PERFORMANCE OF PCS HANDSET ANTENNAS IN MOBILE ENVIRONMENTS

M.G. Douglas, M. Okoniewski, and M.A. Stuchly

Department of Electrical and Computer Engineering, University of Victoria,
Victoria, B.C., V8W 3P6, Canada.
mdouglas@ece.uvic.ca, michal@ece.uvic.ca, mstuchly@ece.uvic.ca

Abstract

FDTD modeling of two handset-mounted antennas in the proximity of the user was performed to investigate the effects of some aspects of the communications environment on antenna performance. We have shown that: (i) the antenna mean effective gain (MEG) is strongly influenced by the type of the environment; (ii) much less power is absorbed in the user's head when the polarization diversity antenna is used instead of the monopole antenna; and (iii) antenna performance is underestimated if ground reflections are not taken into account.

Introduction

Due to the proliferation of mobile communication systems there is a need to understand how the presence of the user and the surroundings affect the antenna performance. There is also an increasing interest in evaluating the absorption of electromagnetic energy in the user's body in order to understand its potential health effects. This paper addresses both areas. The performance of two antennas, mounted on PCS handsets, are investigated in the 900 MHz frequency range. To accurately model the mobile communication environment, the user's head and hand are modeled, the angular distribution of incident signals is considered, and ground reflections are included.

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A polarization diversity antenna (PDA) is analyzed (Fig. 1a). The PDA is a microstrip patch antenna consisting of two shorted rectangular patches [1]. Each patch is fed independently and exciting the two patches in phase or out of phase produces the radiation of horizontally-polarized (HP) or vertically-polarized (VP) waves, respectively. A vertical monopole antenna is also analyzed (Fig. 1b). Both antennas are mounted on handsets which are held vertically next to a head by a hand. The head and hand are modeled as lossy dielectric material representing bone, skin, muscle and 23 other tissues and organs [2]. The head, having 3.6 mm spatial resolution, is an anatomically accurate model that is based on CT and MRI scans [3]. Numerical modeling of the system was based on FDTD using the Yee-cell rectangular grid [4] with a 3 mm uniform mesh. The computational space was terminated by the PML(7, P, 1) absorbing boundary [5]. The antennas were fed using gap excitations with the time envelope of a wide-band frequency-shifted Gaussian pulse.

An experimental version of the PDA was constructed for operation at 856 MHz. Scattering parameter measurements indicate that the HP and VP modes have $VSWR \leq 2$ bandwidths of 2.0% and 3.9% and return losses of 12 dB and 23 dB, respectively. Bandwidths greater than 5% for both modes were obtained using better matching circuits [6]. The minimum isolation between the two modes is 20.2 dB and both modes have radiation patterns that are approximately omnidirectional in the horizontal plane.

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The investigated antennas are compared in terms of the specific absorption rate (SAR) in the body, radiation efficiency, far-field pattern and mean effective gain (MEG). The MEG takes into account the mean angular distributions of power incident on the antenna, $P_\theta(\theta,\phi)$ and $P_\phi(\theta,\phi)$ [7]. In outdoor environments, P_θ and P_ϕ are approximately Gaussian-distributed in the θ direction, (with mean angles above the horizon m_ϕ and m_θ and standard deviations σ_θ and σ_ϕ), and uniformly-distributed in the φ direction [7]. The MEG equations also use the crosspolarization power ratio (XPR), defined as the ratio of the mean received power in E_θ to the mean received power in E_ϕ. For a medium density urban area, XPR = 5 dB, $m_\theta = 19°$, $\sigma_\theta = 20°$, $m_\phi = 32°$ and $\sigma_\phi = 64°$ were used. In a suburban area, we used values of XPR = 0 dB and $m_\theta = \sigma_\theta = m_\phi = \sigma_\phi = 10°$ [7-9]. P_θ and P_ϕ were also modified to account for the presence of the head. For a two-branch diversity antenna, the total MEG is 0.5 ($MEG_1 + MEG_2 - |R_{12}|$) where MEG_i is the MEG of the *i*th antenna of the diversity system and R_{12} is the cross-correlation between the two antennas. The factor 0.5 accounts for the 3 dB power loss when power is split between the two antennas.

