SEPT 27, 2007

TODAY

MODELS OF MR DATA
ACQUISTION

NEXT TIME

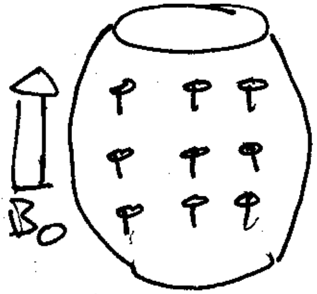
PARTIAL K-SPACE RECONSTRUCTION

ASSIGNMENT

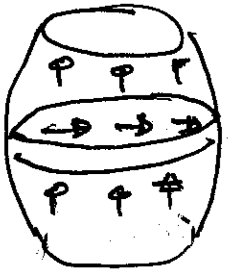
PARTIAL K-SPACE HANDOUT
BERNSTEIN CH 13.4

9/27/2007

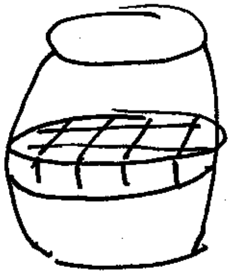
COMPONENTS OF MRI



POLARIZATION



EXCITATION (EE 469B)



RECEPTION (EE 369C)

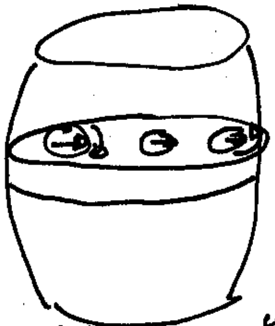
SPATIAL ENCODING

SPATIAL ENCODING

ⓒ

$\omega_0 = \gamma B_0$

$\gamma = (2\pi) \times 4.257$ KRAD/G



$\omega(x) = \omega_0 + \gamma G_x x$

$\omega(\underline{x}) = \omega_0 + \gamma \underline{G} \cdot \underline{x}$

DON'T CARE ABOUT ω_0,
CARRIER FREQUENCY

GRADIENT IS TIME VARYING

$$\omega(\underline{x}, t) = \gamma\, \underline{G}(t) \cdot \underline{x}$$

PHASE IS

$$\phi(\underline{x}, t) = \int_0^t \omega(\underline{x}, s)\, ds$$

$$= \int_0^t \gamma\, \underline{G}(s) \cdot \underline{x}\, ds$$

$$= x \cdot \gamma \int_0^t G(s)\, ds$$

$$\phi(\underline{x}, t) = x \cdot 2\pi\, \underline{k}(t)$$

WHERE

$$\boxed{k(t) = \frac{\gamma}{2\pi} \int_0^t \underline{G}(s)\, ds}$$

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MR SIGNAL EQUATION

MAGNETIZATION:

$$m(\underline{x},t) = m(\underline{x},0)\, e^{-i2\pi \underline{k}(t)\cdot\underline{x}}$$

RECEIVED SIGNAL, UNIFORM COIL

$$s(t) = \int_{\underline{x}} m_{xy}(\underline{x},t)\, d\underline{x}$$

$$= \int_{x} m_{xy}(\underline{x},0)\, \underbrace{e^{-i2\pi \underline{k}(t)\cdot\underline{x}}}_{\text{FOURIER KERNEL}}\, d\underline{x}$$

SIGNAL IS SAMPLES OF FT$\{m_{xy}(\underline{x})\}$

$$s(t) = \mathcal{F}\{m_{xy}(\underline{x},0)\}\Big|_{\underline{k}=\underline{k}(t)}$$

