

Antenna Radiation Efficiency Considerations in Body Area Networks

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ABSTRACT

In this paper, we present a theoretical investigation on the radiation efficiency of small on-body antennas in the context of Body Area Networks. In particular, we show that operation at frequencies above 20 GHz experiences less human-tissue losses than below 6 GHz, and could therefore be a suitable candidate for more efficient off-body wireless communications.

Keywords

Body Area Networks (BAN); complex image method; millimeter-wave; dipole above multilayer half-space.

1. INTRODUCTION

Body area networks (BAN) are networks of sensors embedded on the human body in order to provide healthcare monitoring. A promising application of such networks lies in the “well-being” of the elderly. If BAN can provide a seamless way to monitor in real time the condition of people, it would be then possible to prevent rather than cure. To answer the needs of such long-term applications, BANs have to be completely autonomous in terms of energy while using small sensors (for the user to tolerate wearing them). Power consumption is therefore a critical issue. Sensors are supposed to communicate wirelessly, so a large amount of the consumed power is directly related to the radiofrequency hardware.

When sensors are embedded close to the human body surface, the radiated electromagnetic field strongly interacts with the user and experiences some losses that will ultimately heavily impact the system’s autonomy. While the losses due to the propagation channel have been extensively investigated [1-3], it is more difficult to draw general comments related to the antenna radiation efficiency since among the studies in the literature, different types of antennas are used, and the heights between the antenna and the body varies a lot, thereby making comparison meaningless. Consequently, this paper addresses from a theoretical point of view the question of radiation efficiency when antennas are located close to the human body. The idea is to give some insights regarding the choice of operation frequency. For

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this purpose, a canonical structure, i.e. a vertical dipole, is used as a source located on the human body, which is modeled by a multilayer structure. Section 2 describes the geometry as well as the approach to define a radiation efficiency that is relevant in the BAN context. Section 3 introduces some simulation results and Section 4 provides a more general discussion on these results. The conclusion is drawn in section 5.

2. PROBLEM FORMULATION

The geometry considered in this paper is presented in Fig.1. The human body is modeled as a multilayer structure composed of skin, fat, and muscle. The thickness of the skin and the fat are $h_{skin} = 1$ mm and $h_{fat} = 0.5$ mm, respectively, while the muscle is considered infinite along the negative z -axis. The permittivity of the three layers is taken from [4] and varies with respect to the frequency. The vertical dipole is of length l , at a height h above the human skin. Its radius is kept constant throughout the paper at $a = 0.25$ mm.

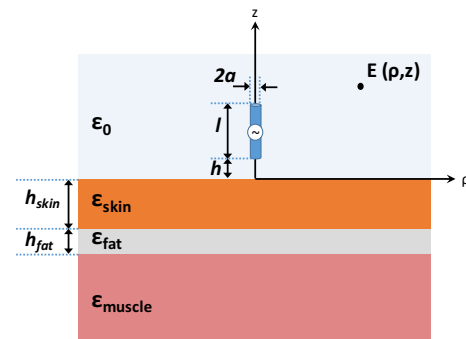


Figure 1. Geometry under investigation: vertical dipole over the human body

In order to theoretically address the issue of radiation efficiency in BAN, we first define the radiation efficiency as:

$$\eta = \frac{P_{rad}}{P_{in}}$$

where P_{in} is the real input power accepted by the dipole and P_{rad} is the radiated power in far field *in the upper half-space only* (the power radiated in the lower half-space is considered not to contribute to the BAN communications, and vanishes anyway in far-field because of the losses). The dipole is supposed to be perfectly matched and $P_{in} = 1$ W for all frequencies of investigation. To do so, the following input current magnitude is applied at the dipole feeding access (located at $z = h + l/2$):

$$I_0 = \sqrt{\frac{2P_{in}}{R_{in}}}$$

where R_{in} is the real part of the dipole impedance Z_{in} above the multilayer structure. The dipole current I is considered sinusoidal:

$$I(z) = I_0 \sin k_0 \left[\frac{l}{2} - \left| z - \left(\frac{l}{2} + h \right) \right| \right], \quad h \leq z \leq l + h$$

where k_0 is the free space wave number. The input impedance Z_{in} is computed as in [5] using the complex image method in order to take into account the multilayer structure shown in Figure 1. P_{rad} is obtained by integrating the Poynting vector in the upper half space (i.e. $z > 0$ in Fig.1). To do so, the expression of the radiated electric far field is calculated using geometrical optics and is therefore the sum of a direct and a reflected ray.

