A Quantitative Study of a New RF-coil for 7 Tesla Small-Animal Imaging

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***Abstract*— In this work we demonstrate a comparative study of the a new proposed coil based on periodic capacitively-loaded thin wires and a conventional loop coil both optimized for small-animal imaging applications at 7 Tesla. The proposed coil uses hybridized eigenmodes of the flat periodic array comprising a number of thin metal wires, excited by a small non-resonant loop. Tunability of the proposed coil within the desired frequency range is ensured by the structural distributed capacity implemented as a PCB attached to the ends of all the wires. The proposed coil was compared to the conventional loop coil with lumped capacitors by numerical simulations. Quantitative comparison has been done in terms of B_1^+ per square root of accepted power efficiency as well as the loaded Q-factor. Up to 42% improvement of the transmit efficiency has been demonstrated over the conventional loop coil in a homogeneous phantom.**

I. INTRODUCTION

In magnetic resonance imaging (MRI) radiofrequency (RF) coils are used to transmit excitation pulses and to detect echo signals. In various biomedical studies preclinical scanners are used, operating at ultra-high permanent fields B_0 (7 Tesla and above). In preclinical scanners, volumetric coils (i.e. so-called 'birdcage' coils surrounding a scanned subject) are commonly used for signal transmission due to good homogeneity over the whole subject's volume. At the same time, birdcage coils have a low sensitivity for MR signal reception, so that small surface coils are used instead having much higher SNR over a limited region of interest (ROI). To the date, there are various preclinical studies where high sensitivity over a relatively large ROI is required (full-body small animal imaging) such as angiography, drug delivery studies etc. In the most of previously proposed coil designs inductive loops are used to create RF magnetic field in a subject [1]. Such coils need to be tuned and matched at the operational frequency of an MR scanner (so-called Larmor frequency) using multiple low-loss ceramic capacitors.

In this work we present a quantitative numerical comparison between recently proposed new RF-coil design [2] based on a periodic structure of wires [3] loaded with a structural capacity and the conventional design of a preclinical coil (i.e. a surface loop tuned to the Larmor frequency with four lumped capacitors).The proposed design uses a fundamental eigenmode of a system of highly-coupled capacitively-loaded metal wires, which is excited due to an inductive coupling with a small non-resonant loop connected to an RF-cable. The numerical study was performed where the proposed coil was simulated as well as the conventional coil having similar dimensions and being placed over the same homogeneous phantom. Circularly polarized magnetic field distribution inside a homogeneous phantom mimicking the small animal was calculated for both designs. The loaded Q-factor of both the considered coils was also compared.

II. NUMERICAL SIMULATIONS

A. Simulation of the proposed coil

Simulations were performed using the Frequency Domain Solver of CST Microwave Studio. In the simulations the proposed coil (Fig. 1a) comprised an array of 6 copper wires (radius = 1 mm, length = 69 mm) located equidistantly with the separation of 10 mm. All the wires at both ends were attached to square copper patches (9×9.5 mm^2) implemented as rectangular strips on a common grounded dielectric substrate Rogers 4003 with the thickness of 0.508 mm. The 40-mm-diameter loop, inductively coupled with the fundamental eigenmode of the wire structure was implemented as a circular strip of the width 4 mm printed on the 1.5-mm-thick FR4 dielectric substrate. The loop was driven in the simulation through a lumped 50-Ohm port. The simulation model also contained a homogeneous phantom mimicking a small-animal subject implemented as an elliptical cylinder with the length of 74 mm and a base radii of 30 and 40 mm. Material properties of the phantom corresponded to the averaged properties of small animal tissues such as the permittivity of 34 and the conductivity of 0.5 S/m. In this geometry the proposed coil was resonant at 300 MHz (the Larmor frequency of a 7 Tesla preclinical scanner) and impedancely matched with no lumped capacitors used. The scanner environment was taken into account by the presence of a cylindrical RF shield with the diameter of 200 mm and the length of 1000 mm.

B. Simulation of the conventional surface loop

As a reference design, a conventional surface loop was chosen and simulated. The loop had a rectangular shape (Fig. 1d) and similar dimensions as the wire structure of the proposed coil (i.e. 60×70 mm^2). The loop was implemented as a copper trace of the width 3 mm on a Rogers 4003 1.5-mm-thick dielectric substrate. To make the loop resonant at 300 MHz, four similar tuning lumped capacitors were placed along the loop connected to its splits. The capacitors had the

