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A MULTI BAND MINI PRINTED OMNI DIRECTIONAL ANTENNA WITH V-SHAPED FOR RFID APPLICATIONS

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Abstract—This paper presents a mini multi-band printed omni-directional antenna with v-shaped structure for radio frequency identification (RFID) applications. The proposed multi-band antenna is developed from the initial v-shaped design which is only capable of working as a single-band antenna. By deploying a concept of dipole antenna to an initial design, the proposed antenna is accomplished to operate with two different modes of RFID system which are passive and active modes at frequencies of 915 MHz and 2.45 GHz respectively. The passive RFID tag is invented when a chip of Ultra High Frequency (UHF) is integrated with a proposed multi-band antenna. This passive tag, which is able to radiate with the measured signal strength, shows that the reading ranges are boosted almost two times compared to the conventional inlay antenna. The maximum reading range of passive RFID tag with inlay antenna is 5 m, though a reading range up to 10 m is achievable through the deployment of the proposed antenna at a measurement field. Implicitly, the measurements carried out on the antenna are in good agreement with the simulated values. Moreover, the size of the mobile passive RFID tag has been substantially as 100 mm $\times$ 70 mm, even though the antenna is fabricated with an inexpensive FR-4 substrate material. With the reasonable gain, coupled with cheaper material and smaller size, the proposed antenna

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has attractive potentials for use in RFID applications with multiple frequency antenna for active and passive tags.

1. INTRODUCTION

RFID technology is used to describe various technologies that utilize radio waves for automatic identifications of human beings or objects. RFID system consists of a tag, readers and a back-end system for processing the information received by the readers. The RFID tag consists of a semiconductor chip and an antenna, and it is divided into two categories, the active and passive types. The tags with internal batteries are said to be active, while those without batteries are said to be passive [1]. Nowadays, most of passive RFID tags normally have a maximum reading range up to 5 meters, depending on the reader power and antenna gain [2].

In order to boost the reading range of passive RFID tag, the antenna gain must be amplified, since its reader's regulation power is limited at maximum of 2 watts for unlicensed handling. Traditionally, passive RFID tags' antennas, otherwise known as inlay antennas, have contributed to a low gain with omni-directional radiation pattern [3, 4]. However, the printed antenna proposed in this paper is capable of doubling the gain compared to the conventional antenna currently used, while at the same time retaining the same radiation pattern. This advancement has significantly extended the reading distance of passive RFID tags up to 10 m in comparison with the conventional antenna with a maximum distance of 5 m.

Either passive or active RFID tag is invented when a certain chip is integrated with an antenna that has the same operating frequency [4, 5]. Conventionally, the RFID system is designed to operate either in active or passive mode. The active mode is specifically located between frequencies of 2400 MHz and 2483 MHz, while for passive mode, the frequency range is between 902 MHz and 928 MHz [1]. In the literature, no single design has incorporated a combination of active and passive modes in a single RFID tag's antenna. This advancement is realizable through the proposed multi-band antenna which is capable of providing both frequency ranges with only a single antenna. Invariably, the antenna proposed in this paper can be dynamically used in both active and passive modes in RFID applications, such as asset tracking system, vehicle tracking and monitoring [6–10].

Furthermore, other improvements of the proposed antenna include reduced size and cost efficiency. With a dimension of 100 mm by 70 mm, the proposed antenna is smaller than the conventional RFID antennas. This proposed antenna is compact in size and light in weight which make this antenna suitable for mobile RFID terminal such as hand-held RFID reader, mini RFID reader, etc. The proposed antenna can be a tag antenna and suitable for middle to large object for example asset tracking system.

2. ANTENNA DESIGN

In this work, the proposed microstrip antenna is designed to generate an omni-directional radiation pattern together with potential of multi-band operating frequency. By using inexpensive material available in the market, the proposed antenna is fabricated using FR4 material with relative permittivity of $\varepsilon_r = 4.7$, height $h = 1.6$ mm and $\tan\delta = 0.019$. The substrate is square in shape, and basic formulas of microstrip antenna are used to calculate its width and length. Initial dimensions of basic antenna are: width = 97 mm and length = 75 mm. As shown in Figure 1, the proposed antenna is then adjusted into 100 mm × 70 mm.

