Centre for the Clinical Application of Particles

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Magnetic Resonance Imaging

Week 5; Lecture 10; Section 1: Slice selective excitation

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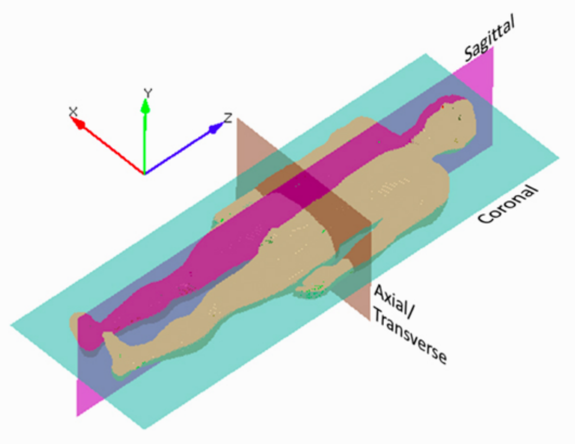
Section 1

Slice selective excitation

Introduction



Conventional terminology & orientation of RH coordinate system

Contrast between tissues is afforded by RF B_1 pulse sequences such as those discussed in the preceding lectures

To make an image, need to localise the signals to appropriately small regions of space

To localise signals exploit:

- Resonance, i.e. Larmor frequency $\nu = \gamma B$
- By making B a function of position

i.e. make ν a function of position:

$$\nu(x, y, z) = \gamma B(x, y, z)$$

Slice selective excitation

Goal: excite a slice of tissue of thickness δ

So far a uniform "main field" $\mathbf{B}_0 = B_0\hat{\mathbf{k}}$ has been considered

Require to make B_z a function of position to make Larmor frequency position dependent

Apply "gradient" fields G_i such that B_z becomes:

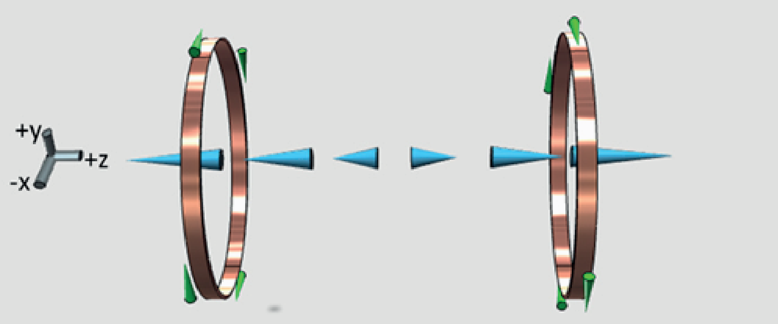
$$B_z(x, y, z, t) = B_0 + xG_x(t) + yG_y(t) + zG_z(t)$$

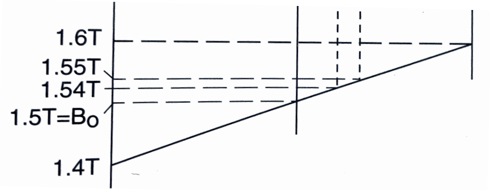
Ideally G_i only have one field component directed along the z direction so that:

$$\mathbf{B} = B_z(x, y, z, t)\hat{\mathbf{k}}$$

With appropriate choice of G_i can generate a field gradient in any direction

Transverse slice; i.e. plane at fixed z





Example:

Helmholtz coils in opposition

Ideal gradient:

G_z = constant

Transverse slice; slice thickness and bandwidth

Lets say that response needs to be isolated to a slice: $\delta z = 5\,\text{mm}$ centred about $z = 0$

Take:

- The magnitude of the main field to be $B_0 = 1.5\,\text{T}$
- The field gradient $G_z = 50\,\text{mT}\,\text{m}^{-1}$
- $\gamma = 42.58\,\text{MHz}\,\text{T}^{-1}$

