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Reduction of the Mutual Coupling Between Two Planar Inverted-F Antennas Working in Close Frequency Bands

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Original scientific paper

This paper presents a solution to reduce the mutual coupling between two Planar Inverted-F Antennas (PIFAs) working in close frequency bands: DCS1800 (1710-1880 MHz) and UMTS (1920-2170 MHz). The antennas are positioned on the top corner of a ground plane whose size is representative of the Printed Circuit Board (PCB) of a typical mobile phone. Two antenna-systems are designed and several arrangements are studied, especially when suspended line is inserted between the radiators. This line is intended to act as a neutralization device and then reduce the mutual coupling. Several prototypes are fabricated and measured to validate the proposed solution.

Key words: planar inverted-F antennas (PIFAs), small antennas, mutual coupling, isolation, mobile phone, efficiency

1 INTRODUCTION

The rapid increase of wireless communications has induced the development of multiband antennas for multistandards and multimode cellular handsets: GSM (880–960 MHz), DCS (1710–1880 MHz), PCS (1850–1990 MHz) and UMTS (1920–2170 MHz). Consequently, a great amount of solutions using the well known PIFA as an internal radiator has been recently proposed [1–4]. However, if these antennas are able to simultaneously radiate in all of these frequency bands, they are always fed as single port devices which does not match with the »one output by mode« radio front-end modules available on the wireless industry market. As a result, compact two-port antennas with high decoupling are now a new target for antenna engineers and researchers.

From the author's knowledge, no studies have been reported on this specific problem dealing simultaneously with PIFAs, on a finite-sized ground plane and working in very close frequency bands. However, it is possible to find interesting work about the physical causes of the mutual coupling between microstrip antennas etched on a dielectric substrate above an infinite ground plane [5]. The mutual coupling between two identical PIFAs located on a large ground plane is also studied in [6, 7]. Other results between monopole-type antennas on a finite size ground plane can be found in [8], but the two operating frequencies are largely separated. One solution to decrease the mutual coupling is therefore reported in [9], where two thin PIFAs are working on a small PCB, at very different frequencies and positioned on a small PCB. It consists of inserting high Q values lumped components at the feeding point of one antenna to achieve a blocking filter at the resonant frequency of the other. If this solution gives significant results in terms of decoupling, it inherently leads to a reduction of the available bandwidth and the efficiency values.

In this paper we propose a method to decrease the mutual coupling between two PIFAs dedicated to DCS and UMTS systems and positioned at the top edge of a 100×40 mm^2 PCB. First, two monoband antennas are designed to respectively radiate in those frequency bands and the mutual coupling is studied with the help of the electromagnetic simulation software tool IE3D [10]. Then, our solution consisting in inserting a suspended line between the PIFAs is implemented. This method is then applied to the combination of a GSM/DCS and UMTS antennas with some further enhancement. Several prototypes are fabricated and measured. The results are compared with simulations to validate this technique.

2 DCS AND UMTS MONOBAND PIFAs

2.1 Separated design of the antennas

The two PIFAs were designed on a separate 100×40 mm^2 ground plane. The goal of the DCS antenna was to cover the 1710–1880 MHz band

