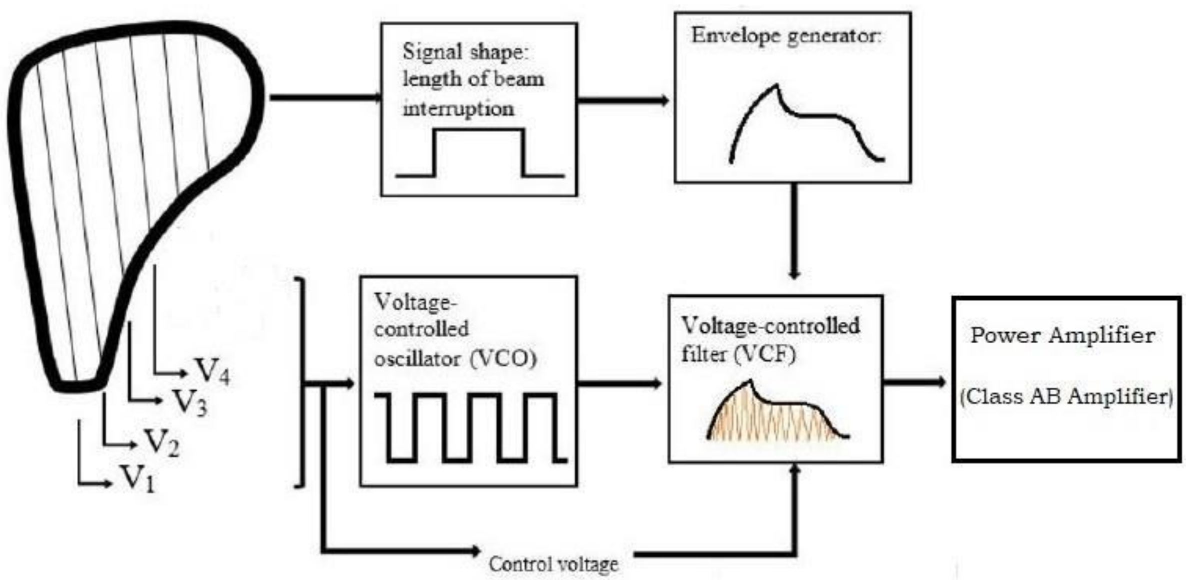
Laser Harp
Project Report

Introduction:

A laser harp is an electronic musical interface that replicates the functions of a harp, using laser beams as strings and analog circuitry to generate tones. Each harp string can be played by passing one's hand through the laser beam to disrupt it, reducing or eliminating the incident light on the LDRs. This will trigger the audio synthesizer to play a tone of the frequency corresponding to that particular harp string. Lastly, an audio amplifier will boost the tones produced by the synthesizer for a louder output signal.

This project was designed in two methods. The details and competency of both methods will be discussed briefly in this report.

