International Journal of Natural and Engineering Sciences 8 (2): 21-24, 2014
ISSN: 1307-1149, E-ISSN: 2146-0086, www.nobel.gen.tr

Single Semi-Fractal Antenna Embracing Wireless Standards of GSM to UWB

Kambakhsh ATHARI[1*] Ghangiz GHOBADI[1] Javad NOURINIA[1]
[1]Department of Electrical Engineering, Science and Research Branch, Islamic Azad University, Urmia, Iran.

*Corresponding author:
E-mail: athari.kambakhsh@gmail.com

Received: May 23, 2014
Accepted: July 01, 2014

Abstract
A novel microstrip-fed printed triangular-shaped semi fractal monopole antenna (TSSFMA) is presented. The fractal unit-cell is based on a triangular geometry. The antenna construction is achieved by assembling the scaled down unit-cells to satisfy fractal space-filling property. It is shown that by increasing the order of iteration, an antenna is realized which is able to operate across a wide spectrum of wireless standards such as GSM, UMTS, GPS, PCS, WCDMA,WIMAX, WLAN (802.11b) and UWB. The antenna is compact with a size of $55\times42\times1$ mm^3 and it operates across a frequency range extending between 1.53 and 12.79 GHz with VSWR < 2. In this paper, the improvement process of the impedance bandwidth is presented and discussed.
Keywords: Fractals, Printed Antennas, Monopole antenna, Ultra wideband (UWB), Global System for Mobile Communications (GSM), Global Positioning System (GPS), Personal Communications Service (PCS).

INTRODUCTION

The fast paced development of wireless communications, in particular ultra-wideband (UWB) technology has created an increased demand for applications in commerce and industry [1]. Design of ultra-wideband antennas for applications in communication systems is a major challenge for engineers. The main parameters expected from ultra-wideband monopole antennas are structures that have good return-loss response, and exhibit desirable radiation characteristics that are essentially Omni-directional [2-4]. There are various techniques to realize a specific bandwidth. In the case of fractal antennas, one of the considerable and substantial methods is keeping up iterations to achieve desirable and agreeable impedance bandwidth. In the design of ultra-wideband antennas, the geometry of the antenna's radiating patch and its ground-plane play a significant role. Examples of various techniques of designing monopole antennas include: rectangular, triangular, circular and elliptical [5]. Because of the self-similarity and space-filling characteristics [6-8], fractal concepts have emerged as a viable method for designing compact UWB, Super wideband (SWB), and multiband antennas.

These antennas are applicable for various uses such as global positioning system (GPS) and personal communications service (PCS) [6], [9]. It is essential the impedance bandwidth of the antennas satisfy the specifications of FCC (Federal Communication Commission). Unfortunately, other systems operate within the ultra-wideband frequency band, such systems include IEEE802.11a WLAN system (5.15-5.825GHz), IEEE802.16 WiMAX system (3.3-3.6 GHz), and C-band satellite communications system (3.7-4.2 GHz). The proposed TSSFMA antenna described here can also be used for low frequency applications such as Global System for Mobile Communications (GSM) band at the centre frequency of 1.78 GHz, personal communication system (PCS 1.85–1.99 GHz), universal mobile telecommunication system (UMTS 1.92–2.17 GHz), Wideband Code Division Multiple Access (WCDMA) band at the centre frequency of 2.15 GHz, wireless local area network (WLAN 2.4–2.484 GHz) and 5.2/5.8 GHz bands, mobile worldwide interoperability for microwave access (MobileWiMAX), and WiMAX, which operate in the 2.3/2.5 GHz (2.305–2.360 GHz/2.5–2.69 GHz) and 5.5 GHz (5.25–5.85 GHz) bands [1-19].

It is also believed that circular and rectangular structures should fill up the antenna's radiansphere [18] better than that of a triangular structure, providing a larger impedance bandwidth.

In this Paper, a novel antenna structure is presented based on a triangular fractal unit-cell for the aforementioned applications. The structure of this antenna is not purely fractal, but shares some structural similarities with fractal ones and it fulfills the fractal space-filling property. By using the fractal space-filling technique a wide impedance bandwidth is attained across 1.53-12.79 GHz, which covers the frequency band of GSM, UMTS, GPS, PCS, WCDMA, WIMAX, WLAN (802.11b) and UWB systems [1-19].

