Pulse Programming Bootcamp
Day 2: Pulse Sequences

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Pulse Programming Bootcamp 2005

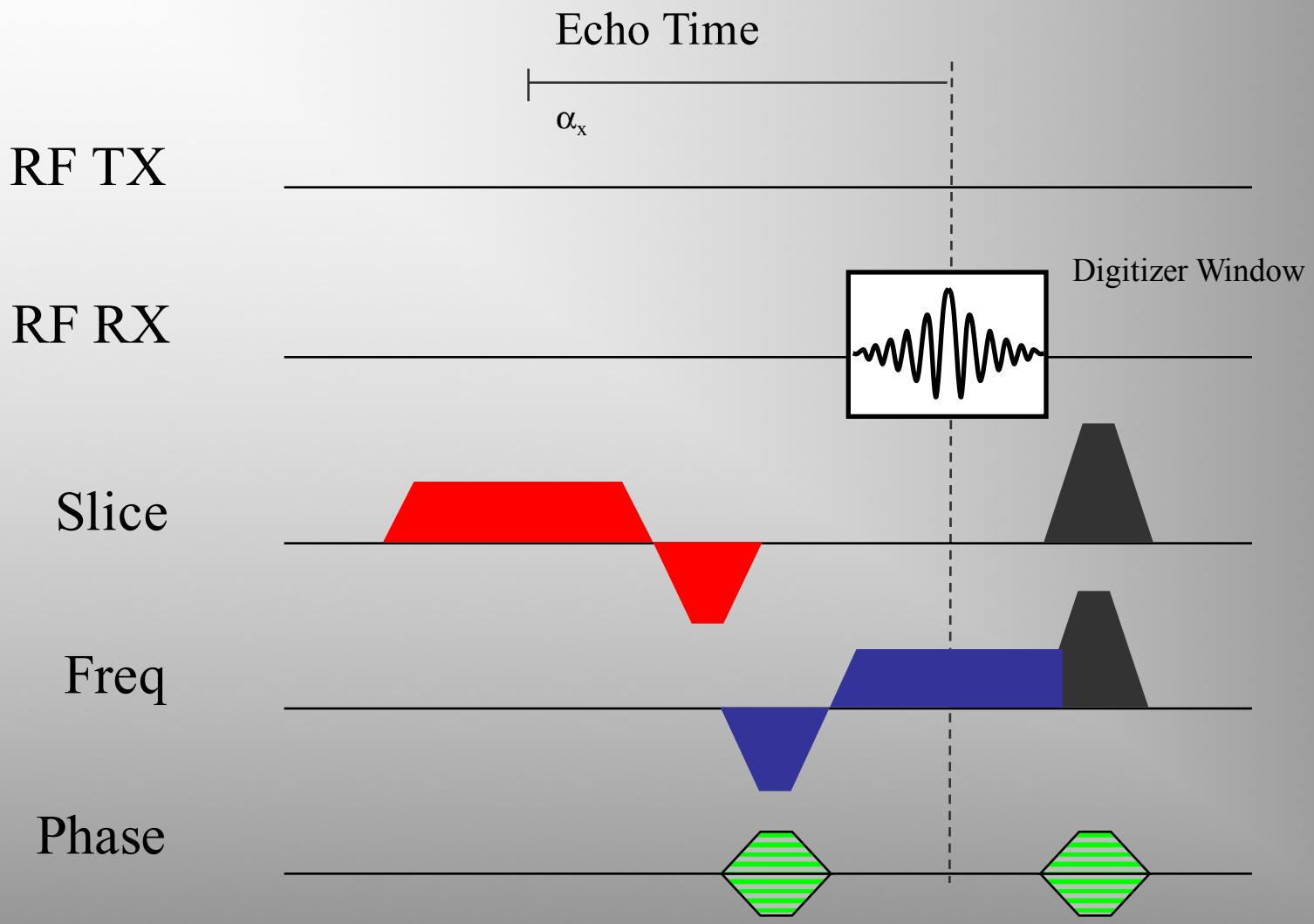
Caltech Brain Imaging Center

California Institute of Technology

2D Multislice vs 3D

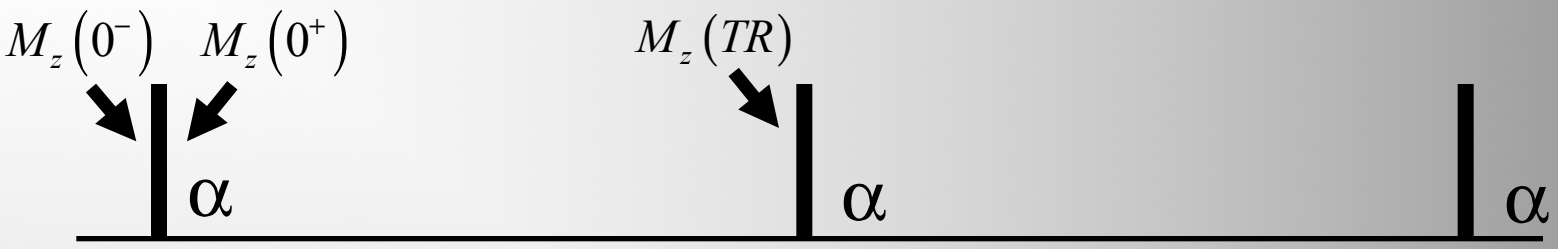
Gradient Echo Sequences

Full Gradient Echo Pulse Sequence



Steady State Free Precession

Longitudinal Steady-State



RF pulse rotates M_z magnetization about x-axis

$$M_z(0^+) = M_z(0^-)\cos(\alpha)$$

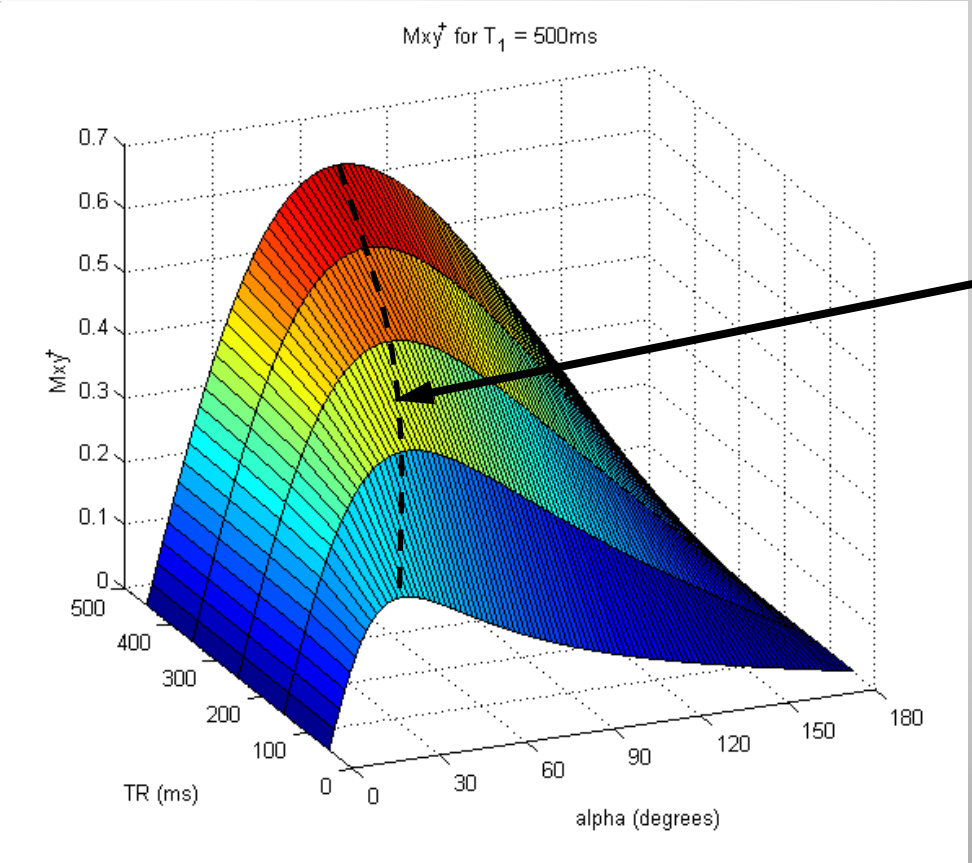
T_1 relaxation during free-precession period (TR)

$$M_z(TR) = M_{xy}(0^+)e^{-TR/T_1} + M_0(1-e^{-TR/T_1})$$

Equate $M_z(0^-)$ with $M_z(TR)$ in steady-state assuming complete M_{xy} spoiling

$$M_z^+ = M_0\frac{1-e^{-TR/T_1}}{1-\cos(\alpha)e^{-TR/T_1}}$$

The Ernst Angle



$$\theta_E = \cos^{-1}\left(e^{-TR/T_1} \right)$$

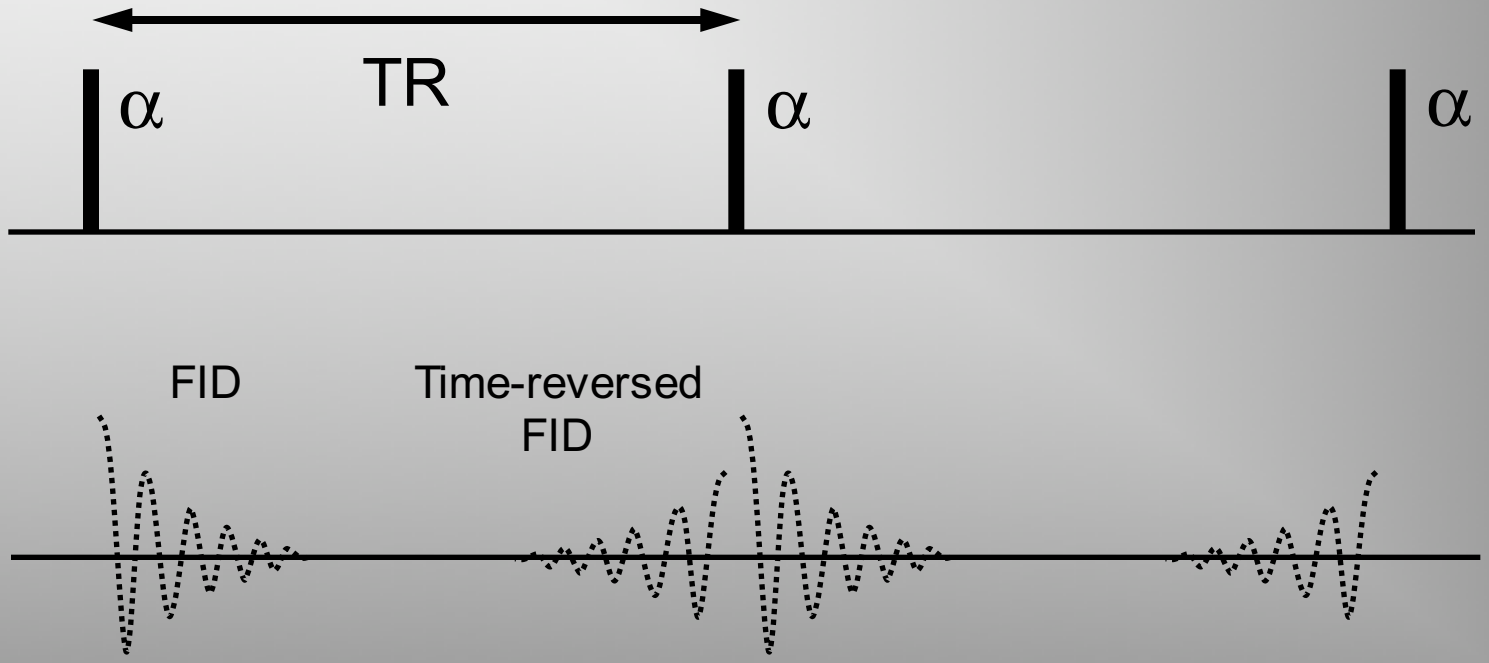
Maximum signal obtained at Ernst angle, **not 90°** when TR < or ≈ T_1

$$M_{xy}^{+} = M_0 \frac{1 - e^{-TR/T_1}}{1 - \cos(\alpha) e^{-TR/T_1}} \sin(\alpha)$$

