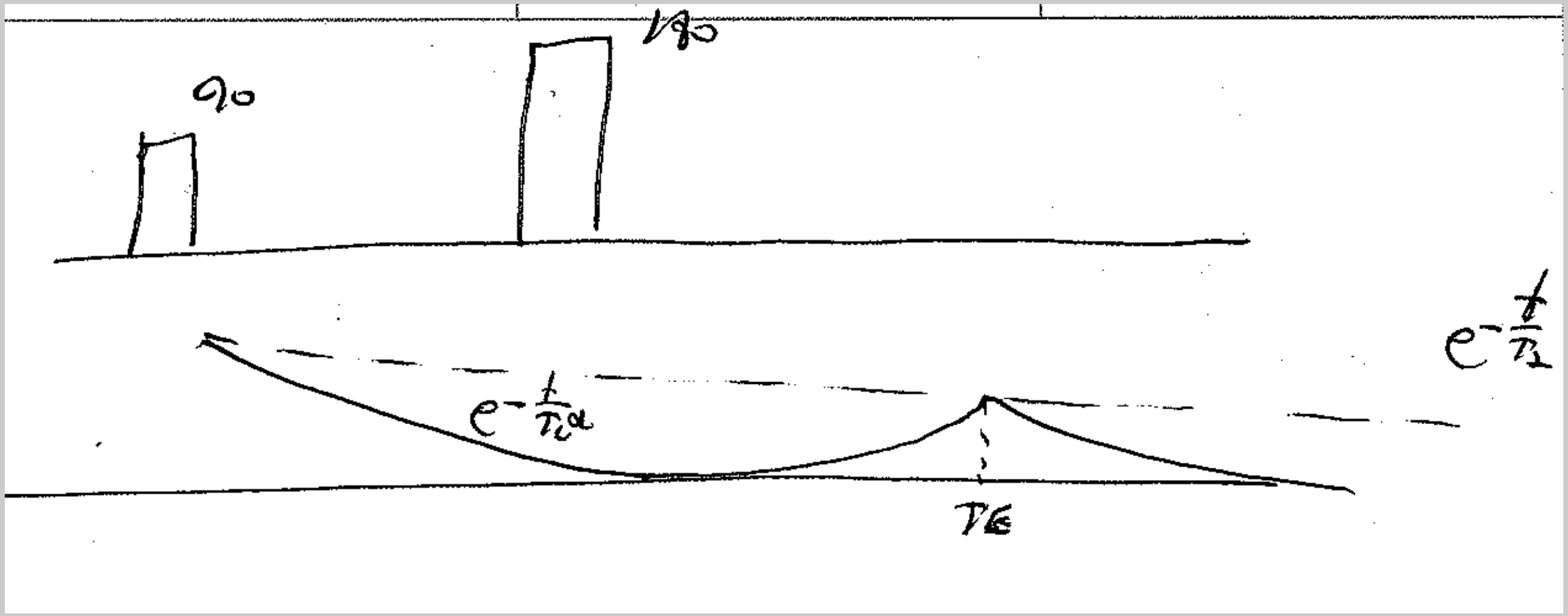
Principles of MRI

EE225E / BIO265

Lecture 20

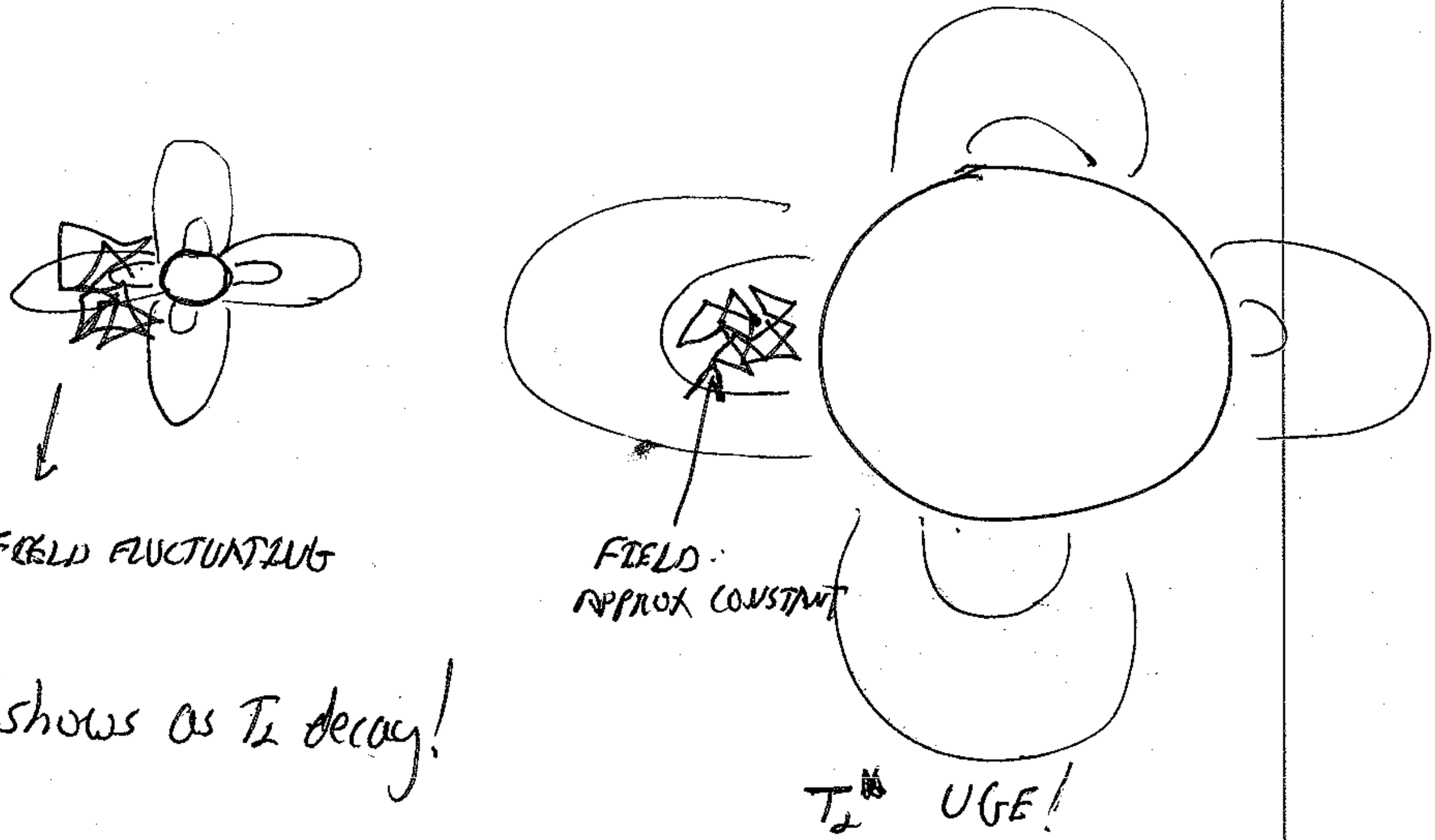
Instructor: Miki Lustig
UC Berkeley, EECS

Spin Echo

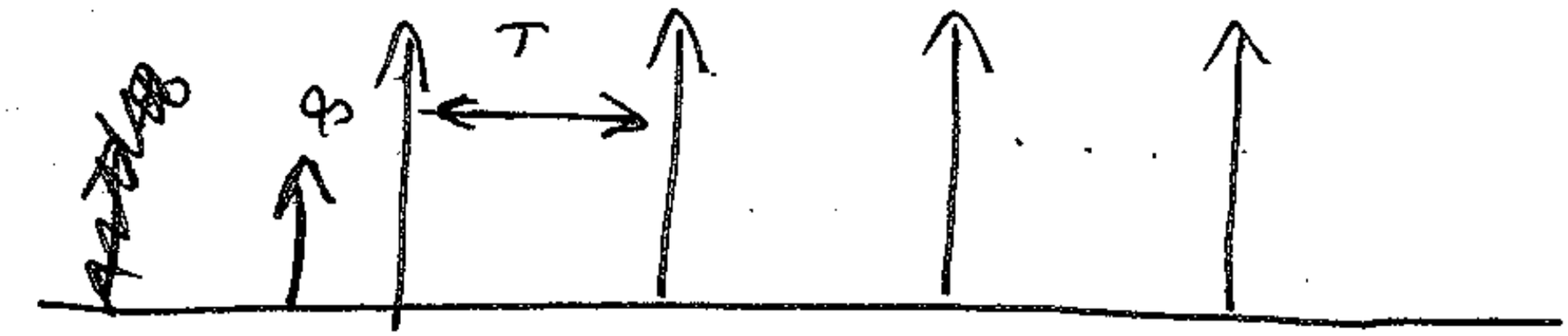


ANY SIGNAL DUE TO DEPHASING $W_E(\vec{r})t$ IS REFOCUSED.

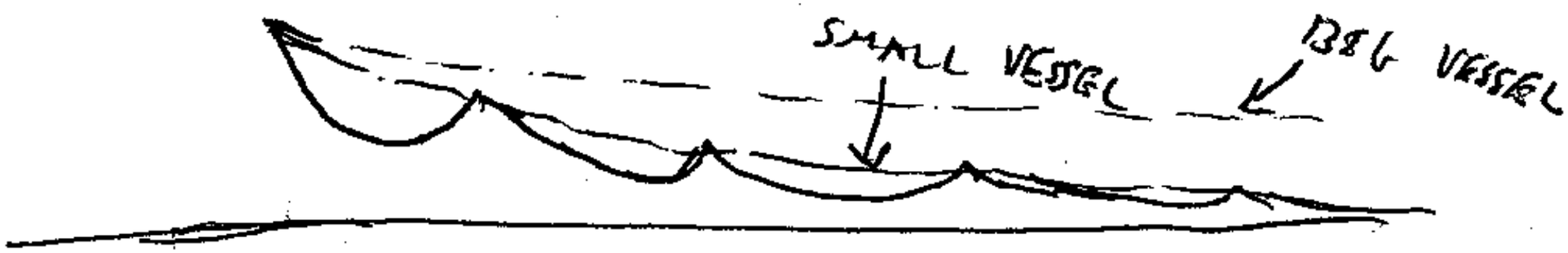
IF $W_E(\vec{r},t) \Longrightarrow$ REFOCUSING NOT PERFECT



