

OCT 7, 2009

ASSIGNMENT

HW 2 DUE FRIDAY OCT 9th (EMAIL)
HW 3 DUE OCT 14th

TODAY

EPI SPATIAL PULSE DESIGN

TRAJECTORY

GRADIENTS

WEIGHTING

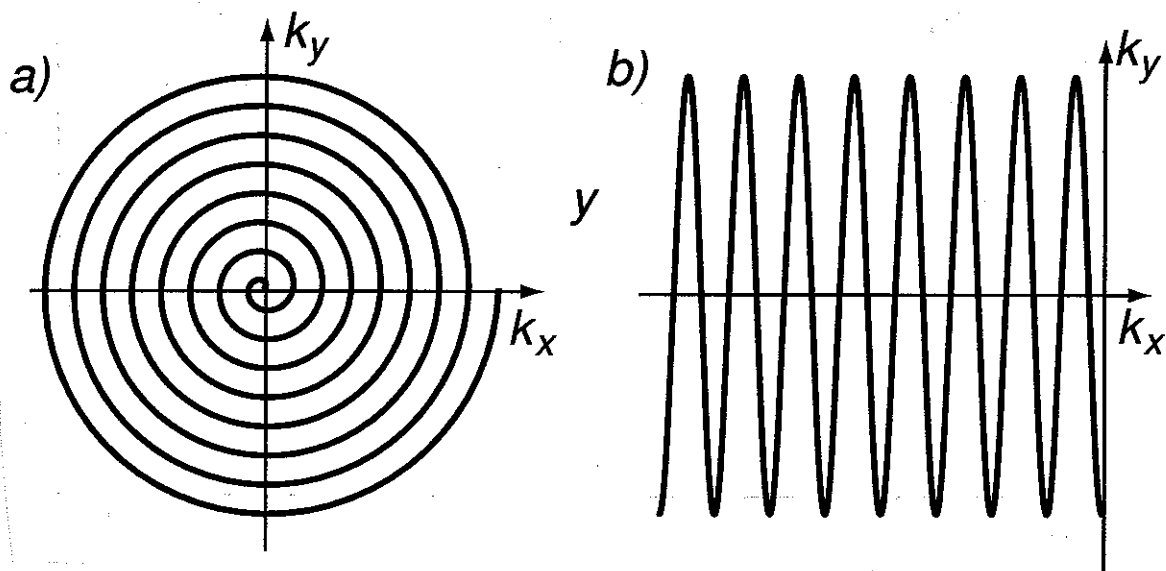
RF

SPATIAL - SPECTRAL PULSES

2D SPATIAL PULSE DESIGN

ANY 2D k -SPACE TRAJECTORY USED FOR IMAGING CAN ALSO BE USED FOR EXCITATION

TWO MOST COMMON:



SPIRAL:

UNITY ASPECT RATIO

MINIMUM LENGTH

CIRCULAR SIDELOBE

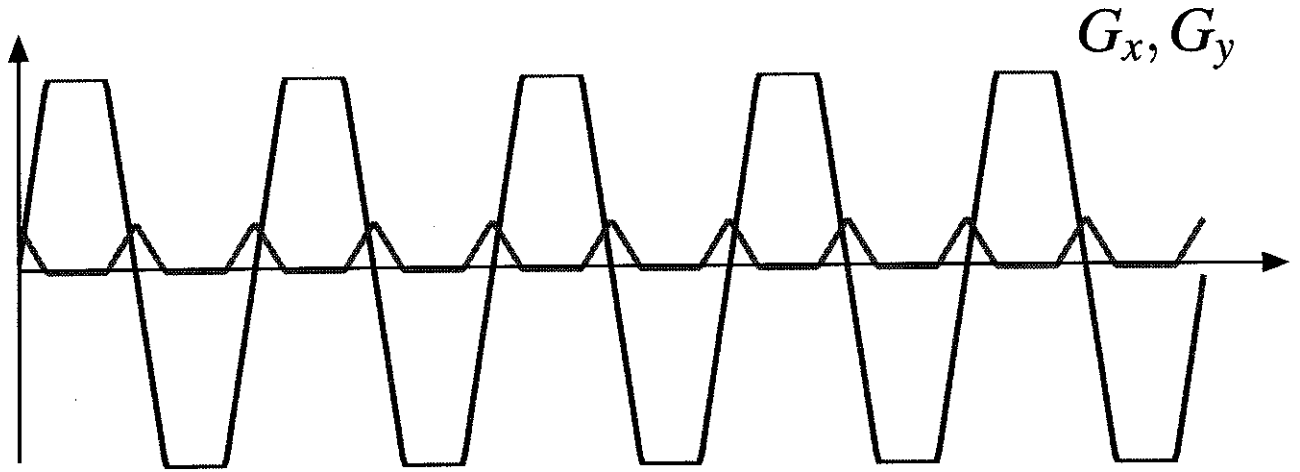
EPI:

NON-ISOTROPIC RESOLUTION

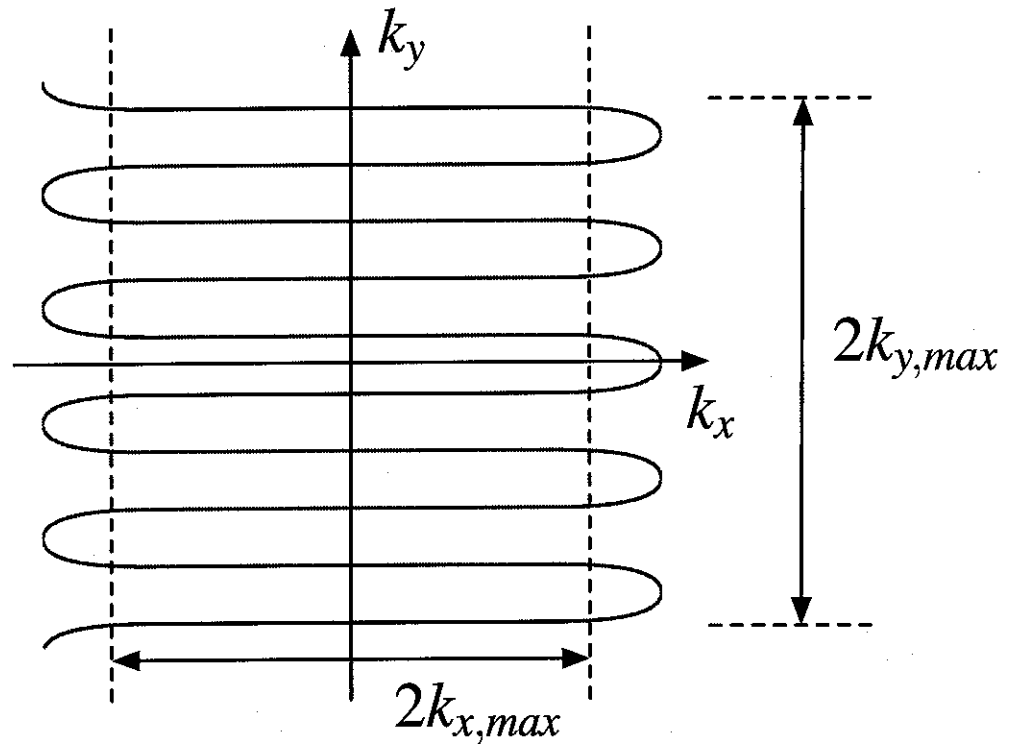
SIDELOBS IN ONE DIMENSION

SPECTRAL-SPATIAL PULSES

Blipped EPI

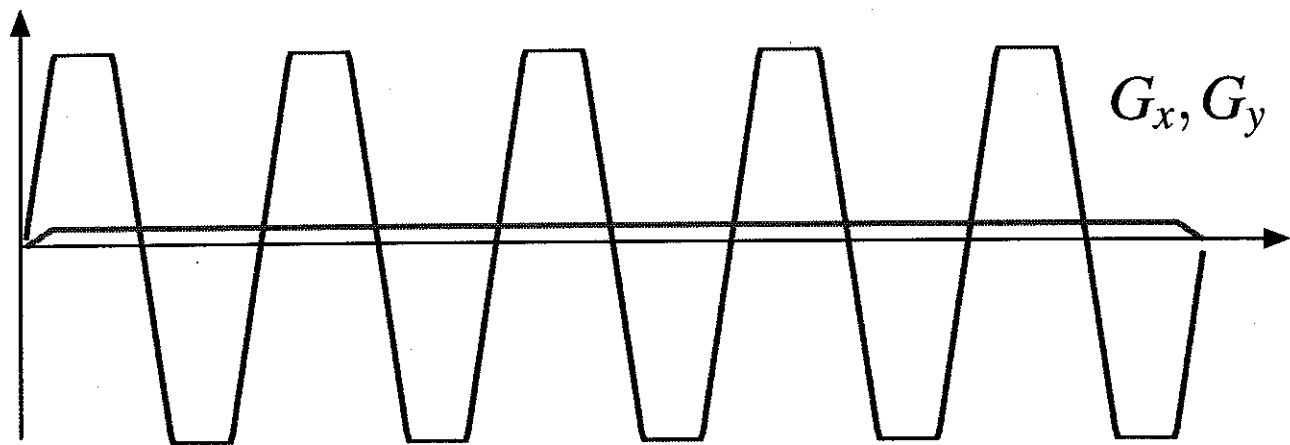


Gradient Waveforms

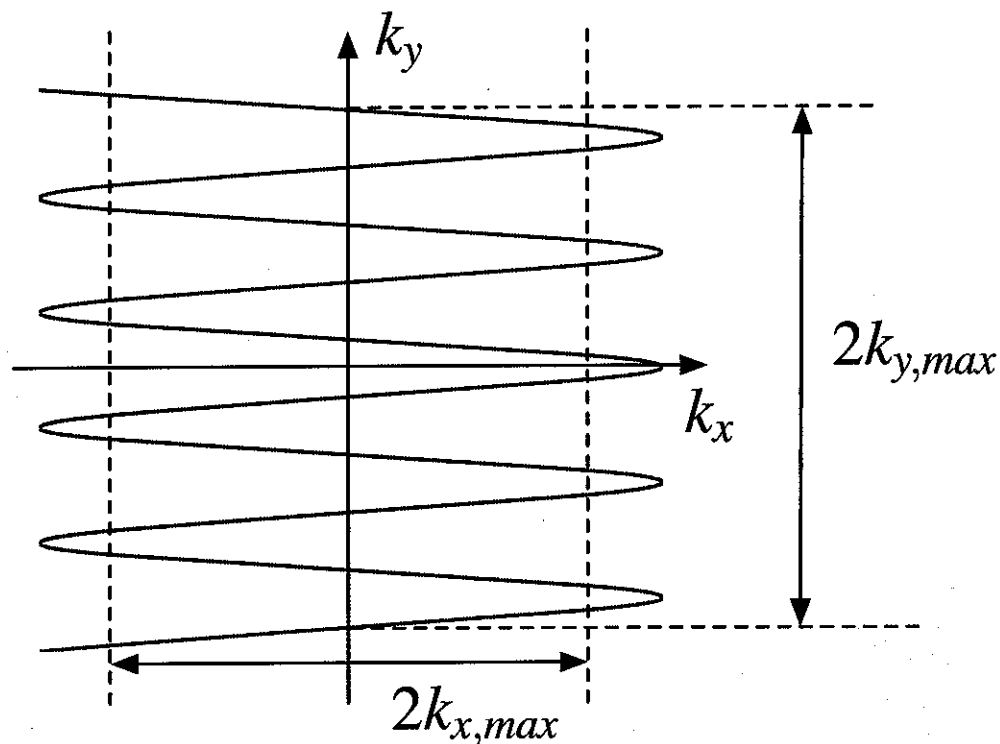


k-Space Trajectory

Continuous EPI

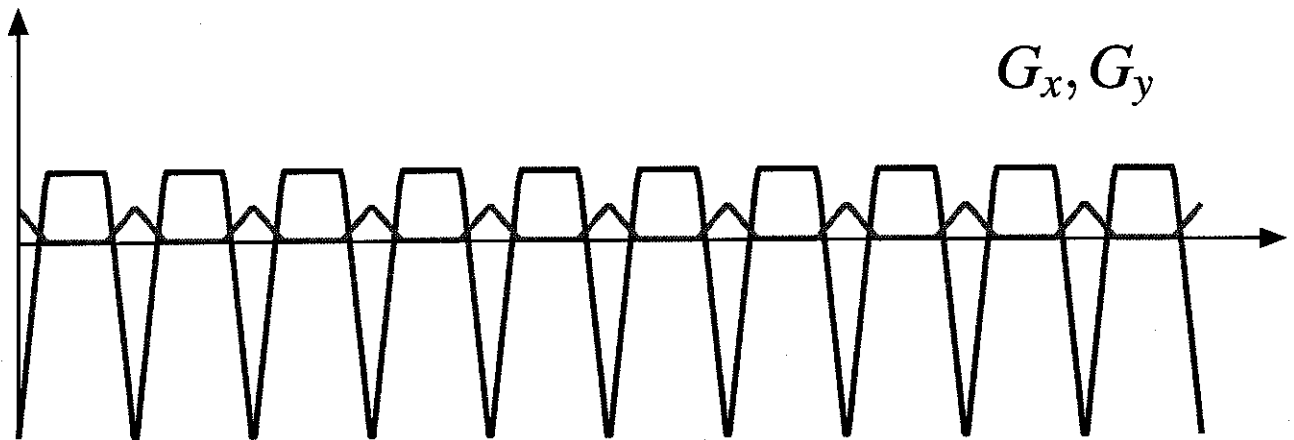


Gradient Waveforms

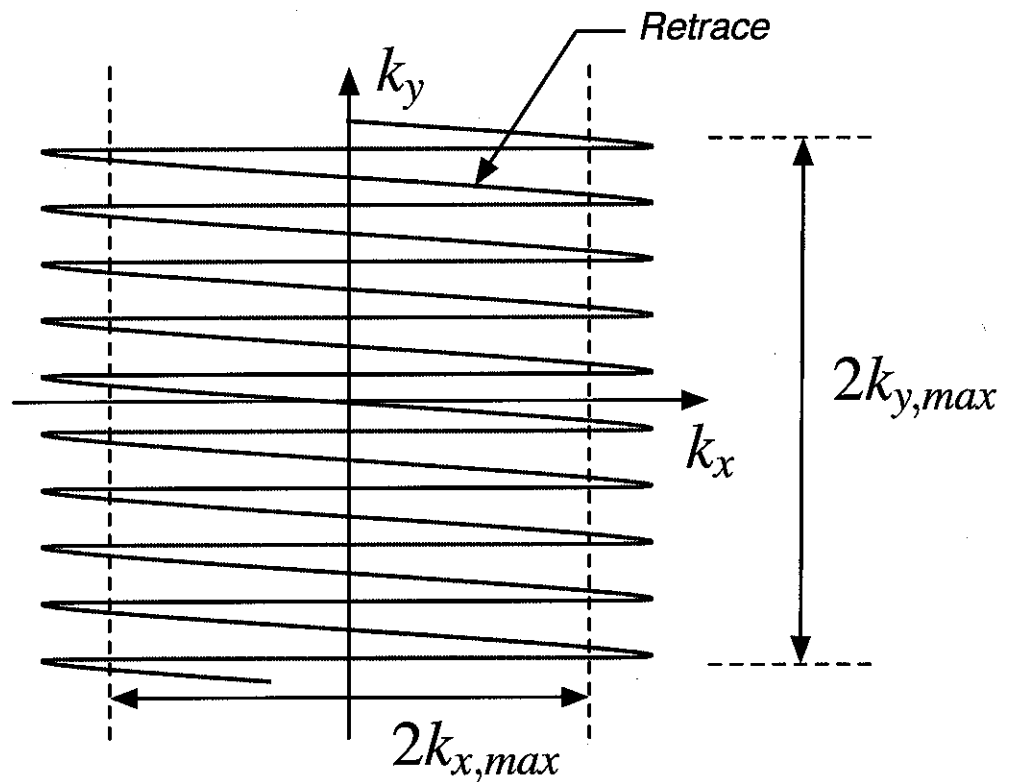


k -Space Trajectory

Flyback EPI



Gradient Waveforms



k-Space Trajectory

BLIPPED EPI

RECTILINEAR SCAN OF k -SPACE

