A COMPACT RESISTIVE ANTENNA "DARK EYES" FOR BIOLOGICAL PULSED MICROWAVE PROBING: ANALYSIS AND DESIGN POSSIBILITIES

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ABSTRACT

In this work, we explore the usage of constant-value resistive loading along the antenna surface and altering its geometry to achieve results aimed by the design of a bowtie with variable resistive loading for pulsed microwave probing. Such an design should ensure minimal reflections from the antenna end so that the antenna is sufficiently broadband to accurately reproduce the pulse Fourier components. Furthermore, we discuss the characteristics of the antenna in the immediate vicinity of a biological substrate. Finally, mutual impedance between two antennas is assessed in order to investigate the suitability of their design for an antenna array.

INTRODUCTION

Pulsed imaging of materials has been used or suggested for a range of applications, e.g. breast cancer detection [1]. A perfectly conducting bowtie antenna is often favored for its remarkable broadband properties. Variable resistive loading is the strategy sometimes used to minimize the reflections from the end of the bowtie antenna. However, it can be shown that the parameters required for the suggested design (a specific variation of the resistive loading; the equivalent surface resistance of the antenna) challenge its practical implementation. Further, the high value of the equivalent surface resistance in formerly suggested design could result in a very low overall efficiency of the antenna. In this work, we investigate an antenna design with a constant resistive loading, where the reflection-minimizing strategy by accurate loading variation is replaced by a favorable change in the antenna geometry.

METHODS

Numerical Analysis

The results presented in this paper were obtained using a frequency-domain CAD tool "GEM" (General ElectroMagnetic code). "GEM" is an entire-domain (E-D) Galerkin Method of Moments (MOM) code, based on the two-potential equation, with power basis functions automatically satisfying boundary conditions [2]. The geometrical structure of interest is approximated with a combination of basic elements: straight-wire segments, bilinear quadrilaterals and trilinear hexahedrons [3]. For each hexahedron, its inner volume conduction and displacement currents are replaced by the equivalent surface electric and magnetic currents over its boundary surfaces. This approach yields higher computational efficiency relative to that of the volume-current version of the same method. The code allows the option of a "line-delta" generator. Under the condition that the generator is much shorter than the wavelength, it is located along an edge of a basic element surface, generating different potentials on two opposite sides of a straight-line segment shared by two quadrilaterals.

Antenna Geometry and Parameters

In this work, we report results for "inverted bowtie" antenna geometry. Such an antenna is wide at its apex, and its width is tapered along its longitudinal axis towards its ends, as shown in Fig.1. With a constant surface resistivity, therefore, the resistance per unit length increases along the longitudinal direction. The gradient of resistance per unit length can be controlled by careful design of the taper. Therefore, the resistance per unit length can be rapidly increased by employing a sharp-taper geometry. In the course of this study, the described geometry was reminiscent of the eyeshape and the authors nicknamed the design as “Dark Eyes” antenna. The antenna is assumed to be excited at its apex by a short line-delta generator.

With reference to Fig.1, the numerical optimization parameters in this study were the antenna end width *b* and the adopted value for the constant surface resistive loading R_s , while the antenna length L = 40 mm and its dimensions at the apex $a = c$ = 5 mm remained unchanged.

We here note that the described design implies possible advantages of “dark eyes” antenna over the bowtie design other than the usage of constant-value resistance. The “dark eyes” antenna is considerably smaller than the bowtie in the transverse direction. This results in a nearly linear field polarization in all directions. Furthermore, the compactness of the “Dark Eyes” antenna would be advantageous for the implementation of an antenna array.

RESULTS

Optimization of the Antenna Geometry

The antenna was considered in air. It was found that the constant surface resistance of R_s = 200 Ω/square yields negligible reflections for a range of end widths $b \leq 20$ mm. The optimal value of end width, which resulted in maximum efficiency, was b = 1 mm, implying the advantage of a compact design. “Skin effect”, and therefore the losses, is most pronounced in the vicinity of the antenna apex. The variation of the antenna end width is expected to have little influence on the losses. However, numerical investigations revealed that the “skin effect” (and, consequently, the losses) near the antenna apex is pronounced proportionally to the antenna end width. This can be illustrated by graphing the current distribution along the antenna for two extreme values of the antenna end width, b = 20 mm (Fig.2) and b = 0.5 mm (Fig.3).

