International Journal of Electrical and Computer Engineering (IJECE)
Vol. 7, No. 4, August 2017, pp. 2018~2026
ISSN: 2088-8708, DOI: 10.11591/ijece.v7i4.pp2018-2026

A New Planar Multiband Antenna for GPS, ISM and WiMAX Applications

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Article Info

Article history:

Received Jan 6, 2017
Revised Mar 10, 2017
Accepted Mar 24, 2017

Keyword:

GPS band
ISM band
Modified Ground Structure
Multibande Antenna
WiMAX band

ABSTRACT

In this paper a design of a new antenna with modified ground plane is validated for multiband applications. The proposed modified ground structure is incorporated with a patch antenna to boost the performance. The antenna's entire area is 59.5x47mm^2 and is printed on an FR-4 substrate and fed by a 50 Ohm microstrip line. This structure is validated in the GPS (1.56-1.58 GHz) band at 1.57 GHz, in the ISM (2.43-2.49 GHz) band at 2.45GHz and in the WiMAX (3.50-3.56 GHz) band at 3.53 GHz. These three frequency bands have good matching input impedance for, $S11 \leq -10$ dB. The antenna presents a good performance in terms of radiation pattern, and it is designed, optimized, and miniaturized by using CST-MW whose results are compared with other solvers HFSS and ADS. The results obtained by the use of the three EM solvers are in good agreement. After realization, we have tested and validated this antenna. The measurement results of the antenna present a good agreement with the numerical results.

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1. INTRODUCTION

These days, several researchers have dedicated large efforts to the development of antennas that meet the needs of the wireless communication industry that requires better performance, particularly in term of multiband operations and miniaturization. In fact, the design and development of a single antenna working in two or more frequency bands, such as in Global System for Mobile Communications (GSM), Digital Communication System (DCS), Global Positioning System (GPS), wireless local area network (WLAN) or Wifi and worldwide interoperability for microwave access (WiMAX) is generally not an easy task. The IEEE 802.11 WLAN standard allocates the license-free spectrum of 2.4 GHz (2.40-2.48 GHz), 5.2 GHz (5.15-5.35 GHz) and 5.8 GHz (5.725-5.825 GHz). WiMAX, based on the IEEE802.16 standard, has been evaluated by companies for last mile connectivity, which can reach a theoretical up to 30 mile radius coverage. The WiMAX forum has published three license spectrum profiles, namely the 2.5 GHz (2.495-2.69 GHz), 3.5 GHz (3.5-3.6 GHz) and 5.5 (5.25 - 5.850GHz) varying from country to country [1-7]. Recently, the microstrip patch antenna has been introduced with the aim of improving performance and obtaining the multiband behavior. This technology offers many advantages such as low weight, low profile planar configuration, low fabrication costs and the ability to integrate with microwave integrated circuits technology. Therefore, the microstrip patch antenna is very well-suited for applications such as wireless communications system, cellular phones, radar systems, and satellite communications systems [8-13].

There are several techniques which can be used with microstrip patch antenna to achieve the multiband behavior. Among these, we can find higher order resonances, resonant traps, combined resonant structures and parasitic resonators [14]. We can also use the modified ground structure to miniaturize and improve the bandwidth and reflection coefficient for multiband antennas [15-18].

In this paper, we have used and developed a new microstrip patch antenna with a modified ground structure. The proposed antenna has been optimized and tuned to operate with the following bands of GPS (1.176GHz / 1.227GHz/ 1.57GHz), ISM (2.45 GHz) and WiMAX (2.5GHz / 3.5GHz / 5.5GHz), and it was initially designed and simulated by using CST microwave studio and verified with other electromagnetic solvers ADS and HFSS, then fabricated to confirm the simulation results.

2. ANTENNA DESIGN

The geometry of the proposed antenna which is shown in Figure 1 is printed on a low cost FR-4 substrate with a total area of 59.5x47 mm^2 (L_{sub} x W_{sub}), and a dielectric constant $\varepsilon r = 4.4$, a thickness h=1.6 mm, a loss tangent tan (δ) = 0.025 and a metallization thickness of t=0.035 mm. The microstrip antenna is fed by a microstrip line with 50Ω characteristic impedance. The dimensions of the antenna are optimized and miniaturized by using CST-MW. The optimization dimension of the parameters of the proposed antenna are illustrated in Table 1.