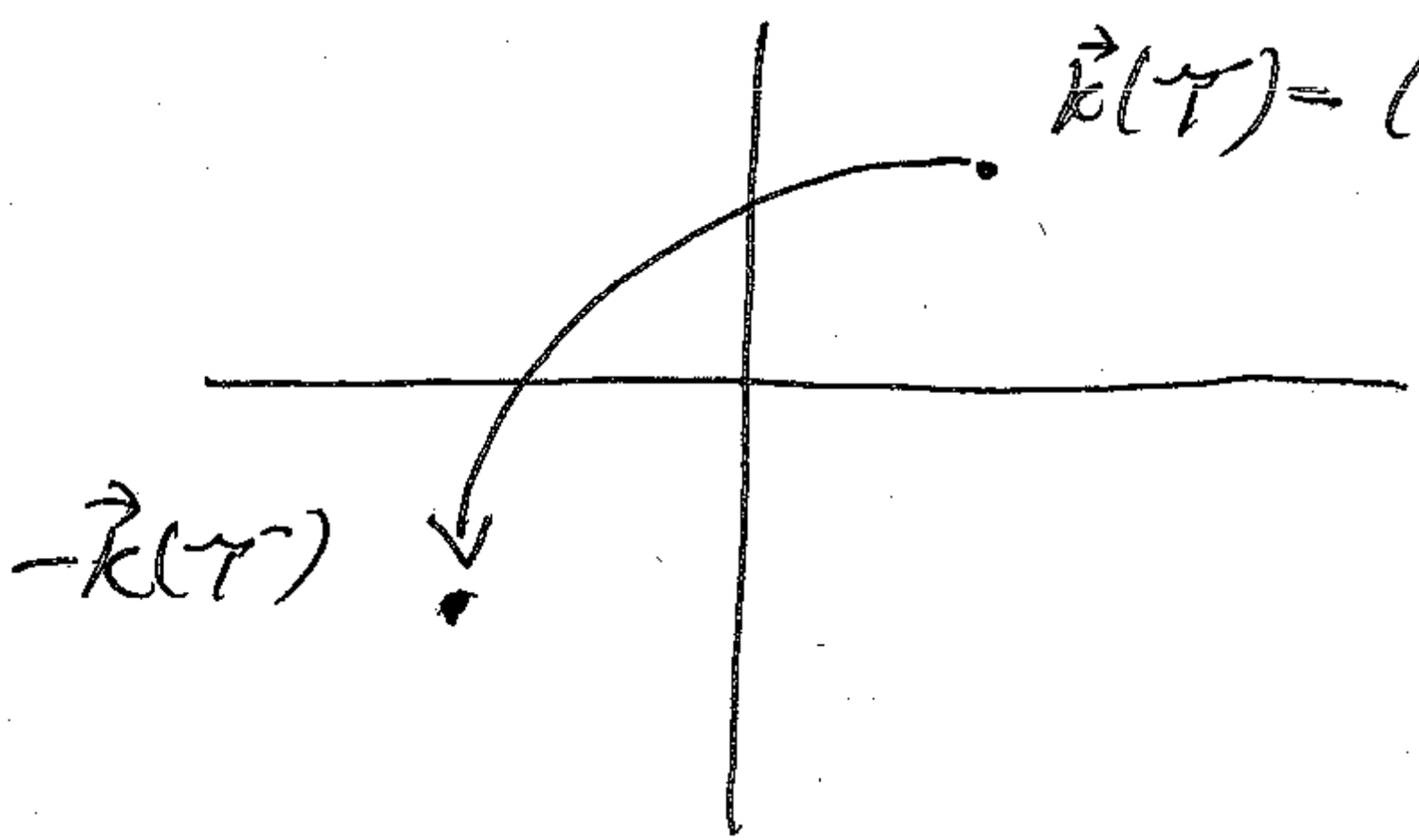
shows as T_2 decay!



$\bar{L}(T)$!

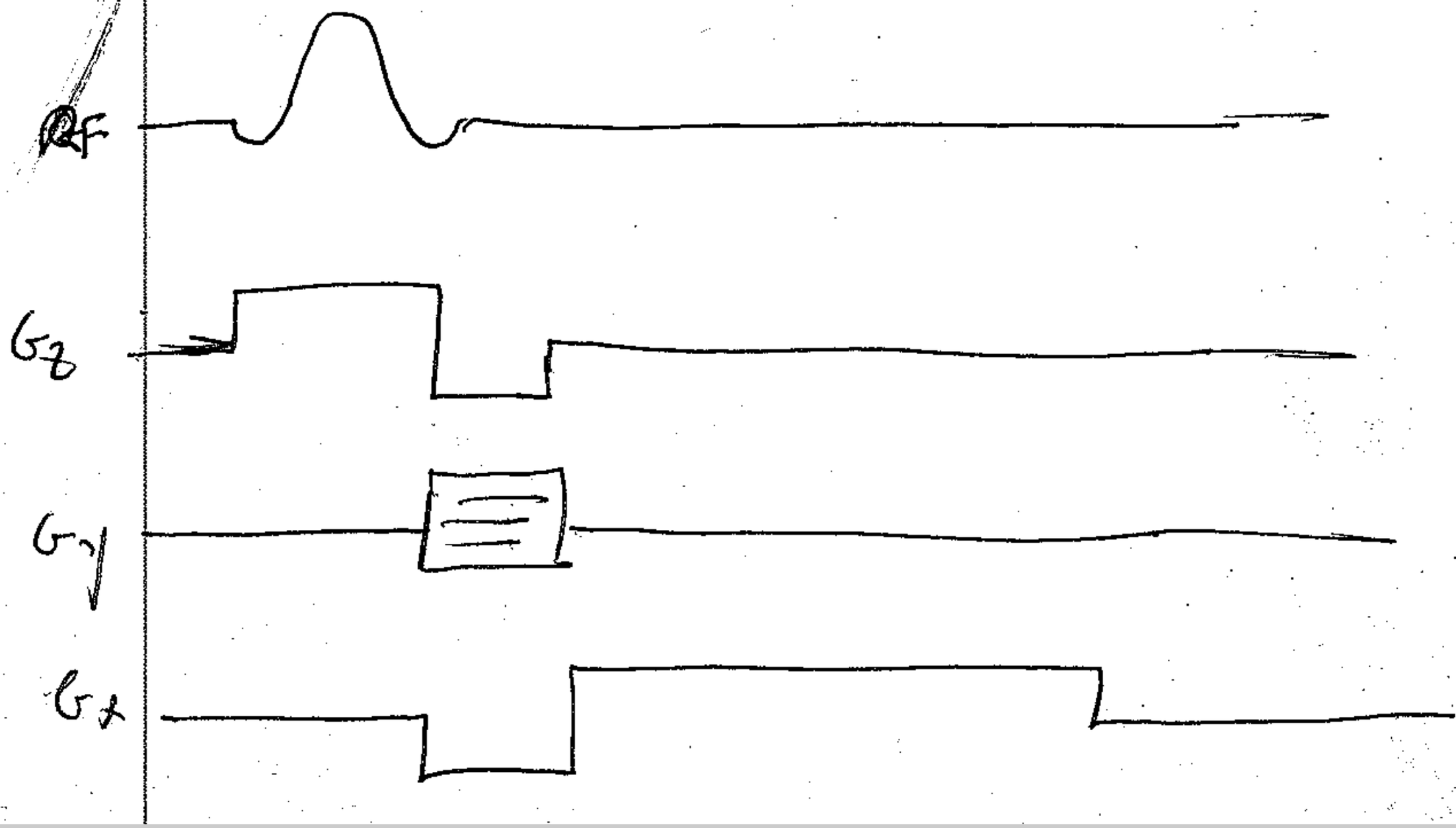


Spin Echo Imaging



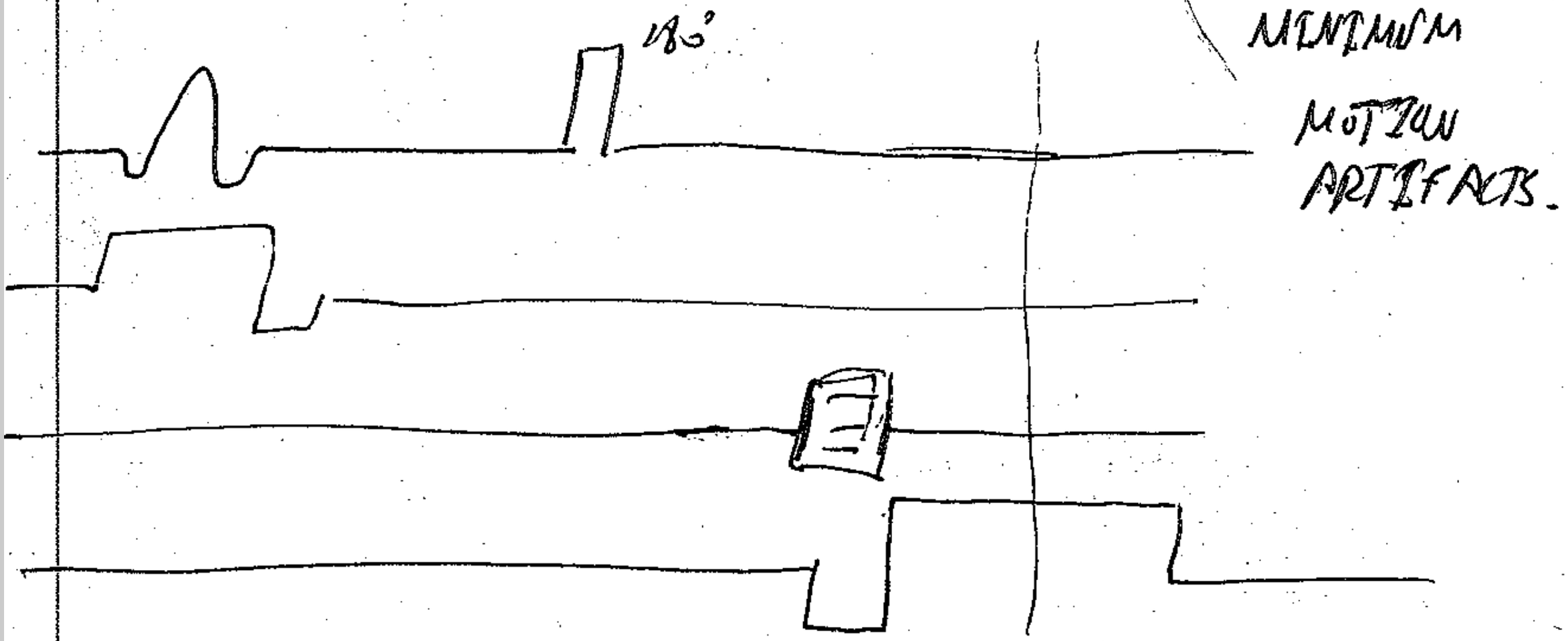
K-SPACE GOES TO CONJUGATE POSITION!

REGULAR 2DFT GRADIENT ECHO!