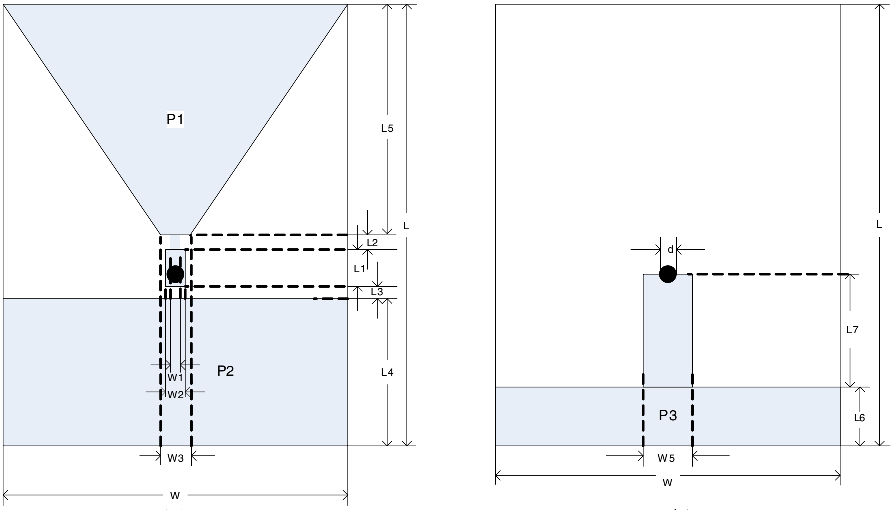


Figure 1. Basic design of the proposed antenna structure: (a) top substrate, (b) bottom substrate.

The antenna is designed with a basic rectangular patch and a ground at another side of the patch. The size of ground has been particularly designed (see Figure 1(b)) to minimize the effect of reflected electrical field to achieve an omni-directional beam at particular operation frequency. The radiating element is invented with v-shaped structure, and coaxial feeding is located below the centre point of the antenna's length.

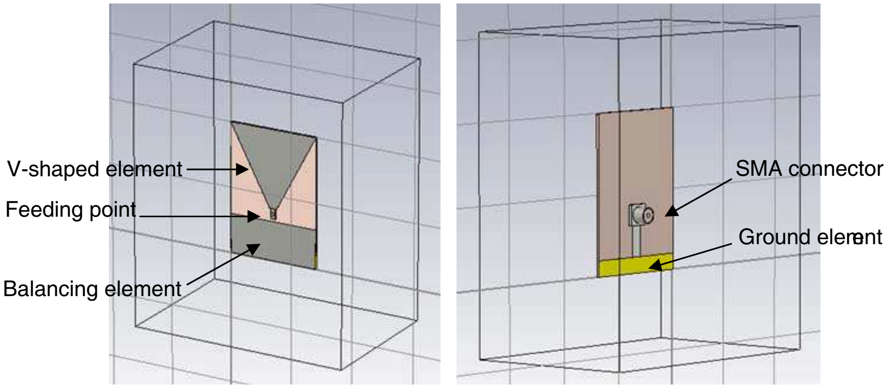
Unlike a normal patch antenna, the proposed antenna has a v-shaped radiating element, square-shaped balancing element and a horizontal ground. All these features have collectively contributed to the omni-directional radiation pattern of the proposed antenna. The top and bottom widths of the v-shaped radiating element are 16 mm and 70 mm, and the length is 50 mm as shown in Figure 1(a). The dimension of the balancing element is 38 mm in height and 55 mm in width. Whereas, in Figure 1(b), the width of the ground is 70 mm while its length is 12 mm. The gap between the radiating and balancing elements is 13 mm from the centre of the feed point. Both elements are etched on the same side of the substrate.

Table 1 summarizes the dimensions of the proposed antenna for both single- and multi-bands. A coaxial feed probe using PCB based square flange SMA connector with outer radius 4.5 mm, inner radius 0.5 mm, teflon lossy material with epsilon 2.08 and an impedance of 50 Ω is fed to the antenna. Figure 2 shows the initial design which is simulated using 3D CST simulation software. This design can only manage to operate at 915 MHz.