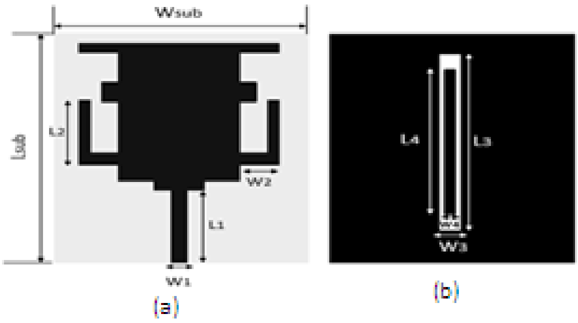

Figure 1. Geometry of the proposed antenna (a) front view (b) back view

Table 1. Dimension of the proposed antenna (unit:mm)

Parameters	Values	Parameters	Values
W_{sub}	47	L_{sub}	59.5
W1	3	L1	19
W2	7	L2	16.5
W3	4	L3	45
L4	37	W4	2

The purpose of this study is to design a novel compact antenna structure for three bands applications. The design procedure of this antenna is as follow. Firstly, the rectangular patch antenna as shown in Figure 2 is calculated from the following Equations [19]:

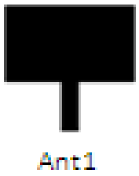

Figure 2. Microstrip patch antenna structure

The Width of the rectangular patch is given by:

$$W = \frac{1}{2 f_r \sqrt{\mu_0 \varepsilon_0}} \sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{c}{2 f_r} \sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

The expression of the effective length constant is given by:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[1 + 12 \frac{h}{W} \right]^{-\frac{1}{2}} \tag{2}$$

The length extension is given by:

$$\Delta L = 0.412 * h * \frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{3}$$

The length of rectangular patch is given by:

$$L = L_{eff} - 2\Delta L = \frac{c}{2 f_r \sqrt{\varepsilon_{eff}}} - 2\Delta L \tag{4}$$

Where: c is the free space velocity of light, εr is the relative permittivity of substrate, L is the length of patch, W is the width of the patch, h is the height of the substrate, εeff is the effective relative permittivity of patch, Leff is the effective length of the patch and fr is the resonant frequency.

The obtained parameters of rectangular microstrip patch antenna are L=28.24mm, W=36.51mm which is validated at fr =2.5GHz.

Secondly, we have modified the structure presented in Figure 3 in order to obtain multiband behavior. An L-shaped arm and a tiny rectangle are put in symmetrically on both sides of the patch antenna, and a rectangular-shaped arm is placed on the upper part of the microstrip patch antenna. We notice the emergennce of new resonant frequencies as shown in Figure 4. The appearance of these resonant frequencies is calculated by using Equations (5) and (6) [20].

$$f_i = \frac{c}{\lambda_g . \sqrt{\varepsilon_{eff}}} \quad where \quad l_j = \frac{\lambda_g}{4} \tag{5}$$

$$\sqrt{\varepsilon_{eff}} \approx \frac{\varepsilon_r + 1}{2} \tag{6}$$

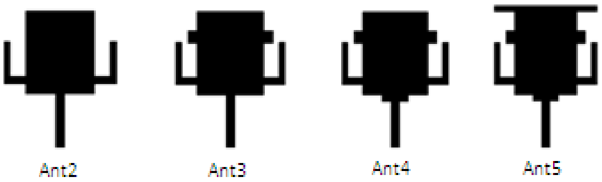

Figure 3. Evolution of the microstrip patch antenna

After designing the antenna as depicted in Figure 2 and Figure 3, we have obtained reflection coefficient corresponding to each antenna from 1 to 5 as shown in Figure 4.

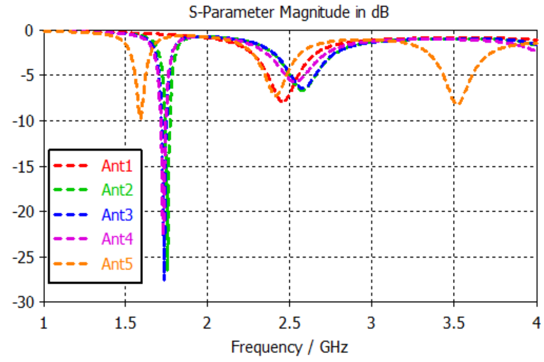

Figure 4. Reflection coefficient versus frequency with of the different modified ground structure

As a last part of the design procedure, a modified ground structure, consisting of two rectangles of different size etched in the ground, is introduced in order to enhance the reflection coefficient as shown in Figure 5. As depicted in Figure 6, the introduction of the second modified ground structure permits to have a good matching of the input impedance. Table 2 shows the simulation results brought about by the modification of the ground plane.

