

Dual-Frequency Wireless Power Transfer with Metasurfaces for Targeted Retinal Stimulation

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This work presents a novel wireless power transfer (WPT) system for retinal therapies, which employs metasurfaces capable to significantly improve power transfer efficiency (PTE) and to allow a locally targeted stimulation. The system is designed to be used in therapeutic applications for retinal degenerative diseases, by delivering non-invasive, patient-specific electromagnetic stimulation with a dual-frequency WPT configuration. Previous studies have shown that integrating metasurfaces within WPT systems improves power transfer efficiency by optimizing the spatial distribution of the magnetic field and mitigating the effects of misalignment between transmitting and receiving coils (Lazzoni, V., Brizi, D. & Monorchio, A. “Spatial filtering magnetic metasurface for misalignment robustness enhancement in wireless power transfer applications”. *Sci Rep*13, 560. 2023.). By relying upon this study, our work applies the metasurface concept to retinal therapy, providing a customized system to meet the specific needs of therapeutic electrical stimulation.

In detail, the proposed system consists of glasses whose lenses are equipped with two planar spiral transmitting coils operating at $f_1=2.5$ and $f_2=6$ MHz, respectively. The transmitting coils are designed to show the size of a typical eyeglass lens. A dual-layer 5×5 metasurface, with dimensions comparable to the TX coils, is placed in between the lens and the patient eye. Conversely, on the eye side, two concentric resonant coils acting as receivers are integrated into a passive contact lens that fits over the sclera while leaving the iris uncovered to preserve vision. The receivers are tuned to the two transmitters operating frequencies, f_1 and f_2 , thus they can exchange energy in an independent manner resulting in a dual-frequency WPT system. The dual-frequency independent operation can be extremely advantageous in retina stimulation, since the two receivers can deliver the collected energy towards separate electrodes positioned in the right and left retina regions, respectively. Thus, it is possible to stimulate both the regions while also select the clinically relevant portion through frequency coding. Numerical simulations showed a significant improvement in PTE when the dual-layer metasurface is incorporated. At f_1 , PTE increased from 4% to 5% and at f_2 from 38% to 46%, compared to a configuration without metasurfaces. These improvements show the advantages of metasurfaces in increasing performance while maintaining accurate targeting.

To conclude, the proposed metasurface-enhanced WPT system demonstrated an improvement in the PTE for neurostimulation of the retina. By encoding power transfer at different frequencies, selective activation occurs, leading to independent stimulation of specific retinal regions. The planar geometry of the receivers remains a challenge as it does not fully conform to the spherical shape of the eye. Future work will focus on the development of anatomically optimized geometries and refinement of the system to ensure minimal invasiveness (particularly for receiver components). The combination of increased efficiency and fine control underlines how metasurfaces can bridge the gap between engineering innovations and therapeutic advances in retinal treatments.