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Bi-Access Tri-band Wideband Antenna for an Opportunistic Communication between 4G Terminals

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Abstract— A new planar antenna with double access and three separated bands is presented in this article. The first access operates over two bands, a narrow band for GPS standard (1.575 GHz), and a wideband covering PCS (1.85-1.99 GHz) and UMTS (1.92-2.17 GHz) standards and also six sub bands of the new norm 3GPP (LTE). The second access operates over a wideband covering WLAN applications (2.4-2.484 GHz) and a sub band of LTE (called also IMT-2000). In total, this antenna covers eleven standards. A new analysis method for bandwidth improvement techniques (parasitic patch) using the equivalent cavity modal analysis is also presented. Simulation and measurement results are proposed.

Keywords-Double Access; Tri-band; Planar Antenna; Cavity Approach; Modal analysis

I. INTRODUCTION

The future generation of mobile phones will certainly exploit the numerous advantages of opportunistic cognitive radio concepts. This opportunistic approach is fundamentally assumed as a flexible system, aware of its immediate environment. Such conditions will offer greatest services and performances to the customer.

We investigate on the concept of a multi-access antenna [1]-[3] in order to exploit the combined flexibility of RF (Radio Frequency) and digital interfaces, then offering enriched information by combining multi-incoming signals for both transmission / reception modes. The intrinsic performances of the antenna directly affect the SDR (Software Defined Radio) performances and one challenge lies in the achievement of infinite isolation values between the antenna access ports at different frequencies (bands) (or within the same (band)).

In this context, we note that in [1] the isolation for bi-access bi-band antenna is performed using stubs. In [2] a new isolation method based on the equivalent cavity modal analysis is developed and illustrated by a bi-access mono-band hexagonal patch antenna. In [3] a multi-access multi-standard antenna is designed on the base of the method in [2]. The isolation performance in [1] is unfortunately quit limited, when considering stub filtering structure. Indeed, this isolation method (using stub) is only available for particular case. Furthermore, in [1]-[3], some antennas access ports were relatively narrow band (4% in [1], 2% in [2], 1% in [3]).

In this article, we present a solution of a bi-access antenna with three bands, among these bands there are two relatively

wideband. This planar antenna uses a bandwidth improvement technique based on electric coupling between several rectangular patches. The innovation of this antenna is first, in the design method (the equivalent cavity modes [2]). Then, in the multi-access approach. With this approach, the filtering structure is integrated in the antenna, then suppressing any additional switching or frequency path selecting components, which would induce losses and noise degradation. Finally in the planar aspect of the antenna, and its radiation characteristics (high gain, polarization diversity ...).

II. OPERATION PRINCIPLE

A. General principle

First, In the literature [5], [6] there are three configurations for bandwidth improvement of a patch by adding resonators of slightly different resonant lengths coupled together by capacitive gap coupling. These configurations are presented in Fig. 1.

The radiation phenomenon of a patch (Length L , Width W , thickness h) is described as two radiating slots (dimensions $W \times h$) separated by a low impedance transmission line of length L . L is almost closed to half a wavelength of the fundamental propagating mode TM_{010}^x (see Fig. 1. for axis convention). In this case (resonance along L), the two edges of dimension W are called “radiating edges”, and the two edges of dimension L are called “non radiating edges” [5]- [7]; note that the equivalent non radiating slots have dimensions of ($L \times h$). On Fig. 1, the configuration (a) is called REGCOMA (Radiating Edges Gap COupled Microstrip Antenna). In this configuration the resonant patches (1 & 3) are coupled to the central patch (2) via the radiating edges (radiating equivalent slots). Since the respective length L_1, L_2, L_3 have close values, the resonant frequencies of these patches are also close, and therefore the bandwidth is improved (relative bandwidth of 10 to 15 %).

The same principle is observed in configuration (b) called NEGCOMA (Non radiating Edges Gap COupled Microstrip Antenna) except that the coupling is done via the non radiating edges (slots). The configuration (c) FEGCOMA (Four radiating Edges Gap COupled Microstrip Antenna) combines the two configurations (a) and (b). The coupling of patch 2 with patches (1 & 3) is done via the radiating edges (slots) while the coupling with patches (4 & 5) is done via the non radiating edges. With five resonant elements, the structure (c) will have a wider bandwidth (25%). Indeed, what is available for the length L , can be applied to the width W , provided that the

excitation is properly placed to excite the suitable mode (TM_{001}^x instead of TM_{010}^x) as we will see in next paragraph. Referring to [4], the coupling type in all cases is capacitive.