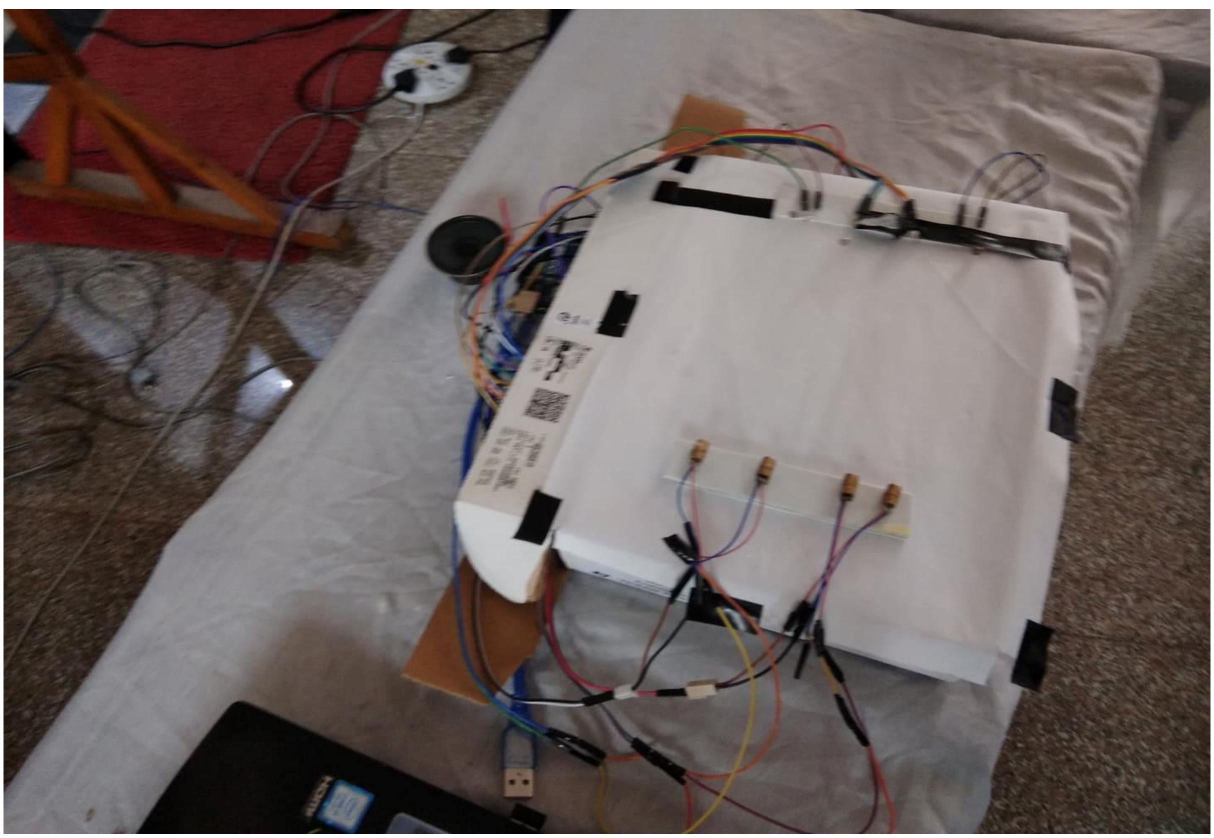


Method 1: Arduino Laser Harp

At the beginning stage of this project, it was decided to tackle the problem the easier way i.e. with the help of a microcontroller. Arduino UNO was chosen as the main component, which performed majority of the tasks taking in very simple instructions to do so.

4 Laser Diodes (5 V , 650nm, 5mW) were connected to the 5V pin of the board. The laser light from these was directed onto an array of LDRs. A voltage divider was formed using the LDRs and 1k Ohm resistors and the node voltage was sensed at the analog input pics of the microcontroller. Based on the voltage that was received by the board, simple instructions were written in the form of a code which instructed the board to play a tone of a given frequency for a fixed duration. The voltage response from the dividers was connected to 4 different pins hence allowing the board to distinguish between different lasers. 4 distinct tones were thus produced each corresponding to one of the lasers.

The main function in the project was tone() of the Arduino library. This is an Advanced IO function. This link describes the function in detail. The Arduino version of the project is shown below. The code for this project can be found here.



Challenges and Improvements:

Main challenge in this method is the calibration of the sensor response in the Arduino. At different locations with different intensities of external lighting, the sensor response value received by the Arduino changes. This can be tackled using a construction where the LDRs are safe from external lighting and the light from Laser diodes is the only light, which falls on each of them. Other solutions include the usage of Ultrasonic sensors to play the music based on distance from the sensor.

Using an Arduino to make a synthesizer is a very simple task. To make things interesting, we decided to design a Music Synthesizer using discrete analog components like opamps, resistors, capacitors and transistors.

