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Mobile Handset Performance Evaluation Using Spherical Measurements

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Abstract— **The mean effective gain (MEG) is an attractive performance measure of mobile handsets, since it incorporates both directional and polarization properties of the handset and environment. In this work the MEG is computed from measured spherical radiation patterns of five different mobile handsets, both in free space and including a human head & shoulder phantom. Different models of the environment allow a comparison of the MEG obtained for realistic models based on measurements with the total radiated power (TRP) and the total isotropic sensitivity (TIS). All the comparisons are based on the MEG values obtained for different orientations of the handsets in the environments.**

I. Introduction

One important aspect of a mobile handset is its ability to receive and transmit signal power. The performance in this respect is important for both the user and the network operator, since the battery lifetime of a handset will be influenced, as will the network coverage and capacity.

When evaluating the communication performance of a mobile handset it is necessary to include the antenna, as the antenna has a large influence on the communication. This can be seen from the fact that all mobile handsets fulfill the system criterion within the small tolerances allowed, but still some handsets have coverage where others do not. This can be explained only by the antenna, which is not included in the type approval but of course will be included in actual use.

In the evaluation of the communication performance of a mobile handset, the single most important parameter is the signal power received by either the mobile handset or the base station. The received signal power depends directly on the transmitted power level in addition to the orientation and polarization properties at the transmitter and the receiver, as described by the antenna radiation patterns. All this comes directly from Friis' transmission law. The amount of transmitted and received power depends for any given antenna on the antenna efficiency including the matching between the antenna and the transmitter or receiver. This part can be obtained in an anechoic room by measuring the transmitted or received power in all directions followed by an integration over the sphere.

Inclusion of the direction and polarization properties of the transmitted or received power is difficult in the case of a mobile handset, since the handsets typically are used in a multipath environment, where the signal may be received from many directions and with different polarizations. In order to find the resulting received power, knowledge of the distribution of the incoming power is needed, as specified in [1]. The mean effective gain (MEG) is defined in [2, 3] as the mean received power in the case of a scattered environment with respect to a reference antenna.

In this work the MEG is computed using spherical measurements of the radiation patterns of four different mobile handsets, one of which is measured with two different antennas. The influence on the MEG of the directional and polarization properties of the environment is investigated through the use of five different models of the mobile environment.

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 [4], the MEG may be obtained using a surface integration,

$$\Gamma = \frac{\oint_S |e_\theta(\Omega)|^2 Q_\theta(\Omega) + |e_\phi(\Omega)|^2 Q_\phi(\Omega)\, d\Omega}{\oint_S Q_\theta(\Omega) + Q_\phi(\Omega)\, d\Omega} \qquad (1)$$

Using ψ to denote either θ or ϕ, $e_\psi(\Omega)$ is the ψ-polarization component of the electrical far field pattern for the handset antenna. The interpretation of $Q_\psi(\Omega)$ depends on the link direction. For the down-link (DL), $Q_\psi(\Omega)$ is the power received on average by the handset from the direction Ω in the ψ-polarization. For the up-link (UL), $Q_\psi(\Omega)$ is the power received on average by the base station stemming from the mobile transmitting in the direction Ω and in the ψ-polarization.

Note that since MEG is a ratio of power values only the cross polarization difference (XPD) and the distribution of power versus direction is important. In this work five models of the power density $Q_\psi(\Omega)$ have been used,

- HUT: a model based on numerous outdoor to indoor measurements in the city of Helsinki, Finland [5, paper 6]. This

model is uniform versus azimuth angle and has an XPD of 10.7 dB.
- AAU: a model based on numerous outdoor to indoor measurements in the city of Aalborg, Denmark [6]. This model is non-uniform versus both azimuth and elevation angle, and has an XPD of 5.5 dB.
- Iso: The isotropic model implies equal weighting of power versus direction in both polarizations and with an XPD of 0 dB. This model results in MEG values equivalent to the total radiated power (TRP) and total isotropic sensitivity (TIS), for the UL and DL, respectively.
- Rect0: The rectangular model has uniform weighting inside the window defined by $45^\circ \leq \theta \leq 135^\circ$ and $0^\circ \leq \phi < 360^\circ$, and zero weighting outside this window, where θ is the elevation angle measured from the z-axis and ϕ is the azimuth angle. The XPD is 0 dB for this model [7].
- Rect6: Similar to Rect0, but with an XPD of 6 dB.

