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A Compact, Tri-Band and 9-Shape Reconfigurable Antenna for WiFi, WiMAX and WLAN Applications

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Abstract

This paper introduces a novel 9-shaped multiband frequency reconfigurable monopole antenna for wireless applications, using 1.6 mm thicker FR4 substrate and a truncated metallic ground surface. The designed antenna performs in single and dual frequency modes depending on switching states. The antenna works in a single band (WiMAX at 3.5 GHz) when the switch is in the OFF state. The dual band frequency mode (Wi-Fi at 2.45 GHz and WLAN at 5.2 GHz) is obtained when the switch is turned ON. The directivities are: 2.13 dBi, 2.77 dBi and 3.99 dBi and efficiencies: 86%, 93.5% and 84.4% are attained at frequencies 2.45 GHz, 3.5 GHz and 5.2 GHz respectively. The proposed antenna has VSWR< 1.5 for all the three frequencies. The scattering and far-field parameters of the designed antenna are analyzed using computer simulation technology CST 2014. The performance of the proposed antenna is analyzed on the basis of VSWR, efficiency, gain, radiation pattern and return loss.

Index Terms: Wi-Fi, WLAN, WiMAX, reconfigurable, monopole, single band, dual band, switches.

1. Introduction

With the tremendous advancement in modern communication devices, researchers have paid all their attentions towards multi and wideband antennas. Portable devices which contain different wireless communication standards, such as Wi-Fi, WiMAX, GSM, UMTS and WLAN use specific frequency band which demands multiband antennas [1]. Multi band antennas have the capability to transmit and receive multiple frequency bands with optimum directivity, gain and efficiency [2].The limitation of multi band antenna is that it is tuned for all frequency bands whether they are required or not, thus consume more power. Moderrn devices need antennas having flexibility to tune to the desired frequency band. An example of mutiple antenna system (such as a mobile handset) shown in Fig. 1 [3], uses several antennas for different wireless services such as:

- *Global Positioing System (GPS):* 1575.42 MHz (L1) and 1227.60 MHz (L2)
- *Bluetooth*: 2.4 GHz (BW=1 MHz/Channel)
- *Wireless Fidelity (Wi-Fi)*: 2.4 GHz {BW=40 MHz (802.11n) and 20 MHz (802.11a or 802.11g) }
- *Personal Global System for Mobile Communication (PGSM):* 900 MHz (890 -915 MHz)
- *Extended (E) GSM*: 900 MHz (880 MHz-915 MHz)
- *Fourth Generation (4G)/ Digitlal Cellular Service (DCS)/Personal Communication Services (PCS):* 1800 MHz and 2600 MHz

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Fig.1. Multi-band, multiple antenna system [3]

Luckily reconfigurable antenna has the ability to cover various frequency ranges. Reconfigurable antennas have the capability to support two or more than two desired wireless services. The reconfigurability can be achieved using various forms of switching circuitry [4]. Recent research show that multi band frequency reconfigurable monopole antenna have brought more attention from researchers because of their attractive feature like compact size, simple integration, easy to fabricate, low cost, optimum efficiency and Omni-directional pattern. Researchers designed different frequency reconfigurable antennas employing different techniques. For Examples Trident shaped [5], G shaped [6], H shaped [7], 7 shaped [8], E shaped [9], Dual Y shaped [10], U shaped [11], C shaped [12], L shaped [13],T shaped [14], F shaped [15] and Triagular shaped [16]. Split ring resonaors and L- shape slots are also used to design multi-band and a non-reconfigurable antenna [17]. By integrating the radiating element with different types of switches (RF-MEMS, lumped elements, varactor diodes and optical switches), the desired resonance frequency can be obtained. Usually the lumped elements are selected due to their high reliability, low cost and require low bias voltage as compared to MEMS switches [18].

In this paper, efficient and compact frequency reconfigurable 9-shape monopole antenna has been designed using an FR4 substrate of thickness 1.6 mm. The propose antenna operates in single mode (WiMAX at 3.5 GHz) and dual band mode (Wi-Fi at 2.45 GHz and WLAN at 5.2 GHz). To obtain reconfiguration, lumped elements are used within the radiating element of the designed antenna.

