Theremin: A Kaleidoscope of Sound

Final Report of Senior Design Project
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Executive Summary

The purpose of the project was to design a theremin and to apply its capabilities towards other applications. A theremin is both the first electronic instrument, and the first and only to be played without touching it, but by moving the hands over two antennas in free space. The theremin should have one or more capacitance dependent beat frequency oscillators responsible for both the tone and volume control of the unit.

The chosen design for the project was a 145 theremin because it is one of the most recent and advanced designs to date. The 145 theremin displays better temperature stability and pitch-arc linearity than any of its known predecessors. The sound quality for varying volume levels from the 145 theremin design is excellent and all components run on a 9-volt battery making it convenient for transportation and applications. Two plate antennas replace the traditional loop and straight antennas for volume and pitch control respectively, giving the player a wider topology to manipulate the sound with.

In order to demonstrate other applications for the theremin, the output signal from one of the oscillators was sent to a Motorola 68HC11 microcontroller to control an elevator model. The varying voltage signal from the theremin determined what floor the elevator would move to.

All four oscillators on the final theremin produced clear sine waves with little distortion. The overall functionality of the instrument was completely attained with only a smaller range on the volume antenna. The tones produced by the theremin alone where clear and distinct. When connected to a Digitech RP300 signal processor the theremin displayed great potential for a variety of musical styles and sound effects. The control application for the elevator model was not completed due to complications with the output signal peak-to-peak voltage.

Keywords

Cakewalk Sonar 2.0 XL

Chorus

Delay

Digital Signal Processing (DSP) Chip

Digitech RP300

Heterodyning

LM339 comparator chip

Low-pass filter

Modulation

Motorola 68HC11

NTE 823

741 Op-amp

Reverb

Theremin

Tremelo picking

Wide vibrato

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Chapter One - Introduction

1.1 Problem Statement

The purpose of the project was to build a 145 Theremin. The 145 theremin is the most recent design of the first electronic instrument first created in the 1920s. There are six major parts to the design:

1. Volume Oscillator
2. Volume Processor
3. Audio Amplifier and Voltage Regulator
4. Variable Oscillator
5. Signal Mixer
6. Pitch Reference Oscillator

The 145 theremin displays better temperature stability and pitch-arc linearity than any other designs. Pitch reference oscillator tuning range is about 700 Hz and volume oscillator tuning range of about 1200 Hz. The sound quality for varying volume levels is greatly improved compared to its predecessors and all of the components run from a single 9-volt battery making it extremely convenient for transportation and usage. Plate antennas of about 8 in. x 5.5 in. replace the traditional straight and loop antennas, for volume and pitch control due to their wider topology which allows for more of a playing surface.

1.2 Historical Background

The Theremin is the first electronic musical instrument invented in the early 1920s by Russian physicist Lev Termen (Leon Theremin). The initial idea behind the theremin came about as an accidental discovery while Theremin worked on vacuum tubes for the Russian Government. Theremin was motivated to build the instrument after observing that a wave produced in a radio frequency oscillatory circuit could be made to change frequencies in relation to the capacitance between a person's body and the circuit. By using heterodyning, a process that combines the varying frequency wave with a fixed frequency, Theremin was able to produce an audible tone, which could be manipulated

according to hand positions. Having a background in music as a trained cellist, Theremin quickly realized the musical potential for this breakthrough. Theremin attained a U.S. patent for his instrument in February 1928, and RCA produced the first theremins for mass distribution soon after, a vacuum-tube version known as the
AR-1264. Traditionally a theremin has a loop antenna for volume control and a straight antenna for pitch control. The instrument is played by moving one hand over each antenna to vary the pitch and volume of the signal produced. Since the AR-1264 many versions of the theremin have been created as technology has allowed a plethora of designs to come to pass, varying in theory and components used. One aspect that has been constant throughout has been the unique playing experience the theremin affords. The theremin could be thought as the invisible instrument since the performer as able to associate points in free space with musical notes instead of fretting and strumming a string a guitar, which is visible to everyone. This freedom, however, makes a theremin difficult to play. In fact, since its invention there are only a handful of accomplished theremin players. Nevertheless, theremins have been used by countless bands including the Beach Boys in the 60s, Led Zeppelin in the 70s, and Incubus and Nine Inch Nails in recent recordings and live shows. The Theremin has also been immortalized by numerous movie sound effects, most notably in science-fiction films.

1.3 Motivation and Goals

When deciding upon a senior design project the 145 Theremin was an enticing endeavor because it encompassed many different aspects of engineering and a certain amount of novelty.

The primary goal of the project was to build a fully functional 145 Theremin. The theremin should meet the design specifications set upon the 145 design including plate antennas, a headphone output, and a higher range of frequencies to work with. Plate antennas where used instead of the traditional straight and loop antennas for pitch and volume control respectively because of their wider topology. The larger surface area allows the player to use broader, more expressive hand movements.

Once the theremin was completed, the secondary goal was to expand upon the theremin's musical capabilities by adding modulation effects such as chorus, delay, and reverb. These effects have been staples for any guitar and synthesizer players since the 60s because they allow vibrant tones that can create a wide range of ambiance and emotion. Thereafter songs including the theremin where to be recorded in order to demonstrate the theremin's genuine application as a musical instrument. The popular recording software Sonar 2.0 XL by Cakewalk was to be used for the recording and arranging process.

The final goal of the project was to extend the theremin's uses outside of music. Once the final output signal from the theremin was determined it would be used as the input to control an elevator model. The varying frequency output from the theremin would determine what floor a three level elevator model would move to. A Motorola 68HC11 microcontroller would be used for the control aspects of the elevator.

1.4 Observed Results

The primary objective of completing a 145 Theremin was accomplished fully with only one minor discrepancy. The range on the volume antenna that the player is supposed to have to play with is specified as 10-12 inches, where the resulting theremin only gave about 2-3 inches. The modulation effects where determined to be more efficiently implemented using a Digitech RP300 modeling unit because it offered more variety and easier application than building individual units. The recording process was stagnated by excessive costs for interfacing the theremin with recording software. Finally, the application towards controlling the elevator was only truncated by time limitations, but many parts where completed including the building of the elevator and writing the C code for the 68HC11 microcontroller.

1.5 Overview of Report

This report represents a comprehensive overview of the steps taken in completing the 145 Theremin. All material necessary to recreate and expand upon the design is included in a straightforward manner. The proceeding chapters are organized as follows. Chapter 2 includes the design specifications for the 145 Theremin including block diagrams and schematics. Chapter 3 gives method of solution and tips to overcome problematic design flaws. Chapter 4 discusses the results of the final design and the test plan used to ensure a complete theremin. Chapter 5 explains the cost analysis and safety concerns. Chapter 6 addresses intangible factors such as economic concerns and aesthetics. Chapter 7 clearly states the accomplished goals for the project. Chapter 8 gives details for possible future work and extended applications. Appendices A-? give useful information including a parts list, user's manual, and a detailed calibration procedure.

Chapter Two - Design and Technical Results

2.1 Problem Statement

The objective of the project is to demonstrate the operation of a basic theremin and to use the theremin as a controller unit. To demonstrate the operation of the instrument, the 145 theremin designed by Arthur Harrison was used. The 145 Theremin consists of six individual components as seen in figure 2.1 and figure 2.2.

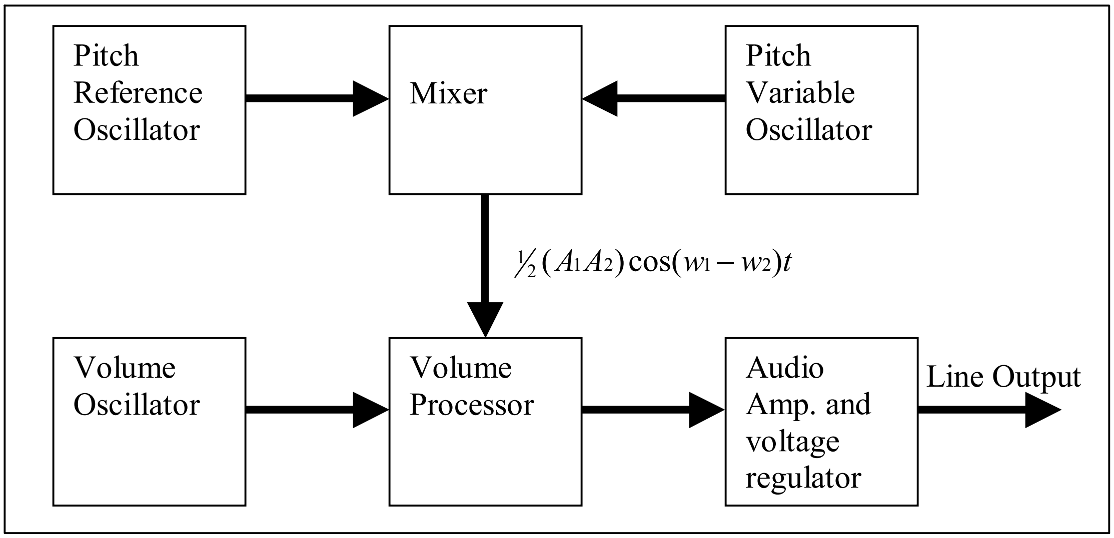

Figure 2.1 Block diagram of theremin

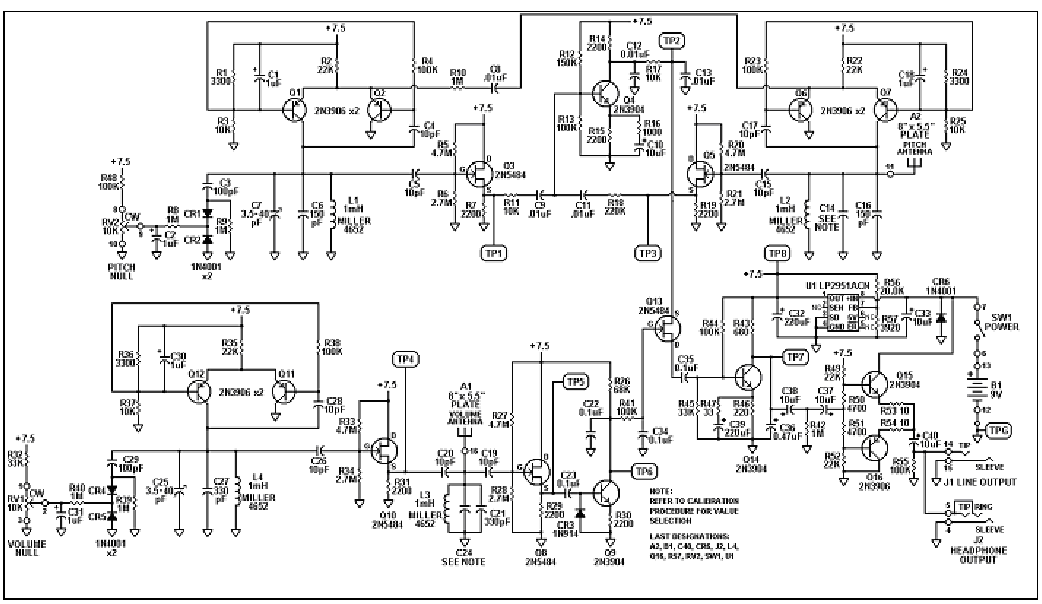

Figure 2.2 Complete Schematic of theremin

The theremin is used to control an elevator, which can move between three floors. The Motorola 68HC11 microcontroller takes in an input from the theremin and sends a signal to the stepper motor to move the elevator to a certain floor. The microcontroller is used to read the frequency of the signal from the theremin. Ranges of frequencies are assigned to move the elevator to the first floor, second, and third floors.

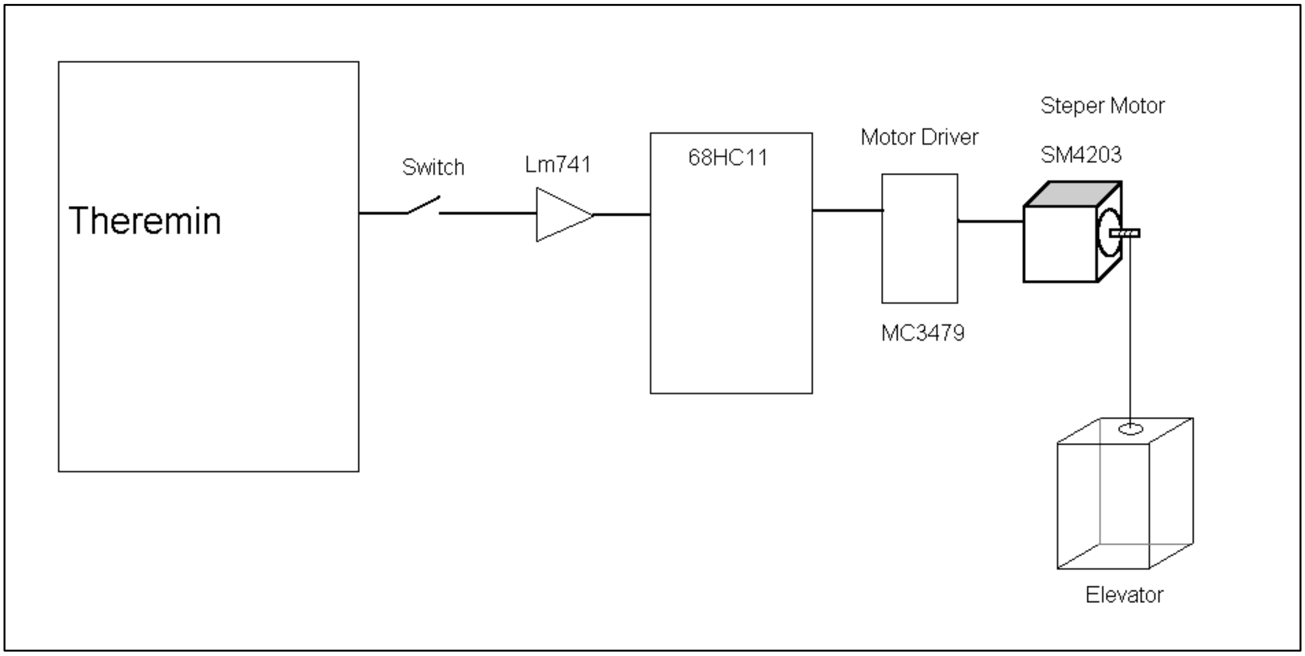

Figure 2.3 Block diagram of theremin/elevator model. Signal from theremin is taken form emitter of Q14

