Senior Design 2003 Final Report

University of California, Riverside

Department of Electrical Engineering

The Theremin and Beyond

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EXECUTIVE SUMMARY

Problem Statement

The theremin is a musical instrument that operates with out actually touching it. Our goal is to study the behavior of the antennas that control the volume and pitch that produces sound. Both the volume and pitch require the use of the oscillators. The oscillators will be design in a way that will allow for easy calibration should it not operate under specifications. Understanding of the behavior will allow us to find more general applications to the device. With the use of the HC6811 micro-controller one of our goals will be to add additional features.

Chosen Method

We used two methodologies in our design. Basing our design on a version available on line, we went ahead and used the software ORCAD, to design and build the theremin. ORCAD provided us with CADENCE, which is where we drew the schematics. The schematics are then incorporated to Layout Plus, where we can design the appropriate footprints to build a perforated circuit board (PCB) on the PC mill. Once we have the PCB we must solder all components. It is required to take your time when soldering, because components could be damaged if overheated. The pads connecting the component with the proper trace could easily fall accidentally if you are not careful. Our project had to be approached with the second methodology since the first approach (PCB) failed to give us any useful results. This new approach was the construction of the circuit on bred board, which is a traditional approach.

Key features

Our projects performance high depends on the antenna design. In doing research we decided that plate antennas will give us the best results. The plate antennas are known to be more efficient. Also important were the variable capacitors used in the reference pitch oscillator and the volume oscillator. In varying the capacitance of the mentioned oscillators, frequency adjustments were possible, a crucial element in calibrating the theremin. Fine adjustments are further accomplished by yet another feature, the use of the potentiometers. What makes the instrument so productive is the amount of current it draws in. The use of a low-dropout integrated circuit regulator, allows a theremin to operate at 10 milliamps of DC current. The theremin easily operates on a single 9-volt alkaline battery.

Method of Solution

Our first methodology by way of the PCB, did not allow testing of certain areas due to the complexity of the circuit. All components were soldered, with out the knowledge of knowing if the circuit will operate correctly. As it turned out it was impossible to debug the circuit. We decided to build the circuit bred board. With the bred board, we were able to test isolated parts of the circuits and see if certain components were operating properly. This was a luxury we were not able to do with the PC board. As it turned out the, results were never obtainable with the PC board, but only with the bred board.

Evaluation Method

The circuit was tested at certain critical points were the results must meet certain specifications. If specifications were not met, calibration of the oscillators was performed.

Important Results

The key in producing a working theremin is in matching frequencies. Making the pitch a priority over the volume, work was heavily put on matching the frequencies of the pitch reference oscillator with that of the variable reference oscillators. Our second attempt at our theremin, this time by the bread board approach, produced a high difference of frequency between the oscillators. We noticed that the circuit itself was not outputting the correct values at many other tests points either. We noticed that are bread board had bad connections so we decided to start clean, on a new bred board with new parts. Our theremin produced instantaneously result in the pitch variable and reference oscillators. The pitch variable and reference oscillators consisted of frequencies very similar, which is what we wanted.

Key words

- Pitch
- Volume
- Oscillators
- Plate Antenna
- Capacitance
- Frequency
- Perforated Circuit Board (PCB)

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Chapter One - Introduction

The theremin was invented in Russia in 1919 by Lev Termen, whose name was later changed to Leon Theremin. His invention became so popular it extended to the United States as well as other parts of the world. The theremin is the only musical instrument that is played without actually touching it. Instead it is played by moving your hands in the free space surrounding the two antennas, which control intonation and volume. Earlier theremins all had the traditional monopole antenna for pitch control and loop antenna for volume control. The volume control antenna is specifically designed as a loop because the circular design creates more surface area and allows for a faster volume response. The theremin is based on the principle of a beat generator. A beat generation is the result of mixing two harmonic signals in order to generate a sound (beat). We will have two harmonic radio frequency signals, which represent the sum and difference of the frequencies of the two original radio frequency signals. If the designer is able to control the frequency oscillation of at least one of the signals then we will be able to obtain an audible signal, which is between 20 Hertz and 20kHertz.

The theremin is often known for the scary, high pitch sound that it creates. However, with the correct player it is quite possible to obtain beautiful music with this instrument. Some well known thereminists are: Clara Rockmore, Pamelia Kursten, Lydia Kavina, Samuel Hoffman and Peter Pringle. The designs of actual Theremins are endless. Although the circuitry is probably basically the same in most Theremins, the actual designs which enclose the circuitry range from automobile hubcaps to hello-kitty lunch pails to more elaborate, wooden designs. Attached in are some pictures that show the variatons of designs. Refer to appendix for the multiple pictures. The Theremin is a fascinating instrument that seems fairly simple, yet holds a huge amount of technology to it.

Chapter Two - Design and Technical Results

Our design is a close replica of Art Harrison's "144 Theremin." Art Harrison himself got this idea for the 144 Theremin from Southwest Technical Products Corporation. Southwest Technical Products Corporation was a prominent electronics kit manufacturer in the early days. The Theremin that Art Harrison replicated was originally manufactured in 1967 with a new and improved kit that came out in 1974. The design itself consists of three sub circuits. The detailed schematics could be clearly seen on the appendixes. A generalized representation of the whole circuit could be seen in the flow diagram below, figure A.

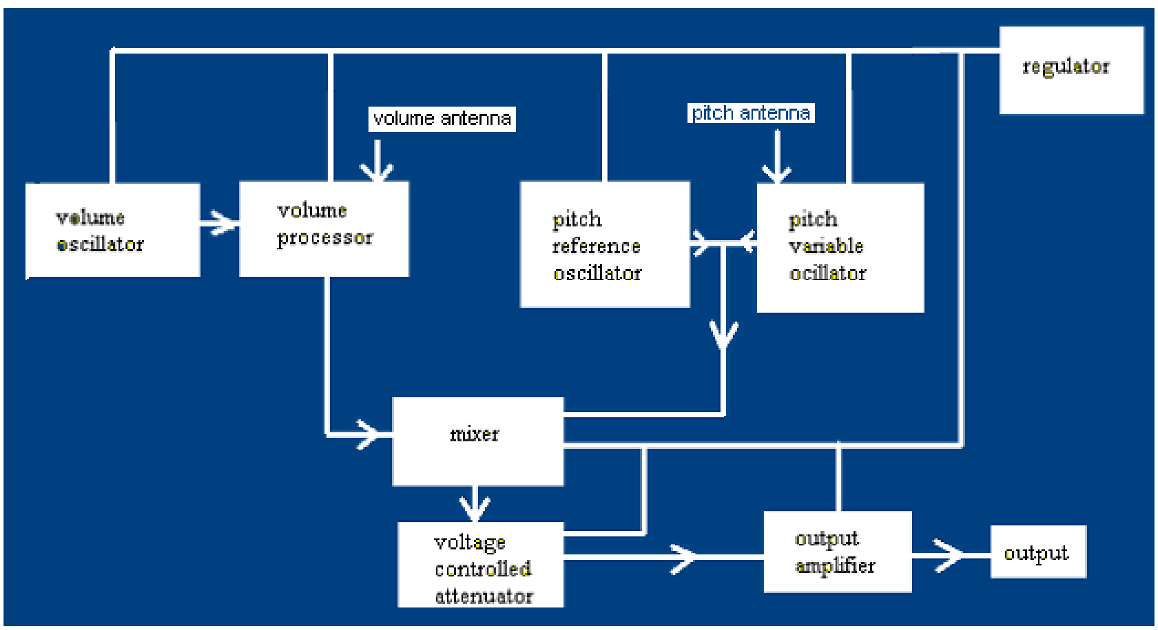


Figure A. Flow diagram representation of the Theremin and Beyond

The first sub circuit consists of the volume oscillator and the volume processor. This first circuit also contains the volume antenna. The second sub circuit consists of the mixer, the voltage controlled attenuator, the output amplifier and the voltage regulator. The third sub circuit consists of the pitch reference oscillator and the pitch variable oscillator. This part of the circuit also contains the pitch plate antenna, which is the essential component in actually making this circuit a playing instrument. Plate antennas are used as a substitution for the traditional types of antennas because they are known to be more efficient to the instrument. Throughout our design we have only made slight changes which we felt might make slight improvements. To complete our design we have enclosed it in a simple wooden box. The top of the box has a Plexiglas cover, which will prevent the circuit from being harmed yet allow it to be viewed by the user when in a playing position. On top of the Plexiglas cover we also have a wooden cover which is separated in half and slides out into two separate pieces and serve as hand rests for the two antennas. Our plate antennas are drilled and bolted into the wood so that they are not easily moved. The circuit is also bolted into the inside of the board in a sturdy fashion to avoid unnecessary movement. Both the circuit and the antennas are in a precise position because the instrument is extremely sensitive to position and as a result, sounds differently in different locations.

Our final product is a working Theremin, which can be played by the average user. Of extreme importance to the quality of sound of the instrument is the pitch null potentiometer in combination with the volume potentiometer. Shown below are tables of frequency variation with respect to distance. Each of the four tables has different potentiometer settings for the volume potentiometer and the pitch potentiometer. The volume potentiometer and the pitch potentiometer are responsible for the fine tuning of the instrument and as a result variations in tuning correspond to different pitch frequency variations. Refer to the figures below corresponding the data. Matlab code for this graphs could be seen in appendix L.

Figure 1.

