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# COMPACT DUAL BAND TAG ANTENNA DESIGN FOR RADIO FREQUENCY IDENTIFICATION (RFID) APPLICATION

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**Abstract**—The increasing need for automatic identification and object tracking in supply chains has led to the development of radio frequency identification (RFID) systems. High frequency (HF) and ultra-high frequency (UHF) bands are frequently used because of their advantages over other bands. Although many HF and UHF band tags exist, some are unsuitable to handle the hostile environment of a supply chain. Therefore, this paper contributes to the research on a dual band RFID tag antenna operating on both the HF (13.56 MHz) and the UHF (919 MHz to 923 MHz) band, the UHF band used in Malaysia, by embracing the advantages of both HF and UHF bands to overcome the previously mentioned problems. The compact design is constructed by locating the UHF band antenna inside the HF band antenna and by reducing the number of turns of the HF band antenna compared to previous designs. The −10 dB bandwidth for the proposed design covers 12.9 MHz to 14.2 MHz for the HF band and 914.0 MHz to 929.0 MHz for the UHF band. The proposed antenna also overcomes the degradation problem by obtaining a high efficiency around 94% and a gain of 3.709 dB.

## 1. INTRODUCTION

Wireless technologies are now a part of modern life. For example, automatic identification (Auto-ID) technology can identify a physical object automatically. Auto-ID technology is implemented in many ways such as voice identification, optical character recognition, barcodes, and biometrics [1]. Among these technologies, barcodes are the most commonly used.

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An ideal Auto-ID technology should enable data transfer without human intervention. However, barcode technology is limited in its data capability and requires line of sight. An Auto-ID technology which could overcome these limitations is RFID technology. RFID technology has many advantages over the existing barcode technology. It uses radio frequency (RF) signals to identify a tagged object in a non-contact manner, that is, it does not require the object to be within its line of sight. Therefore, the popularity of and demand for RFID have increased when compared with those for barcodes in the last several years. RFID tags can also be embedded in an item and detected by the RF signal. This method avoids physical exposure such as that in barcodes. In addition, the read range also can enhance in RFID systems. Furthermore, RFID is particularly useful in applications where an item must have a unique identification.

RFID systems are generally distinguished through four common bands; low-frequency (LF) (125–134 kHz), high-frequency (HF) (13.56 MHz), ultra-high frequency (UHF) (860–960 MHz), and microwave (MW) (2.45 GHz or 5.8 GHz) [2]. However, different operating frequencies are used for UHF band in different regions for RFID systems such as 840.5–844.5 MHz and 920.5–924.5 MHz in China, 866–869 MHz in Europe, 902–928 MHz in the US, 866–869 MHz and 920–925 MHz in Singapore, 920–928 MHz in Hong Kong, and 952–955 MHz in Japan [3]. In Malaysia, based on the Malaysia Communications and Multimedia Commission, the UHF band used is 919–923 MHz [4]. Each operating frequency has its own characteristics. LF bands have low data-transfer rates but are good for operating environments with metals and liquids, while HF bands have more reasonable data-transfer rates compared with LF bands and penetrates water but not metal.

However, a supply chain can have many situations. In warehouses, many objects need to be tagged. Thus, an RFID tag with a high reading speed, such as ultra-high frequency (UHF) band tag, is required to handle the heavy population in the supply chain. Items in liquid form, however, cannot be handled by the UHF band and require a high frequency (HF) band tag. A dual band RFID tag operating on both HF and UHF bands can overcome this problem. This dual band tag can embrace the advantages of HF and UHF bands for more practical usage in supply chains.

## 2. STRUCTURE AND DESIGN

### 2.1. HF Antenna Design

For an operating frequency less than 100 MHz, the antenna receives power via inductive coupling at close range. This means that the data transmission between the tag and the reader antenna is based on inductive coupling, in which the reader antenna generates a magnetic field that couples with the antenna on the tag. Therefore, the antenna configuration suitable for an inductive coupled system is a multi-turn spiral coil with a rectangular cross section. The voltage induced on a coil is proportional to the number of coil turns, the size of the coil, and the operation frequency [5].

The calculation of the coil's inductance, which depends on the geometric parameters, also plays an important role in the design process. Although various empirical formulas exist in the literature for calculating the coil's inductance, the Greenhouse method is the most popular approach because it offers superior accuracy [6]. The relationship between the resonant frequency in Hz and the inductance and capacitance can be expressed by the Thomson equation shown below:

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

where $L$ is the inductance of the coil inductor in Henrys and $C$ is the total capacitance of the circuit in Farads.

