LECTURE 17

CHAPTER 7 — IMAGING CONSIDERATIONS

READ 7-7.3

PRACTICAL ISSUES IN MR IMAGING

T_2 DECAY

OFF-RESONANCE

SPIN-ECHOES

CONTRAST GENERATION

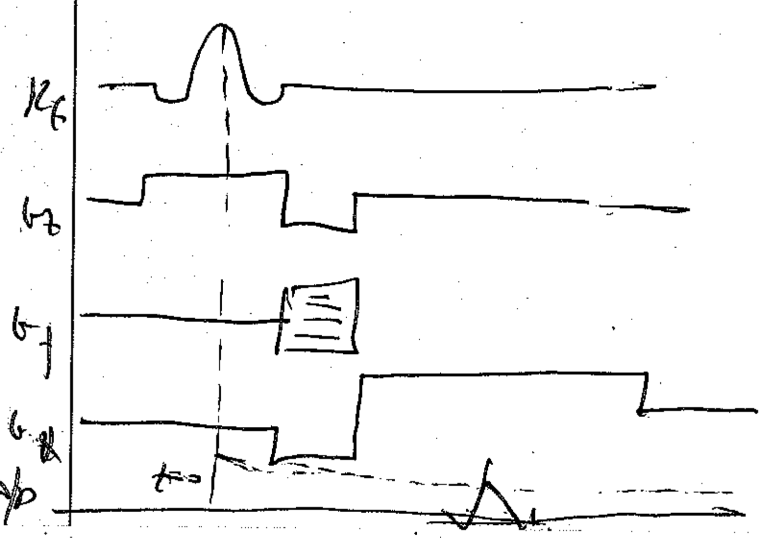
SNR

T_2 DECAY

SIGNAL IS DECAYING DURING AQUISITION

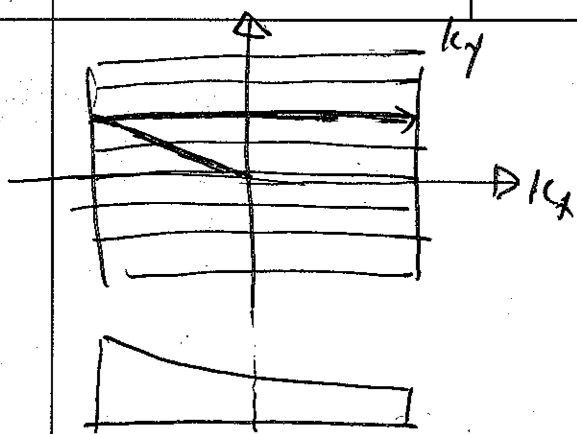
$$s(t) = \int_{\vec{r}} m_{xy}(\vec{r},0) \underbrace{e^{-\frac{t}{T_2}}}_{T_2 \text{ Decay}} e^{-i2\pi \vec{k}(t)\cdot\vec{r}} \, d\vec{r}$$

SIGNAL DECAYS ALONG k-SPACE TRAJECTORY

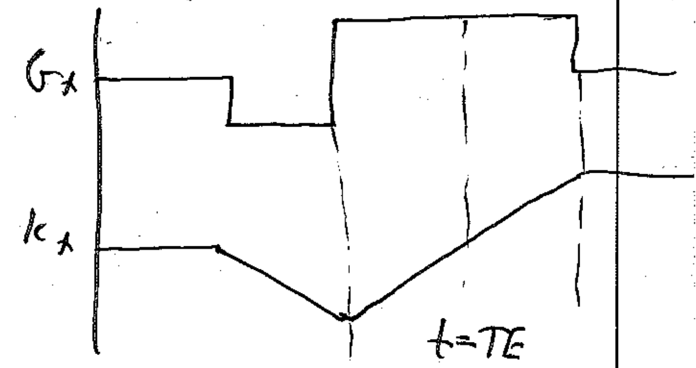


APPROX:

M_{xy} CREATED AT MED RF-
DECAYS WITH T_2 AFTER.



