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

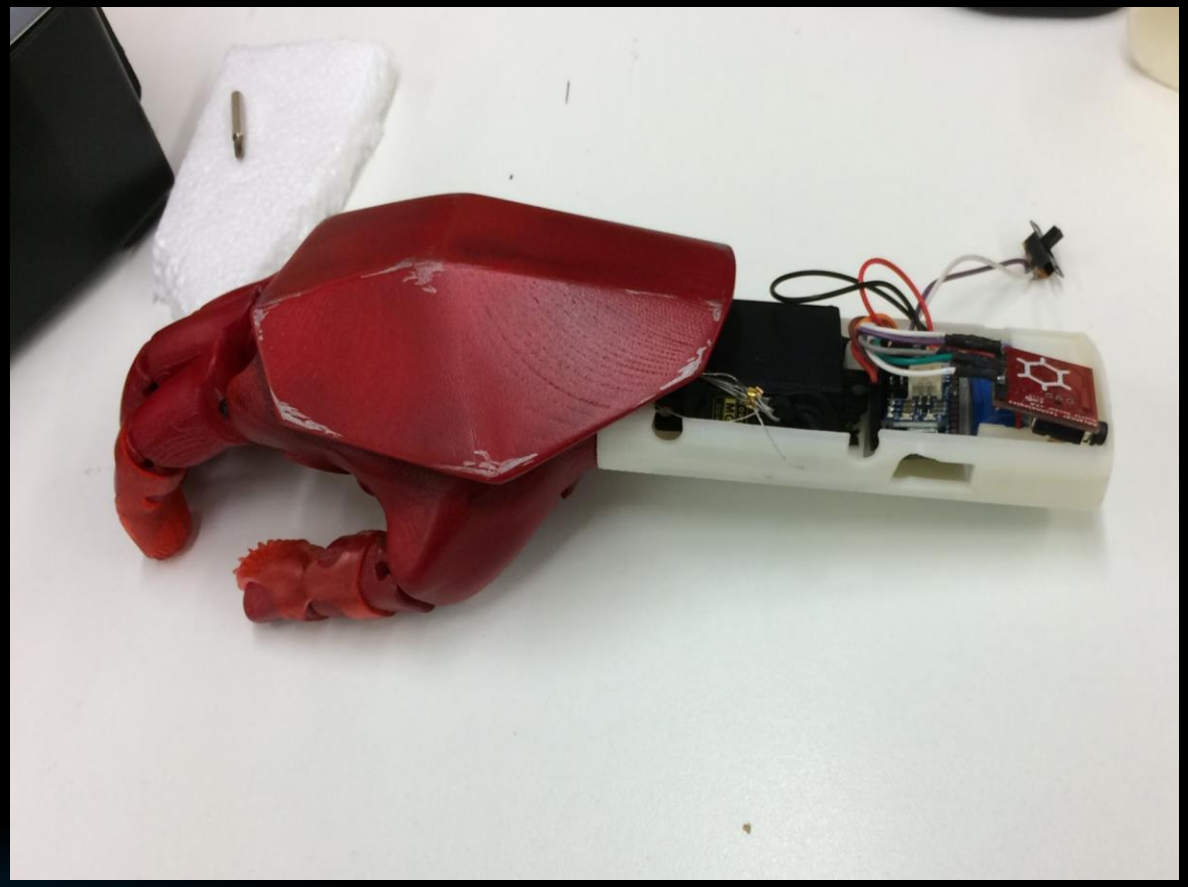
Group 14

- 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.

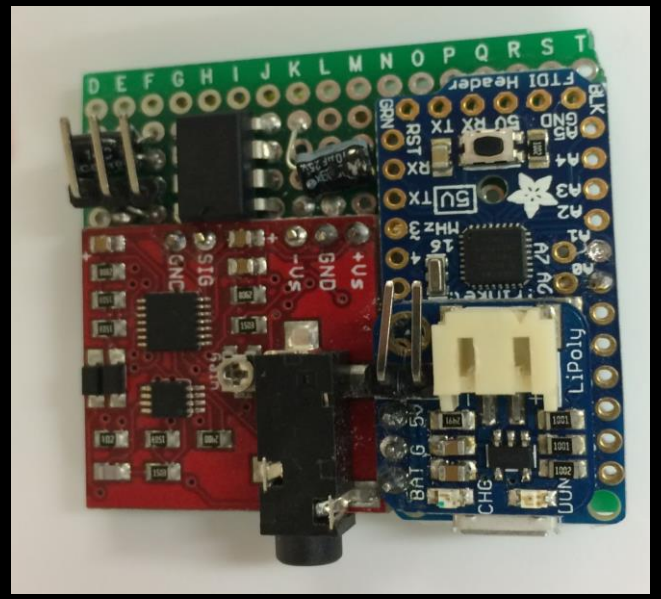
CURRENT SOLUTION

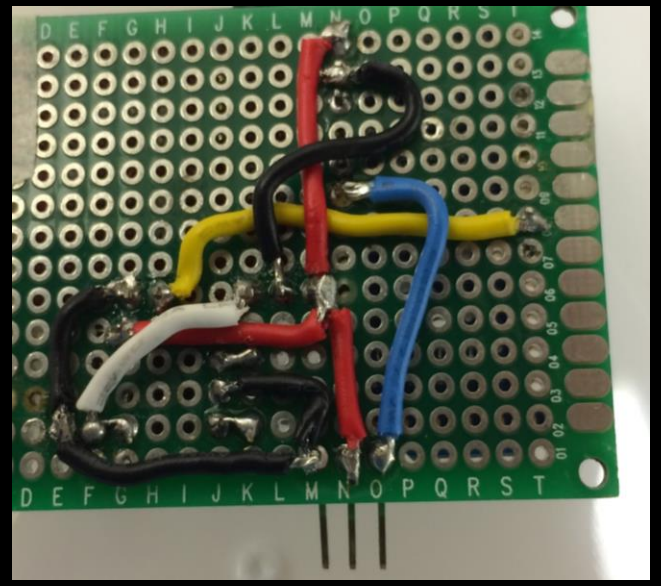


- Simple functionality.
- Potential risk of damaging components with an open housing.
- Connected by jumper cables that are easily disconnected.
- Combination of multiple development boards.
- Features loose components.

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.

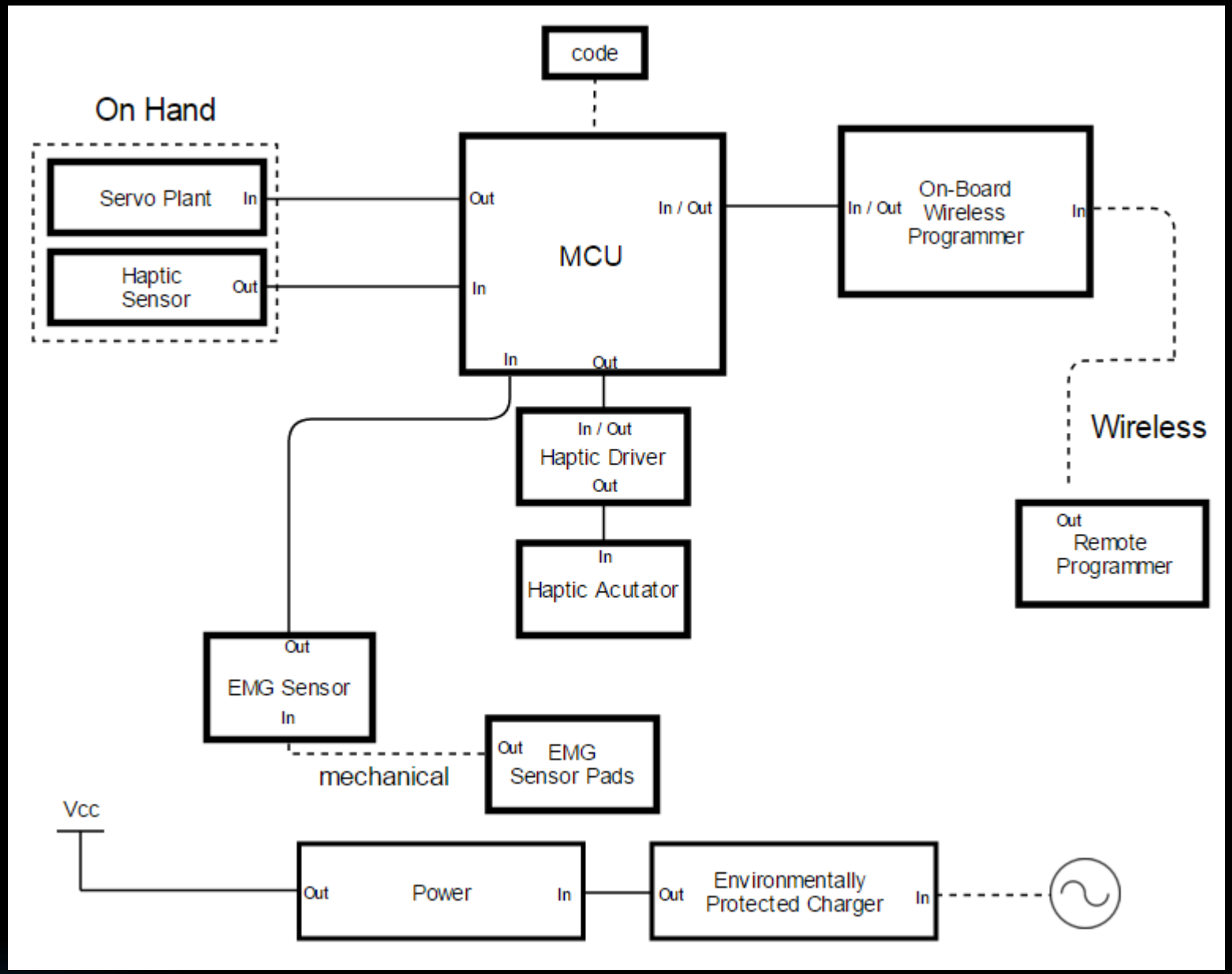
This solution will be a demonstration of what is possible. Limbitless will then decide what components they want to use in future designs.

