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Nielsen, Jesper Ødum; Pedersen, Gert F.

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Jesper Ødum Nielsen, Gert Frølund Pedersen
Niels Jernes Vej 12
9220 Aalborg Ø
Denmark
Phone: +45 9635 8680
Fax: +45 9815 1583
Email: {jni,gfp}@cpk.auc.dk

Frequency Dependence of the Mean Effective Gain for Mobile Handsets

Jesper Ødum Nielsen, Gert Frølund Pedersen

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Abstract

One attractive method for evaluating the performance of mobile handsets is using the so-called mean effective gain (MEG) which is a realistic measure of the handset's ability to receive and transmit power. In this work the MEG is obtained via a measurement of the spherical radiation pattern of the handset and the influence of the measurement frequency on the MEG is investigated. The investigation is based on five different commercially available handsets, which were measured in an anechoic room in a cordless setup using a base station simulator. Since the handsets are battery powered during the measurements it is important to limit the total measurement time. This work proposes a method for reducing the number of measurements in the case where the MEG needs to be computed at several frequencies.

1 Introduction

The performance of a mobile handset with respect to the amount of power it is able to receive and transmit is important for both the user and the network operator, because the performance in this aspect may have a large influence on the battery lifetime as well as for network coverage and capacity.

One way to characterize the performance of a mobile handset in a realistic way is to use the so-called mean effective gain (MEG). Using a known antenna as reference, the MEG measures the mean received or transmitted power in a realistic mobile environment [1]. The MEG is an attractive measure since it incorporates both directional and polarization properties of the mobile channel and the handset. Although the MEG involves properties of both the handset itself and the environment, the use of spherical measurements makes it possible to separate the measurements of the mobile handset and measurements of the mobile channel [2]. In practice the surface integral involved in obtaining the MEG in this way has to be computed from a finite set of samples

of the spherical radiation pattern. The radiation patterns are generally frequency dependent and hence in principle they have to be measured at all relevant frequencies. Based on measurements of commercially available handsets, this work investigates how the MEG depends on the measurement frequency. Furthermore a method is proposed for reducing the total number of measurements.

2 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 [3], the MEG may be obtained using a surface integration,

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

Using ψ to denote either θ or ϕ , $e_\psi(\Omega, f)$ is the ψ -polarization component of the electrical far-field pattern for the handset antenna measured at the frequency f , where Ω is the solid angle describing the direction. The interpretation of $Q_\psi(\Omega)$ depends on the link direction. For the down-link (DL), $Q_\psi(\Omega)$ is the power received on the 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 the average by the base station stemming from the mobile transmitting in the direction Ω and in the ψ -polarization. In this work $Q_\psi(\Omega)$ is assumed to be essentially frequency independent within the band of interest.

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 three spherical 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 [4]. This model is uniform versus azimuth angle.
- MBK: a model is based on numerous outdoor to indoor measurements in the city of Aalborg, Denmark [5]. This model is non-uniform versus both azimuth and elevation angle.
- 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 total radiated power (TRP) and total receiver sensitivity (TRS), for the UL and DL, respectively.

In practice the antenna radiation patterns have to be measured using a discrete set of samples taken on a sphere surrounding the antenna, for example in a 10° by 10° grid defining the azimuth and elevation angles of the measurement points. This measurement procedure is time consuming and may be a problem since the handset has to be battery powered during the measurements. Furthermore, the radiation patterns of handset antennas can be expected to be frequency dependent, since antenna matching circuits typically are frequency selective, and also the antenna itself will to some degree depend on the frequency. Given this, the MEG should be evaluated at all relevant frequencies which, in principle, would require measurements of the spherical radiation patterns for each of those frequencies. However, it is possible that only a reduced set of measurements needs to be carried out, as demonstrated below.

Define the antenna efficiency at the frequency f as

$$\gamma(f) = \oint_S |e_\theta(\Omega, f)|^2 + |e_\phi(\Omega, f)|^2 d\Omega \quad (2)$$

Using this definition, the frequency dependent MEG may be written as

$$\Gamma(f) = \gamma(f)\Gamma'(f) \quad (3)$$

where the normalized MEG $\Gamma'(f)$ is obtained by substituting the normalized radiation patterns given by $e'_\psi(\Omega, f) = e_\psi(\Omega, f)/\sqrt{\gamma(f)}$ in (1).

