# MRI image formation

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## Disclosure

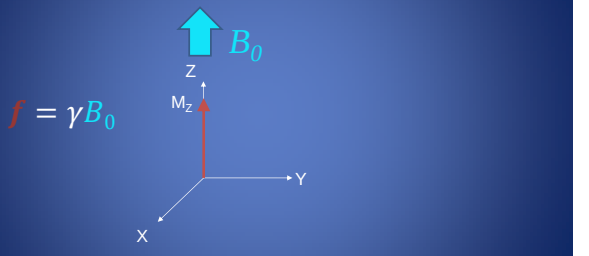
- No conflict of interest for this presentation



## Outlines

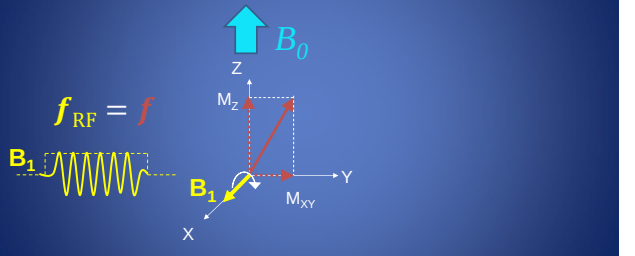
- Data acquisition
  - Spatial (Slice/Slab) selection
  - Spatial encoding (using frequency and phase)
- Image reconstruction
  - *K*-space
  - Fourier Transform
- Signal-to-noise ratio
  - Signal intensity
  - Source of noise

