DRAPER

A Transistor-less, Wireless Neural Stimulator

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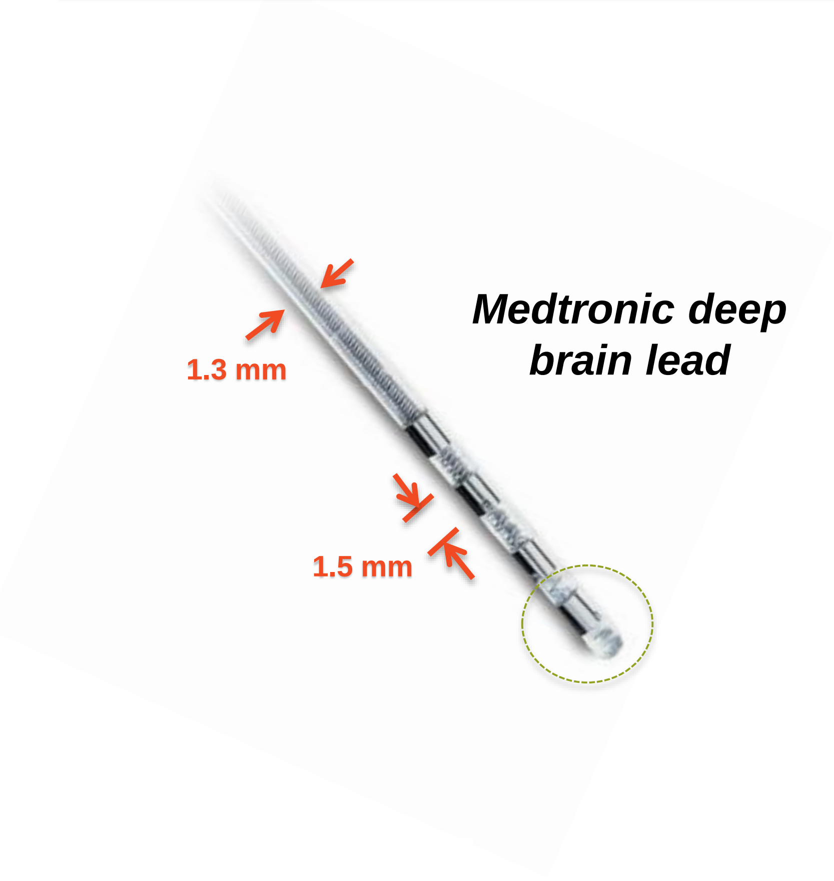
Problem Statement

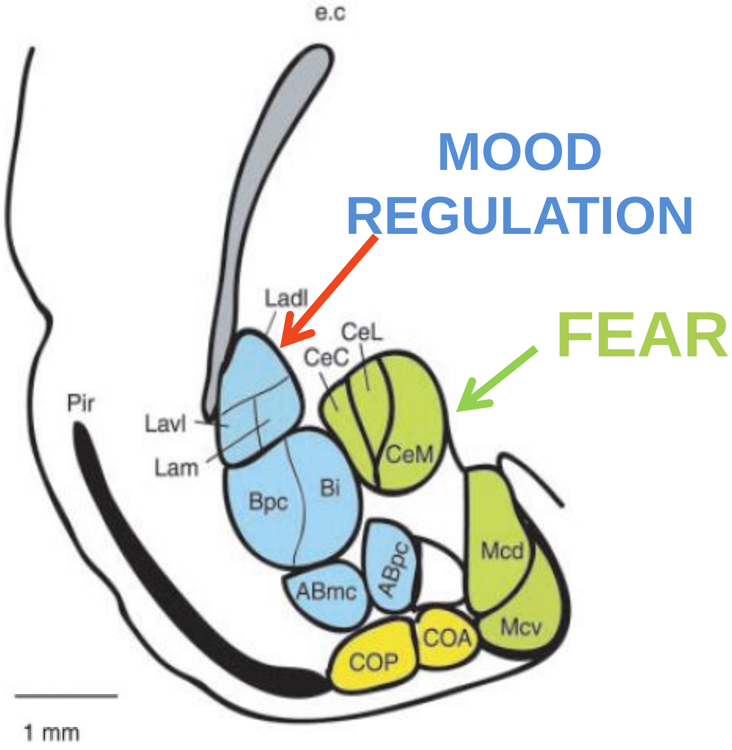
Problem: Tethered implants exhibit scar tissue growth, reducing control over the spatial pattern of neural excitation



Medtronic deep brain lead

Amygdaloid Complex

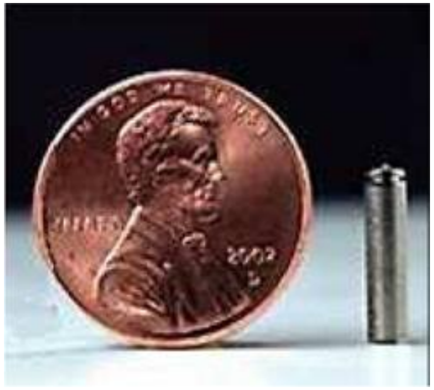
Basolateral Group (blue): Project to prefrontal cortex
Centromedial Group (green): Project to hypothalamus and brainstem



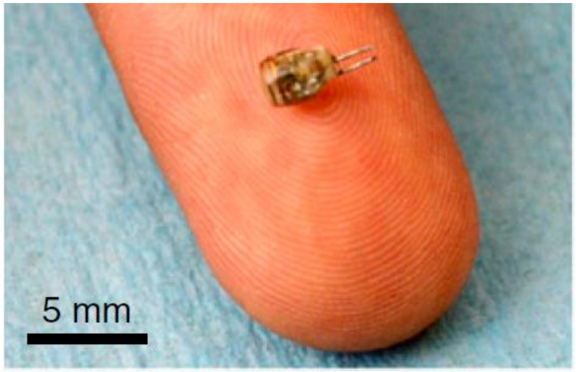
Wireless Neural Stimulators

- **Solution**: Untethered stimulators show less scar tissue growth
- **Problem**: Wireless energy transfer is difficult for sub-millimeter implants