Influence of the Biological Substrate

Impedance of an antenna lying in the vicinity of the air-substrate interface exhibits large variations with the distance of the antenna from the interface. This change is most pronounced near the very air-substrate interface. If previously analyzed antenna is pressed over a surface of living tissue, various levels of contact imperfection (with resulting small air pockets) will cause dramatic changes in antenna impedance. One way to mitigate this problem is to place the antenna in a layer of material with similar properties to those of the living tissue. However, this solution poses number of practical problems. Another solution arises from the fact that negligible variation in antenna impedance is guaranteed with an ensured air gap of a few millimeters between the antenna and the living tissue. This was confirmed for an optimized antenna of the previous section, adjacent to an antenna-shaped 5-mm dielectric slab of relative permittivity of ε_r = 4 at the frequency of 6 GHz. The results presented in Table I suggest that a practical solution for minimal antenna impedance variation in the vicinity of an air-tissue interface is a 5 mm layer of a Styrofoam support separating the antenna and the tissue layer.

Mutual Impedance of Two Antennas

Implementation of an antenna array calls for analysis of mutual impedance of at least two antenna elements. In this study, two “Dark Eyes” optimized antennas discussed in the previous sections were placed in parallel within 2.5 cm of one another. Simulations (at 6 GHz) show that the mutual impedance between the antennas is approximately only 10% of the value of self-impedance of each individual antenna. This result nevertheless implies undesired crosstalk. Therefore, if these antenna elements are to be used in an antenna array, special attention should be paid to the strategic placement ensuring sufficient distance between adjacent array elements.

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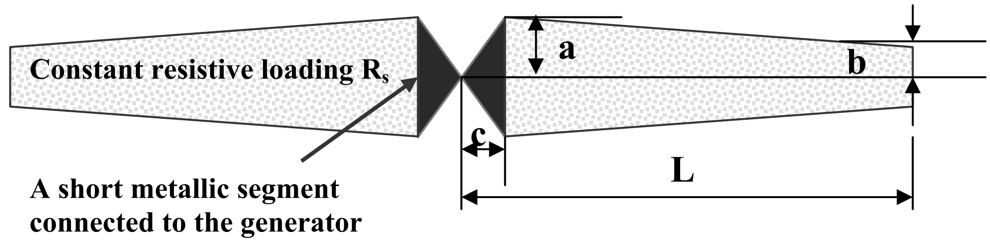


Figure 1. Sketch of the resistively loaded “Dark Eyes” (“inverted bowtie”) antenna. The small bowtie-shaped part of the antenna facilitates easier connection with the generator and is assumed to be made of metal. The numerical optimization parameters are the antenna end width b and the adopted value for the constant surface resistive loading R_s , while the antenna length L = 40 mm and its dimensions at the apex a = c = 5 mm remained unchanged. In the numerical model, the width of the line-delta generator (not shown in the figure) at the antenna “apex” is 0.2 mm.