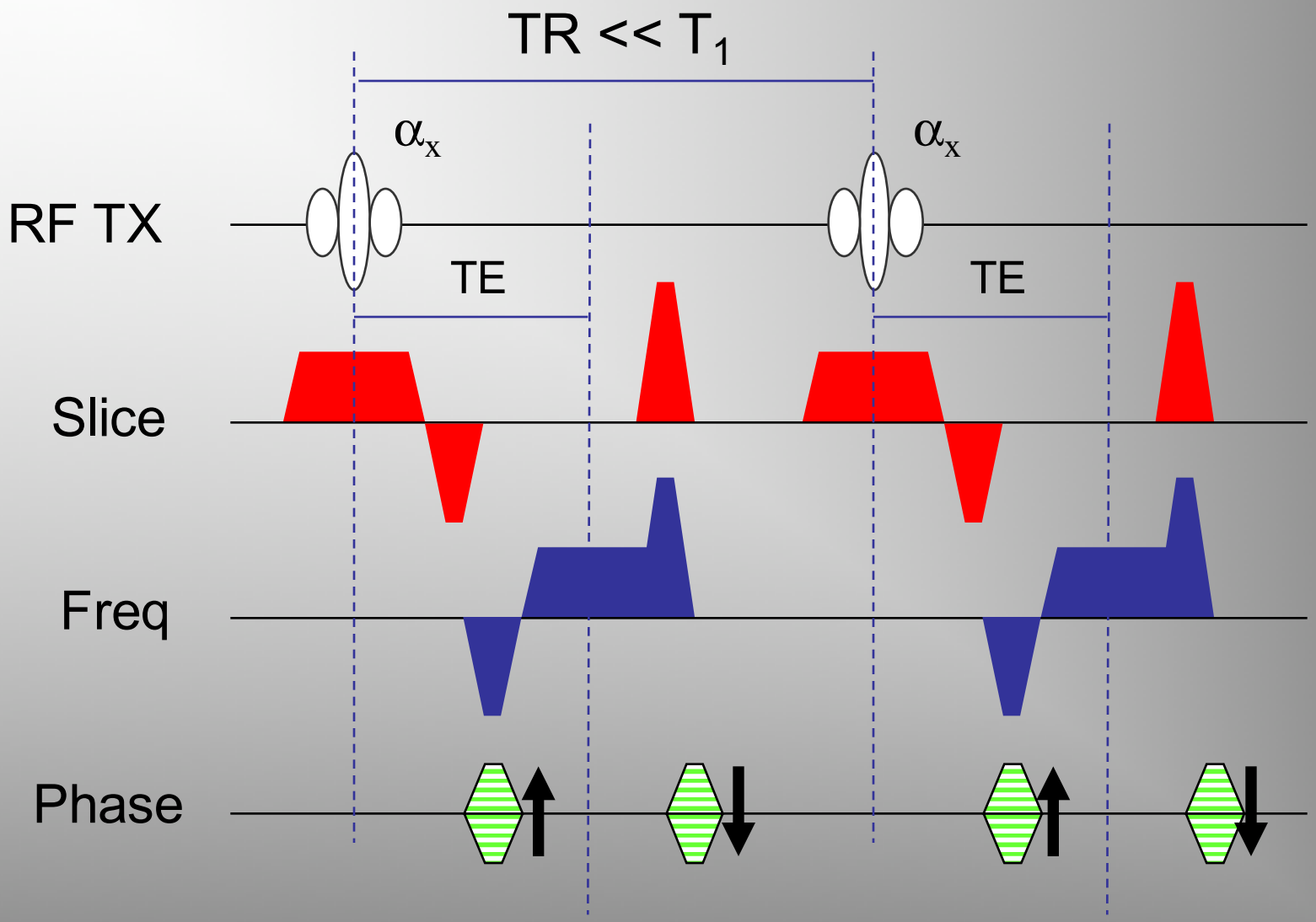
Full Steady-State

Transverse Magnetization Preserved. TR < T_2

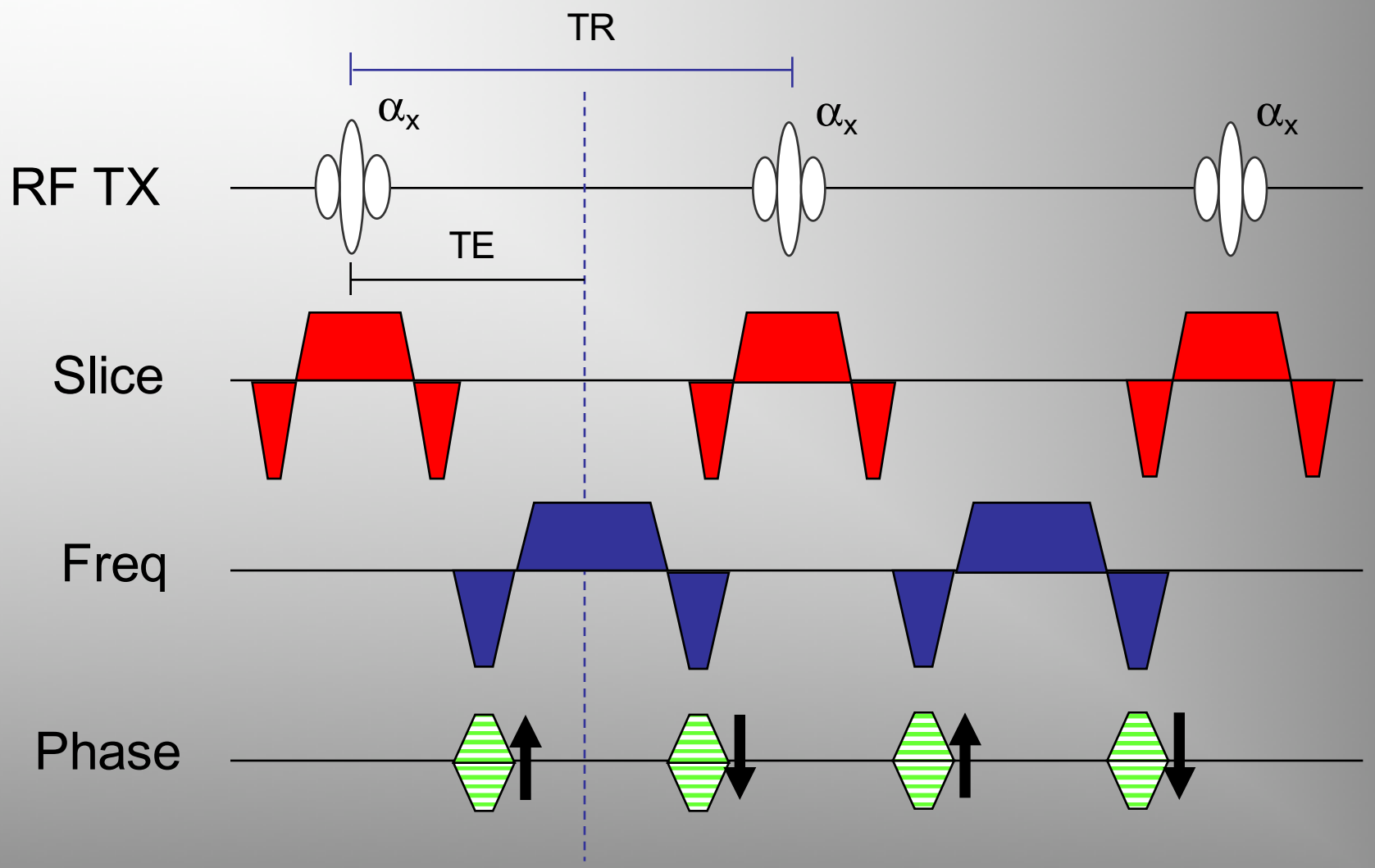
Both M_z and M_{xy} attain a steady-state.