Volume Potentiometer = 19.8k
Pitch Potentiometer = 15.2k

Distance (Inches)	**Frequency (Hertz)**
12	Frequency not detected
11	Frequency not detected
10	Frequency not detected
9	Frequency not detected
8	Frequency not detected
7	Frequency not detected
6	147.7
5	252.8
4	333.1
3	660.1
2	873.4
1.5	1200
1	2200

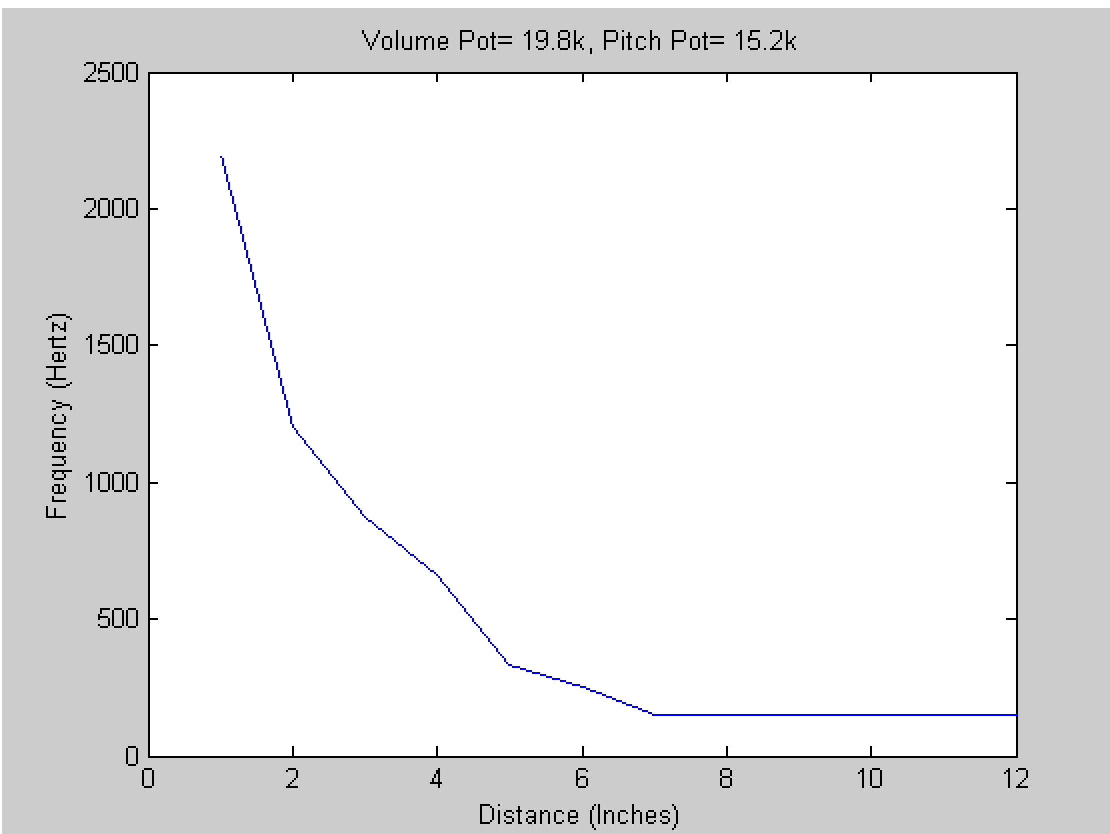


Figure 2

Volume Potentiometer = 20.5k
Pitch Potentiometer = 20.7k

Distance (Inches)	**Frequency (Hertz)**
12	495
11	445.4
10	412.4
9	389.1
8	369.7
7	277
6	260.8
5	157
4	frequency not detected
3	257.7
2	613.5
1	1250

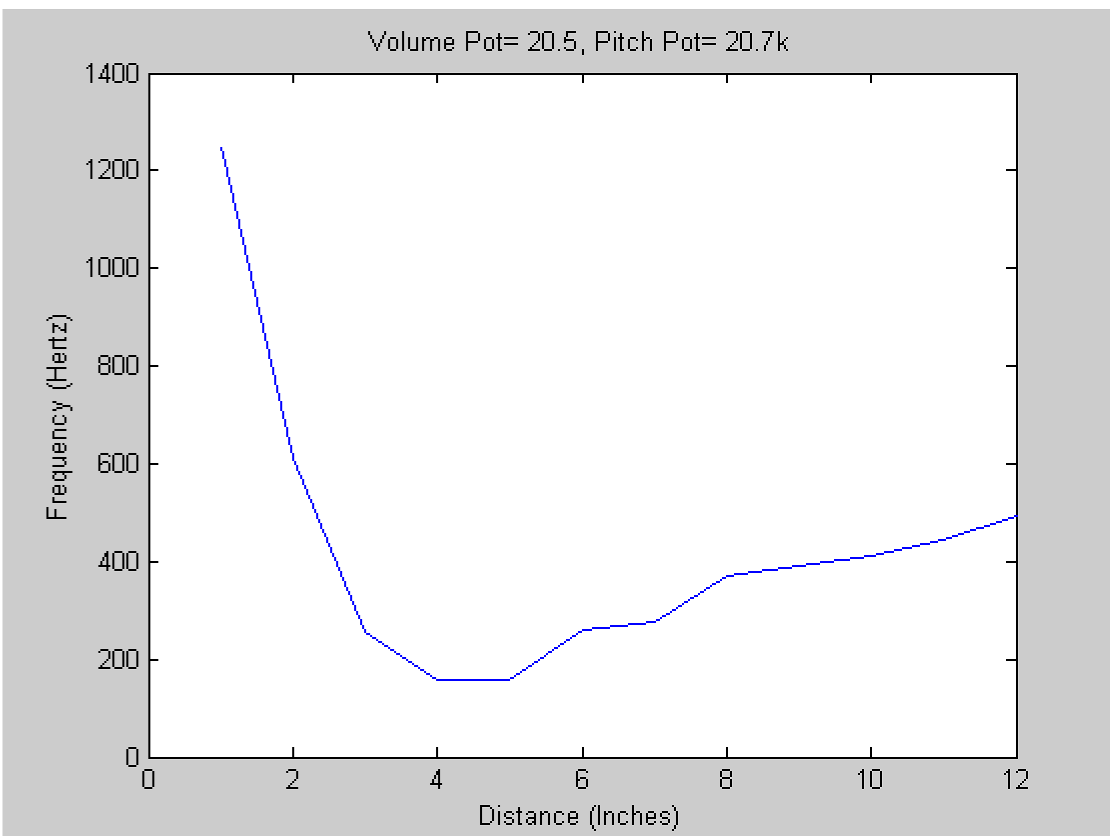


Figure 3

Volume Potentiometer = 10.0k
Pitch Potentiometer = 20.7k

Distance (Inches)	**Frequency (Hertz)**
12	384.6
11	315.0
10	250.3
9	254.1
8	240.1
7	185.4
6	150.8
5	frequency not detected
4	frequency not detected
3	307.7
2	598.1
1	1550

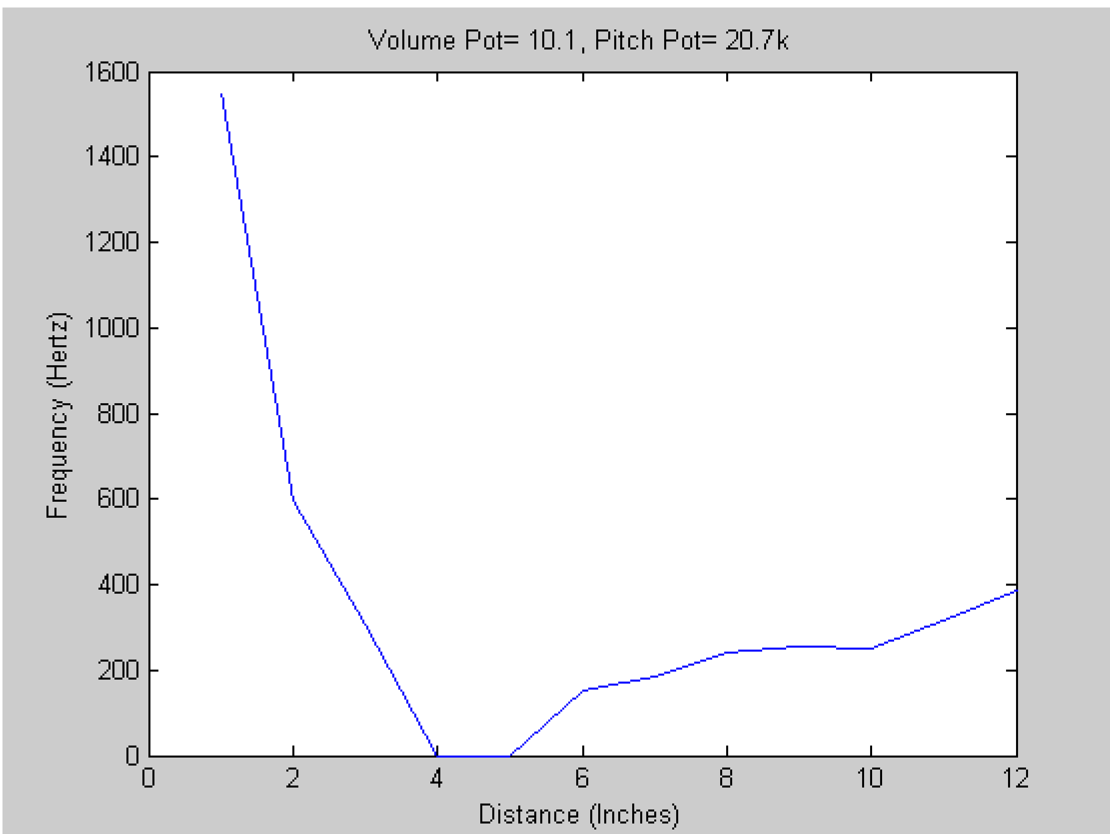
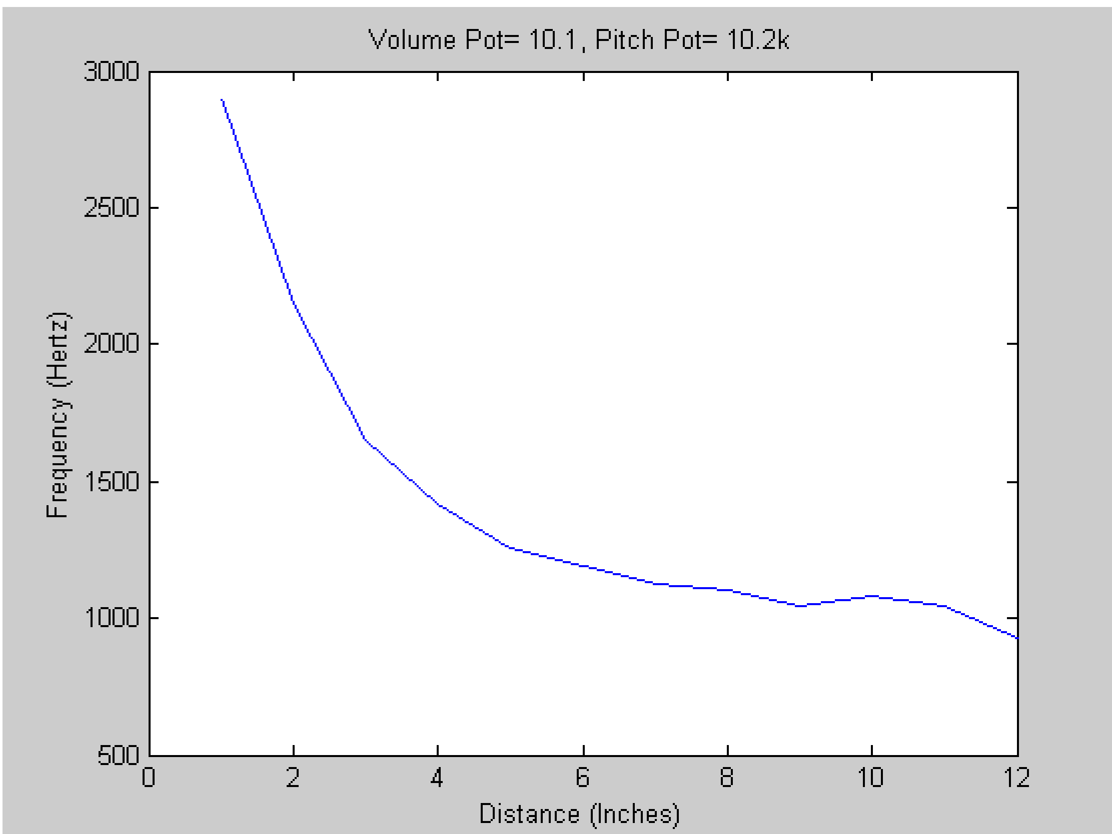


