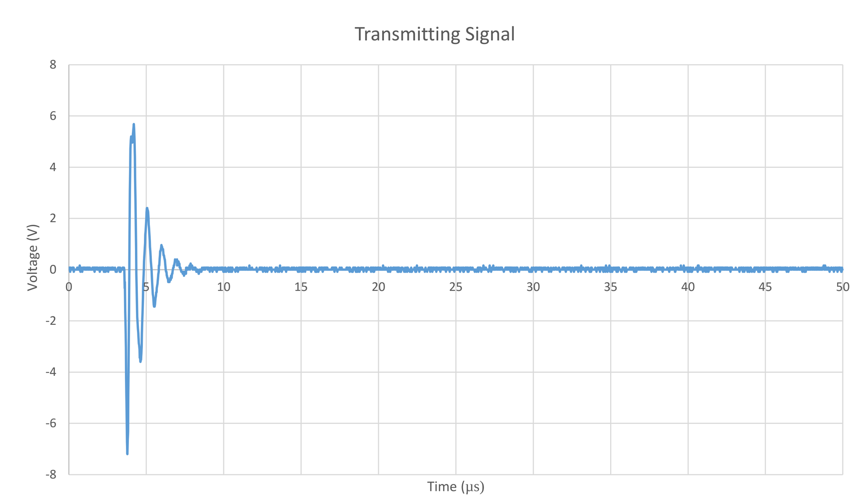

Figure 4: Transmitting Signal

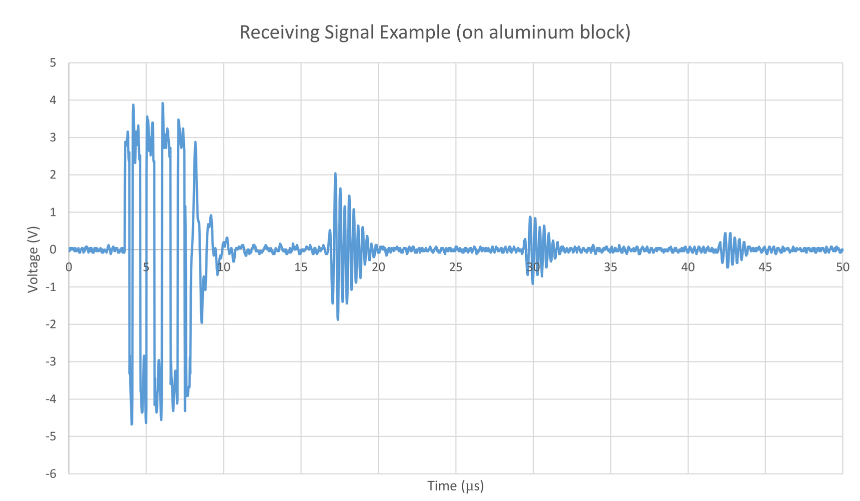

Figure 5: Receiving Signal

Receiver
The receiver receives the input signal from the transducer then filters and amplifies the signal for further processing. First, the signal is passed through a passive high pass filter (f_c = 2.5MHz) in order to prevent the transmit signal from being passed to ground. In parallel are diodes to ground in order to protect the rest of the receiver circuit from the large pulse of the transmitter. As a result, only signals smaller than 1.4Vpp can propagate through the system. The signal is first passed through an operational amplifier (AD8055, all subsequent op-amps will be the same) to be able to drive the rest of the circuit. Then it is passed through a resonant bandpass filter (f_c = 2.5MHz, bandwidth = 2.5MHz, Q factor = 2.5) before being passed the variable gain amplifier (Analog Devices AD603). The variable gain amplifier takes a voltage input in order to vary the gain, for which we use a potentiometer to manually modify. The output of the amplifier is then passed through another bandpass filter (f_c = 2.5MHz, bandwidth = 2.5MHz, Q factor = 2.5) with a gain of 2, before being sent through another op-amp with a gain of 2.5. The overall gain achieved is 30-50dB, with the maximum voltage output limited at 6Vpp, and a waveform of the received signal is shown below. The final output is then sent to the detector to be further processed before being imaged.

