µTheremin

LSU

LOUISIANA STATE UNIVERSITY

Tim Alexander, Gregory Hurst, Subol Shrestha, Chase Bourg

Our Project

- Engineering Outreach
- Service Learning
- Demonstration Design

The Theremin

- Only Instrument with no Haptic Feedback
- Controlled by Hand Position in Relation to the Antenna
- Produces a Unique Electronic Sound

moog™

LSU
LOUISIANA STATE UNIVERSITY

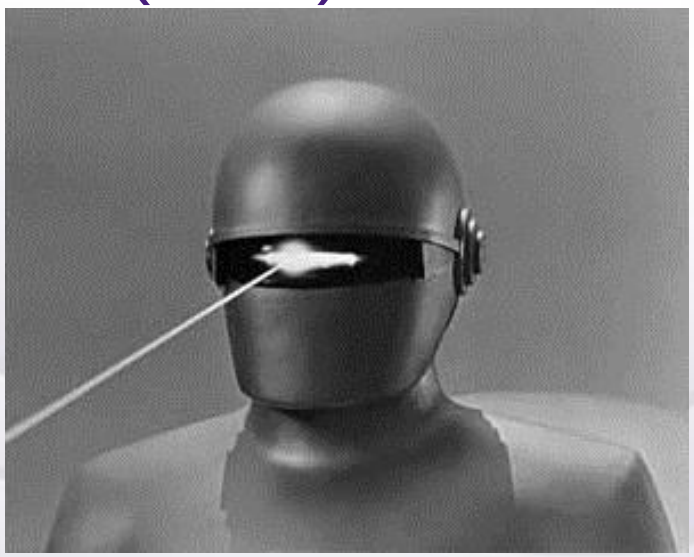
Theremin History

- Invented by Léon Theremin in 1920.
- Commercialized by RCA in 1929
- Revived by Robert Moog in the 1950's

Léon Theremin

Applications

- Musical Instrument
  - -Led Zeppelin – *Whole Lotta Love*
  - -Beach Boys – *Good Vibrations*
- Sound Effects in Movies
  - - *The Day the Earth Stood Still* (1951)
  - - *The Machinist* (2004)
- Hobbyists



