COMPACT MULTI-RESONANT PATCH ANTENNA WITH FRACTAL SLOTS INSPIRED BY SMITH CHART CONFIGURATION

[1]ALI HARMOUCH, [2]IHAB HASSOUN

[1,2]Lebanese University, Faculty of Engineering, CRSI, EDST, Tripoli, Lebanon
E-mail: [1]harmush_ah@hotmail.com, [2]ihab_hassoun1@hotmail.com

Abstract - This paper describes the design and analysis of a multi-resonant compact patch antenna with fractal slots on the basis of Smith Chart geometry for indoor communication systems. A (70mm x 70mm x 4 mm) single circular patch antennas with periodic fractals in the form of combined r and x circles is capable of resonating at some desired sub-bands starting from GPS to WI-MAX with good enough directional characteristics greater than 3 dB in average within the whole frequency band. The dielectric material used for the proposed Microstrip patch antenna is Rogers RO3006 with dielectric constant of 6.15 and the patch is made up of perfect electric conductor (PEC). The proposed fractal geometry possesses multiband behavior at 1.35 GHz, 1.52 GHz, 2.2 GHz, 2.55 GHz, 3 GHz, 3.47 GHz 3.66 GHz, 4 GHz and ultra-wideband from 4.16 GHz till 6 GHz. In comparison with the already existing antenna systems in the wireless market for similar purposes, the proposed antenna has considerably shown better performance and supplementary compactness which makes it competitive among other antenna models.

Keywords - Multi-Resonant; Compact Patch Antenna; Fractal Geometry; Smith Chart; Sub-Band.

I. INTRODUCTION

The reputation of mobile communication systems has increased remarkably during the last years and the market demand is still growing so fast. As a major part of these systems, antenna is one of the most important design issues in modern mobile communication units. Because antennas are frequency dependent, they are designed to operate for definite frequency bands. Nowadays, the cellular industry requires antenna systems capable of performing over many desired sub-bands within the frequency range extended from LTE up to Wi-Max frequencies with a minimum size, weight and cost. Many antennas have been implemented to cover the whole band from 700 MHz up to 6 GHz with good enough electrical characteristics; however, these antennas unfortunately cover some frequencies that are not in use and are out of interest[5,7,8]. This comes in the expense of increasing the size of the designed which makes it inconvenient and impractical in many applications needed in the wireless market. The paper purposes a multiband printed circular patch antenna integrated with periodic fractals in the form of r and x-circles inspired by Smith Chart geometry. These periodic structures would allow a single patch antenna to resonate at multiple frequencies, so that by adjusting their number, shape, width and their positions with respect to each other within the patch, the selection of the desired set of bands is easily achieved. The frequencies of interest include 700 MHz (LTE), 900MHZ (GSM), 1150 MHz (GPS systems), 1800 MHz (GSM), 2400 MHz (IEEE 802.11g W-LAN bands), 3700 MHz (IEEE 802.11y), and 5200/5800 MHz can be used for WI-MAX applications.

Fractals are geometrical shapes, which are self-similar, repeating themselves at different scales [2]. The geometry of fractals is convenient in this project since fractal slots would increase the electrical size of the antenna without affecting its physical geometry and hence enhancing the bandwidth characteristics using a simple and compact model. Fractal is a concept which is recently being implemented in Microstrip antenna to have better electrical and mechanical characteristics than conventional microstrip antennas [1]. These periodic fractals in the form of Smith Chart's r and x-circles are shown in figure 1.

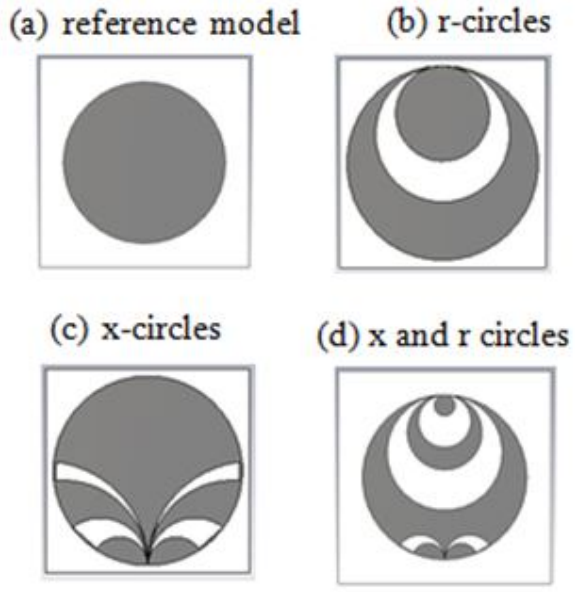


Fig.1. Fractal slots on a circular patch on the basis of Smith Chart configuration

