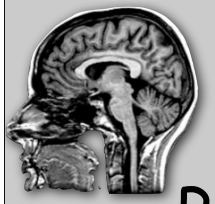
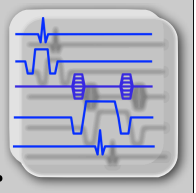




Principles of MRI

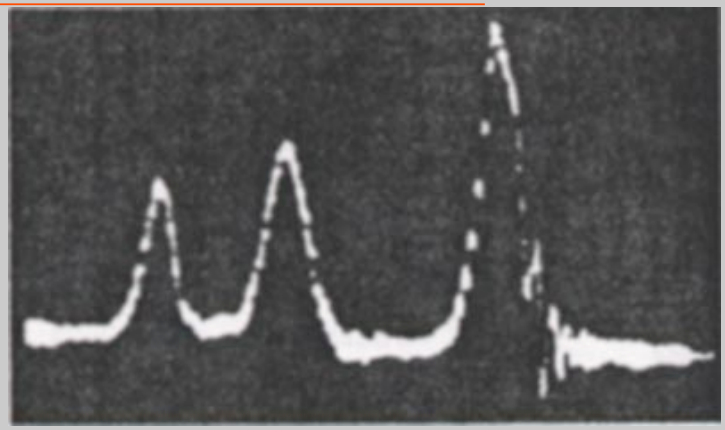
EE225E / BIO265

Lecture 05

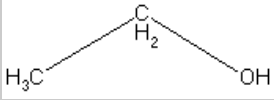
Instructor: Miki Lustig
UC Berkeley, EECS

What is this?

- `



The first NMR spectrum of ethanol 1951.

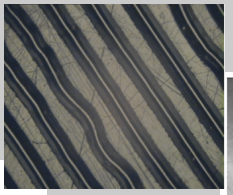


Today

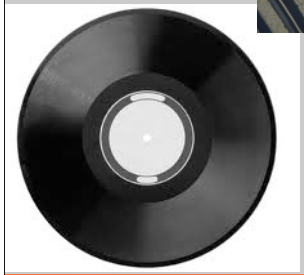
- Last time:
  - –Linear systems, Fourier Transforms, Sampling
- Today:
  - –Ch 3. Overview
    - Classical description of MRI
    - Basic Imaging
- Homework Due tonight!

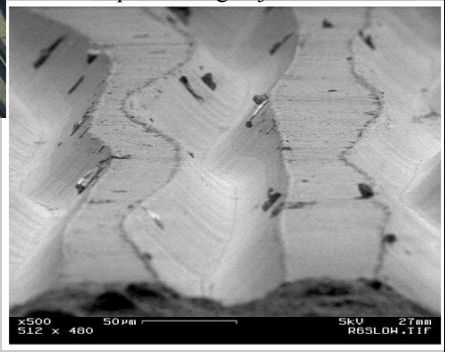
Spatial Frequency

- Vinyl Record
  - –Transforms a temporal signal to a spatial signal



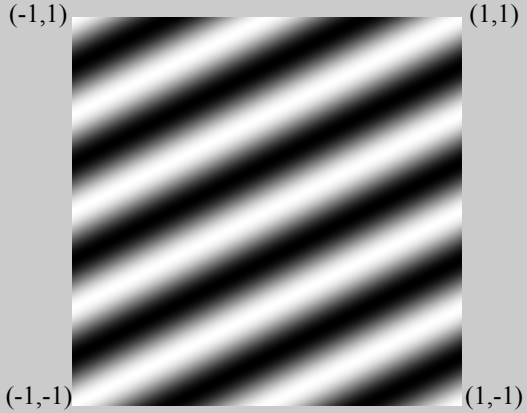
http://offtosognefjord.tumblr.com





What is the frequency?

$$\cos(2\pi(f_x x + f_y y))$$

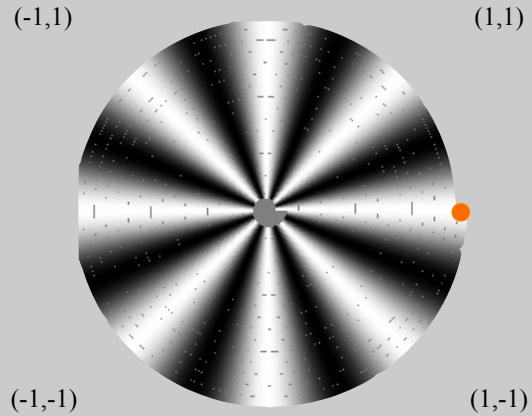


a) $f_x=1$, $f_y=2$ c) $f_x = 4$, $f_y=2$

b) $f_x=2$, $fy=1$ d) $f_x=2$, $fy=4$

What is the Temporal Frequency?

