Lab 10: Optical Theremin

Introduction

In the 1950s and 1960s, a new spooky background sound was introduced to fans of ScFi and horror TV shows and movies. It was not a new sound but a rebirth of the Theremin invented in 1928 by Professor Leon Theremin using 1050s electronics (Fig. 1). The Theremin was the first electronic musical instrument. It had two antennae which were part of resonant RLC oscillators. When you placed you hand near an antenna, the electric field was disturbed, resulting in a shift of the resonant frequency. One antenna controlled the frequency or pitch, while the other antenna modified the amplitude of the sound. The Theremin now has a cult following, and you can see and hear the early sounds in some of the references.

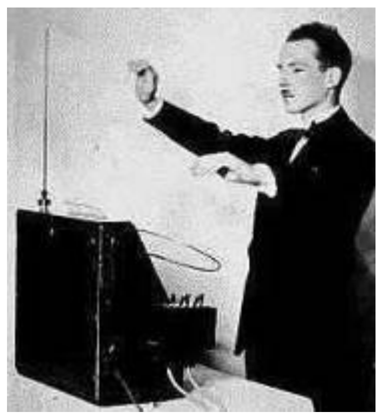

Fig. 1 Leon Theremin in Concert

Purpose

This lab uses myDAQ and two optical sensors to build an optical Theremin with its own unique sound. One hand moves over a photodiode to change the pitch. The other hand moves over a second photodiode to change the amplitude. There is a lot of scope in this project to make your sound unique and to let your creative juices flow.

Equipment

- NI myDAQ
- 3.5 mm Sub-Miniature Stereo Cable (comes with NI myDAQ)
- Stereo Computer Speaker Set

Light-to-Amplitude/Frequency Circuits

- TL2071 Low Noise JFET or 741 Operational Amplifier (x2)
- Resistors: 1.0 MΩ (x2)
- 3.5 mm Sub-Miniature Stereo Socket
- Breadboard (x2)
- Photodiode S15811 or equivalent (x2)

Prerequisite Reference Materials

History of Theremin: http://en.wikipedia.org/wiki/Theremin

Exercise 10-1: Getting Started

The amplitude control circuit uses a low-cost photodiode and an FET Op Amp configured as a current-to-voltage converter.

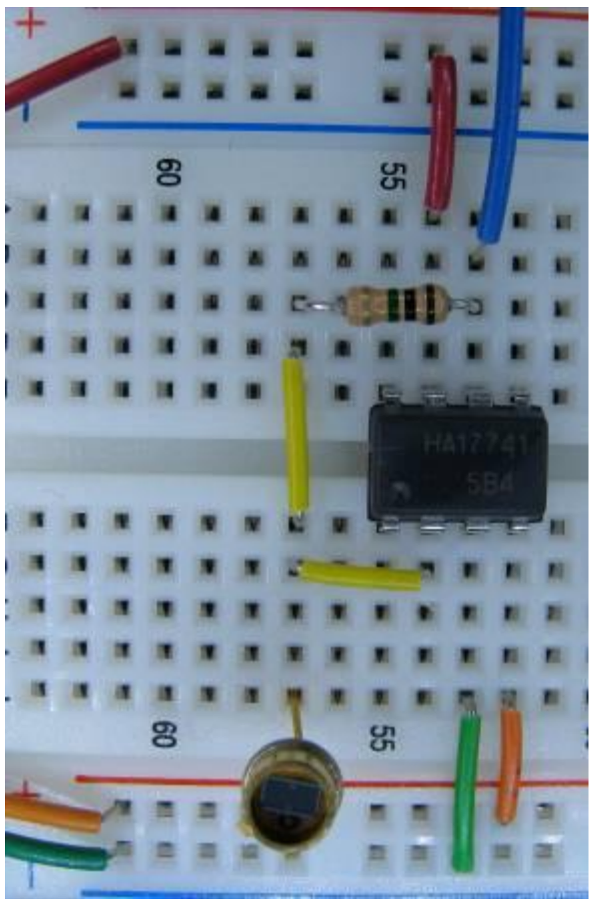

Fig. 2 Component Layout for Photometer Circuit

A photodiode (when radiated by a light source) generates a very small (microamp) current. The signal level can vary over many decades of light intensity, making a photodiode an excellent sensor. To convert this small signal into a useful control voltage, a gain of one million is required. A simple Op Amp current-to-voltage converter does the trick using a 1.0 MΩ feedback resistor.

Assemble the circuit components (Fig. 3) on a breadboard.

