Stacked-Patch Dual-Polarized Antenna for Triple-Band Handheld Terminals

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***Abstract*—In this letter, a novel design of a stacked-patch triple-band antenna in both circular and linear polarizations that can be used on a handheld terminal for surveying and geo-informatics applications is presented. The inculcation of corner truncation and I-slot in both the lower and middle patches has achieved better impedance bandwidth and axial ratio at GPS L1, L2, and GSM 1800 resonant frequency bands. A prototype of the proposed design is fabricated, and its performance is verified in measurement.**

***Index Terms*—Axial ratio (AR), differential global positioning system, dual-polarized, Global System for Mobile Communications (GSM).**

I. Introduction

The GROWING demand of more accurate timing and positioning information using Global Positioning System (GPS) has increased research and development needs in this area. GPS L1 frequency (1.575 GHz) has been used in most of the handheld devices for survey and geo-information applications. It has found its way into various automotive devices as well. For example, the GPS L1 frequency band and GPS L2 (1.227 GHz) frequency band for Differential GPS (DGPS) are used to achieve a higher positioning accuracy with less than 10 cm error margin [1]. The integration of GPS L1 and L2 bands with terrestrial wireless communication networks such as Global System for Mobile Communications (GSM 1800) can boost the dissemination of data from the information sources and the transaction stations. Prompt evaluation with accuracy in timing and position can be obtained by such terminal users.

A system that is capable of exploiting the available wireless functionalities demand an antenna operating in different frequency bands. However, the coexistence of more antennas in a limited space generates the mutual coupling and has a negative effect on the performance of the system. A single antenna with multifunction and multiband operation can solve this problem effectively.

A number of studies have been reported in the literature that propose antenna designs with dual-band operation covering GPS L1 and mobile communication frequencies [2]–[9]. For example, low-cost radiating stacked wire-patch GSM antenna with an active corner truncated GPS printed element is presented in [5]. Two different ground planes are used for this proposed antenna. Kevin *et al.* presented a dual stacked-patch antenna for GPS L1 and satellite digital audio radio systems (SDARS) in [6]. The antenna supports dual polarization: right-hand circular polarized (RHCP) at GPS L1 band, while left-hand circular polarized (LHCP) at SDARS band. A high-permittivity substrate is used to reduce the patch size. An integration of monopoles and Archimedean spiral antenna has been proposed in [7] to achieve GPS, GSM/GPRS/COSPAS-SARSAT frequency bands. In [8], a combination of corner truncated square-ring patch antenna with air substrate for GPS L1 band and a monopole for Universal Mobile Telecommunication Systems (UMTS) produces both circular and linear polarized radiation patterns. A stacked structure is used to realize the dual-band frequency for the applications of GPS/Digital Cellular Service (DCS) in [9]. The truncated square patch for the GPS operates in the fundamental mode, while the annular ring patch used to generate the DCS operates in the TM_{21} mode. The antenna is connected to the dual feeds coupled with four slots embedded in the ground plane, which effectively increases the impedance bandwidth and lowers the resonant frequency. These studies only deal with dual-band antennas combining GPS L1 with a mobile communication frequency band.

In [10], a triple-stacked microstrip patch antenna is built to achieve a triple-band operation for cellular phone, GPS, and Personal Communications Service (PCS). The first and third patches produce the upper frequency bands (GPS and PCS), while the middle patch generates the lower frequency band (cellular phone). An aperture-coupled feed technique is used with a thicker foam material (10.16 mm) to achieve a broader impedance bandwidth. A multiband stacked patch antenna employing five radiating patches is presented in [11]. The ground plane size is 220×180 mm^2 while the largest patch element size is 80×80 mm^2. Triple patches placed side by side are used to achieve multiband by utilizing a microstrip-fed technique [12]. The first patch is directly connected to the microstrip feed, while the other two patches are electromagnetically coupled. The complexity of the feeding systems and the use of high-permittivity dielectric materials in these antennas reduce the gain. It affects the performance of these antennas and reduces the efficiency of handheld terminals. Also, the size of these antennas makes them too big for compact handheld terminals.

