Research Article

A Broadband Circularly Polarized Stacked Probe-Fed Patch Antenna for UHF RFID Applications

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A broadband circularly polarized stacked probe-fed antenna suitable for UHF RFID applications is presented and studied. The proposed antenna is fed by two probes which are connected to a hybrid coupler. Two parasitic patches are stacked above a primary probe-fed patch to enhance the bandwidth of the antenna. The optimized antenna prototype achieves gain of more than 6.5 dBic, axial ratio of less than 3.0 dB, and return loss of less than -15 dB over the UHF band of 820–980 MHz (17.7%). Parametric studies are carried out to demonstrate the effects of antenna geometry parameters on the performance. The proposed antenna can be a good candidate for UHF RFID applications.

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1. INTRODUCTION

Radio frequency identification (RFID) technology has been rapidly developing in recent years and the applications have been found in many service industries, distribution logistics, manufacturing companies, and goods flow systems [1, 2]. The range and the scalability of RFID systems are strongly dependent on the operating radio frequency of the systems. The operating frequency can significantly affect reading distance, data exchange speed, interoperability, and so on.

However, the coexistence of the RFID systems with other existing radio systems, such as mobile phones, wireless local area networks, and marine/aeronautical radio systems, significantly restricts the range of operating frequency available for the RFID systems. As a result, only the frequencies that have been reserved specially for the ISM (industrial, scientific, medical) bands can be used. Due to the merits of high data transfer rate and long detection range, passive RFID systems at ultra high-frequency (UHF) band are preferred in many applications. However, there is not a UHF range worldwide accepted for RFID applications. For instance, the frequency range for UHF RFID application is 902–928 MHz in North America (USA, Canada) and South America (Brazil, Argentina, etc.), and 865.5–867.6 MHz in Europe (Finland, Germany, France, Italy, Sweden, UK, etc.). In Asia-Pacific, the UHF RFID frequency ranges from 840 MHz to 954 MHz in different countries/regions: 840.5–844.5 MHz, 920.5–924.5 MHz in China, 952–955 MHz in Japan, 865–867 MHz in India, 865–868 MHz, 920–925 MHz

in Hong Kong, 908.5–910 MHz, 910–914 MHz in Korea, 866–869 MHz, 923–925 MHz in Singapore, 920–926 MHz in Australia, and so on. In short, the UHF used for RFID systems spans the range of 840–960 MHz. Therefore, a reader antenna covering whole RFID UHF band is conducive to system configuration, system implementation, and cost reduction.

This paper presents a broadband circularly polarized stacked probe-fed patch antenna for UHF RFID applications. The antenna is designed to cover entire RFID UHF band of 840–960 MHz with desired specifications such as high gain, low axial ratio (AR), and good impedance matching. The design is optimized and validated by measurement. The parametric studies provide the engineers with information to design and modify such an antenna.

2. ANTENNA DESIGN AND RESULTS

The challenges of the RFID reader antenna design lie in having a good impedance matching, low axial ratio, and high gain with the constraints of size and cost. Many types of antennas can generate circularly polarized radiation, wherein patch antenna is one of the most commonly used. To achieve circularly polarized radiation, the patch antenna can be fed either with a single strip line, a coaxial line, or a power splitting network to excite two orthogonal patch modes in phase quadrature [3, 4]. In this proposed design, a hybrid coupler is used to form a feeding network for the circular polarization radiation.

FIGURE 1: Geometry of the stacked patch antenna: (a) snapshot of proposed antenna; (b) schematic top view; (c) schematic side view.

The configuration of the proposed antenna is shown in Figure 1. The antenna is composed of a branch line hybrid coupler which is etched on an FR4 substrate ($\epsilon_r = 4.4$, $\tan \delta = 0.02$, thickness = 0.8128 mm), and three radiators which are all made of brass. The hybrid coupler has four ports. Port 1 is fed by RF signal, port 2 is loaded by a 50 Ω resistor, and port 3 and port 4 are used to excite the primary patch radiator. Such a feeding network features the high isolation between two feed ports and less reflection to the RF signal port because the power reflected from a mismatched antenna is absorbed by the resistive load. The primary radiator (patch 1, 150 mm $\times$ 150 mm, 0.5 mm thick) is fed by two feeding probes which are connected to the output ports of the hybrid coupler, that is, port 3 and port 4, respectively. The feed points are positioned symmetrically with the square patches with a distance d of 18.5 mm away from the edge of the primary patch. The height of the feeding probes is 10 mm and the diameter is 2.2 mm.

