Basic ideas

- **Magnetic**: the signal source (magnetization)
- **Resonance**: signal excitation and detection
- **Imaging**: spatial encoding of signals

If magnetic field is spatial-dependent…

- According to Larmor equation, the resonance frequency changes as well.
- Paul Lauterbur
  - Awarded 2003 Noble Prize for “producing the first MRI”
- Basic tool of MRI: **gradient coil**

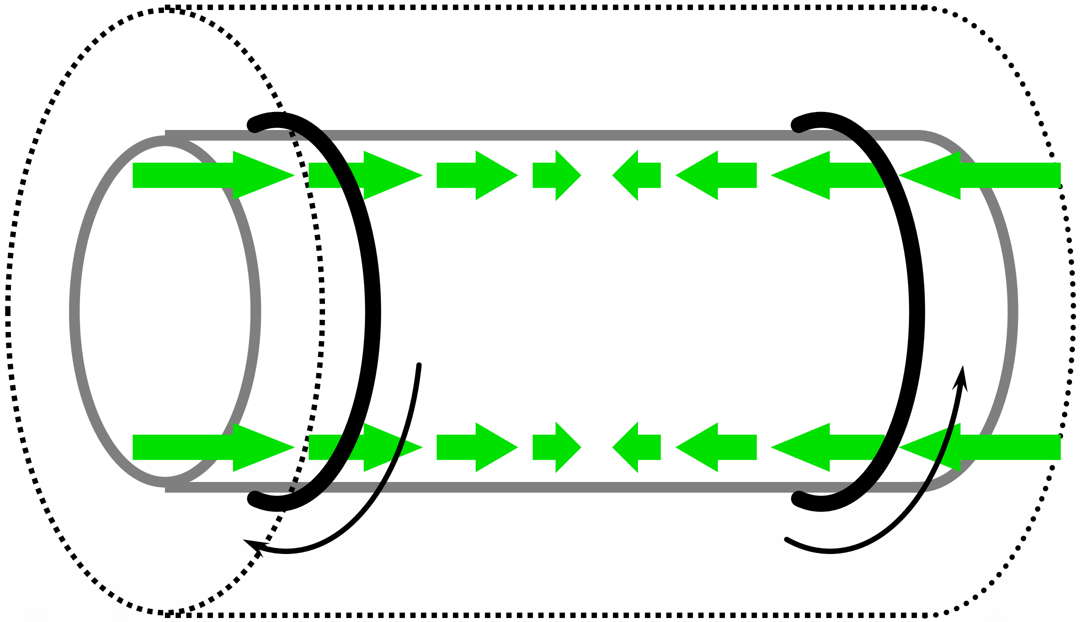
Review: Larmor equation

- The frequency (ω) of precession is obtain by

$$\vec{\omega} = -\gamma \vec{B}$$

  - Larmor frequency
  - 63.87 MHz @1.5 Tesla

How to generate a spatial-dependent field?



Maxwell pair

Gradient coils

- Electromagnetic coil
- The pattern of wiring varies spatially
- Three sets of gradient coils: x-, y-, and z-gradients
  - Driven independently

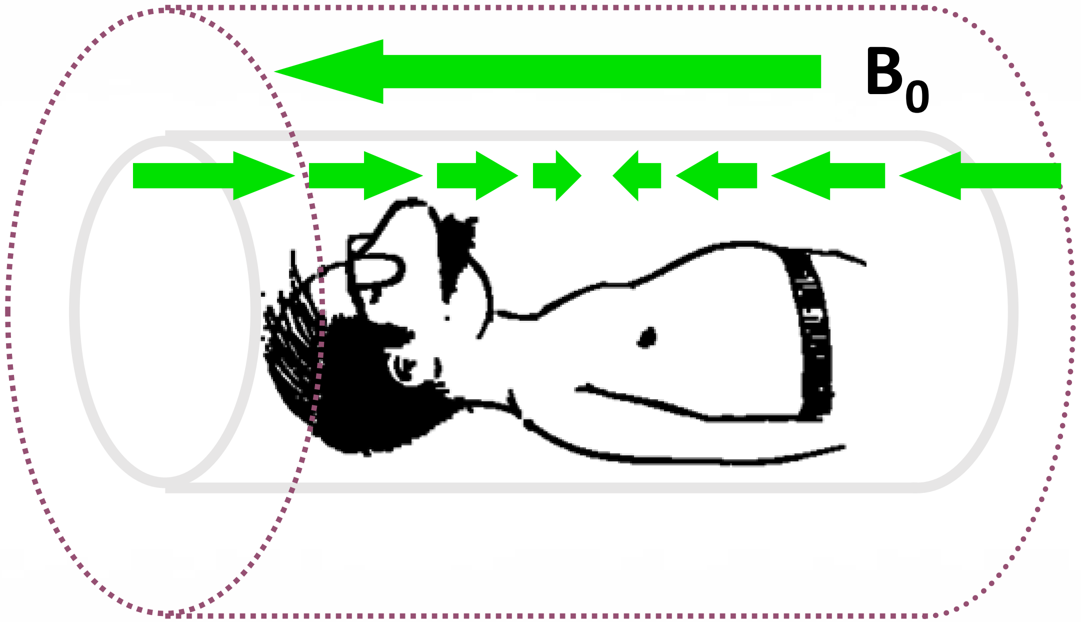
Purpose of the gradient field

- The precession frequency is proportional to the magnetic field strength.
- 1. Selective excitation of a specific slice
- 2. Differentiate signals from different locations
  - Calculation of spectrum = image

