Progress In Electromagnetics Research M, Vol. 89, 73–82, 2020

CPW Fed Flexible Graphene Based Thin Dual Band Antenna for Smart Wireless Devices

Ronak Vashi* **and Trushit Upadhyaya**

Abstract—A coplanar waveguide (CPW)-fed flexible dual-band antenna using graphene as conducting material and Kapton polyimide as a substrate is proposed. The antenna shows increased impedance bandwidth due to the use of CPW-feed having the values of 80.29% (1.64–3.84 GHz) and 6.31% (5.52–5.88 GHz), respectively. The antenna has an overall size of $0.38\lambda \times 0.43\lambda$ at center frequency of 3.4 GHz. The proposed flexible antenna has gain values of 1.82 dBi and 1.68 dBi with efficiency values more than 86% which makes the antenna commercially viable for smart wireless products having space constraints.

1. INTRODUCTION

In the present era of wireless communication, the demand for small size, robust, efficient, and flexible antennas working in the range of Wi-MAX and WLAN is increasing. The use of Graphene as a conductive material brings diversity to the field of antennas as compared to conventional copper based antennas. Graphene is challenging the world from metal to nano-carbon as a seminal material due to its lighter structure and higher sustainability at micro-level with energy harvesting properties [1].

Automotive and aeronautics industries have already shifted to carbon-based materials. Graphene is extracted from Graphite powder and has a 2D layer of hexagonal lattice structure with unique electrical & mechanical properties at a higher frequency spectrum [2]. Graphene was invented in 2004 by great scientists Andre Geim and Konstantin Novoselov at the University of Manchester, who were looking hard for the methods to isolate Graphene from the Graphite structure, for which they were awarded the Nobel Physics prize in the year 2010. Graphene films have been prepared in various ways such as mechanical exfoliation, high-temperature anise, chemical reduction of graphene oxide, and chemical vapor deposition (CVD) [3]. To achieve the desired productivity and properties, CVD process is mostly used. Flexible devices using Graphene structure for NFC communication, RFID tags, and transmission line for wireless communication systems are analyzed in the literature [4–7]. However, many researchers try to investigate the antenna with the help of conductive carbon fiber composite materials which have brought a lot of other possibilities for making flexible structures [8–10]. Such antennas fall into the category of transparent antennas where many researchers have proposed dual-band, wideband antennas with different materials like Silver doped Tin Oxide (AgHT), Indium Tin Oxide (ITO), Zinc Oxide (AZO), etc. [11, 12]. Other Graphene based antennas working in dual-band for millimetre regime and satellite frequencies are also proposed by researchers [13]. The size of this kind of antennas can be reduced further using the concept of electrically small antennas, Fractal Defected Ground Structure with metamaterial-based antennas [14–19]. Flexible antennas with CPW feeding technique are preferred in designs because both the patch and the ground plane are printed on the same side of the substrate which reduces the complexity of the fabrication process and no need for vias and short pins when incorporating active devices with the antenna structure [20].

Received 9 December 2019, Accepted 11 January 2020, Scheduled 30 January 2020
* Corresponding author: Ronak Vashi (ronak.vashi@bvmengineering.ac.in).
The authors are with the Charotar University of Science and Technology, Changa, Gujarat, India.

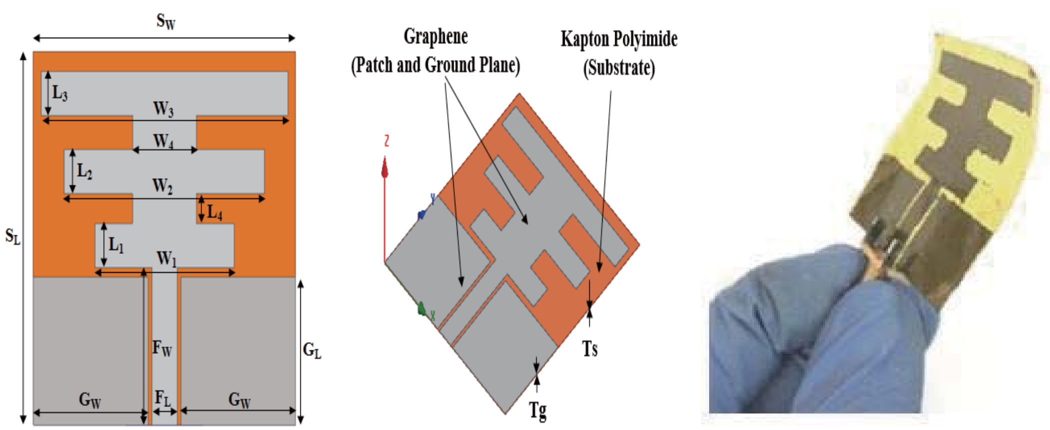
The antennas for smart and flexible devices should be stretchable, foldable, and twistable. Different types of flexible substrates Poly-Tetra-Fluoro-Ethylene (PTFE), polyethylene naphthalate (PEN), polyimide, paper, copper laminated sheet, fabric, etc. have been used for flexible antennas. Some antenna designs are also described with paper substrates, but the paper-based flexible substrate is more fragile than other substrates and has high loss tangent which may degrade the antenna efficiency [21–29]. Fabric cloth is also used in flexible antennas, but it is not stretchable, hence it is intricate to use them for frequency-tuneable applications which is still challenging [30]. It is more advisable to use PTFE, PEN, or Kapton polyimide due to their electrical and mechanical properties. The development of multiband antennas is quite challenging to maintain their performance under the bent position as compared to ordinary single-band antennas [31].

