16. K. Guney and N. Sarikaya, A hybrid method based on combining artificial neural network and fuzzy inference system for simultaneous computation of resonant frequencies of rectangular, circular, and triangular microstrip antennas, IEEE Trans Antennas Propag 55 (2007), 659–668.
17. B. Banerjee, A self-organizing auto-associative network for the generalized physical design of microstrip patches, IEEE Trans Antennas Propag 51 (2003), 1301–1306.
18. A. Bhattacharyya and T. Tralman, Effects of dielectric superstrate on patch antennas, Electron Lett 24 (1988), 356–358.
19. A. Verma and Z. Rostamy, Resonant frequency of uncovered and covered rectangular microstrip patch using modified Wolff model, IEEE Trans Microwave Theory Tech 41 (1993), 109–116.
20. J.P. Damiano and A. Papiernik, A simple and accurate model for the resonant frequency and the input impedance of printed antennas, Int J Microwave Millimeter-Wave Comput-Aided Eng 3 (1993), 350–361.
21. J.P. Damiano, J.M. Rivero, and R. Staraj, Original simple and accurate model for elliptical microstrip antennas, Electron Lett 31 (1995), 1023–1024.
22. S.-S. Zhong, G. Liu, and G. Qasim, Closed form expressions for resonant frequency of rectangular patch antennas with multi dielectric layers, IEEE Trans Antennas Propag 42 (1994), 1360–1363.
23. HFSS (High Frequency Structure Synthesizer) 13: Ansoft's Corporation, Ansoft Corp., Pittsburgh, PA.
24. J.R. James, P.S. Hall, and C. Wood, Microstrip antennas-theory and design, IEE Electromagnetic waves series 12, Peter Peregrinus, London, UK, 1981.
25. E.O. Hammerstad, Equations for microstrip circuit design, In: Proceedings of 5th European Microwave Conference, Hamburg, 1975, pp. 268–272.
26. F. Abboud, J.P. Damiano, and A. Papiernik, Simple model for the input impedance of coax-fed rectangular microstrip patch antenna for CAD, IEE Proc Microwave Antennas Propag 35 (1988), 323–326.
27. F. Abboud, J.P. Damiano, and A. Papiernik, Accurate model for the input impedance of coax-fed rectangular microstrip antenna with and without airgap, In: Proceedings of 6th International Conference on Antennas and Propagation, 1989, pp. 102–106.
28. E. Chang, S.A. Long, and W.F. Richards, Experimental investigation of electrically thick rectangular microstrip antennas, IEEE Trans Antennas Propag 34 (1986), 767–772.
29. H. Wheeler, Transmission-line properties of parallel wide strips by a conformal mapping approximation, IEEE Trans Microwave Theory Technol 12 (1964), 280–289.
30. H.A. Wheeler, Transmission-line properties of parallel strips separated by a dielectric sheet, IEEE Trans Microwave Theory Tech 13 (1965), 172–185.
31. J. Svačina, Analysis of multilayer microstrip lines by a conformal mapping method, IEEE Trans Microwave Theory Tech 40 (1992), 769–772.
32. M. Biswas and D. Guha, Input impedance and resonance characteristic of superstrate loaded triangular microstrip patch, IET Microwave Antennas Propag 3 (2009), 92–98.
33. Raj Kumar and P. Malathi, Effects of superstrates on the resonant frequency of rectangular microstrip antennas, Microwave Opt Tech Lett 49 (2007), 2946–2950.
34. R. Garg, P. Bhartia, I. Bahl, and A. Ittipiboon, Microstrip antenna design handbook, Artech House, Canton, MA, 2001.
35. M. Sen, M. Biswas, and M. Biswas, Improved cad model to compute the resonant frequency of rectangular patch covered by dielectric superstrate, Proc Antenna Test Meas Soc (2013), 207–210.
36. F. Abboud, J.P. Damiano, and A. Papiernik, A new model for calculating the input impedance of coax-fed circular microstrip antennas with and without air gaps, IEEE Trans Antennas Propag 38 (1990), 1882–1885.
37. D. Thouroude, M. Himdi, and J.P. Daniel, CAD-oriented cavity model for rectangular patches, Electron Lett 26 (1990), 842–844.
38. M. Deshpande and M. Bailey, Input impedance of microstrip antennas, IEEE Trans Antennas Propag 30 (1982), 645–650.
39. P. Perlmutter, S. Shritkman, and D. Treves, Electric surface current model for the analysis of microstrip antennas with application to rectangular elements, IEEE Trans Antennas Propag 33 (1985), 301–311.
40. F. Mesa, D.R. Jackson, and M.J. Freire, Evolution of leaky modes on printed-circuit lines, IEEE Trans Microwave Theory Tech 50 (2002), 94–104.



