Off Resonance Effects

B_0 inhomogeneity
susceptibility differences
chemical shift

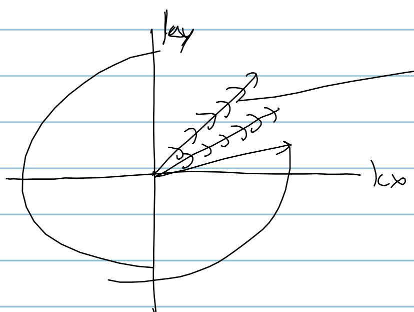
$$s(t) = \iint m(x,y)\, \underline{e^{-i\omega_E(x,y)t}}\, e^{-j2\pi(k_x(t)x + k_y(t)y)}\, dx\,dy$$

@ a given time
1) $e^{-i\omega_E t}$ can create phase dispersion within a voxel $\Rightarrow$ signal loss $T_2 \Rightarrow T_2^*$

2) $e^{-i\omega_E t}$ contributes phase error over kspace
$\Rightarrow$ distorted impulse response

Non-2DFT

ex) 2D PR



phase error $= \underline{e^{-i\alpha k_r}}$ linear

impulse response $= \mathcal{F}^{-1}_{2D}\{\ \}$

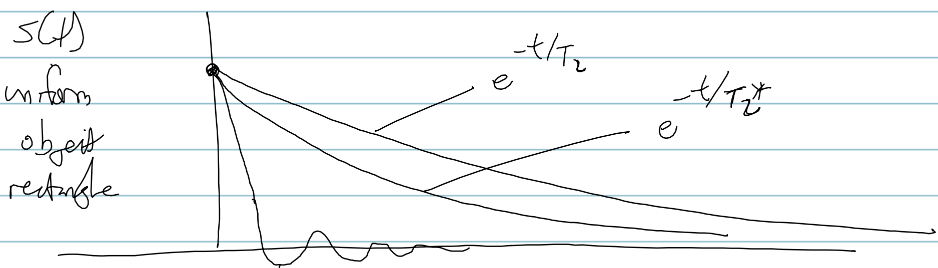
not a shift, but a blur

ECHOES

"undone dephasing"

$$s(t) = \iiint \underbrace{m(\vec{r})}_{\text{object}} e^{-i\underbrace{\phi(\vec{r},t)}_{\text{phase}}} dx\,dy\,dz$$

$$\phi(\vec{r},t) = \underbrace{\underbrace{\omega_E(\vec{r})t + \omega_{CS}(\vec{r})t}_{\text{no control}} + \underbrace{\gamma\left(\int_0^t \vec{G}(\tau)\,d\tau\right)\cdot\vec{r}}_{\text{control}}}_{\text{inhomogeneities}}$$



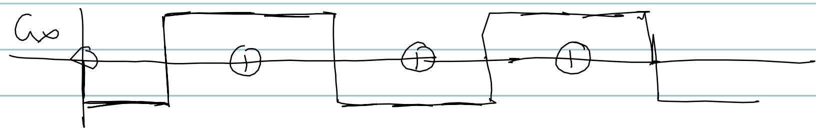
gradient inhomogeneity
(for a rect object
signal will resemble sinc())

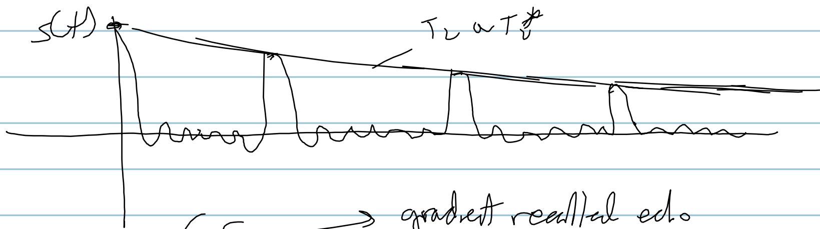
1) GRADIENT ECHO

ignore E, CS $\qquad \phi = \gamma\left(\int_0^t \vec{G}(\tau)\, d\tau\right)\cdot\vec{r}$

Gradient Echo occurs when $\phi = 0 \quad \forall \vec{r}$

$\int G\, d\tau = 0$





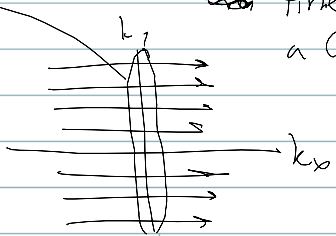
GE → gradient recalled echo
GE → gradient reversed echo

- echo "peaks" at the k-space origin

- in 2DFT, lingo

  time when $k_x = 0$ is called a GE even if $k_y \neq 0$

all considered GE



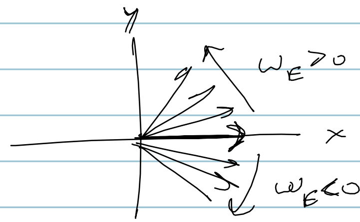
② Spin Echo (SE)

ignore $\vec{G}$

undo dephasing caused by ω_E

- at time τ after excitation

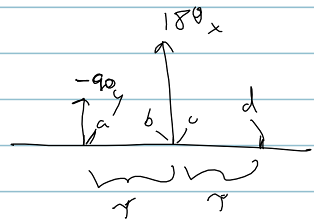
$$\phi(\vec{r}, \tau) = \omega_E(\vec{r})\,\tau$$