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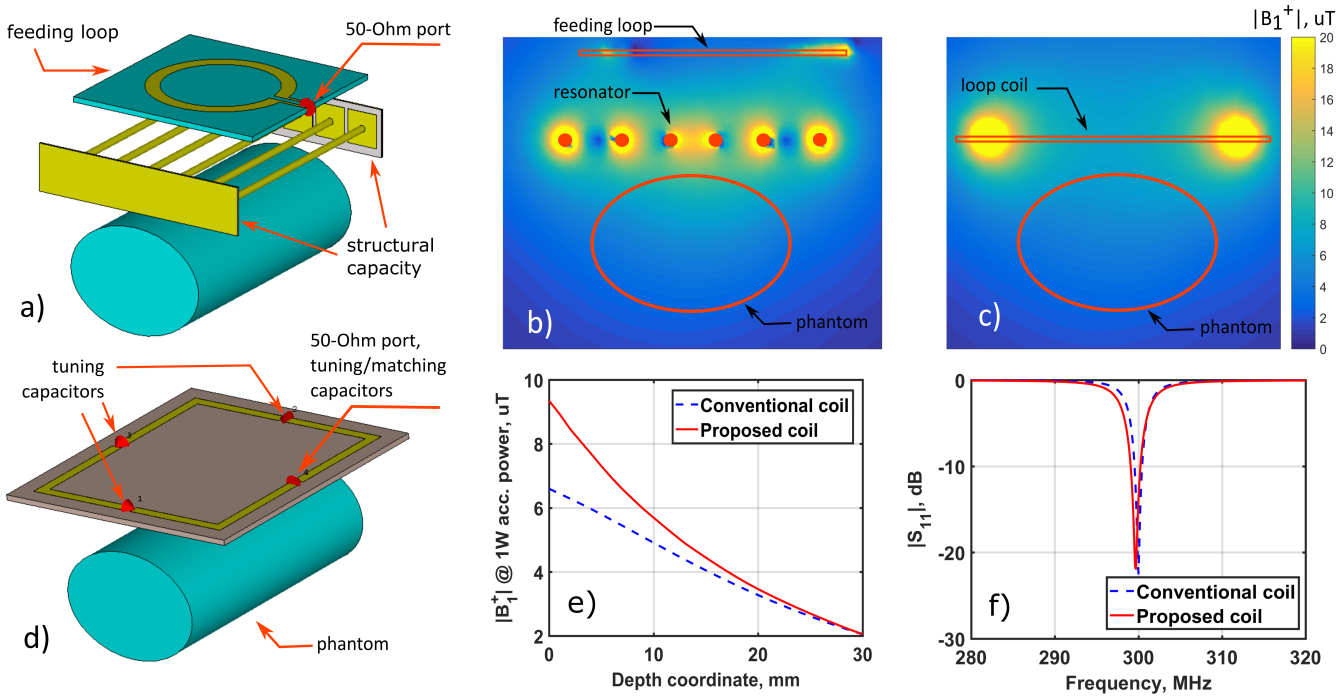

Fig. 1. Simulation setup of the proposed coil (a) and the conventional surface loop coil (d); simulation results: B_1^+ magnitude maps at 1W of accepted power of the proposed coil (b) and the conventional coil (c); B_1^+ magnitude at 1W of accepted power vs. depth coordinate profiles in the phantom of both coils (e); $|S_{11}|$ vs. frequency of both coils (f).

capacity of 5.5 pF and the Q-factor of 900 at 300 MHz. Another capacitor with the capacity of 1.3 pF and the Q-factor of 2000 at 300 MHz was inserted in series to the port for matching with the 50-Ohm port. The same homogeneous phantom as well as the RF-shield were modeled in the simulation.

III. Results of numerical comparison

The coils performance was studied in terms of RF right-hand circularly polarized magnetic field B_1^+ created by a transmitting coil per 1W of accepted power. B_1^+ maps of both the the proposed and the conventional coils are depicted in Fig. 1b and c correspondingly. B_1^+ profiles in the phantom along the axis normal to the plane of the coils are depicted in Fig. 1e. From the profiles, one can clearly see that the proposed coil is depending on the depth up to 42 % more power-efficient in transmission as compared to the conventional coil. This may be explained by weaker concentration of local electric field due to the distributed nature of the employed PCB structural capacity. This leads to lower conservative electric fields. The B_1^+ created by the proposed coil at a given accepted power is especially higher at the surface of the phantom. From Fig. 1f one can also see that the proposed coil has slightly lower quality factor which means that the bandwidth of the proposed coil is similar or wider than one of the conventional coil (i.e. acceptable for 7 Tesla MRI). The bandwidths picked at the level of $S_{11} = -3$ dB are 3.5 and 2.8 MHz for the proposed and the conventional coils, accordingly, while the loaded Q-factors are 86 and 107.

IV. Conclusions

The comparative analysis of the new proposed coil and the conventional loop coil was performed in terms of their transmit efficiency, bandwidth and the loaded Q-factor. The proposed coil has shown up to 42 % better B_1^+ per 1W of accepted power efficiency at the surface of the phantom while having slightly lower loaded Q-factor and wider impedance matching band. It is worth noting that the proposed coil is cost-efficient as composed of only PCB parts, while the conventional coil necessarily requires several expensive non-magnetic high-Q capacitors. The comparative study has shown perspectives of the proposed coil with structural capacity for the small animal imaging due to advantages in its transmit efficiency and design simplicity avoiding expensive lumped capacitors.

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