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# Highly Efficient Power Transmission-Conversion Chain For a Wireless and Battery-Free EEG Cap

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***Abstract*— The goal of this study is to introduce practical state-of-the-art considerations for designing a highly efficient power generation, transmission, and conversion chain system, PGTCC, to power up the front-end's electronics that acquire satisfactory EEG signal acquisition in a portable wireless and battery-free EEG cap. Several solutions, strategies, and unique configurations have been presented to reach this goal, including, a highly efficient and compact resonance-inductive link, multi-resonator power transfer, use of magnetized materials to improve power transmission efficiency, closed-loop power transmission, and a highly efficient power conversion chain. The proposed design has the potential to significantly improve the total efficiency and supply stable power for the front-end units that include the EEG signal, filtering, noise cancelation amplification units, processing units, and transceivers.**

## I. INTRODUCTION

Wearable and implantable devices require energy sources to perform their intended tasks. It is a significant operational difficulty to power up biomedical wearable systems without batteries or cables. Various power-up alternatives have already been reported in the literature, such as external or embedded batteries and wiring techniques, but they all are very limited in terms of energy density, portability, individual comfort, device lifetime and potential dangers to human safety, among others. In addition, some of these approaches are prone to noise effects in the captured EEG signal. As a result, procuring enough energy to power up the front-end units remains a challenge. In the case of implantable EEG recording systems, the use of transcutaneous wires or powering cables for power delivery is not recommended since it might expose the patient to health hazards as well as restrict the patient's movement [1]. Wireless power transmission (WPT) has proven to be a feasible approach for maintaining power without the need to replace batteries. removing the battery from a portable EEG recording system has another advantage and that is delivering adequate and stable power while keeping safety in mind. Using this approach allows for additional electrodes on the EEG cap to have better spatial resolution with less crosstalk. Hence, devices using wireless power transfer are increasingly being utilized for this purpose [2].

## II. SPECIFICATIONS OF CONFORMAL RESONATOR

Remotely powering biomedical wearable gadgets has many benefits that are now being researched [3]. Resonance-inductive coupling is at the heart of today's wireless power transfer technology. That is why improving WPT efficacy necessitates improving resonance-inductive coupling effectiveness. Planar spiral resonators (PSRs) are often utilized in wearable applications for inductive or resonance-inductive coupling because certain spiral topologies allow to have the length of the needed track to provide the calculated inductance while being easily designed and fabricated. Several parameters should be evaluated to determine which shape of the resonance-inductive power transfer link is suitable for the target application. The resonator size is the factor that is defined based on application; however, the most important parameters include the amount of power delivered to the load PDL, driver output resistance (Rs), source voltage (Vs), nominal coupling distance ($d_{23}$), and misalignments tolerance. Because our suggested powering setup is expected to run at 6.68MHz, the length of tracks will be relatively long, and the single loop will not be able to match the other design constraints. As a result, the spiral design allows for resonator size reduction. The overlapping and non-overlapping octagonal forms were designed on 1.5 mm thick FR4 printed circuit boards (PCBs) with copper 35.6 μm in thickness. The 2-loop resonator represented in Figure 1 is used to achieve high PTE as well as adequate PDL. This can be done by improving $k_{34}$ which is the coupling coefficient between the outer loop of Tx and Rx resonator to convert any given $R_L$ into the ideal resistance required in the $L_2$-$L_3$ resonance inductive link. The circuit's power transfer efficiency can be calculated by reflecting the resistive components of each loop from the load towards the primary resonator loop.

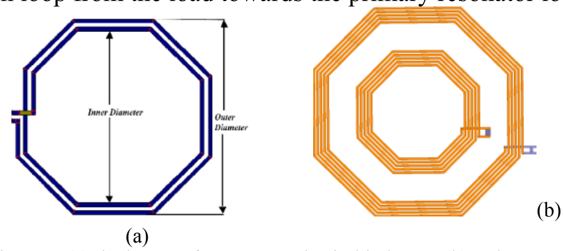


Figure 1. (a) the layout of an octagonal spiral inductor, (b) 2 -loops octagonal resonators

The configuration of a square spiral inductor resonating at 6.78MHz is shown in Figure. 1 with the following parameters: N=5 is the number of turns, W=0.6 mm is the width of the track, S=0.4mm is the allocated spacing, $d_{out}$=60mm is the outer diameter, and din=28mm is the interior most diameter and 170 pF is the resonance capacitor. The biggest power loss happens in the Tx-Rx link due to parasitic resistance; thus, if the link is designed in a highly efficient way, the overall efficiency of the system will increase. Figure 2 shows the suggested link power efficiency which offered 92% PTE with 6 cm coupling distance.

