# THE ULTIMATE BIONIC ARM (T.U.B.A)

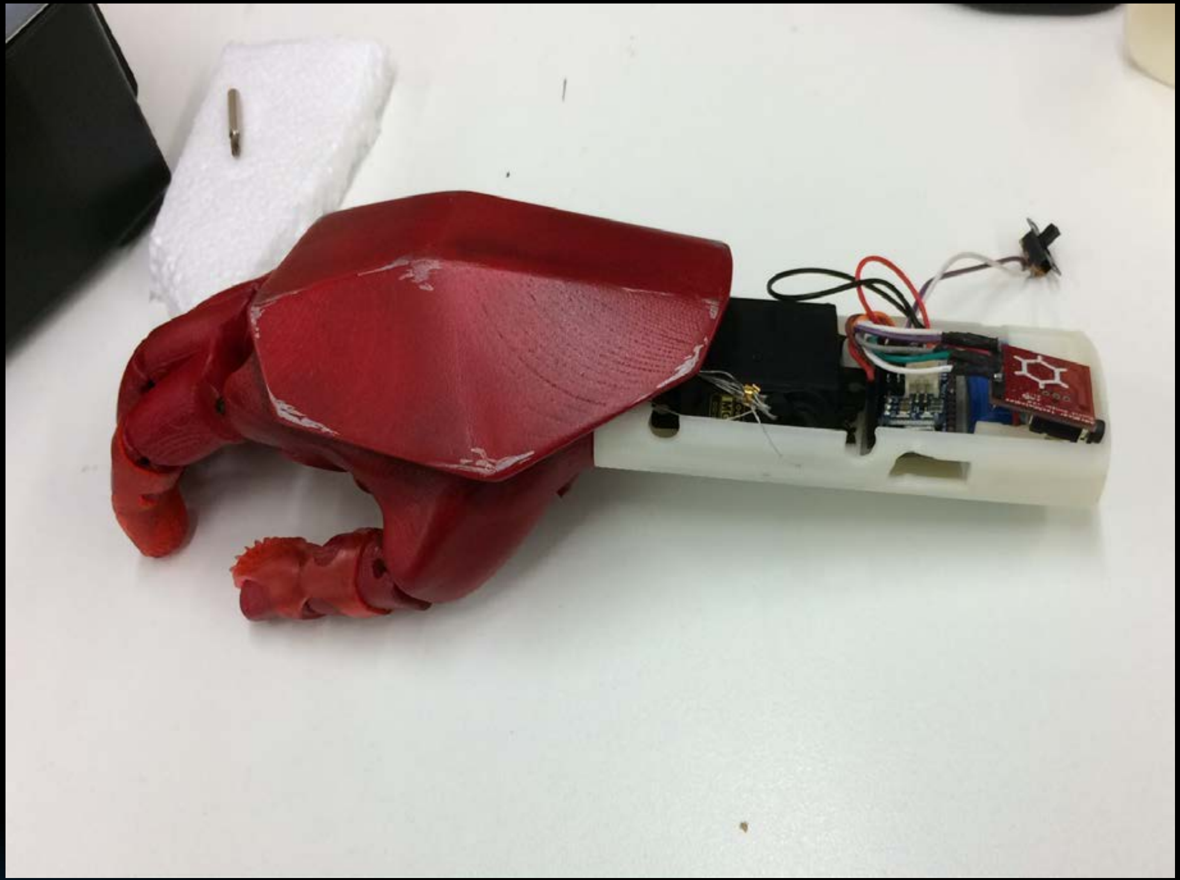
Group 14

- Carolus Andrews - EE
- Ray Brunkow - EE
- Wesley Mullins - EE
- Blake Steiner - EE

# BACKGROUND

- Limbitless makes low cost bionic limbs for children.
- On average, prosthetics cost $20,000 minimum.
- Insurance companies avoid buying for children since they will outgrow the prosthetic in a few years.

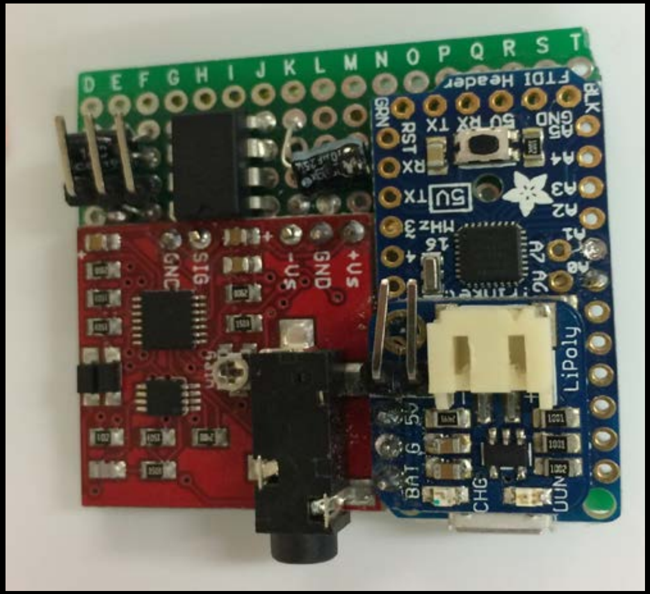
# CURRENT SOLUTION

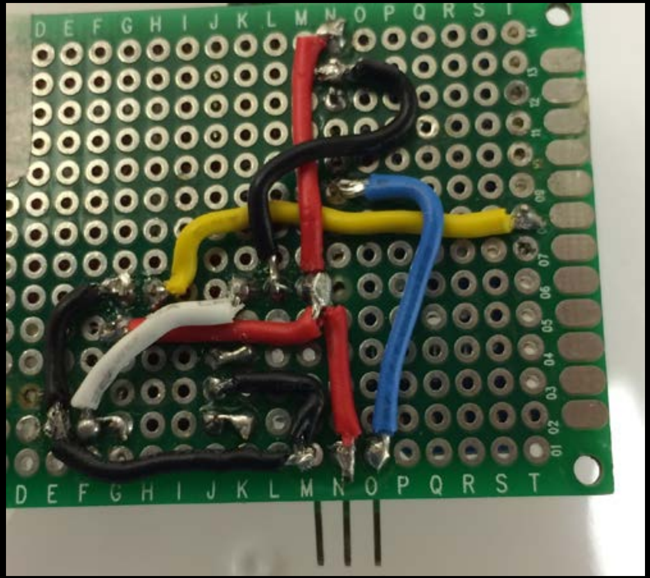


- ❖ Simple functionality.
- ❖ Potential risk of damaging components with an open housing.
- ❖ Connected by jumper cables that are easily disconnected.
- ❖ Combination of multiple development boards.
- ❖ Features loose components.

# PROTOBOARD VARIATION

- Features more unified electronics than the previous model.
- Utilizes a Protoboard, with pins soldered to a predetermined configuration.
- Development boards contain several features not being utilized by the arm, increasing both size and cost of the build.
- Design functionality is very dependent on the skills of the assembler.



# REASONS FOR CHANGE

The current electronics are unstable, with most only being functional for about an hour of use. After this duration, individual components are prone to malfunction.

Battery lifespan of the arm is inadequate and the electronics are sensitive to a low charge.

Expansion is limited due to the larger size of the development boards.

The complex nature of the current solution often results in wasted components, as Limbitless' production team has identified the probability of a successful electronic integration as low as 0.45.

# PROJECT DESCRIPTION

Limbitless Solutions has tasked this team to redesign the electronics behind the Limbitless bionic arm. This includes introducing new functional modules, increasing efficiency in areas such as power and response time, unifying the electronics, and protecting the components from environmental hazards.

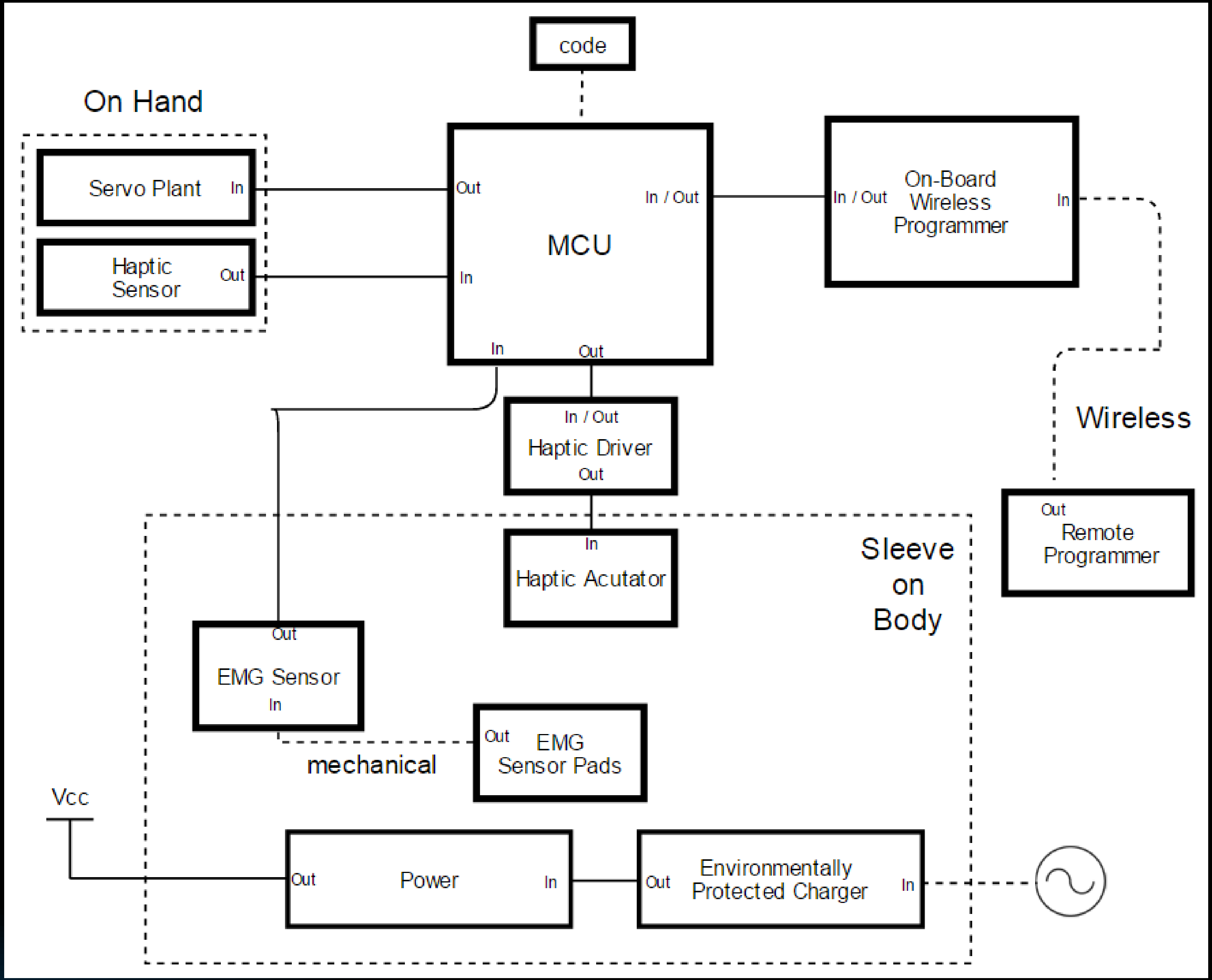
This solution will be a demonstration of what is possible. Limbitless will then decide what components they want to use in future designs.

