

Overhauser-enhanced MRI with SENSE Acceleration in the Johnson Noise Dominated Regime

Cristen D LaPierre¹, Mathieu Sarracanie^{1,2}, Brandon Dean Armstrong^{1,2}, Jonathan R Polimeni^{1,3}, and Matthew S Rosen^{1,2}

¹Department of Radiology, A.A. Martinos Center for Biomedical Imaging, Charlestown, MA, United States, ²Department of Physics, Harvard University, Cambridge, MA, United States, ³Harvard Medical School, Boston, MA, United States

Purpose: MRI acquisition at low magnetic fields can be time consuming owing to small Boltzmann polarization. Enhancement techniques such as Dynamic Nuclear Polarization (DNP) and image acceleration techniques like SENSitivity Encoding (SENSE) are compelling tools to obtain high-quality images in reasonable times. SENSE may be particularly well suited to low magnetic fields because the coil sensitivity profile is independent of the sample in this Johnson noise-dominated regime. The aim of this study was to incorporate Dynamic Nuclear Polarization (DNP) into our current eight-channel parallel imaging setup for imaging at 6.5 mT.

Methods: Previously we constructed an 8-channel, 276 kHz receive-only array¹ for our custom-built 6.5 mT electromagnet-based scanner² and demonstrated SENSE reconstruction. This setup has been dramatically improved to include the ability to perform b-SSFP based Overhauser-MRI (OMRI)³. A 14cm 140 MHz saddle coil for saturation of the electron spin resonance and a 30 cm 276 kHz solenoid for NMR transmit were constructed. A DNP image of a 13 cm structured phantom was acquired both with- and without SENSE acceleration (reduction factor $R=2$).

An assembly for repeatable positioning of phantoms and three coils was 3D printed in polycarbonate (Fortus 360 mc, Stratasys, Eden Prairie, MN, USA), thus ensuring the coil sensitivity profiles generated with a homogenous phantom align properly with the structured phantom (Figure 1), improving image reconstruction. Coil sensitivity profiles were acquired with the saddle coil in position but without DNP.

A 3D balanced Steady State Free Precession (b-SSFP) sequence with full Cartesian acquisition of k -space was acquired with FOV=304x170x60 mm³, acquisition matrix=130x128x3, TE/TR=25.2/50.4 ms, number of acquisitions (NA)=35 except for (b) where NA=140.

Results: Figure 2 shows a) the structured phantom and images obtained b) without DNP or SENSE, c) with DNP but not SENSE and d) using DNP and SENSE. The unenhanced image was acquired in 25.5 min. The DNP-only image was acquired in 11.5 min, and adding SENSE acceleration ($R=2$) reduced this time to 5.5 minutes at 6.5 mT.

Figure 3 shows the noise covariance matrix (a) and the correlation coefficient matrix (b) for the 8-channel array. The 8 channels are fairly well decoupled from each other. Channels 6 and 7 do appear to be not performing as well as the other channels. This could be due to interaction with the saddle coil, the air bubble or an anomaly of the data. It is not the same channel in a given matrix which suggests that both channels are working.

Discussion: Low SNR and long acquisition times are the primary hindrance to deployable MRI scanners. This study seeks to overcome both problems by using DNP to boost the signal strength and SENSE reconstruction to decrease acquisition time. With DNP alone, the SNR efficiency (SNR_{eff}) increased 23.4 fold while there was a 1.8 fold reduction in acquisition time. Combining DNP and SENSE, the SNR_{eff} decreased 22% and acquisition time decreased 4.6 fold. SNR_{eff} is max SNR in the sample normalized by the square root of NA.

Techniques that can increase signal intensity or reduce scan time are needed to keep acquisition times low. Parallel imaging arrays allow us to implement SENSE, reducing scan times by a factor of two or more. DNP provides a means of increasing the proton signal by factors as high as 75.

Conclusions: These results represent the first use of DNP hyperpolarization combined with SENSE acceleration attained at 6.5 mT and represent important steps towards accelerating hyperpolarized imaging at low field. Future work will improve SENSE reconstruction as well as compare it to incoherent random undersampling strategies.

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References: 1. LaPierre CD, et al. ISMRM 2013 #2772
2. Tsai LL, et al. J Magn Reson. Aug 2008;193(2): 274-85
3. Sarracanie, M, et al. Magn Reson Med. doi: 10.1002/mrm.24705

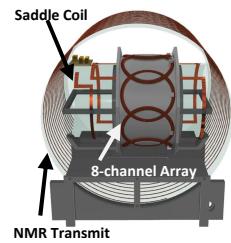


Figure 1. Full DNP + SENSE assembly. The NMR transmit and 8-channel receive are tuned to 276 kHz while the DNP coil is tuned to the EPR frequency at 6.5 mT of 140 MHz.

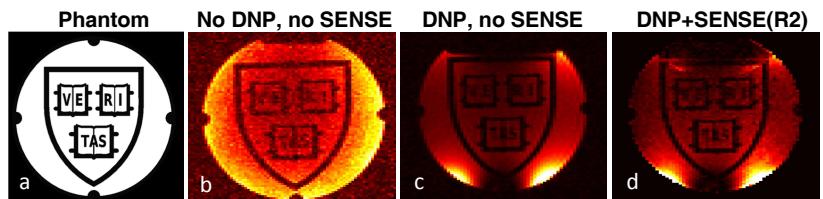


Figure 2: a) Structured phantom (13cm diameter) b) parallel image with no DNP and no acceleration (SNR_{eff} : 3.2; total acq. time 25.5 min) c) parallel image with DNP and no acceleration (SNR_{eff} : 75.0; total acq. time 11.5 mins) d) parallel image with DNP and SENSE acceleration ($R=2$, SNR_{eff} : 2.5; total acq. time 5.5 mins). SNR_{eff} is max SNR normalized by the square root of NA. Color scales are not identical.

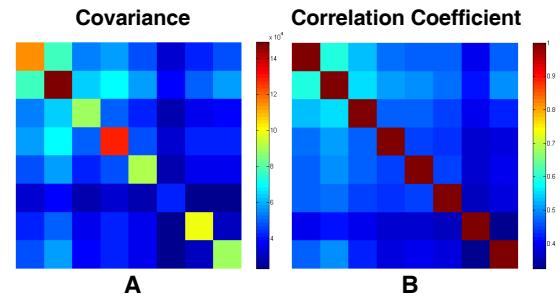


Figure 3. Noise covariance (a) and correlation coefficient (b) matrices for an 8-channel array assembled with NMR transmit and DNP saddle coils.