A Simple Dual-frequency Antenna Design for RFID Tag

Creating A Dual-frequency RFID Tag Readable by Both HF and UHF RFID Readers.

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Abstract*

With good read range and fast data rate, UHF Radio Frequency Identification (RFID) is deployed in the supply chain to identify each item uniquely. However, UHF transmission power is easily absorbed by ionised liquids, such as water. Hence, normally, in an environment with lots of liquid products, an HF RFID system is chosen instead. This paper investigates the feasibility of designing a dual-frequency (HF and UHF) RFID antenna, with frequency ratio of up to 70, to embrace the benefits offered by both the UHF and HF RFID systems. Also, this paper shows that with careful design, a single feed dual-frequency RFID antenna can be achieved. A prototype of the dual-frequency RFID antenna is presented in this paper, with validating simulation and measurement results.

1. Introduction

Radio Frequency Identification (RFID) is a technique used to identify objects by means of electromagnetic waves. An electronic code responding label, also known as a tag, consists of an antenna and an integrated circuit. Upon receiving any valid interrogating signal from any interrogating source, such as an RFID reader, the tag will respond according to its design protocol. RFID has been recently adopted into supply chain tracking systems, revolutionizing the conventional ways of how an object is traced along the supply chain and on how an inventory system works. Not only does RFID bring benefits in saving costs, it also has the potential of increasing security levels along the supply chain, especially in genuine goods authentication. To reduce the cost of RFID deployment, passive tags are used.

There are 4 common bands for RFID applications; these are the LF band (less than 135 kHz), the HF band (13.56 MHz), the UHF band (860 - 960 MHz) and the so-called microwave (2.45 GHz). LF is not suitable for supply chain deployment, as to uniquely identify every object in the supply chain, each tag has to bear a unique EPC number, which must be at least 64 bits in length [1]. A low frequency operation, such as in the LF band, would suffer very slow reading in a heavily tag populated environment. Also, LF requires large antenna components and hence is difficult to implement and is susceptible to electrical noise, which HF can handle [2]. UHF and microwave tags can offer comparatively very fast reading, but their performance will suffer more than the other bands described above in the presence of liquid or metal [3]. It is very difficult to conclude whether HF or UHF is better for RFID application in supply chains. This is because in any supply chain, there are many different

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scenarios, and in some HF is better and in the others, UHF outperforms HF operation. Table 1 summarises comparison between HF and UHF as presented in [3, 4, 5].

Table 1: HF versus UHF in RFID Operation

	HF	UHF
Read Range	≈1m	Up to 10m
Cost (in large volume)	Medium	Low
Read Rate	Lower	Higher
Metallic Area	Bad	Bad
Liquid Surroundings	Better	Worse

To embrace the advantages contributed by HF and UHF, this paper investigates the feasibility of designing a dual-frequency antenna for an RFID tag. In the next section, this paper reviews current technologies of dual-frequency antennas, and their shortcomings in designing an RFID HF and UHF dual-frequency antenna. Design aims to ensure that the designed antenna is feasible for real life application, are presented in Section 3. Section 4 describes the design process in detail, including the problems encountered and the solution of those problems. Section 5 presents the simulation results and Section 6 presents the actual measurement results for the designed dual-frequency antenna, together with some discussions and comments. Section 7 provides the conclusion for this paper.

2. Current Dual-frequency Antenna Design

The intended dual-frequency RFID antenna is planned to function at 13.56 MHz (HF) and also within the UHF band for RFID operation (860 - 960 MHz). If using the highest frequency in the UHF band, which is 960 MHz, the frequency ratio for this dual-frequency antenna is slightly more than 70.

Wong has done extensive research on dual-frequency microstrip antennas, with frequency ratio ranging from 1.8 - 4.9 [6]. However, the frequency ratio of this technique is too low to be applied on the intended RFID dual-frequency antenna. A common aperture, dual-feed dual-frequency antenna for 900 MHz and 60 GHz was presented by Menzel [7]. The Frequency ratio achieved is approximately 70. However, the antenna has dual feeding points.

