Antenna Model for Myelinated Nerve Fiber

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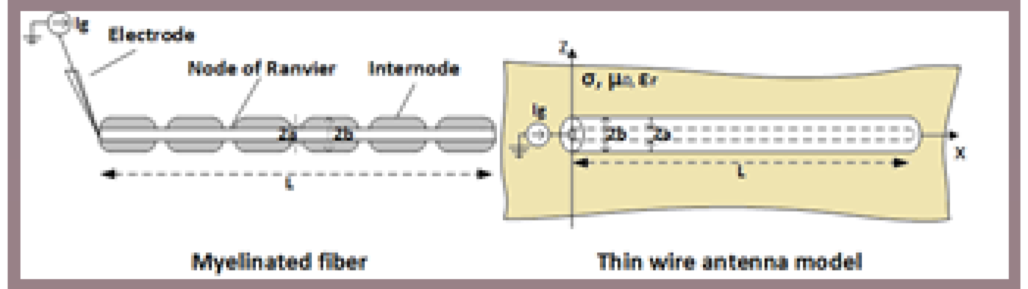
Introduction



- The myelinated nerve fiber with an arbitrary number of Ranvier's nodes is modeled as a straight thin wire antenna
- Electrode nerve fiber stimulation is taken into account in terms of the current generator I_g, placed at the fiber beginning
- The current generator I_g represents the nerve fiber stimulation by using the techniques of electro-acupuncture or percutaneous electrical nerve stimulation (PENS), which make use of thin needles inserted through the skin
- The fiber is immersed in the unbounded homogenous medium defined by conductivity σ, relative permittivity ε_r and permeability μ_0

Mathematical Model

- Current distribution along a straight thin wire is governed by Pocklington integro-differential equation in the frequency domain [1-3]:

$$-\frac{1}{j4\pi\omega\varepsilon_{eff}}\int_0^L\left(\frac{\partial^2}{\partial x^2}-\gamma^2\right)g(x,x')I_a(x')dx'=0$$

- g(x,x') - the lossy medium Green's function defined as:

$$g(x,x')=\frac{e^{-\gamma R}}{R}$$

- γ - the complex propagation constant given by:

$$\gamma=\sqrt{j\omega\mu\sigma-\omega^2\mu\varepsilon_0\varepsilon_r}$$

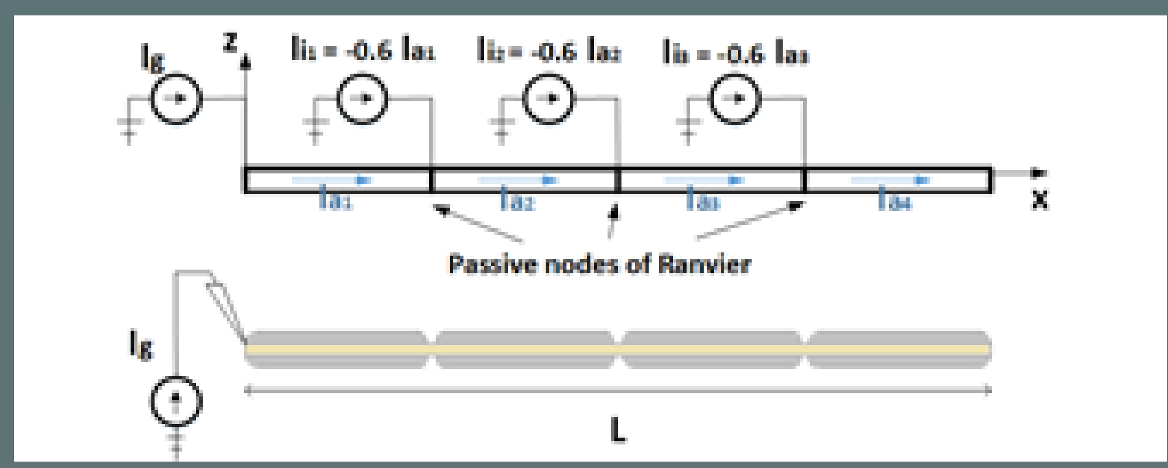
- R - a distance from the source to the observation point:

