

MRI Dynamic Range: Theory and Measurement

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Introduction. We have undertaken MRI dynamic range (DR) measurements in order to determine compatibility of MR multicoil images with fiber optic signal transmission. Our results indicate that such links should be viable at 3T and possibly higher.

The number of coils in phased arrays is increasing as manufacturers add receive channels and MRI researchers pursue increased spatial resolution and effective parallel imaging. Arrays with 32, 64, 96 and 128 coils have been reported (e.g. [1-5]). Electrical interactions among these coils and cable connections to the system interface, and also between cables and the applied RF and gradient fields, can be problematic. A number of research groups have therefore begun to develop fiber optic or wireless links between MRI coils and the MRI system [6-11]. Optical or wireless systems may have limited dynamic range (DR), however, so it is important to accurately determine this parameter. Many estimated DR values have been very high, however: 125 dB for a head scan [12], 150 dB [13] and 193 dB [14], also for human scans..

We have measured the DR of a number of head, spine and cardiac images using a variety of coils and common 2D and 3D MRI protocols at 3T. The signal at the center of k-space contains the maximum signal which is approximately the sum of signals from the entire sensitive volume. We have measured this maximum and have also developed an improved estimator for deriving DR from image data. Image-derived DR tends to overestimate the true DR found in the input signal (k-space center peak) because of partial cancellation of data from various portions of the sensitive volume. The noise figure from the optical or wireless link must be taken into account to determine the final DR value [15]. DR scales as a function of phased array element size, and the measured values appear to be compatible with commercial optical fiber technology [16].

Theory k-space data is the raw signal which has a peak at the center of k-space. The ratio of this peak to the noise is the DR. Most MRI procedures discard the raw data signals. We show that it is possible, however, to obtain a good estimate of the DR from the magnitude signal given by the

formula $DR = (1/\sigma\sqrt{N}) \sum [\text{sgn}(M_n^2 - a\sigma^2) \times \sqrt{M_n^2 - a\sigma^2}]$, where M_n is the magnitude signal for the nth image point and σ is the noise standard deviation. $a = 2.2 - 0.4(M_n/\sigma)$ for $M_n/\sigma < 3$, $a = 1$ for $M_n/\sigma \geq 3$ and sgn is the "signum" or sign function. This approach allows negative contributions to the DR sum and is an improvement over previous attempts to subtract noise from magnitude images (e.g. [17-19]).

Setting the digitized least significant bit equal to the rms Gaussian noise is equivalent to an NF=0.35 dB and thus adds negligibly to the DR.

Measurements. Head, spine and cardiac images were acquired on a Philips Achieva 3.0 T system using a birdcage and 8-channel multicoil array for the head and 6-channel multicoil arrays for the spine and cardiac images. Raw signals were examined for each coil in multicoil arrays and DRs were calculated from the resulting magnitude images using the formula above to see how closely these results agreed with those obtained from k-space.

Figure 1 below shows k-space DRs for different coils and imaging targets. 2D human images had k-space DRs below 75 dB and 3D had k-space DR below 80 dB. The cardiac and spine multicoil arrays have k-space DR below 60 dB. Figure 2 shows the comparison between the k-space DR values and image DRs derived using the formula above to compare these results with those obtained from k-space. The 2D k-space DRs and image DRs are very close. The 3D image DRs are substantially higher than the 3D k-space DRs, showing that the larger region of signal for 3D scans has significant phase cancellation that reduces the required DR.

Discussion and Conclusions. DRs for human images are not as high as some workers have thought. Commercial fiber optic systems (e.g. [16]) have spurious free dynamic range SFDR~104 dB and noise figure NF~10 dB. Reducing the optical device noise effect to 1 dB on the system NF requires a low noise preamp with gain ~ 15 dB. This still gives considerable leeway for operation with the spine and cardiac multicoils. The present head multicoil array is marginally compatible with the fiber optic system. Changing its long rectangle elements to small loops would improve that margin.

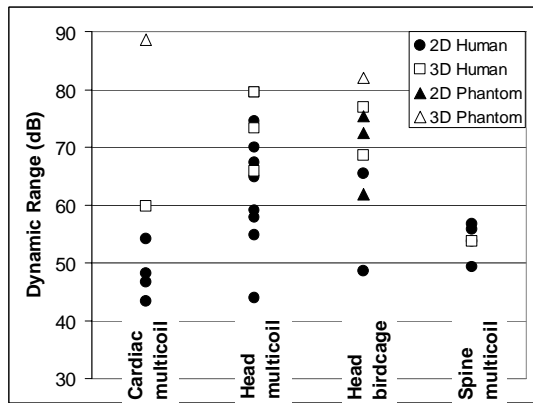


Figure 1. k-space DR for 3T images.

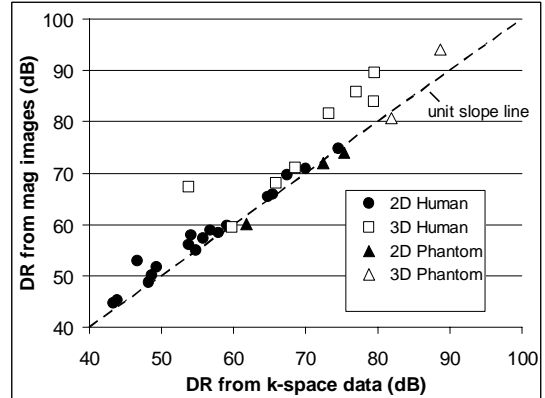


Figure 2. Image DR mages vs k-space (signal) DR.

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