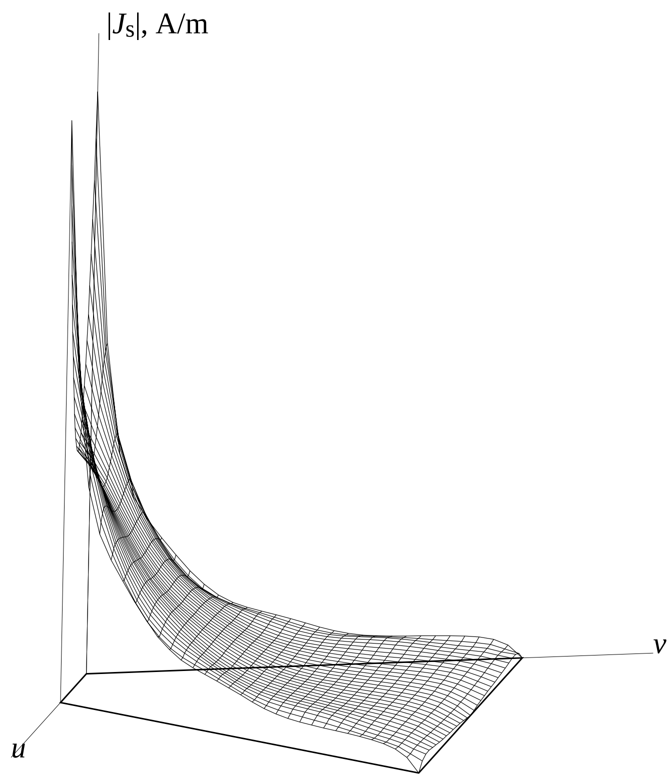


Figure 2. Surface current magnitude ($|J_s|_{max}$ = 1.0 A/m) of the resistive part of the antenna of Fig.1 for b = 20 mm and R_s = 200 Ω/square at 6 GHz.

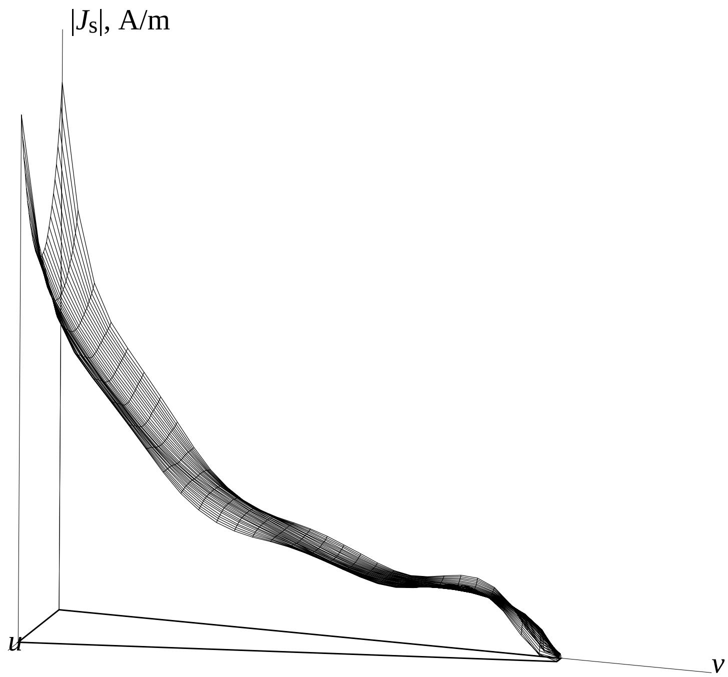
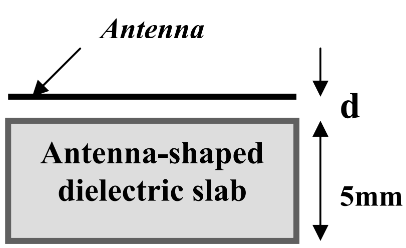


Figure 2. Surface current magnitude ($|J_s|_{max}$ = 0.8 A/m) of the resistive part of the antenna of Fig.1 for b = 0.5 mm and R_s = 200 Ω/square at 6 GHz.

Table I. Resistance R and reactance X of the antenna of Fig. 1 for the optimized parameters (b = 0.5 mm and R_s = 200 Ω/square) at 6 GHz as a function of the antenna distance d from a 5-mm thick antenna-shaped dielectric slab of relative permittivity $\varepsilon_r = 4$.



***d* (mm)**	***R* (Ω)**	***X* (Ω)**
0	**13.4**	**35.8**
0.5	**73.8**	**-18.7**
1.0	**78.1**	**-25.3**
2.0	**80.7**	**-31.4**
5.0	**81.9**	**-34.6**
…	**…**	**…**
∞	**84.7**	**-38.1**