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Compact CPW-fed uniplanar antenna for multiband wireless applications

R. Sujith [b], V. Deepu [b], S. Mridula [a], Binu Paul [a], D. Laila [b], P. Mohanan [b,*]

[a] *School of Engineering, CUSAT, Cochin, India*
[b] *Centre for Research in Electromagnetics and Antennas (CREMA), Department of Electronics, Cochin University of Science and Technology, Cochin 22, Kerala, India*

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ABSTRACT

A compact coplanar waveguide (CPW) fed uniplanar antenna for Quad-band applications is presented. The Quad-band operation is realized by imposing various current paths in a modified T-shaped radiating element. The antenna covers GSM 900, DCS 1800, IEEE802.11.a, IEEE802.11.b and HiperLAN-2 bands and exhibits good radiation characteristics. This low profile antenna has a dimension of 32 mm × 31 mm when printed on a substrate of dielectric constant 4.4 and height 1.6 mm. Details of design with experimental and simulated results are presented.

1. Introduction

The introduction of multisystem applications in present wireless communication gadgets, demands the requirement of frequency bands corresponding to system application such as GSM900 (870–960 MHz), DCS-1800 (1710–1880 MHz), IEEE802.11.b (2400–2484 MHz), 5-GHz WLAN (HiperLAN/2 in Europe: 5150–5350/5470–5725 MHz and IEEE802.11.a in U.S: 5150–5350/5725–5825 MHz) bands. Since no compromise can be made on compactness of these electronic gadgets, the multiple antennas must be replaced by multiband antennas with good radiation characteristics, which are of great demand in the present scenario.

Planar antennas especially coplanar waveguide fed antennas have received great attention in recent years due to ease of integration, low cost, wide bandwidth, flexibility towards multiband operation, low radiation leakage and less dispersion. The CPW-Fed monopole antenna presented in [1] generates two operating modes corresponding to the two monopole lengths while the dual frequency operation in [2] is achieved using a rectangular meander monopole. The slot monopole antenna presented in [3] uses asymmetric CPW grounds (rectangular and inverted L-shaped) for achieving the triple band characteristics, but the polarization purity of this antenna is less. The Quad-band planar inverted F antenna (PIFA) with foam substrate [4] uses three U-shaped slits of different dimensions for achieving three bands in addition to the one due to the fundamental rectangular PIFA. However, the antenna is bulky and not compact. The planar inverted F antenna working in GSM900 band presented in [5] exhibits-6 dB return loss while that in [6] Exhibits 2.5:1 VSWR bandwidth that is wide enough to cover the application band. Researchers have explored lot of antennas based on T-shaped structures for multiband and broadband applications. The modified T-shaped multiband antenna presented in [7] uses two asymmetric horizontal strips to produce two resonant modes corresponding to its resonant length. In the above design the ground plane is asymmetric and the antenna size is very large compared to that presented in this paper. The stacked T-shaped monopole of different sizes presented in [8] generates two independent resonant modes at 2.4 and 5.2 GHz. The CPW fed modified T shaped structure [9,10], generated by top loading a monopole produces two resonant modes, which is the motivation for this work. The CPW fed Quad-band uniplanar antenna presented in this paper is exceptionally compact ($0.14\,\lambda_g \times 0.136\,\lambda_g \times 0.007\,\lambda_g$, where λ_g is the wavelength corresponding to lower resonant frequency 900 MHz). An appreciable size reduction of 60% compared to a conventional CPW-Fed strip monopole is achieved. The antenna operates in four bands: 840–970 MHz(GSM900), 1.56–1.92 GHz(DCS 1800), 2.39–2.49 GHz(IEEE802.11.b) and 5.07–6.23 GHz(IEEE802.11.a/HiperLAN-2). The Quad band operation with good radiation characteristics is obtained by creating various current paths in a modified T-shaped radiating element. Prototypes of the proposed antenna have been constructed and tested using HP8510C Network Analyzer. The experimental results are again validated by simulation studies (Ansoft HFSS). The evolution of the Quad band antenna from a conventional monopole is elaborately discussed along with design details, radiation characteristics and parametric analysis.

* Corresponding author. Tel.: +91 484 2576418; fax: +91 484 2575800.
E-mail address: drmohan@gmail.com (P. Mohanan).

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2. Antenna geometry

The photograph and geometry of the proposed antenna is shown in Fig. 1. The prototype is fabricated on a substrate of dielectric constant (ε_r) 4.4 and thickness (H) 1.6 mm. To excite additional current paths a slit (abcdefgh) is incorporated in the T-shaped structure ($L_1 + L_{2L/R} + L_3 + L_4$) resulting in the final geometry. The strip width (W_s) and gap (G) of the Coplanar Waveguide (CPW) feed are derived using standard design equations for 50 Ω input impedance [11]. Fig. 2 highlights the evolution of the proposed Quad-band antenna from a planar monopole antenna.