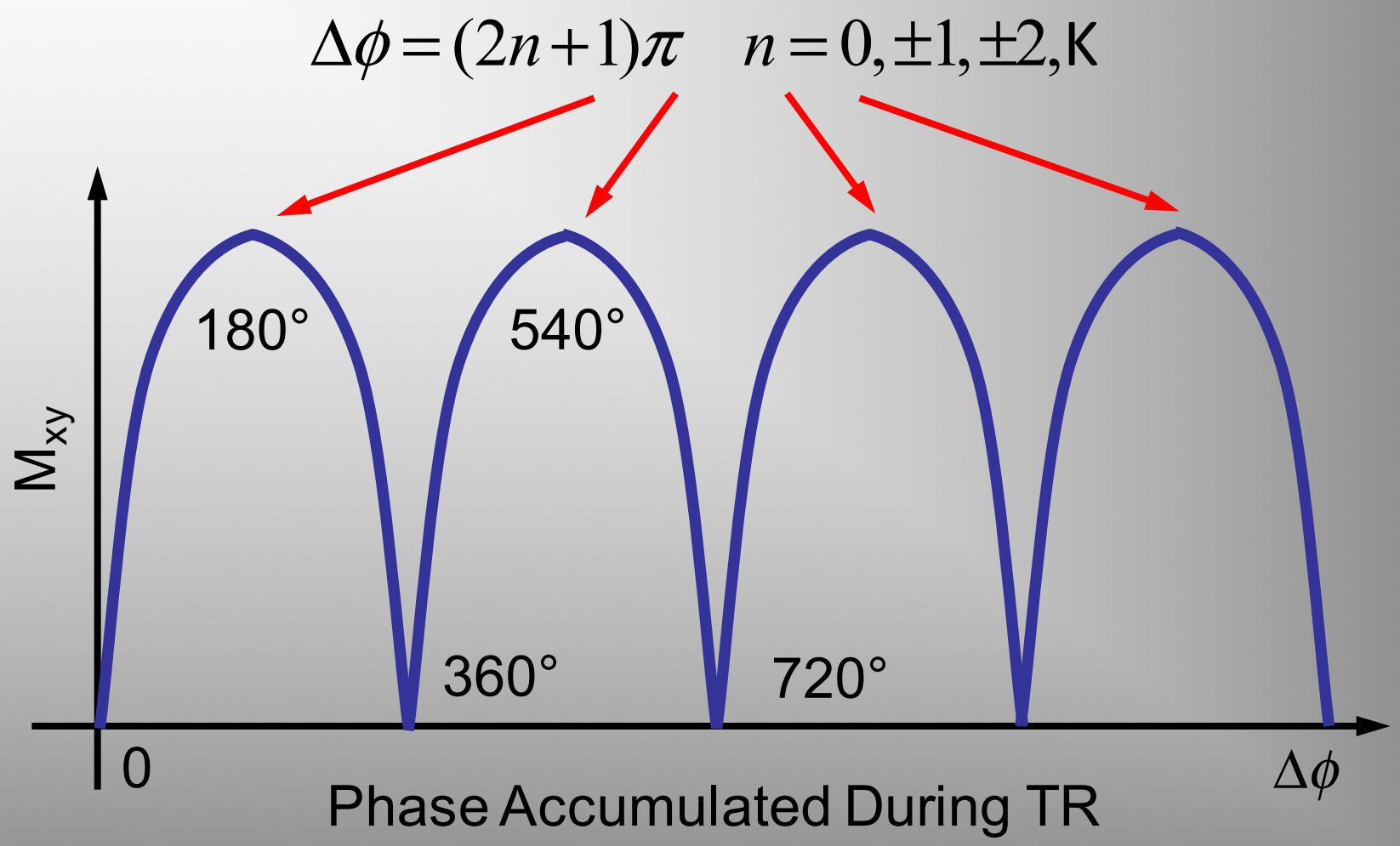
Steady-State Gradient Echo Sequence



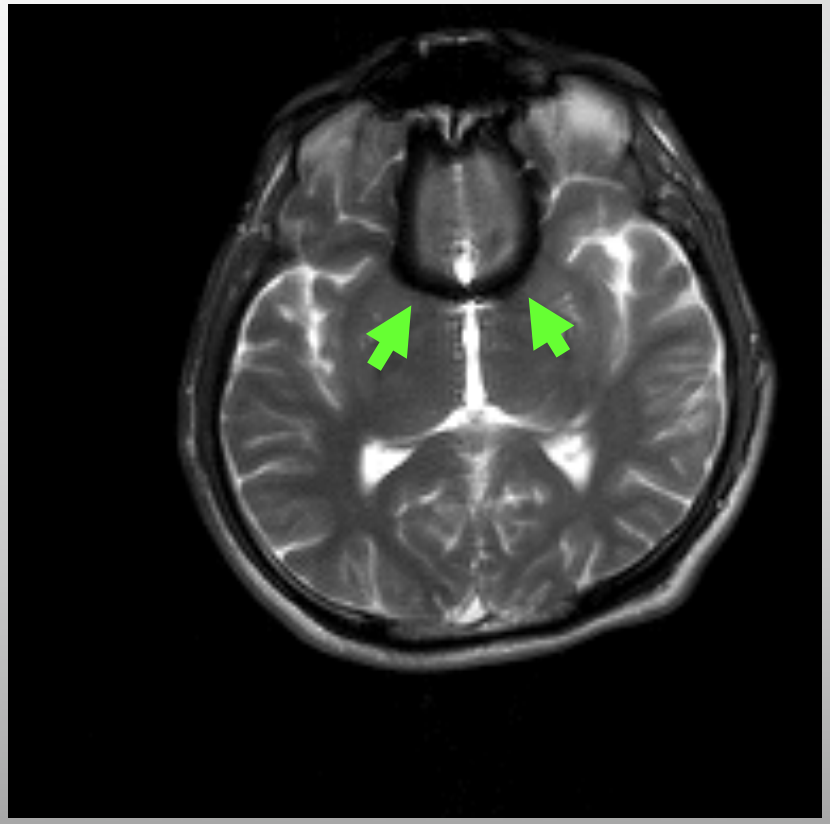
TrueFISP Pulse Sequence

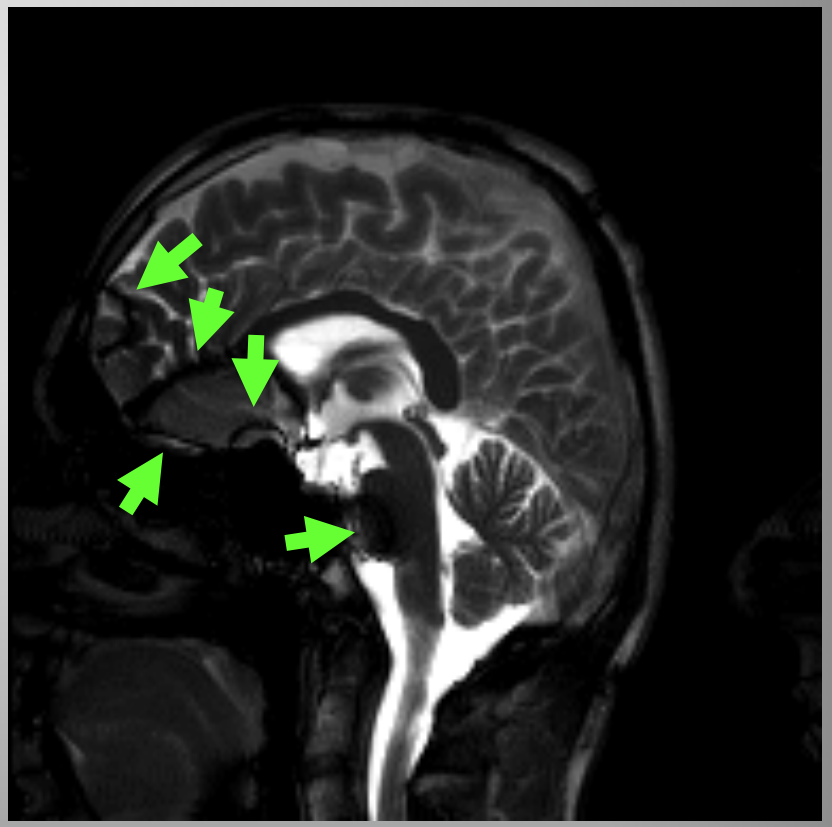


Off-resonance Effects in Full Steady-State



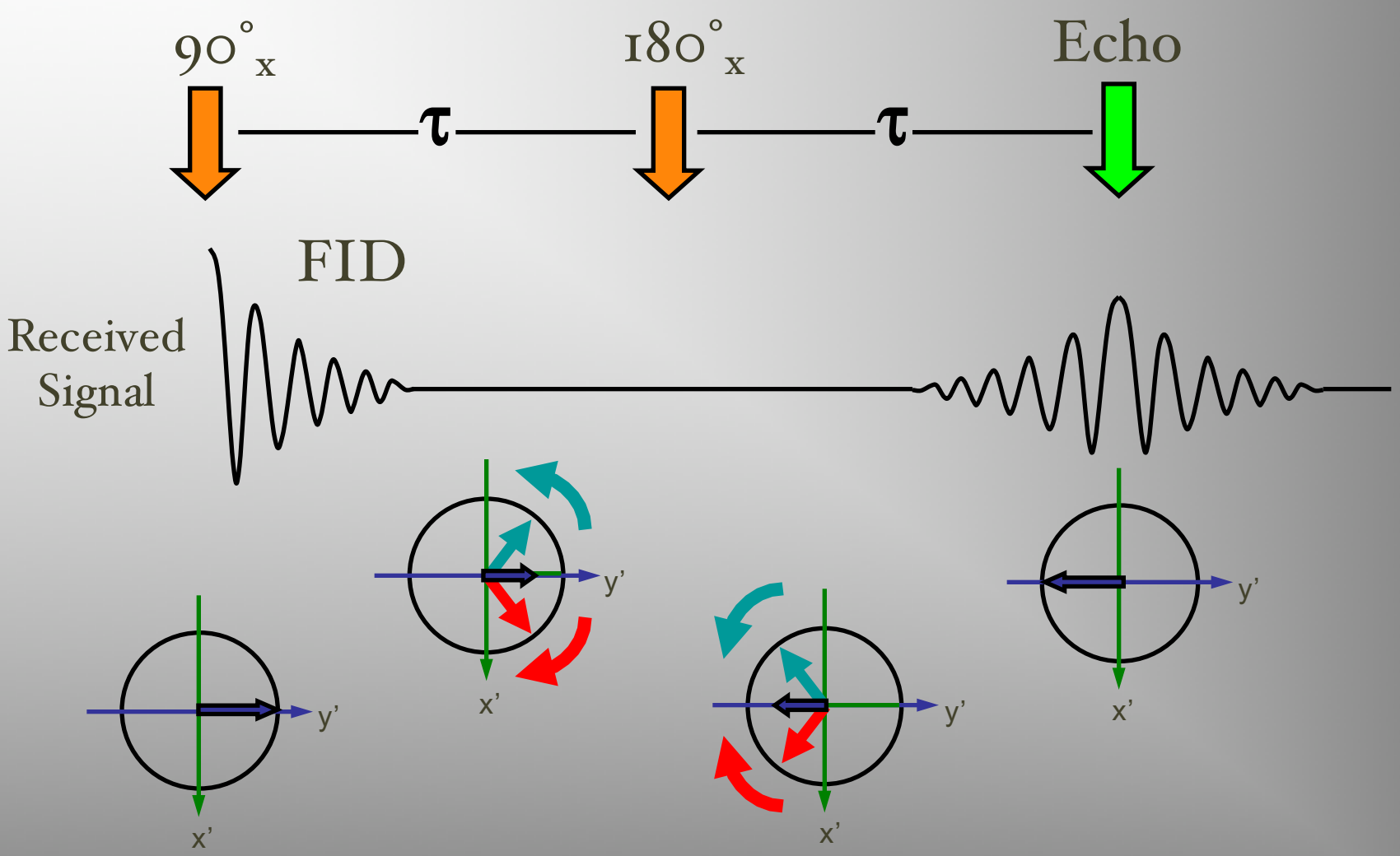
TrueFISP Isofield Null Points



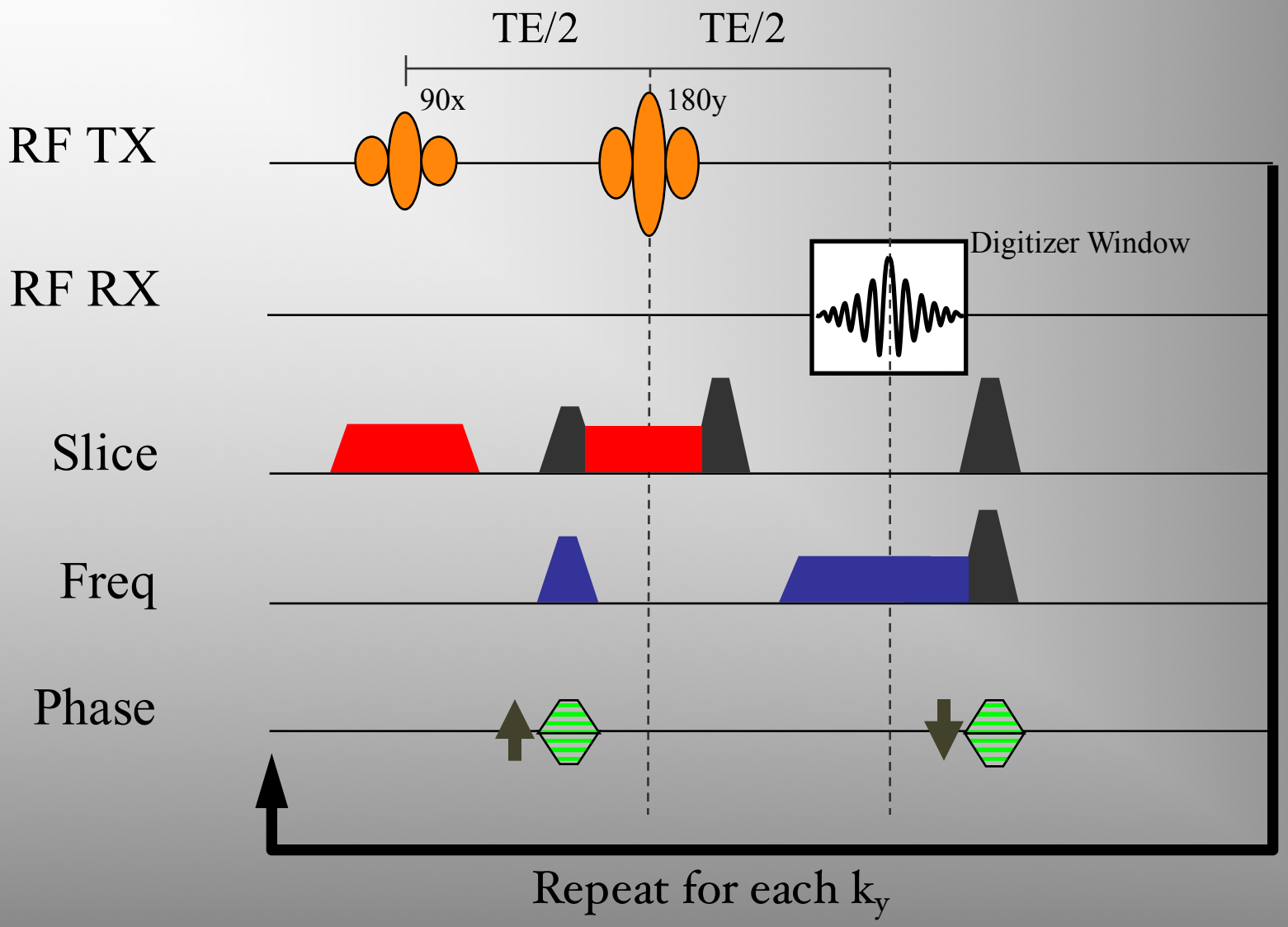


Spin Echo Sequences

The Hahn Spin Echo Explained

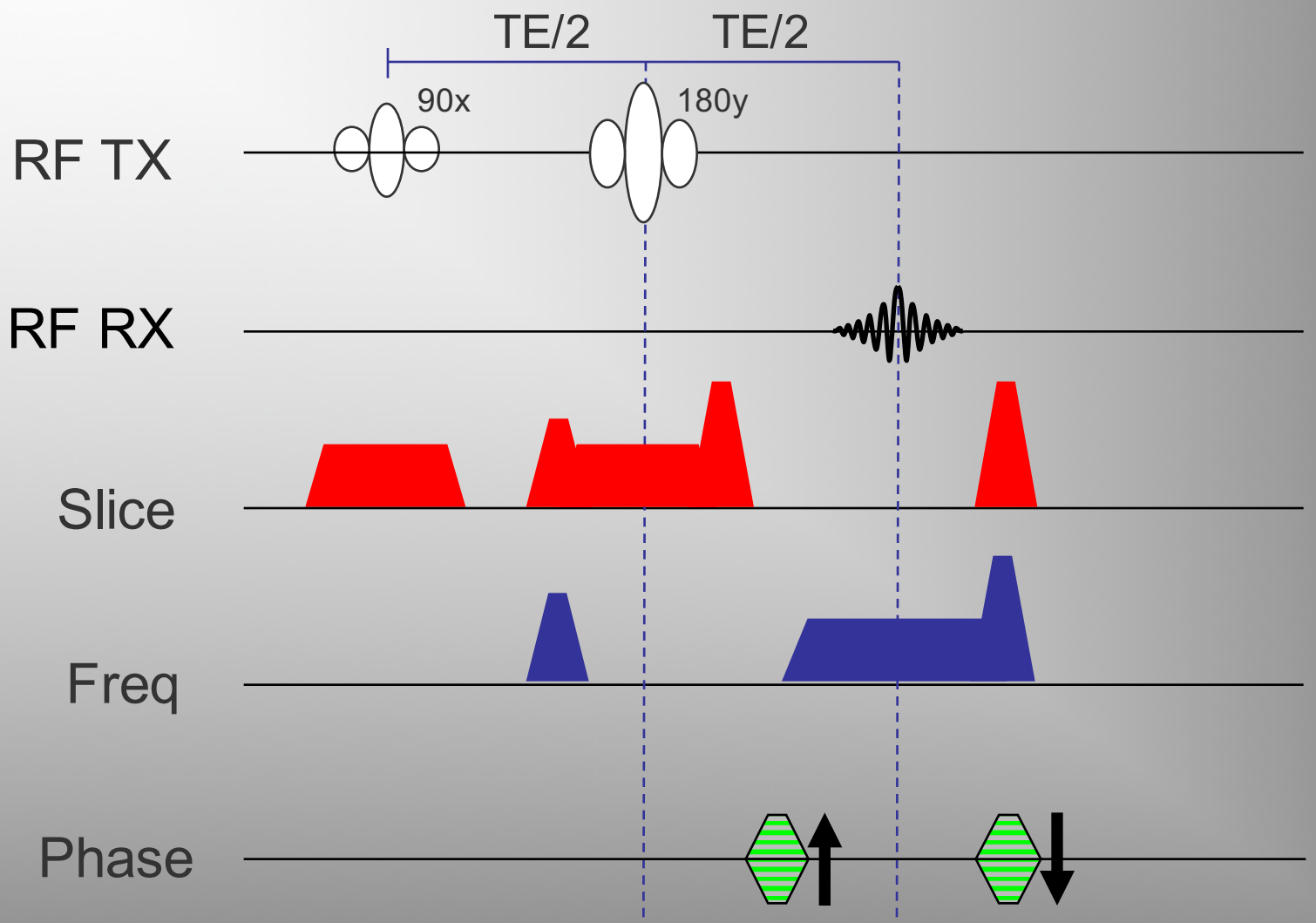