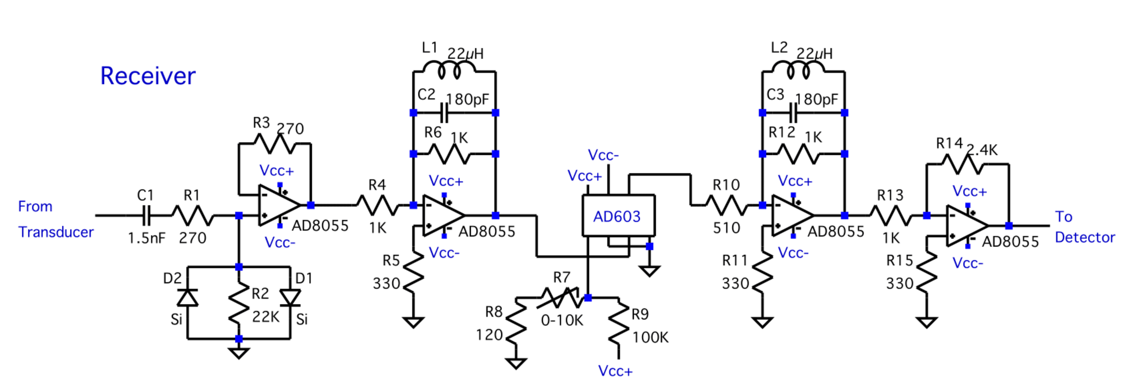

Figure 6: Receiver schematic

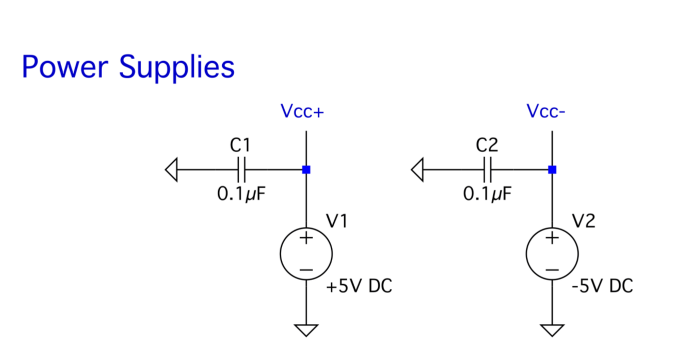

Figure 7: Power supplies schematic

This semester's BME 464 senior design project was a single channel ultrasound machine. This machine transmits a sound wave through a water medium and measures the reflected signal received to determine the size and shape of any objects in the water. It consists of four major components: a transmitter and receiver, a motor, a display, and a controller.

Motor
The stepper motor mounted above the tank rotates back and forth for 90 degrees, allowing the connected transducer to scan through the water inside the tank. The modulated x and y position signals are fed to the ramp generator.

Transmitter and Receiver
The transmitter sends a soundwave through the water, which reflects off any objects in its path. The receiver detects this reflected wave, allowing the distance to be determined as a function of the time between transmission and reception.

Display (XY Ramp and Z-Axis Amplifier)
The signal from the motor is translated into the x and y position by mapping the Cartesian coordinate into the polar coordinates using the angle given by the encoder. Both the x and y signals are fed into the ramp circuit to generate an analog signal that is passed onto the display. For the z-axis signal, the output from the receiver is first rectified through a full-wave rectifier and bandpass filtered for the envelope detection. The respective output is fed into the cathode ray tube, in combination with the x and y signals, to generate an image.

Controller
The controller keeps each of the other three components in sync by tracking their timing and sending signals to the other components when appropriate.