# GOALS AND OBJECTIVES

- Maintain Design Features
- Unify the electronics
- Update the microcontroller
- Improve the software
- Integrate a haptic feedback system
- Environmentally protect the electronics
- Protect the device from user tampering
- Improve the charging system
- Incorporate a form of wireless updating
- Maintain affordability
- Allow for design expansion and
- Keep the design lightweight

# SPECIFICATIONS

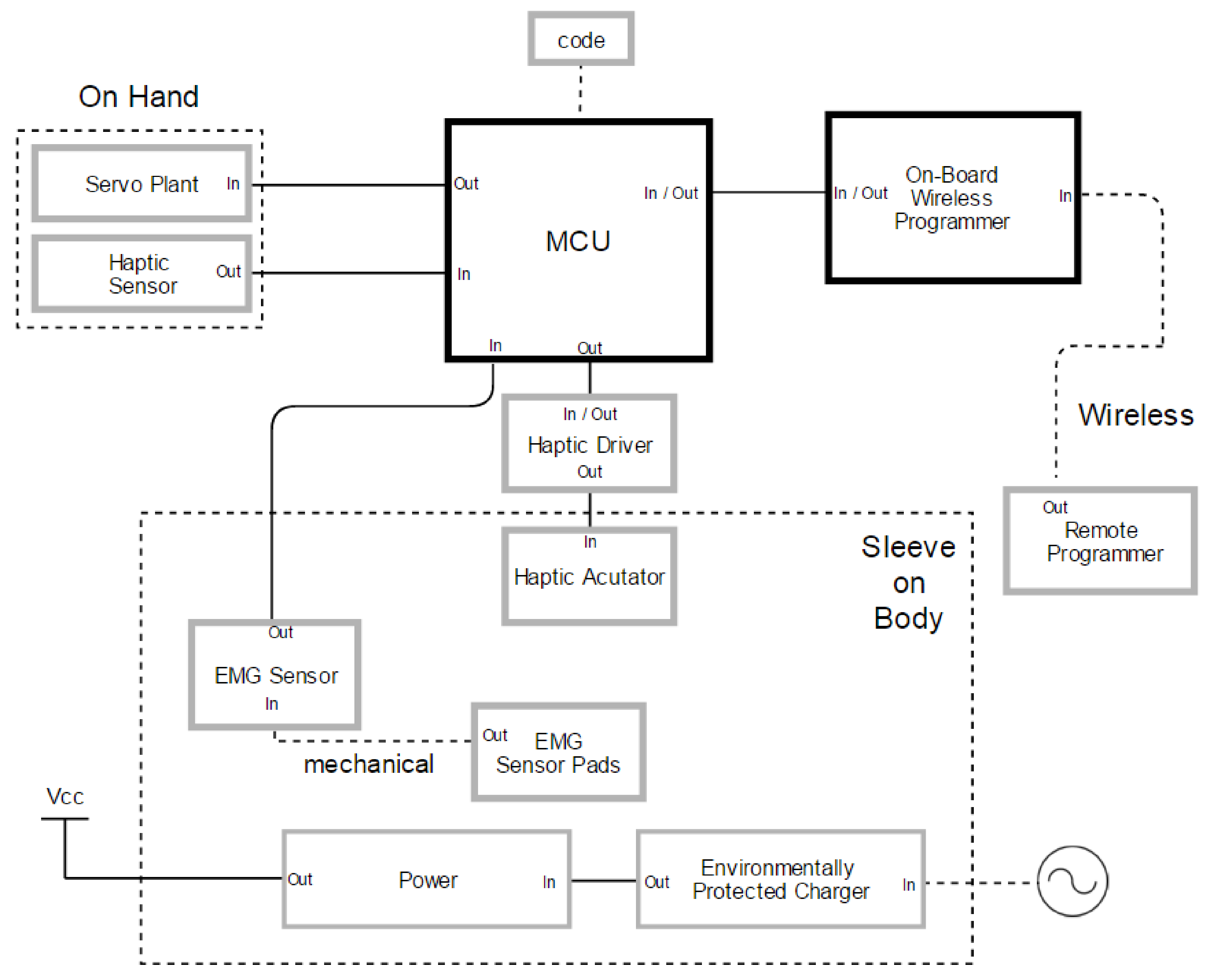
| Description | Quantifiable Specification |
|---|---|
| Electronics Weight | Less than 1.4 kg |
| Battery Life | 10 Hours Standard Usage |
| Price (wholesale) | Under $350 for the overall design |
| Environmental Protection | At least IP27 |
| Wireless Programmable Range | Minimum of 3 meters |
| Charge Time From Entirely Drained Battery | Less than 8 Hours |




# BLOCK DIAGRAM

# PROJECT RESPONSIBILITIES

| Task | Carolus Andrews | Raymond Brunkow | Wesley Mullins | Blake Steiner |
|---|---|---|---|---|
| MCU Hardware | Primary | | Secondary | |
| Programming | Secondary | | Primary | Secondary |
| PCB Design | Primary | | Secondary | |
| Haptic Feedback | | | | Primary |
| Charging | Secondary | Primary | | |
| Power | | Primary | | Secondary |
| Environmental Protection | | Secondary | | Primary |
| EMG Sensing | | | Primary | |
| Servo | | Primary | Secondary | |


code
On Hand
Servo Plant
In
Haptic Sensor
Out
MCU
Out
In
In / Out
In
Out
On-Board Wireless Programmer
In / Out
In
Wireless
In / Out
Haptic Driver
Out
In
Haptic Acutator
Sleeve on Body
Out
Remote Programmer
Out
EMG Sensor
In
mechanical
Out
EMG Sensor Pads
Vcc
Out
Power
In
Out
Environmentally Protected Charger
In

# OVER THE AIR PROGRAMMING

- Wi-fi was discredited as a solution due to both power issues and fear of third party intrusion.
  - Perception of intrusion a far greater problem than actual intrusion

- UWB was discredited due to the level of effort needed for integration and lack of readily available parts. In addition, Zigbee and Bluetooth are already present at the plug and play level on several devices.

- Zigbee, while comparable to Bluetooth, was not discredited, but moved away from due to the nature of request from Limbitless. As they ideally wish to perform updates from a computer, which comes with Bluetooth as a standard today, the choice was easily Bluetooth

# CLASS 2 BLUETOOTH LOW ENERGY

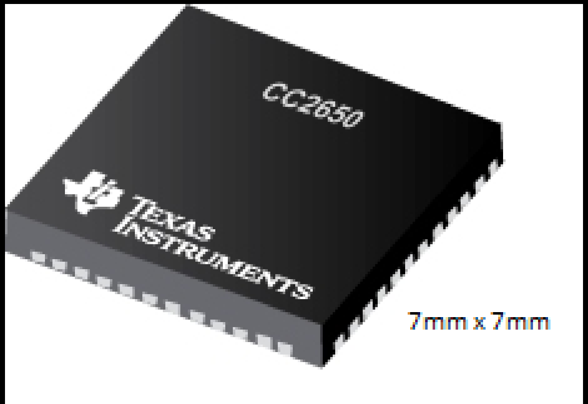
- The CC2650 operates as a class II device at 2.4 GHz. This means the device's effective range is up to 10 meters, while only drawing 2.5 mW of power.

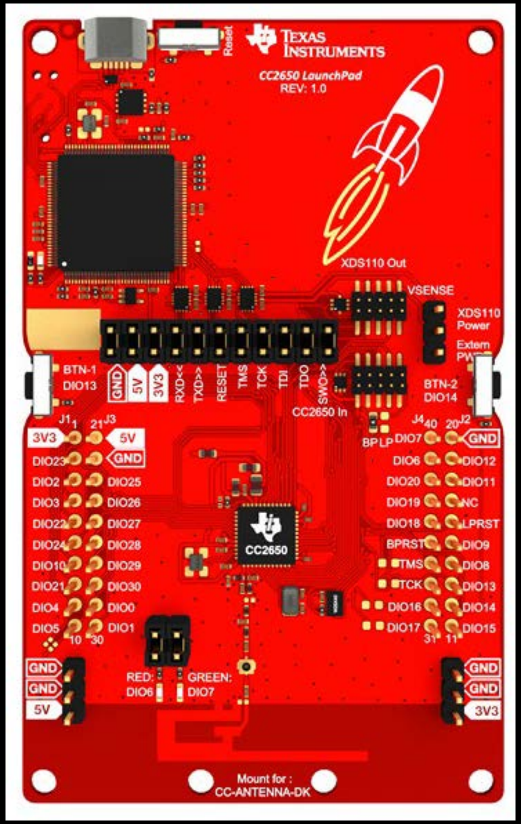
- Bluetooth Low Energy(BLE) can transmit data at speeds of up to 1 Mbps, which is more than sufficient for simple firmware updates.

- The ability exists to implement a timer to only turn the Bluetooth subsystem on when a reprogram request is made in software, and timeouts will ensure that the subsystem's active piconet does not remain active to draw power.

# MICROCONTROLLER

- Texas Instruments CC2650 was chosen due to its ability to serve as a single chip solution
  - Original proposed solution was the CC2560 and MSP430 with FRAM technology working in sync. The 2560 offers the ability to flash the internal memory of the MSP430.
- More expensive than several other MCU options alone, but does not require a second chip to process OTA data, only an external flash source to temporarily store it. Ultimately, it is a far superior solution in terms of cost, power, and board space.
- Prototyping is made easy through the LaunchXL-CC2650 Launch Pad, as well as the TI Sensor tag Module
- CC2650 provides its own internal 1.8 V regulator powered by its 3.3 main input to further reduce power consumption
- 128 KB of internal flash for program storage