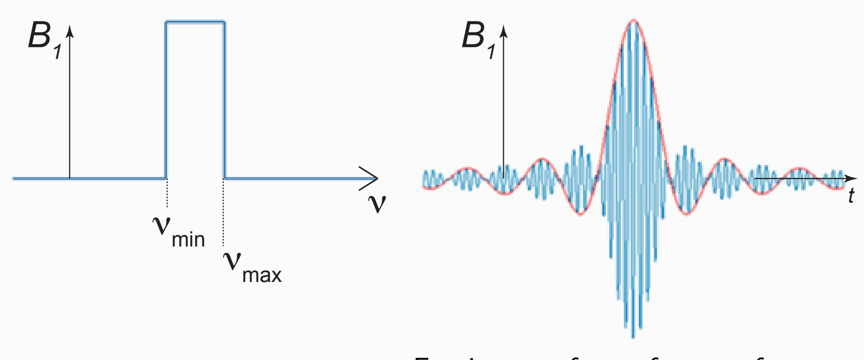
Take the slice to be $-2.5 < z < 2.5\,\text{mm}$, then the Larmor frequency will run over the following range:

$$\begin{aligned}
\nu_{\min} &= (1.5 - 0.125 \times 10^{-3}) \times 42.58 \approx 63.8646\,\mathrm{MHz} \\
\nu &= 1.5 \times 42.58 \approx 63.87\,\mathrm{MHz} \\
\nu_{\max} &= (1.5 + 0.125 \times 10^{-3}) \times 42.58 \approx 63.8753\,\mathrm{MHz}
\end{aligned}$$

So, the spread of frequencies, the **bandwidth**, $\Delta\nu$ is:

$$\Delta\nu = 63.8646 - 63.8753 \approx 10.7\,\mathrm{kHz}$$

Transverse slice; excitation of spins in slice

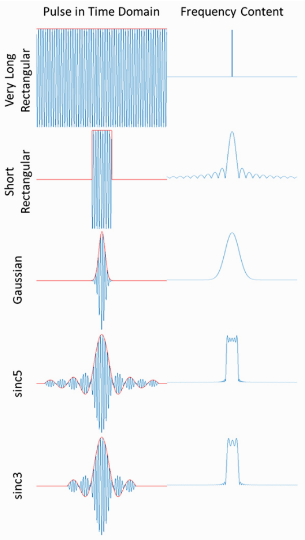


Idealised, square frequency distribution

Fourier transform of square frequency distribution

B_1 oscillates at ν, amplitude is modulated according to "sinc" function (red line)

Transverse slice: excitation pulses



Frequency content of a variety of excitation pulses:

- *Very long rectangular*: narrow band of Larmor frequencies
- *Short rectangular*: frequency distribution follows "sinc" function:

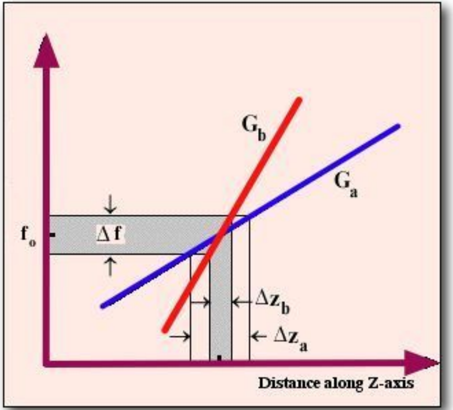
$$A(\nu) \propto \mathrm{sinc}(\nu) = \frac{\sin \nu}{\nu}$$

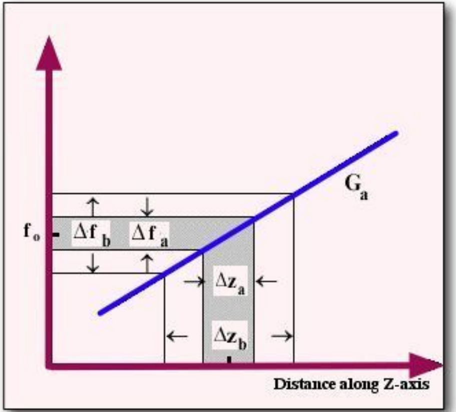
  where $A(\nu)$ is the amplitude of contribution at frequency ν
- *Gaussian*: Fourier transform of Gaussian in t is a Gaussian in ν
- *sincN*: Since square pulse requires contributions over all ν, the frequency range is often truncated. The "sincN" function represents a sinc function for which the frequency range is truncated after N zero crossings

