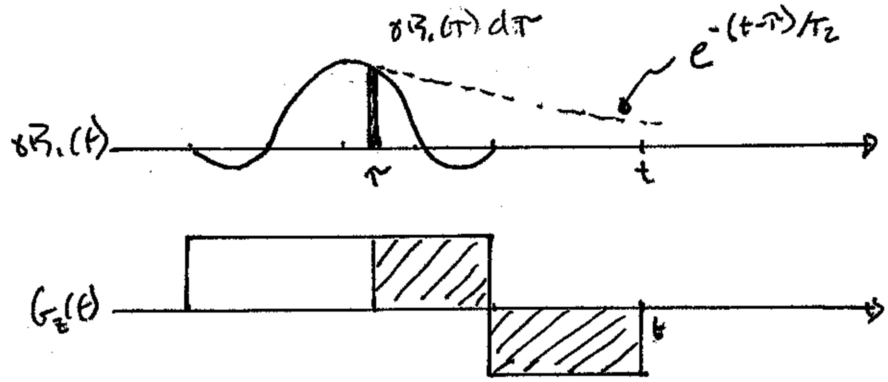
Ultra-short echo time (UTE) pulses, and short T2 contrast

- Short T2 excitation pulses
- Short T2 imaging
- Generating short T2 contrast

T2 DECAY DURING EXCITATION

SMALL-TIP-ANGLE CASE

GRAPHICAL DERIVATION



SMALL INCREMENT IN M_{xy} IS EXCITED AT TIME τ

- DECAYS BY $e^{-(t-\tau)/T_2}$
- PRECESSES BY $k(\tau,t)z$ WHERE

$$k(\tau,t) = -\frac{\gamma}{2\pi}\int_\tau^t G_z(s)\,ds$$

PHASE FACTOR

$$e^{i2\pi k(\tau,t)z}$$

- INCREMENT IN M_{xy} IS

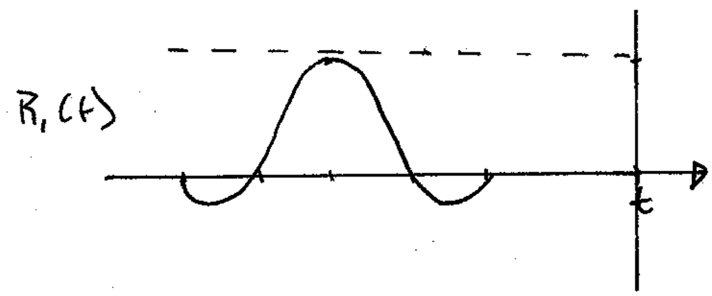
$$\Delta M_{xy} = (\gamma B_1(\tau)\Delta\tau)(iM_0)\,e^{-(t-\tau)/T_2}\,e^{i2\pi k(\tau,t)z}$$

INTEGRATING

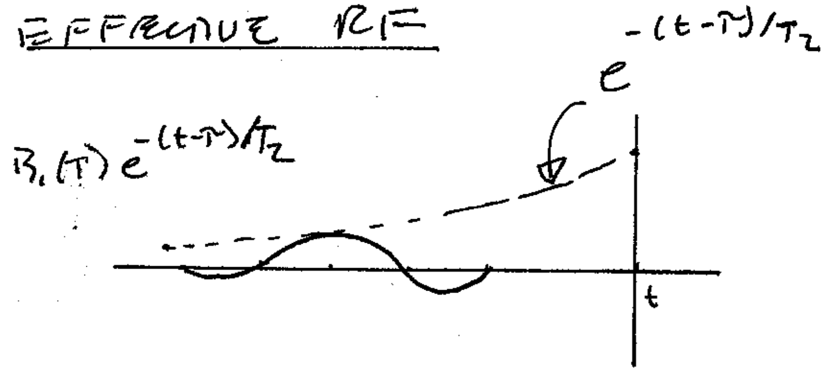
$$M_{xy}(z,t) = iM_0\int_{-\infty}^{t}\gamma B_1(\tau)\,e^{-(t-\tau)/T_2}\,e^{i2\pi k(\tau,t)z}\,d\tau$$