RF BION



Mid-Field Powering



Microwave Powered

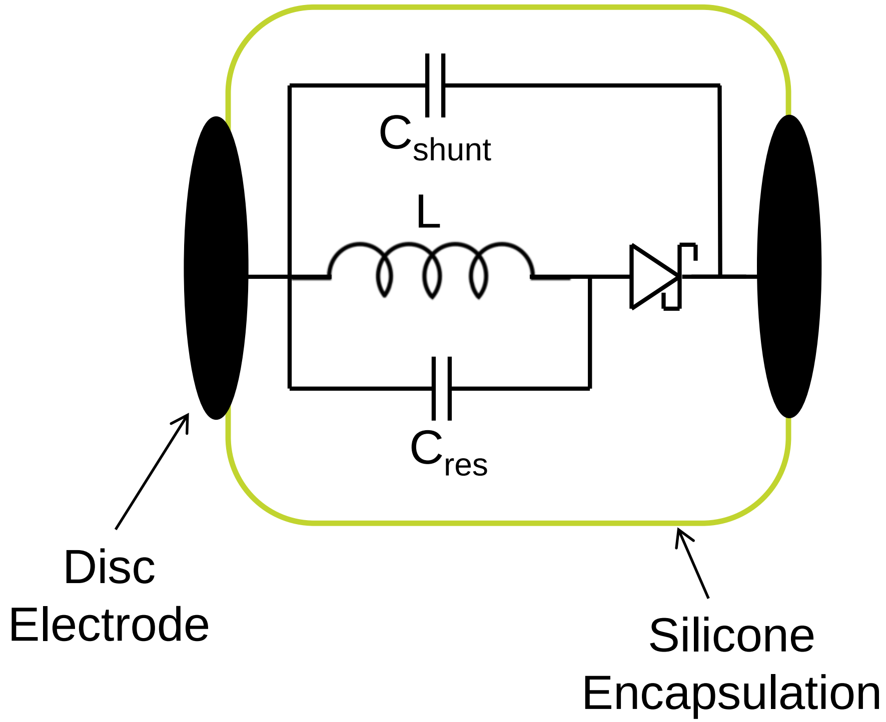
FLAMES Stimulator

(Ho et al., 2014; Loeb et al., 2001; Towe et al., 2012; Freedman et al., 2014)

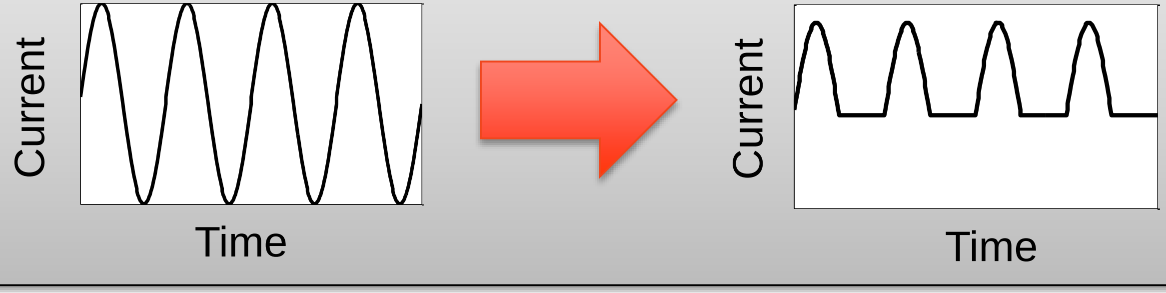
A Transistor-less Neural Stimulator

Size of implant is determined by receive antenna for power

Size can be *reduced* by removing the voltage requirements associated with transistors

