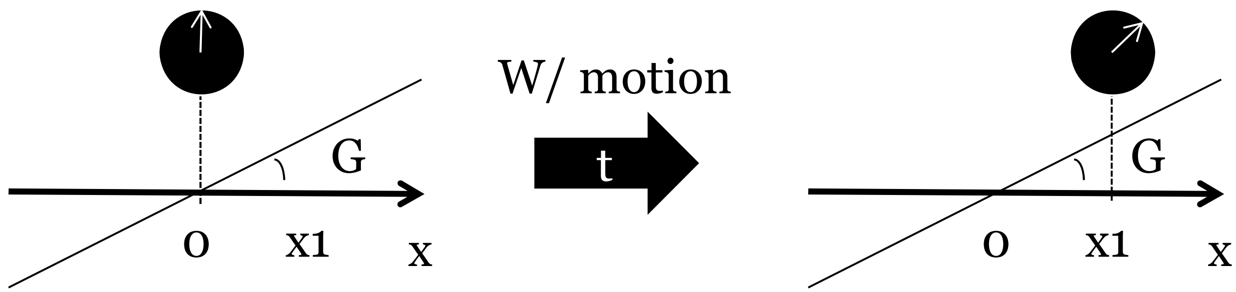
# Chapter 23
# Motion Artifacts and Flow Compensation

Yongquan Ye, Ph.D.
Assist. Prof.
Radiology, SOM
Wayne State University

- **Previous classes:**
  - K-space, phase encoding and spatial encoding (Chaps.10)
  - Segmented k-space (chap.19)
  - DFT (Chaps. 11-12)
- **Today's content**
  - Flow compensation
  - Motion effects and ghosting artifact

# Static vs. moving spin along RO




**Constant flow+ gradient induced signal phase (image):**

$$\phi_v(t) = -\gamma \int G(\tau) v \tau d\tau$$

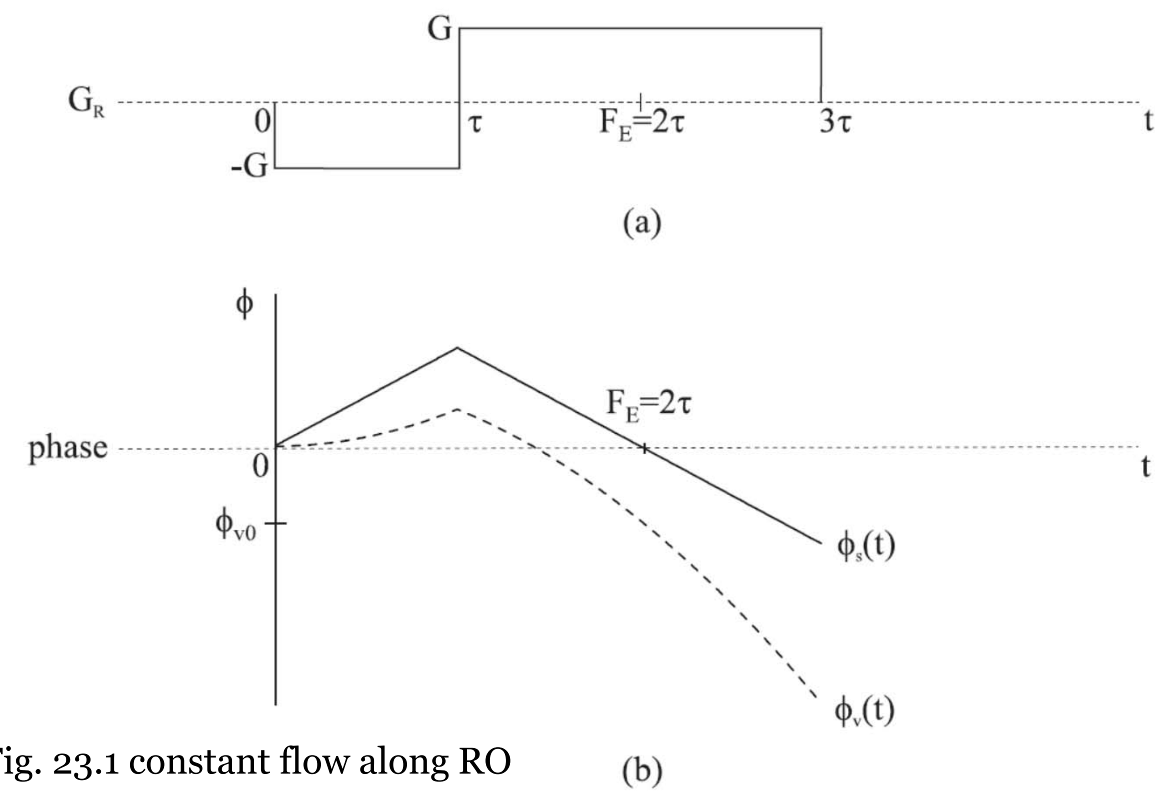
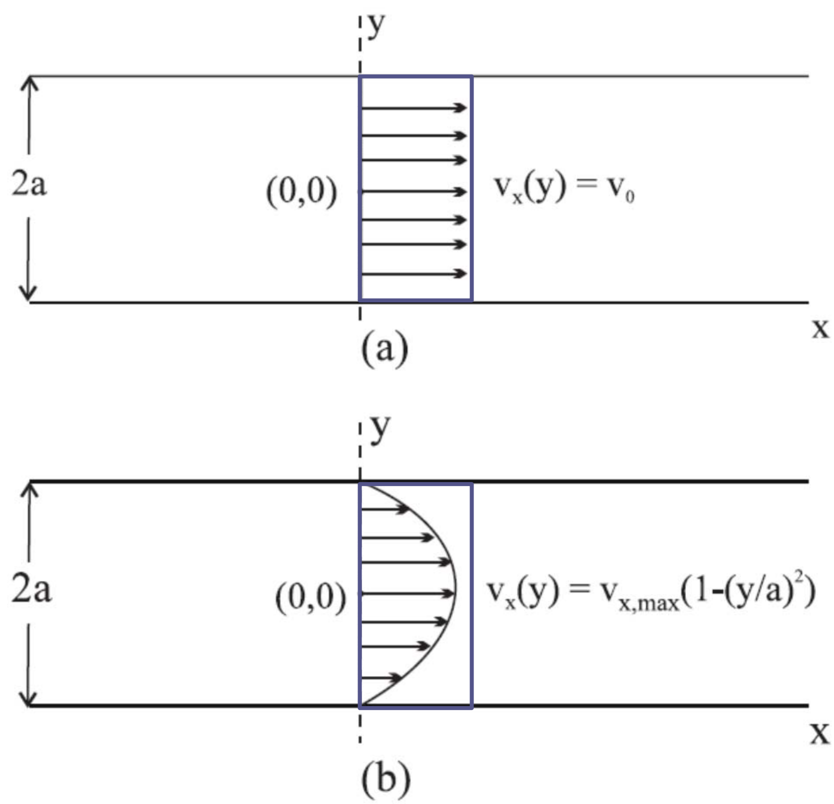



Fig. 23.1 constant flow along RO

# Dephasing due to laminar flow




- For constant plug flow (or practically, slow flow), image magnitude remains unchanged, but image phase is proportional to flow velocity
- For laminar flow, signal dephasing can take place, also reducing the image magnitude