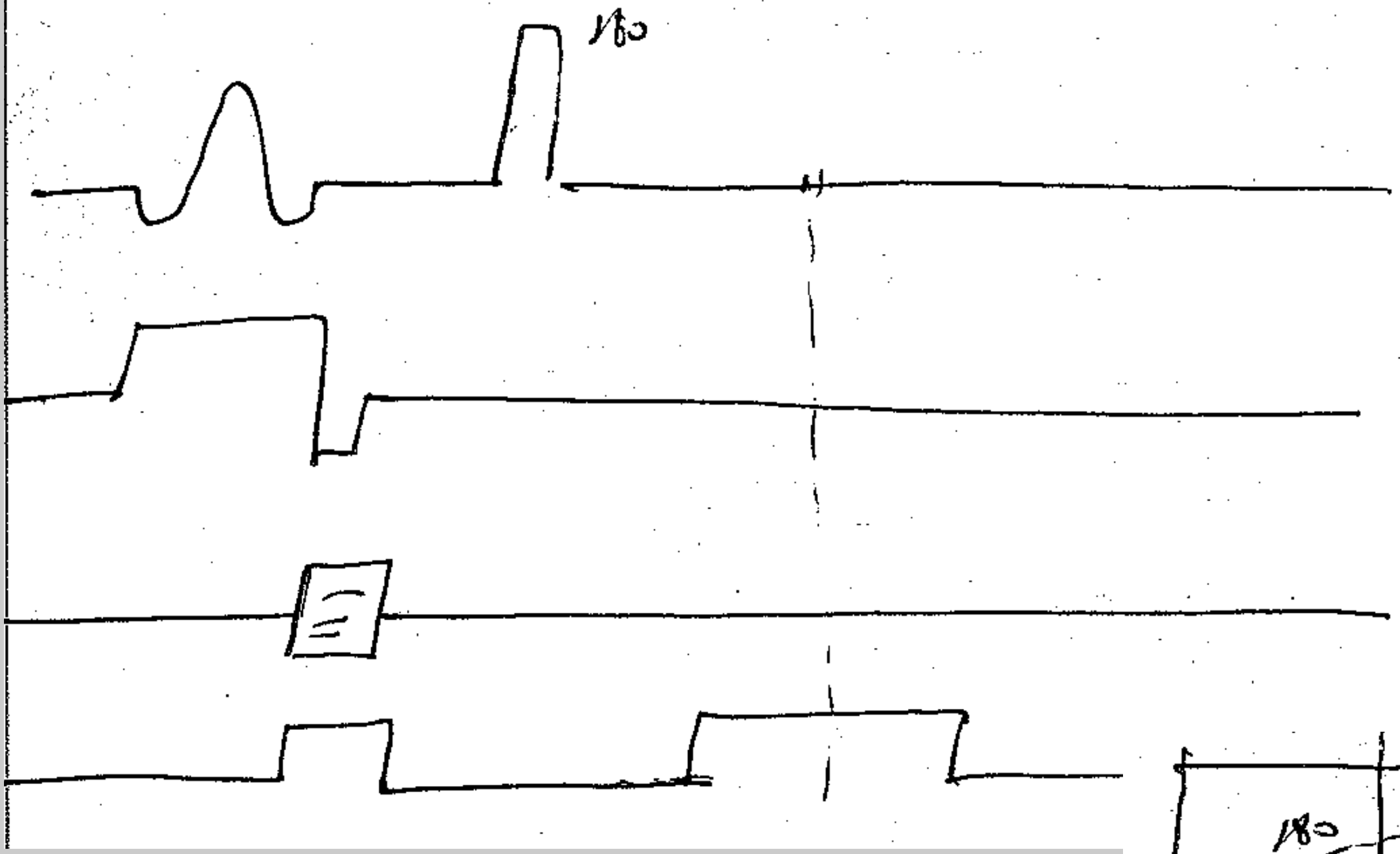
NEGATE GRADIENT LEFT OF 180

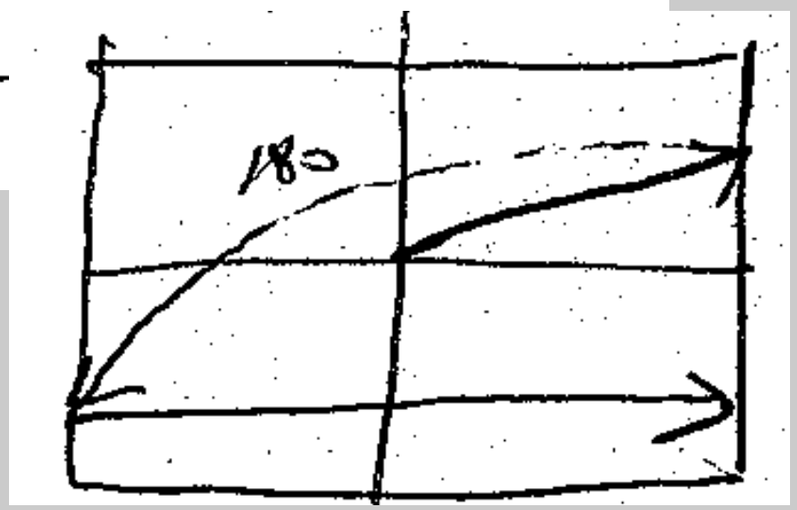
TRIVIAL ADAPTATION:



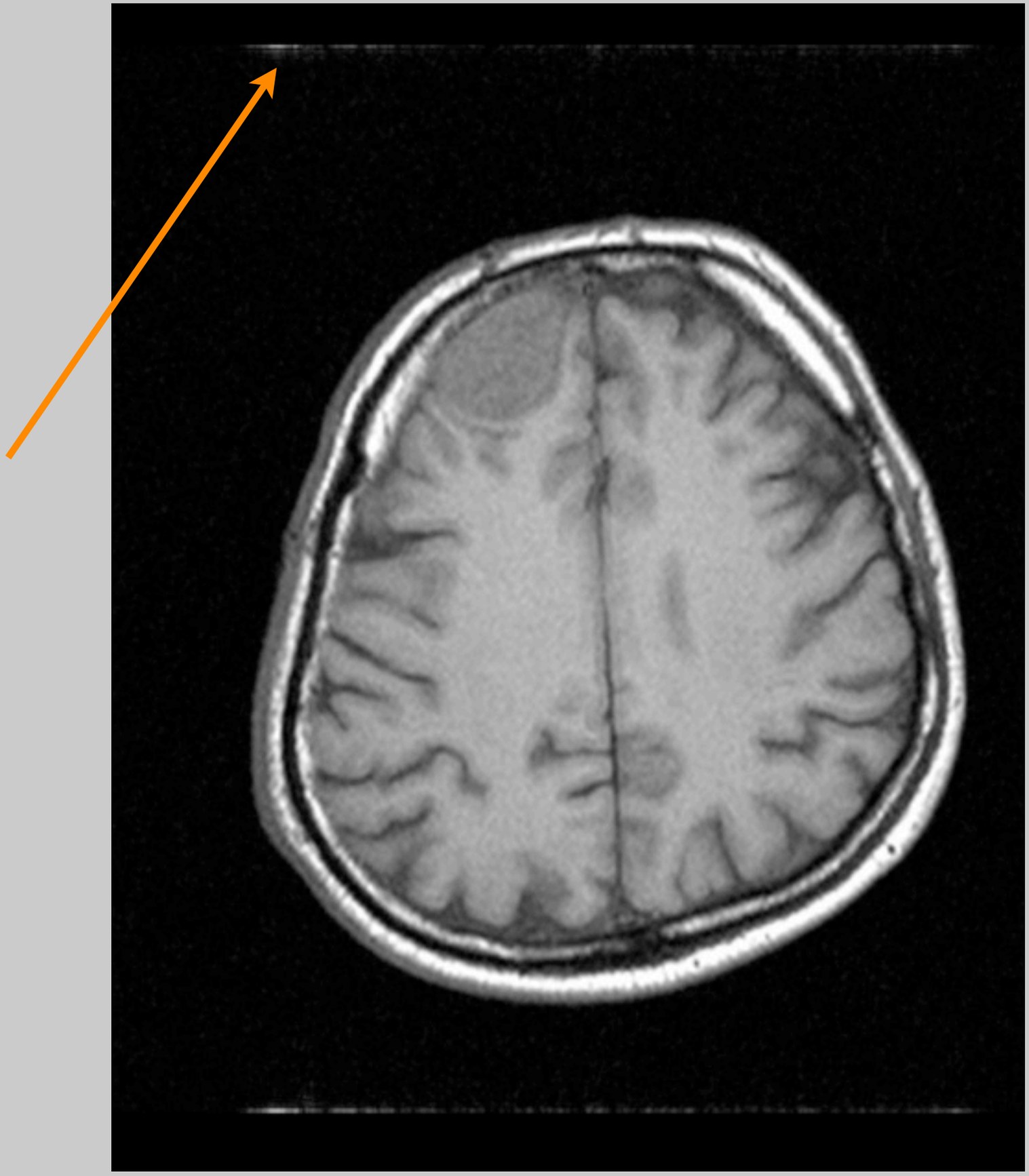
WANT GRADIENT ECHO TO HAPPEN WITH SPIN-ECHO.

SHORTEST ECHO TIME



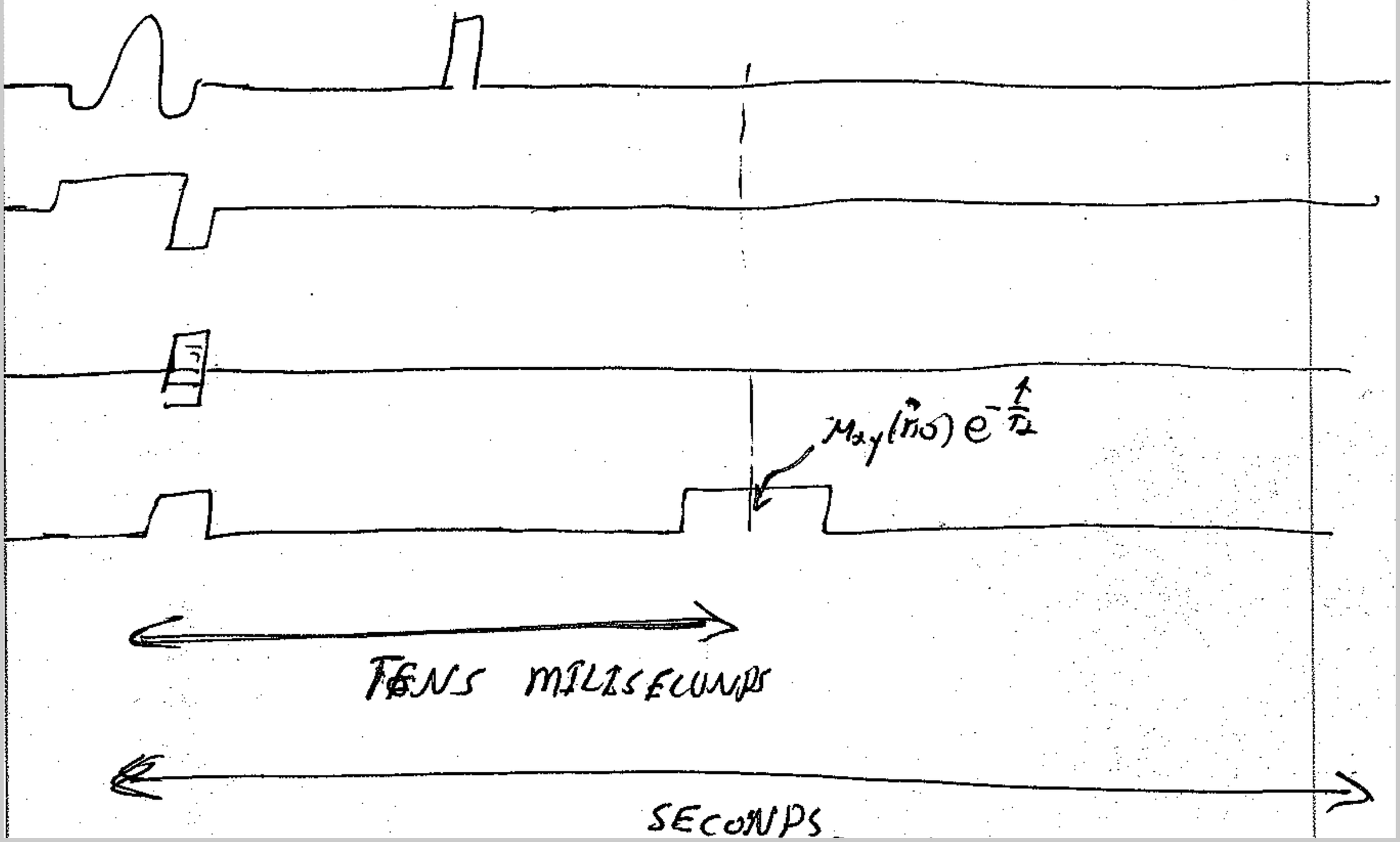


imperfect 180 causes parasitic
which is not phase encoded (HW)

