NerveStim: Progress Report

Group 12: Katie Simons, Taylor Lavender, and Jack Elliott-Higgins

NerveStim: Overview

Who is the client?

Why is it needed?

What does it do?

- **Client**: Matthew MacEwan
- **Need Statement:** There is a need for a new pain management therapy for patients suffering from chronic pain post-invasive surgery that does not foster independence and does not require addition surgery for explantation
- **What it does:** This device will include an external controller wirelessly connected to an internal bioresorbable implant. The implant will create a high-frequency alternating current (HFAC) nerve block.

Changes to Preliminary Report

Design specification for Implant

Nerve cuff diameter	1-1.5 mm
Bioresorbable layers	**9.9 (+-) 0.9 nm**
Bioresorbable device viability	**90 days**
Weight	10 g
Electrical stimulation frequency	14kHz – 26kHz
Output voltage	**50-150 mV**
Wireless communication range	4 cm away
Wireless communication frequency	**2.4 GHz**
Wireless communication protocol	Radio frequency
Wireless power range	4 cm away

Biocompatibility	Must be biocompatible
Power source	Rechargeable
Charge length	**Minimum 1 week**
Recharge duration	**Maximum 3 hours**
Implant safety	On/off mechanism
Implant cost	**Less than $200**
Sufficient power	**0.5-200 mW**
Time to completion	**6 months**
Safe current density	**1-10 mA**
HFAC block	**Block necessary**
Adjustable size	**Size should be adjustable**

Changes to Preliminary Report

Design Specifications for Controller

Size	13x18x5 cm
Weight	200 g
Power source	Rechargeable
Communication	Wireless
Wireless communication range	4 cm away
Wireless communication protocol	Radio frequency (RF)
Wireless communication frequency	**2.4 GHz**
Transmission Rate	**At least 3 Mbps**
Wireless power range	4 cm away
Wireless power safety	**0.5 – 200 mW**
Biocompatibility	Does not need to be biocompatible
Transmission Voltage	150-250 mV
Transmission duration	100 – 300 µS
Charge period	**Minimum 1 week**
Recharge duration	**Maximum 3 hours**
Controller cost	**Less than $200**
Compatibility with hardware	**100% compatibility required**
Security	**100% secure**
Energy consumption	**Less than 6 W**
Rechargeability convenience	**Device should not require the patient to spend excessive time recharging it**
Sufficient output	**7-12 V**
Time to completion	**6 months**
Compatibility with battery	**100% compatible**
Accessibility	**Accessible for all patients – it is not prohibitively expensive and does not depend on smartphone ownership**

Design Alternatives: Overview

- Six Categories of Design:
  - Data Transmission
  - External Power
  - Internal Power
  - Controller Configuration
  - Computer Hardware
  - Electrode Configuration

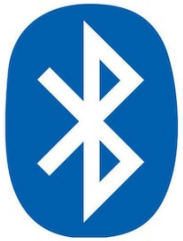
Design Alternatives:
Data Transmission

1. Wifi
2. Bluetooth
3. Zigbee
4. Thread

Wifi

- Advantages
  - Data transmission frequency
  - Security features
  - High data throughput
- Disadvantage
  - Expensive
  - Not as compatible with Arduino
  - Susceptible to security breaches

Bluetooth



- Advantages
  - Data transmission frequency
  - Transmission power
  - Secure
  - Compatible with hardware
- Disadvantages
  - Range of communication
  - Slow transmission rate

Design Alternatives:
Data Transmission

1. Wifi
2. Bluetooth
3. Zigbee
4. Thread

Design Alternatives:
Data Transmission

1. Wifi
2. Bluetooth
3. Zigbee
4. Thread

Table 1. Pugh Chart: Data Transmission

Specification	Weight	Potential Solutions			
Legend 10: Most Preferred 0: Least Preferred		WiFi	Bluetooth	Zigbee	Thread
Safety	10	10	10	10	10
Production Cost	8	7	8	8	7
Compatibility with Hardware	10	9	10	5	5
Security	9	7	9	9	9
Wireless	10	10	10	10	10
Transmission Rate	7	7	6	5	5
Communication Range	5	5	5	5	5
Communication Frequency	5	5	5	5	5
Energy Consumption	7	5	6	7	6
Weighted Total		65	69	64	62

Design Alternatives: External Power

1. Single Use Alkaline
2. Single Use Lithium
3. Rechargeable NiMH
4. Rechargeable Lithium Ion
5. Plug and Socket

Single Use Lithium

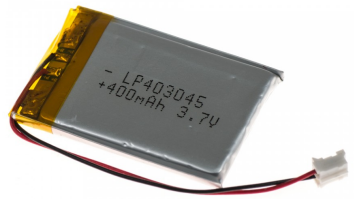
Single Use Alkaline

Design Alternatives:
External Power

1. Single Use Alkaline
2. Single Use Lithium
3. Rechargeable NiMH
4. Rechargeable Lithium Ion
5. Plug and Socket

Rechargeable Lithium

- Advantages
  - Lightweight
  - No need for replacement
  - Longer charge duration
  - High energy density
  - Short charge period
- Disadvantages
  - Very powerful
  - Expensive



