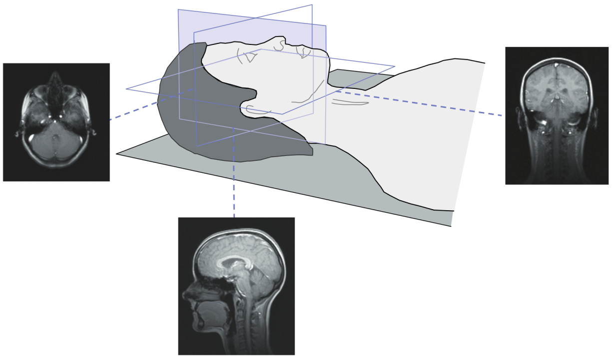
BASICS OF SIGNAL ENCODING

Learning Outcomes

- **Magnetic field gradients** form the basis of MR signal localization
- 2D slices are produced by the combination of an **excitation RF pulse and simultaneous slice-select gradient**
- The in-plane MR signal is encoded in terms of the spatial frequencies of the object using **phase-encoding and frequency-encoding gradients**
- We sample every spatial frequency that exists within the image and then **Fourier transform** these data (known as k-space) to produce an image
- Inadequate or erroneous k-space sampling leads to certain **artifacts**

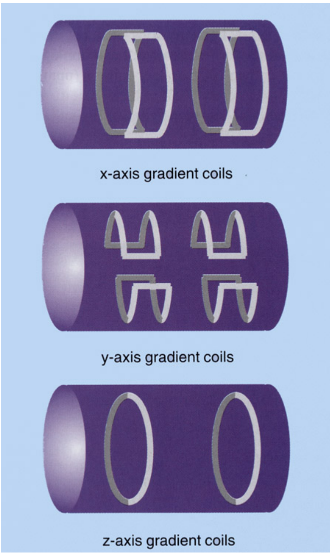
Magnetic Resonance Imaging or Tomography



- Tomography:
  - Tomos: cut, section
  - Graphein: to write

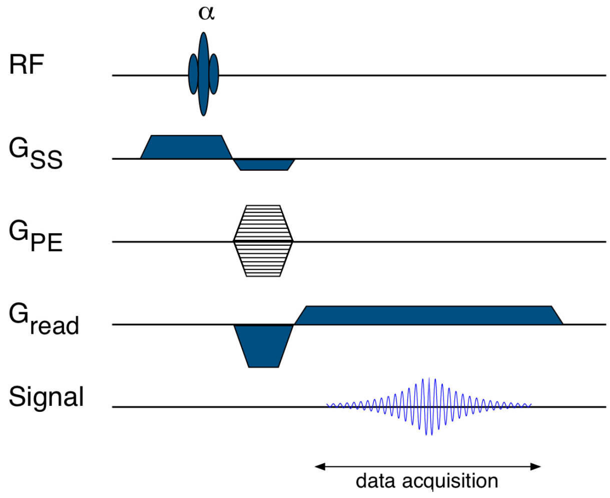
→ Signal measured as a function of space

Imaging Gradients



- There are coils which produce the main magnetic field (B_0 = 7T in our case).
- In addition, there are several other coils making small, additional magnetic fields which vary linearly in space. These are called **gradient coils**.
- These small additional magnetic fields are present in X, Y and Z direction. Without them, we can not say where in the tissue the signals come from.

Basic Pulse Sequence



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Slice, Phase and Frequency Encoding in K-Space

- **Slice-encoding:** a combination of an RF pulse and a gradient excites spins within a plane → slice-selective gradient
- **Phase-encoding:** a constant gradient is applied for a specific duration before acquisition of the signal for every phase-encoding step
- **Frequency-encoding:** a constant readout gradient is applied during acquisition of the signal (echo)
- Total scan time: NSA x N_{PE} x TR

