



HAL
open science

Study of propagation along the body at 60 GHz with analytical models and skin-equivalent phantoms

Guido Valerio, Nacer Chahat, Maxim Zhadobov, Ronan Sauleau

► **To cite this version:**

Guido Valerio, Nacer Chahat, Maxim Zhadobov, Ronan Sauleau. Study of propagation along the body at 60 GHz with analytical models and skin-equivalent phantoms. Antennas and Propagation Society International Symposium (APSURSI), 2013, 2013, pp.2097-2098. 10.1109/APS.2013.6711707. hal-00998676

HAL Id: hal-00998676

<https://hal.science/hal-00998676>

Submitted on 2 Jun 2014

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Study of Propagation Along the Body at 60 GHz with Analytical Models and Skin-Equivalent Phantoms

Guido Valerio, Nacer Chahat, Maxim Zhadobov, and Ronan Sauleau
 IETR, Institut d'Electronique et de Télécommunications de Rennes, UMR CNRS 6164
 Université de Rennes 1
 Rennes, France
 guido.valerio, nacer.chahat, maxim.zhadobov, ronan.sauleau@univ-rennes1.fr

Abstract—Propagation on the surface of the human body is investigated for the first time in the mm-wave frequency range. The study, motivated by the increasing number of applications of body area networks, is performed through an accurate analytical model for the fields excited by a small source in the proximity of the human body. New asymptotic expressions are derived for the fields, uniformly valid for the range of values of the physical and geometrical parameters of interest. The theoretical analysis leads to the rigorous estimation of important parameters of the communication link. Moreover, an experimental setup is built in order to validate the approach and to obtain further physical insight into aspects not modeled by the theoretical analysis.

I. INTRODUCTION

Recent development of body area networks (BANs) enables the implementation of wireless communication systems among small antennas on the human body for health monitoring purposes. Specifically, the mm-wave range of frequencies (57-64 GHz) offer several advantages in terms of small size, very high data rates (beyond several Gb/s), a high level of security and reduced interference among different BANs.

On the other hand, many physical phenomena at those frequencies are not extensively investigated, such as strong absorption and reflections due to the high dielectric contrast between the skin and free space. A deeper knowledge of these effects is needed to define antenna specifications.

With this analysis, we aim at shedding light on the fundamental characteristics of the on-body propagation channel, in terms of different wave contributions (i.e. optical fields vs. surface waves), relevant attenuation rates, path gain, absorption in the human body, impact of the polarization on the performances of the link.

For this purpose, an elementary arbitrarily oriented Hertzian dipole is considered, radiating at a distance h from a flat lossy medium modeling the electromagnetic properties of human body at 60 GHz (see Fig. 1). The fields excited by the dipole are computed according to Norton's formulation valid in the case of radiation over a high loss half space. Norton's formulas are simplified through asymptotic expressions uniformly valid for any value of h , and different distances between source and observation points. The theoretical results are finally compared with a measurement campaign performed by means of an experimental set-up for the characterization of propagation along a flat skin-equivalent phantom [1].

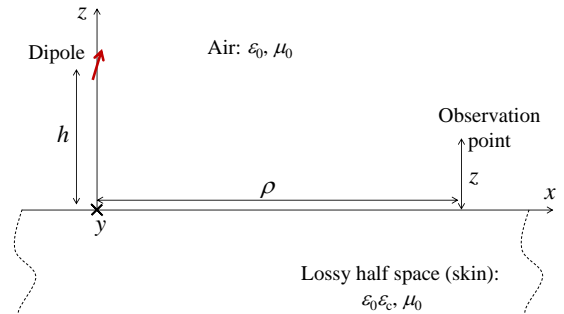


Figure. 1. Lateral view of the theoretical model, with the relevant parameters. A cylindrical coordinate system (ρ, φ, z) is chosen (the azimuthal angle φ is not shown).

II. THEORETICAL ANALYSIS

The fields excited by a dipole in proximity of the human skin (Fig. 1) is studied by resorting to suitable asymptotic approximations of Norton formulas. The skin is modeled as a stratified medium composed by various human tissues (e.g. skin, fat, muscles) whose electromagnetic parameters have been experimentally determined [2]. It is important to remark that the estimated value of skin-depth penetration at mm-waves (δ close to 0.5mm) allows us to retain in the model only the uppermost layer. The skin is thus described as a homogeneous half space having with a suitable complex relative dielectric constant $\epsilon_c = \epsilon_r - j\sigma/\omega\epsilon_0$, where ϵ_0 is the free-space permittivity, $\epsilon_r = 7.98$, the conductivity $\sigma = 36.4$ S/m.

The two cases of *vertical* and *horizontal* dipole should be treated separately. For the sake of brevity, only the former is here addressed, but the same approach has been successfully applied also to the latter. For practical applications, the field is observed in the region $0 < z < h$; the height h of the dipole is assumed to be not greater than one wavelength λ_0 in free space (i.e., 5 mm at 60 GHz).