# RECONFIGURABLE ANTENNA FEEDING NETWORK FOR SWITCHABLE CIRCULAR AND LINEAR POLARIZATIONS

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**ABSTRACT:** *This article presents a reconfigurable antenna feeding network for circular and linear polarization diversity. The proposed circuit consists of two hybrid couplers and two single pole four throw switches for four configuration modes: left-hand circular polarization, right-hand circular polarization, vertical linear polarization, and horizontal linear polarization. For verification, a reconfigurable antenna with the proposed feeding network is designed at 917 MHz and measured for switchable circular and linear polarizations.* © 2014 Wiley Periodicals, Inc. Microwave Opt Technol Lett 56:893–896, 2014; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.28243

**Key words:** *antenna feeding network; circular/linear polarization; switchable polarization; reconfigurable feeding network*

## 1. INTRODUCTION

Polarization diversity is an attractive feature and gains importance in current wireless communication systems, such that it is used to improve communications performance from multipath fading environment. Especially, the use of cross-polarization has become an essential technique in wireless communications as two separate antennas for a transmitter and

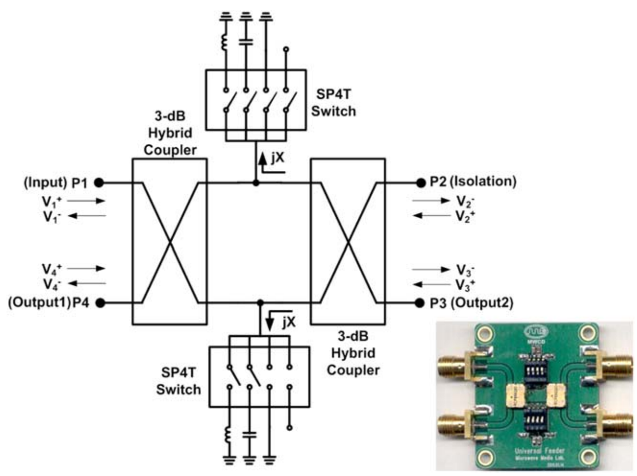


**Figure 1** Structure and photograph of the proposed antenna feeding network. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

**TABLE 1 Summary of Feeding Network Operations**

| Switch | Mode1: $jX = \infty\ \Omega$ | Mode2: $jX = 0\ \Omega$ | Mode3: $jX = +j25\ \Omega$ | Mode4: $jX = -j25\ \Omega$ |
| --- | --- | --- | --- | --- |
| Polarization | LP1 (VP) | LP2 (HP) | CP1 (RHCP) | CP2 (LHCP) |
| Output1 (Port 4) | 0 | 1 | $\frac{1}{\sqrt{2}}$ | $\frac{-j}{\sqrt{2}}$ |
| Output2 (Port 3) | 1 | 0 | $\frac{-j}{\sqrt{2}}$ | $\frac{1}{\sqrt{2}}$ |

a receiver can be simply replaced by a single antenna with a different Tx and Rx polarization pair such as right-hand circular polarization (RHCP) and left-hand circular polarization (LHCP) or vertical linear polarization (V-LP) and horizontal linear polarization (H-LP). For instance, the circular polarization diversity antenna can be used as a modulation scheme in microwave tagging system [1].