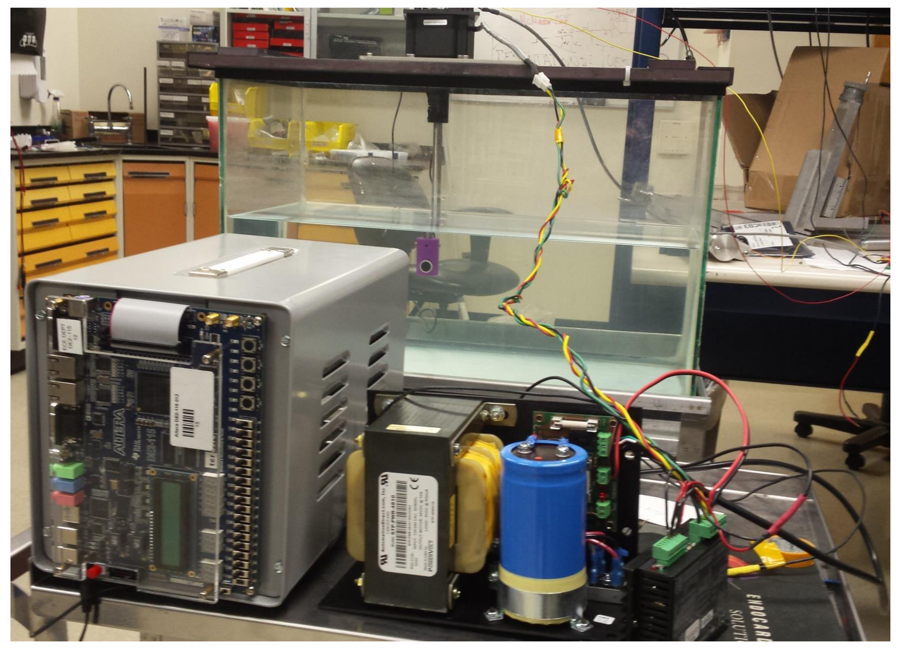

Figure 1: Ultrasound Machine

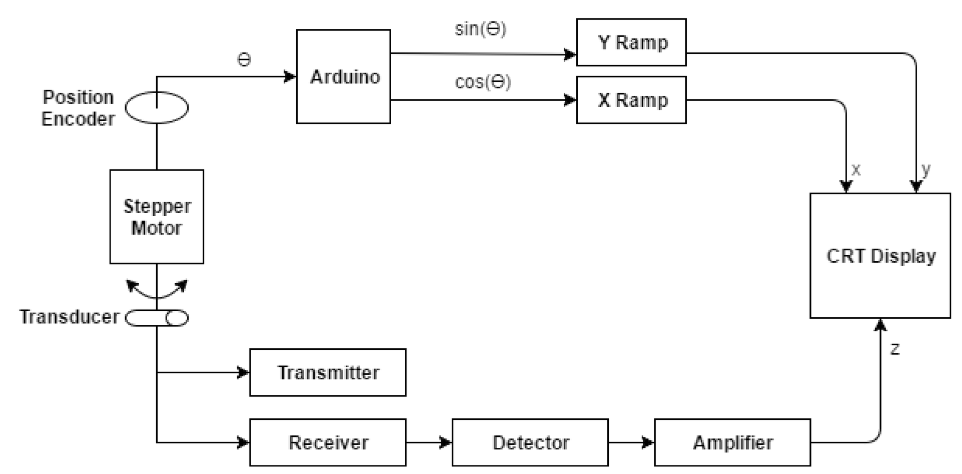

Figure 2: System diagram

Controller

The controller is responsible for sending signals to each of the other components, keeping the whole machine in sync. It passes through three stages (right), sending signals to increment the motor, transmit a sound wave, and receive the reflected signal. While sending the receive signal, it also sends a signal to display (Zon), and marker signals to indicate distance traveled. This finite state machine is actualized in the circuit below, which was programmed in Verilog and simulated on an Altera DE2 board. A timing diagram of all five signals is shown in the bottom figure.