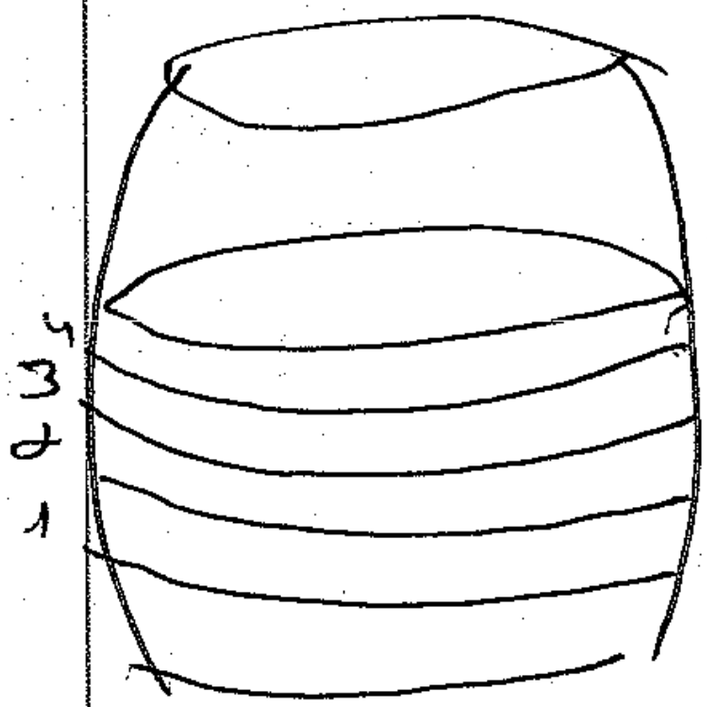


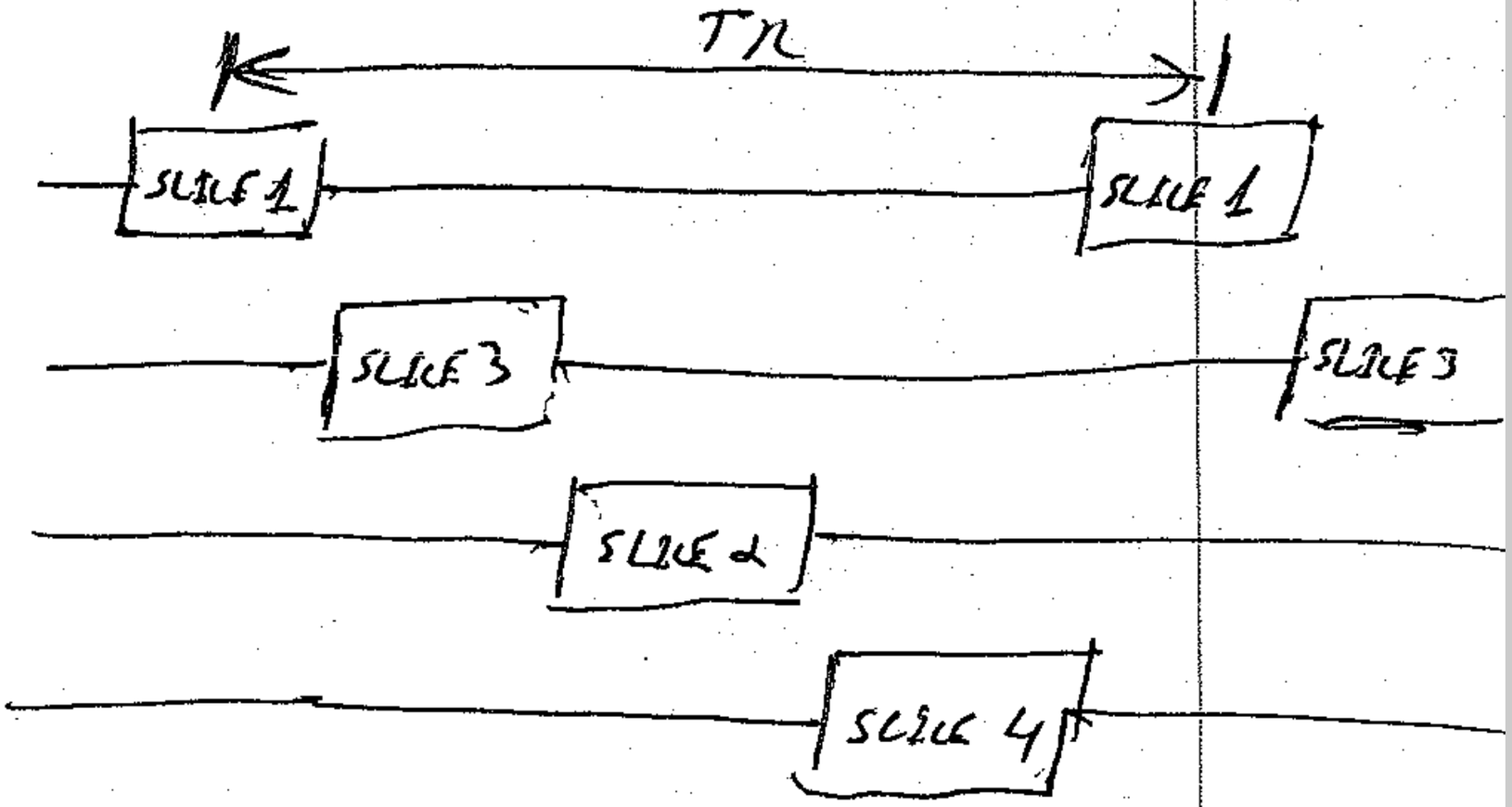
MULTI-SLICE

SIMPLE T_2-WEIGHTED SPIN-ECHO.



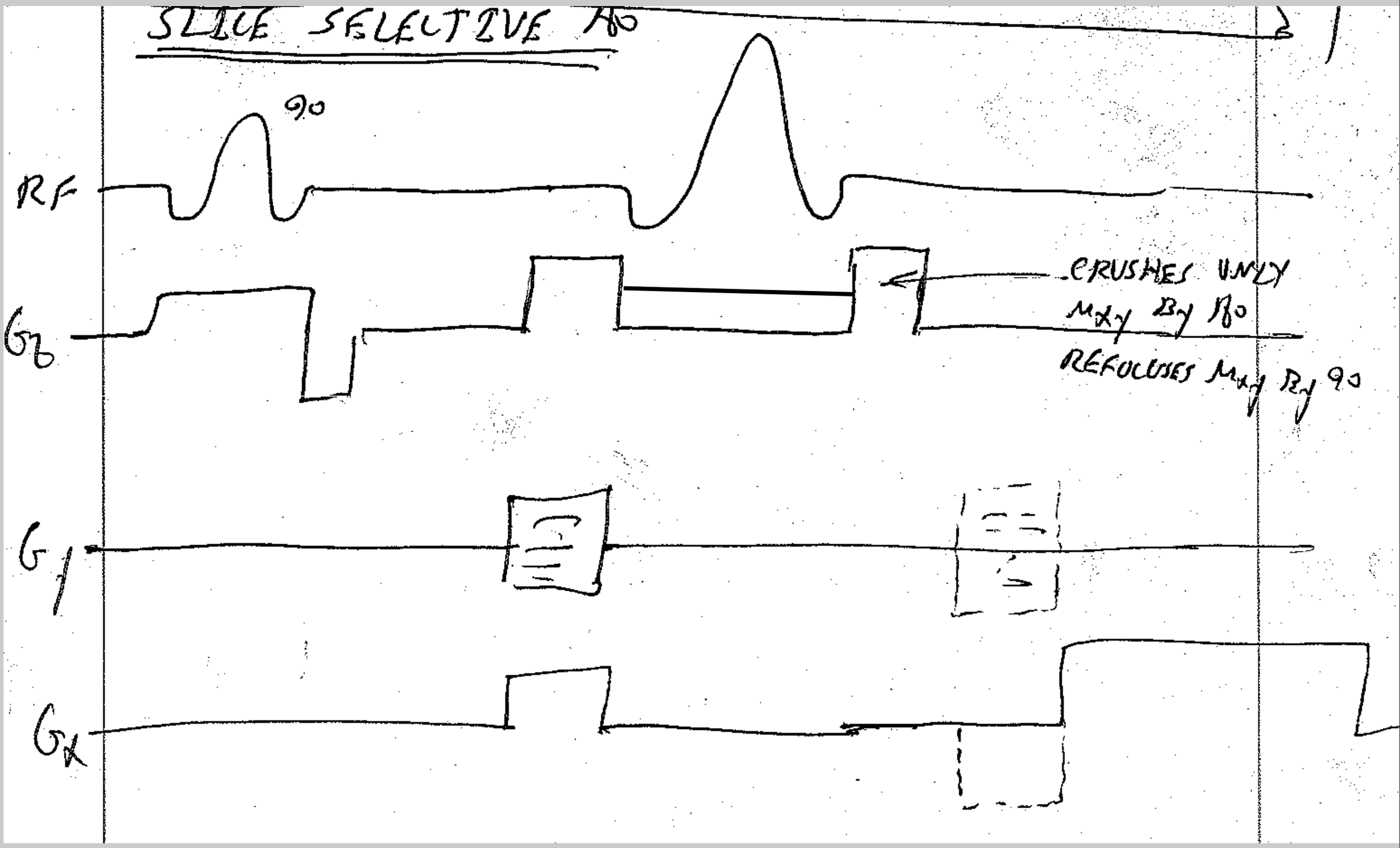
INEFFICIENT! ADD MULTISLICE MAKE NO SELECTIVE





WHEN IMAGING ONE SLICE, OTHER RECOVER!

VERY EFFICIENT ALWAYS NOURISING DATA.

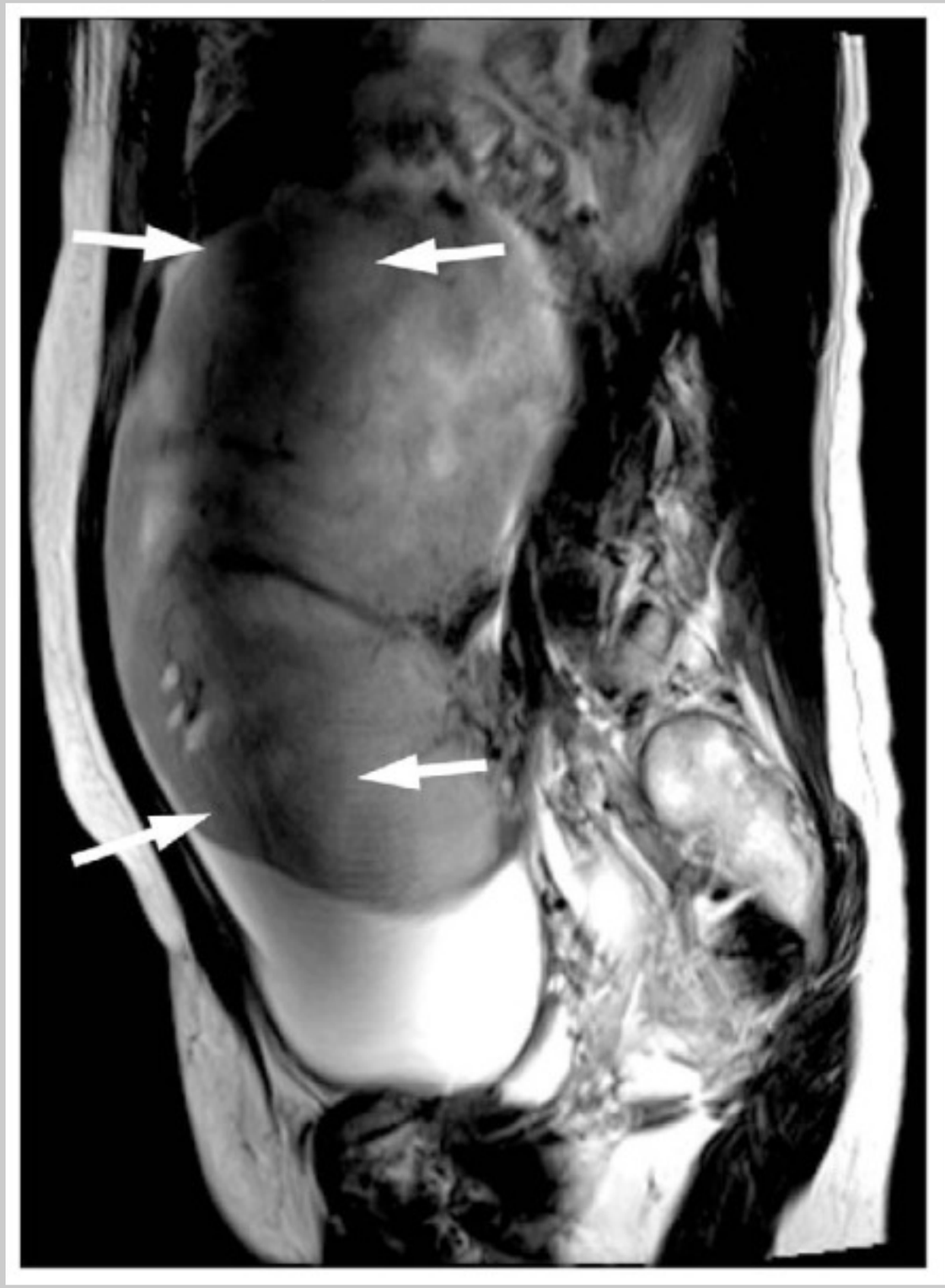

SLICE SELECTIVE 180
90
RF
Gz
CRUSHES ONLY
Mxy By 180
REFOCUSES Mxy By 90
Gy
Gx

Other non-idealities

- RF Inhomogeneity
  - Affects Excitation
    - Spatially varying flip-angle
    - Spatially varying phase
    - Can cause problem for fat saturation
  - Worse @ high field (wave effects)