## Free Precession



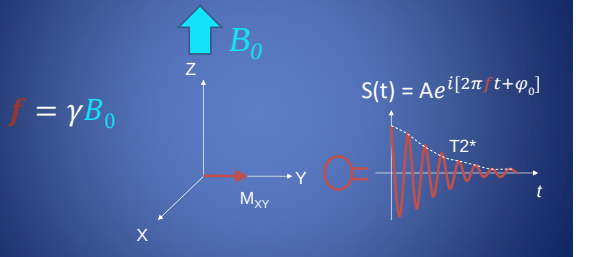



## Excitation



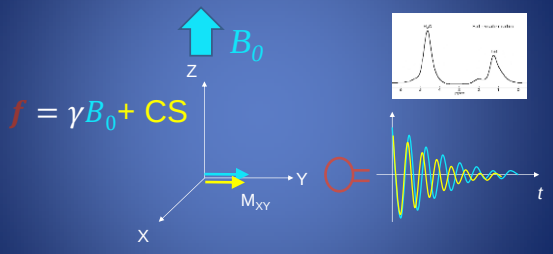



## Signal



## Chemical Shift (CS)

$f = \gamma B_0 + CS$

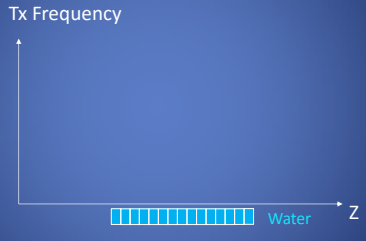


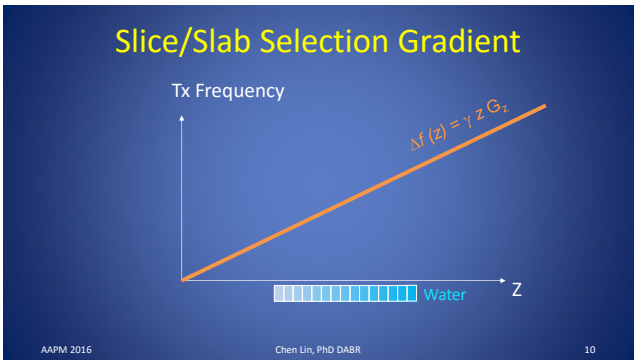



## SPATIAL SELECTION AND ENCODING



## Slice/Slab Selection Gradient




Slice/Slab Selection Gradient
Tx Frequency
Δf (z) = γ z Gz
Water
Z
AAPM 2016
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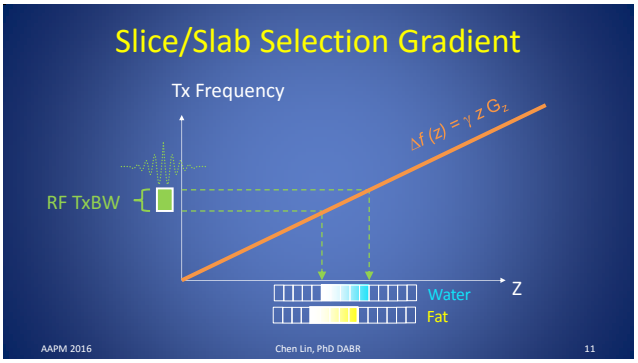
10


Slice/Slab Selection Gradient
Tx Frequency
Δf (z) = γ z Gz
RF TxBW
Water
Fat
Z
AAPM 2016
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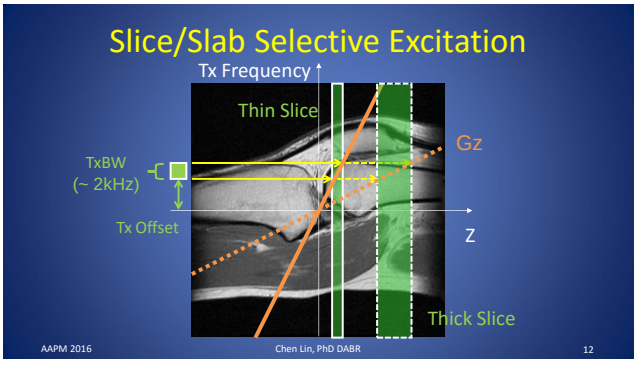
11


Slice/Slab Selective Excitation
Tx Frequency
Thin Slice
Gz
TxBW
(~ 2kHz)
Tx Offset
Z
Thick Slice
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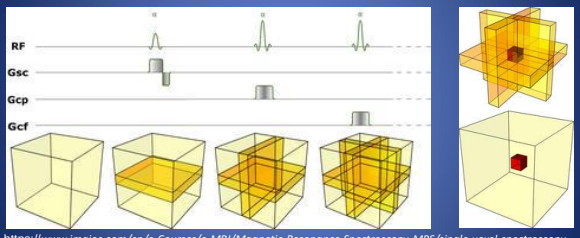
12

## Slice Selective Excitation and Refocusing

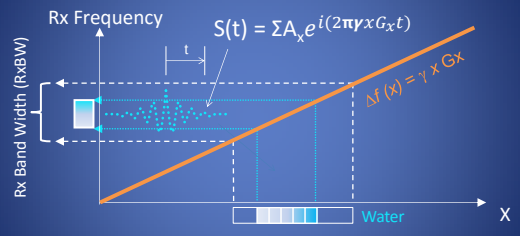





https://www.imaios.com/en/e-Courses/e-MRI/Magnetic-Resonance-Spectroscopy-MRS/single-voxel-spectroscopy

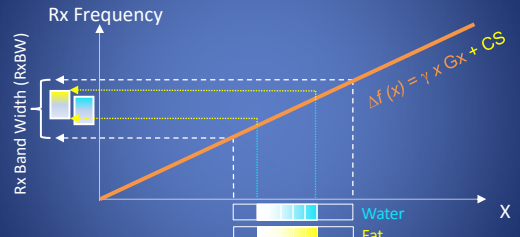


## Frequency Encoding Gradient

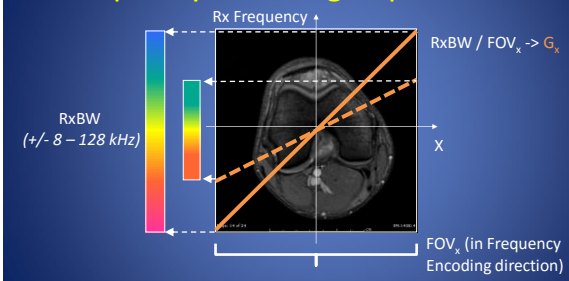





## Frequency Encoding Gradient

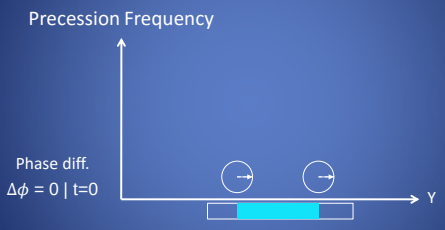


## Frequency Encoding Implementation



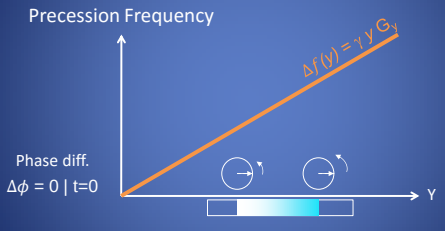



## Phase Encoding

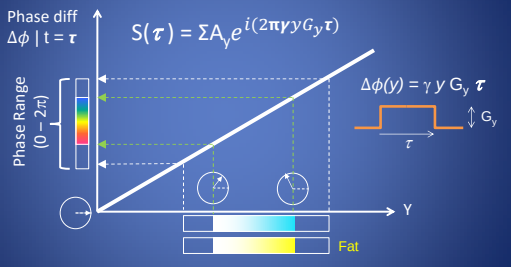





## Phase Encoding Gradient

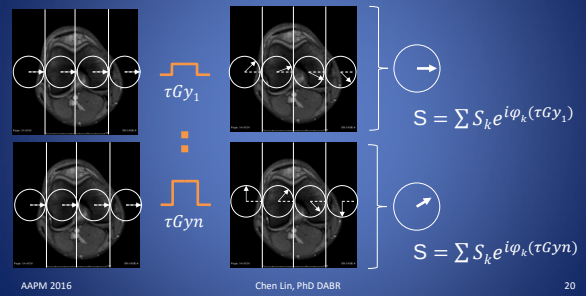


## Phase Encoding Gradient



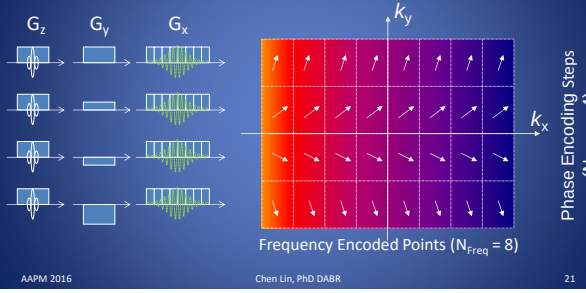



## Phase Encoding Implementation

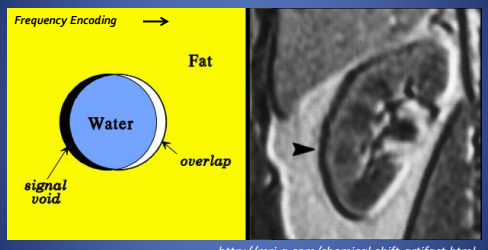





## Spatial Selection and Encoding in 2D MRI



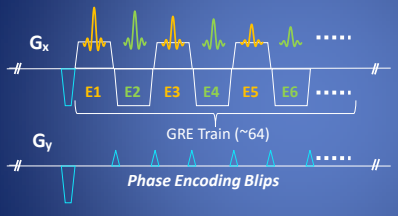
## Chemical Shift Artifact

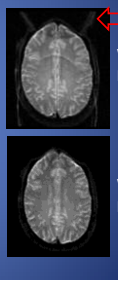



http://mri-q.com/chemical-shift-artifact.html



## Chemical Shift Artifact in SS-EPI



Without FatSat

With FatSat



## Frequency and Phase Encoding

- Each encoded data point is a Fourier series.
- Frequency encoding
  - More efficient, no aliasing (using a low pass filter)
  - Frequency Encoding typically used in the direction of higher resolution or greater coverage
  - Chemical shift artifact (can be minimized with high RxBW)
- Phase encoding
  - More time consuming ($N_{PE}$ * TR), does improve SNR
  - Can be used more than once

## Spatial Selection & Encoding

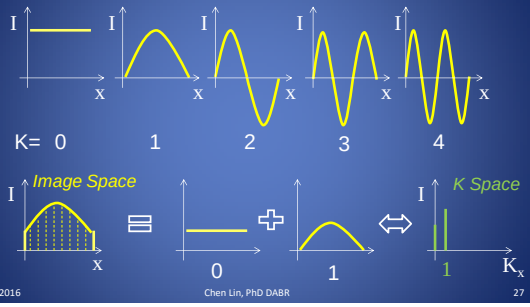
- Heavily rely on the imaging gradients
  - Gradient non-linearity -> Spatial distortion
  - Gradient performance -> Acquisition time and min. FOV
  - Gradient stability -> Artifacts
- Any combinations of the three orthogonal physical gradients can be used for spatial selection or encoding



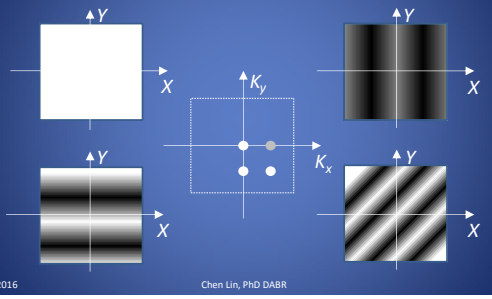
## K-SPACE AND FOURIER TRANSFORMATION



## K: Wave Number or Wave Index

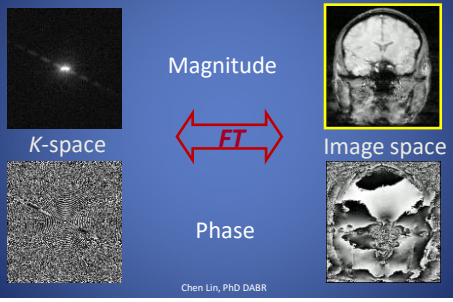


## 2D Image <-> 2D *K*-space





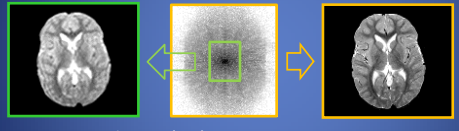

## *k*-space <-> Image space






## Information in *K*-space

- Inner *k*-space (Low spatial freq.) -> Intensity/Contrast.
- Outer *k*-space (High spatial freq.) -> Edges/Details.



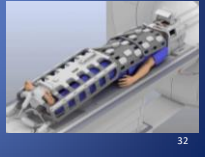
- *K*-space resolution ($\Delta K$) -> Image FOV.
- *K*-space range ($K_{max}$) -> Image resolution.
- Symmetry -> Allows partial *k*-space acquisition.

# SIGNAL-TO-NOISE RATIO (SNR)



## Signal and Noise

- Proton Density (PD)
- Voxel size ($\Delta x\ \Delta y\ \Delta z$)
- Field Strength ($B_0$)
- Receiver coil sensitivity
- Sequence type and parameters
- Relaxation Properties.
- Averages (NEX)
- Patient / Object.
- Components (receiver coils & electronic components) in receiving chain.

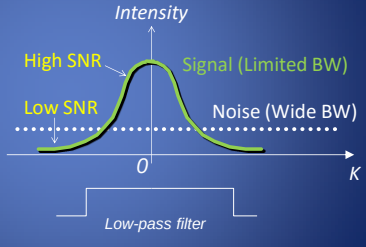




## Noise and *K*-space filter

Noise in MRI

- Stochastic Process / thermal motion of electrons
- "White noise"



## Signal to Noise Ratio (SNR)

- SNR: Signal / Noise
  Signal: Average of pixel intensity (in a signal region)
  Noise: Fluctuation (Stdev ) of pixel intensity (in a noise region)

$$SNR \sim f(\text{Sequence Type, FA, TR, TE, TI ...}) * PD\ B_0\ \Delta x\ \Delta y\ \Delta z\ \left( N_{phase} * NEX / rBW \right)^{1/2}$$

- Scan time = $N_{phase}$ * NEX * TR
- SNR Efficiency = SNR / Scan Time
- Contrast to Noise Ratio (CNR) = $|S_{Tissue1} - S_{Tissue2}|$ / Noise



## Thank you !

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