Propagation for On-Body Wireless Links at 60 GHz

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***Abstract*—A creeping wave model of the propagation of electromagnetic waves around human torso at 60 GHz is presented. The theoretical model should be of interest for Wireless Body Area Networks design at 60 GHz, if the nodes are located on different side of the torso. Both vertical and horizontal polarizations are investigated. Results of a measurement campaign confirm theoretical predictions.**

I. Introduction

The nodes of a Body Area Network (BAN) can be located on the surface of the human body, which must be taken in account in order to design the communication system. In this communication we are interested in the propagation of the electromagnetic waves between two antenna systems located on two different sides of the torso. The frequencies of interest are around 60 GHz, where an unlicensed band can be used for high throughput communications worldwide. After having introduced creeping wave theoretical model, we report measurements results conducted at 60 GHz that confirm analytic predictions.

II. Theoretical model

We consider the interface between the air, having electric permittivity ε_0 and magnetic permeability μ_0, and the surface of a circular cylinder of radius a, which is a simplified model for a human torso. The cylinder is assumed to be filled with an homogeneous material having a complex electric permittivity $\underline{\varepsilon}_1 = \varepsilon_0\underline{\varepsilon}_r = \varepsilon_0\varepsilon_{rr} - \mathrm{j}\,\sigma/\omega$ and magnetic permeability equals to air. Around 60 GHz, the human body can be approximated by only considering the skin, whose electric parameters at these frequencies are $\varepsilon_{rr} = 7.98$ and $\sigma = 36.4$ S/m [1]. We assume a suppressed time dependency $e^{+\mathrm{j}\,\omega t}$, where ω is the angular frequency. Source and observation points will be placed close to the interface in the air region (at heights h_s and h_r above the surface of the cylinder, respectively), since we are considering on-body communication links. Source and observation points are spaced by the radial distance $\rho_s = \theta a$, where θ is the angle measured between them. A cylindrical coordinate system is adopted. The curves shown in this section have been normalized with respect to the ρ component of the electric field radiated by a vertical Hertzian dipole placed on the surface of a PEC cylinder of radius $a = 0.2$ m and calculated at $\rho_s = 5$ mm at 60 GHz.

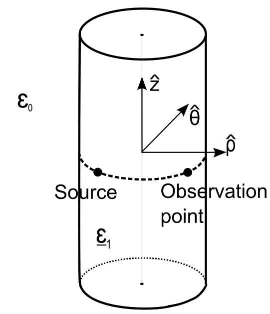

Fig. 1. Geometry.

A. Vertical dipole

Let a Hertzian dipole be radially placed on the surface of the cylinder in the air at $z = 0$. Then, the field on the surface of the cylinder at $z = 0$ is almost vertically polarized and then the $\hat{\rho}$ component of the electric field is [2]:

$$E_v = \frac{\mathrm{j}\,\omega\mu_0 I dl}{2\pi}\frac{e^{-\mathrm{j}\,\omega\rho_s/c}}{\rho_s}e^{-\mathrm{j}\,\pi/4}\sqrt{\pi\xi}\frac{F(h_s)F(h_r)}{\tau_1 - q_v^2}e^{-\mathrm{j}\,\xi\tau_1} \tag{1}$$

with

$$F(h) \simeq \frac{W\left(\tau_1 - \sqrt[3]{\frac{2}{k_0 a}}k_0 h\right)}{W(\tau_1)} \tag{2}$$

$$\xi = \sqrt[3]{\frac{\omega a}{2c}}\frac{\rho_s}{a} \tag{3}$$

$$q_v = -\mathrm{j}\sqrt[3]{\frac{\omega a}{2c}}\sqrt{\frac{1}{\underline{\varepsilon}_r}} \tag{4}$$

and τ_1 is the first zero of

$$W'(\tau_i) - q_v W(\tau_i) = 0 \quad i = 1, 2, ... \tag{5}$$

$W(\tau)$ with its derivative are Fock-type Airy functions defined in [2] by $W(\tau) = \sqrt{\pi}\,[B_i(\tau) - \mathrm{j}\,A_i(\tau)]$. $F(h)$ is the "height-gain" function. Equation (1) is commonly known as creeping wave and it is an evanescent wave. For a source radiating close to the surface of the cylinder, two creeping

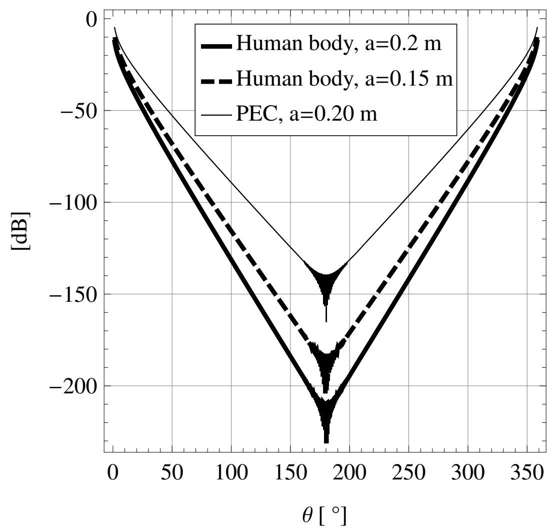

Fig. 2. Vertical Hertzian dipole: magnitude of the ρ component of the electric field as function of θ at the surface of cylinders with different radii and electromagnetic properties. $h_s = 1$ mm, $h_r = 1$ mm.