$$= M_{xy}(\underline{k}(t))$$

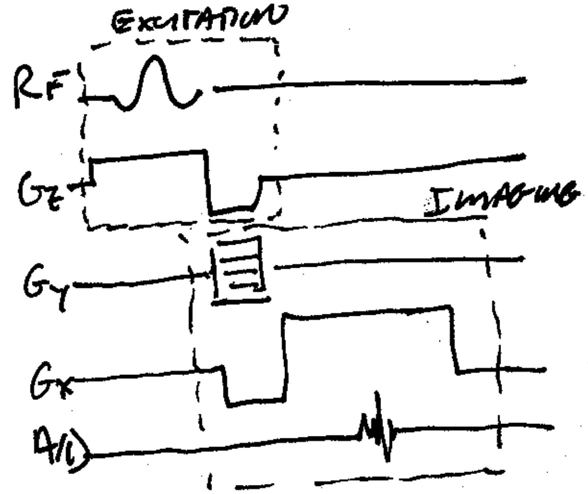
NOTATION

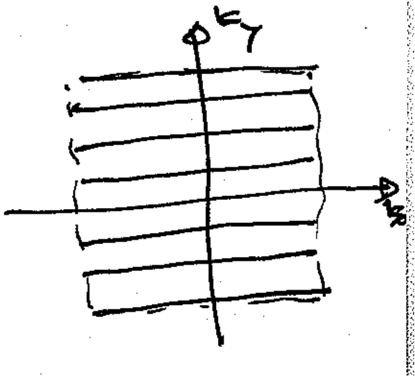
	SPACE	K-SPACE
EE369B	$m(x,y)$	$\mathcal{M}(k_x,k_y)$
	$m(\underline{x})$	$\mathcal{M}(\underline{k})$
EE369C	$m_{xy}(\underline{x})$	$M_{xy}(\underline{k})$
BOOK	$M_{xy}(x,y)$	$S(k_x,k_y)$

MR IMAGING

HOW DO YOU CHOOSE $\underline{k}(t)$?

MOST COMMON IS SPIN WARP





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SPIN WARP

ACQUIRE ONE LINE AT A TIME

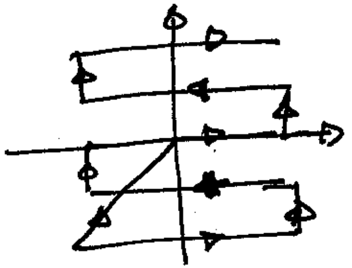
REPEAT 128 OR 256 TIMES

FILL 2D RASTER SCAN

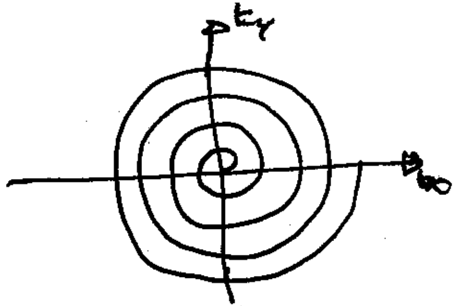
ROBUST

SLOW

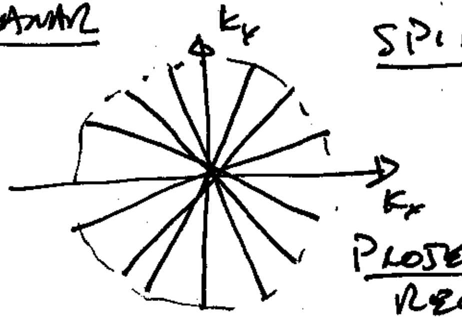
OTHER ALTERNATIVES



ECHO PLANAR



SPIRAL



PROJECTION RECONSTRUCTION

EACH HAS ADVANTAGES

FASTER: EPI, SPIRAL, SOMETIMES PR

FLOW: SPIRAL, PR

BUT:

SENSITIVE TO AQUISITION PARAMETERS

NEED A COMPELLING REASON

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INHOMOGENEITY

ω_0 VARIES IN SPACE

$$\underline{\omega}(\underline{x},t) = \omega_0(\underline{x}) + \gamma\,\underline{G}(\underline{x},t)\cdot\underline{x}$$

SUBTRACT OFF $\omega_{0,I} = \gamma B_0$

$$\underline{\omega}(\underline{x},t) = (\omega_0(\underline{x}) - \omega_{0,I}) + \gamma\,\underline{G}(\underline{x},t)\cdot\underline{x}$$

$$= \underbrace{\omega_E(\underline{x})}_{\text{OFF-RESONANCE FREQUENCY}} + \gamma\,\underline{G}(\underline{x},t)\cdot\underline{x}$$

RECEIVED SIGNAL

MAGNETIZATION

$$m_{xy}(\underline{x},t) = m_{xy}(\underline{x},0)\,e^{-i\omega_E(\underline{x})t}\,e^{-i2\pi\underline{k}(t)}$$

RECEIVED SIGNAL

$$s(t) = \int_{\underline{x}} \underbrace{m_{xy}(\underline{x},0)\,e^{-i\omega_E(\underline{x})t}}_{\text{PHASE DISTORTED OBJECT}}\;\underbrace{e^{-i2\pi\underline{k}(t)\cdot\underline{x}}}_{\text{FOURIER KERNEL}}\,d\underline{x}$$

