Meandered PIFA Antenna with DGS for Smart Phones

Y. Sukanya[1,2], P.V.Y. Jaya Sree[2]

[1,2]Department of ECE, Vignan's Institute of Information Technology, Visakhapatnam, India.

[1,2] Ph.D. scholar, Department of ECE, GITAM (Deemed to be University), Visakhapatnam, India.

[2]Professor, Department of ECE, GITAM (Deemed to be University), Visakhapatnam, India.

Abstract:

We address the challenge of integrating low frequency and high frequency components into a compact design. We present a Meander Line Feed PIFA enhanced with a DGS that operates at multiple frequencies. The antenna structure adheres to pre-approved guidelines, utilizing annealed copper for the ground plane, FR-4 (lossy) with a loss tangent of 0.02 for the substrate, and copper (lossy) for the patch. The meander line feeding technique is employed to minimize the antenna size, while the ground plane features a fractal pattern introduced by the DGS process. The designed antenna is to operate at the frequency of 1.724 Giga Hz, 2.413 Giga Hz, as well as 4.789 Giga Hz, achieving a compact form factor. The reflection coefficients at these frequencies are measured at -12.905 dB, -40.958 dB, and -38.336 dB respectively. This compact antenna supports multiple applications and spans various frequency bands including GSM 1800, Wi-MAX, Wi-Fi, 3G, 4G, as well as potential 5G networks. The suggested antenna design has dimensions of (60 x 30 x 1.6) mm, which translates to approximately 0.70 x 0.35 x 0.018 wavelengths at the center frequency (fc) of the lowest band.

Keywords: Meander line, Defected Ground Structure, reflection coefficients, centre frequency.

1. Introduction

A single device with numerous functions, including Bluetooth, Wi-Fi, as well as technologies of LTE with raised-speed and high-quality information transfer, is now required to gather all wireless services. Due to the limited space available in remote devices, it is vital to build antennas that support multiple band operation in a way that respects standards [2]. Additionally, small antenna sizes and minimal effort are required to solicit the construction. In order to cover them all, this usually calls for multiple antennas, and it is unthinkable to think that one little device could hold them all [4].

For effective communication, an antenna must exhibit wide bandwidth, good radiation performance, and adequate gain. However, traditional strip antennas suffer from drawbacks such as minimal gain, less bandwidth, as well as the capacity of power handling is limited. To overcome these limitations, significant efforts have been made to enhance antenna performance. As a result, the Planar Inverted-F Antenna (PIFA) was developed [6,7].

In the realm of antenna design for compact cellular phones, the challenge intensifies when striving for multi-frequency operation and coverage of diverse LTE bands. In response, the integration of meander line configuration and folding techniques emerges as a pivotal solution, compressing antenna dimensions while preserving functionality across targeted frequency spectrums. This innovative approach, validated in prior research endeavors [5, 8], manifests in a reinforced antenna structure spanning multiple frequency bands, thereby augmenting overall gain [9]

Fractal Defected Ground Structures (DGS) involve introducing irregular breaks or fragments into the ground plane of an antenna. These fractals typically consist of repeated copies of the same intricate shape, which has been results to lower side-lobe levels [11,12]. This innovative approach not only facilitates antenna miniaturization but also enhances the antenna's input impedance bandwidth.

The appeal of a PIFA antenna lies in its compactness, narrow bandwidth, minimal side lobes, low profile, and seamless integration, all while maintaining a good SAR as well as elevated efficiency. It continues to reign as one of the preferred antenna choices for mobile services. The objective is to design an antenna that enhances the efficiency as well as performance of systems of wireless communications while simultaneously accommodating the full spectrum of available wireless frequency bands.

In the pursuit of optimal performance, numerous design parameters must be meticulously adjusted or fine-tuned. Defective Grounding Structure (DGS) stands out as a technique employed to broaden the bandwidth and improve return loss of patch antennas, while also governing the characteristics of propagation of wave of electromagnetic in the layer of the substrate. The proposed antenna was modelled as well as analysed by utilizing CST Studio Suite 2018, a huge-frequency simulation tool depends on the FEM method. The design employs an FR-4 substrate with a constant of dielectric is 4.3 and a loss tangent of 0.02. The substrate has a total thickness of 1.6 mm and is clad with copper layers of 0.035 mm on both sides. This endeavour aims to introduce a multi-radiated smart antenna with a straightforward design approach, all while prioritizing compactness and ensuring sufficient performance [10].

