*1st Invitational Workshop on*
**Body Area Network Technology and Applications**
Future Directions, Technologies, Standards and Applications
June 19-20, 2011
Worcester Polytechnic Institute

# *Connecting the Inside and Outside Worlds: Wideband Communication Across the Skin*


***Maysam Ghovanloo, Ph.D.***

*GT-Bionics Lab*

***School of Electrical and Computer Engineering***

Georgia Tech

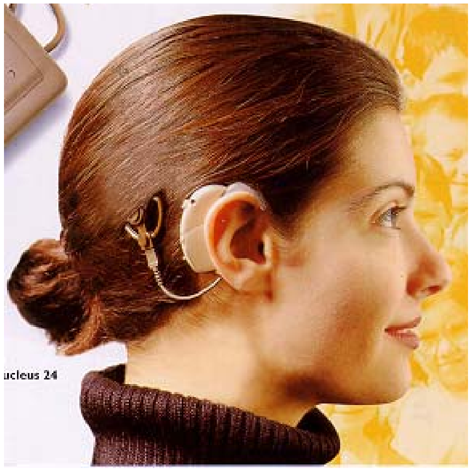
***www.GTBionics.org***

# *Questions*

- A) Important and growth areas in the fields of body area networks and in general signal processing for biomedical engineering?
- B) How these areas could drive communications, signal processing and networking research?
- C) Your views on global standards and their status and impact
- D) Challenging research problems and possible solutions

**Implantable microelectronic devices that need wideband communication channels with outside of the human body**

# *Auditory and Visual Prostheses*



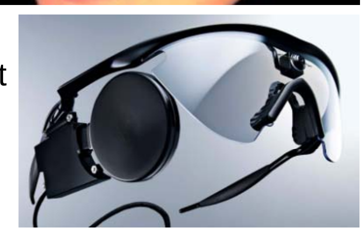
Cochlear Corporation

- **Auditory Prosthesis:**
  - 10% of the world population experience a limited quality of life because of hearing impairment.
  - USA statistics:
    - Profoundly deaf: 0.4 million
    - Hearing Impaired: 20 million

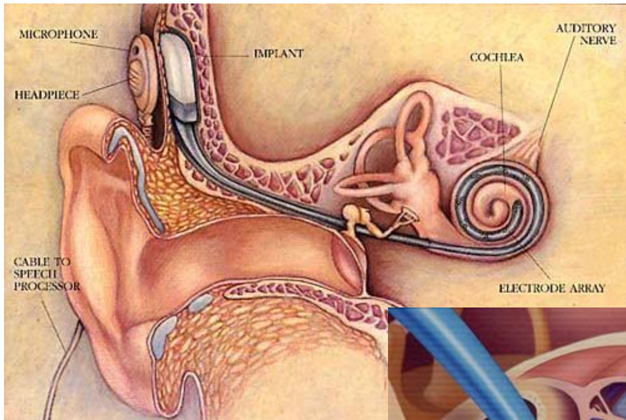
- **Visual Prosthesis:**
  - World statistics:
    - Profoundly Blind: 45 million
    - Visually Impaired: 180 million
  - USA statistics:
    - Profoundly Blind: 1.3 million
    - Visually Impaired: 10 million

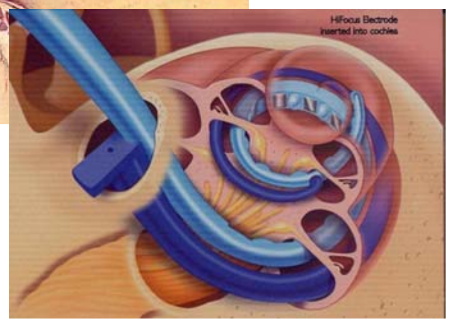
Dobelle Institute

2nd Sight



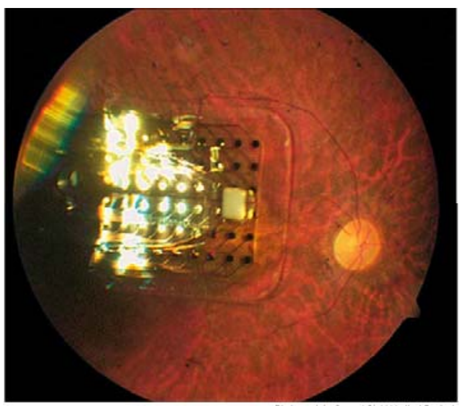
# *Cochlear and Retinal Implants*




Advanced Bionics Inc.

- Commercially available since early 80's.
- About 200,000 children and adults use cochlear implants.
- 30,000 auditory nerves.
- A minimum of 6 ~ 8 stimulating sites needed to converse on the phone.



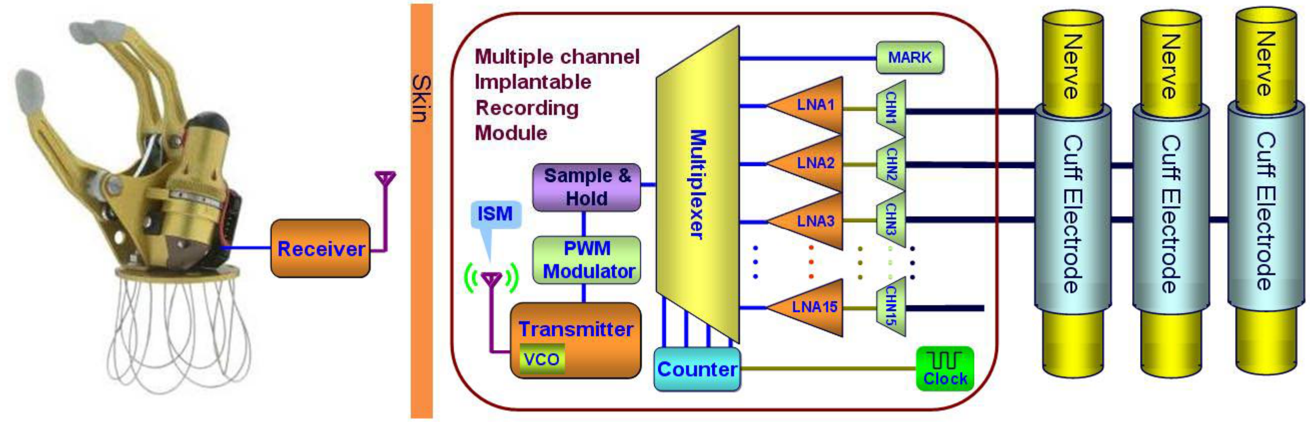

2nd Sight

Boston Retinal Implant

- Currently under development. First chronic human trial in 2002.
- 1.2 Million optic nerves.
- A minimum of 800 ~ 1000 sites needed to read large fonts.