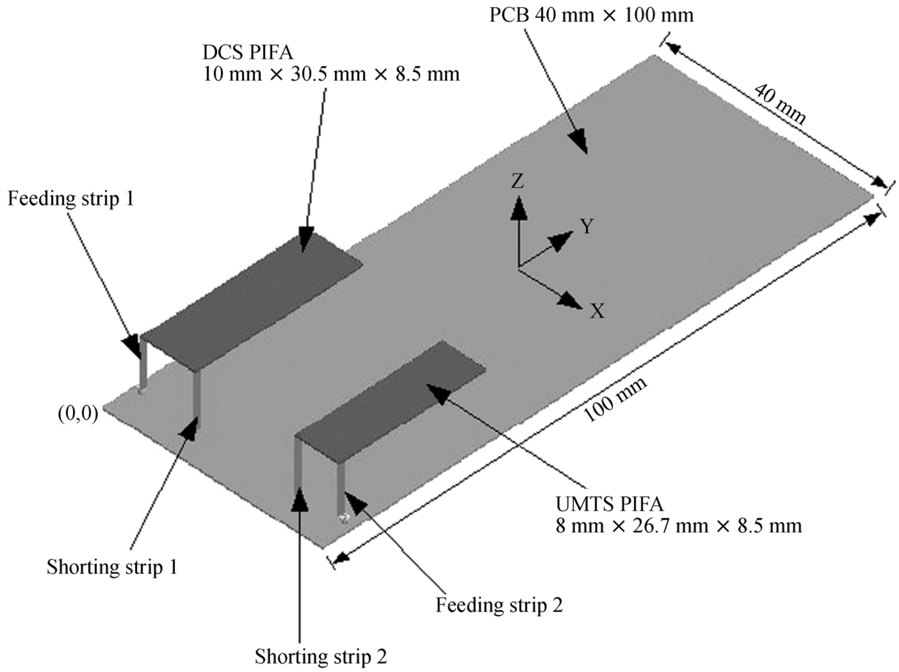

Fig. 1 3D View of the arrangement of the DCS and UMTS PIFAs on the same PCB

with the best return loss as possible while the UMTS antenna had to cover the 1920–2170 MHz band with the same requirement. Each antenna was made of a main plate, fed by a 1 mm wide metallic strip soldered to a SMA connector. For the quarter-wavelength characteristic, this plate was connected to the ground by a shorting strip having the same width. The air thickness between the radiators and the ground plane was set to 8.5 mm. The main parameters to optimize were the length and the width of the PIFA as well as the relative position of the feeding and the shorting strips. The final dimensions of the DCS radiator were found to be 30.5×10 mm^2 and 26.7×8 mm^2 for the UMTS antenna. Two prototypes were fabricated with Nickel Silver material (Cu, Ni, Zn, conductivity $\sigma = 4 \cdot 10^6$ S/m) having a 3 mm thickness. A very good agreement was observed between experimental and simulated curves. The return loss was better than –7 dB in the DCS band and better than –6 dB for the UMTS standard (a return loss less than –6 dB is usually considered as an acceptable value by mobile phone antenna designers).

2.2 Association of the antennas

The two PIFAs were then placed together on the top edge of the PCB with their own feeding strips denoted as port 1 for the DCS element whereas port 2 for the UMTS (Figure 1). We choose to position both shorting strips in front of each other as this configuration is experimentally known to generate better isolation between the antennas. A top view of the structure is shown in Figure 2 with the origin of the coordinates taken on the left corner of the PCB $(x,y) = (0,0)$. The antennas are edge-to-edge spaced by $d = 18$ mm with their DCS and UMTS feeding strips respectively located at ($x = 2$ mm, $y = 5$ mm) and ($x = 38$ mm, $y = 5$ mm). Compared to simulations from Section 2.1, the association of these antennas on the same PCB resulted in small