In our new antenna structure (§ I. B), we added two slots to patches (4 and 5). This bi-access Tri-band antenna combines configurations (b) & (c) simultaneously.

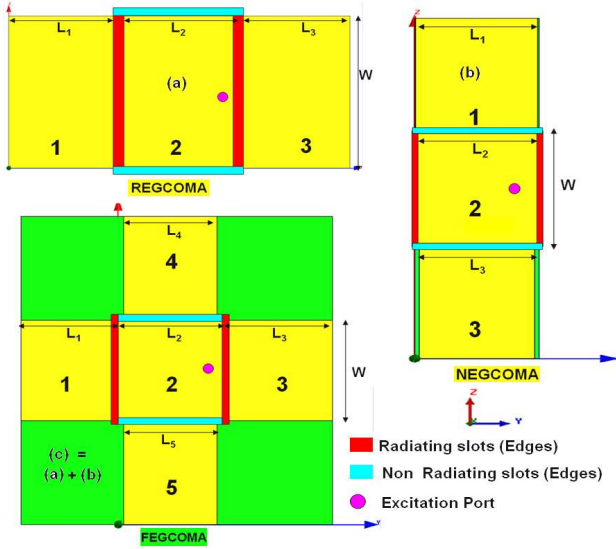


Figure 1. Different configurations of Gap coupled patch antennas

B. Antenna Operation principle

Our bi-access (two ports) antenna structure (top view in Fig. 2) is formed by five resonant patches numbered from 1 to 5. In the patches 4 and 5 there are two slots in (Oy) direction, the roles of these slots will be explained later in this §. These patches (1 to 5) are placed above a common ground plane.

On Fig.2, the port 1 (noted P1) is marked in red color, while the port 2 (noted P2) is marked in blue color. At the same figure, when P1 (respectively P2) is excited, the coupling contribution of the central patch (patch 2) edges (or the equivalent coupling slot surrounded by a dotted line on Fig.2) is written on red color (respectively blue color).

When P1 is excited the antenna operates as FEGCOMA (case (c) of Fig .1). The coupling of patch 2 with patches (1&3) is done via the radiating edges (noted RE in red on Fig. 2) while the coupling with patches (4 & 5) is done via the non radiating edges (noted NRE in red). In this case the close lengths (L_i) of patches control the resonance frequencies.

From the other side, when P2 is excited the antenna operates as REGCOMA (case (b) of Fig .1). The coupling of patch 2 with patches (1&3) is done via the non radiating edges (noted NRE in blue) while the coupling with patches (4 & 5) is not possible at the resonance frequency of the patch 2.

Indeed, at the resonance, the surface currents on each patch if P1 is excited are oriented towards the lengths direction (Oy direction). Nevertheless, if P2 is excited the surface currents are oriented towards the widths direction (Oz direction). Since the slots of patches (4 & 5) are (Oy) oriented (parallel to the

lengths and orthogonal to the widths), they perturb the transversal resonances (widths resonances) of these patch when P2 is excited, while the longitudinal resonances (lengths resonances) when P1 is excited are not influenced. That's why the coupling with patches (4 & 5) is not possible at the resonance frequency of the patch 2 when P2 is excited.

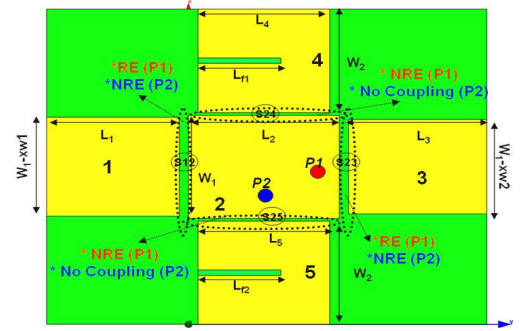


Figure 2. Antenna operation Principle

Briefly the additional slots of patch 4 and 5 have two roles: first they create two additional modes (will be detailed on § III.A). Secondly, they make the design process more systematic. In fact, if these slots didn't exist, the operation when P2 is excited would be analogue to P1 (i.e. as FEGCOMA). In this case the determination of inter-patches distances (noted s_{ij} on Fig. 2), to ensure the simultaneous optimization of FEGCOMAs on P1 and P2 would be difficult. The operation principle will be demonstrated and confirmed in next paragraph by the modal analysis.

