# Porcine skin as human body phantom at 60 GHz

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***Abstract*—This communication presents the results of an experimental campaign carried out at 60 GHz to demonstrate that porcine skin can be used at 60 GHz as a phantom for the human body. Norton formulations above a flat human body are verified using porcine skin.**

## I. Introduction

The wave spectrum around 60 GHz (57-64 GHz) is one of the best candidates for future wireless high throughput communication in a short range (up to 10 m). This is due to the large bandwidth available in the millimeter spectrum. Moreover, it is envisaged that millimeter technology will be deployed in user-oriented scenarios, as for example, Body Area Networks (BANs). In that case, physical insight on the propagation mechanism involving antennas in the close vicinity of the surface of the human body is of importance since it permits a better understanding of the phenomena involved.

In this communication, we aim to demonstrate that at 60 GHz the field attenuation above fresh porcine skin can be predicted by Norton formulations using the electromagnetic properties of human skin at 60 GHz. Human skin is representative of the human body at 60 GHz, since the skin depth is much smaller than human skin thickness.

The communication is organized as follow: theoretical expression of Norton formulations are recalled, then the experimental campaign is introduced. Results are shown and compared to theoretical predictions.

## II. Theoretical

The fields propagating between two vertically polarized antennas above a plane conducting surface can be calculated by using Norton formulations for Hertz dipoles [1]. In a cylindrical coordinate system ($\rho$, $\theta$, $z$), let a transmitting Hertz dipole be located in air ($\varepsilon_0$,$\mu_0$) at (0,0,$h$), where $h$ is a small height, compared to the observation range, above a conducting, non magnetic, homogeneous half space of relative complex dielectric permittivity $\varepsilon_c = \varepsilon_r + \sigma/\omega\sigma\varepsilon_0$. The dominant vertical component of the electric field in air is given by [1]:

$$\begin{aligned}
E_z(\rho, z) &= \frac{\omega\mu_0 I\delta l}{4\pi k_0} \\
&\times \{e^{jk_0 r_1}\left[\frac{jk_0}{r_1} - \frac{1}{r_1^2} - \frac{j}{k_0 r_1^3} - \left(\frac{z-h}{r_1}\right)^2\left(\frac{jk_0}{r_1} - \frac{3}{r_1^2} - \frac{3j}{k_0 r_1^3}\right)\right] \\
&+ e^{jk_0 r_2}\left[\frac{jk_0}{r_2} - \frac{1}{r_2^2} - \frac{j}{k_0 r_2^3} - \left(\frac{z+h}{r_2}\right)^2\left(\frac{jk_0}{r_2} - \frac{3}{r_2^2} - \frac{3j}{k_0 r_2^3}\right)\right] \\
&- 2k_0^2/\sqrt{\varepsilon_c}e^{jk_0 r_2}\left(\frac{\pi}{k_0 r_2}\right)^{1/2}\left(\frac{\rho}{r_2}\right)e^{-jw}F(w)\}
\end{aligned} \tag{1}$$

where $I$ is the current strength, $\delta l$ is the infinitesimal dipole length, $r_1 = \sqrt{\rho^2 + (z-h)^2}$, $r_2 = \sqrt{\rho^2 + (z+h)^2}$, $k_0 = \omega/\sqrt{\varepsilon_0\mu_0}$ and

$$\begin{aligned}
F(w) &= \frac{1}{2}(1+j) - \int_0^w \frac{e^{jt}}{\sqrt{2\pi t}}dt, \\
w &= \frac{k_0 r_2}{2}\left(\frac{r_2/\sqrt{\varepsilon_c} + z + h}{\rho}\right)^2.
\end{aligned} \tag{2}$$

The first two terms of (1) are the direct and reflected waves, while the third one is known as the Norton surface wave. These three terms controls the amount of power that can be collected by a vertically polarized probe located above the conducting surface. Norton equations have been verified at 60 GHz by using a flat phantom of the human body [2].

## III. Experimental

A measurement campaign has been carried out in order to assess the use of porcine skin as a phantom for human body at 60 GHz using Norton formulations. Two open rectangular waveguides at V band were pointing toward each other at the same height ($h = z$ in (1)) above a slice of fresh porcine skin of thickness 2-3 mm and width 5 cm. The antennas were mounted on a mechanical positioner, which permitted to automatically control the separation $\rho$. Both antennas were connected to a calibrated Rohde & Schwarz Vector Network Analyzer ZVA by 1 m long cables. For every distance between antennas, a frequency sweep has been performed, in order to obtain the direct component of the incident field by time gating. A summary of measurement parameters is shown in Table I.

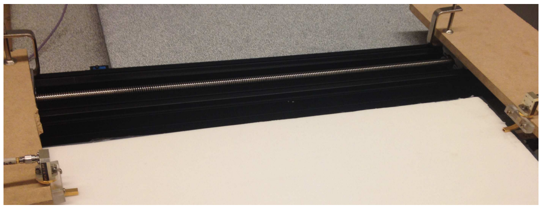

Fig. 1. Experimental setup. Open waveguides are fixed to a mechanical positioner by means of dielectric boards. The porcine skin was placed above the white plank shown in the picture.

