

## COMPACT DUAL BAND PRINTED 2.5-SHAPED MONO-POLE ANTENNA FOR WLAN APPLICATIONS

S. Papantonis\* and E. Episkopou

Optical and Semiconductor Devices Group, Department of Electrical and Electronic Engineering, Imperial College London, Exhibition Road, London SW7 2AZ, United Kingdom

**Abstract**—A novel compact printed antenna for dual band applications is presented. The antenna consists of two monopole elements and operates within the ISM 2.4 GHz and 5.2/5.8 GHz frequency bands. The proposed antenna provides a bandwidth of 403 MHz (2.184 GHz–2.587 GHz) in the lower frequency band and 4004 MHz (3.880 GHz–7.884 GHz) in the upper frequency band, respectively. Thus, it can cover multiple standards such as: HIPERLAN, 5.5 GHz WiMAX, and 2.4/5.2/5.8 GHz WLAN. Moreover, the lower resonant frequency of the proposed antenna can be easily tuned within 2.15 GHz to 3.22 GHz with almost no effect on the upper resonance. Additionally, the small ground plane size of the proposed antenna makes it suitable for almost any portable device.

### 1. INTRODUCTION

Over the last years there has been a rapid increase in the use of wireless portable devices and many commercial applications have arisen in order to cover the demand of services such as data/video transfer. For example, the IEEE 802.11x protocols are some among the most widely used ones. This has led to the need of antennas that can cover multiband applications and can provide large enough bandwidth at all operating frequencies. Moreover, modern devices are usually very small and the space on the printed circuit board (PCB) for the antenna is limited. As a result, compact antennas are more attractive. Although there are antenna designs with some of the above characteristics [1–26], it is not often the case that they provide all of them at the same time. This paper presents an antenna that is not only compact enough to

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\* Corresponding author: Stergios Papantonis (s.papantonis10@imperial.ac.uk).

fit onto almost any portable device but also requires a small ground plane. Furthermore, it provides very good impedance matching at the ISM 2.4 GHz and 5.2/5.8 GHz frequency bands.

## 2. ANTENNA DESIGN

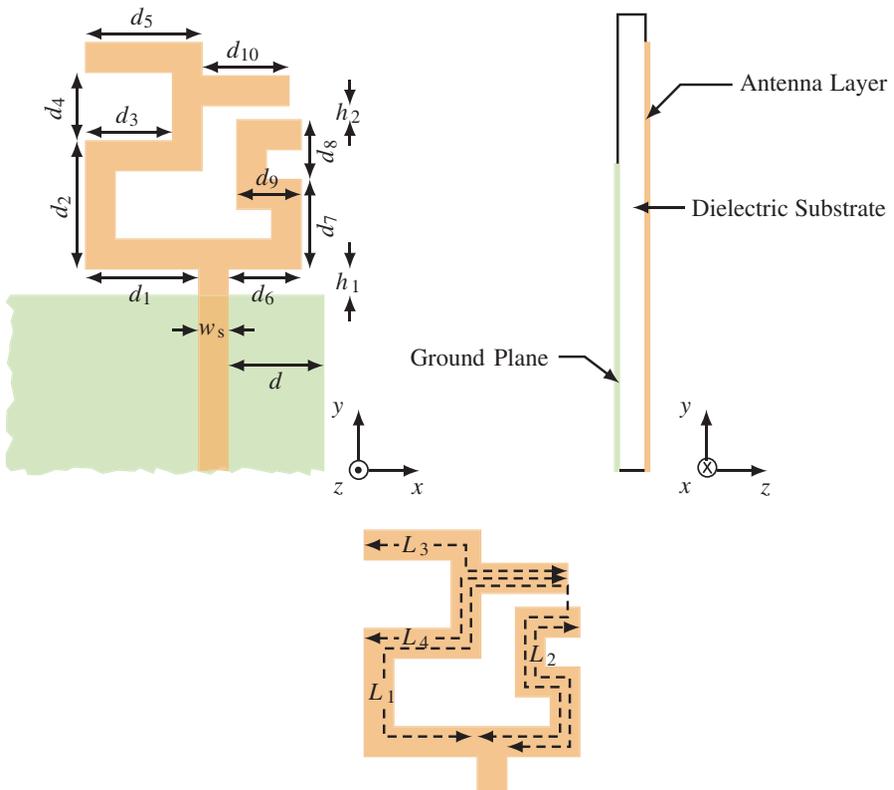
One way to obtain a dual band resonant structure is to have two paths with different lengths so that each one of them corresponds to about a quarter of the wavelength at the resonant frequency. It is well known that a monopole element placed over a ground plane (taking into account the method of images) forms a half-wavelength resonator (Hertz dipole). In our case the starting point is to have two monopoles with lengths that correspond to about a quarter of the free-space wavelength at 2.4 GHz and 5.2 GHz respectively. However, in order to miniaturize the antenna the monopoles need to be placed in a way that they occupy the minimum possible area. For this reason a space-filling approach was employed. Furthermore, in order to achieve a bandwidth enhancement multiple paths with neighbouring resonant frequencies have been designed.