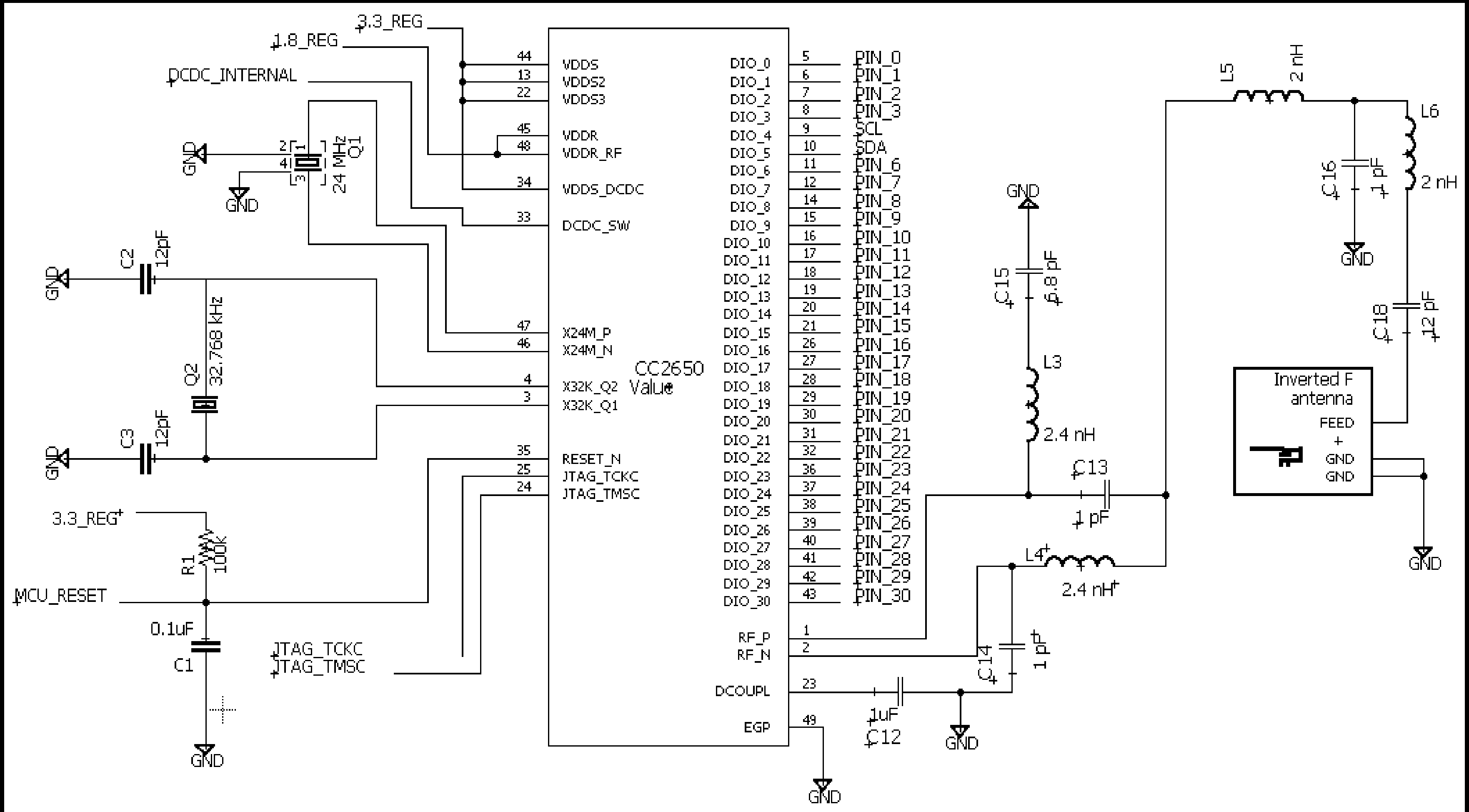
# MICROCONTROLLER CHOICES

| Parameter | MSP430FR5969 | ATMega328 | CC2650 | ATTiny828 |
|---|---|---|---|---|
| Architecture | 16-bit RISC | 8-Bit | 16-Bit | 8-bit RISC |
| Smallest Footprint | VQFN: 6mm x 6mm | VHHD: 5.00mm x 5.00mm | VQN: 7.00mm x 7.00mm | MLF: 5.00 mm x 5.00 mm |
| Input Voltage Range | 1.8 V - 3.6 V | 1.8 V - 5.5 V | 1.8 V – 3.8 V | 1.8 V - 5.5 V |
| Power Consumption, Active Mode | $100 \frac{\mu A}{MHZ}$ | $200 \frac{\mu A}{MHz}$ | $61 \frac{\mu A}{MHz}$ | 0.2 mA, @1.8 V, 1 MHz |
| Power Consumption, Standby | $0.4 \frac{\mu A}{MHZ}$ | $0.75 \frac{\mu A}{MHz}$ | 1 $\mu A$ | 30 $\mu A$, @1.8 V, 1 MHZ |
| Maximum Clock Speed | 16 MHz | 20 MHz | 48 MHz | 10 MHz (for chosen power range) |
| Communication Supported | UART, SPI, I2C | UART, SPI, I2C | UART, I2C, I2S, SPI, AES-128 | UART, SPI, I2C |
| PWM | 5 timers, 7 channels each | 3 timers, 6 channels | 4 timers, up to 8 channels | 2 timers, 2 channels each |
| GPIO | 33 | 23 | 30 | 28 |
| ADC | 12-Bit | 8-channel, 10-bit | 8 channel, 12 bit | 10 - Bit |
| Price | $5.06 from Texas Instruments | $4.00 from Mouser Electronics | $6.93 from Texas Instruments | $2.39 from Mouser Electronics |

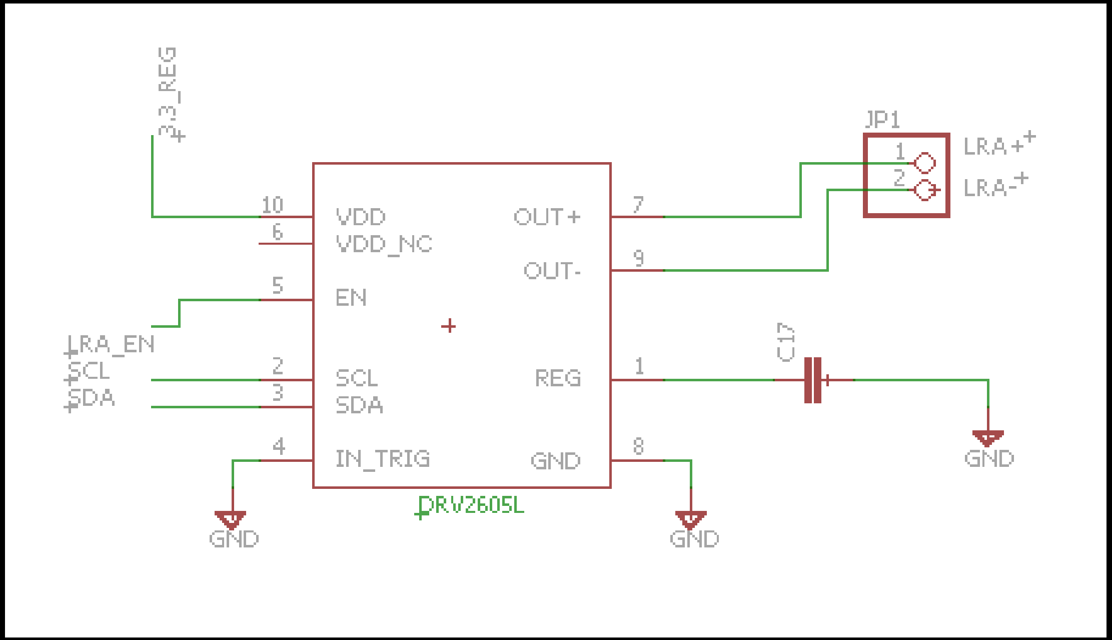
# PCB SCHEMATICS (MCU)

A 24-MHz crystal is required as the frequency reference for the radio. This signal is doubled internally to create a 48-MHz clock

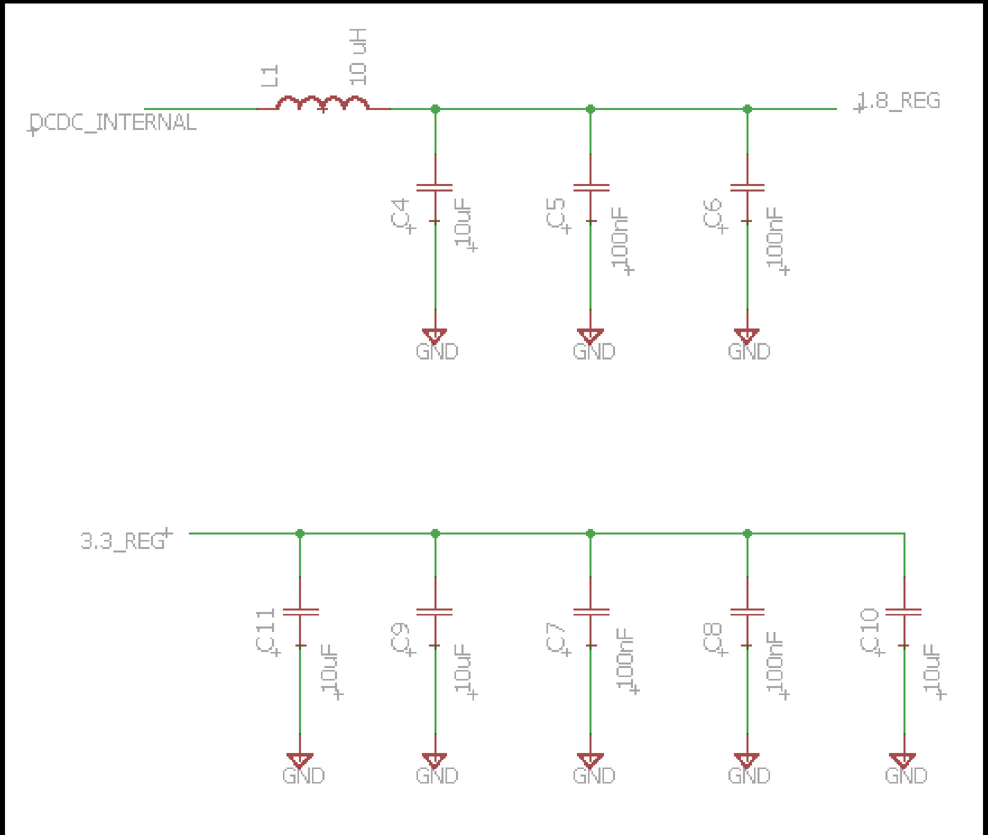
The 32-kHz crystal is optional. BLE requires a slow-speed clock with better than ±500 ppm accuracy for sleep mode to be achievable while maintaining a piconet with an outside system.



# PCB SCHEMATICS (DRV2605, BYPASS CAPS)




DRV2605 is the haptic driver control controlling feedback from the LRA.




Choke and bypass capacitors provide clean DC Power signals throughout the circuit

