Lecture 6

TODAY

2D EPI PULSES

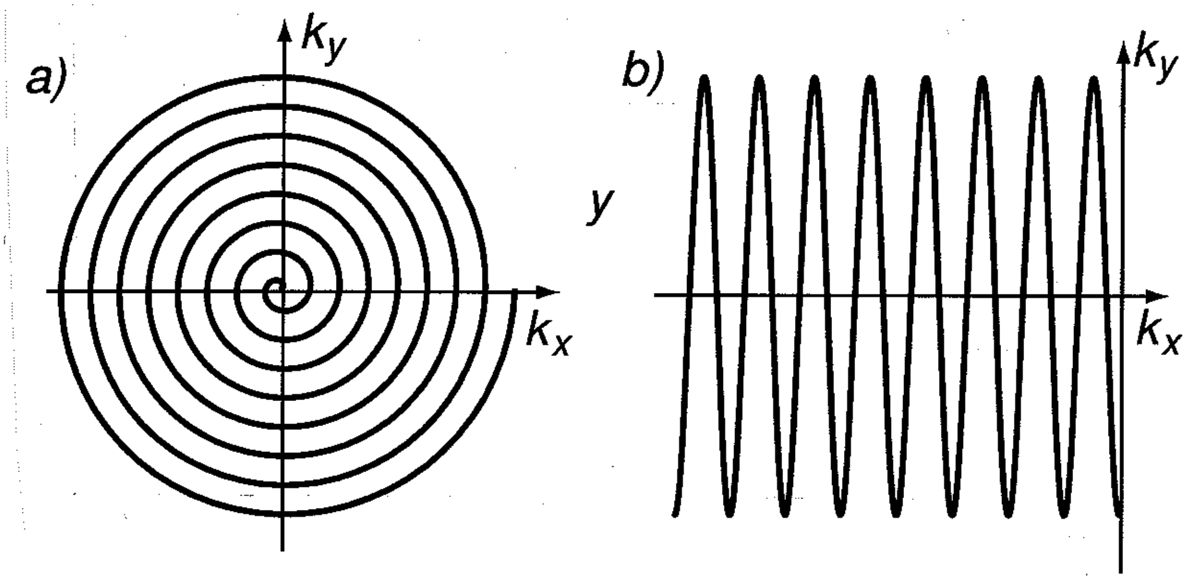
NEXT

SPECTRAL - SPATIAL 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

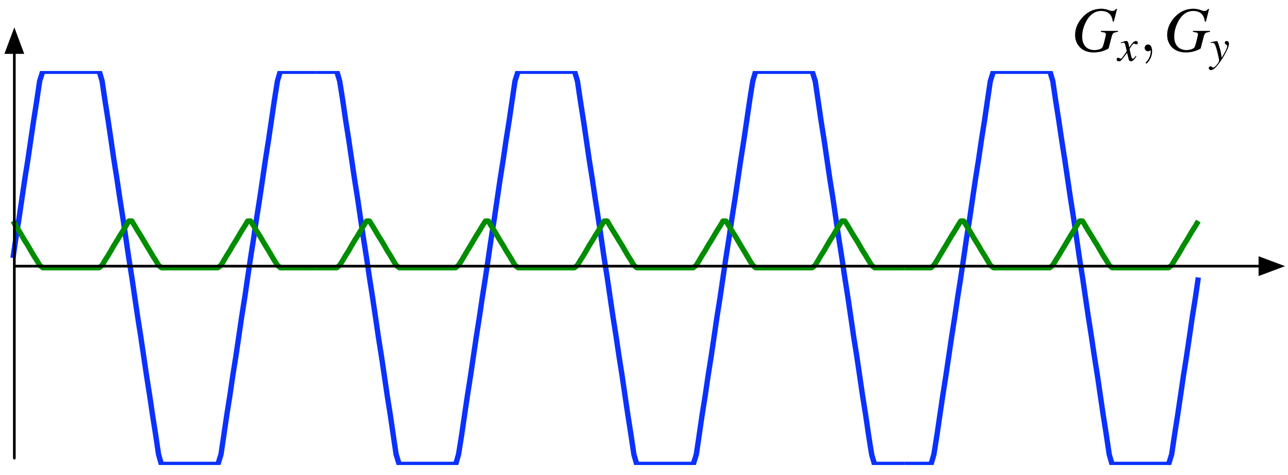
EPI:

NON-ISOTROPIC RESOLUTION

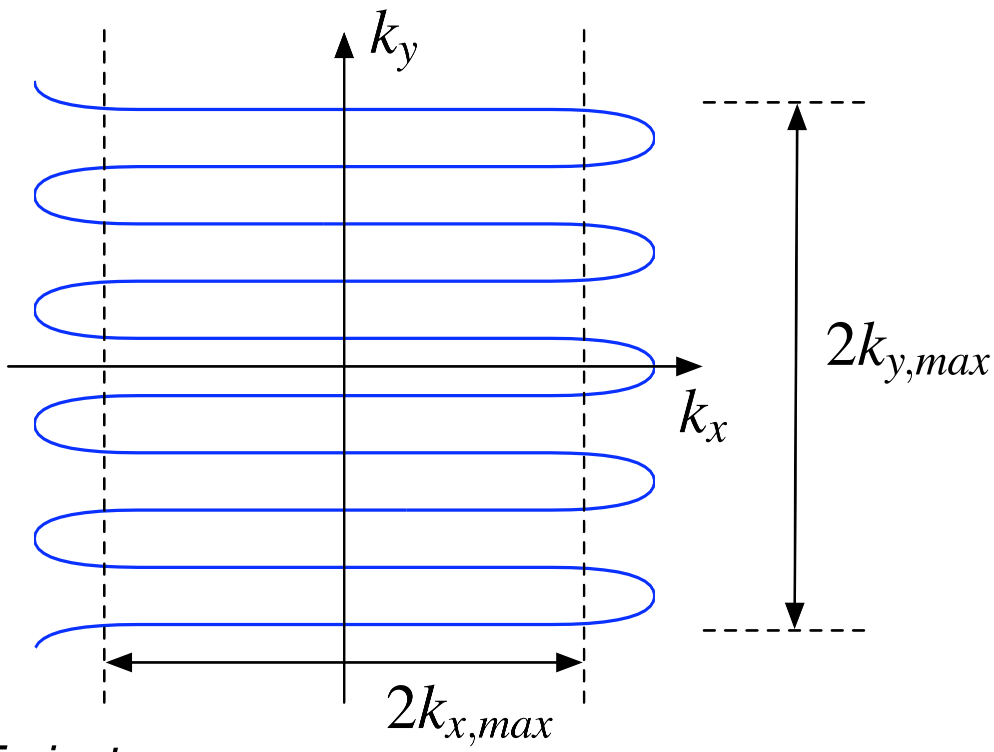
SIDELOBES IN ONE DIMENSION

SPECTRAL-SPATIAL PULSES

Blipped EPI

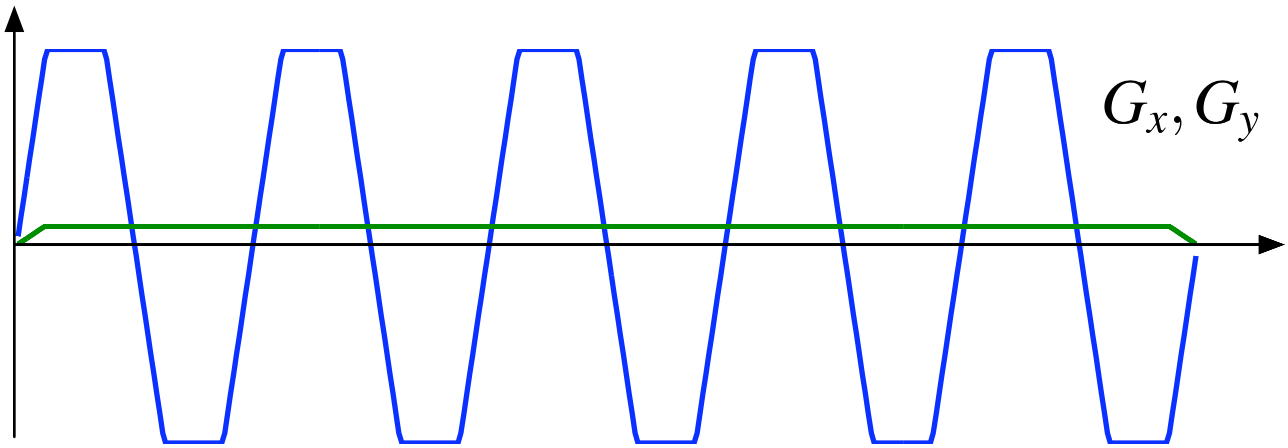


Gradient Waveforms

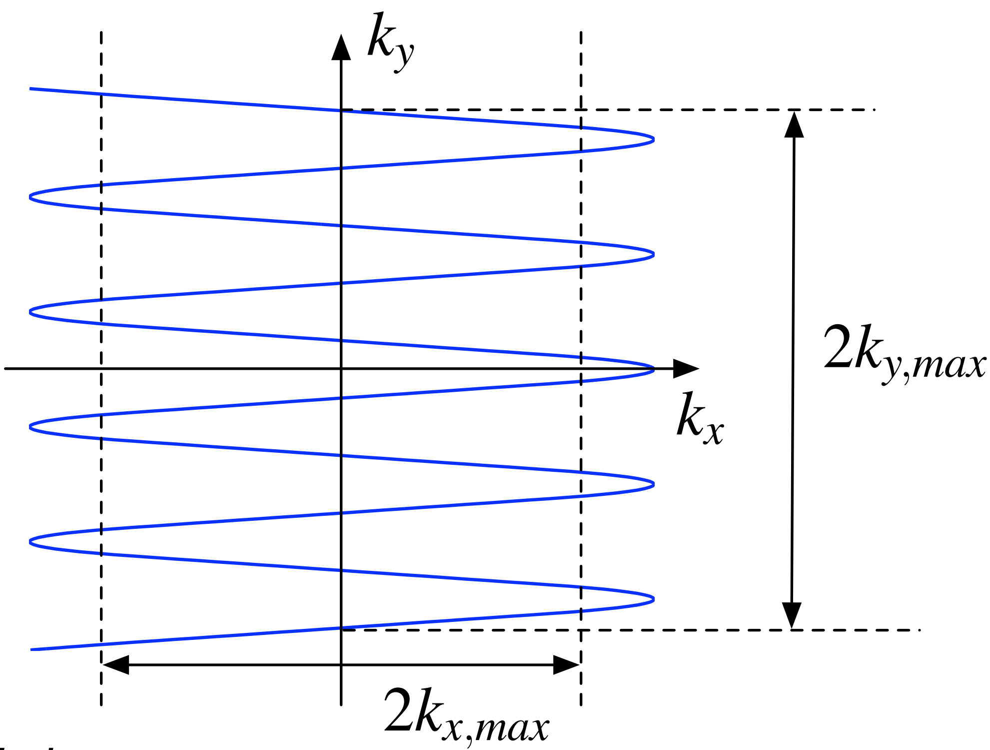


