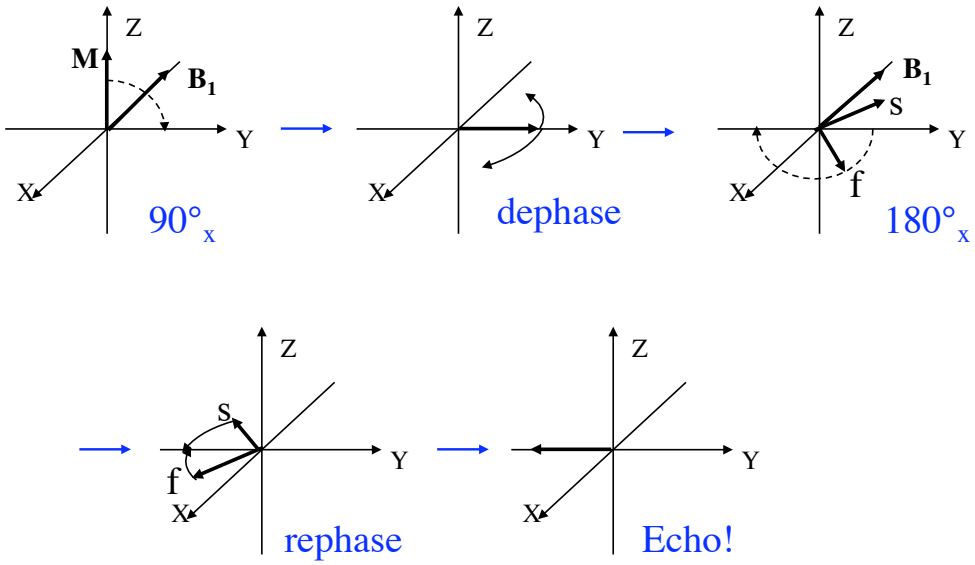
Bioengineering 278
Magnetic Resonance Imaging

Winter 2009
Lecture 3

Echoes
- Spin Echo Formation
- CPMG
- Coherence Diagrams

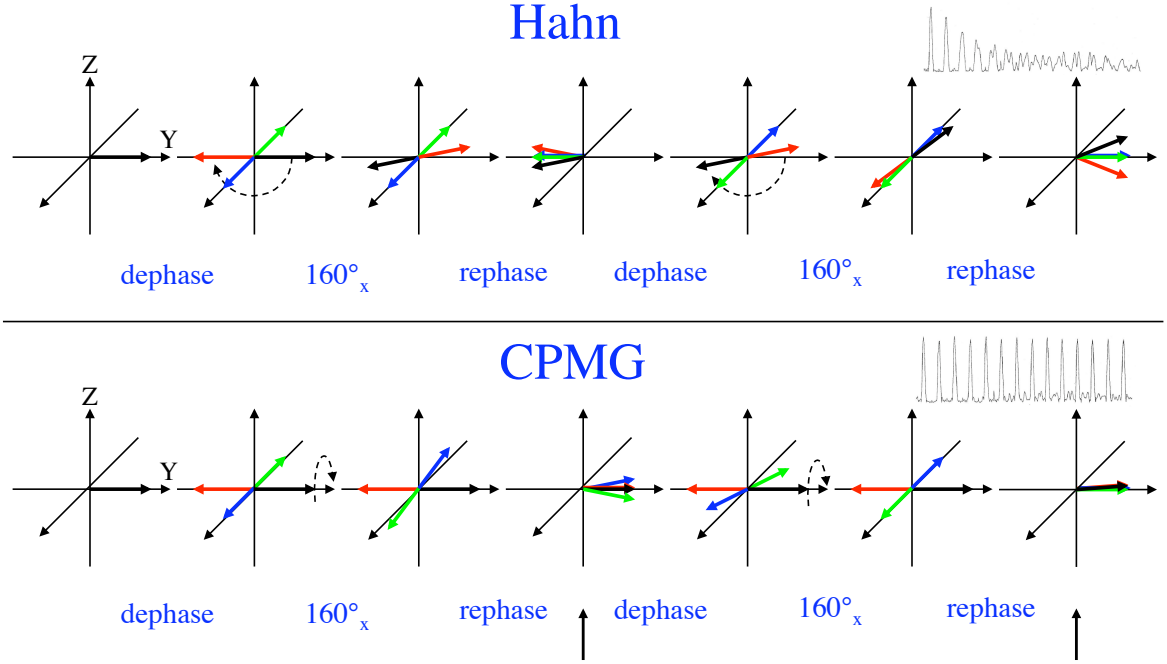
Gradient Echo Imaging
- Spoiled
- Unspoiled steady state
- Totally refocused

