A Miniaturized Dual Band Antenna for Harmonic RFID Tag

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Abstract

A miniaturized antenna is required for a small form factor RFID tag. For harmonic RFID tag, the tag should be capable of receiving and transmitting at two different frequencies (fundamental and harmonic). Implementation of two different antennas for the operation would increase the footprint of the antenna. Hence, an optimized antenna structure is proposed, which will have a small form factor while maintaining a considerable gain. The dual band antenna would be capable of receiving at fundamental frequency and transmit information at harmonic frequency while maintaining small tag size. The dual band antenna has a miniaturized rectangular board dimension of 96.5 mm and 81 mm with resonance at 434 MHz at low frequency and 860 MHz to 1000 MHz at high frequency. The harmonic tag was designed with nonlinear transmission line and the dual band antenna. The harmonic RF tag would be useful for numerous RF applications where the single frequency tags will not be a good option such as underground object tagging, tag detection in an industrial set up with strong reflectors such a metal in the vicinity. In this paper, the design, fabrication and characterization of dual band harmonic RFID tag antenna is presented.

Key words
RFID; Harmonic; Multi-band antenna;

I. Introduction

The wireless technology has evolved over time due to demand of high data rate and emergence or improvement of wireless communication devices and standards. In recent years, with introduction of 5G and Internet of Things (IoT) technology the prospect of wireless connectivity has broadened. Antenna is the major integral part of all the wireless devices. With rapid enhancement of manufacturing technologies, the electronic devices have been miniaturized, which led to requirement of compact, lightweight and miniaturized antenna. Multi-band antennas have become a new area of research as there is a need of different communication technologies to be incorporated using a single antenna [1,2]. Some of the widely used wireless standards are Wireless LAN (WLAN), WiMAX, 5G, harmonic Radio Frequency Identification (RFID), etc. Designing an efficient low profile multi-band antenna for the applications is always a challenge.

RFID technology has become popular in numerous applications starting from object identification to passive sensing. Ultra-high Frequency (UHF) RFID technology have a few benefits such as 1) long range communication (~8m); 2) batteryless tags, hence both long life and low cost; 3) easy integration of different sensors. Harmonic RFID is a special case of RFID, where the RFID uses dual channels for uplink and downlink. Recently, harmonic RFID tags have become popular compared to single frequency commercial RFID tags due to enhanced performance in presence of strong clutter source. The background clutter can arise due to reflections of EM waves from ground or metallic objects in an industrial environment. The clutter would affect the performance of a single frequency RFID tag by limiting the detection rate for a long read range. Hence, a clutter resistance dual frequency harmonic RFID can be effective for a long range operation. With dual frequency design, there is a requirement for the antenna to transmit and receive efficiently at both the frequencies. Hence, a miniaturized antenna operating at both the frequencies is required. Among the earlier reported harmonic RFIDs, primarily two different configurations were proposed earlier 1) dual antenna design and 2) single antenna design [3–5]. For dual antenna design, two antennas are designed separately and each can have miniaturized dimension. Whereas for single antenna, a single broadband antenna was proposed. Miniaturization is specifically difficult for broadband antenna. Hence, to overcome both the problems, a single dual band antenna would be advantageous, which can work at both the frequencies. The design methodology is not only specific for harmonic RFID design but can be adopted for any multi-band wireless technologies.

II. Design and Simulation

A harmonic tag consists of two major parts: 1) Dual frequency antenna and 2) Harmonic circuit. First the antenna is designed and then the harmonic circuit design procedure is discussed step by step. The single antenna tag system diagram is shown in Figure 1. The antenna receives the single frequency RF signal and transmits back the harmonic of it using the same antenna.

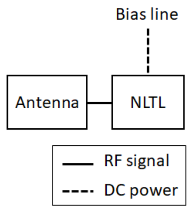

Figure 1: Harmonic tag system diagram with Nonlinear Transmission Line (NLTL) and dual frequency antenna.

