Dynamic Range Requirements for MRI

R. Behin[1], J. Bishop[1], R. M. Henkelman[1,2]

[1]Mouse Imaging Centre, Hospital for Sick Children, Toronto, Ontario, Canada, [2]Department of Medical Biophysics, University of Toronto, Toronto, Ontario, Canada

Introduction

The frequency space (*k*-space) domain of magnetic resonance imaging (MRI) is highly peaked at the centre (low spatial frequencies) and falls off rapidly toward the periphery of *k*-space. Accurate digitization of this space requires representation both at the maximal central point and at the thermal noise level of the system. This range in signal intensity is typically referred to as the dynamic range (DR). This abstract illustrates through experiment the linear relationship between log magnitude and log radius of *k*-space. This relationship can be used to determine the range in *k*-space signal magnitude for any scan resolution. A standard 75 µm isotropic 3D scan of a whole body mouse is compared with a dual gain scan capturing the entire dynamic range [1]. Finally, a method is given to determine the dynamic range requirements for any MRI setup.

Methods

An experiment was set up to capture the entire dynamic range in a whole body mouse MRI scan. Measurements were made using a Varian Unity*Inova* NMR spectrometer (Varian Inc., Palo Alto, CA) with a 7 Tesla magnet. A 3D scan was set up using a spin echo sequence, TE/TR 19.15/600 ms, FOV of 30 mm x 30 mm x 100 mm with isotropic voxel resolution of 75 µm. This produces 400 x 400 x 1330 complex *k*-space sample points in an imaging time of 26 hours. A fixed mouse perfused with Gadolinium (Gd) was inserted into a Varian Millipede coil (30 mm dia., 110 mm long) and imaged twice consecutively using a standard/low gain setting and a much higher gain setting (42 dB higher) to allow proper sampling of the thermal noise floor. Overlapping data points with good *SNR* from the low gain scan and unsaturated points from the high gain scan were used to determine the amplitude and phase shift from the gain switch. This correction was applied to the low gain dataset and the two datasets were combined using 64 read lines from the centre of *k*-space in the low gain dataset.

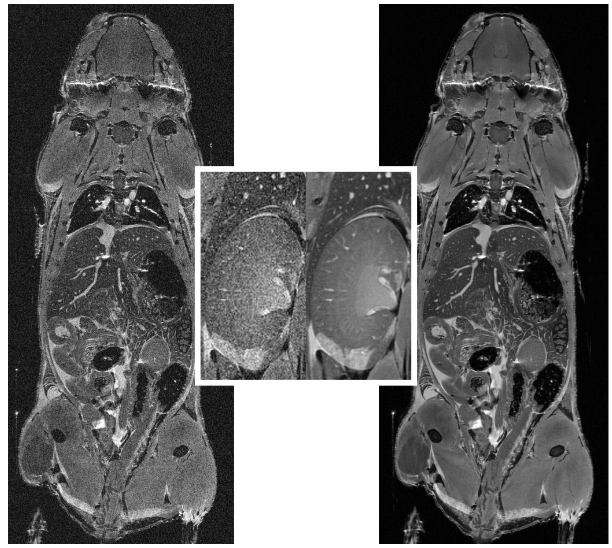

Figure 1. 75 µm whole body mouse scan with kidney insert using a standard gain setting on the left (xSNR = 2.6) and a combined dataset with low and high gain *k*-space samples on the right (xSNR = 20.9)

Results

Figure 1 shows the improvement in image SNR from the standard/low gain 75 µm scan on the left compared to a 75 µm image composed from the combined dataset on the right. The zoom in on a kidney shows much greater detail due to the improvement in voxel SNR (xSNR). xSNR, calculated as the mean of the whole mouse body magnitude image (signal) divided by the mean of the background magnitude image (noise), is 2.6 for the standard/low gain scan image and 20.9 for the combined dataset image which is an 8 fold improvement. Figure 2 shows the mean magnitude *k*-space points for both the low gain and high gain scans; the high gain dataset is level adjusted for comparison with the low gain dataset. The characteristic slope of the combined dataset can be seen to be -1.55 This slope is very similar to the results obtained by Fuderer [2] and Watts [3]. The low gain noise floor shown in dashed red is dominated by the quantization noise of the quadrature pair of analog-to-digital converters (ADCs) whereas the high gain noise floor shown in dashed blue is the thermal noise floor from the receiver.