Rechargeable Nickel-Metal Hydride (NiMH)

- Advantages
  - Cheap
  - No risk of damage
- Disadvantages
  - Long charge period
  - Short charge duration
  - Lower energy density
  - Incompatible with hardware

Design Alternatives: External Power

1. Single Use Alkaline
2. Single Use Lithium
3. Rechargeable NiMH
4. Rechargeable Lithium Ion
5. Plug and Socket

Plug and Socket

- Advantages
  - Sufficient power
  - Compatible with hardware
- Disadvantages
  - No worldwide standard
  - Safety hazard
  - Requires a socket at all times

Design Alternatives:
External Power

1. Single Use Alkaline
2. Single Use Lithium
3. Rechargeable NiMH
4. Rechargeable Lithium Ion
5. Plug and Socket

Table 2. Pugh Chart: External Power

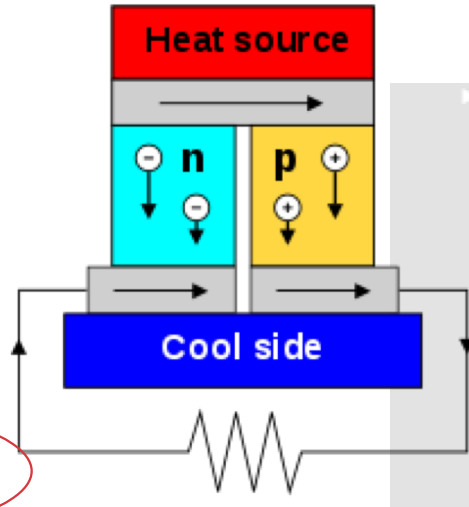
Specification	Weight	Potential Solutions				
Legend 10: Most Preferred 0: Least Preferred		Single Use Alkaline	Single Use Lithium	Rechargeable NiMH	Rechargeable Lithium Ion	Plug and Socket
Safety	10	10	7	10	7	9
Production Cost	8	8	8	7	7	6
Weight	8	7	8	5	6	7
Rechargeability Convenience	7	3	3	7	7	1
Sufficient Output	10	10	0	0	10	10
Charge Period	9	9	9	5	8	9
Charge Duration	8	4	1	8	7	1
Compatibility with Hardware	9	9	0	0	9	9
Weighted Total		60	36	42	61	52

Design Alternatives:
Internal Power

1. Thermoelectric Generator
2. Chemical Energy Battery
3. Piezoelectric Generator
4. Passive Power
5. BIONs

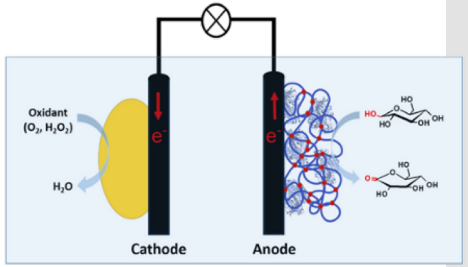
Thermoelectric Generator (TEGs)

- Advantages
  - Power source preexisting
  - Safe
  - Effective
- Disadvantages
  - Insufficient power
  - Costly
  - Not bioresorbable



Chemical Energy Batteries

- Advantages
  - Preexisting power source
  - Safe
- Disadvantages
  - Device lifespan
  - Insufficient power
  - Not bioresorbable

