22485 Medical imaging systems

Magnetic Resonance Imaging III

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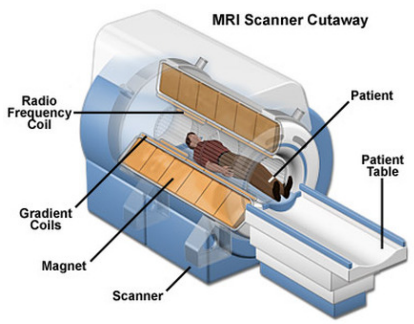
Module E2, Monday kl. 13.00 - 14.30 **in building 349, room 205**
and Thursday kl. 9.00 - 11.00, in building 349, room 205

Overall MRI topics



Coyne, 2012

- 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

MRI Teaching material

- Lecture notes by Lars G. Hanson (47 pages) available in English and Danish. (Link in course plan).
- Chapter 12 and 13 in Prince and Links.
- Today we will use the CompassMR spin simulator https://www.drcmr.dk/CompassMR/ and later other simulators from the same resource
- Matlab exercise on November 27

Simulators

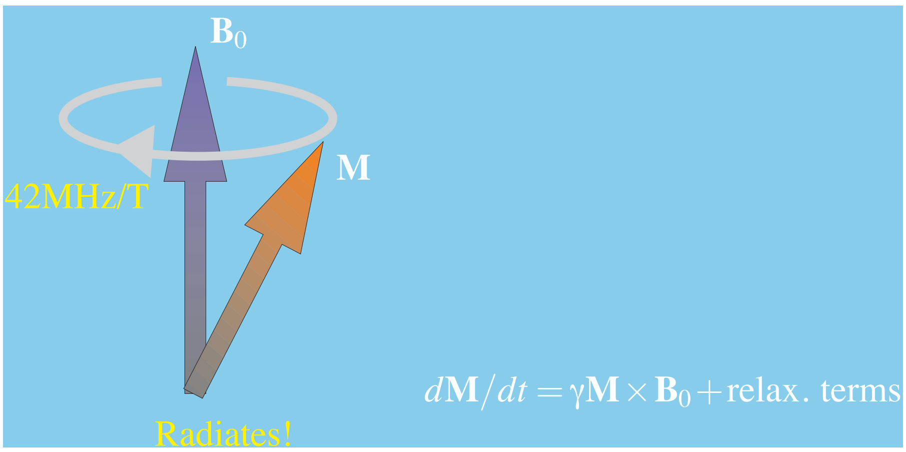
- Go to https://www.drcmr.dk/CompassMR/ on laptop or phone
- Go to https://www.drcmr.dk/BlochSimulator/ (best on laptop)

Quiz-time!

(fully anonymous)

https://forms.office.com/e/XHLkdF5ktZ

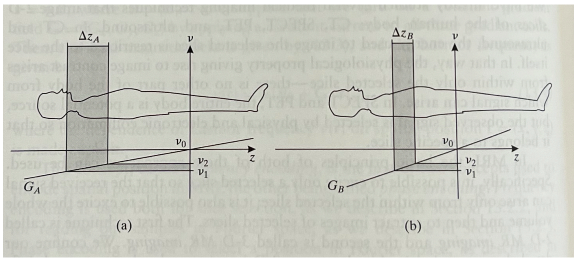
Precession, relaxation and the Bloch equation



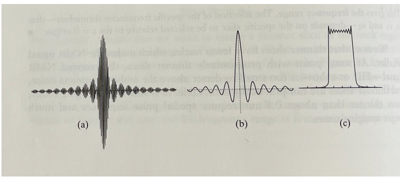
Lars Hanson

Gradients

1. Gradients can be used to excite an arbitrary oriented plane
Position => resonance frequency



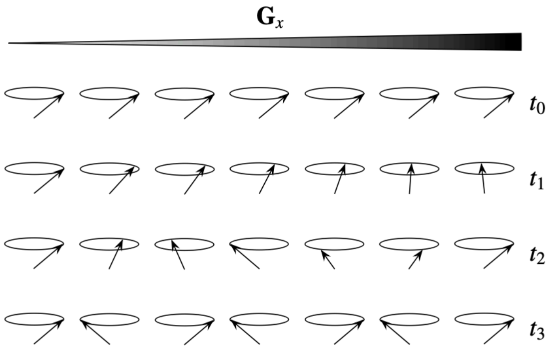
matching the frequency and bandwidth of a B1-field to the desired location and thickness of a slice.



