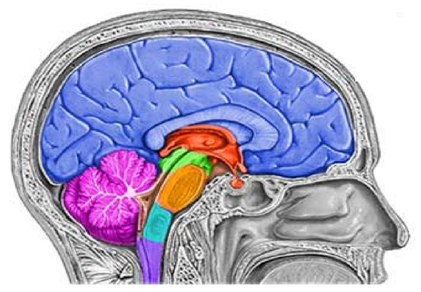
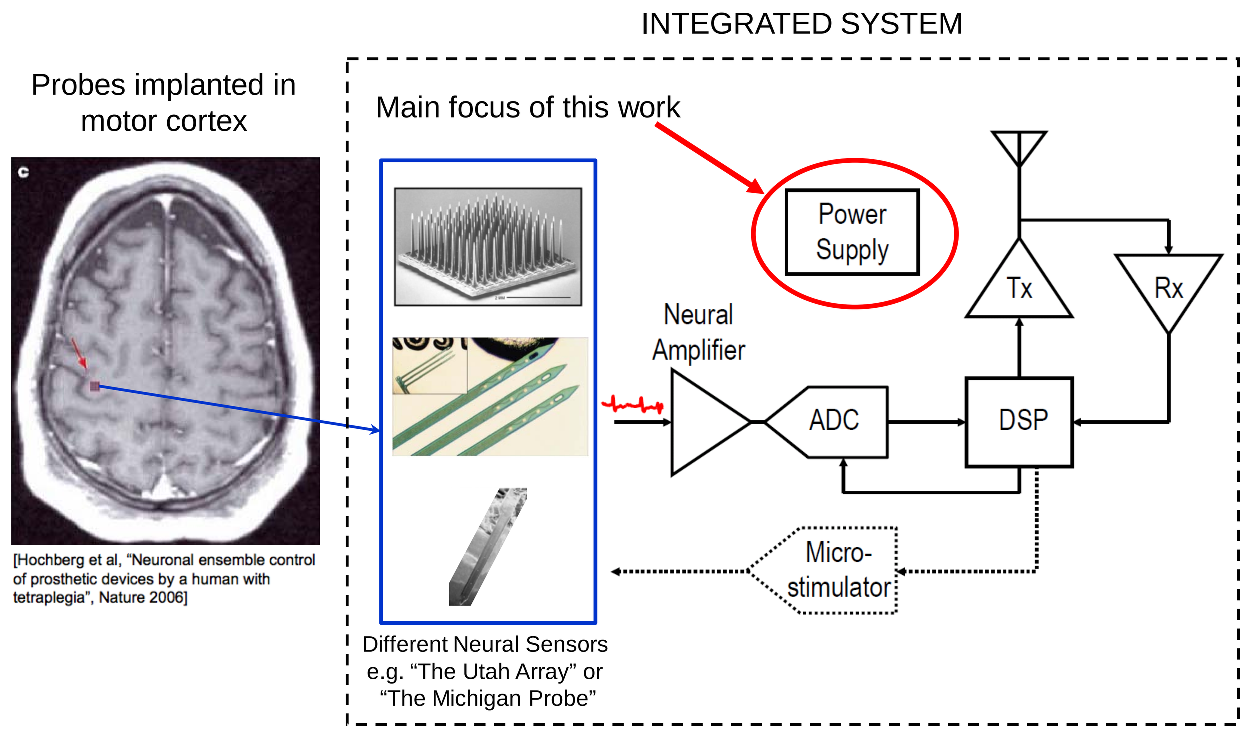


