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Influence of Spherical Radiation Pattern Measurement Uncertainty on Handset Performance Measures

Jesper Ødum Nielsen, Gert Frølund Pedersen

***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), total isotropic sensitivity (TIS), and mean effective gain (MEG) can be computed. Often this kind of measurements are made with a phantom 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 used, *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, TIS, and MEG is investigated. Knowledge about the error due to incorrect mounting is necessary in determining requirements for both the mounting accuracy as well as for other parts of the measurement system that may introduce errors in standardized performance measurements. 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. Despite the deliberately large deviations from the reference position, the changes in TRP and TIS are generally within ± 0.5 dB with a maximum of about 1.4 dB. For the MEG values the results dependon the orientation of the handset with respect to the environment. Standard deviations up to about 0.5 dB and a maximum deviation of about 1.6 dB were found.**

***Index Terms*—Mobile handset performance, MEG, TRP, TIS, spherical radiation pattern, uncertainty, small antenna evaluation**

I. Introduction

The performance of a mobile handset in terms of the power transmitted and received is important since this influences the amount of interference in the network, the network coverage, and the lifetime of the battery. 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, load-pull of the power amplifier, *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 power levels measured at the antenna terminals are specified. 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 (European Co-operation in the Field of Scientific and Technical Research) [4]. This work has focused on performance evaluation based on measurements of the spherical radiation pattern (sometimes referred to as the 3-D 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 [5]. These measures may be seen as a special case of the so-called mean effective gain (MEG) measure [6], [7]. Unlike TRP and TIS, the MEG takes into account both the directional and polarization properties of the handset antenna and the mobile environment.

For practical reasons, measurements of the spherical radiation patterns usually do not include live test persons, as in [8]. 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 [5].

The objective of the current work is to quantify the influence of handset positioning errors on the TRP, TIS, and the MEG. 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 (year 2002). All handsets were measured in both the reference position on the phantom as well as in several slightly changed, *i.e.*, incorrect positions. In this way the influence of handset positioning errors on the phantom can be assessed quantitatively, which is needed for creating an overview of the most important error sources in the handset performance evaluation procedures. Such an overview is useful for setting requirements to the positioning accuracy as well as to other parts of the measurement system.

II. Mean Effective Gain

The MEG is the ratio of the actually received mean power to the mean power received by two hypothetical isotropic antennas matched to the θ- and ϕ-polarizations, respectively. As detailed in [7], [9], the MEG may be obtained using a

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surface integration,

$$\Gamma(f) = \frac{\oint_S G_\theta(\Omega,f)Q_\theta(\Omega,f) + G_\phi(\Omega,f)Q_\phi(\Omega,f)\,d\Omega}{\oint_S Q_\theta(\Omega,f) + Q_\phi(\Omega,f)\,d\Omega} \quad (1)$$

Using ψ to denote either θ or ϕ, $G_\psi(\Omega,f)$ is the antenna power gain in the ψ-polarization for the frequency f, defined as the measured power in the direction Ω normalized to the total input power. The interpretation of $Q_\psi(\Omega,f)$ depends on the link direction. For the DL, $Q_\psi(\Omega,f)$ is the average power incident on the handset from the direction Ω in the ψ-polarization and for the frequency f. For the UL, $Q_\psi(\Omega,f)$ is the average power received by the base station stemming from the mobile transmitting in the direction Ω and in the ψ-polarization. The distribution of power versus direction is not expected to change significantly for the different frequencies used in this work and therefore the frequency variable f in $Q_\psi(\Omega,f)$ is omitted henceforth.

Since MEG is a ratio of power values only the cross polarization ratio (XPR) and the distribution of power versus direction are important. In this work three models of the power densities $Q_\theta(\Omega)$ and $Q_\phi(\Omega)$ have been used,

- HUT: A model based on numerous outdoor to indoor measurements in the city of Helsinki, Finland [10]. In this model the variation versus azimuth angle is assumed uniform and non-uniform versus elevation angle. It has an XPR of 10.7 dB.
- AAU: A model based on numerous outdoor to indoor measurements in the city of Aalborg, Denmark [11]. This model includes variation in both azimuth and elevation angle, and has an XPR of 5.5 dB.
- ISO: The isotropic model is hypothetical and implies equal weighting of power versus direction in both polarizations and with an XPR of 0 dB. This model is not based on measurements but the assumptions lead to MEG values independent of the handset orientation which are equivalent to the TRP and TIS, for the UL and DL, respectively. Hence, this model is implicitly assumed when TRP and TIS values are used.

