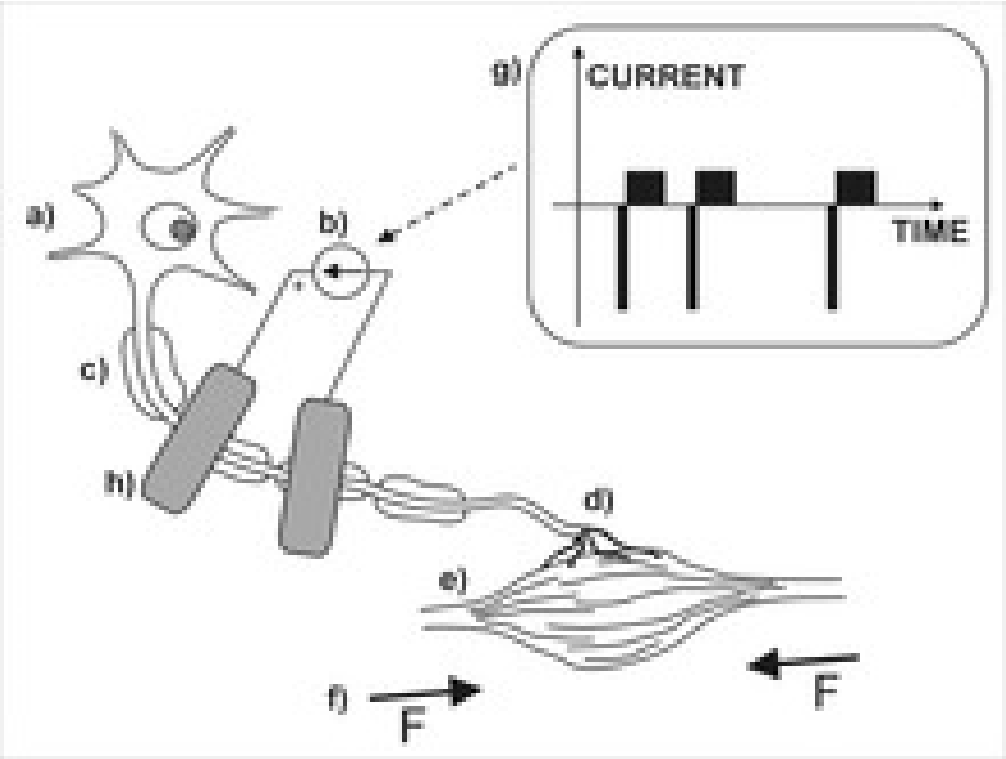
FES System

What is FES?

- Functional Electrical Stimulation(FES) is a technique that uses electrical current to activate nerves/ to control muscles innervating extremities when the brain can no longer control movement. The causes include spinal cord injury, stroke, or various neurological disorders or amputation.

NIH Image Gallery
Functional Electrical Simulation Device Improves Gait in Children with Cerebral Palsy
https://www.flickr.com/photos/nihgov/24233878371/in/photolist-CVsXKa

What is FES?



https://en.wikipedia.org/wiki/Functional_electrical_stimulation

- Following a stroke or spinal cord injury, muscles are impaired because motor neurons no longer receive sufficient input from the central nervous system.
- A functional electrical stimulation system injects electrical current into the cell.
- The intact but dormant axon receives the stimulus and propagates an action potential to the neuromuscular junction.
- The corresponding muscle fibers contract and generate muscle force.

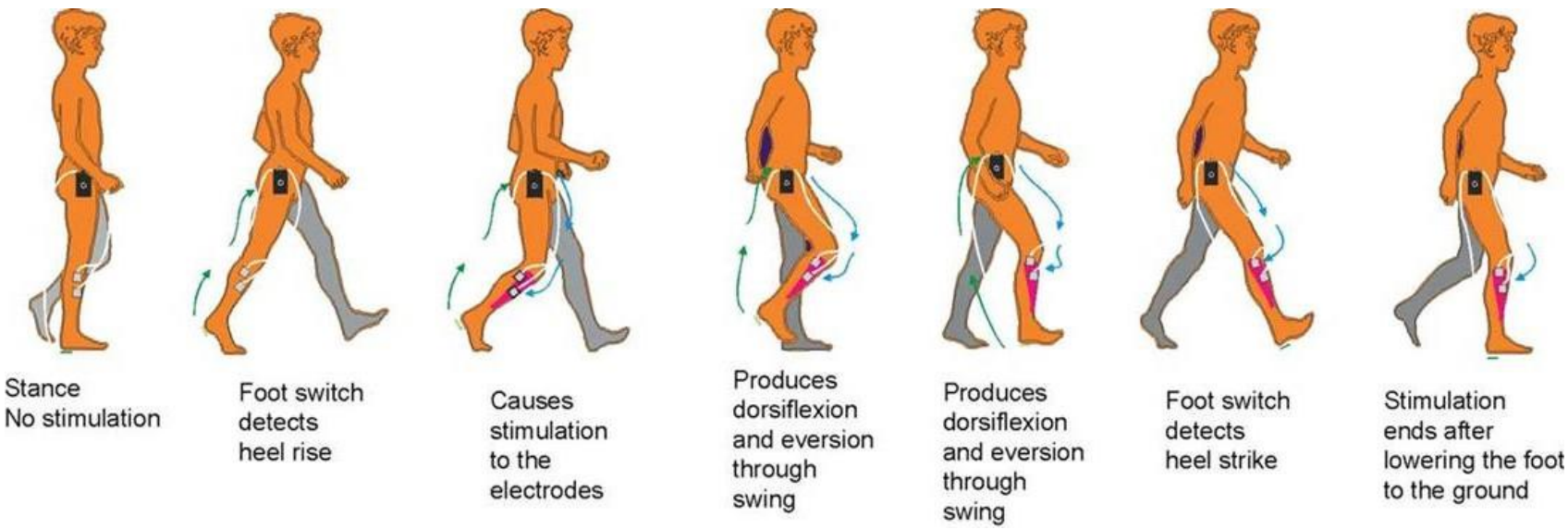
HISTORY OF FES

- Initially referred to as Functional Electrotherapy by Liberson, who proposed portable stimulator to compensate for drop foot in hemiplegic patients.
- 1967 the term Functional Electrical Stimulation was coined by Moe and Post, in a patent that describes a system to treat foot drop
- Since then, several one-channel, dual-channel and multi-channel electrical stimulators have been developed, that apply stimulation via cutaneous, transcutaneous or implantable electrodes.
- Used in subjects with stroke, head trauma and multiple sclerosis to correct abnormal gait pattern and enable opening of spastic hand.
- In paraplegic patients with SCI(spinal cord injury), FES is used for standing and walking.
- In tetraplegic patients FES enables functional grasping by the paralysed hand.

https://en.wikipedia.org/wiki/Functional_electrical_stimulation
http://ifess.org/proceedings/IFESS1998/IFESS1998_065_Stanic.pdf

FES in Foot Drop

- At the moment just before the heel off phase of gait occurs, the stimulator delivers a stimulus to the common peroneal nerve, which results in contraction of the muscles responsible for dorsiflexion. (or stimulate the muscle itself.)