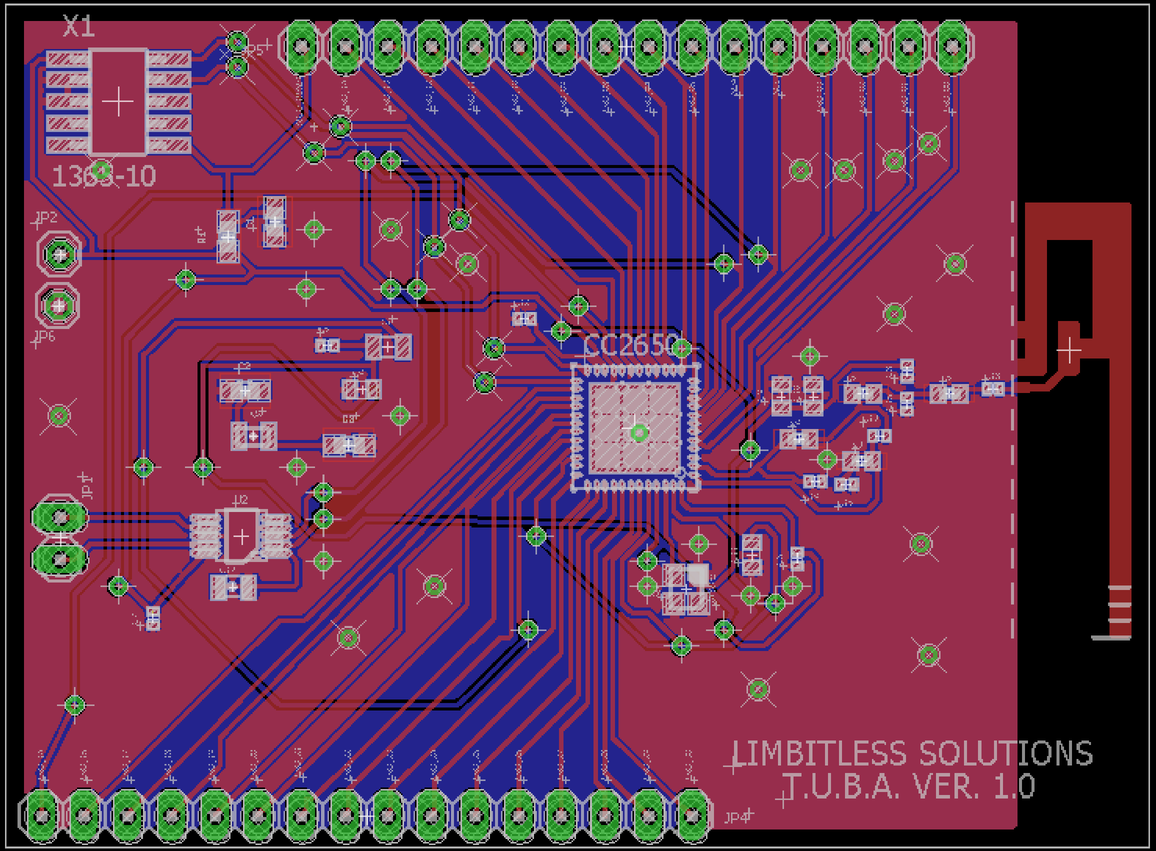
# PRINTED CIRCUIT BOARD

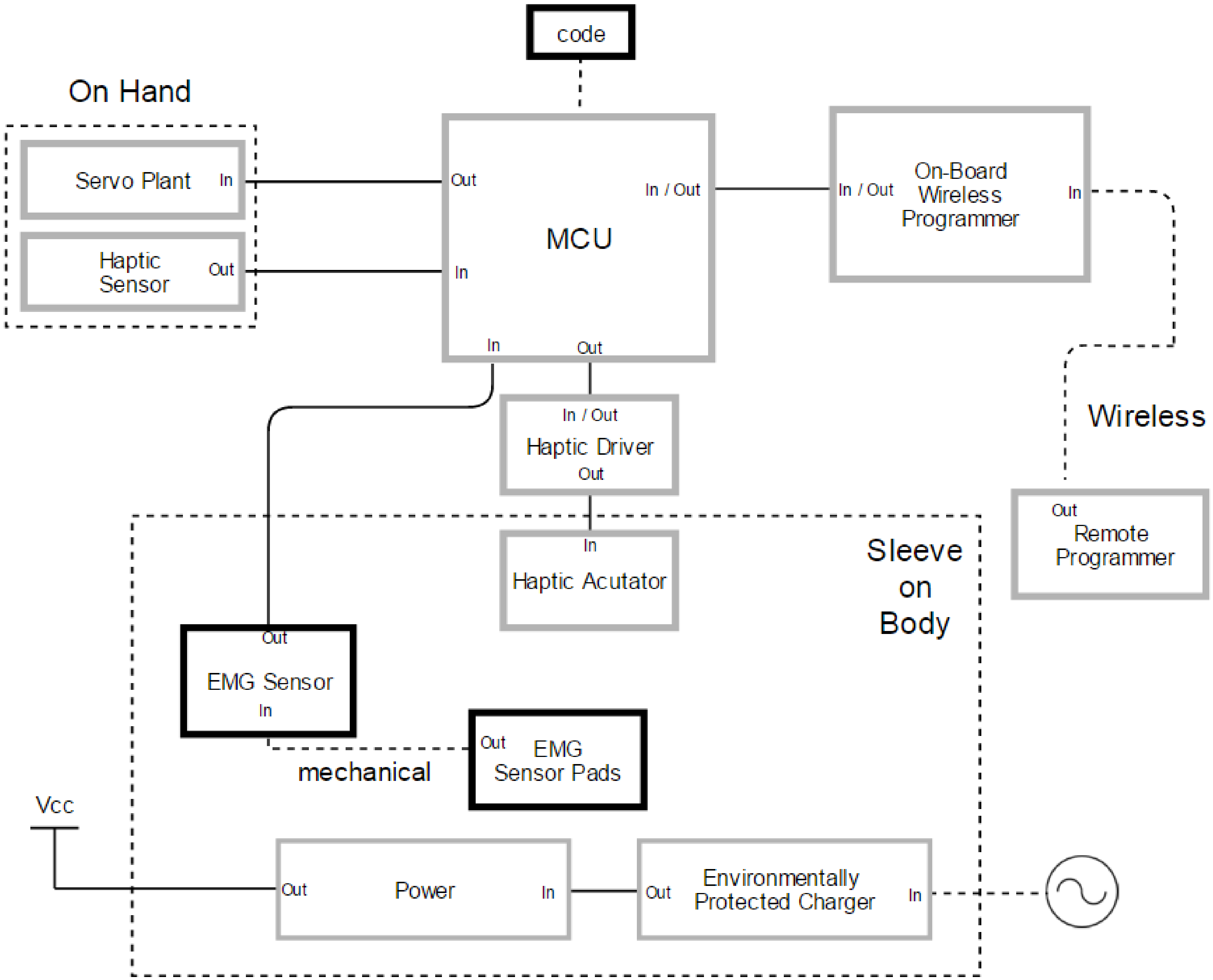
- First version features header pins for every output for analysis, as well as external points for power supply regulation. Designed regulators will be tested at next iteration of design

- Purpose of first design is for testing and overall optimization, as well as iteration of proposed manufacturing process. Final pin assignments may also be made from the breakout pins

- Integrated DN007 inverted F antenna for Bluetooth communication. Antenna is embedded directly within the copper layer of the board.

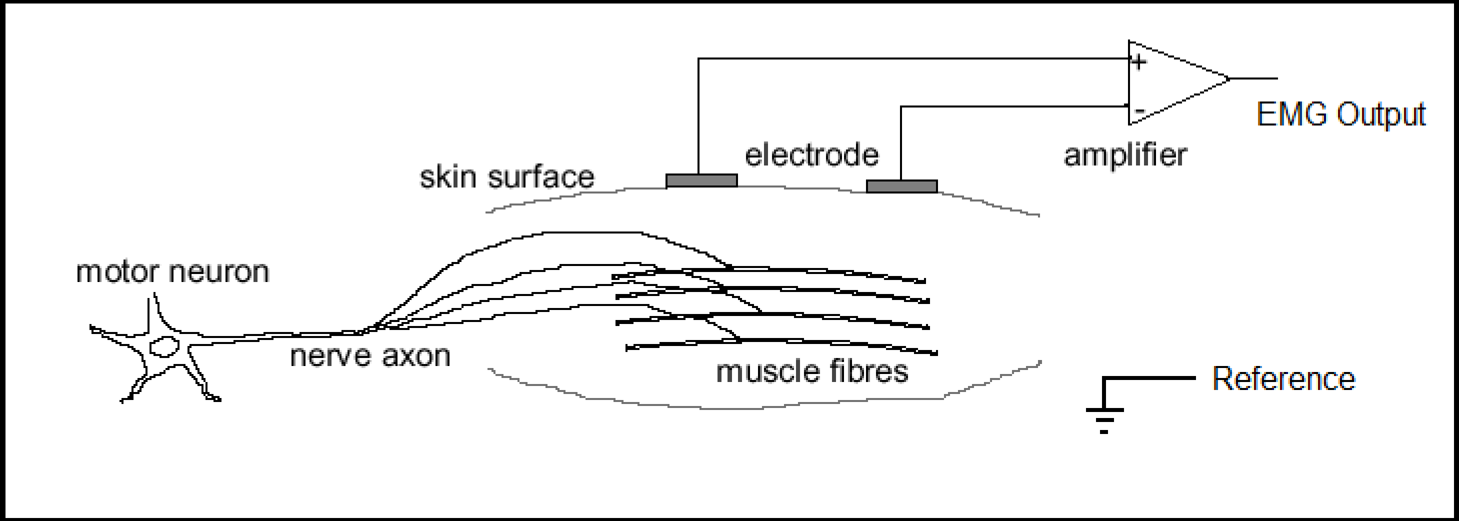
- Second revolution will seek to integrate power regulation, OTA programmability of CC2650, and multiple servo control.




code
On Hand
Servo Plant
In
Haptic Sensor
Out
MCU
Out
In
In / Out
In
Out
On-Board Wireless Programmer
In / Out
In
Wireless
Remote Programmer
Out
Haptic Driver
In / Out
Out
Haptic Acutator
In
Sleeve on Body
EMG Sensor
Out
In
mechanical
EMG Sensor Pads
Out
Vcc
Power
Out
In
Environmentally Protected Charger
Out
In

# ELECTROMYOGRAPHY (EMG) SENSOR

- Converts muscle flexes into an electrical signal
- Controls the actuation of the arm
- Used in many Prosthetic/ Bionic limbs



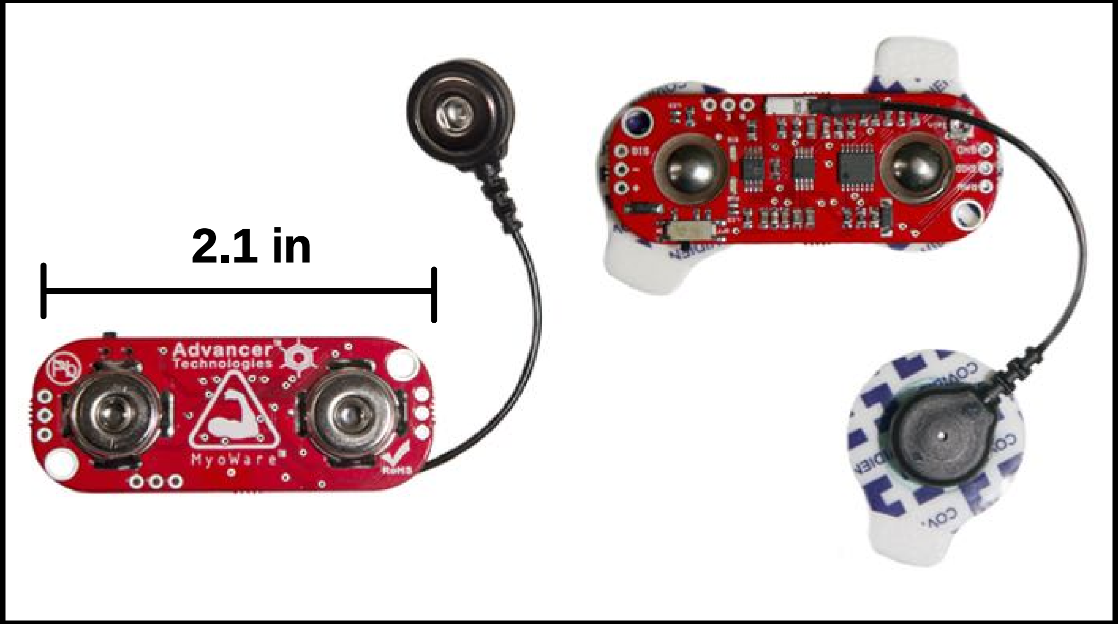
# EMG SENSOR

- Initially, use of Analog Front End (AFE) was investigated
- Pros:
  - Small form factor
  - Low power
  - Built in room for expansions
- Cons:
  - Not built for EMG
  - Difficult to configure properly

| Part | Power (mW) | Bipotetial Channels | Price | Evaluation Board |
|---|---|---|---|---|
| ADS1292 | 0.7 | 2 | $4.65 | Yes |
| ADS1293 | 0.9 | 3 | $5.50 | Yes |
| ADS1194 | 3 | 4 | $7.80 | No |
| ADS1196 | 3.6 | 6 | $11.35 | No |

# EMG SENSOR CONT.

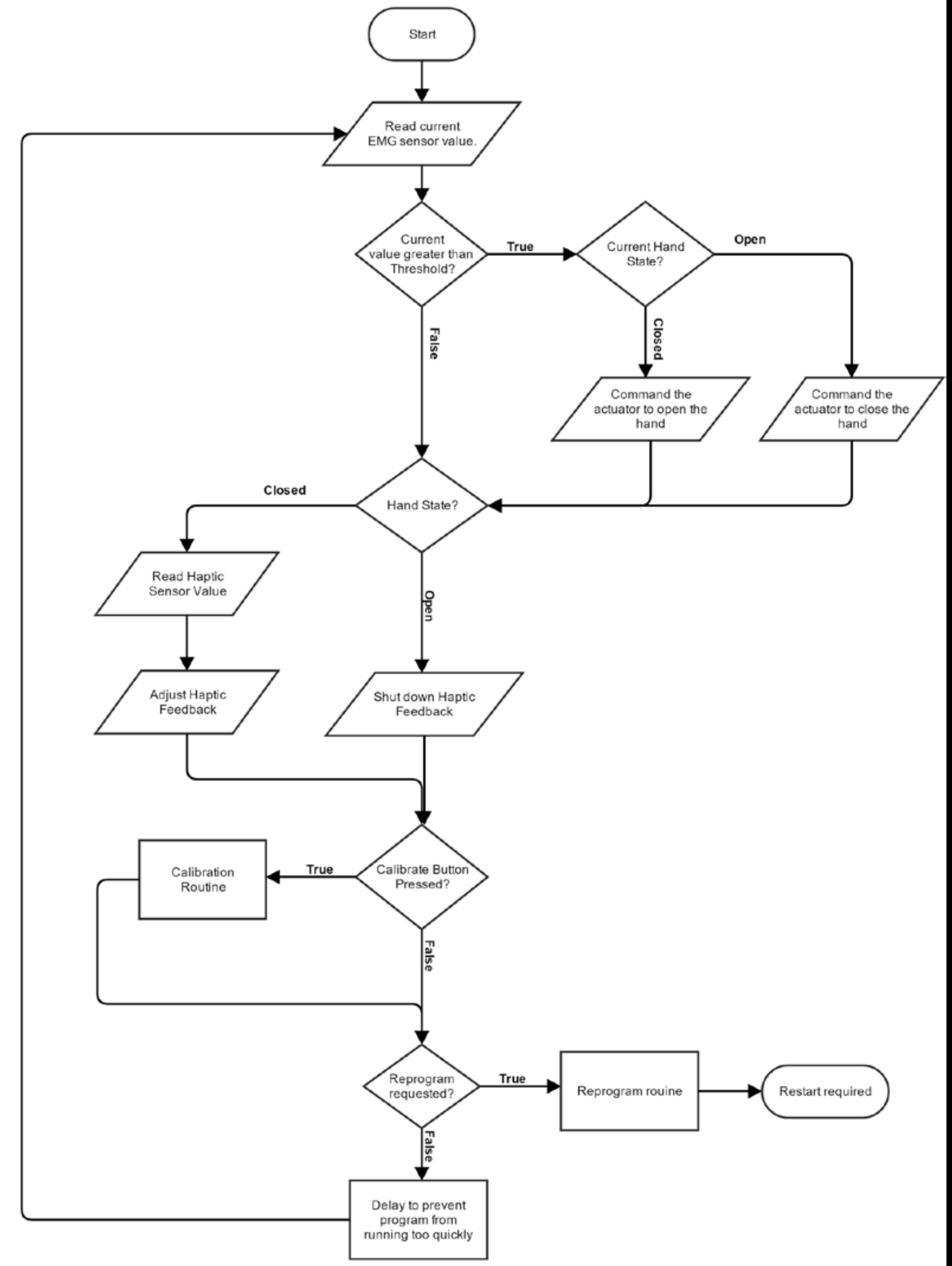
- ❖ After talking with Limbitless, use of AFE was decided against
- ❖ Instead, Pre-Built EMG Sensor was recommended
  - ❖ Another Senior Design group is designing a new EMG sensor
  - ❖ Much better SNR due to electrode placement
  - ❖ Pre-Built sensor recommended to continue partnership with Advancer Technologies