3. OFF-BODY SIMULATION RESULTS

Simulations are performed and the obtained radiation efficiency η is given in Fig.2a with a dipole length $l = 10$ mm and in Fig.2b with $l = 1.6$ mm (which corresponds to a typical substrate thickness). In each figure, η is plotted with respect to frequency for different dipole height h values.

The efficiency largely varies with respect to the frequency but it is interesting that only at lower frequency (typically less than 6 GHz) does the efficiency increase proportionally to the dipole height h above the skin surface for both dipole length l values. This remark is also true in the 20-40 GHz range when $l = 10$ mm whereas when $l = 1.6$ mm, this trend is only noticeable for frequencies above 40 GHz. In the 6-20 GHz band when $l = 10$ mm, and in the 6-40 GHz when $l = 1.6$ mm, the behavior of η with respect to frequency is less predictable and it is therefore more difficult to draw general trends.

If the considered dipole is taken as a reference for vertically polarized antenna without ground plane, it appears that better radiation efficiency can be reached by operating at higher frequencies. This highlights the potential of millimeter-wave operation for off-body links.

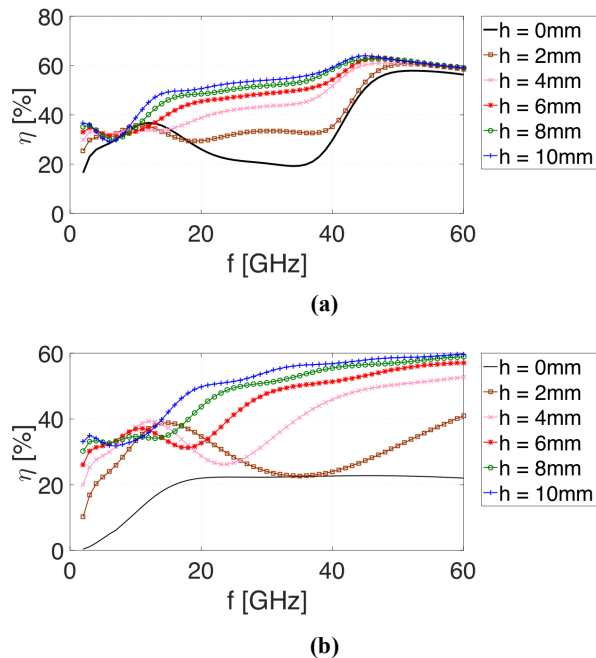


Figure 2. Radiation efficiency η for different dipole length (a) $l = 10$ mm, and (b) $l = 1.6$ mm

4. DISCUSSION

It is worth noticing that unlike in classic link budget that uses Friis formula, results with respect to frequency are given here while keeping a constant antenna size, as opposed to a constant antenna gain. We believe this is a fairer comparison for applications like BAN where the antenna has to be as small as possible. As seen in previous section 3, the fact that efficiency increases with frequency is attributed to two main phenomena. The first one is due to fact that the conductivity of the human tissues increases with frequency, thereby acting more and more as a ground plane as the frequency increases ($\sigma_{skin} = 36$ S/m at 60 GHz). Thus the power radiated from the dipole is more reflected at the skin interface (and less transmitted). The second effect is that the real part of the permittivity decreases with respect to frequency. So at low frequency, the human body permittivity being high, the electromagnetic field is much more concentrated in the lower half-space (i.e. the human body) than in the upper one.

5. CONCLUSION

Based on a theoretical approach, it has been shown that operation at frequencies as high as 20-60 GHz could be suitable in order to reach better radiation efficiency in off-body communications for BAN applications.

As perspectives of this work and in order to provide even more relevant guidelines for the choice of operation frequencies, horizontally polarized antennas will be investigated as well as the losses involved by impedance matching networks.

6. ACKNOWLEDGMENTS

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