Analysis of PIFA antenna coupling in nearby traces and reduction with CSRRs in PCB at 2.45 GHz

Ignacio Gil* and Raúl Fernández-García
Department of Electronic Engineering
Universitat Politècnica de Catalunya
Colom 1, 08222 Terrassa, Spain
*e-mail: ignasi.gil@upc.edu

***Abstract*—The electromagnetic coupling of a conventional planar inverted-F antenna (PIFA) antenna in the nearby layout traces is investigated in the 2.45 GHz industrial, scientific and medical radio band. The impact of a complementary split-ring resonator (CSRR) to reduce the coupling as well as the overall antenna performance after perturbing the ground plane is reported. 2.5D and 3D full electromagnetic simulations are used to design and analyze the proposed layouts. Experimental results validate the CSRR usefulness to significantly decrease the antenna coupling.**

Keywords—Printed antennas, electromagnetic coupling, complementary split ring resonator, metamaterial.

I. Introduction

Antennas are a fundamental device in wireless systems for the transmission and reception of electromagnetic waves. The antenna resonance frequency is highly sensitive to the surrounding layout and nearby electronic circuits. Moreover, the impact of the antenna radiation pattern in the circuit performance must be taken into account with regard to the electromagnetic compatibility (EMC) issues. Recently, some works have been reported in order to reduce the coupling between printed antennas and nearby conducting elements or electronic components. However, these solutions require three-dimensional metal pattern or extra area in order to modify the final layout [1-2].

The planar inverted-F antenna (PIFA) is a common antenna for portable devices because of its excellent balance between low-profile, low-cost and performance [3]. The PIFA behaves like a monopole printed on printed circuit boards (PCBs), presenting a ground point and a feed point along the main resonant structure. Typical PIFA performance consists of bandwidth≥100MHz, VSWR≤2.5 and efficiency≥60%. Those antennas are typically used for commercial standard applications included in the 2.45 GHz industrial, scientific and medical (ISM) radio band [4-5]. Meanwhile, the complementary split-ring resonators (CSRRs) are used to implement a type of metamaterials, the so-called single negative effective media (SNG) with electric permittivity, $\varepsilon<0$ [6]. CSRRs consist of two concentric split rings with opposite cuts etched in a ground plane (Fig. 1) and they are excited by an applied electric field, parallel to the CSRRs axis (normal to the CSRR plane). Those electrical resonance properties have been applied in recent works to mitigate simultaneous switching noise propagation in high-speed printed circuits boards (PCBs) [7] and to reduce the EMI susceptibility of small signal analog circuits [8].

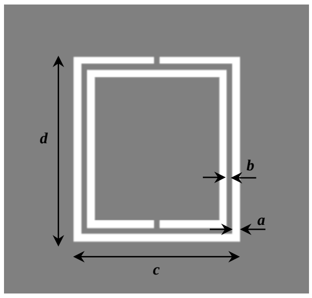

Fig. 1. Topology of the CSRR with its relevant dimensions. Metallization zones are depicted in grey.

In this paper, the coupling impact of a PIFA on the surrounding strip layout elements on the same PCBs has been investigated at 2.45 GHz. In addition, the complementary split-ring resonators (CSRRs) have been implemented in order to reduce the antenna coupling in the nearby traces. The level of coupling reduction has been evaluated as well as the impact on the antenna performance due to the ground perturbation.

The paper is organized as follows. In Section II the PIFA electromagnetic coupling issues considering several layout topologies are discussed by using 2.5D PCB simulations (based on the method of moments) in order to evaluate the corresponding S-parameters. In addition, 3D electromagnetic simulations (based on finite-difference time-domain, FDTD) have been performed to analyze the electric field impact in near-field regime. Moreover, the impact of the CSRRs in terms of coupling reduction and antenna performance are reported. In Section III a prototype antenna, including coupling and CSRR effect has been implemented and tested in order to confirm the previous study. Finally, the main conclusions are drawn and summarized in Section IV.

II. PIFA Electromagnetic Coupling Discussion

A. PIFA antenna and layout coupling

The proposed PIFA and the potential victim layout strip are shown in Fig. 2. A low-cost commercial FR4 substrate (dielectric constant ε_r=4.6, thickness h=1.53 mm) has been used. The antenna is designed to operate at 2.45 GHz. In order to investigate the impact of the coupling between the PIFA and

This work was supported by the Spanish Government-MINECO under Project TEC2013-41996-R and AGAUR 2014 SGR 375.

