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Wideband Coil Based on Microstrip Line for Multiheteronuclear Magnetic Resonance Spectroscopy

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Abstract. Magnetic Resonance Spectroscopy of X-nucleus is a method for mapping metabolite quantity *in-vivo* in the desired region of the human body. However, this method has a lot of difficulties. Since natural abundance of X-nucleus is much lower than for hydrogen, to improve SNR of the spectrum we need to work in higher static magnetic fields. But, even at such high fields, X-nuclei imaging still a very difficult process. One of the problems are RF-coils, which are required for transmission and reception of signals. Traditionally, for human body X-nuclei MRS multi-tuned loop coils are used. However, such coils suffer from additional losses in the circuits required for double-frequency tuning and high complexity. In this work, we propose an alternative approach, based on a recently introduced leaky-wave antenna for MRI, that allows creating wideband excitation which provides wideband transmit and receive. This wideband frequency range covering ^{13}C, ^{23}Na and ^{31}P Larmor resonant frequencies.

1. Introduction

The design of double and triple radio frequency (RF) coils for multi-nuclei spectroscopy is a challenging engineering problem. In the simplest case one loop are tuned to two resonant frequencies using pole-insertion method. This method is based on the addition of capacitance to the resonant LC-circuit. This method can be applied both to the surface and volume coils. However, such an approach leads to the significant decrease of coil's efficiency due to higher losses [1]. Another approach is based on using two separate loops, tuned to different frequencies. To decrease coupling usually high-impedance traps tuned to a particular frequency are used for decoupling. Another approach - using a coil with orthogonal magnetic field distributions. For example, combination of loop and butterfly coil [2] or combination of loop coil and stripline resonator [3].

In this work, we propose an alternative approach, based on the recently proposed leaky-wave antenna (LWA) for ultra-high field (UHF) magnetic resonance imaging (MRI) [5]. This antenna is based on a microstrip line with I-shaped slots, etched in the ground plane. The working principle of such an antenna is based on the fact that the wave propagating in the guiding structure radiates if the speed of propagation is higher than the speed of light [4]. Since the

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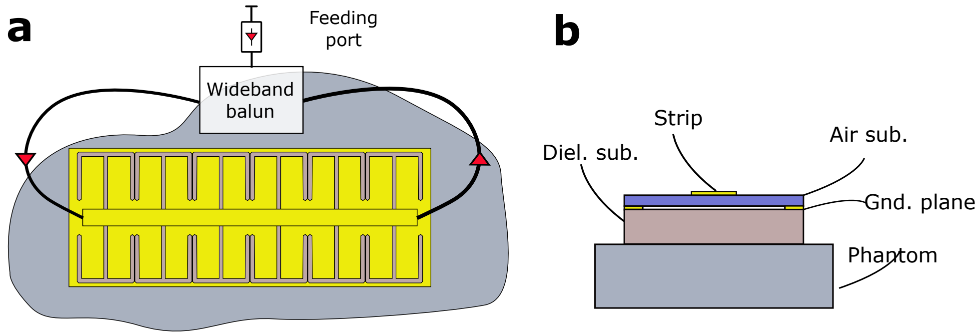

Figure 1. Schematic layout of the proposed leaky-wave antenna placed over a homogeneous phantom: (a) top view; (b) side view

human body has a high relative permittivity (around 60), the wave in the stripline is faster comparison to the wave in the media.

In this work, we showed by numerical simulations, that it's possible to achieve broadband field excitation, which covers the frequency range from 78 to 122 MHz. All simulations were performed in the case of LWA loading for the homogeneous phantom with properties ε=60, ς=0.6 S/m, which mimics human body averaged tissues over the 78 to 122 MHz frequency range.

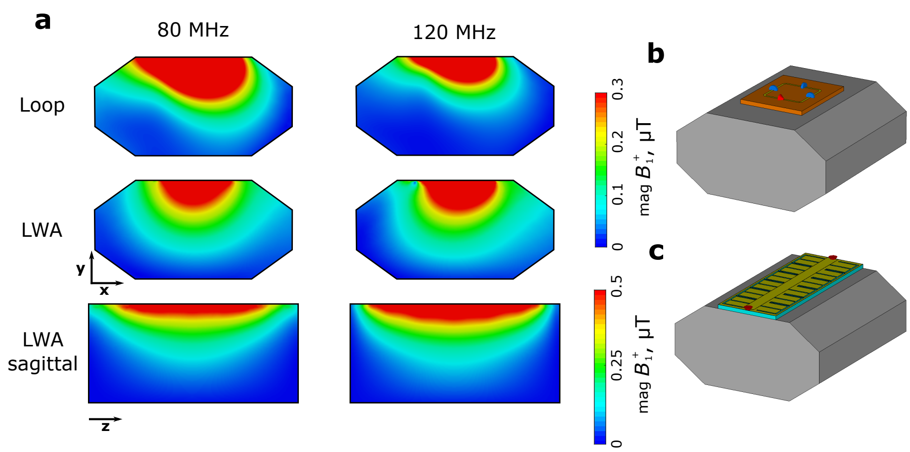

Figure 2. (a) Simulated B_1^+ magnitude distributions normalized by square root of accepted power. (b) CST model of investigated coils, loaded with homogeneous phantom.

