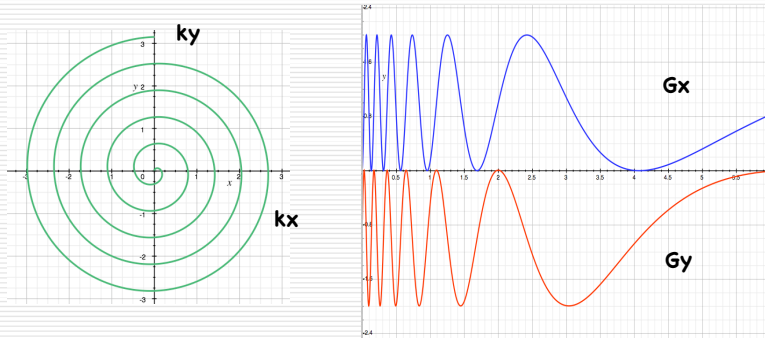
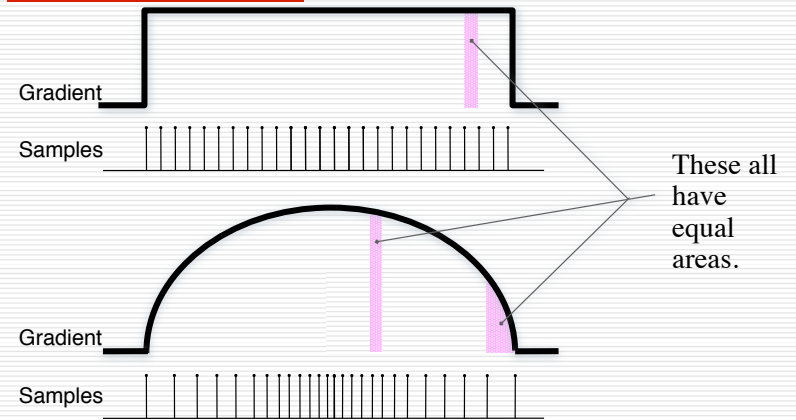


# Spiral



# Equivalent Strategies in k-space\*

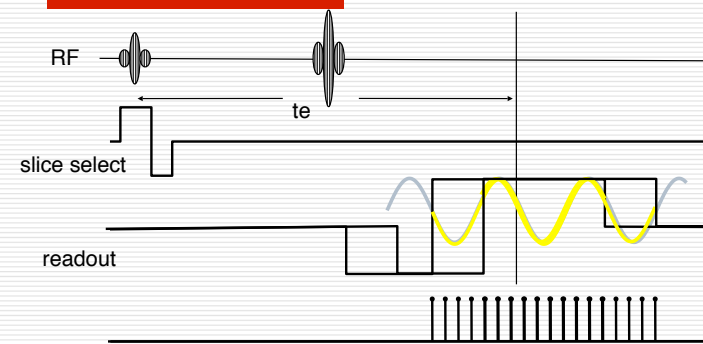


\*Ignoring effects of signal decay and sample motion

# A Pulse Sequence Controls

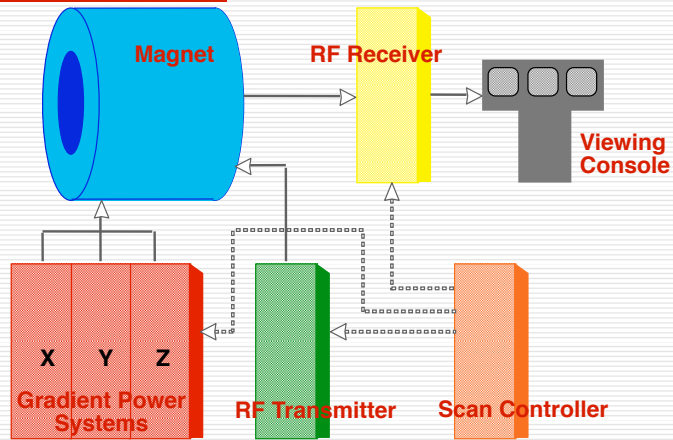
- Slice Location
- Slice Orientation
- Slice Thickness
- Number of Slices
- Resolution (FOV and Matrix)
- Contrast *TR, TE, TI, Flip Angle, Diffusion, etc...*
- Artifact Correction *Saturation Pulses, Flow Comp, Fat Suppression, etc...*

# Phase Maps



- Time shift in data collection amounts to a phase offset
- Spins precessing at different rates (different magnetic fields) will acquire different phase shifts

