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A Compact Capacitive Coupled Dual-Band Planar Inverted F Antenna

Puthiyapurayil V. Vinesh, Chakkanattu M. Nijas, Ramachandran Anitha, Rajan Vivek, Chandroth K. Anandan, Pezholil Mohanan, and Kesavath Vasudevan*

Abstract—A dual-band capacitive coupled planar inverted F antenna is presented. The antenna operates in two bands centered around 1.5 GHz and 2.4 GHz with nearly omnidirectional radiation pattern in the entire operating band. It offers a peak gain of 2.4 dBi at 1.5 GHz and 7 dBi at 2.4 GHz with an average efficiency of 82%, 97% respectively. Effects of key design parameters such as the distance between feed strip and radiator patch, the dimensions of the feed strip on the input characteristics of the antenna and length of slot have been investigated and discussed. The antenna is compact and easy to fabricate. The antenna has an overall dimension of $10 \times 40 \times 6\,\mathrm{mm}^3$, fabricated on substrate of dielectric constant 4.4 and thickness 1.6 mm.

1. INTRODUCTION

The planar inverted F antenna (PIFA) has become popular due to its common use in mobile phone handsets. Commonly coaxial feeding technique is used in PIFA antennas because of its simplicity of design. By adjusting the position of the feed point the input impedance level can be varied. But one of the disadvantages of the coaxially fed antenna configuration is the unavoidable impedance mismatch, even at resonance, due to the inductance of the long probe because of the large gap between top plane and ground. Probe inductance can be cancelled out by various methods like cutting slots on the patch [2], modifying the probe shape [3], making an appropriate matching network at the back of the ground plane or by introducing a capacitive feed strip. Recently many novel compact and broadband antennas have been reported by applying a printed capacitive coupled feed to obtain multiple bands operation [5–8]. The coplanar capacitive feed strip is modified to obtain the best possible match with the antenna input impedance [9, 10]. The capacitive coupling feed allows the PIFA to generate two wide operating bands for covering 698–960 MHz and 1710–2690 MHz, synchronously [11]. Microstrip line fed PIFA has also been designed for internal eight bands in mobile phones [12].

In this paper, a simple capacitive coupled compact planar inverted F antenna suitable for GPS and WLAN application is presented. The proposed antenna offers the required bandwidth of 30 MHz for GPS and 76 MHz for WLAN. The antenna having the overall dimension of $10 \times 40 \times 6\,\mathrm{mm}^3$, fabricated on a substrate of relative permittivity 4.4, $\tan\delta = 0.02$ and thickness $h = 1.6\,\mathrm{mm}$.

2. ANTENNA GEOMETRY AND DESIGN

The fabricated structure and the geometry of the capacitive coupled dual-band PIFA antenna is shown in Figures 1(a) and (b). The antenna consists of metal top plane and system ground plane. It is excited by a single probe feed connected to a square capacitive strip. The antenna also consists of an L shaped

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* Corresponding author: Kesavath Vasudevan (vasudevankdr@gmail.com).
The authors are with the Centre for Research in ElectroMagnetics and Antennas (CREMA), Department of Electronics, Cochin University of Science and Technology, Cochin-22, Kerala, India.