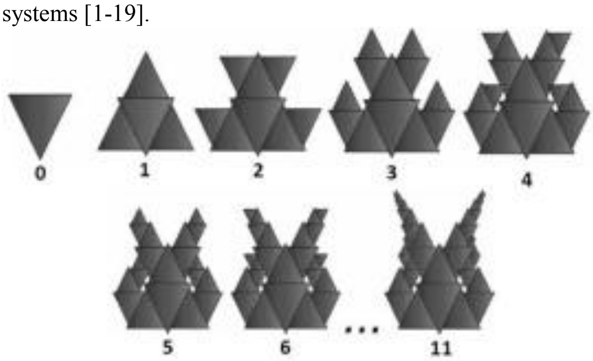

Figure 1. Steps showing evolution of the proposed Semi-fractal monopole antenna patch.

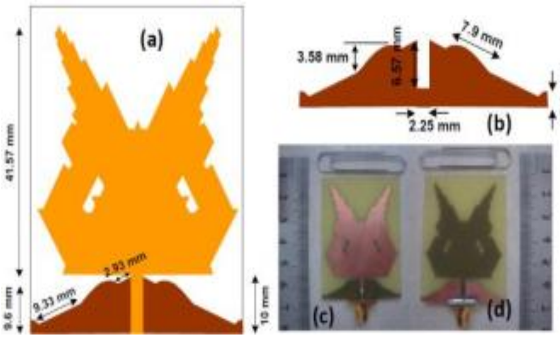

Figure 2. Geometry of the proposed antenna, (a) front view, and (b) back view and Photograph of the proposed realized antenna, (c) front view, and (d) back view.

ANTENNA CONFIGURATION

Patch Structure

The sequence of steps showing the evolution of the proposed TSSFMA antenna geometry is shown in Fig. 1. The antenna was fabricated on FR4 substrate with permittivity of 4.4, a loss tangent of 0.024, and compact dimension of 55×42×1 mm^3. The fractal unit-cell constituting the proposed antenna is based on a triangular geometry. The antenna's development is achieved by scaling and orienting the unit-cells at every iteration, which are assembled together to satisfy fractal space-filling property. The unit-cell is an equilateral triangle. Each iteration step involves adding unit-cells to the structure which are scaled down by a factor of 8/10. The original unit-cell consists of an equilateral triangle of sides 17.32 mm. In the first step, three triangles are created from the basic triangle by factor 8/10 and each created triangle is coincided with one of the basic triangle's side while the center of triangles's sides are coincided, as well. The considerable point in the next step is that the basic triangle for this step is one of those created in the first step and in every step the basic triangle is one of the previous step's created triangles and it will continue until the last step. At the second step, four triangles are created with the above-mentioned scale and two of them are coincided with upper triangle's sides and two remaining, are superposed with external sides of lower triangles. By the way, the fractal shape does not continue in lower part of the basic triangle due to existence of antenna's feed. At the third step, four triangles are made and are coincided on the upper side of four previous triangles. At the fourth step, four new triangles are created. The arrangement of upper and lower triangles is different. In this way the two created triangles are placed on external sides of upper triangles and the other two triangles are placed on the internal sides of lower triangles. In order to prevent from enlargement of the size of the proposed TSSFMA antenna's patch, which causes aggrandizement of antenna's substrate, no triangle is placed on external sides of lower triangles. At the fifth step, four new triangles are created and are coincided on the upper side of the previous step's triangles. Step six is very similar to step four , with only difference in the places of triangles. As previous steps, four triangles are created , two of them are coincided on the external sides of lower triangles and the other two , are superposed on the external sides of upper triangles. The other steps are repetition of step 4, step 5 and step 6. This pattern is repeated up to the eleventh iteration to create the final antenna structure as depicted in Figs.1 and 2. There is a very important point in the presented structure. The main reason of this uncommon number of iterations is that, only in the eleventh step, not previous steps before it, the impedance bandwidth of proposed TSSFMA antenna fulfills the UWB frequency band and also covers the entire frequency band of GSM, UMTS, GPS, PCS, WCDMA and WLAN (802.11b). The top section of the antenna is V-shaped and contains dielectric two gaps. The feed-line is connected to the base of the antenna as shown in Fig. 2. The photograph of the antenna is shown in Fig. 2.

Ground Plane Structure

The ground-plane is shaped from a rectangle having a height and base lengths of 9.6 mm and 42 mm, respectively. The steps used to create the ground-plane are shown in Fig. 3. In the first step two right triangles are subtracted from the rectangle. Each subtracted triangle has the height of 8.6mm and the length of a triangle's base is equal to 19.9mm. A vertical rectangular notch (6.57×2.25 mm^2) is subtracted from the ground-plane at its center. An ellipsoidal shaped conductor is added near the notch, and it has a protrusion of 3.58 mm and a length of 7.9 mm.

