Battery-Free Handheld Game

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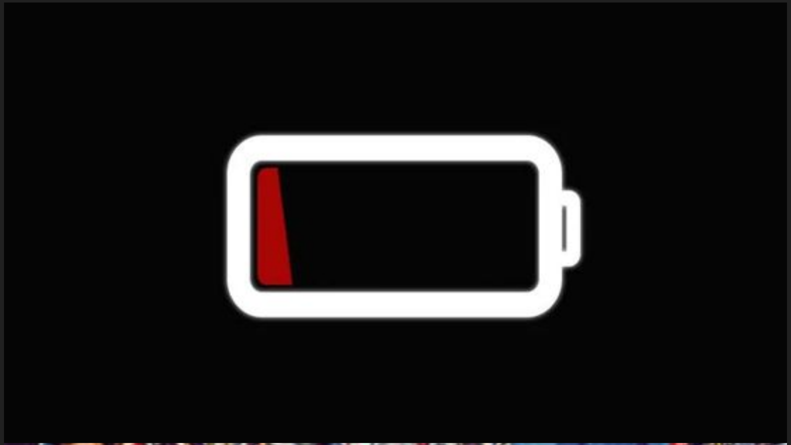
Advisor/Client: Henry Duwe

Problem Statement

- Batteries have problems:
  - Limited storage
  - Need to be recharged or disposed of
  - Large devices
- Goal: create a battery free gaming device
  - Fun proof of concept
  - Show capabilities of a battery free system
  - Further knowledge in energy harvesting devices



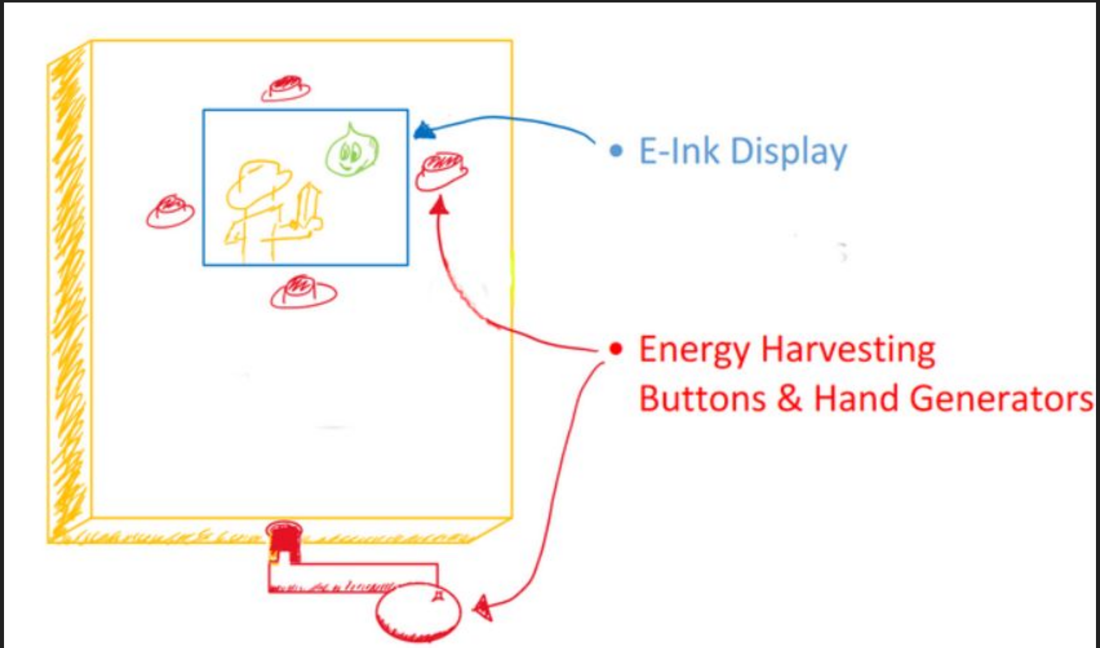
Market Survey

- Battery-Free Game Boy
  - Northwestern University and the Delft University of Technology (TU Delft) September 2020
  - Battery-Free
  - Uses solar panels and kinetic button harvesters