Table 1. Summary of dimensions of the proposed antenna.

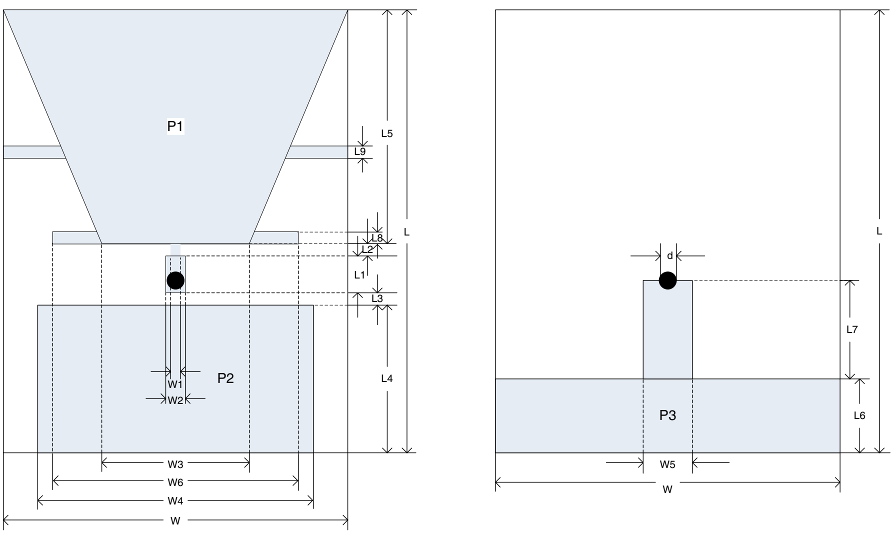
L	Single Band (mm)	Multi band (mm)	W	Single Band (mm)	Multi Band (mm)
L	100	100	W	70	70
L_1	8	8	W_1	3	3
L_2	3	3	W_2	5	5
L_3	2	2	W_3	7	16
L_4	37	37	W_4		55
L_5	50	50	W_5	10	10
L_6	12	15	W_6	-	50
L_7	30	27			
L_8	-	3.5			
L_9	-	3.5			

In addition to its competence of radiating with omni-directional pattern, the proposed antenna is also proficient to operate in multi-band frequency. As shown in Figure 3, with an additional attachment of two parallel lines of Figures 1 and 2, this novel antenna can successfully operate its omni-directional beam at three different frequencies, including 900 MHz for UHF passive RFID's band, 1.4 GHz



(a) (b)

Figure 2. Basic structure a single band antenna (a) patch with v-shape element, (b) ground element.



(a) (b)

Figure 3. Multi-band antenna structure (a) patch with added 2 lines, (b) ground element.

to 2.2 GHz for GSM and 3G bands. Meanwhile, 2.4 GHz up to 2.6 GHz is applied to active RFID and Wi-Fi communication systems. These applications are outside the scope of this study, since the research is principally focused on RFID applications [11–13].

Figure 4 shows the simulation of the proposed multi-band antenna

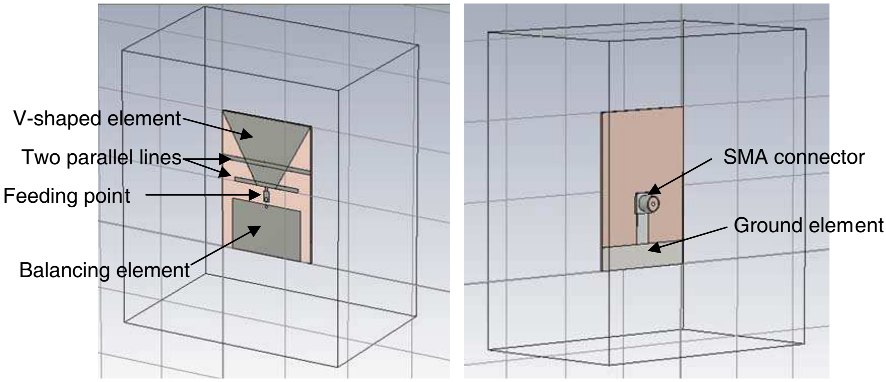


Figure 4. Simulation of multi-band antenna structure.