  - Affects receive

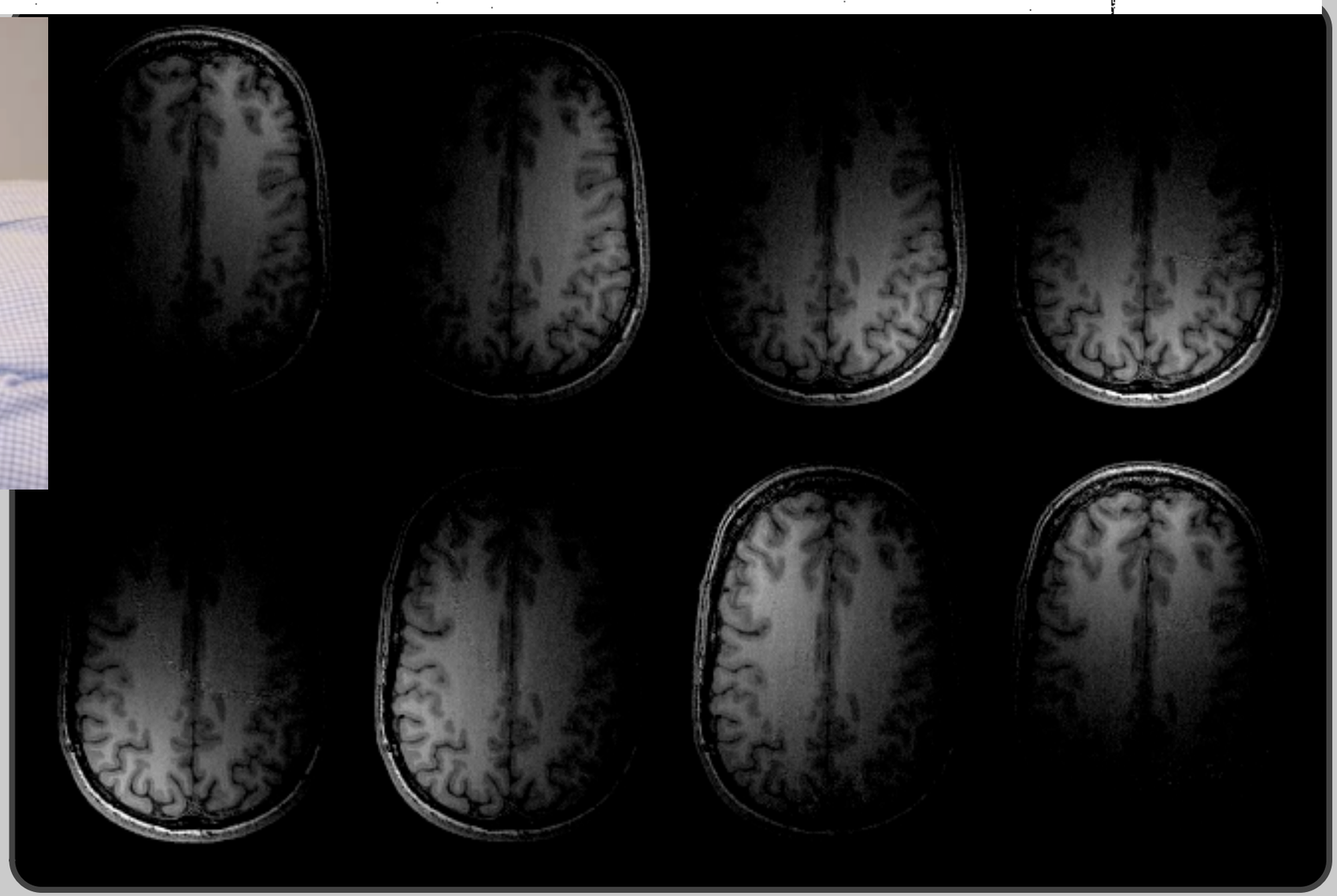
RF excitation inhomogeneity



AFFECTS RECEIVE:

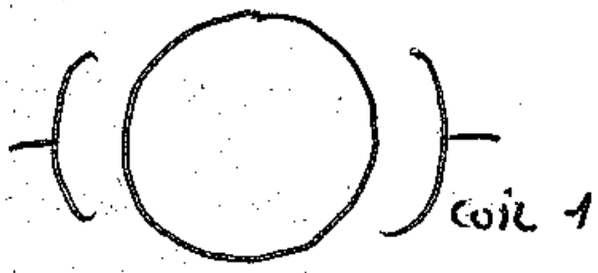
(-) VARYING COMPLEX SENSITIVITY

$$s(t) = \iint_r c(\vec{r}) \, m(\vec{r}) \, e^{-i2\pi(\vec{k}\cdot\vec{r})} \, dr$$



CAN BE A GOOD THING: SENSITIVITY ENCODING.

coil 2



$$s_1(t) = \int_R m(\vec{r},0)\, C_1(\vec{r})\, e^{-i2\pi(\vec{k}\cdot\vec{r})}\, d\vec{r}$$

$$s_2(t) = \int_R m(\vec{r},0)\, C_2(\vec{r})\, e^{-i2\pi(\vec{k}\cdot\vec{r})}\, d\vec{r}$$

TO RECONSTRUCT mC_1 & mC_2 need n encodings

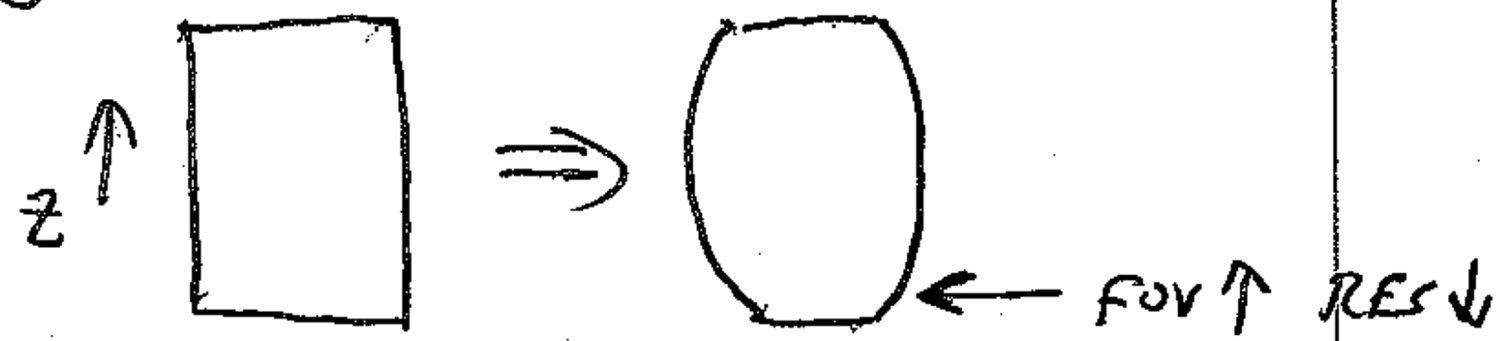
BUT TO RECONSTRUCT m need (maybe) $\frac{n}{2}$ encodings.

More later!

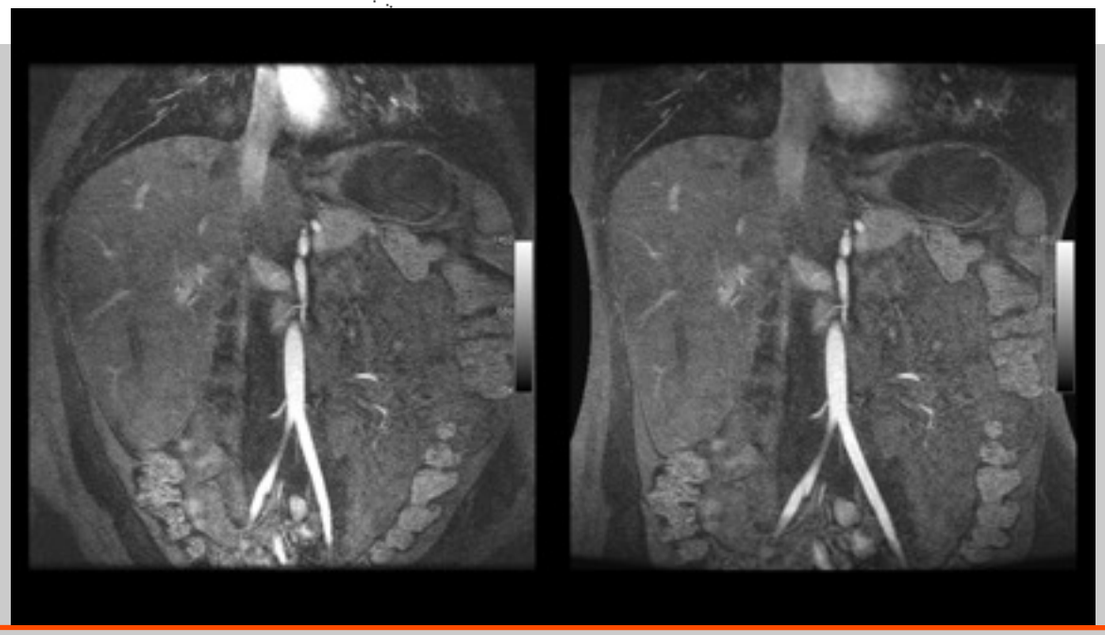
Gradient non-idealities

GRADIENTS

(-) Non Linearity - GRADIENT ROLLES OFF



EASY TO CORRECT BY INTERPOLATION



Concomitant Gradient (Maxwell Terms)

(-) CONCOMITANT GRADIENTS

IDEAL GRADIENTS VIOLATE MAXWELL EQN.