Generally, this work is not an attempt to validate the models of the environment. On the other hand, the HUT and AAU models are based on actual measurements and hence in some aspects they are more credible than the remaining three models. Including all the models in the investigation allows for a comparison of the obtained MEG values, possibly justifying the slightly more complex models based on measurements.

The TRP and TIS have been suggested as handset antenna performance measures for the UL and DL, respectively, but 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 isotropic environment model the TRP/TIS can be compared directly to the MEG obtained with the more advanced models. However, it should be noted that, strictly speaking, the MEG values obtained with the isotropic environment differ from the TRP/TIS values by a non-important scaling. This is disregarded in the following.

The Rect0 model was proposed by the Cellular Telecommunications & Internet Association (CTIA) in [7] as a "Near-Horizon Partial Isotropic Sensitivity" and may be viewed as a very simple model of the power distribution in the environment. Although this model does not appear to be accurate in many cases, it does incorporate that in most mobile environments the power is not likely to arrive *e.g.*, from directly above the handset. The Rect6 model is a simple attempt to add some polarization aspects into the Rect0 model.

III. Measurements and Data Processing

Spherical radiation patterns of four 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 C and D are small handsets with internal and external 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 D was also measured with a substitute antenna (a retractable dipole); these measurements are labeled handset E.

Figure 1. A handset mounted on the head/shoulder phantom.

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 that will change the radiation pattern [8].

All the measurements were made on GSM channel 698, *i.e.*, 1842 MHz for the DL and 1747 MHz for the UL. The spherical radiation pattern was sampled using increments of 10° in both the azimuth angle ϕ and the elevation angle θ. The handsets were measured both in free space and next to a phantom head (Schmid & Partners v. 3.6), see Figure 1. For the free space measurements the handsets are oriented along the z-axis of the coordinate system with the display pointing towards the negative y-axis. When the phantom is included, the handset is mounted on the left side of the phantom at an angle of 45° from the z-axis, still with the display side facing the negative y-axis. Figure 2 shows an example of a measured radiation pattern.

For real handsets in actual use where both the radiation pattern and the spherical power distribution are non-isotropic, 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 and afterwards with an angle μ about the z-axis, using all combinations of $\mu \in \{0^\circ, 15^\circ, 30^\circ, \ldots, 345^\circ\}$

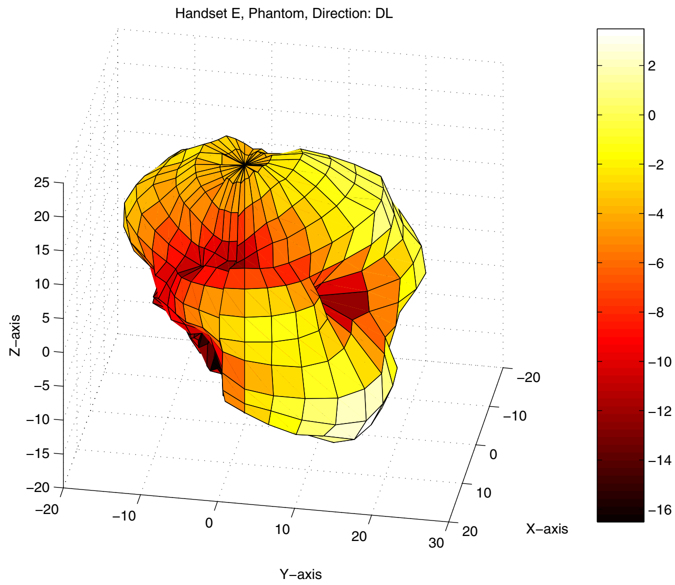

Figure 2. Example of a measured radiation pattern, total power gain in dB versus direction.

and $\lambda \in \{0°, 15°, \ldots, 60°, 300°, 315°, \ldots, 345°\}$. For each combination of λ and μ the MEG was computed. Note that for the phantom measurements 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. It should also be mentioned that spline interpolation has been used to obtain the rotated radiation patterns, since samples are needed from directions not in the original sampling grid.

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

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

where

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

and $G_\psi(\theta_n, \phi_m; \lambda, \mu)$ is the squared magnitude of ψ-polarization component of the E-field 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 $M = 36$ and $N = 19$, respectively. The sampling points of the sphere are given by the angles $\theta_i = i\Delta_\theta$ and $\phi_i = i\Delta_\phi$, with $\Delta_\theta = \Delta_\phi = 10°$.

