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2.5 GHz to 3.5 GHz fractal metasurface microstrip antenna design for high bandwidth wireless applications

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Abstract— In this paper, a microstrip slot antenna is designed for wireless applications with a fractal structure having coverage of 2.5 - 3.5 GHz and 30% bandwidth. It uses a circular slot with six single rings in which triangles are inserted, and seven triangular slots are added. The slot uses a circular slot with six single rings into which triangles are inserted and seven triangular slots are added, the matching is improved by a disk located in the central part of the slot. The fractal model enhances the width of the slot. The fractal model improves bandwidth, antenna matching, and current distribution. S-band (short) is used for wireless applications such as Wi-Max technology, which enables the wireless transmission of voice, data, and data over the air wireless transmission of voice, data, and video over areas of up to 48 km radius. It is also considered a wireless alternative to ADSL and wired broadband access, and a way to connect Wi-Fi nodes in a metropolitan area network. The antenna features a gain of -19.436 dB with a compact size of 60 × 60 mm2. It has been simulated in an antenna design software in which FR4 is used as a suitable material because it is low cost and accessible. It is shown that the fractal shape and the result of combining the metasurface with the antenna achieve a wide antenna width. the antenna achieves a wide bandwidth for wireless applications.

***Keywords*— Antenna, Microstrip, Fractal, WiMAX, Bandwidth.**

I. INTRODUCTION

The microstrip antenna is a type of antenna for various applications such as communication systems, medical applications, mobile services, and radar systems in missiles [1-2]. In addition, radar cross-section (RCS) is important for some of these applications [3]. WiMAX, 'Worldwide Interoperability for Microwave Access', is the mark that certifies that a product conforms to the 'IEEE 802.16' wireless access standards. These standards allow connections at speeds similar to ADSL or cable modem, without cables, and up to a distance of 50-60 km [4]. Unlike Wi-Fi systems that are limited, in most cases, to about 100 meters (and up to 350 meters in open areas) [5]. WIMAX has a higher transmission speed than Wi-Fi and depends on the available bandwidth. WiMAX operates either in licensed or unlicensed spectrum, within the range of 2 to 11 GHz, within which there are four main bands which are:

- 2.5 GHz MMDS band with license (2.5-2.7 GHz) 3.5 GHz band with license (3.4-3.7GHz)
- 3.5 GHz band license (3.4-3.7 Ghz)
- 5 GHz U.NII Band (5.150 - 5.350 GHz and 5.470 - 5.825 GHz)

WiMAX has an important feature, in which the radio automatically searches for an unused channel. As for the channel bandwidths, they are adjustable from 1.25 MHz to 20 MHz, while the channel transmission rate is determined by the modulation of the signal to be used [6].

The patch antenna is considered in various microwave applications. In addition, recently the study of metasurface and selective surface [7-8] is based on the control of the antenna surface current distribution. Fractals are used to represent and explain a multitude of natural phenomena; but also, fractal geometry inspired several practical applications in technology and industry. One of these applications is the use of fractal theory in the study and design of new antennas and radiating systems. The design of fractal antennas is mainly oriented to studying and exploiting two important features of fractal geometry, the equality between its structures (scalability) and the space-filling property of many of its curves [9].

Thanks to this, it overcomes certain limitations associated with the performance and operation of some radiating elements, the fractal method is examined for various applications such as antenna [10] and metamaterial-based absorbers [11]. Recently, fractal shapes are more attractive for reflective [12-13] and monopole [13] antennas to reduce the RCS. The circular microstrip antenna features a straight feed line which is the basic structure. Research shows that better bandwidth is obtained by adding the triangular slots and ring structure. Finally, the circular disk is placed in the central part of the slot to improve the antenna matching and the fractal technique is used which reduces the CSR.