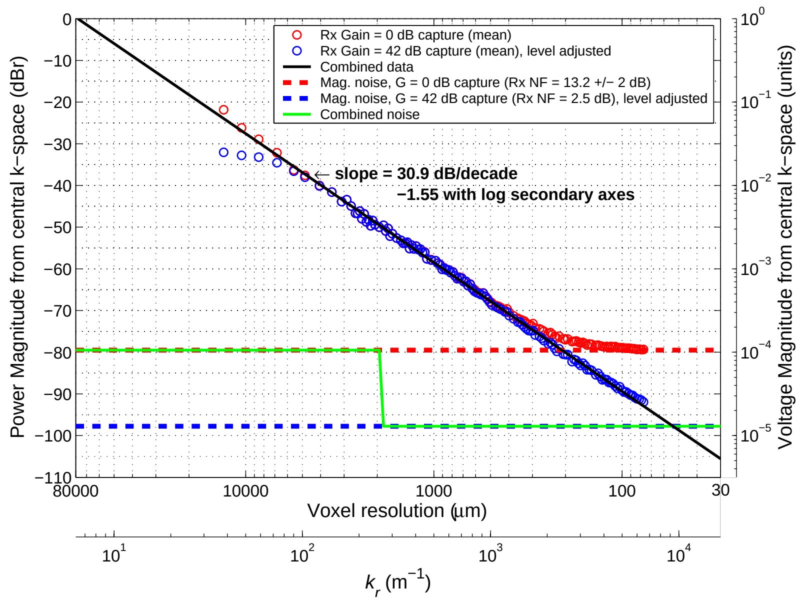

Figure 2. Log magnitude versus log *k*-space radius for whole body mouse scan.

Dynamic range requirements. To determine the dynamic range requirements for proper digitization in a particular MRI setup, the maximum signal and the thermal noise floor of the receiver is needed. For the whole body Gd infused fixed mouse in a 7 Tesla magnet the central *k*-space sample has a maximum signal of -20 dBm. The best noise figure (*NF*) of the receiver at a high gain setting is 2.4 dB at 50 Ω. Therefore, the thermal noise power (N_{out}) from a standard imaging bandwidth (*BW*) of 50 kHz is -124.6 dBm using:

$$N_{out} = -174 + 10 \cdot \log_{10} BW + NF \text{ (dBm)} \qquad [1]$$

Placing the quantization noise floor 10 dB below the thermal noise floor ensures minimal addition to the total noise floor. 3 dB of margin is placed from the full scale of the ADC to the maximum signal to cover a common step size of 2 dB with 1 dB variation in variable gain amplifiers. Therefore, the overall dynamic range required to properly digitize this system is 117.6 dB or 20 bits (Figure 3). A stronger magnet would increase the maximum signal thus increasing the required dynamic range.

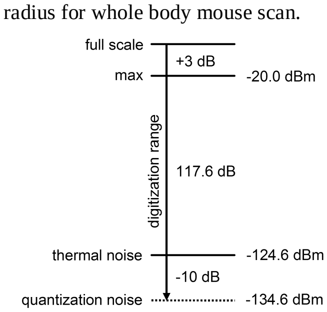

Figure 3. Dynamic range requirements for digitization of a whole body mouse at 7 Tesla over a bandwidth of 50 kHz with a receiver noise figure of 2.4 dB

Conclusion

Ideally an MRI receiver should be able to digitize the full range of signals from the maximum at the central *k*-space point to the thermal noise level of the receiver. The usual 16 bits may not be enough and its limitations become apparent in high resolution scans. A simple method has been presented to determine the dynamic range requirements of any setup. A whole body mouse scan in a 7 Tesla magnet requires 20 bits of dynamic range.

References

[1] Elliott MA, et al., J Magn Reson 130:300-304, 1998.
[2] Fuderer M, IEEE Trans Med Imag 7:368-380, 1988.
[3] Watts R, et al., Magn Reson Med 48:550-554, 2002.