IV. Results

In Figure 3 the MEG results for the free space case are shown for both the UL and the DL, while Figure 4 shows the results

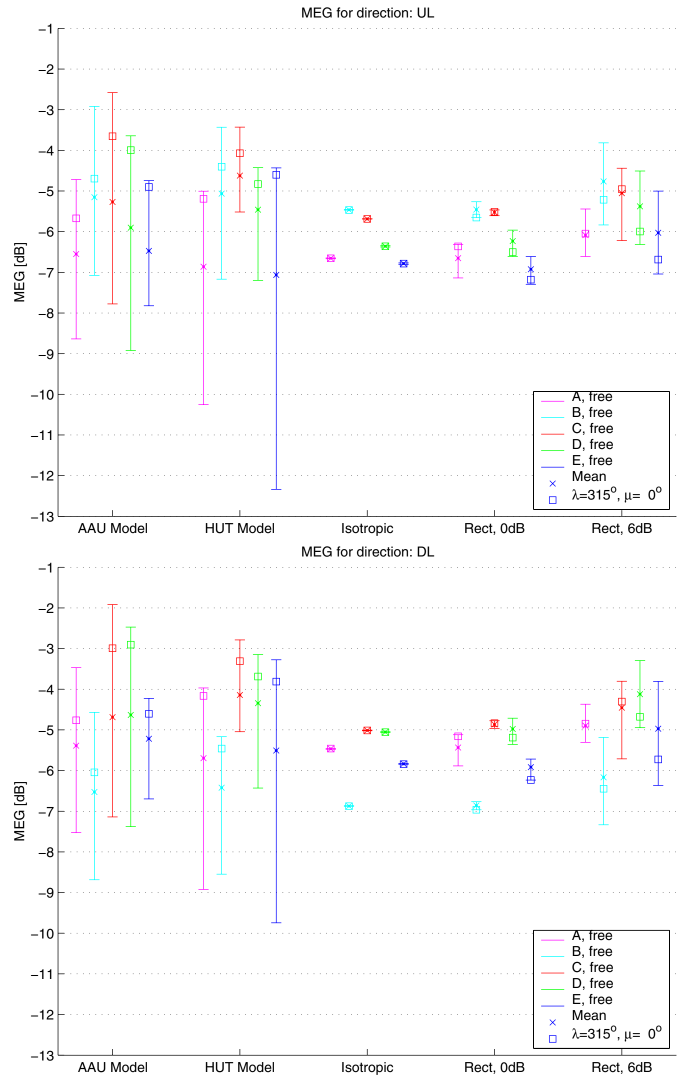

Figure 3. MEG for free space conditions for both the UL (top) and the DL (bottom). The minimum and maximum values are shown as error bars.

for the measurements including the phantom. In the figures the minimum and maximum values of the computed MEG values are shown as the endpoints of a vertical line, one line for each handset. Also shown on each line is the mean value (shown with '×') and a MEG value for a specific rotation, marked with '□' (see later). The results are presented in groups, one for each of the environments defined in Section II.

Comparing the TRP and TIS results with those obtained using the rectangular window model (XPD of 0 dB) it is noticed that the results are very similar. The mean values are roughly identical, which is expected since the rectangular window covers about 71% of the sphere surface area. Hence, most of the power will be included, and as the XPD is zero no polarization weighting is used. Therefore the results will be close to the TRP/TIS results.

Because the measured radiation pattern is rotated up to 60° in elevation angle some variation in the MEG values are observed