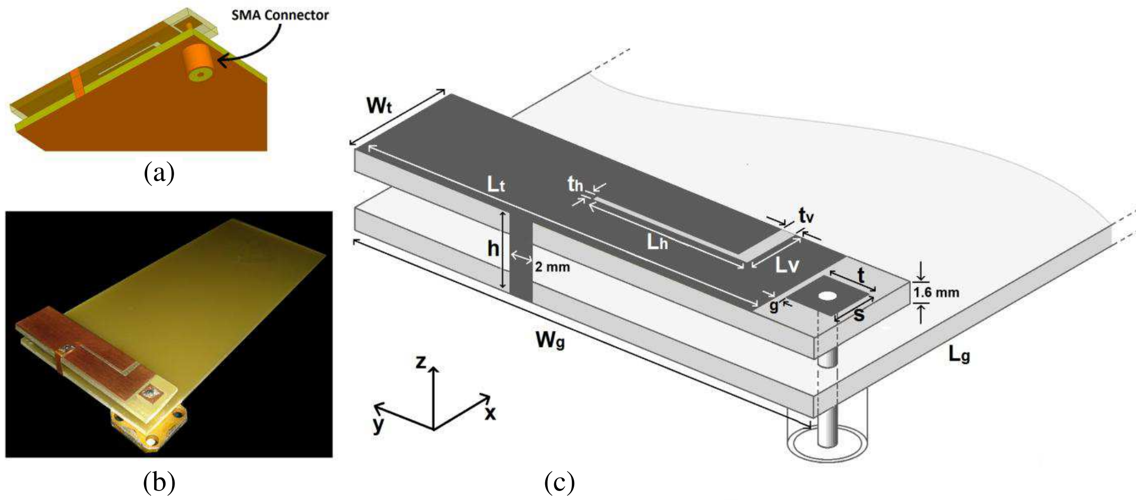


Figure 1. (a) HFSS layout, (b) fabricated PIFA, (c) geometry of the proposed PIFA. The optimised design parameters are $W_t = 10\,\mathrm{mm}$, $L_t = 34.5\,\mathrm{mm}$, $L_h = 13.5\,\mathrm{mm}$, $L_v = 5\,\mathrm{mm}$, $h = 6\,\mathrm{mm}$, $W_g = 40\,\mathrm{mm}$, $L_g = 100\,\mathrm{mm}$, $t_h = 0.5\,\mathrm{mm}$, $t_v = 1.2\,\mathrm{mm}$, $g = 0.5\,\mathrm{mm}$, $s = 4\,\mathrm{mm}$ and $t = 4\,\mathrm{mm}$.

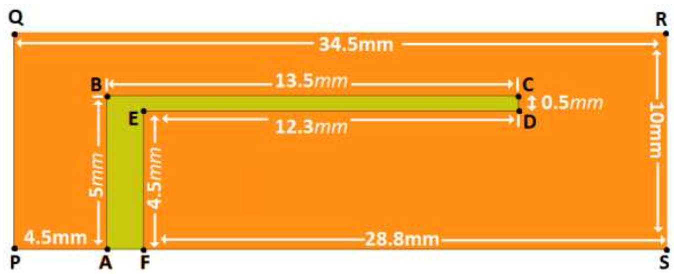


Figure 2. Dimension of top plane.

slotted line on the top plane. It is suspended above the ground plane and shorted to the ground plane with a short metal plane.

According to antenna theory, PIFA antenna has a resonant length $\lambda/4$ which corresponds to $L_1 + L_2 - W$, where L_1 and L_2 are length and width of radiating structure, and W is width of shorting plane [1]. Here the shorting plane is having width 2 mm. Due to the presence of slot in top plane, lower resonance depends not only on length and width of top plane, but also on the edge dimensions of slot. This dependence can be understood from current distributions on top plane at lower resonance. The top plane and slot edge dimensions are illustrated in Figure 2. So the current path length $L_1 + L_2 - W$ is equivalent to length $[(PQ + QR + RS + SF + FE + ED + DC + CB + BA + AP)/2] - 2\,\mathrm{mm}$ and approximately $\lambda/4$, which corresponds to a resonant frequency of 1.5 GHz. There is a slight variation in resonant frequency in calculations due to effective dielectric constant of air and FR4.

From the simulated surface current distributions of the antenna at 2.4 GHz resonant frequency it is clear that the second resonance is due to the half wavelength ($\lambda_g/2$) long variation of surface current present in the L shaped slot.