Rumsey, a well-known scientist, established that an antenna with shapes only defined by angles would be frequency independent, since it would not have any characteristics size to be scaled with wavelength [1]. The terms "fractal" was first used by mathematician Benoit Mandelbrot in 1975.The scarcity of fractal

designs for Microstrip patch antenna has made this topic a premier research area.

II. MATHEMATICAL DESCRIPTION OF " r" AND "x" CIRCLES OF THE SMITHCHART

The Smith Chart is a graphical representation of the input impedance as one move along the line and is plotted along within a circle of radius 1. It is mainly consisting of r and x-circles mapped together within the reflection coefficient circle and with a center point representing the perfect matching condition of an antenna [1]. The mathematical representation of these circles is easily expressed and they are written in the form below.

$$(\Gamma_r - \frac{r}{r+1})^2 + (\Gamma_i)^2 = (\frac{1}{r+1})^2 (1) \quad "r-circles"$$

$$(\Gamma_r - 1)^2 + (\Gamma_i - \frac{1}{x})^2 = (\frac{1}{x})^2 (2) \quad "x-circles"$$

Where Γ_r, is the real part of the reflection coefficient; Γ_i is the imaginary part of the reflection coefficient; r is the normalized resistance indicating the r-circles which may take only positive values from zero up to infinity; and x is the normalized reactance indicating the x-circles which may take positive or negative values from zero up to infinity. The shape of these circles is well illustrated by the well-known Smith Chart configuration.

So introducing these periodic fractal structures in the form of r and x-circles in a specific manner to the conventional circular patch antenna would makes the antenna capable of resonating at multiple desired frequency bands with a good directional capabilities. In addition, the manipulation of these fractals would provide some degrees of freedom to us as designers to select the appropriate place for the resonance without varying the physical dimension of the proposed antenna [2,3,4].

It is important to mention here that introducing all the parameters of the fractals such as their number, width, ratio with respect to each other, and position would be very convenient in the analysis and design process of the proposed antenna model and would provide a parametric tool for performance enhancement of all electrical and mechanical parameters. Such types of slots were selected since they well match the circular geometry of the conventional patch antenna and would not negatively affect any of the three antenna's dimensions. This makes the idea very suitable and promising for any future development of compact multiband antenna systems.

III. ANTENNA DESIGN AND SIMULATIONS

In high performance aircraft, spacecraft satellite and missile application where size, weight, cost, performance, ease of installation and low profile antennas are strictly required compact and multiband antennas are very dominant and of a huge interest. Presently there are many other governmental and commercial applications, such as mobile radio and wireless communication, which have almost similar requirements in terms of parameters and specifications. To meet these requirements printed patch technologies have been used since they are cheap and have a very low profile. However, these antennas are considered as narrow-band devices and not capable of handling a high power level which puts limitations of their usage in some applications. It is theoretically and practically known that using slots in patch antennas can create multiple resonant frequencies, and hence improve the bandwidth characteristics of patch antennas, however the type, shape and position of these slots must be selected properly and a compromise must be followed in every design according to the problem under consideration.

In this paper, it is proposed to create slots with specific forms inspired by the geometry of r and x-circles of the SmithChart. The proposed fractal geometry for Microstrip patch antenna uses the dielectric substrate Rogers TMM4 with a dielectric constant 4.5. The radius of the conventional circular patch is 23.22 mm placed on the top of the dielectric substrate and there is a ground plane below the dielectric substrate. The size of the substrate and ground plane is 70mm x70mmFig.1 (d) shows the top view of the Microstrip patch along with the different iterations of fractal slots on the patch. The scaling ratio for the r-circles k, has a different value according to the simulation analyses 0.7, 0.65 and 0.45 respectively so the consecutive radius of the r-circles is given by k*r. The scaling factor k is to be changed within the range of values stated above in order to control the number of resonant frequencies as well as their locations within the entire bandwidth of interest. The center of the circles is moving along the y-axis. Based on [2,3,4,9], the fractalization process was found to saturate after the 2nd iteration of r-circles which is correct and the number of peaks in the frequency band will also decrease. Therefore, it is suggested introducing x-circles to obtain more peaks and to manipulate the location of the resonances within the desired bandwidth.

