Honeycomb shaped fractal antenna with dual notch characteristic for UWB applications

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- Honeycomb Nest Shape Fractal antenna
- Defected Ground Structure
- Band notch characteristics
Abstract

The paper presents a feasible way to construct the honeycomb structured microstrip antenna for UWB (Ultra-Wideband) applications with dual notch characteristics. The antenna is designed based on the concept of the initial stage of honeycomb nest construction and defected ground structure (DGS) with dual notch for UWB applications. The two notches for WiMAX (3.5GHz center frequency) and WLAN (5.5 GHz center frequency) are introduced by etching two asymmetrical quarter wavelength slots in the ground. The compact antenna of size 12 x 20 mm² with simple geometry achieves very wide bandwidth of 3.1-13.8 GHz (Covers UWB and higher frequency band) with dual notch characteristic.

1 Introduction

Nature is exceptionally large and unique laboratory comprising of efficient explanations and solutions of numerous technical and scientific problems. Honeycomb structures inspired from the Mother Nature’s bee honeycomb construction process have tremendous applications in various fields including, Mechanical engineering, Nanofabrication, Chemical Engineering, architecture, Aerospace engineering, biomedicines, and RF (Radio Frequency) and microwave. The ideas and theories taken from nature have inspired many novel designs of antennas for the various wireless applications [1-3]. The fractal patterns exist in all the areas nature. The fractal structure off honeycomb evolving from natural honeycomb is a tessellation of uniformly distributed double layer hexagonal shapes. There are mainly two viewpoints on how the shape of honeycomb cells becomes hexagonal. One is that the particular structure is merely a result of physics law. The other point of view suggests that honeybees are skilled engineers who operate under simple rules. Due to the advent in technology honeycomb structure’s applications are increasing at nano scale and at micro scale. Various micro and nano antennas based on honeycomb structure have been proposed for various applications [4-7].

The wide-band antennas were built with monopoles of various shapes or fractal shapes [8-9]. For a particular frequency, the antenna normally has to maintain a minimum size, usually of the order of a quarter wavelengths. These factors have been restricting for a long time the antenna performance in telecommunication systems. Fractal electromagnetic engineering embodies a comparatively fresh domain of research that amalgamates aspects of fractal geometry with electromagnetic. Research within this stream has lately resulted into a rich category of innovative structures for antenna along with metamaterial rudiments. Fractals are space-filling structures which could be utilized as electromagnetic devices to efficiently accommodate long electrical lengths into tiny areas. Honeycomb is the most suitable fractal shape found in nature for the design of patch antenna [7]. Since FCC (Federal Communication Commission) regulated the frequency range of 3.1-10.6 GHz for the UWB applications, much attention has been paid to the increasing demand for UWB antennas for the UWB technology [10-11]. For millimeter-wave applications honeycomb fractal antenna array of size 97 x 7 mm² introduced [5]. The 14.337 GHz (25.347-39.684GHz) broad bandwidth is obtained with 4.15 dBi (single component) and 12.7dBi (antenna array) gain. For wireless applications [6] presented hexagon fractal antenna of bandwidth 1.31-6.81 GHz and a gain of 6.8dBi, and the 40 x 45 mm² size. The paper [7] presents an 80 x 80 mm² honeycomb-shaped antenna for Ku band communication at a frequency of 11.85 GHz with a gain of 8.87 dB. The CPW (Coplanar Waveguide) fed hexagonal fractal antenna of size 39 x 36.5 x 1.524 mm³
design is proposed for UWB applications [12]. The modeling of the PIN (Positive-Intrinsic-Negative) diode RF (Radio Frequency) switch on HFSS (High-Frequency Structure Simulator) is presented for the reconfigurable antenna applications [13]. A simple compact size antenna with the partial ground is added with frequency reconfigurable property to switch from ultra-wideband to narrowband mode. In [14] plasmonic mode propagation properties of graphene based terahertz PCA (Photoconductive Antennas) are studied. Some of the nature-inspired algorithms are applied for antenna optimization [15-16].

