Design and Implementation of Harmonic RFID Based on Conventional UHF System

Aditya Purandare, Yihang Chu, Deepak Kumar, Saikat Mondal, Andrew J. Mason, and Prem Chahal

Michigan State University
Electrical and Computer Engineering
428 S. Shaw Lane, Room no. 2120
East Lansing, Michigan 48823 United States
chahal@msu.edu

Abstract

There has been growing interest in the use of passive harmonic RFIDs for diverse range of applications. Conventional RFIDs are prone to self-jamming and multipath interference, and these challenges can be mitigated using the harmonic RFID design. Recently several harmonic RFID designs have been demonstrated. However, there are many designs related, packaging and intellectual property challenges associated with new tag designs. It has been well known that conventional RFIDs produce harmonic content, which is typically suppressed to reduce background noise. Previous experiments have demonstrated that the harmonics generated by conventional RFIDs can be utilized to enhance their performance. In this paper, an RFID chip is characterized for the generation of harmonic frequencies. This is carried out by designing a high frequency board that contains calibration structures along with structures to characterize the RFID chip using a one port network. An equivalent model is then developed, which in turn is used to design a dual band antenna that works at the fundamental and harmonic frequencies. In addition, the conventional RFID interrogator is modified to accommodate the measurement of harmonics generated by the RFIDs. A complete harmonic tag system is designed and implemented, and an example application of harmonic RFID is demonstrated. Here, the harmonic RFID tag is used in an industrial setting where there is large clutter (large reflections from metal structures).

Key words

Conventional UHF RFID, Dual Band Antenna, hRFID, Harmonic RFID, RFID Tag, UHF.

I. Introduction

Radio Frequency Identification (RFID) works on the principles of electromagnetic fields and is used for tracking and identifying purposes across a wide range of applications in a diverse range of fields such as automotive, medicine, transportation, security, retail, and even waste management [1]-[2]. The conventional RFID system operates as a form of communication of radio frequency signals between an RFID tag and the interrogator. The RFID tag is used for tracking and identification (ID) and incorporates an antenna and an RFID Integrated Chip (IC). Likewise, a passive Ultra High Frequency (UHF) RFID tag also consists of an antenna and IC, but the chip can be powered ON using an RF signal rather than with a battery. When the interrogator sends out an RF query signal to the tag, the chip is powered up and can send its unique identification number back to the interrogator [3]. This existent method is very well-proven and widely used but does have some shortcomings, such as self-jamming and multipath interference [4].

When it comes to signals being transmitted and received at a certain operating frequency, unintended losses cause a distortion of the targeted signal resulting in a drop in the signal-to-noise ratio. This is usually caused by inefficient isolation between the transmitter and receiver ends and is known as self-jamming. Self-jamming results in a weaker and less sensitive signal, which in turn creates a less efficient RFID system. In addition to self-jamming, signals also suffer from multipath interference, signal reflections from the interrogator or tag's surroundings interfering with the data signal being transmitted or received, leading to a less accurate reading.

There are multiple ways of countering self-jamming and multipath interference that are already in place today which aim to provide a cleaner signal. However, few of these methods are reliable and effective, and thus the focus has now shifted to utilizing harmonic RFID technology over the conventional RFID designs. Harmonic RFID systems work on the principle of targeting the non-linearities created by the active components when resonated at the operating frequency, which for the case of the experiments was taken as 915 MHz (the FCC approved UHF RFID frequency range is 902- 928 MHz in the North America region). Upon fabrication of the desired RFID tag, the tag can then be used to transmit at the non-linearities such as the second or third harmonic, which is different from the harmonic being transmitted by the interrogator (usually the first harmonic, which is commonly known as the fundamental frequency). The initial transmitted signal can then be compared to the higher harmonic received signal, thus helping to eliminate self-jamming. The existing RFID chips generate harmonics that also carries the digital information [5]. These chips can be used to retrieve the information carried at the harmonic frequencies by modifying the tag antenna to a multiband antenna.

Harmonic generation in commercial tags is achievable if factors such as RFIC activation power (RF power sent from the interrogator needed to turn the RF chip ON) is received, the bandwidth of the signal, and the actual RFID tag's antenna architecture. With the recent growth in harmonic system technology, research around it has shown firm evidence that targeting the third harmonic can help overcome clutter challenges and improve read range [5].

In this paper, harmonic RFID technology is demonstrated using already in-place UHF RFID technology with the help of a new multiband tag antenna design which provides a good read range (>1m) at the fundamental and harmonic frequencies. Further, by placing metal foils around the tag, we demonstrate that the harmonic frequency can be used to reduce self-jamming and enhancing signal to noise. This paper also outlines the tag design and fabrication, and it shows how the fabricated tag compares to some commercially available tags using the same IC.

