Analysis of the Specific Absorption Rate in Handset Antennas with Slotted Ground Planes

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Abstract— **The study of the interaction between human head and handset antennas should be taken into account since all the mobile phones have to guarantee a biological compatibility. This research analyzes several antennas with different slotted ground planes in terms of free space and also in terms of human head interaction. The main objective is to compare the measured bandwidth and efficiency in free space and the impact on measured SAR (Specific Absorption Rate) of such antennas as a function of the slot configuration and the antenna/slot location. Results show that slots may be useful to increase bandwidth and efficiency while keeping a similar SAR compared to the non-slotted ground plane. Changing the antenna and the slot location is a good way to achieve a significant SAR reduction.**

I. INTRODUCTION

Mobile industry has grown very fast over the last years. Nowadays, there are more than 3600 million users requiring small and multifunctional devices [1]. There is a constant evolution in cellular protocols (new frequency bands) and new services which must be integrated in a slim mobile design (camera, QWERTY keyboard, multi-touch displays…). In order to satisfy these requirements, it is necessary to have a small and multiband antenna.

The common way to design antennas is optimizing their geometry, but as it has been shown in [2]-[14], the ground plane of the handset also plays a very important role in the antenna system behavior (the ground plane is the grounded metallic part etched on the PCB, -Printed Circuit Board-). The antenna bandwidth can be improved changing the ground plane length [11]-[12]. The optimum length is approximately 0.4λ at the operating frequencies because the ground plane mode is excited improving the bandwidth. For mobile handset antennas operating at GSM850 or GSM900 (850-900 MHz), the length of 0.4λ means a ground plane length of 133 mm - too long for handset terminals (typical length is 100 mm). Therefore, some other solutions are needed. This problem can be solved using a slotted ground plane (Fig. 2). This technique consists on adding one or more slots in the ground plane in order to emulate a longer electrical path in a shorter physical length.

In the previous literature, the use of slots to electrically enlarge the ground plane has been analyzed as an alternative to the antenna design [2]-[11]. In [7]-[10] an open slot placed underneath the antenna area is introduced to improve bandwidth at two different bands. Furthermore, in [13] different types of central slots (slots with short-circuited ends) are studied in order to improve bandwidth and simplify the feeding transmission line.

In this paper, different slotted ground planes are presented. All of them have different slot configurations while maintaining the same PCB length and the same PIFA antenna (Planar Inverted F Antenna). The objective is to compare all the designs not only in terms of free space performance but also in terms of human head interaction. A question that needs to be answered is if the ground plane with slots presents more SAR (Specific Absorption Rate) since slots are closed to the human head.

Different studies related to the human interaction have already been done [15]-[23]. In [16], the antenna PIFA close to the human head has been analyzed in several simulations. When the antenna is interfered by the human body, the resonant frequency decreases and resistive losses increase. Also, there is another study related to the handset chassis [19] and its contribution to the antenna bandwidth, efficiency and SAR. The author determines that the bandwidth is dependant on the ground plane length and a greater distance between the antenna and the head may lead to have less head absorption. Finally, several types of antenna configurations have been measured and compared in different human interaction environments [20]-[23]. As a conclusion, results shown in [20] confirm that internal antennas have less SAR than the external ones and in general, antennas produce less absorption at 900 than at 1800 MHz.

The paper is divided as follows: section II explains the important role of the ground plane in the antenna system and describes the slotted ground plane designs. Section III shows the free space experimental results for the proposed antennas and in section IV, SAR results are analyzed. Finally, section V presents the conclusions for this research.

II. GROUND PLANE AND ANTENNA CONCEPT

Five ground plane configurations are analyzed (Fig. 2). The first one is a bare PCB with no slots (this case serves for comparison purposes, Fig. 1 and Fig. 2-a) and the second and third designs are PCBs with one and two open slots respectively (Fig. 2-b,c). Finally, the other designs use central slots of different sizes (Fig. 2-d,e).

The proposed antenna for all the experiments is a PIFA having 6 mm height over the ground plane of 100x40 mm^2 (Fig. 1). The PIFA resonates at 950 and 1950 MHz and it has a feeding and a shorting pin.

All of these antennas have been simulated with a MoM commercial package (IE3D software). In order to give a physical insight, current distributions on the ground plane as well as electrical field on the slot aperture are calculated ([7]-[10], [13]). This data is interesting to understand why the slots on the ground plane are useful to increase the bandwidth. At low frequencies, the slots enlarge the current path, while at higher frequencies they enable the coupling to the PIFA.