Vinyl rotates at 1 Hz

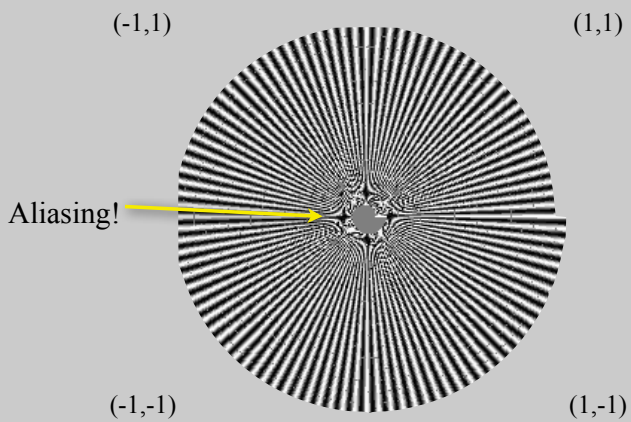


a) $\cos(2\pi 8t)$ c) $\cos(2\pi 4t)$

b) $\cos(2\pi 8t^2)$ d) $\cos(2\pi 4t^2)$

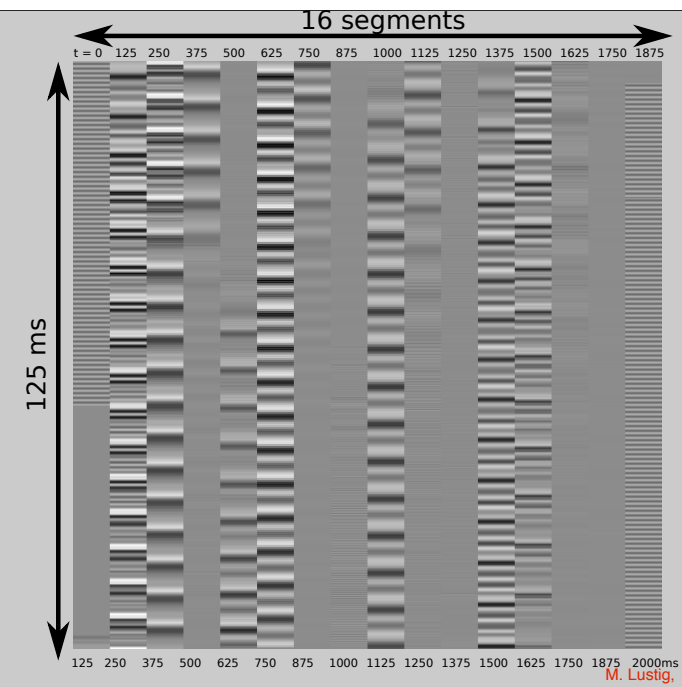
What is the Temporal Frequency?

Vinyl rotates at 1 Hz



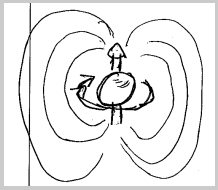
a) $\cos(2\pi 100t)$ c) $\cos(2\pi 40t)$

b) $\cos(2\pi 100t^2)$ d) none of the answers



Classical Description of MR

- Atoms with odd # of protons/neutrons have nuclear spin angular momentum
  - Intrinsic QM property (ch. 4)
  - Also intrinsic magnetic moment
- Like Spinning magnetic dipoles
- In biological tissue:
  - Mostly ^{1}H in H_2O
  - Sometimes ^{31}P, ^{13}C, ^{23}Na - Exotic



Classical Description of MR

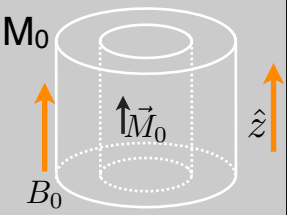
- Interaction of magnetization with 3 fields
  - B0 - Main field ⇒ Polarization and resonance
  - B1 - RF field ⇒ Signal production + reception
  - G - Gradient fields ⇒ Spatial encoding

B0 - Main Field

- Produces polarization of sample M_0
- Resonance at Larmor frequency

$$\omega = -\gamma B_0$$

Gyromagnetic Ratio



- For Protons:

$$\frac{\gamma}{2\pi} = 4.257 \quad \mathrm{KHz/G}$$

$$\gamma = 2\pi 4.257 \quad \mathrm{Krad/G}$$

- Others:
  - ^{23}Na $\frac{\gamma}{2\pi} = 1.127 \quad \mathrm{KHz/G}$
  - ^{13}C $\frac{\gamma}{2\pi} = 1.071 \quad \mathrm{KHz/G}$
  - ^{15}N $\frac{\gamma}{2\pi} = -0.43 \quad \mathrm{KHz/G}$