The basic monopole structure (Antenna1) resonates at 3.6 GHz, corresponding to its quarter wavelength. Top loading this monopole, results in a T-shaped monopole (Antenna2) [9], exhibiting dual bands centered at 1.77 GHz and 5.54 GHz as shown in Fig. 2. An additional resonance can be generated by extending either arm $L_{2L} + L_3$ or $L_{2R} + L_3$ of Antenna2, thereby introducing asymmetry. In the proposed design, the left arm $L_{2L} + L_3$ is extended by L_4, resulting in resonances at 1.61 GHz, 2.4 GHz and 5.8 GHz as illustrated in Fig. 2 (Antenna3). It is found that the resonance at 1.77 GHz due to ($L_1 + L_{2L} + L_3$) is shifted to 1.61 GHz, corresponding to a resonant length ($L_1 + L_{2L} + L_3 + L_4$) of approximately quarter wavelength. On the other hand, the additional resonance produced at 2.4 GHz corresponding to a resonant length ($L_1 + L_{2R} + L_3$) of half wavelength, which is poorly matched due to the high inductive reactance offered by the addition of the strip L_4.The higher resonance at 5.54 GHz is shifted to 5.8 GHz, corresponding to a length ($L_1 + L_{2R} + L_3$) of 0.9 λ_g. Without altering the three resonant paths, a fourth resonance can be generated by introducing a slit 'abcdefgh' (Fig. 1) (Antenna4). This forces the current to flow through a longer path around the slit and produce an additional lower resonance at 900 MHz as shown in Fig. 2. The subsequent resonances are at 1.74 GHz, 2.44 GHz and 5.5 GHz. The high inductive reactance at 2.44 GHz is compensated with capacitive reactance provided by the slit, resulting in better impedance matching without altering the size.

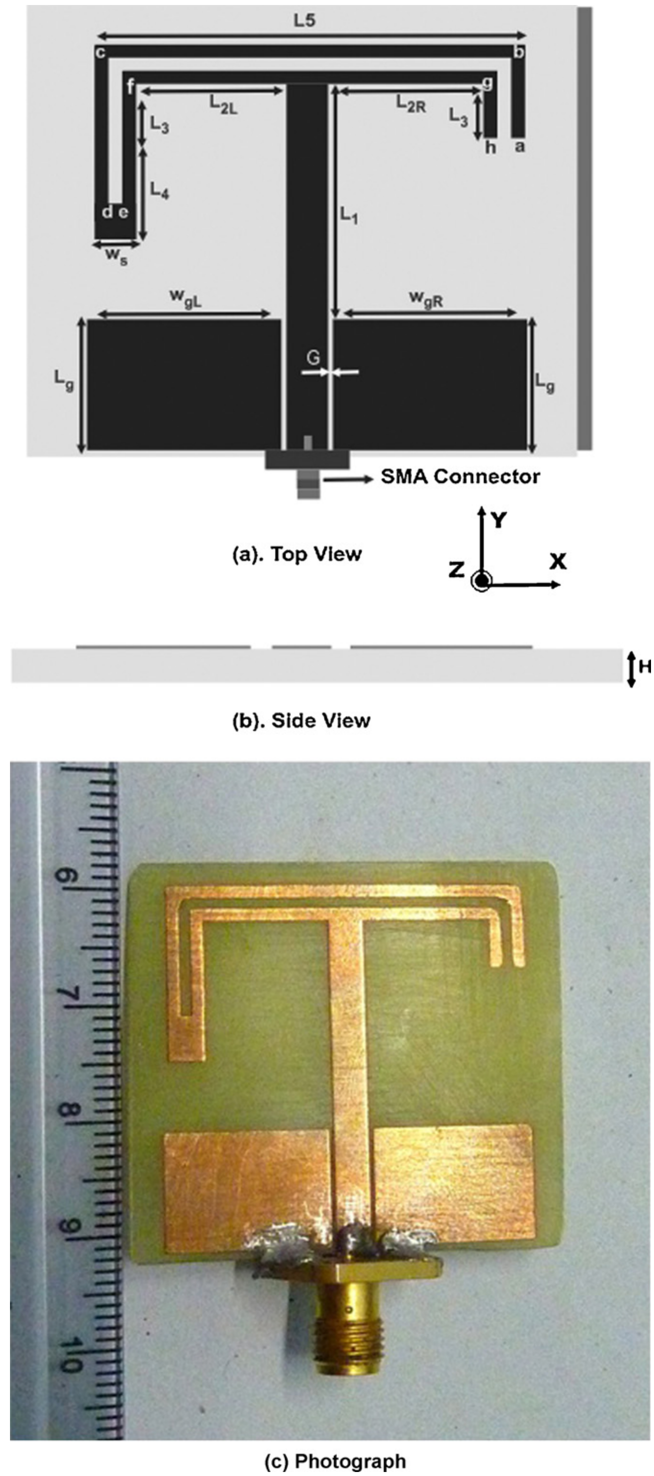

Fig. 1. Geometry and photograph of the proposed Quad band antenna (L_1 = 18 mm, $L_{2R} = L_{2L}$ = 11 mm, L_3 = 4 mm, L_4 = 8 mm, L_5 = 31 mm, W_{gR} = 14 mm, W_{gL} = 14 mm, L_g = 10 mm, W_s = 3 mm, cd = 10 mm, bc = 29 mm, de = ha = 1 mm, H = 1.6 mm, ε_r = 4.4 and G = 0.35 mm).