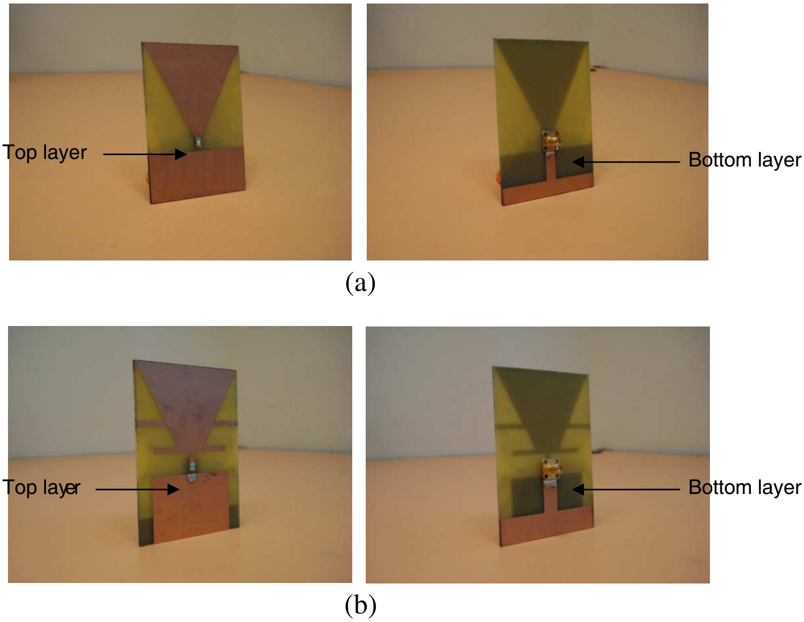
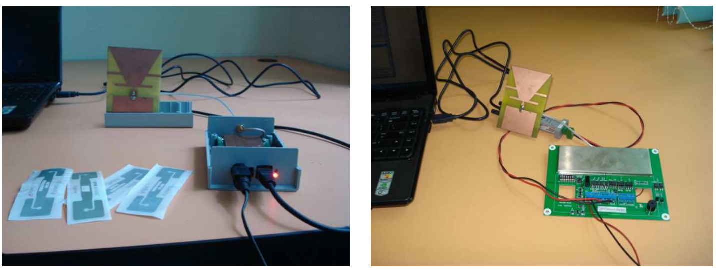


Figure 5. Fabricated antennas (a) Single-band antenna, (b) multi-band antenna.

using 3D simulation software which is CST. Figures 5(a) and 5(b) show the pictures of the fabricated antennas for both single-band and multi-band, respectively. The proposed antenna in an anechoic chamber during the measurement is shown in Figure 6.

Figure 6. Measurement of proposed multi-band antenna's radiation pattern.



(a) (b)

Figure 7. Multi-band Antenna with RFID reader (a) Passive, (b) active.

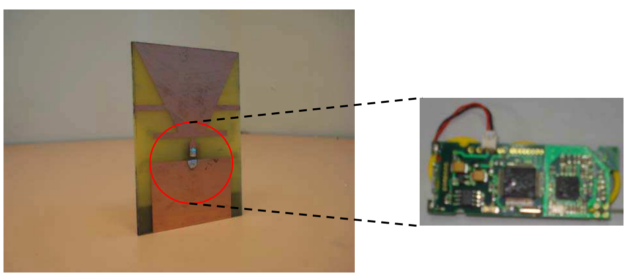


Figure 8. Proposed multi-band antenna as RFID tag.

3. MEASUREMENT SETUP

As mentioned earlier, the proposed multi-band antenna is capable of operating in both active and passive modes, either as a transmitter (RFID reader) or a receiver (RFID tag), as shown in Figures 7 and 8. However, the main focus of this research is on the capability of the

(a) (b)

Figure 9. Measurement setup (a) receiver (RFID tag), (b) transmitter (RFID reader).