As discussed before, the problems involved in using fractal geometries is that there is no mathematical equations describing their exact performance and how they affect the input impedance characteristics of the antenna in which they are placed. Therefore, in order to predict the position of resonant frequencies in the band a series of simulations has been performed using the transient solver of CST Microwave Studio 2014 with 10 cells/wavelengths. The higher iteration of fractal geometries are made and are excited by An SMA connector.

So, adding a set of slots (in the form of **r-circles**) with different scale factor, to the conventional patch antenna, a multiple resonance behavior is created. However, the number of peaks (resonances) would not increase as the number of (slots) iterations is getting more than 3. This can be explained as if the antenna has a saturation level in terms of resonance number.

Now, adding two x-circles on either side of the same circular patch, as shown in figure 1(c), would result in different peaks locations, without being capable of reaching the lower part of the bandwidth which is the LTE band. This can be obviously seen via the Return loss graph in figure 2.

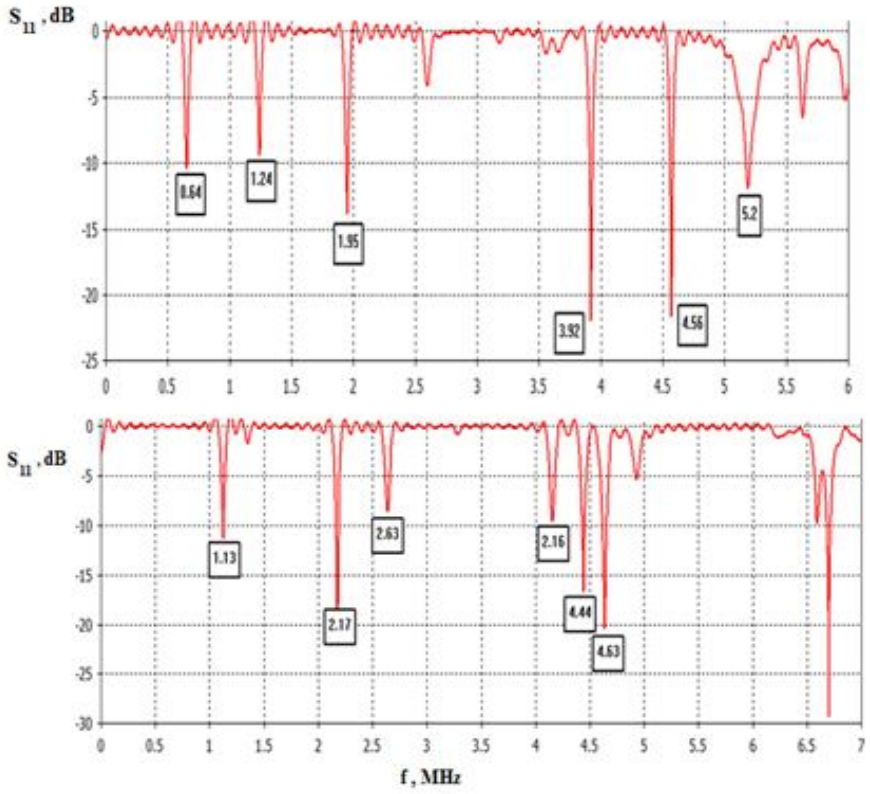


Fig.2.S_{11} of the antenna with fractal structure shown in Figures 1(b) and 1(c)

As seen from the two figures above, it is shown that every type of circles would act differently without achieving the main goal of the project. , therefore, it has been suggested to combine both types of circles in one circular patch antenna (see fig.1"d") in order to increase the number of resonances and also to locate the peaks (resonances) within the entire band in the correct and desired positions. Simulation results of the combined case are shown in figure 3.