FOR CYLINDRICAL COILS USED IN MRI

$$B = \underset{\text{main}}{B_0} + \underbrace{G_x x + G_y y + G_z z}_{\text{gradients}} + \frac{1}{2B_0}\left[\frac{G_z^2}{4}(x^2+y^2) + (G_x^2+G_y^2)z^2 - G_x G_z xz - G_y G_z yz\right]$$

EXAMPLE: AT $z = 20$ CM $\quad G_x = 40$ mT/m $\quad B_0 = 1.5$ T

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EXAMPLE: AT $z = 20\,cm$ $\quad G_x = 40\ mT/m \quad B_0 = 1.5\,T$

$$\frac{G_x^2 z^2}{2B_0} = \frac{(40\cdot 10^{-3}\cdot 0.2)^2}{2\cdot 1.5} = 2.13\cdot 10^{-5}\,T = 14.2\ ppm$$

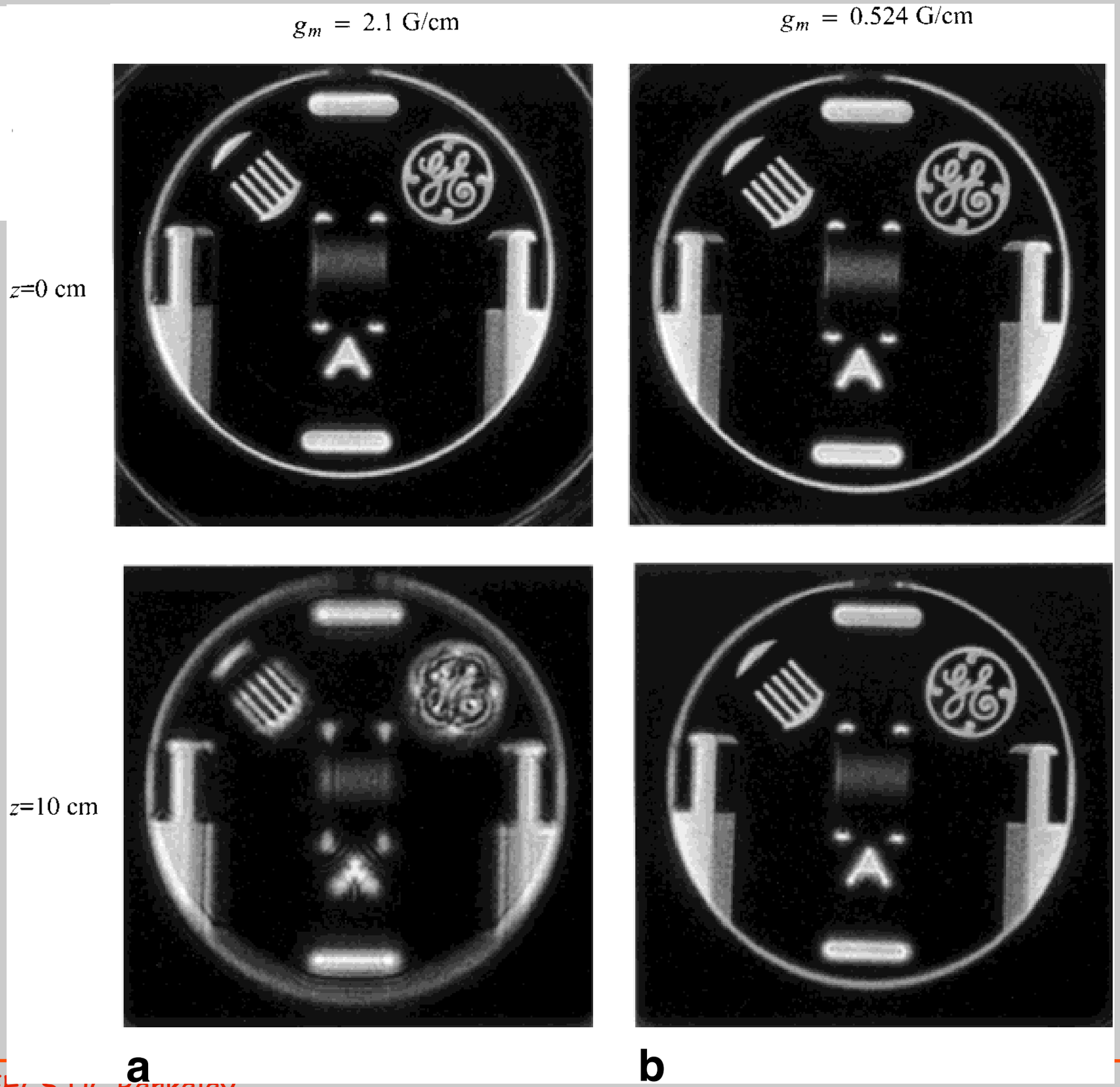
$G = 10\ mT/m \Rightarrow 0.889\ ppm$

$B_0 = 0.7\,T \Rightarrow 65.3\ ppm!$

Concomitant Gradients

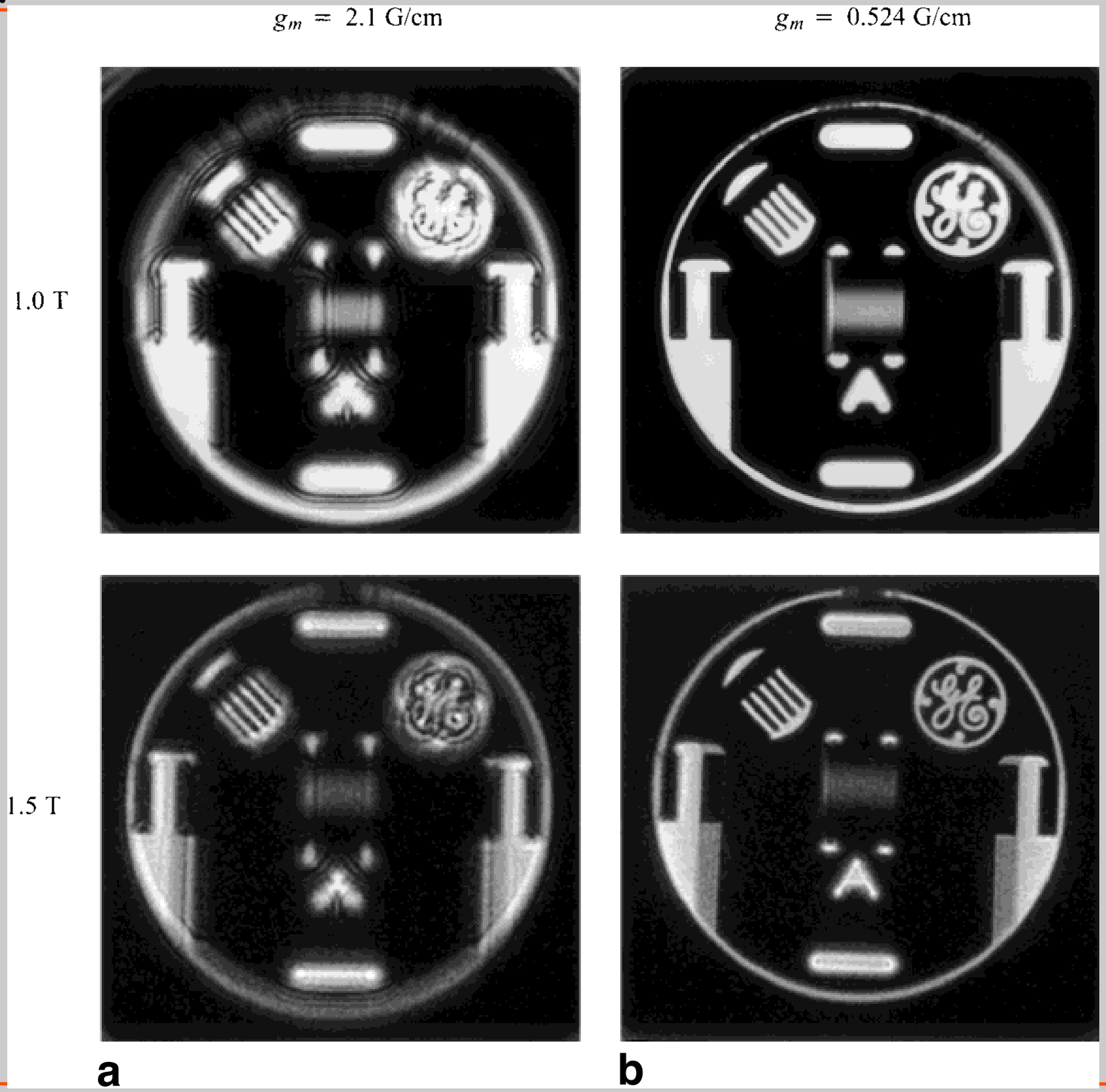
king et. al, MRM 41:103-112(1999)

$$\frac{G_x^2 z^2}{2B_0}$$

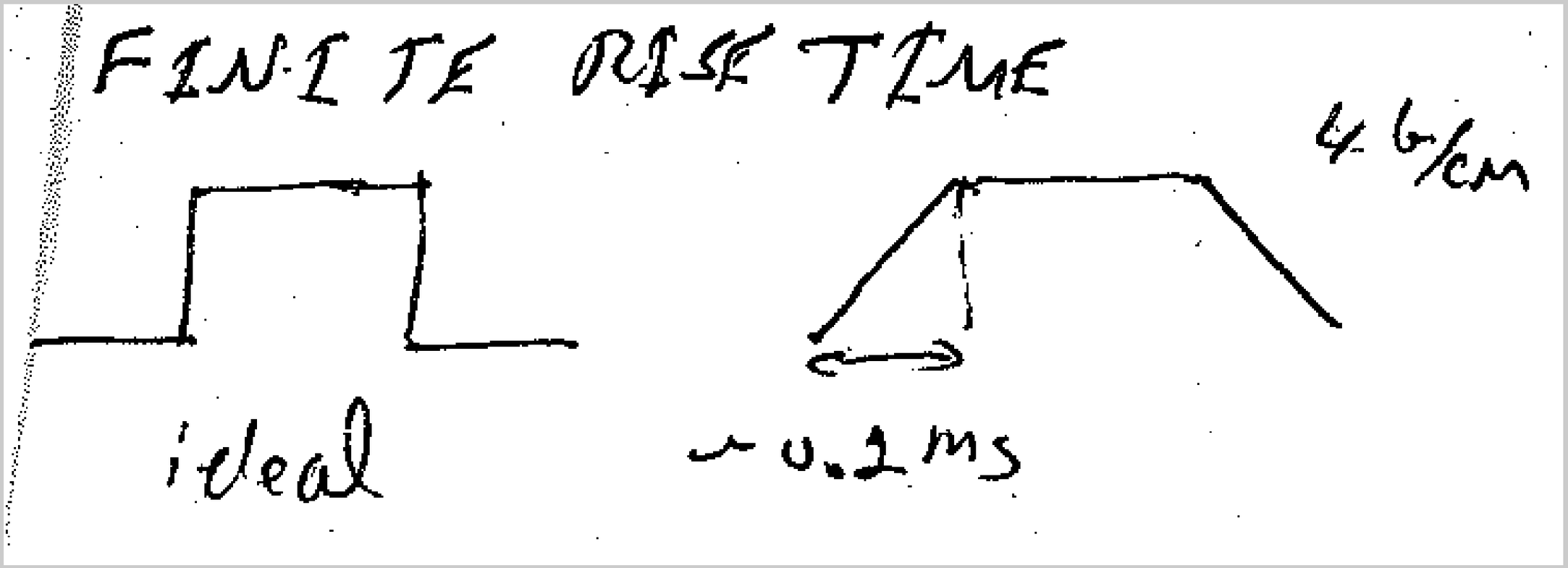


@z=10cm

king et. al, MRM 41:103-112(1999)



