22485 Medical imaging systems

Magnetic Resonance Imaging II

Henrik Lundell
Associate Professor, MR Section DTU
Senior Researcher, DRCMR, Hvidovre Hospital
hmag@dtu.dk

Module E2, Monday kl. 13.00 - 14.30 **in building 349, room 205**
and Thursday kl. 9.00 - 11.00, in building 349, room 205

Errata

- The unit for the proton gyromagnetic ration should be MHz/T on slide 15 in lecture 1!

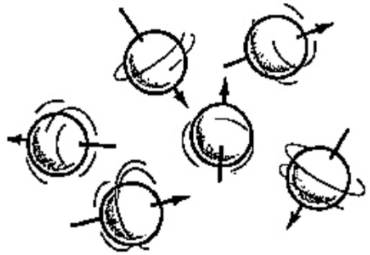
MRI Teaching material

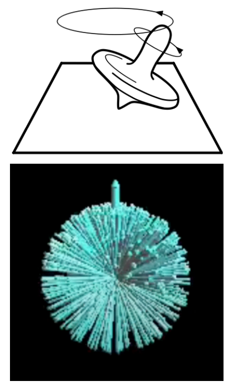
- Lecture notes by Lars G. Hanson (47 pages) available in English and Danish. (Link in course plan). Today: sections 11-16
- Chapter 12 and 13 in Prince and Links. Today: Ch 13
- Matlab exercise on November 27

Precession and excitation

$$f = \gamma \cdot B_0$$

$$\gamma = 42\ \mathrm{MHz/T}$$ **(For protons/hydrogen 1H)**

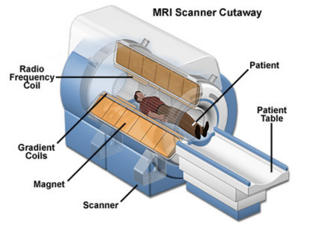




Animation by Lars G. Hanson available online
https://www.drcmr.dk/mr

Overall MRI topics

- The basic hardware components of an MRI system
- Nuclear spins and precession
- RF-pulses (B1-field), magnetic resonance and relaxation
- **2. Signal preparation, sequences and contrast mechanisms**
- **1. Magnetic field gradients, slice selection, and phase and frequency encoding**
- **3. The k-space and image reconstruction**
- Image reconstruction (exercise)
- Advanced and emerging MRI methods and applications
- MRI safety



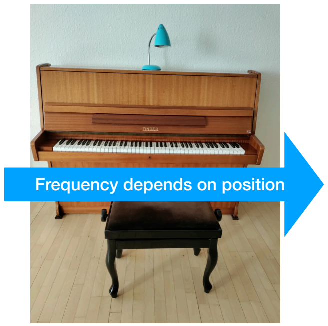
Coyne, 2012

Today's Intended Learning Objectives

- Identify main hardware components of an MRI scanner and their role.
- Understand the role of the gradient system and how it relates to slice selection, frequency and phase encoding.
- Explain dephasing mechanisms resulting in the T2* relaxation and how the T2 relaxation is isolated with the spin echo effect.
- Understand the relation between

Can my shoe size be measured by any of these instruments?

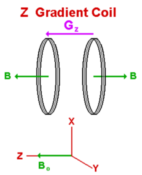
DTU 3T Human MRI scanner



For sale (5000 DKK)
https://www.dba.dk/piano-andet-maerke-klassis/id-1099125080/billeder/1/

Gradients

anti-Helmholtz pair in Z direction



Double saddle coils in X and Y direcitons

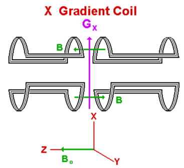


Illustration by Hornak:
https://www.cis.rit.edu/htbooks/mri/chap-9/chap-9-h5.htm

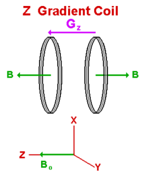
Gradient coils in the MRI scanner are designed to add a z-component to the B0 field in the x, y and z-direction independently

The added gradient field modulate the resonance frequency at different positions along the gradient.

$$f = \gamma \cdot (B_0 + \mathbf{G}\mathbf{r})$$

Gradients

anti-Helmholtz pair in Z direction



Double saddle coils in X and Y direcitons

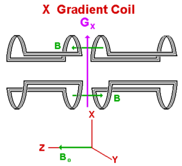


Illustration by Hornak:
https://www.cis.rit.edu/htbooks/mri/chap-9/chap-9-h5.htm

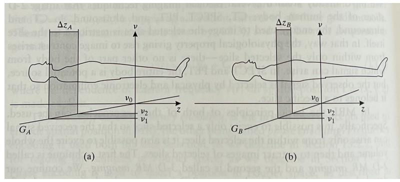
Gradient coils in the MRI scanner are designed to add a z-component to the B0 field in the x, y and z-direction independently

The added gradient field modulate the resonance frequency at different positions along the gradient.