Results of Modeling

The E_θ far-field pattern of the monopole antenna without the user's body is shown in the elevation plane in Fig. 2a for two cases: without ground reflections and with ground reflections. The free-space pattern has a butterfly shape, as expected. Since most of the antenna radiation is directed below the horizon, while the incident power is mostly arriving from above the horizon, the MEG of the monopole is low in both urban and suburban environments (Table 1). The MEG of the monopole is higher in the urban environment (where XPR = 5 dB) than in the suburban environment (where XPR = 0 dB) because the monopole radiates E_θ much stronger than E_ϕ. For the PDA, more power is radiated above the horizon (Fig. 2b for the E_ϕ far-field pattern in the elevation plane) so the MEGs are higher than that of the monopole antenna when neither the user nor ground reflections are considered (Table 1). The inclusion of the ground reflections (with antenna source 1.5 m above ground) significantly improves the monopole antenna performance, but it improves the PDA performance only slightly (Figs. 2a and 2b, Table 1). This is expected, as the ground reflects the downward-directed radiation upwards in more useful directions.

When the user is included, MEG values are reduced (Table 1), partly because the absorption of power in the user lowers the antenna efficiency. Another reason is that the presence of the user distorts the radiation pattern and increases the level of cross polarization (not shown). In the suburban environment, the PDA has higher MEG than the monopole antenna, and in the urban environment, the MEG of the monopole is higher.

The antenna efficiency and peak SAR in the user's body are strongly affected by the antenna type (Table 2). When only the hand is modeled, the monopole antenna has much better efficiency than the PDA, and the peak SAR is much lower. This is because the feed points of the PDA are close to the hand and the currents in the ground plane and patches create strong fields near the hand. Methods of choking the fields near the hand are presently under investigation.

When both the head and hand are modeled, however, the monopole antenna results in high SARs in the head. This causes the efficiency of the monopole antenna to drop below that of the PDA. Peak SAR in the hand is still higher for the PDA, but exposure of the head to electromagnetic fields is of more concern. Thus the PDA shows improved SAR performance compared to the monopole.

Conclusions

The antenna MEG is strongly influenced by the surrounding environment. Overall, the monopole antenna performs better than the PDA in the urban outdoor environment where the incoming signal has a strong vertical polarization. In the suburban environment, the PDA has better performance. Also, the PDA results in much less power absorbed in the user's head. The MEGs of the investigated antennas are underestimated if ground reflections are not taken into consideration.

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Table 1: Mean effective gain (MEG) of the monopole antenna and the PDA (W/kg).

antenna	no user, no ground		no user, with ground		with user, with ground	
	MEG_u	MEG_s	MEG_u	MEG_s	MEG_u	MEG_s
monopole	-4.5	-6.3	-0.75	-2.8	-4.0	-6.3
PDA	-3.7	-2.9	-3.4	-2.8	-5.0	-4.6

Table 2: Efficiency of antennas and peak SAR (averaged over 1g of tissue).

antenna	only hand modeled		both head and hand modeled		
	η (%)	SAR_{hand} (W/kg)	η (%)	SAR_{hand} (W/kg)	SAR_{head} (W/kg)
monopole	87.2	2.52	44.4	1.57	8.44
PDA (HP)	66.0	14.4	51.9	14.4	2.63
PDA (VP)	58.5	19.7	55.4	15.7	3.91

