1.1.1. Material and Equipment Requirements

1.1.1.1. Material

1.1.1.1.1. Circulator: Quest Microwave Inc. part# D25-L9093
1.1.1.1.2. Low-noise amplifier: WJ Communications part# AG604
1.1.1.1.3. Mixer: MXB-1501
1.1.1.1.4. High Bandwidth AmplifierBandpass filter: LM6171
1.1.1.1.5. General Purpose Amplifier: LM741
1.1.1.1.6. Resistors of various values
1.1.1.1.7. Capacitors of various values

1.1.1.2. Equipment

1.1.1.2.1. Power supply
1.1.1.2.2. Function generator
1.1.1.2.3. Digital multimeter
1.1.1.2.4. Spectrum analyzer

1.1.2. The Process of Implementation

The input signal was carried through the patch antenna, then directed through port 2 of the circulator to the low-noise amplifier. The signal coming out of port 3 of the circulator is viewed on the spectrum analyzer. The 915 MHz signal has magnitude of 2 dBm, whereas the tag signal has magnitude of –20 to –30 dBm. To increase the signal to noise ratio (SNR), the signal is sent through a Low Noise Amplifier (LNA). The resulting signal has magnitude of 16dBm at 915 MHz, and the tag signal is -20dBm. Theoretically speaking, the baseband signal could now be extracted simply by passing the received signal through an envelope detector, which would remove the high frequency signal. However, there is an underlying assumption that the received signal strength needs to be greater then the power loss across the envelope detector. Since the system was designed using *passive* tags, the receiver was not receiving enough power from the tags to fulfill this requirement. Thus, in this design the envelope detector was replaced by a mixer. This signal is sent from the LNA to the mixer, along with the local oscillator signal. The mixer takes the receiver signal, and the local oscillator signal, and outputs the baseband signal. The mixer outputs the baseband signal with magnitude of -5dBm, and the 915MHz signal with magnitude of 6dBm. Since the receiver signal not only contains the modulated signal, but also contains a stronger 915MHz signal, the signal is then send through a 5^{th} order low pass Butterworth filter, which attenuates all the signals above 35 KHz at 100dB/dec. The schematic and simulation result obtained from PSpice are shown below.

1.1.3. The Process of Simulation

Figures 3.3 and 3.4 show the PSpice simulation and bode plot for the band-pass filter of the receiver circuit.

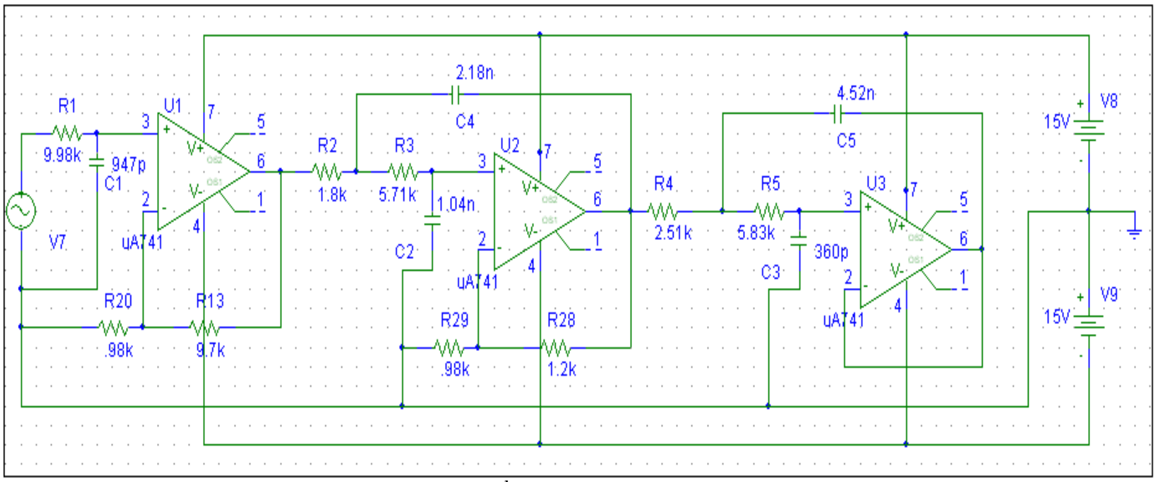

Figure 3.3. 5th order Butterworth filter.