$$R=\sqrt{(x-x')^2+a^2}$$

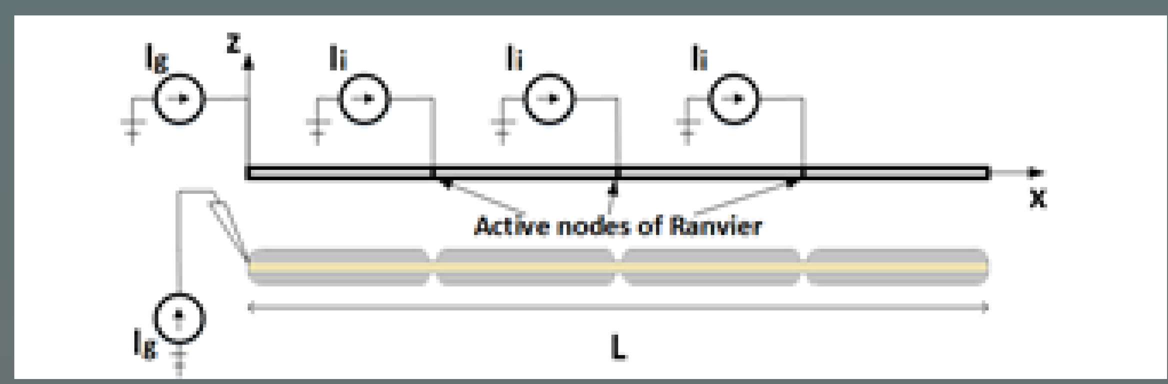
- ε_{eff} - the complex permittivity of a medium:

$$\varepsilon_{eff}=\varepsilon_0\varepsilon_r-j\frac{\sigma}{\omega}$$

Passive nerve fiber

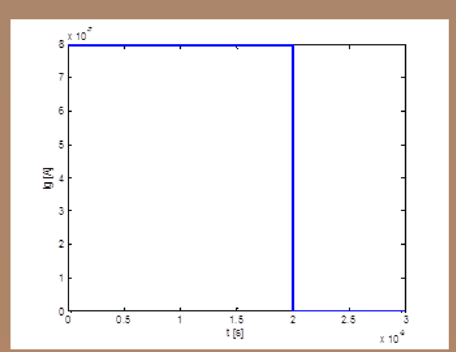


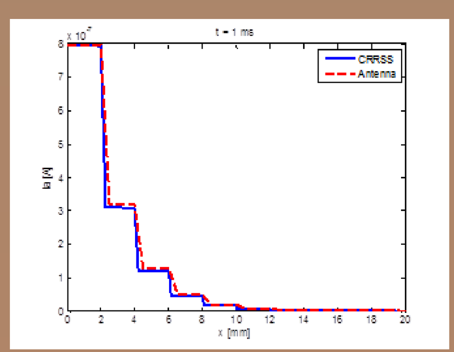
Active nerve fiber

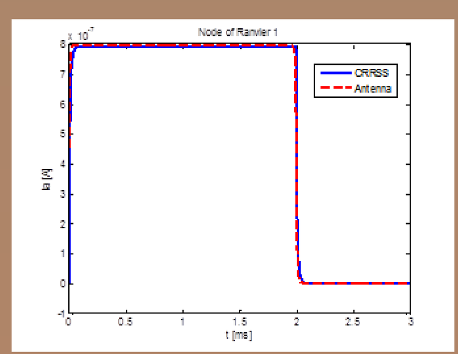


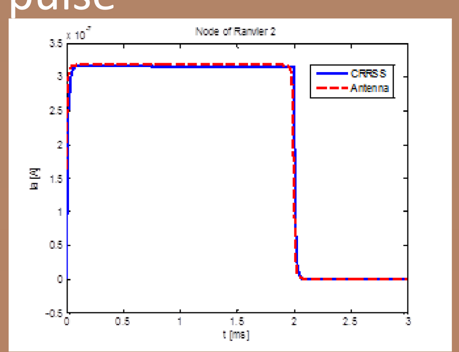
Results

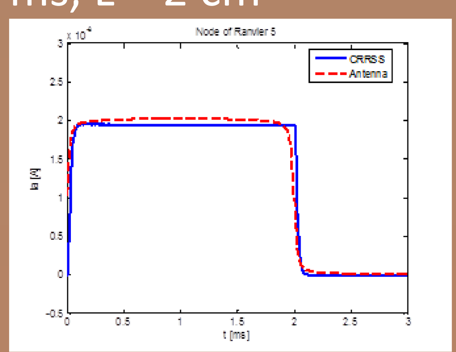
Passive nerve fiber

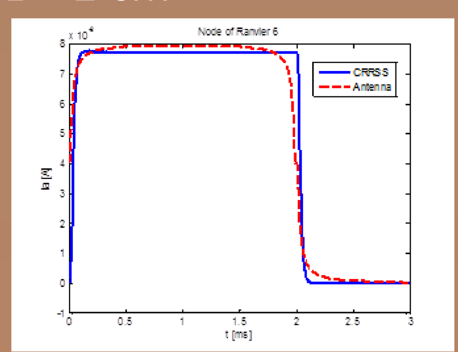

Rectangular subthreshold current pulse


Intracellular current along the fiber, t = 1 ms, L = 2 cm

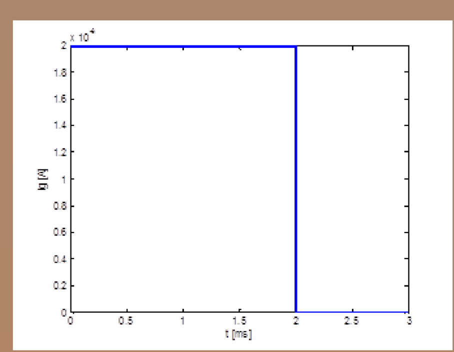

Intracellular current in the Ranvier's node 1, L = 2 cm

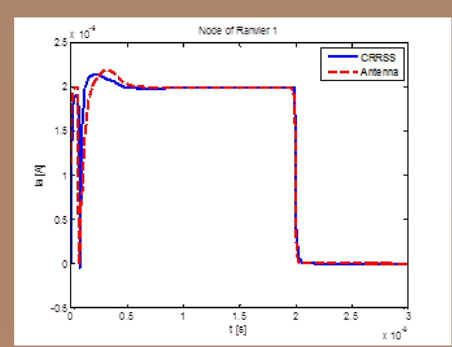

Intracellular current in the Ranvier's node 2, L = 2 cm

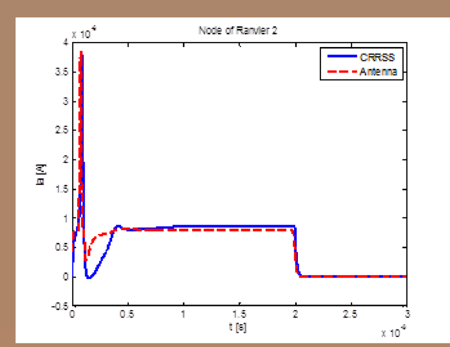

Intracellular current in the Ranvier's node 5, L = 2 cm

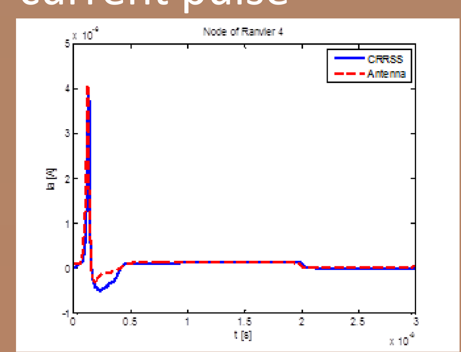

Intracellular current in the Ranvier's node 6, L = 2 cm

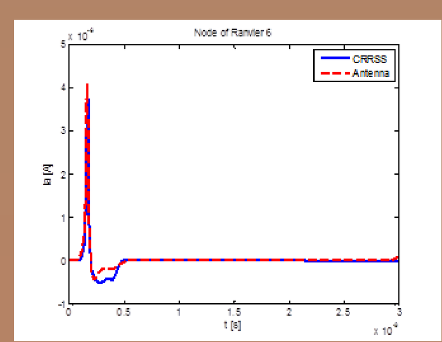
Active nerve fiber

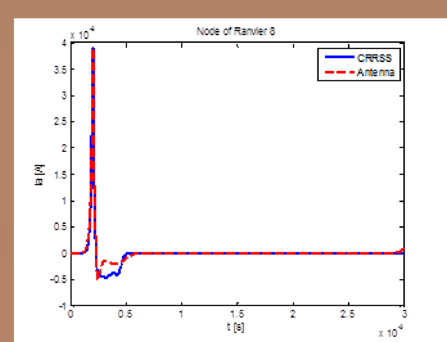

Rectangular superthreshold current pulse


Intracellular current in the Ranvier's node 1, L = 2 cm


Intracellular current in the Ranvier's node 2, L = 2 cm


Intracellular current in the Ranvier's node 4, L = 2 cm


Intracellular current in the Ranvier's node 6, L = 2 cm


Intracellular current in the Ranvier's node 8, L = 2 cm

Conclusions

- The myelinated nerve fiber is modeled as a perfectly conducting straight thin wire antenna, immersed in an unbounded homogenous medium
- The model is based on the corresponding Pocklington integro-differential equation in the frequency domain, solved by means of the GB-IBEM
- The solution of the corresponding Pocklington equation is related to the intracellular current along the nerve fiber I_a, which is for all cases compared to the CRRSS model intracellular current results [4-6]
- **The passive Ranvier's node** is modeled by a current source drain representing the ionic current I_i in each passive node (responses show a rather satisfactory agreement to the CRRSS model)
