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Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

2509

Flexible 8-Channel Array for Hyperpolarized ^{13}C at 3T (32.1 MHz), with Nearly Identical ^{23}Na (33.8 MHz) Sensitivity Profiles

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Synopsis

We describe the design of a flexible coil array tuned optimally for ^{13}C MRI at 3T (32.1 MHz), but with the coil coupling coefficients matched to be nearly identical at the ^{13}C and ^{23}Na (33.8 MHz) frequencies. In this way, the array provides the means to obtain accurate sensitivity profiles for hyperpolarized ^{13}C imaging from the high ^{23}Na naturally present in biological tissue. We show the feasibility of this approach, and compare the performance to other ^{13}C coils, showing that the ^{13}C SNR provided by this array is not compromised despite the modification to equalize the ^{13}C and ^{23}Na profiles.

Introduction

Hyperpolarized ^{13}C imaging is an emerging technique for accurate diagnosis of metabolic disorders[1]. Due to the short-lived nature of the hyperpolarized nuclei, parallel imaging is especially beneficial and has been successfully applied in hyperpolarized imaging with promising results[2]. However, it is not desirable to use the hyperpolarized signal to estimate the ^{13}C sensitivity profiles, and therefore some a priori estimation is needed. We propose to take advantage of the proximity of the ^{23}Na frequency (1.7 MHz difference at 3T) to design a ^{13}C receive array with a coupling matrix tailored such that the coupling levels are nearly identical at ^{13}C and ^{23}Na. In this way, the sensitivity profiles are expected to be similar. Some work has already been done to estimate the transmit parameters of the ^{13}C scans, from the ^{23}Na naturally present in biological tissue[3]. However, for receive arrays, the translation between frequencies is more challenging due to the frequency response of the preamplifier decoupling. We propose an array where the preamplifier decoupling is adjusted such that the coupling levels are nearly identical at the two frequencies. The basis for this design relies on having a high level of preamplifier decoupling, which can be obtained by mismatching the LNA to a higher impedance than the noise optimal in a controlled way[4]. Then, one can tune its response to an intermediate frequency between ^{13}C and ^{23}Na, and the coupling levels will still be low at both frequencies.

Materials and Methods

The coil array is made up of 8 loops of 80 mm of diameter each. Each loop is built with standard flexible copper coax (RG-316), where the outer jacket is used to create the conductive loop. The array is shown in Fig. 1. The measured unloaded-to-loaded Q-ratio for the individual elements is Q_U/Q_L=260/80 when loaded with a human head. The SNR variation as a function of frequency was measured for one of the array elements, as described in Fig. 2. The crucial design feature of the proposed array is that the level of decoupling provided by the mismatched preamplifiers should be as similar as possible for the two frequencies of interest. In this array, we match the coils to an impedance higher than the noise optimal of the LNA (WanTCom) in order to achieve preamplifier decoupling levels above 30 dB. With this level of decoupling, a sacrifice can be done at the ^{13}C frequency in order to match the coupling matrix at the ^{23}Na frequency. MRS measurements (CSI, 360×360×150 mm^3, matrix size = 24 × 24) were performed on a human head phantom filled with ethylene glycol doped with 17g/L of NaCl to emulate tissue loading. The TR used for the ^{13}C acquisition was 1 s (total acquisition time = 9 min 36 s), while for ^{23}Na, TR of 219 ms and 8 averages were used (total acquisition time 16 min 40 s). The sensitivity profiles and noise correlation matrices were measured for the two different nuclei. Finally, a ^{13}C SNR evaluation was performed[5] by comparison with a birdcage volume coil (RAPID Biomedical) and a rigid 8-channel array (GE Healthcare). All measurements were performed using a dedicated ^{13}C transmit coil of the clamshell type (RAPID Biomedical).

Results and Discussion

The results from Fig. 2 show that for a loaded coil, the SNR difference between the ^{13}C and ^{23}Na frequencies is about a factor of 2. In Fig. 3, the measured preamplifier decoupling response is shown, where the coupling level is observed to be nearly identical for all 8 channels. We also see that the difference between the optimal decoupling (obtained around 33 MHz) and the decoupling at ^{13}C and ^{23}Na frequencies is 6 - 7 dB. This is the level of coupling that we sacrifice with this design compared to an array optimized for ^{13}C. In Fig. 4a, the measured sensitivity profiles are shown. The similarities between the profiles at both frequencies are clear, though small variations are still present, which is expected due to the different B_1^+ generated by the transmit coil at the two frequencies[3]. Figs. 4b and 4c show the measured noise correlation matrices, which in general show low values and good agreement of the average correlation levels between ^{13}C and ^{23}Na. Finally, Fig. 5 shows the ^{13}C SNR level of the array compared to a volume coil and to a traditional array. This result confirms that the extra coupling that we accept at the ^{13}C frequency with this method has no notable effect on the final ^{13}C SNR performance. Regarding the SNR of the ^{23}Na acquisition, it should be mentioned that the flip angle used during this measurement is estimated to be 22° because the transmit coil used is not tuned for ^{23}Na, and its efficiency at that frequency is low.

Conclusion

A flexible 8-channel receive array for ^{13}C at 3T (32.1 MHz) has been built in such a way that the ^{13}C sensitivity profiles can be accurately obtained from measurements on the ^{23}Na nuclei that at 3T is only 1.7 MHz apart (33.8 MHz). We show that this design approach can provide a means to obtain accurate ^{13}C sensitivity profiles in cases where the low natural abundance of ^{13}C makes it impossible.

