Theremin

The Theremin (named after its inventor Leon Theremin) is a musical instrument that dates from the early days of radio and electronics. It is a simple radio frequency device which relies on the interaction of two oscillators to produce a range of musical notes. One oscillator serves as a reference while the second oscillator is free to be influenced by the capacitance of the player's hand approaching the instrument's pitch antenna. To achieve control over the volume of the sound produced by the instrument another oscillator arrangement is used.

Playing the instrument is an interesting blend of electronics and theatrics. As the Theremin virtuoso gestures in space, glissandos of sound emanate from the instrument's loudspeaker. Although the Theremin has been used for serious musical performance, it is more usually recognised for the eerie sound effects in 1950's sci-fi movies.

I had being toying with the idea of building a Theremin since the late 60's but never got around to actually doing so until a few of years ago. Here is a description of the results of quite a few hours spent in my backyard shed and a few useful tips for the enthusiast who might want to also have a go.

The Design

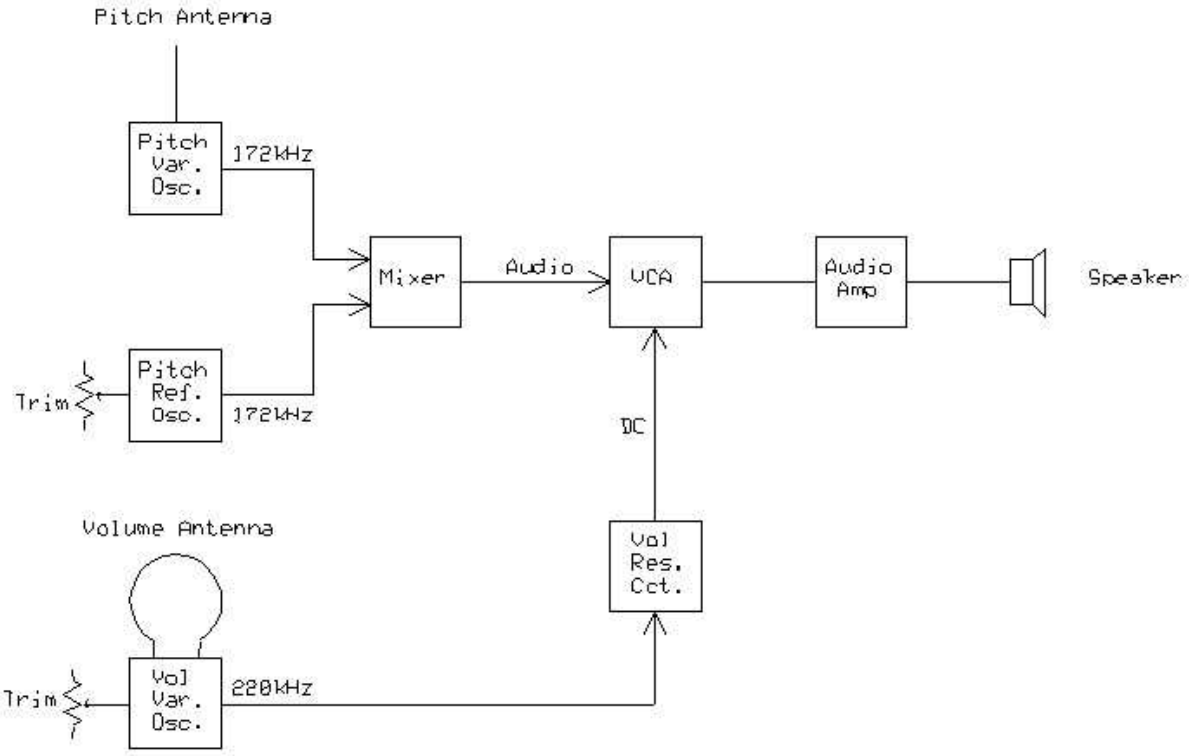
Although I had a strong urge to produce a traditional instrument, it is hard to ignore the benefits of the semiconductor when devising a project of this nature. The result of my labour is an instrument using the same oscillator frequencies and a similar functional arrangement as the original RCA Theremin but utilizing transistors instead of the valves (or toobs).