3. PARAMETRIC STUDIES

3.1. Effect of Gap between Feed Strip and Radiator Patch (g)

ANSOFT HFSS is used for the design and optimization proposed antenna. Extensive parametric studies are conducted to analyze the effect of gap and it is depicted in Figure 3. From the reflection characteristics, it is clear that the gap (g) affects both resonance frequency to shift to lower side due to the capacitance between feed strip and radiator top plane. It also helps in optimizing the impedance matching below −10 dB. From these characteristics, gap (g) = 0.5 mm exhibits optimum response for both frequencies.

3.2. Effect of Length of Feed Strip (s)

Figure 4 shows the effects of feed strip length (s) on the reflection characteristics. This also affects both resonance frequencies, i.e., if length (s) is increased both resonance frequencies shift to lower side. And if its length is increased too much it deteriorates the impedance matching of the first resonance. The use of larger feed strip dimensions comparable to the size of radiator patch degrades the antenna performance [4], i.e., the input impedance is changed suddenly as the dimensions of feed strip are comparable with the wavelength. There is a large inductive shift to input impedance when the feed strip length increased. But in the case of higher resonance, bandwidth increases with increase in length and the reactance value of input impedance lowered. From these characteristics it is observed that a feed strip length of 4 mm exhibits optimum response for both frequencies.

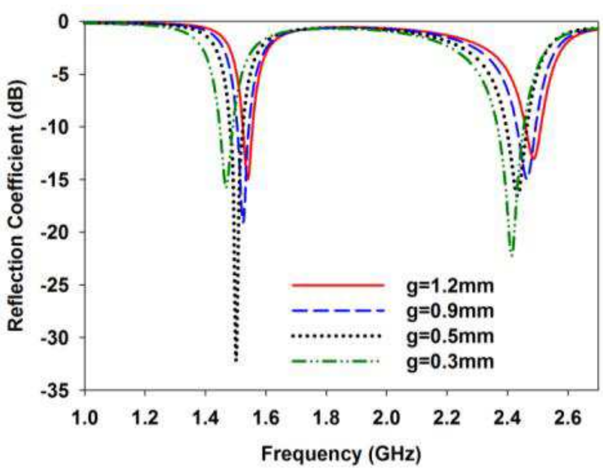


Figure 3. Parametric analysis of gap between feed strip and radiator patch (g).

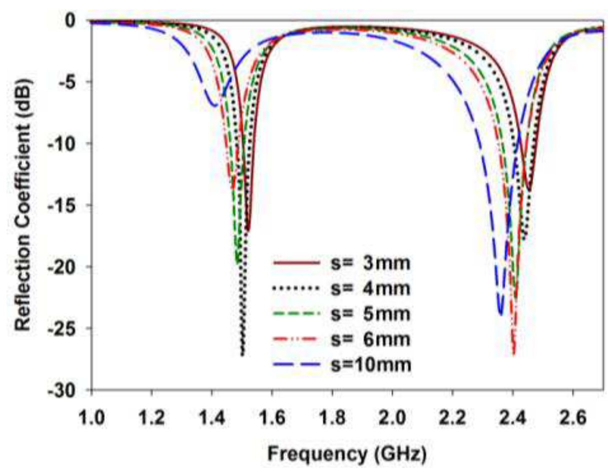


Figure 4. Parametric analysis of length of feed strip (s).

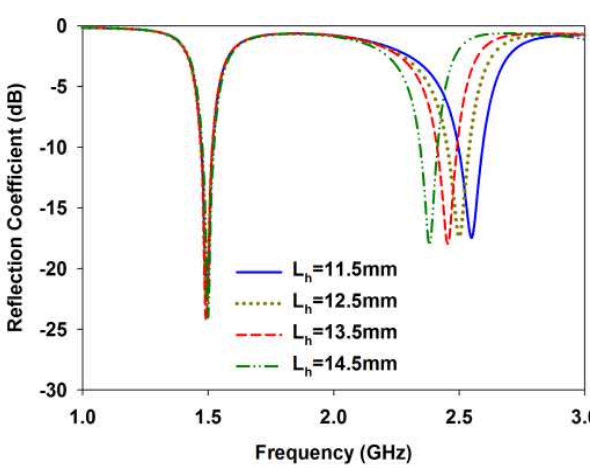


Figure 5. Parametric analysis of horizontal slot length of PIFA (L_h).

