A Novel Planar Design for a 3 T Superconducting "Intrinsically Detuned" MRI Coil

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Introduction.

Noise in MRI systems, in general, is created by conductive losses in the coil and the body. There are two regimes of such conductive losses that control SNR: the first is body loss dominant and the second is primarily coil loss dependent. When the coil loss is the governing source of noise, it has long been recognized that cooling the probe reduces this noise contribution and therefore can significantly increase the measurement's SNR. The discovery and development of high-critical temperature superconducting (HTS) materials (which at 77 K exhibit an extremely low surface resistance R_s of an order of 150 μΩ at 10 MHz) has resulted in several attempts to build practical probes with improved SNR. Indeed, several studies have shown that for selected applications, where the MRI system noise is in the coil loss regime, such as low-field MRI, high-field microscopy, and small-volume MRI, HTS MRI receiver coils perform significantly better than comparable copper coils. For example, for microscopy with resolution as high as 10 μm and for small animals two-fold and higher SNR gains over room temperature copper coils have been reported [1-3]. Since implementation of HTS coils is challenging, most reports refer to coils with inductive coupling and without detuning from the transmit coil (thus in Tx/Rx mode). The detuning can be accomplished through several active and passive methods; however, difficulties can arise in the case of high Q superconducting coils. With these high Qs and, in addition, the prohibitive use of normal metal for even short crossovers, new designs and/or fabrication processes are required. Therefore, we have designed and fabricated a coil, which in principle is intrinsically isolated from the whole body scanner transmit coil. In the uniform rf field, this coil should not require special passive nor active circuitry when the transmit is used for excitation.

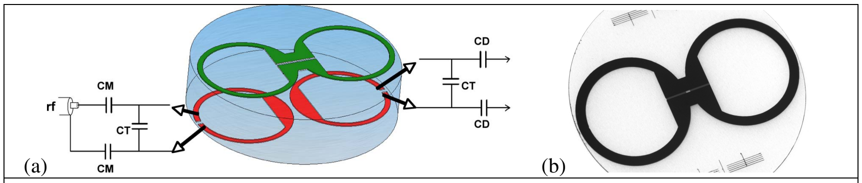

Fig. 1. (a) A sketch of the two-loop split-rings coil. CT and CM are tuning and matching capacitors. The coil is connected on one side to the matching capacitors and a tuning capacitor is placed across the middle gap. The coil can work as an element of linear array; CD indicates decoupling capacitors; (b) a picture of a 128 MHz superconducting coil is shown.

Method and Results.

We followed the designs' principles of loop-gap [4] and planar-pair loop-gap [5] resonators, which have been previously demonstrated as very useful in magnetic resonance. A very important feature of the planar-pair loop-gap, in the uniform rf field, is the compensation of rf current in one coil loop by the current in the other loop. Our design consists of two modified double-sided split-ring resonators connected on one end by two narrow strips. Tuning capacitor can be added across the middle gap. In addition, we have used a double-sided structure concept in order to introduce distributed capacitance in the coil, and to minimize stray electric fields (confined in the substrate) that otherwise would lead to additional dielectric loss in the body. In such a design each "loop resonator" consists of two split-rings. This structure should resonate at required mode when the rf currents in each loop flow in opposite directions. The split-rings have a 22-mm outer diameter, 16-mm inner diameter and 14-mm shorter opening dimensions. Such a design can be treated as two directly connected horse-shoe resonators [6]. The gaps on two sides of the substrate in each ring are rotated 180° from one another. A sketch of the 128 MHz design is shown in Fig. 1a. The HTS coil was patterned using lithography and wet etching processes on 2" YBCO films deposited on both sides of a 0.5 mm thick $LaAlO_3$ dielectric substrate (48 mm in diameter, ε=24). For easy cryo-packaging, the HTS coil includes built-in planar capacitors for coil decoupling as well as a capacitive connection to the matching and tuning system (not shown here). Also in Fig. 1, a picture of the upper side of the fabricated coil is presented. The bottom layer of the patterned coil can be seen through the middle gap. Despite the simple coil form, the resonant frequency of the coil has a complicated dependence on the resonant circuit elements. We have used a HFFS Ansoft Corporation package to calculate modes and coil sensitivity profiles.

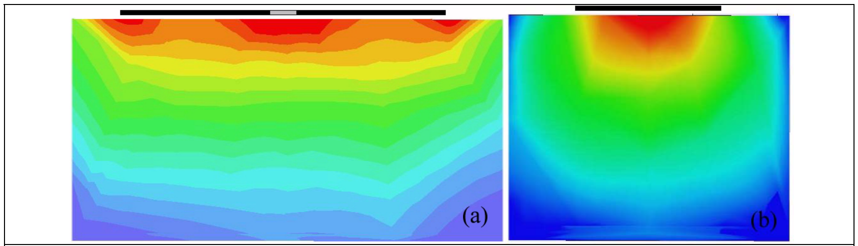

Fig. 2. Simulation of sensitivity contours of the two-loop split-rings resonator is shown in two orthogonal planes. The planes for these plots pass through the middle of the resonator. Contour maps of axial (the coil is designed for B_0 to be perpendicular to longer coil axis) (a) and saggital (b) cross sections are shown.

Fig. 2 shows the sensitivity contour plots obtained for the coil calculated without a body load. These profiles were also confirmed experimentally on the bench using two specially made loops and a vector analyzer.

We have measured and simulated both s_{11} and s_{12} reflection and transmition coefficients for the coil excited from one side only and from a symmetric loop positioned above the coil to induce a uniform field, respectively. In Fig. 3 s_{11} and s_{12} simulations are shown. It is clearly evident that in the uniform field, any resonance excited at 123 MHz is below -40 dB. This result was confirmed with bench measurements for both copper and HTS coils and even greater isolation between transmit and the receiving coil was obtained.

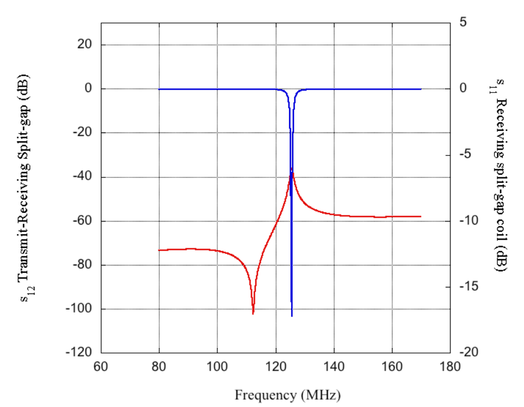

Fig. 3. Ansoft simulated s_{11} and s_{12} response of the designed two-loop split-gap coil. It was confirmed at the bench.

Discussion and Conclusions. The double-sided split-ring coils, both copper and HTS (Fig.1a and 1b) were positively tested for coil detuning at room and liquid nitrogen temperatures. Unloaded Qs were measured as 380 and 15,000 for copper and HTS, respectively. The potential advantage of such a design, in addition to good isolation from the transmitting coil, is also the relatively smaller eddy current losses. The coil showed smaller reduction of Q after loading with the body compared to other designs of a similar size. Such a structure can be also used in a linear array configuration. The two capacitors CD shown in Fig. 1a can be used to decouple the adjacent resonator. Testing with a 3 Tesla scanner with coils mounted in a small plastic cryostat is underway.

Acknowledgements

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