The proposed antenna consists of two monopole elements, printed on an Taconic RF-35 dielectric substrate ( $\epsilon_r = 3.5$ ,  $\tan \delta = 0.0018$ ) with thickness 0.76 mm backed with a  $48 \times 30 \text{ mm}^2$  copper ground plane with thickness 0.018 mm (Fig. 1). The monopole element with length  $L_2 = 14 \text{ mm}$  corresponds to  $\lambda_0/4$  at 5.2 GHz (where  $\lambda_0$  is the free-space wavelength at 5.2 GHz) and thus it is responsible for the upper resonant frequency. However, the resonant frequency is not exactly at 5.2 GHz because this length was derived based on the assumption that the antenna is located in free space, away from any objects and above an infinite ground plane. Of course, this is not the case here. The antenna is placed over a small ground plane and very close to the second monopole element of the structure. Thus, the currents flowing along the monopoles are strongly coupled and in addition there is a current flowing along the edge of the ground plane (Fig. 2) that also affects the overall behaviour of the antenna, resulting in an effective monopole length slightly different than  $\lambda_0/4$ . Similarly, the path  $L_1 = 31.3 \text{ mm}$  is responsible for the lower resonance since it corresponds to about  $\lambda_0/4$  at the operating frequency with  $\lambda_0$  being the free-space wavelength at 2.4 GHz.

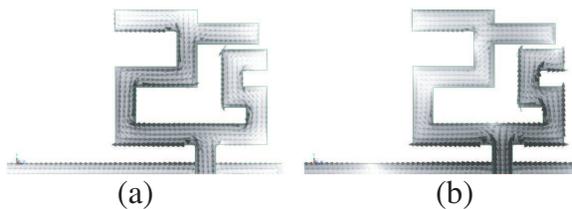
The proposed structure was simulated using Agilent's ADS Momentum, CST Microwave Studio<sup>®</sup> and Ansoft's HFSS<sup>™</sup> which employ the Method of Moments (MoM), the Finite Integration Technique (FIT) and the Finite Element Method (FEM), respectively. However, being ADS Momentum a 2.5D simulator is the natural

**Table 1.** Dimensions in mm of the proposed antenna.

$d_1$	$d_2$	$d_3$	$d_4$	$d_5$	$d_6$	$d_7$	$d_8$	$d_9$	$d_{10}$	$d$	$h_1$	$h_2$	$w_s$
6.5	6.3	5	2.9	6.7	4.2	4.6	2.9	3.7	5	5.5	1.5	0.4	1.7

