Lab 2: Critical Design Review

Team 5.0

EE300W Section 006L Position 5

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Abstract

Team 5.0 built an Optical Theremin that implements auto-tune and equalizer functions. Two OPTEK OP906 photodiodes were used to control frequency and amplitude levels of sound output. Ambient light intensities measured as leakage currents by the photodiodes were converted to voltage signals using transimpedance amplifiers with 10MΩ feedback resistors. The signals were fed to LabVIEW as analog inputs using NI MyDAQ. Auto-tune and equalizer functions were coded as sub-VIs using LabVIEW. The auto-tune feature adjusts sound output to the nearest octave while the equalizer boosts the treble, mid-tone, or bass as determined by the user. MyDAQ was used to output a signal determined by LabVIEW to external speakers.

Introduction

Optical Theremins are musical devices that are operated without being touched by the musician. The device is a fascinating novelty that outputs a sound with controllable amplitude and frequency. In an implementation of an optical theremin, ambient light from the environment must be measured and processed by hardware into a useful data stream that is interpreted by software, which relates variances in the input to variances in a musical tone output produced by speakers. Constrained to the use of photodiodes and operational amplifiers, the production of a cheaper alternative to more traditional devices is realizable. An additional benefit of this design beyond cost savings is that the control mechanism is impressive and intuitive for a person without a background in electrical engineering. This allows the device to engage young people and help them to become interested in the field.

Rationale

Though traditionally controlled by antennae or oscillators, alternative models may utilize photodiodes to relate ambient light to such variables. This allows for a design that realizes significant cost savings and simplification over alternative methods. However, a tradeoff is involved whereby the new design is significantly less robust to physical damage. This parameter may be improved with additional engineering work.

Our optical theremin design utilizes two photodiodes connected individually to operational amplifiers (op-amps). Feedback resistors are used to complete the symmetric transimpedance amplifier circuit whereby op-amp output voltage will vary based on ambient light incident upon the photodiode controls. This is due to the diode's leakage current dependence on light exposure. The leakage current is then converted to a voltage signal through the transimpedance amplifier by the feedback resistor in order to meet the hardware design project requirement. We calculate the value of the resistor to be 10 MΩ using Ohm's Law:

$$V_{out} = -I_{in}R$$

Each half of the symmetric circuit controls one optical theremin sound output parameter. One side controls amplitude, and the other controls frequency. The op-amp outputs are connected to the NI MyDAQ analog input channels. Once analog signals are inputted to the NI MyDAQ, a LabVIEW program utilizes them to control theremin output directly. To ensure myDAQ can run properly, the amplitude and frequency of the output were normalized. The normalization equation for amplitude is:

$$A_{normalized} = (A_{in} - A_{min}) \div (A_{max} - A_{min})$$

The normalization equation for frequency is:

$$F_{normalized} = F_{min} + (A_{in} - A_{min}) \div (A_{max} - A_{min}) \times (F_{max} - F_{min})\ .$$

DAQ Assistant Settings and Observations

Inputs	Outputs
Output data channels:	Input data channel:
Voltage0	VoltageOut
Voltage1	
Signal Input Range: [0V, 10V]	Signal Input Range: [-2V, 2V]
Acquisition Mode: Continuous	Acquisition Mode: Continuous
Samples to Read: 200	Samples to Read: 400
Rate: 1000Hz	Rate: 1000Hz

Implementation

Block Diagram

The initial block diagram we design is shown in figure 17. We constructed each step we need for both hardware and software and finished this lab following this guideline.

Physical Circuit Design

As shown in Figure 1, for each transimpedance amplifier, we used a 10 MΩ resistor, an OP906 photodiode, and a TL074CN operation amplifier. A photodiode generates a leakage current which is proportional to light intensity. The current is converted to a voltage signal using the transimpedance amplifier. The output signals from the circuit are connected to MyDAQ and become the inputs for LabVIEW part. From our measurement, the output voltage from the circuit ranges from 100 mV to 4.85V, which is suitable for MyDAQ to read. The physical circuit implementation is shown in Figure 2.

LabVIEW Design

Overview

As shown in Figure 3, our LabVIEW mainVI reads signals from the physical circuit and separates them into frequency and amplitude signals. Then, frequency and amplitude normalizer subVIs normalize these two data according to a normalization equation. Users can choose to use auto-tune to adjust the frequency or not to determine whether normalized frequency go through auto-tune subVI. Then normalized frequency combines with normalized amplitude into a sine signal. After simulating the signal, the combined sine signal passes through an equalizer, which allows users to control bass, mid-tone, and treble separately. A front panel indicates selected equalizer setting with LED indicators and also shows the waveform reflecting the setting. A block diagram lets users input sound files and control the equalizer to alter the sound.

Main VI Part 1 (Figure 4)

Figure 4 shows the input signal of the mainVI. In this part, the DAQ Assistant receives the input signal and separates frequency and amplitude with Split Data Express VI. Then we take the mean and absolute value of the signal to reduce errors and indicate the value on the front panel. Those data are divided by ambient light calibration to calibrate before we use them. Normally we will set the value to 1 unless the intensity needs to be manually amplified. After calibration, the frequency signal is multiplied by a pitch control, and the amplitude signal is multiplied by volume control. This functionality gives users options to control pitch and volume from the front panel without using photodiodes.

Main VI Part 2 (Figure 5)

As it is shown in Figure 7 and 8, frequency and amplitude are normalized at this part. A frequency normalizer, a red subVI, takes the set maximum and minimum values of frequency and amplitude and an input frequency value as inputs. For an amplitude normalizer, inputs are the set maximum and minimum values of amplitude and an input amplitude value. In the subVI, we use a normalization equation to calculate a normalized value. Another subVI in this diagram is for auto-tune function. Users can choose if they want to enable the auto-tune feature. The function of auto-tune is to adjust the frequency of input signal automatically to match the octave pitches. The detailed design of auto-tune with actual frequencies for an octave is shown in Figure 9. The normalized values are combined into a sine wave in simulate signal VI.

