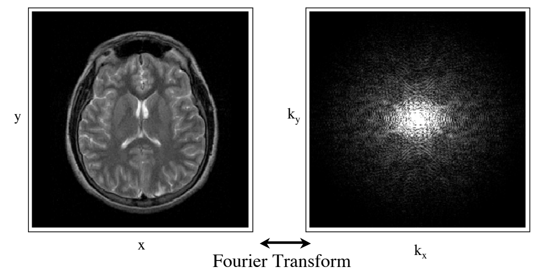
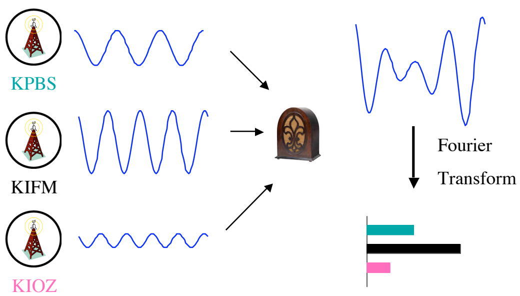
SOMI 276A
FMRI in Cognitive Science: Foundations

Winter Quarter 2006
MRI:
Images and Artifacts

k-space

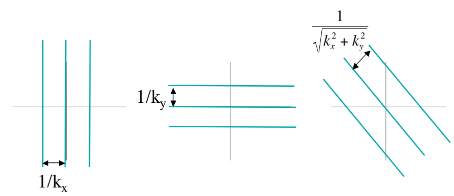


1D Fourier Transform



2D Plane Waves

$$e^{j2\pi(k_x x + k_y y)} = \cos\left(2\pi(k_x x + k_y y)\right) + j\sin\left(2\pi(k_x x + k_y y)\right)$$



$\cos(2\pi k_x x)$ $\cos(2\pi k_y y)$ $\cos(2\pi k_x x + 2\pi k_y y)$

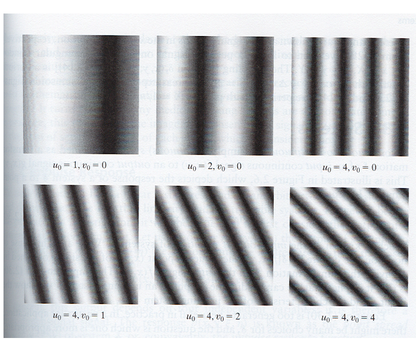
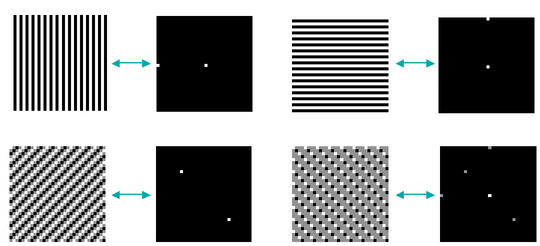
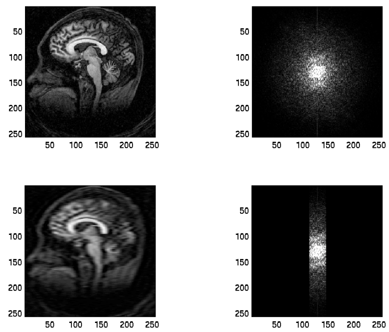