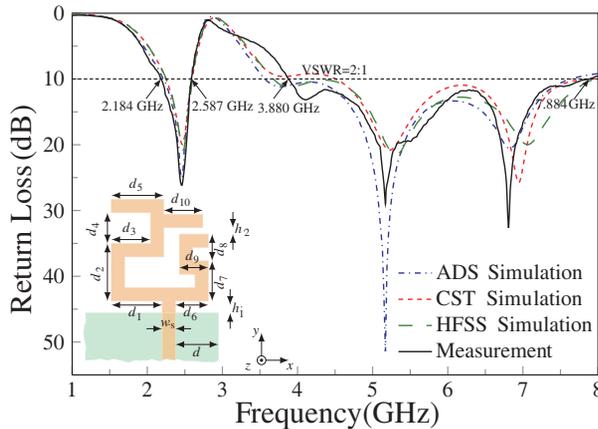


**Figure 1.** Geometry of the proposed antenna. The dimensions are shown in Table 1.

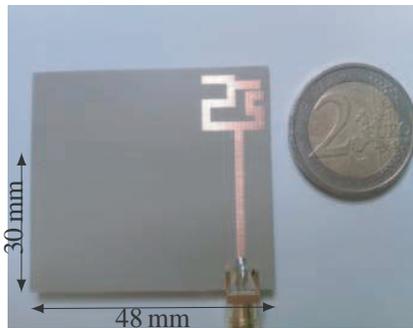


**Figure 2.** Surface current density at (a) 2.4 GHz and (b) 5.2 GHz.

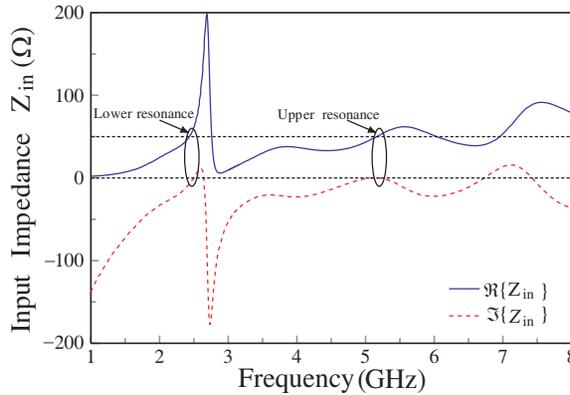
choice for planar structures since the computational resources and computing times needed are significantly less when compared to full wave simulators. The results from the simulations were then validated with experimental measurements of a prototype (Fig. 4) and a very good agreement was noticed. As can be seen in Fig. 3, the bandwidth of the lower band is 403 MHz (2.184 GHz–2.587 GHz), whereas at 5.2 GHz it is 4004 MHz (3.880 GHz–7.884 GHz). Both operation bands provide not only large enough bandwidth to cover the applications operating within these frequency regimes, but also a sufficient frequency margin in case of detuning (i.e., dielectric loading from the device packaging). Particularly, the upper frequency band has a bandwidth that is much wider than the one of a classical monopole and this is partially due to the element with length  $d_{10}$ .



**Figure 3.** Return loss of the proposed antenna having the dimensions of Table 1.



**Figure 4.** Fabricated prototype of the proposed antenna. The dimensions of the ground plane at the back side are also shown.



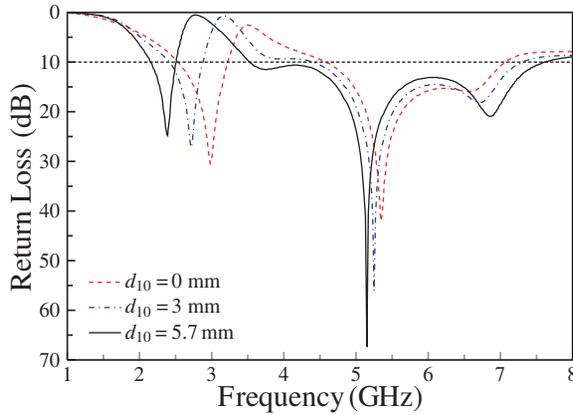
**Figure 5.** Input impedance of the proposed antenna.

