Lecture 13

ASSIGNMENT

READ CHAPTER 6

THINK ABOUT PROJECTS

LAST TIME

ADIABATIC INVERSIONS

TODAY

ADIABATIC ROTATIONS

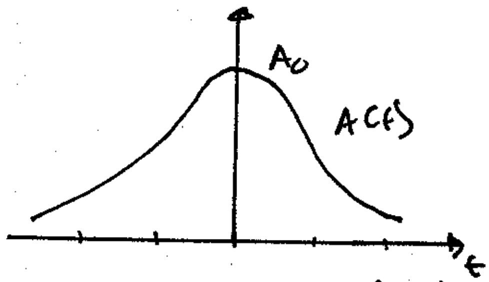
ADIABATIC INVERSIONS: REVIEW

FREQUENCY MODULATED PULSE

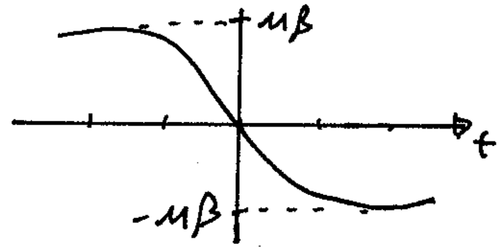
$$B_1(t) = A(t)\, e^{-i\,\omega_1(t)\, t}$$

IN ROTATING FRAME AT LARMOR FREQUENCY

TYPICAL WAVEFORMS:



$$A(t) = A_0 \operatorname{sech}(\beta t)$$



$$\omega_1(t) = -\mu\beta \tanh \beta t$$

MANY OTHER POSSIBILITIES

IN THE ROTATING FRAME AT ω_0

$$\underline{B}(t) = \left(A(t) \cos \omega_1(t) t,\ A(t) \sin \omega_1(t) t,\ 0 \right)$$

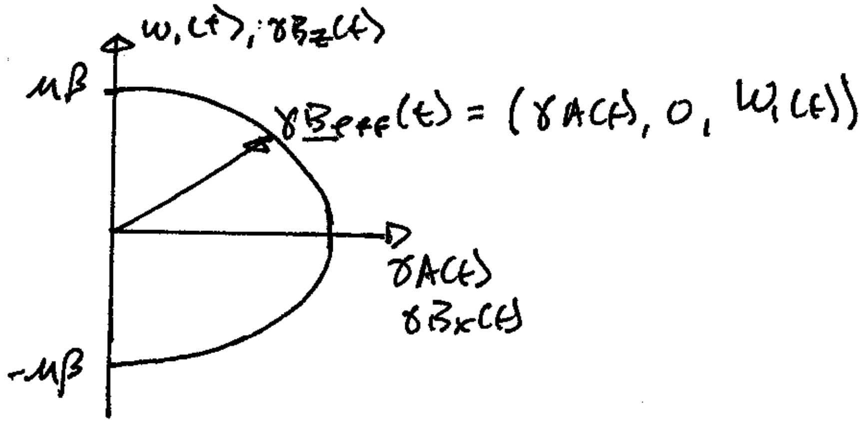
IN THE ROTATING FRAME AT $\omega_0 + \omega_1(t)$

$$\underline{B}_{eff}(t) = \left(A(t),\ 0,\ \frac{\omega_1(t)}{\gamma} \right)$$

FREQUENCY MODULATION OF $B_1(t)$ CORRESPONDS TO Z-FIELD IN ROTATING FRAME AT MODULATION FREQUENCY.

SWEEP DIAGRAM

PLOT OF $\underline{B}_{eff}(t)$

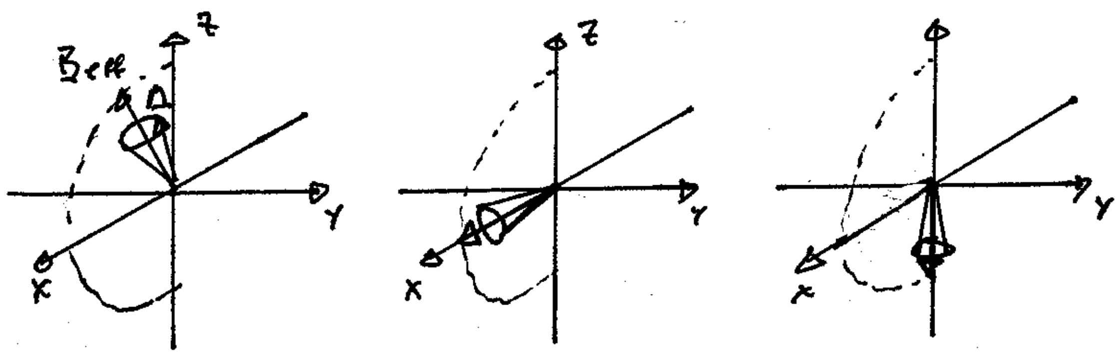


$\underline{B}_{eff}$ SWEEP FROM +Z TO −Z

$\underline{M}$ FOLLOWS, PROVIDED $\psi = \angle B_{eff}(t)$ DOESN'T CHANGE TOO FAST COMPARED TO $|B_{eff}(t)|$

$$\left|\frac{d\psi}{dt}\right| << \gamma \, |B_{eff}(t)|$$

ADIABATIC CONDITION.