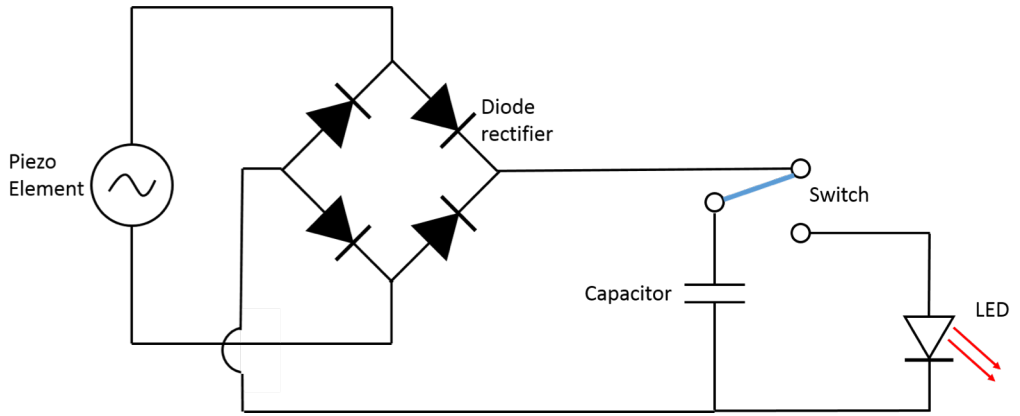


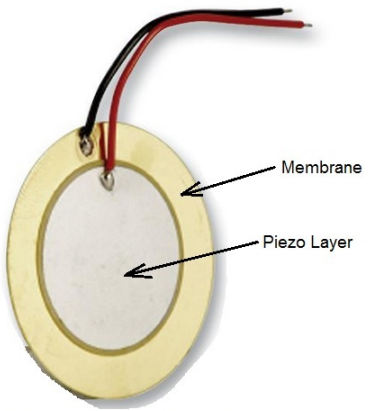
Design Alternatives: Internal Power

1. Thermoelectric Generator
2. Chemical Energy Battery
3. Piezoelectric Generator
4. Passive Power
5. BIONs

Piezoelectric Generator

- Advantages
  - Inexpensive
  - Could be made bioresorbable
- Disadvantages
  - Time cost
  - Power source not preexisting
  - Inefficient power



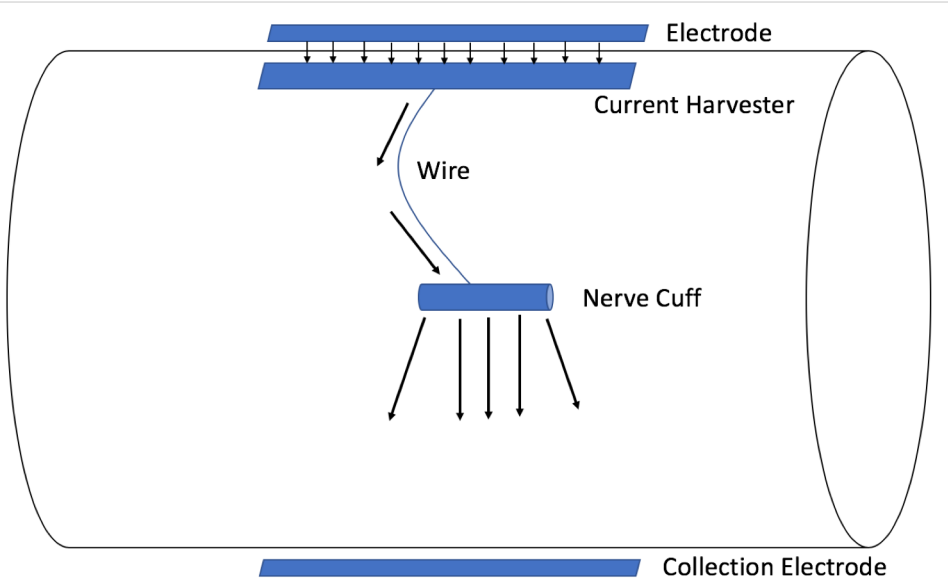


Membrane/Piezo Layer Schematic

ECM 6/14/15

Design Alternatives: Internal Power

1. Thermoelectric Generator
2. Chemical Energy Battery
3. Piezoelectric Generator
4. Passive Power
5. BIONs



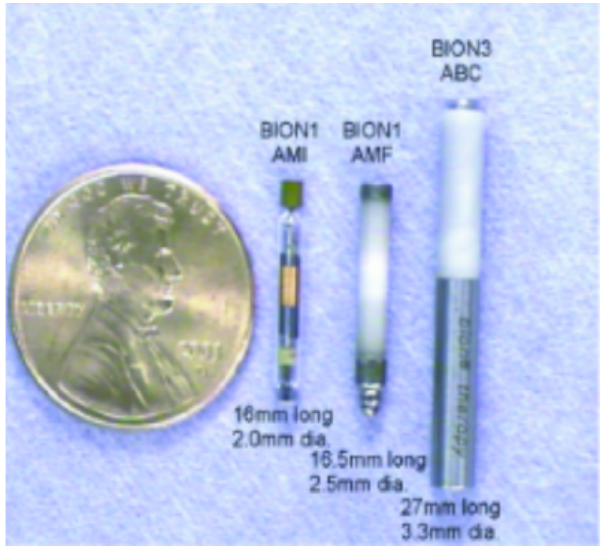
Passive Power

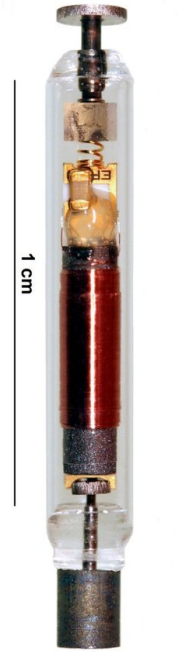
- Advantages
  - Easily controllable
  - Safe
  - Viable
  - Bioresorbable
  - Short production time
- Disadvantages
  - Production cost

Design Alternatives: Internal Power

1. Thermoelectric Generator
2. Chemical Energy Battery
3. Piezoelectric Generator
4. Passive Power
5. BIONs

BIONs





- Advantages
  - Sufficient power
  - Biocompatible
- Disadvantages
  - Production cost
  - Production time
  - Not bioresorbable

