Lecture 12: RF Pulses - Basics

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Lectures 12 and 13 RF Pulses

- Lecture 12 (Oct. 3, 05)
  - Review the basics
  - A closer look of Bloch equation
  - Non-linearity of RF pulses
  - Flip angle and B1-field
  - RF pulse shapes
    - Rectangular pulses
    - Gaussian pulses
    - SINC pulses
  - Pulse functions
    - Excitation
    - Refocusing
    - inversion
- Lecture 13 (Oct 5, 05)
  - SLR pulses
  - Spatial selection and saturation
  - Spectral selection and saturation
  - Spatial-spectral selection
  - Magnetization Transfer
  - Adiabatic pulses
    - Excitation
    - Inversion
    - Refocusing

Reference: Part II, MRI Handbook by Bernstein, King and Zhou,

Review

- What's an RF pulse?
- Bloch equation:

$$\left(\frac{d\vec{M}}{dt}\right) = \gamma \vec{M} \times \left[\vec{B}_1(t) + \hat{z}B_0 \right]$$

- Rotating frame:

$$\left(\frac{d\vec{M}}{dt}\right)_{rot} = \gamma \vec{M} \times \left[B_1(t)\left(\hat{x}\cos(\omega_{rf}-\omega_0)t - \hat{y}\sin(\omega_{rf}-\omega_0)t\right) + \hat{z}\left(B_0 - \frac{\omega_0}{\gamma}\right)\right]$$

- Resonance:

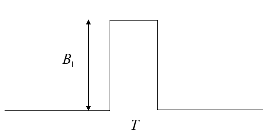
$$\omega_0 = \omega_{rf} = \omega_{Lamor} = \gamma B_0$$

- Bloch equation on resonance: $\left(\frac{d\vec{M}}{dt}\right)_{rot} = \gamma \vec{M} \times \left[\hat{x}B_1(t) \right]$

Let's think …

- Can $\omega_{rf} = \omega_0$ be always satisfied?
- Can $\omega_{Lamor} = \omega_0$ be always satisfied?

Consider a "Rectangular Pulse"

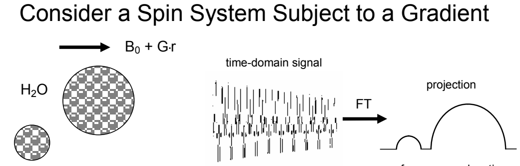


What are its frequency components?

Thus, $\omega_{rf} = \omega_0$ cannot be always true.

RF (or B1) Off-Resonance

Consider a Spin System Subject to a Gradient



What is ω_{Lamor}??

$$\omega_{Lamor}(x) = \gamma\left(B_0 + Gx\right)$$

Thus, $\omega_{Lamor} = \omega_0$ cannot be always true.

B0 Off-Resonance

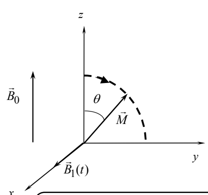
Non-linear Response of RF Pulses

- Off-resonance effect causes the Bloch equation to have non-linear responses.
- The frequency response of an RF pulse cannot be precisely obtained by FT; FT is only an approximation.

Bloch Equation in the RF Rotating Frame

$$\left(\frac{d\vec{M}}{dt}\right)_{rot} = \gamma\vec{M} \times \left[\hat{x}B_1(t) + \hat{z}\left(B_0 - \frac{\omega_{rf}}{\gamma}\right)\right]$$

Consider an RF Pulse



Flip angle: $\theta(t) = \gamma \int_{t'=0}^{t} B_1(t')\, dt'$,

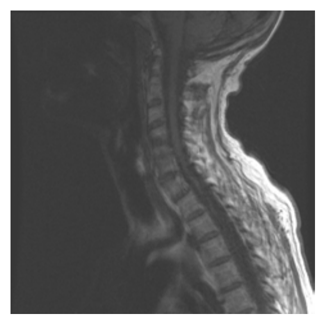
Example 3.1.1: A hard RF pulse has a rectangular shaped envelope. Its pulse width is 100μs, and its flip angle (on-resonance) is 90°. What is its amplitude for proton imaging?

Answer:

$$\theta = \frac{\pi}{2} = \gamma B_1 \times (100 \times 10^{-6} sec) \ ,$$

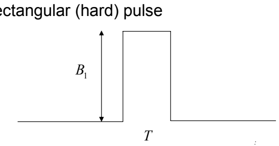
$$B_1 = \frac{\pi}{2\gamma(100\mu s)} = \frac{\pi(rad)}{2 \times 2\pi \times 42.57 \times 10^6 (rad / sec \cdot T) \times 100 \times 10^{-6} (sec)} = 58.7\mu T$$

B1-field inhomogeneity

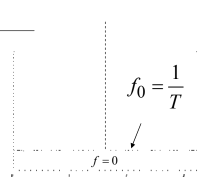


RF Pulse Shapes

- Rectangular (hard) pulse



- Frequency Response
- Hard pulse is commonly used as non-selective pulse.
- RF un-blanking/blanking