# Velocity compensation along RO

$$\phi_v(t) = -\gamma \int G(\tau) v \tau d\tau = -\gamma v \int G(\tau) \tau d\tau \equiv 0$$

$$\Downarrow$$

$$M_1(TE) \equiv \int G(\tau) \tau d\tau = 0$$

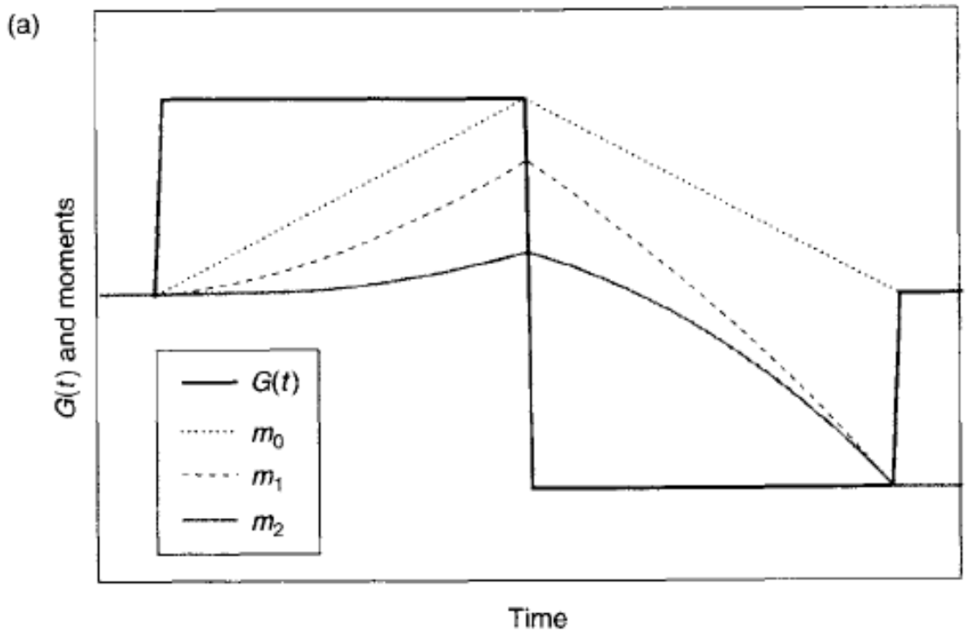
- $n_{th}$ Gradient moment (n=0,1,2…)

$$M_n(t) \equiv \int_0^t G(\tau) \tau^n d\tau$$

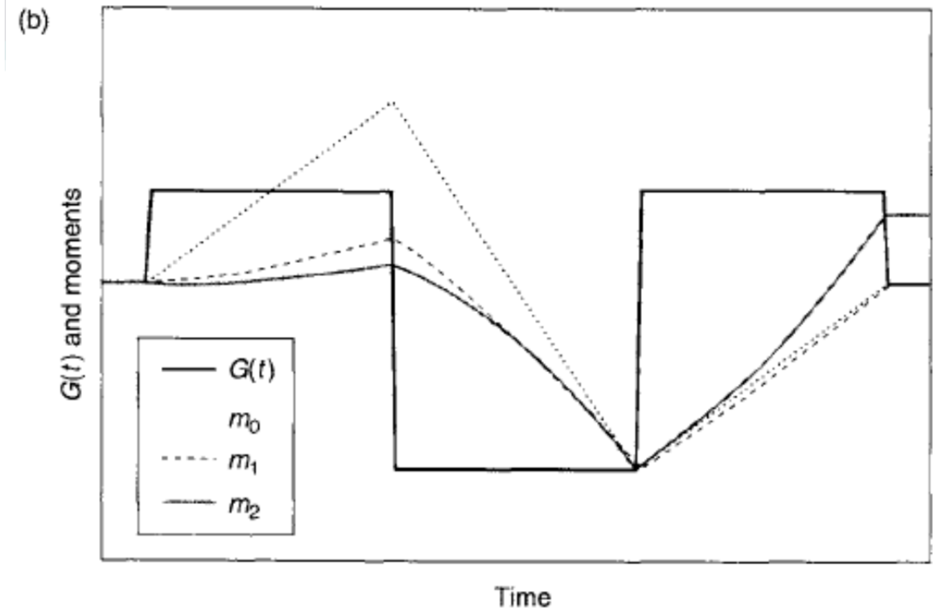
- Gradient moment nulling (GMN)

$$M_{n(t)} = 0$$

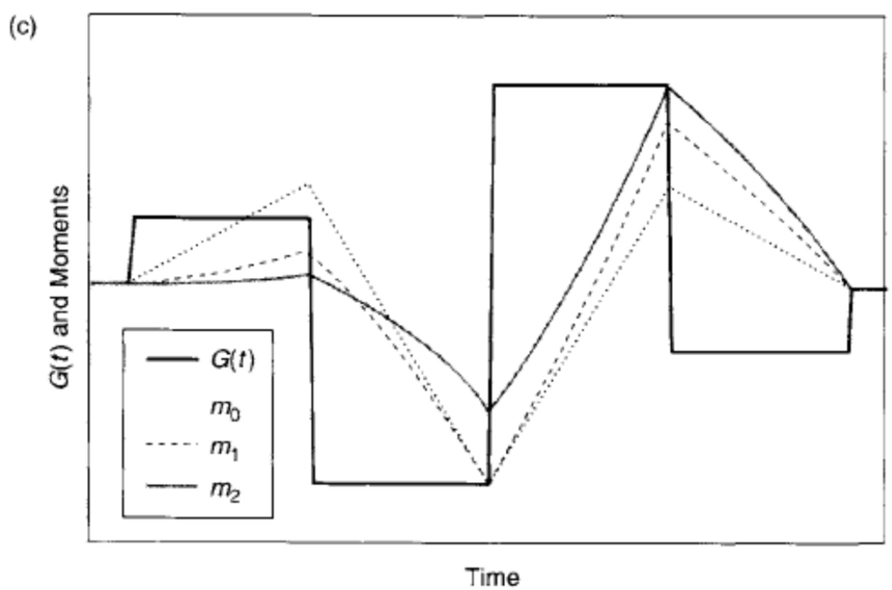
$M_0$=0: ‘static’ compensation
$M_1$=0: velocity compensation
$M_2$=0: acceleration compensation



