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# Closely Located Dual PIFAs with T-Slot Induced High Isolation for MIMO Terminals

Shuai Zhang[1, 2, 3], Buon Kiong Lau[3], Anders Sunesson[3, 4], and Sailing He[1, 2]
[1] School of Electrical Engineering, Royal Institute of Technology, KTH, Sweden
[2] Centre for Optical and Electromagnetic Research, Zhejing University, China
[3] Department of Electrical and Information Technology, Lund University, Sweden
[4] Perlos AB, Lund, Sweden
Email: shuai.zhang@ee.kth.se

*Abstract*—**This paper presents an efficient technique to enhance the isolation between two closely spaced PIFAs for MIMO mobile terminals. The proposed decoupling method is based on a T-shape slot impedance transformer and it enables an inter-PIFA spacing of 1 mm to be achieved. The 10 dB impedance bandwidth and 20 dB isolation bandwidth cover the 2.4 GHz WLAN band (2.4-2.48 GHz), with a maximum isolation of 44 dB. The efficiency, gain, radiation patterns of the two-PIFA prototype are also verified in measurements.**

***Keywords- Antenna array mutual coupling, MIMO systems, parasitic antennas***

## I. INTRODUCTION

MULTIPLE-INPUT multiple-output (MIMO) technology can efficiently increase the channel capacity or reliability of wireless communication systems without sacrificing additional frequency spectrum or power in rich scattering environments. However, the requirement for compactness of mobile terminals can result in a high mutual coupling between MIMO antenna elements, which can dramatically decrease the performance of MIMO systems. This motivates the need for efficient mutual coupling reduction techniques for portable MIMO terminals [1]. Examples of decoupling techniques suitable for compact MIMO antennas are found in [1]-**Error! Reference source not found.**.

Planar inverted-F antennas (PIFAs) have been widely used in mobile terminals. Unfortunately, an earlier work [5] points out that, in order to guarantee an isolation of 20 dB or more, the separated distance between two PIFAs above a common ground plane with air substrate should be at least larger than $0.5\lambda_0$, where $\lambda_0$ is the free space wavelength. Moreover, this conclusion is independent of the orientations of the two PIFAs. In order to find a more efficient way to reduce the mutual coupling of PIFAs, many studies have been done in the recent years, *e.g.,* [6]-[10]. In [6], a small local ground plane is added to each of the two PIFAs in order to achieve good isolation. A neutralization line is inserted between two PIFAs in [7]. Another technique presented in [8] utilizes a parasitic element (with no connection between the active antennas) to provide the decoupling effect. However, no matter how the neutralization lines or parasitic element are positioned, they will still occupy some physical space. In [9], mutual coupling is reduced by a quarter wavelength slot that is formed between the closest edges of the two PIFAs. In this arrangement, the displacement coupling current between the two closely located antenna elements can be blocked by the slot. In order to further enhance the isolation, a new mode is excited, which utilizes the closest edges of the two PIFAs, as well as another slot cut on the ground plane, to form a half wavelength U-shape slot in-between [10]. Due to the resulting resonant mechanism, all coupling currents are "cut off". In particular, not only the displacement coupling current between antennas can be efficiently trapped in the U-shape slot, the coupling current on the ground plane is likewise captured. In theory, this technique facilitates an inter-PIFA spacing of $0.0016\lambda_0$, while maintaining an isolation of greater than 40 dB. However, the methods in [9] and [10] are not suitable in general for a ground plane of arbitrary size and shape, such as the ground plane of a mobile terminal. This is because the decoupling slots may not be well matched in these cases, and consequently, they may not be successfully excited.

In order to overcome this design constraint and thus greatly improve the flexibility of the technique, a modified design is proposed in this paper. In particular, a T-shape slot is inserted at the end of a quarter wavelength decoupling slot formed by the edges of two PIFAs. The T-shape slot functions as an impedance transformer for the decoupling slot. By properly adjusting the length of the T shape, the formed decoupling slot can be excited for any ground plane size and shape. In this paper, the focus is to demonstrate the effectiveness of the modified technique to isolate closely located PIFAs on a mobile terminal.

## II. CLOSELY LOCATED SINGLE-BAND PIFAS WITH A T-SHAPE SLOT IMPEDANCE TRANSFORMER

### A. *Antenna Geometry and Physical Mechanism*

The geometry of our proposed single-band PIFAs for mobile phone applications are shown in Fig.1. The ground plane is of the size 40 mm × 100 mm, and it consists of a 0.03 mm top copper sheet and a FR4 PCB substrate (see areas marked by slanted lines in Fig.1.) with thickness of 1.55 mm, dielectric permittivity of 4.7 and loss tangent of 0.014. Two PIFAs with an edge-to-edge distance of $0.0088\lambda_0$ are mounted on a 1 mm thick hollow carrier, which is commonly used in mobile phones. The dielectric permittivity and loss tangent of the hollow carrier are 2.5 and 0.007, respectively. Each PIFA is fed by a 50Ω coaxial probe. At the end of each probe, an $L_c \times W_c$ copper sheet is added to form capacitive load feeding,

