# Investigation of the frequency response characteristic of the MRI signal receiver system as a factor contributing to the formation of Nyquist ghosting in Echo Planar Imaging


I. Delakis[1], K. Petala[1], J. P. De Wilde[1]

[1]Department of Bioengineering, Imperial College London, London, United Kingdom


## Introduction

During signal acquisition the readout gradient assigns a frequency ($\omega_x$) to each location (x) in the readout direction. The signal receiver system responds differently to the frequency components of the signal, as described by its frequency response characteristic, denoted here by F(ω). As a result of the receiver system's behaviour, signal originating from location x is weighted by $F(\omega_L+\omega_x)$, where $\omega_L$ is the Larmor frequency. Previous studies have identified the role of the receiver system with respect to image uniformity and signal intensity (Hoult and Richards 1976, Willkinson et al. 1990, Simmons et al. 1998). The purpose of this work was to analyse the effect of the receiver system on an additional image quality parameter, namely Nyquist ghosting in Echo Planar Imaging (EPI). In EPI, the readout gradient changes polarity between successive signal acquisitions. As a result, for signal originating from location x, the signal weighting factor introduced by the receiver system's frequency response characteristic alternates between $F(\omega_L+\omega_x)$ and $F(\omega_L-\omega_x)$ for successive signal acquisitions. This signal weighting discontinuity between odd and even k-space lines contributes to the formation of Nyquist ghosting.

## Methodology

Experimental work was undertaken on a 1.5 T MRI system (Signa, GE Medical Systems, with echospeed-plus gradients). A cylindrical test object (height: 21 cm, diameter: 20 cm) filled with water was imaged axially with EPI in the centre of the birdcage quadrature transmit-receive head coil.

In the first set of experiments, the conductivity of the water in the test object was increased progressively with the addition of 1.0 g of NaCl between EPI acquisitions. This way, the loading of the imaging coil and in turn the frequency response characteristic of the receiver system changed between consecutive scans. The imaging protocol for the first set of experiments was: Gradient-echo EPI, TE=117.7 ms, TR=1500 ms, matrix (real)=256×256, slice width=5 mm, FOV=40×40 $cm^2$, NSA=1, ramp-sampling=on, bandwidth= not supplied when ramp-sampling is on.

In the second set of experiments, the conductivity of the water in the test object was kept constant and EPI images were acquired at several different bandwidths. This way, the effective frequency range of the receiver system's frequency response characteristic changed between consecutive EPI acquisitions. The imaging protocol for the second set of experiments was: Gradient-echo EPI, TE=180 ms, TR=1300 ms, matrix (real)=128×128, slice width=5 mm, FOV=51×51 $cm^2$, NSA=1, ramp-sampling=off, bandwidth= 22 different values between 31.25 kHz and 238.10 kHz. The test object was imaged with two different levels of conductivity of the containing water, equal to 1 mS/cm and 3 mS/cm, respectively.

Nyquist ghosting on each of the acquired images was calculated as:

Nyquist Ghosting (%)=100 [(mean intensity in Nyquist ghost area)-(mean background intensity)]/(mean intensity in signal area)

where the mean intensity in Nyquist ghost and signal area were the average intensity of pixel values in the respective areas, as selected with a free-hand Region Of Interest (ROI). The mean background was the average intensity of pixel values in a 20×20 pixel ROI in the image background in areas not affected by Nyquist ghosting (thermal noise only).

## Results

Results from the first set of experiments (see Figure 1) showed that Nyquist ghosting decreased as water conductivity increased. This result can be attributed to the increase of coil loading and the consecutive depression of the receiver system's frequency response characteristic with the increase of water conductivity. As the frequency response characteristic becomes more level, its effect on signal variation between consecutive k-space lines becomes less pronounced and Nyquist ghosting decreases.

Results from the second set of experiments (Figure 2) showed that Nyquist ghosting decreased as image bandwidth decreased. At small image bandwidths, the variation of the frequency response characteristic is limited within a smaller bandwidth range, hence its effect on signal discontinuity between consecutive k-space lines becomes less pronounced and Nyquist ghosting decreases.

## Conclusions

We have identified the frequency response characteristic of the signal receiver system as a factor contributing to the formation of Nyquist ghosting in EPI. Experimental results showed that Nyquist ghosting decreased when coil loading increased and image bandwidth decreased.

## References


Hoult DI, Richards RE. 1979. Jour. Mag. Res. 34:425-433

Wilkinson ID, McRobbie DW, Lunt JA, Williams JL. 1990, Eurospin 25:91-103

Simmons A, Tofts PS, Barket GJ, Arridge SR. Br J Radiol. 1998. 71(841):59-67


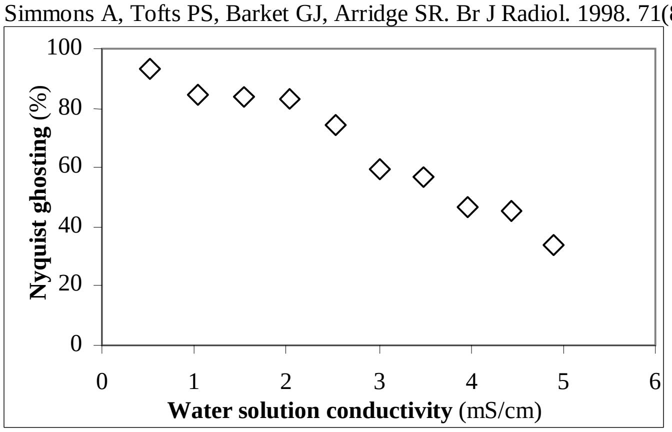


**Figure 1**: Nyquist ghosting for different conductivity levels of the water in the imaged test object.

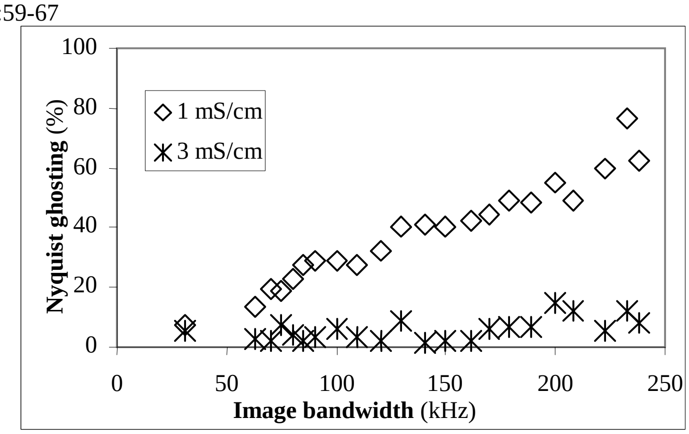


**Figure 2**: Nyquist ghosting for different image bandwidths and for two conductivity levels of the water in the imaged test object.