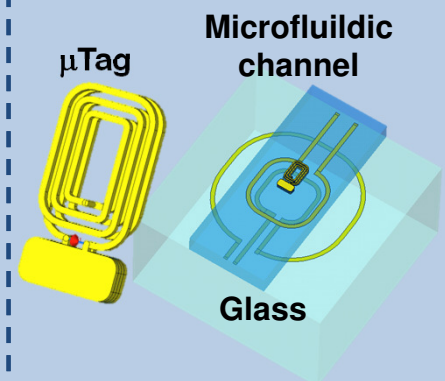
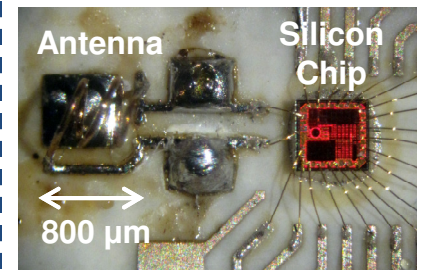
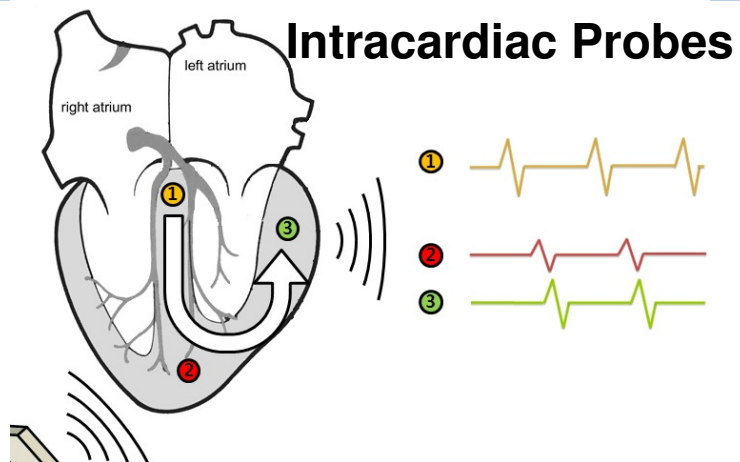
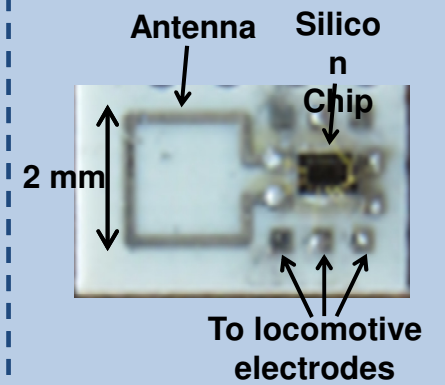
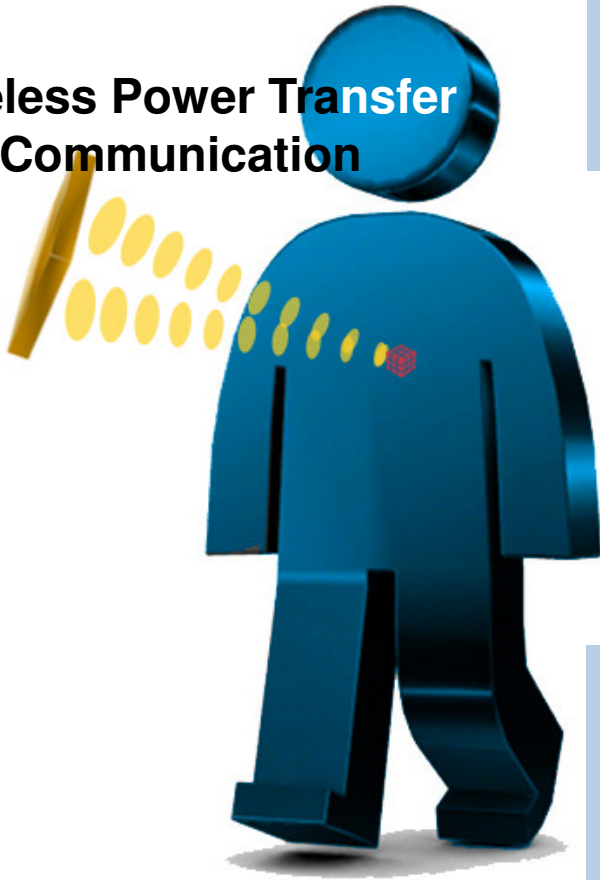