If it can be shown that $\Gamma'(f_1) \simeq \Gamma'(f_2)$ for any f_1, f_2 within the band of interest, then the full spherical radiation pattern of the antenna only has to be measured at one frequency. The MEG at other frequencies may be obtained by a simple scaling, as indicated by (3). Obviously, this is only an advantage if $\gamma(f)$ can be estimated from a fewer number of samples than used in the integration for $\Gamma'(f)$. In

this work it is investigated whether $\Gamma'(f)$ can be approximated as frequency independent for some actual handsets, and furthermore estimation of $\gamma(f)$ from a subset of samples is considered.

3 Measurements and Data Processing

Spherical radiation patterns of four commercially available GSM handsets have been measured. The handsets represent some of the most important handset types used today. Handset A and B are large handsets with external and internal antennas, respectively. Handset C and E 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 E was also measured with a substitute antenna; these measurements are labeled handset F.

The measurements were performed in a large anechoic room using a GSM test base station and a positioning device with two axes. Both the base station and the positioning device are controlled by software, allowing automatic measurement of the complete spherical radiation pattern in both the θ - and the ϕ -polarization. The 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 extra cables *etc.* to the handsets that might change the radiation pattern [6].

All the handsets were measured on the GSM-1800 channels 512, 698, and 885, corresponding to 1805 MHz, 1842 MHz, and 1880 MHz for the DL, respectively, and 1710 MHz, 1747 MHz, and 1785 MHz for the UL.

The spherical radiation patterns were sampled using increments of 10° in both the azimuth angle ϕ and the elevation angle θ . The handsets were measured in free space with the length of the handsets oriented along the z-axis of the coordinate system and with the display pointing towards the negative y-axis.

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

$\lambda \in \{0^\circ, 15^\circ, \dots, 60^\circ, 300^\circ, 315^\circ, \dots, 345^\circ\}$. For each combination of λ and μ the MEG was computed, as described below. It should 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 following the difference in the MEG for different measurement frequencies is evaluated using the normalized MEG,

$$\Gamma^*(f; \lambda, \mu) = \frac{\Gamma(f; \lambda, \mu)}{\Gamma(f_c; \lambda, \mu)} \quad (4)$$

where f_c is the frequency of the center GSM-1800 channel 698, and where $\Gamma(f; \lambda, \mu)$ is the MEG value obtained with the rotation angles λ, μ and with the measurement made at the frequency f . The MEG value as given by (1) is approximated using the formula,

$$\Gamma(f; \lambda, \mu) \simeq \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} \left[G_\theta(\theta_n, \phi_m; f; \lambda, \mu) Q_\theta(\theta_n, \phi_m) + G_\phi(\theta_n, \phi_m; f; \lambda, \mu) Q_\phi(\theta_n, \phi_m) \right] \frac{\sin(\theta_n)}{P_{\text{env}}} \quad (5)$$

where

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

and $G_\psi(\theta_n, \phi_m; f; \lambda, \mu)$ is the squared magnitude of ψ -polarization component of the E-field in the direction given by (θ_n, ϕ_m) , with a rotation of the antenna using the angle pair (λ, μ) , and a measurement frequency f . The number of samples in the azimuth and elevation angles are $M = 36$ and $N = 19$, respectively. The sampling points of the sphere are given by the angles $\theta_n = n\Delta_\theta$ and $\phi_m = m\Delta_\phi$, with $\Delta_\phi = \Delta_\theta = 10^\circ$.

As mentioned above, $\gamma(f)$ should be estimated from as few measurements as possible, in order to minimize the measurement time. Due to the physical shape of the measured handsets, where the length is larger than the width, it can be expected that the variation in the radiation pattern is more pronounced versus the elevation angle than versus the azimuth angle. Therefore, the original sampling density of 10° is retained for the elevation angle, but in the azimuth angle a reduced number of samples are considered. By decimation of the original measurements, sampling densities of $d \cdot \Delta_\phi$ is tested, where $d \in \{1, 2, 3, 4, 6, 9\}$. The values of $\gamma(f)$ obtained for the different decimation factors are evaluated using the ratio,

$$\gamma_d^*(f) = \frac{\gamma_d(f)}{\gamma_1(f)} \quad (6)$$

where

$$\gamma_d(f) = d \cdot \Delta_\phi \Delta_\theta \sum_{n=0}^{N-1} \sum_{m=0}^{\frac{M}{d}-1} \left[|e_\theta(\theta_n, \phi_{dm}; f)|^2 + |e_\phi(\theta_n, \phi_{dm}; f)|^2 \right] \sin(\theta_n) \quad (7)$$

using a discrete version of (2).