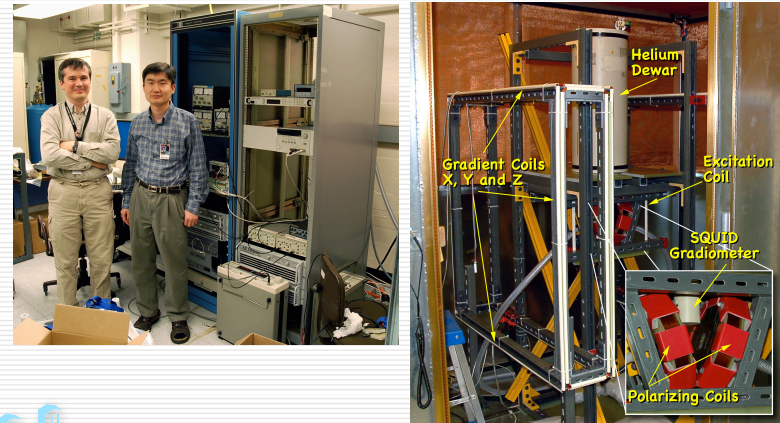
# Imaging System Components



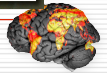
©2007 Mark Cohen, all rights reserved



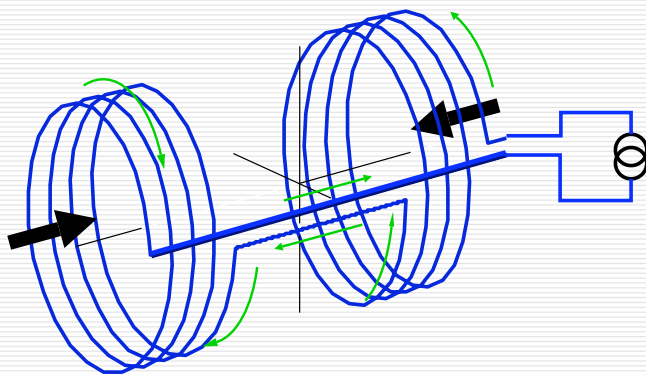
# System Components



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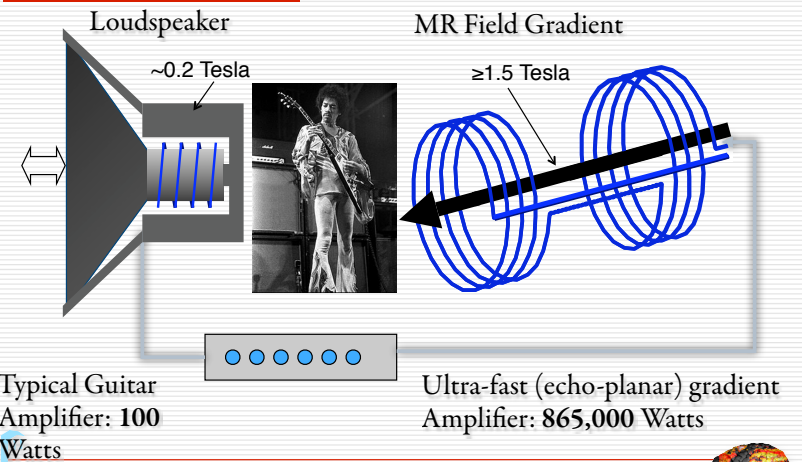
# MR Field Gradient Coil



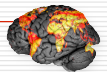
©2007 Mark Cohen, all rights reserved



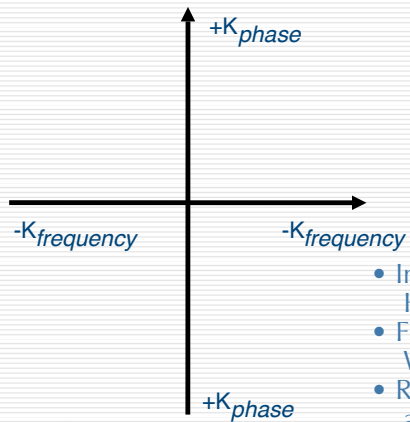
# Why is MRI So Noisy?



