Design and Measurements of a Five Independent Band Patch Antenna for Different Wireless Applications

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***Abstract*— This paper presents the design of a compact microstrip patch antenna with the ability of controlling the number of bands and the operating frequencies independently. Numerical equations are derived using a curve fitting technique to obtain the centre frequency of each band. The antenna comprises a main patch and four sub-patches fed by a 50Ω microstrip line. It is designed to generate up to five separate modes to cover the frequency range from 900MHz to 3GHz for the operation of wireless devices supporting multiple standards including Global System for Mobile communication (GSM900, 880-960 MHz), Digital Communication System (DCS1800, 1710-1880 MHz), Universal Mobile Telecommunication System (UMTS, 1920-2170 MHz), Wireless Local Area Network (WLAN, 2400-2483.5 MHz) and low band Worldwide Interoperability for Microwave Access (WiMAX, 2.5 to 2.8 GHz).**

***Index Terms*—Small Patch Antenna, Multiband Antenna, Antenna Measurements**

I. INTRODUCTION

ANTENNAS for mobile and wireless terminals supporting several standards simultaneously are currently receiving a large amount of interest. The use of an Ultra WideBand (UWB) antenna for narrow band applications may result in unwanted emissions in the transmission mode hence the increasing demand for multi-band antennas serving multiple standards that can be easily integrated in a wireless device. Different techniques have been investigated to reach either dual band or wideband operation for microstrip patch antennas. The design of microstrip patch antenna with different shapes to create multi-band and wideband characteristics has been confirmed by using different shaped-slots [1]-[10], stack and multi-layers [11]-[12]. Additionally, an approach of designing independent multi-band antenna has been reported in [13] by using a coplanar waveguide with finite lateral strips. As a different approach to the multi-band antenna design, three resonant frequencies were achieved and controlled by employing two forked parts to the main radiated patch [14]. In [15], four slots were added to a planar inverted F antenna (PIFA) to control the bandwidth and the resonant frequencies for WiMAX applications.

This paper presents further investigation into the design and measurements of a microstrip patch antenna with five independent bands to be used in wireless applications. The design presented in this paper aims to achieve a multi-band design with independent control of the centre frequency for each band. The antenna occupies a total volume of 50 x 45.5 x 1.57 mm^3. The ground plane total area is 50 x 50 mm^2.

II. MULTI-BAND CONFIGURATION AND DESIGN PROCEDURE

The geometry of the proposed antenna is shown in Fig. 1. The key antenna parameters are shown in Table I. It consists of a main radiating patch, four sub-patches, a ground plane and a 50 Ω microstrip feed line. The antenna is mounted on an FR-4 substrate of 1.57 mm thickness and with a relative permittivity of 4.4. The main rectangular patch antenna was first designed (W_0 and L_0) to operate in the Wireless Local Area Network (WLAN) band from 2400 to 2483.5MHz while the four sub-patches have been injected to the main radiated patch to induce multiband frequencies for different other standards and applications. The unique property of the presented antenna lies in the fact that it can be used for single band or multi-band operation.

The design was initiated from the basic conventional patch antenna, which can be calculated from the equations given in [16]. The fine-tuning of the length, width and the position of the feeding line results in the final targeted WLAN band (2400-2483.5 MHz). To induce five resonant frequencies, the first sub-patch was added to generate the second band among the five targeted frequencies. Equations (1) and (2) are used to determine the size of the patch for a target resonant frequency "f_r". Adding sub-patch 1 to the structure generates the resonant frequency for the GSM900 band (880-960 MHz).

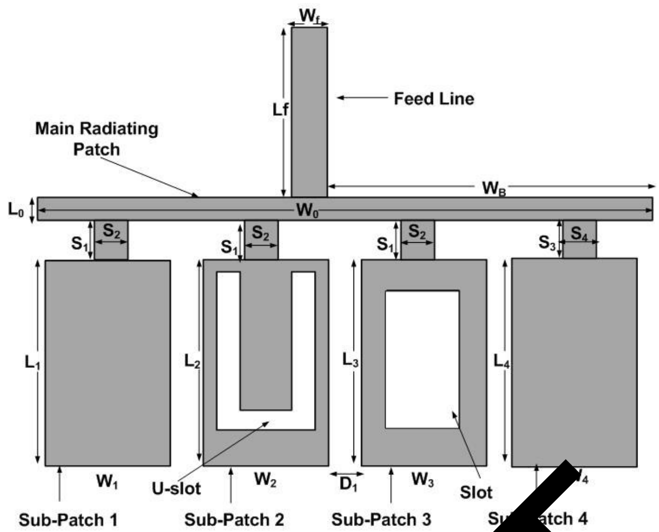


Fig. 1. The structure of the proposed antenna

TABLE I
THE DIMENSIONS OF THE PROPOSED ANTENNA (UNITS IN MM)