Figure 2.5 from Prince and Link

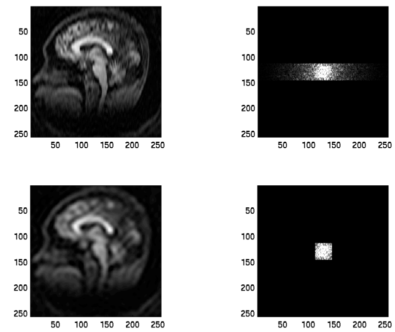
2D Fourier Transform



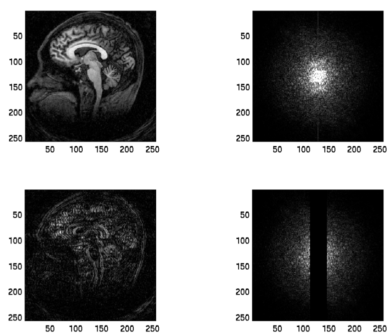
Examples



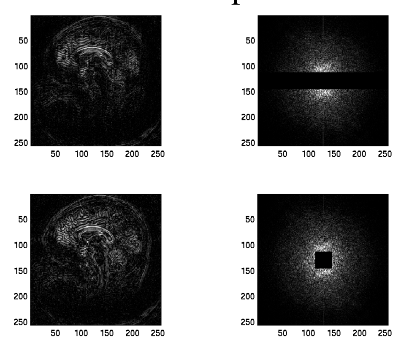
Examples



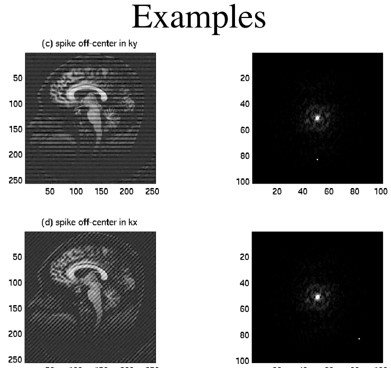
Examples



Examples



Examples



2D Fourier Transform

Fourier Transform

$$G(k_x,k_y)=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} g(x,y)e^{-j2\pi(k_x x+k_y y)}dxdy$$

Inverse Fourier Transform

$$g(x,y)=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} G(k_x,k_y)e^{j2\pi(k_x x+k_y y)}dk_x dk_y$$

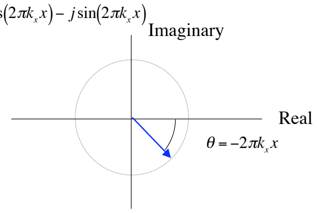
Phasor Diagram

Recall that a complex number has the form

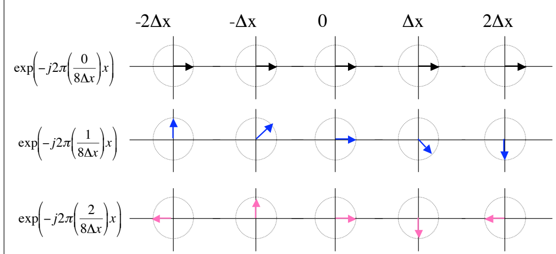
$$z = a + jb = |z|\exp(j\theta) = |z|(\cos\theta + j\sin\theta)$$

where $|z| = \sqrt{a^2+b^2}$ and $\theta = \tan^{-1}(b/a)$

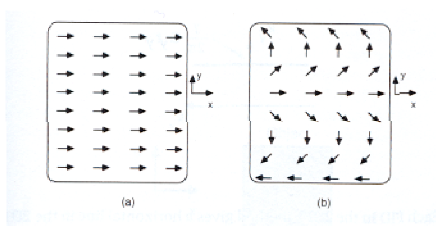
$$e^{-j2\pi k_x x} = \cos(2\pi k_x x) - j\sin(2\pi k_x x)$$



Interpretation



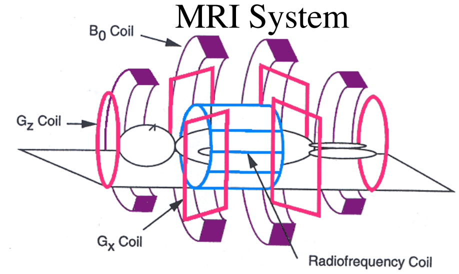
Interpretation



$k_x=0$; $k_y=0$ $k_x=0$; $k_y \neq 0$

Fig 3.12 from Nishimura

MRI System

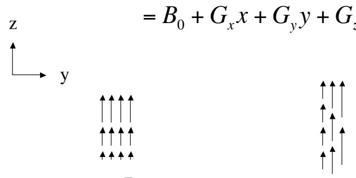


Simplified Drawing of Basic Instrumentation.
Body lies on table encompassed by
coils for static field B_o,
gradient fields (two of three shown),
and radiofrequency field B_1.

