Study of Fractal Tree Antenna for Multiband Applications

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Abstract. Present day is witnessing a very rapid growth of wireless communication, for which antenna with very large bandwidth are in strong demand, so that various application are covered with fewer or preferably with single antenna. Fractals are profoundly intricate shapes that are easy to define. Fractals are space-filling contours, electrically large features can be efficiently packed into small areas. Fractal tree structures can be utilise to enhance the performance of the antenna such as widening the frequency band while reducing the size of an antenna. This paper summarize the different kind of tree design structure, development process, current research and application of the fractal tree antenna.

Keyword. Fractal Antenna, Fractal Tree, multi-band, ultra-wideband, miniaturization

1 Introduction

A fractal is rough fragmented geometric shape that can be split into parts, each of which is a reduced sized copy of the whole. The term fractal is coined by Benoit Mandelbrot in 1975 and was derived from the Latin word fractus, meaning broken or fractured [1].

Fractal provides the features such as fine structures at arbitrarily small scales, irregular to be easily describe in traditional Euclidean geometric language, self-similar, it has Hausdoff dimension which is greater than its topological dimension, it has simple and recursive definition. Fractal antenna response differs from traditional antenna design, in that it is capable of operating with good-to-excellent performance at many different frequencies.

Various fractal types other than fractal tree used in antenna are shown below **Fig. 1**

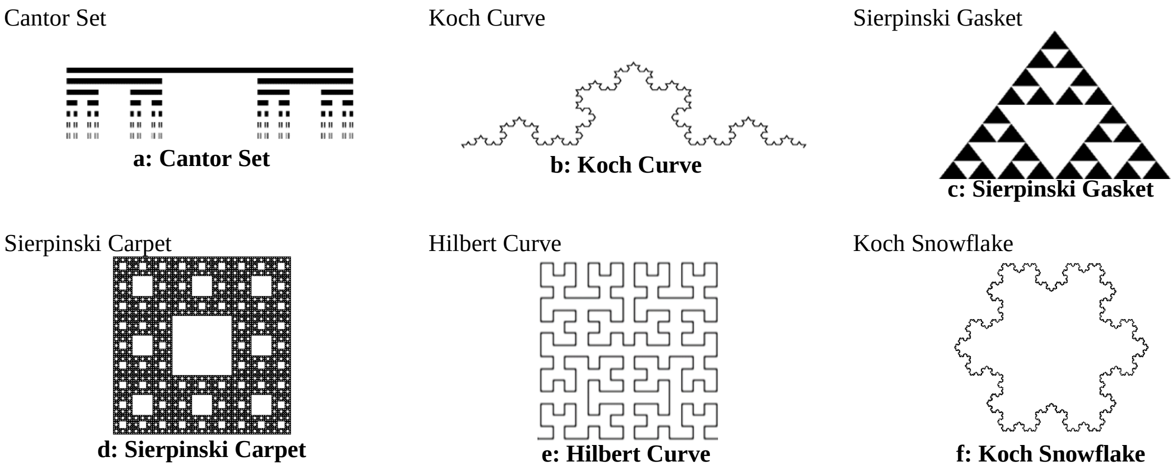

Fig.1. Various Fractal other than fractal tree

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2 Literature Review

In 1973, Benoit Mandelbrot first proposed the idea of fractal geometry and fractal dimension. He define as fractal geometry is based on a form of symmetry that had previously been underused, namely invariance under contraction and dilation. He also says that fractal geometry is conveniently viewed as a language that as proven its value by its uses. Then, fractal theory was applied in various field of science and engineering [1]. In 1986, Kim and Jaggard [4] first time put forward that the theory of fractal could be implemented to the design of antenna and its array shown in Fig. 2. They combines the strength of both uniform and random arrays in the fractal array procedure, and concludes that uniform array possess relatively low side lobes and less sensitive to error compare to random array.

