Gradient generated announcements during running MR scans

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Introduction and Background

The main magnet and gradient coil arrangement of the MR scanner is not unlike that of a loud speaker. Although the design is driven by very different criteria, we observed that the acoustic quality of the Siemens scanner when used as a loud speaker is surprisingly good. We verified informally that this is the case on Siemens (Erlangen, Germany) 1.5T Sonata, 1.5T Avanto and 3T Trio scanners. The acoustic properties of the gradient coils have been examined closely [1,2,3], although usually with the aim of reducing acoustic noise. The acoustic environment in the scanner is not especially conducive to communication with the patient, particularly during scanning. We have adapted our audio sequences to allow prerecorded messages, MP3s or wave files, to be played on any of the gradients. We found that these messages are quite intelligible to the subject inside the scanner bore. As a demonstration we modified the standard MP-RAGE sequence to announce the duration of the scan (e.g. "eight minutes, forty two seconds") immediately before imaging. We also modified the FLASH sequence by inserting a few seconds of audio at intervals throughout acquisition, but included appropriate gradients and RF pulses so as to maintain the steady-state of the spins. In this way the subject can be informed of the time remaining during scanning without disrupting the imaging sequence.

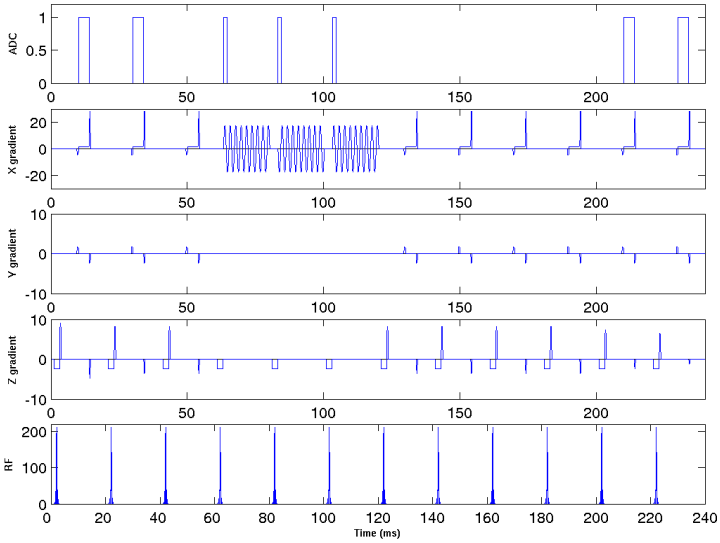

Figure 1: Pulse sequence diagram for annotated FLASH. 0-60 ms: regular sequence; 60-120 ms: audio portion; 120-200ms: eddy current section; 200 ms on: regular sequence. Portions are reduced in length to illustrate principle.

Methods

We generate the sound by playing samples of audio as arbitrary gradient waveforms on an operator-selected gradient coil (X, Y or Z) at a rate of 20k or 5k samples/s. The waveform is divided into snippets of 6 ms or 18 ms. At every TR we acquire a dummy line of k-space and trigger the image reconstruction computer to transmit the next snippet of audio to the gradient control computer. This computer uploads the snippet to the DSP which plays it on the gradient as an analogue signal after it is amplified by the gradient power amplifier. The snippets of audio are read from files on the image reconstruction computer. To generate arbitrary messages such as "two minutes, thirty seconds", we assemble the message from a set of standard audio clips used in the telephone industry. We implemented the time announcement as a stand-alone sequence with the time specified on the UI, and also integrated it with the MP-RAGE in which case it calculates the scan duration and assembles the message automatically.

Figure 1 shows how we included portions of audio within a running FLASH scan. To preserve steady-state magnetization, we included RF pulses with the same timing as the main sequence, along with the appropriate slice select gradients. We also included 500 ms of "rest" TRs i.e. blocks with RF excitation and spoiling, and the phase and frequency encoding of the next valid line of k-space, with no data acquisition. During these blocks the eddy currents of the audio waveforms dissipate and the steady-state is preserved. Inserting gaps in the audio stream for the RF pulses degrades the quality of the audio, and these gaps are kept as short as possible.

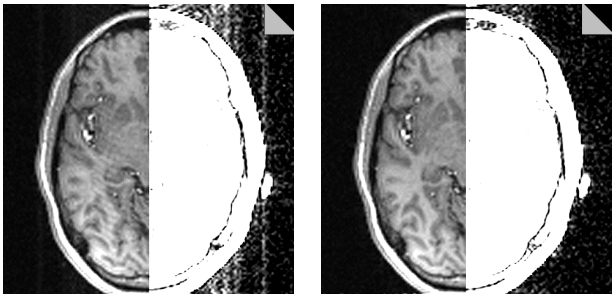

Figure 2: Slices through an axial FLASH acquisition with 5 s auditory annotations every 30 s. Left image shows ringing artifacts (left half) and background noise (right half) that result if the RF steady-state is not maintained and eddy currents aren't allowed to dissipate. Right image shows slice acquired with the sequence illustrated in Figure 1.

Results and Conclusion

Figure 2 shows the same slice through two 3D volumes acquired with the 3D FLASH with embedded audio annotations, and the FLASH with annotations and preserved steady state/eddy currents. We inserted 5 seconds of audio every 30 seconds (TR=20 ms, 128x128 matrix, 1.5 mm slices). It appears that the steady state is maintained and image quality is not degraded by the auditory annotation (not shown). Image reconstruction is performed on the scanner.

The implementation lends itself to real-time modification of the waveform. In further work, we could implement real-time presentation on the gradients of comments spoken into a microphone during a running scan, or a real-time message such as "please do not move" if motion is detected automatically during scanning. The quality of the audio could be improved by convolving it with the inverse of the impulse response of the gradient coil. Inserting audio within running sequences while maintaining steady-state may also be useful in auditory fMRI studies.

Acknowledgement

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References

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