Spin Echo Pulse Sequence

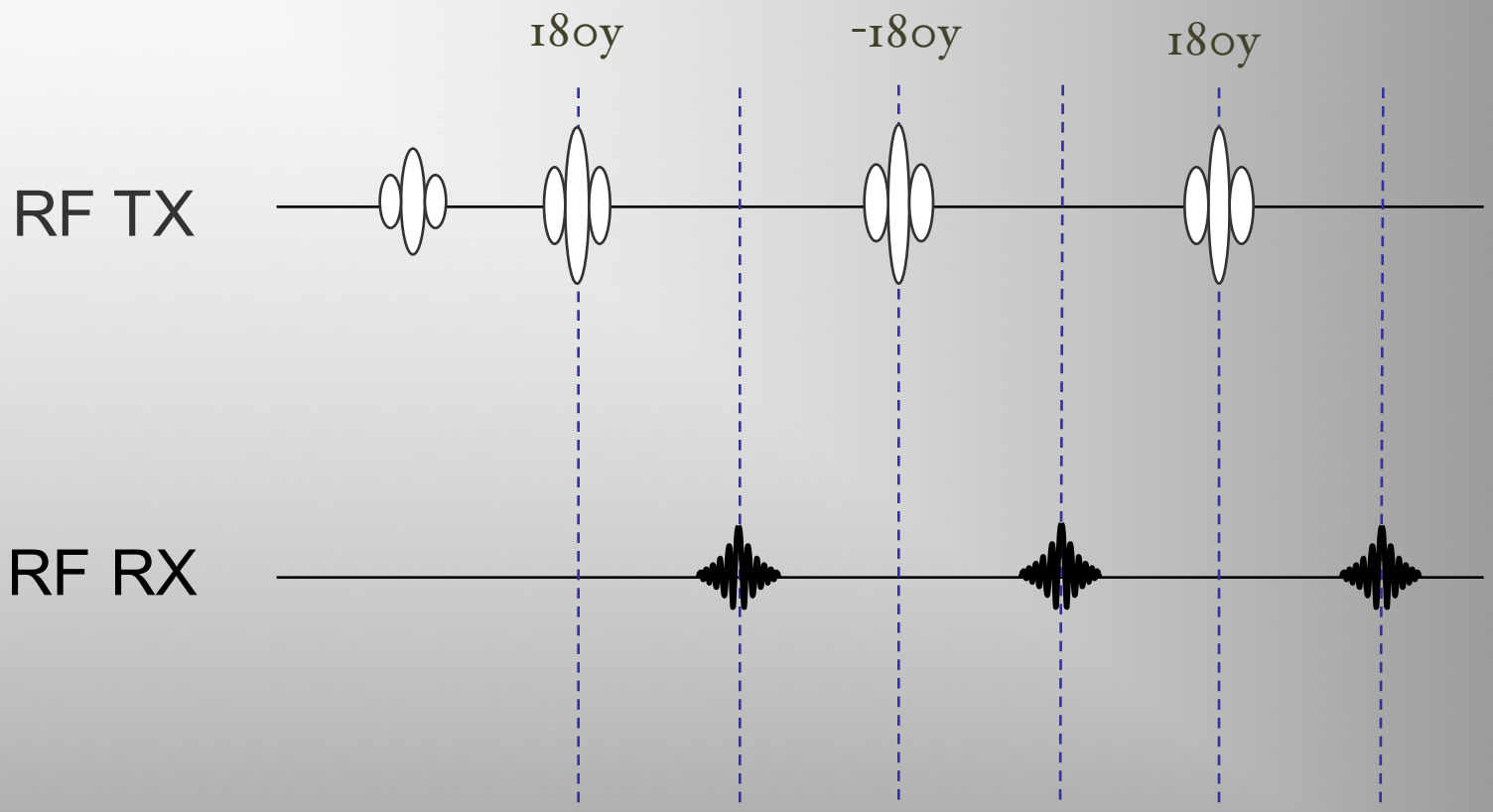


RARE and Turbo Spin Echo

Spin Echo Pulse Sequence

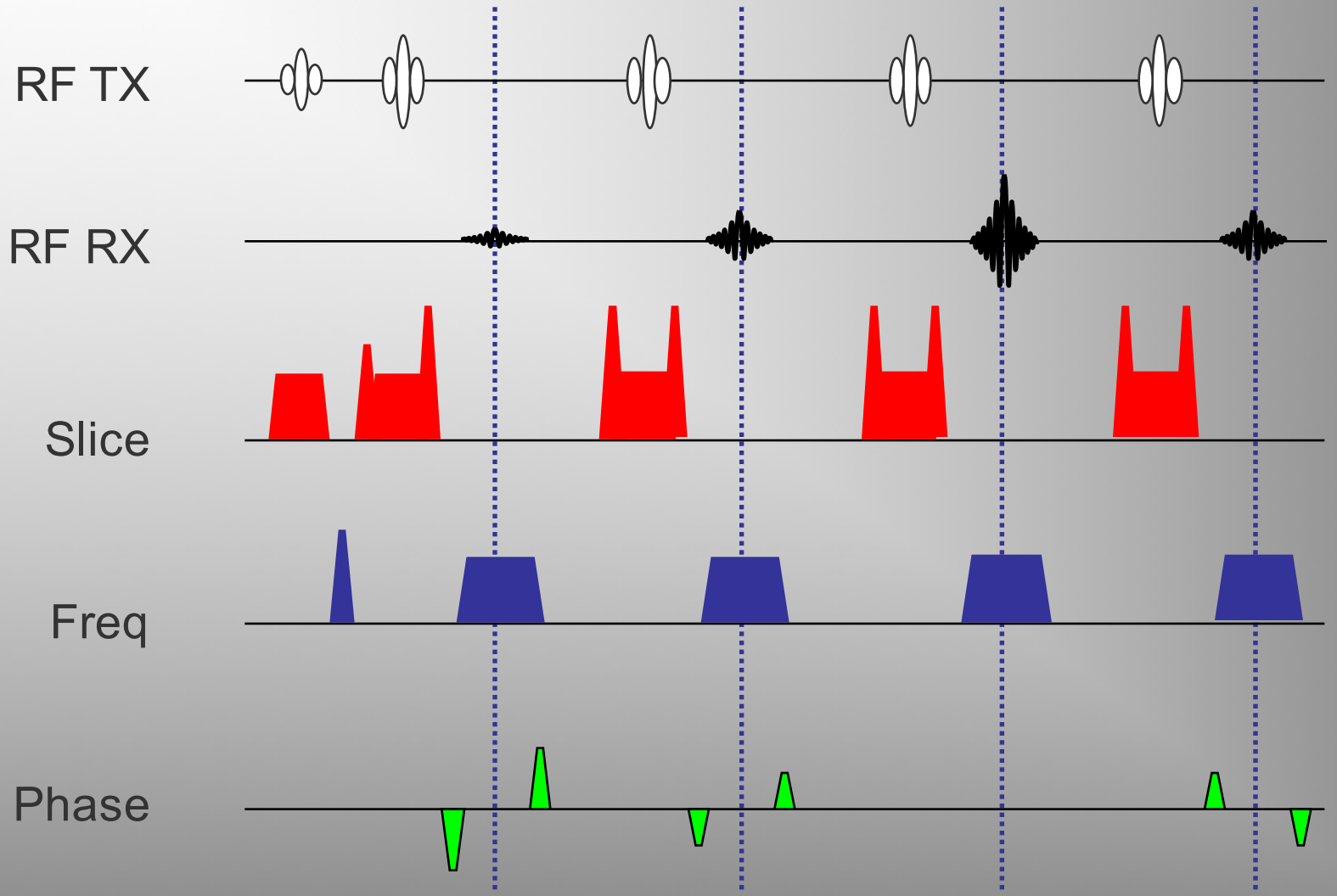


Carr-Purcell-Meiboom-Gill (CPMG) Sequence

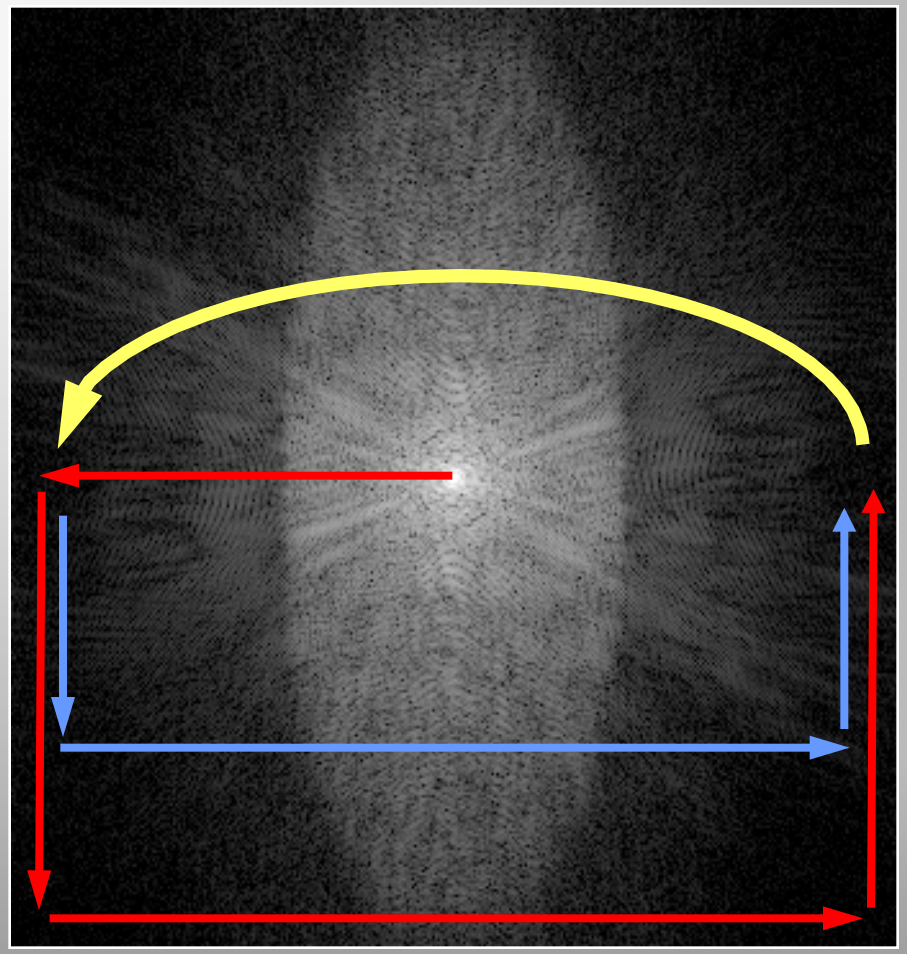


Multiple spin echoes refocused from single excitation

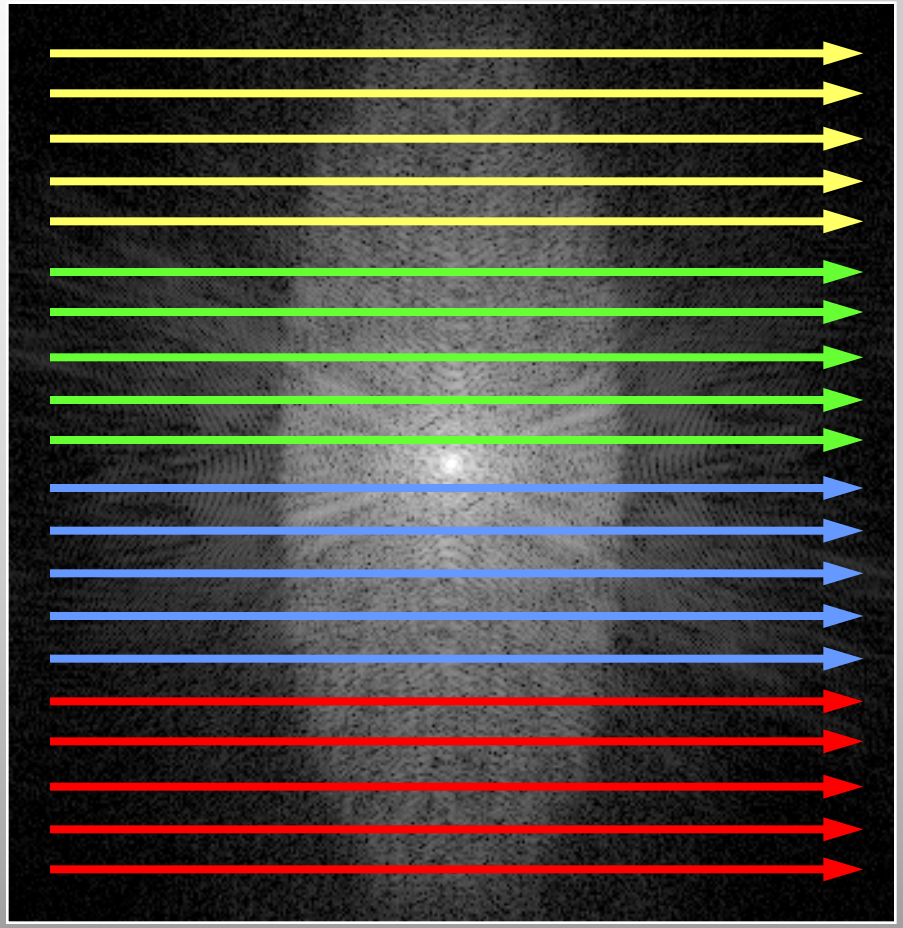
Turbo Spin Echo Pulse Sequence



TSE k-space trajectory



TSE k-space trajectory (continued)



