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# Temporal Interference Modeling Error using Purely Conductive Medium Approximation

Gabriel Gaugain<sup>1</sup>, Julien Modolo<sup>2</sup>, and Denys Nikolayev<sup>1</sup>

**Abstract**—This study quantifies the error of electric field computation for temporal interference brain stimulation modeling using purely ohmic medium (brain tissues are represented by real conductivity) over general dielectric medium (complex conductivity). The results show a relative error up to 68% depending on the value of permittivity.

**Clinical Relevance**—These results demonstrate the need of reliable dielectric properties measurements of living tissues to accurately model the temporal interference.

## I. INTRODUCTION

Temporal Interference (TI) is a recent development in the field of non-invasive deep brain stimulation [1]. It provides the possibility to achieve stimulation of deep brain structures with scalp electrodes. Setups involving slightly different frequencies (a few Hz) in the kHz range are currently used to induce interference patterns in deep brain regions with the goal to produce beatings at this low frequency. Here, we discuss the limitations of static approximation in the numerical modelling of electric field in the brain and quantify the induced errors of purely ohmic medium by comparing it with the more general case of complex dielectric properties of tissues.

## II. METHODS

TI is commonly modelled by solving the Laplace's equation on a numerical model of the head considering only the real conductivity  $\sigma$  of brain tissues according to the quasi-static approximation [2]. However, the tissues exhibit high relative permittivity  $\epsilon_r$  at low frequencies (up to  $\sim 10^7$ ) [3], which could substantially impact simulation accuracy [4]. Taking into account the contribution of  $\epsilon_r$ , the Laplace equation becomes:

$$\nabla \cdot (\sigma + j\omega\epsilon_r\epsilon_0) \nabla V = 0,$$

with  $\epsilon_0$  the vacuum permittivity,  $\omega$  the angular frequency, and  $V$  the electric potential. This equation was solved over a head model using COMSOL (COMSOL Inc., MA, USA) at 1 kHz and 1.01 kHz for the two pairs of electrodes P7-FT7 and P8-FT8. Two set of conductivities were used, one being the set of data provided by [3] and the other from [5] considering two values of  $\epsilon_r$  for brain tissues:  $10^5$  and  $10^7$ .

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## III. RESULTS

The relative error of purely ohmic medium assumption over the generalized case of capacitive contribution was higher using properties with a brain relative permittivity of  $10^7$  [5] where it reaches 68% (Fig. 1a). The error was only 3.38% if the value of  $10^5$  was used instead (Fig. 1b). The dielectric values reported in [3] exhibited a distribution of relative error with 99<sup>th</sup> quantile at 10.5% (Fig. 1a).

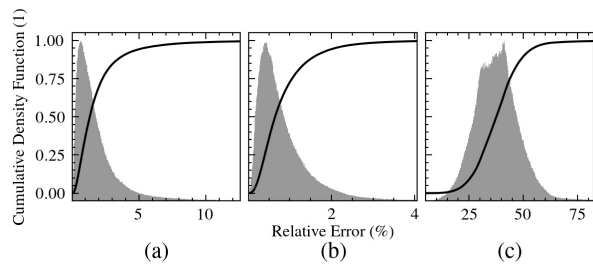


Figure 1. Relative error distributions and associated cumulative density function for (a) dielectric data reported in [3] as well as data in [5] with (b)  $\epsilon_r = 10^5$  and (c)  $\epsilon_r = 10^7$ .

## IV. DISCUSSION & CONCLUSION

The results presented here quantify the relative computational error of TI analysis assuming a purely ohmic medium as a function of the brain dielectric properties within the range reported in [3], [5]. Let us emphasize that reliable low-frequency dielectric data are needed for accurate modeling of TI. Finally, the capacitive properties should be taken into account in the numerical model given the low added computational cost as compared to the purely ohmic medium assumption.

## REFERENCES

- [1] N. Grossman *et al.*, "Noninvasive deep brain stimulation via temporally interfering electric fields," *Cell*, vol. 169, no. 6, pp. 1029–1041, Jun. 2017.
- [2] R. Plonsey and D. Heppner, "Considerations of quasi-stationarity in electrophysiological systems," *Bull. Math. Biol.*, vol. 29, no. 4, pp. 657–664, Dec. 1967.
- [3] S. Gabriel, R. Lau, and C. Gabriel, "The dielectric properties of biological tissues: II. Measurements in the frequency range 10 Hz to 20 GHz," *Phys. Med. Biol.*, vol. 41, no. 11, pp. 2251–2269, Nov. 1996.
- [4] G. Gaugain, L. Quéguiner, R. Sauleau, M. Zhadobov, J. Modolo, and D. Nikolayev, "Quasi-static approximation error of electric field analysis for transcranial current stimulation," arXiv:2204.03555 [physics], Apr. 2022.
- [5] T. Wagner *et al.*, "Three-dimensional head model simulation of transcranial magnetic stimulation," *IEEE Trans. Biomed. Eng.*, vol. 51, no. 9, pp. 1586–1598, Sep. 2004.