For mobiles operating in an indoor environment and communicating with a base station located outdoors, the power can in many cases be expected to be transmitted mainly through building openings such as windows and doors, and hence the power distribution will be non-uniform. Also the radiation patterns of mobile handsets in use can be expected to be non-uniform due to the blocking by the user in normal handheld operation. Therefore, the received power can be expected to vary depending on the orientation of the handset/user in the environment. Although the user orientation in the environment in general is arbitrary the variation in power over different orientations may be significant. In order to evaluate the power variation models with non-uniform power distribution are needed.

The TRP and TIS have been suggested as initial handset antenna performance measures for the UL and DL, respectively [1], [5]. However, the TRP/TIS does not include the directional and polarization aspects, and hence may be misleading compared to the actual performance of the handset in a real network. By including the hypothetical isotropic environment model the TRP/TIS can be compared directly to the MEG obtained with the realistic models. However, it should be noted that the MEG values obtained with the isotropic environment differ from the TRP/TIS since they are based on the antenna gain patterns. It is easily derived that the TRP is $P_{\mathrm{TRP}} = 2P_{\mathrm{Tx}}\Gamma_{\mathrm{Iso}}$ where P_{Tx} is the nominal (or conducted) transmit power level of the handset and Γ_{Iso} is the MEG value obtained with the isotropic model. Likewise, the TIS is $P_{\mathrm{TIS}} = P_{\mathrm{c}}/(2\Gamma_{\mathrm{Iso}})$ where the conducted power (at the receiver input) resulting in receiver operating with a bit error rate of 2.44% is defined to be $P_{\mathrm{c}} = -102$ dBm, which is the maximum allowed according to the GSM standard [12]. Since only relative values are considered in this work the scaling can be ignored.

Label	H×W×D	Antenna type	Ant. dist. to front	Handset type
A	130×47×23	External	19	Candybar
B	129×47×18	Internal	18	Candybar
E	97×50×15	Whip	11	Candybar
F	97×50×15	Helix	11	Candybar
G	88×50×19	External	13	Clamshell
H	96×43×19	Internal	19	Candybar

TABLE I
OVERVIEW OF THE MEASURED HANDSETS. DISTANCES ARE GIVEN IN MM. THE CLAMSHELL HANDSET G IS MEASURED IN CLOSED CONDITION. WHEN OPENED THE ANTENNA IS LOCATED NEAR THE JOINT OF THE TWO HALVES.

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. An overview is shown in Table I. 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. It may be noted that it has been verified by measurements that the TRP and the TIS obtained with the original helix antenna are within a few tenths of a dB of the corresponding values obtained with the withdrawn replacement 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, see Figure 1. Both the CMU tester and the positioning device are controlled by locally developed 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

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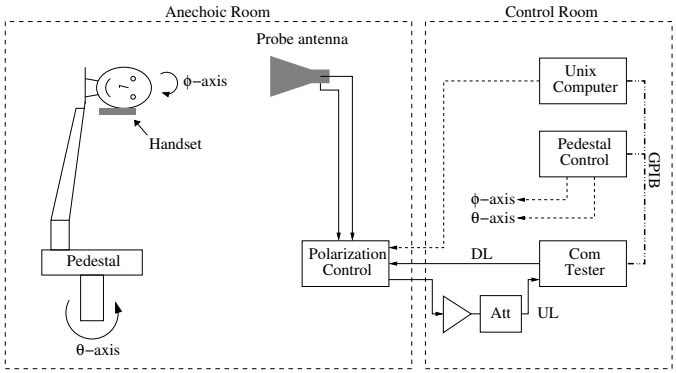

Fig. 1. Overview of measurement system. The measurements are made using different combinations of rotation about the vertical axis of the phantom and the pedestal. The reference coordinate system is depicted in Figure 2.

by the handset, as required by the GSM standard. In this way the measurements can be made without any modifications of the handsets, such as attaching cables *etc.*, which will change the radiation pattern [13], [14].

