Two-Element PIFA Array Structure for Polarization Diversity in UMTS Mobile Phones

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Abstract. *In this paper, we demonstrate the possibility to strongly modify the radiated fields of a UMTS handset by using a phased two-element PIFA array. The structure is composed of a 100x40 mm² metallic ground plane acting as the Printed Circuit Board (PCB) of the mobile phone. Two UMTS PIFAs are located at the top edge of this PCB. They are fed by a double Quasi-Lumped Coupler able to provide a 360° phase difference between its two outputs. By properly choosing the DC bias of the double Quasi-Lumped Coupler, we can set a specific phase difference between the two PIFAs. In this way the two-element array is able to radiate different electromagnetic fields. Simulated and measured radiation patterns in the two main planes of the chassis are presented for different phase differences. It is especially revealed that the novel two-antenna structure is able to radiate vertically-polarized electric fields in the azimuthal plane of the phone and horizontally-polarized electric fields in the same plane when changing the phase shift between the antennas from 0° to 180°. Potential applications are polarization-diversity techniques and Specific Absorption Rate reduction for handsets.*

Keywords

Planar Inverted-F Antennas, UMTS Mobile Phones, Polarization Diversity.

1. Introduction

Today, one of the major problems to solve in a communication between a portable unit and a base station is dealing with signal fading caused by the multi-path propagating environment. A solution consists in using some polarization or pattern-diversity technique at the terminal side of the wireless link by means of employing several antennas [1]. However, although these techniques can easily be theoretically described, implemented and controlled for a regular-sized antenna positioned over a large ground plane, the situation is somewhat different for several small antennas integrated within a communicating object. The small devoted space for the antennas in a mobile phone or a PDA, the strong coupling between these radiating elements and the unintended coupling with nearby metallic components may drastically degrade the array capability. For example, pointing the main polarized beam in any wanted direction may be difficult or quite impossible to achieve. However, at cellular frequency bands, the PCB is also a radiating element [2] and modifying the phase difference between the PIFAs has a strong influence on the radiating currents flowing on this PCB and the associated excited characteristic mode. This effect could be helpful in trying to achieve different radiation patterns. Recently we designed several UMTS two-antenna systems operating on a small ground plane whose size is representative of a typical mobile phone [3]. Some of these prototypes are using a neutralization technique to achieve high port-to-port antenna isolation and enhance their total efficiency [4].

In this paper, we demonstrate the possibility to strongly modify the radiated fields of a UMTS handset. The structure is composed of a 100x40 mm² metallic ground plane acting as the Printed Circuit Board (PCB) of the mobile phone. Two UMTS PIFAs are located at the top edge of this PCB. The PIFAs are designed to operate in the UMTS band [1920-2170 MHz] with a -6 dB return loss. They are fed by a double Quasi-Lumped Coupler (d-QLC) able to provide a 360° phase difference between its two outputs. The d-QLC is printed on a very thin Duroid substrate (h=0.127mm, ε_r=2.2). By properly choosing the DC bias of the d-QLC, we can set a specific phase difference between the two PIFAs: the two-element array is able to radiate different electromagnetic fields on purpose. Simulated and measured radiation patterns are presented for two phase differences. It is especially revealed that the novel structure is able to radiate vertically-polarized electric fields in the azimuthal plane of the PCB for a 0° phase shift between the PIFAs and horizontally-polarized electric fields in the same plane when changing the phase shift to 180°. Potential applications are polarization diversity techniques for handsets and Specific Absorption Rate reduction when modifying the near-field of the Phone.

