Design of Microstrip Antennas Based on Fractal Geometry with Parasitic Patches for Ultra-Wideband Applications

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Abstract

In this paper two design of fractal geometry for microstrip antennas is presented for ultra-wideband applications. The first structure is implemented on four upright triangular patches and several iterations are applied on its initial shape. While, the second design based on the same fractal geometry with four direct coupled and other electromagnetic coupled (EMC) parasitic patches. The idea of inserted parasitic patches will make the current path became longer than the topological length, then UWB characteristic is achieved her. The computed bandwidth is 1.69 *GHz* for the first geometry, and it is 10.5 *GHz* for the second. A comparison is made up between the computed bandwidths for the two designs and the advantage of inserting the parasitic patches became clear. The comparison shows the enhancement in bandwidth for the second design. Furthermore, these structures have low profile, lightweight and are easy to be fabricated and have successfully demonstrated UWB characteristics. The simulated results show that, the proposed antenna has very good performance in impedance bandwidth with accepted radiation pattern.

Keywords: microstrip antenna , ultra-wideband, current path, parasitic patche

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1. Introduction

The accelerating progress of the wireless communication and the ever increasing number of communication and navigation services such as cellular phones (GSM, GPRS, WCDMA), Global Positioning System (GPS), ground penetrating radars, high data rate short wireless local area communications (WLAN), parking radars, and other applications in the last few years, has created an ever-growing demand for multi systems application. To cover many or all of these services by one system, it's required a very high bandwidth antenna or as called ultra-wideband (UWB) antenna with compact size and adequate performance that can be exploited in wireless communication systems. There is an important relation between antenna dimensions and wavelength. This relation states: if antenna size is less than the quarter of the wavelength ($\lambda/4$) then the antenna is not efficient because radiation resistance, gain and bandwidth is reduced and therefore antenna size is increased[1]. Fractal geometry [1-3] is a very good solution for these problems. These structures are recognized by their self-similarity properties and fractional dimension. In the recent years, the geometrical properties of self-similar and space filling nature has motivated antenna design engineers to adopt this geometry a viable alternative to meet the target of multi, Broad-band as well as ultra-wideband operation. T. Kikkawa, K. Kimoto and S. Watanabe was modified the characteristics of Sierpinski carpet fractal antenna for UWB operation. The antenna is fabricated on silicon substrates with the resistivities of (2290 Ω, 79.6 Ω, and 10 Ω) [4]. New fractal geometry for microstrip antennas is presented by A. Azari and J. Rowhani. This fractal structure is implemented on hexagonal and several iterations are applied on initial shape. This antenna successfully demonstrated (UWB) characteristics (from 0.1GHz to 24GHz) [5]. S. N. Khan, J. Hu, J. Xiong, and S. He introduce circular ultra-wideband fractal monopole antenna based on descartes circle theorem (DCT) with elliptical iterations. Their design is optimized for return loss below (−15 dB) [6]. G. M. Yang, R. H. Jin, G. B. Xiao, C. Vittoria, V. G. Harris, and N. X. Sun design novel ultra wideband (UWB) antennas with multi resonant split-ring loops and with coplanar waveguide (CPW) feed [7]. A. Aggarwal and M. V. Kartikeyan show the design of a fractal patch antenna, which uses a unique fractal geometry known as Pythagoras tree with co-planer waveguide (CPW) feeding. The antenna has been designed for dual band operation at the WLAN/WiMAX (2.4GHz) and WiMAX (3.5GHz) for ultra-wide bandwidth applications [8]. K. Song, Y.-Z. Yin, B. Chen, and S.-T. Fan, introduced novel compact microstrip fed ultra-wideband (UWB) step-slot antenna with a rotated patch. The antenna has effective combination of the step-slot and rotated patch and proper dimensions bandwidth enhancement for UWB operation is obtained [9].

In this paper, it used the attributes of fractal properties with aid of direct and indirect EMC parasitic patches to design UWB antenna. The proposed antennas are created two probes feeding with zero phase shifts. The characteristics of the proposed antenna structure has been predicated using full–wave numerical Method of Moment (MOM) by Microwave Office v.7.5, of the applied wave research includes a full wave electromagnetic solver that uses a modified spectral domain method of moments to accurately determine the multi-port scattering parameters for planar structure.

