Broadband Resonant Wireless Power Transfer Using a Metamaterial Resonator Embedded with Non-foster Impedance Circuitry

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Wireless and wearable implantable biomedical devices are ushering in a new paradigm in health care and medicine with potential to improve health outcomes at reduced cost and improved quality of life. Magneto-inductive telemetry is widely used for wireless power and data transfer. The typical inductive telemetry core consists of a pair of antenna/coils placed coaxially in space, one inside the device and one placed externally as part of the reader/interrogator. The external coil typically transmits data, which is also harvested for its power and regulated to power up the implant circuitry. One of the most important design criteria is to maximize the coupling between external and implanted coil.

Recently, there has been an effort utilizing metamaterials for improved wireless energy transfer. Split Ring Resonator (SRR) forms the basis of many metamaterial structures and has been studied extensively in the literature. SRR can exhibit a strong magnetic resonance to EM wave with high quality factor (Q) at resonance. This makes it an excellent candidate for near-field resonant power/data transfer. The SRR also enables sub-wavelength focusing of the incident energy at resonance in the capacitive gap of the metamaterial which could be harvested for energy/power. Compared to conventional antenna/coil system for power telemetry, SRR provides a compact and low profile geometry due to an integrated antenna and resonator function built into the structure.

Coupled Mode Theory (CMT) predicts that when the resonances of both coils are matched, under the condition of the "strongly coupled regime", it results in maximal energy transfer between coils. However, if the resonance of either of coils deviates from one another, the power transfer efficiency drops sharply. Since the biological environment is expected to vary due to physiological changes, it is very hard to match their resonances. This issue will be exacerbated for any metamaterial-based energy harvesters due to their sharp narrowband resonance. In this paper, we propose an embedding of a non-foster impedance circuitry inside the SRR metamaterial to achieve optimal power transfer over a broadband condition without the need for any tuning.

Briefly, the approach relies on overcoming the well-known Foster's reactance theorem, which states that the reactance for both passive inductor and capacitor increases with frequency. In contrast, the non-foster elements are essentially negative inductors and capacitors that exhibit negative slope of reactance, which can be realized by active negative impedance converters (NICs). We employ this non-foster impedance matching to a single split ring resonator on the implant side for power telemetry. This guarantees a "strongly coupled regime" over a broad frequency range overcoming the narrowband limitation of SRR resonator antenna. We present detailed numerical simulation results, and the design of such an SRR antenna for the implant (a conventional wound coil is used for an external antenna). The SRR antenna is designed for self-resonance of 500 MHz and contains a non-foster circuitry embedded within its structure. Experimental results are also presented for a prototype agrees with numerical results. We show that the power transfer between SRR receive antenna and the external transmit loop antenna is broadened by almost 400 MHz which corresponds to increase in $\Delta f/f_C$ from 0.49 to 1.65, before and after non-foster circuit activation.