Colin McNeill
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PHYS 406

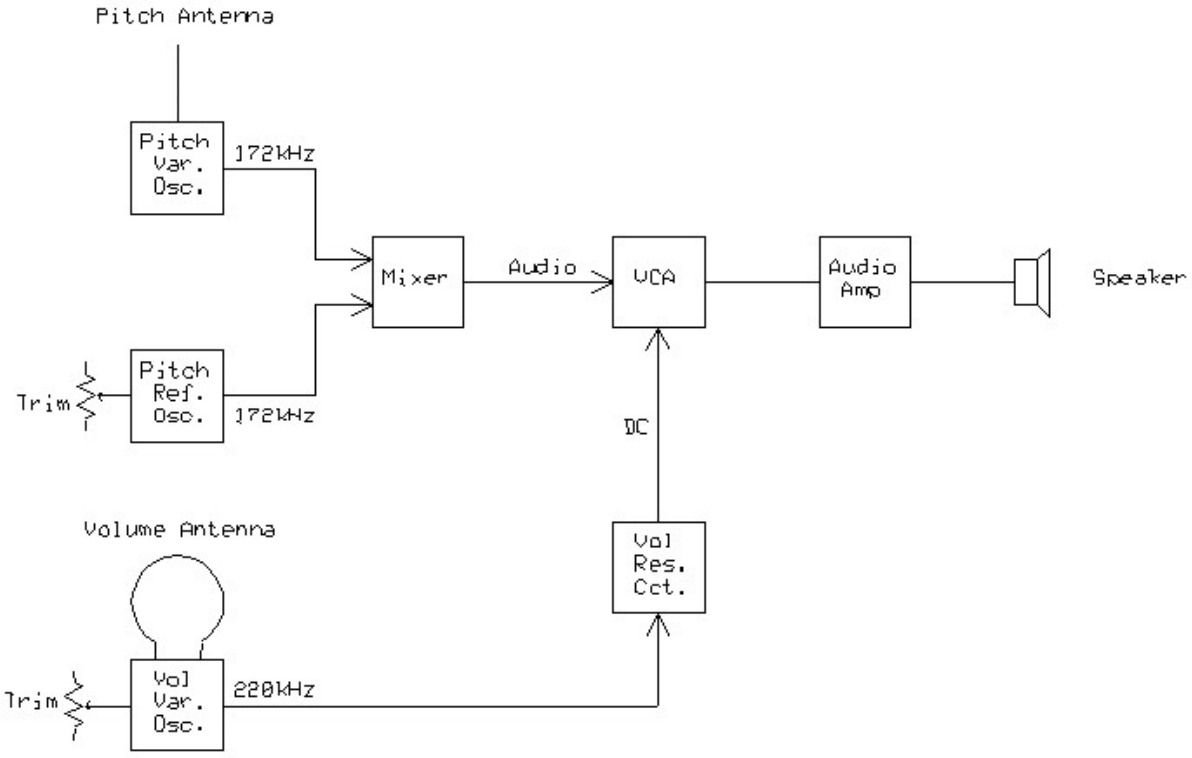
Building a Theremin

What is a Theremin?

A theremin is an electronic musical instrument in which the operator uses no physical contact to play the instrument. The Theremin is composed of two antennas (one for volume, the other for pitch manipulation) connected to a center console, containing the circuits and electronic components. The theremin is a product of Russian government research for proximity sensors. Levn Sergeevish Termen (aka Leon Theremin) was a Russian Physicist who created the theremin in October of 1920 after the start of the Russian Civil War. In a few years time, Leon found his way to the United States and patented his invention in 1928. Then RCA purchased the commercial rights from Theremin.

A theremin essentially is two oscillators that produce a reference frequency much higher than human ear can hear. One of the frequencies is constant and the other frequency is influenced by the extra capacitance the player's hand provides. The actual sound or tone that is produced is the difference between the two reference pitches, or the beat frequency. The volume control acts as a voltage controlled amplifier (VCA) which has 2 more independent oscillators. The resonant

frequency of the VCA is tuned by a variable capacitor and potentiometer, then when the variable oscillator (changing frequency similar to the variable pitch component) matches the resonant frequency of the VCA, it decreases the amplitude (muting the sound when your hand is almost touching the antenna).