Main VI Part 3 (Figure 6)

Referencing to Figure 6, a path and read file VI let users input sound files, and users can choose to use the signal from the optical theremin circuit or their own files for the input. Figure 10 shows the equalizer, which allows users to control bass, mid-tone and treble settings from the front panel. While the equalizer settings can change in live, LED indicators let users know the current setting. It also produces a power spectrum and equalizer waveform to demonstrate the change in output sound signal according to the selected setting.

DAQ Assistants Setting

Two DAQ Assistants are described in our schematic. One is used to acquire data and one to output data. The first is used in mainVI part 1. It receives an input signal from the optical theremin and generates a sine wave signal that consist of frequency and amplitude. Figure 11 shows the setting of input DAQ Assistant. After several trials, we set the acquisition mode to continuous samples, samples to read, 200, rate, 1kHz, signal input range from 10 volts to 0 volts.

The second DAQ Assistant outputs the signal to myDAQ which will produce audio from it. We received error messages saying that the frequencies received had to be equal or less than half the sampling rate, violating the Nyquist Sampling Rate requirements. Figure 12 shows the final setting that we get after many attempts: acquisition mode to continuous samples, samples to write, 20k, rate, 44kHz, signal input range from 2 volts to -2 volts.

Value Statement

The optical theremin is beneficial because it relates science and the arts in a low cost and accessible manner. This is useful from a didactic perspective because it can help relate the seemingly unrelated interests of young people who have yet to grasp the interrelation of all academic disciplines. A person who is very interested in music can explore this device and an interest in electronics may be sparked. This device can engage the public and be used as an outreach tool.

Conclusion

An optical theremin was successful realized under the constraints of using two photodiodes and an op-amp configuration. Using a transconductance amplifier configuration, a photodiode was converted into an analog signal, which was then processed using LabVIEW to produce the desired output sound. Several design changes occurred throughout the process. Initially, Team 5.0 used feedback resistors 1 MΩ. After testing the design, this configuration was found to not produce a large enough output voltage at the analog input MyDaq terminal. Through trial and error, it was determined that a 10 MΩ feedback resistor produced the desired signal, which was then verified theoretically using Ohm's Law.