MOST EFFICIENT EPI TRAJECTORY

COMMON CHOICE FOR SPATIAL PULSES

SENSITIVE TO EDDY CURRENTS, GRADIENT DELAYS

CONTINUOUS EPI

NON-UNIFORM k -SPACE COVERAGE

NEED TO OVERSAMPLE TO AVOID SIDELOBES

→ LESS EFFICIENT THAN BLIPPED

SENSITIVE TO EDDY CURRENTS, GRADIENT DELAYS

ONLY CHOICE FOR SPECTRAL-SPATIAL PULSES

FLYBACK EPI

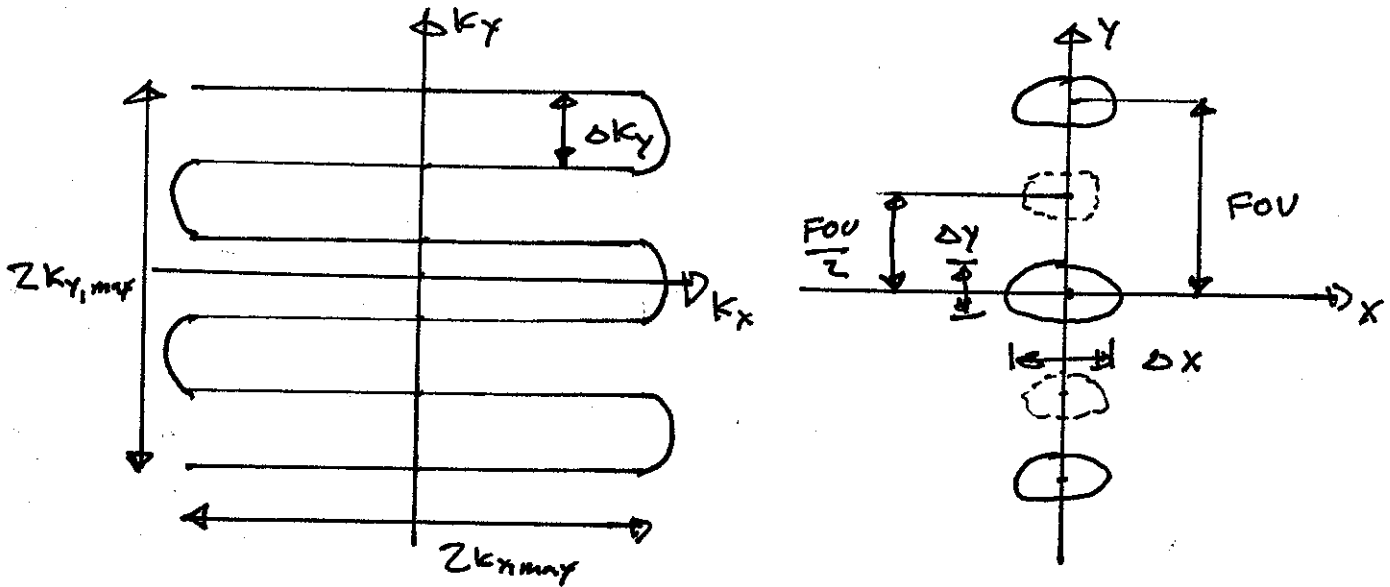
CAN BE BLIPPED OR CONTINUOUS

LESS EFFICIENT SINCE RETRACES NOT USED (DEPENDS ON GRADIENT SYSTEM)

ALMOST COMPLETELY IMMUNE TO EDDY CURRENTS, GRADIENT DELAYS

DESIGNING EPI K-SPACE TRAJECTORIES

IDEALLY, AN EPI TRAJECTORY SCANS A
2D RASTER IN K-SPACE



K-SPACE TRAJECTORY GOES FROM

$\pm k_{x,max}$ IN k_x

$\pm k_{y,max}$ IN k_y

SAMPLED AT Δk_y IN k_y , L LINES

RESOLUTION IS

$$\Delta x = \frac{1}{2k_{x,max}}$$

$$\Delta y = \frac{1}{2k_{y,max}}$$

TRUE FOV

$$FOV = \frac{1}{\Delta k_y}$$

"GHOST" FOV

$$FOV_G = \frac{1}{2\Delta k_y}$$

(THESE WILL OFTEN
BE DIFFERENT)

(EDDY CURRENT,
DELAYS PRODUCE
THIS)

