Spatial Localization II

M219 - Principles and Applications of MRI

Kyung Sung, Ph.D.

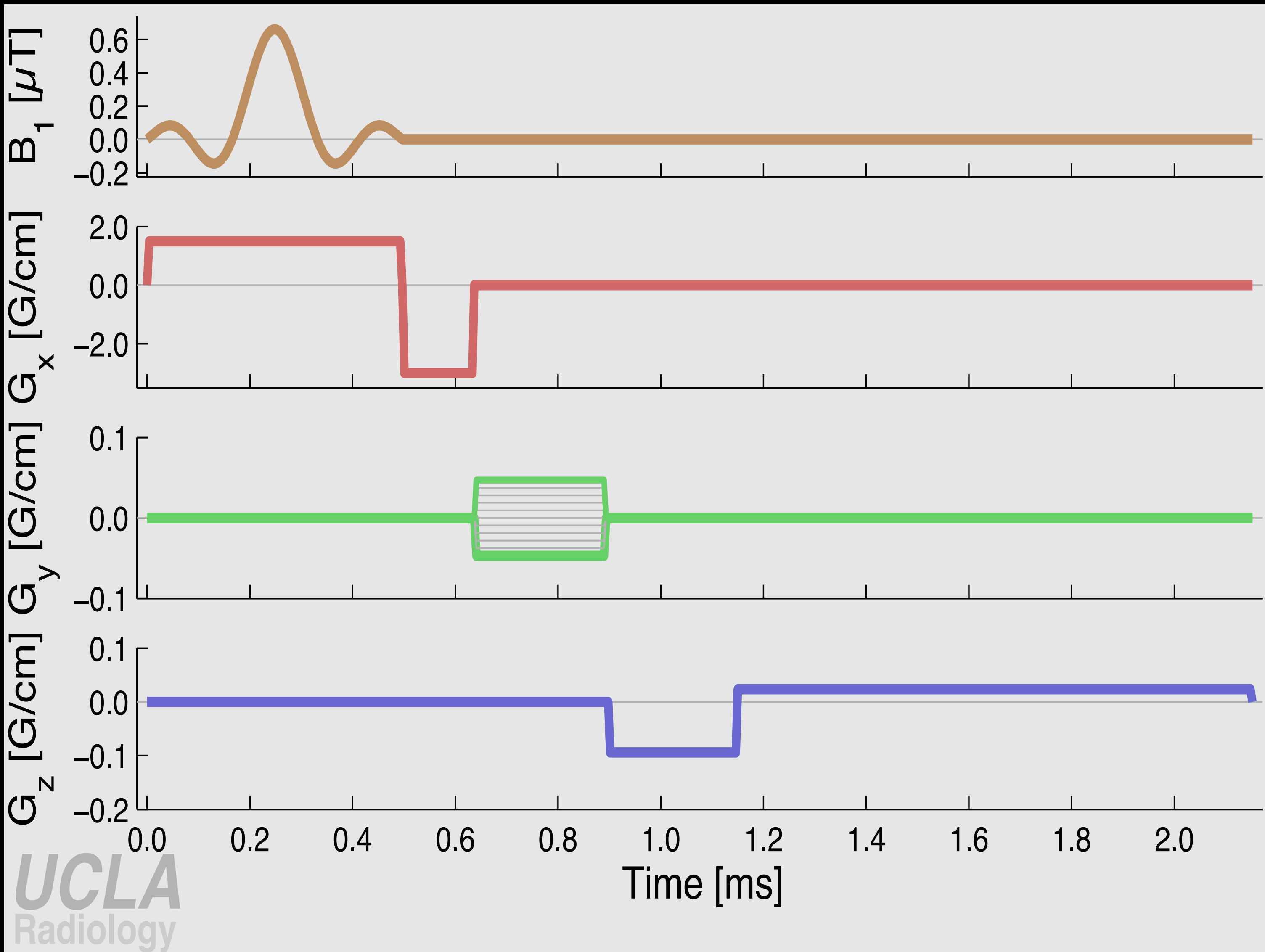
2/8/2023

Course Overview

- 2023 course schedule
  - https://mrrl.ucla.edu/pages/m219_2023
- Assignments
  - Homework #2 is due on 2/15
- Office hours, Tuesday 1-3pm
  - Zoom is also available (https://uclahs.zoom.us/j/98066349714?pwd=cnVmV1J5QjR1d3I3cmJkQnVLSFZVZz09)

