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1. Abstract

The evolution of mobile communications has increased the need for more complex antennas on the mobile side than the standard whip antenna. The need arises from several aspects, one being the cautionary measure of limiting the absorption and absorption density in the user's head, the other being optimisation of the communication quality, including ease of use. Although not used widely as yet, antenna diversity on the handset is an important possibility of improving the performance. Knowledge about the spatial distribution of energy around the user is necessary for the evaluation of mean effective gains and correlation coefficients for mobile antennas, and this together with numerical and experimental results for radiation patterns from various antennas, including the effect of the user, determines the end performance measures. Antennas discussed are patch, helical and dipole antennas integrated within or outside the phone itself.

The effect of different users on the performance is also of interest since it turns out that the variability from person to person is quite large, and that the variations are reproducible. This means that testing antennas for this application is a complicated process.

2. Introduction

A major part of all telephones in the future will be portable according to market predictions. In the existing portable phones the antennas have not been a major issue, often more an add-on feature, which was necessary, but not the focus of major research and development. This is likely to change, since new demands on coverage, sensitivity, and bandwidth make the antenna an important component. As is well-known an ‘antenna’ has much improved qualities in a random environment, if it consists of several antennas with uncorrelated signals,
utilising the diversity effect, or in general a more ‘smart’ antenna, able to adapt to the environment with interference reduction capabilities. In the case there are multiple antennas at each and of a link, then large gains in spectral efficiency may be obtained. This is still in the research phase, but considering the huge gains that can be achieved, it is likely that this also will be utilized commercially in the future. Integration of the antenna into the handset is an interesting area of research as well, promising not only convenience from a user point of view, but also reduces the absorption in the user, which is an unfortunate use of valuable electromagnetic energy. The biological issues related to this absorption are to some extent still unresolved, although norms and recommendations exist. In this paper the emphasis is on the telecommunications systems, and the biological aspects will only be dealt with to a minor degree.

An ideal antenna from a user and manufacturer point of view is invisible, small, has sufficient bandwidth, is lossless, and well matched. A number of constraints of a theoretical and practical nature make this an impossible goal, but the art of engineering is of course, to approach the goal as near as possible. In the paper first the single antenna performance is described together with relevant parameters, which are necessary for a description of the antenna performance in a fading environment, including the effect of the user. Next, in section 4 multiple antennas are introduced, and the diversity gains at a given probability level introduced.

3 Single Antennas

3.1 Various antenna types - independent of user influence

The classical handset antennas are simple monopoles on top of the handset, and a short normal mode helix, when the antenna is not extracted. The telephone box itself may have a major influence on the radiation pattern, which may be calculated numerically or measured experimentally in a radio anechoic room. The main influence of the box may be derived from the fact that it becomes part of the antenna, especially for the unbalanced ¼ wavelength monopole and the helix, where currents flow on the box on all sides, giving a tendency of the radiation pattern having a skew downwards directed beam [Toftgård et al., 1993].

Recently, other types of antennas have been introduced, partly to make the antenna smaller and more convenient for the user, partly to reduced the absorption in the user. Since these antenna may have complicated geometries, the effect of the box and the user needs to be included, the analysis often being performed using the FDTD (Finite-Difference Time-Domain technique). These new antenna types include the PIFA, Planar Inverted-F Antenna [Pedersen et al., 1994; Jensen et al., 1994; Virga et al., 1997], other types of microstrip-like antennas, and loops [Muramoto et al., 1997; Katsibas et al., 1998]. The main design criterion is bandwidth of matching for electrically small antennas, since fundamental limitations exist for the volume. Recently [McLean, 1996] a more accurate expression for the Q-value has been obtained for the relevant frequency range,
where the antenna is not electrically extremely small. For modern systems or handsets used for different carrier frequencies, the bandwidth need not be instantaneous, and some sort of diode-switching may be incorporated, although care should be taken concerning non-linear effects. For an FDD (frequency division duplex) system with a difference in carrier frequency between the uplink and downlink, the matching should only be over the relevant bandwidths and frequencies, and not necessarily in between.

