

# Bioengineering 208 Magnetic Resonance Imaging

Winter 2007  
Lecture 3

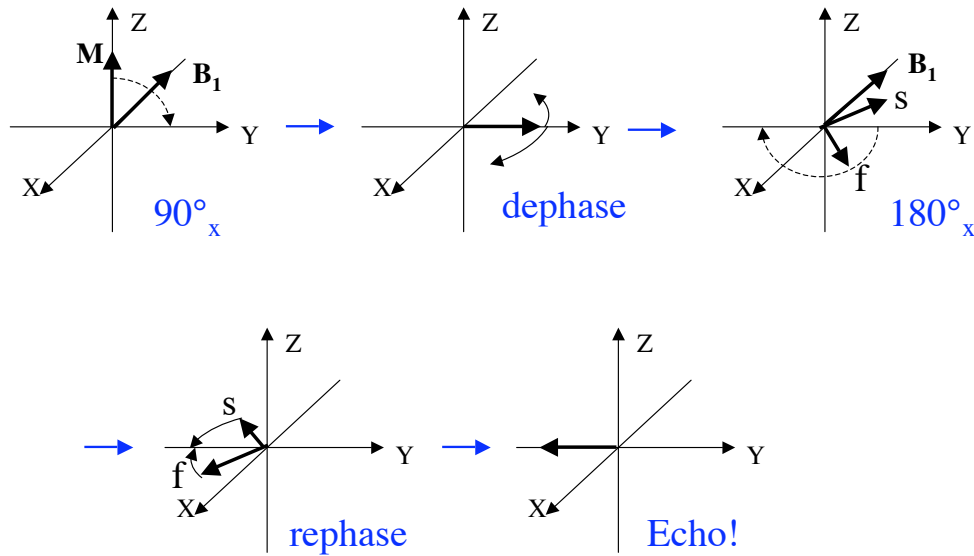
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## Topics

- Echoes
  - Spin Echo Formation
  - CPMG
  - Coherence Diagrams
- Gradient Echo Imaging
  - Spoiled
  - Unspoiled steady state
  - Totally refocused

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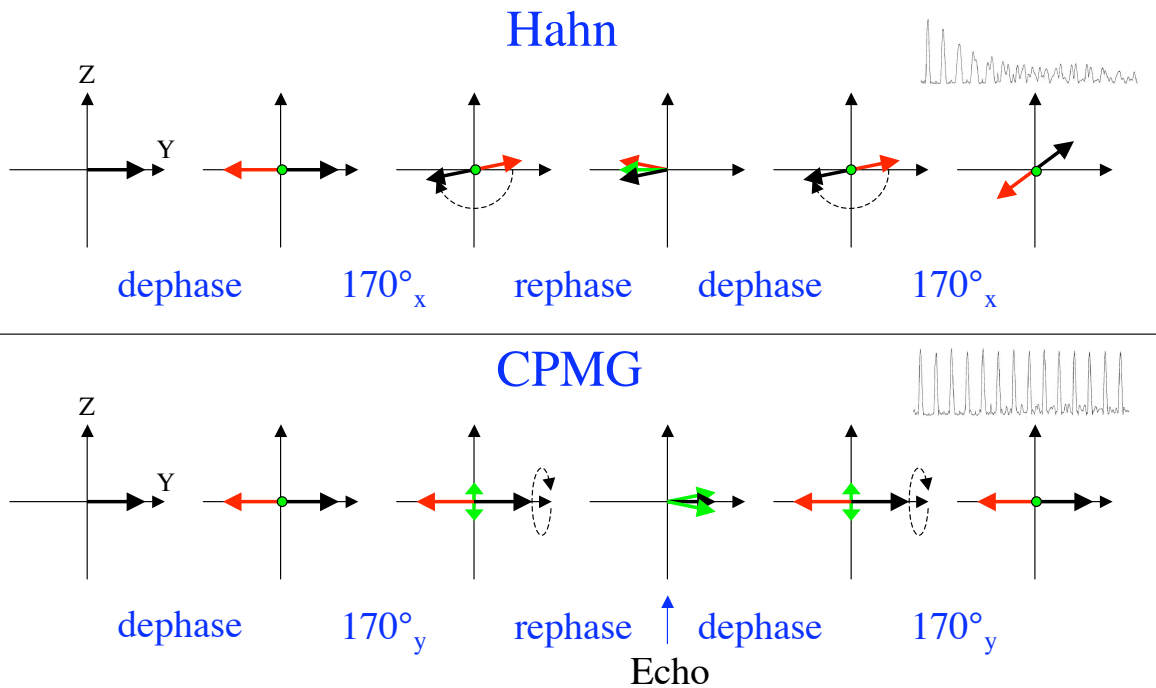
# The Hahn Spin Echo