RESULT DEPENDS ON $\underline{k}(t)$

SPIN WARP ⇒ SMALL SHIFT IN x

EPI ⇒ BIG SHIFT IN y

SPIRAL, PR ⇒ BLURRING

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FLOW

MOVING SPIN AT

$$\underline{x}(t) = \underline{x}_0 + \underline{v}t$$

PHASE IS

$$\phi(\underline{x},\underline{v},t) = \int_0^t \omega(\underline{x},\underline{v},s)\,ds$$
$$= \int_0^t \underline{x}(s)\cdot\gamma\underline{G}(s)\,ds$$
$$= \gamma\int_0^t (\underline{x}_0+\underline{v}t)\cdot\underline{G}(s)\,ds$$
$$= \gamma\int_0^t \underline{x}_0\cdot\underline{G}(s)\,ds + \gamma\int_0^t (\underline{v}s)\cdot\underline{G}(s)\,ds$$

$$\phi(\underline{x},\underline{v},t) = \underline{x}_0\cdot\gamma\int_0^t G(s)\,ds + \underline{v}\cdot\gamma\int_0^t s\,G(s)\,ds$$
$$= \underline{x}_0\cdot 2\pi\,\underline{k}(t) + \underline{v}\cdot 2\pi\,k_v(t)$$

WHERE

$$\underline{k}(t) = \frac{\gamma}{2\pi}\int_0^t \underline{G}(s)\,ds$$
$$\underline{k}_v(t) = \frac{\gamma}{2\pi}\int_0^t s\,\underline{G}(s)\,ds$$

FIRST MOMENT

RECEIVED SIGNAL

$$s(t) = \int_{\underline{x}}\int_{\underline{v}} m_{xy}(\underline{x},\underline{v},0)\,e^{-i2\pi k_v(t)\cdot\underline{v}}\,e^{-i2\pi\underline{k}(t)\cdot\underline{x}}\,d\underline{v}\,d\underline{x}$$

ALTERNATIVES

1) TREAT $\underline{k}_v(t)$ AS ADDITIONAL K-SPACE DIMENSION

2) TREAT

$$m_{xy}(\underline{x},\underline{v},0)\,e^{-i2\pi\underline{k}_v(t)\cdot\underline{v}}$$

AS A PHASE DISTORTED OBJECT

RESULT DEPENDS ON $\underline{G}(t), \underline{k}(t), \underline{k}_v(t)$

SPIN WARP ⇒ ARTIFACTS IN Y DISPLACEMENT

EPI ⇒ ARTIFACTS IN Y

SPIRAL, PR ⇒ RELATIVELY IMMUNE

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T_2 DECAY

M_{xy} DECAYS WITH T_2

$$m_{xy}(\underline{x},t) = m_{xy}(\underline{x},0)\, e^{-t/T_2}$$

SIGNAL

$$s(t) = \int_{\underline{x}} m_{xy}(\underline{x},0)\, e^{-t/T_2}\, e^{-i2\pi \underline{k}(t)\cdot\underline{x}}\, d\underline{x}$$

EFFECT DEPENDS ON $\underline{k}(t)$

SPIN WARP ⇒ SLIGHT BLURRING IN X

EPI ⇒ SIGNIFICANT BLURRING IN Y

SPIRAL, PR ⇒ RADIAL BLURRING

LOOKS LIKE k-SPACE APODIZATION IN SLOW TRAJECTORY DIMENSION

TIME DELAY

DELAY BETWEEN GRADIENT AMP INPUT, AND ACTUAL GRADIENT IN BORE

MANY CAUSES

- AMP RESPONSE
- GRADIENT SYSTEM BANDWIDTH
- EDDY CURRENTS

TYPICALLY 100 - 150 μs!

SIGNAL

$$s(t) = \int_{\underline{x}} m_{xy}(\underline{x},0)\, e^{-i2\pi \underline{k}(t-t_d)\cdot\underline{x}}\, d\underline{x}$$

THIS CAN HAVE A PROFOUND EFFECT

SPIN WARP ⇒ NO EFFECT

EPI ⇒ LARGE GHOSTS

SPIRAL ⇒ IMAGE ROTATION

PR ⇒ BLURRING, STREAKS

EDDY CURRENTS ARE PREDOMINANTLY INHOMOGENEITY + DELAY

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