An open slot placed underneath the antenna area (Fig. 2-b) is introduced in the ground plane having two objectives. The first one is to tune the ground plane at the low frequency region (GSM850-GSM900, 824-960 MHz) and the other is to reuse the slot to be a parasitic element at the higher frequency region (DCS-PCS-UMTS, 1710-2170 MHz). Both configurations increase the bandwidth. Another design is the one corresponding to Fig. 2-c, which has 2 open slots in the ground plane in order to obtain even more bands at the high frequency region.

Ground planes with open slots (Fig. 2-b,c) feature good bandwidth results since the ground plane mode is excited [7]-[9]. However, this solution needs generally a long feeding transmission line, which may be difficult to integrate. In order to reduce the integration issue, central slots (Fig. 2-d,e) have also been studied. The purpose of this type of slots is to analyze a way to minimize the length of the feeding line maintaining as much as possible the advantages of the bandwidth benefits of the open slots [13].

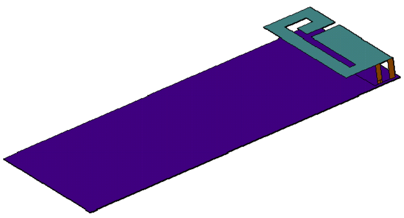

Fig. 1. 3D view of the PIFA dual band. Ground plane is 100 x 40 mm^2 and PIFA is 40 x 15 x 6 mm^3. [6],[24]

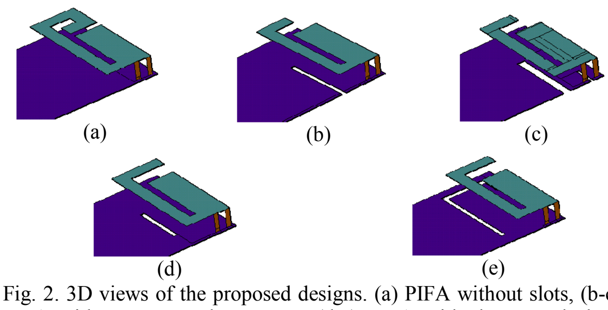

Fig. 2. 3D views of the proposed designs. (a) PIFA without slots, (b-c) PIFA with one open slot or two, (d-e) PIFA with the central slots. [6],[24]

III. Free Space Experimental Results

For validating the simulated results, the five designs have been fabricated in order to measure antenna parameters in free-space (Fig. 3). The material used for the PCB is FR4 (1 mm thickness) and the antenna is located on a plastic support. The reflection coefficient has been measured using a network analyzer and efficiency and radiation patterns have been measured in the anechoic chamber Satimo Stargate-32 at Fractus-Lab.

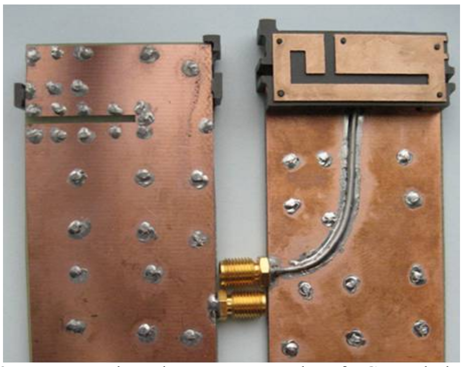

Fig. 3. Prototypes have been constructed. Left: Ground plane configuration for Fig. 2-b. Right: PIFA antenna.

The reference antenna (PIFA on a bare PCB) is a dual band antenna having 14.6% of bandwidth (SWR $\leq$ 3) at low region and 8.2% at high region (Table I). On the other hand, a broader bandwidth is obtained with the antennas having slotted ground planes (Fig. 4).

The antenna with open slot has good matching at both regions because it has been designed to satisfy both objectives: good position to enlarge the current path at low region, and resonance length (0.4λ) for slot excitation at high region. This antenna has good matching from 0.809 to 1.016 GHz and from 1.767 to 2.054 GHz. This means a 22.7% and a 15% of bandwidth at low and high regions, respectively.

