Dual-feed PIFA diversity antenna for wireless applications

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A novel dual-feed planar inverted-F antenna (PIFA) suitable for wireless diversity/MIMO applications is presented. By exploiting the pattern diversity, successful provision of two isolated feeding ports using one common radiating plate has been achieved. The main technique introduced is to etch the ground plane under the radiating plate to reduce the mutual coupling between the two ports. It is found that the envelope cross-correlation is less than 0.02 and the ratio of the mean effective gain between the two ports is close to unity. Thus, this new PIFA antenna can provide a better solution than two separate antennas for diversity and MIMO applications by saving space and cost. Simulated and measured results verify the conclusion.

Introduction: Future wireless communications systems are expected to support a wide range of high-quality services which may include data, high-quality voice, still pictures, and even videos. These services are likely to include applications which require high transmission rates of several megabits per second. Growing interest in both antenna diversity and multiple-input multiple-output (MIMO) systems has emerged owing to their ability to combat multipath fading and to deliver higher data rates, respectively [1, 2]. In a MIMO system, several transmitter antennas and receiver antennas are used at each end of the radio link and, to achieve a high capacity, the signals received should be uncorrelated. There have been wide-ranging efforts to develop advanced antennas for diversity/MIMO wireless communications [3, 4]. An essential requirement for these systems is that the antennas must provide diverse reception, i.e. they must be capable of receiving signals independently, even though they are closely spaced. But it is quite difficult to implement multiple antennas within small devices such as mobiles, PDAs and laptops. Placing multiple antenna elements in small space increases mutual coupling and results in high correlation coefficients.

Since the inverted-F antenna is now widely used in mobile and portable applications owing to its simple design, light weight, low cost, conformal nature, attractive radiation pattern and reliable performance [5], it is desirable to have a dual-feed PIFA antenna which can produce diversity gain and thus be used for diversity and MIMO applications.

In this Letter, a novel dual-feed PIFA diversity antenna is presented which uses pattern diversity. To reduce mutual coupling between the two ports and to increase isolation, part of the ground plane under the top radiating plate is etched out. As an example, the PIFA antenna in this Letter covers the 2.45 GHz band (for applications such as Bluetooth, Wifi and WLAN) and can be used in mobile and PDA terminals as a diversity or MIMO antenna.

Antenna diversity prelimanaries: The diversity gain in a diversity or MIMO system depends on two factors: envelope-correlation ρ_e and relative signal strength levels between the two received signals. To achieve reduction in signal fading or to obtain diversity gain, the following two conditions must be satisfied [1]:

$$\rho_e < 0.5 \quad \text{and } P_1 \simeq P_2 \tag{1}$$

where P_i is the average signal power received at each branch of the antenna and $i = 1$ or 2. The envelope-correlation can be found either from radiation patterns [6] or S-parameters measured at each antenna terminal [7]:

$$\rho_e = \frac{|S_{11}^* S_{12} + S_{21}^* S_{22}|^2}{(1 - |S_{11}|^2 + |S_{21}|^2)(1 - (|S_{22}|^2 + |S_{12}|^2))} \tag{2}$$

The average received power P_i from each branch can be obtained from the radiation patterns by using the mean effective gain (MEG). The MEG of an antenna is defined as the ratio of the mean received power to the mean incident power of the antenna. The ratio of the MEG between the two antennas must be close to unity to ensure $P_1 \simeq P_2$.

Antenna design and analysis: The configuration of the new dual-feed PIFA is shown in Fig. 1. The radiating top plate has dimensions $W \times L$ and the ground plane dimensions are $W_g \times L_g$. The dielectric material used between the rectangular ground plane and the two feeds is FR-4 having thickness $t = 1.5$ mm and relative permittivity $\varepsilon_r = 4.4$. The antenna height h is filled with air (free space). In practice, a low dielectric material may be used to support the top plate. The shorting plate has dimensions $W_s \times (h + t)$ and the widths of feed plates 1 and 2 are W_{f1} and W_{f2}, respectively, and both feed plates have height h. The horizontal distances of feed 1 and feed 2 from the side edge of the ground plane are L_{f1} and L_{f2}, respectively, and the distance between feed 2 and the upper edge of the ground plane is L_u. The bottom view of the etched ground plane is shown in Fig. 1*b*. The length of the etched part of the ground plane is S_{ug}. The two parts of the ground plane are connected through a small strip of thickness S_x. The width of the upper part of the ground plane which is connected to the shorting plate and feed 1 is S_y. The PIFA is fed by coaxial cables through SMA connectors.