Method 2: Analog Laser Harp

As mentioned before, the project consists of 3 sub-systems:

Laser Interface

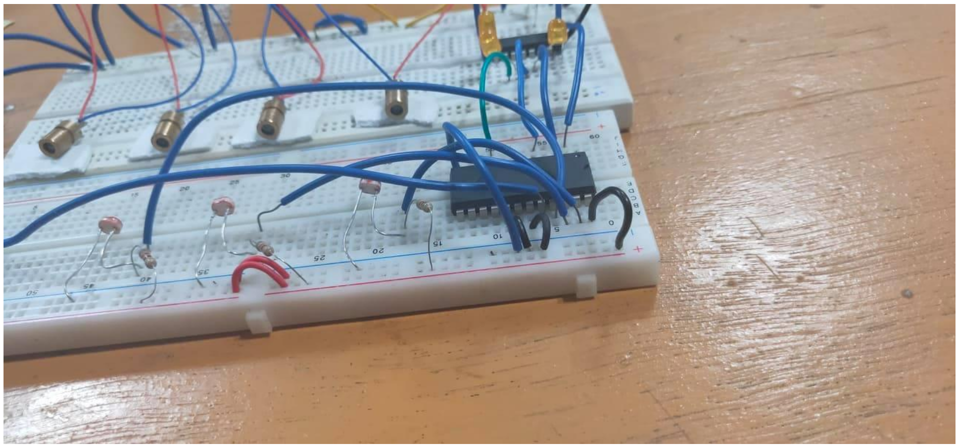
The harp interface and the overall design of connecting the action of hitting a laser beam and tone generation is by nature a more digitally inclined circuit. As such, the circuits behind it use digital signals, versus a more analog approach, because there was no need for an analog approach.

IC74154 i.e. 4x16 Decoder was the main block used for linking the strings. The laser light falling on the LDRs produced a voltage. A voltage divider was made with LDR and 1k ohm resistor such that the generated voltage lied between 0 and 5 V. These voltages from 4 different string outputs were connected to the 4 inputs of the decoder. The output from the Y1,Y2,Y4 and Y8 was then passed through a NOT gate (IC7404) because the decoder gave active low outputs. From here, the four signals were sent to four different voltage dividers, which would generate a fixed control voltage corresponding to each string. The control voltages would then be used in the further modules.

Each voltage divider output sums into a single node through a diode, preventing backflow of the voltage into the other voltage divider outputs, which could pull a desired signal to ground or to some other voltage.

The main reason for the working of this kind of setup is due to the Static discipline of digital logic. The digital circuits used here have good noise margins. With the help of a proper voltage divider setup at the LDR part, the circuits maintain their discipline. Even though this does not look like a robust solution, it works perfectly in all kinds of environment with different lighting.

The harp interface in picture is shown below.



Tone Synthesizer

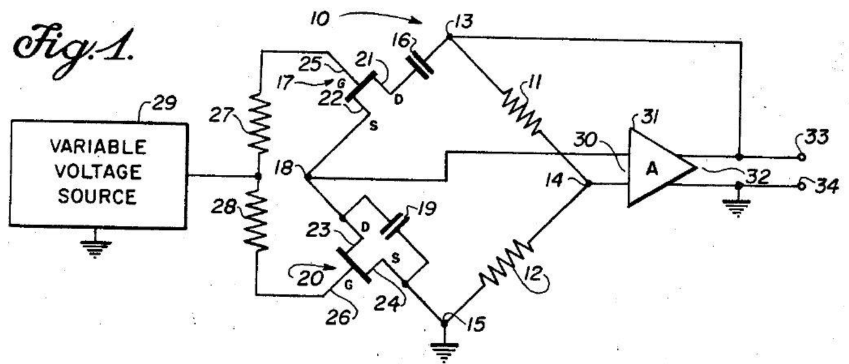
At the heart of the problem is the challenge of processing a signal from any given string and generating a waveform with the predetermined frequency, corresponding to the string's pitch. This was accomplished by implementing a voltage-controlled oscillator. Additional systems were designed such as a voltage controlled filter, amplitude modulator, a low frequency oscillator and an envelope generator which will be discussed later.