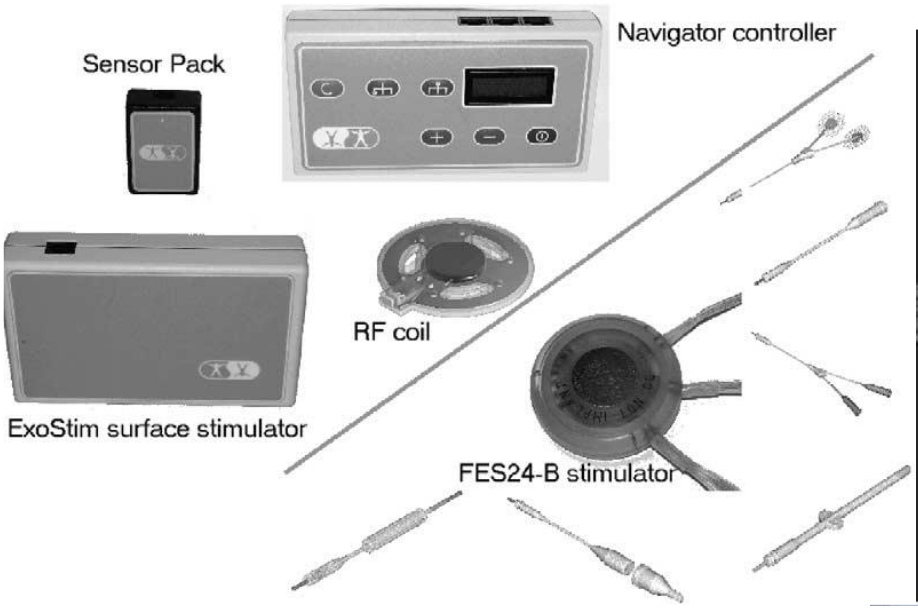


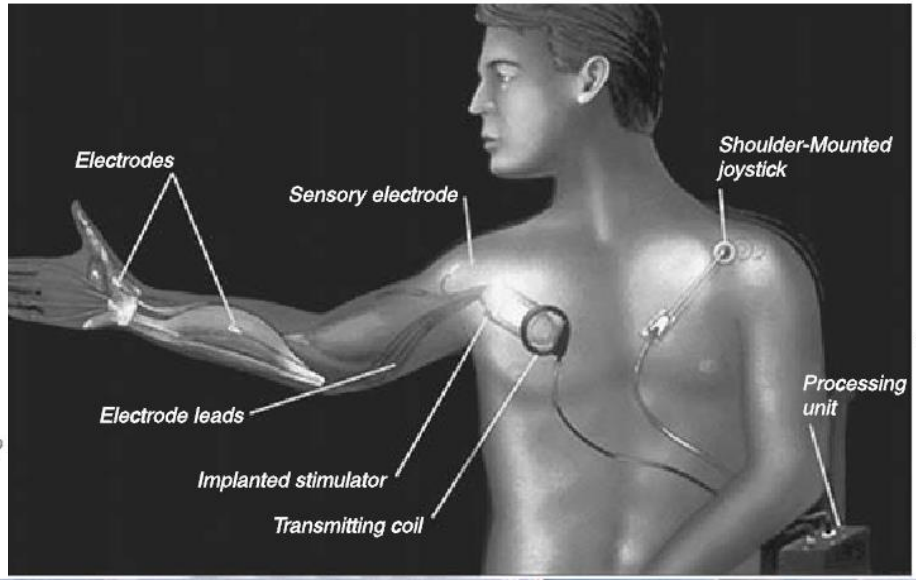
http://research.bournemouth.ac.uk/impact/the-use-of-function-electrical-stimulation-fes-in-neurological-rehabilitation/
For inversion/eversion/plantaflexion/dorsiflexion see
https://www.youtube.com/watch?v=ROloTSQ2h3M

FES

- Input from CNS/PNS/ EMG/ Sensors
- Process the input
- Output to muscle/ robotics

FES Devices examples





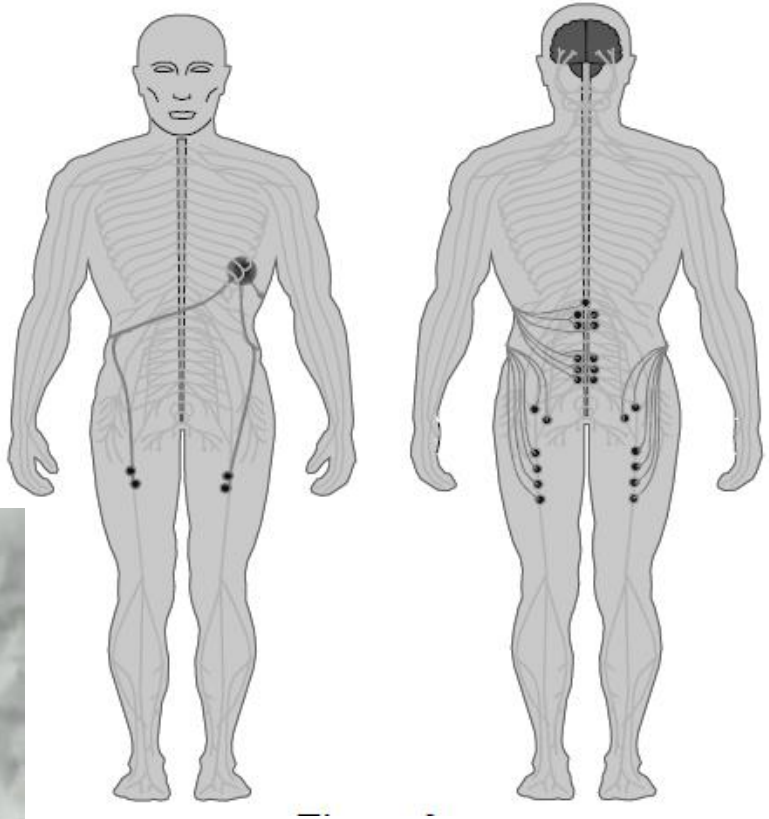
- Praxis FES System
- Freehand System

R. David, et al., *Medical engineering & physics,* 2001.

Morita, et al., *Reconstruction of upper limb motor function using functional electrical stimulation (FES)*, Springer Vienna, 2007.

Praxis FES System

- Bladder Control & Standing/Exercise for paraplegic

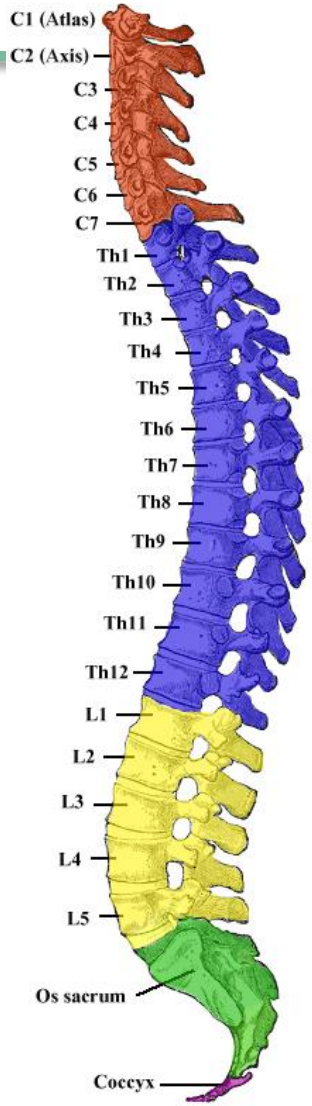


R. David, et al., *Medical engineering & physics,* 2001

. Spinal Cord (2005) 43, 713–723. doi:10.1038/sj.sc.3101797; published online 5 July 2005

Praxis FES System

1. Neuropraxis- a subsidiary of Cochlear Ltd-modified from nucleus 22
2. To provide standing and stepping function as well as enhanced bladder and bowel management for individuals with thoracic level SCI.
3. Initial development of the device included only mobility functions. In 1991, the initial device, the Nucleus FES-22, was implanted in a 21-year-old male with paraplegia. In the laboratory, this subject was able to stand continuously for up to 60 min.
4. A later version of the device, the FES 24, included channels for stimulated bladder and bowel function. It was implanted in a 35-year-old male with paraplegia in 1998. The subject was able to perform one handed reaching tasks while standing.