FOURIER TRANSFORM OF EXPONENTIALLY WEIGHTED RF

APPLIED RF



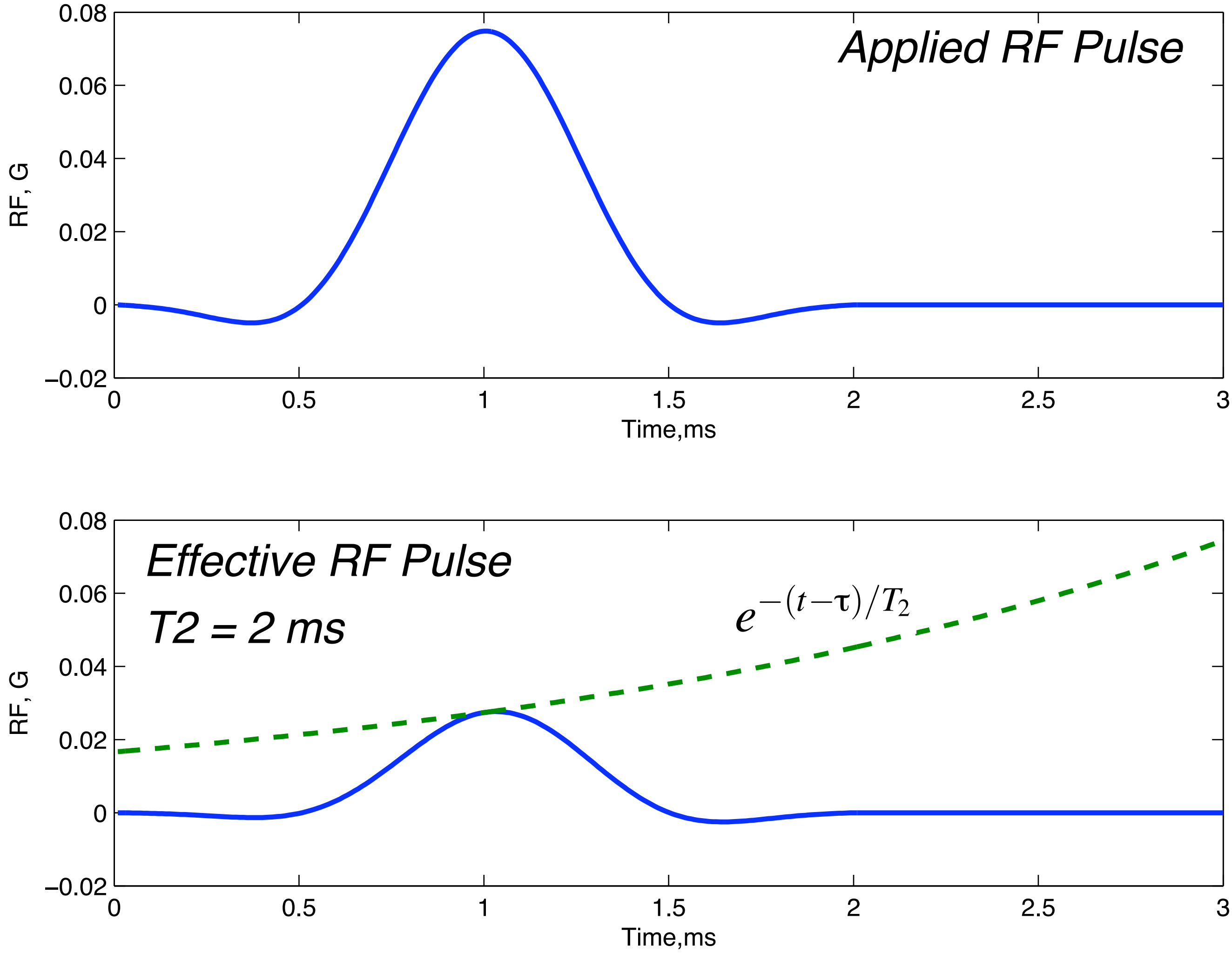
EFFECTIVE RF



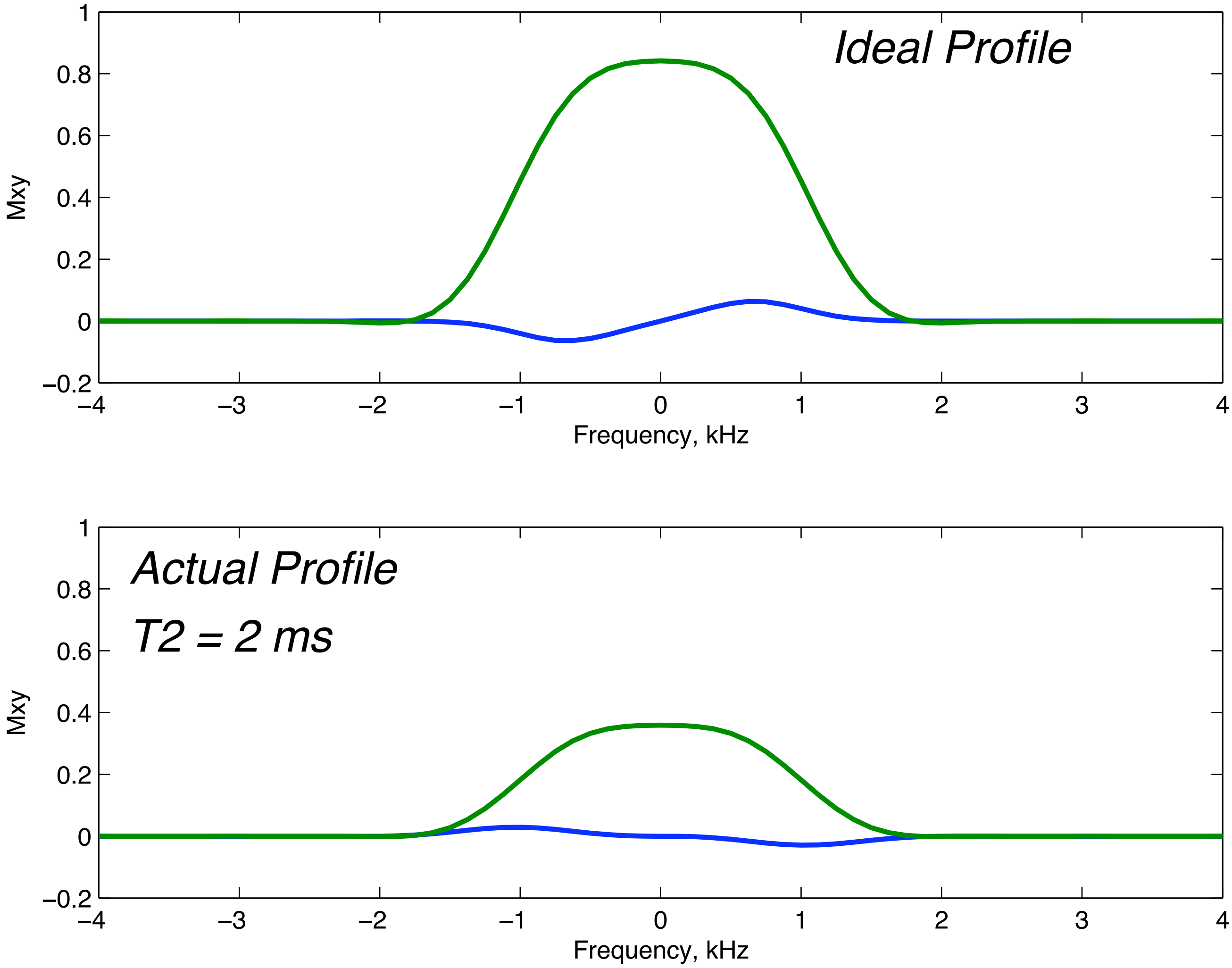
PRIMARY EFFECT:
LOSS OF SIGNAL

SECONDARY EFFECT:
LOSS OF SELECTIVITY

Effect of T2 on Small-Tip-Angle Excitation

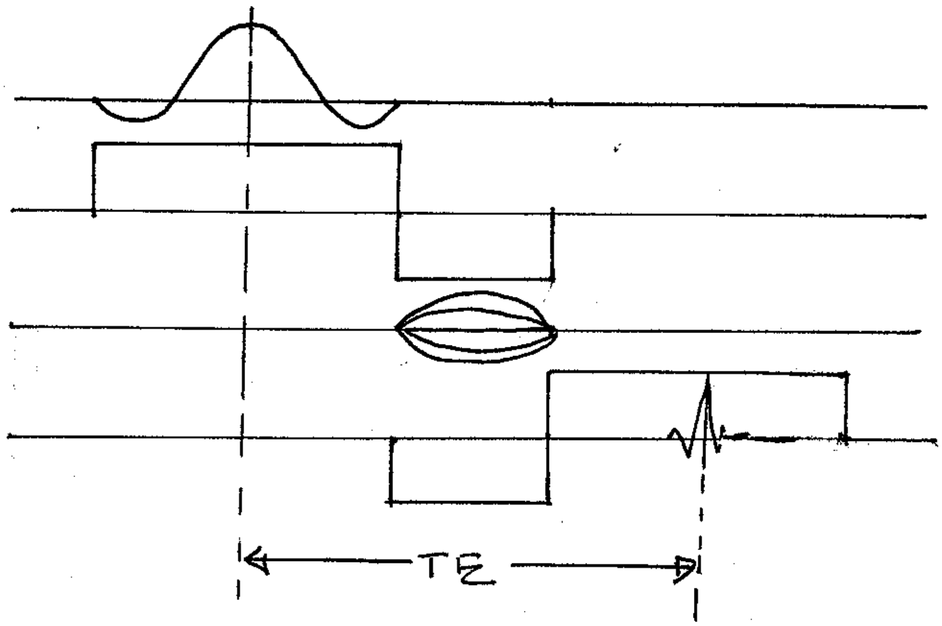


Effect of T2 on Small-Tip-Angle Excitation



ECHO TIME IN A GRADIENT RECALLED SEQUENCE

ECHO TIME IS DELAY FROM CENTER OF RF TO K-SPACE ORIGIN IN READOUT



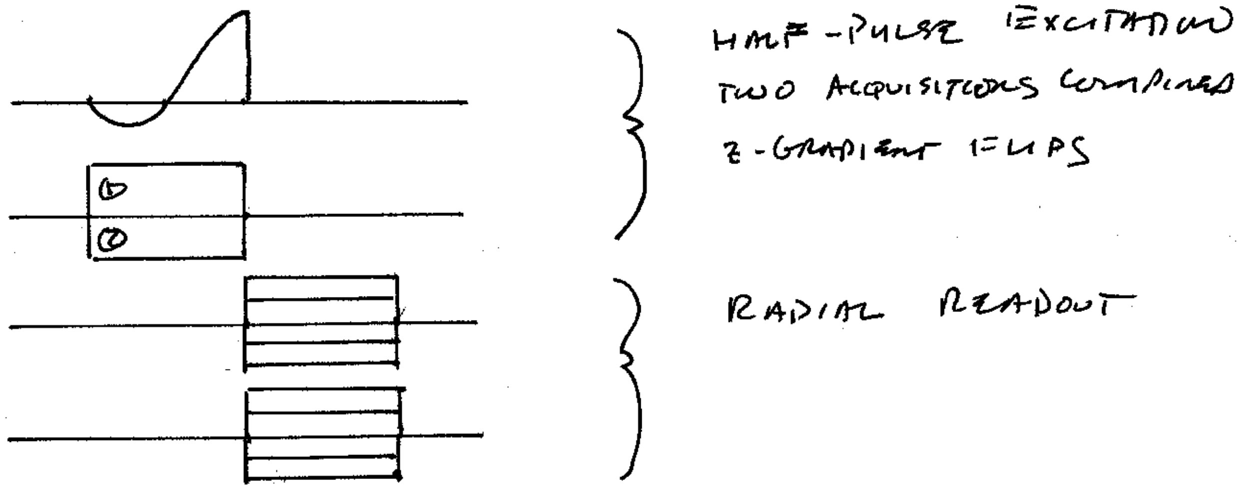
MINIMIZE T_2 DECAY BY MINIMIZING TE

