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REFERENCES


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A multi-functional tri-mode patch antenna supporting dual-band GPS and wireless communication system

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Abstract
This letter presents a trimode multi-functional patch antenna for GPS and wireless communication applications. The antenna consists of a folded annular slot, a section of coaxial cable, shorting copper columns and the ground plane. Tri-band operation is realized by exciting three different working modes including microstrip antenna mode, slot antenna mode and monopole antenna mode. The proposed antenna is designed to cover the GPS L1 and L2 bands, UMTS-band 5. At the GPS bands, the antenna is
1 | INTRODUCTION

Because of the rapid development of wireless communication, multi-functional wireless systems supporting several services integrated into one operating unit are highly desired. To reduce the number and volume of the antennas in multi-functional systems, multiband antennas are required. Many multiband antenna designs reported in previous literatures have similar radiation characteristic including radiation pattern and polarization in each operation band. However in different systems, the required radiation characteristics are not always similar. For example, the global position system (GPS) requires right hand circularly polarization (RHCP) unidirectional antenna to receive signal from satellites with multipath mitigation capability, while omnidirectional antennas are in demand in wireless communication systems to provide wide signal coverage. Therefore antennas with different radiation characteristic are desirable for multi-functional systems.

To generate different radiation patterns and polarizations in multi-frequencies, the structures of multiple radiation elements are used. The coplanar annular ring patch antenna with air substrate \((\varepsilon_r = 1)\) and truncated square patch antenna printed on ceramic substrate \((\varepsilon_r = 15.5)\) are designed to cover GPS L1 and DCS bands in Ref. [1]. The annular ring patch antenna working at TM_{21} mode for linear polarized (LP) conical beam, while the fundamental mode truncated square patch antenna provides broadside circularly polarized (CP) radiation. Stacked patch antenna is another approach to design such antennas. Multiple patches are stacked together to generate different radiation patterns and polarizations at the multi-frequencies.

Beside the multi-elements design approach, using the different modes with different radiation patterns and polarizations of a single radiator are also reported. The antenna designs in Refs. [6–8] are fed with a single port. It is relatively difficult to use a single feed to excite multiple radiators, however the single radiator working at multimodes can be excited by one feeding port.

From these previous designs in literatures, most of multi-functional antennas with different radiation characteristic are dual-band. It seems relatively difficult to design single feed multi-frequency antenna with different radiation characteristic supporting three working frequencies. Although the design in Ref. [8] presents a single feed trimode antenna, active switches are used.

In this letter, a novel single-feed trimode patch antenna is proposed for GPS and telecommunication band. The tri-band radiation characteristic is achieved by exciting three different modes. Moreover, at GPS L1 and L2 bands, the antenna is unidirectional and RHCP, while the antenna is omnidirectional and LP at UMTS-band 5 telecommunication band.

2 | ANTENNA GEOMETRY AND DESIGN PROCESS

2.1 | The antenna geometry

The geometry of the proposed antenna is shown in Figure 1. The values of the design parameters are listed in Table 1. This antenna consists of a folded annular slot, coaxial cable, shorting copper columns and ground plane. The FR4 substrate is used in this antenna design with a relative permittivity of 4.4, a loss tangent of 0.02 and a thickness of 1 mm. The folded annular slot is printed on the bottom of the FR4 square substrate and microstrip feeding structure with two perpendicular branches is printed on the top. The ground plane with size of \(G \times G\) is placed under the FR4 slab. A section of rigid 50 \(\Omega\) coaxial cable, located in the center of antenna, passes through the ground plane to feed the slot radiator. The shorting copper columns are placed surrounding the coaxial cable and in parallel to it. The inner conductor of coaxial cable is welded with the microstrip feeding structure, while, the outer conductor of cable and the copper columns are connected with both the ground and the rear metal surface of the RF4 substrate. The number of copper columns is \(N\), the diameter is \(D_c\) and the distance between column center and coaxial cable center is \(R_c\). These shorting metal columns play an important role in altering the antenna performance. They act like inductances to constitute and tune the resonant mode at telecommunication band.

2.2 | The working principle of the monopole mode

The design evolution of the proposed antenna is shown in Figure 2. We first model the structure of the antenna I, shown in Figure 2, with the use of High Frequency Structure Simulator (HFSS v.14). This antenna is the initial design of the proposed antenna. Similar to the antenna design in Ref. [9], antenna I can work at both the microstrip mode and the slot mode. As a matter of fact, beside those two modes, antenna I can work at monopole mode at lower frequency.
band. Figure 3 shows the working principle of the antenna at monopole mode. The upper radiation patch are connected with the ground plane by the outer conductor of the coaxial cable. Normally, the height of the monopole antenna is a quarter wavelength. By loading the capacitance provided by the radiation patch and the inductance provided by the coaxial cable, the height of the monopole is greatly decreased. The simulated resonant frequency of the monopole mode of antenna I is 650 MHz, and the distance between ground plane and radiation patch is 0.054 $\lambda_0$ ($\lambda_0$ is the wavelength in free space at 650 MHz). Figure 4 shows the simulated radiation pattern at 650 MHz. The antenna is omnidirectional and LP which indicates that the antenna work at monopole mode. In antenna I, the outer conductor diameter of the semi-rigid coaxial cable is chosen to be 2.2 mm (0.0865 In), which matches the standard copper 50 $\Omega$ semi-rigid UT-085 cables.