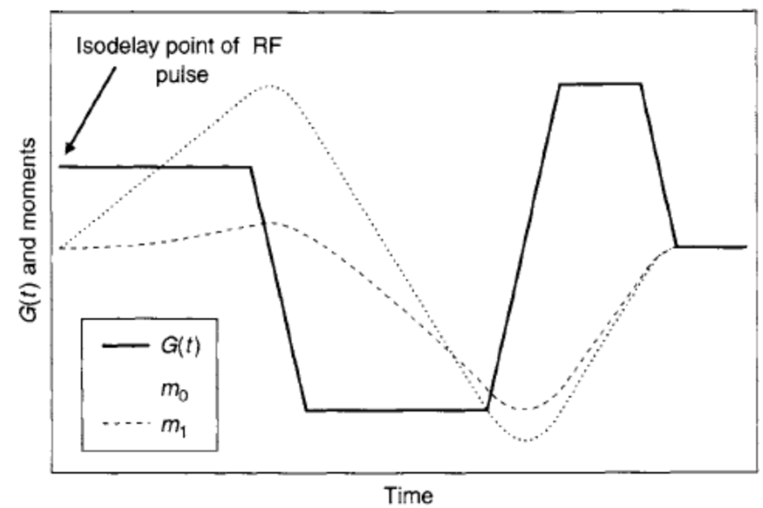

1:-1




1:-2:1

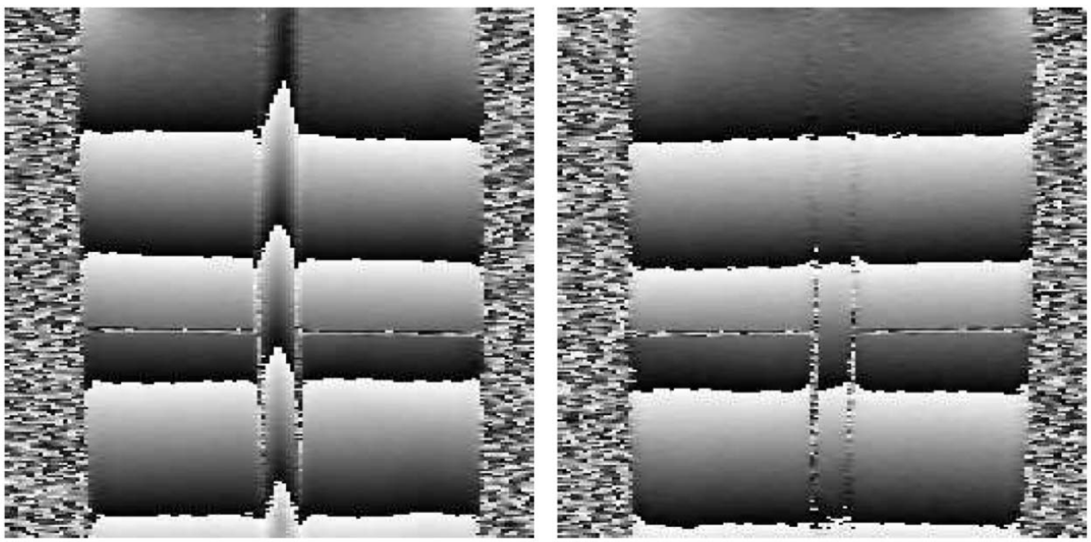



1:-3:3:-1

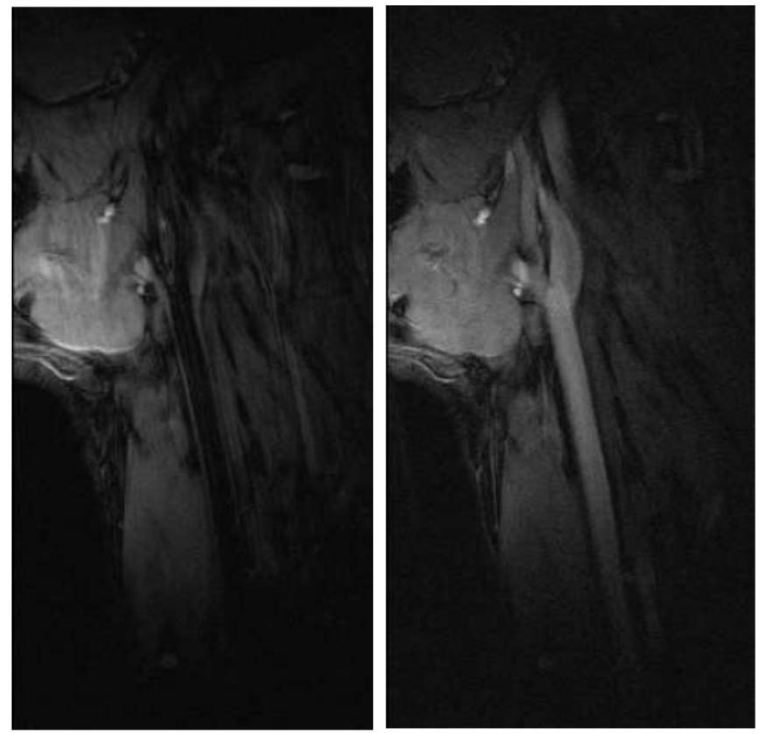



(Handbook of MRI pulse sequence)

# Velocity compensation examples

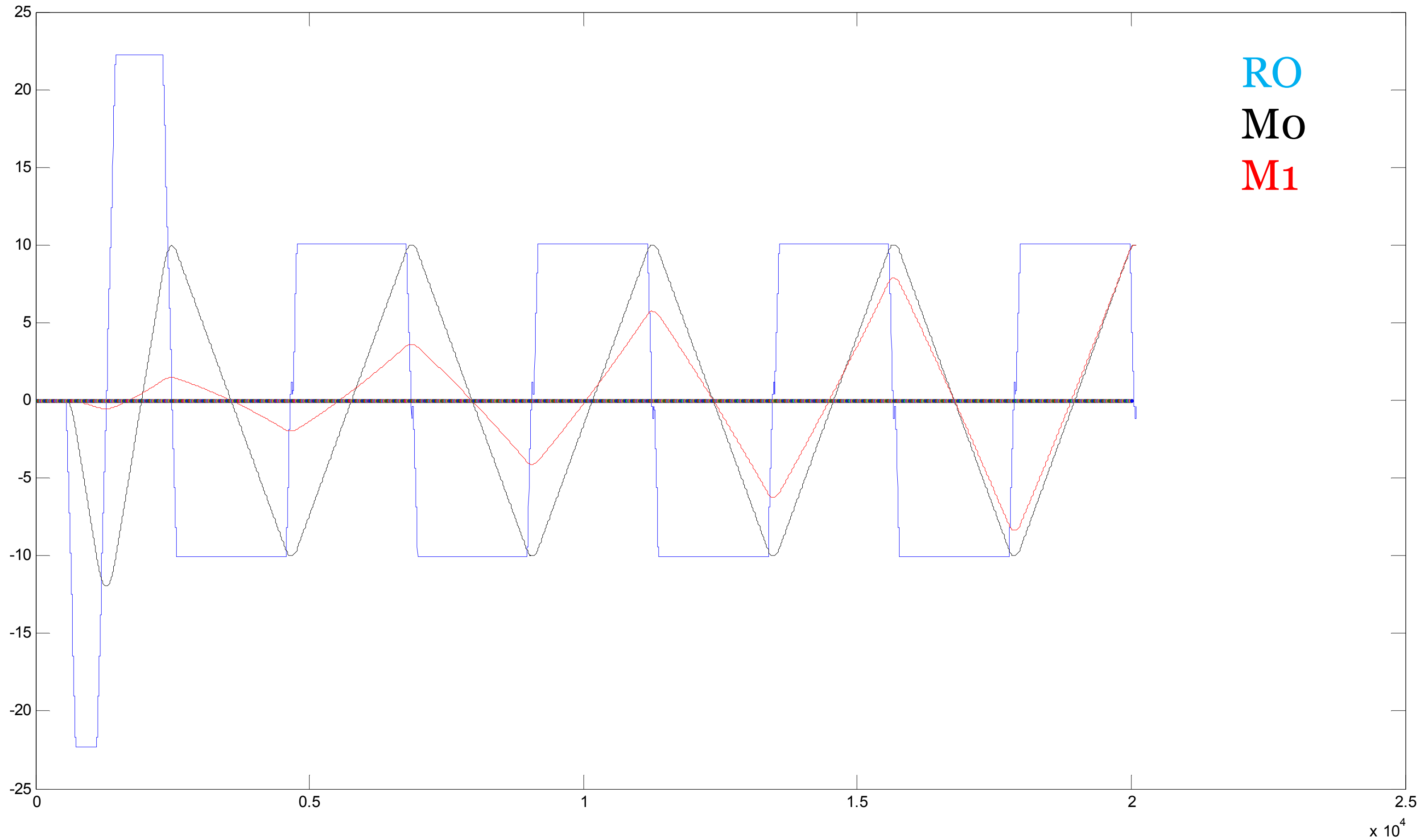


(a) (b)



(a) (b)