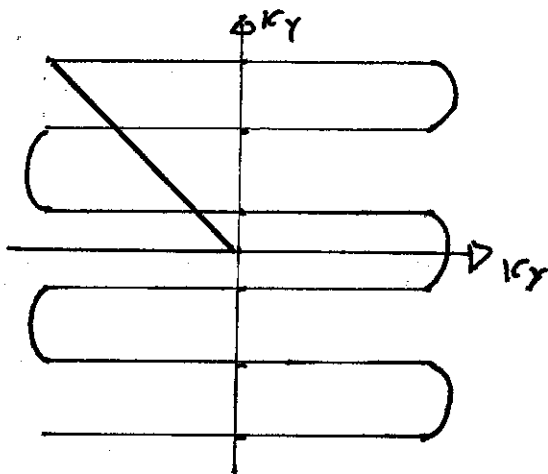
SINCE THERE ARE L LINES

$$\Delta k_y = \frac{2k_{y,max}}{(L-1)}$$

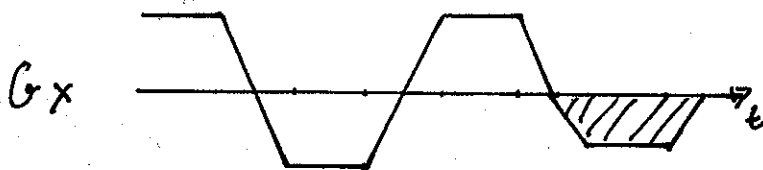
$$FOV = \frac{1}{\Delta k_y} = \frac{(L-1)}{2k_{y,max}} = (L-1)\Delta y$$

$$FOVG = \frac{1}{2} FOV = \left(\frac{L-1}{2}\right)\Delta y$$

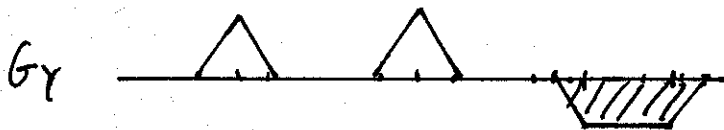
REFOCUSING LOBE



RETURNS TO ORIGIN AT
END OF PULSE



HALF AREA OF
 G_x LOBE

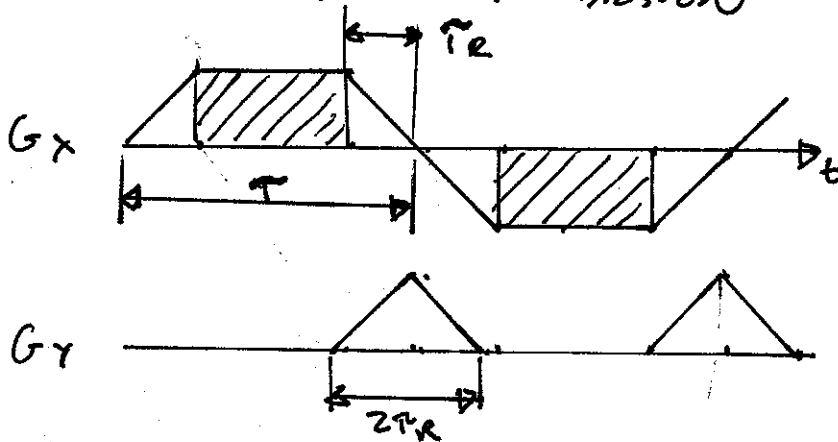


HALF AREA OF
 $(L-1)$ G_y LOBE (BCIP)

DESIGNING EPI GRADIENTS

DESIGNING READOUT LOBES AND BLIPS

FLAT-TOP ONLY DESIGN



RF ONLY PLAYED DURING FLAT PART (SAMPLER)

TYPICAL VALUES

$$\tau = 1 \text{ ms}$$

$$\tau_R = 46 \text{ cm} / 156 \text{ cm/ms} \approx \frac{1}{4} \text{ ms}$$

THEN

$$\begin{aligned} z_{kmax} &= \frac{\gamma}{2\pi} (\tau - 2\tau_R) G_{max} \\ &= (4.257 \text{ kHz/G}) \left(\frac{1}{2} \text{ ms}\right) 4 \text{ G/cm} \\ &\approx 8.5 \text{ cycles/cm} \end{aligned}$$

RESOLUTION LIMIT

$$\Delta x = \frac{1}{z_{kmax}} = \frac{1}{8.5 \text{ cycles/cm}} = \underline{\underline{0.12 \text{ cm}}} \quad (\text{TBW} = 1)$$

WITH A TBW = 4 PULSE (TYPICAL)

$$4(\Delta x) = \underline{\underline{0.47 \text{ cm}}}$$

B LIPS

B LIP AREA, Δk_y IS

$$\begin{aligned}\Delta k_y &= \frac{\partial}{\partial t} \frac{1}{2} (2\pi r) G_{\max} \\ &= (4.257 \text{ kHz/G}) \left(\frac{1}{4} \text{ ms}\right) 4 \text{ G/cm} \\ &= 4.257 \text{ CYCLES/cm}\end{aligned}$$

ASSUME $L = 11$ k-SPACE LINES

$$\begin{aligned}2k_{y,\max} &= (L-1) \Delta k_y \\ &= 42 \text{ CYCLES/cm} \\ \Delta y &= \frac{1}{2k_{y,\max}} = 0.024 \text{ cm} \\ \text{FOV} &= \frac{1}{\Delta k_y} = 0.23 \text{ cm}\end{aligned}$$

MUCH SMALLER THAN WE NEED

EASY TO GET k-SPACE COVERAGE IN k_y

HARD TO GET k-SPACE COVERAGE IN k_x

WE CAN GET MORE k_x COVERAGE BY

MAKING B LIPS NARROWER

PLAYING RF DURING PART OF RAMP

FOR EXAMPLE ABOVE

$$\begin{aligned}2k_{x,\max} &\text{ GOES FROM } 8.5 \text{ TO } 12.75 \text{ CYCLES/cm} \\ y(\Delta x) &\text{ GOES FROM } 0.47 \text{ cm TO } 0.31 \text{ cm}\end{aligned}$$