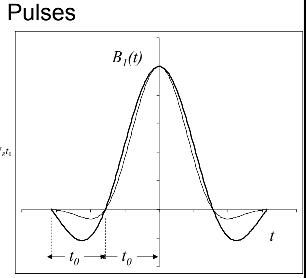
SINC Pulses

- Truncated SINC and windowed (Hamming/Hanning) SINC

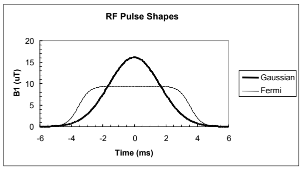
$$B_1(t) = \begin{cases} A\, t_0 \left[(1-\alpha) + \alpha\cos\left(\frac{\pi t}{N t_0}\right)\right] \frac{\sin\left(\frac{\pi t}{t_0}\right)}{\pi t}, & -N_L t_0 \le t \le N_R t_0 \\ 0, & \text{elsewhere} \end{cases}$$

α=0.46 for Hamming window, and 0.5 for Hanning window

- Apodization
- Frequency response $\Delta f = \frac{1}{t_0} = \frac{N_{lobe}}{T_{pulse\_width}}$ (The central lobe is counted Twice)
- SINC pulse is commonly used as selective pulse.



Gaussian/Fermi Pulses



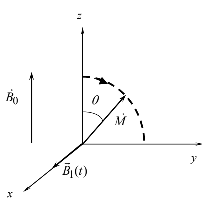
$$B_1(t) = A_G\, e^{-\frac{t^2}{2\sigma^2}}\, e^{i\Delta\omega_{rf} t}$$ Gaussian

$$B_1(t) = \frac{A_F\;\; e^{i\Delta\omega_{rf} t}}{1+\exp\left(\frac{|t|-t_0}{a}\right)}$$ Fermi

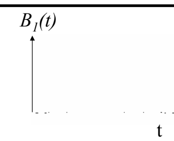
Tailored Pulse Shapes

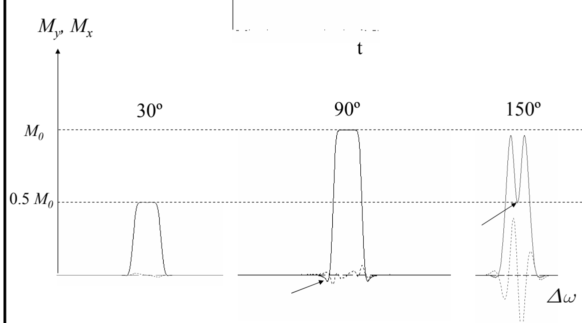
- Shinnar-Le Roux Pulses
- Adiabatic Pulses
- …

RF Pulse Functions - Excitation



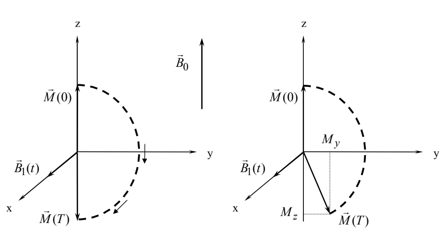
Non-linearity in excitation



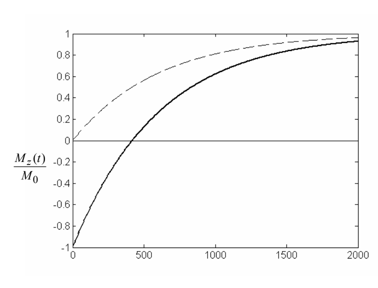


(figures were taken from “Handbook of MRI Pulse Sequences”)

Inversion

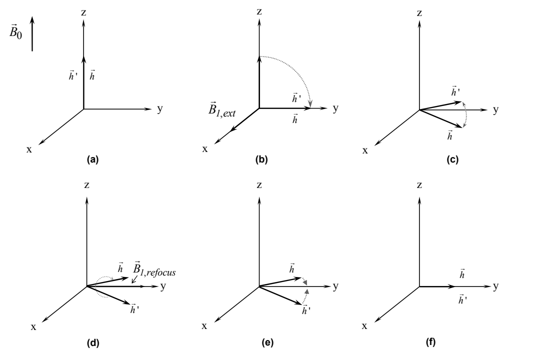


Saturation Recovery and Inversion Recovery



$$M_z(t) = M_0\left[1-\left(1-\cos\theta_{inv}\right)e^{-t/T1}\right]$$

Refocusing



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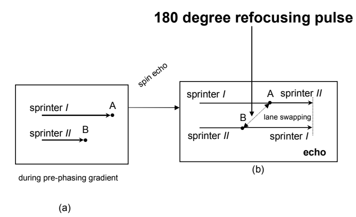
An Analogy for a Refocusing Pulse



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