- What Makes Ours Unique
  - Soley uses human input to generate power
  - Incorporates energy harvesting into gameplay interaction

Concept & Functional Requirements

- Handheld batteryless gaming device
- Powered through human interaction
- No need to have charging accessories/batteries
- Multiplayer capabilities
- Fun gameplay that creatively incorporates energy harvesting



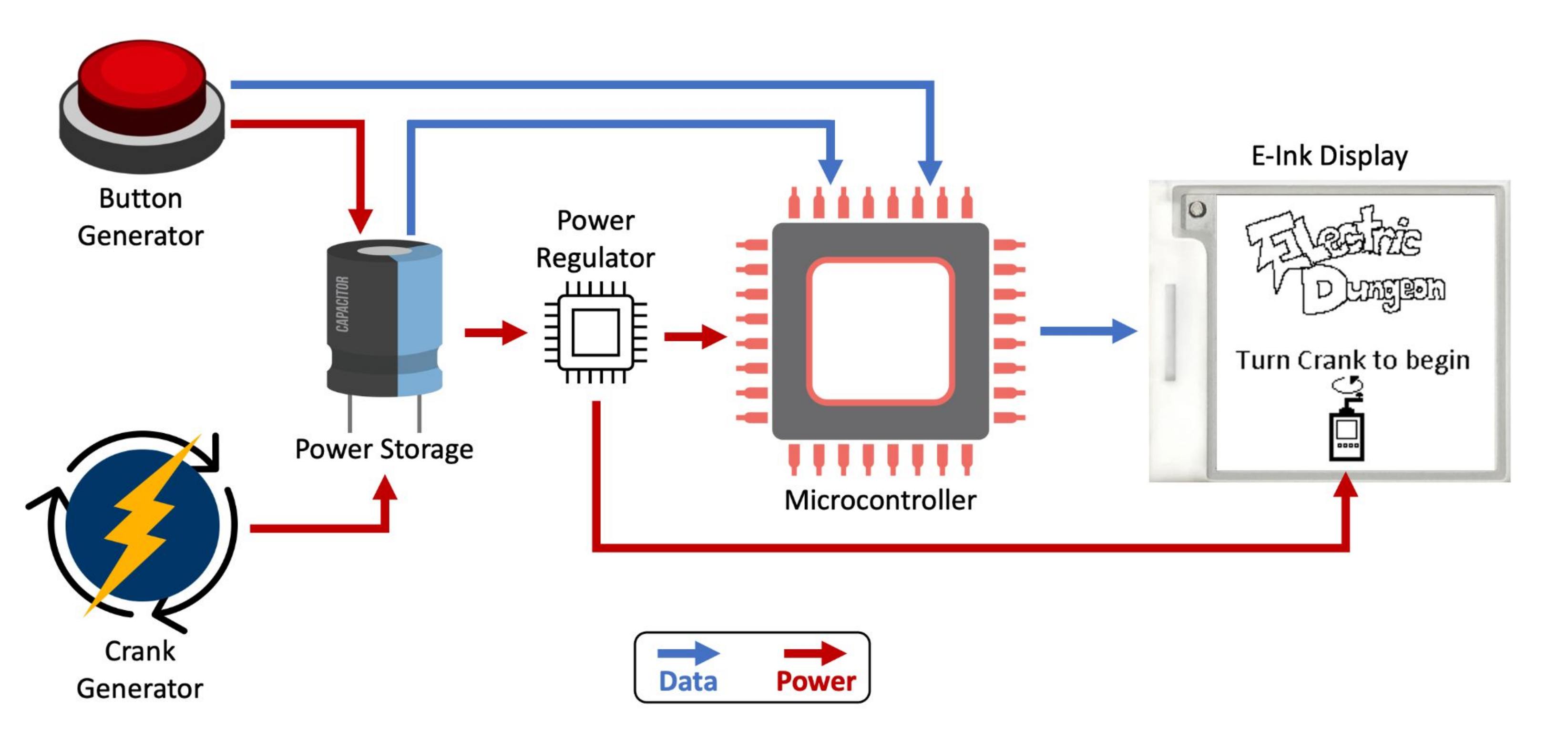
Constraints

- The device must be successfully designed and built within 26 weeks.
- The device must be produced at a reasonable cost of around $100
- The operating environment must be acceptable to the integrated hardware.
- The device must be unique from any other battery-free gaming devices available.

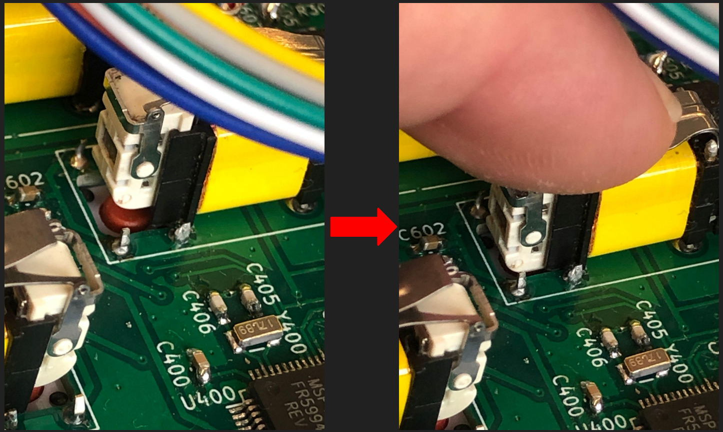
Resources & Cost

Part	Price	Qty	Price for Qty
MSP430FR5994	$ 9.79	1	$ 9.79
Power Buttons	$ 11.15	4	$ 44.60
E-ink Display	$ 19.50	1	$ 19.50
Hand Crank	$ 9.99	1	$ 9.99
PCB	$ 8.00	1	$ 8.00
Other	$ 35.23		$ 35.23
		Total:	$ 127.11

Functional Diagram



Power Generation



Mini Motor Generator

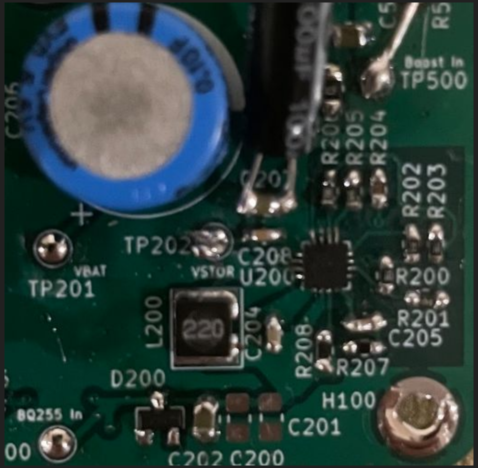
- Full-wave 3-phase rectification
- 1 to 3 Gear ratio to optimize output