k_y

k_x

Echo 4

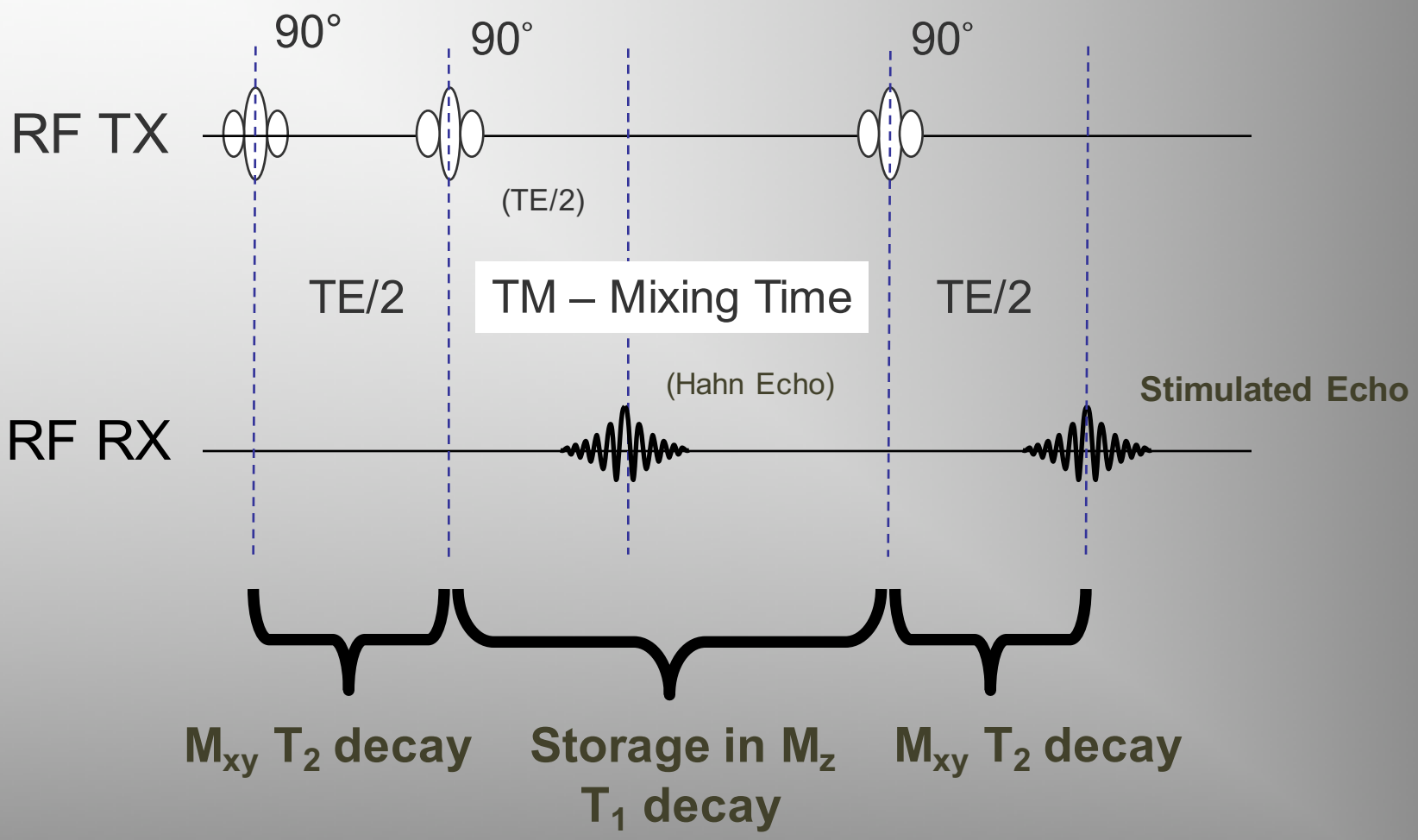
Echo 3

Echo 2

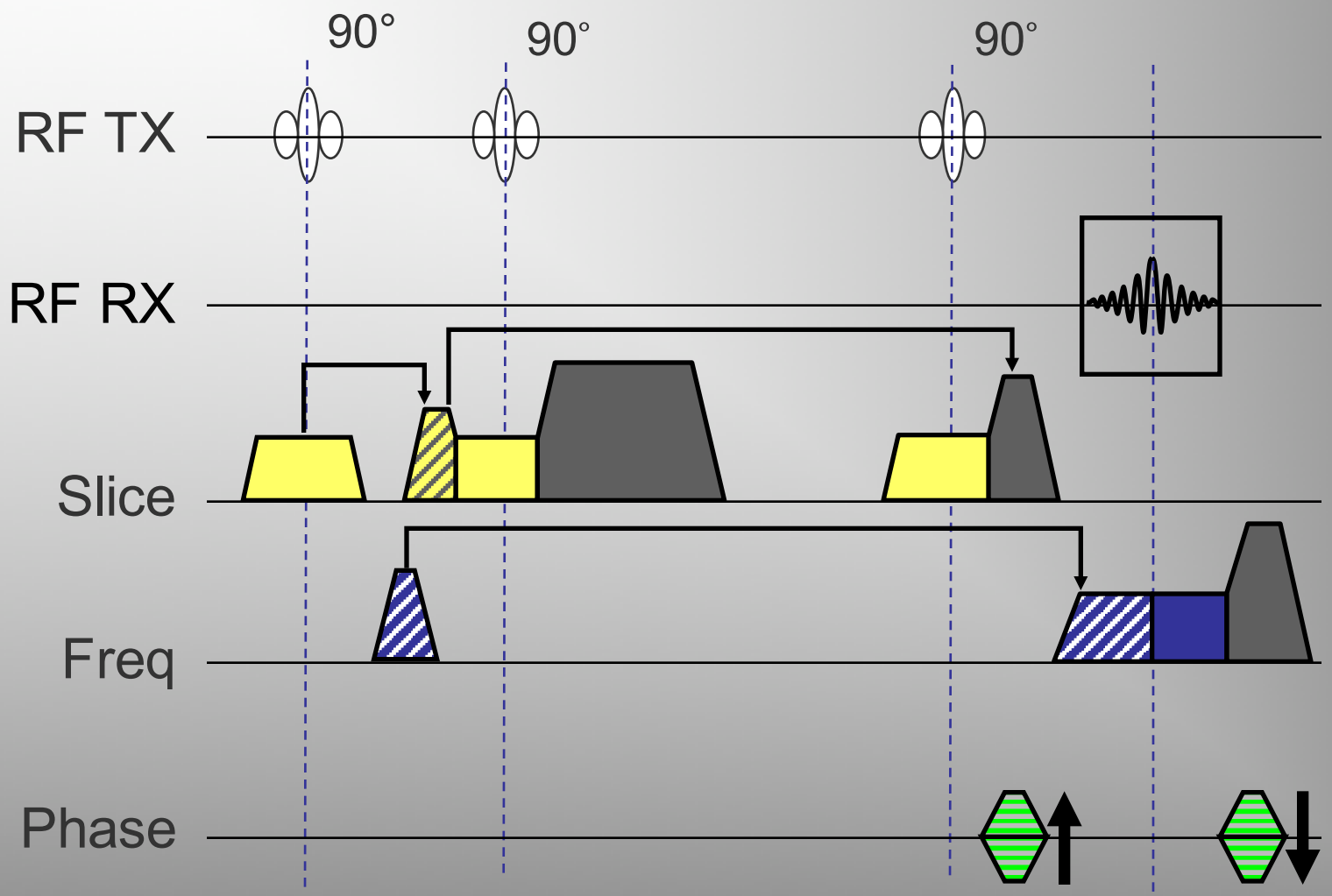
Echo 1

Stimulated Echoes

Stimulated Echo Sequence

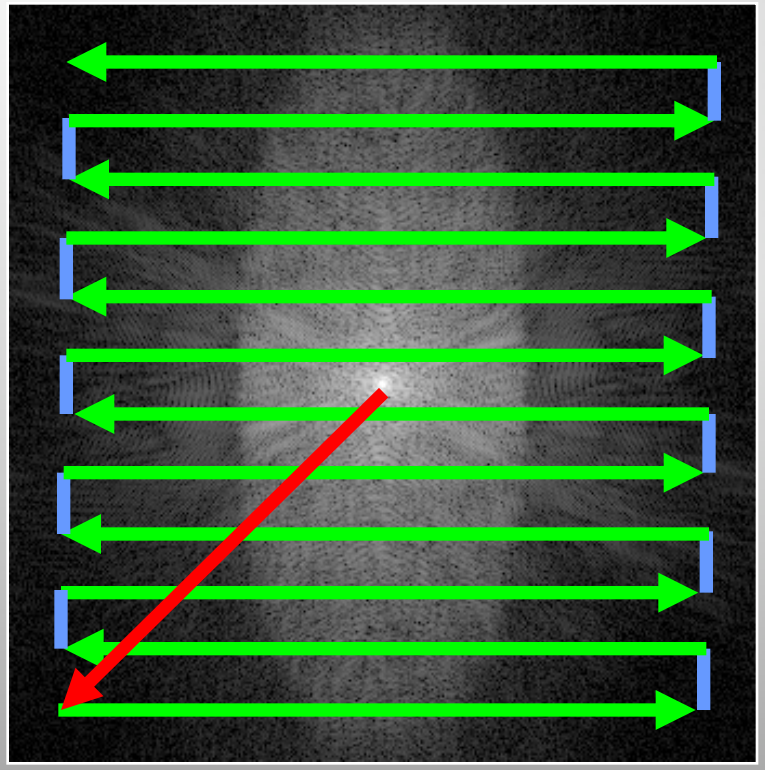


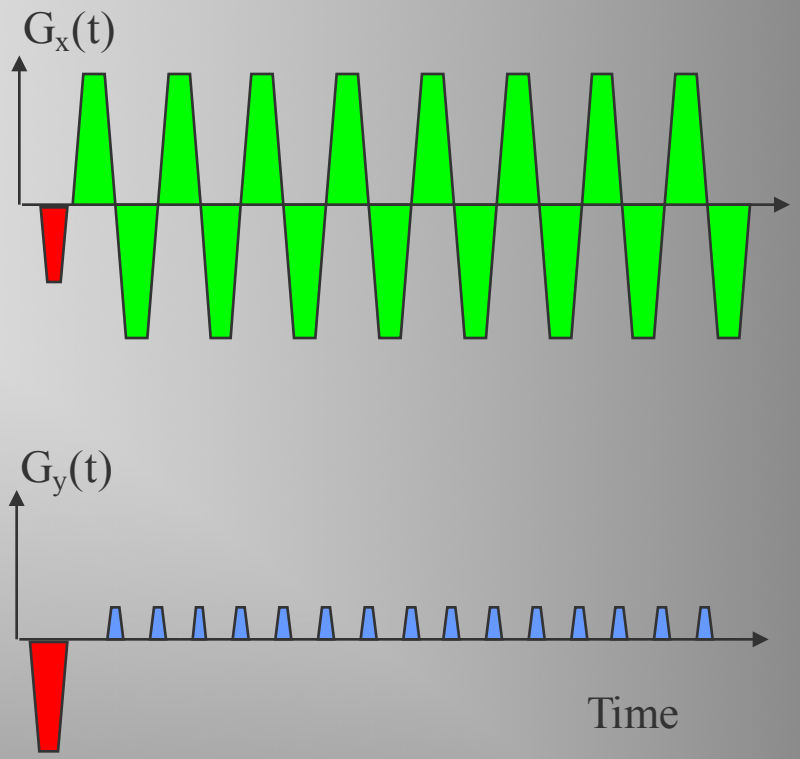
Stimulated Echo Imaging



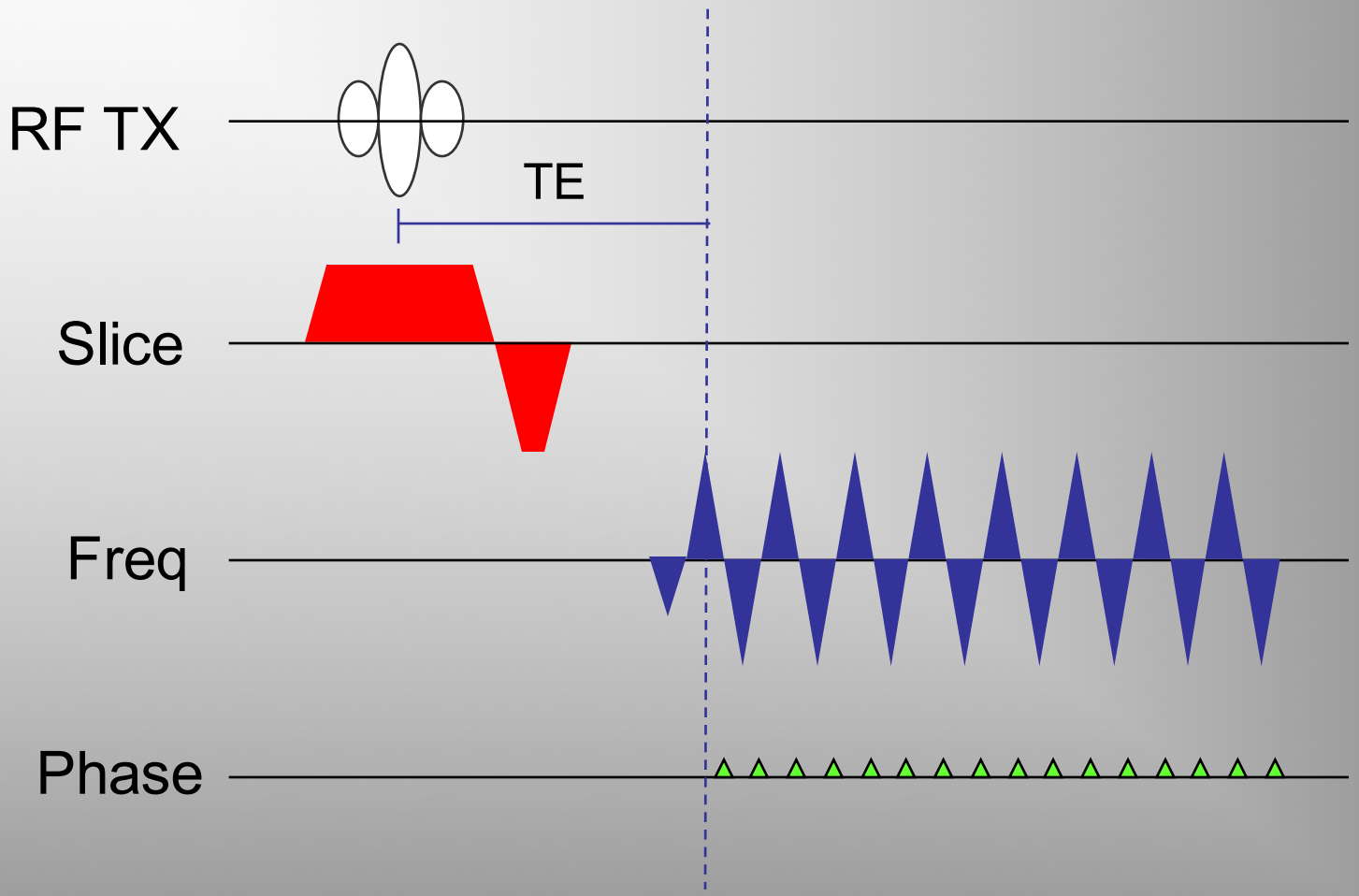
Echo Planar Imaging

Echo-planar Imaging

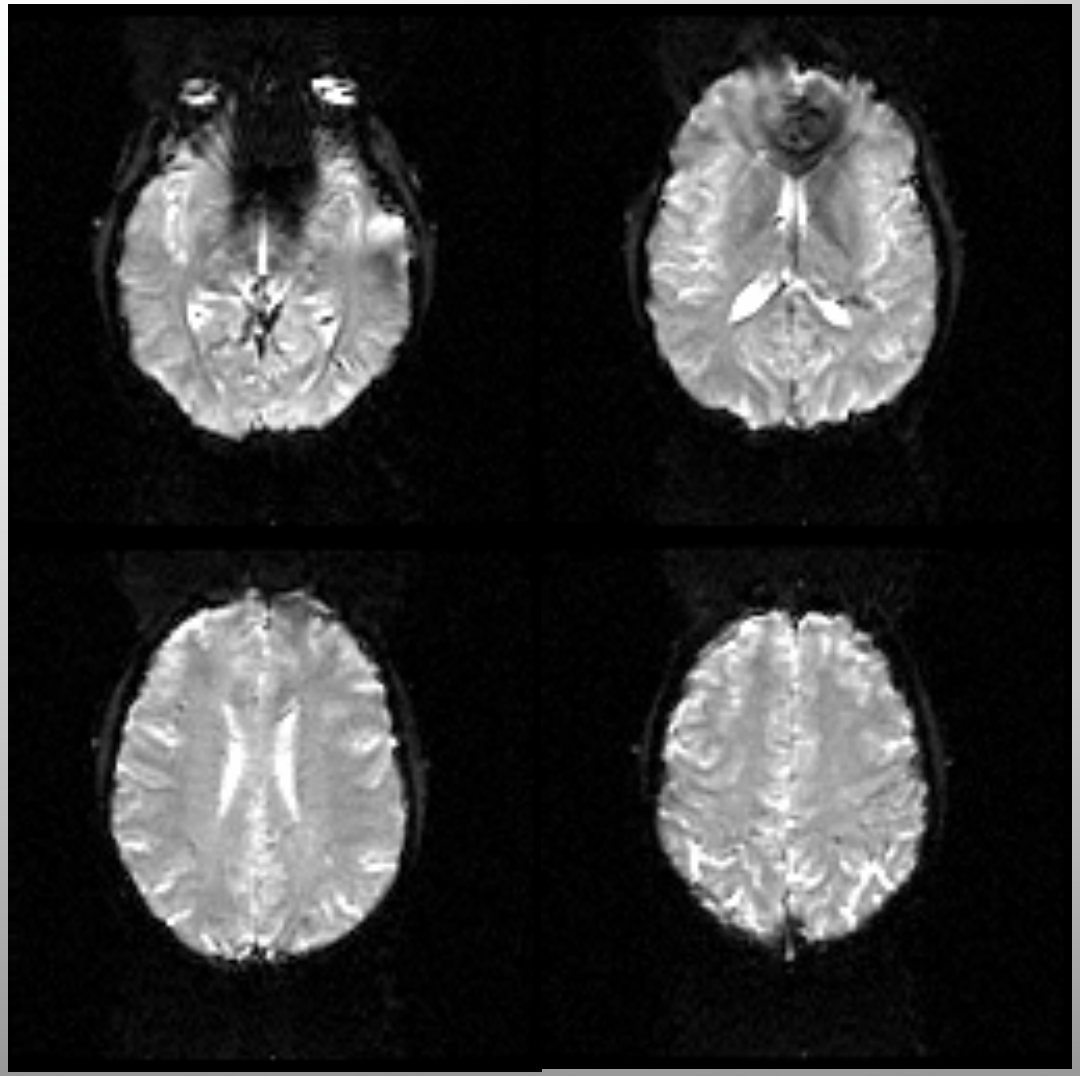




Gradient Echo EPI



GE-EPI Images

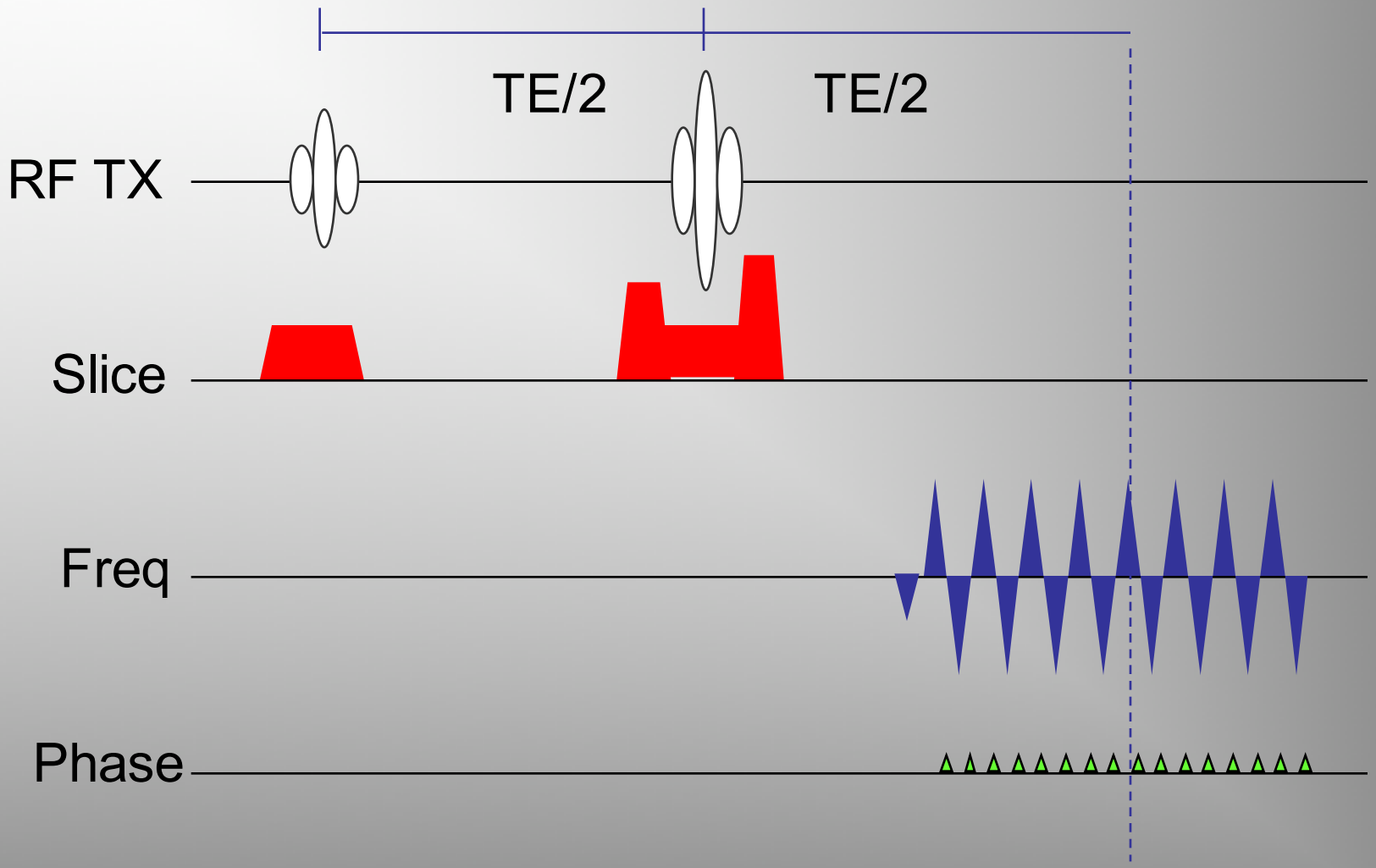


Gradient Echo EPI Images

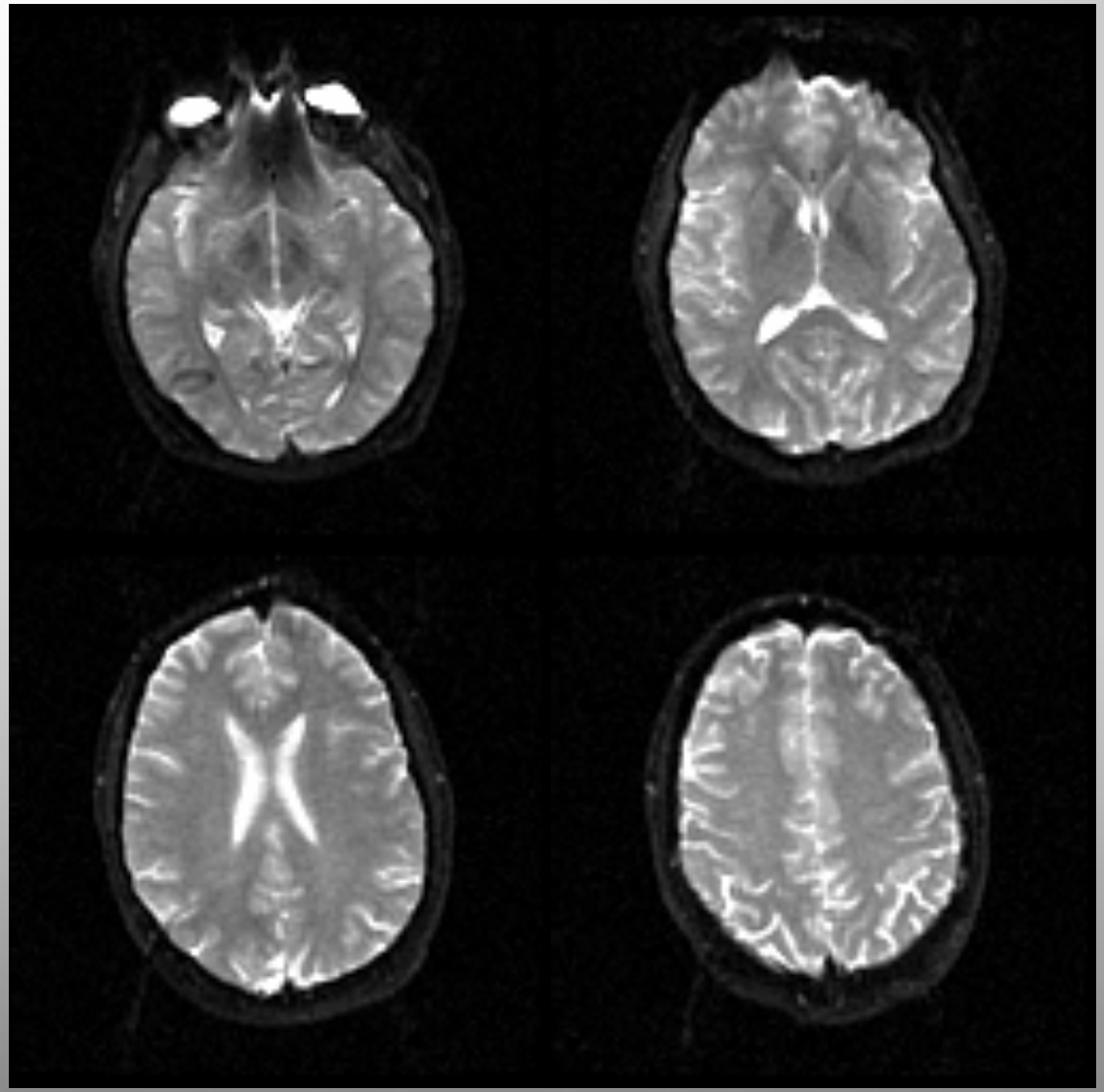
GE-EPI

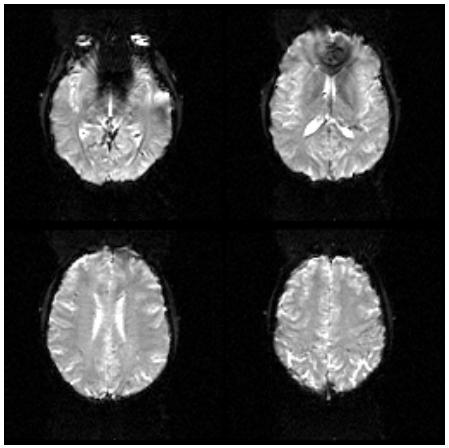
Shots	: 1
TR	: 3000ms
TE	: 60ms
Slice	: 5mm/2.5mm (18)
Matrix	: 128 x 128
FOV	: 24cm x 24cm
Time	: 6s
NEX	: 1

Spin Echo EPI



SE-EPI Images



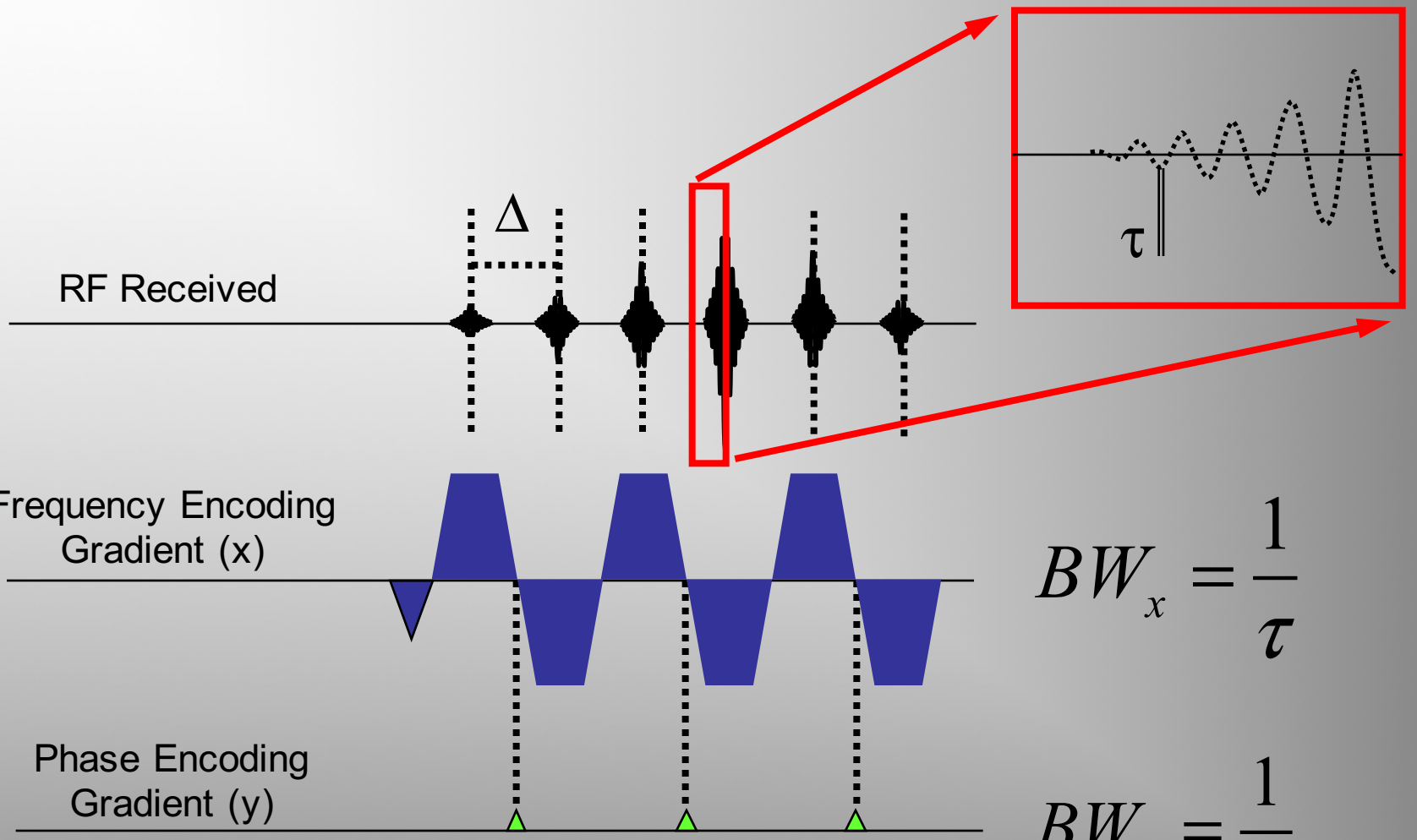


GE-EPI for reference

SE-EPI

Shots	: 1
TR	: 3000ms
TE	: 60ms
Slice	: 5mm/2.5mm (18)
Matrix	: 128 x 128
FOV	: 24cm x 24cm
Time	: 3s
NEX	: 1

