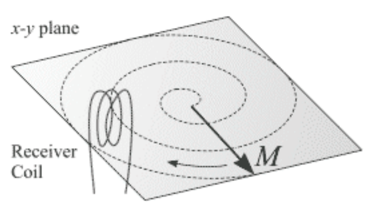
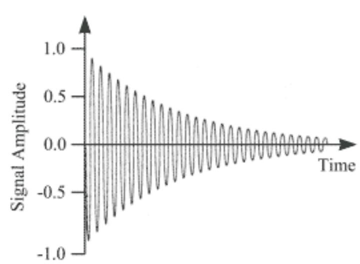
Bioengineering 208
Magnetic Resonance Imaging

Winter 2007
Lecture 6

- RF Coils
  - MR signal detection
  - Reciprocity
  - Coil Q and Noise
  - Classes of RF coils
  - Coil Geometry
  - Coil Coupling

MR Signal Detection

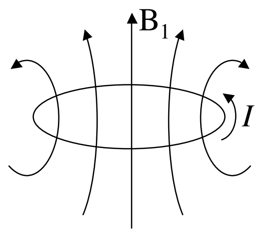




Faraday's Law of Induction: $\oint_C \mathbf{E} \cdot d\mathbf{l} = -\frac{d}{dt}\int_S \mathbf{B} \cdot d\mathbf{A}$

Reciprocity

The spatial distribution the sensitivity of an RF coil is proportional to the field generated by a unit current flowing in the coil



If unit current I produces a transverse RF field B_1, then transverse magnetization M_{xy} induces:

$$Voltage \propto \int B_1(r) \bullet M_{xy}(r)dV$$

Note: Only transverse components of B_1 and M count

For (a lot) more details, see: http://coecs.ou.edu/Tamer.S.Ibrahim/Reciprocity_In_MRI.htm

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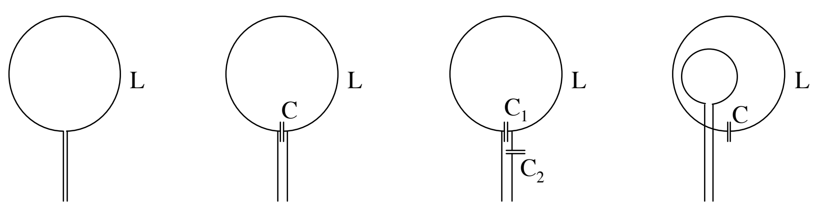
RF Coil Basics



$Z=R+j\omega L$
$\sim (1+100j)\Omega$

$$Z = \frac{j}{\frac{1}{\omega L} - \omega C} \approx \infty$$
on resonance

Z can be tuned to ω_L and matched to 50Ω using capacitive coupling …

… or inductive coupling

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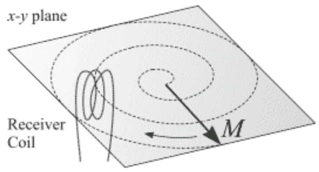
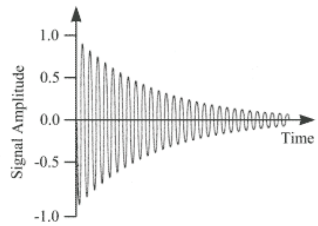
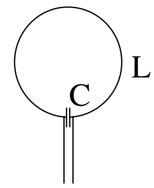
RF Coil Q

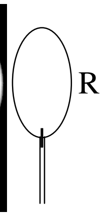






- Definition: Q = # oscillations before amplitude -> 1/e
  - or: 1/(fractional energy loss per oscillation)
- Q(spins) = $\omega_L T_2$ ~ 10 million
- Q(coil+sample) ~ 20-500
- Therefore: spins **cannot** be closely coupled to coil
- So, what limits coil Q?

Coil losses and Sample losses



$$\frac{1}{Q_{total}} = \frac{1}{Q_{coil}} + \frac{1}{Q_{sample}}$$

- Sample losses are <u>not</u> from spins, but from random thermal motion of ions in sample
- Goal: minimize noise by minimizing losses
- Not much control over Q_{sample}
- Try to get $Q_{coil} >> Q_{sample}$
- Maximize: $\frac{B_1(ROI)}{\int |B_1| dV}$ (roughly)

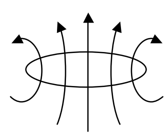
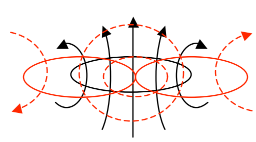
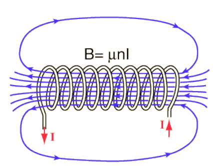
Classes of RF coils

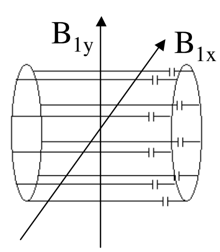
- * Transmit Only: Used only to apply RF pulses - typically large with uniform B_1
- * Receive Only: Used only to receive RF signal - optimized for high sensitivity
- Transmit / Receive: Apply RF pulses and receive signal through same coil
- * Multicoil Arrays: Typically Receive Only, used to increase sensitivity over large ROI, or to implement parallel imaging

* These need active and/or passive T/R switching

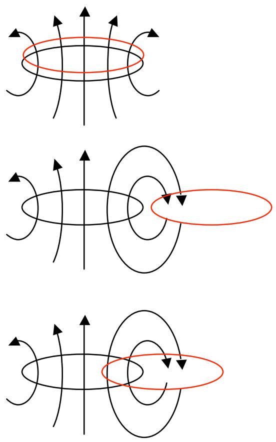
RF Coil Geometries

Where is B_z?

- Surface Coil: 
- Quadrature Surface Coil: 
- Solenoid: 

- Birdcage Coil: 

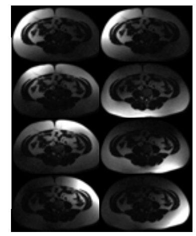
RF Coil Coupling



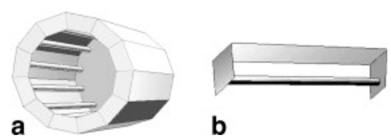
M~1

M<0

M=0



Coupling:
- Correlates Signal
- Correlates Noise
- In the limit, coupled coils are one coil



TEM coil, Vaughan et al