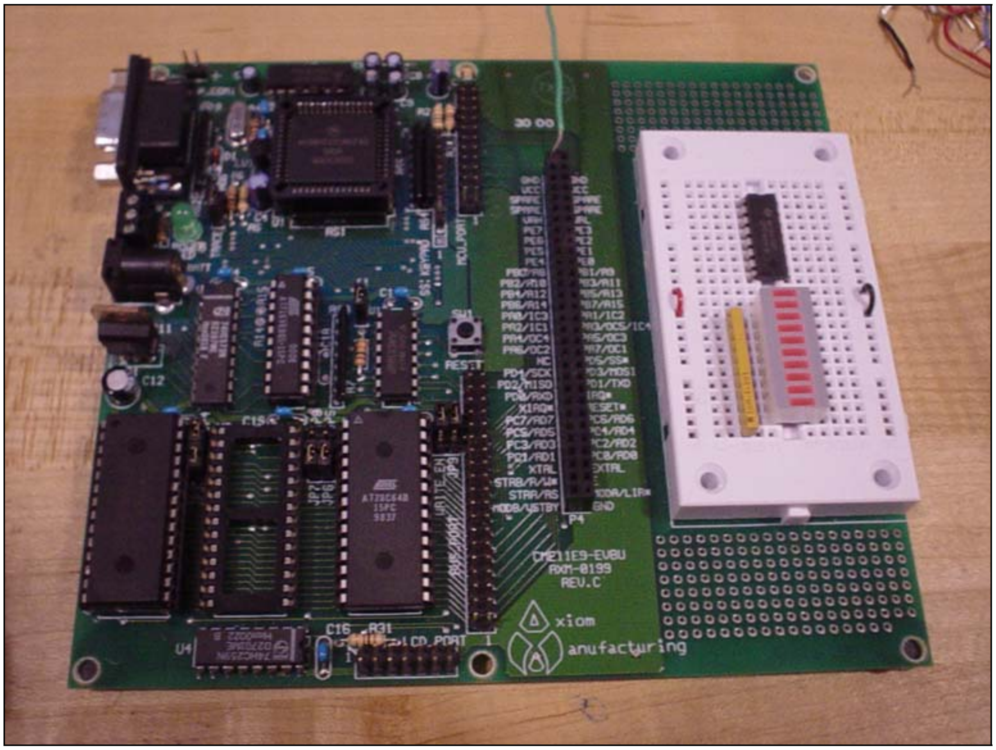

Figure 2.4 Motorola 68HC11E9

2.2 Design Specification

The core of any theremin rests upon one or more beat frequency oscillators. The 145 theremin design requires four capacitance dependent oscillators. Two are used to create a pitch frequency and two are used for volume control. The modulation of two output signals from separate oscillators can be shown to be:

$$V = A_1(\sin \omega_1 t) * A_2(\sin \omega_2 t) \qquad \textbf{Equation 2.1}$$

After some algebra the result of the modulated wave is as follows:

$$V = \tfrac{1}{2}(A_1 A_2)[\cos(\omega_1 - \omega_2)t - \cos(\omega_1 + \omega_2)t] \qquad \textbf{Equation 2.2}$$

This output signal has two frequency components, at the difference and the sum of the oscillator frequencies. The carrier frequency is formed by the sum of the two frequencies, and the beat frequency is the difference of the frequencies from the two sine waves. By making the beat frequency oscillators ultrasonic (>20,000kHz) with similar frequencies, but no closer than 20Hz, the carrier frequency remains ultrasonic and inaudible, while the beat frequency falls between the audible human ranges of 20Hz to 20,000kHz. Passing the modulated wave through a low pass filter isolates the beat frequency resulting in:

$$V = \tfrac{1}{2}(A_1 A_2)\cos(\omega_1 - \omega_2)t$$ **Equation 2.3**

Thus, a slight variation of the frequency in one oscillator will change the beat frequency($\omega_1 - \omega_2$) in equation 2.3. These variations will be provided by the player's hand, resulting in varied tone and volume from varied capacitance.

To control the elevator the microcontroller must determines the frequency of the input by detecting the duty cycle of a square wave. The code has no interrupts since response time of the elevator is not a problem. The code is broken up in three segments illustrated by the flow chart on the following page:

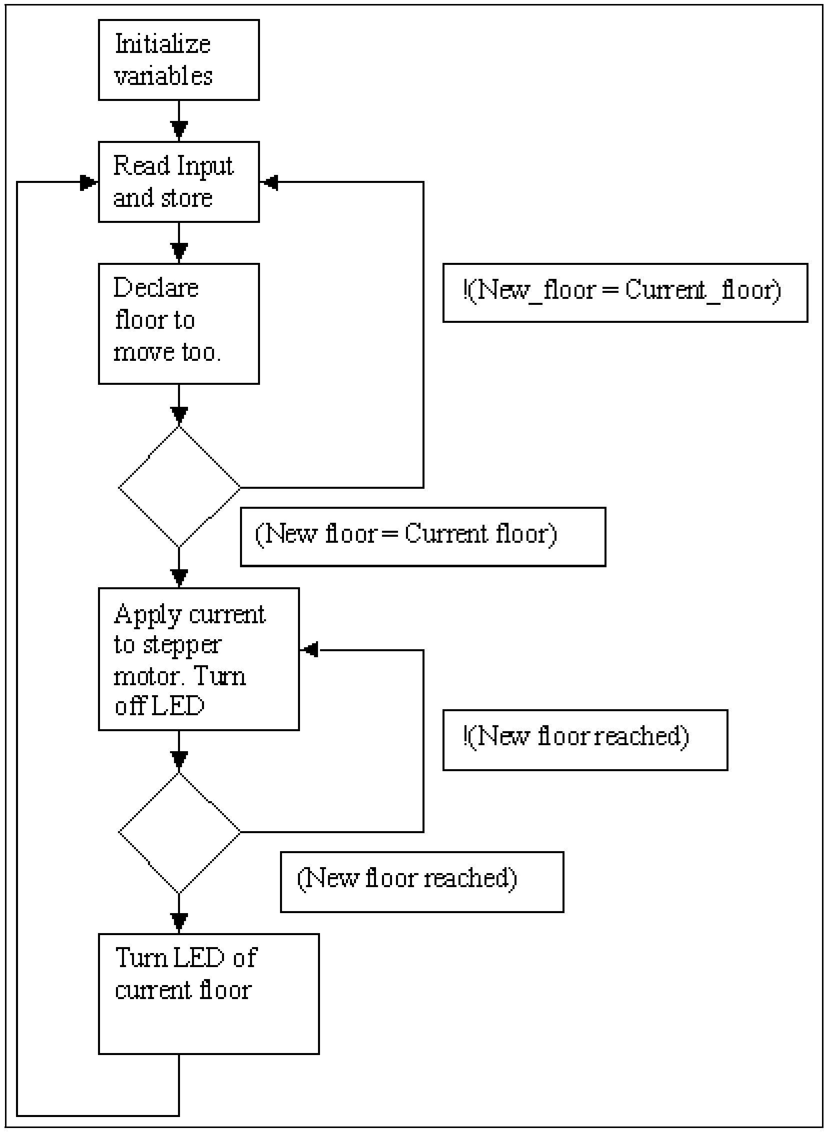

Figure 2.5 Flow chart for elevator control

2.3 Technical Results

The pitch reference and variable oscillator produce a sine wave with frequencies of about 375kHz. The input to the mixer is a heterodyned sine wave. At the output of the mixer there is a low pass filter composed of a 10K resistor and a .01µF capacitor that eliminates the summed frequency component. The amplitude of this wave is within the 40-80mV range.