In the final step a circular quadrant of radius 2.1 mm are attached to the ends of the ground-plane structure.

Figure 3. Sequence of steps required to realize the ground-plane structure.

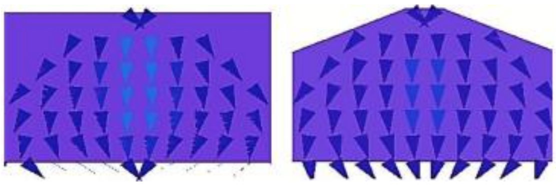

Figure 4. Simulated surface current distribution over the ground-plane at 7 GHz, (a) without modification, and (b) modified.

ANTENNA DESIGN

Ground-Plane Geometry

As mentioned before, the ground plane's first shape is rectangle. The first cuttings are two right triangle subtracted from the ground plane, and this procedure causes S_{11} curve to get below -10dB edge, due to increased radiation current path under antenna's patch, as shown in Fig. 4. The next one is a vertical rectangular notch in the ground-plane of the antenna which causes the low frequency edge to decrease, as depicted in Fig. 5 (a). The ellipsoid shapes and two quadrants shapes added to ground plane to increase the path length of radiation current are created which cause high frequency cut-off to increase, as shown in Fig. 5 (a). The simulated S_{11} curves for previous cuttings are plotted in Fig. 5 (a). The significant note in simulated S_{11} curves is that the S_{11} curves are for the antenna patch with iteration of zero.

Patch Design

The number of resonance responses generated by the patch antenna generally increase with increasing iteration order of its construction [6]. It was found that the width of antenna's patch is related to low frequency edge of its operation, and its height is related to its high frequency edge, so iterations are continued to achieve profitable impedance bandwidth. Fig. 5 (b) shows the effect on the return-loss and impedance bandwidth of increasing the order of iteration. The desired impedance bandwidth is achieved by increasing the iteration to the eleventh order.

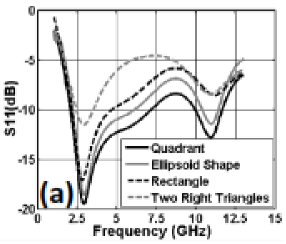

Figure 5. (a) Simulated ground-plane return-loss for each step of construction. Antenna patch is maintained at zero iteration, and (b) Effect of iteration order on the antenna's return-loss response.

RESULT AND DISCUSSION

Return-Loss Response

The prototype antenna was fabricated on FR4 substrate with permittivity of 4.4, thickness of 1 mm and loss tangent of 0.024 using conventional printed circuit board (PCB) technique. 50Ω SMA connector was used to feed the antenna. The width and height of the microstrip feed-line are 1.99 and 10mm, respectively, to achieve 50Ω characteristic impedance.

The performance of the antenna was investigated using Ansoft HFSS (ver. 13). The impedance bandwidth of the antenna was measured using the Agilent 8722ES Vector Network Analyzer. The simulated and measured return-loss performance is shown in Fig. 6.

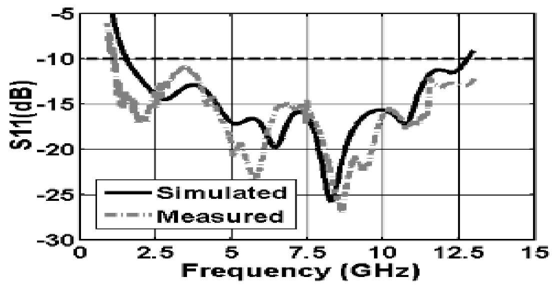

Figure 6. Simulated and measured return-loss of the antenna.

The antenna operates between approximately 1GHz and 13 GHz. There is a good agreement between the measured and simulated response, however; the discrepancy in the response is due to manufacturing tolerance and imperfect feed-line connection. Anyhow, the results do give a ballpark to the resonance frequency of the proposed TSSFMA antenna.