2. Design of Antenna

A compact PIFA antenna with a simple structure has been designed for seamless integration into mobile devices. Operating at 2.14 Giga Hz with a return loss of -25 dB, the antenna satisfies LTE coverage requirements, making it suitable for mobile phones and tablets. It exhibits a single resonance at 2.14 GHz while effectively covering GSM 1800 and LTE bands ranging from 1.72 Giga Hz to 2.37 Giga Hz at -10 dB, providing a bandwidth of 670 Mega Hz, as shown in Figure (1a) (1b) illustrates the meandered-line PIFA antenna, which, when integrated, supports the establishment of an appropriate LTE communication band. The geometric configuration of the suggested meandered antenna with a DGS is presented in Fig-(1c), with a detailed view of the DGS in Fig-(1d). This integration enables a response of multi-band, ensures isolation of frequency, as well as facilitates antenna miniaturization while preserving the desired characteristics performance.

Fig. (a): Conventional PIFA Antenna Fig. (b): Meandered PIFA Antenna

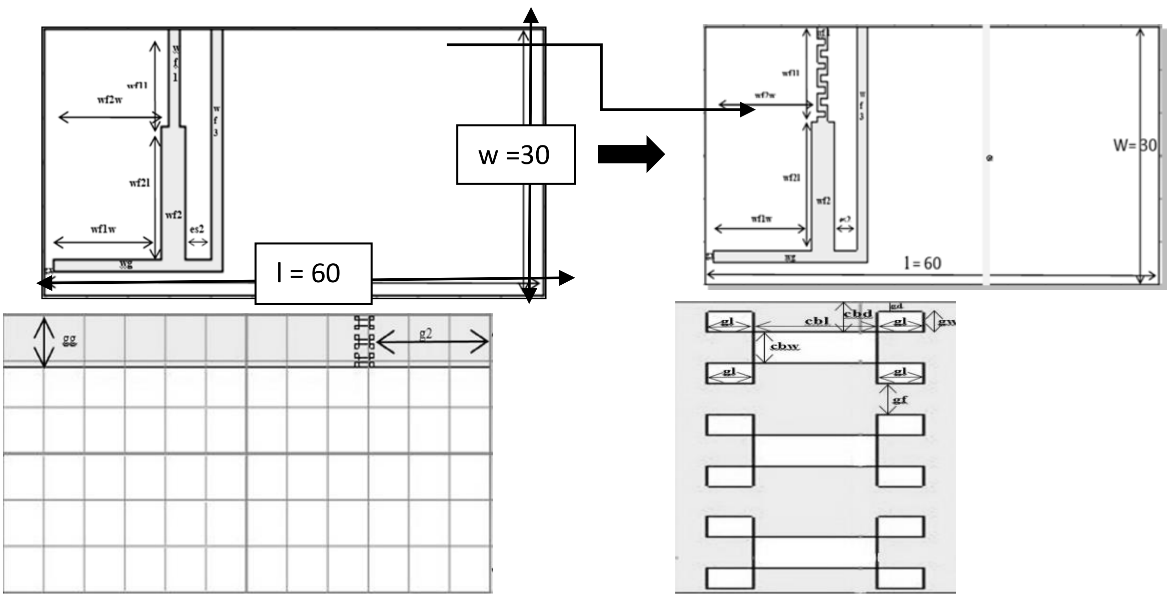


Fig. (c): Meandered PIFA Antenna along with DGS (Proposed Antenna) Fig. (d): Magnified view of DGS

Figure 1: Design Process of Proposed antenna

Utilizing a meandered feed PIFA enhanced with a DGS has endowed the antenna with remarkable multi-band resonating capabilities while maintaining desired characteristics. Table-1 encapsulates the antenna parameters crucial for its design. The incorporation of DGS, specifically tailored in a fractal shape as depicted in figure 1d, has not only compacted the antenna size but also facilitated the attainment of multiple resonances. Notably, the DGS design has significantly improved isolation between individual frequencies, rendering the antenna more efficient and versatile.