Slice-selective excitation

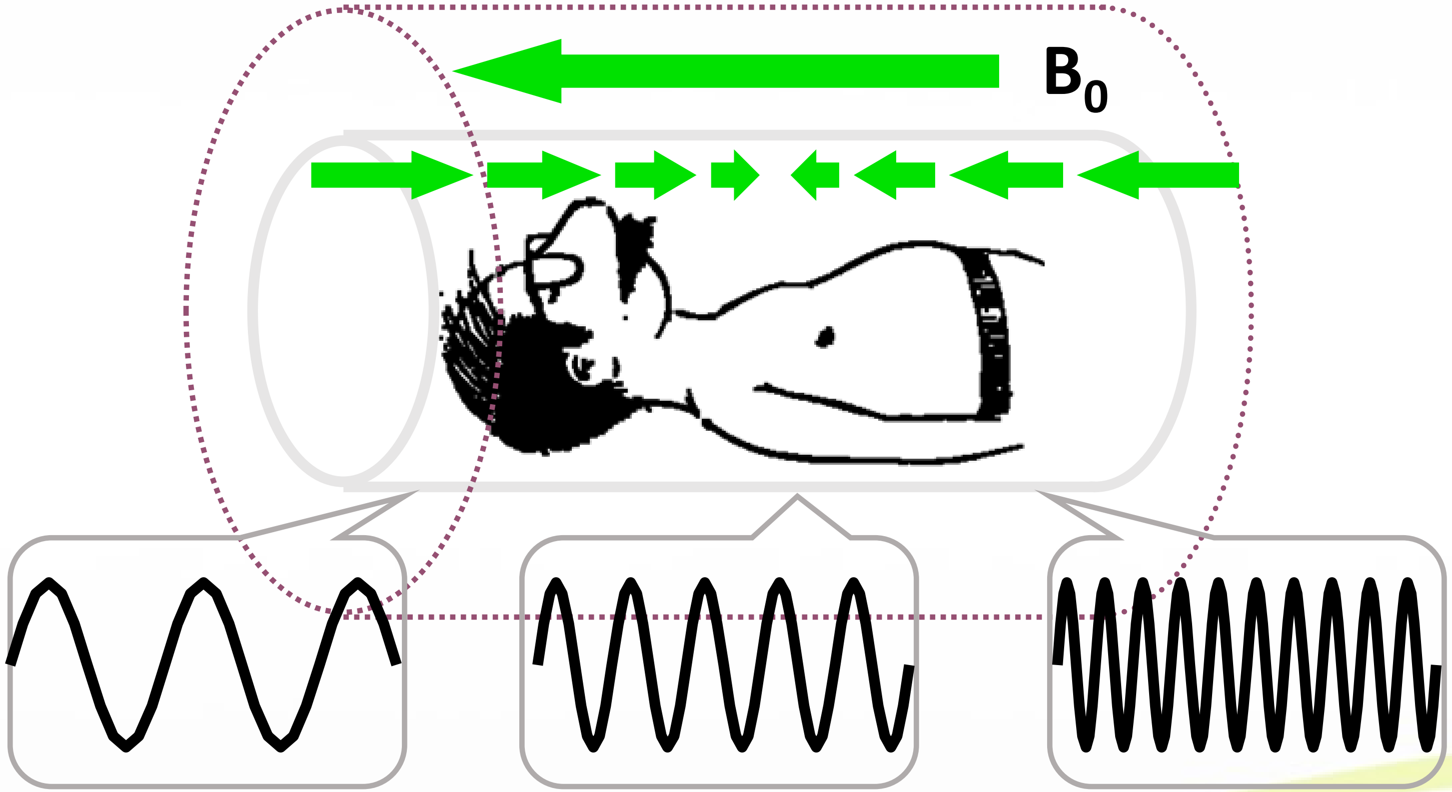
- Goal: to stimulate signals from a single slice only
- By applying a gradient field, Larmor frequency becomes spatially dependent.
- Tune the resonance frequency of B_1 field to match the slice location.