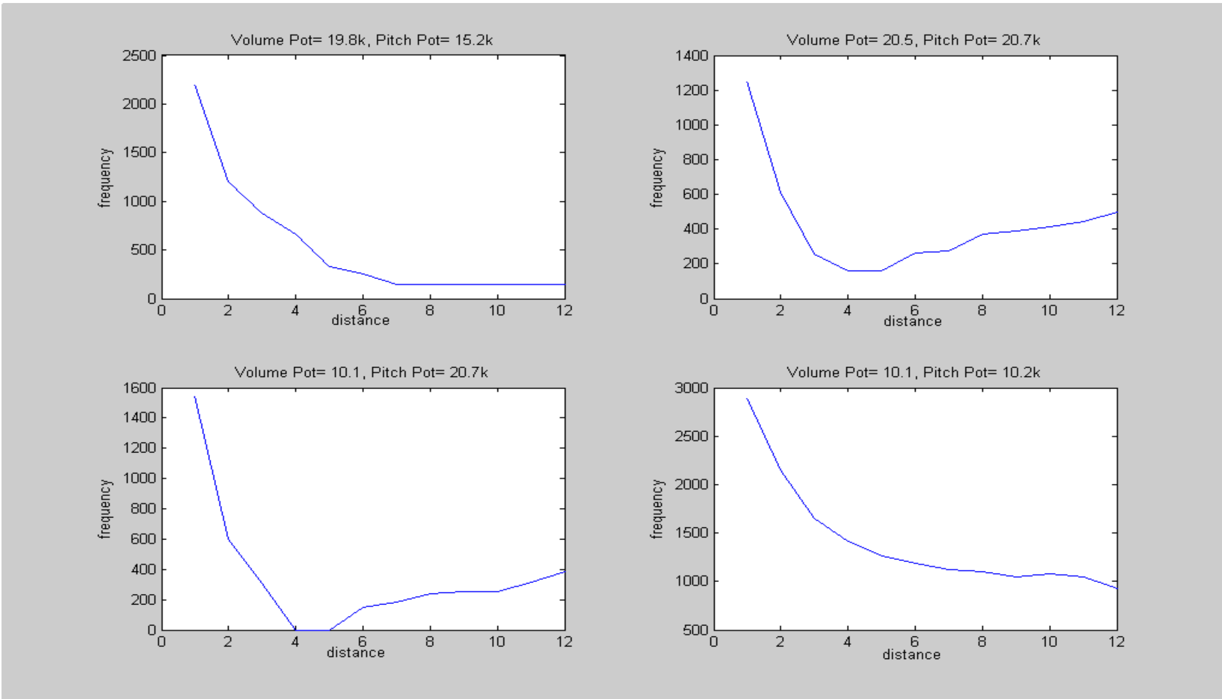
Figure 4

Volume Potentiometer = 10.0k
Pitch Potentiometer = 10.0k

Distance (Inches)	Frequency (Hertz)
12	925.1
11	1040
10	1080
9	1047
8	1100
7	1124
6	1190
5	1258
4	1418
3	1653
2	2151
1	2899



We can summarize all the results in the following form to simply comparison.



Another point that was important for our technical results were certain frequency specifications that should have been met in order for us to produce an audible output. The table below shows these frequencies.

Table 1:

Section	Component	Frequency (Hertz)
Volume Oscillator	C2	467,480-508,640
Pitch Reference Oscillator	C22	287,910-296,790

The final frequencies we had recorded at this point were as follows:

Table 2:

Section	Component	Frequency (Hertz)
Volume Oscillator	C2	453,500
Pitch Reference Oscillator	C22	303,500

Even though our recorded frequencies were slightly different from the frequency values required, it did not make a huge impact on the actual playability of the instrument. Perhaps it would have had a more positive effect such as greater ranges over the pitch and volume antennas. However, overall our pitch specifications were met and our volume specifications were met to an extent.

Chapter Three - Methods of Solution

Usually when people begin designing something they opt to breadboard the design first to ensure that it works and then continue on to a printed circuit board once everything is okay with the breadboard. However, upon other advice we took the opposite approach. We chose to throw ourselves into the printed circuit board. To begin with we redraw our schematic in Cadence, a software program. We placed interconnections on each schematic to ensure that the three sub circuits are connected overall. Once we drew the schematics correctly we ran a Design Rules Check to verify that we did not have any errors in our schematics. Upon successful completion of this, we created a net list file from our schematics. We then begin working in a program called Layout Plus. Layout Plus is compatible with Cadence since they are all from AutoCAD. We started off by loading our net list file that was created in Cadence into Layout Plus. Now, all of the components that we have used in all of the circuits are available to us in Layout Plus. Each component we used becomes a footprint, which represents the correct size and type of component. We proceeded by linking all of our footprints to components in the parts library. After we linked all of our footprints to corresponding components we arranged them in an order similar to the schematics. Although this was not necessary we felt it would help us out for debugging purposes as well as give our layout a cleaner look. We then ran AutoRoute, which attempted to create traces so that all of the components in our Layout were connected in a manner corresponding to our original schematics and also such that there were no electrical interferences. This was probably the most challenging task of all because the computer attempts to draw out a trace but it would only route perhaps 97% of the board. This meant that we had to rearrange the board and go through the whole process again. Sometimes this was obvious from knowledge and observation of the board but more often than not it became a guessing game. 97% is very good in terms of everything else, but in situations such as this it must be all or nothing. Overall, this took us at least a solid week. Finally, once the above steps were completed Dan Giles created a copper board for us. However, once it was all soldered it did not work as specified. See appendix E and F for all software development.

Our next step was to breadboard this circuit in hopes of getting a working version, however, in the essence of time Milton and I split up the circuit. I completed the second sub circuit while he completed the first and third. We both have different bread boarding styles and as a result it was very difficult to debug this circuit (since it did not work either). We both went over the circuit, individually and as a group. We found nothing wrong with it but yet, it still didn't work. Finally, in desperation I suggested we rebuild it from scratch. It was a lot of bread boarding but I took on the task of rebuilding the entire circuit. In the end we had a very nice looking circuit which also worked to its expectations. So, in summary we went from printed circuit board to breadboard to breadboard and our final method of solution became our breadboard (version three).
If you refer to our Appendix, you can see all three versions of theremin.

Chapter Four - Evaluation

We have three versions of our circuit, but the evaluation process was basically the same for all three with the exception of some extras we had to incorporate for the printed circuit board. It is only fair that we mention it all since it all consists of the work we have been doing for the past two quarters. With the printed circuit board, upon completion of soldering of all components we began testing for continuity. In other words, we would pick a section of copper and touch it with one lead of the multimeter then we would touch each of the other nodes (solder bubbles) within a close distance of the solder bubble with the other lead of the multimeter. If the multimeter were to beep then this indicated that there was a short at that point or somewhere along the trace of the corresponding solder bubble. The most probable cause for this is that there was excess solder either directly surrounding the bubble or on one of the traces. We had a lot of points with this situation. One of the reasons for this problem was that I unknowingly purchased larger solder than I should have. However, the soldering instructions indicated that the thinner solder was not recommended for electronics. I did not want to chance using incorrect solder. Once the soldering problem was cleaned up we began testing the amplifiers. We would inject a signal into a certain point in the circuit and then test another point on the circuit with the oscilloscope to check whether or not the circuit was being amplified. Of all the transistors we checked it seemed as if none of our signals were being amplified. Also, we tested all points that should have been receiving 7.5 volts of power supply and we noticed that not all points were receiving the correct voltage. It didn't really make sense but from one spot to another the voltage seemed to cut in half on the trace. We had to chalk this up to a defect with the board but we still continued with the calibration procedures that will be described shortly. We finally decided it would be a further waste of time to continue with the method we were using. This is where our breadboard versions came into play.

Aside from the usual double checking of polarities, power supply connections and ground connections we also followed calibration procedures (to some extent) given by the author of this original design. They version which we followed are as follows

1. Apply power to the instrument by connecting the 9-volt battery and setting the power switch to the "ON" position.

2. Place both potentiometers in their central positions. Remove any objects (test leads, hands, etc.) within two feet of the antennas.