This letter presents a novel design of a single-feed, stacked-patch, triple-band, dual-polarized antenna for the operation in GPS L1 and L2 and GSM 1800 band. The GPS performance

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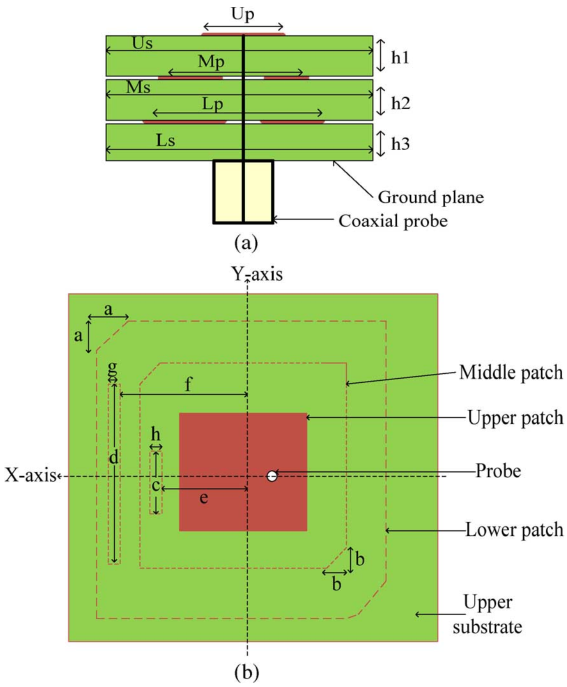


Fig. 1. Geometry of the proposed stacked-patch, triple-band, dual-polarized antenna. (a) Configuration of the antenna. (b) Top view of the antenna.

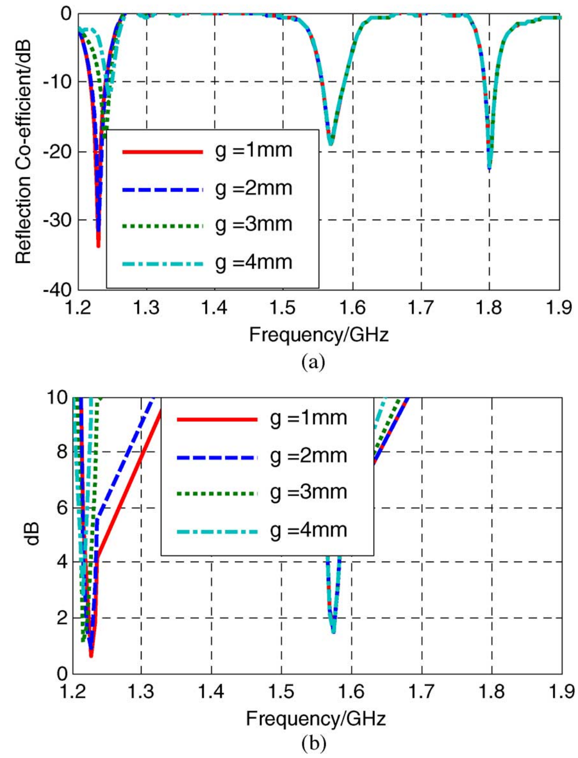


Fig. 2. Variation of the antenna parameters for different values of breadth g of I-slot in the lower patch: (a) reflection coefficient and (b) axial ratio.

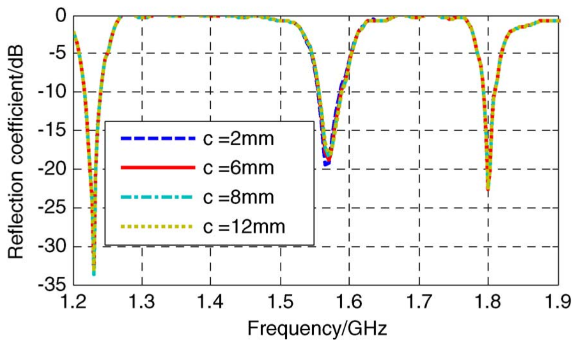
in both L1 and L2 bands has a circular polarization (CP) with a broadside radiation, pattern while a linear polarization (LP) is achieved in GSM 1800 band. The compactness, simplicity, and distinct frequency bands make this proposed antenna quite suitable for handheld terminals. The letter is organized as follows. Section II describes the antenna configuration and analysis, while Section III presents the experimental results and discussion. The conclusions are drawn in Section IV.