In this paper, the honeycomb structure construction is considered for the design of the conducting patch of an antenna. The paper presents the honeycomb structured fractal antenna with dual-band notch rejection characteristic for UWB applications.

### 2 Antenna Design

#### 2.1 Initial antenna design

The mechanism through which honeybees assemble honeycomb cells in such a particular order is nevertheless an open discussion. When honeycomb structure is subjected to different load and stress much attention had been paid to the mechanical properties [17]. In this paper, the honeycomb structure is explored for the microstrip antenna design. The critical understanding behind the construction principle of the honeycomb structure for the design of an antenna is important. In order to construct the honeycomb antenna the focus of attention is the initial structure of the honeycomb. By taking this initial honeycomb structure construct procedure [18], the design of an antenna is started as shown in Figure 1. Figure 1(a) shows the first stage of honeycomb construction and Figure 1(b) shows the antenna patch using conducting material. The antenna is constructed on the FR-4 substrate of size 20 x 12 mm².

As it can be observed from the above antenna design that the antenna forms the quarter wavelength monopole or the half-wavelength monopole. The length of the radiating patch is approximately quarter wavelength and the total length \( l_{total} \) is given by

\[
\frac{\lambda_0}{4} = \frac{\lambda_r}{4\sqrt{\varepsilon_{eff}}} = \frac{C}{4f_r\sqrt{\varepsilon_{eff}}} 
\]

(1)

\[
\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2}
\]

(2)

Where \( C \) is the speed of light in free space, \( \lambda_r \) is the free space wavelength, \( \varepsilon_{eff} \) is effective dielectric constant, and \( f_r \) is the resonant frequency of quarter wavelength monopole [19]. The total patch length \( l_{total} \) for the above design is approximately 10mm (\( l_1=1.4\ mm, \ l_2=2\ mm, \) and \( t=0.5mm \)). The resonating frequency for the quarter-wavelength monopole of 10mm length is 4.4 GHz. It can be depicted from the obtained return loss characteristic shown in Figure 2 the resonating frequency is 4.3 GHz and the bandwidth obtained is from 3.6-7.2GHz (3.6GHz).

The initial design is optimized by the tessellation of the hexagonal fractal shapes in a circular manner and hence, the initial design of quarter wavelength is modified to honeycomb shape [20] as shown in Figure 3.

For wide bandwidth, the parametric analysis of ground is done by varying the ground size. The variation of return loss (S\(_{11}\)) with frequency for different ground size is shown in Figure 4. By observing the obtained graphs closely it can be noted that the results are optimum when the ground
length L₁ is 10mm. With a ground length of 10 mm, the bandwidth ranges from 6.749- 13.743GHz, which covers the part of UWB and Ku-band.

To further enhance the bandwidth for the UWB range, the ground is modified to DGS by inserting a triangular slot in the upper part of the partial ground plane [21]. In addition to triangular slot, hexagonal patches are introduced in the patch as shown in Figure 5. The incorporation of hexagon shapes in the patch and triangular slot in partial ground further improves the bandwidth of an antenna by changing the current distribution and electrical path lengths. The electrical path length for the ground without a triangular slot is \( L_g + W \) (8.5mm+12mm=20.5mm). The electrical path length is changes to \( L_g + l_3 + l_3 + (W - S_g) \) (8.5mm + 8.2mm +8.2mm + (12mm-6.67mm) = 30.23mm). The impedance bandwidth is highly enhanced from 6.749- 13.743GHz to 3.74-13.85GHz as shown in Figure 5.