$k_x(t) = \gamma \int_0 G_x(t)\,dt$



DURING READOUT

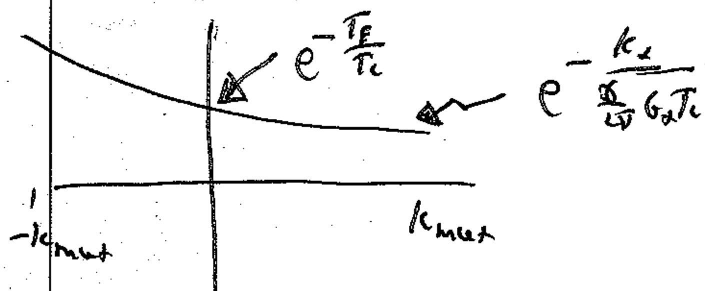
$$k_x = \frac{\gamma}{2\pi} G_x (t - TE)$$

OR

$$t = \frac{k_x}{\frac{\gamma}{2\pi} G_x} + T_E$$

DURING EACH READOUT

$$e^{-\frac{t}{T_2}} = e^{-\left(\frac{k_x}{\frac{\gamma}{2\pi} G_x} + T_E\right)/T_2} = e^{-\frac{k_x}{\frac{\gamma}{2\pi} G_x T_2}} e^{-TE/T_2}$$



TWO EFFECTS:

(1) SIGNAL LOSS BY $e^{-\frac{TE}{T_2}}$ (T_2 WEIGHTING)

(2) APODIZATION BY $e^{-\frac{k_x}{\frac{\gamma}{2\pi} G_x T_2}}$

BLURRING IN IMAGE DOMAIN (x Direction)

USUALLY A MINOR EFFECT

REDUCED BY? INCREASE G_x

OFF RESONANCE

SO FAR WE ASSUMED B_0 constant
But B_0 varies due to:

1. MAIN MAGNET HOMOGENEITY
2. OBJECT MAGNETIC SUSCEPTIBILITY
3. CHEMICAL SHIFT

MAIN MAGNET HOMOGENEITY

- DESIGNED TO BE HOMOGENEOUS OVER A (SPHERICAL) VOLUME

TYPICAL NUMBERS

BARE MAGNET ~10 – 100 PPM
SHIMMED MAGNET ~1 PPM.

@ 64 MHz (1.5T) 1PPM is 64 Hz
@ 3T it is 128 Hz

GENERALLY MAIN MAGNET HOMOGENEITY
IS NOT A LIMITATION

OBJECT SUSCEPTIBILITY

Most Biological OBJECTS PERTERB THE FIELD

$$B_{0,Tissue} = (1+\chi) B_{0\,FREESPACE}$$

χ is THE MAGNETIC SUSCEPTIBILITY

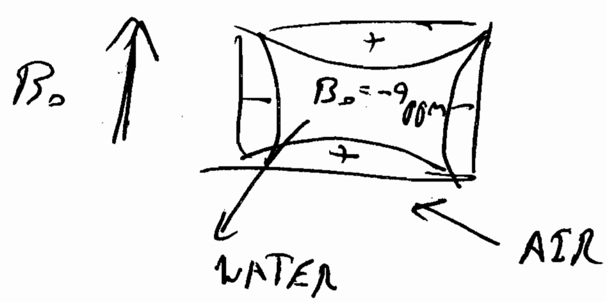
Tissue is mostly water, which is DIAMAGNETIC $\chi < 0$

LARMOR FREQ LOWER IN TISSUE THAN AIR

WATER $\chi = -9\,ppm$

OTHER TISSUES HAVE OTHER SHIFTS
CALCIUM, BLOOD (PARA/DIA MAGNETIC)

COMPLEX BEHAVIOR AT BOUNDRIES



DEPENDS ON GEOMETRY
LARGE AT BOUNDRIES.