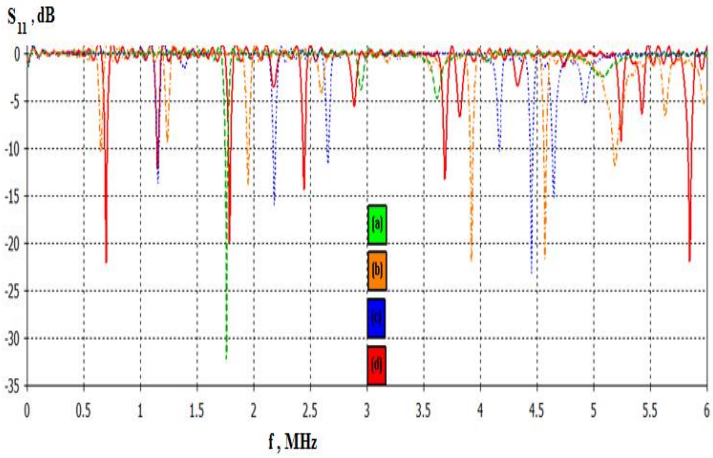


Fig. 3. $S_{11}$of the antenna with fractal structure shown in fig. 1(d)

To better illustrate these results it has been suggested to cut the above figure into subfigures, each covering a sub-band of the desired bandwidth: (0.5 - 2 GHz), (2 – 4 GHz) and then (4 – 6 GHz). This is illustrated in figure 4 below.

