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Modified Compact High Gain Multiple Patch Slotted Microstrip Antenna for Multiband Wireless Applications

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Abstract— A modified approach for the design of a compact multi-element patch antenna which operates in pentaband is proposed. The antenna comprises of a main patch with subpatches containing resonating slots. The main patch is fed with a 50Ω microstrip line. The antenna operates with multiple operational frequencies covering the bands from 1.9GHz to 9.5GHz with good impedance matching. The design is verified using simulation software ANSOFT HFSS and tested using the laboratory experimental approach which resembles the simulated output with an omnidirectional radiation characteristics.The multipatch antenna achieved a Peak Gain of 14.47 dB at 8.38 GHz and stays above 2.42 dB through the entire operating band. The frequency of operation is suitable for wireless devices supporting multiple standards including 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— ANSOFT HFSS, Compact, High Gain Microstrip feed, Multi-element Patch, Omni directional, Slotted Patch, Wireless Applications.

1 Introduction

IN today's modern communication industry, antennas are the most important components required to create a communication link. Microstrip patch antennas are increasingly used structure in various wireless applications fields [1], because of their low profile, light weight and low power handling capacity [2]. They can be designed in a variety of shapes in order to obtain enhanced gain and bandwidth for multiband frequency application independent of the operating frequency [3].

The concept of miniaturization is widely used in the present technological developement arena to minimize the effective electrical length of the antenna operatable at lower frequencies. Several methodologies were adapted to miniaturize a patch antenna [4]. Electromagnetic bandgap (EBG) structure is used as defected ground plane structure to reduce size and achieve multiband resonant frequencies [5]. To have multiple resonant frequencies one of the methods implemented is using slots on the radiating patch [6]. Many novel structures like Tapered Slot, Square Slot, U-Slot, T-Slot, V-Slot and many other shapes and structures were used by researchers reported in literatures [7], [8], [9]. The operating frequency characteristics obtained depend on the shape and position of the slots and also determine the ultra wideband characteris -tics of the antenna [10]. When the slot is generated on the radiating patch element the currents and the excited mode is perturbed which helps to reduce the effective designed resonant frequency towards achieving miniaturization.

Another technique to obtain the multiband frequency is meandering the patch. Meandering is achieved by inserting several narrow slits at the patch elements non radiating edges. The excited patch radiating elements surface current is effectively meandered leading to a greatly lengthened current path for a fixed patch linear dimension. This behavior results in a greatly lowered antenna fundamental resonant frequency and thus a large antenna size reduction at a fixed operating frequency is achieved [11]. The microstrip antenna with dual, triple and quad band antennas are reported for the applications of mobile wirelss applications. Similarly multielement antennas with multiband operational capabilities were proposed to suit the various requirements of the wireless application demand. Antennas operated in more than a band and extend over a wideband suffers gain over the entire band of operation. A multielement antenna for multiband antenna is proposed with modifications in the antenna slots available with the structure proposed as in [12]. The antenna is designed to attain high gain by adding up the benefits of the sub-patcges connected with the main patch and making the antenna to operate in the specific wireless bands. Antenna with multiple elements and multiband applications are repoted in literature as in [13]. A simple compact antenna is designed to cover five operating frequency bands usable for variety of communication appli

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-cations spreading in the frequency range from 1.9GHz to 9.5GHz.

2 RECTANGULAR MICROSTRIP PATCH ANTENNA

Microstrip patch antenna in its basic form consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Fig1.

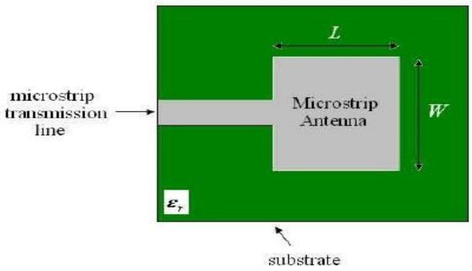

Fig. 1. Microstrip Line Feed.

The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiation pattern is dependent on the patch. Micro-strip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. The radiating patch and the feed lines are usually photo etched on the dielectric substrate. In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, elliptical or some other common shape.

Microstrip patch antennas can be fed by a variety of methods. The four most popular feed techniques used are the microstrip line, coaxial probe, aperture coupling and proximity coupling.The microstrip line feed is used. In this type of feed technique, a conducting strip is connected directly to the edge of the microstrip patch as shown in Fig2. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure. Hence this is an easy feeding scheme, as it provides ease of fabrication and simplicity in modeling.

