

# OptoPhone

Ranjit Puri, Anuj Arora  
ECE Department,  
The University of Texas at Austin.  
{rpuri, aarora}@ece.utexas.edu

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# Chapter 1

## Project Overview

This report describes the construction and working of a novel musical instrument, the OptoPhone. Very briefly, an OptoPhone works as follows: distance sensors are uniformly spread co-linearly on one axis, with each distance sensor responsible for the production of a particular musical note. By placing one's hand some distance above a distance sensor, it is possible to produce a sound dominated by the note corresponding to that particular distance sensor. The distance of the hand from the distance sensor decides the amplitude of the sound produced. This musical instrument is inspired by the Theremin, which continues to gain acceptance as a useful orchestra element. However, the Theremin requires two hands to create music. One hand controls the pitch and the other hand controls the amplitude of the sounds produced. We contend that the OptoPhone, which requires only a single hand to describe both the pitch and amplitude is more suited to musical expression. The instrument is so named since it relies on reflective IR sensors to gauge the distance to the performer's hand (Opto - Light, Phone - Sound/Voice). The working of the instrument is captured schematically in the diagram below.

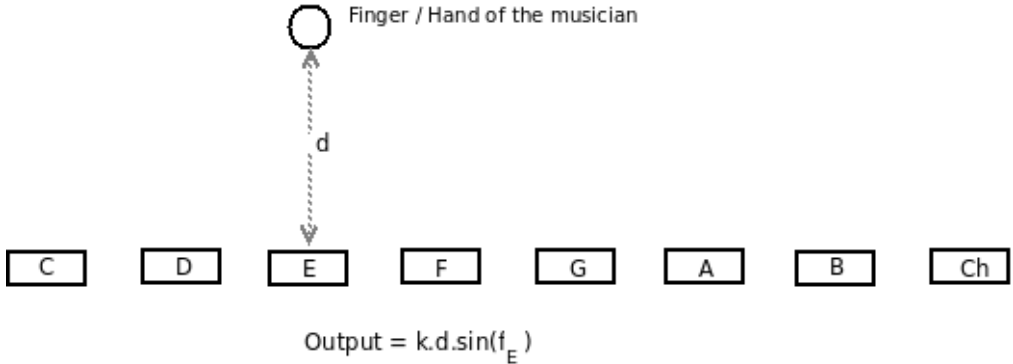


Figure 1.1: Schematic representation of the working principles of the OptoPhone

In reality, the situation is slightly more complex in comparison to the one depicted in Figure 1.1 above, since more than one sensor may detect the presence of the musician's hand above it at the same time. There are also some other effects which affect the quality of music produced by the instrument these phenomenon and methods to counter their effect are described in the following sections.

## Chapter 2

# Elementary music theory

Since the OptoPhone deals primarily with the production of music, we shall devote some attention to a brisk review of modern music theory. The chapter concludes with the list of frequencies that may be produced by the current design of the OptoPhone.

A musical piece can be viewed as a time ordered set of notes. with each note having a frequency and duration assigned to it. Notes may be viewed as a succession of frequencies arranged in a geometric progression. Each note varies from it's adjacent note by the same ratio. For any note  $N_i$  we have :

$$N_{i+1} = N_i \times 2^{\frac{1}{12}} \quad \text{or} \quad N_{i+1} = N_i \times 1.059463 \quad (2.1)$$

The generally accepted smallest frequency step between two notes is thus defined by the above ratio. This minimum interval is also called a semi-tone and an octave is the interval defined by 12 such successive semi-tones <sup>1</sup>. It is thus easy to see why successive octaves differ by a factor of 2 from each other.

Notes are typically organized in pitch classes with each pitch class containing notes with frequencies spaced at unit octave distances from each other. Each pitch class thus has infinite notes in it. Notes from the same pitch class are perceived similarly by the human ear. The octave is thus sometimes referred to as the magical interval.

Traditional musical theory considers 7 pitch classes, the name given to these classes varies from country to country. In English speaking countries, the first seven Latin alphabets are used to identify the different pitch classes, *i.e.*  $\{A, B, \dots, G\}$  are used. The major pitch following  $G$  is represented again by  $A$ , to emphasize that it sounds similar to the first  $A$  which is an octave lower. However, as described earlier there are 12 semi-tones which means every octave has five notes which are not part of a major pitch class. These notes are called the *accidentals*. Accidentals may be described as being a semi-tone interval higher than or a semitone interval lower than the major notes *e.g*  $D_{\sharp}$  (D sharp) is the note which is a semi-tone interval higher than  $D$ , similarly  $B_{\flat}$  (B flat) is the note which is one semi-tone lower than  $B$ .

The standard tuning frequency in the western world is  $A4$  which corresponds to 440 Hz. Using equation 2.1 it is easy to see that a note  $N_i$  which is  $i$  semi-tone intervals away from the note

---

<sup>1</sup>The 12 Tone Equal Temperament tuning system is assumed

$A4$  will have an absolute frequency  $F_{N_i}$  given by:

$$F_{N_i} = 2^{\frac{i}{12}} \times 440 \text{ Hz} \quad (2.2)$$

The current design of the OptoPhone assigns a frequency corresponding to a major pitch to each of the distance sensors. There are eight such distance sensors thus all majors within an octave can be produced. No attempt is made to produce accidental notes in the current version. The current design can generate the 8 major notes of the fifth octave, or the octave centered around  $A5$  *i.e.* 880  $Hz$ . We thus produce the notes  $\{C5, D5, E5, F5, G5, A5, B5, C6\}$  in terms of Eq 2.2  $i$  starts from 3. The table below lists the notes which can be generated, it also notes the distance of each note in semi-tone intervals from  $C4$ .