II. Design, Setup and Simulations

The setup for the following set of experiments can be broken down into two parts: A) Design of dual band hRFID tag, and B) hRFID interrogator setup. The RFID tag antenna was designed first to operate in the required conditions and the interrogator was then set up to accommodate for harmonic detection. A brief visualization of how the system communicates can be seen in Figure 1.

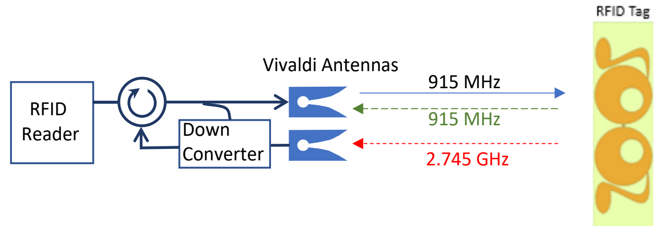

Figure 1: Harmonic communication system overview diagram.

A. Dual Band RFID Tag Antenna Design

The antenna design for the tag is pretty simple and was chosen to optimize the bandwidth as well as to effectively operate at the fundamental frequency of 915 MHz and the third harmonic of 2.745 GHz with a good gain. The antenna design and its details can be seen outlined in Figure 2. In reference to the figure, the inner two circular shapes mimic the behavior of a bowtie antenna and mainly deal with the behavior of the tag at the higher frequency of 2.745 GHz. The radius of the bowtie circles can be used to vary the bandwidth around the higher frequency and the circular cavities within further help increase the bandwidth while also assisting with keeping the radii of the outer circles small to promote miniaturization of the antenna. As for the curved lines that follow the bowtie circles on either side, these are used to deal with the lower frequency of 915 MHz. The lines start out narrow and then widen out as they move further away from the circles. This was intentionally implemented to optimize the bandwidth at the lower frequency. In the case of either frequency, a wider bandwidth helps compensate for any changes brought about by the fabrication process, and the size of the individual components (as well as the antenna as a whole) is determined by the wavelengths the antenna is operating at [6]. The antenna was simulated in HFSS in Ansoft which allows the user to simulate a lumped port which was placed right in between the bowtie. The lumped port's impedance was manipulated to carry out impedance matching with the Higgs 3 RFIC which was soldered in place of the port upon fabrication. The spacing between the circles can be manipulated to have the trace act as a capacitor to help with the matching process.

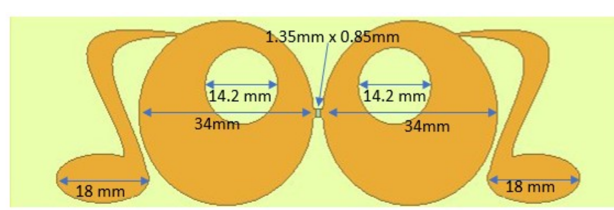

Figure 2: RFID tag Dual band antenna design with dimensions (in millimeters). The antenna operates at 915 MHz and 2.745 GHz.

B. Interrogator Setup

At the fundamental level, the system uses a conventional UHF RFID interrogator setup by utilizing the Impinj Speedway R420 reader to transmit RFID communication signals to and from the tag. However, some circuitry is added to the reader before the antenna sends and receives the RF signals to measure the signal at the harmonic frequency. As seen in Figure 3 above, the reader sends out a signal which is then passed through a circulator (or a collection of circulators for better isolation, >60dB) to help isolate the signal from any unwanted reflections, and then through a directional coupler which sends out a portion of signal at fundamental frequency to the tag and the other to a multiplier. The multiplier serves as a liner multiplier by a factor of two. When the tag sends back a signal with a frequency equal to that of the third harmonic of the fundamental frequency, the received signal is amplified using low noise amplifiers (gain = 36 dB) and sent to the frequency mixer along with the amplified (gain = 34 dB) doubled frequency which results in the fundamental frequency, and this is sent back to the interrogator. The whole purpose of the added components is to accommodate for the readers ability to only work with a singular frequency at a given time and since the third harmonic provides the best signal-to-noise ratio, this frequency is picked up and processed back into the fundamental frequency. This setup does demand two separate antennas- one for transmission at 915 MHz and the other to receive the 2.745 GHz signal. Here, two Vivaldi antennas of high gain were used for transmission and reception.

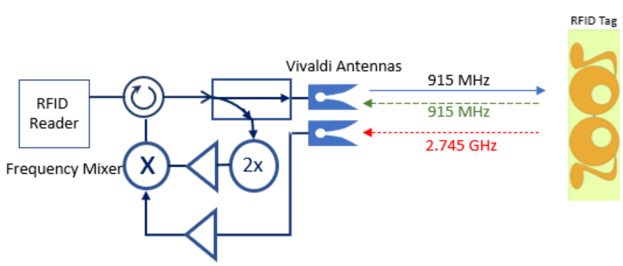

Figure 3: Diagram describing the modifications carried out on the RFID interrogator to accommodate for the 3rd harmonic frequency.