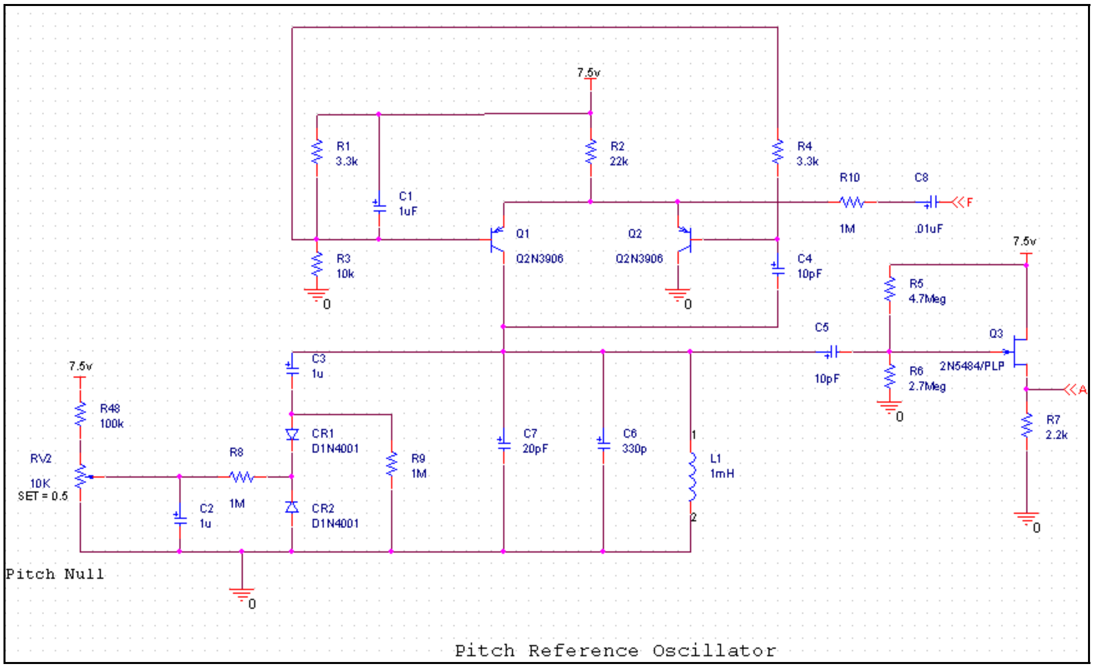

Figure 2.6 Pitch reference oscillator

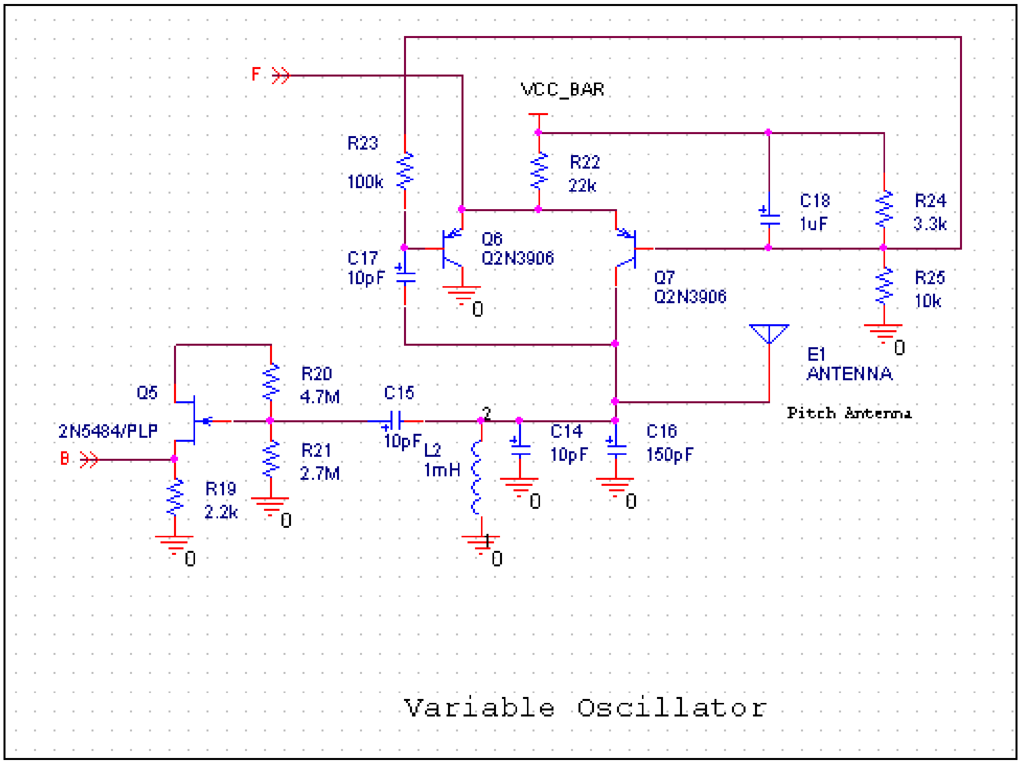

Figure 2.7 Variable oscillator

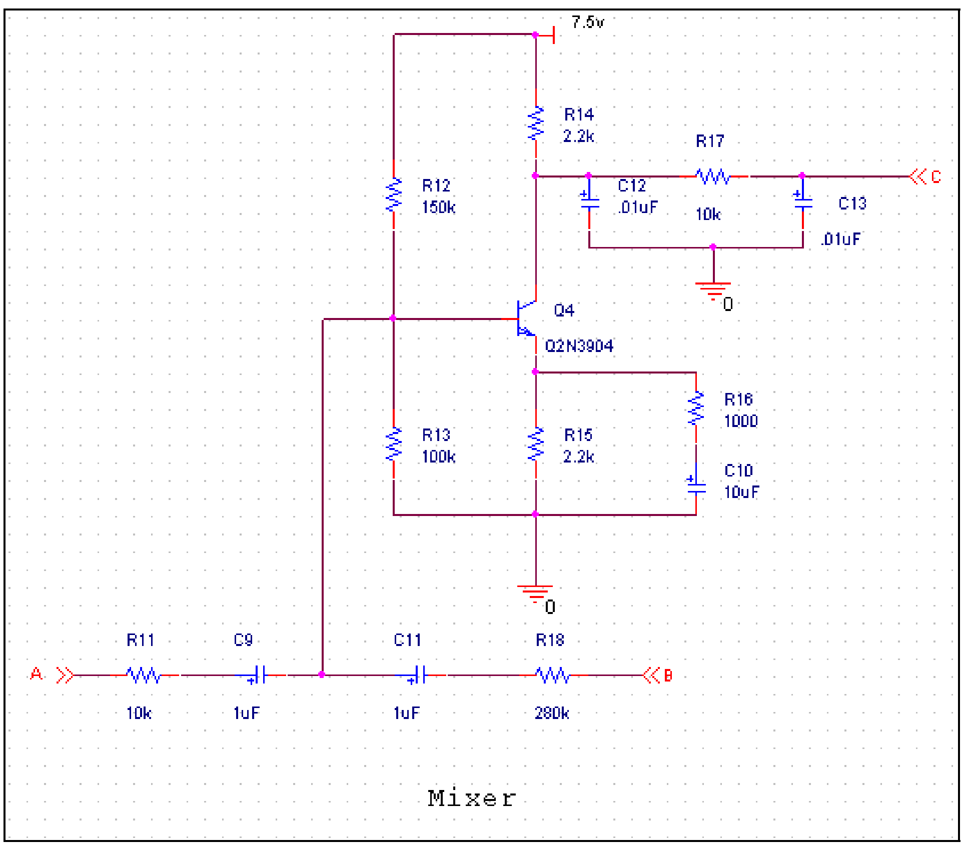

Figure 2.8 Mixer

To get an output from the mixer the frequencies of the pitch and variable oscillators must be similar. The reference oscillator is set to a frequency of about 376kHz and the variable oscillator is tuned to a similar frequency. With the hand away from the antenna the variable oscillator generates a wave with a frequency of 375.4kHz. When calibrating the theremin the capacitance of C16 had the strongest effect on the frequency of the variable oscillator. The highest frequency obtained was 714.3 kHz with a capacitance value of C16 = 130pF. The relationship between the frequency and the capacitance of C16 is not linear, but the frequency settles at about 400kHz with large values of C16. To match the variable oscillator to the reference oscillator, C16 was chosen as 189pF. The frequencies between the two oscillators differ by less than 20Hz, therefore a wave is present at the output of the mixer with the absence of the player's hand.

C16 Value (pF)	C16 configuration	Frequency (kHz)	Period (us)	Vpp
150		403.2	2.48	2.57
180		350	2.85	2.578
130	100+30	714.3	1.405	3.094
23.08	100//30	386.1	2.582	3.25
130	150+30	500	1.8	3.201
175	(150+150)//100	465.1	2.15	3.142
189	150//39	376.647	2.655	2.612

Table 2.1 Frequency of pitch variable oscillator related to capacitace of C16

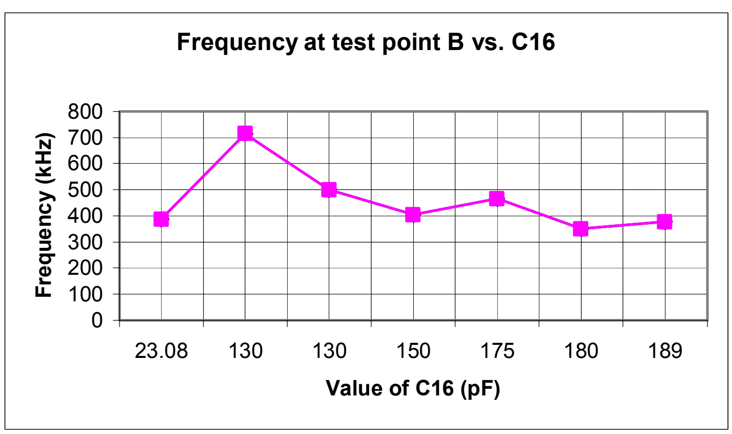

Figure 2.9 The frequency at test point B vs. capacitance at capacitor C16

The input to the volume processor is a sine wave whose amplitude is controlled by the volume oscillator. The task of the volume processor it to output a DC voltage at a potential equal to the amplitude of the input wave. In this design the range of the DC signal varies form 2V to 5.5V

The values of capacitors and resistors were chosen in order to attain a frequency range between 200Hz and 2.1kHz (see Appendix A for parts list and component values). All four oscillators produce stable sine waves with small deviation from the expected frequency.

	Period (micro-sec)	Frequency (kHz)	Frequency Deviation (kHz)
Pitch variable oscillator (No hand near antenna)	2.66	374.8	$\pm$0.2
Pitch reference oscillator	2.655	376.647	$\pm$0.3
Volume oscillator	3.46	286.9	$\pm$0.2

Table 2.2 Frequency of oscillators determined by the values of the components of the oscillators

In order control the elevator, a square wave must be detected by the 68HC11. To make the elevator go to the 1^{st}, 2^{nd}, and 3^{rd} floors the input wave must be at a predetermined frequency range. Table 2.2 shows the relationship between frequencies and floor level.

Range of frequencies	Floor
300-833	1st
834-1467	2nd
1468 and higher	3rd

Table 2.3 Relationship between frequencies and floor Position

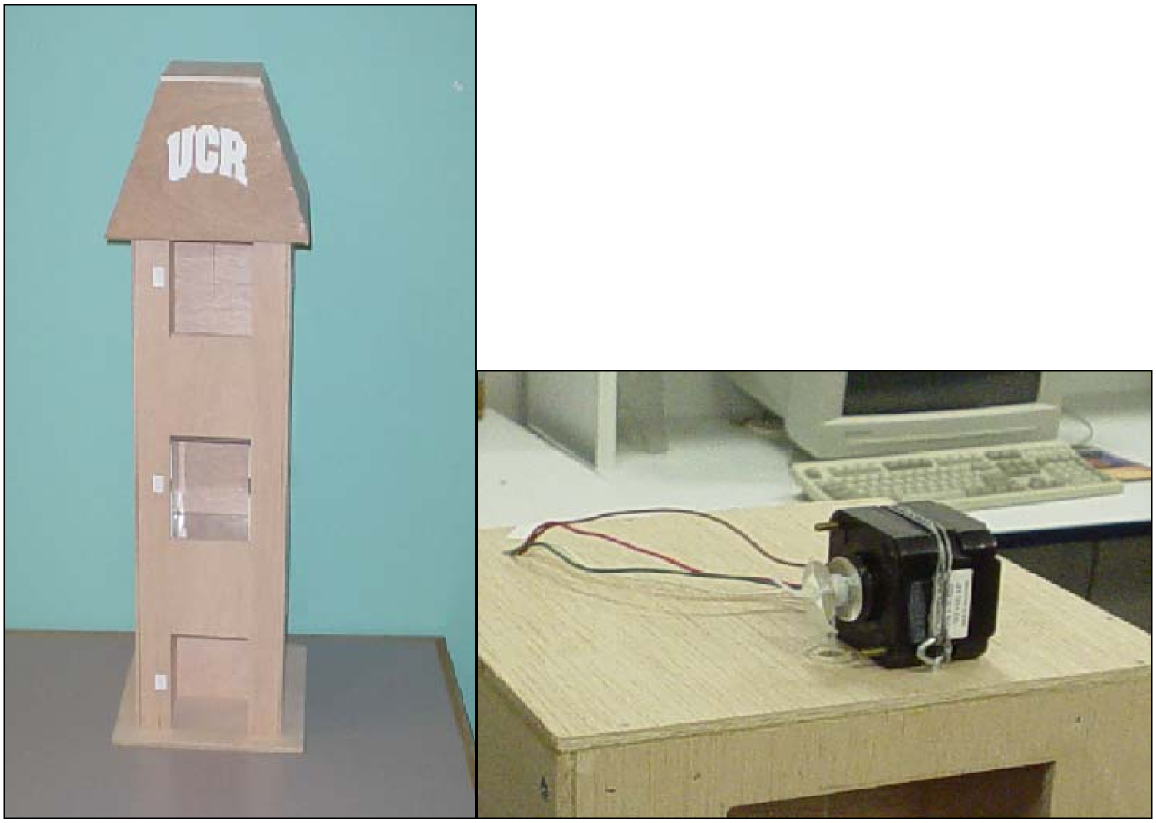

Figure 2.10 Elevator model and stepper motor

The voltage potential produced by the volume oscillator and the volume processor must be large enough to give the output of the mixer sufficient power to be detected by the speaker. To achieve a high potential at the source of transistor Q8, a capacitor C24 is placed in parallel to C21, and varied between the ranges 5pFand 30pF. The results of the calibration are as follows.

C24 Value (pF)	Vpp (V)
5	1.219
10	1.562
15	1.750
22	1.438
30	0.923

Table 2.4 Amplitude from volume processor related to C24 placed in parallel to C21

