A UWB Fractal Antenna for Body Area Network Applications

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***Abstract*— A compact ultra-wideband antenna is used to demonstrate a notching method using a fractal for the amelioration of interference from legacy users such WiMAX and WLAN. The achieved results show that this antenna operates in the range of frequencies specified by FCC for BAN and relatively stable characteristics in the presence of simulated biological tissue representing a forearm. The antenna is fed with a compact waveguide and has useful properties with a main beam parallel to and perpendicular to the skin. The antennas have footprints of 1.6cm ×2.2cm and 2cm x 2.6 cm including co-planar feed.**

***Keywords*— Fractal antennas, body-area networks, co-planar waveguide.**

I. INTRODUCTION

Recently, the use of body area network devices in pain management, diagnostic and treatment has drawn attention [1-4]. Many of these devices have been designed to work in the range of ultra-wide band (UWB) frequencies from 3.1GHz to 10.6 GHz [5]. In general, narrowband access for medical implants was previously covered by the MICS band (402-405 MHz), and the MEDS band (401 – 406 MHz) [6]. However, UWB technology promises much greater flexibility in device choice for communications devices near to or on the surface of the body. Recently the IEEE task group six (TG-6) standardised the media access and physical layers for body area networks (BAN) [7]. UWB in its current form has been designed as a low power technology with transmitters having an FCC emission limit of -41.3 dBm/MHz. Inside the UWB band are two important interferers, namely IEEE 802.16 WiMAX system that operate at 3.3-3.7 GHz and IEEE 802.11a WLAN systems that operates at 5.15-5.825 GHz. A good UWB antenna would seek to ameliorate interference into and out of these bands. Hence the concept of frequency notched UWB antennas. Several approaches to the design of multiband broadband antennas have been tried. These include a response composed of several narrowband elements combined to form a composite antenna. A trivial case would be to use simple dipoles. However, such antennas are difficult to realize in practice because whilst the individual elements for the pass-bands are all easily made the devices they support are required to be small thus mutual coupling between the elements can be high.

A second method would involve the use of a wide band antenna connected directed to an active or passive stop band (notch) filter. This is a more complex and expensive alternative, which may be attractive due to the steep skirts achievable with filters, particularly active surface acoustic wave filters that are well suited to the low power systems UWB comprises.

A third method involves designing an antenna with a wide bandwidth as a single element and then subtracting from the metallization (radiating elements), slots such that at the desired stop bands current in flow is restricted. An efficient method for the arrangement of slots within the radiating element is the fractal and in this paper the fractal is shown to be useful in the design of on-body antennas suitable for body area networks.

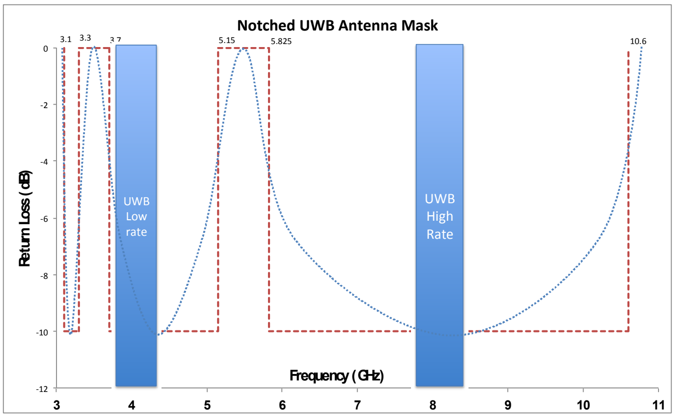

Figure 1. Example UWB Antenna Mask - dotted line - 10dB passband with notches, dashed line - an example passband based on a -6dB criteria for S11, Boxes - High and Low Rate Pass bands for FCC ODFM UWB Radio

Antennas therefore have an important role in providing the desired communication system allow for reconfigurable and adjustable body worn systems [8, 9]. A small size of antenna is a desired parameter that allows integration into several personal accessories, such as cloths and mobile devices. When worn close to, but not on the skin, an antenna is coupled to body and the reactive properties of the biological matter interact with the electric magnetic fields from the source. This leads to loss of Q and changes to resonant frequency. In the limit antennas worn on the skin short out and are not able to function properly as a transducer.