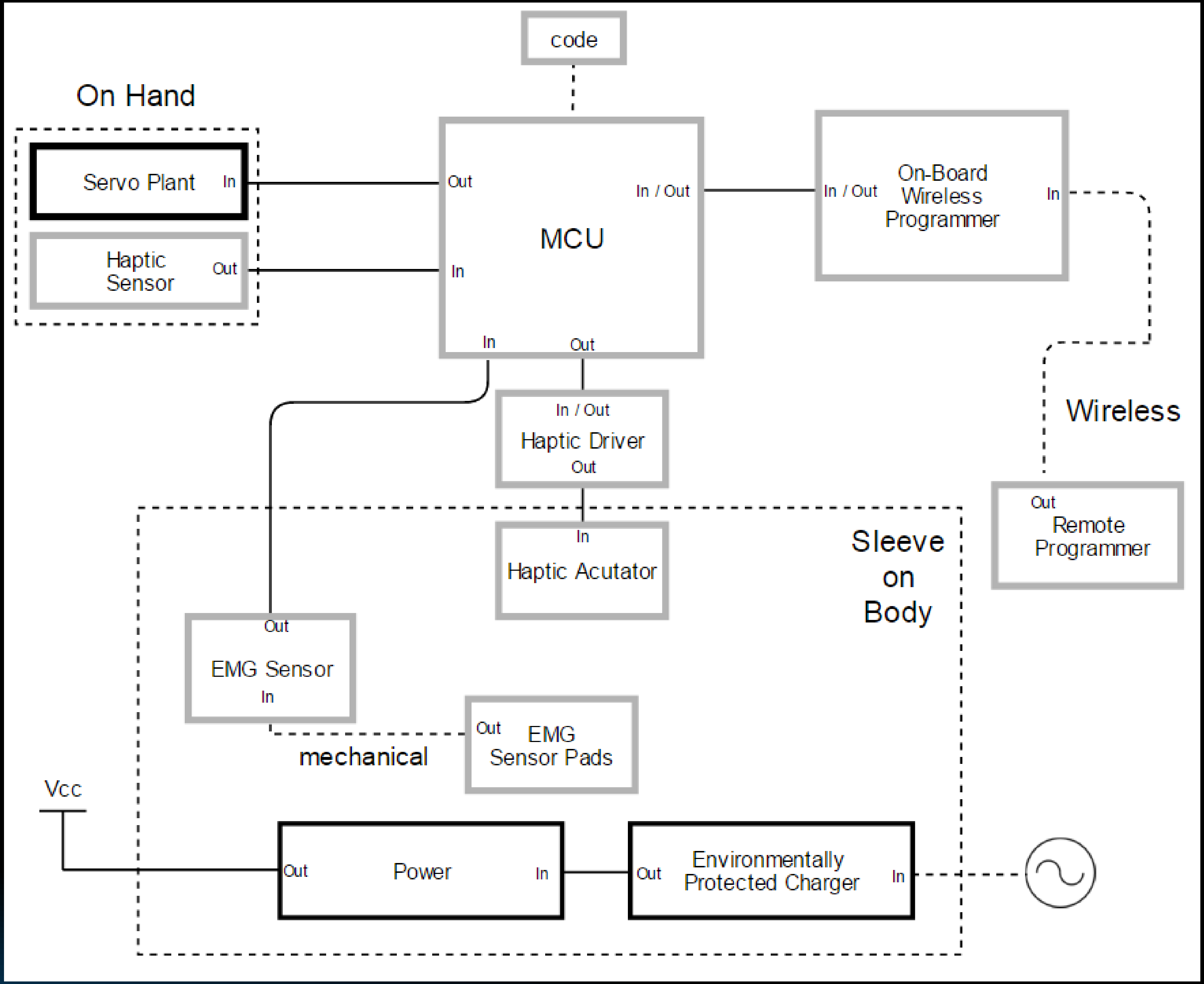

| Parameter | Value |
|---|---|
| Seller | Advancer Technologies |
| Cost | $37.95 |
| Vin | 3.1-6.3 V |
| Current Draw | 9 mA |
| Output | Analog Signal |

# CODE

- Using CC2650 running TI-RTOS
- Pros:
    - Built in Functionality
    - Makes code very portable
- Cons:
    - Large learning curve
    - Makes simple tasks difficult
- Programming in Code Composer Studio (CCS)

Start
Read current EMG sensor value.
Current value greater than Threshold?
True
Current Hand State?
Open
Closed
False
Command the actuator to open the hand
Command the actuator to close the hand
Closed
Hand State?
Read Haptic Sensor Value
Open
Adjust Haptic Feedback
Shut down Haptic Feedback
Calibration Routine
True
Calibrate Button Pressed?
False
Reprogram requested?
True
Reprogram rouine
Restart required
False
Delay to prevent program from running too quickly


code
On Hand
Servo Plant
In
Haptic
Sensor
Out
MCU
Out
In
In / Out
In
Out
On-Board
Wireless
Programmer
In / Out
In
Wireless
Remote
Programmer
Out
In / Out
Haptic Driver
Out
In
Haptic Acutator
Sleeve
on
Body
Out
EMG Sensor
In
mechanical
Out
EMG
Sensor Pads
Vcc
Out
Power
In
Out
Environmentally
Protected Charger
In

# CHARGING- TRANSMITTER

- 100% Qi-compliant.
- Input is a standard 12V DC.
- Standard 5W output with any Qi receiver.
- Proprietary 10W output when paired with the BQ51025 or its evaluation board from Texas Instrument's.
- Built in foreign object detection (FOD)

*The module was donated to the team by Texas Instruments along with the receiver.

| Parameter | Specification |
| --- | --- |
| Cost | $499.00* |
| Vendor | Texas Instruments |


BQ500215EVM-648 Wireless Transmitter

# CHARGING - Receiver

BQ51025EVM-649 Wireless Receiver


Qi-compliant receiver that is paired with Texas Instruments’ BQ500125 wireless transmitter (10W). Robust 5 W solution with 50% lower losses.

The output voltage is adjustable from 4.5 – 8.0 V, with 97% efficient post regulation.

*The module was donated to the team by Texas Instruments along with the receiver.

| Parameter | Specification |
| --- | --- |
| Cost | $249.00* |
| Vendor | Texas Instruments |

# Li-Ion Battery Charger

BQ24120 Li-Ion Battery Charger


- Switch-mode 1, 2, or 3-cell Li-Ion charger with a 2 Amp FET
- 2 Amps continuous output, limited to 1.33 Amps
- Input range from 5 – 16 V
- Output regulated voltage 4.2 V
- Compatible with 2S batteries
- Available in 20-pin 3.5mm x 4.5 mm VQFN package
- Price: $5.18

# BATTERY

Venom Racing 15083 LiPo 7.4 V battery


The Venom Racing battery fills the specifications of the design. The minimum discharge voltage is 6 V. The team has set the limit to 7.2 V.

The battery comes standard with a hard case from the manufacturer.

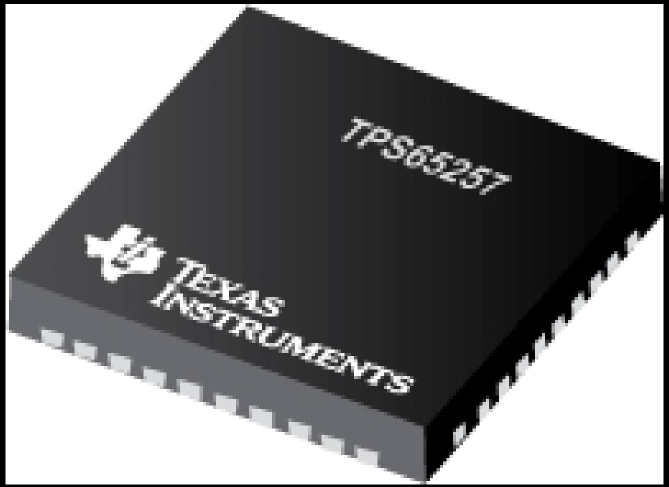
C-rating: Amps x C = Maximum continuous discharge

| Parameter | Specification |
|---|---|
| Mass | 260.8 grams |
| Dimensions | 69 X 46.2 X 23 mm |
| Capacity | 4200 mAh |
| Vendor | RC Planet |
| Cost | $45.87 |
| Charge Rate | 4.2 Amps |
| C-rating | 30 C |

# DC-DC CONVERTER

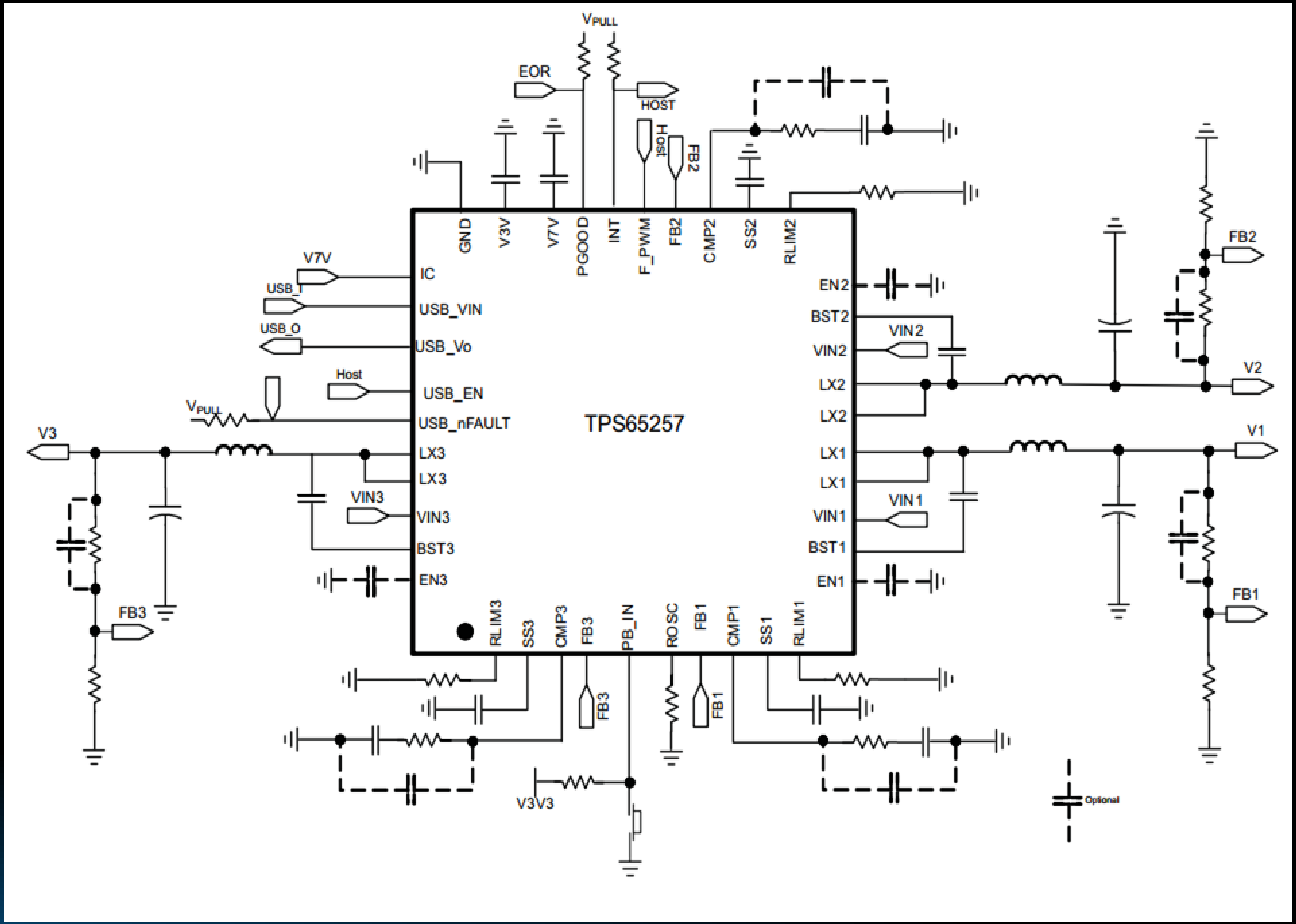
Features:

- ❖ Synchronous step down three DC-DC converter
- ❖ Continuous loading [3 A (Buck 1), 2 A (Buck 2 and 3)].
- ❖ Integrated FET, USB switch and push button control.
- ❖ Switching frequency set by external resistor
- ❖ External soft start pins
- ❖ Adjustable cycle-by-cycle current limit set by external resistor
- ❖ Automatic low pulse skipping power mode allowing for an output ripple better than 2%.
- ❖ Thermally Efficient with small package size (6 x 6 mm).



