Microwave Microstrip Antenna Bio-Inspired from Dendritic Tree

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Abstract. A new compact microstrip antenna technology for wireless sensor network is proposed in this paper. The shape of the planar microstrip line network is inspired by the dendritic tree of the natural neuron architecture given in free international neuron data bases. The major considerations of the bio-inspired antenna are compact size, multi resonant response, omnidirectional or directional pattering, beam scanning and frequency agility. The resonant frequencies, current distribution on the central strip, and radiation patterns are evaluated by simulation software tools. Several key parameters are discussed. The scope and future perspective of this paper are to develop new bio-inspired microwave antennas with tree structure having unequal and diversity spatial distribution of branches, small size and multi resonant operating capabilities.

Keywords: Dendritic tree · Microwave antenna · Microstrip lines
Radiation pattern · Electromagnetic field

1 Introduction

The number of the mobile communication systems has increased very much in the last few years. The main trend noticed in their technology was decreasing the weight and size. Therefore, new architectures have to be investigated in order to maintain the operational parameters and compatibility inside of an environment which has become more and more electromagnetic polluted. Small, compact, easy to integrate with the entire system, low profile, and omnidirectional radiation pattern in one plane are only few of the characteristics of wireless equipment [1]. The antenna, as part of the transmitting or receiving systems, could be realized as: wire, aperture, printed, array, and lens or reflector architectures.

The electric antenna characteristics as: operating frequency, input impedance, bandwidth, radiation pattern or directivity can be significant controlled by antenna topology. There is a large variety of antennas, many simulation software tools, and numerical optimization algorithms [2]. Even so the modern computer capabilities have been improved; the convergence to a desired radiation pattern by the phase and amplitude manipulation for smaller antennas is not always possible. There is a strong interdependence between the morphology and information processing capabilities of

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systems [3, 4]. Perfection of biological systems has inspired scientists to achieve more models like of natural processes. The human brain is one of the most compact and complicated systems regarding understanding, control and production of the various activities. There are 10^{11} neurons in the 6 layers of the cortex, a density of 10^5 neurons/mm^3, and a synaptic density of 6 10^8/mm^3.

At the individual level, the morphology and behavior of neurons are similar for all species. Differentiation occurs at the level of their architecture or connectivity. Computational neuroscience attempts to explain the information communication by encoding and decoding, but the processes remain incomplete elucidated. In neuron, electrical signals propagates in a single direction, dendrites-soma-axon. A hypothesis of information encoding in peripheral neurons is that this process is made by firing rates or firing time. At the neurons from the central nervous system arguments are harder to prove, though some authors assert that the process of encoding is dependent on time and space [5]. In vivo measurements are difficult to be done because of the neuron real activity perturbation.

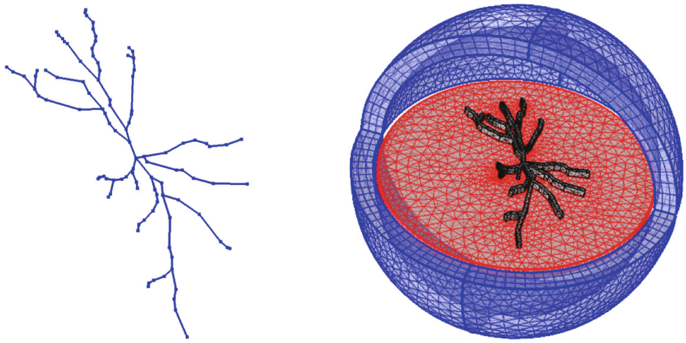
A multipolar neuron can integrate data from 200,000 neurons. In order to be able to process this vast amount of information it must be selective. The model has been proposed in order to explain or describe certain experimental observations relating to the selectivity of neurons or emphasizing the potentials evoked. It constitutes a simplified mathematical representation, can be biologically motivated and relies more on an abstraction of biological processes.