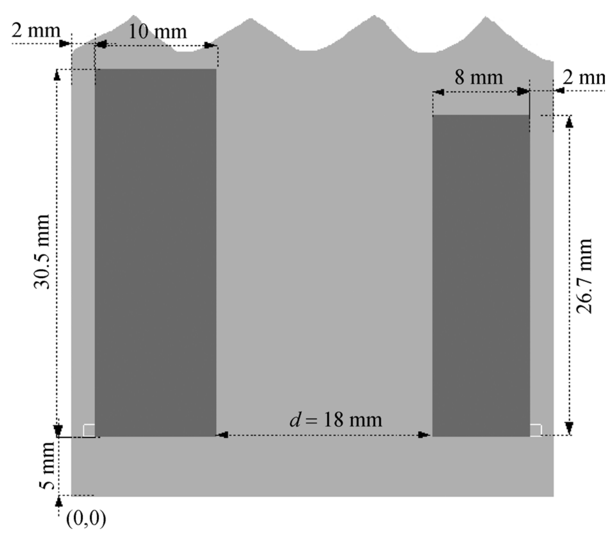

Fig. 2 Top view of the arrangement of the DCS and UMTS PIFAs on the same PCB

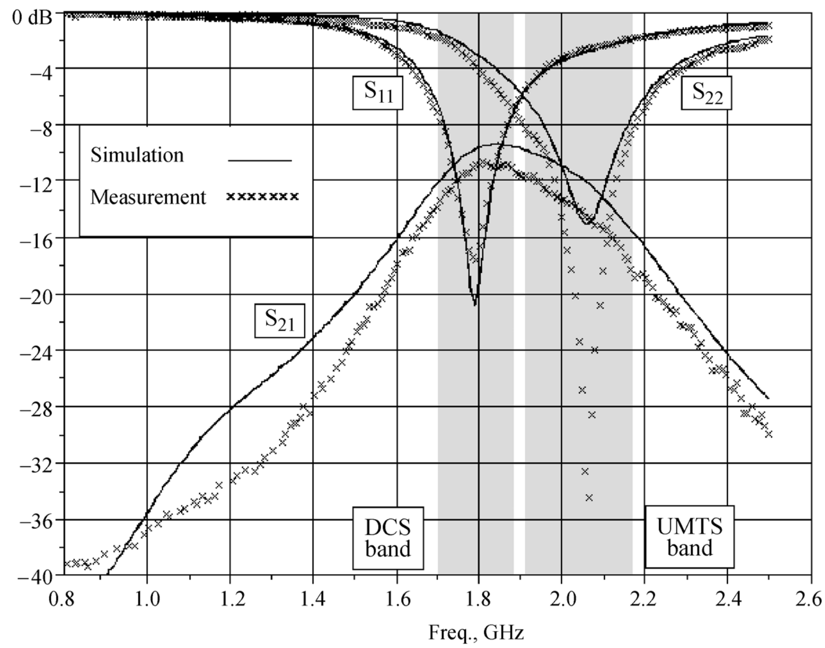

Fig. 3 Simulated and measured S_{11}, S_{22}, S_{21} of the DCS/UMTS PIFAs when shorting strips are facing

frequency shifts of their resonances (less than 5 %), however without any degradation of their bandwidths.

A prototype of this antenna-system was fabricated using Nickel Silver material. The measurements were done with the SMA outputs of the DCS and UMTS PIFAs simultaneously connected to ports N°1 and N°2 of a Vector Network Analyzer via coaxial cables circled by ferrite chokes. For each antenna, the simulated and measured reflection coefficients are shown in Figure 3, as well as their isolation. A very good agreement is seen between all these curves. The magnitude of the measured S_{21} parameter reaches a maximum (minimum isolation) of –10.6 dB at 1.81 GHz where the S_{11} and S_{22} curves are approximately crossing. These results are consistent with the data reported in [6, 7]. They are even better if we take into account that our radiators are only separated by a distance of 0.11 λ_0 and placed on a 0.62 $\lambda_0 \times 0.25$ λ_0 ground plane.

Only few authors have already tried to explain the physical causes of the mutual coupling between patch antennas. It appears that it is made of a combination of the near-field and far-field coupling as reported in [5]. In our case, surface wave coupling is not involve but the mutual coupling phehomenon is even more complicated with a combination of the electromagnetic coupling from the open end of the PIFAs [6], the magnetic coupling from the short-circuit strips where a large current is flowing [7, 11], plus the PCB contribution as it is a fraction of the operating wavelength and thus an obvious radiating element where strong surface currents are flowing [8]. Dealing with the antenna's positions, these currents have the possibility to add or destruct at each feeding strip. We decided to take into account the constraints of the mobile phone designer's that is the antennas are only allowed to take few positions on the PCB due to electronic components occupancies and the next step was then to improve their mutual coupling.