Augment a spatially varying field

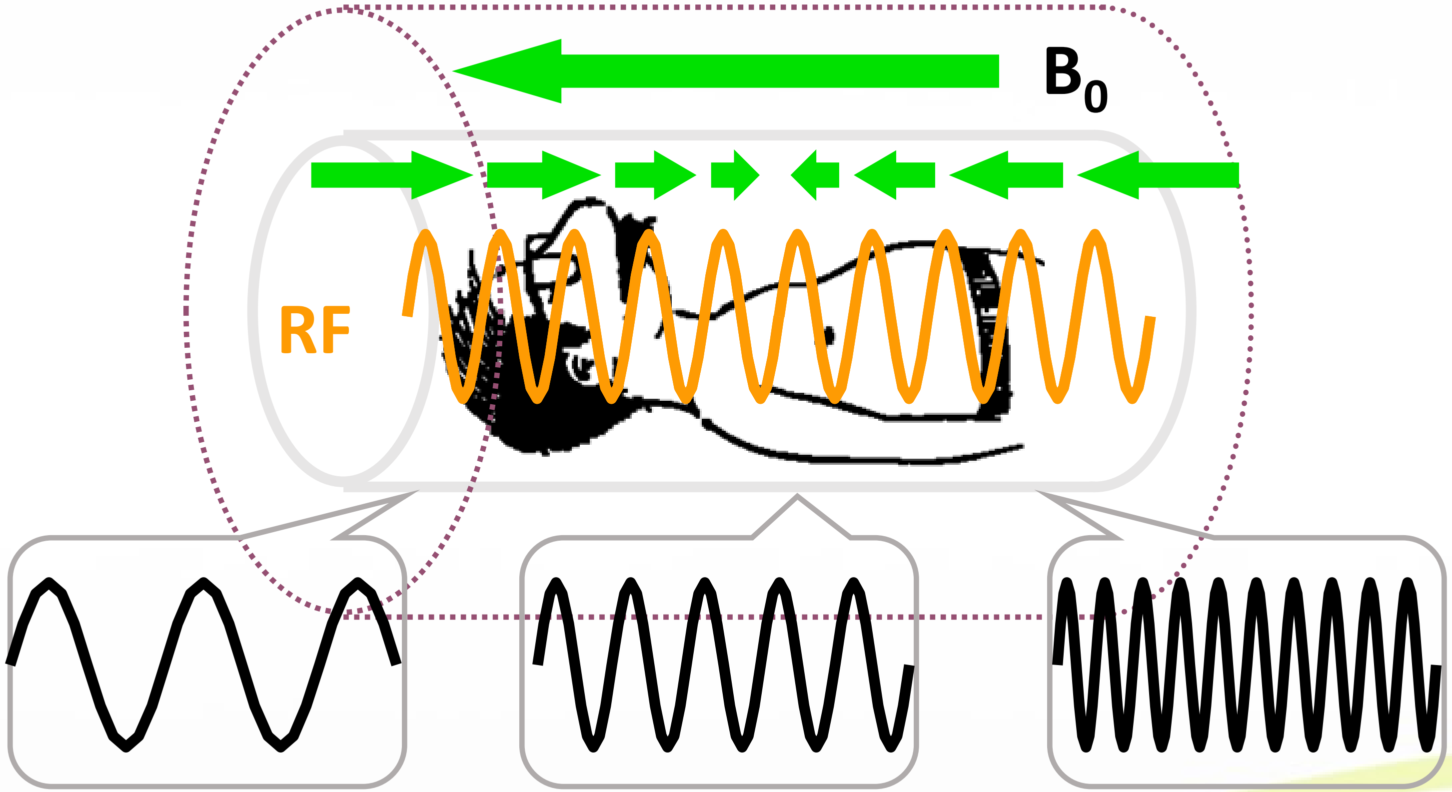


Summation of main field and gradient field

Spatial-dependent frequency

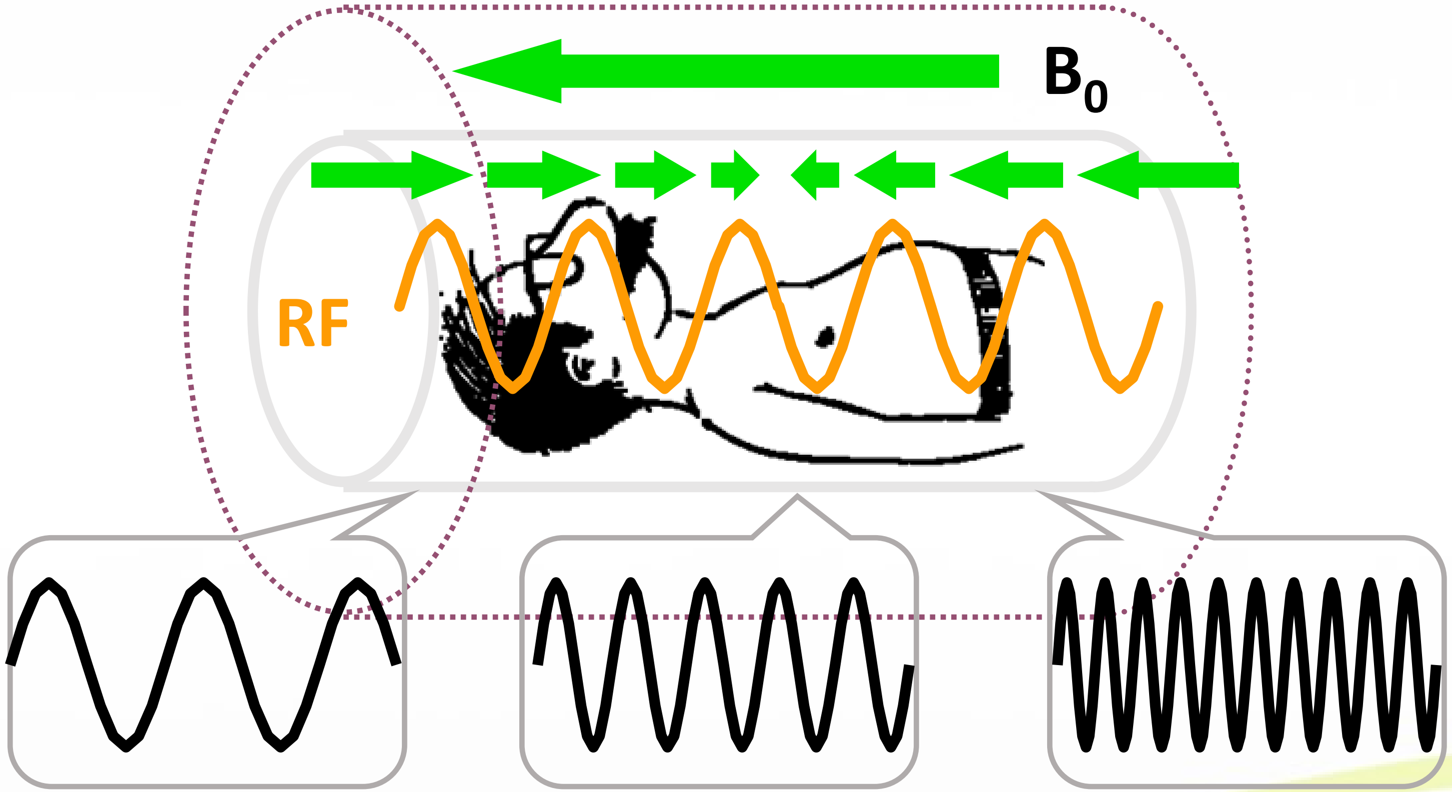


RF excitation: chest



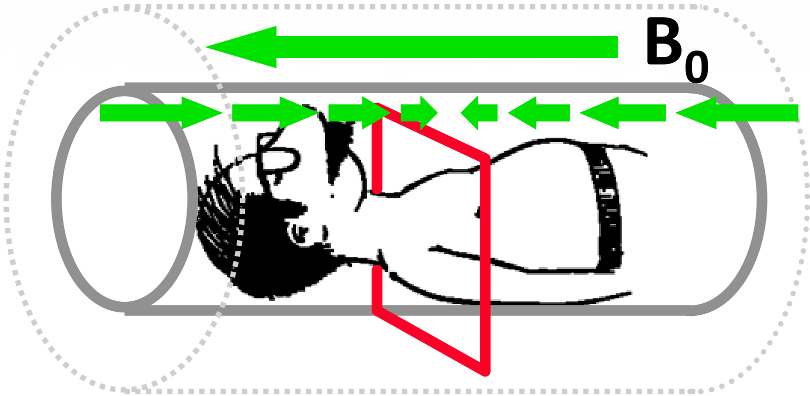
Only spins with the same frequency are excited