My Theremin is constructed using separate modules representing each functional unit of the instrument. In this way it is a simple matter to build each element of the Theremin, get it operating correctly and then finally assemble the whole instrument. The Theremin's modules are:

- Pitch reference oscillator
- Pitch control oscillator
- Mixer

- Volume control oscillator
- Volume resonant circuit and voltage controlled amplifier
- Audio amplifier
- Power supply

Each oscillator used in this Theremin is of the Colpits type and uses a miniature ferrite core inductor and three capacitors as the frequency determining components. Two of the oscillators incorporate a means to allow the operator to adjust their frequency with a front panel control.

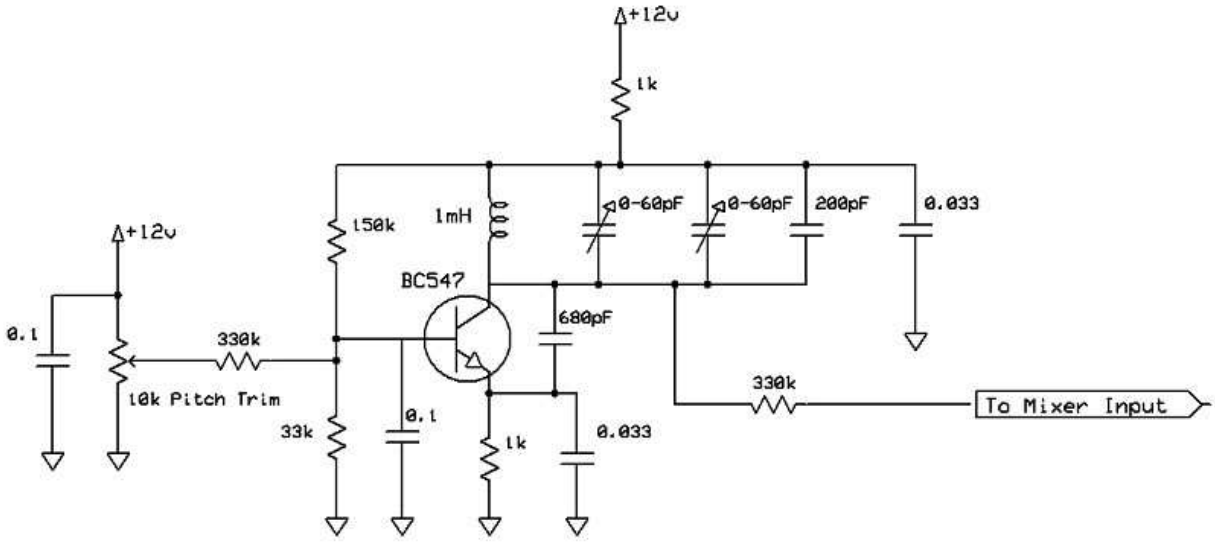


Theremin Block Diagram

The block diagram shows the general arrangement of the Theremin's modules. The signals from the two pitch oscillators are fed to the mixer where sum and difference products of these signals are produced. After filtering, only the audio difference signal emerges which is fed to the voltage-controlled amplifier (VCA). The gain of the voltage-controlled amplifier is varied by the DC signal from the detector in the volume resonant circuit. This DC signal is produced as the volume oscillator is pulled away from its set frequency by the capacitance of the players hand as it approaches volume antenna. The audio tone from the VCA is fed to the amplifier and finally to the loudspeaker.