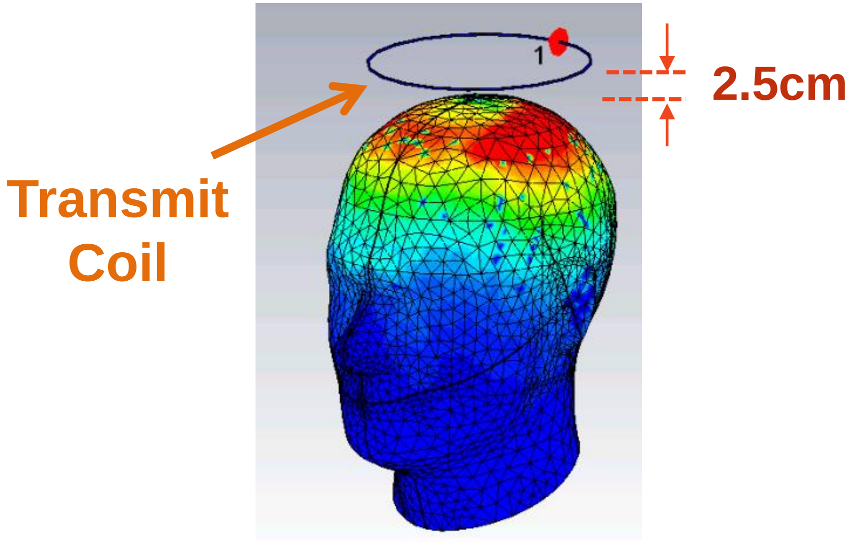


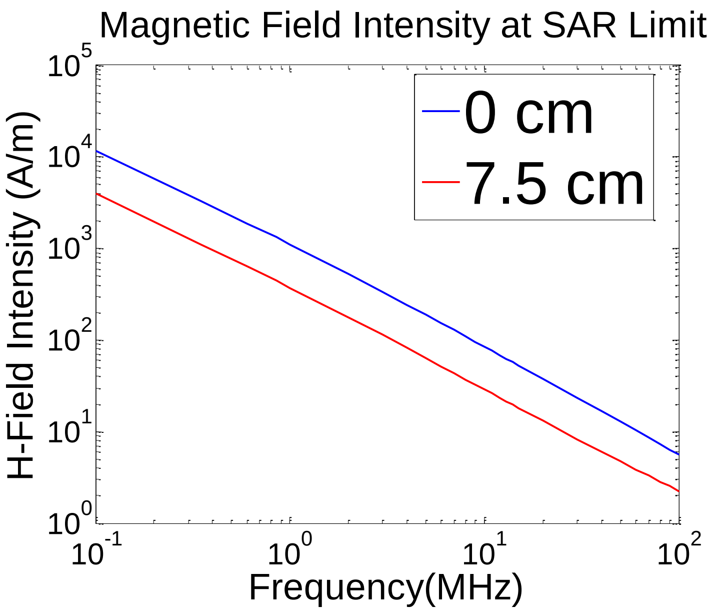
Rectification with Diode Produces DC

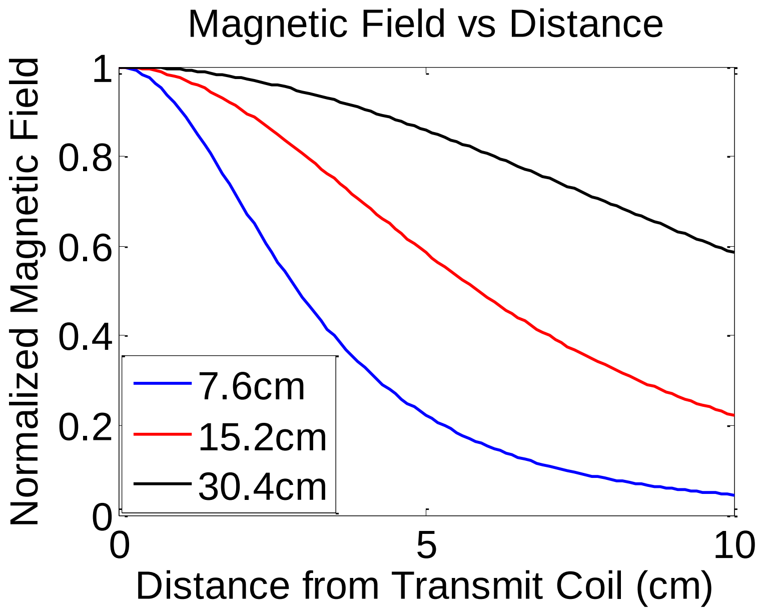


Estimating the Magnetic Field Intensity in the Body

- Maximum allowed magnetic field set by FCC
- SAR Limit estimates the amount of heating in the body



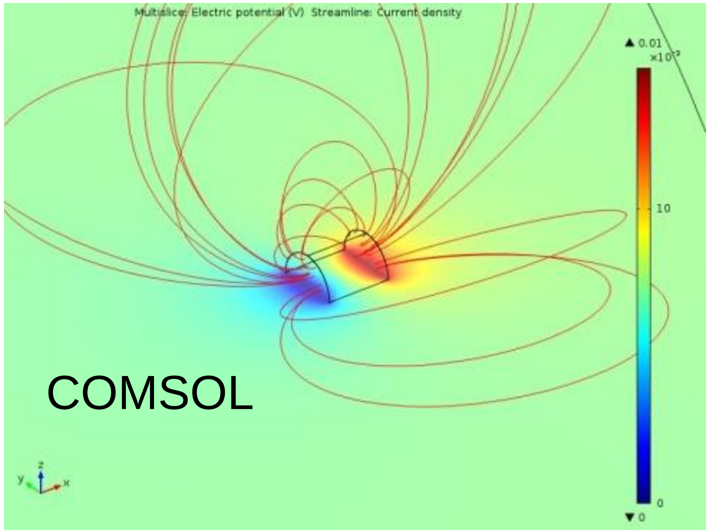




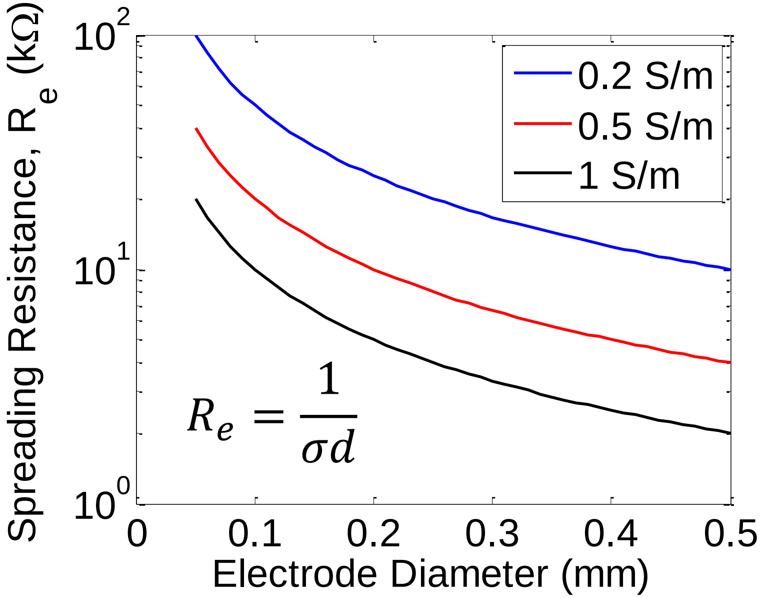
Estimating the Load Impedance

- Total load for electrodes of 300 - 500µm and a conductivity of 0.5 S/m = **10kΩ**
- To reach a threshold current of 25µA, we need 250mV across the load