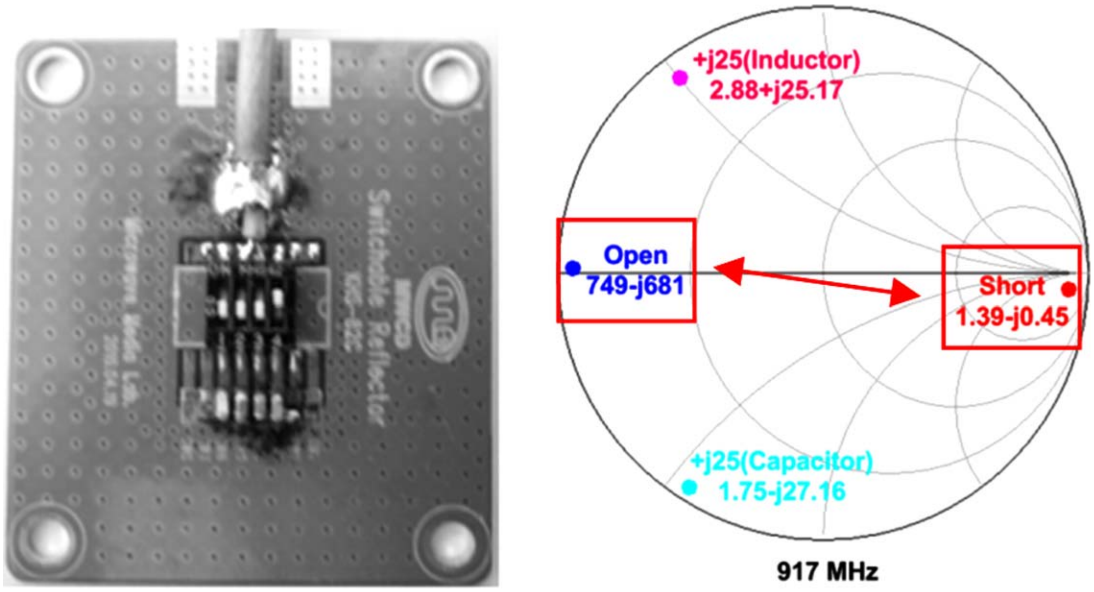


**Figure 2** Measured results for the reflective load impedance of the SP4T switch with LC elements. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

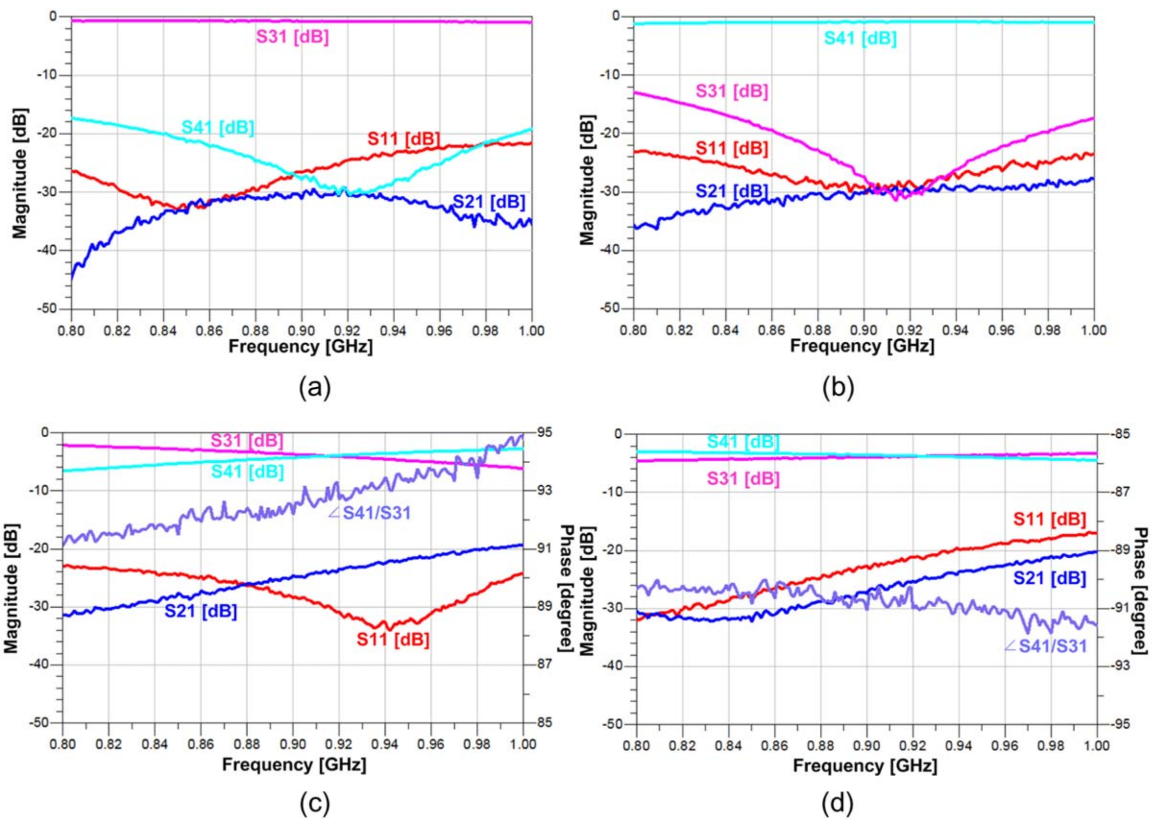


**Figure 3** Measured results of the proposed circuit when switch is (a) mode1: $jX = \infty$, (b) mode2: $jX = 0$, (c) mode3: $jX = +j25\ \Omega$, and (d) mode4: $jX = -j25\ \Omega$. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