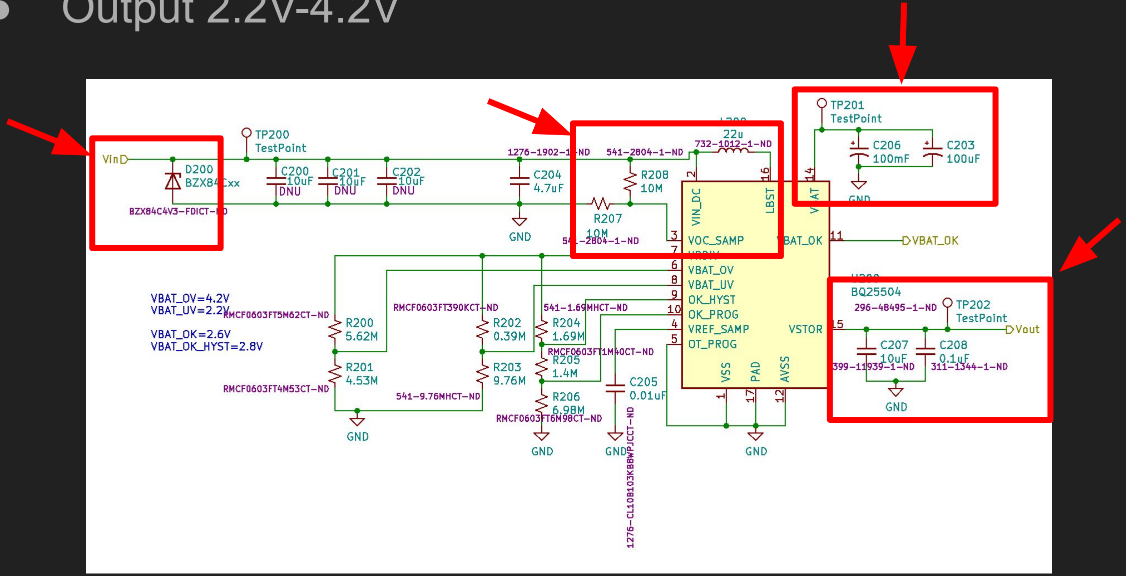
Kinetic Button Harvester

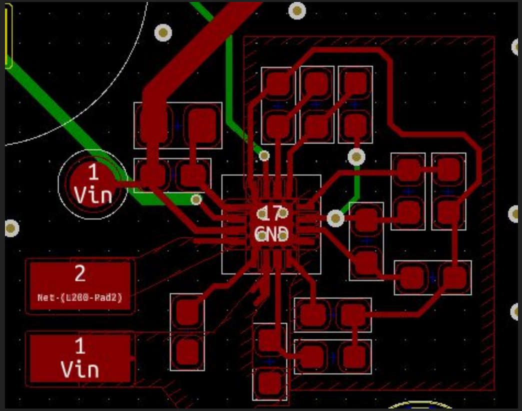
- Full-wave rectification
- GPIO input support

Power Storage

- BQ25504 boost converter/charger
- Input limit
- Boost converter
- Energy storage
- Output 2.2V-4.2V