Appendix I: Hardware

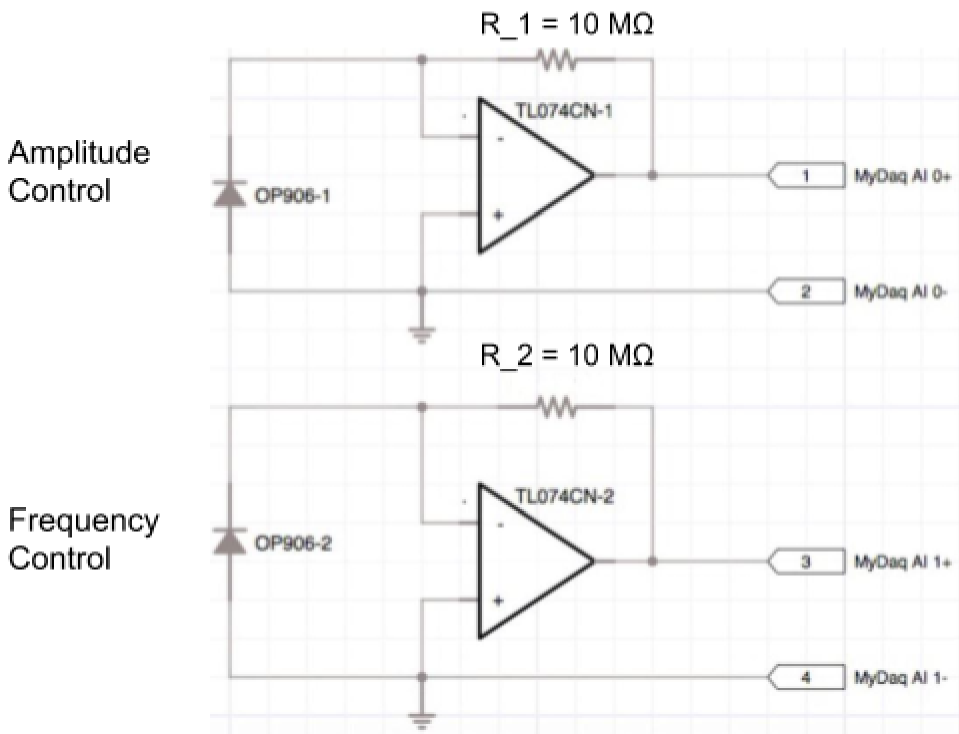

Figure 1: Circuit Design

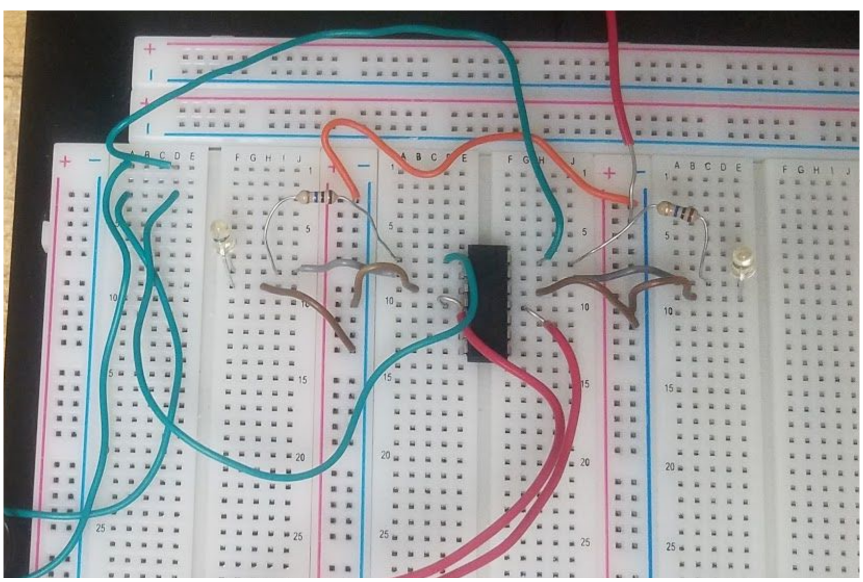

Figure 2: Physical Circuit Implementation

Appendix II: Software

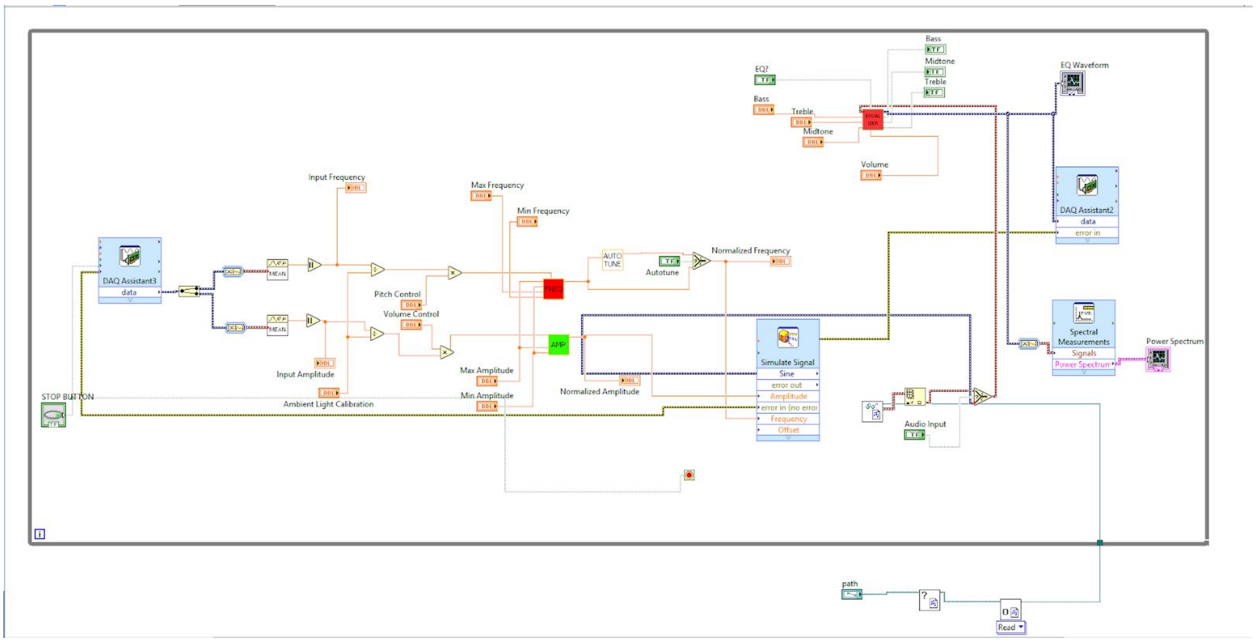

Figure 3: MainVI Block Diagram