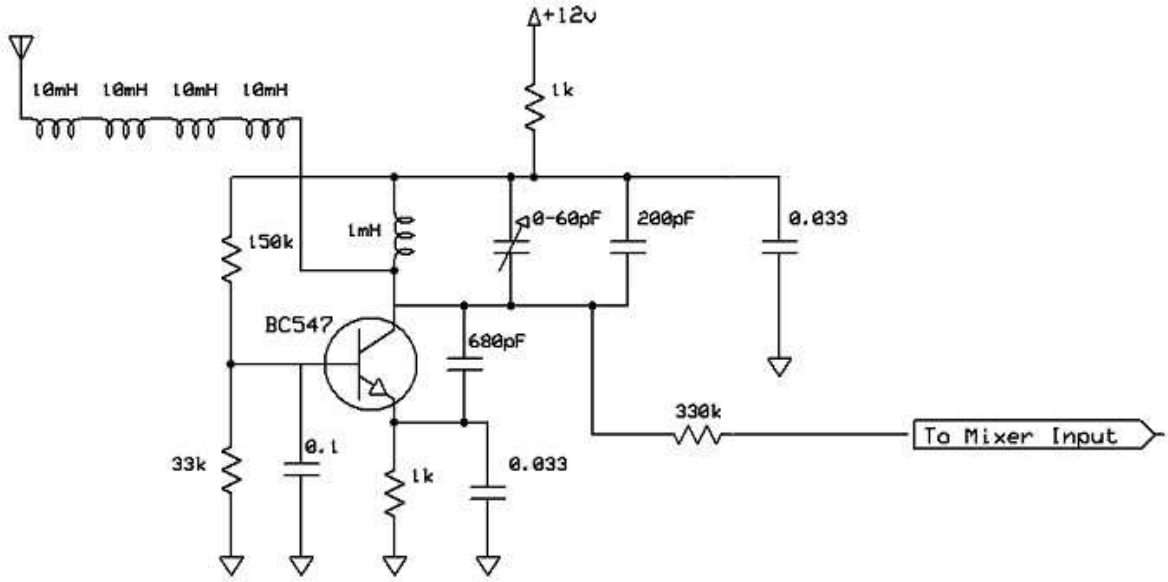
The Circuits
Each module can be built, tested and tuned so that the final assembly is the simple process of hooking everything together and performing a few final adjustments. In order to test and tune the modules, an oscilloscope is required.

Note: All capacitor values are in uF unless otherwise noted.



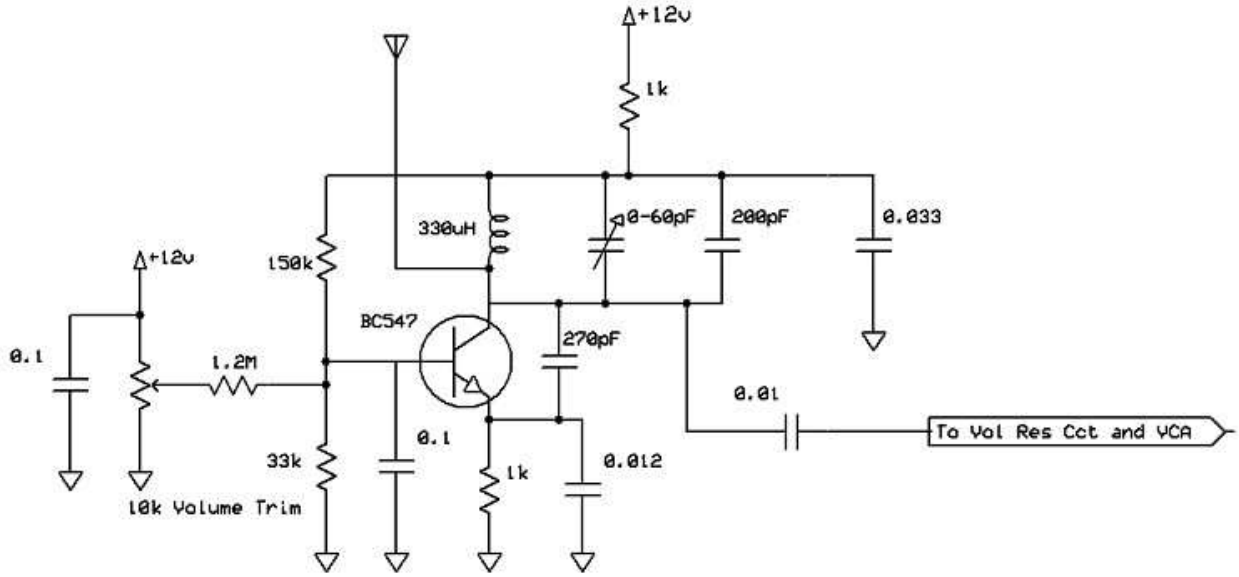
Pitch Reference Oscillator (172kHz)

The pitch reference oscillator operates at around 172kHz and is trimmed to the correct frequency by the operator using the 10k potentiometer. A small ferrite core inductor and several capacitors form the frequency determining network. The 172kHz output signal of this oscillator is fed to the mixer module using a length of screened cable.