Since the 1950's the theremin (or etherphone) has gotten a reputation for its eerie sounds and its use in Sci-fi media and electronic music arts. Some famous bands to include the theremin in their work include but certainly not limited to Led Zeppelin and The Rolling Stones. The theremin also has a history of being involved with movie scores like *Hellboy, Monster House,* and *The Machinist.* Some Sci-fi media that included the theremin included *The Spiral Staircase, Rocketship X-M, The Day the Earth Stood Still, The Thing (From Another World),* and *The Ten*

Commandments. The theremin is also used in recent TV media, including the CBS comedy *The Big Bang Theory* where main character Sheldon Cooper plays a theremin.

We initially had a few different ideas before we landed on the theremin project. Ideas like a noise canceling gun, and a keyboard with dynamically changing pitches so the chords are always perfectly in tune. But we realized that for these ideas, we did not know where to really start. We wanted to get some electronics experience along with circuit building through the course this lab and since playing music was a passion we shared, the theremin was the perfect solution. We are both physics majors concentrating in computational physics. This was our chance to gain some hardware experience; a crash course in analog components that make up this electronic musical instrument. In our future of computer endeavors, we will now have a firm foundation in circuit building, soldering, and electronic components.

We are very pleased that we have a working product, especially because we worked through the issues with the guidance of Professor Errede. Even though we didn't finish the volume component, we both feel that we accomplished a great deal regardless. Through all the trials and errors, our circuit building and soldering got better, along with our ability to troubleshoot problems. We both learned a great deal and were able to apply our knowledge of music and physics together.

Our Process

There were quite a number of frustrating moments during this project. Colin and I have not had extensive circuit building experience prior to this class which made the project difficult in the beginning. At times we were convinced that we bit off more than we could chew with this project. The first thing we did was look at the block diagram and broke up the theremin into many sub-projects by creating each component and testing them as we went.

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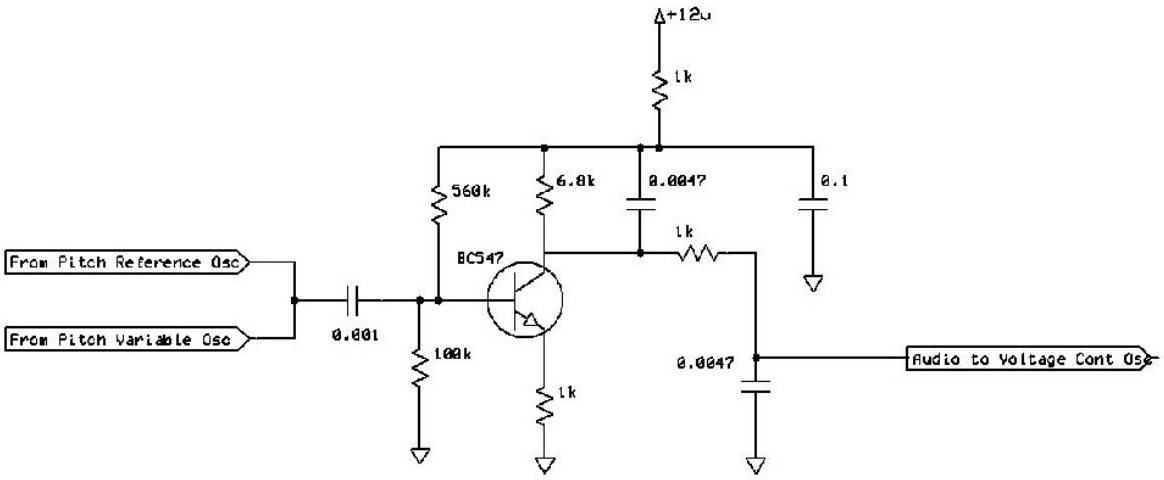
We first built the mixer because it was the simplest circuit. This part of the circuit takes the two oscillator outputs and superimposes and filters them onto each other such that the output of the mixer is the beat frequency between the two oscillators. We first test we did on both the circuit and our circuit building skills was build the mixer in a solder-less breadboard, then hook up and 12V power supply, 2 wave generators and an oscilloscope to read the output. The first few tries we were unable to get any signal or an unexpected signal. We then tried again with the