TYPICAL VARIATIONS are ±3 ppm w.r.t water
~ 200 Hz @ 1.5 T

PROBLEM AREAS:
BRAIN ABOVE SINUSES, AUDITORY CANALS
HEART SURROUNDED BY LUNGS
ABDOMINE

CHEMICAL - shift

PROTONS IN COMPLEX MOLECULES ARE "SHIMMED" BY ADJACENT SPINS

EFFECTIVE FIELD SEEN BY SPIN IS

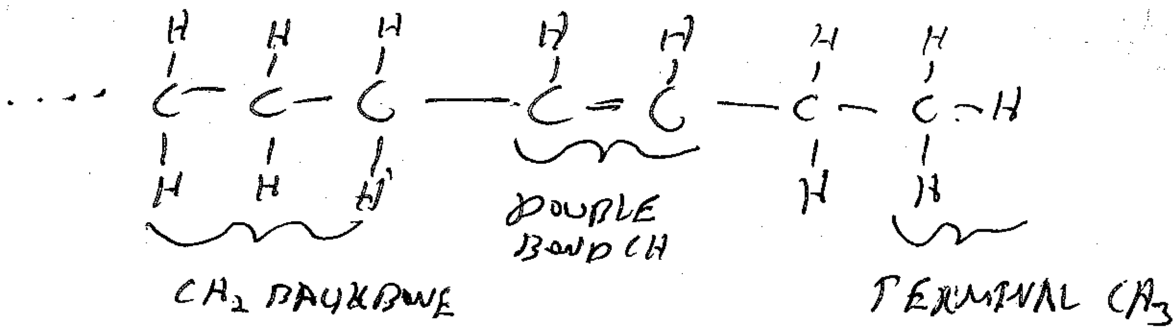
$$B = B_0(1-\sigma)$$

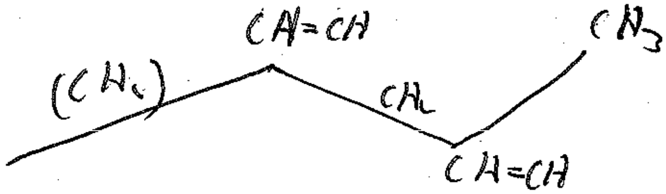
σ is SHIELDING CONSTANT

DEPENDS ON STRUCTURE!

EXAMPLE : LIPIDS

LONG CHAIN



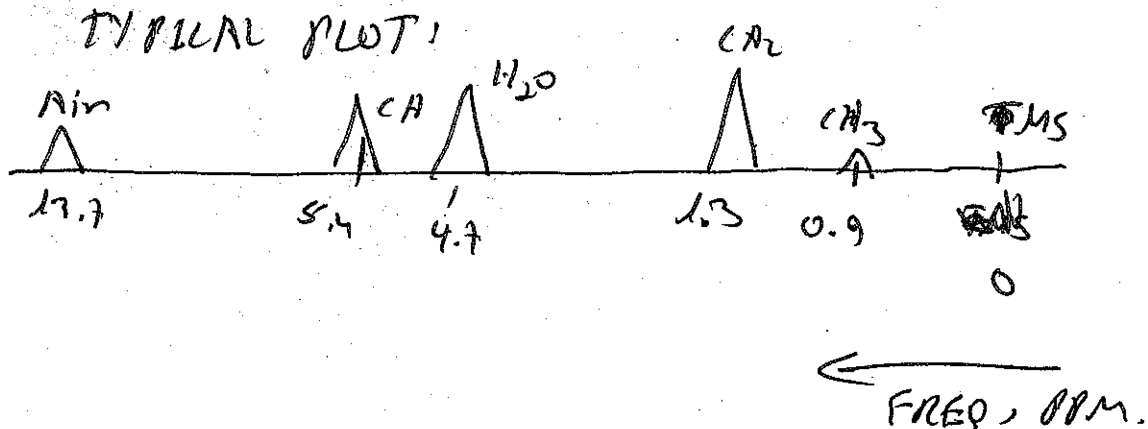


SATURATED, NO CH → STREIGHT MOLLECULE.

NOT HEALTHY!

