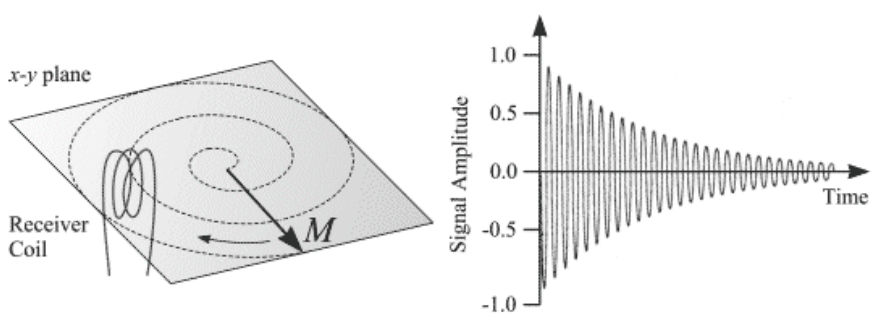
Bioengineering 278
Magnetic Resonance Imaging

Winter 2011
Lecture 7

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

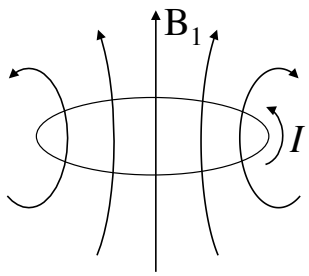
MR Signal Detection



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



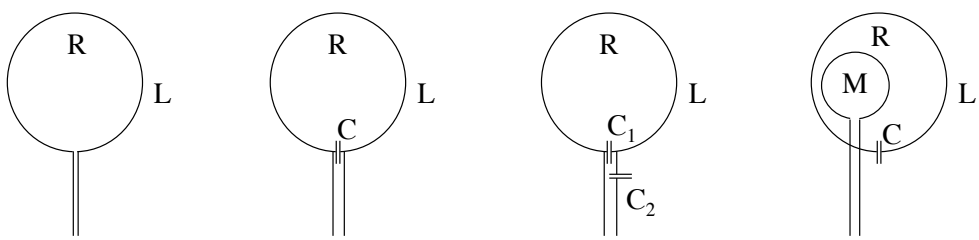
If unit current I produces a transverse RF field B_1, then transverse magnetization M_{xy} induces:

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

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

RF Coil Basics



Z=R+jωL
~ (1+100j)Ω

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

on resonance

$$Z = \frac{A\left(R - j(A\omega C_1 - \omega L)\right)}{R^2 + \left(A\omega C_1 - \omega L\right)^2} - \frac{j}{\omega C_2}$$

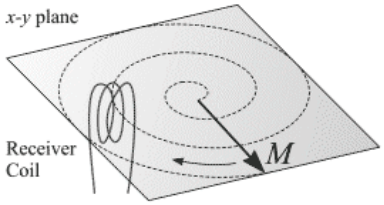
$$A = R^2 + \omega^2 L^2$$

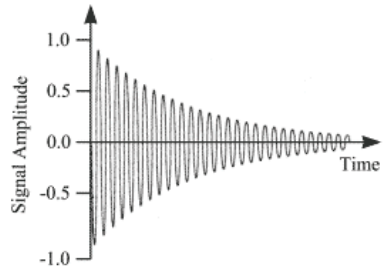
… or inductive coupling

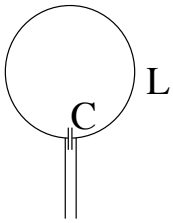
<u>Goals:</u>

- Coil resonant at Larmor frequency
- Z = 50Ω:
  - Match cables
  - Match preamp

RF Coil Q

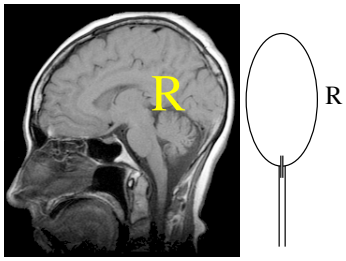






- Definition: Q = # oscillations before amplitude -> 1/e
  - or: 1/(fractional energy loss per oscillation)
  - or: ratio of resonance frequency to width of resonance peak
- Q(spins) = $\omega_L T_2$ ~ 10 million
- Q(coil+sample) ~ 20-500
- Therefore: spins **cannot** be closely coupled to coil
- So,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

Coil losses and Sample losses



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

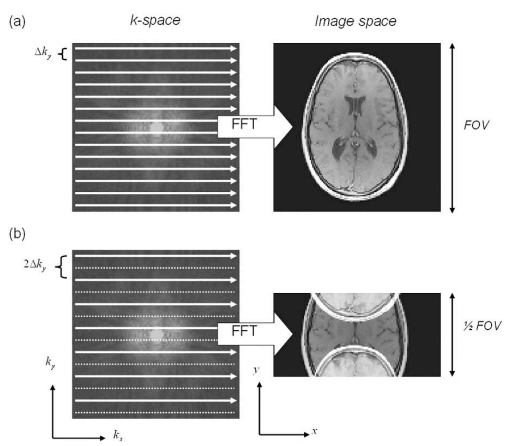
- Sample losses are <u>not</u> from spins, but from random thermal motion of ions in sample
- Goal: minimize noise by minimizing losses
- Not much control over Q_{sample}
- Try to get $Q_{coil} >> Q_{sample}$
- Maximize: $\frac{B_1(ROI)}{\int_{\infty} |B_1| dV}$ (roughly)