Design Alternatives: Internal Power

1. Thermoelectric Generator
2. Chemical Energy Battery
3. Piezoelectric Generator
4. Passive Power
5. BIONs

Table 3. Pugh Chart: Internal power

Specification	Weight	Potential Solutions				
Legend 10: Most Preferred 0: Least Preferred		Thermal Energy Generator	Chemical Energy Battery	Piezoelectric Generator	Passive Powering	BIONs
Device Viability	6	6	2	5	6	6
Sufficient Power	10	0	2	10	10	10
Time to Completion	5	3	3	3	5	1
Safety	10	10	10	10	10	10
Production Cost	8	2	5	8	7	3
Biocompatibility	9	0	0	8	9	5
Weighted Total		21	22	44	47	35

Design Alternatives:
Computer Hardware

1. Arduino
2. Raspberry Pi
3. Waspmote

Arduino

- Advantages
  - Small power consumption
  - Ideal size
  - Cheap
  - Many accessories available
- Disadvantages
  - Weight
  - Communication

Design Alternatives:
Computer Hardware

1. Arduino
2. Raspberry Pi
3. Waspmote

Raspberry Pi

- Advantages
  - Versatile
  - More input/output options
- Disadvantages
  - Weight
  - Size
  - Costly

Design Alternatives:
Computer Hardware

1. Arduino
2. Raspberry Pi
3. Waspmote

Table 4. Pugh Chart: Computer Hardware

Specification	Weight	Potential Solutions		
Legend 10: Most preferred 0: Least preferred		Arduino	Raspberry Pi	Waspmote
Size	9	9	6	7
Production Cost	8	8	8	2
Weight	10	9	8	10
Necessary Power	8	8	8	5
Compatibility with Battery	7	7	7	3
Communication	7	6	7	4
Transmission Voltage	8	8	8	8
Weighted Total		55	52	39

Design Alternatives:
Controller Configuration

1. Full Custom Build
2. Phone app and Custom hardware

Full Custom Build

- Advantages
  - Freedom of design
  - Inexpensive
  - Highly accessible
- Disadvantages
  - No disadvantages seen

Phone app and Custom Hardware

- Advantages
  - Size
  - Inexpensive
- Disadvantages
  - Coding-intensive
  - Accessibility issues
  - Hardware compatibility

Design Alternatives:

Controller Configuration

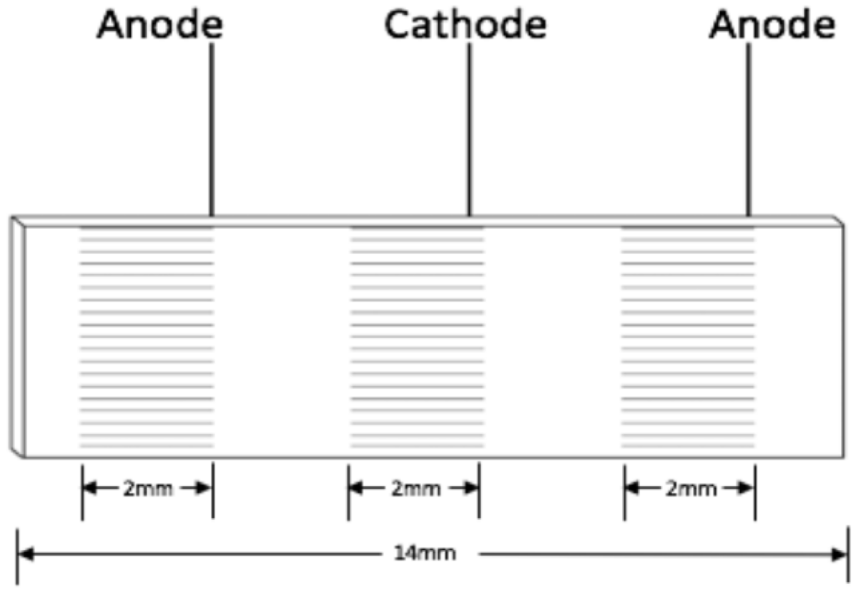
1. Full Custom Build
2. Phone app and Custom hardware

Table 5. Pugh Chart: Controller Configuration

Specification	Weight	Potential Solutions	
Legend 10: Most preferred 0: Least preferred		Custom Build	Phone App / Custom Hardware
Size	10	10	10
Accessibility	10	10	3
Production Cost	8	8	8
Time to Completion	8	8	2
Weight	9	9	9
Power Source	9	9	4
Hardware Compatibility	10	10	1
Safety	10	10	10
Weighted Total		74	47