However, based on [7], for an antenna with an operating frequency range between 4 and 24 MHz, a coil antenna with less than 10 turns and a capacitor should be included in the antenna design. Therefore, a substrate capacitor and a coil antenna are required in the design of the HF band antenna. Since the substrate capacitor is added in the design to control the capacitance required by the coil antenna to achieve the resonant frequency, which is 13.56 MHz, the number of turns of the coil antenna can be fixed. For the design of the HF band antenna, the number of turns is fixed at two and three substrate capacitors are used. The overall size of the proposed antenna is 102.88 mm × 64.45 mm.

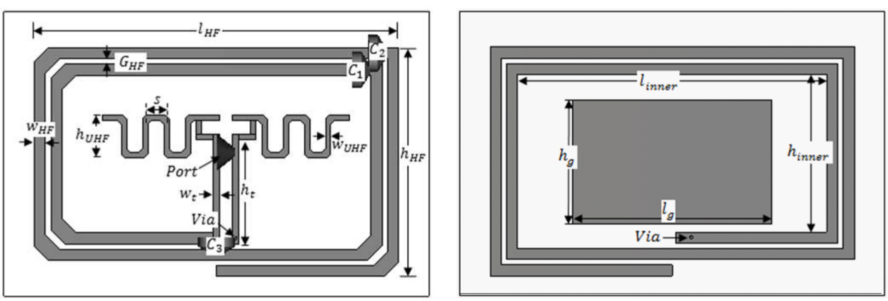
### 2.2. UHF Antenna Design

For the UHF band antenna, the data are transferred between the tag and the reader by the backscattering of an electromagnetic wave. A tag partially rectifies the electromagnetic wave from the reader and uses it as a power source while sending a coded signal back to the reader. Various antennas are suitable for a UHF band operating frequency, such as a folded dipole antenna [8], meander line antenna [9], patch antenna [10] and slot antenna [11]. However, taking into consideration the tag antenna requirement in miniaturizing the geometry of the antenna, the planar meander line antenna is the most suitable antenna for use in the design because it possesses the advantages of a size reduction and a simple configuration. The design for the UHF band antenna consists of a meander line antenna, and a rectangular loop feed is combined with the body of the meander line antenna.

## 2.3. Dual Band Antenna Design

After completing the designs of the HF band antenna and UHF band antenna separately, the final step is to merge the HF and UHF band antennas together. This process combines both antennas to become a single antenna that can operate in dual bands with a single feeding point, so that the proposed antenna only have one chip which can help reduce the cost of production. However, when combined, the HF and UHF band antennas affect each other. Therefore, modifications on both antennas are required to reduce the adverse effects between the HF and UHF band antennas, and to ensure that the final design of the proposed antenna still operates at the desired frequency, 13.56 MHz for the HF band and 919 MHz to 923 MHz for the UHF band.

According to the law of inductance, the voltage can be increased by enlarging the diameter of the winding motion to gather more magnetic flux. Therefore, it is important that the HF band antenna be located at the outermost region of the design.




(a) (b)

**Figure 1.** (a) Front view of the dual band antenna. (b) Rear view of the dual band antenna.

### 2.4. Configuration of the Final Design

Since the HF band antenna is important to be located at the outermost region of the design, the design of the proposed antenna must have the UHF band antenna inside the HF band antenna as shown in Figure 1(a). To merge the HF and UHF band antennas together, two transmission lines are required. One transmission line is used to connect the UHF band antenna to the front side of the coil antenna, as shown in Figure 1(a) while the other is used to connect the UHF