L₀	***W₀***	***W₁***	***L₁***	***W₂***	***L₂***
33	50	8	24	10	24
W₃	***L₃***	***W₄***	***L₄***	***W_f***	***L_f***
10	24	12	24	3	12.5
S₁	***S₂***	***S₃***	***S₄***	***D₁***	***W_B***
2	4	2.5	4	2	27

To reduce cut-and-try design cycles, curve-fitting formulae are introduced to give the exact size of the length and the width of the designed patch. The curve fitting design equations (1- 5) resulted from extensive simulation using the HFSS electromagnetic simulation tool.

Sub-patch 2 targets the Digital Communication System (DCS1800) band from 1710 to 1880 MHz. The characteristics resulting from the main patch and sub-patch 1 remain unchanged after the addition of sub-patch 2. A U-shaped slot is incorporated to sub-patch 2 to achieve the required matching for the band resulting in a return loss of -10 dB and a wider bandwidth. Equation (3) is used to obtain the length for the required centre frequency.

To generate an additional band, a long current path is needed. This basic rule was confirmed in many publications (e.g. [12] and [13]). Another band has been generated after adding sub-patch 3 targeting Worldwide Interoperability for Microwave Access WiMAX applications up to 2.9 GHz. A 4 x 4 mm^2 rectangular slot is attached to sub-patch 3 to achieve a -10 dB return loss and to lower the resonant frequency.

Since one of the objectives of this study is to investigate the ability of getting multi-band support from small conventional antennas and to easily control the generated resonant frequency, sub-patch 4 has been added supporting the UMTS band from 1920 to 2170 MHz. For this band, equation (5) is used to determine the length of sub- patch 4.

The design equations are summarised as follows:

$$W_I = \frac{W_0 - \dfrac{0.020 \times c}{f_r} - 4\sqrt{\varepsilon_r} - 11h}{2} \qquad (1)$$

$$L_1 = \frac{0.175 \times c}{f_r} - L_0 \qquad (2)$$

$$0.82GHz \le f_r \le 1.1GHz$$

$$L_2 = \frac{0.33 \times c}{f_r} - L_0 \qquad (3)$$

$$1.6GHz \le f_r \le 1.82GHz$$

$$L_3 = \frac{0.55 \times c}{f_r} - L_0 \qquad (4)$$

$$2.65GHz \le f_r \le 2.98GHz$$

$$L_4 = \frac{0.36 \times c}{f_r} - L_0 \qquad (5)$$

$$1.87GHz \le f_r \le 2GHz$$

Where W_I is the width of patches 1, 2, 3 and 4. L_1, L_2, L_3 and L_4 are the length of sub-patch 1, 2, 3 and 4 respectively. W_0 is the width of the antenna, c is the speed of light and h is the substrate thickness. The coefficients 0.20, 0.175, 0.33, 0.36 and 0.55 were obtained from a curve fitting technique through an extensive simulation study.

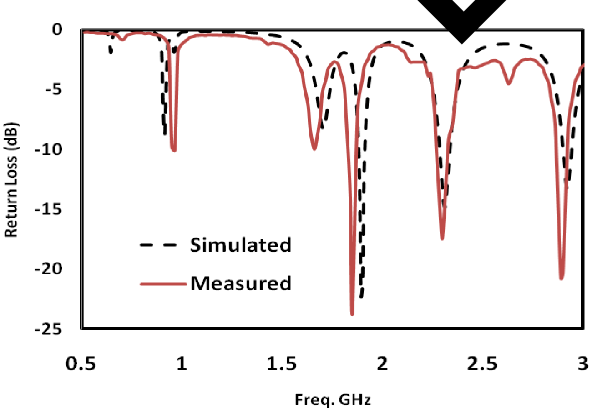


Fig. 2 The measured (solid) and simulated (dashed) return loss (S11)