Design Alternatives:
Electrode Configuration

1. Tripolar ribbon-type cuff electrode
2. Bipolar anode-cathode cuff electrode
3. Dual macro-sieve electrode assembly

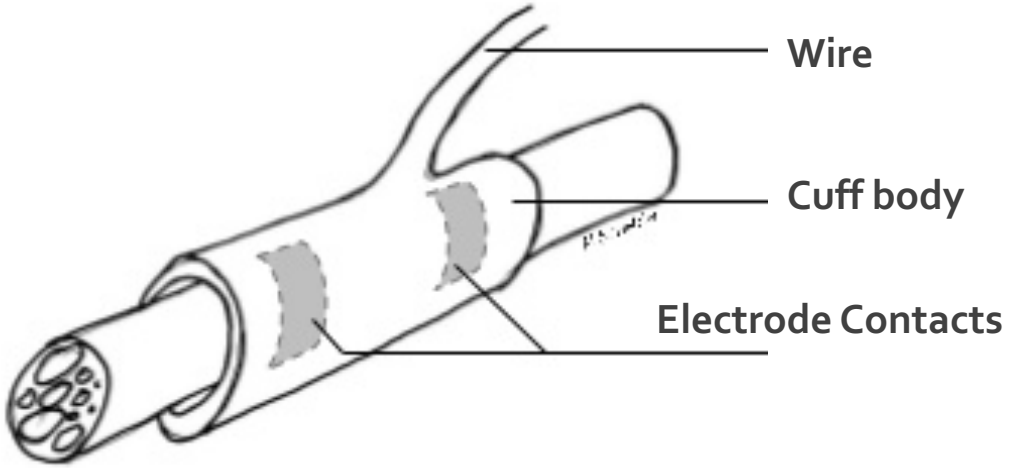


Tripolar ribbon-type cuff electrode

- Advantages
  - HFAC block
  - Adjustable size
  - Safe current density
- Disadvantages
  - Not bioresorbable yet
  - Production cost

Design Alternatives:
Electrode Configuration

1. Tripolar ribbon-type cuff electrode
2. Bipolar anode-cathode cuff electrode
3. Dual macro-sieve electrode assembly

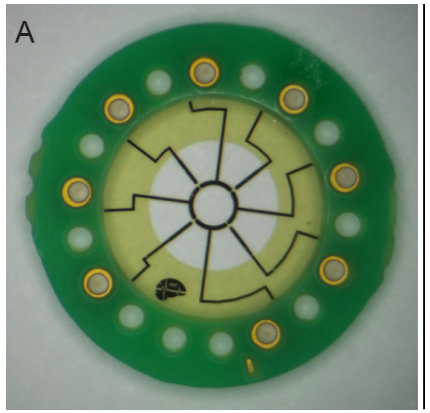


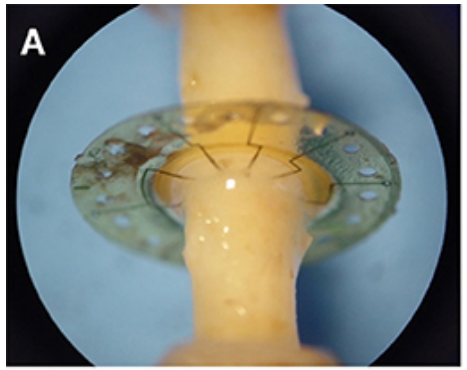
Bipolar anode-cathode cuff electrode

- Advantages
  - Creates HFAC block
  - Bioresorbable
  - Inexpensive
  - Safe current density
- Disadvantages
  - No disadvantages seen

Design Alternatives:
Electrode Configuration

1. Bipolar anode-cathode cuff electrode
2. Tripolar ribbon-type cuff electrode
3. Dual macro-sieve electrode assembly





Dual macro-sieve electrode assembly

- Advantages
  - HFAC block
  - Safe current density
- Disadvantages
  - Production cost
  - Not yet bioresorbable
  - Adjustability

Design Alternatives:
Electrode Configuration

1. Bipolar anode-cathode cuff electrode
2. Tripolar ribbon-type cuff electrode
3. Dual macro-sieve electrode assembly

Table 6. Pugh Chart: Electrode Configuration

Specifications	Weight	Potential Solutions		
Legend 10: Most Preferred 0: Least Preferred		Bipolar anode-cathode	Tripolar ribbon type	Dual macro-sieve
Safe current density	10	10	10	10
HFAC block	9	8	8	7
Bioresorbable	10	10	8	8
Production Cost	8	8	7	6
Adjustable size	5	5	5	4
Weighted Total		41	38	35