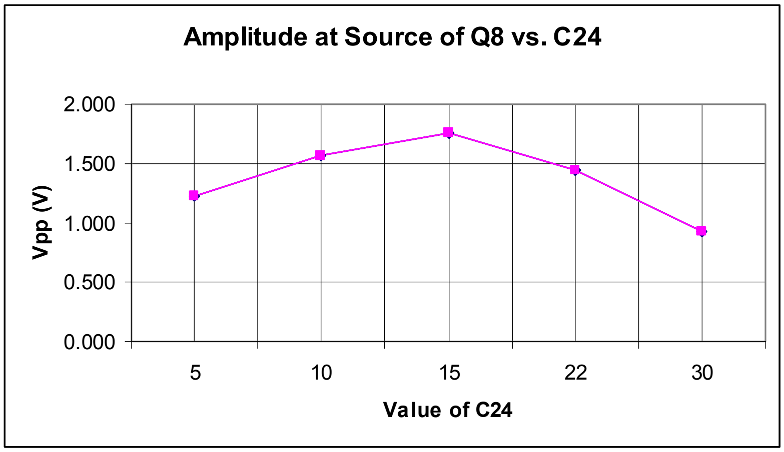

Figure 2.11 Amplitude at transistor Q8 vs capacitance at C24

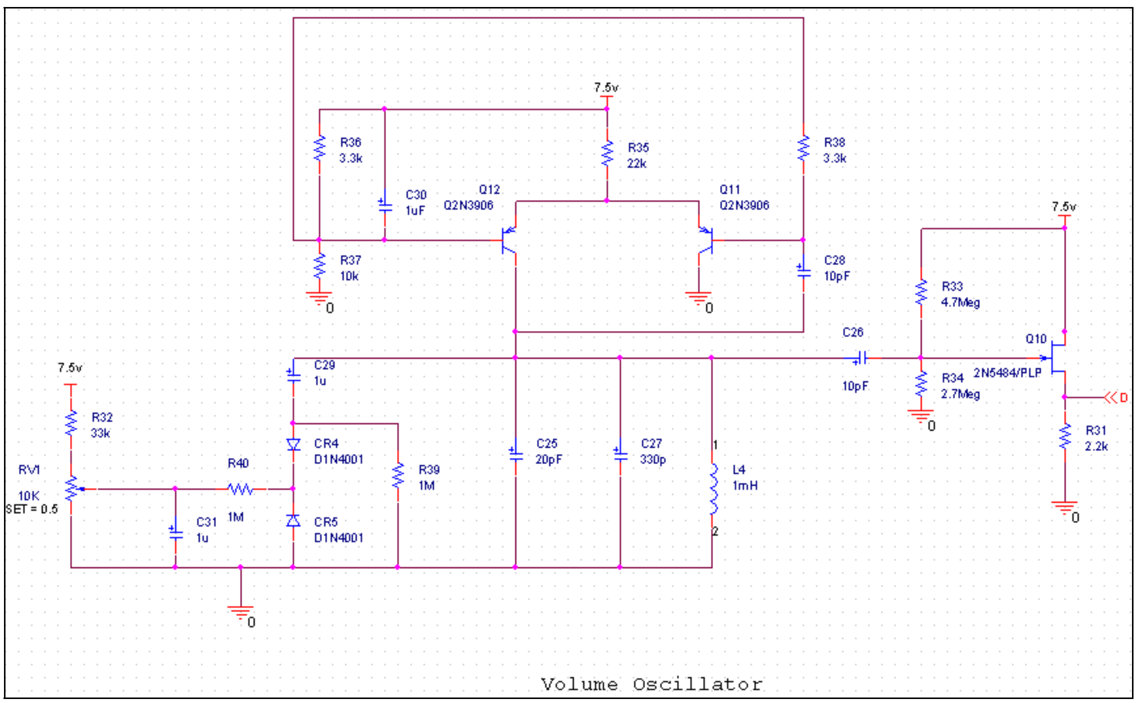

Figure 2.12 Volume Oscillator

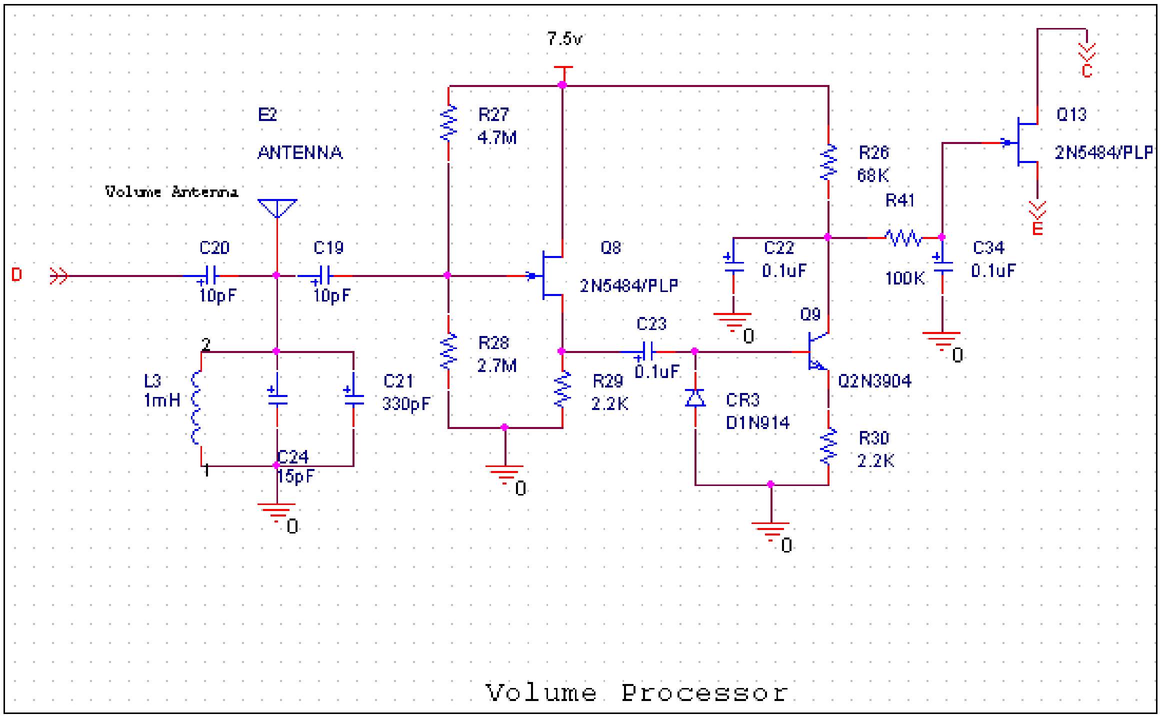

Figure 2.13 Volume Processor

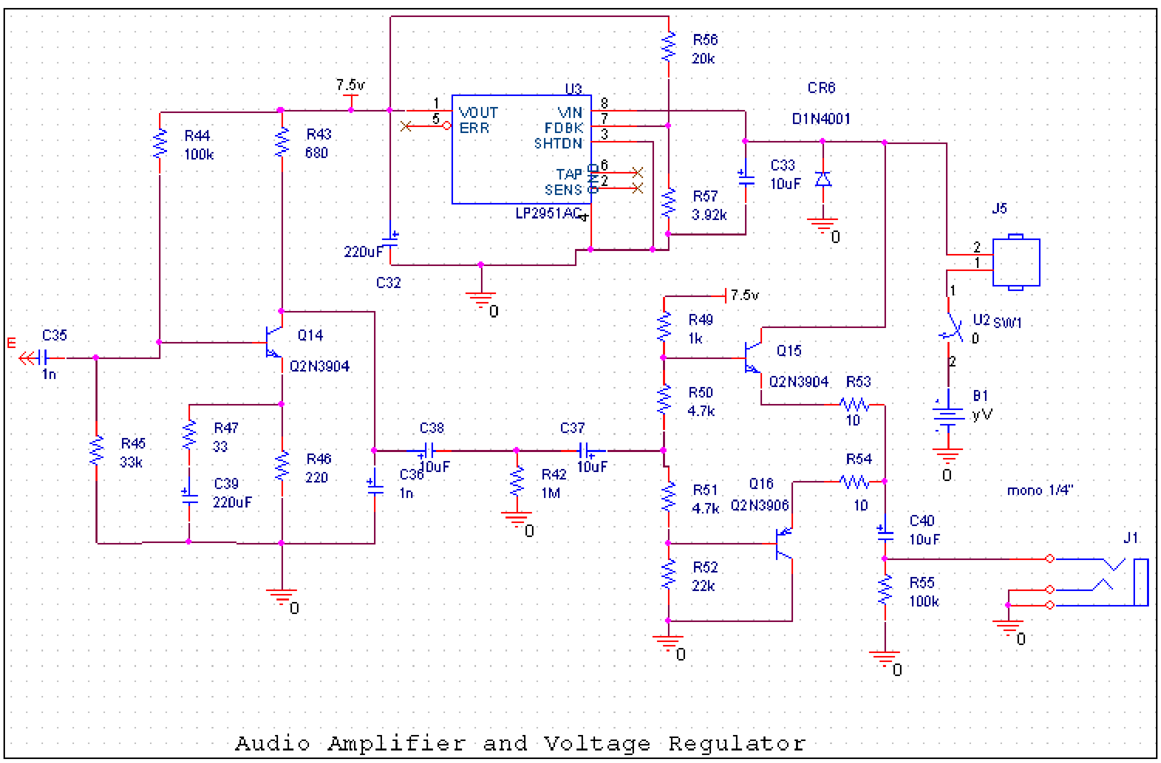

Figure 2.14 Audio Amplifier and voltage regulator

The amplitude at the source of transistor Q8 has a quadratic relation to the value of capacitor C24. The highest amplitude reached was 1.750 Vpp, which is enough to produce sound at the line output.

Notes	Frequency (Hz)	Distance From Pitch Antenna (cm)
D	550.37	5.25
B	464.69	5.50
A	440	7.00
G	391.995	8.25
E	329.627	11.00

Table 2.5 Musical Note vs. hand distance from antenna

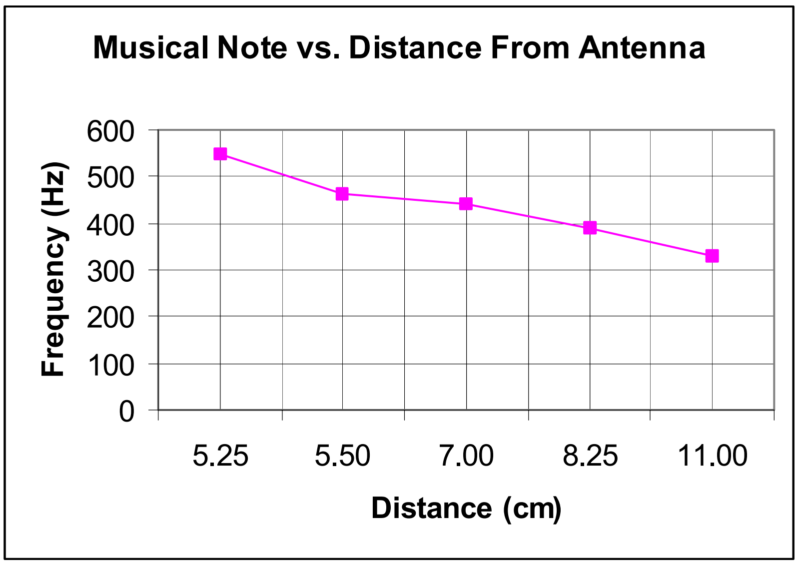

Figure 2.15 Musical Note vs. hand distance from antenna

The code for the elevator is successful in detecting the frequency from a square wave, moving between the three floors, and staying at its current floor when the input frequency matches the floor or there is not input wave. Applying a signal from a wave generator tested these functionalities. However, once the theremin signal replaced the wave generator, it was no longer possible to make the elevator function properly. Using the LM741 op-amp to amplify the signal also proved to be unsuccessful due to varying frequency problems.

Chapter Three - Method of Solution

3.1 Overview of Design Solution

Many designs and variations of the original theremin have been created since 1919. Some of the designs include the use of inductor tubes, IC chips and transistors to create the oscillators for the beat and carrier frequencies. Others incorporate lasers and sensors instead of antennas to create digital theremins. Each design is unique and there are tradeoffs with each design. Some are easier to implement, while others include more stable oscillators. The shape of the antenna also varies for one design to the next. Originally the pitch and volume antennas were strait and oval shaped, respectively. Modern theremins have incorporated varying antenna designs including hubcaps, lunch boxes, and cooking utensils. All, however, use the same principle of playing the theremin without any physical contact with the instrument.

For this project an existing schematic was used to construct the theremin. The model chosen was that of Arthur Harrison's 145 theremin. Some of the components were modified on this design and a single mono line output was incorporated for both a guitar amplifier and headphones. The final design was done on a solderless breadboard, instead of a PCB. The casing for the theremin was constructed of pinewood with outer dimensions of length = 27", width = 26" and height = 6¼".

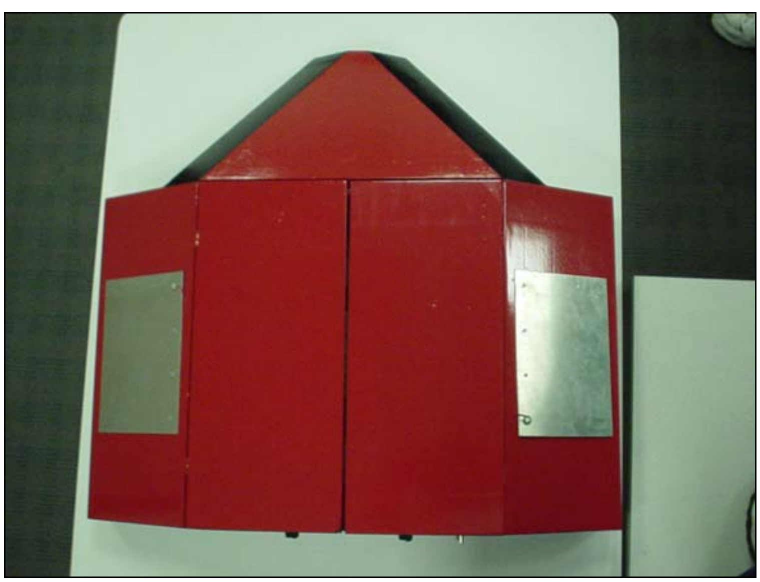

Figure 3.1 Top view of theremin

3.2 Alternative Solutions

A similar design to the 145 theremin is the 144 theremin designed by Arthur Harrison. The 144 theremin consists of Colpitts oscillators. This design was easier to construct, but it exhibits lower sound quality and half the range of hand movement than the 145 theremin.

The final theremin circuit could have been done on a printed circuit board. This would reduce both the dimension of the circuit and the dimensions of the case. This solution was initially attempted, but a short in the circuit caused the voltage regulator to draw too much current and overheat. Since this approach requires far more time then the breadboard, the PCB was not reattempted for the final design.

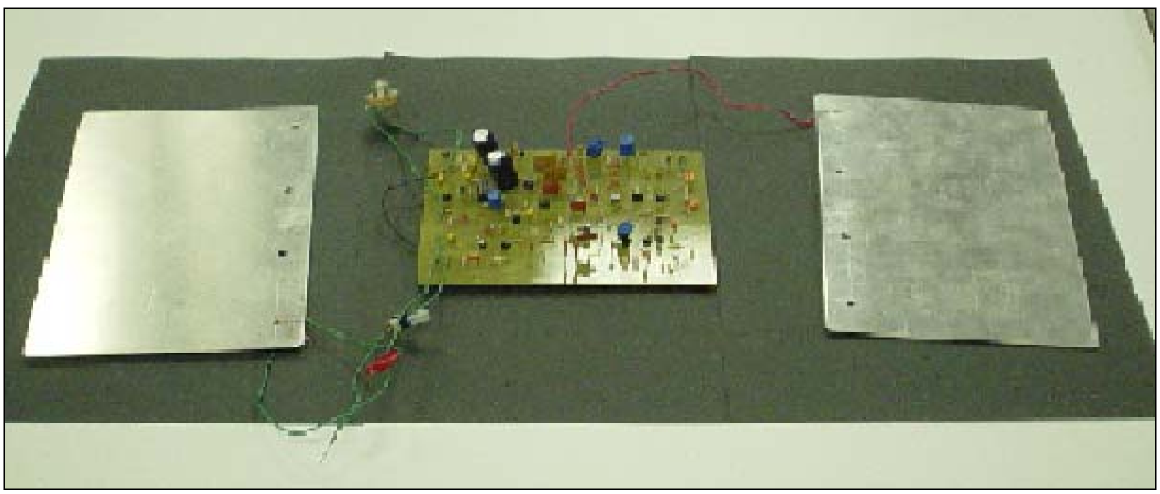

Figure 3.2 Theremin on PCB and plate antennas

3.3 Solution

The 145 theremin was chosen because it incorporates L-C pair resonators and the outputs produced are sine waves with low distortion. The audio voltage regulator used was an LP2951ACN that was programmed to generate the needed 7.5V used as the reference voltage for the rest of the components. Although the circuit required 126 components, the structure of the 145 theremin is very symmetrical. The pitch variable oscillators and volume oscillator are identically structured, and differ only in the values of the components.

The signal from the volume processor of the theremin was sent to an LM741 operational amplifier, and the resulting output was then sent to a 68HC11 microcontroller to be used as a controlling signal for an elevator model. The signal from the theremin is passed through a switch to enable a disconnection from the 68HC11 and the instrument (Figure 2.2). This was essential since it eliminates any interference from the 68HC11. To move the elevator between the three floors, the 68HC11 reads the frequency from the output of the LM741 op-amp and sends the elevator to a specific floor determined by a set of pre-set range of frequency values for each floor. The values 833.99Hz and 834.00Hz, correspond to the 1st and 2nd floors respectively, and does not confuse the 68HC11.

Chapter Four - Evaluation

4.1 Results

All four of the oscillators produce clear sine waves with minimal distortion. Based on the specifications of the 145 theremin, the frequency of oscillation is in the ultrasonic range. In order for the human input to change the pitch frequency between 200Hz and 2.1kHz, the frequency of the oscillator had to be about of 370kHz. With such high frequencies, a small variation in the capacitance of the variable oscillators produced sufficient change both in the output of the mixer and the output of the volume processor.

The final design and the prototype have the same basic functionality. The differences between the two are in the size and ease of adjustment once the circuit is complete. Originally the final product was to be done in a printed circuit board. However, the cons outweighed the pros and the final design was completed on a breadboard. The deciding factor for choosing breadboard is that the PCB completed has a short that caused the IC to draw too much current and overheat after 4 minutes of usage. Some of the grounds were not milled correctly, causing transistors Q3, Q4, Q5, Q13, and Q14 to overheat and burn. The actual short circuit in the design was never found, and there is a possibility of more then one short circuit in the design. Sound was never produced with the PCB. Soldering and testing the PCB took approximately three months, therefore creating a second PCB was not attempted and a breadboard was used as a replacement.

