1 Introduction

The Pixie II is a small, versatile radio transceiver that is very popular with amateur radio operators the world over. The design schematic is readily available all over the Internet, which is where we found it. In its unmodified form, it is a QRP CW transceiver. In HAM parlance, QRP is a code for “please reduce power”, and CW stands for “continuous wave”. What these things really mean is that this radio is a low power radio that transmits a tone; basically, it can be used for Morse code communication.

One of the most impressive features of the Pixie II is that it can operate at a wide range of RF frequencies. The main modifications required to change the operating band are replacing the crystal and altering the output filter. Still, the real beauty of this radio is its simplicity. The design is fairly transparent and easy to follow, and it is easily modifiable.

The board you will be using for this project is one milled here in the department using Eagle board layout software and a milling machine. Milling our own boards cuts down on costs and increases flexibility. We do not need to have fifty or a hundred boards etched commercially for quite high cost and we are not locked into using that same board over and over. All the components necessary for the project are common parts and will be made available to you.

2 Theory and Design

As with almost any circuit, the Pixie II can be broken into several sections. There are four main parts to this radio including the oscillator, the power amplifier, the output filter, and the audio section. On this board we have also provided space for two decoupling capacitors which suppress noise caused by switching transients produced by the transistor section of the oscillator.

2.1 Oscillator

The oscillator the Pixie II employs is a Colpitts crystal oscillator. The crystal is a common circuit component often used in circuits requiring accurate timing; RF devices are one set of these. The crystal is simply a piece of quartz that is specially cut and shaped to resonate at a very precise frequency.

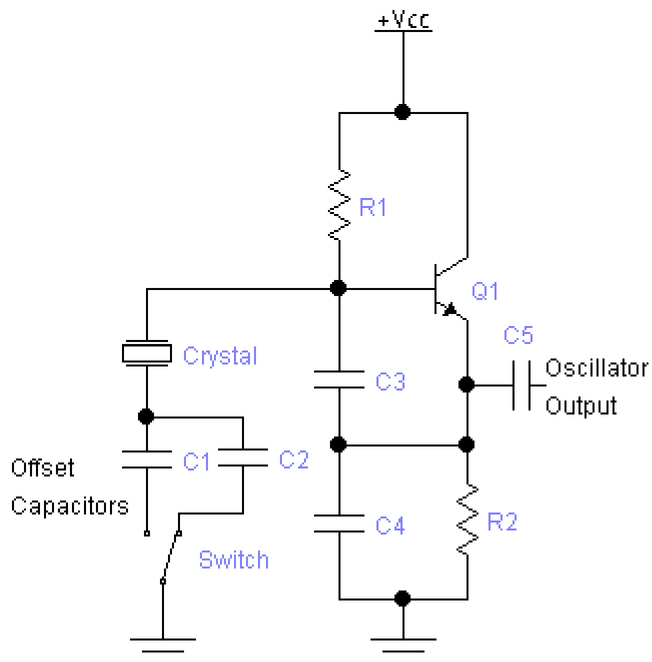

Figure 1: The Oscillator section of the Pixie II

In brief, the basic idea behind crystal operation is that quartz is a piezoelectric material, which means that when it is placed under a strain it produces a voltage across the contact points on the crystal, vice versa. That strain manifests itself in the oscillating output signal with amplitude of something below the input DC voltage; the exact level depends on how the crystal is being driven and other components in the circuit. It is unnecessary for this course to go any deeper into this, but if you are interested in finding out more about crystals, there are lots of books that cover the subject; check the library.

Designers often favour crystal oscillators for RF devices because they are very stable and are fairly immune to frequency drift. The main drawback is that they are not readily tuneable. The only way to change the operating frequency even within a band is to swap out the crystal, or to set up some kind of crystal switching system. It is for this reason that commercial radios no longer rely on crystal oscillators. For the purposes of this project, changing the channel within a given band is quite straightforward; all that is required is to replace the crystals, but to go from one band to another (for example from 80 m to 11 m) is another story altogether. Fortunately, one does not need to overhaul the entire radio to get another band, but there are many things to consider. Many of the RC and RLC units in the circuit must resonate at a frequency that agrees with the oscillator, or the thing will not work.