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

   Meter NEGATIVE lead to the board's lower-most, right-most terminal (circuit ground).
   Meter POSITIVE lead to the positive (lower) lead of 220uF capacitor C14 (regulated +7.5v).

   Observe +7.50vdc +/-0.35vdc.

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

   Oscilloscope GROUND LEAD to circuit ground.
   Oscilloscope PROBE to positive (lower) lead of 220uF capacitor C14 (regulated +7.5v).

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

5. Connect the oscilloscope PROBE to R35's left terminal, which is the output of the PITCH REFERENCE OSCILLATOR. (Oscilloscope set for 2v/div. vertical sensitivity, DC coupled; 1uS/div. horizontal sweep rate, internally triggered.)

   Observe a sine wave: 3.8v peak-to-peak and a period of approximately 3.6uS.

6. Connect the oscilloscope PROBE to R39's lower terminal, which is the output of the PITCH VARIABLE OSCILLATOR.

   Observe a modified sine wave form: 3.8v peak-to-peak and a period of approximately 3.6uS.

7. Move your hand to and from the PITCH ANTENNA and observe that the wave form period increases slightly with decreasing hand distance.

   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.

8. Connect the oscilloscope PROBE to R13's lower terminal, which is the output of the MIXER. (Oscilloscope set for 200mv/div. vertical sensitivity, AC coupled; 1mS/div. horizontal sweep rate, internally triggered.)

   Observe the waveform while slowly adjusting capacitor C22.

9. Adjust C22 so that the AC waveform is absent with the hand away from the PITCH ANTENNA, and rising as the hand approaches the antenna.

   If the two oscillators' frequencies differ substantially, no AC wave form will be evident at the MIXER output, and either C23 in the PITCH REFERENCE OSCILLATOR or C29 in the PITCH VARIABLE OSCILLATOR will require an additional paralleled capacitor to lower its respective oscillator frequency.

   If the adjustment of C22 alone does not produce satisfactory results follow the steps below to add the extra capacitor.

10. To lower the frequency of an oscillator, add paralleled capacitance to:

C23 for the PITCH REFERENCE OSCILLATOR or
C29 for the PITCH VARIABLE OSCILLATOR.

Obtain two each of the following capacitors: 5pF, 10pF, 22pF, and 47pF.
(One set is reserved for adjustments in the volume circuit.)

11. Continue the paralleling procedure, as necessary, until the oscillator's frequency becomes just less than the desired value. Then, readjust C22 slightly so that 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.

12. 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 will occur with the hand at about two feet from the antenna.

13. Connect the oscilloscope PROBE to R4's lower terminal, which is the output of the VOLUME OSCILLATOR. (Oscilloscope set for 2v/div. vertical sensitivity, DC coupled; 1uS/div. horizontal sweep rate, internally triggered.)

14. Observe the modified sine wave form: 1.4v peak-to-peak and a period of approximately 2.2uS.

    Move your hand to and from the VOLUME ANTENNA and observe that the waveform period remains constant.

15. Connect the oscilloscope PROBE to Q2's source terminal. (Oscilloscope set for 1v/div. vertical sensitivity, DC coupled; 1uS/div. horizontal sweep rate, internally triggered.)

Slowly adjust C2 while observing the oscilloscope. Observe a sine wave that varies in amplitude as C2 is adjusted. The amplitude value of the sine wave should vary from approximately 0.5v to 2v peak-to-peak.

If the VOLUME OSCILLATOR frequency differs substantially from the parallel-resonant frequency of L2 and C7 in the VOLUME PROCESSOR, an insufficient sine wave amplitude and amplitude variation will result at Q2's source. In this case, either C3 in the VOLUME OSCILLATOR or C7 in the VOLUME PROCESSOR will require an additional paralleled capacitor to properly match the VOLUME OSCILLATOR's frequency to the VOLUME Processor's resonance.

If the adjustment of C2 alone does not produces satisfactory results, follow the above steps to match the frequencies of the VOLUME OSCILLATOR and the VOLUME PROCESSOR.

16. Connect headphones to the OUTPUT JACK 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.

Although I was confident that the third version would work we still went through with the above procedures so that our data would correspond to what we should be getting. The corresponding data to the above procedures will be attached in the appendices for further analysis. We did have some slight variations from what the above asked for but whatever the variations were we felt that they were minimal and would not make a huge difference.

Chapter 5 – Administrative

5.1. Introduction

Our budget was based on the Theremin 144 model. We noticed that the 144 budget was approximately $120.00. We decided that was a reasonable price for a group of two people. We opted to provide all expenses so the final product would be our property and not the university's. The estimate for the 144 was based on on-line distributor prices. For the future user, should you want to order all the parts on-line, please see [3]. Three resources provided most of our parts: the Electronics Warehouse, IEEE at UCR and the Technical Shop at UCR operated by Dan Giles.

5.2. Budget and/or Cost Analysis

Our first attempt in building our product required the use of designing our own PC board. Dan Giles provided the copper metal sheet and the PC mill required to create the PC board we designed. IEEE provided ¼ of the parts for a fraction of the actual cost. Parts cost turned out to approximately $30 dollars. Since our PC board Theremin was not a successful, we needed to buy all parts again to build our theremin on bread board. We used previous bred boards to build our circuit. Obtaining once again most of the parts from IEEE and Dan Giles, our expenses were once again around $30.00. We were not getting the correct results so we proceeded with the third and final option. We completely started all over a third version of our product, with a new bread board and new parts. We came to the conclusion to buy a new bread board because we noticed that the previous boards were worn out from previous use of the EE curriculum. We bought all new parts again, to prevent the hassle of dealing with parts we might have burned out. Plus, leaving the second circuit in place, it was going to be much easier to troubleshoot the new circuit, since we had logged all testing on the second circuit. In our final circuit, we bought all our parts from the Electronics Warehouse, and this resulted in a higher price, around $58.00 to be more precise. Up to then we had spent $118.00. That sum itself reached our expected budget. This does not include the actual box of our final product. Which actually cost $70 to make. We were fortunate to find a friend that worked in carpentry, and he decided to donate the box to us. This was certainly appreciated. In regard to parts purchased to build our box, we only provided the plexiglass which cost us $5.00 because we happened to find the perfect size. The plexiglass sheet would have cost us $20 if we would have not been fortunate enough to find the correct size. The final product will cost us around $125. Ironically the actual cost of the theremin has a value of approximately $140.

5.3. Final Product Cost

The following table shows an estimate on how much our product costs. As you can see the only thing we don't mention is labor. We can conclude that the product is marketable at $140. Should a company find interest in selling our design, $140 is not much. We believe the uniqueness of this musical instrument can attract many buyers. A detail cost of all the parts can be seen on Appendix A.

Part	Cost ($)
Resistors	28.675
Capacitors	9.25
Transistors	4.25
Plate Antennas	10
voltage regulator	1.05
Box Design	25
Bred Board	33
Miscellanous	26.89
Inductors	2.00
Diode	.5
Total	**140.62**

Fig. 1 Distribution of expenses

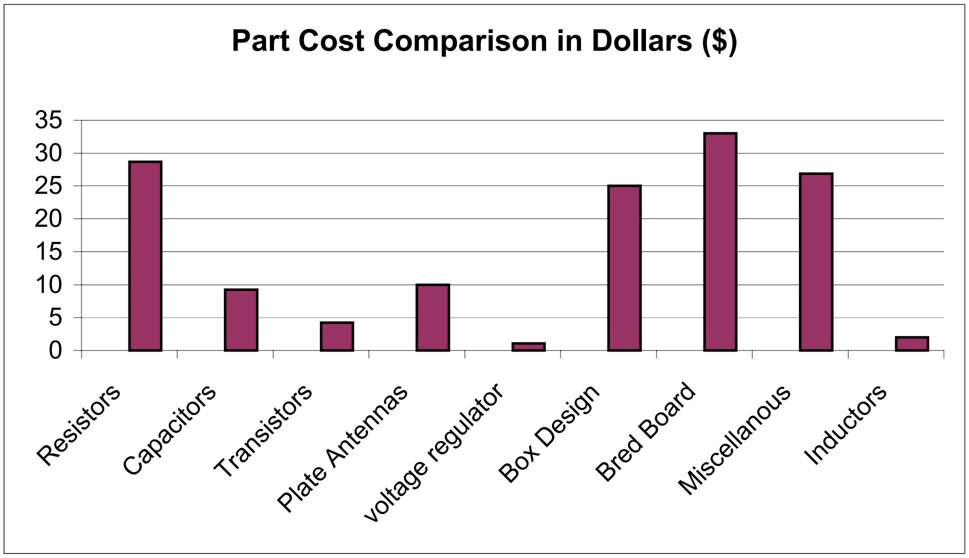


Figure 2. Comparison part cost

5.4. Group Work

It is very important for anyone to be able to work with other people. I(Milton) felt that this project really gave us the opportunity to work with the opposite sex. As engineering gets more diverse with men and women, it is very important that we get this experience while you are still in school. Like in any group, it is very important to know what type of person you are working with. Even though we had some differences in personalities, we were able to work together. We were able to establish such a relationship by letting each other know how we felt about certain subjects. We can advise anyone that if you have a problem with your group it is best to try to take care of it as soon as possible. Do not let it build up, as it could only get worst. Today, the use of the email, could serve as problem solver. We made use of the email, to state out our initial problems. That prevented the most common "you should listen to me first" response that one normally encounters. With email we both expressed our thoughts allowing both views to be analyzed at separate times. After the email, came the actual one on one confrontation. I noticed that we were not upset as we sounded in the email. In our case, this approach worked out O.K., but it does not mean that it will work for everyone.

Since we were only two in a group, we founded it easier to work together most of the time when building and testing the circuit. This allowed us to get first hand information on any progress on our project. We worked around our class schedule and work schedule and set up fixed hours and which we worked in our project. A typical week for us was Monday, Wednesday and Friday from 10am –3pm. There were occasions that we definitely needed to work separate. These included for example, research and typing the proposals and final reports. However, in those situations we managed to make use of email to keep each other up to date on what the other person was doing.