2. Design of the Antenna-Structure

The structure is composed of a 100x40 mm^2 metallic ground plane acting as the PCB of the mobile phone. Two UMTS PIFAs are located at the top edge of this PCB and 0.12 λ_0 spaced if we consider the middle of the UMTS band [1920-2170 MHz] as the operating frequency. They are fed by a d-QLC able to provide a 360° phase difference between its two outputs. A Quasi-Lumped Coupler (QLC) is a circuit where the vertical branches of a traditional hybrid coupler are replaced by lumped capacitors. The structure consists of two horizontal transmission line sections of length 1/8 of the guided wavelength and with characteristic impedance Z_1. These lines are linked by varactors (admittance=Y_2). The DC biasing circuit is simple thanks to the fact that the two horizontal transmission lines are electrically isolated. When the capacitance is tuned, the S_{21}/S_{31} phase difference can be set to 90°. Thus, the QLC operates as a quadrature tunable power splitter. QLC capabilities can be extended by cascading two of them (d-QLC). First, the 3-dB bandwidth is enlarged and the magnitude ratio S_{31}/S_{21} is additionally doubled. For the same capacitance variation, matching and isolation are improved. In a second stage, one output branch of the d-QLC is phase shifted by 90° by using a quarter wavelength transmission line (Fig. 1). The two in-phase outputs of the second stage are then combined through another QLC with fixed capacitors used as a classical 3-dB quadrature hybrid coupler. As long as the input signals of the third stage are in phase, the power levels of the two output Ports 2 and 3 will remain equal. However, the phase quadrature is only acceptable over a 5% bandwidth.

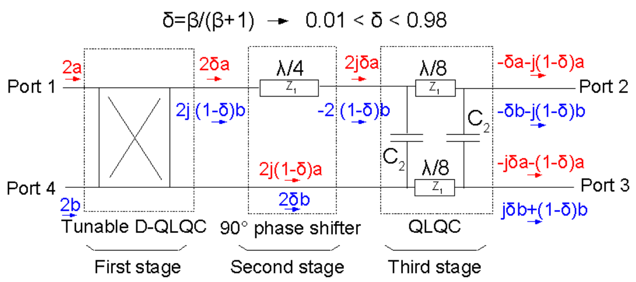


Fig. 1. Topology and theoretical analysis of the d-QLC.

This circuit has been simulated with the IMST EMPIRE software [5]. Using a capacitor ranging from suitable computed values, feeding Port 1 will lead to keep S_{11} and S_{41} below -10 dB with a variable output phase shift (Ports 2&3) ranging from -92° to 91°. When Port 4 is fed, the relative phase shift varies from 89° to 273°. The overall controllable phase shift capability of the circuit is then 367°. It should be noticed that the operating bandwidth directly depends on the bandwidth of the 90° shifts introduced in the second stage and the 3-dB coupler. Here, we use a simple quarter wavelength transmission line but this could be enhanced using a metamaterial phase-less line. The layout of the fabricated structure is presented in Fig. 2. Theoretical developments of the d-QLC are given in [6]–[9]. The d-QLC has been printed on a very thin Duroid substrate (h=0.127mm, ε_r=2.2) and later glued on a metallic ground. A picture of the whole structure is given in Fig. 3.

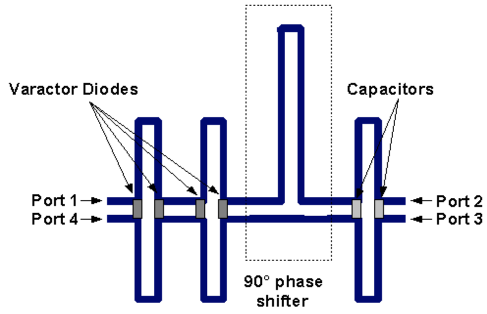


Fig. 2. Layout of the fabricated d-QLC.