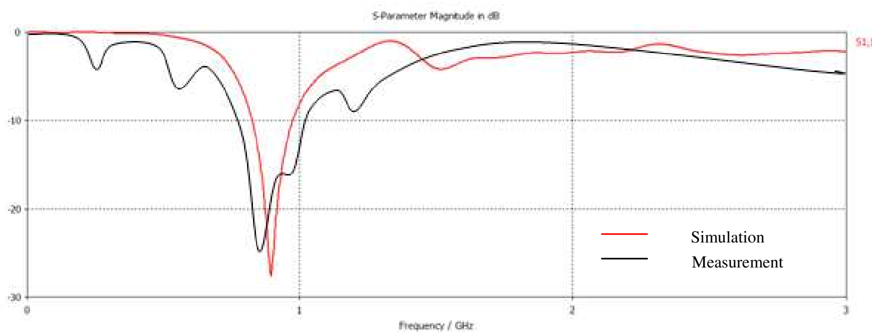


Figure 10. Reflection coefficient parameter for a single band antenna.

proposed antenna functioning as a passive RFID tag (receiver). Thus, the core objective is investigation and verification of the maximum reading range that could be reached by the proposed antenna.

Integrating the proposed antenna with UHF chip and emitting certain level of received signal strength indicator (RSSI) signals at frequency of 915 MHz to the RFID reader, the arrangement is indirectly turned to RFID tag's antenna. This is clearly illustrated in Figures 8 and 9(a). On the other hand, Figure 9(b) shows the micro miniature coaxial, MMCX connector, which is fed by RFID reader magic module M_9 with 27 dBm transmitting power as a transmitter.

All indoor experiments, shown in Figure 9, have been carried out in Wireless Communication Centre (WCC) of Universiti Teknologi Malaysia (UTM). The experiment is implemented by taking 12 measurements of reading distance within 10 m of direction. Figures 9(a) and 9(b) show the measurement setup of the transmitter (RFID reader) and receiver (RFID tag), respectively.

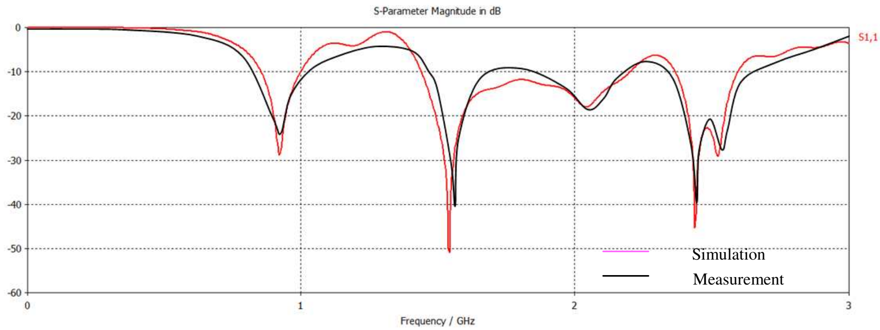


Figure 11. Reflection coefficient parameter for a multi-band antenna.

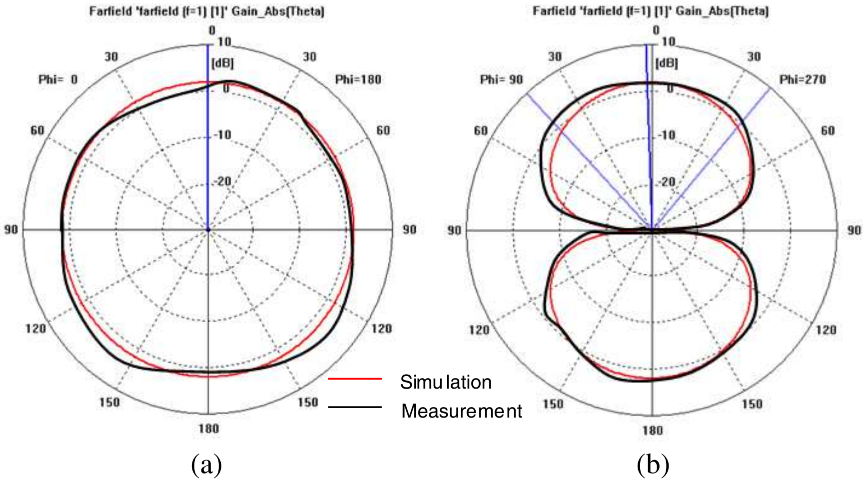
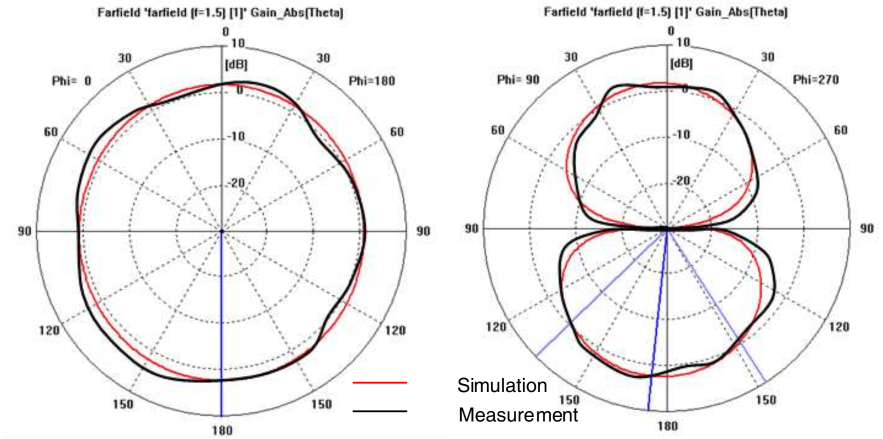