2. Antenna Configuration and Design

For this paper, there are three main parameters that had to satisfy. Those parameters were the bandwidth of the antenna, the radiation pattern of the antenna, and the antenna size. These parameters will help us understand if the antenna we are designing will be the optimal design for our application. The antenna utilized in this paper is combinations of four triangular patches with several iterations are applied on its initial shape, with four direct coupled triangular parasitic patches and four EMC parasitic patches. The antenna consists of single layer with substrate with thickness (h) and dielectric constant (ε_r).

The generation of the antenna fractal geometry is explained in Figure (1). The base fractal geometry consists of four triangular patches. The explanation of the generation base on two criteria: first is multiple scaling copies, and secondly is shifting. The scaling copy patches, and the shifting in position for iteration level *n* and triangular side lengthcan be expressed in the mathematical forms as:

$$\left[Z_1^n(x,y)\right] = \begin{bmatrix} 0.5 & 0 \\ 0 & 0.5 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \ell^{n-1} \begin{bmatrix} 0.5 \\ 0.5 \end{bmatrix} \ldots\mathbf{(1)}$$

$$\left[Z_2^n(x,y)\right] = \begin{bmatrix} 0.5 & 0 \\ 0 & 0.5 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \ell^{n-1} \begin{bmatrix} -0.5 \\ 0.5 \end{bmatrix} \ldots\mathbf{(2)}$$

$$\left[Z_3^n(x,y)\right] = \begin{bmatrix} 0.5 & 0 \\ 0 & 0.5 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \ell^{n-1} \begin{bmatrix} 0.5 \\ -0.5 \end{bmatrix} \ldots\mathbf{(3)}$$

$$\left[Z_4^n(x,y)\right] = \begin{bmatrix} 0.5 & 0 \\ 0 & 0.5 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \ell^{n-1} \begin{bmatrix} -0.5 \\ -0.5 \end{bmatrix} \ldots\mathbf{(4)}$$

While, the total length (perimeter) in terms of side (topological) length is:

$$\ldots\mathbf{(5)} \qquad D = \left(\frac{1}{2}\right)^n \left[1 + \left(\frac{1}{2}\right)^n\right] \ell$$

Where: ℓ is the side length.

Figure (1) shows the base shape of four triangular patches fractal and its first and second iterations. In this paper only the first and the second iterations are considered since higher order iteration does not make significant affect on the antenna properties.

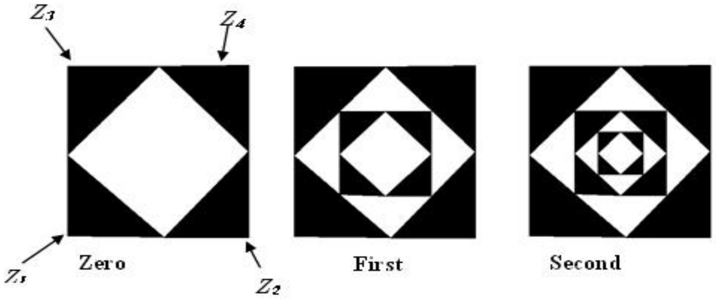


Figure (1) Fractal Proposed Geometry

3. Results and Discussion

Theoretical performance of the modeled antenna structures have been predicated using full–wave numerical Method of Moment (MOM) Microwave Office of the applied wave research includes a full wave electromagnetic solver that uses a modified spectral domain method of moments to accurately determine the multi-port scattering parameters for planar structure (Microwave Office). The First structure of the designed fractal antenna is shown in figure (2) and had been located parallel to x-y plane and centered at the origin (0, 0, 0) for the following specifications:

Table (1) Antenna Structure Specifications

Patches Size	Substrate Thickness (h)	Substrate Material (εr)	Ground Plane	Feed Type
13.5× 13.5 mm (zero iteration)	1.589 mm	4.4	20 × 20 mm	Coaxial Cable (50 Ω)

The simulated input return loss is shown in figure (3). The computed bandwidth is 1.69 GHz$(at\, which S11 \leq 10\, dB)$. Figure (4) shows E and H-plane radiation power pattern plots for three frequencies. It can be show that, no pattern phase shift occurs in this design.