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

An MRI sequence

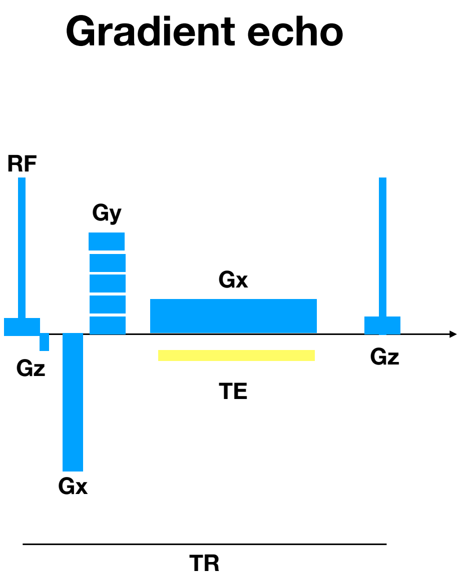
- A sequence of B1/RF-pulses, gradient pulses and periods of data collection.

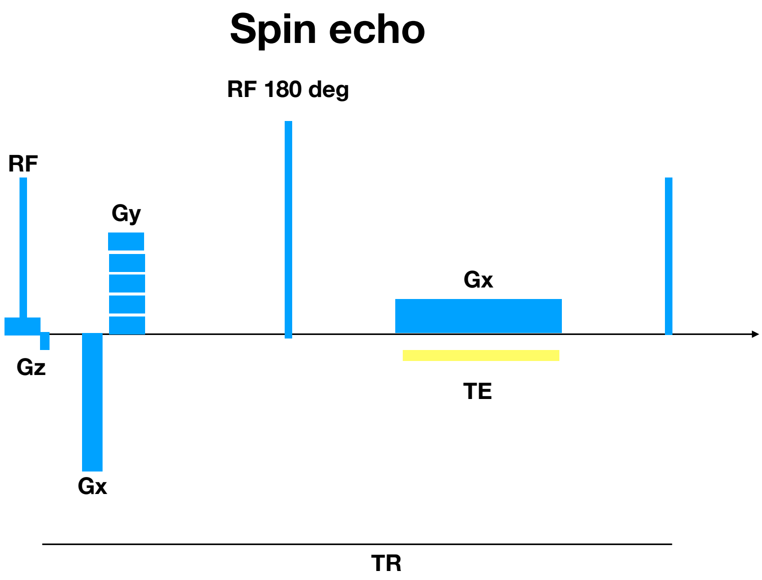
Signal preparation	Image readout (k-space data)	Signal preparation	Image readout (k-space data)

- ***Signal preparation***, e.g. how the contrasts between T1 or T2 relaxation times are weighted in the signal. This could also be sensitivity to diffusion, flow etc.

- ***Image readout****, part of the sequence that defines the region and collects k-space data.*

