Design and study of a microstrip defected ground structure antenna operating at 2.9/3.78/4.7/5.8 GHz.

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Abstract. A novel design of a defected ground structure multi band microstrip antenna is presented in this work. The modified bident microstrip antenna with defection at ground plane is designed, simulated and fabricated to operate at 3 GHz (between 2.925 to 3.133 GHz), at 3.9 GHz (between 3.471 to 4.355 GHz), at 4.9 GHz (between 4.537 to 5.317 GHz), and at 5.9 GHz (between 5.681 to 6.162 GHz) for WiMAX/WLAN applications. One of the main challenges was to miniaturize the antenna keeping a low profile and low cost substrate (1.2mm and FR4 respectively) with tetra-band frequency response. Each resonant frequency is accomplished by adding and modifying a defection at ground plane, and modifying the cross position at feed line. Simulations had been conducted using HFSS software and measured parameters such as reflection coefficient (S11 parameter) was also performed with a vector network analyzer. Measured results confirm simulated results that the antenna could work within mentioned frequencies. Parametric study was conducted in order to study the effect of slots variation over the design.

Key-Words: Defected ground, microstrip, multiband

1 Introduction

Wireless communication is a technology, which offers the opportunity to transmit/receive information without wires, using electromagnetic waves and air as a way to transport information. From the appearance of this technology at 19th century [1] it has played a key role in humankind development. Making it possible to overcome the need to communicate or connect people around the world and beyond, such as manned and unmanned spaceflight, geolocation (GPS); and in recent times this need also involves the desire to interconnect things through the internet of things (IoT) and radio frequency identification (RFID). All these factors contribute to the research, appearance and continuous development of microstrip antenna (MSA) technology [2] and therefore the defected ground structure (DGS) as technique to improve MSA characteristics.

A DGS antenna consists on cutting off a piece of shape in the ground plane of a MSA, disturbing the shielded current distribution in the ground plane according to the shape and dimensions of the defect; resulting in a controlled excitation and propagation of the electromagnetic waves through the substrate layer. The defection could be single or complex, periodic or non-periodic depending on the characteristics which are intended to be improved [3][4].

As inherent properties of MSAs, these show disadvantages such as narrow bandwidth, low gain, and so on. However, these structures also show advantages such as capability to work at multi-frequency bands, are also capable to adapt to different kinds of surfaces, low profile, low cost, among other characteristics; allowing these structures to be applied on current and future wireless communication system [5].

As wireless technology increases its applications on every aspect on human life [6][7] it has been necessary to develop low profile - low cost devices with excellent performance and therefore the enhancement on MSA characteristics including radiation pattern, gain [8], bandwidth [9], multiple band response [10][11], antenna dimension [12][13] and so on. This continuous search for improvement led DGS to be used as a common technique in the MSA design because it offers a good freedom degree of designs/results ratio to design and improve antenna characteristics compared with other techniques such as monopole [14], fractal [15], EBG [16], slots [17], reconfigurable antenna [18] among others.

In [19] for instance, a triple band antenna for wireless communication is proposed by using high dielectric substrate (C-MET LD10.2) material with

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a dielectric constant of 10.2 and a loss tangent of 0.002, in combination with other techniques such as DGS. Through the patch radiator slotting it is possible to reduce antenna dimension by near to 40% and achieving a return loss of -12 dB, -14 dB and -14 dB for 2.4 GHz, 3.6 GHz and 5.3 GHz respectively.

As it is shown in [20] it is possible to get triple frequency response using DGS technique by cutting off a U and L-shaped slots. Getting overall dimensions of 52x58x5 mm. and the patch is fed it by a coaxial cable. Bulky antennas might be necessary on cases which the space is not a problem and improving the gain is the main target (from 4 to 5 dB) with bandwidth from 100 MHz to 1 GHz.

WiMAX/WiFi mobile communications antenna is designed and studied in [21] through defecting the ground plane by gap coupling either rectangular or circular shapes. The patch radiator is a double F shape slotted antenna located to the right and left sides of the patch radiator. The structure resonate between 2.0-2.76 GHz, 3.04-4.0 GHz and 5.2-6.0 GHz with 19x25x1.6 mm as total dimension with a gain variation between 1.4 to 3 dB and the resonance frequency is achieved by modification of F slots dimensions.

An ultra-wideband antenna was designed in [22] with overall dimensions of 21x18x1.6 mm. This structure is capable to operate at different frequency bands such as WLAN band (5.15-5.825) GHz, C band (4-8) GHz and lower frequencies of X band (8-12) GHz as the antenna resonates between 3.58 GHz to 9.93 GHz, which means a 6.384 GHz bandwidth with gain between 1.8 to 3.1 dB. The defected ground structure has the form of triangular shape connected to a six-sided polygon through one triangle's vertex.

In this paper, a modified bident planar defected ground structure microstrip antenna is designed, simulated and fabricated to operate at 2.8/3.1/3.6/4.7/5.4 GHz for wireless communication services applications.