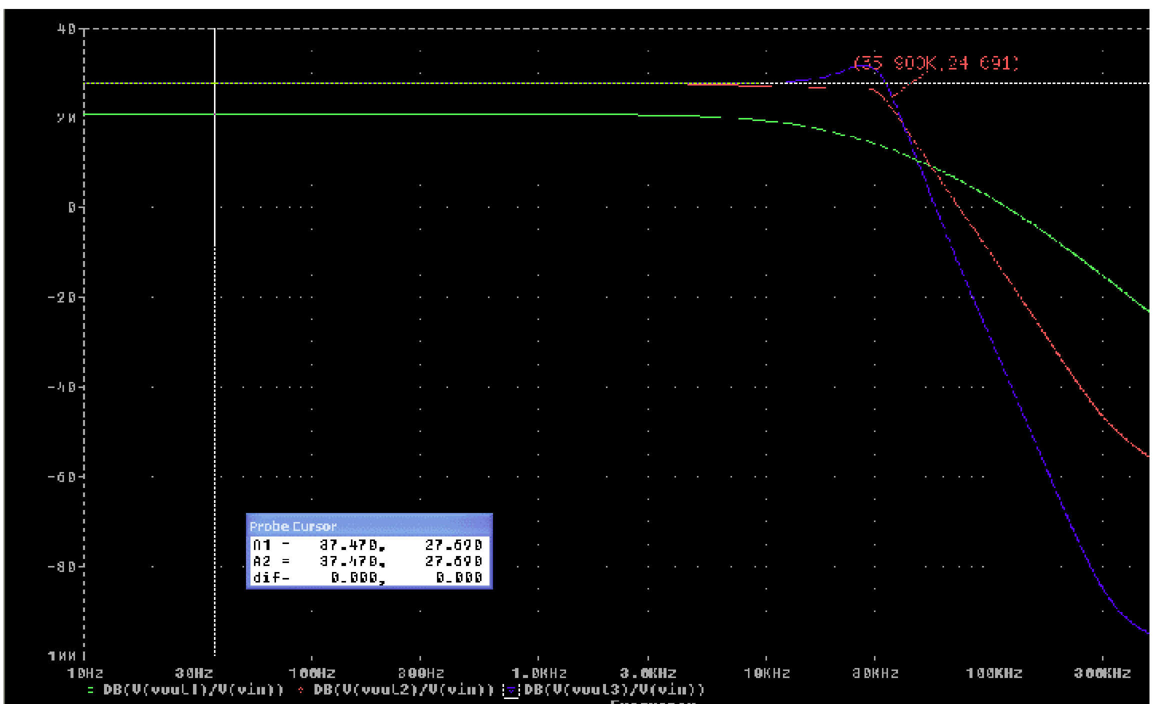

Figure 3.4. Bode plot of 5th order Butterworth low-pass filter.

1.1.4. End Results

The resulting base band signal is then fed into 4 different band pass filters, each centered at one tag frequency (20 kHz, 24 kHz, 28 kHz, 32 kHz) by RC tuning. As the band pass filters have Q factor of 20 and passband of only .3 KHz, they provide excellent isolation of 20dBm between each tag frequency.

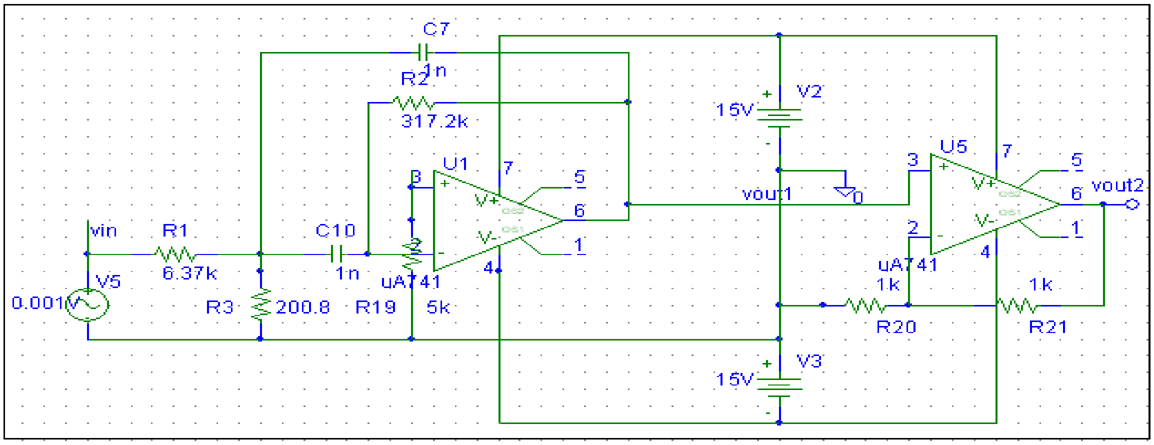

Figure 3.5. PSpice schematic of each band-pass filter.