3.2 Various antenna types - user influence

As soon as the user is involved in an active mode with the handset grasped by a hand and held close to the head, several new phenomena appear. The obvious effect is one of absorption, and especially for the monopole-like antennas, where the currents flow on both sides of the handset, the problem is serious. By numerical analysis it has been found that between 50% and 70 % of the power may be absorbed [Toftgård et al, 1993; Chuang,1994; Jensen and Rahmat-Samii ,1995], depending on the distance from the antenna to the surface of the head. The polarization properties are changed considerably, and a major shadowing takes place, from 10-15 dB in a free space environment. The shadowing seems to be dependent on the length of the part of the antenna protruding above the head [Arai et al.,1997], creating a line-of-sight situation diminishing the shadowing.

The absorption and the absorption density (the so-called SAR values in W/kg) is sensitive to the local distribution of the current. By forcing the current to flow on the side of the phone directed away from the head it was possible to reduce the SAR-values by a factor of 10 [Pedersen et al., 1994]. A way of reducing the magnetic fields generated by thin wire antennas close to the human head was shown by [Tay et al., 1998]. By using two closely spaced wires, the one closed to the human head acting as a reflector the SAR values was reduced by a factor of 2 to 3 times relative to a half wave dipole.

3.2.1 Performance criteria and power distributions

It is a characteristic of antennas in mobile or cellular systems that their performance depends on the environment. The environment for the portables consists of the user, which in some respects can be considered as part of the antenna, and the external environment. The multiplicity of waves usually incident on the user creates a Rayleigh fading channel, the distribution of which a single, one-port antenna cannot change. In stead it is necessary to look at averaged environments, including the polarization properties, and look at the use of several antennas for changing the statistical distribution.

An expression for the complex signal at a matched antenna port was first given in [Jakes, 1974] derived with the assumptions that
1. The phase of the incoming electric field is independent of the arrival angle for both polarisations.

2. The phase of the incoming electric field in the two polarisations are independently distributed between 0 and 2π.

\[
V(t) = \int \{ \tilde{E}(\Omega) \cdot \tilde{A}(\Omega, t) \} d\Omega
\]

(1)

where \( \tilde{E}(\Omega) \) is the electric far-field pattern of the antenna, \( \tilde{A}(\Omega, t) \) is proportional to the electric field of the incident plane waves, and \( t \) indicates that the environment is changing with time, usually by movement of the user. The average received power at the antenna is \( \frac{1}{2} \langle V(t)V^*(t) \rangle \) giving

\[
P_{\text{rec}} = \int \{ P_1 P_\theta(\Omega) G_\theta(\Omega) + P_2 P_\varphi(\Omega) G_\varphi(\Omega) \} d\Omega
\]

(2)

where \( P_1 \) is the power in the \( \theta \)-polarisation, \( \int P_\theta(\Omega) d\Omega = 1 \), similarly for \( P_2 \) and the \( \varphi \)-polarization. The gains are as usual normalised such that

\[
\int \{ G_\theta(\Omega) + G_\varphi(\Omega) \} d\Omega = 4\pi
\]

(3)

By also normalising the powers [Taga, 1990] arrived at the very useful definition of the MEG, the Mean Effective Gain, as

\[
MEG = \int \left[ \frac{XPD}{1 + XPD} P_\theta(\Omega) G_\theta(\Omega) + \frac{1}{1 + XPD} P_\varphi(\Omega) G_\varphi(\Omega) \right] d\Omega
\]

(4)

using the ratio between the two polarisations and defining the cross-polar discrimination, XPD, as

\[
XPD = \frac{< P_\theta >}{< P_\varphi >}
\]

(5)

The MEG is a normalized measure of the received power, equal to \( \frac{1}{2} \) for isotropic antennas (\( G_\theta = G_\varphi = \frac{1}{2} \)).

