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U-shaped Slot PIFAs for Multi-Antenna Mobile Applications

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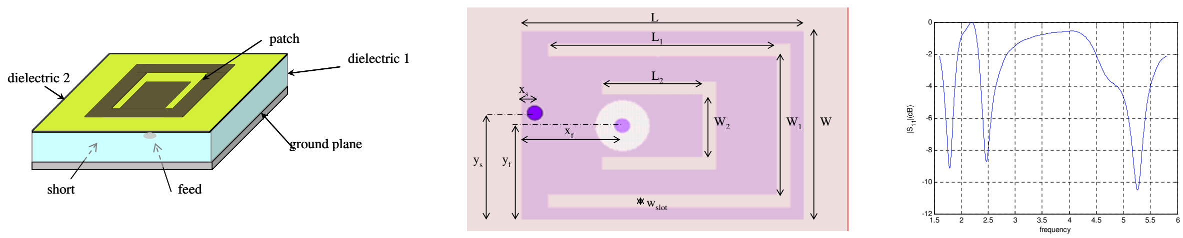
1. Introduction

In recent years, Multiple-Input Multiple-Output (MIMO) systems have widely been studied as a solution to improve the radio link reliability. In order to introduce it in mobile communications, it is necessary to design antennas with several features to fit multiple elements in the space reserved for the antenna, such as the type of element or array configuration. In this paper, a 2×2 prototype MIMO system is presented regarding the next-generation WLAN (802.11n). Two tri-band Planar Inverted-F Antennas (PIFAs) for a PDA terminal have been design for GSM and WLAN bands (1800/2400/5200 MHz) and two dual-band PIFAs for WLAN bands have been designed for a laptop. This type of antenna has been chosen as it can be integrated in the small space in user terminals. Implementation and measurements of tri-band antenna is also presented in this paper. The results have been taken into account to obtain the MIMO channel capacity including radiation pattern and mutual coupling, depending on the employed configuration.

2. Tri-band antenna for a PDA terminal

The PIFA structure is shown in figure 1(a), where the layers configuration is detailed. In the first place, the ground plane is situated on the bottom of the antenna. Then, the dielectric 1 is made of Rohacell foam with a dielectric constant (ε_r) of 1.05. The second dielectric, fiber glass (0.9 mm of thickness and ε_r = 4.1), supports the printed patch. Moreover, two vias go through the two dielectrics from the ground plane to the patch: short and feed.



(a) Antenna structure (b) Dimensions (c) $|S_{11}|$ dB

Figure 1: Tri-band antenna

2.1 Design

Two U-shaped slot [1] has been placed in order to achieve the three resonant frequencies: 1.8, 2.45 and 5.4 GHz. The external patch is rectangular whose dimensions are represented in figure 1(b) and they are (in mm): L = 21, W = 15, L_1 = 18, W_1 = 13, L_2 = 8.5, W_2 = 7 and W_{slot} = 1. On the other hand, the feed and the short are situated in x_f = 7, y_f = 7, x_s = 1 and y_s = 8.5, due to enhance the reflection coefficient and a linear polarization in the center of the patch. Figure 1(c) represents the reflection coefficient with a bandwith at S_{11} = −6 dB (typical for this antennas) of 140, 154 and 310 MHz for each frequency band (1800, 2400 and 5200 MHz). It is worth notice here that all the antenna simulations have been carried out with CST Microwave Studio.

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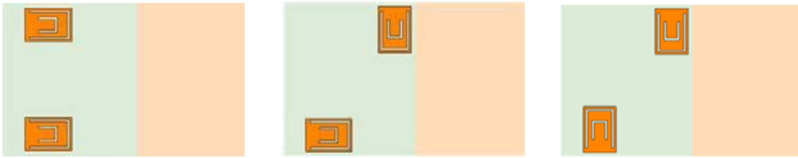
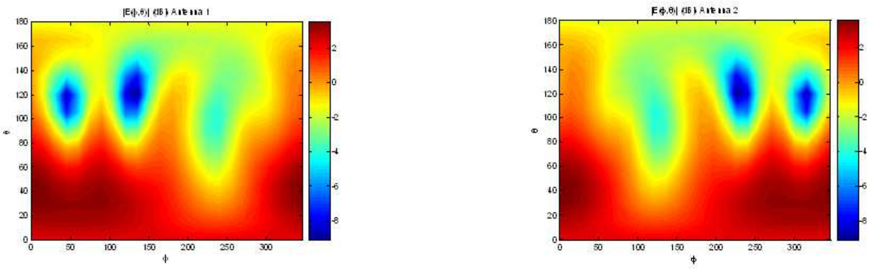
Regarding a 2×2 MIMO system, several array configurations have been simulated in a device with a size typical for high-end mobile applications: a PDA of 60×100 mm^2. Figure 2 shows the three different configurations simulated. The PIFAs are placed varying x and y axis and rotated, reserving space for the device battery (right side of each figure).



