How much can be reduced the internal FM antenna of mobiles phones?

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***Abstract*—The paper introduces both a new internal FM antenna for mobile phones based on the fractal Hilbert curve, and a new evaluation criterion for quantifying the quality of the signal received by the FM antenna of mobile phones.**

The main attribute of the new internal FM antenna is its reduced size; which is only 30*10*1 mm^3.

The measurements demonstrate that the power received by the internal FM antenna is 20 dB lower than the power received by the external wire antenna under the same measurement conditions. Despite the reduction of the power level, the evaluation criterion reveals that, owing to the threshold effect in FM receivers, the signal quality indicator is similar for both antennas. Additionally, the value of the signal quality indicator achieved by both antennas guarantees to listen to the FM radio channels clearly without noise nuisance and without interferences.

I. INTRODUCTION

Nowadays no one can question about the success of mobile telephony during the last two decades. Mobile telephony together with mobile phones have revolutionized the world and the way people communicate. While the first mobile phones were simple devices whose main and only features were the voice communication and the messaging capability, today's mobile phones are innovative devices that provide a wide variety of services to users. Among such wide variety of services, one of the most attractive mobile phone services are the entertainment services, and specially the functionality that allows users to listen to FM radios through their mobile phones. Such preferences result in a growing demand of FM antennas for mobile phones, and the necessity of innovative technologies to develop internal FM antennas, which replace the external wire antennas that exhibit current mobile phones in the market.

Internal FM antennas for mobiles phones have been introduced for instance in [1-2]. Such antennas, known as packed antennas, are spiral based antennas that pack a long wire length into a reduced volume of 40*20*5 mm^3. Previous papers analyse the performance of such antenna in terms of the reflection coefficient, the gain, and the power received. An internal FM antenna consisting on a half-loop radiator is also introduced in [3]. A U-shape internal FM antenna is introduced in [4] where the human body interaction is analysed; the measurement of the return loss and the power received is performed there when the user holds the mobile phone with the hand.

The main benefit of the internal FM antenna is that suppresses the need for an external wire antenna. Until now, FM mobile phone listeners required to use a wired headset or a wired speaker whereby this wire served as the antenna for the FM radio. The internal FM antenna for mobile phones allows users to use wireless Bluetooth headsets or Bluetooth enabled speakers to listen to the FM radio.

The remainder of this paper is organized as follows: section II describes the antenna geometry, the scenarios where the measurements are performed, and the measurement conditions for evaluating the human body interaction, section III shows the measurement of the reflection coefficient, section IV presents the measurement of the power received and section IV describes the new measurement criterion and the measured quality factor indicators.

II. ANTENNA GEOMETRY, MEASUREMENT SCENARIOS AND HUMAN BODY INTERACTION

The internal FM antenna for mobile phones is based on the fractal Hilbert curve; Fig.1 shows a photo of the FM Chip Hilbert antenna whose size is only 30*10*1 mm^3. The FM Chip Hilbert antenna is integrated in a typical smart phone platform of 110 by 60 mm^2.

The performance of the internal FM Chip Hilbert antenna is compared with the performance of the classical external wire antenna. The wire FM antenna is a long monopole of 750 mm length attached to the reference platform (110*60 mm^2). Fig.1 shows the comparison of the external wire antenna with the internal FM Chip Hilbert antenna. Highlight that the internal FM Chip Hilbert antenna provides a significant size reduction in relation to the external wire antenna, the size reduction factor for the internal FM Chip Hilbert antenna is 25.

In order to test the performance of the internal FM Chip Hilbert antenna, the measurements are carried out in two different scenarios (Fig.2); such scenarios have been selected for its relevance in the evaluation of the antenna's performance:

- Urban scenario; the Football Stadium from the FC Barcelona (Nou Camp) in the city of Barcelona. Such scenario is very representative as football supporters watch football matches while listening to the broadcast of the game in the FM receivers of their mobile phones.
- Suburban scenario; the village of Sant Cugat del Vallés, which is a place 20 Km away from the city of Barcelona.

In the urban scenario, the measurements of the power received by the antenna are done for two propagation modes:

- LOS (Line of Sight), where there is not an obstruction between the base station (transmitting antenna- Torre de Collserola) and mobile phone antennas (receiving antenna).
- NLOS (Non Line of Sight), where there is obstruction between the transmitting and receiving antennas.