## III. PTE ENHANCEMENT USING MAGNETIZED STRIPS

The proposed setup is supposed to be used as a power transmission and conversion chain for a wireless and battery free-EEG cap. The final design includes a testbed with an array of Tx resonators embedded in a pillow on which the subject being tested may lay his head. The pillow height should be between 5cm and 10cm, based on the standard pillow size. Within a 6cm distance between the resonators, the power transmission efficiency is 95%, as shown in figure 2. However, to keep the PTE above 90% at distances more than than 6 cm, ferrite materials with a specific structural design located between the loops or at the back of the octagonal substrate aid the powering resonator Tx, to intense magnetic field into the coupling channel and guiding the radiation in a specific direction, which this results in significantly increased resonance inductive coupling. The ferrite material may magnetize itself and modify the spatial distribution of the magnetic field as long as the operating frequency is less than the ferrite's hysteresis response. As a result, increase in the mutual inductance between the two resonators with the ferrite strips can be to confirm the coupling enhancement.

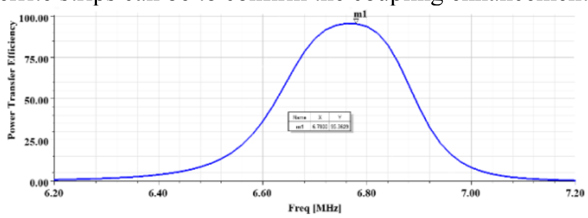


Figure 2. Power transmission efficiency of the proposed 4-loops Tx-Rx link operating in 6.78MHz

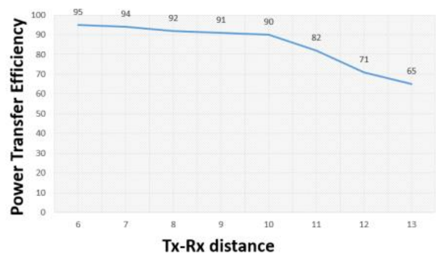


Figure 3. Power transmission efficiency of the proposed 4-loops Tx-Rx link equipped with magnetized strip in the distances above the 6 cm.

## IV. Power Generation, transmission, and Conversion

The suggested wireless and battery-free readout system's powering chain is made up of two independent parts which are coupled to each other by powering link. The powering back-end is connected to the Tx resonators, while the powering front end is attached to the RX resonator. As seen in Figure 4, the operational characteristics of a DC voltage source followed by a voltage control filter can be adjusted by an input control voltage. The power is generated by the AC power supply unit, and then gets boosted by a Class-E power amplifier, which is linked to a matching network between a source and a Tx resonator. The matching network circuitries are often designed to transfer nearly all generated power from the source to the Tx resonator while having an input impedance equal to the complex conjugate of the source's output impedance. All these components work together to drive the TX resonator. The power conversion chain units in the front-end, on the other hand, receive the transmitted power from the Tx to Rx resonator to provide a stable and reliable voltage level for the front-end's succeeding components, which include particularly voltage-sensitive ICs, as shown in Figure.5. A network of Rx resonators which are placed in a specific order around the proposed EEG cap, a full-wave active rectifier that supplies the DC voltage, several low drops out voltage-regulators that provide the stable DC voltage levels for different units, and a power management unit that includes a command generator and command modulator that controls the front-end's power level are the subsystems of the front-end's power transmission and conversion chain.

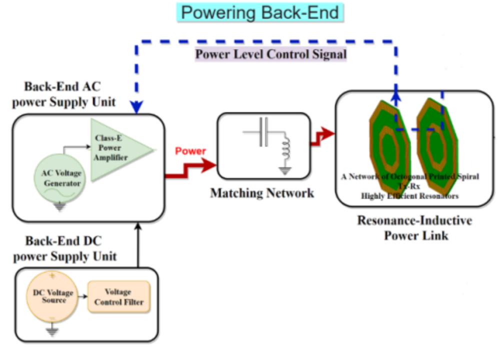


Figure.4 Schematic of back-end powering units

Power level control signal contains information about the required power level which must be transmitted from powering back end to the front end. Since this system is designed in a way to allow more channels to be added to the EEG recording procedure if more spatial resolution is required, the required power level signal is transmitted from the same power link to the powering back end. In addition, foreign object detection signal or excessive current usage will be reported immediately through the powering link to the back end to decrease the power level or turn off the entire front-end system.

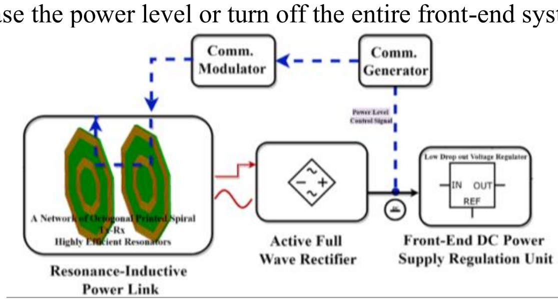


Figure 5. front-end power transmission-conversion chain units

## V. Conclusion

There are significant elements that need to be examined to increase the performance of the powering link. Effective power transmission to the front-end electronics is possible just a unique interconnection in between the different modules in the front and back ends. A high-efficiency Tx-Rx link has a significant impact on the overall efficiency of the powering system. Many techniques in this research are developed to improve the quality and efficiency of the powering system to be utilized as the power source for a wireless and battery-free EEG cap.


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