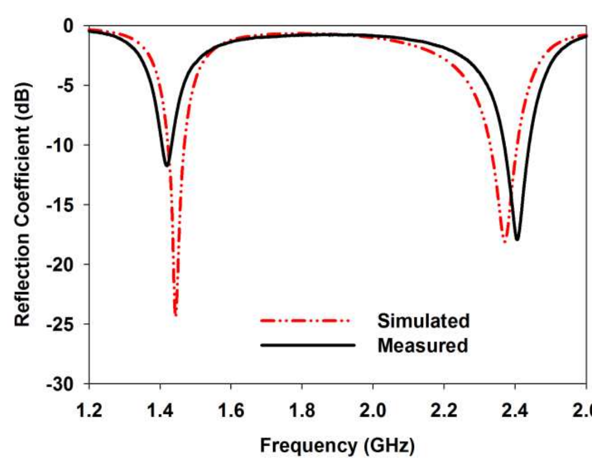


Figure 6. Measured and simulated Return loss of the proposed PIFA.

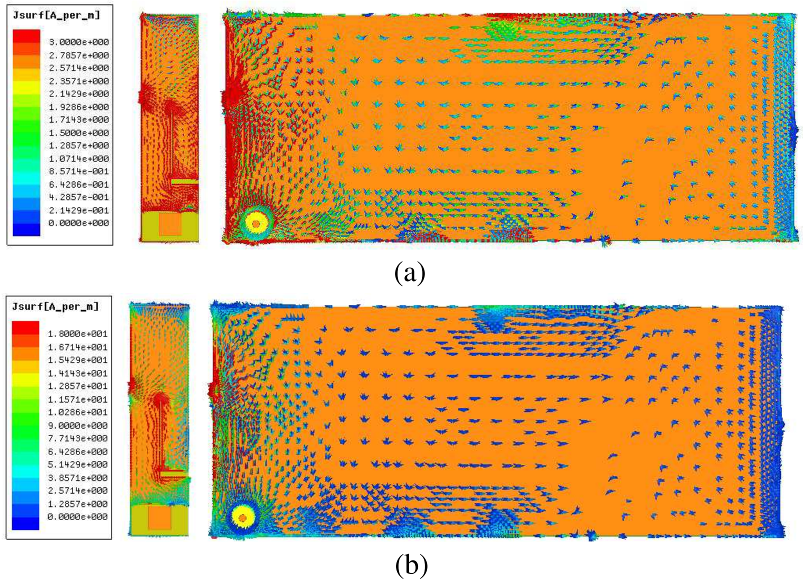


Figure 7. Surface Current Distribution of the PIFA (a) at 1.5 GHz, (b) at 2.4 GHz.

3.3. Effects of Horizontal Length of L Slot (L_h)

Variation of reflection coefficient of the PIFA with different slot length of L_h is shown in Figure 5. From the figure it is clear that, as L_h increases, the second resonance comes to lower frequency while the first resonance remains unchanged. Thus it is very clear that the second resonance is dependent of the slot length L_h. The lower shift in second resonance is due to the increase in surface current path length with increase in L_h.