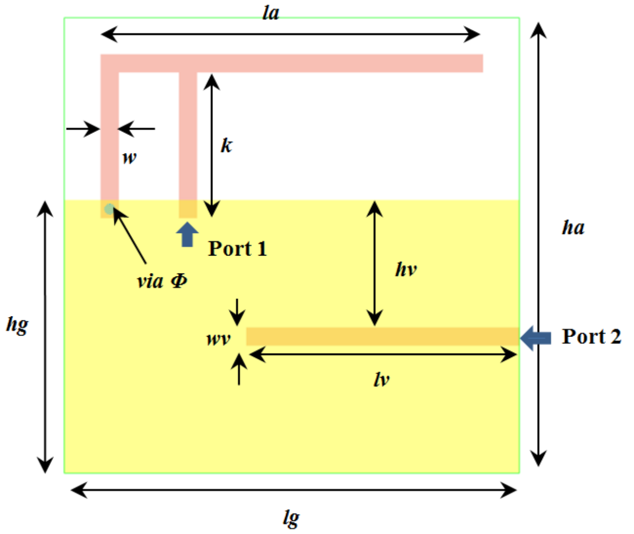

Fig. 2. Geometry of the considered PIFA and victim strip.

the nearby layout victim trace, a variable separation between both has been considered in 4 cases. The layout geometrical parameters are summarized in Table I. The antenna performance has been simulated by means of the commercial *Agilent Momentum* software in order to obtain the antenna parameters. Figs. 3 and 4 show the antenna return losses and the electric far-field radiation pattern. The antenna main parameters @ 2.45 GHz are: gain=0.41 dBi, directivity=2.63 dBi and efficiency=60 %.

The electromagnetic coupling has been evaluated by means of the S21 parameters between the feeding antenna port (Port 1) and the victim port (Port 2). Fig. 5 illustrates the coupling for the 4 analyzed cases. Obviously, the higher the separation between the PIFA and the victim, the higher the coupling level. This fact is due to the radiation pattern of the antenna. The minimum coupling @ 2.45 GHz corresponds to -13.4 dB (case 1) whereas the maximum coupling level is -7.7 dB (case 4). No significant variation is appreciated for the antenna parameters including the victim trace impact (Table II).

TABLE I. DESIGN PARAMETERS OF THE PROPOSED ANTENNA AND VICTIM STRIP

PIFA dimensions (mm)				Victim dimensions (mm)			
ha	25	*la*	21	*lv*	15	*hv (case 2)*	6
lg	25	*k*	8	*wv*	1	*hv (case 3)*	8
hg	15	*via Φ*	0.6	*hv (case 1)*	4	*hv (case 4)*	10
w	1						

TABLE II. PIFA PERFORMANCE @ 2.45 GHZ

Performance	PIFA	Case 1	Case 2	Case 3	Case 4
Gain (dBi)	0.41	0.40	0.43	0.56	0.56
Directivity (dBi)	2.63	2.62	2.62	2.66	2.64
Efficiency (%)	60.00	59.91	60.51	61.65	61.97

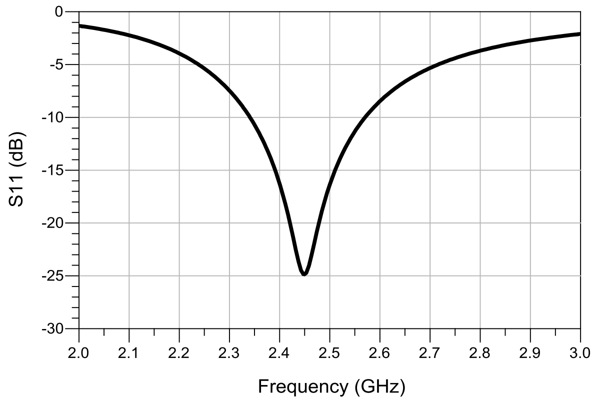

Fig. 3. Simulated PIFA return losses.

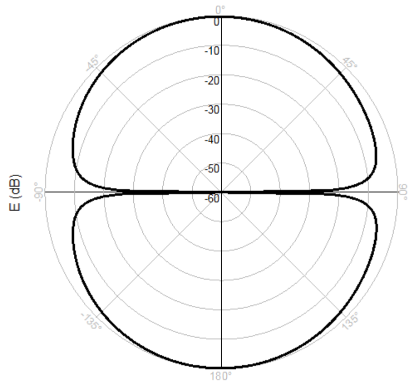

Fig. 4. PIFA normalized radiation pattern for ϕ=90º at 2.45 GHz.