An optimum handset antenna will be one which maximizes MEG for the relevant environmental scenarios. Antenna designers are used to stringent requirements in free-space environments with a single wave incident, maximizing gain, minimizing sidelobes et cetera. It is therefore a sobering observation that designing handset antennas for totally random environment (XPD=1, \( P_\theta = P_\varphi = 1/4\pi \)) is in principle easy, since

\[
MEG_{\text{random}} = \int \left[ \frac{1}{1 + 1} \frac{1}{4\pi} G_\theta(\Omega) + \frac{1}{1 + 1} \frac{1}{4\pi} G_\varphi(\Omega) \right] d\Omega = \frac{1}{2}
\]

(6)

independent of the radiation patterns. These assumptions are not exactly valid in practice as will be seen, but it does indicate that the radiation pattern is not the most important parameter to optimize. Examples of measured environments are shown in Figure 1 and 2.
Figure 1. The measured incoming power (from the three-dimensional incoming multipath field), as a function of both azimuth and elevation in an office room. Most of the power is coming from the window, which is the usual case when considering an outdoor base station. On the left is shown the total power $P_\theta + P_\phi$, and on the right the XPD values. The elevation is displayed on the radial direction, close to the centre correspond to +50 degrees and the maximum radial correspond to -20 degree in elevation. The circles display the azimuth direction from, 0 degree to 360 degrees.

The set-up for measuring the incoming multipath consist of a dual polarised horn antenna mounted on a two axis pedestal able to rotate the antenna in all azimuthal directions as well as in elevation from -20 degrees to 55 degrees. The phase centre of the antenna is located in the centre of the rotation whereby the complete measurement is conducted in a single point in space. The antenna has a smooth radiation pattern with the 3 dB beamwidth of approximately 30 degrees in both azimuth and elevation for both polarisations, and the polarisation purity in the mainbeam is better than 40 dB. The incoming signals are measured simultaneously for both polarisations, giving $P_\theta$ and $P_\phi$ by using a dual channel sounder. By measuring with a bandwidth much larger than the coherence bandwidth the fast fading is suppressed.

The Figures show the total power and XPD as a function of elevation for the upper half space (ρ=0 corresponds to vertically upwards) and azimuth. The power is not uniform and the XPD is not unity. In Figure 1 the environment is an indoor office room, and the base is an external outdoor station with vertical polarisation. The power is distributed over some angles, but the dominant contributions seem to come from a window and reflections from the other side of the room. The XPD shows that the polarisation is dominantly vertical, but not necessarily correlated with the directions of maximum power. It should be noted that the incident field reaching the window has already been partially depolarised in the external environment. Figure 2 shows a different environment, a corridor with a bend, and the base is again an external outdoor station with vertical polarisation. It seems
clear that most of the power travels down the corridors, acting as over-moded waveguides, and the XPD follows the power to a greater extent than before. These are typical distributions that the handheld phone is exposed to.

3D Incoming multipath field

![Intensity [dB] and XPD [dB]](image)

**Figure 2.** Measured incoming power as a function of both azimuth and elevation in a corridor with a 90-degree bend. Most of the power is coming along the corridor. Left the total power $P_0 + P_\phi$, and right the XPD values.

In [Taga, 1990] the $MEG$ was studied for inclined dipoles in different environments and various XPDs, supported by experimental results indicating that there are many propagation conditions where the $MEG$ is $\frac{1}{2}$, -3 dB, especially for an inclined dipole with an inclination angle of 55° measured from the vertical axis.

### 3.2.2 Average gain values and variability among users

It should be noted that the $MEG$ is independent of the losses with the present definition, so it should in reality have been called *Mean Effective Directivity*, but of course an absorption coefficient may be added to describe the true gain. Experimentally, the $MEG$ of the antenna under test is often measured relative to a lossless reference antenna, with average powers measured along the same measurement routes [Andersen et al., 1977]. In the following the absorption is included in the $MEG$ values, and they are relative to a given antenna in the same environment.