3. Results and discussions

The measured and simulated return loss characteristics of the proposed antenna are shown in Fig. 3. The GSM900 band (840–970 MHz) Exhibits 2.5:1 VSWR and is better than that presented in [5,6] which is wide enough to cover the GSM application band. The antenna Exhibits 2:1 VSWR band width on DCS-1800 (1.56–1.92 GHz), and ISM-2.4/5.2/5.8 GHz WLAN (2.39–2.49 GHz and 5.07–6.23 GHz) bands.

A detailed study is performed to investigate the effect of various parameters on antenna performance. The variation in the return loss characteristics of the antenna with respect to the slit perimeter 'abcdefgh' (by varying length cd) is shown in Fig. 4. As slit perimeter increases, the lower resonance at 900 MHz shifts down, worsening the impedance matching. Thus by adjusting the slit length we can easily tune the lower resonant mode.

The variation of return loss characteristics with strip length $L_3 + L_4$ (on the Left arm) is shown in Fig. 5. It is found that the strip length mainly affects the second resonance. The length is optimized (12 mm) so as to cover the required operating bands. As the length increases the inductive reactance at third resonance increases, changing the impedance matching. Variation of the strip length L_3 (on the right arm) affects the third and fourth resonances significantly as shown in Fig. 6. Since variation in L_3 results in variation of the effective slit length; the lower resonance at 900 MHz is also affected. The second resonance is not affected since the total length $L_3 + L_4$ remains constant. The variation in the return loss characteristics of the antenna with respect to the strip length L_1 is shown in Fig. 7. It is found that the strip length affects the fourth resonance significantly. The impedance matching of the third resonance is also affected. In the performance of compact antennas the effect of ground plane is also very crucial. There is a considerable change in the return loss characteristics of the antenna with ground length and width as shown in Figs. 8 and 9 respectively. Considering the application band and compactness of the antenna,

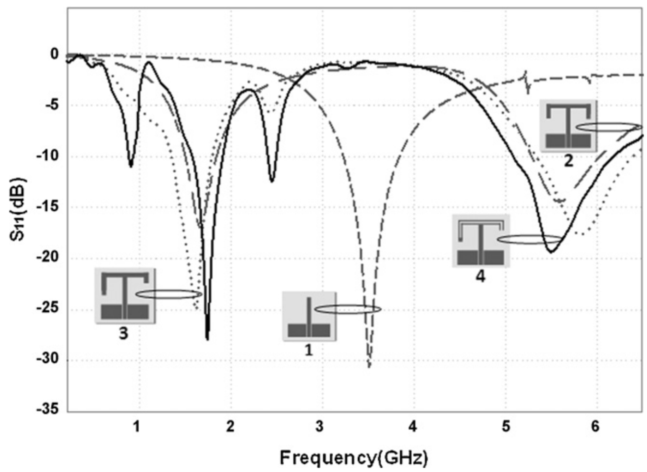

Fig. 2. Measured return loss characteristics detailing the evolution of the proposed Quad band antenna (H = 1.6 mm, ε_r = 4.4).

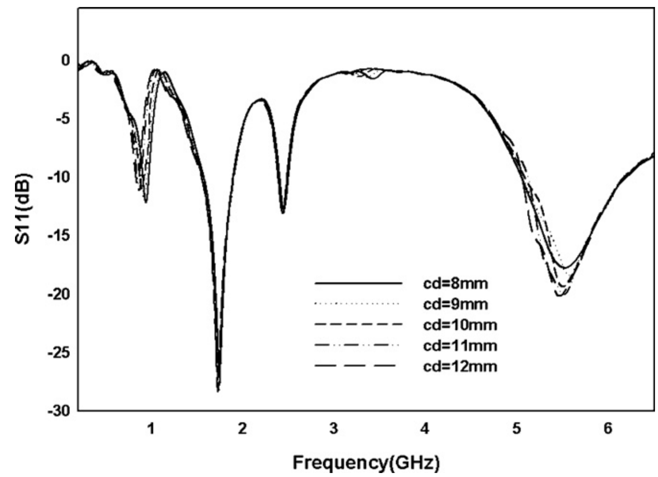

Fig. 4. Measured return loss variation with slit length cd (L_1 = 18 mm, $L_{2R} = L_{2L}$ = 11 mm, L_3 = 4 mm, L_4 = 8 mm, L_5 = 31 mm, W_{gR} = 14 mm, W_{gL} = 14 mm, L_g = 10 mm, W_s = 3 mm, bc = 29 mm, de = ha = 1 mm, H = 1.6 mm, ε_r = 4.4 and G = 0.35 mm).

the length and width of the ground are optimized as 0.27 λ_g and 0.38 λ_g respectively.