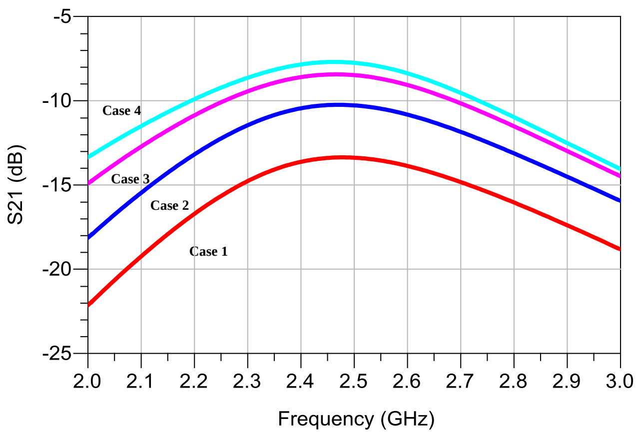

Fig. 5. Simulated electromagnetic coupling between the PIFA and the victim trace.

B. CSRR coupling reduction

To reduce the antenna coupling impact, a rectangular CSRR has been designed and etched in the ground plane, underneath the victim trace. The width and separation of the rings has been fixed at the minimum resolution of the manufacturing process, *a*=*b*=0.3 mm (all the PCBs were manufactured by means of a LPKF S62 drilling machine), whereas the perimeter dimensions are *c*=4.6 mm and *d*=10.4 mm in order to obtain a stop-band frequency response at 2.45 GHz, to mitigate a potential ISM band interference. An example of the proposed layout is shown in Fig. 6 (case 2). As a result of the CSRR impact, the coupling level is significantly reduced. Fig. 7 depicts the S21 parameter including the CSRR effect for the cases under analysis. The maximum coupling reduction is obtained for case 2 (attenuation of 18.8 dB). Moreover, the antenna parameters are not significantly affected by the CSRR perturbation. The maximum deviation with regard to the conventional PIFA corresponds to the cases 1: gain difference 0.15 dBi, directivity 0.03 dBi and efficiency 1.92 %. Indeed, the antenna return losses and radiation pattern are practically unaltered (Figs. 8-9). Table III summarizes the obtained results for all the studied cases.

TABLE III. PIFA PERFORMANCE AND COUPLING REDUCTION WITH CSRR @ 2.45 GHz

Performance	PIFA	Case 1	Case 2	Case 3	Case 4
Coupling S21 (dB)	-	-13.4	-10.3	-8.4	-7.7
CSRR Coupling reduction (dB)	-	4.2	18.8	12.9	16.1
Gain (dBi)	0.41	0.56	0.29	0.31	0.38
Directivity (dBi)	2.63	2.66	2.66	2.64	2.63
Efficiency (%)	60.00	61.58	58.03	58.52	59.51

Alternatively, the near-field effect of the electromagnetic coupling and CSRR has been investigated by using the FDTD method by means of the SEMCAD X [9] platform (3D). Fig. 10 shows the electric field distribution on the PCB for case 2 with and without CSRR. It can be observed the CSRR resonance effect at 2.45 GHz, due to its LC tank equivalent circuit behavior at the maximum coupling frequency.

III. EXPERIMENTAL

The antenna performance has been tested by using a 50 Ω RG405 coaxial cable with a length equivalent to λ/2 in order to obtain the same input impedance at the measuring port. As a reference, the case 2 detailed in the previous Section has been tested. Fig. 11 depicts the implemented boards. The S-parameters have been measured by means of an *Agilent FieldFox N9916A Microwave Analyzer* by selecting the vector network analyser mode. The experimental return losses of the designed PIFA are depicted in Fig. 12. It can be observed a good performance of the antenna, since |S11|<-10 dB at the operation frequency. Fig. 13 illustrates the PIFA coupling to the victim trace as well as the impact of the CSRR implementation. As can be observed, the electromagnetic simulation overestimates the level of coupling between the PIFA and the victim trace, as well as the level of coupling reduction due to the CSRR. An experimental 7 dB coupling reduction is achieved by using a single CSRR at 2.45 GHz. This level could be improved by adding extra sub-wavelength resonator stages.

