Remote RF excitation for a small-bore MR imager at 15.2 T

F. Vazquez¹, S. E. Solis-Najera¹, J. Lazovic², L. M. Zopf², R. Martin¹, L. Medina¹, O. Marrufo³, A. O. Rodriguez⁴

¹Physics Department, Faculty of Sciences, Universidad Nacional Autonoma de Mexico, Mexico City 04510, Mexico. ²Campus Science Support Facilities GmbH, Austria. ³Department of Neuroimage, INNN MVS, Mexico City, Mexico. ⁴Department of Electrical Engineering, Universidad Autonoma Metropolitana Iztapalapa, Mexico City 09340, Mexico.

Abstract. The travelling-wave MRI approach is an alternative to overcome the B1 inhomogeneity at UHF MRI for human applications. More recently, this concept has been also used with animal MR imagers. We used a parallel-plate waveguide and a bio-inspired surface coil to generate mouse images at 15.2T. Ex vivo mouse images were acquired without high dielectric materials to conduct the signal at the right frequency. These results are in very good concordance with results obtained at 3T and 9.4T. These results show that travelling wave MRI with high SNR can be performed with a simple waveguide.

I. INTRODUCTION

The limited sensitivity of magnetic resonance imaging (MRI) originates a poor spatial and spectral resolutions. These limitations can be overcome with high field MR imagers which enable the research of human organ structure, function and chemistry under unprecedented conditions [1-4]. The B1 inhomogeneity inside the sample to be imaged at ultra high field MRI for human applications is a major drawback. This is a vital aspect because the RF field wavelet approaches the size of the sample. Another important matter is the power deposition in the human tissue/organ too. The travelling-wave MRI (twMRI) approach is an alternative to overcome the B1 inhomogeneity at ultra high field MRI for human applications [5-6].

A very limited number of laboratories have access to UHF MR imager sfor human imaging across the world. However, preclinical imagers are a commodity and many research groups have access to perform research in different areas of human and animal model diseases. The installed preclinical MR imager base has been designed to accommodate high field magnets raging from 4.7 T up to 21 T, although there is a number of higher field magnets in development [7]. The large experience gained over the past decades on the pros and cons of preclinical UHF MRI may prove useful for the development of UHF MRI for humans. Preclinical systems have been developed for UHF MRI to study various diseases using animal models [8]. More recently, this concept of twMRI has been also used with animal MRI systems [9-11].

This approach offers the advantages of keeping the high volatges away from the patient and nuclei are more homogenously excited. Under standard circumstances only one transceiver coil is used for the entire MRI experiment. This might be an important limitation because of the low SNR produced, then, high fields are mandatory to partially overcome this disadvantage. The critical frequency of the waveguide to transmit the energy depends on the dimensions of the waveguide itself. This is a major problem, because the dimensions may be larger than the magnet bores commonly found in both human and small-bore MR imagers. Dielectric paddings with high permittivity have been successfully used to run twMRI experiments [11].

We have previously demonstrated that the PPWG can transmit the RF signal at 3 T [6] and 9.4 T [10] without dielectric materials, and that the waveguide dimensions play no role to run twMRI experiments. These encouraging results motivated to put the PPWG to the test at higher resonant frequencies. We investigated the use of a parallel-plate waveguide (PPWG) and a bio-inspired surface coil to generate mouse images with a preclinical MR imager at 15.2 T. We demonstrate that the PPWG can transmit all frequencies at 650 MHz (proton frequency at 15.2 T) because its critical frequency is zero.

II. WAVEGUIDE AND RF COIL

We built a PPWG To test the viability of this remote RF excitation approach at 15.2 T. This waveguide offers the advantage that all frequencies can propagate because its critical frequency is zero for the TE principal mode. The PPWG prototype was built using 2 aluminium strips (4 cm wide and 6 nm thickness) were mounted on an acrylic tube with a 3 cm diameter and 1.2 m long.