Johnson et.al., Spinal Cord (2005) 43, 713–723. doi:10.1038/sj.sc.3101797; published online 5 July 2005

By Tomwsulcer - Own work, CC0, https://commons.wikimedia.org/w/index.php?curid=15006027

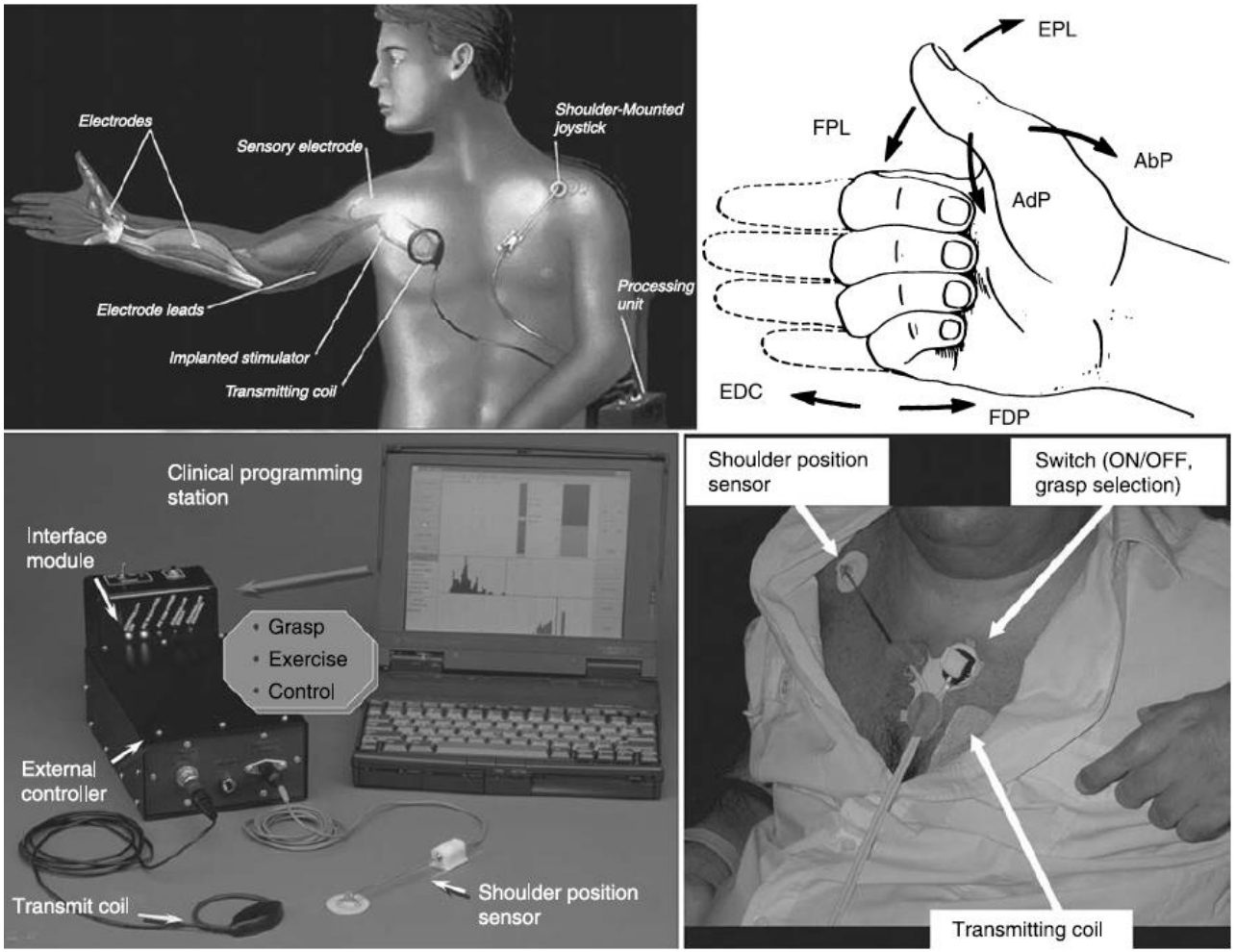
R. David, et al., *Medical engineering & physics,* 2001.

Praxis FES System (2)

1. Controller: A body-worn controller transcutaneously powers and controls the implanted Stimulator via a Transmit Coil
2. Sensor Packs: provide the Navigator's software Strategies with real time information on the position of the lower extremities and the trunk; consists of accelerometers and gyroscope sensors
3. FES Stimulator: placed subcutaneously above the left costal margin. 22-24 channel, 8 mA, pulse rate up to 14,400 Hz.
4. Leads and Electrodes: The implanted Stimulator is connected to 22 Electrodes by highly flexible and stretchable insulated leads.

R. David, et al., *Medical engineering & physics,* 2001.

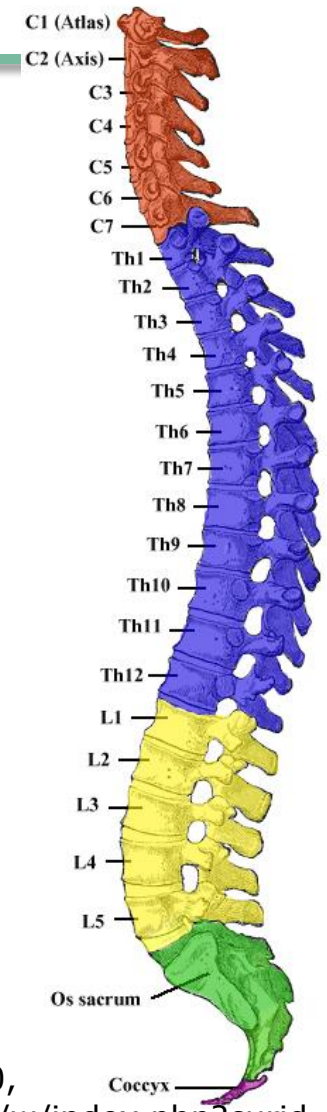
Freehand System



Morita, et al., *Reconstruction of upper limb motor function using functional electrical stimulation (FES)*, Springer Vienna, 2007.

Freehand System

- Manufactured by NeuroControl Corp, OH, FDA approval 1997
- Intended to Restore hand function(to grasp, hold, and release objects) in C5 and C6 level tetraplegics.
- Stimulate eight different muscles in order to produce a useful grip and key pinch.
- The system consists of a surgically implanted receiver/stimulator unit and electrodes with an external controller and power supply/microprocessor.