GOALS AND OBJECTIVES

- Maintain Design Features
- Unify the electronics
- Update the microcontroller
- Improve the software
- Integrate a haptic feedback system
- Investigate environmental protection of electronics
- Demonstrate wireless charging capabilities
- Incorporate hardware for wireless updating
- Maintain affordability
- Allow for design expansion
- 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	Demonstrate at least IP27
Wireless Connection 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			Primary	Secondary
PCB Design	Primary		Secondary	
Haptic Feedback				Primary
Charging	Secondary	Primary		Secondary
Power		Primary		Secondary
Environmental Protection		Secondary		Primary
EMG Sensing	Secondary		Primary	
Servo		Primary	Secondary	
Fabrication /Integration	Primary			Secondary

CLASS 2 BLUETOOTH LOW ENERGY

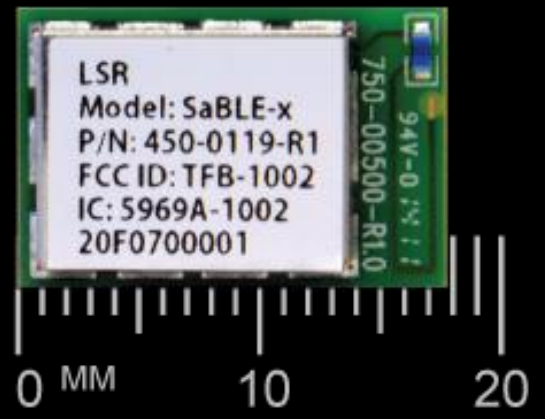
- The CC2640 operates as a class II device at 2.4 GHz. This means the device's effective range is up to 10 meters, while only drawing 2.5 mW of power.

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

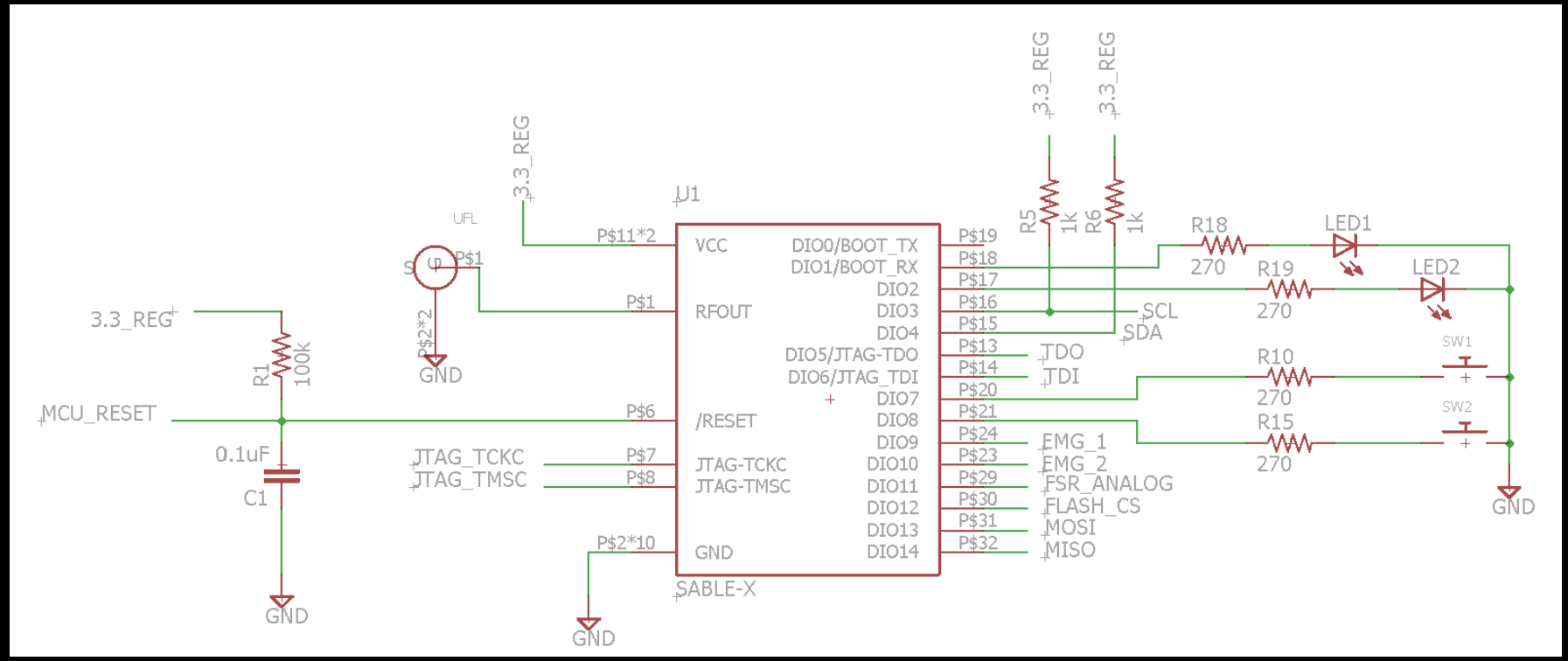
- Texas Instruments CC2640 was chosen due to its ability to serve as a single chip solution
- SaBLE-x module features a built-in CC2640, as well as integrated RF lines and oscillator crystals.
- Sports an ARM Cortex-M3, a predominantly more powerful microcontroller versus the current Atmel328p.
- Prototyping was made easy through the LaunchXL-CC2650 Launch Pad, as the machine language is binarily equivalent between microcontrollers. There are, however, subtle issues that are challenging to debug.
- CC2640 provides its own internal 1.8 V regulator powered by its 3.3 main input to further reduce power consumption
- Contains 128 KB of internal flash for program storage, as well as 20KB of SRAM



MICROCONTROLLER CHOICES

Parameter	MSP430FR5969	ATMega328	SaBLE-X	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 μA, @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	$16.52 from Digikey	$2.39 from Mouser Electronics

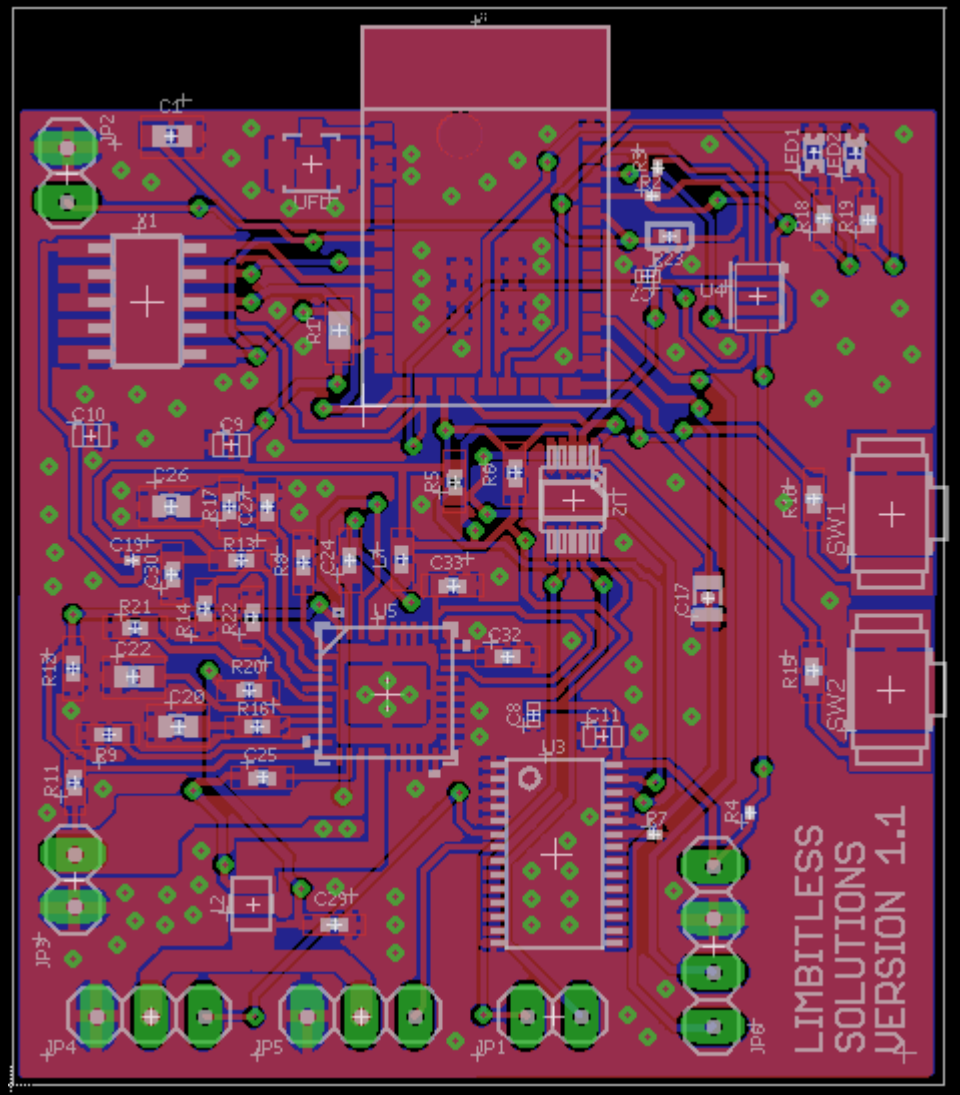
PCB SCHEMATICS (MCU)



- Schematic features a 32 pin output with14 DIO pins.
- Surface mounted LEDs and switches for debugging and programming purposes.
- Processes all peripheral integrated circuits on the board.
- Pins may be salvaged in future designs through elimination of SPI and use of LEDs through PCA9685.