In this paper, a dual wideband flexible antenna is proposed using Graphene as a conductive material with Kapton polyimide as a substrate. The proposed antenna design and characterized system setup parameter are discussed in Section 2. In Section 3, parametric design and performance analysis are analyzed. Section 4, simulated and fabricated results are presented and explored. Bending analysis of the antenna is carried out in order to test its return loss characteristics under bending conditions. Section 5 is the conclusion.

2. PROPOSED ANTENNA DESIGN

A Graphene, Dual-Band Planar Antenna based on a Kapton Polyimide substrate, which is commercially available material with a linear polarization antenna, is presented. Instead of complex Fractal or DGS (Defected Ground structure) techniques, this antenna is fabricated using a simple configuration of CPW as shown in Figure 1. Designing wide-band, robust, smart, flexible antennas with acceptable radiation efficiency and performance is quite challenging when the antenna is expected to have light-weight, low-profile, and tailored characteristics. The physical dimension of the proposed antenna structure is shown in Table 1.

The antenna performance is evaluated after simulating and fabricating the antenna using Graphene



(a) (b) (c)

Figure 1. Proposed antenna. (a) Top view. (b) Perspective view. (c) Fabricated prototype.

Table 1. Design parameters of proposed antenna (all dimensions are in mm).

S_w	S_l	G_w	G_l	F_w	F_l	T_s	T_g
34.0	38.0	14.18	15.0	16.0	5.05	0.05	0.05
W_1	W_2	W_3	W_4	L_1	L_2	L_3	L_4
18.0	26.0	32.0	8.25	4.5	4.5	4.5	4.0

Table 2. Design data of the substrates and patch of antenna [32, 33].

PARAMETERS	VALUE	UNIT
Patch	**Graphene Sheet**	**- - -**
Carbon Content	97%	- - -
Thickness	50	μm
Density	1.9	g/cm^3
Electrical Conductivity	3700	S/cm
Thermal Conductivity	500(x-y plane) 3 (z plane)	W/(m)x(k)
Electrical Resistivity	0.06	Ω/sq.
Sheet resistance	2.70	μΩ-m
Substrate	**Kapton Polyimide**	- - -
Thickness	50	μm
dielectric constant ε_r	3.4	- - -
loss tangent (tanδ)	0.002	- - -

sheet and Kapton polyimide as in Table 2. Due to skin depth effect, thickness of the Graphene sheet is a major concern in terms of performance. For that in this simulation 50 μm of patch and Ground plane has been taken as a reference to simulate and optimise the design.

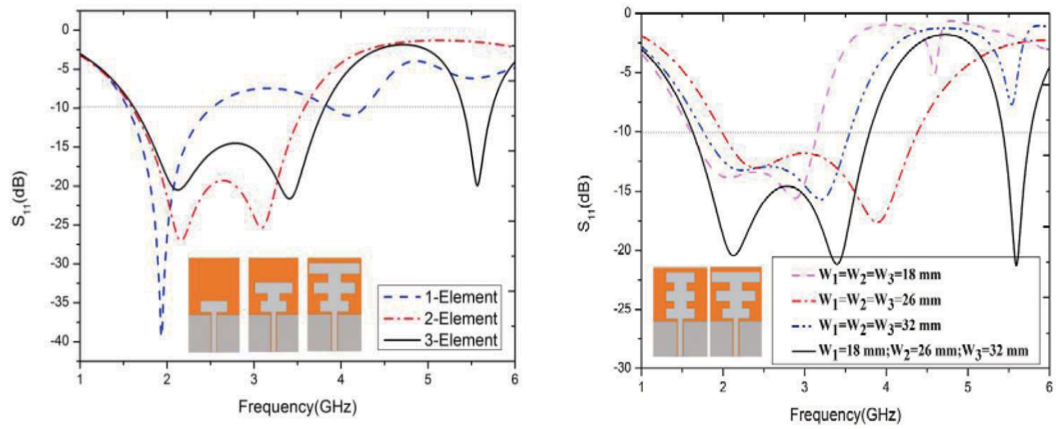
In CPW antennas gap between patch and coplanar ground plays a pivotal role in achieving wide band. Due to the effect of coupling capacitance, the impedance bandwidth of the antenna is reduced with increasing the gap between patch and coplanar ground plane. For the same achieved wider bandwidth gap between fed line and ground plane is kept at 0.3 mm each side. The impedance of 50 Ω with an SMA connector is achieved by using a feed line of width 5.05 mm. Laser cutter technique is used to achieve higher precision in geometric dimensions with low power cutting flame to protect the sheet form being damaged. The SMA connector is connected using conductive Cyanoacrylate Adhesive in order to avoid the Graphene sheet from being affected due to heat produced by the soldering process.