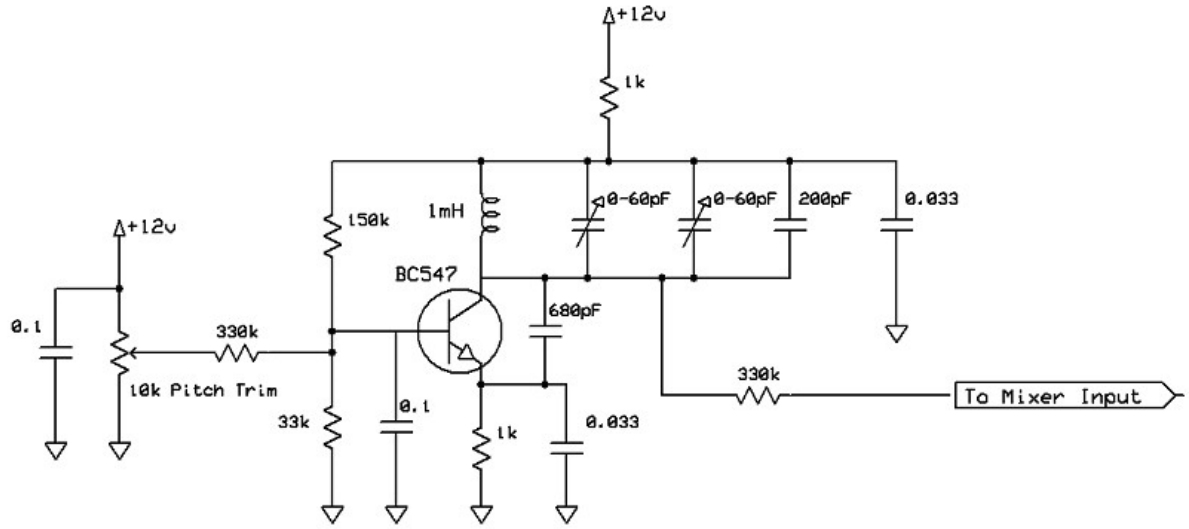
The mixer schematic



330kΩ resistors between the inputs and the circuits so that the signals did not fight each other and we were able to get the signal we were expecting, the beat frequency between the two input waves. We then played with the generators to make sure the beats held as we changed the difference frequency between the two generators. After finishing the circuit, we soldered it to a circuit-board and retested it.

The reference pitch oscillator was a bit more difficult to construct. Mostly because the variable capacitors were (1) hard to get a hold of, and (2) did not fit very well into the circuit-

Reference Pitch Oscillator Schematic



board. The first few capacitors had to be tossed because when not installing them very neatly, the plates were compressed together enough to not allow full rotations when adjusting the capacitance. Eventually, we were able to get a proper signal of 1.2V at about 172kHz which was sensitive to the adjustments of the variable capacitors and the potentiometer.

The variable pitch oscillator was probably the most annoying part of the circuit. Tested by itself, it produced the proper signal similar to the reference pitch oscillator, however when we hooked both oscillators into the mixer, the amplitude of the variable oscillator dropped to about 500mV. After analyzing the circuit with Professor Errede, it was determined that the two oscillators were too close together physically in the circuit, so the variable oscillator was transferred to a second board and we eventually put filters into the power supply (described later) so that the signals were not fighting each other and not dropping out. The mixer worked very well with the two oscillators so this project was coming along fairly well, and when looking