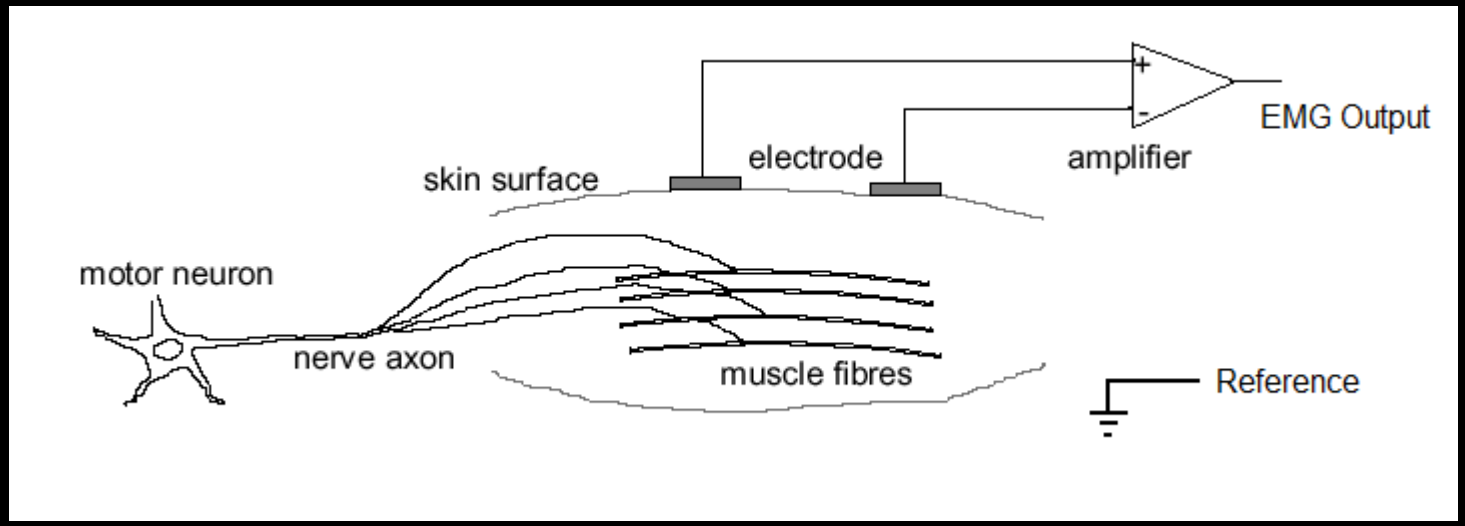
PRINTED CIRCUIT BOARD

- The P.C.B. design incorporates all components required for design functionality.
- The Sable-X module includes an integrated antenna with plug and play capability. It also allows the client to operate on LSR's FCC license, saving on expensive fees that are not achievable.
- Large power traces help to regulate heat throughout the board, allowing for full enclosure of the board.
- Via stitching unifies the ground plane effectively acting as a heat sink to the board.



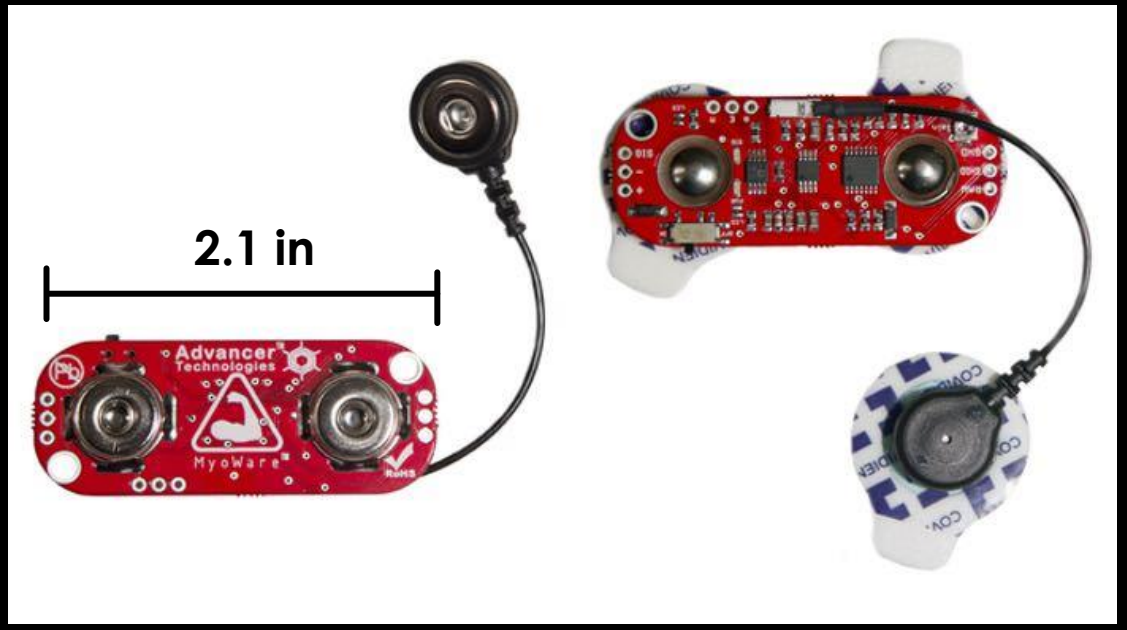
ELECTROMYOGRAPHY (EMG) SENSOR

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



EMG SENSOR

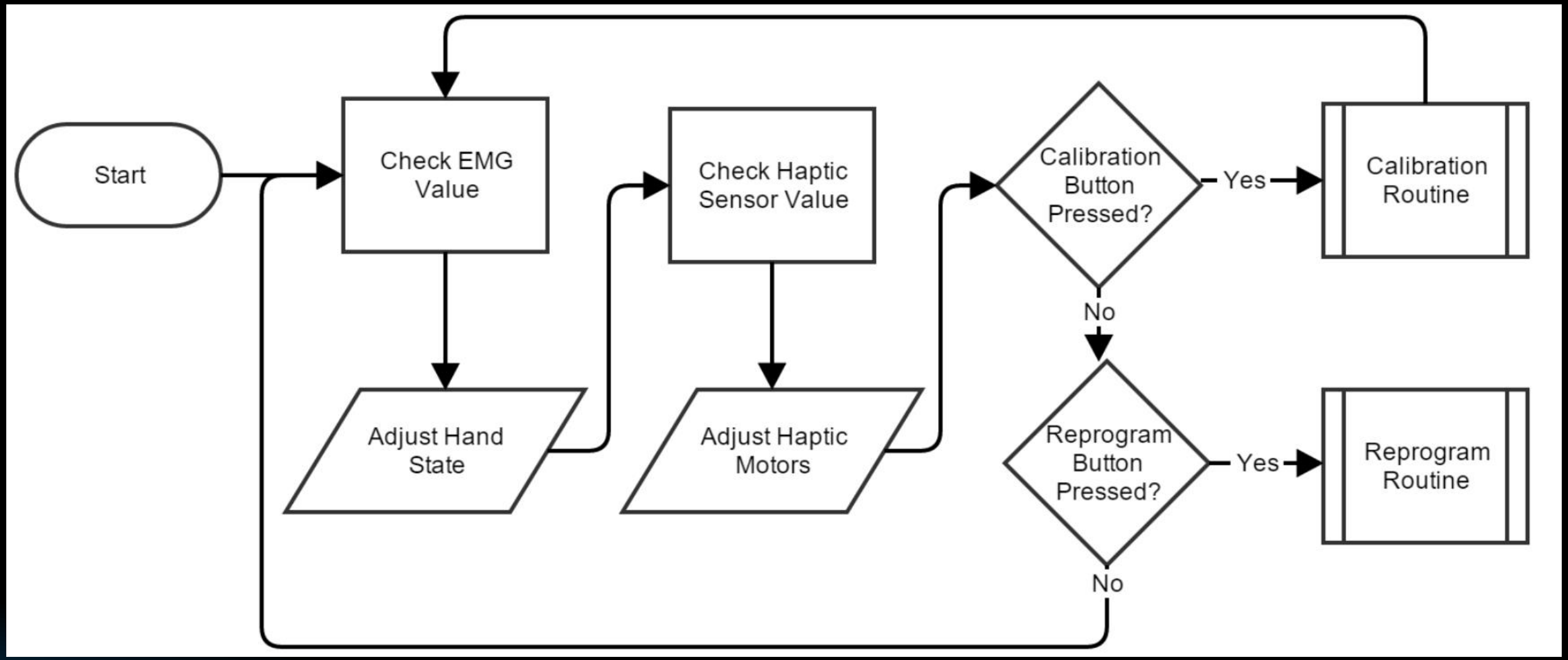
- Use of Analog Front End was decided against
- Instead, Pre-Built EMG Sensor was recommended
  - Another Senior Design group is designing a new EMG sensor
  - Much better SNR than AFE due to proximity of electrodes to filters
  - Pre-Built sensor recommended to continue partnership with Advancer Technologies



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

CODE

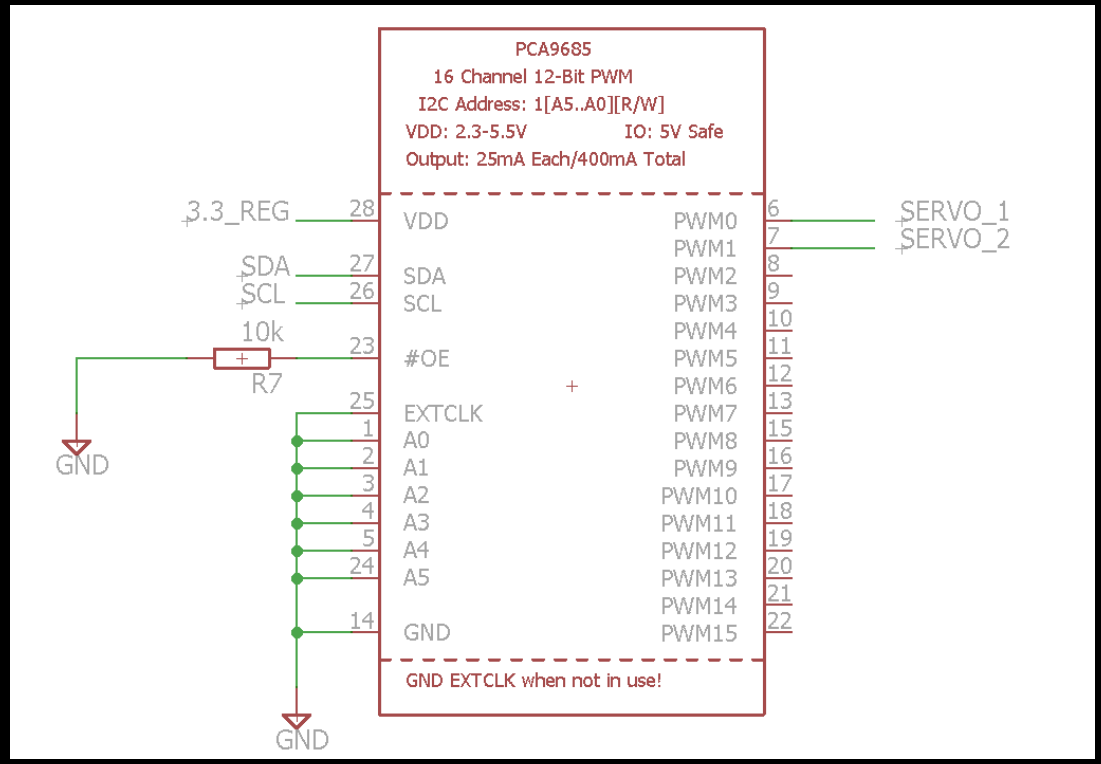
- Using CC2640 running TI-RTOS
- Pros:
  - Built in Functionality
  - Makes code very portable
- Cons:
  - Large learning curve
  - Makes simple tasks difficult
- Programming in Code Composer Studio (CCS)