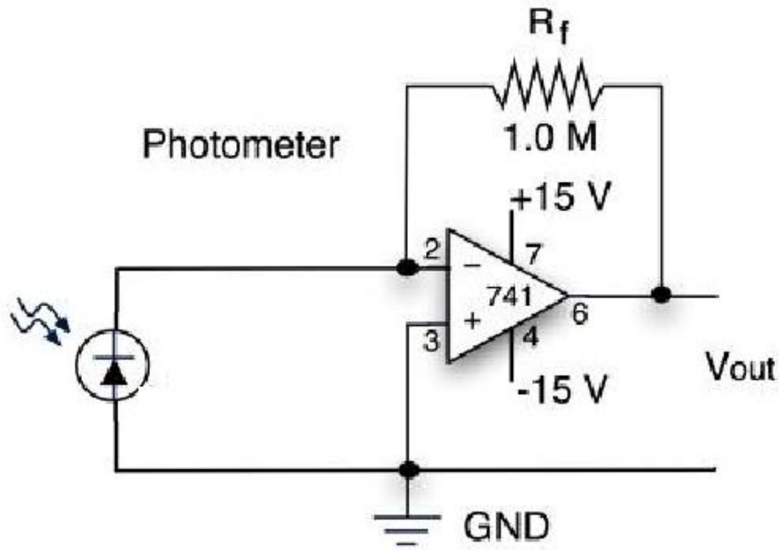

Fig. 3 Circuit Diagram for Simple Photometer

MyDAQ analog ground (socket AGND) goes to Op Amp pin 3. Connect the Op Amp output (pin 6) to AI 0+ and AI 0– to AGND. This will be the signal that controls the audio amplitude.

Build another similar circuit on a second breadboard. Use three wires from the +15, –15, and GND of the first breadboard to pass power onto the second breadboard. Connect the second output (pin 6) to AI 1+ and AGND to AI 1–. The second output will be the signal that controls the sound frequency.

Place the two boards about the distance between your hands when your arms are along your sides.

From the Instrument Launch Strip, select and [Run] myDAQ DMM(V).

Observe the amplitude level in ambient light. Now wave your hand between the sensor and a light source and see the amplitude change. Get a feel for the voltage range as you move your hand up and down in the light environment where you plan to play the Theremin. Repeat this procedure for the second circuit.

Sensor Background

A photodiode is a special semiconductor diode with a window to allow light to fall on the pn junction. Photons of light falling on the junction liberate electrons and holes in the semiconductor. These carriers can be swept away to produce a photocurrent. The photodiode current can be expressed as

$$i = \mathbf{R}L$$

where i is the output current (μA), L is the optical power (μW), and the responsivity **R** is a property of the semiconductor materials. To convert the photocurrent into a voltage, a current-to-voltage converter is used. Its response equation is

$$V_{out} = -iR_f$$

where R_f is the feedback resistor and i is the input current. Putting these equations together yields the transfer equation

$$V_{out} = -\mathbf{R}LR_f$$

Adding a voltmeter to the circuit produces a very simple optical photometer, converting light into voltage with units of volts per Watt (V/W).

Note: Any photodiode has a small (μA), dark current when the photodiode is completely covered. It is called the reverse bias back current or, in this case, the dark current. The Op Amp converts this current into an offset voltage, which is the minimum voltage V_{min} *of the photometer circuit. The maximum voltage* V_{max} *will be determined by the sensitivity of the photodiode, the feedback resistor, and the maximum light the sensor sees when uncovered.*

Exercise 10-2: Calibrating the Signals

Calibrating the Amplitude Signal

The maximum amplitude signal for line-input audio devices is 1Vpp. We need to match the photometer signal created by your hand motion with the line input levels.

Step 1: Determine the voltage signal when you hand covers the sensor (lowest position) and the voltage signal in the highest hand position (V_l and V_H, respectively).

Step 2: Convert (V_l and V_H) to the audio range (0 to 1 V).

A small LabVIEW subVI called Scale Amplitude.vi does the trick. Load this program and view the front panel, as shown in Fig. 4.

On the left side is a slide control called 'Limits' with two sliders. The bottom (blue) slider can be used to set V_{min}, and the upper (yellow) slider to set V_{max}. A single slider simulates the photometer signal. In the Theremin program, this slider will be the actual measured signal. The scaled output is shown on the 'Amplitude versus Time' graph.