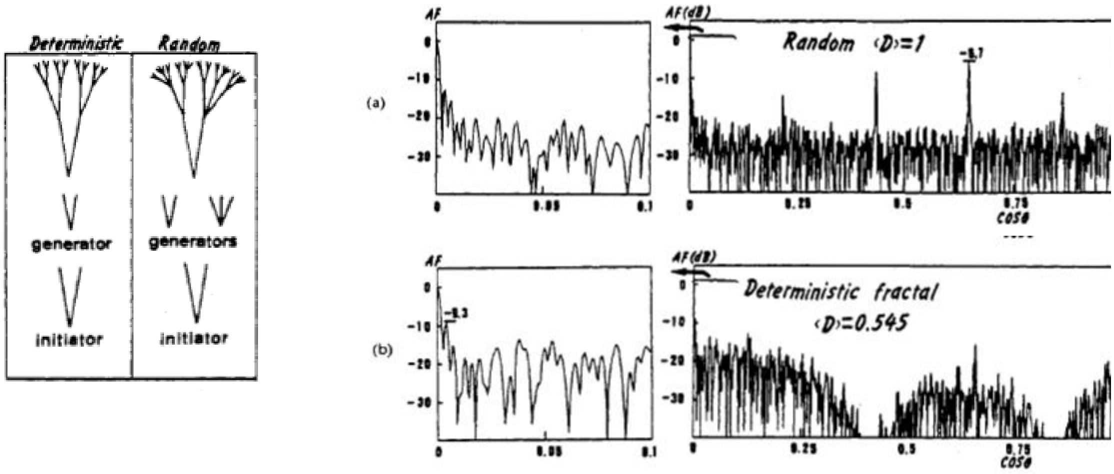

Fig. 2 Design and result proposed by Kim and Jaggard

In 1996, Puente et al., J. Claret, F. Saguks, J Romeu, M.Q. Lopez – salvans and R. Pous studied the multiband properties of fractal tree non deterministic antenna generated electrochemical deposition [5] shown in Fig. 3. They concludes that radiation properties of a random fractal aggregate generated by electrochemical deposition with monopole configuration shows rich distribution of scales into multifrequency behaviour. The distribution of the frequencies has been shown to be related to the distribution of length over the antenna.

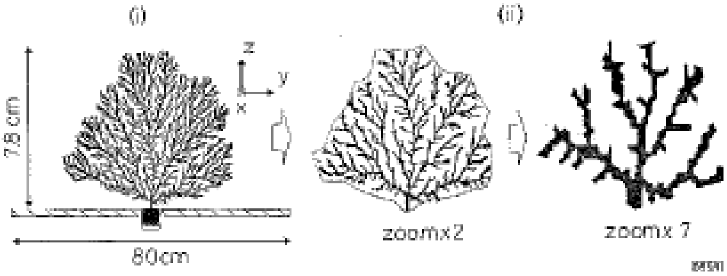

Fig. 3 Design with chemical deposition by Puente et al., J. Claret, F. Saguks, J Romeu, M.Q. Lopez – Salvans and R. Pous

In 1999, D. H. Werner Rubio Bretones and B R Long shown in Fig. 4, Present the work based on thin wire ternary fractal tree and conclude with self-similarity behaviour at specific bands [6]. In 2000, John P. Gianvittorio and Yahya Rahmat Samii [3] researched the miniaturization of dipole antenna that using fractal tree structure as end load. They compared the types of the fractal as a dipole also as a Koch dipole for 5 iteration shown in Fig. 5. Further in 2003, Douglas H. Werner and Suman Ganguly [7] proposed Tri-band ternary fractal tree antenna which suggest the reduction in the resonant frequency of a standard dipole can be achieved by end loading it with two dimensional or three dimensional tree like fractal structure shown in Fig. 6. This decreases in the resonant frequency shown asymptotically approach a limit as the number of iteration are increased. Since then, more and more researcher have been studying fractal tree antenna