Start
Check EMG Value
Adjust Hand State
Check Haptic Sensor Value
Adjust Haptic Motors
Calibration Button Pressed?
Yes
Calibration Routine
No
Reprogram Button Pressed?
Yes
Reprogram Routine
No

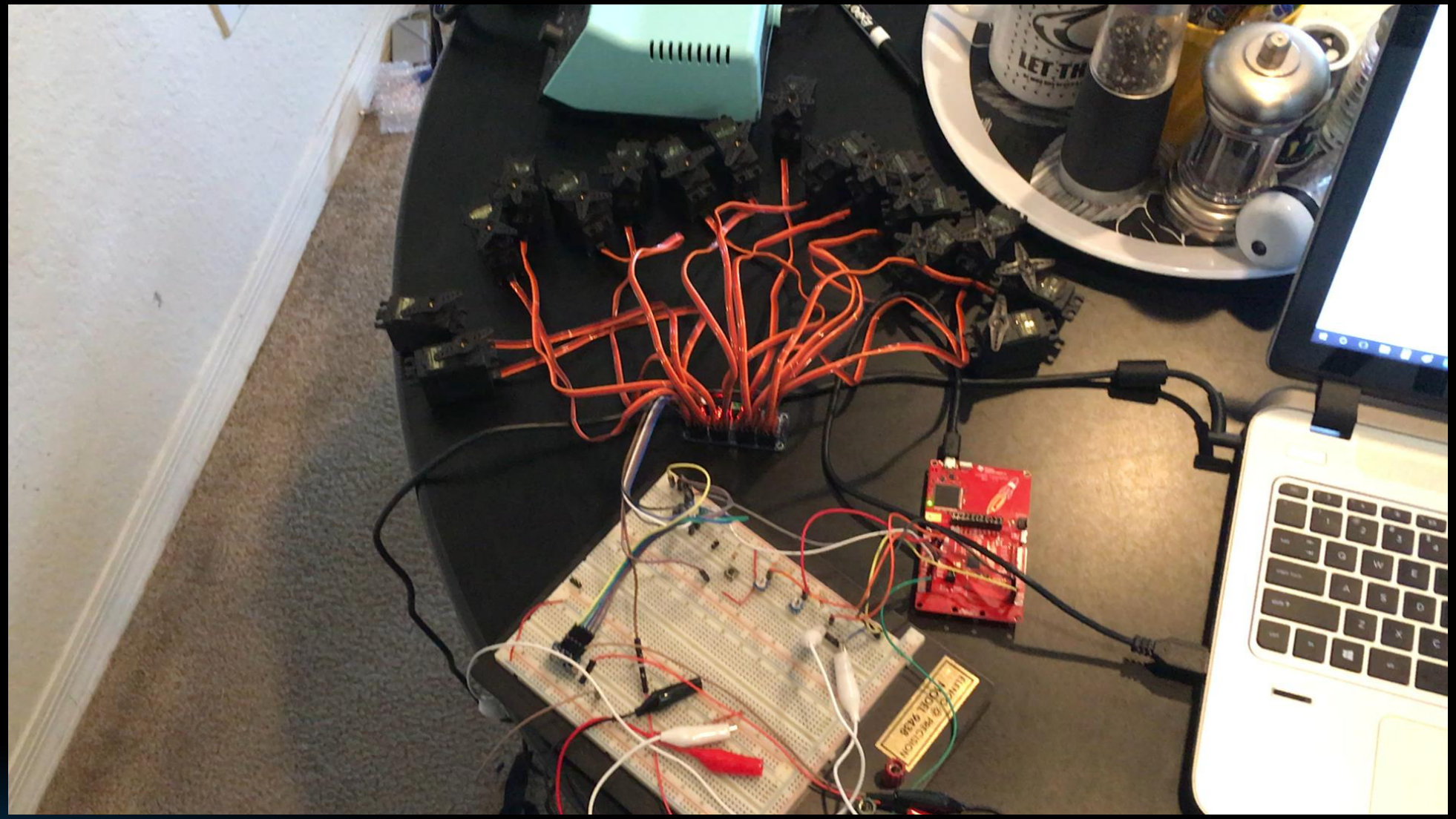
SERVO DRIVER- PCA9685

- Operates over I2C communication
- Allows for the ability to simultaneously control up to 16 servos.
- Minimizes utilization of GPIO pins on the microcontroller.
- Can be used in future revisions to the design to drive LEDs or additional actuators.

Parameter	Value
Seller	Digikey
Cost	$1.08
Vin	2.3-5.5 V
Current Draw	6 mA
Control	I2C Bus



16 SERVOS



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

CHARGING- TRANSMITTER

- 100% Qi-compliant.
- Input is a standard 12V DC.
- 10W Output when paired with its corresponding wireless receiver.
- 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

Qi-compliant receiver that is paired with Texas Instruments' BQ500125 wireless transmitter (10W).

The output voltage was adjusted on the board to 10 V, with 97% efficient post regulation.

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

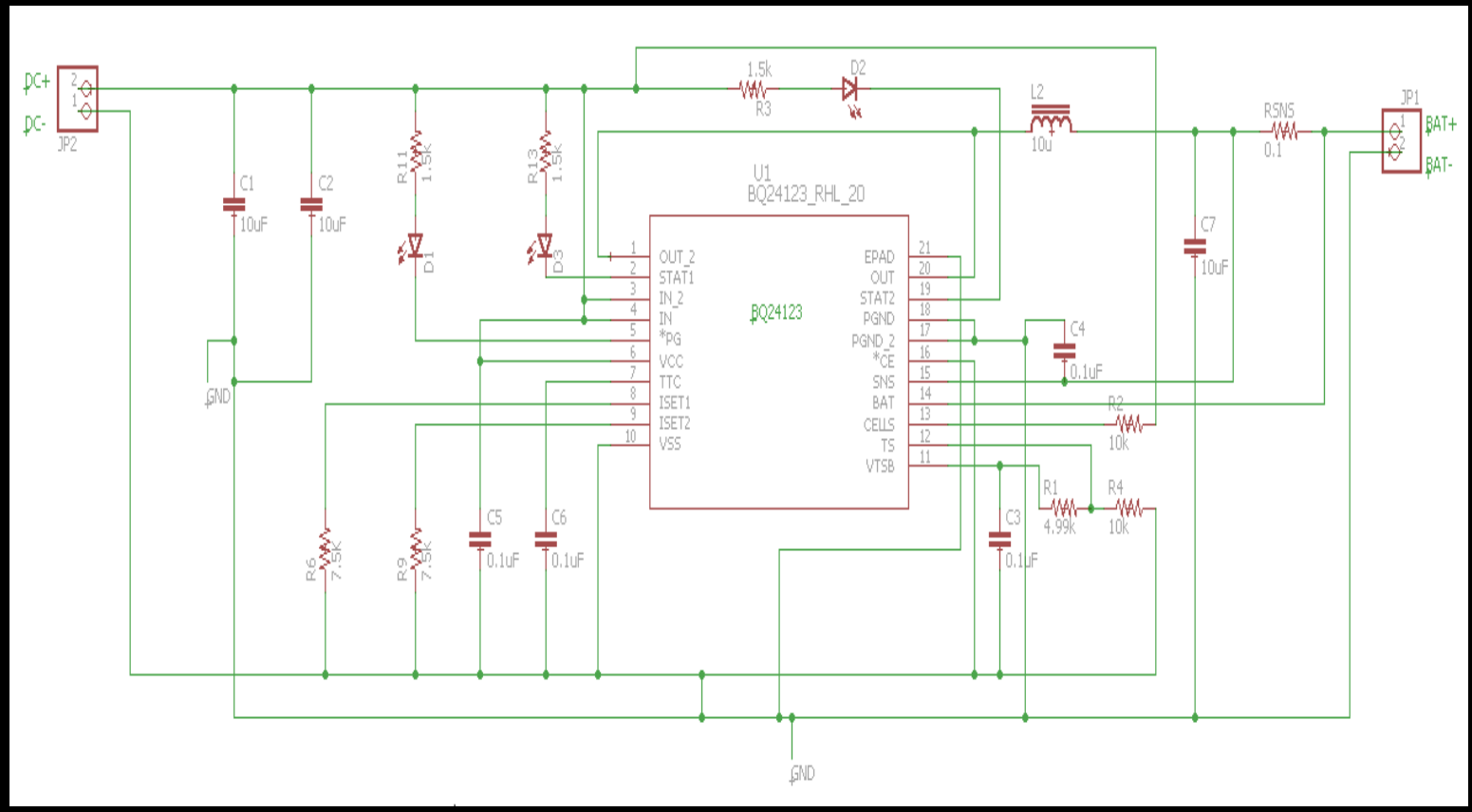
Parameter	Specification
Cost	$249.00*
Vendor	Texas Instruments

