Change in TRP and TIS due to Handset Mounting Errors During Measurements

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Change in TRP and TIS due to Handset Mounting Errors During Measurements

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***Abstract*— An important characteristic of a mobile handset is its ability to receive and transmit power. One way to characterize the performance of a handset in this respect is to use measurements of the spherical radiation pattern from which the total radiated power (TRP) and total isotropic sensitivity (TIS) can be computed. Often this kind of measurements are made with a phantom user head next to the handsets in order to simulate the influence of a real user. The measured radiation patterns are only expected to be repeatable if the same setup is reproduced, *i.e.*, the same phantom and the same mounting of the handset on the phantom. In this work the influence of mounting errors on the TRP and TIS is investigated. Radiation patterns of six handsets have been measured while they were mounted at various offsets from the reference position defined by the Cellular Telecommunications & Internet Association (CTIA) certification. The change in the performance measures are investigated for both the GSM-900 and the GSM-1800 band.**

***Keywords*— Mobile handset performance, TRP, TIS, spherical radiation pattern, uncertainty**

I. Introduction

The performance of a mobile handset in terms of the power transmitted and received is important since this influences the lifetime of the battery, the network coverage, and the amount of interference in the network. It is well known that the amount of transmitted and received power varies greatly among different handset models, as the result of different designs where matching losses, losses in the antenna, *etc.*, may vary, see chapter 3 of [1]. Furthermore, the user of the handset may also have a large influence on the performance and hence the shape and the size of the handset are also important [2], [3].

The variation in the performance among handsets is possible because there are so far no requirements in, *e.g.*, the GSM standard with respect to the actually transmitted and received power. Only so-called conducted tests, *i.e.*, excluding the antenna, are carried out. In an attempt to improve on this situation some work has been done in a working group of COST 259 and its successor COST 273 (COoperation européenne dans le domaine de la recherche Scientifique et Technique) [1]. This work has been focused on performance evaluation based on measurements of the spherical radiation pattern of the handsets. Similarly, the Cellular Telecommunications & Internet Association (CTIA) has been working on a certification of mobile handsets in terms of the total radiated power (TRP) relevant for the up-link (UL) and total isotropic sensitivity (TIS) for the down-link (DL), see [4].

For practical reasons, measurements of the spherical radiation patterns usually do not include live test persons. Instead the influence of the handset user on the performance is simulated by a phantom of the user's head which is placed next to the handset during the measurements. In order to ensure correct and repeatable measurements it is important that the position and orientation of the handset on the phantom is exactly as intended, *e.g.*, as described in [4].

The objective of the current work is to quantify the influence of handset positioning errors on the TRP and TIS. With this aim a series of spherical radiation pattern measurements were carried out on six handsets representing today's most common types on the market. All handsets were measured in both the correct position on the phantom as well as in several incorrect but controlled positions.

II. Total Isotropic Sensitivity and Total Radiated Power

According to the CTIA certification document [4] the total isotropic sensitivity (TIS) is given by the expression

$$P_{\text{TIS}}(f) = \frac{4\pi P_c}{\oint_S G_\theta^{\text{DL}}(\Omega;f) + G_\phi^{\text{DL}}(\Omega;f)\,d\Omega}$$

Using ψ to denote either θ or ϕ, $G_\psi^{\text{DL}}(\Omega;f)$ is the squared magnitude of the ψ-polarization component of the electrical far field pattern for the handset antenna measured at the frequency f and in the DL, where Ω is the solid angle describing the direction. The DL antenna gain may also be written as

$$G_\psi^{\text{DL}}(\Omega;f) = \frac{P_c}{\text{EIS}_\psi(\Omega;f)} \tag{1}$$

where $\text{EIS}_\psi(\Omega;f)$ is the power necessary from the direction Ω in the ψ-polarization for the receiver to operate with a bit error rate (BER) of 2.44%. At this BER the conducted power is $P_c = -102$ dBm, by definition. In practice P_{TIS} is approximated from a set of discrete samples,

$$P_{\text{TIS}}(f) \simeq \frac{4\pi P_c}{P_{\text{tot}}^{\text{DL}}(f)}$$

where

$$P_{\text{tot}}^{\text{DL}}(f) = \Delta_\theta\Delta_\phi \times \sum_{n=0}^{N-1}\sum_{m=0}^{M-1}\left[G_\theta^{\text{DL}}(\theta_n,\phi_m;f) + G_\phi^{\text{DL}}(\theta_n,\phi_m;f)\right]\sin(\theta_n)$$

in which $\theta_n = n\Delta_\theta$ is the *nth* sample of the elevation angle measured from the z-axis, and $\phi_m = m\Delta_\phi$ is the *mth* sample of the azimuth angle measured from the x-axis. The sampling intervals are given by $\Delta_\theta = \pi/(N-1)$ and $\Delta_\phi = 2\pi/M$, respectively. In the current mesaurements $N = 13$ and $M = 24$, corresponding to $\Delta_\theta = \Delta_\phi = 15°$.

