EE90 Function Generator

Hwang, Saehui
shwang@caltech.edu

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Contents

1 Introduction

In this paper, an analog function generator design is proposed. This is a part of the EE 90: Analog Electronics Project Laboratory, an integral part of the Caltech EE undergraduate curriculum. This design places emphasis on its compact size. Furthermore, efforts have been made to ensure that the design is user friendly.

2 Goals/Specifications

The proposed device is able to produce sinusoidal, square, and triangle waveforms with a frequency range from 50Hz to 5MHz. The user is able to choose a waveform type, specify a DC offset, amplitude gain, and frequency. The proposed function generator takes power from a standard wall outlet. It is able to output current more than 1A, allowing the device to be used for a variety of purposes such as driving an audio output.

Waveforms	Sine, Square, Triangle
Frequency Range	50Hz to 5.1MHz
Amplitude Range	0V to 4.9V
Output Modes	High Power Output (1A), Normal Output
DC offset	$\pm 4.9V*$
Power Source	120V, 60Hz
Dimensions	132mm by 115mm by 83mm
Operating Temperature	10°C to 30 °C

* The output saturates at $\pm 4.9V$
** Though the output can be up to 5.1MHz, frequencies above 1.6MHz suffer from distortions, especially for the triangle waveform. The specifications described below are applicable for 50Hz to 1.6MHz.

2.1 Sine Wave

THD	$\leq 5\%$

2.2 Square Wave

Rise/fall time	$\leq$ 60ns

2.3 Triangle Wave

Linearity Error	$\leq$5% of amplitude

3 Block Diagram

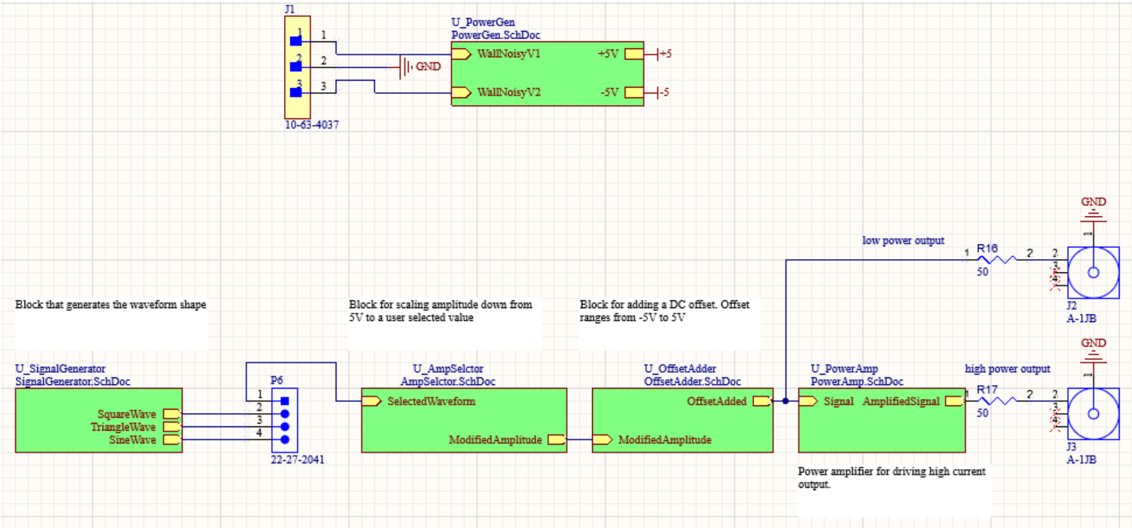

Figure 1: High level block diagram

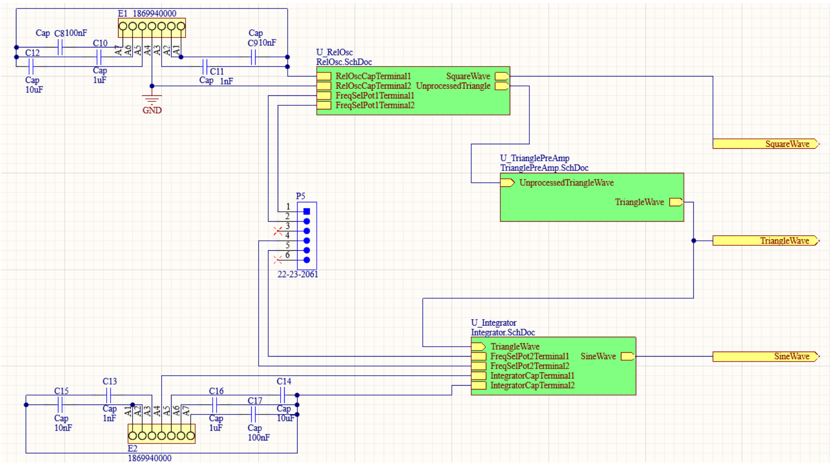

Figure 2: Signal Generator block diagram

4 Schematic Overview/Method of Approach

4.1 Relaxation Oscillator

This is a standard relaxation oscillator. It generates both a square wave and a triangle wave. The output switches between the rails, triggered by the charging and discharging of the capacitor up to the threshold voltages. The voltage across the capacitor is approximately triangular and is picked up by the triangle preamplifier block, which presents a high impedance node to not disturb the operation of the relaxation oscillator.