In [Pedersen et al., 1998] the $MEG$ was measured in an indoor environment from an outdoor base station for a large number of test persons at 1800 MHz. Three antennas, a helix, a 3/8 wavelength whip, and a directive $PIFA$ were compared, with and without a user present. The reference is the $MEG$ of an inclined whip on a handheld with no user present. The average gains were reproducible within 0.5 dB. The result was, that the average user influence was a loss of 10 dB for the helix, 6 dB for the whip and 3 dB for the patch, see Table 1.
Note that the body-effect includes absorption, polarisation mismatch, impedance mismatch, and average body shadowing, it is however impossible from these data to conclude how much is due to absorption and how much to the other effects. In a similar investigation [Arai et al., 1997] found a loss on average of approximately 6 dB for a ¼ wave whip relative to a vertically mounted dipole. Both [Arai et al., 1997] and [Pedersen et al., 1998] found a considerable variation among different users, up to a reproducible 10 dB. As an example Figure 3 shows the variation among different users for a whip, a helix and a patch antenna. The peak variation is largest for the helical, then the patch and lowest for the whip. This holds for all four measured locations having 50 test users on each location.

<table>
<thead>
<tr>
<th>ANTENNA</th>
<th>LEVEL 1</th>
<th>LEVEL 2</th>
<th>LEVEL 3</th>
<th>LEVEL 4</th>
<th>TOTAL</th>
<th>BODY-EFFECT</th>
</tr>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td></td>
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<tr>
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<td>0.97</td>
<td>0.60</td>
<td>0.41</td>
<td>0.67</td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>Patch</td>
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<td>-3.46</td>
<td>-2.69</td>
<td>-0.9</td>
<td>-2.42</td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whip</td>
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<td>-7.04</td>
<td>-5.08</td>
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<td>-6.37</td>
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<td>with user</td>
<td></td>
<td></td>
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<td></td>
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<tr>
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<tr>
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<td>-3.43</td>
<td>-5.80</td>
<td>-3.38</td>
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<tr>
<td>with user</td>
<td></td>
<td></td>
<td></td>
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</table>

Table 1. Measured average MEG with a tilted whip on a handheld as reference, in dB. On each level of the building the MEG was measured for 50 users, to obtain the average values. The average body-effect was found for each antenna as the difference between values with and without the user present. The inclination angle from vertical of the handheld was 60 degrees without the user present, whereas the user held the hand held in whatever position he or she felt was natural.

It is interesting that the single integrated patch antenna is the worst antenna without the user, but is slightly superior in most locations when the user is present. The rather large individual differences for the gain when the user holds the antenna is somewhat unexplored, although [Arai et al., 1997] find a correlation with the length of antenna protruding above the head. This, however, does not explain the variation with the helix and with the patch.

An alternative to complete measurements is to use Equation 4 for the MEG where a combination of numerical analysis and measurements is applied. FDTD calculations of the antenna gains (including a model of the user) may be used together with independent measurements of $XPD$, $P_\theta$ and $P_\phi$ in various environments. This allows the user to be rotated in the environment, and the study of the various mechanisms.
Figure 3. Measured relative MEG for 50 users at level 2, the reference is a whip on a handheld for one location. The users are sorted according to MEG for the helical antenna. The solid and dashed lines are the regression lines for the whip and patch, respectively. From the regression lines, it is clear that there was no clear connection between MEG values obtained for one antenna and MEG values for another antenna, for the same user.

The formula for the MEG in equation 4 assumes that the antenna has a fixed orientation with respect to the environment. For inhomogeneous environments such as shown on Figure 1 and 2 the MEG clearly will depend on the orientation of the user. This is illustrated in Figure 4 for two different orientations where the shaded areas indicate the distribution of energy entering the windows on top and reflected from the walls. Results for the MEG as a function of rotation is treated below.