PARAMETER	VALUE	PARAMETER	VALUE
L	60	wf1	1.4
W	30	wf1l	11
hg=hp	0.035	wf1w	13.8
Hs	1.53	wf2	3
Gx	1	wf2l	15
es2	3	wf2w	13
Gg	5.7	wf3	1.4
Wg	1.4	wf3l	26
Gl	0.5	Cbl	1.4
Gw	0.4	Cbw	1.4
Gd	0.2	Cbd	0.6
g2	14.3	Gf	0.5

Table 1: Parameters of the proposed design

2 a) Designing of Equation:

The design equations utilized for the development of the PIFA antenna are presented below

1) The key equations governing the design of a conventional microstrip patch antenna are given as follows [1]:

a. Patch width (w):

$$W = \frac{C}{2f_o}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

b. Effective Constant of Dielectric (ε_{reff}):

$$\varepsilon reff = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-\frac{1}{2}}$$

c. Estimation of actual patch length:

$$L = L_{eff} - 2\Delta L$$

Where,

i) Effective of Length (L_{eff}):

$$L_{eff} = \frac{C}{2f_o\sqrt{\varepsilon_{reff}}}$$

ii) Calculation of extended length:

$$\Delta L = \frac{(\mathcal{E}reff + 0.3)\,(\frac{W}{h} + 0.264)}{(\mathcal{E}reff - 0.258)\,(\frac{W}{h} + 0.8)}$$

2) The equations of design for a traditional microstrip PIFA antenna are presented below [3]:

a. Vacuum of Centre Frequency (fc):

$$f_c = \frac{c}{4\,(W + L_p)}$$

b. Resonating Frequency (f_r) in other medium:

$$f_r = \frac{c}{4\,(W + L_p)\sqrt{\mathcal{E}_r}}$$

i) Return Loss, S_{11}:

S-parameters play an important role in determining the amount of signal reflected back to the source during antenna radiation. The traditional antenna of PIFA exhibits resonances at 1.724 GHz, 2.413 GHz, as well as 4.789 GHz, yet its return loss remains relatively low, with values of -10.308dB, -17.327dB, and -9.8658dB, respectively. Seeking improvement, a modification is introduced utilizing a meandered line structure in the feed (Fig. 1b), resulting in enhanced return loss performance. This modified PIFA antenna now showcases better loss of return figures of -12.608 dB, -32.75 dB, as well as -25.872 dB at the same resonant frequencies.

Further enhancement is achieved by introducing a Defective Grounding Structure (DGS) with a fractal design (Fig. 1c), significantly boosting the loss of return performance of the antenna. With this addition, the antenna demonstrates remarkable improvements in return loss, recording values of -12.976dB, -39.665dB, as well as -39.191dB at the respective resonant frequencies.

The comparison in Figure 2 exhibits the superior return loss performance of the suggested Meandered PIFA antenna along with DGS. Notably, this antenna achieves an perfect bandwidth, spanning 180MHz at 1.725GHz, 378.8MHz at 2.412GHz, as well as 912.9MHz at 4.788GHz, showcasing its versatility and effectiveness.

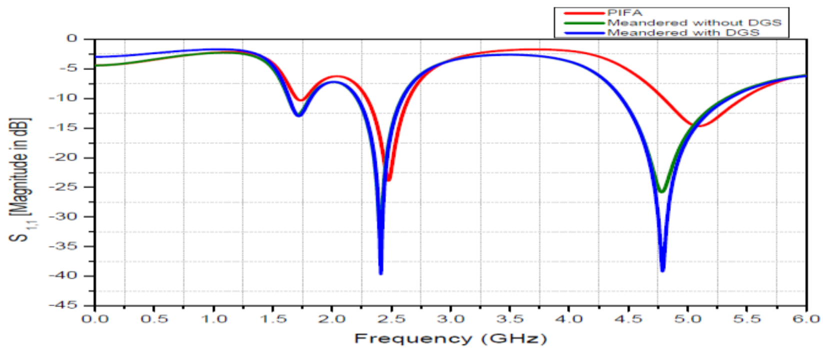


Fig-2: Return Loss

ii) VSWR:

The reflection of signal resulting from mismatch during antenna radiation is notably minimized in the designed antenna, with VSWR values consistently below 2. At frequencies of 1.725GHz, 2.478GHz, and 5.1GHz, the VSWR measurements stand at 1.8785, 1.1369, and 1.4536 respectively. Fig-3 below vividly illustrates the VSWR characteristics of the meandered feed PIFA alongwith DGS, showcasing its effectiveness in mitigating signal mismatches and ensuring optimal performance across various frequency bands.

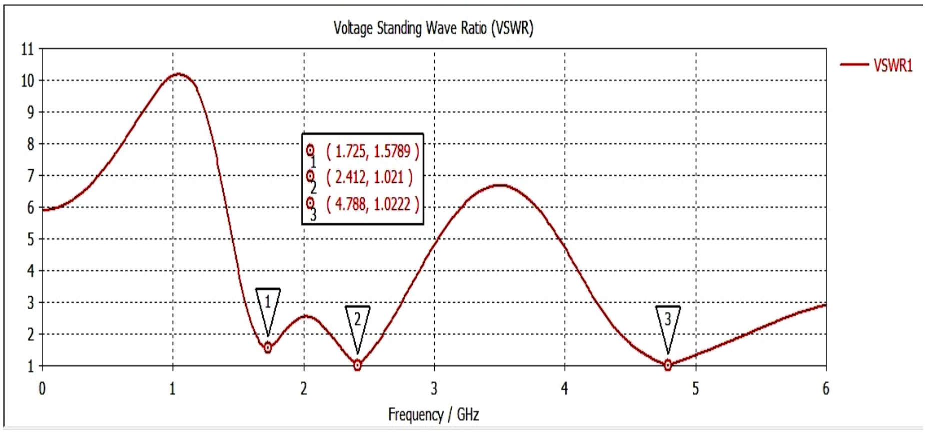


Fig. 3: Voltage Standing Wave Ratio

iii) Gain:

In assessing antenna performance, gain emerges as a critical metric, representing the ratio between the maximum intensity of radiation from the antenna under test and the reference antenna. In this context, the designed Meandered PIFA with DGS showcases notable improvements in gain compared to its predecessors. Specifically, the antenna achieves gains of 1.74dB at 1.725GHz, 1.53dB at 2.412GHz, and 3.49dB at 4.788GHz. Detailed analysis, depicted in Figure 4, illustrates the relationship between gain and frequency across various frequencies. It becomes evident that the Defective Grounded Meandered PIFA Antenna consistently delivers efficient gains, underscoring its effectiveness and superiority over previous designs.

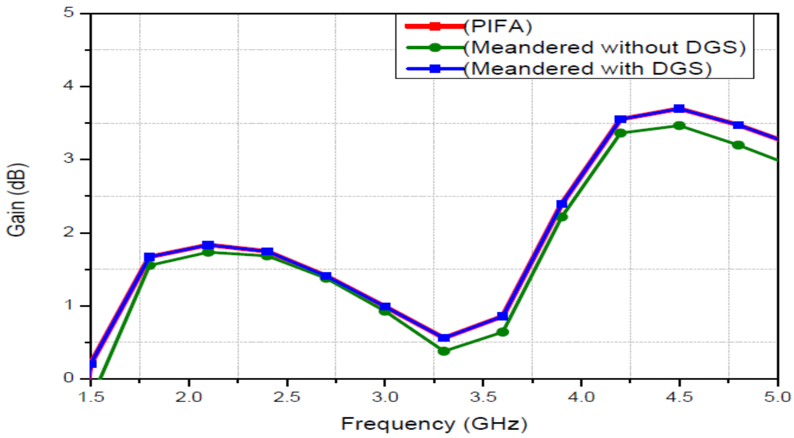
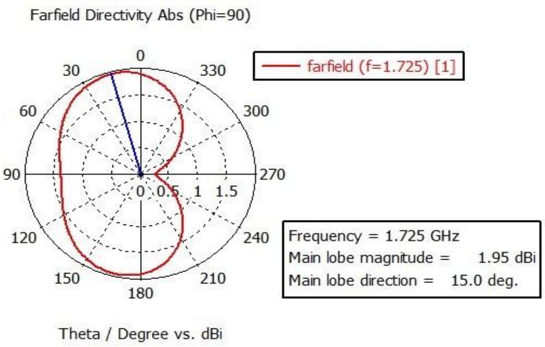