The mechanical properties of the first prototype allow us to have constant cross-section for this particular length (Fig. 1). The prototype was used together with an RF surface coil located at one end of the waveguide and an aluminium blocker was at the opposite end. The coil prototype consisted of 6 circular petals (0.45 cm diameter) and a total radius of 1 cm, then it was matched and tuned to 50 Ω and 650 MHz. Fig. 1 shows an illustration of the surface coil and the experimental setup.
Coil performance was measured via the quality factor, $Q$, and the coil noise figure. To test both the feasibility of remote RF excitation approach and performance of the MR scanner, we performed ex vivo imaging experiments with a formaldehyde-fixed mouse phantom.

To assure the transmission of the energy inside the PPWG [12], saline-solution filled tubes and the mouse phantom were inserted inside the waveguide, see Fig. 1.

A. Waveguide testing

An electromagnetic semi-anechoic chamber was used to test the viability of the PPWG. The chamber is 3m x 3m and it can be operated from 30 MHz to 1 GHz with a normalized attenuation of ±4 dB and, from 1.1 GHz to 18 GHz with a normalized attenuation of ±3 dB. Fig. 2 shows an illustration of the testing setup using both the waveguide and the RF surface coil. The PPWG was air-filled and the surface coil was linearly polarized for all testing experiments.

Figure 3. Polar diagrams of amplitude patterns for the vertical and horizontal planes for the bioinspired surface coil and the PPWG.

Ex vivo mouse images were acquired with the PPWG and our coil prototype, see Fig. 4. Standard gradient sequences with a low flip angle were used to acquire ex vivo mouse images. These images showed very good image quality with clear delineation of anatomical structures, and compatibility with standard pulse sequences.

B. Imaging experiments

A mouse (40g) was used for ex vivo imaging experiments. The mouse was positioned at the magnet isocentre and was 56 cm away from the coil, as shown in Figure 1.b). We used a GE sequence (FLASH) and the following acquisition parameters: TR/TE=100/1.6 ms, FA=250, FOV=18x18 mm$^2$, matrix size=256x256, thickness=1 mm, NEX=2. All experiments were run in a 15.2T/11 cm MR imager (BioSpec, Bruker Co, Ettlingen, Germany).

III. RESULTS AND DISCUSSION

The coil quality factors were approximately: $Q_u/Q_l = 21/13$, and its noise figure (NF) was 10.5. This bench test results and the NF show a good performance of the bio-inspired coil. Radiation patterns were acquired for two differences distance and orientations, shown in Fig. 3. As expected, because the bioinspired surface coil has a symmetrical configuration, so the radiation pattern is necessary symmetrical.
Figure . Ex vivo mouse images acquired with the parallel-plate waveguide and bio-inspired coil.

There was no need to use high dielectric materials to conduct the signal at the right frequency [2]. These results are in very good concordance with results obtained at 3 T [4] and 9.4 T [5]. From these results, we can conclude that the MR signal can be transmitted regardless the resonant frequency and the magnet bore size, to acquire mouse images at ultra high field. In vivo experiments can be conducted under more comfortable conditions for the animal model. These results shows that travelling wave MRI with high SNR can be performed with a simple waveguide only.

IV. CONCLUSIONS

We have experimentally demonstrated that the use of PPWGs can produce good SNR images for relatively large fields of view via the travelling-wave approach. We have shown that the waveguide approach can also be used with magnetic field intensities larger than 7T and small-bore MRI systems. Overcoming the limitation of a cutoff frequency, as demonstrated in this work, provides further freedom of implementation in a variety of geometries and for multinuclear operation, or for measuring several or extended samples. Further investigation is required to explain the physical mechanisms involved in the RF signal with a dielectric non homogeneous object inside a waveguide and its implications on image quality. A natural step ahead is to extend this approach to acquire images of the entire human body. These results pave the way to a further implementation of the travelling-wave approach in other applications using lower magnetic field intensities and multinuclear experiments with bores of different dimensions.

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