Pitch Variable Oscillator (172kHz)

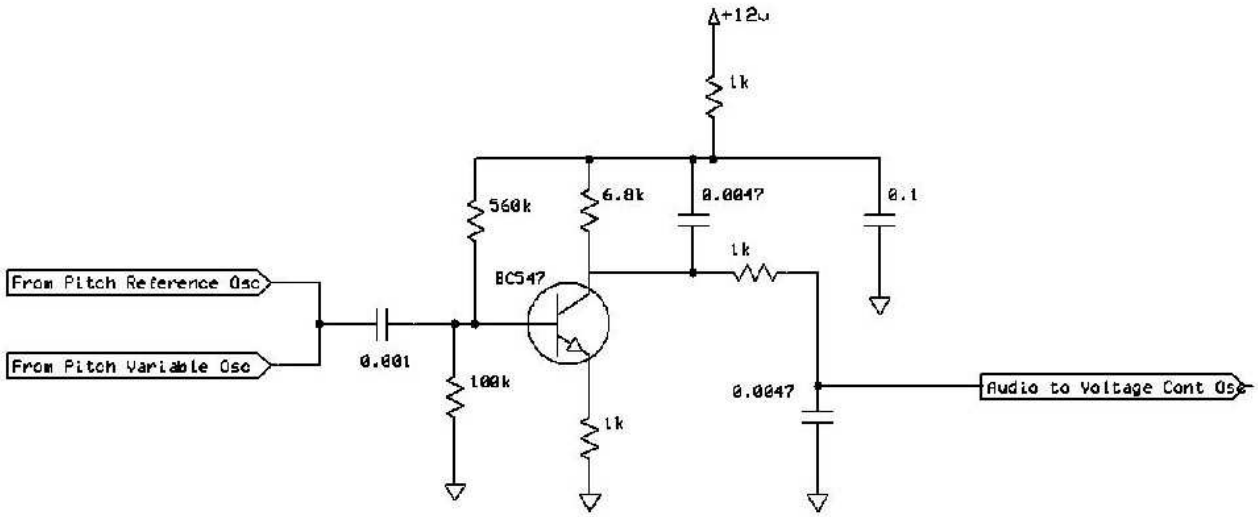
The pitch variable oscillator also runs at 172khz and is influenced by stray capacitance associated with the pitch antenna. The purpose of the four 10mH ferrite inductors is to improve the linearity of the relationship between the player's hand position and pitch. Without these components, the Theremin pitch would rise slowly at first and then suddenly rise through several octaves in just a few millimetres of hand movement, making the instrument difficult to play. As these inductors form a series resonant circuit with stray capacitance associated with the antenna, it is difficult to predict their optimum values. The value of these components is best adjusted by trial and error to achieve the best hand movement/pitch relationship. The output of this oscillator is also fed to the mixer module using a length of screened cable.