$\underline{M}$ TRACKS $\underline{B}_{eff}(t)$

OTHER ADIABATIC PULSES

EXCITATION

SPIN-ECHO

ROTATION BY ARBITRARY ANGLE

EXCITATION

WHY NOT SCALE ADIABATIC INVERSION TO $\pi/2$?

TWO ANSWERS:

1) BELOW ADIABATIC THRESHOLD (i.e. π PULSE) AN "ADIABATIC" PULSE IS THE SAME AS ANY OTHER PULSE, WITH

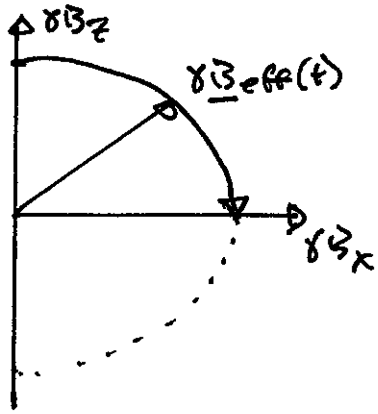
$$\Theta = \int_0^T \gamma B_1(t)\, dt$$

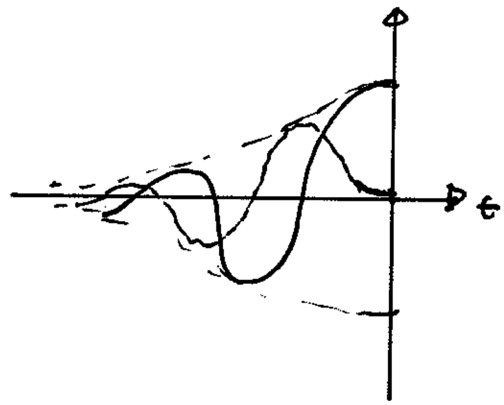
WHICH IS NOT B_1 INSENSITIVE

2) ADIABATIC PULSES ARE GENERALLY APPROXIMATELY QUADRATIC PHASE, DON'T REFOCUS.

Simple Adiabatic Excitation

Adiabatic Half Passage: half of an inversion sweep.

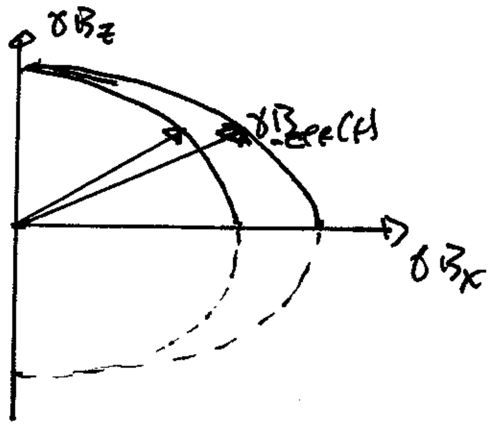




First half of hyperbolic secant

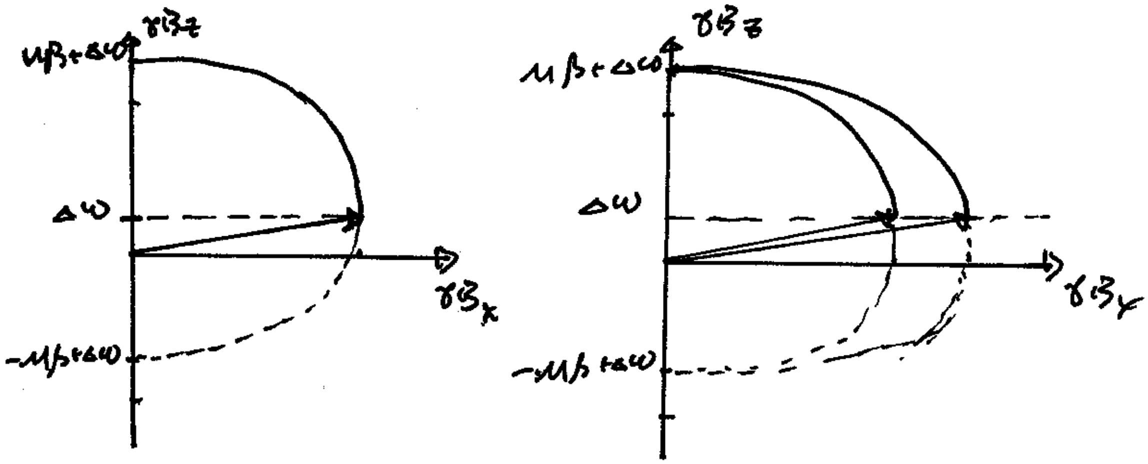
$$\left.\begin{aligned} A(t) &= A_0 \operatorname{sech}(\beta t) \\ \omega_1(t) &= -\mu\beta \tanh(\beta t) \end{aligned}\right\} -\infty < t < 0$$

