ISSN:2231-0711

Design of Printed Fractal Tree Monopole Antenna for EM Radiation Monitoring

M. Z. Hadi[1], and J. S. Aziz[2]

[1]*Electronic & Communications Department, Al-Nahrain University, Baghdad, Iraq.*

[2] *Computer Communications Department, Al-Rafidain University College, Baghdad, Iraq*

***Abstract*— In the present-days, the growth of wireless communication is going on rapidly leading to very crowd spectrum, that's call for monitoring systems, and antennas with ultra-wide bandwidth and reduced size so as to control and monitor the spectrum. Planar monopole antenna PMA is one of the solutions to design an ultra-wide bandwidth antenna but it still suffers from large size. This paper presents the design and implementation of printed fractal tree monopole antenna PFTMA that operating in the frequency range from 2 GHz to 18 GHz for the applications of EM radiation monitoring. The design based on modifying predesigned antenna by upgrading the design using fractal tree process in order to reduce the lower edge frequency and the overall antenna size leading to proper antenna size that could be used for the desired purpose. Simulation results are presented and validated with measured ones. The antenna was printed on an FR4 substrate of 1.6 mm thickness and the resulting size of the proposed antenna is 30 mm × 38 mm.**

***Keywords*— Antennas, Ultra-wide bandwidth, printed monopole antenna (PMA), printed fractal tree monopole antenna (PFTMA), electromagnetic (EM).**

I. Introduction

Electromagnetic spectrum (EMS) is regarded as an essential resource for wireless communications, propagation behavior and standards render EMS as an international resource. Which implies the national and international execution of observation and control tasks.in general, the spectrum monitoring comprises the interception, recording, processing, and evaluation of collected spectrum data. The process of interception call for an antenna and receiving system [1]. The electromagnetic waves properties including signal and noise propagation, resonance, and wavelength help the choosing of the antenna in relation to the following points [2]:

- Directivity and gain: which are the most vital technical parameters when antenna design is considered where the antennas could be categorized into two groups rendering to these two parameters:
  - i. Omnidirectional antennas: that are usually used for general monitoring tasks when the transmitter location is unidentified (scanning, occupancy rates).
  - ii. Directional antennas: that are usually used for specific tasks (technical measurements, directional finding) when a superior sensitivity is required.
- VLF, LF, HF, VHF, UHF or SHF frequency bands.
- Size and weight of the antenna might be taken into consideration when selecting an antenna, depending on the monitoring station type: portable, transportable mobile, or fixed.

Monitoring and scanning tasks sought after omnidirectional antennas since Slant-linear polarized omnidirectional antennas receive the signals from all azimuthal directions and polarizations comprising left/right-hand circular polarization, horizontal polarization, and vertical polarization could be received [2]. The 2-18 GHz band is a very large band that requires more than one antenna or an exceptional antenna to cover it. Classic planar monopole antennas (PMA) seem to be appropriate to use for this purpose. This type of antenna present appealing physical features, such as simple structure, small size, omnidirectional radiation pattern, compact, and low cost. Due to all these characteristics, planar monopole antennas (PMA) are extremely attractive to be used for designing antennas that are utilized in monitoring systems, and growing research actions are being concentrated on them. In order to find the planar shape, which offers wider input bandwidth and reduced size vital efforts have been made. Consequently, a number of planar monopole antennas (PMA) with dissimilar geometries have been experimentally characterized and automatic design methods have been settled to realize the optimum planar shape [3]. Planar Monopole Antenna (PMA) is regarded as an equivalent thick cylindrical monopole antenna. In the radiating patch, where numerous higher-order modes get excited. With an increased lateral dimension (i.e., larger width of the patch) and optimum feed all the modes will have a superior bandwidth, and hence will experience slighter impedance variation and hence, we can attain a very large bandwidth by using the connotation of the closely spaced multiple resonance modes overlapping [3]. In the last years, a lot of antenna designs with different impedance bandwidth have been introduced in order to be used for different tasks, like the CPW fed Monopole Antenna that operates from 2 GHz to 10.7 GHz [4]. Also the Ultrawideband Antennas With Multiresonant Split-Ring Loops (2-20) GHz [5], the broken heart-shaped printed monopole antenna that covers bandwidth from 2.9-10.7GHz [6] and many other designs [7-11]. The bandwidth (2-18) GHz was achieved by most of these works but the size can be more optimized. In the present work, the fractal tree modification is proposed to achieve the ultra-wide bandwidth and small size compared to this band and the lower edge resonance frequency.

II. Reference Antenna Configurations

Printed fractal tree monopole antenna PFTMA was designed using the beveled monopole antenna as a reference antenna [8] ,which is shown in Fig 1 in addition to the fractal tree concept [12] in order to miniaturize the reference antenna, and reducing the lower edge frequency. The reference antenna for designing fractal tree antenna covers the band 2.4 -18 GHz as shown in Fig 2. The antenna is printed on an FR4 substrate having a relative permittivity of 4.3, and thickness of 1.6 mm with total area of Lsub (40 mm) × Wsub (30 mm) as illustrated briefly in TABLE 1. The design of the antenna based on a conventional rectangular monopole antenna with the partial half-elliptical ground. The radiating patch structure consists of a rectangular patch and two trapezoidal patches. The antenna structure is fed by a 50 Ω microstrip line. The upper section of the feed line is tapered for impedance matching improvement.