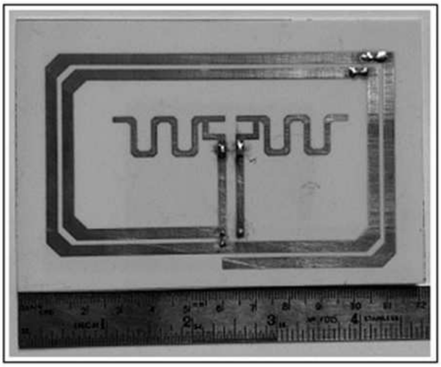


**Figure 2.** Photo of the fabricated dual band antenna.

**Table 1.** Parameters and values for the dual band antenna.

| Parameter | Values (in mm) |
|---|---|
| Length of the HF band antenna, $l_{HF}$ | 102.80 |
| Height of the HF band antenna, $h_{HF}$ | 64.45 |
| Width of the HF band antenna, $w_{HF}$ | 3.10 |
| Gap between the spacing of the HF band antenna, $G_{HF}$ | 1.55 |
| Inner length of the HF band antenna, $l_{inner}$ | 87.30 |
| Inner height of the HF band antenna, $h_{inner}$ | 44.3 |
| Height of the UHF band antenna, $h_{UHF}$ | 11.90 |
| Spacing between the pitch, $s$ | 6.00 |
| Width of the UHF band antenna, $w_{UHF}$ | 1.50 |
| Height of the transmission line, $h_t$ | 29.20 |
| Width of the transmission line, $w_t$ | 2.00 |
| Length of the ground, $l_g$ | 56.00 |
| Height of the ground, $h_g$ | 35.00 |

band antenna to the back side of the coil antenna through the via, as shown in Figure 1(b). When the UHF band antenna is connected together with the HF band antenna, the inductance of the UHF band will also affect the inductance of the HF band antenna. Therefore, adjustments on substrate capacitors are made to maintain the values at the desired resonant frequency of 13.56 MHz. However, the overall size of the proposed antenna is still maintained at 102.80 mm × 64.45 mm, which is the dimension of the HF band antenna as discussed in the previous section. The values of the substrate capacitors in Figure 1(a) are $C_1 = 1\,\mathrm{nF}$, $C_2 = 1.0\,\mathrm{nF}$ and $C_3 = 2.7\,\mathrm{nF}$. The other parameters and values of the proposed antenna are listed in Table 1 and a photo of the fabricated antenna is shown in Figure 2.

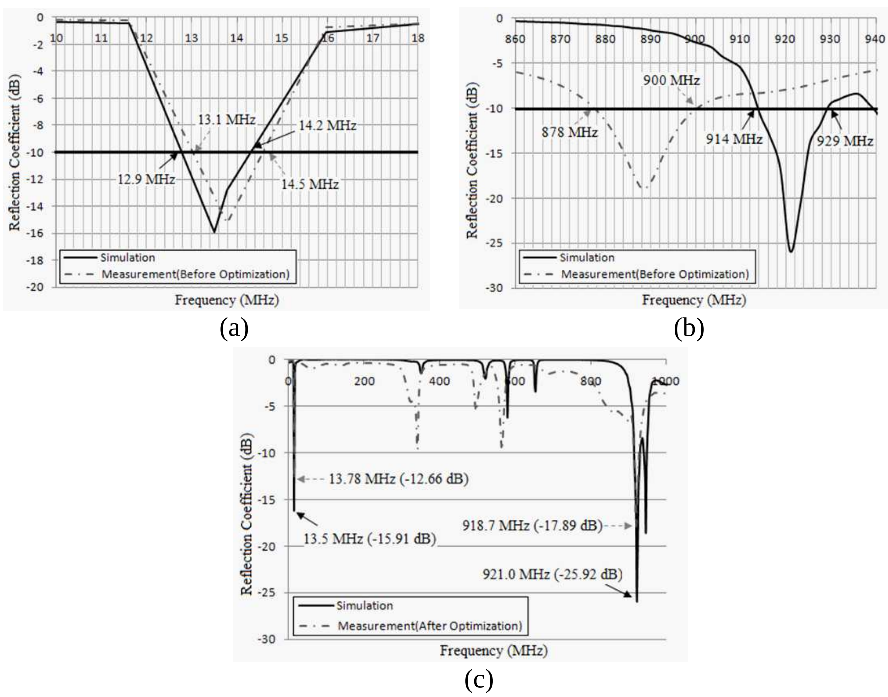



**Figure 3.** (a) Simulated and measured reflection coefficient for the dual band antenna at HF band before optimization. (b) Simulated and measured reflection coefficient for the dual band antenna at UHF band before optimization. (c) Simulated and measured reflection coefficient for the dual band antenna after optimization.

## 3. RESULTS AND DISCUSSION

The −10 dB bandwidth for HF band of the dual band antenna is shown in Figure 3(a). The simulated bandwidth at −10 dB covers 12.9 MHz to 14.2 MHz while the measurement bandwidth covers 13.1 MHz to 14.5 MHz. Both results also achieve the desired HF band frequency, which is 13.56 MHz, and there is good agreement between simulation and measurement results. The −10 dB bandwidth for the UHF band of the dual band antenna is shown in Figure 3(b). The simulation result covers 914 MHz to 929.0 MHz, which includes the desired frequency range.