B_1 insensitive, above adiabatic threshold



$\underline{M}$ left along +x axis

SENSITIVE TO OFF-RESONANCE



OFF-RESONANCE SHIFT OF $\Delta\omega$ LEAVES $\underline{B}_{eff}$ AND $\underline{M}$ AT AN ANGLE

$$\phi = \tan^{-1}\left(\frac{\Delta\omega}{\gamma A_0}\right)$$

ABOVE THE TRANSVERSE PLANE

ϕ DECREASES AS B_1 INCREASES.

WORKS REASONABLY WELL FOR CREATING M_{xy} INSENSITIVE TO ϕ

WORKS VERY POORLY FOR ELIMINATING M_z, (i.e SATURATION PULSES)

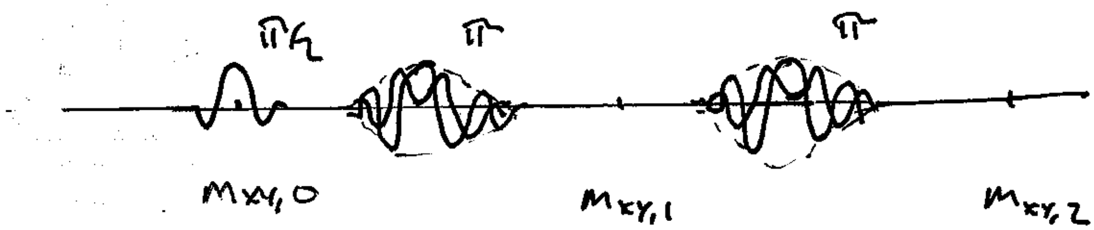
ADIABATIC REFOCUSING PULSES

WHY NOT USE AN ADIABATIC INVERSION?

1) ACCURATELY RETURNS TRANSVERSE MAGNETIZATION TO TRANSVERSE PLANE

2) ADDS NON-LINEAR PHASE

SIMPLE SOLUTION: USE A PAIR OF ADIABATIC INVERSIONS



THE ADIABATIC π PRODUCES A ROTATION DESCRIBED BY (α_π, β_π)

$$M_{xy,1} = (M_{xy,0})^* \beta_\pi^2$$

$$M_{xy,2} = (M_{xy,1})^* \beta_\pi^2$$

$$= \left((M_{xy,0})^* \beta_\pi^2 \right)^* \beta_\pi^2$$

$$= M_{xy,0} \, |\beta_\pi|^4$$

AS LONG AS WE USE TWO IDENTICAL REFOCUSING PULSES, PHASE PROFILES CANCEL.

CHANGES IN B_1 AMPLITUDE WILL CHANGE B_1 PHASE, BUT DOESN'T MATTER

DISADVANTAGE:

MUST FORM FIRST ECHO

LONGER DELAY UNTIL FIRST USEFUL ECHO, WHICH IS THE SECOND

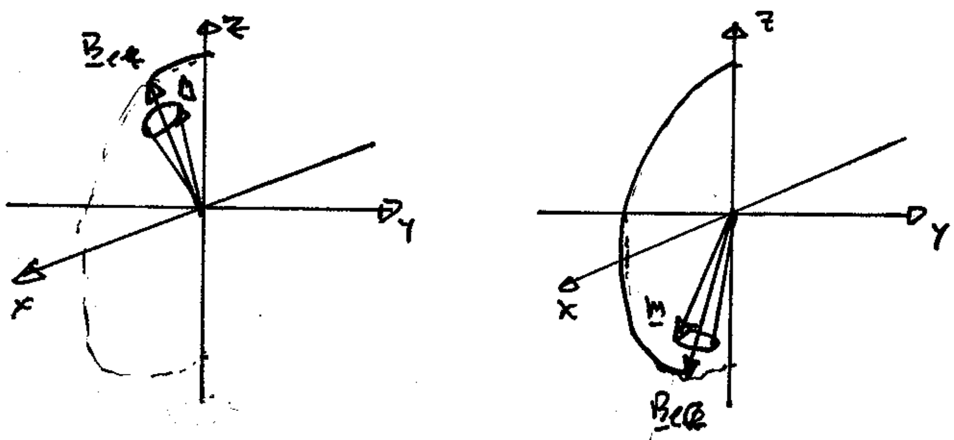
ONLY EVEN ECHOES USABLE

IDEALLY WE WANT A SINGLE PULSE.