Many crystals use what is known as "overtone mode" which means that they have a given fundamental frequency, but can also oscillate at certain multiples, or harmonics, of that frequency. Usually crystals for frequencies above about 10 MHz are overtone crystals. For example, a crystal with Channel 32 stamped on it (referring to CB Channel 32, which is 27.325 MHz) is likely a 9.108 MHz crystal intended for operation at the third overtone. It is not at all unusual to find a crystal oscillator operating at its fundamental frequency instead of the desired overtone. The way to fix this problem is to adjust the bias on the transistor in the oscillator arrangement.

2.2 Power Amplifier

The power amplifier amplifies the oscillator's output so that it is suitable to be filtered and transmitted through the antenna, but it can only do that when the key is closed, providing a short circuit from the emitter to ground. Only when the power amp is running can the signal reach the output filter. When the key switch is open, there is basically a straight route for DC through R3, L1, and R4, so the voltage at the base will be relatively high, and the current through that route will be very low. When the switch is closed, there will be a short circuit from the emitter to ground, which will put the base voltage to 0.7 V. The signal coming in will be forced into the base (it can't go through the inductor), which will cause the signal to appear amplified at the collector. This signal then goes into the filter and out through the antenna.

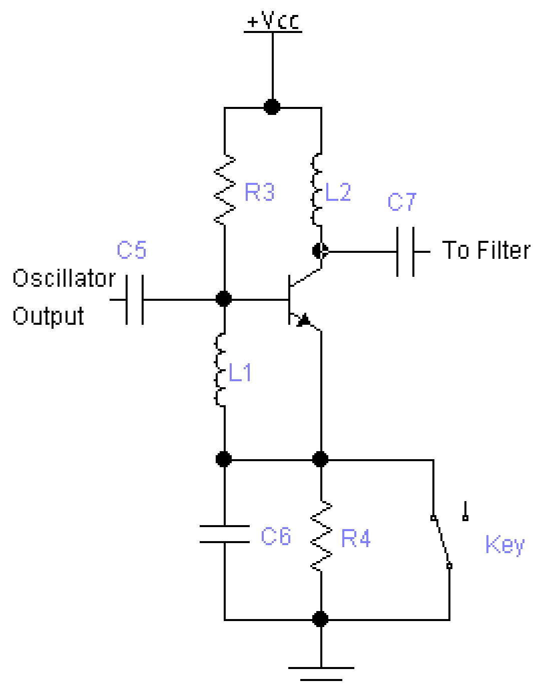

Figure 2: Power Amplifier Circuit Segment

A crystal oscillator produces many harmonics of its fundamental frequency, but it is necessary to have only one. That is why the power amp has a built in resonant element. As a result, the power amp only responds to a certain range of frequencies. This is something to bear in mind when modifying this circuit.

2.3 Output Filter

The filter itself is not too complicated; it is a basic pi connected LC bandpass filter. The values for this filter can be easily computed using this formula:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

This formula works for using the same value for C8 and C9. C7 is an AC coupler.

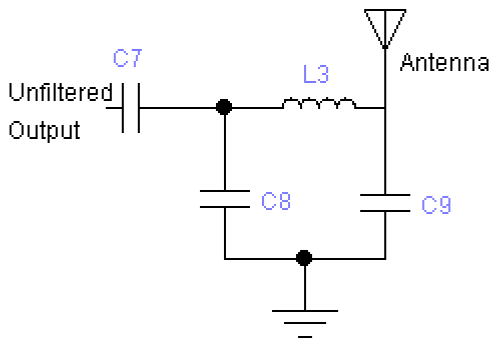

Figure 3: Output filter circuit segment

2.4 Audio Section

The audio section is basically the receive part of the radio. Its input is the antenna output mixed with the oscillator output. This input is the audio frequency offset between the two signals which goes into the audio amp input at pin 2. The audio output is at pin 5 to the speaker. Note the AC coupling capacitors at every stage (C11, C17). C12 is for gain control; the LM 386 has adjustable gain which is controlled between pins 1 and 8. More detailed information on this feature can be found on the manufacturer's data sheet for the chip.