2 Antenna Design

2.1. Antenna Parameters

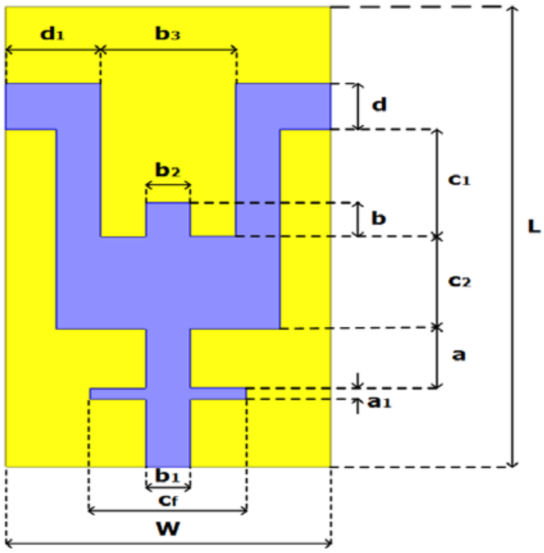

Fig. 1 Top View Parameters Design

The geometry of the proposed antenna from top and bottom view is shown in Fig. 1 and Fig. 2 respectively. The antenna is designed and simulated on a FR4 substrate with relative permittivity εr = 4.4; the substrate is selected due to its easy access in the domestic market and because it is cheaper than other substrates for high-frequency applications. The proposed design has follow dimensions 30x14.5mm with a thickness h = 1.2mm, and a loss tangent δ = 0.02. The used software is HFSSv17.2, which is based on Finite Element Method (FEM). The rest of parameters are summarized in Table 1.

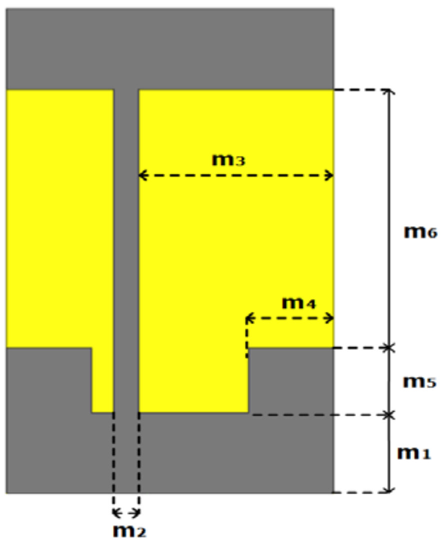

Fig. 2 Bottom View Parameters Design

Table 1 Parameters Design

Parameter	Value (mm)	Parameter	Value (mm)
L	30	h	1.2
W	14.5	b3	6
a	3.875	d	3
a1	0.75	m1	5
b	2.25	m2	1.1
b1	2	m3	8.65
b2	2	m4	3.75
c2	6	m5	4
cf	2	m6	16
c1	7		

Defected Ground Structure (DGS) technique offer the opportunity to improve antenna characteristics such as multi-frequency operation, miniaturization, gain improvement, bandwidth improvements and so on through the modification of either patch radiator or ground plane or both simultaneously as is studied in [8]-[13], [19], [20] among others. This characteristics give researchers wider options to achieve their goals. The antenna is fed with sma connector in order to keep a low profile in quest of the opportunity to insert such kind of miniaturized structure within any suitable compact circuit or equipment.

2.2 Simulation Results

2.2.1 Reflection Coefficient (S_{11} Parameter)

Based on reflection coefficient results (S11 parameter curve) of Fig. 3, it is emphasized that at the 1st frequency band of 2.9 GHz the resulting impedance bandwidth is going from 2.86 to 3.01 GHz (150 MHz), getting the lower reflection coefficient of -14.3279dB at 2.912 GHz. At 2nd frequency band of 3 GHz, the impedance bandwidth is going from 3.28 to 4.28 GHz (1 GHz) with the lower reflection coefficient of -24.3474dB at 3.926 GHz. At the 3rd frequency band of 4 GHz the impedance bandwidth is going from 4.44 to 5.17 GHz with the lower reflection coefficient of -34.8106dB at 4.706 GHz. The 4th frequency band of 5 GHz the impedance bandwidth is going from 5.59 to 6.09 GHz with the lower reflection coefficient of -15.501dB at 5.837 GHz to operate for wireless applications.