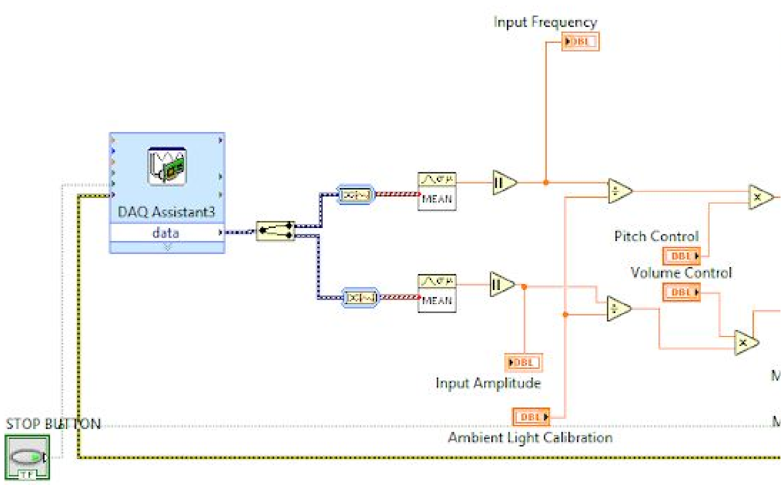

Figure 4: MainVI Part 1

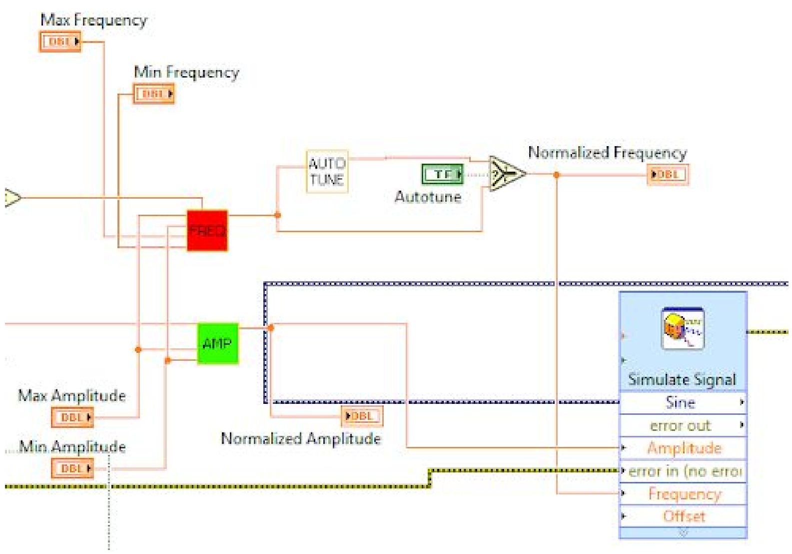

Figure 5: MainVI Part II

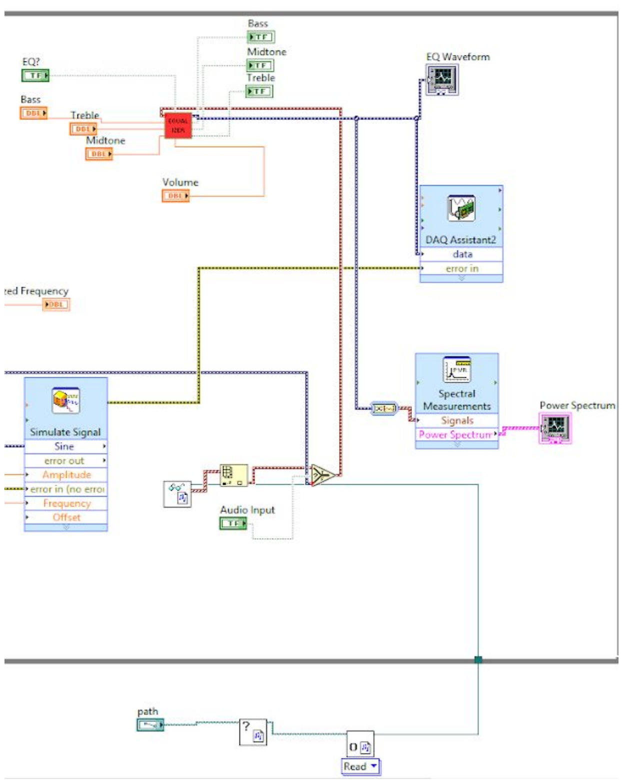

Figure 6: MainVI Part 3

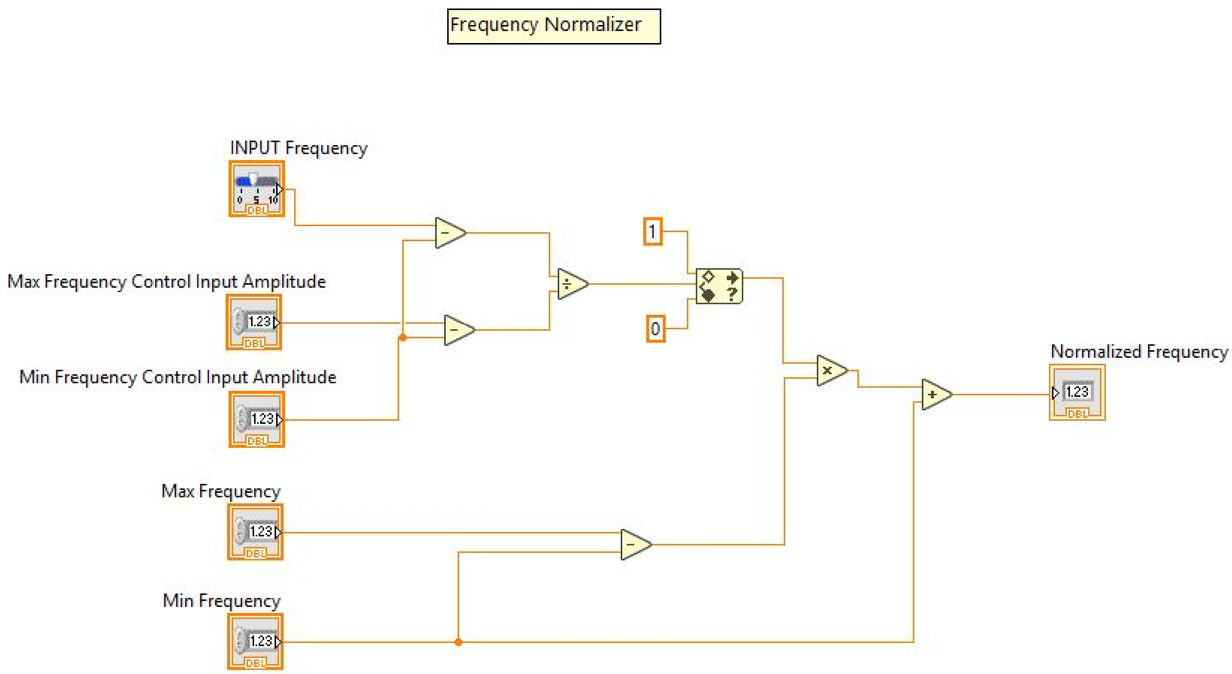