E. Hahn, 1950

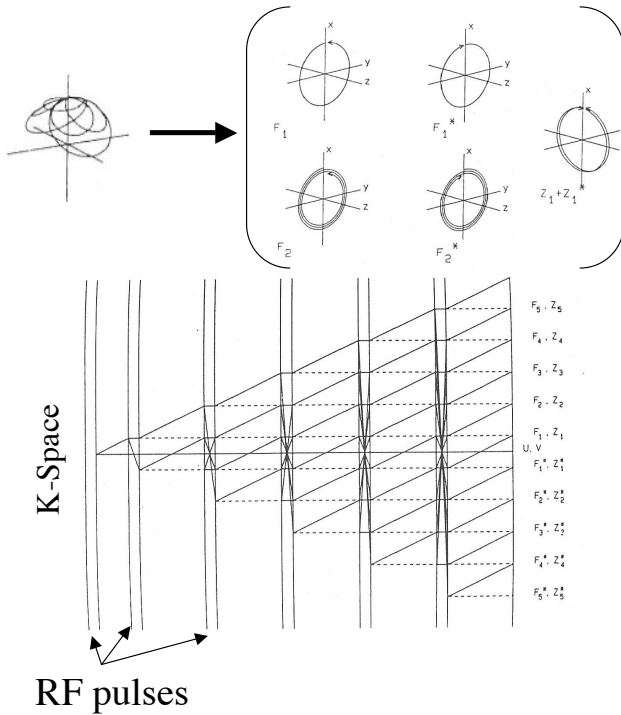
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# The CPMG Spin Echo



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# Coherence Diagrams



RF<sub>x</sub> pulse operating on **M**:

$$T_0 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha) & -\sin(\alpha) \\ 0 & \sin(\alpha) & \cos(\alpha) \end{bmatrix} \begin{bmatrix} M_x \\ M_y \\ M_z \end{bmatrix}$$

RF<sub>x</sub> pulse operating on **F/Z**:

$$T_1 = \begin{bmatrix} \cos^2(\alpha/2) & \sin^2(\alpha/2) & \sin(\alpha) & 0 \\ \sin^2(\alpha/2) & \cos^2(\alpha/2) & 0 & \sin(\alpha) \\ \sin(\alpha)/2 & -\sin(\alpha)/2 & \cos(\alpha) & 0 \\ -\sin(\alpha)/2 & \sin(\alpha)/2 & 0 & \cos(\alpha) \end{bmatrix} \begin{bmatrix} F_n \\ F_n^* \\ Z_n \\ Z_n^* \end{bmatrix}$$

Hennig, 1991

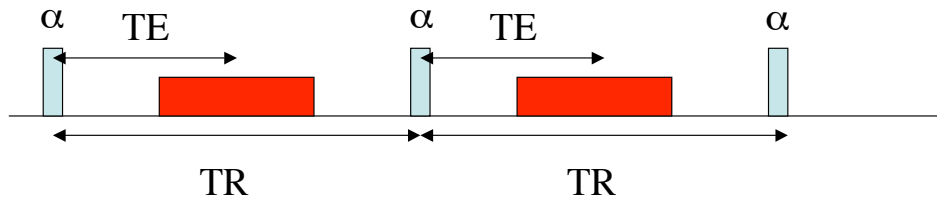
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## Topics

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# Spoiled gradient echo sequence