4 Results

For each handset the value of $\Gamma^*(f)$ in (4) was computed for all the orientations mentioned in Sec. 3. Fig. 1 shows an example of the results for handset A, where the endpoints of each vertical line indicate the minimum and maximum values in dB, respectively, of the $\Gamma^*(f)$ values obtained for handset orientations. The point on each line is the mean value.

A summary of the values obtained with all the handsets and environment models are shown in Tab. 1, where the mean and maximum values of $|\Gamma^*(f)|$ are given for the UL. The table shows that computing the MEG from a measurement made at the center frequency may result in an error of up to 1.7 dB at the band edges. The similar maximum error value for the DL is 2.6 dB. For the isotropic model the maximum values equal the mean, since the MEG is independent of the handset orientation in this case.

It is easily shown that

$$\frac{\Gamma'(f; \lambda, \mu)}{\Gamma'(f_c; \lambda, \mu)} = \frac{\Gamma^*(f; \lambda, \mu)}{\Gamma_{\text{iso}}^*(f; \lambda, \mu)} \quad (8)$$

where $\Gamma_{\text{iso}}^*(\cdot)$ is the MEG value computed for the isotropic environment. Hence, the variation over frequency of the normalized MEG $\Gamma'(\cdot)$ for the non-isotropic environments may be obtained by normalizing $\Gamma^*(f)$ with the value from the isotropic case. From Fig. 1 it is evident that this leads to a reduction of the maximum error in the MEG. Tab. 2 shows the ratio in (8) for the UL. Only values for the MBK and HUT models are shown, since, by definition, the normalized MEG does not vary with frequency for the isotropic model. Comparing the values in Tab. 2 with the corresponding values in Tab. 1 a clear reduction in the maximum values is noticed. A reduction of up to 1.2 dB has been realized, so that all maximum values are below or equal to 0.8 dB. In one case the maximum value was increased by 0.1 dB.

Using the method proposed in Sec. 3, the values of $\gamma(f)$ were estimated using decimated versions of the measured radiation patterns and compared to the values obtained without decimation. As an example, Fig. 2 shows the values of $\gamma^*(f)$ for handset C on the

	MBK model				HUT model				Isotropic model			
	Ch512		Ch885		Ch512		Ch885		Ch512		Ch885	
	mean	max. abs.	mean	max. abs.	mean	max. abs.	mean	max. abs.	mean	max. abs.	mean	max. abs.
A	1.0	1.3	1.2	1.5	1.1	1.7	1.2	1.5	1.0	1.0	1.1	1.1
B	0.2	0.4	0.7	1.0	0.3	0.8	0.6	1.0	0.1	0.1	0.7	0.7
C	0.3	0.7	1.0	1.2	0.3	0.7	1.1	1.2	0.5	0.5	1.0	1.0
E	1.0	1.3	0.4	0.9	1.0	1.4	0.4	0.7	1.0	1.0	0.4	0.5
F	0.7	1.1	0.9	1.4	0.7	1.0	0.8	1.3	0.7	0.7	1.0	1.0

Table 1: Statistics of the difference in MEG due to the measurement frequency. All values are in dB and for the UL.

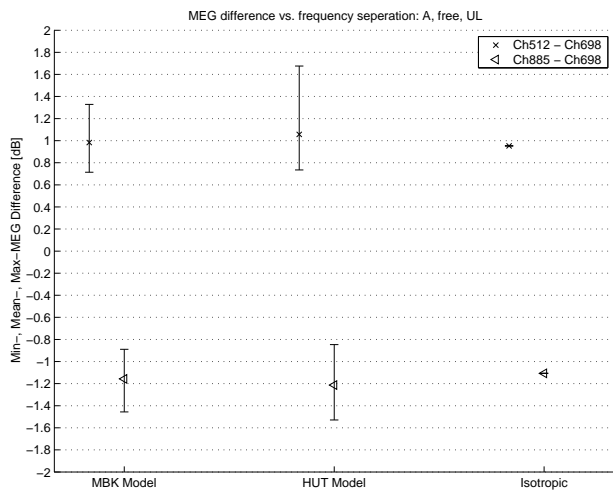


Figure 1: Difference in the MEG, $\Gamma^*(f)$, for handset A in the UL.

three UL channels when different decimation factors were used in the estimation.