Voltage Controlled Oscillator:

The designing of VCO was the most challenging part of the project. There were numerous ideas that came to my mind while thinking of such an oscillator whose frequency can be controlled by the control voltages generated by the first module.

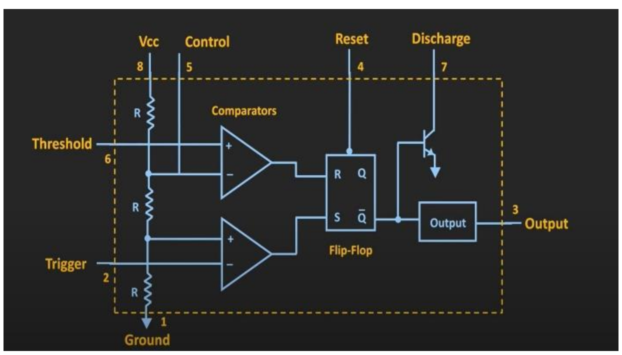
Voltage Controlled Wein Bridge Oscillator –

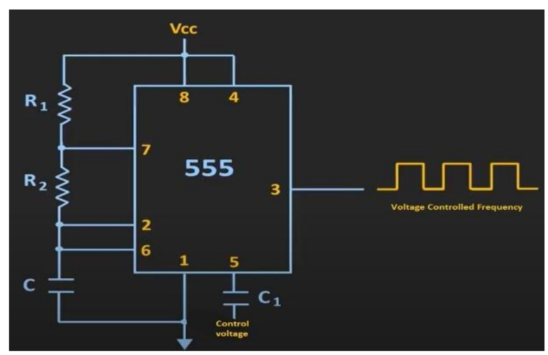
The figure clearly shows how the circuits works. The variable voltage source is our Laser interface module, which sends controlled voltages. The FETs resistance changes according to the gate voltage applied. The FET is operating in the Linear/ triode region.



555 VCO-

This is a very famous circuit. IC555 is known to generate clocks for digital circuits. Here, we tried to implement a VCO using 555. The circuit design is very straight forward; there is no problem of biasing or other analog type issues. The only problem was that the output was a frequency controlled square wave (not sinusoidal).
The usual Astable Multivibrator circuit of 555 was tweaked to get a VCO.





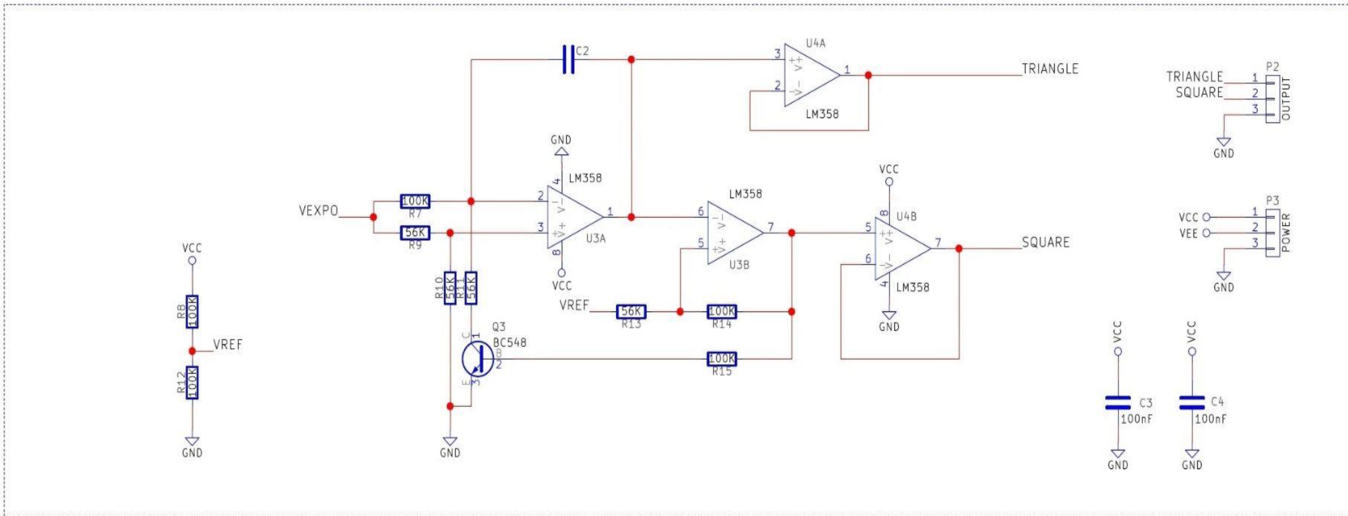
Precision voltage-controlled waveform generator-