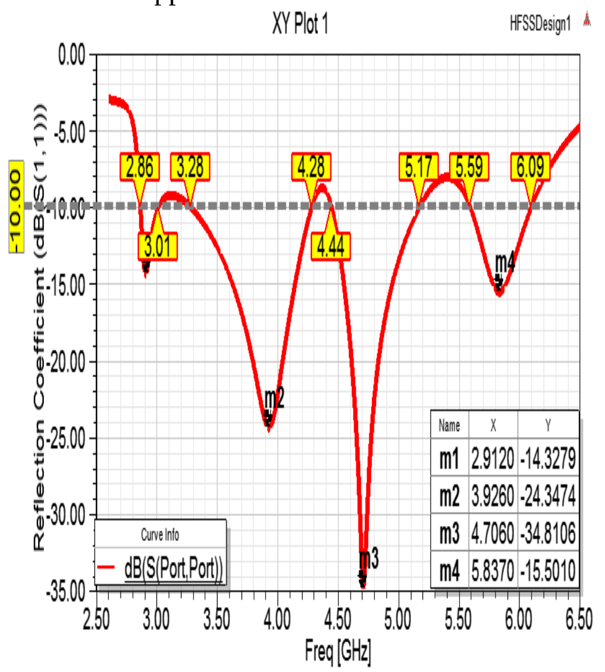

Fig. 3 Reflection Coefficient

2.2.2 Current Density

In order to put forward the study of tetra-band operation properties of the proposed DGS antenna, surface current distributions (A/m) of designed antenna (patch and ground plane) at frequencies of 7 (solution frequency), 2.912, 3.926, 4.706 and 5.837 GHz are given in Fig. 6–15.

The patch radiator and the defected ground plane have been divided into several regions (A~H for patch radiator and I~M for ground plane) as shown in Fig. 4 and Fig. 5 respectively for better understanding on current density paths analyzes.

As starting point, in Fig. 6 and Fig. 7 the current path has a very low flow and magnitude at ground plane except on region M located beneath the feedline. Moreover, a higher density and magnitude of current path at the region H is observed.

Also it is possible to notice that current path is flowing from cross feed to upper and lower sides of region H, and the ground plane has very low current flow, i.e., did not contribute to antenna resonance, therefore the antenna does not resonate at 7 GHz as expected.

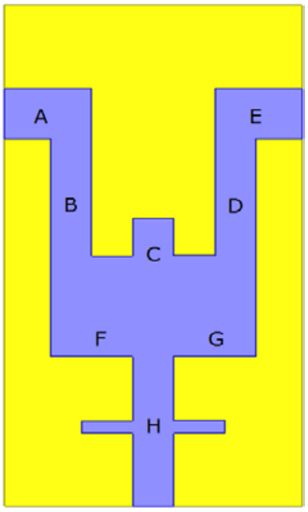

Fig. 4 Top View Antenna Regions

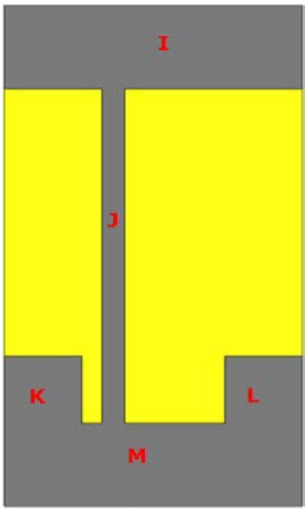

Fig. 5 Bottom View Antenna Regions

At 2.912 GHz it is possible to observe a uniform and strong current flow from region A to B, C and D (as is observed in Fig. 8); having a moderate magnitude on mentioned regions, which means that any modification at these regions will affect the current distribution and therefore the radiation pattern and reflection coefficient.

In Fig. 9 the current with low flow and magnitude is flowing from region F to H. On ground plane, the current flows from J to L and M (beneath the feed line) through M region. Regions B, C, D and M act as resonator for DGS antenna at mentioned frequency.