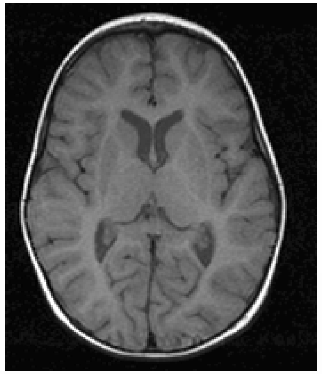
RF excitation of another plane: head



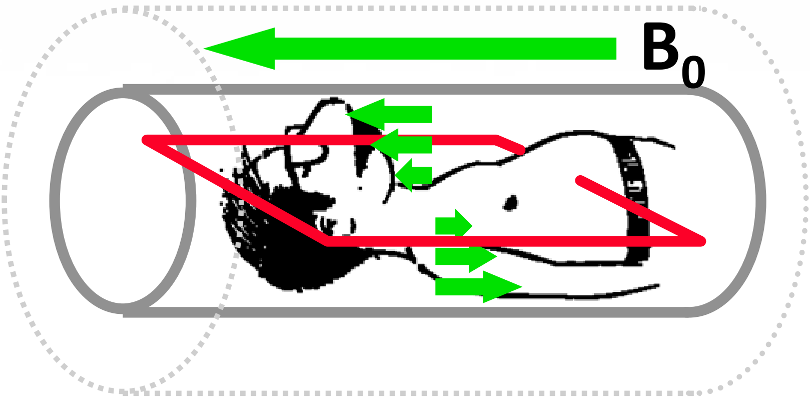
Adjust the frequency to determine slice location

