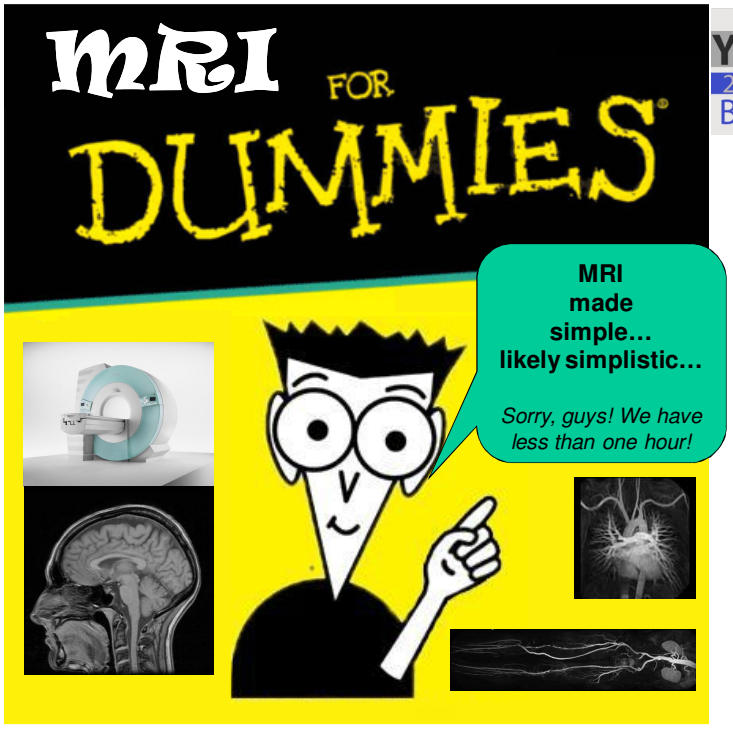
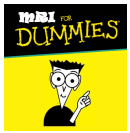


Young Belgian Magnetic Resonance Scientist 2011
YBMRS 2011
21st - 23rd NOVEMBER
BLANKENBERGE

U. Himmelreich
K.U.Leuven

B. Gallez
U.C.Louvain

B. Jordan
U.C.Louvain

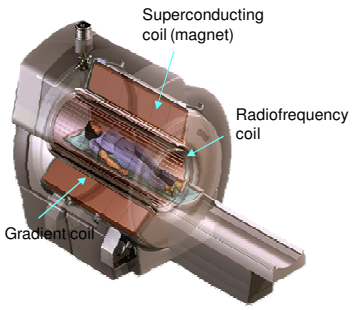


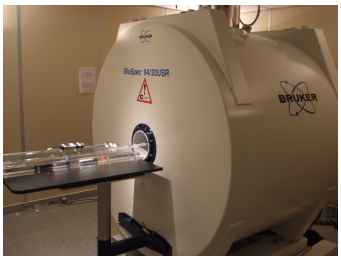
Part 0: What we will not talk about.

- We assume that you know how a magnetic resonance signal comes about and what is required for its detection:

  Magnetic field – r.f. pulse – detection free induction decay – Fourier transformation

- In contrast to NMR spectrometer, **magnetic field gradients** (x, y, z) are not only a nice thing to have but essential for MRI.

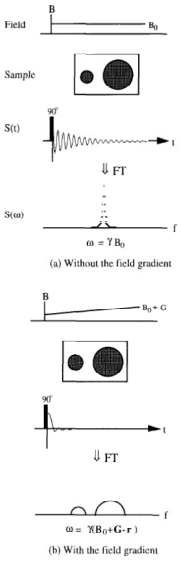


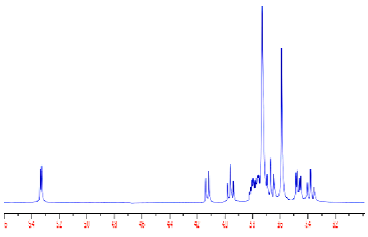


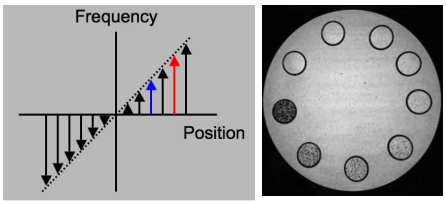
Part 1: Spatial encoding

- How to generate an MR IMAGE?
- How to acquire localized NMR spectra?