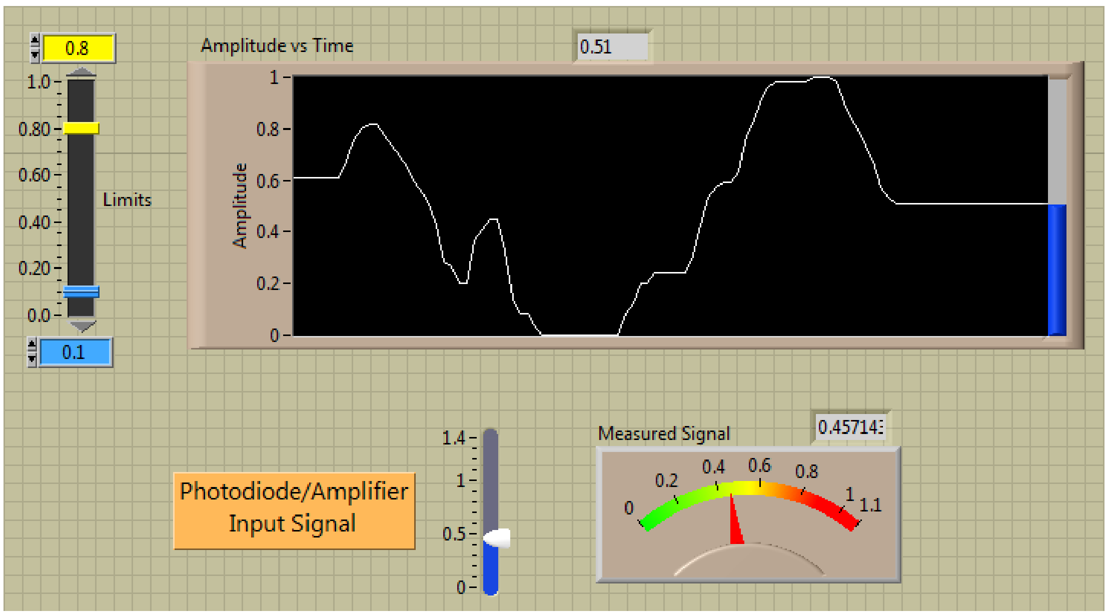

Fig. 4 Scale Amplitude.vi Front Panel used to Calibrate Theremin Amplitude Levels

Example:

In the case shown here, the lower hand voltage is 0.1 V and the upper hand voltage is 0.8 V. The photometer output ranges from about 0 V covered to 1.4 V uncovered.

[Run] the program continuously to see how the input signal is transposed into the output audio level. Check the block diagram for the scaling algorithm.

In the Theremin circuit, the input signal will come from the amplitude photometer circuit. A second program called Check Amp.vi demonstrates how the sub-VI Scale Amplitude.vi is used to display the real signal from the amplitude photodiode circuit.

Note: You will have to set the front panel levels for your photometer circuit.

Calibrating the Frequency Signal

The frequency range for the Theremin should be at least two octaves (220 to 880 Hz). A second LabVIEW subVI called Scale Frequency.vi, as shown in Fig. 5, converts the second photometer signal level into a frequency level. The photometer input (0 to 6 V) is converted into an audio range (0 to 1 V), which in turn is converted into the frequency range (220 to 880 Hz).