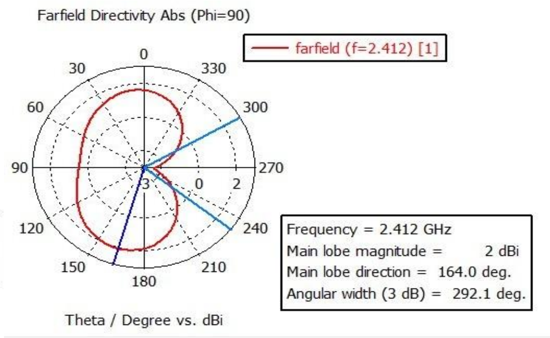
Figure 4: Gain vs frequency

iv) Directivity:

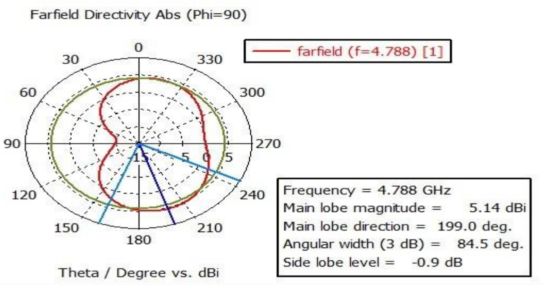
Directivity, crucial in antenna performance evaluation, signifies the ratio between radiated intensity in a specific direction and the average intensity radiated in all directions. In the designed antenna, directivity surpasses gain, emerging as a primary criterion in antenna design. Notably, the antenna demonstrates efficient directivity when compared with the reference model across three frequencies. At 1.725GHz, the directivity reaches 2.07dBi, while at 2.412GHz, it stands at 2dBi, and at 4.788GHz, it peaks at 5.32dBi.

Figure 5 (a), 5 (b), and 5 (c) visually depict the directivity performance of the antenna at individual frequencies, emphasizing its effectiveness in directing radiation towards desired targets. This underscores the antenna's capability to efficiently focus and concentrate radiated energy in specific directions, enhancing overall performance and versatility.





a. Fig-5(a): Directivity At 1.725GHz Fig-5(b): Directivity At 2.412GHz



c

Fig-5(c): Directivity At 4.788GHz

v) Surface Current Distribution:

Surface current, pivotal in antenna performance, delineates the flow of current across a metal surface at specific frequencies. The proposed antenna exhibits sufficient distribution of current over its structure at required frequencies, ensuring optimal functionality.

In Figures 6 (a), (b), and (c), the current distribution is visually depicted at particular frequencies. At 1.725 GHz, the current primarily propagates through the shorting arm, the meandered section, and across the plane of the ground surface. Analogously, at 2.412GHz, distribution of the current extends across the arm of short as well as meandered, as well as the surface plane of the PIFA Antenna, with a noticeable presence on the plane of ground. Interestingly, the distribution of current over the plane of the ground appears reduced compared to 1.725GHz, indicating frequency-dependent behavior.

At 4.788GHz, current distribution primarily concentrates along the feeding as well as shorting arms, as illustrated in Fig-6(c). This comprehensive analysis underscores the antenna's ability to effectively manage current flow across its structure, contributing to its overall performance and functionality across different operating frequencies.