k-Space Trajectory

Continuous EPI

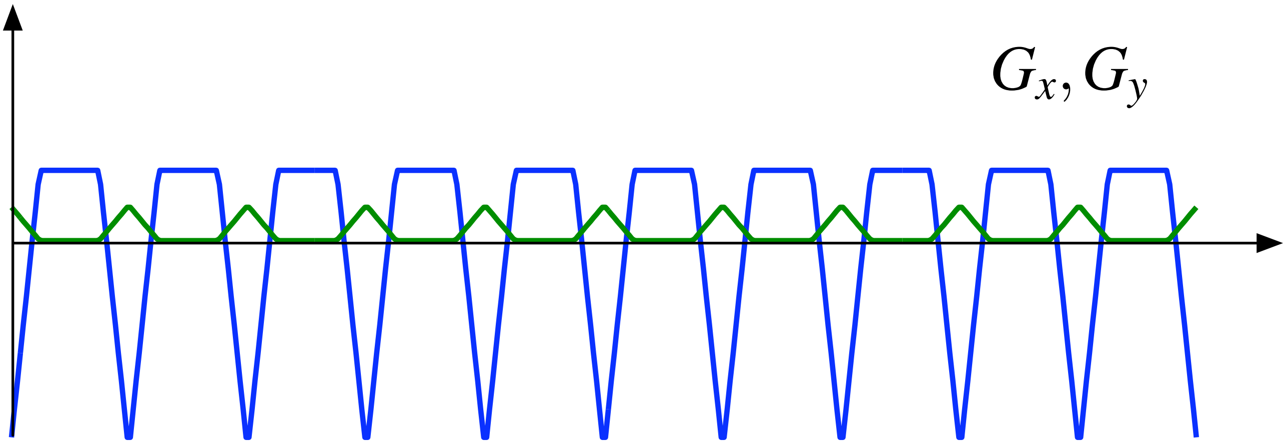


Gradient Waveforms

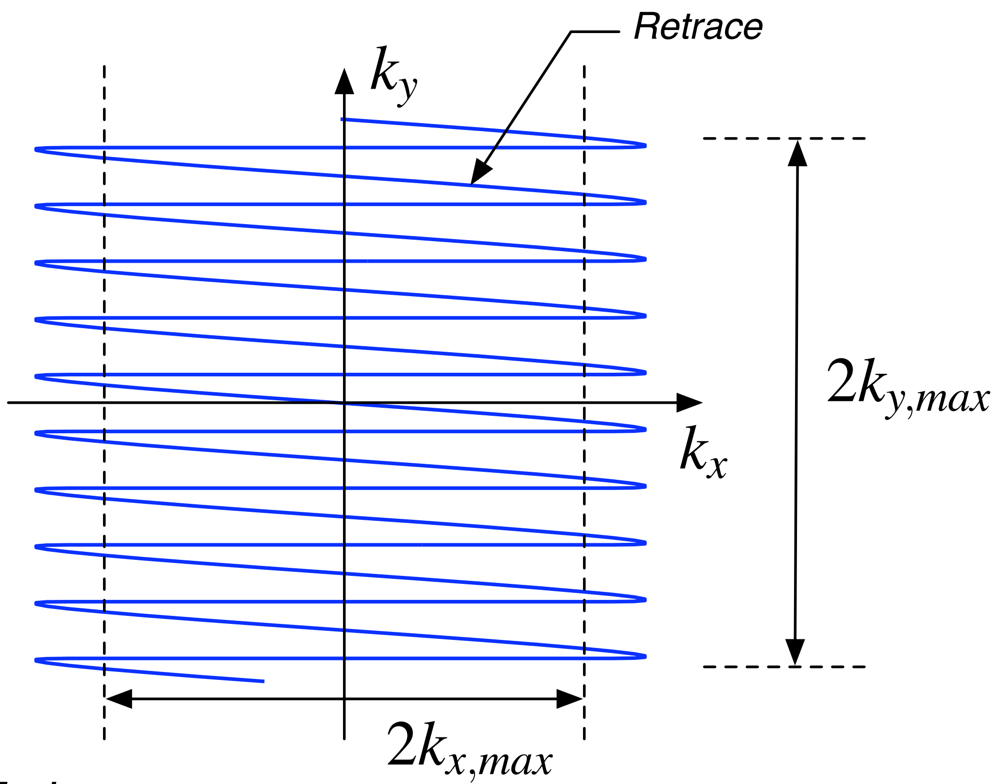


k-Space Trajectory

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
$\Rightarrow$ LESS EFFICIENT THAN BLIPPED