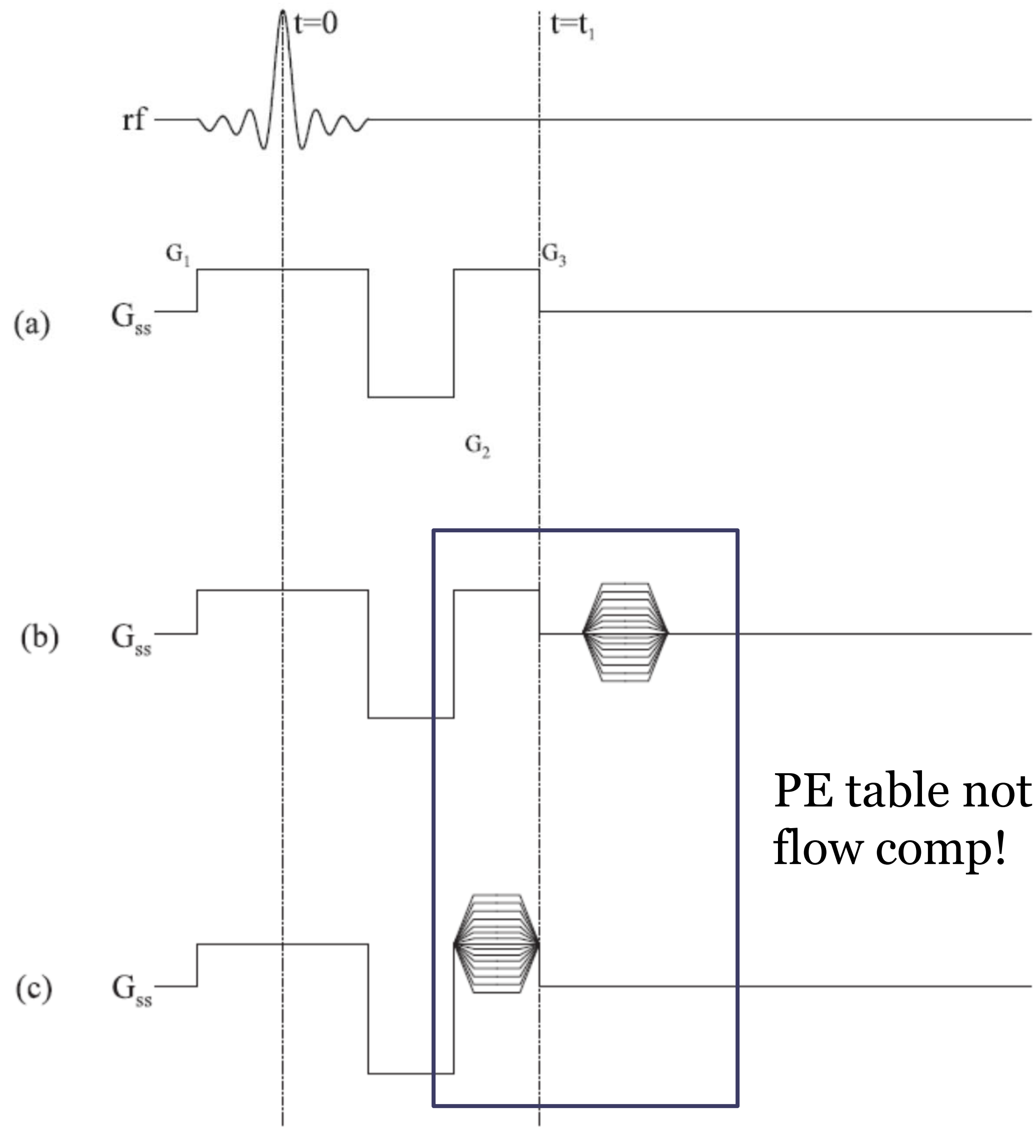
# Velocity compensation in multi-echo scan




- Only odd echoes can be flow compensated
- RO gradient amplitude/duration must be the same

# Velocity compensation on SS

- Problem
  - Signal loss via motion related dephase
- Solution
  - Achieve nulled zeroth and first moment for SS gradients



# Time origin for gradient moment

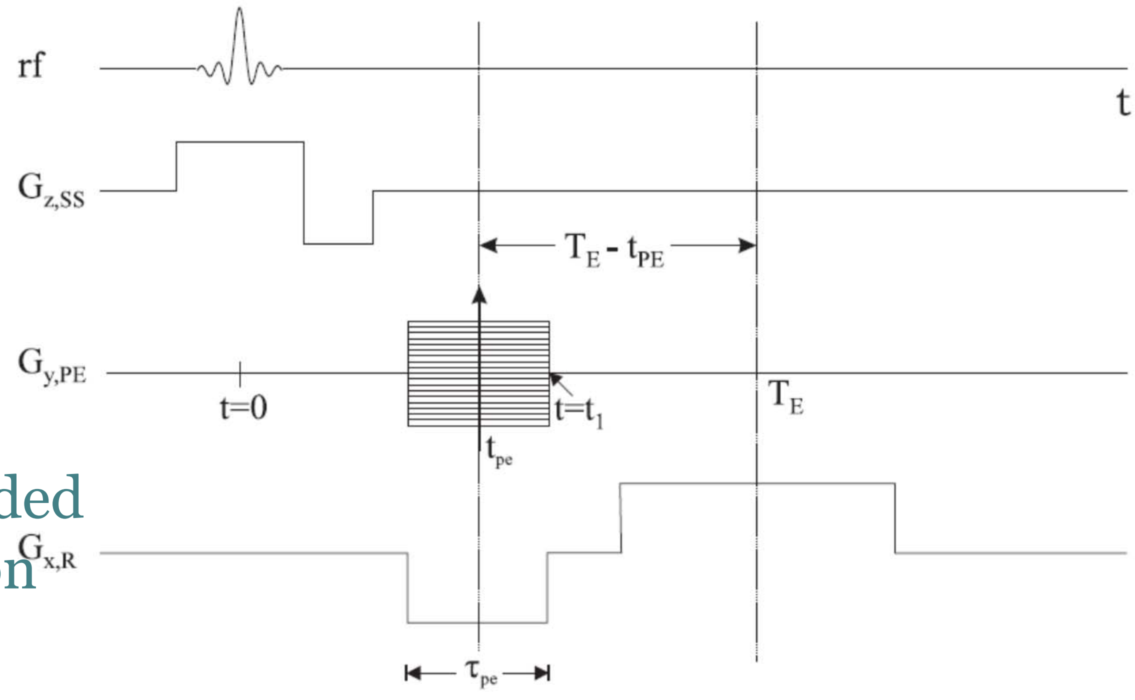
- The time-origin in a general nth moment calculation can be arbitrarily chosen only when all lower order moments of that gradient waveform are zero at the point of interest (for example, at TE), e.g, RO and SS

- Otherwise, moment calculations must be with respect to a particular time (for example, at TE) , e.g. PE

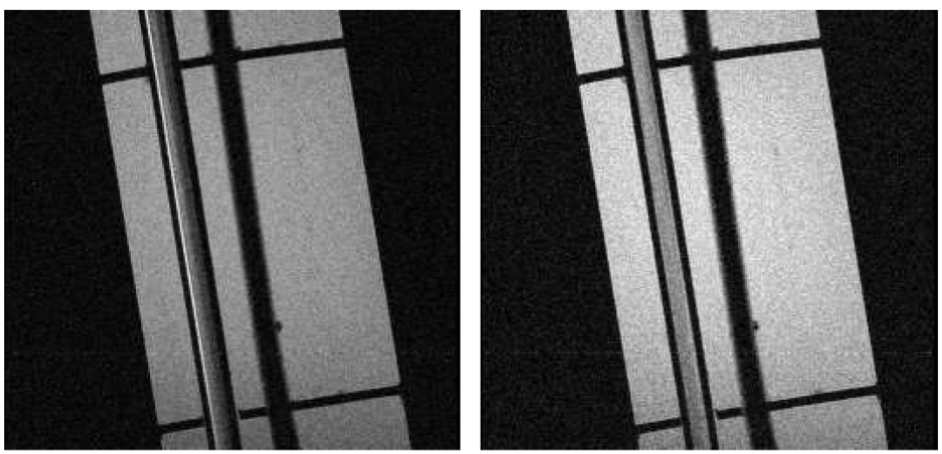
$$
\begin{aligned}
M_n(t_0, t_1) &\equiv \int_{t_0}^{t_1} dt\, t^n G(t) \\
&= \int_0^{t_1 - t_0} dt' \left( (t')^n + \begin{pmatrix} n \\ 1 \end{pmatrix} t_0 (t')^{n-1} + \begin{pmatrix} n \\ 2 \end{pmatrix} t_0^2 (t')^{n-2} + \cdots + t_0^n \right) G(t' + t_0)
\end{aligned}
\tag{23.30}
$$