The output is then fed into a amplifier, increasing the magnitude by 20 dBm, then fed into a micro-controller that analyzes the signal strength of the signals coming out of the band pass filter to indicate which tags are present in the field.

1.2. **Patch Antenna**

1.2.1. Design

The goal of the antenna design was to transmit and receive data with a carrier frequency of 915 MHz.

1.2.2. Material and Equipment Requirements

1.2.2.1. Material

1.2.2.1.1. Copper sheets

1.2.2.1.2. Coaxial cable connector

1.2.2.1.3. Solder

1.2.2.2. Equipment

1.2.2.2.1. Spectrum analyzer

1.2.3. Process of Implementation

As both the transmitter and receiver are detecting the same frequency, rather than have two separate antennas for each, one antenna was used. A circulator was placed between the transmitting and receiving circuit to direct the input and output signals.

Due to the potential of increasing input power simply by increasing the number of antennas, the patch antenna style was chosen. This consisted of two thin copper rectangles separated by a dielectric h = 4.29 mm thick – in this design, the dielectric used was air. The top plate was sized with a length of $\lambda/2 - h$ =

159 mm. The width was sized at 15.4 cm, as this was a convenient measurement, and the width is not a crucial measurement of functionality.

1.2.4. End Results

The final antenna had the following dimensions: length = 159 mm, width = 154 mm, dielectric thickness = 15 mm (see Figure 3.6).

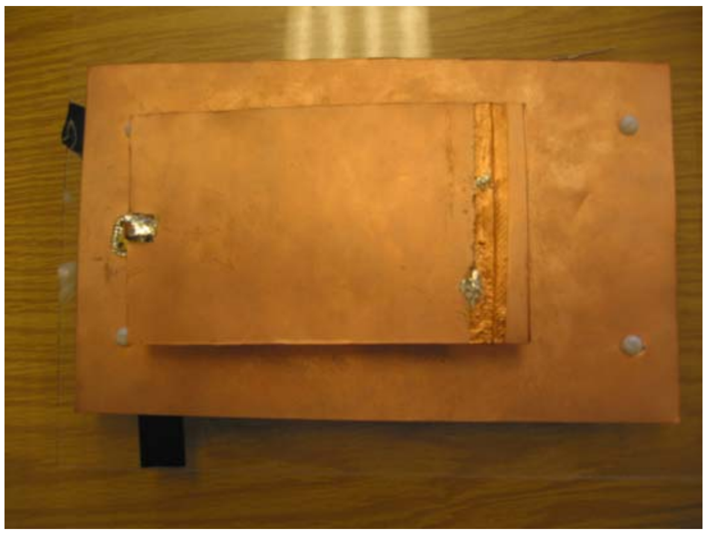

Figure 3.6. Patch antenna.

1.3. **Tags**

1.3.1. Design

The goal of the tag design was to create a circuit that would receive a 915 MHz signal, then reflect back a unique modulated frequency to identify the tag as distinct when seen with other tags. In order to realize this design, each tag must have a frequency that is distant not only from the frequencies of the other tags, but also from their harmonics.

1.3.2. Material and Equipment Requirements

1.3.2.1. Material

1.3.2.1.1. Antenna
1.3.2.1.2. LM555 timer
1.3.2.1.3. Bipolar junction transistors
1.3.2.1.4. Schottky diodes
1.3.2.1.5. Capacitors
1.3.2.1.6. Resistors

1.3.2.2.Equipment

1.3.2.2.1. Power supply (for initial testing)
1.3.2.2.2. Functional 915MHz RFID reader (for functional testing)
1.3.2.2.3. Digital multimeter
1.3.2.2.4. Spectrum analyzer

1.3.3. <u>The Process of Implementation</u>

The tag required a means of receiving electromagnetic energy at 915 MHz; therefore, an antenna was attached with a length of $\lambda/2 \approx 7.6$ cm. Converting the AC signal to DC to supply the circuit required a bridge rectifier; due to the extremely low power being received through electromagnetic coupling, Schottky diodes were used, as they require less voltage to conduct (~0.3-05 V vs. 0.7 V for a silicon diode). In order to reflect the tag data back to the reader, an oscillator was connected to the base of a BJT placed across the antenna. This design would create a difference in impedance of the reflected signal at the frequency of the tag. With this design, no impendence matching is necessary, as the reader will only detect the difference in impedance, rather than impedance matching.

