Current limited superconducting RF coils

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Introduction: High signal-to-noise ratios (SNR) in MR images can be achieved by using receive coils with high Q-factors. Self-resonant high temperature superconducting (HTS) coils[1,2] which are inductively coupled to a TX/RX coil, e.g. the body coil, can be used for raising the SNR in comparison to standard local coils. Those HTS coils distort the TX magnetic field without detuning. The investigated method shows a way to passively detune self-resonant superconducting receive coils using a current limiting effect to not interfere with the TX magnetic field. The matter of current limiting could also be an issue for patient safety. The results can be used in research of superconducting receive coils and are addressed to RF engineers who are concerned with new concepts of TX/RX coils and in particular with design and development of high-Q receive coils and self-resonant coils in MRI. Due to this method of transferring the signal and because of the self-resonance, the high Q-factor of the superconductor will have the maximum effect.

Method: The investigated HTS coils are tapered which decreases the maximum current and hence the distortion of the TX field. In this work the dependence of the maximum current on the resulting trace width due to the taper was measured. Fig. 1 shows the top layer of the loop. The bottom layer is identical in design but rotated by 90°. The material is YBCO on a sapphire substrate. Because the dimensions of the taper are confined circumferentially, the Q factor is not reduced much by this method. To measure the current in the loop, the setup of Fig. 2 was used. The stimulus of the NWA is pulsed by a switch, amplified and fed to the HTS coil via a probe. The transformation due to the inductive coupling was calibrated beforehand, based on calculated inductance and a time-domain ring-down measurement for the small-signal Q-factor. The power-dependent series resistance of the HTS coil was calculated from the reflection coefficient. Then the current was derived from resistance and absorbed power.

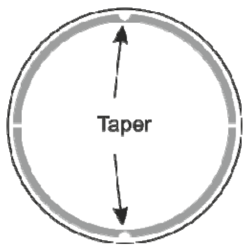

Fig. 1: HTS antenna with taper (Top layer)

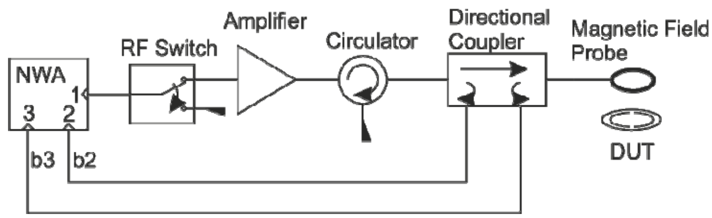

Fig. 2: Setup for measurement of reflection coefficient at varying source powers

Results: The output power of the amplifier was varied from -20 dBm to +55 dBm. The RF resistance of the loop is increased as the power increases. In Fig. 3 the dependence of the resistance on the current is shown for a trace width of 0.2 mm at the taper. At about 28 dBm absorbed power the current is clamped to a maximum value. Fig. 4 shows the dependence of the maximum current on the trace width of the taper. For the value at 3 mm trace width the current limitation was not reached at the applied RF power.

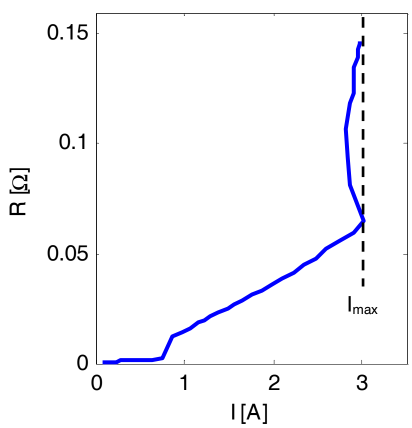

Fig. 3: HTS current dependent on resistance for 0.2 mm trace width

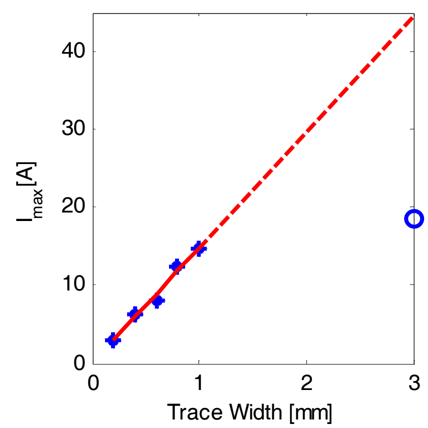

Fig. 4: Maximum current in HTS loop for varying trace widths

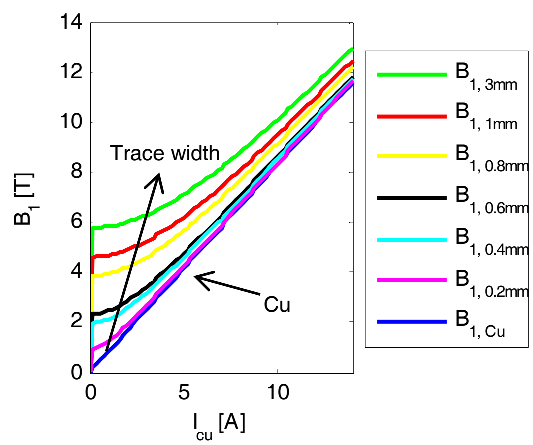

Fig. 5: Distortion of magnetic TX field for different trace widths

Discussion:. The resistance of the superconducting loop depends on the current, and increases approximately linearly at lower currents. Above a threshold, the current is however hard limited to the maximum current density[3]. For a smaller residual trace width, this happens at lower current. The current creates an unwanted B1 contribution which is in quadrature phase to the primary transmit field. This can be seen in analogy to passive detuning diodes, where a limited RF voltage at the diodes leads to a limited current in the antenna. For a hypothetical scenario of twelve HTS loops in proximity to standard copper transmit loops on a 65 cm cylinder, the magnitude of the total B1 field was calculated from the measured current dependency (Fig. 5). The nonlinear B1 distortion could be reduced significantly by indenting the conductor.

Conclusion: In this work, a simple way to passively detune self-resonant HTS coils is shown. It has been demonstrated that the current in the loops is clamped to a maximum value and that this value can be influenced by varying the trace width of the taper. Due to this effect the distortion of a TX field caused by the HTS receive coils is reduced with negligible decline of the Q-factor.

References: 1. C. Ginefri, et al., Technical aspects: Development, manufacture and installation of a cryo-cooled HTS coil system for high-resolution in-vivo imaging of the mouse at 1.5 T, Methods 2007, 43(1), 54-67. 2. M.Vester, et al., High Temperature Superconducting Surface Coils with Liquid Nitrogen or Pulse Tube Refrigeration, ISMRM 1997 p. 1528 3. S. Futatsumori, et al., HTS split open-ring resonators with improved power-handling capability for reaction-type transmitting filters, Electron Lett. 2007;43(17):956-7