A very clever circuit borrowed from the application notes of several manufacturers. The circuits consists of 4 parts:

1. Integrator
2. Inverting Schmitt Trigger
3. Reset circuit (feedback through transistor)
4. Buffer for output

The detailed working can be explored [here](#).

VCO



Additional Systems:

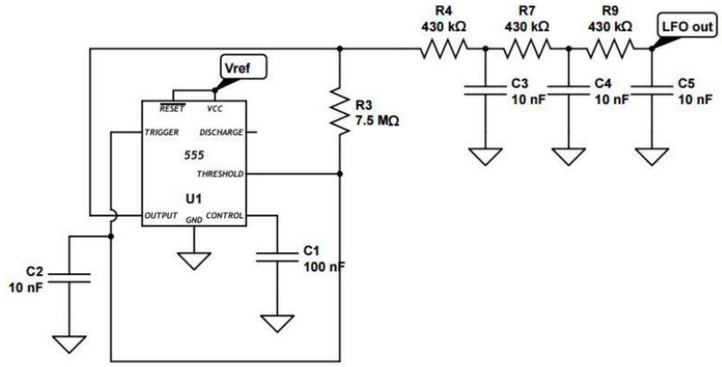
Low frequency oscillator –

An added effect that we were able to integrate was the addition of a low frequency oscillator. Our LFO produces a 10 Hz approximated sine wave that is added to the linear control voltage. This second signal attenuates the control voltage up and down which the VCO then generates into a tone with small oscillations in frequency. To the ear, this sounds like a tremolo or vibrato that moves around the fundamental frequency of the note.

An elegant approached to this is a single 555 timer circuit that produces a 10 Hz sine wave. By configuring the timer in astable mode, the timer becomes a fast switching oscillator that produces a square wave as long as V is on. The frequency of this oscillation is set by the RC pair present at the threshold pin.

$$F = 1/(2\pi RC)$$

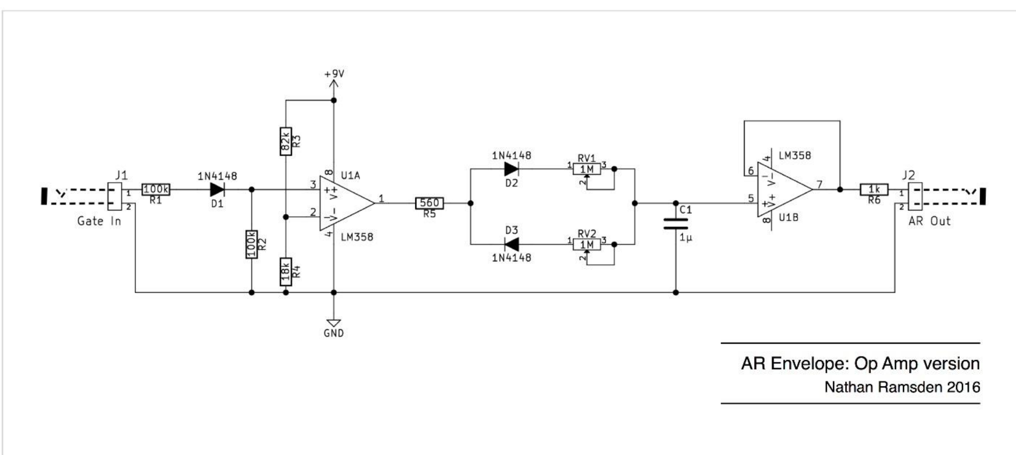
Appropriate RC relationship will achieve around 10 Hz, as well as some additional passive filtering is done to approximate the wave shape as more of a sine wave.