The antenna is fed by a  $50\ \Omega$  power supply, therefore in order to avoid reflections from the antenna structure — which result in low efficiency — a microstrip transmission line with characteristic impedance  $Z_0 = 50\ \Omega$  is used. Thus, the width of the strips  $w_s$  is chosen to be 1.7 mm. Furthermore, the input impedance of a monopole placed at the centre of the ground plane is usually quite low (lower than  $50\ \Omega$ ) so it is difficult to obtain good impedance matching with a  $50\ \Omega$  power supply. Therefore, the antenna is shifted towards the corner of the ground plane where the input impedance is higher. Fig. 5 shows the impedance matching of the antenna; it is clear that at the resonant frequencies the input impedance of the antenna  $Z_{in}$  matches the impedance of the power supply.

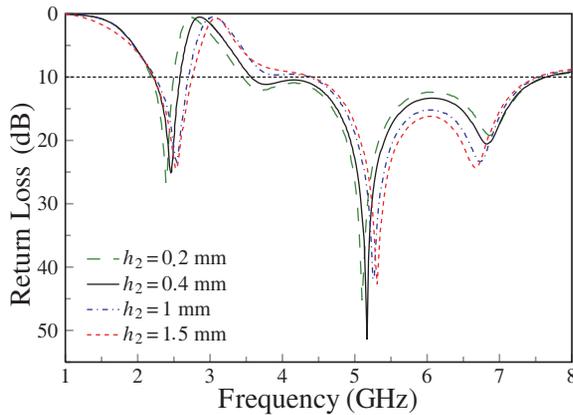
### 3. DISCUSSION

To this end, let us investigate the effect of the element  $d_{10}$  in more detail. At first, the antenna was studied for different lengths of  $d_{10}$  and spacing distance  $h_2$  (Figs. 6 and 7). It is obvious that the length and the position of  $d_{10}$  have little effect on the upper resonance but they do change the resonant frequency of the lower band. Thus,  $d_{10}$  can be used to shift the lower resonance covering a span from 2.15 to 3.22 GHz and hence, the antenna can be easily tuned around a specific frequency within this band (Fig. 6). It is interesting to notice that when  $d_{10}$  is zero the lower resonance is due to the monopole element with length  $d_1 + d_2 + d_3 + d_4 + d_5$  which corresponds to about  $\lambda_0/4$  at 2.9 GHz.

In addition,  $d_{10}$  provides a significant bandwidth enhancement of the order of 1 GHz in the upper resonant frequency when placed



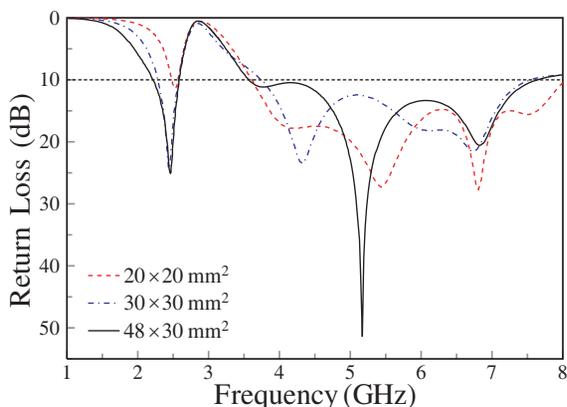
**Figure 6.** Return loss of the proposed antenna for various lengths of  $d_{10}$  when  $h_2 = 0.4$  mm.



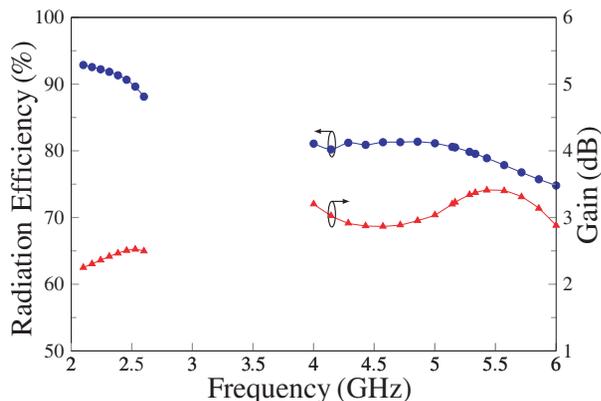
**Figure 7.** Return loss of the proposed antenna for various heights  $h_2$  when  $d_{10} = 5$  mm.