The power measurements carried out by the handsets are intended for power control and handover decisions and hence are not precision measurements. According to the GSM standard the reported power levels are allowed to deviate up to 6 dB from the actual power level [15]. Therefore, a calibration procedure must be applied before the data can be used for the DL. This is possible using the reported power levels for a sweep of known input power levels in addition to a single measurement of the power levels necessary for the receiver to operate at the sensitivity level defined at the 2.44% bit error rate. In practice deviations are small for the handsets used in this campaign. The deviations 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, the relative errors are of the same order as the quantization error due to the 1 dB steps. In addition there may be a constant offset in the absolute values reported by the handsets. This offset could be determined but since only relative values are used in this work, these offsets have no influence on the results.

The setup for radiation pattern measurements was tested and calibrated in the following way.

- The absolute gain of the probe antenna was found from a three-antenna measurement.
- The combined gain of all cables, switch, splitter, and amplifiers was determined using network analyzer measurements of scattering parameters versus frequency in both polarizations and directions.
- The power values measured by the CMU were calibrated by comparing to values obtained by a precision peak power meter (Rohde & Schwarz sensor, TDMA model NRV-Z31).

The calibration outlined above was carried out several times during the period of handset measurements (roughly one and half month). The probe antenna gain was determined within a variation of ± 0.25 dB, while the gain of the cables *etc.* was within ± 0.1 dB, due to a very stable power supply for the amplifier. The calibration for the CMU changed less than ± 0.2 dB in the range needed (error specified to be smaller than 0.5 dB). Due to the fact that the differences found were small and since only relative values are used only one calibration was used for all the measurements.

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 about 1842 MHz and 1747 MHz for the DL and UL, respectively. Channel 62 was used in the GSM-900 band, corresponding to about 947 MHz for the DL and about 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. The reason for the more dense sampling in the elevation angle is that the dimensions of the combined handset and phantom are larger along the elevation angle than the azimuth angle. Investigations have shown that the choices of sampling densities in the azimuth and elevation angles lead to negligible errors in the MEG values, with a standard deviation of 0.1 dB and a maximum observed error of 0.4 dB, as shown in a paper to be published [16]. Some limited information is also available in [17].

It should be mentioned that all the results presented in the current paper are based on processing of spherical radiation patterns sampled in a 15° by 15° grid, obtained via interpolation of the measured data. This was done in order to meet the requirements of the CTIA certification document [5]. The interpolation is needed in any case to obtain rotated radiation patterns (see below), since samples are needed from directions not in the original sampling grid. The spline interpolation method was used.

The handsets were measured next to a SAM phantom head [18], which was filled with a tissue simulating liquid as required by the CTIA certification.

In assessing the changes in the MEG and TRP/TIS values the repeatability of the measurement procedure itself must be known. In a similar campaign carried out in the same anechoic room this was investigated using repeated measurements of the radiation patterns. The measurements included dismounting and mounting of the handset and the MEG results were found typically to be repeatable within 0.1–0.3 dB [16].

During measurements the handset is mounted on the left side of the phantom, as shown in Figure 2 where also the reference coordinate system is depicted. The coordinate system is defined such that the x- and y-axis span 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. The z-axis is parallel to a line directed from the base and upward 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

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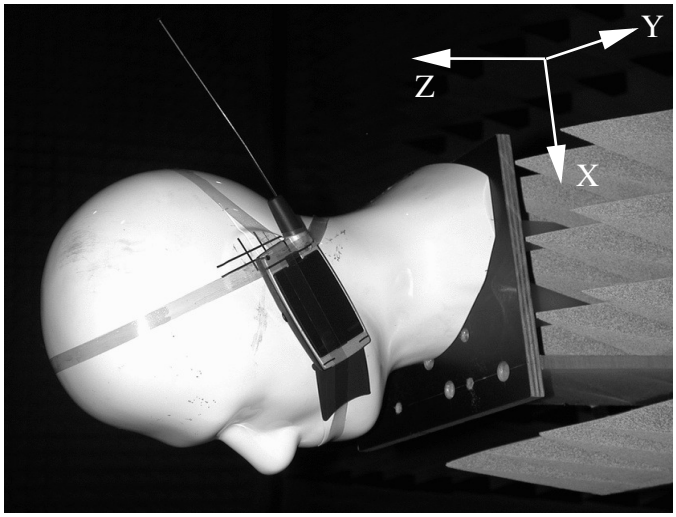

Fig. 2. A handset mounted on the phantom.