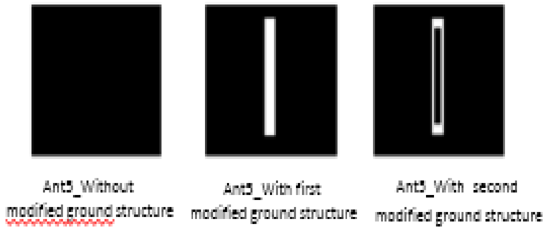

Figure 5. Evolution of the modified ground structure

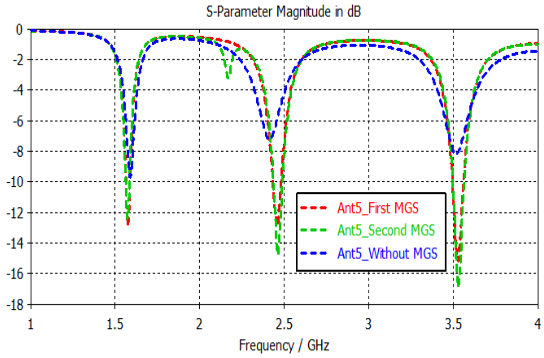

Figure 6. Reflection coefficient versus frequency with of the different modified ground structure

Table 2. Simulation results related to the changes of the ground plane

Evolution without and with modified ground structure	S11≤ -10dB		BP≤ -10dB
Ant5_Without Modified ground	--		--
Ant5_First Modified Ground	First resonance	1.57 Ghz	1.56-1.58 Ghz
	Second resonance	2.45 Ghz	2.43-2.48 Ghz
	Third resonance	3.52 Ghz	3.49-3.56 Ghz
Ant5_Second Modified Ground	First resonance	1.56 Ghz	1.55-1.58 Ghz
	Second resonance	2.45 Ghz	2.43-2.49 Ghz
	Third resonance	3.53 Ghz	3.50-3.56 Ghz

As depicted in Figure 7, we have obtained an optimized antenna with the first resonant frequency of 1.56 GHz and a bandwidth (1.55-1.58 GHz), that can be suitable to the GPS band and the second resonant occurs at 2.45 GHz with a bandwidth (2.43-2.49 GHz), that covers the ISM band, and the third resonant occurs at 3.53 GHz with a bandwidth (3.50-3.56 GHz), that covers the WiMAX band.

Another way to verify the different performances of the proposed antenna is the use of other electromagnetic solvers HFSS and ADS. As shown in Figure 8, we can conclude that there is a good agreement between these three solvers.

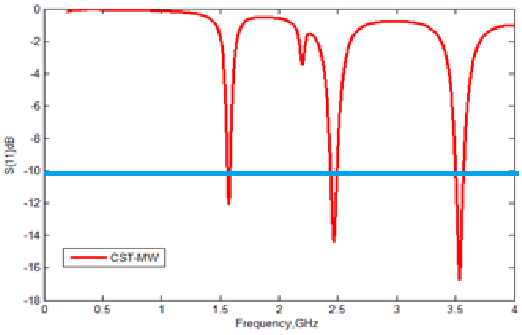

Figure 7. Final reflection coefficient versus frequency

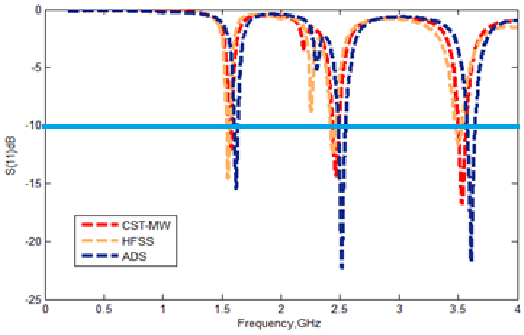

Figure 8. Comparison of reflection coefficient |S11| between CST-MW, HFSS and ADS

In order to better understand the antenna behavior, the current distributions of the three bands antenna at resonants frequencies of 1.56, 2.45 and 3.53 GHz are simulated and shown respectively in Figure 9(a) and 9(c).