ELIMINATE EVERYTHING BETWEEN DASHED LINES

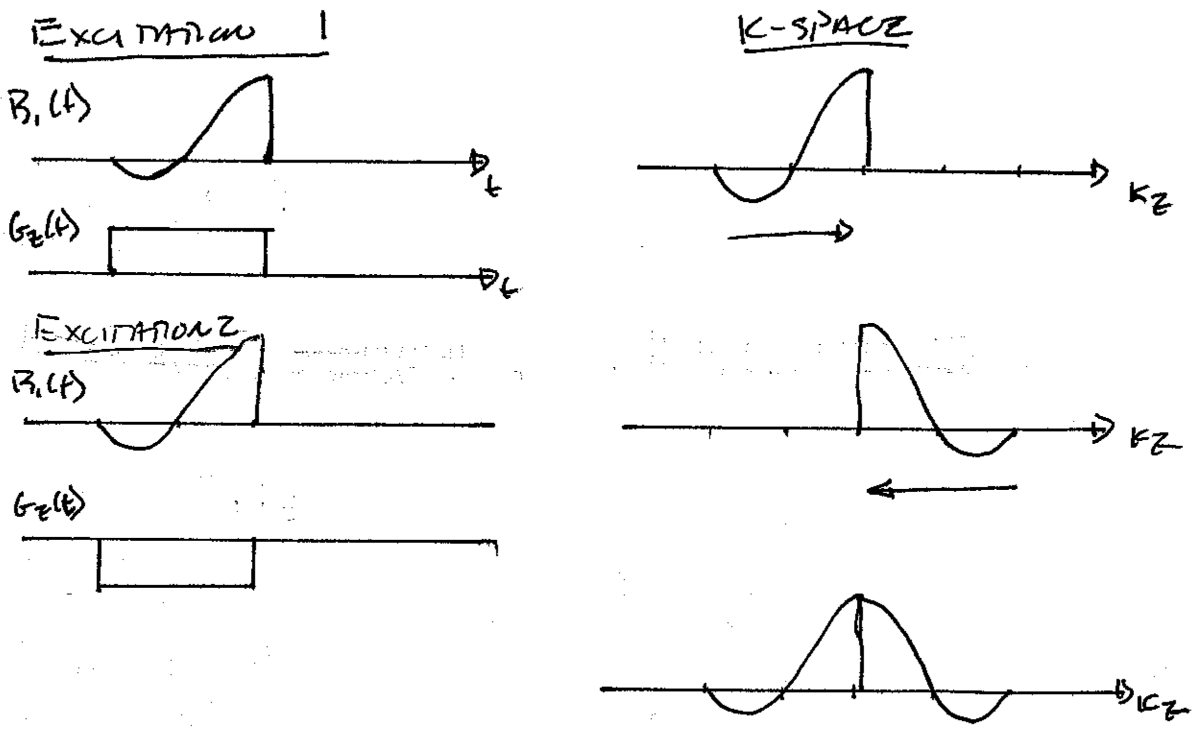
- HALF-PULSE EXCITATION
- RADIAL READOUT

SHORT T2 PULSE SEQUENCE

IDEAL PULSE SEQUENCE



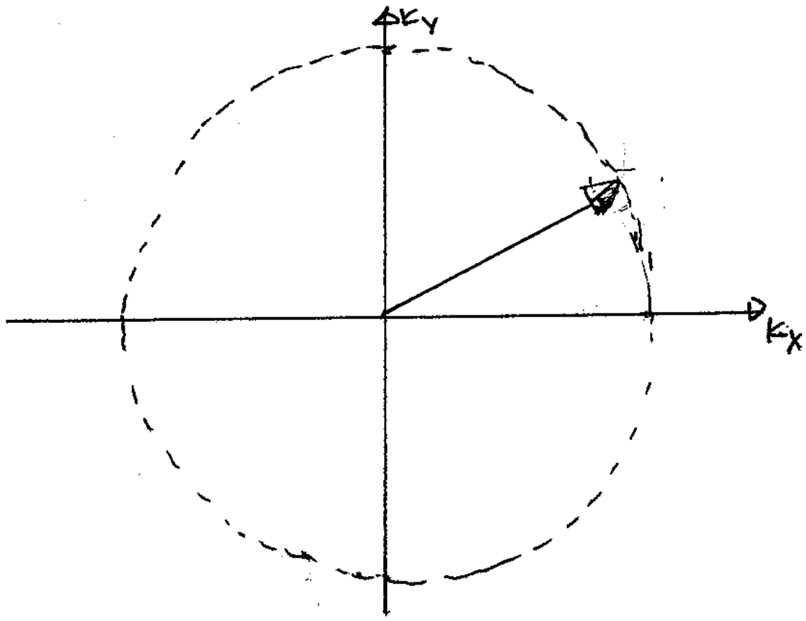
HALF-PULSE EXCITATION



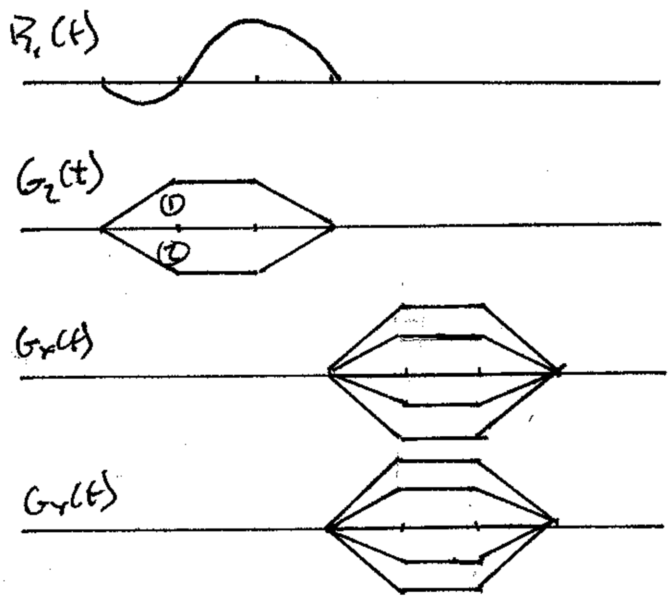
SUM OF TWO ACQUISITIONS
SAME AS CONVENTIONAL
SLICE SELECTIVE PULSE!

RADIAL READOUT

START AT K-SPACE ORIGIN, GO DIRECTLY OUT



PRACTICAL PULSE SEQUENCE



LARGE FLIP ANGLE HALF PULSES

HALF PULSES ARE BASED ON A SMALL-TIP ANGLE (FOURIER) MODEL.