Simple MRI sequences

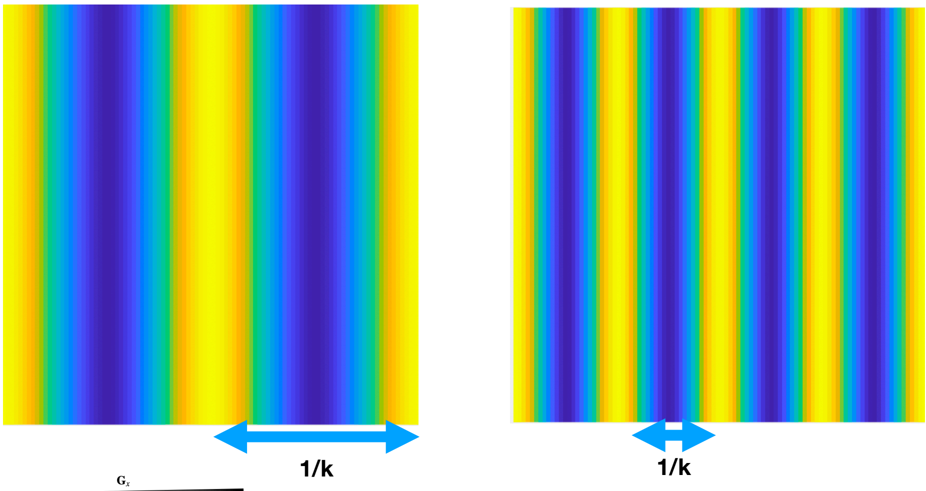


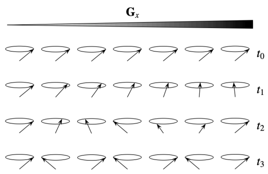


How and why do we create…

- …a T1 weighted signal?
- …a T2 weighted signal?
- …a proton density weighted signal?

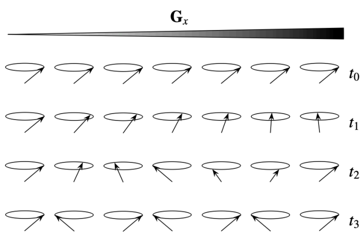
How is a phase roll created in space?

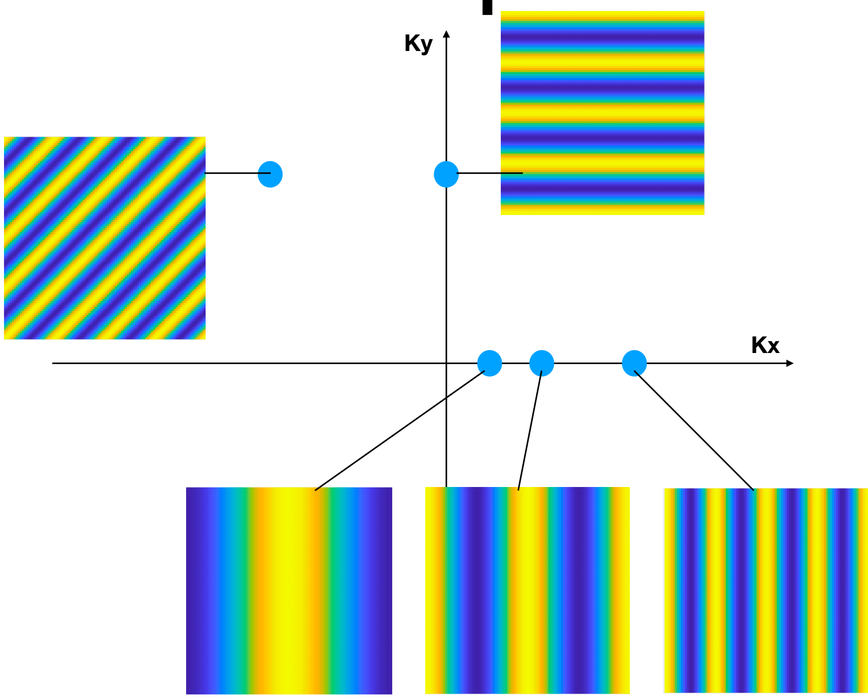




$$B_z(\mathbf{r},t) = B_0 + \mathbf{r}\cdot\mathbf{G}(t)$$
$$\phi(\mathbf{r},t) = \int_0^t \gamma(B_0 + \mathbf{r}\cdot\mathbf{G}(t'))\,dt'$$

Phase roll and k-space



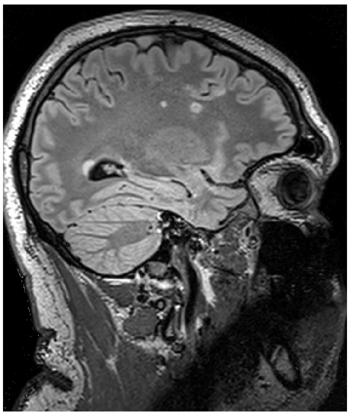


From 3D to a 1D signal

The MR signal density in space after preparation

The phase in space for one k

$\int$



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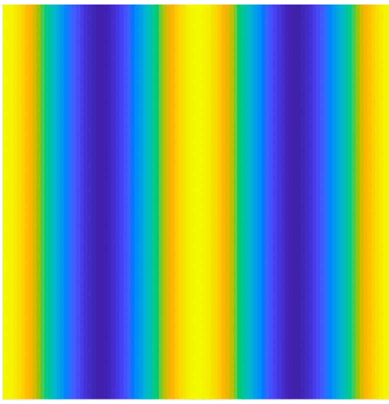


