San Jose State University
Department of Electrical Engineering
Senior Design Project

Radio Frequency Identification (RFID) System

Project Group Members
Laura Hughes
Sahel Jalal
Kartik Patel
Mike Ra
Cory Wong

Project Advisor
Dr. Raymond Kwok
of
Alien Technology

TABLE OF CONTENTS

1

1. **ABSTRACT**

This paper presents a novel, complete RFID system consisting of the following elements:

- A *transmitter*, operating with a 915 MHz RF signal
- Four *tags*, consisting of a small circuit passively reflecting a modulated identifying signal to the receiver; to provide a power supply for the timer and BJTs of the tag, the tag is energized by the RF electromagnetic field of the transmitter; the tag then sends back a modulated signal to the receiver by means of an oscillator connected to the base of a BJT, with the tag antenna connected across the collector and emitter
- A *receiver*, which amplifies and filters the incoming signal by means of operational amplifiers and band-pass filters set at the resonant frequency of each tag
- A *microcontroller,* which inputs the modulated, filtered signal, and outputs a digital signal into the computer
- *Software,* which reads the digital signal and then processes the information to determine which tags are within the detection range (approximately 50 cm), and then displays the tag information on a computer display

The project was designed as a representation of the library application of a complete RFID system. The requirements were that four unique tags be detected within a distance of .5 m or more from the transmitter/receiver, with the programming set to identify each tag, and list information about each object tagged.

The project was successful in that a complete, fully functional RFID system was demonstrated, with a reader that sent out a 915 MHz signal, and was able to not only wirelessly detect and distinguish between four unique objects, but also display data regarding each object onto a computer display.

2. SYSTEM OVERVIEW

2.1. Introduction

Radio frequency identification (RFID) is a new advent in technology in the domain of radio frequency and communication; it is a force taking the industries of inventory tracking and identification by storm. The project goal was to deliver a representation of a fully functional RFID system intended to be used for library applications. Designed from the ground up, we harnessed knowledge of electrical engineering aspects that included electromagnetics, RF circuit design, transmission line theory, micro-controller programming, operational amplifier optimization, filter design, VCO design, voltage regulation, analog to digital conversion, analog communication theory, RF antenna design, and system interfacing. This manuscript details the fruits of our labor.

2.2. Background

RFID has been developed recently in standards and variants established by the EPC Global Organization. The technology can be implemented in myriad fashions of communication theory. On the most basic of levels, an RFID system can be modeled by merely three components: a transmitter, transponder, and receiver. Generally, the transmitter and receiver are a combined entity as a transceiver called the reader or interrogator. The transponder would be the device in the middle of a field (tag) to be detected by the reader. Tags are essentially the devices that uniquely identify an object. One of the main applications of RFID systems is inventory tracking for supply-chain management.

Tags can be of the following categories: active, passive, or semi-passive. Active tags are devices that consist of a local power source, such as a battery. Passive tags, on the other hand, have the power transmitted wirelessly, through either induction or electromagnetism. Finally, semi-passive would be a kind of hybrid design that powers a tag in a combined effort. Since the project specifications imply the design of passive tags, the others will not be discussed further.

Passive tags can be powered by many different methods, with the most significant means by way of inductive coupling and electromagnetic coupling. Inductive coupling refers to inducing current from a magnetic field, which limits the tag-to-reader distance to a few centimeters. Analogous to transformer windings, the tag and reader would represent two sides of the coil. Electromagnetic coupling is the method by which waves are passing through in near field and far field. The tag would receive this signal and rectify it to generate power from the wave's energy. In this approach, the distances that tags can communicate at are much larger.

Once a tag is powered, it can send data to the reader by sending its unique signal to the reader; this is accomplished by reflection of the reader signal. Commonly, the reader is constantly sending signals attempting to detect the presence of a tag in its field. This reader would be transmitting its commands modulated onto a local carrier frequency. The antenna within the tag circuitry would then receive this signal through electromagnetic coupling, with the tag responding by reflecting the incoming signal. The tag would initially decode the incoming command, and then respond to those commands by shorting the tag circuit at a unique frequency.