Typical B_0

0.1T	4.2MHz	Very Low!
0.5T	21MHz	Low (permanent/ resistive)
1.5T	63MHz	"High" Diagnostic (superconducting)
3T	127MHz	"High" Diagnostic (superconducting)
4T	170MHz	Rare
7/9.4T	300/400 MHz	Very High - research only

B0 Field

- For Spatial/Spectral Localization we require homogeneity

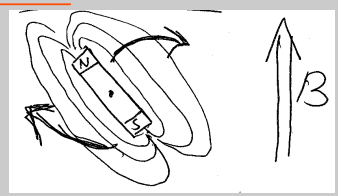
$$\Delta B_0 \sim 1\text{ppm}$$

over 40cm³ FOV

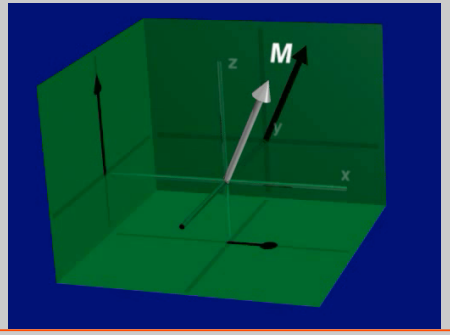
- This is: 64Hz @ 1.5T
  - Pretty remarkable!

Why Resonance

- For a bar magnet
  - Torque, but no resonance
  - Missing angular momentum



- Resonance is like a spinning-top



B_1 - RF Field

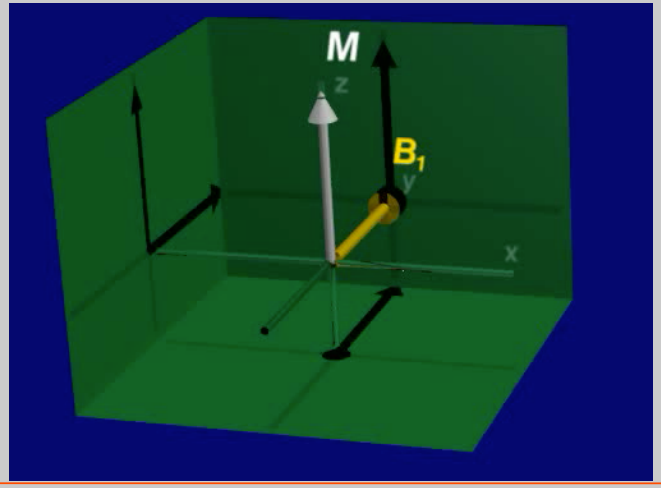
- Can't Directly Detect M_0
  - $M_{\text{induced}} = \mu_0^{-1} V \chi B \qquad \chi \approx 4 \cdot 10^{-9}$

Q: Why?
A: Huge field!

- Resonance is the key!
  - B0 is DC while spins resonate ⇒ Detection!
  - Sample resonates at $\omega_0 = -\gamma B_0$
- Excite magnetization off the z direction
  - Apply RF field at $\omega_0 = -\gamma B_0$ in the x-verse plane
  - Has to be resonant to do something