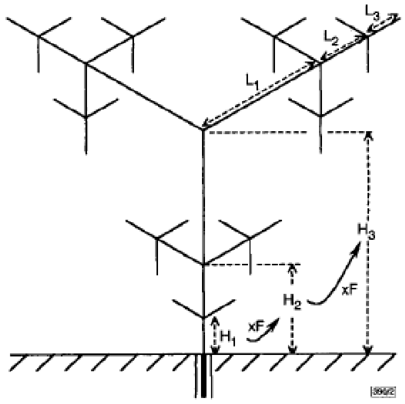

Fig. 4 Design by D. H. Werner Rubio Bretones and B R Long

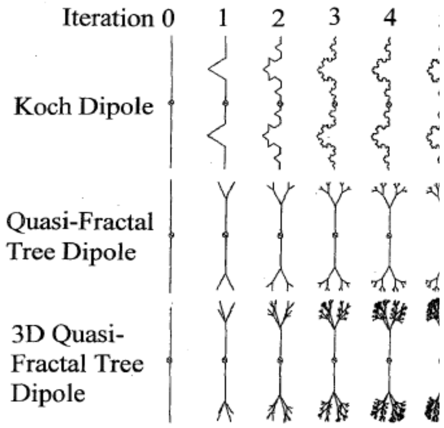

Fig. 5 Design proposed by John P. Gianvittorio and Yahya Rahmat Samii

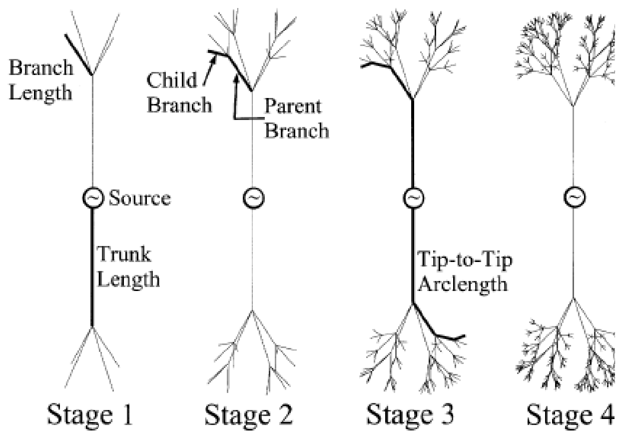

Fig. 6 Design proposed by Douglas H. Werner and Suman Ganguly

In 1996, Puente et al. demonstrated the multiband behaviour of the Sierpinski gasket antenna. They observe the multiband behaviour of the antenna which is dependent on the self-similarity property of the gasket. This may provide the new design of frequency independent and multiband antenna for researchers [5].

In 2004, Joshua Petko and D H Werner present the paper based on miniature configurable three dimensional fractal tree antenna in which they apply LC traps or RF switches strategically placed throughout the branches and /or along the trunk of the trees. A prime advantage of this is resonant frequency of the antenna can be spaced much closer than if they were applied to the tree trunks. They shows 57% in the size reduction for lowest band of operation [8]. In 2004, B. Ozbakis and A. Kustepeli proposed Novel design for fractal tree antenna application. They design fractal tree antenna using Fibonacci number sequence and non-uniform branch length ratio shown in Fig 7. Results shows 6 to 13% shift in the resonant frequency for different iteration [9].

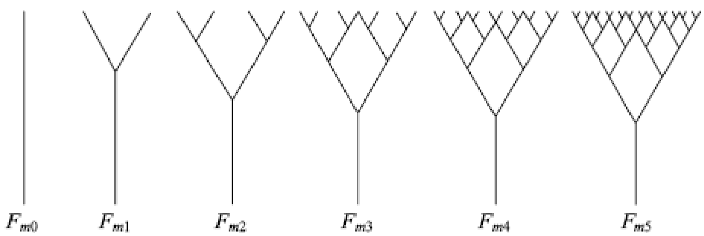

Fig. 7 Design with non-uniform branch length ratio

In 2005, Mohammadi Bharmal and Dr. K J Vinoy proposed 5-iteration tree antenna shown in Fig. 8, the proposed antenna printed on 1.5 mm thick substrate ($\varepsilon_r = 3.5$) and conductor thickness of 5 µm. This antenna maintain S_{11} (10 dB Bandwidth) for frequency 6.2 to 6.8 GHz, 7.5 to 8.2 GHz and 8.5 to 10 GHz. This is CPW feed UWB antenna explored to UWB Bandwidth, more variable to tune to the desired response like length of the stem, separation between ground and feed, iteration, scale factor, angle. It has CPW feed which simplifies the fabrication process [10].