BASIC TOOLS FOR ADIABATIC PULSE DESIGN

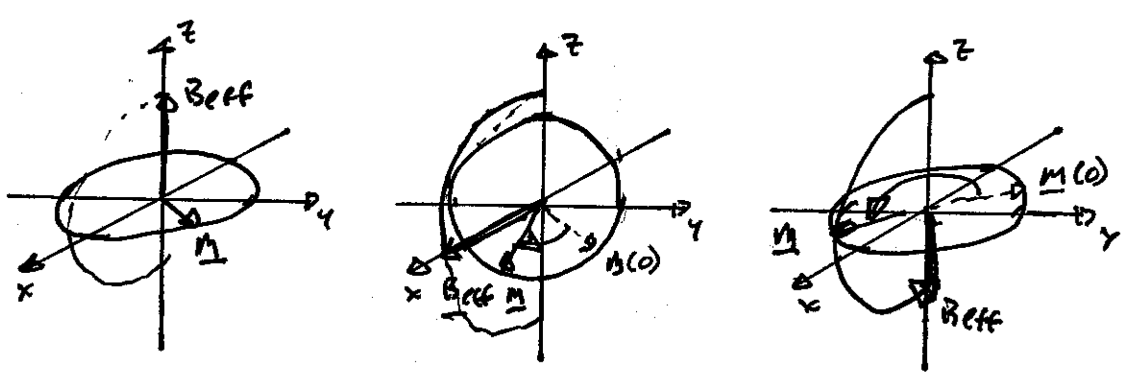
FOR ADIABATIC SWEEPS:

PARALLEL COMPONENT STAYS PARALLEL



THIS IS WHAT WE USE FOR ADIABATIC INVERSION PULSES

PERPENDICULAR COMPONENT STAYS PERPENDICULAR



FOR INITIAL TRANSVERSE MAGNETIZATION

1) INVERTED

2) ADDITIONAL PHASE DUE TO PRECESSION

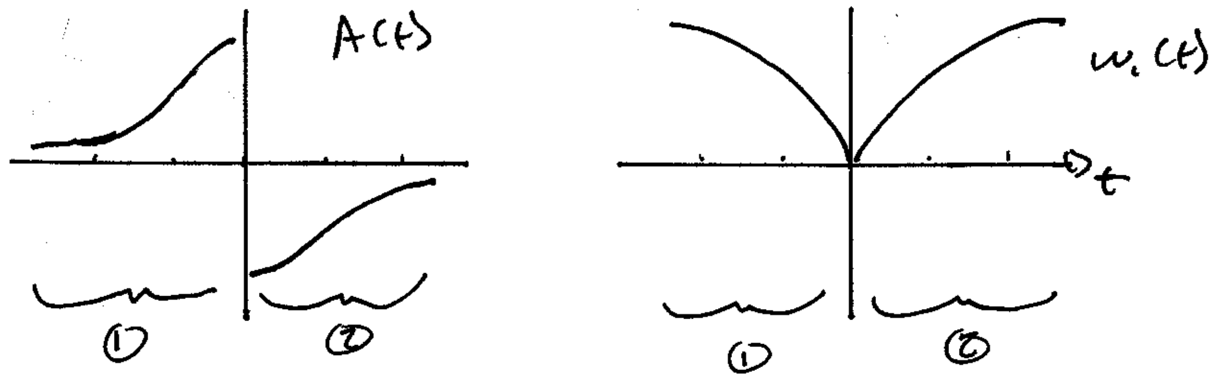
$$\Theta_{eff} = \int_0^T \gamma |\underline{B}_{eff}(t)| dt$$

REFOCUSING PULSES COMBINE PARTIAL SWEEPS TO DO THE INVERSION WHILE CANCELING OUT THE PRECESSION PHASE SHIFTS

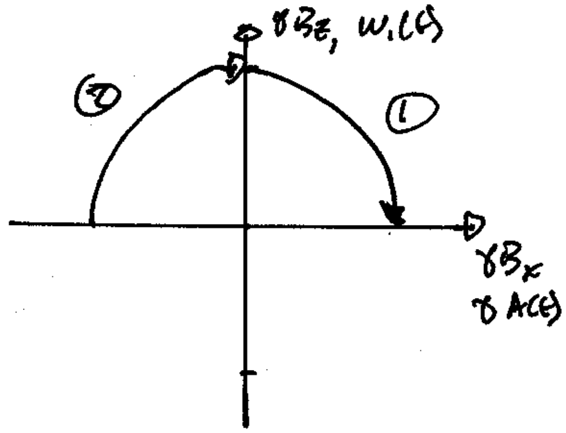
SIMPLE ADIABATIC REFOCUSING PULSE

B1 INSENSITIVE REFOCUSING PULSE - 1 (BIREF-1)