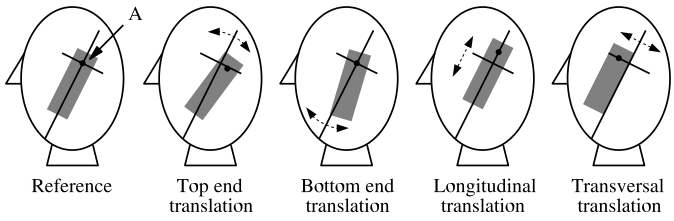

Fig. 3. Handset positions on the phantom. Only one direction is shown for each type of translation. The 'A'-point is defined as the crossing of the vertical center line and the horizontal line of the handset.

in the way the handset is mounted on the head, as given below and sketched in Figure 3. 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.

- Reference. In this reference measurement series the handset is mounted according to the CTIA document [5].
- 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 toward 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 which is passing through the lower reference point and is perpendicular to the vertical center line of the handset.
- 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, and thus this mounting is unrealistic.
- Transversal Translation. In this series of measurements the handset is translated either toward the face of the phantom (-15 mm) or toward the back ($+15$ mm) while the handset center line is kept parallel to the line connecting the mouth and ear reference points (the 'MB'-line).

The translation distances used in this work have been chosen rather large deliberately in order to create a worst case scenario. If the handset is carefully mounted on the phantom the translations will be smaller in practice.

For all handsets in actual use both the radiation pattern and the spherical power distribution are directive, and the MEG will vary depending on the orientation of the handset with respect to the environment. In order to investigate this, the measured radiation patterns have been rotated firstly with an angle of λ about the y-axis, corresponding to the phantom either bending forward or backward, and afterwards with an angle μ about the z-axis, corresponding to the phantom turning around in azimuth. All combinations of $\mu \in \{0^\circ, 15^\circ, 30^\circ, \ldots, 345^\circ\}$ and $\lambda \in \{0^\circ, 15^\circ, \ldots, 60^\circ, 300^\circ, 315^\circ, \ldots, 345^\circ\}$ have been used and for each combination of λ and μ the MEG was computed. Note that the described post processing rotation procedure corresponds to a rotation of both the handset and the phantom. Thus, this is not a rotation of the handset relative to the phantom, but rather a rotation of the phantom with the handset at a fixed angle relative to the phantom. Evaluation of the MEG for different rotations of the handset relative to the phantom requires measurement of the radiation pattern for each rotation angle. This was not done in this work since it would result in a large number of measurements. Furthermore, only small differences are expected comparing the MEG computed from data obtained via a rotation, using the post-processing procedure described above, and the MEG obtained using measurements of the radiation pattern obtained with the handset fixed at the desired angle on the phantom.

In the investigations the MEG value as given by (1) is approximated using the formula

$$\Gamma(\lambda,\mu) \simeq \sum_{n=0}^{N-1}\sum_{m=0}^{M-1}\Big[G_\theta(\theta_n,\phi_m;\lambda,\mu)Q_\theta(\theta_n,\phi_m) + G_\phi(\theta_n,\phi_m;\lambda,\mu)Q_\phi(\theta_n,\phi_m)\Big]\frac{\sin(\theta_n)}{P_{\text{env}}} \tag{2}$$

where

$$P_{\text{env}} = \sum_{n=0}^{N-1}\sum_{m=0}^{M-1}\big[Q_\theta(\theta_n,\phi_m)+Q_\phi(\theta_n,\phi_m)\big]\sin(\theta_n)$$

and $G_\psi(\theta_n,\phi_m;\lambda,\mu)$ is the ψ-polarization component of the antenna power gain in the direction given by (θ_n,ϕ_m) and a rotation of the antenna using the angle pair (λ,μ). The number of samples in the ϕ and θ angles are $M=24$ and $N=13$, respectively. The sampling points of the sphere are given by the angles $\theta_i = i\Delta_\theta$ and $\phi_i = i\Delta_\phi$, where $\Delta_\theta = \Delta_\phi = 15^\circ$.