Previously in other applications fractals have been used to design antennas that are small enough for BAN devices [10]. Such uses have included the cellular phone, wireless local area

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network (WLAN) [11], medical devices [12, 13]. Such fractal antennas are designed and manufactured based on the properties of self-similar objects [10, 14]. Other related antennas have included [15, 16, 17].

Two new antenna designs are discussed in this paper. Both antennas involve the simulation of a small footprint UWB antenna with a classical fractal incorporated within it as a cut-out. In this way the current distribution of a simple probe type antenna is enhanced to generate a stop band at a desired frequency.

The rest of this paper is structured as follows. Section II presents an example antenna that incorporates a binary tree fractal and compares simulations for with and without a fractal notch. In section III a second type of antenna is presented that is achieved using a T-Fractal to generate a fractal notch within the UWB spectrum for IEEE 802.11a WLAN systems that operate at 5.15-5.825 GHz. The effects of close proximity to a phantom arm are also considered in this part. Conclusions are then presented in section IV.

II. EXAMPLE ANTENNA STRUCTURE USING A BINARY TREE

An example method for a fractal design is given in [18] Starting with a "stem" the structure to branches off in two directions symmetrically with an angle of 120° branch to stem and branch to branch. The process may be continued infinitely but a binary tree with five interactions n=5 is shown in Figure 2. The two main characteristics of a fractal are self-similarity and self-affinity. Self-similarity means that the small regions of the geometry duplicate the overall geometry on a reduced scale. Self-affinity means small regions of the geometry are not identical to the overall geometry but are skewed or distorted and may have differing scale factors [14]. For the same spatial area the effective length of the antenna can be increased with increasing number of iterations [19].

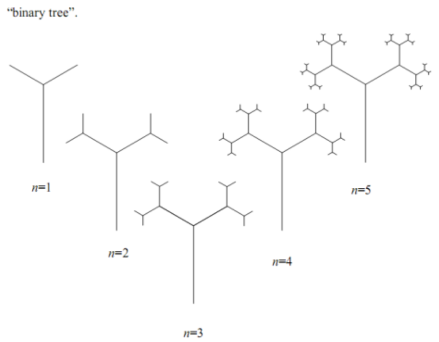

Figure 2. Five iterations of a binary tree structure.

An example of the design is shown in Figure 3. This binary tree has several features common with other fractals such as Koch curves. The dimensions are as listed in the Table 1. The antenna is constructed modelled Rogers RO4003 substrate with a thickness of ~ 1.5 mm and a relative dielectric constant ε_r = 3.38 with dimensions of 16mm x 22mm.

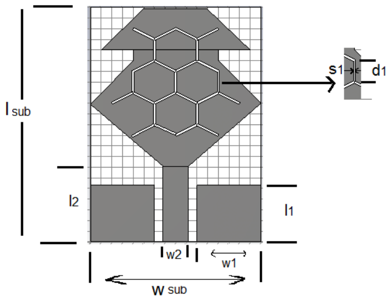

Figure 3. The geometry of a binary tree UWB antenna

Table 1. Parameters for two UWB antennas suitable for WBAN with fractal notches.

The parameter	Binary Tree Antenna (mm)	T-Fractal Antenna (mm)
W_{sub}	16	20
l_{sub}	22	26
W_1	6	8
W_2	2.4	2.8
l_1	5.3	6.6
l_2	7.1	7.1
D_1	2.1	
S_1	0.2	

IV- RESULTS AND DISCUSSION

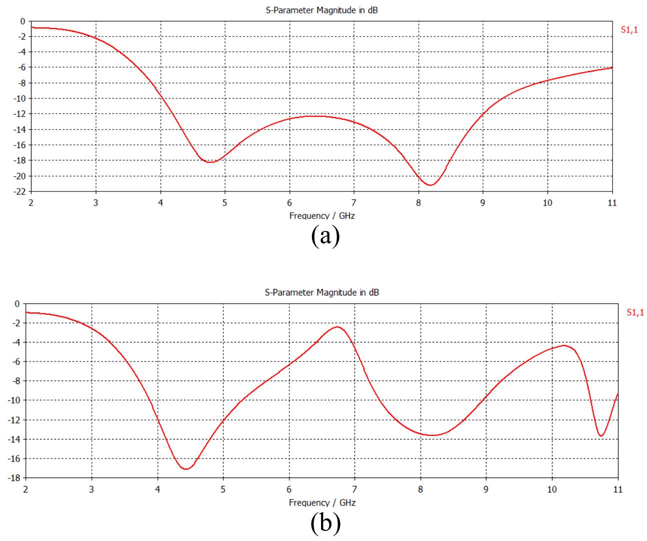

Figure 4. $S_{1,1}$ of a UWB antenna, a) without the fractal slots b) with the fractal slots