Examples are shown in Figure 5 and 6 for a dipole and a PIFA antenna on a conducting box with and without a simple model of the human head, where the effect without the user is shown to the left. As an additional reference a vertical dipole is included due to its well known behaviour from car mounted antennas used frequently in the early days of mobile communications. Note that due to its symmetry in the horizontal plane the rotation does not change the MEG values of the vertical mounted dipole antenna.
The average polarisation and shadowing loss for a whip antenna in many environments is of the order 3 dB in agreement with [Taga, 1990], while the user presence adds an extra 3-4 dB in good agreement with the experimental results above. For the patch the corresponding numbers are 5 and 1 dB. These values do not include losses due to impedance mismatch, and the model of the human is a simple ellipsoid of muscle tissue. It is noted from the right hand sides that the variation in gain when turning in the environments is approximately the same for the whip and the patch, indicating that from an overall point of view, they have the same performance.
Figure 5. The combined experimental and numerical MEG values for a dipole antenna on a handheld when the handheld was rotated 360 degrees in the horizontal plane for 18 locations. The handheld was indoors and the base station was outdoors. The handset had an inclination angle from vertical of 60 degrees. The outermost thin circles are MEG values for a vertical reference dipole in the same environments. The left-hand plot was without a user, and to the right-hand plot was with a model of a user’s head.

Figure 6. MEG values for a PIFA on a handheld when the hand-held was rotated 360 degrees in the horizontal plane for 18 different locations. The hand-held was indoor and the base station was outdoor. The handset had an inclination angle from vertical of 60 degrees. To the left-hand plot was without a user, and to the right-hand plot was with a model of a user’s head.

4. Diversity from several antennas on the handset

It is normal to have receive space diversity at base stations, while only some systems allow multiple antennas on the handset for reasons of complexity. There are some basic differences, since for the base station the signals are usually arriving over a limited range of angles, and it is therefore necessary to separate the
antennas by many wavelengths. The two power levels will be equal on average. For the handsets the signals will be arriving over a large range of angles, making it fairly easy to obtain uncorrelated signals, while the two antennas may be of a different nature leading to different mean values of the power, and usually the orientation of the handheld phone with respect to the environment is changing with time. More importantly, the presence of a user will affect both the correlation coefficient and the MEGs (branch powers). The diversity gain depends on the combining method and the probability level chosen. In Figure 7 is shown how the diversity gain for both Selection Combining and Maximal Ratio Combining at the 99.5% level depends on the correlation coefficient between the branches and the power branch difference in dB. Roughly speaking, the correlation coefficients should be below 0.5 and the powers within 5 dB to realize the maximum combining gain within a few dB for Selection Combining.

Figure 7a. The diversity gain for selection combining at the 99.5% level as a function of correlation between the branches and the branch-power difference. By transforming the data into a look-up table, the diversity gain can be obtained for any correlation and branch power difference. The results shown are obtained from close form expressions in [Schwartz, 1966]. For each simulation one element in the look up table is obtained.
Figure 7b. The diversity gain for maximal-ratio combining at the 99.5% level as a function of correlation between the branches and the branch power difference. This figure is used as described in caption of Figure 7a. These results were obtained by simulations of two Rayleigh-distributed signals with a certain correlation and branch power difference which were combined according to Maximal ratio. For each simulation, one element in the look up table was obtained.

