1. PROBLEM

The theremin is one of the first electronic musical instruments ever made. Leon Theremin, a Russian physicist, invented it in 1919. The theremin is played by moving one's hands closer or farther away from two antennas. A capacitance is created between the player's hand and the pitch antenna that is used to control the frequency of a variable oscillator circuit. The output of this circuit is combined with the output of a fixed frequency oscillator. These oscillators both operate at supersonic frequencies. After the outputs of both of the circuits have been mixed, the signal is filtered to extract a beat frequency created by the difference in frequency between the oscillators. The volume antenna creates a capacitance with the player's other hand that is used to control an amplifier circuit that the filtered signal is fed through before being output to a speaker.

The theremin is a truly unique instrument. It is the only known instrument to be played without touching it [2]. It has a relatively wide range of pitches, usually spanning about five octaves, allowing it to play music from pitches from basso to high soprano. The timbre of the theremin is somewhat like a violin; very rich in harmonics and complex .It has what is usually described as a "spooky" or "ethereal" sound.

Despite being one of the earliest electronic musical instruments, the theremin is also one of the least used or well known. The very qualities that set it apart from other instruments introduce problems that have prevented it from becoming very popular. It has traditionally been a difficult instrument to learn because it lacks any physical reference for the performers, forcing them to rely heavily on their ears in determining what notes are being played [3]. Most novice musicians' ears are not very well developed, leading to a frustrating experience for those trying to learn to play the theremin, discouraging casual players, who are not already experienced with music or sorely determined to learn it, from taking it up. Clara Rockmore, one of the most widely known theremin virtuosos, once said in an interview "One should not learn to play the theremin as his first instrument," [1] explaining that the fundamentals of music should be learned first on another instrument before the theremin is taken up. Those beginners that do choose to endure the difficulties in learning the theremin as their first instrument are further hindered by the inherent problems in self-study caused by the aforementioned limitations: that is, with no tactile or visual reference and a less-than-perfect sense of pitch, the students may have difficulty in ascertaining whether their performance is in tune or otherwise acceptable without guidance from a teacher. This is an unfortunate problem, because the fact that the theremin is such a rarely played instrument leads to difficulty in finding teachers, making self-instruction an all but necessary element in learning.

Our group proposes to address these problems by building a theremin that is geared toward making learning to play easier, even for those with no prior musical experience. Our theremin will be designed with an LCD display that shows the note that is being output and how closely in tune it is. This provides visual feedback to the players, giving them a more reliable reference than their ears as to the accuracy of their performance. Our theremin will also have a MIDI compatible output that will be used to interface the instrument with a computer. This will allow the users to study the theremin with the aid of software that we will write. The software will evaluate and rate their playing, according to exercises it provides for them to play. This software is what will set our theremin apart from other MIDI theremin models, as it will provide the students with an objective, accurate method of evaluating their playing ability and a more effective way of practicing. The software will be designed such that exercises can be added to it as needed, allowing for greater challenges to be introduced as the user's playing ability grows.

These improvements will make the theremin an easier instrument to learn to play and improve the quality and effectiveness of theremin pedagogy in general. This will make the theremin more accessible and attractive to a broader group of musicians and make it a less opposing challenge for those who lack musical training on another instrument. In addition to these improvements, the theremin will be designed for a lower cost than currently available models, which can typically range from \$370 to \$3500, further widening the prospective user-base by making it more attractive to casual users. Providing a usable instrument with better tools and methods for evaluating the user’s performance at a lower cost than existing models will provide for a more enjoyable learning experience and may allow the theremin to finally obtain the popularity and mainstream acceptance that have eluded it for almost the entire eighty years of its existence.

4. OBJECTIVES

The three main issues that we intend to focus on in designing our theremin are ease of use, ease of learning, and cost. In order for it to be accessible to a broader range of people, the theremin will need to be easy to set up and play. Along with making it easy to use, the cost of the theremin will need to be minimized by making certain considerations in its design. These include reducing the octave range and choosing the lowest costing components as possible. In order to make the theremin easy to learn, computer software will be created that is compatible across a broad range of PC's along, and an onboard LCD interface will be included to display the pitch being played.