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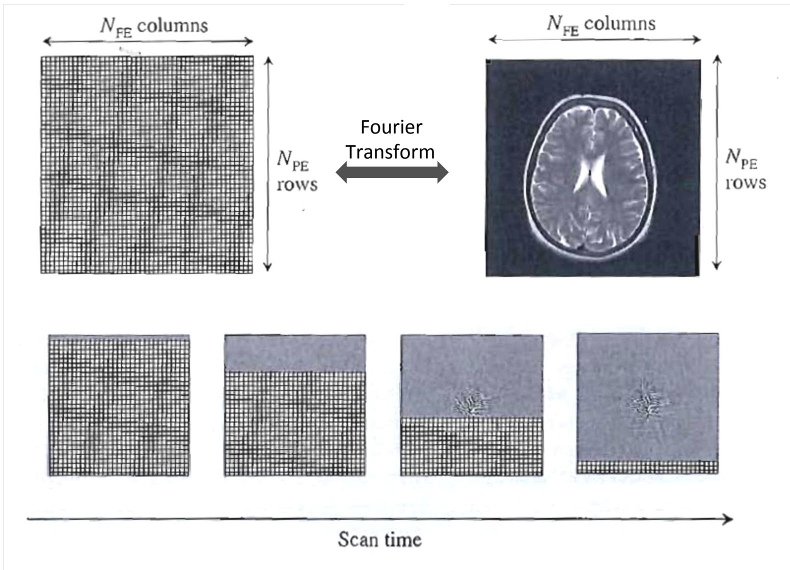
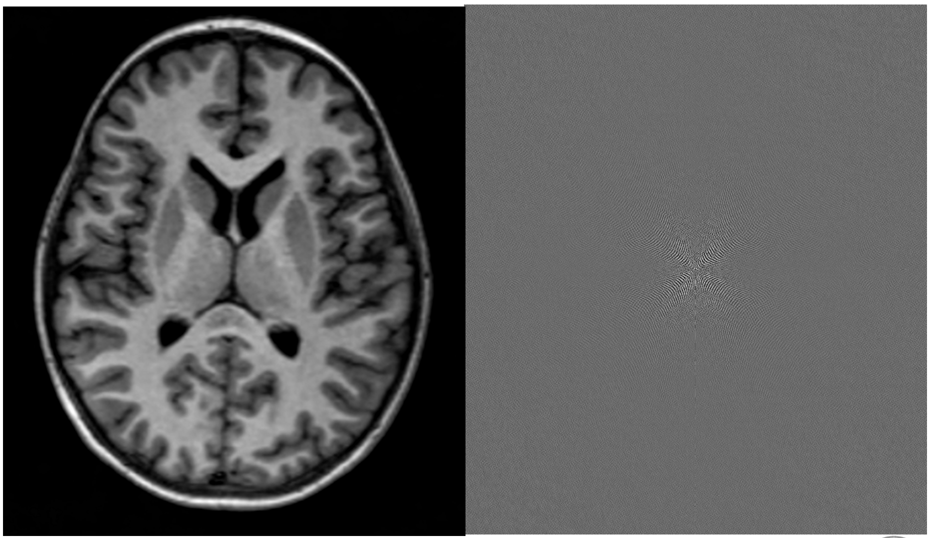
From K-Space to Image Space



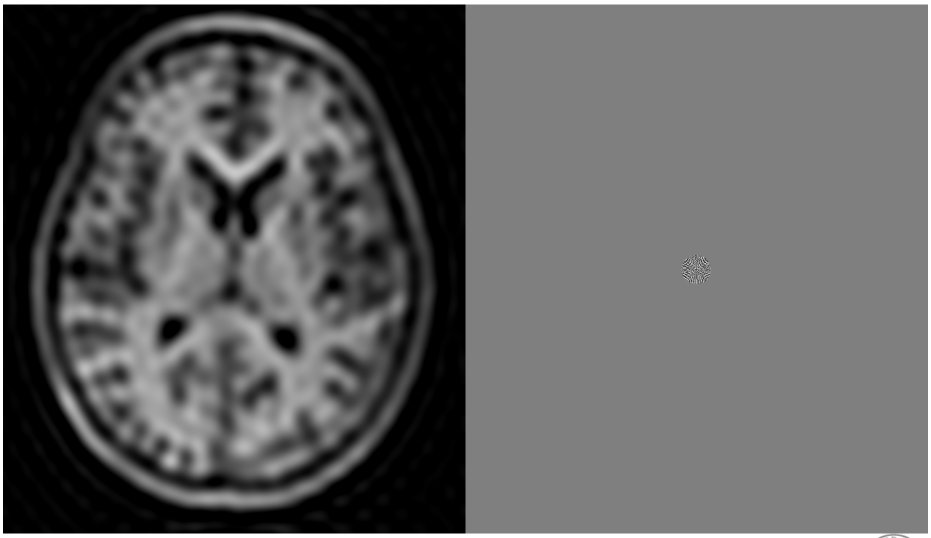
The K-Space

- Think of it as temporary image space
- Data is collected in k-space and then FT to image space
- The matrix size of the final image is the same as the matrix size of k-space
- There is no pixel-to-pixel correspondence between k-space and image space; instead, each pixel of image space contains information from the entire k-space, and vice-versa
- Data in the middle of k-space contain SNR and contrast information
- Data from the edges of k-space contain all the information about the image resolution