The initial tag design was a chipless circuit, with the following components: an *antenna* receiving the 915 MHz signal, a *bridge rectifier* rectifying the signal, an *oscillator* designed using cross-coupled bi-polar junction transistors, and a *transistor* across the antenna to reflect the signal. However, the output of the BJT oscillator was an unstable, unclean signal. Adjusting the RC circuitry of the oscillator improved the signal quality, but only by a small amount. Therefore, the design was changed to have one IC – a low-power LM555 timer – replace the cross-coupled transistor oscillator. This produced a very clean signal.

Though the tags were set for specific frequencies using RC frequency tuning of the timer, the output frequencies were not always ideal, generally resulting in a range of output frequencies that depended on tag rotational alignment with the reader, and distance from the reader. Essentially, with the energy supply location-dependent, the timer supply voltage was changing with position, creating an unintentional voltage-controlled oscillator. Initially, one tag had a frequency range of 62 KHz (at over 2 meters from the reader) to 158.9 KHz (at less than 1 meter from the reader). With such a large frequency range, each tag must be designed at over 150KHz from the next tag frequency! In order to reduce the frequency range, a voltage regulating circuit, consisting of three diode-connected bi-polar junction transistors, was placed across the circuit to constrain the upper bound of the V_{cc} of the timer to approximately 2.1 V_{DC}. In addition, a BJT/diode circuit was placed at the reset pin of the timer to constrain the bower bound of the V_{cc} of the timer to approximately 2 V_{DC}.

1.3.4. <u>End Results</u>

The frequency range of the final tag design (as shown in Figure 3.1) was then tested, using a spectrum analyzer. With the tags 50 cm from the reader, the various frequencies resulting from tag rotation and distance are shown in Chart 3.1.

Tag	**Goal Frequency**	**Actual Frequency**
1	20 KHz	18.5-20 KHz
2	24 KHz	21.7-24 KHz
3	28 KHz	25.6-28.5 KHz
4	32 KHz	29.4-33.3 KHz

Chart 3.1. Actual Tag Frequencies.

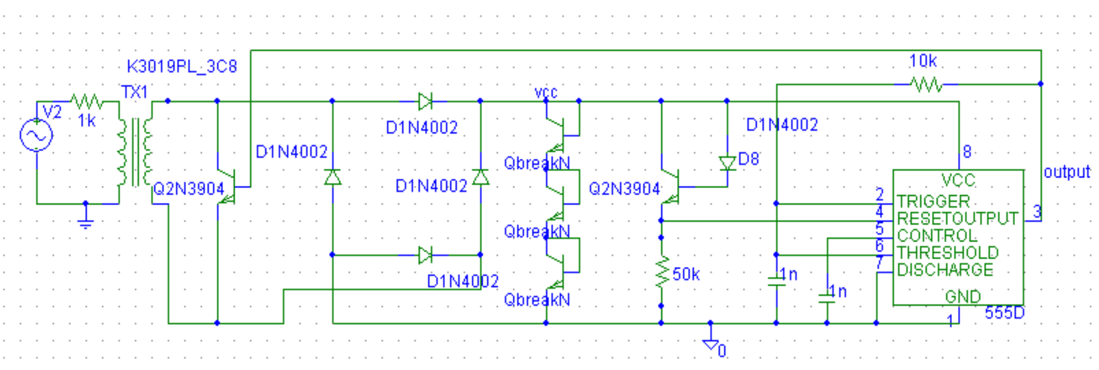

Figure 3.7. Final Tag Layout.

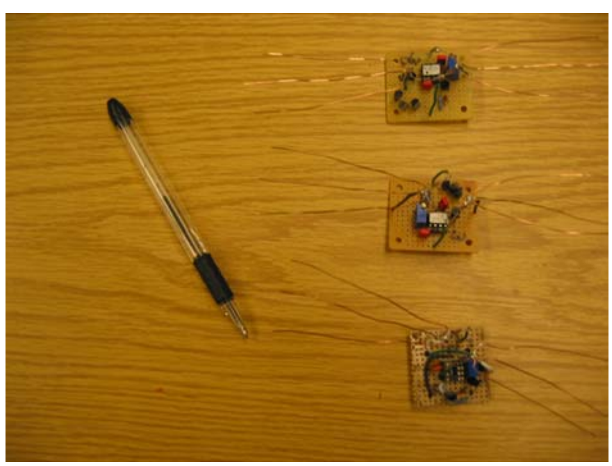

Figure 3.8. Actual tag size (tags 1 through 3 shown).