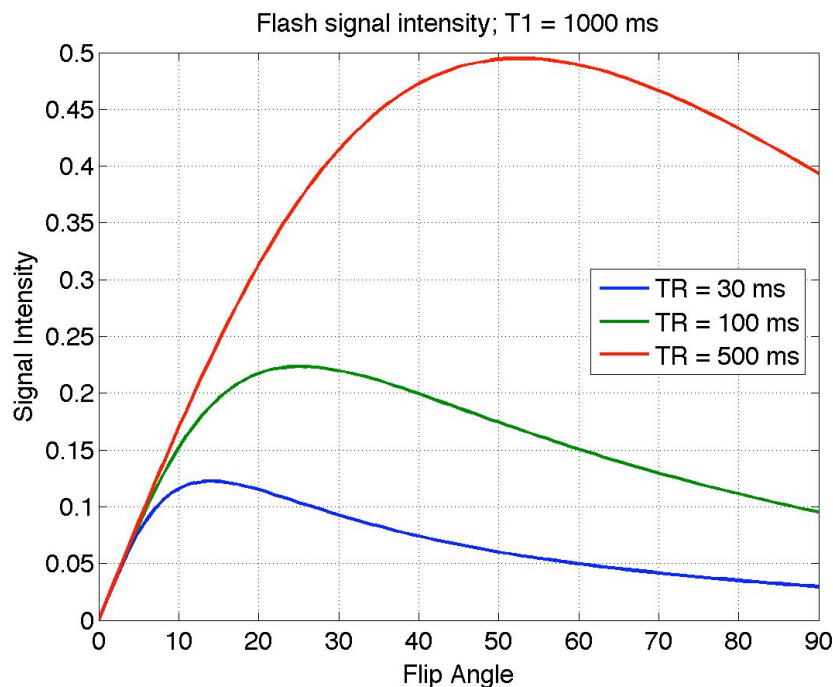
$$I(x, y) = \rho(x, y) \frac{\left[1 - e^{-TR/T_1(x,y)}\right] \sin \alpha}{\left[1 - e^{-TR/T_1(x,y)} \cos \alpha\right]} \exp(-TE/T_2^*)$$

Signal intensity is maximized at the Ernst Angle

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

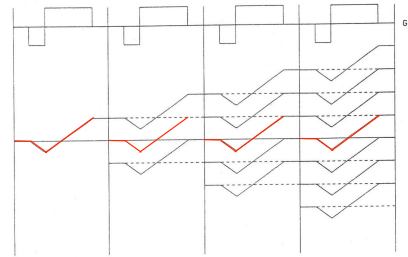
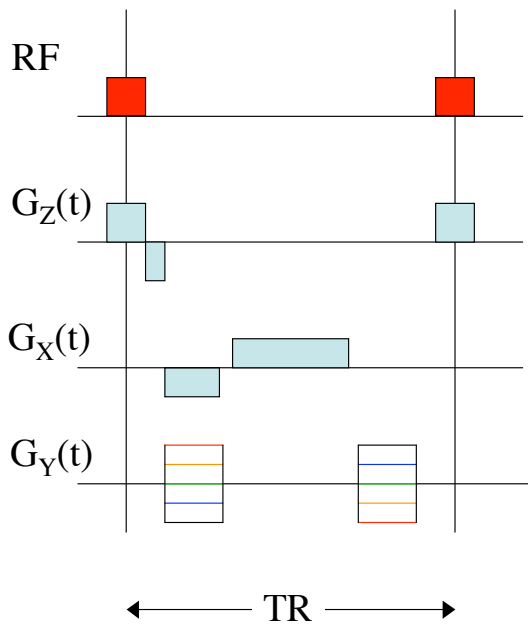
Spoiled gradient echo equation assumes no coherence from shot to shot. In practice this is achieved with RF spoiling.

# Spoiled gradient echo sequence



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

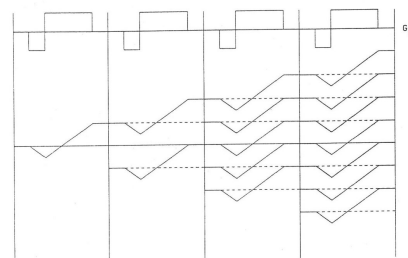
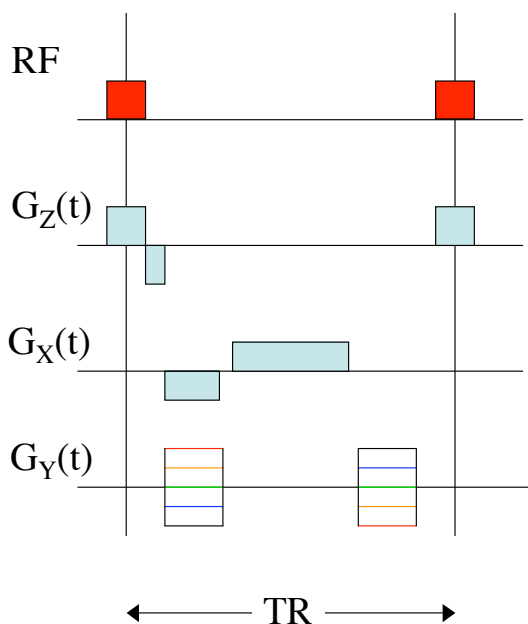
# Spoiled gradient echo sequence