2.3 Reduction of the mutual coupling

The idea was to compensate for the complex existing electromagnetic coupling of this structure by introducing an opposite coupling. It was supposed that this could be done by a neutralization effect when linking the two antennas by a suspended line, positioned at the same height as the antennas. Several simulations were conducted to find the optimal location, length and width of this line. It was found that this line had to be connected in a low impedance area of the PIFAs i.e. far away from its open end where the voltage and the charges are maxima, but rather in the vicinity of the feeding and the shorting strips where the currents have the highest intensity. We also studied the level of the mutual coupling as a function of the width and the length line which, in turns, corresponds to vary its characteristic impedance. These parameters were found to have a great influence. One promising structure was found when linking the shorting strips of the PIFAs by a $18 \times 0.5\,mm^2$ line (Figure 4).

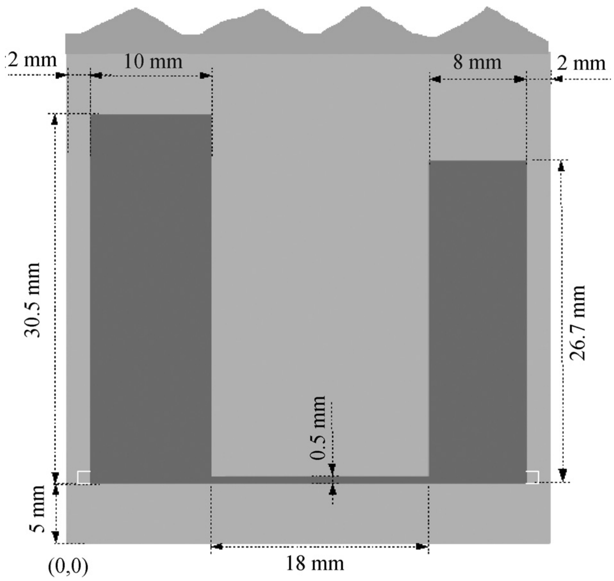

Fig. 4 Top view of the arrangement of the PIFAs with the shorting strips facing and linked by a suspended line (length = 18 mm, width = 0.5 mm)

A small frequency shift (less than 4 %) toward the high frequencies appeared when linking the PIFAs however, without any degradation of their bandwidths. The simulated and measured scattering parameters are shown in Figure 5. A very good agreement is found between all these curves. The S_{21} parameter exhibits now a flat shape with a magnitude level always below –20 dB. Considering the results of the initial structure (Figure 3), a minimum improvement of 10 dB is revealed on the whole bandwidth.

The line acts like a neutralization device by picking up a certain amount of the signal on the UMTS shorting strip and bringing it back to the DCS PIFA producing an opposite coupling to the existing one. Positioning the line on the shorting strip i.e. in a very low impedance area of the PIFA, and ending it in an area with the same low impedance behavior consists in picking some amount of the signal via an inductance divider. In these areas, inductances are low, voltages too: the impedance does not vary so much with frequency neither the amplitude nor the phase of the picked signal. This is why the neutralization effect introduced by the link is efficient on a large frequency band. The question is how to pick the correct (current intensity) signal on one antenna and reinject it to maximize the isolation. We conducted a parametric study where the width and the length of the link were progressively varied. All the simulated cases achieved the same flat shape of the S_{21} parameter curve as the one encountered in Figure 5. It was found that some combinations of width and length were leading to better minima which indicates that a good choice of these parameters can achieve very low mutual coupling on the whole bandwidth. Particularly, an optimum isolation of –20.8 dB was found for a 30.5×0.3 mm^2 suspended line.