BQ51025EVM-649 Wireless Receiver

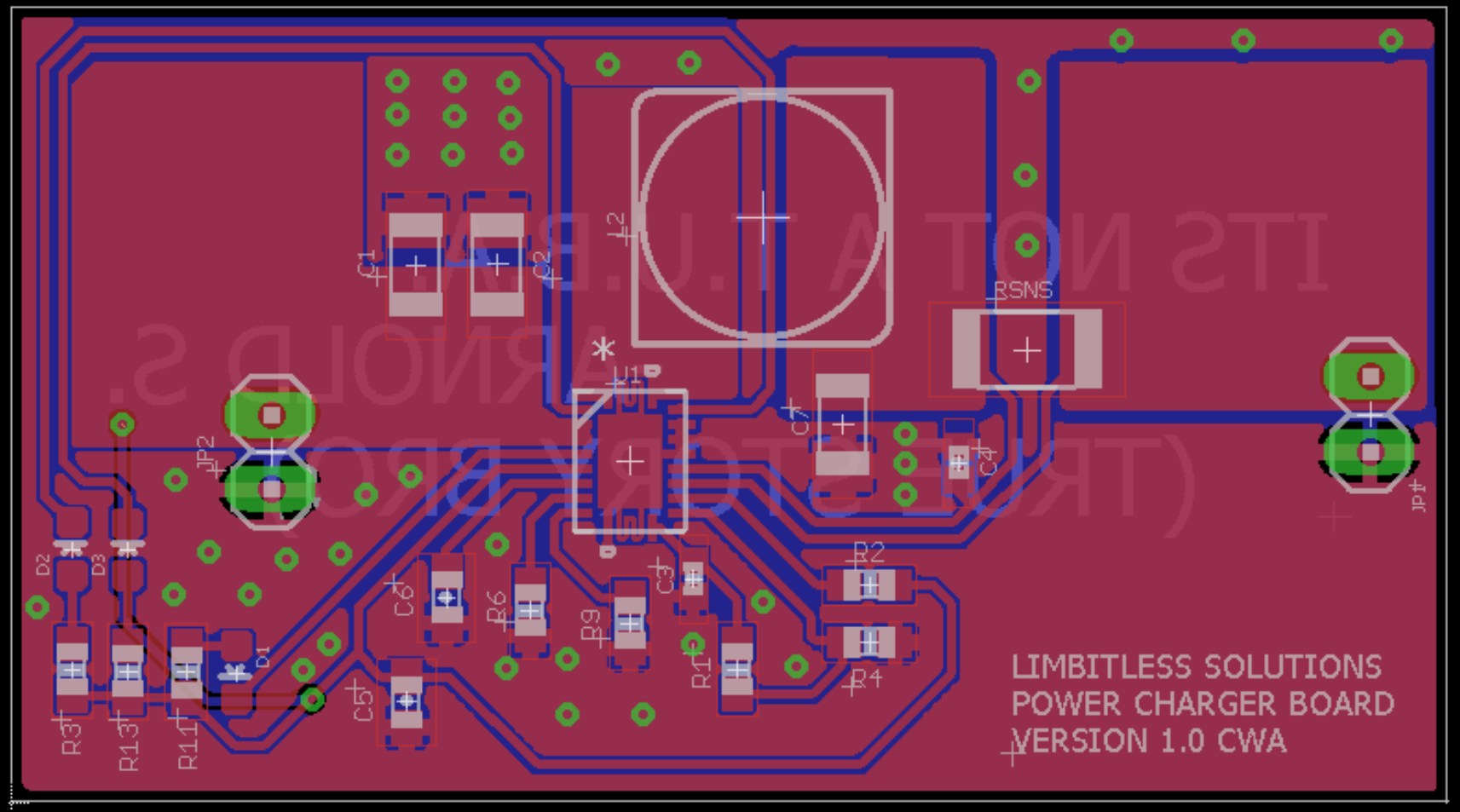
Li-Ion Battery Charger

- Switch-mode 1, 2, or 3-cell Li-Ion charger with a 2 Amp FET
- Designed for input range from 9–16 V
- Output regulated voltage 8.4 V
- Compatible with 2S batteries
- Available in 20-pin 3.5mm x 4.5 mm VQFN package
- Price: $5.18

BQ24123 Li-Ion Battery Charger Schematic



CHARGING BOARD



BATTERY

Tenergy Li-Ion 7.4V 5200mAh Rechargeable Battery

The Tenergy Li-Ion battery meets all of the specifications of the design. It is a 2-cell battery, that can discharge up to 5A.

The battery has built-in charging protection, to prevent overcharging.

The capacity is up to 5200mAh, to meet the 85% requirement of the arm

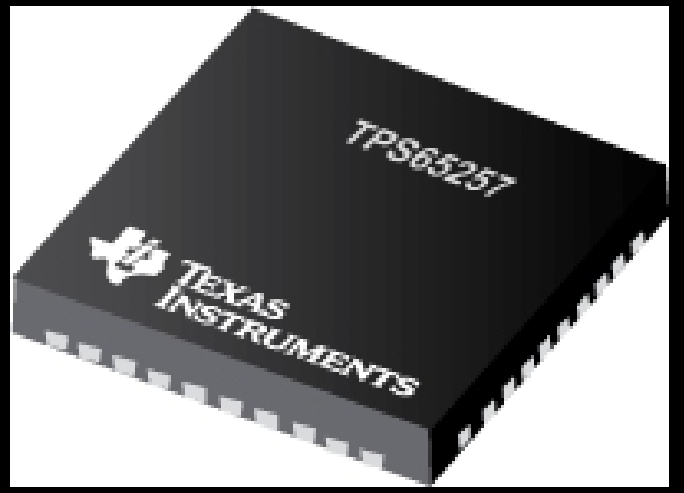
Parameter	Specification
Mass	191g
Dimensions	70 x 36 x 36 mm
Capacity	5200 mAh
Vendor	Tenergy
Cost	$47.94
Charge Rate	2.5A (up-to)

DC-DC CONVERTER

The TPS65257 is a triple buck converter, that handles an input range of 4.5-16 V.

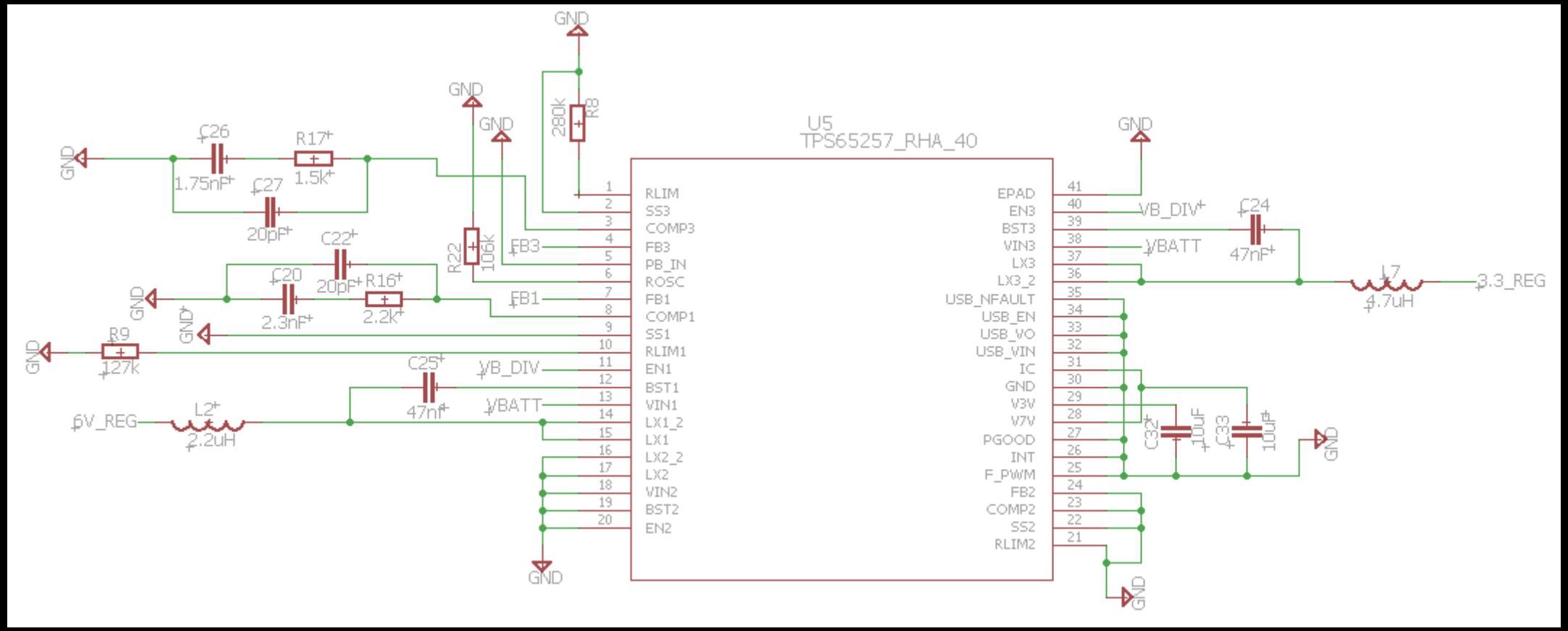
For this chip, each individual rail can be configured to be enabled or disabled, through the design or through push-button input.

Supports up to 3.5 A on a single Buck, allowing for the ability to power up to two servos at load.