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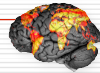
## Properties of K-Space



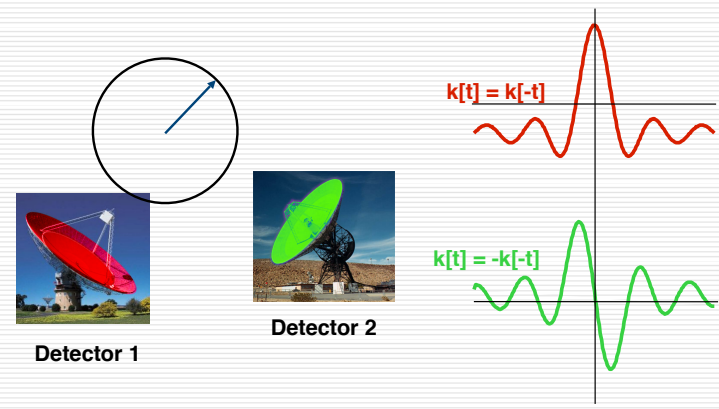
- Increasing K values Represent Higher Resolution
- Finer Grain Sampling Results in Wider FOV
- Reflections Across  $K=0$  are approximate Complex Conjugates



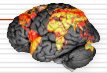
©2007 Mark Cohen, all rights reserved



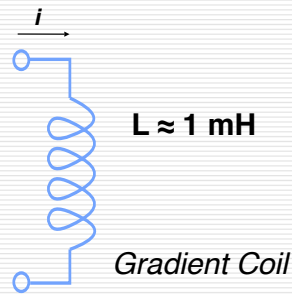
## Raw Data Symmetry



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## Gradient Coil Characteristics

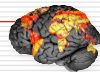


**Gradient Strength =  $k i$**

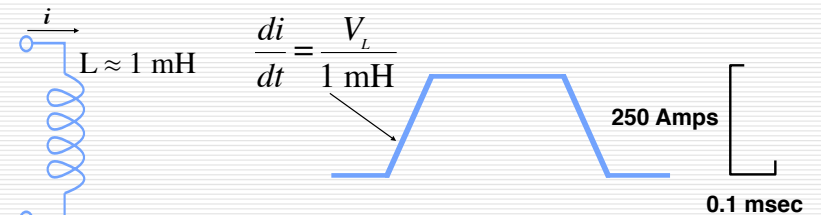
**$k \approx 1 \text{ Gauss/cm} / 100 \text{ Amps}$**



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## Rise Time, Current and Voltage

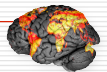


For: 250 Amps in 100  $\mu\text{sec}$   
 $V_L = 2500 \text{ Volts}$

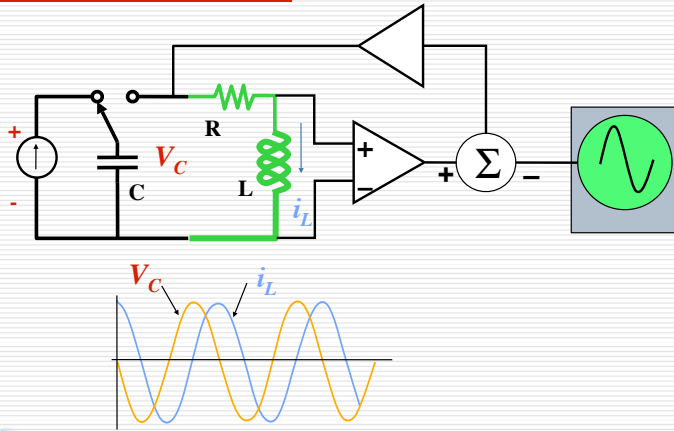
Power = 2500 Volts  $\times$  250 Amps  
 $= 6.25 \times 10^5 \text{ Watts}$



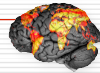
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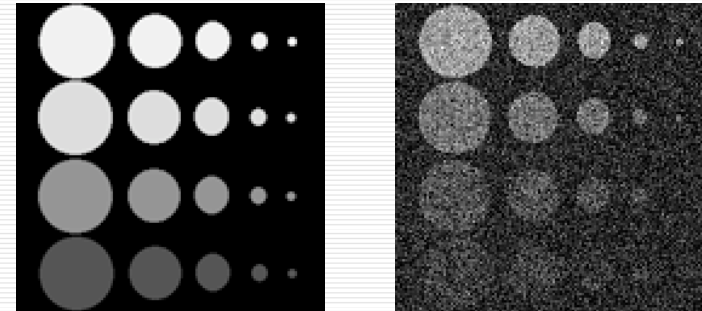
# Resonant Gradient