Image, caption: copyright Nishimura, Fig. 3.15

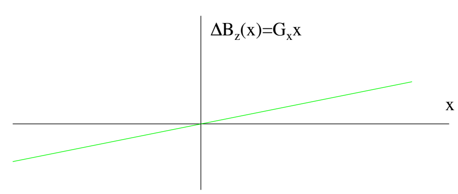
Gradient Fields

$$B_z(x,y,z) = B_0 + \frac{\partial B_z}{\partial x}x + \frac{\partial B_z}{\partial y}y + \frac{\partial B_z}{\partial z}z$$
$$= B_0 + G_x x + G_y y + G_z z$$



$$G_z = \frac{\partial B_z}{\partial z} > 0 \qquad G_y = \frac{\partial B_z}{\partial y} > 0$$

Interpretation

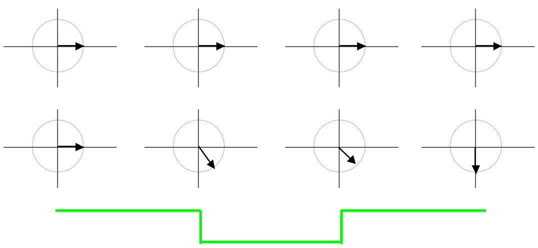


Spins Precess at $\gamma B_0 - \gamma G_x x$ (slower)

Spins Precess at γB_0

Spins Precess at $\gamma B_0 + \gamma G_x x$ (faster)

Phase with time-varying gradient



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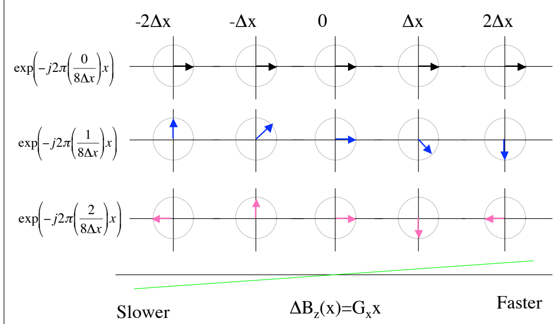
Interpretation



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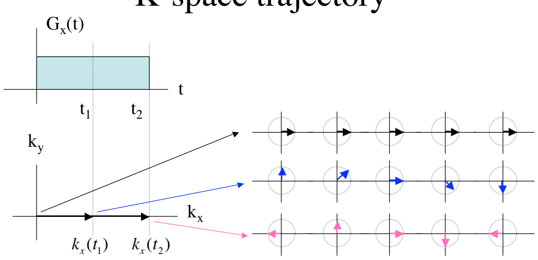
K-space trajectory



$$k_x(t) = \frac{\gamma}{2\pi}\int_0^t G_x(\tau)d\tau$$

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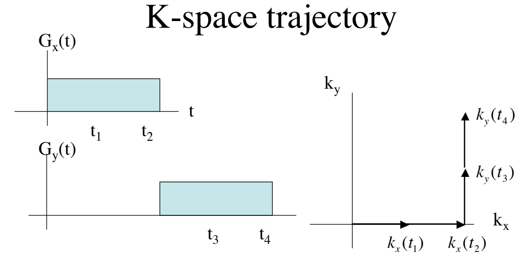
K-space trajectory