Spatial Localization

3 Steps for Spatial Localization



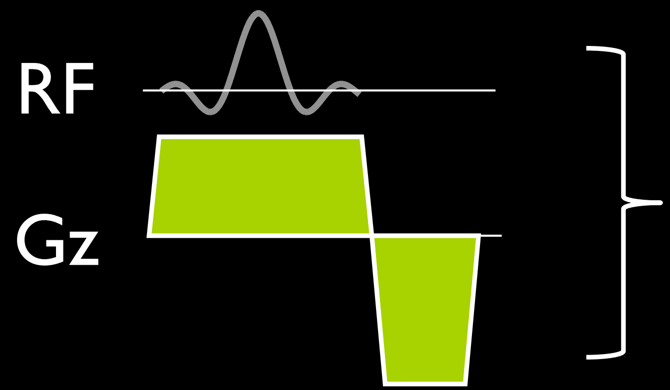
Slice Selection

Phase Encoding

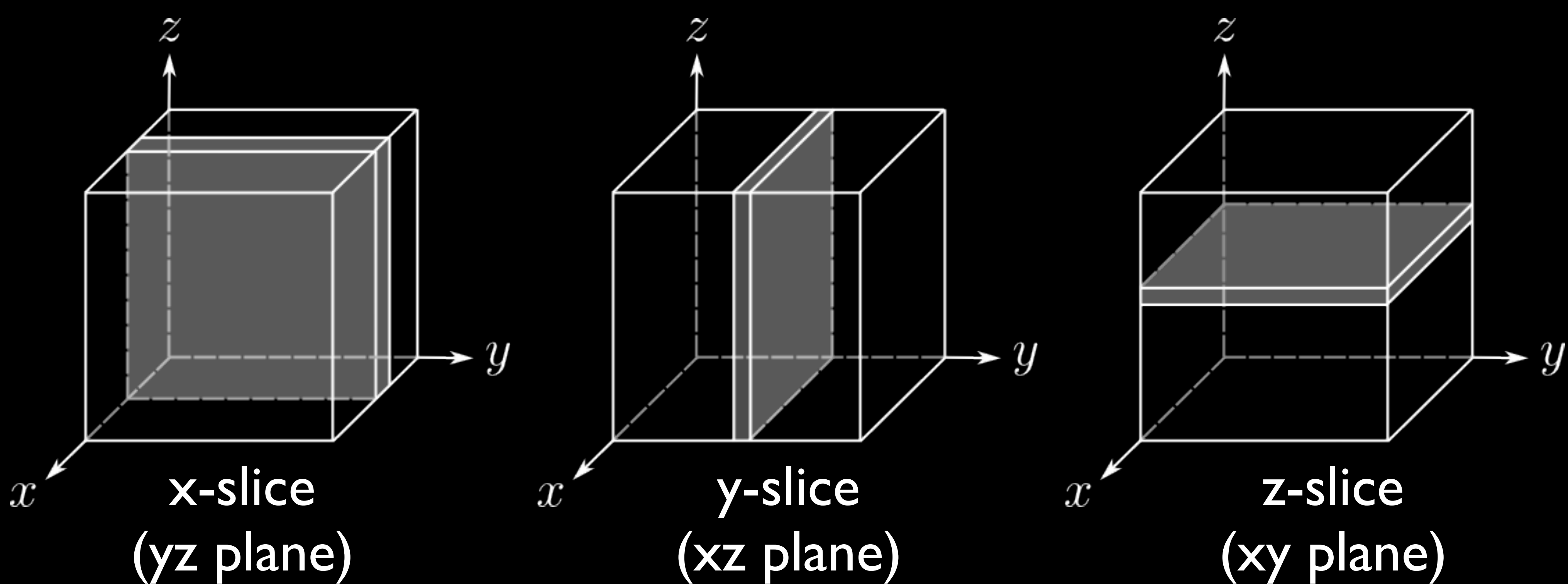
Frequency Encoding

Pulse Sequence Diagram - Timing diagram of the RF and gradient events that comprise an MRI pulse sequence.

