MRI practical course 2

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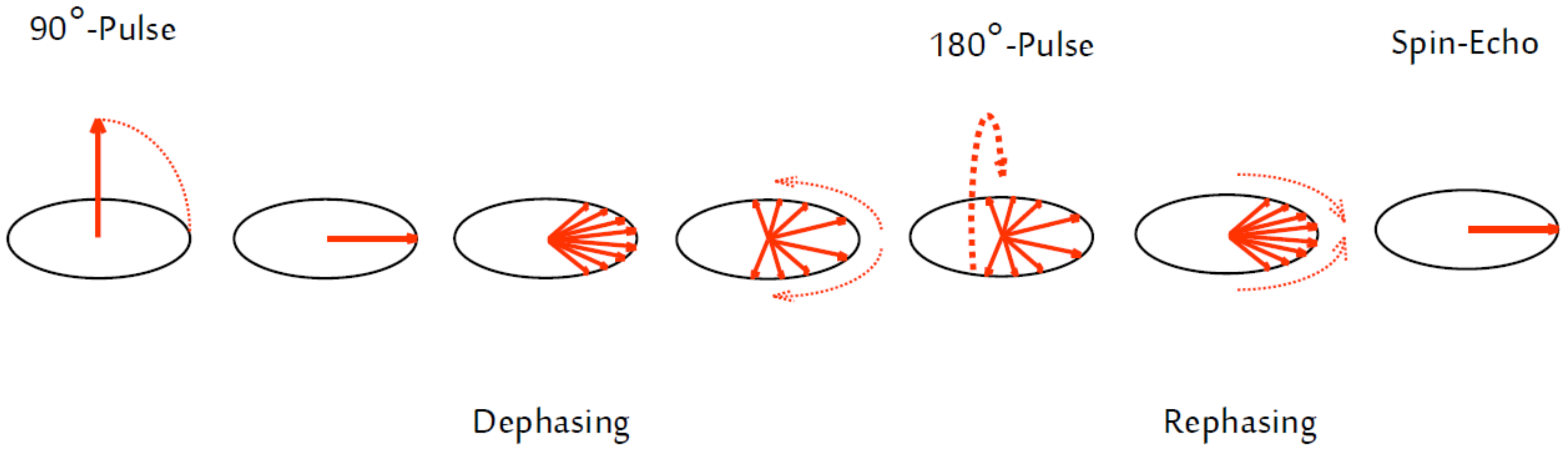
Question from last week

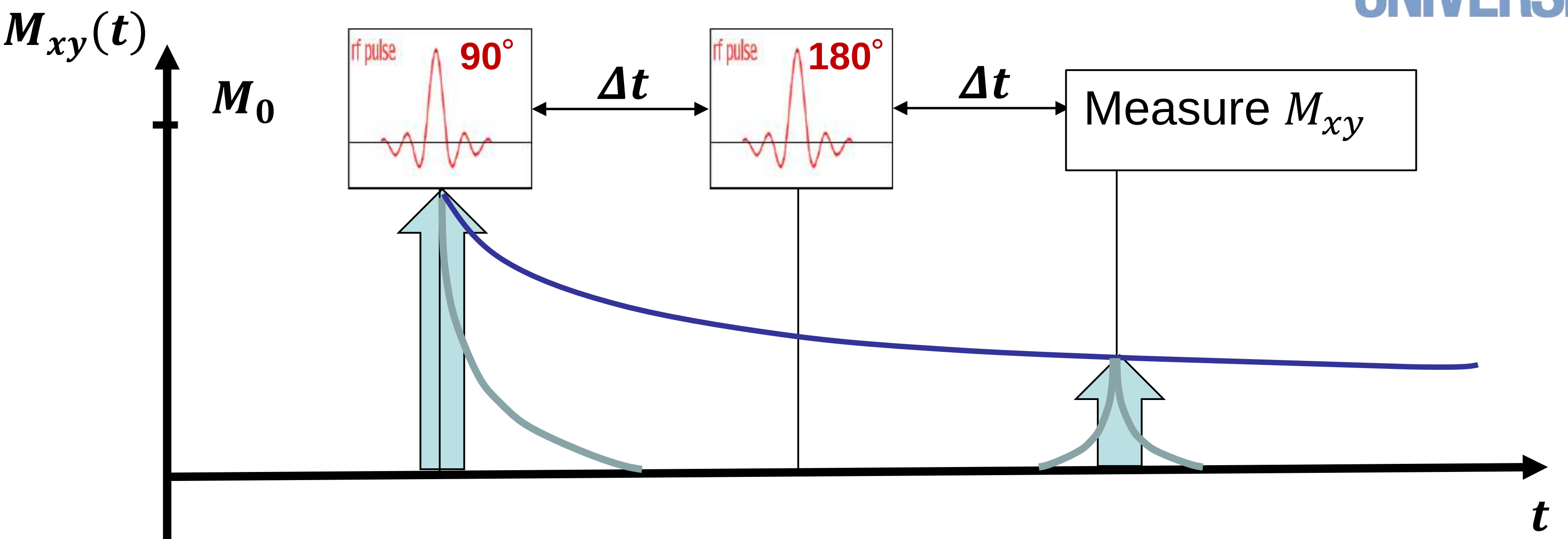
Refocusing signals

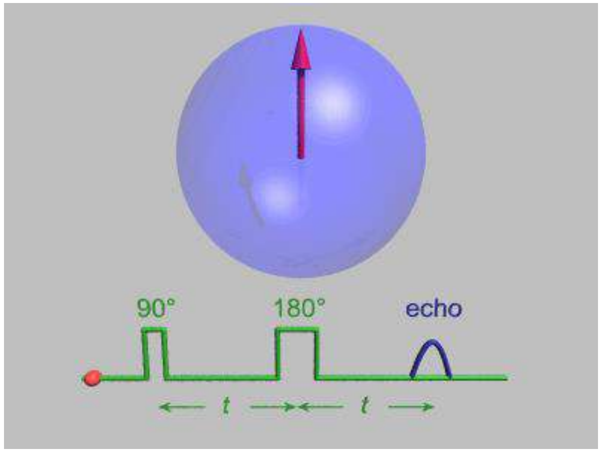
- 180° pulse can refocus M_{xy}, because B_0-inhomogeneities are time-independent



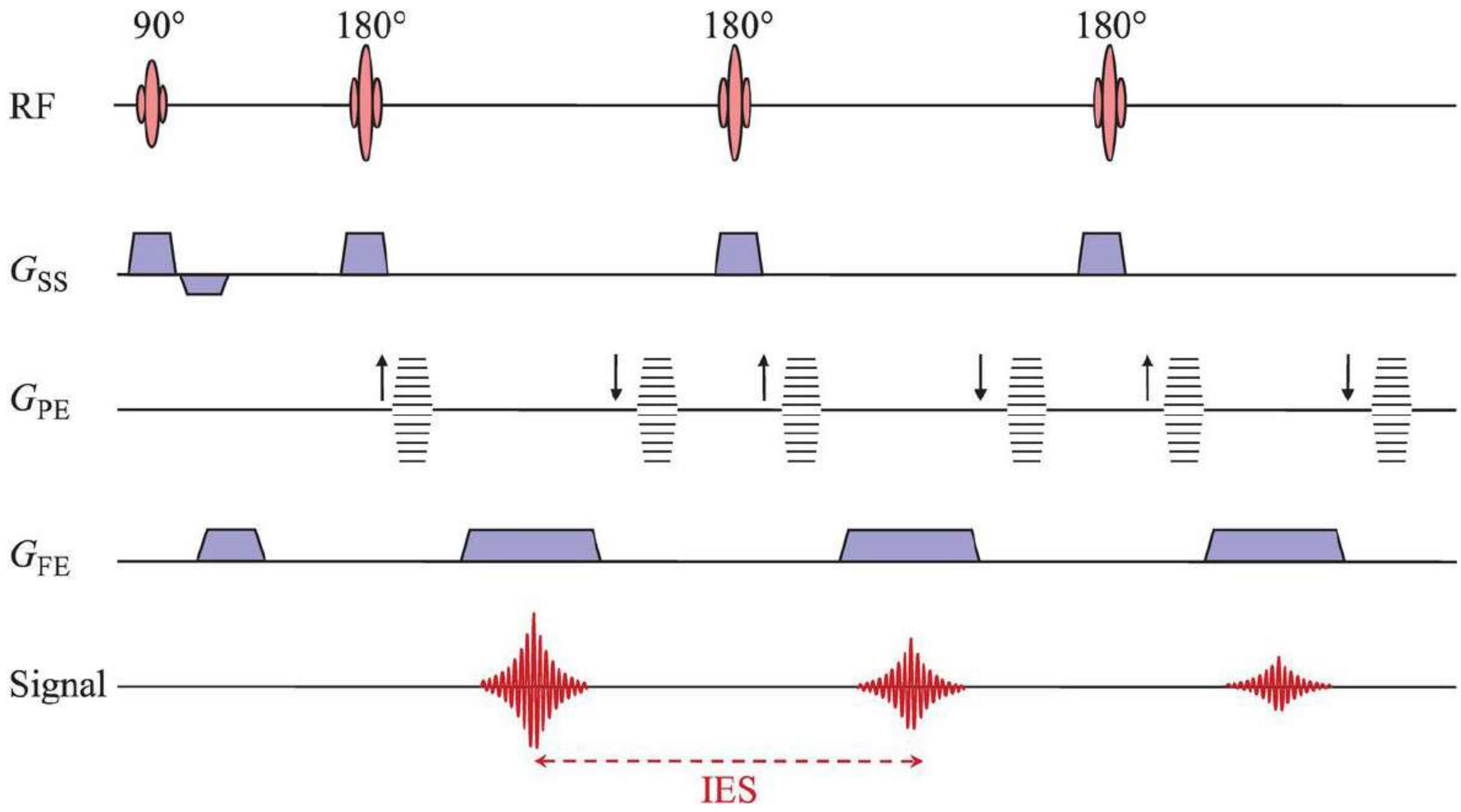
- Spin Echo used e.g. in SE, TSE, RARE (Bruker)

T2 sequence: spin echo





T2 sequence: spin echo

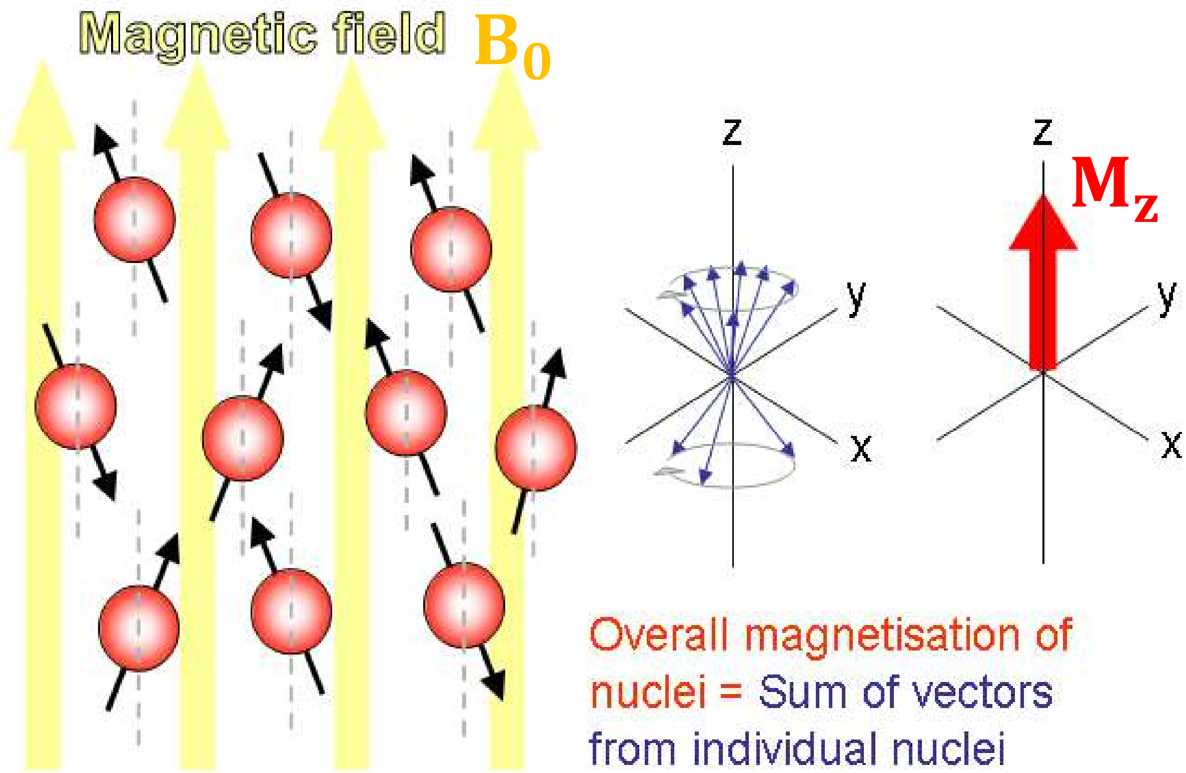


IES: Inter echo spacing

McRobbie, Donald W., et al. *MRI from Picture to Proton*. Cambridge university press, 2017.

Why do we need the B0-field?

- Nuclear magnetic moments

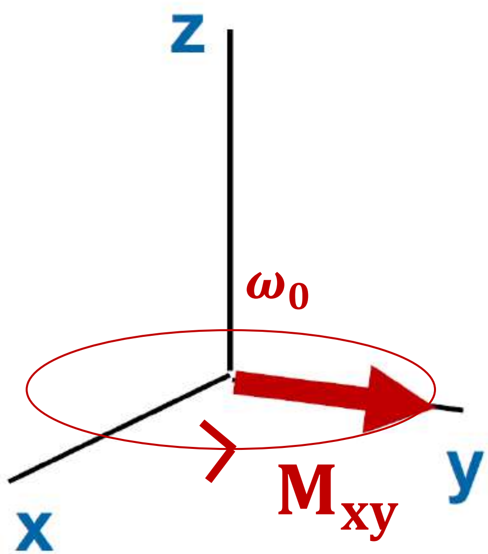


http://physiology-physics.blogspot.de/2010/06/understanding-basic-principles-of.html

Why do we need the B1-field?