3. PARAMETRIC ANALYSIS

Parametric study is carried out to optimize the antenna design in terms of variations in patch length and width dimensions. Full Electromagnetic (EM) solver with FDTD (Finite Difference Time Domain) method, High-Frequency Structure Simulator (HFSS) ANSYS software 17.2 is used for numerical modeling.

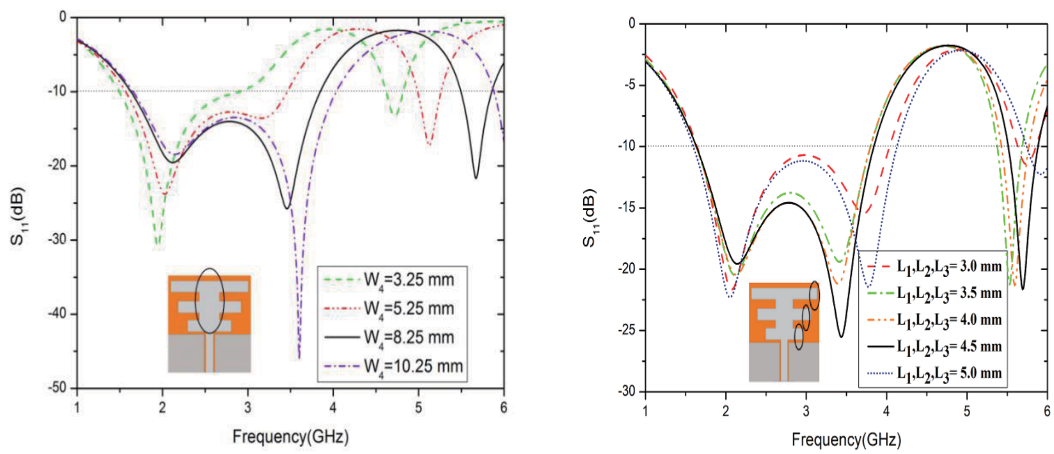
To achieve 50 Ω feed line impedance in CPW antenna, coaxial feed line is kept at 16 mm × 5.05 mm constant. The dimensions of antenna in terms of patch width and length are varied in order to optimise the desired frequency bands as shown in Figures 2(a)–2(b). The effect on reflection coefficient with increase in element number is carried out which shows that as element number increases, the frequency bands also increase leading to a multiband characteristics. To achieve the compatibility and flexibility three elements are selected for the antenna. Parameters W_1 to W_4, and L_1 to L_3 are examined in order to achieve a wide resonance band. To achieve the optimized size of an antenna, width of the patch, W_1 to W_3, is changed to 18 mm, 26 mm, and 32 mm, respectively, as shown in Figure 2(b).

Figure 3(a) shows the change in center arm width (W_4) from 3.25 mm to 10.25 mm. A change in center arm width (W_4) from 3.25 mm to 10.25 mm shifts the resonant frequency band towards higher side. Same as L_1, L_2 and L_3 are increased 3.0 mm to 5.00 mm which gives resonance band shifts to a higher frequency as shown in Figure 3(b). The optimized values W_4 and L_1-L_3 are 8.25 mm and 4.5 mm, respectively.



(a) (b)

Figure 2. (a), (b) Effect on reflection coefficient (S_{11}) due to variations of patch element and width.



(a) (b)

Figure 3. (a), (b) Effect on reflection coefficient (S_{11}) due to variations of patch center arm and arm's length of an antenna.

4. RESULTS AND DISCUSSION

Antenna is designed at dual operating frequencies covering 1.64–3.84 GHz and 5.52–5.88 GHz bands. Figure 4 shows the simulated and measured return loss plots where the fabricated antenna return loss is measured using Anritsu MS2037C Vector Network Analyzer (VNA). It can be depicted from the figure that simulated and measured results match well; however, a slight discrepancy is observed due to variation in dielectric constant, SMA connector coupling loss, and fabrication tolerance as Laser cut method is used. The wide operating band is achieved due to basic CPW-fed antenna.