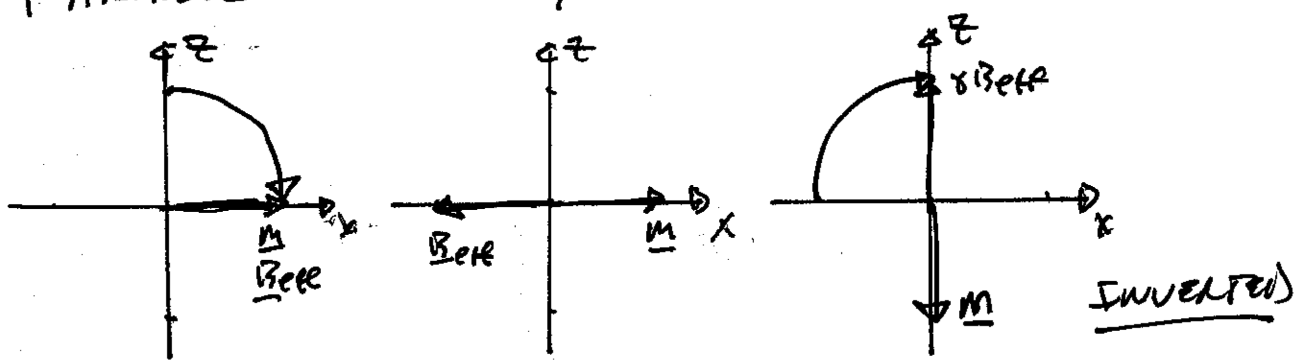
ENVELOPE / MODULATION WAVEFORMS



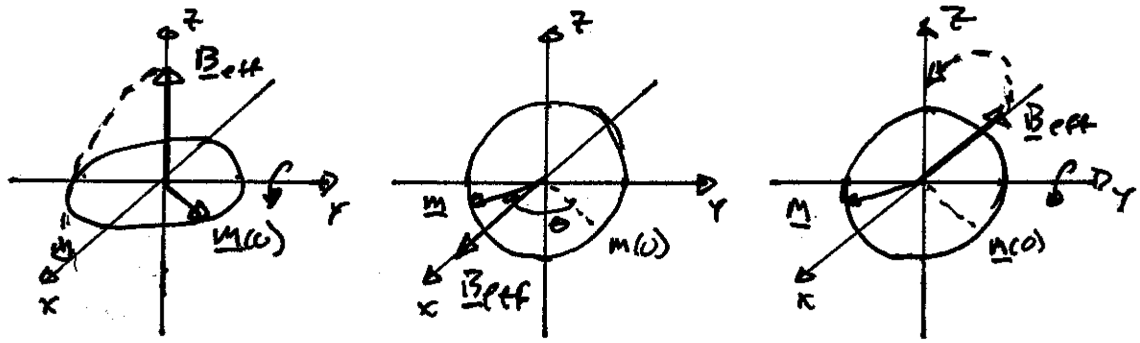
SWEEP DIAGRAM

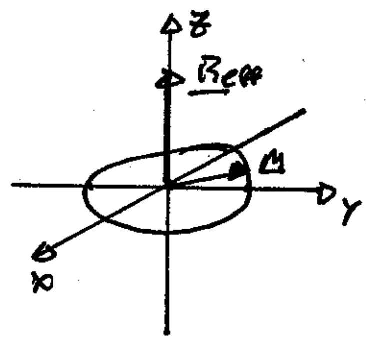


PARALLEL COMPONENT, INITIALLY ALONG +Z



PERPENDICULAR COMPONENT, INITIALLY TRANSVERSE





$\underline{M}$ HAS BEEN REFLECTED ABOUT +Y AXIS!

RESULT IS A SPIN-ECHO PULSE.

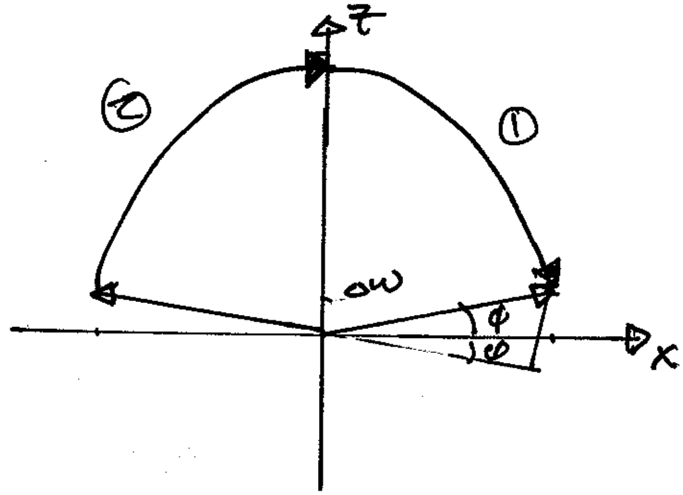
PULSE IS ADIABATIC, BECAUSE IT DEPENDS ONLY ON THE SWEEP

B_1 AMPLITUDE ONLY EFFECTS

$$\theta_{eff} = \int_{-\infty}^{0} |B_{eff}(t)|\, dt$$

WHICH CANCELS OUT AT END.