dr= signal

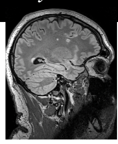
From precession to k-space

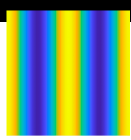
Signal in xy-plane

Prepared signal

Precession in xy-plane

$$M_{xy}(t) = \int M_{xy}^{t=0}(\mathbf{r}) \exp(-i\phi(\mathbf{r},t))\, d\mathbf{r}$$





The phase of the signal at position r at time *t*

$$\phi(\mathbf{r},t) = \int_0^t \gamma B_z(\mathbf{r},t')\, dt'$$

From precession to k-space

$$M_{xy}(t) = \int M_{xy}^{t=0}(\mathbf{r}) \exp(-i\phi(\mathbf{r},t))\, d\mathbf{r}$$

$$\begin{aligned}\phi(\mathbf{r},t) &= \int_0^t \gamma(B_0 + \mathbf{r}\cdot\mathbf{G}(t'))\, dt' \\ &= \gamma B_0 t + \gamma \mathbf{r}\cdot\int_0^t \mathbf{G}(t')dt' \\ &= \gamma B_0 t + \mathbf{r}\cdot\mathbf{k}(t) \quad \text{with} \quad \mathbf{k}(t) \equiv \gamma\int_0^t \mathbf{G}(t')dt'\end{aligned}$$

$$\begin{aligned}M_{xy}(t) &= \exp(-i\gamma B_0 t)\int M_{xy}^{t=0}(\mathbf{r}) \exp(-i\mathbf{k}(t)\cdot\mathbf{r})\, d\mathbf{r} \\ M_{xy}^{rot}(t) &= \int M_{xy}^{t=0}(\mathbf{r}) \exp(-i\mathbf{k}(t)\cdot\mathbf{r})\, d\mathbf{r} = M_{xy}^{rot}(\mathbf{k})\end{aligned}$$

From precession to k-space

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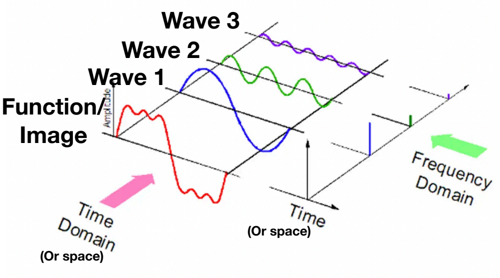
This is a Fourier relation!



Similarity with wave

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

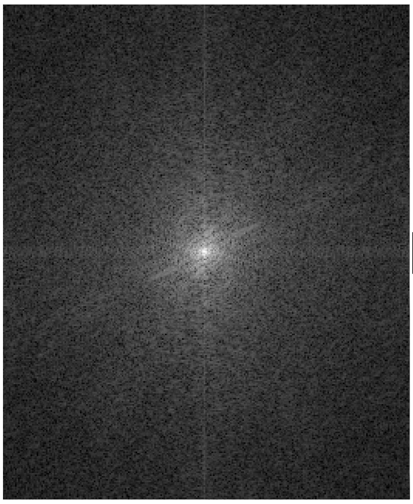
Wave

Function

https://kinder-chen.medium.com/denoising-data-with-fast-fourier-transform-a81c

Fourier transform, 1D, 2D, 3D …

FT



FT^{-1}

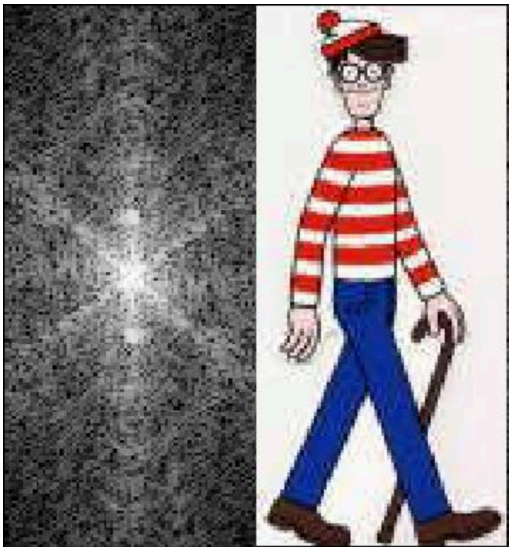
Questions

$$M_{xy}(t) = \exp(-i\gamma B_0 t) \int M_{xy}^{t=0}(\mathbf{r}) \exp(-i\mathbf{k}(t)\cdot\mathbf{r})\, d\mathbf{r}$$