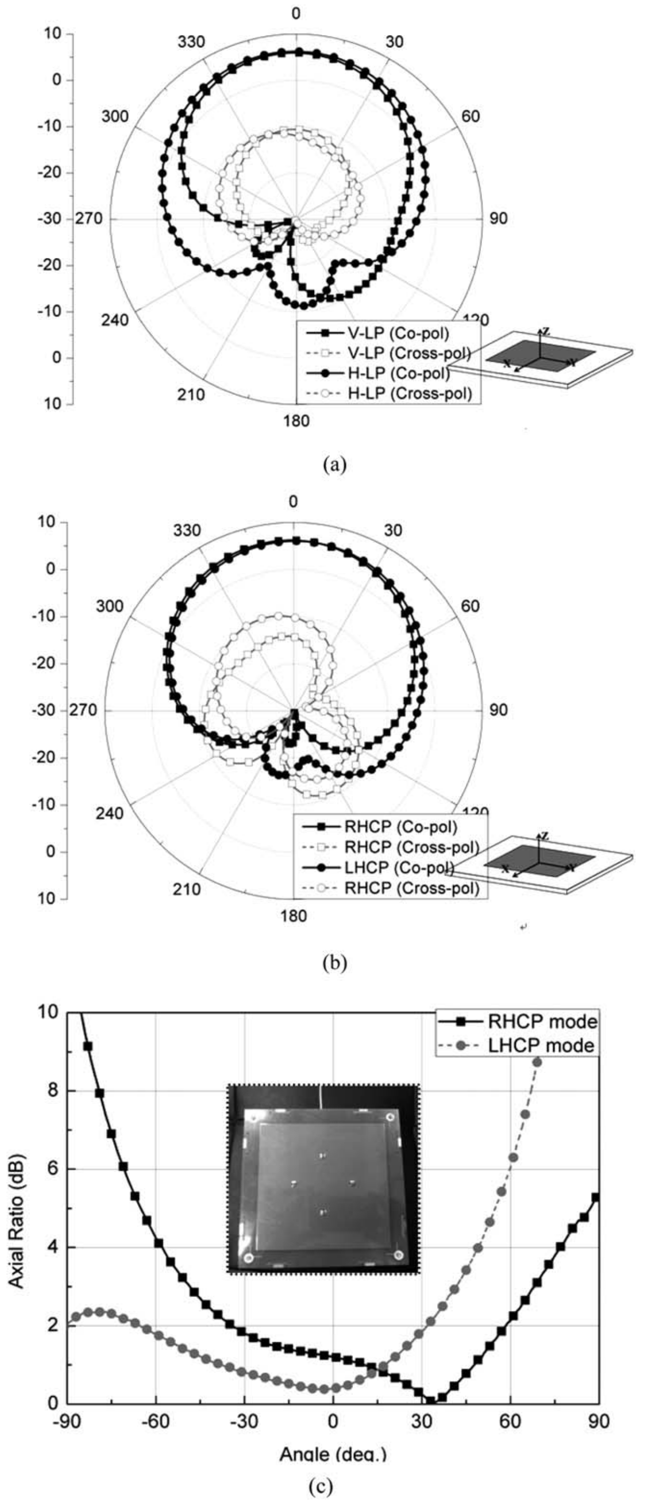


**Figure 4** Measured radiation pattern and axial ratio in *X-Z* axis for the proposed feeding network integrated antenna at 917 MHz, (a) radiation pattern in open (V-LP) and short (H-LP) mode, (b) radiation pattern in $j25$ (RHCP) and $-j25$ (LHCP) mode, (c) axial ratio in $j25$ (RHCP) and $-j25$ (LHCP) mode with photograph of the measured antenna

Among many polarization diversity techniques, the simplest way to switch circular polarization is to use a single pole double throw switch with a branch line hybrid. Also, some other techniques for switchable polarizations [2–4] also have been proposed. The structure in [2] uses a probe-fed patch antenna using PIN diode to switch between RHCP and LHCP. Similarly, the antennas reported in [3, 4] use PIN-diodes and piezoelectric transducer (PET)-controlled perturbers, respectively, to achieve a polarization switching mechanism. However, previous structures produce only two kinds of polarizations, RHCP and LHCP.