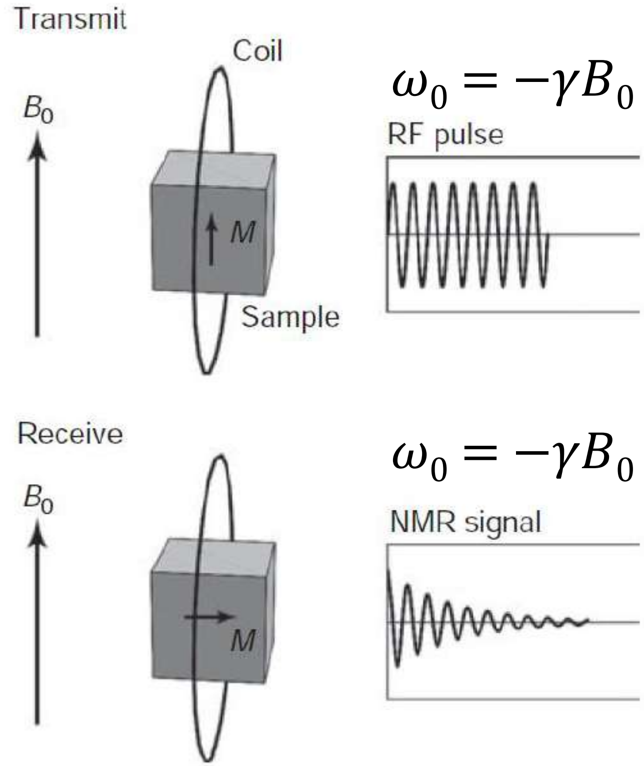
↳ *Synonym: RF field*

- Flip magnetization into xy-plane, alternating magnetic field → nuclear magnetic resonance (NMR) signal



$\omega_0 = \gamma B_0$ → RF field

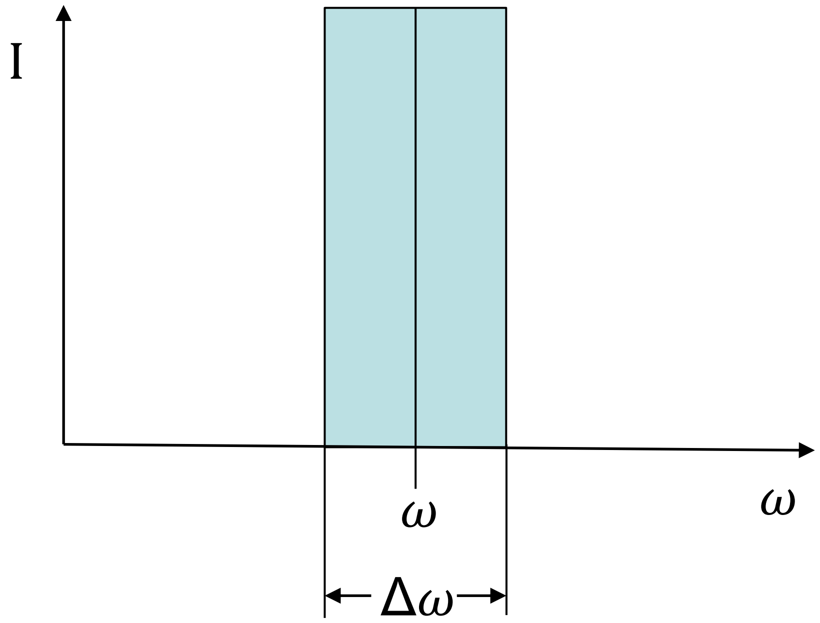
γ: gyromagnetic ratio



Buxton: Introduction to fMRI. Cambridge University Press, 2009

B1 field properties

- B1 field properties: center frequency and bandwidth
- Used to excite the magnetization = flip of the magnetization vector



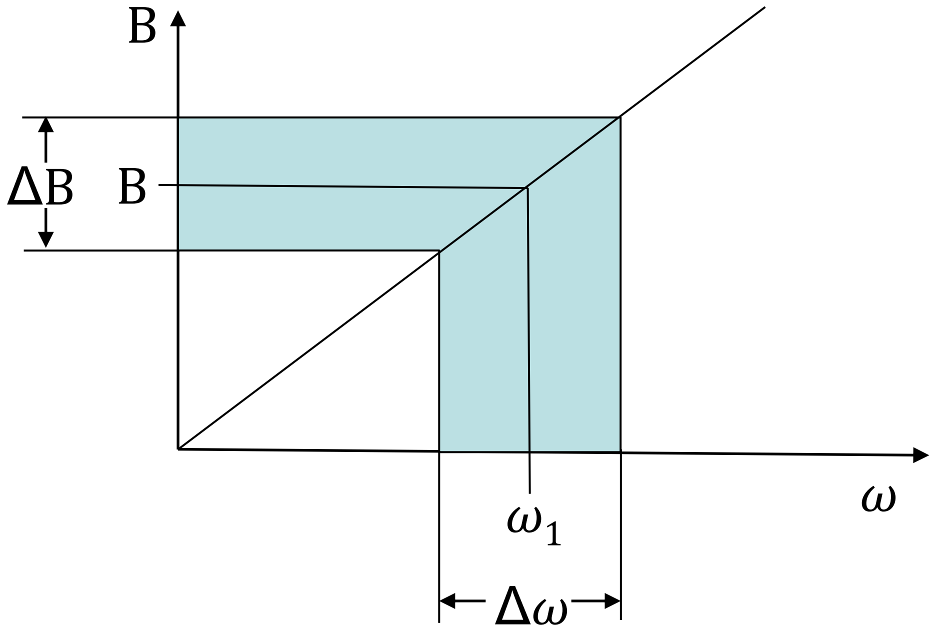
$$\omega = -\gamma B$$

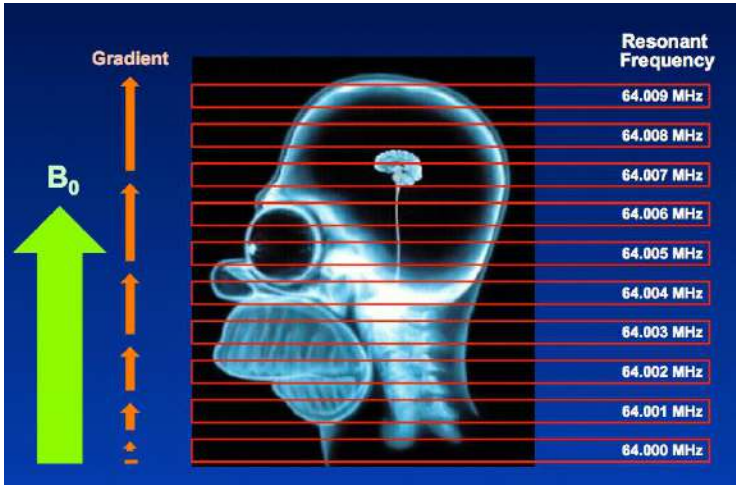
Excitation of the magnetization: Nuclear magnetic resonance

- B1 field with center frequency ω and bandwidth $\Delta\omega$ exites magnetization with field strength B $\pm\ \Delta B/2$

$$\omega = \gamma\ B$$

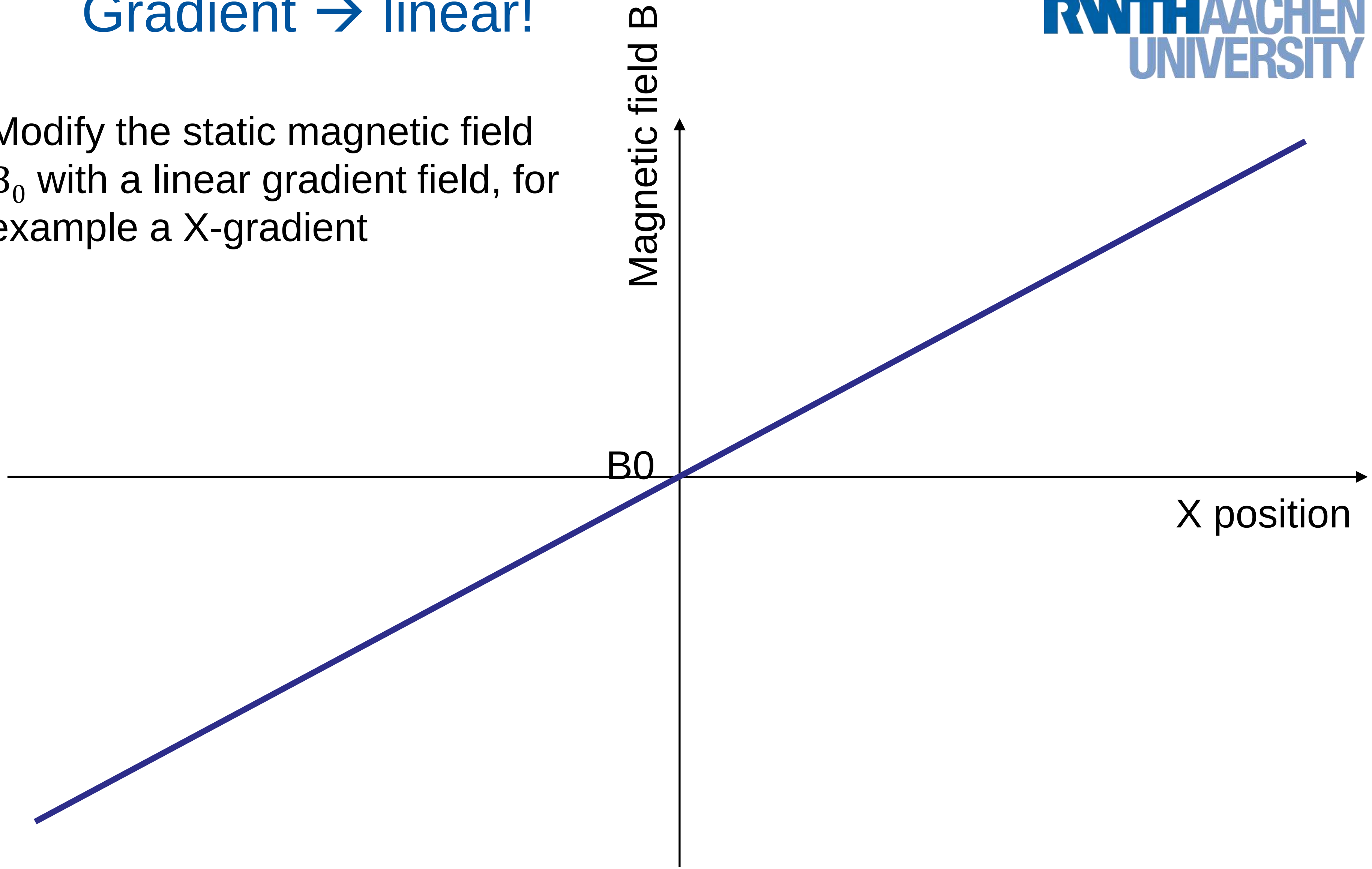
$$\Delta\omega = \gamma\ \Delta B$$





Gradient → linear!

Modify the static magnetic field B_0 with a linear gradient field, for example a X-gradient



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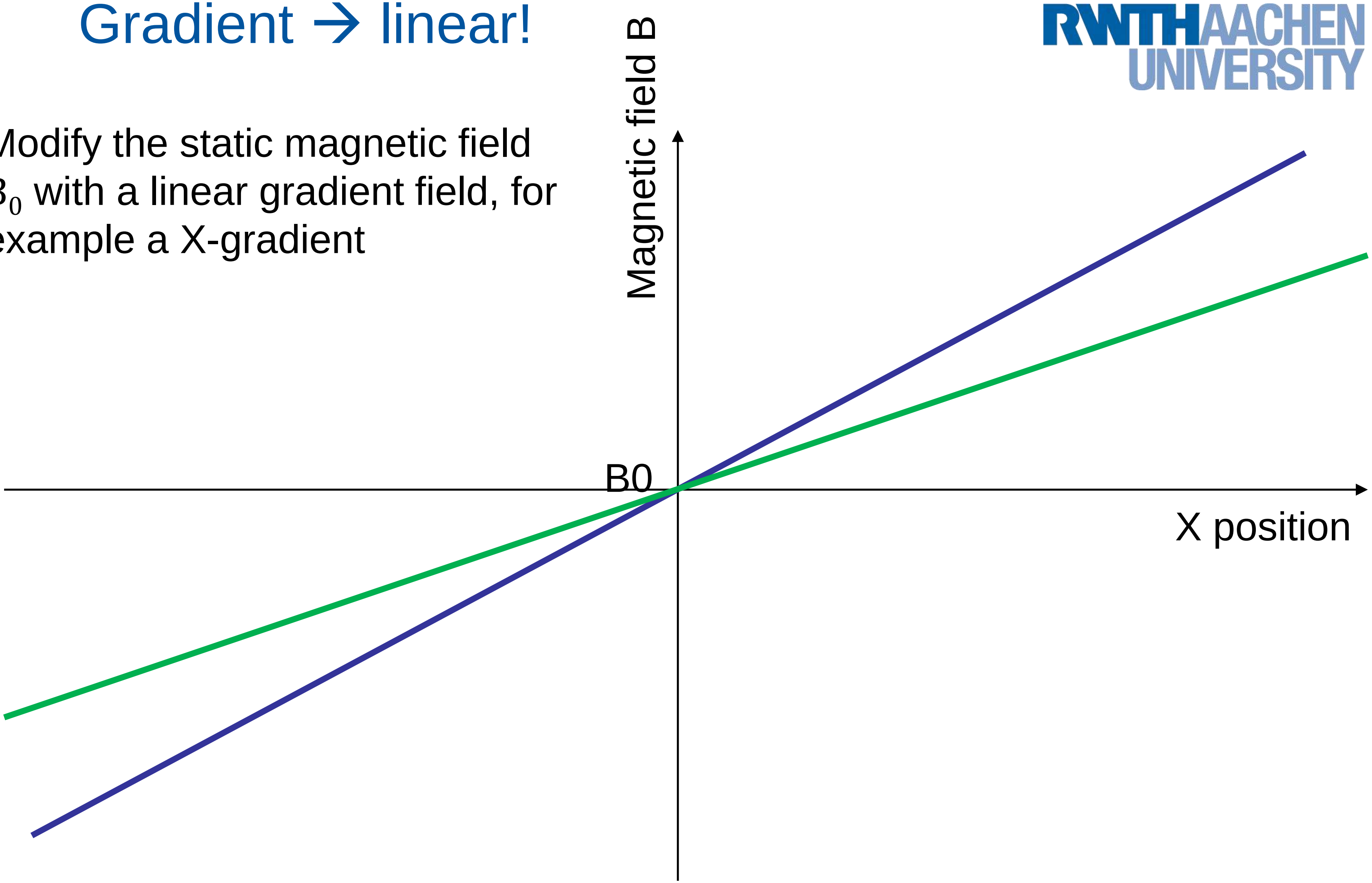
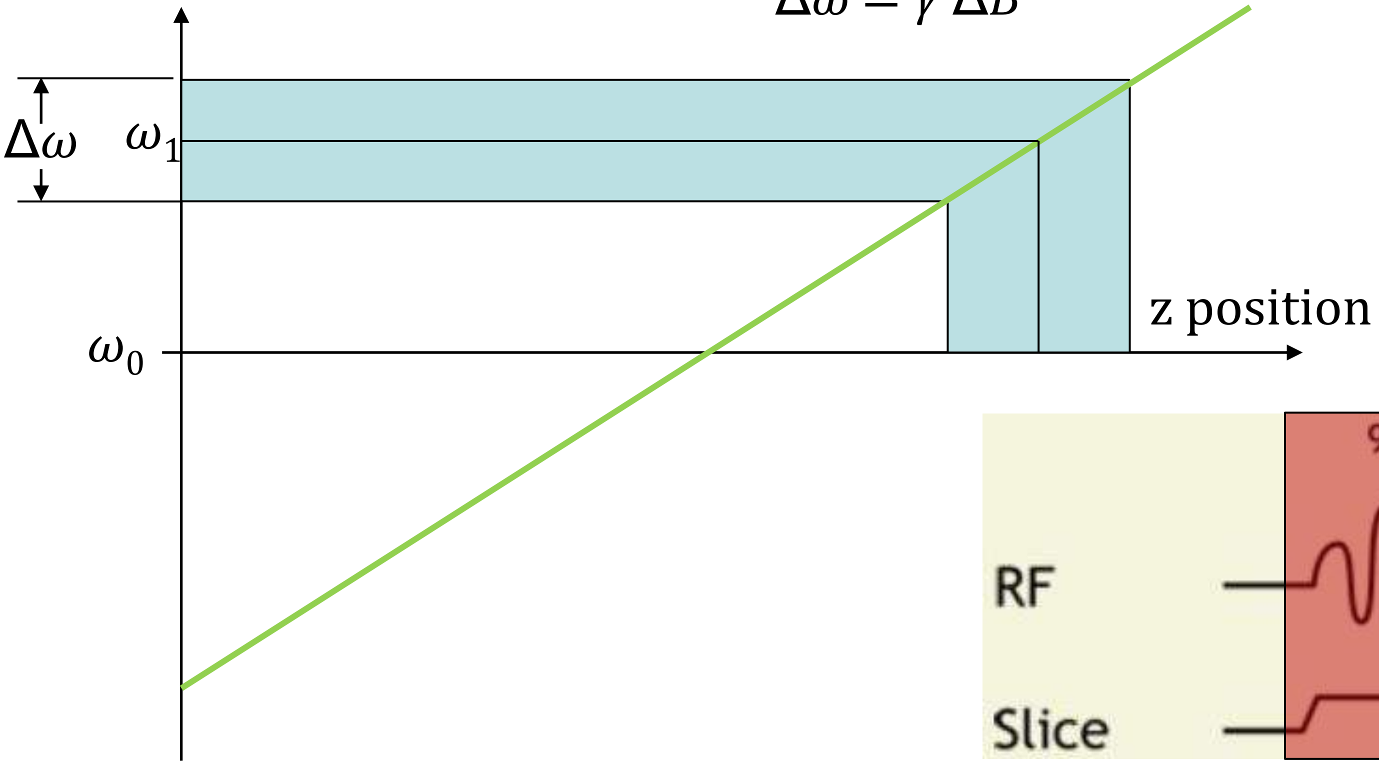