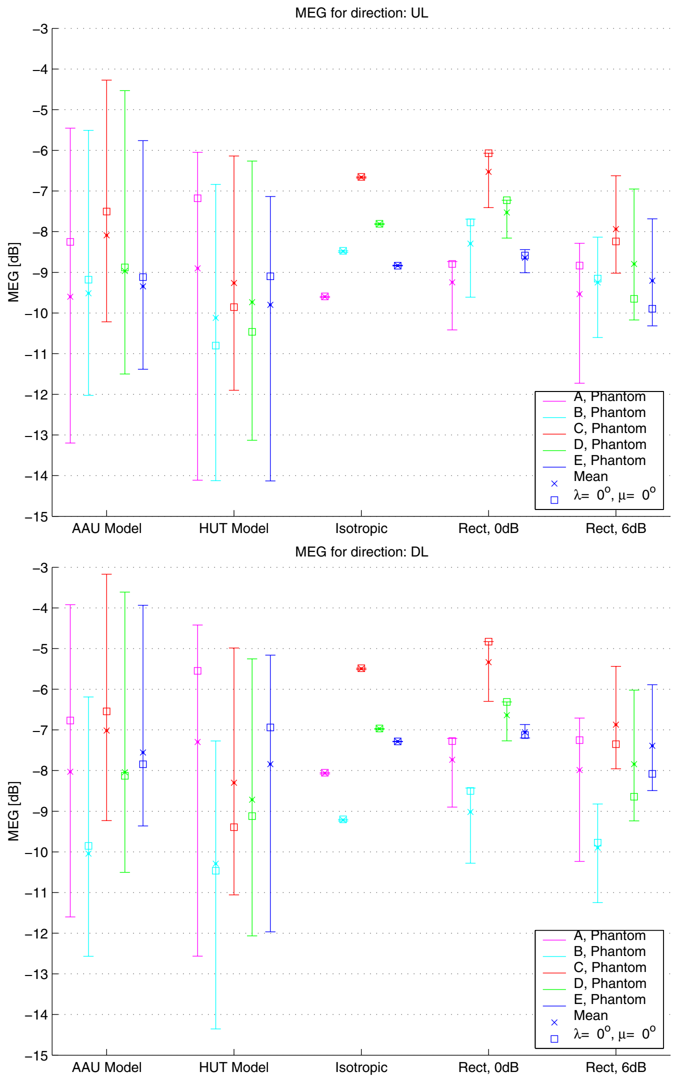

Figure 4. MEG for handset including phantom for both the UL (top) and the DL (bottom). The minimum and maximum values are shown as error bars.

for the rectangular window model, but only small changes are noticed compared to the changes seen with the two environment models derived from measurements. The rectangular window model with an XPD of 6 dB causes more changes, but the results are still far from to those obtained with the HUT and AAU models.

Although the results obtained with the AAU model and the HUT model have some similarities, it is also clear that there are significant differences in some cases. For example for handset E in the free space case the two models result in a MEG variation of about 2.5 dB and 6.4 dB for the AAU and HUT model in the DL direction, respectively, and about 3.1 dB and 7.9 dB for the UL direction.

Regarding the mean MEG values Table I shows the differences in the mean MEG values obtained with the various environment models compared to the TRP/TIS (*i.e.*, isotropic environment). The table is for the measurements including a phantom. A similar table for the free space shows that all differences are within the range -0.2 dB up to 1 dB.

The mean values are also quite small with the phantom in case of the rectangular window model with an XPD of 0 dB, where all differences are smaller than 0.4 dB. However, for the other models larger differences are found. In particular the HUT model results in differences from -2.8 dB up to 0.8 dB.

Larger differences are expected for phantom measurements and the non-isotropic environment models as compared to the corresponding free space measurements. The phantom blocks some of the power and effectively makes the radiation patterns more directive than the free space patterns. This causes more changes in the MEG when the handset is rotated and the environment model is directive as well.

It is important to realize that even if the mean values are identical for two different models of the environment this does not imply that the MEG values obtained with the two models are identical for a specific rotation of the radiation pattern.

For the free space an example is the rotation of the measured radiation pattern with $\lambda = 315°$ and $\mu = 0°$, corresponding to a tilt angle of $45°$ in typical talk position. The MEG values obtained with these rotations are shown on the vertical lines in Figure 3 with a '□'. It is clearly not possible to predict the MEG values shown with the □-marks from the mean values. The same is also true for the phantom measurements (Figure 4). For the phantom measurements $\lambda = 0°$ and $\mu = 0°$ is used since the handset is already mounted at an angle of $45°$ on the phantom.

The differences in the values obtained with the different models is depicted in Figure 5, where the MEG is shown sorted for increasing TRP and TIS in the UL and DL cases, respectively. Each line in the plots represents a model of the environment and the values are all obtained with the same orientation of the handset/phantom, as used above.

The MEG for the AAU, HUT, and Rect6 models are not monotonically increasing, showing that the MEG values for these models cannot easily be predicted from the TRP or TIS values. As expected, the results for the Rect0 model are roughly similar to the TRP/TIS values, except for a constant offset.

V. Conclusion

The mean effective gain (MEG) is an attractive measure of the mobile handset performance, since it incorporates both directional and polarization properties of the handset and environment. In this work the MEG has been computed using spherical measurements of the antenna radiation pattern in addition to models of the mobile propagation environment. Five different handsets have been measured in both free space and next to a phantom of the human head and chest. In total five different models of the spherical power distribution in the environment have been used, two of which are based on measurements. For each combination of handset measurement and environment model, the MEG was computed for 216 different combinations of azimuth and elevation rotations of the handsets.

