Stacked Patch Triple-band Dual-polarized Antenna for Handheld Terminals

ESA/ESTEC, Noordwijk, The Netherlands
3-5 October 2012

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ABSTRACT

This paper presents a novel design of a stacked patch triple-band antenna in both circular and linear polarizations that can be used in a handheld terminal for surveying and geo-informatics applications. The inculation 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 measured.

1. 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 accuracy with less than 10cm error margin in surveying systems [1]. The integration of GPS L1 and L2 band 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 system operating in different frequency bands. However, the co-existence 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 multi-band operation can solve this problem effectively and simultaneously.

A number of studies has been reported in the literature that propose antenna designs with dual-band operation covering GPS L1 and mobile communication frequencies [2-9]. For example, a 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. The GPS L1 is Right Hand Circular Polarized (RHCP) while the SDARS is Left Hand Circular Polarized. A high dielectric permittivity is used to reduce the patch size. An integration of monopoles and Archimedean spiral antenna has been used 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 and a monopole for 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/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 at the TM_{21} mode. The antenna is fed using dual-feed coupled with four slots embedded in the ground plane. It effectively increases the impedance bandwidth and lowers the resonant frequency. These studies only deals with dual-band antennas combining GPS L1 with a mobile communication frequency band. The complexity of the feeding systems and the use of high permittivity dielectric materials in these antennas reduces the gain. It affects the performance of these antennas and reducing the efficiency of handheld terminals.

This paper presents a novel design of a single feed, stacked patch, triple-band, dual-polarized antenna for the GPS L1, L2 and GSM 1800 operation. The GPS L1 and L2 band performance has a broadside circularly polarized radiation pattern while a linearly polarized working is achieved in GSM 1800 band. The compactness, simplicity and distinct frequency bands enable this proposed antenna a well suitable for handheld terminals. The paper is organized as follows: section II describes the antenna configuration and analysis, section III presents the experimental results and discussion. The conclusions are drawn in section IV.
2. ANTENNA CONFIGURATION AND ANALYSIS

The configuration of the proposed stacked patch dual-polarized antenna for GPS L1, L2 and GSM 1800 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 \( h_1=h_2=h_3=1.6\,\text{mm} \) and relative permittivity of 4.4. The lower patch is used to produce the GPS L1, the middle patch produces the GPS L2 and the upper patch for the GSM 1800. A slot is used in the lower and middle patches which 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 [10]. Second, it is used to overcome the challenge of poor axial ratio (AR) due to resonant degradation of singly-fed patch antenna [11]. The lower and middle square patches are corner truncated. They operate in the fundamental mode to generate circular polarized (CP) radiation pattern. The upper patch gives a linear polarized pattern required for a GSM system. A single probe (radius 0.65mm) feed of 50\(\Omega\) input impedance located along the x-axis is connected to the upper patch through via holes in the lower and middle patches. The lower and middle patches are electromagnetically coupled. The via holes in both the lower and middle patches introduces a capacitive coupling that reduced the inductance effect of the inner conductor of the probe.

In order to be able to predict the antenna performance, extensive optimization was conducted using the Finite Integral Techniques (FIT) based EM simulation. The commercial Computer Simulation Technology (CST) Microwave Studio software is used for the analysis [12]. For the operating frequencies 1.227 GHz (RHCP), 1.575 GHz (RHCP) and 1.800GHz (LP), the patches lengths are the lower patch (Lp) 55.3mm, middle patch (Mp) 43.0mm and upper patch (Up) 39.6mm respectively while the via diameter for both the lower patch and middle patch is 3.6mm and 4.0mm. The sensitivity of the element performance on the resonant frequency and axial ratio are investigated on the changes of the I-slot in the lower and middle patch. Fig. 2 shows the effect of the I-slot breadth, \( g \), of the lower patch on the reflection co-efficient 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 bands. 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.