III. Results

As stated previously, the fundamental design of the antenna is based around the general bowtie design and the high frequency part is wrapped around the sides of the circles. The substrate was chosen to be of Rogers RO4350 material with a thickness of 1.52 mm. The simulated gain at 915 MHz was around -18.8 dB and approximately -9 dB at 2.745GHz. Upon fabrication, the measured gain at 915 MHz is approximately -17.3 dB and -12.8 dB at 2.745 GHz. Fabrication processes can cause a change to be brought about from simulated to actual measured quantities and thus it is a good precautionary measure to design the antenna with a wide bandwidth to ensure the antenna works at the desired frequencies. Once the antenna was fabricated and the Higgs 3 RFIC was soldered onto the tag, the tag was designated to be run at a power level of -10 dBm. As can be seen in Figure 4 below, the chip behaves differently at different power levels and does not actually activate till it receives a power of -8 dBm. For optimal results, -10 dBm was chosen for the purpose of the trials. In addition, the tag was run alongside commercially available tags at both 915 MHz and 2.745 to compare the tags performance in a normal setting. The results can be seen in table 1 and the fabricated tag is able to perform much better at the higher frequency as a result of a higher signal-to-noise ratio after reduced self-jamming. In addition, trials were also conducted with the tags placed on a mounting surrounded by metal surfaces to imitate an industrial setting to study the behavior of the tag with exposure to immense cluttering. In the presence of metal surroundings, the fabricated tag was the only one to produce a higher read rate at 2.745 GHz than that at 915 MHz, thus combating the effect of cluttering.

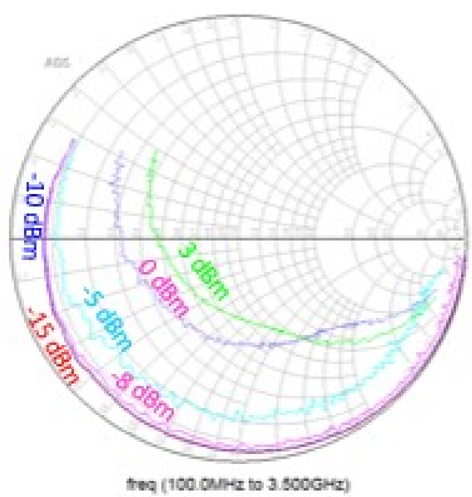

Figure 4: Frequency response of the RFID chip at different power levels.

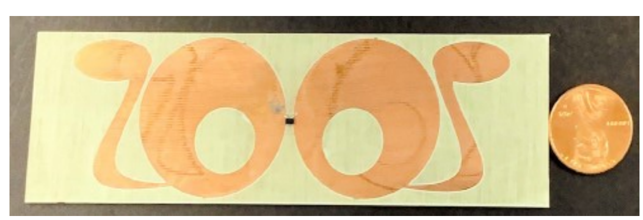

Figure 4: Fabricated harmonic RFID tag on RO4350 substrate. A US penny is shown for size comparison.

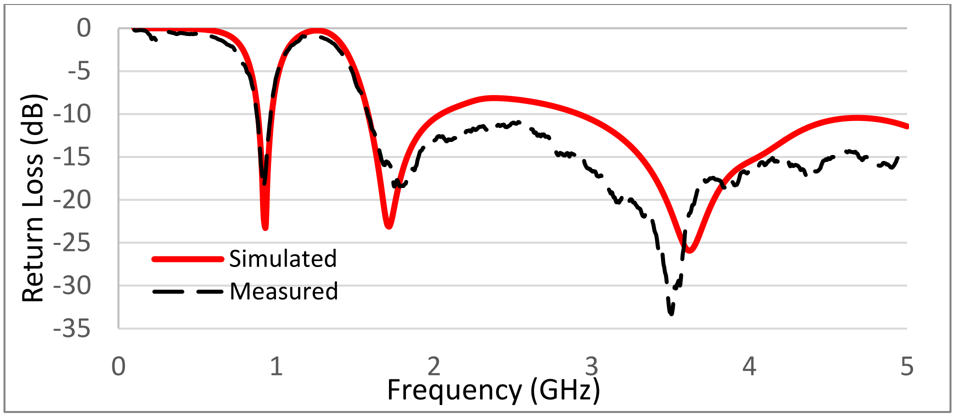

Figure 6: Simulated and measured reflection coefficient (S11) of designed antenna. Simulation and measurements are shown for 50 Ω input impedance.