2. Design and methods

In our work, we use the general approach based on unitcell optimization, described in the paper about 7T LWA [5], but with a different goal - to obtain a broadband excitation for heteronuclear spectroscopy. The proposed coil consisted of an array of six slots, placed at the top of the homogeneous phantom. The total length of the coil was 42 cm. Slots were etched in the common ground plane. The overall length of the slot was L=30.5 cm. I-shaped slots were used to increase the real part of the slot's input impedance and improve the loading of the antenna onto the phantom. Additional dielectric spacers were used to improve the loading of individual slots. Period of the slots was equal to 6,7 cm. This combination of slot length and period was chosen to provide good matching in the whole frequency range from 78 to 122 MHz. Slots had a period of 6 cm and were distributed equally along the z-axis. The width of antennas

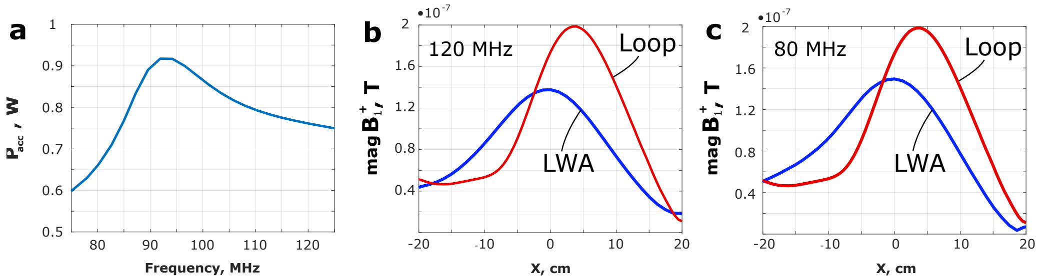

Figure 3. Results of numerical simulations: (a) Simulated power, dissipated in the phantom, over the wide frequency range for leaky-wave antenna. (b) Simulated B_1^+ magnitude at the 10 cm depth in the phantom for the LWA and loop coil at 120 MHz. (c) Simulated B_1^+ magnitude at the 10 cm depth in the phantom for the LWA and loop coil at 80 MHz.

was chosen to fit 8 channel configuration in a human body imaging application. The design of the proposed antenna is presented in Fig. 1.

The length and period of slots, as well as the permittivity of dielectric spacer were optimized to achieve the maximum efficiency of 10 cm while keeping a broadband excitation. Numerical simulation software CST Studio Suite 2020 (CST, Darmstadt, Germany) was used for the calculation of the RF magnetic field of the proposed antenna. Two loops, tuned to 80 MHz (^{23}Na resonant frequency) and 120 MHz (^{31}P resonant frequency) with four distributed capacitors were used as reference coils. Loop coils were simulated with the same homogeneous phantom loading. All results were obtained using Frequency Domain Solver with finite element meshing.

3. Results and discussion

The simulation has shown that the proposed coil design based on the leaky-wave approach is suitable for broadband RF-excitation of objects. Distributions of circular polarized magnetic RF-field B_1^+ for the LWA and loop coils are presented in Figure 2. Power accepted in the LWA in the broad frequency range is presented in Figure 3 (a). From this we can see that, in the whole frequency range, the power absorbed in the phantom is higher than 65 %. To compare leaky-wave antennas with loop coils more precisely B_1^+ fields measured in the depth of 10 cm at 80 at 120 MHz frequency along X-axis are presented at the Figure 3 (b) and (c). From these plots, we see that LWA creates a 30 % lower magnetic field at 120 MHz and 40 % lower at 80 MHz correspondingly. Such a decrease of field happens due to a substantially larger field of view of the leaky-wave antenna.

4. Conclusion

In this work, we propose a new RF-coil for heteronuclear 7 Tesla MRS based on the leaky-wave approach that could simultaneously receive and transmit signals of several frequencies. The results have shown that using this coil, one can create an RF-magnetic field comparable with conventional multi-tuned loop RF-coils.

5. Acknowledgment

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