II. Antenna Configuration and Analysis

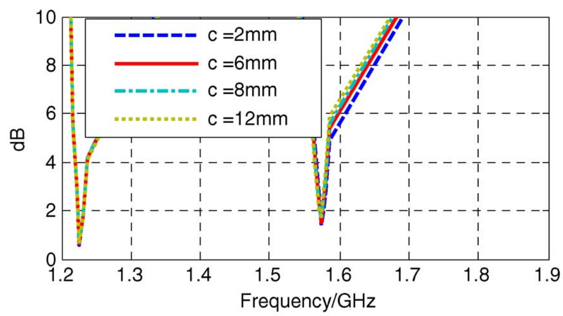
The configuration of the proposed dual-polarized antenna is shown in Fig. 1. This antenna is made up of three stacked radiating elements. The three square patches are etched on the same side of an inexpensive FR4 substrate with thickness of $h1 = h2 = h3 = 1.6$ mm and relative permittivity of 4.4. The lower patch is used for producing the GPS L1 band, the middle patch for the GPS L2 band, and the upper patch for the GSM 1800 band. A slot is used in the lower and middle patches that serves two purposes. First, it lengthens the surface current path of the antenna and thus lowers the resonant frequency by lowering the physical length of the patch [13]. Second, it is used to improve axial ratio (AR) due to the resonant degradation of a singly fed patch antenna [14]. The lower and middle square patches are corner truncated to generate the CP broadside radiation patterns. The upper patch without corner truncation gives a linear polarized pattern required for the GSM system. A single probe (radius 0.65 mm) of 50 Ω input impedance is connected to the upper patch through via holes in the lower and middle patches. The lower and middle patches are electromagnetically coupled to the probe.

In order to be able to predict the antenna performance, extensive optimizations are conducted using the finite integral techniques (FIT)-based electromagnetic (EM) simulation. The commercial Computer Simulation Technology (CST) Microwave Studio package is used for the analysis [15]. For the operating frequencies 1.227 GHz (RHCP), 1.575 GHz (RHCP), and 1.800 GHz (LP), the square patch size is 55.3 mm for the lower patch (Lp), 43.0 mm for the middle patch (Mp) and 39.6 mm for the upper patch (Up) respectively, while the via hole diameter for the lower patch and middle patch is 3.6 and 4.0 mm. The sensitivity of the antenna performance on the resonant frequency and axial ratio are investigated with the change of the I-slot size and position in respect to the x-axis and y-axis in the lower and middle patch. Fig. 2 shows the effect of the I-slot breadth, g, of the lower patch on the reflection coefficient and the axial ratio of the antenna. It can be observed that as the I-slot breadth decreases, the resonant frequency decreases while the bandwidth increases. This mainly affects the lower frequency band with little or no effect on the middle and upper frequency band. The axial ratio improves as the breadth decreases and coincides with the centre frequency of the lower-band frequency. No effect is observed on the axial ratio of the middle frequency band. Similar effect was observed in the I-slot breadth h of the middle patch. The effect of the I-slot length c in the middle patch is shown in Fig. 3. When the length c increases, the resonant frequency also increases with a reduction of the return loss by 1 dB. The axial ratio improves as the length c decreases at the detriment of return loss. The optimum length $c = 6$ mm gives the best axial-ratio bandwidth for this middle frequency band.

There is no significant effect on the lower and upper frequency bands. Similar effect is observed in the I-slot length d of the lower patch. From these studies, it can be deduced that the

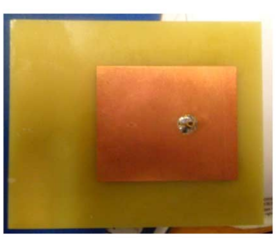


(a)



(b)

Fig. 3. Variation of the antenna parameters for different values of length c (middle patch I-slot): (a) reflection coefficient and (b) axial ratio.