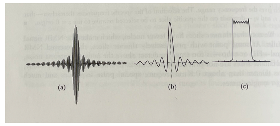
$$f = \gamma \cdot (B_0 + \mathbf{Gr})$$

Gradients

1. Gradients can be used to excite an arbitrary oriented plane



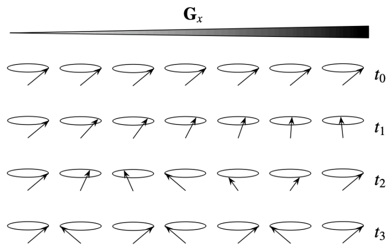
matching the frequency and bandwidth of a B1-field to the desired location and thickness of a slice.



From Links and Price

2. Gradients can be used to modulate the received signal

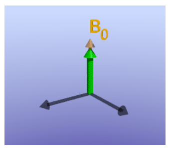
$$f = \gamma \cdot (B_0 + G_x x)$$



Frequency encoding - the modulation of precession frequency during a gradient
Phase encoding - the modulation of precession phase after an applied gradient

Recap: Relaxation

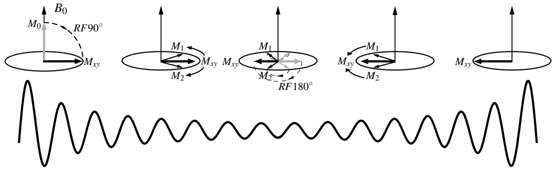
- Longitudinal relaxation T1: Restores polarisation of the spin ensemble with the net magnetisation along the stationary B0-field
- Transverse relaxation T2*: Dephasing of precessing spins after excitation with a B1-pulse. Both due to microscopic interactions (T2 - irreversible) and macroscopic field inhomogeneities (T2' - reversible through a spin echo). T2*=1/T2'+1/T2
- The relaxation times are different for different materials/tissues and images highlighting different tissue properties can be explored through different signal preparations in imaging sequences.



Exercise I

- Go to https://www.drcmr.dk/BlochSimulator/ (best on laptop)
- Try out the different B1-pulse buttons (90/180 deg hard/soft). You can switch between the stationary and rotating frame perspective with the XYZ option to the right.
- Go to the equilibrium setting and set to inhomogeneity.
- Excite the spins and observe the signal. What is happening?
- Try the spoil button (this is a short strong gradient field). What is happening?
- Try again and apply a 180-pulse some time after the 90-pulse. What is happening?

Spin-Echo



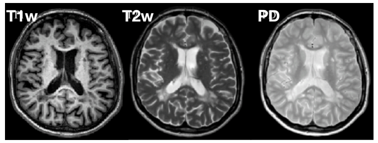
90-pulse at t=0

180-pulse at t=TE/2

Spin-echo at t=TE

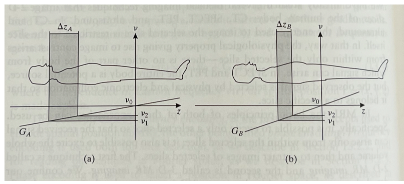
- Spins experiencing slightly different B0 fields and precess at different frequencies leading to T2'-decay.
- A 180-pulse will reverse the phase such that slow spins get ahead of the average and fast spins gets behind. Rephasing will occur at the echo time TE leading to a recovery of the T2' part of T2*
- Spin interactions that lead to random dephasing (collisions, diffusion…) leads to additional dephasing that leads to an additional T2-effect that is isolated in the spin echo signal.

Contrast weighting and sequences

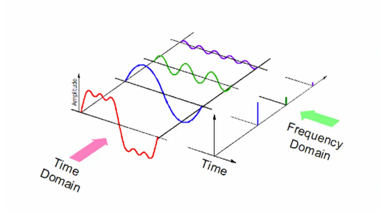


- Proton density (maximize signal from all materials) by short TE and long TR.
- T1-weighting by modulation of TR (repetition time) or IT (inversion time) with an inversion preparation (simulator).
- T2* and T2-weighting by modulating TE (echo time) in gradient echo (excite and aquire) or spin echo (excite, 180-pulse, aquire).