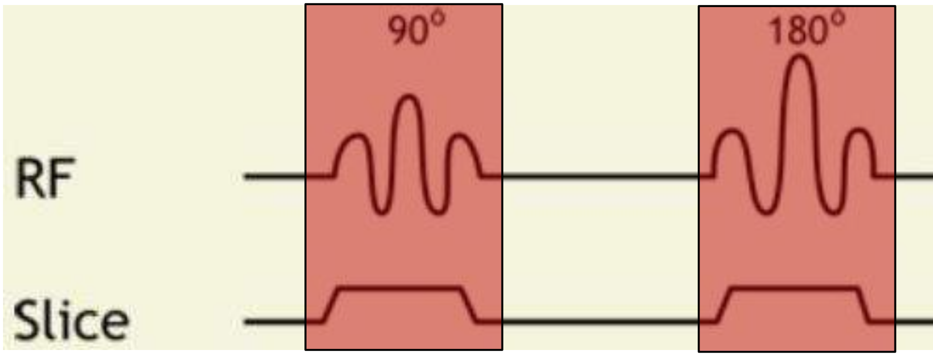
Gradient strength → slope of the line => blue > green

Slice selection gradient

- Apply B1 field and gradient at the same time
- Excite slice with $\omega = \gamma \, B$

$$\Delta\omega = \gamma \, \Delta B$$

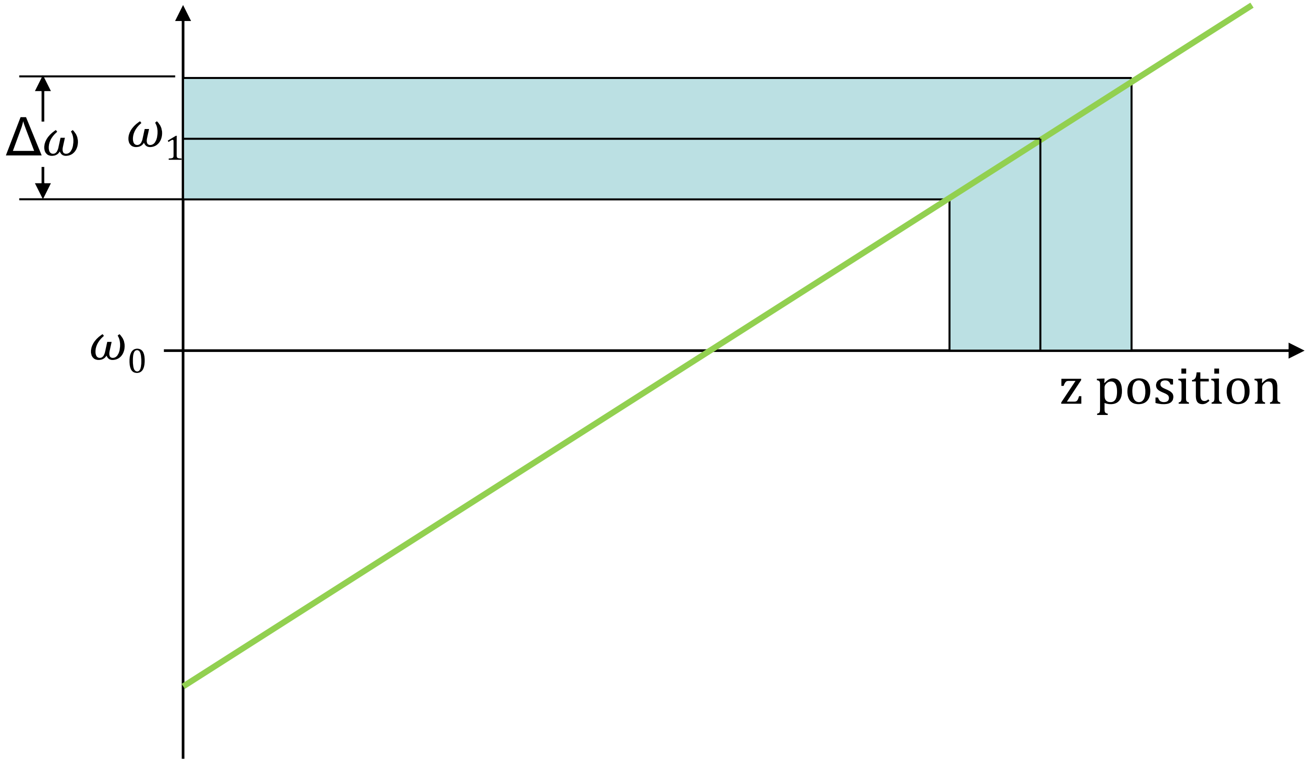




Exercise:
Slice excitation

Question

- How can we change the position of the slice?
- How can we change the thickness of the slice?
- How can we change the orientation of the slice?