II. PROPOSED ANTENNA

Microstrip slot antennas are developed based on feed layer to ground coupling. Various shapes of slot antennas, such as triangular and circular, are studied for decades [14-15]. Also, the metamaterial is considered for different qualifications such as circular polarization or broader bandwidth [16-17]. The resonant frequency of a common ring antenna is obtained from equation (1), C is the speed of light and εr is the substrate resistance [18]. The final antenna is obtained after the combination of fractals, rings, and triangles Fig. 1. The resonant frequency of the slot antenna is obtained from [18].

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$$f = \frac{c}{2d\sqrt{\varepsilon r}} \qquad (1)$$

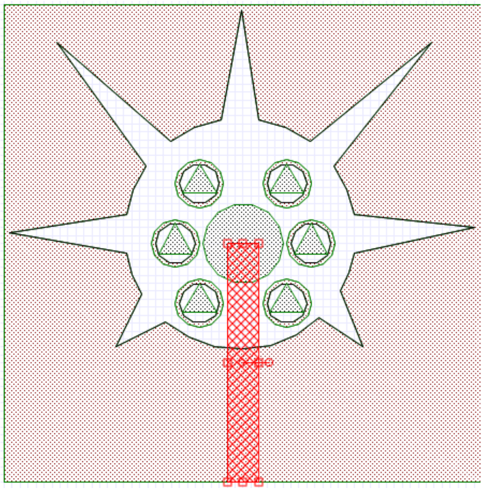
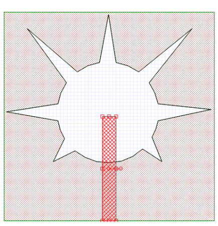


Figure 1: Proposed Antenna.

A. ANTENNA METHODOLOGY

The antenna approach in Fig. 2 presents 5 steps that start with the main circular-shaped slot with 7 simple triangular slots. Next, 6 circles are formed which become ring structures that act as parasitic loads and increase the gain, triangular structures are also incorporated inside, and a disk is inserted in the center to achieve matching.



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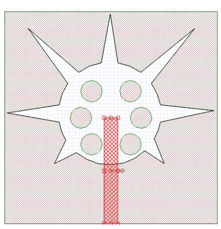

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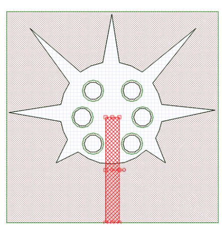

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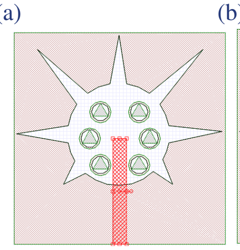

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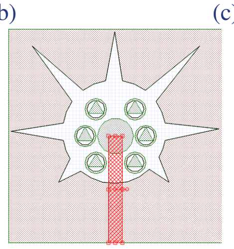
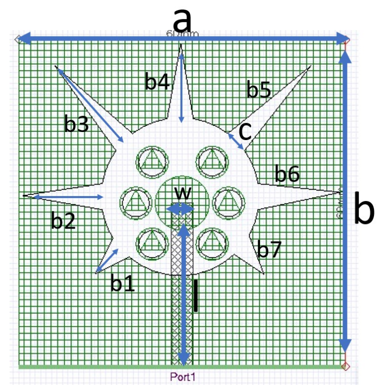


(e)

Figure 2: The five steps in antenna design, from the slot antenna to the slot antenna with the fractal ring.

The antenna geometry is presented in Fig. 3 for the ground layer and feed line, respectively, where the feed line is connected to a 50-ohm SMA connector. The overall size of the antenna is 60 x 60 mm2. It is designed in FR4 with a thickness of 1.6 mm as a low-cost substrate with a permittivity of 4.4 and a loss tangent of 0.02. All the optimized antenna parameters are tabulated in Table I.