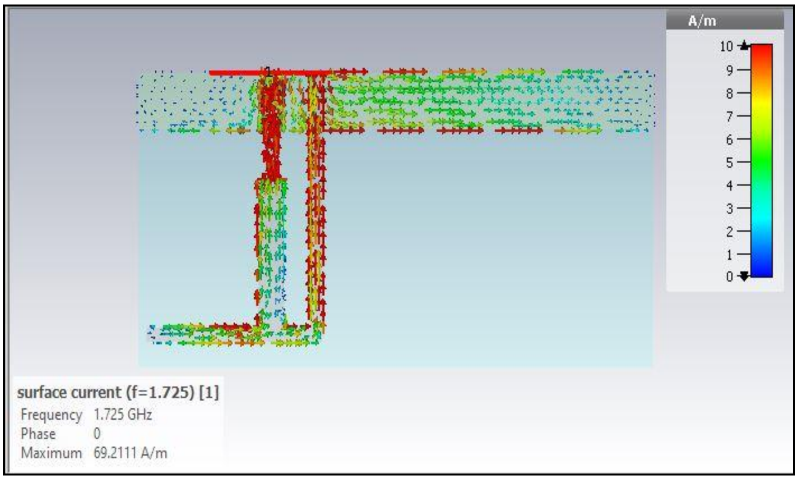


Fig 6(a): Distribution of Current at 1.725GHz

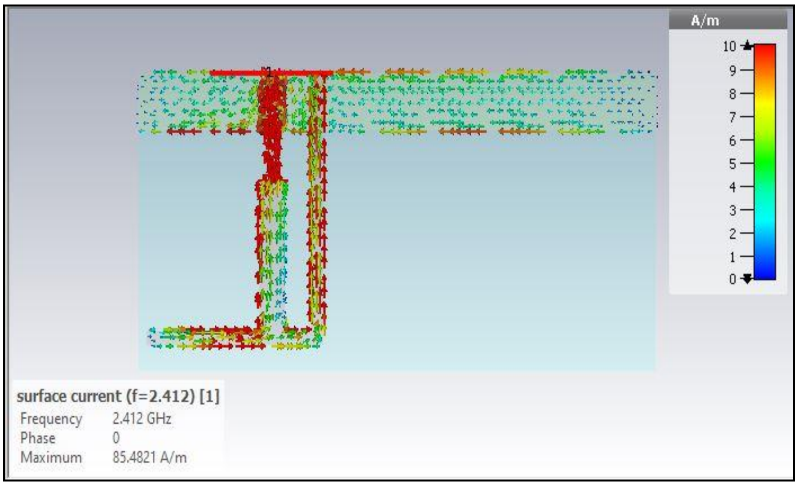


Fig 6(b): Current distribution at 2.412GHz

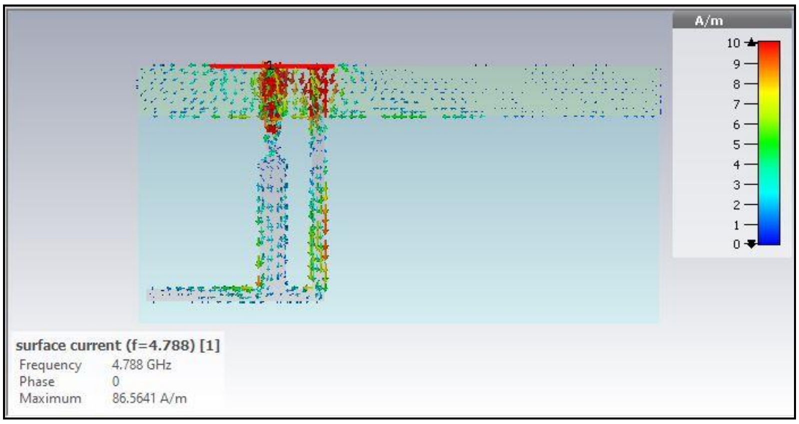


Fig 6(c): Distribution of Current at 4.788GHz

Table-2 outlines the metrics of functioning of the Meandered PIFA with DGS across various parameters of radiation at frequencies of 1.725GHz, 2.412GHz, and 4.788GHz. Notably, the proposed design demonstrates resonance at these three distinct frequencies. The VSWR measurements exhibit values of 1.578, 1.021, and 1.022 at the frequencies of 1.724GHz, 2.413GHz, as well as 4.789GHz respectively, indicating favorable impedance matching across the frequency spectrum. With regard to gain, the antenna achieves its maximum of

5.32dBi at 4.788GHz, showcasing its efficiency in radiating electromagnetic energy at this frequency. This peak gain performance is particularly noteworthy for applications demanding high signal strength and coverage, such as WLAN. Furthermore, the antenna's bandwidth presents notable improvements, particularly at 4.788GHz, where it offers a bandwidth of 912MHz, marking an 18% enhancement. This expanded bandwidth is highly advantageous for 5G applications, where increased data throughput and network capacity are essential.