WORKS WELL TO 45°, OR EVEN 60°

SIGNIFICANT DISTORTION AT 90°

SOLUTION

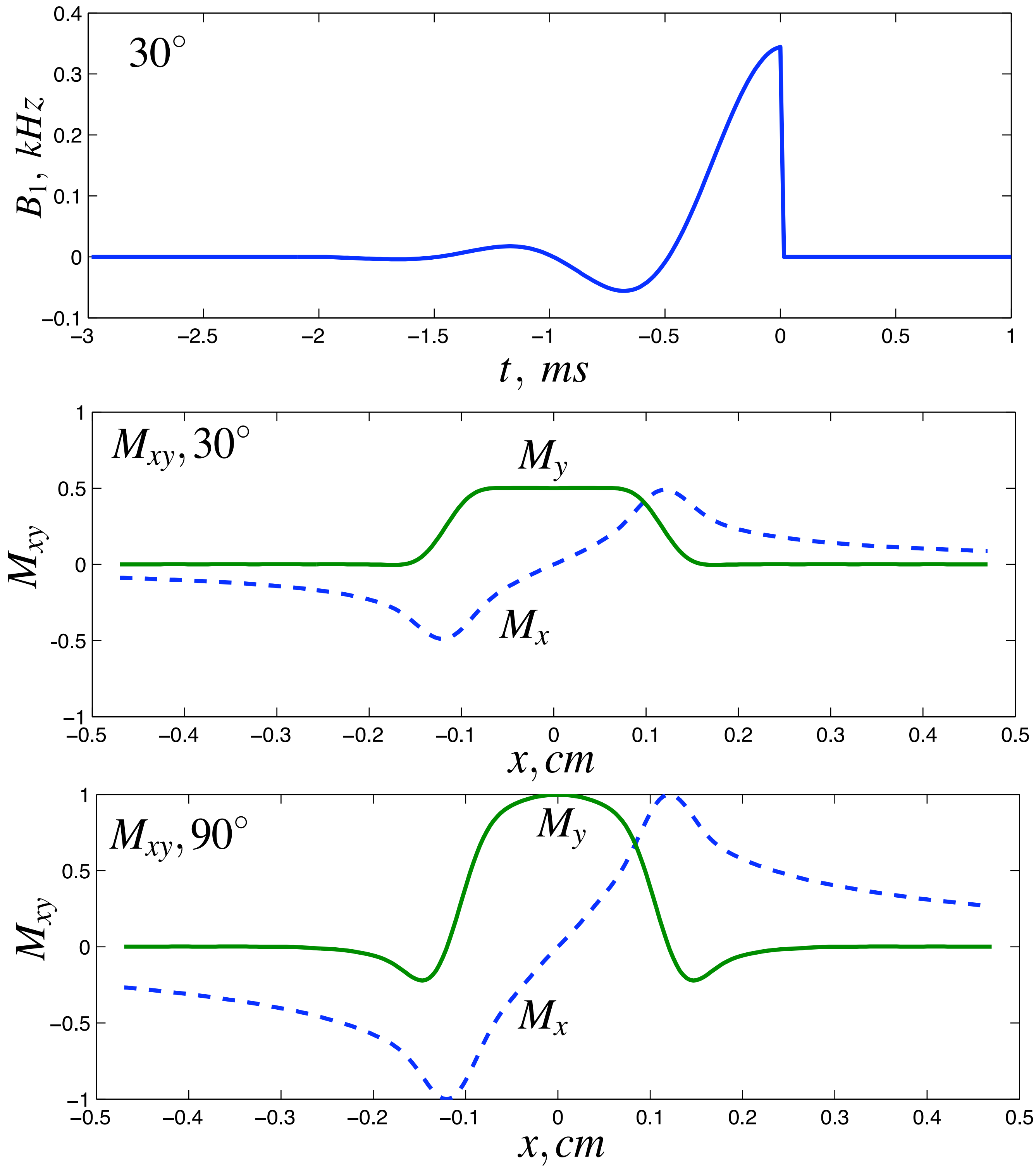
TO DESIGN A HALF PULSE FOR A FLIP ANGLE θ

1) DESIGN AN SLR PULSE FOR ANGLE 2θ

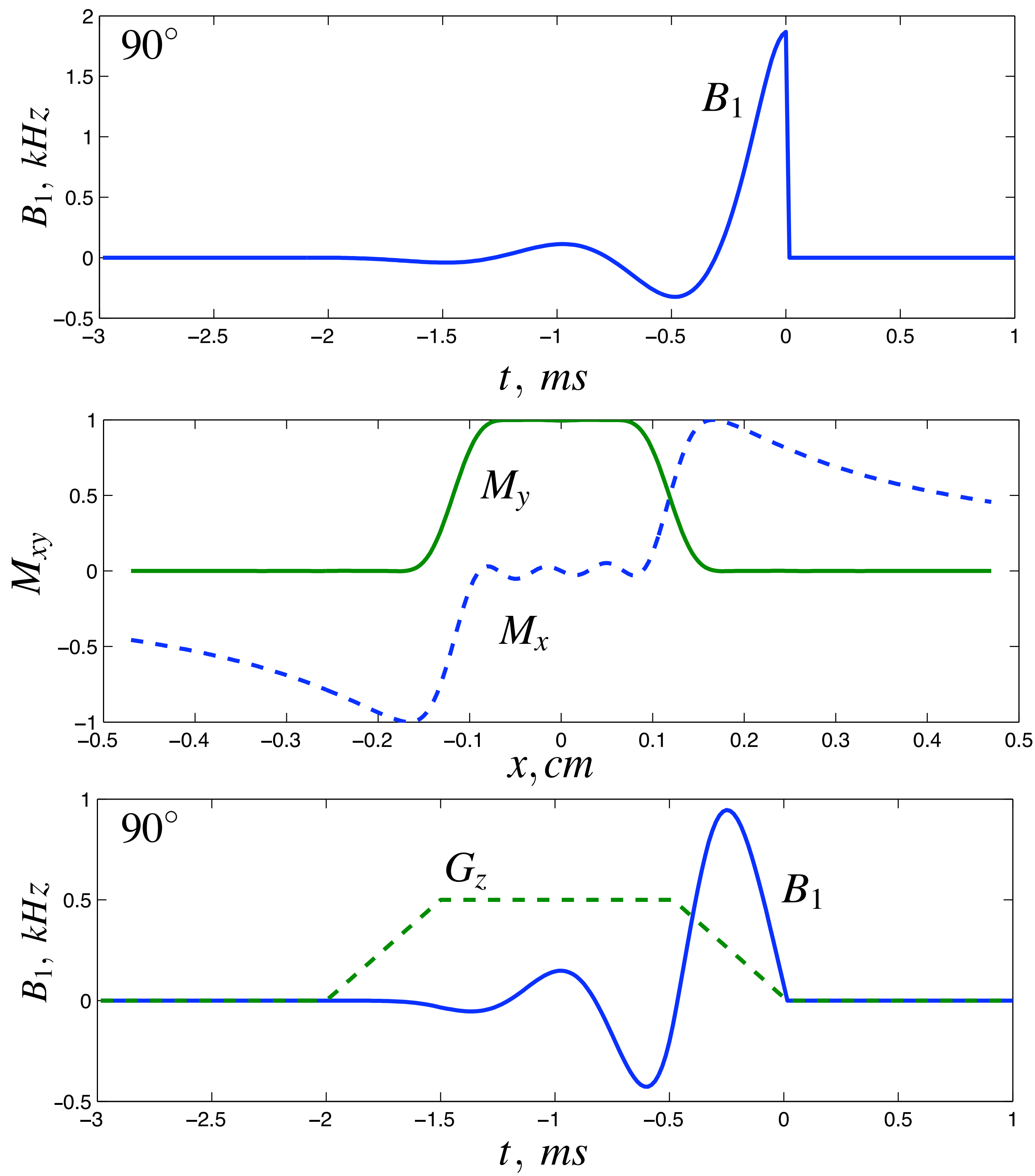
2) TAKE THE FIRST HALF.