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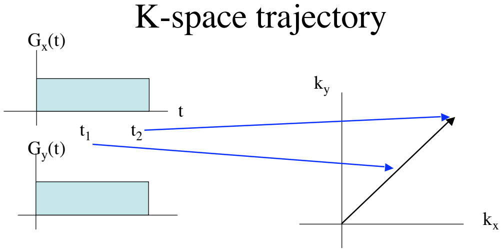
K-space trajectory



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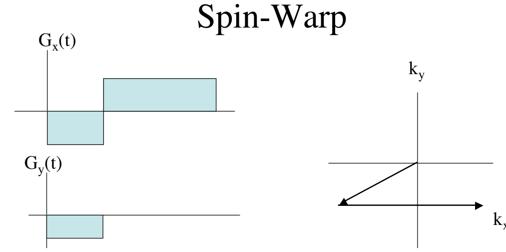
Spin-Warp



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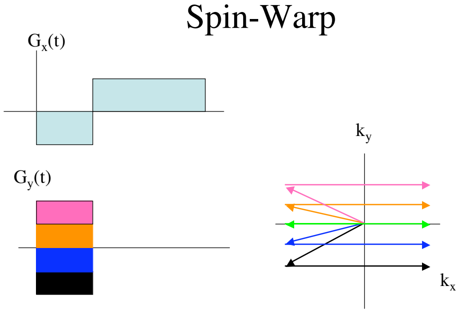
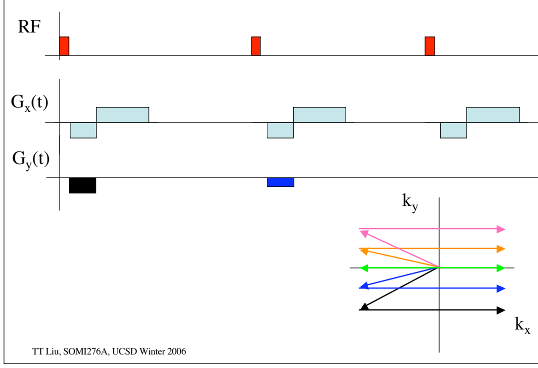
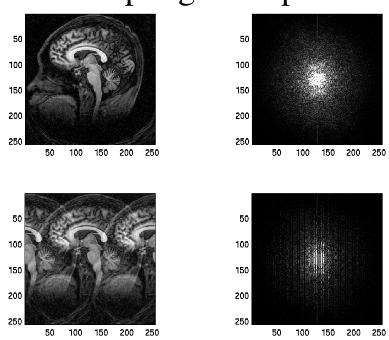
Spin-Warp



