Measuring the Gradient Subsystem Bandwidth at 7T

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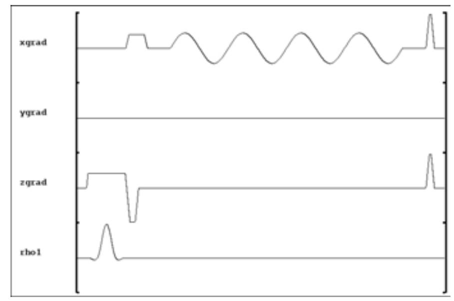
INTRODUCTION

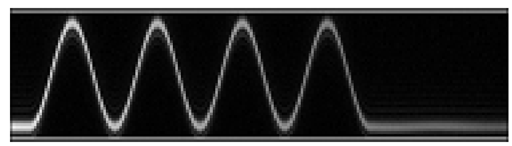
Gradient trajectory mapping using a self-encoding gradient has been used since the early days of human MRI to characterize the actual response of the gradient system to a shaped gradient waveform, with the aim of correcting the waveform for distortions produced by eddy currents [1-3]. Similar methods are used here to characterize the frequency response of the gradient system, in order to identify the usable frequency range for gradient waveforms for spatial-spectral RF pulses, which require higher spectral bandwidths at 7T than at lower field strengths. At higher fields, gradient vibration through the static field due to Lorentz forces can produce a significant electromotive force (increasing quadratically with field strength) which must be compensated by the amplifier. Near a mechanical resonance, this motion, and hence this voltage, will become quite severe.

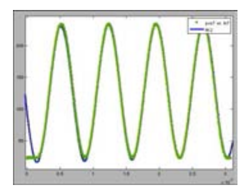


METHODS

These data were acquired with a Signa 7T Human Research MR System running 12.0 software, using a TRM gradient and a single HFD gradient amplifier per axis. A single slice through a small phantom is used with a transmit-receive RF coil. The amplitude of the gradient waveform, the self-encoding gradient area, and step size are adjusted to keep the trajectory waveform centered in the raw data matrix. Waveform amplitude was 1 G/cm for 600 Hz and below, and 1.5 G/cm for higher frequencies. Self-encode areas varied from 3500 G/cm-μs at 200 Hz to 1800 G/cm-μs at 1800 Hz.

Four sinusoidal sections at the desired frequency are played out as the readout waveform of a gradient echo sequence as shown in Figure 1, while a self-encoding gradient is played out on the same axis, analogous to a phase encoding gradient in a conventional imaging sequence. An echo is generated whenever the net gradient area is 0, producing a signal peak in the time domain. The raw data matrix (Figure 2) then directly represents a map of the gradient area as a function of time.





For each time step, the location of the echo peak is determined by low-pass filtering the time domain data and identifying the peak location as the maximum of the filtered signal for that time step. The set of these peak locations is then fit to a sinusoid with a linear drift term and a DC offset (Figure 3), the linear drift term accounting for phantom positioning errors and residual static field inhomogeneity. The fitted amplitude of the sinusoid should correspond to the area of one lobe of the gradient waveform.

Frequency	Target	X	Y	Z
200	795.77	785.84	790.12	790.30
400	397.89	392.70	396.44	394.13
600	265.26	262.72	264.71	263.28
800	298.42	296.24	297.64	296.80
1000	238.73	236.63	238.70	237.44
1200	198.94	197.88	200.20	198.53
1400	170.52	168.83	170.56	168.80
1600	149.21	147.68	148.75	146.53
1800	132.63	130.18	131.07	

RESULTS AND DISCUSSION

Table 1 shows the calculated target area and fitted results for all 3 axes and for sinusoids from 200 Hz to 1800 Hz for X and Y, and 1600 Hz for Z. Above this frequency, the amplifiers shut down due to waveform distortion faults. Although the measured areas are all slightly less than the targets, the errors are quite small. At the conclusion of the waveform, there was a brief period of 0 amplitude, and Figure 4 shows a slight distortion at 1600 Hz on the Z axis consistent with underdamped motion of the gradient coil in response to the Lorentz forces. Note that the distortion has the period of the initial waveform.

These results do indicate, however, that the gradient system faithfully generates sinusoids out to the frequencies shown, providing confidence for the ability of these systems to support the higher frequencies needed for spatial-spectral pulses with higher spectral bandwidths.

REFERENCES

[1] Onodera, et al. J Phys E 20 (1987) pp 416-9.
[2] Frahm & Hänicke J Phys E 17 (1984) pp 612-6.
[3] Takahashi & Peters MRM 34 (1995) pp 446-56.