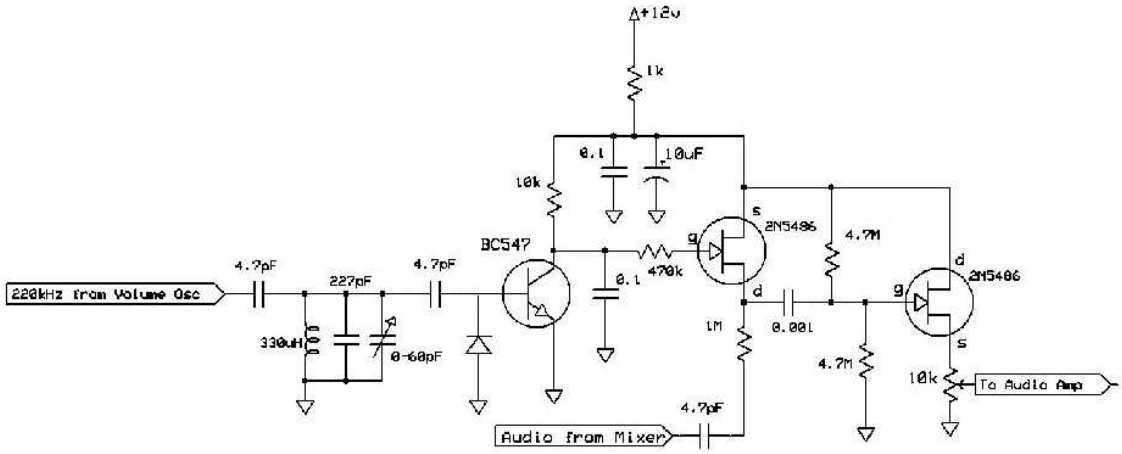
Volume Variable Oscillator Circuit

The volume oscillator operates near 441kHz and is strongly influenced by the volume antenna. When correctly tuned, and the operator's hand is almost touching the antenna, the frequency of this oscillator will match the tuning of the volume resonant circuit. This condition causes maximum signal to appear across the tuned circuit and corresponds to audio cut-off. The 10k trim potentiometer enables the operator to set the oscillator to the correct frequency.

Mixer

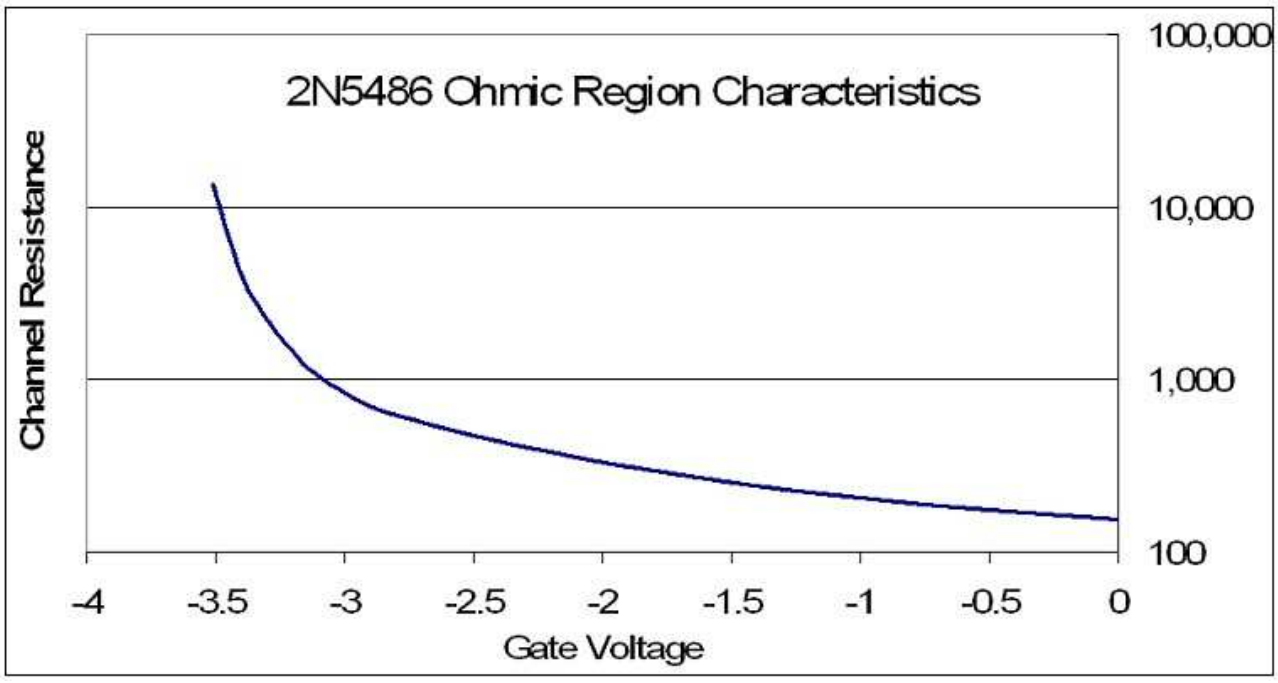


The mixer is the simplest module to assemble and requires no adjustment. Its function is to mix the signals from the two pitch oscillators to produce an audio signal. As the mixer is fed with the two slightly different oscillator frequencies, it produces a complex waveform at its output as a result. If the output waveform was to be analysed it would be seen to actually contain two frequencies, one equivalent to the addition of the input frequencies and the other equivalent to the subtraction (or difference) of the two input frequencies. As the former would be inaudible and useless to our purpose, we use a low pass filter (two 0.0047uF capacitors and a 1k resistor) to extract the latter which will be in the audible range.