The results in Figure 4. shows that the antenna maintains a reasonable -10 dB bandwidth with an obvious stop band due to the presence of fractal slots. The bandwidth is from 4 – 9.3 GHz without using notches while the multi-band yields that

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the bandwidth is from 3.8 – 5.3 GHz, 7.4 – 9 GHz and 10.6 – 11 GHz.

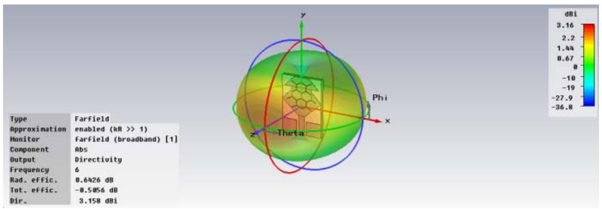


Figure 5. 3D Far field showing the simulated pattern and efficiencies of a UWB antenna with fractal slots

The simulated radiation and total efficiencies were generally good for the fractal antenna (shown in Figure 5).

In the azimuth angle which is perpendicular at the antenna plane, the strength of the gain was 2.8dBi but is increased to aprroximately 3.1dBi when the fractal is used.

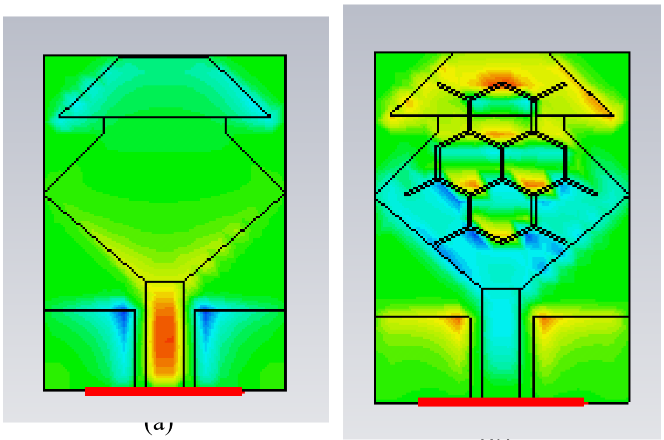


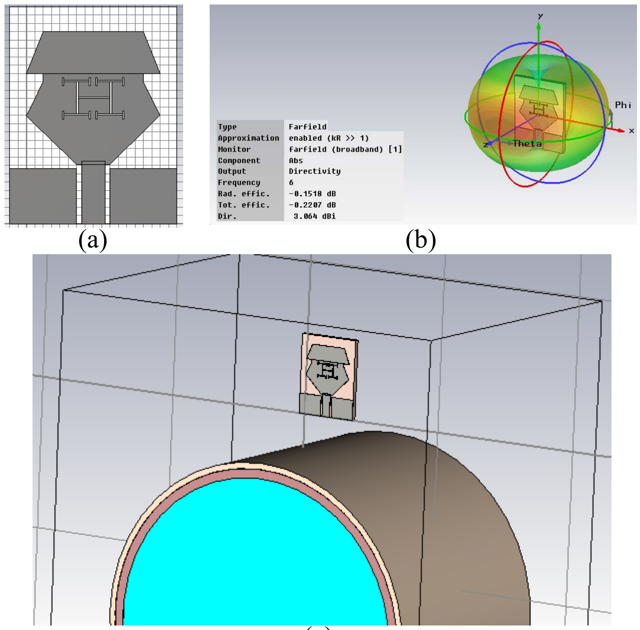
Figure 6. Current distributions (a) UWB Antenna, (b) UWB Antennas with Fractal Slot at 6.5GHz

The figure above shows how the current distribution is significantly changed from that of a simple wideband monopole (a matched probe), to that of a multiresonant structure without altering the footprint of the original antenna.