To understand radiation characteristics, the E-field current distributions of antenna at resonant frequencies 3.4 and 5.7 are illustrated in Figures 5(a)–5(b), respectively. From Figure 5(a), it can be observed that the current is mainly concentrated on upper and lower arms of the patch, which creates resonance around 3.4 GHz. The resonance at about 5.7 GHz is created because the current is mainly concentrated on middle arm. This will specify that each of them acts as a half-wavelength resonator to generate respective operating bands as shown in Figure 5(b). Surface current distribution is to validate the design with good agreement of linear polarization antenna, which enhances the performance of an antenna in terms of gain and radiation efficiency.

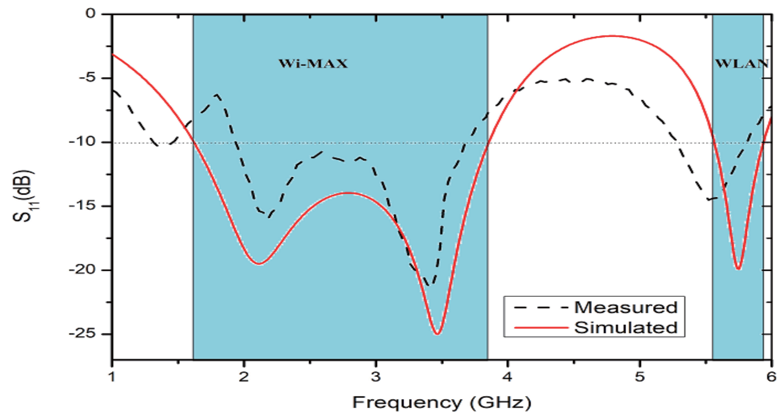
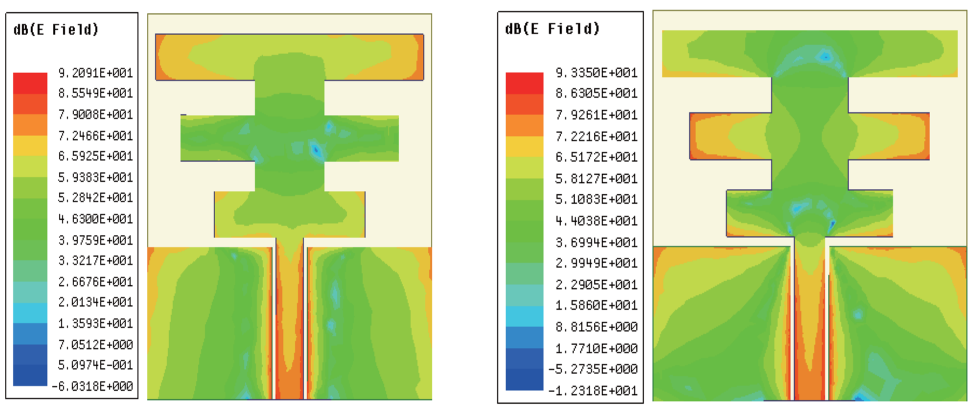


Figure 4. Comparison of simulated and measured return loss.



(a) (b)

Figure 5. E-field distribution of proposed antenna at (a) 3.4 GHz, (b) 5.7 GHz.

The normalized radiation patterns in both the E-plane and H-plane are measured in an anechoic chamber, which show a good agreement as shown in Figure 6. Due to stronger current distribution of the excited mode in the transvers direction, the radiation pattern exhibits peaks along the $\pm z$ axis at 3.4 GHz and 5.7 GHz where the observed gains are 1.822 and 1.683 dBi, respectively.

The setup for antenna measurement is shown in Figure 7 where an anechoic chamber in the range of 800 MHz to 14 GHz is used. Figure 8 shows gain variation because as frequency increases, directivity of the antenna increases. Measured results are not as much simulated due to connector loss. SMA connector is attached with conductive glue and not possible to match the impedance of 50 Ω to simulation. Table 3 compares the simulated and measured return losses, impedance bandwidths, antenna gains, and radiation efficiencies for lower frequency 3.4 GHz and higher 5.7 GHz operation frequency bands.

In a realistic smart device application, the antenna must be integrated into a curved surface. Therefore, the effects of bending are investigated through measurements in the E-plane and H-plane. To measure bending moment Styrofoam material ($\varepsilon_r = 1.03$) having a radius of 15 mm is used. Figure 9 demonstrates snapshots of a bending moment measurement environment with antenna prototype.

The return loss performances of an antenna in bending conditions are nearly the same with slight fluctuations in return loss as compared with the antenna in planar position as shown in Figure 10. As bending moment occurs, the effective length of the patch is increased, which will affect the overall performance of return loss curve. The antenna confirms high robustness against deformation on antenna performance, making the design well-suited for flexible wireless device applications.