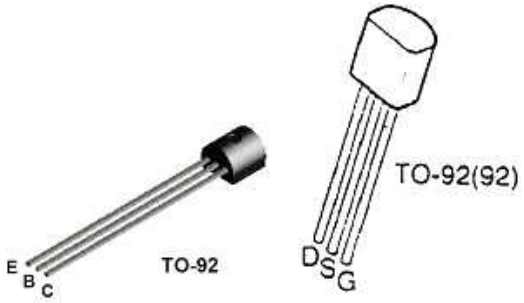


Volume Resonant Circuit and Voltage Controlled Amplifier

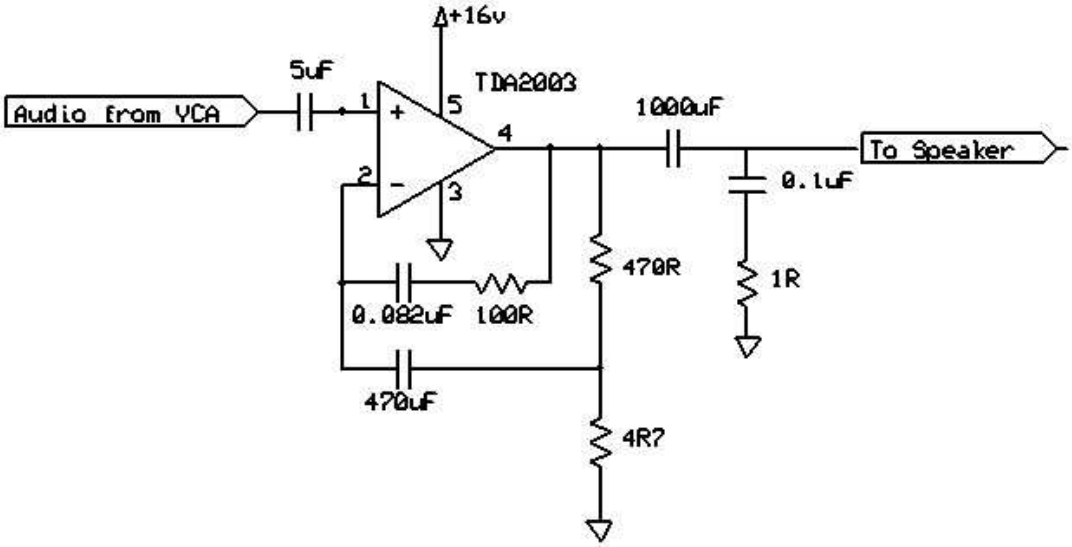
This module alters the volume of the Theremin in response to the player's hand gestures. It consists of a resonant circuit tuned to the same frequency as that produced by the volume oscillator when the player's hand is close to the antenna. This causes maximum signal voltage to be developed across the tuned circuit. As the player's hand moves away from the volume antenna, the frequency of the volume oscillator also moves away from the resonant frequency of the tuned circuit. This causes the DC bias at the base of TR1 to fall away and its collector voltage to rise. As FET 1 is biased into the ohmic region, the rising voltage at its gate causes its channel resistance to increase. This reduces the effect of the shunt across the audio feed to FET 2 and increases the volume of the audio signal.