EPI Bandwidths

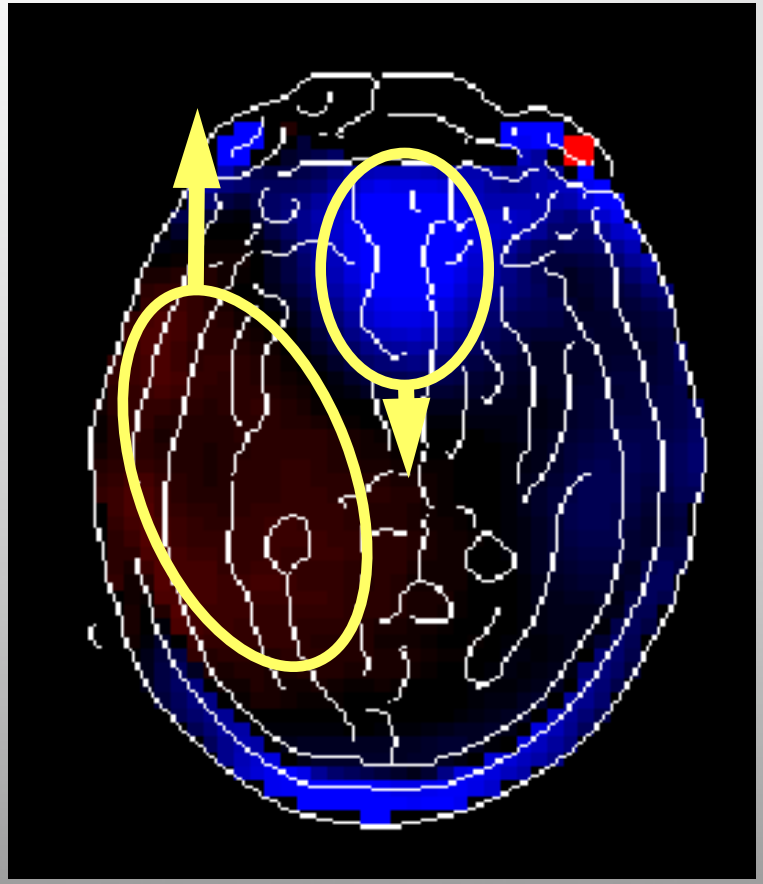


$$BW_x = \frac{1}{\tau}$$

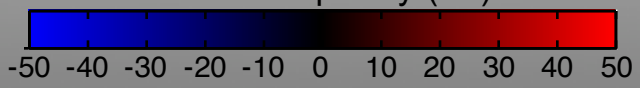
$$BW_y = \frac{1}{\Delta}$$

Static Inhomogeneity and EPI

Frequency Encoding Direction



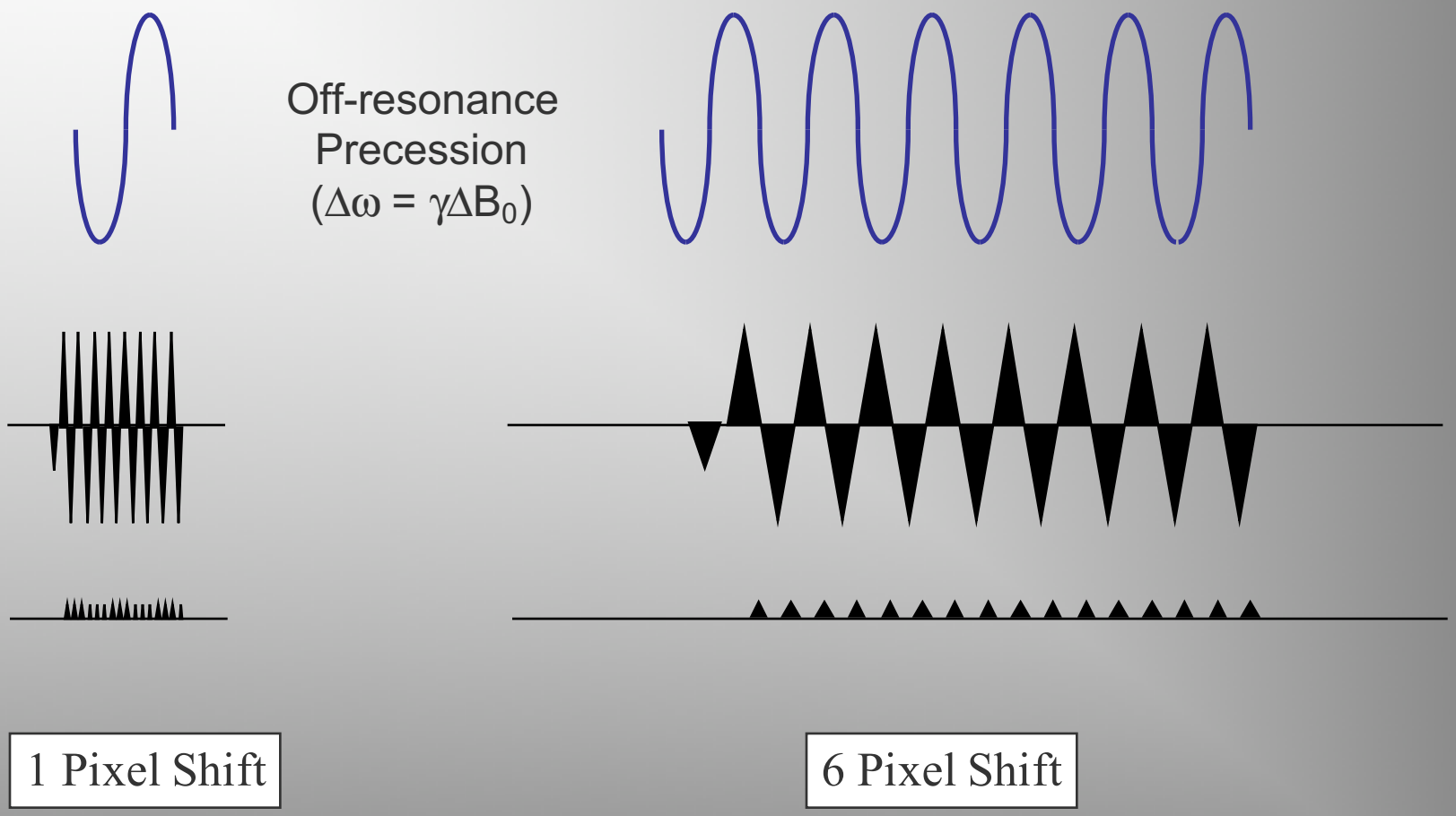
Phase Encoding Direction



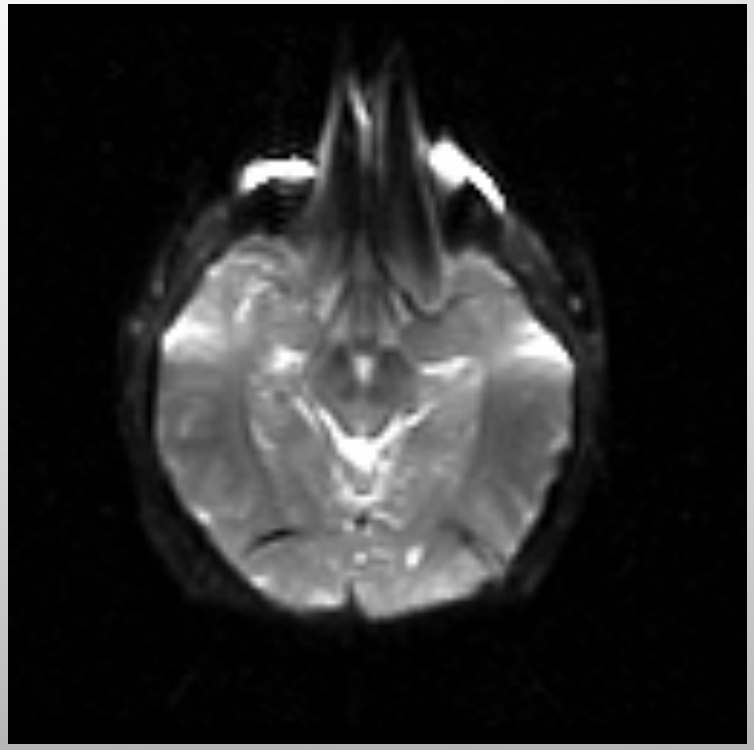
Voxel displacement due to static field inhomogeneity