Chapter Six – Elements of Design

6.1 Economic Factors

Being that the theremin was a recent senior design topic in the electrical engineering department, considering a low cost product was the best decision for us. I wanted to emphasize that we chose the 1/4 inch thick wood frame, which allowed the box to be lighter and cheaper. A 3/8 inch thick wood frame would have cost us more and would have made the product heavier. We decided on such material to make the product more marketable. Our product has a reasonable size and weight, and is portable.

6.2 Safety

Provided that all the seniors have knowledge and experience in designing circuitry, building the theremin did not cause any safety hazards for us. The voltage we operated with was never higher than 10 volts and the current we drew in was very low, in the range of 10 to 20 milliamps. Like we mentioned before, we had no problems in respect to safety because we have plenty of experience from previous classes. We do though, recommend that the project should not be attempted with out the experience of any upper division course in microelectronics. In our final product we took in consideration that our project could be played by anyone with knowledge of understanding how the pitch and volume antennas operate. We also considered the possibilities of children sticking their hands in the actual circuit themselves. For display purposes we design our final product so the circuitry can be viewed by anyone curious to see it. We were able to maintain safety by adding a layer of plexiglass across the top of the cover. Plexiglass will a bend but won't break. Oppose to glass that would have given a clearer and cleaner view of the circuit, we chose plexiglass for safety purposes, even though it was more expensive.

6.3 Reliability

We mentioned a couple of times the importance of the 9 volt battery operated theremin. Our theremin draws current in the 10 to 20 milliamp range. We noticed that the

9 volt battery endured for great deal of time. For the user this is a big plus. The theremin is guaranteed to play for a good length of time without the need of changing batteries constantly.

6.4 Aesthetics

Our final product, you can say, was not the most innovated shape, but it was made to our liking. We liked the idea that our product had access to view the circuit. In addition, we design our box to have output flexibility. The output is the sound control by the pitch and volume antennas. Flexibility is obtained when we move the antennas closer and farther away from the circuit, since our design allows for the antennas to operate at different frequencies. We initially thought that the design of the box was not going to work. Since we were able to achieve this minor goal we are very happy with final product of the box.

6.5 Ethics

We approached our senior design with the best intentions in mind. We used other resources to design our project but we acknowledged their work. In building our final product we made appropriate safety features to accommodate the user. We also build our product so anyone can play it. Physical limitations by a person is out of reach. With this in mind, in future work, hopefully continuous research will lead in helping people with disabilities.

6.5 Social Impact

When people ask ,"what is your senior design project?", we answer, "a musical instrument, called a theremin". People's reaction toward our project is, "what is that". When we tell them that the theremin is played without the use of the hands, the most common response is, "cool". It seems to arouse their interest. The theremin is an instrument that few people know about. Those that know of the instrument appreciate the way the instrument operates. We were fortunate to provide you with feedback on the response by people toward our final product. During our final presentation, the audience got to see a live performance of our theremin. Although we did not present a specific tune, we were able to produce distinct sounds from the pitch antenna. The audience seemed to be please, not so much about the performanc, but on how just slight movements could produce such different sounds. There was a particular guest in the audience that was so interested, that he would ask question after question. As we analyzed his question, his main concern was how he could develop this instrument with other musical technology. Letting us know that he had musical background, he suggested a drum with touch-free applications. Over all, our demonstration showed the audience the capabilities of a theremin as a musical instrument, and at the same time an opportunity for us to show we met our specifications.

Chapter Seven - Future Work

Our senior design project was by all means interesting and very gratifying when we were able to produce sound. Having no prior knowledge, or any guidelines from previous senior design reports, we did not have the luxury of knowing up front whether we were approaching out problems the correct way. Having gone through the struggle ourselves this year, we believe next year's senior design groups could design a more sophisticated and more efficient theremin. Our methodology will help future designers in understanding the theremin operation quicker, allowing more time to concentrate on more advance ideas to the design. As an application to the theremin, the micro-controller, HC6811E9 looks like a high prominent. Please see appendix ?? for further knowledge of this controller.

An alternative approach could be the following. As you know, the theremin traditionally involves the use of our hands. Producing an instrument that would incorporate other ways of playing could definitely be a feature future designers might consider. The theremin in time could develop into a research that could help the disable. There are many people who by misfortune are not blessed with all body organs, thus disabling them from performing their daily routines independently. The theremin someday may reach such capabilities.

Chapter Eight - Conclusions

“The Theremin and Beyond”, was a success. We have a final product as was demonstrated in our final presentation. The audience got to see how the pitch and the volume antenna operate with the movement of your hands only. Our specifications were to have volume and pitch control, and we did meet both. We can say that pitch did work more efficiently than volume. The only thing we fell to accomplish was the application of the HC6811 micro-controller to our theremin.

Chapter Nine – Acknowledgements

We feel deep appreciation for our advisor Alexander Korotkov, who guided us through out Senior Design Project. Our weekly meetings were beneficial in the success of our project.

We also would like to thank Dan Giles, who provided us with the knowledge for the Software ORCAD. We learned a lot from this software tool that will be very useful in our future work in design. He also provided us with parts.

We also want to acknowledge Art Harrison which provided us with the model of our design, Higinio for helping us build our theremin frame, Rudy for providing us with the output amplifier for demonstration purposes, and IEEE for providing us parts as well.

A special thanks also goes to Mr. Theremin himself, who is the originator of this wonderful musical instrument.

Our greatest gratitude goes to our parents. With out the support of our families we would have not reached this far.

Chapter Ten – References

[1] Hearing Safety
http://www.headwize.com/articles/hearing_art.htm

[2] Art Harrison's Webpage
http://home.att.net/~theremin1/

[3] Theremin 144 Wepage
http://home.att.net/~theremin1/144/144.htm

[4] www.library.ucr.edu

[5] University of California, Riverside
Electrical Engineer Network- Pass Reports

Appendix A – PARTS LIST

Part	value	Cost ($)	Description
R1	100K	0.25	Resistor, carbon film 1/4 WATT
R2	33K	0.25	Resistor, carbon film 1/4 WATT
R3	47K	0.25	Resistor, carbon film 1/4 WATT
R4	4700K	0.25	Resistor, carbon film 1/4 WATT
R5	10K	0.25	Resistor, carbon film 1/4 WATT
R6	4.7M	0.25	Resistor, carbon film 1/4 WATT
R7	4.7M	0.25	Resistor, carbon film 1/4 WATT
R8	2200	0.25	Resistor, carbon film 1/4 WATT
R9	68K	0.25	Resistor, carbon film 1/4 WATT
R10	2200	0.25	Resistor, carbon film 1/4 WATT
RV1	20K	1.75	Linear Taper, Conductive Plastic
R11	150K	0.25	Resistor, carbon film 1/4 WATT
R12	100K	0.25	Resistor, carbon film 1/4 WATT
R13	10K	0.25	Resistor, carbon film 1/4 WATT
R14	10K	0.25	Resistor, carbon film 1/4 WATT
R15	1K	0.25	Resistor, carbon film 1/4 WATT
R16	100K	0.25	Resistor, carbon film 1/4 WATT
R17	120K	0.25	Resistor, carbon film 1/4 WATT
R18	33K	0.25	Resistor, carbon film 1/4 WATT
R19	680	0.25	Resistor, carbon film 1/4 WATT
R20	220	0.25	Resistor, carbon film 1/4 WATT
R21	20K	0.25	Resistor, carbon film 1/4 WATT
R22	3.92K	0.25	Resistor, carbon film 1/4 WATT
R23	1M	0.25	Resistor, carbon film 1/4 WATT
R24	22K	0.25	Resistor, carbon film 1/4 WATT
R25	4.7K	0.25	Resistor, carbon film 1/4 WATT
R26	4.7K	0.25	Resistor, carbon film 1/4 WATT
R27	22K	0.25	Resistor, carbon film 1/4 WATT
R28	10	0.25	Resistor, carbon film 1/4 WATT
R29	10	0.25	Resistor, carbon film 1/4 WATT
R30	100K	0.25	Resistor, carbon film 1/4 WATT
R31	100K	0.25	Resistor, carbon film 1/4 WATT
R32	33K	0.25	Resistor, carbon film 1/4 WATT
R33	47K	0.25	Resistor, carbon film 1/4 WATT
R34	4700	0.25	Resistor, carbon film 1/4 WATT
R35	100K	0.25	Resistor, carbon film 1/4 WATT
R36	100K	0.25	Resistor, carbon film 1/4 WATT
R37	33K	0.25	Resistor, carbon film 1/4 WATT
R38	47K	0.25	Resistor, carbon film 1/4 WATT
R39	4700	0.25	Resistor, carbon film 1/4 WATT
RV2	20K	1.175	Linear Taper, Conductive Plastic