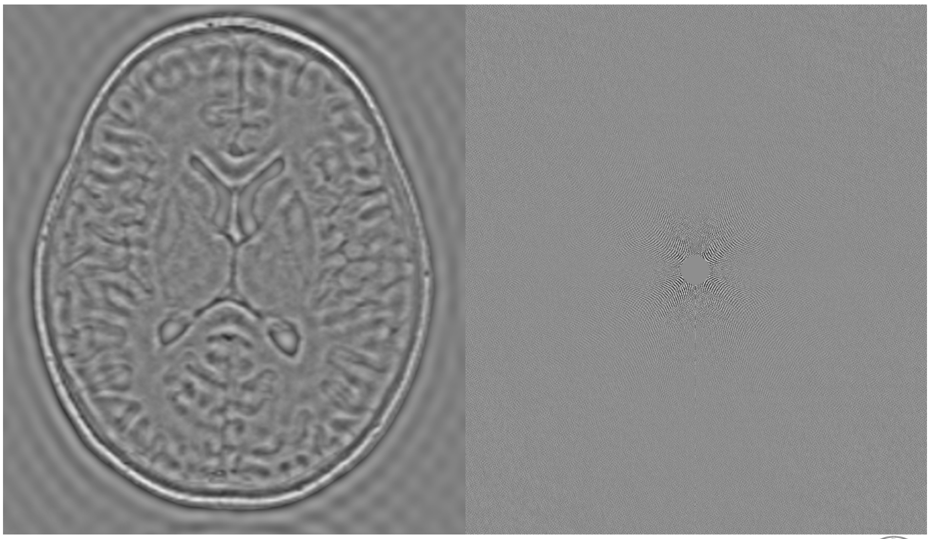
Understanding K-Space: Image and K-space



Understanding K-Space: Low-Pass Filtering

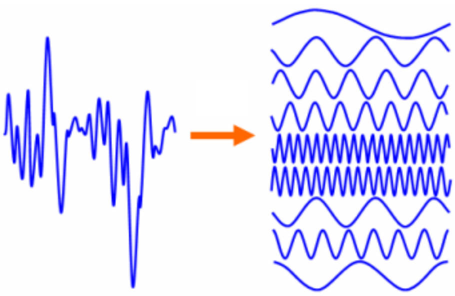


Understanding K-Space: High-Pass Filtering



How to move between image and k-space: Inverse Fourier Transform

Joseph Fourier



Any signal in time could be split into a series of Fourier components, each at a different frequency

Time domain →FT→ *Frequency Domain*

K-space domain →IFT→ *Image domain*

Time domain, Frequency domain, K-space and Image domain: How it all relates?