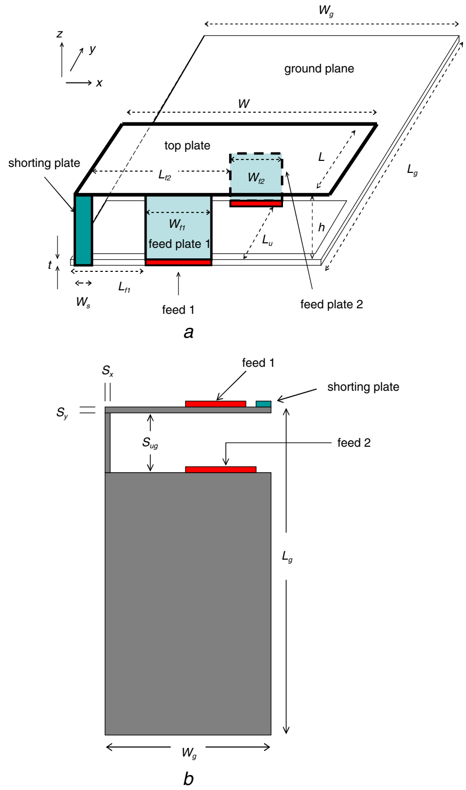

Fig. 1 *Geometry of proposed PIFA antenna*

a 3-D view
b Bottom view

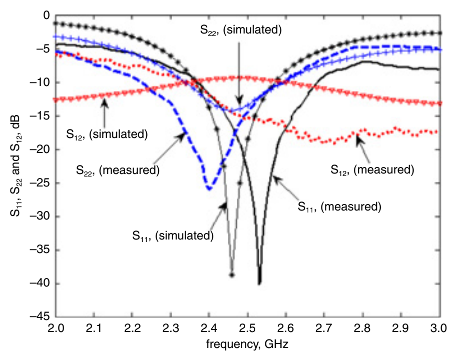

Fig. 2 *Measured and simulated S-parameters (dB) against frequency (GHz) for feeds 1 and 2*

Since there are many variables which can affect antenna performance, it is challenging to obtain an optimised design. Ansoft's High Frequency Structure Simulator (HFSS) has been employed to aid the design and a parametric study has been conducted. The optimised parameters of this dual-feed PIFA for 2.45 GHz applications are as follows: $W_{f1} = 14$ mm, $W_{f2} = 20$ mm, $W_g = 40$ mm, $L_g = 100$ mm, $W = 40$ mm, $L = 20$ mm, $h = 10$ mm, $W_s = 1$ mm, $L_{f1} = 2$ mm, $L_{f2} = 4$ mm, $L_u = 19$ mm, $S_y = 1$ mm, $S_x = 1$ mm, $S_{ug} = 17$ mm. The simulated and measured S-parameters are shown in Fig. 2. The simulated and measured results are similar; the major causes for the discrepancies are (a) the cables, which are not included in the simulation but presented in the measurements; (b) the connectors, which are also not considered in the simulation; and (c) the inaccuracy of the parameters in manufacturing this PIFA since it is made manually in the laboratory. It is evident that both branches of the antenna cover the 2.45 GHz band from 2.35 to 2.55 GHz having a bandwidth of more than 200 MHz for $S_{11} < -10$ dB. The average radiation efficiency of this antenna is found to be around 90%.

The measured radiation patterns of this antenna for feed 1 and feed 2 at 2.5 GHz are shown in Figs. 3 and 4. They clearly show that the two branches of the antenna can receive different signals, at the same time, from different directions which is the definition of pattern or angle diversity. Thus, this PIFA can achieve diversity gain due to pattern diversity.