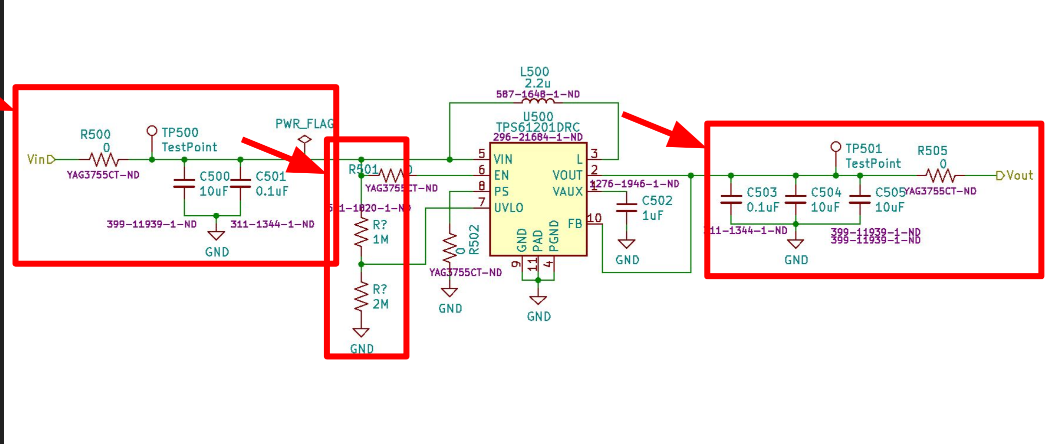


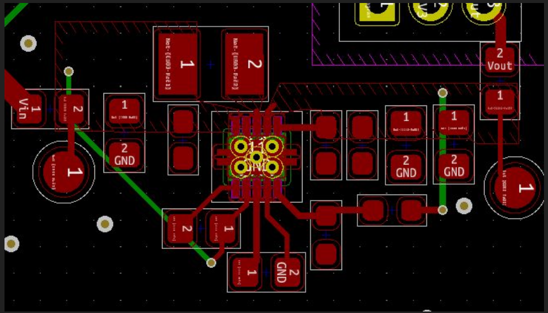




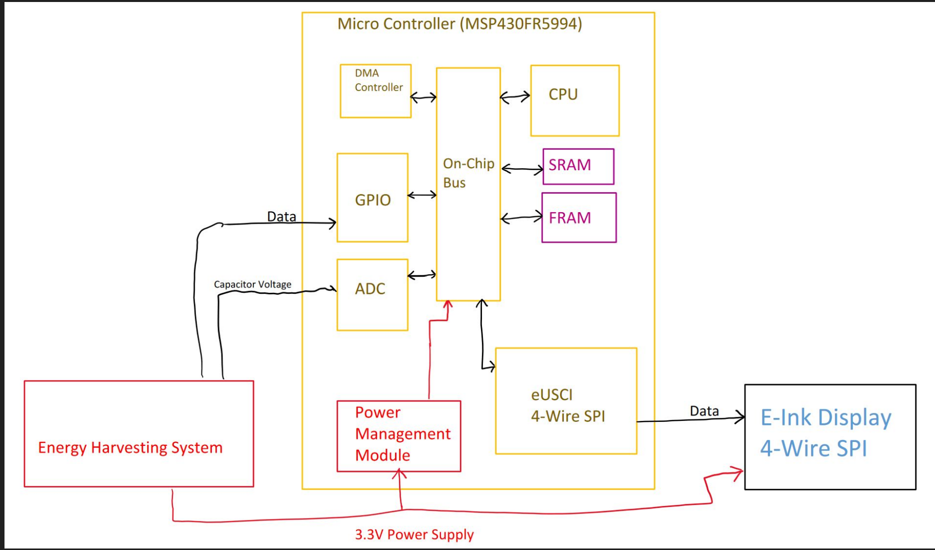
Power Regulation

- TPS61201 Boost Converter