Gradient Finite Rise-Time

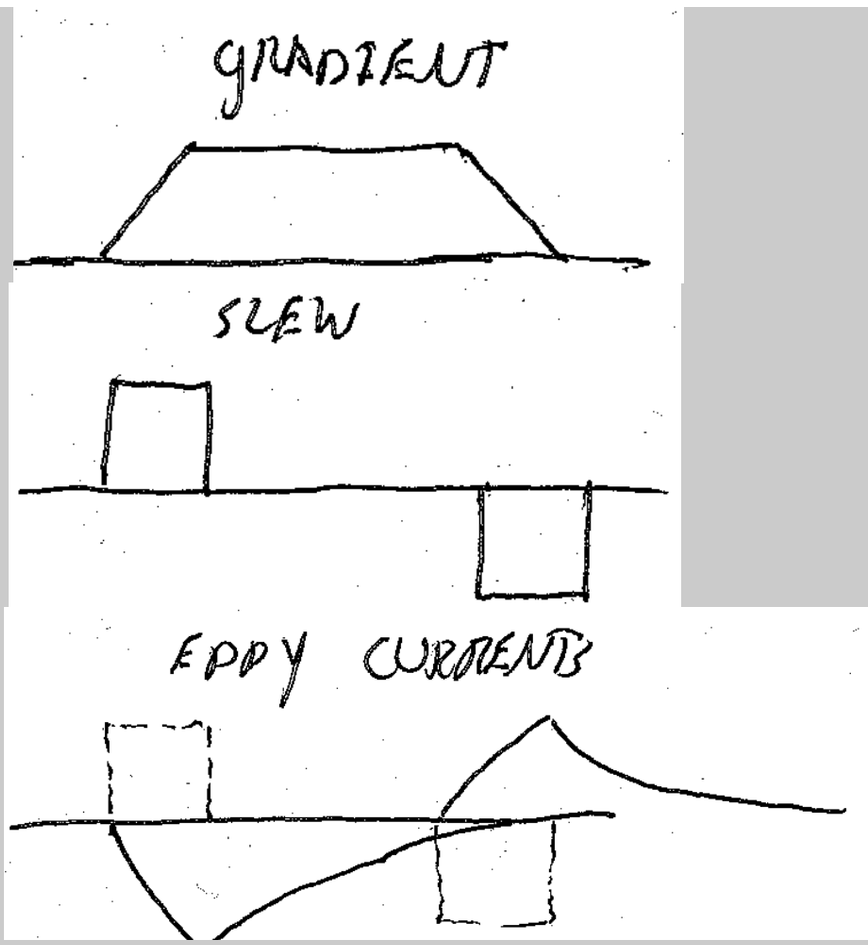


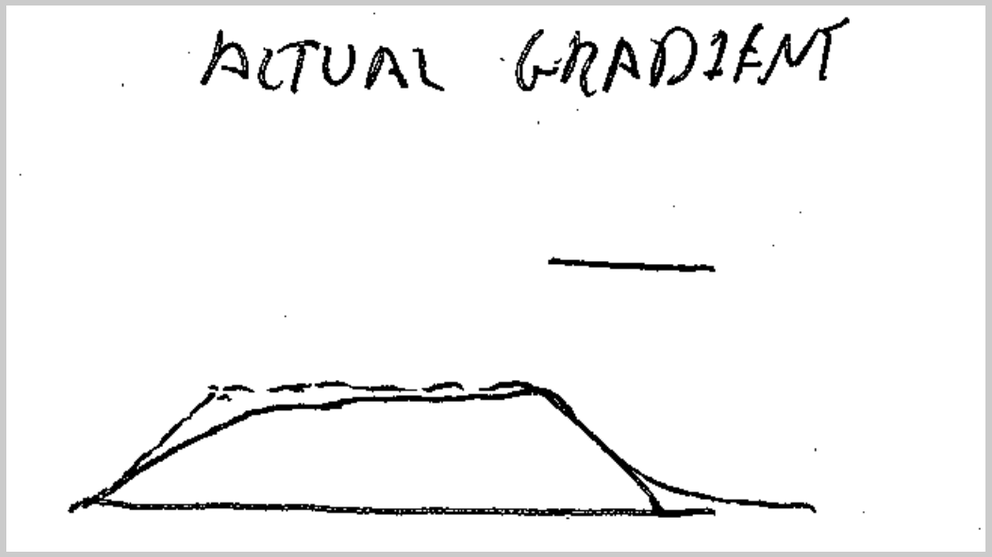
Even finite-rise-time rate! (often ignored)

Eddy Currents

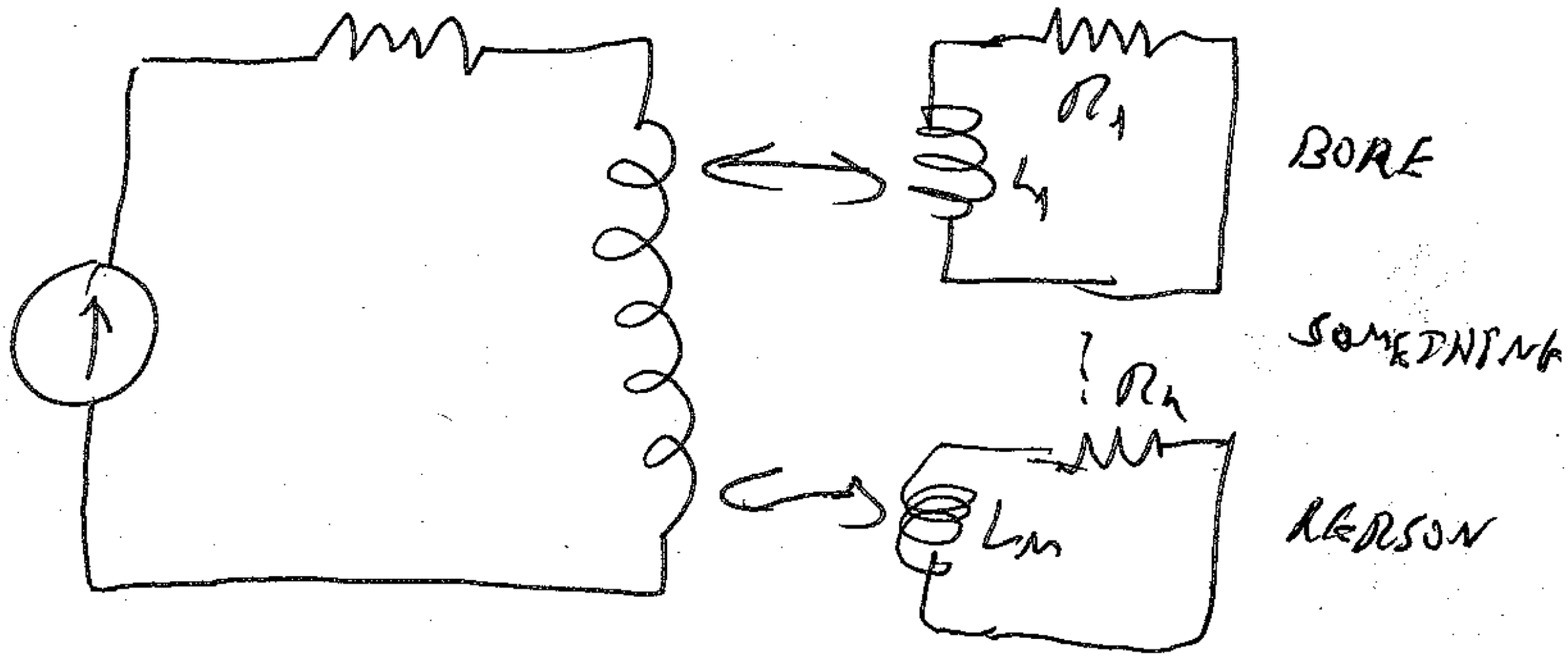
GENERATED BY ELECTRIC FIELD FROM CHANGING MAGNETIC FLUX.

BUILD UP IN TIME VARYING GRADIENTS AND DECAY IN CONSTANT $\propto$ SLEW RATE





$$B_e(\vec{r},t) = b_0(t) + \vec{r}\cdot\vec{g}(t) + \ldots +$$



Eddy Currents

$$g(t) = -\frac{dG}{dt} \circledast e(t)$$

$$e(t) = H(t) \sum \alpha_n e^{-\frac{t}{t_n}}$$

step function

intensity

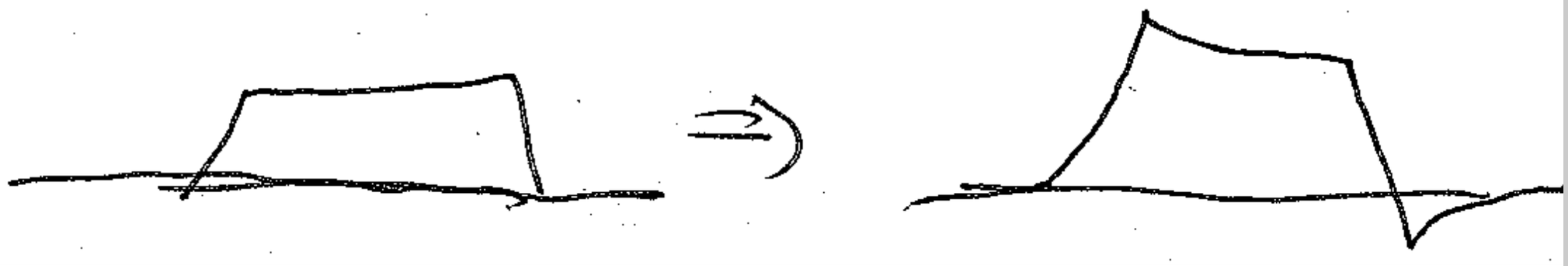
time constant

Pre-emphasis

PREMPHESIS!

$B_0 \rightarrow$ chung exciter phase

gradient



FOR SHORT TIME constants

$$G_{net}(t) = G_{applied}(t - \alpha\tau)$$

Bernstein CH. 10.3

IMAGE CONTRAST

SO FAR ASSUMED

$$\vec{M}(0) = [0, 0, M_0]^T$$

SAMPLE IS FULLY RELAXED $TR \gg 3T_1$

IN PRACTICE THIS IS SELDOM TRUE

- $$\underbrace{I(x,y)}_{\text{IMAGE}} = f(\underbrace{\rho, T_1, T_2}_{\text{PHYSICAL PARAMETERS}}, \underbrace{\theta, TR, TE}_{\text{INSTRUMENTAL PARAMETERS}})$$

TISSUE HAS INHERENT VARIABILITY IN T_1, T_2, ρ

WANT TO EMPHASIZE IT

$m(x,y,t)$ IS A FUNCTION OF TIME!