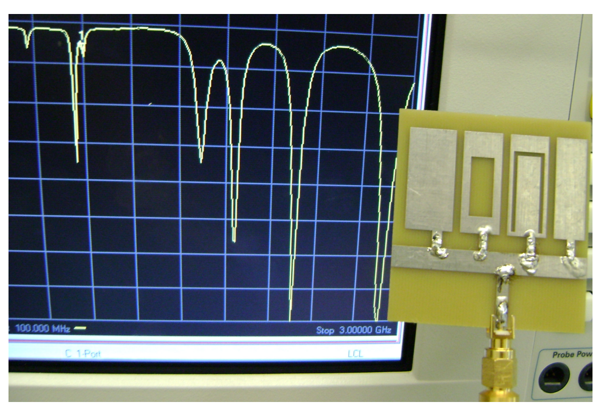


Fig. 3 Prototype of the Multiband Antenna

III. Experimental Results

Simulated results of the designed five-band antenna were verified by fabricating the antenna and measuring its performance. The return loss was measured using an Agilent N5230A network analyzer. The measured return loss is in good agreement with the simulated five band results obtained using the HFSS full-wave simulator (version 11.2) as shown in Fig. 2. It can be seen that the proposed antenna has five resonant frequencies controlled by the four sub-patches described above with centre frequencies of 0.92, 1.70, 1.95, 2.4 and 2.9 GHz. Fig.3 shows the fabricated multiband antenna.

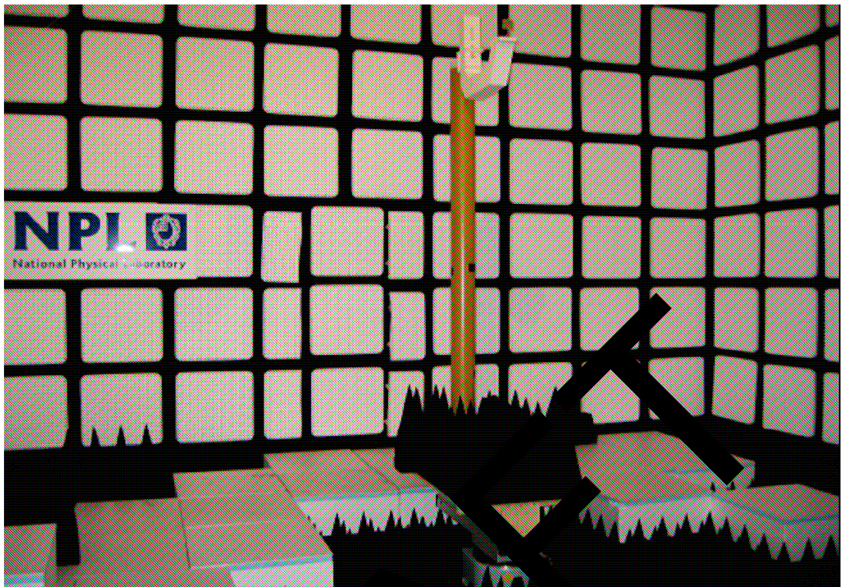
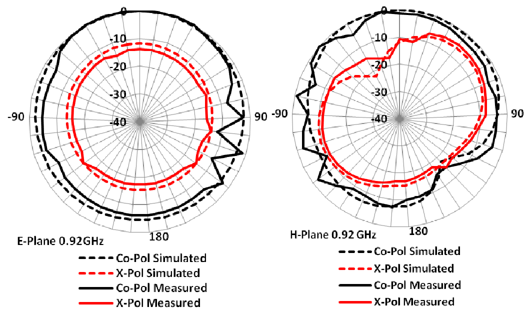


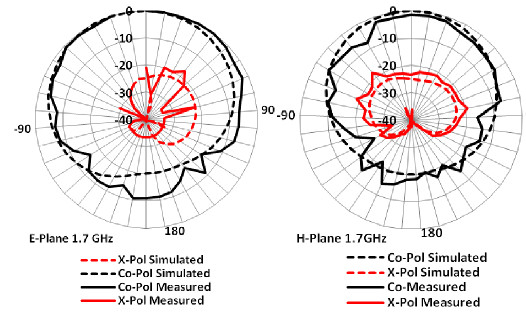
Fig.4 The measured antenna on the receiving mast at the NPL SMART anechoic chamber

As one of the most important parameters is the radiation pattern, therefore, measurements were conducted at the Small Antenna Radiated Testing Range (SMART) at the National Physical Laboratory (NPL) as shown in Fig. 4. After measuring the co and cross polar, the results were normalized to the maximum value therefore, The normalized measured and simulated radiation patterns for the co- and cross polar field E-plane (y-z Plane) and H-plane (x-z plane) at 0.92, 1.70, 1.95, 2.4 and 2.9 GHz are shown in Fig 5(a)-(e) respectively.