Overview of Chosen Solution

Issue 1: Bluetooth

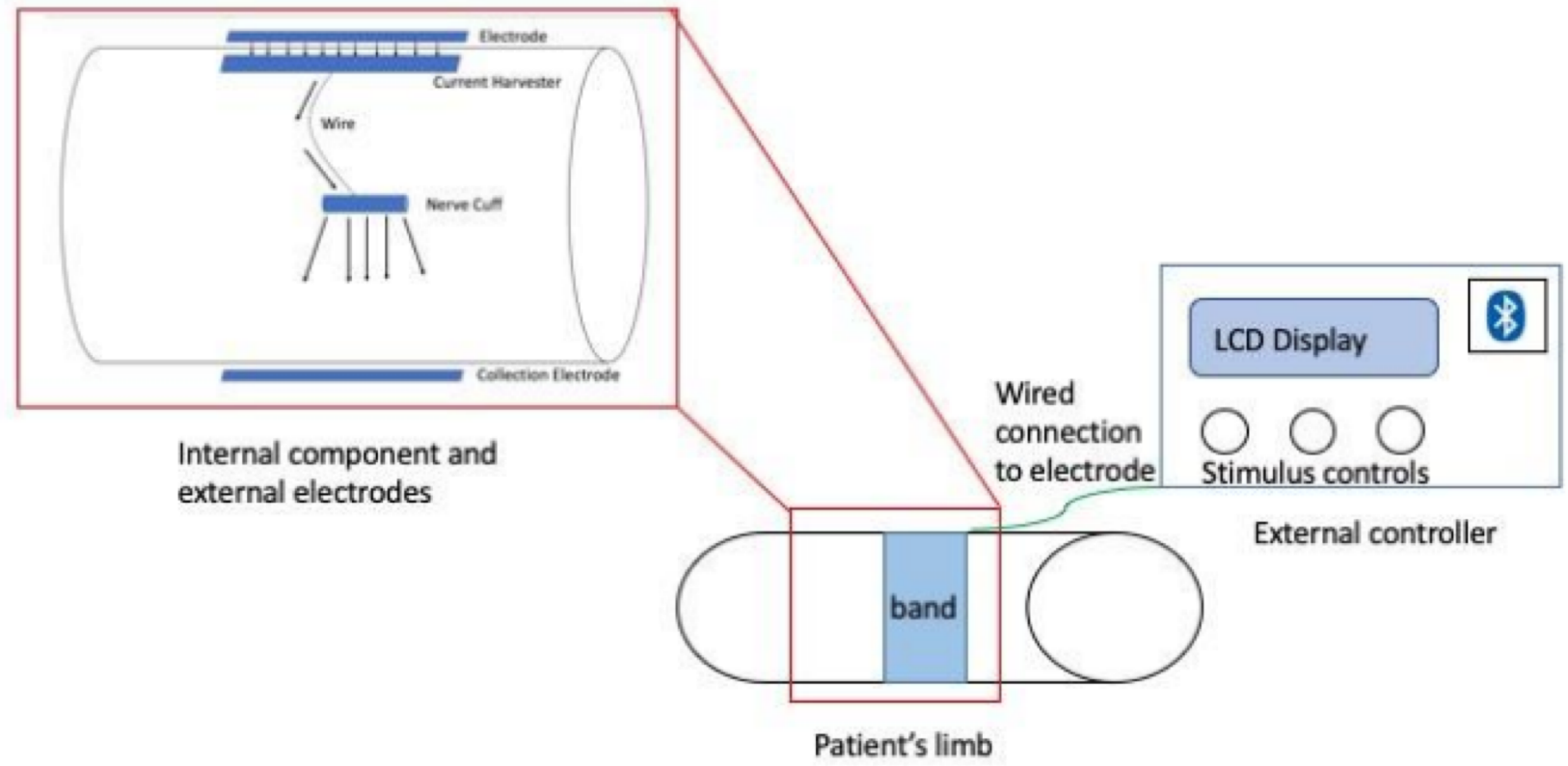
Issue 2: Rechargeable Lithium Ion Battery

Issue 3: Passive Power

Issue 4: Arduino

Issue 5: Full custom build

Issue 6: Bipolar cuff electrode



Questions?