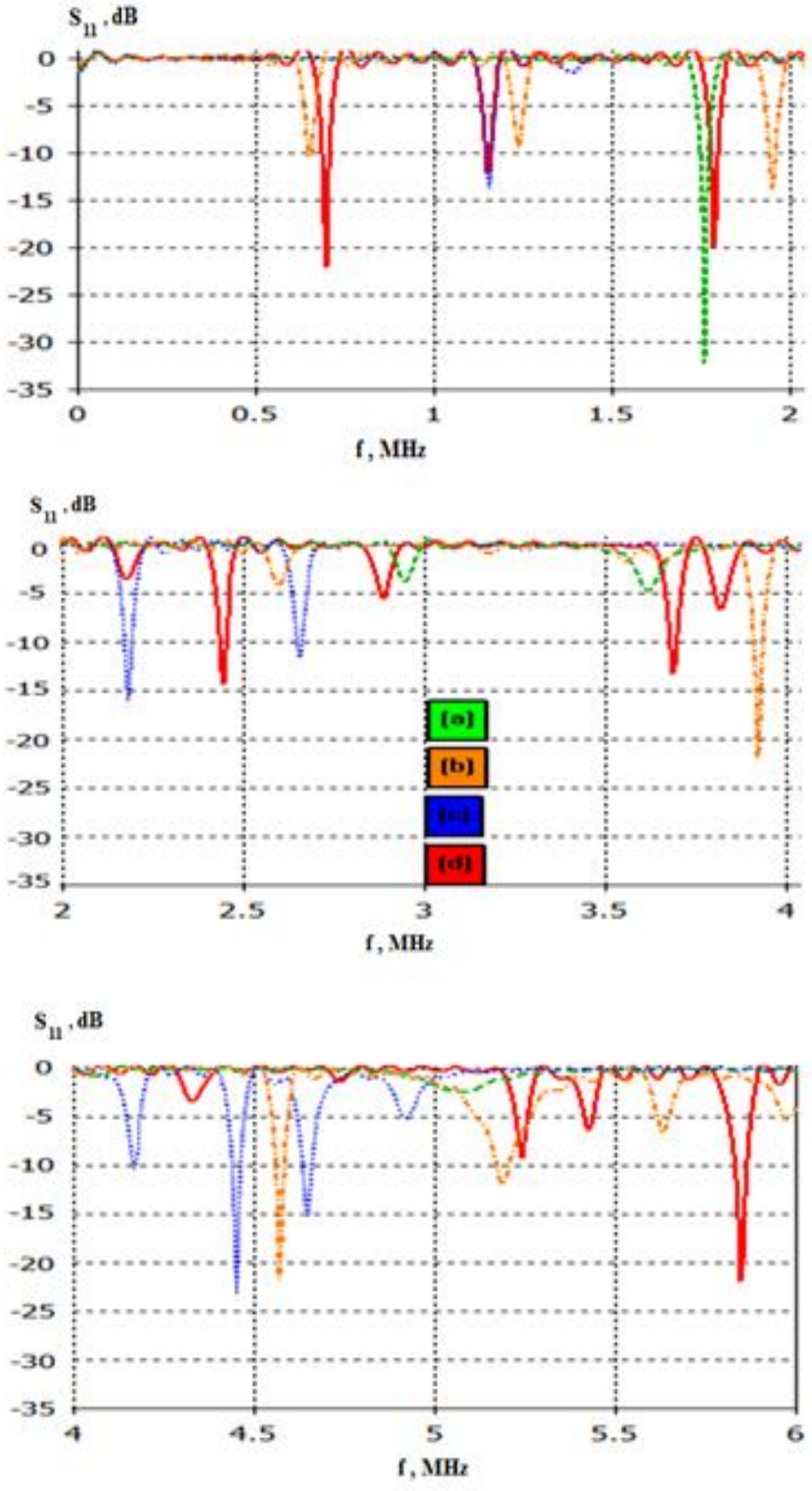


Fig. 4.Subdivided $S_{11}$of the antenna with combined fractal structure shown in fig.1 (d)

The radiation patterns of the proposed antenna of fig.1 (d) are showing an acceptable gain all over the frequency bands stated in this paper. This is reflected in figure 5.