As expected the error generally increases for increasing decimation factor, although in some cases a local decrease in error is observed for an increased decimation factor. A likely explanation is that not only the number of sampling points, but also their location on the sphere surrounding the handset is important.

An overview is shown in Tab. 3, where the maximum values of $\gamma^*(f)$ for the three bands are given for the various combinations of the handsets and decimation factors. The table shows that the errors are small; even for a sampling interval in the azimuth angle of 90° , the maximum error observed is only 0.33 dB.

Handset	MBK model		HUT model	
	Ch512	Ch885	Ch512	Ch885
A	0.4	0.3	0.7	0.4
B	0.3	0.4	0.8	0.7
C	0.7	0.2	0.7	0.2
E	0.3	0.5	0.4	0.8
F	0.7	0.4	0.4	0.7

Table 2: The maximum absolute values of the normalized MEG in the UL. All values are in dB.

5 Conclusion

This work considers computation of the mean effective gain (MEG) from measurements of spherical radiation patterns of mobile handsets, and in particular the variation in the MEG for different measurement frequencies. To investigate this, full spherical radiation patterns of five different mobile handsets were measured in an anechoic room. The measurements were performed using a base station simulator for the GSM-1800 system at the center channel as well as the two channels at the band edges. The MEG was then computed for three different environments and for 216 orientations of the handsets.

A difference in MEG at the band edges of up to 1.7 dB was found compared to the MEG at the center channel, and considering all handset orientations.

A straightforward measurement of the full spherical radiation patterns at all desired frequencies may require a significant number of measurements. In this work a method is proposed for reducing the total number of measurements. Assuming that the frequency variation is mainly in the total power received or transmitted by the antenna, the radiation pattern is normalized, resulting in a, ideally, frequency independent and normalized MEG. The normalized MEG can then be scaled to any frequency using the total power. It was shown in this work that the frequency dependent total power can be estimated within a frac-

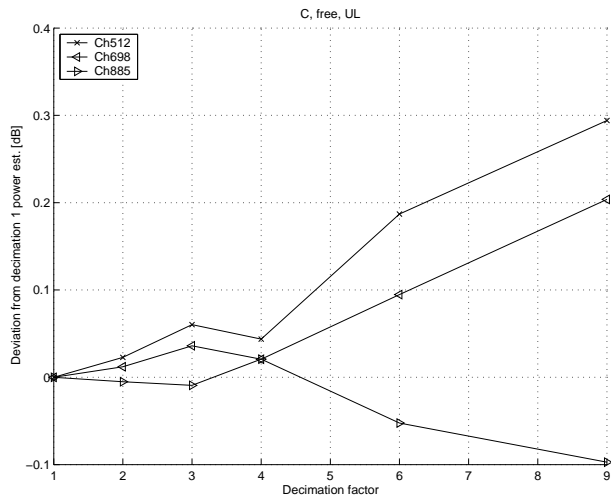


Figure 2: Deviation in γ estimation versus decimation factor for handset C in the UL.

	Decimation factor				
	2	3	4	6	9
A	0.00	0.01	0.01	0.02	0.04
B	0.01	0.01	0.01	0.03	0.05
C	0.02	0.06	0.04	0.19	0.29
E	0.04	0.08	0.04	0.19	0.30
F	0.04	0.08	0.05	0.21	0.33

Table 3: Deviation of estimated $\gamma(f)$ from values obtained with no decimation. All values are in dB and for the UL.

tion of a dB by using only a small subset of the full spherical radiation pattern.

For the proposed method to be useful the power normalized radiation patterns must result in frequency independent MEG values. From the measurements it was found that the changes in the normalized MEG over frequency for different handset orientations was maximum 0.8 dB. This error introduced in the MEG should be compared to the variation in the MEG for different handset orientations in realistic environments, which may be 3–7 dB [7].

Acknowledgments

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