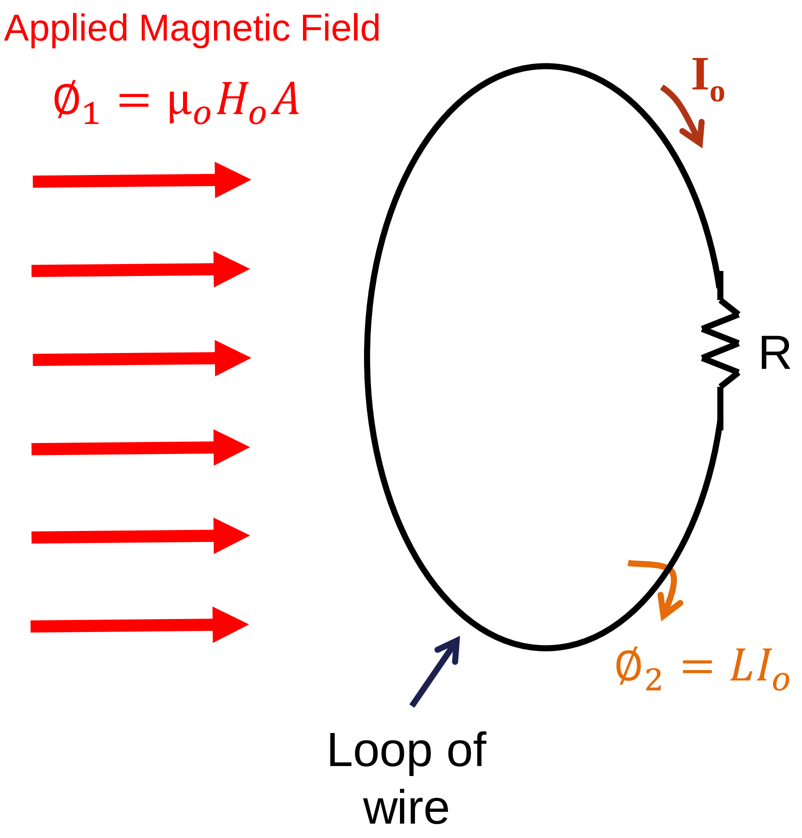
Computational Estimates



Analytical Estimates



Estimate Current and Power Delivered to Load



Faraday's Law

$$\oint E \cdot dl = -\int \frac{\partial B}{\partial t} \cdot dA$$

Flux Rule

$$\varepsilon = -\frac{d\emptyset_{total}}{dt}$$

$$\varepsilon = -\frac{d(\emptyset_1)}{dt} + \frac{d(\emptyset_2)}{dt} = -I_o R$$

Laplace Domain

Power

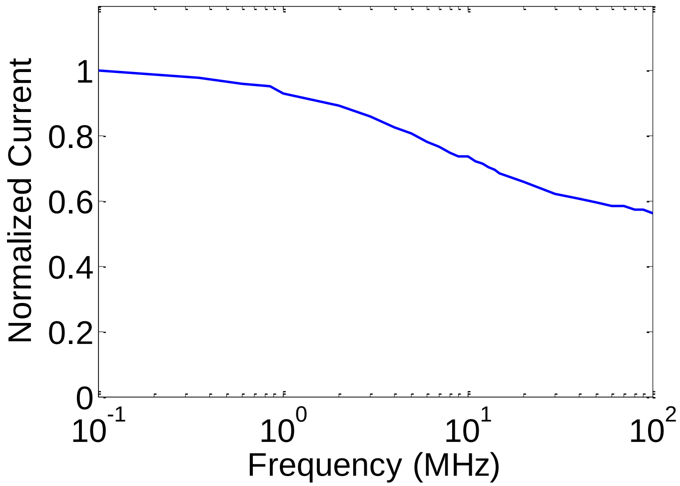
$$P(s) = \varepsilon(s) I_o(s) = \frac{(s\mu_o H_o A)^2 R}{(sL + R)^2}$$

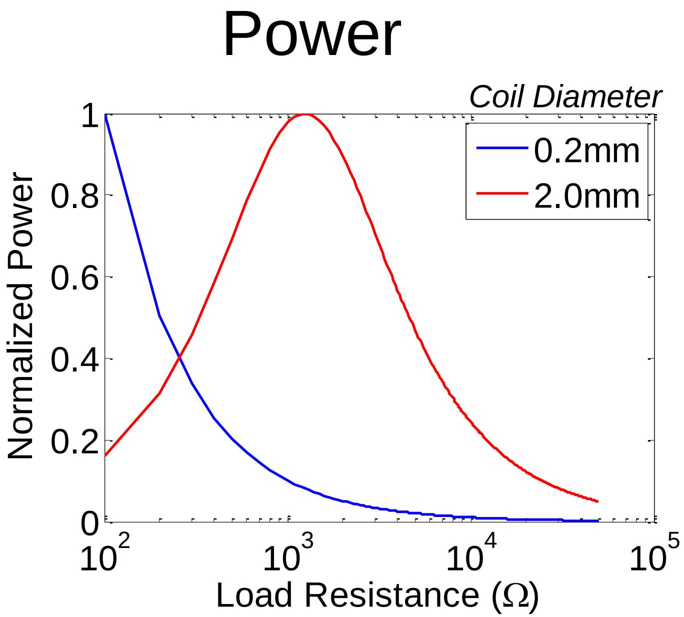
Current

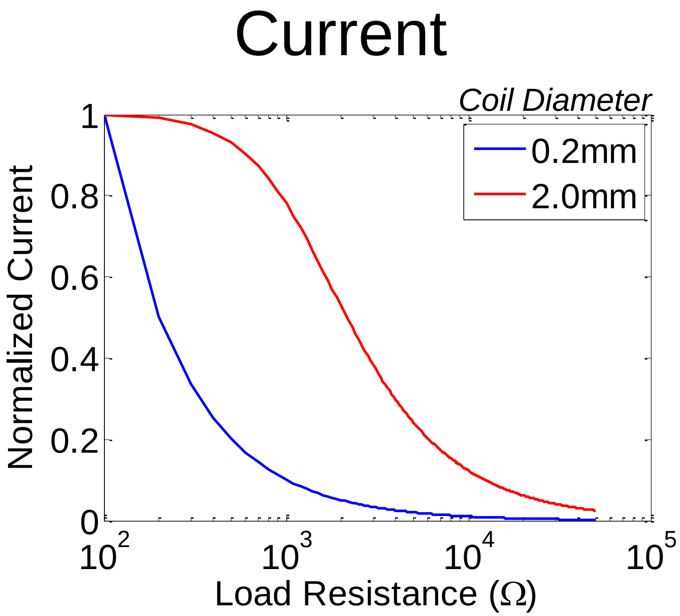
$$I_o(s) = \frac{s\mu_o H_o A}{sL + R}$$

Estimate Optimal Load and Optimal Frequency

- **Optimal Load**: Make load as small as possible to maximize current
- **Optimal Frequency**: Slight improvement at lower frequencies