Making images



Fourier transform



Correlation between a signal along one dimension (e.g. time or space) and a harmonic oscillation (frequency)

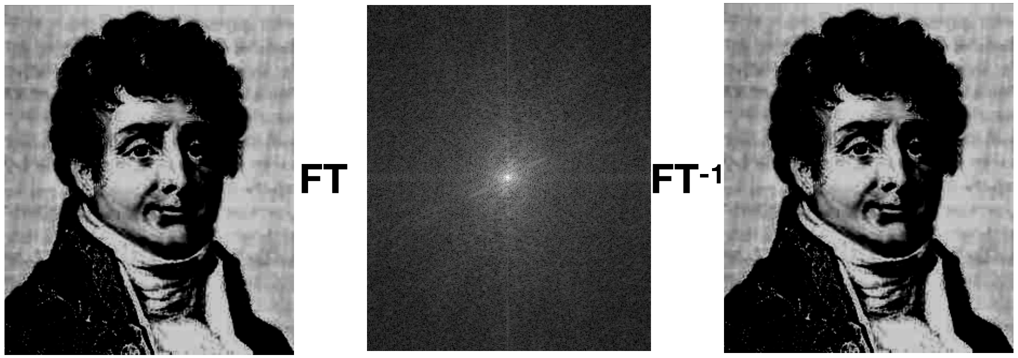
$$\hat{f}(\xi) = \int_{-\infty}^{\infty} f(x)\, e^{-2\pi i \xi x}\, dx.$$

Wave

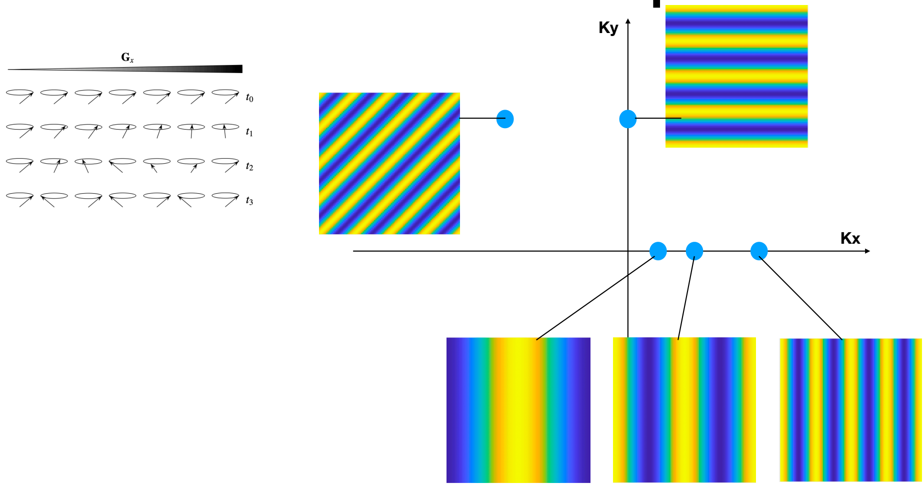
Function

https://kinder-chen.medium.com/denoising-data-with-fast-fourier-transform-a81d9f38cc4c

Fourier transform, 1D, 2D, 3D …



Phase roll and k-space



Phase roll and k-space

The k-space reflect spatial frequencies
(Unit 1/m 1/[wavelength])