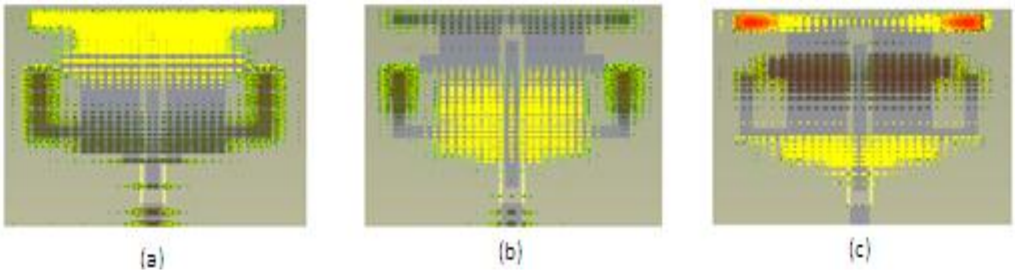

Figure 9. Current distributions of the proposed antenna at: a: @ 1.56 GHz b: @ 2.45 GHz c: @ 3.53 GHz

As we can see from Figure 9. Current distribution affects different parts of the patch depending on the frequency band. When the frequency reaches 1.56 GHz, the current distribution is heavily concentrated in the upper part of the microstrip patch antenna. When the frequency reaches 2.45 GHz, the density of the current distribution is concentrated in the lower part of the microstrip antenna and on the upper parts of the L-shaped arms. When the frequency is 3.53 GHz, the current distribution is concentrated along the rectangular shape which is placed on the upper part of the microstrip patch antenna and the lower part of the microstrip patch antenna.

The simulated Far-field radiation patterns in CST-MW for the three resonant frequencies are shown in Figure 10. It can be seen that the antenna presents a stable radiation and a quasi-omnidirectional radiation pattern for the resonant frequency bands for each resonant frequency.

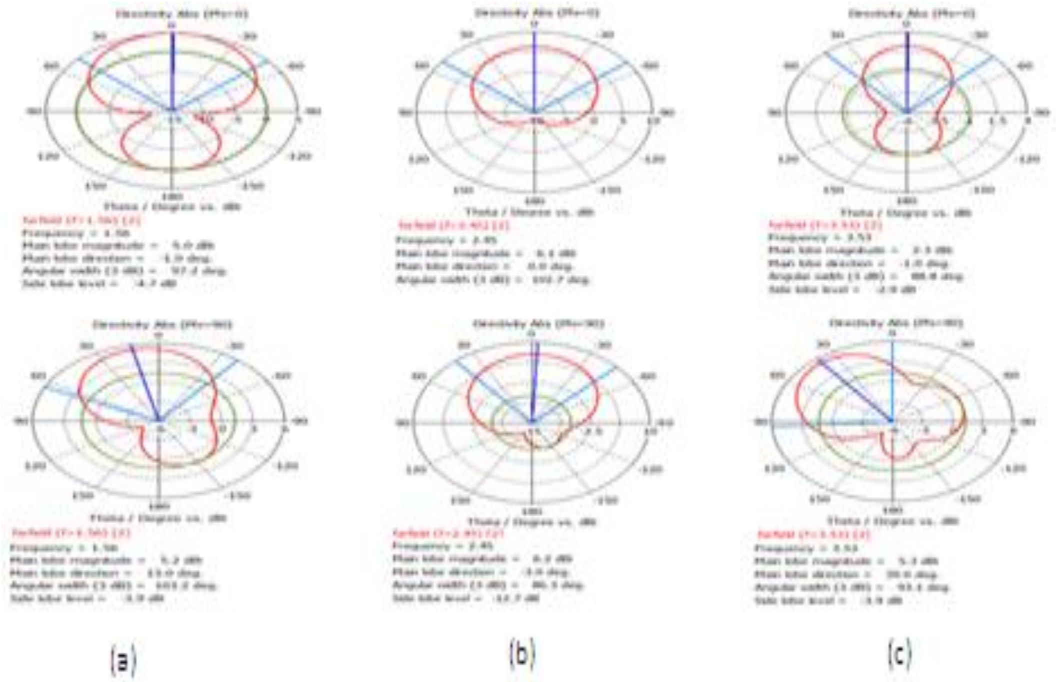

Figure 10. Radiation pattern of the proposed antenna (a) @ 1.56 GHz, (b) @ 2.45 (c) @ 3.53 GHz

From Figure 11, we notice that the VSWR is less than 2 at the frequency range of (1.558-1.588GHz), (2.434-2.501GHz) and (3.498-3.572GHz).

Figure 12 presents the variation of the gain versus frequency. After the simulation, we have obtained the gain 2.123 dB at 1.56 GHz, 3.355 dB at 2.45 GHz and 2.299 dB at 3.53 GHz.