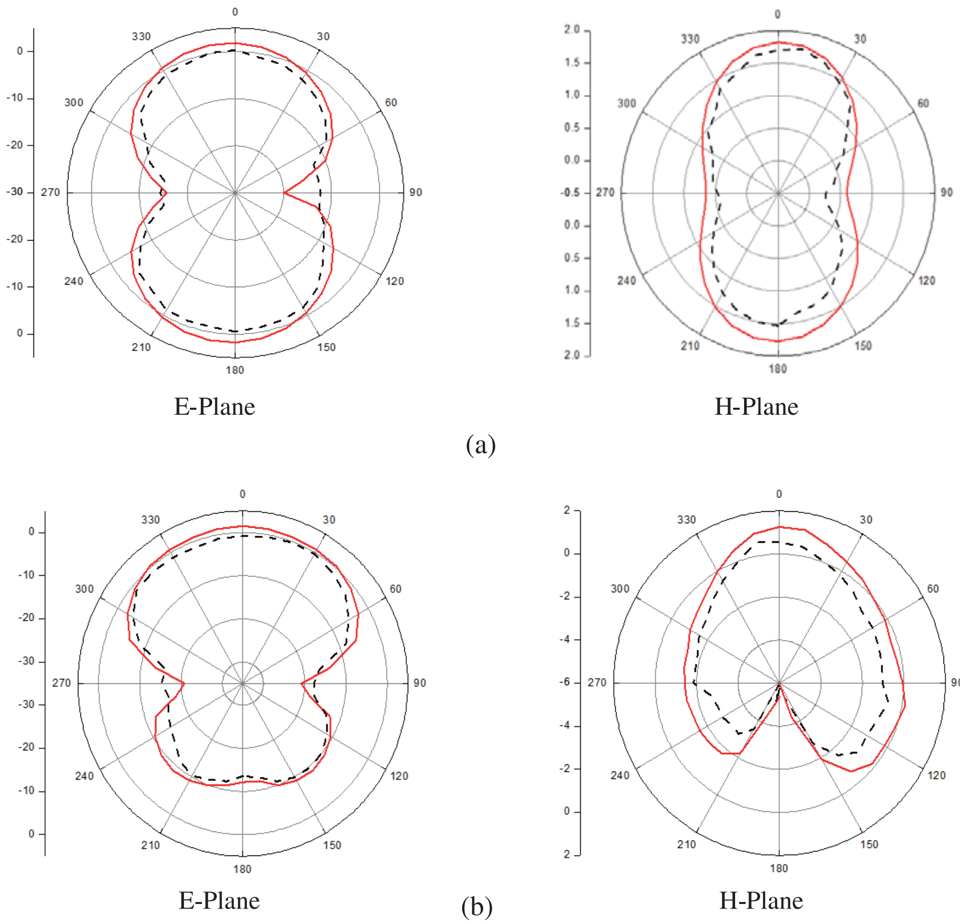


Figure 6. Radiation pattern measured (dashed) and simulated (solid) at frequency (a) 3.4 GHz, (b) 5.7 GHz.

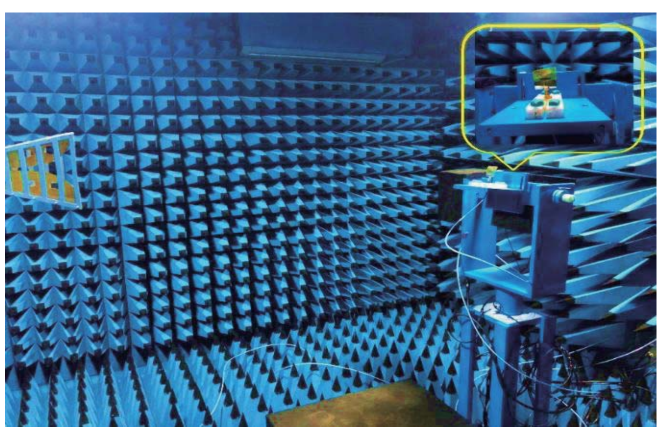


Figure 7. Measurement setup in the anechoic chamber.

Table 4 shows the antenna performance comparison with other previous works. It is observed that the proposed antenna is very thin and flexible with a reasonable gain. Due to electrical conductivity of Graphene compared to carbon composite material, a somehow low value of gain and radiation efficiency is achieved, but it can be overcome with the help of research in material science and modern fabrication technology.

Table 3. Antenna characteristics.

