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Printed Multiband Monopole Antenna for Smart Energy Meter/WLAN/WiMAX Applications

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Abstract—The proposed antenna structure is excited for multiple operational modes by means of meandered strips. The compact planar monopole antenna is demanded enormously for handheld devices especially automatic meter reading and tablet devices. Due to Chu limit, it is extremely vital to miniaturize an antenna by balancing tradeoff between bandwidth and radiation efficiency. The designed antenna is formed by two interconnected broad monopole open slots which covers multi-bands for smart energy meter and tablet computer applications. The cost effective FR4 laminate of size $50 \times 200\,\mathrm{mm}^2$ $(0.4\lambda \times 1.6\lambda)$ is employed to match standard tablet computer communication module dimensions. The impedance bandwidth, for all excited resonant modes, is above typical requirement of 2%, and the VSWR is well below the necessary requirement of 1.5. The peak gain ranges from 0.94 dBi to 1.92 dBi. Radiation patterns along with other antenna parameters are satisfactorily meeting the demand of Wireless Energy Meter and Tablet Devices. The effects of varying dimensions of a monopole on the radiation characteristics have also been presented. The return loss and radiation patterns computed through simulations are validated through experimental measurements in an anechoic chamber environment.

1. INTRODUCTION

Embedded antennas have gone through substantial development. Especially in last decade, significant rise has been observed in utilization of portable devices. There has been noteworthy rise in wireless energy meters installation across the globe. Government of United States invested around $4.8 billion in 2016, and it is expected to increase manifold to $13 billion by year 2024–25 [1]. Across the globe, this investment is significant. In the United Kingdom, by September 2018 around 12.8 million home and business opted for smart and advanced metering system [2]. The communication required for smart meters and smart grid technology operates over a mesh network incorporating multiple sensors. Data loggers are responsible for grabbing data from smart meter devices, phasor measurement units, and intelligent applications, transmitted to regulatory centers. Slot antennas usually support such wireless communication. Slot antennas present great mechanical flexibility for integration along with circuit boards. Several engineered slot antennas have been presented in the literature. Closed ended slot antennas primarily function at the half-wavelength fundamental resonant mode; however, open-ended slot antennas are able to produce quarter-wavelength. Monopole slot antenna provides antenna miniaturization for specific resonant frequency, and hence it becomes an obvious choice for the antenna in smart meters and tablet antennas. The impedance bandwidth is hence restricted in the fundamental resonant mode. Printed antennas have been extensively utilized in laptops, portable smart grid communication devices, and mobile phones. The space constraint to adjust the embedded antenna in these devices is crucial for antenna designers. The available space is considerably small and narrow in communication devices. For a tablet antenna, while the antenna is integrated in the edges of the

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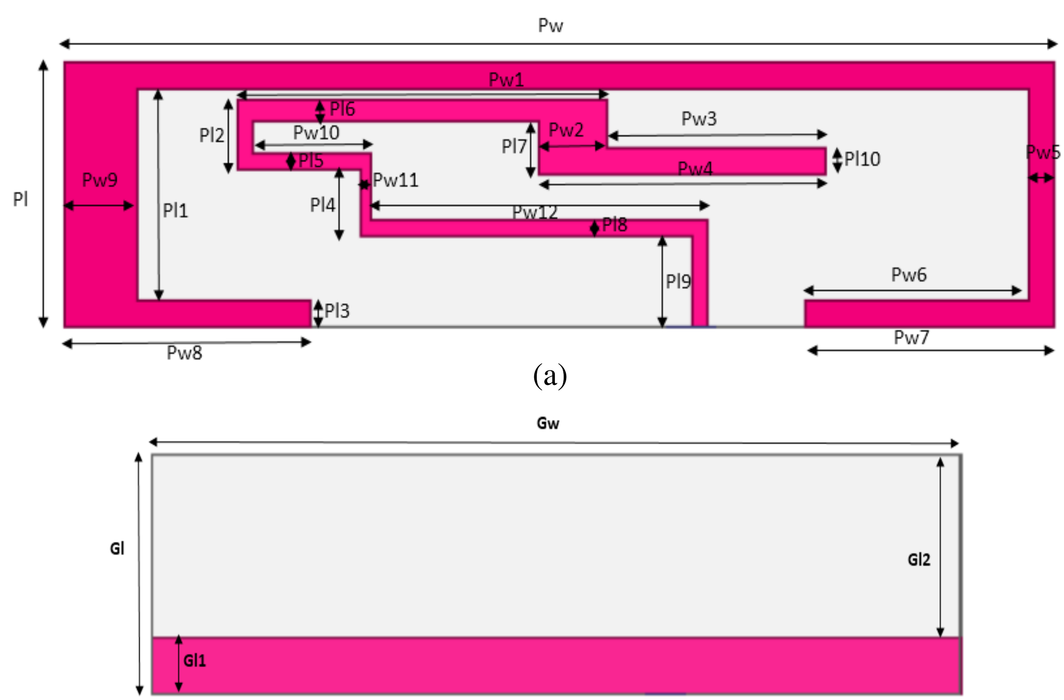
Liquid Crystal Display panel, it becomes quite essential that antenna thickness should be quite low, and it needs to have long length to width ratio.