www.GTBionics.org

# *Effective Control of Prosthetic Devices*




C-Leg (Otto Bock)

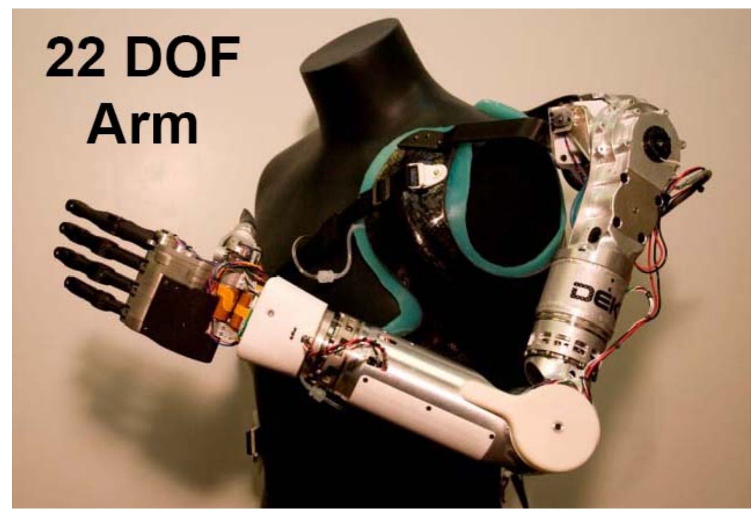
Bion (Advanced Bionics)

<u>Bottleneck:</u>

How to effectively control sophisticated prosthetic devices in real time?

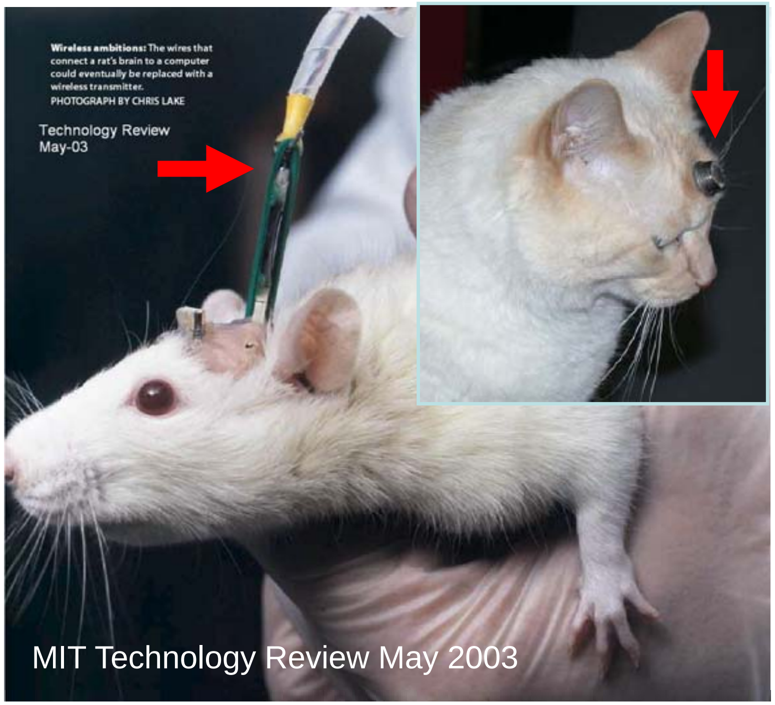
<u>Solution:</u>

Direct interface with the nervous system



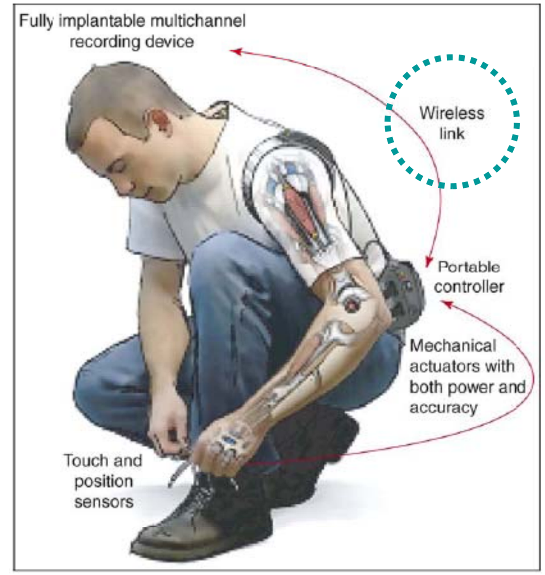

DEKA Arm (DARPA – J. Judy)

# *Multichannel Wireless Neural Interfacing*




MIT Technology Review May 2003


Hochberg et al. Nature 2006




Lebedev and Nicolelis,
Trends in Neuroscience 2006

## In animal experiments:

1. Improve SNR
2. Reduce motion artifacts
3. Eliminate the tethering effect, which can bias the animal behavior

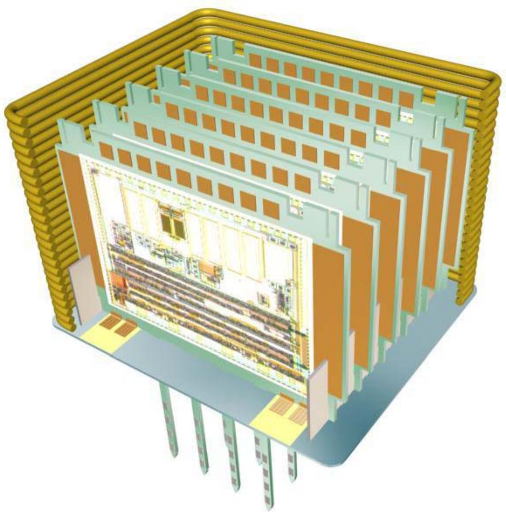
## In human applications:

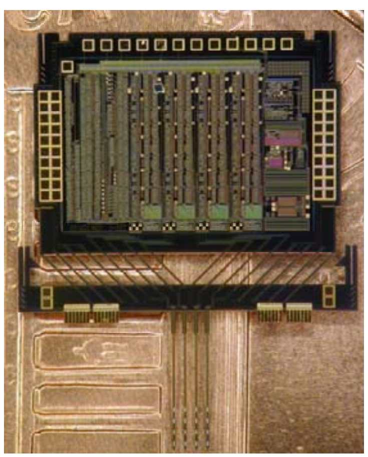
1. Reduce the risk of infection
2. Reduce the risk of damage
3. Improve user's comfort level
4. Increase mobility
5. More aesthetically acceptable

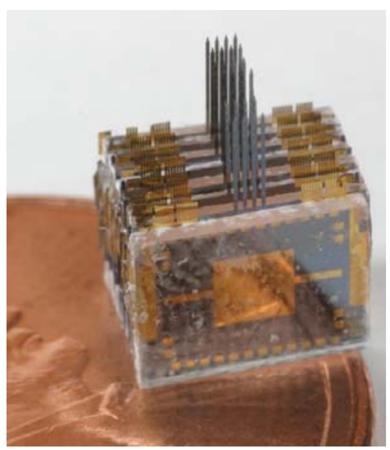


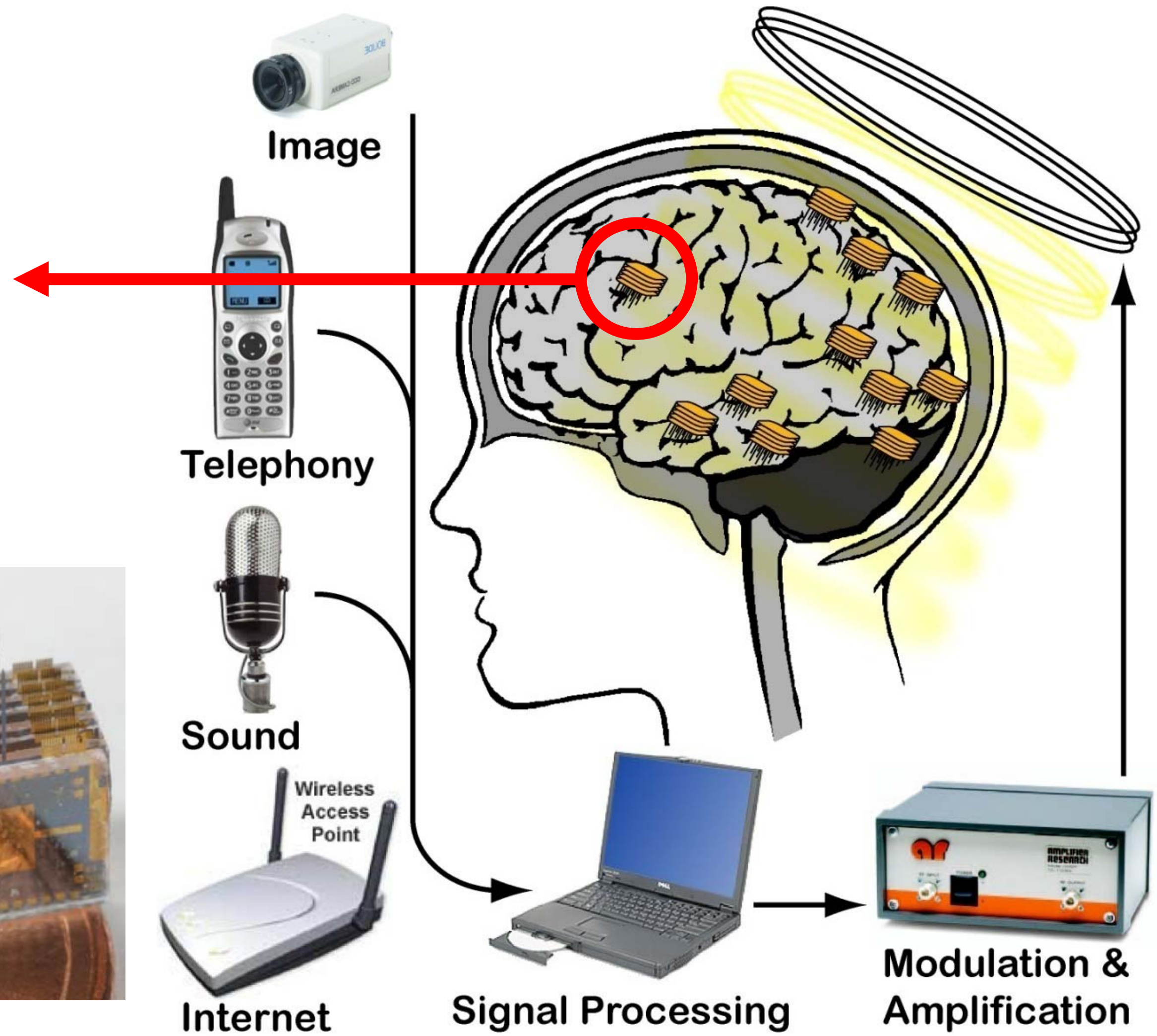

Yin and Ghovanloo, TNSRE 2009

# *A Distributed Network of Wireless Implants for the Central Nervous System*



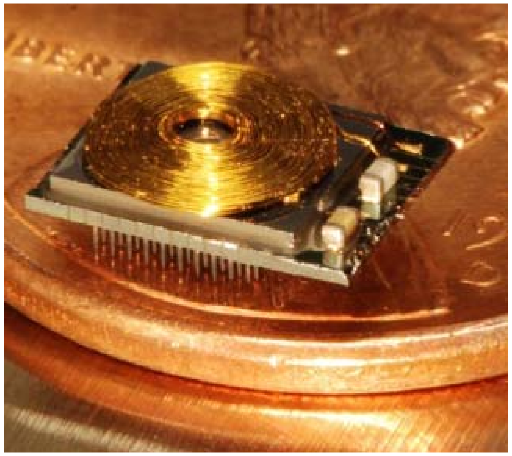




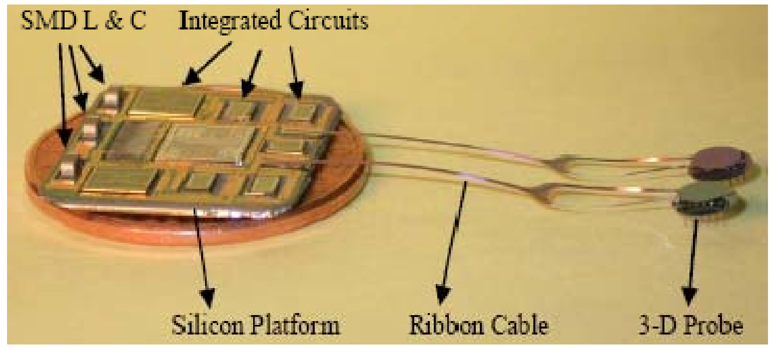



Ghovanloo and Najafi, JSSC 2004

# *State-of-the-Art in Wireless Neural Recording*

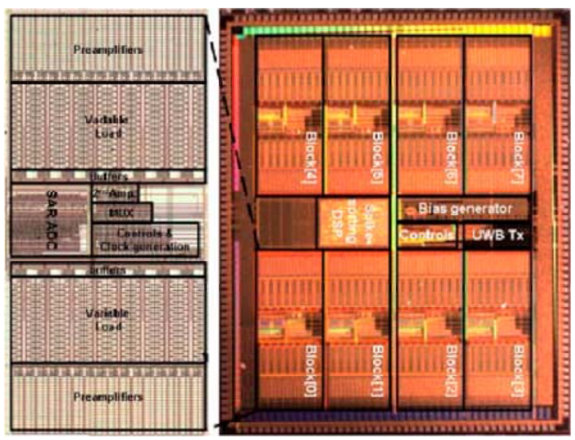