RV2 final	20K	8	Linear Taper, Conductive Plastic
RV1 final	20K	8	Linear Taper, Conductive Plastic
C1	.1uF	0.45	Ceramic Capacitor
C2	VAR 7-25pF	1.48	Variable Capacitor
C3	100pF	0.85	Ceramic Capacitor
C4	1000pF	0.95	Ceramic Capacitor
C5	5pF	0.54	Ceramic Capacitor
C6	5pF	0.54	Ceramic Capacitor
C7	100pF	0.85	Ceramic Capacitor
C8	.1uF	0.45	Ceramic Capacitor
C9	.1uF	0.45	Ceramic Capacitor
C10	.1uF	0.45	Ceramic Capacitor
C11	10uF	0.98	Tantalum Capacitor 20 V
C12	.1uF	0.45	Ceramic Capacitor
C13	.1uF	0.45	Ceramic Capacitor
C14	220uF	0.85	Aluminum Electrolytic Capacitor
C15	10uF	0.98	Tantalum Capacitor 20 V
C16	.47uF	0.54	Tantalum Capacitor 35 V
C17	10uF	0.98	Tantalum Capacitor 20 V
C18	10uF	0.98	Tantalum Capacitor 20 V
C19	10uF	0.98	Tantalum Capacitor 20 V
C20	.1uF	0.45	Ceramic Capacitor
C21	.1uF	0.45	Ceramic Capacitor
C22	2-20pF	1.48	Variable Capacitor
C23	390pF	0.77	Ceramic Capacitor
C24	1000pF	0.95	Ceramic Capacitor
C25	.1uF	0.45	Ceramic Capacitor
C26	.1uF	0.45	Ceramic Capacitor
C27	.1uF	0.45	Ceramic Capacitor
C28	.1uF	0.45	Ceramic Capacitor
C29	390pF	0.77	Ceramic Capacitor
C30	1000pF	0.95	Ceramic Capacitor
Q1	2N3906	0.84	PNP transistor
Q2	NTE451	1.75	Junction Field Effect Transistor
Q3	2N3904	0.45	NPN Transistor
Q4	2N3904	0.45	NPN Transistor
Q5	NTE451	1.75	Junction Field Effect Transistor
Q6	2N3904	0.45	NPN Transistor
Q7	2N3904	0.45	NPN Transistor
Q8	2N3904	0.84	PNP transistor
Q9	2N3906	0.84	PNP transistor
Q10	2N3906	0.84	PNP transistor
Pitch Antenna		5	8"x5.5" Aluminum 1/8 thick
Vol Antenna		5	8"x5.5" Aluminum 1/8 thick
U1	LP2951	1.05	Integrated Chip Voltage Regulator
DC Battery		2.14	Alkaline 9 volt

¼" adapter		1.75	From output jack to headphones/amp
Switch		3	On/Off
Battery adapter		2	Clip
Knobs		3	Knob, potentiometer
Box Frame		25	Custom made, 1/4 inch MVS wood
Bred Board		33	26.6cm x 24.4 cm
L1		0.5	Inductor
L2		0.5	Inductor
L3		0.5	Inductor
L4		0.5	Inductor
CR1	1N914	0.5	Diode
Total		**140.595**	

Appendix B – Software List

- MATLAB – The Language of Technical Computing
  Version 6.5 Release 13
- CADENCE PSD 14.2
  1. Capture CIS/version 9.2.3
  2. Orcad Layout Plus 9.2.3

Appendix C – Equipment List

- Tektronic TDS 340 Two Channel DIGITAL Real-Time OSCILLISCOPE
- Hewlett Packard 34401A Multimeter
- Hewlett Packet E3630A Tripleout DC Power Supply
- Hewlett Packard 33120A 15 MHz Function/ Arbitrary WAVEFROM GENERATOR
- Pace MBT Soldering Station

Appendix D – Special Resources

- Corey Laughlin and Nawid Jacuby
  Juan Arredondo, Alex Cuevas, Mike Mesin
- Pass Reports
- Science Library

Appendix E – PCB Instructions

Orcad Capture to Layout Procedures:

In Orcad Capture, save schematic, annotate, then create Netlist for layout (.mnl file).

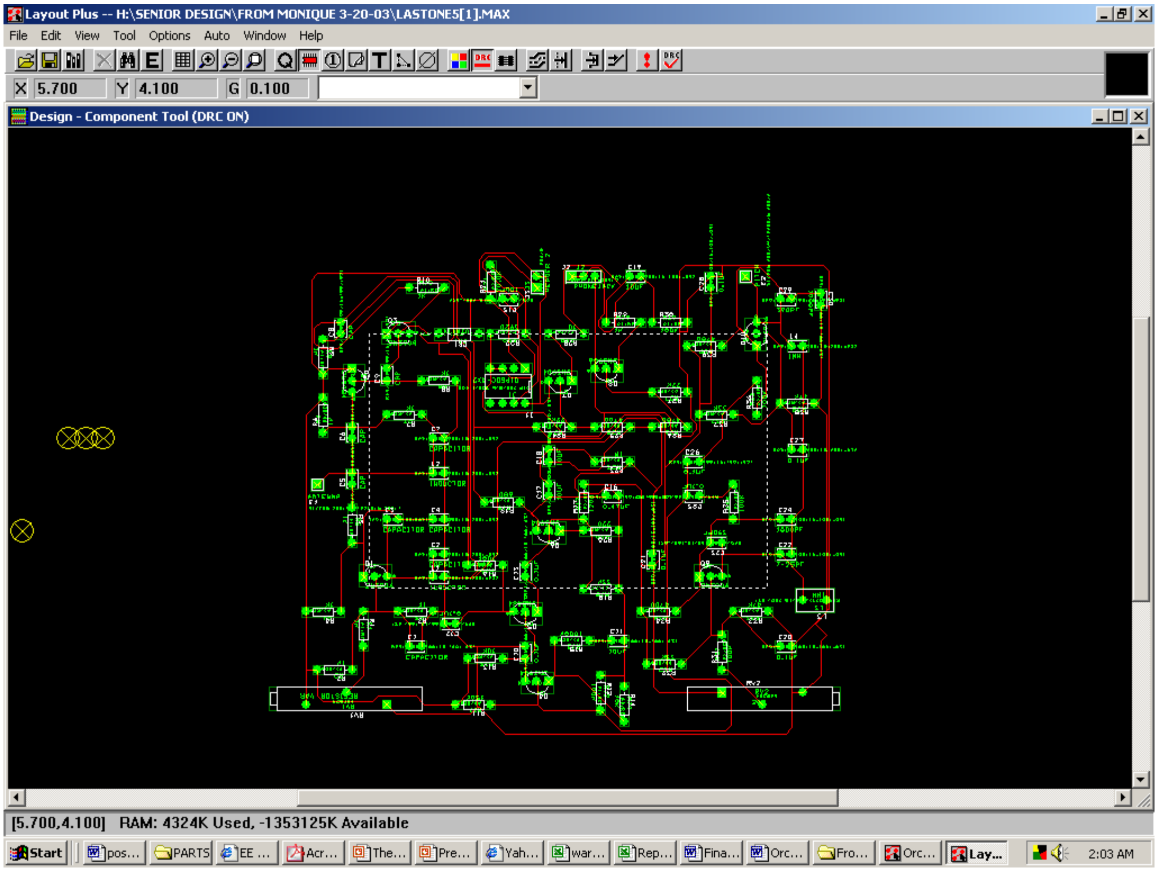
Open Layout Plus
  Click File-New
  Select default.tch
  Load your .mnl file (Saves it as a .max file)
  Link Footprints to components
  Arrange components
  Setup:
    Layers, (Tool, Layer, Select from Spreadsheet, Double-click Layer Type)
Drill layer type should always be Drill, Top and/or Bottom layers set to Routing, All other layers set to Unused
    Trace Width, (Tool, Nets, Select from Spreadsheet, Double-click Width [def.=12])
    Pad & hole sizes (Tool, Padstack, Select from Spreadsheet, Double-click Pad Width)
  Autoroute

Optional:

  To create Gerber files for the PCB Mill:
    Click Options, Post Process Settings, *Enable used layers by double-clicking layer. Select Extended Gerber, Create Drill Files, Overwrite Existing Files & Enable for Post Processing.*
    Click Options, Gerber Settings, *Select 2.3 Format & CR After Each Block*
    Click Auto, Run Post Processor
  Minimal Files used by the PCB Mill software have these extensions:
    .TAP (Thruhole.tap, NC Drill info)
    .BOT (Bottom Layer)
    .TOP (Top Layer)

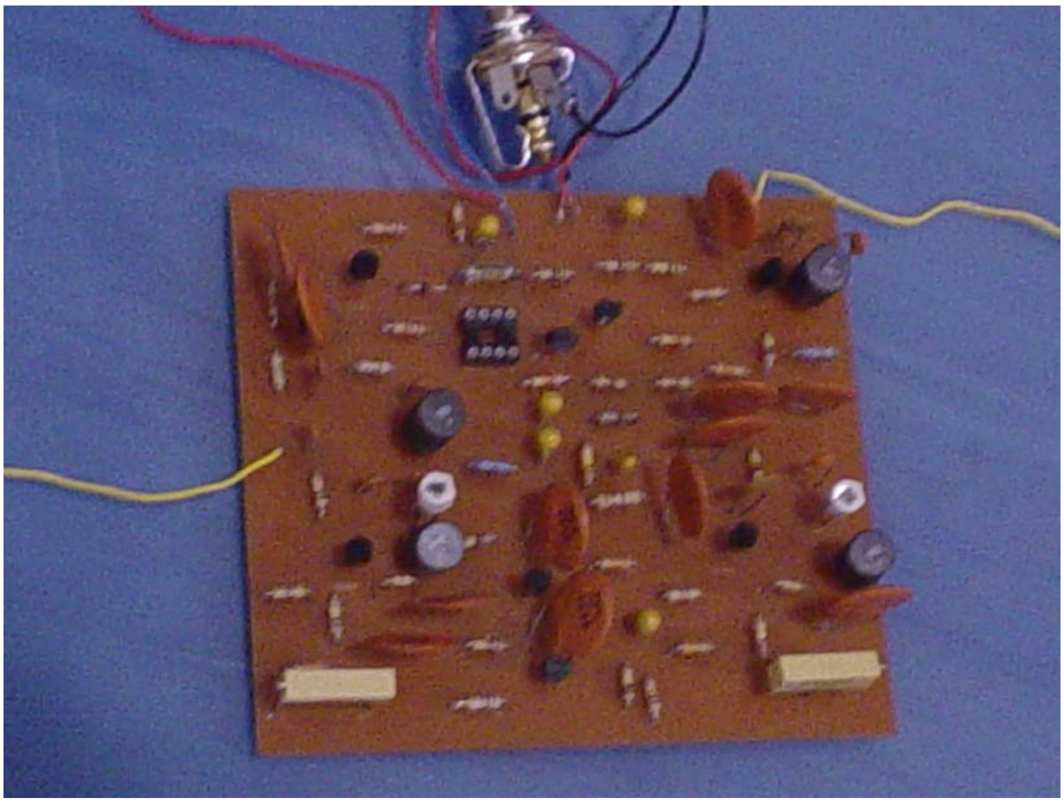
6/10/02 Dan Giles

Appendix F – Layout Plus Design



The design above was used to construct the PCB used in the first attempt to build the theremin. Almost the whole winter quarter was spent on the design, building and testing of the PCB, so it is worth seeing the blueprint of the PCB.

