Bioengineering 208
Magnetic Resonance Imaging

Winter 2007
Lecture 3

Topics

• 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

Hahn

CPMG

E. Wong, BE208, UCSD Winter 2007
Coherence Diagrams

RF\textsubscript{x} pulse operating on $\mathbf{M}$:

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

RF\textsubscript{x} pulse operating on $\mathbf{F}/\mathbf{Z}$:

$$T_1 = \begin{bmatrix} \cos^2(\alpha/2) & \sin^2(\alpha/2) & \sin(\alpha) \\ \sin^2(\alpha/2) & \cos^2(\alpha/2) & 0 \\ \sin(\alpha)/2 & -\sin(\alpha)/2 & \cos(\alpha) \end{bmatrix} \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = \begin{bmatrix} \sin^2(\alpha/2) & \cos^2(\alpha/2) & 0 \\ \sin(\alpha)/2 & -\sin(\alpha)/2 & \cos(\alpha) \end{bmatrix} \begin{bmatrix} Z_x \\ Z_y \\ Z_z \end{bmatrix} \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix}$$

Topics

- **Echoes**
  - Spin Echo Formation
  - CPMG
  - Coherence Diagrams

- **Gradient Echo Imaging**
  - Spoiled
  - Unspoiled steady state
  - Totally refocused
Signal intensity is maximized at the Ernst Angle

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

Spoiled gradient echo equation assumes no coherence from shot to shot. In practice this is achieved with RF spoiling.
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 $\alpha$, TE, TR, $T_1$, $T_2$, $T_2^*$
**Echo-only gradient echo sequence**

- \( G_X(t) \)
- \( G_Y(t) \)
- RF phase uniform
- Signal comes from echoes only
- Signal depends on \( \alpha, TE, TR, T_1, T_2 \)

**Fully refocussed gradient echo sequence**

- \( G_X(t) \)
- \( G_Y(t) \)
- RF phase alternates
- No net gradient per TR
- No dephasing -> no echoes
- VERY frequency sensitive
- Large signal
- Signal depends on \( \alpha, TE, TR, T_1, T_2 \)