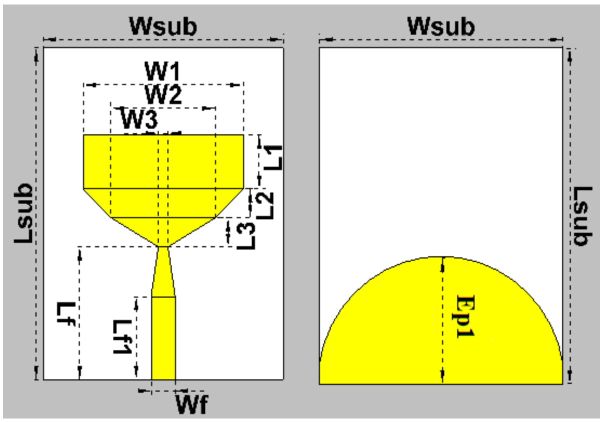
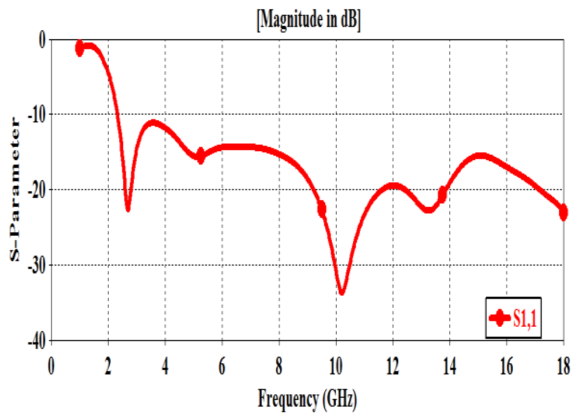


Fig 1. Reference antenna.

TABLE 1: Dimensions of the reference antenna.

Dimension	Description	Value
Lsub	The length of the substrate	40 mm
Wsub	The width of the substrate	30 mm
L1	The length of the bottom section of the radiator	8.5 mm
L2	The length of the bottom section of the radiator	3.5 mm
L3	The length of the bottom section of the radiator	3.5 mm
W1	The width of the top section of the radiator	20 mm
W2	The width of the middle section of the radiator	13 mm
W3	The width of the bottom section of the radiator (upper width of the tapered feed line)	1.2 mm
Wf	The bottom width of the tapered feed line	3 mm
Lf	The total length of the feed line	16 mm
Lf1	The length of the tapered part of the feed line	10 mm
Ep1	The radius of the circular ground	15.2 mm



.Fig 2. Reference antenna return loss.

The reference antenna covers the band from 2.4 GHz to up to 18 GHz as shown in Fig 2. In order to miniaturize the antenna size and lowering the lower edge frequency, some modifications have been executed on the reference antenna. The following steps describe these modifications and how can they improve and affect the performance of the antenna.

A. *Cutting the Patch*

The first step was to cut off the upper part of the radiating patch with keeping the other dimensions the same as for the reference antenna as shown in Fig 3 in order to build up the fractal tree antenna geometry.

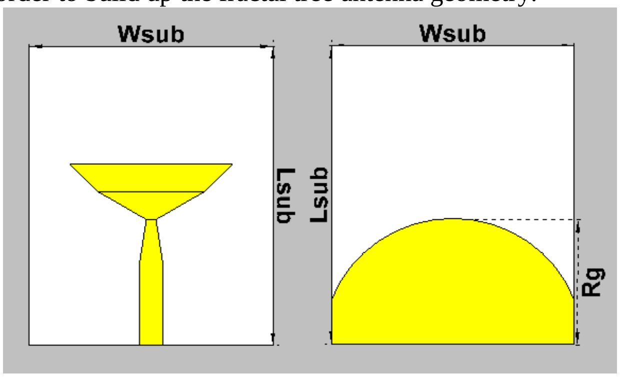


Fig 3. First modification step.

B. *Fractal Tree*

In order to build up the fractal tree antenna, a triangular shape basement with equal side length b (the side length of triangular) and angle α was established as shown below in Fig 4 then the fractal tree iterations was applied as in the next two points.

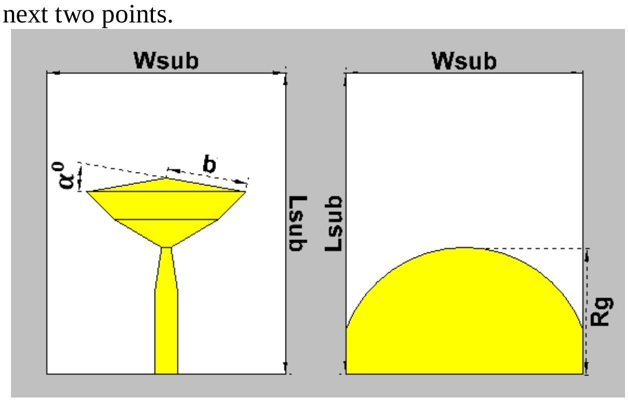


Fig 4. Second modification step.

Where α, and b equal to 10^0 and 10.15 mm respectively.

i. Fractal Tree (1st iteration)

After removing, the upper part of the patch and adding the triangular basement two rectangular patches (b × b1) were added to each side of the triangular as shown below Fig 5 in order to form the first iteration of the fractal tree.