Acknowledgements

No acknowledgement found.

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Figures

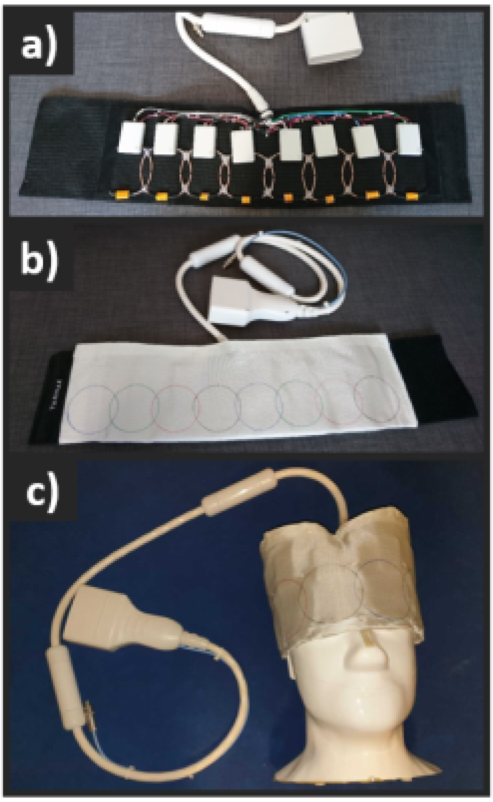

Figure 1. Fabricated flexible 8-channel ^{13}C receive array (f = 32.1 MHz): a) with the 8-elements visible sewn into a flexible cloth, b) covered with a flame-retardant protective cloth and, c) wrapped over the head-size phantom used for imaging. All the electronic components (matching network, active decoupling, LNA) are integrated into one PCB, and enclosed into an ABS box (60x35x15 [mm]).

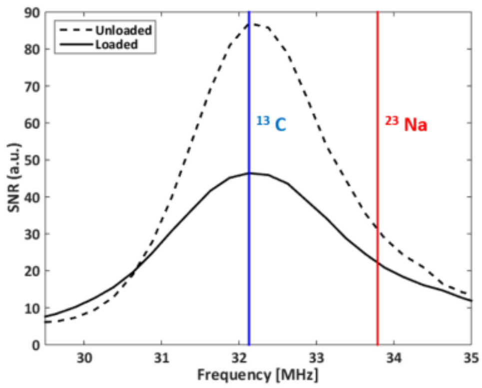

Figure 2. Frequency dependence of the SNR, measured on one of the array elements, with the coil unloaded and loaded. This measurement was done by exciting an RF tone through a pickup loop placed at a fixed distance of the coil element, and the measured spectrum was recorded with a spectrum analyser (PSA E4440A, Keysight, CA, USA). The excited tone was then swept over frequency, and the SNR was measured as the ratio of the recorded spectrum, divided by the average of a noise spectrum.

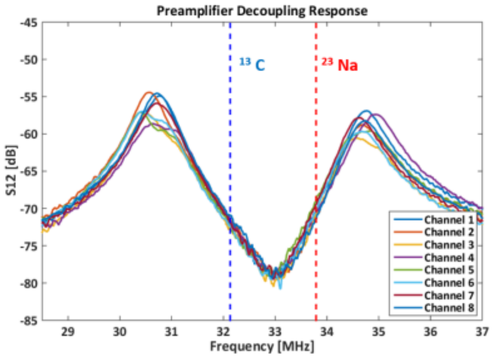

Figure 3. Measured S_{12} of a loosely coupled double-loop probe, where the frequency response of the coils (when connected to the preamplifier) can be observed. This response would normally be tuned to be minimum at the frequency of interests, but in this case we have tuned it to be similar at the ^{13}C and ^{23}Na frequencies.

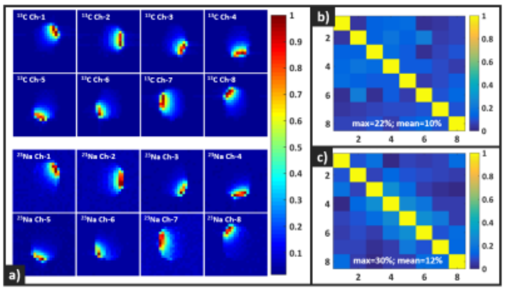

Figure 4. (a) Measured sensitivity profiles of the individual array channels for ^{13}C (top) and ^{23}Na (bottom). (b) ^{13}C Noise correlation matrix. (c) ^{23}Na Noise correlation matrix.

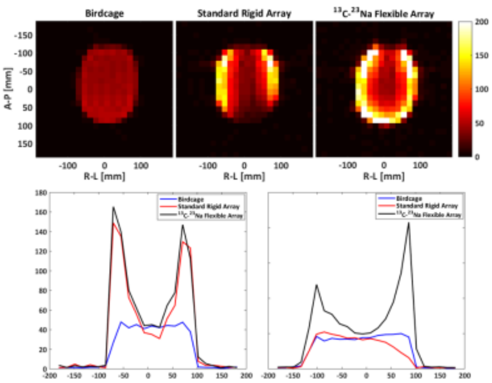

Figure 5. Measured SNR (a.u.) of the fabricated 8-channel flexible array, compared to a volume coil (of the birdcage type), and to a standard rigid ^{13}C 8-channel array (with two movable paddles of 4-channels each). More information about the reference coils is available in[5].