OFF-RESONANCE EFFECTS AND ECHOES

p. 127-139 in NISHIMURA

- THUS FAR, WE HAVE ASSUMED A PERFECTLY UNIFORM (OR HOMOGENEOUS) MAGNETIC FIELD B_0 IN OUR DEVELOPMENT OF MR IMAGING.

- UNFORTUNATELY, THINGS AREN'T THAT SIMPLE! (THEY NEVER ARE...)

- THERE ARE 3 MAIN REASONS FOR VARIATIONS IN B_0 (AND THUS THE RESONANT FREQUENCY) ACROSS OUR SAMPLE:

(1) MAIN FIELD INHOMOGENEITY (OUR BIG SUPERCONDUCTING MAGNET ISN'T PERFECT!)

(2) SUSCEPTIBILITY-INDUCED FIELD VARIATIONS

(CHANGES IN BULK MAGNETIC SUSCEPTIBILITY χ FROM TISSUE TO TISSUE WARP OUR FIELD!)

- REALLY BAD NEAR AIR-TISSUE INTERFACES

(WATER OR TISSUE IS SLIGHTLY DIAMAGNETIC W/ $\chi < 0$. AIR IS SLIGHTLY PARAMAGNETIC W/ $\chi > 0$.)

(3) CHEMICAL SHIFT

- SOME SPINS JUST SING OFF KEY! :)
- MAGNETIC FIELD SEEN BY NUCLEUS IS REDUCED SLIGHTLY BECAUSE OF ELECTRONIC SHIELDING.
- ^1H IN FAT SINGS ~3.5 ppm (PARTS PER MILLION) LOWER IN FREQUENCY THAN ^1H IN WATER!

- THESE INHOMOGENEITIES IN FIELD EFFECT IMAGING (YOU SHOULD REVIEW p. 129-134)

- NOW LET'S TALK ABOUT SOME OTHER IMAGING NON-IDEALITIES:

$T2^*$ DECAY

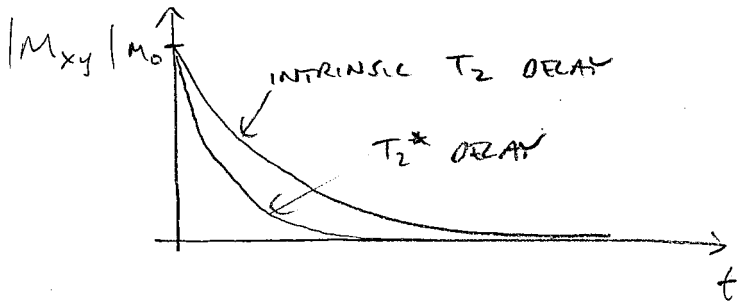
- WE'VE TALKED ABOUT T2 DECAY, AND SAID THAT OUR SIGNAL TYPICALLY DECAYS AS T_2.
  - THIS IS ACTUALLY NOT STRICTLY TRUE WHEN WE HAVE INHOMOGENEITY IN OUR MAIN FIELD B_0
  - ACROSS A VOXEL (OR ANY VOLUME), WE CAN HAVE SLIGHT VARIATIONS IN FREQUENCY, SO:

$$s(t) = \iiint_{x\,y\,z} m(x,y,z)\, e^{-i\omega_E(x,y,z)t}\, e^{-t/T_2(x,y,z)}\, dx\,dy\,dz$$

WHERE:

$$\vec{B} = \left(B_0 + E(x,y,z)\right)\hat{k} \quad \text{AND} \quad \omega_E(x,y,z) = \gamma E(x,y,z)$$

- THIS DEPHASING CAUSES OUR SIGNAL TO DECAY MORE RAPIDLY THAN SIMPLE INTRINSIC T2 DECAY! WE CALL IT "$T2^*$" DECAY



PLAY T_2^* SONG

ECHOES IN MRI:

WE CAN WRITE THE SIGNAL PHASE OF OUR MR SIGNAL AS:

$$\phi(x,y,z,t) = \int_0^t \omega(x,y,z,\tau)\,d\tau$$

$$\phi(x,y,z,t) = \underbrace{\omega_E(x,y,z)t}_{B_0\ \text{INHOMOGENEITY}} + \underbrace{\omega_{CS}t}_{\text{CHEMICAL SHIFT}} + \underbrace{\gamma\int_0^t [G_x(\tau)x + G_y(\tau)y + G_z(\tau)z]\,d\tau}_{\text{GRADIENTS}}$$

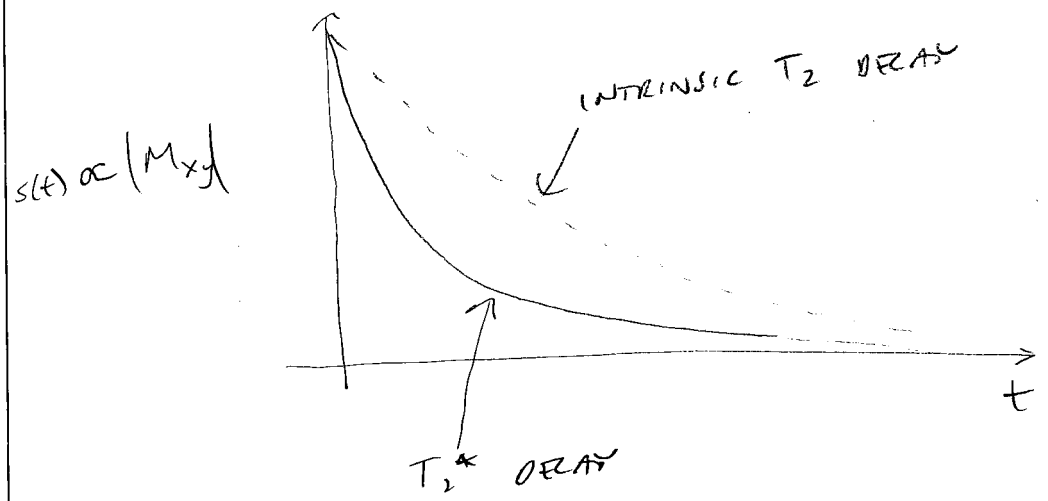
WE DON'T CONTROL THESE TERMS ("OFF-RESONANCE")

WE CONTROL THIS TERM

WE ARE GOING TO TALK ABOUT TWO TYPES OF "ECHOES" IN MR IMAGING:

① GRADIENT ECHOES: "ECHOES" IN THE SIGNAL FROM UNDOING PHASE SHIFTS FROM GRADIENT FIELDS

② SPIN ECHOES: ECHOES IN SIGNAL FROM UNDOING PHASE SHIFTS (OR DEPHASING) FROM B_0 INHOMOGENEITY AND ~~GRADIENT FIELDS~~ CHEMICAL SHIFT.

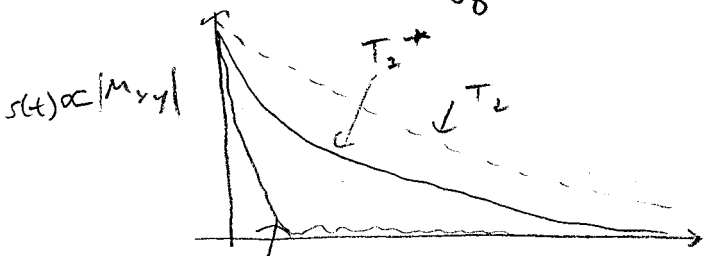


- WITH NO GRADIENTS ON, WE GET T_2^* DECAY.

- WHAT HAPPENS TO SIGNAL WHEN WE TURN GRADIENTS ON?