However, the measurement result before optimization only covers 878.0 MHz to 900.0 MHz. There is a frequency shift of around 3.56% between the simulation and measurement results. This shift in frequency is caused by various factors such as fabrication tolerance, losses during measurement process, and environment or mismatching between the feedline to the antenna in real fabrication. Therefore, optimization is required to ensure that the measurement result covers the desired frequency band.

In an electronic system, the delivery of power requires the connection of two wires between the source and the load. At low frequencies, power is considered to be delivered to the load though the wire. However, when the operating frequency moves towards the microwave frequency region, power is considered to be in the electric and magnetic fields that are guided from place to place by the physical structure of the design. Therefore, the parameters that should be considered are the overall dimensions of the proposed antenna, that is, the length and height of the coil antenna. The optimization process is performed manually by adjusting the parameters of the design on the simulator and also on the real prototype. The optimization parameters and their original size versus optimized size are shown in Table 2.

After optimization, the measured reflection coefficient at −10 dB bandwidth for the UHF band covers 914 to 926 MHz and that for the HF band attains 13.56 MHz, as shown in Figure 3(c). This means, the measurement results after optimization reach the desired frequencies in both the HF and UHF bands.

The 3-D radiation pattern obtained using CST Microwave Studio for the dual band antenna at 921 MHz is shown in Figure 4. The gain for the proposed antenna is 3.709 dB, and both of the radiation efficiency and total efficiency show good performance, 94.33% and 94.21%, respectively. The measurement gain obtained by using the gain comparison method as suggested by [12] is shown in Figure 5.

By using the equation below with 3 dB as reference gain, we can calculate the gain of the antenna under test (AUT) as

$$Gain_{AUT} = Gain_{reference} + Gain_{relative} \tag{2}$$

The gain of the dual band antenna from 919 MHz to 921 MHz ranges from 1.97 dB to 2.74 dB, that is, a bit lower compared to the simulated gain as predicted. The radiation patterns in the $E$- and $H$-planes in polar form corresponding to simulation and measurement are shown in Figure 6. Both planes also show a good agreement between the simulated and measured results, that is, both are dipole-shaped.

There are various factors that make it impossible to have an absolute comparison of the related works with the proposed antenna such as different design methodology and different measurement

**Table 2.** Optimized dimension versus original dimension for the dual band antenna.

| Parameters of dual band antenna | Original size (mm) | Optimized size (mm) | Difference (mm) |
|---|---|---|---|
| Length of the coil antenna, $l_{HF}$ | 102.80 | 98.80 | 4.00 |
| Height of the coil antenna, $h_{HF}$ | 64.45 | 63.45 | 1.00 |

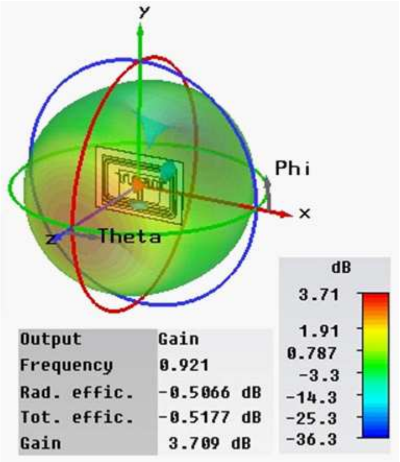



**Figure 4.** The 3-D radiation pattern for the dual band antenna at 921 MHz.

methods used by other researches in contrast to what is used in this paper. However, there still exists some possible comparisons that can be done considering overall size, number of ports that are used, the number of turns, and the efficiency performance of the antenna which are presented as shown in Table 3. The dual band antenna proposed in [13] has combined two antennas together in parallel while the proposed antenna has combined the meander line antenna within the coil antenna. Therefore, the size of the proposed antenna (102.80 mm $\times$ 64.45 mm) is smaller. The design of [14] has faced the degradation of