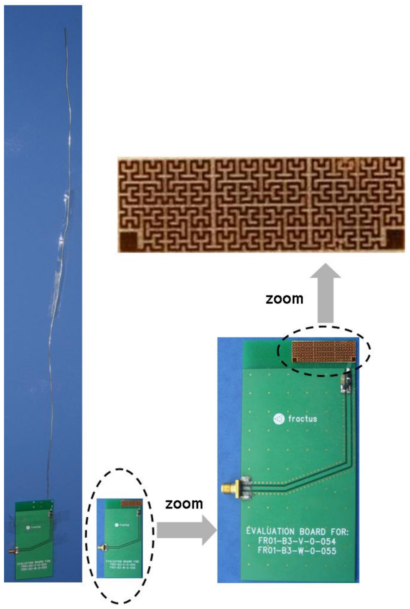

Fig.1 External wire and internal FM Chip Hilbert antennas attached to a typical smart phone platform, [5-6]

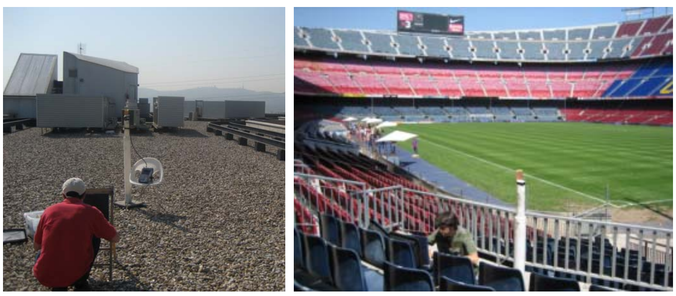

Fig.2. Measurement scenarios. Suburban scenario - the village of Sant Cugat (left), and urban scenario - Football Stadium of FC Barcelona (right)

Apart from the measurements in free space, the paper also describes the interaction of the human body. That is, how the reflection coefficient, the power received and the signal quality indicator are influenced by the human body interaction. The human body interaction is evaluated for two measurement conditions, which reflect two common ways of holding the mobile phone by the users (Fig.3):

- FracMan condition considers that the user is standing up and holds the mobile phone with the hand.
- SiteMan condition considers that the user is seated down and the mobile phone is placed in the trouser's pocket.

Under the FracMan condition, two different ways of holding the mobile phone with the hand are also considered:

- Direct coupling measurement, the user holds the mobile phone directly with the hand.
- Indirect coupling measurement, the user holds the mobile phone with the hand through a dielectric cover.

Fig.3. Human body interaction. FracMan (left), and SiteMan (right) measurement conditions

Under the SiteMan condition, two different ways of placing the mobile phone in the user's pocket are also considered:

- Direct coupling measurement, the user places the mobile phone directly in the trouser's pocket.
- Indirect coupling measurement, the user places the mobile phone in the trouser's pocket considering a dielectric cover.

III. REFLECTION COEFFICIENT MEASUREMENT

First of all, the reflection coefficient of the internal FM Chip Hilbert and external wire antennas are measured in free space (Fig.4). Typical handset antennas operating at mobile services such as GSM feature a reflection coefficient better than -6dB. However, internal FM antennas are difficult to be matched at such levels across band. For this present case, the internal FM antenna has been matched following the teaching of [1, 2].

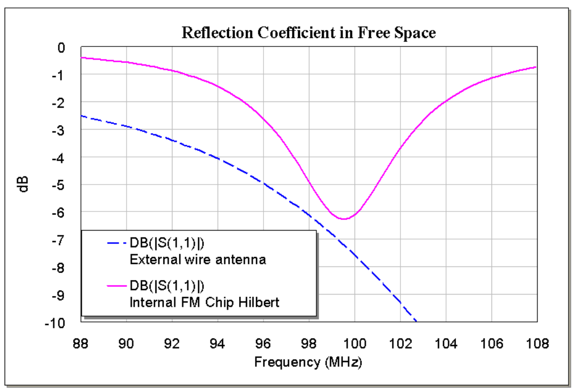

Fig. 4 Free space measurement of the reflection coefficient for the internal FM Chip Hilbert and external wire antennas.

Regarding to the human body interaction, this section also shows the measurement of the reflection coefficient for the FracMan and SiteMan conditions, which are described in detail in the previous section.

The measurements under the FracMan condition (Fig.5) are done for the two ways of holding the mobile phone with the hand, the direct coupling and indirect coupling measurements (see previous section).