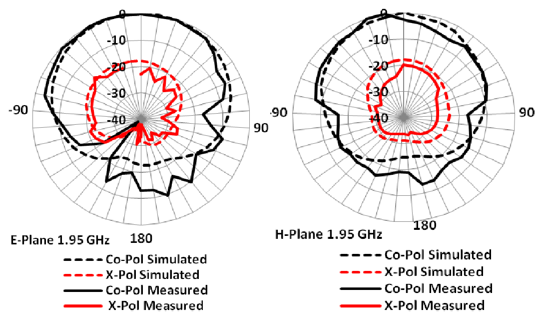
Examples of measured 3D patterns are shown in Fig. 6 for 0.95 and 2.9 GHz. The gain for the five bands ranges between 1 to 2 dBi. The measured gain (using the substitution method) at 1.95 GHz is approximately 1.19 dBi. The antenna is fabricated on a PCB. The dielectric substrate material is FR-4 with a relative permittivity (εr) of 4.4 and loss tangent of 0.02 as shown in the photograph of the antenna in Fig.3. The relative low antenna gain is due to the FR-4 material. If the loss tangent of the substrate material is reduced to zero, simulation results show that the gain will be between 6 to 7 dBi for the five bands.



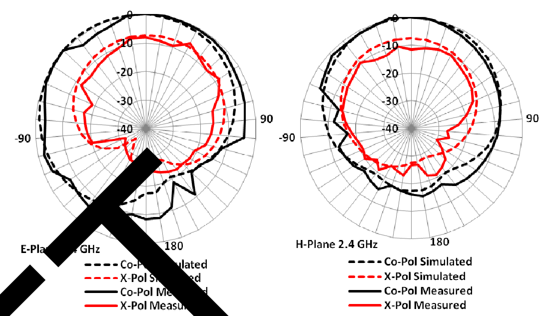
(a) 0.92GHz



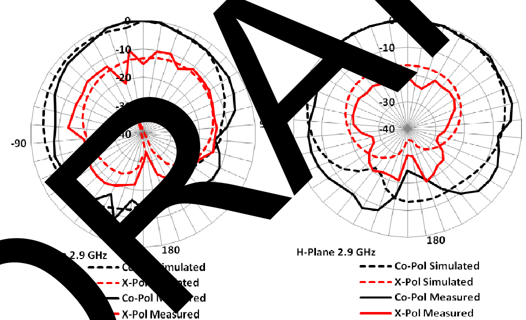
(b) 1.7 GHz



(c) 1.95GHz

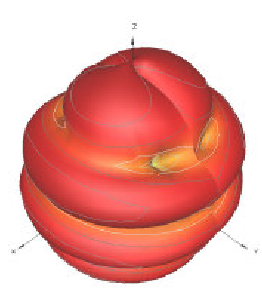


(d) 2.4 GHz

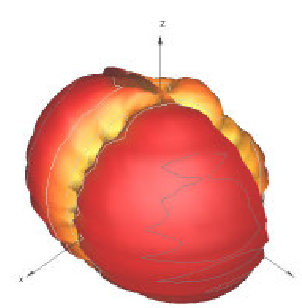


(e) 2.9GHz

Fig.5 Measured versus simulated Co-Pol and X-Pol radiation patterns for E and H planes at (a) 0.92 GHz (b) 1.7 GHz (c) 1.95 GHz (d) 2.4 GHz and (e) 2.9 GHz



(a) 0.95GHz



(b) 2.9GHz

Fig. 6. Example of 3D patterns at (a) 0.95 GHz and (b) 2.9GHz

IV. CONCLUSIONS

This paper presented a compact five-band microstrip patch antenna for wireless applications from 900 MHz to 3 GHz. The antenna can be used for single band or multi-band applications using four sub-patches. The antenna design targeted GSM, DCS, UMTS, WLAN and WIMAX frequency bands. Numerical equations obtained through a curve fitting technique to estimate the length and the width of each patch have been introduced. It is also possible to obtain design parameters for other frequencies and applications using these equations. It has been noted that, this technique does not affect the compactness of the antenna. Measurements of the return loss and co and cross-polar patterns are in good agreement with simulated results at the different frequencies.

The relatively low gain achieved is mainly due to the dielectric material and can be improved using a low loss higher quality material. Future work will focus on reconfigurable designs by including switches.

ACKNOWLEDGMENTS

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