	145 THEREMIN	Design on Breadboard	Deign on PCB
Mounting base Area	17" x 11"	27"x26"	17"x11"
Circuit board Area	7.2" x 5.4"	7.5" x 13.5"	6.2" x 4.2"
Complexity in Debugging	N/A	Medium	Difficult
Ease of component Adjustments	N/A	Easy	Difficult
Time to complete Circuit	N/A	Days	Weeks
Noise added to the circuit	Low	Medium	Low
Reliability Over time (months)	High	Low	High
Danger of Component Disconnecting	Low	High	Low

Table 4.1 Tradeoffs between designs

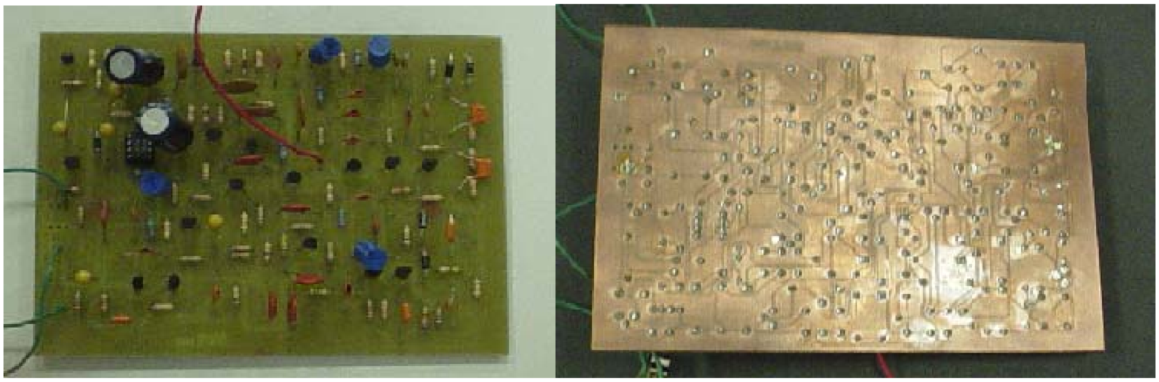

Figure 4.1 Top and bottom views of PCB

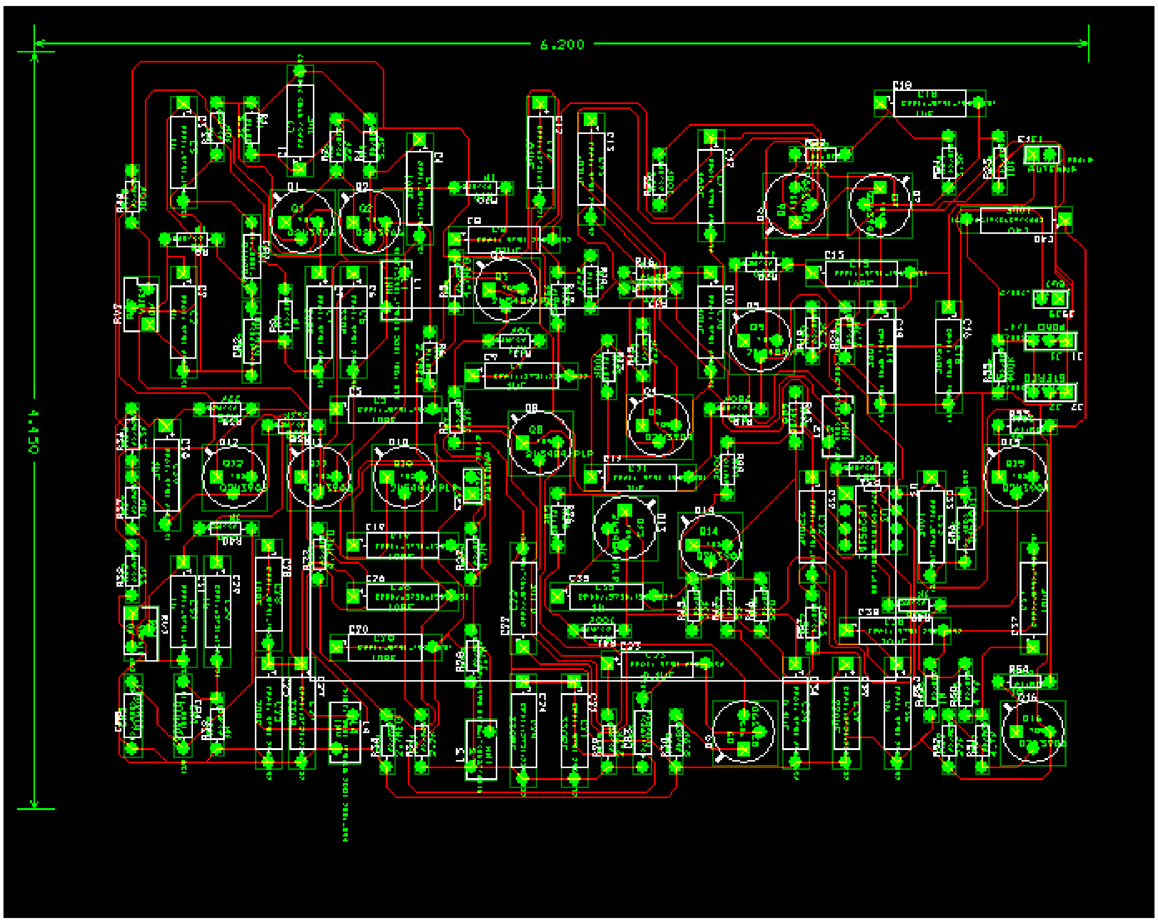

Figure 4.2 Cadence layout of PCB

4.2 Test Plan

The details for the test plan can be found in Appendix D. Each component was tested independently of each other. The first test was to make sure that each oscillator was in fact giving an output. The voltage regulator was tested individually to make sure that the reference voltage could be adjusted to a desired level. Figure 4.3 shows the test circuit used for the IC. The purpose of the test was to make sure that the chip was not damaged and to make sure that the output at pin 1 was in fact 7.5 V.

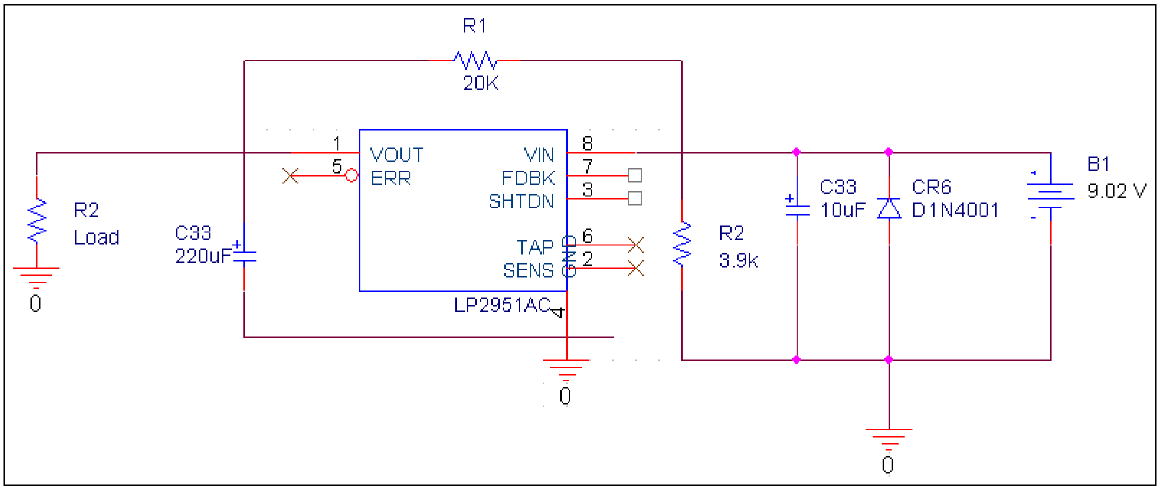

Figure 4.3 Schematic to test voltage regulator (LP2951AC)

In order to use a signal form the theremin in the 68HC11 the signal had to be amplified. This task was attempted with two different op-amps, and operational amplifier LM741 and an audio amplifier NTE823. The following schematics show the circuits that were used to test the amplification of the signal from the collector of transistor Q14.

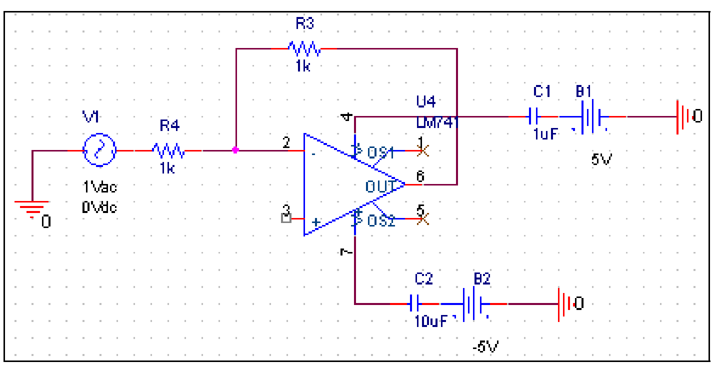

Figure 4.4 Schematic used to amplify signal from collector of transistor Q14

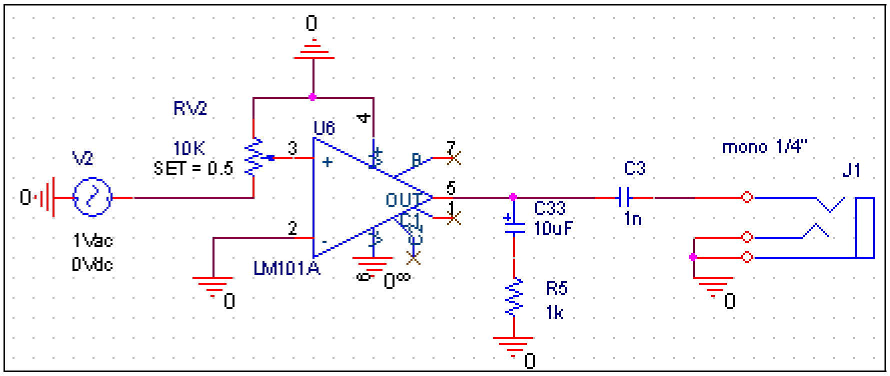

Figure 4.5 Alternative schematic used for amplify signal from collector of transistor Q14

The test for the software was broken up into four phases. The first phase was to check that the A/D conversion worked properly, second phase was the to test that the signal from the theremin could be digitized with good accuracy. The third phase was to control the stepper motor and to make sure that it stopped when there was no input. The final phase was to make the elevator respond to the input from the theremin and move to the designated floor. For the first and third phase a signal from a power supply was used to insure that the digitized signal was accurate, and to make sure that control of the stepper motor was accurate. For the second and third step the theremin was the only input.

4.3 Strengths and Weaknesses

The two major weaknesses in the design are the high potential of accidental disconnection of components and the interference between the instrument and the surroundings. Incasing the circuit board and giving it plenty of inner space reduced the risk of disconnecting any components. The case with the circuit board inside weighs a total of 25lb. Although the portability of the instrument is reduced, the ½" walls of the case help minimize the interference of its surroundings. The circuit board is attached to the case with velcro to allow the user to remove the instrument from the incasing for special tunings and to make it easier to replace any components in the circuit.

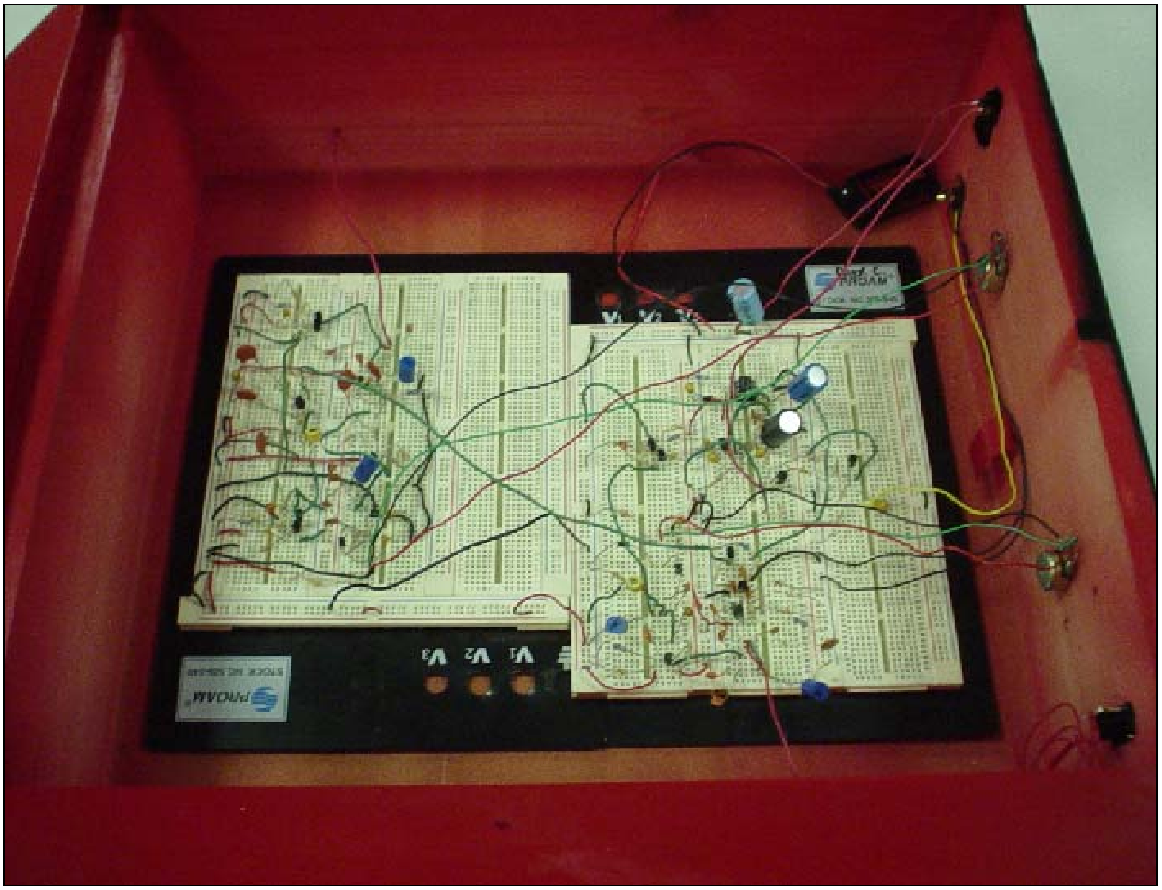

Figure 4.6 Internal view of theremin

Chapter Five - Administrative

5.1. Cost Analysis

The expected cost of building the theremin was approximated at about $440. The cost approximation was determined based on the number of parts and supplies allocated in the parts list for the project. Much of the test equipment e.g.: oscilloscope, multimeter, voltage supply and prototyping equipment, e.g.: Cadence, PCB etching and soldering irons were readily available by the college of engineering labs. Many of the passive components such as resistors, capacitors and inductors were also obtained from the college of engineering, in particular Dan Giles. Other parts such as the LP2951ACN low-drop-out voltage regulator was obtained from an online electronic store, while some extra passive components, knobs, buttons, variable capacitors and potentiometers were obtained from a local electronic store. Both the wood and the paint to build the Theremin incasing was bought at a local hardware supply store. After careful cost analysis, the total cost for the Theremin design was about $325.

