Lecture 13: RF Pulses – Advanced Topics

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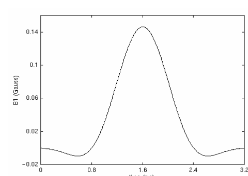
A Brief Review of Lecture 12

- What is the equation that governs the interaction between magnetization and an RF pulse?
- Where does the non-linear response of an RF pulse come from?
- What is the relationship between the flip angle of an RF pulse and the B1-field?
- Name a pulse shape commonly used for frequency selection, and non-frequency selection, respectively.
- Consider a SINC pulse that has one central lobe, and one side-lobes on each side of the central lobe. If the pulse width is 3.2ms, what is the bandwidth of its frequency response?
- What are the three commonly used functions of RF pulses?
- What are the typical flip angles for excitation, refocusing, and inversion pulses, respectively?

Outline of Lecture 13

- Parameters for specifying an RF Pulse
- Tailored RF Pulses:
  - SLR pulses
- Spatially Selective Pulses:
  - Spatial selection
  - Spatial saturation
- Spectrally Selective Pulses:
  - Chemically selective excitation
  - Chemically selective saturation (CHESS)
- Adiabatic Pulses:
  - Principles
    - Amplitude modulation (AM)
    - Frequency modulation (FM) or phase modulation (PM)
  - Functions
    - Excitation
    - Inversion
    - Refocusing

What Parameters Are Needed to Specify an RF Pulse?



- Shape
- Amplitude
- Pulse width
- Flip angle
- Frequency selectivity – bandwidth
- Power – Specific absorption rate (SAR in units of W/kg)

$$SAR \propto B_1^2$$

Tailored RF Pulses -SLR

- Inverse problem
  - If B1(t) is known, its frequency response can be completely and uniquely determined.
  - If a desired spectral response is specified, its corresponding RF pulse cannot be easily and uniquely determined.
- SLR (Shinnar-Le Roux) algorithm
  - Allows the inverse problem of RF pulse design to be "solved" directly and efficiently without iteration.
  - It relies on two key concepts:
    - Two-dimensional mathematic representation of rotation, known as SU(2) notation.
    - "Hard pulse" approximation.
  - Reduces RF pulse design to an FIR filter design problem
  - Forward SLR transform vs. Backward SLR transform

Rotation with SU(2) Notation

$$\mathbb{Q} = \begin{bmatrix} \alpha & -\beta^* \\ \beta & \alpha^* \end{bmatrix}$$

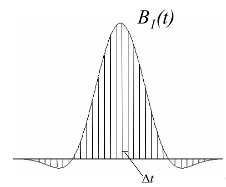
where α and β are complex numbers known as the Cayley-Klein parameters

$$\alpha\alpha^* + \beta\beta^* = |\alpha|^2 + |\beta|^2 = 1$$

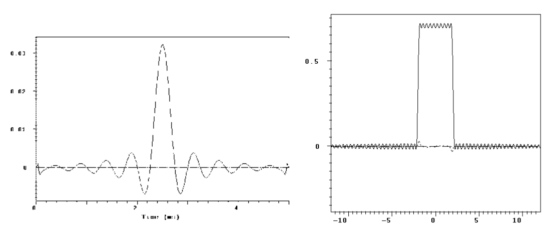
Interaction of an RF Pulse with Magnetization

$$\begin{bmatrix} M_{\perp}(+) \\ M_{\perp}^{*}(+) \\ M_{z}(+) \end{bmatrix} = \begin{bmatrix} (\alpha^{*})^{2} & -\beta^{2} & 2\alpha^{*}\beta \\ -(\beta^{*})^{2} & \alpha^{2} & 2\alpha\beta^{*} \\ -(\alpha\beta)^{*} & -\alpha\beta & \alpha\alpha^{*}-\beta\beta^{*} \end{bmatrix} \begin{bmatrix} M_{\perp}(-) \\ M_{\perp}^{*}(-) \\ M_{z}(-) \end{bmatrix}$$