Note Name	Frequency ( $Hz$ )	semi-tone distance from $C4$
$C5$	523.25	3
$D5$	587.33	5
$E5$	659.26	7
$F5$	698.46	8
$G5$	783.99	10
$A5$	880.00	12
$B5$	987.76	14
$C6$	1046.50	15

Table 2.1: Frequencies corresponding to each of the eight distance sensors

## Chapter 3

# Hardware Design

This section describes the hardware that is responsible for the operation of the OptoPhone. The current version of the OptoPhone is fabricated by connecting a custom designed PCB to a Tech-Arts board that holds the MC9S12DP512 microcontroller which runs all of the software necessary to make the OptoPhone work. The custom designed PCB houses the distance measurement sensors (fashioned out of IR emitting and detecting pairs) and also the audio output module (DAC, filter and an audio amp). The schematic and the PCB design for this project have been attached at the end of the report. The reverse side of the PCB design page was signed by Paul Landers after careful inspection of the soldering of components on the custom PCB.

The two boards are connected to each other using the SMH-125-02-G-D connectors from Samtec. This connector thus carries the analog output from the distance measurement sensors onto the microcontroller and also carries the input to the DAC from the microcontroller to the custom PCB. The table below gives a list of the major components employed in the current version. Other than these the fabrication of an OptoPhone also requires standard passives and common connectors such as a power jack and an audio o/p jack. However the list below serves as a reasonable first order estimate of the Hardware complexity of the OptoPhone.

Sr. No.	Part	Description	Quantity
1.	MC9S12DP512	Tech Arts Board	1
2.	SMH-125-02-G-D	Connector	2
3.	BR31	Bridge Rectifier	1
4.	UA7805	Voltage Regulator	1
5.	OPT101	Optical Sensor	8
6.	TSAL6400	940nm IR LED	8
7.	NT43-953	IR Long Pass Filter	2
8.	MAX539	Serial 12-Bit DAC	1
9.	TLC2272-ACP	Rail to Rail Op-Amp	1
10.	MC34119	Audio Amp	1
11.	REF 03	2.5V Precision Voltage Reference	1

Table 3.1: List of the major components employed in the fabrication of an OptoPhone

Ceramic capacitors of value  $0.1F$  are used as bypass capacitors connected between the biasing voltage and ground pins on every chip. These capacitors are used to smooth out the supply voltage as seen by every chip in the system. Additionally electrolytic capacitors are used both at the input and the output of the of the regulator in an attempt to further stabilize the supply voltage. The block diagram of Figure 3.1 traces the flow of signals between hardware components.

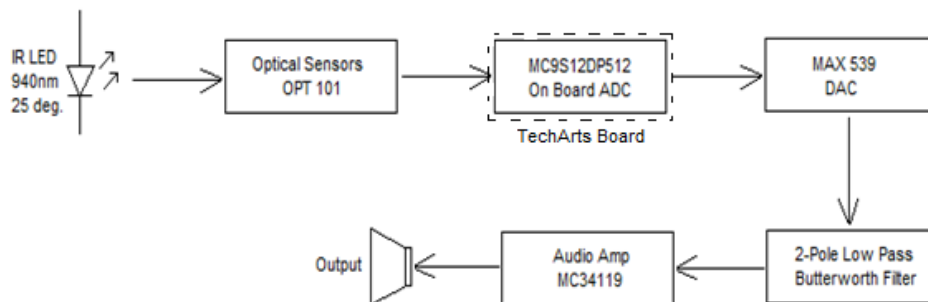


Figure 3.1: A block diagram of the hardware, tracing the flow of signals between components.

## 3.1 Circuit Design

This section describes the circuit modules that are required for the functioning of the OptoPhone. Since this was a prototype build, every attempt was made to keep the circuit board as reconfigurable as possible (mainly thorough the use of jumpers). The hardware components described below are not necessarily the optimal design choices for the desired functions. We learnt better while building this version and summarize our observations in the concluding sections of this report.

### 3.1.1 Power Supply Module

The power budget for the system was calculated by taking care of the current that was to be delivered to each component in the circuit. The input power to the system was provided using a DC wall adapter. This input supply was then fed to a BR-31 bridge rectifier. We used a bridge rectifier to guard against the variations in the connector polarity orientations of DC wall adapters. The output of the bridge rectifier was fed into a 5V, 2A voltage regulator. The output of this regulator was used as the power supply rail for the circuit. The ground reference of this regulator served as the ground rail for the circuit. An electrolytic capacitor of  $100\mu F$  in parallel with a small ceramic capacitor of  $0.1\mu F$  was added between the power supply and ground to filter out any ripples in the supply voltage. Two test points connected to the power supply rail and ground rail were added in this part of the circuit to ensure that correct voltage was being delivered to all the components in the circuit. The minimum input voltage that must be supplied to the current circuit is  $5V + 2 \times V_{fd} + V_{LDO} = 5 + 1.4 + 2 = 8.4V$ . Where  $V_{fd}$  is the forward drop voltage of a rectifier diode and  $V_{LDO}$  is the dropout voltage of the regulator.

A 2.5 volt reference power supply was designed using a REF03. This voltage was used to pro-

vide an input reference voltage to the Max539 DAC. The circuits employed for the design of this module are shown in figures 3.2, 3.3 below.