III. UWB Antenna with a T-Fractal

A second antenna was designed to improve the accuracy of the stop band. Figure 7. shows a second design which was simulated using a simple arm phantom which consisted of three tissue types, namely skin, fat and muscle with appropriate electrical parameters. In this case the fractal used was a T-shape the dimesions of which are shown in Table 2.

The dimensions of the fractal which were tuned using a short series of simulations, are shown in Figure 8. The fractal had a track cut out of 0.2mm. The simulated phantom used for this set of experiments was designed to represent a section of arm as if the antenna were being used above, but away from the skins surface. Therefore the co-planar waveguide feed port was made to be 1cm above the skin which is reasonable if clothing were considered. Note the antenna is generally omnidirectional about the axis perpendicular to the skins surface giving a main beam parallel to the phantom surface.



(a) (b) (c)

Figure 7. UWB Antenna with a T-Fractal (a) Design on a 1mm grid, (b) radiation pattern at 6.5GHz, (c) Antenna perpendicular to a generic 8cm dia. arm phantom.

Table 2. Generic Arm Phantom Electrical Properties @ 6.5GHz

Parameter	Skin	Fat	Muscle
ε_r	31.29	4.6	49.54
Conductivity (S/m)	8	0.58	4
Thickness (mm)	4	6	100

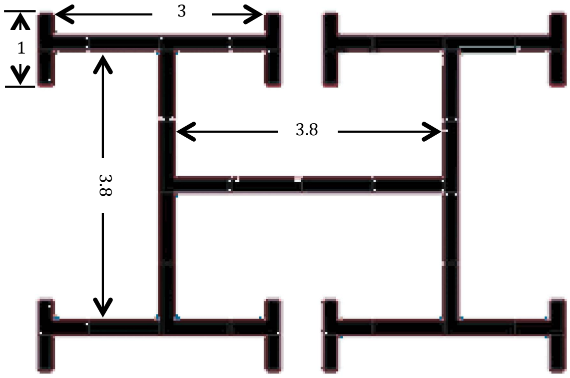


Figure 8. T-Fractal Geometry. All dimensions in mm, 0.2mm cut out. Fractal is symmetrical about the y-axis of the UWB antenna at 15.1mm above the port.

The return loss for this antenna is shown in Figure 9. for simulations with and without the phantom arm. In this case -10dB pass bands occur from approximately 3.7-5.3GHz and 5.8-10.2GHz which would satisfy the requirments given for UWB in WBAN as shown in the mask of Figure 1.

Purturbations on the on-body response (green line) are due to meshing problems in the simulation that we were unable to solve at the time of publication however we believe the trend is correct other than a false null at 9.3GHz. In this range of frequencies the body is generally capacitive which accounts for the uptune in the response.

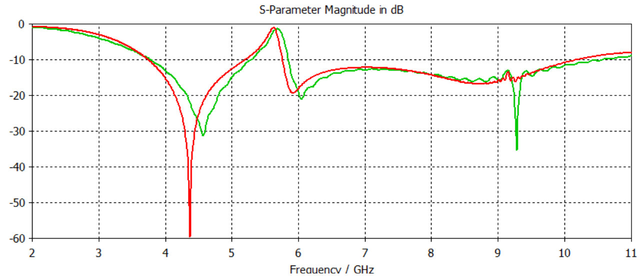


Figure 9. S11 for a UWB antenna over a section of 8 cm dia. phantom arm. Red without arm, Green with arm.

IV. Conclusions

This paper has demonstrated a useful method for the design of WBAN UWB antennas using an etched fractal within the footprint of the radiating element. Two types of fractal were used to produce a stop band for legacy communications equipment having spectrum within the FCC UWB proposed passband. It was shown that because of the properties of self similarity and self affinity fractals can achieve complex modifications to the current distributions on printed antennas in a controlled way. These designs are well suited to optimisation using methods such as genetic algorithm or simulated annealing. The antenna footprints shown here are 1.6cm x 2.2cm and 2.0cm x 2.6cm, with stable impedance characteristics close to the body. Future work for this research includes the application of a genetic search algorithm to produce a fractal notch for the IEEE 802.16 WiMAX system that operate at 3.3-3.7 GHz and measurements to better define any effects of a co-planer waveguide feed extension running at right angles to the plane of the two antennas.