5.2. Budget

Parts	Expected Cost	Actual Cost
Resistors, Capacitors	$100	$30
Potentiometers	$5	$5
Knobs, Switches	$10	$10
Breadboards	$70 x 2 = 140	$140
PC Board	$140	$0
68HC11	$100	$100
Antennas	$15	$15
Box	$60	$10
Paint	$15	$15
Total:	$440	$325

Table 5.1 Comparison between the expected cost and the actual cost of the theremin design.

5.3. Contributions and Experiences

Working as a team is a great experience for any student engineer, especially since teamwork plays a major factor in how accurate, efficient, and elaborate a project turns out to be. The experience to work as a team with friends was great. Problems did arise, specifically with the times that the team would meet to work on the project and/or discuss new discoveries or problems. Since our group consisted of three group members it was somewhat troublesome to meet everyone's desired times to meet, but with careful planning it became possible to meet and accomplish the set forth goals. Many real life situations were encountered while working on this design project including meeting deadlines, encountering delays, troubleshooting, planning, and most of all working as a team. In order to have an efficient team environment there has to be an equal work and time contribution made by every member of the team. This is done by assigning each member an individual task. This project was essentially split into three parts.

- Research and design
- PCB design (Software)
- Soldering/Breadboard (Hardware)

There were times when some of these parts overlapped and at least two of the team members were always working together. This way there could be useful feedback and interaction between the members.

Chapter Six - Elements of Design

6.1 Economic Factors

The overall cost of the project did not supersede our initial estimates therefore cost was not an imposing issue during the process.

6.2 Safety

The components used for the project where not a danger to the group while the theremin was being built. The only danger that the theremin poses is to the hearing of the player when using headphones, and to the player and bystanders while the theremin is being played through an amplifier. The theremin should not be played at high volumes, especially when using headphones.

6.3 Reliability

The theremin's reliability on producing consistent tones depends on a number of issues. First, the theremin must be properly calibrated before each use (see Appendix ? for details). If the theremin is not calibrated it will produce either altered tones or none at all. Second, the theremin is highly dependent on its environment. The theremin should not be played near a highly metallic surrounding because the added capacitance of the metal will alter the tones. Third, since the components are in a breadboard there lays the potential for components to be pulled out and disconnected. Therefore, care must be taken while transporting the theremin. Finally, the theremin will not produce satisfactory tones if the supply battery is low. Therefore, the 9-volt battery used to power the theremin should be kept as new as possible.

6.4 Aesthetics

One unique feature that a theremin encompasses is that it does not depend on its aesthetics for its functionality. Each theremin has the potential to be unique visually and still give the same sound. The theremin designed for this project has a unique aesthetic look that commands attention and resembles a space shuttle complete with wings.

6.5 Social Impacts

Although the theremin is not revolutionary scientifically it does hold other social impacts. The theremin is so unique that it can be used to inspire children to pursue the sciences by having demonstrations at schools. The presenter can give a basic explanation about the science behind the theremin, and then play the theremin by itself or along with other musicians to give a theatrical feel to the music.

Chapter Seven - Conclusions

7.1 Conclusions

The primary goal of building a 145 theremin was completed according to the original design. The playability of the instrument is as proficient as most theremins researched. The tone produced by the theremin was bright and clear. Passing the output of the theremin through an RP300 signal processor unleashed the potential of the instrument by producing a wide variety of sound. The final aesthetic design was radically different from the original idea, but became more interesting and increased the marketability of the theremin. The secondary goals of building individual signal processing units for chorus, delay, and reverb and controlling an elevator where determined to be completed as future work.

Figure 7.1 Digitech RP300 effects processor

Chapter Eight - Future Work

8.1 Impact of Work

The completed theremin has terrific potential as a musical instrument beyond its current applications. In a recording studio the theremin offers a wide range of unique sounds to work with. It can also be used as a substitute for a more traditional instrument because it can easily hold a note for a long period of time. Therefore it can substitute for a guitar being played with tremelo picking, a violin being played with a wide vibrato, or a jazz trumpet. In a live setting the theremin the theremin offers a unique experience for both the performer and the audience. Led Zeppelin guitarist Jimmy Paige played a theremin throughout the band's legendary career to produce many psychedelic tones. These brief musical interludes where always where always regarded as highlights for Zeppelin fans.

8.2 Expansion

The primary objective for future work would be to transfer the design onto a PCB board. A PCB design would greatly enhance the stability of the theremin during transportation and decrease any noise created by the breadboard. The overall size of the project would also decrease making it more marketable for musicians with limited space.

Next, three different methods for producing a stable digitized signal to input into the 68HC11 would be tested. First, an audio amplifier, NTE 823, can be used to amplify and digitize the signal from the theremin and inputted directly into the 68HC11. This powerful chip can receive a sine wave and output a square wave with a gain ranging from 20-200. The NTE 823 is readily available at a low-cost both online and at local electronics stores.

One alternative would be to use a comparator chip, LM339. This chip also inputs a sine wave and outputs a square wave, but it does not have a set gain amount. Instead the chip output peak-to-peak value depends on the supply voltage fed into the chip. For example if 7V are used as the supply voltage to the chip, then the resulting square wave would have a 7V peak-to-peak voltage, as long as it is inputted a readable signal. The LM339 is also inexpensive and widely available.

The other alternative would be to use a Digital Signal Processor or DSP chip because it is capable of higher analog-to-digital conversion clock rates, has a larger memory space, and can process signals with small amplitudes (~50mv). The trade offs for this processing speed are that the chips are costly and generally difficult to program.

Once one of three methods is chosen and implemented then the code for the elevator will set a range of frequencies for the first, second, and third floors of the elevator model.

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References

Books

C programming

[1] Deitel, Deitel, C++ How to Program 2nd edition, New Jersey, Prentice Hall, 1998

Circuits

[2] Nilsson, Riedel, Electronic Circuits 6th edition, New Jersey, Prentice Hall, 2000

[3] Sedra, Smith, Microelectronic Circuits 4th edition, Oxford University Press, 1998

[4] Hill, Horowitz, The Art of Electronics 2nd edition, Cambridge University Press, 1994

Microcontroller

[5] Spasov, Microcontroller Technology: The 68HC11, New Jersey, Prentice Hall, 2002

Websites

General information on theremins

http://www.thereminworld.com/

http://www.thereminvox.com/

http://www.theremin.info

http://home.att.net/~theremin1/145/145.html#Introduction

Microcontroller

http://www.motorola.com

General information on components

http://www.mouser.com/

http://www.nteinc.com/

http://www.national.com/

Appendix A – Parts List

ITEM	DESCPT	VALUE	MFR	MFR PART #	SUPPLIER	SUPPLIER STOCK #	QTY
A1,A2	ANTENNA						2
B1	BATTERY	9V	DURACELL	PROCELL			1
C1,C2,	DIPPED	1uF, +/-10%	KEMET	T350A105K035AS	MOUSER	80-T350A105K035	5
C30,C31	CAPACITOR	35V, RADIAL					
C3,C29	CERAMIC	100pF, +/-10%	MALLORY	CK05BX101K	MOUSER	539-CK05101K	2
	CAPACITOR	50V, RADIAL					
C8,C9,C11	CERAMIC	0.01uF, +/-10%	MALLORY	CK05BX103K	NEWARK	65F639	5
C12,C13	CAPACITOR	50V, RADIAL					
C4,C5,	CERAMIC	10 pF					
C15,C17,	CAPACITOR	+/-10%, X7R,	MALLORY	CK05BX100K	MOUSER	539-CK05100K	8
C19,C20,		50 V, RADIAL					
C26,C28							
	MICA	150 pF	CORNELL				
C6,C16	CAPACITOR	+/-5%,	DUBILIER	CD10FD151J03	NEWARK	15F1364	2
		RADIAL					
C16	MICA	130 pF	CORNELL				
(ALTERNATE	CAPACITOR	+/-5%,	DUBILIER	CD15FD131J03	NEWARK	15F1229	1
		RADIAL					
C7,C25	POLYPROPYLENE	3.5 TO 40 pF	SPRAGUE/	GYC40000	DIGI-KEY	SG3008-ND	2
C10,C33,	TANTALUM	10 uF					
C37,C38,	CAPACITOR	+/-10%,	SPRAGUE/	199D106X9020CA1	DIGI-KEY	74-199D20V10	5
C40		20 V,					
		RADIAL					
C14	CAPACITOR	CAL. PROCEDURE					1
C21,C27	MICA	330 pF	CORNELL				
	CAPACITOR	+/-5%,	DUBILIER	CD15FD331J03	NEWARK	15F1239	2
		RADIAL					
C21	MICA	300 pF	CORNELL				
	CAPACITOR	+/-5%,	DUBILIER	862-4027	ALLIED	CD15FD301JO3	1

C24	CAPACITOR	CAL. PROCEDURE					1
C22,C23,	CERAMIC	0.1 uF					
C34,C35	CAPACITOR	+/-10%, X7R,	MALLORY	CK05BX104K	NEWARK	65F651	4
		50 V, RADIAL					
C32,C39	ALUMINUM	220 uF	XICON	XRL-10V220	MOUSER	140-XRL-10V220	2
	ELECTROLYTIC	+/-20%,					
	CAPACITOR	10 V,					
		RADIAL					
C36	TANTALUM	0.47 uF	VISHAY/	199D474X0035AA1	NEWARK	17F2049	1
	CAPACITOR	+/-10%,	SPRAGUE				
		35 V					
CR1,CR2,	RECTIFIER	(USE PART NUMBER)	RECTRON	1N4001	MOUSER	583-1N4001	5
CR4,CR5,							
CR6							
CR3	DIODE	(USE PART NUMBER)	CENTRAL	1N914	MOUSER	610-1N914	1
			SEMICON-				
			DUCTOR				
J1	JACK	MONO, 1/4"	SWITCHCRAFT	111	MOUSER	502-111	1
J2	JACK	STEREO, 1/4"	SWITCHCRAFT	112B	MOUSER	502-112B	1
Q1,Q2,		PNP,	FAIRCHILD				
Q6,Q7,	TRANSISTOR	TO-92 CASE	SEMICONDUCTOR	2N3906	DIGI-KEY	2N3906-ND	7
Q11,Q12,							
Q16							
Q3,Q5,	JUNCTION FIELD EFFECT TRANSISTOR	N-CHANNEL, TO-92 CASE	CENTRAL	2N5484	MOUSER	610-2N5484	5
Q8,Q10,			SEMICON-				
Q13			DUCTOR				
Q4,Q9	TRANSISTOR	NPN,	FAIRCHILD	2N3904	DIGI-KEY	2N3904-ND	4
Q14,Q15		TO-92 CASE	SEMICONDUCTOR				
R1,R24,	RESISTOR,	3300 OHM	XICON	29SJ250-3.3K	MOUSER	291-3.3K	3
R36	CARBON	+/-5%,					
	FILM	1/4 WATT					

R2,R22,	RESISTOR,	22K OHM	XICON	29SJ250-22K	MOUSER	291-22K	5
R35,R49,	CARBON	+/-5%,					
R52	FILM	1/4 WATT					
R3,R11,	RESISTOR,	10K OHM	XICON	29SJ250-10K	MOUSER	291-10K	5
R17,R25,	CARBON	+/-5%,					
R37	FILM	1/4 WATT					
R4,R13,	RESISTOR,	100K OHM	XICON	29SJ250-100K	MOUSER	291-100K	8
R23,R38,	CARBON	+/-5%,					
R41,R44,	FILM	1/4 WATT					
R48,R55							
R5,R20,	RESISTOR,	4.7M OHM	XICON	29SJ250-4.7M	MOUSER	291-4.7M	4
R27,R33	CARBON	+/-5%,					
	FILM	1/4 WATT					
R6,R21,	RESISTOR,	2.7M OHM	XICON	29SJ250-2.7M	MOUSER	291-2.7M	4
R28,R34	CARBON	+/-5%,					
	FILM	1/4 WATT					
R7,R14,	RESISTOR,	2200 OHM	XICON	29SJ250-2.2K	MOUSER	291-2.2K	7
R15,R19,	CARBON	+/-5%,					
R29,R30,	FILM	1/4 WATT					
R31							
R8,R9,	RESISTOR,	1M OHM	XICON	29SJ250-68K	MOUSER	291-1M	6
R10,R39,	CARBON	+/-5%,					
R40,R42	FILM	1/4 WATT					
R12	RESISTOR,	150K OHM	XICON	29SJ250-150K	MOUSER	291-150K	1
	CARBON	+/-5%,					
	FILM	1/4 WATT					
R16	RESISTOR,	1000 OHM	XICON	29SJ250-1K	MOUSER	291-1K	1
	CARBON	+/-5%,					
	FILM	1/4 WATT					
R18	RESISTOR,	220K OHM	XICON	29SJ250-220K	MOUSER	291-220K	1
	CARBON	+/-5%,					
	FILM	1/4 WATT					
R26	RESISTOR,	68K OHM	XICON	29SJ250-68K	MOUSER	291-68K	1
	CARBON	+/-5%,					
	FILM	1/4 WATT					
R32,R45	RESISTOR,	33K OHM	XICON	29SJ250-33K	MOUSER	291-33K	2
	CARBON	+/-5%,					
	FILM	1/4 WATT					