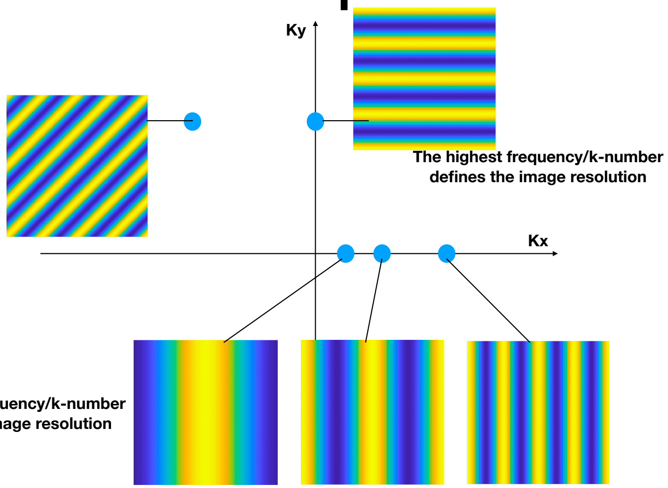
The frequency at a given position

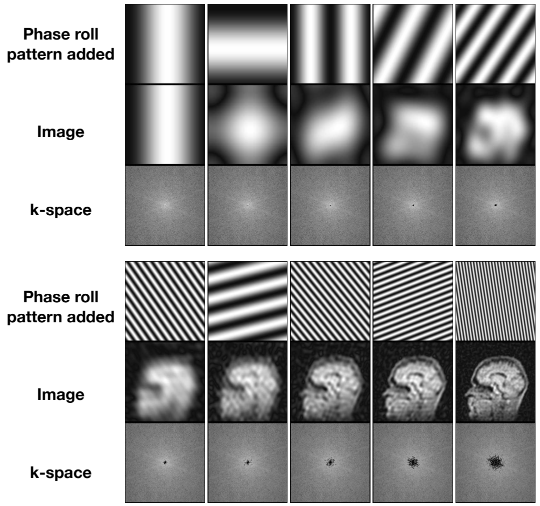
$$f = \gamma \cdot (B_0 + G_x x)$$

The accumulated phase at a given location

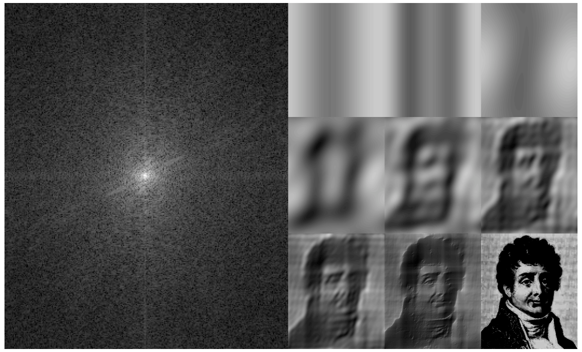
$$\phi = \gamma G T \ x$$

The lowest frequency/k-number
defines the image resolution

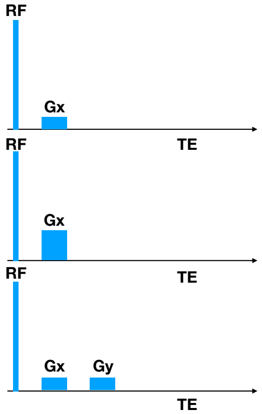


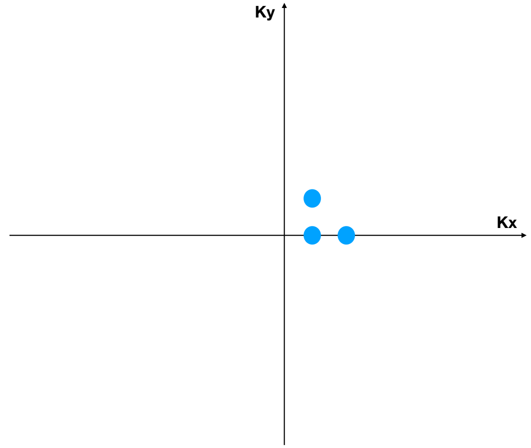


Fourier transform, 1D, 2D, 3D …

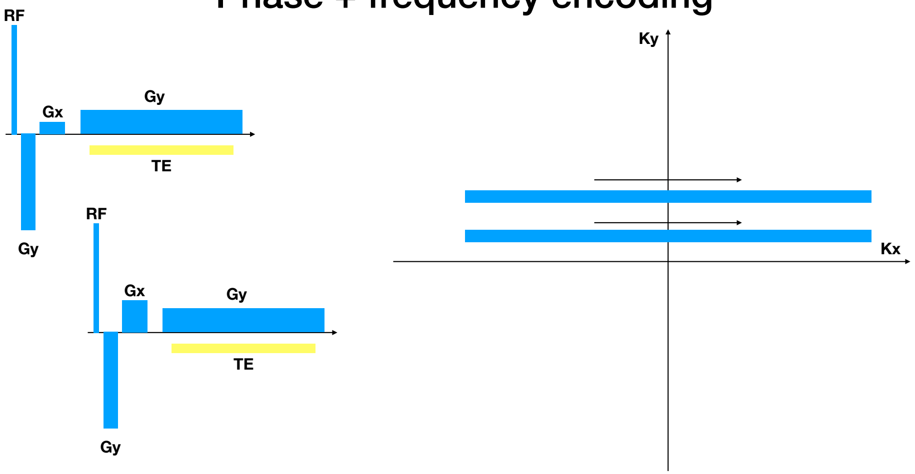


Filling up k-space
Phase encoding





Filling up k-space
Phase + frequency encoding



Filling up k-space faster
Multiple phase + frequency encoding (echo planar imaging)