Below you can see our first design with all the parts soldered. There were some flaws on the tracings of the PCB that did not allow to proceed.



Appendix G – Hearing Safety

Trough out the testing procedure we used the headphones to hear the sound produced by the theremin. It highly recommended that noise levels in decibels should be carefully be studied. Some useful information was extracted from [3].

90 dbA	**8 hrs**

92 dbA	**6 hrs**
95 dbA	**4 hrs**
97 dbA	**3 hrs**
100 dbA	**2 hrs**
102 dbA	**1.5 hrs**
105 dbA	**1 hr**
110 dbA	**0.5 hr**
115 dbA	**0.25 hr or less**

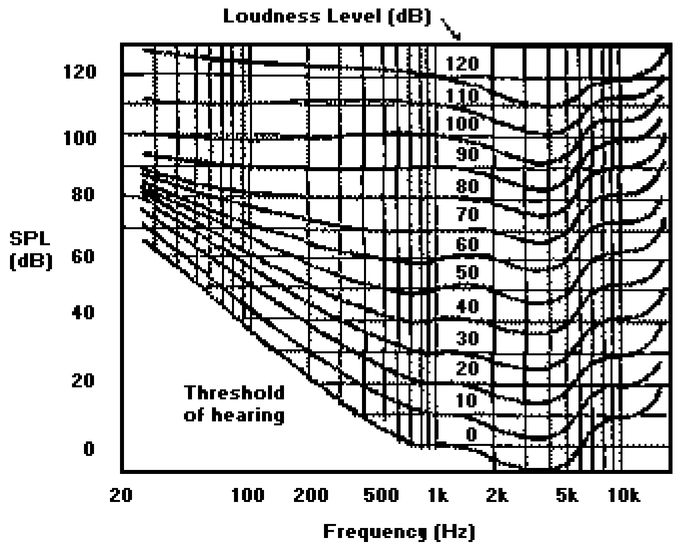
Note: When the daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered, rather than the individual effect of each. Exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level.

Figure 2: OSHA Regulation 1910.95 - Occupational noise exposure

SOUND PERCEPTION IN HEADPHONES VS. LOUDSPEAKERS

In loudspeaker reproduction, sounds must travel several feet before reaching the listener's ears. By the time they arrive, a portion of the high frequencies have been absorbed by the air. Low frequencies are not absorbed as much, but they are more felt through bone conduction than actually heard. With headphones, the ears hear all frequencies without any attenuation, because the transducers are literally pressed against them. Thus, when listening to headphones at the same effective volume level as loudspeakers, headphones may still transmit louder high frequencies that are more likely to cause hearing damage.

SETTING SAFE HEADPHONE VOLUME LEVELS



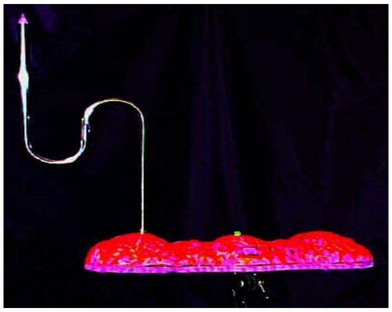
Fletcher-Munson Loudness Curves

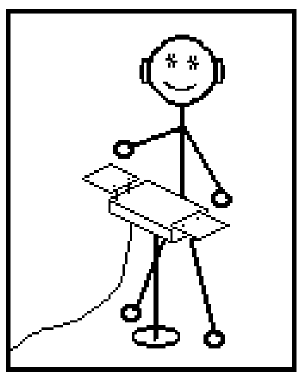
The Fletcher-Munson loudness curves (shown above) indicate that low-level listening may not be as satisfying because perception of loudness is not linear, but is dependent on frequency and volume. The curves are flattest when the SPL is at the threshold of pain. Tone controls can rebalance sound to have the same pleasing amplitude spectrum at lower listening levels. The most accurate loudness compensation would dynamically adjust to both frequency and volume. Such dynamic filters are not widely available to consumers. Still, a small amount of equalization (treble and bass boost) can restore naturalness to the sound of headphones, so that listening at safe levels is appealing (or at least, not unappealing).

Appendix H – Report Breakdown

Milton	Title Page
Milton	Executive Summary
Monique	Chapter One – Introduction
Monique	Chapter Two – Design and Technical Results
Monique	Chapter Three – Methods of Solution
Monique	Chapter Four – Evaluation
Milton	Chapter Five – Administrative
Milton	Chapter Six – Elements of Design
Milton	Chapter Seven – Conclusion
Milton	Chapter eight – Future Work
Milton	Chapter nine – Acknowledgement
Monique	Chapter ten – References

Appendix I – Variety of Theremin Models



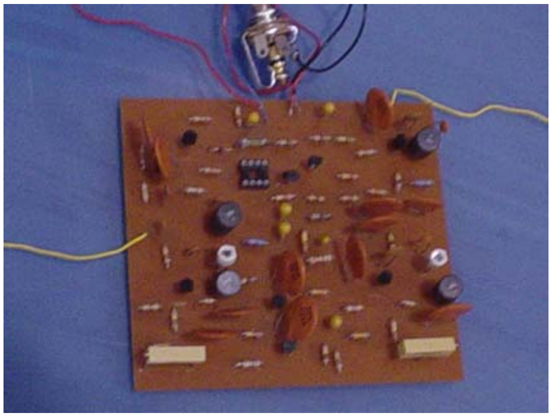


the happy thereminist

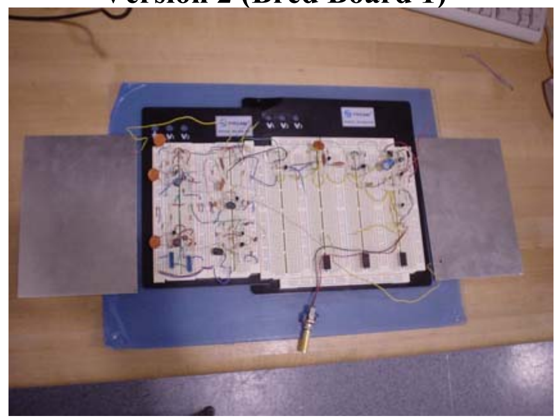
Theremin and Beyond

Appendix J - Our Thermin Pictures: Version 1-3

Version 1 PCB



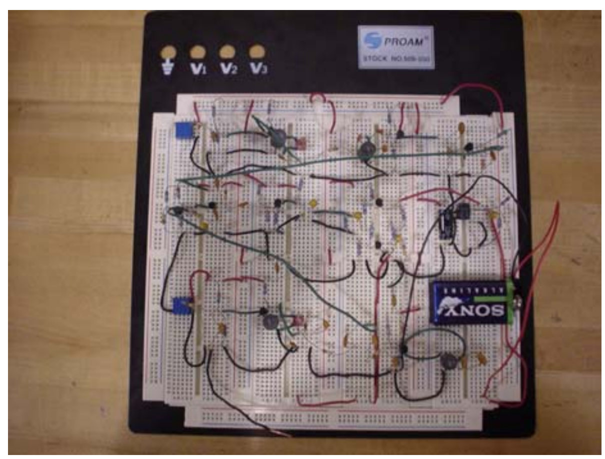
Version 2 (Bred Board 1)



Vaersion 3

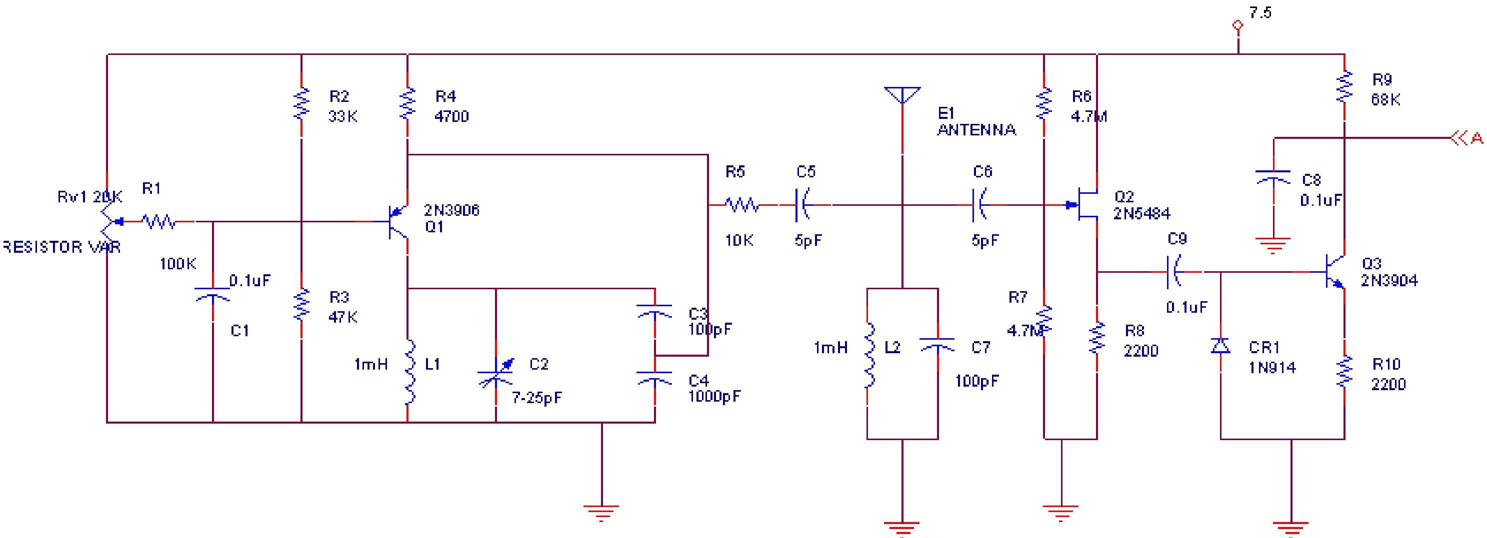
Final Product (Theremin and Beyond)

Picture of the final circuit.