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In the following the change in MEG due to the various translations has been investigated using the normalized MEG defined as

$$\Gamma'(\lambda,\mu) = \frac{\Gamma(\lambda,\mu)}{\Gamma_{\text{ref}}(\lambda,\mu)}$$

where $\Gamma(\lambda,\mu)$ is the MEG for a specific radiation pattern measurement and using the rotation angles (λ,μ), and $\Gamma_{\text{ref}}(\lambda,\mu)$ is the corresponding reference measurement for the same handset. Thus, for each measurement a large number of values are obtained, one for each orientation of the handset. For this reason the mean and standard deviation have been used for the analysis, except for the isotropic environment which yields the same value irrespective of the handset orientation.

IV. Error in Total Radiated Power and Total Isotropic Sensitivity

Figure 4 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.

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. This suggests that the observed changes in TRP/TIS are mainly determined by changes in the losses in the phantom. On the other hand, changes in TIS/TRP due to changes in the antenna impedance cannot be expected to be the same for the UL and DL.

Another general observation is that there seems to be no clear frequency dependence. The results indicate about the same influence for the low and high frequency bands, perhaps with slightly larger deviations for the high band.

Concerning the results for translation at the bottom end of the handsets, Figure 4(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, Figure 4(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 Figure 4(c) and 4(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. The handset dimensions are given in Table I.

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 transversal 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 transversal translation is within the accuracy.

For longitudinal translations, Figure 4(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 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. Error in Mean Effective Gain

Figure 5 shows an overview of the obtained MEG values for the top end and transversal translation measurements, where each vertical bar is given by the mean value (the middle point of the bar) and the standard deviation shown as the distance from the middle point to each bar end.

Comparing the results obtained with the three environment models for the different translation types it was found that the mean values of the AAU and HUT model values roughly equals the hypothetical ISO model results. Hence, in some

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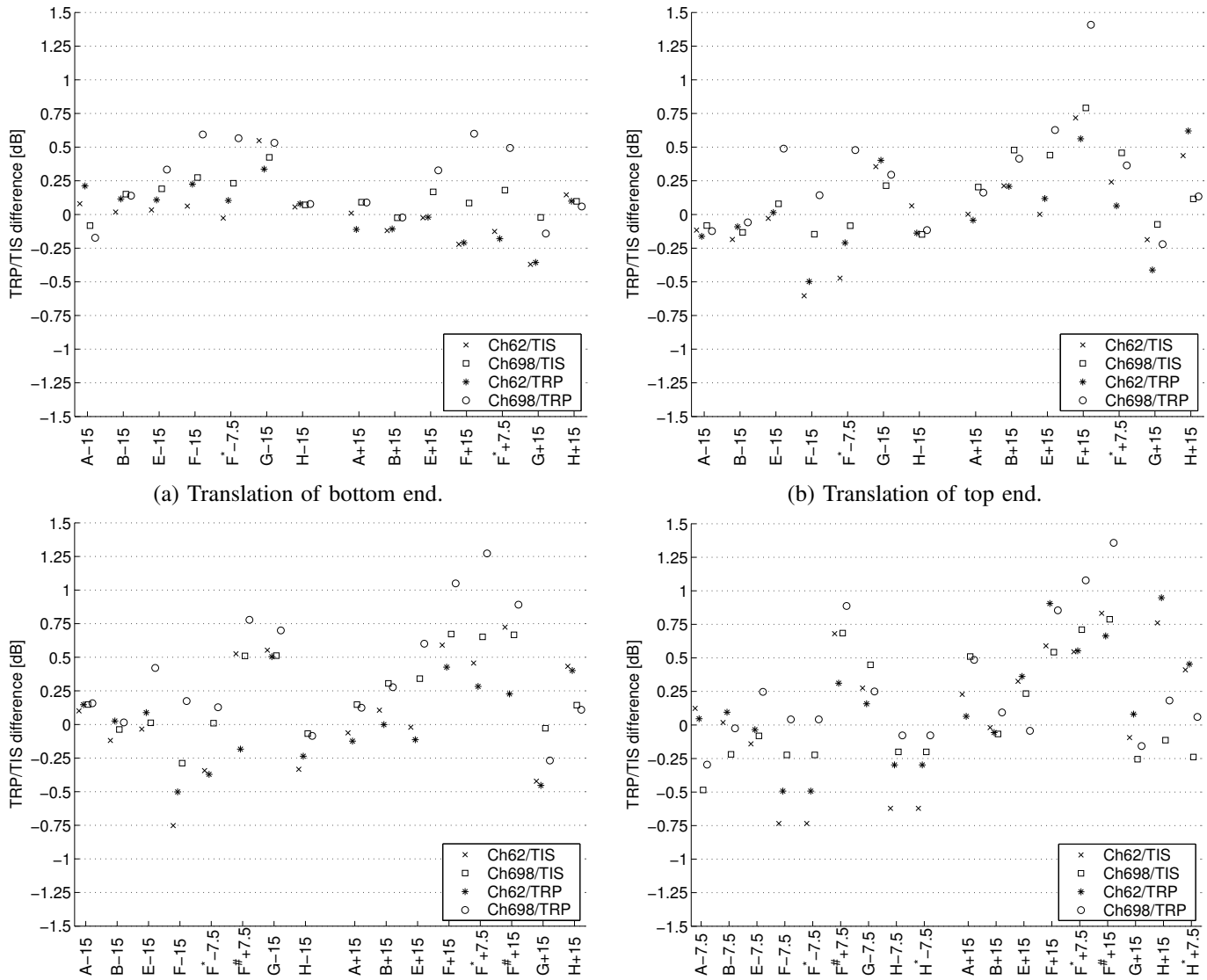