Gain and Measured Radiation Patterns

The measured gain of the TSSFMA antenna is shown in Fig. 7 (a). It can be seen that for low frequencies the antenna's gain is almost stable with almost 1 dB tolerance, however the gain is increased as frequency increases in high frequencies. The proposed TSSFMA antenna's maximum gain in entire band is 4.54 dB approximately around 10 GHz. The measured radiation characteristics of the antenna are shown in Fig. 8. The antenna exhibits a stable radiation pattern over the operating band. Both, its E-plane and H-plane radiation patterns are Omni-directional across its operational bandwidth, since the proposed antenna's structure is symmetrical. In the E-plane, the radiation patterns remain a dumbbell shape over the frequency band. the cross-polarization levels are generally lower than the co-polarization ones.

Group Delay

In the design of UWB antennas it is not sufficient to evaluate the antenna's performance using the traditional parameter such as return-loss, radiation patterns and gain. It is important to appraise systems transfer function with the prototype antenna for transmission and reception of signals. The magnitude of this transfer function should be as flat as possible across its operating band. In addition, the group delay needs to be constant over the entire band as well [16-17].

The key point in the UWB antenna design is to obtain a good linearity of the phase of the radiated field because the antenna should be able to transmit the electrical pulse with minimal distortion. Usually, the group delay is used to evaluate the phase response of the transfer function because it is defined as the rate of change of the total phase shift with respect to angular frequency [20]. Ideally, when the phase response is strictly linear, the group delay is constant (2), [20].

$$\text{group delay} = \frac{-d\theta(\omega)}{d\omega} \qquad (2)$$

Measurement of group delay was performed by exciting two identical prototype antennas, which were located in their farfield, in two orientations: side-by-side and face-to-face [20]. The system's transfer function was measured in an anechoic chamber [20]. The separation between the identical monopole antenna pair was 0.5m. Fig. 7 (b) shows the magnitude of the group delay for side-by-side and face-to-face orientations. It is observed that the group delay variation is less than 6ns over UWB.

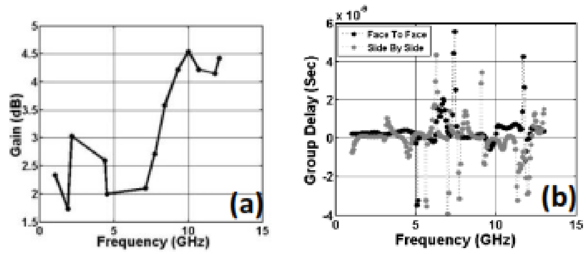

Figure 7. (a) Measured gain response of the proposed antenna, (b) Measured group delay of the prototype antenna.

CONCLUSIONS

A semi fractal monopole antenna was described that for its construction triangular shaped unit-cells were used in which each iteration was scaled down and then triangular shapes were assembled together to satisfy fractal space-filling property. It was shown that by increasing the fractal iteration, the required impedance bandwidth can be obtained. The operating bandwidth of the antenna extends between 1.53 GHz and 12.79 GHz. This makes the TSSFMA antenna suitable for applications such as GSM, UMTS, GPS, PCS, WCDMA, WIMAX, WLAN (802.11b) and UWB systems.

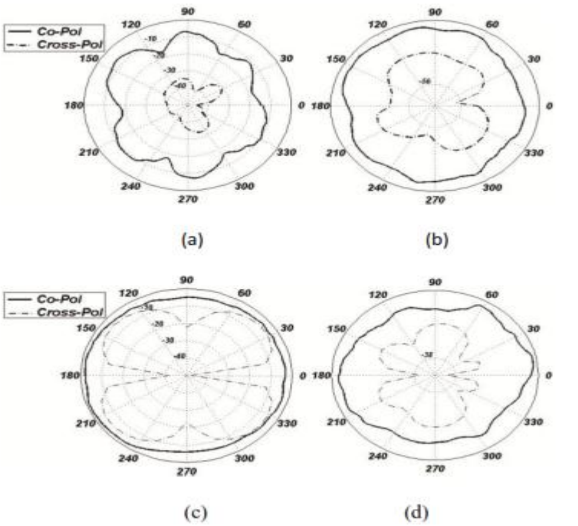

Figure 8. Measured E-plane radiation patterns for the proposed antenna at: (a) 6.39 GHz, and (b) 8.55 GHz and H-plane radiation patterns for the proposed antenna at: (c) 6.39 GHz, and (d) 8.55 GHz.

REFRENCES

[1] H. Schantz, The Art andScienceofUltra WidebandAntennas.Norwood,MA:ArtechHouse, 2005.

[2] Q. Wu, R. Jin, J. Geng, and M. Ding, “Printed omni- directionalUWB monopole antenna with very compact size,” IEEE Trans.Antennas Propag., vol. 56, no. 3, pp.896–899, Mar. 2008.