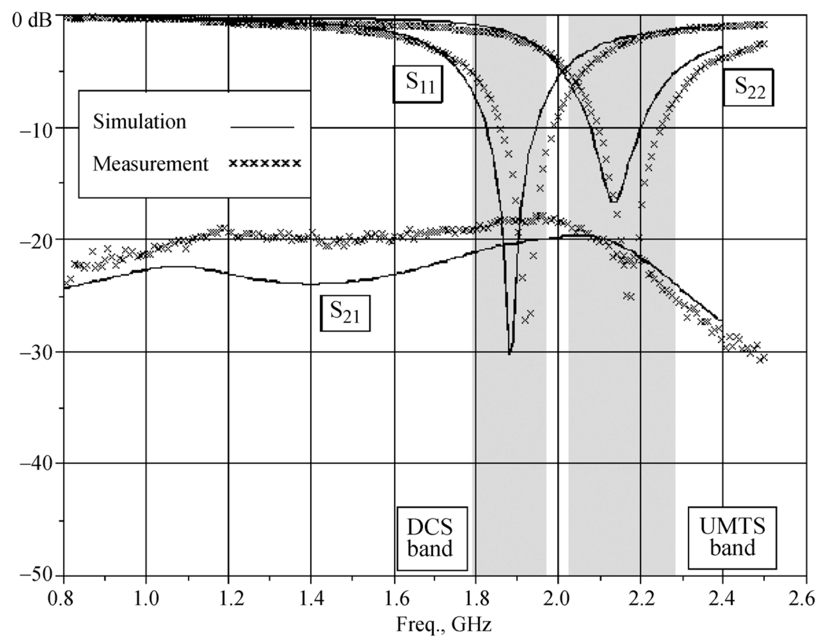

Fig. 5 Simulated and measured S_{11}, S_{22}, S_{21} of the PIFAs arrangement when the shorting strips are facing and linked by a suspended link (W = 0.5 mm, L = 18 mm)

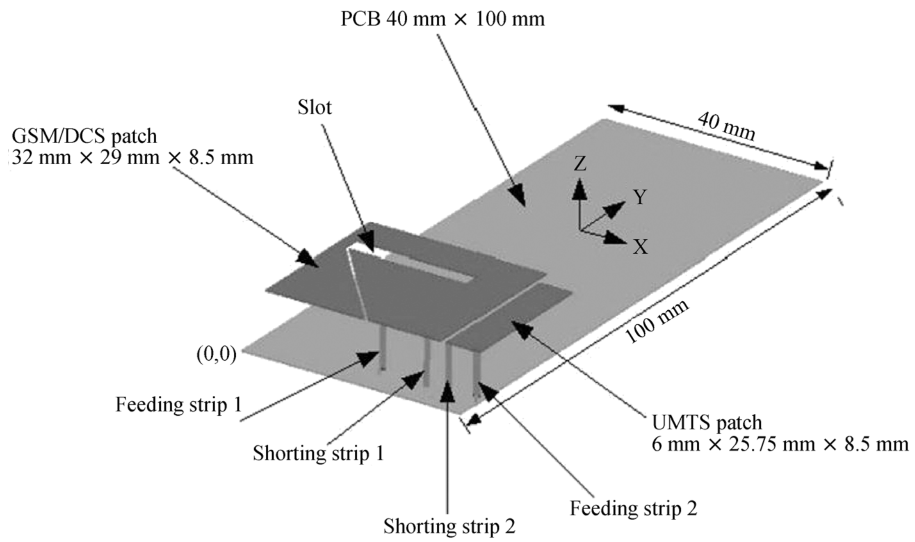

Fig. 6 3D view of the GSM/DCS and UMTS antenna-system without any neutralization line

3 MUTUAL COUPLING BETWEEN A GSM/DCS AND A UMTS PIFA

The neutralization technique was also applied to a more practical structure that can be encountered in dual mode tri-band celular handsets: very closely spaced PIFAs, and independently fed to respectively operate in the GSM900/DCS1800 and UMTS standards. The previous UMTS PIFA was used as the 3G monoband antenna. The GSM/DCS1800 antenna was obtained by slightly modifying the dimensions of a previous concept, extensively described in [1, 2]. The main plate was found to be 32×29 mm^2 to resonate around 940 MHz and 1810 MHz.

The two antennas were then placed together at the top edge of the PCB with their feeds called port1 for the dual-band element and port2 for the UMTS radiator. Their shorting strips were positioned in front of each other (Figure 6). The antennas were separated by a 1 mm gap: 0.005 λ_0 at 1.8 GHz.