The following is an overview of what will be needed to accomplish our objectives:

4.1. **MIDI compatibility**: The product will be able to connect to the computer for use with the learning software. A MIDI signal output will be used for this purpose.

4.2. **3-octave range**: The theremin's musical range will be three octaves. These octaves will be:

1st octave: from 130.81 Hz to 246.94 Hz
2nd octave: from 261.63 Hz to 493.88 Hz
3rd octave: from 523.25 Hz to 987.77 Hz

4.3. **Pitch detection**: The theremin will be able to detect the pitch being played. The accuracy will be within 5% of actual note as defined by Appendix A.

4.4. **Audio specifications**: The theremin will have a preamp voltage of 2V and a pitch drift of at most 2% of the expected pitch.

4.5. **Power supply**: Power will be supplied by a 110/120VAC input - DC output wall transformer.

4.6. **Speaker jack**: There will be a standard 3.5mm jack to be used by external speakers.

4.7. **Teaching Software**: The software will have lessons for Beginner, Intermediate, and Advanced Musicians and will be developed for the Windows API. It will be compatible with Windows 98® or higher and the Sound Blaster® sound card.

4.8. **Dimensions:** The theremin will weigh less than 15 lb and be no larger then 1.5 ft by 1 ft by .5 ft.

4.9. **Cost**: The theremin will cost less than $200.

4.10. **Interface**: An LCD screen will be used as an interface.

Low cost, easy setup, and PC learning software will make our theremin more appealing than current designs. Meeting these objectives will improve the marketability of our theremin. We hope to create a design that will allow a broad range of players to enjoy the theremin.

The following is a more detailed explanation of important specifications:

- **MIDI compatibility:** The device will utilize an output that conforms to the MIDI protocol. This will allow it to interface with other MIDI compatible devices such as mixers, PC's, and synthesizers. The learning software will use this feature to evaluate the performance of music being played in real time with pre-stored lesson files.

- **Pitch detection:** To minimize cost while maintaining an acceptable level of musical versatility, the theremin, like many beginning level instruments, will have a three-octave range (see Appendix A). The analog output will be sent to a standard 3.5mm output jack with a 2V preamp. The analog to digital converter will sample the output so the microcontroller can output the appropriate pitch and volume data to the MIDI port and LCD module. The human ear is very sensitive to changes in frequency [4]. Therefore, the theremin will not vary from the expected frequency by %2. The pitch detection, which does not need to be as strict, will be accurate to within 5%.

- **Cost:** The main objective of this theremin is to design it so it will appeal to a large market. If the cost is lower, more people will be interested in the product. To help reduce the cost to less than $200, a standard external wall transformer will be used to supply power to the theremin rather an internal power supply. The user will also have the option to plug in an externally amplified speaker. This will allow players to use whichever speakers they choose.

- **Dimensions:** The weight and dimensions will be similar to other comparable theremins on the market.

- **Interface:** The LCD interface will display the pitch of the output, keeping the users from having to purchase expensive tuners to verify what they are playing.

4. TEST SPECIFICATION

Both the theory and application of the solutions detailed in section 2 must be thoroughly tested before the product is built. This section deals with the different aspects of design that will be tested and gives a brief description of how testing will be conducted.

4.1. Simulations:

- **Waveform Output Pitch Accuracy**: PSpice will be used to simulate frequency, volume amplitude, and antennae capacitance circuitry.

- **MIDI**: The computer software accepts MIDI inputs and the theremin will send MIDI outputs. Both sides will be tested. Using existing MIDI equipment that is known to send proper MIDI messages, the computer software will be tested. The microcontroller can be tested in a similar fashion by using equipment that is known to accept proper equipment. If the test operates the same way with known equipment versus the theremin, it is known to work correctly.

- **Software**: The software will be tested with IBM-compatible computers with Intel processors running Windows 98, 2000, and XP Professional. This will ensure that the software will operate on a wide range of computers. A MIDI keyboard will be used to test the functionality of the software. A MIDI keyboard can send known notes. A known note can be sent to test if the software reacts properly.