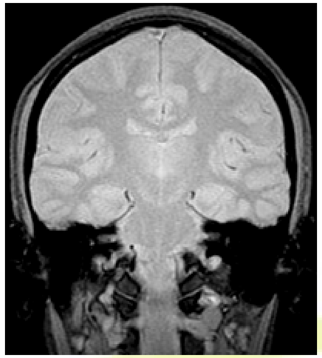
RF excitation of other orientations





Axial



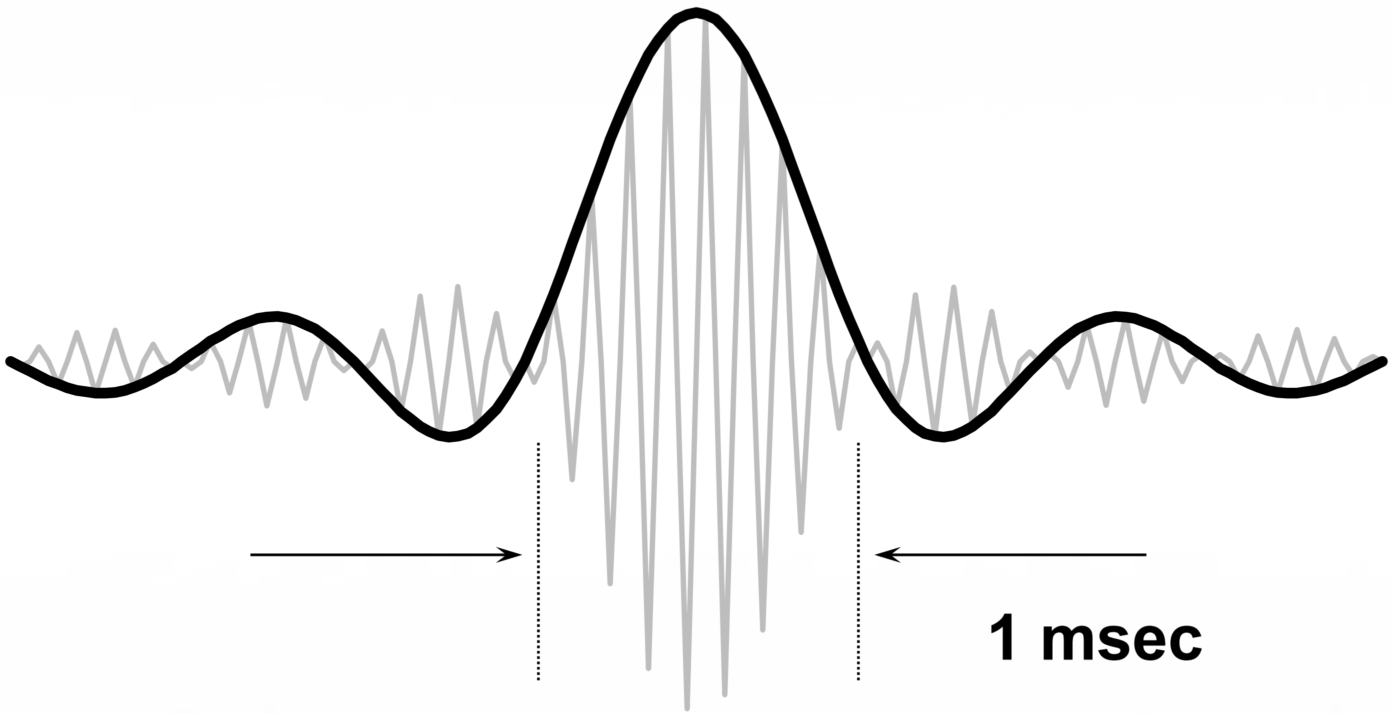


Coronal

Slice location and thickness

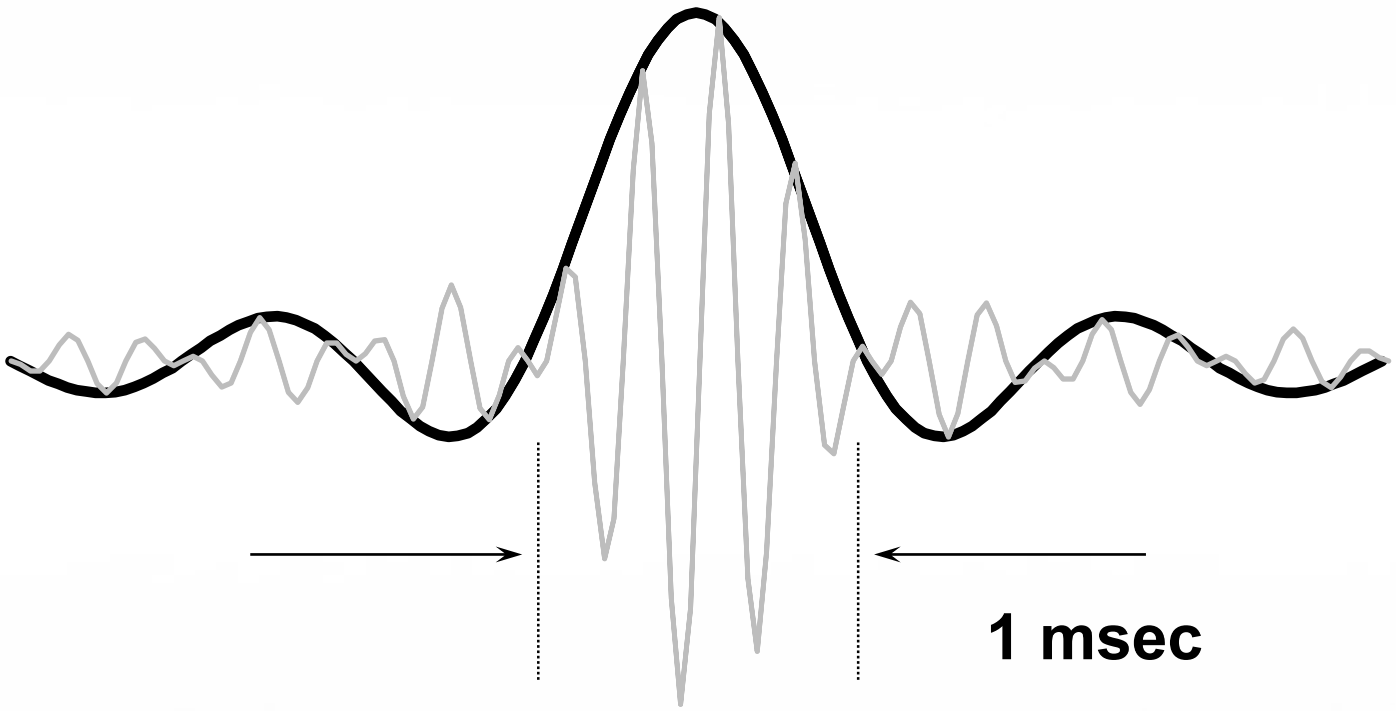
- When z gradient field is turned on,
$$\omega = \gamma B = \gamma(B_0 + G_z \cdot z)$$
  - Linear relationship between ω and z
- Excitation has to be performed on a slice with certain thickness.
$$\Delta\omega = \gamma G_z \cdot \Delta z$$
  - $\Delta\omega$: the corresponding bandwidth of the rectangular impulse response

Sinc pulse (B_1)



