Flexible Magnetic Flux Guides for Magnetic Resonance Imaging

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Introduction: Space is often very limited in magnetic resonance systems imposing unwanted geometric constraints on applications such as interventional MRI. During MR-guided interventions instruments need to be introduced into the MR system, which leads to a suboptimal position of the imaging coil and, consequently, to a reduced SNR. In this work the magnetic flux created during signal reception is guided by an elastic signal guide to a remote receiver coil to overcome such restrictions.

Methods: The elastic signal guide consists of a series of inductively coupled electric resonators which are arranged linearly on an elastic carrier substrate, which allows the structure to be bent as desired (Fig. 1). When one end of this resonant waveguide is placed in an RF field, a voltage is induced in the closest resonator. By inductive coupling, the RF signal then travels to the adjacent resonators and, eventually, through the whole waveguide, thus transmitting the magnetic flux over a considerable distance even when the structure is bent. A theoretical model was developed based on existing work[1,2] to determine the optimal spacing of the RF resonators. The arrangement was also simulated numerically with the commercial simulation software HFSS to validate the frequency behavior.

The resonators are made of copper solenoids with 5 windings and a diameter of 2.3 mm, leading to an inductance of 83 nH; and SMD capacitors with a capacitance of 75 pF, which resulted in a resonance frequency of 64 MHz. A prototype consisting of four resonators with a distance of 9 mm was fabricated and experimentally characterized at an Agilent E5071C Network Analyzer. Here, transmission (S_{12}) of the waveguide was measured by placing probe coils at both its ends. To demonstrate the functionality of the waveguide, magnetic resonance imaging was performed at a clinical 1.5 T MR system (Magnetom TIM Symphony, Erlangen, Germany).

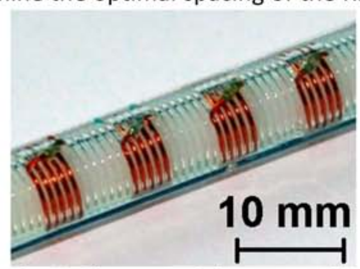

Fig. 1: Close-up of the waveguide. The structure was cast in silicone to achieve flexiblity.

Results and Discussion: The expected transmission behavior of straight and bent waveguides could be verified experimentally (Fig. 2). In an early imaging experiment with a rigid version, a waveguide between receiver coil and sample increased the signal to noise ratio from 9 to 350 (Fig. 3), indicating that they could become a valuable alternative to conventional receive coil arrangements.

References: [1] Shamonina E, et al. Magnetoinductive waves in one, two, and three dimensions. J.Appl.Phys. 2002; 92,6252.
[2] Syms R R A, et al. Low-loss magneto-inductive waveguides. J.Phys.D: Appl.Phys. 2006; 39 3945.

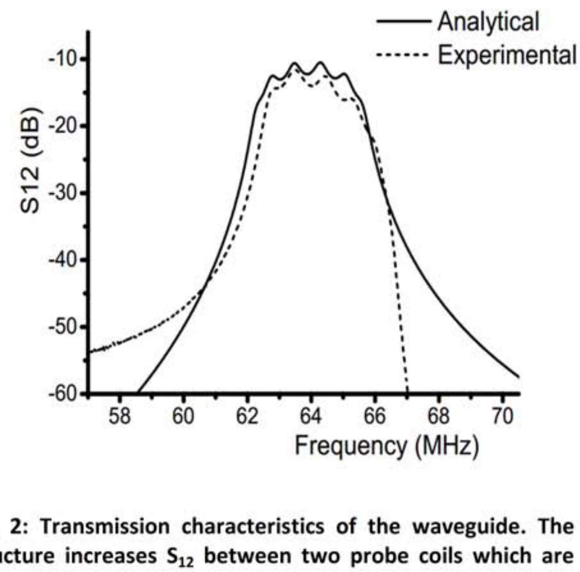

Fig. 2: Transmission characteristics of the waveguide. The structure increases S_{12} between two probe coils which are 4 cm apart from −60 to −12 dB. It can be seen that the experimental data matches the theoretical expectations.

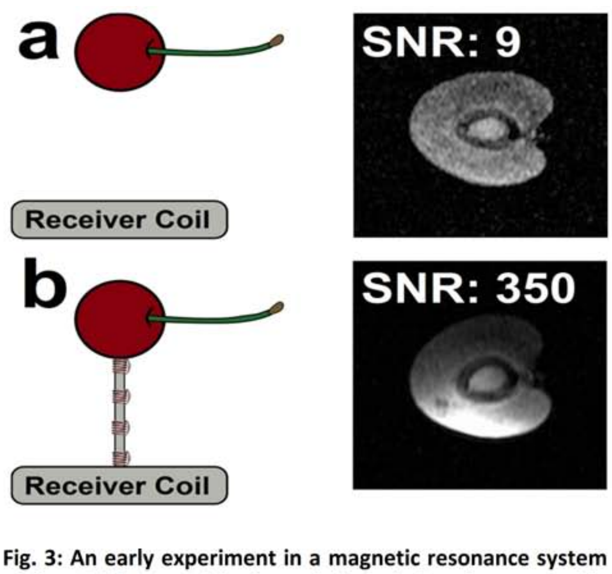

Fig. 3: An early experiment in a magnetic resonance system with a rigid waveguide showed that placing the waveguide between a loop coil with a diameter of 5 cm and a cherry as sample resulted in a significantly increased signal to noise ratio in the vicinity of the waveguide.