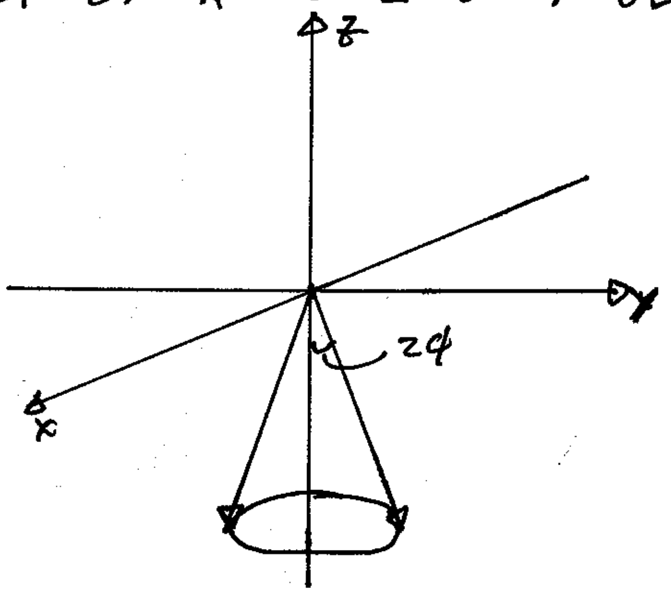
OFF-RESONANCE SENSITIVITY



$$\phi = \tan^{-1}\left(\frac{\Delta\omega}{\gamma A_0}\right)$$

AFTER SIGN CHANGE, PARALLEL COMPONENT TRACKS, PERPENDICULAR COMPONENT TRACKS AND PRECESSES.

RESULT IS INITIAL MAGNETIZATION ALONG +Z IS LEFT ON A CONE OF ANGLE ±2φ



SIMILAR PROBLEM FOR TRANSVERSE COMPONENT.

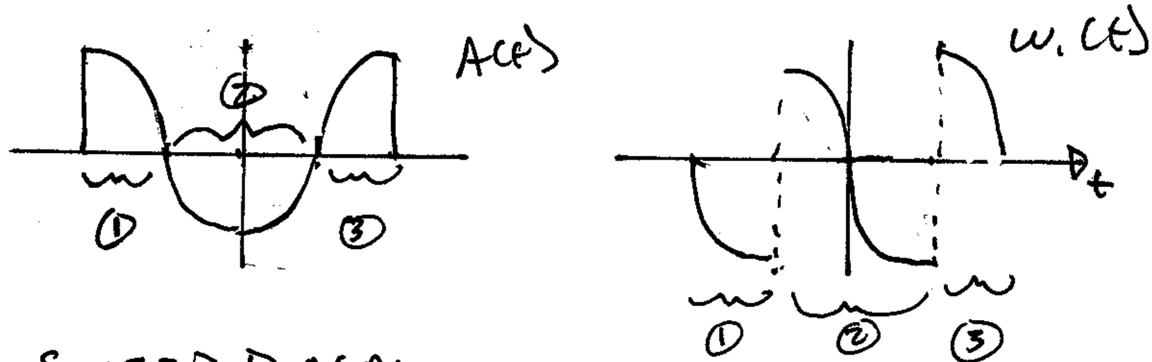
ADIABATIC ROTATION PULSES

ROTATION BY SOME ARBITRARY ANGLE

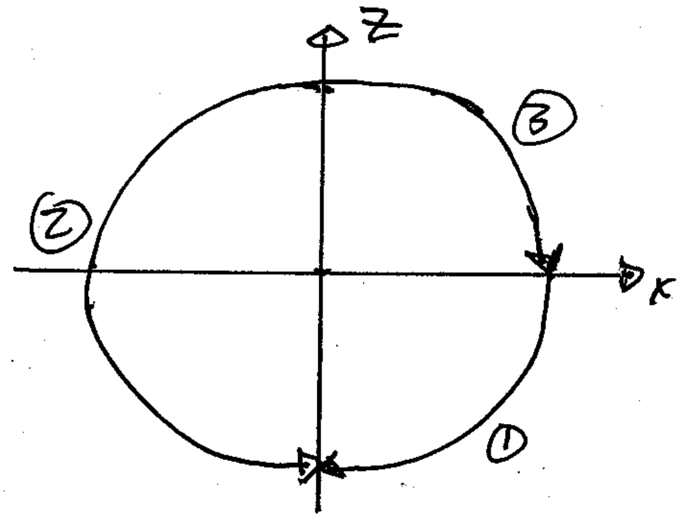
- SMALL TIP ANGLE
- $\pi/2$ EXCITATION / SATURATION
- SPIN-ECHO REFOCUSING PULSE

B_1 INSENSITIVE ROTATION-4 (BIR-4)