Due to symmetry, a vertical dipole excites electric fields with no azimuthal dependence. Furthermore, in the region of interest, the total field \mathbf{E} is mainly vertically polarized: only E_z is here analyzed. Provided the distance between the source and the observation point is greater than λ_0 , the electric field in the air can be expressed as the sum of two contributions: a direct term E_z^{GO} due to the geometrical-optics field excited by the source and its image in free space, and a corrective term E_z^N

(the Norton wave) taking into account the boundary conditions at the interface:

$$E_z(\rho, z) = E_z^{\text{GO}}(\rho, z) + E_z^{\text{N}}(\rho, z). \quad (1)$$

E_z^{GO} and E_z^{N} are computed and shown in Fig. 2 for typical heights h of the dipole. In a far region, both the waves have a ρ^{-2} radial dependence (such a region is not visible in the usual application at a few GHz). In an intermediate region the two fields have different decay: the total field exhibits more complex behavior, depending on the value of h . Accurate limiting values of h , distinguishing between different regimes, can be rigorously derived by developing asymptotic approximations of the fields in the various regions.

By means of these results, according to the distance from the source, we can estimate the index n in the path gain G (in dB along the propagation path)

$$G(\rho) = G(\rho_0) - 10n \log\left(\frac{\rho}{\rho_0}\right), \quad (2)$$

where ρ_0 is a suitable reference distance. In particular, in the far region $\rho > 200$ mm, $n = 4$ rigorously holds from the ρ^{-2} asymptotic behavior of the fields. On the other hand, in the intermediate region, different values of n should be considered according to the height h of the dipole. Further details are omitted for the sake of brevity.

A similar study can be performed for a horizontal dipole, exciting a field which depends on the azimuthal angle. In this case the field propagation features and the n parameter in (2) depend on the observation plane. Relevant results are discussed in a related work [1].

III. EXPERIMENTAL SETUP

An experimental setup has been implemented to verify the results obtained in the previous Section. The setup consists of

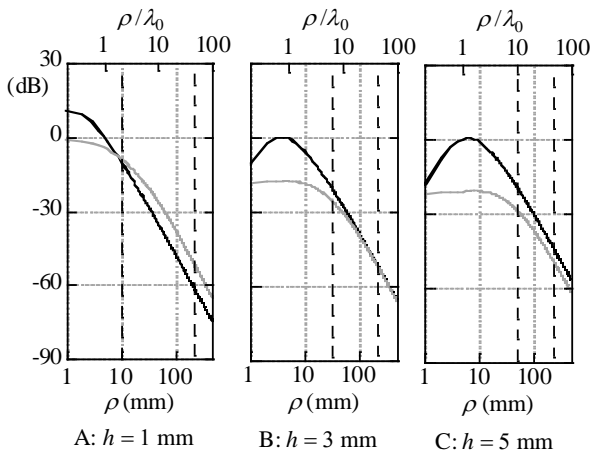


Figure 2. Magnitude of E_z along the radial direction on the surface of the skin ($z = 0$) by means of (1). (b) The GOF (—) and Norton wave (---) in (1) for three different heights of the vertical dipole.

two linearly-polarized standard open-ended WR-15 waveguides close to a skin-equivalent phantom realized as in [3] (see Fig. 3). The phantom permittivity and conductivity at 60 GHz agree with the values used in the previous Section, and have been measured using a technique based on heating kinetics for an independent validation of the setup [1].”

Experimental data are compared to the theoretical model (Fig. 4), confirming the analysis performed. For instance, the choice $n = 4$ perfectly agrees with the measurements in the far zone, as predicted in the previous section.

ACKNOWLEDGEMENT

This work was supported by Labex CominLabs and Brittany Region under ResCor/BoWi project and performed using HPC resources from GENCI-IDRIS (grant 2012-050779).

REFERENCES

- [1] N. Chahat, G. Valerio, M. Zhadobov, and R. Sauleau, “On-body propagation at 60 GHz,” accepted for publication on *IEEE Trans. Antennas Propag.* (13 pp.).
- [2] N. Chahat, M. Zhadobov, R. Sauleau, and S. I. Alekseev, “New method for determining dielectric properties of skin and phantoms at millimeter waves based on heating kinetics,” *IEEE Microw. Theory Tech.*, vol. 60, no. 3, pp. 827–832, Mar. 2012.
- [3] N. Chahat, M. Zhadobov, and R. Sauleau, “Broadband tissue-equivalent phantom for BAN applications at millimeter waves,” *IEEE Microw. Theory Tech.*, vol. 60, no. 7, pp. 2259–2266, Jul. 2012.

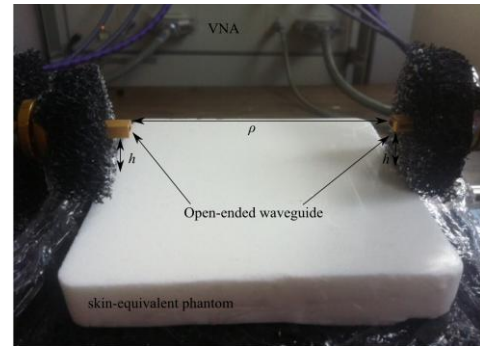


Figure 3. Measurement set-up: two open-ended waveguides close to a skin-equivalent phantom.

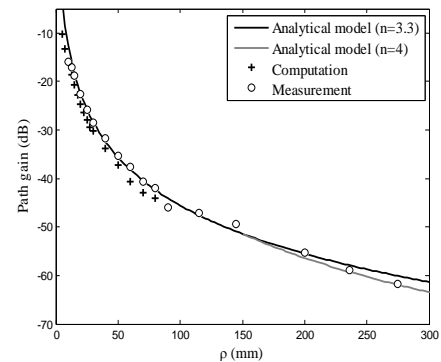


Figure 4. Comparison between path gain model (black and grey solid lines), computed (+), and measured results (O) for $\lambda_0 < \rho < 60 \lambda_0$, $h = 0$ mm.