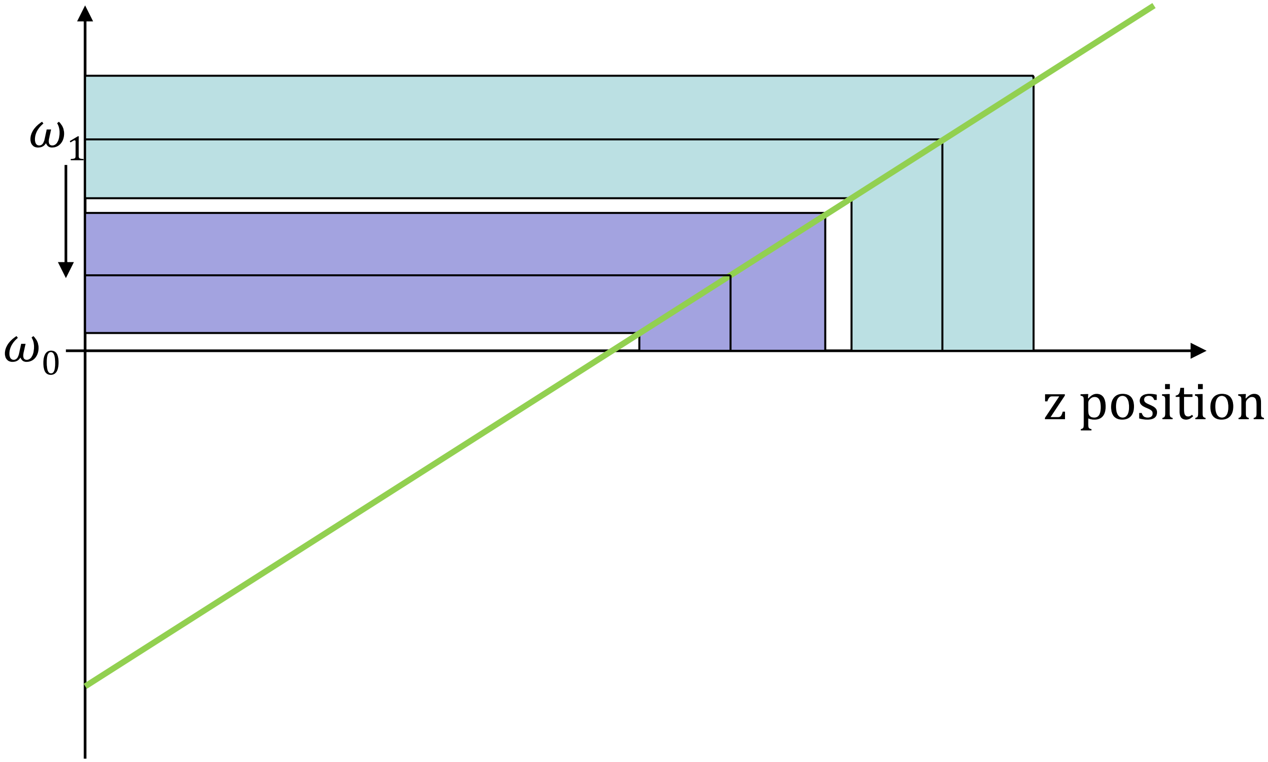


Results Exercise: Slice excitation

Change slice position
→ change ω_1

$$\omega = \gamma\ B$$

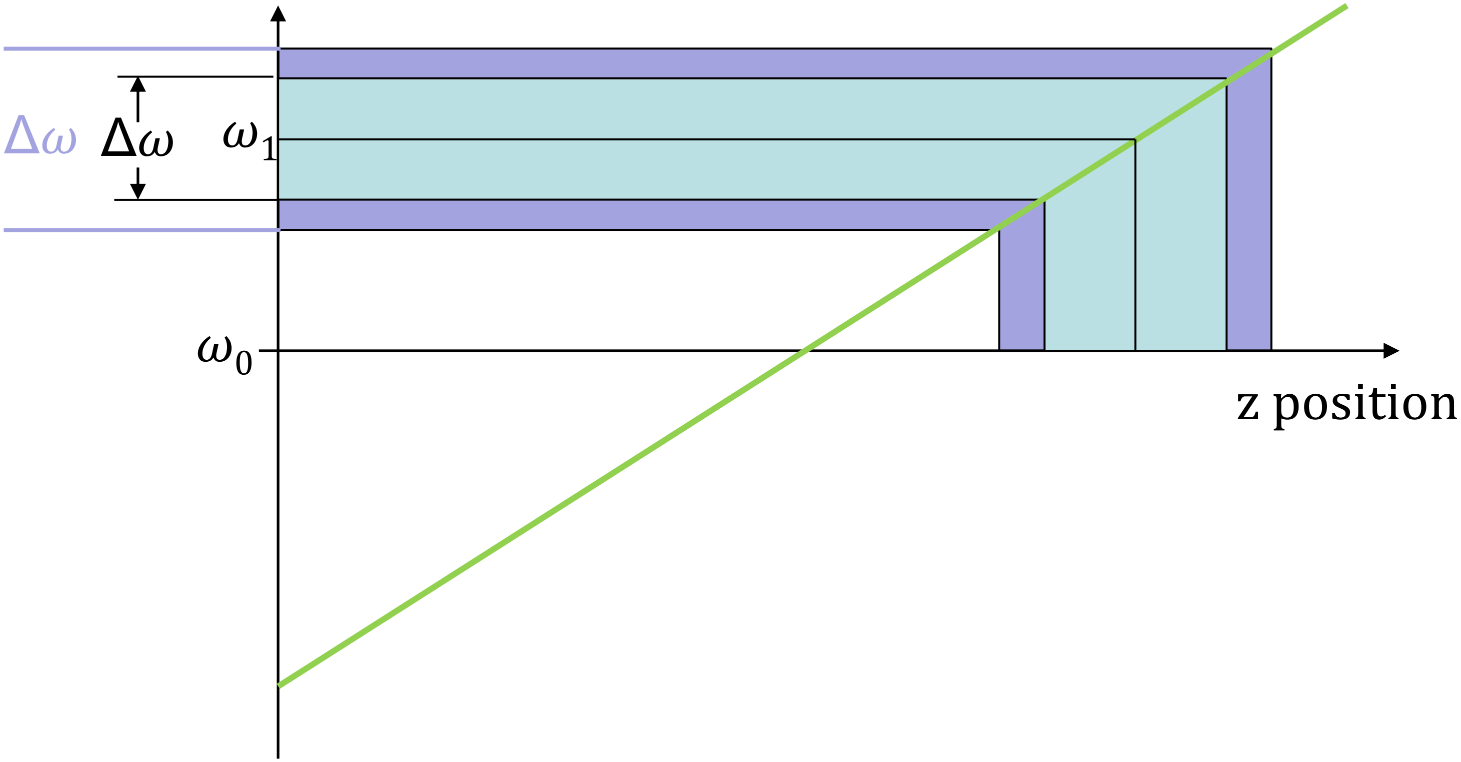
$$\Delta\omega = \gamma\ \Delta B$$



Change slice thickness
→ change $\Delta\omega$

$$\omega = \gamma\ B$$

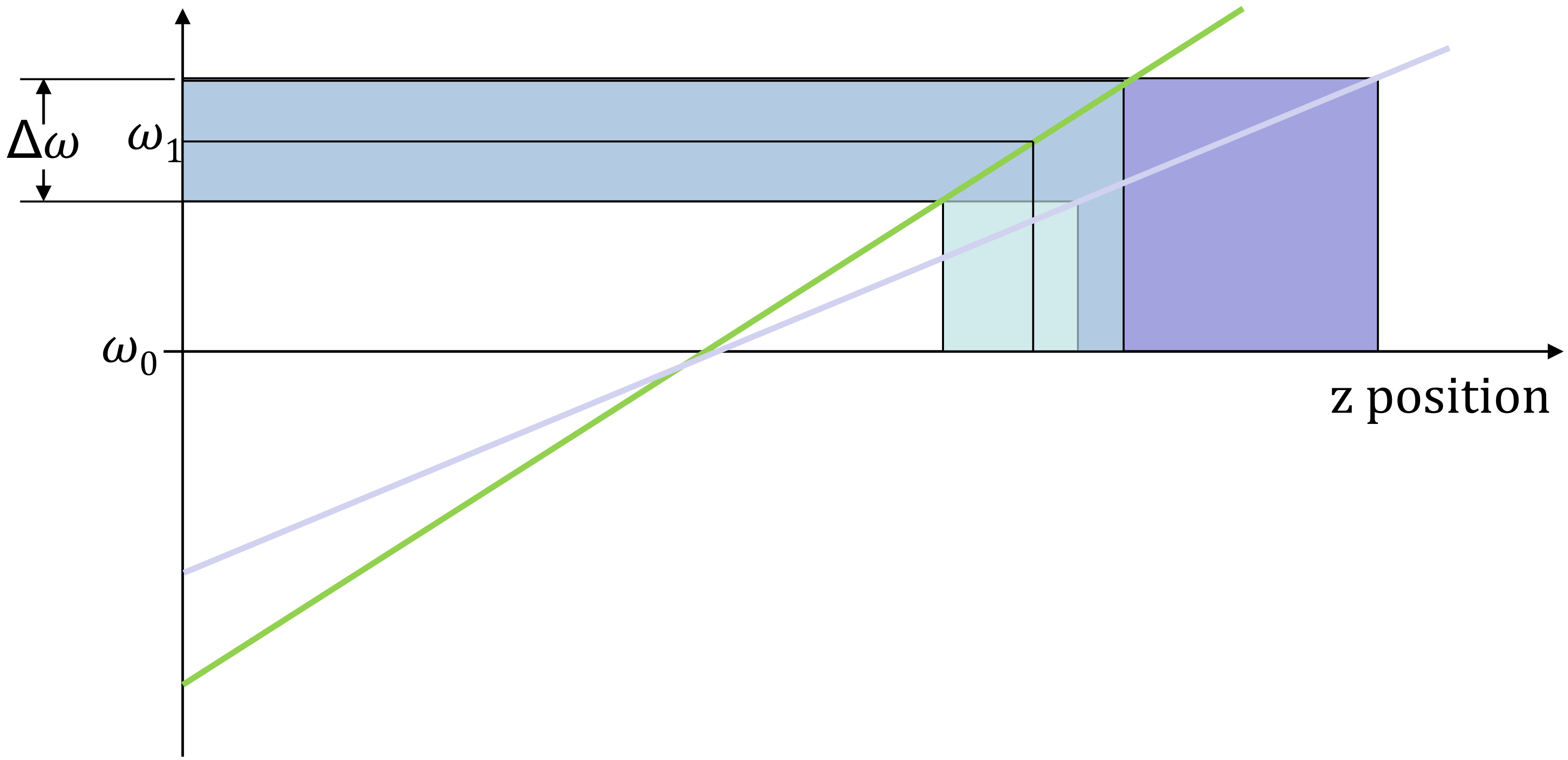
$$\Delta\omega = \gamma\ \Delta B$$



Change thickness and position → change gradient strength

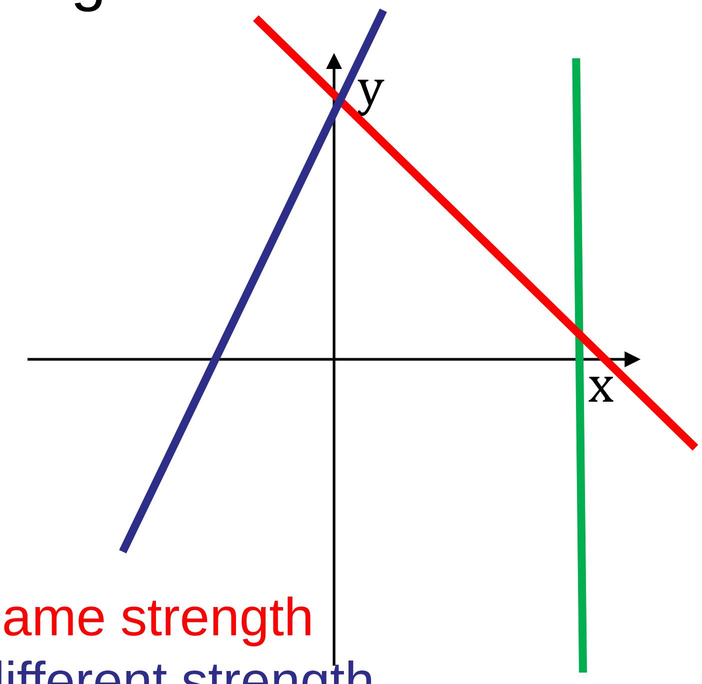
$$\omega = \gamma \, B$$

$$\Delta\omega = \gamma \, \Delta B$$



Change slice orientation → change gradient orientation

- Apply x-, y- and z-gradient → excite slice perpendicular to x-, y- and z-gradient
- Or apply for example x- and y-gradient with different strength:



Only X-gradient
X- and Y-gradient with same strength
X- and Y-gradient with different strength

Exercise:
Slice excitation → calculations

Question

$$\omega = \gamma \, B \qquad \omega = 2\pi \mathrm{f}$$

$$\Delta\omega = \gamma \, \Delta B \qquad \frac{\gamma}{2\pi} = 42.6 \, \frac{\mathrm{MHz}}{T}$$

1) Calculate the Larmor frequency of hydrogen a 3T.
2) We apply a slice selection gradient of 30 mT/m in z direction.
    1) How thick is the slice excited by an RF pulse with a bandwidth of 20 kHz at the Larmor frequency?
    2) How do we need to change the center frequency of the RF pulse to shift the slice by 10 cm?

Question

$$\omega = \gamma\, B \qquad \omega = 2\pi \mathrm{f}$$

$$\Delta\omega = \gamma\, \Delta B \qquad \frac{\gamma}{2\pi} = 42.6\, \frac{\mathrm{MHz}}{T}$$

1) Calculate the Larmor frequency of hydrogen a 3T.

$$\mathrm{f} = \frac{\omega}{2\pi} = \frac{\gamma}{2\pi} B = 42.6 \frac{\mathrm{MHz}}{T} * 3\, T = 127.8\, MHz$$

2) We apply a slice selection gradient of 30 mT/m in z direction.
   1) How thick is the slice excited by an RF pulse with a bandwidth of 20 kHz at the Larmor frequency?

$$\Delta\mathrm{f} = \frac{\gamma}{2\pi} \Delta B \Rightarrow \Delta B = \frac{\Delta\mathrm{f}}{\frac{\gamma}{2\pi}} \qquad \text{Thickness } s = \frac{\Delta_B}{G} = \frac{\Delta\mathrm{f}}{\frac{\gamma}{2\pi} G} = 15.6\, mm$$

   2) How do we need to change the center frequency of the RF pulse to shift the slice by p = 10 cm?

$$\Delta B = p\, *\, G \qquad \Delta\mathrm{f} = \frac{\gamma}{2\pi} \Delta B = \frac{\gamma}{2\pi} * p\, *\, G = 127.8\, kHz$$

Frequency and Phase Encoding

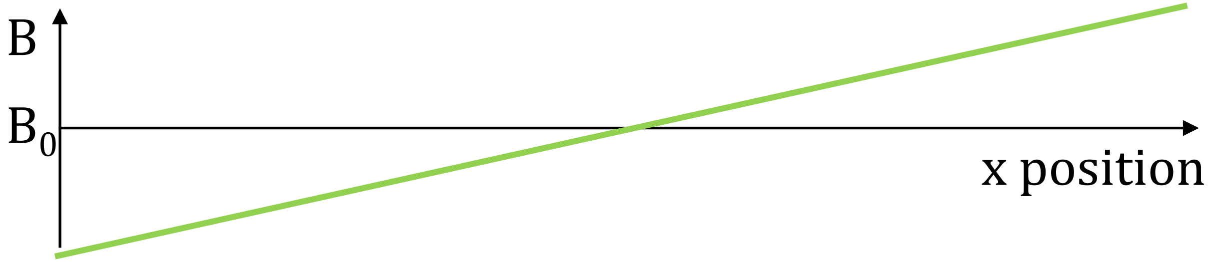
Spatial encoding within 2D slice

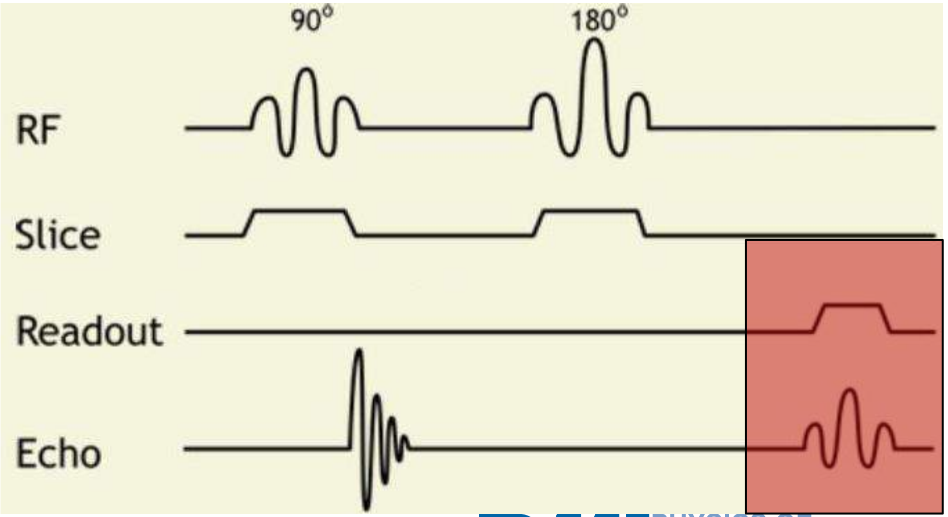
- Data is acquired in the k-space: $\vec{k}(t) = \gamma \int \vec{G}(t)dt$
- k-space: frequency space
- Fourier Transform (FT): frequency space → image space
- Inverse FT: image space → frequency space
- 2 types of moving in the k-space and acquiring data:
  - Frequency encoding
  - Phase encoding

Frequency encoding gradient

Synonym: readout gradient

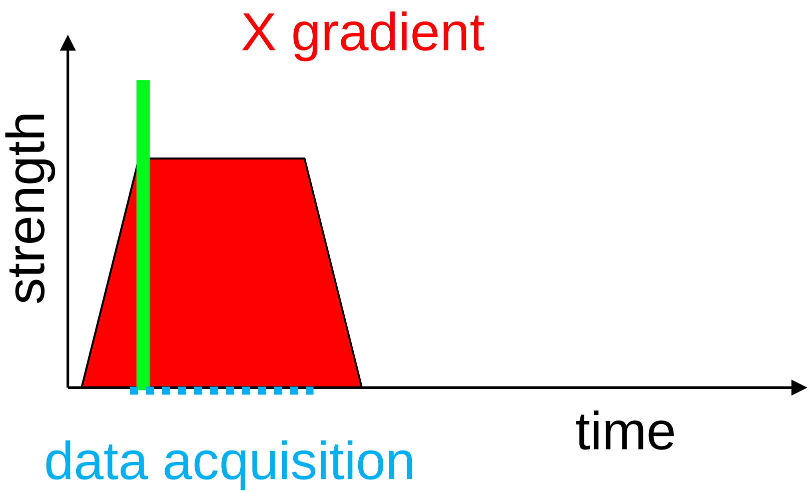
- Apply gradient during readout (signal aquisition)
  → magnetic field depends on the position (here x)
  → NMR signal depends on the position $\omega = -\gamma\, B$

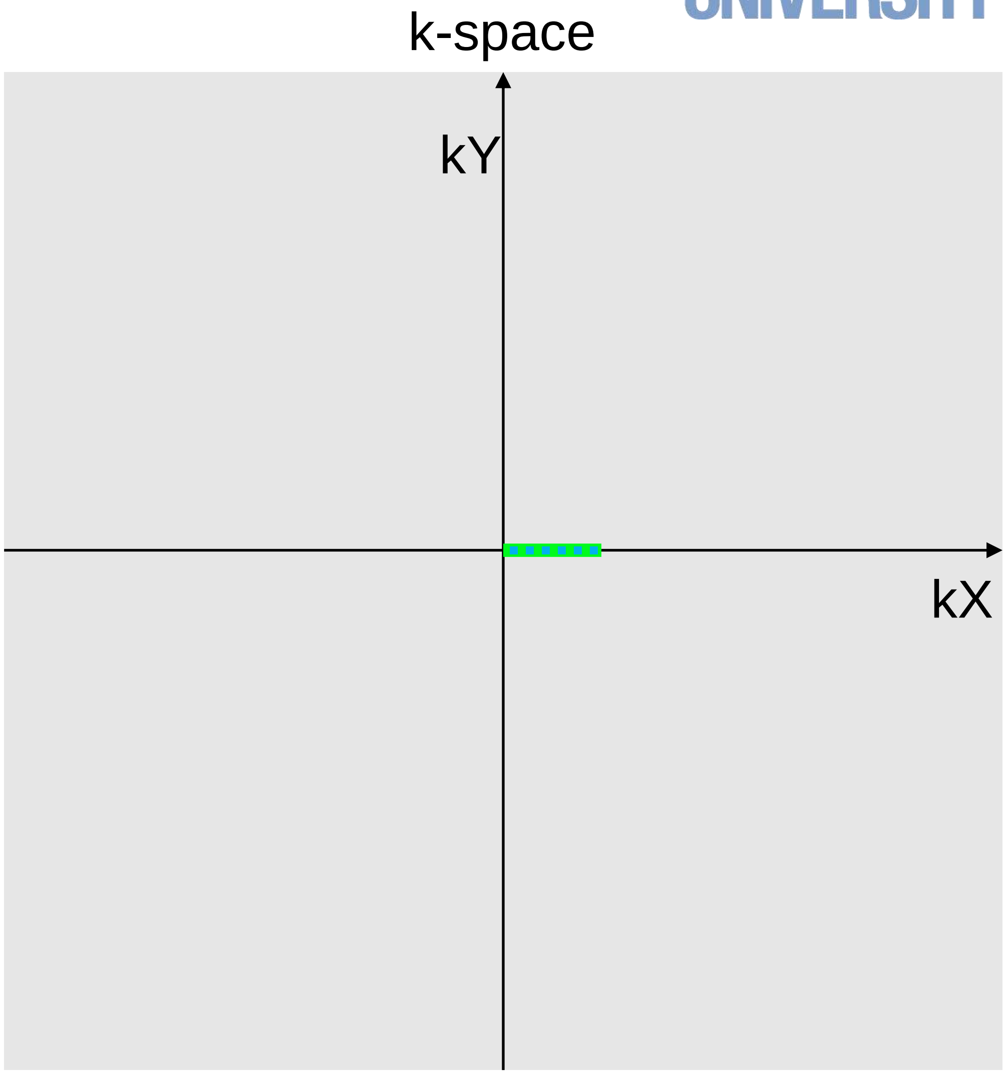




Frequency encoding

$$\vec{k}(t) = \gamma \int \vec{G}(t)dt$$





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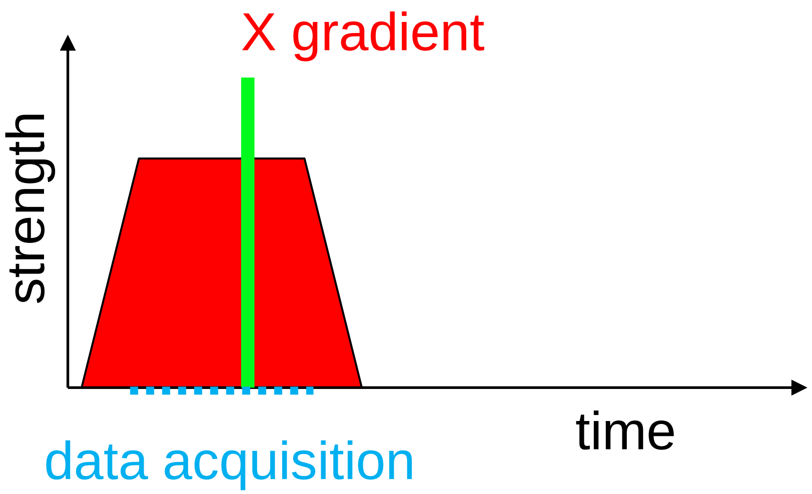