TABLE I
EXPERIMENTAL SETUP

| Parameter | Value |
|---|---|
| IF Bandwidth | 10 Hz |
| Center frequency | 60 GHz |
| Measurement bandwidth | 10 GHz |
| Frequency points | 101 |

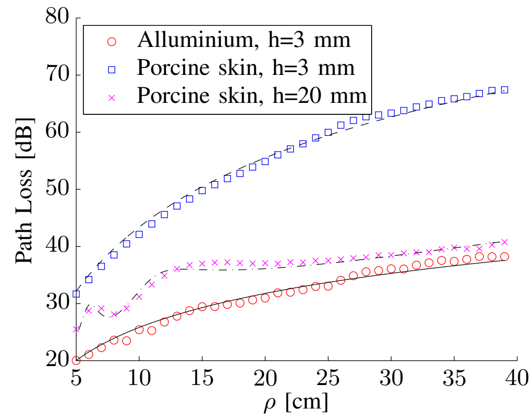


Fig. 2. Measured path loss and normalized Norton expressions. Theoretical curves for porcine skin have been obtained by using the electromagnetic characteristics of human skin at 60 GHz.

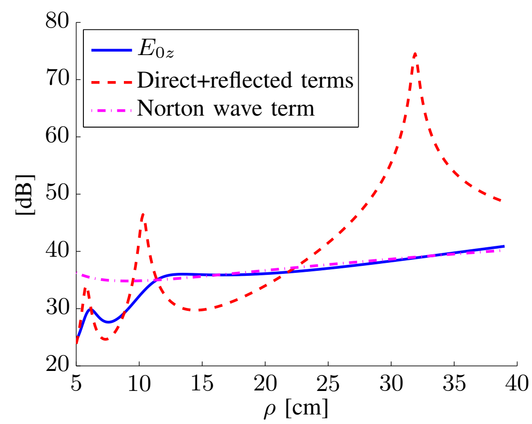


Fig. 3. Normalized Norton expression for the path loss and contribution of direct and reflected wave terms and Norton surface wave term. The curves are evaluated above a conductive half plane having the same electromagnetic properties of human skin at 60 GHz and $h = 20$ mm.

## IV. RESULTS

To obtain the results of Fig. 2, two measures have been performed. Firstly, the received field above the porcine skin has been measured for increasing distances with the antennas at $h = 3$ mm. Secondly, an aluminium tape ($\sigma = 37$ MS/m, thickness = 100 $\mu$m) has been placed above the swine skin and the measures have been repeated. The height of the antenna above the surface of propagation is then only altered by the negligible thickness of the tape. Measures above aluminium tape permit to validate the measurement setup: from Fig. 2 it can be seen that the measured power deviates no more than 1.5 dB from the path loss predicted by (1) when aluminium is considered. In this case, the path loss is proportional to $\rho^2$, since the contribution of the Norton surface wave above good conductors is negligible. Direct and reflected waves add almost in phase and no interference pattern is visible.

Moreover, the normalization of (1) to the power received at 5 cm above alumium means that we are imposing a value of $I\delta l$ (the only degree of freedom in (1) when all the others variables are set). This value of $I\delta l$ is used to evaluate (1) at two different heights of the antennas by using the complex permittivity of the human skin ($\varepsilon_r = 7.98$ and $\sigma = 36.4$ S/m). This is done in order to prove that not only the predicted the path loss is verified by measurement, but also the relative power with respect to a reference case, i.e. the aluminium surface. Results are shown in Fig. 2.

When the height of the antennas above the porcine skin is 3 mm, Norton surface wave term contribution to $E_z$ is dominant: the path loss is proportional to $\rho^4$. Moreover, also the gain of the antennas is affected by the presence of the swine skin in their closeness: a 12 dB gap at $\rho$=5 cm between aluminium and swine cases is observed.

Increasing the height of the antennas to 20 mm produces as a result the simultaneous effect of the three terms in (1): direct and reflected wave terms add in constructive and destructive ways depending on the value of $\rho$, while Norton term, whose amplitude is almost constant in the considered range, reduces or even extinguishes the oscillations of the electric field amplitude. A graphic illustration of this effect is shown in Fig. 3.

## V. CONCLUSIONS

This communication presents the results of a measurement campaign conducted above fresh porcine skin at 60 GHz. It is shown that Norton formulations predict the field decay above porcine skin by using the electric permittivity and conductivity of the human skin at 60 GHz. The porcine skin can so be used as a phantom of the human body at 60 GHz for on-body propagation studies.

## REFERENCES


[1] R. W. P. King, G. J. Fikioris and R. B. Mack, *Cylindrical Antennas and Arrays*. Cambridge University Press, Cambridge, 2002, pp. 290–296.

[2] N. Chahat, G. Valerio, M. Zhadobov and R. Sauleau, "On-body propagation at 60 GHz", *IEEE Trans. Antennas and Propagation*, vol. 61, pp. 1876–1888, April 2013.