Impedance modulation is one method by which tags respond to reader requests. This can be accomplished effectively by considering a signal block. The amount of reflection seen by the transmitter can be changed if the impedance of the tag is changed. The load is the tag, which can alternatively short and open its antenna, enabling the reader to detect a change in impedance; this method is essentially on/off keying. The level of signal power received by the tag is in the milliwatt range, with the reflected signal decreasing to microwatts. At such low amplitudes of a signal, a careful system must be designed to account for all erroneous parameters such as white noise, multipath construction and destruction.

At this point, the reader must amplify the weak signal, and then decode the information that is encoded on it. Once complete, the process continues by some software protocol between tag and reader and eventually any and all tags in the field must be read, provided that the protocol takes care of any collisions that can occur. This in effect is the basic overview of an elementary RFID system, such as the system designed here. Though there may be many other variants and a multitude of methods, the above information was given in the spirit of providing a general understanding of the project at hand.

2.3. **Overview**

The following RFID system was designed to operate at 915 MHz. It consists of four passive tags with a transceiver capable of identifying multiple tags within the field at any given time. Most tags currently in use are designed with a memory chip or EEPROM data storage facility, with the system using one to two channels for the baseband frequency, or the information frequency. In the following system, no memory devices were used, with no protocol for transmission. Therefore, the tags cannot implement any formal logic that could be used for anti-collision purposes, and the luxury of protocol to differentiate tags is not available. Thus, we chose to operate at multiple tag frequencies to avoid collisions and to distinguish the tags. While this limited the number of tags that the reader was able to detect clearly, it still allowed us to demonstrate the fundamental qualities of an RFID system. The block diagram of our system is outlined in Figure 1.

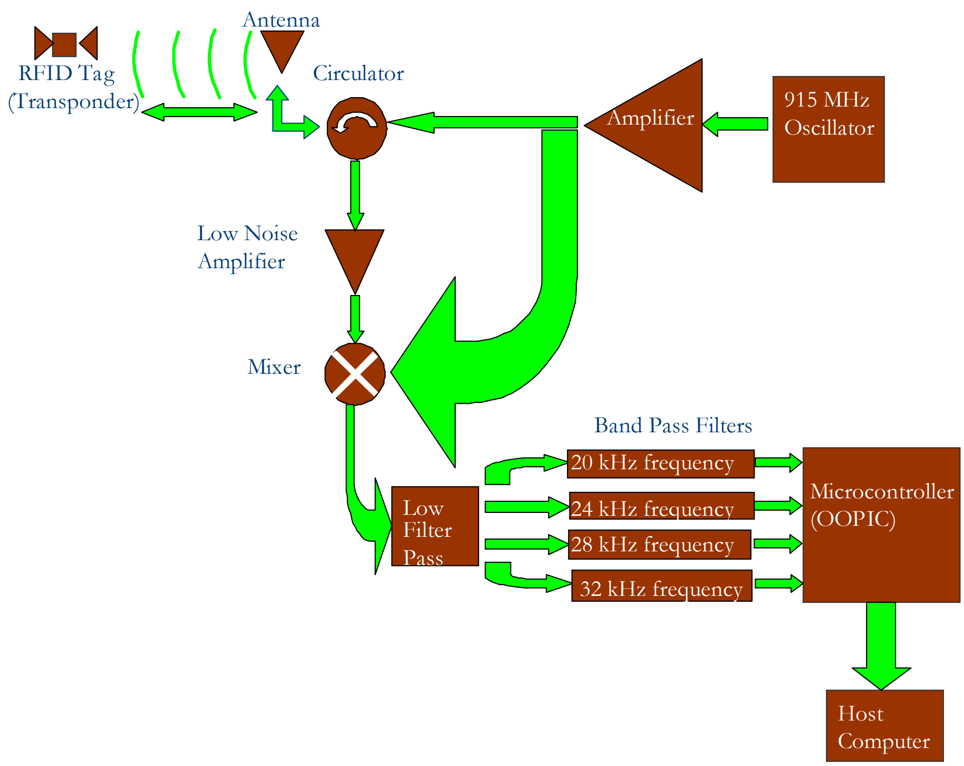

Figure 1.1. Block diagram of the designed RFID System.