SENSITIVE TO EDDY CURRENTS, GRADIENT DELAYS

<u>ONLY CHOICE FOR SPECTRAL-SPATIAL PULSES</u>

FLYBACK EPI

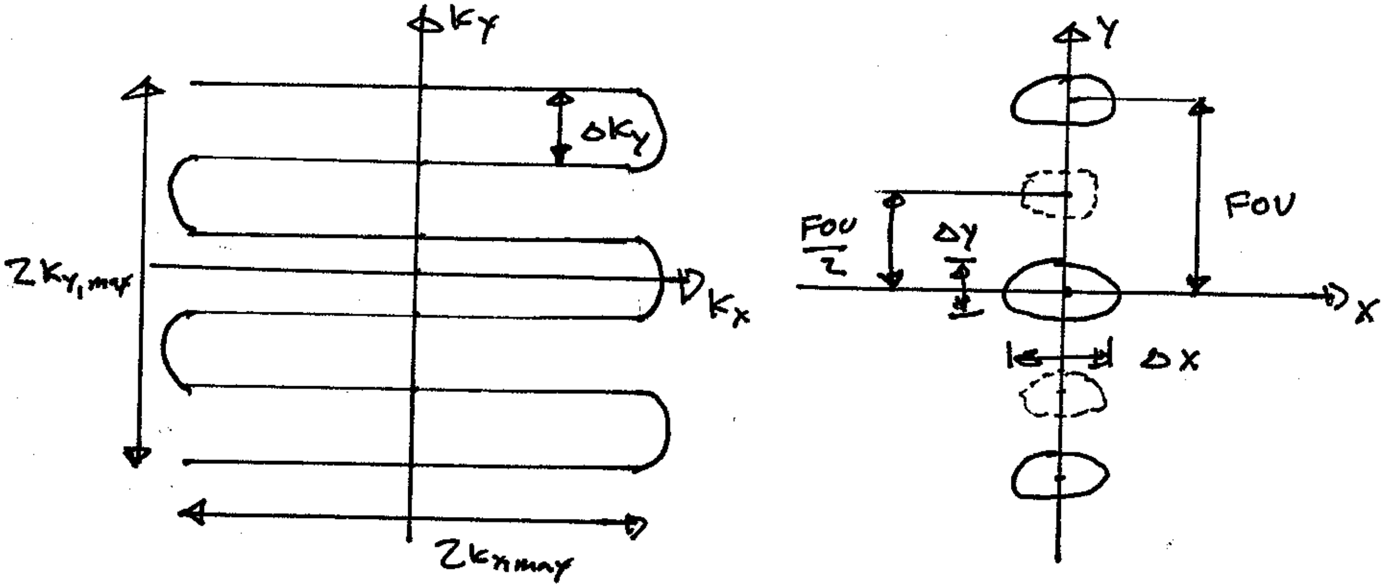
CAN BE BLIPPED <u>OR</u> CONTINUOUS

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

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

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

(THESE WILL OFTEN BE DIFFERENT)

TRUE FOV

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

"GHOST" FOV

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

(EDDY CURRENT, DELAYS PRODUCE THIS)