2.2 Dual band notch antenna

After obtaining wide bandwidth the next step is to address the issue of interference from the coexisting microwave systems by introducing slots in the ground as shown in Figure 6. The first notch for WiMAX (3.25-3.85GHz) is introduced by etching quarter wavelength (\( \lambda_g/4 \)) slot of length 10.5mm. Here the \( \lambda_g \) is guided wavelength for the corresponding notch band center frequency. As depicted from Figure 7 slot 1 introduces a notch for WiMAX. Similarly, the WLAN notch is introduced at a center frequency of 5.5 GHz by etching a quarter wavelength inverted L-shaped slot in the ground as shown in Figure 8. The inverted L-shape is chosen to accommodate the quarter wavelength slot in very compact size DGS. The length of the quarter wavelength slot is calculated as given in equation (1) [19], [22].

3 Results and Discussions

The effective lengths of the two slots (slot 1 and slot 2) are 10.5mm and 7.75mm respectively. Here, the effective lengths of slots are considered \( \lambda_g/4 \) instead of \( \lambda_g/2 \) to accommodate the slots in very compact size ground and to reduce the design complexity. When both slots are added together return loss, VSWR (Voltage Standing Wave Ratio), gain characteristics, and efficiency variations obtained are displayed in Figure 9. The band rejection notches are created at the center frequencies of 3.5GHz and 5.5 GHz to mitigate the issue of interference. The gain is reduced to -2.7dBi and -4.75dBi at the WiMAX and WLAN notch respectively and a maximum gain of 2.6dBi is acquired at 11GHz as shown in Figure 9(b). Due to the introduction of band notches at 3.5 GHz and 5.5GHz, the gain is reduced at these two frequencies, and in reaming frequency band the gain variation is positive and above 0 dB. Also, the efficiency of an antenna is reduced at band notch frequencies as shown in Figure 9(c). The optimized antenna parameters are shown in Table 1.

To get an insight into antenna characteristics the surface current distributions and normalized radiation pattern are shown in Figure 10 and Figure 11 respectively at resonating frequencies. Figure10 (b) shows the surface current distribution at band notch frequencies for WLAN and WiMAX. The current is mainly distributed slot 1 and slot 2 and is responsible for the current disturbance and hence for the notch creation. The current flows around the periphery of the L-shaped slots, which in turn act as a resonator and prevent the signal propagation. As it can be noted from the current distributions shown at notch band frequencies that for the frequency of 3.5 GHz maximum current is distributed around 3.5GHz and responsible for the creation of WiMAX band notch. On the other hand, the maximum current is flowing in the periphery of slot 2 which resulted
in a band notch for the WLAN at 5.5 GHz. At higher frequencies, the current is flowing in the patch and responsible for the high frequency resonance. In thermal equilibrium considering the collective effects of absorption, reflection, and emission in practical materials the universality of cavity radiation collapses. The radiation inside the cavity depends on the walls, external temperature, and frequency of observation. So the frequency in a perfectly reflecting or arbitrary cavity may differ from that emitted from the ideal case. Emitted radiation pattern inside the considered hexagonal honeycomb cavity follows the back and forth wave propagation that depends on the honeycomb cavity wall [23]. Cavity radiation was said to be free from the nature of the cavity wall and some other external factors like temperature and frequency of observation if, cavity walls have a symmetrical shape or plane nature, and contained radiation inside the cavity has the same radiation nature [24]. Observed simulated results of EM wave patterns at resonant frequencies shown in Figure 11, the emitted radiation pattern are not symmetrically distributed in the hexagonal shape cavity and it depends on mimicked honeycomb’s cavity wall. Kirchhoff’s law in term of radiated emissive power (E) and absorptivity (a) is given as [25]

\[ E = a.f (T,v) \]  

(3)

We know that sum of emissivity (ε) and reflectivity (k) is always equal to 1 for all materials.

\[ \varepsilon + k = 1 \]

But, this rule is also validation for emissivity ε and absorptivity a[26-27], so

\[ a + k = 1 \]

or

\[ a = 1 - k \]

(4)

This equation contains reflectivity of cavity material that totally depends on the nature of the cavity’s wall. Using equation (3), we can calculate the total emissive and absorptive power for the proposed geometry.