Frequency encoding in MR imaging and NMR spectroscopy







2D MR Imaging

- Spatial encoding using magnetic field gradients in x, y and z direction

  -> magnetic field strength varies in each voxel

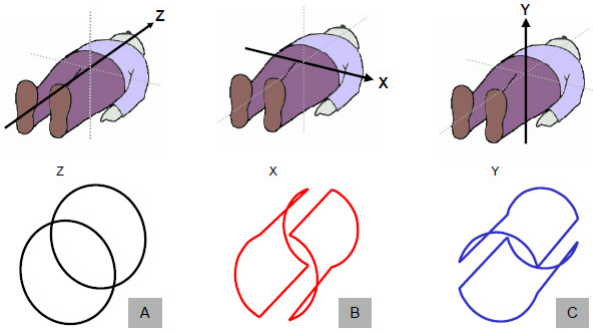
  -> resonance frequency varies in each voxel ($\nu = (\gamma/2\pi)\, B_0$)

- Selection of slices (along z-axis) using z-gradient

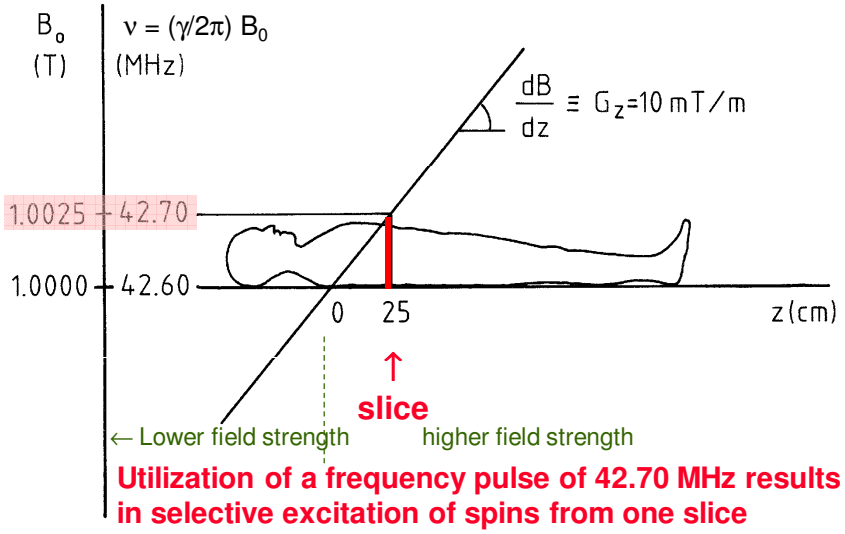
- Analysis of frequencies/ phases of the resonance frequencies provides a map of local spin distribution (image)

Slice selection

Combination of field gradient with selective excitation pulses

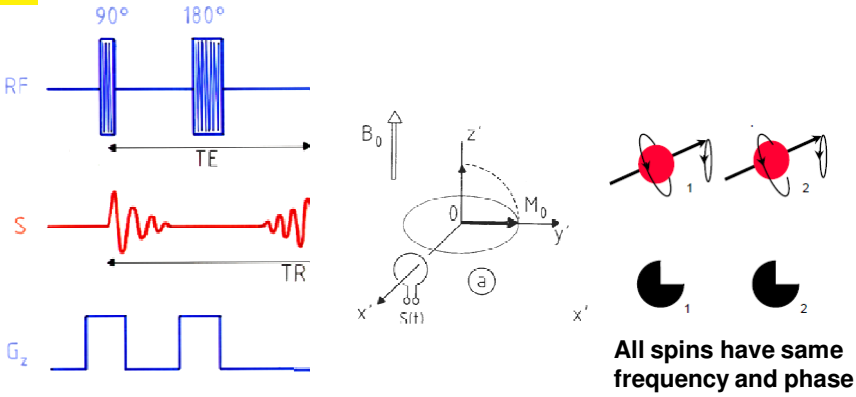


Slice selection



Utilization of a frequency pulse of 42.70 MHz results in selective excitation of spins from one slice