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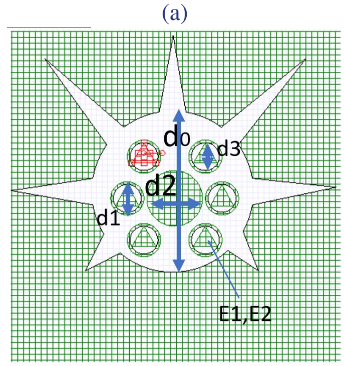

(b)

Figure 3: Dimensions of the designed Antenna.

Table I: Antenna dimensions

Parameters	Dimension[mm]
a	60
b1	7.071
b2	14.05
b3	18.43
b4	13.53
b5	18.43
b6	6.47
b7	6.47
c	5
d0	28
d1	6
d2	10
d3	5
w	47
l	30
E1	4.03
E2	3.7

III. Simulation and Result

For this antenna, the software is used to obtain the reflec-tion coefficient plot, impedances, radiation pattern, and data necessary for its analysis. The return loss of the antenna is obtained from the reflection coefficient plots according to the steps in Fig. 2.

The circular slot antenna has no effective resonance in this spectrum. When the triangular slots are added to the antenna, a resonance appears at 3 GHz, but it does not have a good gain which is below -10 dB as shown in Fig. 4.

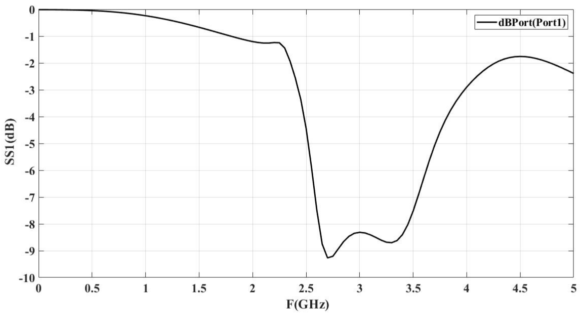

Figure 4: Antenna design with circle and triangles ,gain -9.3 dB.

When the first 6 circles are placed, a gain of -10.80 dB is obtained with a bandwidth of 14 MHz. This result is not effective because although it is above -10 dB, its bandwidth is insufficient to cover some technologies, but compared to the previous result, its gain is considerably higher as shown in Fig. 5.

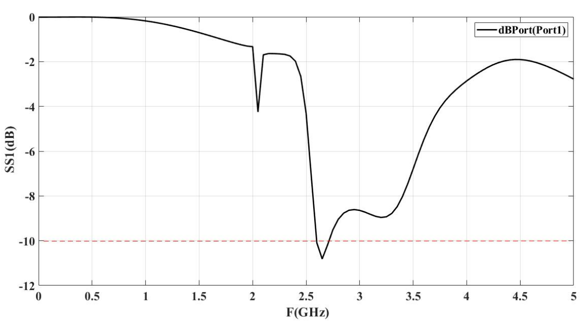

Figure 5: Antenna design with circle inside, gain -10.80 dB.

When the ring structures are implemented in the antenna, similar results are obtained in terms of bandwidth, its gain reaches -12.03 dB as shown in Fig. 6. In this way, structures are introduced until a considerable bandwidth is obtained.

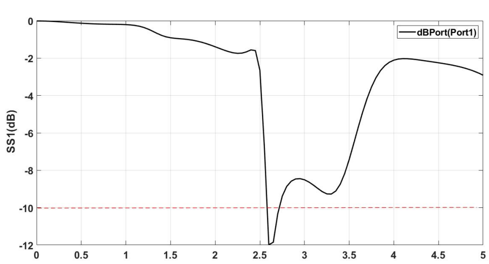

Figure 6: Antenna design with formed rings inside the antenna, gain -12.03 dB.

The triangles are added inside the rings and a gain of -12,108 dB is obtained as shown in Fig. 7 which is similar to the previous step. Using these fractals does not increase their bandwidth or gain, but it improves their adaptation.