(a)

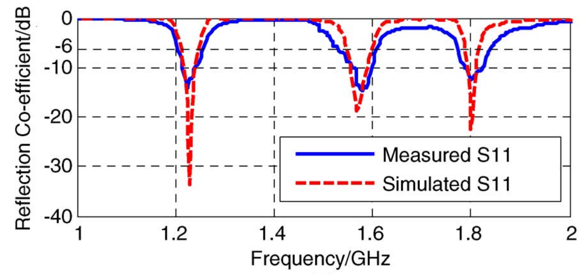

(b)

Fig. 4. Fabricated prototyped stacked-patch, triple-band, dual-polarized antenna: (a) top view and (b) bottom view.

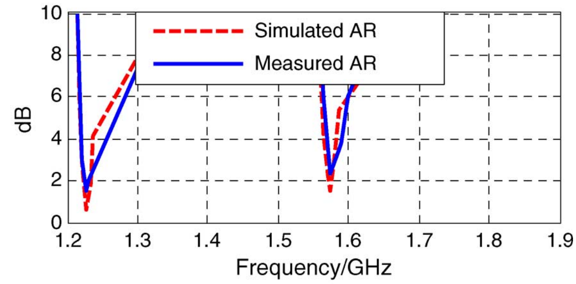
lower and middle patch operates independently with the inclusion of the I-slot. The optimized dimensions for the lower and middle I-slot are "$d \times g$" $=$ 29.2 mm $\times$ 1 mm and "$c \times h$" $=$ 6 mm $\times$ 1 mm. Other parameters used for the final design of this antenna are $a = 5.7$ mm, $b = 4.9$ mm, $f = 25.0$ mm, and $e = 16.0$ mm, while the ground plane size is 70×70 mm^2. The size of the ground plane can be reduced, but at the detriment of the antenna gain, efficiency, and large backlobe in the radiation pattern.

III. Experimental Results and Discussion

The antenna prototype is fabricated as shown in Fig. 4, using optimized dimension and tested in the Antenna Measurement Laboratory at Queen Mary University of London. The return loss is measured using Agilent vector network analyzer N5230C PNA-L while the radiation patterns are evaluated in the anechoic chamber. The simulated and measured reflection coefficient are shown in Fig. 5(a). A good agreement between the two results is observed. Small discrepancies between the middle frequency band (GPS L2) and the upper frequency band (GSM 1800) are attributed to fabrication errors. The measured minus 10 dB impedance bandwidth in the GPS L1 and L2 bands are 1.215–1.241 GHz (26 MHz) and 1.560–1.598 GHz (38 MHz) respectively; while the measured minus 6 dB impedance bandwidth at GSM 1800 band is 1.771–1.846 GHz (75 MHz). The measured and simulated axial ratio of the proposed antenna is presented in Fig. 5(b). The $\leq$3 dB axial ratio bandwidth at GPS L1 and L2 frequency band is 1.6% (1.220–1.240 GHz) and 0.8% (1568–1.580 GHz) respectively.



(a)



(b)

Fig. 5. Measured and simulated reflection coefficient and axial ratio of the proposed antenna: (a) measured and simulated reflection coefficient and (b) measured and simulated axial ratio.

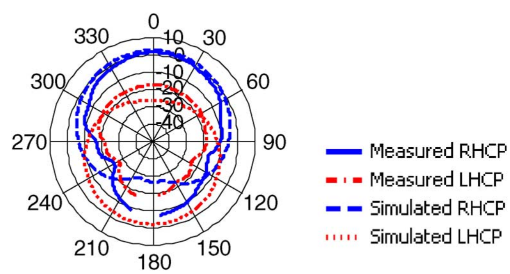


Fig. 6. Measured and simulated RHCP and LHCP radiation patterns in xz-plane of the proposed antenna at 1.227 GHz.