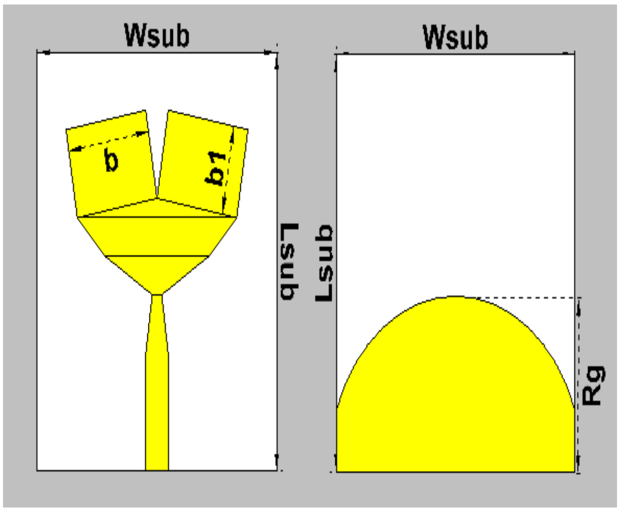


Fig 5. Fractal tree (1st iteration).

Where b And b1 equal to 10.15 mm and 8.12 mm respectively.

The return loss for the first iteration PFTMA is shown in Fig 6. The figure shows that the first iteration lowered the return loss of the antenna to 2.2 GHz.

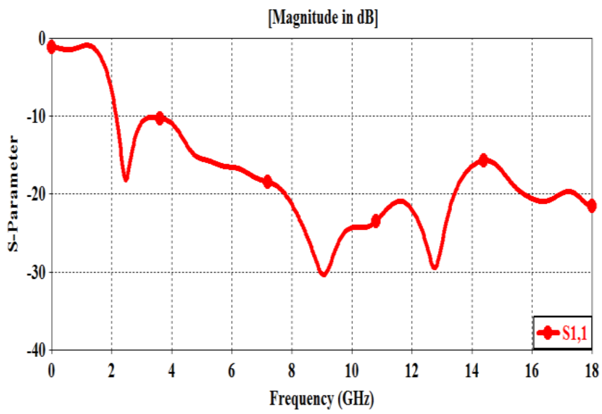


Fig 6. Return loss for the fractal tree (1st iteration).

ii. Fractal Tree (2nd iteration)

As shown in Fig 6 the first iteration fractal tree lowered the return loss of the antenna to 2.2 GHz for that the second iteration was applied to study its effects and reduce the return loss to 2 GHz.

The second iteration consists of adding another two triangular basements with a side length of b2 with the same angle α^0 and basement of b and adding four rectangular patches of dimensions (b2 × b3) as shown in Fig 7 the dimension of the second rectangular patches was reduced by a factor of 1.967.

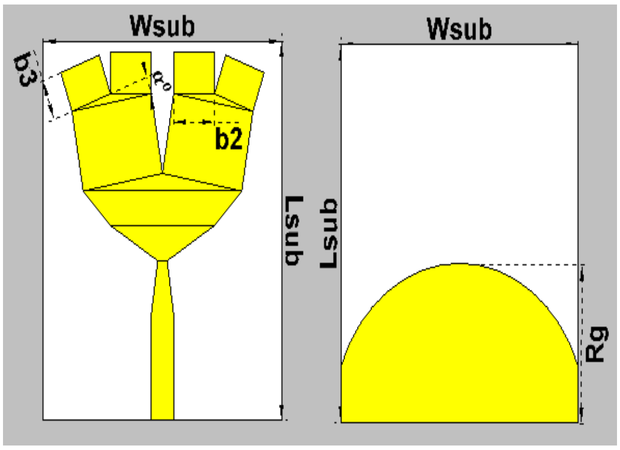


Fig 7. Fractal tree (2nd iteration).

Where α^0, b2, and b3 equal to 10^0, 5.16 mm, and 4.13 mm respectively.

As shown in Fig 8 the result display acceptable return loss where antenna operates from 2 GHz to more than 18 GHz with a notch from 3-4 GHz.

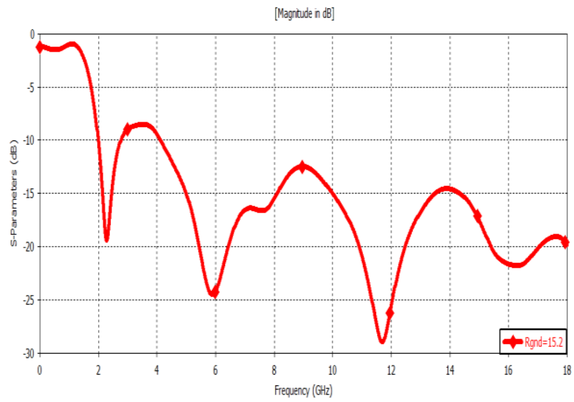


Fig 8. Return loss for the fractal tree (2nd iteration).

In order to remove the notch and make the antenna operate without notch from 2-18 GHz, the ground radius Rg and the upper width of the feed line wf1 were adjusted in order to adjust the matching between the feed line and the radiating patch.