In printed monopole antennas, branches of open or closed loops can control the excited modes. The surface current density of these loops determines the resonance and radiation patterns. By merely tailoring the dimensions of these branches, the resonance modes and radiation patterns can be engineered for target application. Lump elements can be added along with one or more branches of the antenna to tune the antenna resonance to a specific frequency or set of frequencies; however, use of lump elements may cause the reduction in antenna efficiency. In addition, lump elements are also prone to mechanical wear and tear. One of the greatest challenges posed by the tablet computer antenna is the presence of extremely large system ground plane, and hence the antenna bandwidth is restricted.

Planar multiband antenna has attractive design properties viz. low profile and ease in fabrication, hence planar monopole antennas are utilized extensively in handheld devices such as mobile phones, tablet computers, and laptops [3–5]. The fundamental cause of this over dependency is due to flexibility in the resonator design. Copper loops on the planar substrate offers a convenient option in monopole antenna design [6, 7]. Planar Inverted-F Antenna (PIFA) also offers good utilization in handheld device [8]. PIFA antenna requires large vertical space and also has mutual coupling issues with substrate. Electrically small antennas suffer from the issue of efficiency and hence gain at target resonance [9, 10]. Advanced techniques of metamaterial inspired antennas can also help in miniaturization [11, 12]. There are a few tablet and laptop embedded antennas available in literature, which are recommended for end-users [13–16]. Other literature addresses varied designs of monopole antennas [17–24]. The proposed planar antenna is able to support Wireless Energy Meters, Wireless Local Area Network (WLAN), and World Wide Interoperability for Microwave Access (WiMAX) applications. The planar antenna configuration is designed in such a way that feed excites two dipoles joined by a small resistive copper strip. The design is further optimized by introducing an external boundary strip for fine-tuning of the antenna. Section 2 describes the antenna design considerations, and Section 3 provides the design outcomes and discussions.



(b)

Figure 1. Geometry of proposed monopole antenna. (a) Top side, (b) ground plane side.

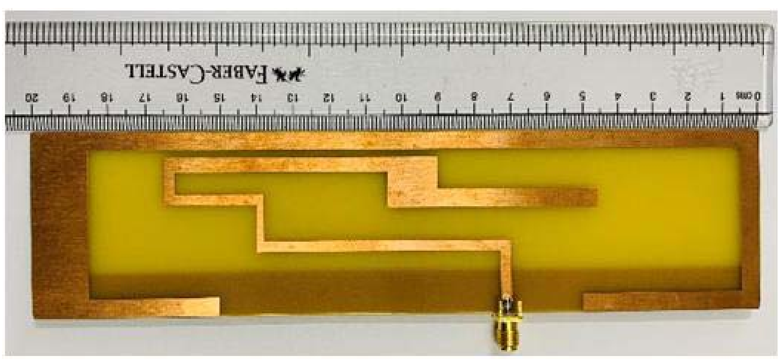
2. ANTENNA CONFIGURATION AND DESIGN CONSIDERATIONS

The antenna configuration is illustrated in Figure 1. A cost effective FR4 substrate of thickness 1.6 mm having dielectric constant of 4.4 is utilized. The substrate dimensions are $50 \times 200\,\text{mm}^2$. The FR4 substrate is quite lossy, especially for frequencies in GHz regime due to this high loss tangent, but it supports bulk production of the communication devices. Various copper strips are inducted in the resonator design to excite multiple resonating modes, both at quarter-wavelength and half-wavelength. The microstrip feeding matched at $50\,\Omega$ is used for excitation. Optimal feed location is selected for impedance matching and hence return loss improved. A gold plated SMA connector is utilized to minimize the loss. Sufficient space is kept on the substrate material so that other components of communication module can be placed on the front and back sides of the antenna.