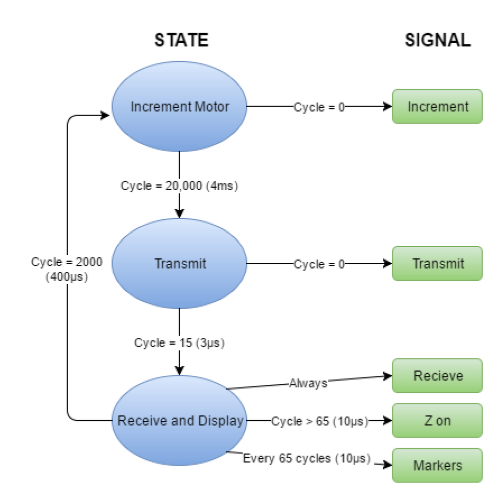

Figure 8: Finite state diagram for controller states and signals

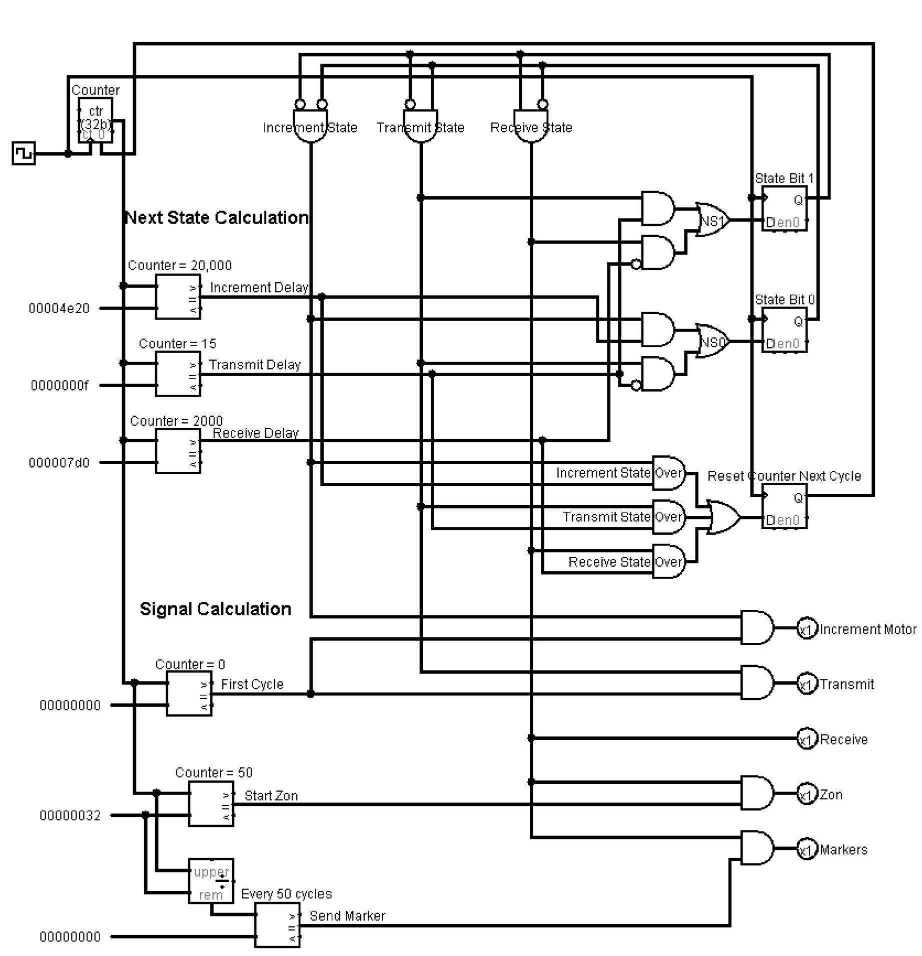

Figure 9: Digital circuit of FSM used to generate signals

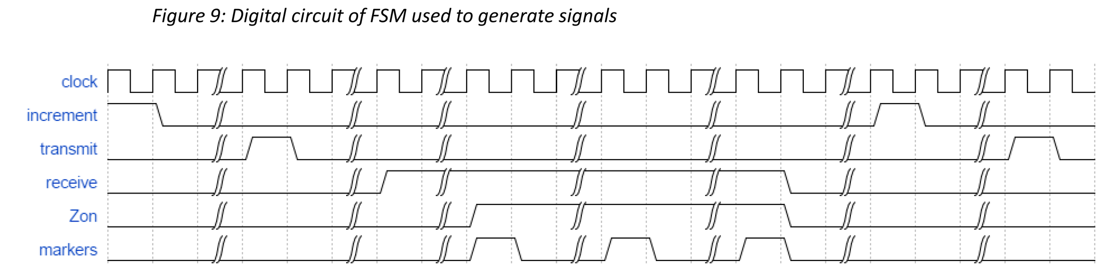

Figure 10: Relative timing of all signals

Motor

Position Sensing
The stepper motor used in this project has 1600 steps per revolution and the E6 encoder has 1024 pulses per revolution. The motor shaft position is encoded and set to rotate 90º back and forth with no delay between cycles. The Arduino controls the shaft to first swipe counterclockwise from the right-side switch until hitting the left-side switch and then swipe clockwise to reach the zero position and start the rotation loop.

Mounting
To mount parts together, a steel plate holds the stepper motor stably above the tank. A clamp-on rigid coupling connects the front shaft with one side of the extended long rod. A 3D printed connector (as shown in Figure 11) connects the other side of the rod with the transducer.

X and Y Position Modulation
For modulation of x and y position signal (as shown in Figure 12), a second-order RC active low-pass filter is followed by a non-inverting unity amplifier, whose output serves as the source of the transistor. The transistor has a gate connected to the clock and a drain connected to the ramp generator. The resistor connected to ground from the drain can speed up the switching action of the transistor.