4.1 Correlation Coefficient

The envelope correlation thus needs to be low in order to obtain a worthwhile diversity gain, but it is difficult to give a closed form expression for the envelope correlation. For Rayleigh fading signals the envelope correlation is closely related to the power correlation coefficients [Schwartz, 1966]

$$\rho_e \approx \frac{|R_{xy}|^2}{\sigma_x^2 \sigma_y^2}$$

(7)

where $R_{xy}$ is the cross covariance, $\sigma_x$ and $\sigma_y$ are the standard deviations of the complex envelopes of antenna X and Y given by Equation 1, which gives

$$\rho_e = \frac{\left| \int \left[ XPD \cdot E_{\Omega x} (\Omega) \cdot E^{*}_{\Omega y} (\Omega) \cdot p_x (\Omega) + E_{\Omega x} (\Omega) \cdot E^{*}_{\Omega y} (\Omega) \cdot p_y (\Omega) \right] d\Omega \right|^2}{\int \left( XPD \cdot G_{\Omega x} (\Omega) \cdot p_x (\Omega) + G_{\Omega x} (\Omega) \cdot p_y (\Omega) \right) d\Omega \cdot \int \left( XPD \cdot G_{\Omega y} (\Omega) \cdot p_x (\Omega) + G_{\Omega y} (\Omega) \cdot p_y (\Omega) \right) d\Omega}$$

(8)
Figure 8 shows the correlation coefficient between different antennas on one handset calculated from Equation 8 and turning in different environments with and without the presence of a human head-model. The three antenna configurations investigated are two dipoles on top of the handset, a dual polarized patch antenna on the back of the handset and one dipole on top and a patch on the back of the handset, see Figure 9. The three diversity configurations are selected from the criterion that both omnidirectional-like antennas and more directional antennas, as well as a combination must be covered to investigate the correlation behaviour.

The complex farfield patterns used in Equation 8 are obtained from FDTD simulations, four FDTD simulations for each configuration. Two simulations in free space, one for antenna X and one for antenna Y, and two simulations in the presence of the human head. In each simulation one antenna is excited while the other antenna is open circuited. The dual polarized patch antenna, though, has only one antenna port and therefore no open circuit exist. The polarization of the dual polarized patch antenna is selected by switching PIN diodes mounted on two consecutive sides of the antenna element and the ground on and off. This antenna has several advantages; it is compact, no switch is situated in the receiving or

![Figure 8. The correlation coefficients for three antenna configurations: in the top row, without a user, and the bottom row with a model of a user’s head. The three fat curves in each sub plot display the average correlation in a specific environment whereas the thin curves represent the correlation for one specific location within one environment.](image-url)
transmitting chain and the antenna impedance does not change depending on which polarization is active. This antenna configuration is of course only feasible for switching combining.

In general it is seen that the correlation in free space is very low, less than 0.4, and lowest for dissimilar antennas. When the user head is present the correlation rises considerably for the similar antennas, up to 0.6. The reason is the shadowing of the head, leading to a spectrum of waves incident from a more narrow range of angles, and thus an increased correlation. If the signals only came from one direction, they would be highly correlated. The dissimilar antennas are still uncorrelated, indicating that symmetries are effective. Note also that the correlation in the different environments are quite similar although the environments are very different (an office environment, a railway station and a large shopping mall).

4.2 Diversity Calculation

Having the correlation between the two antennas (from calculated or measured complex far-field patterns and the distribution of incoming multipath fields) and the ratio of the mean received signal power by the antennas, the MEG values, the diversity gain can be found for a chosen combining method and for the given environment. The diversity gain for a combining method can be obtained by either:

- Closed form expressions.
- Link simulations.
- Measurements.

Closed form expressions exist only for a few combining methods and often special requirements related to specific systems of interest leave only simulations or measurements of the diversity gain as an option. What is needed is a look up table of correlation, difference in branch power and diversity gain as the one shown in Figure 7 for the combining method of interest. Using link simulations of e.g. the DECT system with a given speed and combining algorithm this look up table can be obtained by one simulation for each pair of correlation and branch power difference of interest [Risom et al., 1997]. Similarly, measurements can be conducted to obtain the look up table, but this requires the HW combiner and two radio channel emulators.