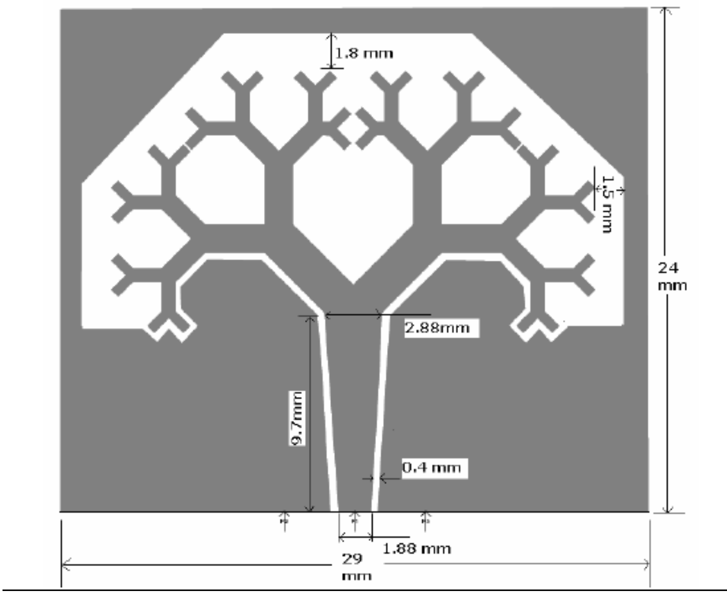

Fig. 8 Proposed 5-iteration tree antenna by Mohammadi Bharmal and Dr. K J Vinoy

In 2007 to 20015 many research scholar and scientist proposed different antenna based on different fractal tree antenna design shown in Fig. 9. In 2008 Yan su, Xiao Zheng Lai and Sheng Li Lai design fractal tree RFID tag antenna on papery substrate [11]. Hyo Won Song, He Soon An, Jung Nam Lee, Jong Kweon Park and Jin Suk Kim Design the Tree shaped UWB Antenna using fractal concept [12]. This antenna is good candidate for UWB application and show good impedance matching, radiation characteristics and gain characteristics for the range of 3.1 – 4.8 GHz operating frequency. In 2009, Joshua S. Petko and Douglas Werner paper demonstrate Interleaved UWB Antenna array on optimized polyfractal tree structure. They used specially formulated genetic algorithm as well as multi objective optimization technique for the design [13]. One more design tried in the same year by Rui Guo, Xing Chen and Kama Huang for wideband Microstrip fractal Antenna based on fractal binary tree. They also used Genetic Algorithm with full wave EM simulation using FDTD on a cluster system [14]. Paper shows the wide impedance bandwidth up to 42.8% from 2.46 to 3.8 GHz range.

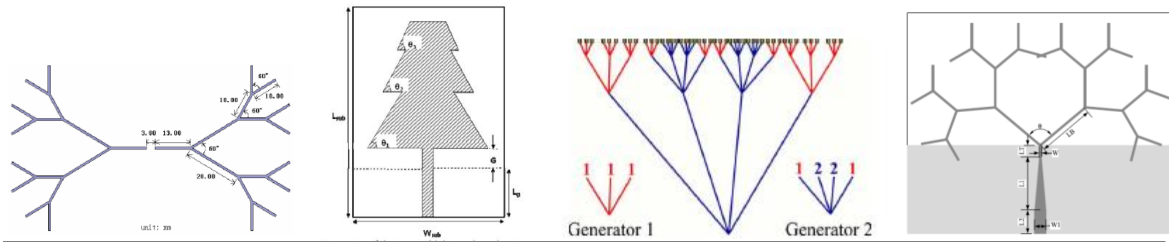

Fig. 9 Antenna proposed by different researches

In same year 2009, A Falahati, Naghshvarian Jahomi and R. M. Edwards design dual band notch CPW Ground fed UWB Antenna based on fractal binary tree [15]. This is miniaturize size delivers a good radiation patterns with monopolar characteristics.