Our Demonstration

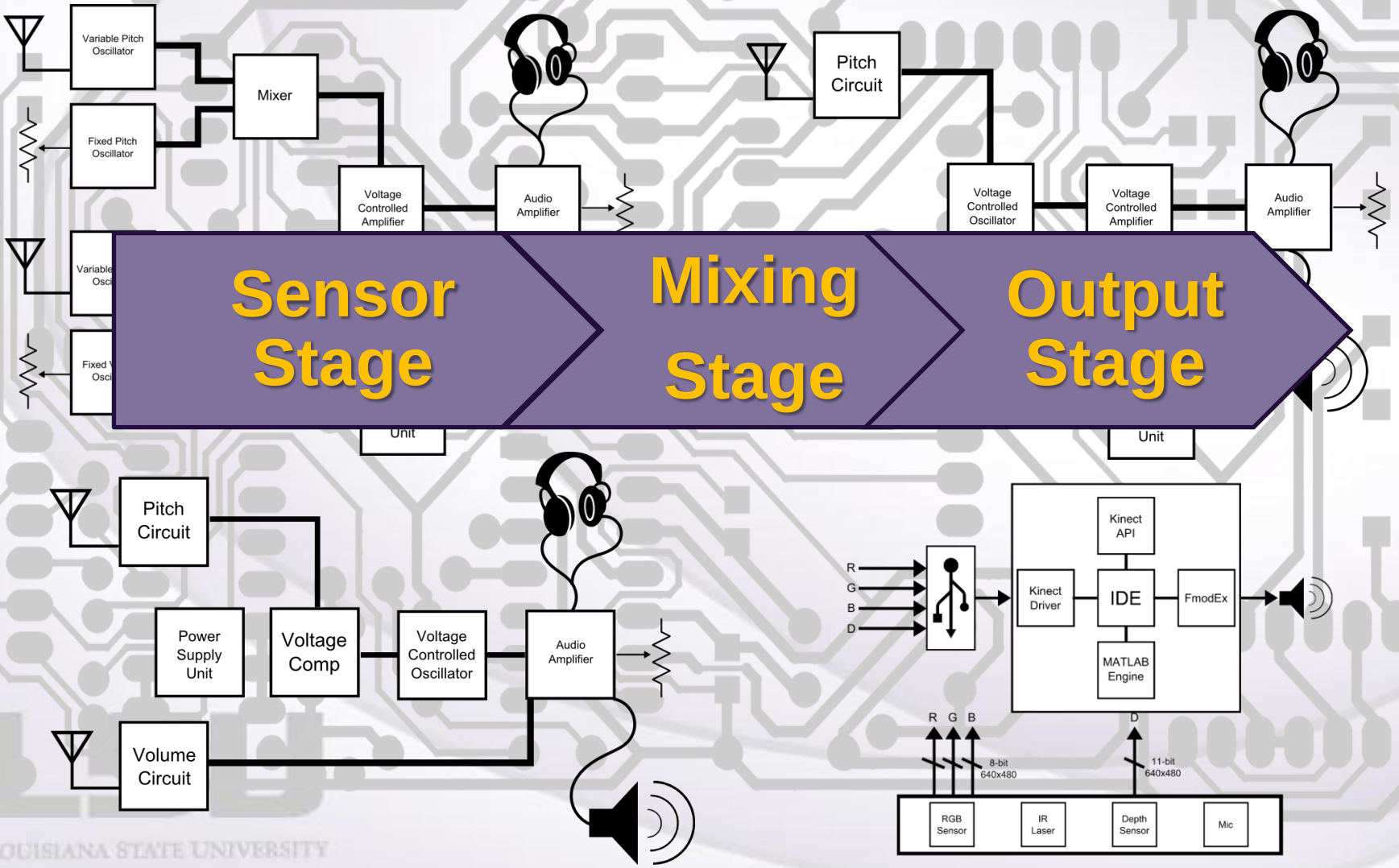
Requirements

– Portable
– Repeatable
– Marketable
– Power Limitation

Deliverables

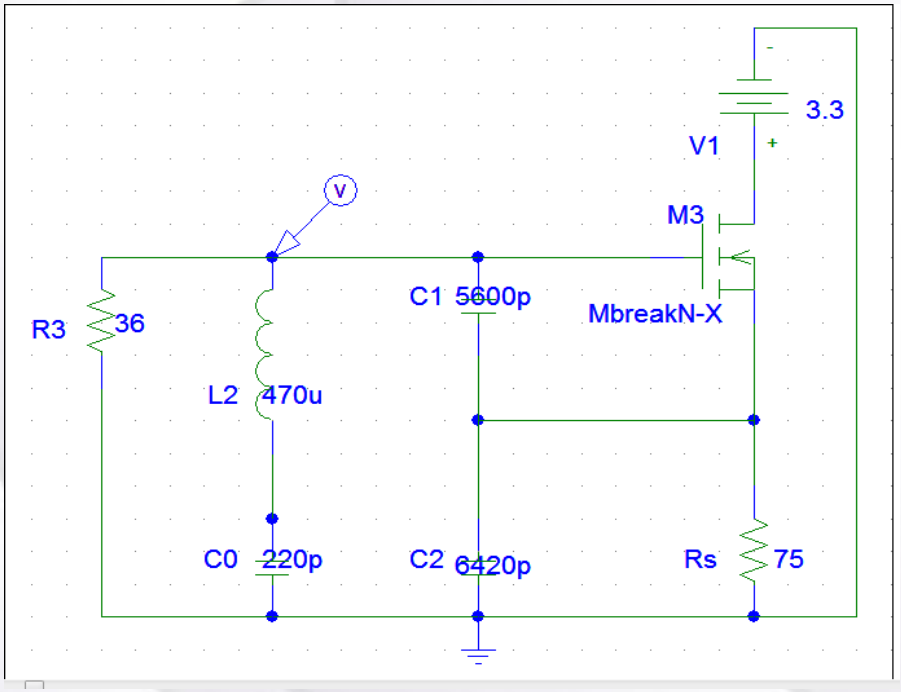
– Lesson Plans
– Manual
– Apparatus

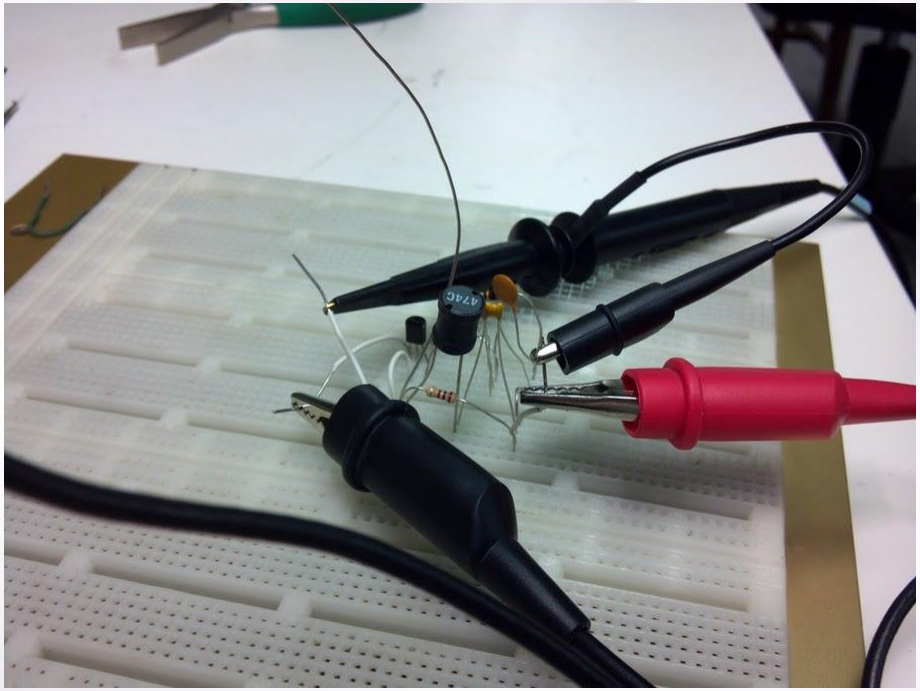
Functional Decomposition



Sensor Stage

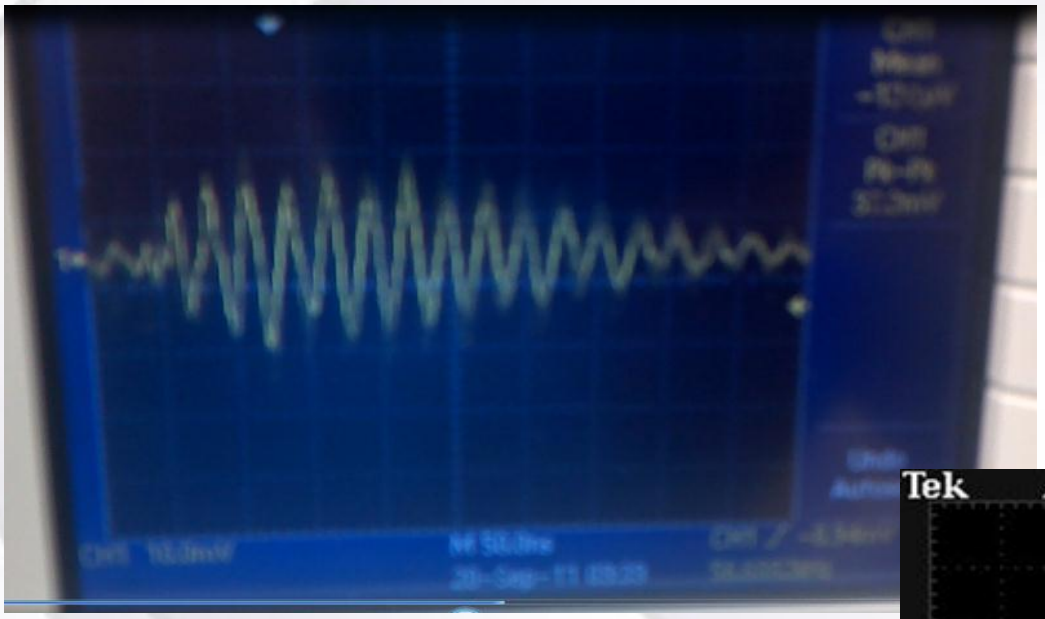
Original Oscillator

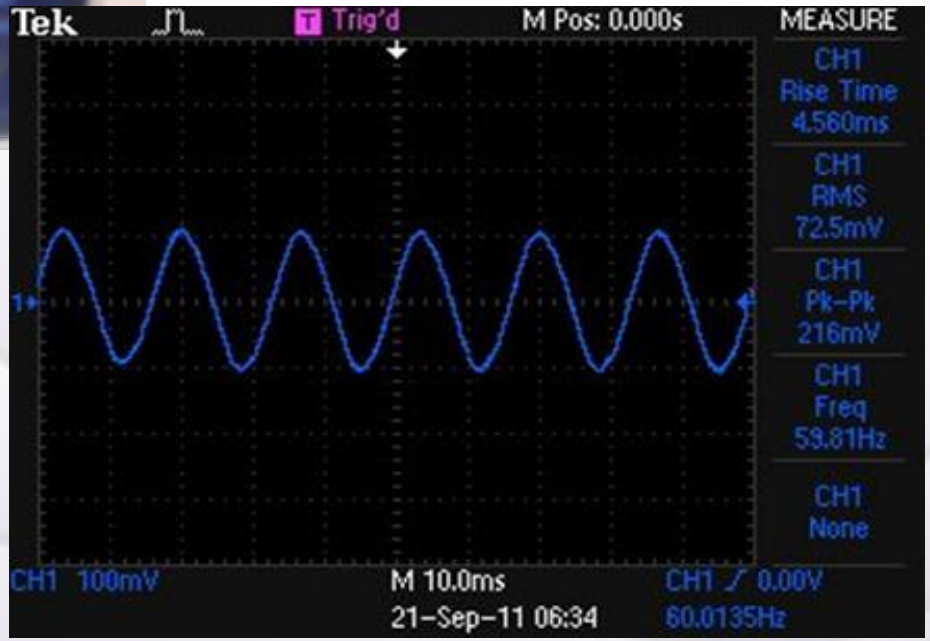




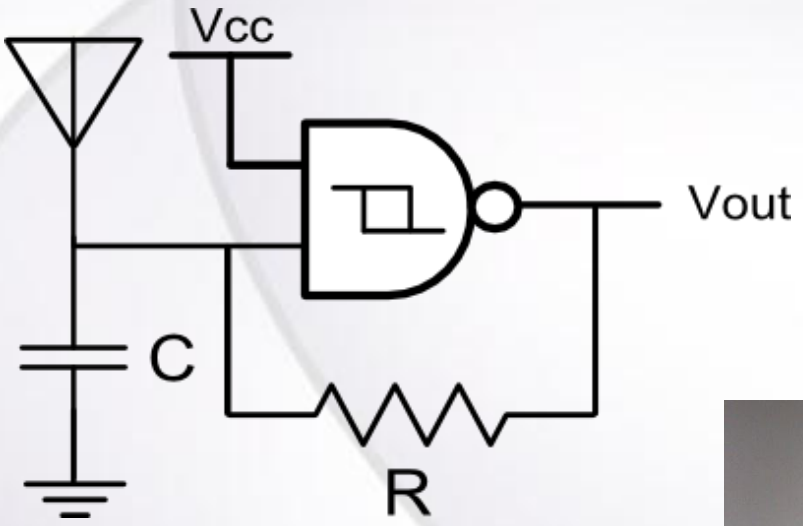
$$\omega = \frac{1}{\sqrt{LC_T}}$$

Oscillator

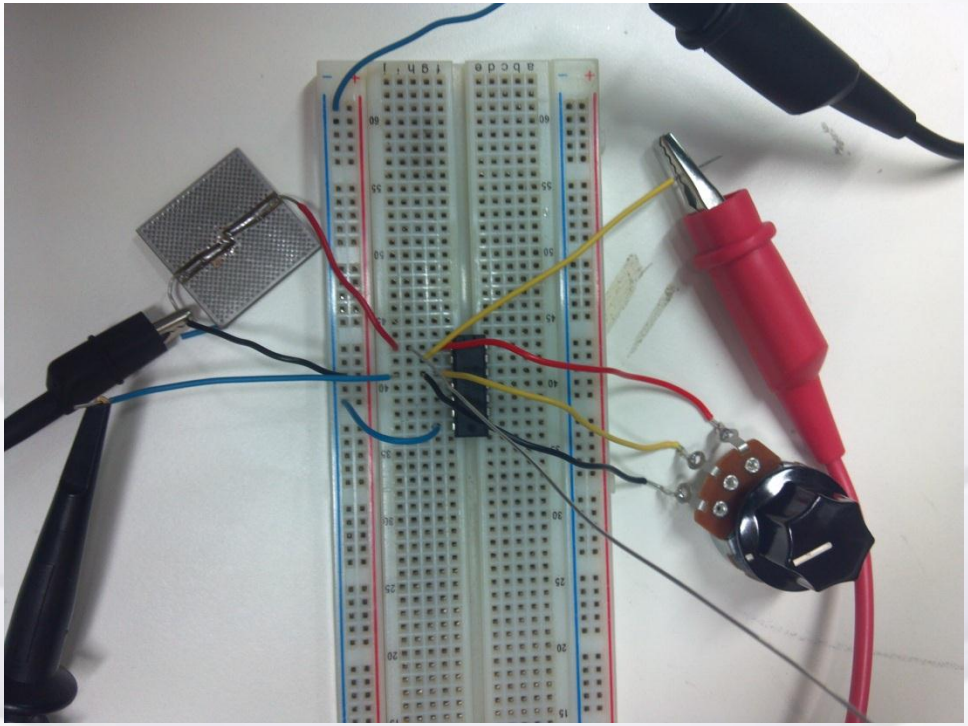




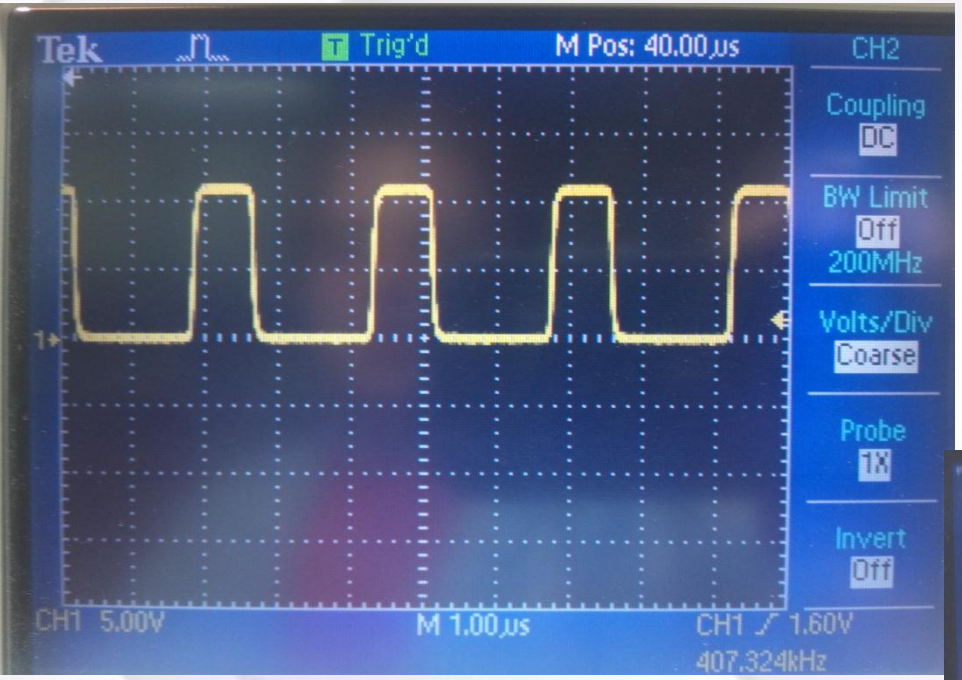
Re-designed Oscillator



$$f = \frac{1.2}{RC}$$



Oscillator Verification

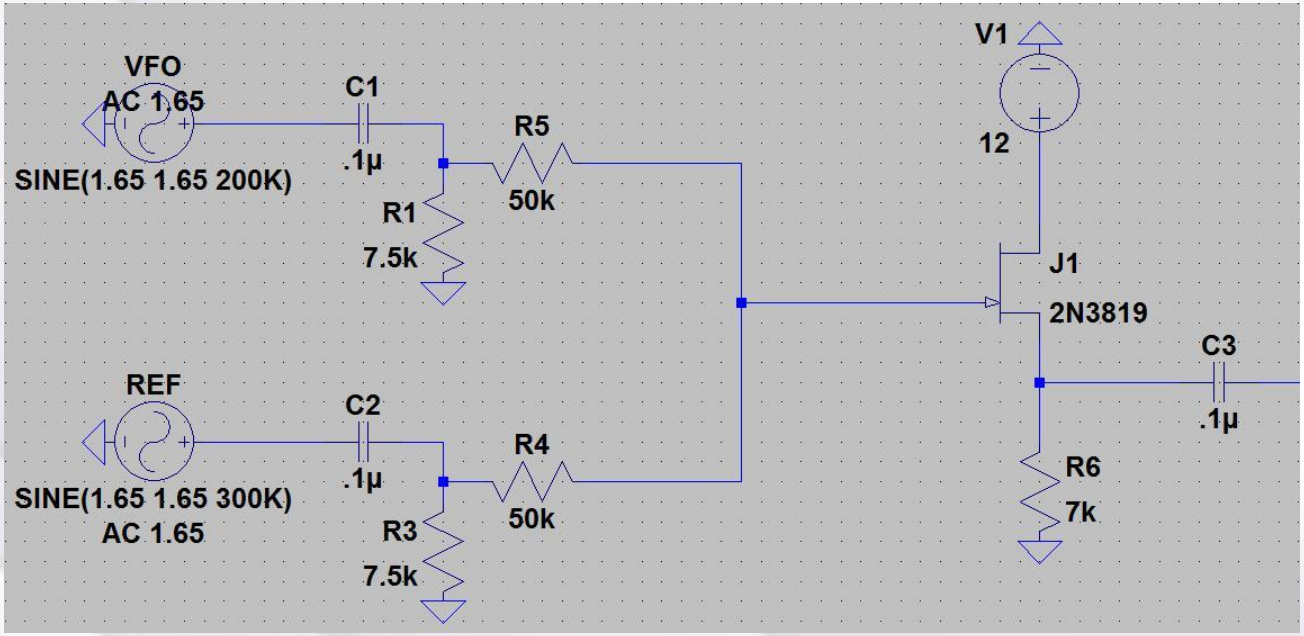


LSU
LOUISIANA STATE UNIVERSITY

Mixing and Filtering Stage

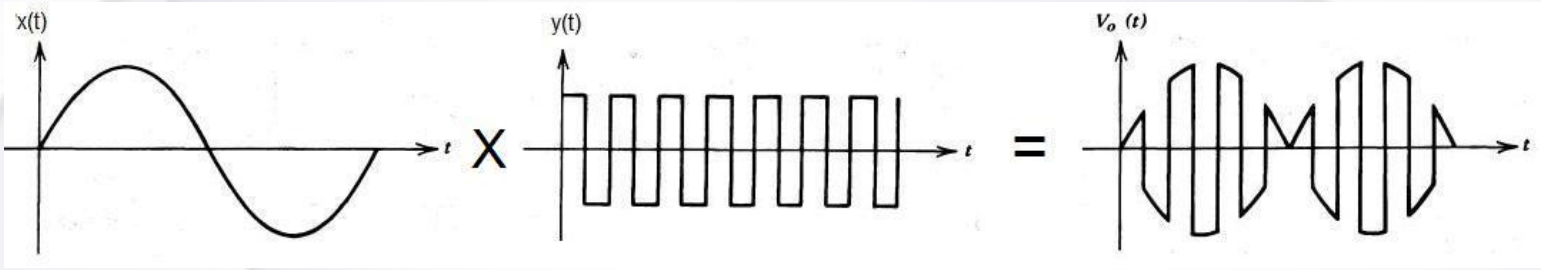
Mixing Circuit

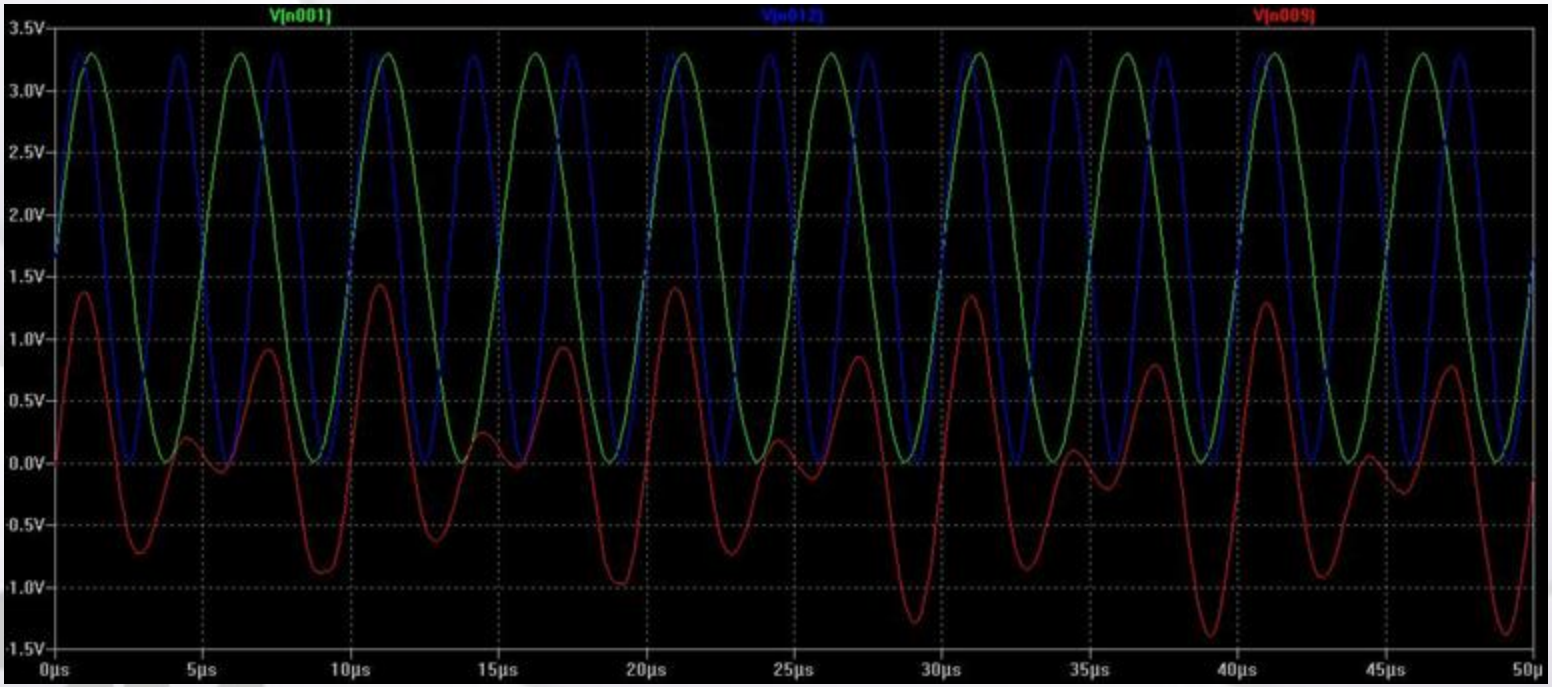
- Each dual oscillator circuit feeds to a mixer
- Multiplies two signals together to create one modulated signal



$$\mathrm{A}\sin(x)\,\mathrm{B}\sin(y) = \frac{AB}{2}[\cos(x-y) - \cos(x+y)]$$

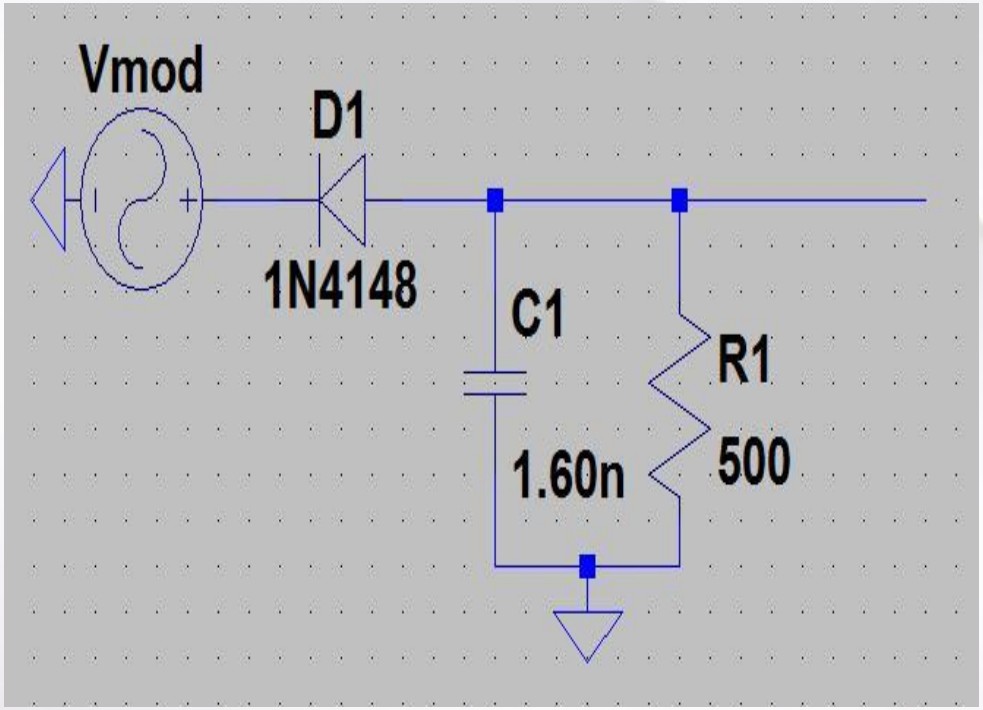
Simulation & Analysis

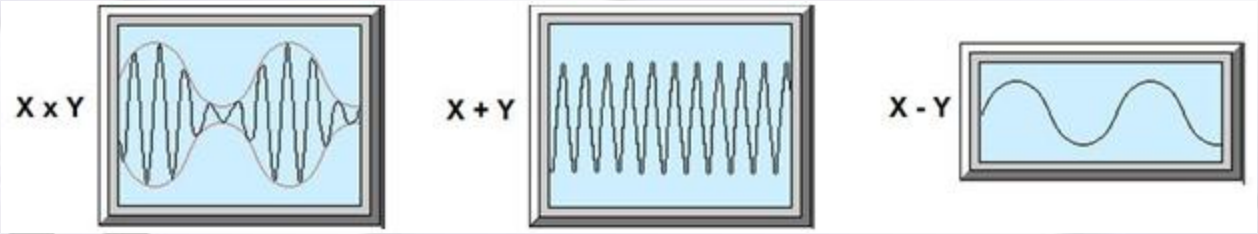




Envelope Detector

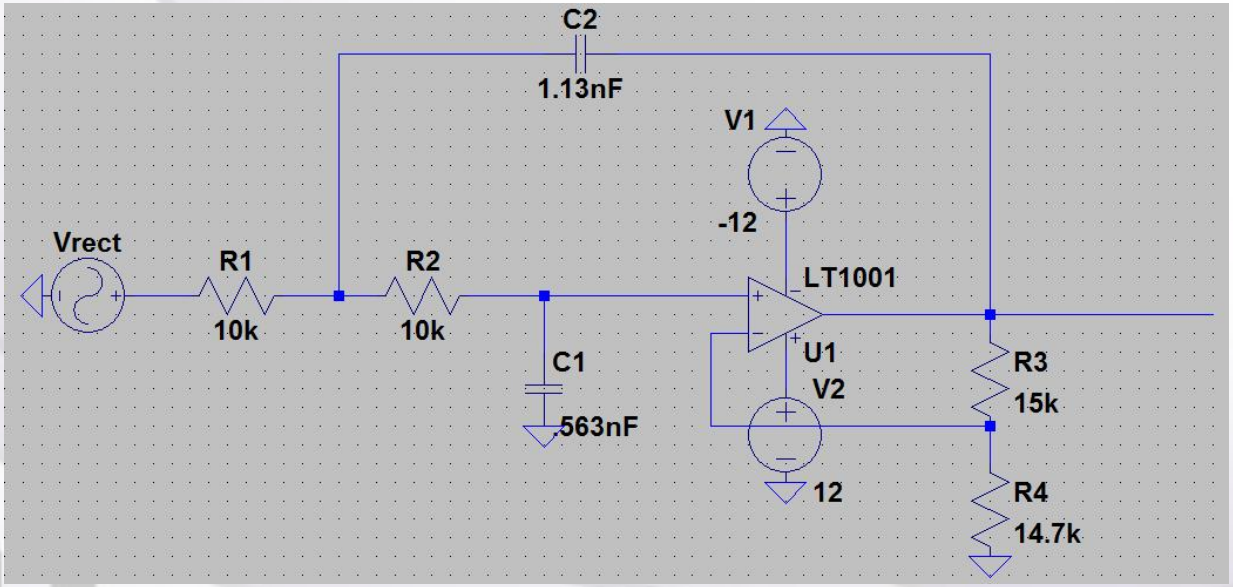
- Extracts the signal that operates at the difference between the two input frequencies