4.2 Triangle Preamplifier

This stage simply picks up the voltage signal from the capacitor on the relaxation oscillator by presenting a large input impedance. It then amplifies the triangular waveform to have a 5V amplitude.

4.3 Integrator

The integrator exists to create a sine wave from a triangular wave. Its governed by 1/(RCs). The same resistor and capacitor values used in the oscillator is used in the integrator to prevent bandwidth limitations. This arises from the fact that the transfer function 1/(RCs) slopes down for higher frequencies. Had we not used the same resistor and capacitor values, the integrator will not integrate higher frequency signals properly. There is a resistor parallel to the integration capacitor to prevent DC signals from saturating to infinite gain

Once the three waves are generated, a switch is used to select the output waveform.

4.4 Offset Adder

This block is an amplifier configured as an adder. One input of this adder is the selected signal, the other input is the offset voltage, generated by the user-configured potentiometer, which is hooked up as a voltage divider between the rails.

4.5 Amp Selector

This block is an inverting amplifier that reduces the amplitude down from 5V to a user selected value. The potentiometer allows the user to choose the ratio of attenuation.

4.6 Power Generator

The power used in this function generator is derived from a wall outlet. The wall power is first passed through a transformer to step down the voltage. Then the signal goes to a rectifier to create a purely positive voltage. This then passes through filtration capacitors, then to a positive buck converter and a negative buck converter which efficiently steps down the voltages. Each signal is passed to a linear regulator to create more stable rails.

4.7 Power Amplifier

The power amplifier is there to allow for the high power output. It is a commercially available amplifier in the inverting configuration.

5 Simulation Methods & Results

5.1 Via Parasitics

Via parsitics were calculated using Saturn PCB's "Via Characteristics Tool". Only the vias that are on signal paths were simulated. The capacitance, inductance, and impedance values were added to the simulation schematic as an RLC circuit.

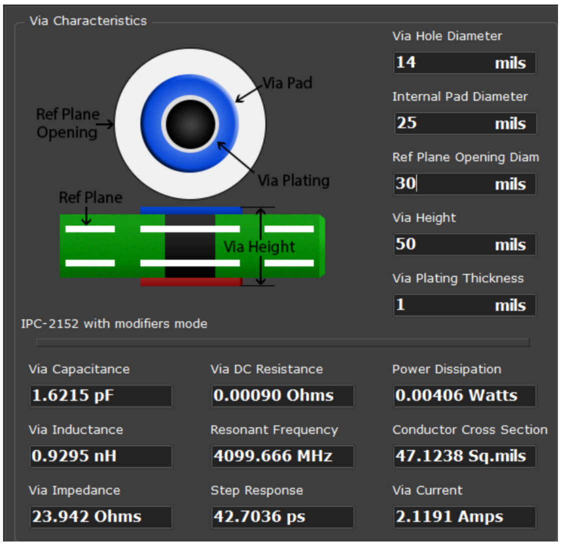

Figure 3: Via Parasitics

5.2 Trace Parasitics

Trace parasitics were calculated using Saturn PCB's "Conductor Impedance" tool. Traces carrying signal paths were simulated to verify specs. Wire parasitics (connecting from panel mount part to board) were simulated as well, using an online wire inductance calculator. (http://www.consultrsr.net/resources/eis/induct5.htm)

5.3 Pin Parasitics

Pin capacitances were simulated as 3pF capacitors connected to ground

Displaying screenshots of all the simulations that were conducted would be too lengthy. The following screenshots present a selection of various waveforms, offsets, and amplitudes. For clarity, they are organized by waveform shapes