1.4. **Microcontroller/Software Programming**

1.4.1. Design

In order for our system to be functional and visibly enticing, we needed to employ a back end application, something on the computer screen to depict tag entry and exit from the field. RFID system readers require a controller to process the base logic from all the surrounding tags. It provides the brains of the operation to moderate flow of communication and traffic between the tags and readers. Thus, we used an Object-Oriented Programmable IC (OOPic) controller - a higher-level programmable controller that allowed us to write code in Basic rather than assembly language. The OOPic controller is based on the PicMicro devices from Microchip. The built in capability of the controller would be used to convert analog signals to digital and stream the information to a connected computer to do further processing.

1.4.2. Material and Equipment Requirements

1.4.2.1. Material

- 1.4.2.1.1. OOPic
- 1.4.2.1.2. RS232 cable

1.4.2.2.Equipment

- 1.4.2.2.1. PC with OOPic software and Visual Basic installed

1.4.3. The Process of Implementation

The controller came enveloped as a development board, with all pins drawn out of the circuit and made easily available for debugging and programming. A serial (RS232) cable was included, which was used to connect to a PC.

A Visual Basic back end program was developed that would communicate with the OOPic, sending and receiving data as tags entered and left the field. The controller would initially be fed analog signals into 4 of its A2D pins, then convert this to a digital value between 0 and 255 representing the percentage of 5V at that precise time of conversion. This data in a set of 5 would be sent to the PC back end application to be processed. The processing consisted of checking whether this amplitude of our incoming signal from the bandpass filters was above the desired threshold to indicate their existence in the field. Finally, the output of this software smoothing of the data was displayed on the computer screen showing present tags as they entered and left the field.

1.4.4. The Process of Simulation

We simulated the process by simply providing constant analog signals from a function generator and then detected the data through the controller and to the computer. This process yielded successful tests for our logic.

1.4.5. End Results

After implementing the entire system, we needed to adjust the threshold from the A2D converters so that our signals were more or less as accurate as possible. Smoothing the data, as we called it, was necessary to provide accurate results.

2. **CONCLUSION**

In testing the complete, final system, two issues arose that caused minor setbacks. The first issue was the *sensitivity of the OOPic;* during the initial testing of the OOPic with real-time input, one of the four inputs was permanently damaged, rendering that input useless. To prevent the same event with the other three input lines, resistors were placed in series with each input, protecting them from future damage. The second issue was the *VCO/ICO aspect of the tags*. Although the upper and lower bounds of the voltage were set to create minimal supply voltage change, the tag current was still location-dependent, and still presented a *range* of frequencies to the reader, rather than one unique frequency. The low-pass filter f_c = 32KHz, which gave little room for large frequency spacing between tag signals. For example, the top signal frequency from tag 1 is less than 2 kHz from the lowest signal of tag 2. Therefore, when only tag 1 is within the reader detection range, the reader may detect tag 1 *and* tag 2, depending on its position. Fortunately, this was a rare occurrence.

In the end, the system worked quite well, with the following events demonstrating the success of the project:

- Each tag was successfully detected by the receiver
- The OOPic successfully received each signal passed to it, and correctly identified each tag
- The software successfully displayed data regarding each tag – 2 tags were set as library books, with the third set to a library card. When the library card was detected, the PC displayed information regarding the card holder – name, title, late fees, recently check-out books

3. **APPENDICES**

3.1. References

3.1.1. Finkenzeller, Klaus, *RFID Handbook*. (West Sussex, England: Wiley & Sons, Ltd. , 2004)

3.1.2. Shepard, Steven, *RFID*. (New York, NY: McGraw-Hill, 2004)

3.1.3. Sedra & Smith, *Microelectronic Circuits*. (New York, NY: Oxford University Press, 1998)

3.2. Data Sheets

3.2.1. LM6171 operational amplifier: http://www.national.com/pf/LM/LM6171.html

3.2.2. LM741 operational amplifier: http://www.national.com/pf/LM/LM741.html

3.2.3. OOPic: http://www.oopic.com/

3.2.4. Cougar amplifier: http://www.cougarcorp.com/databasePDF_Files/AR2589.pdf

3.2.5. Low-noise amplifier: http://www.wj.com/datasheets/index.asp

3.2.6. 915 KHz oscillator: http://www.rfm.com/products/data/ho1045.pdf

3.2.7. Amplifier 1 (Hela 10B): http://www.minicircuits.com/dg03-164.pdf

3.3. Thanks

Many thanks to Dr. Raymond Kwok for greatly assisting the group members in their quest to implement an RFID system.