$$M_{xy}^{rot}(t) = \int M_{xy}^{t=0}(\mathbf{r}) \exp(-i\mathbf{k}(t)\cdot\mathbf{r})\, d\mathbf{r} = M_{xy}^{rot}(\mathbf{k})$$

- What is the signal in the centre of k-space (k=0)?
- What is the signal from a homogeneous region when k increases?

Find Waldo/Holger!



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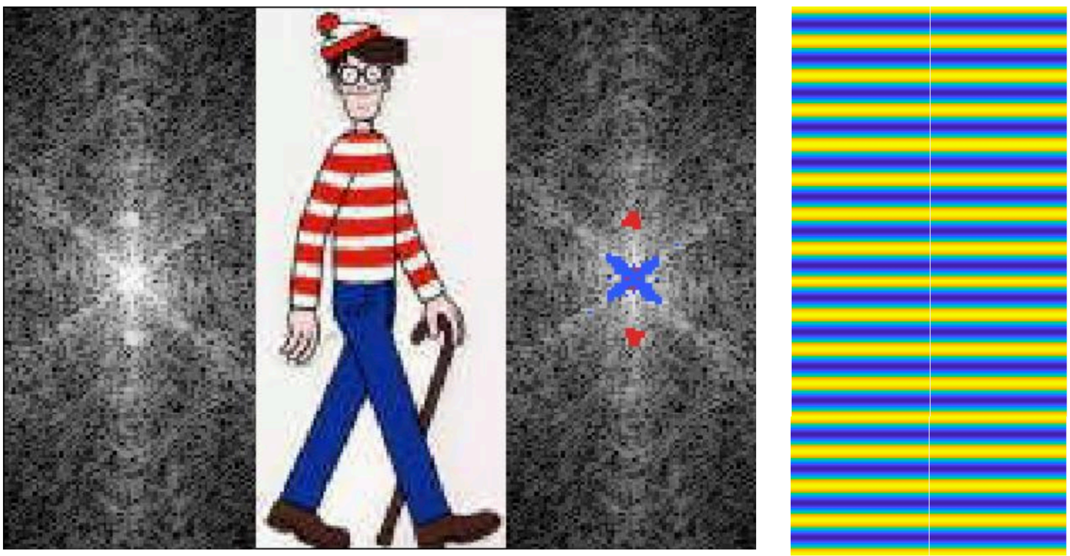

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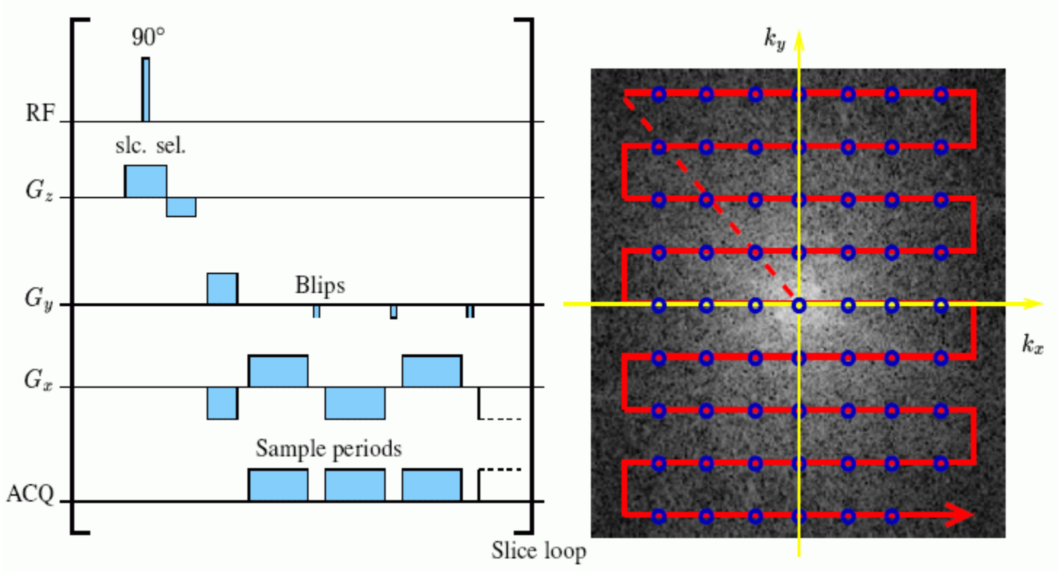
Echo-planar imaging (EPI)