EACH GROUP HAS UNIQUE RESONANT FREQ.

TYPICAL PLOT:



ZERO FREQUENCY IS RESONANCE OF TMS → ARBITRARY REFRENCE (DOES NOT CHANG WITH TEMP)

PLOT INCREASING TO LEFT

(OLD SPECTROMETERS SWEPT FREQ FROM HIGH TO LOW
OUTPUT WAS STRIP CHART RUNING FROM LEFT TO RIGHT)

MOST LIPID SIGNAL FROM CH_2 @ 1.3 PPM

4.7 − 1.3 = 3.4 PPM BELOW WATER

@ 1.5 T 3.4 PPM · 64 MHz ≈ 220 Hz

HETEROGENEOUS TISSUES

TISSUE OFTEN COMBINATION OF
- CHEMICAL SHIFT
- SUSCEPTIBILITY
- GEOMETRY

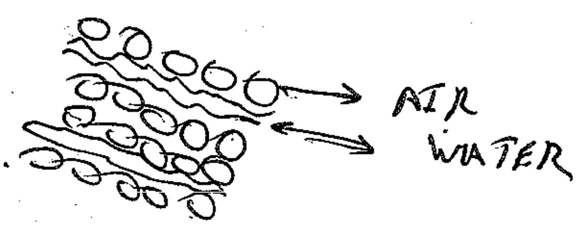
RESULTS ARE COMPLEX!

INTERESTING CASES:

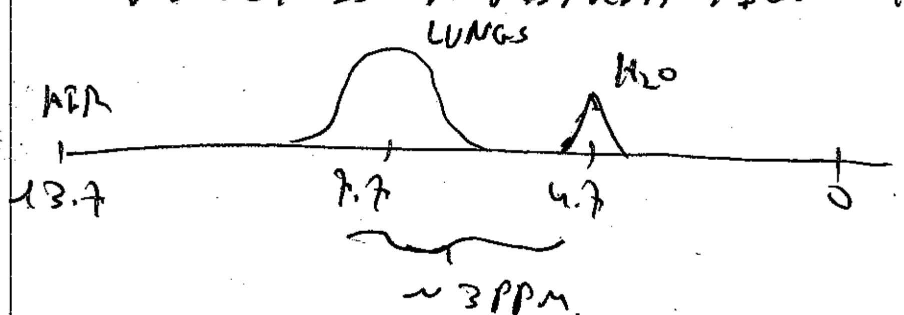
- BLOOD, fMRI
- LUNGS
- TRABECULAR BONE
- IRON IN BRAIN.

LUNGS

APPROX: $\frac{1}{6}$ TISSUE, $\frac{5}{6}$ AIR



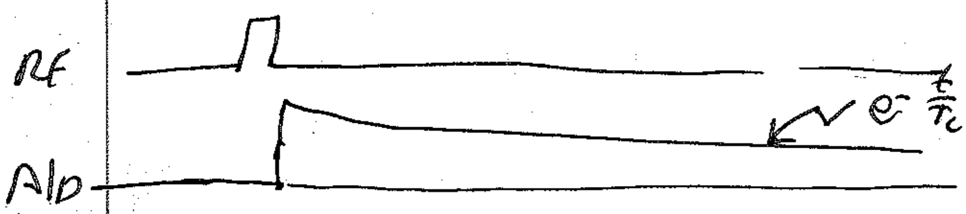
RESULT IS A DISTRIBUTION OF FREQS:



TELLS ALOT ABOUT SMALL STRUCTURES.

OFF-RESONANCE EFFECTS ON FID

ON-RESONANCE FREE-INDUCTION DECAY (FID)



SIMPLE SPECTROSCOPY EXP.