When the look up table is obtained the diversity gain is found by a simple lookup using the correlation and branch power difference as the entry. As an example the dipole-patch configuration shown in Figure 9 is examined in the following. First the handset is either built and 3D complex farfield patterns are measured or simulations are made to obtain the 3D complex farfield patterns. Next the environment is either measured to obtain the distribution of 3D incoming multipath field in both polarizations or a model describing the distribution of incoming multipath field is used. By using Equation 4 the received power on both antennas can be calculated while turning in the environment, see Figure 10. The solid lines represent the MEG of the patch antenna and the dashed lines represent
the MEG of the dipole antenna in the measured environments. The distance between the solid and dashed lines display the branch power difference for each direction.

Figure 9. The three antenna configurations examined. The handset had the same dimensions, but is either equipped with two dipole antennas on top or one dipole on top and a patch on the back or a dual patch on the back. All configurations are examined with and without a model of a user’s head.

To obtain the correlation while turning in each environment the 3D complex farfield patterns and the 3D incoming multipath field for each environment is again used now in Equation 8. The results are shown in the centre column of Figure 8. To obtain the diversity gain for the handheld employing Selection
Combining at the 99.5\% level each value of branch power ratio and correlation must be mapped using Figure 7, see Figure 11.

**Figure 10.** The MEG values for both the dipole and patch antenna shown in Figure 9 b) when the handheld is turned 360 degrees. The solid lines represent the patch antenna and the dashed lines represent the dipole antenna. The difference between the solid and dashed lines for each direction gives the branch power ratio. The hand-held and the base station are located indoors, in the same building.

**Figure 11.** The diversity gain obtained by selection combining at the 99\% level, for the handheld equipped with a dipole and a patch antenna, as shown in Figure 9. The left-hand plot is without a user, and to the right-hand plot is with a model of the user. The hand-held and the base station are located indoors, in the same building.

The diversity gain is nearly the same with and without the user present but the performance is not the same with and without the user. The diversity gain expresses the gain, at a certain level, relative to the best of the branches. Therefore, the performance can be found from the level of the strongest received power in each direction and the diversity gain. By adding the diversity gain to the
strongest of the received power in each direction the Effective MEG can be found. This is shown in Figure 12.

Figure 12. The effective MEG for selection combining at the 99% level, for the dipole-patch configuration shown in Figure 9. As a reference the circles near 1 dB represent the MEG (without diversity) in the same environments for a vertical dipole. The left-hand plot is without a user, and the right-hand plot is with a model of the user. The hand-held and the base station are located indoors, in the same building.

The Effective MEG results are less directional compared to the MEG curves of the individual antennas. This is not due to the change in correlation or diversity gain but to the complimentary MEG curves for the two antennas (when one is high, the other is low), see Figure 10. The gain due to the changing in MEG from the turning of the user is not included when diversity gain is usually considered, and this is an extra gain which corresponds to macro diversity. It can be obtained if the MEG curves are complimentary i.e. only one antenna has a notch in the MEG curve in a given direction.

5. Conclusion

Handset antennas for mobile communications have been discussed in a systems context, where the interaction between the environmental distributions of energy and the properties of the antenna itself is of major influence. Intuitively, directionality has been avoided in the past since it has been believed to lead to unacceptable minimum gain values for certain directions. It has been demonstrated here that this is not true when the effect of the user is taken into account, where the user has an influence on both the absorption and redistribution of the energy. Actually, the integrated patch antenna is shown to have less influence from the body, and slightly higher average gain than a normal whip antenna. A special peculiarity, still somewhat unresolved, is the high variability between users of the mean effective gain.
With two antennas on the handsets and a selection facility in the receiver further gains are possible. Although the space available on a handset is limited, it is not a problem to create effective diversity antennas with low correlation, even though the correlation increases with a user present. Two types of diversity gain is available, the short term avoidance of fading depths, and the antenna pattern diversity from different types of antennas.

6. References