Figure 7:Frequency Normalizer SubVI Block Diagram

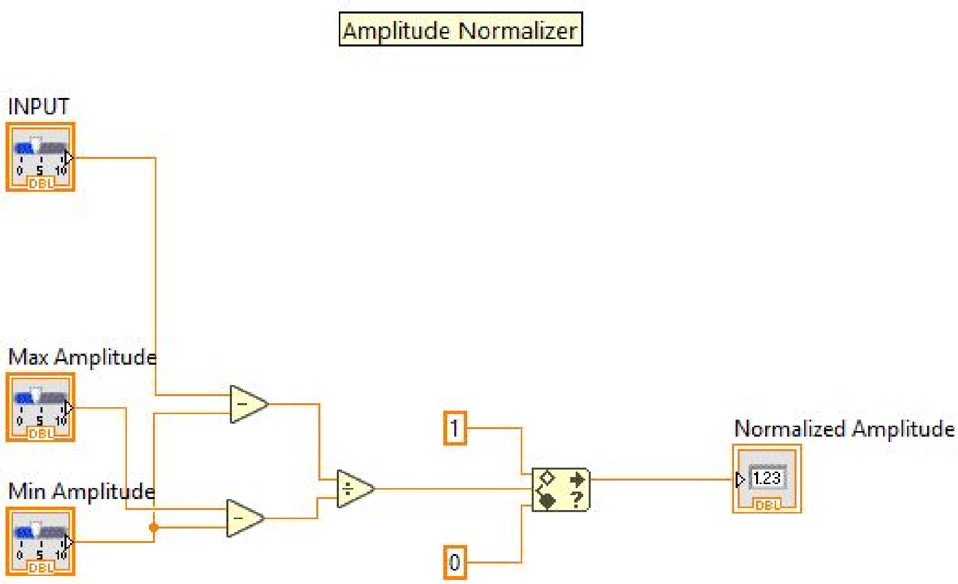

Figure 8: Amplitude Normalizer SubVI Block Diagram

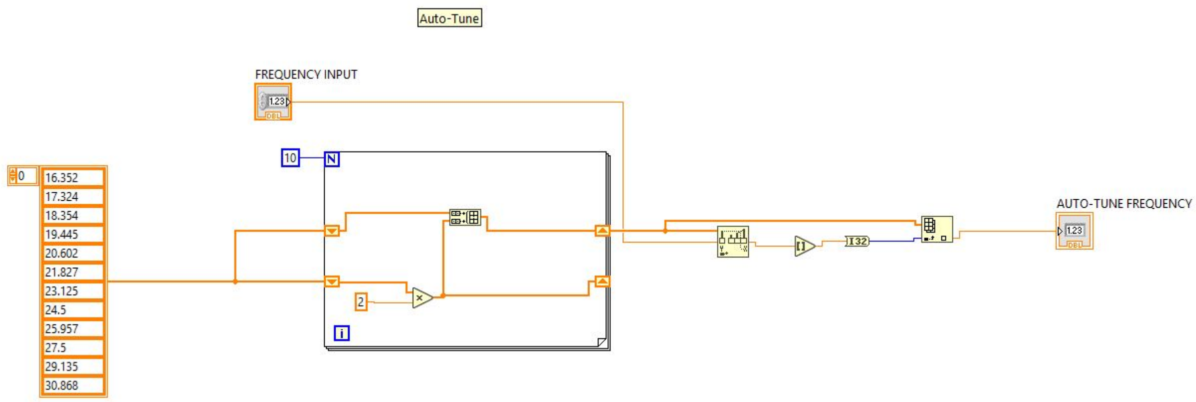

Figure 9: Auto-Tune SubVI Block Diagram

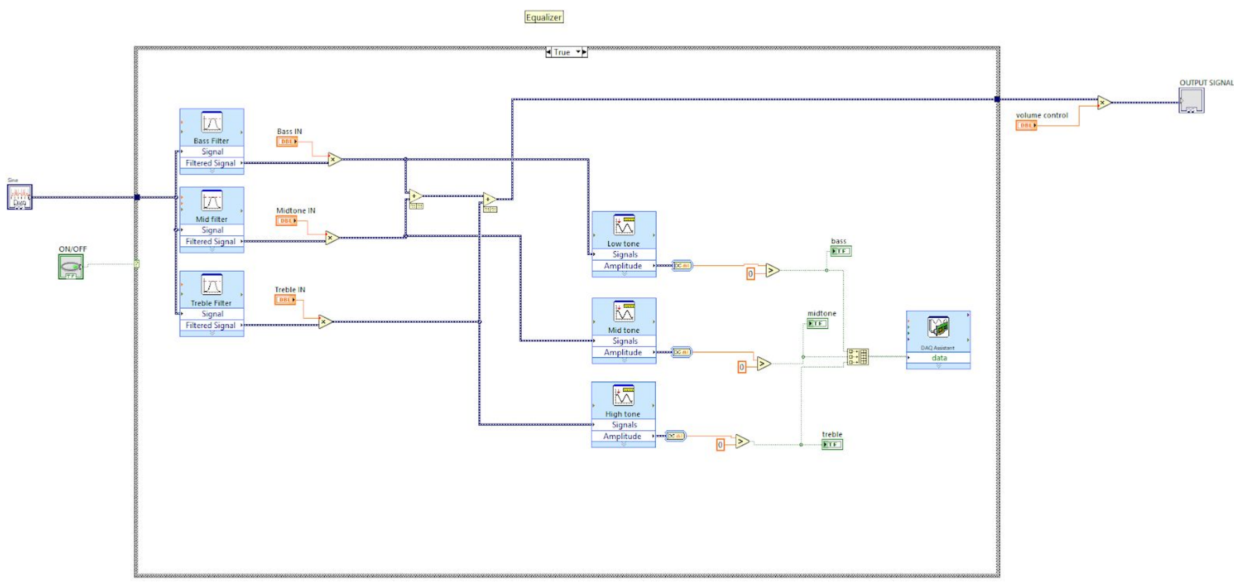