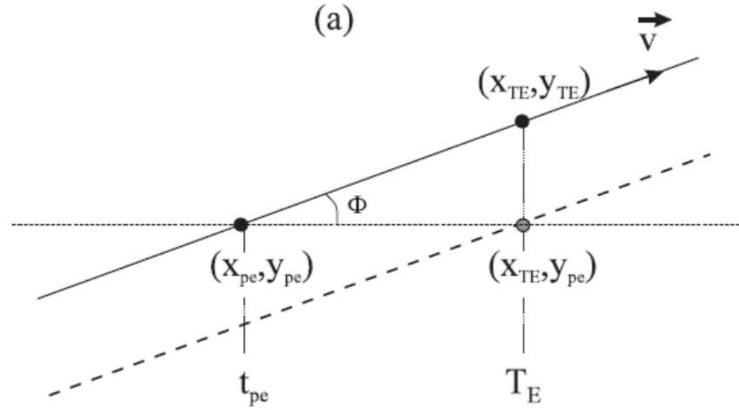
# Velocity compensation on PE

- Problem
  - Signal misregistration along PE, by motion between PE and TE
  - Motion along RO is needed to see the misregistration




(a)






(b)

# Flow compensation along PE

- Goals

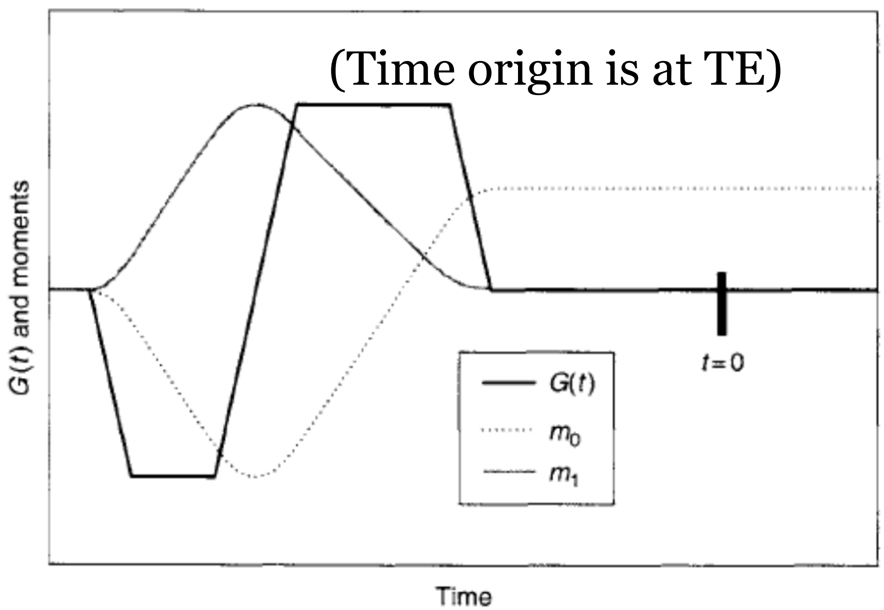
$$M_0(0) \equiv \int_{-\infty}^{0} \Delta G_y(t)dt = \frac{1}{\gamma L_y}$$

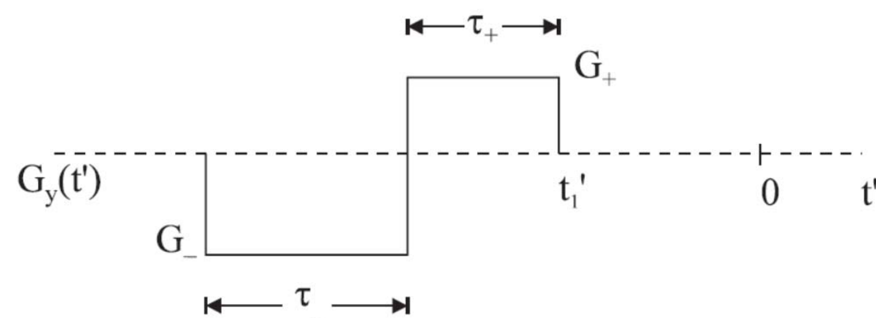
$$M_1(0) \equiv \int_{-\infty}^{0} t\Delta G_y(t)dt = 0$$

- Solution

$$G_- = \frac{1}{\gamma L_y \tau_-}\frac{(2t_1' - \tau_+)}{(\tau_- + \tau_+)}$$

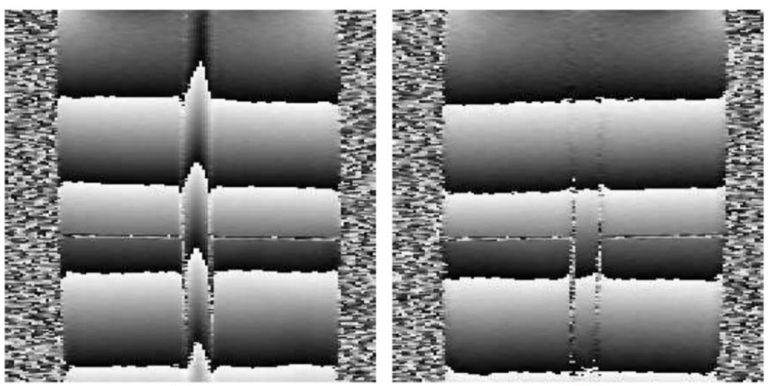
$$G_+ = \frac{1}{\tau_+}\left(\frac{1}{\gamma L_y} - G_-\tau_-\right) = \frac{(-2t_1' + 2\tau_+ + \tau_-)}{\gamma L_y \tau_+(\tau_+ + \tau_-)}$$



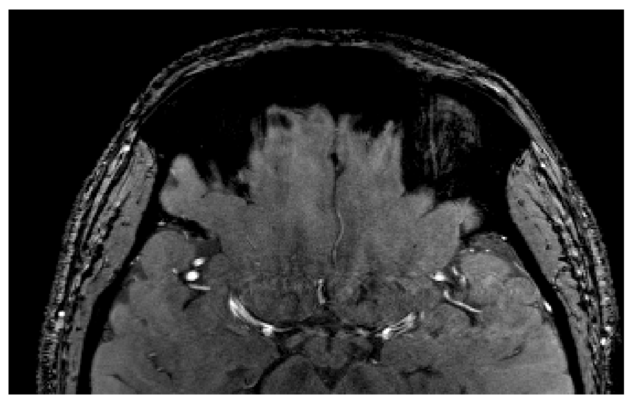



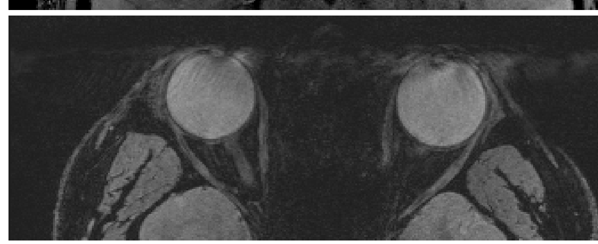
# Ghosting artifact

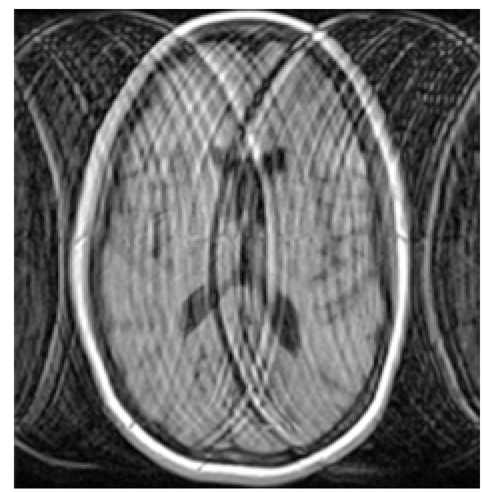
- Cause
  Phase inconsistency in k-space
- Constant motion: No ghosting artifact
- Pulsatile/periodic motion
- Random bulk motion