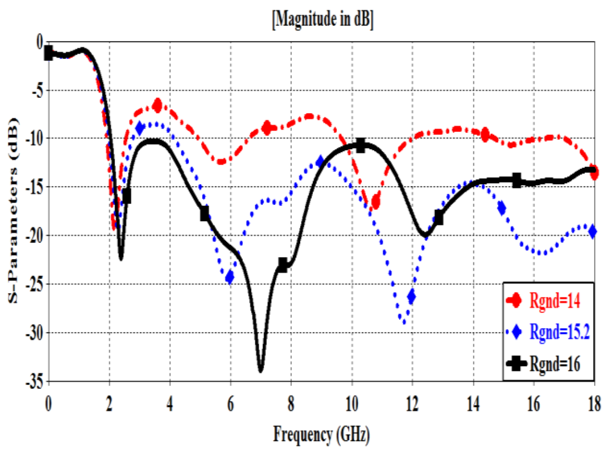


Fig 9. Rg parametric study for the fractal tree (2nd iteration).

Fig 9 shows the effects of changing Rg on the performance of the antenna. While Fig 10 shows the effects of changing the upper width of the tapered feed line and as shown in these figures adjusting these two parameters enhance the return loss performance and make the antenna operate from 2 GHz to 18 GHz without a notch.

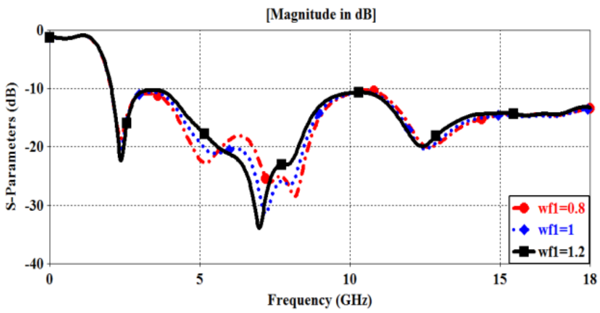


Fig 10. Wf1 parametric study for the fractal tree (2nd iteration).

III. Proposed Antenna And Results

The previous modifications on the reference had led to the final geometry and dimensions of the PFTMA illustrated in Fig 11 and TABLE 2 that supports the ultra-wide bandwidth starting from 2 GHz up to 18 GHz. All the simulations were done using CST MW Studio. The designed antenna was designed on a very low-cost FR-4 substrate having a thickness (height) 1.6 mm, and dielectric constant (ε_r) 4.3.

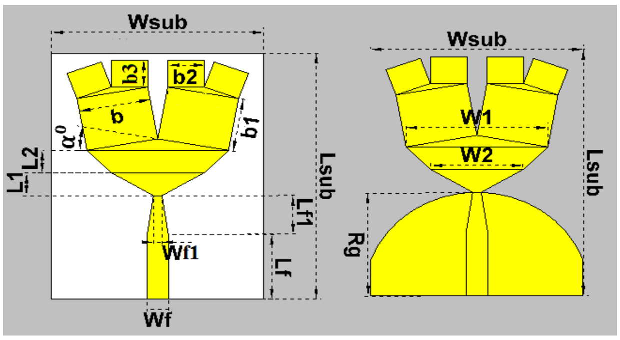


Fig 11. The Proposed PFTMA.

The simulated results for the proposed PFTMA are illustrated in the following figures. Where Fig 12 illustrates the return loss of the proposed PFTMA indicating that the antenna has the capability to operate in a frequency range starting from 2 GHz to 18 GHz, with a small size (38×30 mm^2).

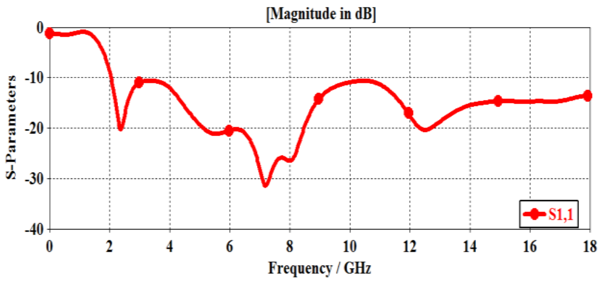


Fig 12. Return loss for the proposed PFTMA.

TABLE 2: Dimensions of the proposed PFTMA.

Dimension	Value
Wsub	30 mm
Lsub	38 mm
L1	3.5 mm
L2	3.5 mm
b	10.15 mm
b1	8.12 mm
b2	5.16 mm
b3	4.12 mm
α	10^0
Lf	10 mm
Lf1	6 mm
Wf	3 mm
Rg	16 mm
W1	20 mm
W2	13 mm
Wf1	0.8 mm

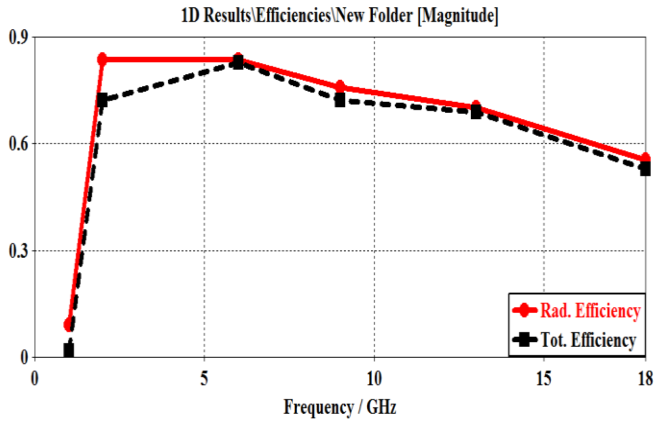


Fig 13. The efficiency of the proposed PFTMA.