Figure 12. Polar radiation pattern for a single-band antenna at 900 MHz (a) H-Field (b) E-Field.

4. RESULTS AND DISCUSSION

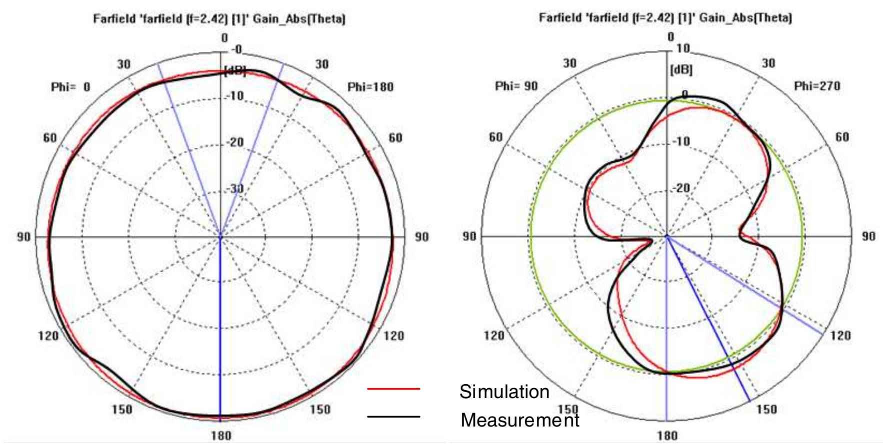
The simulated value of reflection coefficient parameter of single band antenna operating frequency of 915 MHz is −28 dB, whereas, the measurement value is −27 dB. This single band antenna is suitable for RFID applications in UHF band at operating frequency ranging from 902 MHz to 928 MHz. In Figure 11, as for multi-band antenna, the chosen reflection coefficient values are −20 dB, −38 dB and −25 dB for the operating frequencies of 915 MHz, 1.6 GHz and 2.45 GHz, respectively [14].

Figure 12 shows the polar radiation patterns of E- and H-



(a) (b)

Figure 13. Polar radiation pattern for multi-band antenna at 1.6 GHz (a) *H*-Field (b) *E*-Field.



(a) (b)

Figure 14. Polar radiation pattern for multi-band antenna at 2.45 GHz (a) *H*-Field (b) *E*-Field.

fields for a single-band antenna operating at a frequency of 900 MHz. Figures 12(a) and (b) show the *H*-field radiation pattern at 360° and *E*-field radiation pattern at 80°, respectively. Figures 13 and 14 further justify that the simulation results are in good agreement with the