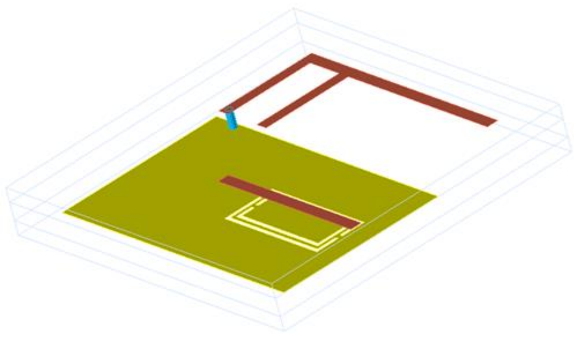

Fig. 6. Layout including CSRR (case 2).

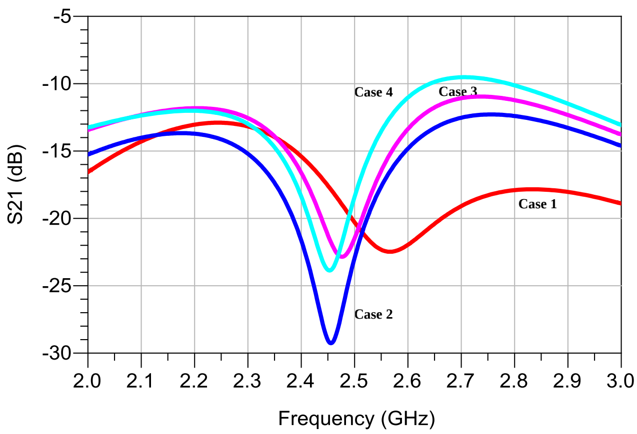

Fig. 7. Simulated electromagnetic coupling between the PIFA and the victim trace including the CSRR effect.

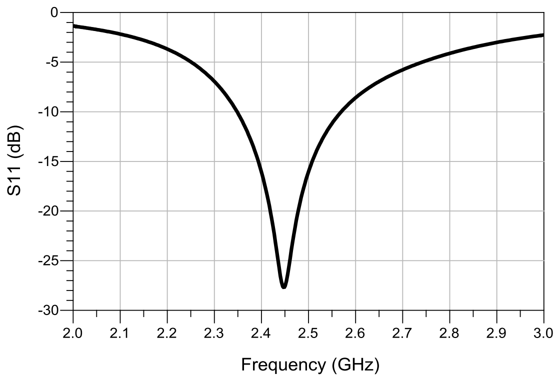

Fig. 8. Simulated PIFA return losses including the victim trace and CSRR effect (case 2).

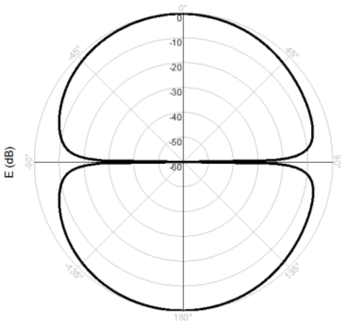

Fig. 9. PIFA normalized radiation pattern for ϕ=90º at 2.45 GHz including the victim trace and CSRR effect (case 2).

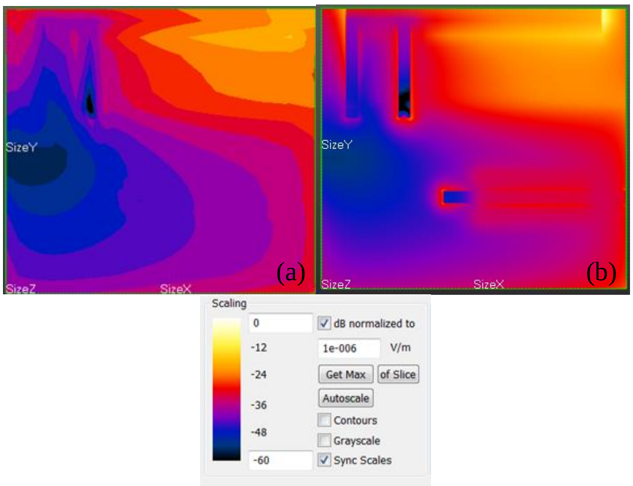

Fig. 10. Near-field radiated electric field for the PCB case 2 (a) without and (b) with CSRR.