4. Design of the Quad band antenna

The design criterion for the Quad band antenna based on the above observations is explained in this section. The first resonance centered at 900 MHz is due to the total perimeter of slit. Slit perime-

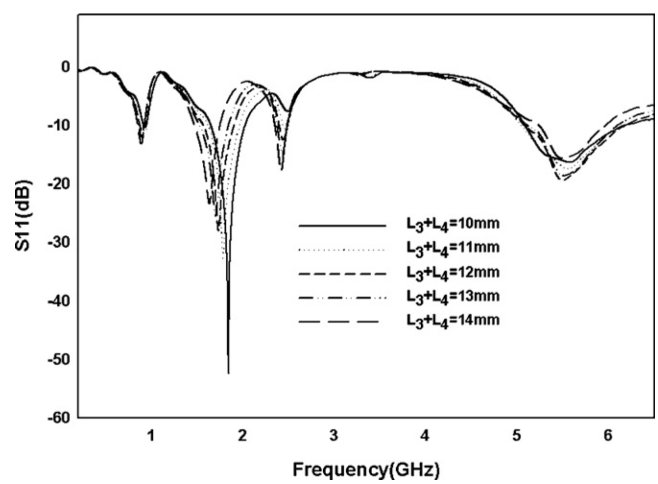

Fig. 5. Measured return loss variation with strip length $L_3 + L_4$ (L_3 = 18 mm, $L_{2R} = L_{2L}$ = 11 mm, L_3 = 4 mm, L_5 = 31 mm, W_{gR} = 14 mm, W_{gL} = 14 mm, L_g = 10 mm, W_s = 3 mm, cd = 10 mm, bc = 29 mm, de = ha = 1 mm, H = 1.6 mm, ε_r = 4.4 and G = 0.35 mm).

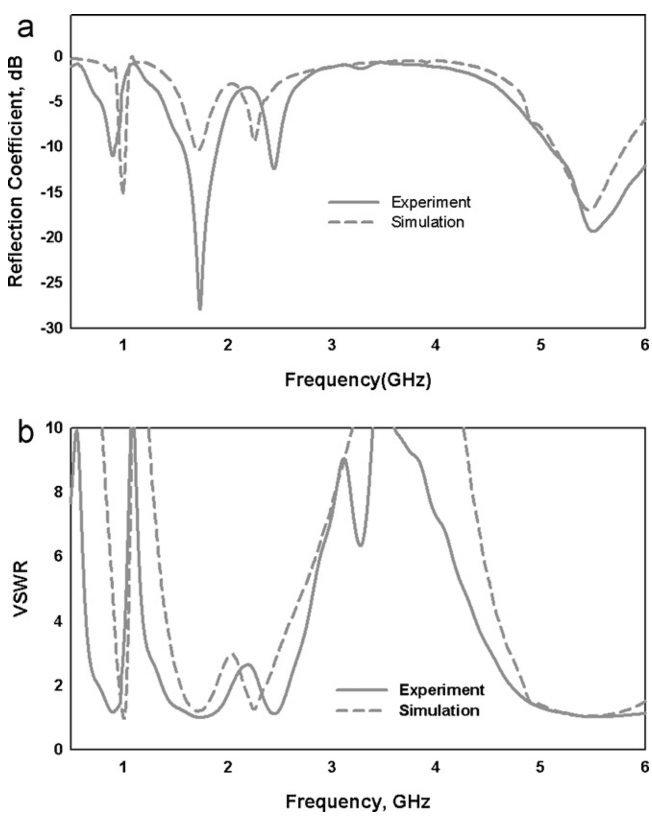

Fig. 3. (a) Reflection characteristics and (b) VSWR of the proposed Quad band antenna (L_1 = 18 mm, $L_{2R} = L_{2L}$ = 11 mm, L_3 = 4 mm, L_4 = 8 mm, L_5 = 31 mm, W_{gR} = 14 mm, W_{gL} = 14 mm, L_g = 10 mm, W_s = 3 mm, cd = 10 mm, bc = 29 mm, de = ha = 1 mm, H = 1.6 mm, ε_r = 4.4 and G = 0.35 mm).

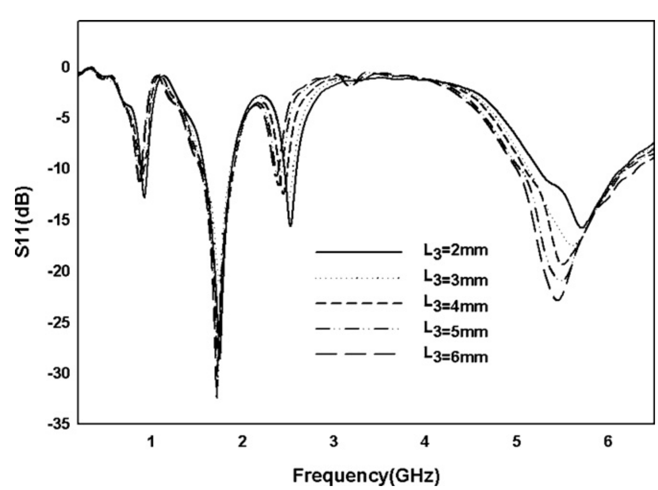

Fig. 6. Measured return loss variation with strip length L_3 (L_1 = 18 mm, $L_{2R} = L_{2L}$ = 11 mm, $L_3 + L_4$ = 12 mm, L_5 = 31 mm, W_{gR} = 14 mm, W_{gL} = 14 mm, L_g = 10 mm, W_s = 3 mm, cd = 10 mm, bc = 29 mm, de = ha = 1 mm, H = 1.6 mm, ε_r = 4.4 and G = 0.35 mm).