- Input 2.52V-5.5V
- Under Voltage Lockout
- 3.3V fixed output





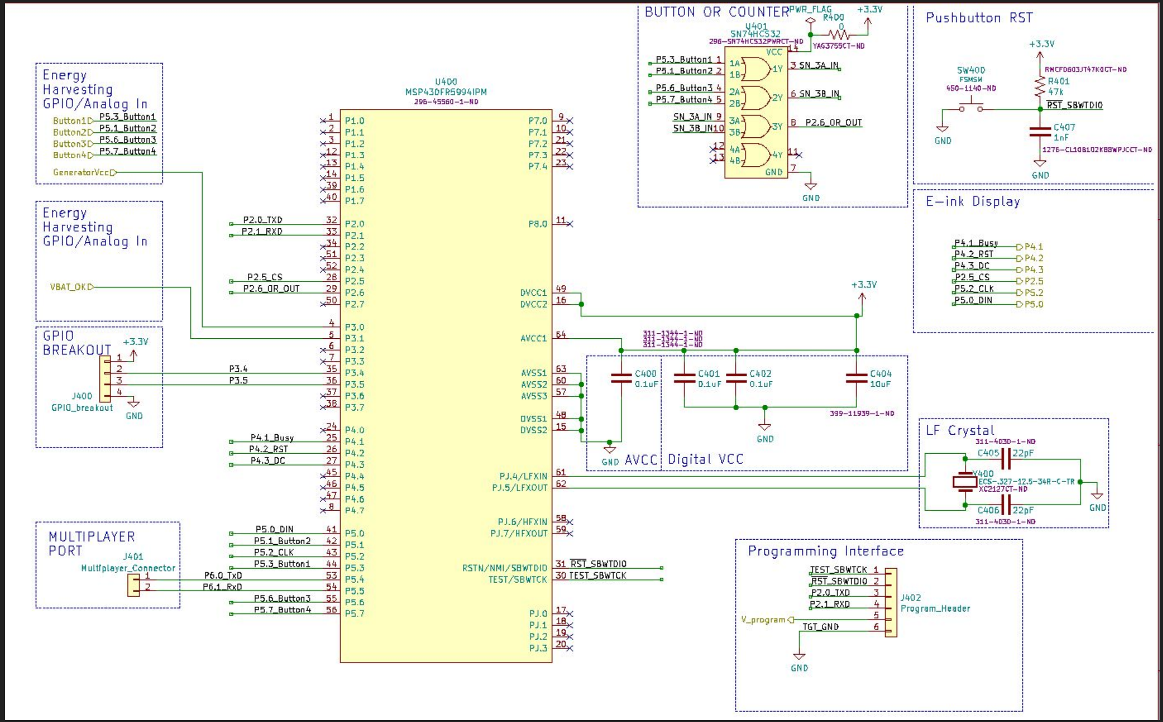
Microcontroller (MSP430FR) - Peripherals