Corresponding to 63.87 MHz ± 1 kHz

Sinc pulse: adjusting slice location

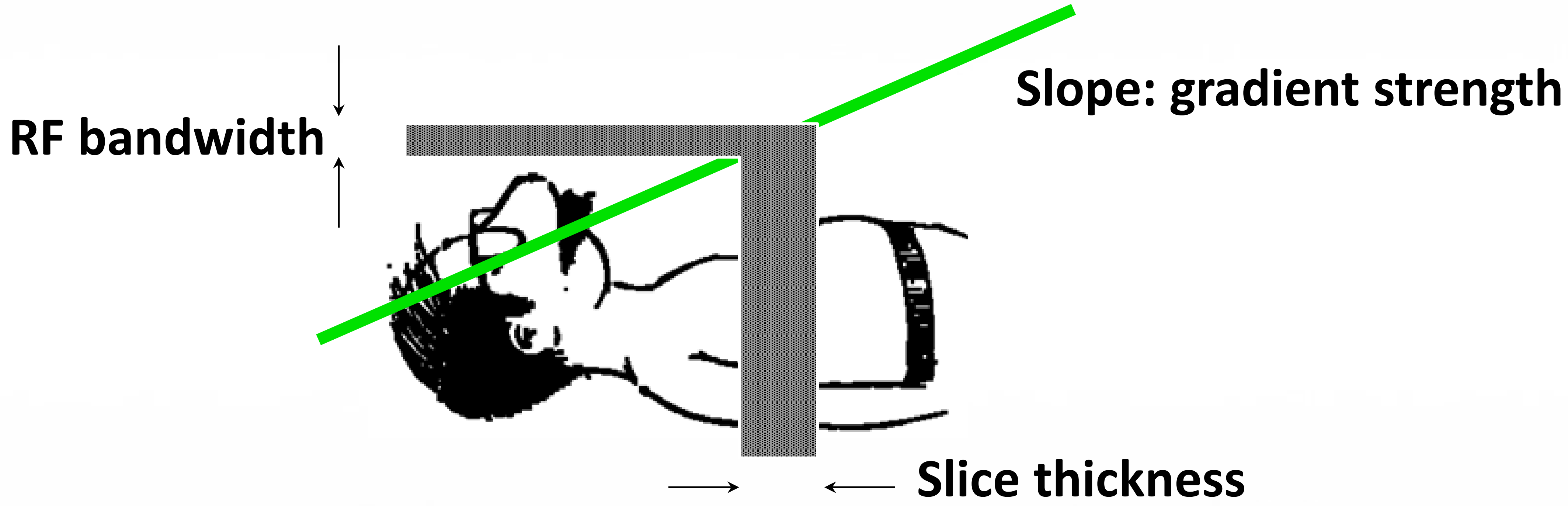


Corresponding to 63.67 MHz ± 1 kHz

Pursuit of high spatial resolution

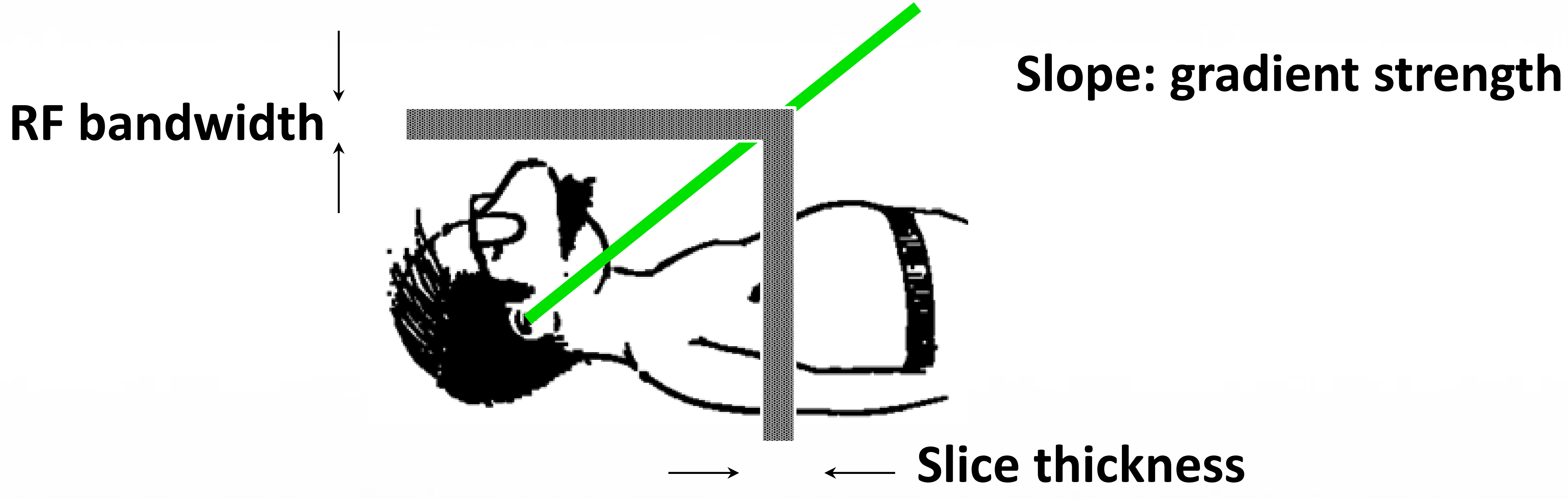
- Thin slice(s) for excitation
- $\Delta\omega = \gamma G_z \cdot \Delta z$
- Narrow bandwidth
  - Long duration of excitation
- Strong gradient
  - Hardware limitation

Thickness and gradient strength



Low gradient for thick slice (with fixed BW)

Thickness and gradient strength



Strong gradient for thin slice (with fixed BW)

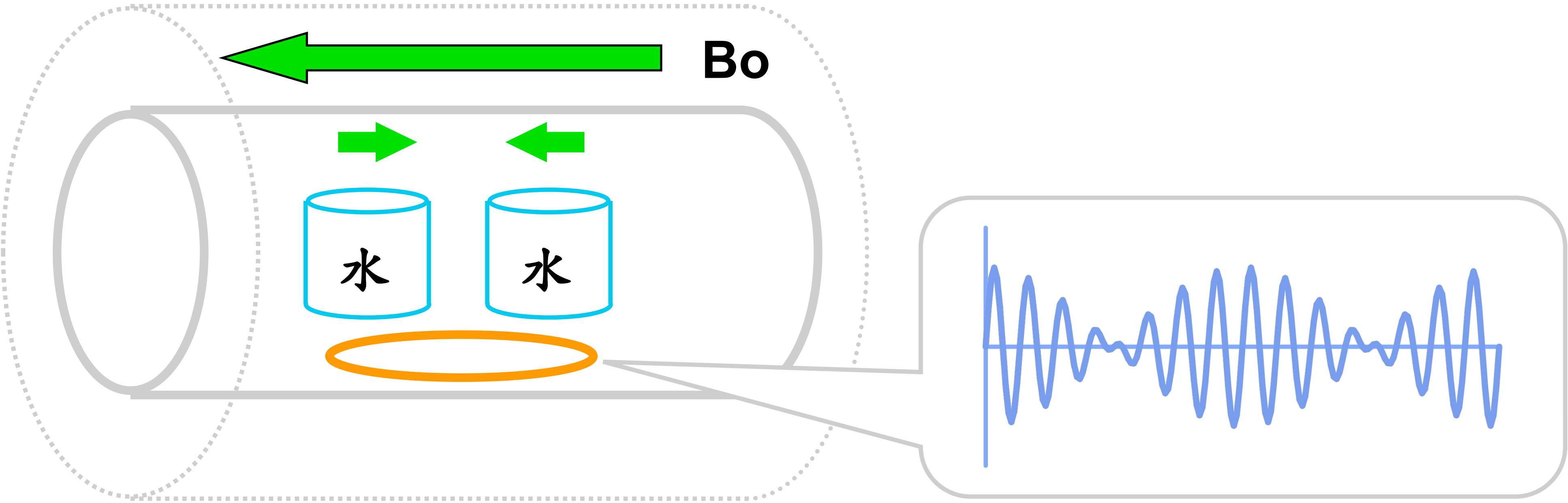
After excitation, you need to…

- Prepare for spatial encoding of signals

Spatial encoding of MR signals

- Frequency of MR signals = precession frequency
- The frequency changes as a function of position
- Information of position is encoded in frequency
- Concept of **frequency encoding**