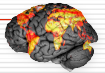
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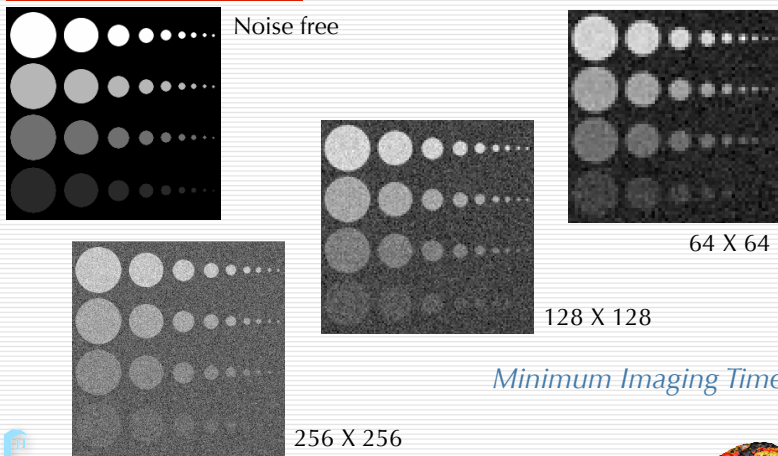
# Contrast to Noise Ratio



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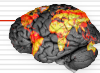
# CNR vs. Resolution



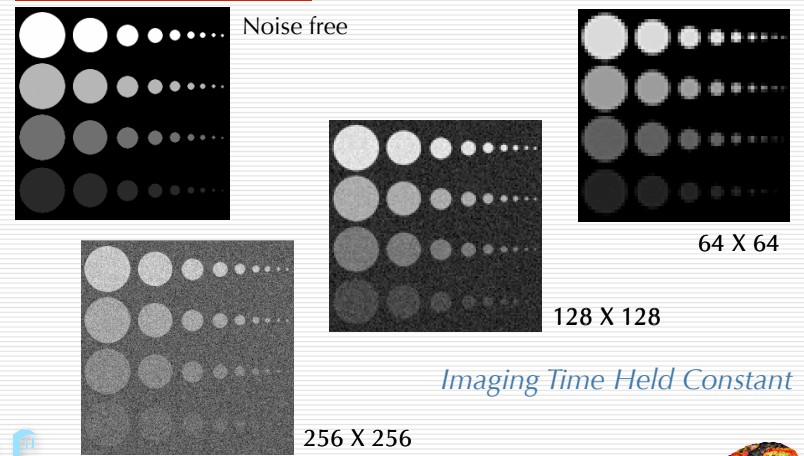
*Minimum Imaging Time*



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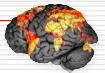
# CNR vs. Resolution



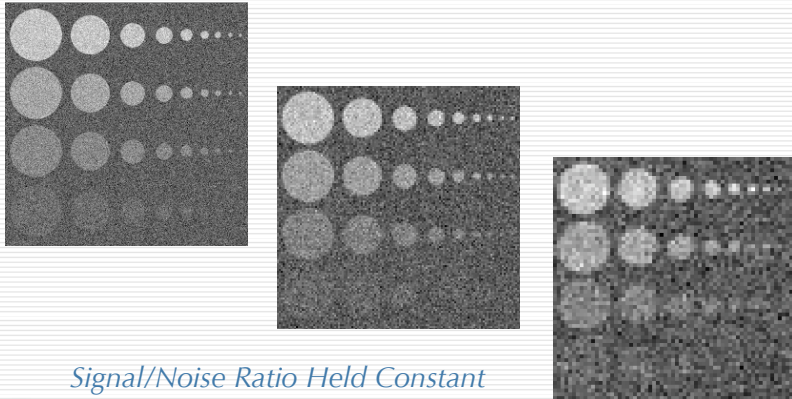
*Imaging Time Held Constant*



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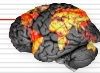
## CNR vs. Resolution



Signal/Noise Ratio Held Constant



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## An "Equation" in Resolution

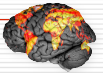
Because MR is an emission modality the temporal resolution, spatial resolution and contrast are inter-dependent:

$$\text{Signal} = k B_0 \text{voxel size} \sqrt{\text{imaging time}} \\ \text{-- contrast}$$

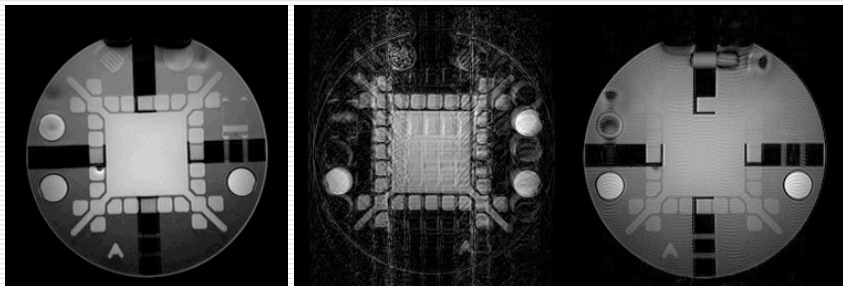
where  $B_0$  is the field strength.



