Fast EPR Acquisition with Adaptive Heterogeneous Clocking (AHC)

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ABSTRACT

Electron Paramagnetic Resonance Imaging (EPRI) can provide insight into in vivo anatomic and functional imaging of free radicals and paramagnetic molecules and their role in disease in small animal models. However, there is a need to expedite the data acquisition and post-processing to enable new EPRI applications. While previous work has used a fixed-rate master clock to pace all A/D and D/A conversion activities of the data acquisition electronics, Adaptive Heterogeneous Clocking (AHC) significantly reduces communication between the host computer and gradient hardware by using different clocks to pace the A/D and D/A functions of our acquisition cards. Projections containing up to 4096 points can be acquired in as little as 10 – 20 ms using AHC. Nearly real-time acquisition can be performed for complex computer-generated gradient waveforms, which will enable a variety of new sampling patterns.

INTRODUCTION

The previous fixed-rate oversampling homogeneous clocking acquisition scheme needs to transfer significant amount of redundant data between the computer and electronic acquisition cards, hence the acquisition speed and system performance are severely limited, as illustrated in Fig. 1 and 2.

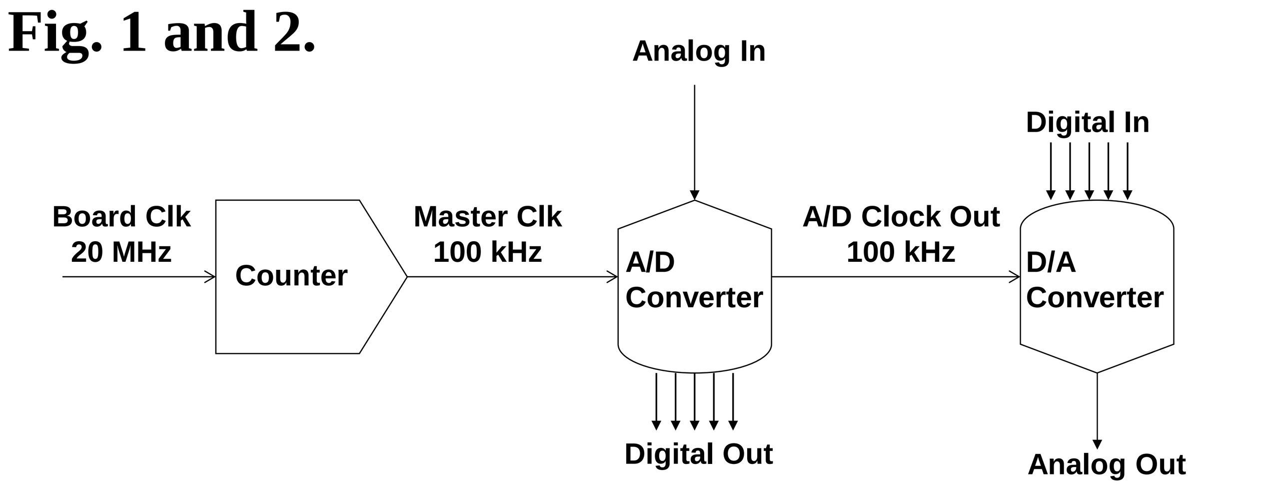


Fig. 1. Block diagram of the previous design of the EPR acquisition system with fixed-rate homogeneous clocking.