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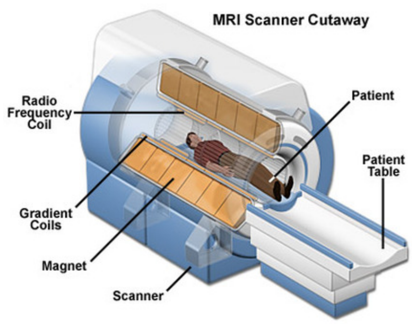

Coyne, 2012

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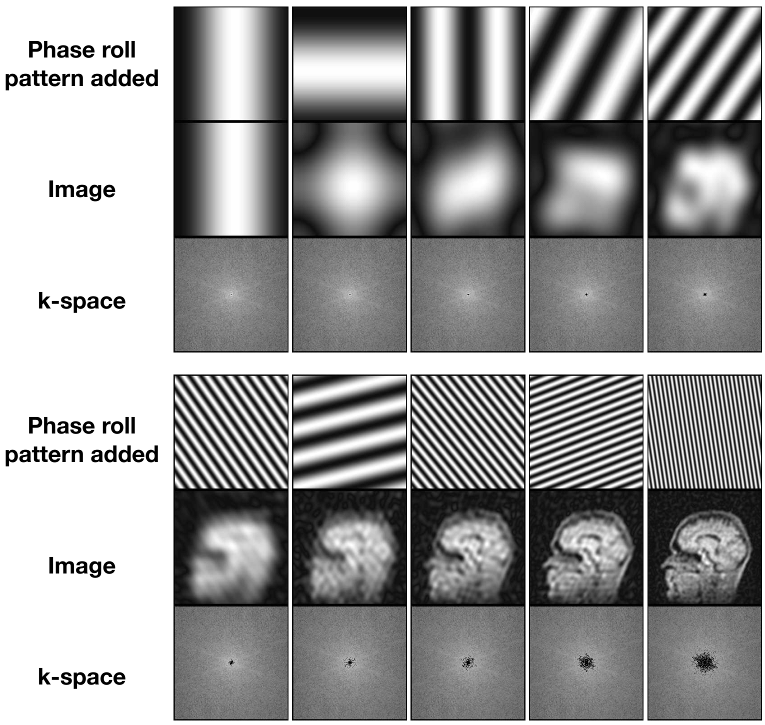
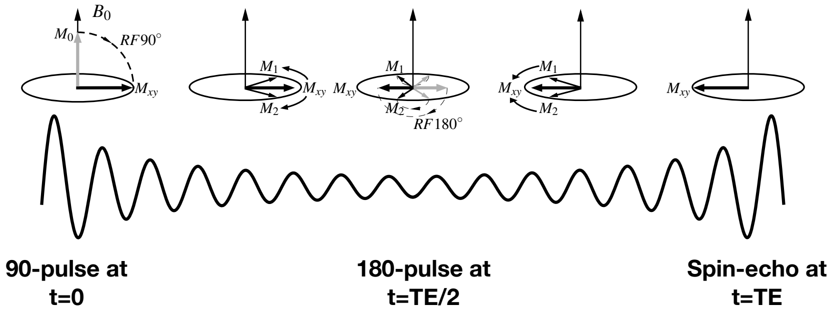
Today's Intended Learning Objectives

- 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.
- Explain strategies for collecting k-space data and how to reconstruct the image from it.



From Lars' lecture notes

Spin-Echo



- 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.