Slice selection

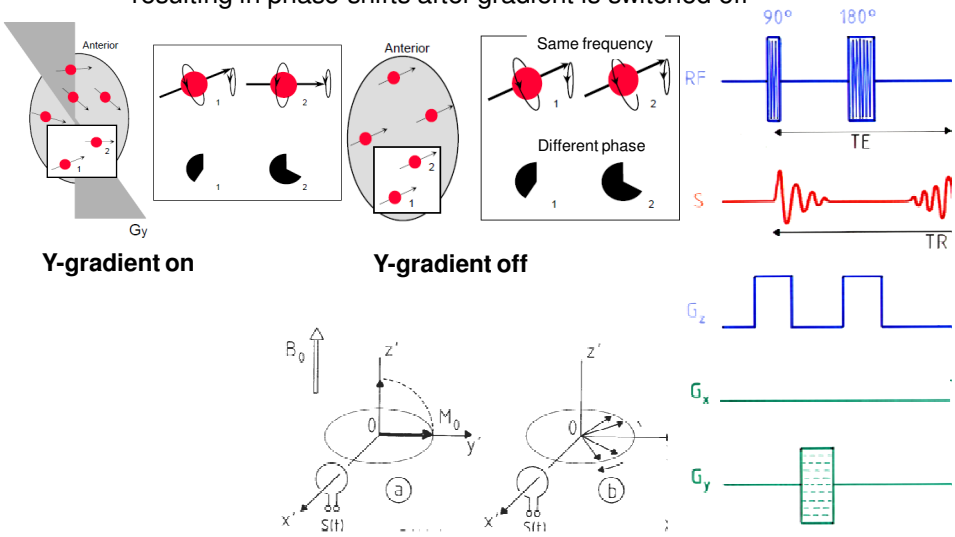


All spins have same frequency and phase

Signal comes from one slice but we don't know the position within the slice -> selection of rows

Y gradient – phase encoding

Application of a gradient in y-direction results in Lamor frequency differences of spins according to their position along the y-axis resulting in phase shifts after gradient is switched off

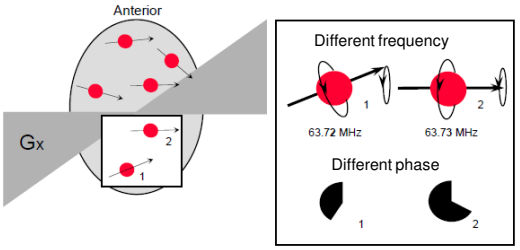


Y-gradient on **Y-gradient off**

X gradient – frequency encoding

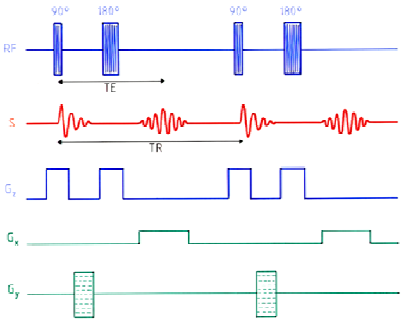
- So far: Signal from a particular slice with phase encoded rows.

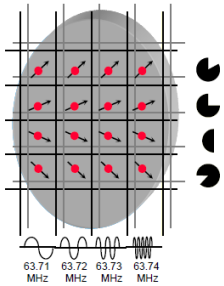
- Application of a gradient in x-direction during signal acquisition results in encoding of columns due to frequency differences.



Different frequencies encode for spatial distribution in x-direction

2D Spatial encoding





Due to z-gradient -> slice selection
Due to y-gradient -> different phases
Due to x-gradient -> different frequencies

