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Correlation Evaluation on Small LTE Handsets

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***Abstract*—This paper presents total efficiency and correlation measurements of the first MIMO-LTE handset on the market. It investigates the correlation value computed from coaxial cable measurements and from optical fiber measurements. Isotropic and Gaussian channel models are used. Additionally the effect of the user is investigated. The results are compared and discussed. The question of the actual feasibility of low correlation for the LTE-700 band in small terminals is raised.**

Keywords— 4G mobile communication; MIMO; Correlation; Antenna measurements; Antenna radiation patterns.

I. Introduction

Consumer's demand for increased data access through their wireless devices has driven the development of multi-antenna systems in small handsets. Multiple-Input Multiple-Output (MIMO) and diversity systems are potential techniques for enhancing the transmission rates. However the feasibility of these solutions is challenged by antenna design constraints. The fundamental limitations for small antennas to perform at low frequencies were first described by Harrington in [1]. It highlights the dependency of bandwidth, size and efficiency of the antenna design. Hence designing an efficient antenna in a small terminal, for Long Term Evolution (LTE) communications, is a major challenge. Indeed LTE frequency bands extend from 2.7 GHz to 700 MHz, and the lower frequencies are the toughest to cover as their wavelength is about 3 times larger than the dimension of nowadays handsets.
Mutual coupling between antennas at low frequency bands happens as a result of the reduced available space on the device, and of the common ground plane that the resonators share. It increases dramatically as the number of integrated antennas increases. This phenomenon can significantly degrade the efficiency of the antennas. Moreover it can produce undesirable signal correlation between multiple antenna outputs, which will noticeably degrade the throughput of a MIMO system. These challenges lead to extensive research for antenna engineers, proposing new designs as in [2] for example.
Recently the first phone on the market able to cover LTE-700 bands and announcing good performances with MIMO was released [3]. In this paper we present measurements performed on the device. The correlation is computed from measurements with coaxial cables and with optical fibers, as it has been shown - in simulations [4] and in measurements [5] - that the use of cables for measurements can lead to significant errors.

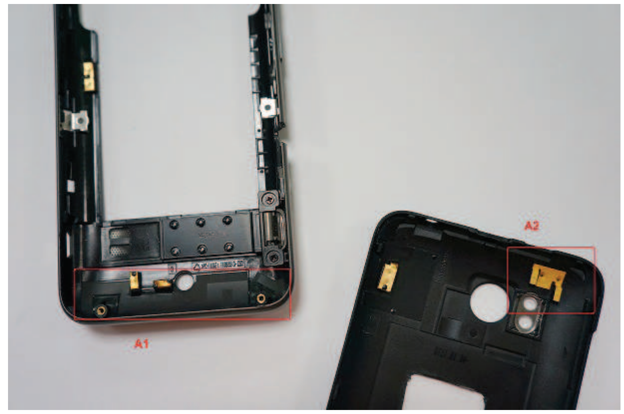

Fig. 1. MIMO Set-up on Thunderbolt.

The paper is structured in seven sections. Section II describes the MIMO antennas that will be tested. Successively, measured efficiencies and isolation of the antennas are shown in Section III. Section IV will compare - in Free Space (FS) - the correlation coefficient computed from measurements with and without the optical solution. The optic fibers set-up will be used to evaluate the correlation values with a user, and the results will be presented in Section V. Finally discussion and conclusion are disclosed in Section VI and VII.

II. An LTE Enabled Phone

The measurements are conducted on an existing device; the recently released Thunderbolt is the first 4G-LTE smart-phone. It will be used in the following as an example to test different radiation pattern measurements and conclude on the antenna correlation.

A. Diversity Antennas

The phone is 1$\times$2 MIMO enabled, with a main and a secondary antenna, as shown in Fig. 1. The two antennas are placed in a top-bottom configuration and the dimensions of the phone are 121 $\times$ 62 $\times$ 14 mm^3. The main antenna (A1) is used for LTE-700 as a receiver only, whereas the secondary antenna (A2) is used as a transmitter and a receiver.

B. Cellular Frequencies

The phone is designed to operate with the operator Verizon in the band 13 of the LTE frequency spectrum. Thus the

TABLE I
AVERAGED TOTAL EFFICIENCIES AT LTE-700

	FS	Hand	SAM+Hand
A1 [dB]	-4.9	-8.9	-11.2
A2 [dB]	-7.7	-8.3	-16.4
BPR [dB]	2.8	0.6	5.2

frequencies that need to be covered in transmitting mode are between 777 MHz and 787 MHz. The receiving bandwidth is between 746 MHz and 756MHz. This study will focus on the receiving band.