(a) Configuration 1 (b) Configuration 2 (c) Configuration 3

Figure 2: Configurations of tri-band PIFA in a PDA

On the other hand, antenna array response in terms of radiation pattern is shown in figures 3(a), for the first antenna, and 3(b), for the second one in the case of configuration 1.



(a) $|E(\theta, \phi)|$ (dBi) of antenna 1 (b) $|E(\theta, \phi)|$ (dBi) of antenna 2

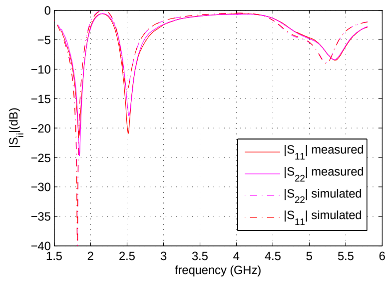
Figure 3: Radiation patterns

2.2 Implementation

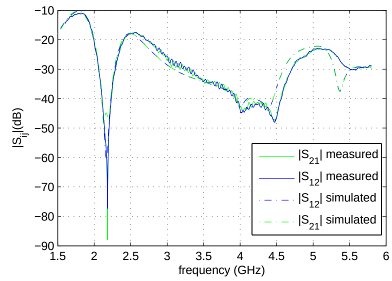
Once the antennas have been design, the configuration 1 has been implemented taking into account the results in section 4. Figure 4 shows the final construction of the antennas. Moreover, figure 5 represents the comparison of simulated and measured S parameters.

(a) Top view (b) Side view

Figure 4: Tri-band antenna implementation



(a) S_{11} and S_{22} parameters



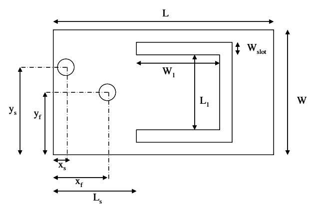
(b) S_{12} and S_{21} parameters

Figure 5: S parameters of tri-band antennas

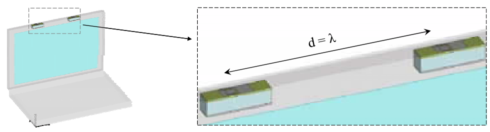
3. Dual-band antenna design for Laptop

The structure of this antenna is similar to the previous one for dual-band antenna, thus the layer configuration is the same. In this case, only one U-shaped slot is needed for the two resonant frequencies: 2.45 and 5.4 GHz. The antenna dimensions are depicted in figure 6(a). The patch is rectangular of dimensions (in mm) $L = 17$ and $W = 9$; the slot has the dimensions $L_1 = 6$, $W_1 = 5$, $W_{slot} = 1$, $L_s = 2$, $x_f = 3$, $y_f = 4.5$, $x_s = 1$ and $y_s = 8$.

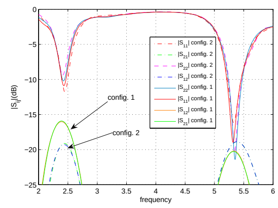
In order to obtain MIMO performances, two configurations have been studied regarding the spacing between array elements: λ and 2λ (at 2.45 GHz). The antennas are located in the lip of a laptop as figure 6(b) shows. The laptop dimensions are 210 mm of high, 320 mm of length and 14 mm of thickness, similar to a typical laptop used nowadays. Both antennas and laptop has been created with CST Microwave Studio. The laptop has been configured as follows: the base is made up by a solid (made of dielectric with ε_r=3.6), the screen is PEC and the lid of laptop is cover by a thin layer of the same dielectric as the base. Figure 6(c) represents S parameters obtained from configuration 1 and 2. As it can be seen, the



(a) Antenna dimensions



(b) Dual-band PIFA in a laptop



(c) S parameters

Figure 6: Dual-band PIFA array

bandwith for the WLAN bands at $S_{11} = -6$ dB is 180 and 360 MHz for 2.45 and 5.4 GHz, respectively.