Harrison et al. (Utah)
100-ch spike + 1-ch Digital

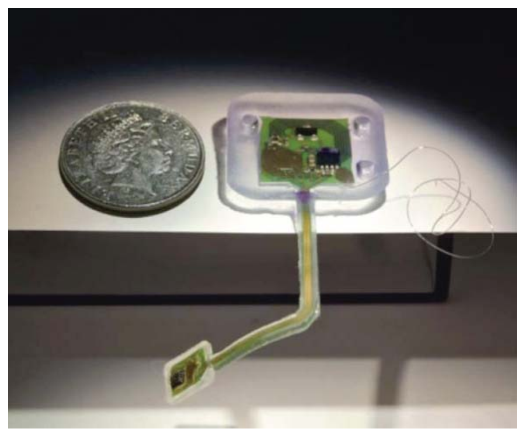



Wise et al. (Michigan)
64-ch spike + 2-ch Digital

Ghovanloo et al. (GT)
32-ch PWM / TDM




Liu et al. (U.C. Santa Cruz)
128-ch Digital

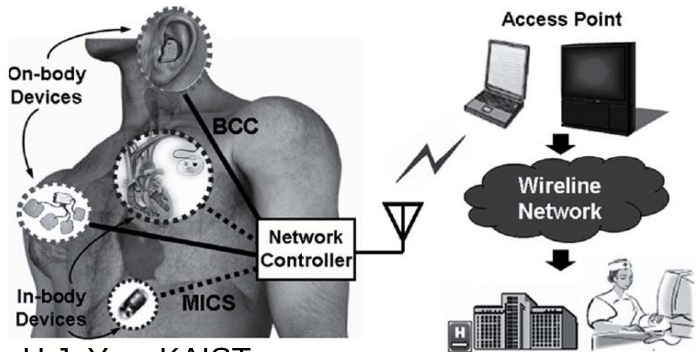


Nurmikko et al. (Brown)
16-ch Optical / Digital


Morizio et al. (TBSI, Duke)
15-ch Analog / TDM

***www.GTBionics.org***

# *Wireless Transcutaneous Power and Bi-Directional Data Transmission*

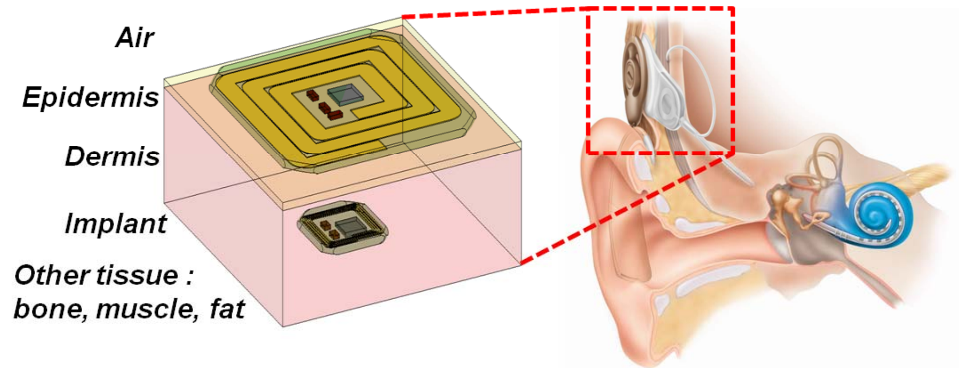



H.J. Yoo, KAIST

Body Channel Communication (BCC) 30-70 MHz