Midfield Powering for Implantable Systems

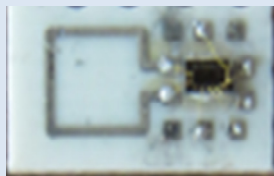


Wireless Power Transfer and Communication

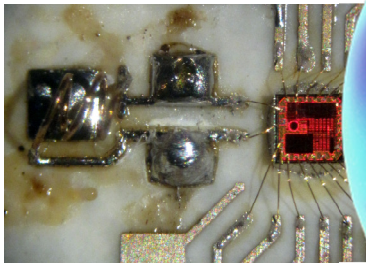
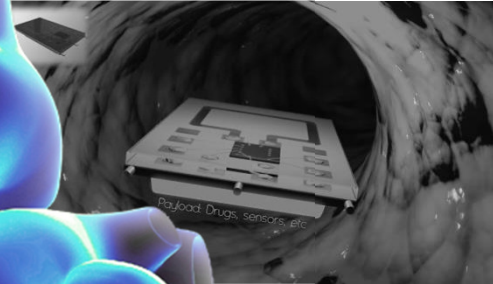


Introduction

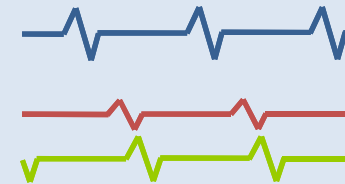
Locomotive Implant



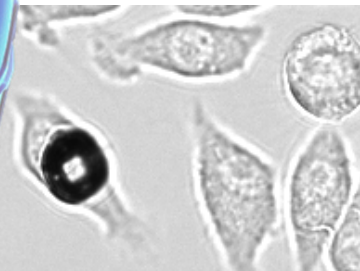
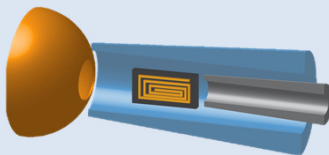
1 mm



Intracardiac Probes



Intracellular Tags



Midfield Power Transfer

Can we do better than inductive coupling?

$$\nabla \times \mathbf{H} = -i\omega\epsilon_0\epsilon_r\mathbf{E} + \sigma\mathbf{E}$$

$$\nabla \times \mathbf{E} = i\omega\mu_0\mathbf{H}$$

Existing analyses on power transmission through tissue disregard the displacement current term in Maxwell's equations.
As a result, all existing systems operate at less than 50 MHz.

Replacing the displacement current term, we find that the optimal frequency is in the low GHz range.



Midfield Power Transfer

$$\omega_{opt} = \sqrt{\frac{c\sqrt{\epsilon_{r0}}}{d\tau(\epsilon_{r0} - \epsilon_{\infty})}} \cdot \sqrt{1 - \frac{4a_{\perp}^2 + \left(\sigma d\sqrt{\frac{\mu_0}{\epsilon_0\epsilon_{r0}}} - 1\right)a_{\parallel}^2}{\left[\frac{d\epsilon_{r0}^{3/2}}{c\tau(\epsilon_{r0} - \epsilon_{\infty})} + 1\right]a_{\parallel}^2}}$$