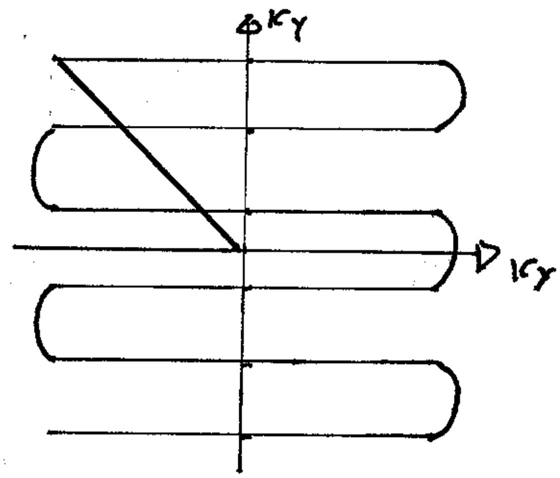
SINCE THERE ARE L LINES

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

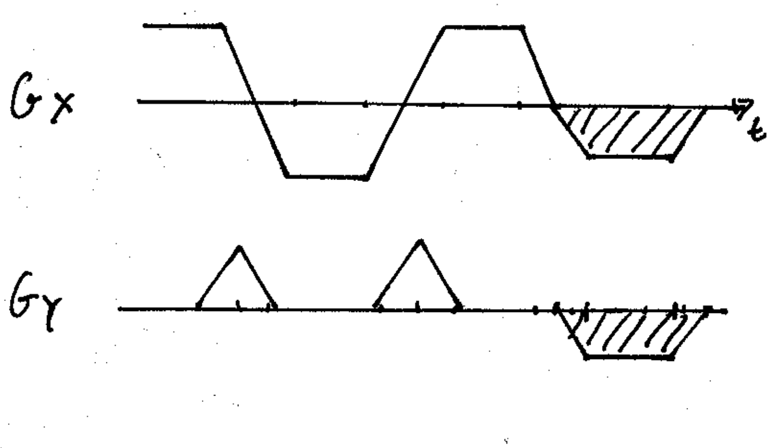
$$FOV = \frac{1}{\Delta k_y} = \frac{(L-1)}{2k_{y,max}} = (L-1)\Delta y$$

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

<u>REFOCUSING LOBE</u>



RETURNS TO ORIGIN AT END OF PULSE



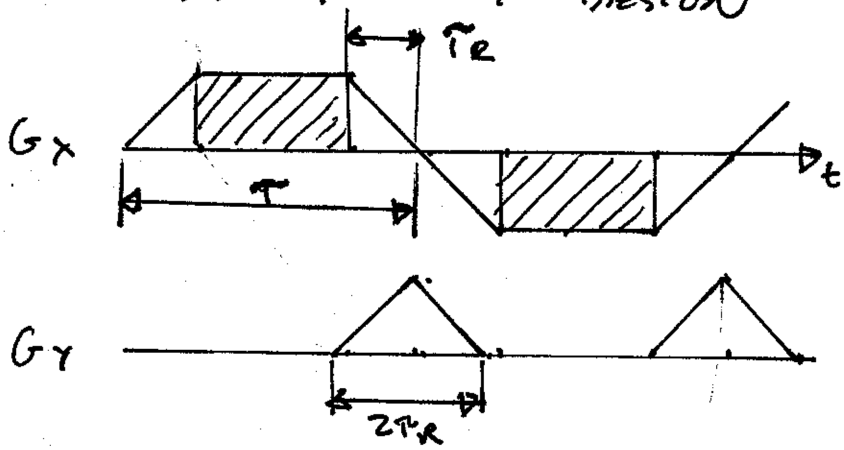
HALF AREA OF Gx LOBE

HALF AREA OF (L-1) Gy LOBE (BLIP)

DESIGNING EPI GRADIENTS

DESIGNING READOUT LOBES AND BLIPS

FLAT-TOP ONLY DESIGN



RF ONLY PLAYED DURING FLAT PART (SIMPLER)

TYPICAL VALUES

$\tau = 1\,ms$

$\tau_R = 4\,G/cm / 15\,G/cm/ms \simeq 1/4\,ms$

THEN

$$2k_{max} = \frac{\gamma}{2\pi}(\tau - 2\tau_R)\,G_{max}$$

$$= (4.257\,kHz/G)(\tfrac{1}{2}\,ms)\,4\,G/cm$$

$$\simeq 8.5\ \text{cycles/cm}$$

RESOLUTION LIMIT

$$\Delta x = \frac{1}{2k_{max}} = \frac{1}{8.5\ \text{cycles/cm}} = \underline{0.12\,cm} \quad (TBW=1)$$

WITH A TBW=4 PULSE (TYPICAL)

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

BLIPS

BLIP AREA, Δk_y IS

$$\Delta k_y = \frac{\gamma}{2\pi} \frac{1}{2} (2T_r) G_{max}$$

$$= (4.257 \text{ kHz/G})(\tfrac{1}{4} \text{ ms}) \, 4 \text{ G/cm}$$

$$= 4.257 \text{ CYCLES/cm}$$

ASSUME $L = 11$ K-SPACE LINES

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

$$= 42 \text{ CYCLES/cm}$$

$$\Delta Y = \frac{1}{2k_{y,max}} = 0.024 \text{ cm}$$

$$FOV = 1/\Delta k_y = 0.23 \text{ cm}$$

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 BLIPS NARROWER

PLAYING RF DURING PART OF RAMPS

FOR EXAMPLE ABOVE

$2k_{x,max}$ GOES FROM 8.5 TO 12.75 CYCLES/cm

$4(\Delta X)$ GOES FROM 0.47 cm TO 0.31 cm

DESIGNING 2D EPI SPATIAL PULSES

TWO MAJOR OPTIONS

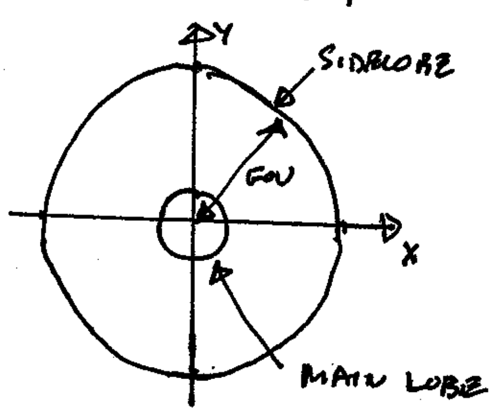
1) GENERAL APPROACH, SAME AS 2D SPIRAL PULSES
2) SEPERABLE, PRODUCT DESIGN (EASIER)