III. DESIGN METHOD

A. Modal Analysis

A conception method for multi-access antenna based on modal analysis of cavity approach is developed in [2]. This method is aimed to identify the Eigen resonant modes of a structure. Indeed, this identification links each mode to one or more structure dimensions. It also permits to locate the suitable area of the excitation ports to excite one or several modes while respecting the isolation and matching constraints of the multi-access operation.

The cavity approach is based on the fact that Microstrip antennas can be assumed as dielectric loaded cavities, so that the normalized field within the dielectric substrate can be determined by considering this region as a cavity delimited by perfect electric (top & bottom metallization levels) and magnetic (perimeters of the metallization parts) walls [2]. This approach can be extended to our structure by considering all non metal part in the upper face as magnetic walls to simulate an open circuit. The equivalent cavity is shown in Fig .3 – (a).

The resonance frequencies of the cavity Eigen modes was calculated using the Finite Element method of HFSS *without any excitation*. The dimensions of Fig. 2 in mm are ($L_1= 43.53$, $L_2= 49.45$, $L_3= 45.33$, $L_4= L_5= 43.27$), ($W_1= W_2=37.72$, $xw1=1.509$, $xw2=3.18$, $Lf1= Lf2=21.75$), the distance inter-patches ($s_{12}= s_{23}=3$, $s_{24}=1$, $s_{25}=0.5$), and the substrate permittivity is ($\epsilon_r=2.2$) and of thickness 4.68 mm. The first

eleven Eigen modes with resonance frequencies are presented in Fig. 3-(b). Fig 4 shows the current densities distributions of the first ten modes. From such analysis on Fig.4 we can deduce that: First we have two modes (modes 1 & 2) created by the two additional slots of patches 4 and 5. Their frequencies (see Fig. 3 – (b) and Fig.4 mode 1 & 2) are at the proximity of GPS band (1575 GHz) and they will constitute the GPS band of our antenna.

To prove that only modes 1 & 2 depends from the slots lengths, the value of these lengths are changed from ($L_{f1}=L_{f2}=21.75\text{mm}$ to $L_{f1}=L_{f2}=23.75\text{mm}$) while conserving all other dimensions. The new resonance frequencies are presented in Fig. 3-(c). This later shows that only modes 1 & 2 frequencies change, while the frequencies of other modes are almost unchanged.

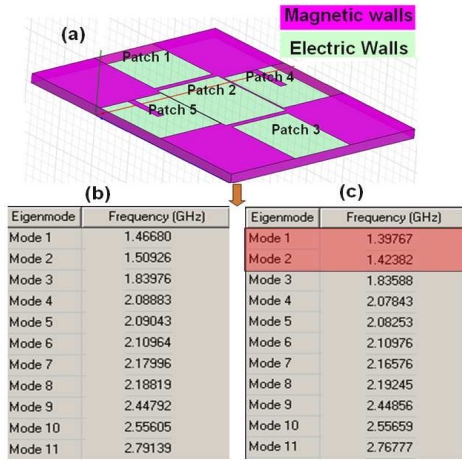


Figure 3. (a) Cavity approach (b) Initial cavity Eigen modes (c) Effect of slots length on Eigen modes.

Secondly, there are five resonant modes (modes 3, 4, 5, 6, 8) noted TM_{010}^x representing the classical resonance ($L_i=\lambda_g/2$) along y direction of the patches 2, 5, 4, 3 and 1 respectively. Therefore we have *five* resonances along the length, thus the antenna in this case operate as FECSOMA as explained of above. The frequencies of these modes are between 1.84 GHz and 2.18 GHz (Fig. 3-(b)) and they will constitute the PCS, UMTS bands and LTE sub-bands of our antenna.

Third, there are three resonant modes (modes 7, 9, 10) noted TM_{001}^x representing the classical resonance ($W=\lambda_g/2$) resonance along z direction of the patches 2, 1 and 3 respectively. Therefore we have *three* resonances along the width, thus the antenna in this case operate as NECSOMA. The frequencies of these modes are between 2.17 GHz and 2.55 GHz (Fig. 3-(b)) and they will constitute the WLAN and IMT-2000 bands of our antenna.