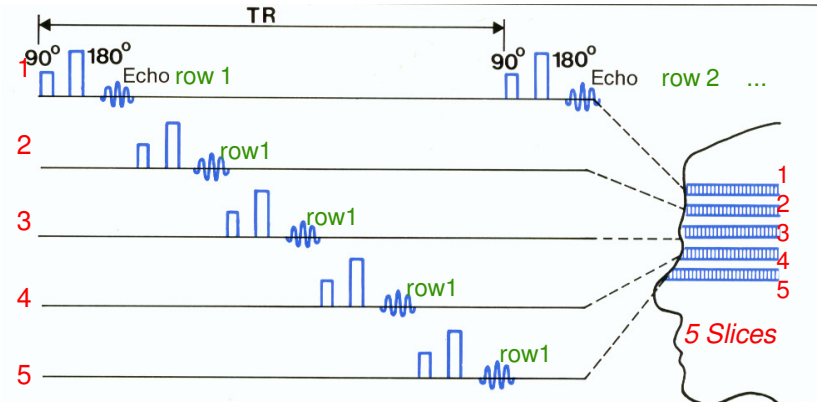
{ 90 - TE/2 - 180 - TE/2 - echo - TR }$_N$

Acquisition time and resolution:

- N pixel in x-direction are encoded by their frequency.
- To reconstruct the phase encoding, excitation of N different y-gradient values are necessary

⇒ ***N Excitations are necessary to acquire an N x N matrix!***

Multislice acquisition – spin echo



- N = number of phase encoding steps/ matrix size (64, 128, 256, ...)
- TR = repetition time for each acquisition
- NA = number of acquisitions (1, 2, 3, …)

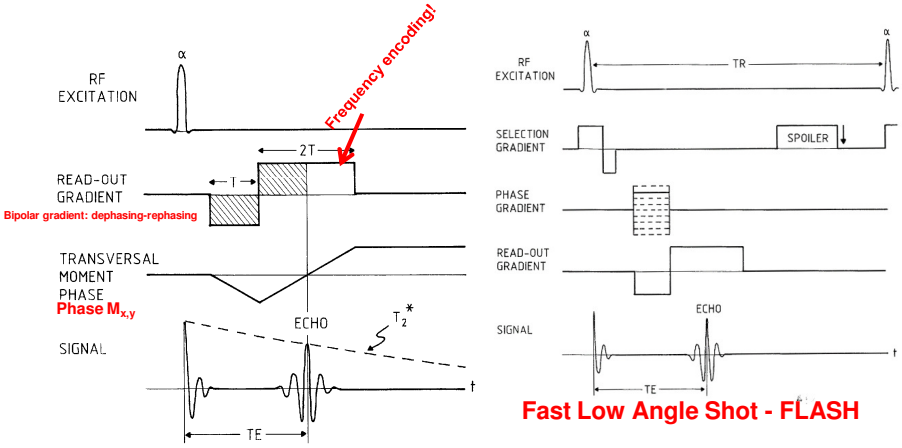
Acquisition time = N x TR x NA

(with N = 256, TR = 1s, NA =1 ⇒ 256s = long acquisition time)

More rapid acquisition protocols

Gradient echo sequences (FLASH, FISP, ...)

- Generation of echoes using re-focussing gradients
- Excitation pulse with small flip angle (α<< 90°)



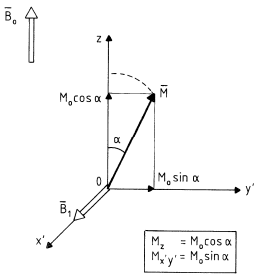
Fast Low Angle Shot - FLASH

More rapid acquisition protocols

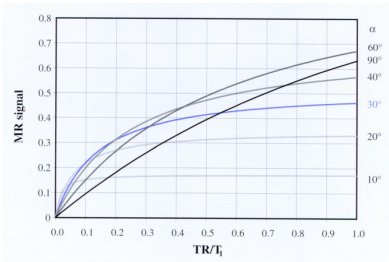
Gradient echo sequences (FLASH, FISP, ...)

Why are they rapid?