The measured and simulated radiation patterns in xz-plane for the proposed antenna at 1.227 and 1.575 GHz are shown in Figs. 6 and 7, respectively. The RHCP pattern is stronger than the LHCP pattern by more than 20 and 18 dB at both frequency bands in the boresight direction. The right-hand backlobe is less than -20 dB, while the front-to-back ratios of the RH polarization is more than 25 dB. The measured and simulated linear radiation pattern at 1.8 GHz in the xz-plane is presented in Fig. 8. The measurement agrees well with the simulation, and the copolarization is about 16 dB higher than the cross polarization. The measured and simulated radiation efficiency of the antenna in the three bands is above 70% and 80%, respectively. The Cartesian plot of the axial ratio at 1.227 and 1.575 GHz depicts that

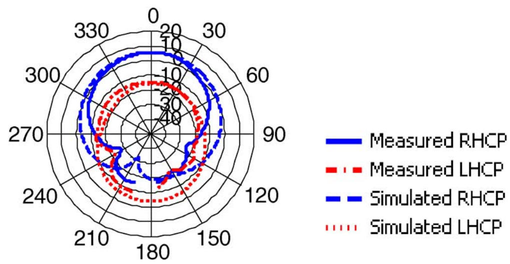


Fig. 7. Measured and simulated RHCP and LHCP radiation patterns in xz-plane of the proposed antenna at 1.575 GHz.

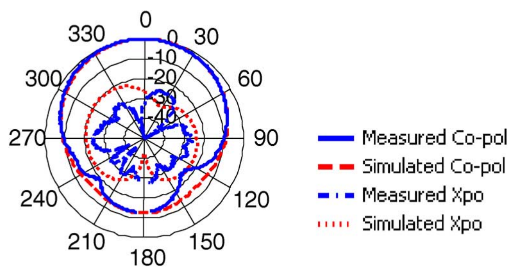


Fig. 8. Linear polarized radiation pattern at 1.8 GHz showing both the measured and simulated co- and cross polarization at xz-plane.

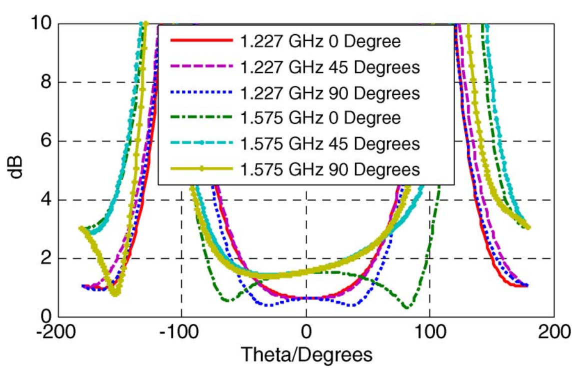


Fig. 9. Cartesian plot of the axial ratio of the proposed antenna at the boresight for 1.227 and 1.575 GHz at $\phi = 0°$, 45°, and 90°.

at the boresight, minimum axial ratio of 0.62 and 1.52 dB is achieved. At $\leq$3 dB axial ratio, the beamwidth is about 126° for $\phi = 0°$, 127° for $\phi = 45°$, and 190° for $\phi = 90°$ at 1.227 GHz. At 1.575 GHz, the axial-ratio beamwidth is 136° in $\phi = 0°$, 148° for $\phi = 45°$, and 148° in $\phi = 90°$ plane, as shown in Fig. 9.

IV. Conclusion

A novel compact triple-band, dual-polarized antenna with stacked patches for GPS L1, L2 and GSM 1800 bands has been proposed and investigated. The simulated results are verified in measurements. The antenna can operate in three distinct frequency bands with a desired performance through a design optimization. Good circular polarization with a broadside radiation pattern is achieved at the lower and middle bands, respectively, while a better linear polarized conical radiation pattern with low cross polarization is achieved at the upper operating frequency. The antenna can easily meet the required CP bandwidth of $\pm$2 MHz for the GPS L1 and L2 bands, while it provides a $-$6-dB impedance bandwidth of 75 MHz for the GSM 1800 band. Therefore, this antenna can work effectively in the mobile communication products that integrate satellite and terrestrial communications, such as GPS L1, L2 and GSM.

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