SIGNAL "DEPHASES", AND DECAYS RAPIDLY, SINCE:

$$\phi(x,y,z,t) = \gamma \int_0^t \left[G_x(\tau)x + G_y(\tau)y + G_z(\tau)z \right] d\tau$$

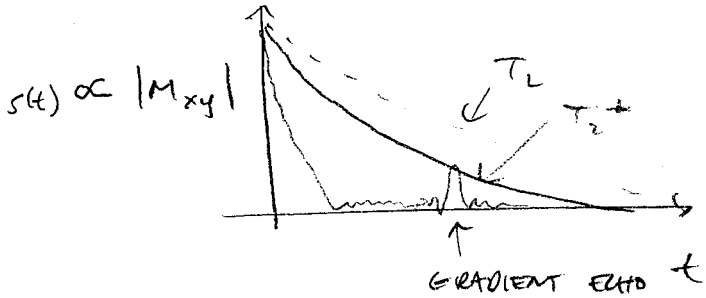


POSSIBLE ACTUAL SIGNAL AS WE TRAVERSE K-SPACE

- WHAT HAPPENS WHEN

$$\phi(x,y,z,t) = 0 ?$$ ⟸ "GRADIENT ECHO"

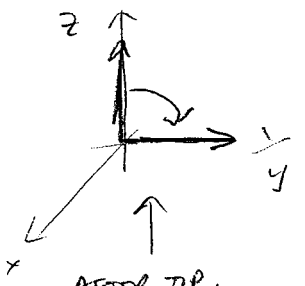
- WE ARE BACK AT THE CENTER OF K-SPACE! ANY LINEAR PHASE ACROSS OUR OBJECT, IS UNDONE! DUE TO GRADIENTS



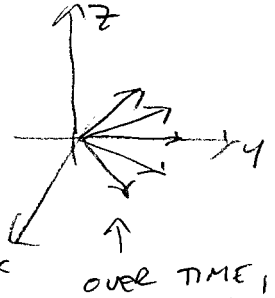
- TECHNICALLY, A GRADIENT ECHO ONLY OCCURS WHEN WE CROSS THE CENTER OF K-SPACE, BUT IT IS COMMON TO REFER TO A CROSSING IN THE READOUT DIRECTION (i.e, $k_x = 0$ FOR 2DFT IMAGING) AS A GRADIENT ECHO AS WELL.

SPIN ECHOES:

- NOW CONSIDER THE SPINS IN A VOLUME. T_2^* DECAY HAPPENS FROM DEPHASING DUE TO OFF-RESONANCE SOURCES.



AFTER TIP,

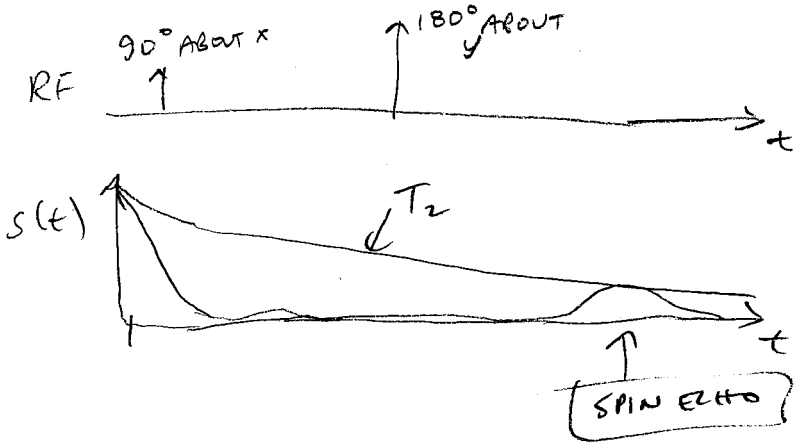


⟸ IN ROTATING FRAME!

OVER TIME, SPINS ... (DEPHASE)

- WHAT HAPPENS IF, SOME TIME AFTER OUR INITIAL TIP, WE DO A 180° FLIP AROUND THE y-AXIS??

FORM A "SPIN ECHO"!



2DFT "SPIN ECHO" SEQUENCE: