Comparison of MEG and TRPG of practical antennas

Alayon Glazunov, Andres; Pasalic, Ermin

Published in:
15th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC 2004.

2004

COMPARISON OF MEG AND TRPG OF PRACTICAL ANTENNAS

Andres Alayon Glazunov[1], Ermin Pasalic[2]
[1]TeliaSonera Sweden AB, Mobile Networks R&D, Augustendalsv.7, 13186 Nacka Strand, Sweden, andres.alayon@teliasonera.com
[2]AMC Centurion AB, Design Management, P.O. Box 500,S-18425, Åkersberga, Sweden, ermin.pasalic@centurion.com

Abstract-In this paper two figures of merit of UE antenna performance are compared, the Mean Effective Gain (MEG) and the Total Radiated Power Gain (TRPG). The ratio between these magnitudes has been evaluated first theoretically and later from measurements of four different handsets in the GSM, AMPS bands. In the evaluation different power angular distribution models were assumed. It is also shown that in practice an estimate of MEG could be obtained from the TRPG.

I. INTRODUCTION

The development of new applications in the realm of mobile communications demands more reliable user equipment (UE), which is an important element of 3G networks. One of the vital components of the UE is the antenna, which together with its corpus determines the radiation/reception performance of the whole communication device. For that reason, UE equipment with a poor performance will have a negative impact on the communication link quality, giving rise not only to isolated unsatisfied users but the performance of the whole network will be, as in the case of UMTS systems [1,2], worsened by a number of such network elements of degraded performance. Therefore there is an urgent need for a dependable yet straightforward test method that ensures the quality of UE exposed in cellular networks.

The focus here is on antenna efficiency or in a more general sense, on the performance of the wireless communication user equipment (UE) with the antenna.

Following, we first present the definition of the parameters we aim at analyzing, which are the Mean Effective Gain (MEG), Total Radiated Rower Gain (TPRG). We proceed further to the theoretical examination were we draw some important conclusions on the expected difference between them and finally, present measurement results of practical antenna performance.

II. PARAMETER DEFINITION

Total Radiated Power (TRP) and the Mean Effective Gain (MEG) are presently some of the most commonly used parameters for the characterization of UE performance from the antenna efficiency viewpoint. They are however not comparable in practice since they measure different magnitudes, TRP measures power (efficiency is of course implicitly included) and MEG measures efficiency in terms of gain in real scenarios. In order to bring clarity on this issue and make them comparable the notion of TRPG is introduced. However, before providing the definitions of these figures of merit we will first remind some relevant parameter related to antenna efficiency.

According to the IEEE standard definitions [3], the antenna radiation efficiency, $e_{radiation}$, is defined as the ratio of the total power radiated to the net power accepted by the antenna and includes power loss dissipated as heat. On the other hand the total efficiency must also include losses arising from impedance mismatches, $e_{mismatch}$, expressed through the voltage reflection coefficient at the input terminals of the antenna. Hence, the actual efficiency of an antenna incorporates impedance match, radiation efficiency and aperture to give the overall radiated signal for a given input. The most widely used figure of merit of this efficiency is the obtained combining overall efficiency with directivity of the antenna and express the efficiency times directivity and is known as gain. Gain, strictly speaking, the absolute gain, is the ratio of the radiation intensity in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically, [3]. It is worthwhile to notice that, when the antenna gain is provided the above losses are included in the specified figure.

The parameters above determine some aspects of antenna performance as an isolated item. In real life, antennas are attached to other transmitting or receiving devices becoming a part of the whole radiating system and are influenced by objects in its surroundings, that is, the propagation environment inclusive the user's head, hands and body, [4], [5]. In mobile applications the polarization and spatial distribution of the transmitted and received electromagnetic waves varies with time and place and are subjected to different propagation mechanisms that make the link communication quality very sensitive to these factors. Therefore, a good figure of merit of the antenna performance must consider all these aspects as well.

Below we are going to analyze two figures of merit that are usually considered when estimating terminal antenna

0-7803-8523-3/04/$20.00 ©2004 IEEE.

performance. Both figures assume the involvement of a user that operates the wireless communications device.

A. Total Radiated Power Gain (TRPG)

Above antenna efficiency is defined detached from the user. If the user is brought in, further losses are introduced due to absorption by the users head, hand and/or body. The losses induced in that way will be called body loss, $e_{bodyloss}$. So now we have to add this magnitude to the total loss. If we are in the presence of an otherwise hundred percent efficient antenna in terms of radiation and mismatch, the efficiency of the antenna will be entirely determined by the body loss.

Hence, the TRPG, that is, the performance of the antenna integrated in the UE that is exposed to the effects of the user's body in free space (no multipath propagation) is defined as follows,

$$G_{TRP} = \frac{\oint \left(G_\theta(\theta,\phi) + G_\phi(\theta,\phi) \right) d\Omega}{4\pi} \qquad (1)$$

It is important to point out here that the effects of the head phantom are included in the antenna gain pattern, which is the common practice when measuring the antenna performance for mobile and wireless communications. Further, it should be noticed that in practice instead of the antenna gain the EIRP (Effective Isotropic Radiated Power) is used, which equals the antenna gain times the output power of the transmitting device.

It should be noticed that equation (1) externally looks like the definition of radiation efficiency [3]. However, it should be understood in a more general sense that includes not only radiation efficiency, but also the body loss.

B. Mean Effective Gain (MEG)

The mean effective gain refers to all radiated (received) power over all directions and polarizations weighted by a factor corresponding to a real field distribution divided by the sum of the total available power in vertical and horizontal polarizations that would be received by isotropic antennas, [6&7],

$$G_{MEG} = \oint \left(\frac{\chi_V G_\theta(\theta,\phi) P_\theta(\theta,\phi) + G_\phi(\theta,\phi) P_\phi(\theta,\phi)}{\chi_V + 1} \right) d\Omega \qquad (2)$$

Here the new parameters are the cross-polarization ratio (χ_V) of the channel, which is defined as the ratio of the total power available in the vertical polarization (P_V) to the total power available on the horizontal polarization (P_H), both measured with isotropic antennas,

$$\chi_V = \frac{P_V}{P_H} \qquad (3)$$

The other new functions are P_θ and P_ϕ which denote the angular power distribution densities of the vertical and horizontal polarizations respectively. As can be seen from the definition of MEG, the performance of the antenna in a multipath environment depends on the spatial distribution of the incoming waves and on the depolarization of the transmitted wave due the prevailing propagation mechanisms. The MEG takes in fact also in to account the polarization mismatch losses, $e_{polarization}$, between the transmitted and received signals, which the TRP or TRPG do not. This is an important issue since it is actually may have a major impact on the overall antenna efficiency of UE in actual cellular networks. The overall efficiency may now be expressed as the product of the radiation efficiency, the mismatch losses, the body loss and the polarization loss,

$$G_{MEG} \propto f\left(e_{radiation}, e_{mismatch}, e_{bodyloss}, e_{polarization}, \ldots\right)$$

From the antenna design point of view it is interesting to measure this figures separately, however from the point of view of the UE in-network performance the final product is what counts and should be correctly measured too.

Consequently, in order to assess the MEG in laboratory conditions, the antenna gain of the UE has to be measured as in the case of the TRPG. But now realistic models for both the angular distribution of the incoming waves and the cross-polarization ratio of the channel have also to be devised in order to make a correct estimate of what MEG should be expected in practice. Several studies of MEG can be found in the open literature [4,5,6,8,9,10,11,12].

The MEG may also be obtained by field measurements. However, such a method is impractical in most cases due to the need for access to a real up and running network, the choice of a representative propagation environment and finally it is in general quite cumbersome to perform such measurements efficiently. However, field measurements are crucial to gain a better understanding of actual performance of UE in authentic scenarios.

C. Average partial gain and antenna XPD

In practice due to the users' movement and the diversity of usages, the UE takes different orientations in space with different probability, resulting in different values of the considered parameters. Therefore we can rearrange equations (1&2) as follows:

$$G_{TRP} = \gamma_\theta^0 + \gamma_\phi^0 \qquad (4)$$

$$G_{MEG} = \frac{\chi_V \gamma_\theta + \gamma_\phi}{\chi_V + 1} \qquad (5)$$

where the total average gain in polarization x is given by,

$$\gamma_x = \oint G_x P_x d\Omega \tag{6}$$

For instance if the isotropic angular power distribution is assumed, then average partial gain becomes,

$$\gamma_x^0 = \frac{\oint G_x d\Omega}{4\pi} \tag{7}$$

The analysis may, in the future, be extended to take into account the stochastic nature of the χ_V. It is also important to keep in mind that the distribution of the χ_V given in [10] is altered by the antenna pattern of the used antenna. The χ included in the equations given here assumes the "true" one, which would be obtained if measured with isotropic antennas. However, though it is impractical it may serve as a good approximation.

In order to ease the analysis let us consider, a special case. Namely, the isotropic distribution in spherical co-ordinates is assumed,

$$P_\theta(\theta,\phi) = P_\phi(\theta,\phi) = \begin{cases} \frac{1}{4\pi} & 0 \le \theta \le \pi, 0 \le \phi \le 2\pi \\ 0 & otherwise \end{cases} \tag{8}$$

It is not difficult to see that the average partial gains are identical to the partial gains of the antenna included in the TRPG (see equations (1) and (7)). Hence MEG is now calculated as follows,

$$G_{MEG} = \frac{\chi_V \gamma_\theta^0 + \gamma_\phi^0}{\chi_V + 1}$$

In this case, the TRPG and the MEG depends on the same average gain in each polarization, γ_θ^0 and γ_ϕ^0.

Let finally introduce the ratio between the average partial gains of the theta polarization to the corresponding value of the phi polarization (κ),

$$\kappa = \frac{\gamma_\theta^0}{\gamma_\phi^0} \tag{9}$$

This parameter is a generalization of the known cross-polar discrimination (XPD) of the antenna [7]. It is shown below that it will be of paramount importance when estimating the MEG through the TRPG.

D. TRPG / MEG

Let consider the ratio between TRPG and MEG,

$$\frac{G_{TRP}}{G_{MEG}} = \frac{(\chi_V + 1)(\gamma_\theta^0 + \gamma_\phi^0)}{\chi_V \gamma_\theta^0 + \gamma_\phi^0} \tag{10}$$

We can see that the equation above may be reduced to a function of two variables instead of three.

$$\frac{G_{TRP}}{G_{MEG}} = \frac{(\chi_V + 1)(\kappa + 1)}{\chi_V \kappa + 1} \tag{11}$$

The parameter κ defines how well the antenna discriminates two orthogonal polarizations and if it is multiplied by χ will provide the perceived (measured) polarization cross coupling by the antenna under test. Equation (11) above is symmetric with respect to both parameters. As soon as one of them equals one the TRPG becomes 3 dB higher than the MEG independently from the value the other variable takes. The difference will be exactly 0 dB in two other limit cases, either when χ is zero at the same time as the κ or when they approach infinity at the same time. The reason to that is that while the MEG is defined relative the total power available in both polarizations, the TRPG on the other hand is defined to the power radiated by an isotropic antenna with the same input power as the antenna under test.

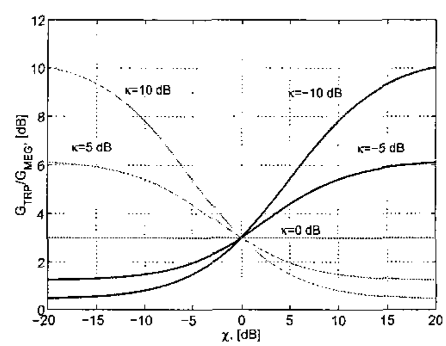

Fig. 1. Average TRP to MEG ratio vs. the cross-polarization ratio for different antenna cross-polar discrimination. The isotropic distribution model has been assumed.

III. MEASUREMENT SET-UP DESCRIPTION

In this section passive mode antenna gain measurements of four dual-band handsets are described. The characteristics of the antennas are enumerated as follows, three EGSM/GSM handsets were measured, one of which had an external antenna and the other two had embedded antennas. The fourth antenna was operated in the AMPS/PCS bands and had a retractable external antenna. Both left and right talk positions were measured. A left edge, a mid and a right edge were measures for both uplink and downlink frequency bands.

The measurements were done in the real time spherical near field antenna test facility at AMC Centurion. The system consisted of the probe array with 64 dual polarized wideband probes, covering the frequency bands between

800MHz and 3200MHz. The diameter of the arc was 3.2m. The device under test, (DUT), was placed in the center of the arc in horizontal position, (to minimize the influence of the cable hanging vertically in the rotation axis). The DUT was positioned with the display side always towards the head phantom, (negative y-axis direction) but antenna side is oriented in positive x-axis direction, (to the right of the head phantom), or in the negative x-axis direction, (to the left of head phantom), depending of which side of the DUT the cable was mounted on. For measurement in talk position, (TP), head phantom V3.5, (by Schmid & Partner) is attached without destroying set-up from free space (FS). In this way the comparison between FS and TP measurement is most accurate. The head phantom was filed with the "SAR" liquid prepared for 900 or 1800MHz.