[3] K. G. Thomas, and M. Sreenivasan, “Printed elliptical monopole with shaped ground plane for pattern stability,” Electron. Lett., vol. 45, no. 9, pp. 445-446, Apr. 2009.

[4] M. Moosazadeh, C. Ghobadi, and Z. Esmati, “Monopole antenna based on wrench-shaped slot on circular disc patch for UWB application,” Microwave Opt Technology Letters Vol. 53, no. 8, pp. 1927-1931, Aug. 2011.

[5] X.L. Bao and M.J. Ammann, Printed band-rejection UWB antenna with H-shaped slot, antenna technology: Small and smart antennas metamaterials and applications, pp. 319-322, 2007.

[6] J. Pourahmadazar, C. Ghobadi, J. Nourinia, and H. Shirzad, “Multiband ring fractal antenna for mobile devices,” IEEE Antennas Wireless Propag. Lett., vol. 9, pp. 863–866, 2010.

[7] C.T.P. Song, P.S. Hall, and H. Ghafouri-Shiraz, “Multiband multiplering monopole antennas,” IEEE Trans. Antennas Propag., vol. 51, no.4, pp. 722–729, Apr. 2003.

[8] S. R. Best, “The effectiveness of space-filling fractal geometry in low-erring resonant frequency,” IEEE Antennas Wireless Propag. Lett., vol.1, pp. 112–115, 2002.

[9] K. J. Vinoy, J. K. Abraham, and V. K. Varadan, “Fractal dimensionand frequency response of fractal shaped antennas,” in Proc. IEEE Antennas Propag. Soc. Int. Symp., Jun. 2003, vol. 4, pp. 222–225.

[10] R. Zaker, C. Ghobadi, and J. Nourinia, “Novel modified UWB planar monopole antenna with variable frequency band-notchfunction,” IEEE Antennas Wireless Propag. Lett., vol. 7, pp. 112-114, 2008.

[11] K. Chung, J. Kim, and J. Choi, “Wideband microstrip-fedmonopole antenna having frequency band-notch function,” IEEEMicrow.WirlessCompon. Lett., vol. 15, no. 11, pp. 766–768, Nov.2005.

[12] K. Chung, S. Hong, and J. Choi, “Ultrawide-band printed monopoleantenna with band-notch filters,” Microw. Antennas, Propag., vol.1, pp. 518–522, Apr. 2007.

[13] L.-N. Zhang, S.-S. Zhong, X.-L. Liang, C.-Z. Du, “Compact omnidirectional band-notch ultra-wideband antenna,” Electron. Lett., vol.45, no. 13, pp. 659-660, 2009.

[14] M. Ojaroudi, G. Ghanbari, N. Ojaroudi, and C. Ghobadi, “Small square monopole antenna for UWB applications with variable frequency band-notch function,” IEEE Antennas Wireless Propag.Lett., vol. 8, pp. 1061-1064,2009.

[15] R. Eshtiaghi, J. Nourinia, C. Ghobadi, “Electromagnetically coupled band-notched elliptical monopole antenna for UWB applications,” IEEE Trans. Antennas Propag. vol. 58, no. 4, pp. 1397-1402, Apr.2010.

[16] Z. N. Chen, X. H. Wu, J. F. Li, N. Yang, and M. Y. W. Chia, “Consid-erations for source pulses and antenna in UWB radio systems,” IEEE Trsns. Antenna Propag., vol. 52, no. 7, pp. 1739-1748, Jul. 2004.

[17] D. D. Krishna, M. Gopikrishna, C. K. Aanandan, P. Mohanan, and K. Vasudevan, “Ultra-wideband slot antenna for wireless USB dongle applications,” Electron Lett., vol. 44, no. 18, pp.1057-1058, 2008

[18] H. A. Wheeler, “ Small antenna,” IEEE Trans. Antennas Propagat., vol. 23, pp. 462-469,1975.

[19] M. Hammond, P. Poey, and F. Colombel, “Matching the input impedance of a broadband disc monopole,” Inst. Elec. Eng. Electron. Lett., vol. 29, no. 4, pp. 406-407, 1993.

[20] K. Athari, G. Ghobadi, J. Nourinia, M. Abbasi Layegh, V. Karimzade, “Novel microstrip slot antenna for MIMO systems and super-wideband applications,” International Journal of Natural and Engineering Sciences 7 (2): 67-71, 2013, ISSN: 1307-1149, E-ISSN: 2146-0086.