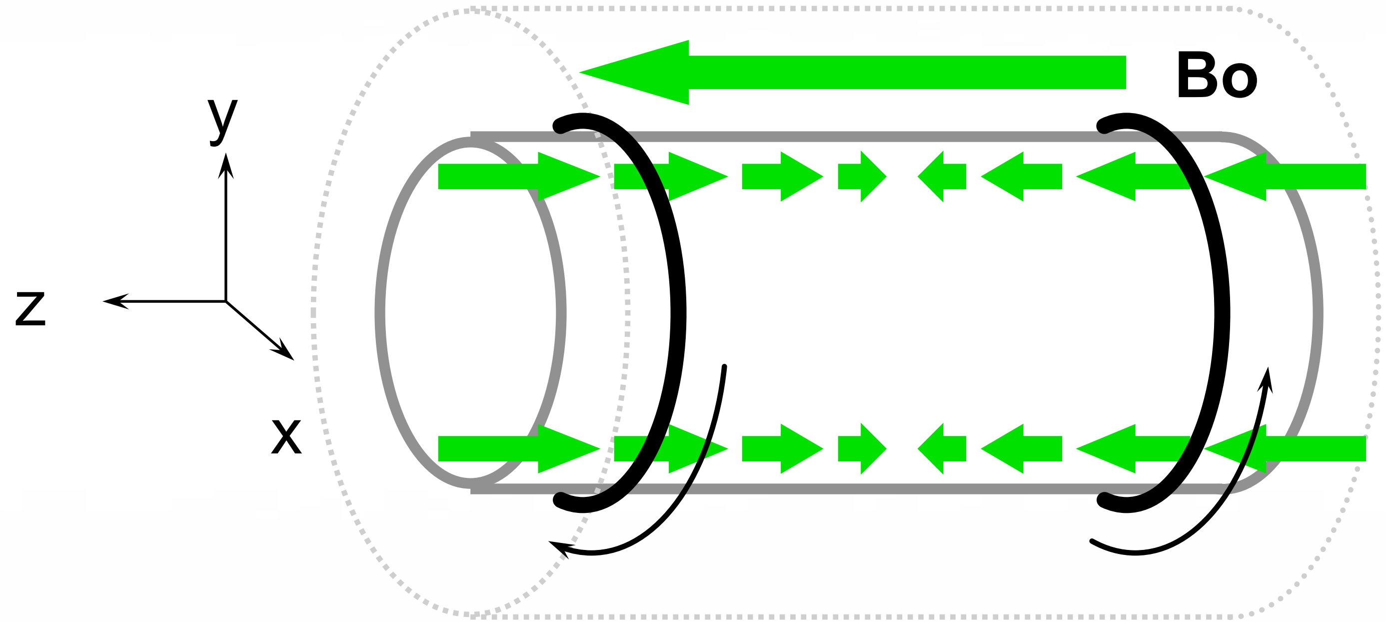
Spatial encoding of MR signals



How to calculate an image?

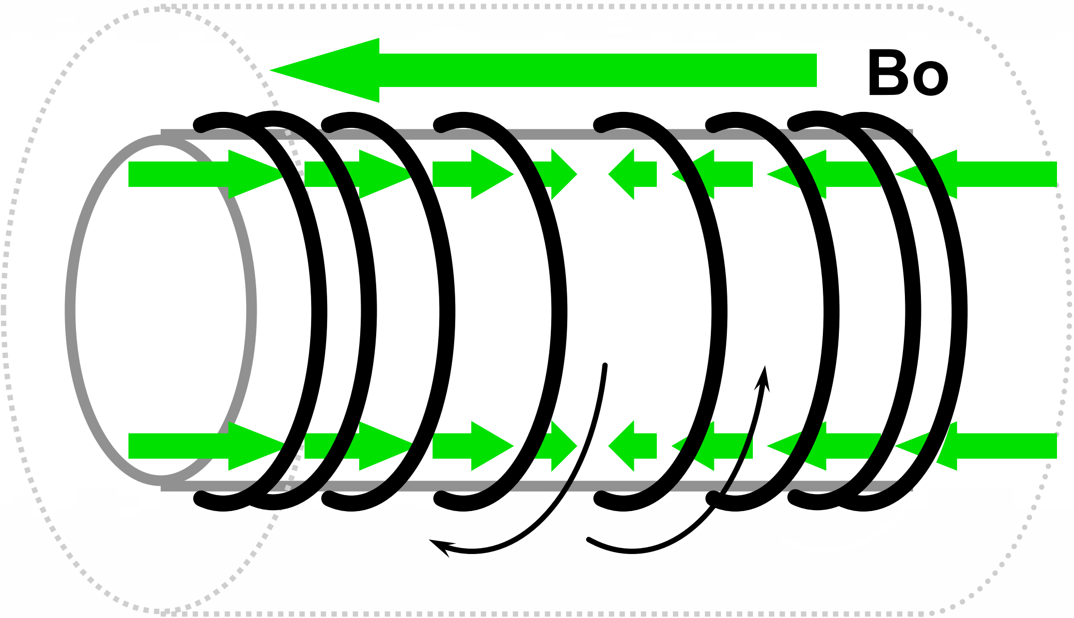
- Frequency = location
- Spectrum = distribution of signal = image
- Fourier transform

Z gradient



The magnitude of gradient field varies in z direction.