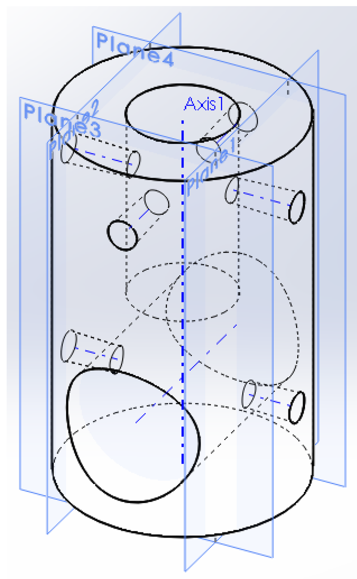

Figure 11: Connector from motor shaft to transducer

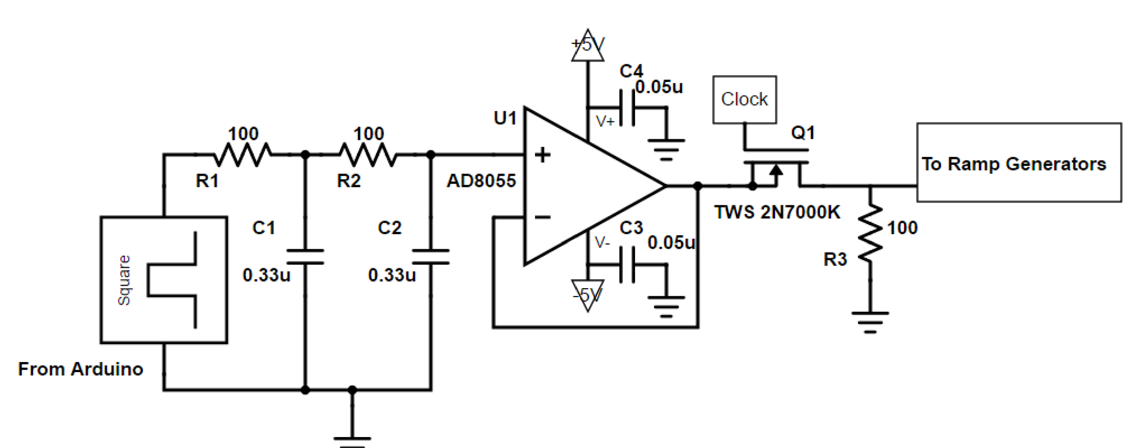

Figure 12: Rotary position encoding circuit schematic

Display: XY Ramp and Z-Axis Amplifier

Ramp Generators
The X and Y axis ramp generators are used to position the output on the CRT display. The circuit is composed of a simple switched integrator and an inverting variable amplification stage. Input received from the Arduino is a step function corresponding to the value of either sin(θ) or cos(θ), where θ is the angle of the transducer, for a duration of 200µs during signal transmission and reception. Resistor and capacitor values of 620kΩ and 1000pF, respectively, were chosen to set the integration time constant (τ) to 620µs. AD8055 (Analog Circuits) amplifiers