One of the antennas which has a high frequency ratio and used in RFID is the one produced by IPICO [8]. Under the IPICO dual-frequency system, the RFID reader transmits a signal using the LF spectrum (125kHz to 135 kHz) in order to power the tag and the tag uses the HF spectrum (3 to 30 MHz) to transmit its signal back to the reader. The tag produced by IPICO is using LF and HF while the aim of this paper is to combine both HF and UHF.

3. Design Aims

The aim is to design, simulate and fabricate a dual-frequency RFID antenna, which can demonstrate the following characteristics:

1. Antenna impedance equals to the complement of the input impedance of the RFID chip at UHF operation.

This is to ensure a matching network to have maximum power transfer from the antenna to the RFID chip. The RFID chip used in the fabrication process has an approximate input impedance of 17 -150jΩ at RFID UHF band. Hence the final antenna design must have an input impedance of approximately 17 + 150jΩ. Note that in actual fact, the chip impedance will change within the RFID UHF band, but is assumed to be the same in our design steps.

2. A resonance point at HF.

It is expected that a dual-frequency antenna will behave like a parallel resonant circuit at HF. To ensure good read range performance, the antenna should have a resonance point at 13.56 MHz, and a high quality factor.

3. A single feed antenna.

The final antenna design is planned to be attached to a UHF RFID chip. Hence a single feed antenna is desired to avoid any modification required to the currently available UHF RFID chip.

4. Reasonable antenna size and cost.

The material used for fabrication is FR4, with relative permittivity, ε_r, equal to 4.4. The overall area should not exceed 14400 $(mm)^2$. However, it is not the focus of this paper to minimise the size of the antenna. Hence, the final design may not be of the smallest possible size.

4. Dual Frequency Antenna Design

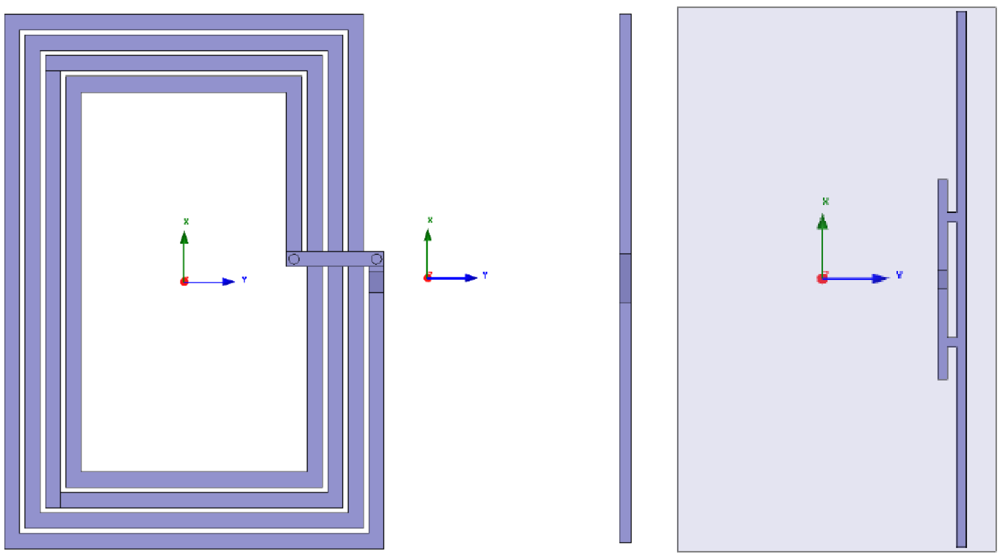
The basic idea in making a dual-frequency antenna (HF and UHF), is to design an HF and an UHF antenna separately, and merge these two antennas together with a single feed. However, since these two antennas are joined together in parallel, the UHF antenna will affect the HF operation of the HF antenna, and vice versa. Ways of minimizing this problem will be discussed in a later part. Also, the UHF operation spans a huge frequency band. In this paper the UHF antenna is designed to be matched at the highest RFID operating frequency (960 MHz). We believe that if an antenna can work at the highest frequency (having the highest frequency ratio), we can also tune the antenna to operate at the lowest frequency (860 MHz).