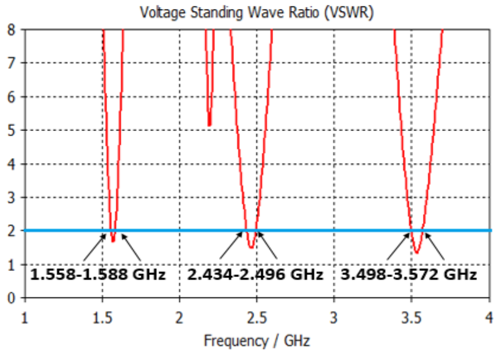

Figure 11. VSWR versus frequency

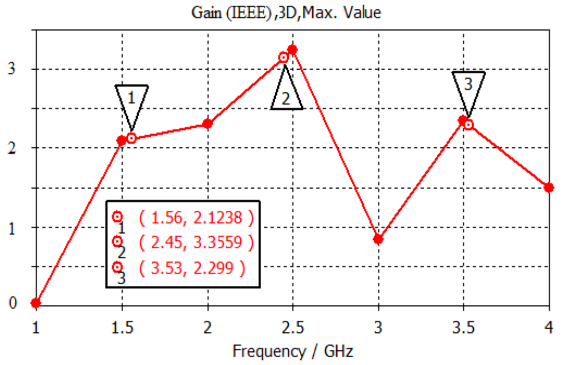

Figure 12. Gain versus frequency

Table 3 presents a comparison of the proposed antenna with bibliography regarding antenna size, resonance frequency and antenna purpose. As we can see from the same table that the proposed antenna is smaller in terms of size and suitable for tri-band applications.

Table 3. Comparison of proposed antenna performance with other compact antennas

Published literature versus proposed work	Antenna Size (mm^2)	Resonance Frequency (Ghz)	Antenna purpose
Ref[21]	75x75	2.4/5.2	Dual-Band
Ref[22]	50x75	2.4/5.2	Dual-band
Ref[23]	100x45	2.4/3.5/5.2	Tri-band
Proposed work	59.5x75	1.56/2.45/3.53	Tri-band

3. EXPERIMENTAL RESULTS AND DISCUSSION

After the design and optimization of the multi-band antenna by using CST-MW, the prototype of the investigated antenna is achieved and measured. Figure 12 presents a photograph of the fabricated multiband antenna, the proposed circuit is fabricated on an FR-4 substrate.

Figure 12. Photo of the fabricated antenna structure (a) Top face (b) Back face

The achieved antenna is tested by using a VNA from Agilent Technologies. The calibration Kit used is a 3.5 mm from Agilent technologies. After taking into account the losses in cable used for the test, we have conducted comparison between simulation and measurement results as presented in Figure 13.

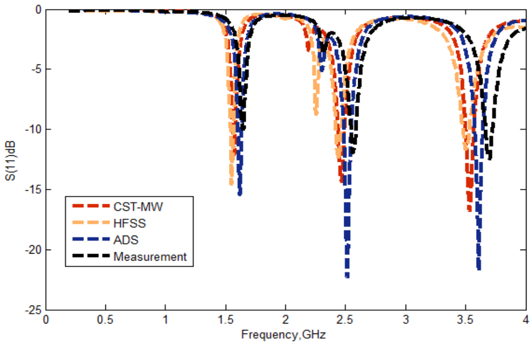

Figure 13. Comparison of simulated and measured at the level of reflection coefficient

As we can see in Figure 13 there is a good agreement between the simulation and the measurement albeit a slight difference. This is due to the fabrication constraints, uncertainties in the dielectric constant and substrate thickness and soldering effects.

4. CONCLUSION

In this work, we have carried out the design of a microstrip patch antenna with a modified ground structure. This antenna has been designed and optimized by using CST-MW and verified by other solvers HFSS and ADS. The achieved and tested microstrip patch antenna with modified ground structure presents a good agreement between simulation and measurement results. The measurement results allow us to validate a new multiband antenna structure for GPS (1.56-1.58GHz), ISM (3.50-3.56 GHz) and WiMAX (3.50-3.56 GHz) frequency bands with a compact size of 59.5x47mm^2. The antenna is compact, lightweight, low cost, simple to fabricate and easy to integrate with microwave printed devices.

ACKNOWLEDGEMENTS

We would like to thank Mr. Angel Mediavilla Sanchez Director of DICOM Laboratory in Spain, for allowing us to perform simulations by using electromagnetic solvers and to use many instruments for measurement.

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