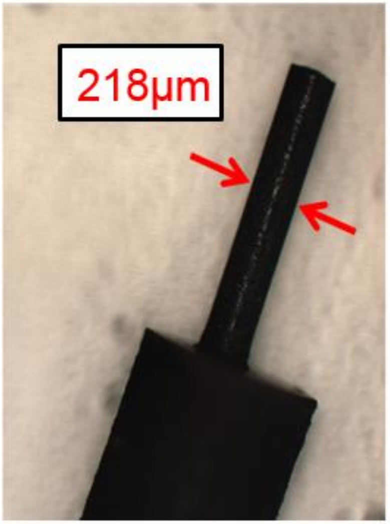


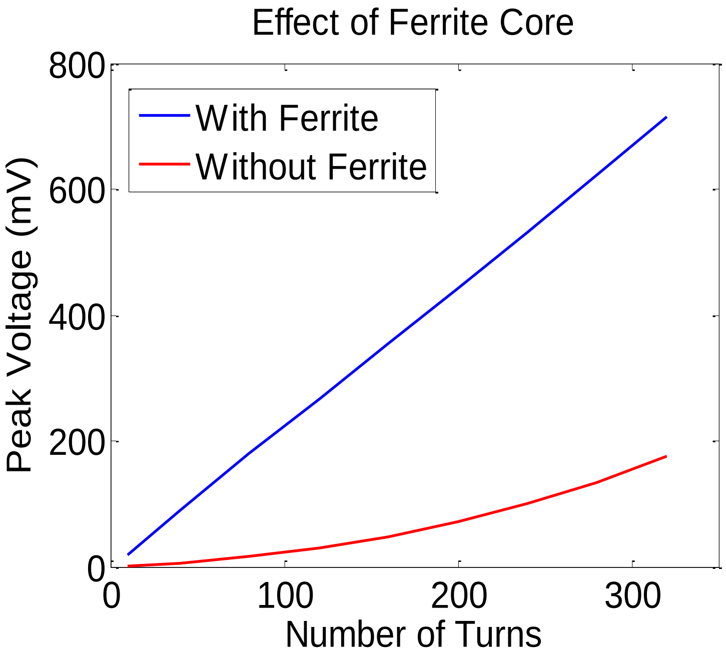

Power

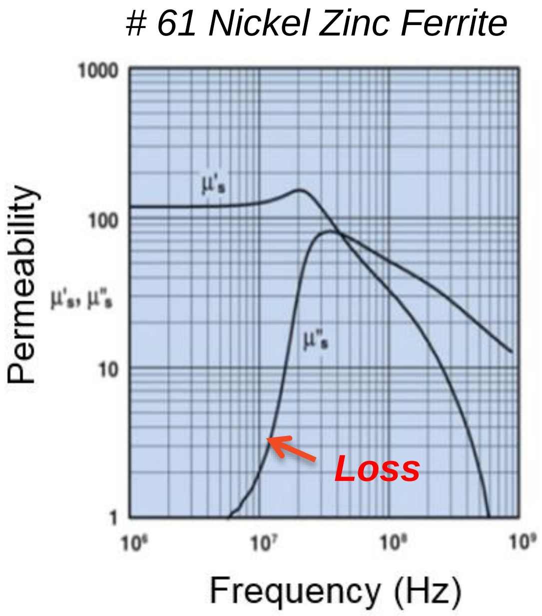

Current

Effect of the Ferrite Core

- FEM Model suggests a ferrite core is critical to achieve desired current
- **Problem**: Manufacturers do not make ferrite cores of < 0.5mm diameter
- **Solution**: We shaved down the cores to 0.2mm with a diamond-tipped grinder

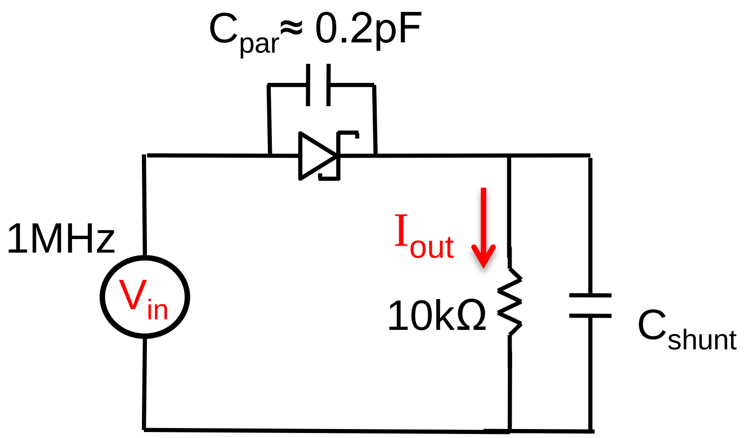


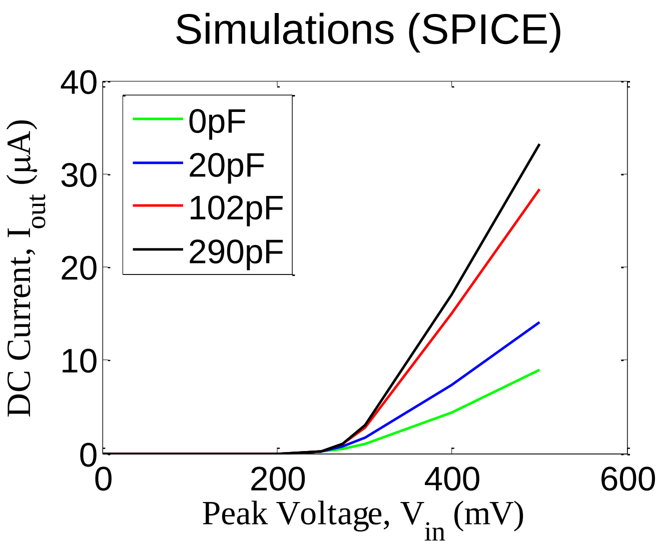


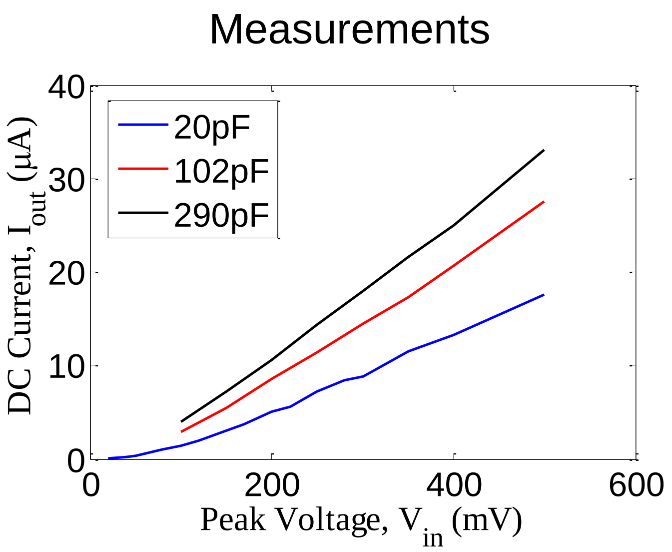


Rectification with the Diode

- Rectification achieved with an RF Schottky diode
- A shunt capacitor is used to facilitate rectification by compensating for parasitic capacitance (C_{par})