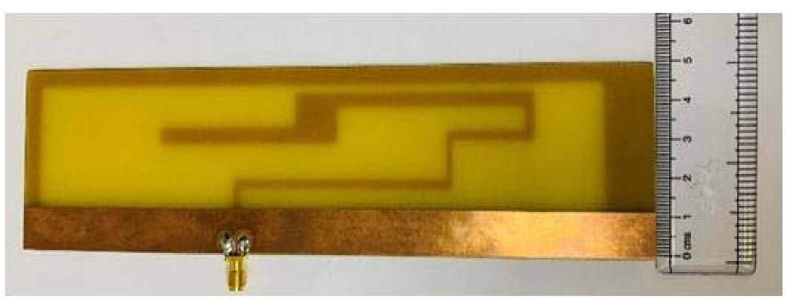
Partial ground plane is utilized to significantly enhance the bandwidth of the antenna; however, this shall reduce the antenna gain at the excited resonant modes. The engineered dimensions of the notations used in Figure 1(a), in mm, are: $Gw = 200$, $Gl = 55$, $Gl1 = 12$, $Gl2 = 38$, $Pw = 200$, $Pw1 = 75$, $Pw2 = 14$, $Pw3 = 44$, $Pw4 = 58$, $Pw5 = 5$, $Pw6 = 45$, $Pw7 = 50$, $Pw8 = 50$, $Pw9 = 15$, $Pw10 = 24$, $Pw11 = 2$, $Pw12 = 70$, $Pl = 50$, $Pl1 = 40$, $Pl2 = 13$, $Pl3 = 5$, $Pl4 = 13$, $Pl5 = 3$, $Pl6 = 4$, $Pl7 = 10$, $Pl8 = 34$, $Pl9 = 17$, $Pl10 = 5$, $Hs = 1.6$.

3. RESULTS AND DISCUSSIONS

The proposed resonator is simulated in finite element analysis based full wave simulator. The antenna is fabricated with standard printed circuit board technique. The fabricated prototype is depicted in Figure 2. The numerically computed return loss by software simulator and measured return loss are compared in Figure 3. The simulated return loss is below standard requirement for all the excited modes, and the measured return loss meets the minimum required Voltage Standing Wave Ratio (VSWR) levels of 2 : 1. The other antenna parameters are tabularized in Table 1. The antenna has multiple application specific resonant frequencies viz. 2.4 GHz (WLAN), 2.59 GHz (WiMAX), 2.95 GHz



(a)



(b)

Figure 2. Fabricated prototype. (a) Top side and (b) bottom side.

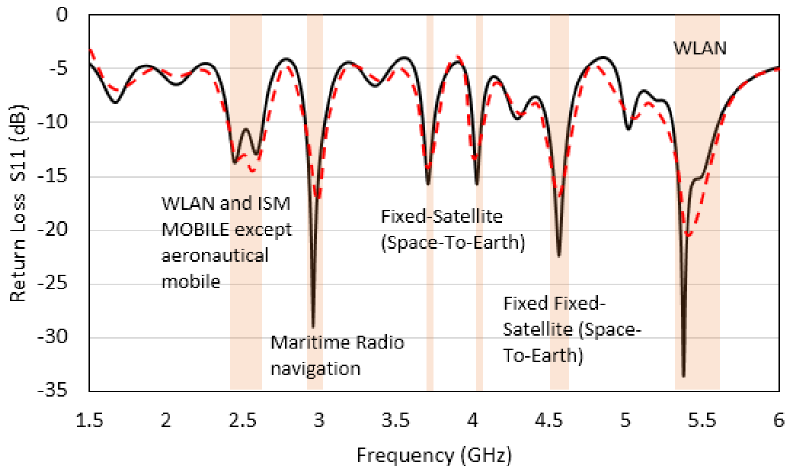


Figure 3. Antenna return loss measurement simulated and measured return loss (dashed: measured, continuous: simulated).