5.4 Square Wave

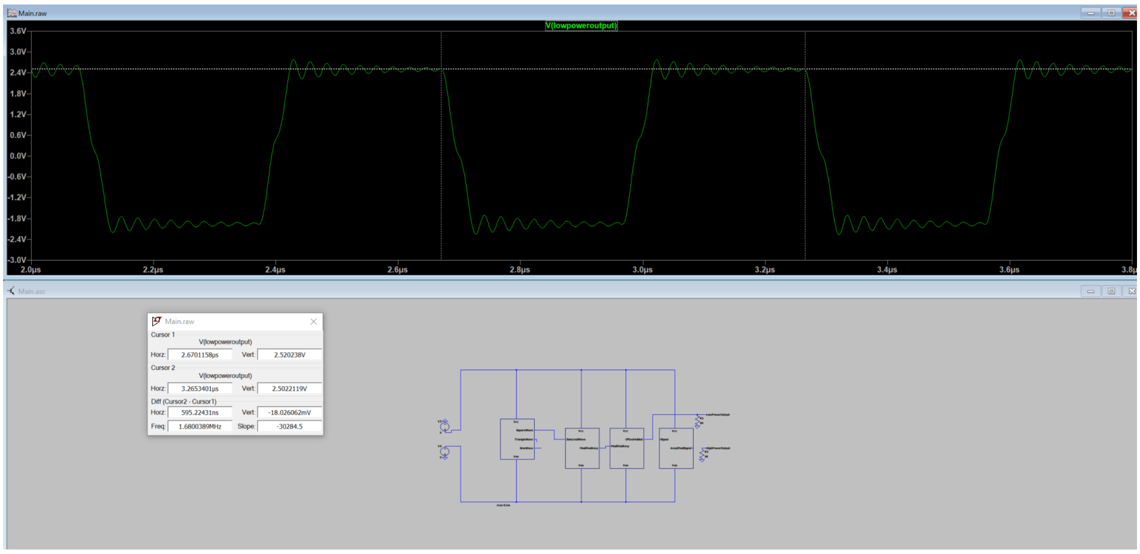

Figure 4: 1.6MHz Square Wave. Overshoot: 10%, Rise Time : 43ns

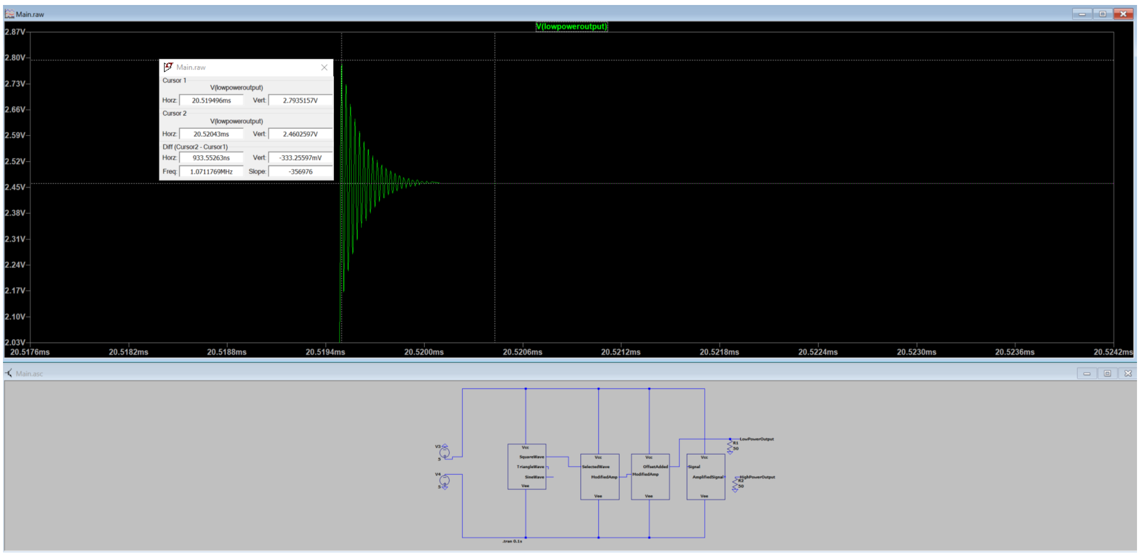

Figure 5: 50Hz Square Wave. Overshoot: 12%, Rise Time : 53ns

5.5 Triangle Wave

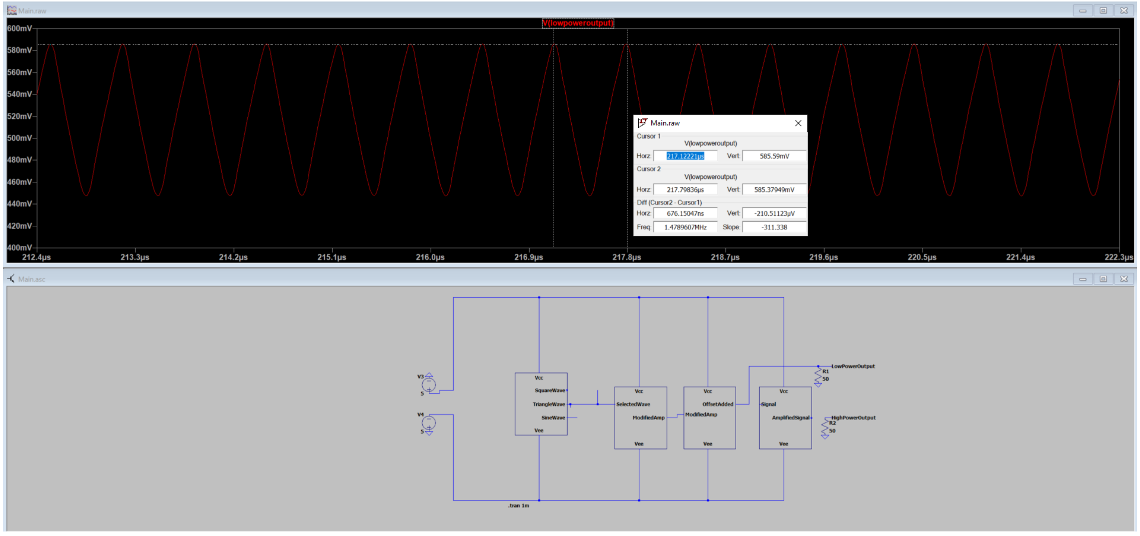

Figure 6: 1.5MHz Triangle Wave. Linearity: 4.9%

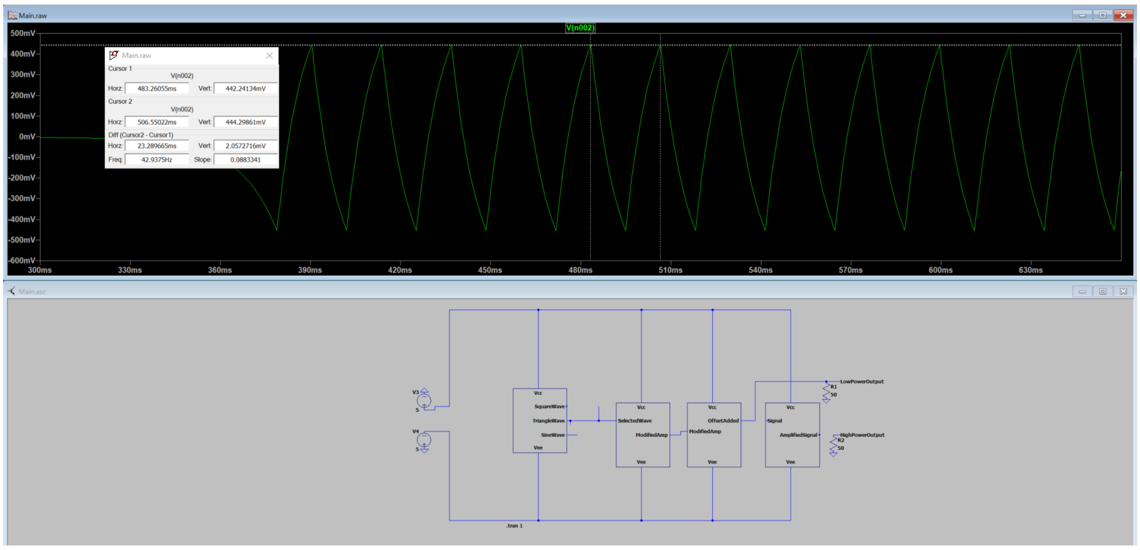

Figure 7: 43Hz Square Wave. Linearity: 2.2%

To measure the linearity the following method is used: connect a line from the peak to the trough of the signal. Measure the maximum error between the generated signal and this line. Linearity (%) = Maximum error/Amplitude. It is worth noting that this design satisfies 5% linearity up to 1.5MHz.