GENERAL APPROACH

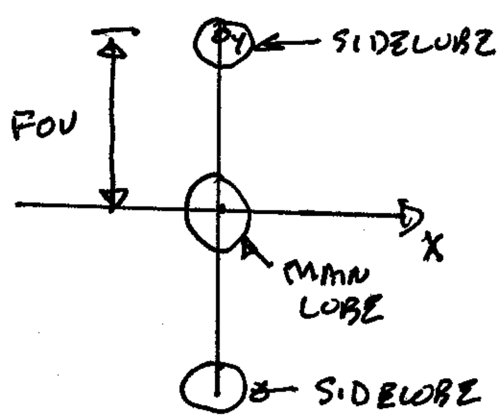
1) CHOOSE EPI k-SPACE TRAJECTORY
2) DESIGN GRADIENT WAVEFORMS
3) DESIGN $W(k)$, THE k-SPACE WEIGHTING
4) DESIGN $B_1(t)$

$$B_1(t) = |G(t)|\, W(k(t))$$

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



SPIRAL
IMPULSE RESPONSE



EPI
IMPULSE RESPONSE

SEPIERABLE, PRODUCT DESIGN

ASSUME

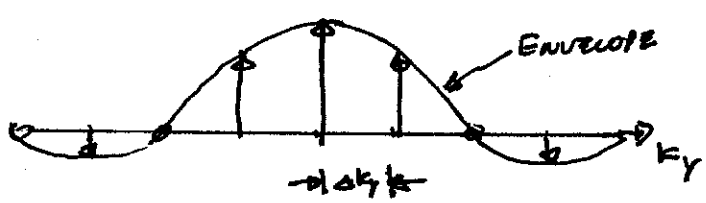
$$W(\underline{k}) = A_S(k_y)\, A_F(k_x)$$

WHERE

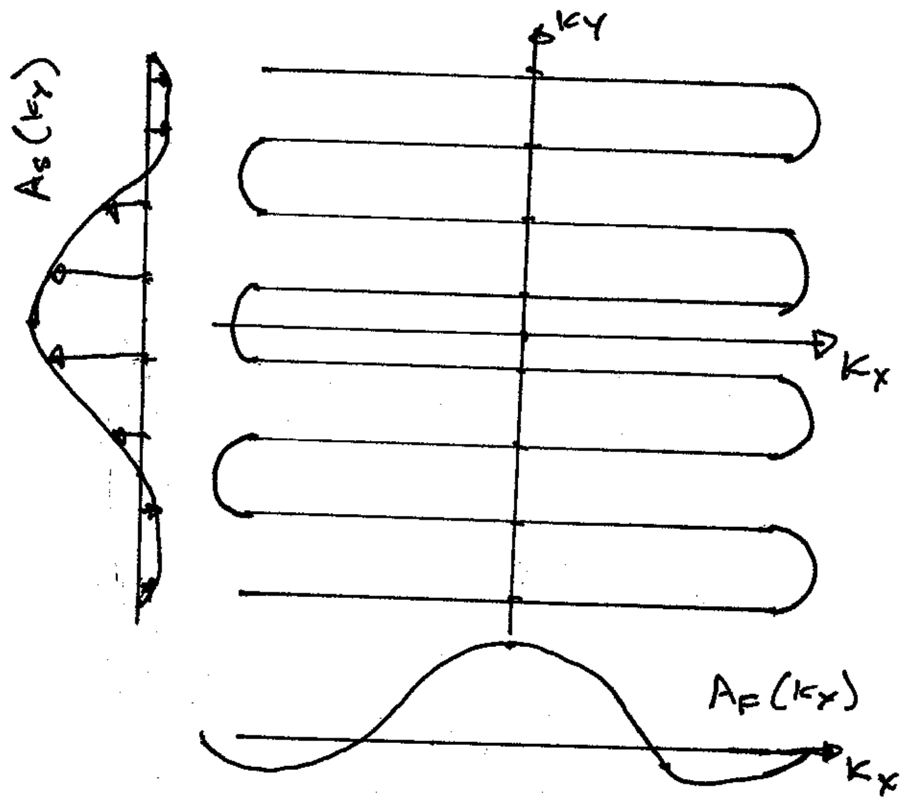
$A_S(k_y)$ WEIGHTING IN THE SLOW, BLIPPED DIRECTION