(a) (b)

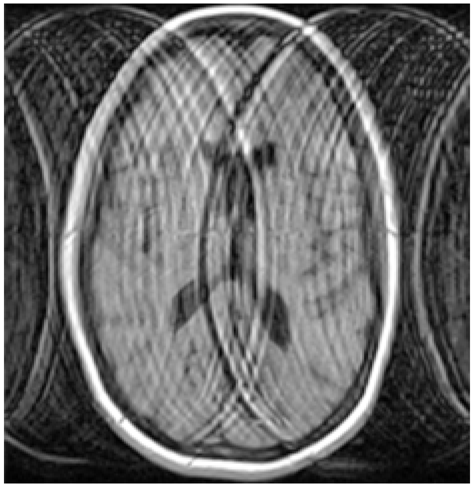






# Ghosting artifact

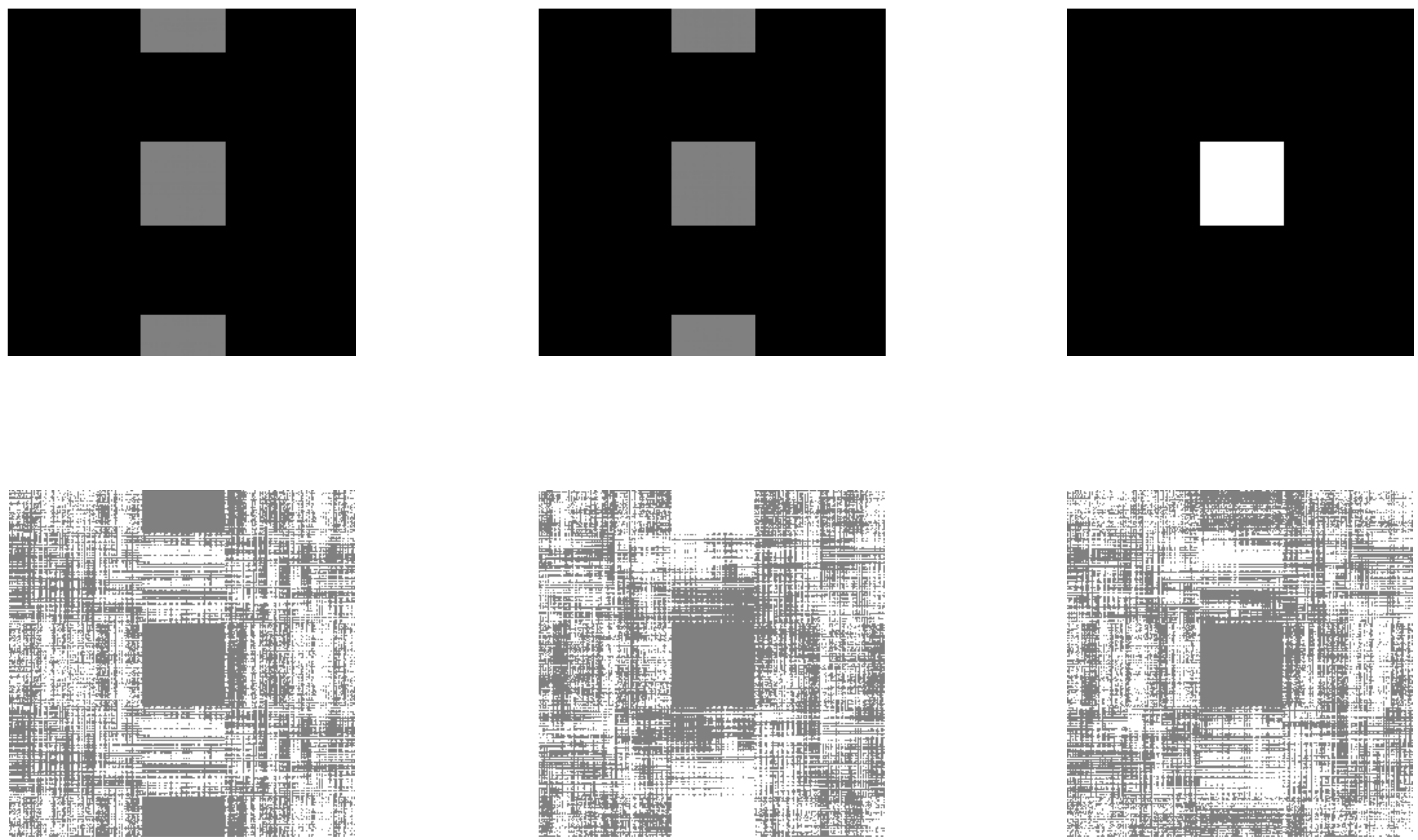
- Ghosting artifact properties
  - Direction is PE
  - Spatial frequency
  - Amplitude (high pass filtered)



- Solution
  - Flow compensation
  - Cardiac gating/ breath hold/ restriction
  - Short TE/single shot imaging/