Figure 10: Equalizer SubVI Block Diagram

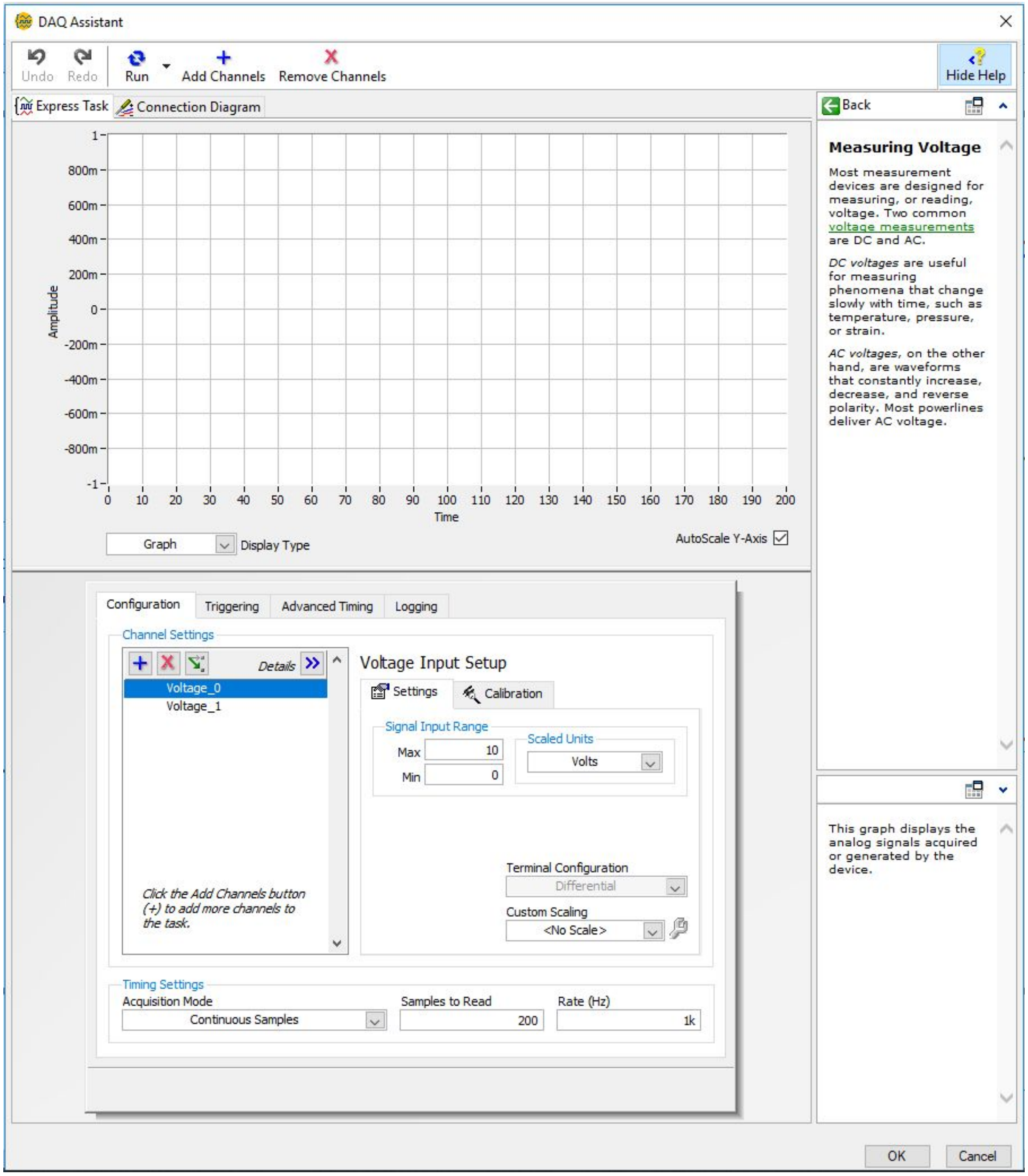

Figure 11: DAQ Assistant Input Settings

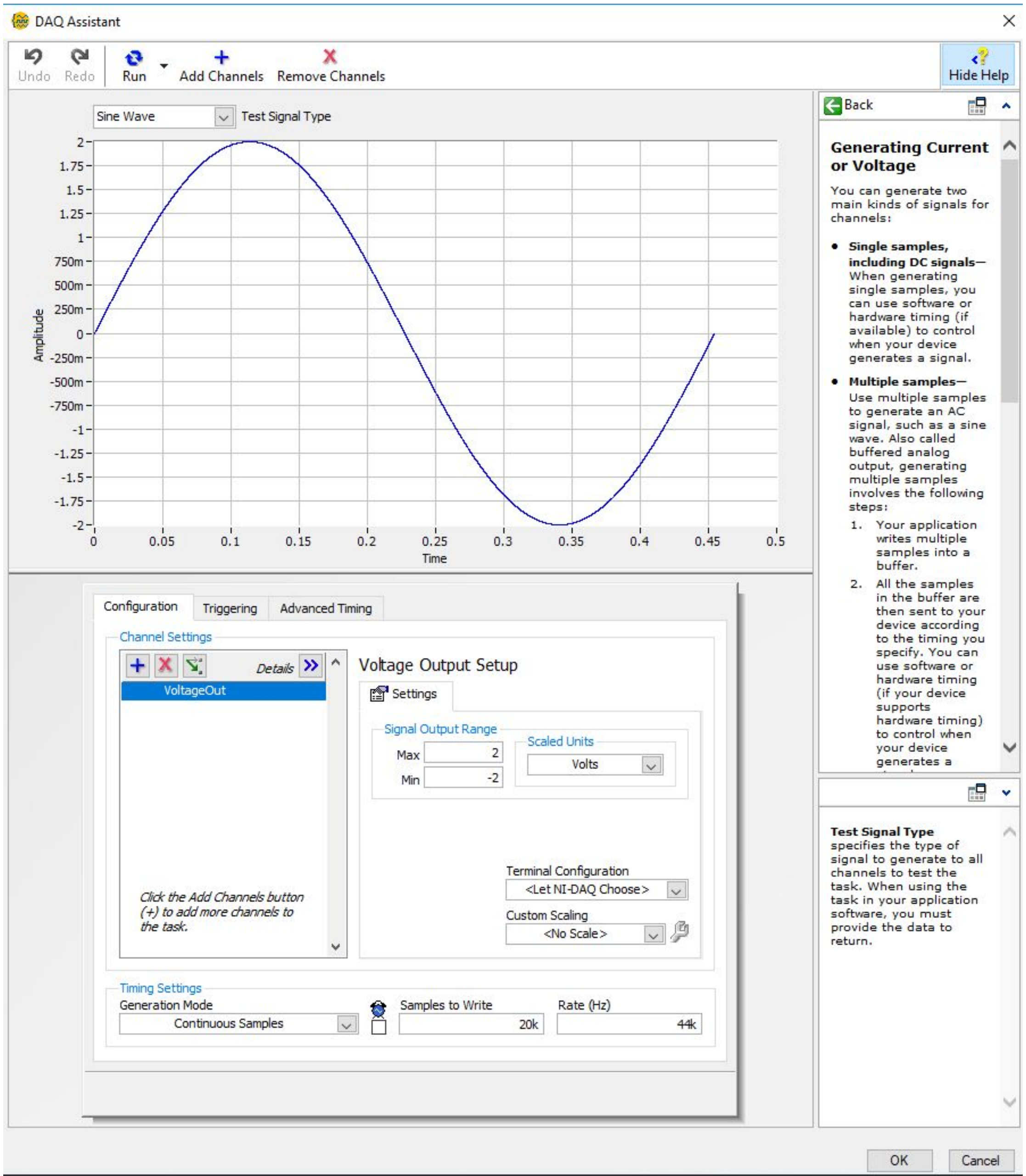

Figure 12: DAQ Assistant Output Settings

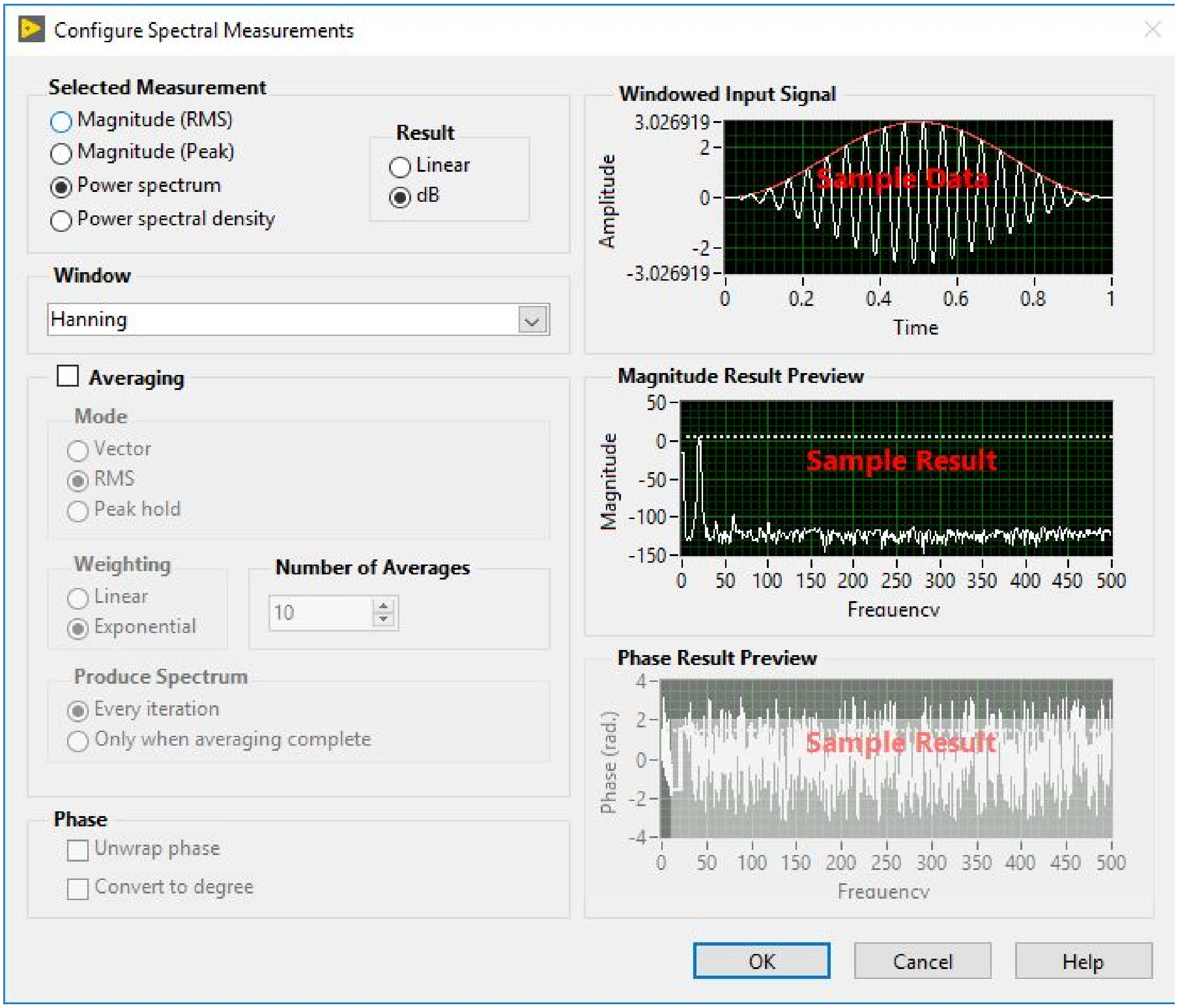

Figure 13: Spectral Measurements Settings