3. THE ENGINEERING PROCESS

3.1. Transmitter

3.1.1. Design

The goal of the transmitter is to transmit a 915 MHz signal to transponders (tags) placed at a distance of up to 1 meter from the transmitter. Therefore, amplification of the signal is crucial. The block diagram of the transmitter is shown in Figure 3.1.

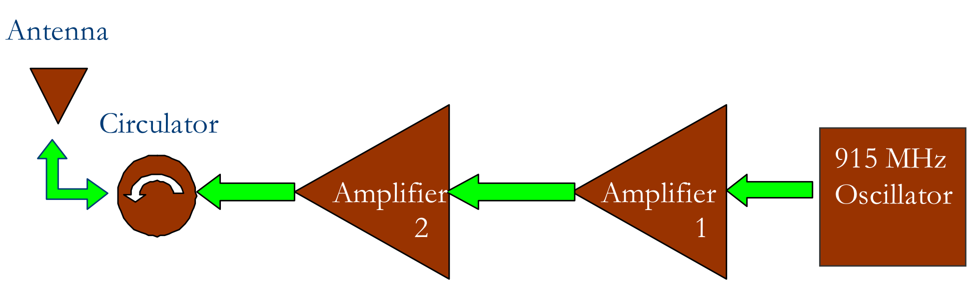

Figure 3.1. Transmitter Block Diagram.

30 dBm is the desired output of the transmitter. Achieving this level of power will provide the ability to energize the tags from a distance of approximately 1 meter. In searching for one operational amplifier to achieve this power, the major obstacle was heat dissipation due to the large amount of current being drawn. Therefore, the amplification was divided between two operational amplifiers placed in series, with the most heat-sensitive component secured to a large heat sink attached to a fan.

	INPUT	OUTPUT
Power Max	17 dBm	27 dBm
Current Max	300mA	NA

Table 3.2. Amplifier 1 (Cougar) power and current data.

	INPUT	OUTPUT
Power Max	20 dBm	29 dBm
Current Max	275mA	NA

Table 3.3. Amplifier 2 power and current data.

The amplified carrier signal then goes through a circulator, which directs the incoming and outcoming signals; as the 915 MHz signal will be output, the circulator then directs this signal toward the antenna.

3.1.2. <u>The Material and Equipment Requirements</u>

- 3.1.2.1. Material
  - 3.1.2.1.1. Oscillator: 915 MHz Saw oscillator, part# HO1045
  - 3.1.2.1.2. Amplifier 1: Cougar Components part# AR2589
  - 3.1.2.1.3. Amplifier 2: Mini Circuits Hela 10B
  - 3.1.2.1.4. Circulator: Quest Microwave Inc. part# D25-L9093
  - 3.1.2.1.5. Fan/heat sink combination: attached to the
- 3.1.2.2.Equipment
  - 3.1.2.2.1. Power supply (for initial testing)
  - 3.1.2.2.2. Functional 915MHz RFID reader (for functional testing)
  - 3.1.2.2.3. Digital multimeter
  - 3.1.2.2.4. Spectrum analyzer

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

The initial step was verification of the oscillator frequency, which was done on the spectrum analyzer. When 12.5 V was applied to the oscillator, the analyzer displayed a 915.2 MHz signal with approximately 14.2 dBm of output power.

The next step was to connect Amplifiers 1 and 2. The applied voltage to the amplifiers was determined by the max current allowed and the max input power of the amplifier. The applied voltage was then fine tuned by evaluating the voltage-power dependency. For example, when 11.8 – 12.8 V are applied to the amplifier, the output power is approximately 21 dBm. Because there was no need to have such large output, and heat dissipation is a major issue, Amplifier 1 was set to 11.9 V, wit an output power of less than 20 dBm.

With 10 V applied to the oscillator, and 11.9 V applied to Amplifier 1, the output of Amplifier 1 increased to 25.5 dBm. After Amplifier 1, the signal was split, with the first path leading to Amplifier 2, and the second leading to the mixer (discussed in the receiver section), with each area receiving 18 dBm of output power.