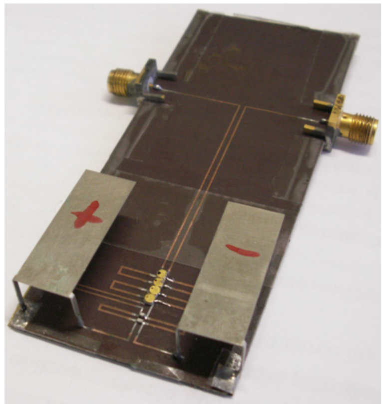
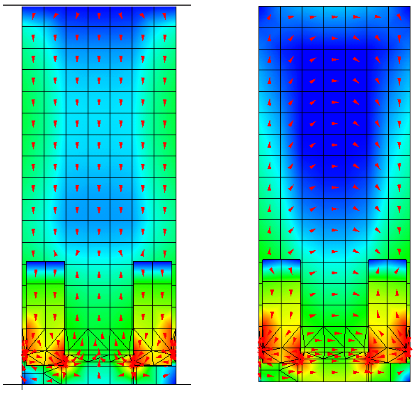


Fig. 3. Photograph of the phased two-element UMTS PIFA on a handset-like chassis.

3. Measurement of the Antenna-Structure

By properly choosing the DC bias of the d-QLC, a specific phase difference can be set between the two PIFAs. For a two-element array, we have chosen to vary this phase difference from 0° to 180°. The matching of the structure is not presented here for sake of brevity, but we succeeded in keeping it below -6 dB over the whole UMTS band for all the different phase values. In Fig. 4a, we present the simulated surface currents flowing on the PIFAs and the PCB when the two antennas are fed in phase at 2 GHz (IE3D Software). It is clearly seen that in-phase currents are flowing on the antennas and more important, vertical currents on the PCB result from this phase configuration (the first radiating mode of the PCB is excited, [10]). In Fig. 4b, we present the simulated surface currents flowing on the PIFAs and the PCB when the two antennas are fed out-of-phase. It is clearly seen that out-of-phase currents are flowing on the antennas but again, really more important, horizontal currents on the PCB result from this phase configuration (the second radiating mode of the PCB is excited, [10]).



(a) (b)

Fig. 4. Simulated (IE3D) surface currents flowing on the PIFAs and the PCB when the two antennas are fed in phase (a) and out-of-phase (b) at 2 GHz

The analysis of the behavior of the structure for both states can be achieved in terms of characteristic modes [11]-[12]. A first mode, resonating at 1.2 GHz is excited for in-phase feeding (Fig. 5), J_y component being the most significant. The dominant λ/2 path L1 can be estimated with (1), where L_1 has been estimated to be ~131 mm. According to the modal analysis, this mode has a quite big bandwidth potential and therefore will still exist around the operating frequency 2 GHz.

$$f_1 \approx \frac{c_0}{2\,L_1} = 1.15\text{ GHz} \qquad (1)$$

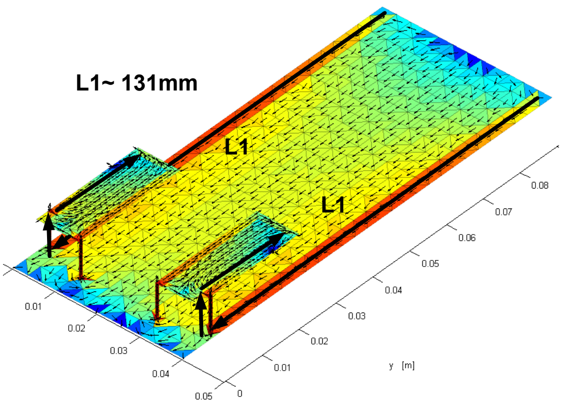


Fig. 5. Simulated surface currents J_1 flowing on the PIFAs and the PCB and associated resonant path of the first mode that corresponds to the case when the two antennas are fed in phase.

A second mode, resonating at 1.85 GHz is excited for out-of-phase feeding (Fig. 6) – now the J_x currents are dominating over the antenna surface. The estimated resonant frequency according to the dominant λ/2 path L_2~90 mm can be evaluated similarly:

$$f_2 \approx \frac{c_0}{2L_2} = 1.7\ \text{GHz}. \qquad (2)$$

"Geometric" resonant frequency estimation as given by (1) and (2) is in good agreement with the results calculated by the characteristic modes (actual eigenvalue behavior is not shown here). Characteristic mode approach also nicely explains the dual-polarization ability since the eigen-currents for both excitation scenarios are more or less orthogonal.