The mode 11 is a hybrid mode, it is the first higher order (or hybrid) modes and it will not be exploited here. This analysis shows that the modes (3, 4, 5, 6, and 8) that resonate along y direction are, from one part, orthogonal to the modes (7, 9, and 10) that resonate along z direction and from the other part quasi-orthogonal at the proximity of the patch 2 to modes (1 and 2). Thus a port (P1) that excites modes (3, 4, 5, 6, and 8) will be isolated from a port (P2) that excites modes (1, 2, 7, 9,

and 10). Note that to excite a given mode by a coaxial feed; the excitation should be done in a point where the E-field is non zero. By the modal analysis, the field distribution is determined for a given mode, as we have done for the current, and thus we can determine the suitable area to excite a given mode.

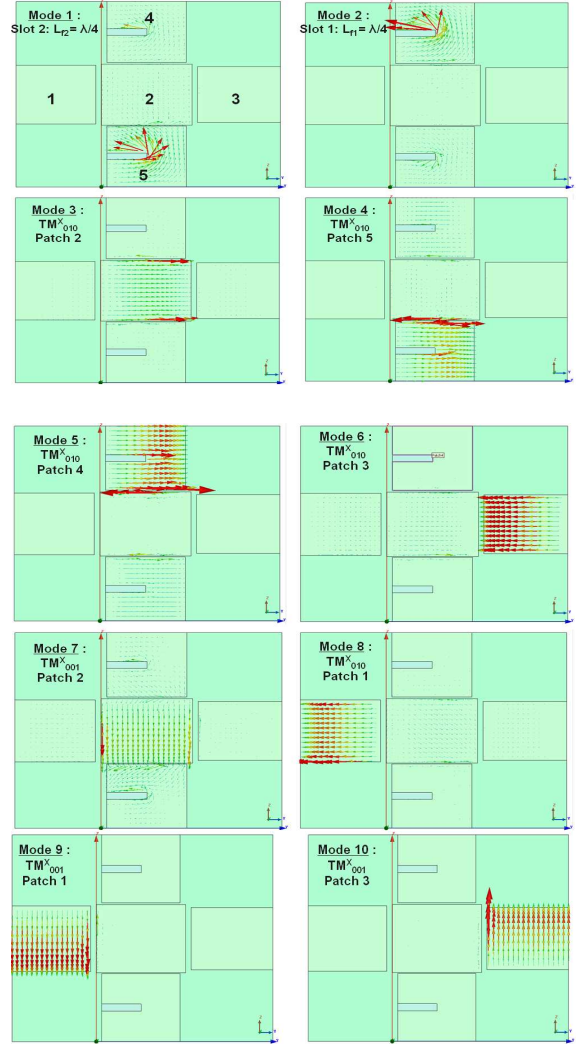


Figure 4. Current distribution of the first ten Eigen modes.

B. Final Optimization and prototype

The above modal analysis permits the modes identification with the resonance frequencies control. It determines also the approximate ports locations that allow the excitation of specific modes under the isolation between ports. But the question is: How we ensure the matching of excitation ports to 50 Ohms? Indeed for a suitable position of (P1) along y and of (P2) along z , the distances (s_{ij}) between patches (see Fig.2) and the slots widths determines the antenna input impedance. (s_{ij}) control the capacitive equivalent impedance, while the slots control the inductive one. Referring to [4], [5] when (s_{ij}) decreases, the correspondent resonance loop in the smith chart will increase. Using this effect, and for a fixed slot widths, (s_{12}) and (s_{23}) are first optimized to ensure the matching of (P2). In fact, when

(P2) is excited only patches (1&3) are involved in the resonance. Then for fixed values of (s_{12}) and (s_{23}), the optimization of (s_{24}) and (s_{25}) is done to ensure the matching of (P1). According to all the analysis, the final dimensions are those presented in the previous § (III. A). The remaining dimensions are presented with antenna prototype in Fig. 5 where ($d_1=5.15$, $d_2=5.092$, $S_f=4$) in mm.