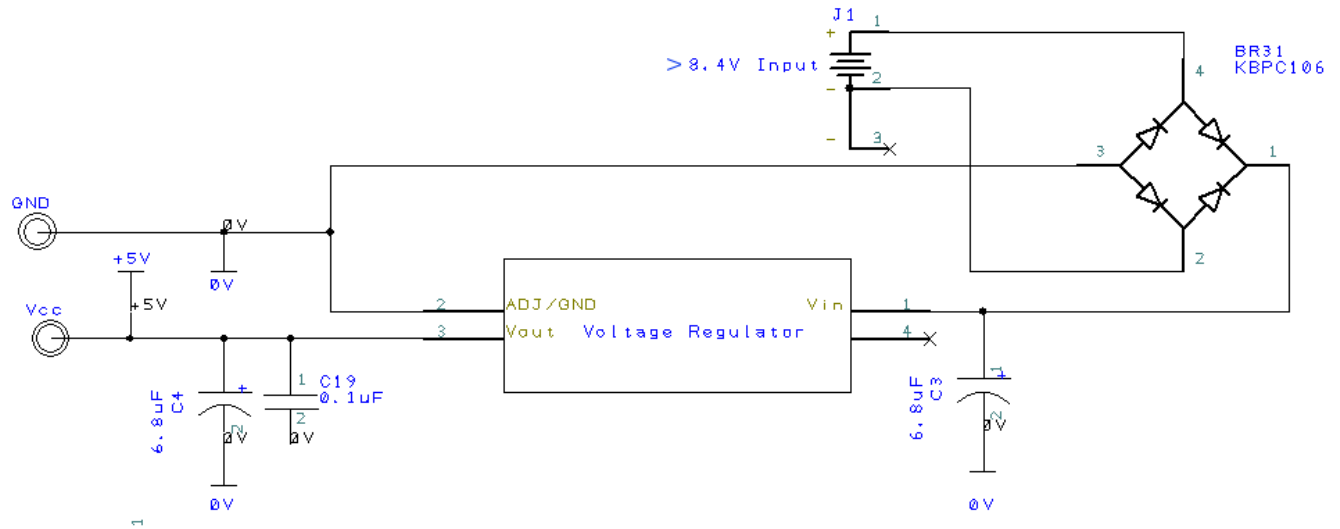


Figure 3.2: The circuit block responsible for the production of the +5V supply.

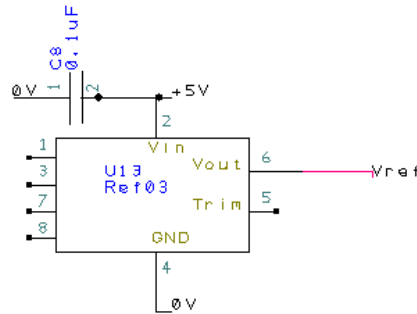


Figure 3.3: The circuit block responsible for the production of the 2.5V reference supply.

### 3.1.2 IR LEDs and Detectors

This section was the most critical part of the circuit serving as the backbone for the entire system. This part of the circuit enables us to obtain the input signals (distance of the performer's hand from a sensor) to the instrument and based on the signals generated from this part of the circuit, we play musical notes at different frequencies.

We measure distance using an IR emitter detector pair. The IR LEDs emit light at a wavelength of 940nm. This light is reflected off by the performer's fingers onto an optical sensor. This optical sensor (OPT101 from TI) is sensitive to both IR and visible light. Hence care has to be taken to make the output of the optical sensor sensitive to only changes in the IR radiation falling on it. Figure 3.4 shows the response of OPT101 to light of varying frequencies<sup>1</sup>. We use IR longpass

<sup>1</sup>This figure was taken from TI's datasheet for OPT101.

filters, briefly described in Sec 3.2 for this purpose.

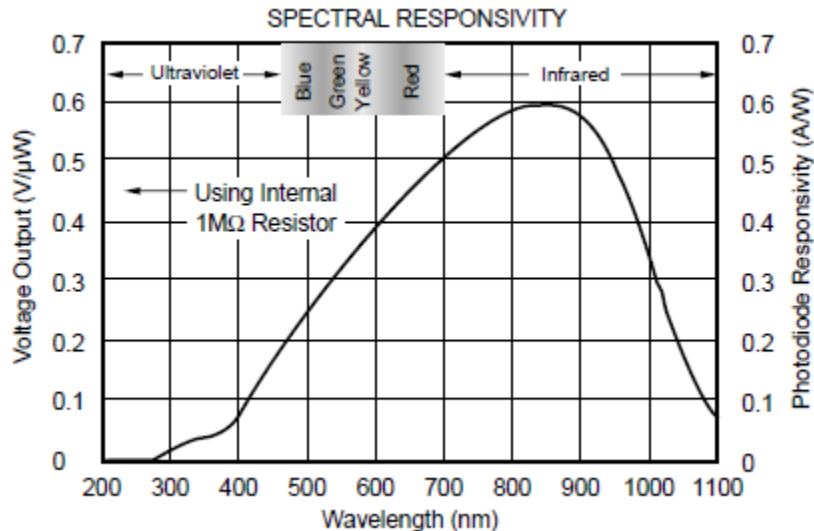


Figure 3.4: The spectral response of OPT101.

The breadboard prototype of this instrument was built with LEDs having lower power output. Hence more than one LED was used to reflect light at each of the optical sensor. In the final PCB, we provided for an option to configure either one, two or three LEDs connected near each optical sensor to allow an adequate amount of IR light to fall on the optical sensor. Each LED is powered using from the 5V supply provided through a  $220\Omega$  resistor and is thus able to draw 150mA of current.

The output of each optical sensor is connected to one ADC channel of the MC9S12DP512 on the Tech-Arts board. The signal processing done in the microcontroller on the signals obtained from these channels is discussed in the software section. Figure 3.5 shows the connection between any OPT 101 and an analog channel on the MC9S12DP512.

### 3.1.3 ADC and DAC

As briefly discussed in the above subsection we used the onboard ADC of the MC9S12DP512. The onboard ADC has a 10 bit precision and 8 channels which perfectly suits our requirements.

We made use of a MAX 539 DAC to output an analog voltage to the input of the audio amplifier. The MAX 539 is a 12 bit SPI bus controlled DAC. It's connections with the microcontroller present on the Tech-Arts board are shown in figure 3.6.

### 3.1.4 Two pole low-pass Butterworth filter

The highest frequency in the output signal of interest is  $1046.5Hz$ . A 2-pole low pass Butterworth filter with a cutoff frequency of  $1650Hz$  was designed in order to keep the unwanted signals with frequencies higher than  $1650Hz$  from interfering with the signals of interest. The capacitors used