Hard-Pulse Approximation



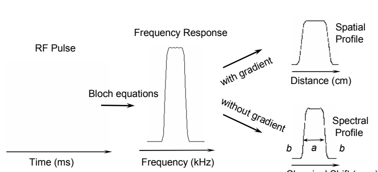
An Example of SLR Pulse



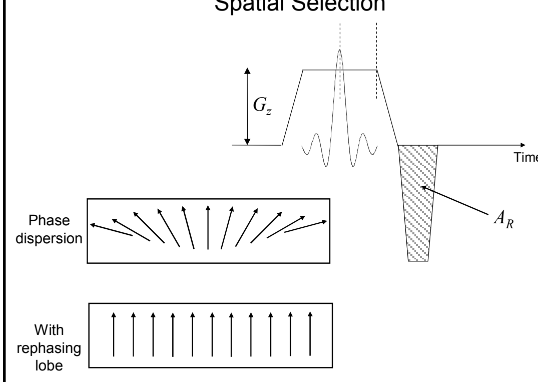
Interesting Properties of SLR Pulse

- The pulse is NOT scalable
  - The pulse shape depends on the flip angle, and the pulse function
  - Doubling the B1-field (or the pulse with) of an α pulse does not give an SLR pulse with tip angle of 2α ! (???)
  - SLR pulse has to be designed for specific flip angles
- The sharpness of the frequency response can be traded with the amount of the ripples.
- An SLR inversion pulse and an SLR refocusing pulse are not interchangeable.

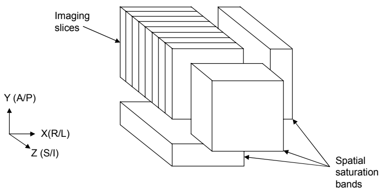
Spectral and Spatial Selection

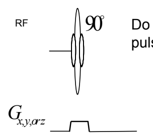


Spatial Selection



Spatial Saturation



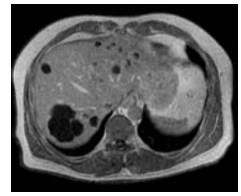


Do we need to have a refocusing gradient pulse for spatial saturation?

No!

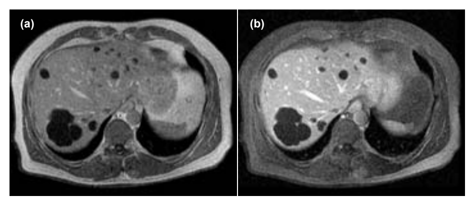
Spectral Selection

Why do we need to have spectral selection?



… because of the presence of FAT

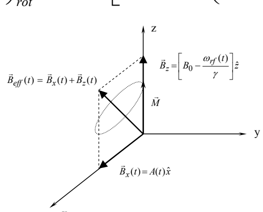
- Spectral selection is difficult to achieve because of phase dispersion.
- Thus, instead, spectral saturation is much more frequently used.



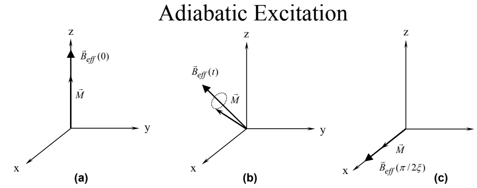
CHESS Image

Adiabatic Pulses

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



Adiabatic Excitation

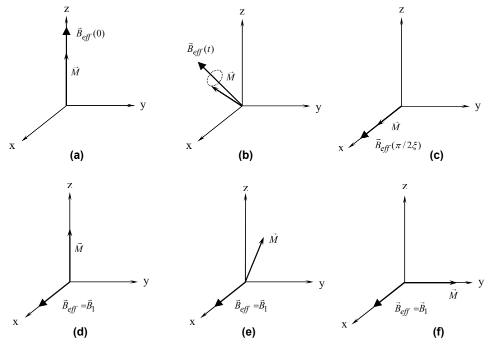


- $|\vec{B}_{eff}(t)|$ is constant, but its direction is changing.
- B1-field amplitude must change throughout the pulse.
- The z-component of $\vec{B}_{eff}(t)$ must change as well.

How can we change the z-component of $\vec{B}_{eff}(t)$?

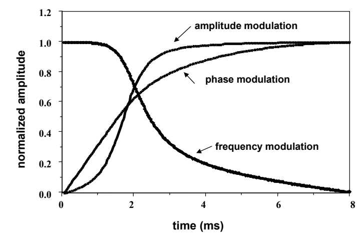
B1 must be frequency modulated!

Adiabatic Excitation



Non-adiabatic Excitation

An Adiabatic Pulse Waveform



Interesting Properties of Adiabatic Pulses

- Difficult to make a spatially selective adiabatic excitation pulse.
- An adiabatic refocusing pulse can be used for inversion; but an adiabatic inversion pulse typically cannot be used for refocsuing.
- Adiabatic pulses have very high power deposition
- For adiabatic pulses, flip angle is independent of B1, provided that the B1-field is sufficiently strong.