### 2.3 Frequency tuning of the monopole mode

The effect of coaxial cable is studied, and it is found out that it can tune the resonant frequency of the monopole mode. As shown in Figure 2, the diameter of the coaxial cable in antenna II is enlarged and the characteristic impedance of cable is fixed to be 50 $\Omega$. The simulated $S_{11}$ with respect to different cable diameters are superposed in Figure 5. When the diameter of the coaxial cable $D$ increases from 4 to 8 mm, the resonant frequency of monopole mode shifts from 735 to 825 MHz, which indicates that the working band at lower frequency is influenced significantly by the diameter of coaxial cable. Because of the inductance introduced by the outer conductor of cable decrease, the resonant frequency is decreased simultaneously. The simulation results also show that, the diameter of coaxial cable can hardly change.

<table>
<thead>
<tr>
<th>Table 1: Design Parameters of the Proposed Antenna</th>
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<tr>
<td>$G = 150$ mm</td>
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<tr>
<td>$a = 6.5$ mm</td>
</tr>
<tr>
<td>$W_f = 0.65$ mm</td>
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<tr>
<td>$R_s = 4.5$ mm</td>
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the working frequencies of the two higher bands. Therefore the resonant frequency of the lowest band can be altered independently.

The 850 MHz telecommunication bands are desired in this design and the diameter of coaxial cable should be

**FIGURE 4** The radiation pattern of the monopole mode (Antenna I at 650 MHz)

**FIGURE 5** Simulated $S_{11}$ of Antenna II in Figure 2 with different coaxial cable diameter D. [Color figure can be viewed at wileyonlinelibrary.com]

**FIGURE 6** Simulated $S_{11}$ of antenna III

**FIGURE 7** Prototype of proposed tri-band antenna. (A) side view, and (B) the assembled antenna under test in the anechoic chamber. [Color figure can be viewed at wileyonlinelibrary.com]

**FIGURE 8** Simulated and measured $S_{11}$ of the proposed antenna. [Color figure can be viewed at wileyonlinelibrary.com]
larger than 8 mm to cover it. However, the custom-made coaxial cable will increase the cost and assemble complexity. To overcome this problem, antenna III is proposed, and metal columns are introduced as shown in Figure 2. By arranging the metal columns parallel to the cable, four additional equivalent inductances introduced by the columns are connected in parallel with the equivalent inductance introduced by the coaxial cable, and the total inductance will decrease. According to the analysis before, the decrease of the inductance will lead to the increase of monopole mode resonant frequency.

The simulated result of antenna III is shown in Figure 6. As expected, the resonant frequency of monopole mode is tuned to be 850 MHz successfully by loading four copper columns.

**FIGURE 9** Simulated and measured AR of the proposed antenna. [Color figure can be viewed at wileyonlinelibrary.com]

**FIGURE 10** Simulated and measured radiation patterns at (A) 0.85 GHz, (B) 1.227 GHz, and (C) 1.575 GHz
3 | MEASURED RESULT AND DISCUSSION

To verify the design concept, a prototype of the proposed antenna was fabricated, as shown in Figure 7. A section of 50Ω UT-085 copper semi-rigid coaxial cable which has an outer copper diameter of 2.2 mm, and four copper columns with diameter of 2 mm are used in the prototype. The $S_{11}$ is measured with the WILTRON 37269A vector network analyzer. The axial ratios, antenna gains and radiation patterns are evaluated in an anechoic chamber using the SATIMO near field antenna measurement system.

The simulated and measured $S_{11}$ results are shown in Figure 8. The measured 3:1 VSWR band ($S_{11} < -6$ dB) at the lowest band are 105 MHz (804–909 MHz), and the measured $-10$ dB $S_{11}$ working bands at dual higher bands are 1.20–1.35 GHz and 1.50–1.81 GHz. Meanwhile two measured 3 dB AR bandwidth are 45 MHz (1.205–1.25 GHz) and 80 MHz (1.555–1.635 GHz) as shown in Figure 9. Reasonable agreement between measurement and simulation are observed. Small discrepancies between the measured and simulated results are due to cable effects, assembly and fabrication imperfection.

The simulated and measured radiation patterns at 0.85, 1.227, and 1.575 GHz are plotted in Figure 10. The antenna radiates omnidirectional LP wave at 850 MHz. The $E$ plane of antenna is 8-shaped, the $H$-plane is omnidirectional. At two higher bands, the proposed antenna is broadband unidirectional and RHCP. The measured antenna gains at those three frequencies are 0.2, 7.5, and 8.0 dBi, respectively.

4 | CONCLUSIONS

A novel tri-mode, tri-band antenna with linear and circular polarizations, omnidirectional and unidirectional radiation patterns is demonstrated for dual-band GPS and wireless commutation multi-functional system. This antenna is based on author’s previous dual-band unidirectional CP antenna design. An additional monopole mode is introduced to achieve omnidirectional LP radiation in communication band while two unidirectional radiation CP bands are maintained for dual-band GPS. The method of independently tuning the frequency of additional monopole mode are derived from analyzing the working principle of the monopole mode. The annual slot mode, microstrip patch antenna mode, and monopole antenna modes are elaborately used in our new antenna design, and dual GPS band (L1, L2), UMTS-band 5 (824–894 MHz) communication band are successfully covered. Measured results show that the proposed antenna has three working band of 804–909 MHz, 1.205–1.25 GHz, and 1.555–1.635 GHz. At telecommunication band, the omnidirectional radiation pattern is obtained, which can cover all 360° azimuthal angles and provide wide signal coverage. At two GPS bands, RHCP unidirectional radiation patterns for receiving GPS satellites signal are acquired. The different radiation patterns in different bands can fulfill the requirements of GPS and mobile communication multi-functional system.

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REFERENCES


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