20 kHz Low Pass Filter

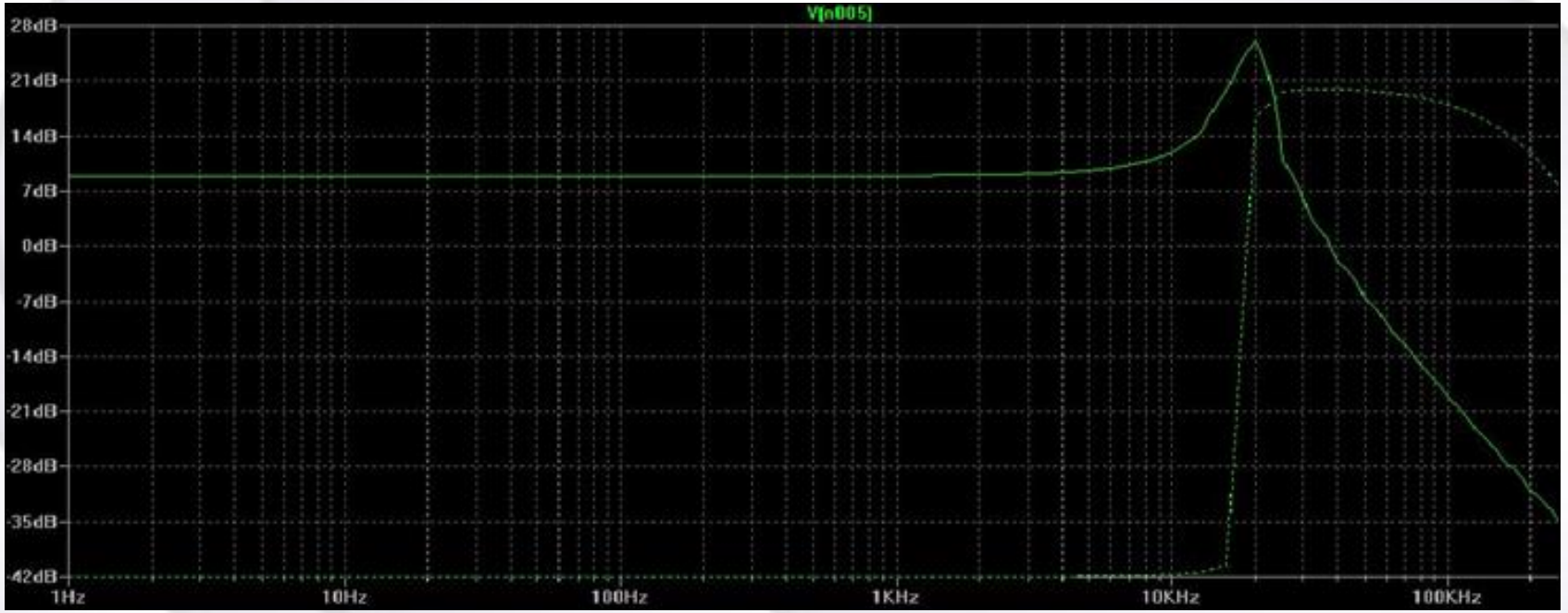
- Cuts off any frequencies that lie above the human audio range of 20 Hz – 20 kHz
- Amplifies the signal to give it a 3V amplitude



$$f_c = \frac{1}{2\pi R_2 C_1 \sqrt{2}}$$

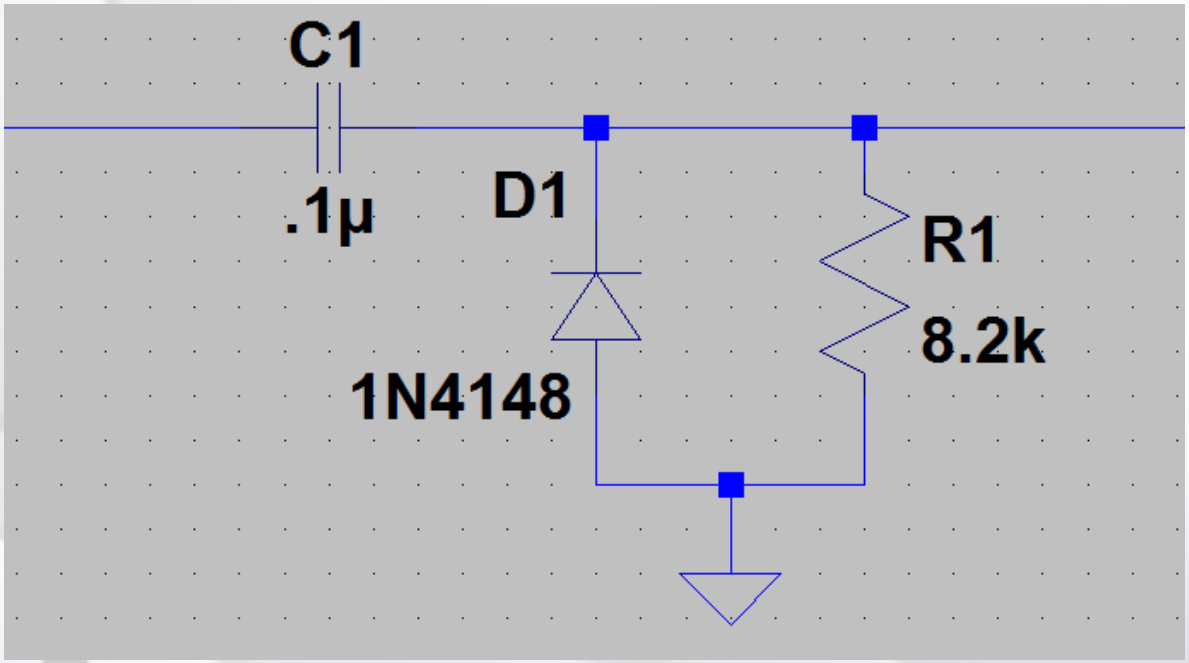
$$\frac{V_{out}}{V_{in}} = \frac{R_3 + R_4}{R_4}$$

Simulation & Analysis

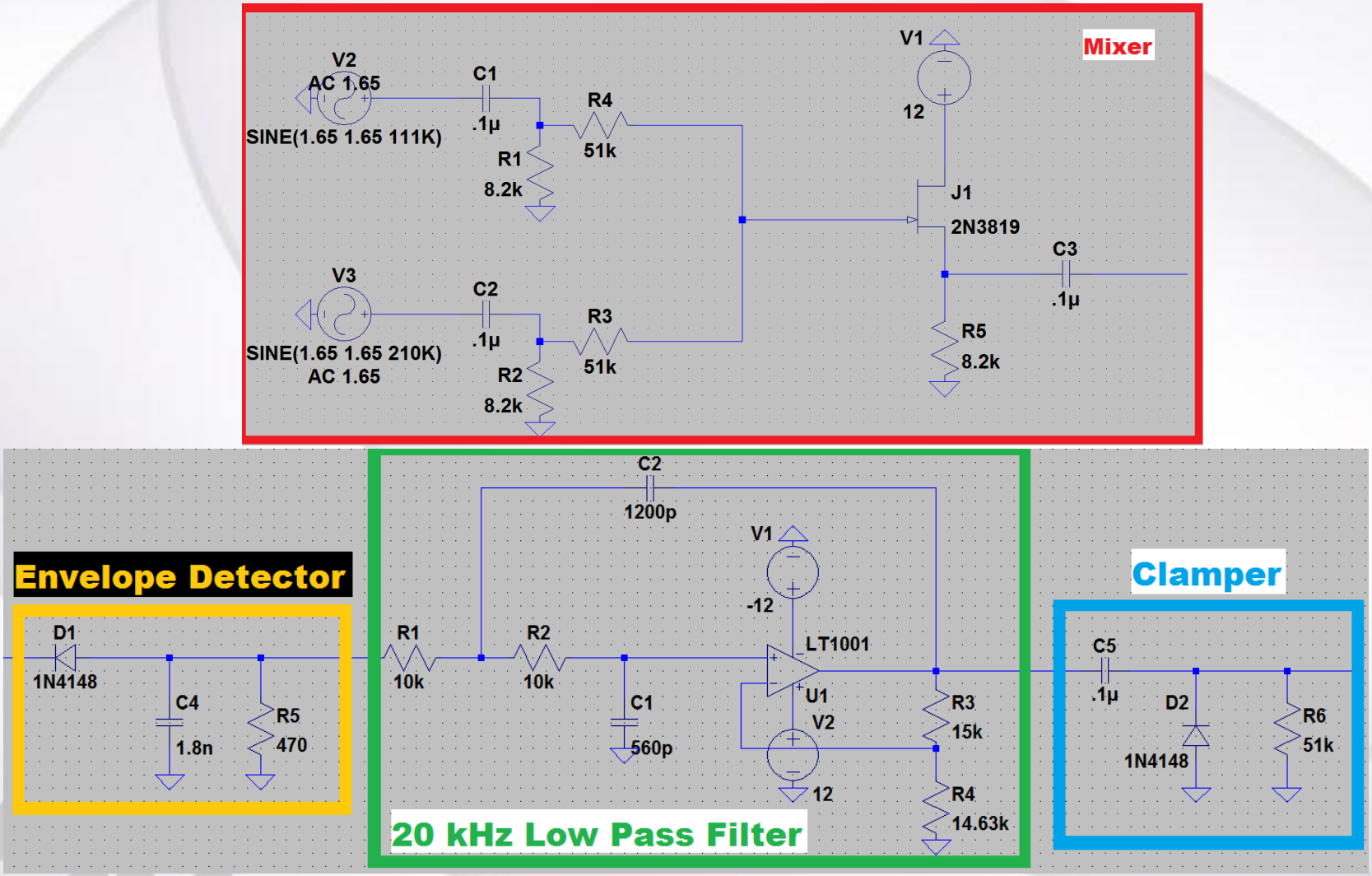


Clamping Circuit

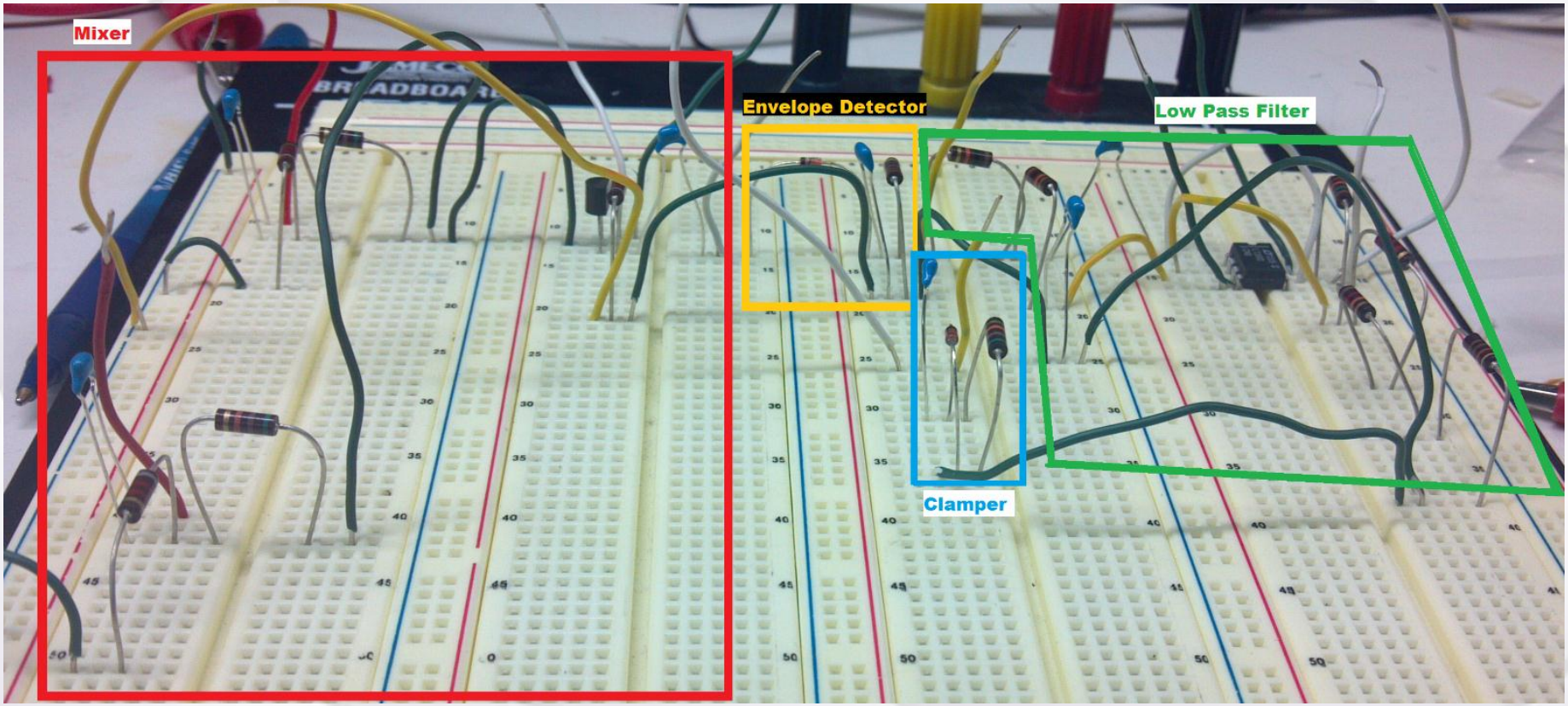
- DC level shifter to put signal in 0-3V range