Selective Excitation



excite a slice perpendicular to z



Bloch Equation with Gradient

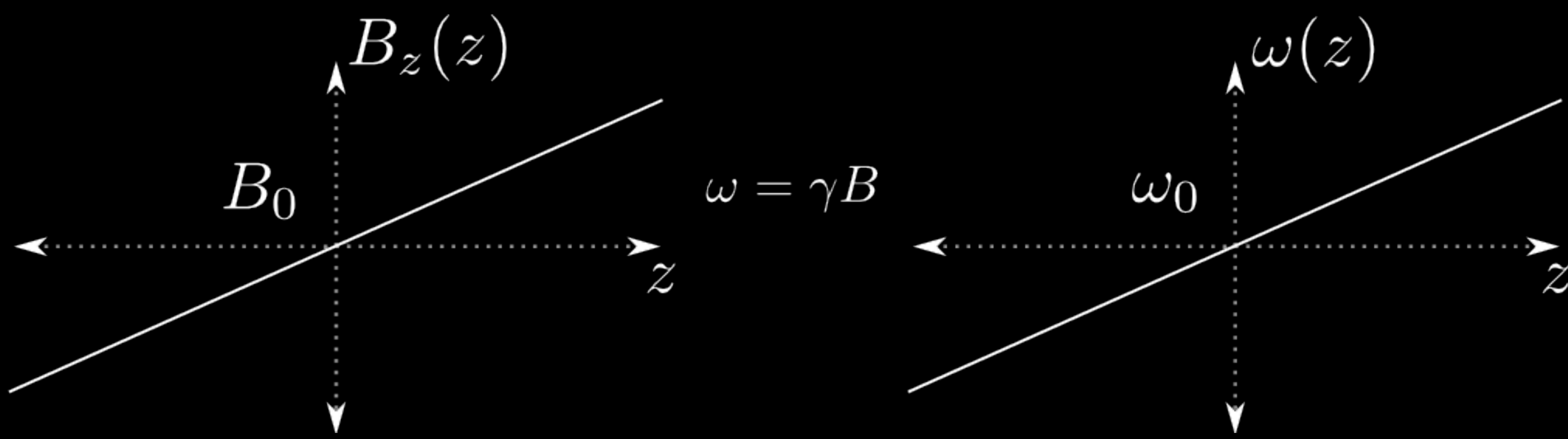
$$\frac{d\vec{M}_{rot}}{dt} = \vec{M}_{rot} \times \gamma \vec{B}_{eff}$$

$$\vec{B}_{eff} = \left(\begin{array}{c} B_1(t) \\ 0 \\ B_0 - \frac{\omega_{RF}}{\gamma} \end{array} \right) \Rightarrow \vec{B}_{eff} = \left(\begin{array}{c} B_1(t) \\ 0 \\ B_0 - \frac{\omega_{RF}}{\gamma} + G_z z \end{array} \right)$$

Gradients?