Time Domain → FT → Temporal Frequency Domain

t → FT → *f*

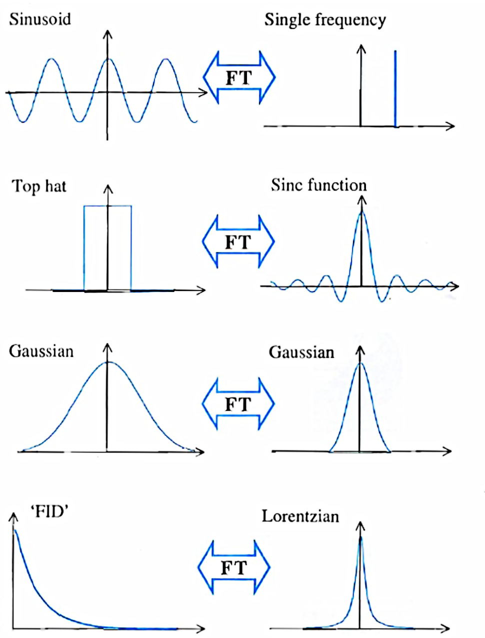
seconds → FT → Hz

K-space domain or
Spatial Frequency Domain → IFT → Image Domain

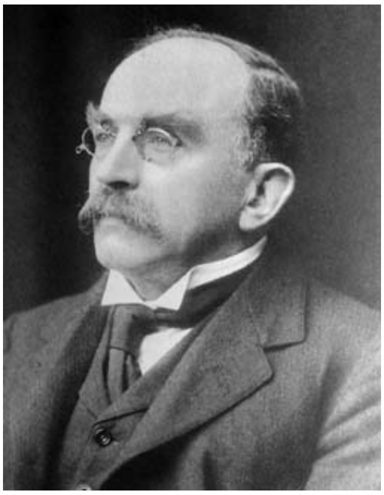
k → IFT → r

1/cm → IFT → cm

Fourier Pairs



Back to Image Encoding: Larmor Frequency



Sir Joseph Larmor

$$f = \frac{\gamma}{2\pi} B_0 \text{ or } \omega = \gamma B_0$$

$$\frac{\gamma}{2\pi} = 42 \text{ MHzT}^{-1} \quad \gamma = 2.67 \times 10^{8} \text{radians s}^{-1} \text{ T}^{-1}$$

Spin precession is proportional to magnetic field strength

Gradients

Signal localization

Magnetic Field Gradients

- Gradient = spatially-linear variation in the static field strength in the z-direction

$$G_x = \frac{\partial B_z}{\partial x} \quad G_y = \frac{\partial B_z}{\partial y} \quad G_z = \frac{\partial B_z}{\partial z}$$

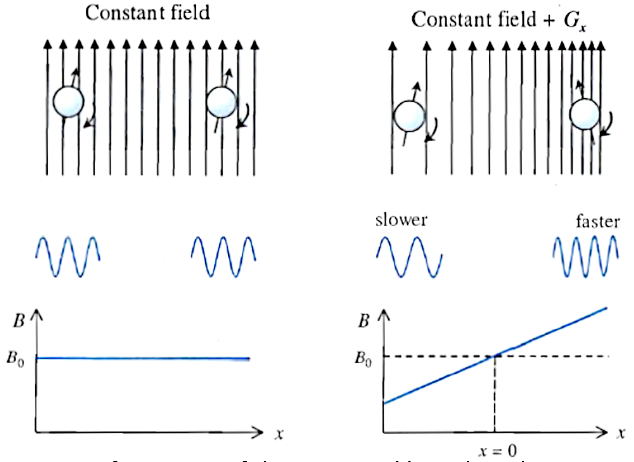
$$B_z(x) = B_0 + x \cdot G_x$$

$$B_z(y) = B_0 + y \cdot G_y$$

$$B_z(z) = B_0 + z \cdot G_z$$

Magnetic Field Gradients: Freq. of Precession

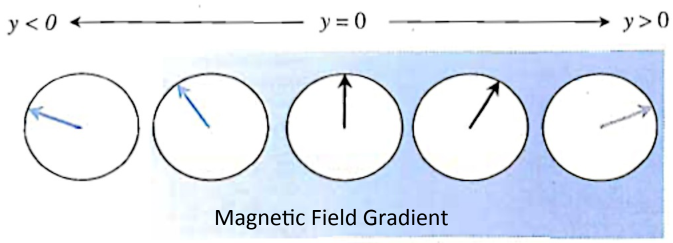
What happens to the MR signal if we apply a gradient field?



- Variation in frequency of the MR signal based on the position of spins with respect to the gradient field