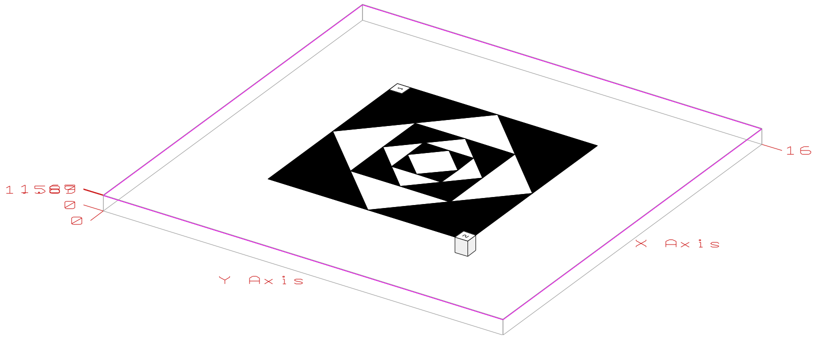
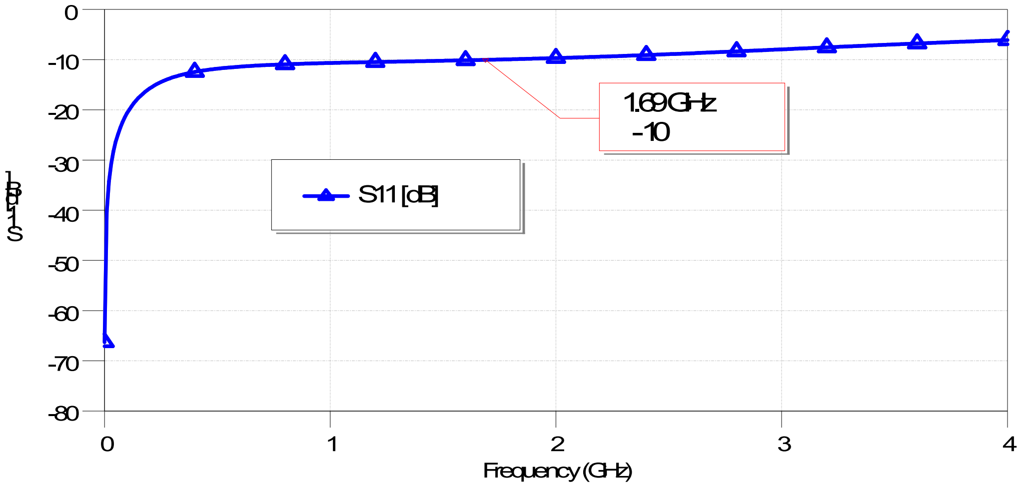


Figure (2) First Design (Fractal Geometry Proposed)