4.1. HF and UHF Antenna Design

For the operation of HF, a multi-turn planar loop antenna is designed. The calculation of the inductance of a multi-turn planar loop antenna is done using [9], which includes the computation of the positive and negative mutual inductances. From:

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

with an intended resonance frequency of 13.56 MHz, we know that a large inductance is required. The problem is that at the later stage, when this loop antenna is merged with the UHF dipole, the resonance frequency will change. Hence, the number of turns of the multi-turn loop is not fixed at this stage, and will only be finalised during the fine-tuning stage after the merging of the HF and the UHF antennas. An example of a generic multi-turn planar loop antenna is as shown in Fig. 1 (A). For the operation of UHF, a dipole is used. A half wave-length (of 960 MHz) dipole is designed (Fig. 1(B)).



(A) (B) (C)

Figure 1: (A) A generic HF coil antenna. (B) A generic UHF dipole antenna. (C) A UHF dipole with tuned matching network.

However, a dipole shown in Fig 1 (B) with length shorter than half wave-length will be capacitive in nature. To have a maximum power transfer between the antenna and the RFID tag chip, the UHF dipole should be approximately 17 + 150jΩ in impedance as discussed in Section 3. Hence, an appropriate matching network is required to transform the input impedance of the antenna to 17 + 150jΩ. The matching network chosen is a modified version of the T-match [10]. The final design of a dipole is as shown in Fig. 1 (C).

4.2. Merging

We suggest to have a transmission line between the two antennas of interest as shown in Fig. 2. The single feed point is to be located at one of the original feed points. Feed point B is chosen, and *l* equals λ (UHF)/4. The loop antenna can be designed to have low impedance at UHF, to be transformed into high impedance using the λ (UHF)/4 transmission line, so it will not interfere with the UHF dipole. The UHF dipole has small capacitance and will not interfere with the HF antenna at HF.

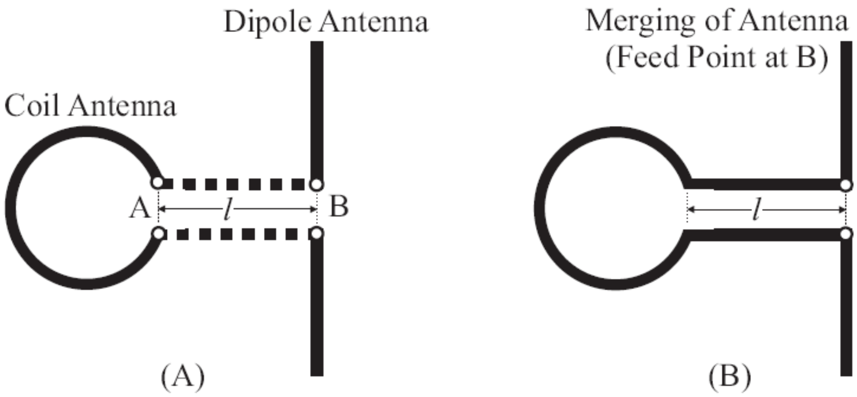


Figure 2: (A) A transmission line is added between the two antennas. (B) Feed point located at B.

The first problem discovered after the merging is that the matching network for the dipole will provide a short circuit at HF (Fig. 1 (B)), which will render the HF antenna useless. The solution is the addition of adding series capacitor in the matching network of the UHF antenna. The series capacitor is created by having a gap in the track and adding an overlapping underpass track. This capacitor will have negligible impedance at UHF but will have a very high impedance at HF. The UHF antenna is also bent at the sides to reduce the overall dimension of the dual-frequency antenna.

At HF, this UHF dipole antenna (Fig. 3) has a relatively large impedance as compared to the HF coil antenna. Though the real part is significantly smaller than the imaginary part, at 13.56 MHz, its impedance is 57.4 - 4461.67jΩ. At UHF, its impedance is a bit higher at the 860 MHz end, but can be adjusted easily, by changing the width of the underpass track below the gap. As mentioned before, the design is focussed at 960 MHz, which is the highest end of the RFID operating frequency. At 960 MHz, we have 6.68 + 139.27jΩ.