Frequency (GHz)		Return Loss (dB)		Impedance Bandwidth (%)		Gain (dBi)		Radiation Efficiency (η)	
Simulated (S)	Measured (M)	(S)	(M)	(S)	(M)	(S)	(M)	(S)	(M)
3.4	3.356	−22.88	−22.435	80.29	64.28	1.8224	1.52	0.97192	0.95
5.7	5.523	−22.14	−14.515	6.31	9.36	1.68336	1.26	0.90438	0.86

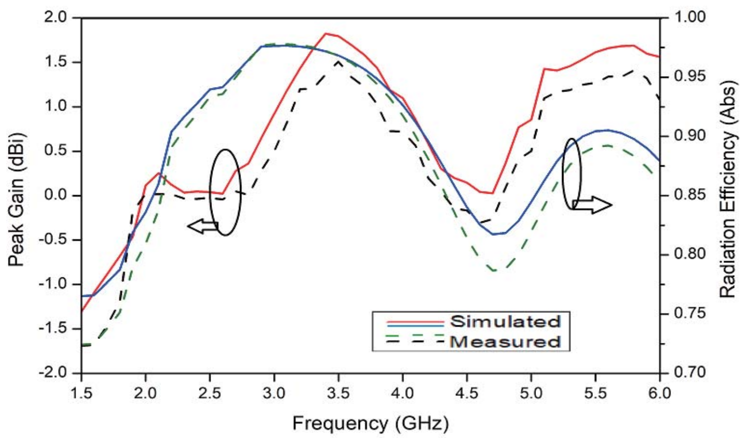


Figure 8. Peak gain and radiation efficiency (η) of the proposed antenna.

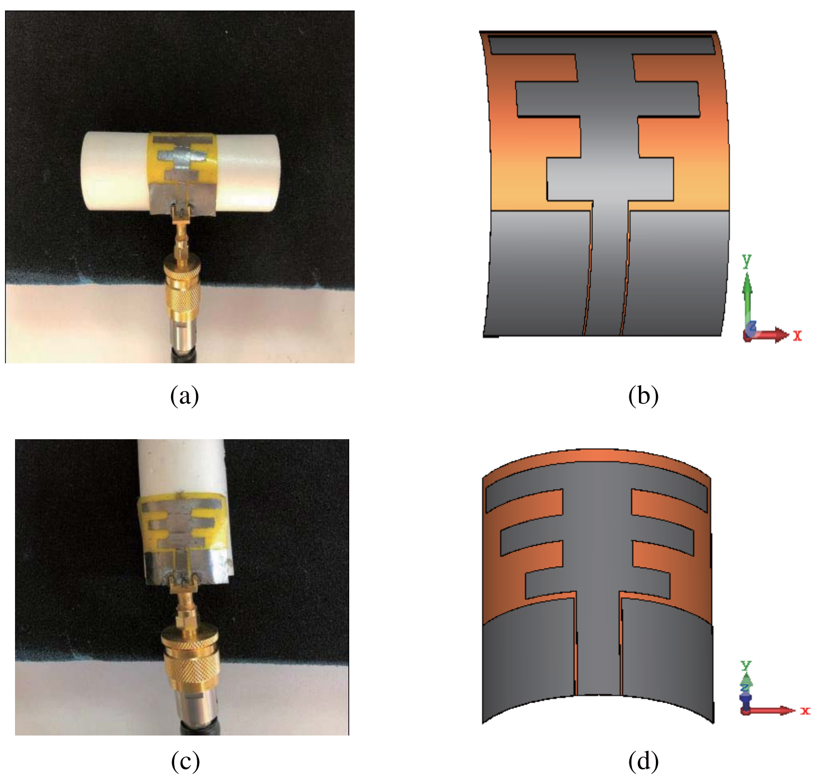


Figure 9. (a), (b) Antenna bending on a cylindrical surface with a radius of 15 mm. (c), (d) Simulation bending in E-plane and H-plane respectively.

Table 4. Comparison of proposed antenna with existing work.

References	Material	Size (mm^3)	Frequency Band (GHz)	Center Frequency (GHz)	Gain (dBi)
[8]	Carbon Composite with FR4	41 × 41 × 1.6 **(2689.6)**	0.609–9.105	5.00	3.0
[21]	Graphene Nanoflakes (Paper substrate)	92 × 25 × 0.8 **(1840)**	0.835–0.90	0.870	(-) 4.0
[25]	Flexible RT-Duroid 5880	90 × 60 × 0.127 **(685.8)**	0.94–1.20 2.23–2.43 3.58–3.74 4.93–5.29	1.2 2.4 3.5 5.2	5.47 5.88 1.97 3.5
[26]	Kapton base ink-jetted (silver Ink)	70 × 70 × 0.11 **(539.0)**	0.8–1.0 1.4–2.2 2.5–2.7	0.9 2.0 2.5	(-)1.0 1.3 2.7
[27]	Flexible conductive cloth (MKKTN260)	15 × 17 × 1.0 **(255)**	5.578–5.898	5.8	4.85
[28]	Copper laminated sheet with PTFE	25 × 50 × 0.127 **(158.75)**	3.4–3.6 7.4–14.4	3.5 13.8	Unspecified
[29]	Carbon Nano Tube with Kapton	48 × 33 × 0.13 **(205.92)**	1.65 –2.62 4.2–7.58	2.45 5.8	0.1 2.48
Proposed Work	Graphene with Kapton Polyimide	34 × 38 × 0.10 **(129.20)**	**1.64–3.84** **5.52–5.88**	3.4 5.7	1.822 1.683