4.2. Hardware:

The hardware is fairly modular. Each test will be performed on each element. The frequency generator circuit will be simulated in PSpice and checked with a musician’s handheld tuner. The volume (amplitude) varying circuitry will be simulated in PSpice and checked by listening to the output. Higher-level circuitry, such as the microcontroller can be tested with simulator software distributed by the chip’s manufacturer.

Specific Hardware Tests:

- **Antenna Proximity Detection**: The antenna will be tested with an LCR meter to find the range of capacitance it covers to aid in designing the signal-generating hardware.

- **Dimensions**: The prototype must conform to certain restrictions in order to fit the specified enclosure size.

- **Power Regulation**: The power regulation circuit must be analyzed to be certain that it will not interfere with the waveform generation circuitry.

See the following table for a summary:

Table 1: Summary of Tests and Simulations

Object	*Simulation*	*Testing*
Software		
Program itself	MS Visual C++	IBM-compatible computers with Intel processors running Windows 98, 2000, and XP Professional will be used to check that the software runs on different machines.
MIDI		MIDI keyboard that sends known MIDI notes will be used to send known notes to check that the program reacts properly.
Hardware		
Frequency	PSpice	There are numerous hand held pitch detection devices that musicians use. One can be used to check that the expected note is being played.
Volume amplitude	PSpice	A human ear will be used to detect changes in volume.
Antennae	PSpice	An LCR meter will test the capacitance.
Microcontroller	Microcontroller Simulator software	The various outputs can be tested, such as MIDI.
LCD	Microcontroller Simulator software	Sending known values to see if they are displayed will test the LCD.
MIDI		MIDI keyboards can also receives notes. Having the MIDI keyboard play the sent note can test the hardware.

References

[1] "In Clara's Words: An Interview with Clara Rockmore", http://www.maxiespages.com/theremin/rockmore.shtml,

[2] "Learn - What's a Theremin?", http://www.thereminworld.com/learn.asp, ThereminWorld, 2002.

[3] S. J. Aldrich, “The History and Significance of the Theremin”, http://www.stanford.edu/~aigeanta/theremin/, Stanford University, 2000.

[4] R. Nave, “Sensitivity of Human Ear”, http://hyperphysics.phy-astr.gsu.edu/hbase/sound/earsens.html,

[5] Jeff Glatt, “MIDI Note Number to Frequency Conversion Chart”, http://www.borg.com/%7Ejglatt/tutr/notefreq.htm, MIDI Technical Fanatic's Brainwashing Center, 2002

APPENDIX A
Frequencies of Pitches in the Chromatic Scale [5]

a. 1st octave:

C3	130.81 Hz
C#3/Db3	138.59 Hz
D3	146.83 Hz
D#3/Eb3	155.56 Hz
E3	164.81 Hz
F3	174.61 Hz
F#3/Gb3	185.00 Hz
G3	196.00 Hz
G#3/Ab3	207.65 Hz
A3	220.00 Hz
A#3/Bb3	233.08 Hz
B3	246.94 Hz

b. 2nd octave:

C4	261.63 Hz
C#4/Db4	277.18 Hz
D4	293.66 Hz
D#4/Eb4	311.13 Hz
E4	329.63 Hz
F4	349.23 Hz
F#4/Gb4	369.99 Hz
G4	392.00 Hz
G#4/Ab4	415.30 Hz
A4	440.00 Hz
A#4/Bb4	466.16 Hz
B4	493.88 Hz

c. 3rd octave:

C5	523.25 Hz
C#5/Db5	554.37 Hz
D5	587.33 Hz
D#5/Eb5	622.25 Hz
E5	659.26 Hz
F5	698.46 Hz
F#5/Gb5	739.99 Hz
G5	783.99 Hz
G#5/Ab5	830.61 Hz
A5	880.00 Hz
A#5/Bb5	932.33 Hz
B5	987.77 Hz