gradients produce a spatial distribution of frequencies

$$B_z(z) = B_0 + G_z \cdot z$$

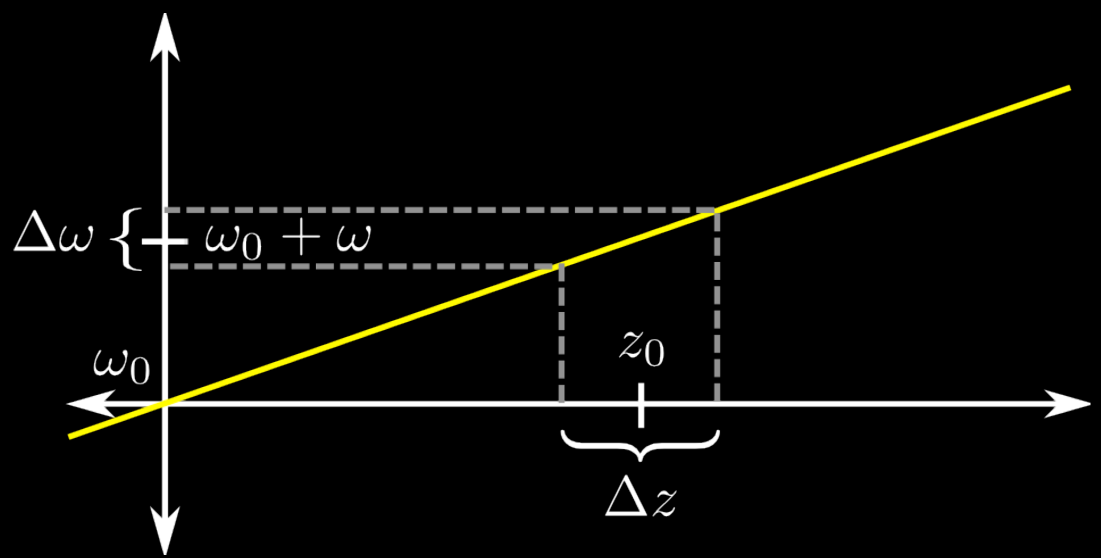


$$\omega(z) = \omega_0 + \gamma G_z \cdot z$$

there is a direct correspondence between frequency and spatial position

Slice Selection

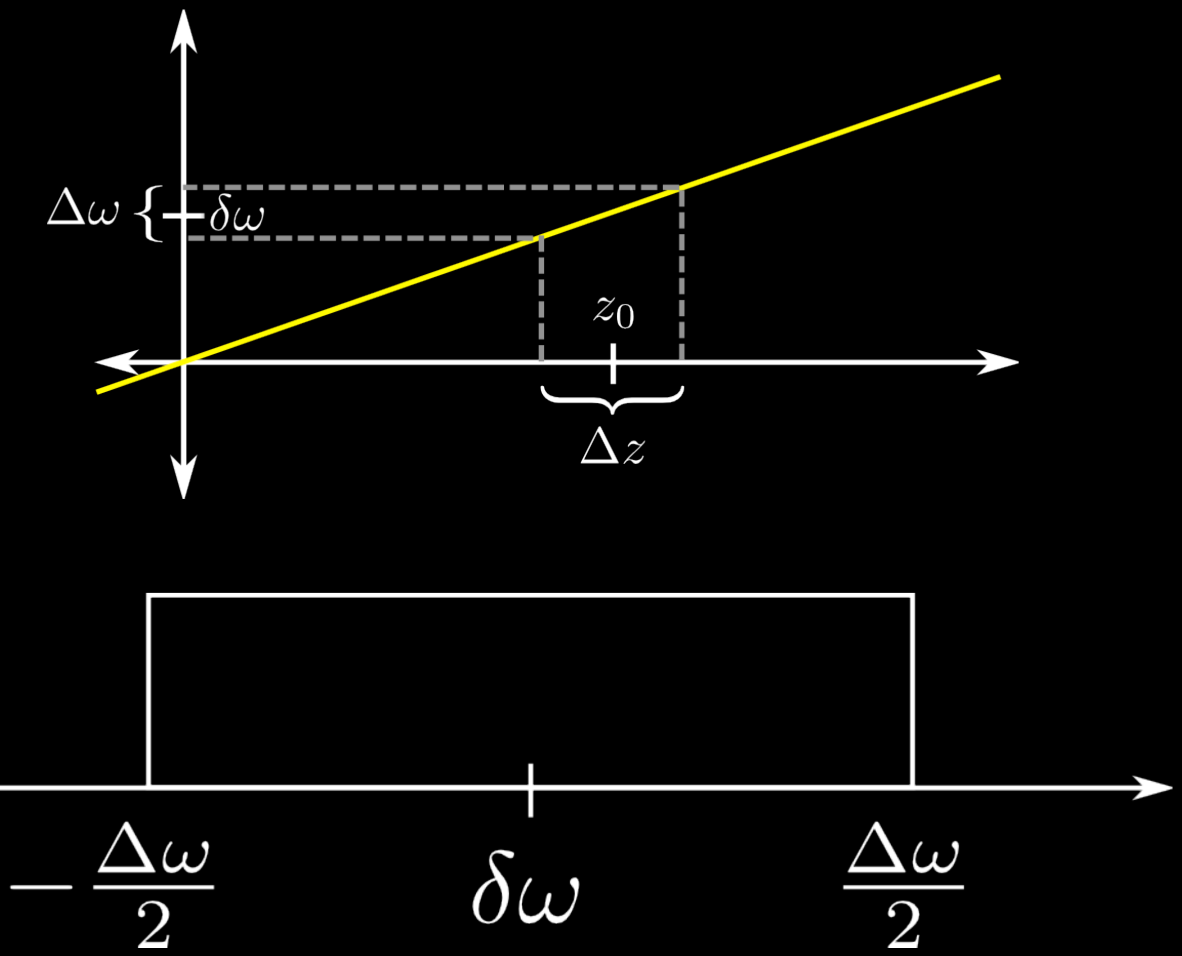
how do we physically set the parameters?