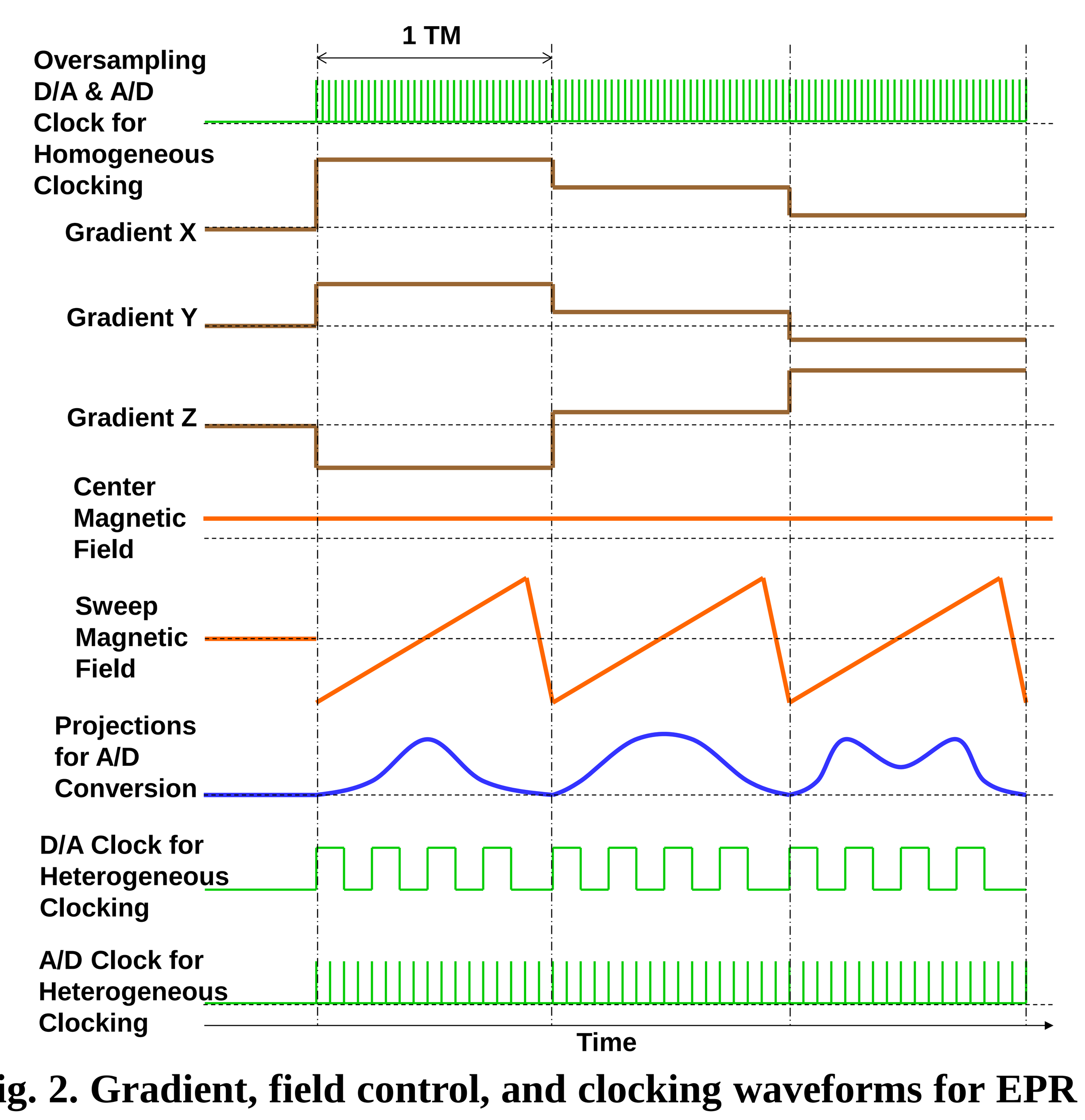


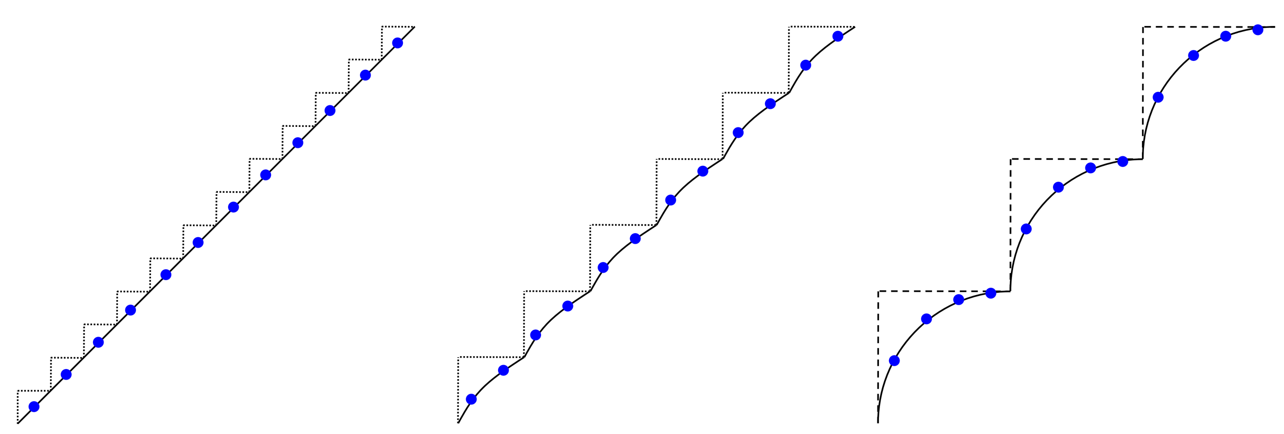
Fig. 2. Gradient, field control, and clocking waveforms for EPR acquisition.