Zarlink

Medical Implant Communication Service (MICS) 402–405 MHz

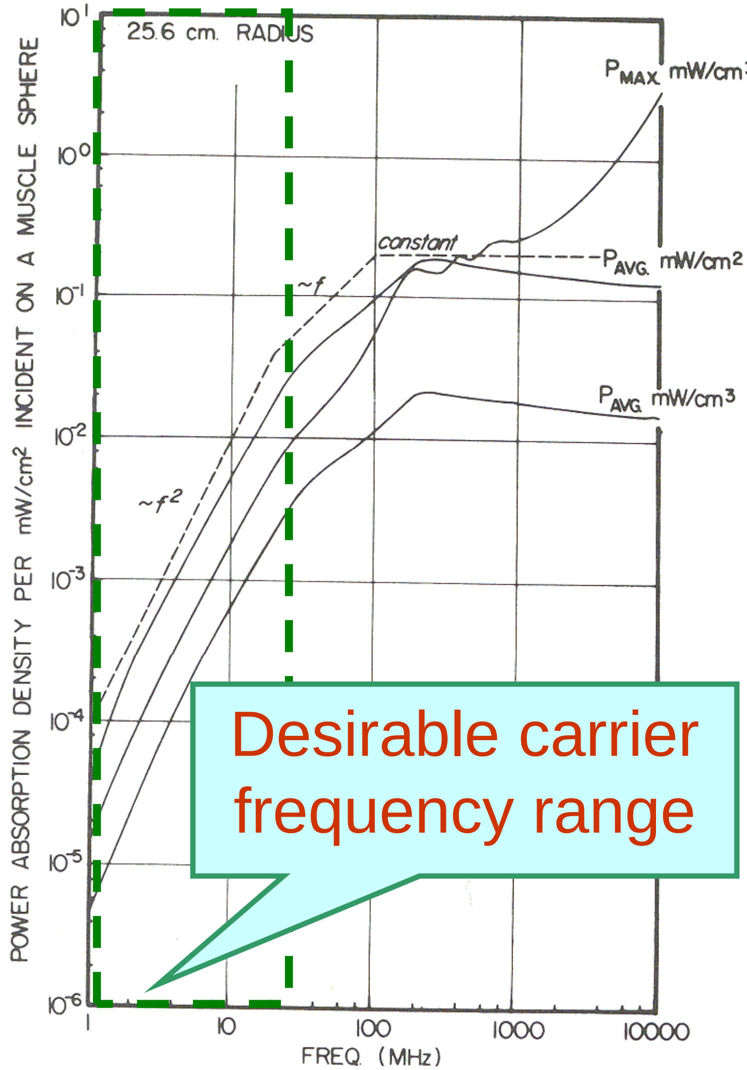



Cho et al., JSSC 2009

- Battery powered devices:
  - Small number of sites
  - Ultra low power and low data rates
  - Autonomous (after initial adjustments)
- Inductively powered devices:
  - High current (Neuromuscular stimulators)
  - High stimulus rate (Cochlear implants)
  - Large number of sites (Visual prostheses)
- All implants need wireless data.

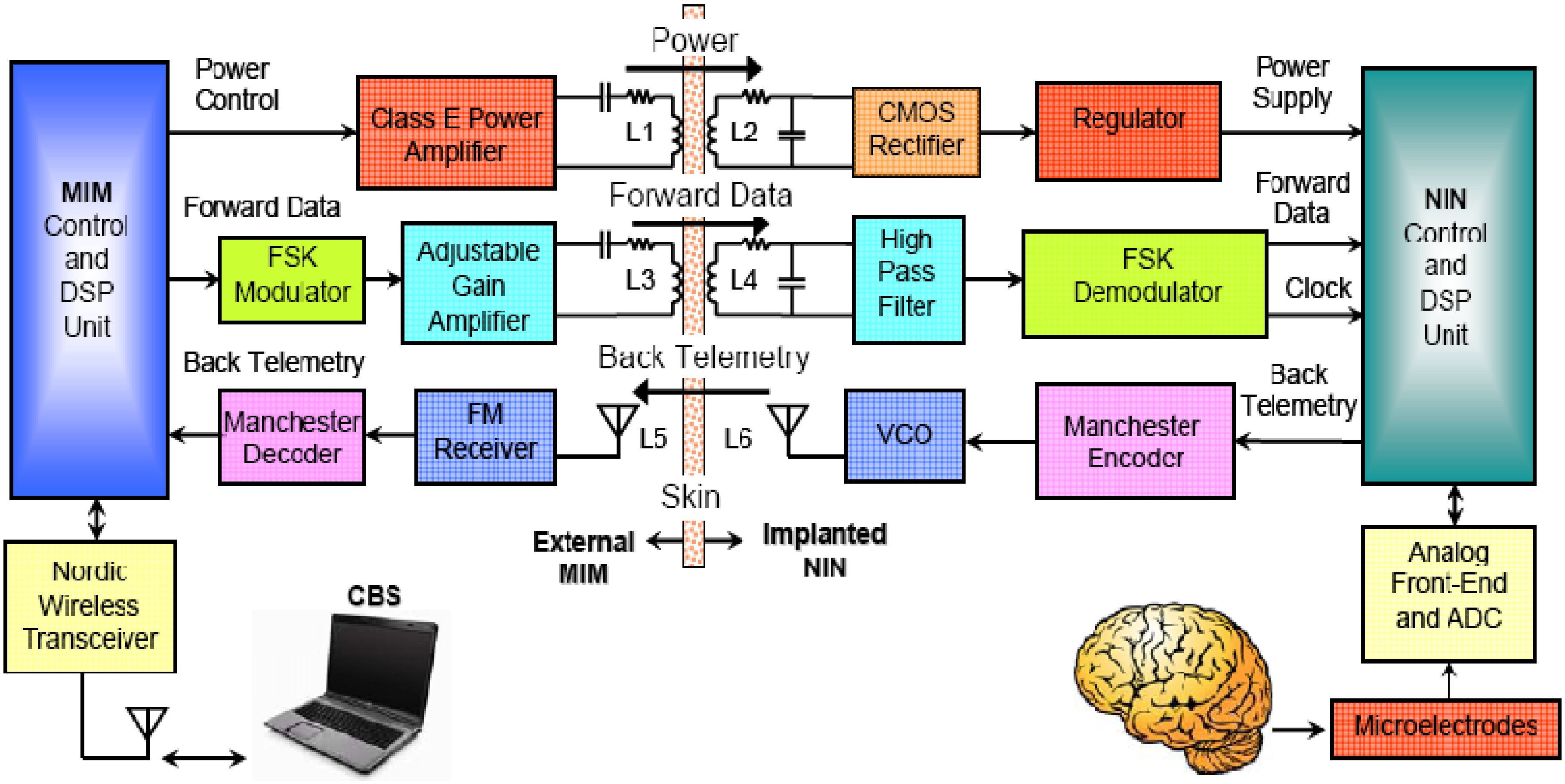
# Efficient Power: Carrier Frequency as Low as Possible