A prototype of this antenna-system was fabricated using Nickel Silver material. The simulated (Figure 8) and measured (Figure 9) reflection coefficients on each port were found to be in a good agreement, even if in the higher bands we revealed a 10 % shift towards the low frequencies of the measured curves (Figure 9). An isolation of 9.8 dB was measured (Figure 11) which is just over the expected value (11 dB, Figure 10). Even if the measured S_{21} is quite low for so closely spaced antennas, too much power is lost in the termination of the second antenna when the one is radiating: the isolation must be increased to achieve an efficient two-port antenna-system. One additional optimized structure has been designed, fabricated and tested where the main changes with the previous one were a swap of the feeding and the shorting strips (in both PIFAs) to make the feeding strips facing and the introduction of a meandered suspended line linking the shorting strips of the antennas (Figure 7).

The introduction of the neutralization device induced a small frequency shift of the reflection coefficient of both antennas in the upper bands (Figures 8 and 9). However, it can been seen in simulation (Figure 10) and measurement (Figure 11)

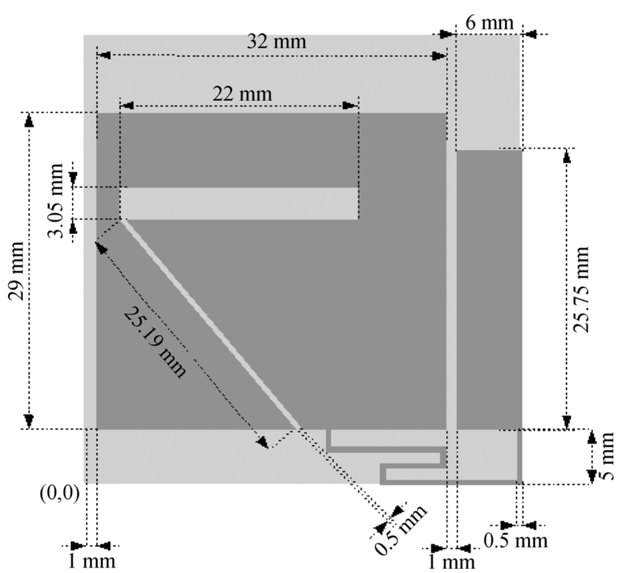

Fig. 7 Top view of the GSM/DCS and UMTS antenna-system with a neutralization line (feeding and shorting strips have been swapped when compared with the structure of Figure 6)

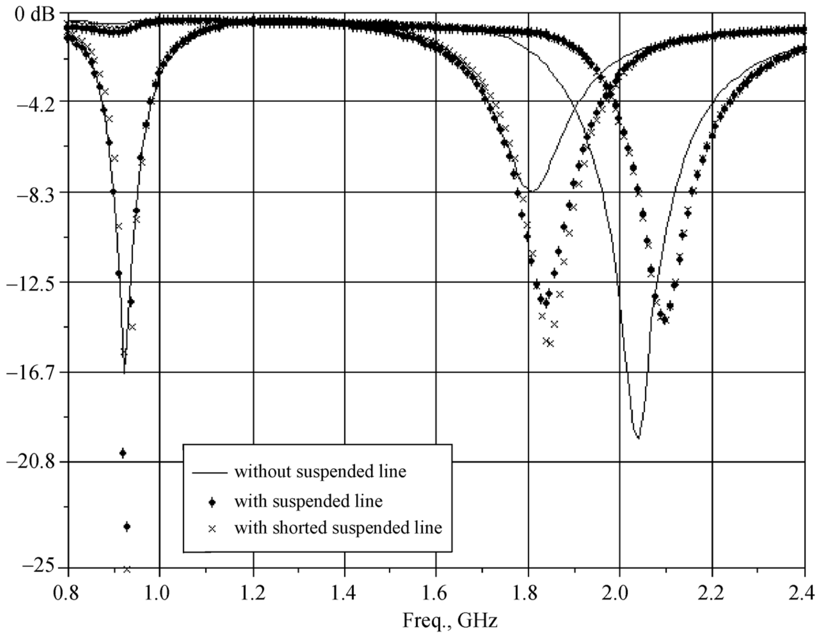

Fig. 8 Simulated S_{11} and S_{22} of the different GSM/DCS and UMTS antenna-systems