FOR A 90° HALF PULSE, USE THE FIRST HALF OF AN SLR 180!

Large-Tip-Angle Half Pulses, Fourier Design



Large-Tip-Angle Half Pulses
SLR Design



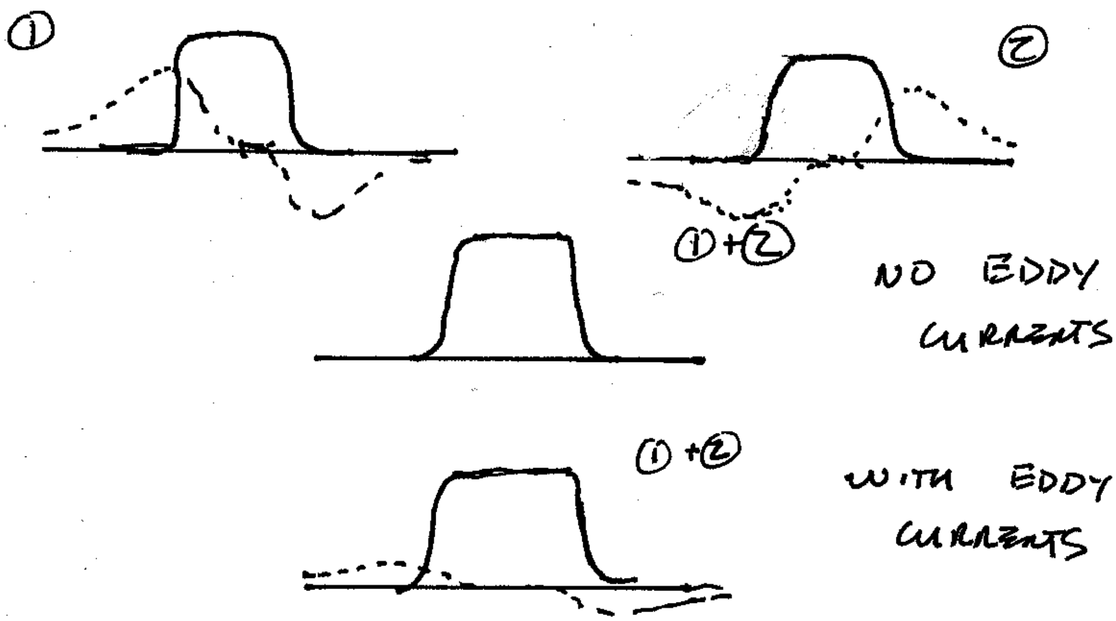
ISSUES WITH HALF PULSES

1) GRADIENT FIDELITY + EDDY CURRENT EFFECTS

WE ARE COUNTING ON

- SLICE PROFILE ADDING
- ANTI-SYMMETRIC TAILS CANCELING

BETWEEN TWO EXCITATIONS



SMALL PHASE ERRORS LEAVE RESIDUAL TAILS

THIS CAN BE A LARGE SIGNAL OVER A VOLUME

2) STEADY STATE EFFECTS

CENTER OF SLICE SEES

$\theta_x, \theta_x, \theta_x$

TAIL SEES

$\phi_y, -\phi_y, \phi_y, -\phi_y$

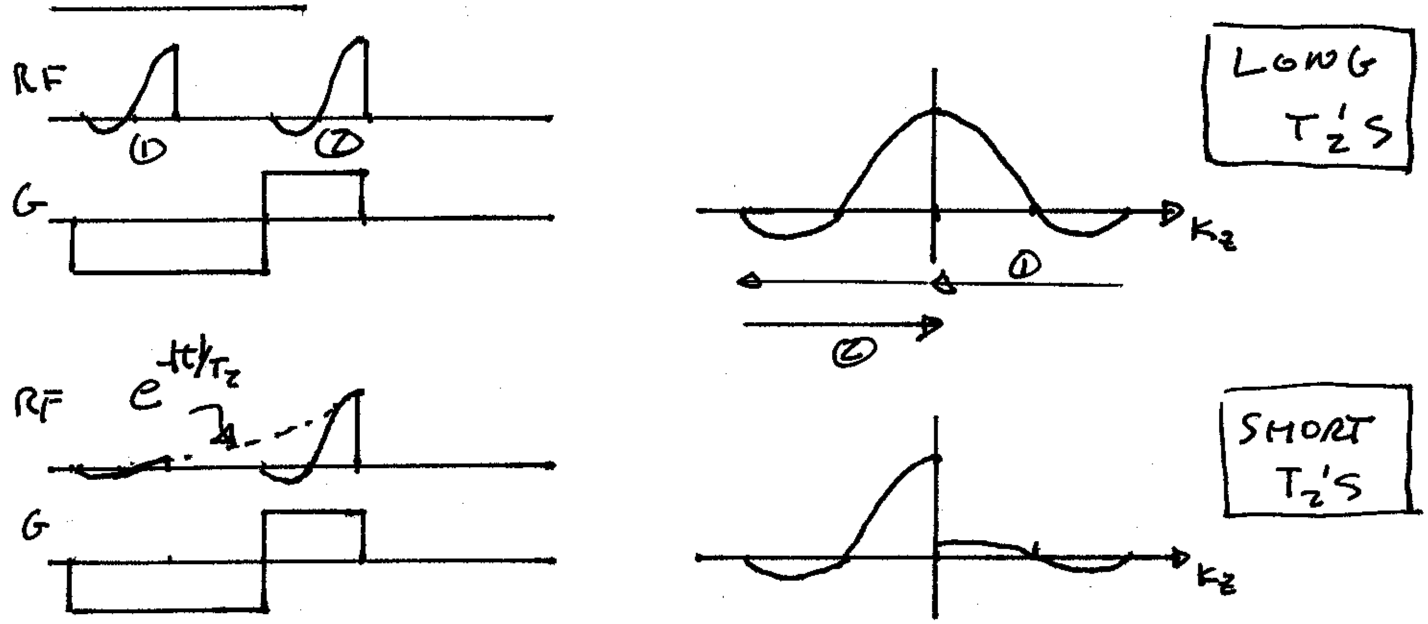
STEADY STATES CAN BE VERY DIFFERENT

DOUBLE HALF PULSES

DESIGN PULSES THAT ARE

- SLICE SELECTIVE FOR LONG T_2'S (NO ASSYMETRIC TAILS)
- HALF PULSES FOR SHORT T_2'S

EXAMPLE



ADVANTAGES

NO OUT-OF-SLICE TAILS FOR LONG T_2'S

NO CANCELLATION PROBLEMS, STEADY STATE EFFECTS

IMMUNE TO EDDY CURRENT EFFECTS

EASIER TO CALIBRATE

NO EFFECTS DURING READOUT

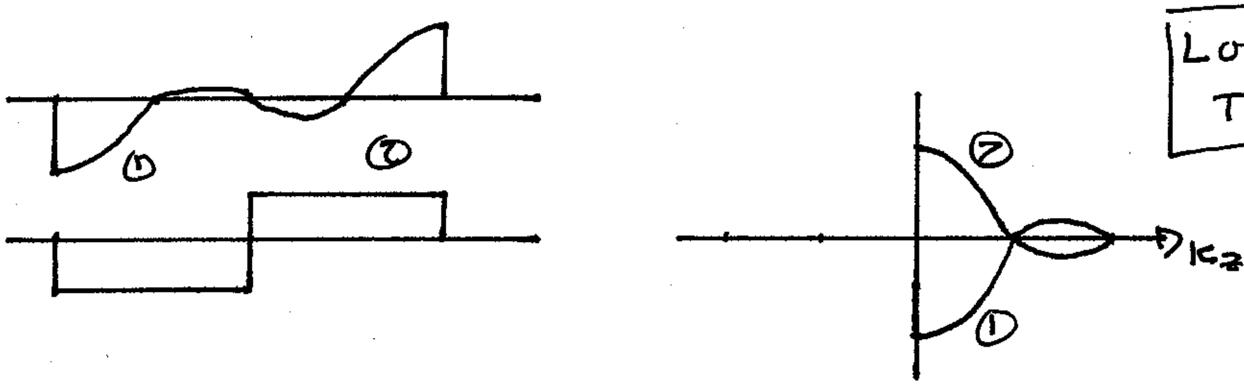
ISSUES