TABLE I
MEASURED ANTENNA BANDWIDTHS

	f_1 (GHz)	f_2 (GHz)	BW (SWR<3)	f_1 (GHz)	f_2 (GHz)	BW (SWR<3)
PIFA dual band	0.904	1.046	14.6 %	1.934	2.100	8.2 %
PIFA + open slot	0.809	1.016	22.7 %	1.767	2.054	15.0 %
PIFA + central slot	0.924	1.036	11.4 %	1.958	2.123	8.1 %
PIFA + U-shaped slot	0.904	1.091	18.8 %	1.939	2.221	13.6 %
PIFA + 2 open slots	0.824	1.022	21.4	1.773	2.463	32.6

The central slot has good matching at low region (11.4%) but at higher region it still behaves similar to the reference antenna (8.1%). This means that this slot does not operate as a parasitic element. The antenna with the U-shaped slot in the ground plane satisfies the same requirements as the open slot. Since the U-shaped slot is short-circuited, its length must be twice the open slot length [13].

Finally, the antenna with 2 open slots is the one that can operate in more bands. This antenna has a 21.4% and a 32.6% of bandwidth at high and low region, respectively. This means that it could operate in GSM850, GSM900, DCS, PCS, UMTS and Bluetooth, for example.

The total antenna efficiency values ($\eta_a=\eta_r\cdot(1-|S_{11}|^2)$, where η_r is the radiation efficiency and S_{11} the reflection coefficient for the antenna) have also been measured (Fig. 5). All the antennas have more than a 50% of total antenna efficiency in a region close to 900 MHz and 1900 MHz. However, all the antennas with slotted ground planes have higher values in a wider frequency range than the reference antenna at both regions (Fig. 5).

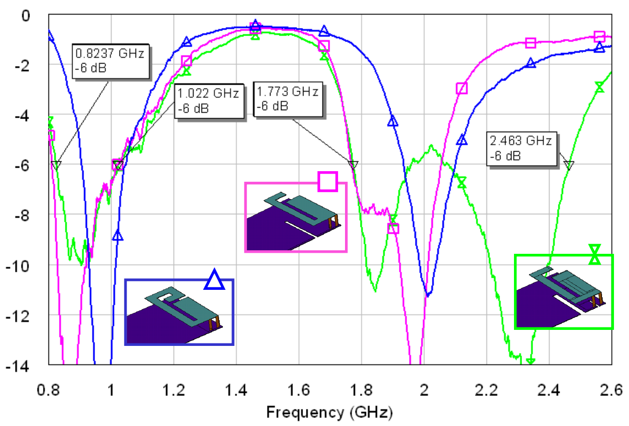

Fig. 4. Comparison of the measured reflection coefficient between PIFA dual band and PIFAs using open slots.

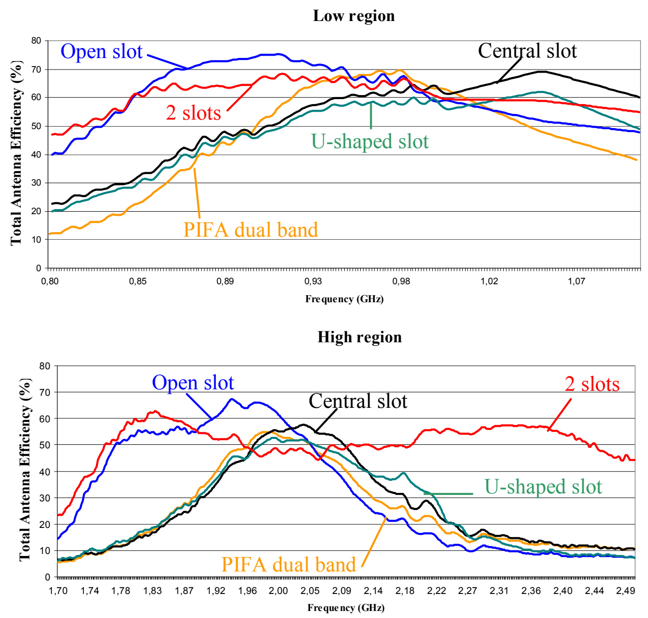

Fig. 5. Measurements of the Total Antenna Efficiency at low and high region

Introducing slots in the ground plane does not modify the radiation pattern at low frequencies. The radiation pattern at 900 MHz is the same as a standard dipole antenna (omnidirectional structure in φ=0º and a null in the y-axis) for all the prototypes.

At higher frequencies, the radiation pattern is less uniform, and as the slot becomes an active element, the directivity increases. For example, the antenna with U-shaped slot has a directivity of 4.9 dB at 2100 MHz whereas the antenna without slots has only 3.5 dB (Fig. 6).