$$\Delta y = \frac{\gamma \Delta B_0 \cdot \mathrm{FOV}_y}{\mathrm{BW}_y}$$

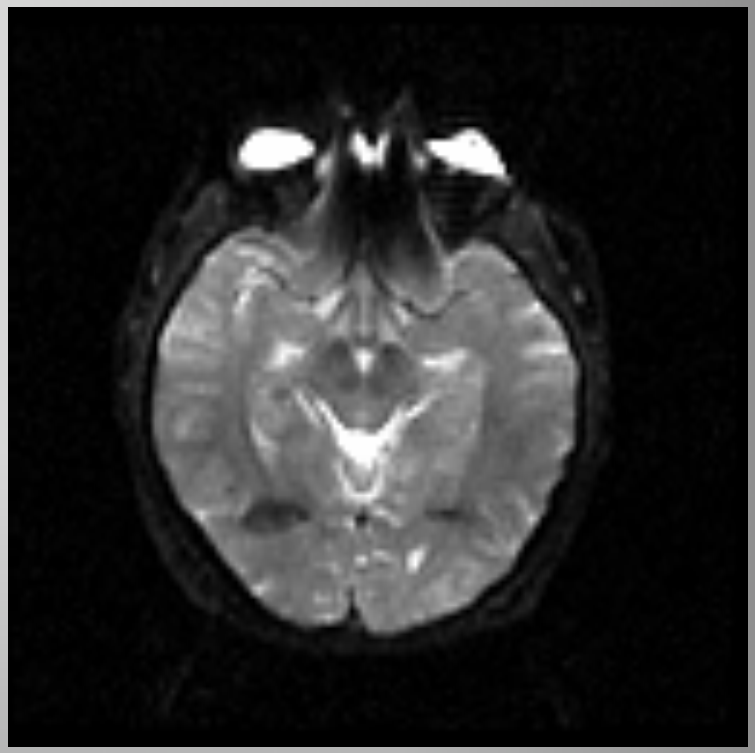
Effect of Echo Train Length



Ramp Sampling



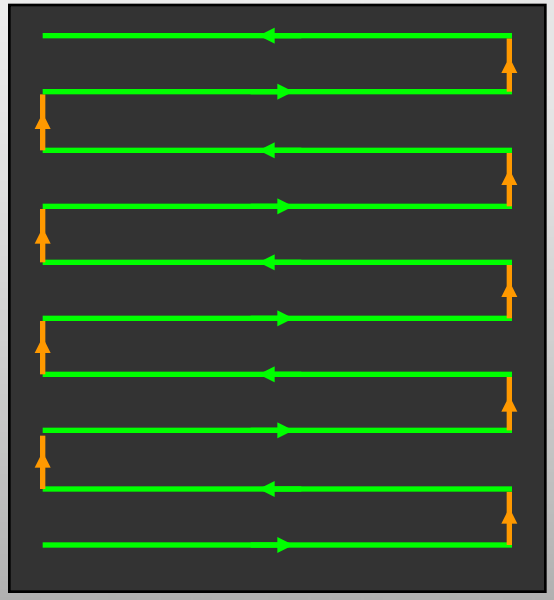
Without Ramp Sampling



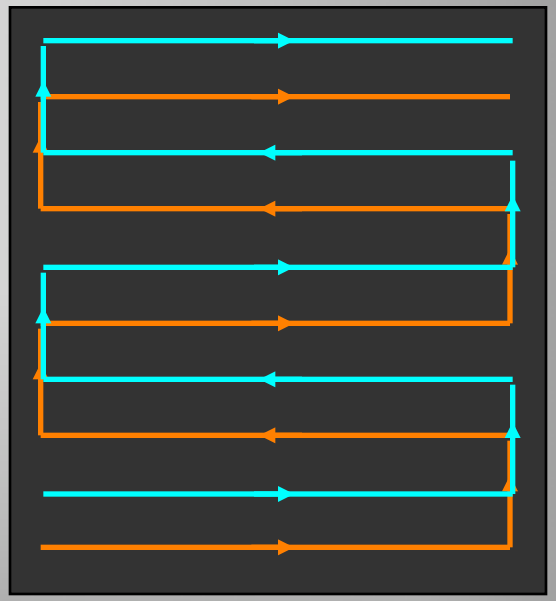
With Ramp Sampling

Multi-shot EPI k-space Trajectory

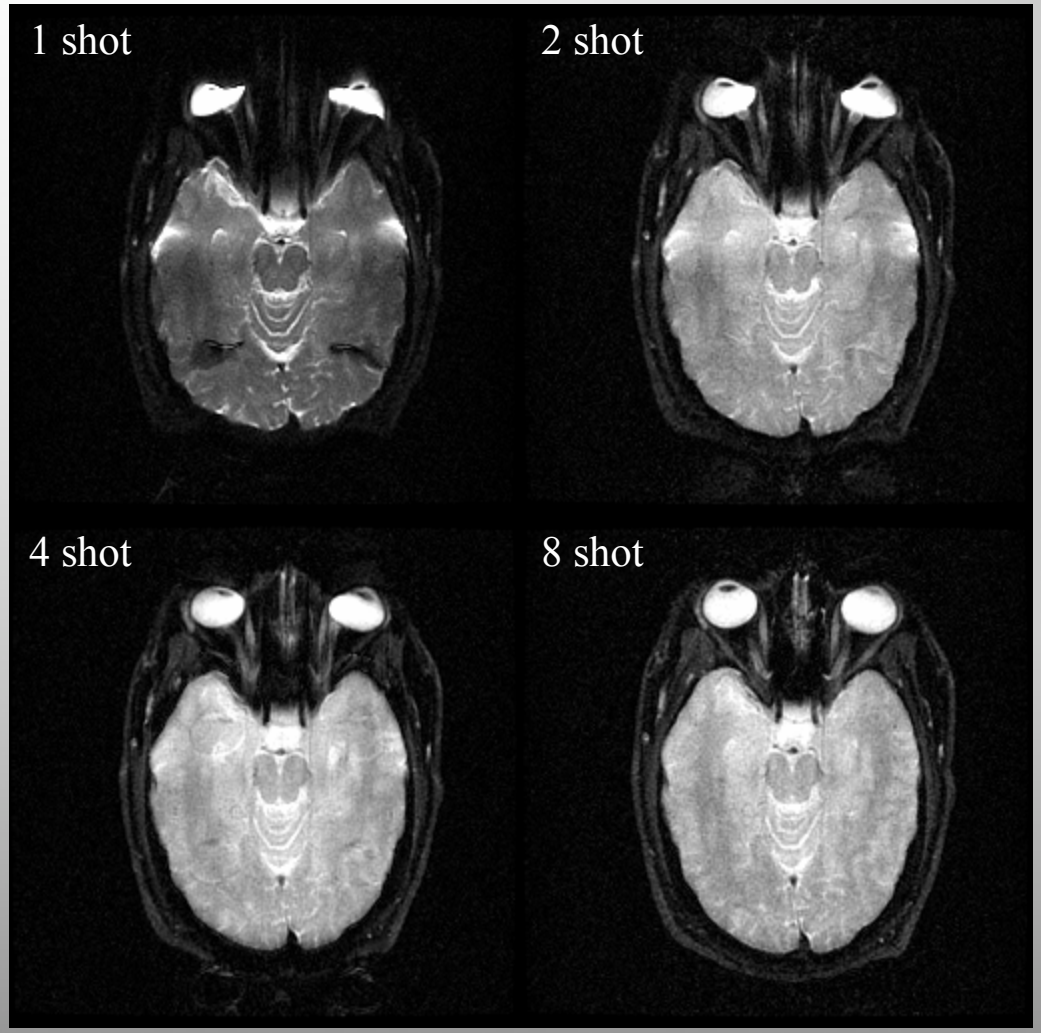
Single Shot



Two Shot



Effect of Multi-shot

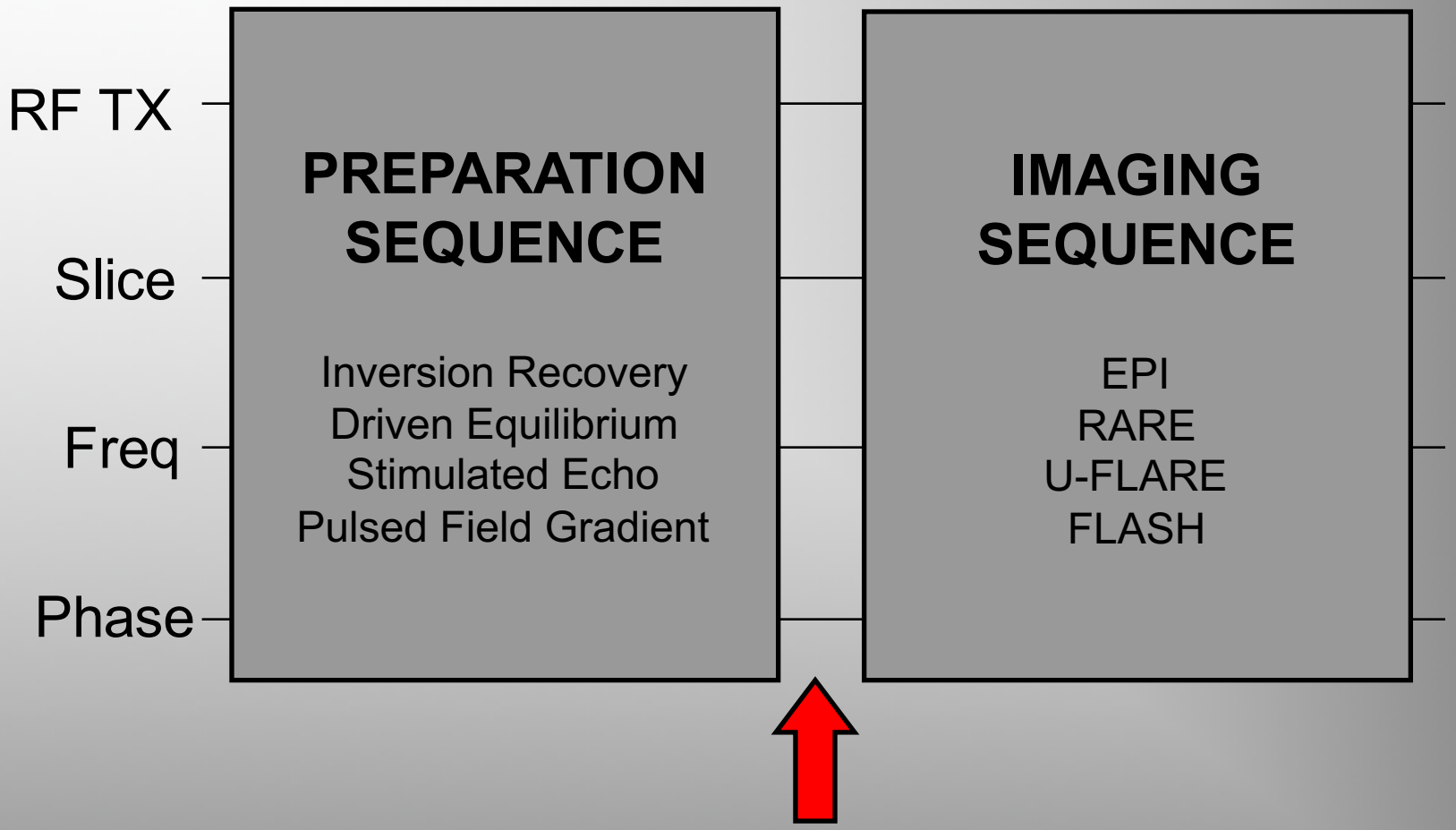


Increasing the number of shots per image decreases the EPI echo-train length per shot.

SE-EPI

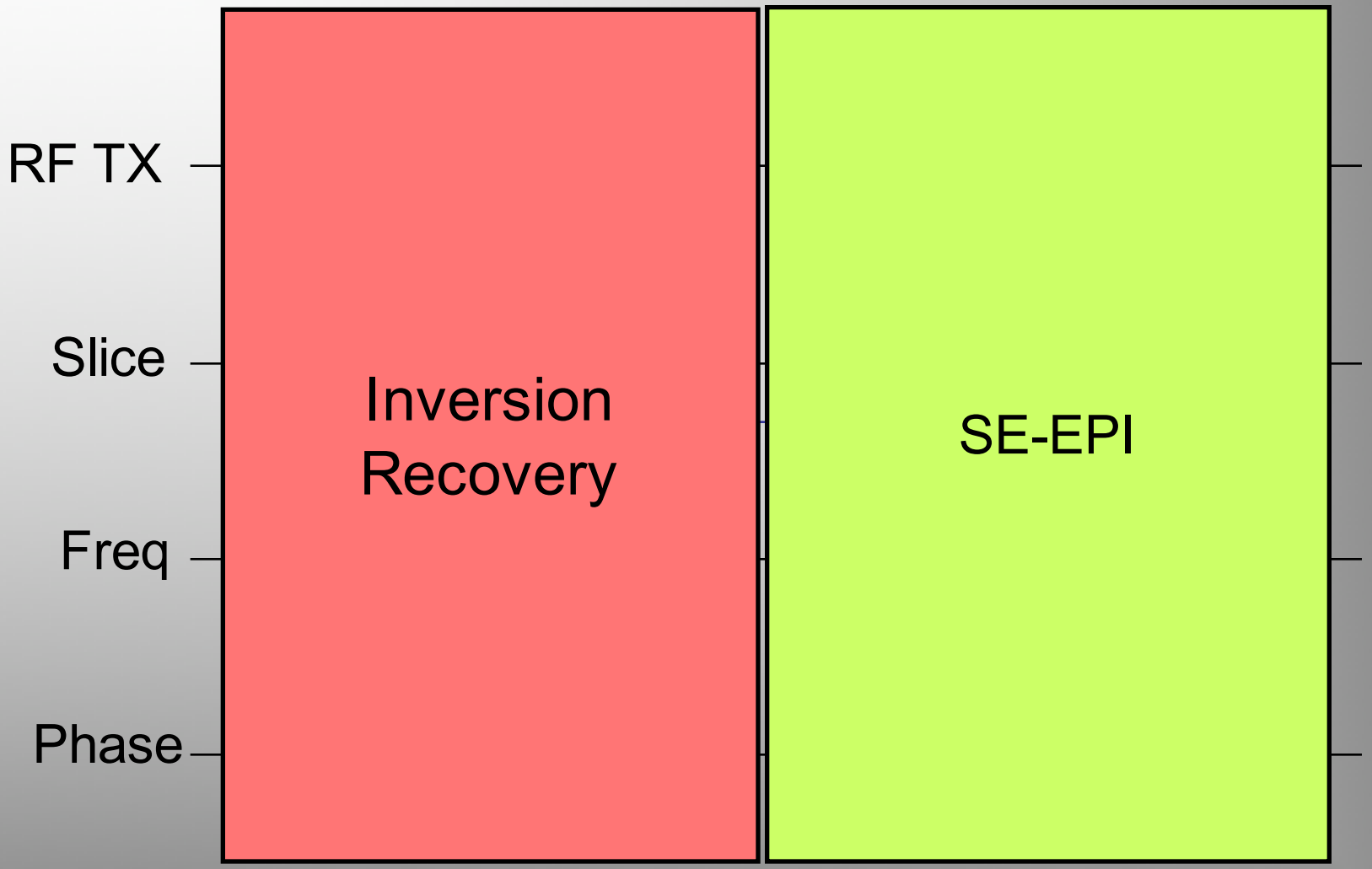
Shots	: 1-8
TR	: 3000ms
TE	: 60ms
Slice	: 5mm/2.5mm (18)
Matrix	: 256 x 256
FOV	: 24cm x 24cm
Time	: 12s-27s
NEX	: 1

Magnetization Preparation

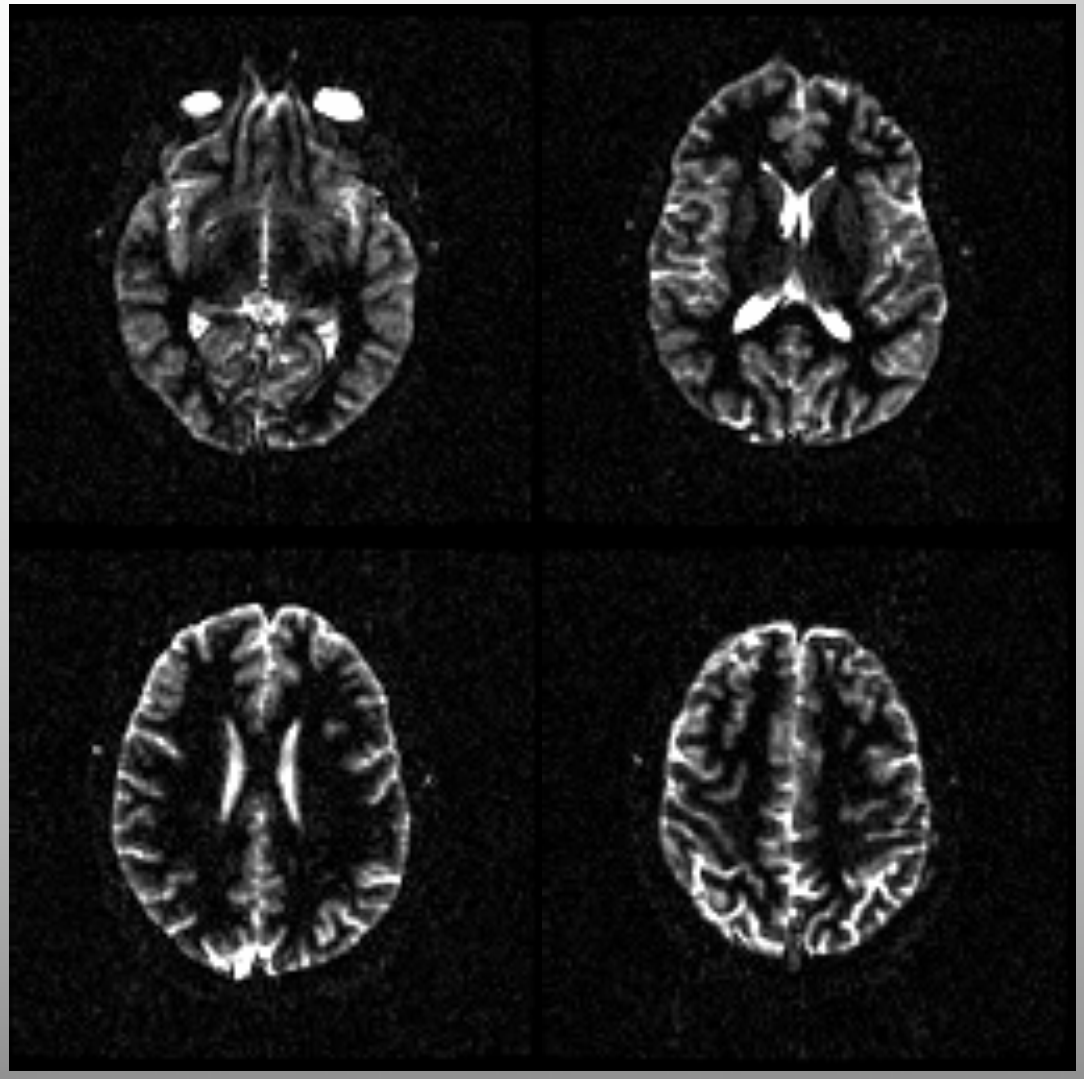


Longitudinal or transverse magnetization carries magnetization contrast prepared by initial pulse sequence

Inversion-Recovery EPI



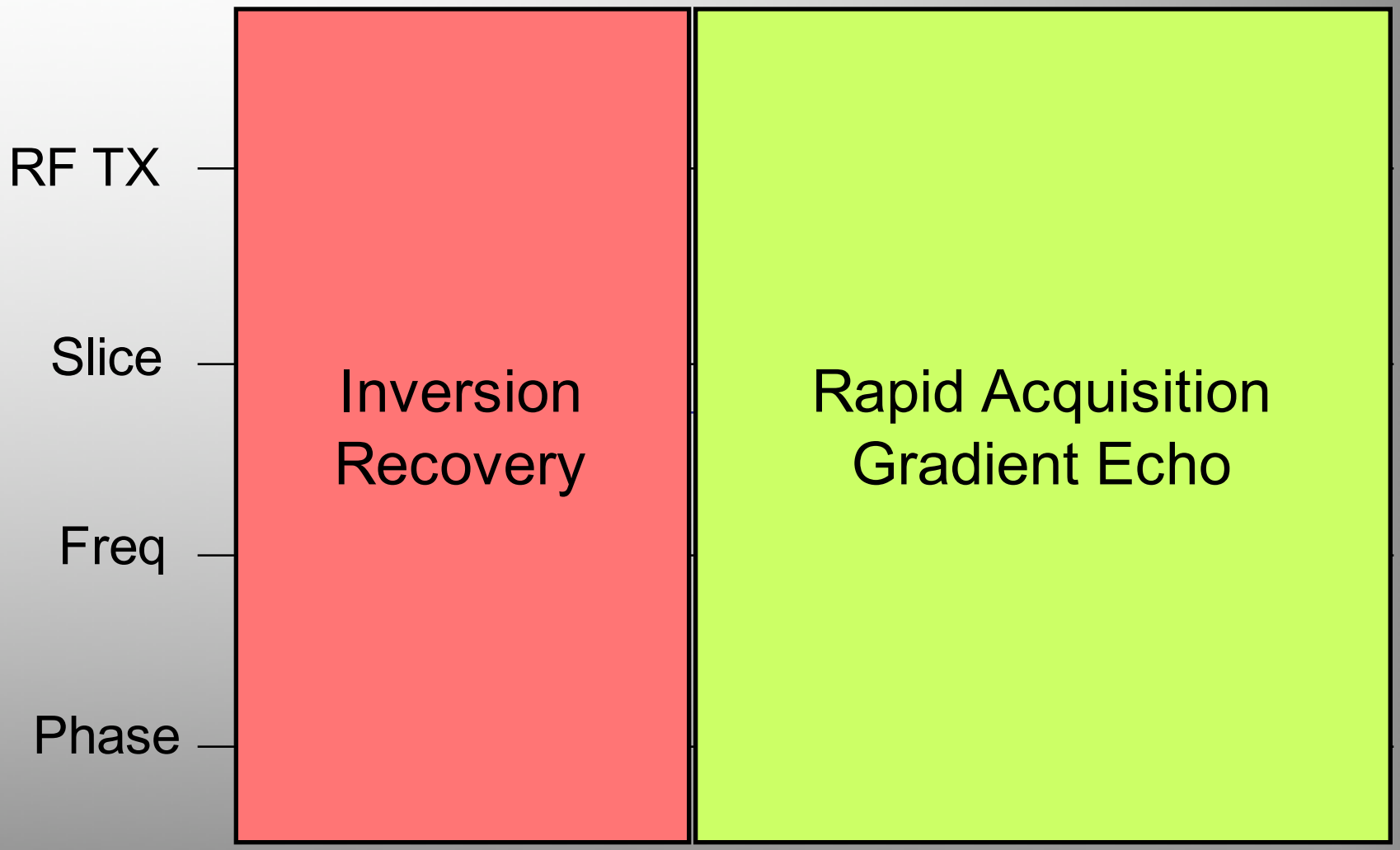
IR-EPI Images



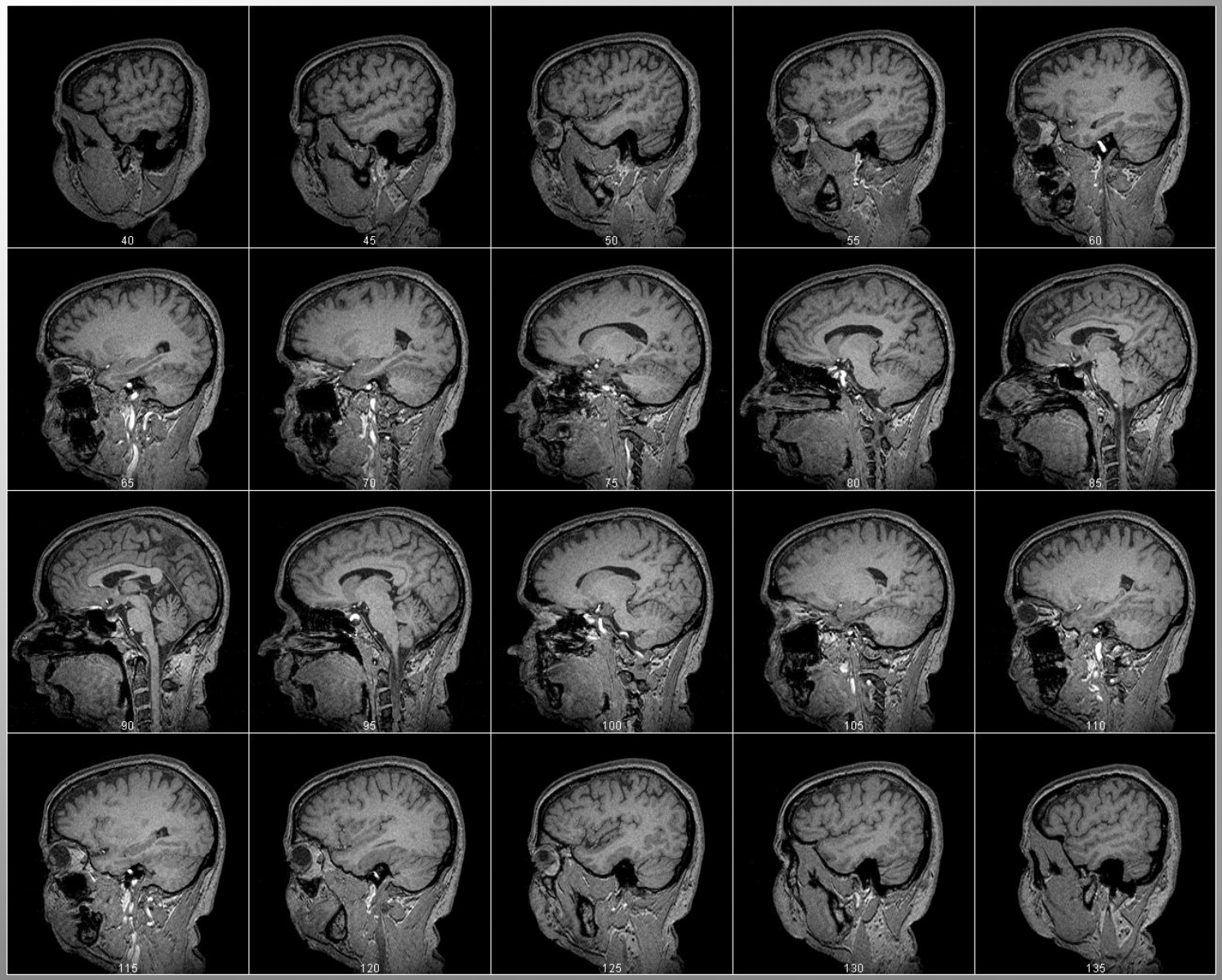
IR-SE-EPI

Shots	: 1
TI	: 400ms
TR	: 3000ms
TE	: 60ms
Slice	: 5mm/2.5mm (18)
Matrix	: 128 x 128
FOV	: 24cm x 24cm
Time	: 12s
NEX	: 1