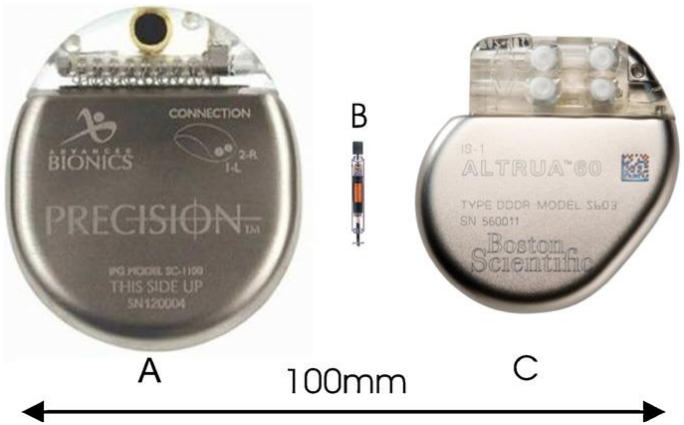
By Tomwsulcer - Own work, CC0, https://commons.wikimedia.org/w/index.php?curid=15006027

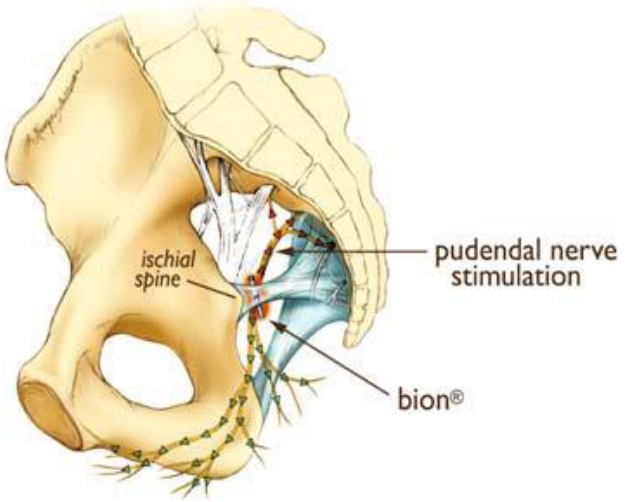
http://www.scireproject.com/,http://www.mrisafety.com/

Morita, et al., *Reconstruction of upper limb motor function using functional electrical stimulation (FES)*, Springer Vienna, 2007.

Bion- a wireless compact implantable FES

- A leadless, miniaturized FES system
- Designed to be injected directly to muscle or nerves through simple injection methods
- Small size allows placement of device in proximity to the target nerve or muscle
- RF- or self-powered
- RF- controllable

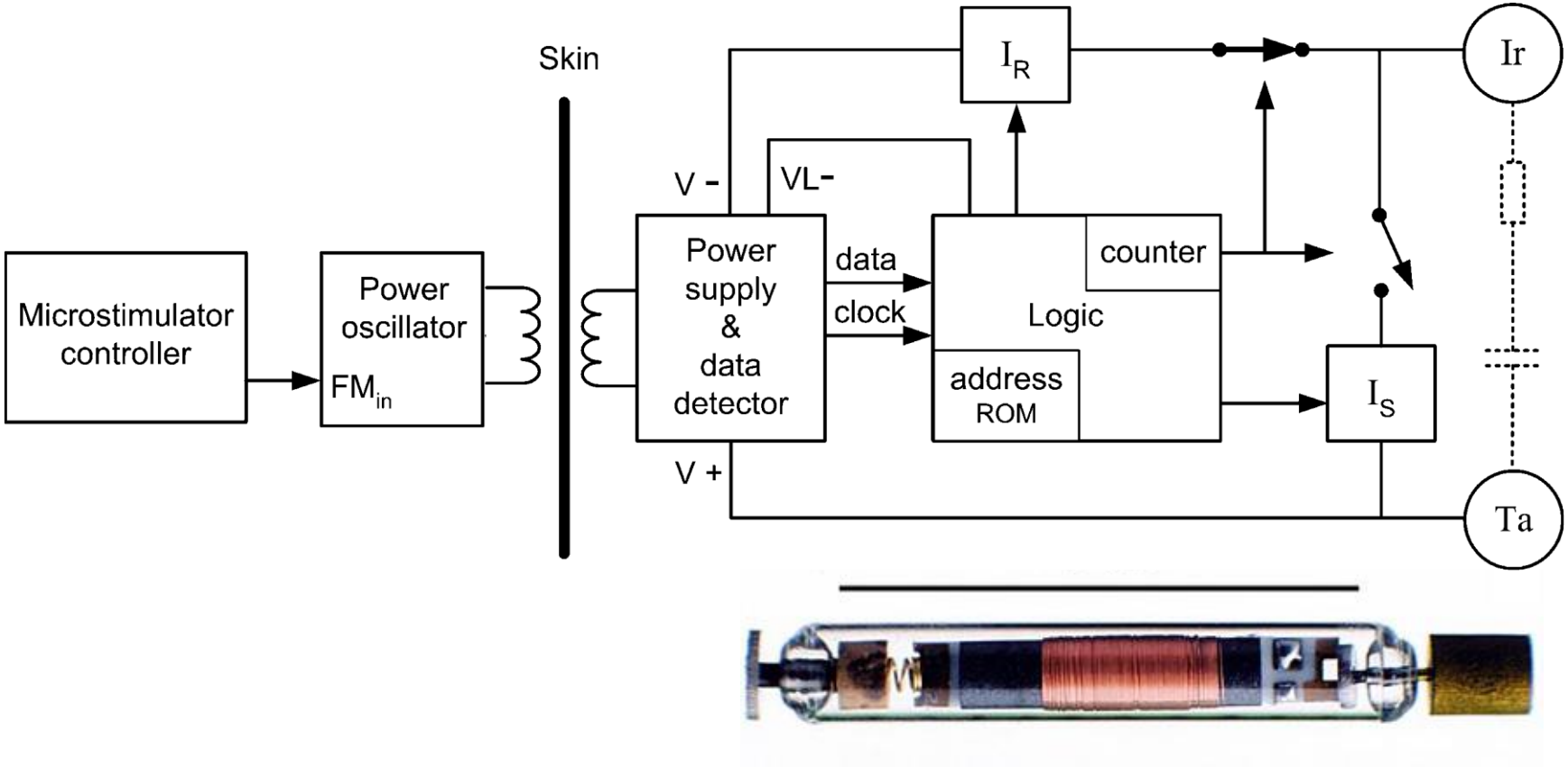




Kane, Michael J., et al., *Medical engineering & physics,* 2011.

Bion System (1)

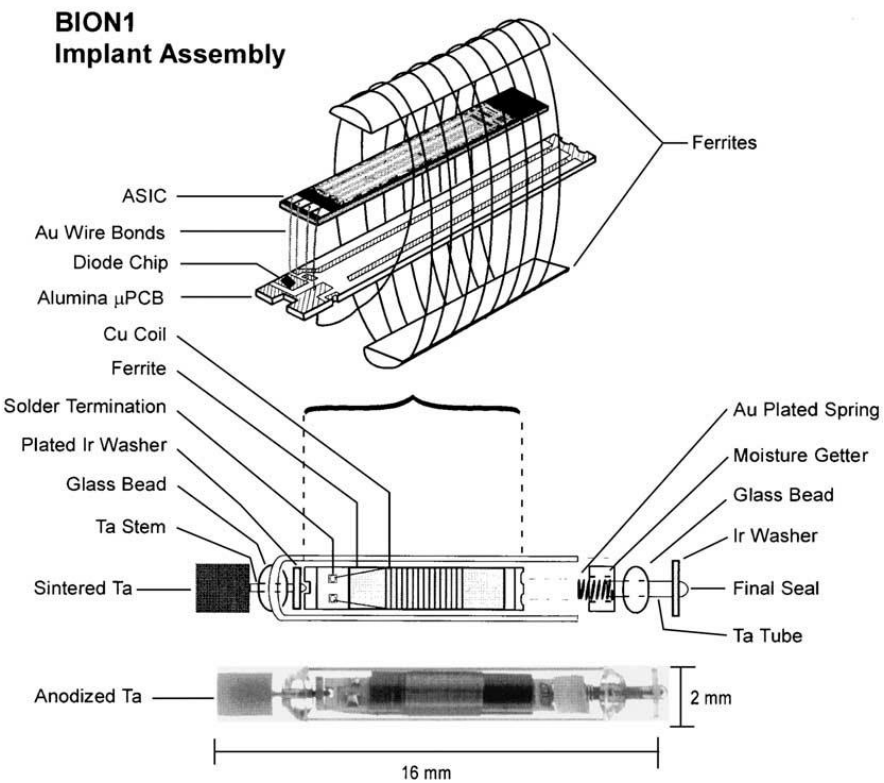
- RFB1 (1st Generation RF-Powered Bion Microstimulator)