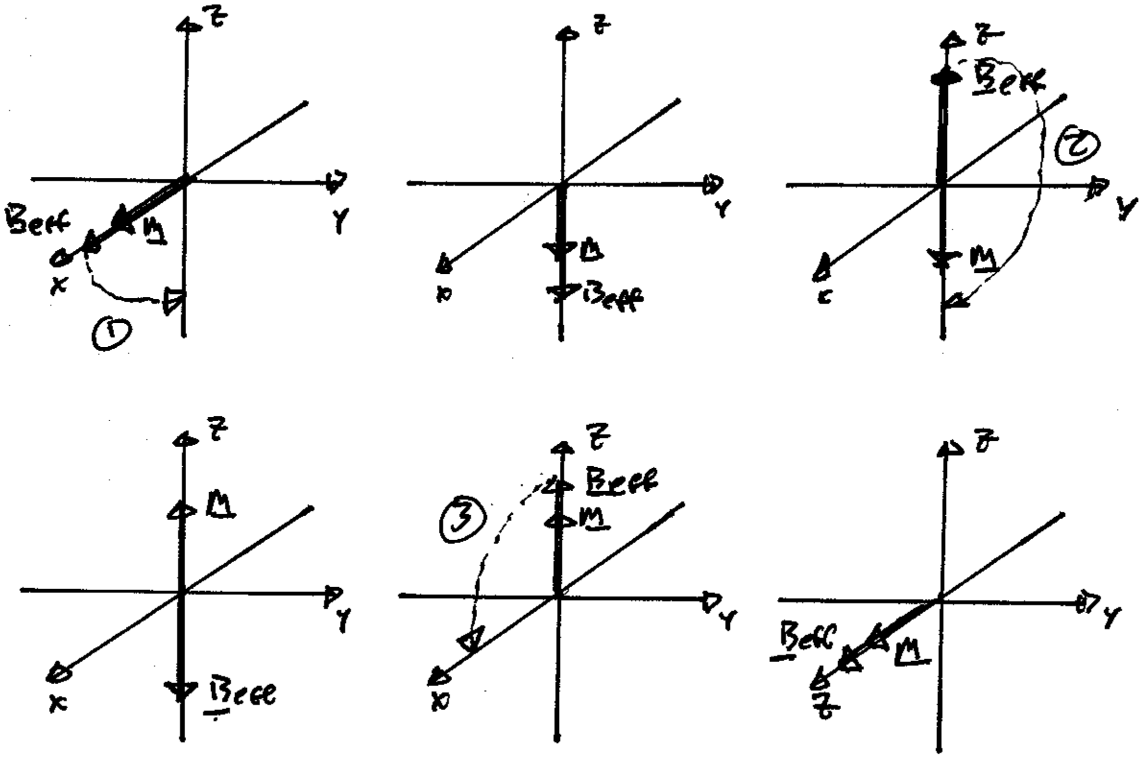
ENVELOPE / MODULATION WAVEFORMS



SWEEP DIAGRAM



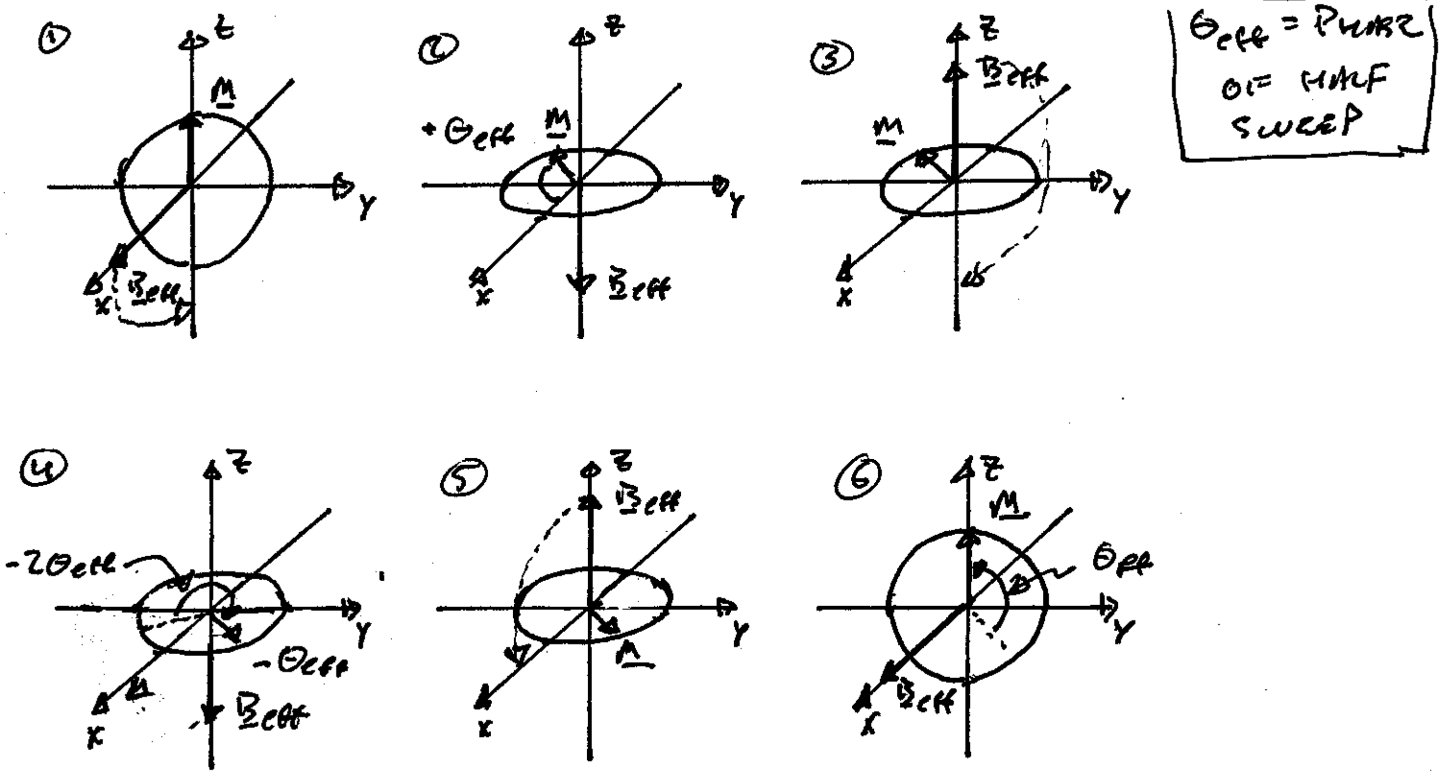
SPIN INITIALLY ALONG +X, PARALLEL



RETURNS M TO +X

DOES **NOTHING**!

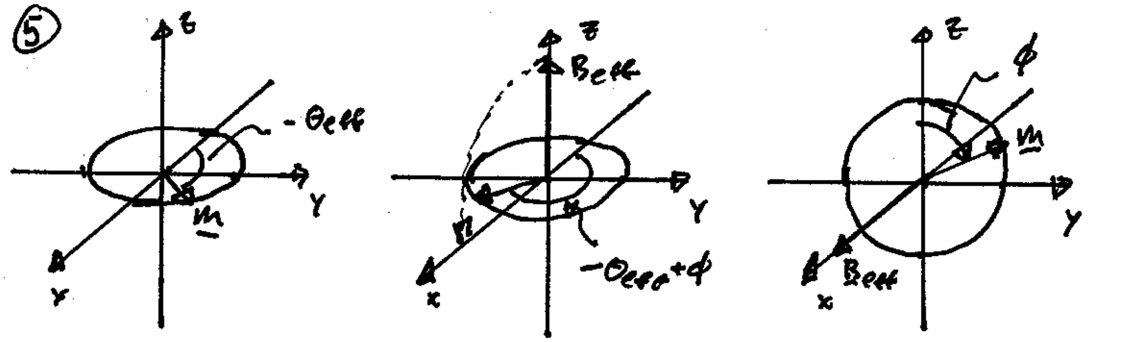
SPIN INITIALLY PERPENDICULAR (+Z, FOR EXAMPLE)



RETURNS $\underline{M}$ TO +Z

DOES <u>NOTHING</u>!

KEY IDEA: ADD PHASE SHIFT IN RF BEFORE FINAL SWEEP