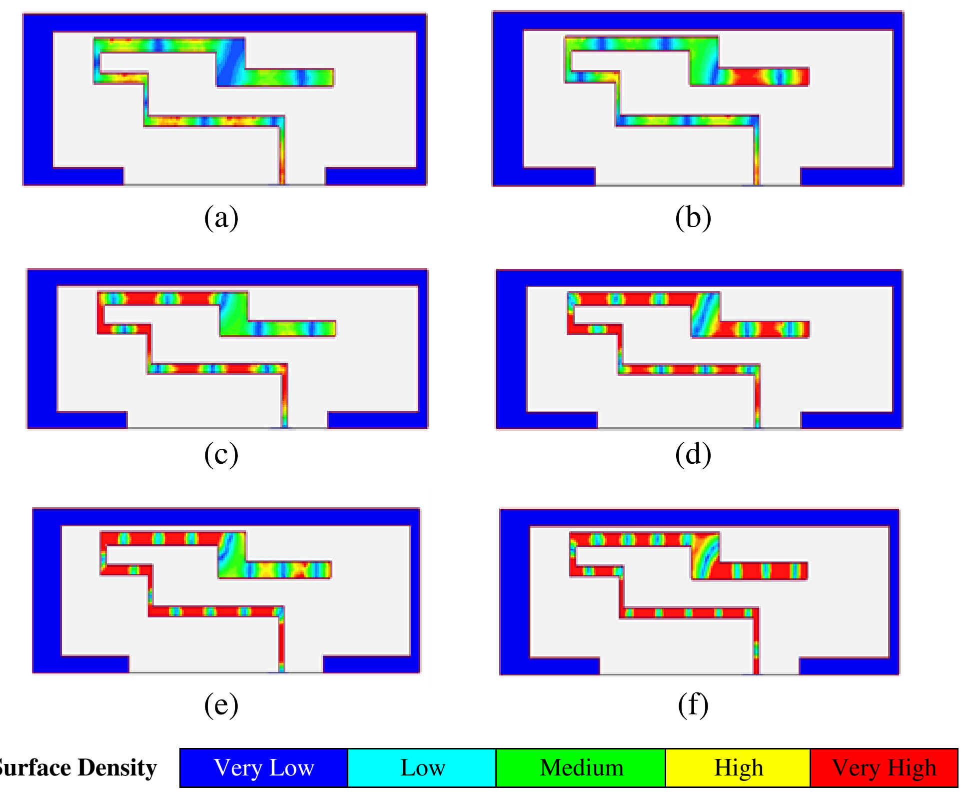


Figure 4. Antenna current distribution (a) 2.4 GHz, (b) 2.59 GHz, (c) 2.95 GHz, (d) 3.70 GHz, (e) 4.5 GHz and (f) 5.5 GHz.

(Maritime Radio navigation), 3.7 GHz (Fixed Satellite Communication), 4.12 GHz and 4.5 GHz (Fixed Satellite Communication), 5.5 GHz (WLAN). These bandwidths are ample enough to cover practical targeted applications. The engineered design has multiple vacant slots on the top side of the resonator, which enables further addition of conducting slots for incorporating other resonant frequencies.

The mismatch in results is due to fabrication inaccuracies, temperature variations, and soldering slippages. Figure 4 depicts the current distribution of the antenna at targeted frequencies. The current

Table 1. Proposed antenna parameters.

Antenna Parameters	First Resonance	Second Resonance	Third Resonance	Fourth Resonance	Fifth Resonance	Sixth Resonance
Frequency (GHz)	2.4	2.95	3.7	4.12	4.5	5.5
VSWR	1.154	1.125	1.152	1.439	1.123	1.105
Bandwidth (%)	14.16	6.78	6.21	3.15	7.77	8.18
Peak Gain (dBi)	1.89	1.61	0.97	0.98	1.72	1.92