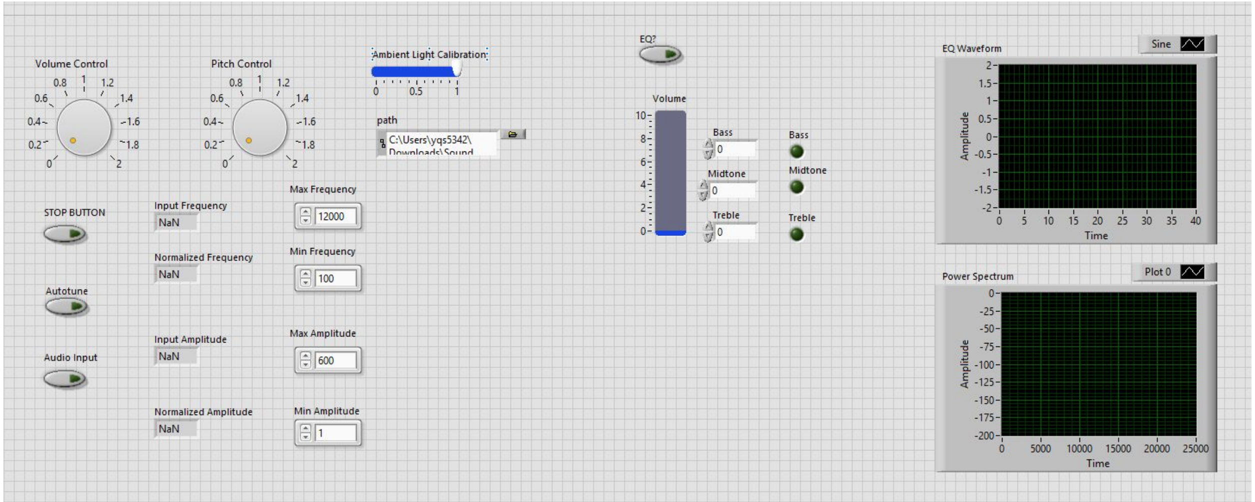

Figure 14: LabVIEW Front Panel

Appendix III: Bill of Materials

Material	Quantity	Cost per Unit (USD)
OPTEK OP906 Photodiode	2	0.60
TI TL047CN Operational Amplifier	1	0.064
10 MΩ Resistor	2	0.01
Breadboard	1	5.99