DESIGNING 2D EPI SPATIAL PULSES

TWO MAJOR OPTIONS

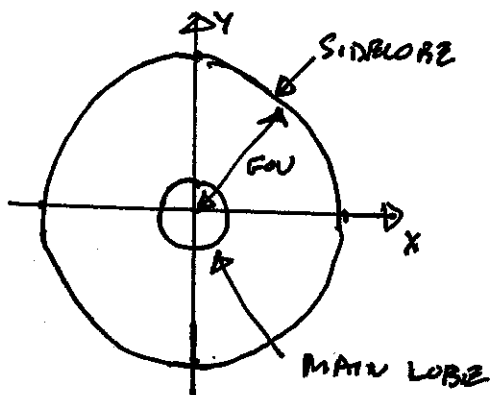
- 1) GENERAL APPROACH, SAME AS 2D SPIRAL PULSES
- 2) SEPERABLE, PRODUCT DESIGN (EASIER)

GENERAL APPROACH

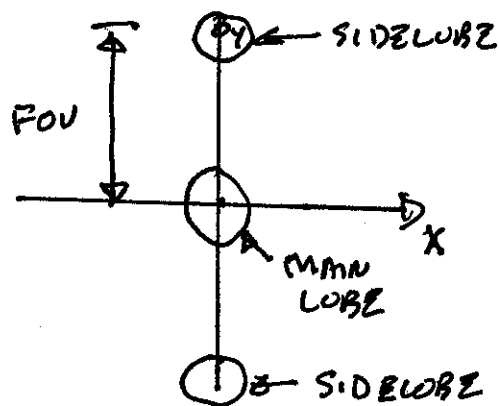
- 1) CHOOSE EPI K-SPACE TRAJECTORY
- 2) DESIGN GRADIENT WAVEFORMS
- 3) DESIGN $W(k)$, THE K-SPACE WEIGHTING
- 4) DESIGN $B, C(t)$