Because the applied voltage affects the output power of the amplifier, and reducing heat dissipation was a major issue, the voltage supply for Amplifier 1 was specifically set so that the output power of Amplifier 1 would be below 20 dBm (which is the input to Amplifier 2). Coming out of Amplifier 2, 28.5 dBm of power is output when 12.5 V is applied. The signal is then sent into port 1 of the circulator.

Observing the signal at port 2 we encounter a loss within the circulator, with the output 26.5 dBm. The carrier signal is then sent to the antenna for transmission.

3.1.4. End Results

The following tables (tables 3.4, 3.5) show the input and output power of the transmitter circuit elements.

	INPUT			OUTPUT
	Power (dBm)	Voltage (v)	Current (mA)	Power (dBm)
Oscillator	-	12.5	75	26.28
Amplifier 1	26.28	10	210	18.65
Amplifier 2	18.65	12.5	250	27.8

Table 3.4. Transmitter element power input and output.

	Port 1 (dBm)	Port 2 (dBm)	Port 3 (dBm)	
			w/ tag	w/o tag
Circulator	27.8	26.5	10.2	7.2

Table 3.5. Circulator port powers

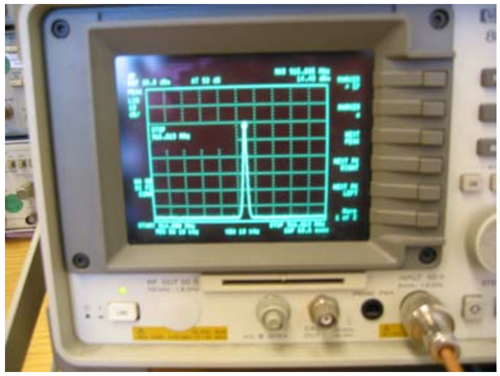

Figure 3.2. Transmitter output, centered at 915.2 MHz.

3.2. **Receiver**

3.2.1. Design

The goal of the receiver is to take the incoming signal and identify which tag is present in the field. However, many obstacles need to be resolved in order to achieve this goal. First and foremost, the received signal would be very weak, and thus in great need of amplification, *without* amplifying the noise floor. A low-noise amplifier will be applicable. The baseband signal will then be extracted, and then filtered to identify the unique frequency that is representative of each tag.

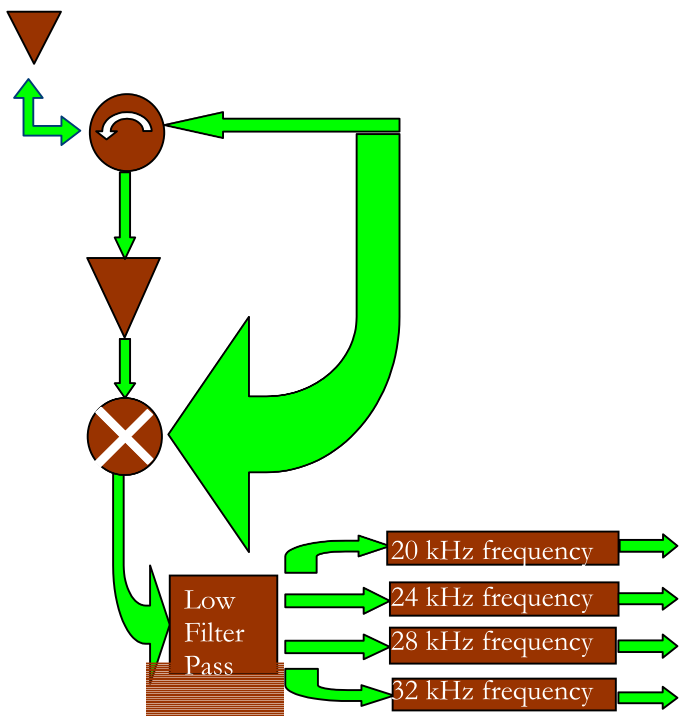

Figure 3.2. Receiver block diagram.