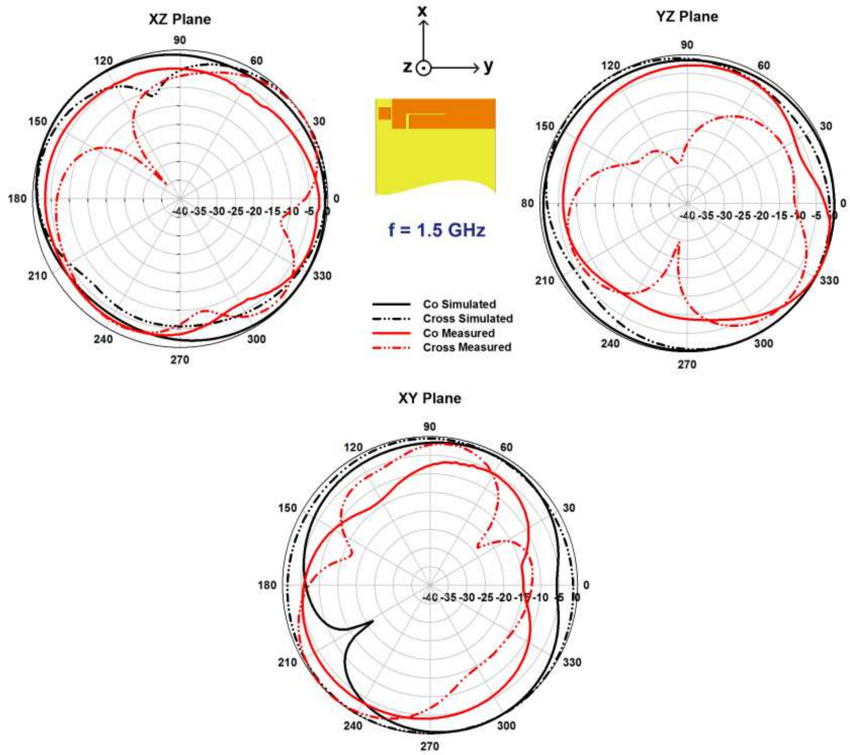
4. RESULTS AND DISCUSSIONS

The experimental analysis of the optimized antenna is performed using PNAE6362B network analyzer. The far field measurements of the antenna are measured inside the Anechoic chamber. The simulated and measured reflection coefficient curves of the proposed PIFA are shown in Figure 6. The proposed antenna offers the resonance frequency of 1.5 GHz having the bandwidth of 30 MHz and 2.4 GHz with a bandwidth of 76 MHz.

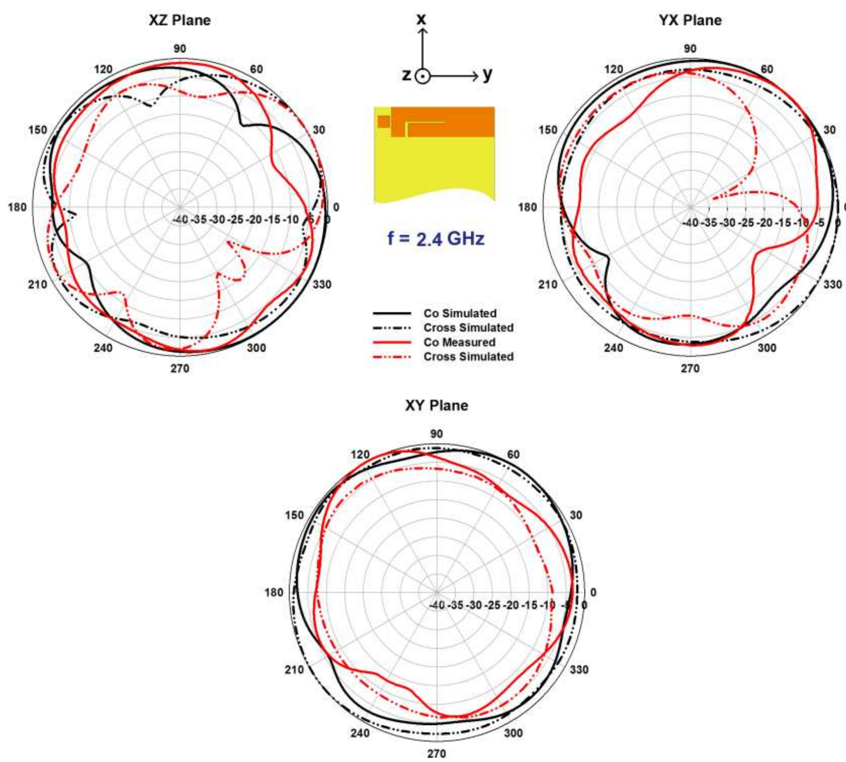
The simulated surface current distributions of the antenna at frequencies 1.5 GHz and 2.4 GHz are shown in Figures 7(a) and (b). From the figure it is clear that, the first resonance is due to the quarter wavelength $\lambda_g/4$ variation of surface current present in the top plan and the second resonance is mainly due to the half wavelength $\lambda_g/2$ long variation of surface current circulating across the L slot of dimension $13.5 \times 5\,\text{mm}^2$.