Loeb, Gerald E., et al., *Medical engineering & physics*, 2001.
http://www.medgadget.com/

Bion System (1)

- RFB1 Specification
  - Glass case
  - Tantalum oxide capacitor electrode(cathode)
  - Iridium electrode(anode)
  - Monophasic
  - Ferrite wound coil
  - Power and data transceiver using AM
  - 8-bit device addresses
  - $I_{max} = 30\ mA$
  - $PulseWidth_{max} = 512\ ms$
  - $f_{max} > 500\ Hz$
  - $Radius = 2\ mm$
  - $Length = 16\ mm$



- Limitations of RFB1
  - Easily broken
  - Low RF efficiency
  - ESD susceptible

Loeb, Gerald E., et al., *Medical engineering & physics*, 2001.

Bion System (2)

- RFB2 (2nd Generation RF-Powered Bion Microstimulator)
  - Hermatic ceramic case
  - Coil wrapping ferrite-IC-hybrid sandwich
  - Zener diode around electronics module
  - Capacitor in the package

Todd K. W., et al., *Pain physician*, 2009

Bion System (2)

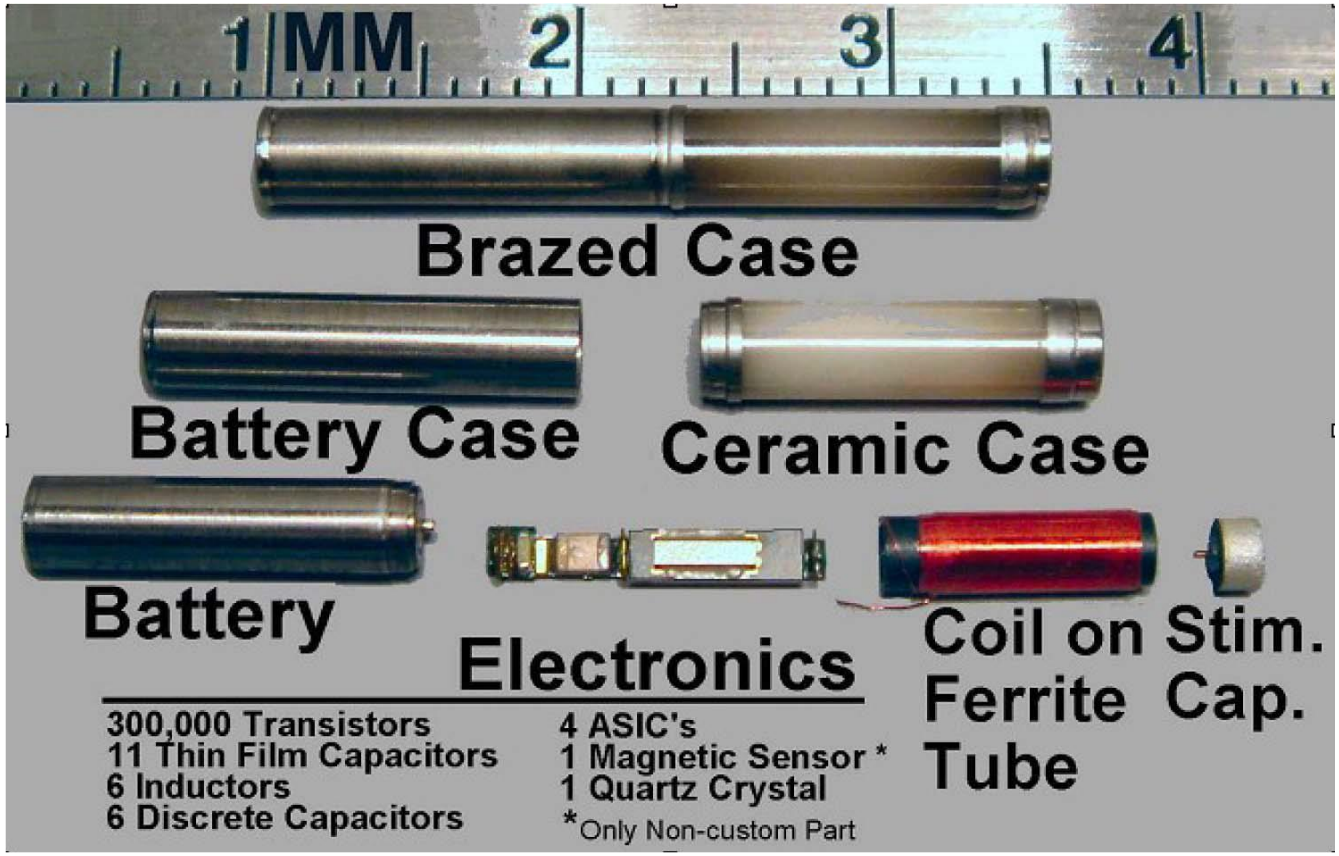
- RFB2 Specification
  - Hermetic ceramic case and titanium cylinder cap
  - Eyelet for suture
  - Platinum-Iridium stimultation electrode
  - Biphasic
  - Static protection
  - Power and data transceiver using AM
  - 8-bit device addresses
  - $I_{max} = 40\ mA$
  - $PulseWidth_{max} = 512\ ms$
  - $f_{max} = 3472\ Hz$
  - $Radius = 2.5\ mm$
  - $Length = 15.6\ \mathrm{mm}$

- Limitations
  - RF-powered-should maintain coil orientation for proper operation
  - External devices needs to be worn always-discomfort for daily long term use

Todd K. W., et al., *Pain physician*, 2009

Bion System (3)

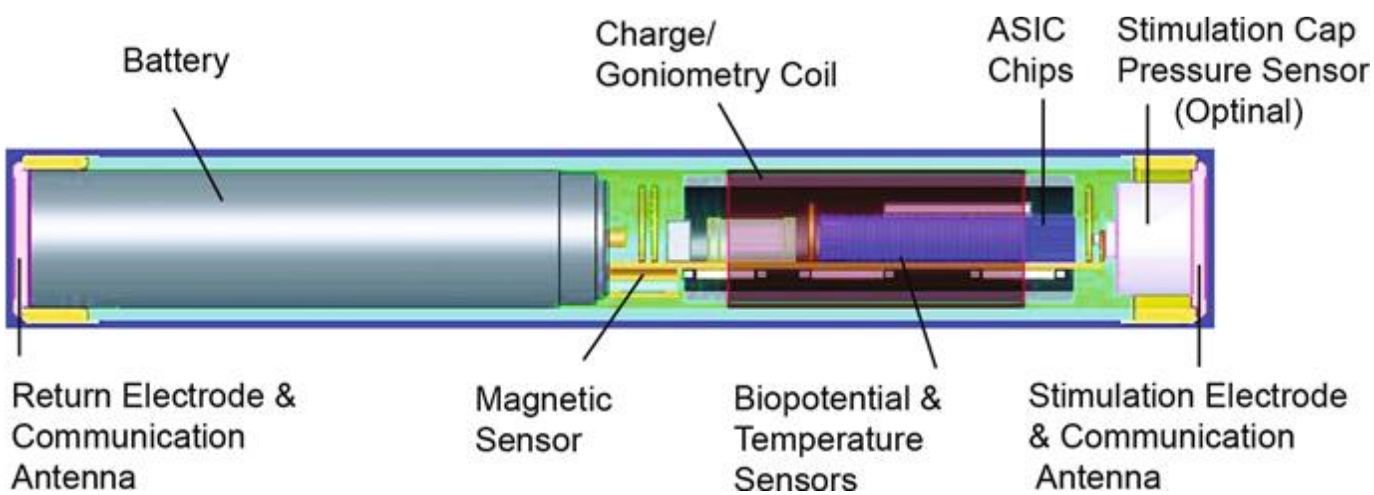
- BPB (Battery-Powered Bion Microstimulator)