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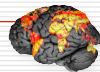
## Motion Artifact



[http://porkpie.loni.ucla.edu/BMD\\_HTML/SharedCode/Motion/motion.html](http://porkpie.loni.ucla.edu/BMD_HTML/SharedCode/Motion/motion.html)



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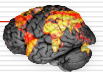
## Bandwidth and Readout

- Position is encoded by FREQUENCY
- Bandwidth refers to the Frequency Difference from the center of the image to its edge:  
$$\text{Frequency per pixel} = \frac{2 * \text{Bandwidth}}{\text{number of pixels}} = \frac{1}{\text{readout duration}}$$

- Bandwidth decreases with readout duration:  
$$\text{Bandwidth} = 2 * \frac{\text{number of pixels}}{\text{readout duration}}$$



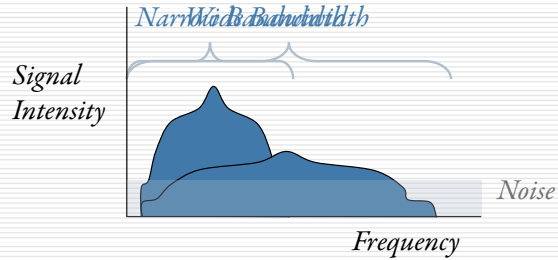
©2007 Mark Cohen, all rights reserved



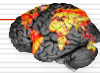
## Bandwidth and SNR

Decreasing the Bandwidth Improves SNR:

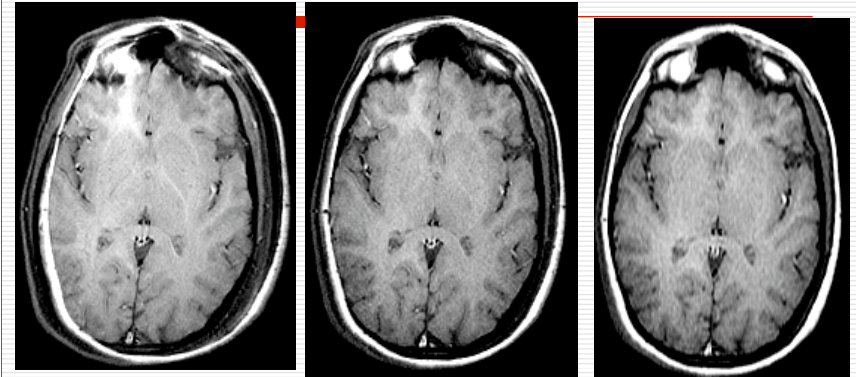
Imaging Time is INCREASED and high frequency noise is excluded



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## Bandwidth



BW=4kHz

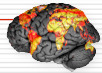
BW=8kHz

BW=16kHz

TE=11-14 NEX=1 Thick=3mm  
TR=500 Matrix=256x256

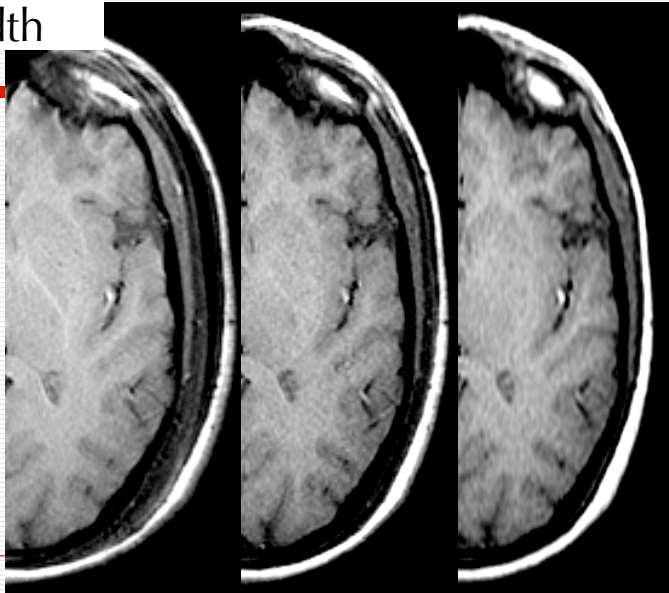


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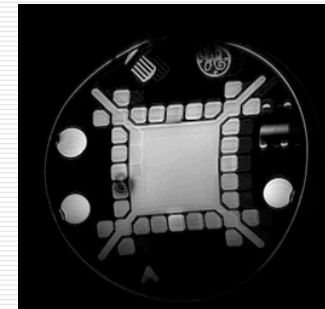
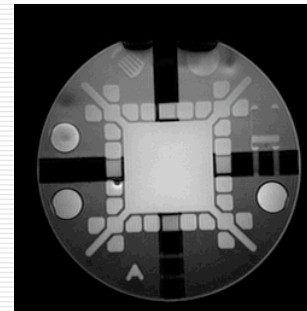
## Bandwidth