Figure(3) Return Power Loss Variation w.r.t Frequency

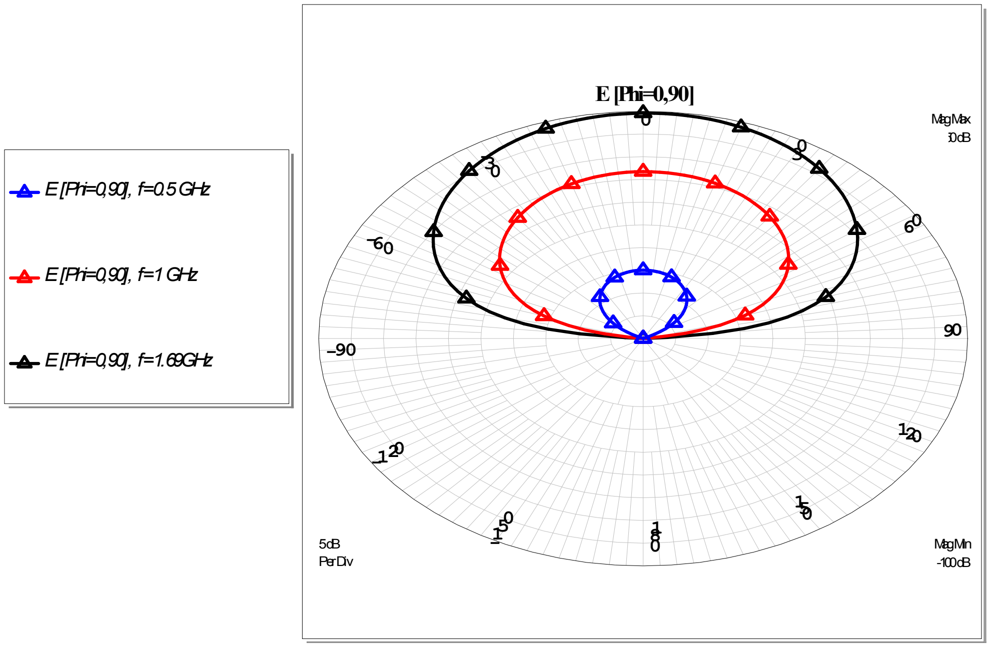


Figure (4) Normalized Power Pattern for the First Design

The second designed structure which represents two types of parasitic patches (direct and electromagnetic coupled) based on the first fractal structure geometry ha the specifications shown in table (2). Figure (5) show the design structure. The return power loss is shown in figure (6). The bandwidth is 8.5 *GHz*$(S11 \leq 10\,dB)$. Figure (7) shows the input impedance response. The E and H-plane are shown in figure (8) which show a phase shift will established along the broadside direction with frequency variation. Figure (9) shows the variation of the phase shift established as a function of frequency. Figure (10) shows the directivity variation with frequency.

Table (2) Antenna Structure Specifications

Patches Size	Substrate Thickness (h)	Substrate Material (εr)	Ground Plane	Feed Type
13.5 × 13.5mm (zero iteration)	**1.589 mm**	**4.4**	**20 × 20 mm**	**Coaxial Cable (50 Ω)**

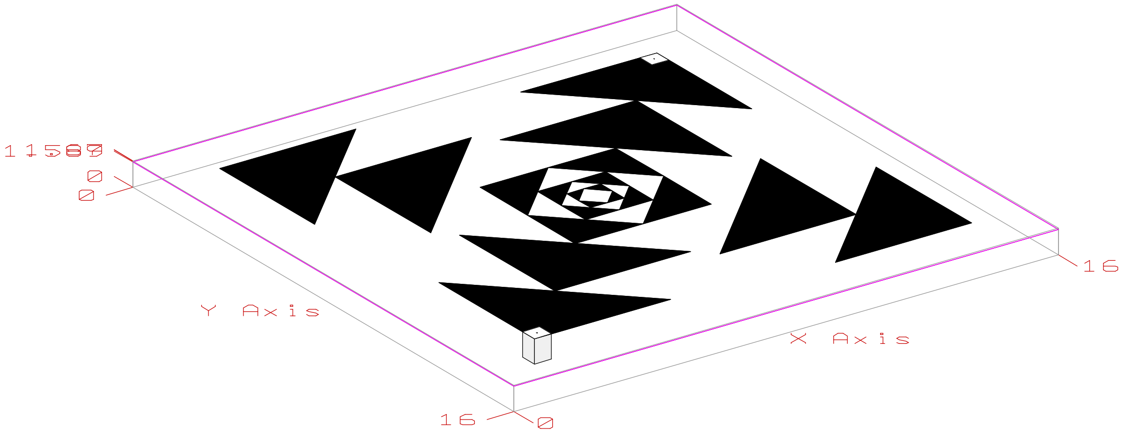


Figure (5) Second Design (Fractal Geometry Proposed)