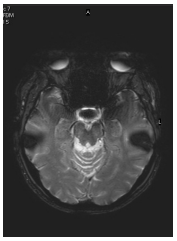
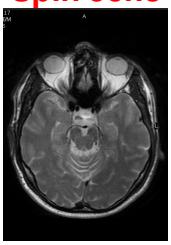
- Utilization of only a part of Mz -> most still available for excitation
- Rapid pulsing (small TR) is possible
- TR = 10-100ms, TA < 1 minute



Optimization of signal intensity with α, TR and T_1

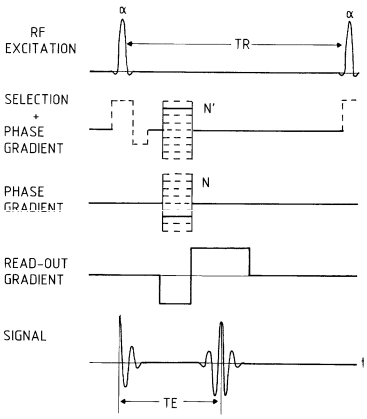


Spin echo vs. Gradient echo

	Gradient echo	Spin echo
		
Speed	Rapid	Slow
T2* artifacts	Yes	No
T1, T2, T2* weighting	mixed	well defined

3D MR imaging

- Excitation of the whole volume of interest (no slice selecting pulses)
- Spatial encoding (z-direction) with a second phase encoding gradient



N = number of phase encoding steps (y-axis)
N' = number of phase encoding steps in 'slice direction' (z-axis)
TR = repetition time for each acquisition
NA = number of acquisitions

Acquisition time = N x N' x TR x NA

(with N = 256, N' = 32, TR = 50ms, NA =1 ⇒ 7 minutes)

Advantages over 2D acquisition:

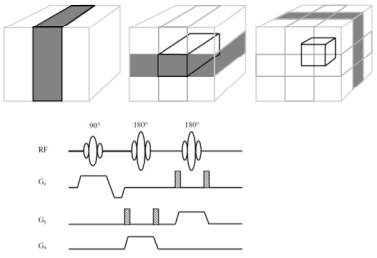
- High-resolution, true 3D images possible
- Very thin 'slices'

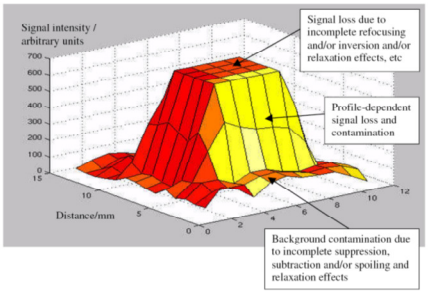
Localization in NMR spectroscopy

- Low concentration of metabolites -> larger VOI than in MRI

(1) Localization by using small surface coils over VOI (bad localization)

(2) Localization using slice selective gradients:





- The 90° pulse excites a slice.
- The first 180° pulse refocuses the transverse magnetization in a row within the slice
- The second 180° pulse refocuses the magnetization within a column of the row - single voxel.

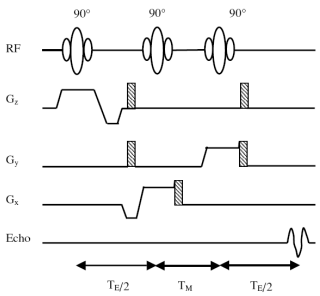
The signal represents a combination of spins in that voxel, frequency differences due to different chemical shifts.

Localization in NMR spectroscopy

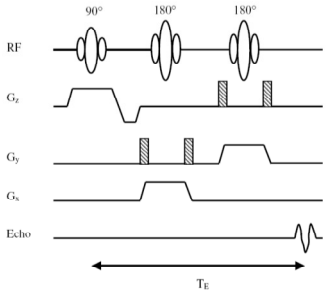
Different localization techniques possible (STEAM, PRESS, …)

1. Single volume MR spectra

Three slice selective Rf pulses select a volume of interest (VOI)
Pulse sequences: 1. Stimulated echo acquisition (STEAM)
2. Point resolved spectroscopy (PRESS)



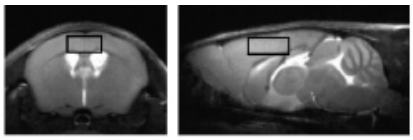
STEAM

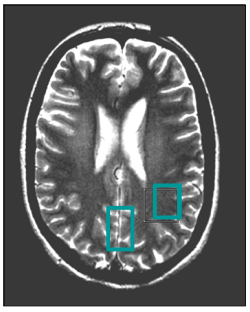


PRESS

Localization in NMR spectroscopy

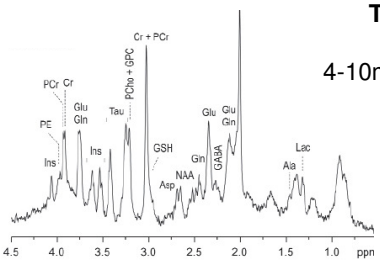
Examples for localized, in vivo, single-voxel brain spectra in humans and rats. And key brain metabolites.