SIGNAL DECAYS WITH T_2

WITH SUSCEPTIBILITY VARIATIONS, FID IS:

$$\underbrace{B_0}_{\text{UNIFORM FIELD}} + \underbrace{E(\vec{r})}_{\text{ERROR FIELD}}$$

(NOT JUST SPATIAL, ALSO SPECTRAL)

ROTATING FRAME DELETES B_0, LEAVING $E(\vec{r})$

$$\vec{B} = E(\vec{r})\hat{k} = [0, 0, E(\vec{r})]^T$$

$$\omega_E(\vec{r}) = \gamma E(\vec{r})$$

$$f_E(\vec{r}) = \frac{\gamma}{2\pi} E(\vec{r})$$

THEN $m_{xy}(r,t)$ IS

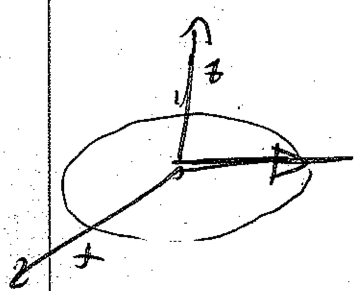
$$m_{xy}(r,t) = m_{xy}(\vec{r},0)\, e^{-i\omega_E(\vec{r})t}\, e^{-\frac{t}{T_2}(\vec{r})}$$

THE RECEIVED SIGNAL IS THEN

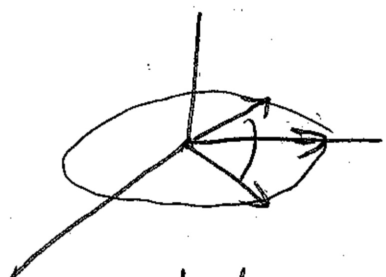
$$s(t) = \int_{R} m_{xy}(\vec{r},t)\, d\vec{r} =$$

$$= \int_{\vec{R}} \underbrace{m_{xy}(\vec{r},0)}_{\text{magnetization}}\ \underbrace{e^{-i\omega_E(\vec{r})t}}_{\text{DEPHASING}}\ \underbrace{e^{-t/T_2(\vec{r})}}_{\text{DECAY}}\, d\vec{r}$$

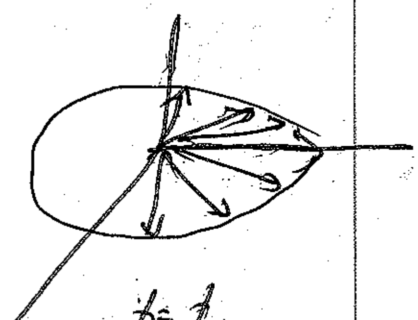
WITH TIME, PHASE DISPERSION CAUSES SIGNAL CANCELATION AND LOSS.