At 2.412GHz, the antenna provides a bandwidth of 378MHz, catering to various applications including Bluetooth, LTE-U, WCS, and IMT-E. For lower frequencies, such as 1.725GHz, the antenna offers a bandwidth of 180MHz, suitable for applications like DCS-1800. In summary, the proposed antenna design exhibits versatile performance characteristics, making it well-suited for a broad spectrum of wireless communication applications across multiple frequency bands.

Table No. 2: Functioning of Meandered PIFA with DGS

S. No	**Resonant Frequency (GHz)**	**VSWR**	**Gain (dB)**	**ectivity (dBi)**	**Higher frequency (GHz)**	**Lower frequency (GHz)**	**Band Width (MHz)**
1.	1.725	1.578	1.53	2.07	1.8205	1.6399	180
2.	2.412	1.021	1.74	2.00	2.5944	2.2156	378
3.	4.788	1.022	3.49	5.32	5.3529	4.44	912

Table-3 offers a comprehensive comparison among three antenna designs: traditional PIFA, PIFA along with meandered line feed, as well as PIFA along with meandered feed as well as DGS. It's evident from the table that the proposed antenna design outperforms the others in terms of radiation parameters. Notably, the proposed antenna demonstrates an impressive 18% enhancement in bandwidth at the 4.788GHz frequency, making it particularly well-suited for latest mobile 5G/6G applications. This expanded band-width, estimated at -10dB loss of return, which covers multiple bands of frequencies relevant to various wireless communication applications.

Table No. 3: Comparison between all the designs

S. No	Frequency (GHz)	**Conventional PIFA Antenna**				**MEANDERED PIFA Antenna**				**MEANDERED PIFA along with DGS**			
		Parameters				**Parameters**				**Parameters**			
		S11 (dB)	VSWR	Gain (dB)	Bandwidth at -10dB (MHz)	S11 (dB)	VSWR	Gain (dB)	Bandwidth at -10dB (MHz)	S11 (dB)	VSWR	Gain (dB)	Bandwidth at -10dB (MHz)
1	1.725	10.31	1.878	1.4	67.9	12.61	1.611	1.37	177	12.976	1.5789	1.53	180
2	2.412	17.327	1.31	1.6	357.1	32.7	1.04	1.6	377	39.6	1.02	1.7	378

			49	5		4	73	8		65	1	4	
3	4.788	9.8658	1.94 62	3.2 9	681	25.8 17	1.10 84	3.2 1	875	39.1 91	1.02 22	3.4 9	912

Moreover, the proposed design exhibits superior gain as well as bandwidth compared with the remaining two designs, underscoring its suitability for a wide range of wireless applications. With its enhanced performance metrics, the proposed antenna stands out as a compelling choice for diverse wireless communication needs.

4. Conclusion

The Meandered Feed PIFA antenna with DGS exhibits remarkable versatility, catering to multiple frequency bands essential for various wireless applications including GSM 1800, WLAN, WCS-2300, IMT-E 2600, LTE-U, DCS, and even 5G/6G. Its ability to efficiently operate across these bands underscores its adaptability and utility in modern communication systems. A significant highlight of this antenna design is its 18% enhancement in bandwidth at 4.788GHz, a crucial factor for 5G applications, all while maintaining a compact form factor. This expanded bandwidth ensures compatibility with the evolving demands of high-speed data transmission and network connectivity inherent in 5G technology.

Moreover, the proposed antenna consistently outperforms other designs in terms of gain across desired frequencies. This superior gain, coupled with its wide bandwidth and compact size, positions the proposed design as a top choice for a myriad of wireless applications. Its versatility, efficiency, and performance make it a valuable asset in the realm systems of wireless communications.