IDEA use an RF pulse to flip phases at time τ

180° along x or y

Relative phase after 180° x

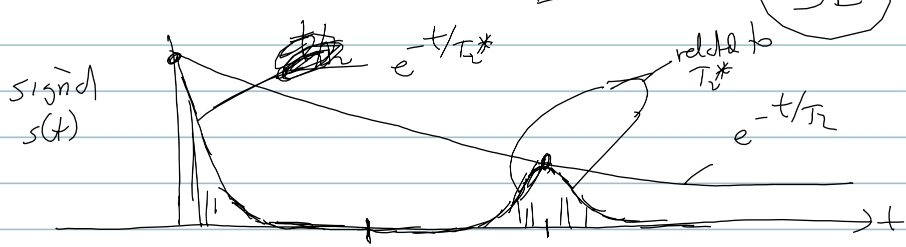


a) $\phi = 0$

b) $\phi = \omega_E(\vec{r})\,\tau$

c) $\phi = -\omega_E(\vec{r})\,\tau$

d) $\phi = -\omega_E(\vec{r})\,\tau + \omega_E(\vec{r})\,\tau = 0$ SE



180° pulse

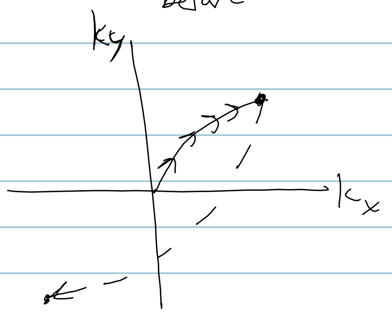
- spin echo pulse (M_{xy})
  → phase reversal
  "pancake flipper pulse"
- inversion (M_z)

180° pulse affects k-space trajectory

$e^{-i\phi} \Rightarrow e^{+i\phi}$

before → after

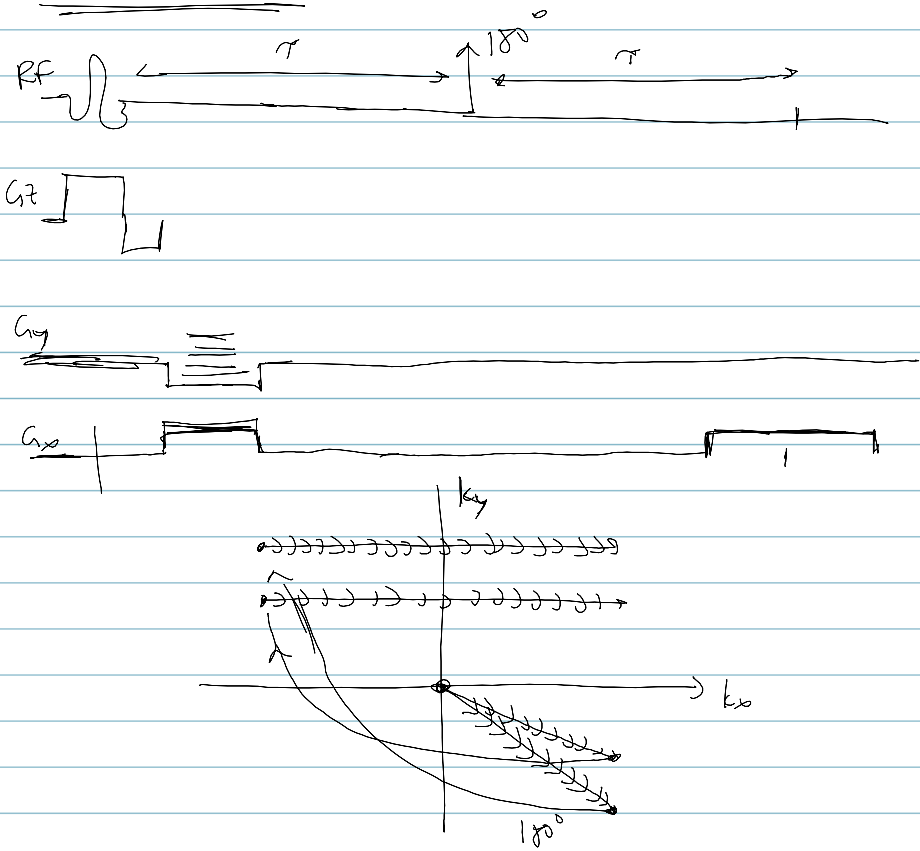
includes offresonance & gradients



$(k_{x_0}, k_{y_0}) \longrightarrow (-k_{x_0}, -k_{y_0})$

before → after

2DFT w/ SE



NOTES
- TE = gradient echo time $\int G_x \, dt = 0$
- 2τ = spin echo time depends on timing of 90° & 180°
- usually set TE = 2τ, max signal
- at TE signal amplitude e^{-TE/T_2} ← not T_2^*

SE — pure T_2 weighting, coherent signal
(T_2^* problematic)

GE — faster, no 180° pulse needed
- shorter TE possible