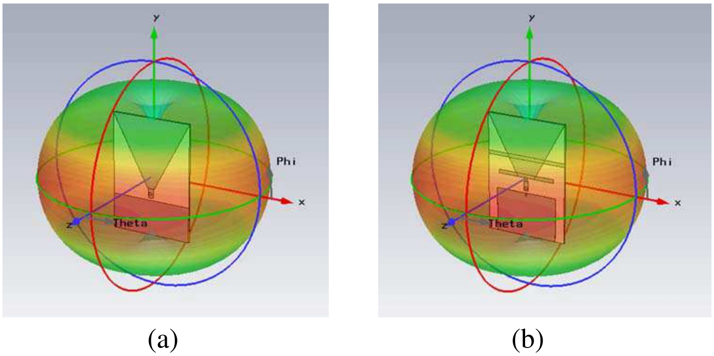


Figure 15. 3-D radiation patterns at 900 MHz (a) Single-band antenna, (b) multi-band antenna.

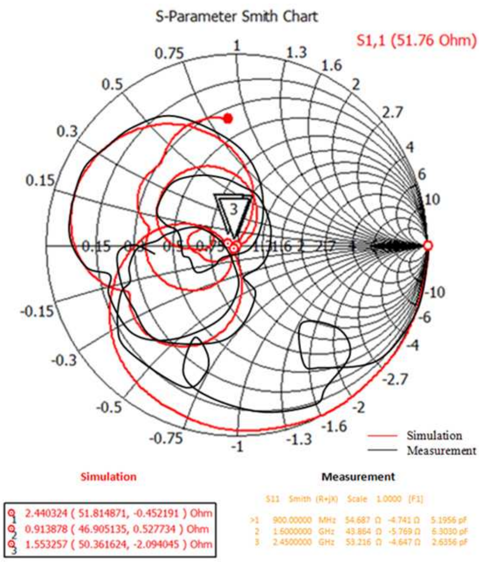


Figure 16. Impedance graph of multi-band antenna.

measurements. The unavoidable minor ripples which occur between simulation and measurement results are due to such factors as material used and semi-auto process employed in the fabrication processes.

It is observed that both the multi- and single-band antennas have the same polar radiation patterns for the H-field. While for the E-field, the 900 MHz and 1.6 GHz bands have the same radiation pattern but slightly different from that of 2.4 GHz band, as shown in Figures 12, 13 and 14. The angles are 360° for H-field and 80° for E-field. The

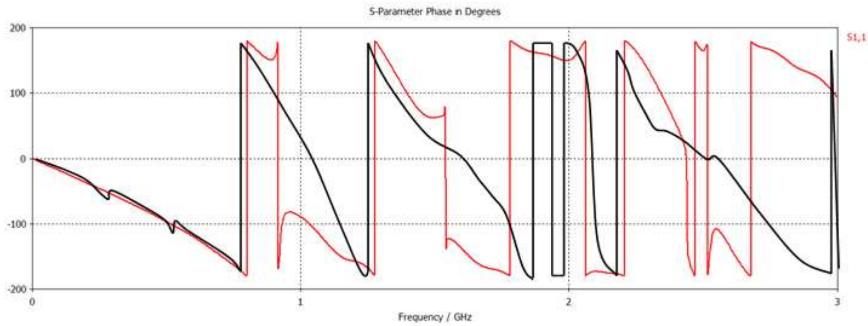


Figure 17. Impedance graph of multi-band antenna.

Table 2. Transmission power of passive RFID reader.

Distance meter (m)	Passive RFID transmit power setting
1	2.5 dBm
2	5 dBm
3	9 dBm
4	13 dBm
5	16 dBm
6	18 dBm
7	21 dBm
8	24 dBm
9	28 dBm
10	31 dBm

3-D omni-directional radiation pattern of the corresponding antenna is shown in Figure 15. These numbers and figures show that the multi-band antenna is capable of maintaining its omni-directional radiation pattern with multi-band frequencies.

The proposed multi-band antenna also shows impedance plot (Smith chart), the center of the Smith chart represents zero reflection coefficients so that the antenna is perfectly matched. Figure 16 shows simulated and measured input impedances of the proposed multi-band antenna. The value is close to the center of the Smith chart and is the same as for 1.6 GHz and 2.4 GHz bands. The simulated antenna's overall input impedance, using CST simulation software, will match at 51.76 Ohm. Figure 17 shows the simulated and measured phase responses of proposed antenna, where all the three bands, 900 MHz, 1.6 GHz and 2.4 GHz, grant acceptable responses.