The Hahn Spin Echo

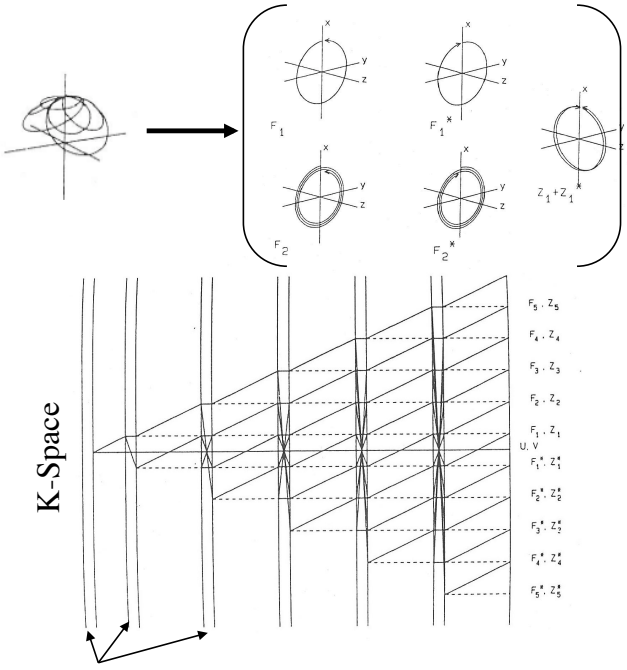


E. Hahn, 1950

The CPMG Spin Echo



Coherence Diagrams



RF$_x$ pulse operating on **M**:

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

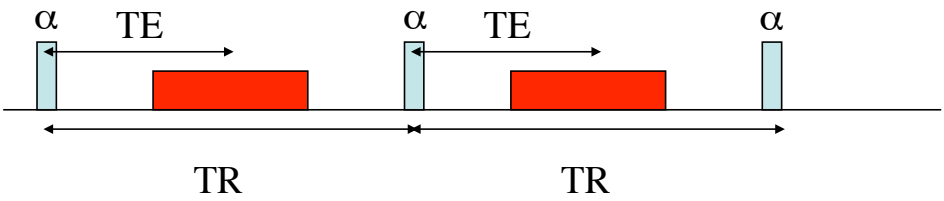
RF$_x$ pulse operating on **F/Z**:

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

Hennig, 1991

See also Scheffler 1999: PDF on class web site

Spoiled gradient echo sequence



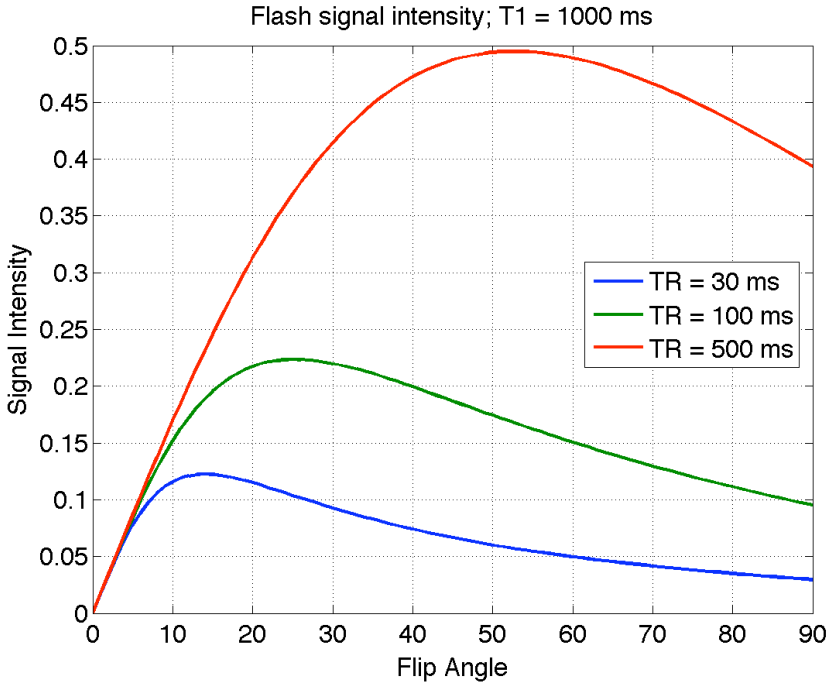
$$I(x,y) = \rho(x,y)\frac{\left[1-e^{-TR/T_1(x,y)}\right]\sin\alpha}{\left[1-e^{-TR/T_1(x,y)}\cos\alpha\right]}\exp(-TE/T_2^*)$$