Mixing and Filtering Circuit

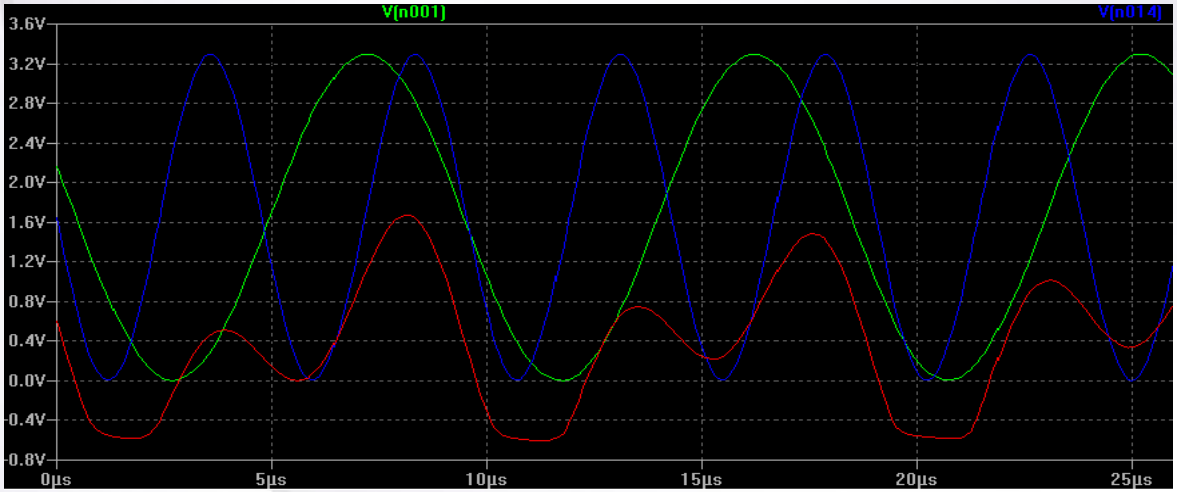


Actual Assembly

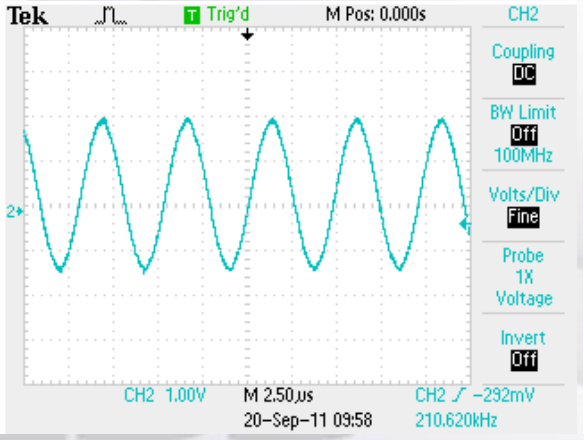


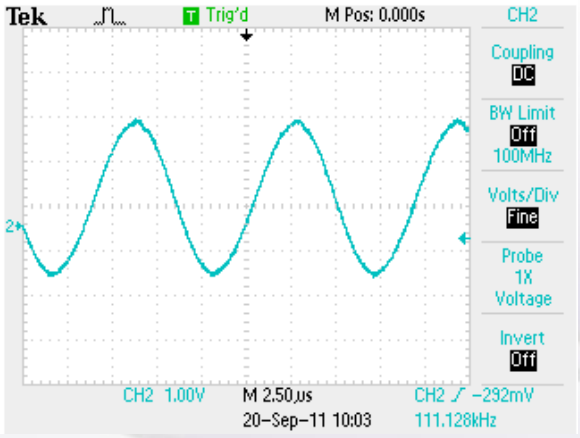
Mixing Verification

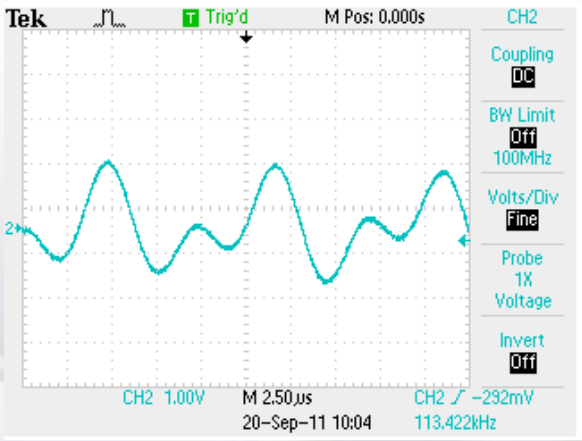
Simulated Results



Experimental Results

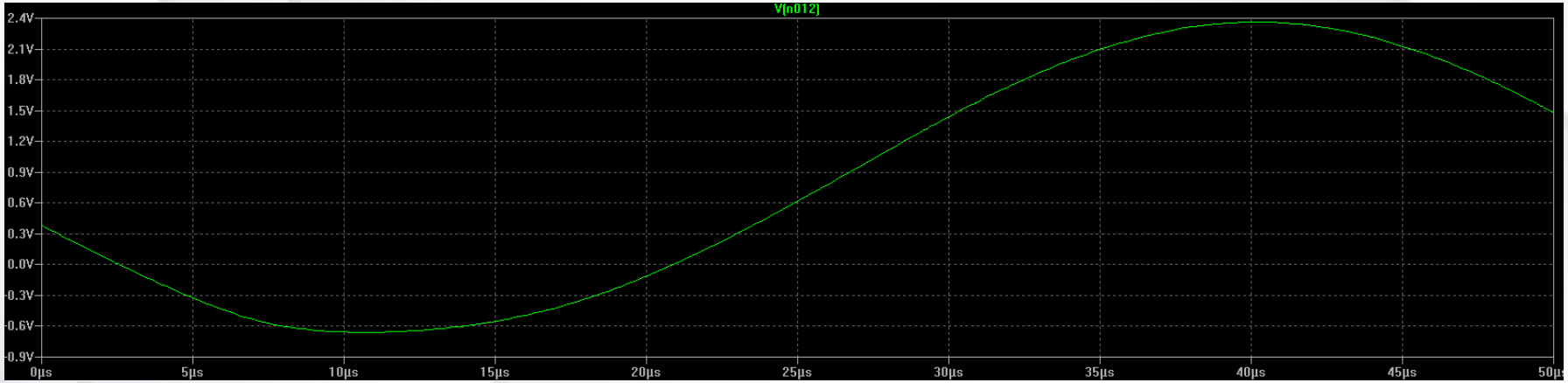




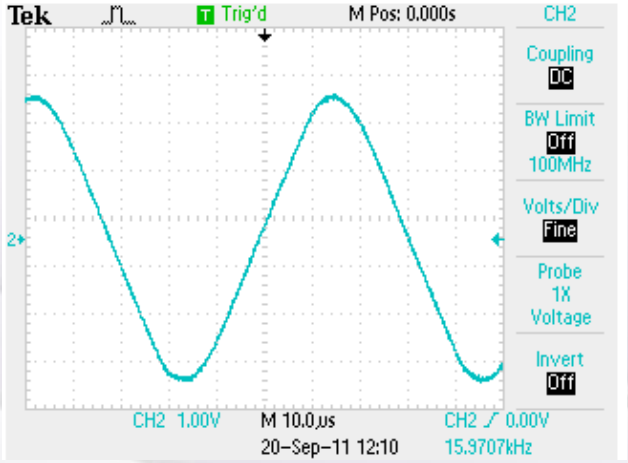


Filtering Verification

Simulated Results



Experimental Results

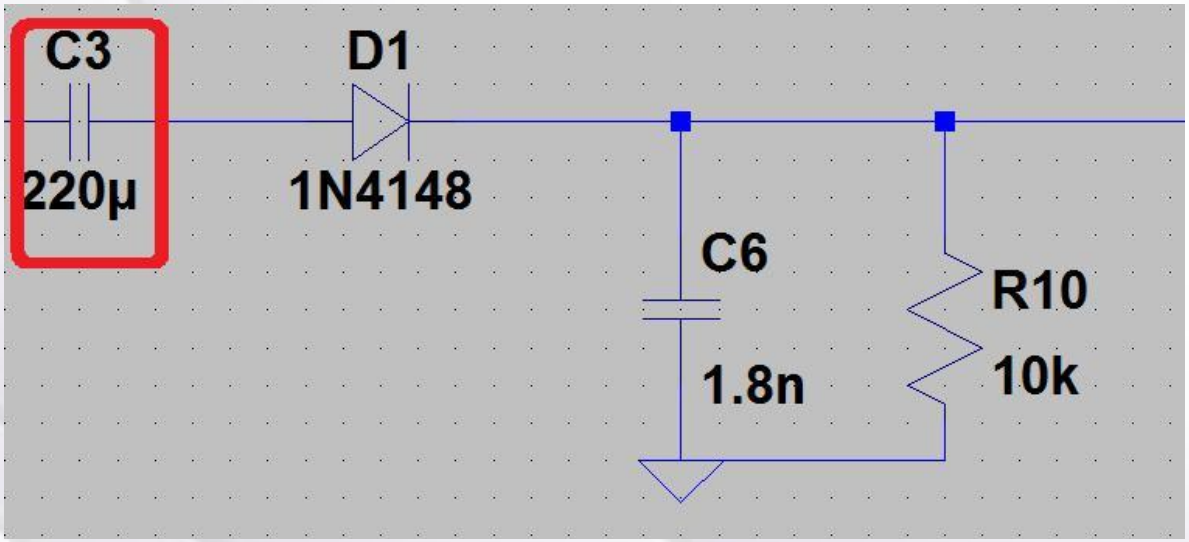


Mixing/Filtering Problems

- Butterworth filter was oscillating at 16 kHz
- Envelope Detector was killing the signal passing through

Envelope Detector Solved

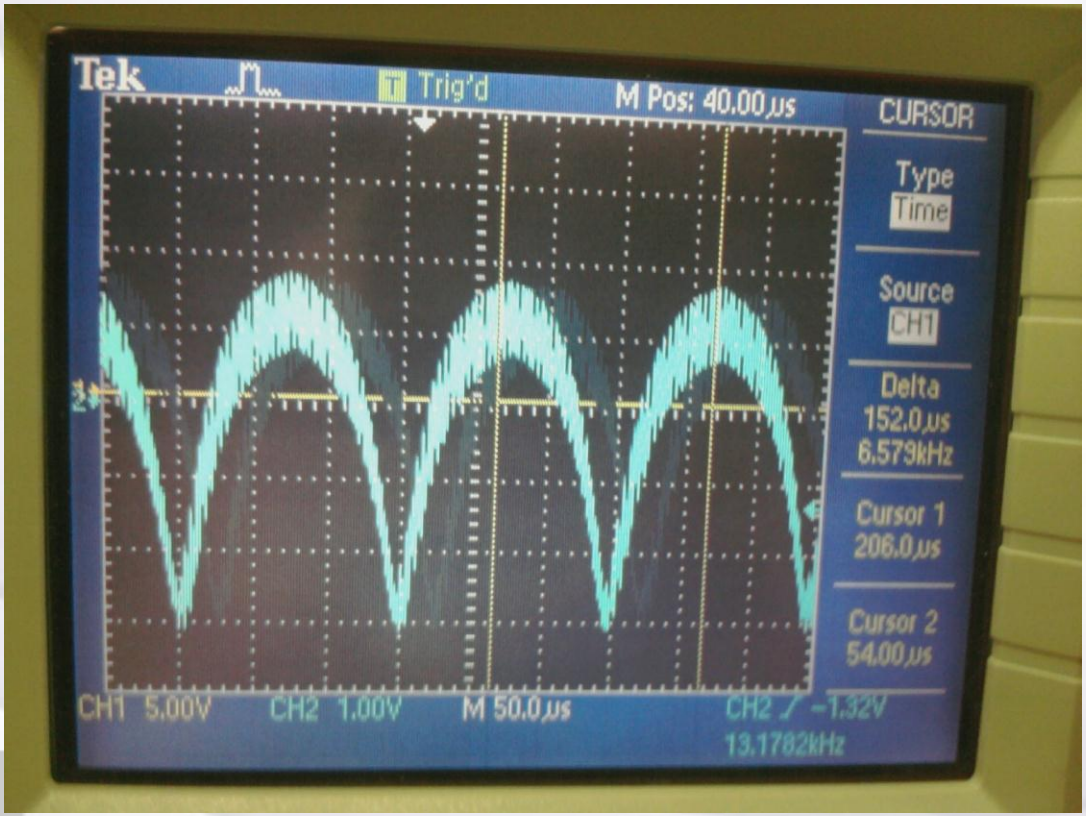
- Discovered that the capacitor after the mixer was blocking signal
- Changed the capacitor value drastically



- Thanks Mr. Scalzo!

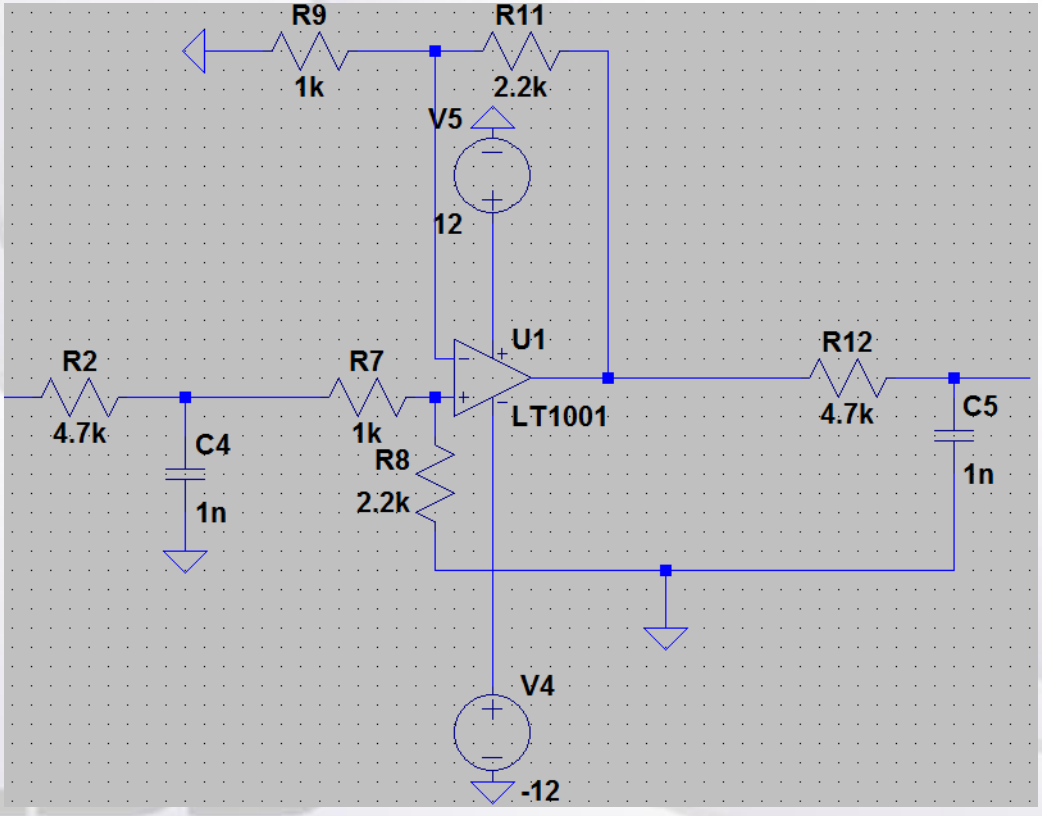
Envelope Detector Results

- Extracting difference between input frequencies
- Contains noise



Filter Adjustments

- Passive low pass filter
- DC level shifter with gain adjustment
- Passive low pass filter