The rest of the research work is organized in the following fashion: Section 2 describes the designing procedure and geometry of 9-shaped monopole antenna. Section 3, discusses simulation results. Section 4 is the conclusion part of the paper.

2. Antenna Geometry and Theory

This section presents the basic geometry and design theory of the proposed 9-shape frequency reconfigurable printed antenna. The antenna is reconfigured using a single switch (SW) to obtain dual band (2.4 GHz and 5.2 GHz) and single band (3.5 GHz) modes. A truncated metallic ground plane is used for obtaining better radiation efficiency and optimum far-field radiation patterns.

2.1. Geometry

The geometry and structural dimensions of the designed 9 shaped monopole antenna for Wi-Fi (2.45 GHz), WiMAX (3.5 GHz) and WLAN (5.2 GHz) is depicted in Fig. 2. The 9-shaped radiating element is backed by an FR4 substrate (with relative permittivity 4.5 and tangent loss of 0.019) with a truncated metallic ground surface. The FR 4 substrate is easily available at lower costs so it makes the design of the antenna more feasible and affordable. The advantage of truncated ground plane is to attain optimum directivity, good gain and efficiency. The proposed antenna is fed through the 50 Ω micros-trip line with width (w=3mm). A waveguide port is assigned to the feed line in order to energize the antenna in the transmitting mode. A slot of 1 mm width is reserved in the upper part of the vertical arm of the proposed antenna for installing the switch (*SW*) as shown in Fig. 1. The overall dimension of the designed antenna is 40x35x1.6 mm^3.

Table 1. Outlines the design dimensions of the antenna.

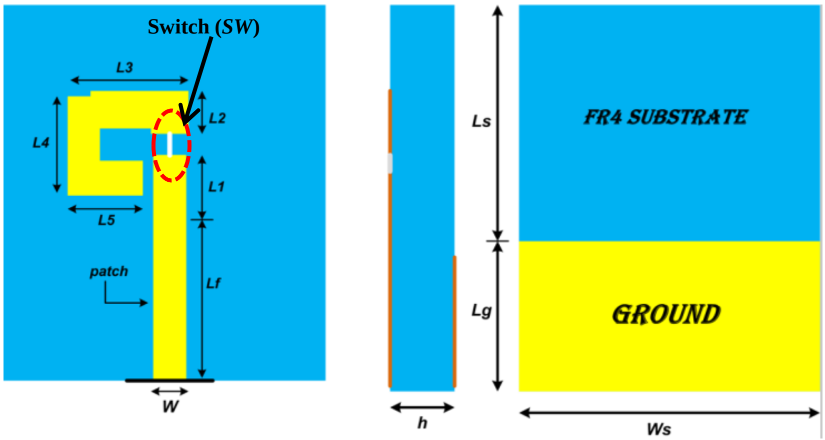


Fig.2. 9 shape reconfigurable monopole antenna (a) Front View (b) Side View (c) Rear View

Table 1. Dimensions of 9 shape antenna

Lengths	Values(mm)	Lengths	Values(mm)
L1	7	***Lf***	18
L2	3	***Ls***	40
L3	5	***Ws***	35
L4	4	***W***	3
L5	6	***h***	1.6

2.2. Theory

A 1 mm wider slot is reserved in order to install the switch (*SW*) at a proper position in the radiating structure of the proposed antenna. According to the theory of transmission line model [19], the effective resonance lengths of the antenna are computed, i.e. $L_{2.45}$= 17.5 mm (L_1+L_2+L_3/2+L_4/2+L_5/2+w), $L_{3.5}$= 10 mm (L_1+W) and $L_{5.2}$ = 7.5 mm (L_3/2+L_4/2+L_5/2). Single band (WiMAX at 3.5 GHz) and dual band (Wi-Fi at 2.45 GHz and WLAN at 5.2 GHz) frequency mode are obtained by altering state of the switch. The resonant lengths and guided wavelengths are related as:

$$L_{2.45}=\lambda_{2.45}/4 \tag{1}$$

$$L_{3.50}=\lambda_{3.50}/4 \tag{2}$$

$$L_{5.20}=\lambda_{5.20}/4 \tag{3}$$

The guided wavelength can be calculated as

$$\lambda_{f_r}=\frac{c}{fr\sqrt{\varepsilon_e}} \tag{4}$$

Where f_r is the resonance frequency is the speed of light and ε_e is the effective permittivity:

$$\varepsilon_e=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}(1\ +\ 12h\ /w)^{\ -1/2} \tag{5}$$

Where ε_r is relative permittivity, *h* is the thickness of the substrate and *W* is the width of the radiating component in equation (5).