$t = t_0$

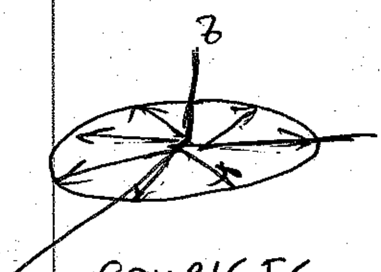


$t = t_1$



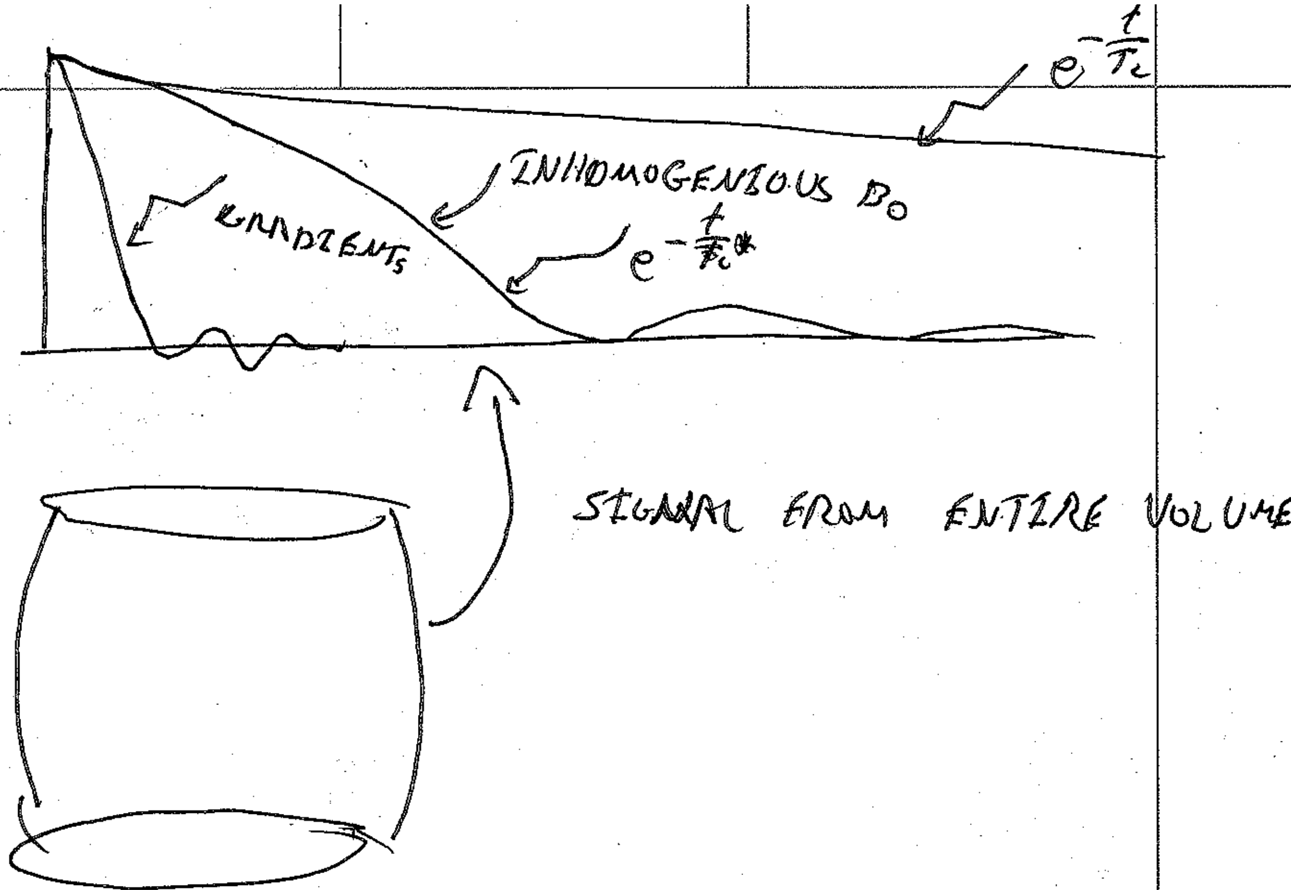
$t = t_2$

SOME LOSS



COMPLETE LOSS

$t \gg t_2^*$



GRADIENTS ARE VERY STRONG INHOMOGENEITY!

INHOMOGENEITY ⇒ SIGNAL LOSS KNOWN AS T_2^*

APPROXIMATE AS EXPONENTIAL

$$s(t)\Big|_{voxel} = \left[\int_{voxel} m_{xy}(\vec{r},0)\, e^{-i\omega_E(\vec{r})t}\, e^{-t/T_2(\vec{r})}\, d\vec{r}\right]$$

$$\simeq \left[\int_{voxel} m_{xy}(\vec{r},0)\, d\vec{r}\right] e^{-\frac{t}{T_2^*(\vec{r})}}$$

$$\frac{1}{T_2^*} = \frac{1}{T_2} + \frac{1}{T_2'}$$

$\frac{1}{T_2}$ → RELAX

$\frac{1}{T_2'}$ → DEPHASE

$$R_2^* = R_2 + R_2'$$

T_2^{*} **NOT** A GOOD MODEL FOR LARGE-SCALE VARIATIONS (DEPHASING NEAR SINUSES)

T_2^{α} **IS** A GOOD MODEL FOR SMALL SCALE DISTRIBUTED VARIATIONS (DEPHASING NEAR DEOXYGENATED CAPILLARIES)