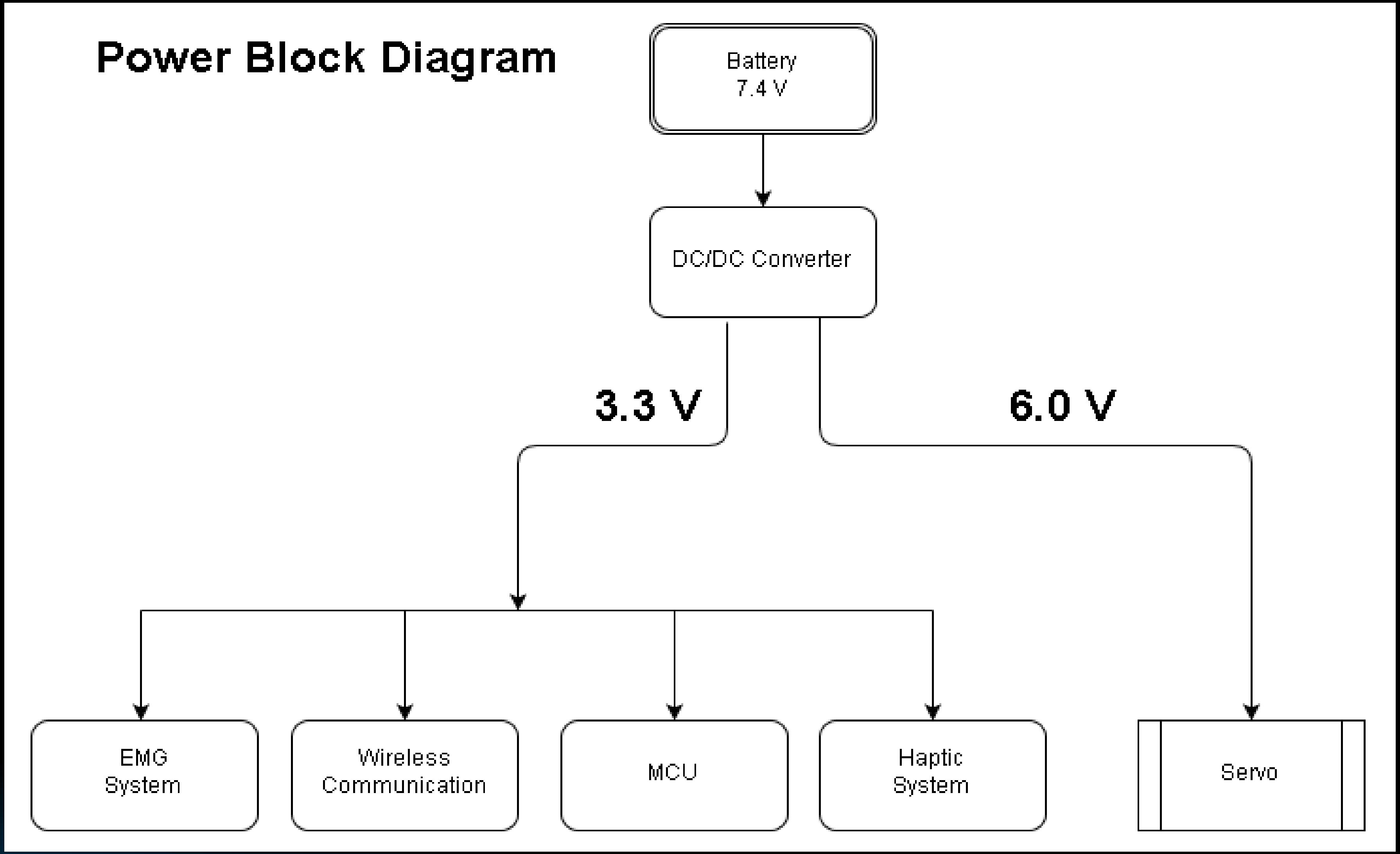

| Parameter | Specification |
|---|---|
| Package Type | QFN |
| Temperature Range | -40 C – 125 C |
| Input Voltage | 4.5 V – 16 V |
| Vendor | Texas Instruments |
| Cost | $8.19 |

# DC-DC CONVERTER




Overview required for the three voltage outputs to maintain switching and stability:

# POWER DISTRIBUTION

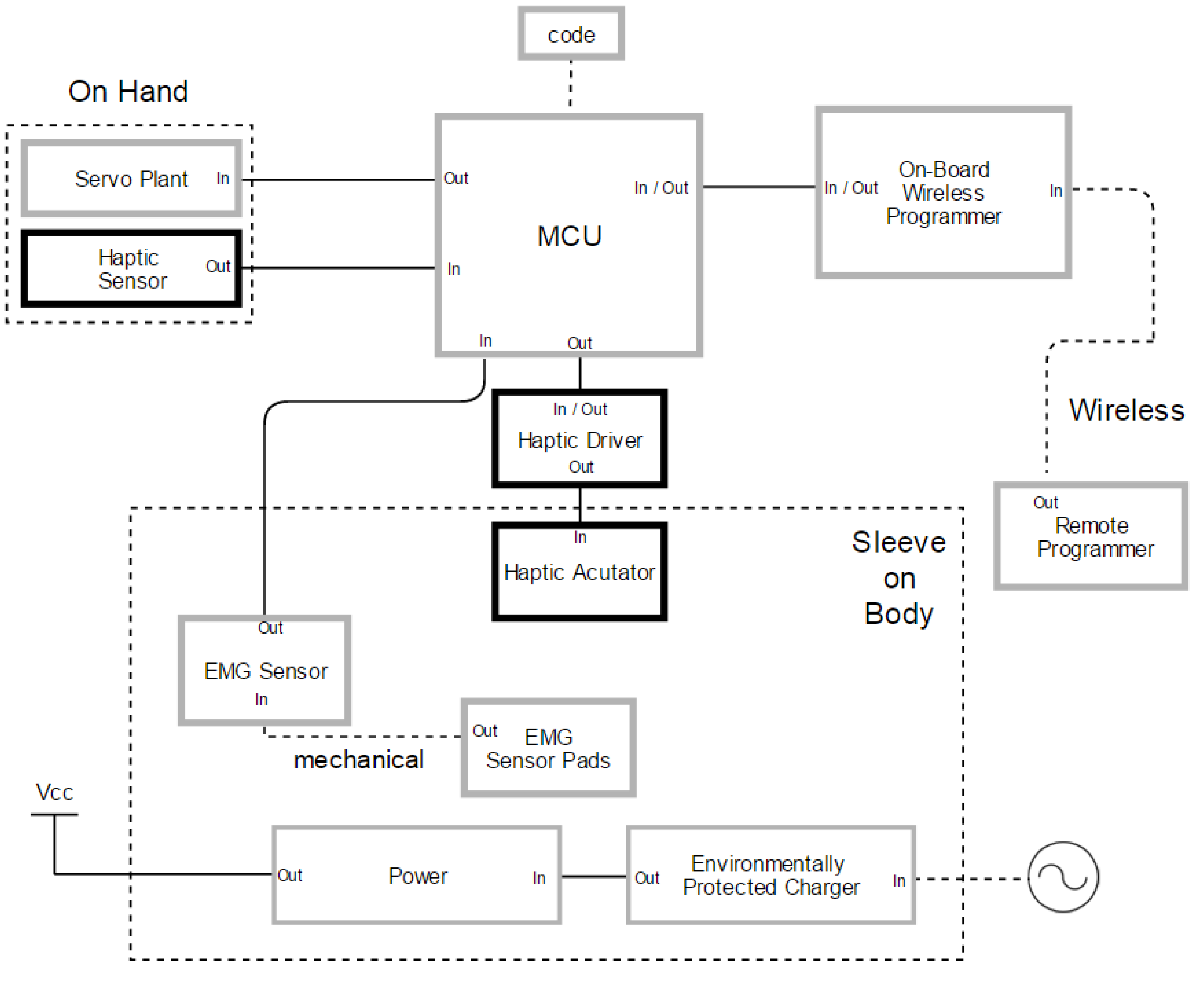


# SERVO OF CHOICE

After careful revision and consideration of several servos, the current servo that Limbitless uses, the Tower Pro, is the best choice.

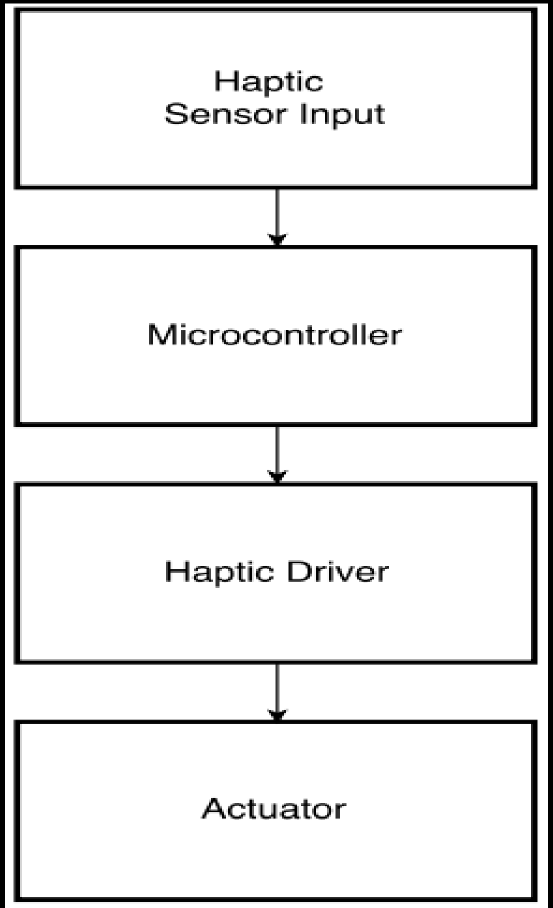
It maintains a relatively small profile and comes at an affordable cost.

| Parameter | Specification |
|---|---|
| Part name | MG995 – Tower Pro |
| Vendor | Amazon |
| Cost | $6.99 |

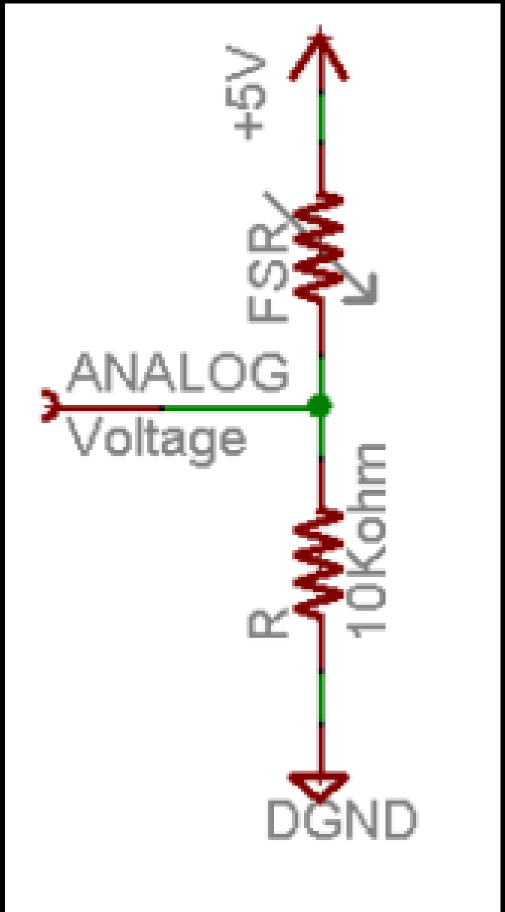

code
On Hand
Servo Plant
In
Haptic Sensor
Out
Out
In
MCU
In / Out
In
Out
In / Out
On-Board Wireless Programmer
In
In / Out
Haptic Driver
Out
Wireless
In
Haptic Acutator
Sleeve on Body
Out
Remote Programmer
Out
EMG Sensor
In
Out
EMG Sensor Pads
mechanical
Vcc
Out
Power
In
Out
Environmentally Protected Charger
In

# HAPTIC FEEDBACK SYSTEM

- ❖ Introduces a way for the user to sense that the arm’s hand is closed on an object.
- ❖ Features a sensor for detection of signal and driver to enact the response.
- ❖ The microcontroller processes the input from the sensor.
- ❖ Actuator is enabled by the driver and vibrates to notify the user.