The dimensions of the proposed antenna are optimized for better radiation efficiency (η_{rad}), which is defined as the ratio of the radiated power (P_{rad}) of the antenna to its input power (P_{in}).

$$\eta_{rad}=\frac{P_{rad}}{P_{in}} \tag{6}$$

The efficiency is higher if the antenna is fed at the right point, resulting in minimum value of reflection coefficient (Γ). This factor is the ratio of reflected and incident electric fields. Mathematically it is quantified as:

$$|\Gamma| = \frac{Z_{ant} - Z_c}{Z_{ant} + Z_c} \quad (7)$$

Where, Z_{ant} is the driving point impedance of the antenna and Z_c is the characteristic impedance of the microstrip feed line. Reflection coefficient, voltage standing wave ratio (VSWR) and return loss are interrelated parameters of the antenna, i.e. mathematically:

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \quad (8)$$

If reflection coefficient is small then VSWR approaches unity. The return loss is the ratio of the reflected power (P_r) to the incident power (P_{in}) of the antenna and is usually expressed in decibel (dB) scale.

$$Return\ Loss\ (dB) = \frac{P_r}{P_{in}} = -20 \log_{10}|\Gamma| \quad (9)$$

Lower value of return loss at the design frequency is achieved if the antenna is properly matched (i.e. low Γ). The gain (G) and directivity (D) of the proposed antenna are related by the radiation efficiency. The gain is usually expressed in decibel (dB) as follows:

$$G\ (dB) = 10 * \log_{10}(\eta_{rad} D) \quad (10)$$

3. Results

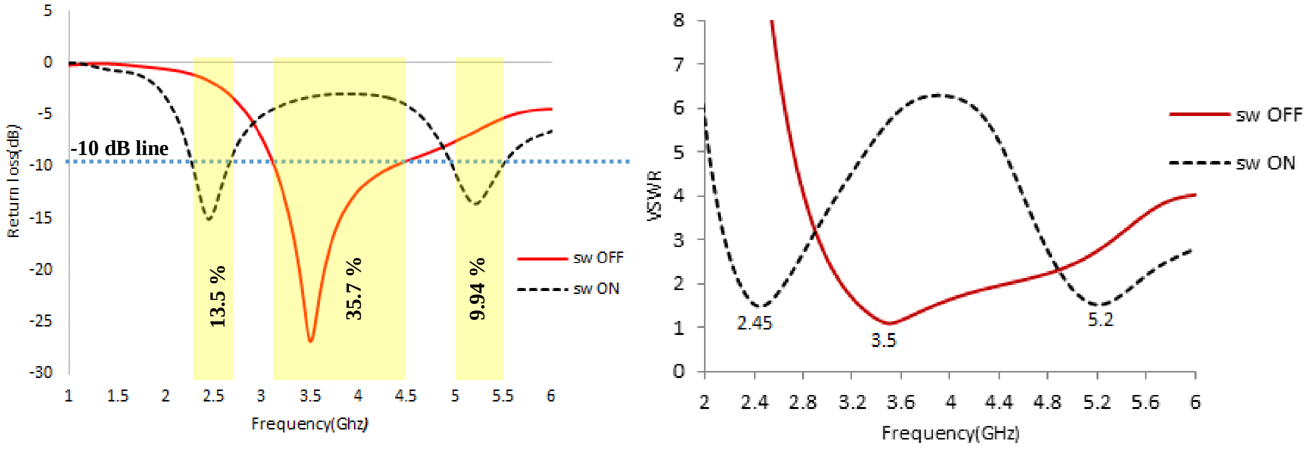
To examine the performance of the designed monopole antenna,the radiating components are designed,analyzed and simulated employing CST Micro Wave Studio MWS 2014 [20].