(a) Translation of bottom end.

(b) Translation of top end.

(c) Transversal translation.

(d) Longitudinal translation.

Fig. 4. Change in TRP and TIS for the different types of translation.

cases much of the change in the MEG is due to a power scaling and not as much a change in the distribution of power versus direction. This is particularly true for the transversal and longitudinal translations and to a smaller extend the top and bottom end translations.

There is a clear difference between transversal/longitudinal and top/bottom translations with respect to the standard deviation. For the AAU model the standard deviations for the different types of translation are more or less similar, whereas for the HUT model the standard deviation is generally larger for the top/bottom than for the transversal/longitudinal translations. A likely reason is that the large XPR value of the HUT model makes it sensitive towards changes in the cross polarization difference (XPD) of the antenna.[1] Changes in the shape of the antenna radiation pattern will also introduce more changes in the MEG due to the highly selective nature of the model as compared to the AAU model.

It has been found that in terms of XPR the measurements obtained with top and bottom end translations deviate more from the reference measurements than the measurements with transversal and longitudinal translations. As an example, Figure 6 shows the change in XPR for the bottom end and transversal translations. For the transversal translations the change in XPR is within a range of about ± 0.5 dB, which should be compared to the values for the bottom end translations where the change is generally outside the ± 0.5 dB interval, with handset F and H as exceptions. The same is the case for the top end translation measurements, but with the opposite sign of the XPR change. This suggests that the XPR change for these handsets are linked to the angle between the

[1] defined as the ratio of the power in the two polarizations.