# Ghosting artifact analysis

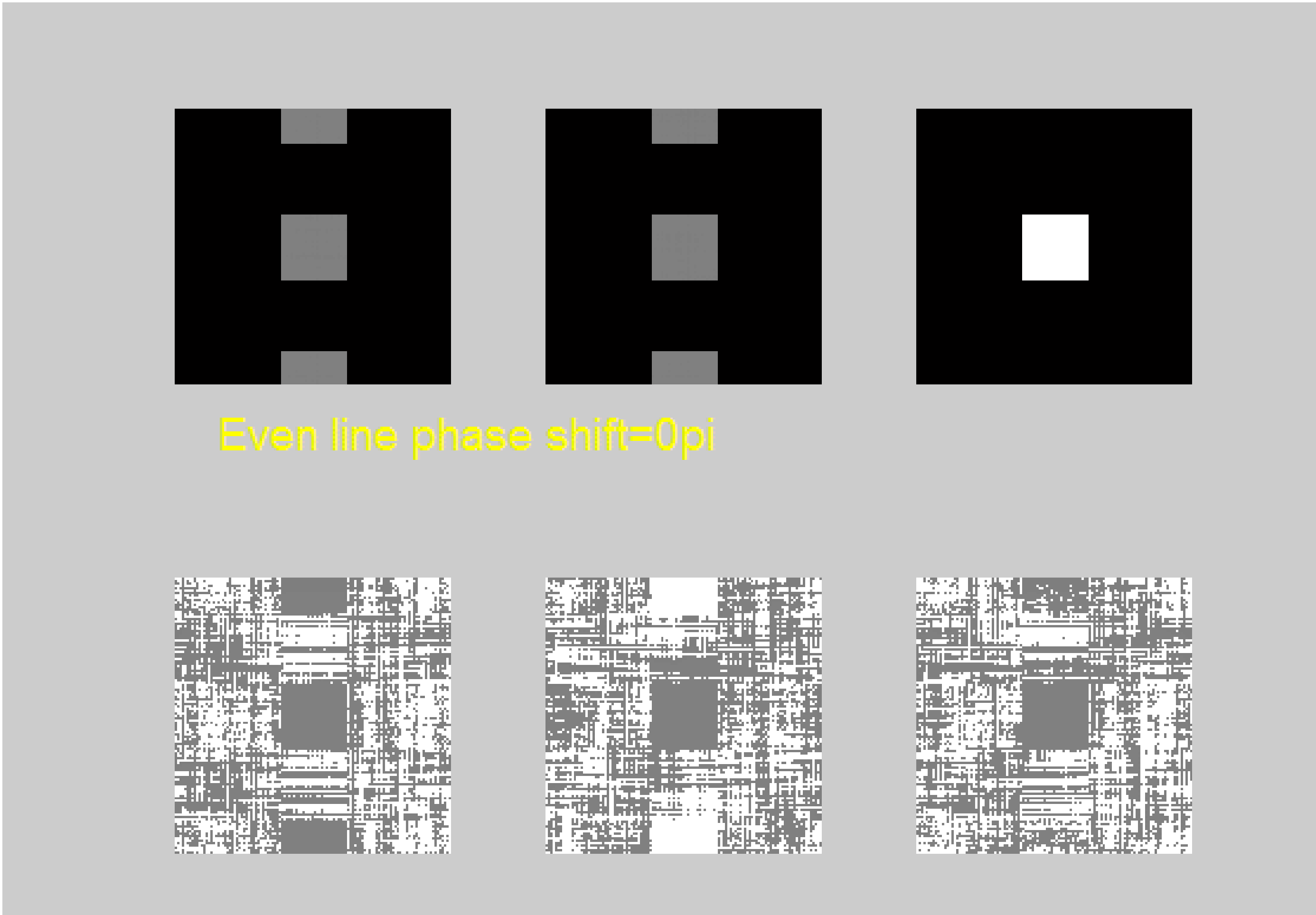
- No phase inconsistency



Odd k-space lines | Even k-space lines | All k-space lines

# Ghosting artifact analysis

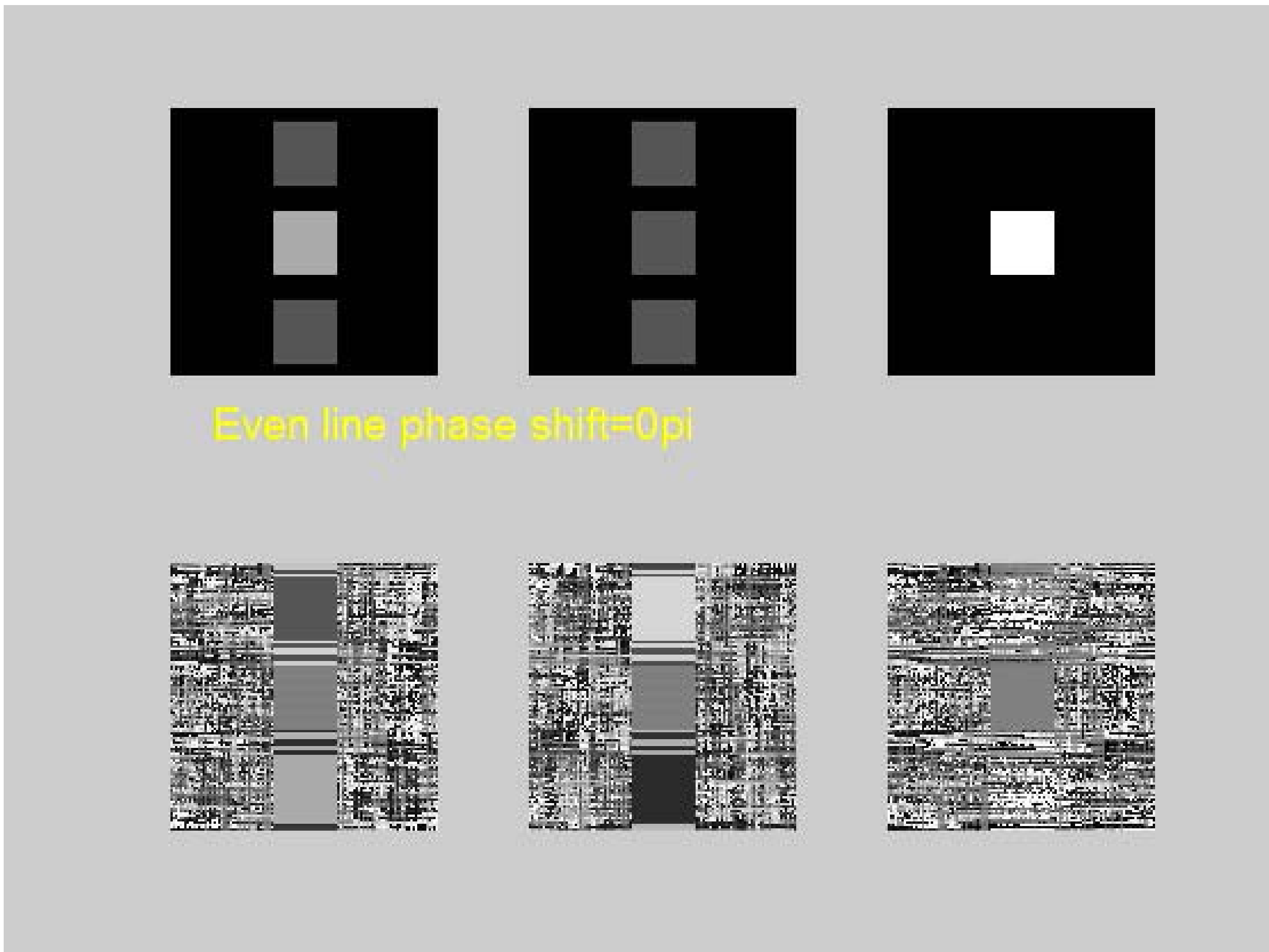
- Phase shift in even lines




Odd k-space lines Even k-space lines All k-space lines

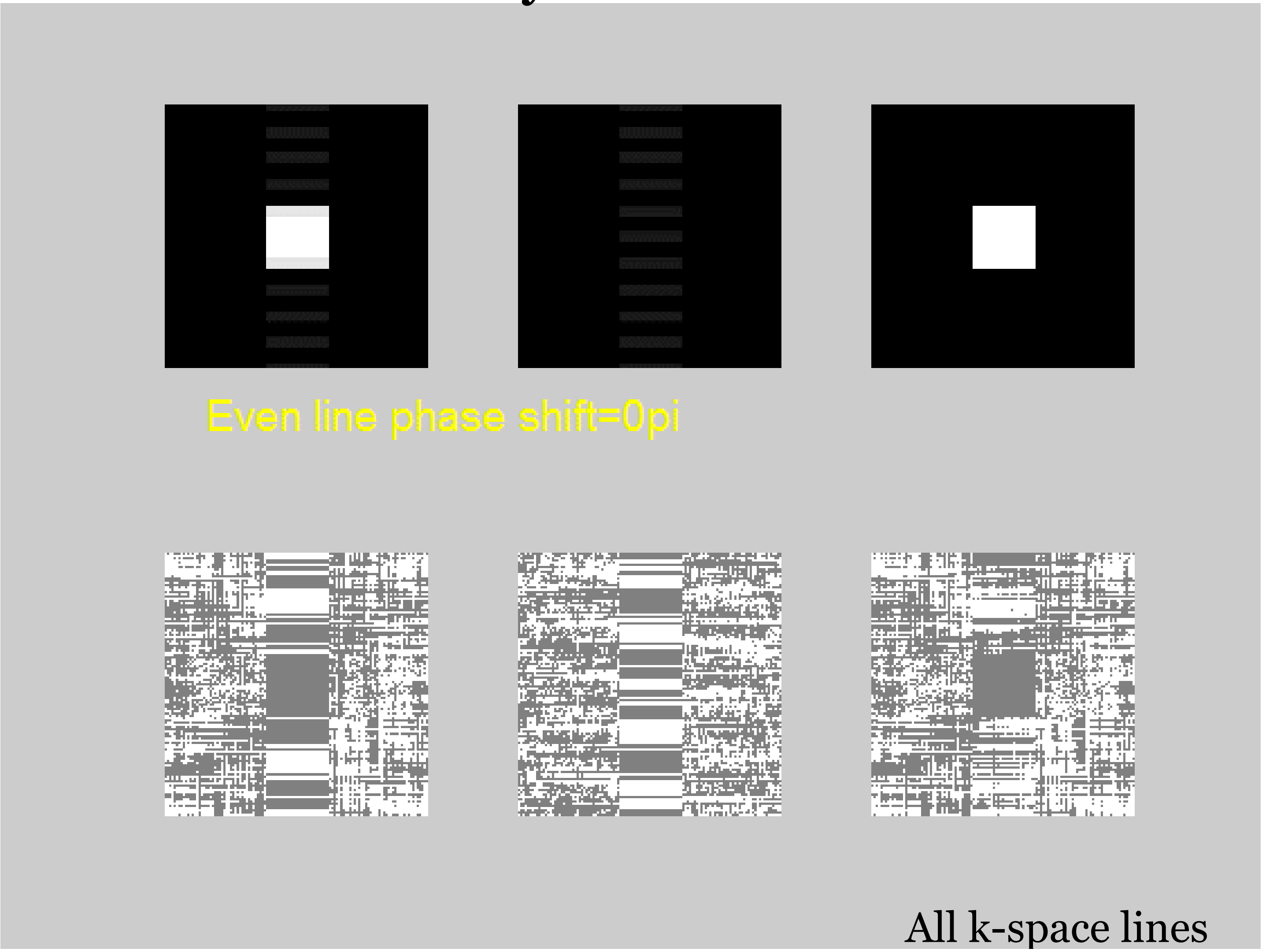
# Ghosting artifact analysis

- Phase shift in 1 in every 3 lines