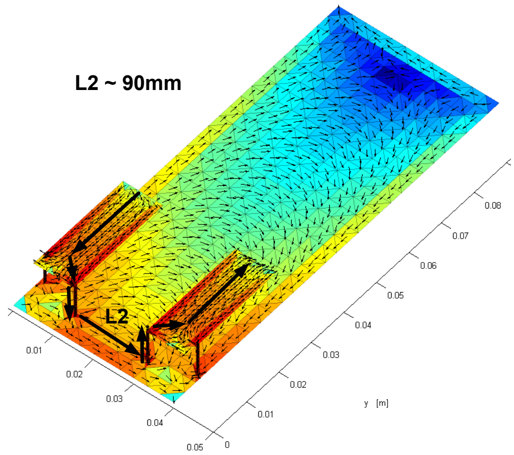


Fig. 6. Simulated surface currents flowing on the PIFAs and the PCB and associated resonant path of the second mode J_2 that corresponds to the case when the two antennas are out-of-phase fed.

In Fig. 7 and 8, we present the simulated and measured radiation patterns obtained with IE3D when the phase difference between the elements are respectively set to 0° and 180°. The simulated patterns are obtained when setting the proper phase on each PIFA, the d-QLC being omitted from this simulation. The measured patterns are obtained with the structure presented in Fig. 3, the d-QLC being part of the set-up. The measured patterns are obtained only in half planes due to practical limitations in our anechoic chamber. The antenna is positioned in the X-Y plane and Z (0°) is the broadside direction of the antennas. In those two situations (0° and 180° phase difference between the elements), one can see that the structure is still pointing in the same direction in the horizontal plane of the PCB (φ=0°) but the polarization of the electric field is turned from vertical to horizontal (Fig. 9). A better 3D representation to visualize the polarization state and magnitude of the E field in both states is given in Fig. 10 based on the visualization technique introduced in [16]. From our best knowledge, this is the first time we can observe such a phenomenon in a UMTS mobile phone even if some attempts have been made at higher frequencies [10, 13]. These two patterns are especially said to be suitable for polarization diversity in MIMO applications [14]. They might be especially suitable for SAR reduction [15]. They can be simply obtained by setting the proper DC bias on the varactor diodes of the d-QLC and choosing which antenna-port is fed.

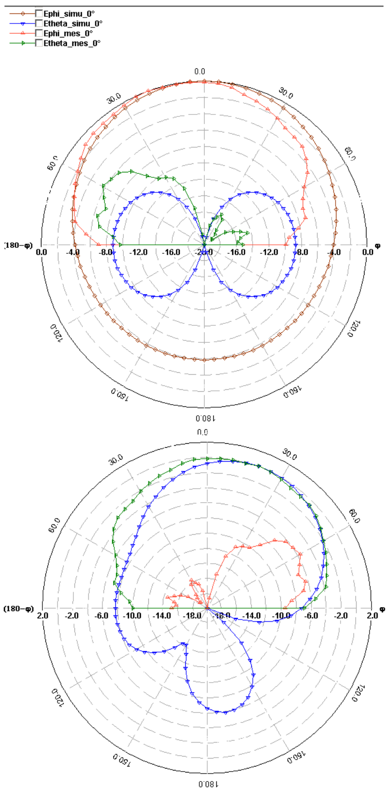


Fig. 7. Simulated and measured radiation patterns of the structure (0° phase difference) in the azimuthal plane of the PCB (upper diagram, φ=0°) and one elevation plane of the PCB (lower diagram, φ=90°).