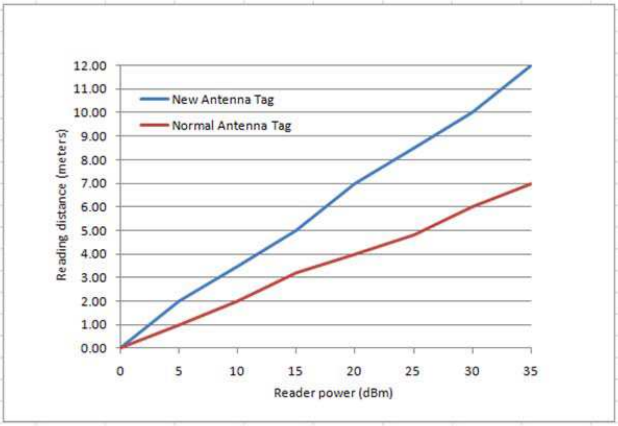


Figure 18. Comparison between RFID tag with normal antenna and proposed new antenna.

The maximum distance for the RFID reader to detect the passive RFID tag with multi-band antenna backscattered signals is shown in Table 2. It is observed that transmission power increases with increasing range. For instance, when the RFID tag, with frequency of 915 MHz, is moved from 1 m up to 10 m the RFID reader transmitting power increases from 2.5 dBm to 31 dBm as shown in Table 2. The values of the proposed antenna's reading range are then inferred from Figure 15 and compared with those of conventional inlay antennas.

It has been shown in Figure 18 that, with the same RFID reader transmission power of 5 dBm, the RFID tag with the proposed antenna could achieve a reading range up to 2 m compared to the 1 m achievable by the conventional inlay antenna. The transmission powers are 2.5 dBm and 31 dBm for ranges of 1 m and 10 m, respectively justifying the fact that transmission power of the conventional inlay antenna increases with increasing range. It is therefore worthy of noting that with the same transmission power, the proposed antenna could cover a much higher range (6 m) than 3.5 m covered by the inlay antenna.

Figure 18 shows the comparison between the proposed antenna and conventional inlay antenna in terms of reading range coverage. The maximum transmission power is 35 dBm for both cases. It can be observed from the figure that by increasing the transmission power of the new RFID tag's antenna from 21 dBm to 31 dBm, the reading range increases from 7 m up to 10 m. Whereas, by using the inlay antenna, this would correspond to increasing the range only from 4.1 m up to 6.1 m for the same increase in power. This undoubtedly shows that by integrating UHF chip into the proposed antenna, it is possible to increase the reading range up to 10 m compared to the maximum range of 7 m by using conventional inlay antenna. The results have demonstrated that the new RFID tag, deployed in the measurements, seems to have better performances in terms of reading range compared to existing conventional inlay antenna.

5. CONCLUSION

A new multi-band antenna for RFID applications is proposed in this paper. The proposed antenna is designed with the capabilities of functioning simultaneously with two different types of RFID modes, active and passive modes. A single-band of basic V-shaped antenna combined with the concept of dipole antenna has given V-shaped antenna ability to operate in multi-band frequency. By integrating a chip into the multi-band proposed antenna, the passive and active RFID tags are invented with two different operating frequencies (915 MHz and 2.45 GHz). The ultimate goal of this research is to achieve optimal reading range between RFID reader (with transmission power of 2 watts) and passive RFID tag.

It is found that the antenna gain of RFID has significant effects on reading range performance. The proposed antenna has a higher gain, thus it has contributed to the reading range up to 10 m compared to the traditional inlay antenna which is only 5 m. It is revealed that with the same signal strength of RFID reader, the higher gain of RFID tag (receiver) results in a better reading range than lower gain of inlay antenna. The proposed antenna, which has a shape of four-sided figure with a width of 100 mm and length of 70 mm, can be considered as a compact-size antenna.

The size of the proposed antenna is also tremendously reduced, compared to the size of the existing antennas. With all the demonstrated capabilities, the proposed system has great potentials and seems to be a better alternative than the conventional switching beam array (SBA) antenna.

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