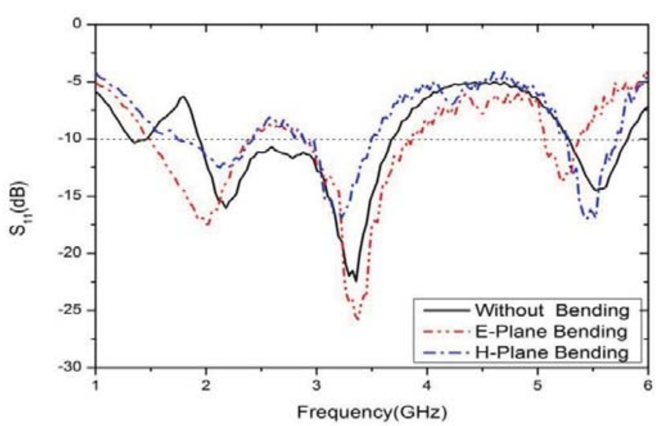


Figure 10. Reflection coefficient to frequency for bending analysis.

5. CONCLUSION

A dual-band flexible antenna for smart portable devices is proposed. The antenna is fabricated using Kapton polyimide and a novel carbon-based material Graphene sheet which offers benefits of high flexibility, cost effectiveness, and ease in fabrication. The measured results of reflection coefficient parameter, radiation pattern, and gain show good agreement with the simulated ones for the desired frequency for its flexible applications in the field of smart wireless communication systems. In recent fabrication technologies in Graphene various forms of sheet, ink, powder, etc. has brought a lot of other possibilities for making smart devices flexible.

ACKNOWLEDGMENT

The research was performed and carried out at the ELARC-ELectromagnetics and Antenna Research Centre, which is operated for BVM Engineering College, Vallabh Vidyanagar, Gujarat-India.

REFERENCES

1. Geim, A. K. and K. S. Novoselov, "The rise of graphene-nature materials," *Nature Materials*, Vol. 6, 183–191, 2007.
2. Bunch, J. S., "Mechanical and electrical properties of graphene sheets," Ph.D. dissertation, Cornell University, 2008.
3. Lee, Y. and J. Ahn, "Graphene-based transparent conductive films," *World Scientific*, Vol. 8, No. 3, 1330001–16, 2013.
4. Moon, J. S. and D. K. Gaskill, "Graphene: Its fundamentals to future applications," *IEEE Trans. Microwave Theory Technology*, Vol. 59, No. 10, 2702–2708, Oct. 2011.
5. Scida, A., S. Haque, E. Treossi, S. Smerzi, S. Ravesi, S. Borini, and V. Palermo, "Application of graphene based flexible antennas in consumer electronic devices," *Materials Today*, Vol. 21, No. 3, Apr. 2018.
6. Akbari, M., J. Virkki, L. Sydanheimo, et al., "Toward Graphene-based passive UHF RFID textile tags: A reliability study," *IEEE Trans. Antennas Propagation*, Vol. 16, No. 3, 429–431, 2016.
7. Huang, X., T. Leng, M. Zhu, X. Zhang, J. C. Chen, and K. H. Chang, "Highly flexible and conductive printed graphene for wireless wearable communications applications," *Scientific Reports*, Vol. 5, 1–8, 2015.
8. Reyes-Vera, E., M. Arias-Correa, A. Giraldo-Muno, D. Catano-Ochoa, and J. Santa-Marin, "Development of an improved response ultra-wideband antenna based on conductive adhesive of carbon composite," *Progress In Electromagnetics Research C*, Vol. 79, 199–208, 2017.
9. De Assis, R. and I. Bianchi, "Analysis of microstrip antennas on carbon fiber composite material," *Journal of Microwaves, Optoelectronics and Electromagnetic Applications*, Vol. 11, 154–161, Jun. 2012.
10. Mehdipour, A., T. A. Denidni, A. Sebak, and C. W. Trueman, "Reconfigurable TX/RX antenna systems loaded by anisotropic conductive carbon-fiber composite materials," *IEEE Transactions on Antennas and Propagation*, Vol. 62, No. 2, 1002–1006, Feb. 2014.
11. Desai, A., T. Upadhyaya, and R. Patel, "Compact wideband transparent antenna for 5G communication system," *Microwave and Optical Technology Letters*, 2019.
12. Kantharia, M., A. Desai, T. K. Upadhyaya, R. H. Patel, P. Mankodi, and M. Kantharia, "High gain flexible cpw fed fractal antenna for bluetooth/WLAN/WPAN/WiMAX applications," *Progress In Electromagnetics Research*, Vol. 79, 87–93, 2018.
13. Kumar, J., B. Basu, F. A. Talukdar, and A. Nandi, "Graphene-based multimode inspired frequency reconfigurable user terminal antenna for satellite communication," *IET Microwave, Antennas and Propagation*, Vol. 12, 67–74, 2017.
14. Desai, A., T. Upadhyaya, M. Palandoken, and C. Gocen, "Dual band transparent antenna for wireless MIMO system applications," *Microwave and Optical Technology Letters*, 2019.