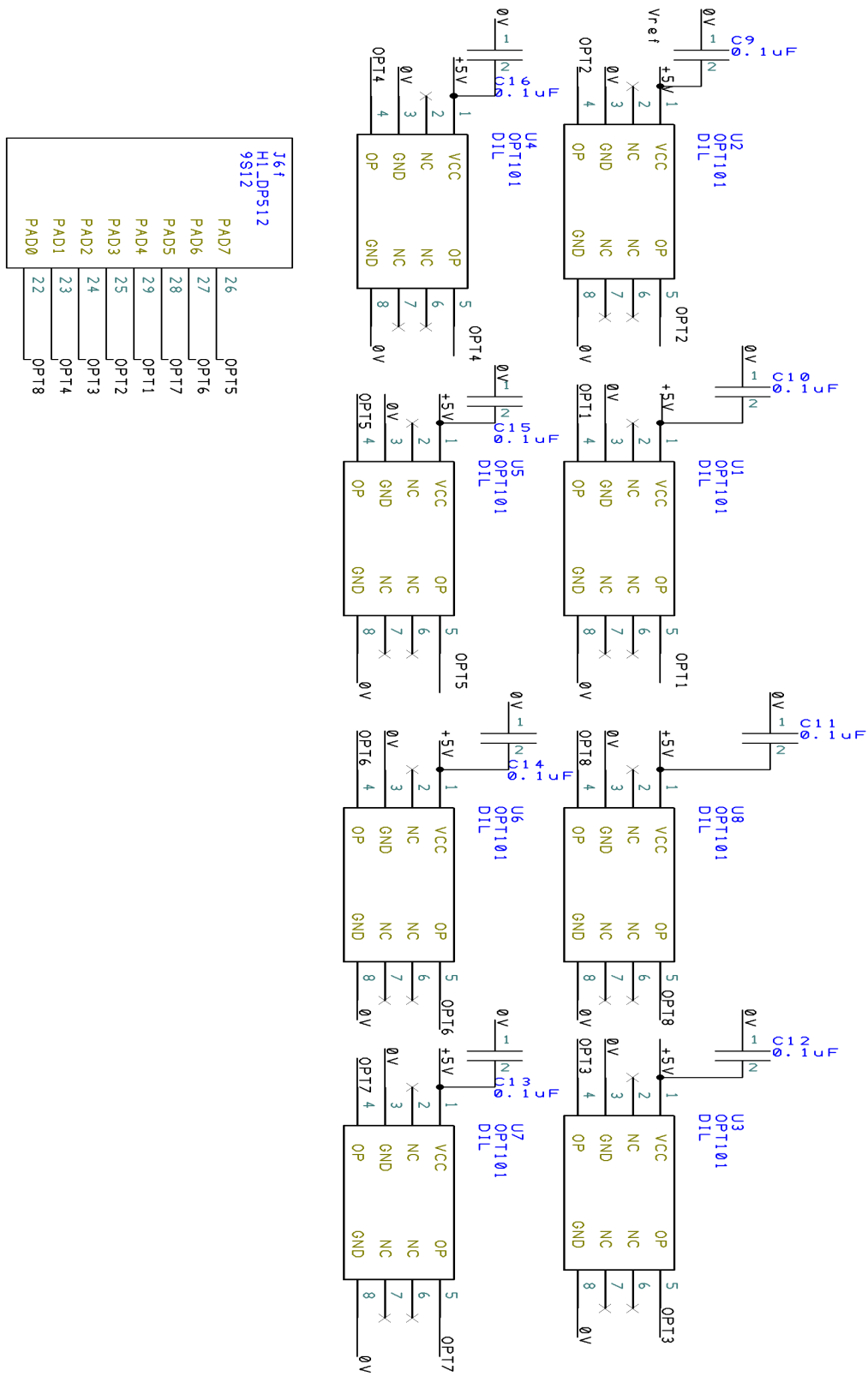


Figure 3.5: 8 OPT101s which function as IR detectors.

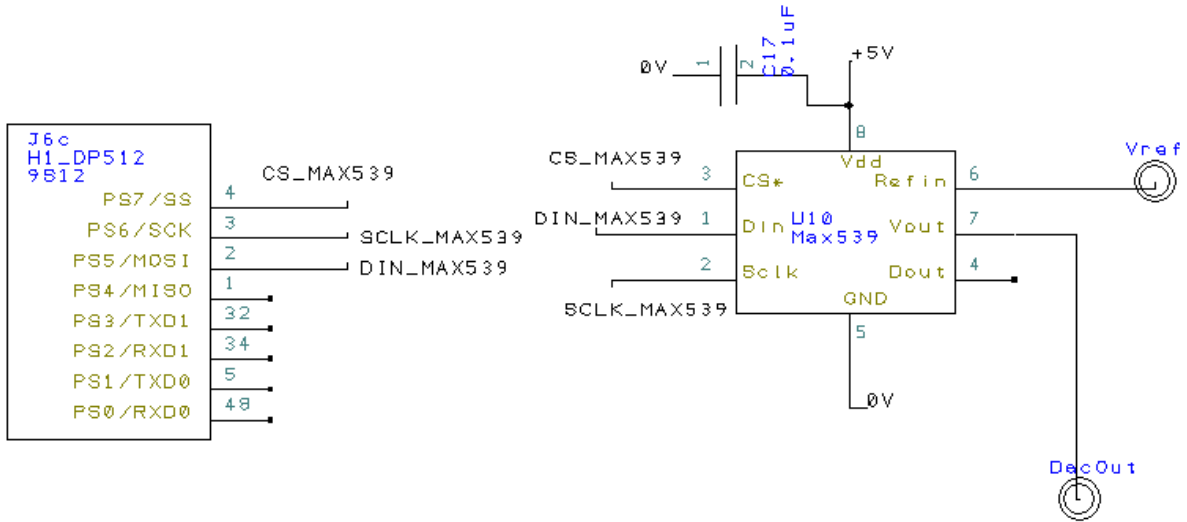


Figure 3.6: Connections to the MAX 539 DAC.

for the design are ceramic capacitors of value  $6.8nF$  each. 2 resistors of  $10k\Omega$  are also used in the design. The filter was constructed as shown in fig 3.7.