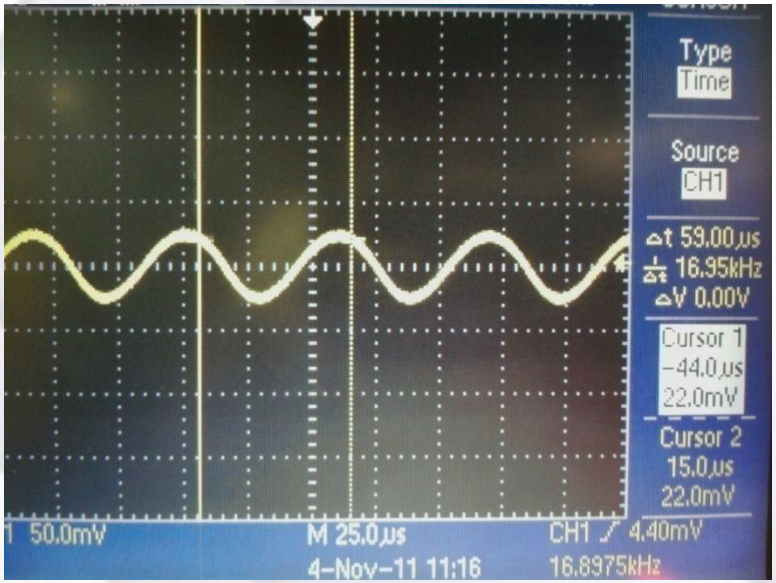


$$f_c = \frac{1}{2\pi RC}$$

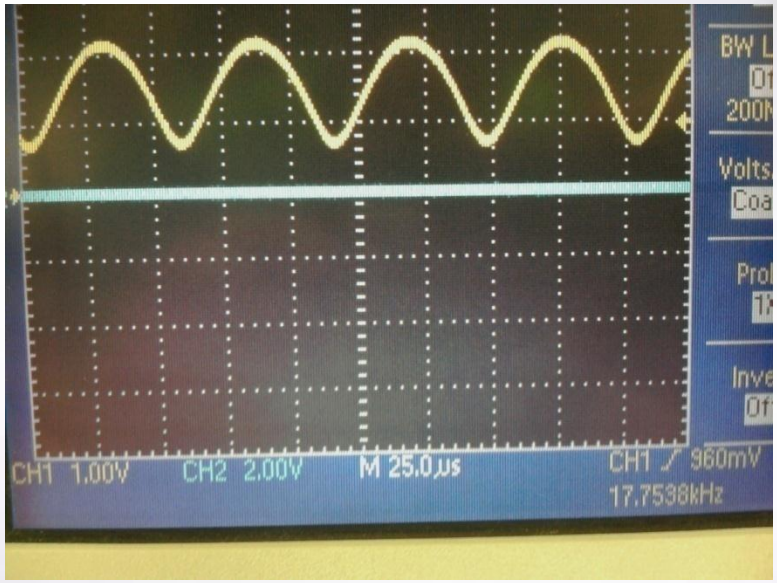
$$Gain = \frac{R8}{R9} = 2.2$$

$$Offset = \frac{R7}{R9} = 1$$

Filter Results

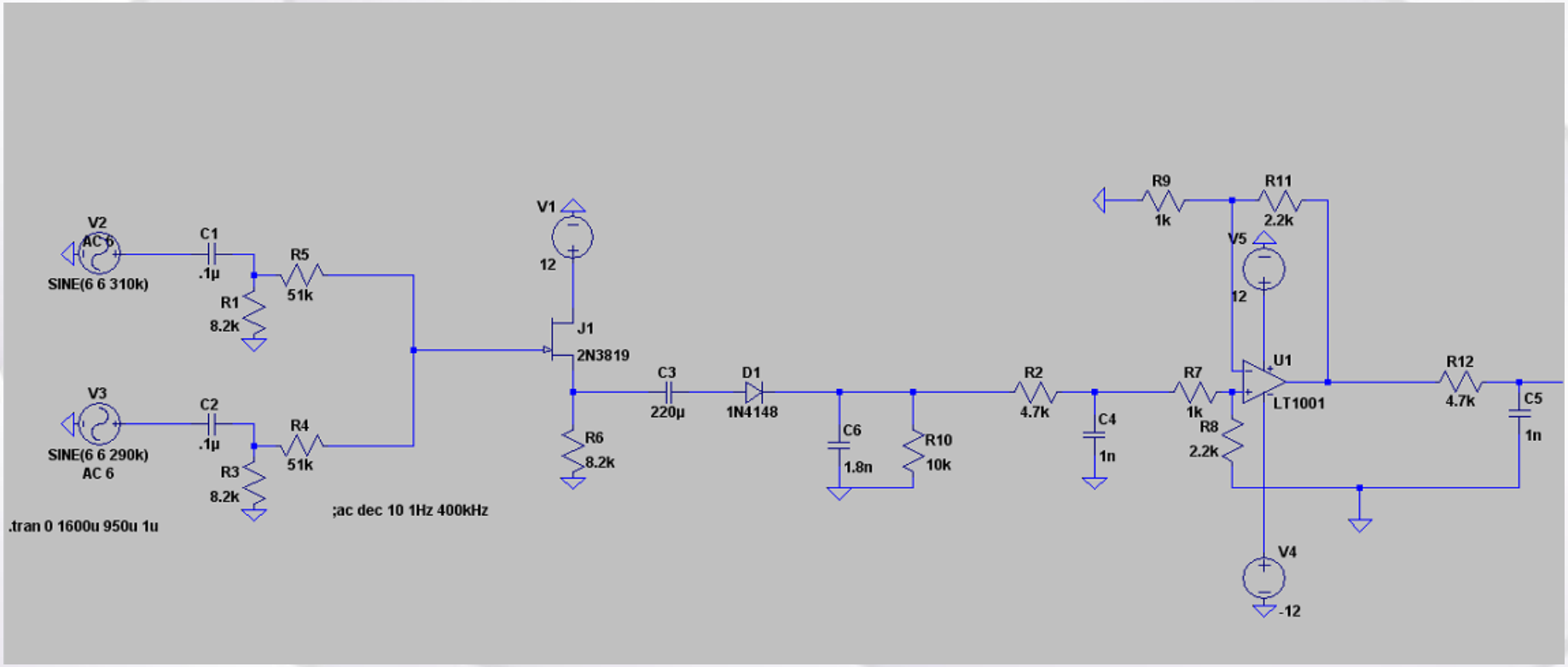


- After first filter
- Still contains noise

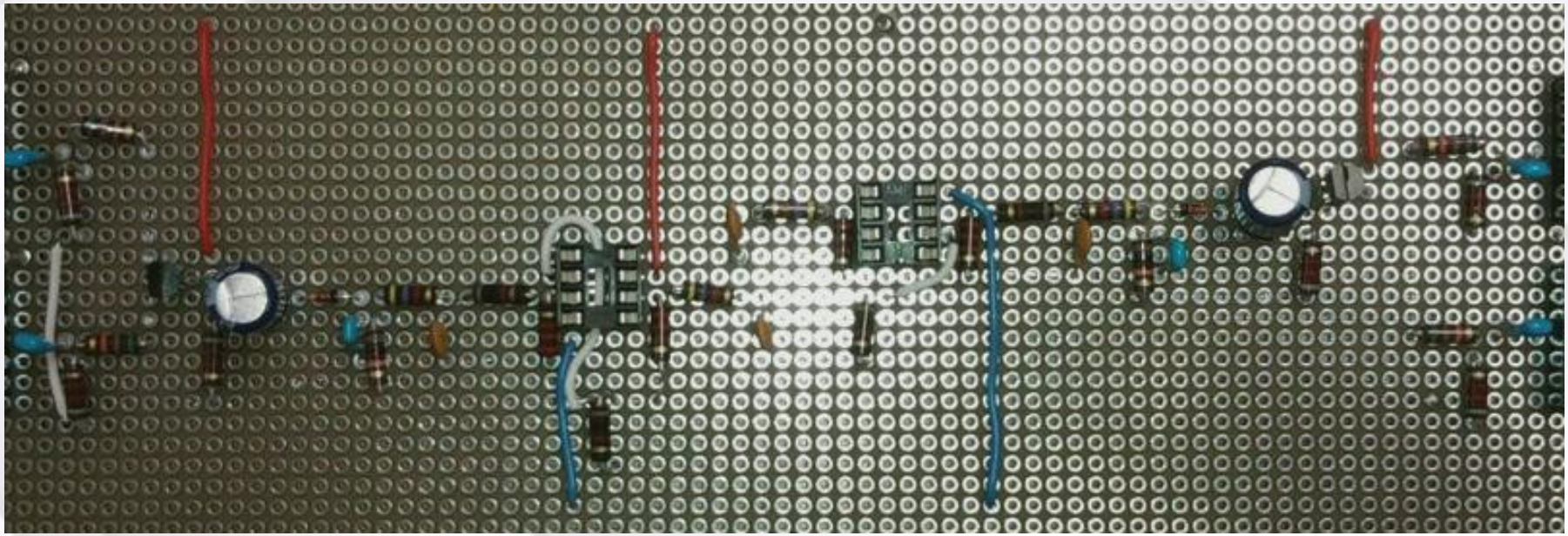


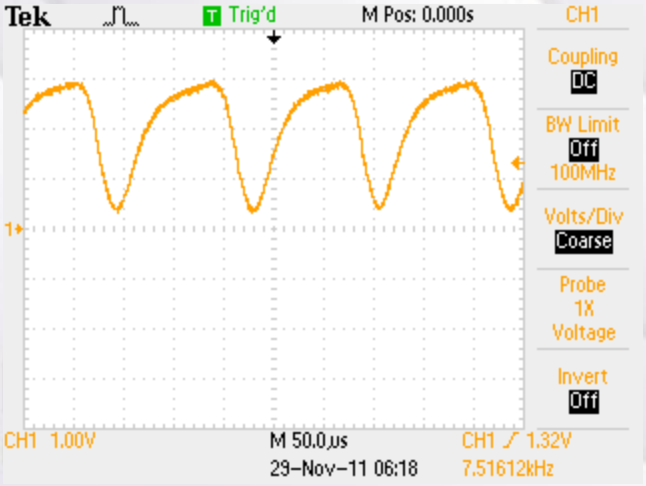
- After DC-shifter
- After second filter
- Within 0-3.3V

Final Mixing/Filtering Circuit



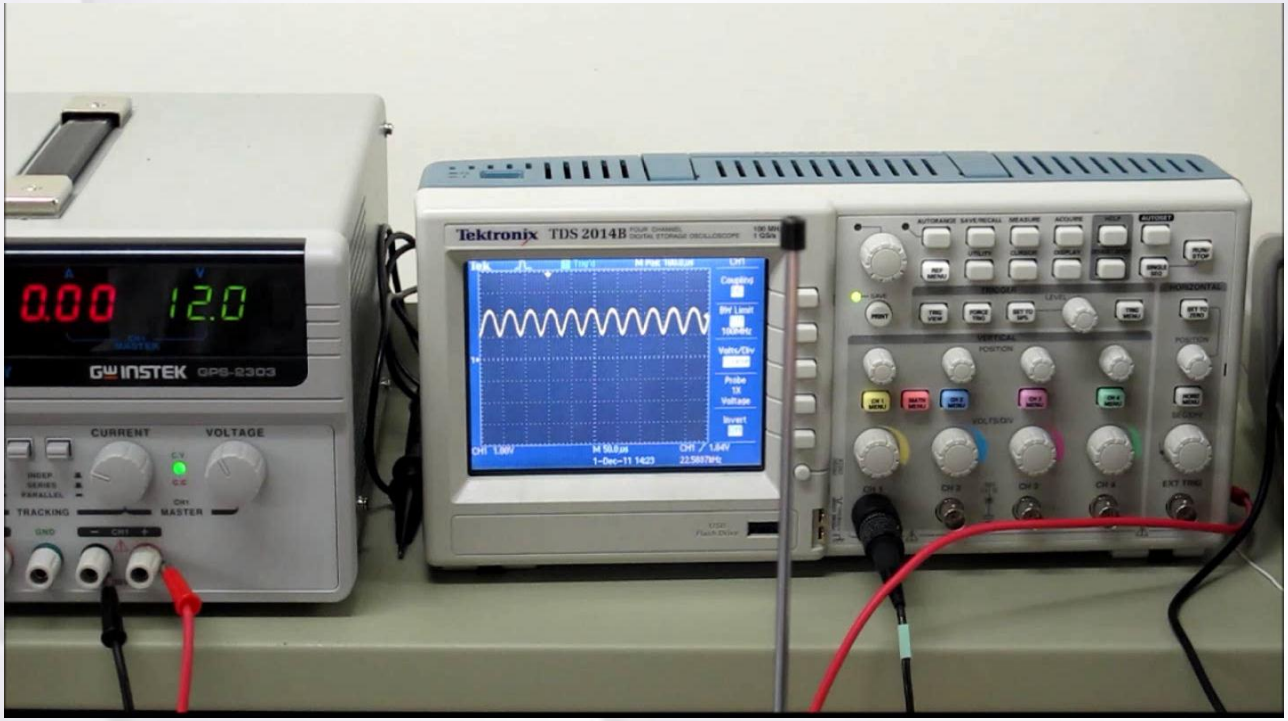
Soldered Circuit Results





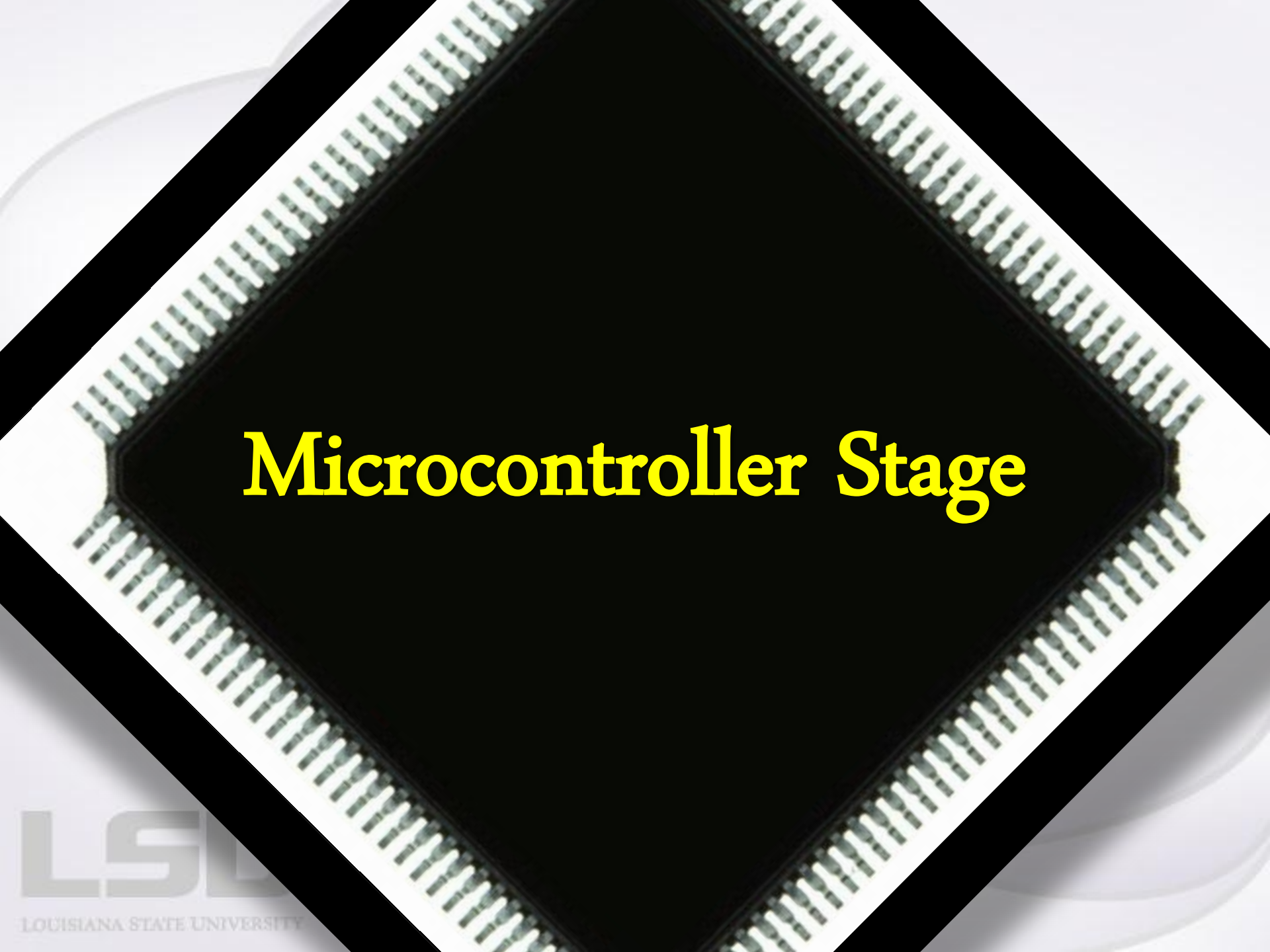
- Results are comparable to both the simulations and previously constructed circuit

Sensitivity Results



Lessons Learned

- Always double check component values
- When testing circuits, check it step-by-step, and test for various scenarios



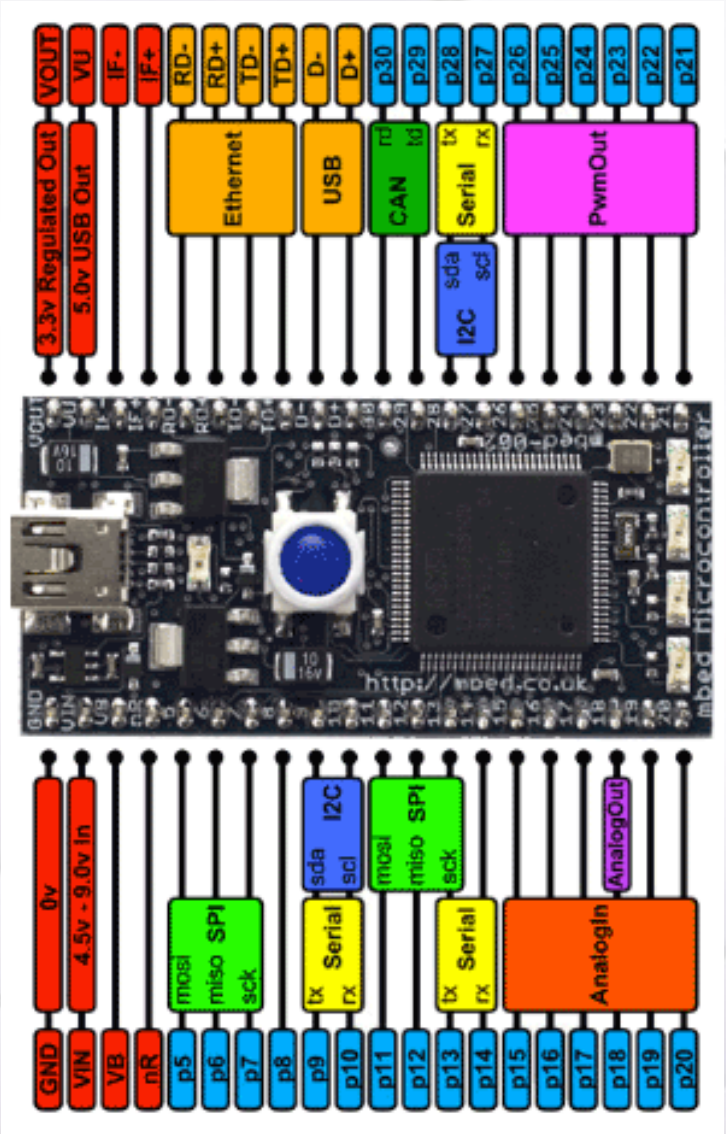
Programming

3 Main Components

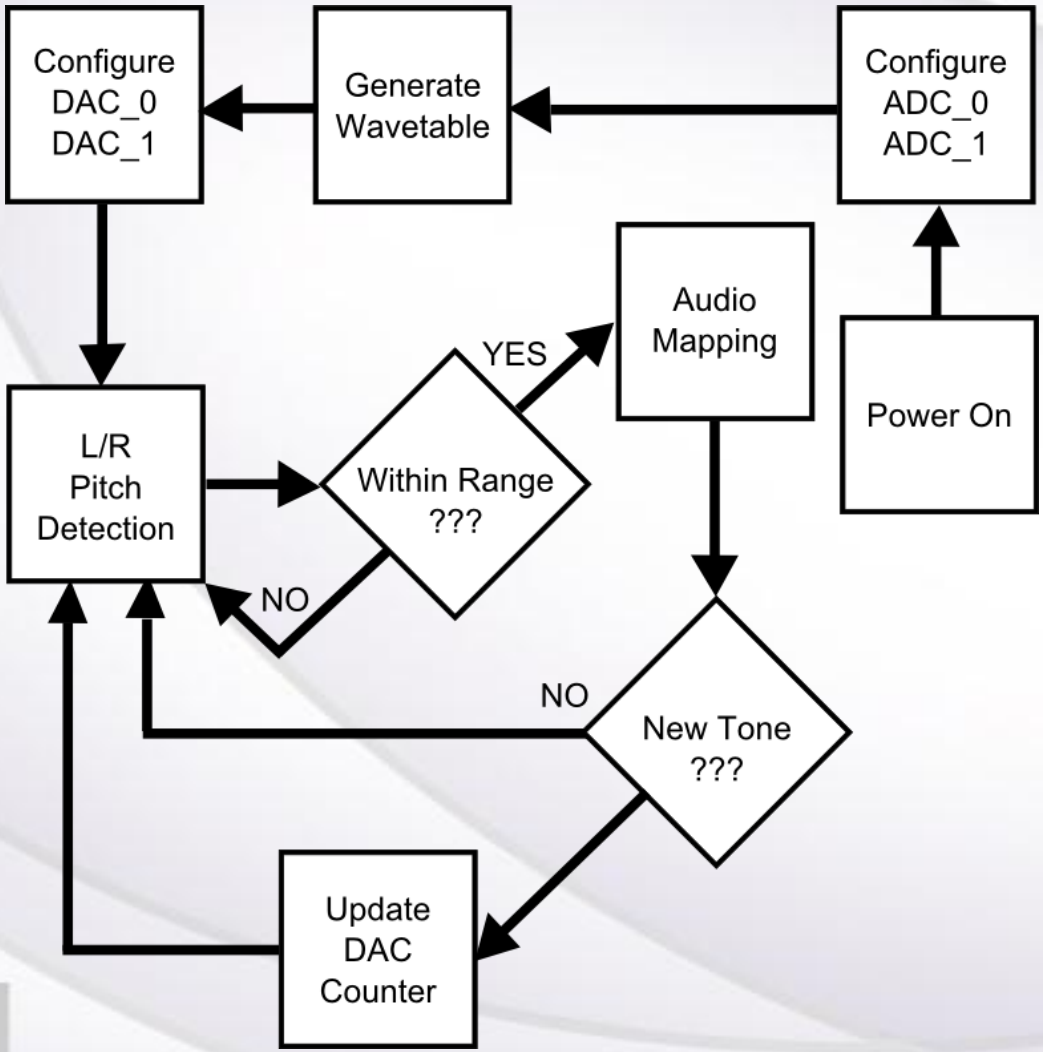
- Frequency Detection
- Linearization
- Waveform Output