To further improve the bandwidth, two more 0.5 mm thick square brass patches (138 mm $\times$ 138 mm, 130 mm $\times$

FIGURE 2: Measured and simulated return losses of the proposed antenna.

130 mm) are stacked over the primary patch with separation of $h_2 = h_3 = 5$ mm [5]. Referring to the configuration shown in Figure 1, the proposed antenna will generate a left-hand circularly polarized (LHCP) radiation. A right-hand circularly polarized (RHCP) radiation can easily be achieved by interchanging hybrid coupler's RF in and loading ports. The proposed antenna was designed with the aid of IE3D software, which is based on the method of moments [6].

Based on the optimization by IE3D, the proposed antenna was fabricated and measured. The measurement was conducted in an anechoic chamber using an Agilent 8510C vector network analyzer (VNA) and a Midas 4.0 antenna measurement system.

Figure 2 shows that the measured return loss of the proposed antenna is less than -15 dB over 800 MHz to 980 MHz. Figure 3 depicts that the measured gain is more than 6.5 dBi over 800 MHz to 980 MHz. There is a frequency shift of about 30 MHz for measured return loss and gain with respect to simulated results, which may be mainly caused by the fabrication tolerance as well as the possible uncertainty of in-house antenna assembly. In addition, the inaccuracy of the numerical mode used in the commercial simulator is the possible cause as well because of the 3-dimensional structure with finite-size dielectric substrate. The measured 3 dB axial ratio shown in Figure 4 covers the range of 820–1000 MHz and the axial ratio is lower than 2.6 dB across 860–960 MHz. The measured radiation patterns for the proposed antenna in the x - z and y - z planes at 867 MHz, 915 MHz, and 954 MHz are shown in Figure 5. The normalized radiation patterns show symmetry and wide angular circular polarization performance especially in x - z plane where the angle for 3 dB axial ratio is up to 90° . The 15 dB front-to-back ratio is achieved in both planes at all frequencies.

FIGURE 3: Measured and simulated gains of the proposed antenna.

FIGURE 4: Measured and simulated axial ratios of the proposed antenna.

3. PARAMETRIC STUDIES

The parametric studies were carried out to provide antenna engineers with the information for antenna design and optimization. The performance of the proposed antenna is mainly determined by the characteristics of the hybrid coupler, the feeding probes, the configuration of the radiators including dimensions and separations of the stacked patches, and the size of the ground plane. The hybrid coupler has been well studied by others so that we will not discuss it in this paper, but we would instead focus on the effects of the feeding probes, the stacked patches, and the ground plane on the performance of the antenna. The studies were conducted using

IE3D. Each physical attribute of the antenna is independently varied, while all other parameters are kept unchanged.

3.1. The effect of the feeding probes

As shown in Figure 1, the parameters related to the feeding probes are their position (d , m) and diameter (D). Figures 6–9 show the effects of these parameters on the impedance matching. As shown in Figure 6, the impedance matching is hardly changed with varying d . It suggests that the location of the feeding probes is not critical (of course they are required to be positioned symmetrically with the patch) for impedance matching, which offers more tolerance for feed points positioning.

Figure 7 shows the effects of the strip line extension (m) on the impedance matching. The larger extension of the strip lines exhibits a wider bandwidth for specific impedance matching since the lower edge of the operating frequency band is shifted down while the higher edge is kept unchanged. The return loss of the proposed antenna with different probe diameters is exhibited in Figure 8. The probe diameter does not affect the impedance matching at the lower frequencies, while the higher frequencies are shifted up as the diameter increases, and thus the impedance matching bandwidth is slightly widened. It is found that the dimensions of the feeding probes hardly affect the gain and axial ratio of the antenna. For brevity, the results are not shown here.

3.2. The effect of the patches

Figure 9 illustrates the effect of the height of the primary patch, h_1 , on the antenna performance. Figure 9(a) shows the return loss of the proposed antenna against h_1 . It is obvious that the frequency band for impedance matching is shifted down when h_1 increases. From Figure 9(b), it is seen that h_1 has much impact on the gain performance of the proposed antenna. Higher primary patch broadens bandwidth of the gain especially at the lower frequency and offers flatter gain response. A similar effect on the axial ratio performance is observed as shown in Figure 9(c). Increasing h_1 is an effective way to enhance the gain and axial ratio bandwidth of the antenna. However, it should be noted that larger h_1 mainly contributes to the overall height of the antenna. It is necessary to make a tradeoff between gain, axial ratio, and height of the antenna in practical design.