The gain of the antenna is suppressed very well in WLAN bands. 2010, A Aggarwal and M. V. Kartikeyan design Pythagoras tree fractal patch antenna for multifrequency and UWB operations. It was design for WLAN / WiMAX (2.4 GHz) and WiMAX (3.5GHz) [16]. This antenna shows the dual band performance and achieve more than 20% impedance bandwidth achieved at both the frequency bands. In 2011, Javed Pourahmadazar, Changiz Ghobadi and Javad Nourinia work on the same kind of Pythagoras tree fractal patch antenna with slight modification. This antenna shows the result in UWB band and good impedance matching with the improvement in the impedance bandwidth too [17]. In 2012, Sanjay Khobragade and Anitha V R present the papers on two design based on fractal tree antenna. One design based on the tree with the help of rectangular and triangular patches connected with the wire antenna and other with simple design with five iteration. First antenna design for 2.4 GHz and 3.6 GHz frequency and shows the S_{11} bandwidth of 9.5% and 31.5% respectively [18] [20]. Second design presented by Sanjay Khobragade and Anitha V R present antenna for the range of 2.1 to 2.8GHz resonant frequency. It is good candidate of multiband frequency application which have the application in Bluetooth, Wireless LAN etc. [19] [20]. All antennas are shown in Fig. 10.