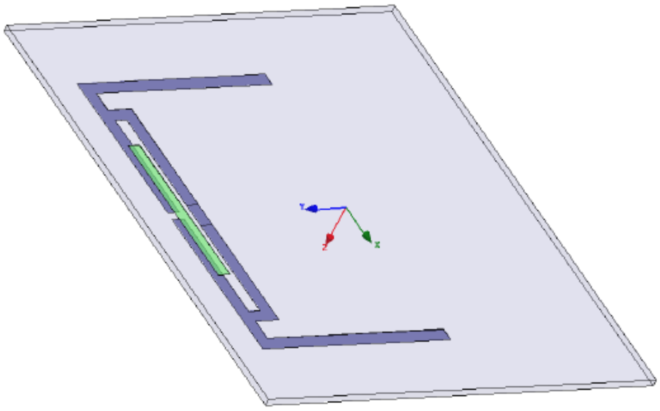


Figure 3: A UHF dipole with bent sides and gap.

The next problem is to have a resonance point at 13.56 MHz. The UHF dipole will be acting like a capacitor in parallel with the HF loop antenna (which is an inductor). However, the inductance and the capacitance is not high enough to have a resonance point at 13.56MHz, which is actually a very low frequency to achieved with respect to the size of the antenna. The solution is to have a back to back multi-turn loop antenna on the both sides of the FR4, to provide the extra capacitance required. Via holes are used to connect the planar tracks on both sides. Having a back to back multi-turn loop antenna also reduces the impedance of the loop antenna at UHF with the addition of parallel capacitance. By using a high characteristic impedance transmission line (which in our case, is a 250Ω coplanar waveguide), the relatively low impedance loop antenna will be normalised to the left hand side of a Smith Chart. Using *l* equals a quarter of a wave-length, this relatively low impedance loop antenna is transformed to the right hand side of the Smith Chart, or in other words, transformed into high impedances. The final design of the antenna is as shown in Fig. 4. The size of the antenna is approximately 110 mm by 100 mm.

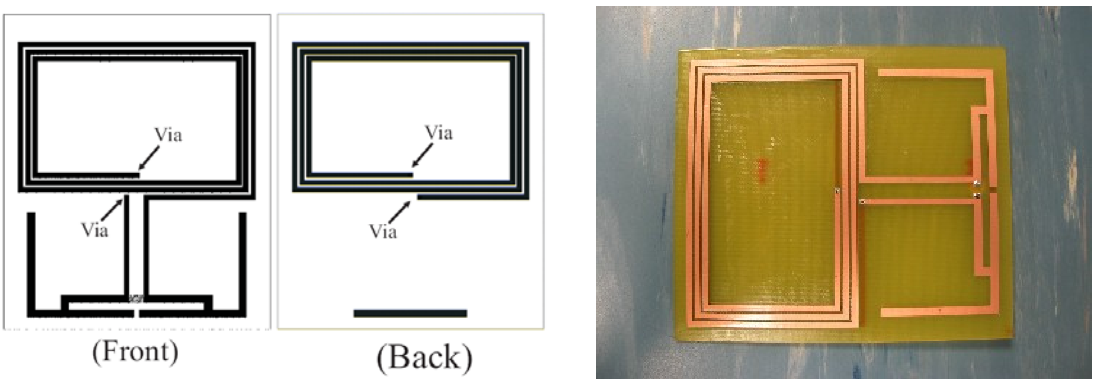


Figure 4: Final design for dual-frequency antenna

5. Simulation

The antenna fine-tuning and simulation is carried out using HFSS simulation software. The simulation is mainly on the impedance of the dual-frequency antenna in the frequencies of interest. Fig. 5 shows the simulated impedance values of the dual-frequency antenna within the UHF band. At 960 MHz, the antenna impedance is 24 + 143jΩ, which is very near to the intended impedance of 17 + 150jΩ. For HF, since the antenna represents a parallel resonance circuit, the resistance is theoretically infinite at 13.56 MHz, while the reactance is 0Ω. Through simulation a parallel resonance was obtained near the target frequency of 13.56 MHz.