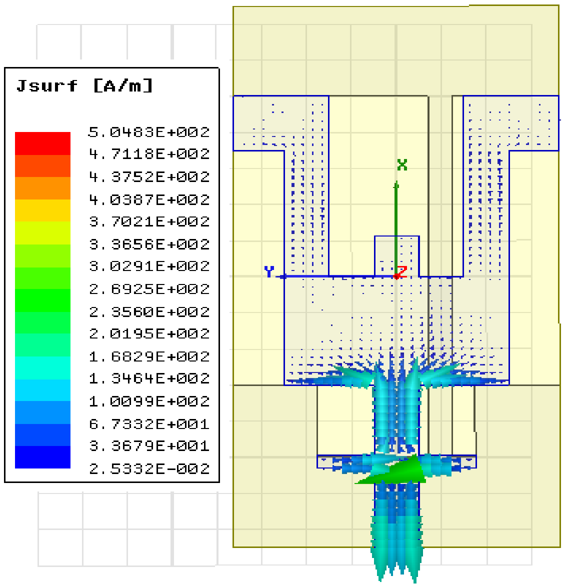

Fig. 6 Top View of Surface Current Density at 7 GHz

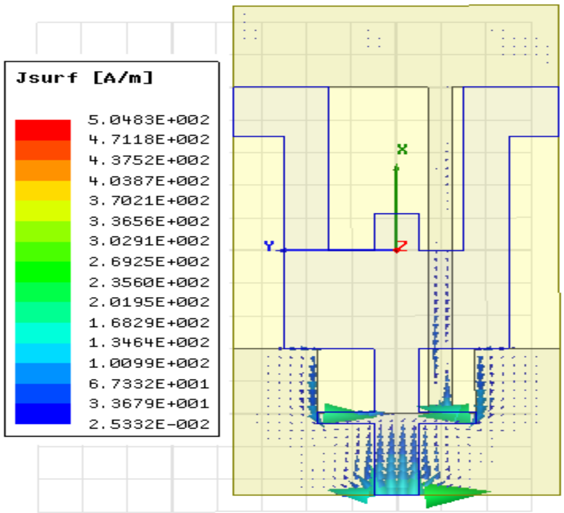

Fig. 7 Bottom View of Surface Current Density at 7 GHz

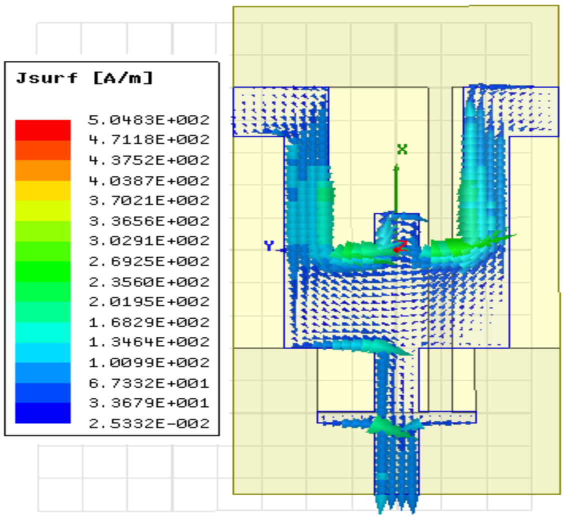

Fig. 8 Top View of Surface Current Density at 2.912 GHz

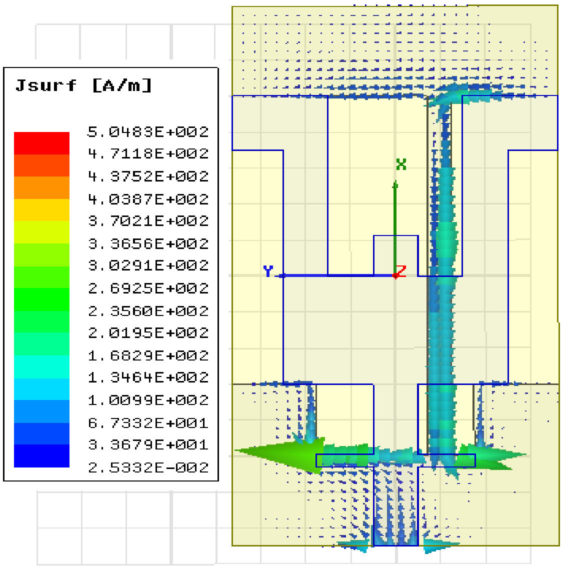

Fig. 9 Bottom View of Surface Current Density at 2.912 GHz

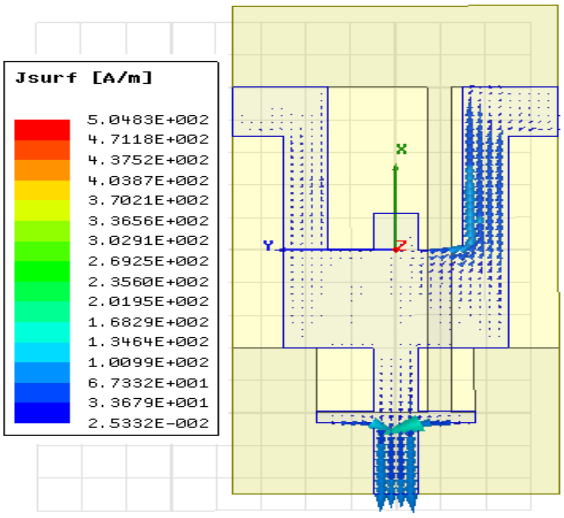

Fig. 10 Top View of Surface Current Density at 3.926 GHz

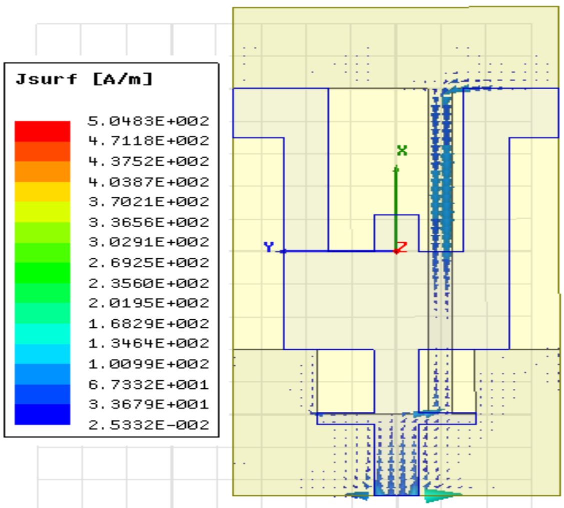

Fig. 11 Bottom View of Surface Current Density at 3.926 GHz

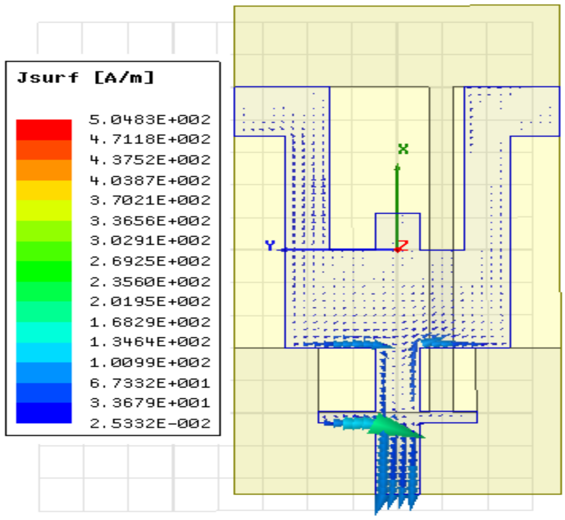

Fig. 12 Top View of Surface Current Density at 4.706 GHz

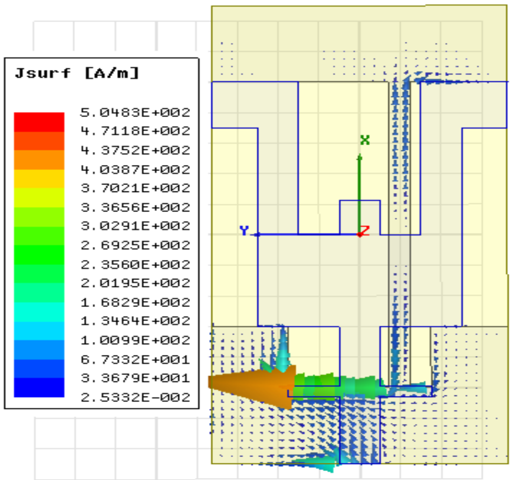

Fig. 13 Bottom View of Surface Current Density at 4.706 GHz

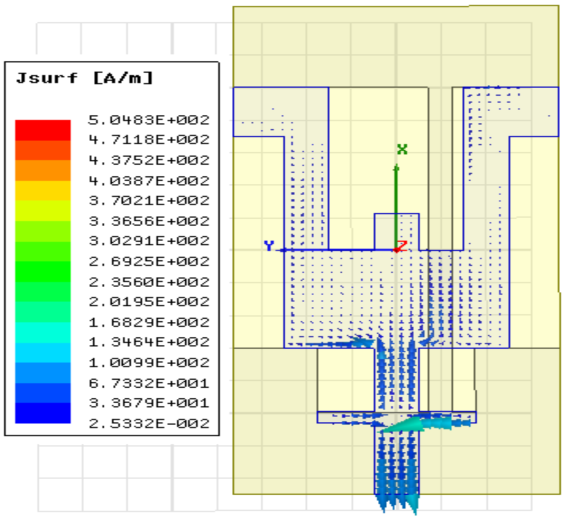

Fig. 14 Top View of Surface Current Density at 5.837 GHz

A low current flow and magnitude is observed at patch radiator and ground plane in Fig. 10 and Fig. 11 respectively when antenna operates at 3.926 GHz. At top of the structure, the current path is flowing from region D to E and from the cross to the