METHODS

Goal **— Significantly reduce the amount of redundant data in waveforms by:**

1. *Heterogeneous clocking* — The D/A output clock rate is reduced to take advantage of the time constant of the sweep magnetic field (Fig. 3(a)), which is a result of the inductive load of the magnetic field hardware. The D/A output clock rate can be reduced and yet still produce a linear sweep of the magnetic field. A faster A/D input clock is used to acquire the projection data (Fig. 3(b), Fig. 4).

2. *Adaptive clock rate* — The A/D input clock rate is adjusted according to the magnetic field sweep time (*TM*) to avoid unnecessarily high clock rates on the electronic acquisition cards (Fig. 4).



(a) (b) (c)

Fig. 3. Timing diagrams show the computer generated sweep field (dashed lines), the resulting magnetic field (solid lines), and the A/D sampling points (blue dots) in the EPR acquisition. (a) Homogenous clocking with a high D/A clock. (b) Heterogeneous clocking with a slightly lowered D/A clock rate results in nearly the same output magnetic field. (c) Heterogeneous clocking with an excessively low D/A clock rate results in non-linear field.

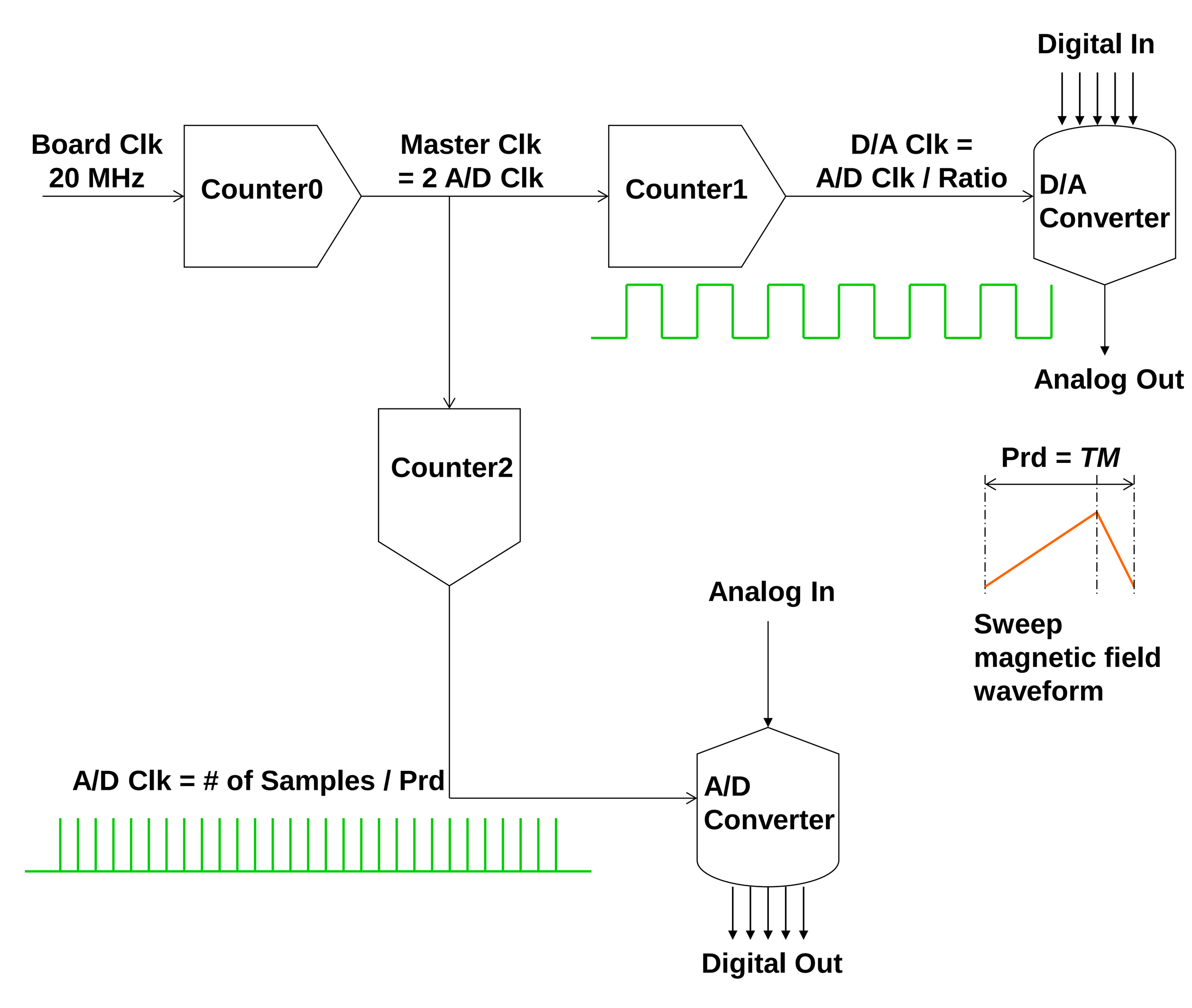


Fig. 4. Block diagram of the design of the EPR acquisition system with adaptive heterogeneous clocking.

REFERENCES AND ACKNOWLEDGEMENTS

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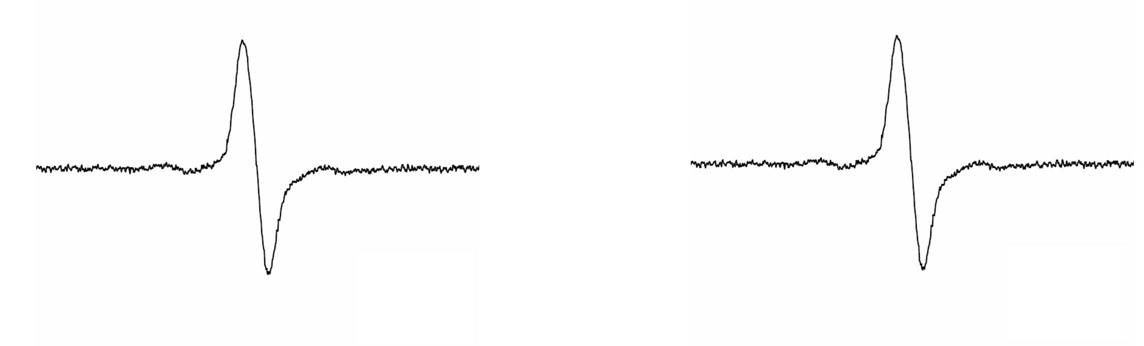
EXPERIMENTAL RESULTS

We empirically determined a relationship between the acceptable clock ratios according to Eq. (1), which relates magnetic field sweep time (*TM*, seconds), the A/D clock rate ($Clock_{AD}$, Hz), and D/A clock rate ($Clock_{DA}$, Hz) for sampling 4096 data points.