$$B, C(t) = |G(t)| W(k(t))$$

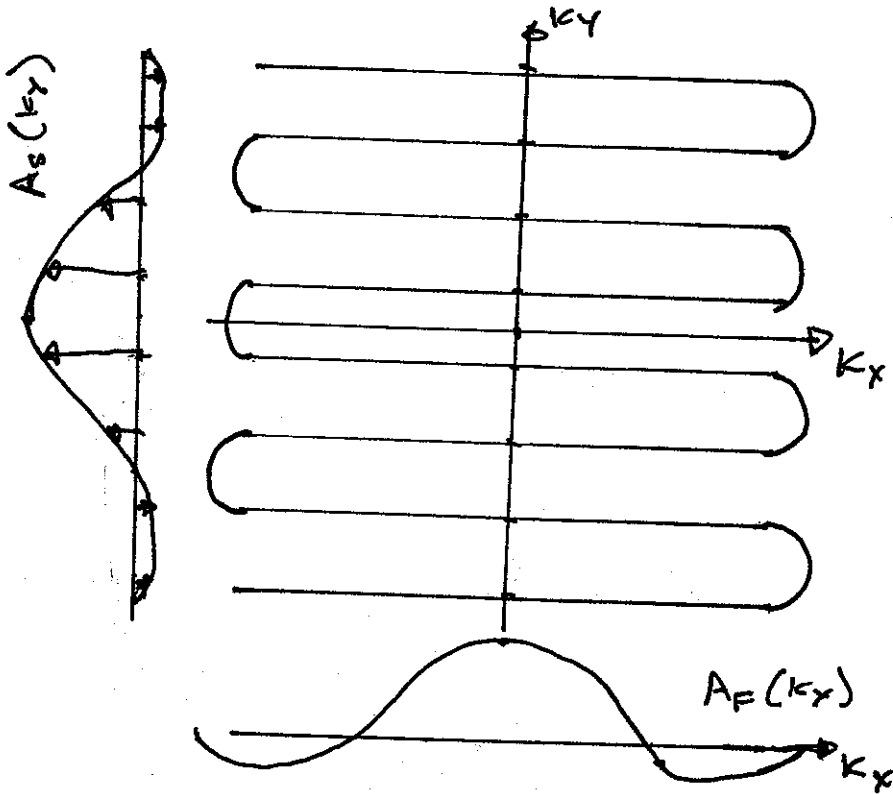
MAJOR DIFFERENCE FROM 2D SPIRAL PULSE DESIGN IS WHERE SIDELOBES END UP



SPIRAL
IMPULSE RESPONSE



EPI
IMPULSE RESPONSE



TRACE OUT TRAJECTORY

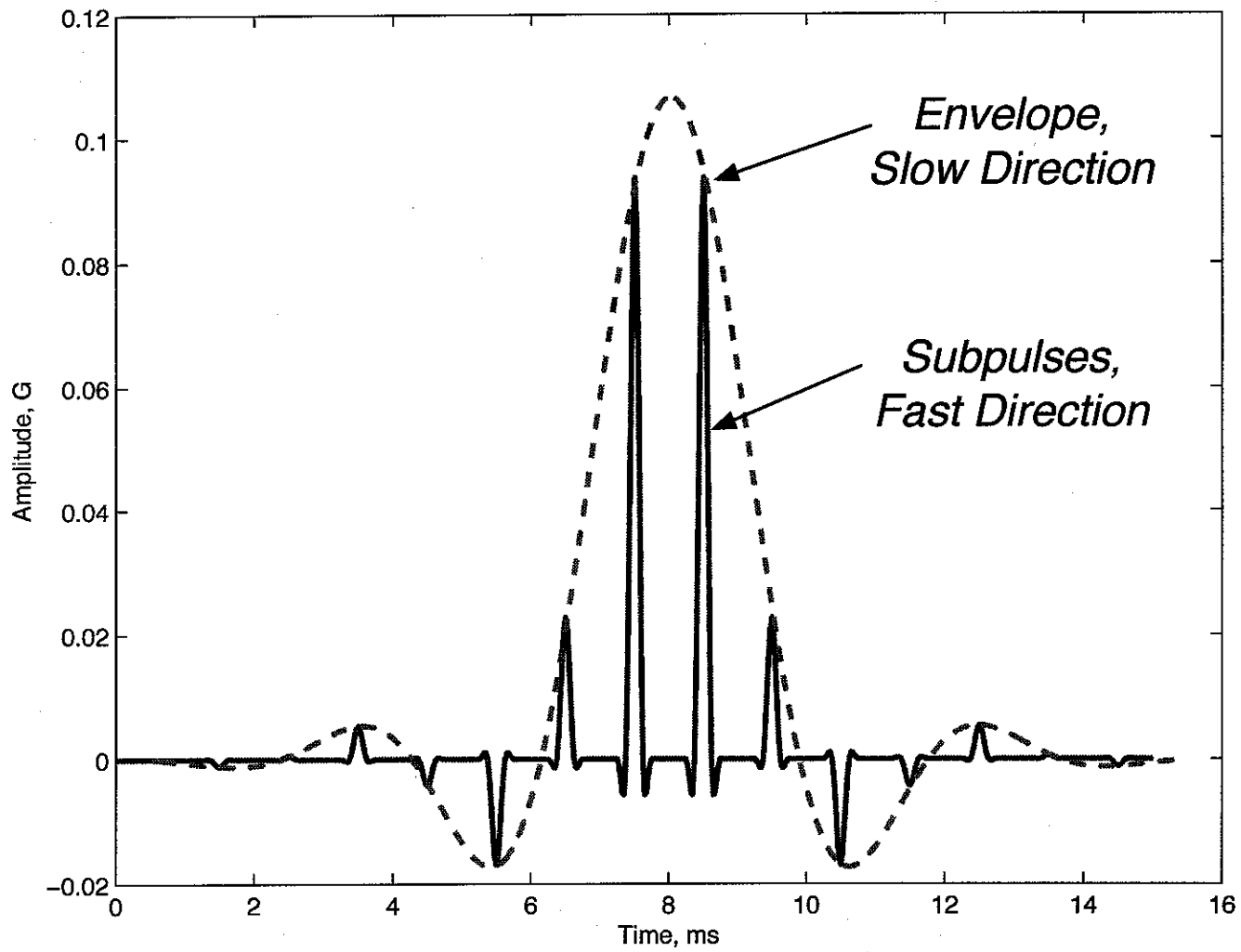
SEQUENCE OF $A_f(k_x)$ SUBLOBES

MULTIPLIED BY SAMPLES OF $A_s(k_y)$

ENVELOPE

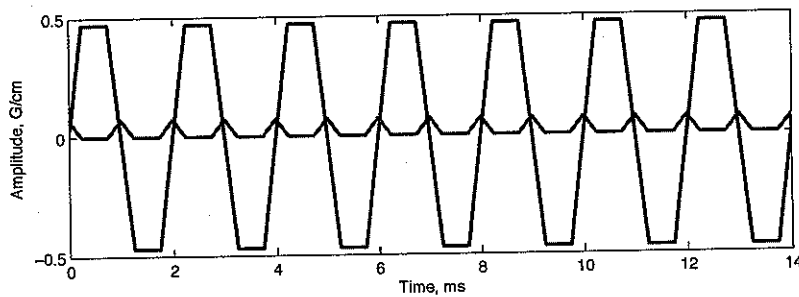
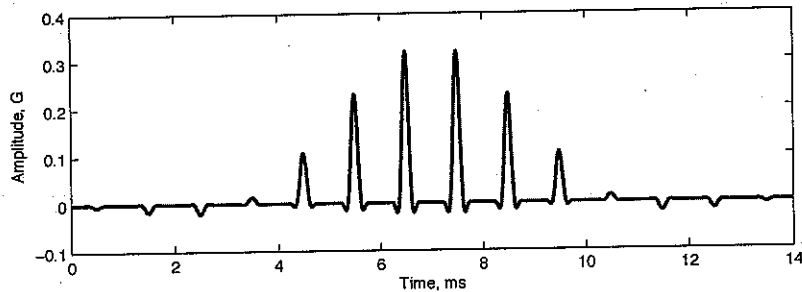
VERY SIMPLE TO COMPUTE