lower side of region H, which has a similar direction on ground plane as the current is flowing from the upper to the lower side of region J. The resonance contribution is mainly performed by regions D and G. At 4.706 GHz, there is a uniform but low current flow across the whole patch. As it can be seen in Fig. 12, the main current path flow is concentrated from the cross to the lower side of region H.

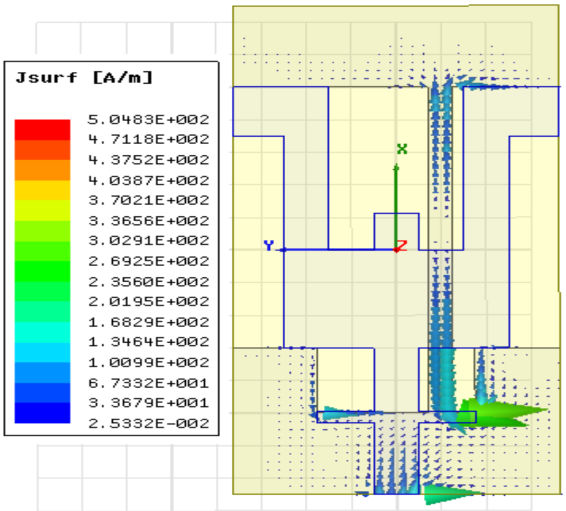

Fig. 15 Back View of Surface Current Density at 5.837 GHz

A stronger current intensity and flow is easily observed at ground plane as shown in Fig. 13. This intensity is mainly concentrated at L region; the path is going from the lower side of J and M regions. At 5.837 GHz there is a uniform and a low current flow across the whole patch except for the H region, where the main and uniform current intensity and density concentrate, as it can be seen in Fig. 14. Also is noticed a strongest current intensity and flow at ground plane are noticed as shown in Fig. 15. This intensity is mainly concentrated at K region, where the current path is going from the lower side of J and M regions to K.