SPECTRAL RESPONSE

LOSS OF SHORT T_2 SIGNAL

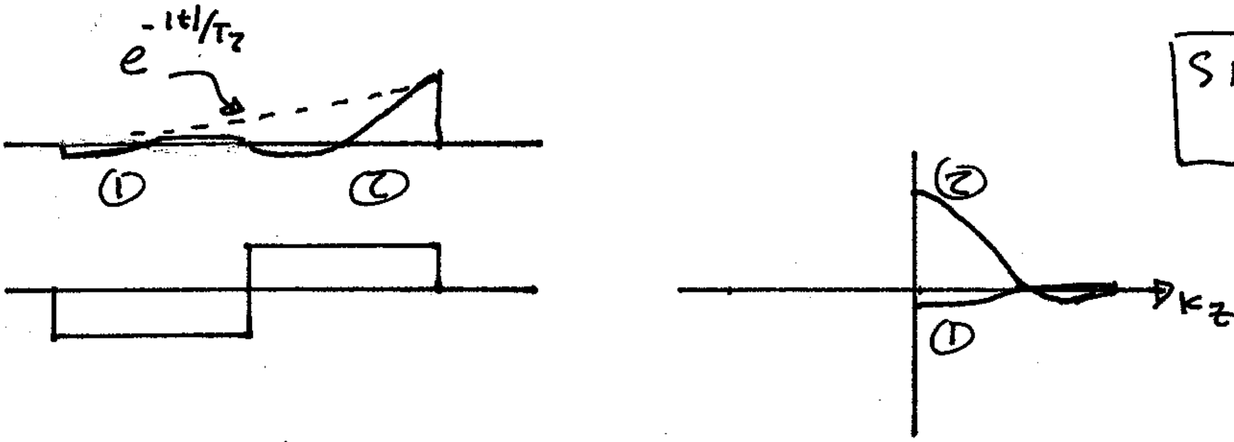
ANOTHER OPTION

LONG T_2's



LONG T_2's CANCEL.

SHORT T_2's



SHORT T_2's SEE A HALF PULSE

PROBLEM WITH SHORT-T_2 PULSE SEQUENCE

EVERYTHING SHOWS UP

IMAGES SHOW PROTON DENSITY ONLY

HARD TO TELL WHAT HAS SHORT T_2'S

NEED <u>SHORT-T_2 CONTRAST</u>

SHORT-T_2 CONTRAST OPTIONS

1) COLLECT SECOND IMAGE WITH TE2, COMPUTE DIFFERENCE IMAGE.

$$I_{ST2} = I_{TE1} - I_{TE2}$$

SHOULD SHOW ONLY SHORT-T2 COMPONENTS.

PROBLEMS:

- SECOND IMAGE ONLY ADDS NOISE TO SHORT-T2 VOXELS
- INHOMOGENEITY IN A VOXEL LOOKS LIKE SHORT-T_2

2) EXPLOIT T_1 DIFFERENCES

TISSUES WITH SHORT T_2'S TEND TO HAVE SHORT T_1'S (NOT LIKE SOLIDS)

RF SPOILED SHORT TR SEQUENCES WILL SHOW SHORT T1'S, EMPHASIZE SHORT T2'S

PROBLEMS:

- STILL NOT T_2 SELECTIVE UNLESS COMBINED WITH (1).

3) EXPLOIT EXCITATION DIFFERENCES

T2 EFFECTS OUR ABILITY TO EXCITE OR INVERT MAGNETIZATION

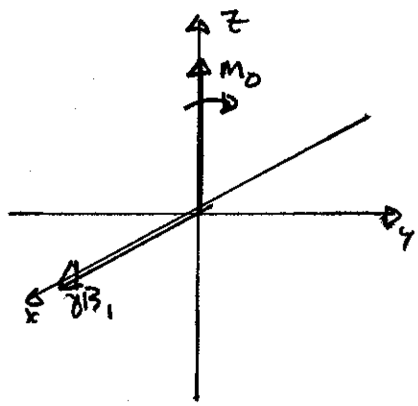
USE PREPULSES TO ESTABLISH SHORT-T_2 CONTRAST.