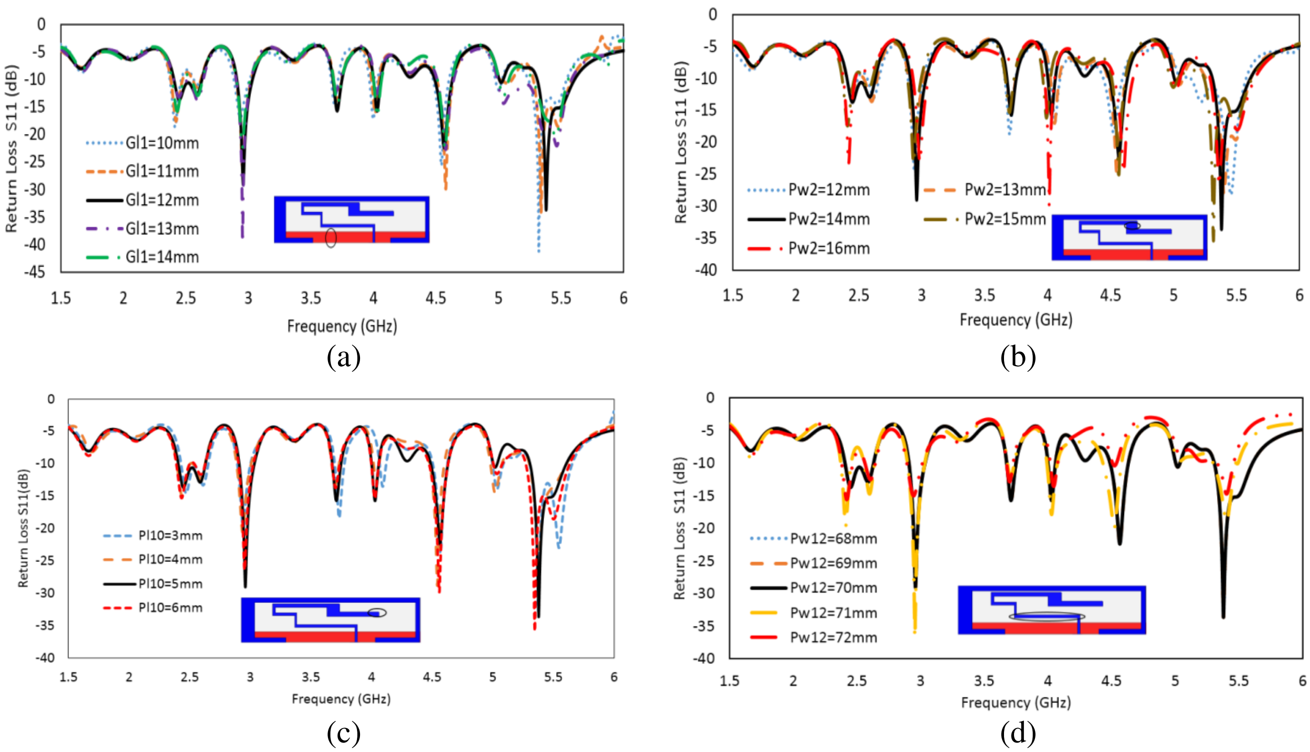
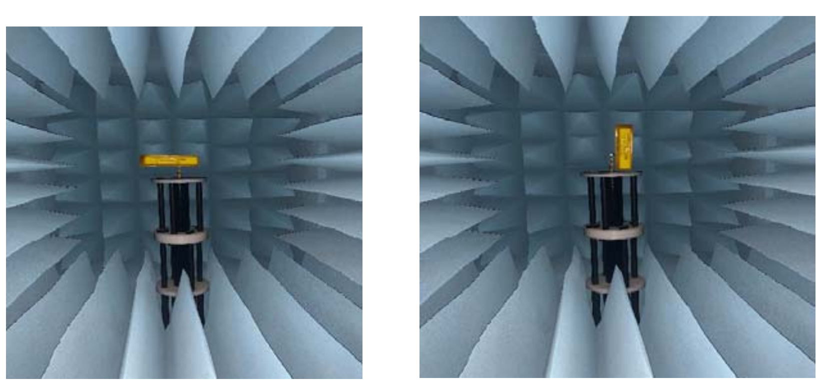


Figure 5. Parametric variations of (a) $Gl1$, (b) $Pw12$, (c) $Pl10$, and (d) $Pw12$.



(a) (b)

Figure 6. Antenna measurement setup in anechoic chamber (a) E-plane measurement, (b) H-plane measurement.