2.2.3 Radiation

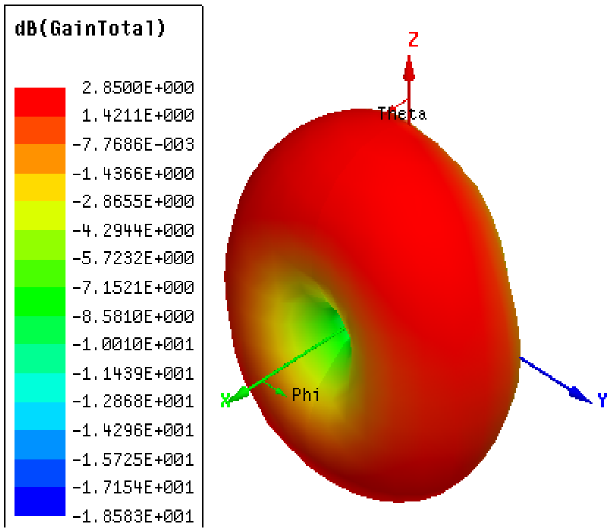

Fig. 16 Radiation Pattern

As Fig. 16 shows, the radiation pattern exhibits a broadside direction at E plane (y-z plane) with a total gain of 2.85 dB achieved at 20° and 150° on mentioned plane.

3 Parametric Study

Parametric study of a defected ground structure microstrip antenna is conducted by varying the width, length and position of antenna striplines at patch radiator and ground plane which helps understand the way it affects these variations over the reflection coefficient, impedance bandwidth and resonance frequencies.

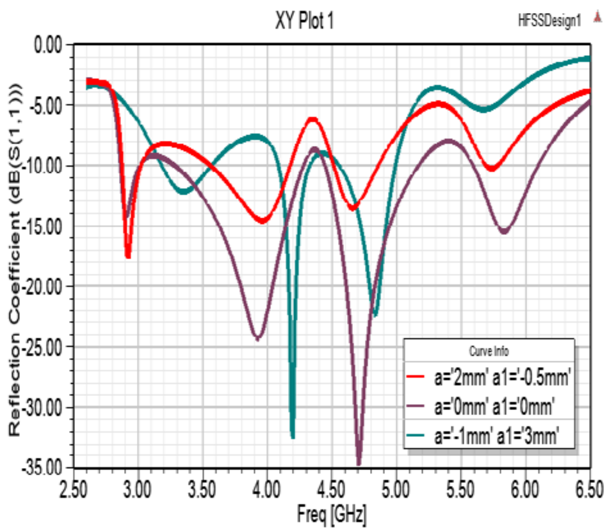

Fig. 17 Parameters ***a*** and ***a1***

As it can be seen in Fig. 17 it is possible to study the effects of the slot variations defined by parameters a and a1. Taking as reference point the parameters without modifications (a = 0 and a1 = 0) is observed that when parameters a increase and a1 decrease their dimensions, the 4th frequency is suppressed (becomes a triple band antenna); 2nd and 3rd frequencies reduced both impedance bandwidth and reflection coefficient values and 1st frequency increases its reflection coefficient value.

Otherwise, when a decrease and a1 increase, the 4th frequency is suppressed, it is also possible to evidence that the 1st frequency band is shifted to higher frequencies and reduced its reflection coefficient values, but 2nd and 3rd frequency bands only reduced their impedance bandwidth. The effects of slot parameters defined by a1 and cf are simulated as shown in Fig. 18. When mentioned parameters increase their dimensions a suppression of 1st frequency is observed, meanwhile 2nd frequency band reduces its reflection coefficient values and is shifted towards lower frequencies, but 3rd frequency band is shifted to lower frequencies and increases its reflection coefficient values; 4th frequency is shifted to higher frequencies and a 5th frequency appeared at 5.15 GHz. When a1 decreases and cf increases their dimensions compared to previous variations it is noticed that the DGS antenna resonates at a wideband frequency from 3.1 to 5.5 GHz.