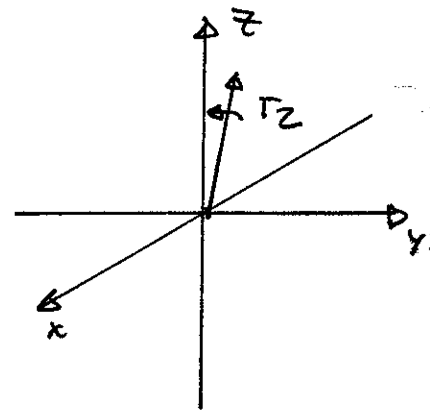
DESIGN T_2 SELECTIVE EXCITATIONS

LONG T_2 SUPPRESSION PULSES

BASIC IDEA: EXCITATION AND RELAXATION ARE COMPETING PROCESSES

EXCITATION CREATES MAGNETIZATION (M_{xy}) -AND- RELAXATION DESTROYS MAGNETIZATION





BOTH ARE EFFECTIVELY ROTATION RATES FOR SMALL-TIP-ANGLE CASE

IF $\gamma B_1 >> T_2$

MAGNETIZATION IS ROTATED AWAY FROM +z

IF $\gamma B_1 << T_2$

NO TRANSVERSE MAGNETIZATION IS CREATED

$\underline{M}$ STAYS <u>UNTOUCHED</u> ALONG +z

LONG T_2 SUPPRESSION PULSE

LONG, LOW AMPLITUDE 90° PULSE

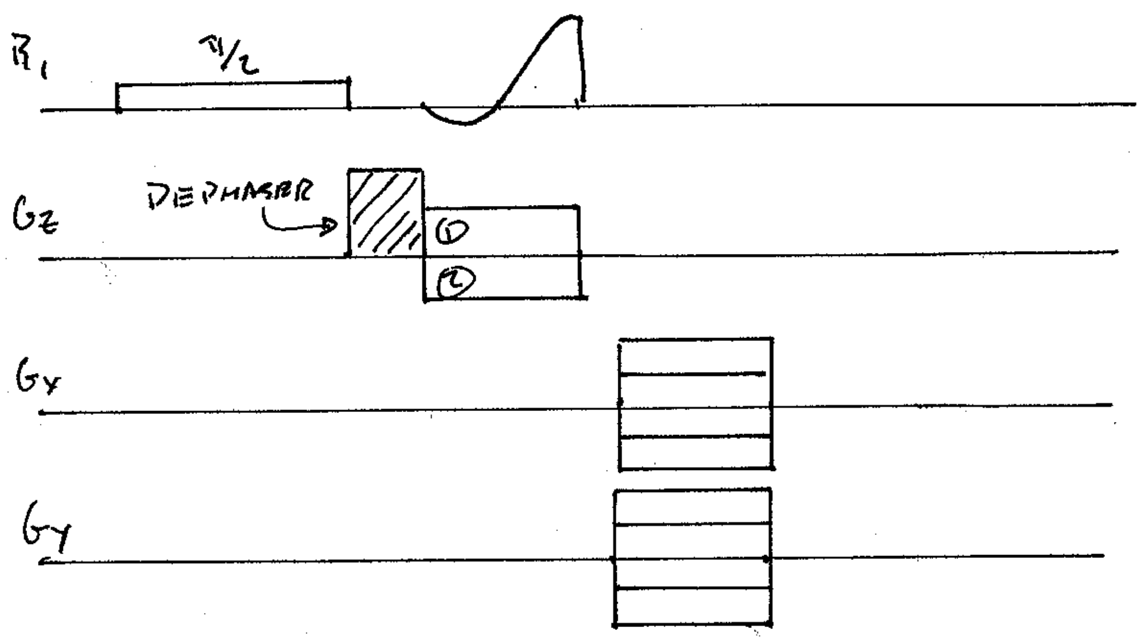
IF T IS PULSE LENGTH

T_2's << T ARE UNEXCITED

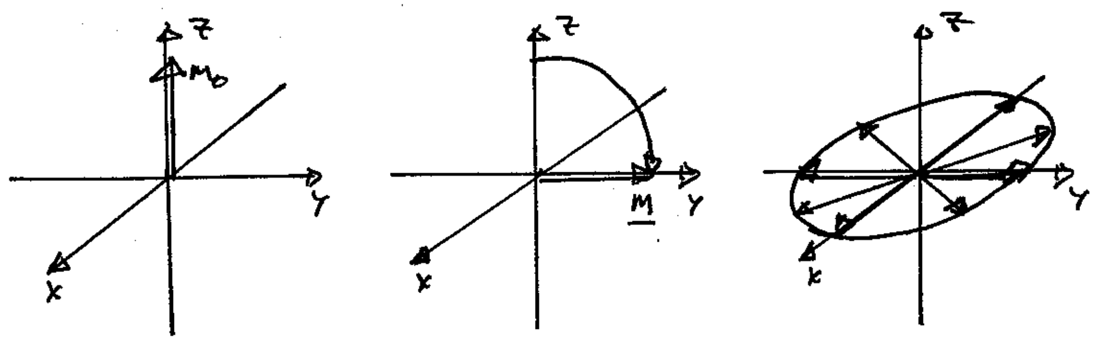
T_2's >> T ARE COMPLETELY EXCITED

EXCITED MAGNETIZATION IS DEPHASED

REMAINING MAGNETIZATION IS IMAGED WITH SHORT-T_2 PULSE SEQUENCE

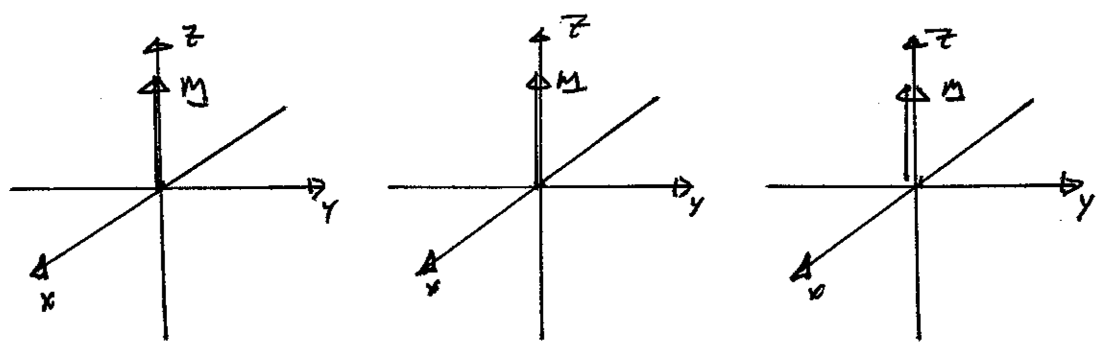


LONG-T_2 SPECIES



EQUILIBRIUM EXCITATION DEPHASING

SHORT-T_2 SPECIES



EQUILIBRIUM EXCITATION DEPHASING

LONG-T_2 SPECIES ARE EXCITED AND DEPHASED

SHORT-T_2 SPECIES ARE NOT EXCITED AT ALL.

LONG-T_2 SUPPRESSION RESPONSE

RECTANGULAR $\pi/2$ PULSE

$$\begin{pmatrix} \dot{m}_x \\ \dot{m}_y \\ \dot{m}_z \end{pmatrix} = \begin{pmatrix} -1/T_2 & 0 & 0 \\ 0 & -1/T_2 & \gamma B_1 \\ 0 & -\gamma B_1 & 0 \end{pmatrix} \begin{pmatrix} m_x \\ m_y \\ m_z \end{pmatrix}$$

LAST TWO EQUATIONS DECOUPLE

$$\begin{pmatrix} \dot{m}_y \\ \dot{m}_z \end{pmatrix} = \begin{pmatrix} -1/T_2 & \gamma B_1 \\ -\gamma B_1 & 0 \end{pmatrix} \begin{pmatrix} m_y \\ m_z \end{pmatrix}$$

WRITE AS A SINGLE EQUATION IN m_z

$$\ddot{m}_z + \frac{1}{T_2}\dot{m}_z + (\gamma B_1)^2 m_z = 0$$

LINEAR CONSTANT COEFFICIENT ODE. ROOTS ARE

$$\lambda_{1,2} = -\frac{1}{2T_2} \pm \sqrt{\left(\frac{1}{2T_2}\right)^2 - (\gamma B_1)^2}$$

SOLUTION FOR m_z IS

$$m_z(t) = \frac{1}{\lambda_1 - \lambda_2}\left[\left(\lambda_1 + \frac{1}{T_2}\right)e^{\lambda_1 t} - \left(\lambda_2 + \frac{1}{T_2}\right)e^{\lambda_2 t}\right]$$