15. Desai, A. and T. Upadhyaya, "Transparent dual band antenna with μ-negative material loading for smart devices," *Microwave and Optical Technology Letters*, Vol. 60, No. 11, 2805–2811, 2018.
16. Kumar, A., V. Sankhla, J. Deegwal, and A. Kumar, "An offset CPW-fed triple-band circularly polarized printed antenna for multiband wireless applications," *International Journal of Electron. Commun. (AEÜ)*, Vol. 86, 133–141, 2018.
17. Patel, R., A. Desai, and T. Upadhyaya, "A discussion on electrically small antenna property," *Microwave and Optical Technology Letters*, Vol. 57, No. 10, 2386–2388, 2015.
18. Prajapati, P. R., G. G. K. Murthy, A. Patnaik, and M. V. Kartikeyan, "Design and testing of a compact circularly polarized microstrip antenna with fractal defected ground structure for L-band applications," *IET Microwaves Antennas and Propagation*, Vol. 9, No. 11, 1179–1185, 2015
19. Upadhyaya, T., "Design of wide band printed monopole antenna for low rate wireless personal area networks," *Microwave and Optical Technology Letters*, Vol. 60, No. 11, 2769–2773, 2018.
20. Li, Y. J., Z. Y. Lu, and L. S. Yang, "CPW-fed slot antenna for medical wearable applications," *IEEE Access*, Vol. 7, 42107–42112, 2019.
21. Leng, T., X. Huang, K. H. Chang, J. Chen, M. Abdalla, and Z. Hu, "Graphene nanoflakes printed flexible meandered-line dipole antenna on paper substrate for low-cost RFID and sensing applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 15, No. 11, 1565–1568, 2016.
22. Qiu, Y., N. Behdad, J. Lee, Y. H. Xu, R. Xu, W. Lin, N. Behdad, and Z. Ma, "Compact parylene-c-coated flexible antenna for WLAN and upper-band UWB applications," *Electronics Letters*, Vol. 50, No. 24, 1782–1784, 2014.
23. Faisal, F., Y. Amin, Y. Cho, and H. Yoo, "Compact and flexible novel wideband flower-shaped CPW-fed antennas for high data wireless applications," *IEEE Transactions on Antennas and Propagation*, Vol. 67, No. 6, 4184–4188, 2019.
24. Li, X., Y. C. Jiao, and L. Zhang, "Wideband low-profile CPW-fed slot loop antenna using an artificial magnetic conductor," *Electron. Lett.*, Vol. 54, No. 11, 673–674, May 2018.
25. Yan, S., P. J. Soh, and G. A. E. Vandenbosch, "Low-profile dual band textile antenna with artificial magnetic conductor plane," *IEEE Transactions on Antennas and Propagation*, Vol. 2, No. 12, 6487–6490, Dec. 2014.
26. Lago, H., et al., "Textile antenna integrated with compact AMC and parasitic elements for WLAN/WBAN applications," *Applied Physics A*, Vol. 122, No. 12, 1059, 2016.
27. Liu, H., P. Wen, S. Zhu, B. Ren, X. Guan, and H. Yu, "Quad-band CPW-fed monopole antenna based on flexible pentangle-loop radiator," *IEEE Antennas and Wireless Propagation Letters*, Vol. 14, 1373–1376, 2015.
28. Ahmed, S., F. A. Tahir, A. Shamim, and H. M. Cheema, "A compact kapton-based inkjet-printed multiband antenna for flexible wireless devices," *IEEE Antennas and Wireless Propagation Letters*, Vol. 14, 1802–1805, 2015.
29. Liu, H., S. Zhu, P. Wen, X. Xiao, W. Che, and X. Guan, "Flexible CPW-fed fishtail-shaped antenna for dual-band applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 13, 770–773, 2014.
30. Hamouda, Z., Wojkiewicz, A. A. Pud, L. Kone, B. Belaabed, S. Bergheul, and T. Lasri, "Dual-band elliptical planar conductive polymer antenna printed on a flexible substrate," *IEEE Transactions on Antennas and Propagation*, Vol. 63, No. 12, 5864–5867, 2015.
31. Mohandoss, S., S. K. Palaniswamy, and R. R. Thipparaju, "On the bending and time domain analysis of compact wideband flexible monopole antennas," *International Journal of Electronics and Communications*, Vol. 101, 168–181, 2019.
32. Graphene paper [online] https://www.sigmaaldrich.com/catalog/substance/graphenepaper.
33. Kapton polyimide [online] https://www.kaptontape.com/1_Mil_Kapton_Tapes.php.