Taking in consideration that the neuron succeeds to manage a huge amount of information and has a compact spatial structure, a new antenna topology based on neuron morphology is proposed and investigated in this paper. The dendritic tree is modeled by a planar microstrip network. The bio-inspired model uses uniform strips and the resonance is given by the dendritic tree branches, but not the patch dimensions, as at the other printed antennas. Design of conventional microstrip antennas depends on the shape and size of the patches. The design and global capabilities of the patch antennas were published in [6]. The design of the proposed antenna is based on Maxwell's equations solving, and the multi-resonant response is argued and justifies the neuron selectivity that retrieves data from many neurons and can send them to different spatial areas. The resonant frequencies, radiation patterns and directivity are evaluated by simulation.

2 Material and Methods

The printed antennas are fabricated using photolithography techniques, most of them are microstrip lines on planar or non-planar surfaces, and are embedded in mobile devices, or on the surface of satellite, aircrafts, missiles, etc. Microstrip lines radiate the fringing electromagnetic field between strip and ground plane. Different shapes and dimensions are used for microstrip antennas having following common resonator shapes: circular, elliptical, rectangular, and triangular or ring. In the last years, their study has done important progress because of their important and useful capabilities: low volume, light in weight low cost, smaller in dimensions, easy of fabrication, provide linear or circular polarizations, multi-frequency operation, frequency agility, omnidirectional patterning, beam scanning, etc.

To investigate the microwave antenna with many branches, a neuron dendritic tree model with an archetypical multipolar morphology, P44-DEV192 available at the NeuroMorpho.org [7] was selected, Fig. 1a. The branch lengths have been changed from μm to mm. The dielectric substrate has electric permittivity of 4, 4 mm as height, and strips have 3 mm width. The entire structure is embedded within a sphere, Fig. 1b. The sphere outer boundary of 20 mm is a perfect match layer, an artificial medium that omnidirectional absorbs incident waves with virtually no reflection, simulating an infinite space [7]. The feed point, a coaxial line, was put in the soma area, and the microstrip lines were excited by continuous waves with different frequencies.



(a) (b)

Fig. 1. The dendritic tree of P44 DEV - 192 (a) and the modeled microstrip network (b)

The process of selective frequency response of dendritic tree was noticed by several authors [8, 9]. They modeled dendrites with the Rall's cable theory [4, 5] and analyzed the neurophysiological process at the mono-dimensional level of cell membrane. The investigation of proposed antenna model uses Maxwell's equations which allows assessment of dendrite topology, can prove the existence of potentials evoked and selective transmitting of data in different cortical areas. Solving the electromagnetic field equations inside the sphere was made with Finite Difference Frequency – Domain FDFD method that is used widely in microwave circuit analysis [6]. In the frequency domain, partial differential equations that govern electromagnetic phenomena are:

$$rot(E(r,\omega)) = -i\omega\mu H(r,\omega) - M(r,\omega) \tag{1.1}$$

$$rot(H(r,\omega)) = i\omega\epsilon E(r,\omega) + J(r,\omega) \tag{1.2}$$

where E and H are the electric and magnetic fields; M and J are the magnetic and electric current source densities; ε and μ are the electric permittivity and magnetic permeability and ω is angular frequency. A system of linear equations is obtained after finite difference approximation in the Cartesian coordinate system.

The maximum radiation efficiency takes place at resonant frequencies, when the electromagnetic waves have the highest amplitudes. Therefore, the resonant frequencies should be evaluated before. As a result, in the first step, the eigenvalues (resonant frequencies) and eigenvectors (electromagnetic field components) were evaluated from the linear system equation. It should be noted that these eigenvectors will only show own the electromagnetic field distribution along the microstrip lines.

In the second step, for each resonant frequency, the electromagnetic field generated by microstrip line network has computed inside of sphere.

3 Simulation Results and Discussion

A lot of resonant frequencies were obtained as eigenvectors by solving the Maxwell's equations in frequency domain. In Fig. 2 is shown the first 26 resonant frequencies. The first, fundamental, resonant frequency is at 0.3644 GHz. There is no relation between the first and the following resonant frequencies. This is because these resonant frequencies appear as the action of different branches. They have a specific spatial distribution and different lengths.

