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Intelligent Remote Powering System With PTE Auto-Balancing For a Wireless and Batteryless EEG Cap

M. SharafiMasouleh, M. Sajedi, and M. Adjouadi

Center for Advanced Technology and Education
Department of Electrical and Computer Engineering
Florida International University, Miami, Florida, USA
(Mshar052@fiu.edu and adjouadi@fiu.edu)

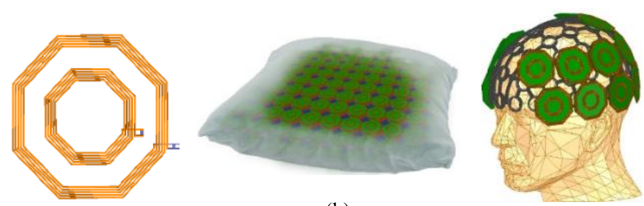
***Abstract*—** This work presents a fully battery-less and wireless (untethered) EEG readout cap. The powering system is equipped with a highly efficient and compact power transmitter mosaicked by an array of 8×11 Tx resonators in a certain pattern operating at the lowest ISM band of 6.78 MHz. The front-end's power receiver block Rx includes multi-resonators mounted all-around an EEG cap that can be worn by a subject. Furthermore, considering the subject's head which could assume different positions, a well-designed positioning system and an intelligent feeding setup are developed to balance the efficiency drop due to misalignment and to involve the most associated resonators with the powering scenario with the potential of switching off the extraneous resonators that are not engaged with Transmit and Receive (Tx-Rx) power.

I. INTRODUCTION

In recent years, remote powering has raised the interest of certain complex domains of research and innovations, such as wearable and implantable biomedical systems for neuromuscular stimulation and neural recording. For long-term operations with better resolution, lightweight wearable devices should have the potential to be remotely powered. The use of wires and cables for powering and for data recording and transmission restricts the movement of test participants and makes them tethered and uncomfortable. The first solution that comes to mind is to develop a wireless EEG cap, with a battery as a source of energy to power up the front-end's electronics. However, batteries have a short lifespan and may leak heavy metals, resulting in serious health hazards. So due to safety measures and considering the weight and limited level of power, utilizing a replaceable energy source such as a battery is not a viable option for long-term bio-signal monitoring or stimulation. On the other hand, wireless power transmission has shown to be a feasible approach for maintaining power without the need to replace the battery [1]. Wireless power transmission (WPT) enables us to provide an adequate power level to the load for an extended period while maintaining safety. Particularly the use of more electrodes on the EEG cap to improve spatial resolution is feasible using WPT. However, the power transfer efficiency is quite low in many reported experiments, particularly those that are linked through inductive coupling [2]. To ensure the functionality of the front-end unit under any circumstance, at least the minimum level of required energy must be delivered to the Rx resonator. So, the Tx resonator must operate at maximum capacity to ensure the setup function flawlessly. This matter may be achieved by using multiple resonators to make up an array of them on either side of the powering link through a non-radiating method called Resonance inductive coupling. For optimal power transfer efficiency with an acceptable power level that can be delivered to load, a highly efficient multi-Tx–Rx resonance-inductive link is newly developed in this proposed setup.

II. POWERING PILLOW AND EEG CAP

Because we intend to establish a power and data link to monitor EEG signals when a person lays his head on a pillow, power must be continually provided to the worn EEG cap based on the subject's head location and pillow position. If the powering Tx and wearable Rx resonators are misaligned too much, the wireless power transfer efficiency drops drastically, and the front-end electronics won't be able to work properly. After examining various conditions, an appropriate remote powering system is designed as shown in Figure 1.



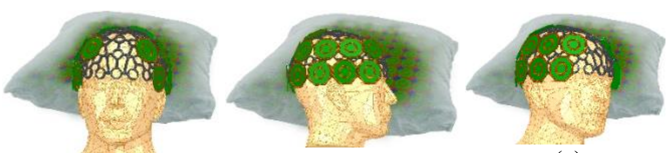
(a) (b) (c)

Figure1. (a) Resonator Structure (b) an array of Tx power transmitter resonators embedded in the pillow and (c) an array of Rx power receiver resonators placed around the EEG cap

The shape of the resonator itself has a significant influence on power transfer efficiency. The Tx-Rx powering link operates at 6.48 MHz and is made up of an optimized octagonal spiral resonator, as shown in figure 1 (a). On one end of the power link, an array of Tx resonators embedded into a pillow serves as a power source, while Rx multi resonators of the same size put around the EEG cap serve as power receivers. Due to the specific structure of the proposed EEG cap and the design limitations imposed by the testbed, octagonal shape resonators are preferred. Even though the angular bends in the edges of octagonal resonators collect electrons and increase parasitic resistance, the overall design is preferable to the other configurations. For example, about the rectangular spiral shape, the angle is sharper than octagonal, and that dramatically increases the parasitic resistance effect, whereas the circular spiral resonator cannot provide the desired calculated length L within the limited predefined size, so the size of the resonator would undoubtedly be larger. Furthermore, most configurations have dead zones on the substrate edges where no power is delivered, which may give the suggested EEG cap an unfavorable shape and act as a barrier when the person rolls his head. For the testbed, considering the standard size of the pillow (51×66×6 cm^3) used and considering an individual's head position, at least a 6 cm space must be set between the Tx-Rx resonators.