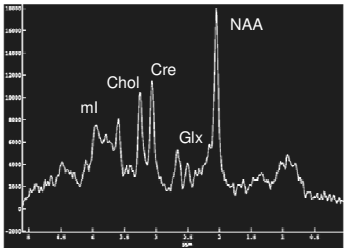




Typical volumes:

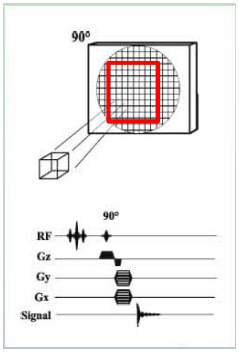
4-10mm^3 4-10cm^3

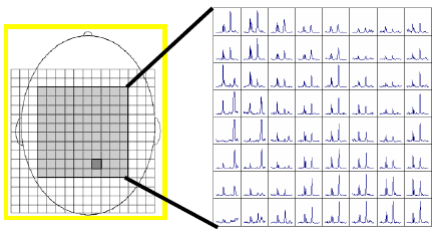


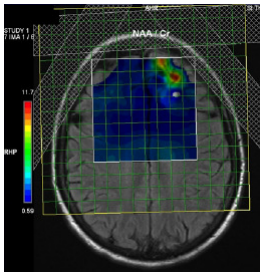


Chemical Shift Imaging (CSI)

- Phase encoding gradients utilized as in imaging -> spatial encoding
- Single slice defined through the area of interest.
- Frequency encoding switched off -> frequency differences = chemical shift
- Process is repeated with various gradients -> full set of phase-encoding
- Fourier transformation -> array of space and frequency encoded signals

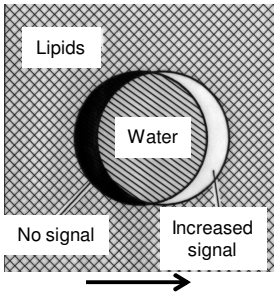




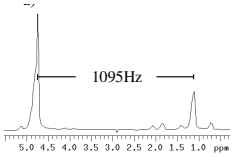


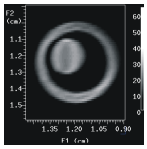
Potential problems associated with chemical shift and spatial encoding

- Artifacts due to spatial shift based on frequency differences in metabolites (chemical shift displacement effect)
- Example: shift between water and lipid images (Δ = 3.5ppm (CH_2 lipids))
- Frequency encoding will result in different locations for water and lipids



Frequency encoding

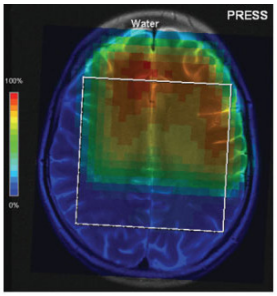




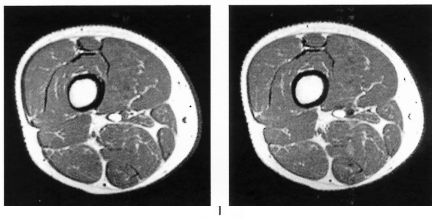
Phantom at 7T

- Inner tube: oil
- Outer tube: H_2O

Potential problems associated with chemical shift and spatial encoding



H_2O intensity CSI maps,
$\nu_{carrier}$ = 2.2 ppm, ν_{H2O} ~ 4.7 ppm



1
Chemical shift by 3 pixels
Bandwidth 45 Hz/pixel

2
Chemical shift by 1 pixel
Bandwidth 130 Hz/pixel

Possible solutions/ suppression:
- Change carrier frequency (middle of the spectrum rather than water)
- Selective suppression (e.g. fat resonance)
- lager amplitude for frequency encoding gradients ($\Delta x = \Delta B / G_{FE}$); lager bandwidth to keep FOV