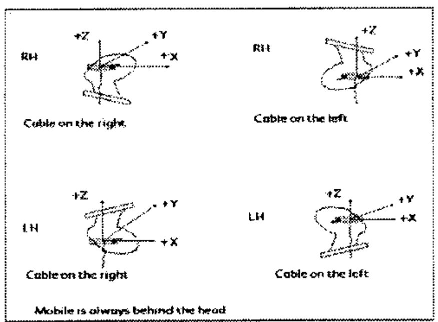

Fig. 2. Talk position set-up, RH=right hand, LH=left hand

During the measurement the DUT was rotated in the phi-cut, (horizontal plane), 180° by approximately a 5°step. At each phi position, the gain was measured in the theta-cut, (vertical plane) by 64 probes mounted with ca 5° step. The radiation pattern is not measured in 'truncation area', (ca 50° around theta = 180°, it's at bottom of the arc or negative z-axis direction). Data in this area was obtained by expanding the measured data. A rotation of the data matrix was applied extract data, which corresponded to DUT's co-ordinate system, necessary for correct calculation of mean effective gain, (MEG).

IV. MEASUREMENT RESULTS

The average cross-polar discrimination of the antenna, κ, which is the ratio of the theta average partial gain to the phi average partial gain is plotted in Fig.2 , and their sum is plotted in Fig.3. Three different angular power distribution models have been considered, the isotropic model, the MBK model described in [3], which was derived from outdoor to indoor propagation scenarios and the HUT model, [8], which was mainly obtained from measurements in outdoor urban environments.

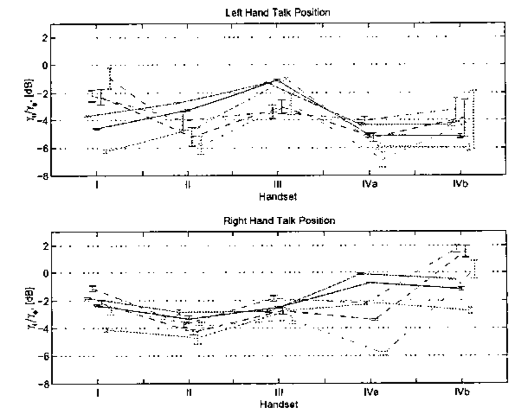

Fig. 3. Ratio of the average theta-polarized power to the average of the phi polarized power for the left hand talk position (upper plot) and the right hand talk position. The low band (around 900 MHz) results denoted by the continuous line, the high band (around 1800 MHz) is given by the dashed line. Isotropic model (red), MBK model (blue) and HUT model

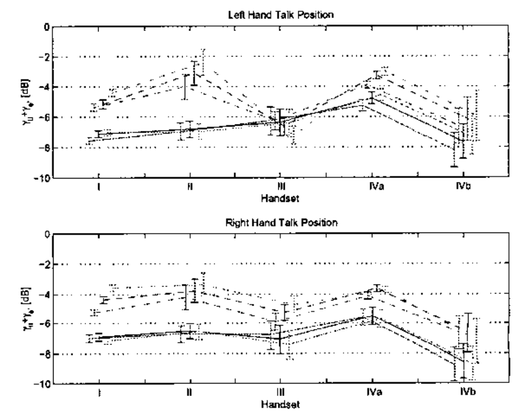

Fig. 4. Sum of the average theta-polarized power plus the average of the phi polarized power for the left hand talk position (upper plot) and the right hand talk position. The low band (around 900 MHz) results denoted by the continuous line, the high band (around 1800 MHz) is given by the dashed line. Isotropic model (red), MBK model (blue) and HUT model (green.)

The first observation is, as expected, that all the power transmitted by the handsets is overwhelmingly horizontally polarized (approx. 3dB larger in average) for almost all the frequencies, except some isolated cases as for example the handset IV.b which is the handset, working at the high band and the right talk position with the antenna retracted and more specifically for the HUT model (Fig.3). In that case the average powers of the two polarizations are quite similar. An analogous result is obtained for the same terminal but for the isotropic model at the low band. For the other models this handset will perform not as good. So from this point of view, this handset for some angular power models actually will be a good candidate for optimal performance in the cross-polarization ratio independency sense, [1]. On the other hand it performance would not be the best among the handsets. As we can see from Fig. 4 (Right hand talk position, handset IV.b. Indeed the total power is almost the lowest of all the five tested handsets. A closer comparison of Fig.2 and 3 reveals that the handsets that show the largest transmitted total power are further away from having the power evenly distributed in both orthogonal polarizations and vice versa. That means that independency from the cross-polarization ratio and maximum MEG is not achieved for the measured terminals and the average cross-polar discrimination and the MEG of the antennas are negatively correlated.