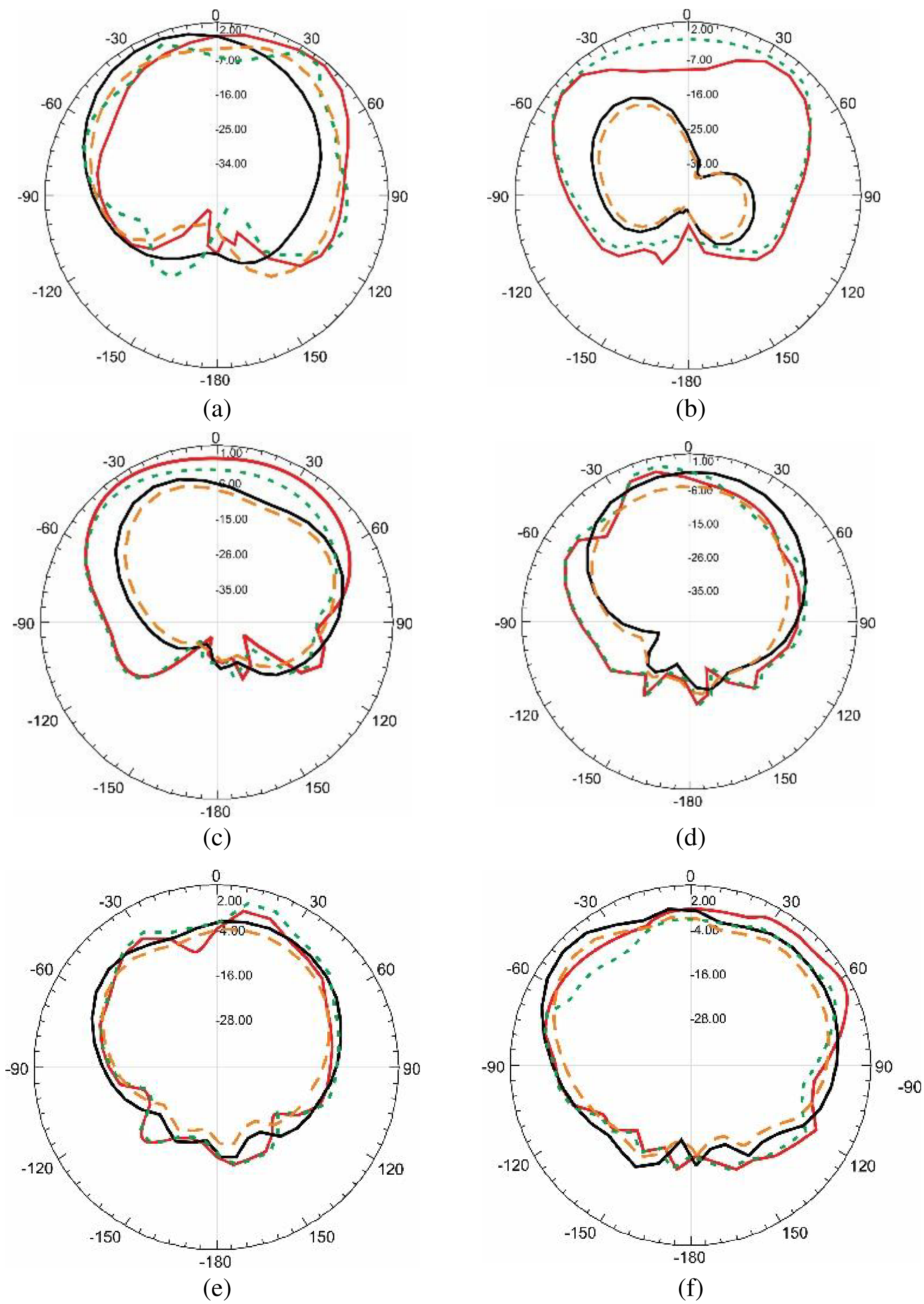


Figure 7. Antenna radiation patterns (a) 2.4 GHz, (b) 2.59 GHz, (c) 2.95 GHz, (d) 3.70 GHz, (e) 4.5 GHz and (f) 5.5 GHz (Continuous black/red: simulated E-plane/H-plane, dashed green/orange measured E-plane/H-plane).

densities are quite high at high frequencies. The outer strip has almost negligible charge density as it is separated from the rest of the copper loops, and it is engineered for fine-tuning of antenna parameters. In the case of minor tuning requirement and to optimize the antenna for specific target applications, the variations in physical parameters of the antennas are carried out as in Figure 5. The variations in $Gl1$ and $Pl10$ improves the VSWR of the antenna with minor compromise in the impedance bandwidth. The frequency shifts can be achieved by $Pw2$ and $Pw12$, which enables the antenna to be tuned for other applications. The fabricated antenna is measured in an anechoic chamber environment for radiation pattern measurements. The measurement setup and radiation patterns are depicted in Figure 6 and Figure 7, respectively. The radiation patterns are omnidirectional due to absence of full ground plane, which virtually acts as a reflector. Figure 7 illustrates both E-plane and H-plane radiation patterns at all six resonant frequencies. Figure 8 represents the antenna peak gain and directivity against the antenna resonance.