# HAPTIC SENSOR

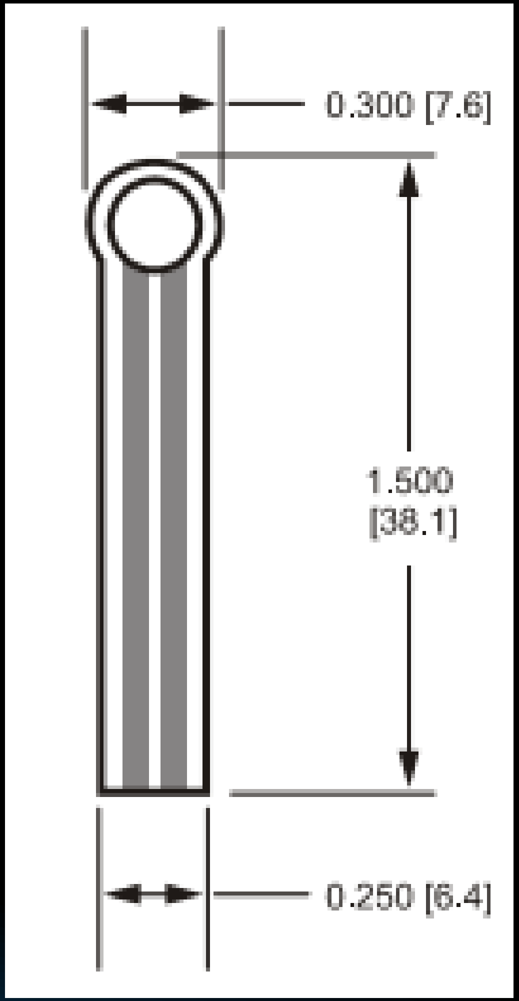



- ❖Used to detect when a hand is closed on an object.
- ❖Feeds an output voltage to an Analog GPIO pin and converted by an internal ADC to be read.
- ❖This type of input works with variable resistors.

# FORCE SENSITIVE RESISTOR

- ❖ Resistance of the force sensitive resistor decreases when pressure is applied on the pad.
- ❖ With no pressure the resistance is about 10 mega-ohms. Approximately an open.
- ❖ The resistance of the sensor decreases linearly with pressure.
- ❖ At full pressure this resistance can be decreased to approximately 2.5 kilo-ohms.

# CHOSEN HAPTIC SENSOR




For the purposes of this project, the ideal sensor is the Force Sensitive Resistor (FSR). This sensor has little to no current draw when attached while no pressure is applied.

| Parameter | Value |
|---|---|
| Seller | Sparkfun |
| Cost | $5.95 |
| Resistance Range (ohms) | 10M – 2.5K, |
| Length of Sensor | 1.75 inches |
| Width of Sensor | 0.3 inches |

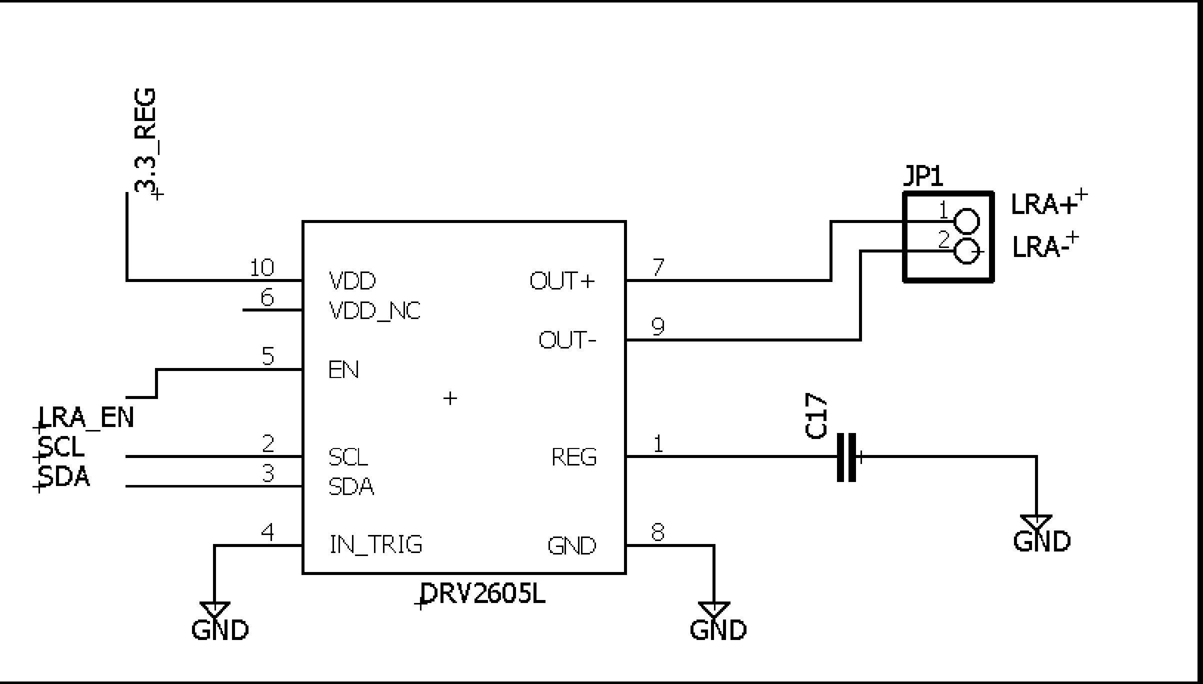
# HAPTIC DRIVER

- Haptic Drivers are used because the microcontroller can not supply enough current to the actuator that enables the response.
- Used in many cellular devices, as well as game controllers.

# AVAILABLE HAPTIC DRIVERS

| Parameter | DRV2605L | DRV2603 | DRV2604 |
|---|---|---|---|
| Vs (Min) (V) | 2.5 | 2.5 | 2.5 |
| Special Features | Integrated Haptic Effects Smart Loop | Auto Resonance | Smart Loop RAM Available |
| Input Signal | PWM, Analog, I2C | PWM, Analog | PWM, Analog, I2C |
| Vout (Max) (V) | 11 | 10.4 | 11 |
| Supported Actuator Types | ERM, LRA | ERM, LRA | ERM, LRA |
| Startup Time (ms) | 0.7 | 1.3 | 0.7 |
| Approximate Cost (per 1k units) | $1.60 | $0.70 | $1.32 |

# DRV2605L




- ❖ Haptic Driver that communicates with the microcontroller over the I2C.
- ❖ Contains an integrated library of 123 different waveform effects to sent to actuator.
- ❖ Compatible with different actuator types.

# ACTUATOR VARIATIONS

Eccentric Rotating Mass (ERM)

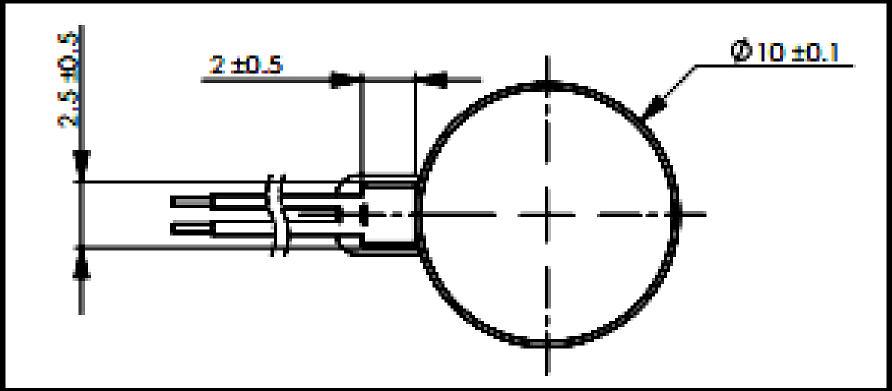
- ❖ Mass is rotated around a point, creating a sense of vibration.
- ❖ Motor is exposed and would need an extra casing to contain the actuator.
- ❖ Require detailed calibration routines to provide an accurate response.

Linear Resonant Actuator (LRA)

- ❖ Moves on one axis pushing a weight back and forth to create a vibration.
- ❖ Simplistic Design.
- ❖ Typically runs faster than ERM devices, due to a lower response time.

# LINEAR RESONANT ACTUATOR

For this application, the LRA is the pick of choice due to its more simplistic design. It will be attached to the user near the mounting strap.




| Parameter | Specification |
|---|---|
| Body Diameter | 10 mm |
| Resonant Frequency | 175 Hz |
| Operating Current | 69 mA |
| Rated Voltage | 2 V (RMS) |
| Purchased From | Precision Microdrives |
| Cost | $8.19 |

# ENVIRONMENTAL PROTECTION

In the past, the Limbitless arm has failed after its production due to external factors. The group has been tasked to ensure that the design is more reliable by implementing forms of protection.

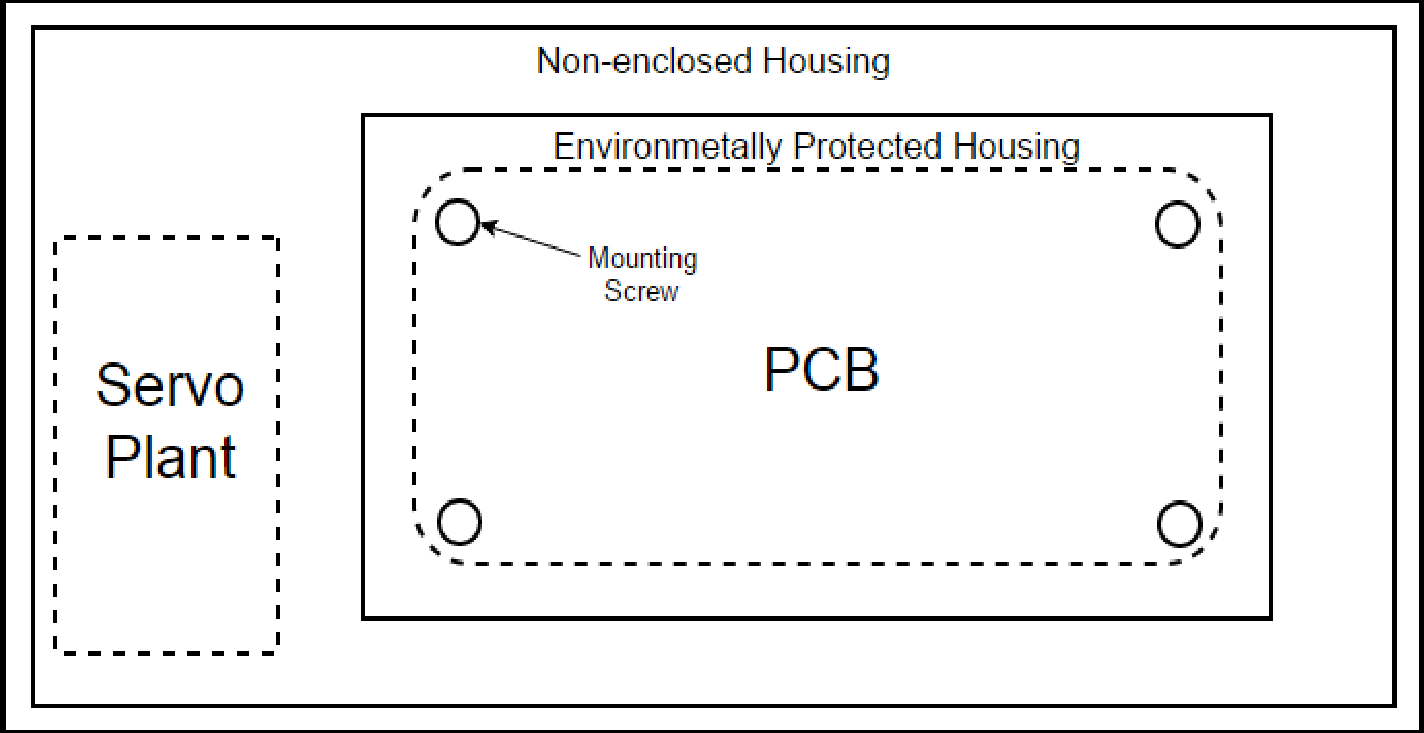
Limbitless has asked the team to incorporate protection against shock, water, dirt, ESD, and user interference.