Linear z gradient field

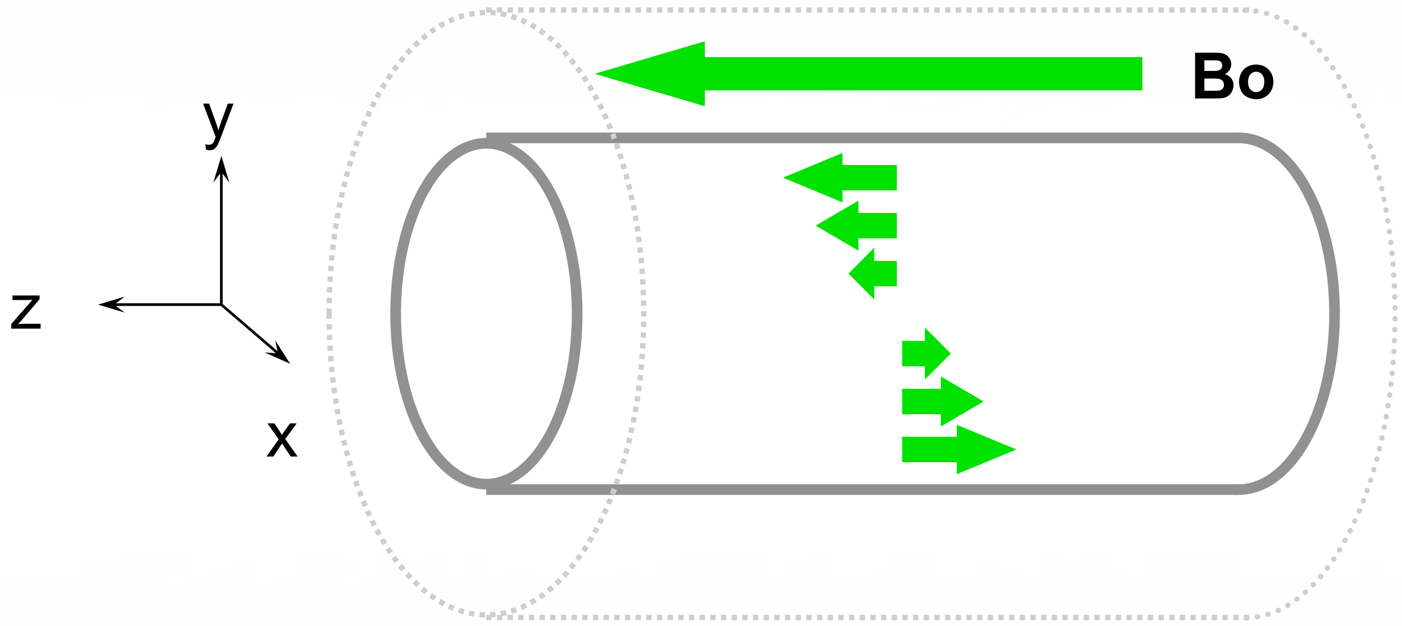


The magnitude of gradient field varies in z direction.

Direction of gradients

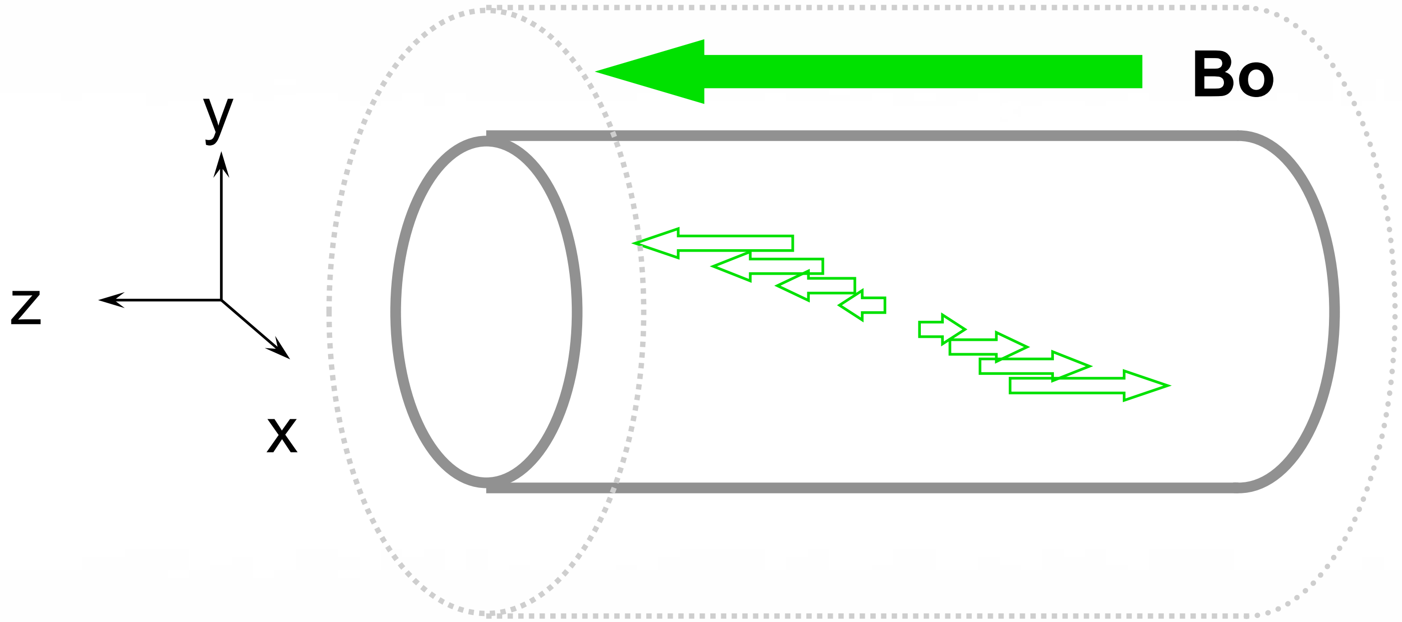
- The direction of magnetic field produced by a gradient coil is **always** along z direction
  - Parallel to B_0
- The magnitude of gradient field (z-component) varies linearly along certain direction.
  - For example, y gradient produces a field with its magnitude varying along y direction.

Y gradient



The magnitude of gradient field varies in y direction.

X gradient



The magnitude of gradient field varies in x direction.

Signal excitation and reception

- Both excitation and detection require spatially varying fields
  - Excitation: gradient along through-plane direction
  - Detection: gradients along in-plane direction
- Switch the gradients on and off precisely
- Pulse sequence