- Carrier frequency should be below the coil self resonance frequency.
- More power loss in the power transmission and conditioning circuitry at higher frequencies.
- 1 MHz < Carrier Frequency < 20 MHz Average density of electromagnetic power absorption in tissue increases as $f^2$.
- Tissue is more transparent to EM field at lower frequencies.
- Carrier Frequency↑ ⇒ Penetration Depth↓




J. C. Lin, A. W. Guy, and C. C. Johnson
IEEE Trans. Microwave Theor. Tech. 21, 1973

# *Wireless Link with Multiple Carriers*




- Low frequency for power transmission (1~10 MHz)
- Medium frequency for forward data transmission (50~100 MHz)
- High frequency for back telemetry (1~4 GHz)

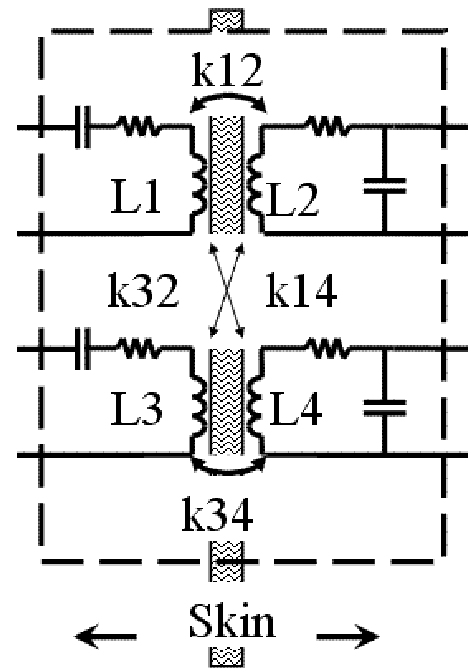


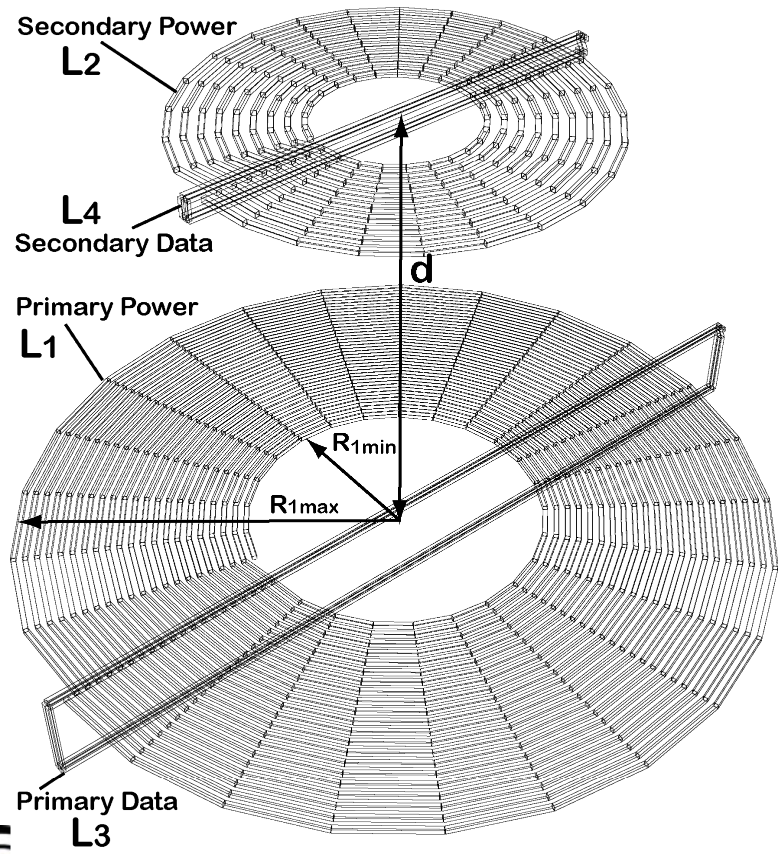

Ghovanloo and Atluri, TCAS-I 2007

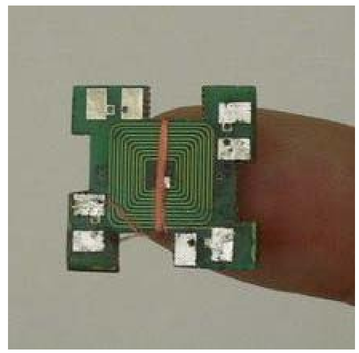
# *Direct and Cross Coupling*

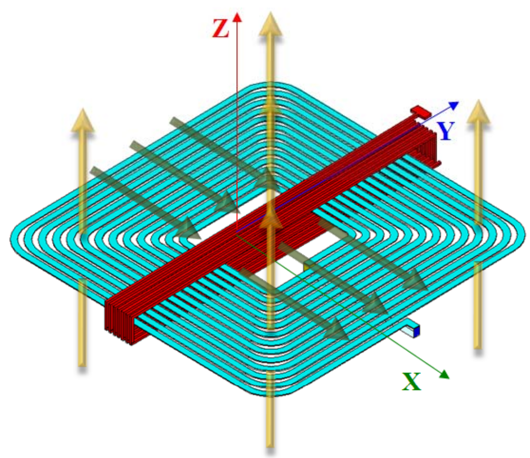
Geometry and orientation of the power and data coils were chosen to:

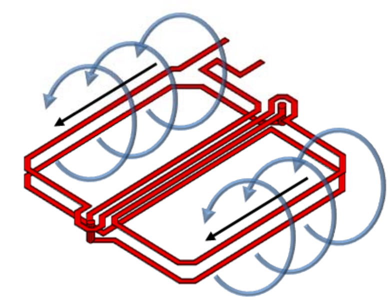
- Maximize direct coupling coefficients ($k_{12}$, $k_{34}$)
- Minimize cross coupling coefficients ($k_{14}$, $k_{32}$)