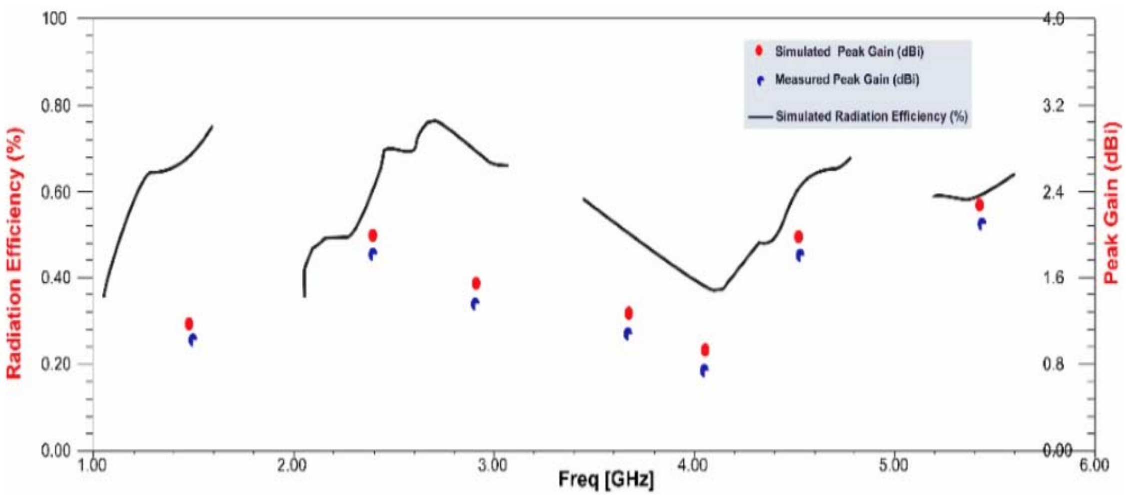


Figure 8. Antenna peak gain and radiation efficiency.

Table 2. Performance comparison with other designs.

Citation	Resonant Frequencies (GHz)	Antenna Dimensions (mm^3)	Gain (dBi)	Bandwidth (%)
[3]	0.7, 0.85, 0.9, 1.8, 1.9, 2.3, 2.5	$35 \times 10 \times 0.8$	0.8, 0.9, 1, 1.2, 1.6, 2, 1.8	28 (covering first three resonance) 44 (covering remaining three resonance)
[4]	0.83, 1.95, 2.35, 2.66	$60 \times 200 \times 4$	−0.9, 0.1, −0.95, −0.98	36.47 (covering first two resonance) 59.37 (covering remaining two resonance)
[6]	0.85, 0.92, 1.79, 1.92, 2.045	$60 \times 200 \times 0.8$	0.6, 0.5, 1.2, 2.2, 1.8	22.59 (covering first two resonance) 37.22 (covering last three resonance)
Proposed Antenna	2.4, 2.95. 3.7, 4.12, 4.56, 5.5	$50 \times 200 \times 1.6$	1.89, 1.61, 0.97, 0.98, 1.72, 1.92	14.16, 6.78, 6.21, 3.15, 7.77, 8.18

4. CONCLUSION

A standard size multiband monopole antenna having dimensions of $50 \times 200\,\text{mm}^2$ is presented. The presented surface mountable antenna is fabricated on an FR4 substrate, which provides cost effective solution for mass production. The presented antenna offers bandwidth more than 2% for all resonant frequencies including ISM band. The antenna can be further engineered for utilization in other wireless applications without modifying the base hardware dimensions. The antenna presents a fair gain which is satisfactory for the specified tablet computer applications.