$A_F(k_x)$ WEIGHTING IN THE FAST OSCILLATING DIRECTION

NOTE THAT FOR THE BLIPPED EPI DESIGN, $A_S(k_Y)$ IS SAMPLED



EACH IMPULSE CORRESPONDS TO A PULSE IN THE FAST DIRECTION, $A_F(k_x)$



TRACE OUT TRAJECTORY

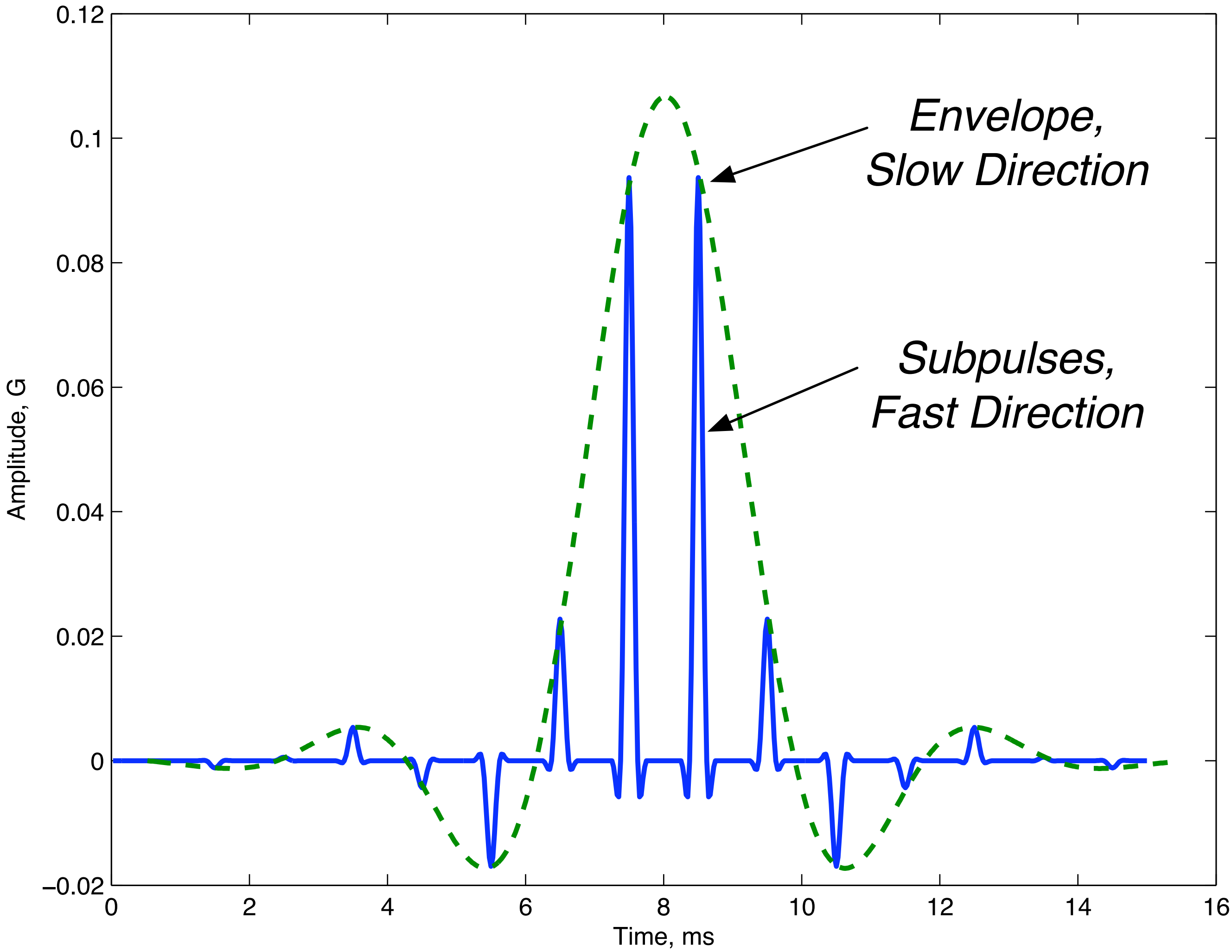
SEQUENCE OF $A_F(k_x)$ SUBLOBES

MULTIPLIED BY SAMPLES OF $A_S(k_y)$

ENVELOPE

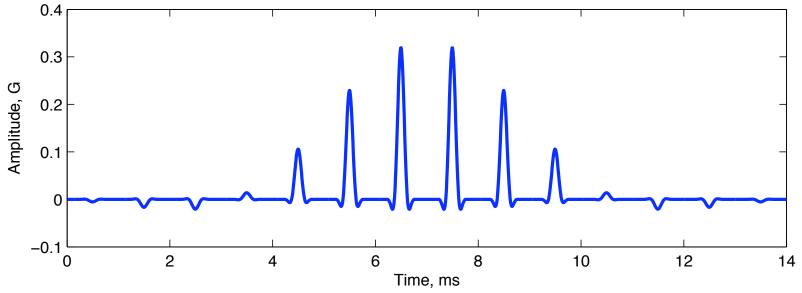
VERY SIMPLE TO COMPUTE

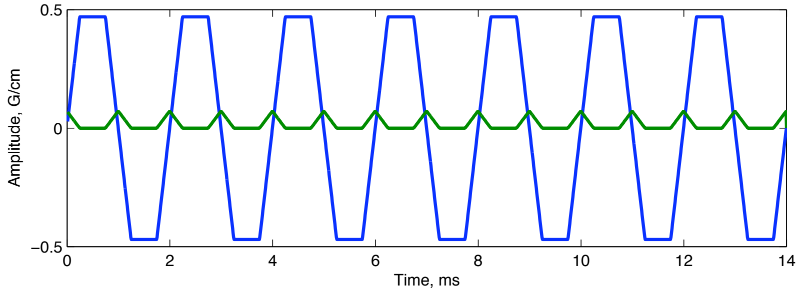
Product Pulse Design



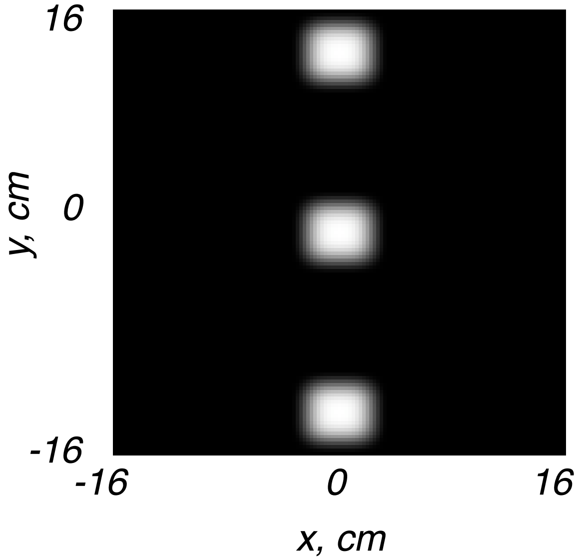
Example: 2D EPI Pulse

Waveforms





Excited Volume



kx,max = ky,max = +/- 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 (SPIRAL, EPI)

EXCITE ONLY WATER TO LIMIT OFF-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)

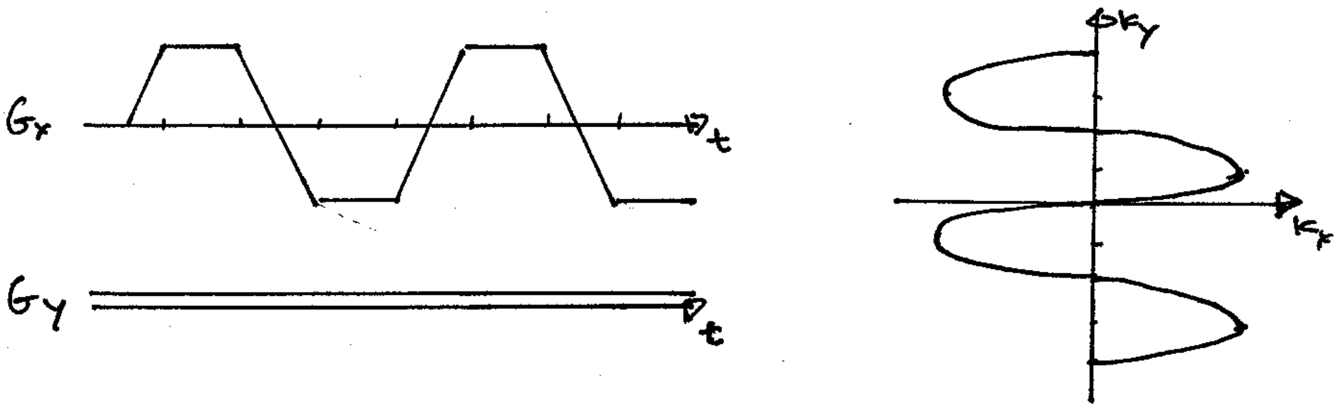
WATER SUPPRESSION / ATTENUATION