2.1 Design Parameters

The basic design considerations for a rectangular patch were considered for the design. The length L of the patch is usually $0.3333\lambda o < L < 0.5\lambda o$, where λo is the free-space wavelength. The patch is selected to be very thin such that $t << \lambda o$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\lambda o \le h \le 0.05\lambda o$. The dielectric constant of the substrate (ε_r) is typically in the range $2.2 \le \varepsilon_r \le 12$. Formulas used for the patch design is given below,

Patch Width, $W = \dfrac{c}{2f\sqrt{\dfrac{(\varepsilon_r+1)}{2}}}$ (1)

Patch Length, $L = L_{eff} - 2dL$ (2)

Where $$L_{eff} = \frac{C}{2f\sqrt{\varepsilon_{reff}}} \quad (3)$$

$$dL = 0.412h\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (4)$$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{W}\right)^{-\frac{1}{2}} \quad (5)$$

Ground Length, $L_g = 6h+L$ (6)

Ground Width, $Wg = 6h+W$ (7)

Substrate height is h and Substrate material choosen is FR4.

2.2 Design Parameter Values

The design formulae were used to determine the antenna dimension parameters. This antenna is designed with the consideration of a main patch connected with four sub-patches to attain the multiband operation characteristics. The detailed parameters attained for the design are shown in Table 1.

TABLE 1
DIMENSIONS OF ANTENNA

Parameters	Value (mm)
Main patch(l x b)	7 x 38.5
Subpatch 1(l x b)	24 x12
Subpatch 2(l x b)	24 x10
Subpatch 3(l x b)	24 x10
Subpatch 4(l x b)	24 x 8
Resonating slot of subpatch 2 (l x b)	20 x 6
Resonating T slot of subpatch (3l x b)	2 x 8 1 x 22
strip of subpatches (l x b)	2 x 4
strip of main patch (l x b)	12.5 x 7
Feed at position (x, y)	(56,39)
Feed (l x b)	2.4 x 3
Radius of Circle in subpatch 1,4	1

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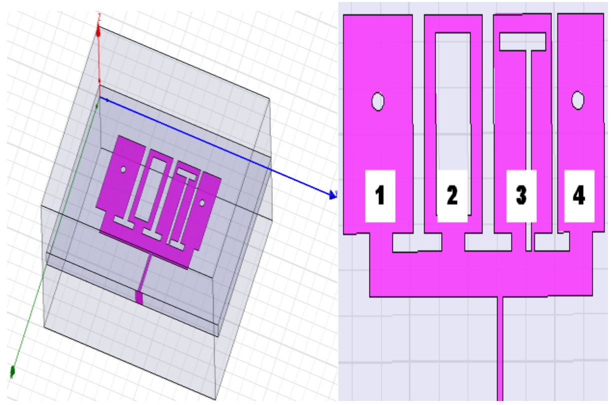
3 Antenna Design

3.1 Antenna Physical Structure

The dimensional parameters are estimated for the multiband antenna design and shown in Table 1. The antenna structure consists of a main patch connected to four sub patches. The four connected sub-patches are designed with slots of various shapes to attain the desired operational bands. The introduction of a slot alters the operational frequency of the radiating structure to attain miniaturization [14], [15].



(a) (b)

Fig. 2. (a) Corrugated MSA Design (b) Structure with four slots

The sub-patch1 and sub-patch 4 is designed with a circular slot. The sub-patch 2 is introduced with a rectangular slot and the sub-patch 4 is inserted with a T-shaped slot with a précised dimension to attain the required operating band. The structure of the antenna is shown in Fig 3.

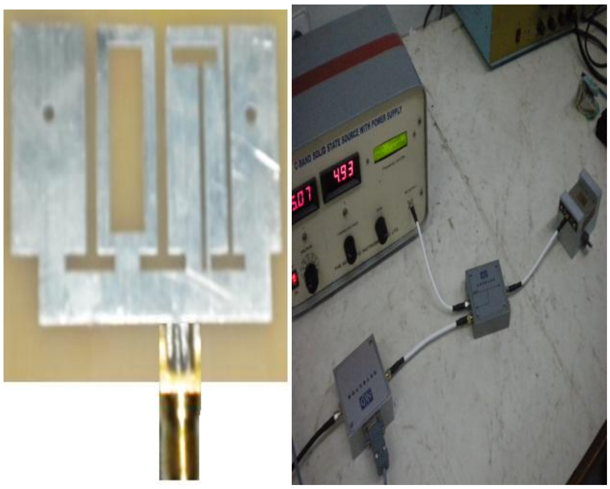
The radiating patch is fabricated on a FR4 substrate with permittivity ε_r = 4.4. The radiating patch is placed above the ground over the substrate with the height of h = 2.4mm.The height of the substrate is increased to attain better miniaturization characteristics.