Schulman, Joseph H, *Proceedings of the IEEE* , 2008.

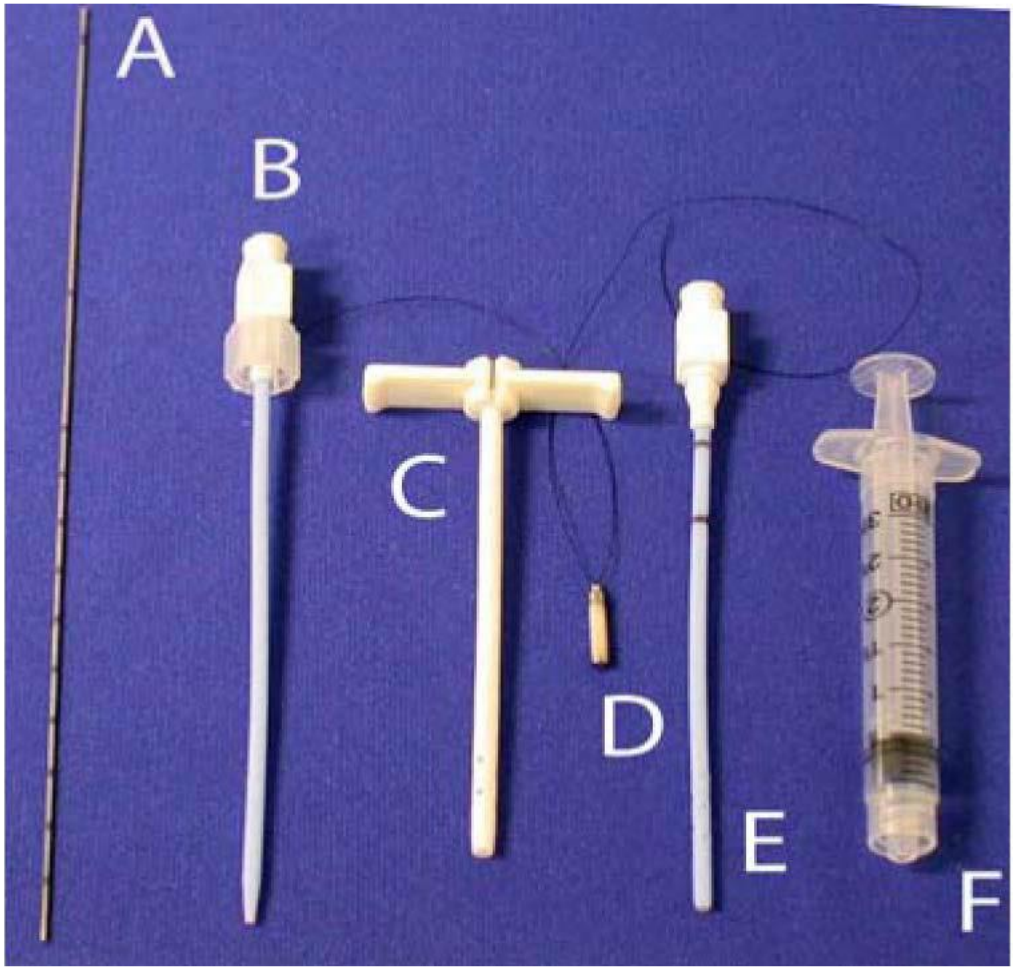
Bion System (3)

- BPB Specification
  - Zirconia case, Titanium cap
  - Iridium electrodes
  - 8-bit device addresses
  - $I_{max} = 20\ mA$
  - $PulseWidth_{max} = 1000\ ms$
  - $f_{max} = 4096\ Hz$
  - $Radius = 3.15\ mm$
  - $Length = 25\ mm$



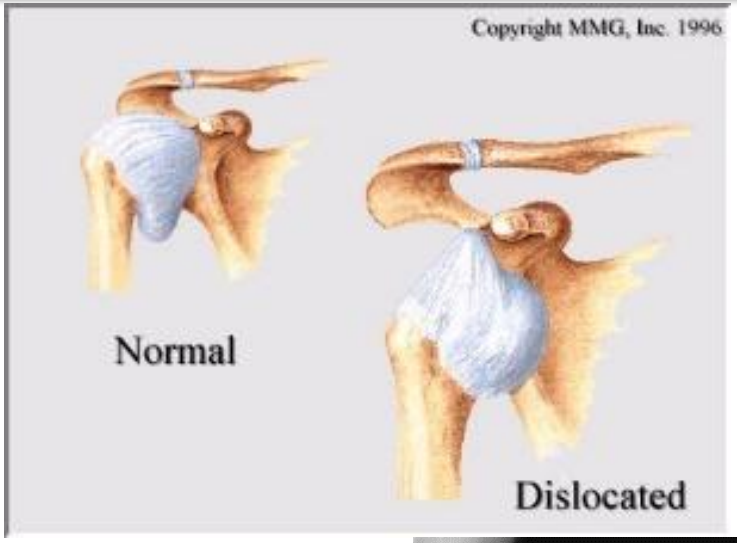
Todd K. W., et al., *Pain physician*, 2009

