

# Using Gradient Waveforms Derived from Music in MR Fingerprinting (MRF) to Increase Patient Comfort in MRI

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**Purpose:** Acoustic noise during the operation of an MR scanner causes discomfort for both patients and technicians. On the other hand, people routinely pay money to hear live music concerts that are significantly louder than an MRI scan. Thus it is largely the unpleasant “banging” sound that is the problem, and not necessarily the volume. The goal of this study is to take advantage of the additional degrees of freedom provided by the new concept of Magnetic Resonance Fingerprinting (MRF) to directly convert digitized music into encoding gradients [1]. Unlike previous methods that interspersed music and readouts (e.g. ALOHA [2]), this MRF-based method uses these music-derived waveforms for encoding during readout, thus maximizing efficiency. In this study, we demonstrate that mp3 encoded music can be converted and optimized to arbitrary encoding gradients, including factors such as gradient moment nulling for SSFP readouts. Afterwards these gradient waveforms are used in combination with variable FAs and TRs to simultaneously quantify four tissue properties ( $T_1$ ,  $T_2$ ,  $M_0$ , and off-resonant frequency).

**Methods: Gradients Design:** As shown in Figure 1a, b, the music was first low pass filtered to 2kHz in order to remove the high frequency oscillations that cannot be replicated by a gradient. In order to match the gradient output raster time, the optimized gradients were then resampled to 100kHz. Since we will use an SSFP-based MRF sequence, each arbitrary gradient in each TR of the MRF sequence was designed to start and end at the center of the k-space. Therefore, zero crossings of the music segments were first located. The odd numbered music segments were used for RF excitation and slice selection gradients (Z) and have zero amplitude in both phase (Y) and frequency (X) encoding directions. The even numbered music segments were used as k-space encoding gradients. An optimization algorithm was applied as shown in Figure 1b to solve for each encoding gradient in order to 1) satisfy the scanner constraints of the maximum gradient amplitude and maximum slew rate, 2) have 0<sup>th</sup> moment compensation and 3) generate sampling trajectories to cover 128x128 pixels in a 300mm<sup>2</sup> field of view (FOV). In the cost function,  $G$  is the target gradient,  $s$  is the filtered music segment,  $\lambda$  is a factor that balances gradient fidelity and gradient refocusing. This optimization was performed on the 1D music waveform. In order to encode more than a single line in k-space, low frequency balanced trapezoidal gradients with 10% of the maximum amplitude of the music encoding gradients were designed as shown in Figure 1d. Both gradients were rotated by 0.9 degrees from one TR to the next, so that each image had different spatial encoding while the music sound was not altered. Since the duration of arbitrary gradients depends on the duration of signal segments, TR values of the MRF acquisition were inherently random. These gradient waveforms result in k-space trajectories that are dependent on the music. For example, Figure 2 shows example trajectories from ‘Mr.Tambourine Man’ as performed by The Byrds and ‘Roar’ by Katy Perry, the black lines enclose the sampled points that were used in the reconstruction.

**Acquisition:** In vivo experiments were performed in compliance with the IRB and were performed at 3T scanner (Siemens Skyra) with a 16-channel head receiver array using “Mr. Tambourine Man.” A total of 5 repetitions of the music sequence, each with 4000 data points, were acquired. All trajectories were rotated 111.2 degrees from one repetition to the next. The total acquisition time was 5 minutes. **Data Analysis:** Undersampled images were reconstructed using NUFFT<sup>[3]</sup>, and the signal evolutions from these images were used to quantify  $T_1$ ,  $T_2$ ,  $M_0$  and off-resonance simultaneously as described in [1]. White matter (WM), gray matter (GM) and cerebrospinal fluid (CSF) regions of interest were selected from the resultant  $T_1$  and  $T_2$  maps. The mean values of  $T_1$  and  $T_2$  obtained from each region were calculated and compared with literature values<sup>3</sup>.