Hardware

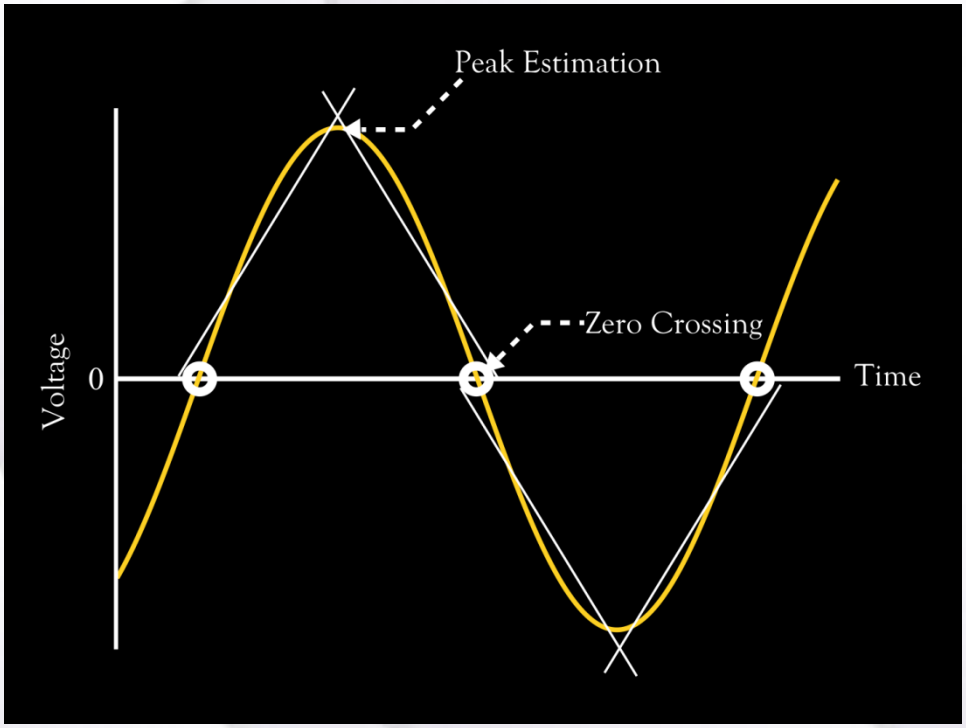
- Mbed Prototyping Platform
- 100Mhz ARM Cortex M3 Core
- Onboard 8 Channel ADC and 1 Channel DAC



Flow Control



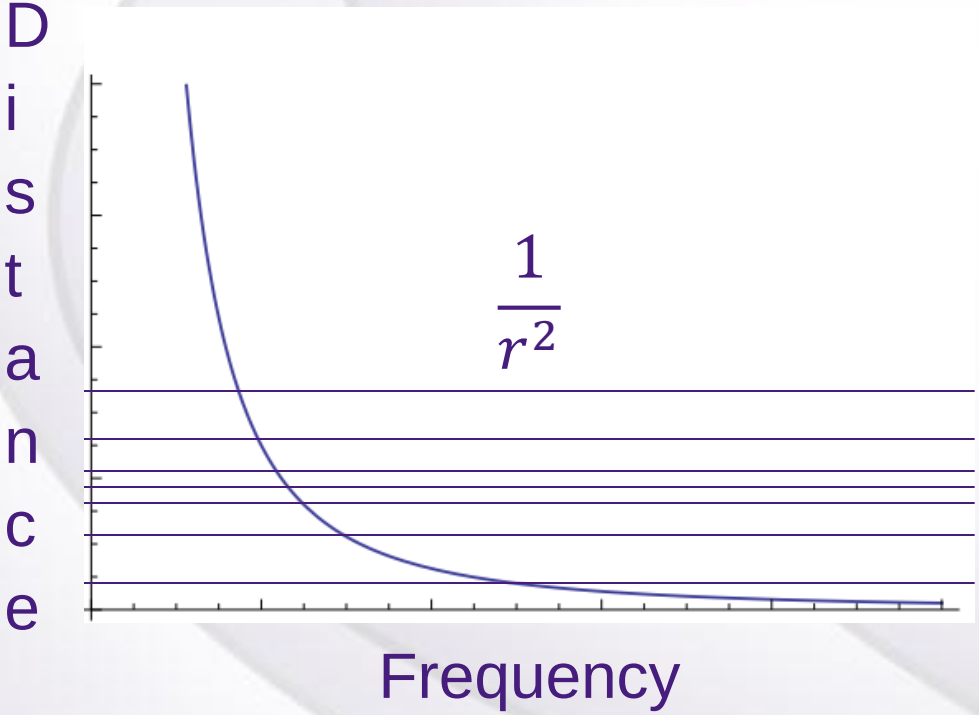
Frequency Detection



- 200Khz Sampling Rate
- Peak Estimation using 1st derivative testing
- Zero Crossing Detection
- Frequency Domain Techniques hard to implement in embedded hardware

Actual Frequency	Sampled Frequency	% Error
2kHz	2.1Khz	+/- 5%
20kHz	20.8kHz	+/-7%

Linearization/Audio Mapping



- Single Tone Audio Output
- Piecewise Linearization using estimation of field as a guideline

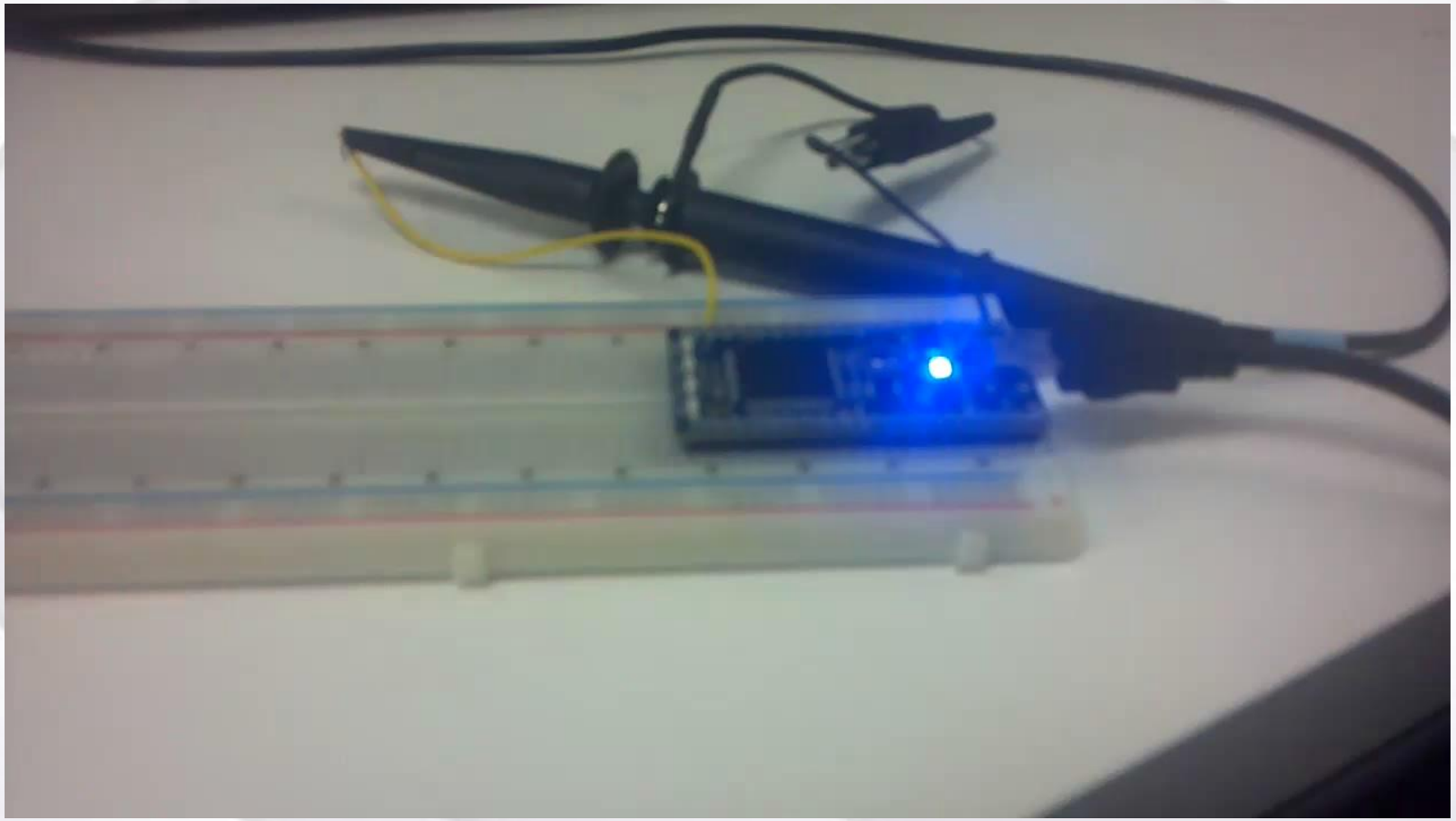
DAC Output

- Piano Key Frequencies 1-64

$$(f)n = 440\sqrt[12]{2}^{n-49}$$

- Double Buffering for cleaner output
- 360 point Wave Table
- Waveforms very close to target frequency, retuned manually

Double Buffering Test



Outcomes

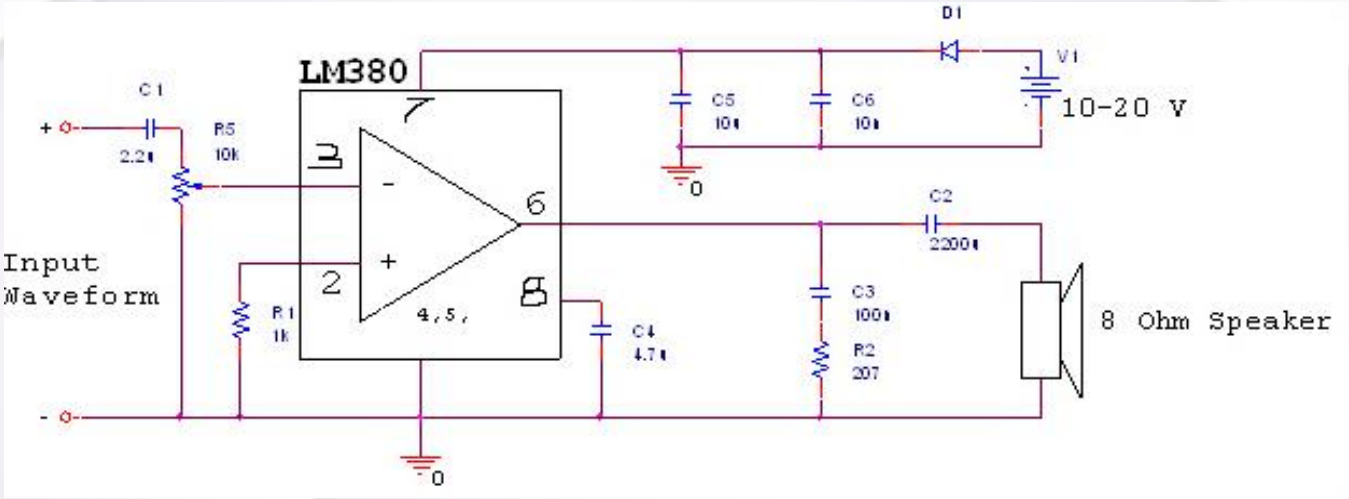
- All Functions work in Isolation
- Complete Program not functioning
- Microcontroller DMA capability is overloaded
- Offloading more computation to the main CPU core will decrease load on DMA Controller

Lessons Learned

- Software always takes longer to develop than planned
- Difficulty of integrating with hardware, even if it is tailored to your device.

Output Stage

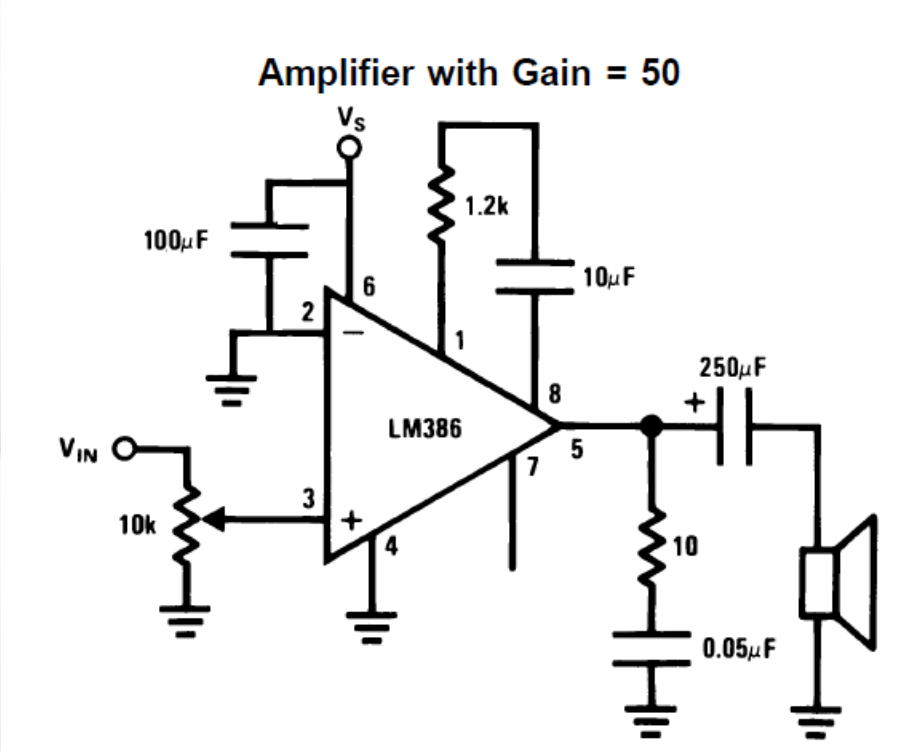
Audio Amplifier



Original Design

- Utilizes the LM380 (Class A-B Audio Amp)
- Mostly used in consumer applications
- Fixed Voltage Gain=50

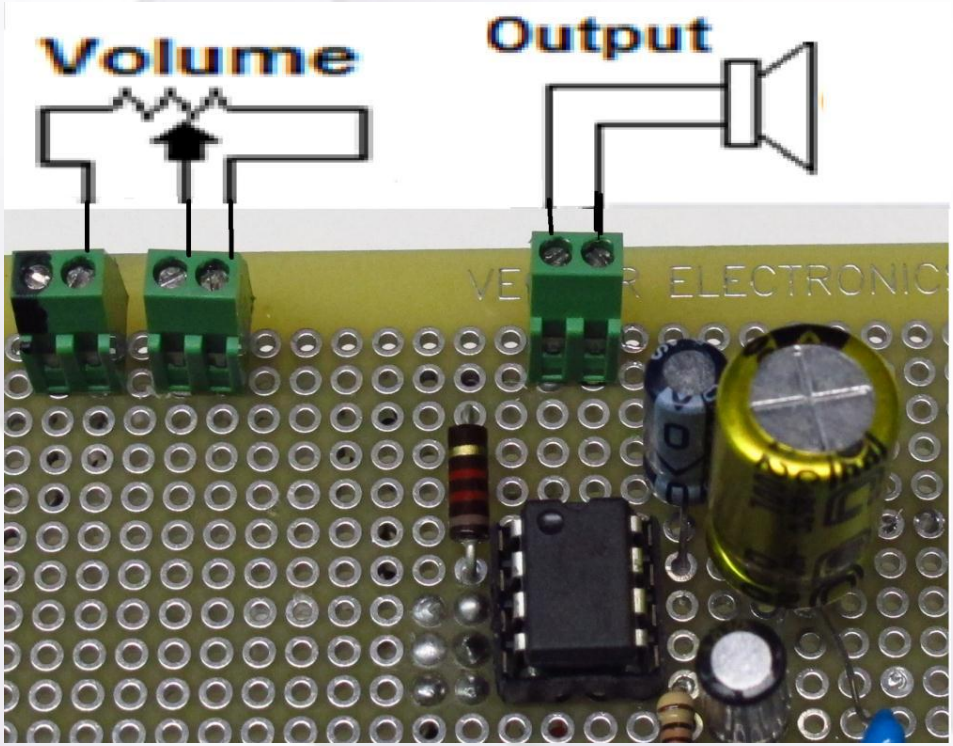
Audio Amplifier



Revised Design

- Utilizes the LM386
- Fewer Components
- Cheaper
- Variable Gain (20 -200)