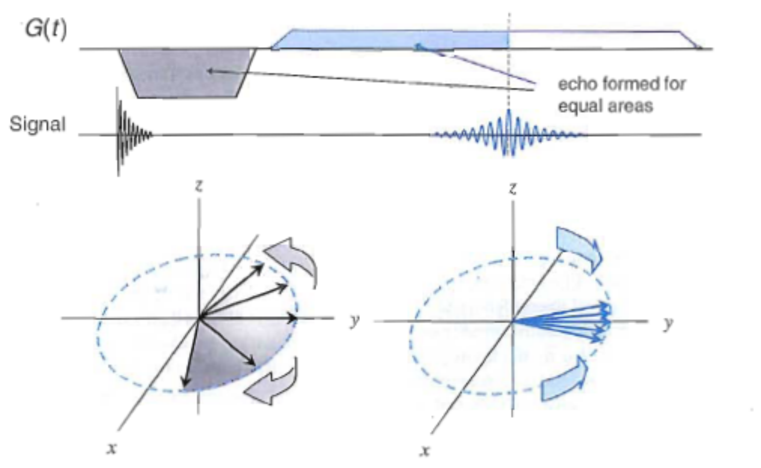
Magnetic Field Gradients: Spin Phase

- What happens to the MR signal if we apply a gradient field for a period of time (and then turn it off)?

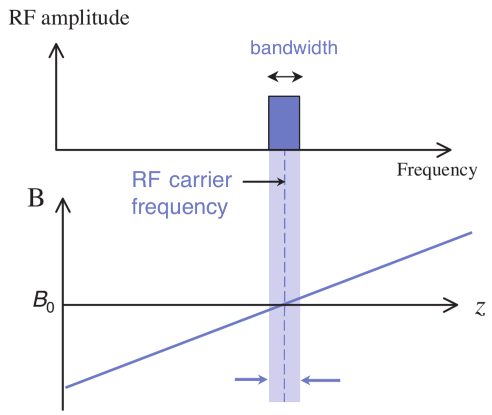


- Dephasing of spins → Fanning out
- Angle of dephasing depends on the strength of the gradient and its duration

Dephasing and Rephasing: Gradient Echo



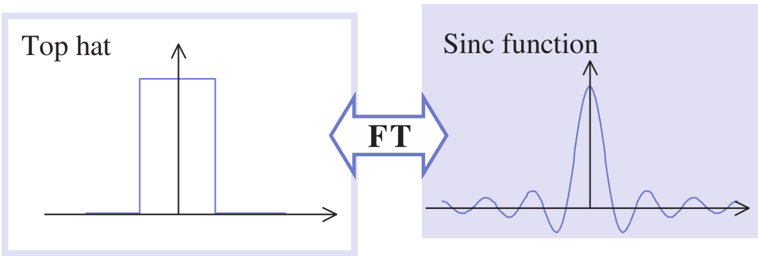
Slice Selection: Selective Excitation



- Applying a gradient in z-direction during the RF pulse
- Larmor frequency: $\omega_0(z) = \gamma(B_0 + G_{ss}z)$

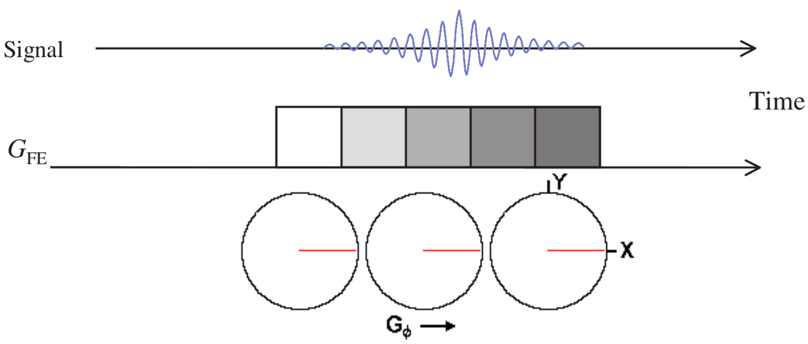
Slice Selection: Selective Excitation

- Applying RF pulse with desired spectrum results in transversal magnetization in selected slice
- Slices with sharp transitions are desired (distinct slices)
- Envelope function of RF pulse approximates the sinc function