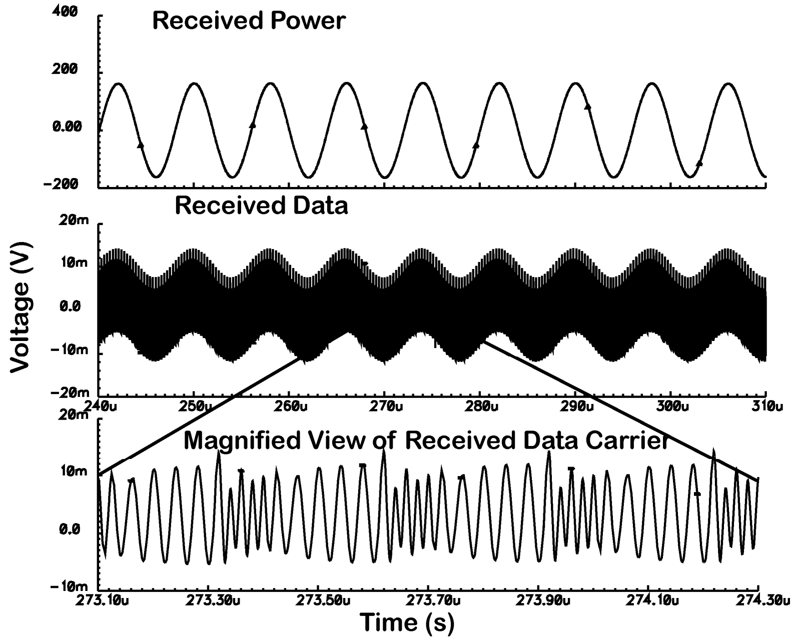


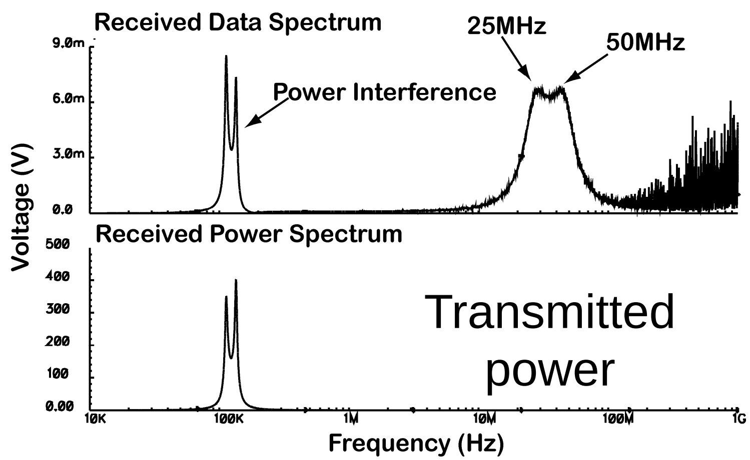





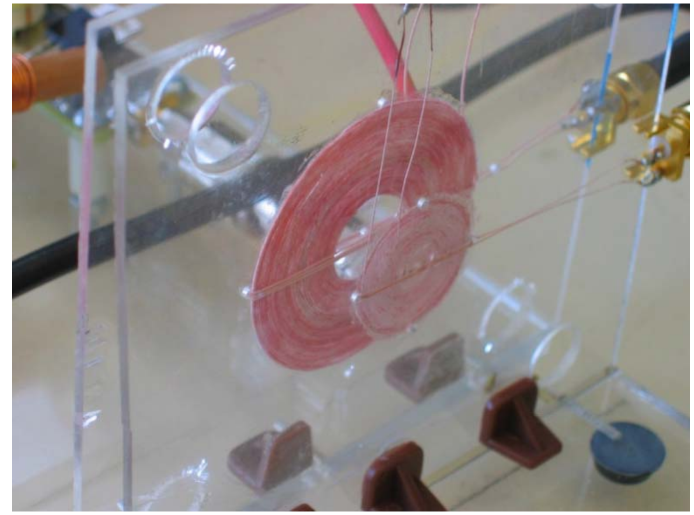

Jow and Ghovanloo, TBioCAS 2010

# *Simulation and Measurement Results*



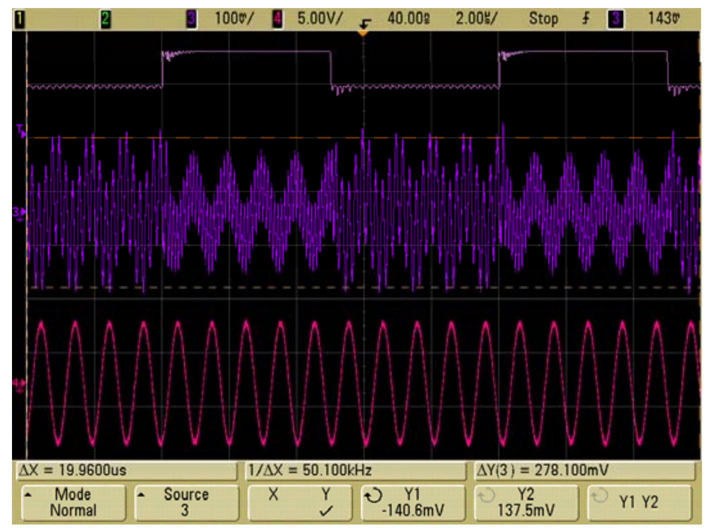

Measurement Setup →



Demodulated Data →

Received Data →

Received power →

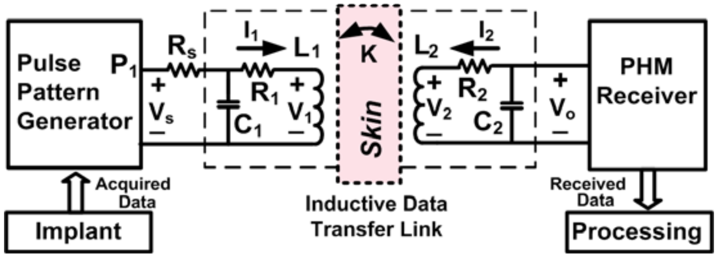


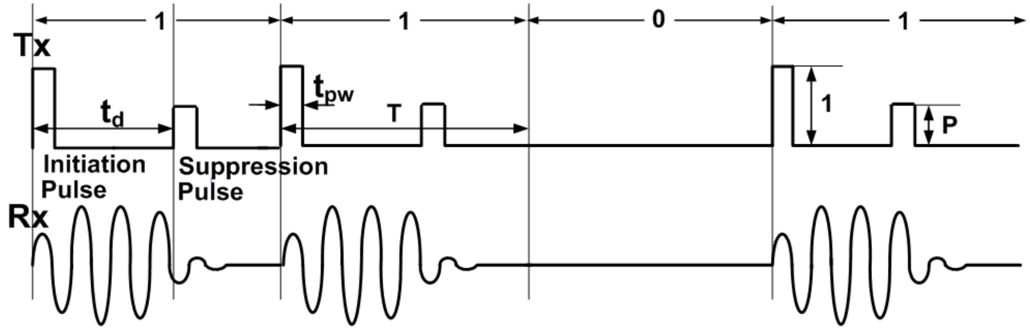


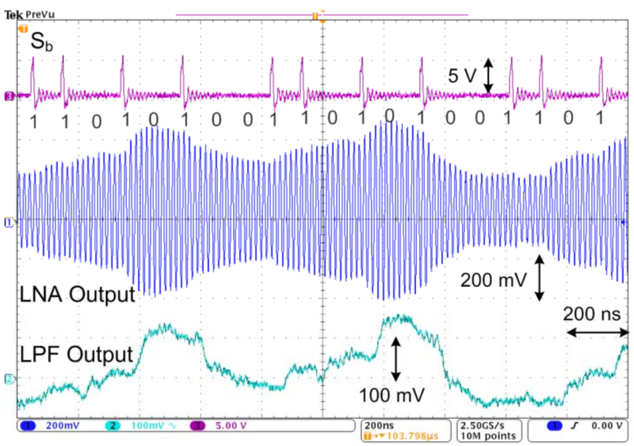



Ghovanloo and Atluri, TCAS-I 2007

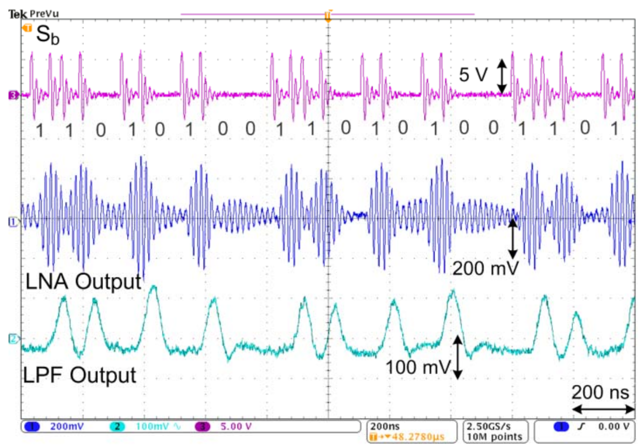
# *Pulse Harmonic Modulation*



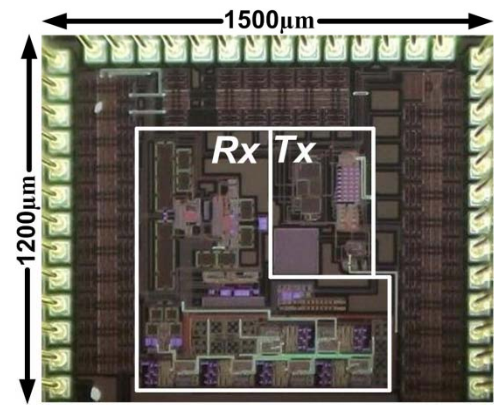




Without PHM (10.2 Mbps)




With PHM (10.2 Mbps)




PHM Transceiver

A string of narrow pulses with specific amplitudes and timing is transmitted. Each pulse generates a decaying oscillation at the harmonic frequency that the receiver LC-tank is tuned at, which is then superimposed with other oscillations across the receiver at the same frequency, to minimize the ISI.



Inanlou and Ghovanloo, TCAS-I 2011, JSSC 2011

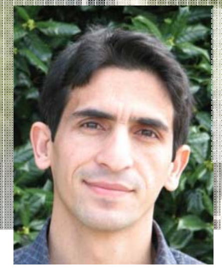
# *GT- Bionics Lab Members*

Xueliang Huo
Ph.D. Student
xhuo@gatech.edu

Uei-Ming Jow