The total radiated power (TRP) is defined as

$$P_{\text{TRP}}(f) = \frac{P_{\text{Tx}}}{4\pi}\oint_S G_\theta^{\text{UL}}(\Omega;f) + G_\phi^{\text{UL}}(\Omega;f)\,d\Omega$$

where $G_\phi^{\text{UL}}(\Omega;f)$ is the ψ-polarization component of the antenna gain in the UL, in the direction Ω, and at the frequency f. During the measurements the handset is commanded to transmit using the maximum power level, $P_{\text{Tx}} = 30$ dBm. Again, discrete samples are used in practice to approximate the integral,

$$P_{\text{TRP}}(f) \simeq \frac{P_{\text{Tx}}}{4\pi}\,P_{\text{tot}}^{\text{UL}}(f)$$

where $P_{\text{tot}}^{\text{UL}}(f)$ is defined similarly to $P_{\text{tot}}^{\text{DL}}(f)$ above.

III. Measurements and Data Processing

Spherical radiation patterns of six commercially available GSM handsets have been measured. The handsets represent some of today's most frequently used handset types. Handset A and B are large handsets with external and internal antennas, respectively. Handset F and H are small handsets with external and internal antennas, respectively. Here 'small' handsets are among the smallest handsets available today, about 10 cm by 4.5 cm, and the 'large' handsets are about 13 cm by 4.5 cm. Handset A, B, and H are of the 'candybar' type while handset F is of the 'flip' type. Also a clamshell type handset has been included, which is labelled handset G. The antenna on handset F is a substitute of the antenna originally delivered with the handset. The substitute antenna can be either a helix, when the antenna is withdrawn, or a whip, when extracted. In the measurements handset F denotes the helix antenna, and handset E is the whip antenna.

The measurements were performed in a large anechoic room using a GSM tester (Rohde & Schwarz CMU 200) and a positioning device with two axes. Both the CMU tester and the positioning device are controlled from software running on a SUN workstation, allowing automatic measurement of the complete spherical radiation pattern in both the θ- and the ϕ-polarization. The CMU tester, acting as a base station, measures the UL power while the DL measurements are obtained from the power levels measured by the handset, as required by the GSM standard. In this way the measurements can be made without attaching cables *etc.* to the handsets, which will change the radiation pattern [5]. The deviation from linearity versus input power of the measurements made by the handsets were determined via measurements to be less than about 0.6 dB within a dynamic range of 35 dB from the maximum received power. Hence, relative errors are negligible. In addition there may be an constant offset in the measurements made by the handsets. Since only relative values are used in this work, these errors have no influence on the results.

All the handsets are dual-band and are measured on the center channel in both bands. For the GSM-1800 band channel 698 was used, corresponding to 1842 MHz and 1710 MHz for the DL and UL, respectively. Channel 62 was used in the GSM-900 band, corresponding to 947 MHz for the DL and 902 MHz for the UL.

The spherical radiation patterns were sampled using increments of 10° in the elevation angle θ and 20° in the azimuth angle ϕ. It should be mentioned that all the results presented in the current document are based on processing of spherical radiation patterns sampled in a 15° by 15° grid, obtained via interpolation of from the measured data. This was done in order to meet the requirements of the CTIA certification document [4].

The handsets were measured next to a SAM phantom head, which was filled with a tissue simulating liquid as required by the CTIA certification. During measurements the handset is mounted on the left side of the phantom, as shown in Fig. 1 where also the reference coordinate system is depicted. The coordinate system is defined such that the x- and y-axis spans the base of the phantom with the x-axis pointing away from the face of the phantom while the y-axis is pointing away from the phantom's left ear (see Fig. 1). The z-axis is parallel to a line directed from the base and upwards through the top of the phantom and in the center. The origin of the coordinate system is at the left ear reference point which is also the center of rotation during the measurements.