References

[1] Saeid Bahanfar, Ladan Darougaran, Helia Kousha, Shahram Babaie, "Reliable Communication in Wireless Body Area Sensor Network for Health Monitoring", International Journal of Computer Science, vol. 8, no. 5, pp. 366 – 372. Sept. 2011
[2] Huan-Bang Li and Ryuji Kohno, "Standardization on Body Area Network and a Prototype System Based on UWB", Journal of Medical Systems, vol. 35, no. 5, 2011.
[3] Veerpal Kaur, "Performance Evaluation of Binary Modulations through Wireless Body Area Network Channel", International Journal of Computer Applications, vol. 18, no. 3, pp. 1 -5, 2011.
[4] T. Henriksson, M. Klemm, D. Gibbins, J. Leendertz, etc., "Clinical trials of a multistatic UWB for breast imaging", Loughborough Antennas & Propagation conference, 14 – 15 Nov. 2011, Loughborough, UK.
[5] K. Yekeh Yazdandoost, R. Kohno, "Ultra wideband antenna," IEEE Communication Magazine, vol. 42, 63 – 66, 2004.
[6] http://www.fcc.gov 95.628 Cluse.
[7] https://mentor.ieee.org/802.15/documents?is_group=0006, IEEE 802 WPAN Low rate alteative PHY Task Group 4a (TG4a), IEEE 802.15 [ONELIN] .
[8] Akram Alomainy, Yang Hao, Clive Parini and Peter Hall, "Characterization of printed UWB antenna for on-body communications". Wideband and Multi-band Antennas and Arrays, 2005. IEE (Ref. No. 2005/11059) , vol., no., pp. 53- 57, 7 Sept. 2005
[9] Kamya Yekeh Yazdandoost, Kiyoshi Hamaguchi,"Very small UWB antenna for WBAN applications", IEEE 2011.
[10] Frank B. Gross, "Frontiers in Antennas: Next Generation Design and Engineering", McGraw Hill, 2011.
[11] Guterman, J., Moreira, A. A., and Peixeiro, C., "Microstrip fractal antennas for multistandard terminals", IEEE Antennas and Wireless Propagation Letters, vol. 3, 2004, pp. 351 – 354.
[12] James C. Lin and Konstantina S. Nikita, "Wireless Mobile Communication and Healthcare", Springer, 2011.
[13] George Thomas DeVries III, "Innovations in Workplace wellness: six new tools to enhance programs and maximize employee health and productivity", Compensation & benefits review, vol. 42, no. 1, 2010, pp. 46 – 51.
[14] Constantine A. Balanis,"Modern Antenna Handbook", A John Wiley & Sons, Inc., 2008.
[15] Amer B. Shaalan, "Design of fractal quadratic Koch antenna" IEEE 7th International Multi- Conference on Systems, Signals and Devices, pp. 1-4, 2010.
[16] P. J. Soh, G.A.E. Vandenbosch, S.L.Ooi, M.R.N. Husna, , "Wearable dual-band Sierpinski fractal PIFA using conductive fabric", IEEE Electronics Letters, vol. 47 no. 6 pp. 365-36, 2011.
[17] Hassan M. Elkamchouchi, and Mona N. Abd El-Salam, "Square loop antenna miniaturization using fractal geometry ", IEEE Antennas and Propagation Society International Symposium", vol. 4 pp. 254-257, 2003.
[18] K. J. Vinoy, "Fractal shaped antenna elements for wide – and multi – band wireless applications", Ph.D. dissertation, The Pennsylvania State University, 2002.
[19] M. Ahmed, Abdul-Letif, M. A. Z. Habeeb, etc., "Performance characteristics of the Minkowski curve fractal antenna", J. of Eng. and Appl. Sci., vol. 1, no. 4, 2006.
[20] David A. Sanchez-Hernandez, "Multiband Integrated Antennas for 4G Terminals", Artech House, 2006.
[21] Rahmat-Samii, Y., and Gianvittorio, J. P., "Fractal Antennas: A novel antenna miniaturization technique and applications", IEEE Antennas and Propagation, vol. 44, no. 1, February 2002, pp. 20 – 36.