TE=11-14  
NEX=1  
Thick=3mm  
TR=500  
Matrix=256x256

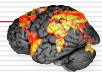


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## Shape and Bandwidth



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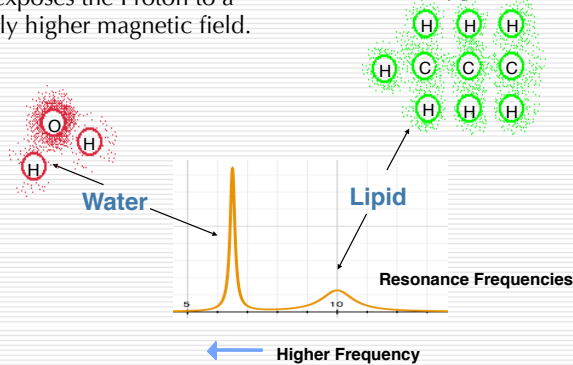


## The Origin of Chemical Shift

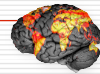
In water, electrons move from Hydrogen towards Oxygen.

This exposes the Proton to a slightly higher magnetic field.

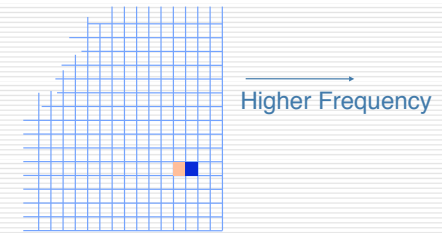
Electrons in lipid are shared equally between Hydrogen and Oxygen



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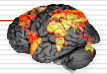
## Chemical Shift Artifact



If the frequency *width* of each pixel is less than the frequency *difference* between **water** and **lipid**, then **water** and **lipid** will appear in separate pixels



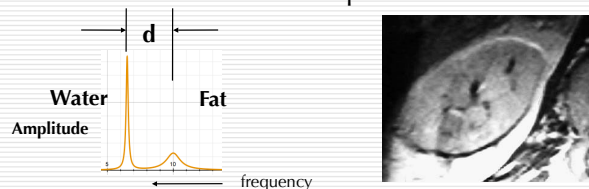
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## Chemical Shift

**The Fat-Water chemical shift is about 3.5 ppm or:**

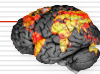
<i>Which is:</i>	<i>with a 32 kHz readout</i>
75 Hz @ 0.5 Tesla	< 1 pixel
150 Hz @ 1.0 Tesla	≈ 1 pixel
220 Hz @ 1.5 Tesla	> 1 pixel
440 Hz @ 3.0 Tesla	≈ 3.5 pixels



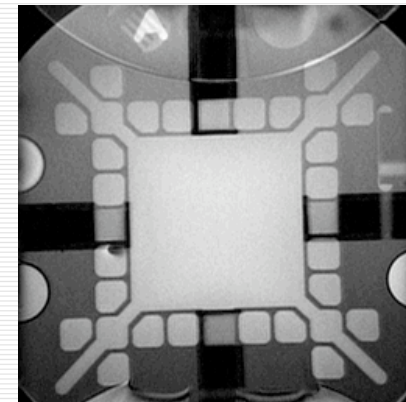
Lowering the Bandwidth/pixel increases the Chemical Shift in pixels