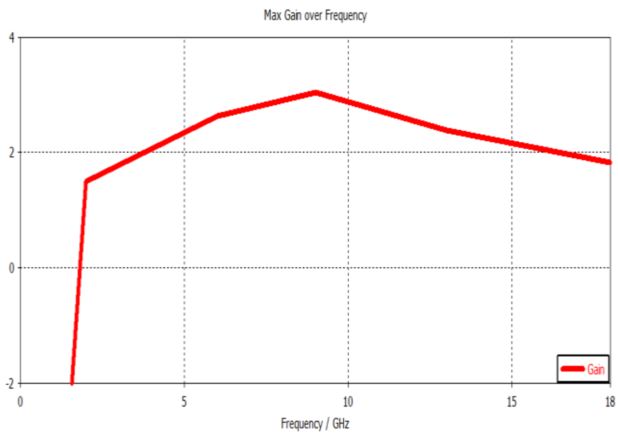


Fig 14. The gain for the proposed PFTMA.

The antenna radiates efficiently over the required band as shown in Fig. 13 where the radiation efficiency measurements are above 0.5 for the frequencies from 18 GHz and below which acceptable measurements giving a lossy material as FR4 [13].

Fig 14 illustrates the gain of the proposed PFTMA which as it shows in acceptable range (2.5 dBi) over the required band. Also, the antenna has an omnidirectional radiation pattern over the operating bandwidth as is shown in the figures [15-24] where these figures demonstrate the 2-D and 3-D pattern of the far-field directivity of the Proposed PFTMA for different frequencies. The return loss result of the proposed PHMA was also verified using HFSS simulation program Fig 25 and as shown in the figure the result is correspondence to that of the CST simulation program.

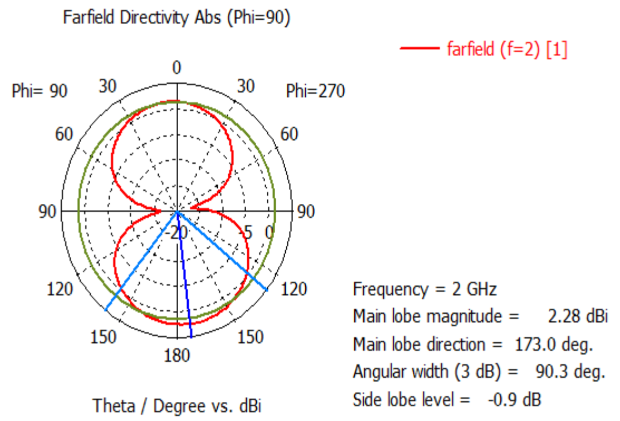


Fig 15. Radiation pattern at 2GHz.

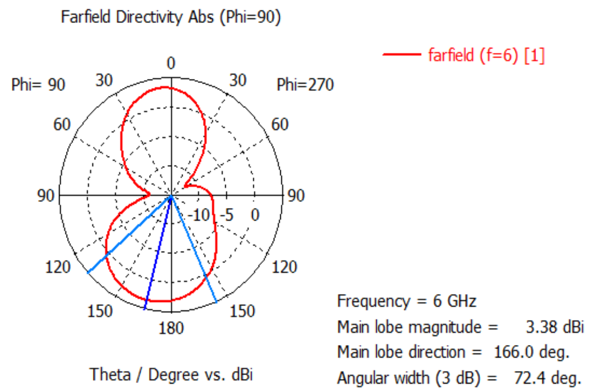


Fig 16 Radiation pattern at 6 GHz.

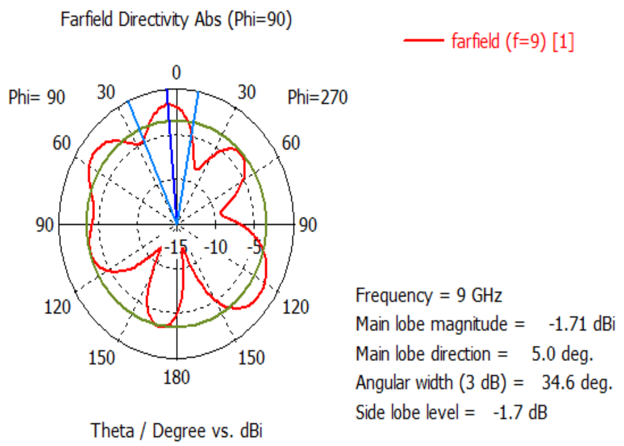


Fig 17. Radiation pattern at 9 GHz.

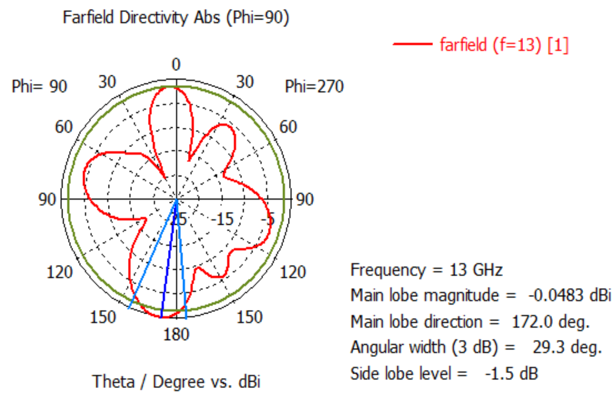


Fig 18. Radiation pattern at 13 GHz.