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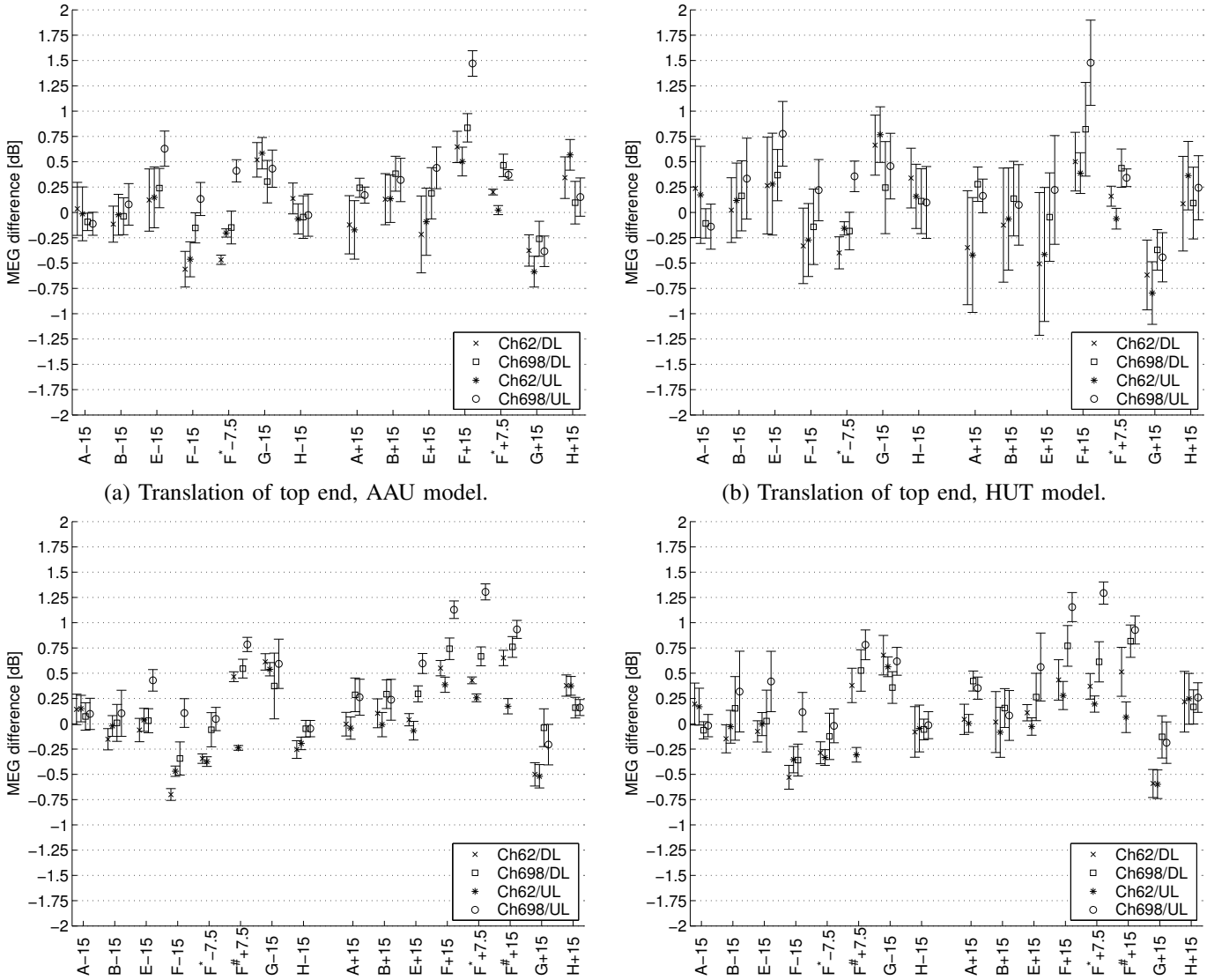

(a) Translation of top end, AAU model.

(b) Translation of top end, HUT model.

(c) Transversal translation, AAU model.

(d) Transversal translation, HUT model.

Fig. 5. Change in MEG for top end translation (a)–(b), and transversal translation (c)–(d).

vertical centerlines of the translated handset and the handset in the reference position. This was expected since much of the power is transmitted/received along the axis about which the handset is rotated for the top and bottom end translations.

Table II shows statistics based on the combined data of changes in MEG for all handset orientations, link directions, frequencies, and translation distances. The data have been split in two sets, one for the data obtained with handsets A, B, E, G and H, and another set obtained with handset F, $F^{\#}$ and F^{*}. The data for handset F was treated separately since it was found that this handset differs significantly from the other handsets, as described above.

Note that unlike for the AAU and HUT model, the MEG for the ISO model does not change due to rotation of the radiation patterns and hence the observed variation is only due to the different handsets, translation distances, and frequencies.

VI. Conclusions

This work investigates the change in the TIS, TRP, and MEG when the spherical radiation pattern of a handset is measured while it is mounted incorrectly on the phantom. Four different types of translations of the handset from the reference position were 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. The results of this work were obtained with deliberately rather large translations of the handsets on the phantom. With careful mounting of the handsets smaller deviations from the correct position can be obtained and smaller changes in the results are expected.