Figure 10 illustrates the effect of the height of the first stacked patch, h_2 , on the antenna performance. Figure 10(a) shows the return loss of the proposed antenna against h_2 . It is observed that the bandwidth for impedance matching is unchanged when varying h_2 . The h_2 shows the effect on antenna gain especially at higher frequencies as shown in Figure 10(b). Smaller h_2 shifts up the upper edge of the operating frequency band but degrades the gain flatness over the band. Figure 10(c) demonstrates the effect of h_2 on axial ratio; narrow bandwidth with better axial ratio over the band is observed for larger h_2 . Decreasing h_2 raises the higher frequencies and results in worse axial ratio performance. It is concluded that varying h_2 is helpful for optimizing gain and axial ratio over specified frequency bandwidth.

FIGURE 5: Measured radiation patterns of the proposed antenna.

FIGURE 6: Effect of the position of the feeding probes on impedance matching.

FIGURE 8: Effects of varying diameters of the feeding probes on impedance matching.

FIGURE 7: Effect of varying extensions of the feed lines on impedance matching.

Figure 11 illustrates the effect of the height of the second stacked patch, h_3 , on the antenna performance, which is similar to that of h_2 . However, compared to h_2 , h_3 shows less impact on the antenna as the second stacked patch is further separated from the primary patch and contributes less to the overall antenna radiation.

The effect of the size of the patches on the performance of stacked patch antennas has already been discussed by Rowe et al. [7] and therefore it is not covered here.

3.3. The effect of the ground plane

The effect of the size of the ground plane on the antenna performance is illustrated in Figure 12. Figure 12(a) shows

the return loss of the proposed antenna with respect to ground planes with different dimensions. The best return loss performance is achieved for adequate ground plane size ($L = W = 250$ mm); bigger or smaller ground planes degrade impedance matching of the antenna. The gain response of the antenna against ground planes with different dimensions is shown in Figure 12(b). As expected, higher gain is achieved for the antenna with bigger ground plane, and more increase of gain is observed at lower frequencies. As shown in Figure 12(c), the best axial ratio of the antenna is achieved with the adequate ground plate dimensions ($L, W = 250$ mm); other ground planes with different dimensions can broaden the bandwidth of the axial ratio of the antenna in one way or another. However, the axial ratio is degraded within the operating frequency. In conclusion, the size of ground plane shows observable effect on the antenna performance; it can be used to optimize the antenna for achieving required specifications.

4. CONCLUSION

In this paper, a broadband circularly polarized stacked probed-fed patch antenna has been proposed for UHF RFID applications. The measurement has showed that the optimized antenna can cover the UHF band of 820–980 MHz (17.7%) with gain of more than 6.5 dBic, axial ratio of less than 3.0 dB, and return loss of less than -15 dB. Therefore, it is suitable for the UHF RFID reader antennas operating within the UHF band of 840–960 MHz.

Moreover, the parametric studies have addressed the effects of the height of the patches, the locations of the feeding probes, and the size of the ground plane on the performance of the antenna. It has been found that the height of the primary patch has the largest effect on the performance of the proposed antenna, while the effects of the locations

(a)

(a)

(b)

(b)

(c)

(c)

FIGURE 9: Effect of the height of the primary patch on the performance of the proposed antenna: (a) return loss; (b) gain; (c) axial ratio.

FIGURE 10: Effect of the height of the first stacked patch on the performance of the proposed antenna: (a) return loss; (b) gain; (c) axial ratio.

FIGURE 11: Effect of the height of the second stacked patch on the performance of the proposed antenna: (a) return loss; (b) gain; (c) axial ratio.

FIGURE 12: Effect of the size of the ground plane on the performance of the proposed antenna: (a) return loss; (b) gain; (c) axial ratio.

and dimensions of the feeding probes are very limited. Adequate size of the ground plane is helpful for optimizing the antenna for achieving specific design requirements. The information presented in this paper will be helpful for antenna engineers to design and optimize the antenna for UHF RFID applications.

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