ω - the carrier frequency of the RF pulse

$\Delta\omega$ - frequency bandwidth of the RF pulse

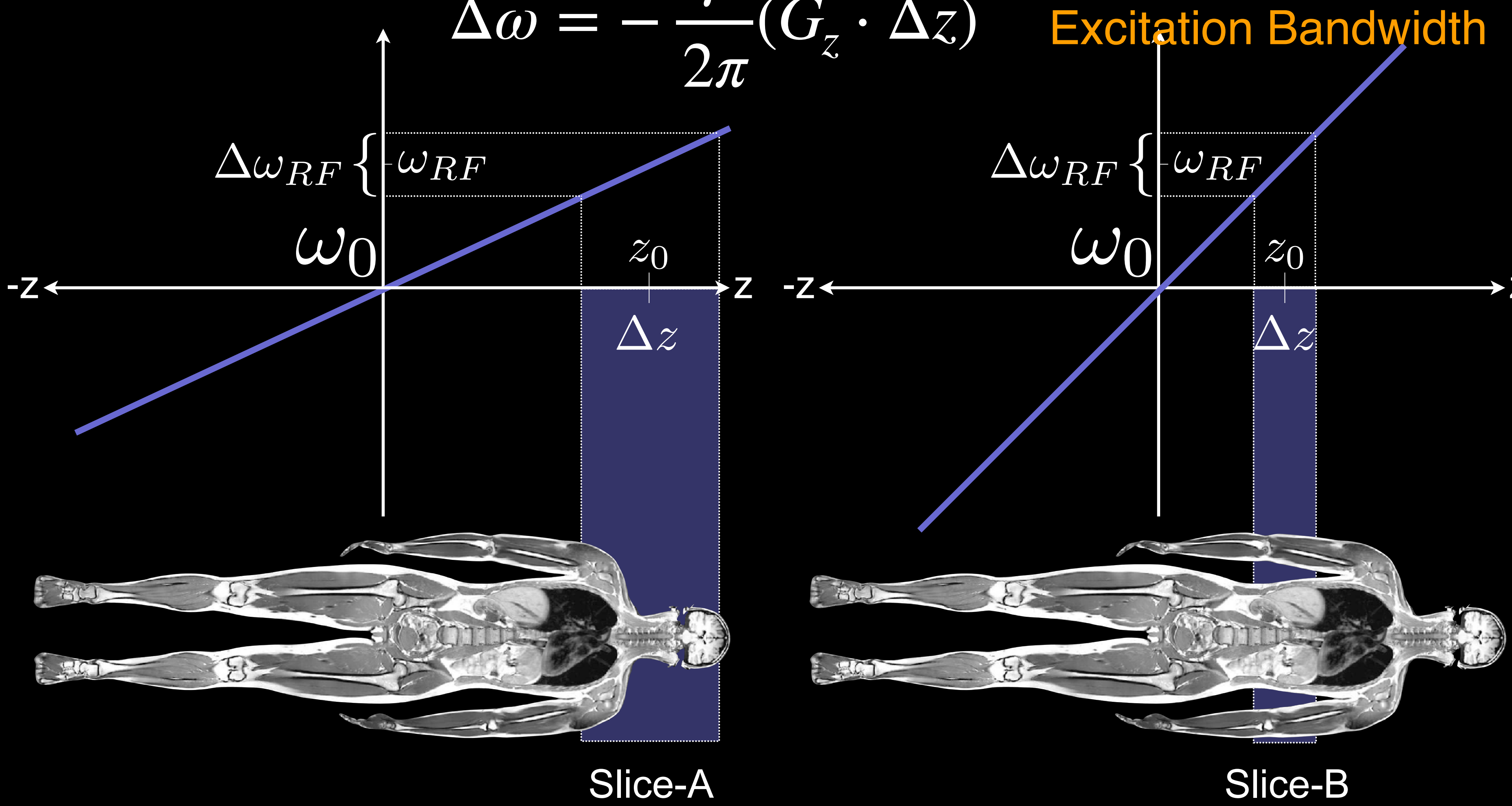
Slice Selection



we want a pulse with as rectangular of an slice profile as possible

Slice Selective Excitation