Powering Wireless Brain-Machine Interfaces

Michael Mark, Andrey Somov, Professor Jan Rabaey

Berkeley Wireless Research Center

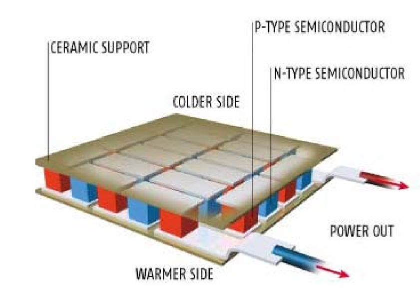
A Wireless Neural Implant



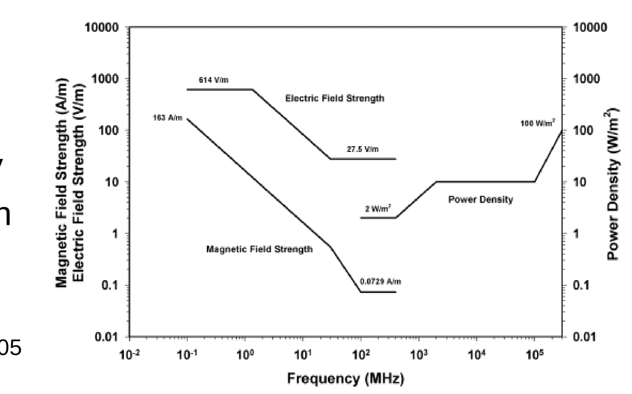
Options for Powering Implants

- Batteries
  - problems: size and replacement

- Energy scavenging inside the body
  - e.g. utilizing body heat (thermoelectric) 0.6 µW / mm² @ ΔT=5° [Paradiso05]

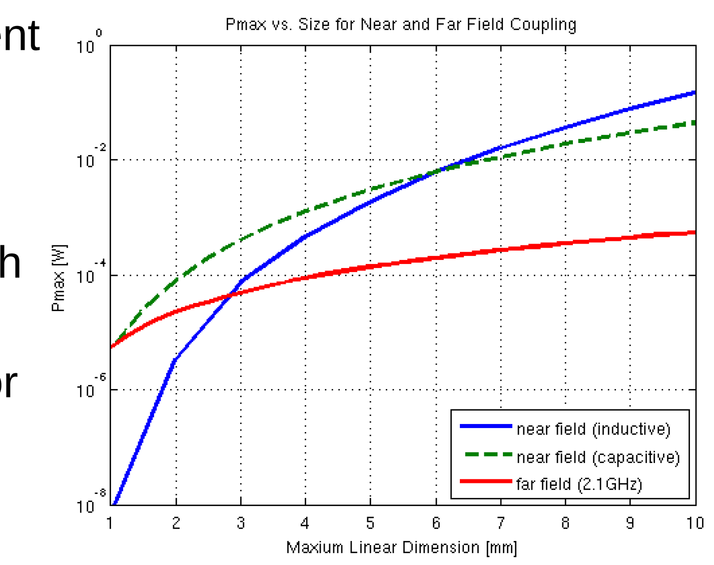


- Powering via RF
  - energy source sits outside the body
  - possible health risks of EM radiation

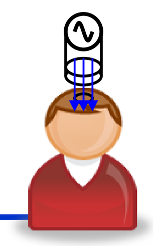


Powering via RF

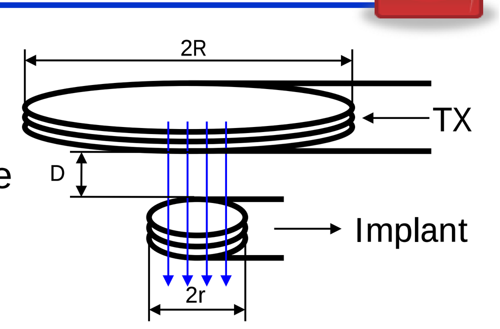
- Different coupling mechanisms show different dependencies on size
- Capacitive coupling problematic due to large "leakage" currents through body
- Inductive coupling best for antennas > 3 mm
- Radiative energy transfer best suitable for further miniaturization



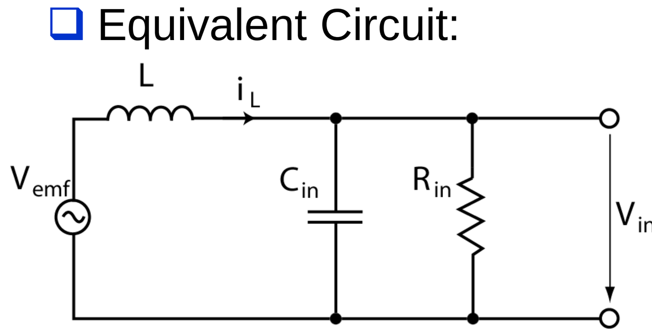
Inductive Coupling



- Principle:
  - External source creates magnetic field
  - Magnetic field induces voltage at receive
  - side which is used to power implant



- Equivalent Circuit:

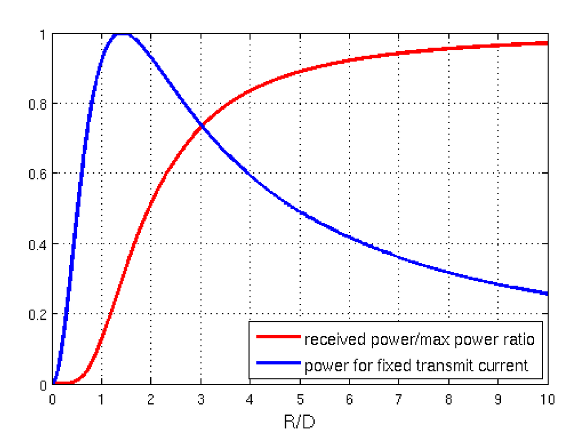


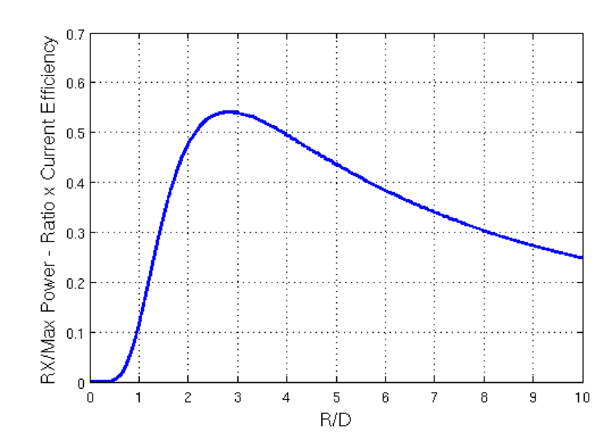
$$\hat{V}_{emf} = -N_{RX} \times A_{RX} \times \mu \times \frac{dH_{tx}}{dt} = -N_{RX} \times A_{RX} \times \mu \times \omega \times \frac{N_{TX} \times I_{TX} \times R^2}{2\left(\sqrt{R^2+D^2}\right)^3}$$

- Utilizing resonance $V_{in} = Q_{equ} \times V_{emf}$ → $P_{Rin} = \frac{V_{emf}^2 \times Q_{equ}^2}{2 \times R_{in}}$

System Trade-Offs: Transmitter

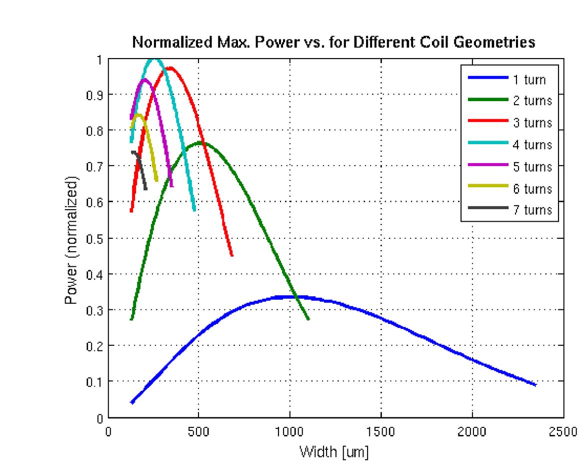
- Limitations:
  - Maximum magnetic field at transmitter (IEEE C95.1)
- System Implications:
  - Large transmit coil increases field at receiver, but lowers overall power transfer efficiency

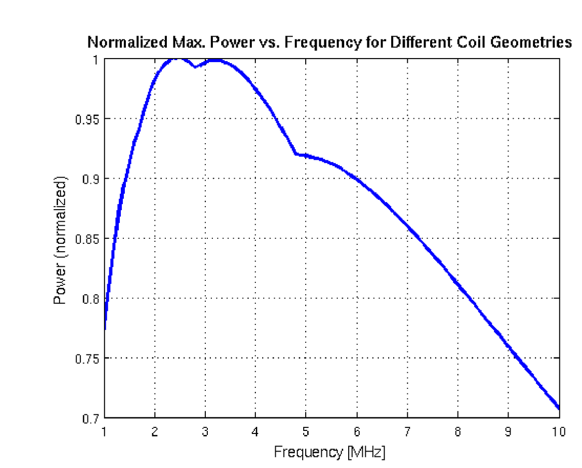




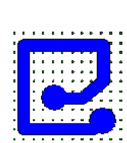
System Trade-Offs: Receiver

- Maximizing V_{emf} x Q_{equ} product of receive coil / circuit
  - Maximizing V_{emf} → maximizing N_{RX} and A_{RX} (= maximizing L)
  - Fixed R_{in} of receiver reduces Q_{equ} if L is too large
  - Same happens when frequency is too high

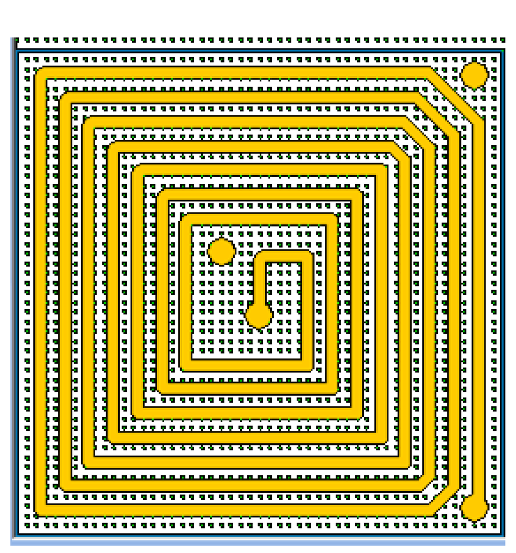




Experiments: Verifying Theory

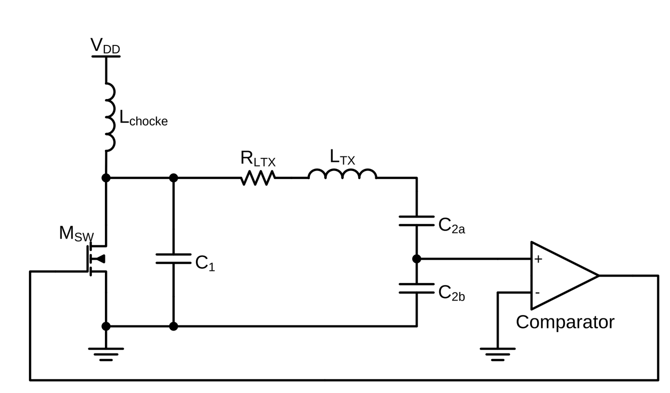


- Building a variety of transmit and receive coils to verify analytical inductor model using standard 4-layer PCB technology
- Measuring coupling between different coils to verify coupling model
- Optimizing final coil geometries and deriving specification for RF-DC conversion

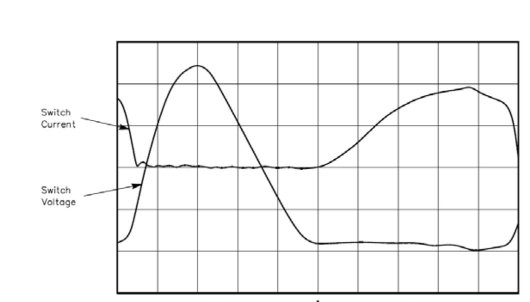


Implementation: Transmitter

- Discrete class-E power oscillator
- High efficiency due to class E operation
- Feedback eliminates loss due to mismatch between switching and tank resonant frequency



[Ziaie et al 2001]



Transistor voltage and current waveforms of low-order class-E amplifier [Sokal 2001]

Implementation: Receiver

- A possible architecture [Peters07]
  - requires $V_{in} > V_{th}$
  - no voltage drop across rectifier