close (in our design 0.4 mm) to the monopole with length  $L_2$ . In this case, due to coupling with  $L_2$  new elements with resonant frequencies around 4 GHz are formed (e.g.,  $L_2 + L_3$ ,  $L_2 + L_4$  and  $d_1 + d_2$ ) which yield enlargement of the bandwidth. However, the closer  $d_{10}$  to  $L_2$  is, the smaller the bandwidth of the lower resonance becomes (Fig. 7).

Also, a parametric analysis with respect to the ground plane size was performed in order to demonstrate that the proposed antenna can operate even with a very small ground plane (Fig. 8). In the case that the ground plane is smaller than  $20 \times 20 \text{ mm}^2$  the lower resonance at 2.4 GHz vanishes and a wideband resonance occurs instead that covers



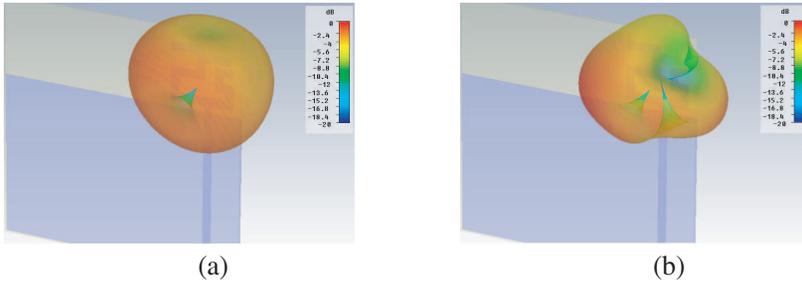
**Figure 8.** Return loss of the proposed antenna for various ground plane sizes.



**Figure 9.** Simulation results for the radiation efficiency and gain of the proposed antenna having the dimensions of Table 1.

the C-band (4–8 GHz).

Finally, the radiation efficiency and radiation patterns for the proposed antenna having the dimensions of Table 1 are presented in Figs. 9–11, respectively. The radiation efficiency in the lower resonance is more than 90% while in the upper resonance is about 80% and drops below 75% as the frequency goes above 6 GHz. The lower efficiency in the 5.2/5.8 GHz frequency bands is due to the trade-off between efficiency and bandwidth. In our case, the proposed antenna has a very large bandwidth at the expense of high efficiency. For an electrically small antenna the relation between gain  $G$ , bandwidth  $BW$  and electrical size  $k\alpha$  is given by  $\frac{G \cdot BW}{k\alpha}$  where  $k$  is the wavenumber and



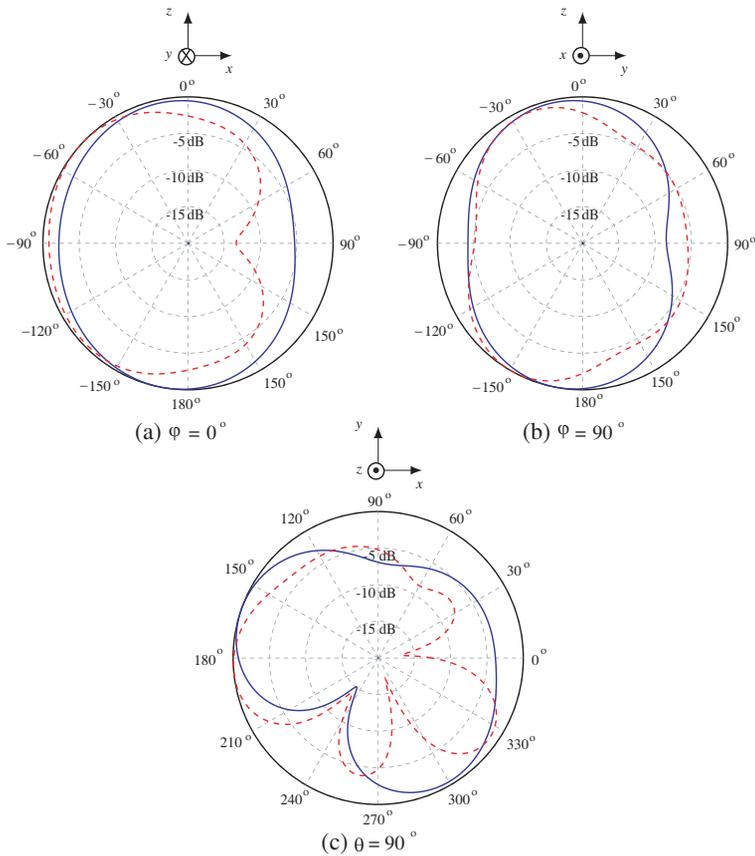
**Figure 10.** Simulated 3D radiation pattern for the electric field at (a) 2.4 GHz and (b) 5.2 GHz for the proposed antenna having the dimensions of Table 1.