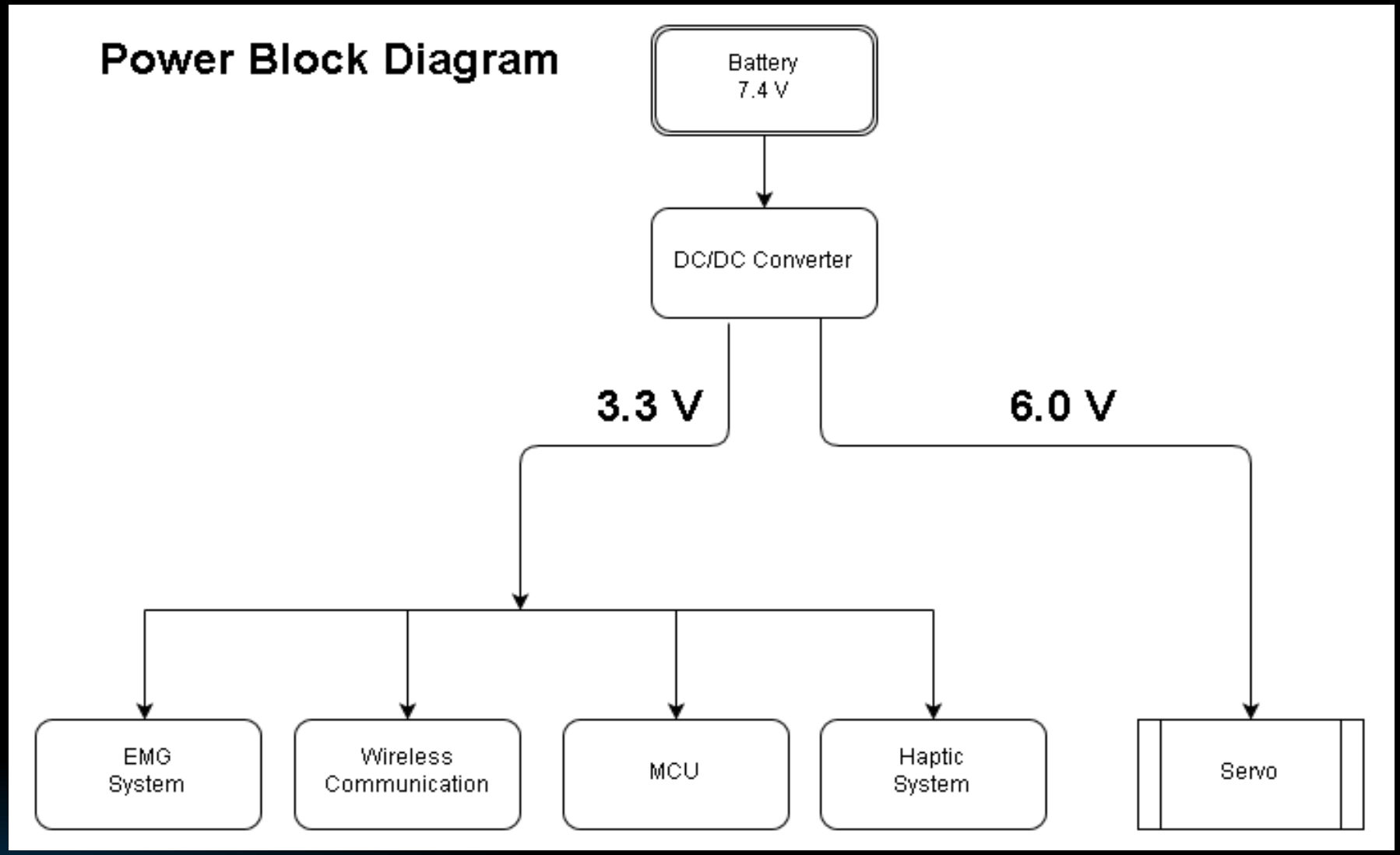
Parameter	Specification
Package Type	QFN
Temperature Range	-40 C – 125 C
Input Voltage	4.5 V – 16 V
Vendor	Texas Instruments
Cost	$8.19
Dimensions	6 X 6 mm

SWITCHING REGULATOR SCHEMATIC



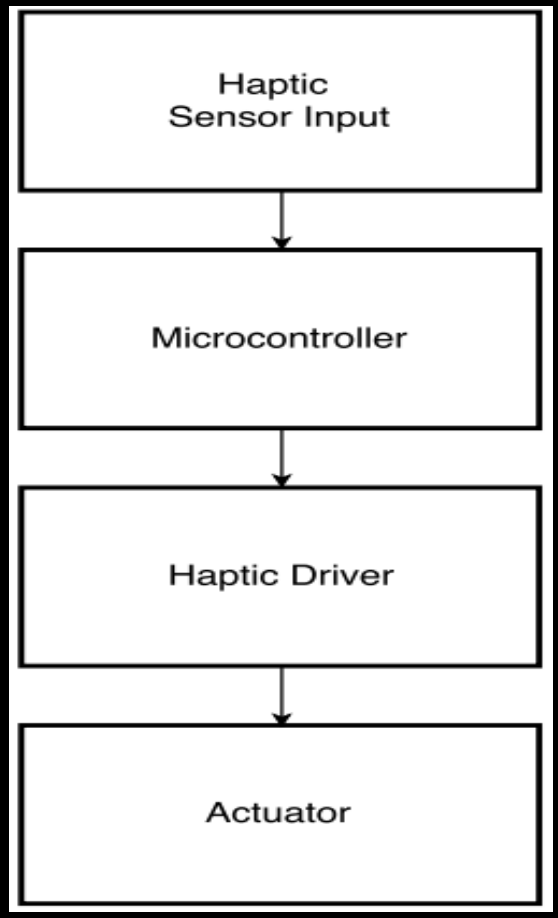
Features two populated outputs for 3.3 and 6V. The third rail was left unpopulated for the purposes of future expansion.

POWER DISTRIBUTION

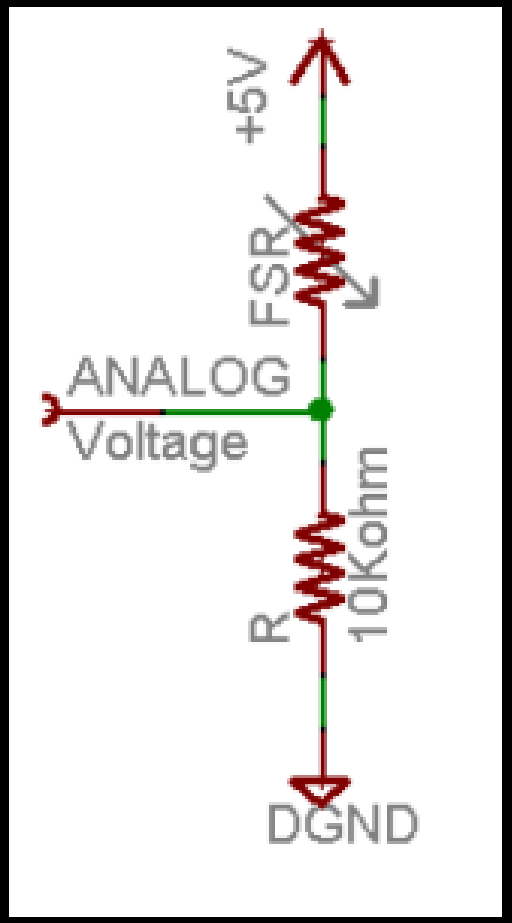


HAPTIC FEEDBACK SYSTEM

- 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.



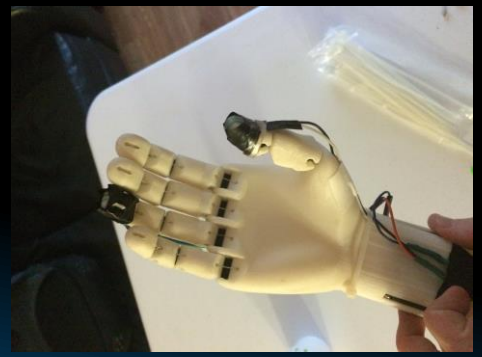
HAPTIC SENSOR



- 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 best 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 with pressure.
- At full pressure this resistance can be decreased to approximately 2.5 kilo-ohms.
- Multiple can be connected in parallel for the same effect for multiple finger placement.



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

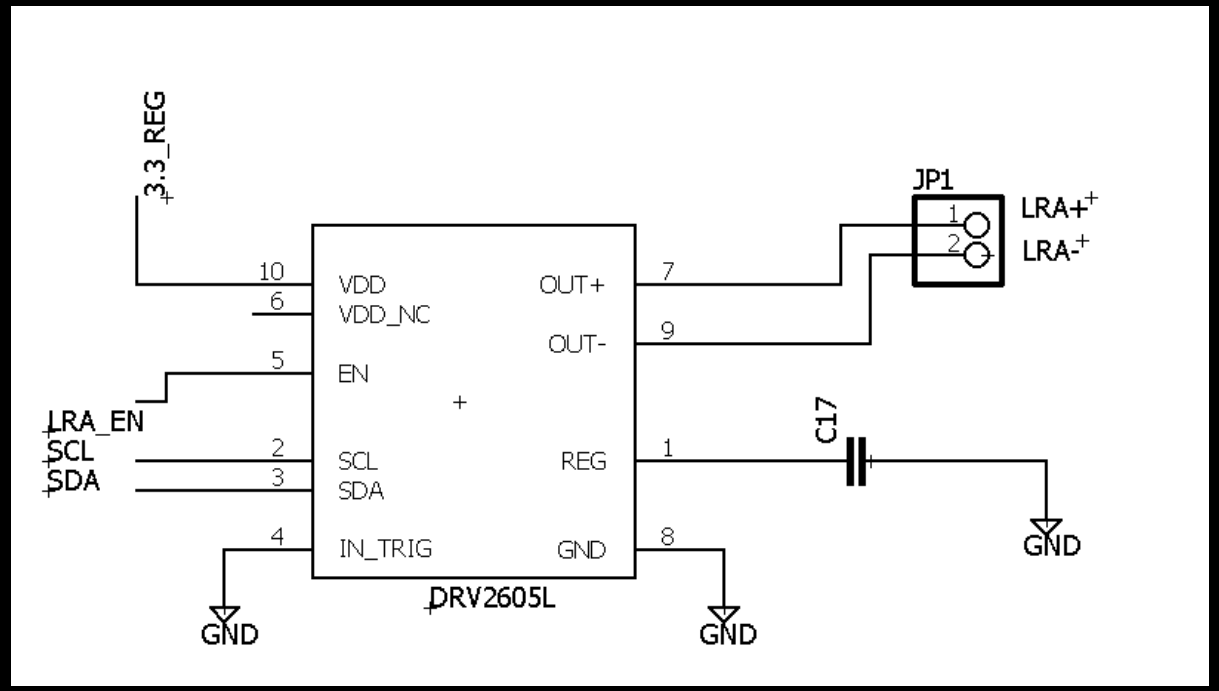
- Haptic Drivers are used because typically the microcontroller can not supply enough current to the actuator that enables the response.

- They are used in many cellular devices, as well as game controllers.

AVAILABLE HAPTIC DRIVERS

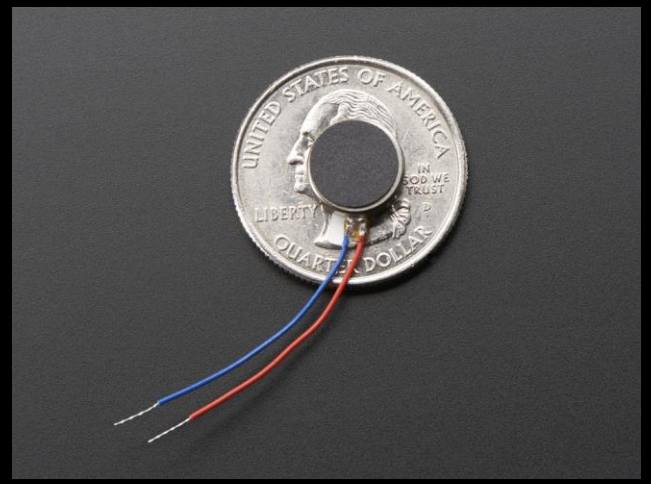
Parameter	DRV2605L	DRV2603	DRV2604
Vs (Min) (V)	2.5	2.5	2.5
Special Features	Integrated Haptic Effects Smart Loop	Auto Resonance	Smart Loop RAM Available
Input Signal	PWM, Analog, I2C	PWM, Analog	PWM, Analog, I2C
Vout (Max) (V)	11	10.4	11
Supported Actuator Types	ERM, LRA	ERM, LRA	ERM, LRA
Startup Time (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 be sent to actuator.
- Compatible with different actuator types.
- Takes little board space, and requires no additional GPIO pins

ACTUATOR OF CHOICE



Parameter	Specification
Body Diameter	10 mm
Operating Current	69 mA
Rated Voltage	2 V (RMS)
Purchased From	Adafruit
Cost	$1.95

Eccentric Rotating Mass (ERM)

- Mass is rotated around a point, creating a sense of vibration.
- Motor is enclosed.
- Vibration is much stronger than LRA devices.