5.6 Sine Wave

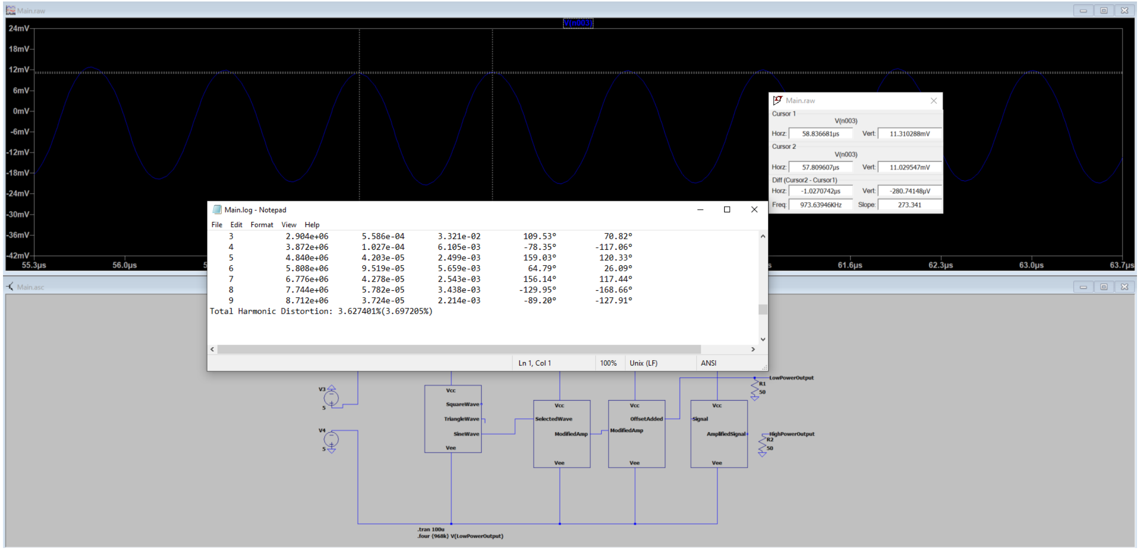

Figure 8: 1MHz Sine Wave. THD: 3.7%

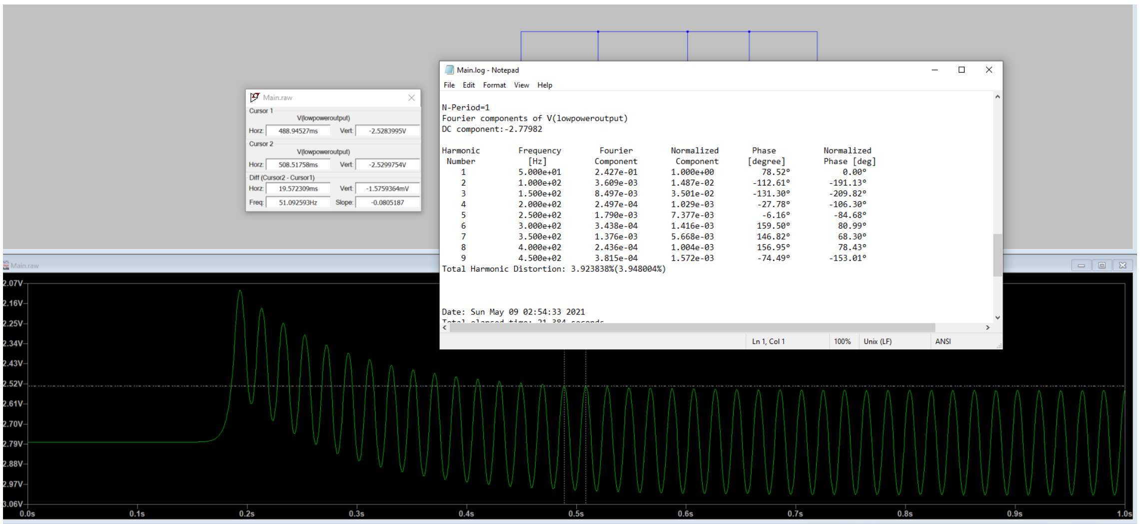

Figure 9: 50Hz Sine Wave. THD: 3.9%

5.7 Power Amplifier

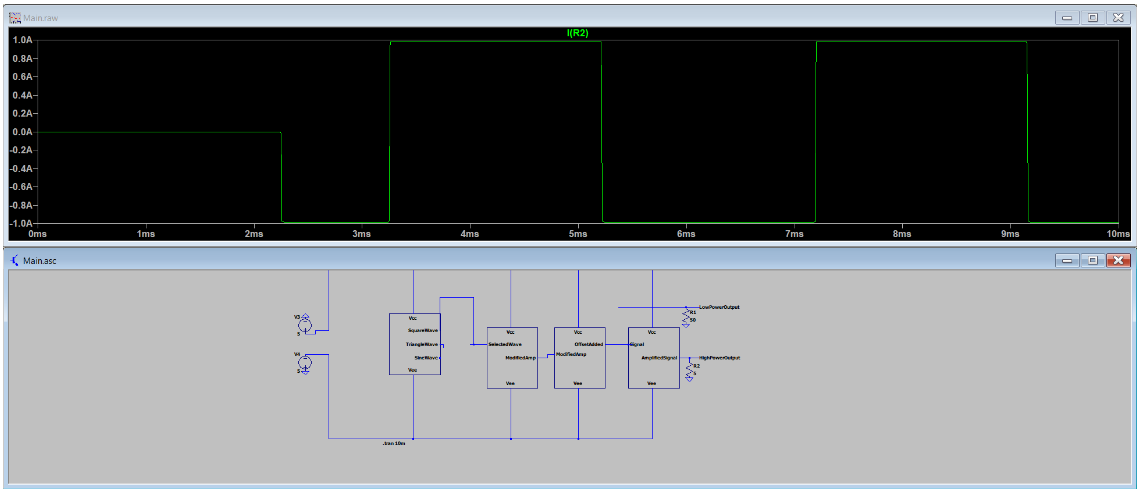

Figure 10: Able to generate 1A high power output

5.8 Power Generator

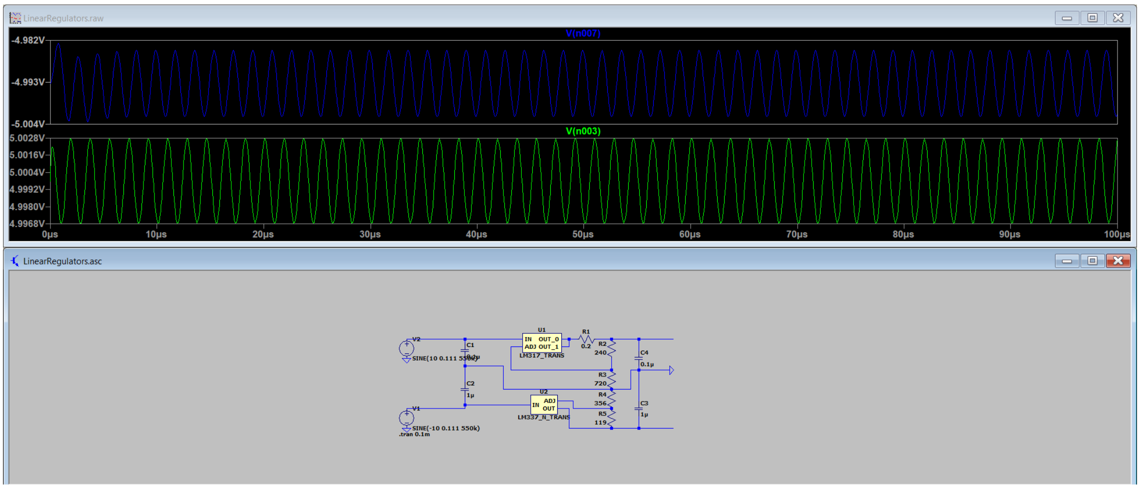

Figure 11: $\pm 5V$ rail with minimal ripple

The $+5V$ supply has 5.8mV ripple, while the $-5V$ supply has 17mV ripple.

6 PCB Overview

6.1 Layout

The board is extremely compact and efficient, with a board size of 110mm by 60mm. It has four layers, With all the components placed on the top layer for ease of access. This avoids potential problems arising from bottom layer components touching the bottom of the enclosure. The middle two places are ground and power. The components were placed in a logical way: power generation at the top, signal generation at the bottom. Single op-amp chips were chosen to allow for readability of circuit and wiring simplifications, at the expense of board space. All parts were placed according to recommendations from their datasheets.

6.2 Connectors