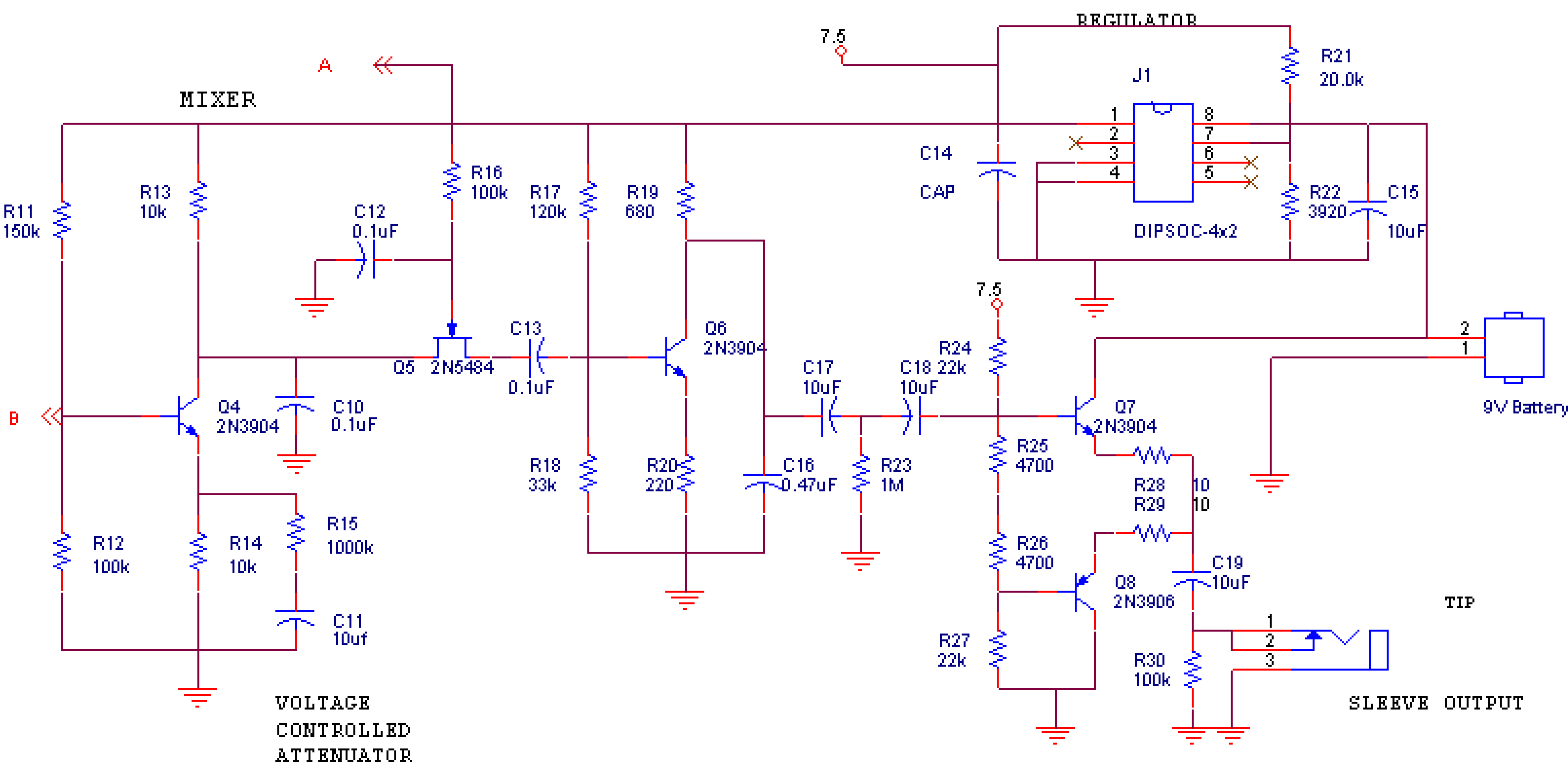


Appendix K – Schematics

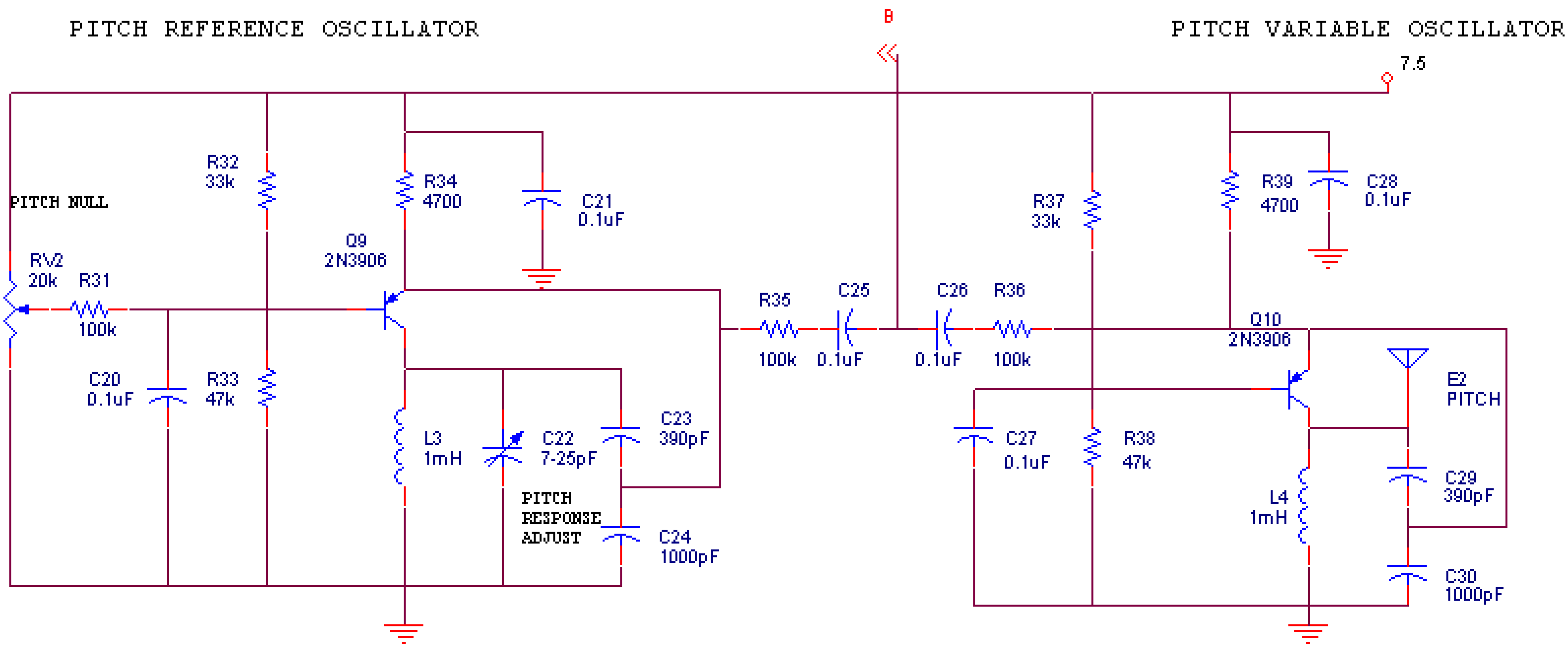
Schematic 1: Volume Oscillator and Processor



Schematic 2: Mixer, Amplifier, Output, Voltage Regulator



Schematic 3: Pitch Oscillators



Appendix L – MATLAB Code

```
%Senior Design Plots
%Frequency Variation with respect to Distance

inches = [12 11 10 9 8 7 6 5 4 3 2 1];
freq = [150 150 150 150 150 147.7 252.8 333.1 660.1 873.4 1200 2200];
figure(1);
plot(inches, freq);
title('Volume Pot= 19.8k, Pitch Pot= 15.2k');
xlabel('Distance (Inches)');
ylabel('Frequency (Hertz)')'

inches = [12 11 10 9 8 7 6 5 4 3 2 1];
freq1 = [495 445.4 412.4 389.1 369.7 277 260.8 157.9 157.6 257.7 613.5
1250];
figure(2);
plot(inches, freq1);
title('Volume Pot= 20.5, Pitch Pot= 20.7k');
xlabel('Distance (Inches)');
ylabel('Frequency (Hertz)')'
```

```
inches = [12 11 10 9 8 7 6 5 4 3 2 1];
freq2 = [384.6 315 250.3 254.1 240.1 185.4 150.8 0 0 307.7 598.8 1550];
figure(3);
plot(inches, freq2);
title('Volume Pot= 10.1, Pitch Pot= 20.7k');
xlabel('Distance (Inches)');
ylabel('Frequency (Hertz)')'

inches = [12 11 10 9 8 7 6 5 4 3 2 1];
freq3 = [925.9 1042 1080 1047 1100 1124 1190 1258 1418 1653 2151 2899];
figure(4);
plot(inches, freq3);
title('Volume Pot= 10.1, Pitch Pot= 10.2k');
xlabel('Distance (Inches)');
ylabel('Frequency (Hertz)')'
```

Appendix M – How to play a theremin?

Key to playing:

Body must remain motionless
Hand movement is vital

Sensitivity:

Metal objects within two feet can alter the pitch drastically.

Our theremin varies frequency since the antennas can move in and out.

Some key notes follow [3].

As a Thereminist, I can say that this musical instrument is not an easy instrument to play -- It is downright difficult! So far, not one person I know can come close to playing it even with my instruction! One must remain perfectly motionless other than movement from the hands and arms. Metal objects near the Theremin will alter pitch drastically.

The most difficult thing about a playing a Theremin is that you have no reference point. If there is a rest in the music, and one has to start on a different, note ... well, it is there, and your judgment and experience is the only way to find it.

The loudspeaker for the tone or pitch is usually behind the performer. This gives the performer a slight advantage in that the volume of a pitch, can be made so low that the audience hopefully cannot hear it.

Once the correct pitch is found, and it has to be done swiftly, the volume can be brought up. Anyone coming within a few feet of the performer while the instrument is being played will ruin a performance.