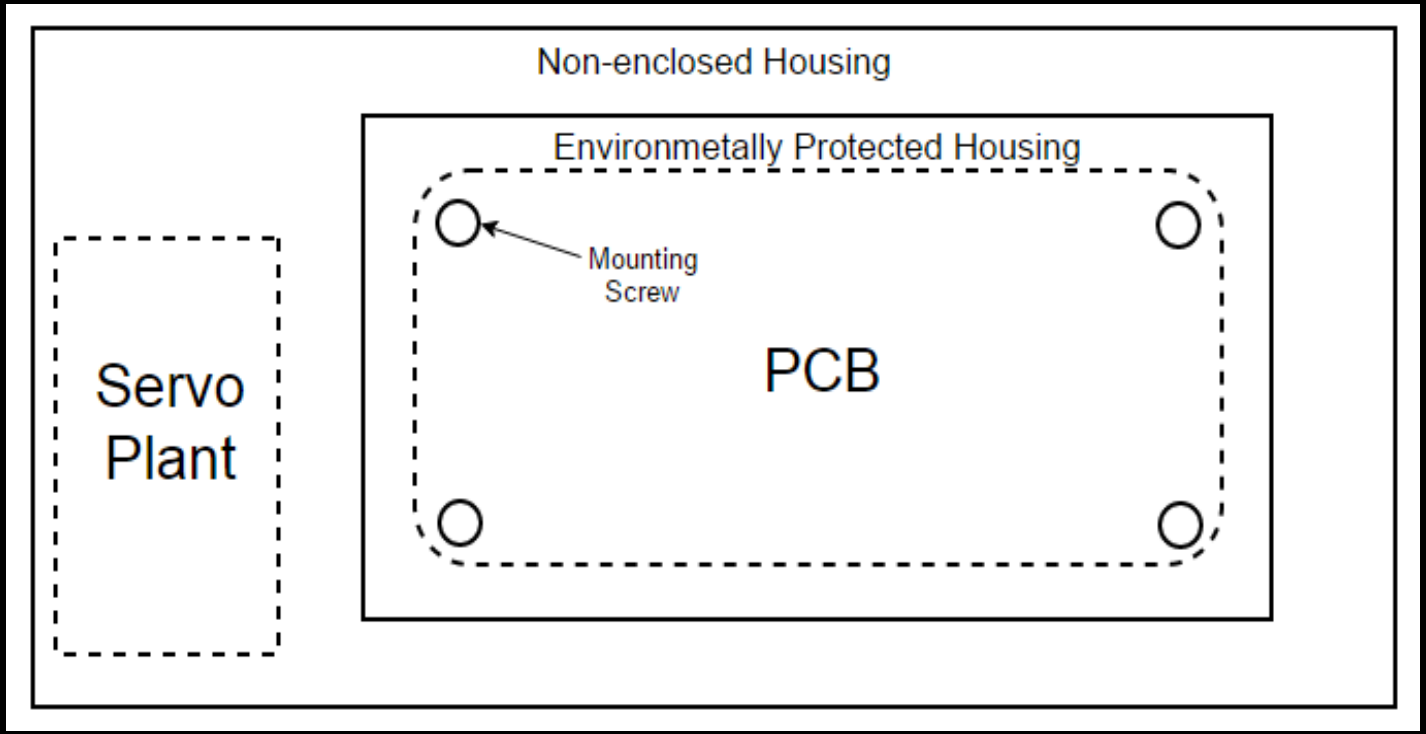
CONFORMAL COATING

Conformal coating will be used to protect the boards electronics in the future implementation.

Use of this coating was demonstrated for Limbitless. The conformal coating provides resistance against dirt and water for the board.

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"



- Limbitless requested the team to recommend a design that protects the electronics to be used in the future.
- For this, the team recommended creating an enclosed housing.
- Epoxy sealing the casing was recommended to prevent user interaction with components.
- PCB will be mounted to prevent movement .
- This enclosed case will increase resistance to water and dirt exposure as well.
- All connections would run out of the casing.

ENVIRONMENTAL PROTECTION

- Conformally coating the board added significant protection to the Adafruit Trinket Pro, allowing it to be submerged in water

- This has been demonstrated to be included in the production cycle for the Limbitless Arm, along with plans for a protected enclosure for the PCB

EVALUATION

TESTING - WEIGHT

- Specification requires less than 1.4 kg

Weight testing	
Object	Measured Weight (g)
Main P.C.B. - Populated	15.0
Battery	191.0
EMG Sensor Package x 2	56.0
Charging Evaluation Module	14.0
Limbitless Arm w/ Enclosure	145.0
Servo x 2	110.0
Haptics Actuator	0.9
Force Sensitive Resistor	0.3
Miscellaneous Wires	0.9
Total weight in grams:	533.1
Total weight in grams (Electronics):	388.1
Total weight in Pounds:	0.856

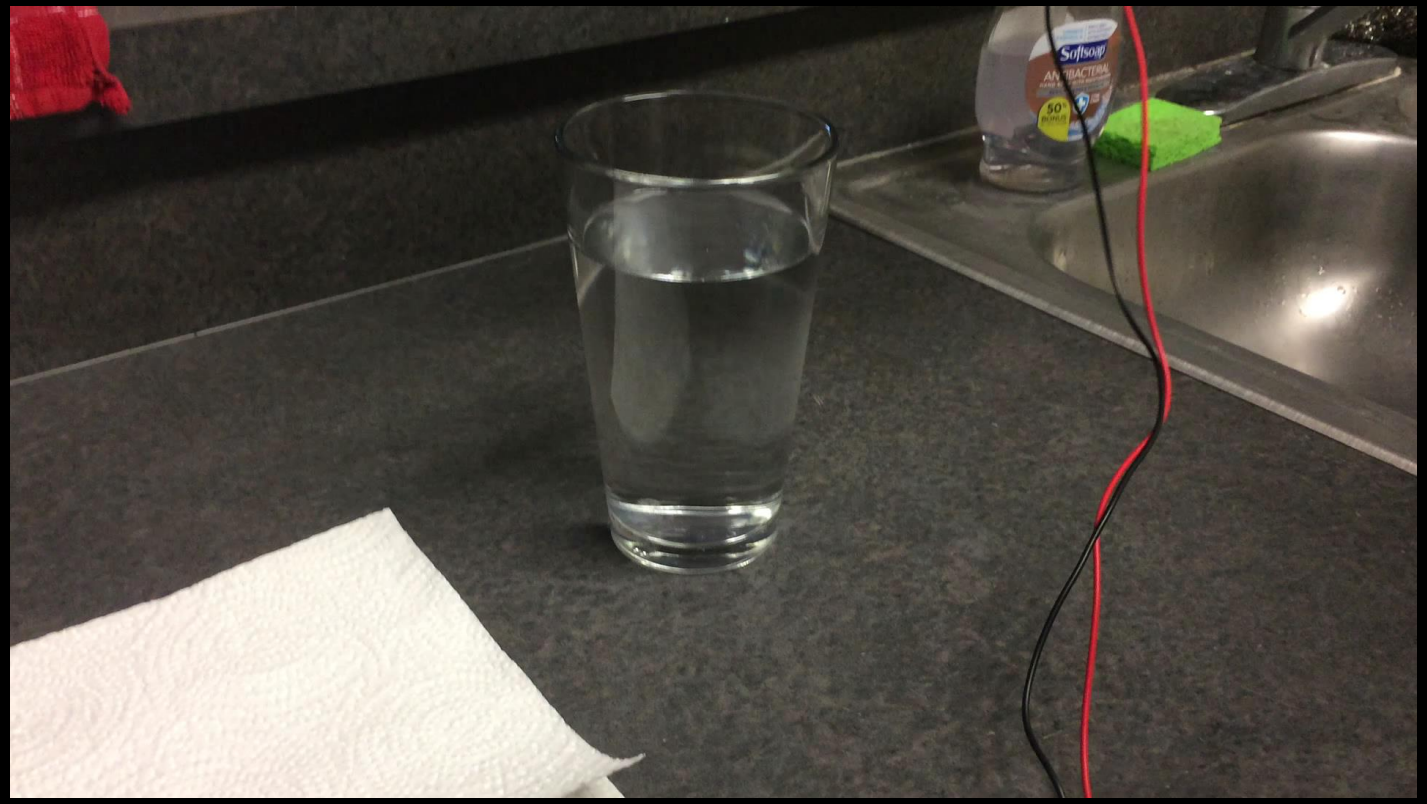
EVALUATION– BATTERY LIFE

- Specification requires greater than 10 hours standard usage

Condition	State	Power draw (mA)	Percent time hand idle	Battery Capacity (mA*hr)	Battery Life (hr)
2 Servos, 1 with heavy load	Open	30	85%	5000	19.96
	Closed	1500			
2 Servos, 1 with heavy load	Open	30	68%	5000	10.00
	Closed	1500			