The simple geometry and compact size antenna have achieved dual notch characteristics in addition to the very wide bandwidth of 10.7GHz (3.1-13.8 GHz). The comparison of the proposed design with reported work is shown in Table 2.

5 Conclusion

The compact honeycomb shaped fractal antenna based on the concept of the initial stage of honeycomb nest construction with dual notch characteristic is presented for UWB applications. The antenna obtained very wide bandwidth from 3.1-13.8GHz with WiMAX and WLAN rejection notches at 3.5 GHz and 5.5 GHz respectively. Stable radiation pattern and notch band characteristic makes an antenna suitable for UWB application with high immunity from the existing interference.

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**Figures and Tables with Captions**

![Figure 1](image1.png)  
![Figure 2](image2.png)

**Figure 1.** (a) Initial stage of honeycomb structure [18] (b) Initial antenna design

![Figure 2](image3.png)

**Figure 2.** Return loss variation for quarter wavelength patch
Figure 3. (a) Honeycomb shaped fractal antenna (left panel), (b) single hexagonal fractal (middle panel), and (c) Back view of antenna (right panel).

Figure 4. Variation of Return loss ($S_{11}$) with frequency for various ground size
Figure 5. (a) Honeycomb structure filled with hexagonal front view (left panel) patches and with DGS (Right panel) (b) single hexagonal fractal with filled patch (left panel) and return loss variation (right panel)
Figure 6. Quarter wavelength slots in DGS for band notch characteristic (proposed antenna design) and enlarged view of ground slots

Figure 7. WiMAX notch by quarter wavelength slot

Figure 8. WLAN notch by quarter wavelength slot
Figure 9. (a) Return loss and VSWR variation with frequency (b) Gain variation with different frequency (c) Efficiency variation with frequency
Figure 10. (a) Surface current distributions at resonating frequencies (3.2, 4.5, 8.7, 11.2, and 12.8 GHz) (b) Surface current distribution in slots at band notch frequencies
Figure 11. Radiation pattern at resonating frequencies (3.2, 4.5, 8.7, 11.2, and 12.8 GHz)
Table 1. Optimized parameters of an antenna

| Parameters | Value (mm) | Parameters | Value (mm) |
|------------|------------|------------|------------|
| L          | 20         | L<sub>g</sub> | 8.5        |
| W          | 12         | S<sub>g</sub> | 6.67       |
| W<sub>1</sub> | 3         | l<sub>3</sub> | 8.2        |
| L<sub>1</sub> | 10        | l<sub>h</sub> | 2          |
| W<sub>2</sub> | 0.3       | L<sub>2</sub> | 1          |
| W<sub>3</sub> | 0.5       | l<sub>1</sub> | 1.4        |
| t          | 0.5        | l<sub>2</sub> | 2          |
| l<sub>4</sub> | 1.5       | l<sub>5</sub> | 6          |
| l<sub>6</sub> | 3.5       | l<sub>7</sub> | 3.7        |

Table 2. Comparisons of proposed work with reported antenna

| Reference          | Size of Antenna (in mm<sup>2</sup>) | BW                                  | Gain                                |
|--------------------|-------------------------------------|-------------------------------------|-------------------------------------|
| H. Ullah et al 2017[5] | 97 x 7                             | 14.337 GHz (25.347-39.684GHz)       | 4.15 dBi (single antenna)          |
| A. Desai et al 2018[6] | 40 x 45                            | (1.31-6.81 GHz)                     | 6.8 dBi                            |
| Roopan et al 2016[7]    | 80 x 80                            | 11.85 GHz (Single frequency)       | 8.87 dBi                           |
| D Aissaoui et. al 2016[12] | 39 x 36.5                  | 10.57 GHz (3.1-13.67 GHz)           | Not given                           |
| **Proposed design**     | **20 x 12**                        | **10.70GHz (3.1-13.80GHz)**         | **2.6 dBi**                         |
|                       |                                     | With dual notch                     |                                     |