Process Flow for Assembly

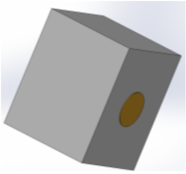
Components

(x1)

Ferrite rod
(200 um x 1mm)

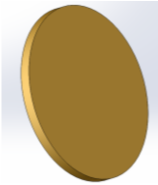
(x2)

Capacitor (250 um x 200 um x 250 um)



(x1)

Skyworks diode (250 um x 200 um x 250 um)

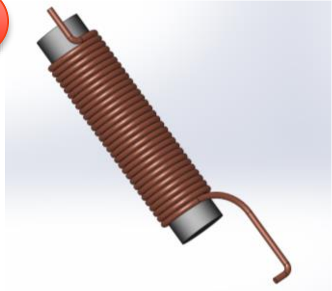


(x2)

Roughened Pt electrode
(300 um x 18 um)

Assembly

1

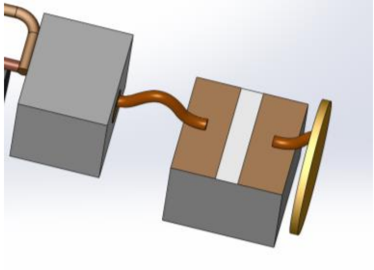


Wind the Coil

2

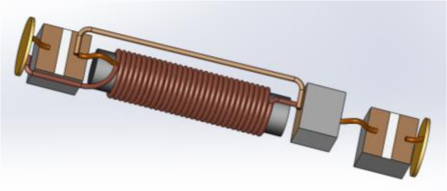
Connect resonant cap to electrode

3



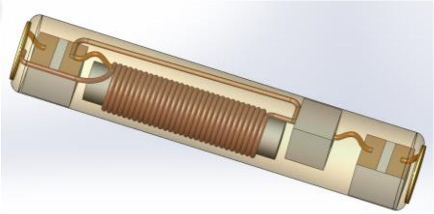
Connect diode, shunt cap, and Pt electrode

4



Connect coil to two assembled pieces

5

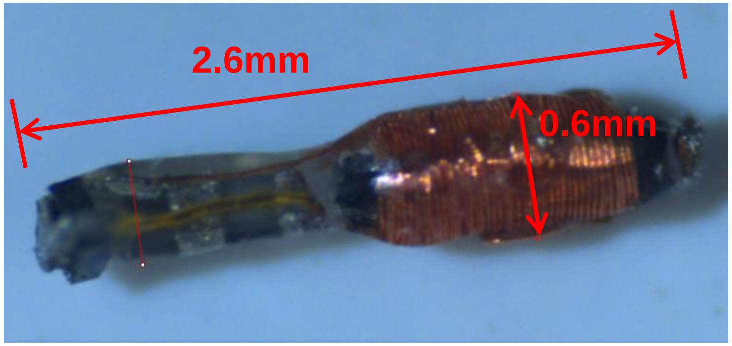


Encapsulate in silicone

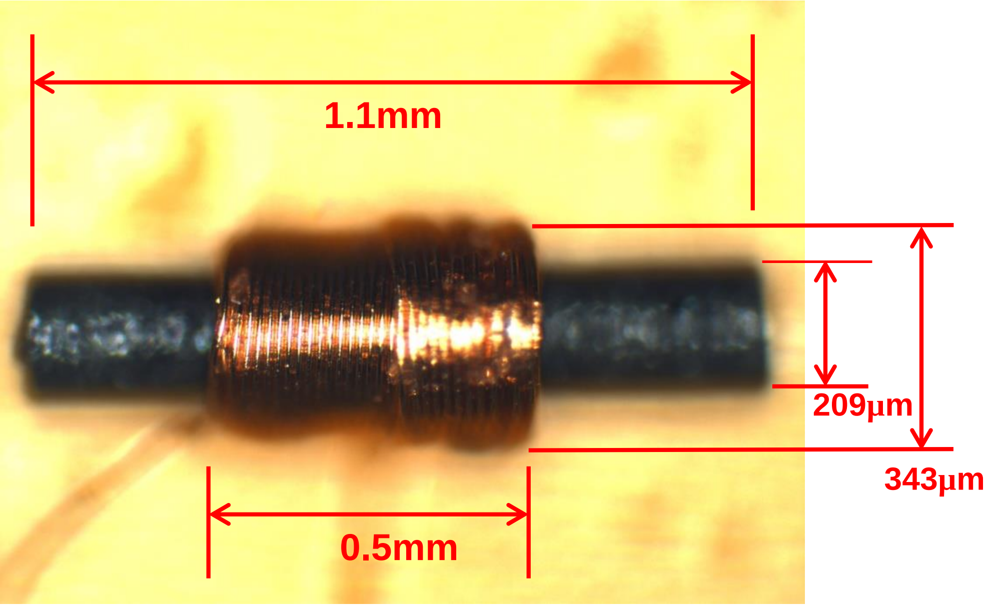
Built Prototypes

- Prototypes assembled by hand
- Solder past and 1-mil gold wires used for interconnects
- Volume achieved: 0.5 mm^3

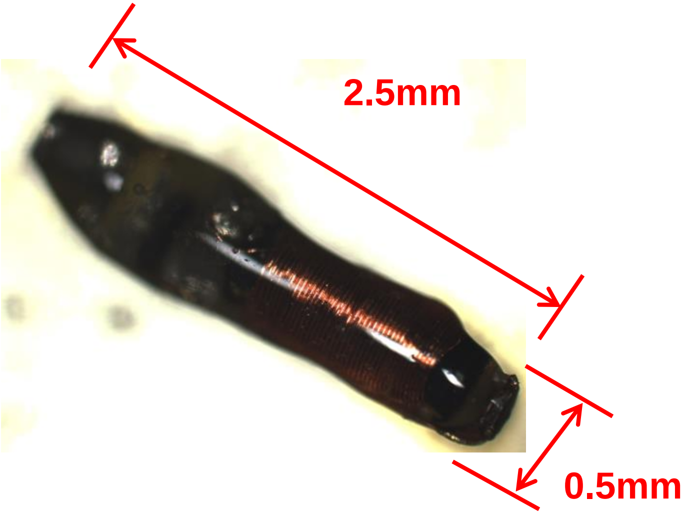
Prototype with 0402 Caps



Coil and Ferrite (100-turns)