were chosen for high slew rate (1400V/µs) and wide bandwidth (300MHz). An NMOS transistor (Taiwan Semiconductor 2N7000K) is implemented as a switch in the feedback loop of the integrator to avoid saturation. A 5V signal is maintained at the gate during non-transmit/receive periods to create a simple buffer/follower, and drops to 0V during integration. Output offset is adjusted via a 20kΩ potentiometer and 200kΩ resistor in shunt at the noninverting input. A variable-gain inverting amplifier (A = 2.89) follows the integrator to create a ramp with positive slope with range 0-1V.

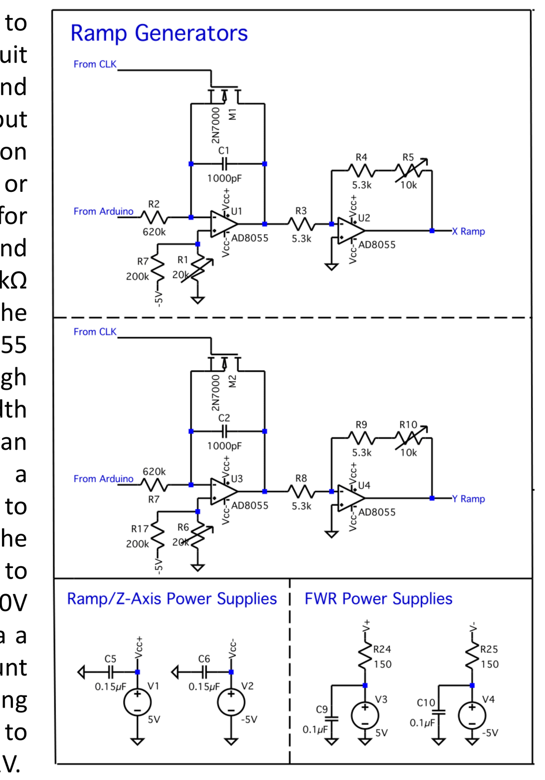

Figure 13: Ramp generator schematics

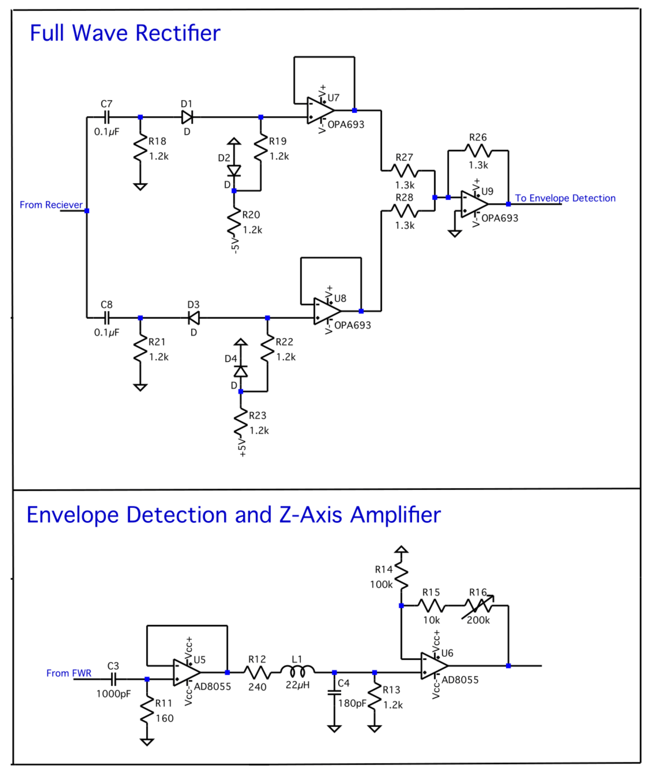

Figure 14: Full wave rectifier, envelope detection, and z-axis amplifier schematics