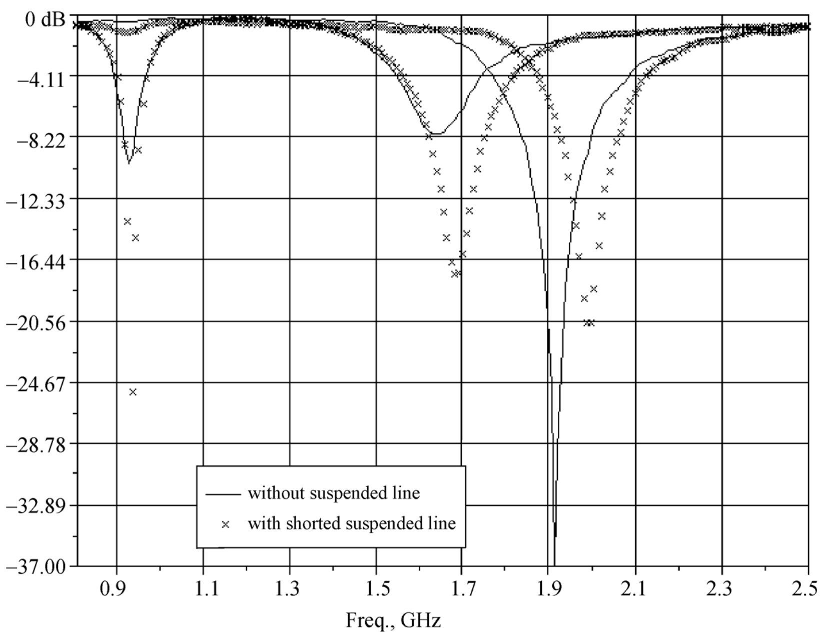

Fig. 9 Measured S_{11} and S_{22} of the different GSM/DCS and UMTS antenna-systems

that joining these strips resulted in enhancing the isolation to 15 dB in the DCS-UMTS bands, at the expense of an decrease of the S_{21} to –12 dB in the GSM band. To overcome this effect and get back to the previous value in this band, it was found helpful to introduce a low-pass filter effect by short circuiting the suspended line in its middle (connection to the PCB via a vertical thin strip). The resonant frequencies of the structure were again slightly detuned by all these operations without any degradation of the bandwidths (Figure 8 and 9). The measurement and simulation curves of the S_{11} and S_{22} were found to be in a very good agreement. In Figure 10, we can see the enhancement of the insertion loss in the GSM band when short circuiting the suspended line. A very good agreement is found when comparing these curves with the corresponding ones in Figure 11.