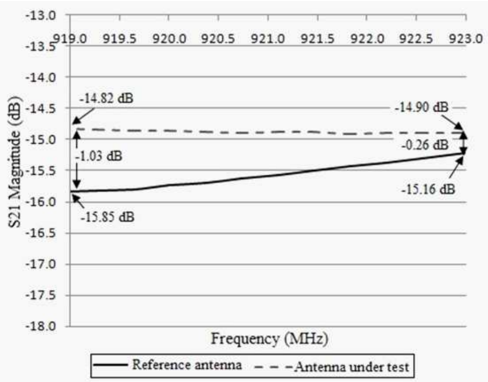



**Figure 5.** Measured gain using gain comparison method for the dual band antenna.

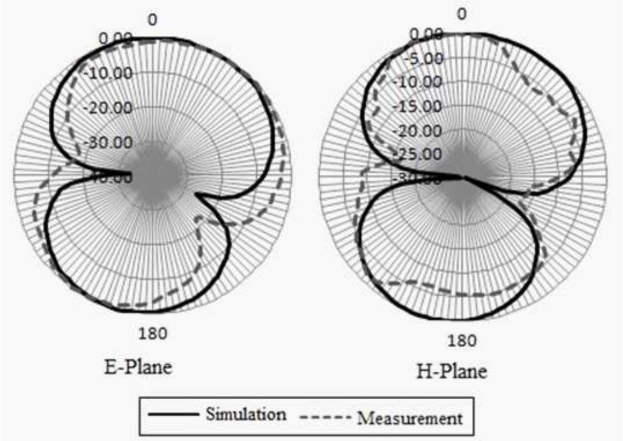



**Figure 6.** Simulated and measured radiation patterns in polar form for the dual band antenna at 921 MHz.

**Table 3.** Related work comparison with the proposed antenna..

| Research | Substrate | Overall dimension | Number of ports | Type of antenna used | | Performance | |
|---|---|---|---|---|---|---|---|
| | | | | HF band | UHF band | HF band | UHF band |
| [13] | FR4 substrate with $\varepsilon_r$ = 4.4 | 110 mm × 100 mm | One port | Coil antenna with three turns | Half wavelength dipole antenna | Measured resonant frequency at 13.94 MHz with −11.03 dB | Impedance at 960 MHz with 56.26+134.5 |
| [14] | Copper-plated polyimide substrate | 71 mm × 46 mm | One port | Printed spiral antenna with four substrate capacitors | Shorted loop slot antenna | Resonant frequency at 13.56 MHz with quality factor of 54 | Loss with −4.69 dBi at 868 MHz |
| [15] | $h$ = 0.7 mm $\varepsilon_r$ = 2.2 | 83 mm × 49 mm | Two ports | Coil antenna with six turns | *S*-dipole antenna | Resonant frequency at 16.1 MHz with quality factor of 10.1 | Gain with 2.3 dBi and radiation efficiency is 96% |
| [16] | $h$ = 0.8 mm $\varepsilon_r$ = 4.4 tan$\delta$= 0.02 | 84 mm × 54 mm | One port | Coil antenna with nine turns | Dipole antenna | Resonant frequency at 13.56 MHz with quality factor of 120 | Maximum range up to 8.8 m in USA, 6 m in Japan and 7 m in Europe |
| Proposed antenna | Roger 4003C substrate with $\varepsilon_r$ = 3.38 | 102.80 mm × 64.45 mm | One port | Coil antenna with two turns and three substrate capacitors | Meander line antenna | Simulated: 13.5 MHz (−11.94 dB) Measured: 13.78 MHz (−12.66 dB) | Simulated: 952.5 MHz (−22.82 dB) Measured: 918.7 MHz (−17.89 dB) Gain with 3.709 dB at 921 MHz |

the efficiency during combination of the HF and UHF bands together and obtained a loss of about −4.69 dBi but the proposed antenna has successfully overcome the degradation in efficiency and obtained a gain of 3.709 dB and radiating efficiency of 94.33%. Even though the design that is proposed in [15] also obtained a high efficiency in radiation, it requires two chips which will increase the cost of production. Another design presented in [16] is constructed using nine turns of the coil antenna with the dipole antenna. The structure of the design is complicated compared to the proposed antenna which only has two turns of coil antenna with the meander line antenna.

## 4. CONCLUSION

In this paper, a dual band antenna with operating frequencies at 13.56 MHz and 919 MHz to 923 MHz in a single platform had been presented. This implementation has successfully embraced the advantages of both HF and UHF bands to overcome the problem faced by a single band. In addition, the proposed antenna also has overcome the major problem which it will face when the HF band and UHF band combine together, i.e., the degradation of the efficiency. It is found that the proposed antenna has high efficiency with its radiation performance around 94% and a gain of 3.709 dB. Radiation patterns in the $E$- and $H$-planes both show a dipole-shape.

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