For the environment models based on measurements, a variation in the MEG of 6–8 dB for different orientations was found

TABLE I

DIFFERENCE IN MEAN MEG VALUES WITH THE ISOTROPIC CASE AS REFERENCE, ALL VALUES ARE IN DB AND FOR THE PHANTOM CASE.

	DL					UL				
Environment	*A*	*B*	*C*	*D*	*E*	*A*	*B*	*C*	*D*	*E*
AAU	0.0	−0.8	−1.5	−1.1	−0.3	0.0	−1.0	−1.4	−1.2	−0.5
HUT	0.8	−1.1	−2.8	−1.7	−0.6	0.7	−1.6	−2.6	−1.9	−1.0
Isotropic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rect, 0 dB	0.3	0.2	0.2	0.3	0.2	0.4	0.2	0.1	0.3	0.2
Rect, 6 dB	0.1	−0.7	−1.4	−0.9	−0.1	0.1	−0.8	−1.3	−1.0	−0.4

when the handset is next to the phantom. In addition, some significant differences in the MEG variation have been observed for the two models based on measurements. The models not based on measurements do not result in as much variation in the MEG. In particular, the isotropic environment resulting in MEG values corresponding to TRP and TIS, has no variation by definition. A slightly more realistic rectangular window model having an XPD of 6 dB resulted in a variation up to about 3 dB.

Comparing the mean of the MEG values computed for different orientations of the handsets, all the values were found to be within about 1 dB of the isotropic results for the free space case. When the phantom is present, the variation is larger, about 3 dB,

Finally, it was found that though the mean MEG values obtained with different environments in some cases are roughly the same, the MEG values for particular orientations, such a typical talk position, cannot be predicted from the mean.

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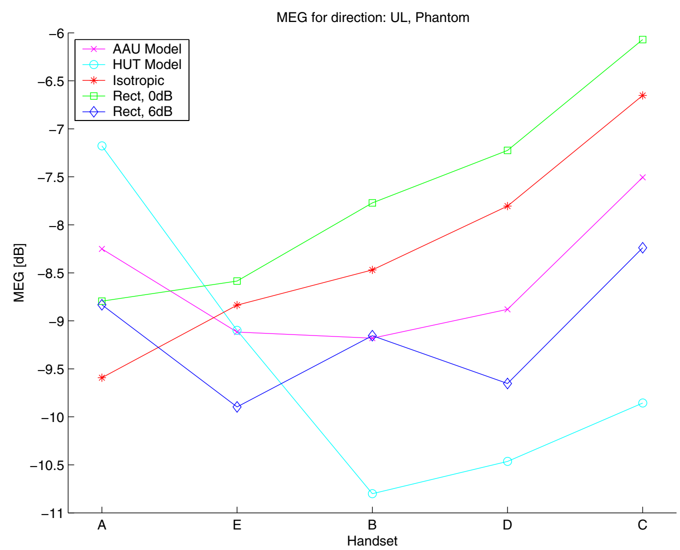

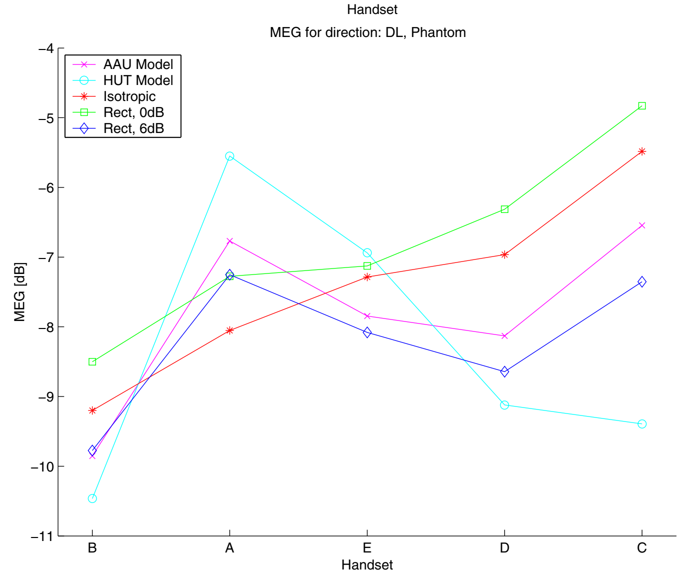

Figure 5. The MEG for a specific orientation ($\lambda = 0°$ and $\mu = 0°$) sorted for increasing TRP (top) and TIS (bottom). All values are for the phantom case.