PREPHASED BY $-\theta_{eff}$ — PHASE SHIFT BY ϕ — $-\theta_{eff}$ CANCELED LEFT WITH ϕ

ROTATION BY ϕ ABOUT THE +x AXIS!

PHASE SHIFT IS VERY ACCURATE.

⇒ VERY ACCURATE ROTATION

ANY ANGLE POSSIBLE

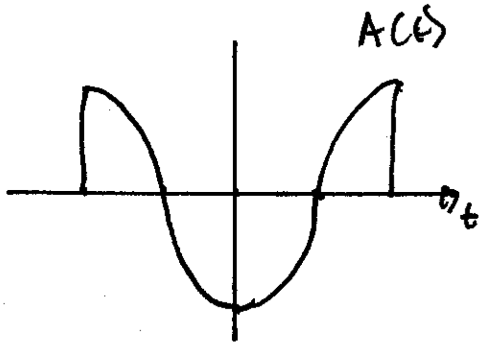
SMALL TIP (i.e 30°)

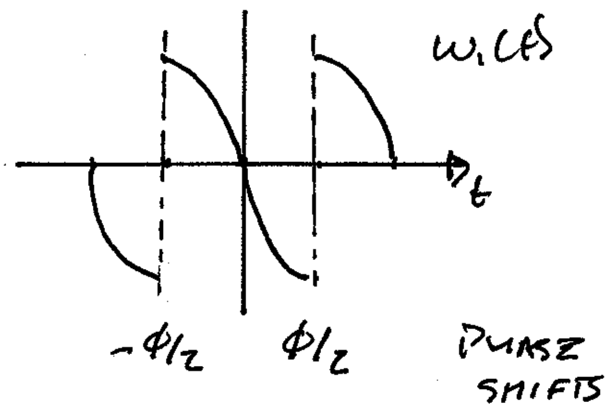
EXCITATION (90°)

REFOCUSING (180°)

ALL HAVE SAME POWER

BETTER APPROACH: SPLIT PHASE SHIFT OVER BOTH JUMPS





BIR-4