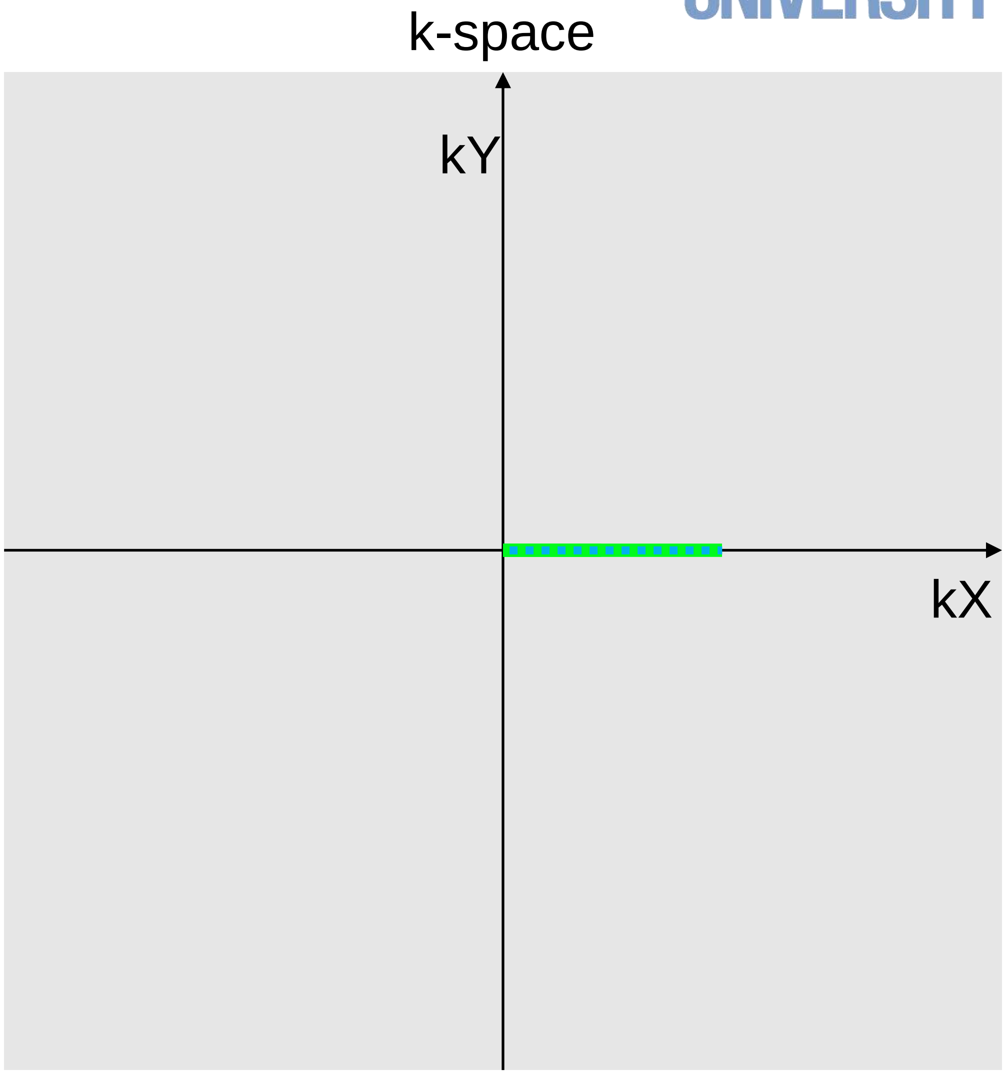

Frequency encoding

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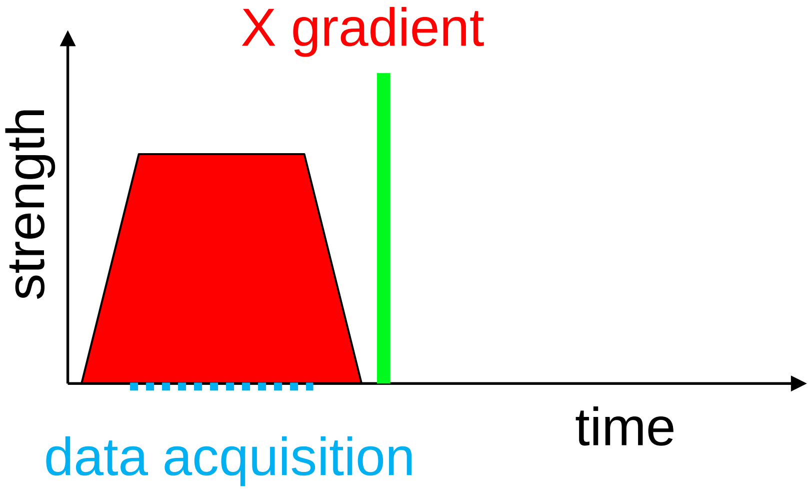
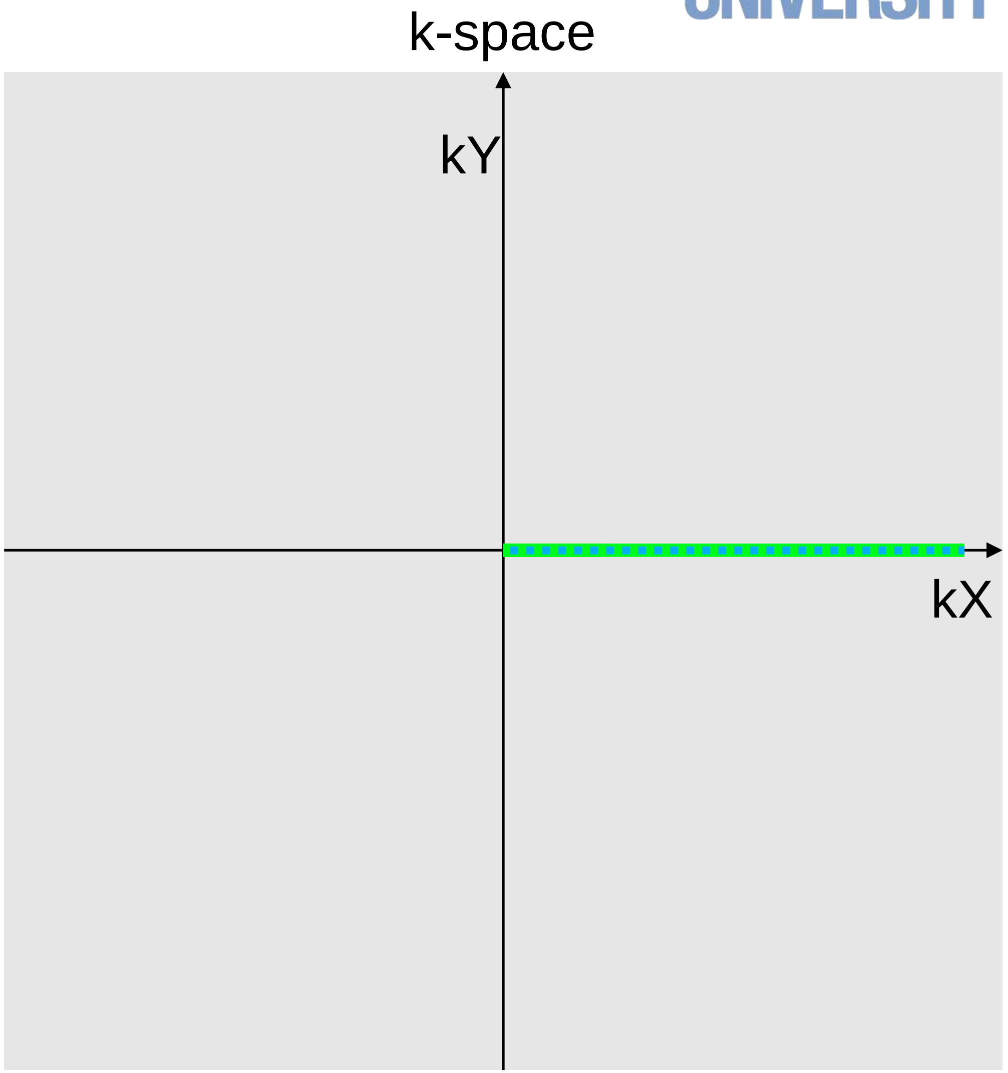
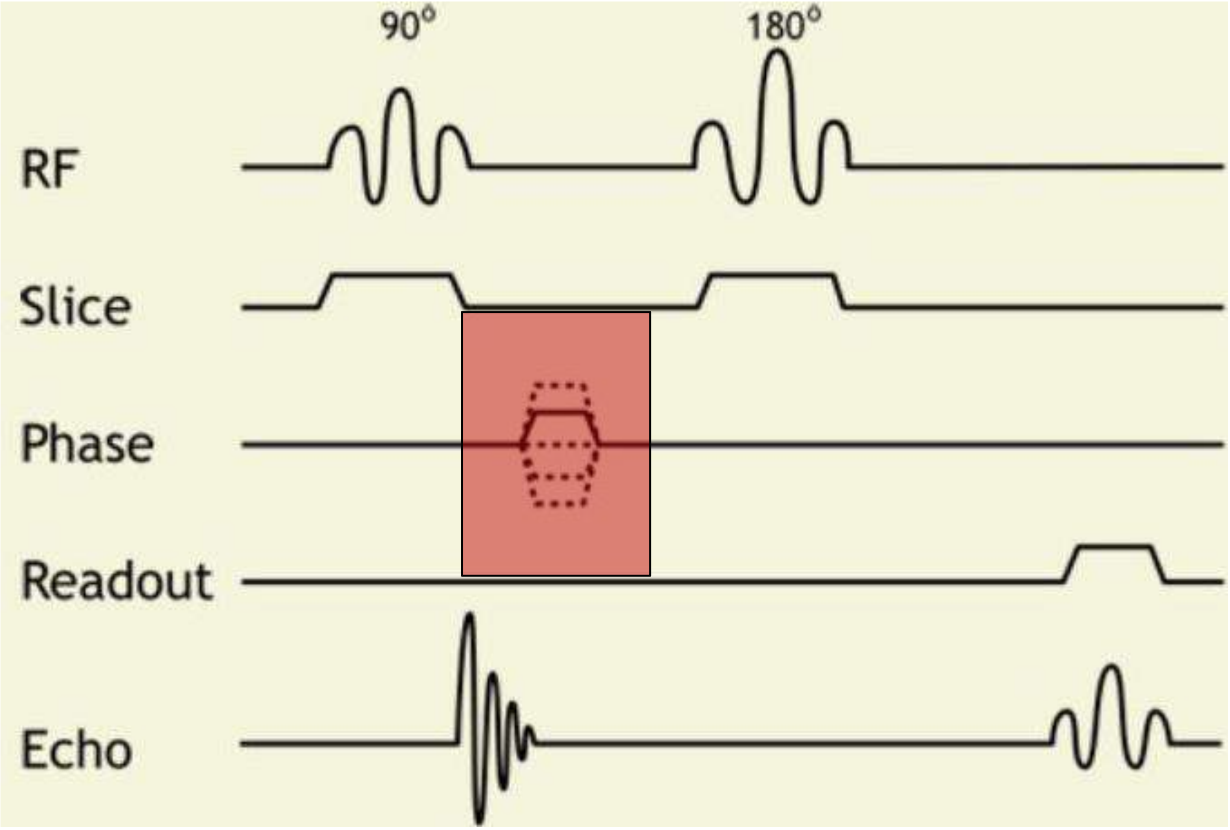