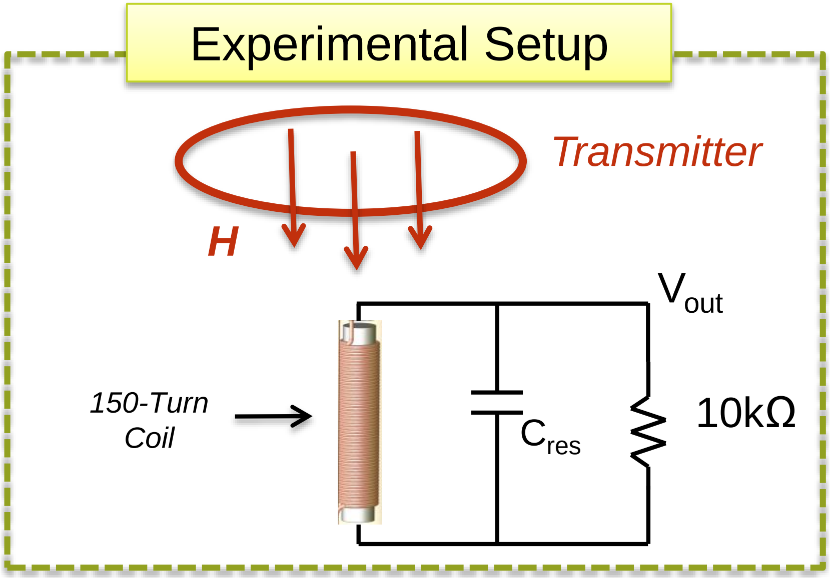


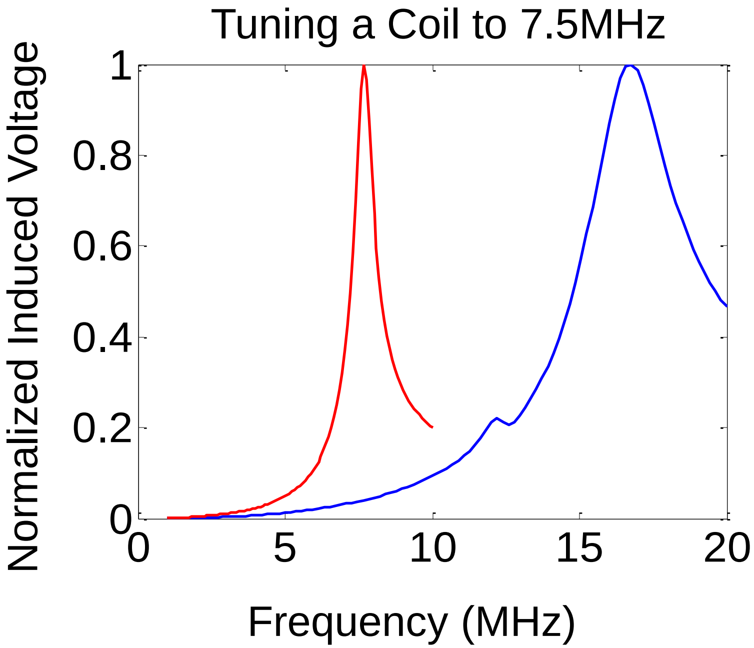
Prototype with 0201 Caps

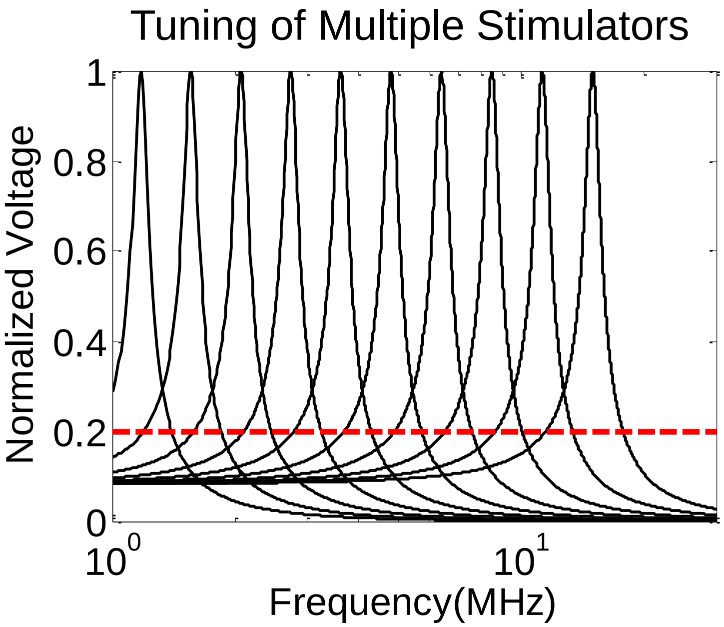


Tuning of the Coils

- Coil of 25µH tuned with 7pF capacitor, resulting in a quality factor of 12
- Approximately ten individually addressable stimulators over 1 – 20MHz