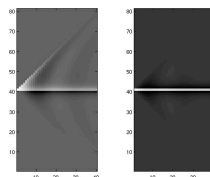
- Spoiled FLASH, Spoiled GRASS
- RF phase pseudo-randomized
- Signal comes from FIDs only
- No echo pathways build up

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# Unspoiled gradient echo sequence

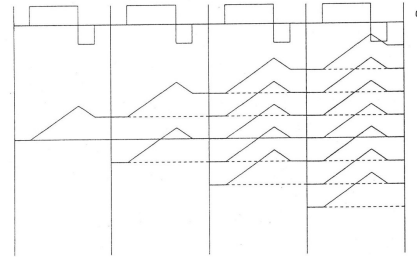
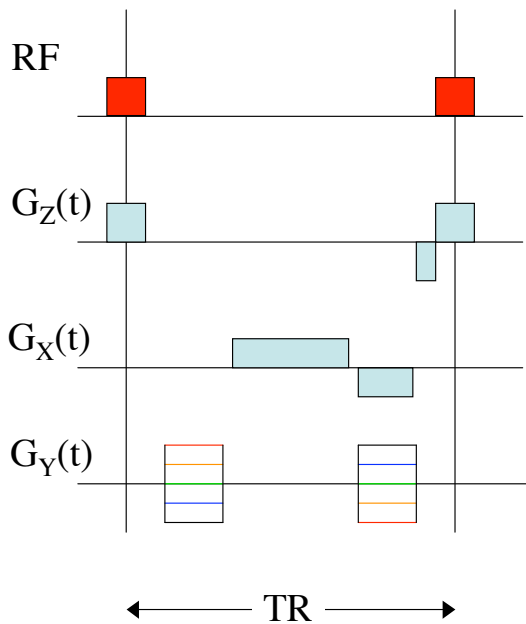


- FLASH, GRASS
- RF phase uniform
- Signal comes from FIDs and Echoes
- Signal depends on  $\alpha$ , TE, TR,  $T_1$ ,  $T_2$ ,  $T_2^*$



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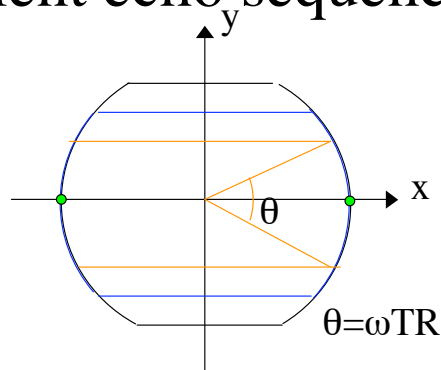
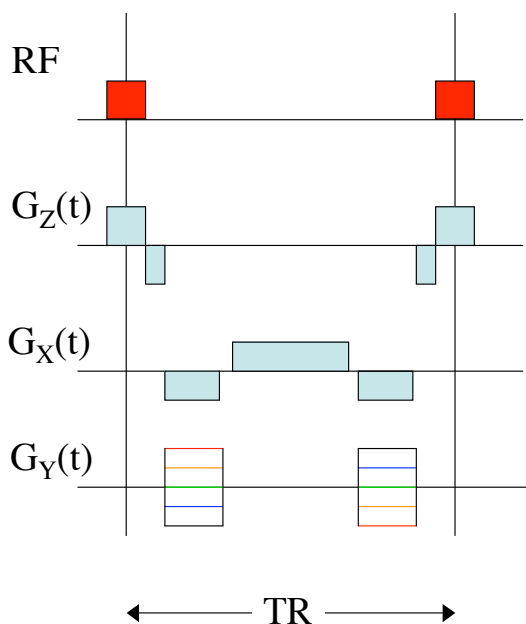
# Echo-only gradient echo sequence



- CE-FAST, SSFP
- RF phase uniform
- Signal comes from echoes only
- Signal depends on  $\alpha$ , TE, TR,  $T_1$ ,  $T_2$

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# Fully refocussed gradient echo sequence



- FISP, FIESTA, balanced SSFP
- RF phase alternates
- No net gradient per TR
- No dephasing -> no echoes
- VERY frequency sensitive
- Large signal
- Signal depends on  $\alpha$ , TE, TR,  $T_1$ ,  $T_2$

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