A GOOD APPROXIMATION $\Rightarrow m(x,y)\big|_{t=TE}$

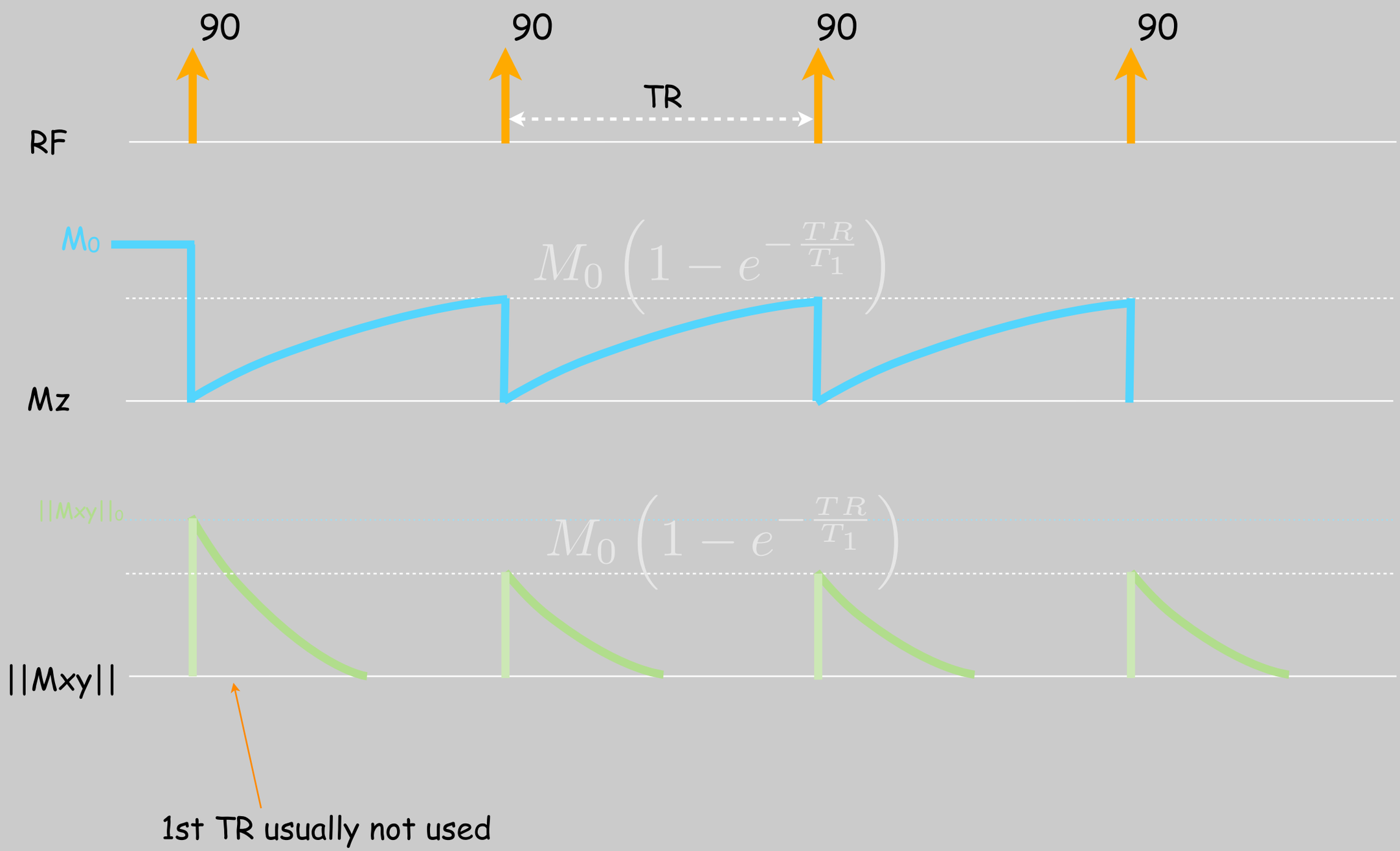
FOR $I(x,y)$

WE WILL CONSIDER: $T_1 > TR > T_2 \cdot 3$

(•) M_{xy} DELAYS BETWEEN ACQUISITIONS

(•) M_z NOT FULLY RECOVERED.

SATURATION RECOVERY



STEADY-STATE SIGNAL: $M_0\left(1-e^{-\frac{TR}{T_1}}\right)$

IMAGE IS:

GAIN CONSTANT

$TE=0$

$$I(x,y) = \underbrace{K\rho(x,y)}_{\text{spin density}}\underbrace{\left[1-e^{-\frac{TR}{T_1(x,y)}}\right]}_{T_1\ \text{WEIGHTING}}$$

$TR \ll T_1$

$$I(x,y) \cong K\rho(x,y)\left(\frac{TR}{T_1(x,y)}\right)$$

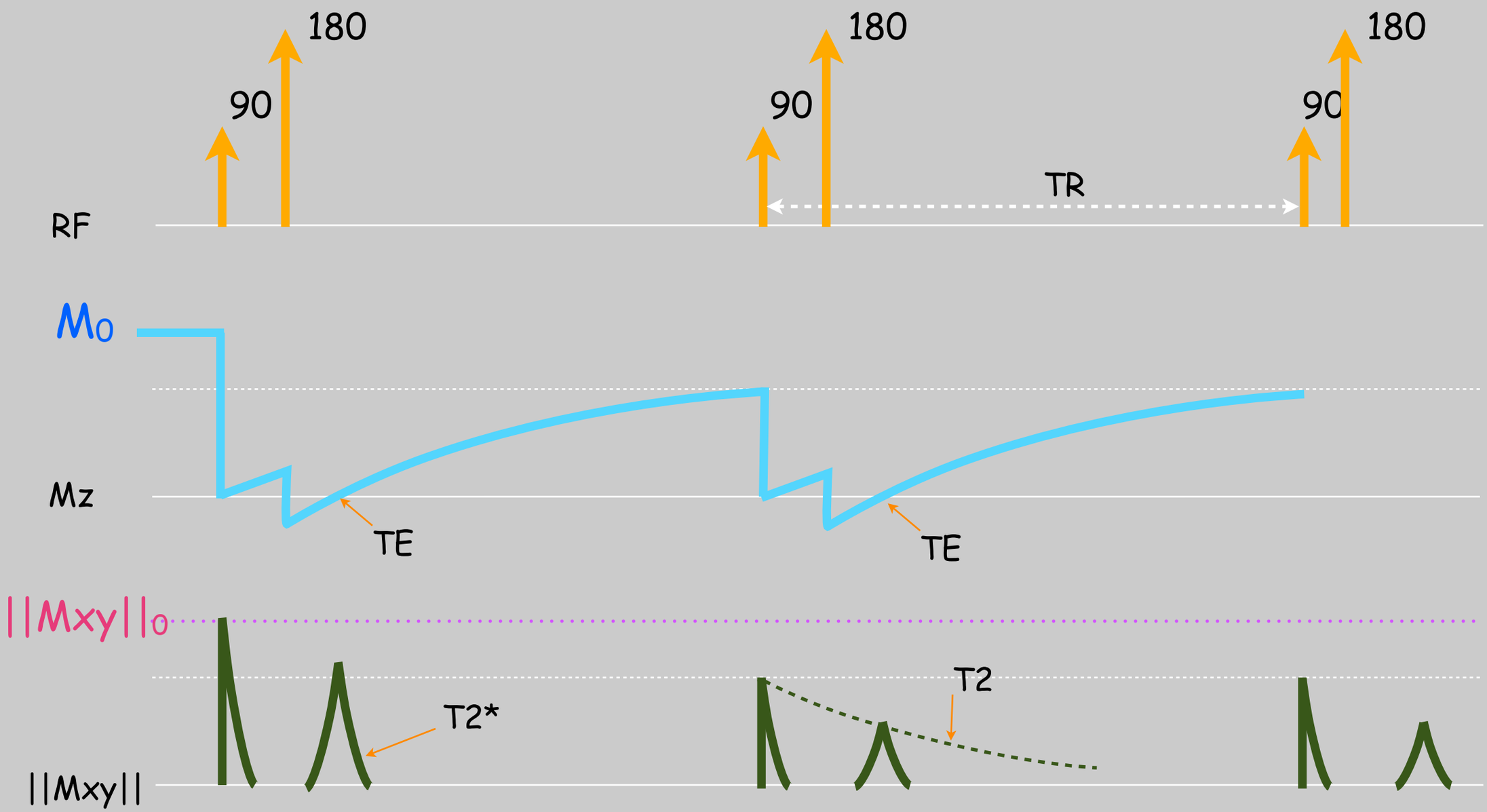
SHORT T_1 BRIGHT

LONG T_1 DARK

$TE \neq 0$

$$I(x,y) = K\rho(x,y)\left[1-e^{-\frac{TR}{T_1(x,y)}}\right]e^{-TE/T_2^*}$$

SPIN-ECHO VERSION



IF $TE < TR$

$$\boxed{I(x,y) = k\rho(x,y)\left[1 - e^{-\frac{TR}{T_1(x,y)}}\right] e^{-\frac{TE}{T_2(x,y)}}}$$

<u>PROTON DENSITY:</u>

$$\left.\begin{array}{l} TE \text{ SHORT} \ll T_2 \\ TR \text{ LONG} \gg T_1 \end{array}\right\} I \cong k\rho(x,y)$$

<u>T_1 WEIGHTING</u>

$$\left.\begin{array}{l} TE \text{ SHORT} \ll T_2 \\ TR \sim T_1 \end{array}\right\} I \cong k\rho\left[1 - e^{-\frac{TR}{T_1}}\right]$$

($TR = 400\,ms$, $TE = 15\,ms$ @ 1.5T BRAIN)

<u>T_2 WEIGHTING</u>

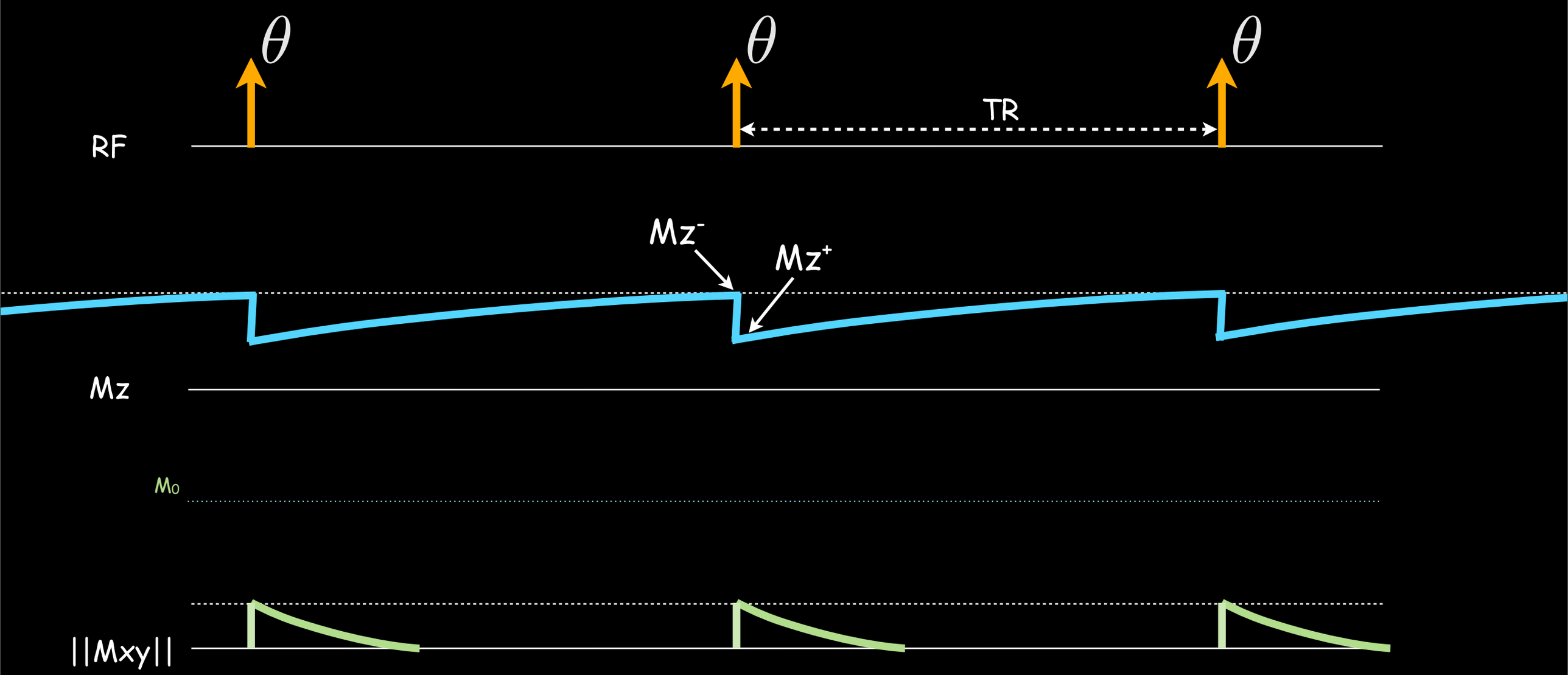
$$\left.\begin{array}{l} TR \text{ LONG} \gg T_1 \\ TE \sim T_2 \end{array}\right\} I \cong k\rho e^{-\frac{TE}{T_2}}$$

($TR = 2500\,ms$, $TE = 80\,ms$ BRAIN @ 1.5T)

T_1 – ANATOMY

T_2 – LESION SENSITIVE

GENERAL EXCITATION RECOVERY



GENERAL EXCITATION RECOVERY