NI MyDAQ	1	200.00
Logitech Stereo Speakers	1	9.99
Total Cost	-	217.26

Figure 15: Bill of Materials

Appendix IV: Gantt Chart

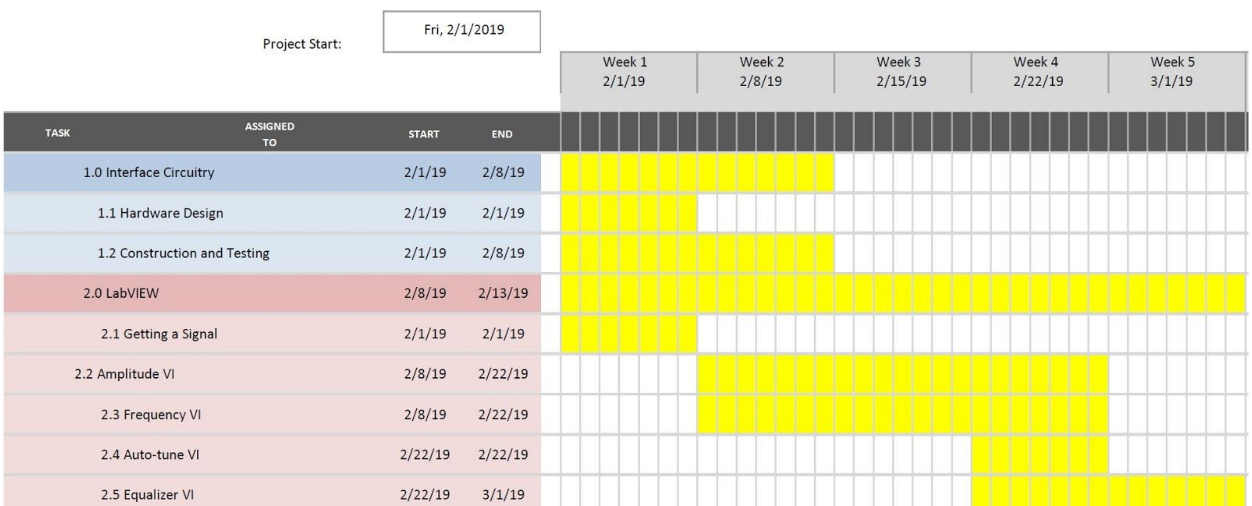

Figure 16: Gantt Chart

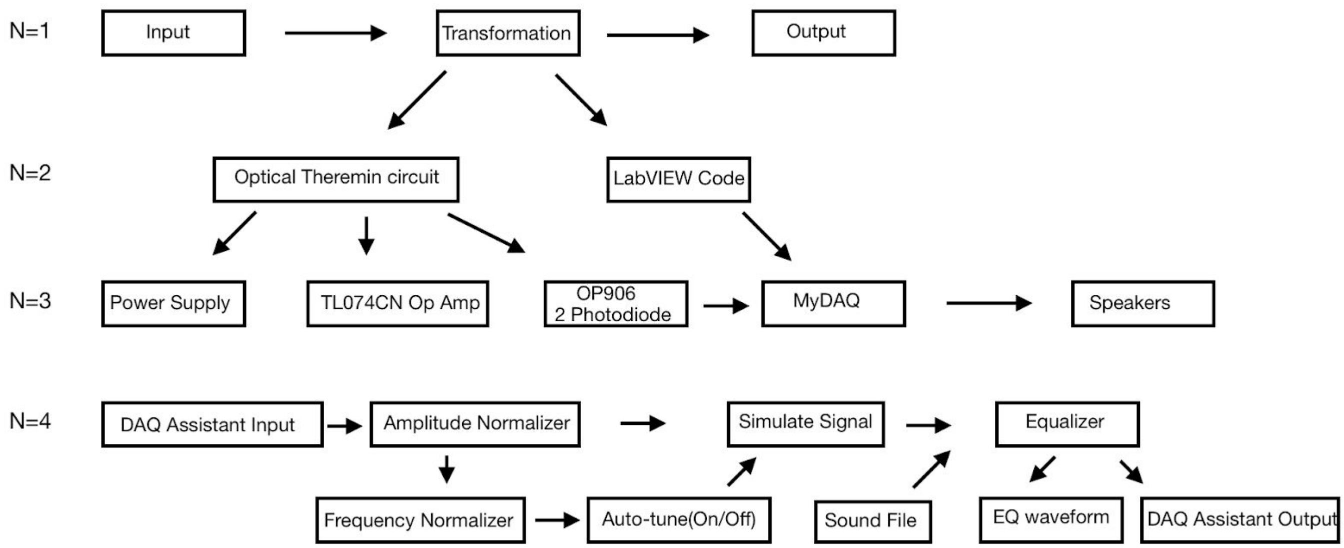

Figure 17: Initial Block Diagram