FOR A $\pi/2$ PULSE, IF THE PULSE LENGTH IS T,

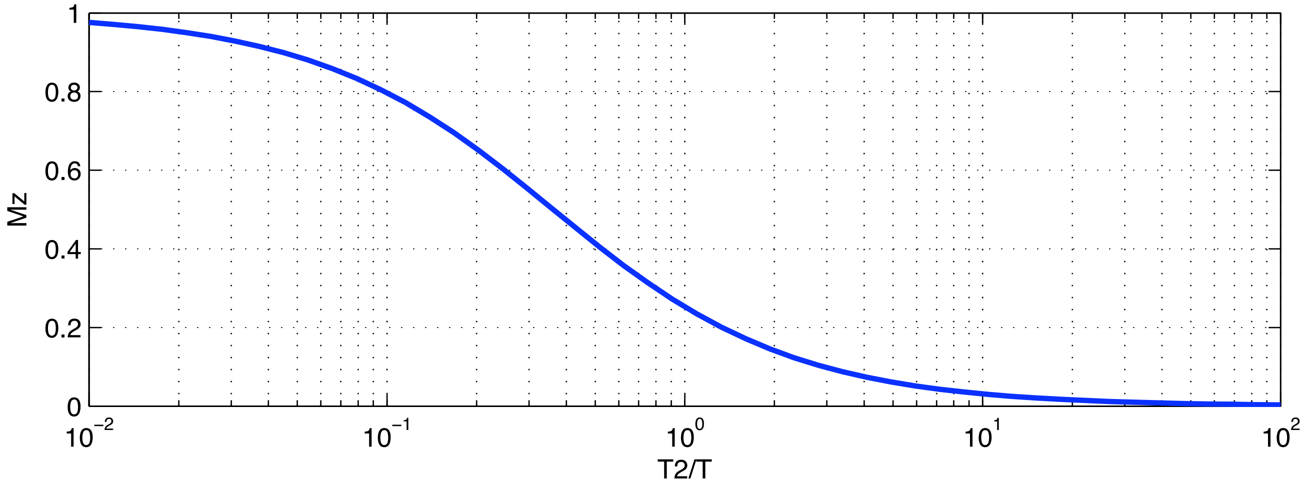
$$\gamma B_1 = \frac{\pi/2}{T} = \frac{\pi}{2T}$$

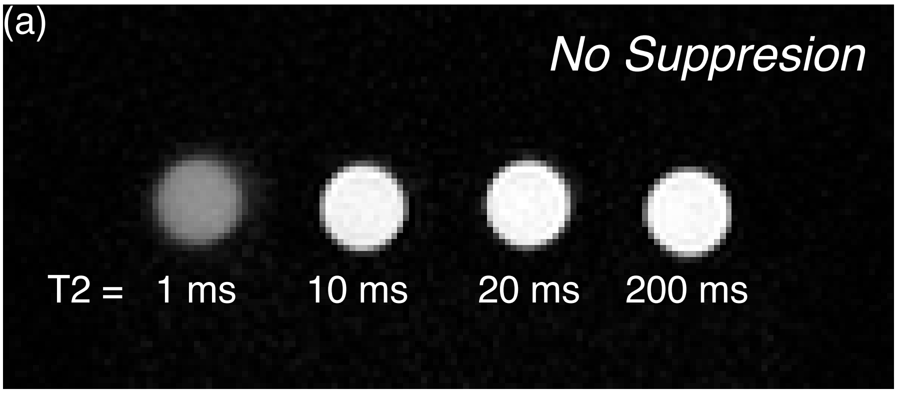
SUBSTITUTING FOR $t=T$, AND γB_1, AND SIMPLIFYING CONSIDERABLY

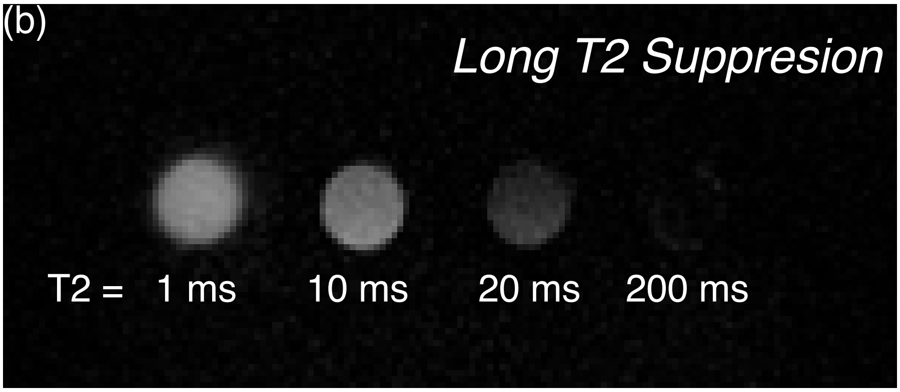
$$m_z(T) = e^{-\frac{\pi}{2}\left(\frac{T}{\pi T_2}\right)}\left\{\frac{\left(T/\pi T_2\right)}{\sqrt{\left(\frac{T}{\pi T_2}\right)^2-1}}\sinh\left(\frac{\pi}{2}\sqrt{\left(\frac{T}{\pi T_2}\right)^2-1}\right) + \cosh\left(\frac{\pi}{2}\sqrt{\left(\frac{T}{\pi T_2}\right)^2-1}\right)\right\}$$

THIS IS A FUNCTION OF T_2/T.

Long-T2 Suppression







FOR A GIVEN PULSE LENGTH T

- T_2'S < T ARE PRESERVED
- T_2'S > T ARE SUPPRESSED

IF WE WANT TO PRESERVE T_2'S OF 2ms WITH 80% EFFICIENCY, WE NEED A 10×2ms = 20ms PULSE!

PROBLEM: A 20ms RECTANGULAR PULSE HAS A BANDWIDTH OF

$$\frac{1}{20ms} = \underline{50\ HZ}$$

THIS IS MUCH LESS THAN B_0 INHOMOGENEITY EXPECTED OVER MUCH OF BODY (@ 1.5T)

CAN I USE ANOTHER WAVEFORM TO BROADEN THE BANDWIDTH?

UNDER REASONABLE ASSUMPTIONS, WE CAN SHOW:

$$M_z(T) \simeq M_0 \left(1 - T_2 \int_{-\infty}^{T} (\gamma B_1(\tau))^2 \, d\tau \right)$$

THIS MEANS THAT THE DECREASE IN M_z IS DUE ONLY TO

1) T_2

2) RF POWER

T2 IS FIXED, SO OUR ONLY VARIABLE IS RF POWER.

RESULT:

WIDER BANDWIDTH SUPPRESSION PULSE WILL ALSO SUPPRESS SHORT T_2's MORE, DUE TO PARSEVAL'S THEOREM.

IF

$$\omega_1(t) = \gamma B_1(t)$$
$$\Omega_1(f) = \mathcal{F}\{\omega_1(t)\}$$

THEN

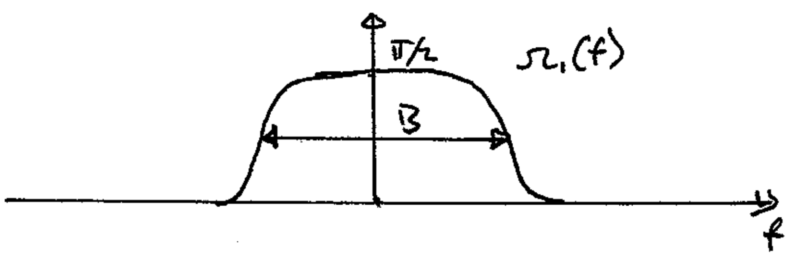
$$\int_{-\infty}^{\infty} |\omega_1(t)|^2 \, dt = \int_{-\infty}^{\infty} |\Omega_1(f)|^2 \, df$$

IN ORDER TO MINIMIZE SUPPRESSION OF SHORT T_2'S, WHICH IS

$$M_z = 1 - \underbrace{T_2 \int_0^T |\omega_1(t)|^2 dt}_{\text{MINIMIZE THIS}}$$

$$= 1 - T_2 \int_{-\infty}^{\infty} |\Omega_1(f)|^2 df$$

FOR LONG-T_2'S THE EXCITATION PROFILE IS $\mathcal{F}\{\gamma B_1(t)\} = \Omega_1(f)$ AND THIS SHOULD BE $\pi/2$ IN THE SUPPRESSION BAND



BANDWIDTH B

THE SUPPRESSION IS THEN

$$M_z \simeq 1 - T_2 \left(\frac{\pi}{2}\right)^2 B$$

NEED TO MINIMIZE B.

Approximate vs Exact Solution Rectangular Suppression Pulse