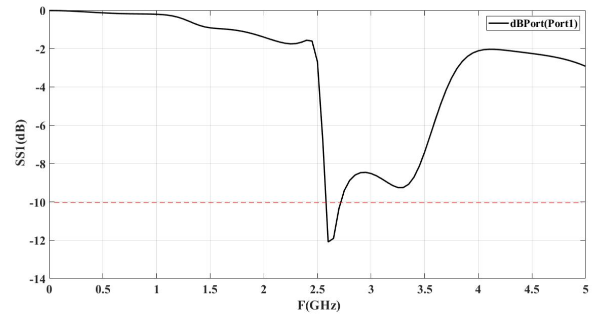

Figure 7: Antenna design with triangles inside the rings,gain -12.108dB.

Finally, the central circle is added to improve the adaptation and a gain of -19.436 dB is obtained and its bandwidth is 2.5 - 3.5 GHz (1000 MHz bandwidth) which is equivalent to 30 % of the bandwidth, the adaptation is improved, and the gain value is drastically increased as shown in Fig. 8.

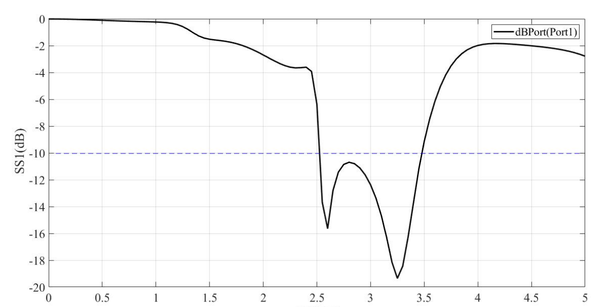

Figure 8: Final antenna design, gain -19.436 dB.

It covers various wireless bands such as LTE and Wi-Max. According to research, metasurface is effective in improving antenna bandwidth and different parametric studies can reveal the effect of rings and disk on antenna gain. The effect of disk diameter d2 on gain shows how reducing the diameter reduces the antenna bandwidth. However, the diameter of the outer rings influences the bandwidth and antenna matching. When d1 = 5 mm, the antenna bandwidth improves, while for d1 = 6 mm it increases to -10.80 dB. The triangles have no effect on the antenna bandwidth but can be used for matching improvement.

The antenna radiation pattern for Ephi, EPhi = 0 and EPhi = 90 at 3 GHz. And etheta, Etheta = 0 and Etheta = 90. Fig. 9 shows the 2D radiation pattern of the antenna for the simulation.

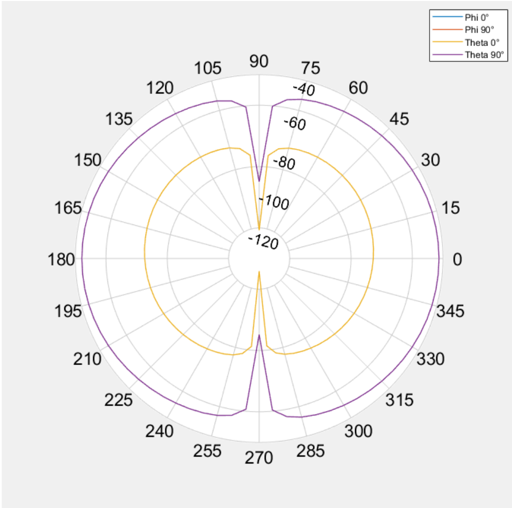

Figure 9: Radiation Pattern.

IV. Conclusion

The slot antenna is known as the best antenna for wireless applications such as WiMAX with wide bandwidth which is necessary for this technology. So the slot antenna with fractal formation and parasitic element is suggested for licensed (2.5-2.7 GHz) 2.5 GHz MMDS S-band (short) application. Evidently, the realized antenna achieves a gain at the fifth step of the design of -19,436 and as known , the metasurface is effective in improving the antenna bandwidth thus having a bandwidth of about 30%, which is sufficient for various wireless applications compared to some previous researches.Fractal loads play an important role in controlling and distributing the current on the antenna surface. In this paper, the elements and their dimensional effect on the antenna bandwidth are studied.

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