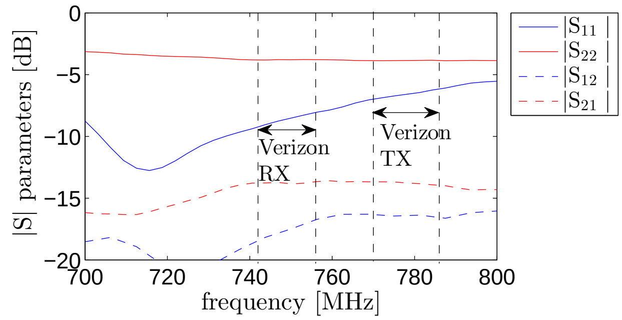

Fig. 2. Measured magnitude of S parameters for A1 and A2 in FS.

III. EFFICIENCY AND ISOLATION

In this section the performances of the above-described LTE phone are measured, using the efficiency as a simple metric. Measurements in an anechoic chamber are conducted with a resolution of 5 degrees in order to achieve high accuracy. Isolation between antennas is also presented.

A. Total Efficiencies

The total efficiencies have been measured in a full anechoic chamber using a 3D pattern integration method. The measurements cover the transmitting and receiving frequencies of the band 13 for Verizon. The values that are presented are an average between the performances on the TX and the RX band. For the averaging three frequencies were measured per band: the low bound (746 MHz), the center frequency (751 MHz) and the high bound (756 MHz). The total efficiency of the antenna is also evaluated in a user proximity. Hand and head phantoms model the user. The hand phantom is the grip for PDA phones: SHO V2RP-LP, [6] and the phantom used for the head is the Specific Anthropomorphic Mannequin (SAM). Both phantoms are compliant with the latest CTIA release [7] for reproducibility purposes. Three cases are tested: the FS case, the case where the phone is held with the right hand model (Hand) and the case where the phone is placed between the head and the hand (SAM+Hand). Measurement results are summarized in TABLE I and show efficiencies of -5 dB and -8 dB for the main and the secondary antenna. When the right hand is holding the phone, the efficiencies drop to -9 and -8 dB respectively. The secondary antenna suffers less from the absorption due to the hand phantom than the main antenna. This is explained by the greater distance separating A2 at the bottom of the phone from the palm, than A1 at the top of the phone from the index finger. Finally the user's head is added to the measurements. Its proximity adds about 10 dB of loss to the FS efficiency, as it can be expected, leading to total efficiency values of -11 dB for the main antenna, and up to -16 dB for the secondary antenna. Additionally the Branch Power Ratios (BPR), as they have a great impact on the diversity performances, are also computed and shown in TABLE I for the FS and the user cases.

B. Isolation

Even though the design of multiple well-matched antennas - with respect to the 50 Ω feed line - on a small chassis at low frequencies seems achievable, reaching low isolation between them is a real challenge. Nevertheless this task is fundamental to ensure that most of the power is used to improve the total efficiency, and that it is not lost in the other radiator. Fig. 2 depicts the magnitude of the measured S parameters for A1 and A2. The transmitting (TX) and receiving (RX) bands of the operator Verizon are also shown on the figure. The isolation is below -13 dB in free space over the targeted bands. Therefore it could be concluded that the two diversity antennas are highly isolated even though they are closely spaced. However their efficiencies are very low in FS, as seen in the previous section. Thus it is concluded that the high isolation values are only a result of poor matching of the antennas. This is confirmed with the reflection coefficient curves of A1 and A2 in Fig. 2
The next section will compute the correlation coefficient of A1 and A2. Even though well-matched and highly isolated antennas might have a low correlation, if the high isolation results from a poor matching there is no rule for the correlation estimation.

IV. CORRELATION COEFFICIENT EVALUATION

The envelope correlation coefficients are computed from the measured radiation patterns in the anechoic chamber. As in the previous sections the mean value over the RX band is displayed. Coaxial cables have a significant effect on antenna measurements as currents can be running down its metallic part and alter the radiation pattern. To rule out the effect of the cable and obtain accurate results on the antenna radiation two different set-ups are tested and compared. The first one uses coaxial cables whereas the second one uses optic fibers. The calculation of the envelope correlation (ρ_e) is done according to equation (1), which holds for Rayleigh fading signals as demonstrated in [8]:

$$\rho_e \simeq \frac{|R_{xy}|^2}{\sigma_x^2 \sigma_y^2} \text{ [8]}, \quad (1)$$

This formula is adopted to present all the following correlation results as it is the most commonly used. It relies on the exported radiation patterns as explained in [9]. In this section the correlation computation is done for an isotropic incoming power distribution model.

Fig. 3. Measurement set-up with a coaxial cable.

Fig. 4. Measurement set-up with optic fibers.