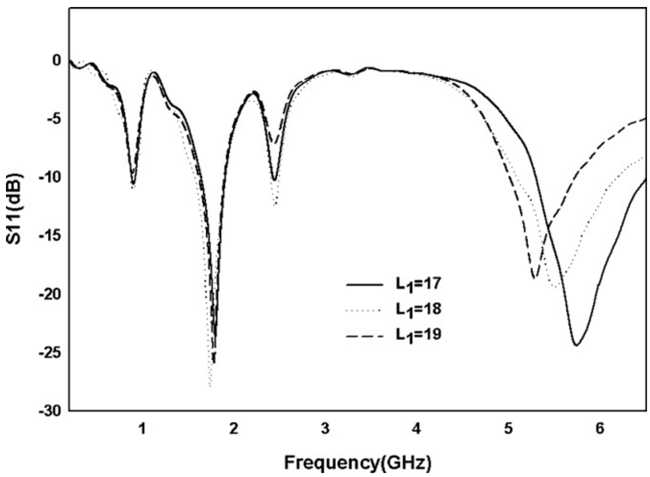

Fig. 7. Measured return loss variation with strip length L_1 ($L_{2R} = L_{2L} = 11$ mm, $L_3 + L_4 = 12$ mm, $L_5 = 31$ mm, $W_{gR} = 14$ mm, $W_{gL} = 14$ mm, $L_g = 10$ mm, $W_s = 3$ mm, cd = 10 mm, bc = 29 mm, de = ha = 1 mm, $H = 1.6$ mm, $\varepsilon_r = 4.4$ and $G = 0.35$ mm).

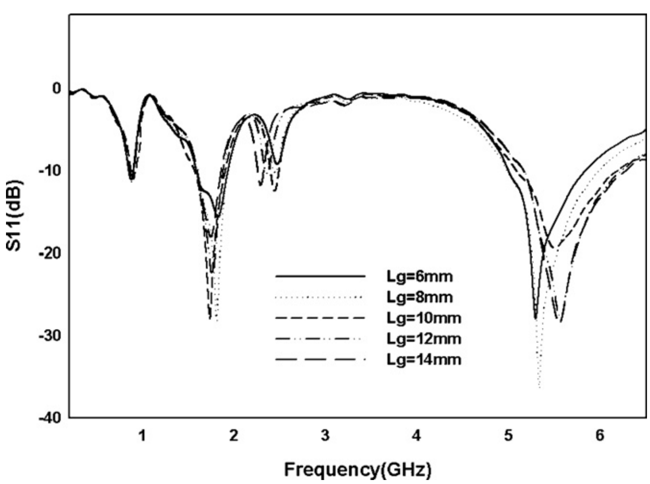

Fig. 8. Measured return loss variation with ground length L_g ($L_1 = 18$ mm, $L_{2R} = L_{2L} = 11$ mm, $L_3 + L_4 = 12$ mm, $L_5 = 31$ mm, $W_{gR} = 14$ mm, $W_{gL} = 14$ mm, $W_s = 3$ mm, cd = 10 mm, bc = 29 mm, de = ha = 1 mm, $H = 1.6$ mm, $\varepsilon_r = 4.4$ and $G = 0.35$ mm).

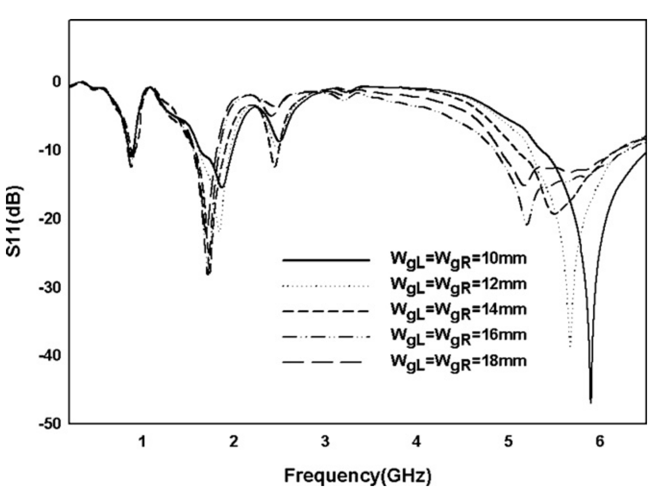

Fig. 9. Measured return loss variation with ground width W_{gL} and W_{gR} ($L_1 = 18$ mm, $L_{2R} = L_{2L} = 11$ mm, $L_3 + L_4 = 12$ mm, $L_5 = 31$ mm, $L_g = 10$ mm, $W_s = 3$ mm, cd = 10 mm, bc = 29 mm, de = ha = 1 mm, $H = 1.6$ mm, $\varepsilon_r = 4.4$ and $G = 0.35$ mm).