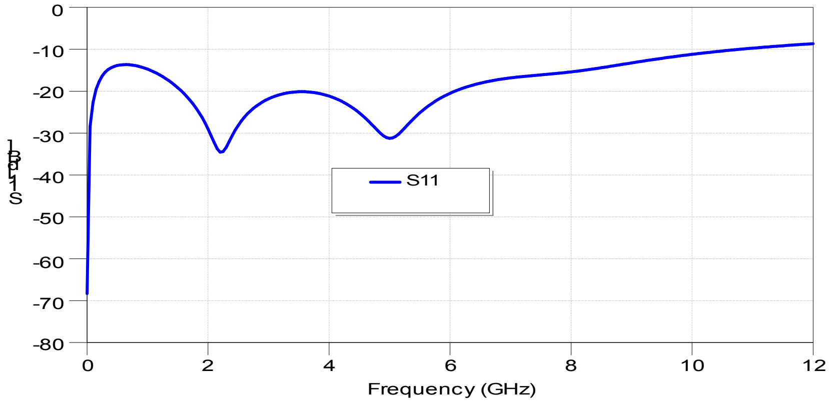
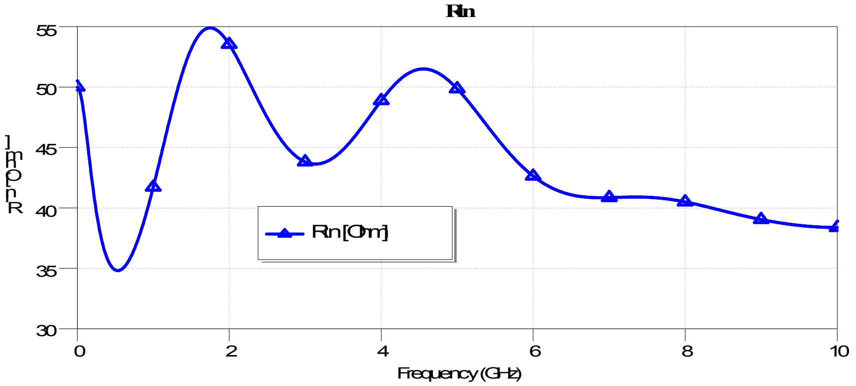
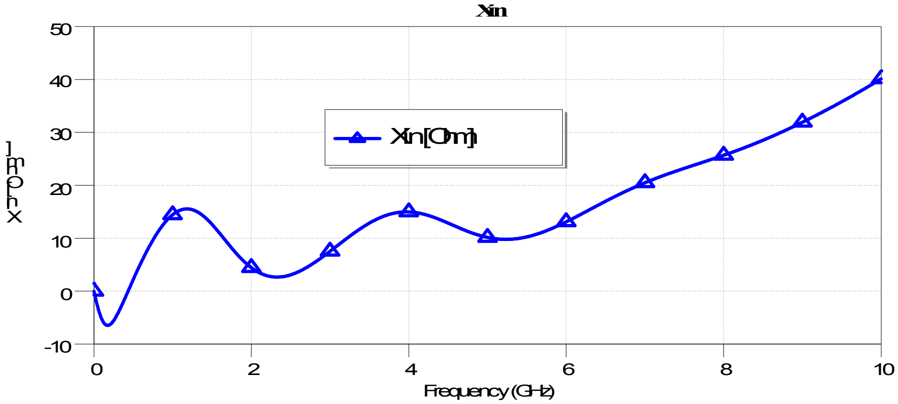


Figure (6) Return Power Loss Variation w.r.t Frequency for the Second Design



(a)



(b)

Figure (7) Input Impedance Variation w.r.t Frequency: (a) Input Resistance, (b) Input Reactance

Table 3 shows all frequency bands obtained with size reduction compared with traditional rectangular patch for each band. No interested reduction in size occurs in the 6 GHz frequency band and above that frequency.

Table (3) Reduction in Size

Resonance Frequency (GHz)	Reduction in size
f_1=1	92%
f_2=2	82%
f_3=3	68%
f_1=4	47%
f_2=5	16%
f_3>6	No Reduction