waves traveling in opposite directions have to be taken in account and then the total field is:

$$E_T = E_v(\theta) + E_v(2\pi - \theta) \tag{6}$$

The vertical component of the electric field radiated by a vertical Hertzian dipole around the surface of different cylinders is drawn in Fig. 2. Source and observation points are 1 mm above the surface of the cylinder. The attenuation rate of the electric field at 60 GHz traveling around the cylinder is approximately equals as 3 dB/cm for a radius of 20 cm.

B. Horizontal dipole

Formulations similar to the previous case have been given in [3], but are not reported in this abstract for the sake of brevity.

III. Measurements

In this section we report results of Network Analyzer (*Agilent E8361C*) measurements carried out in an anechoic chamber on a brass cylinder. The cylinder radius has been chosen equal as 0.2 m and its height equal as 1.2 m. The cylinder was vertically mounted on a rotor and could thereafter rotate around its axis.

Antennas are 3 cm x 2.3 cm pyramidal horns with a gain of approximately 20 dBi. A pyramidal horn antenna has been attached to a vertical support and placed as close as possible to the cylinder. A second, identical horn antenna was joined to the surface of the cylinder. Then, different distances between the two horn antennas were achieved with a precision of 1 ° by simply turning the cylinder around its axis. In Fig. 3 we have drawn vertical and horizontal polarization measurements and the corresponding theoretical predictions. Experimental results fit very well by the creeping wave formulations introduced in the previous section. However, it can be noticed that horizontal polarization measurements diverge from the theoretic prediction from 80 ° . This should be explained because of the strong attenuation of horizontal polarized waves, which fall under the signal reflected by the anechoic chamber walls. A similar issue has already been observed in [4]. This consideration clearly reveals that, in an indoor environment, the signal propagating on the body surface can be overcome by the reflections on the environment. However, the knowledge of the attenuation on the surface of the body is necessary before conducting investigations on wireless BAN at 60 GHz in real environments.

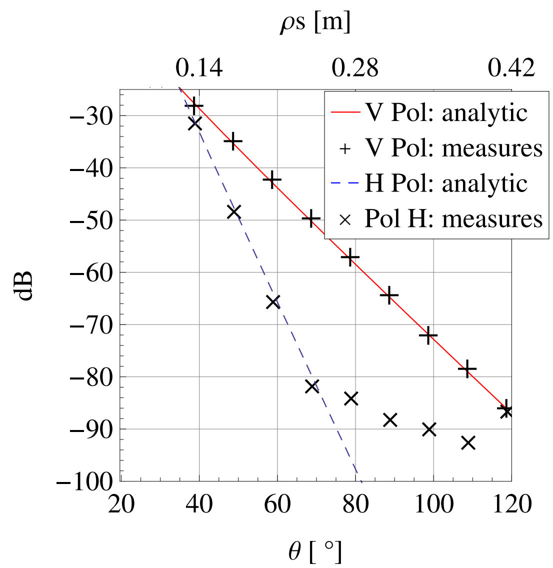

Fig. 3. Vertical and horizontal polarization measurement results compared with theoretical attenuation prediction for a PEC cylinder of radius a=0.2 m.

IV. Conclusion

In this paper, the creeping wave model is used to predict the propagation of vertical and horizontal polarized waves around the human torso at 60 GHz. Measures conducted on a brass cylinder fit very well with theoretical results. As expected, even in anechoic chamber, reflections on floor and walls can overcome the field propagating at the surface of the cylinder.

References

[1] P. A. Hasgall et al., ”IT’IS Database for Thermal and Electromagnetic Parameters of Biological Tissues”, Version 2.2, July 11th, 2012, www.itis.ethz.ch/database.

[2] R. Paknis and N. Wang, ”High-Frequency Surface Field Excited by a Magnetic Line Source on an Impedance Cylinder”, *IEEE Trans. Antennas Propag.*, vol. 35, pp. 293-298, March 1987.

[3] K. Li and Y. L. Lu, ”Electromagnetic Field from a Horizontal Electric Dipole in the Spherical Electrically Earth Coated with N-Layered Dielectrics”, *Progr. Electrom. Res., PIER*, vol. 54, pp. 221-244, 2005.

[4] A. M. Eid, N. Murtaza and J. W. Wallace, ”Green?s function models and measurements for body area network (BAN) channels”, *Proc. IEEE Int. Conf. on Wireless Information Technology and Systems (ICWITS10)*, Honolulu, HI, Aug. 2010.