Classes of RF coils

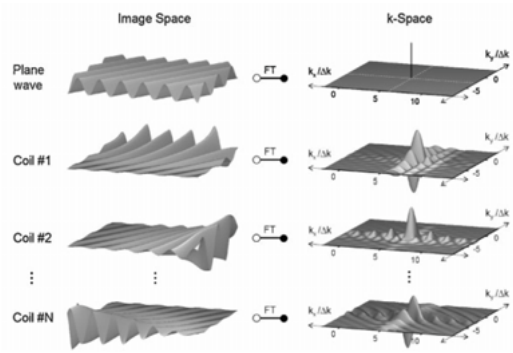
- Transmit / Receive: Apply RF pulses and receive signal through same coil
- * Transmit Only: Used only to apply RF pulses - typically large with uniform B_1
- * Receive Only: Used only to receive RF signal - optimized for high sensitivity
- * Multicoil Arrays: Typically Receive Only, used to increase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

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

Parallel Imaging

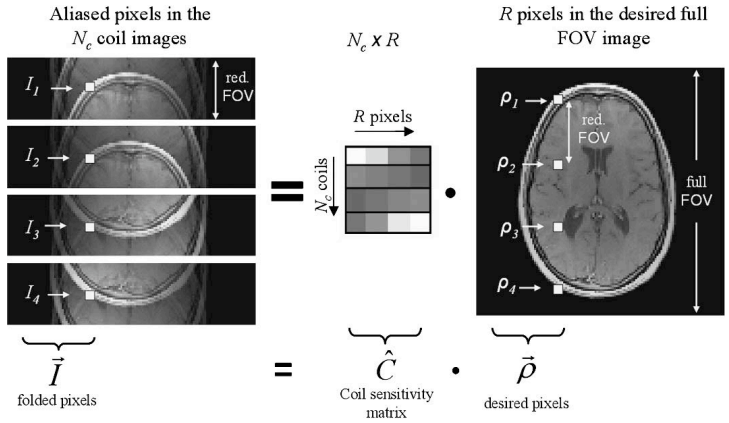


Blaimer et al, Top Magn Reson Imaging 2004;15:223–236



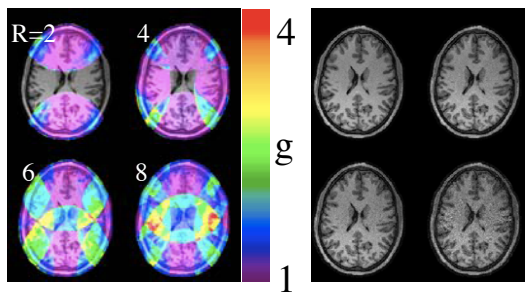
$$S_j(t) = \int C_j(r) M_{xy}(r) e^{iK(t)\bullet r} dr$$

Parallel Imaging - SENSE



$$\vec{\rho} = (\hat{C}^H \hat{C})^{-1} \hat{C}^H \bullet \vec{I}$$

$$SNR \propto \frac{1}{g\sqrt{R}}$$



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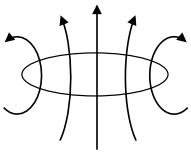
Blaimer et al, Top Magn Reson Imaging 2004;15:223–236

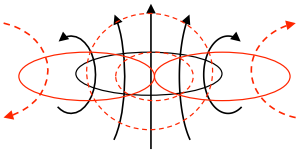
RF Coil Geometries

Where is B_z?

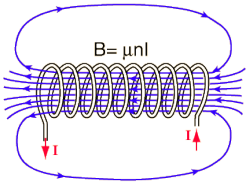
- Surface Coil:



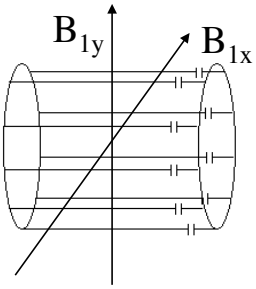
- Quadrature Surface Coil:



- Solenoid:



- Birdcage Coil:



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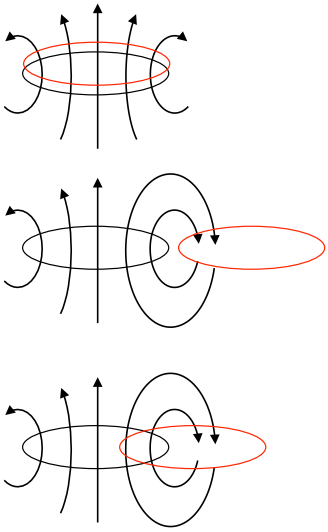
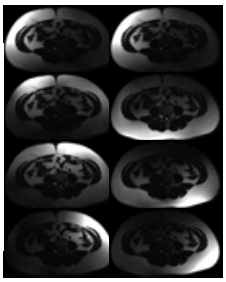
RF Coil Coupling



M~1

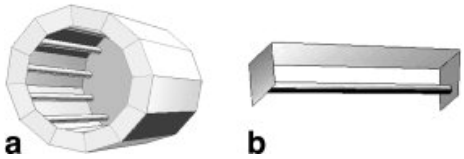
M<0

M=0



<u>Coupling:</u>

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



TEM coil, Vaughan et al