4. Results

In order to obtain MIMO channel capacity including antenna radiation pattern and mutual coupling, the 3GPP-3GPP2 Spatial Channel Model (SCM) in Matlab [2] has been used with a cell radius of 100 m and a polarized channel with an $A_oD_{max} = 180°$. Once the wideband channel matrix $H(t, \tau)$ is obtained, an equivalent narrowband channel matrix is computed for $f = 2.45$ GHz given by (1), where L is the number of paths.

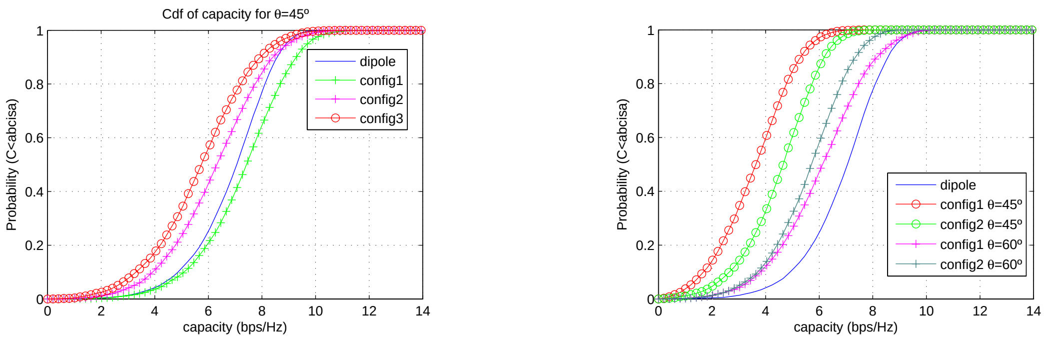
$$H(t) = \sum_{n=1}^{L} H(t, \tau_n) \exp(-j2\pi f \tau_n) \tag{1}$$

The capacity is calculated by (2), where $\mathbf{I}_{M_R}$ is the eye matrix, ρ represents the signal to noise ratio, M_T indicates the number of transmitter antennas, M_T the number of receiver antennas, $\mathbf{H}$ is the channel matrix including antenna radiation patterns, $\mathbf{C}_R$ and $\mathbf{C}_T$ are the Multi-Element antenna (MEA) correlation matrices in the receiver and transmitter, and there is no Channel State Information (CSI) in the transmitter. $\mathbf{C}_R$ is given by (3), where $\mathbf{S}$ represents S parameters matrix. In this case, $\mathbf{C}_T = \mathbf{I}_{M_T}$ due to obtain the effects only in user terminal.

$$C = \log_2 \left[\det \left(\mathbf{I}_{M_R} + \frac{\rho}{M_T} \mathbf{C}_R \mathbf{H} \mathbf{H}^H \mathbf{C}_T \right) \right] \qquad \text{bps/Hz} \tag{2}$$

$$\mathbf{C}_R = \mathbf{I}_{M_R} - \mathbf{S}^H \mathbf{S} \tag{3}$$

Figure 7 details the cummulative distribution function of the capacity obtained for several configurations in the case of dual (several tilts) and tri-band antenna ($\theta = 45°$) as figures 7(b) and 7(a) show, comparing them to a ideal dipole case.



(a) PDA (b) Laptop

Figure 7: Cdf of capacity for different MIMO configurations

5. Conclusions

In this paper, both tri- and dual-band PIFAs have been presented for WLAN and GSM MIMO applications. Dual-band PIFA has been designed for a laptop and the tri-band one for a PDA terminal, which includes simulations and results. The measurements obtained from the tri-band antenna configuration 1 present similar response than the simulated one. On the other hand, Several MIMO configurations have been considered to compare performances in terms of channel capacity including radiation patterns and mutual coupling with the Spatial Channel Model from 3GPP, obtaining higher capacity in configuraton 1 for PDA and for laptop, mainly due to the mutual coupling and thus to correlation between MIMO subchannels. Antenna measurements with a MIMO testbed [3] in indoor environments are currently carrying out.

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