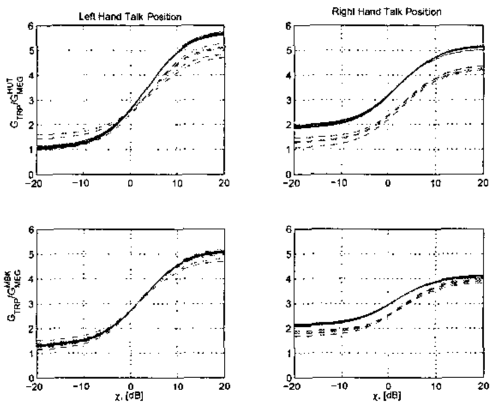

Fig. 5. Average TRPG to HUT MEG (upper plot) respectively MBK MEG (lower plot) ratios at a given frequency as function of the cross-polarization ratio. Results for the left and right talk position are shown. The low band (around 900 MHz) results denoted by the continuous lines, the high band (around 1800 MHz) is given by the dashed line.

In Fig.3 the bars denote the spreading of κ across the frequency band for a given terminal. For most terminals it is less than ± 1 dB except for terminal IV.b, at the left hand talk position, which is double as high. As pointed out in [9], the variation due to the implementation of different angular power distribution models may be large, which even once emphasize the necessity for different models describing specific propagation environments.

From Fig.4 it is clear that the MEG at 1800 GHz is in average 3 dB higher than the MEG of the same antenna at 900 MHz. It is also clear that the spreading of MEG or TRPG may be as the same magnitude or even larger for one terminal but at different frequencies and propagation environments than the corresponding variation from one terminal to another.

The ratio between the TRPG and the MEG is plotted in Fig.5. As anticipated by equation (11) the difference in dB increases with the cross-polarization ratio. It should be noted that equation (11) was obtained for the isotropic power distribution model in contrary to results displayed in Fig.5, which shows the true difference. However, taking into account the diversity of usage of the UE in talk position the final figure will even out and may become more isotropic like. Based on this the error introduced would be reasonably small and therefore equation (11) may serve as good estimate of MEG if TRPG is measured provided that κ and χ are known.

V. SUMMARY

The average cross-polarization discrimination of the measured antennas varied between -7.5dB to 2dB with an approximate average of -2.7 dB, which means that the received/transmitted power is mainly horizontally polarized. It was shown that the TRPG overestimates the antenna performance relative the MEG, however a rough estimate of the average MEG may be obtained through the TRPG if the average cross-polar discrimination of the UE antenna, κ and cross-polarization of the channel, χ are known.

VI. REFERENCES

[1] 3GPP TSG-RAN Working Group 4 (Radio) meeting #27, R4-030546Paris, France 19th -23rd May, 2003, "UE antenna efficiency impact on UMTS system coverage/capacity"

[2] Alayon Glazunov, "Joint Impact of the Mean Effective Gain and Base Station Smart Antennas on WCDMA-FDD Systems Performance", Nordic Radio Symposium 2004, Oulu, Finland, (Accepted)

[3] Ballanis C. A., "Antenna Theory Analysis and Design", John Wiley & Sons, Inc., 1997.

[4] G. F. Pedersen, M. Tartiere, M. B. Knudsen, "Radiation Efficiency of Handheld Phones", Proceedings of VTC'2000, May, 2000

[5] M. B. Knudsen, "Handset Performance Test Including the Antenna", COST 273, Temporary Document (01) 043, Bologna, Italy, October 15-17, 2001, 17 p.

[6] Tokio Taga, "Analysis for mean effective gain of mobile antennas in land mobile radio environments", IEEE Transactions on Vehicular Technology, 39(2): 117-131, May 1990

[7] A. Alayon Glazunov, "Mean Effective Gain of User Equipment antennas in Double Directional Channels", PIMRC2004, Barcelona, Spain (In these proceedings)

[8] K. Kalliola, K. Sulonen, H. Laitinen, O. Kivekäs, J. Krogerus, P. Vainikainen, "Angular Power Distribution and Mean Effective Gain of Mobile Antenna in Different Propagation Environments", Accepted for publication in IEEE Transactions on Vehicular Technology, May 2001, 36 p.

[9] J. Ø. Nielsen and G. F. Pedersen, "Comparison of Total Received Power and Mean Effective Gain for Mobile Handsets", COST 273 in Guildford, UK, January, 2002, TD (02) 021

[10] L. Correia (Editor), "Antennas for Mobile Phones", Wireless Flexible Personalised Communications, John Wiley & Sons, 2001

[11] Bo G. H. Olsson, "Telia scattered field measurements of mobile terminal antennas", Proceedings of Mobile Terminal and Human Body Interaction, COST259 Final Workshop, Bergen Norway, 2000/04/26-27