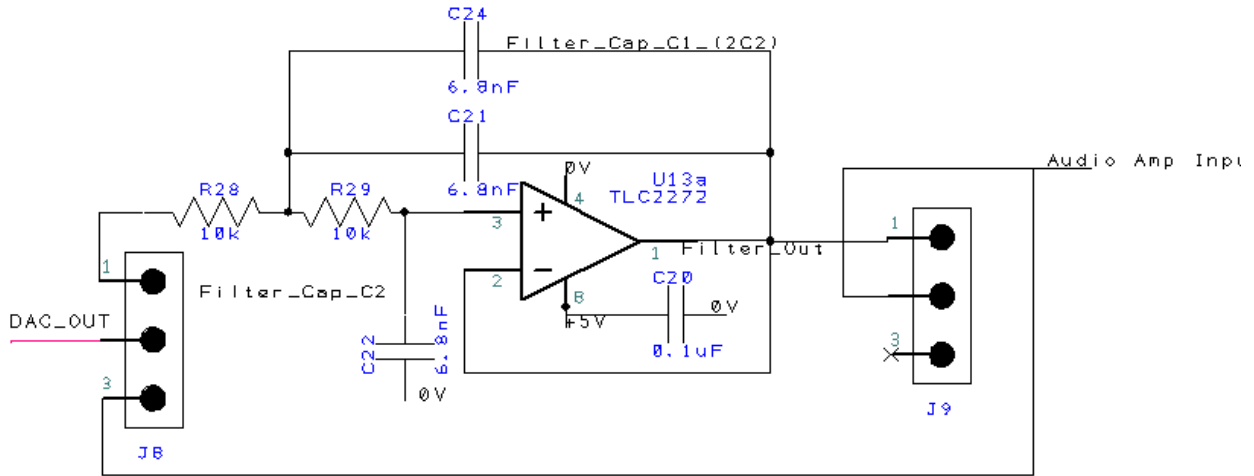


Figure 3.7: The 2 pole low pass butterworth filter.

### 3.1.5 Audio Amplifier

The output of the DAC after being filtered as described above (this filtering can be turned off as described later) is fed into a MC34119 audio amp. The gain of the audio amp set to 4 by selecting the feedback resistor to be 4 times the input resistor. The output of the audio amp is connected to a head phone jack to enable the user to listen to the output on speaker system / headphones. This part of the circuit is connected as shown in fig 3.8.

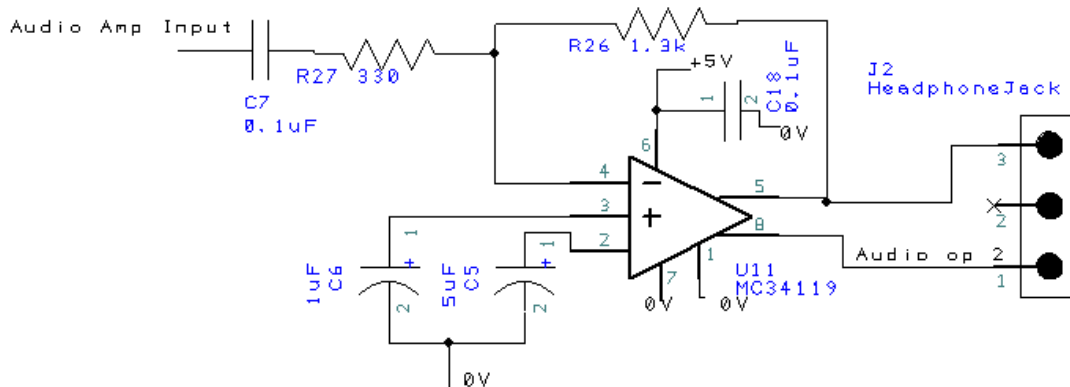


Figure 3.8: Circuit connections for the MC34119 Audio Amplifier.

### 3.2 IR longpass Filters

After our initial research into materials that would block visible light and allow only IR to pass through, we decided to focus on low cost materials such as processed camera film and magnetic films extracted from floppy disks. These materials though low cost and readily available did not actually serve our purpose adequately. For instance, the magnetic film had very low transmissivity while the processed camera film was not very effective in altogether blocking visible light from reaching the sensors.

We thus extended our search to materials used in the field of optics and finally found a suitable material made by Edmund Optics which met our requirements more or less perfectly. The part (NT43-953) used as an IR Long Pass filter is made of a material called Thermoset is highly effective in blocking the visible light and passing only IR and near IR wavelengths through. The filtering characteristics of the IR filter used are shown in the figure 3.9 below<sup>2</sup>.

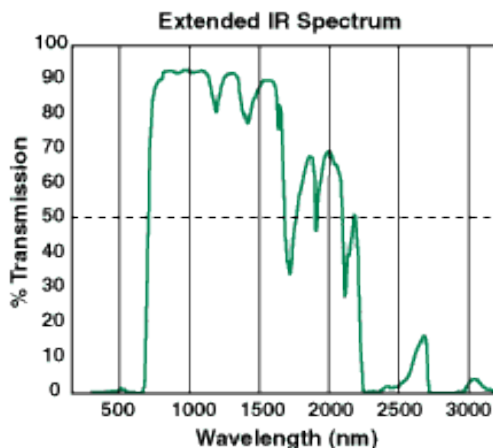


Figure 3.9: Transmissivity characteristics of the IR longpass filter.

<sup>2</sup>Figure obtained from the online catalog of Edmund Optics.

### 3.3 Flexibility in Design

Since this was a prototype run, a conscious effort was made to keep the design flexible such that adjustments could be made to the design while we continued to test and write software for it.

The first consideration kept in mind while designing the circuit was that we might need more than just one LED to reflect light onto the optical sensor depending on the ambient conditions under which the instrument was used. However connecting more than one LED without knowing the need would mean that the input current in the circuit would go up and the LEDs would always be powered on irrespective of whether they were actually needed or not. Hence, we decided to add jumpers between the power rail and the terminal of the LEDs connecting to the power rail. The LEDs connected in the system were divided into three groups and a jumper was connected to each of these groups. The first group consisted of one LED to the left of each optical sensor, the second group consisted of LEDs aligned at the center of each sensor and the third group had one LED to the right of each sensor. Hence we had the option to power any one LED, two LEDs or all three LEDs at a time depending on which the jumper heads were connected and which were not.

Another flexibility added to the design was to allow bypassing the 2-Pole Low Pass Butterworth Filter by connecting jumpers both at the input to the filter and at the output of the filter. This enabled us to bypass the filter when we wanted to study how the instrument sounded at a different octave etc.