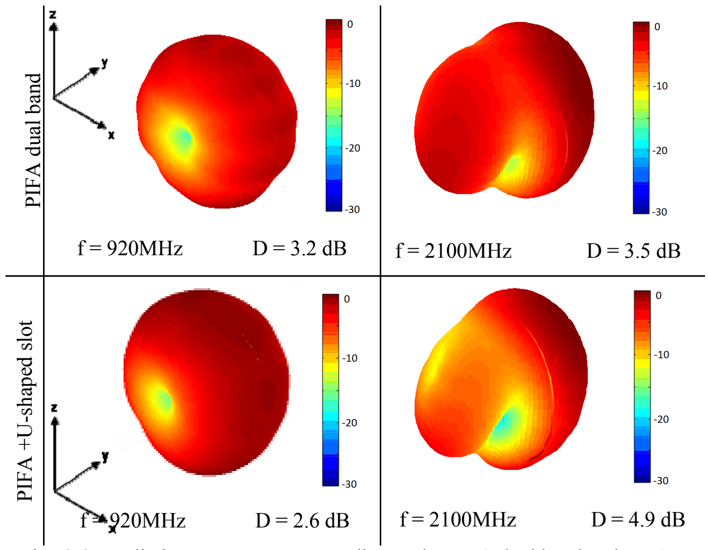

Fig. 6. 3D radiation patterns corresponding to the PIFA dual band and PIFA with U-shaped slot.

IV. SAR MEASUREMENTS

In order to analyze the biological compatibility of all the antennas, SAR measurements have been carried out with the Dasy4 equipment at Fractus-Lab (Fig. 7).

Fig. 7. SAR experiments have been measured with DASY4.

SAR is a very important parameter related to the human head interaction. SAR measurements indicate the localized power that is absorbed by the body when exposed to a radio frequency electromagnetic field emitted by the handset antenna. SAR value is strongly dependant on the ground plane geometry and the antenna position [15]. These variables provide useful information to minimize the SAR caused by the interaction between the head and the antennas.

SAR has been tested in a passive mode [9]. For all the measurements, a methacrylate spacer of 1 mm thickness has been used to emulate a realistic distance between the PCB and the cheek. SAR has been evaluated in two positions: in the first one, the antenna is located near the phantom ear (up position), and in the second one, the handset device is rotated 180º (down position, Fig. 8). Also, measurements have been done in all the operating frequencies of the different antennas (900, 1800, 1900 and 2000 MHz). In Fig. 8, the diagrams obtained for the antenna with U-shaped slot are shown. At each diagram, the hotspot location and the SAR value (measured in 1 or 10 grams of volume) have been indicated. The hotspot corresponds to the maximum absorption inside the head.

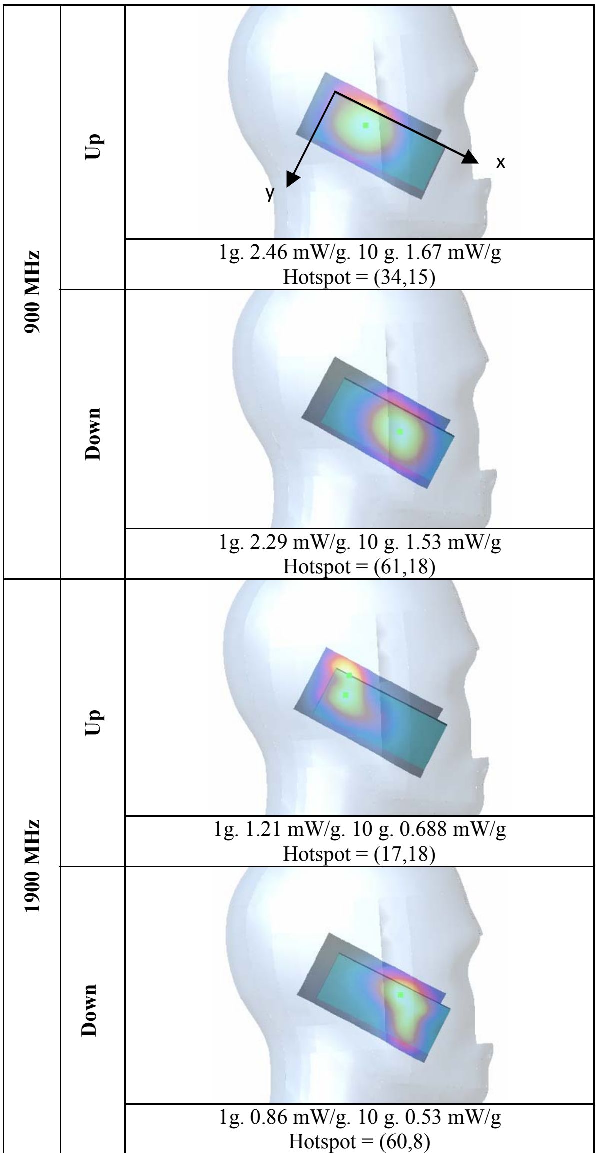

Fig. 8. SAR diagrams of the PIFA dual band. The hotspot indicates the position of the maximum absorption (x,y) in cm.