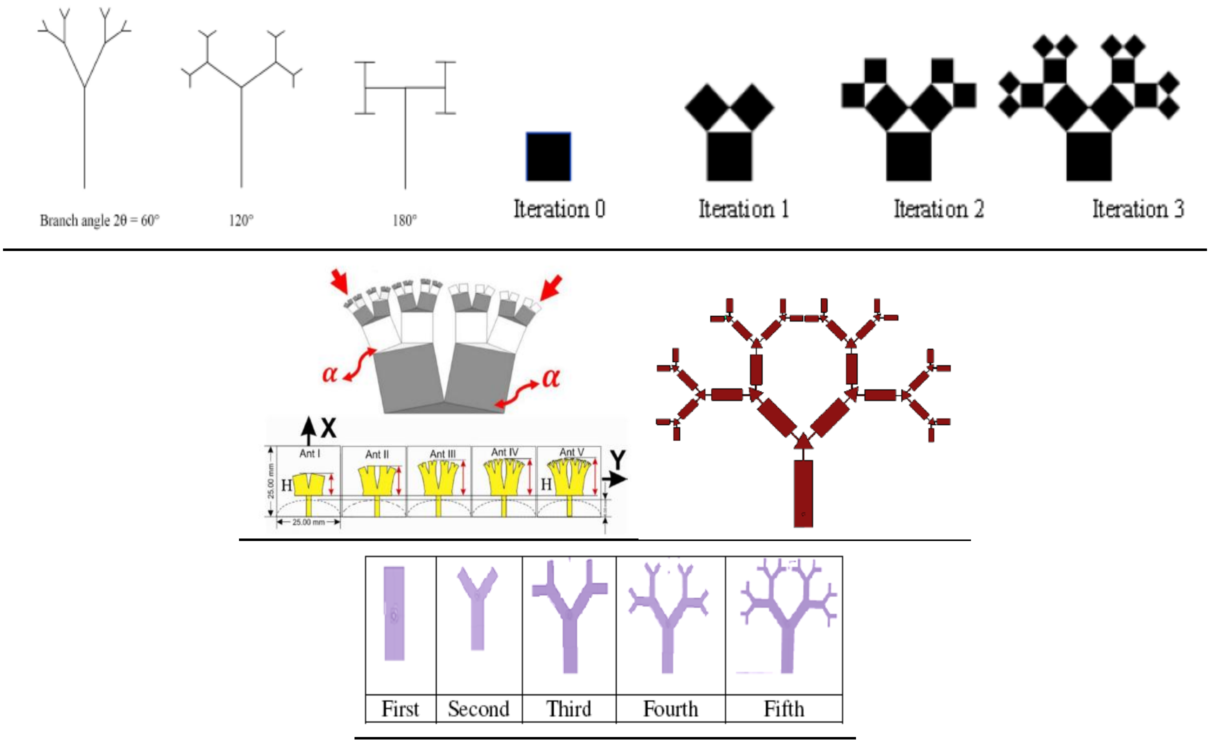

Fig. 10 Antenna proposed by different researches

In 2011 first time Huseyin Altun, Erdal Korkmaz and Bahattin Turetken present the paper based on fractal tree reconfigurable antenna for multiband application. They uses 8 PIN diode 4 at the corners of part 1 and remaining four at the joint of parent and child branches [21]. They got multiband output for the different possible ON- OFF condition of the PIN diode switches shown in Fig. 11. The frequency range varied from 1.51 to 8.6 GHz. In 2013 Anitha V R and Malli Yuva Sindhu [22] tried the same in the design which is the extension of design presented by Sanjay Khobragade and Anitha V R [18], [19], [20] based on rectangular and triangular patches where wire replace by switches. This antenna covers the service band such as WLAN 2.4 – 2.42GHz and WiMAX 3.4 – 3.8 GHz resonant frequency also shows the other band 2.4 to 3.8 GHz. In 2014 Sumit Rakibe, Sonali Sahu and Sanjay Khobragade present the paper on reconfigurable antenna for application such as WiMAX (2.4-2.483) GHz WiMAX (3.4 – 3.6) GHz and WLAN (5.15-5.825) GHz and some other frequencies between 2-10 GHz. 6 PIN diodes used for the design of the antenna and tested for the different possible ON-OFF condition of the switches shown in Fig. 12 [23].

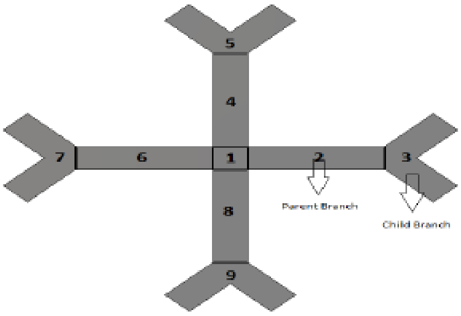

Fig. 11 Reconfigurable Antenna proposed by Huseyin Altun, Erdal Korkmaz and Bahattin Turetken

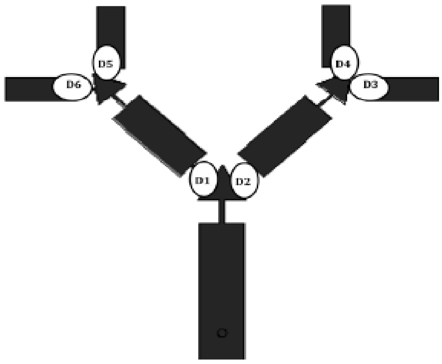

Fig. 12 Reconfigurable Antenna proposed by Sumit Rakibe, Sonali Sahu and Sanjay Khobragade

3 Comparative study of the Reference Antennas

Following table shows the comparative studies of the reference antenna. Reference number 2 to 23 antenna are used for the comparison.