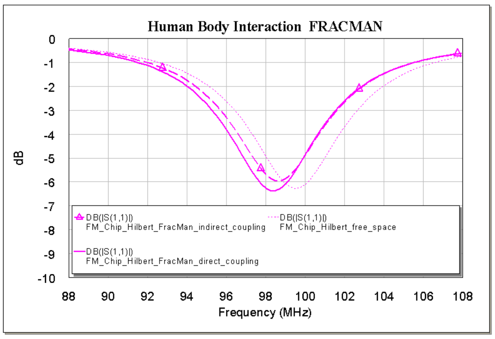

Fig.5 Measurement of the reflection coefficient for the internal FM Chip Hilbert antenna performed under the FracMan condition.

The measurements under the SiteMan condition (Fig.6) are also performed for the two ways of placing the mobile phone in the user's pocket, direct coupling and indirect coupling measurements (see previous section).

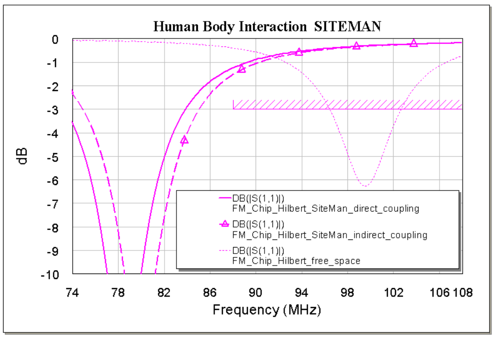

Fig.6. Measurement of the reflection coefficient for the internal FM Chip Hilbert antenna performed under the SiteMan condition. The doted line at -3dB corresponds to the FM band.

According to the measurements of the reflection coefficient, the external wire antenna exhibits better reflection coefficient than the internal FM Chip Hilbert antenna across FM band (Fig.4).

Regarding to the human body interaction, the FracMan condition barely modifies the reflection coefficient (Fig.5). However, the SiteMan condition strongly influences the reflection coefficient; it is observed that the minimum of the reflection coefficient is shifted outside the FM band, which is indicated in Fig.6 with a reference mark at -3dB. Therefore in the FM band, the reflection coefficient under the SiteMan condition is wore than the reflection coefficient in free space.

IV. POWER RECEIVED BY THE ANTENNA

This section depicts the measurement of power received by the internal FM Chip Hilbert antenna. The FM antenna is connected to a spectrum analyser, and a ferrite cable is used to mitigate the currents flowing to the outer conductor. As it is explained in section II, the measurements of the power received are done in two different scenarios; the urban and suburban scenarios.

The free space measurement of the power received by the internal FM Chip Hilbert and external wire antennas are performed in the urban (Fig.7) and suburban scenarios (Fig.8). In the urban scenario, the measurements are done for the two propagation modes, LOS and NLOS propagating modes (see section II).

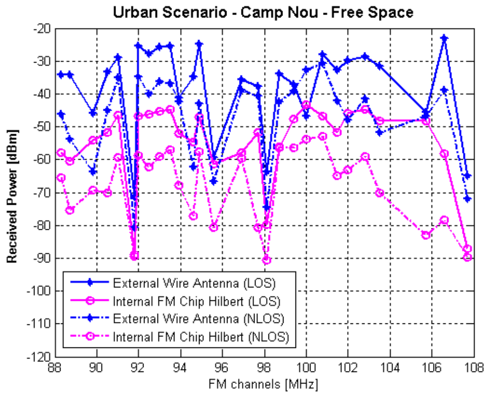

Fig.7 Free space measurement of the power received by the external wire and internal FM Chip Hilbert antennas in the urban scenario.

Under the FracMan condition, the power received by the internal FM Chip Hilbert antenna is measured in the suburban scenario (Fig.8). Such measurement corresponds to the direct coupling measurement. It should be added that in the case of the indirect coupling measurement, the received power by the internal FM Chip Hilbert antenna is almost similar to the power received in the direct coupling measurement.

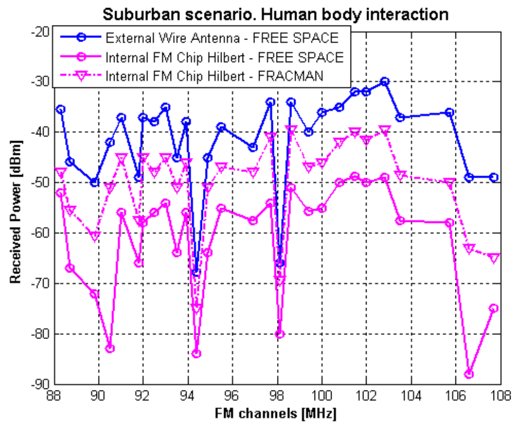

Fig.8 Free space measurement of the power received by the external wire and internal FM Chip Hilbert antennas in the suburban scenario. Together with the power received by the internal FM chip Hilbert antenna under the FracMan condition.