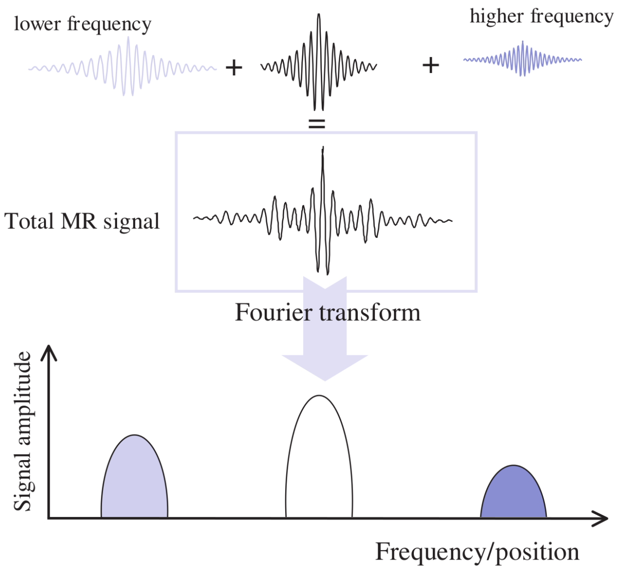


Frequency Encoding

- Applying gradient (e.g. along x direction) during readout
- Larmor frequency: $\omega_0(x) = \gamma(B_0 + G_{FE}x)$
- Amplitude of measured signal is 1D projection of the object along frequency-encoding direction



Frequency Encoding



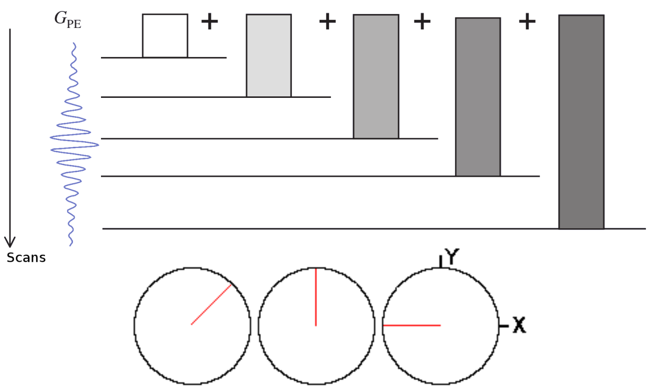
Phase Encoding

We now encoded the signal along x (readout) direction. Can we do the same for the y direction?

- No, the frequency encoding method works only in 1 spatial dimension
- Combining gradients (x and y, for instance) would lead to an oblique slice in the frequency-encoding direction
- Another mechanism must be employed to encode the second dimension –> **Phase encoding**

Phase Encoding

- Gradient (e.g. along y direction) is applied for a fixed amount of time before readout
- Results in a phase angle $\phi_P = \gamma G_{PE} y T_y$



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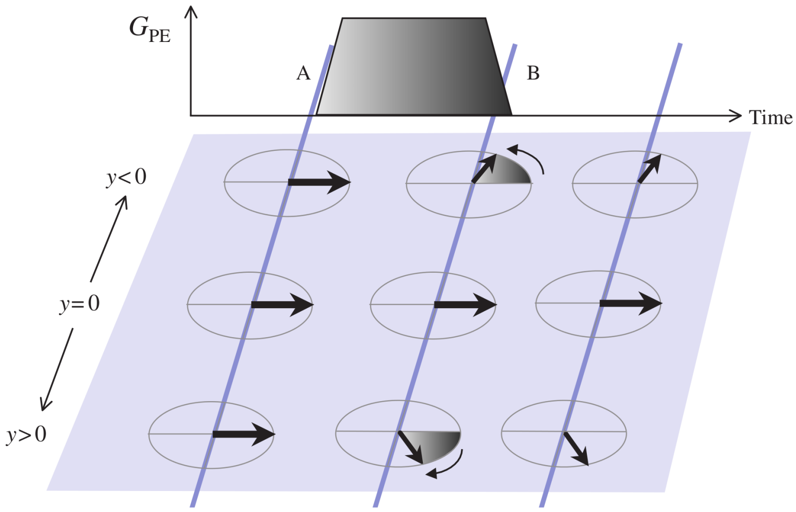
Phase Encoding