Sources

1. Pullen, John Patrick. "Here's How Wi-Fi Actually Works." Time, Time, 24 Apr. 2015, time.com/3834259/wifi-how-works/.
2. "Bluetooth vs Wi-Fi." Bluetooth vs Wi-Fi - Difference and Comparison | Diffen, www.diffen.com/difference/Bluetooth_vs_Wifi.
3. Franklin, Curt. "How Bluetooth Works." HowStuffWorks, 28 June 2000, electronics.howstuffworks.com/bluetooth4.htm.
4. Rouse, Margaret. "What Is Zigbee? - Definition from WhatIs.com." IoT Agenda, 2017, internetofthingsagenda.techtarget.com/definition/ZigBee.
5. Stables, James. "Zigbee Explained: Plus the Best Devices That Use It." The Ambient, 11 Sept. 2018, www.the-ambient.com/guides/zigbee-devices-complete-guide-277.
6. Pfeil, Alisa. "Press Releases." Introducing Thread: A New Wireless Networking Protocol for the Home > Thread Group, 15 July 2014, www.threadgroup.org/news-events/pressreleases/ID/20/Introducing-Thread-A-New-Wireless-Networking-Protocol-for-the-Home.
7. Parrish, Kevin. "ZigBee, Z-Wave, Thread and WeMo: What's the Difference?." Smart Home. 12 Dec. 2017, https://www.tomsguide.com/us/smart-home-wireless-networkprimer,news-21085.html.
8. Bausch, Jeffrey. "Rechargeable Battery vs Regular Battery." Electronic Products, 23 Sept. 2016, www.electronicproducts.com/Power_Products/Batteries_and_Fuel_Cells/Rechargeable_ battery_vs_regular_battery.aspx.
9. "How to Choose Batteries." REI, www.rei.com/learn/expert-advice/batteries.html.
10. Leakeem, John. "NiMH vs. Li-Ion: A Battery Comparison." TurboFuture, 24 Mar. 2017, turbofuture.com/misc/Which-is-better-Nickel-Metal-Hydride-NiMH-or-Lithium-Ion-Li-ionbatteries.
11. . "A Better Understanding of Rechargeable and Replaceable Batteries." A Better Understanding of Rechargeable and Replaceable Batteries, Omnica Corporation Product Development , www.omnica.com/a-better-understanding-of-rechargeable-andreplaceable-batteries/.
12. "Plug & Socket Types." World Standards, 9 Oct. 2017, www.worldstandards.eu/electricity/plugs-and-sockets/.
13. 13. Romero, Edwar. Powering Biomedical Devices. Elsevier Academic Press, 2013.
14. "Scientific Guide to Understanding and Using TEG Power!" Knowledge Base for Understanding TEGs - TEG Talk, 21 Apr. 2018, www.tegmart.com/info/guide-tounderstanding-and-using-teg-power-and-products/.
15. "Building a Piezoelectric Generator." Teach Engineering, www.teachengineering.org/activities/view/uoh_piezo_lesson01_activity1.
16. Prochazka, et al. "First Permanent Implant of Nerve Stimulation Leads Activated by Surface Electrodes, Enabling Hand Grasp and Release." Neurorehabilitation and Neural Repair, vol. 26, no. 4, 2011, pp. 335–343., doi:10.1177/1545968311420443.
17. Loeb, Gerald E., et al. "The BION Devices: Injectable Interfaces with Peripheral Nerves and Muscles." Neurosurgical Focus, 2006, pp. 1–9., doi:10.3171/foc.2006.20.5.3.

Sources

18. "Tech Specs." Arduino Uno Rev3, 2018, store.arduino.cc/usa/arduino-uno-rev3.

19. "Raspberry Pi 3 Model B+ - Specifications." Raspberry Pi Forums, 2018, www.raspberrypi.org/products/raspberry-pi-3-model-b-plus/.

20. Adafruit Industries. "Raspberry Pi 3 - Model B+ - 1.4GHz Cortex-A53 with 1GB RAM." Adafruit Industries Blog RSS, 2018, www.adafruit.com/product/3775.

21. "Waspmote Technical Overview." Libelium Connecting Sensors to the Cloud R 21

22. Koo, Jahyun, et al. "Wireless Bioresorbable Electronic System Enables Sustained Nonpharmacological Neuroregenerative Therapy." Nature Medicine, Aug. 2018, doi:10.1038/s41591-018-0196-2.

23. Ray, Soumyajit, "Characterization of the high frequency alternating current block in the rat sciatic nerve using cuff electrodes and macro-sieve electrode" (2017). Engineering and Applied Science Thesis & Dissertations. 265.

24. Arduino Uno Rev3, store.arduino.cc/usa/arduino-unorev3?fbclid=IwAR095wFEDpYxgD9EAHeQzLGkPhuivyd5qn7z8TjhBQI7wRvBzsH1iQ5M-Q.

25. "HiLetgo HC-05 6 Pin Wireless Bluetooth RF Transceiver Module Serial BT Module for Arduino." Amazon, Amazon, www.amazon.com/HiLetgo-Wireless-BluetoothTransceiver-Arduino/dp/B071YJG8DR.

26. "TRIBE Water Resistant Cell Phone Armband Case." Amazon, Amazon, https://www.amazon.com/Resistant-Armband-Samsung-AdjustableElastic/dp/B00SXRXUFE/ref=sr_1_1_sspa?ie=UTF8&qid=1543247625&sr=8-1- spons&keywords=arm+band&psc=1.

27. "TENS Electrodes - Value Wired 2x4 Replacement Pads for TENS Units." Amazon, Amazon, https://www.amazon.com/TENS-Electrodes-Value-ReplacementDiscount/dp/B01MRJ93AK/ref=sr_1_16_a_it?ie=UTF8&qid=1543259155&sr=8- 16&keywords=tens%2Belectrode&th=1.

28. "EBL 9V Li-ion Rechargeable Batteries (2PC) Smart 9V Battery Charger." Amazon, Amazon, https://www.amazon.com/EBL-Rechargeable-Batteries-BatteryCharger/dp/B079G37Y61/ref=sr_1_8?ie=UTF8&qid=1542651313&sr=8- 8&keywords=rechargable+batteries+9v. 22

29. "Parts Express 9V Battery Clip (2 Pack)." Amazon, Amazon, https://www.amazon.com/Parts-Express-Battery-ClipPack/dp/B01IFP0N3U/ref=sr_1_7?ie=UTF8&qid=1542651064&sr=8- 7&keywords=9v+battery+connector.