Five different measurement series were made each differing in the way the handset is mounted on the head, as given below. In all cases the handsets are mounted on the phantom using teflon tape. The terminology used for specifying the handset position is adopted from the CTIA certification document, and illustrated in Fig. 2.

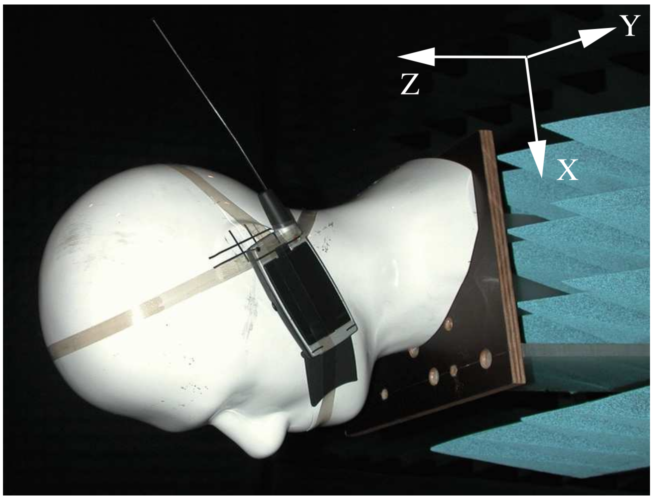

Fig. 1. A handset mounted on the phantom.

- Reference. In this reference measurement series the handset is mounted according to the CTIA document [4].
- Top Translation. In this series the handsets are mounted in the reference position except that the 'A' point of the handset is rotated about the bottom (the point touching the phantom) so that the 'A' point is ±15 mm off the correct position, where the distance is the position of the 'A' point projected on the horizontal reference line of the handset, and where the negative offset is towards the face of the phantom.
- Bottom Translation. Similar to the top translation series, this series rotates the bottom reference point about the ear reference point. The distance is measured along the line passing the lower reference point and is perpendicular to the vertical center line.
- Longitudinal Translation. In this series of measurements the handset is moved along the vertical handset center line so that the 'A' point is either above (+15 mm) or below (−7.5 mm) the ear reference point. The negative value was chosen to be −7.5 mm rather than −15 mm because handset E/F cannot rest on the phantom ear in a reasonable way if the larger translation is used.
- Transverse Translation. In this series of measurements the handset is translated either towards the face of the phantom (−15 mm) or towards the back (+15 mm) while the handset center line is kept parallel to the 'MB'-line.

In the following the changes in the TIS and the TRP due to the various translations has been investigated using the normalized measures defined as

$$P'_{\mathrm{TRP}} = \frac{P^{\mathrm{trans}}_{\mathrm{TRP}}}{P^{\mathrm{ref}}_{\mathrm{TRP}}} \qquad\qquad P'_{\mathrm{TIS}} = \frac{P^{\mathrm{ref}}_{\mathrm{TIS}}}{P^{\mathrm{trans}}_{\mathrm{TIS}}}$$

where $P^{\mathrm{trans}}_{\mathrm{x}}$ is either TIS or TRP obtained from measurements with a translated handset, and $P^{\mathrm{ref}}_{\mathrm{x}}$ is the corresponding reference measurement. Note that the definition of P'_{TIS} differs from that of P'_{TRP} so that an increase in the total antenna gain results in a positive change (in dB) for both P'_{TRP} and P'_{TIS}.

IV. Error in Total Radiated Power and Total Isotropic Sensitivity

Fig. 3 shows the change in TRP and TIS for each handset and frequency band, grouped in the different types of translations from the reference position. The different combinations of handsets and translations are shown along the x-axis where, *e.g.*, 'E-15' means handset E translated −15 mm.

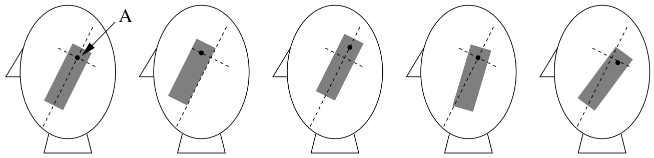

Fig. 2. Handset positions on the phantom. Only one direction is shown for each type of translation.

It is noticed in all the plots that TIS and TRP values are correlated so that, *e.g.*, an increase of the transmitted power due to a translation is usually associated with a corresponding increase in the received power. Another general observation is that there seems to be no clear frequency dependence. The results indicate about the same influence on the results obtained for the low and high frequency bands, perhaps with slightly larger deviations for the high band. This is somewhat surprising since the absorption in phantom heads previously has been reported to be about two times larger (in dB) for the low band than for the high band [6].