Signal intensity is maximized at the Ernst Angle

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

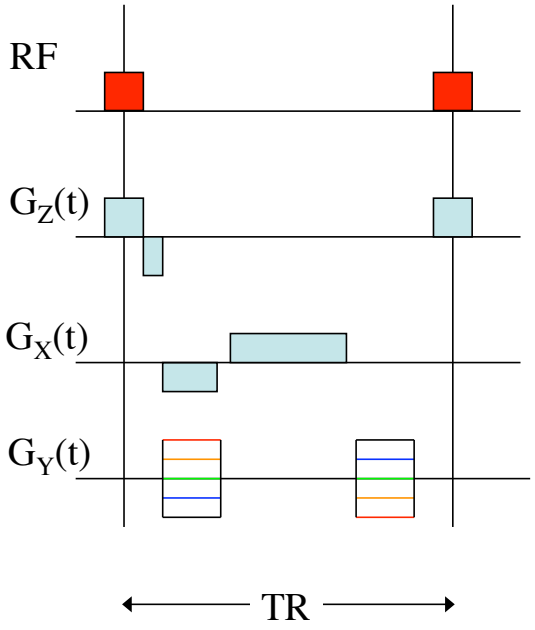
Spoiled gradient echo equation assumes no coherence from shot to shot. In practice this is achieved with RF spoiling.

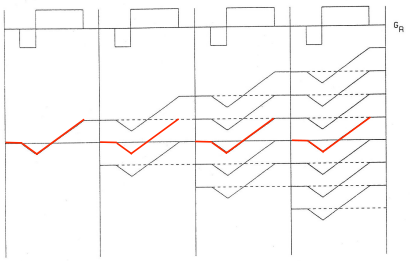
Spoiled gradient echo sequence



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

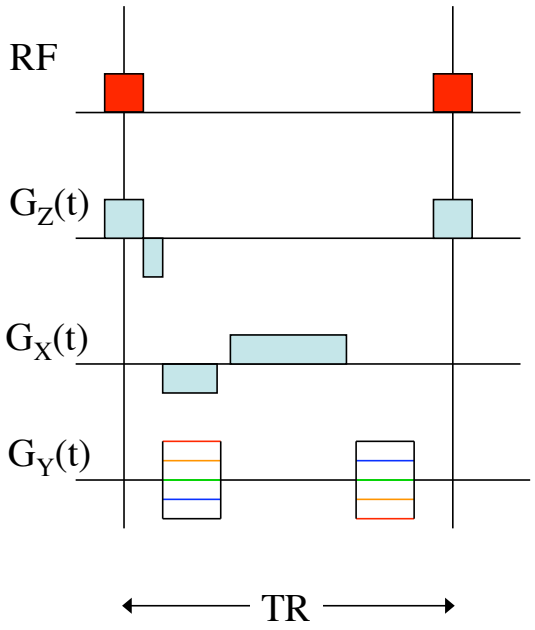
Spoiled gradient echo sequence

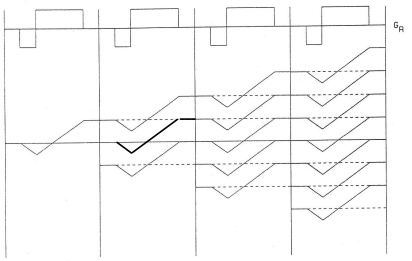




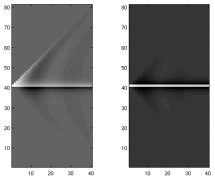
- Spoiled FLASH, Spoiled GRASS
- RF phase pseudo-randomized
- Signal comes from FIDs only
- No echo pathways build up