$$\Delta\omega = -\frac{\gamma}{2\pi}(G_z \cdot \Delta z)$$



How do you move the slice along ±z?

Compare $\Delta\omega$ and ω_{RF} for Slice-A and Slice-B.

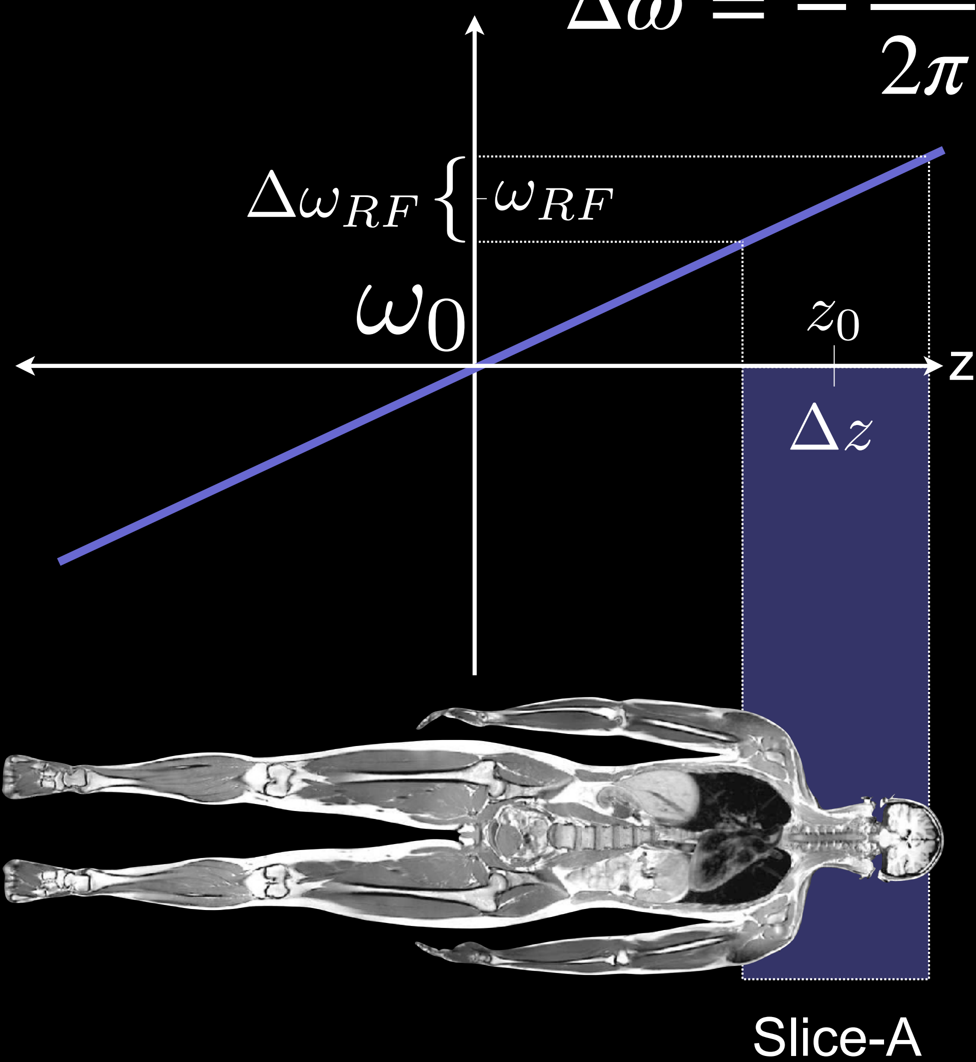
Do we usually acquire $\omega_{RF}>\omega_0$?