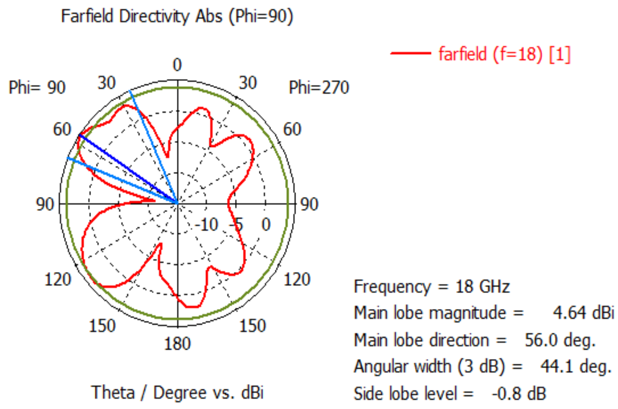


Fig 19. Radiation pattern at 18 GHz.

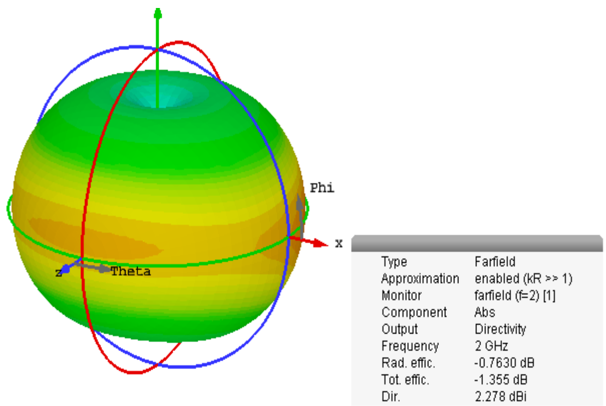


Fig 20. Radiation pattern (3D) at 2 GHz.

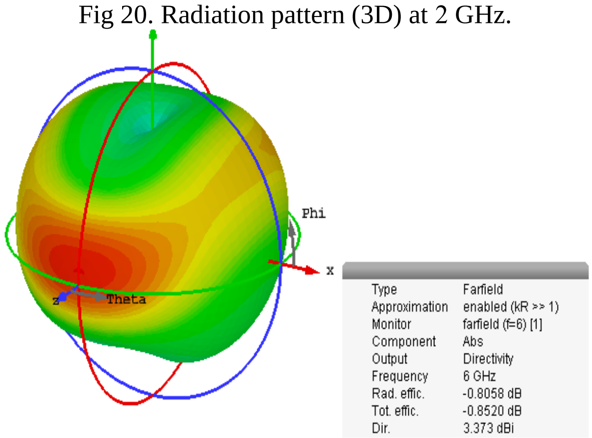


Fig 21. Radiation pattern (3D) at 6 GHz.

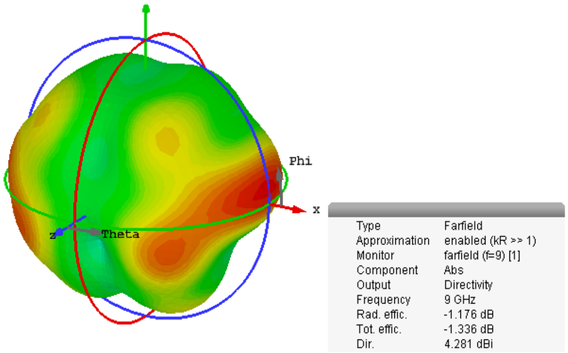


Fig 22. Radiation pattern (3D) at 9 GHz.

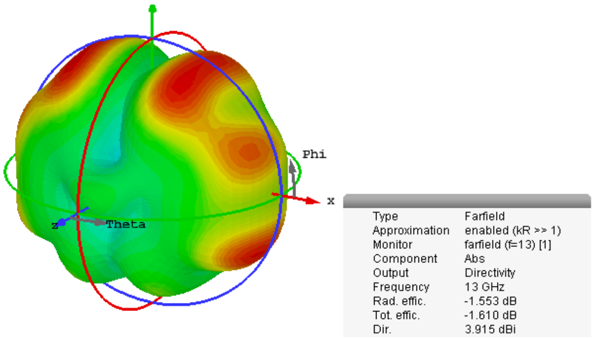


Fig 23. Radiation pattern (3D) at 13 GHz

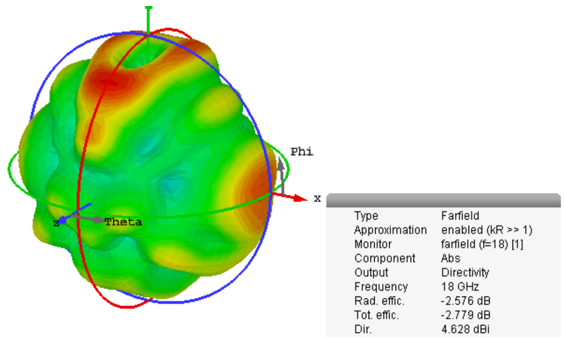


Fig 24. Radiation pattern (3D) at 18 GHz.

