Multi-band Wireless Power Transfer via Resonance Magnetic

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***Abstract*— The wireless power transfer (WPT) efficiency of the multi-band system based on strongly coupled magnetic resonance (SCMR) is studied here. The efficiency of the system depends on the coupling and Q-factor of the system elements. This paper shows that the multi-band SCMR system, which has potentials in wireless power and data transfer.**

I. INTRODUCTION

Wireless Power Transfer (WPT) achieved via magnetically coupled resonators is presently drawing significant attention. WPT has been achieved using near-field coupling in several applications such as, RFID tags, telemetry activities and medical implants [1], [2]. Some inductive coupling techniques have been shown with high transfer efficiencies for very short distances (1-3 cm) [3]. However, the efficiency of such techniques drops drastically for longer distance since it decays as $1/r^6$ [4], [5].

This paper focuses on the design of wireless powering systems based on the strongly coupled magnetic resonance (SCMR) method. The SCMR method is a novel non-radiative wireless mid-range power transfer method (10 – 300 cm) that has been recently developed [6-9]. The SCMR method has achieved 40% wireless power transfer efficiency in the air for a distance of 2 m for a single receiver [6], and the SCMR technique was used to simultaneously power multiple receivers in the air, and has achieved a 60% at a distance of 2 m [7]. A recent article has shown that SCMR provides wireless power transfer efficiencies that are significantly larger than efficiencies of conventional inductive coupling methods [9]. In order for SCMR to achieve high efficiency, it requires that the transmitting and receiving elements (typically loops or coils) are designed so that they resonate at the desired operating frequency that must coincide with the frequency of where the elements exhibit maximum Q-factor. In [10] a three-coil multiband system is embedded in a ferromagnetic material and achieved a combined energy and data transmission with multiple receivers. Wireless power transfer system is analyzed in [11] with band-pass filter model. The paper also describes a methodology for multi-receiver system using band-pass filter model and impedance matching network to support multiple loads. This shows a multiband SCMR system, which can to simultaneously transfer wireless power and date a different frequencies.

II. MULTIBAND SCMR SYSTEM

The basic structure of the multi-band system is as shown in Fig. 1. It comprises of a number of concentric conducting loops elements and each connected to a capacitor to achieve resonance at a desired frequency. The multi-band resonators is implemented on both the transmitter and receiver side, to enable power transfer from multiple transmitters to multiple receiver devices operating at identical frequencies with the transmitters, this will enable wireless power transfer to several device operating at their unique frequencies.

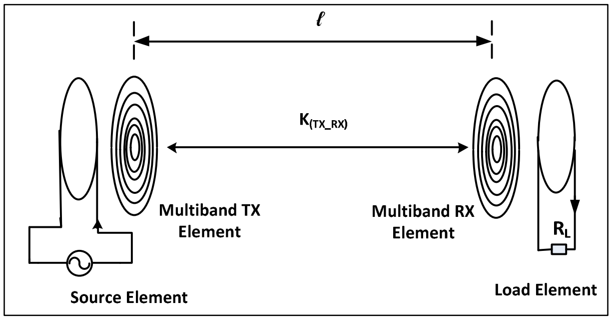

Fig. 1. A Schematic of the Multiband SCMR power transfer system.

The source element is connected to the power source, and it is inductively coupled to the TX elements. The TX elements are resonating at a set of desired resonant frequency, where its Q-factor is naturally maximized. Similarly, the RX elements also resonate at a set of resonant frequencies identical with the TX elements, that coincides with the frequencies where there Q-factor are naturally maximized, and the load element is terminated with a load. Based on the equivalent RLC circuit of the SCMR system, its resonant frequency, f_r, can be calculated, by following equation:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

The resonant frequency, f_r is also the operational frequency of the SCMR wireless powering system. The Q-factor of a resonant RLC circuit is given by:

$$Q = \frac{\omega_r L}{R} = \frac{2\pi f_r L}{R} \tag{2}$$

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Therefore, the Q-factor of a resonant helix (i.e., self resonant) can be written as:

$$Q = \frac{2\pi f_r L}{R_{ohm} + R_{rad}} \tag{3}$$

where L, R_{rad}, and R_{ohm} are the self-inductance, radiation resistance and ohmic resistance of the loop. The maximum Q-factor, Q_{max}, and the frequency, f_{max}, where Q_{max} occurs, can be derived from (9) using calculus as:

$$f_{\max} = \frac{c^{8/7}\mu^{1/7}\rho^{1/7}}{4 \cdot 15^{2/7} N^{2/7} r_c^{2/7} \pi^{11/7} r^{6/7}} \tag{4}$$

$$Q_{\max} = \frac{2\pi f_{\max} \mu_0 r \ln(8r / r_c - 2)}{\left(\frac{\mu_0 \rho \pi r^2 f_{\max}}{r_c^2}\right)^{\frac{1}{2}} + 20\pi^2 \left(\frac{2\pi f_{\max} r}{c}\right)^4} \tag{5}$$

where μ is the permeability of free space, ρ is the helix's material resistivity, r is the radius of the helix, r_c is the cross sectional wire radius, N is the number of turns, f is the frequency, η_o is the impedance of free space and c is the speed of light. It should also be noted that (3)–(6) are valid only when $r < \lambda / 6\pi$ [3].

The measurement and simulation setup of a 3-loop multiband system, with centered source and load loops is as shown in Fig. 2 and Fig. 3 respectively.

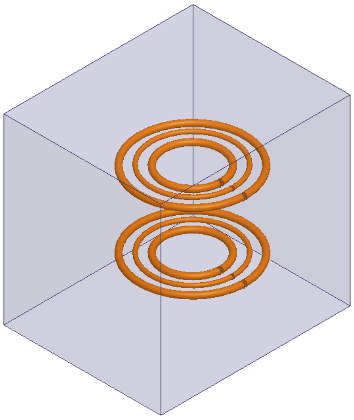

Fig. 2. HFSS model of the Multiband SCMR system.

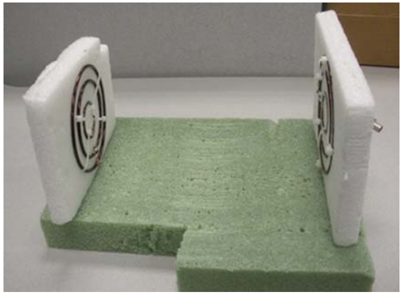

Fig. 3. Measurement setup of the Multiband SCMR system.

The comparisons between the measurement and simulation are as shown Fig. 4. This specification are : r_1 = 0.02 m, r_2 = 0.1 m, r_3 = 0.13 m , while the distance between adjacent loops is 2 cm, r_c = 2.2 mm. This potential application in power and data transfer over several band efficiently.

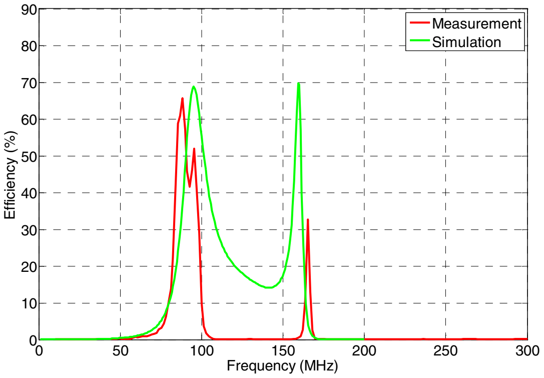

Fig. 4. Measurement and simulation comparisons.

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