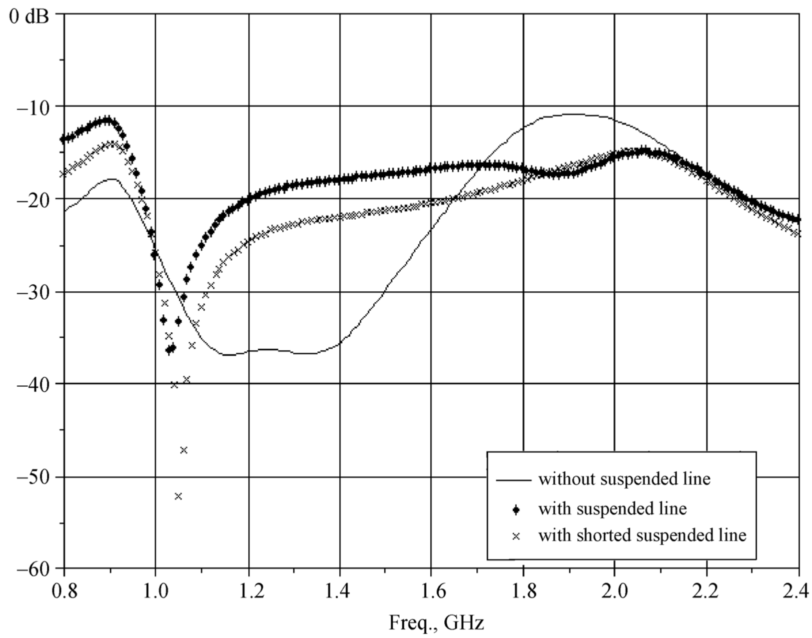

Fig. 10 Simulated S_{21} of the different GSM/DCS and UMTS antenna-systems

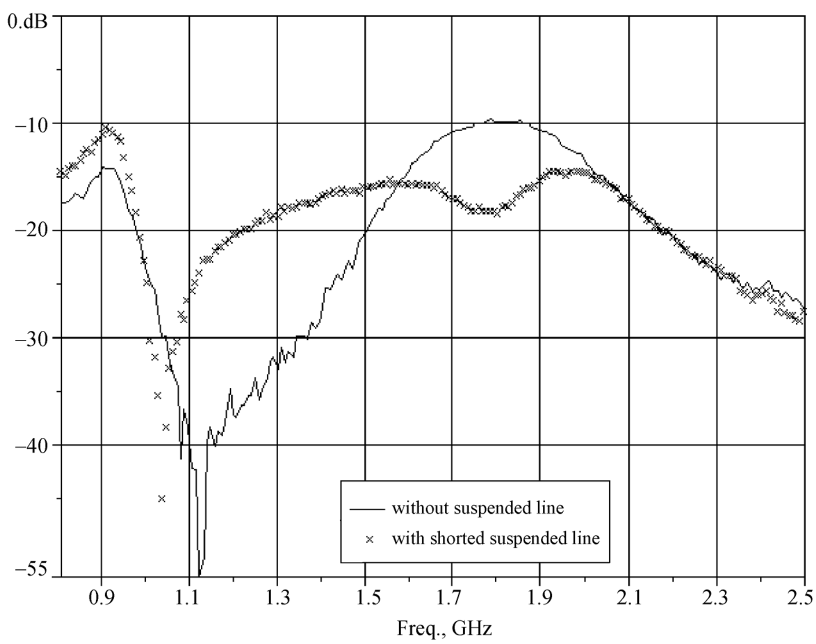

Fig. 11 Measured S_{21} of two GSM/DCS and UMTS antenna-systems

4 CONCLUSION

This paper shows that it is was possible to reduce the mutual coupling between two PIFAs positioned on the corner of a finite ground plane and working in very close frequency bands. A neutralization technique has proved to be efficient for two different configurations. It consists in inserting a suspended line between the shorting strips of the PIFAs to create a neutralization effect by picking up some signal on one antenna and bringing it back to the other with the proper amplitude and phase. Several prototypes have been made/built and measured/tested to validate the simulation results. The main advantages of this solution consist largely in its simplicity and the occupied space: it is physically acceptable for practical implementations in realistic handsets as the PIFAs are able to stay closely spaced and positioned at the top edge of the PCB. To further extend the usability of our concept, we are actually focusing on the implementation of this technique when the PIFAs are operating in the same frequency band for diversity and MIMO applications.

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Smanjenje sprege između dviju planarnih obrnutih-F antena s područjem rada u bliskim frekvencijskim pojasima. U radu je predstavljeno rješenje smanjenja sprege dviju planarnih obrnutih-F antena (PIFA) s područjem rada u bliskim frekvencijskim pojasima: DCS1800 (1710–1880 MHz) i UMTS (1920–2170 MHz). Antene su postavljene u vrh uzemljene ravnine čija je veličina predstavnik tiskanih pločica (PCB) tipičnih mobilnih telefonskih uređaja. Tri antene su konstruirane i nekoliko modifikacija je proučavano, posebice u vezi postavljanja neaktivne prijenosne linije između njih. Ta prijenosna linija je zamišljena da služi kao neutralizirajuća komponenta i da stoga smanjuje međusobnu spregu. Nekoliko prototipova je izvedeno i izmjereno u cilju verifikacije predloženog rješenja.

Ključne riječi: planarna obrnuta-F antena (PIFA), male antene, sprega, izolacija, mobilna telefonija, efikasnost

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