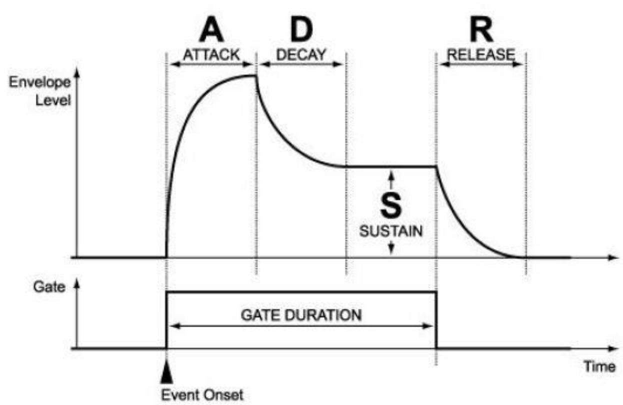


Envelope Generator and Amplitude Modulator-

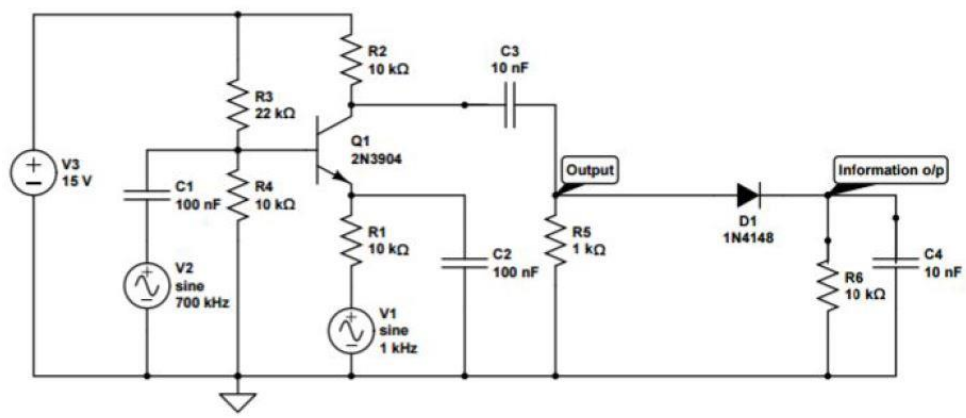
The envelope generator creates an envelope, which has a varying amplitude, which is used to control an amplitude modulator, described in the following section, in order to integrate the envelope shape with signal output of the voltage-controlled amplifier. The figure below depicts the ideal shape of the envelope generated, with an ADSR form, standing for an attack, or initial pluck of a string, the decay of the note, the ringing sustain of a note, and an eventual sustain, and release of the note into silence. The envelope would add a more realistic sound to each note being generated by the voltage-controlled oscillator.

We made a simple AR envelope generator for this project.





The recommended method of integrating the envelope shape with the signal output was voltage controlled amplifier that worked as an amplitude modulator. This would take both the signal and the envelope and scale the signal by the magnitude of the envelope.

