# Fast and Direct Generation of Encoding Gradients for the MRF-Music Acquisition

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**Purpose:** Unpleasant acoustic noise is an important drawback of almost every MR scan. A Magnetic Resonance Fingerprinting (MRF)[1]-based method "MRF-Music" has been proposed[2] to directly convert the music signal to encoding gradients. By combining these gradients with variable acquisition parameters such as flip angles and TRs, the MRF-Music sequence allows one to efficiently quantify multiple MR parameters with a pleasant sounding acquisition. In the original implementation, the conversion of the music from an mp3 file to the encoding gradients involved an optimization of the music signal at each TR, which took around 25.2 hours to generate gradients for a 30 second long 2D MRF-Music sequence. Here we introduce a new conversion method that generates all gradients, including slice encoding and readout encoding gradients, in 15 seconds for the same acquisition. This new method allows significantly reduction of the conversion time while still maintaining the same high image and sound quality.

**Methods:** As shown in Figure 1, the first few steps of the music conversion were the same as the methods described in [2], which include scaling, low pass filtering and resampling of the music signal, followed by locating zeros crossings for the subsequent gradient design. The zero crossings were then grouped such that each TR had three music segments of sufficient durations for the RF pulse and acquisition that start and end at zero. The first segment was used for RF excitation and the slice selection gradient. The second segment was used for slice selection rewinding. The third segment was the balanced readout gradient that not only must start and end at zero, but must also have zero total gradient area. The endpoints are chosen to already be zero, however, instead of using iterative optimization as described in [2] to optimize both the gradient area and sound, the gradients from these three music segments in each TR were designed using the addition of simple waveforms to each section. Any function with zero endpoints and a non-zero area can be added to the waveform to meet all of the requirements for encoding. In this case we used a half-sine wave. The required amplitude of this waveform can be easily calculated according to Eq 1, 2 and 3, respectively, where $G_{ss}$ is the required gradient area for the slice selection encoding, which is determined by RF duration, time bandwidth product and slice thickness, $s$ is the music signal in the third segment, $G_{sinei}$ is the scaled half-sine waveform shown in Eq. 4, $N_{si}$ is the number of signal points in each of the segments, and $t_i$ is from 1 to $N_{si}$. The slope of each two points was then checked to make sure that the absolute value of the slew rate was smaller than the maximum slew rate from the scanner. In this method, no iterative optimization was applied in any of the segments, thus saving the computing time. The music gradients derived from the previous iterative optimization and the new fast method were applied to the 2D MRF-Music acquisitions. For each scan, 4000 time points were acquired using same flip angle and TR pattern. Because 2D MRF sequence used a total 2-pi dephasing gradient in the slice direction to avoid sensitivity to $B_0$ effects[3], $T_1$, $T_2$ and $M_0$ maps were obtained after the template matching of the signal with the dictionary.

| | |
|---|---|
| $G_{s1} = G_{\text{sine1}} \times \dfrac{G_{ss}}{\sum G_{\text{sine1}}}$ | Eq. 1 |
| $G_{s2} = G_{\text{sine2}} \times \dfrac{-G_{ss}/2}{\sum G_{\text{sine2}}}$ | Eq. 2 |
| $G_{s3} = s - G_{\text{sine3}} \times \dfrac{\sum s}{\sum G_{\text{sine3}}}$ | Eq. 3 |
| $G_{\text{sinei}} = \sin(\dfrac{t_i}{N_{si}} \times \pi), i = 1,2,3$ | Eq. 4 |

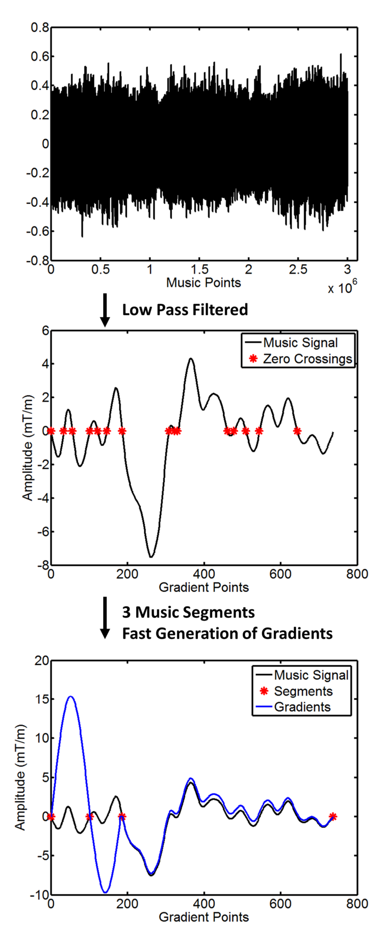


Figure 1: Process of the fast music gradient design

**Results:** Figure 2 compares the readout gradients derived from the iterative optimization method and fast methods. Figure 3 compares the $T_1$, $T_2$ and $M_0$ maps obtained from these two methods. Although the gradient waveforms are different, the corresponding maps from these two methods are in good agreement. In addition, there is no perceptible difference in the sound from these two scans.

**Conclusions**: This study introduces a fast method to convert the music to the encoding gradients for the MRF-Music acquisition. For a 30 second-long 2D MRF-Music scan, only 15 seconds are needed to convert the music to the encoding gradients, which largely eliminates the roadblock of the preparation time and thus facilitates the further optimization and utilization of the MRF-Music scan.

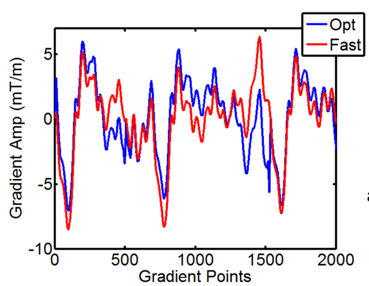


Figure 2: Encoding gradients generated from the optimization code and the fast method.

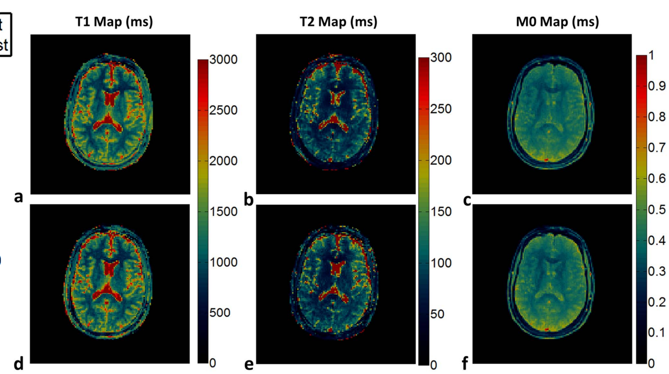


Figure 3 : T1, T2 and M0 maps generated from the MRF-Music sequence using the encoding gradients derived from optimization code (a, b, c) and the fast method (d, e,f).

**Reference:** [1] D.Ma et al. Nature (2013). [2]D.Ma et al. ISMRM.22 (2014). [3]Y,Jiang et al. ISMRM 4290(2014).

**Acknowledgement:** The authors would like to acknowledge funding from Siemens Healthcare and NIH grants NIH 1R01EB016728-01A1 and NIH 5R01EB017219-02.