Full Wave Rectifier, Envelope Detection, and Z-Axis Amplification
The incoming signal from the receiver is first passed into the full-wave recitification circuit. The input signal is split into two half-wave rectifiers that can rectifiy 500mVpp to 15Vpp signal at 3.5 Mhz. Each half-wave rectifier consists of either forward or reverse-biased diodes offset by the corresponding voltages that are fed into a TI OPA698 unity gain stable, wideband voltage limiting amplifier, chosen for its high frequency application. The two rectified signals are combined using a non-inverting summing opamp circuit. The rectified signal is then fed into a passive RC highpass filter (f_0 = 950kHz) and buffer/follower, then lowpass filtered (passive LC circuit, f_0 = 4MHz) to detect the signal envelope, and is sent to a variable gain amplifier (A = 2).

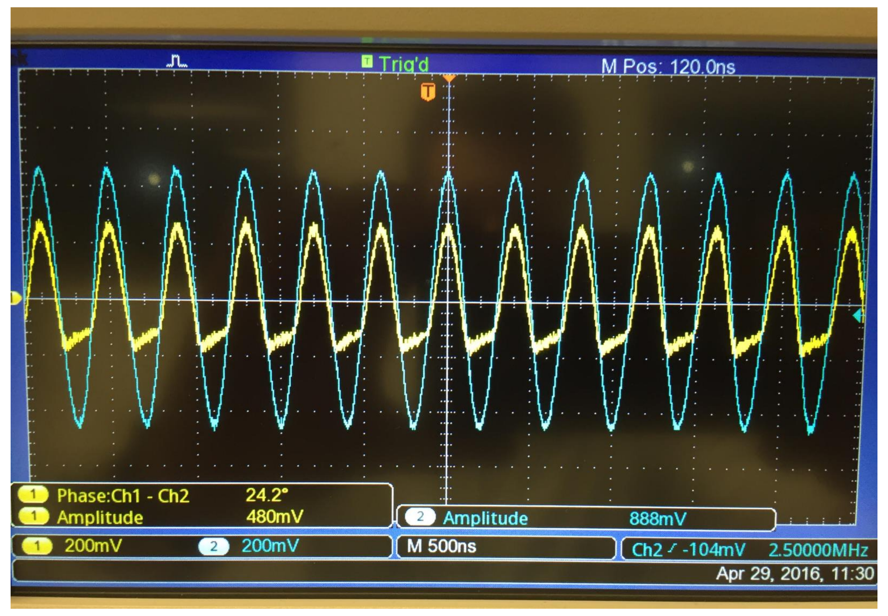

Figure 15: Half wave rectifier output

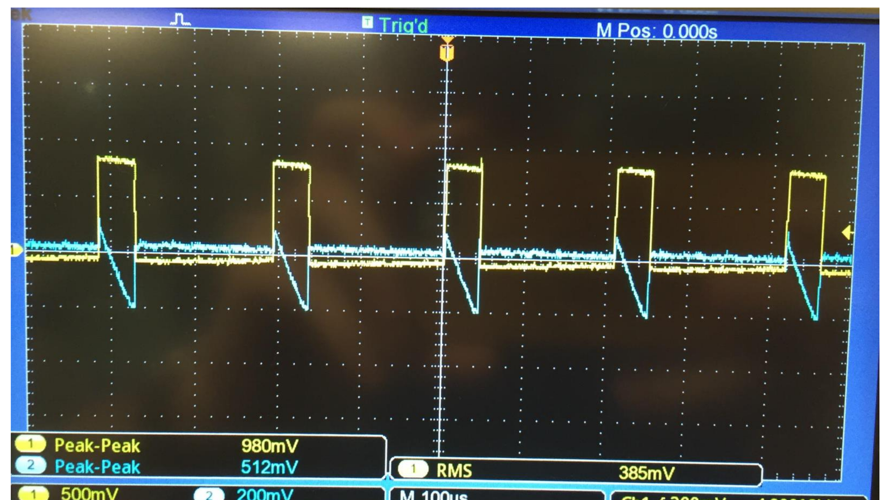

Figure 16: Ramp generator output