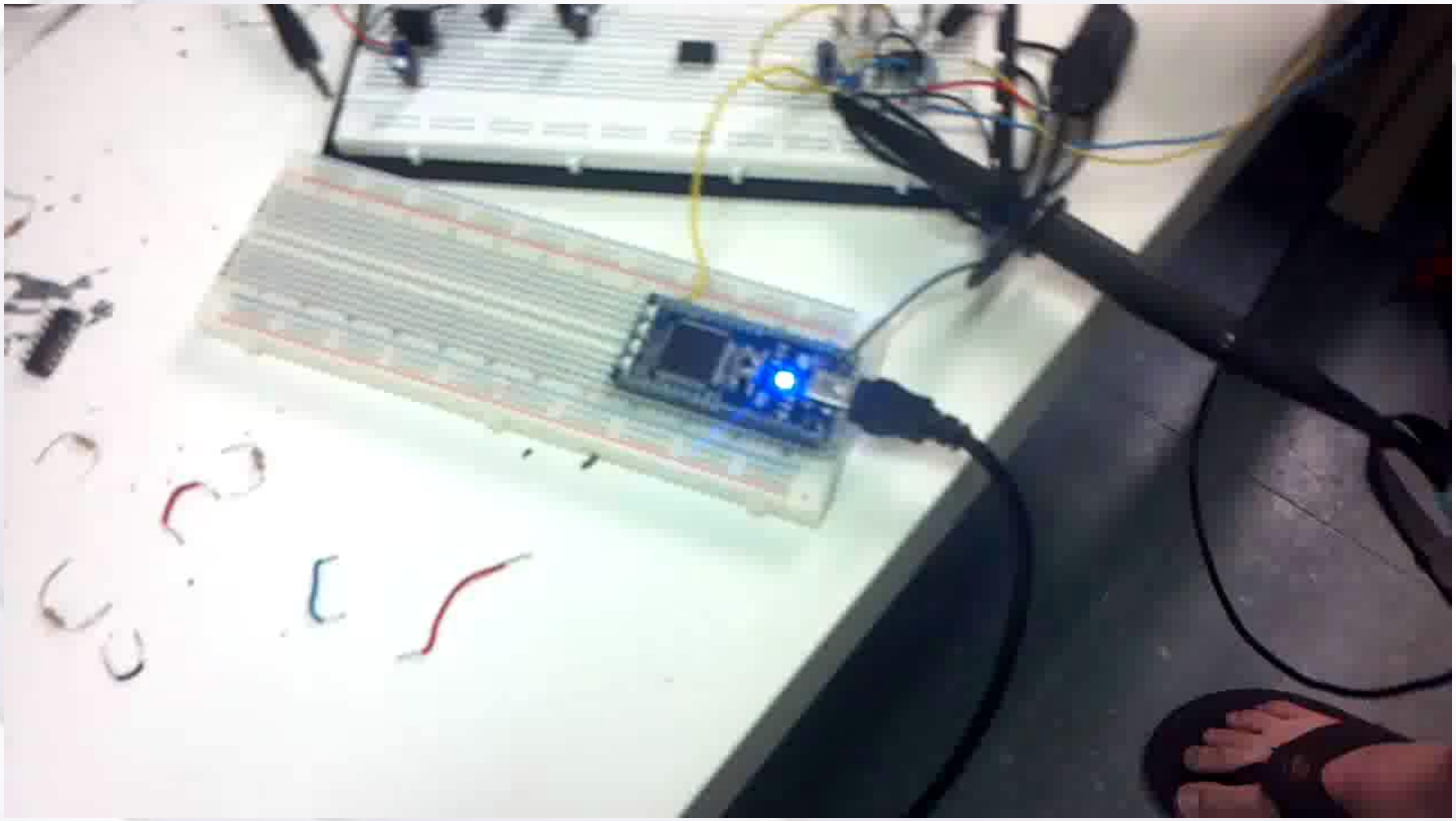
Audio Amplifier



Results

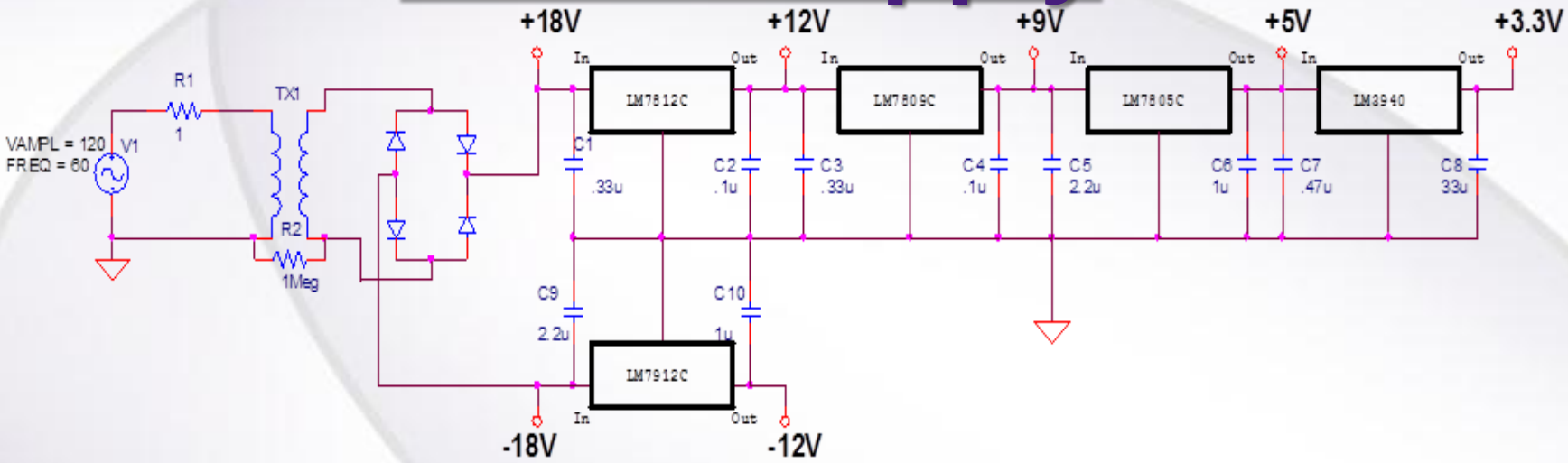
- Max Output is Loud
  - Not Ear Shattering
- Volume Regulation
  - With Control Knob
- More Evident in Demo

Audio Amplifier



Power Supply

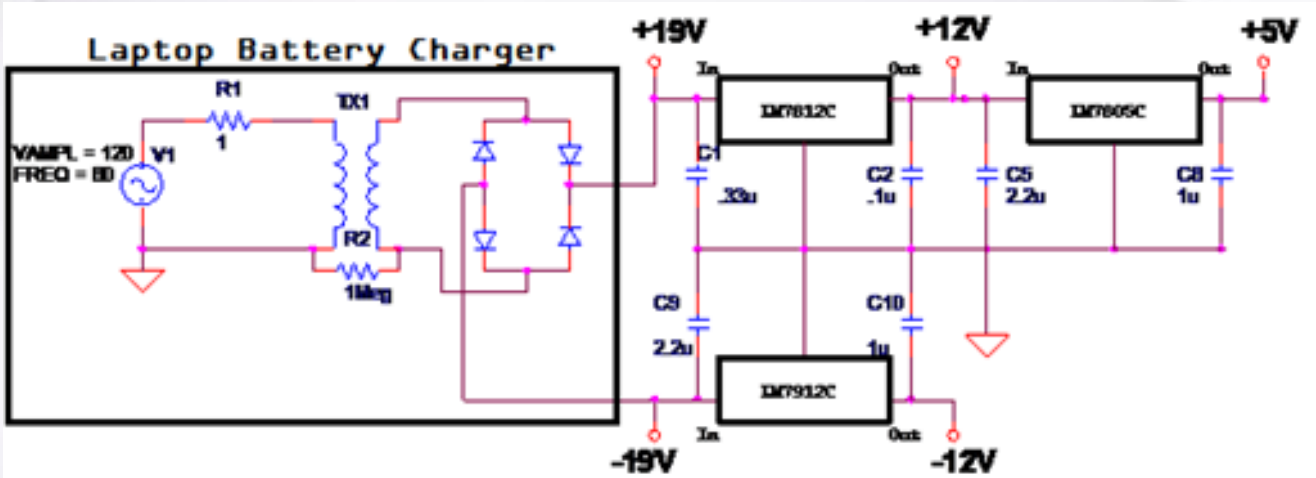
Power Supply

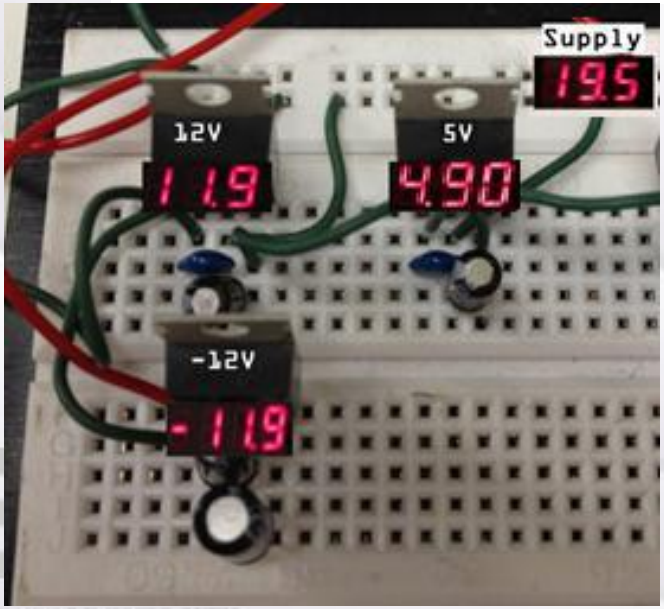


Original Design

- Set of Regulators to Step Down Voltage
- Transformer -> Bridge Rectifier -> Regulators

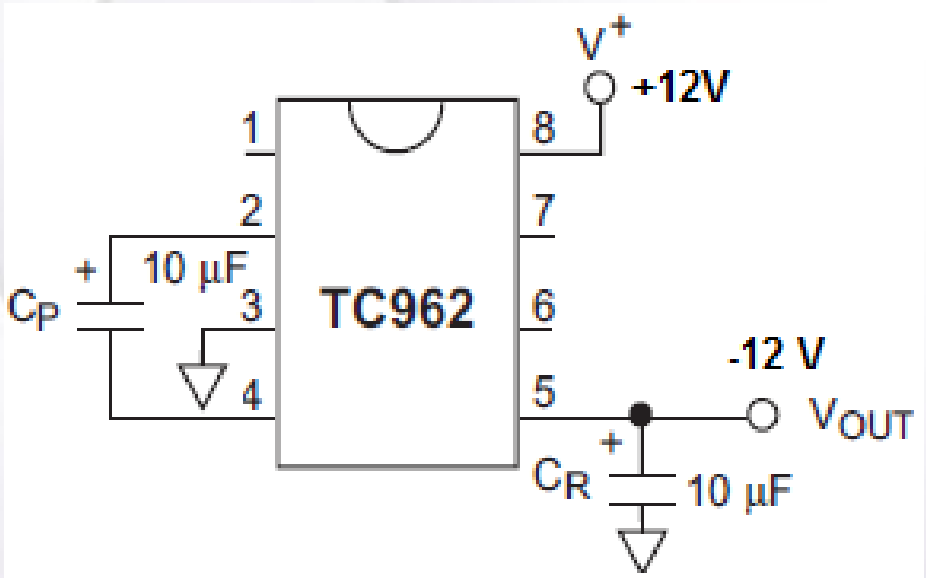
Power Supply





- Problems with -12V Regulator
- Reads the correct voltage
- Potential Difference from -12 to +12
  = 5.05 V (Wrong)
- Scrap Negative Regulator

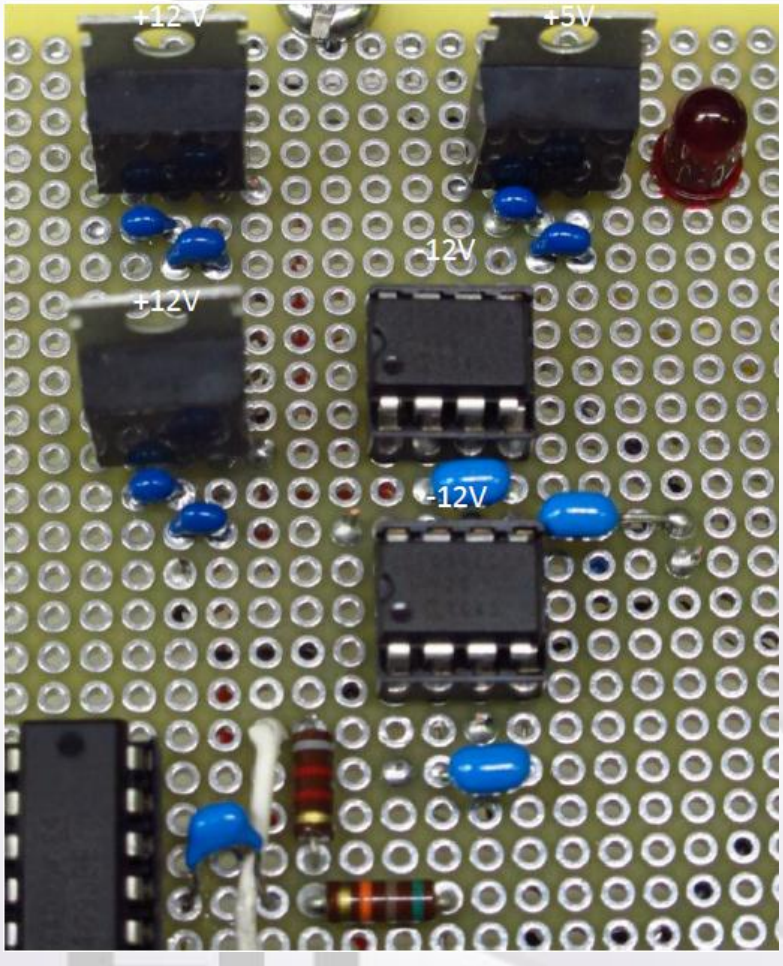
Power Supply

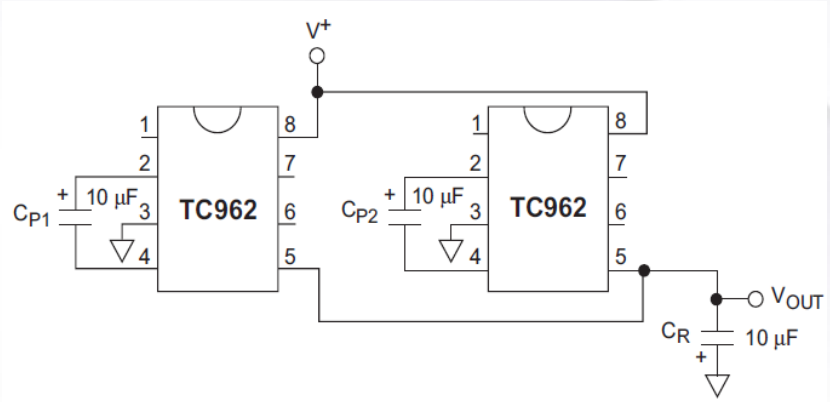


New Negative Voltage Source

- TC962 Charge Pump
- Input Range 3-18V
- Output = (-)Input
- Output Current = 80mA

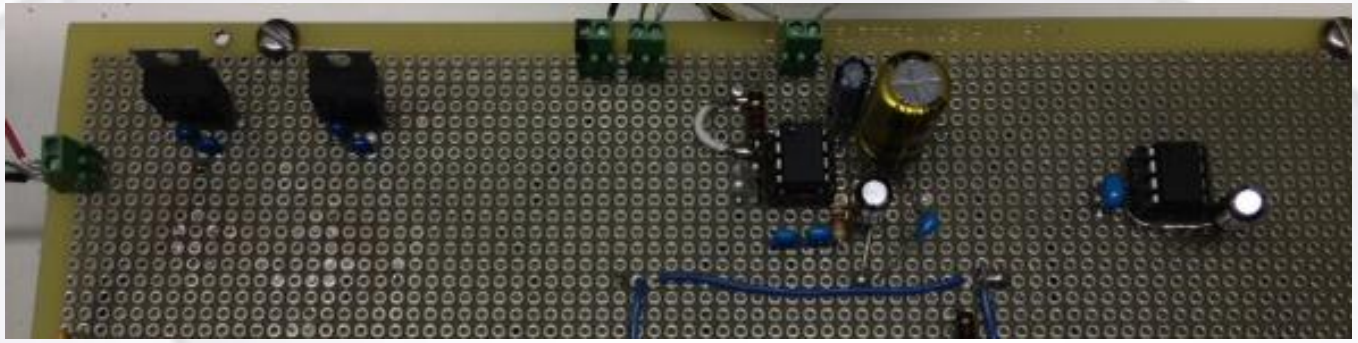
Power Supply





- Cascade Chips to Increase Current
- Worked on Breadboard
  - Successful Regulation of all Voltages
- Not When Soldered
  - Negative Output = 1.04V
  - Pulled Very High Current (.8 Amps)
  - Could Have Been Soldering Issue

Power Supply



- Simplified the Entire Circuit
  - 2 Regulators (+12, +5)
  - 1 Charge Pump (-12)
- WORKS!!!
- Tested with Wall Charger
  - Doesn't Work ☹
- Now Only Works Sporadically

Outcomes

- Positive Rail Always Worked
- Negative Never Reliably Worked
- Cannot Be Implemented into Design

Lessons Learned

- Never Underestimate the Difficulty of a Simple Circuit
- Begin Testing as Early as Possible
- Always Have Backup Designs
  - Every Circuit Doesn't Work Like it Should

Theremin Enclosure

- 18 x 8 x 6 in
- ¼ inch thick
- Solid Acrylic
- Laser Cut
- Incredible Amount of Detail