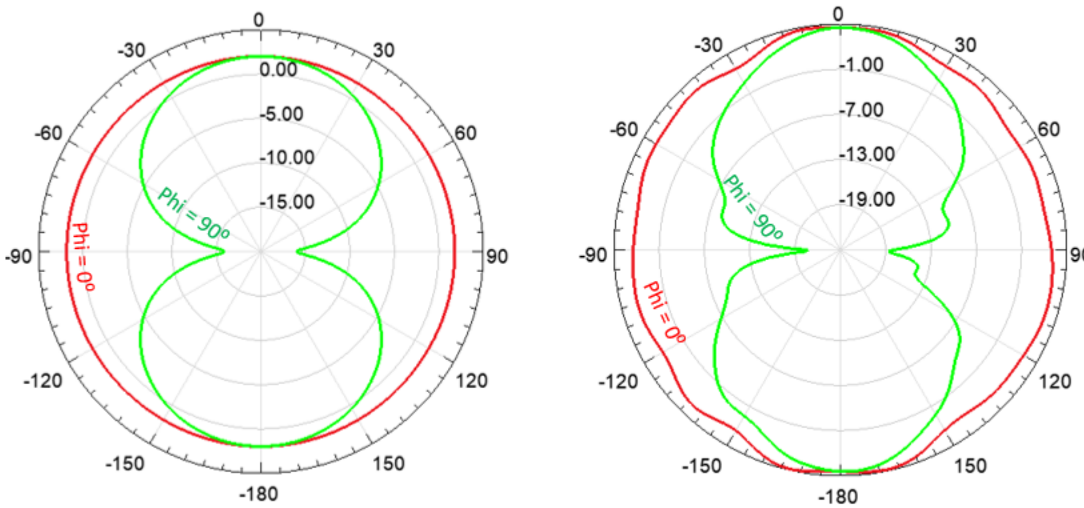

Figure 7: Radiation patterns of designed antenna simulated at phi = 0 degrees and 90 degrees at 915MHz (Left) and 2.745GHz (Right).

Table 1: Tag readings received by the reader in 120 seconds

RFID Tag	Reads Per Second at 915MHz	Reads Per Second at 2.745GHz
Fabricated Tag	19.7 ± 0.5	25.5 ± 1.0
Alien 9654	23.7 ± 1.0	12.5 ± 0.7
Alien 964X	25.4 ± 0.2	11.4 ± 2.0
Smartac DogBone	21.0 ± 1.0	9.2 ± 0.5

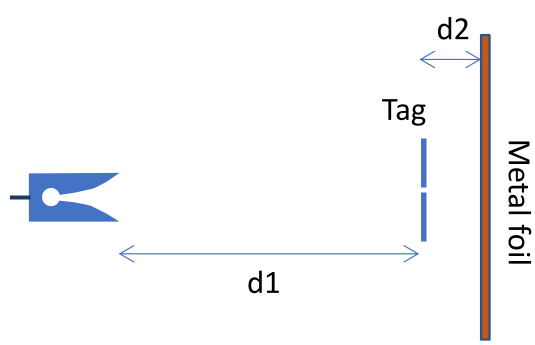

Figure 8: Setup to test tags in industrial setting in the presence of metal in close vicinity; d1 = 1.27 m and d2 = 0.18 m.

Table 2: Tag readings received by the reader in 120 seconds with metal surroundings (tolerances were measured from a collection of five trials)

RFID Tag	Reads Per Second at 915MHz	Reads Per Second at 2.745GHz
Fabricated Tag	19.1 ± 1.0	21.8 ± 0.6
Alien 9654	22.3 ± 0.2	14.9 ± 1.5
Alien 964X	22.5 ± 0.3	20.4 ± 0.1
Smartac DogBone	19.7 ± 1.2	11.8 ± 0.6

IV. Conclusion

This paper aims at describing and demonstrating a Harmonic UHF RFID system compatible with conventional RFID systems and its advantages. The harmonic system works by transmitting a signal at its fundamental frequency while receiving a signal in the form the third harmonic of the fundamental frequency to help reduce the effect of cluttering and mitigating self-jamming, thus increasing the signal-to-noise ratio. The system utilizes a pre-existing interrogator system and adds on a layer of circuitry to help accommodate for the received signal from the tag. The deigned tag consists of a dual band antenna design that provides good gain throughout and helps improve the read range of the tag. The tag was designed to have a wideband to compensate for any changes brought about during fabrication. Further, when the tag is implemented with the reader setup, the effects of multipath interference and self-jamming are diminished, and a much more efficient reading is obtained. The tag design and reader setup put forth helps deal with cluttering, especially in an industrial setting, esp. metal surroundings, and can be easily implemented as an add on to a conventional UHF RFID system.

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