MP-RAGE Pulse Sequence

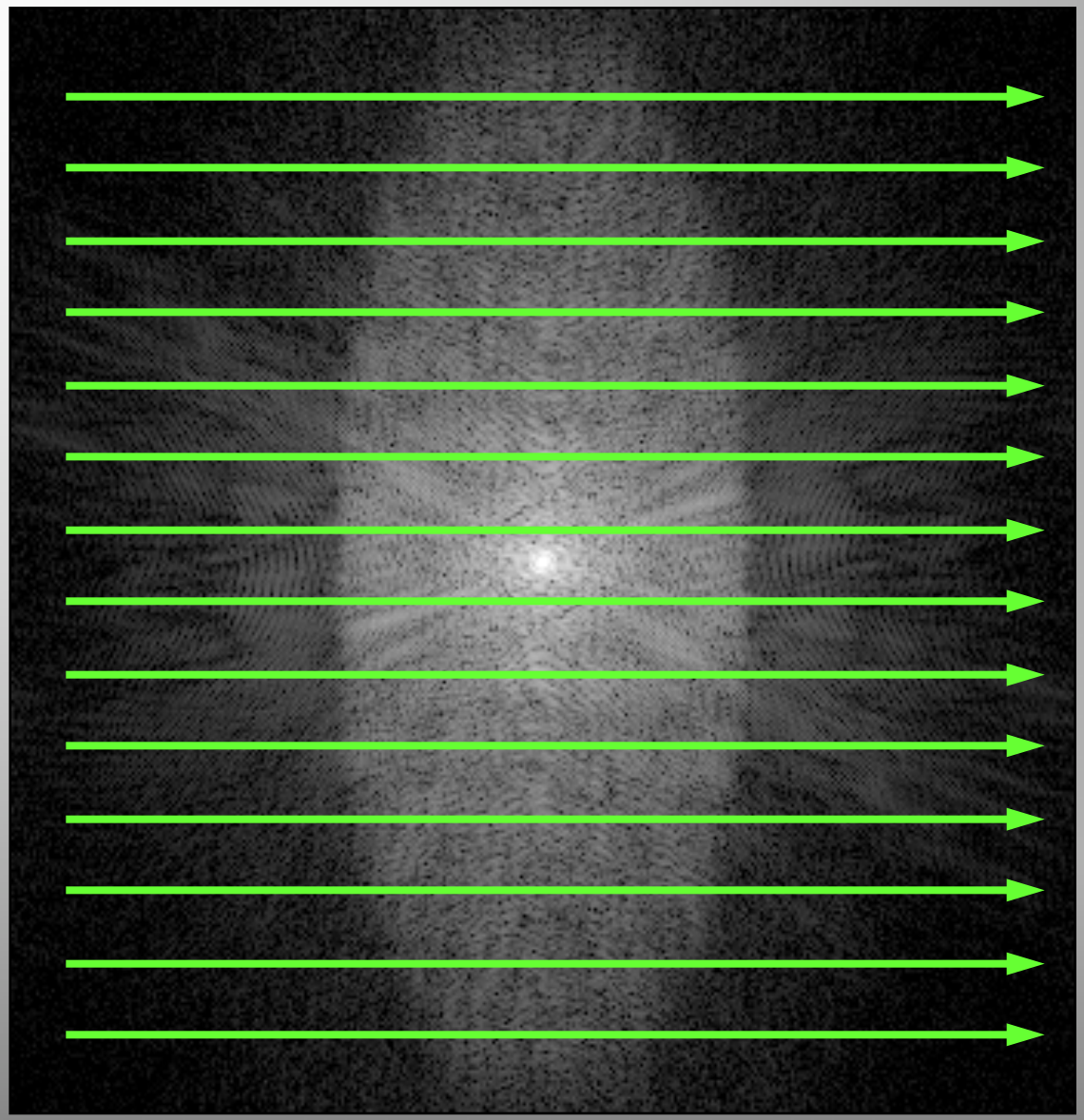


T_1-weighted MP-RAGE

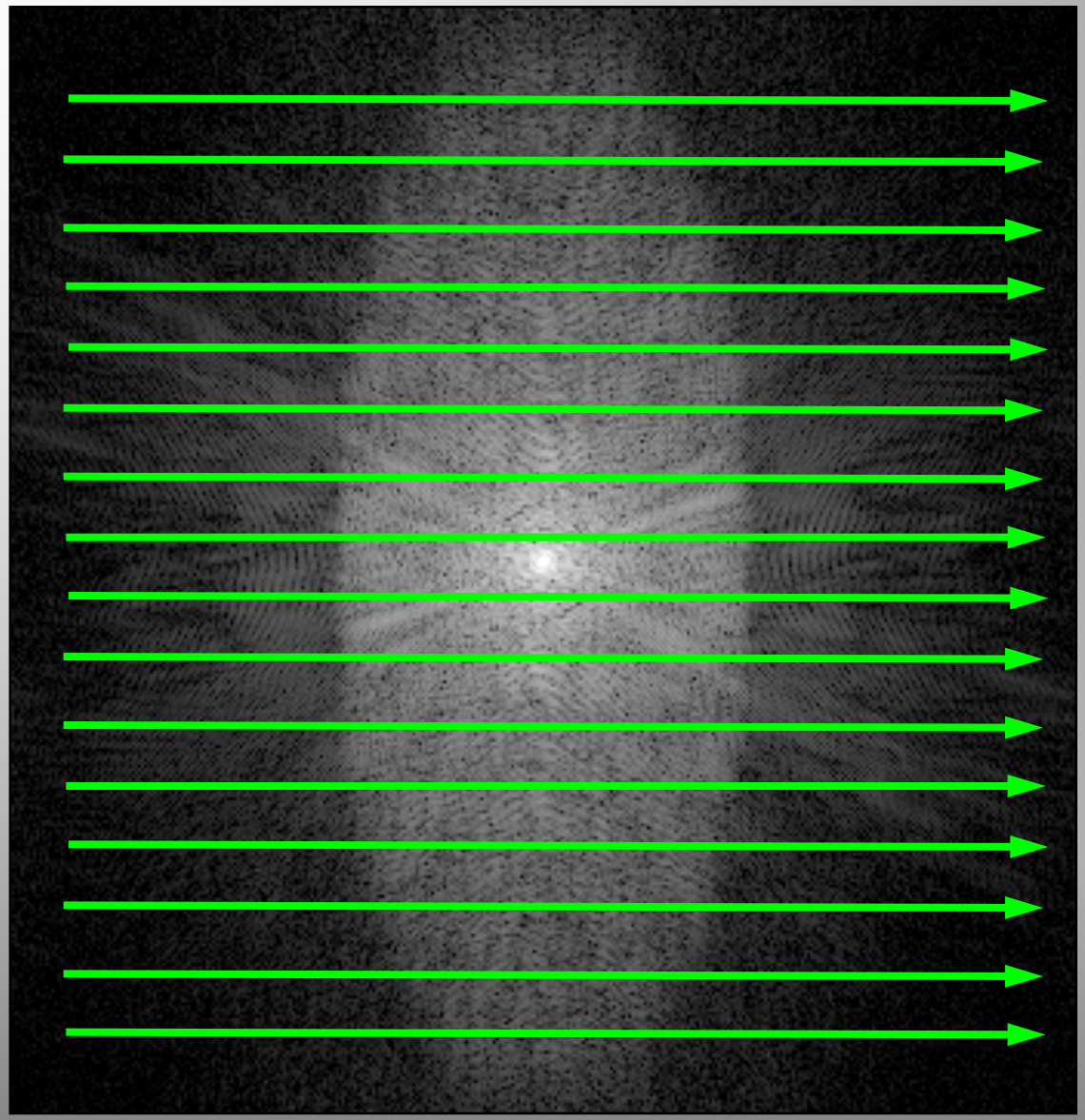


Phase Encode Ordering

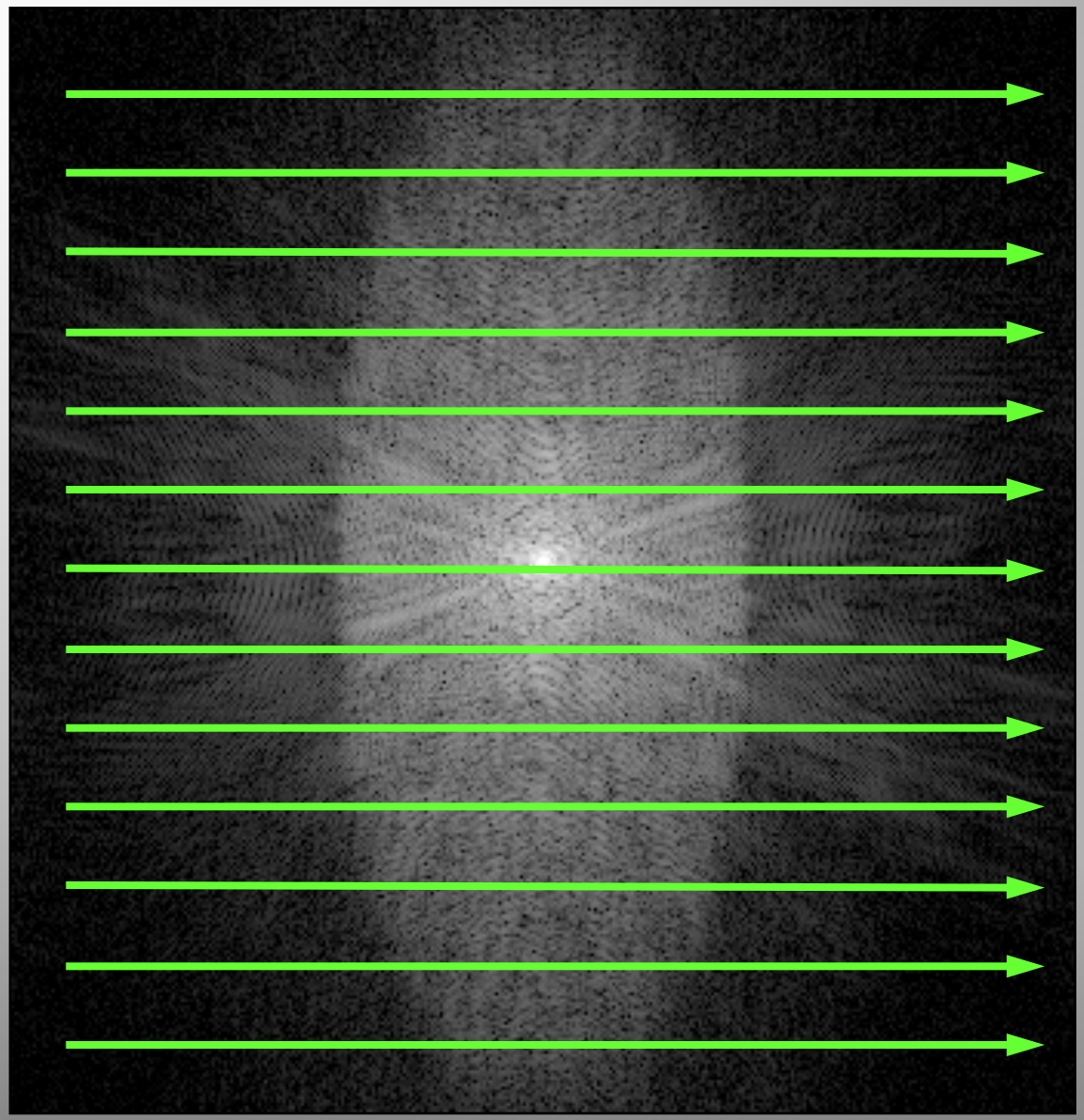
Sequential



Interleaved

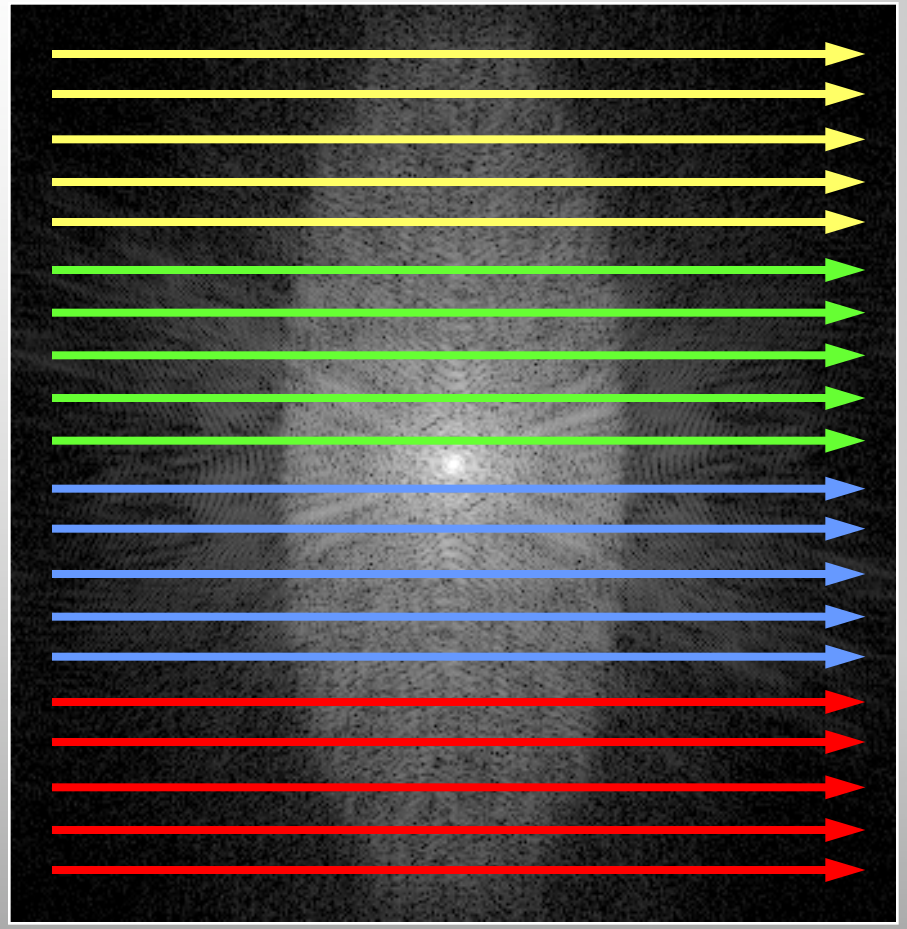


Centric



Segmented Acquisitions

Segmented Acquisition (eg TSE/RARE)



Echo 4 →
Echo 3 →
Echo 2 →
Echo 1 →

Segment Ordering? **Sequential**

Intrasegment Ordering? **Sequential**

Tomorrow :
Corrections and Compensations