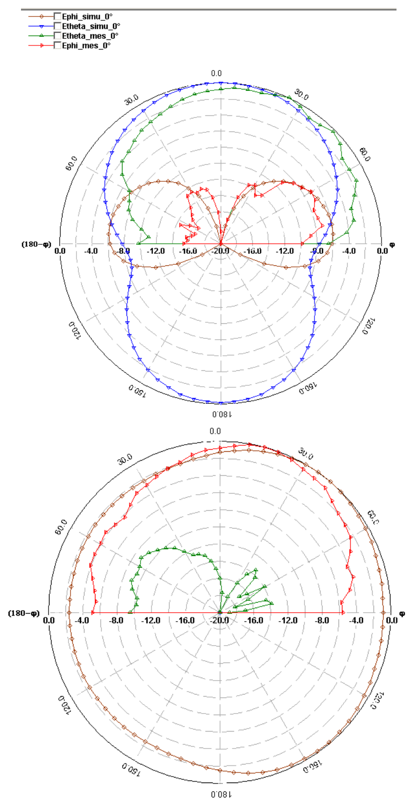
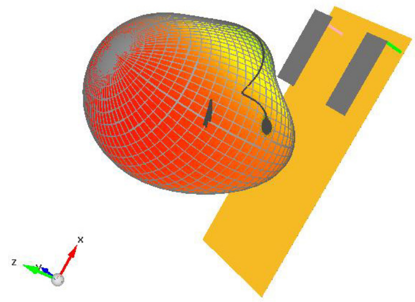
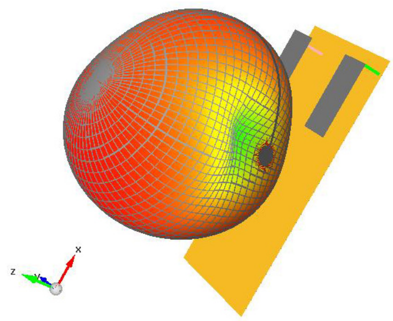


Fig. 8. Simulated and measured radiation patterns of the structure (180° phase difference) in the azimuthal plane of the PCB (upper diagram, φ=0°) and one elevation plane of the PCB (lower diagram, φ=90°).

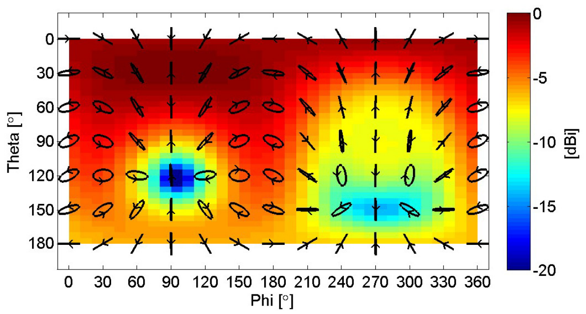


(a)

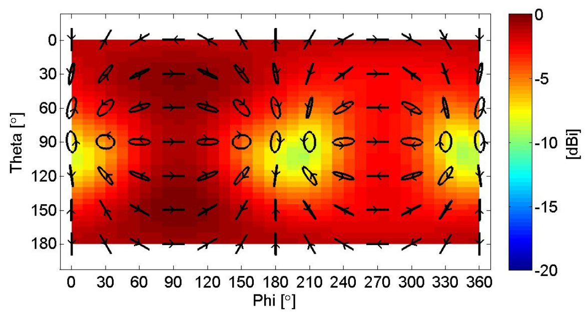


(b)

Fig. 9. Simulated 3D total E field of the two-element PIFA array – (a) 0° phase difference – (b) 180°.



(a)



(b)

Fig. 10. Simulated 3D E-field polarization state and magnitude of the two-element PIFA array – (a) 0° phase difference – (b) 180° phase difference. For each direction, the color represents the realized gain and the ellipses denote the curves that the electric field vector traces as a function of time.

4. Conclusion

In this paper, we described the design of a novel two-antenna UMTS mobile phone structure able to radiate either vertically or horizontally polarized electric fields in the azimuthal plane of the phone depending on which antenna is fed. Potential applications are polarization diversity and SAR reduction. Further work could concentrate on computing the diversity performance in various ideal and realistic propagation environments and also to measure it in a reverberation chamber. The idea will be to check if there is a need to achieve sophisticated diversity polarization scheme at the terminal side of the wireless link.

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