The two dimensional radiation patterns of the PIFA antenna in the three principal planes for the two resonance frequencies 1.5 GHz and 2.4 GHz are shown in Figures 8(a) and (b). From the figure it is clear that the antenna offers nearly omni directional radiation pattern in both the resonances. It is noted that that for the lower resonance, cross polar currents are accumulating on the top and bottom edges of the ground plane. This is the reason we are getting a low cross polar isolation for the first resonance at 1.5 GHz. The unbalanced return current effects the measured radiation pattern due to the SMA connector. So the radiation pattern shows some discrepancy between simulated and measured radiation pattern.

The measured gain of the antenna in the entire operating band is shown in Figure 9. As seen in the figure, the antenna offers peak gain of 2.24 dBi in the operating band of 1.5 GHz and 7 dBi in the operating band of 2.4 GHz. The antenna also offers an average radiation efficiency (simulated) of 82% in the entire operating band of 1.5 GHz and 95.8% in the operating band of 2.4 GHz.



(a)



(b)

Figure 8. (a) Radiation patterns at 1.5 GHz for the proposed PIFA. (b) Radiation patterns at 2.4 GHz for the proposed PIFA.

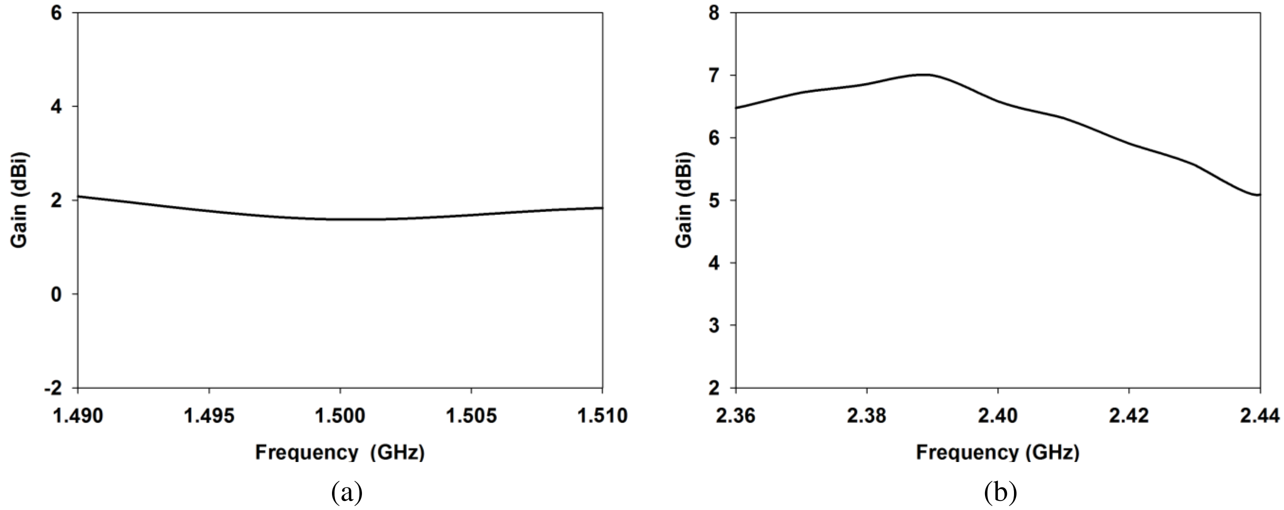


Figure 9. Measured Gain of the proposed antenna (a) at 1.5 GHz (b) at 2.4 GHz.