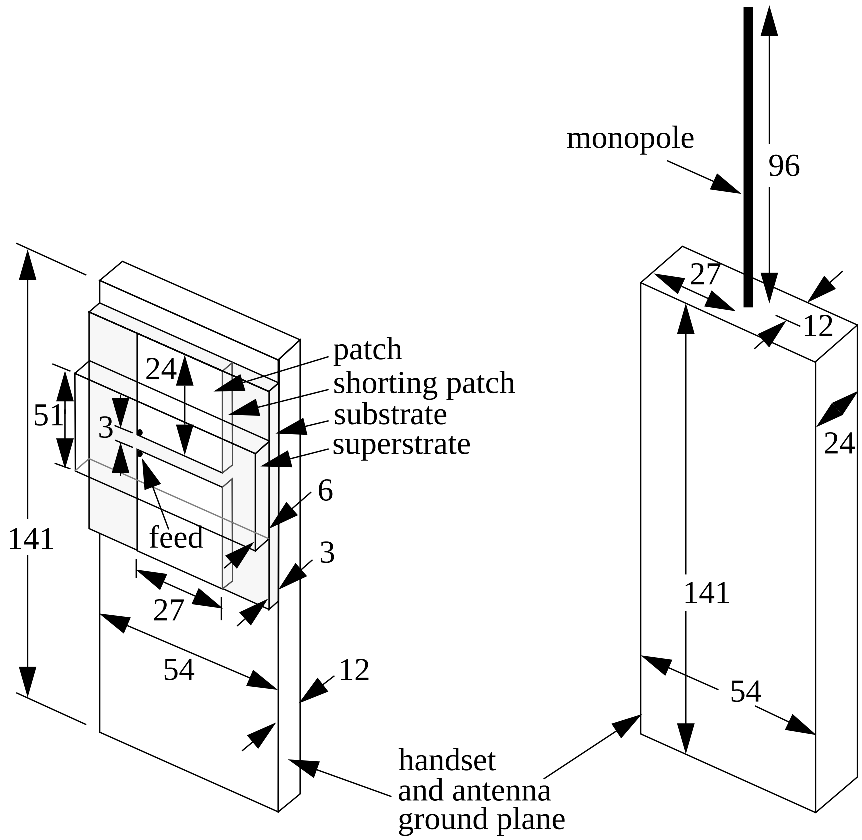

Fig. 1 (a) Polarization diversity antenna (PDA) and (b) monopole antenna mounted on handsets (dimensions in millimeters).

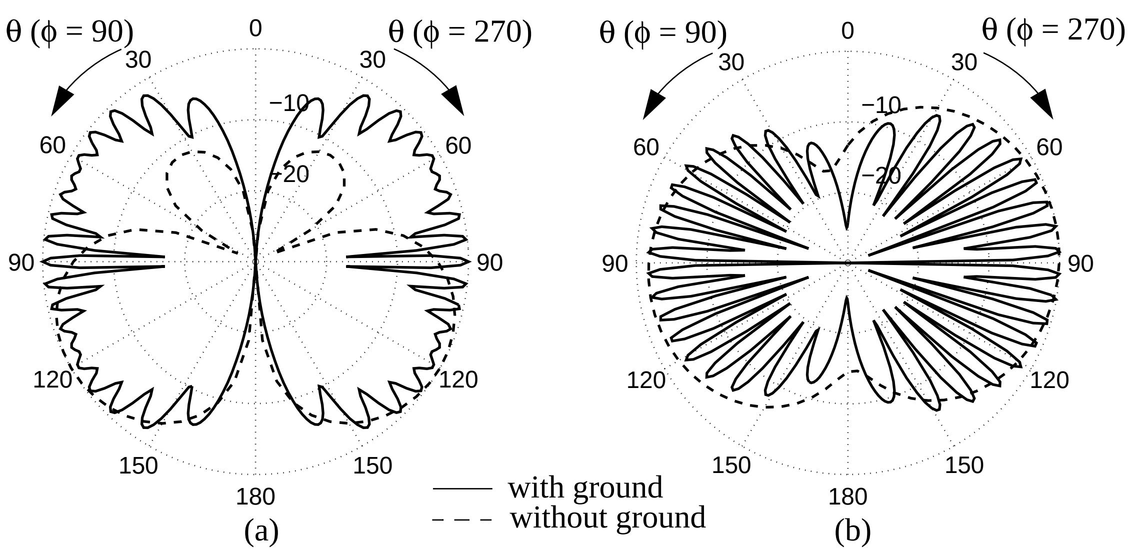

Fig. 2: Far-field patterns in the elevation plane of (a) E_θ of the monopole antenna and (b) E_ϕ of the PDA. Patterns do not include the presence of the user.