- **The active Ranvier's node** is modeled as a thin wire junction with the additional current source, representing the ionic current of the activated node (the results display minor discrepancies in relation to the CRRSS model which stem from the approximate modeling of an active state in which the additional current source should represent all the biological effects occurring during the fiber activation)
- The antenna nerve fiber model of a myelinated nerve fiber can provide a theoretical framework for studying a wide variety of stimulus parameters, including wave shape and the amplitude of the excitation pulse
- Thus, the model can be beneficial and versatile tool for interpreting experimental results and studying variables for which there could be difficulties in the laboratory implementation

References

[1]D. Poljak, Advanced Modeling in Computational Electromagnetic Compatibility, New Jersey: Wiley-Interscience, 2007.

[2]D. Poljak, "New numerical approach in the analysis of a thin wire radiating over a lossy half-space", Int. J. Numer. Methods Eng., vol. 38, no. 22, pp. 3803–3816, 1995.

[3]D. Cerdic, "Advanced Transient Analysis of Complex Grounding Systems", Master Thesis, University of Wales, Wessex Institute of Technology, 2008.

[4]S. Y. Chiu, J. M. Ritchie, R. B. Rogart, and D. Stagg, "A quantitative description of membrane currents in rabbit myelinated nerve", J. Physiol., vol. 292, pp. 149–166, 1979.

[5]J. D. Sweeney, J. T. Mortimer, and D. Durand, "Modeling of mammalian myelinated nerve for functional neuromuscular electrostimulation", Proc 9th Ann Conf IEEE EMBS, pp. 1577–1578, 1987.

[6]W. Rall: "Core Conductor Theory and Cable Properties of Neurons", in Comprehensive Physiology, R. Terjung, Ed. Hoboken, NJ, USA: John Wiley & Sons, 2011.

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