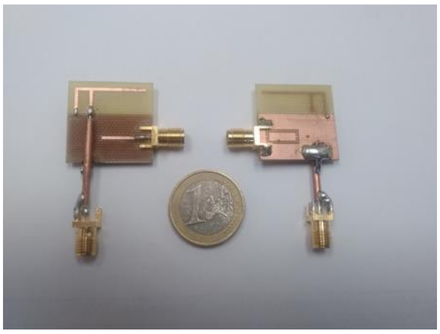

Fig. 11. Tested PCBs.

IV. Conclusion

In this work, the CSRR has been used in order to improve the electromagnetic compatibility of a PIFA antenna with nearby conducting elements. The electromagnetic coupling in several cases depending on the trace distance has been studied. The experimental results show a significant reduction of the

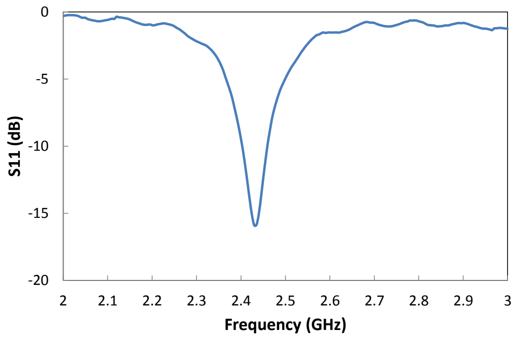

Fig. 12. Experimental PIFA return losses.

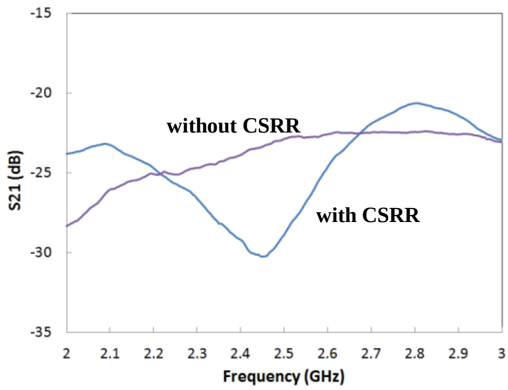

Fig. 13. Experimental electromagnetic coupling between the PIFA and the victim trace (case 2).

coupling with CSRRs. In addition, no impact in the antenna performance due to the PCB ground plane perturbation is observed. The results demonstrated the usefulness of implementing CSRR as a method to reduce the coupling between antenna and nearby traces.

References

[1] K.–L. Wong, C.-H. Chang and Y.-C. Lin, "Printed PIFA EM compatible with nearby conducting elements", IEEE Transactions on Antennas and Propagation, vol. 55, pp. 2919–2922, October 2007.

[2] A.C.K. Mak, C. R. Rowell and R. D. Murch , "Isolation enhancement between two closely packed antennas", IEEE Transactions on Antennas and Propagation, vol. 56, pp. 3411–3419, November 2008.

[3] K. L. Wong, "Planar antennas for wireless communications", John Wiley & Sons Inc., 2003.

[4] C.-T. Lee and K.-L. Wong, "Uniplanar printed coupled-fed PIFA with a band-notching slit for WLAN/WiMAX operation in the laptop computer", IEEE Transactions on Antennas and Propagation, vol. 57, pp. 1252–1258, April 2009.

[5] "AN-1811 Bluetooth Antenna Design", Texas Instruments Application Report, May 2013.

[6] F. Falcone, T. Lopetegi, J.D. Baena, E. Marqués, F. Martín and M. Sorolla, "Effective negative- ε stop-band microstrip lines based on complementary split ring resonators", IEEE Microwave and Wireless Component Letters, vol. 14, pp. 280–282, June 2004.

[7] M. M. Bait-Suwailam and O. M. Ramahi, "Ultrawideband mitigation of simultaneous switching noise and EMI reduction in high-speed PCBs using complementary split-ring resonators", IEEE Trans. on Electromagnetic Compatibility, vol. 54, pp. 389-396, April 2012.

[8] D. Pérez, I. Gil, J. Gago, R. Fernández, J. Balcells, D. González, N. Berbel and J. Mon, “Reduction of EMI susceptibility in circuits based on operational amplifiers using complementary split-ring resonators”, IEEE Trans. on Components, Packaging and Manufacturing Technology, vol. 2, pp. 240-247 February 2012.

[9] Schmid & Partner Engineering AG (SPEAG). SEMCAD. [Online]. Available: http://www.speag.com