Unspoiled gradient echo sequence

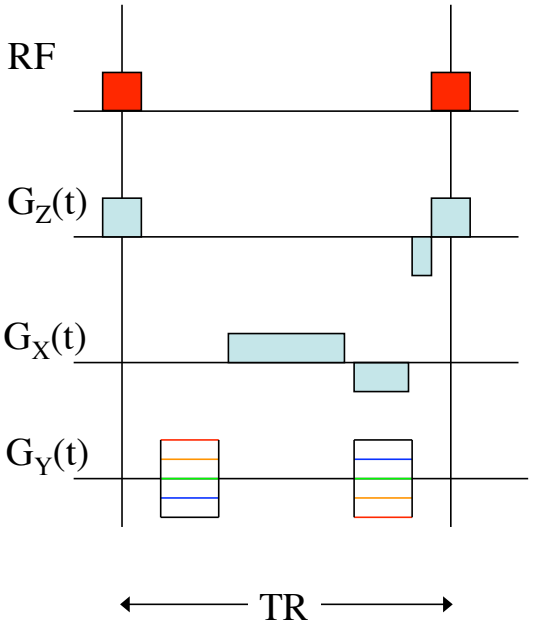


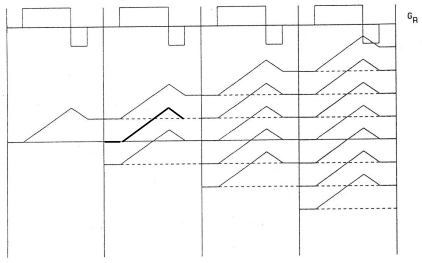


- FLASH, GRASS
- RF phase uniform
- Signal comes from FIDs and Echoes
- Signal depends on α, TE, TR, T_1, T_2, T_2*



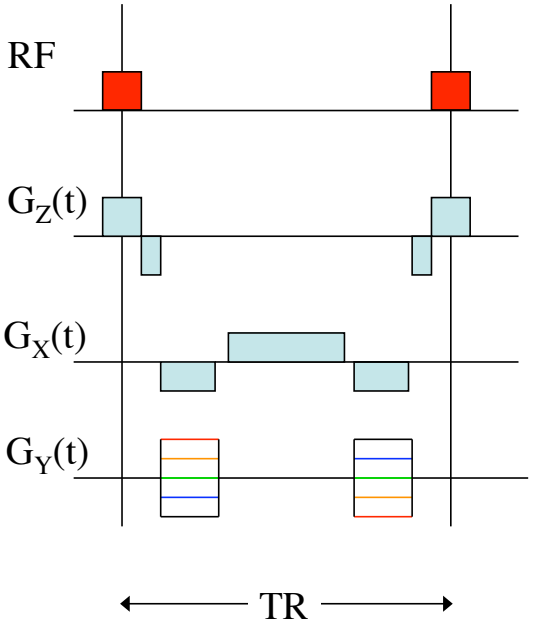
Echo-only gradient echo sequence

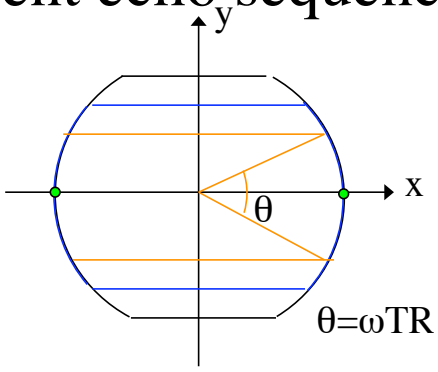




- CE-FAST, SSFP
- RF phase uniform
- Signal comes from echoes only
- Signal depends on α, TE, TR, T_1, T_2

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 α, TE, TR, T_1, T_2