ter can be calculated as,

$$\text{Slit perimeter} = \frac{0.4 \times \lambda_1}{\varepsilon_{reff}} \tag{1}$$

where $\varepsilon_{reff} = (1 + \varepsilon_r + 1)/3$ is the effective dielectric constant of substrate, and λ_1 is the wavelength corresponding to the first resonant frequency. It is presumed that the capacitive coupling between the strips (abcd & efgh) across the slit effectively increases the overall length of the antenna, thereby reducing the physical length to 0.4 times the guided wavelength. The second resonance centered at 1.74 GHz occurs due to the combined effect of the length $(L_1 + L_{2L} + L_3 + L_4)$ and abcd (Fig. 10.b). The length abcd will adjust in accordance with $(L_1 + L_{2L} + L_3 + L_4)$ and therefore it can be calculated as below

$$(L_1 + L_{2L} + L_3 + L_4) = \frac{0.35 \times \lambda_2}{\varepsilon_{reff}} \tag{2}$$

where $L_{2L} = 2.75\ L_3$ is chosen for minimum capacitive coupling between L_1 and L_3. The additional capacitive coupling contributed by top loading results an increasing the physical length hence assuring compactness. The third resonance is due to the length $L_1 + L_{2R} + L_3$ (Fig. 6). It is interesting to note that the matching is severely affected by L_1 (Fig. 7) and $L_3 + L_4$ (Fig. 5) without affecting the resonant frequency. On increasing L_1 the real part of impedance is decreased causing a corresponding deterioration in impedance matching. As $L_3 + L_4$ increases the inductive reactance increases with corresponding increase in the real part of impedance contributing to better impedance matching. The design criterion for the third resonance is:

$$L_1 + L_{2R} + L_3 = \frac{0.4 \times \lambda_3}{\varepsilon_{reff}} \tag{3}$$

The fourth resonance centered at 5.5 GHz is affected by the variation in L_1 (Fig. 7), L_3 (Fig. 6) and $L_3 + L_4$ (Fig. 5). A significant change in resonance with ground dimensions is also observed (Figs. 8 and 9). The shift in resonance is due to the change in reactance, resulting from a change in the coupling between the ground and the signal strip. Hence the fourth resonance is due to two parallel symmetrical paths $L_1 + L_{2R} + L_3$ and $L_1 + L_{2L} + L_3 + L_4$. These two resonances merge to give a broad band at 5.5 GHz. The path lengths are found to be equal to three quarter wavelengths at the corresponding resonant frequency. Since a significant variation is only due to L_1, the length should be selected in such a way so as to cover the application band as given below.

$$L_1 = \frac{0.49 \times \lambda_4}{\varepsilon_{reff}} \tag{4}$$

The decrease in the physical length of the antenna as observable in the design equations at the different resonant frequencies is due to the top loading effect, by virtue of which the antenna exhibits the performance of electrically larger antennas [12]. From the parametric studies, it is inferred that the ground plane affects the impedance matching of the resonant modes. Hence placement of any additional circuitry on the ground plane will also affect the antenna performance [8]. By considering the compactness and antenna performance the ground plane length and width are optimized as follows.

$$L_g = \frac{0.27 \times \lambda_4}{\varepsilon_{reff}} \tag{5}$$

$$W_{gL} = W_{gR} = \frac{0.38 \times \lambda_4}{\varepsilon_{reff}} \tag{6}$$

To justify the design equations various Quad band antennas are designed for different dielectric substrates. The above equations are validated by characterizing. The designed antenna resonances are in reasonably good agreement with the obtained results as shown

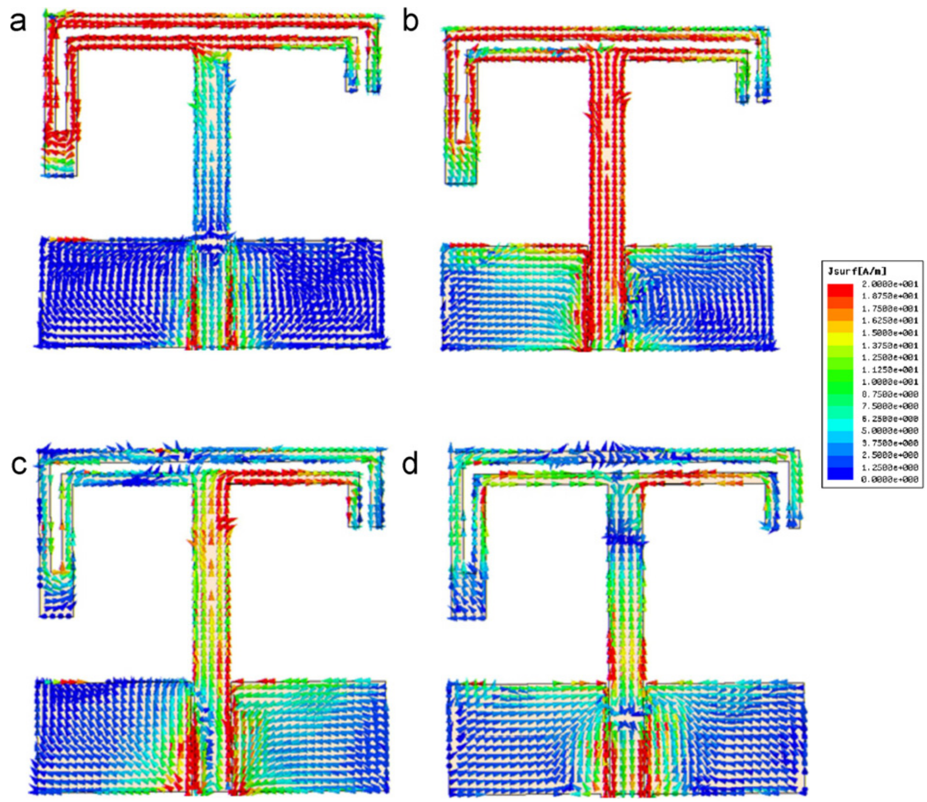

Fig. 10. Simulated current distribution at (a) 900 MHz, (b) 1.74 GHz, (c) 2.44 GHz and (d) 5.5 GHz.