Transverse slice: determining the slice thickness

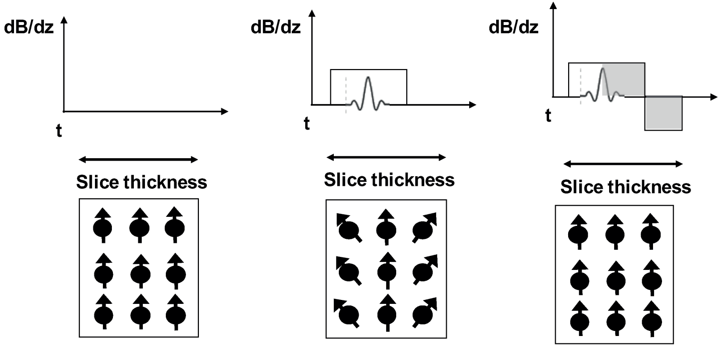
Slice thickness is determined by bandwidth ($\Delta\nu$) and field gradient (G_z)

Sorry for the change in notation!





Transverse slice: spin rephasing pulse



Larmor frequency across slice changes. So, over the time that the gradient pulse is applied, the spins precess at different rates

Therefore, at the end of the pulse the phase of the spins differs as a function of z

A rephasing pulse which reverses the field gradient (i.e. for which $G_z \to -G_z$) is applied

Transverse slice: spin rephasing pulse

Size of the spin rephasing pulse is determined by considering the rate at which the phase difference accumulates

Rate of precession is given by the Larmor frequency, ω, so change in phase of a spin during the gradient pulse is given by:

$$\Phi = \omega\tau = \gamma\left(B_0 + zG_z\right)\tau$$

where τ is the length of the gradient pulse in time

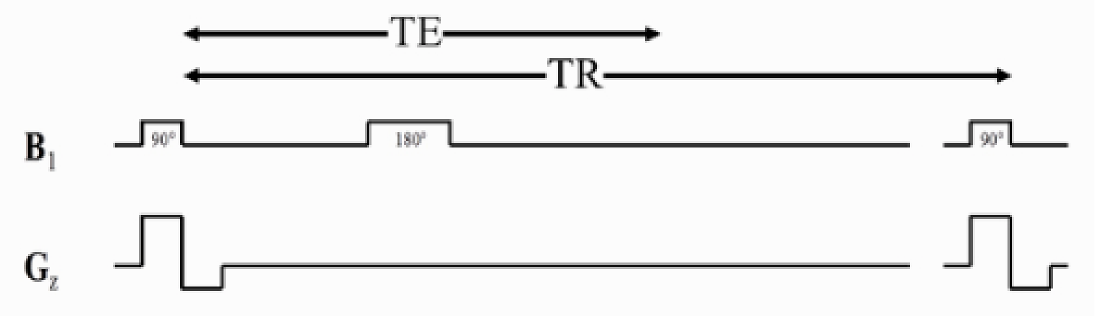
So, phase difference between edges of the slice and the centre is:

$$\Delta\Phi = \gamma\tau G_z \frac{\delta z}{2}$$

So, rephasing pulse, $G_z^{\rm rephase}$, and the length over which it is applied, $\tau^{\rm rephase}$ must satisfy:

$$G_z^{\rm rephase}\tau^{\rm rephase} = G_z\frac{\tau}{2}$$

Transverse slice: partial spin-echo pulse sequence



B_1 rotates net magnetisation in the selected slice with gradient pulse applied

Summary of section 1

Localisation of MRI signal to plane achieved using magnetic-field gradient combined with frequency-dependent readout of radiowave generated by precession of net magnetisation

Frequency content of RF (B_1) pulse determines spread of perturbations to Larmor frequency

Spin-rephasing pulse applied after main B_1 pulse. Length of rephasing pulse required is half that of the main B_1 pulse