A. Antenna design

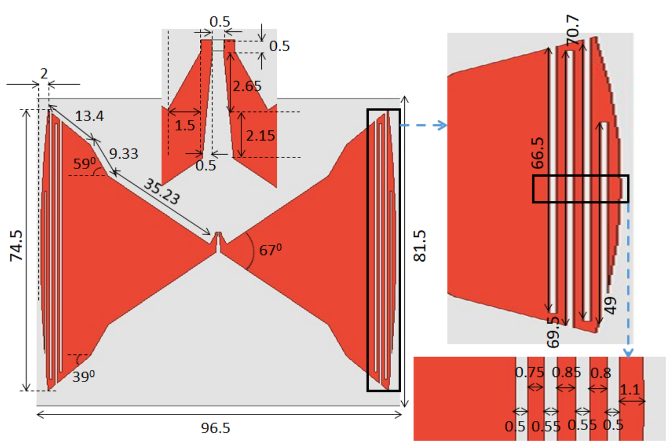

Figure 2: Dual band antenna design with dimensions at 434 MHz and 868 MHz. All the dimensions mentioned are in mm scale.

The design procedure of the dual frequency antenna is described step by step in this section. Among multiple topologies available, slotted bow-tie antenna was chosen as it can offer immunity due to fabrication tolerance. First, a simple bow-tie was designed for the maximum one between the two frequencies. In the next step, meandering is performed at the side edges of the bow tie until a second resonance is observed at the other low frequency. However, it should be noted that although the meandering will create a second resonance, the radiation will not be efficient at that frequency. As meandering is used to miniaturize the antenna at low frequency, the bandwidth at low frequency is very narrow and due to fabrication tolerance, the resonance frequency can shift. The designed antenna should show a second resonance at twice of the new low resonance frequency for the harmonic tag. Hence, a wider bandwidth is required at the high frequency to compensate for the fabrication tolerance. The design objective is to make a comparatively wider bandwidth at the high frequency and a narrow band at low frequency. The overall dimension of the tag would be governed by the wavelength of the maximum frequency. The design of the antenna is shown in Figure 2 with the lower frequency at 434 MHz and higher frequency at 868 MHz.

B. Harmonic circuit

The harmonic circuit was designed using Nonlinear Transmission Line (NLTL) by periodically mounting inductors and varactor diodes [6, 7]. The nonlinearity arises from the variable capacitance dependance of the capacitors at different bias voltage. The nonlinear relation of the I-V characteristics of the varactor diodes generates multiple harmonics when a single frequency signal is fed into the input. The efficiency of the harmonic generation depends on the number of inductor and varactor. Among the harmonics, the second harmonic is the strongest and the difference in power between output second harmonic and input fundamental frequency is termed as conversion loss.

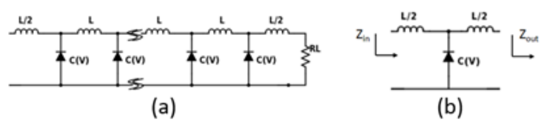

Figure 3: Nonlinear transmission line (NLTL) with discrete components and load termination (a) the complete line, (b) a single cell.

In Figure 3, a single cell NLTL and a chain formed by multiple single cells is shown. A three stage NLTL is designed with SMV1405 varactor diodes and L=10 nH inductor as illustrated in 3. The NLTL has 50 Ω input impedance for both the frequencies at 434 MHz and 868 MHz when terminated with a 50 Ω load. Unlike Schottky diode, a DC bias point is required for varactor diodes. The conversion loss strongly depends upon the DC bias, as the bias point sets the nonlinear operation region for the diodes. In the design, the DC bias point was set at 0.56 V forward bias, which showed a conversion loss of 16 dB. When the varactor diodes are forward biased, a small amount of DC power is required. For a three stage NLTL, at 0.56 V bias, the required DC power is 1.2 μW power.