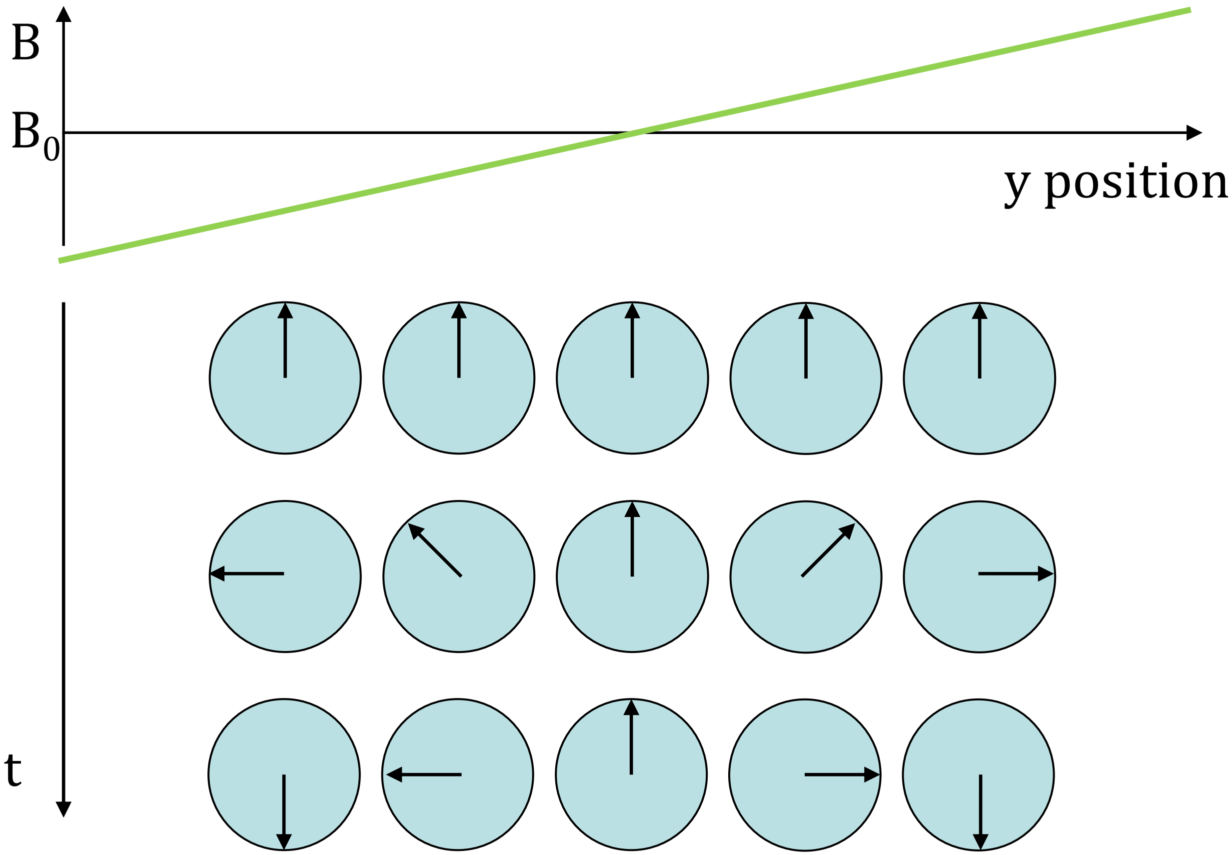
Phase encoding gradient

- Apply gradient before acquisition



Phase encoding

- Apply gradient before acquisition → change phase of the spins



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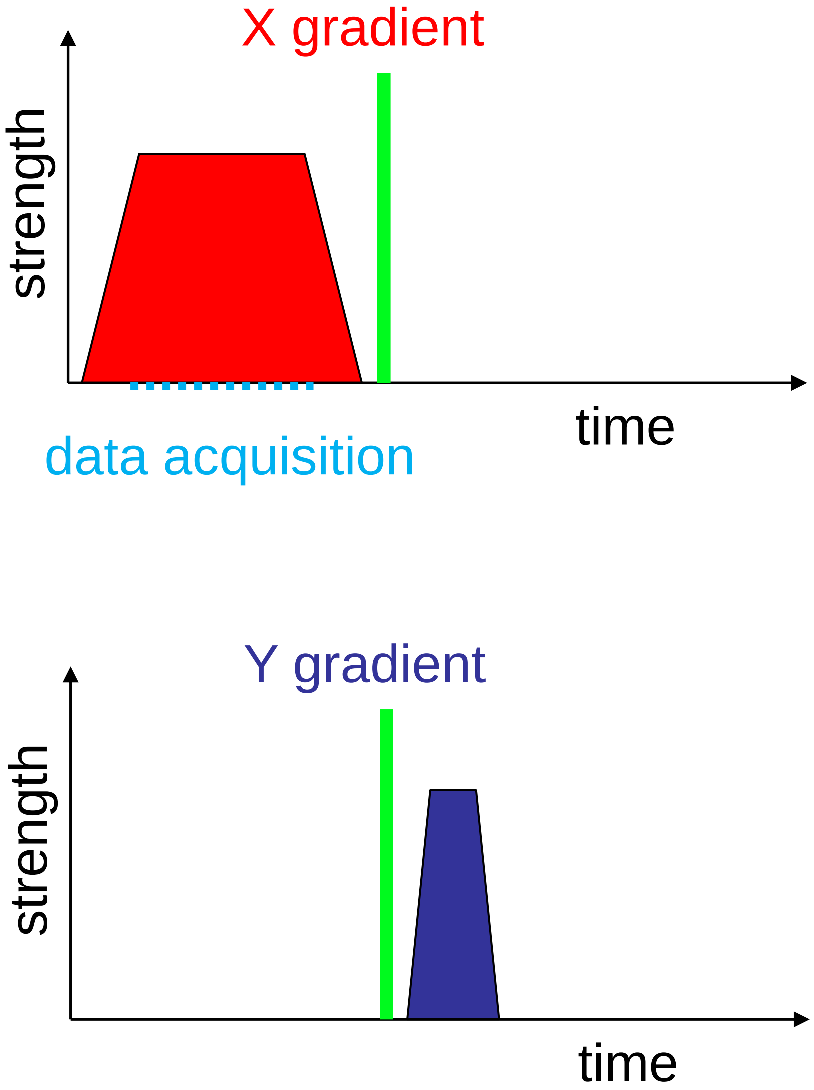
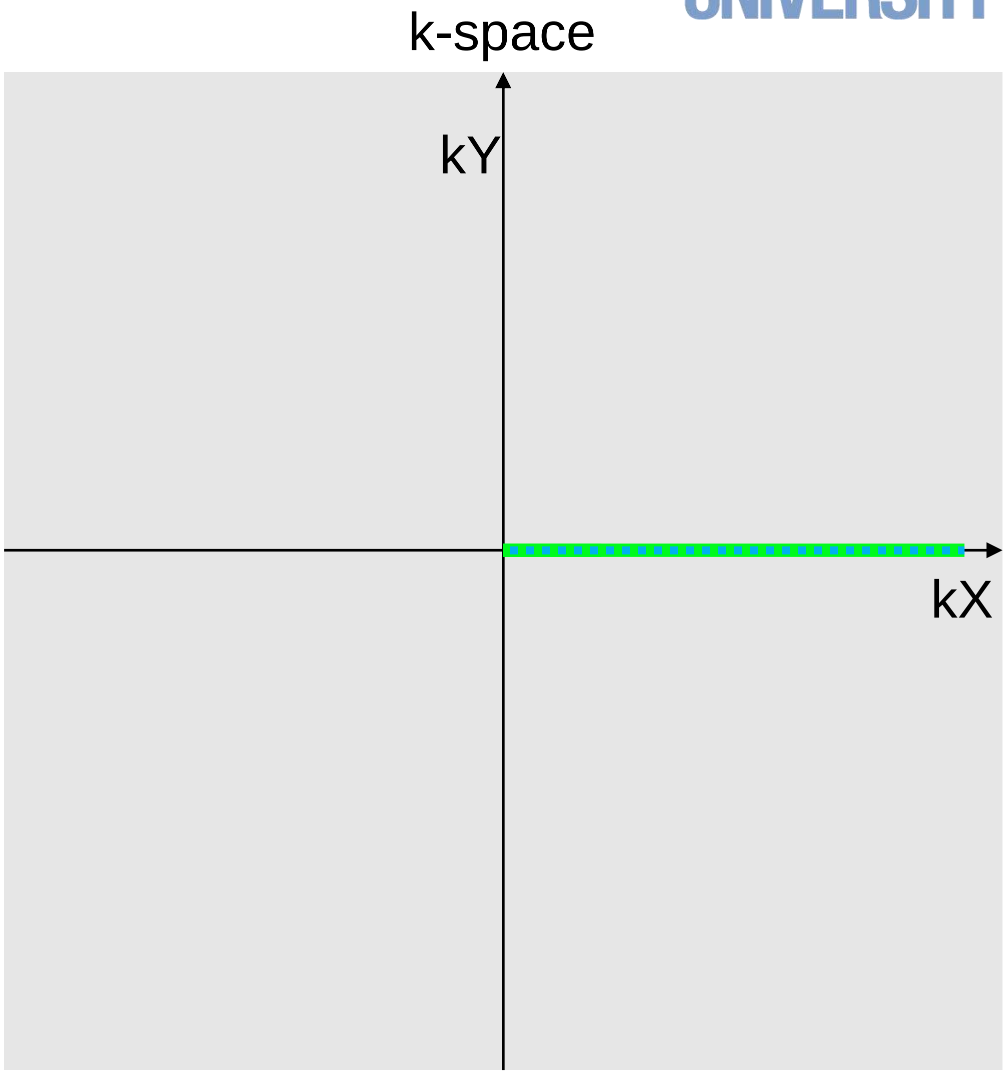
Phase encoding

$$\vec{k}(t) = \gamma \int \vec{G}(t)dt$$





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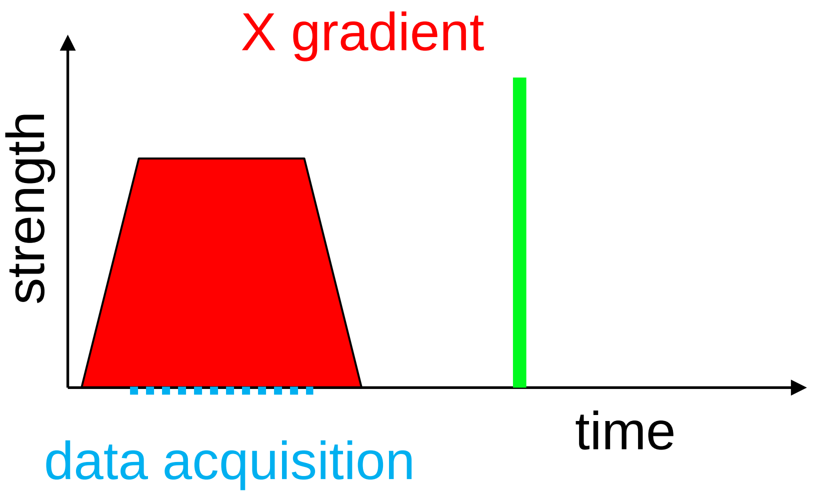