Product Pulse Design

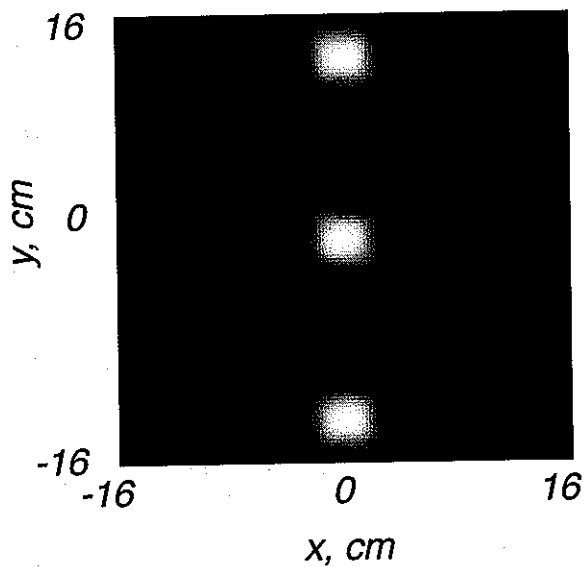


Example: 2D EPI Pulse

Waveforms



Excited Volume



$k_{x,max} = k_{y,max} = \pm 0.5$ cycles/cm
 $SBWX = SBWY = 4$
1 ms subpulses
14 subpulses
Flattop only (0.5 ms)
4 cm x 4 cm mainlobe
Sidelobes at ± 13 cm

SPATIAL - SPECTRAL PULSES

2D PULSES SELECTIVE IN
SPACE, AND
FREQUENCY

EXCITE A SLICE AT A LIMITED BAND OF
FREQUENCIES

APPLICATIONS:

HIGH SPEED IMAGING (SPINAL, EPI)

EXCITE ONLY WATER TO LIMIT DIFF-RESONANCE

ELIMINATES LIPIDS

VERY COMMON

ROBUST LIPID SUPPRESSION

DOESN'T EXCITE LIPIDS AT ALL

NOT B_1 SENSITIVE

MORE ROBUST THAN FAT SAT

SPECTROSCOPIC IMAGING (MRSI)

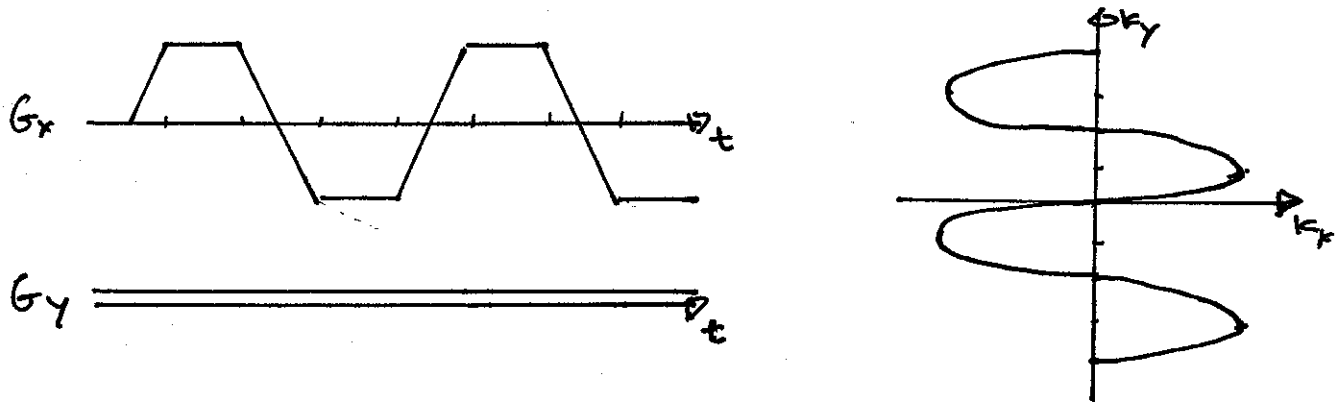
WATER SUPPRESSION / ATTENUATION

LIPID SUPPRESSION

COMBINING FUNCTIONS TO REDUCE
DIMENSIONALITY

BASIC IDEA

CONSIDER A CONTINUOUS EPI 2D SPATIAL PULSE



THE G_y GRADIENT SIMPLY ESTABLISHES A LINEAR RELATIONSHIP BETWEEN POSITION AND FREQUENCY

HENCE

SPATIAL SELECTIVITY IN y

\Rightarrow FREQUENCY SELECTIVITY

PROFILE IN y IS

$$M_{xy}(y, t) = i m_0 \int_{-\omega}^{\omega} \delta B_1(\tau) e^{i 2\pi k_y(\tau, t) y} d\tau$$

$$k_y(\tau, t) = -\frac{\gamma}{2\pi} G_y (t - \tau)$$

SO

$$\begin{aligned} M_{xy}(y, t) &= i m_0 \int_{-\omega}^{\omega} \delta B_1(\tau) e^{i 2\pi \left(\frac{\gamma}{2\pi} G_y (t - \tau) \right) y} d\tau \\ &= i m_0 \int_{-\omega}^{\omega} \delta B_1(\tau) e^{-i \underbrace{(\gamma G_y y)}_{\omega} (t - \tau)} d\tau \\ &= i m_0 \int_{-\omega}^{\omega} \delta B_1(\tau) e^{-i 2\pi \left(\frac{\gamma G_y y}{2\pi} \right) (t - \tau)} d\tau \end{aligned}$$

CONSIDER m_{xy} AS FUNCTION OF f

$$m_{xy}(f, t) = i m_0 \int_{-\infty}^{\infty} \delta B_y(k_f) e^{i 2\pi f k_f} dk_f$$

WHERE

$$f = \frac{\partial \phi_{xy}}{2\pi}$$

$$k_f = -(t - T)$$

THIS HOLDS NO MATTER WHERE THE FREQUENCY COMES FROM

NOTE THAT k_f IS TIME!

SINCE TIME EVOLVES CONTINUOUSLY, MUST USE CONTINUOUS EPI TRAJECTORY.

THIS COMPLICATES PULSE DESIGN

→ NEXT TIME