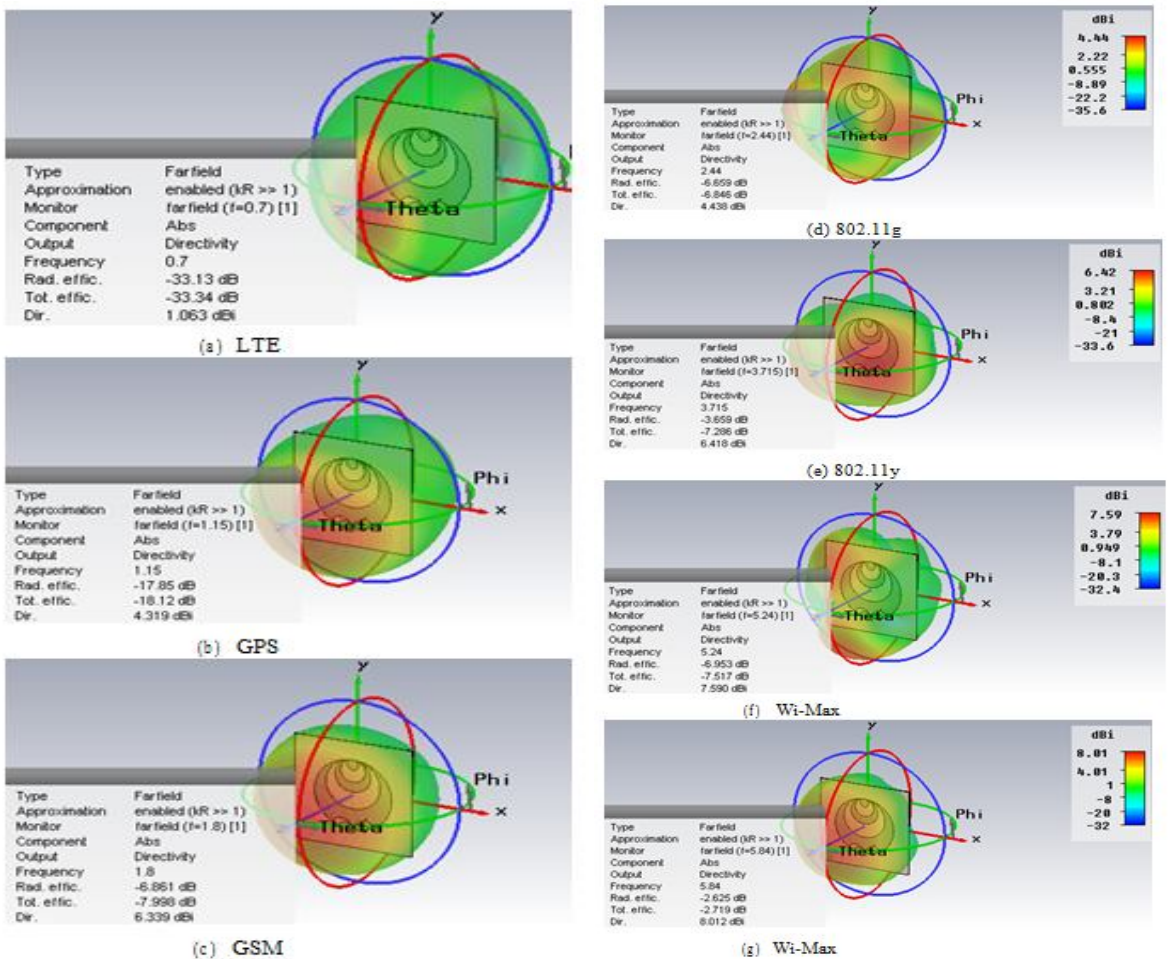


Fig. 5. Radiation pattern of the proposed antenna (fig.1 "d") for the bands:LTE, GPS, GSM, Wi-Fi and WiMAX

As a summary of this project, a comparison has been done on different antenna models found in literature as well in the antenna market. This comparison is provided in a tabular form as shown in table 1.

Reference	Patch area	Resonant frequencies
Fractal slots on Circular patch inspired by smith chart for GSM, Radar, WLAN and ITS application	71 mm x 71mm	1.734 GHz 2.505 GHz 2.991 GHz 4.428 GHz
A self-affine fractal multi-band antenna	44.69 mm x 45.46 mm	2.435 GHz 4.880 GHz 10.050 GHz
Synthesis of a Galileo and Wi-Max three-band fractal-eroded patch antenna	78 mm x 61 mm	1.189 GHz 1.577 GHz 2.500 GHz
Design of simple multiband patch antenna for mobile communication applications using new E-shape fractal	150 mm x 130 mm	0.940 GHz 1.810 GHz 2.425 GHz

Proposed Antenna	70 mm x 70 mm	0.70 GHz 1.15 GHz 1.80 GHz 2.40 GHz 3.70 GHz 5.20 GHz 5.80 GHz

TABLE I. Comparison of Performance

For further improvement in the resonance behavior of this compact antenna, it has been suggested to introduce a combination of r and x slots within the patch surface. Simulation results have shown a serious improvement in the reflection loss characteristic i.e. more resonance points have appeared with less S11 values as shown below in Fig.6