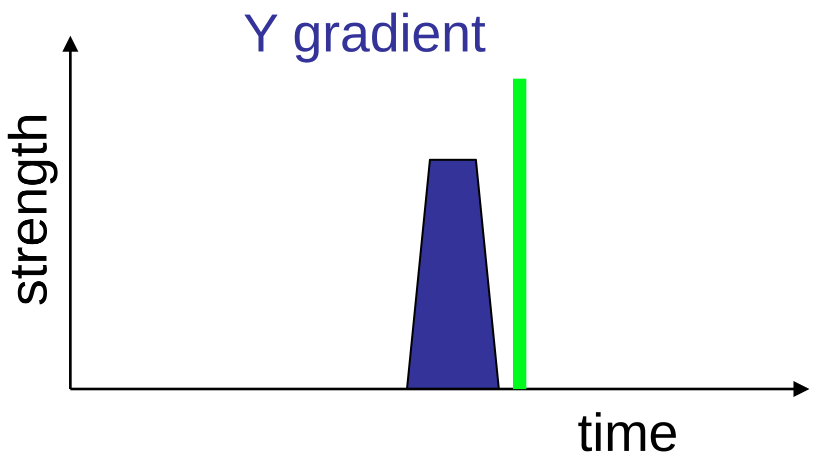

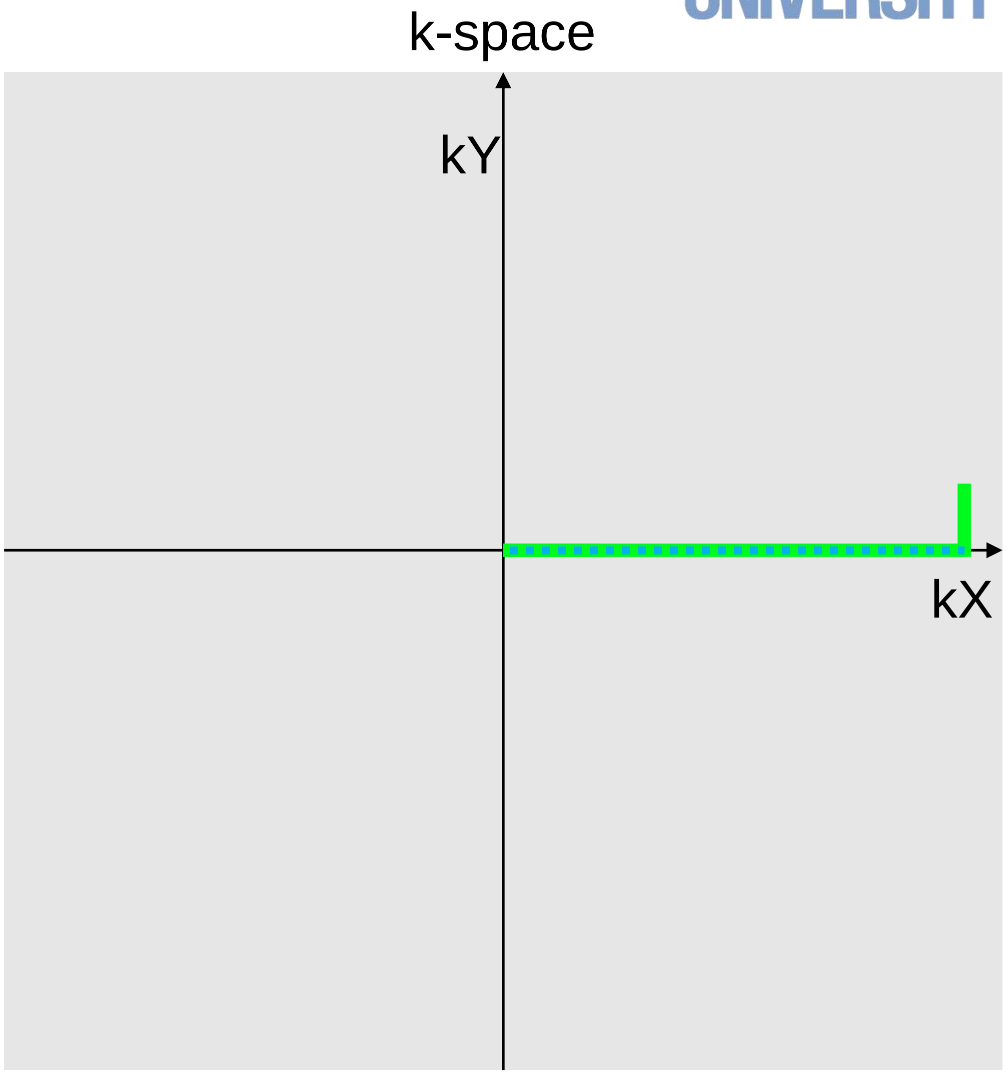

PHYSICS OF MOLECULAR IMAGING SYSTEMS

Frequency encoding

$$\vec{k}(t) = \gamma \int \vec{G}(t)dt$$

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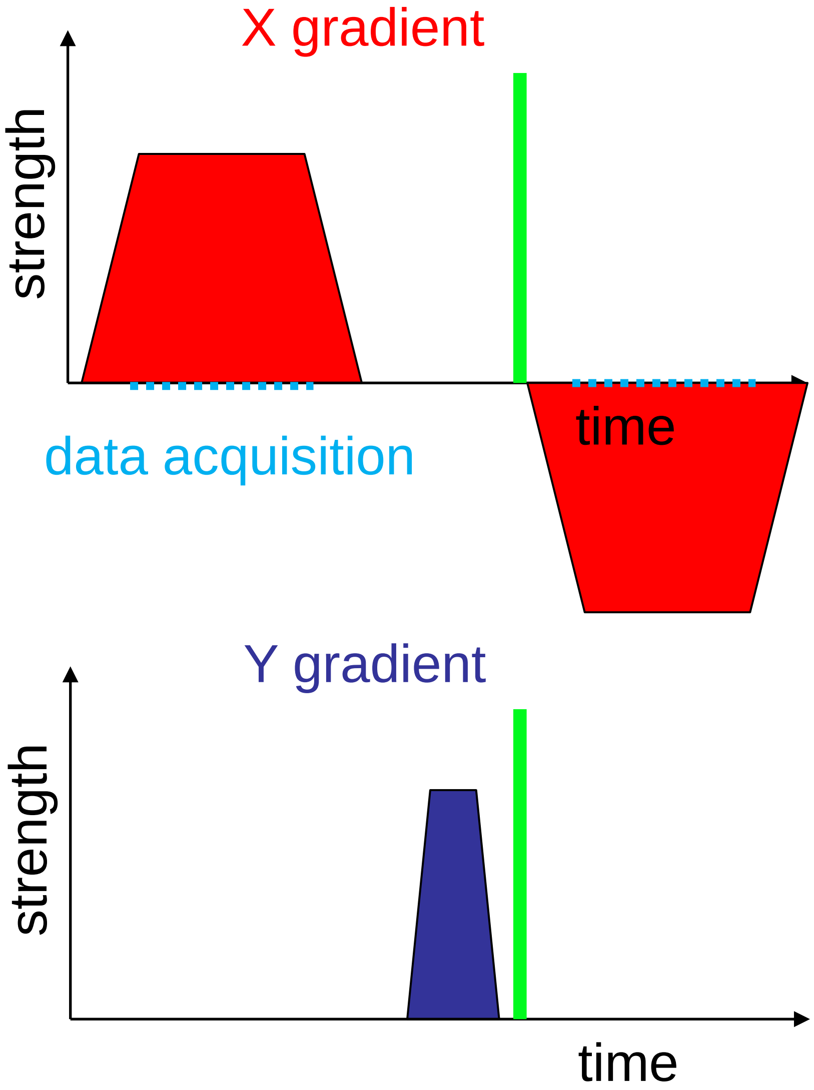

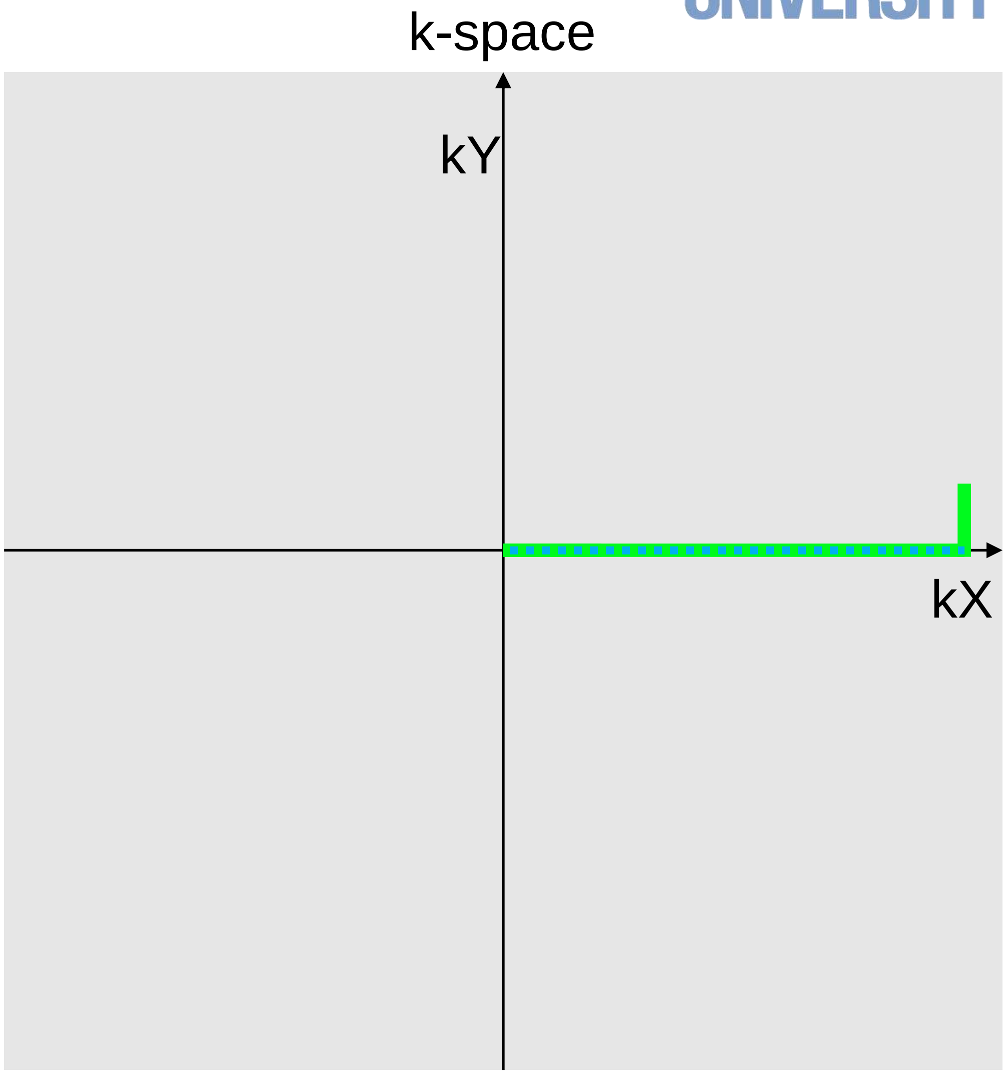

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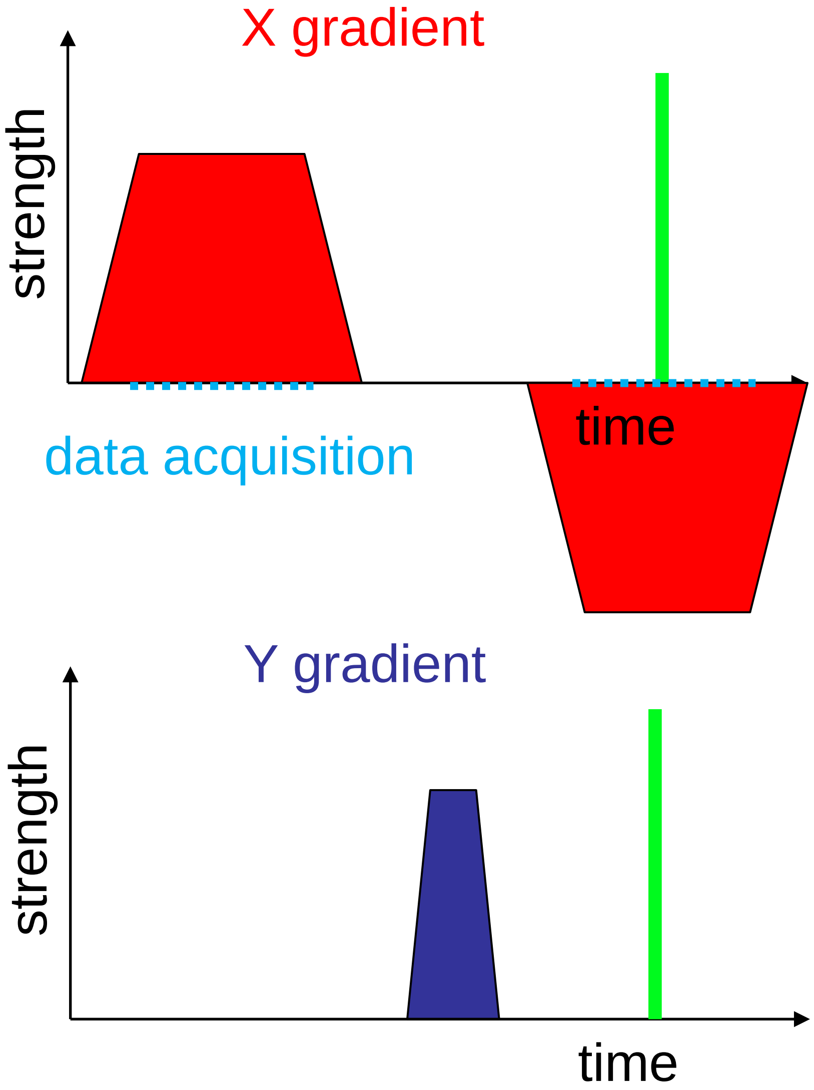