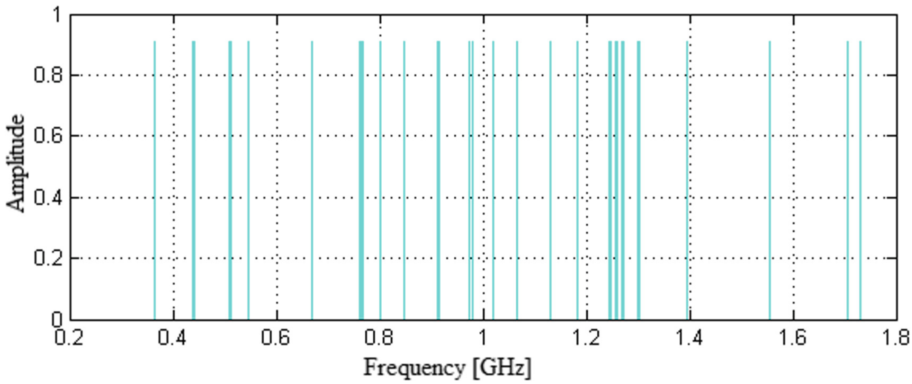
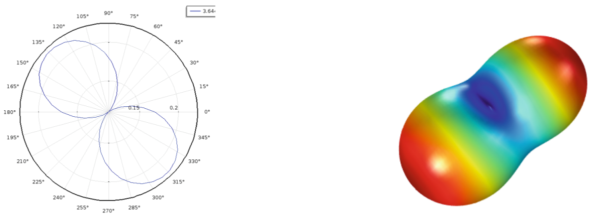


Fig. 2. The first 26 resonant frequencies for the simulated dendritic tree.

The field distribution in the plane situated at a half distance between central strip and ground plane is shown in Fig. 3. Figure 3a shows a suggestive image of the field distribution along the lines and around them, and b shows a 3D image of the field along the microstrip lines. Some lines are not excited and the maximum values are not the same at the other lines. This field distribution is the same as the voltage dipole distribution. This mode can be excited by the antenna feed point. Far field radiation is presented in Fig. 4. The antenna radiates electromagnetic energy in the microstrip plane, and the electric field is parallel to excited line axe.

(a) (b)

Fig. 3. Bi-dimensional (a) and tri-dimensional (b) field distribution for 0.3644 GHz

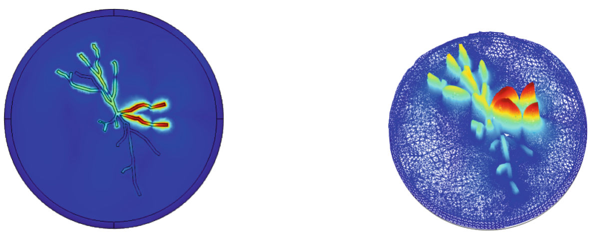


(a) (b)

Fig. 4. Bi-dimensional (a) and tri-dimensional (b) radiation pattern for 0.3644 GHz

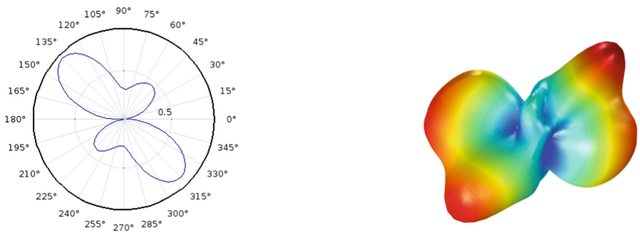
Up to 1.8 GHz, the radiation patterns look like the dipole pattern. Different lines or combination of them are excited. There is only one difference: the maximum radiation direction is moved in accordance to the direction of excited lines.

At the frequency of 1.8 GHz, the field distribution along the microstrip lines changes dramatically as it shown in Fig. 5a and b. More than one maximum value appears along line combination. As a result, the radiation pattern becomes larger, with more picks. The electromagnetic field appears in a plane perpendicular to the dielectric plane, as well, Fig. 6b.



(a) (b)

Fig. 5. Bi-dimensional (a) and tri-dimensional (b) field distribution for at 1.8 GHz



(a) (b)

Fig. 6. Bi-dimensional (a) and tri-dimensional (b) radiation pattern at 1.8 GHz

4 Conclusions

The new microstrip antenna bio-inspired by a real neuritis architecture have successfully demonstrated diversity in radiation patterns and multiband characteristics.

Neural field model is described by Maxwell's differential equations and emphases the role and importance of the dendrite topological structure for information processing at the neuron level.

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