Experimental Setup

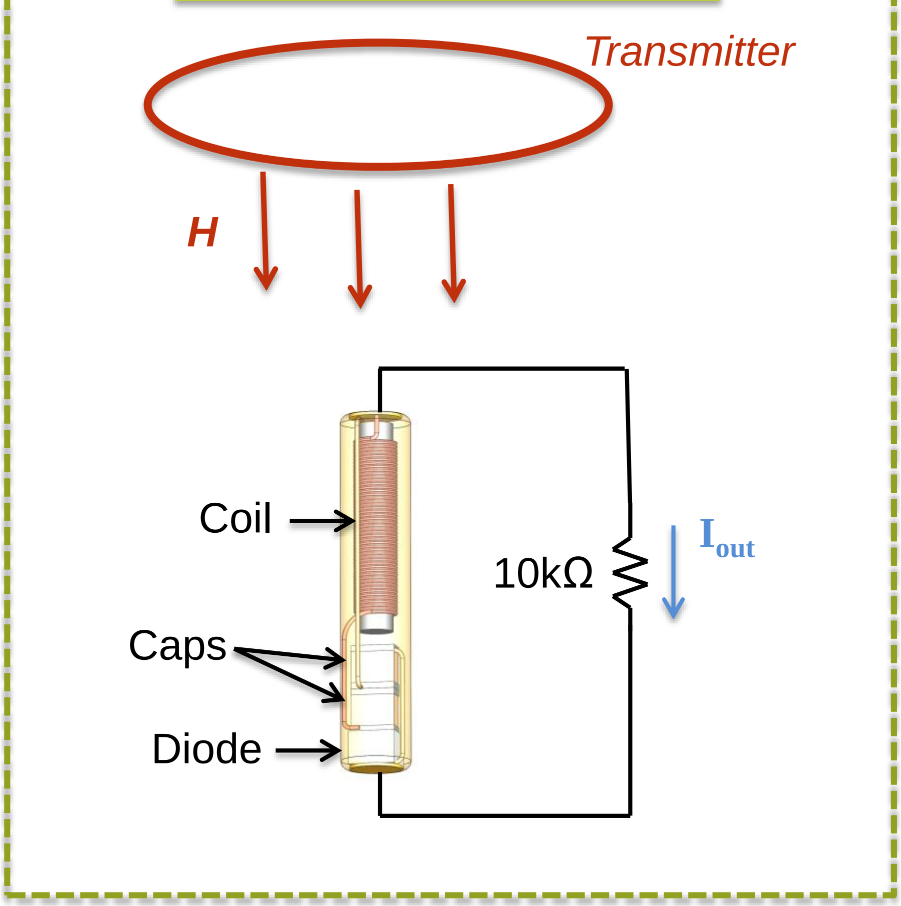

Tuning a Coil to 7.5MHz


Tuning of Multiple Stimulators

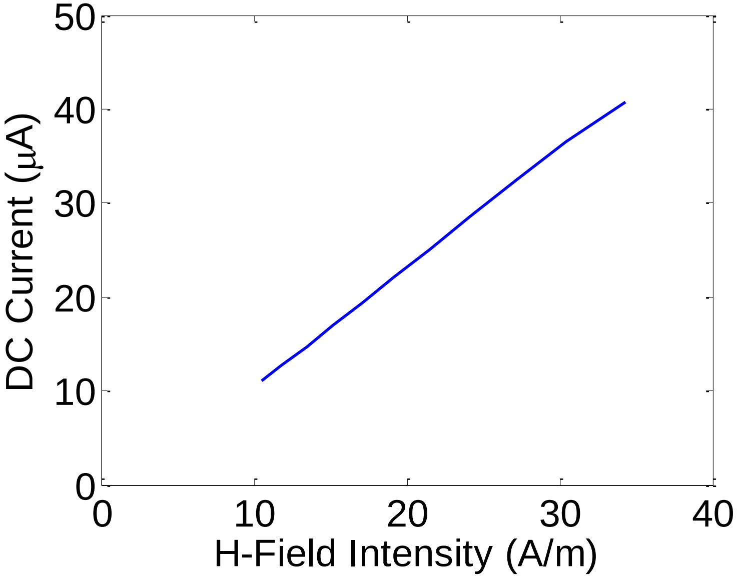
Measuring DC Output Current of Coils

At maximum allowed magnetic field, the stimulator delivers >40μA to a 10kΩ load

Experimental Setup

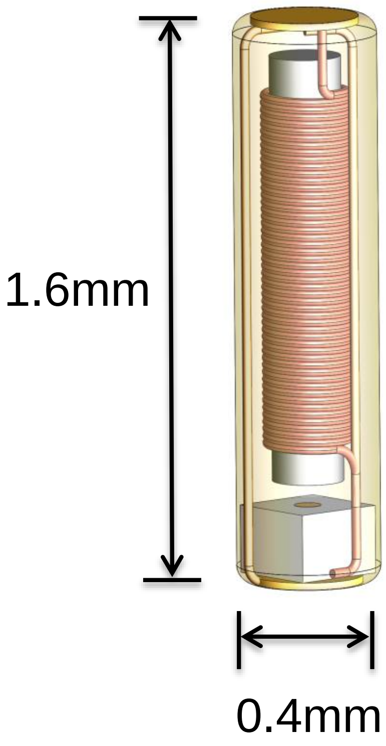


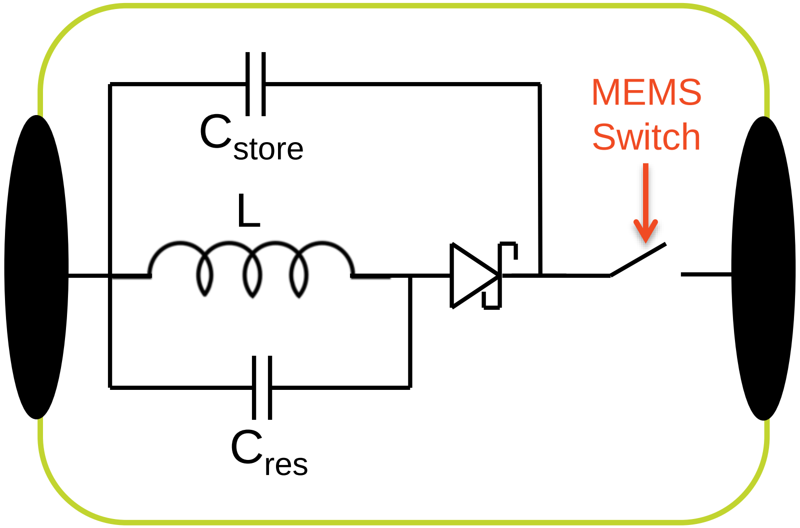
Output Current vs Applied Field



Going Forward

- Integration of capacitors into disc electrodes will reduce length to 1.6mm
- Exploring a magnetically actuated MEMS switch to increase Q





Thank You

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