In the case of the SiteMan condition, the power received by the internal FM and external wire antennas is measured in the urban scenario (Fig.9). The measurements are done for the two propagation modes, LOS and NLOS propagating modes (see section II).

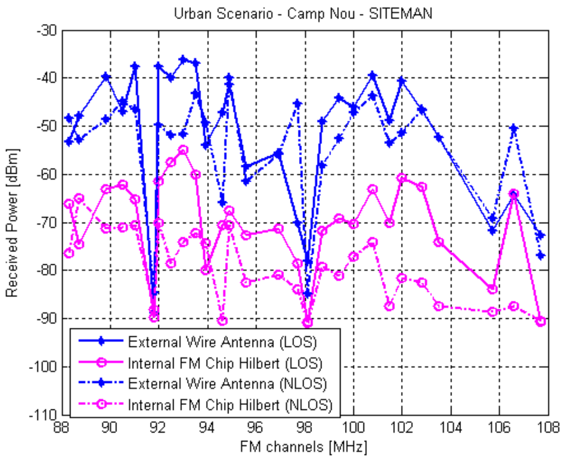

Fig.9. Measurement of the power received by the internal FM Chip Hilbert and external wire antennas under the SiteMan condition in the urban scenario.

The measurement of the power in the different scenarios reveals that the power received by the external wire antenna is higher than the power received by the internal FM chip antenna. The following results should be remarked:

- In free space, the average power received by the external wire antenna is almost 20dB higher than the power received by the internal antenna. Such result is observed for the urban and suburban scenarios, and for the two propagation modes considered in the urban scenario.
- The FracMan condition improves the level of the power received by the internal antenna. The average power received by the internal antenna under the FracMan condition is almost 10 dB higher than the power received in free space.
- Under the SiteMan condition in the urban scenario, the average power received by the external wire antenna is 20 dB higher than the power received by the internal antenna for the LOS propagation mode, and 25 dB for the NLOS propagation mode
- The SiteMan condition strongly modifies the level of the power received by the internal antenna. The average power received by the internal antenna in free space is about 13dB higher than the power received under the SiteMan condition.

Looking to the measured data for the received power, the question that arises is whether such levels of the power received by the internal FM Chip antenna are suitable to properly listen to the FM radio channels. In order to answer such question, a new evaluation criterion is proposed in the following section.

V. EVALUATION CRITERION

This paper also introduces a new evaluation criterion for evaluating the proper performance of FM antennas for mobile phones. When designing antennas for mobile phones, antenna engineers are mainly focused in achieving outstanding values for reflection coefficient, efficiency and received power. However, the question that arises from such antenna parameters is whether these three parameters are enough to guaranty that a FM radio user will be able to listen to the radio properly. To answer such question, an additional measurement is proposed here: a new evaluation criterion based on the signal quality of the FM radio, as perceived by the user.

It is well known that the main requirement from the FM radio users is to listen to the FM radio properly, that means, to listen to the radio clearly without interference or distortion. The new evaluation criterion provides a signal quality indicator that allows evaluating the actual antenna performance and determining if the antenna under evaluation is suitable for its functionality.

The evaluation criterion consists on quantifying the quality of the FM radio signal received by the antenna under test. The quantification is performed by several users that listen to the FM channels, which are received by the antenna under test, and follow a given procedure. Such quantification procedure is done for 28 different FM channels of the FM spectrum, so each user defines 28 signal quality indicators for each measurement condition. In order to check the validity of the signal quality indicator, the evaluation criterion also assesses the correlation between the measurements performed by several users.

Fig.10 describes in detail the steps of the procedure performed for quantifying the quality of the FM radio signal received by the antenna under test.

The signal quality indicator is ranked with values from 0 to 10 depending on the quality of the FM radio channel listened by the user. A value of 0 means the user can not listen to any music or conversation. And a value of 10 means the user would be totally satisfied with the device since the signal quality is outstanding.

The evaluation criterion has been applied for quantifying the quality of the FM radio signal received by the external wire and internal chip antennas. Such evaluation has been done in the suburban and urban scenarios, and the impact of the human body interaction in the signal quality indicator has been also analyzed.

The signal quality indicator is evaluated for the internal FM Chip Hilbert and external wire antennas in free space; such evaluation is performed in the suburban scenario (Fig.11).

In order to evaluate the impact of the human body interaction, the signal quality indicator for the internal FM Chip Hilbert antenna is assessed in the suburban scenario under the FracMan condition. The users hold the mobile phone directly with the hand, that is, the direct coupling measurement. Results of the signal quality indicator are shown in Fig.11.