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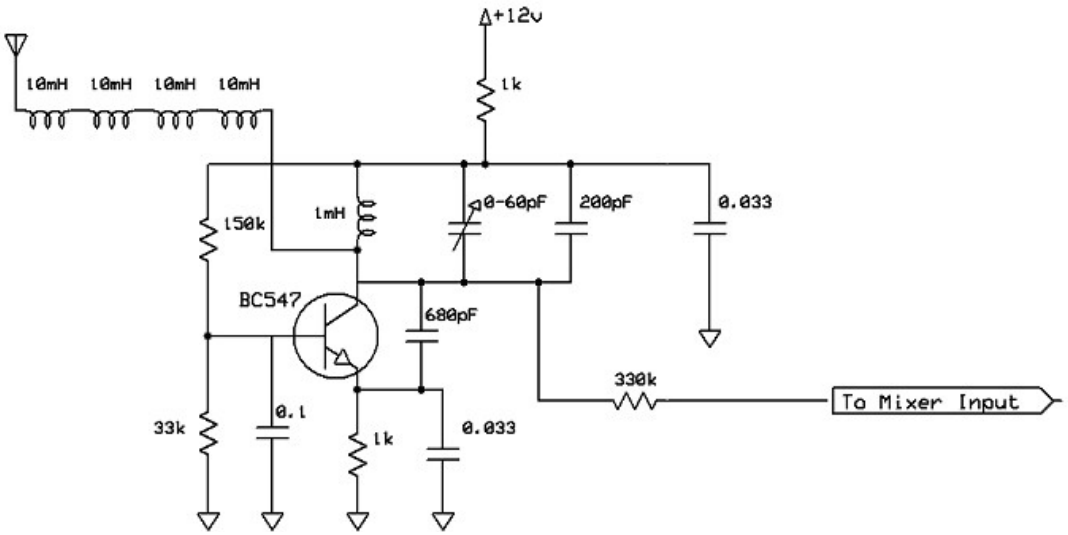
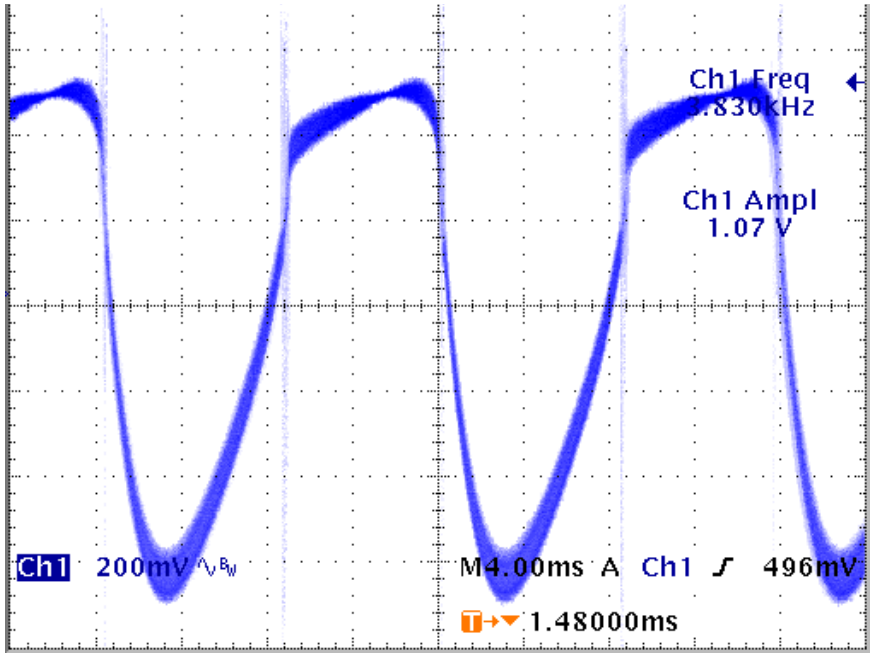


Variable Pitch Oscillator Schematic

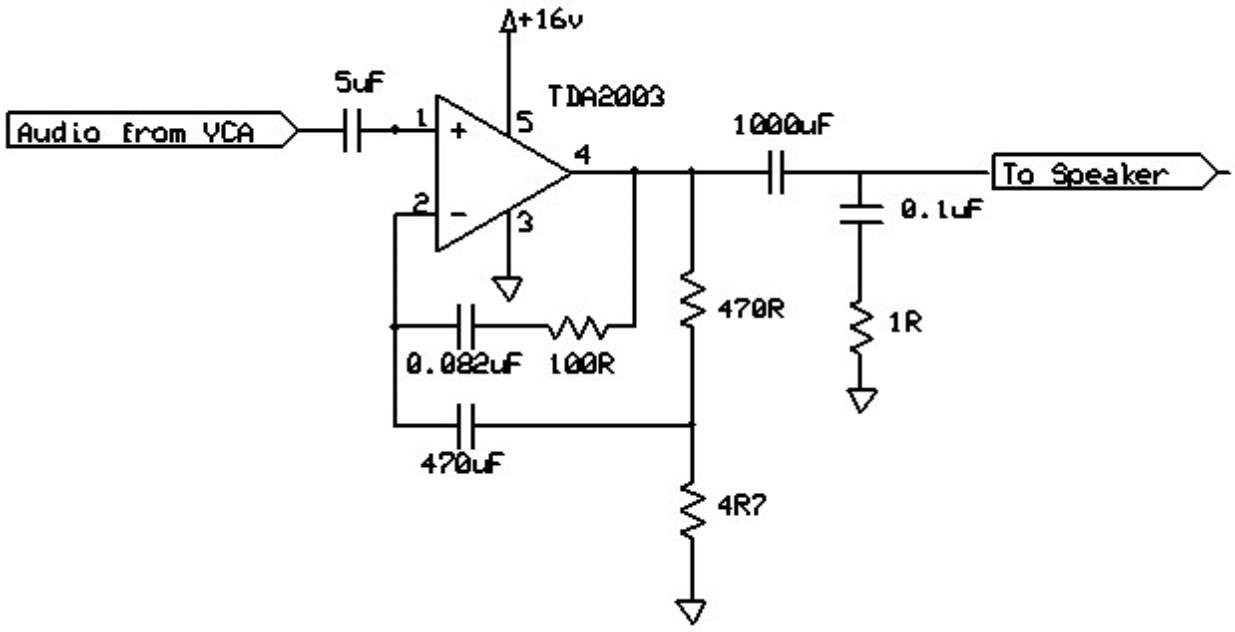
at the oscilloscope, we observed the mixer output was a semi-square wave (see below) probably because of a slight amplitude difference in the two input oscillators. The variable oscillator was eventually equipped with a telescoping antenna.