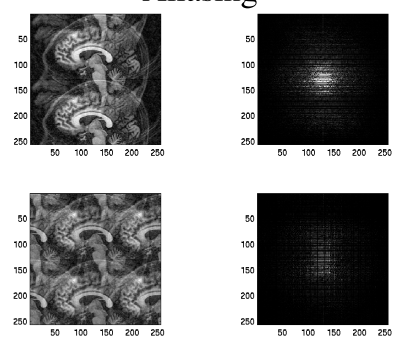
Spin-Warp Pulse Sequence



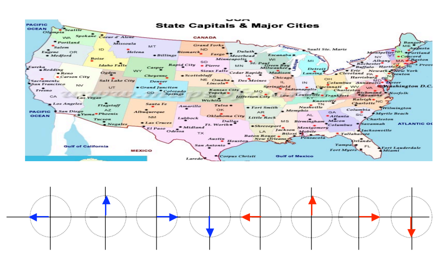
Sampling in k-space



Aliasing

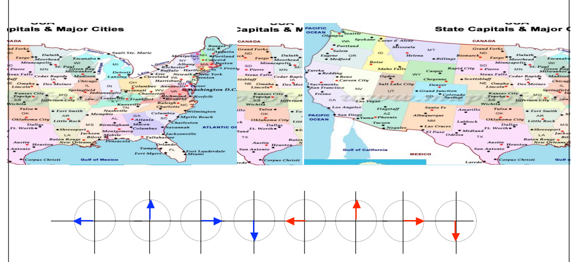


Aliasing



Period $=1/k_x$

Aliasing

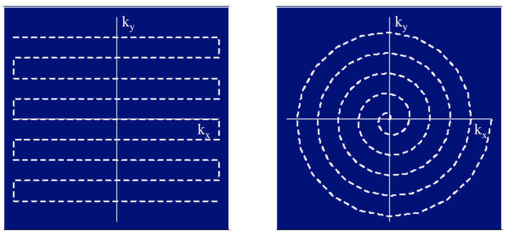


Period $=1/k_x$

K-space trajectories

EPI

Spiral



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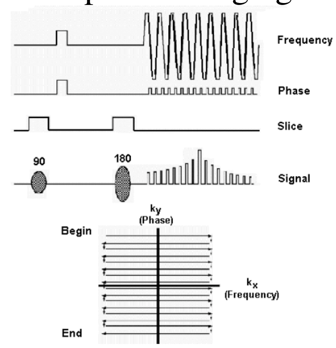
Credit: Larry Frank

Echoplanar Imaging



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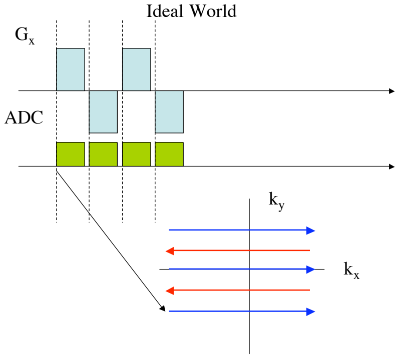
GE Medical Systems 2003

Ideal World



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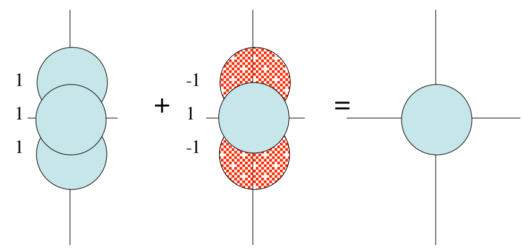

Image from
Even lines

Image from
Odd lines

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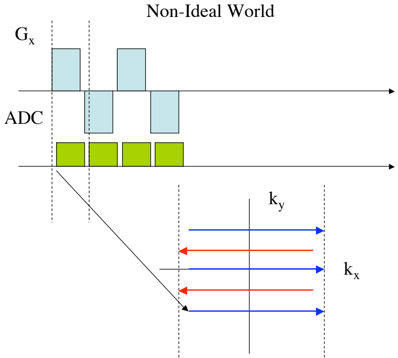
Non-Ideal World



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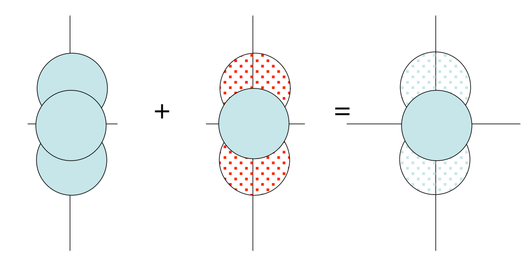

Image from
Even lines

Image from
Odd lines

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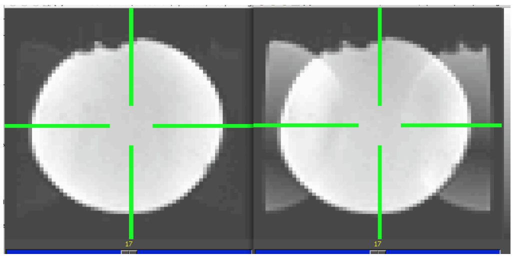
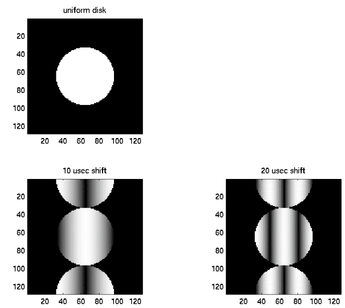
Nyquist Ghosts