R43	RESISTOR,	680 OHM	XICON	29SJ250-680	MOUSER	291-680	1
	CARBON	+/-5%,					
	FILM	1/4 WATT					
R46	RESISTOR,	220 OHM	XICON	29SJ250-220	MOUSER	291-220	1
	CARBON	+/-5%,					
	FILM	1/4 WATT					
R47	RESISTOR,	33 OHM	XICON	29SJ250-33	MOUSER	291-33	1
	CARBON	+/-5%,					
	FILM	1/4 WATT					
R50,R51	RESISTOR,	4700 OHM	XICON	29SJ250-4.7K	MOUSER	291-4.7K	2
	CARBON	+/-5%,					
	FILM	1/4 WATT					
R53,R54	RESISTOR,	10 OHM	XICON	29SJ250-10	MOUSER	291-10	2
	CARBON	+/-5%,					
	FILM	1/4 WATT					
R56	RESISTOR,	20.0K OHM	XICON	271-20K	MOUSER	271-20K	1
	METAL	+/-1%,					
	FILM	1/4 WATT					
R57	RESISTOR,	3920 OHM	XICON	271-3.92K	MOUSER	271-3.92K	1
	METAL	+/-1%,					
	FILM	1/4 WATT					
RV1,RV2		10K OHM					
(NOTE 7)	POTENTIOMETE R	+/-10%,	CLAROSTAT	308N10K	DIGI-KEY	308N103-ND	2
SW1	SWITCH	SPDT	C & K	7101SYZQE	MOUSER	611-7101-001	1
U1	INTEGRATED	(USE PART	ON SEMICONDUCTO R	LP2951ACN	NEWARK	01F2166	1
	CIRCUIT	NUMBER)					
	KNOB,	0.848"D,	ALCO	PKES70B-1/4	NEWARK	57F2347	2
	POTENTIOMETE R	0.744"H,					
	CONNECTOR		KEYSTONE	72-8	NEWARK	16F441	1
	9 Volt Battery						

Appendix B – Equipment List

B.1 Software

I. Cadence PSD 14.2
- Capture CIS
- Layout Plus

II. IAREW

III. AxIDE
- Buffalo

B.2 Hardware

I. PROAM Breadboard 509-040

II. LPKF ProtoMat C30s

III. Weller PES50 soldering iron

IV. Weller WES50 soldering iron base

V. Epiphone 10 Guitar Amplifier

VI. Digitech RP300

VII. Seiko tuner ST737

VIII. Hewlett Packard 54600B oscilloscope

IX. Hewlett Packard 34401A multimeter

X. Hewlett Packard 33120A function generator

XI. Hewlett Packard E3630A Triple output DC power supply

C.1 MATLAB Code

```
% Simulates the heterodyning of two sine waves
% Clears memory and closes all other graphs
clear all;
close all;
clc;
% Used to create a vector to store the values
% of the sine waves
x=1;
% Frequencies of sine waves
w1 = 2*pi*25;
w2 = 2*pi*3500;
% Sets increment for running time interval
b=.001; %.1

% Subroutine to create a sine wave to be ploted
% and modulated.
Amp = 2;
for t = 0:b:.2
   % Sine waves
   A(x) = Amp*sin(w1*t);
   % Plot of sin(f2*t) does not look much like a sine
   % Wave beacuse of the sampling time used (b)
   % A2 only used to show a sine wave with different frequency
   A2(x)= Amp*sin(60*pi*t);
   B(x) = Amp*sin(w2*t);
   % Two multiplied sine waves
   D(x) = .5*(Amp*Amp)*(cos((w1-w2)*t)+cos((w1+w2)*t));
   % Component of beat frequency
   V(x) = .5*(Amp*Amp)*cos((w1-w2)*t);
   % Incriments the pointer to the vector
   x=x+1;
end

% Set time vector used to plot the generated waves
time = 0:b:t;
% Plots figures
figure (1);
plot(time,A), title('sin(w1*t)');
xlabel ('time (sec)'), ylabel ('Amplitude');
figure (2);
plot(time,A2), title('sin(w2*t)');
xlabel ('time (sec)'), ylabel ('Amplitude');
figure (3);
```

```
plot(time,D), title('.5*(Amp*Amp)*(cos((w1-w2)*t)+cos((w1+w2)*t));');
xlabel ('time (sec)'), ylabel ('Amplitude');
figure (4)
plot(time,V), title('.5*(Amp*Amp)*cos((w1-w2)*t)');
xlabel ('time (sec)'), ylabel ('Amplitude');
```

C.2 C Code

```
/*Code to control elevator, using theremin output as input signal*/

#define first 1
#define second  2
#define third 3

#define first_floor 1
#define second_floor 2
#define third_floor 3
#define stop_elevator 4

#include "io6811.h"
#include <stdio.h>

unsigned int interval, i;
unsigned int motor_output;
unsigned int Rise_time, Fall_time, Pulse_width, frequency, elev_floor;
int elevator, current_floor;
int temp;
int floor = 1;


void main(void){

   PACTL |= 0x80;   /*A6 - A3 as output*/
   OC1M = 0x80;     /*enables OC1 to A7*/
   OC1D = 0x00;    /*set A7 response to low*/
   elevator = first_floor;
   PORTE &= 0x00;
   while(1){

   switch (elevator){

      case first_floor:
         switch (current_floor){

            /*Going from 1st to 2nd floor*/
            case second:
```

```
  PORTA &= 0xDF;    /*set direction CW to go up and turn engine on*/
  for(interval= 0; interval < 650; interval++){

      OC1D = 0x00;      /*drives output low*/
      TOC1 = TCNT + 3250;   /*delay set*/
      TFLG1 |= 0x80;        /*clear flag*/
      while(!(TFLG1 & 0x80));  /*waits for rising edge*/
      OC1D = 0x80;            /*drives A7 high*/
      TOC1 = TCNT + 3250;     /*delay set*/
      TFLG1 = 0x80;           /*clear flag*/
      while(!(TFLG1 & 0x80));  /*wait for rising edge*/

  }
  temp = second_floor;
  elevator = stop_elevator;
  PORTE &=0x00;
  TCTL1 = 0x00;
  PORTA |= 0x20;    /*Stops the motor*/
  /*printf("floor 2\r");*/
  floor = 2;
  break;

/*Going from 1st to 3rd floor*/
case third:
  PORTA &= 0xDF;    /*set direction CW to go up and turn engine on*/

  for(interval= 0; interval < 1176; interval++){

      /*motor_ouput = delta_function[interval++];*/
        OC1D = 0x00;      /*drives output low*/
          TOC1 = TCNT + 3250;   /*delay set*/
          TFLG1 |= 0x80;        /*clear flag*/
          while(!(TFLG1 & 0x80));  /*waits for rising edge*/
          OC1D = 0x80;            /*drives A7 high*/
          TOC1 = TCNT + 3250;     /*delay set*/
          TFLG1 = 0x80;           /*clear flag*/
          while(!(TFLG1 & 0x80));  /*wait for rising edge*/

  }

  temp = third_floor;
  elevator = stop_elevator;
  PORTE &=0x00;
  TCTL1 = 0x00;
  PORTA |= 0x20;    /*Stops the motor*/
  /*printf("floor 3\r");*/
```

```
            floor = 3;
            break;

        default:
            temp = first_floor;
            elevator = stop_elevator;
            PORTE &=0x00;
            TCTL1 = 0x00;
            PORTA |= 0x20;    /*Stops the motor*/
            /*printf("floor 1\r");*/
            floor = 1;
            break;

    }
break;

case second_floor:
    switch (current_floor){

        /*Going from 2nd to 3rd floor*/
        case third:
            PORTA &= 0xDF;    /*set direction CW to go up and turn engine on*/

            for(interval= 0; interval < 530; interval++){

                    /*motor_ouput = delta_function[interval++];*/
                    OC1D = 0x00;      /*drives output low*/
                    TOC1 = TCNT + 3250;   /*delay set*/
                    TFLG1 |= 0x80;         /*clear flag*/
                    while(!(TFLG1 & 0x80));  /*waits for rising edge*/
                    OC1D = 0x80;             /*drives A7 high*/
                    TOC1 = TCNT + 3250;     /*delay set*/
                    TFLG1 = 0x80;            /*clear flag*/
                    while(!(TFLG1 & 0x80));  /*wait for rising edge*/

            }
            temp = third_floor;
            elevator = stop_elevator;
            PORTE &=0x00;
            TCTL1 = 0x00;
            PORTA |= 0x20;    /*Stops the motor*/
            /*printf("floor 3\r");*/
            floor = 3;
            break;

        /*Going from 2nd to 1st floor*/
```

```
        case first:
          PORTA &= 0xf8;    /*set direction CCW to go down and turn engine on*/
          for(interval= 0; interval < 650; interval++){

              /*motor_ouput = delta_function[interval++];*/
              OC1D = 0x00;      /*drives output low*/
              TOC1 = TCNT + 3250;   /*delay set*/
              TFLG1 |= 0x80;         /*clear flag*/
              while(!(TFLG1 & 0x80));  /*waits for rising edge*/
              OC1D = 0x80;             /*drives A7 high*/
              TOC1 = TCNT + 3250;     /*delay set*/
              TFLG1 = 0x80;            /*clear flag*/
              while(!(TFLG1 & 0x80));  /*wait for rising edge*/

          }
          temp = first_floor;
          elevator = stop_elevator;
          PORTE &=0x00;
          TCTL1 = 0x00;
          PORTA |= 0x20;    /*Stops the motor*/
          /*printf("floor 1\r");*/
          floor = 1;
          break;

        default:
          temp = second_floor;
          elevator = stop_elevator;
          PORTE &=0x00;
          TCTL1 = 0x00;
          PORTA |= 0x20;    /*Stops the motor*/
          /*while(current_floor == second);*/
          /*printf("floor 2\r"); */
          floor = 2;
          break;
    }
  break;

  case third_floor:
    switch (current_floor){

        /*Going from 3rd to 2nd floor*/
        case second:
          PORTA &= 0xf8;    /*set direction CCW to go down and turn engine on*/
          for(interval= 0; interval < 530; interval++){

              OC1D = 0x00;      /*drives output low*/
```

```
        TOC1 = TCNT + 3250;   /*delay set*/
        TFLG1 |= 0x80;        /*clear flag*/
        while(!(TFLG1 & 0x80));  /*waits for rising edge*/
        OC1D = 0x80;          /*drives A7 high*/
        TOC1 = TCNT + 3250;     /*delay set*/
        TFLG1 = 0x80;           /*clear flag*/
        while(!(TFLG1 & 0x80));  /*wait for rising edge*/

    }
    temp = second_floor;
    elevator = stop_elevator;
    TCTL1 = 0x00;
    PORTA |= 0x20;    /*Stops the motor*/
    /*printf("floor 2\r");*/
    floor = 2;
    break;

/*Going from 3rd to 1st floor*/
case first:
    PORTA &= 0xf8;    /*set direction CCW to go down and turn engine on*/
    for(interval= 0; interval < 1176; interval++){

        /*motor_ouput = delta_function[interval++];*/
        OC1D = 0x00;      /*drives output low*/
        TOC1 = TCNT + 3250;   /*delay set*/
        TFLG1 |= 0x80;        /*clear flag*/
        while(!(TFLG1 & 0x80));  /*waits for rising edge*/
        OC1D = 0x80;          /*drives A7 high*/
        TOC1 = TCNT + 3250;     /*delay set*/
        TFLG1 = 0x80;           /*clear flag*/
        while(!(TFLG1 & 0x80));  /*wait for rising edge*/

    }
    temp = first_floor;
    elevator = stop_elevator;
    PORTE &= 0x00;
    TCTL1 = 0x00;
    PORTA |= 0x20;    /*Stops the motor*/
    /*printf("floor 1\r"); */
    floor = 1;
    break;

default:
    temp = third_floor;
    elevator = stop_elevator;
    PORTE &=0x00;
```

```
            TCTL1 = 0x00;
            PORTA |= 0x20;    /*Stops the motor*/
            /*printf("floor 3\r");*/
            floor = 3;
            break;
    }
break;
case stop_elevator:
    TCTL1 = 0x00;
    PORTA |= 0x20;    /*Stops the motor*/
    TCTL1 = 0x00;
    printf("floor %d\r", floor);
    elevator = temp;

    DDRD = 0xFF;
    PORTD &= 0x00;
    PORTA = 0x00;
    PACTL |= 0x80;

    TCTL2 = 0x10;                    /*config. to rising edge*/
    TFLG1 = 0x04;                    /*clear capture flag*/

    while((TFLG1 & 0x04)==0){}             /*wait for rising edge*/
    Rise_time = TIC1;

    TCTL2 = 0x10;                    /*config. to falling edge*/
    TFLG1 = 0x04;                        /*clear capture flag*/
    while((TFLG1 & 0x04)==0){}             /*wait for falling edge*/
    Fall_time = TIC1;
    Pulse_width = Fall_time - Rise_time;           /*get pulse width*/

    frequency = (20000/Pulse_width)/10;          /*Frequency devided by 10 to
                                       only take into acoount the most sig figs*/

    if ((frequency == 30)||(frequency == 83)){
        current_floor = first;
    }
    if ((frequency == 84)||(frequency == 146)){
        current_floor = second;
    }
    if ((frequency >= 147)){
        current_floor = third;
    }

break;
default:
```

```
        elevator = stop_elevator;
        PORTE &= 0x00;
        TCTL1 = 0x00;
        PORTA |= 0x20;    /*Stops the motor*/
        break;
     } /*closes main switch */
  } /*closes the while loop*/
}
```

Appendix D – Test and Calibration Procedure

1. Open doors to theremin. Apply power by connecting the 9 volt battery and setting the power switch to the "ON" position. Connect the instrument's ground to earth ground. The earth ground connection to the instrument may be made via the "sleeve" contact of the LINE OUTPUT JACK, J1, or its metal support bracket.