This article proposes a new antenna with reconfigurable feeding network for two circular and two linear polarization diversity modes operated at 917 MHz.

## 2. ANTENNA FEEDING NETWORK DESIGN

Figure 1 shows the simple diagram and photograph of the proposed antenna feeding network. Two hybrid couplers are configured with two single pole four throw (SP4T) to adjust load reflections. For the proposed structure shown in Figure 1, Port 1 is an input port and Port 2 is an isolation port, whereas Port 3 and 4 are output ports.

If the incident and reflected voltages at each port are denoted by $V^+$ and $V^-$, respectively, the port relationship for the proposed feeding network can be calculated by,

$$\begin{bmatrix} V_3^- \\ V_4^- \end{bmatrix} = \begin{bmatrix} \frac{j2X}{2X+jZ_o} & \frac{Z_o}{2X+jZ_o} \\ \frac{Z_o}{2X+jZ_o} & \frac{j2X}{2X+jZ_o} \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix} \tag{1}$$

where $Z_o$ is the characteristic impedance (50 Ω) and $X$ is the impedance connected between two hybrids. If $P_1$ is used as the input, the relationship between two outputs can be expressed as follows,

$$\frac{V_3^-}{V_4^-} = \frac{j2X}{Z_o} \tag{2}$$

According to Eq. (2), the magnitude and phase of each output signal are changed with respect to $jX$ controlled by two SP4T switches with reactance components. Eventually, the proposed circuit has reconfigurable signal transfer capability for polarization diversity antenna.

If reflective load $jX$ is capacitive, the phase difference between output ports $\angle V_3^-/V_4^-$ is $-90°$ [5]. To obtain the phase difference of $+90°$, the reflective load should be inductive. When the both outputs have equal magnitude with $\pm 90°$ phase difference, RHCP or LHCP can be produced. In addition, a single output can produce V-LP or H-LP depending on which one of the two outputs is activated. The circuit operations are summarized in Table 1. For verification, the proposed circuit is designed to operate at the center frequency of 917 MHz and the calculated values for $L$ and $C$ at target frequency are 4.34 nH and 6.94 pF, respectively.

## 3. MEASUREMENT

The proposed antenna feeding network requires two branch-line couplers and two SP4T switches. For the implementation of the proposed circuit, 3-dB directional couplers were used. The input of the switches are tied together as SP4T switches and connected between two 3-dB directional couplers. In practical implementation, the values of switch load impedances for open, short, and $\pm j25$ Ω must be compensated by considering the characteristics of the switch such as electrical length and insertion loss. Figure 2 shows the measured switch load impedances with compensation for each mode taken into account.

Based on the measured switch load impedances in Figure 2, the circuit insertion loss including switch and LC loss can be calculated. The insertion loss for switch load is determined by

$$\mathrm{IL} = 1 - |\Gamma|^2 - |T|^2 \quad (3)$$

where $\Gamma$ and $T$ are reflection and transmission coefficients in the junction of transmission line and parallel load. Then, $\Gamma$ and $T$ can be found by

$$\Gamma = \frac{(Z_L//Z_o) - Z_o}{(Z_L//Z_o) + Z_o}, \; T = \frac{2(Z_L//Z_o)}{(Z_L//Z_o) + Z_o} \quad (4)$$

where $Z_L$ is the measured impedance for each mode as shown in Figure 2. Therefore, the calculated insertion losses are 0.16, 0.45, 0.47, and 0.27 dB corresponding to open, short, and $\pm j25$ $\Omega$ modes, respectively.

Figure 3 shows the measured results of the proposed circuit at the center of 917 MHz. The insertion losses are 0.73, 0.87, 1.06, and 0.80 dB corresponding to open, short, and $\pm j25$ $\Omega$ modes, respectively. Considering the insertion losses of two couplers (0.2–0.3 dB), the measured results are reasonable compared with the calculated insertion losses. The return losses for all cases are more than 20 dB and the phase differences between two output ports are $\pm 90°$ within a deviation of 3° when switch is set to $\pm j25$. In addition, when the switch is set to open and short, only a single output is generated.