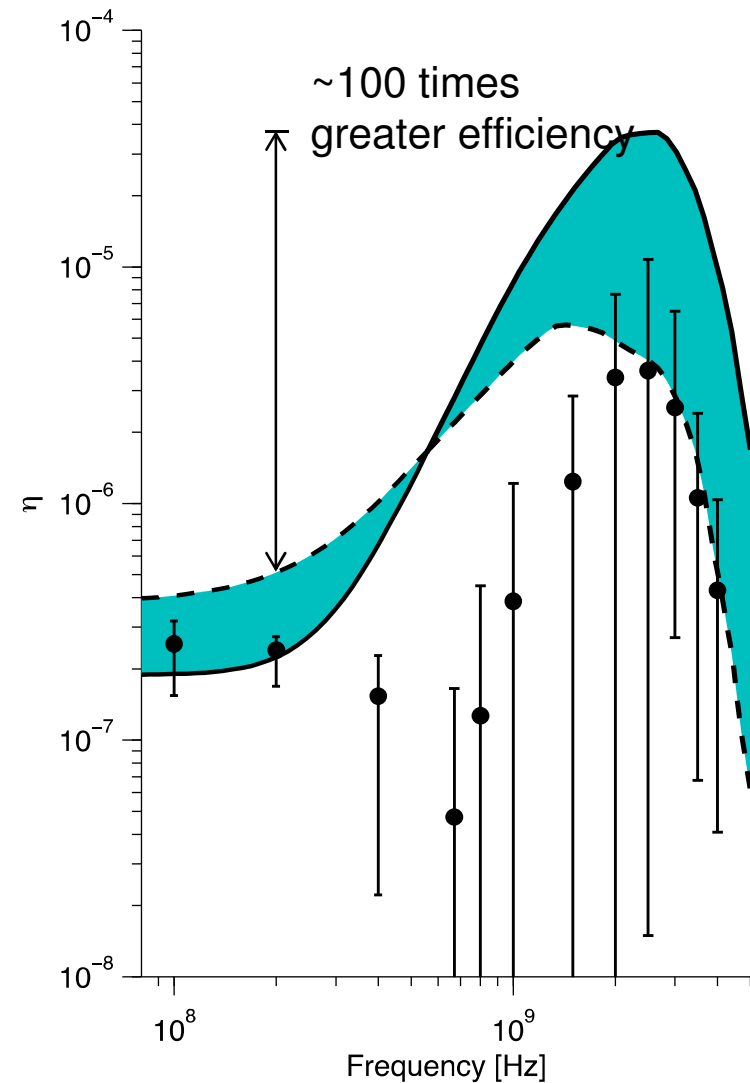
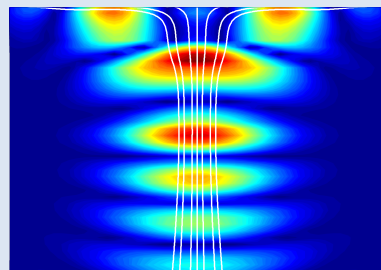
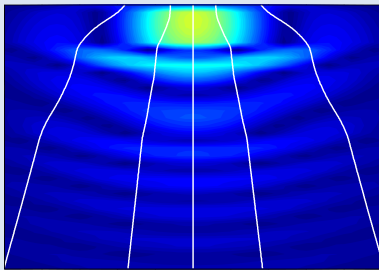
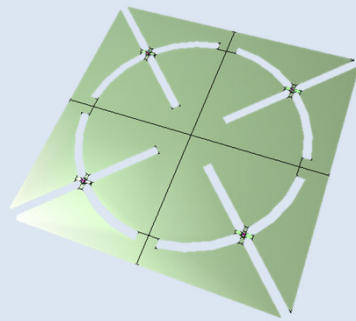
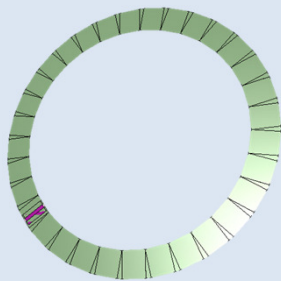
Tissue Type	Freq (GHz)
Blood	3.54
Bone (cancellous)	3.80
Bone (cortical)	4.50
Brain (grey)	3.85
Brain (white)	4.23
Fat (infiltrated)	6.00
Fat (not infiltrated)	8.64
Heart	3.75

Tissue Type	Freq (GHz)
Kidney	3.81
Lens cortex	3.93
Liver	3.80
Lung	4.90
Muscle	3.93
Skin	4.44
Spleen	3.79
Tendon	3.71



Midfield Power Transfer

A class of focused field sources provides sufficient power to drive mm sized implants.

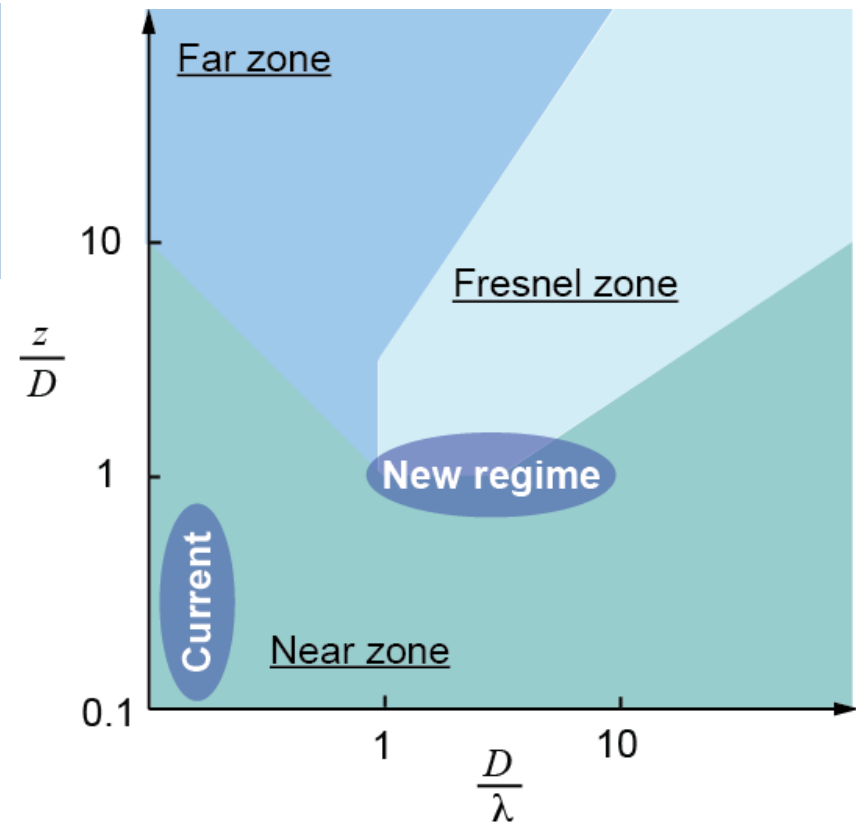
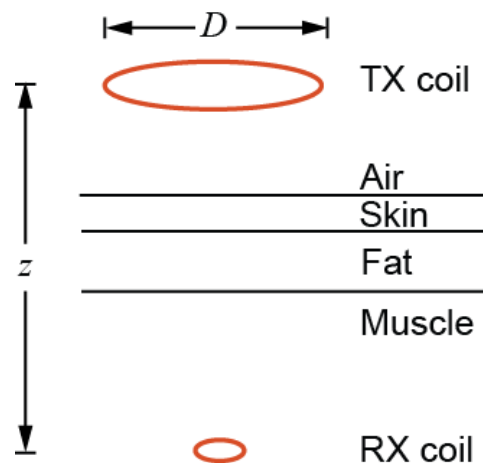