**Results:** Figure 3 shows four maps generated from an *in vivo* experiment using MRF method. The sound generated at the scanner was audibly very similar to the original waveform even with the additional slice and trapezoidal gradients. The mean values of  $T_1$  and  $T_2$  from three typical regions in the brain are in good agreement with the literature[3].

**Conclusion:** In this study, music waveforms were converted into arbitrary gradients that can be used in the MRF acquisition to significantly increase patient comfort (and likely, patient compliance) in MRI. Given the flexibility of the gradient shapes and TR patterns, any music file could be played in the MRF scan (although the scan efficiency will vary depending on the music). Further optimization of the sampling trajectories would also reduce the acquisition time and improve quality of both the maps and the acoustic performance.

**Reference:** [1] D.Ma et al. Nature 495, 187-192(2013) [2]R.Loeffler, Proc.Intl.Soc.Mag.Reson.Med,10(2002) [3]J.A.Fessler et al. IEEE Trans.Signal Process 51. 560-574 (2003). [4]S.Deoni, JMRI, 26,1106-1111(2007).

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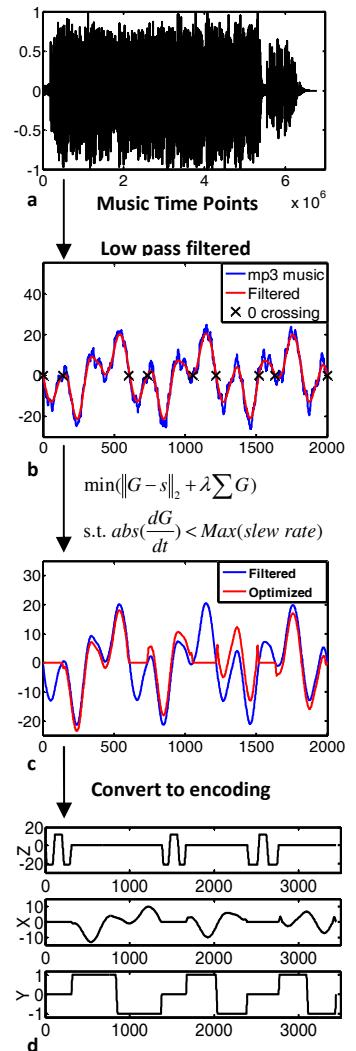


Figure 1: Flow chart of the music gradient design

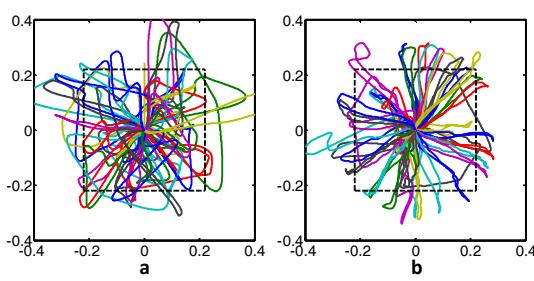


Figure 2: Example of 50 k-space trajectories From ‘Mr. Tambourine Man’ by The Byrds (a) and ‘Roar’ by Katy Perry(b)

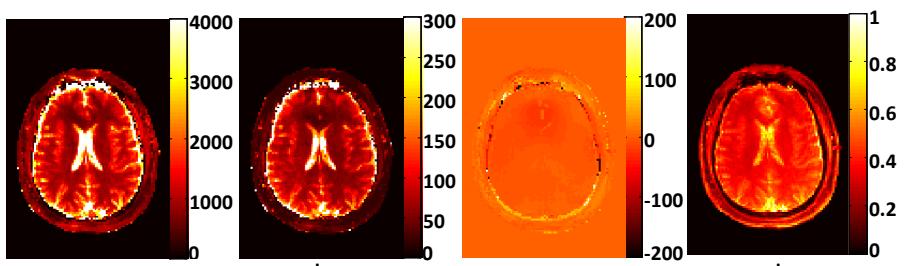


Figure 3: In vivo results: (a) T1 map (ms), (b) T2 map (ms), (c) off-resonance map (Hz) and (d) M0map