in Table 1. The current distributions on the Quad-band antenna in four bands are shown in Fig. 10. These current distributions again confirm our earlier arguments about the different resonances. The measured co- and cross-polarization level of the antenna along with return loss is shown in Fig. 11. Since the *Y*-component dominates over the *X*-component on all the four bands, the antenna is polarized along the *Y* direction. The antenna shows good polarization purity in the first and fourth band and moderately on the second and third band. The first resonance at 900 MHz is due to the perimeter of the slit abcdefgh. Since the direction of current is opposite in its parallel arms it is seen that the *X*-component gets cancelled in the far field resulting the polarization along *Y* direction. In the second band centered at 1.74 GHz, the *Y*-component dominates the *X*-component resulting in polarization along *Y*-direction. But for the third band centered at 2.44 GHz, the polarization purity is poor, because here the *X* (due to L_{2R}) and *Y* (due to L_1+L_3) components have approximately same contribution. At 5.54 GHz the symmetrical contribution from both horizontal strips makes the *X*-component cancel in the far field resulting in polarization along the *Y*-direction. The radiation patterns of the antenna in the four resonant bands are shown in Fig. 11. The antenna shows good radiation

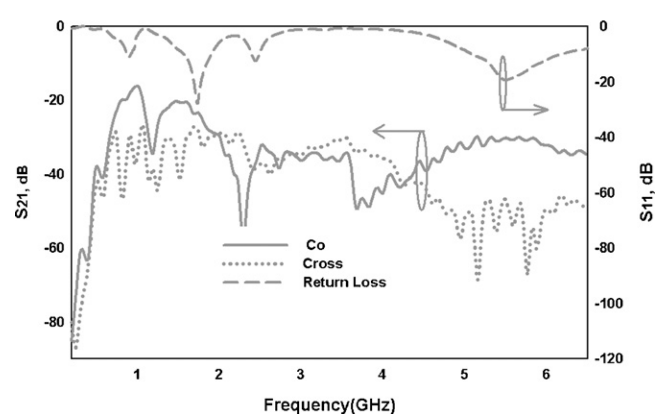

Fig. 11. Measured polarization of the antenna along the boresight direction.

characteristics in the entire band of operation. The peak gains of the antenna in the four bands are −1.25 dBi, 1.94 dBi, 1.11 dBi and 3.71 dBi respectively (Fig. 12.).

Table 1
%Error in resonant frequency of the antenna for different dielectric substrates at 0.9, 1.8, 2.4 and 5.2 GHz.

	Simulated frequency (GHz)				%Error			
	F_1	F_2	F_3	F_4	F_1	F_2	F_3	F_4
Rogers RT/duroid 5880 (2.2)	0.95	1.70	2.30	5.42	5.55	5.55	4.347	4.23
Taconic RF-35 (3.5)	0.92	1.76	2.42	5.12	2.22	2.22	0.833	1.53
Alumina (9.4)	0.98	1.94	2.36	5.78	8.88	7.77	1.66	11.15
Rogers RO6010 (10.2)	0.98	1.93	2.39	5.77	8.88	7.2	0.416	10.96