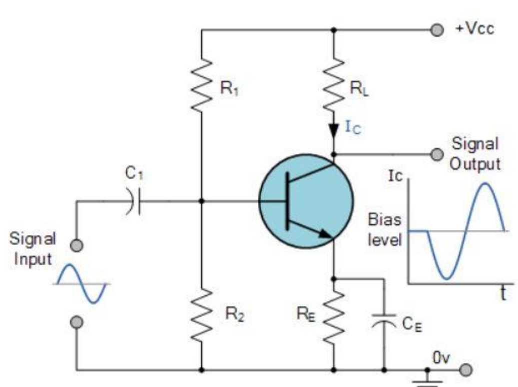


Voltage Controlled Filter-

This circuit was part of the plan but wasn't built due to lack of time. We plan to work on it once we get back to the institute.
Such a filter whose cutoff frequency can be controlled by a fixed voltage is very essential to design a complete synthesizer. Things can work without this module, but the VCF is important if one wants to hear a clean sound. The design for this will be based on Moog Filter.

Amplifier Module

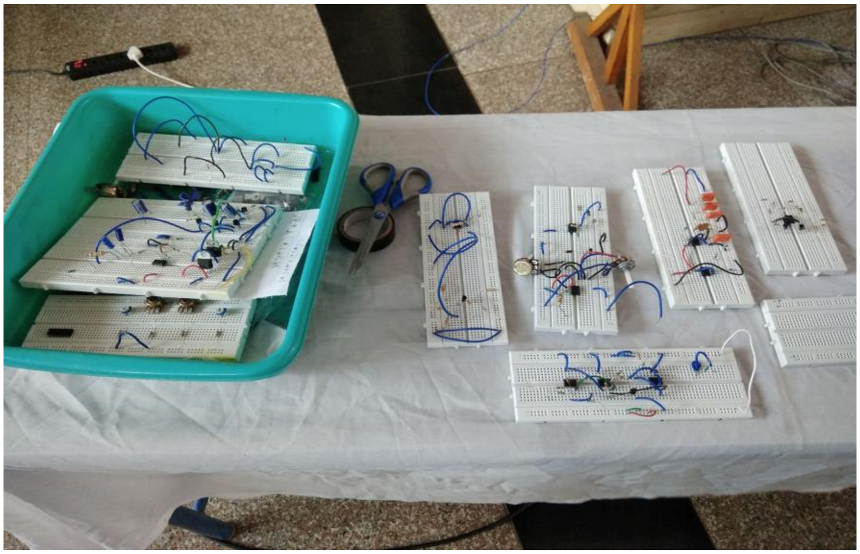
This module simply consists of a simple single stage BJT amplifier. We plan to extend this circuit to Class AB and Class D power amplifiers.



Implementation and Results:

Due to the Corona Virus Pandemic, the entire project couldn't be completed. Individual modules were tested and demonstrated in front of officials. The results are the following-

1. The Laser Interface worked perfectly in all environments. LEDs were used to test the output of the interface. 4 different voltage dividers were constructed and connected to get controlled voltage. The first module was complete and perfect.
2. The 3rd and final module was also tested. A simple CE amplifier was constructed and the output was tested both on an oscilloscope and a speaker. The signals were provided using function generator.
3. Synthesiser module is still a work in progress module. The VCO, envelope generator, amplitude modulator and the low frequency oscillator were tested separately; all yielding convincing results. The picture below shows all the modules separately.



Conclusion:

Integration of the subsystems is going to be fairly simple due to the fact that the system is designed to be highly modular. A majority of the challenges faced were the result of physical non-idealities in the devices being used. As a result, we all experienced valuable technical growth by frequently being challenged to understand theoretical expectations for our signals, identify causes of distortion, and devise robust solutions.

It is our goal to put all of our circuitry on PCBs and to rebuild a harp that is more aesthetically pleasing. We are excited by the range of possibilities that this particular analog circuit is capable of achieving, and we believe it would be incredibly rewarding to see our complete vision come to fruition. As engineers, it is vital to recognize what is feasible to achieve within the time allotted, but seeing as how we were very close to implementing a number of additional effects, it seems worthwhile to revisit this project in the future.

This project was inspired from the MIT 6.101 Course Project of 2017 – Laser Harp 2.0.