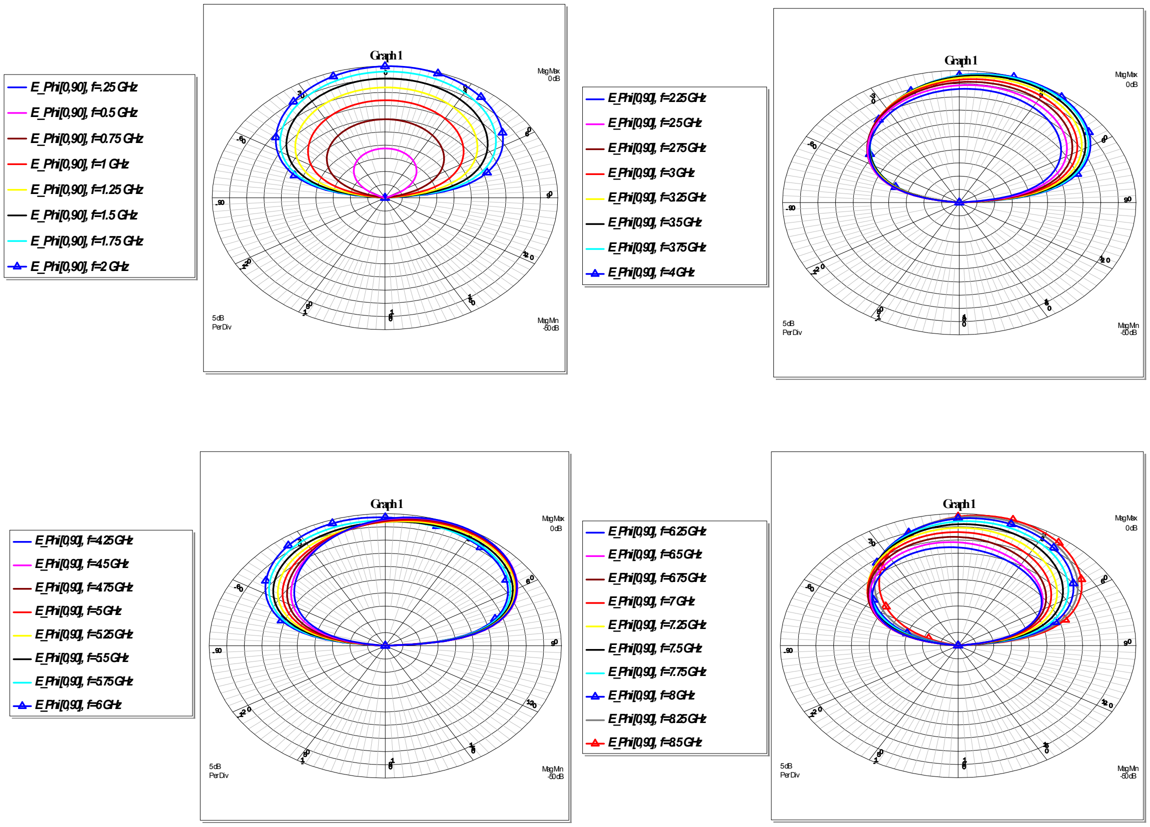


Figure (8) Normalized Power Pattern for the Second Design

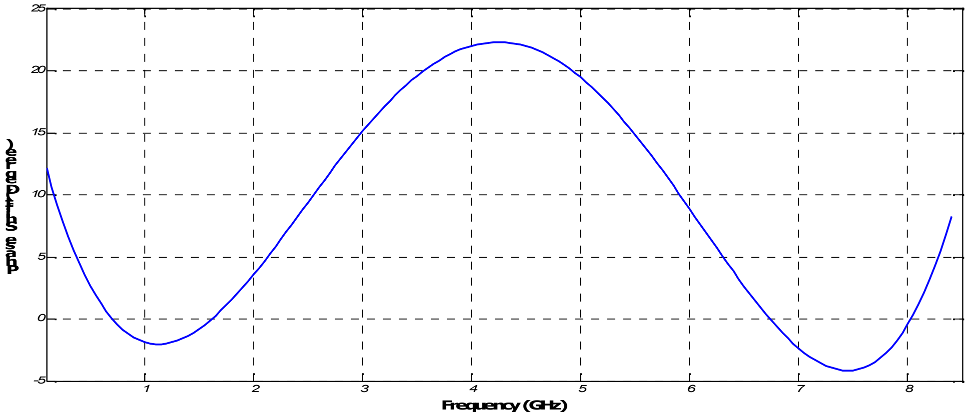


Figure (9) Phase Shift Established w.r.t Frequency

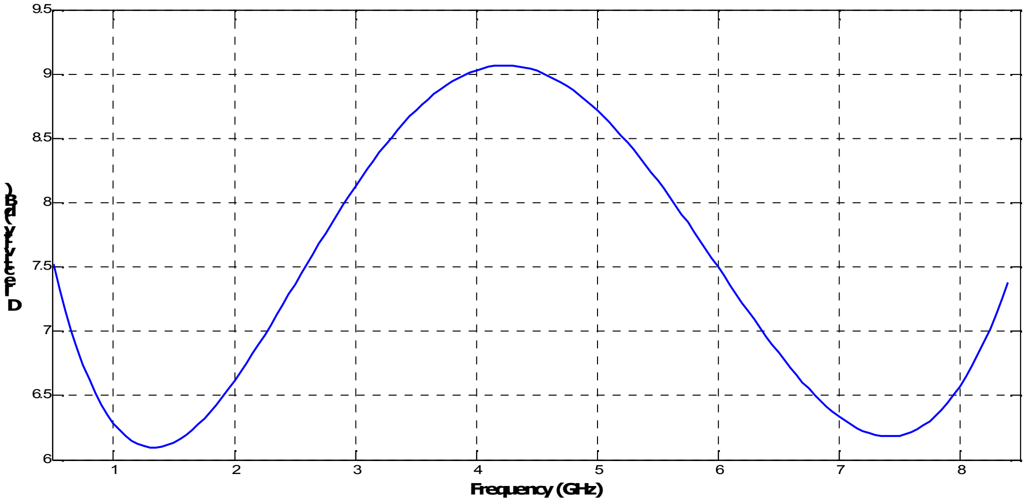


Figure (10) Directivity Variation w.r.t Frequency

4- Conclusions

From the above presentations, the following points are concluded:

1. The geometric structure of the antenna and also the length was derived, The antenna structure presented in this paper is compact, has low profile, light weight and is easy to be fabricated and have successfully demonstrated ultra-wideband (UWB) characteristics (the computed bandwidth is 1.69 *GHz* for the first geometry, while it is 10.5 *GHz* for the second), without increasing the substrate thickness or decreasing the substrate dielectric constant.
2. Broadside radiation characteristics are achieved from the first antenna design, while a phase shift angle (from broadside direction) will be established for the second design (about -4 to 22^o) in impedance frequency band. This is because the different phase between the parasitic patches due to geometry.