5. CONCLUSION

A compact capacitive coupled PIFA antenna has been designed and fabricated on FR4 substrate. From the experimental and simulation analysis it is evident that the antenna offers a 2 : 1 VSWR bandwidth of 30 MHz for 1.5 GHz band and 76 MHz for 2.4 GHz with peak gain of 2.4 dBi and 7 dBi in the entire operating band. The overall dimension of the fabricated antenna is $10 \times 40 \times 6\,\mathrm{mm}^3$ which is more simple and compact than existing designs. The antenna offers nearly omni directional radiation pattern in both resonant frequencies.

REFERENCES

1. Garg, R., P. Bhartia, I. Bahl, and A. Ittipiboon, *Microstrip Antenna Design Handbook*, Artech House, Norwood, MA, 2001.
2. Tong, K. F., K. M. Luk, K. F. Lee, and R. Q. Lee, "A broad-band U-slot rectangular patch antenna on a microwave substrate," *IEEE Trans. on Antennas and Propagat.*, Vol. 48, No. 6, 954–960, Jun. 2000.
3. Kish, A. A., K. F. Lee, W. C. Mok, and K. M. Luk, "A wide-band small size microstrip antenna proximately coupled to a hook shape probe," *IEEE Trans. on Antennas and Propagat.*, Vol. 52, No. 1, 59–65, Jan. 2004.
4. Balanis, C. A., *Antenna Theory: Analysis and Design*, 2nd Edition, John Wiley & Sons, Inc., 1997.
5. Kumar, S., M. Rai, R. Kumar, and J. Ghosh, "Analysis and design of capacitive coupled wideband microstrip antenna in C and X band," *International Journal of Engineering and Advanced Technology*, Vol. 2, No. 4, Apr. 2013.
6. Kasabegoudar, V. G., D. S. Upadhyay, and K. J. Vinoy, "Design studies of ultra-wideband microstrip antennas with a small capacitive feed," *Hindawi Publishing Corporation International Journal of Antennas and Propagation*, Vol. 2007, 8 p., Oct. 2007.
7. Kasabegoudar, V. G. and K. J. Vinoy, "A wideband microstrip antenna with symmetric radiation patterns," *Microwave and optical Technology Letters*, Vol. 50, No. 8, Aug. 2008.
8. Ridgers, G. M., J. W. Odendaal, and J. Joubert, "Single-layer capacitive feed for wideband probe-fed microstrip antenna elements," *IEEE Trans. on Antennas and Propagat.*, Vol. 51, No. 6, Jun. 2003.

9. Musale, P. D., S. V. Hobragade, and V. R. Anitha, "A broadband microstrip antennas with different shapes of capacitive feed strip," *International Conference on Electronics Computer Technology*, Kanyakumari, Apr. 8–10, 2011.
10. Kasabegoudar, V. G., "Dual frequency ring antennas with coplanar capacitive feed," *Progress In Electromagnetics Research C*, Vol. 23, 27–39, Jul. 2011.
11. Chen, J. H., Y. L. Ban, and L. J. Ying, "Compact PIFA using capacitive coupled-fed for LTE/GSM/UMTS/WWAN operation in the mobile application," *Cross Strait Quad-regional Radio Science and Wireless Technology Conference*, Harbin, Jul. 26–30, 2011.
12. Wong, K. L., M. F. Tu, T. Y. Wu, and W. Y. Li, "Small-size coupled-fed printed PIFA for internal eight-band LTE/GSM/UMTS mobile phone antenna," *Microwave and Optical Technology Letters*, Vol. 52, No. 9, 2123–2128, Sep. 2010.