### 3.4 Packaging

We used a black LH89-130 Pactec box as an enclosure for our system. The external dimensions of this box are:

- Length = 9.5 inches
- Width = 8.1 inches
- Height = 1.5 inches

The recommended length for the PCB is 9 inches and width is 7.6 inches. We designed the custom PCB to be 9.18 inches in length and 4.06 inches in width. The Tech-Arts board is 3.25 inches in length and 2.3 inches in width. Once the two boards were connected together the complete circuit fit perfectly in the box.

The box was machined to make provisions for powering the circuit and connecting the speakers/headphones to the instrument. The top of the box was also machined to expose the LEDs, optical filter and the optical sensors to the performer.

## Chapter 4

# Software Design

The software for this project was written in C++ primarily because we felt that C++ afforded more expression ability to the programmer<sup>1</sup>. An attempt was made to keep the software design modular and flexible. The basic operation of the software is as shown in the following figure:

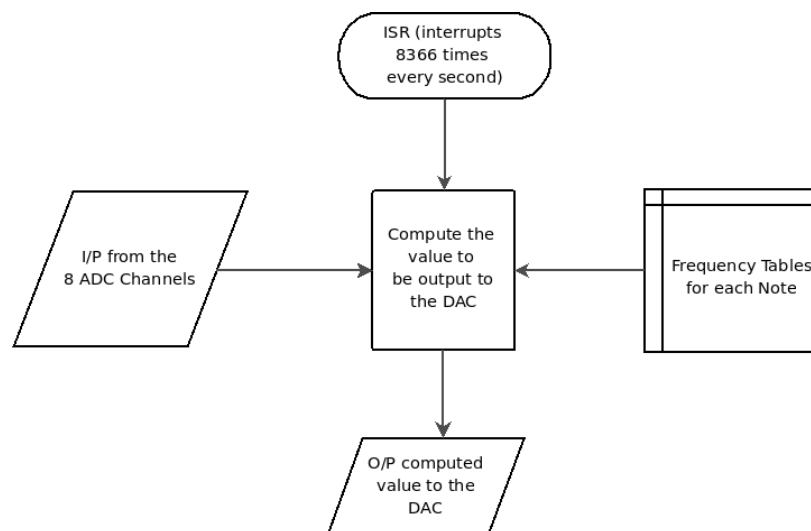


Figure 4.1: A high level description of the working of the software that resides in the OptoPhone

## Software Components

This section describes in some detail, the software components of the system. We do not list any code snippets in this section, instead we describe the functioning of the software through text and illustrations. A detailed code listing may be found in the Appendix to this report.

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<sup>1</sup>An evaluation version of the CodeWarrior development studio was used for compiling.

## 4.1 The *note* class

The *note* class encapsulates a note. It provides 3 methods which are visible to the code block employing an object of that class. Firstly, the *note* class provides a method to construct a note. This involves linking a *static const* array of locations which hold the frequency table for that note frequency to the note object. The note class also provides a set of basic operators and copy constructors etc. Thirdly, it also encapsulates the mechanism to loop around the frequency table in a manner that is totally transparent to the block using an object of the *note* class. The block using the object only has to make repeated calls to a `get_next_val` function which returns the next value needed to be summed and output to the DAC in order to have a component corresponding to the principal frequency of the note at the output.

## 4.2 Detection Thresholds

Despite the presence of longpass IR filters covering the IR detectors, some ambient light still makes through to the IR detectors. Thus a constant DC value corresponding to the ambient light seen by the IR detector is present at each ADC channel. The software must assume that the performer's hand was hovering over a detector only when the ADC channel corresponding to the detector reports a reading greater than the threshold corresponding to the ambient light<sup>2</sup>.

These thresholds are held in an array of 8 locations, with a threshold corresponding to each detector being present in each location. These thresholds are tuned automatically each time the OptoPhone is power cycled. A simple averaging loop for a few thousand timer interrupt cycles is sufficient to establish the thresholds required for each IR detector.

## 4.3 Spatial Filtering

We found out that when we placed our hand on the OptoPhone such that it was not very close to any particular IR detector (*i.e.* the hand was away from a detector in both the x and y dimensions. ) then a dissonant sound corresponding to the summation of all the nearby playable notes would be produced. There was a need to boost the output of the channel to which the hand was closest to and lower the gain of the channels adjacent to the one to which the hand was closest to.

To achieve this end a spatial filter was designed in software such that any IR detector channel whose output was greater than the threshold and also higher than both its neighbors received a 10:1 boost in gain compared to its neighbors. The two detectors at the edges were treated differently in that they compared their output to their solitary neighbour as opposed to both neighbors as is the case for other sensors. The edge sensors also received a greater gain in respect to their neighboring sensor, since there is a lesser amount of IR illumination at the edges as opposed to the more medial regions of the board.

## 4.4 Dynamic Amplitude Scaling

We discovered that our system often produced scratchy sounds (caused due to a constant high value being fed into the DAC) when 4 or more notes were played together. These sounds are unpleasant

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<sup>2</sup>This is not entirely accurate since the performer's hand may also reduce the ambient light falling over the sensor, but it is a convenient approximation that works reasonably well

to hear and are thus undesirable. It was therefore felt necessary to dynamically scale the output being fed into the DAC in response to the number of active notes (IR detector channels which report their output to be greater than their corresponding threshold are considered active). We thus scale down the output that is fed into the DAC by the number of active channels. Thus if only a single channel is active, the frequency table corresponding to that channel is scaled by the distance measured and output to the DAC. However, if two channels are active then the frequency table for both the channels is scaled down by a factor of half in addition to being scaled by the distance measured.

## Chapter 5

# Performance Evaluation

### 5.1 Specific Measures

After the instrument had been built, various experiments were designed to measure the performance characteristics of the instrument. The volume of the note being played is dependent on the amount of IR light reflected onto the optical sensor and this in turn is a function of distance of the finger from the LED. This distance from which the IR light is reflected onto the optical sensors was chosen to be the input variable that helped us quantify various characteristics of the system such as its Repeatability and Reproducibility. The response variable that we choose for the purpose of measuring the performance characteristics of the system is the output voltage of the OPT 101 responsible for the generation each musical note

The following section describes the experimental setup for measurement of each of these parameters.