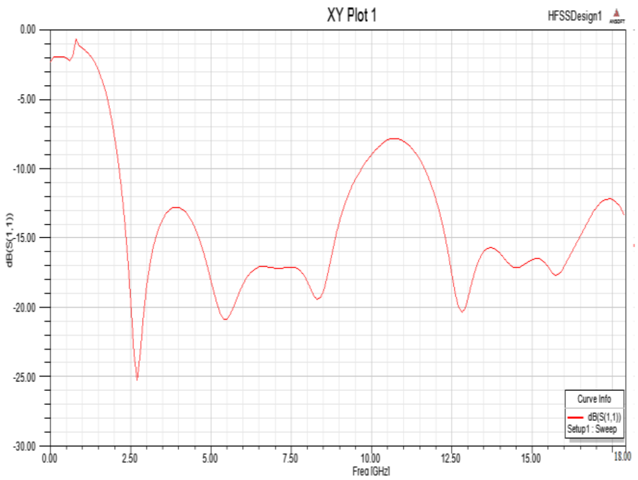


Fig 25. Return loss (S11) verification for the proposed PFTMA using HFSS.

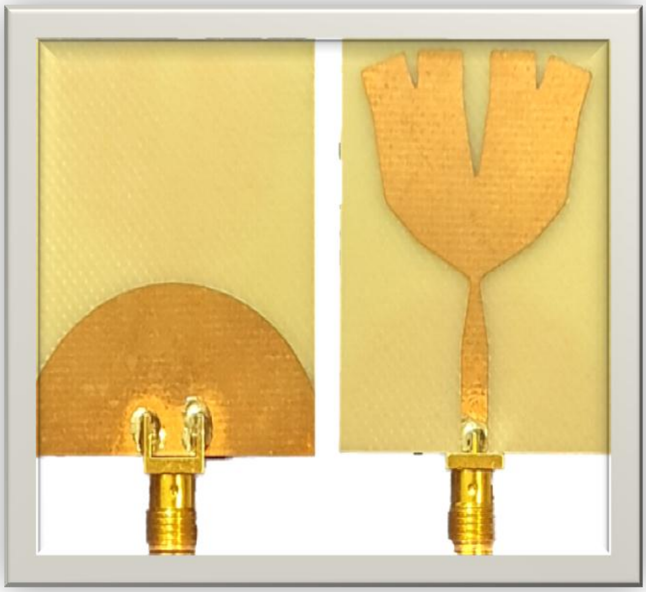


Fig 26. Practical implementation of the proposed PFTMA.

IV. Practical Implementation

The proposed PFTMA was practically implemented as shown in Fig 26 in order to compare the practical measurements with those obtained from the simulations. Fig 27 demonstrate the return loss of the fabricated antenna. These results indicate that the antenna bandwidth covers the range from 2 GHz to 18 GHz, which is the required bandwidth, and as is shown; the practical implementation measurement and the simulation measurement are in close correspondence.

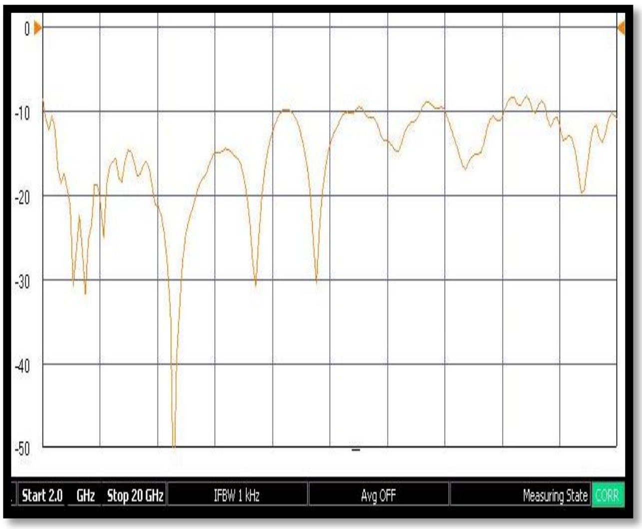


Fig 27. Return loss (S11) of the implemented PFTMA.

V. Comparison With Other Works

The obtained results show that the proposed antennas give ultra-wide bandwidth, small size, good gain, and radiation efficiency. The performance of the proposed antenna needs to be compared with the other similar works as well as the reference antenna. So in order to compare the designed antenna with these similar works, we need an equitable mechanism that can compare all these works of different parameters. This comparison depends on a factor called Bandwidth to Dimension Ratio (BDR) that can provide an equitable comparison between two wideband or ultra-wideband antennas [14]:

$$BDR = \frac{BW\%}{\lambda length \times \lambda width} \quad (1)$$

$$BW\% = \frac{2(fh-fl)}{(fh+fl)} \times 100\% \quad (2)$$

Where

λ is the wavelength of the lower end resonance frequency.
BW is the percentage bandwidth.
fh is the higher end resonance frequency.
fl is the lower end resonance frequency.

TABLE 3 display a comparison between the designed antenna and similar works in the last few years.

The comparison shows that the BDR of the proposed antennas is more than the BDR of the previous works, which is mean that the proposed antennas have small dimensions and larger bandwidth compared to other works. In addition, the comparison shows that applying the fractal tree led to enhance the BDR to the PFTMA by reducing the lower edge frequency and the dimensions.