Table I. Comparative study of the reference Antennas

Ref	Feeding Technique	Resonant Frequency	Branch Angle	(Return Loss)	Mode of Operation	B/W	Remark
2	Coaxial, Monopole	f_1,f_2,f_3,f_4	30^0 to 180^0	NA	Multiband	NA	Comparison of resonant frequency ratio
3	Coaxial	1 – 1.9Ghz	60^0	NA	Single band	NA	Calculate Resonant Freq. and quality factor
4	Coaxial	NA	NA	NA	Multiband	NA	Discuss deterministic and random array
5	Monopole	0.9 – 8 GHz	NA	NA	Multiband	NA	Radiation properties has been tested
6	Monopole	0.1 – 2 GHz	120^0		Multiband		Impedance behaviour is studied
7	Coaxial	0.1 – 2 GHz	120^0	NA	Multiband	NA	Impedance behaviour is studied
8	Monopole	0.8–6.4GHz	$0\text{-}315^0$	-32dB max.	Multiband / Reconfigurable	70%	Effective in significant size reduction (57%)
9	Coaxial	1.1-1.9GHz	60^0	NA	Multiband	NA	Design the antenna with Fibonacci seq.
10	CPW	6.2-10GHz	Variable	-28dB	Multiband	UWB	Matched to desired Impedance
11	Coaxial	0.6-1.0 GHz	$0\text{-}180^0$	-24.2dB max	Multiband		Shows the size reduction of RFID tag ant. Effectively
12	Monopole	2.7-6.4GHz	$0\text{-}90^0$	-48dB max	Multiband	81.3%	Proposed antenna id good candidate of UWB apps.
13	Coaxial	$10f_0$	60^0 from Broadside	NA	Multiband	20:1	Presented Interleaving antenna array using GA
14	Monopole	2.4-3.8GHz	102.4^0	-42.8dB	Multiband	40.8%	Antenna is optimise using GA and FDTD
15	CPW	3.5-10.2GHz	$60^0\text{-}180^0$	NA	Multiband	UWB	Dual band notch antenna design using single slot
16	CPW	2.4-3.5GHz	45^0	-38dB max	Multiband	33.5%	Pythagoras Tree Antenna, 20% BW enhancement
17	Monopole	3.8-8.26GHz	45^0	-46dB Max	Multiband	123%	Good Impedance match and improvement in BW
18	Proximity Couple	2.4-3.6GHz	60^0	-44dB max	Multiband	31.5%	Shows the adequate BW and Gain
19	Coaxial	2.3-3.6GHz	60^0	-17 dB	Multiband	87.8%	The proposed antenna show the good BW

20	Coaxial / Microstrip	2 GHz	60^0	-37dB max	Multiband	32%	comparison between coaxial v M/strip line feed
21	Coaxial	2.9-8.6GHz	$0-90^0$		Multiband Reconfigurable	NA	Reconfigurable structure is discuss with PIN diode
22	Coaxial	2.4-3.8GHz	60^0	-18dB max	Multiband Reconfigurable	60%	Reconfigurable structure is discuss with PIN diode
23	Coaxial	2-10GHz	$90^0,45^0$	-27dB	Multiband Reconfigurable	NA	Reconfigurable structure is discuss with PIN diode

4 Conclusion

This paper introduces the review of the paper based on fractal tree antennas which start from the definition of the fractal by Mandelbrot. Fractal has space filling and self-similarity properties so compact fractal may operate at RFID, Mobile phones, WI-FI, Bluetooth, WIMAX and so many applications at the same time. Out of the 23 reference antennas 19 antennas are purely based on the multiband behaviour. Remaining four antennas shows the multiband as well as reconfigurable property. Many antennas show the resonance frequency bandwidth and application in UWB range. Some antennas like reference number [13] and [14] present the paper with genetic algorithm. Reconfigurable antenna presents the technique of adding the PIN diode or RF/ MEMS switches in fractal antenna geometries. By making the switches ON-OFF the resonant frequency can be shifted accordingly. Some Antennas are Coaxial, monopole, CPW and one antenna is proximity coupled antenna, so there is scope for other types of feeding techniques to use in the fractal tree antenna design. There is scope to use this antenna for the bandwidth and gain enhancement too since none of the antenna focus on this area. There are two papers discuss with the chemical deposition techniques. Its shows the multiband, wideband behaviour with good gain and radiation characteristics. So researchers can try with many ways in the chemical deposition methods to see the different parameters behaviour. Researchers can also work on multilayer fractal structure with different dielectric substrate or metamaterials. It can be summarised that increasing the fractal tree dimension leads to fractal miniaturization. Applications are increasingly widespread in the field of science and engineering.

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