Enclosure Details

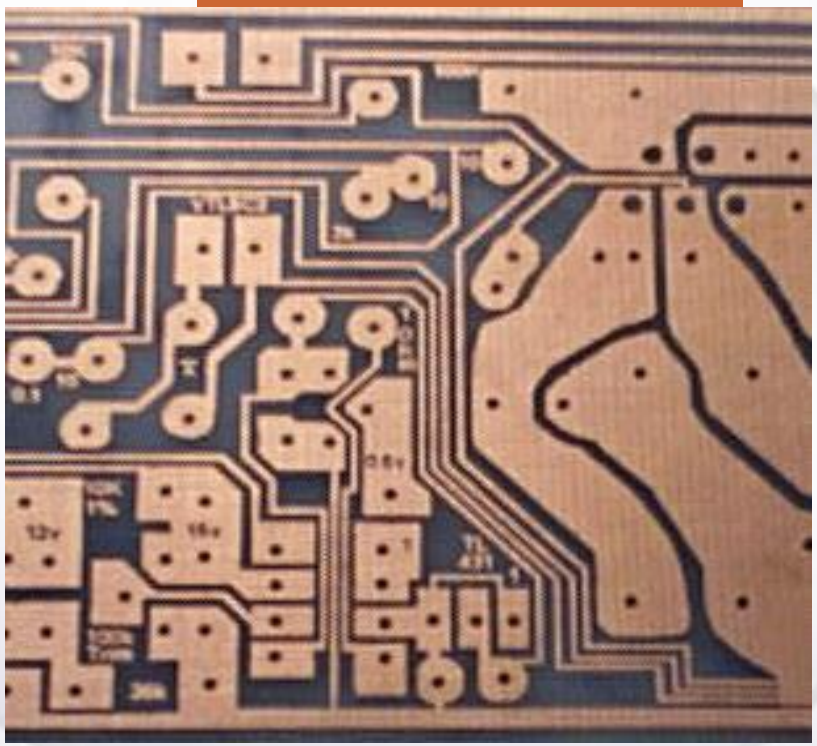
Top Face View

Speaker Grill

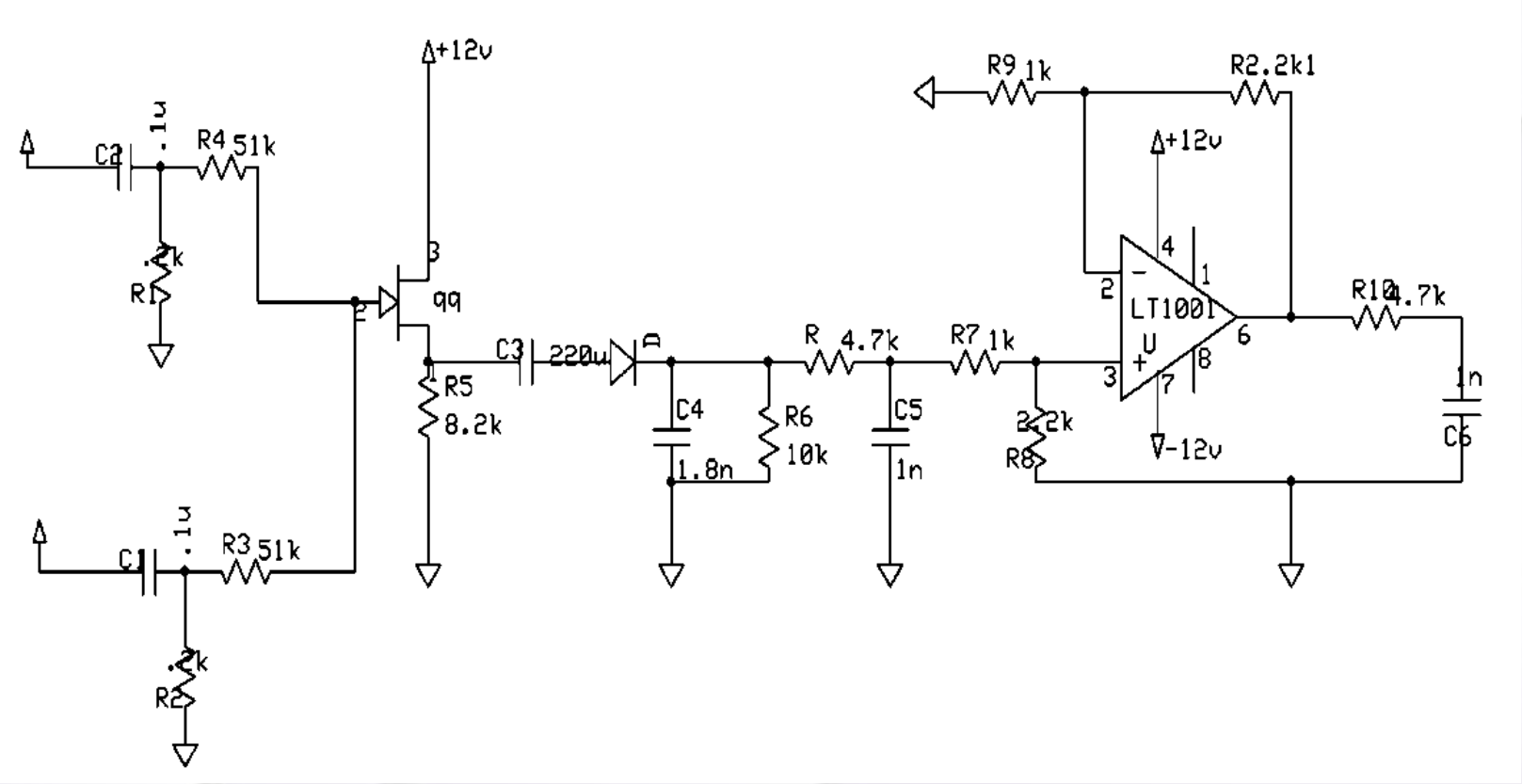
PCB Design

PCB Fabrication

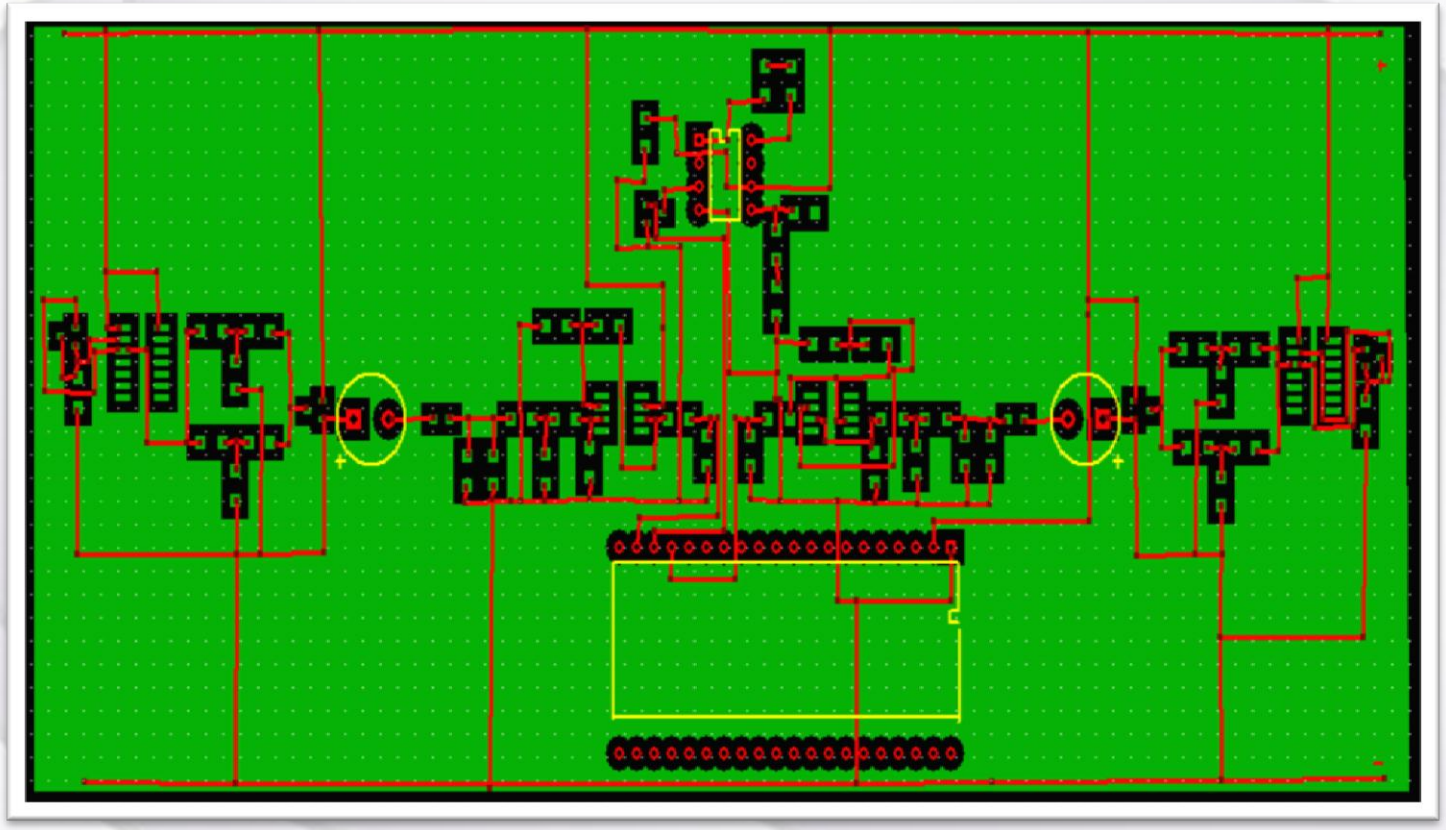
- Used Expresspcb
- Free Schematic and CAD Software Provided
- Recommended by Alumni
- One-Day Turnaround



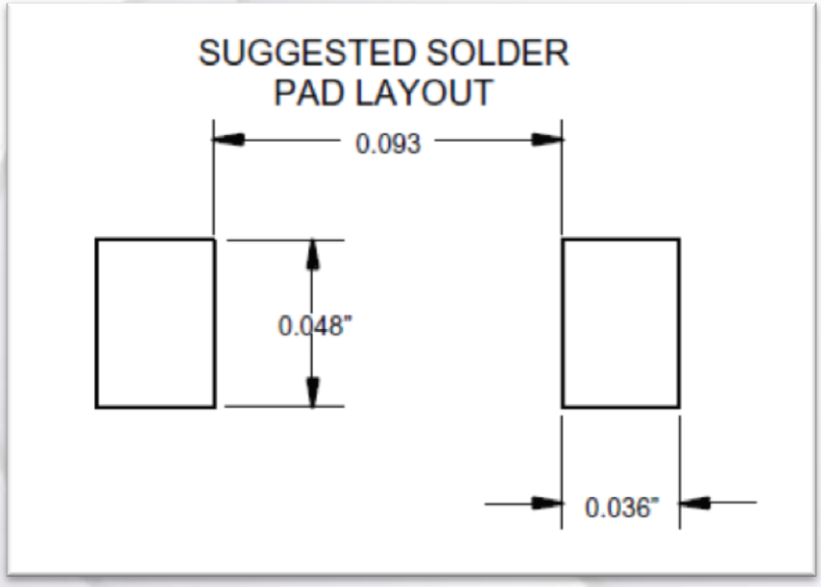
Schematics for PCB



PCB Layout



Custom Pad for PCB



Diode Pad layout

$X_1 = 2.3”$

$X_2 = 2.425”$

$X_2 - X_1^* = 0.093"$

$X_1^* = 2.332"$

Budget Analysis

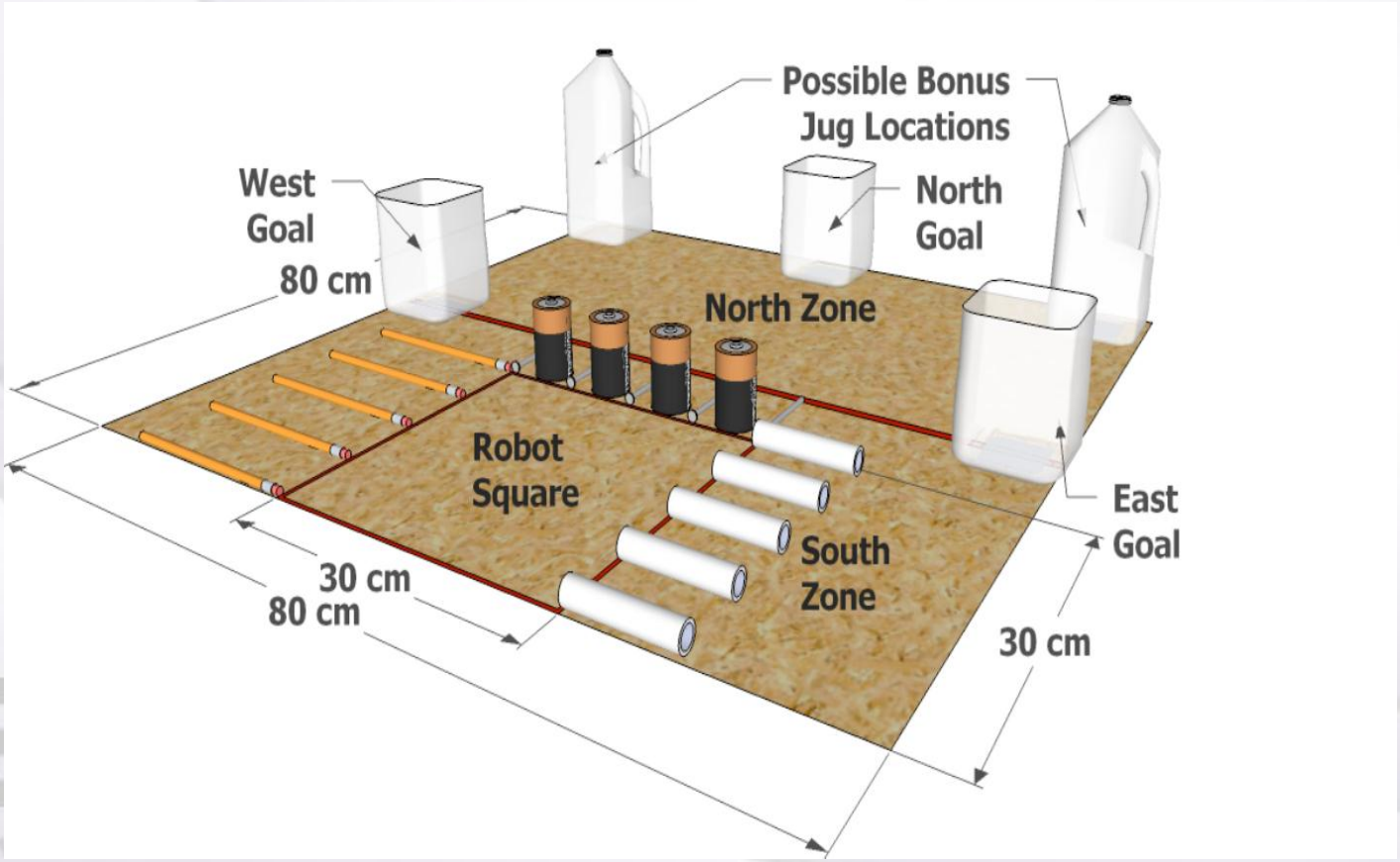
Perf-Board	
Items	Price
Enclosure	$56.00
Microcontroller	$60.00
Components	$95.89
Antenna	$30.00
Speaker	$6.15
Perforated Board	$11.52
Total	$259.56

PCB Board	
Items	Price
Enclosure	$56.00
Microcontroller	$60.00
Components	$121.64
Antenna	$30.00
Speaker	$6.15
PCB	$103.82
Total	$377.61

Service Learning

High School Robotics Project

- Help Baton Rouge Magnet High's students to build Robotic arm to compete in Science Olympiad.

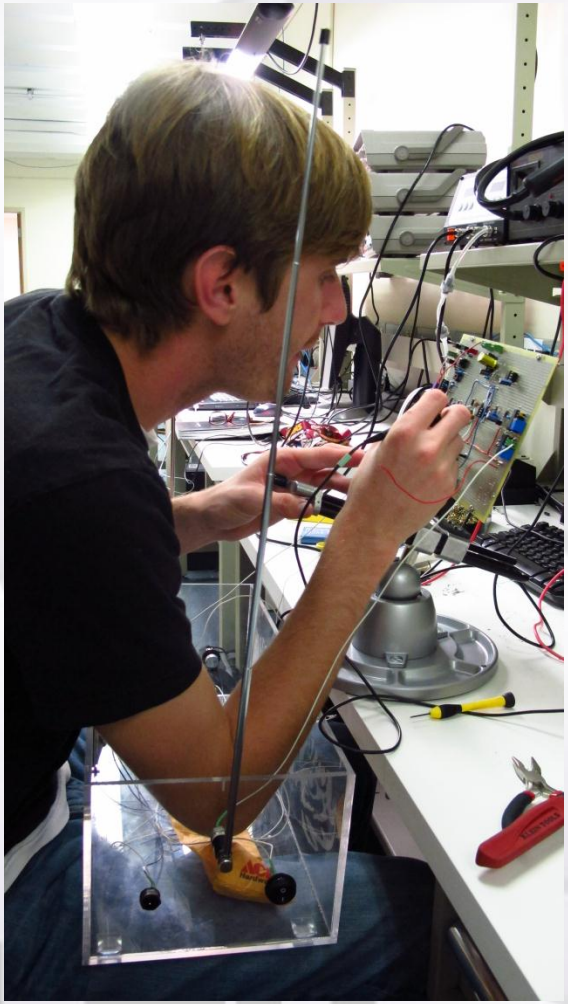


Progress

- Constructed Playing Field
- Collected Target Objects
- Decided on a Design
- Functional Breakdown
- Components Look-Up

Improvements

Room for Improvement



- Oscillator Drift
  - Frequency Variance on Start-up
- Power Supply
  - Revert Design to Using Transformer and Rectifier
- Reconfigurable Controls
- Microcontroller Bypass
- Antenna Sensitivity/Range
- Always More Troubleshooting

Lessons Learned This Year

Questions?