![Figure 1: Geometry of the proposed stacked patch triple band dual polarized antenna (a) configuration of the antenna (b) top view of the antenna](image)

![Figure 2: Variation of the antenna parameters for different values of breadth \( g \) of I-slot in the lower patch: (a) reflection co-efficient and (b) axial ratio](image)
The optimized dimension for the lower and middle I-slot are \(d \times g' = 29.2\text{mm} \times 1\text{mm}\) and \(c \times h' = 6\text{mm} \times 1\text{mm}\). Other parameters used for the final design of this antenna are, \(a = 5.7\text{mm}\), \(b = 4.9\text{mm}\) while the ground plane size is \(70\text{mm} \times 70\text{mm}\). The size of the ground plane can be reduced further but at the detriment of the antenna gain, efficiency and large back lobe in the radiation pattern.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The antenna prototype is fabricated using optimized dimension and tested in the Antenna Measurement Laboratory at Queen Mary University of London. The fabricated prototype is shown in Fig. 3. The measured results are compared with simulated results. The return loss is measured using Agilent vector network analyzer N5230C PNA-L while the radiation patterns are evaluated in anechoic chamber. The simulated and measured reflection co-efficient are shown in Fig. 4(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 three frequency bands are 26MHz, 38MHz and 35MHz respectively. The simulated axial ratio in the broadside direction is presented in Fig. 4(b). The \(\leq 3\text{dB}\) axial ratio bandwidth at GPS L1 and L2 frequency band is 1.0% and 0.8% respectively.

The measured and simulated radiation patterns in xz-plane are shown in Fig.5 and 6 for the proposed antenna at 1.227GHz and 1.575GHz. The Right Hand Circular Polarization (RHCP) pattern is stronger than the Left Hand Circular Polarization (LHCP) pattern by more than 20dB and 18dB at both frequencies in the boresight direction. The right hand back lobe is less than -20dB while the front-to-back ratios of the RH polarization is more than 25dB. The measured and simulated linear radiation pattern at 1.8GHz in the xz-plane is presented in Fig. 7. The measurement agree well with the simulation and the co-polarization is about 16dB higher than the cross polarization.

![Figure 3: Fabricated prototyped stacked patch triple band dual polarized antenna: (a) top view (b) bottom view](image)

![Figure 4: Measured and simulated Reflection coefficient and axial ratio of the proposed antenna: (a) Measured and simulated reflection co-efficient and (b) simulated axial ratio](image)

![Figure 5: Measured and simulated RHCP and LHCp radiation patterns in xz-plane of the purposed antenna at 1.227GHz](image)

![Figure 6: Measured and simulated RHCP and LHCp radiation patterns in xz-plane of the purposed antenna at 1.575GHz](image)
The Cartesian plot of the axial ratio at 1.227 GHz and 1.575 GHz depicts that at the boresight, minimum axial ratio of 0.62 dB and 1.52 dB is achieved. At $\leq 3$ dB axial ratio, the beamwidth is about $126^\circ$ for $\phi=0^\circ$ and $190^\circ$ for $\phi=90^\circ$ at 1.227 GHz. At 1.575 GHz, the axial ratio beamwidth is $136^\circ$ in $\phi=0^\circ$ and $148^\circ$ in $\phi=90^\circ$ plane. These are shown in Figure 8.

4. CONCLUSION

A novel design of a compact stacked patch triple band dual polarized antenna for GPS L1, L2 and GSM 1800 bands has been presented. The simulated results are confirmed using measurements and a good agreement between two results is observed. Distinct frequency bands have been achieved with improved operational bandwidth and axial ratio in both simulation and measurements. A circular polarization with broadside pattern is radiated at the lower and middle band while a good linear polarized conical radiation pattern is achieved at upper operating frequency. This antenna can work effectively in the mobile communication products that integrate satellite and terrestrial communications, such as GPS L1, L2 and GSM.

5. REFERENCES