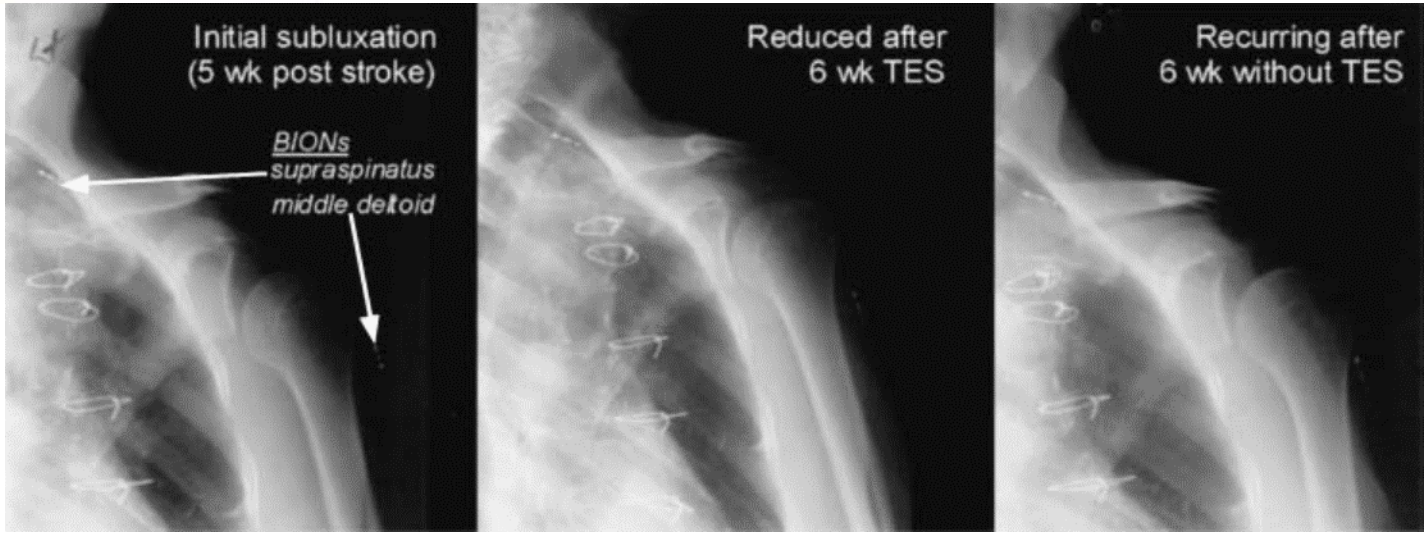
Insertion Tools



Schulman, Joseph H, *Proceedings of the IEEE* , 2008.

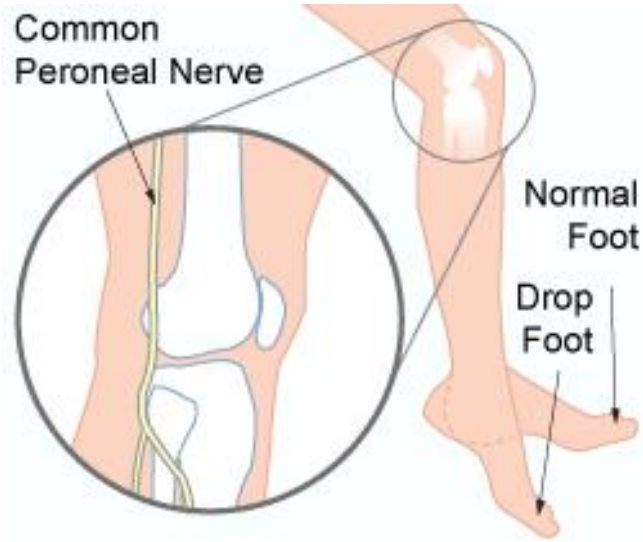
Bion for Post-Stroke Shoulder Subluxation

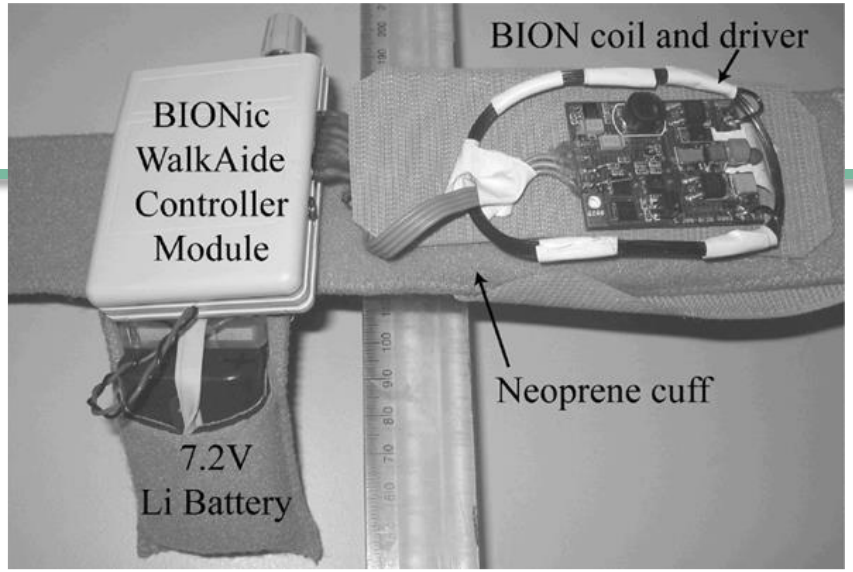


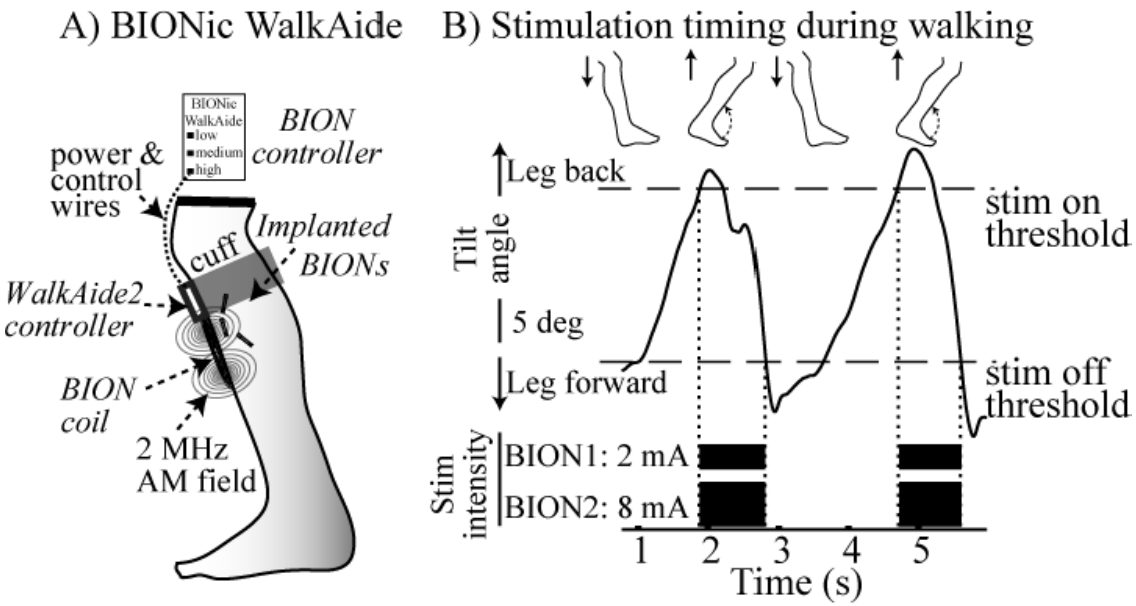


http://www.oocities.org/
Misawa, A., et al., *9th Annual Conference of the International FES Society,* 2004.

Bion for Foot Drop







http://ourhealthnetwork.com/
Weber, Douglas J., et al., *Neural Systems and Rehabilitation Engineering, IEEE Transactions on*, 2005.
Weber, D. J., et al., *Canadian journal of physiology and pharmacology*, 2004.