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

$$m_{xy}(y,t) = i m_0 \int_{-\infty}^{t} \gamma B_1(\tau)\, e^{i 2\pi k_y(\tau,t) y}\, d\tau$$

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

SO

$$m_{xy}(y,t) = i m_0 \int_{-\infty}^{t} \gamma B_1(\tau)\, e^{i 2\pi \left(\frac{\gamma}{2\pi} G_y (t-\tau)\right) y}\, d\tau$$

$$= i m_0 \int_{-\infty}^{t} \gamma B_1(\tau)\, e^{-i \underbrace{(\gamma G_y y)}_{\omega}(t-\tau)}\, d\tau$$

$$= i m_0 \int_{-\infty}^{t} \gamma B_1(\tau)\, e^{-i 2\pi \underbrace{\left(\frac{\gamma G_y y}{2\pi}\right)}_{f} \underbrace{(t-\tau)}_{k_f}}\, d\tau$$

CONSIDER m_{xy} AS FUNCTION OF f

$$m_{xy}(f,t) = i m_0 \int_{-\infty}^{0} \gamma B_1(k_f)\, e^{i 2\pi f k_f}\, dk_f$$

WHERE

$$f = \frac{\gamma G_Y Y}{2\pi}$$

$$k_f = -(t-\tau)$$

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

$\Rightarrow$ NEXT TIME