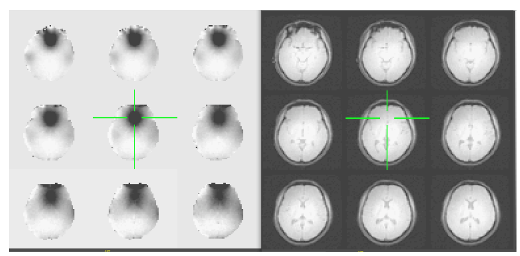


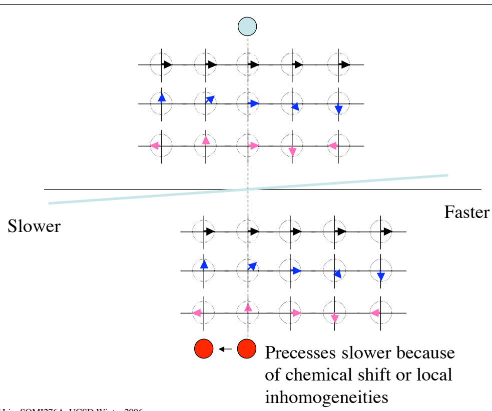
Field Inhomogeneities

In the ideal situation, the static magnetic field is totally uniform and the reconstructed object is determined solely by the applied gradient fields. In reality, the magnet is not perfect and will not be totally uniform. Part of this can be addressed by additional coils called “shim” coils, and the process of making the field more uniform is called “shimming”. In the old days this was done manually, but modern magnets can do this automatically.

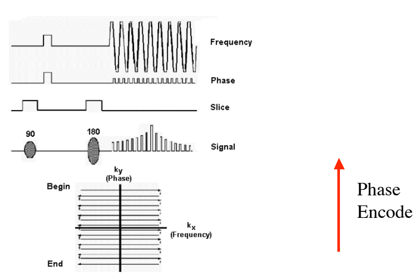
In addition to magnet imperfections, most biological samples are inhomogeneous and this will lead to inhomogeneity in the field. This is because, each tissue has different magnetic properties and will distort the field.

Field Inhomogeneities

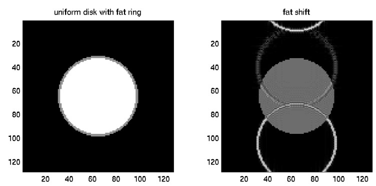




For EPI scans, distortion occurs mostly in the phase-encode direction, since data are acquired more slowly in this directon. For spiral scans, the picture is more complicated.



GE Medical Systems 2003



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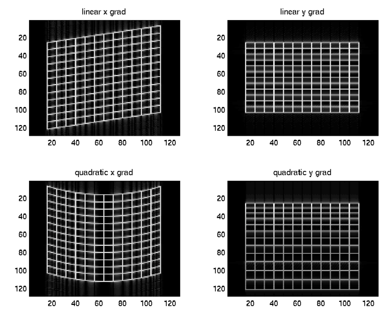

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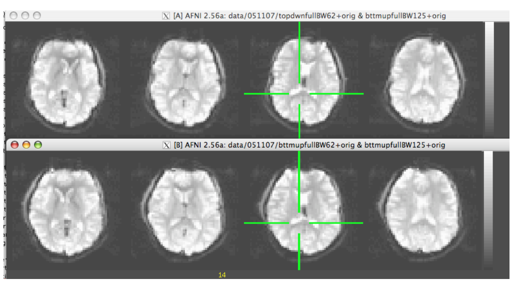
Top down vs. bottom up



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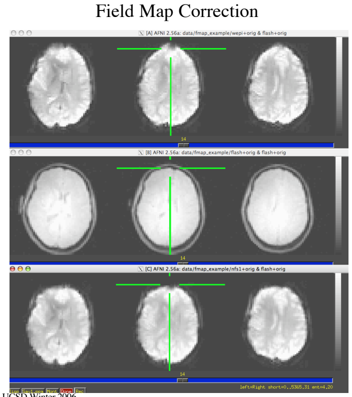
Field Map Correction



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Distortions can be reduced by moving more quickly through k-space. This can be achieved with interleaved EPI or Spiral scans, albeit with a loss of temporal resolution.