Wire connector parts placed close to edge of board to minimize parasitics and free hanging wire. There are two sets of BNC connectors involved in this design: One on board, one on panel. A short (3") BNC cable will connect the two planes. This allows for flexibility in taking the front panel on and off easily.

7 Power Plane

For efficient use of space and to reduce the number of vias (and thus its parasitics), the power plane shape has been precisely configured such that minimal power vias are required. This involved placing the op amps right at the edge of the power plane.

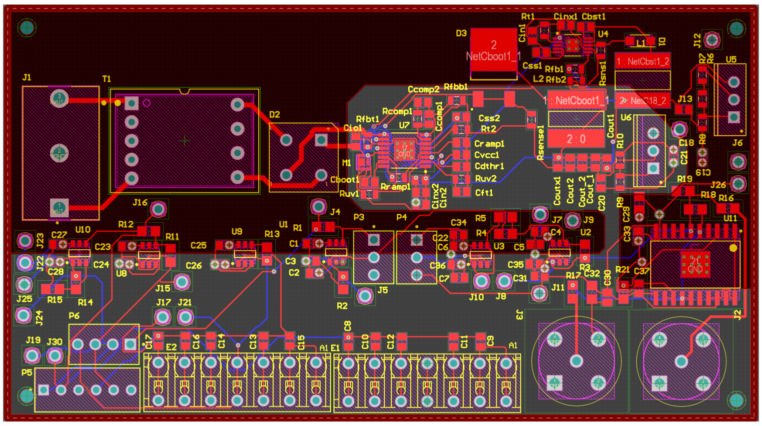

Figure 12: The -5V Plane (shaded gray)

7.1 Trace Widths

The trace widths leading up to the BNC connectors were set such that the impedance is 50 ohms. Traces dealing with signals coming from the wall outlet were also set to be thicker, so that it is able to handle higher voltages

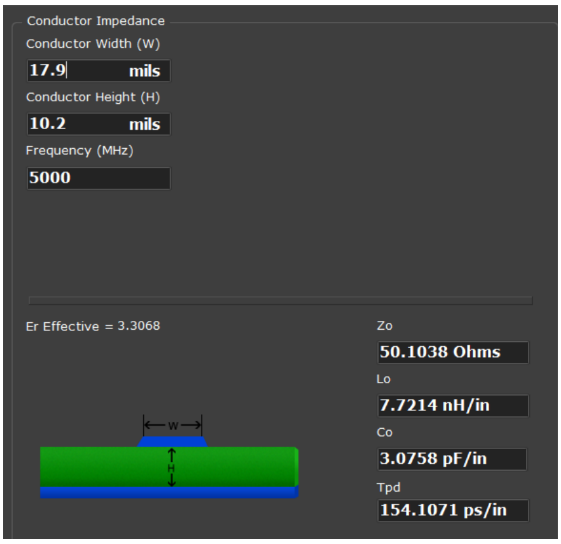

Figure 13: BNC trace width

8 Test Plan/Assembly

8.1 Visual Inspection

First, a visual check must be conducted to verity that there are no shorts and burns that occurred during fabrication.