# CONFORMAL COATING

Conformal coating will be used to protect the boards electronics. Upon fabrication of the final design the coating will be applied by the group.

| Parameter | Value |
|---|---|
| Size | 55 milliliters |
| Part Number | 419C-55ML |
| Brand Name | MG Chemicals |
| Temperature Range | -65/125 Degrees Celsius |
| Price | $10.14 |
| Seller | Amazon |

# MAKING THE DEVICE "PARENT PROOF"




- This image demonstrates the purpose of why the team has decided to use inductive charging and Bluetooth programming.
- Epoxy Sealed casing, to prevent user interaction with components.
- PCB will be mounted to prevent movement .
- Enclosed case will increase resistance to water and dirt exposure.
- Wires will run out of the casing.

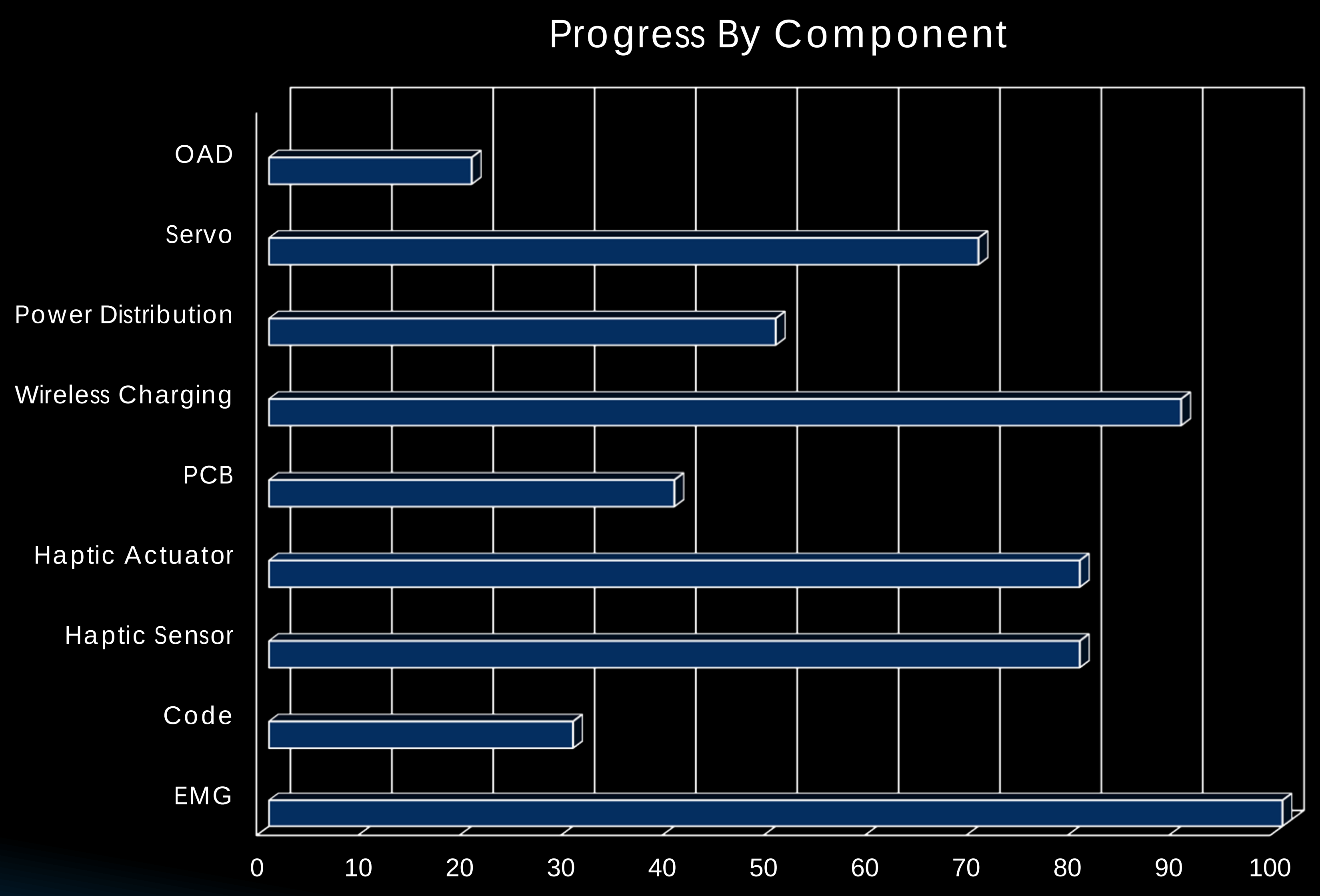
# ADMINISTRATIVE

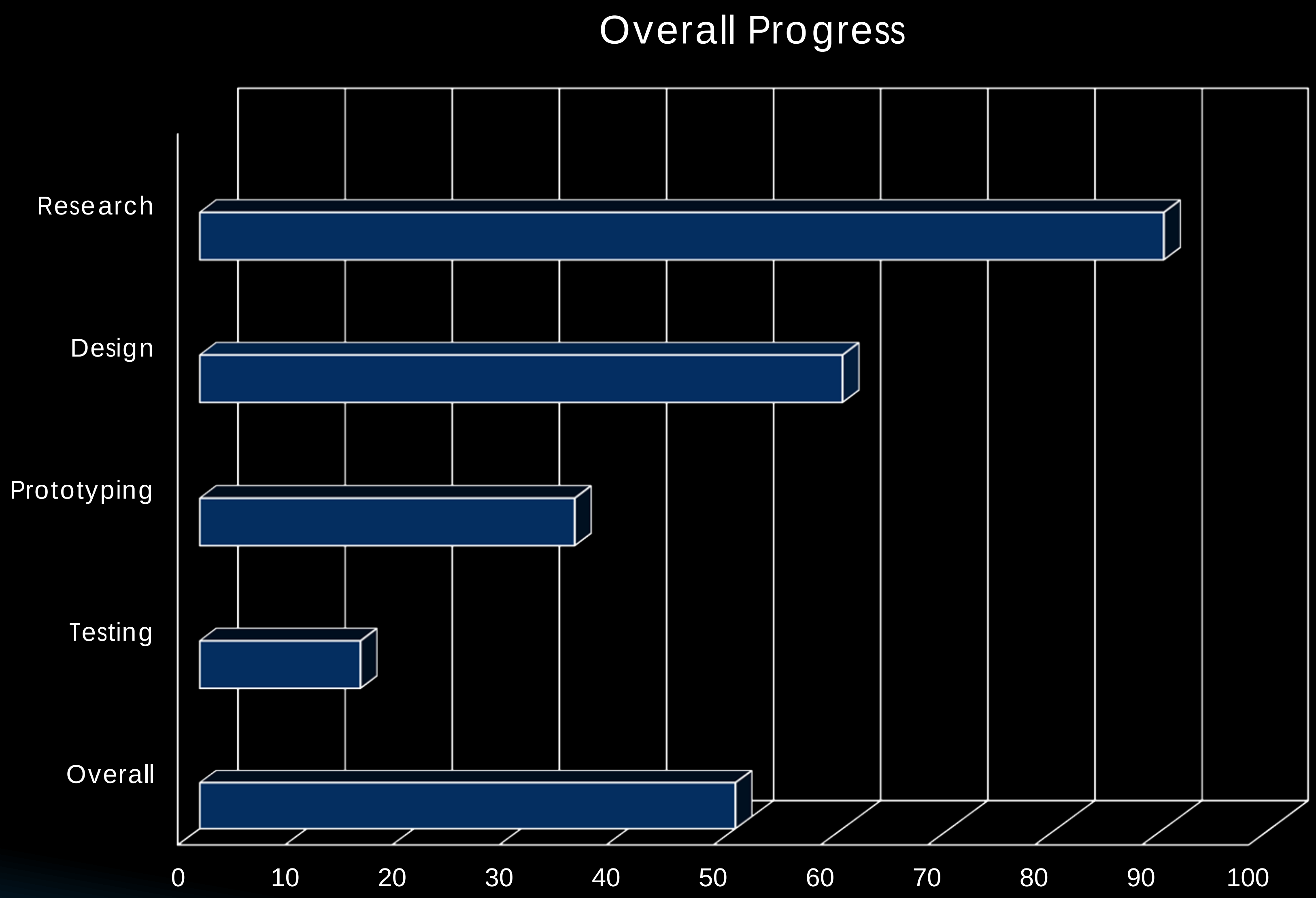
# BUDGET

| Part | Part Number | Price per unit | Quantity Needed | Quantity Ordered | Expected Cost | Real Cost | Cost of Arm |
|---|---|---|---|---|---|---|---|
| Microcontroller | CC2650 | $6.93 | 1 | 1 | $6.93 | $0.00 | $0.00 |
| P.C.B | Limbitless V1.0 | $8.90 | 1 | 3 | $26.70 | $26.70 | $8.90 |
| Haptic Driver | DRV2605L | $1.60 | 1 | 5 | $8.00 | $0.00 | $0.00 |
| Servo | MG995 | $6.99 | 1 | 4 | $27.96 | $27.96 | $6.99 |
| EMG Sensor | N/A | $37.95 | 1 | 4 | $151.80 | $0.00 | $0.00 |
| LRA Actuator | C10-100 | $9.19 | 1 | 5 | $45.95 | $45.95 | $9.19 |
| Force Sensitive Resistor | SEN-09375 | $5.95 | 1 | 5 | $29.75 | $29.75 | $5.95 |
| Li-Ion Battery Charger | BQ24120 | $5.18 | 1 | 5 | $25.90 | $0.00 | $0.00 |
| Induction Transmitter | BQ500215EVM-648 | $499.00 | 1 | 1 | $499.00 | $0.00 | $0.00 |
| Induction Receiver | BQ51025EVM-649 | $249.00 | 1 | 1 | $249.00 | $0.00 | $0.00 |
| Battery | 15083 | $45.87 | 1 | 1 | $45.87 | $45.87 | $45.87 |
| DC/DC Converter | TPS65257 | $8.19 | 1 | 5 | $40.95 | $0.00 | $0.00 |
| Conformal Coating | 419C-55ML | $10.14 | 1 | 1 | $10.14 | $10.14 | $10.14 |

Limbitless Budget: $1000

| | Totals: | | |
|---|---|---|---|
| Cost | $1,157.81 | $176.23 | $76.90 |
| Budget | $1,000.00 | $1,000.00 | $300.00 |
| Difference | ($157.81) | $823.77 | $223.10 |


Progress By Component
OAD
Servo
Power Distribution
Wireless Charging
PCB
Haptic Actuator
Haptic Sensor
Code
EMG
0
10
20
30
40
50
60
70
80
90
100


Overall Progress
Research
Design
Prototyping
Testing
Overall
0
10
20
30
40
50
60
70
80
90
100

# CHALLENGES

- Complexity of updating the code through Bluetooth communication.

- Ensuring that the arm meets the runtime requirement.

- Availability of actuator types and ensuring that the product creates a strong enough response.

# QUESTIONS?