To verify the polarization diversity by the proposed feeding network, a reconfigurable antenna is designed at 917 MHz. The designed antenna has an air dielectric rectangular patch structure for high radiation performance. The size of the patch and ground-plane size are 120 × 120 mm$^2$ and 150 × 150 × 0.7 mm$^3$, respectively. When the mode of the proposed feeding network is set to open, short, or $\pm j25$, V-LP, H-LP, RHCP, or LHCP are generated accordingly. The measured radiation pattern and axial ratio are shown in Figure 4. The measured gains are about 5.9–6.2 dB and the co/cross-pol ratios are about 15–20 dB for each mode. Also, the axial ratios are less than 1.5 dB in center of antenna for two CP modes. According to Figures 3 and 4, the proposed reconfigurable feeding network has shown proper operations for the polarization diversity antenna.

## 4. CONCLUSION

Because polarizations of a given system are determined by antenna feeding network, polarizations of the antenna in use cannot be changed unless feeding circuits are redesigned. In this article, the proposed antenna feeding network can manipulate LHCP, RHCP, VP, and HP with a use of switch. The output of the proposed circuit can be a selectable single output or selectable two outputs with an equal magnitude with phase difference of $\pm 90°$.


## ACKNOWLEDGMENT

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## REFERENCES


1. M.A. Kossel, R. Küng, H. Benedicter, and W. Bächtold, An active tagging system using circular polarization modulation, IEEE Trans Microwave Theory Tech 47 (1999), 2242–2248.
2. F. Yang and Y. Rahmat-Samii, A reconfigurable patch antenna using switchable slots for circular polarization diversity, IEEE Microwave Guided Wave Lett 12 (2002), 96–98.
3. M.K. Fries, M. Gräni, and R. Vahldieck, A reconfigurable slot antenna with switchable polarization, IEEE Microwave Wireless Compon Lett 13 (2003), 490–492.
4. S.-H. Hsu and K. Chang, A novel reconfigurable microstrip antenna with switchable circular polarization, IEEE Antennas Wireless Propag Lett 6 (2007), 160–162.
5. S. Bulja and A. Grebennikov, A novel variable power divider with continuous power division, Microwave Opt Technol Lett 55 (2013), 1684–1686.




# A DUAL-BAND MONOPOLE ANTENNA FOR UHF-BAND APPLICATIONS


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**ABSTRACT:** *A dual-band monopole antenna for UHF-band applications has been demonstrated in this work. The dual-band characteristics are achieved using several strip monopole radiators. In addition, a small planar inverted-F monopole antenna is connected to the ground plane. The bandwidth improvement for the antenna is obtained mainly by modifying the geometrical configuration of the strip monopoles added at the antenna and the ground plane. The measured results of the impedance-bandwidth are about 44 MHz (458–502 MHz) and 118 MHz (701–819 MHz).* © 2014 Wiley Periodicals, Inc. Microwave Opt Technol Lett 56:896–900, 2014; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.28192



**Key words:** *UHF-band; planar inverted-F monopole antenna; surface current distribution*


## 1. INTRODUCTION

Because of its relatively wide bandwidth, compact size, easy impedance matching, light weight, low profile, and good radiation efficiency, the monopole antenna has become the subject of great interest to antenna designers. In addition, the monopole antenna with one-dimensional current distribution excites the

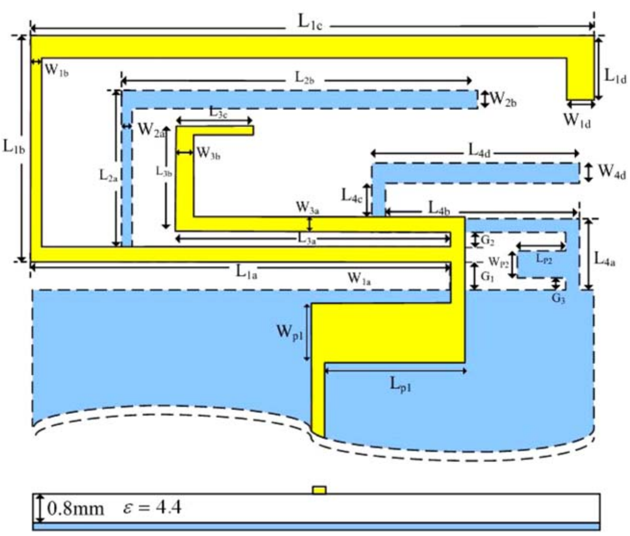


**Figure 1** Geometrical diagram of the proposed microstrip-fed monopole antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]