On modern imaging systems, parallel imaging offers another way of reducing the acquisition time, albeit with a loss of signal-to-noise.

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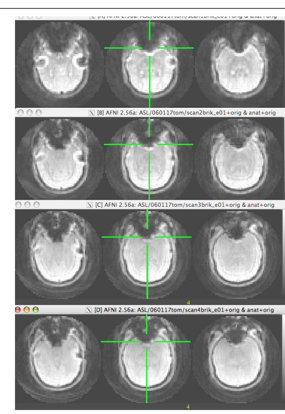
Interleaved
Spirals

1

2

3

4



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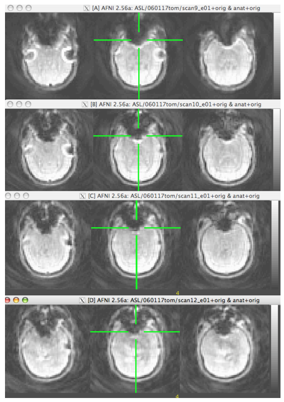
Spiral SENSE

1

2

3

4



Signal Dropouts

Field inhomogeneities also cause the spins to dephase with time and thus for the signal to decrease more rapidly. To first order this can be modeled as an additional decay term.

T_2^* decay

The overall decay has the form.

$$\exp\left(-t/T_2^*(\vec{r})\right)$$

where

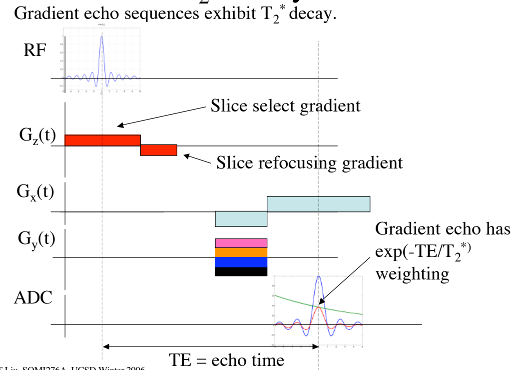
$$\frac{1}{T_2^*} = \frac{1}{T_2} + \frac{1}{T_2'}$$

Due to random motions of spins. Not reversible.

Due to static inhomogeneities. Reversible with a spin-echo sequence.

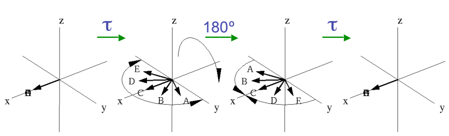
T_2^* decay

Gradient echo sequences exhibit T_2^* decay.



Spin Echo

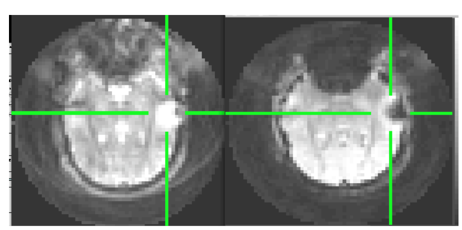
Discovered by Erwin Hahn in 1950.



The spin-echo can refocus the dephasing of spins due to static inhomogeneities. However, there will still be T_2 dephasing due to random motion of spins.

There is nothing that nuclear spins will not do for you, as long as you treat them as human beings. Erwin Hahn

Image: Larry Frank



Spin-echo TE = 35 ms   Gradient Echo TE = 14ms