Bion to Neurodust

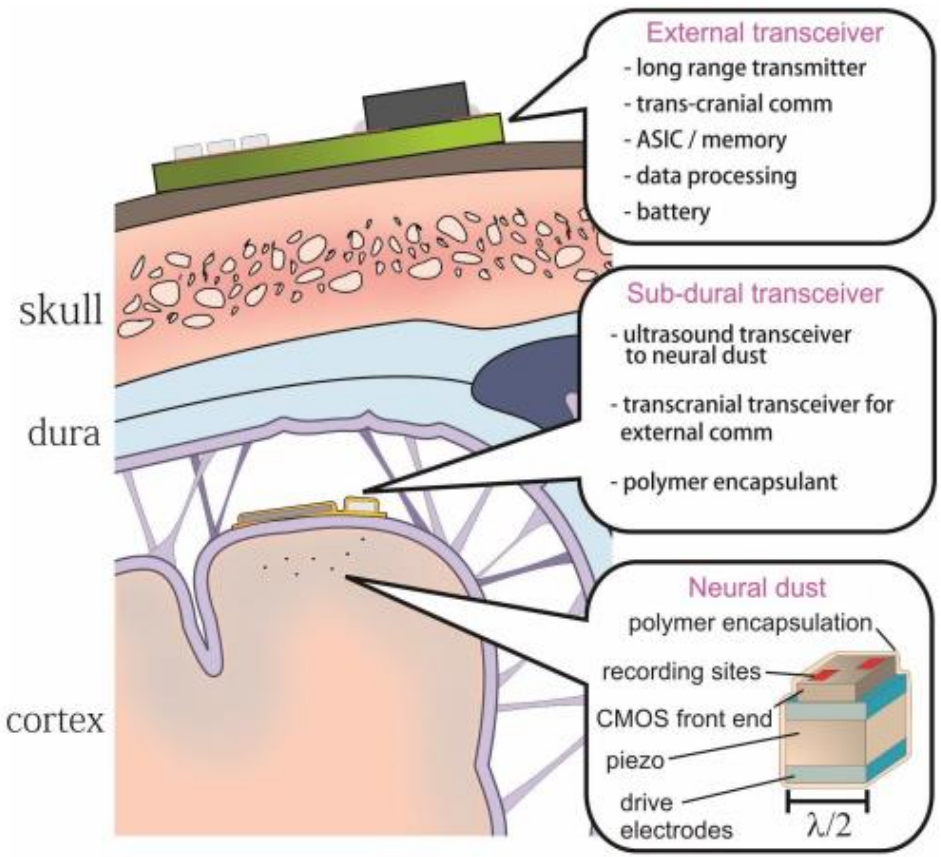


Fig. 1. Neural dust system diagram showing the placement of ultrasonic interrogator under the skull and the independent neural dust sensing nodes dispersed throughout the brain.

Neuron
Volume 91, Issue 3, 3 August 2016, Pages 529–539
Cover image
NeuroResource
Wireless Recording in the Peripheral Nervous System with Ultrasonic Neural Dust

Dongjin Seo1, 4, Ryan M. Neely2, 4, Konlin Shen1, Utkarsh Singhal1, Elad Alon1, Jan M. Rabaey1, Jose M. Carmena1, 2, 3, 5, , , Michel M. Maharbiz1, 3, 5, ,

https://arxiv.org/pdf/1307.2196v1.pdf

Modular Prosthetic Limb: Johns Hopkins (Shoulder level amputee)

- https://youtu.be/9NOncx2jU0Q
- 2015
- https://www.youtube.com/watch?v=x_zGiqV7Bmk

https://vimeo.com/114880353

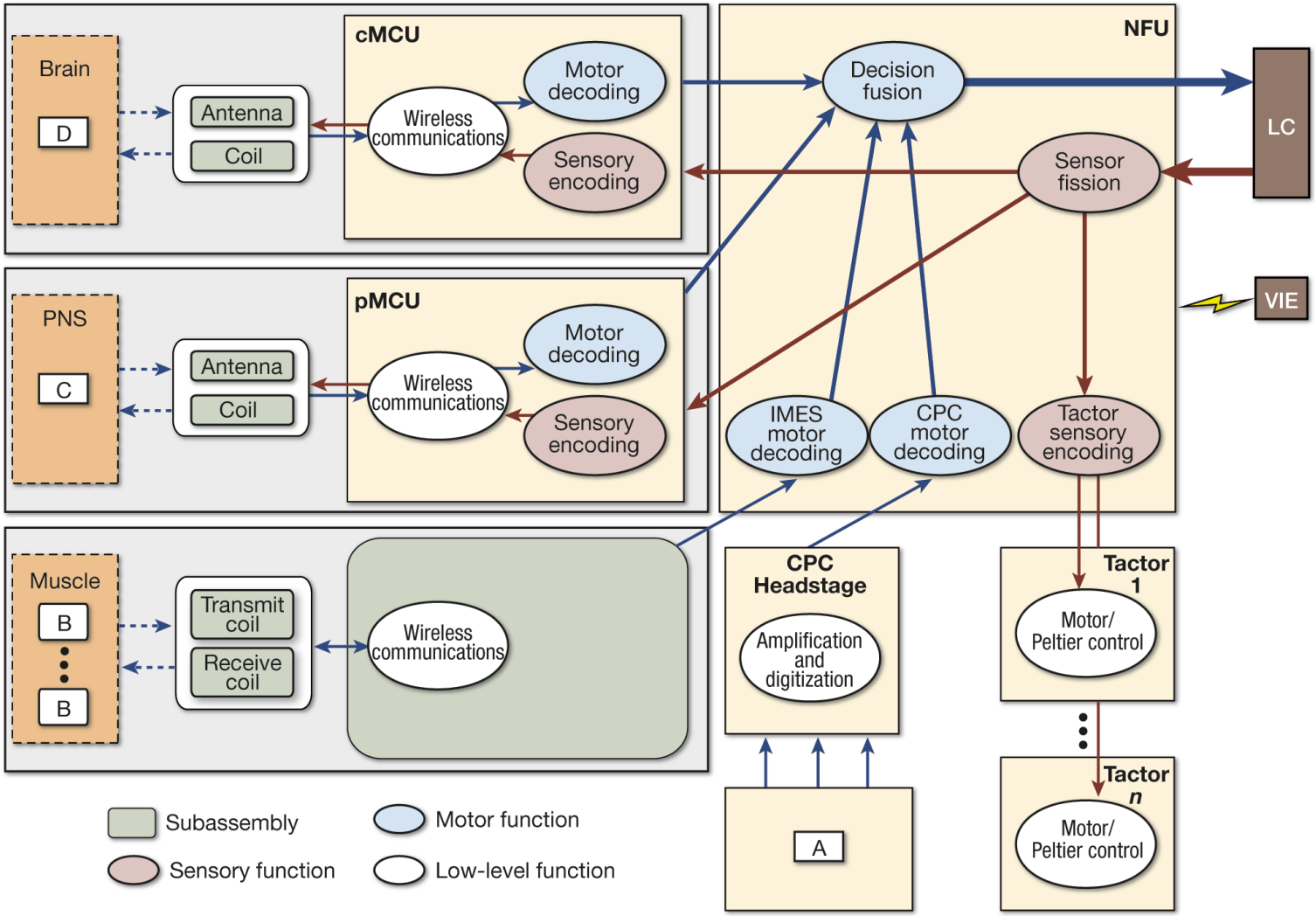
https://www.youtube.com/watch?v=9NOncx2jU0Q&feature=youtu.be

Modular Prosthetic Limb: Johns Hopkins (Elbow level amputee)

- https://www.youtube.com/watch?v=-0srXvOQlu0

https://vimeo.com/114880353

Modular Prosthetic Limb



Revolutionizing Prosthetics: Neuroscience Framework (*Johns Hopkins APL Technical Digest*, Volume 30, Issue 3, pp. 223–229, 2011)

Summary- FES

- FES using own muscles
- Bion microstimulator approach
- Prosthetic Limb using robotic arms/legs

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- Revolutionizing Prosthetics: Neuroscience Framework (Johns Hopkins APL Technical Digest, Volume 30, Issue 3, pp. 223–229, 2011)