Ph.D. Student
jow0209@gatech.edu

Seung Bae Lee
Ph.D. Student
slee87@gatech.edu

Hyung-Min Lee
Ph.D. Student
hyungminlee@gatech
.edu



Mehdi Kiani
Ph.D. Student
mkiani3@gatech.edu

Jeonghee Kim
Ph.D. Student
jkim448@gatech.edu

Elnaz B. Sadeghian
Ph.D. Student
hpark90@gatech.edu

Hangue Park
Ph.D. Student
hpark90@gatech.edu

Sergio Carlo
Ph.D. Student
sergio.carlo@gatec
h.edu

Undergraduate researchers:

- Mingjie Zhou
- Rui Ding
- Chukwuyem (Doyle) Emelue
- Peter McMenamin
- Jecolia Longtchi

*www.GTBionics.org*

# Acknowledgements


- Funding provided by:
  - National Science Foundation
  - Christopher and Dana Reeve Foundation
  - National Institutes of Health
  - Army Research Office (ARO)


- Collaborators:
  - Dr. Michael Jones, Shepherd Center, Atlanta, GA
  - Dr. Ann Laumann, Northwestern University, Chicago, IL
  - Dr. Joseph Manns, Emory University, Atlanta, GA
  - Dr. Elliot Roth, Rehab. Institute of Chicago, Chicago, IL
  - Dr. Elizabeth Bailey, University of Arizona, Tucson, AZ
  - Dr. Karim Oweiss, Michigan State University, Lansing, MI
  - Dr. Kimberly Wilson, Emory Hospital, Atlanta, GA
  - Dr. Stephen Sprigle, Georgia Tech, Atlanta, GA