Oscilloscope image (low fequency, far from antenna)



At this point in time, we were already halfway into the semester and needed to speed up the process. That is why we actually skipped over the volume control momentarily and went straight for the amplifier. The schematic we had was actually meant for the audio amplifier for a car radio. It took some time to complete but was not too difficult except for the monster sized capacitors it called for. We ended up using polarized electrolytic capacitors (which in turn had to be flipped because they were installed incorrectly) because of the availability of parts. The amplifier amplified the 1V signal from the mixer to 18V. The amplifier was actually made to amplify the signal much more, but because of our power supply restrictions, the amplifier became saturated and got cut off at 18V, outputting a completely square wave. We expect this issue to fix itself when the volume control is installed. For the output of the amplifier, we installed a 1/8 inch mono phone jack in which we can plug a speaker. The speaker designated is not of a high enough quality to sustain the maximum volume of the theremin signal and it sounds

Audio Amplifier Schematic



very harsh as the signal over-drives the speaker.

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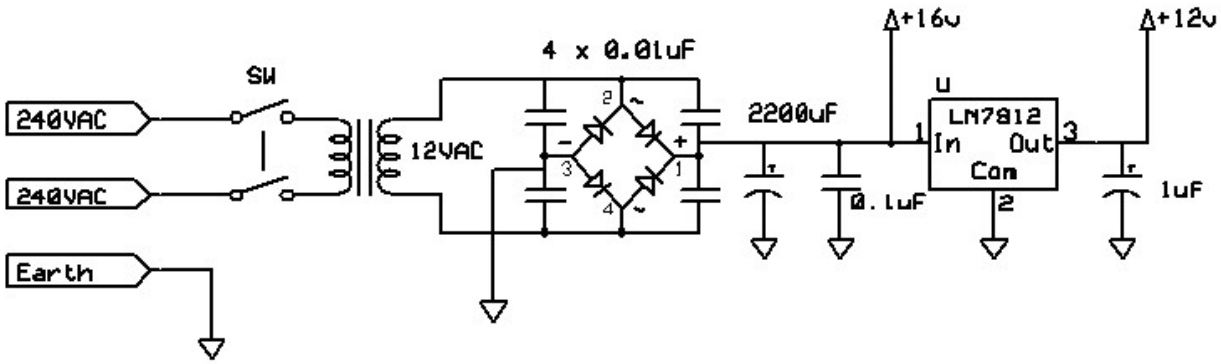
This specific design required a custom power supply because the amplifier ran on 16V and the rest of it ran on 12V. After making a silly mistake of a capacitor not having a high enough volt rating and frying the full-wave bridge, Professor Errede assisted in constructing a new bridge from scratch so it fit better in the circuit board and also installing some electrolytic capacitors to filter out noise. The modified bridge allowed the power supply to put out 18V which still worked with the amp.

Power Supply Schematic



The theremin is complete and despite the harshness from the low-quality speaker, it sounds like a theremin. We plan to continue this project and finish the volume control and put the entire theremin in an enclosed box. We took some last minute data on the theremin recording the oscilloscope images and analyzing the harmonic content using the spectrum analyzer (see the next page for more data images).

We would like to give a special thanks to our great TAs Cody and Matt, and Professor Errede for all the help with this project and a great semester.