Concerning the results for translation at the bottom end of the handsets, Fig. 3(a), a rather low variation is observed for any of the combinations of offset, frequency, and TRP/TIS, mostly within about ± 0.25 dB. A noticeable exception is handset F which has an error of about 0.6 dB in the TRP in the high frequency band for both offsets.

Translation of the top end of the handsets, Fig. 3(b), is generally worse than translation of the bottom end with more values outside a ± 0.25 dB range and a maximum value of about 1.4 dB. Since the antennas are located in the top of the handsets the difference between the top end and bottom end translation is expected.

Comparing Fig. 3(c) and 3(b) it is noticed that the results obtained with the transversal translation are quite similar to those obtained with translation of the top end of the handsets. This is to be expected since translation of the bottom end only has a small influence on the results.

Comparing the results obtained with the different handsets, handset F is generally one of the most sensitive towards the correct placement on the phantom, since the largest error values are observed with this handset. The most likely explanation is the external antenna on this handset which is located close to the front of the phone and thus near the phantom head when it is mounted. The other handset with a small external antenna (handset A) is thicker than handset F and probably less influenced for this reason.

Initially the measurements were made with translations of ± 15 mm for all handsets and kinds of translations, with the exception of the longitudinal translations, as described above. Given that handset F turned out to be very sensitive towards the translations it was decided to supplement the measurements for this handset with another set carried out with ± 7.5 mm translations. In the plots the results based on these extra measurements have been labeled handset F^*.

The measurements with 7.5 mm translations usually results in a lower difference than for 15 mm translations but in many cases still higher than for the other handsets. One remarkable exception is the result for the high band, TRP for the transverse translation case. Here the results for the $+7.5$ mm are actually about 0.25 dB higher that those for $+15$ mm.

Having obtained this result it was decided to repeat some of the measurements in order to confirm these results. The results for $+15$ mm labeled 'handset $F^{\#}$' are repetitions and thus can be compared to the the $+15$ mm for handset F. In addition the $+7.5$ mm translation was repeated, also shown as handset $F^{\#}$. Comparing the results for the different offsets it can be concluded that the TRP/TIS values can be repeated within 0.25–0.5 dB even for the most sensitive handset. Thus, the result mentioned above for the $+7.5$ mm transverse translation is within the accuracy.

For longitudinal translations, Fig. 3(d), the situation is similar to the case of translating the top end. Again the TRP/TIS for handset F is mostly influenced while for handset B it is only changed slightly, which could be due to the size of these handsets and the antenna types. However, despite the thickness of handset A it seems also to be somewhat influenced by the translations, at least for the high frequency band. Also handset H is quite sensitive with changes up to about 0.9 dB, but only for the low band. Due to the relatively large change found for this handset some extra measurements were made, this time with a $+7.5$ mm translation. In the plots these results are labeled handset H^*, similarly to above. The results for the translation in the negative direction are copies of the results for the 'handset H'. It is noticed that the changes for handset H^* in the low band are smaller than the corresponding changes observed for handset H.

V. Conclusions

This work investigates the change in the TIS and TRP when the spherical radiation pattern of a handset is measured while is mounted incorrectly on the phantom. Four different types of translations of the handset from the reference position was used, namely translation of the bottom/top end of the handset, longitudinal translation, and transversal translation. Six different handsets were measured on both GSM-900 and GSM-1800 at channel 62 and 698, respectively.

Generally it was found that TIS and TRP values are correlated so that, *e.g.*, an increase of the transmitted power due to a translation is usually also associated with an increase in the received power. Furthermore, the results indicate about the same influence on the results obtained for channel 62 and channel 698.

For the translations of the bottom end the deviations are mostly within about ± 0.25 dB and only handset F has a deviation larger than 0.5 dB, about 0.6 dB. Top end translations results in deviations that are somewhat larger but all values are within ± 0.5 dB, except handset E with 0.6 dB deviation and handset handset F with 1.4 dB. The results for the transversal translation are similar to the top end translation results, with all values within about ± 0.5 dB, except for handset F which has a deviation up to 1.1 dB.

The reason for handset F generally being more sensitive towards translations is most likely that this handset has an external antenna which is close to the front of the handset, and hence closer to the phantom.