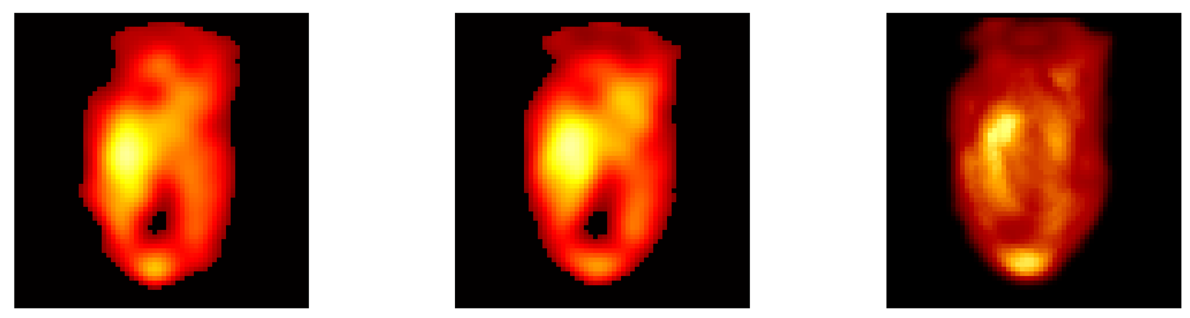
$$Clock_{AD}/Clock_{DA} = 10 - 30\log TM \quad \text{for } 0 < TM \le 1\,\text{sec} \qquad \textbf{Eq.(1)}$$

Spectra acquired using AHC showed no signs of distortion or baseline drift for a clock ratio of 16 and a very short sweep time of 25 ms (Fig. 5). Reconstructed 2D images from AHC data were also undistorted and had high SNR (Fig. 6(b, c)). Compared to the fixed homogeneous clocking acquisition scheme, AHC reduces the dead time in acquisition by up to 80%, and reduces the post-processing time by more than 96% for long sweep times (Fig. 7). Furthermore, AHC can also achieve very short sweep time of 10 – 20 ms, which is not achievable with fixed homogeneous clocking due to insufficient sampling rate.



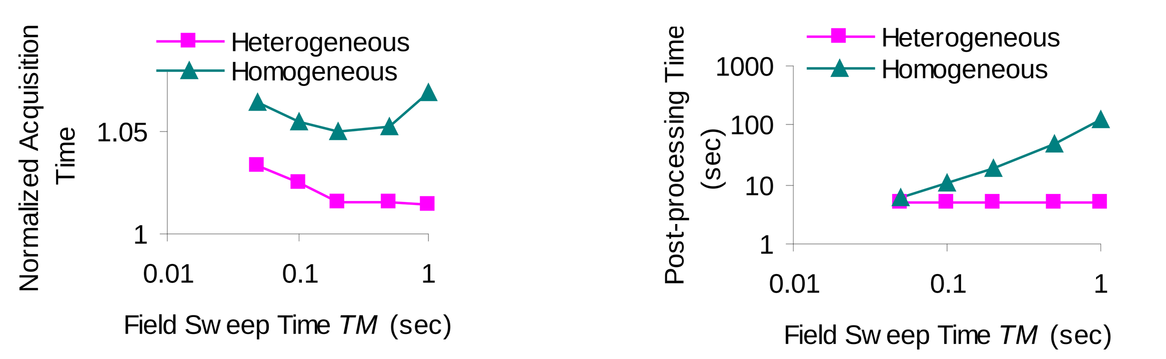
(a) (b)

Fig. 5. Acquired spectra with magnetic field sweep time, *TM*, of 25 ms. (a) Homogeneous clocking. (b) Heterogeneous clocking with an input/output ratio of 16.



(a) (b) (c)

Fig. 6. (a) Acquired image slice of an isolated heart by homogeneous clocking without gating. (b) Acquired image slice of a paced isolated heart by gated heterogeneous clocking and *TM* = 25 ms. (c) Surface rendering of an acquired 3D image of a paced isolated heart by gated heterogeneous clocking and *TM* = 25 ms.



(a) (b)

Fig. 7. (a) The EPR data acquisition time is reduced by 5% to 10% by adaptive heterogeneous clocking. (b) Post-processing times are 10 to 100 times faster.

CONCLUSIONS AND DISCUSSION

The adaptive heterogeneous clocking (AHC) acquisition scheme has significantly reduced EPR projection acquisition time from 1 sec down to 10 ms, with uncompromised image quality. In addition, it successfully achieved gated cardiac EPR imaging. Potential applications of this work include measurement and imaging of myocardial oxygenation, redox state, nitric oxide formation. Previous experiments have been limited by long minimum projection acquisition time and long dead time. While others have developed high performance hardware-based gradient waveform generation using function generators [5, 6], AHC is based entirely on software-generated waveforms, allowing much more flexibility in designing novel acquisition schemes.