### 5.2 Experimental Design

#### 5.2.1 Accuracy

Accuracy of any system can be defined as the error in measurement as a % of the reading obtained. We calculate the accuracy of our system by calculating the error in the output frequency as a % of the true value of frequency for any particular musical note and then calculate the average accuracy of reading. The frequency at any note is obtained by taking an FFT of the output sound using open source software called Audacity. This value of frequency is tabulated as the measured value

The results of this experiment are summarized in table 5.1: The average accuracy is calculated as:

$$\text{Average Accuracy of reading \%} = \frac{100}{8} \sum_{i=1}^8 \frac{|X_{ti} - X_{mi}|}{X_{ti}} = 0.182\% \quad (5.1)$$

Figure 5.1 shows the plot of spectrum obtained for the note C5, as can be seen the spectrum shows a distinct peak at the desired frequency.

#### 5.2.2 Repeatability

Repeatability is the variability of the measurements obtained by the same operator while measuring the same data repeatedly keeping as many parameters fixed as possible. For this experiment, the

Note Name	True Frequency ( $Hz$ )	Measured Frequency ( $Hz$ )	$\frac{ X_{ti}-X_{mi} }{X_{ti}} \times 100$
C5	523.25	525	0.334
D5	587.33	588	0.114
E5	659.26	661	0.264
F5	698.46	698	0.066
G5	784.00	785	0.128
A5	880.00	882	0.227
B5	987.77	986	0.179
C6	1046.5	1048	0.143

Table 5.1: Calculation of accuracy in the production of each note.

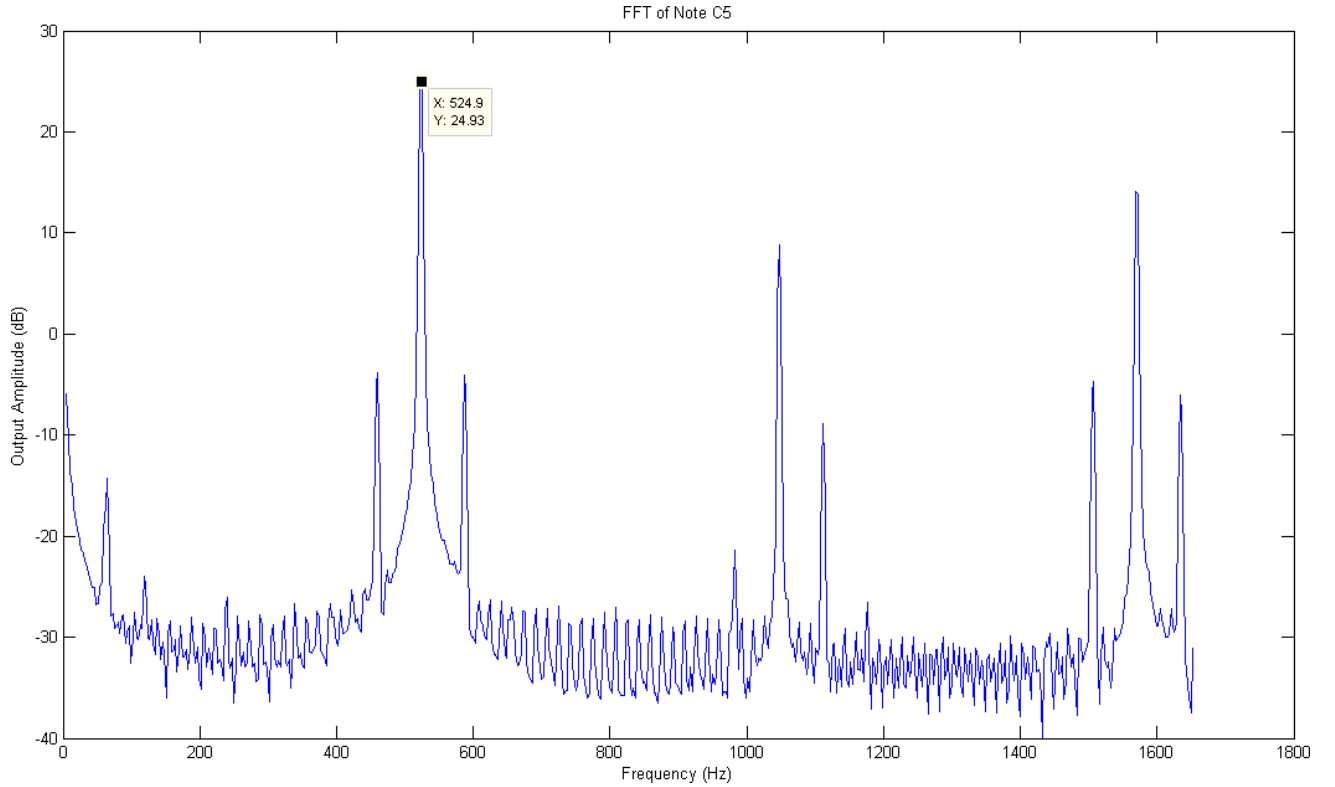


Figure 5.1: A spectrum plot of the note C5

same operator recorded the output of each IR detector channel (in Volts) as seen by the ADC, at a constant distance of 1.5 inches from the IR detector every 10 seconds for 10 minutes for each musical note (C5 to C6). This was done on a different day than the original design and calibration of the instrument. The repeatability is calculated as follows:

$$Repeatability = X_{max} - X_{min} \quad (5.2)$$

Where,  $X_{max}$  and  $X_{min}$  are the maximum and minimum values recorded for the IR detector output.

The repeatability of output at the various musical notes is tabulated as shown in Table 5.2:

Note Name	Max ADC I/P ( $X_{max}$ ) (Volts)	Min ADC I/P ( $X_{min}$ ) (Volts)	Repeatability (Volts)
C5	1.445313	1.323242	0.12207
D5	1.474609	1.430664	0.043945
E5	1.420898	1.37207	0.048828
F5	1.518555	1.469727	0.048828
G5	1.435547	1.386719	0.048828
A5	1.547852	1.479792	0.068359
B5	1.513672	1.455078	0.058594
C6	1.582031	1.499023	0.083008

Table 5.2: Repeatability as a difference between Max and Min readings.

