Influence of RF Synthesizer Phase Noise on MR Imaging Stability

M. Nisznansky[1], J. Stapf[1], M. Vester[1], P. Hoecht[1], J. Bollenbeck[1], and W. Schnell[1]
[1]Siemens AG Medical Solutions, Erlangen, Germany

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Introduction

Functional magnetic resonance imaging (fMRI) is able to detect active areas in brain. This imaging method is demanding on the MR scanner's radio frequency (RF) and gradient stability and a signal-to-noise ratio (SNR) of the acquired images since the detected signal changes are quite small [1]. Therefore, the noise and stability contribution of each scanner component has to be carefully evaluated. Experimental results presented below show that phase noise of the employed RF synthesizer has considerable influence and may degrade the scanner's fMRI performance. Thus we investigated the physical mechanisms of the phase noise influence on the echo planar imaging (EPI), which is mostly employed in the fMRI experiments, in order to estimate the phase noise requirements for the RF synthesizer.

Methods

Since many MR scanner components contribute to the image-to-image instability it was necessary to make the synthesizer phase noise dominant and minimize relative contribution of other components to the overall instability. For this purpose, relatively strong artificial phase perturbations were introduced into a highly stable RF synthesizer. Since the phase perturbations were generated in a digital way, it was easily possible to change basic noise parameters like phase variance and power spectral density. Furthermore, it was possible to activate this perturbation exclusively at the time of transmission or reception. The experimentally observed image-to-image instability was statistically evaluated similar to the Weisskoff method [2]. A number of image series has been acquired, each with constant phase noise parameters. First, the mean signal intensities for a region of interest (ROI) 10x10 pixels were calculated in each image in the acquired series. Second, the relative variance of the ROI mean signal intensity over a whole image series was calculated. Our goal was to observe how the image intensity variance is affected by the change of phase noise parameters during transmission or reception. A modified 1.5T MR scanner and a standard EPI sequence have been used for image acquisition. A cylindrical phantom with a diameter of 115mm filled with a saline solution was applied as the scanned object. Furthermore, some simplified MR system simulations were performed using the numerical calculation tool MATLAB® in order to get a better understanding for the physical background of our experimental results.

Results

Phase noise is a random phase fluctuation of a sinusoidal signal generated by an oscillator. This relatively small random phase fluctuation gives rise to two side-bands in the RF synthesizer's output spectrum [3]. The RF synthesizer phase noise can affect MR imaging in two independent ways. The first one is during transmission while applying an RF excitation pulse, and the second one is during reception of a MR signal. Since EPI is a single shot sequence and the repetition time was chosen much longer than the spin relaxation times, a scan-to-scan interaction was excluded.

At the time of transmission, a slice selection gradient is applied. Therefore, the spin resonance frequency is spatially dependant and the phase noise side-bands can excite two additional adjacent slices in the scanned object. These two undesired slices contribute to the received MR signal and can interfere with the signal from the excited slice of interest as shown in Figure 1 on the left side. However, these two side-bands represent only phase perturbation of the wanted signal in the frequency-domain, and this perturbation signal is orthogonal to this wanted signal. It can be simply shown that such phase perturbation cannot directly affect the resulting signal intensity in the reconstructed images. Therefore, a second coexisting effect has to be considered to explain the measured image intensity variance caused by the phase noise at the time of transmission. This is a weak B_0-field inhomogeneity caused by the magnetic susceptibility of the scanned object. The B_0-field inhomogeneity can convert the phase perturbation into an amplitude perturbation, since the spins in the adjacent slices resonate at slightly different frequencies than the spins in the main slice. Therefore, the signal from adjacent slices is no longer orthogonal to the signal from the main slice and can affect the resulting amplitude of the MR signal and the image intensity. This hypothesis has been verified by two further experiments using a disc and a spherical phantom.

At the time of reception, the signal from the RF synthesizer is used for down-conversion of the received MR signal to a low intermediate frequency (IF) where it can be digitized by a high performance analog-to-digital converter. If the signal from the RF synthesizer carries phase noise side-bands then the spectrum of the digitized MR signal in the IF band is affected by these side-bands as well. These reciprocal mixing products can be seen after image reconstruction as ghosts of the main object as shown in Figure 1 on the right side. Since the phase noise side-bands are incoherent random signals the resulting ghosts are blurred. These undesired ghosts interfere with the desired object and cause a random signal intensity variation in the reconstructed images.

In addition, our experimental results show that the EPI image stability has a different sensitivity on particular spectral components of the phase noise as shown in Figure 2. In this experiment, an artificial narrow-band phase noise with a constant phase variance but a variable centre frequency was applied in the RF frequency synthesizer. It could easily be seen that the fMRI sensitivity on phase noise during the RF pulse transmission is considerably different than during the MR signal reception. The physical background of this observed behaviour will be discussed in detail in our presentation.

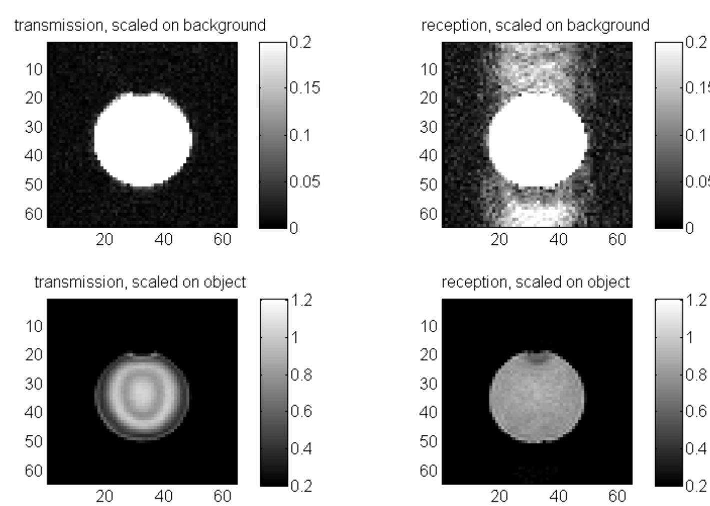

Figure 1: Measured influence of phase noise on EPI images

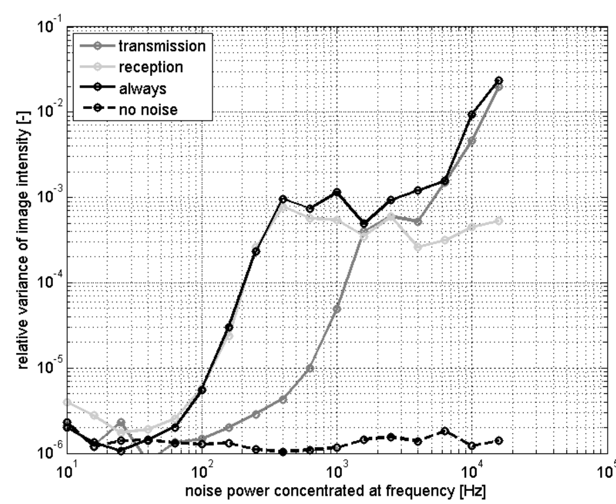

Figure 2: Influence of phase noise spectral components on image stability

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