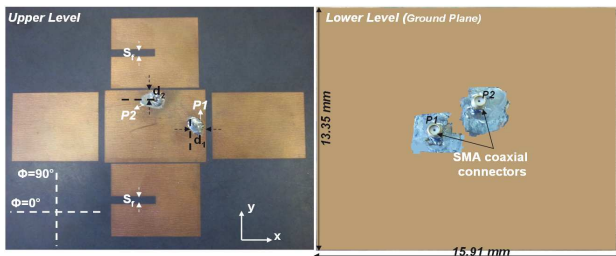


Figure 5. Antenna Prototype with new axis axis convention

IV. MEASUREMENT

A. Reflection and isolation coefficients

After assembling, we have proceeded to the S parameters measurements. On Fig.6 the results are compared with simulation ones on HFSS™. This figure shows the coverage of the involved bands (see Fig.6) and the ports isolation. Port 1 (in blue) presents a wideband (vis-à-vis of a classical patch) of 16% @ ROS=2. The minimal isolation over this band is (14 dB). Port 2 (in blue) presents a narrowband of 1% and a wideband of 10% @ ROS=2. The *minimal isolations* over these bands are (16 dB) and (10 dB) respectively.

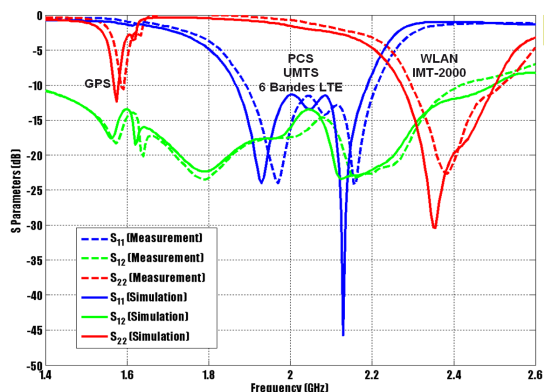


Figure 6. Reflection Coefficient (S_{11}) for P1, (S_{22}) for P2 and the isolation coefficient (S_{12}) between P1 & P2.

B. Radiation Characteristics

At Fig.7-(a), we present the simulated and *measured* radiation patterns (co-polarization gain for $\Phi=0$ and $\Phi=90^\circ$ (see new axes convention on Fig. 5) on P1 (when P2 is loaded to 50 Ohms) at several frequencies covering the bandwidth of P1. At Fig.7-(b), we present the simulated and *measured* radiation patterns (co-polarization gain for $\Phi=0$ and $\Phi=90^\circ$) on P2 (when P1 is loaded to 50 Ohms) at several frequencies covering the wideband of P2. These patterns show from a part the correspondence between simulation and measurement and

from other part the good radiation performance over all the bands of P1 and P2. Furthermore, the antenna *measured* peak gain is very high (around 11 dBi) and almost constant with the frequency (> 9 dBi overall bands of P1 and P2).

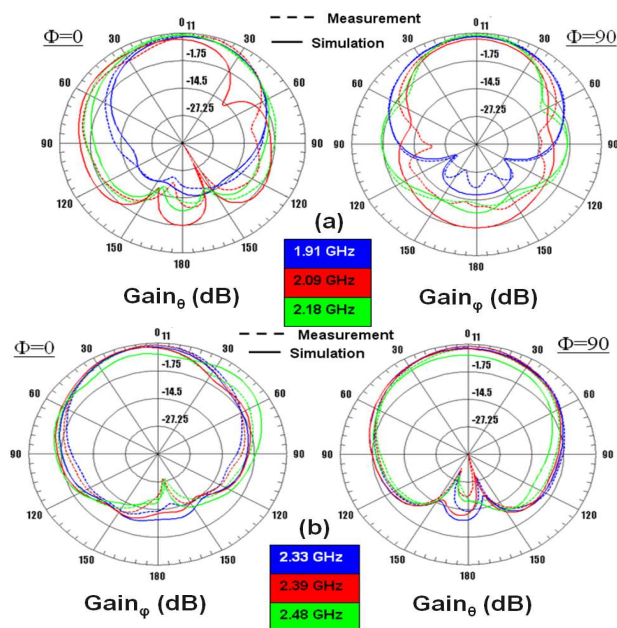


Figure 7. Radiation Patterns (a) Port 1 (b) Port 2

V. CONCLUSION

A new antenna structure with two accesses simultaneously matched and isolated on three different functional bands is presented. It offers new prospects in the reconfigurability of antennas once digitally controlled after direct A/D conversion. An original design and analysis method of this kind of antenna based on the cavity modal analysis approach is also presented and applied. Furthermore, an extension of the method to extra ports and extra bands and to other antenna types is possible. That offers numerous possibilities for identifying generic antenna configurations attractive for SDR, MIMO or Spectrum sensing applications.

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