The antenna structure is designed, constructed and simulated using simulation software ANSOFT HFSS. The simulation return loss against frequency characteristics result of the antenna is shown in Table II. The antenna is fed with a microstrip line matched to the radiating patches. The position of the microstripline feed is optimized by changing the feed location and observed good responses at feed locations at 56mm, 39mm (x,y) with feed length of 2.4mm and feed width of 3mm where it offered good impedance matching.

The antenna exhibited good impedance matching in five bands with center frequencies of the bands 1.89 GHz, 5.73 GHz, 7.66 GHz, 8.40 GHz and 9.74GHz. The corresponding return loss and bandwidth are shown in Table II. The obtained return loss shows the ability of the antenna to operate effectively in the five bands with reduced bandwidths in two of its operating bands.

4 Experimental Results

The antenna structure is fabricated and tested using a simple experimental setup in the laboratory. The experimental set up consists of C-Band and X-Band sources connected with microstrip trainer modules comprising of a Directional Coupler, Test Jig, detector unit and suitable R.F connectors with motorized radiation pattern monitoring units to record the radiation pattern of the antenna.



(a) (b)

Fig. 3. (a) Fabricated MSA Design (b) Testing Method

The antenna is connected with the test jig unit using the directional coupler to observe the return loss characteristics in the specific bands of operation. The return loss matched with the simulation results in the tested bands.

The antennas are then tested in the free space environment connected with the radiation pattern monitoring and recording unit which also resulted in a good radiation characteristics similar to the simulated radiation characteristics.

The 3-D radiation characteristics shows good directional characteristics of the antenna with a gain of 5.4235 dB. The radiation characteristics exhibits good front to back radiation characteristics as the ground plane helps to reduce the back radiation. The radiation suffered minimum sidelobe level with broad beamwidth suitable for wireless applications. The radiation characteristics show the directivity of the antenna reaching a value of 4.7496 dB.

4.1 Simulation Result

The Return loss against frequency characteristics of the proposed antenna is simulated using Ansoft HFSS and it

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is shown in Fig 4. The characteristics provides good impedance matching at five bands with operating frequencies centered at 1.89 GHz, 5.73 GHz, 7.66 GHz,8.40 GHz, 9.74 GHz with return loss values less than -10dB and their respective bandwidth in Table 2.

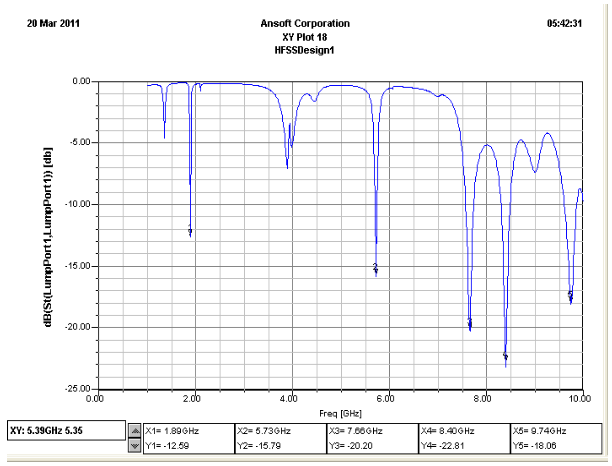


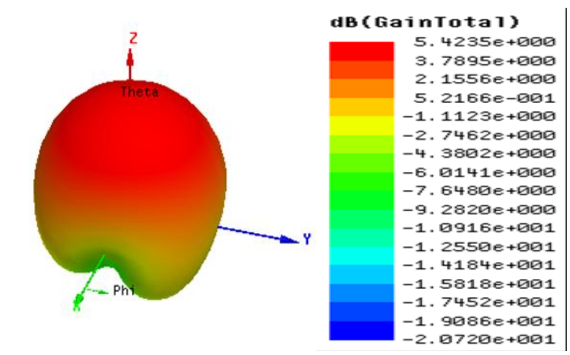
Fig. 4. Frequency vs Return loss

TABLE 2
RETURN LOSS CHARACTERISTICS

Frequency (GHz)	Return Loss (dB)	Bandwidth (MHz)
1.89	-12.59	10
5.73	-15.79	40
7.66	-20.20	160
8.40	-22.81	180
9.74	-18.06	250