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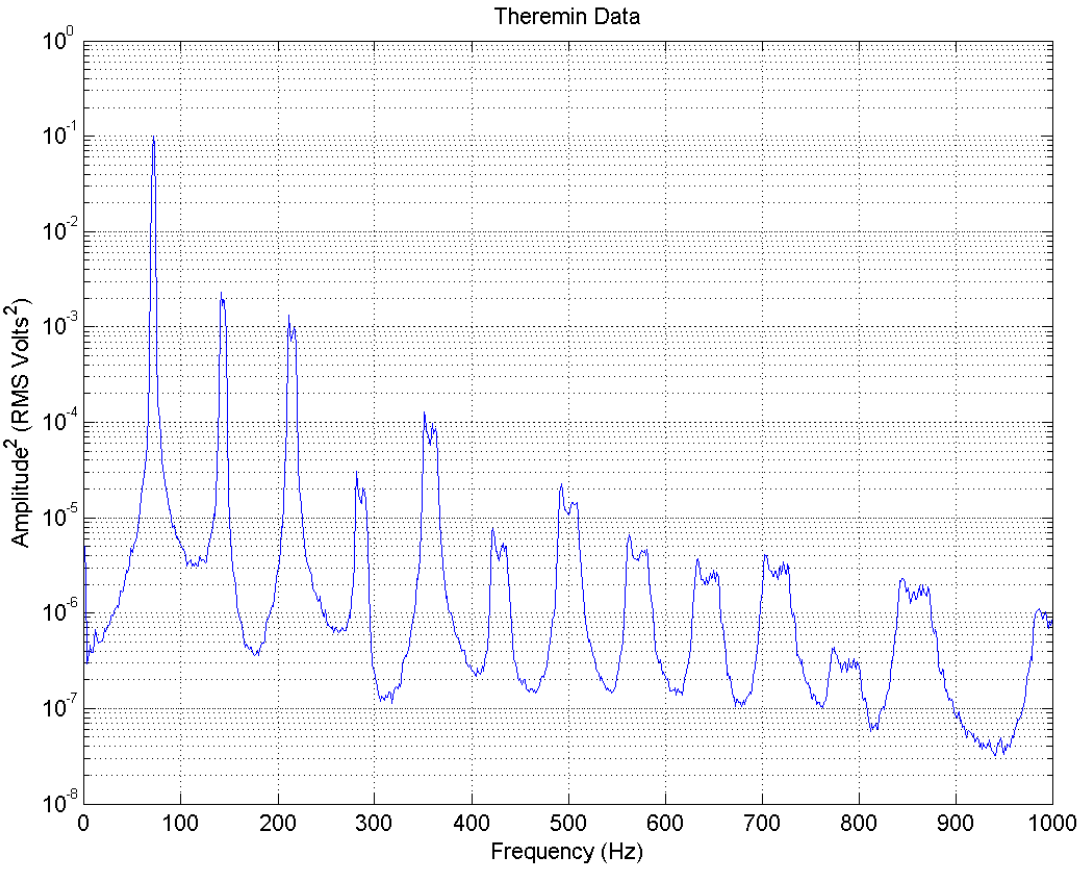
Harmonic Content at low frequency (note that the harmonics here agree with the oscilloscope images as the wave is semi-square with all harmonics, with some of them a little weaker than the rest)