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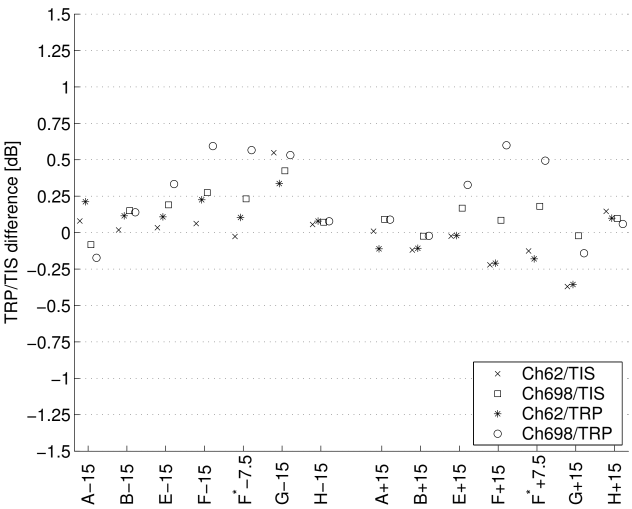
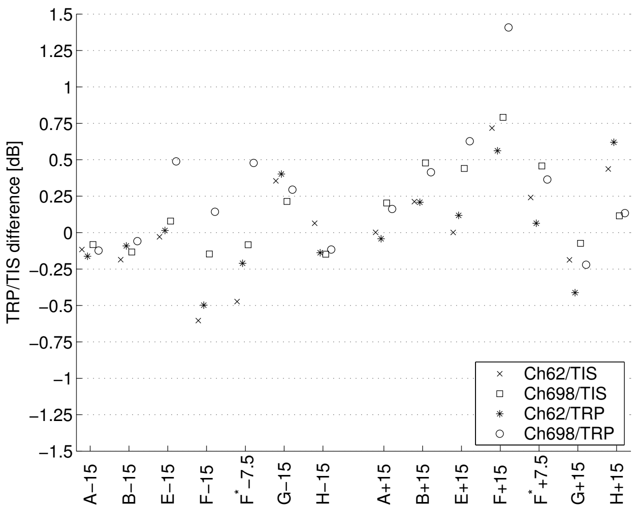
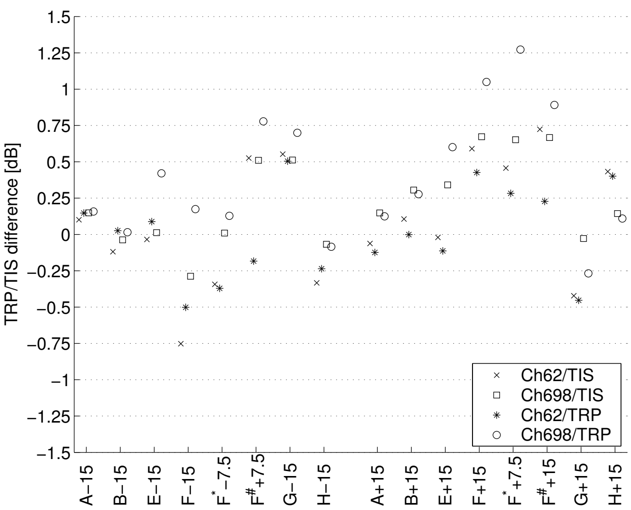


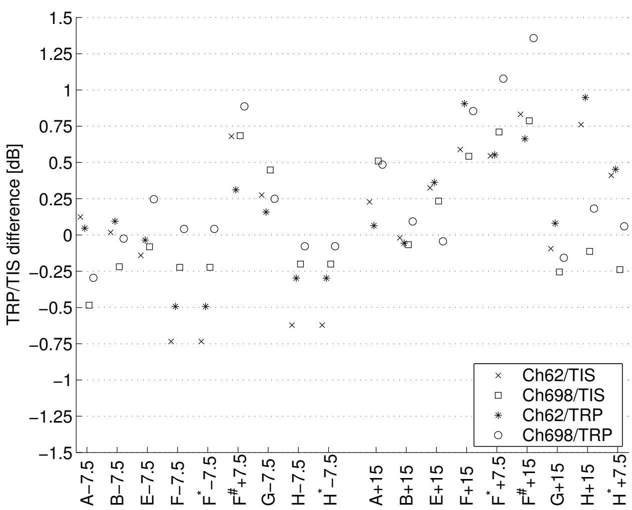
(a) Translation of bottom end.



(b) Translation of top end.



(c) Transversal translation.



(d) Longitudinal translation.

Fig. 3. Change in TRP and TIS for the different types of translation.