We also calculated the repeatability as a standard deviation of the obtained output results at each node. The standard deviation is calculated as usual and these results are summarized in Table 5.3.

Note Name	Mean Output Value ( $\bar{X}_m$ ) Volts	Repeatability Standard Deviation $\sigma$ Volts
C5	1.385742	0.039772
D5	1.449707	0.016349
E5	1.391113	0.015518
F5	1.501465	0.015654
G5	1.415527	0.016349
A5	1.519531	0.022529
B5	1.495605	0.016765
C6	1.561523	0.023899

Table 5.3: Repeatability as a standard deviation.

### 5.2.3 Reproducibility

Reproducibility is the variability of the measurement system caused by differences in operator behavior. Mathematically, it is the variability of the average values obtained by several operators while measuring the same data repeatedly under varying environmental conditions.

For this experiment, we took measurements at a constant distance of 1.5 inch for every note on two different days by different operators. The reproducibility is calculated as follows:

$$\text{Reproducibility} = X_{max} - X_{min} \quad (5.3)$$

where  $X_{max}$  and  $X_{min}$  are the maximum and minimum output values obtained for each IR detector for the fixed input (1.5 inch) as measured on two different days by different operators.

The results for this experiment are tabulated in Table 5.4:

Note Name	Max ADC I/P ( $X_{max}$ ) Volts	Max ADC O/P ( $X_{min}$ ) Volts	Reproducibility
C5	1.450195	1.323242	0.126953
D5	1.475609	1.425781	0.048828
E5	1.425781	1.37207	0.053711
F5	1.518555	0.976563	0.541992
G5	1.435547	1.37207	0.063477
A5	1.547852	1.479492	0.068359
B5	1.513672	1.455078	0.058594
C6	1.582031	1.499023	0.083008

Table 5.4: Reproducibility as a difference between Max and Min readings.

We also calculated the reproducibility as a standard deviation of the obtained output results at each node. The standard deviation is calculated as usual and these results are summarized in Table 5.5.

Note Name	Mean Output Value ( $\bar{X}_m$ ) Volts	Reproducibility Standard Deviation $\sigma$ Volts
C5	1.396484	0.034381
D5	1.44873	0.015121
E5	1.397461	0.01681
F5	1.465088	0.116764
G5	1.409668	0.018684
A5	1.520264	0.022024
B5	1.492676	0.014441
C6	1.537842	0.029994

Table 5.5: Reproducibility as a standard deviation.

## 5.2.4 Resolution

Resolution is defined as the smallest change in the input that can be successfully measured at the output. For the purpose of our system, the resolution can be calculated in both the X and Y dimensions. The X dimension represents the changing frequency of the various musical notes and the Y dimension represents the change in the output amplitude corresponding to any particular note.

We keep our finger at a point 150 mm above a particular optical sensor and mark this point as origin. We then move our finger downward towards the optical sensor till a change is seen in the IR detector output as observed by the ADC. We ignore any change in the IR detector output that keeps the detector output below the threshold explained in 4.2 since such output is not considered while summing up the various frequency components that are output to the DAC. Thus the smallest change in the position of the finger with respect to the origin that brings about a change in output of the IR detector when the output of the IR detector is above the threshold is recorded as the resolution in the Y direction.

In our case this change happens to be less than or equal to the minimum distance we can measure with our equipment (a ruler, which can measure in mm). Thus being as pessimistic as our measurement setup allows us to be, we report the vertical resolution to be 1 mm.

For determining the resolution in the X dimension, we keep a thin reflective material at an arbitrary point on the line passing through the center of all IR detectors and mark this point as origin. We then gradually move towards one direction along the line. The smallest change in distance that brings about a change in the musical note being played is recorded as the resolution in the X direction.

Experimentally this distance was found to be 25 mm which is very close to the 23.24 mm spacing between adjacent OPT101s on the PCB board. This is likely due to the spatial filter, which boosts the output of the channel whose IR detector reports an output greater than its neighbors in a ratio of 10:1 over its neighbors.

# Chapter 6

## Conclusion

This chapter concludes this report, we attempt to enumerate what we have learned about making such a musical instrument and in an attempt to improve upon the current implementation we also discuss what alternative design choices these learnings lead to.

### 6.1 Lessons Learned

One of the biggest mistakes we made was to design our own distance sensor fashioned out of an ambient and IR light sensor and IR emitting LEDs. This forced us to focus on nuances of fabricating a distance sensor such as what wavelength of an LED should be used, where should the LED(s) be placed, what should be the lens angle of the LEDs etc. These issues have infact been near optimally solved in commercially available IR distance measurement sensors and we should have just straightaway used those instead of focusing our attention on trying to build a sensor ourselves.

Another mistake that became quite apparent after we fabricated the current version was that 8 notes were less than adequate for producing any meaningful music. Most musical pieces that we attempted to play on the OptoPhone had either made use of accidentals or had notes shifted to adjacent octaves, both of which are flexibilities we do not have in the current design.

Also, since we had never implemented something similar before, we should have brought out a few spare IO pins and provisioned for LED outputs or switch inputs that may need to be added when we were prototyping. For instance, we could have used a switch input to perform auto thresholding at times other than startup, but we had no such flexibility.

### 6.2 Ideas for a future revision

A future revision of this instrument will likely have the following features.

- **More than 8 notes** : The instrument will definitely have more than one octave, it would also be interesting to simulate accidental notes in the space between two adjacent sensors which correspond to the two major tones which have an accidental in between themselves.
- **Programmability** : The performer should be able to shift the musical scale an octave or two down as suited to his performance, moreover controls that typically aid in the generation

of electronic music, such as a looper should be added. It should also be possible to simulate different instruments and select between them while playing.

- **COTS** : As far as possible components off the shelf should be used, in particular readily available IR distance sensors would allow us to focus on the generation of music more than worrying about the nuances of the particular parts chosen to form a custom sensor.

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