TABLE 3: Performance Comparison of the proposed PHMA with other works.

Antenna	Bandwidth (F_L-F_H)	Dimensions	BDR
[4]	2-10.7 GHz 137%	51 mm × 52 mm 0.34λ×0.346λ	1164.5
[5]	2-20 GHz 164%	54 mm × 56.25 mm 0.36λ×0.375λ	1214.8
[6]	2.9-10.7 GHz 114.7%	30 mm × 18 mm 0.29λ×0.174λ	2273
[7]	3.1-18 GHz 141%	27.5 mm × 32 mm 0.28λ×0.33λ	1525.9
[8] Reference antenna	2.4-18 GHz 153%	30 mm × 40 mm 0.24λ×0.32λ	1992
[9]	2.8-10.6 GHz 116%	40 mm × 20 mm 0.37λ×0.186λ	1685.5
[10]	2.4-24.3 GHz 164%	30 mm × 41 mm 0.24λ×0.328λ	2083.3
[11]	2.7-12.55 GHz 129%	28 mm × 28 mm 0.25λ×0.25λ	2064
Proposed PFTMA	**2-18 GHz 160%**	**30 mm × 38 mm 0.2λ×0.25λ**	**3200**

VI. Conclusion

This paper demonstrates a printed fractal tree monopole antenna (PFTMA). The antenna has the property of small size (30 mm × 38 mm × 1.6 mm) compared with the reference antenna and is suitable for EMS monitoring because it operates from 2 GHz to 18 GHz for S_{11} < -10dB with an acceptable gain and efficiency. It is found that the modifications on patch have the major role for bandwidth enhancement and miniaturizing the antenna size. The designed structure has been simulated, verified using CST and HFSS simulation programs; also, the design has been practically implemented and the measurements of the implemented antenna have a good correspondence with those of the simulations.

References

[1] A. Boyacı, A. R. Ekti, S. Yarkan, and M. A. Aydın, "Monitoring, Surveillance, and Management of the Electromagnetic Spectrum : Current Issues in Electromagnetic Spectrum Monitoring", Electrica, vol. 18, no. 1, pp. 100–108, 2018.

[2] ITU, "Handbook - Spectrum Monitoring - Supplement", Radiocommunication Bureau, Geneva, Switzerland, 2008.

[3] S. N. Naji, J. S. Aziz, and L. A. Salman,"Design and Simulation of UWB Monopole Disk Antenna", International Journal of Computer Science Engineering and Technology, vol. 4, no. 12, pp. 404–411, 2014.

[4] S. Gupta, M. Ramesh, and A. T. Kalghatgi, "Design of optimized CPW fed monopole antenna for UWB applications", 2005 Asia-Pacific Microwave Conference Proceedings, Suzhou, China, Dec. 2005.

[5] G. M. Yang, R. H. Jin, G. B. Xiao, C. Vittoria, V. G. Harris, and N. X. Sun, 116 "Ultrawideband (UWB) antennas with multi resonant split-ring loops", IEEE Transactions On Antennas And Propagation, vol. 57, no. 1, pp. 256–260, Jan. 2009.

[6] M. N. Rahman, M. T. Islam, M. Z. Mahmud, S. Kibria, and M. Samsuzzaman, "Broken-heart shaped microstrip patch antenna design for ultra-wideband applications", IEEE Antennas and Propagation Magazine, vol. 59, no. 9, pp. 2324–2330, Oct. 2017.

[7] M. H. Abbas and J. S. Aziz, "Design and Simulation of an Enhanced Bandwidth Microstrip Antenna Using Metamaterial", IJCSET, Vol 5, no. 12, pp. 399-405. December, 2015.

[8] S. Singhal. and A. K. Singh, "Beveled Monopole Antenna With Slot Loaded Semicircular Like Ground Plane For Uwb Applications", Microwave And Optical Technology Letters, Vol. 57, No. 6, June 2015.

[9] A. Ramadan, M. Al-husseini, A. El-hajj, and K. Y. Kabalan, "Design of a Small Printed Monopole Antenna for Ultra-wideband Applications", 2009 International Conference on Electrical and Electronics Engineering - ELECO 2009, Bursa, Turkey, Nov. 2009.

[10] C. Deng, Y. J. Xie, and P. Li, "CPW-fed planar printed monopole antenna with impedance bandwidth enhanced", IEEE Antennas and Wireless Propagation Letters, vol. 8, pp. 1394–1397, Dec. 2009.

[11] A. Dastranj and F. Bahmanzadeh, "A Compact UWB Antenna Design Using Rounded Inverted L-Shaped Slots and Beveled Asymmetrical Patch", Progress In Electromagnetics Research C, vol. 80, pp. 131–140, 2018.

[12] J. Pourahmadazar, C. Ghobadi, and J. Nourinia, "Novel modified pythagorean tree fractal monopole antennas for UWB applications", IEEE Antennas and Wireless Propagation Letters, vol. 10, pp. 484–487, Apr. 2011.

[13] J. Powell, "Antenna Design for Ultra Wideband Radio", M.Sc. Thesis, Massachusetts Institute Of Technology, Department of Electrical Engineering and Computer Science, 2004.

[14] K. Chen, C. Sim, and J. Row, "A compact monopole antenna for super wideband applications", IEEE Antennas and Wireless Propagation Letters, vol. 10, pp. 488–491, May 2011.