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which can increase the impedance bandwidth [11]. Since the performance of PIFA is sensitive to the distance between the copper sheet and the top part of PIFA, and to ease the antenna fabrication process, an $L_c \times W_c$ dielectric block is added in-between. The added block has a thickness of 1 mm and is of the same material as the hollow carrier. A T-shape slot is etched on the ground plane and it performs as an impedance transformer of the slot formed by the edges of two PIFAs. In our design, route (1) as indicated in Figs. 1(f) and 1(g) is the formed decoupling slot (of length $L_a + L_s + H + L_{low}$) and route (2) is the impedance transformer (of length $L_{high}+W_{high}$) for the decoupling slot. By proper optimization of the parameters $L_{high}$ and $W_{high}$, the formed slot can be excited in a ground plane of any size and shape, and at any position on the ground plane.

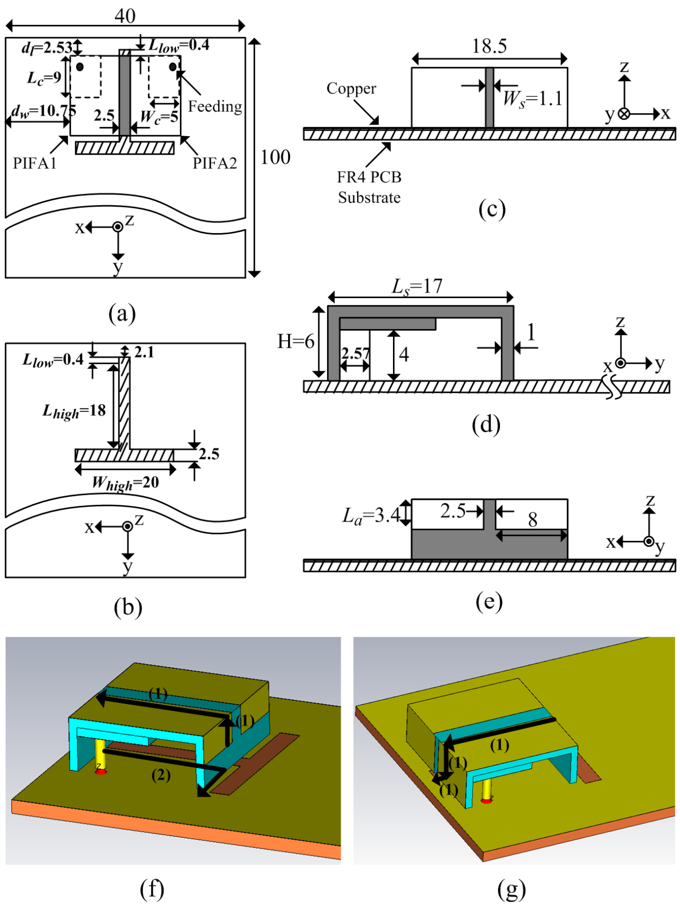


Fig. 1. Geometry of the proposed single-band dual-PIFA array (indicated lengths are in *mm*): (a) top view, (b) ground plane, (c) back view, (d) side view, (e) front view, (f) and (g) 3D views.

The simulated scattering (or S) parameters for the dual PIFAs with and without the T-shape impedance transformer are show in Fig. 2. It can be observed that the proposed T-slot enhances the isolation between the two PIFAs from 6.3 dB to over 40 dB.

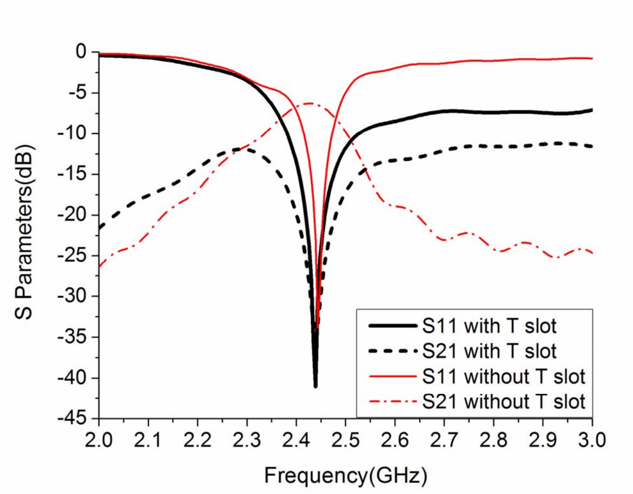


Fig. 2. Comparison between the simulated S-parameters of the proposed single-band PIFAs with and without the T-shape slot impedance transformer.