To excite the designed monopole antennna wave guide port is employed. Return loss, scattering parameters,VSWR, impedence, surface electric field, surface current and directivity (in *E* and *H* planes) are examined using open add space boundry conditions and transient solver in CST MWS 2014.

When the switch *SW* is ON,the designed antenna radiate in dual band frequency mode (2.45 GHz and 5.2GHz) giving return loss of -15 dB and -13.55 dB respectively, when the switch SW is turned OFF the 9 shape antenna works in single band mode (3.5GHz) with return loss of -27.1 dB (Fig. 3a). The antenna gives relatively broader -10 dB bandwidth in this band, i.e. 13.5 %, 35.7 % and 9.94 % at 2.4, 3.5 and 5.2 GHz respectively. The switchinh states are listed in Table 2. The voltage standing wave ratio (VSWR) of the proposed 9 shape antenna is less than 1.5 for all the three frequency bands. VSWR of the antenna is 1.48, 1.09 and 1.49 at 2.45, 3.5, 5.2 GHz, respectively as depicted in Fig. 3b.

Table 2. Switching states

S.	SW	Frequency Modes
1	ON	Dual band 2.45 GHz & 5.2 GHz
2	OFF	Single band 3.5 GHz



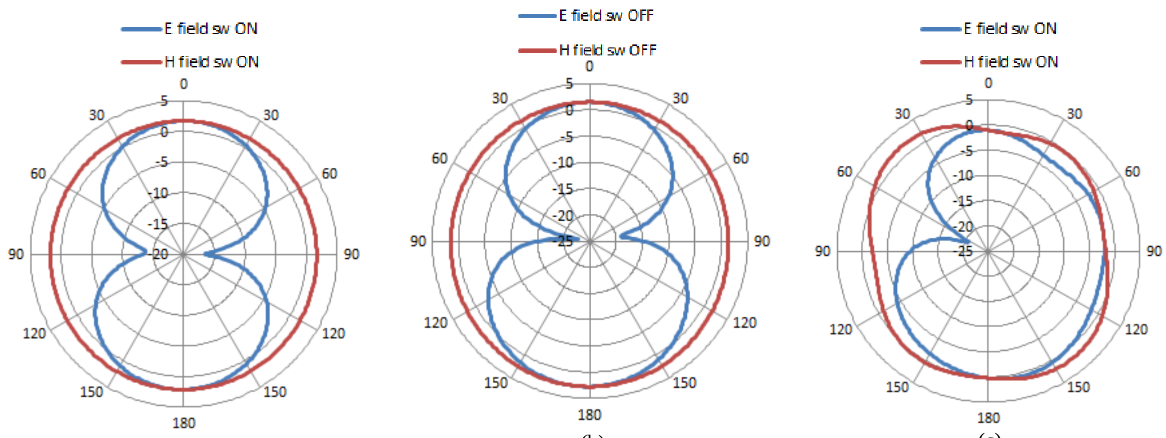
(a) (b)

Fig.3. Scattering parameters of the 9-shape antenna in single and dual band frequency modes (a) Return loss (b) VSWR

Directivity patteren (in the *E* and *H* planes) of the monopole antenna at 2.45 GHz, 3.5 GHz and 5.2 GHz are illustrated in Fig. 4. In single frequency mode the antenna radaites in the far-field with a peak directivity of 2.77 dBi. By altering the state of the switch (SW=ON) the antenna performs in dual frequency mode with directivity values of 2.13 dBi and 3.99 dBi at 2.45 and 5.2 GHz, respectively. For further clarity the 3D directivity far-field plots are shown in Fig. 5. The effieciency of the proposed 9 shape monopole antenna is 86 % at 2.45 GHz, 93.5 % at 3.5 GHz and 84.6 % at 5.2 GHz. The corresponding peak absolute gain of the proposed anttenna is 1.48, 2.47 and 3.26 dB respectively at 2.45, 3.5 and 5.2 GHz..