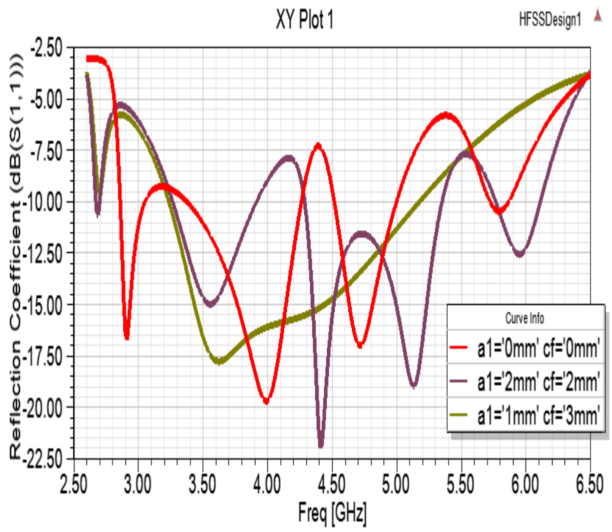

Fig. 18 Parameters ***a1*** and cf

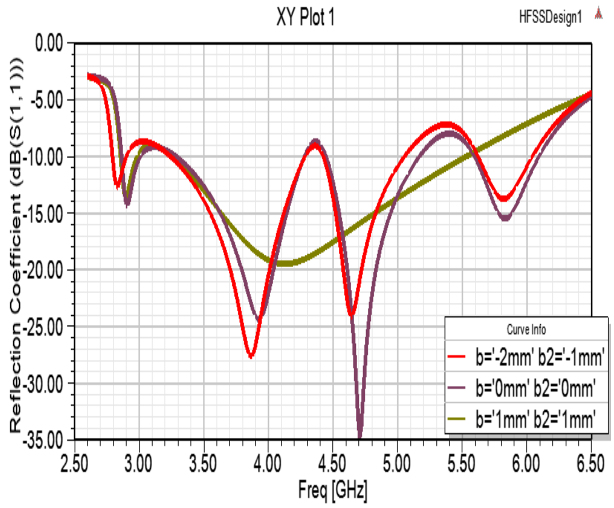

Fig. 19 Parameters b and b2

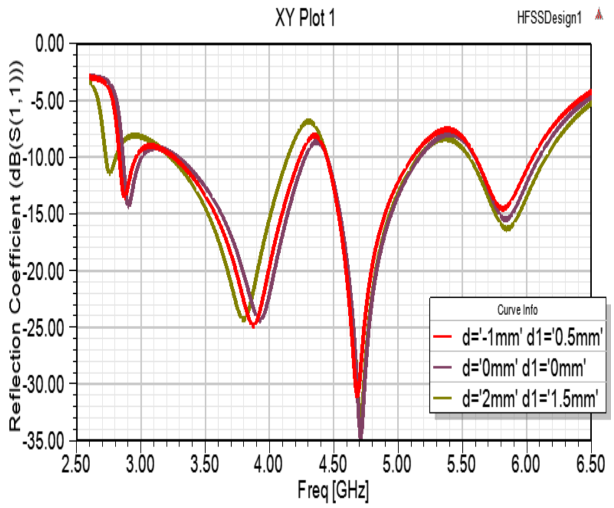

Fig. 20 Parameters d and d1

When slot dimension defined by b and b2 both decrease their dimensions, the antenna shows a bare variation on reflection coefficient values and a slight increment on resonance frequencies at lower ones as shown in Fig. 19. When mentioned parameters increase their dimensions, the antenna exhibits a unique frequency resonance between 3.3 to 5.5 Ghz.

A similar situation is shown in Fig. 20 as it was described in Fig. 19, where one of the parameters variation defined by d and d1 does not affect the reflection coefficient, resonance frequencies, nor bandwidth value, considerably; either the parameters increase or decrease there is not significant affections over the antenna properties.

Major variations are observed at Fig. 21 when m2 and m3 parameters vary. When mentioned parameters decrease the antenna becomes a dual band antenna merging the three first frequencies into a unique one with an impedance bandwidth of 2.5 GHz and the 4th frequency is shifted to higher ones in the same time it reduces its bandwidth and reflection coefficient values.

However, when mentioned parameters increase, the antenna becomes a dual band antenna and the three first frequencies turn into a unique one with an impedance bandwidth of 0.4 GHz in the same time it reduces its reflection coefficient values, and the 4th frequency is shifted to lower frequencies.

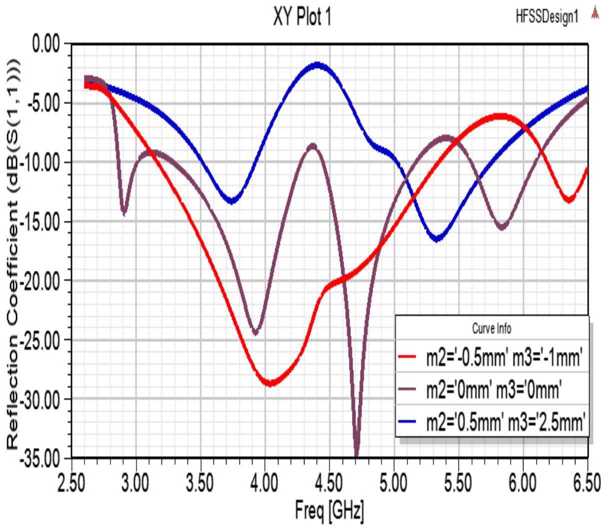

Fig. 21 Parameters m2 and m3

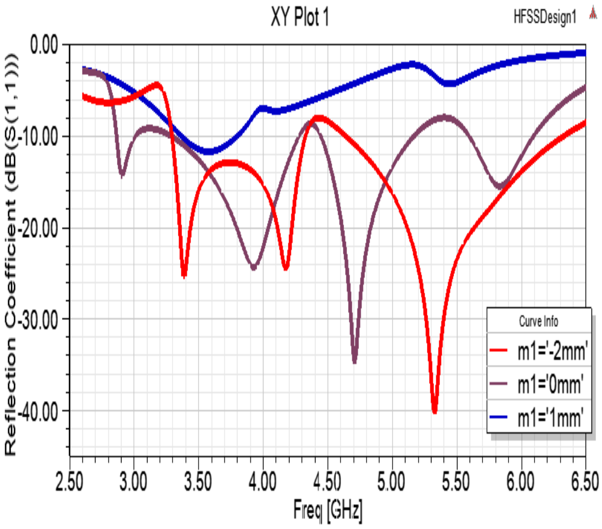

Fig. 22 Parameter m1

The effect of m2 variations over reflections coefficient, impedance bandwidth and resonance frequency can be observed in Fig. 22. When m1 increases, the suppression of all frequencies is observed, which means the antenna does not resonate at any frequency (1st frequency is barely lower than -11dB). However when mentioned parameter decreases 3rd and 4th frequency bands are merged into one band, it is also observed that 1st frequency is shifted to higher frequencies but it increases its reflections coefficient and the 2nd frequency is shifted to lower frequencies.