III. ANALYSIS OF ALIGNMENT OF PROPOSED POWERING LINK

As shown in Figure 2, two significant displacement scenarios alter the interaction between the resonators and drastically affect the power transfer efficiency. However, from Figure 3, the negative impacts of misalignment can be compensated by the proposed Multi Tx-Rx resonators arrangement. The first type of misalignment might happen when the subject's head deviates by an angle α. In consequence, the Rx resonators on the EEG cap become misaligned with the Tx resonators positioned under the pillow. In this situation, called angular misalignment, the efficiency drops drastically when the powering system comprises two Tx-Rx resonators, but this efficiency drop can be compensated with our proposed multi resonator system. For lateral or diagonal displacement, the Rx resonator is moved by an offset distance d in respect to the Tx resonator's axis. Considering the clinical situation [3], since the subject spends 90% of their testing time sleeping on the Tx powering pillow, lateral misalignment is not the primary source of power efficiency drop utilizing our proposed EEG cap and can be neglected. However, angular misalignment may offer a barrier for our design because of patients' tendency to turn their heads to the right or to the left side while sleeping.



(a) (b) (c)

Figure 2. (a) good alignment (b) angular misalignment (c) lateral and angular misalignment

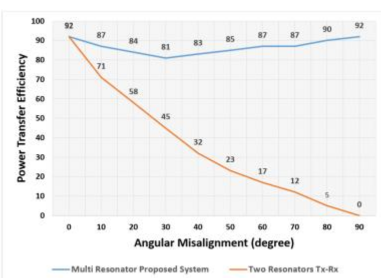


Figure 3. angular misalignment versus normalized power transfer efficiency

The simulated power transfer efficiency for several different misalignment conditions as shown in Figure 3. Under the perfect alignment situation, the power transfer efficiency is 92%, but when Rx gets misaligned, the efficiency drops drastically in the Two Tx-Rx resonators system, while the proposed multi-resonator system maintains its efficiency above the 80% power transfer efficiency.

IV. INTELLIGENT REMOTE POWERING

By expanding the number of resonators, better homogeneous spatial distribution can be achieved, which eliminates position-dependent power transmission efficiency. Yet, as the number of resonators grows, the system may require more power. To address this issue, by placing a permanent magnet on specific locations between the Tx resonator and putting Hall-effect sensors on the EEG cap, an intelligent feeding system can be used to feed just the linked resonators in Tx sides. This setup requires a feedback system to adjust the power level of the source. Figure 4 depicts an array of resonators regulated by a feedback system and supplied by an intelligent feeding mechanism. The total energy usage of the system is reduced through the feedback loop, which involves the most probable resonator among the others with a powering scenario based on the subject's head position and the powering pillow. Using this system at maximum, only four resonators in the array would be powered up, and the remaining resonators would be turned off as the subject's head deviates from the normal position.

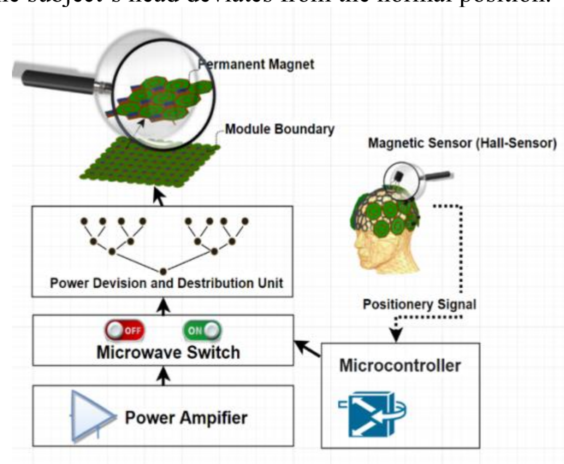


Figure 4. Intelligent positioning and feeding system

V. CONCLUSION

A wireless misalignment-resistant powering system for a portable wireless EEG recording cap is proposed. This design can be used for the wireless recording of EEG data. A design that can also be used as an ambulatory device, or as a fast-diagnostic tool for assessing brain signals and related connectivity patterns pre and post treatment. This setup helps to increase safety precautions and reduce the negative impact of excessive magnetic field exposure in a remotely powered EEG cap. The proposed setup reduces the negative impact of angular and lateral misalignment and maintains the power link's PTE above 80% as the results indicate.

ACKNOWLEDGMENTS

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VI. REFERENCES

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