At 900 MHz, SAR values do not differ from up and down position (Table II). In all the antennas, the hotspot is situated approximately in the middle of the ground plane because at these frequencies the ground plane plays an important role in the antenna radiation [19]. For this reason, when the handset device is rotated 180º the hotspot remains in the same position and SAR values do not change. The antenna with the open slot is the one which produces more absorption (3.1 mW/g). This may be caused by the excited ground plane mode.

At 1900 MHz, SAR performance is different since the hotspot is more concentrated in the upper part of the ground plane, corresponding to the antenna area. Therefore, when the handset is rotated 180º (down position) the antenna is farther from the head and the absorption decreases. That is the main reason why SAR values in the down position are lower than the ones measured in the up position in nearly all the measured cases (Table II). The antenna with the lowest SAR value is the antenna with the U-shaped slot (1.21 mW/g).

The antenna with the open slot does not follow this behavior because at high frequencies it has two hotspots. As they are distributed along the ground plane, a handset rotation does not modify the head absorption (Table II).

TABLE II
SAR MEASUREMENTS – LOW REGION

SAR 1g. (mW/g)	900MHz	
	Up	**Down**
PIFA dual band	2,46	2,29
PIFA + open slot	3,1	2,77
PIFA + central slot	2,36	2,29
PIFA + U-shaped slot	2,46	2,27
PIFA + 2 open slots	2,42	2,02

TABLE III
SAR MEASUREMENTS – HIGH REGION

SAR 1g. (mW/g)	1900 MHz		2000 MHz	
	Up	**Down**	**Up**	**Down**
PIFA dual band	2,68	0,79	2,76	1,8
PIFA + open slot	2,63	2,67	1,58	2,67
PIFA + central slot	2,3	0,84	2,73	1,75
PIFA + U-shaped slot	1,21	0,86	2,03	2,09
PIFA + 2 open slots	3,28	1,63	2,81	1,33

V. CONCLUSIONS

Several types of slotted ground planes have been analyzed in terms of free space performance and also in terms of human head interaction.

An open slot placed underneath the antenna area has been introduced in the ground plane having two objectives: the first one is to tune the ground plane at low frequencies (GSM850-GSM 900) and the other is to reuse the slot to be a parasitic element at higher frequencies (DCS-PCS-UMTS). Antennas with open slots have good matching and efficiency across the low and high regions.

The central slots also follow these requirements, but although their bandwidth is narrower, they also take into account the simplification of the feeding transmission line [13].

Measurements show that central slots present less SAR than the open ones. Comparing the values obtained for slotted ground planes with the reference antenna, it can be demonstrated that slots do not increase SAR. At low frequencies, all designs have the hotspot located at the centre of the ground plane because the ground plane is the main contributor. On the other hand, at high frequencies, the hotspot can be found next to the antenna area. As at these frequencies the hotspot is so dependant on the antenna position, changing its location is a good way to reduce SAR. When the antenna is located in the bottom part of the phone (further from the head), SAR can be reduced in more than a factor 2.

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REFERENCES

[1] F.Frost & Sullivan, *Antennas Systems 2006*, Washington, USA, 2006

[2] P.Vainikainen, J.Ollikainen, O.Kivekäs, and I.Kelander, "Resonator-based analysis of the combination of mobile handset antenna and chassis", *IEEE Transactions on Antennas and Propagation*, Vol. 50, No. 10, October 2002, pp. 1433-1444

[3] M.Cabedo, E.Antonino, V.Rodrigo, and C.Suárez, "Análisis modal de un plano de masa radiante doblado y con una ranura para terminales Móviles", *XXI Simposium Nacional de la Unión Científica Internacional de Radio, URSI '06*, Oviedo, September 2006

[4] R.Hossa, A.Byndas, and M. E.Bialkowski, "Improvement of Compact Terminal Antenna Performance by incorporating Open-End Slots in Ground Plane", *IEEE Microwave and Wireless Comp. Lett.* Vol 14, nº6, June 2004