3. The change in the directivity in the impedance frequency band is about 3.9 dB (from 5.2 dB to 9.1 dB), which means that, the second design has not very good field variation.

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تصميم الهوائيات الشريطية الدقيقة استنادا على الهندسة الجزئية مع بقع طفيلية للتطبيقات فائقة الحزمة الترددية

م . زيد اسعد عبدالحسين*

المستخلص

يقدم هذا البحث تصميمين للهوائيات الشريطية الدقيقة ذات الهندسة الجزئية للتطبيقات الواسعة الحزمة جدا(UWB) . إنّ التصميم الأولَ مُطَبَّق ُعلى أربع رقعِ مثلثيةِ قائمة الزاوية وعِدّة تكرارات طبقت على شكلِها الأولي. بينما، التصميم الثاني مستند على نفس الهندسةِ مع أربعة رقع طُفيلية مربوطة بشكل مباشر(direct coupled) واخرى بطريقة الحث الكهرومغناطيسي (EMC). ان فكرة أضافة الرقع الطفيلية هو لزيادة طول مسار التيار وبالتالي الحصول على حزمة عريضة جدا.ان عرض الحزمة التي تم التوصل لها بالنسبة للتصميم الاول هو 1.69 *GHz* بينما هو 10.5 *GHz* للتصميم الثاني. تم مقارنة عرض الحزمة لكلا التصميمين بالاضافة الى ان عرض حزمة الهوائي تزداد وبشكل كبير جدا بأضافة تلك الرقع. هذه التراكيب لِها منظر صغير، وزن خفيف وسهلة التصنيع و تظهر الخصائص العريضة الحزمة جدا. كما ان نموذج الهوائي المقرح ان الهوائي المقدم يعطي اداءا عاليا جدا من ناحية عرض حزمة ممانعة الدخل وكذلك شكل الأشعاع.

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