5. References

1. Balanis, Constantine A. *Antenna theory: analysis and design*. John wiley & sons, 2016.
2. Naser-Moghadasi, M., Mansouri, Z., Sharma, S., Zarrabi, F. B., & Virdee, B. S. (2016). Low SAR PIFA antenna for wideband applications. *IETE Journal of Research*, *62*(5), 564-570.
3. Sharif, S. M., & Abdalla, I. D. (2019). AN EMPIRICAL APPROACH TO DESIGN A PIFA ANTENNA. *University Of Khartoum Engineering Journal*, *9*(2).
4. El Halaoui, M., Asselman, H., Kaabal, A., & Ahyoud, S. (2014). Design and simulation of a planar inverted-F antenna (PIFA) for Wi-Fi and LTE Applications. *International Journal of Innovation and Applied Studies*, *9*(3), 1048.
5. Naser, A. A., Sayidmarie, K. H., & Aziz, J. S. (2016, November). Design and implementation of a PIFA antenna for multi-band LTE handset applications. In *2016 Loughborough Antennas & Propagation Conference (LAPC)* (pp. 1-5). IEEE.
6. Naser, A. A., Sayidmarie, K. H., & Aziz, J. S. (2015, November). A meandered line-PIFA antenna for LTE (Band-Class-13) handset applications. In *2015 Loughborough Antennas & Propagation Conference (LAPC)* (pp. 1-5). IEEE.
7. El Halaoui, M., Asselman, H., Kaabal, A., & Ahyoud, S. (2014). Design and simulation of a planar inverted-F antenna (PIFA) for Wi-Fi and LTE Applications. *International Journal of Innovation and Applied Studies*, *9*(3), 1048.
8. Zhang, Y., Wang, D., Zhang, L., & Tong, M. S. (2018). A Modi Ed Planar Inverted-F Antenna with Triple-Band for Wi-Fi and LTE Applications. *Progress In Electromagnetics Research M*, *73*, 173-181.
9. Verma, A., Punetha, D., & Pant, D. (2015, May). A novel quad band compact meandered PIFA antenna for GPS, UMTS, WiMAX, HiperLAN/2 applications. In *2015 Second International Conference on Advances in Computing and Communication Engineering* (pp. 404-408). IEEE.

10. Guha, D., Biswas, S., & Kumar, C. (2014, March). Printed antenna designs using defected ground structures: a review of fundamentals and state-of-the-art developments. In *Forum for electromagnetic research methods and application technologies (FERMAT)* (Vol. 2, No. 1, pp. 1-13).

11. Khola, R. K., & Gupta, N. K. (2015). Design of multiband microstrip patch antenna for wireless 1 GHz TO 5 GHz band applications with microstrip line feeding technique. *Int J Comput Sci Mob Comput*, *4*(6), 64-69.

12. Sankar Ponnapalli, V. A., & Jayasree, P. V. Y. (2015). Heptagonal fractal antenna array for wireless communications. In *Microelectronics, Electromagnetics and Telecommunications: Proceedings of ICMEET 2015* (pp. 387-394). New Delhi: Springer India.

Authors:

Mrs.Y.Sukanya is as an Associate Professor in Electronics and Communication Engineering Department from Vignan's Institute of Information Technology (A), Duvvada, Visakhapatnam. she is presently pursuing Ph. D from GITAM University at Visakhapatnam, obtained M. Tech. in 2008 and B.E in 2001. Her research interests include Antennas and signal processing.

Mr. A. S. SAI KUMAR is as a pursuing M. Tech. student in Electronics and Communication Engineering Department from Vignan's Institute of Information Technology (A), Duvvada, Visakhapatnam.

Dr.P.V.Y.Jayasree received her M.E. and Ph. D degrees in Electronics and Communications Engineering from Andhra University, Visakhapatnam and JNT University, Kakinada in 1999 and 2010 respectively. She is currently serving as a Professor and Head of the Department of Electronics and Communications Engineering with GITAM University, Visakhapatnam, India. Her research interest lies in the areas of EMI/EMC, Antennas, Microwaves.