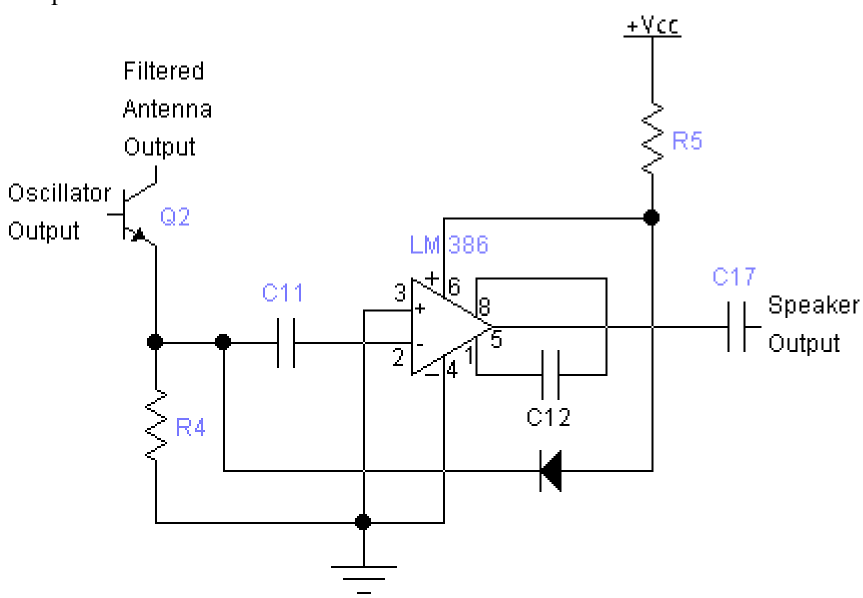

Figure 4: Audio amp circuit segment in receive mode (with key open)

The key not only switches the output on and off, but the audio amp as well. When the key is open, the LM 386 is connected as it should be, and will output any audio signal it receives. On the other hand, when the switch is closed, the power input at pin 6 is only getting the diode drop voltage of roughly 0.7 V. This is not enough to run the amplifier, so the speaker will not produce any sound while the key is pressed.

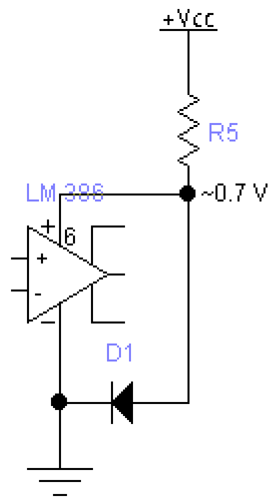

Figure 5: Audio amp during transmit (with key closed)

3 Construction

3.1 General Hints

3.1.1 Soldering

For many of you this will be your first time using a soldering iron, so it may be useful to go over the basics of soldering now. Soldering is really no more complicated than it seems. The main things to remember are not to use too much solder, to use enough heat, and to try to get it right the first time. Of course, this takes some practice, but once you get the hang of it, it is not too difficult. These boards are fairly robust, so it is not too serious if you need to repeatedly solder the same pad. That being said, it is preferable to only do it once. Later modifications do require second or third or fourth resolderings; just use solder wick to keep the board tidy and to reduce the risk of unintentional shorts.

3.1.2 Components

Capacitors are the most common elements on Pixie II. For the purposes of this project they come in two types: electrolytic and ceramic. The electrolytics are can shaped and, as in previous labs, are polarised. There will be a stripe on one side of the can denoting the negative leg. It is important that this leg be placed towards the more negative side in DC terms. Ceramic capacitors, on the other hand, have no polarity; they can be installed without considering positive or negative placement.

Everybody in this course should be familiar with resistors. Just keep in mind that sometimes resistors are returned to the wrong drawer; check the colour code before using any resistor.

3.2 The Board

One of the first things you may notice about the board upon comparison with the schematic is that there is space for more parts than are listed. These are optional components that were considered during the design process. You should also notice that this is a two-sided board. The top (component side) is all a ground plane. This is an important feature in RF design; it is key to have good grounding at these frequencies. The traces are found on the bottom (solder side). It is necessary to place solder on the top of the board for components with a connection to ground, so components that can be (resistors and capacitors, for example) should be raised slightly off the board so that you can reach in there with the soldering iron.

3.3 Off Board Connections

There are several off board connections on the Pixie II. They are +9 V, ground, an antenna/ground pair, a speaker output/ground pair, receive, transmit, and two wires for the key. Wires coming off the board can sometimes cause unwanted antenna behaviour. A good way to combat this effect is to twist the wire around a ground wire, so for the power, speaker, RX, TX, and key wires it is a simple matter to twist them up with their corresponding ground wires.