The measured characteristics of FET 1 when biased into the ohmic region

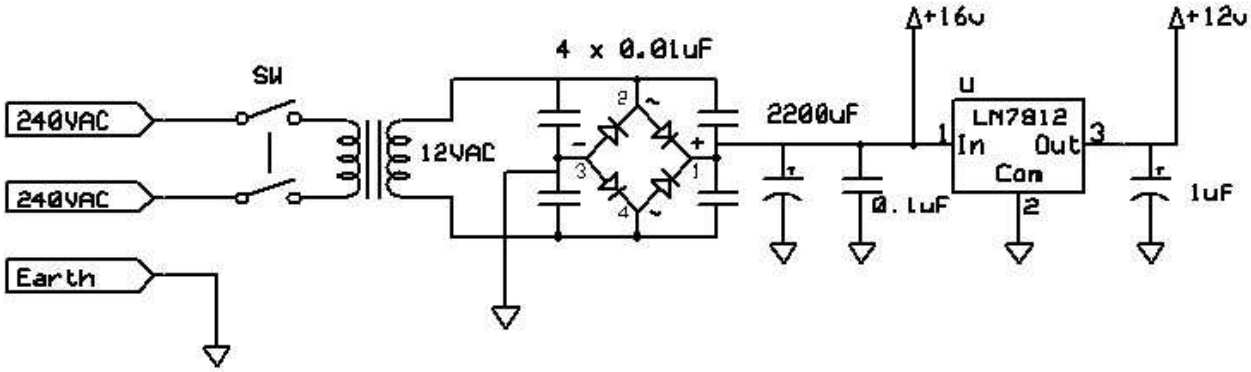


Semiconductor Pin-outs



Audio Amplifier

The audio amplifier uses a TDA2003 monolithic amplifier originally designed for car radio applications. The circuit comes directly from the manufacturer's data sheet.



Power Supply

WARNING - LETHAL VOLTAGE

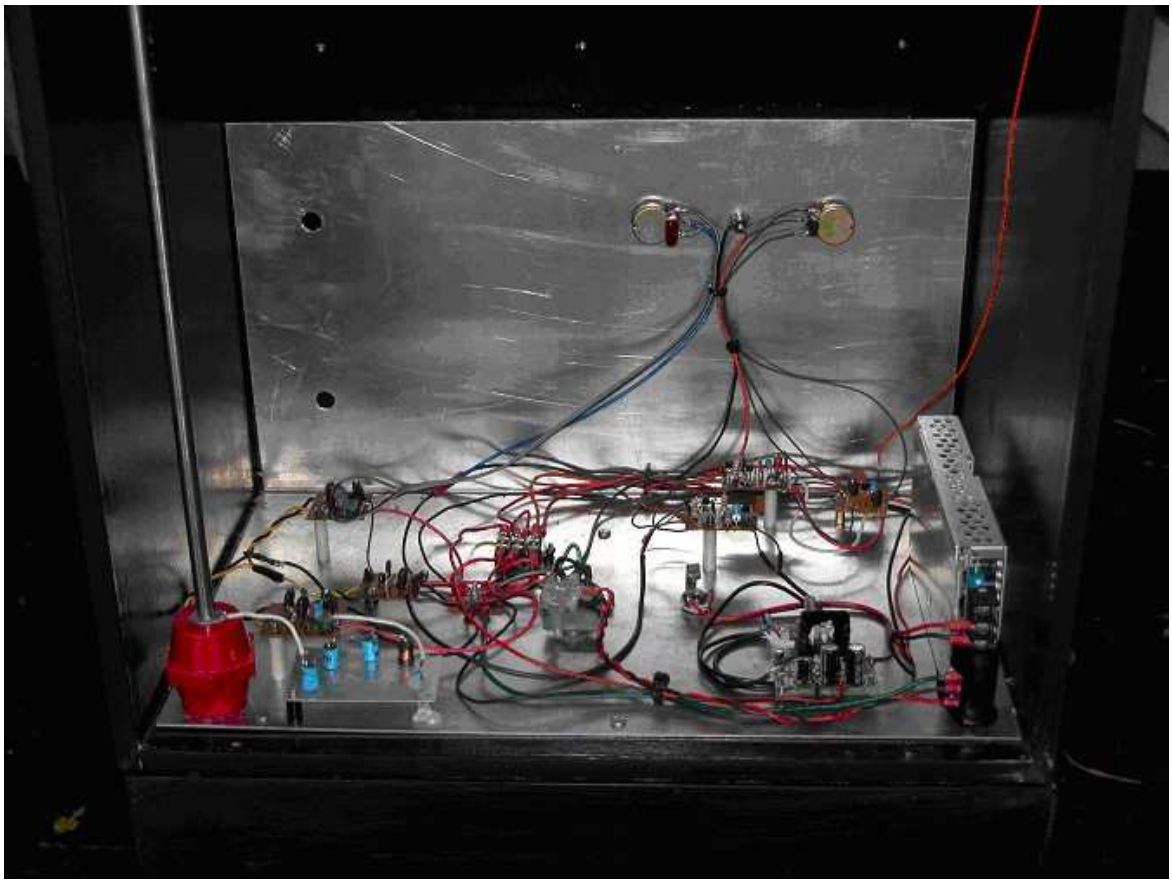
If you are unsure, use a 12VAC plug-pack type power unit in place of the transformer and switch indicated in the schematic. A separate earth connection will be required.