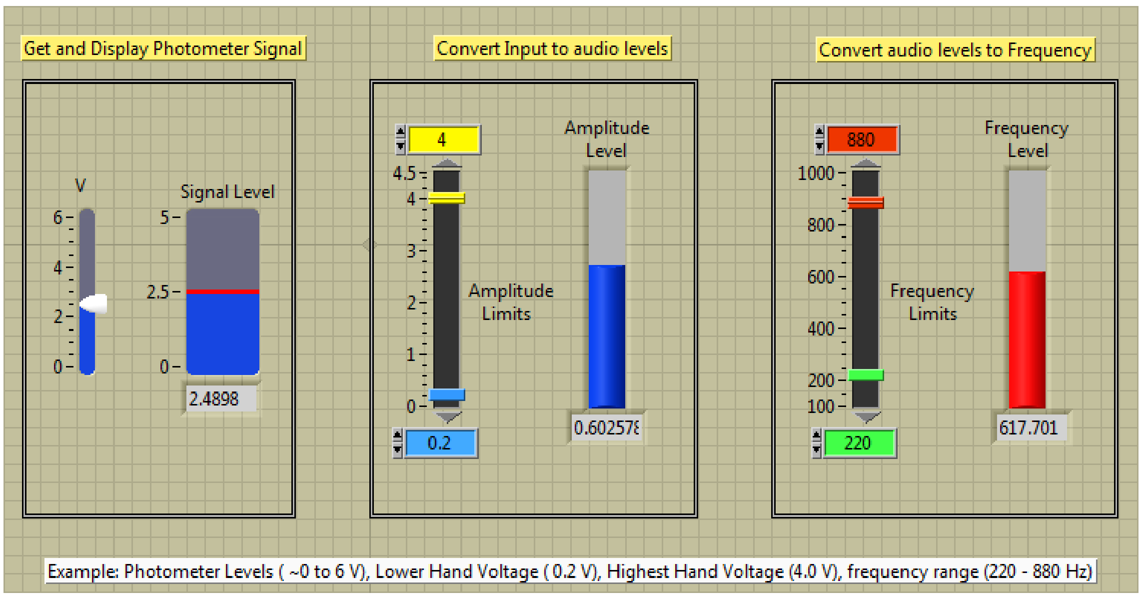

Fig. 5 Scale Frequency.vi Front Panel used to Calibrate Theremin Frequencies

It uses an algorithm similar to the scale amplitude to generate an operating range (0 to 1 V) for frequency hand motions. A few more functions then convert this range into frequency levels, as shown in Fig. 6.

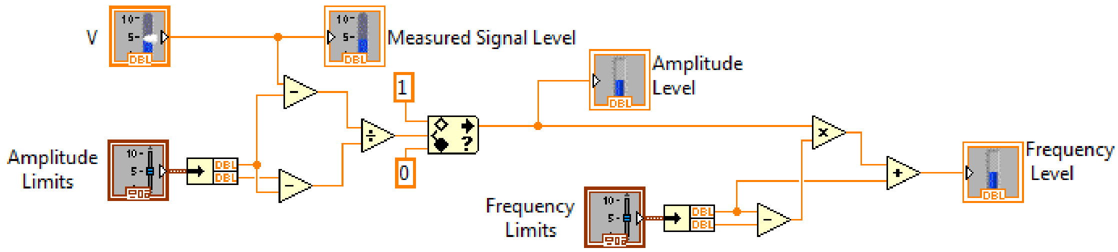

Fig. 6 Scale Frequency.vi Block Diagram

Creating the Theremin Audio Signal

The Theremin sound source is our old friend (Lab 7) the simulate signals function.

Look in Functions/Express/Input/Simulate Sig/.

Place it on a blank VI configured as
  Sine Frequency 10.1
  Amplitude 1
  Samples per sec [80000]
  Number of samples [20000]

Note: The Nyquist theorem requires a sample rate to be two times the highest frequency.

To output the sound, use the DAQ Assist configured as
  DAQ Assistant/Generate Signals/Analog
  Output/Voltage/AudioOutputLeft [Finished]
  Signal Output Range Max [2] Min [–2]
  Generation Mode [Continuous Samples]
  Samples to Write [20000]
  Rate [80000]
  [OK]

To test, just add an amplitude and a frequency control on the front panel: right click amplitude/frequency on simulate signal VI→create→control.

Note: To get a decent continuous sound, you may have to adjust the [Samples per sec/Number of Samples] and [Rate/Samples to Write]. Be sure the numbers are the same in both the Simulate Signal and second DAQ Assist.

Exercise 10-3: Theremin Software Circuit

Connect the ‘Amplitude Photodiode Amplifier’ circuit to myDAQ inputs AI 0+ and AI 0–.

Connect the ‘Frequency Photodiode Amplifier’ circuit to myDAQ inputs AI 1+ and AI 1–.

Load the LabVIEW program Optical Theremin.vi and view the front panel, as shown in Fig. 7.