4.2 Radiation Pattern

The radiation pattern of the antenna is simulated and tested in free space environment using automatic system interface radiation pattern plot generator unit. The tested results resembled the simulated results. The 3-D radiation plot of the antenna is shown in Fig. 5, which shows the peak gain achieved by the antenna in the far field region.



The directivity of the antenna radiation is observed and resulted as 4.7496 dB with omni directional characteristics. The radiation makes the antenna more suitable for the present day wireless communication which requires broad beam coverage in a specific direction to provide the required coverage area with minimum antennas.

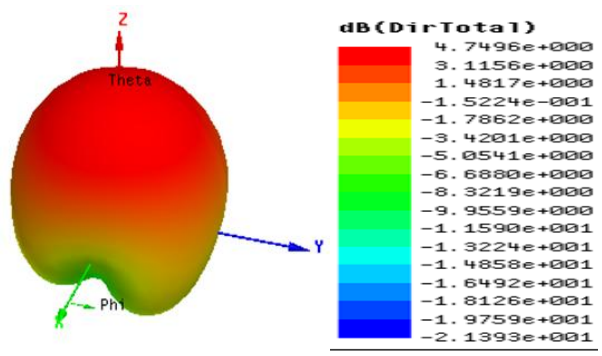
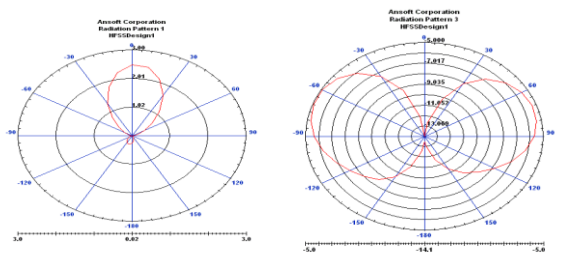


Fig. 6.Directivity

The 2-D polar plots for the E-Field and H-field are shown in the Fig. 7 a) and Fig. 7 b). The E-field pattern gives a wide beam with minor back radiation. The main lobe magnitude has reached more than 2.01 dB.



(a) (b)

Fig. 7.a). E-Field pattern, b). H-Field pattern

The test is performed for all the bands of frequencies and a frequency against the Gain plot is attained as shown in Fig. 8. The graph shows the antenna achieving a peak Gain of 14.47 dB at 8.37 GHz. Miniaturized antenna suffers from poor gain characteristics and require added circuits or devices to boost up the signals. This compact antenna achieved a high gain in almost all the bands of operation and makes it an attractive candidate for lots of communication applications as it has the capability to pick very weak signals and can radiate effectively into the far field over large distance when compared to miniaturized antennas.

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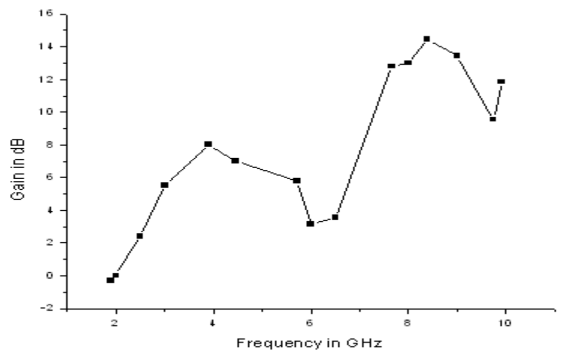

Fig. 8. Frequency vs Gain.

5 Conclusion

The antenna is designed successfully, simulated and tested with simple experimental approach to study the multiband antenna. The antenna covers the operating frequency band from 1.89GHz to 9.74GHz with good return loss characteristics. The result shows in two of the operating bands the antenna suffered in bandwidth performance which can be further optimized to improve. The antenna exhibited good impedance matching in all the operating bands and attained a peak gain of 5.4235 dB. The radiation characteristics resulted with a directivity of 4.7496 dB without sidelobes and possess broad beamwidth to provide good coverage in desired directions for communication applications. The attained bands of operation make the antenna most suitable for applications such as UMTS, WLAN, WIMAX communications.

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