[5] M. F.Abedin and M.Ali, "Modifying the Ground Plane and Its Effect on Planar Inverted-F Antennas (PIFAs) for Mobile Phone Handsets", *IEEE Antennas and Wireless Propagation Letters*, Vol. 2, 2003

[6] Patent appl. WO 03/023900

[7] J.Anguera, I.Sanz, A.Sanz, D.Gala, A.Condes, C.Puente, J.Soler, "Enhancing the performance of the handset antennas by means of groundplane design", *IEEE International Workshop on Antenna Technology: Small Antennas and Novel Metamaterials (iWAT 2006).* New York, USA, March 2006

[8] J.Anguera, A.Cabedo, C.Picher, I.Sanz M.Ribó, C.Puente, "Multiband Handset Antennas by Means of GroundPlane Modification", *IEEE Antennas and Propagation Society International Symposium*, Honolulu, Hawaii, USA, June 2007

[9] A.Cabedo, J.Anguera, C.Picher, M.Ribó, C.Puente, "Multi-Band Handset Antenna Combining a PIFA, Slots, and Ground Plane Modes", *IEEE Transactions on Antennas and Propagation*, vol.57, no.9, 2526-2533, September 2009

[10] C.Picher, J.Anguera, A.Cabedo, M.Ribó, L.Pijoan, C.Puente, "Diseño de antenas multibanda para telefonía móvil mediante la manipulación del plano de masa"*, XXII Simposium Nacional de la Unión Científica Internacional de Radio, URSI '07*, Tenerife, September 2007

[11] K.L.Wong, *Planar Antennas for wireless communications*, Wiley Series in Microwave and Optical Engineering, New Jersey: John Wiley & Sons, 2003

[12] P. Salonen, "Effect of Groundplane Size on Radiation Efficiency and Bandwidth of Dual-Band U-PIFA", *IEEE*, 2003

[13] C.Picher, J.Anguera, A.Cabedo, C.Puente, S.Kahng, "Multiband handset antenna using slots on the ground plane: considerations to facilitate the integration of the feeding transmission line", Progress *In Electromagnetics Research C*, Vol. 7, 95-109, 2009

[14] J.Anguera, I.Sanz, J.Mumbrú, C.Puente, "Multi-Band Handset Antenna with a Parallel Excitation of PIFA and Slot Radiators", *IEEE Transactions on Antennas and Propagation*, to appear in Feb. Issue, 2010

[15] Iskander M.F., Yun, Z., Quintero-Illera, R., *IEEE Transactions Microwave Theory Tech.*, vol. 48, no. 11, pp. 1979-1987, 2000

[16] K.R.Boyle, Y.Yuan, L.P.Lighthart, "Analysis of mobile phone antenna impedance variations with user proximity", *IEEE Transactions on antennas and propagation*, vol.5, no.2, February 2007

[17] K.R.Boyle, "The performance of GSM 900 antennas in the presence of people and phantoms", *IEE, Michael Faraday House*, Six Hill Way, Steveneage, SG1 2AY

[18] O.Kivekäs, T.Lehtiniemi, P.Vainikainen, "On the general energy-absorption mechanism in the human tissue", *Microwave and Optical Technology Letters*, vol.43, no.3, November 2004

[19] O.Kivekäs, J.Ollikainen, T.Lehtiniemi, P.Vainikainen, "Bandwidth, SAR, and efficiency of internal mobile phone antennas", *IEEE Transactions on Electromagnetic Compatibility*, vol.46, no.1, February 2004

[20] P.Kildal, C.Carlsson, "Comparison between head losses of 20 phones with external and built-in antennas measured in reverberation chamber", *IEEE Antennas and propagation Society International Symposium*, vol.1, pp.436-439, 2002

[21] J.J.Arenas, J.Anguera, C.Puente, "Balanced and single-ended handset antennas: free space and human loading comparison", *Microwave and Optical Technology Letters*, vol.51, nº9, pp.2248-2254, September 2009

[22] J.Anguera, A.Camps, A.Andújar, C.Puente, "Enhancing the robustness of handset antennas to finger loading effects", *Electronics Letters*, vol.45, nº15, pp-770-771, July 2009

[23] J.Vergés, J.Anguera, C.Puente, D.Aguilar, "Analysis of the human body on the radiation of FM handset antenna", *Microwave and Optical Technology Letters*, vol.51, n11, pp.2588-2590, November 2009

[24] Patent appl. WO 01/22528