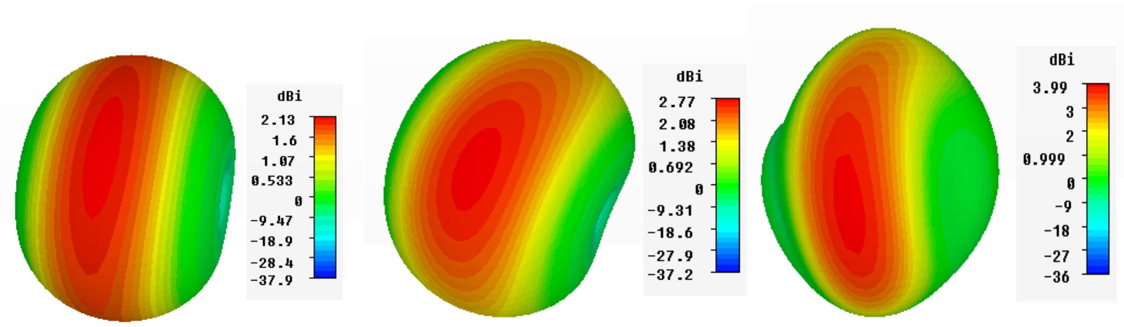
It is worth noticing that the proposed antenna radiates predominently omni-directionally in the H-plane in all the three frequency bands, (WiFi, WLAN and WiMAX) for a given state of the switch. The E-plane radiation pattern is a ‘figure of 8-shape’ having a single ‘null’ appearing at θ=90 degrees for 2.4 GHz and 5.2 GHz frequencies as shown in Fig. 4a and b respectively. The position of the ‘null’ is shifted to θ =60 degrees in the E-plane pattern at 3.5 GHz. In this frequency band the shape of the E-plane pattern is nearly omni-directional except the null point.

Summary of the simulation results is outlined in Table 3.



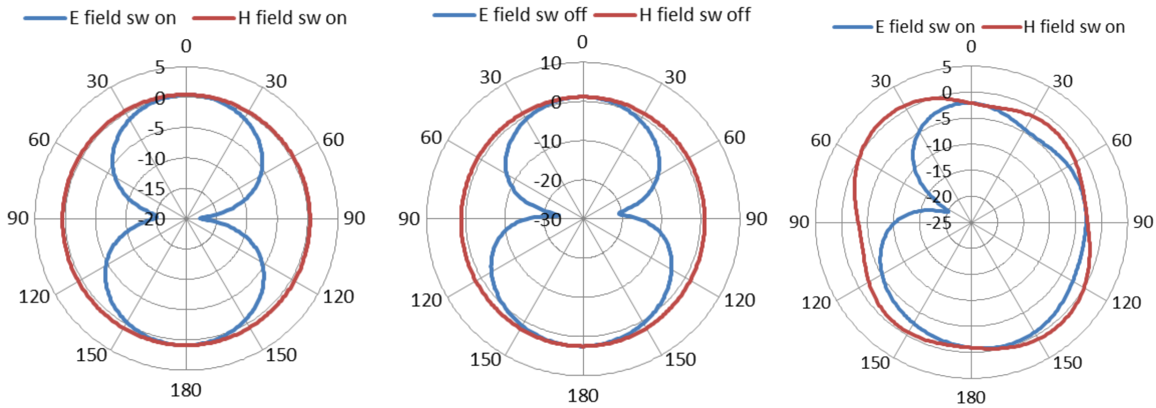
(a) (b) (c)

Fig.4. Directivity of the antenna in the *E* and *H* planes at (a) 2.45 GHz and (b) 3.5 GHz (c) 5.2 GHz



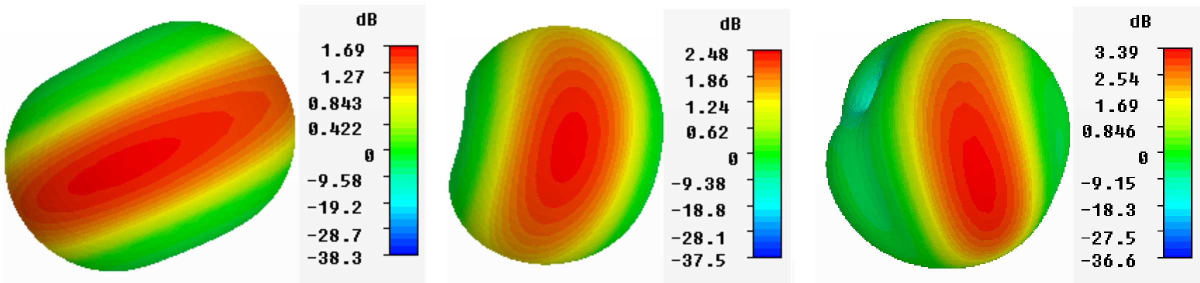
(a) (b) (c)