EVALUATION– ENVIRONMENTAL PROTECTION

- Demonstrate at least IP27 protection



EVALUATION- COST

Part	Part Number	Price per unit	Quantity Needed	Quantity Ordered	Expected Cost	Real Cost	Cost of Arm
Original Microcontroller	CC2650	$6.93	0	10	$69.30	$0.00	$0.00
Sable-X 2640	450-0119C	$14.28	1	10	$142.80	$142.80	$14.28
P.C.B V1.1	Limbitless V1.1	$5.40	1	6	$32.40	$32.40	$5.40
Charging P.C.B.	Limbitless_ChargeV1.0	$4.80	1	3	$14.40	$14.40	$4.80
P.C.B V1.0	Limbitless V1.0	$8.90	0	6	$53.40	$53.40	$0.00
Haptic Driver	DRV2605L	$4.25	1	5	$21.25	$0.00	$4.25
Servo	MG995	$6.99	2	4	$27.96	$0.00	$6.99
EMG Sensor	N/A	$37.95	2	4	$151.80	$0.00	$37.95
ERM Actuator	N/A	$1.99	1	6	$11.94	$11.94	$1.99
LRA Actuator	C10-100	$9.19	0	5	$45.95	$45.95	$0.00
Servo Driver	PCA9685	$2.43	1	5	$12.15	$12.15	$2.43
Force Sensitive Resistor	SEN-09375	$5.95	1	5	$29.75	$29.75	$5.95
Li-Ion Battery Charger	BQ24123	$5.18	1	5	$25.90	$0.00	$5.18
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
Old Battery	Venom7.4V	$43.99	0	2	$87.98	$87.98	$0.00
Battery	Tenergy34042	$47.99	1	1	$47.99	$47.99	$47.99
DC/DC Converter	TPS65257	$8.19	1	5	$40.95	$0.00	$8.19
Surface Mount Components	N/A	N/A	N/A	N/A	$141.10	$141.10	$9.49
Flash Module	W25X20CLUX	$0.46	1	10	$4.63	$4.63	$0.46
Shipping Cost for PCB	N/A	$89.00	N/A	N/A	$89.00	$89.00	$0.00
Conformal Coating	419C-55ML	$10.14	1	1	$10.14	$10.14	$0.51

- Specification requires less than $350
- With donated components the design cost was only $138.24 for the electronics

	Totals:		
Cost	$1,808.79	$723.63	$155.86
Budget	$1,000.00	$1,000.00	$350.00
Difference	($808.79)	$276.37	$194.14

EVALUATION– WIRELESS CONNECTION RANGE

- Specification requires greater than 3 meters
- Using CC2650 Launchpad, the range was roughly 12 meters before connection became unreliable

EVALUATION–BATTERY CHARGE TIME

- Specification requires less than 8 hours to recharge from fully drained
- Using an off the shelf charger running at 1 Amp, the battery will charge in roughly 6.3 hours

Unit	Number
Battery Capacity	5200 mAh
Charge Rate Current	1000 mA
Maximum Time To Full Charge (20% Efficiency Loss)	6.24 Hours

Calculate Clear Values

CHALLENGES

- Complexity of updating the code through Bluetooth communication
- Availability of components
- General learning curve for P.C.B. design.

HONORABLE MENTIONS

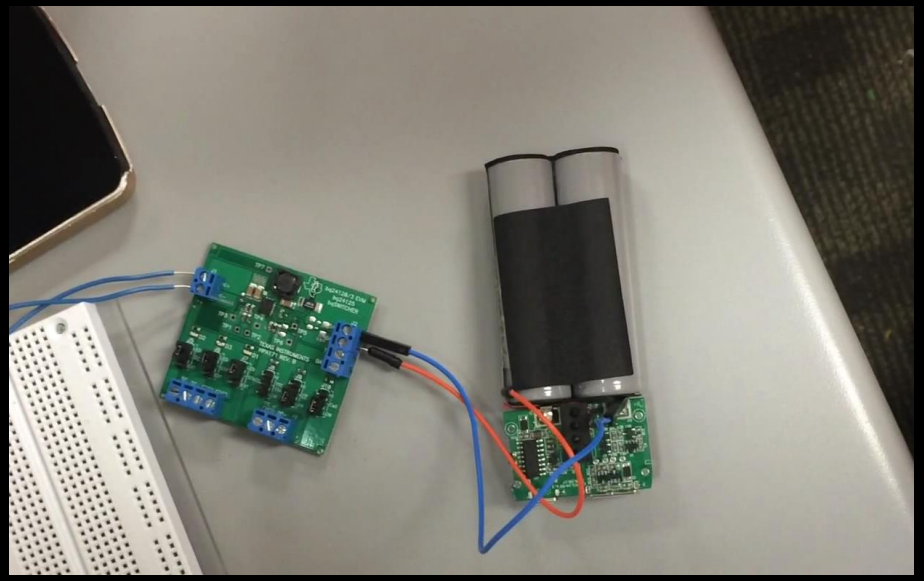
- Trey German – Techincal Advisor from TI
- Cathy Wicks – University Program lead at TI
- Sam Hanna – QMS Productions Director
- Al – QMS Technician
- Albert Manero – Executive Director of Limbitless Solutions
- Dominique Courbin – Director of Production at Limbitless Solutions

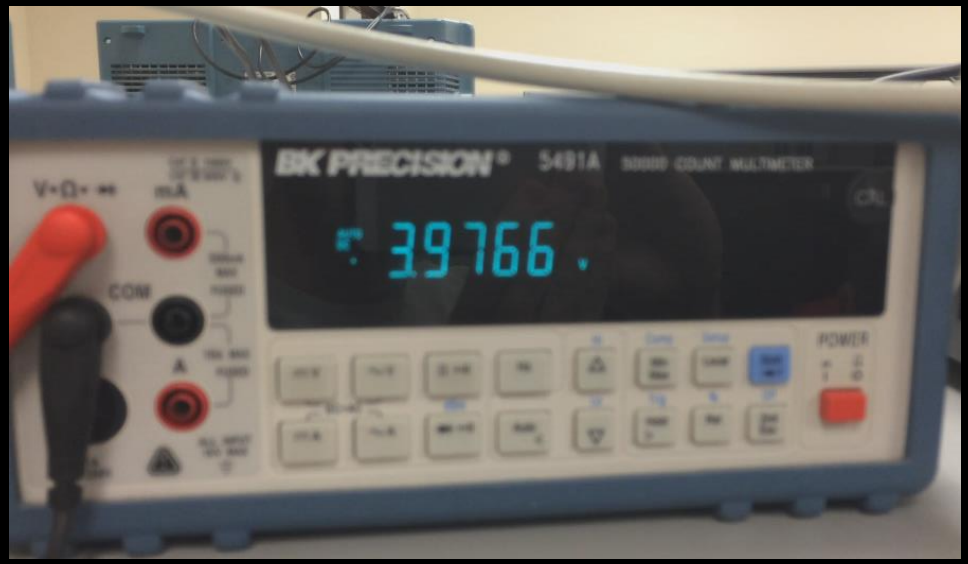
limbitless SOLUTIONS

QUALITY MANUFACTURING SERVICES, INC.

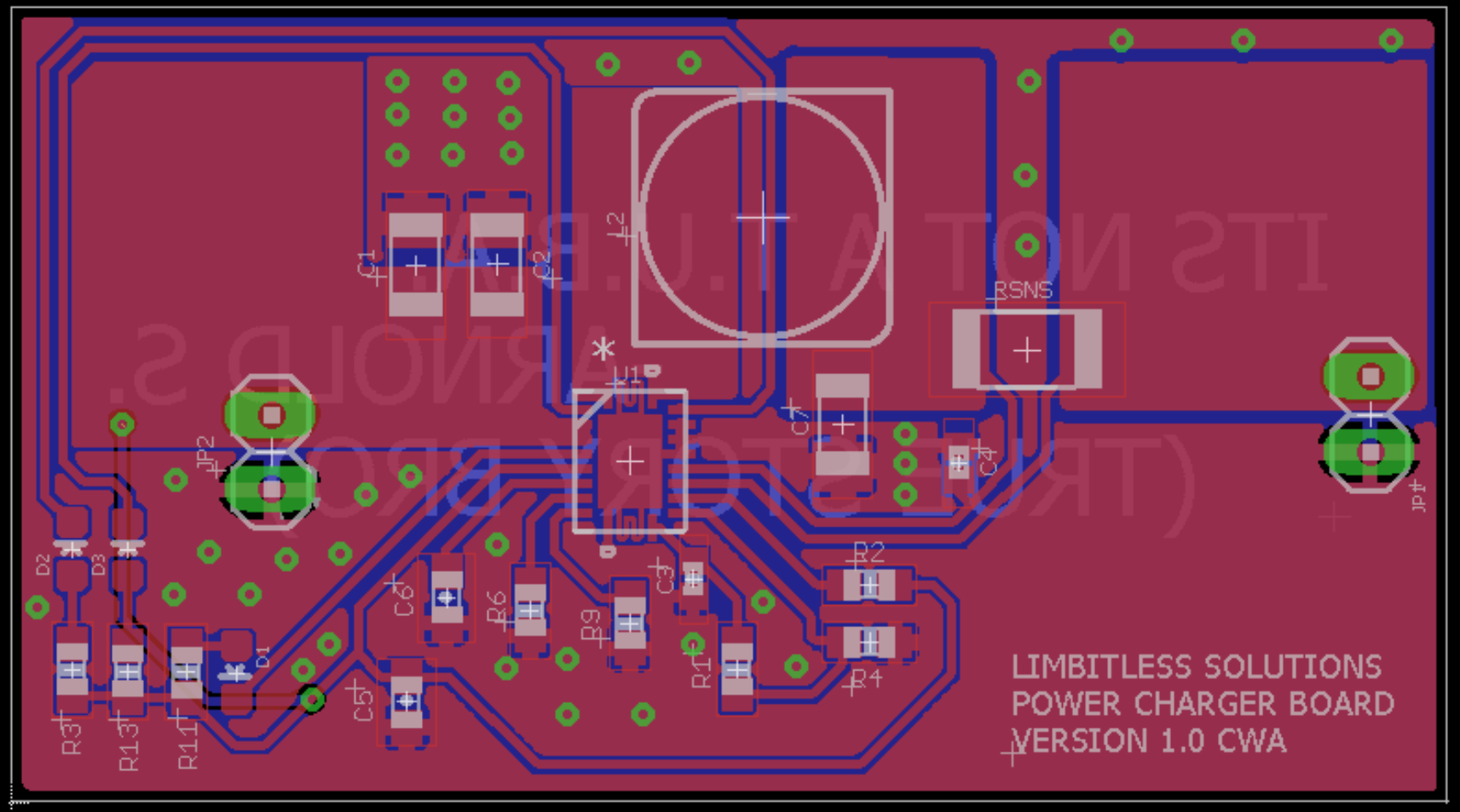
QUESTIONS BEFORE DEMO

CHARGING





CHARGING BOARD



QUESTIONS?