A. Cable Measurement

In the first case the radiation pattern is measured with coaxial cables. The cable measurement set-up is shown in Fig. 3. In the LTE-700 band the chassis is the main radiator, thus the metallic coaxial cable will have a great influence on the radiation pattern, as it will increase the effective length of the chassis [10]. Thus the thin cables are lead out on the side of the handset - which are low field locations - as an attempt to minimize their impact on the radiation pattern. The correlation coefficient between A1 and A2 is computed and its mean value for the RX band is shown in TABLE II. The resulting correlation of 0.4 is a nominal and adaptable value for LTE communications. However the contribution of the cable to this correlation value is still unknown.

B. Optic Fiber Measurement

In order to remove the disturbance introduced by the cable on the radiation pattern, the test is repeated with optic fibers. The optical fiber unit with RF optical link - described in

TABLE II
MEASURED CORRELATION WITH CABLES AND WITH OPTIC FIBERS

	Coaxial cable in FS	**Optic fibers in FS**
Correlation	0.4	0.8

[11] - is placed on the device and the measurement set-up is shown in Fig. 4. In this case the antennas are correlated with a coefficient of 0.8, as it can be seen it TABLE II. This value is significantly higher than the correlation computed with the coaxial cables and it will significantly degrade the antenna performance. Furthermore this correlation is calculated based on an isotropic distribution of the incoming power, which is the most optimistic case and leads to the lowest correlation coefficient. Therefore a correlation of 0.8 in this case is a very high value and it can not be expected in this set-up to greatly benefit from diversity reception.

V. User Cases

The correlation coefficients are now evaluated in the cases where the user has an impact on the radiation pattern. Two typical scenarios involving the PDA hand grip and the SAM are tested. Firstly the effect of the hand alone is measured. Secondly the hand and the phone are placed next to the head phantom, in order to reproduce a talk-mode use case. On the one hand the correlation coefficient for these measurements are computed using an isotropic channel model, in order to compare them to the ones in FS. On the other hand they are also computed using a Gaussian model, in order to consider a realistic environment. The Gaussian model that is used is described in [12], where Taga presented an analysis for evaluating the mean effective gain of antennas moving in mobile communication environments. Experimental results supported his statistical distribution model where the incident waves are mainly and uniformly concentrated in azimuth. The measurements are conducted in the same anechoic chamber as previously and with the optical unit. For accuracy purposes the measurements are done with 5 degrees resolution.

A. Optic Fiber Measurement with Hand

In this measurement the phone is placed with a tilt in elevation close to 45 degrees. It is supported by the PDA hand grip and the appropriate spacer. The set-up is shown in Fig. 5. When the phone is held the correlation coefficient between A1 and A2 is 0.3 in an isotropic channel model and 0.4 for a Gaussian distribution.

B. Optic Fiber Measurement with SAM and Hand

The phone is now placed next to the SAM and held in the PDA hand grip. The optical measurement leads to a very low correlation value of 0.1 for both isotropic and Gaussian distribution models.

VI. Discussion

In FS the measured radiation pattern is highly disturbed by the presence of the coaxial cables used to feed the

Fig. 5. Measurement set-up with optic fibers and a user's hand model.

Fig. 6. Measurement set-up with optic fibers in SAM+Hand configuration.

antennas. This change in the radiation dramatically affects the computed correlation. The correlation coefficient being an essential metric for MIMO performances must be calculated with the undisturbed radiation patterns, this is without the metallic coaxial cable attached to the phone as demonstrated in the measurements. At a first glance, the measurements indicated high isolation of A1 and A2 and low correlation between them with coaxial cables. These results tend to indicate that the proposed phone is a very good candidate for MIMO operation. But it appears with further investigation that the very poor matching of the antennas and the very low efficiencies are the reason of the high isolation. Furthermore the low correlation value is measured when using a cable set-up. The actual correlation, without disturbing the radiated fields, is considerably higher and would rank the phone as less suitable for MIMO use.

VII. CONCLUSIONS

Measurements of efficiencies, isolation and correlation have been performed on the first MIMO for LTE phone. The correlation measurements with coaxial cable and optic fibers have shown the significant effect of the coaxial cables while testing a phone. Correlation coefficients are highly affected by any radiation disturbance. Unlike the coaxial cables, the optic fibers do not affect the radiation pattern of an antenna. It is shown that - in an isotropic channel model - the correlation increases from 0.4 to 0.8 when fibers are used instead of cables. This study shows that the set-up used to provide correlation values nowadays must be chosen very carefully in order to avoid measurements that are not reproducing the reality. The optic fibers technique seems to be a very good and convenient candidate to measure accurate results. This investigation is intended to be extended to other antennas from LTE phones having the same size in order to obtain more knowledge on the achievable correlations on smart-phones.
User's hand and head phantoms have been tested with optic fibers as well. They have a de-correlating effect on the antennas, as they force their environment to be different. It is shown that with the SAM head model and the PDA hand grip the correlation coefficient drops to 0.1. Ways to de-correlate the antennas for small terminals at frequencies as low as 750 MHz are still under extensive research and the required performances for MIMO-LTE are not yet met.

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