Simulation-improved Transducer Design for Non-invasive, Focused Brain Stimulation

A. De Angelis(1), M. Leonetti(1,2), M. Liberti (1,3), F. Apollonio(1,3), S.M. Aglioti(1,4,5) and G. Ruocco(1,6)

(1) Center for Life Nano Science@Sapienza, Istituto Italiano di Tecnologia, Rome, Italy; e-mail: annalisa.deangelis@iit.it, e-mail: marco.leonetti@iit.it, e-mail: salvatore.aglioti@iit.it, e-mail: giancarlo.ruocco@iit.it
(2) CNR NANOTEC-Institute of Nanotechnology, Soft and Living Matter Lab, Rome, Italy;
(3) Department of Information Engineering, Electronics and Telecommunications, Sapienza University of Rome, Italy; e-mail: francesca.apollonio@uniroma1.it, e-mail: micaela.liberti@uniroma1.it
(4) Department of Psychology, Sapienza University of Rome, Italy; e-mail: salvatoremaria.aglioti@uniroma1.it
(5) Fondazione Santa Lucia, IRCCS, Rome, e-mail: sm.aglioti@hsantalucia.it
(6) Department of Physics, Sapienza University of Rome, Italy; e-mail: giancarlo.ruocco@uniroma1.it

Focused Ultrasound Stimulation (FUS) is an emerging, non-invasive, focal and ultra-selective brain stimulation technique. Neurosurgical applications indicate that ablative use of ultrasounds can help to treat patients with movement disorders [1] like Parkinson’s disease [2], brain tumors [3], and neuropatic pain [4]. Importantly, non-invasive FUS has recently proven effective in modulating neuronal activity by acting on the mechanosensitive ion channels [5]. Despite the FUS’ spatial selectivity (in the order of millimeters) is much better with respect to that of widely used, non-invasive transcranial magnetic stimulation (TMS) (in the order of centimeters), a major challenge is represented by the accurate choice and design of the stimulator as it has to be capable to efficiently deliver the acoustic wave to selectively target a specific brain region, despite the major obstacle to FUS represented by the skull. Indeed, the strong difference of the sound speed in the skull and the surrounding soft tissues contribute to the high acoustic impedance mismatch at the skin/bone and bone/dura mater interfaces, as well as the heterogeneous bone structure (lateral tables are dense, central diploe is porous), causing severe loss of acoustic energy, distortion of the propagating beam and a consequent shift of the stimulation focus [6]. The transcranial transmission of the ultrasound beam could be improved by introducing an ad hoc device characterized by transducers with specific aperture, numbers of active elements and control of amplitude and phase of each element that optimize the energy deposition on the focal region, ultimately decreasing the dispersion on the scalp and the skull surfaces.

In this study we implement a full-wave realistic numerical modelling that allows for a robust prediction of the transducer application performance. Our approach could represent a valid and feasible manner to select a cost-effective transducer design based on the degree to which the skull-induced aberrations could be corrected and the beam steered given a specific element count and geometry.

References