   Keep test leads and other objects away from the circuit board and antennas, as they will adversely affect the calibration.

2. Place both potentiometers in their central positions.

3. Connect a DC voltmeter (10v DC scale) to the circuit as follows:

   Meter NEGATIVE lead to TPG (circuit ground).

   Meter POSITIVE lead to TP8 (output of the voltage regulator).

4. Observe +7.50vdc +/-0.35vdc.

5. Connect an oscilloscope (50mv/div. vertical sensitivity, AC coupled; 5uS/div. horizontal sweep rate, internally triggered) as follows:

   Oscilloscope GROUND LEAD to TPG.
   Oscilloscope PROBE to TP8 (output of the voltage regulator).

6. Observe less than 40mv peak-to-peak power supply noise.

7. Connect the oscilloscope PROBE to TP1 (output of the PITCH REFERENCE OSCILLATOR). (Oscilloscope set for 2v/div. vertical sensitivity, DC coupled; 1uS/div. horizontal sweep rate, internally triggered.)

8. Observe a sine wave form: 4v peak-to-peak with the upper excursion at 5.5v, and a period of approximately 2.8uS.

9. Connect the oscilloscope PROBE to TP3 (output of the PITCH VARIABLE OSCILLATOR).

10. Observe a sine wave form: 5v peak-to-peak with the upper excursion at 6v, and a period of approximately 2.8uS.

11. Move your hand to and from the PITCH ANTENNA and observe that the wave form period increases slightly with decreasing hand distance. The total period variation will be approximately 75nS, corresponding to a frequency deviation of approximately 10kHz.

12. NOTE: To obtain an audible output from the theremin, the two pitch oscillators must be very similar in frequency; it is their difference frequency, generated by the MIXER, that equals the audible pitch. Therefore, critical adjustment of these oscillators' frequencies is important.

    For uncalibrated instruments, the initial relation of the two pitch oscillators will not produce an audible MIXER output. Assuming this is the case, the next step is to adjust variable capacitor C7, and observe if the MIXER output shifts toward an audible frequency.

    Connect the oscilloscope PROBE to TP2 (output of the MIXER). (Oscilloscope set for 200mv/div. vertical sensitivity, AC coupled; 1mS/div. horizontal sweep rate, internally triggered.)

13. Observe the wave form while slowly adjusting capacitor C7.

    Adjust C7 so that the AC wave form is absent with the hand away from the PITCH ANTENNA, and rising in frequency as the hand approaches the antenna. For a difference frequency of 50Hz, the MIXER output wave's amplitude will be about 80mv AC peak-to-peak. At this frequency, the wave will be pulse-shaped with significant asymmetry. As the frequency increases, the wave will become more sinusoidal. At 5kHz, the wave's amplitude will be about 40mv AC peak-to-peak.

    If the two oscillators' frequencies differ substantially, no AC wave form will be evident at the MIXER output. In this case, a selected value will have to be inserted in the PITCH VARIABLE OSCILLATOR's C14 position, or C16 will have to be replaced with a different value capacitor, or both.

14. When calibrated, the mixer's AC output wave form is absent with the hand away from the PITCH ANTENNA, and commences, rising in frequency, as the hand approaches the antenna. Use the PITCH NULL POTENTIOMETER to "fine-tune" the instrument's response to the pitch hand's position. Optimally, the onset of the MIXER output at TP2 will occur with the hand at about two feet from the antenna.

    NOTE: The distance-to-pitch relationship may be reversed, the highest pitch evident with the hand away from the antenna, depending on the specific adjustment of C7 and the PITCH NULL POTENTIOMETER.

15. Connect the oscilloscope PROBE TP4, (output of the VOLUME OSCILLATOR). (Oscilloscope set for 2v/div. vertical sensitivity, DC coupled; 1uS/div. horizontal sweep rate, internally triggered.)

16. Observe a sine wave form: 3.5v peak-to-peak with the upper excursion at 5v, and a period of approximately 3.7uS.

17. Move your hand to and from the VOLUME ANTENNA and observe that the wave form period remains constant.

18. Connect the oscilloscope PROBE to TP5 (slope detector buffered output). (Oscilloscope set for 1v/div. vertical sensitivity, DC coupled; 1uS/div. horizontal sweep rate, internally triggered.)

19. Slowly adjust C25 while observing the oscilloscope. Observe a waveform, centered at approximately 3.5 volts, that varies in amplitude as C25 is adjusted. The amplitude value of the sine wave should vary from approximately 0.8v to 3v peak-to-peak. Symmetrical clipping distortion will occur at approximately 2v peak-to-peak.

    If the VOLUME OSCILLATOR frequency differs substantially from the parallel-resonant frequency of L3 and C21 in the VOLUME PROCESSOR, an insufficient sine wave amplitude and amplitude variation will result at TP5.

    In this case, a selected value will have to be inserted in the VOLUME PROCESSOR C24 position, or C21 will have to be replaced with a different value capacitor, or both.

    If the adjustment of C25 alone produces satisfactory results, proceed to step 22. If not, refer to step 20, which provides a procedure for matching the VOLUME PROCESSOR's resonance to the VOLUME OSCILLATOR's frequency.

20. With the oscilloscope PROBE still at TP5, set the vertical amplifier to AC coupling and center the trace. Increase the oscilloscope's vertical sensitivity until a wave form is visible.

    Start by inserting a 5pF capacitor in the C24 position in the VOLUME PROCESSOR circuit. Note the wave form's amplitude. If it increases with the addition of the 5pF capacitor, replace the 5pF capacitor with a 10pF capacitor and determine if a further increase is evident. Repeat this procedure with successively larger-valued capacitors until the greatest possible wave form amplitude is obtained.

    If the above procedure does not result in an increase in wave form amplitude, remove any capacitors from the C24 position, replace C21 with a lower-value capacitor such as 300pF, and return to step 19.

21. With the oscilloscope PROBE still at TP5, adjust C25 so that the wave form amplitude is maximum with the hand furthest from the VOLUME ANTENNA, becoming smaller as the hand approaches the antenna. The wave form amplitude

is greatest when the parallel-resonant frequency of L3, C21, and C24 in the VOLUME PROCESSOR equals the frequency of the VOLUME OSCILLATOR.

22. Connect the oscilloscope PROBE to TP6 (VOLUME PROCESSOR output). (Oscilloscope set for 1v/div. vertical sensitivity, DC coupled; 1mS/div. horizontal sweep rate, internally triggered.) Observe a DC voltage level that varies from approximately 2v to 6v with the hand's proximity to the VOLUME ANTENNA. The DC voltage level at TP6 is lowest when the parallel-resonant frequency of L3, C21, and C24 in the VOLUME PROCESSOR equals the frequency of the VOLUME OSCILLATOR.

23. Once an adequate response at TP6 is observed, connect the oscilloscope PROBE to TP2 (the MIXER's output). Adjust the PITCH NULL POTENTIOMETER so that a wave form is present regardless of the hand's proximity to the PITCH ANTENNA. This will provide a constant signal to further calibrate the volume circuit. The exact frequency of the wave form is not critical; any frequency around 400Hz will work.

24. Connect the oscilloscope PROBE to TP7 (audio preamplifier output). Slowly adjust C25 while observing the oscilloscope. An AC wave form should appear within a segment of C25's adjustment range. Set C25 to the position where the wave form just appears.

25. Move your hand near the VOLUME ANTENNA and observe that the wave form's amplitude increases as the hand's proximity decreases. NOTE: There are two different C25 positions that will satisfy this criteria, however, only one of the adjustment positions will provide the proper volume response. Correct calibration will be evident when the onset of the wave form at TP7 occurs with the volume hand approximately 12 inches from the VOLUME ANTENNA, increasing in amplitude as the hand becomes closer. "Fine-tune" the volume response with the VOLUME NULL POTENTIOMETER. Return the PITCH NULL POTENTIOMETER to its normal position.

    C25 may be readjusted to obtain an inverted (traditional) volume response, in which the output amplitude is highest when the volume hand is furthest from the antenna.

DANGER: The following step uses headphones. In the event of a circuit malfunction, dangerous volume levels may occur in the headphones. If the headphones have a built-in volume control, initially set the control for minimum volume. If the headphones do not have a volume control, be sure that the volume level is reasonable under all circuit conditions, before wearing them.

Do not play this instrument at a high volume, especially when using headphones.

Use headphones that have a built-in volume control, and adjust the volume control for a comfortable level.

---

26. Connect headphones to the HEADPHONE OUTPUT JACK, J2 of the instrument. Place each hand in the proximity of their respective antennas, and observe an audible pitch that may be frequency modulated with one hand's proximity to the PITCH ANTENNA and amplitude modulated with the other hand's proximity to the VOLUME ANTENNA.

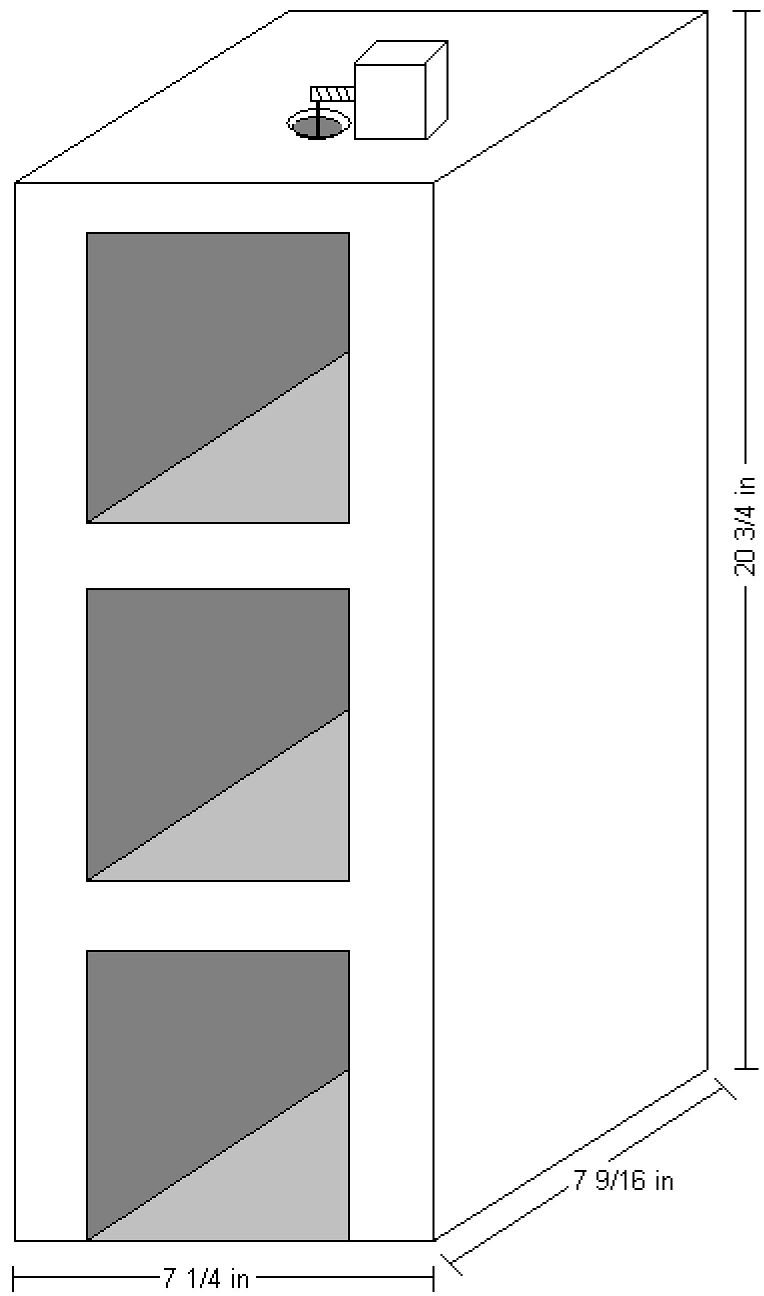
    Note: Procedure provided by Arthur Harrison

Appendix E – How to play a theremin

Playing a theremin is a unique and enjoyable experience. The plate antenna configuration of the 145 theremin makes playing it intuitive and easy. When facing the knobs of the theremin, the volume antenna is on the left and the pitch antenna is on the right. The player should move their left hand up and down over the volume antenna in order to vary the volume of the produced pitch. The closer the player's hand is to the volume antenna the lower the volume will become. The player should move their right hand over the pitch antenna to change the frequency of the tone. The closer the player's hand is to the pitch antenna the higher the frequency will become. Once the player has experience with the instrument then more expressive movements such as sweeping the hands around the antennas can be used.

Figure E.1 Playing a theremin

Appendix F – Dimensions of elevator model



Appendix G – Specifications for LP2951 voltage regulator

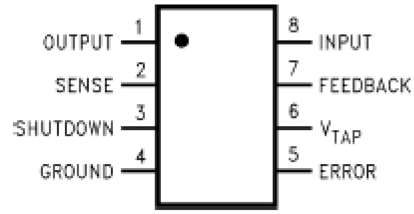
LP2950/LP2951
Series of Adjustable Micropower Voltage Regulators

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Input Supply Voltage -0.3 to +30V
SHUTDOWN Input Voltage,
Error Comparator Output
Voltage, (Note 9)
FEEDBACK Input Voltage -1.5 to +30V
(Note 9) (Note 10)
Power Dissipation Internally Limited
Junction Temperature (T_J) +150°C
Ambient Storage Temperature -65° to +150°C
Soldering Dwell Time, Temperature
Wave
Infrared
Vapor Phase
4 seconds, 260°C
10 seconds, 240°C
75 seconds, 219°C
ESD Rating
Human Body Model(Note 18) 2500V

Dual-In-Line Packages (N, J)
Surface-Mount Package (M, MM)



Operating Ratings (Note 1)

Maximum Input Supply Voltage 30V
Junction Temperature Range
(T_J) (Note 8)
LP2951 -55° to +150°C
LP2950AC-XX, LP2950C-XX,
LP2951AC-XX, LP2951C-XX -40° to +125°C

LP2950/LP2951