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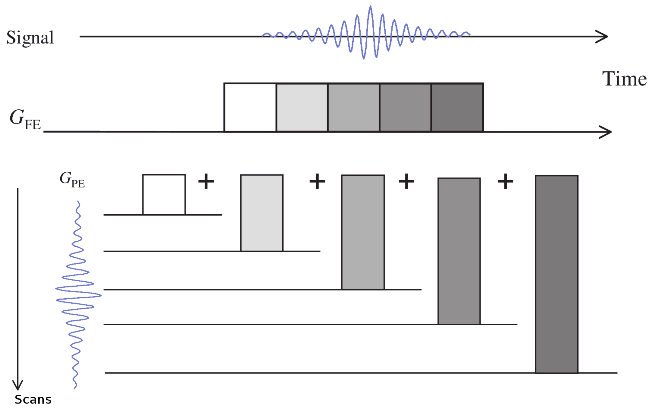
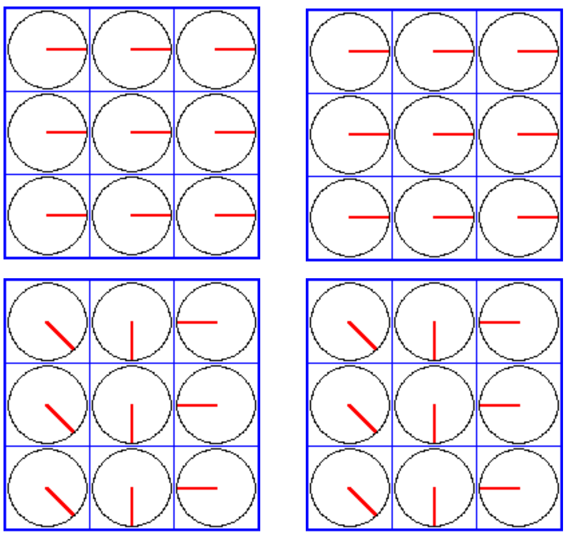
Phase and Frequency Encoding

- Unlike frequency encoding, phase encoding can be done in multiple dimensions
- As many measurements as scanned rows needed
- Can think of it as frequency encoding in pseudo time



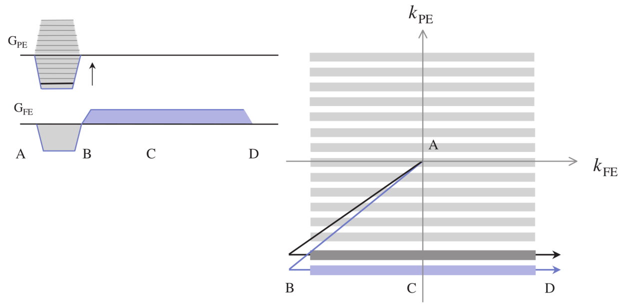
Phase Encoding



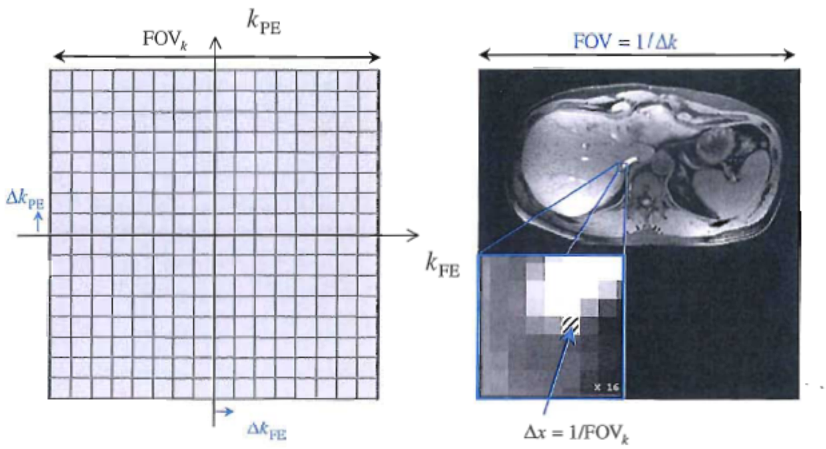
Stepping through K-Space

- To reconstruct an image, k-space has to be adequately sampled
- Different sampling techniques
  - Minimization of imaging artifacts
  - Time-saving techniques
- Steps through k-space:

$$\Delta k_x = \gamma G_{FE} \Delta t$$
$$\Delta k_y = \gamma \Delta G_{PE} T_y$$



Relationship between k-space and image resolution and FOV



Video 2: Introduction to k-space

References

- D. W. McRobbie, E. A. Moore, M. J. Graves, M. R. Prince: MRI: From Picture to Proton, 2nd edition, Cambridge University Press, Cambridge, 2006.
- Joseph P. Hornak: The Basics of MRI: http://www.cis.rit.edu/htbooks/mri/inside.htm
- http://epileptologie-bonn.de/cms/upload/homepage/lehnertz/JKoch_MRISignaltoImage.pdf