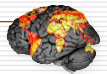
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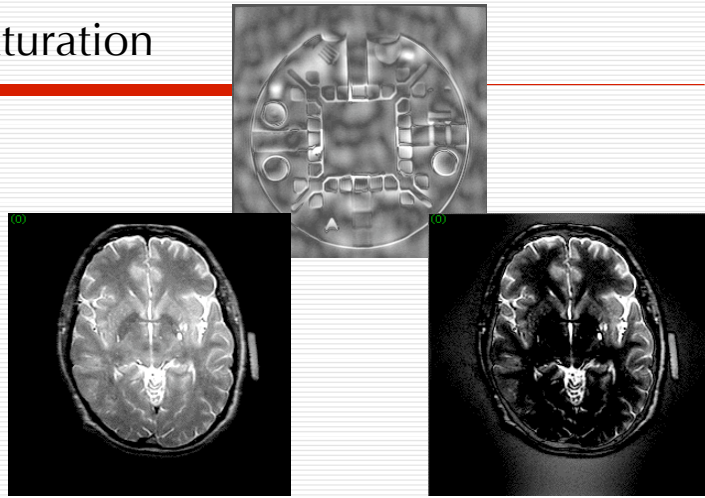
## Aliasing



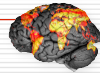
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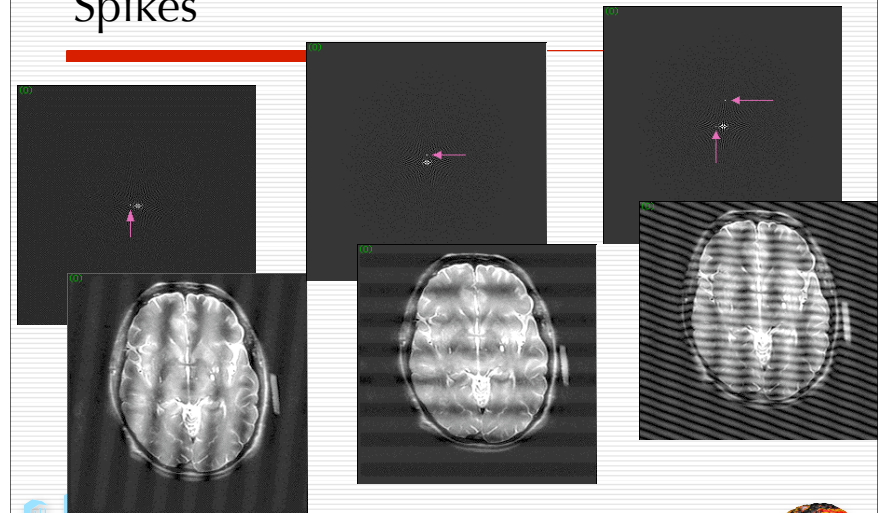
## Saturation



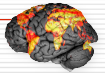
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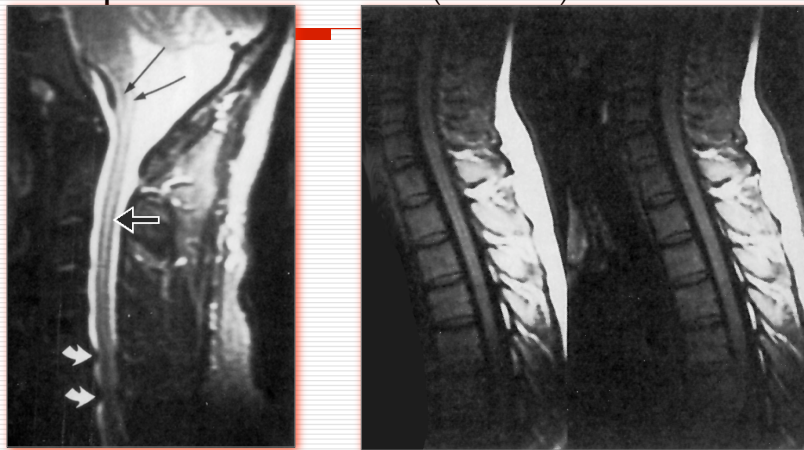
## Spikes



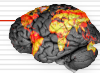
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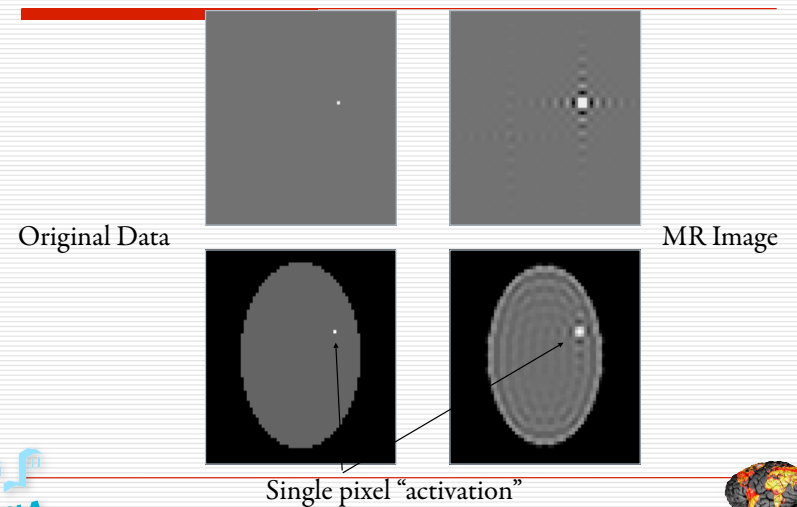
## k-Space Truncation (Gibbs)