And regarding to the SiteMan condition, the signal quality indicator is evaluated for the internal FM Chip Hilbert and external wire antennas in the urban scenario (Fig.11). The users place the mobile phone in the trouser's pocket with a dielectric cover, that is, the indirect coupling measurement.

Remark that the correlation coefficient is larger than 0.75 for the measurements performed by several users. Despite being a subjective measurement, such value guaranties that all users measure similar signal quality indicators.

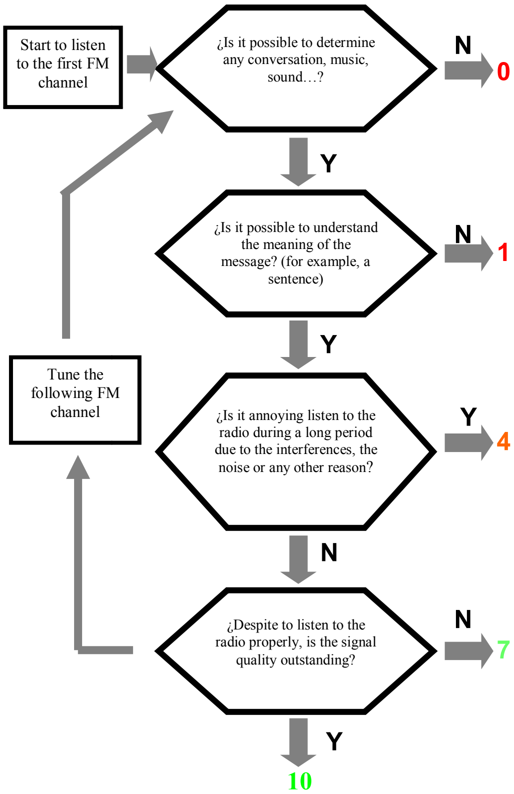

Fig.10. Procedure for evaluating the signal quality indicator.

The measurements provided by the new evaluation criterion reveal the following results:

- The signal quality indicator of the external wire antenna is very similar to the signal quality indicator of the internal FM chip Hilbert antenna.
- The value of the signal quality indicators is almost independent of the measurement condition and scenario.
- The values of the signal quality indicator range from 7 to 8.
- The FracMan and SiteMan condition barely modifies the value of the signal quality indicator in relation to the measurements in free space.

Therefore, it can be concluded that despite the internal antenna receives lower power than the external antenna and owing to the threshold effect in FM receivers, the internal FM antenna allows to listen to the FM radio channels with the same quality than the external wire antenna. And the value of the signal quality indicator for the internal FM antenna guarantees to listen to the FM radio channels clearly without noise nuisance and without interferences.

Taking into account the results achieved by the proposed evaluation criterion, antenna engineers should not be just focused in optimizing the reflection coefficient and the power when designing internal FM antennas for mobile phones.

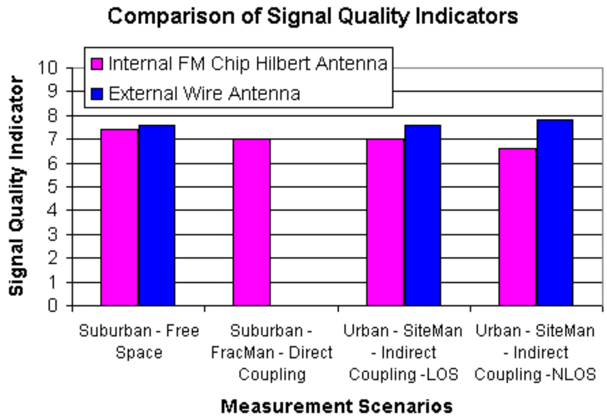

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Fig.11. Signal quality indicators which quantify the quality of the FM radio signal received by the internal and external antennas.

VI. Conclusions

The measurements demonstrate that the power received by the internal FM Chip Hilbert antenna is 20 dB lower than the power received by the external wire antenna under the same measurement conditions. Despite the reduction of the power level, the evaluation criterion reveals that, owing to the threshold effect in FM receivers, the signal quality indicator is similar for internal and external antennas independently of the measurement condition and scenario.

When using the internal FM Chip Hilbert antenna, the values of the signal quality indicator guarantee to listen to the FM radio channels clearly without noise nuisance and without interferences for the FracMan and SiteMan conditions.

Finally, it is has been demonstrated that is possible to significantly reduce the size of the external wire antennas by means of an internal antenna as the FM Chip Hilbert, whose size is only 30*10*1 mm^3 and the factor size reduction is 25.

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