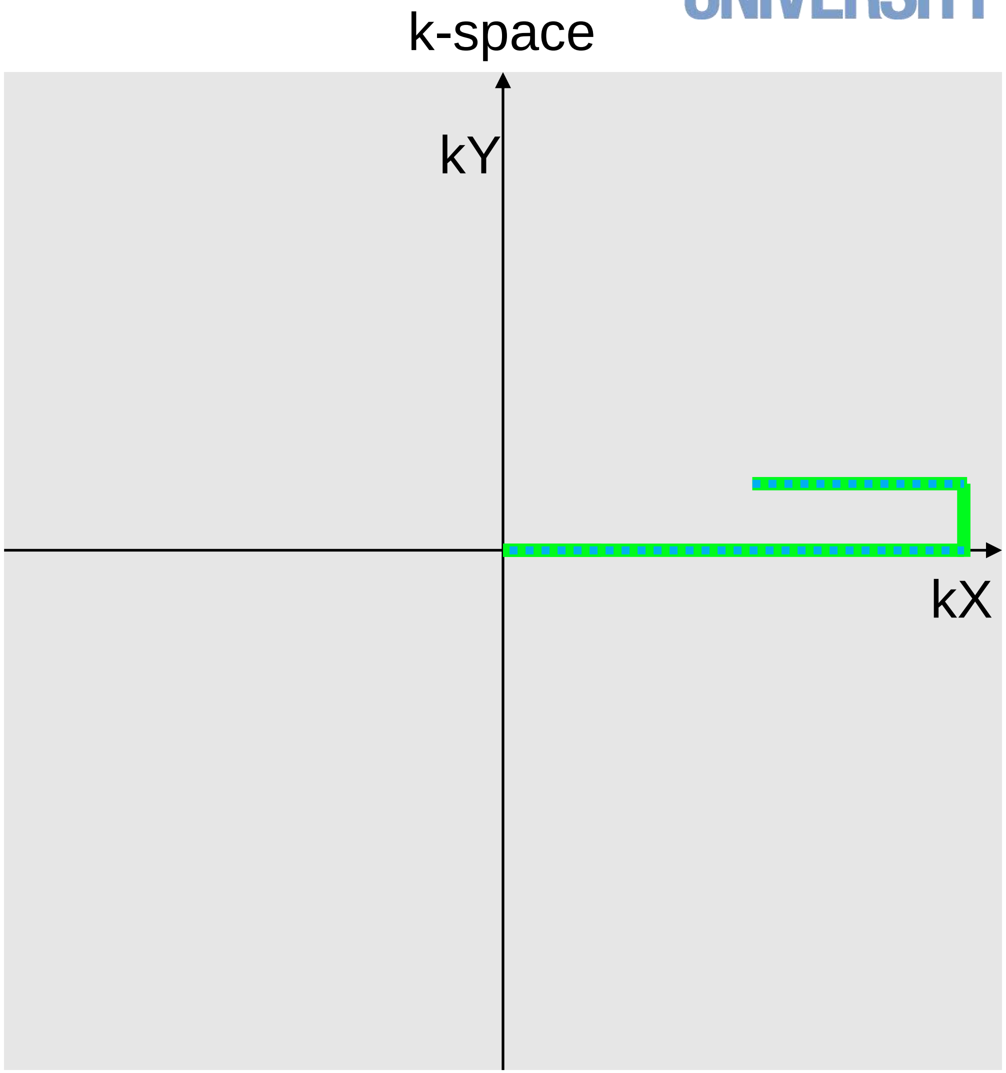

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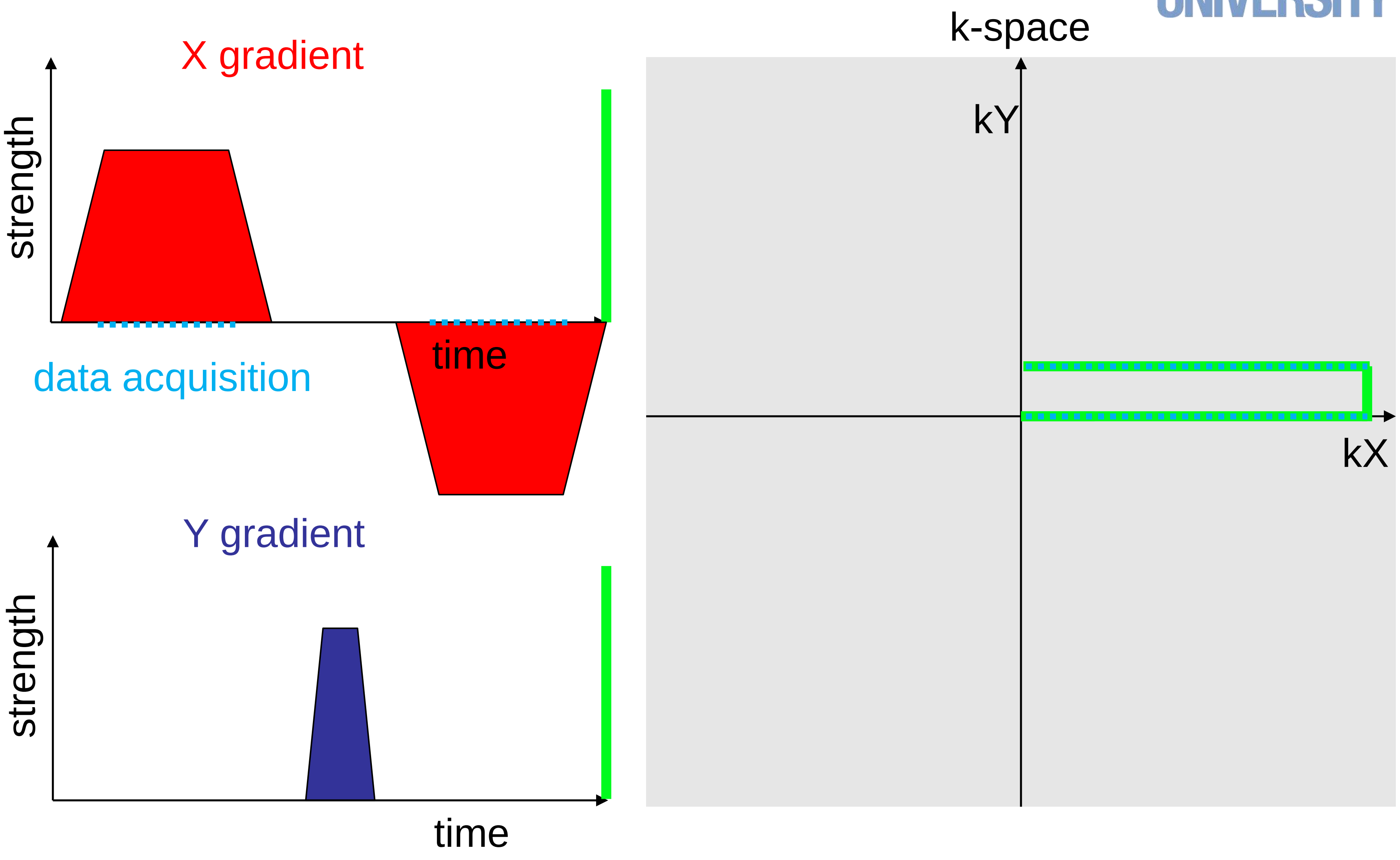
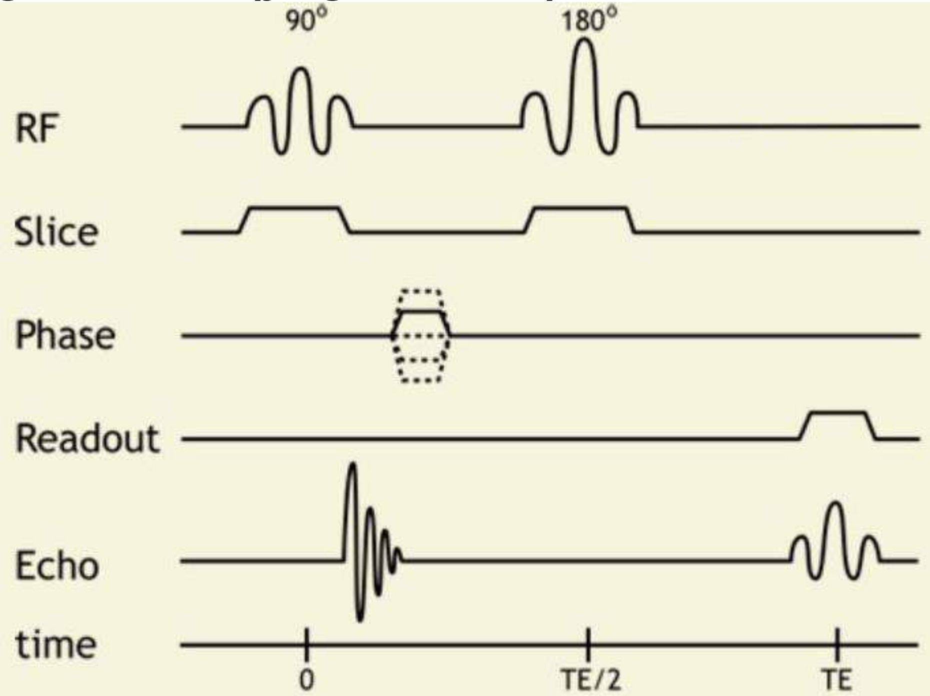


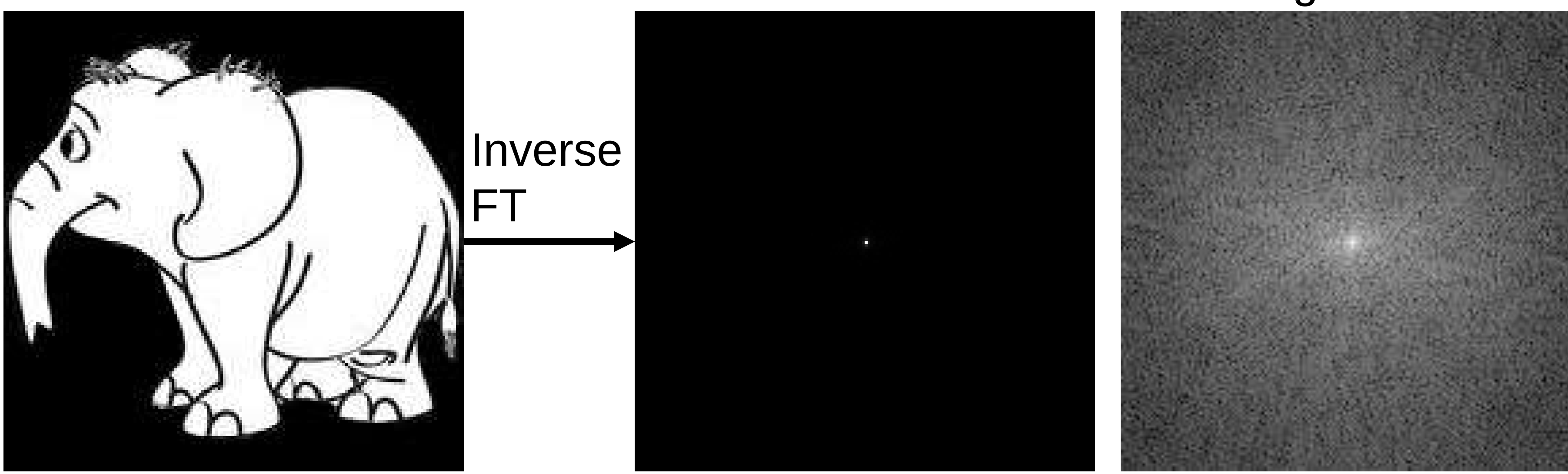
Acquire 3D image → typical sequence object

- Excite magnetization by simultaneously applying B1 field and slice selection gradient (z-gradient)
  → 2D slice
- Apply a phase encoding gradient (y-gradient)
  → 1D line
- Apply a frequency encoding gradient during acquisition (x-gradient)
  → voxel

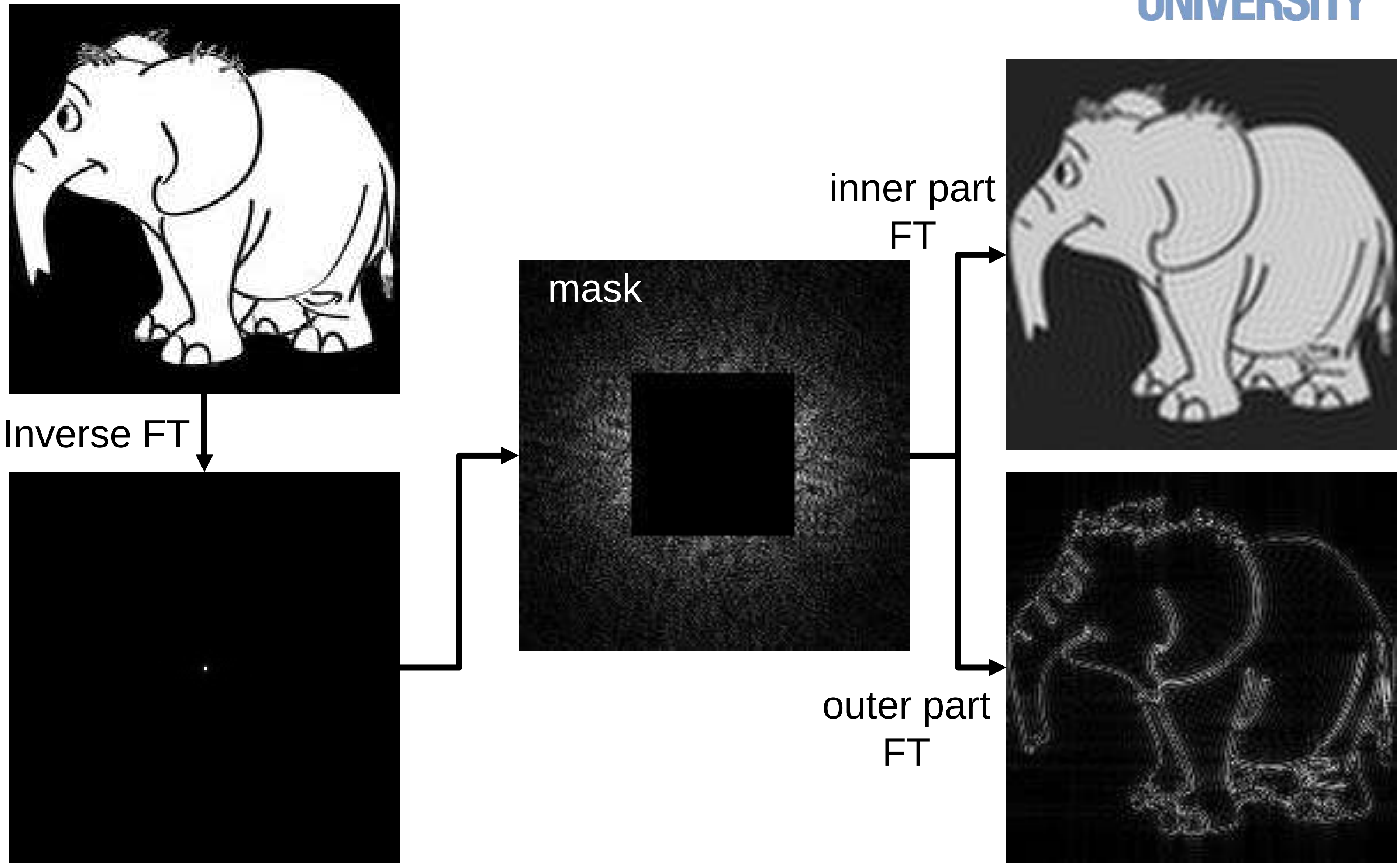


Fourier Transform (FT) of k-space data → image

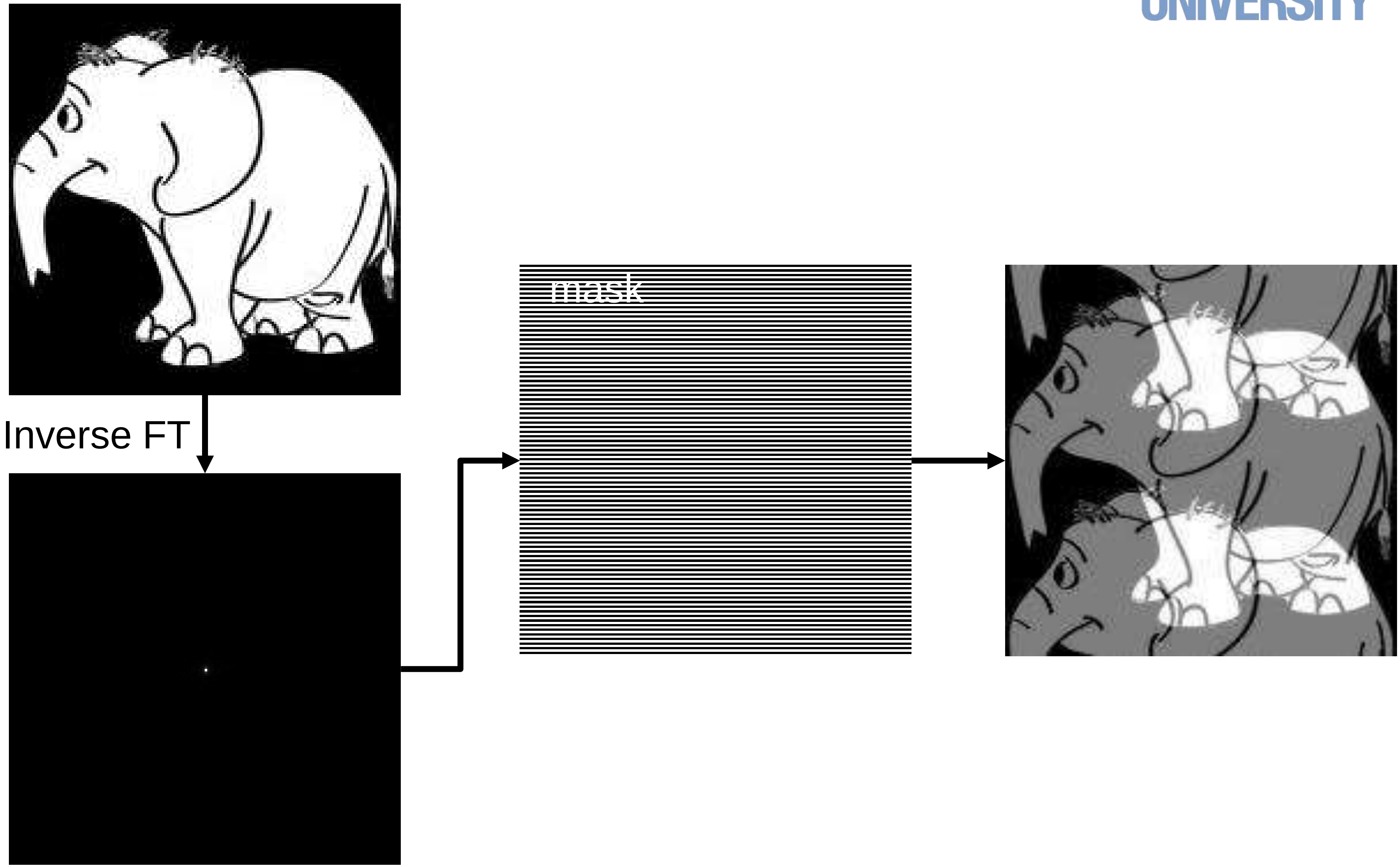
- k-space: frequency space
- FT: frequency space → image space
- Inverse FT: image space → frequency space
- Low frequencies in the center of the k-space
- High frequencies → high intensity fluctuation in the image (i.e. edges)



High and low frequency filter



Under-sampling → Ghosting



Questions?

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mriquestions.com

Vielen Dank für Ihre Aufmerksamkeit!

Tianyu Han

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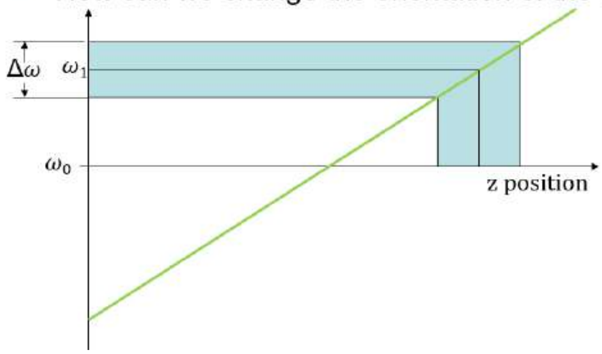
MRI – Practical Course 2

Task 1: Slice selection

- How can we change the position of the slice?
- How can we change the thickness of the slice?
- How can we change the orientation of the slice?



Task 2: Calculations

$\omega = \gamma\, B$	$\omega = 2\pi f$
$\Delta\omega = \gamma\, \Delta B$	$\frac{\gamma}{2\pi} = 42.6\, \frac{\mathrm{MHz}}{T}$

1. Calculate the Larmor frequency of hydrogen a 3T.

2. We apply a slice selection gradient of 30 mT/m in z direction.

   - How thick is the slice excited by an RF pulse with a bandwidth of 20 kHz at the Larmor frequency?

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