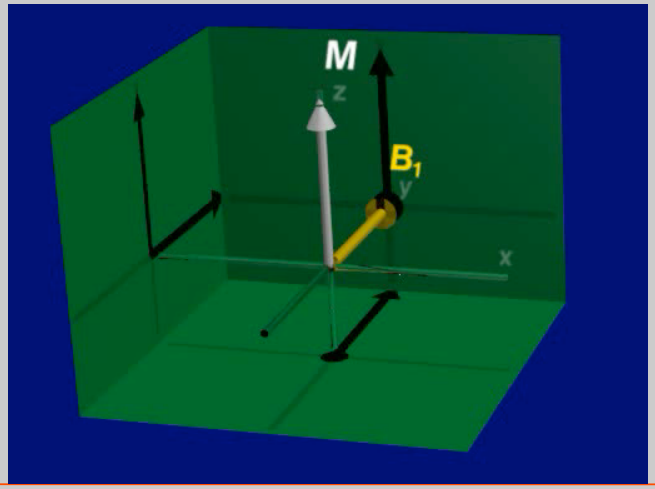
RF Excitation

- In the lab frame $B_1(t) = A\hat{y}$



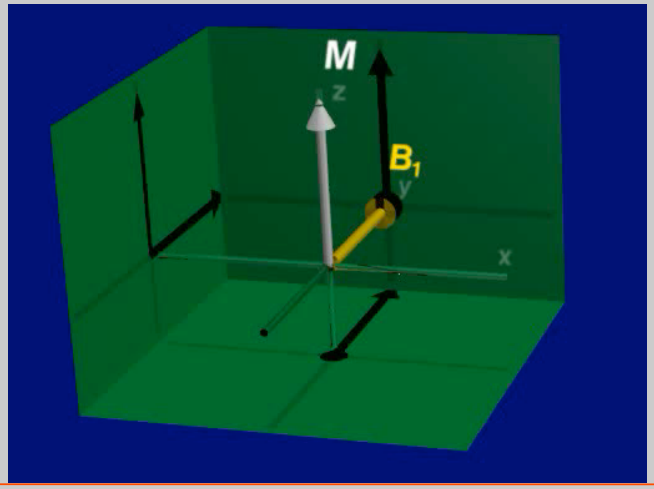
RF excitation

- In the lab frame $B_1(t) = Ae^{-i\omega_0 t}$



RF excitation

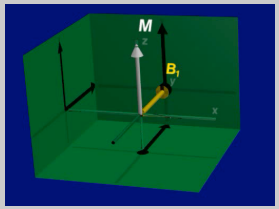
- In the rotating frame @ω_0 $B_1(t) = A\hat{y}_{\text{rot}}$



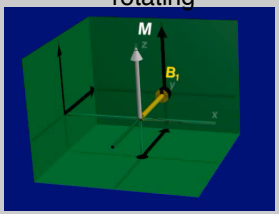
RF Excitation

- In the rotating frame: Precession about B_1

lab



rotating

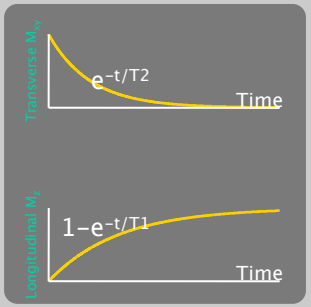


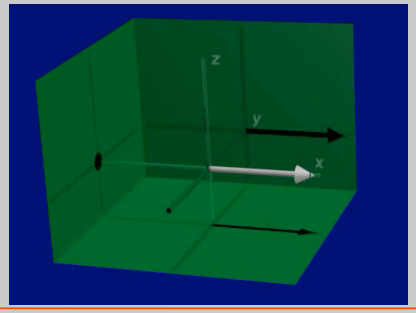
- Typical B_1's: 0.14 - 0.35G ± (10%/20%) accuracy @(1.5T/3T)
- Duration 1-3ms which is a long time at 64MHz!
- Peak power 20KW!

$$\omega_0 = \gamma B_1 = 4.257 \cdot 0.16 \quad = \quad 0.68 \text{ KHz}$$
$$0.367\text{ms } 90^\circ \quad \Rightarrow \quad 23000 \text{ rotations}$$

Relaxation

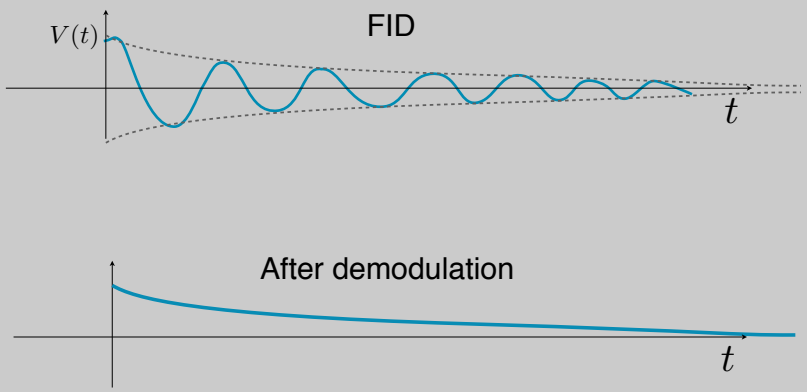
- T_1 : Longitudal relaxation ~ 10-2000ms
- T_2 : Transverse relaxation ~ 10-300ms
- Main source of contrast (Later!)
- $T_2 < T_1$ Always!





RF Reception

- Precession enduces EMF in coil: Faraday's law ⇒ Free induction decay

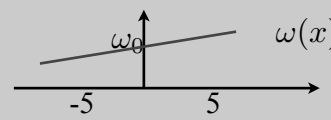


Gradient Fields

- B1 has poor localization λ@64MHz ~ 0.5m in tissue
- Instead encode position in **frequency**

$$\vec{G} = \left[\frac{\partial B_z}{\partial x}, \frac{\partial B_z}{\partial y}, \frac{\partial B_z}{\partial z}\right]$$

- Small concomitant fields Bx, By are also created. These do not contribute much to precession - fields are NOT oscillating at Larmor freq.



$$\omega(x) = \omega_0 + \gamma G_x x$$

Gradient Fields

- Typical #
  - G = 1-10 G/cm = 10-100 mT/m = 4.2-42 KHz/cm
  - Waveforms in audio frequency
  - Slew-Rate = 15-20 G/cm/ms
    - Safety concern is in dB/dt
    - Peripheral nerve stimulation can happen
  - Big Amplifiers: 1200 Volts, 200 Amps