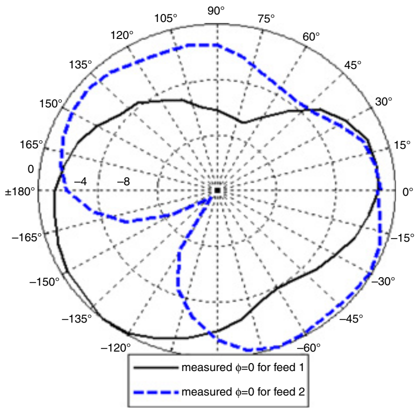

Fig. 3 *Measured radiation pattern (dB) for XZ ($\varphi = 0°$) plane for feeds 1 and 2 at 2.5 GHz*

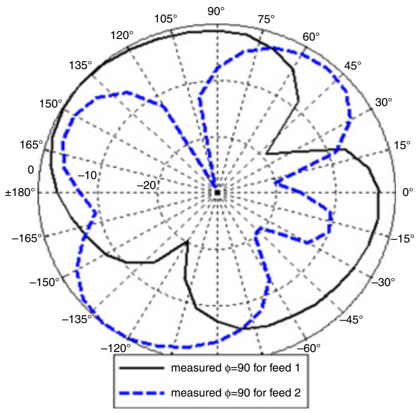

Fig. 4 *Measured radiation pattern (dB) for YZ ($\varphi = 90°$) plane for feeds 1 and 2 at 2.5 GHz*

As a good diversity/MIMO antenna, the conditions described in (1) must be met. The value of the envelope correlation coefficient, calculated using (2), is obtained to be smaller than 0.02 over the whole frequency band of interest. The MEGs of the two branches of the antenna are 0.56 and 0.50 and their ratio is approximately equal to unity, i.e. $0.56/0.50 \simeq 1$. Thus, this antenna satisfies the two conditions of achieving good diversity gain. This single element dual-feed PIFA can therefore be used as a diversity/MIMO antenna in wireless applications. The design can be scaled up or down to other frequencies.

How such a single element antenna works as a diversity antenna can be explained by the theory of characteristics modes: diversity gain can be achieved by exciting different modes of the antenna which result in different radiation patterns [8]. Here different modes on the radiating top plate and ground plane of the PIFA are excited to produce the desired diversity gain. It is observed from the parametric study that the dimension of ground plane greatly affects the resonant frequency of port 2, whereas the resonant frequency of port 1 is not affected significantly. Thus, diversity is achieved owing to the fact that port 1 uses the top plate as the main radiating element whereas port 2 uses the top plate as well as the ground plane as the radiating elements. Thus, the radiation patterns produced by the two ports are different, as shown in Figs. 3 and 4, and good diversity gain is achieved through pattern diversity.

Conclusion: A new compact single element dual-feed PIFA has been developed as a diversity/MIMO antenna for wireless applications.

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One or more of the Figures in this Letter are available in colour online.

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References

1 Vaughan, R.G., and Andersen, J.B.: ‘Antenna diversity in mobile communications’, *IEEE Trans. Veh. Technol.*, 1987, **36**, pp. 147–172
2 Kildal, P.S., and Rosengren, K.: ‘Correlation and capacity of MIMO systems and mutual coupling, radiation efficiency, and diversity gain of their antennas: simulations and measurements in a reverberation chamber’, *IEEE Commun. Mag.*, 2004, **42**, (12), pp. 104–112
3 Ko, S.C.K., and Murch, R.D.: ‘Compact integrated diversity antenna for wireless communications’, *IEEE Trans. Antennas Propag.*, 2001, **49**, pp. 954–960
4 Yeap, S.B., Chen, X., Dupuy, J.A., Chiau, C.C., and Parini, C.G.: ‘Integrated diversity antenna for laptop and PDA terminal in a MIMO system’, *IEE Proc., Microw. Antennas Propag.*, 2005, **152**, (6), pp. 495–504
5 Huang, Y., and Boyle, K.: ‘Antennas: from theory to practice’ (John Wiley & Sons, 2008)
6 Jensen, M.A., and Samii, Y.R.: ‘Performance analysis of antennas for hand-held transceivers using FDTD’, *IEEE Trans. Antennas Propag.*, 1994, **42**, pp. 1106–1113
7 Blanch, S., Romeu, J., and Cotbella, I.: ‘Exact representation of antenna system diversity performance from input parameter description’, *Electron. Lett.*, 2003, **39**, (9), pp. 705–707
8 Fabres, M.C., Daviu, E.A., V-Nogueira, A., and Bataller, M.F.: ‘The theory of characteristic modes revisited: a contribution to the design of antennas for modern applications’, *IEEE Antennas Propag. Mag.*, 2007, **49**, (5), pp. 52–68