# A Calibration for Radial Imaging with Large Inplane Shifts

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## Motivation:

Radial k-space trajectories are increasingly preferred over Cartesian acquisition schemes, especially in interventional MRI mainly for three reasons:

1. In radial imaging structures from outside the FOV are not folded into the FOV as they are in Cartesian acquisition schemes in the phase encode direction. This enables one to work effectively with FOVs substantially smaller than the imaged object.
2. In radial imaging the sampling density is proportional to 1/r, allowing interpretation of severely undersampled images.
3. Every radial line passing through the center of k-space is ideally suited for sliding window reconstruction techniques.

One drawback of radial k-space sampling is the required fidelity of the k-space trajectory which is higher than for Cartesian imaging. The deviations from the ideal trajectory can be determined using calibration measurements and can be compensated for in the sequence or during image reconstruction. The fidelity of the k-space trajectory is determined by the gradient shapes actually played out and the relative timings between the gradients on the three physical axes and the acquisition of the spin signal.

In addition, there is another relative timing that is only critical in radial imaging but not in Cartesian: The relative timing between signal acquisition and reference signal. For large inplane shifts of the FOV such a shift will lead to artefacts in radially acquired images as shown in Figure 1a.

## Background:

Shifts $\Delta x$ of the FOV away from the gradient isocenter in the read-out direction are realized by multiplying the spin signal with a reference signal $S_r = \exp(-i*(\omega*t + \phi))$, where $\omega = G*\Delta x$ with G being the applied gradient.

The control software calculates the initial phase $\phi$ of the reference signal $S_r$ so to aim for it's phase, $\omega*t_{DC} + \phi$ to be zero at the special data point $t_{DC}$. Here $t_{DC}$ is the data point that the FFT converts into the DC component; it represents the integral of the complex 1D-image. Any unaccounted for timing shift between acquisition and reference signal would make the phase of the data point $D(t_{DC})$, acquired at time $t_{DC}$, dependent on $\omega$ and thus on the off-center shift $\Delta x$ in the read-out direction. The reference and MR signals can be delayed with respect to each other due to various signal processing and routing steps.

In Cartesian imaging a subtle timing shift $\Delta t$ can be safely ignored because all k-space lines are parallel and thus share the same $S_r$ . A timing shift $\Delta t$ only adds a constant phase to the image that varies with $\Delta x$. In radial imaging however, each line has a different read-out direction and thus is multiplied with a different reference signal $S_r$ . For $\Delta x! \neq 0$ this results in a harmonic phase variation of $D(t_{DC})$ with the readout direction.

The resulting characteristic image artefacts are shown in figure 1a, measured off centered by about ½ FOV with a radial TrueFisp sequence.

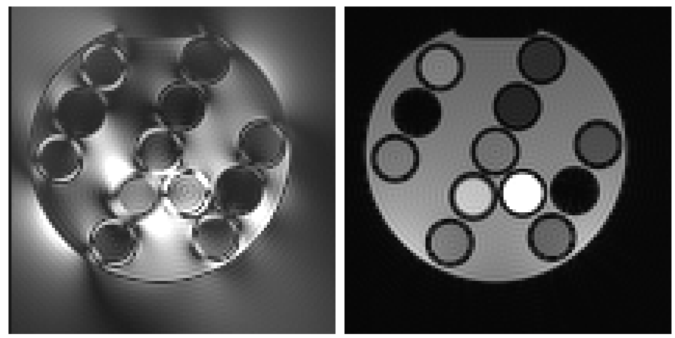

**Figure 1:** transverse image plane cut through phantom, FOV = 400mm, inplane shift = 193mm, phantom diameter = 129mm, BW=560Hz/pixel, base resolution = 256.

a) without correction
b) with clock shift correction

## Measurements and Results:

The timing shift between data acquisition and reference signal was determined using phantom calibration measurements: The same Cartesian gradient echo central k-space line was measured for 256 FOV shift values in the read-out direction with twofold oversampling. The phantom was chosen small enough to fit into the FOV for all shift values. The values of $D(t_{DC})$ were extracted for each FOV shift. Measurements were carried out on Magnetom Avanto (Siemens AG, Erlangen).

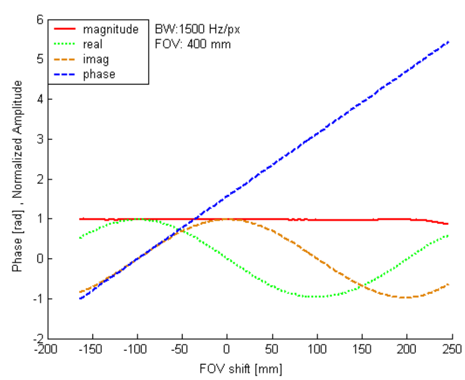


**Figure 2:** mean signal of image (=$D(t_{DC})$ ) vs. shift of FOV, 256 samples, FOV=400mm, twofold oversampling

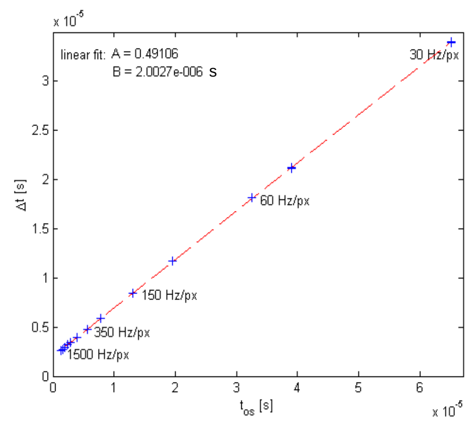


**Figure 3:** measured shift $\Delta t$ measured for varied BW vs. dwell time $t_{os}$.

Figure 2 shows an example data set of $D(t_{DC})$ versus off-center shift. While the amplitude stays constant, the phase varies linearly with the FOV shift. The corresponding timing shift $\Delta t$ is determined from the slope of the phase plot.

The dependency of $\Delta t$ on a variety of measurement parameters such as FOV, resolution, BW and sequence type was studied. Figure 3 shows as an example $\Delta t$ as a function of BW plotted versus $t_{os}$. It turns out that on one system $\Delta t$ depends only on the inverse oversampled sampling rate $t_{os}$ and can be represented by a linear equation $\Delta t = A*t_{os} + B$. The value of coefficient A was determined to be $0.495 \pm 0.011$. The value of coefficient B was determined to be $(1.97 \pm 0.05)$ µs.

The timing shift model was then incorporated into the radial TrueFisp sequence by adding for each projection $(A*t_{os} + B)*\omega$ to the phase of the reference signal $S_r$. The quality of the correction is demonstrated in figure 1b.