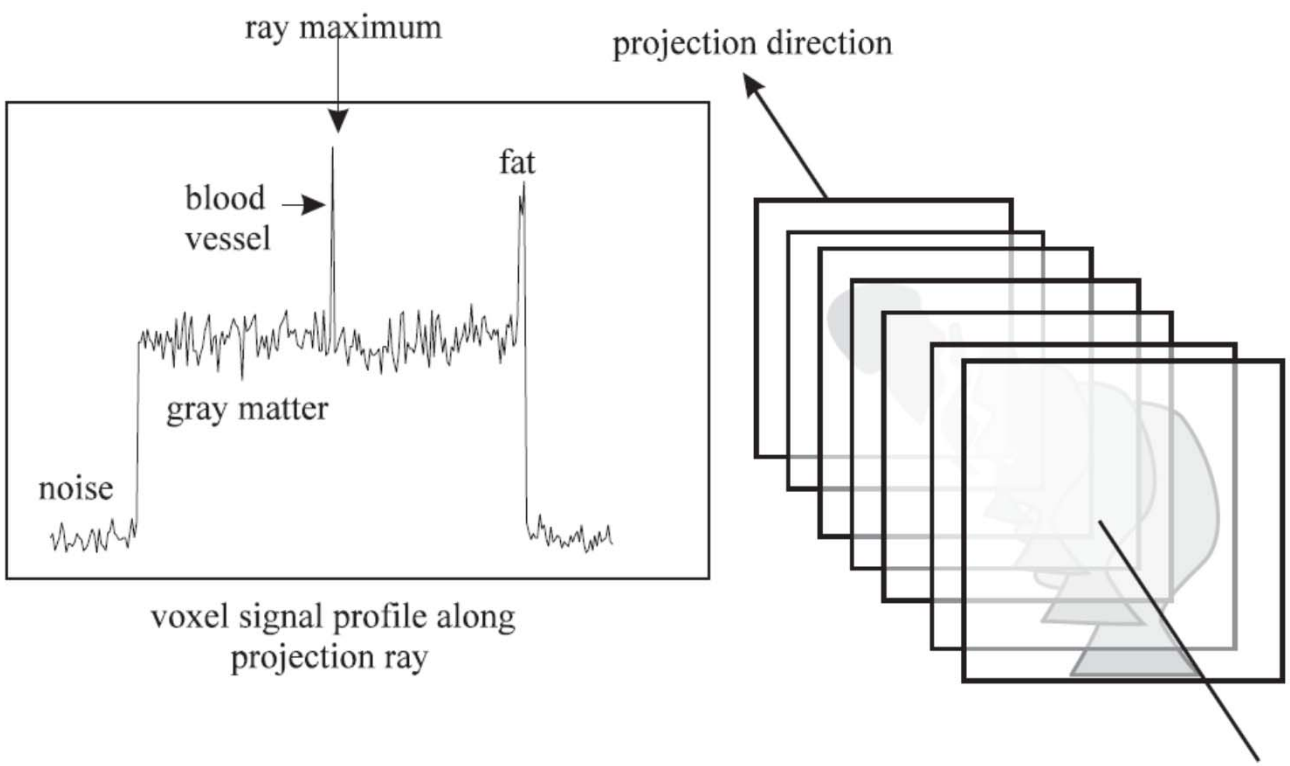


# Ghosting artifact analysis

- Phase shift in 1 in every 10 lines

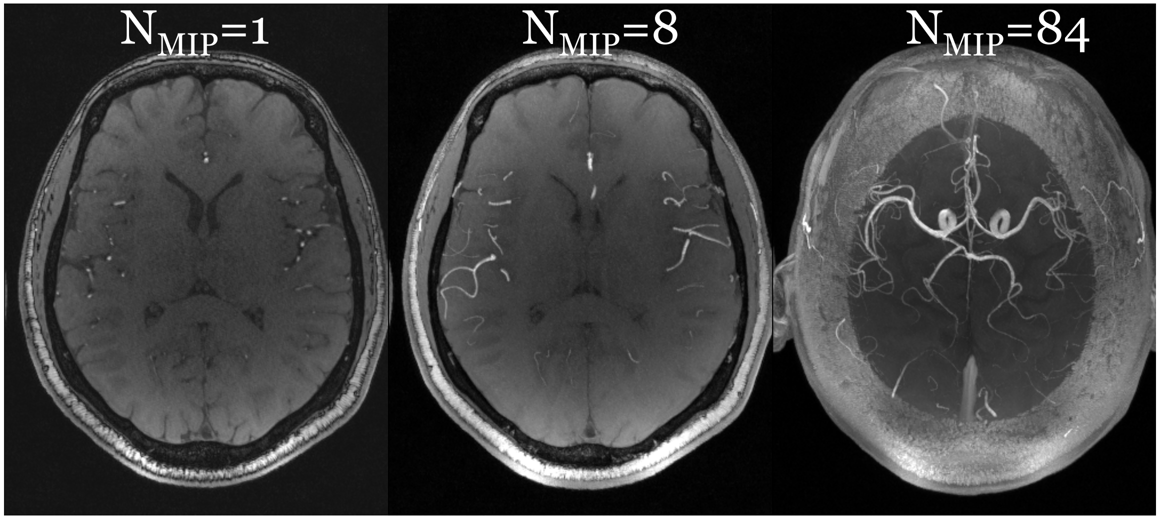


# Maximum intensity projection (MIP)



# Minimum intensity projection

- Considerations
  - MIP range (slab thickness)
  - MIP angle
  - Imaging resolution/contrast
  - Other hyperintense structures
  - Vessel localization



# Homework

- Prob 23.1, 23.2

# Next Session

Chapter 24