REFERENCES

1. "Smart grid system report," Report to Congress, U.S. Department of Energy, Government of United States, 2018.
2. "Smart metering implementation programme," 2018 Progress Report, Department of Business, Energy & Industrial Strategy, Government of UK, 2018.
3. Lu, J. H. and Y. S. Wang, "Planar small-size eight-band LTE/WWAN monopole antenna for tablet computers," *IEEE Transactions on Antennas and Propagation*, Vol. 62, No. 8, 4372–4377, 2014.
4. Upadhyaya, T. K., A. Desai, and R. H. Patel, "Design of printed monopole antenna for wireless energy meter and smart applications," *Progress In Electromagnetic Research Letters*, Vol. 77, 27–33, 2018.
5. Ban, Y. L., S. C. Sun, J. W. Li, and W. Hu, "Compact coupled-fed wideband antenna for internal eight-band LTE/WWAN tablet computer applications," *Journal of Electromagnetic Waves and Applications*, Vol. 26, Nos. 17–18, 2222–2233, 2012.
6. Wong, K. L. and L. C. Lee, "Multiband printed monopole slot antenna for WWAN operation in the laptop computer," *IEEE Transactions on Antennas and Propagation*, Vol. 57, No. 2, 324–330, 2009.
7. Chiu, C.-W., C.-H. Chang, and Y.-J. Chi, "Multiband folded loop antenna for smart phones," *Progress In Electromagnetics Research*, Vol. 102, 213–226, 2010.
8. Naser-Moghadasi, M., Z. Mansouri, S. Sharma, F. B. Zarrabi, and B. S. Virdee, "Low SAR PIFA antenna for wideband applications," *IETE Journal of Research*, Vol. 62, No. 5, 564–570, 2016.
9. Patel, R. and T. Upadhyaya, "An electrically small antenna for nearfield biomedical applications," *Microwave and Optical Technology Letters*, Vol. 60, No. 3, 556–561, 2018.
10. Ntaikos, D. K., N. K. Bourgis, and T. V. Yioultsis, "Metamaterial-based electrically small multiband planar monopole antennas," *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, 963–966, 2011.
11. Saadh, A. W. M. and T. Ali, "A compact coaxial fed metamaterial antenna for wireless applications," *Journal of Instrumentation*, Vol. 14, No. 6, P06025, 2019.
12. Upadhyaya, T. K., V. V. Dwivedi, S. P. Kosta, and Y. P. Kosta, "Miniaturization of tri band patch antenna using metamaterials," *Fourth IEEE International Conference on Computational Intelligence and Communication Networks*, 45–48, 2012.
13. Chen, Z., Y.-L. Ban, S.-C. Sun, and J. L.-W. Li, "Printed antenna for penta-band WWAN tablet computer application using embedded parallel resonant structure," *Progress In Electromagnetics Research*, Vol. 136, 725–737, 2013.
14. Elshennawy, W. S., E. A. Hashish, and A. M. Attiya, "Multiband LTE-A/WWAN antenna for a tablet," *Open Journal of Antennas and Propagation*, Vol. 3, No. 3, 19, 2015.
15. Ban, Y.-L., J.-H. Chen, J. L.-W. Li, and W. Hu, "Printed multi-resonance antenna embedding two inductors in radiating strips for internal mobile phone LTE/WWAN operation," *Journal of Electromagnetic Waves and Applications*, Vol. 26, Nos. 17–18, 2211–2221, 2012.
16. Nie, L. Y., X. Q. Lin, B. Wang, and J. Zhang, "A planar multifunctional four-port antenna system for sub-urban mobile tablet," *IEEE Access*, Vol. 7, 56986–56993, 2019.
17. Subbaraj, S., M. Kanagasabai, G. N. A. Mohammed, Y. Panneer Selvam, S. Kingsly, and R. R. Yeragudipati Venkata, "Miniaturized quad-band coplanar-fed monopole antenna for tablet

computers," *COMPEL — The International Journal for Computation and Mathematics in Electrical and Electronic Engineering*, Vol. 37, No. 3, 1118–1130, 2018.

18. Subbaraj, S., M. Kanagasabai, M. G. N. Alsath, G. Ganesan, Y. Panneer Selvam, and S. Kingsly, "Compact multiservice monopole antenna for tablet devices," *International Journal of Electronics*, Vol. 105, No. 8, 1374–1387, 2018.
19. Huang, J. W., T. C. Chu, Y. S. Zhan, B. L. Ke, and H. L. Su, "A uniplanar monopole antenna for LTE/UMTS/WLAN in tablet computer applications," *2018 International Symposium on Antennas and Propagation (ISAP)*, 1–2, IEEE, October 2018.
20. Ke, J. F., M. Chou, Z. C. Zhang, and W. J. Liao, "A dual-band WLAN antenna design for placement in hinges of convertible notebooks," *2019 Cross Strait Quad-Regional Radio Science and Wireless Technology Conference (CSQRWC)*, 1–2, IEEE, July 2019.
21. Chen, C. H., Y. C. Jiao, and Z. B. Weng, "Low profile octa-band antenna without lumped elements for WWAN/LTE metallic narrow-frame tablet computers," *Microwave and Optical Technology Letters*, Vol. 61, No. 3, 665–670, 2019.
22. Su, S.-W., "Very-low-profile, small-sized, printed monopole antenna for WLAN notebook computer applications," *Progress In Electromagnetics Research Letters*, Vol. 82, 51–57, 2019.
23. Chen, S. C., C. C. Huang, and M. C. Hsu, "Reconfigurable long-term evolution/wireless wide area network antennas integrated with the metal frame of tablet computers," *Journal of Electromagnetic Waves and Applications*, Vol. 31, No. 15, 1609–1623, 2017.
24. Lu, J. H. and Y. M. Yan, "Planar LTE/WWAN monopole antenna for 4G tablet computer," *2015 IEEE International Symposium on Antennas and Propagation* & *USNC/URSI National Radio Science Meeting*, 1142–1143, IEEE, July 2015.