30. Adafruit Industries. "Assembled Standard LCD 16x2 + Extras - White on Blue." Adafruit Industries Blog RSS, www.adafruit.com/product/1447.

31. Adafruit Industries. "Breadboard Trim Potentiometer." Adafruit Industries Blog RSS, www.adafruit.com/product/356.

32. Adafruit Industries. "Potentiometer Knob - Soft Touch T18 - White." Adafruit Industries Blog RSS, www.adafruit.com/product/2047.

33. Adafruit Industries. "Half-Size Breadboard." Adafruit Industries Blog RSS, www.adafruit.com/product/64.

34. Adafruit Industries. "Breadboard-Friendly SPDT Slide Switch." Adafruit Industries Blog RSS, www.adafruit.com/product/805.

35. "22 AWG Light Blue Solid Tinned-Copper Hook-Up Wire 100 Feet." How It Works: Xbox Kinect, www.jameco.com/z/9313-LB-22-AWG-Light-Blue-Solid-Tinned-Copper-Hook-UpWire-100-Feet_36768.html.

36. "CJMCU AD9833 Function Generator Module." Amazon, Amazon, www.amazon.com/CJMCU-9833-AD9833-AD9833BRMZ-squaretriangle/dp/B073TWLHLZ.

37. "Charging by Conduction." The Physics Classroom, www.physicsclassroom.com/class/estatics/Lesson-2/Charging-by-Conduction.

38. "Charging by Induction." The Physics Classroom, www.physicsclassroom.com/class/estatics/Lesson-3/Charging-by-Induction.

Slide Appendix

Design Alternatives:
Data Transmission

1. Wifi
2. Bluetooth
3. Zigbee
4. Thread

Zigbee

- Advantages
  - Transmission frequency
  - Inexpensive
  - Low power rate
  - Range of communication
- Disadvantages
  - Incompatible with hardware
  - Low data communication rate

Thread

- Advantages
  - Low power
  - Secure
  - Transmission frequency
- Disadvantages
  - Incompatible with hardware
  - Low data communication rate

Design Alternatives: External Power

1. Single Use Alkaline
2. Single Use Lithium
3. Rechargeable NiMH
4. Rechargeable Lithium Ion
5. Plug and Socket

Single Use Lithium

- Advantages
  - Safe
  - Lightweight
- Disadvantages
  - Insufficient output
  - Potential of corrosion
  - Incompatible with hardware

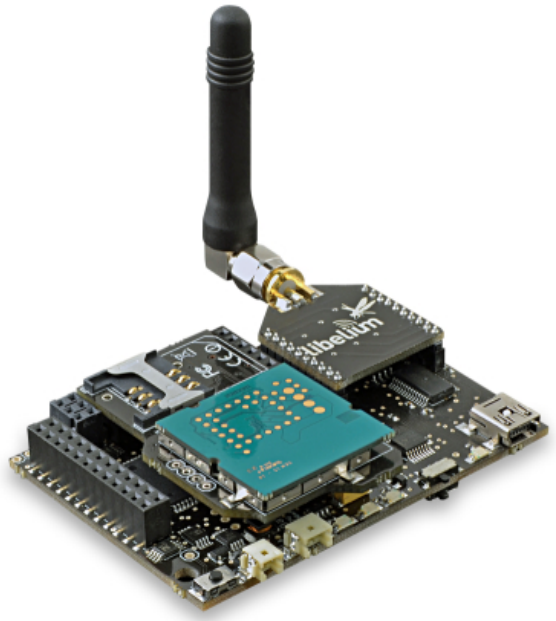
Single Use Alkaline

- Advantages
  - Safe
  - Sufficient output
  - Compatible with hardware
  - Cheap
- Disadvantages
  - Cannot recharge
  - Potential for corrosion

Design Alternatives:
Computer Hardware

1. Arduino
2. Raspberry Pi
3. Waspmote

Waspmote



- Advantages
  - Complex
  - Compatible and versatile
  - Lightweight
- Disadvantages
  - Extremely expensive
  - Communication

Budget

Table 7. Budget			
Item	**Quantity**	**Cost**	**Source**
Arduino Uno Rev3	1	$22	Arduino Store
HC-05 Bluetooth Transceiver	1	$8.50	Amazon
Band	1	$20	Amazon
TENS Electrodes	1 pack	$9.95	Amazon
Battery	2	$17	Amazon
Battery connector	1	$5	Amazon
LCD Screen	1	$11	Adafruit
Potentiometer	3	$3.75 ($1.25 each)	Adafruit
Potentiometer Knobs	3	$1.50 ($0.50 each)	Adafruit
Half-size Breadboard	1	$5	Adafruit
Power Switch	1	$0.95	Adafruit
Wiring	100 feet	$8.50	Jameco Electronics
Function Generator	1	$10	Amazon
Bioresorbable Implant	1	$0	Dr. MacEwan
3D Printed Casing	1	$0	BME Department
Total		**$123.15 (before tax)**	