As it can be seen from Fig. 17 to Fig. 22 the defection on the ground plane play a key role in appearance and modification of resonance frequencies, impedance bandwidth of each frequency, reflections coefficient values and miniaturization of microstrip antenna. Also and as a result of parametric study, it was possible to stablish that the main contributors to improve or modify the antenna characteristics are B, C, D and J regions. Each time these regions vary, the current was perturbed in such a way that inductive and capacitive reactance modify antenna properties, especially those related with the ground plane.

4 Fabrication and Measurements.

Fig. 23 Top View of DGS Microstrip Antenna

Fig. 24 Bottom View of DGS Microstrip Antenna

The antenna was made using the LPKF ProtoMat S103 circuit board plotter for producing PCB/antenna prototypes. Once the antenna was fabricated (top and bottom view of fabricated antenna are shown in Fig. 23 and Fig. 24 respectively), the reflection coefficient parameter was measured (S11) using a vector network analyzer.

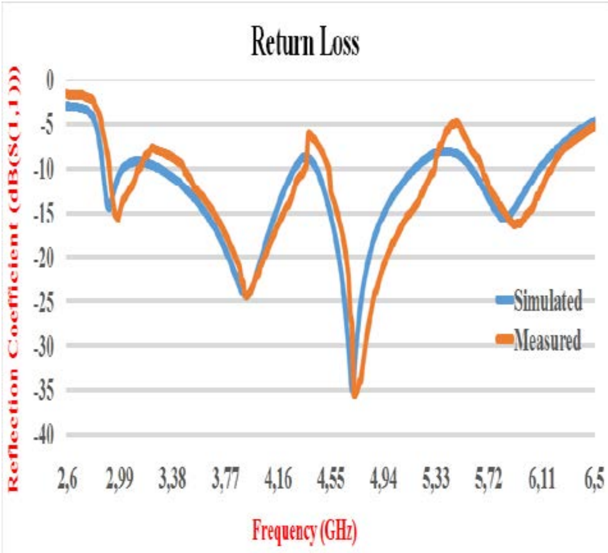

Fig. 25 Simulated vs. Measured Results

As shown in Fig. 25 there is a good agreement between simulated and measured results. Some discrepancies can be seen between the simulated and measured results, which may occur due to the effect of the SMA connector at solder point, fabrication imperfections and human error while carrying measurements on, using the vector network analyzes. According to measurements, the antenna resonates at 3 GHz (between 2.925 to 3.133 GHz), at 3.9 GHz (between 3.471 to 4.355 GHz), at 4.9 GHz (between 4.537 to 5.317 GHz), and at 5.9 GHz (between 5.681 to 6.162 GHz) for wireless communication applications.

In this design, it is not possible to achieve neither miniaturization nor multiband response without the ground plane defection. However, with this technique, the current path is disturbed and perturbed at both ground plane and at patch radiator, creating the tetra-band operation with reduction of antenna size.

5 Conclusions

In the current work, a tetra-band modified bident defected ground structure microstrip antenna is designed, simulated and fabricated keeping a low profile (1.2mm) and using a low cost substrate (FR4). The antenna parameters were simulated using ANSYS HFSS software and measurements were carried out with a Vector Network Analyser for reflection coefficient parameter measurement. Simulated and measured results showed that the antenna resonate at 3 GHz (between 2.925 to 3.133 GHz) with an impedance bandwidth of 208 MHz, at 3.9 GHz (between 3.471 to 4.355 GHz) with an impedance bandwidth of 884 MHz, at 4.9 GHz (between 4.537 to 5.317 GHz) with an impedance bandwidth of 780 MHz, and at 5.9 GHz (between 5.681 to 6.162 GHz) with an impedance bandwidth of 481 MHz for wireless communication applications.

Defection at ground plane plays a key role as it controls the resonance frequency along with structure miniaturization. A proper dimension and position modification at grounds defection (I to M regions), patch radiator and cross (BCD and H regions) current distribution can be modified, which means a modification of the resonance frequencies, enabling the antenna to resonate at other frequencies (four in total). As the current paths change according to dimension and position variation of defection and path, it will have a subsequent effect over radiation pattern, gain and bandwidth.

Therefore, the designed antenna can work within WiMAX and WLAN compliance applications. Current antenna may work as a reference for future works related to optimization and improvement of defected ground structure antennae aiming ongoing miniaturization over current dimensions, gain enhancement or modifying other desired characteristic with the intention of improve it.

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