$2\alpha$  is the maximum spatial dimension of the antenna [27]. Moreover, the antenna can be considered as a resonant system and thus a quality factor  $Q$  can be defined by the expression:

$$Q = \begin{cases} \frac{2\omega_0 W_{e,avg}}{P_{r,avg}} & \text{for } W_{e,avg} > W_{m,avg} \\ \frac{2\omega_0 W_{m,avg}}{P_{r,avg}} & \text{for } W_{m,avg} > W_{e,avg} \end{cases} \quad (1)$$

where  $\omega_0$  is the angular resonant frequency and  $W_{e,avg}$ ,  $W_{m,avg}$ ,  $P_{r,avg}$  are the average stored (in the near field, i.e., non-radiating) electric and magnetic energy and average radiated power, respectively. Thus, in order to obtain maximum radiation efficiency and hence maximum radiated power one needs to have minimum  $Q$ . It can be proven that the quality factor  $Q$  is a function of the electrical size  $k\alpha$  and is inversely proportional to the bandwidth BW [28]. However, there is a lower bound for the quality factor for a given (electrical) antenna size [29]. Additionally, since the bandwidth is inversely proportional to the quality factor there is an upper bound for the quality factor. Similarly, the gain  $G$  is a function of the electrical size of the antenna [30]. Thus, the design procedure of the antenna is a compromise between the above three conflicting parameters.

The radiation patterns for the (total) electric field (Fig. 11), particularly at 2.4 GHz, are close to those of a classical monopole antenna having omnidirectional characteristics. On the other hand, at 5.2 GHz there are a few nulls in the radiation patterns but the overall omnidirectional characteristics are retained. It should be noticed that the polarization of the antenna is elliptical (as is the typical polarization of printed monopole antennas). However, the co- and cross-polarization components are not presented here since the main use of the proposed antenna is for portable devices where the



**Figure 11.** Simulated radiation patterns for the electric field on the (a)  $x$ - $z$ , (b)  $y$ - $z$  and (c)  $x$ - $y$  planes. Solid line: 2.4 GHz. Dashed line: 5.2 GHz.

polarization of the received signal is in all likelihood unknown. Thus, even when the transmitted signal has a specific polarization (known a priori) in typical environments severe multipath effects are common which may result in change in the polarization state. For this reason only the total electric field is given so that an evaluation in terms of received power is possible upon inspection of Fig. 11.

#### 4. CONCLUSION

A novel compact dual band antenna was presented. After various parametric studies and taking into account the possible trade-offs the optimum design was obtained. The performance of the proposed

antenna has been evaluated using different electromagnetic simulation software packages and the results obtained have been compared against measurements with very good agreement. Thus, the proposed antenna provides a large bandwidth at both bands and especially at the upper resonance. Furthermore, the lower resonant frequency can be easily tuned at will simply by adjusting the length or positioning of the strip  $d_{10}$ . Thus, the proposed antenna is a very attractive solution for small portable devices and for spatial diversity systems where compact antennas that can operate with a small ground plane are required.

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