MR Signal Detection

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

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

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

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

$$Z = \frac{j}{\omega C} = \infty \quad \text{on resonance}$$

$$Z = \frac{A(R - j(A\omega C_1 - \omega L))}{R^2 + (A\omega C_1 - \omega L)^2} - \frac{j}{\omega C_2} \quad \text{… or inductive coupling}$$

Goals:
• Coil resonant at Larmor frequency
• $Z = 50\Omega$:
  • Match cables
  • Match preamp
RF Coil Q

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

Coil losses and Sample losses

- Sample losses are **not** from spins, but from random thermal motion of ions in sample
- Goal: minimize noise by minimizing losses
- Not much control over \( Q_{\text{sample}} \)
- Try to get \( Q_{\text{coil}} \gg Q_{\text{sample}} \)
- Maximize: \( \frac{1}{Q_{\text{total}}} = \frac{1}{Q_{\text{coil}}} + \frac{1}{Q_{\text{sample}}} \)

\[ \int_{\text{ROI}} B_1 |dV| \]

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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

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

Parallel Imaging - SENSE

\[ \tilde{\rho} = (\hat{C}^H \hat{C})^{-1} \hat{C}^H \cdot \tilde{I} \]

\[ SNR \propto \frac{1}{g\sqrt{R}} \]

RF Coil Geometries

- Surface Coil:

- Quadrature Surface Coil:

- Solenoid:

- Birdcage Coil:

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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