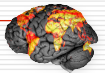
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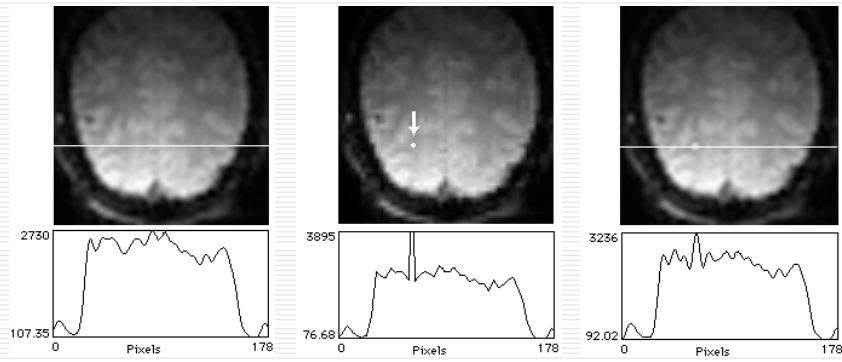
## What is the actual resolution of MRI?



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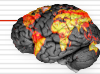
## The Actual Resolution of fMRI



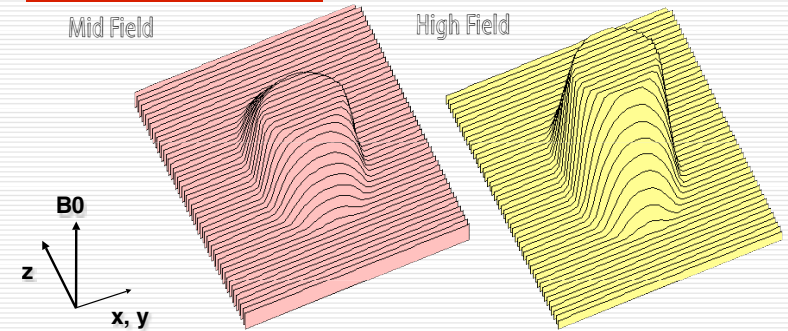
[http://porkpie.loni.ucla.edu/BMD\\_HTML/SharedCode/MRArtifacts/MRArtifacts.html](http://porkpie.loni.ucla.edu/BMD_HTML/SharedCode/MRArtifacts/MRArtifacts.html)



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## Distortions are More Severe at High Magnetic Field Strength

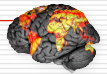


Variation in sample magnetization is proportional to field strength.

→ High Field images lose more signal from field inhomogeneity



Research supported under DA13054  
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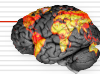


## Crucial Tradeoffs

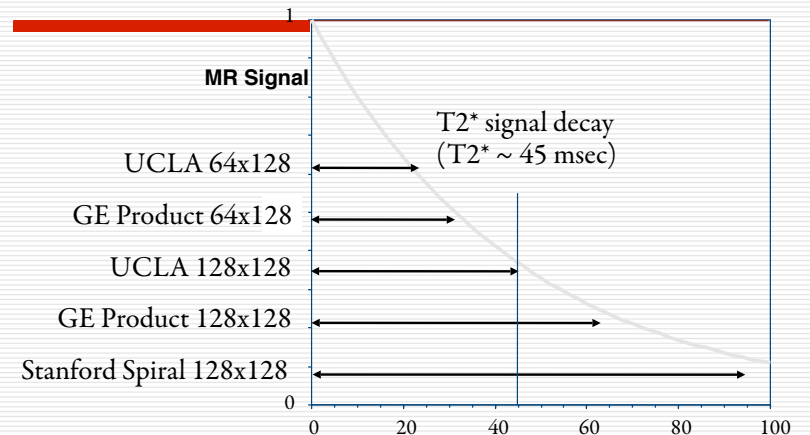
- Magneto-stimulation, spatial resolution, chemical shift artifact, gradient power and signal to noise ratio are ALL interdependent



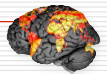
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## EPI Readout Durations



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# Apodization from Long Readouts