Fig.5. 3D Far field directivity pattern (a) 2.45 GHz (c) 3.5GHz (c) 5.2GHz



(a) (b) (c)

Fig.6. Gain of the antenna in the *E* and *H* planes at (a) 2.45 GHz and (b) 3.5 GHz (c) 5.2 GHz



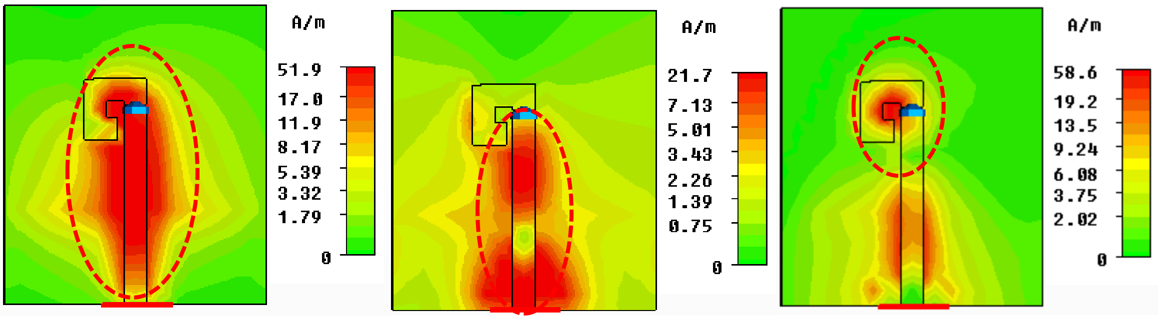
(a) (b) (c)

Fig.7. 3D Far field gain pattern (a) 2.45 GHz (c) 3.5GHz (c) 5.2GHz

Table 3. Summarized simulated results

Parameters	**SW ON**		**SW OFF**
Frequencies(GHz)	2.45	5.2	3.5
Gain(dB)	1.48	2.47	3.26
Return Loss (dB)	-15	-13.55	-27.1
Bandwidth (%)	13.5	9.94	35.72
Directivity(dBi)	2.13	2.27	3.99
VSWR	1.48	1.09	1.49
Efficiency (%)	86	92.5	84.6

To observe resonant lengths, surface electric fields (E field) recorded at the frequencies of interest (i.e. 2.45, 3.45, 5.2 GHz) are illustrated in Fig. 8. The entire length of the 9-shape patch radiates at lowest (2.4 GHz) frequency. The vertical arm of the patch up to the switch position, mainly contributes in radiating at 3.5 GHz. It is worth noticing that the upper loop in the 9-shape patch is primly responsible for radiation at the highest frequency band (5.2 GHz). The effective resonant lengths are encircled in Fig. 8.



(a) (b) (c)

Fig.8. Electric Field Surface Plots at (a) 2.45 GHz (b) 3.5GHz (c) 5.2 GHz

4. Conclusions

In this paper a novel 9-shaped frequency reconfigurable planer monopole antenna for Wi-Fi (2.45 GHz), Wi-MAX (3.5 GHz) and WLAN (5.2 GHz) has been presented to support multi band operations. The re-configurability has been achieved by changing the state of switch (lumped element). The designed antenna performed in single band mode (Wi-MAX at 3.5 GHz) when the switch was in the OFF state, while the same antenna worked in dual band mode (Wi-Fi at 2.45 GHz and WLAN at 5.2 GHz) when the switch was turned ON The designed antenna is of compact size, light weight highly efficient (84-92 %), and can be used in Wi-Fi, Wi-MAX and WLAN based wireless applications in modern communication devices like laptops, smart phones and other portable devices. A prototype of the proposed antenna will be fabricated to validate the numerical results. The directivity and gain can be further enhanced by using a multi-band electrometric bandgap (EBG) structure as a ground plane.

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