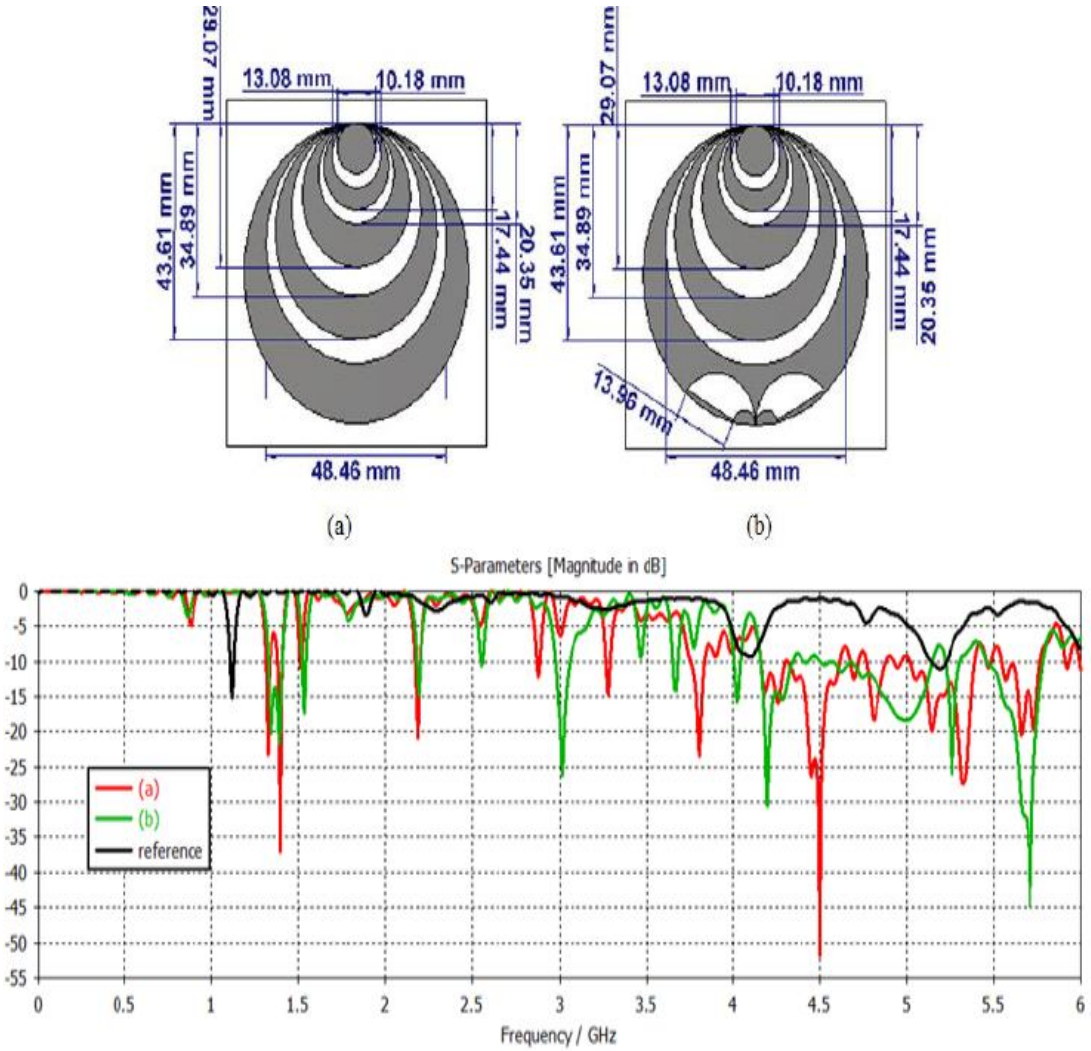


Fig.6. S_{11} of the antenna with combined fractal geometries (a) and (b).

CONCLUSION

The proposed single patch antenna with fractal slots in the form of r and x-circles of the Smith Chart is capable of resonating at multiple desired frequency sub-bands including LTE systems, GSM (900/1800 MHz) mobile communication systems, Wi-Fi systems, W-LAN systems in addition to (5.2/5.8 GHz) WI-MAX applications. The designed antenna is efficient, directive, weightless, compact, multiband and easy to fabricate which makes it very convenient and competitive in many wireless communication applications.

REFERENCES

[1] Constantine A. Balanis, Antenna Theory: Analysis And Design, 3-d Edition, Published by Wiley India (2009), ISBN 10: 8126524227 ISBN 13: 9788126524228.

[2] N. Rao and D. Kumar. ”Fractal slots on circular patch

inspired by Smith Chart for GSM, Radar, WLAN, and ITS application" Loughborough Antenna & Propagation Conference (LAPC) 2015.

[3] Pons, Jaume Anguera, Carles PuenteBaliarda, and Jordi Romeu Robert. Fractal and broadband techniques on miniature, multifrequency, and high- directivity microstrip patch antennas. 2003(x2-11)

[4] Bayatmaku, Nima, et al."Design of simple multiband patch antenna for mobile communication applications using new E-shape fractal."Antennas and Wireless Propagation Letters, IEEE 10 (2011): 873-875.

[5] Harmouch, A. El Sayed Ahmad, W. Harmouch, M.Kenaan, Jean-Marie Floc'h, " On TheMiniaturization of an Efficient Ultra-Wideband Printed Quazi-Yagi Array Antenna for Indoor Applications" Journal of Radioelectronics and Communications Systems, Vol 60, N6, 2017.

[6] Sung, Y. J."Bandwidth enhancement of a wide slot using fractal-shaped Sierpinski."Antennas and Propagation, IEEE Transactions on 59.8 (2011): 3076-3079.

[7] Harmouch, A. El Sayed Ahmad, W. Harmouch, M.Kenaan, Jean-Marie Floc'h, " Ultra-Wideband Printed Quazi-Yagi Array Antenna for Indoor Applications" LAAS conference, USEK, April 2016, Beirut, Lebanon.

[8] Harmouch, R. Mourad "Miniaturized Broadband Printed Unidirectional Antenna with Parasitic Slots for Indoor Wireless Applications" International Conference on Antenna Theory and Techniques, 2017, Kyiv, Ukraine.

[9] Anguera, Jaume, et al."Broad-band dual-frequency microstrip patch antenna with modified sierpinski fractal geometry." Antennas and Propagation, IEEE Transactions on 52.1 (2004): 66-73.

★★★