Wireless Power Transfer

Mid-field Power Transfer

$\lambda_{\text{muscle}} @ 1 \text{ GHz} = 4 \text{ cm}$

All dimensions of interest is comparable to a wavelength.



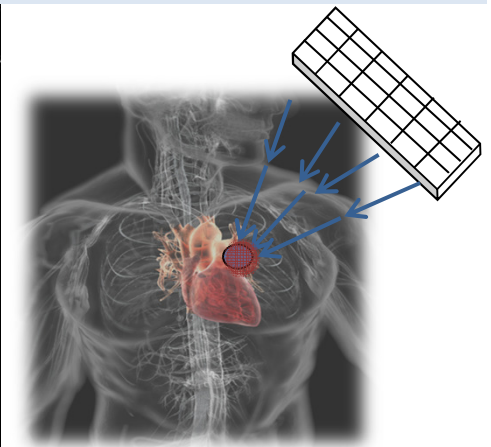
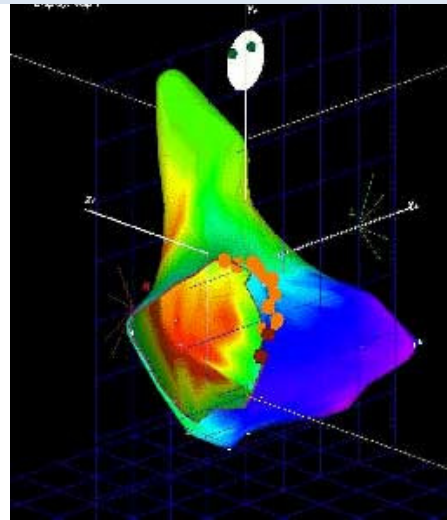
Both evanescent and propagating fields contribute. Sources can be designed to focus the power flow as well as to desensitize the link efficiency to implant orientation and position.

Wirelessly Powered Transceiver

Wireless Powering and Data Transfer



Wireless powering: removes the need for bulky batteries and would help the with battery replacement surgeries.

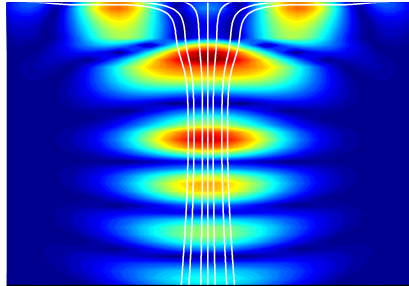


Wireless data: allows repeated, remote data interrogation of fully ambulatory animal models.



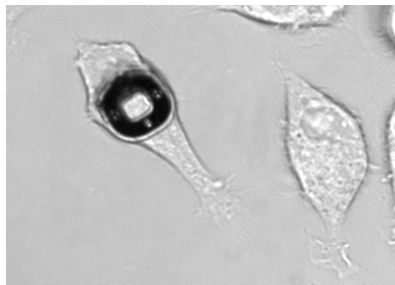
Wireless Biomedicine

Summary



Deep understanding of wireless powering principles can advance medical technology.

Integrated Circuits are the key to enabling miniature implantable technology.



The convergence of wireless technology, nanofabrication, and cellular delivery techniques enables a wide range of biomedical devices.