III. Results

The antenna design was optimized using HFSS in Ansoft. First the bow tie was designed with 90^0 flaring angle. Later, the flaring angle was reduced to 67^0 to impedance match the antenna at the high frequency. The antenna was designed on 1.52 mm thick

Rogers RO4350 board with dielectric constant of 3.66. After design optimization, the antenna was fabricated using wet copper etching process. After fabrication, the antenna response was measured using a VNA. The antenna had a simulation gain of -3 dBi at 434 MHz and 1.5 dBi at 868 MHz. In the measurement, however, there is a frequency shift distinctly at the lower resonance at 434 MHz in between the measurement and the design. The difference can be due to fabrication tolerance, where the the current in the line widths at bow-tie's flaring edge interact in complex way. And if the line width changes, it can effect in resonance frequency change. One way to compensate this shift is to make the high frequency resonance wider bandwidth. In that case, even with resonance frequency change at low resonance, the harmonic of the shifted resonance will fall inside the high resonance frequency bandwidth.

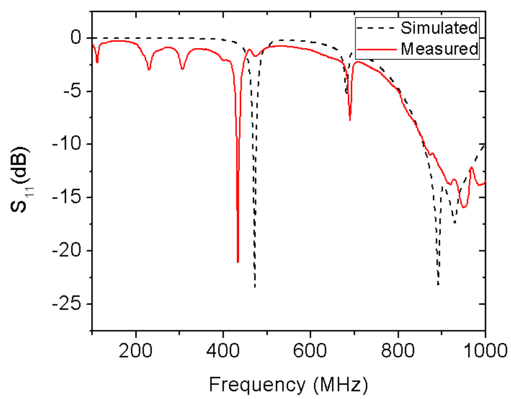

Figure 4: Comparison of simulation and measurement results of the dual band antenna.

The antenna was integrated with the harmonic circuit and the harmonic power was measured for the harmonic tag. The tag was kept at 1 meter and 13 dBm power was transmitted from a signal source at 434 MHz. After the tag receives the signal, it converts the signal into harmonic and transmits back. The interrogator receives the harmonic frequency and the signal power is measured using a spectrum analyzer. The NLTL section is shown in Figure 5 with both ends SMA connectors and line for DC bias.

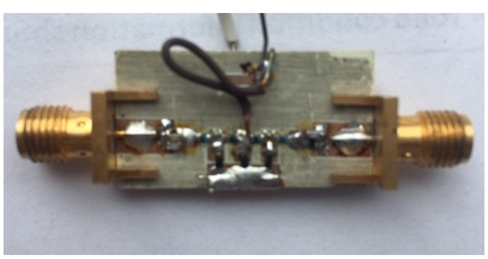

Figure 5: Fabricated NLTL with periodically arranged varactor diodes and inductors.

The effect of DC bias was measured on the harmonic generation. Hence, the harmonic tag was kept at 1 m from the transmitter antenna and the bias point was varied with other conditions unaltered. The received harmonic power at the interrogator is measured and provided in Table 1.

Table 1. Output power level at different bias settings

DC bias	Received harmonic power (dBm)
0.55 V	-58 dBm
0.57 V	-56 dBm
0.6 V	-51 dBm

IV. Conclusion

In this work, a multi-band antenna was demonstrated for miniaturized harmonic tag fabrication at 434 MHz and 868 MHz. The antenna demonstrated return loss of more than 10 dB at both the frequencies. The antenna is also immune to fabrication tolerance, which means even with the resonance frequency shift of the low frequency, the antenna performance will not be degraded. The tag uses a nonlinear transmission line to generate the second harmonic from the fundamental frequency. The efficiency of harmonic generation was also investigated in the wireless setup at different operating conditions of the harmonic tag. The proposed antenna and harmonic tag design architecture will result in a miniaturized harmonic RFID tag.

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