3.3.1 Power

Power can be supplied to the board from a regular 9 V battery, an adjustable power supply, or any other DC source. Batteries will work better because they are not susceptible to power line noise like power supplies are. The design includes a power line filter (C15 and C16) to combat this problem, but still a battery is preferable.

3.3.2 Antenna

For the very simplest of antennas it is only necessary to use one of the two antenna connections; the ground needs to be used for more complicated antennas than a single wire. Such antennas include a simple dipole of two equal lengths of wire stretched in opposite directions, a ferrite rod antenna, or a loop antenna of some kind. It is very important to note that antenna design changes drastically as the desired frequency and other factors change. Indeed, the antenna is one of the most important parts of a radio system, and antenna design is a field of study in itself. There is much literature available on the subject, so it is not difficult to find examples of antenna circuits.

3.3.3 Switches

There are two switches on the Pixie II: the key and the RX/TX switch. The two are not linked, but they are for similar purposes. The RX/TX switch operates the frequency offset, which produces the tone heard through the speaker; it is something like a push to talk button. It should be set to TX while the user wants to transmit, and set to RX for receive. The key is simply the Morse code key used to send the message. There are many designs for Morse code keys available on the Internet that can be made from simple parts. You can also use a computer to control the key.

3.3.4 Speaker

An earphone will likely work best because it can not only produce sound right into a listener's ear, but it also blocks out some ambient noise. This is important because the output tone cane be a little faint; it is definitely audible in a quiet room, but not necessarily if there is a lot of noise in the area. The speaker output is essentially the signal output. That means that an oscilloscope connected to a bare wire out of the speaker connection will also pick up the incoming signal.

4 Testing and Operation

Like any circuit, it is wise to test the Pixie II in stages as you build it. That way, it is possible to see if you have made any errors along the way, or if a part is not functional. It is much easier to ferret out problems like these in small units than in a large complete circuit, especially one with which you are not completely familiar. Don't be discouraged if things do not work exactly as they should right away; you will likely need to make adjustments.

4.1 Oscillator

The first part to test is the oscillator. Install C1 through C5, R1 and R2, Q1, and the crystal. Now hook up power. Take an oscilloscope and check the signal at the output of C5. Ideally you will be getting a sine wave with a peak voltage of roughly three or four volts and no DC offset. It is unlikely that you will get a perfect sine wave. Do not worry too much about that as long as the frequency is correct. There are ways to clean up this wave, mostly by adjusting the bias on the transistor Q1.

4.2 Power Amplifier

Once your oscillator is functioning properly and you have installed the parts for the amp (L1 and L2, R3 and R4, C6, Q2, and the key) use an oscilloscope to check the difference between the signal at the base and the collector of Q2. The collector should read completely dead when the key is open, but it should give the same shape signal as at the base, only 5 or so times greater in amplitude when the key is closed.

4.3 Output Filter

The output filter is quite easy to test; all you need is a signal generator that is capable of producing a sine wave at the desired frequency (the oscillator and power amp should do) and an oscilloscope. Install the parts for the filter (C7 through C9 and L3), and hook up the signal generator in front of C7. Now put the oscilloscope probe at the antenna output. If the signal is not attenuated, then the filter is working fine. If you need to make any adjustments to component values, remember the formula in section 2.2. If you want to change the frequency by a factor of two, you must change either the capacitor or inductor value by a factor of four.

4.4 Audio Amplifier

To test this stage you just need to place a function generator at the input to the LM 386 (pin 2) and listen through the speaker. Most function generators are not capable of signals as low in amplitude as the antenna will produce. The antenna will produce signals in the order of microvolts while the generator will likely only be able to go down to millivolts. That means that the tone out of the speaker during this test will be much louder than the tone when the radio is in regular operation.

4.5 The Whole Thing

You need two radios on the same frequency to see if they work completely. Start small; set the radios fairly close to one another and see if you can hear the tone from one through the other. If you can, take them further apart. Find out how far apart you can get them to talk. If that is far enough for your purposes, you are ready to start inventing. If not, there are a few problems that could be to blame; the antenna may need work, or the power output may not be high enough.