The power supply uses a 240VAC/12VAC transformer, bridge rectifier and a 3-terminal voltage regulator. Capacitors

across the rectifier diodes are required to reduce common-mode induced hum.

Assembly and Testing

When each of the modules have been built and tested it is a simple matter to assemble them and perform some final adjustment. The layout of the modules is not especially critical but obviously the pitch variable oscillator should be mounted close to the pitch antenna and the volume oscillator close to the volume antenna.



The Layout of an Early Prototype

The volume trim is adjusted so that the sound reduces to zero as the operator's hand almost touches the volume antenna. The pitch trim is then adjusted so that no tone is heard when the player is standing in the playing position. The Theremin is now ready to play.

Technical Discussion

Why does altering the DC bias of an oscillator change its frequency?

I must admit that this is not something that concerned me unduly when I was fiddling about with this project in the early 90's (the redbacks in my garden shed gave me more than enough distraction from the task at hand).

However, this is clearly something that interests quite a few people and several visitors to this site have offered explanations as to why this effect occurs.

Non-linearity of the B-H curve of the inductor

The inductor has an iron (ferrite) core and the variation of the transistor's bias changes the DC current in the inductor thereby shifting its operating point along the B-H curve. Due to the non-linearity of the B-H curve, this results in a change in oscillator frequency.

See the following Wikipedia article on magnetic saturation for an explanation of the B-H curve.

http://en.wikipedia.org/wiki/Saturation_%28magnetic%29

This explanation seems quite plausible. It would be interesting to substitute an air-cored inductor for the ferrite cored inductor and note the difference in circuit operation.

Collector-Base Junction Capacitance

Mike Page-Jones from the UK pointed out that the change in bias would also alter the collector-base voltage of the transistor and thereby alter its junction capacitance.

Recently, Elmar Grom provided a compelling description of what is really going on. His edited comments follow:

"What actually happens is that you are changing the gain of your transistor, which in turn changes the Miller-Capacitance. This is not a real existing capacitor, but a capacitor like behaviour exhibited by the transistor, as a result of the collector base capacitance, multiplied by the circuit gain."

"I assume you have seen the circuit diagram for Bob Moog's Theremin kit. He wrote an article about it in the early nineties, before it became a kit. You might notice that there is a 'strange' circuit connected to the fixed pitch and volume oscillators. It consists of a transistor and a few capacitors and resistors. The tuning pots are connected through a resistor to each of the emitters of those transistors. These function in the same way, by exerting the Miller capacitance on the oscillator tank. This is a bit better for a couple of reasons:

1) The oscillator transistor does not have to do double duty, i.e. you don't have to screw around with the gain, possibly creating a situation where the oscillator might stop because the gain got too low.

2) The underlying capacitance for the Miller capacitance is not the collector to base capacitance, but the capacitor that is installed from the collector to the base. Since it is much larger than the 'natural' capacitance there, it dominates the effect. This means that the value is much better understood and so the circuit behaves more predictably. This is an important aspect when publishing circuits for others to copy or when designing a kit or production circuit."

Some Useful Links

Wikipedia article on Leon Theremin

Instructions on how to play the theremin

Thomas Grillo provides some excellent theremin video instruction on YouTube

Theremin kit available from Jaycar

... and a couple of links suggested by Tara Pattinson's class of young technologists:

http://www.designerappliances.com/articles/electric-appliance-hobbies-resources-and-projects/

http://www.electronics-lab.com/links/links.html

The following links to Theremin related products available through Amazon might be useful:

Strange Apparatus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