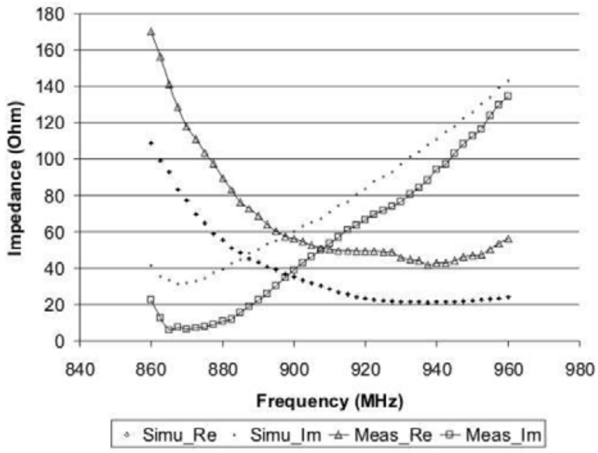


Figure 5: The simulated and measured results for the frequency response of the fabricated dual-frequency antenna within the RFID UHF band from 860 - 960 MHz.

6. Antenna Fabrication and Testing

The final design for the dual-frequency antenna (Fig. 4) is fabricated on a double-sided FR4 material and the actual measurement is taken for both HF and UHF operation. In the case of HF, the antenna resistance is too high at resonance to have a proper impedance measurement using a network analyser. The unbalanced input of the analyser also poses problems of measurement. To demonstrate the fabricated antenna has a resonant point at HF, a transmission measurement is used, where a 80 mm diameter wide-band loop antenna is used as the transmitting antenna and the fabricated antenna is used as the receiving antenna at 10 mm axial separation. Rotation of the loop confirms that coupling is via magnetic field. The result is shown in Fig. 6. The exact resonance point is at 13.94 MHz, which is very near to the designed frequency of 13.56 MHZ.

Impedance measurement was carried out from 860 - 960 MHz, and compared with the simulated results, as shown in Fig. 5. It is discovered that the measured resistance is higher than the simulated results, but the measured reactance is lower than the simulated results. The impedance at 960 MHz is measured to be 56.26 + 134.5jΩ. This is probably due to balanced load measuring problem, where the antenna is a balanced load while the network analyser is unbalanced. This can be solved by having a RF transformer or by connecting a BALUN to the antenna or employing other means of suppressing common mode currents. Nonetheless, the measurements have shown that a dual-frequency antenna has been successfully designed and fabricated to be used in RFID dual-frequency operation.

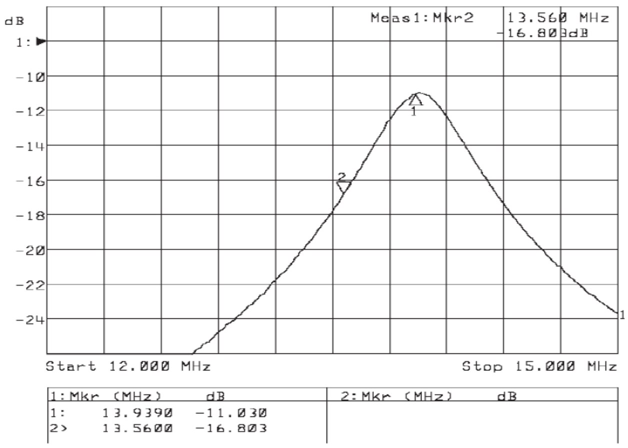


Figure 6: Transmission measurement using network analyser to locate the resonance point at HF.

7. Conclusions

This paper has presented a detailed design for a high frequency ratio dual-frequency antenna. With this dual-frequency antenna, an RFID tag can be read using a UHF reader when the product to which the tag is attached is directly exposed to UHF, while also can be read by HF reader when the product to which the tag is attached to is behind liquid items. Simulated and measured results are shown to confirm its functionality at both HF and UHF, as specified in the design aims. This shows that with proper design, a single feed dual-frequency antenna of very high frequency ratio can be achieved. This paper does not focus on the antenna size optimisation, which is left as future research. Actual testing, with RFID chip attached to the antenna, will be carried out in the future too. With the dual-frequency antenna, and a chip and reader protocol that can adopt to both frequencies, RFID tag can be attached to a liquid product, which will encourage wider deployment of RFID system along the supply chain.

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