8.2 Ohmic check

We must check the power planes and make sure that nothing is shorted. After doing an initial round of probing some of the +5V, -5V pads, install the testpoints. The power signals should have minimal ripple with a constant DC voltage as outlined below.

Test Point Number	Relevant Block	Goal Value (DC)
7	Offset Adder	+5V
22	Relaxation Oscillator	+5V
12	Linear Regulator	+5V
11	Offset Adder	-5V
23	Relaxation Oscillator	-5V
13	Linear Regulator	-5V
9	Offset Adder	0V
26	Relaxation Oscillator	0V
6	Linear Regulator	0V

Then a check of the important resistance and capacitance should be conducted. This is particularly important since this design involves dual gang potentiometers and DP switches. Before installing these parts, ensure that they work as intended by using a breadboard. Then, connect the panel mount parts to the connectors on the board. An ESR meter, which allows for capacitaces on boards to be measured, should be used to verify that the DP switch works as intended. In particular, the capacitance between J17 and J21 should match the capacitance between J30 and J24. A multimeter should then be sued to verify that the dual gang potentiometer works as intended. The resistance between J19 and J17 should match the resistance between J30 and J25.

8.3 Assembly

After the ohmic check all surface mount parts will be soldered onto the PCB. Then, front panel parts will be assembled as follows.

8.3.1 Front Panel Parts

12 gauge wires will be used to connect the panel mount potentiometers and switch to the circuit. 3cm pieces of these wires will be cut and soldered onto the solder lugs, then secured using heat shrink tubes. The other side of the wire will be crimped to a dupont connector. As for the power adapter, 18 gauge wires will be used, as recommended by the datasheet. It will be soldered to the solder lug and heat shrunk for protection.

Once all the parts are secured to the front panel, connect the dupont connectors to the appropriate pin headers on the PCB. Solder the 18 gauge wire to the Molex connector. Attach a very short BNC cable from the front panel BNC connector to the board BNC connector. Use heatshrink tubes to secure the connections. Then, attach the front panel to the rest of the enclosure using M3 screws.

9 Block Verification

Now we will verify some of the main block to verify that they are working as intended.

Action	Block	Desired Effect
N/A	SignalGenerator	J4 has 5V amplitude
Rotate “Amplitude” knob	AmpSelector	J5 is proportionately smaller than J4
Rotate “Offset” knob	OffsetAdder	J10 is a DC voltage between 0 and 5V
Rotate “Offset” knob	OffsetAdder	J8 = J10 + J5
N/A	TrianglePreAmp	J16 = 100 × J15
N/A	TrianglePreAmp	J15 is not sawtooth shape

9.1 Functional Verification

To test the THD of the sine waves, set the frequequency to the minimum 50Hz. Use an oscilloscope to probe each of the outputs (Normal mode, high power mode). Check the THD on the oscilloscope and verify that it is under . Repeat measurement for the maximum frequency, 5MHz.

To test the linearity of the triangular waves, set the frequency to the minimum, 50Hz. Use a commercial function generator to generate a triangle wave at the same frequency with the same amplitude. Use an oscilloscope to measure the error between the two signals and its percent ratio to the amplitude. Repeat measurement for the maximum frequency, 5MHz.

To test the rise time of the square wave, set the frequency to the minimum, 50Hz. Use an oscilloscope to measure the time it takes for the waveform to go from 10% to 90% of the final value. Repeat measurement for the maximum frequency, 5MHz.

9.2 PCB assembly

Lastly, M2 Brass standoffs will be installed to the PCB (971100244, Wurth Elektronik). Then the standoffs will be installed to the enclosure using four M2 bolts. There are four holes at the bottom of the enclosure for this purpose. Using these standoffs will allow for the board to be secured to the enclosure while preventing bottom traces from getting damaged.

10 Integration Plan

10.1 Front Panel

The front panel was designed on Front Panel Express. The panel is made of aluminum with milled holes for panel mount parts. Engravings are also made on the surface for ease of usage. The expected cost of this panel is $60

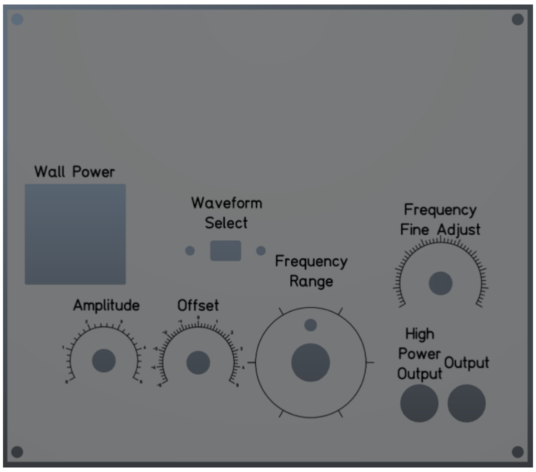

Figure 14: Front Panel

10.2 Enclosure

The enclosure is a box big enough to house the PCB. It has four holes for M2 screws to be used to attach the standoff at the bottom of the box. It also has four holes for M3 screws to be used to mount the front panel.