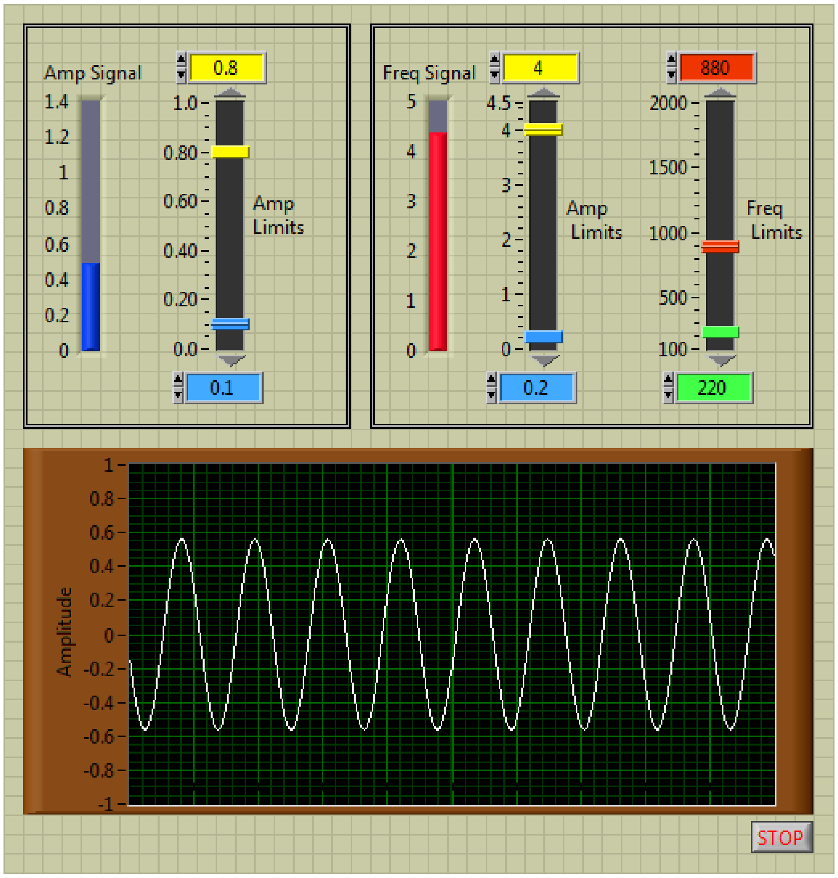

Fig. 7 Optical Theremin.vi Front Panel

The front panel is composed of familiar controls and indicators. Use these to set the signal levels for the light environment. We have added a scope-like display so you can see the sine wave.

View the block diagram in Fig. 8.

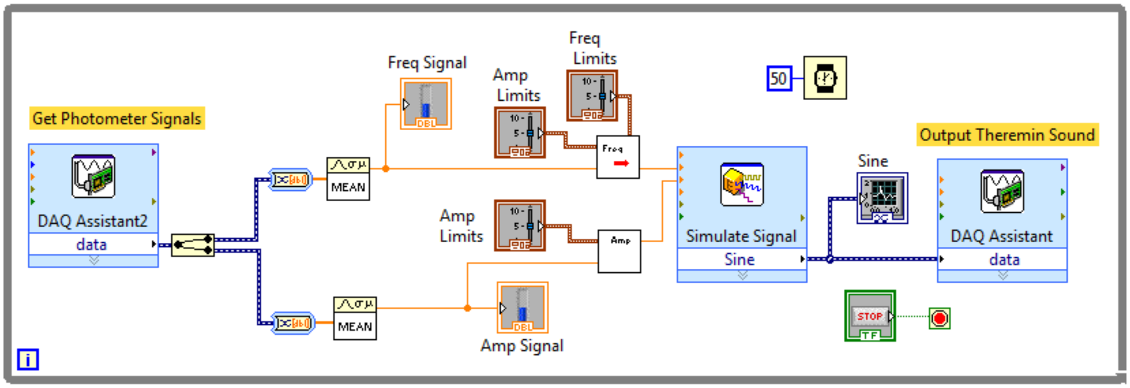

Fig. 8 Optical Theremin.vi Uses Sub-VIs Scale Amplitude.vi and Scale Frequency.vi

The only new addition is a front-end DAQ Assist programmed to capture the current photometer signals for the amplitude and frequency channel.

Add DAQ Assist from 'Functions/Express/Input/DAQ Assist' configured as

Acquire Signals/AnalogInput/Voltage/ai0 and ai1 [Finished]
Signal Input Range Max [10] Min [0]
Acquisition Mode [N Samples],
Samples to Read [2k]
Rate [80k]
[OK]

You can rearrange the front panel in anyway it suits your fancy. Enjoy!

Note: There maybe a problem with the speed that the program can slew to a new frequency. It is related to the sampling speed and the amount of processing that is required to generate the signal. For example, it is a lot easier (faster) to output a signal voltage to an external analog voltage-controlled sine wave generator than have the computer generate all the N amplitudes in a 20 kHz sine wave. A way to fix this problem is to output only the notes of a scale, as we did in Lab 7 (the digital piano). This involves auto tuning the frequency control signals, which is an excellent LabVIEW challenge.

To see and hear a solution, look at Barron Stone's Autotuned Optical Theremin at

http://decibel.ni.com/content/groups/mydaq?view=blog
(scroll down to 'Build an Optical Theremin with NI myDAQ')