Time Bandwidth Product (TBW)

- **Time bandwidth (TBW) product:**
  - **Pulse Duration [s] x Pulse Bandwidth [Hz]**
  - **Unitless**
  - **# of zero crossings**
  - **High TBW**
    - Large # of zero crossings ∴ fewer truncation artifacts
    - Longer duration pulse
- **Examples:**
  - **TBW = 4, RF = 1ms**
    - Excitation (RF) bandwidth?
    - Required G_z for 1cm slice?
  - **TBW = 16, RF = 1ms**
    - Excitation (RF) bandwidth?
    - Required G_z for 1cm slice?

Slice Selective Excitation - Example

$$\Delta\omega = -\frac{\gamma}{2\pi}(G_z \cdot \Delta z)$$



Excitation Bandwidth

$$\mathrm{TBW} = \tau_{RF} \cdot \Delta\omega_{RF}$$

$$\Delta\omega_{RF} = \frac{\mathrm{TBW}}{\tau_{RF}} = \frac{4}{1\mathrm{ms}} = 4\mathrm{kHz}$$

$$G_z = \frac{\Delta\omega_{RF}}{\gamma\Delta z} = \frac{4000\mathrm{Hz}}{42.57e6\,\frac{\mathrm{Hz}}{\mathrm{T}}\,\frac{1\mathrm{T}}{10000\mathrm{G}} \cdot 10\mathrm{mm}} = 0.94\,\frac{\mathrm{G}}{\mathrm{cm}}$$

David Geffen School of Medicine
UCLA Radiology

MATLAB Demo

```
%% Design of Windowed Sinc RF Pulses
tbw = 4;
samples = 512;
rf = wsinc(tbw, samples);
```

```
%% Plot RF Amplitude
flip_angle = pi/2;
rf = flip_angle*rf;

pulseduration = 1;        % in msec
dt   = pulseduration/samples;
rfs = rf/(gamma*dt);      % Scaled to Gauss

bw = tbw/pulseduration; % in kHz
gmax = bw/gamma_2pi;

bl     = [rfs zeros(1,samples/2)];                   % in Gauss
g      = [ones(1,samples) -ones(1,samples/2)]*gmax;  % in G/cm
t_all = (1:length(g))*dt;  % in msec
```

MATLAB Demo

```
%% Simulate Slice Profile using Bloch Simulation
x  = (-2:.01:2);              % in cm
f  = 0;                       % in Hz
dt = pulseduration/samples/1e3;
t  = (1:length(b1))*dt;  % in usec

% Bloch Simulation
[mx,my,mz] = bloch(b1(:),g(:),t(:),1,.2,f(:),x(:),0);

% Transverse Magnetization
mxy_bloch = mx+1i*my;

%% Simulate Slice Profile using Small Tip Approximation
samples_st = 4096;
f_st = linspace(-0.5/dt,0.5/dt,samples_st)/1e3;
x_st = -f_st/(gamma_2pi*gmax);

rfs_zp = zeros(1,samples_st);
rfs_zp(1:samples) = rfs;

mxy_st = fftshift(fftn(fftshift(rfs_zp)))/30;
```

http://www-mrsrl.stanford.edu/~brian/blochsim/