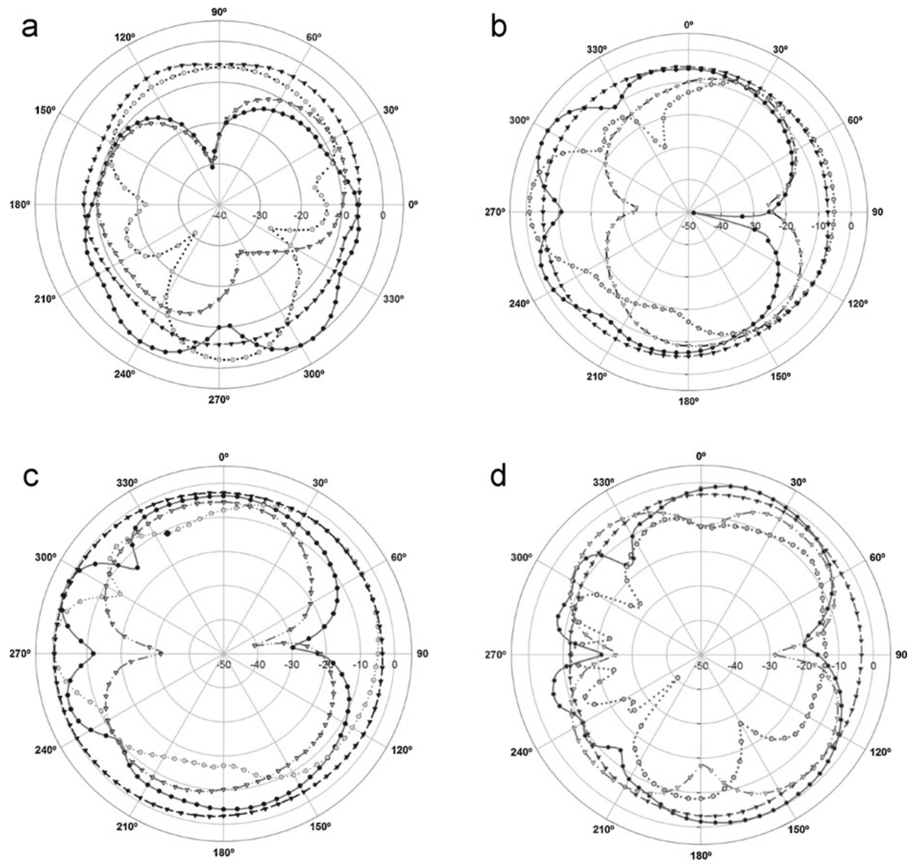

Fig. 12. Measured radiation pattern at (a) 900 MHz, (b) 1.74 GHz, (c) 2.44 GHz and (d) 5.5 GHz.

5. Conclusion

A compact planar Quad Band antenna having dimension $0.14\,\lambda_g \times 0.136\,\lambda_g \times 0.007\,\lambda_g$ is presented. This uniplanar antenna resonates in four bands and is suitable for GSM, DCS, IEEE 802.11.a, IEEE 802.11.b and HiperLAN-2 bands. The presented Quad band antenna exhibits good radiation characteristics with a gain of −1.25 dBi, 1.94 dBi, 1.11 dBi and 3.71 dBi in the respective bands.

Acknowledgements

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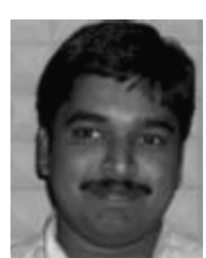
R. Sujith received the B.Sc degree in physics from Govt. Victoria College, Palakkad, University of Calicut, India, Bachelors Degree in Education from University Teacher Education Centre, Palakkad, University of Calicut, and M.Sc. degree in Electronic science from Cochin University of Science and Technology (CUSAT), India, in 2003, 2005 and 2007, respectively, where he is currently working towards his Ph.D. degree. His research interests include the designing of Compact Uniplanar antennas, Multiband antennas and Ferroelectric Tunable devices.

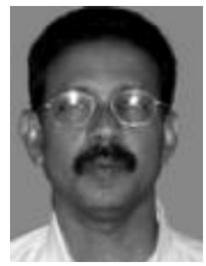


V. **Deepu** received the B.Sc. degree in physics from Mahatma Gandhi College, Thiruvananthapuram, University of Kerala, India in 2003 and the M.Sc. degree in electronic science from Cochin University of Science and Technology (CUSAT), India, in 2005. Currently he had received his Ph.D. degree from CUSAT, India. His research interests include the designing of mobile antennas, WLAN antennas and uniplanar antennas.

S. Mridula received the B.Tech Degree in Electronics and Communication from the Kerala University in 1988, M.Tech degree in Electronics from the Cochin University of Science and Technology (CUSAT) in 1999 and was awarded the K.G. Nair endowment gold medal for securing the first rank in the university. She received her Ph.D. in Microwave Electronics from CUSAT in 2006 May. She has over 19 years of teaching experience in various professional institutions in Kerala and is presently serving as Reader, Division of Electronics Engineering, School of Engineering, CUSAT. Her areas of interest include Planar antennas, Dielectric Resonator Antenna, Radiation Hazards of Mobile handset antennas and Computational Electromagnetics. She is a member of IEEE, life member of the Institute of Electronics and Telecommunication Engineers (India) and life member of the Indian Society for Technical Education.

Binu Paul received her M.Tech and Ph.D. degree in Electronics from Cochin University of Science and Technology in 1996 and 2006 respectively. During 1995–1999, she served the Institute of Human Resources Development (IHRD), Government of Kerala, India, as Lecturer in Electronics. She joined the Division of Electronics and Communication Engineering, School of Engineering, Cochin University of Science and Technology, as Lecturer in January 1999. Her research interests include Microstrip Antennas, FDTD Analysis of Antennas and Wireless Communication. Binu Paul is a member of the Indian Society for Technical Education and Institute of Electrical and Electronics Engineers.

D. **Laila** received Bachelors degree in physics from Mahatma Gandhi University in1987, B.E. degree from Bharathiar University in 1991, M.Tech Degree from Regional Engineering College Calicut in 2002. She has more than 15 years of teaching experience in Engineering College, Kerala. She is presently working towards Ph.D. degree in CUSAT, India. Her research interest includes Ultra Wideband Uniplanar Antennas, Metamaterials, and Radiation Hazards reduction in Mobile handset.



P. Mohanan (SM'05) received the Ph.D. degree in microwave antennas from Cochin University of Science and Technology (CUSAT), Cochin, India, in 1985. He worked as an Engineer in the Antenna Research and Development Laboratory, Bharat Electronics, Ghaziabad, India. Currently, he is a Professor in the Department of Electronics, CUSAT. He has published more than 120 referred journal papers and numerous conference articles. He also holds several patents in the areas of antennas and material science. His research areas include microstrip antennas, uniplanar antennas, ultrawideband antennas dielectric resonator antennas, superconducting microwave antennas, reduction of radar cross-sections, and polarization agile antennas. Dr. Mohanan received the Career Award from the University Grants Commission in Engineering and Technology, Government of India, in 1994.