## B. *Measurement Results*

Fig. 3 shows the comparison between the simulated and measured S parameters for the proposed single-band PIFAs with a T-shape slot impedance transformer. As can be seen, the measured results agree well with the simulated results. For the measured results, the 10 dB impedance bandwidth is 100 MHz (*i.e.,* 2.4-2.5 GHz), which covers the WLAN band (*i.e.,* 2.4-2.48 GHz). The isolation within the impedance bandwidth is greater than 20 dB, and up to a maximum of 44 dB.

The normalized radiation gain patterns of the single-band PIFAs with T-slot is measured in an anechoic chamber and shown in Fig. 4. The radiation patterns are obtained when PIFA1 is measured, with PIFA2 terminated in a 50Ω load (see also Fig. 1(a)). The measured peak gain and total efficiency are 1.84 dBi and 70% (-1.5 dB), respectively, which are suitable for MIMO terminal applications.

## C. *Current Distribution*

The current distribution of the proposed single-band MIMO PIFAs, when PIFA1 (see Fig.1(a)) is excited, is shown in Fig. 5. From the current distribution, it can be deduced that: First, most of the coupling current is trapped in the formed slot and cannot flow into the other PIFA. Second, the current distribution in route (1) (see Figs. 1(g) and 1(f)) is similar to that of a quarter-wavelength slot. At the end of the quarter-wavelength slot (*i.e.*, the $L_{low}$ part in Figs. 1(a) and 1(b)), the current is very strong. Concurrently, the current on route (2) of length $L_{high}+W_{high}$ (see Fig. 1(g)) is much weaker, because it only works as a T-shape impedance transformer of the decoupling slot and does not contribute significantly to the radiation.

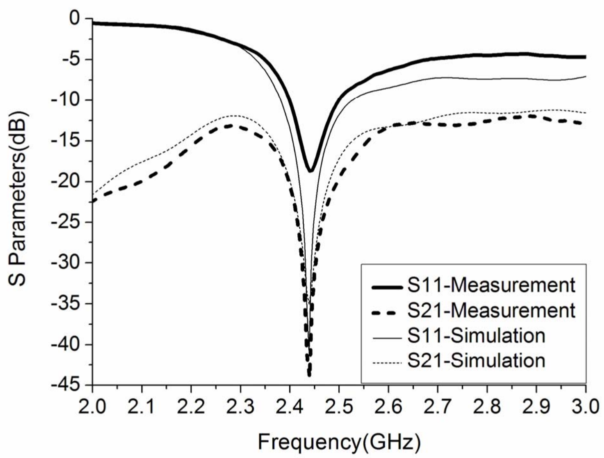


Fig. 3. Comparison between the measured and simulated S parameters of the proposed single-band PIFAs.

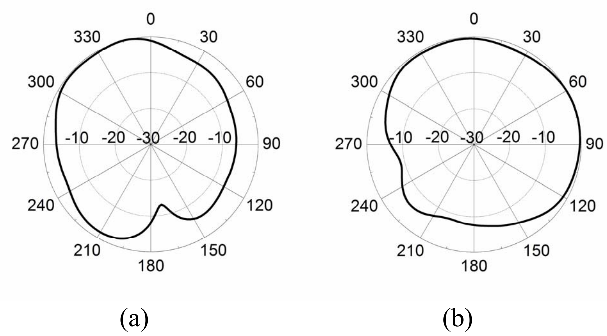


Fig. 4. Measured normalized radiation gain patterns of the proposed single-band PIFAs at 2.45 *GHz*: (a) x-z plane, (b) y-z plane.

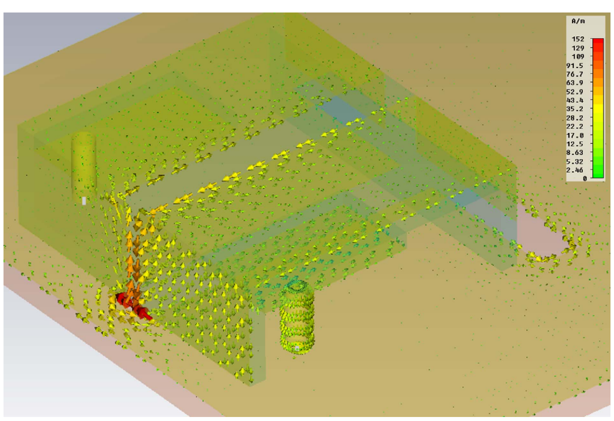

Fig. 5. Current distribution of the proposed single-band PIFAs at 2.45 *GHz*

## III. CONCLUSION

This paper proposes an efficient decoupling technique for two closely located PIFAs using a T-shape slot impedance transformer. The technique can be used for a ground plane of any size and shape, and is demonstrated with an example for MIMO mobile terminal applications in the 2.4 GHz WLAN band. It is shown that both the 10 dB impedance bandwidth and the 20 dB isolation bandwidth of the proposed structure are sufficient to cover the required frequency band (2.4-2.48 GHz). In addition, a total efficiency of 70% (-1.5 dB) is also obtained.

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