Stability of alternating bSSFP signal in the presence of driving perturbations

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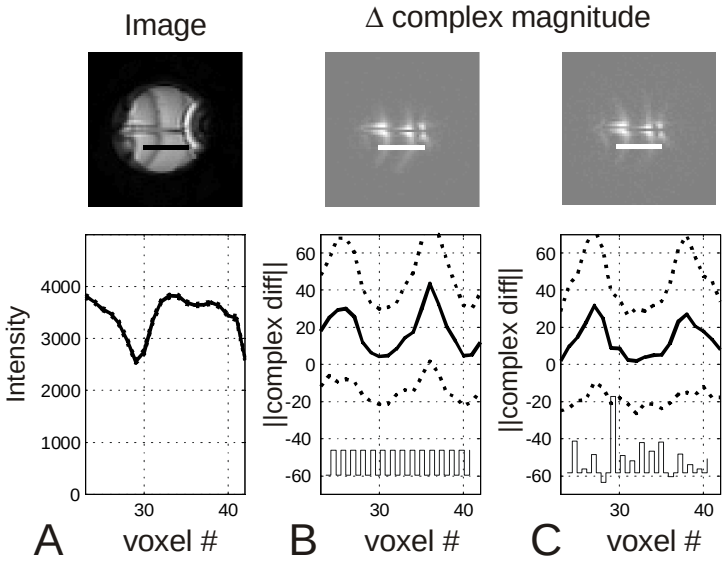
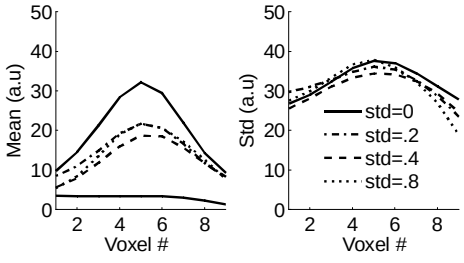
Introduction. Recently a number of researchers have explored a possibility of using MRI to detect currents generated during neuronal activity in the brain (e.g. Bodurka and Bandettini, 2002; Bianciardi et al., 2004; Petridiou et al., 2007). We have previously demonstrated that an MRI imaging method based on alternating balanced steady states (ABSS) is more sensitive to weak magnetic fields than traditional GRE or SE methods (Buracas et al., 2008).

To date, however, ABSS analyses and experiments have been performed assuming a deterministic periodic driving force (i.e. deterministic alternating current). Neuronal responses in the brain, however, are inherently highly variable. In fact, individual neurons are often characterized using Poisson noise, for which variance is equal to the mean. Therefore, in order for the ABSS method to be potentially applicable for neural current MRI (ncMRI), it is critical for it to be insensitive to a large variation in the neuronal response magnitude. We have addressed the sensitivity of the ABSS signal to amplitude variations of the driving periodic current pulses by means of MRI experiments on an agar current phantom. Our preliminary results suggest that the ABSS signal exhibits a high degree of stability and only moderate signal reduction in the presence of strong perturbations akin to those found in cerebral cortical responses.

Methods. A spherical current phantom 100mm in diameter filled with agar was used. The phantom recipe used $NiCl_2$ and an agar mixture such that T1 and T2 (~1000/110ms) were comparable to grey matter. An insulated copper wire was placed in the middle of the phantom along the X-Y direction and perpendicular to the B_0 vector of the 3T scanner. The applied current alternated with each RF pulse between 0 and a current pulse of variable amplitude. The amplitude of the pulses (applied on every other TR) was drawn from the Gaussian random distribution with mean=100μA and standard deviation for different scans set to one of the following values: 0%, 20%, 40%, 80%, and 160% of the mean. The current pulses were synchronized (precision of 20μs) to the scanner RF pulses via an analog output port of a National Instruments I/O card that received trigger TTL pulses from the scanner. Images were acquired using GE 3T Signa HDx with a knee quadrature coil. A balanced SSFP sequence with single shot spiral-out readout (TE=3.3ms, TR = 31msec, nreps = 1000, FOV=18cm, 64x64 matrix, 3mm slice thickness) was used to acquire a single axial slice through the plane containing the wire inside a current phantom. A static linear gradient (~.5 G/m) along the X axis was applied, which resulted in a characteristic periodic banding artifact (see A panel of figure to the right). The image and modulation profile (corresponding to the bSSFP off-resonance profile) was explored at the distance of 33mm from the wire (indicated by a bar under the wire in the top row panels of the figure above). According to Biot-Savart law for a straight conductor, at this distance the 100μA current results in magnetic field perturbations of ΔBz=0.6nT. We have explored the variability of the ABSS signal as a function of the amplitude variability of the periodic driving current for standard deviation values of the following fractions of the mean: 0, 0.2, 0.4, 0.8, and 1.6. Modulation patterns were calculated as the mean absolute value of the complex difference between odd and even steady states.



Results. A typical modulation pattern induced by deterministic periodic current pulses is shown in the figure above, panel B. The. The graph underneath displays the mean (continuous line) and standard deviation (dotted line) as a function of spatial location, marked by a white bar on the modulation image above (and hence, off-resonance). The jagged line at the bottom symbolizes the deterministic periodic driving signal. Panel C of the figure above displays the modulation pattern and the off-resonance profile for the case when the variability of the current pulses was 0.8 of the mean (symbolized by the jagged line at the bottom). Remarkably, the pattern of modulation is preserved for such a high variability, but the maximum of the modulation profile is reduced by ~ 30% as compared to the deterministic case. Interestingly, the variability of the ABSS signal is not affected noticeably by the variation in the input signal. The figure on the right displays the mean and standard deviation profiles of the signal around the off-resonance profile peak as a function of voxel location (smoothed with a Gaussian kernel, stdev=3 voxels). The mean modulation decays as the amount of the injected noise increases (left panel), but the standard deviation of the modulation (right panel) remains virtually indistinguishable for the range of input variability used and is dominated by the scanner thermal noise.



Discussion. Our results suggest that ABSS is remarkably insensitive to large fluctuations in driving force, given that it is applied periodically on every other TR. Fluctuations with standard deviation as large as 100% of the mean (i.e. compatible with the Poisson noise observed in cerebral neuronal networks) result in relatively stable alternating steady states albeit at reduced magnitude. Such high stability of the ABSS signal is likely to be due to the interplay of (i) ABSS integration time comparable to T2 and (ii) the fact that the power of the stochastic envelope waveform is concentrated in bands that do not overlap the alternation (i.e. carrier) frequency.

References. Bodurka J and Bandettini (2002) Magn. Reson. Med., 47, 1052-8; Bianciardi et al. (2004) Magn. Reson. Imag., 22, 1429-40; Buracas et al. (2008) Magn. Res. In Med.,59, 140-8; Petridiou et al. (2006) PNAS, 103, 16015-20. *Supported by NIH/NIBIB R21EB008187.*