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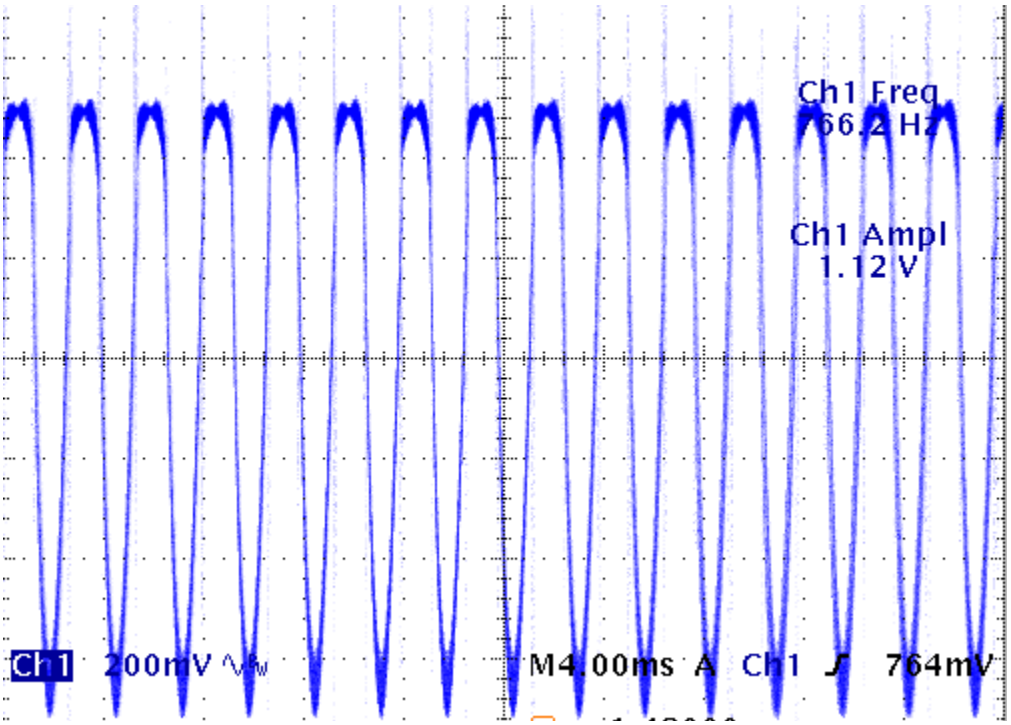
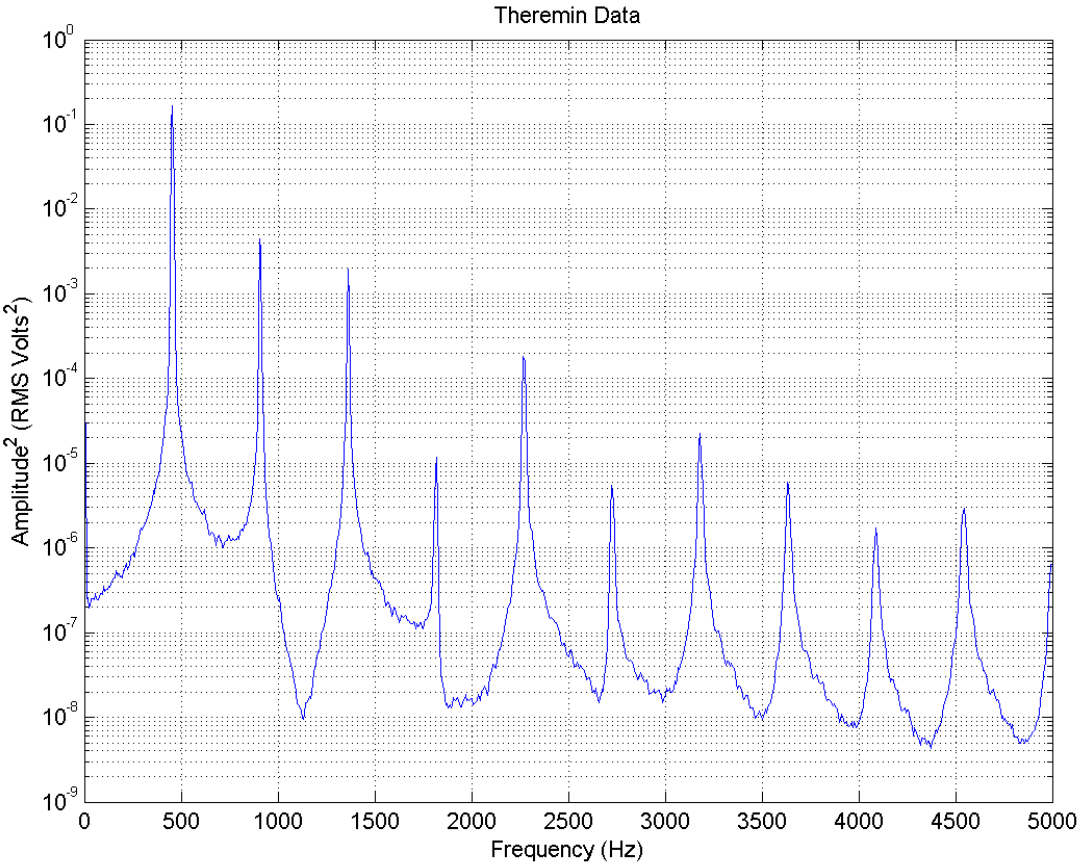
Oscilloscope Image at High Frequency (hand close to antenna)



1 Harmonic Content at High Frequency



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