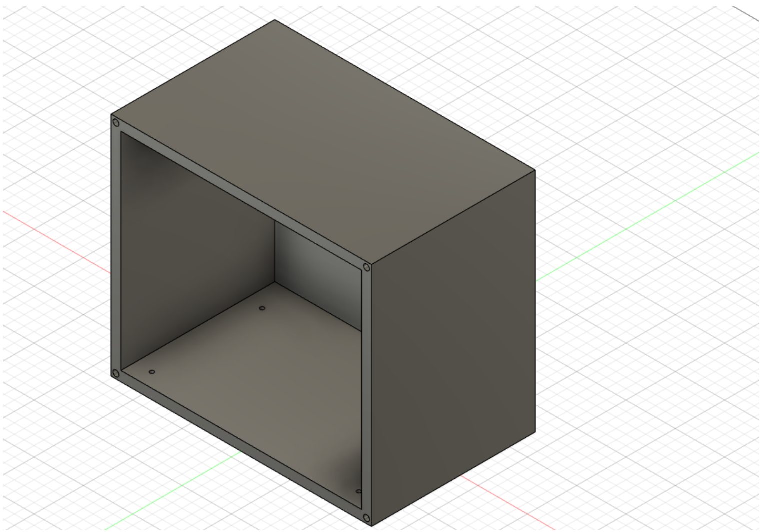

Figure 15: Enclosure

11 Operating Manual

To operate the function generator, first plug in power. Observe the output though an oscilloscope by connecting to either one of the outputs. The “Frequency Range” knob is a coarse selection of

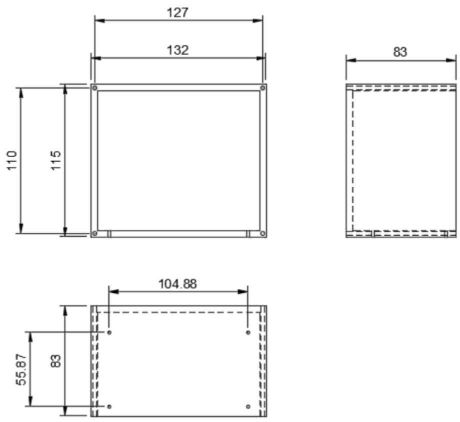

Figure 16: Drawing of Enclosure

frequency range. Rotate through until you are close to the desired frequency. Use the “Frequency Fine Adjust” knob to fine tune the frequency. Then, use the “Amplitude” knob to adjust the amplitude. Turning clockwise will reduce the amplitude eventually to 0. Turn the “Offset” knob to adjust the offset. This knob at middle position will have 0V offset. Turn clockwise for a positive offset, turn to the left for negative offset.

12 Bill of Materials

In addition to the BOM generated from Altium, the following were added to the BOM.

- 12 gauge wire spool
- 18 gauge wire spool
- dupont Connectors
- Heat Shrink Tubes
- M2 Standoffs
- M2 screws
- M3 screws
- Knobs (two different sizes)
- Panel Mount Components
  - Dual Gang Pot (P082D-27CBR10K)
  - 10k Pot (P164K101PNN20B103)
  - DP6T Switch (A20603RNZQ)
  - SP3T Slider Switch (L103012TS03Q)
  - Power Entry Connector(CD213598)

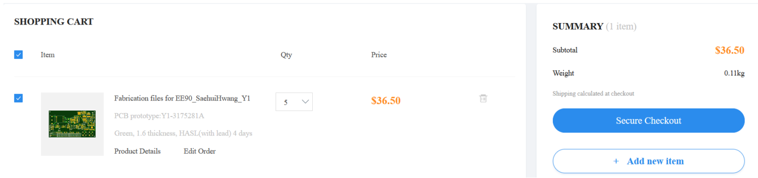

Figure 17: PCB Quote; Shipping approx. $10

Pos.	Quantity	Description	Unit price	Discount	Expedite fee	Total
10	1	Front panel Front Panel.fpd Width: 132.00mm, Height: 115.00mm, Thickness: 1.50mm, Material: Aluminum raw, Color: Natural	$59.77	0%	0%	$59.77

Figure 18: Front Panel Quote; Shipping approx. $10

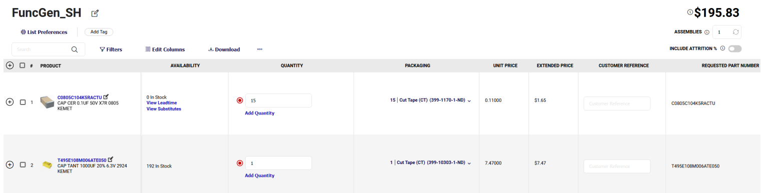

Figure 19: DigiKey Quote