Generally it was found that TIS and TRP values are correlated so that, *e.g.*, an increase of the transmitted power due

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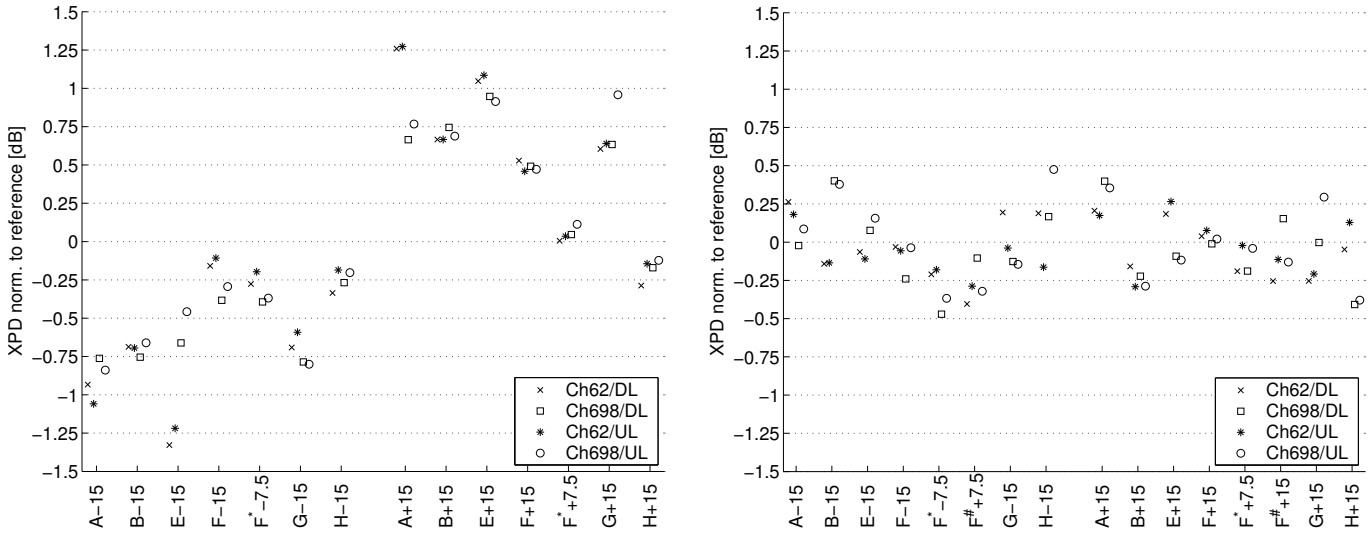
TABLE II
STATISTICS ON DEVIATION IN MEG. ALL VALUES ARE IN DB.

		AAU Model			HUT Model			ISO Model		
		Mean	Std	MaxAbs	Mean	Std	MaxAbs	Mean	Std	MaxAbs
A, B, E, G, H, H*	Bottom	0.1	0.3	0.9	0.0	0.5	1.5	0.1	0.2	0.6
	Top	0.1	0.3	1.0	0.1	0.5	1.6	0.1	0.3	0.6
	Long	0.0	0.4	1.2	0.0	0.4	1.4	0.0	0.3	1.0
	Trans	0.1	0.3	1.1	0.1	0.3	1.1	0.1	0.3	0.7
F, F*, F#	Bottom	0.2	0.1	1.0	0.2	0.2	1.4	0.2	0.1	0.6
	Top	0.2	0.3	1.8	0.2	0.3	2.0	0.2	0.3	1.4
	Long	0.4	0.4	1.8	0.4	0.4	1.8	0.4	0.3	1.4
	Trans	0.3	0.3	1.5	0.3	0.3	1.5	0.3	0.3	1.3



(a) Translation of bottom end. Transversal translation.

Fig. 6. Change in XPR.

to a translation is usually associated with an increase in the received power. Furthermore, the results show similar influence on the results obtained for the low and high frequency bands. The deviations found for the TIS and TRP values are generally within ± 0.5 dB with a maximum deviation of about 1.4 dB.

From statistics of the computed MEG values based on data from all handsets, link directions, orientation, and offsets, it is found that the mean MEG deviations due to translations are generally low, about 0–0.2 dB. Furthermore, standard deviations of 0.1–0.5 dB and maximum deviations up to 1.6 dB were found for most handsets, with one exception having a maximum up to 2 dB.

The changes due to the incorrect position of the handsets on the phantom should be compared to the uncertainty due to the measurement system and the methods used. Using repeated measurements, the MEG results were found typically to be repeatable within 0.1–0.3 dB in [16]. In addition, the changes in the MEG introduced by positioning errors should be compared to the variation in the MEG of 6–8 dB that may be observed for a handset depending on its general orientation in the environment. For the TRP/TIS a difference of 3–4 dB was found between different types of handsets [19].

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