- Low Power Modes
  - Disabling components when not in use
  - Interrupt triggered state changes
- ADC
  - Monitor voltage on super capacitor
  - Interrupt for ctpl shutdown
- FRAM Utilities
  - Storage for game state
  - DMA CPU-less memory R/W
- Timers
  - HW timer interrupt for delays
- GPIO
  - Buttons

Microcontroller (MSP430FR)

- Integrate onto PCB
- Programming Interface
- Risk Mitigation

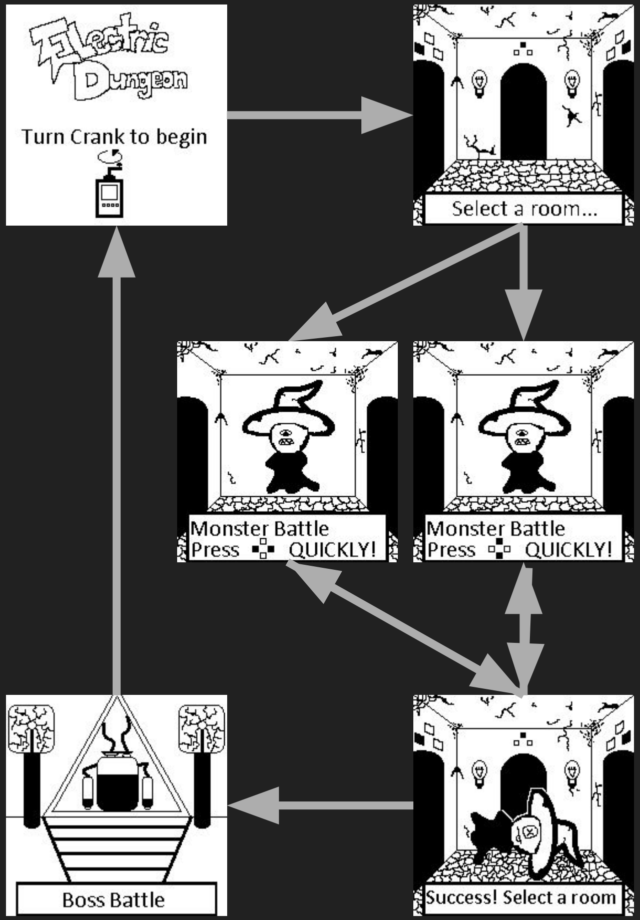


E-ink Display

- Interface
  - 4-wire SPI
  - Implementation Libraries from WaveShare Inc.
- Hand-drawn static images
  - Stored in FRAM as 5-kilobit C-arrays
  - Limited to 50 kilobits total for image storage
- Configuration nuances for Low Power
  - Largest current consumption module
  - Reset signal active high
  - Screen clearing

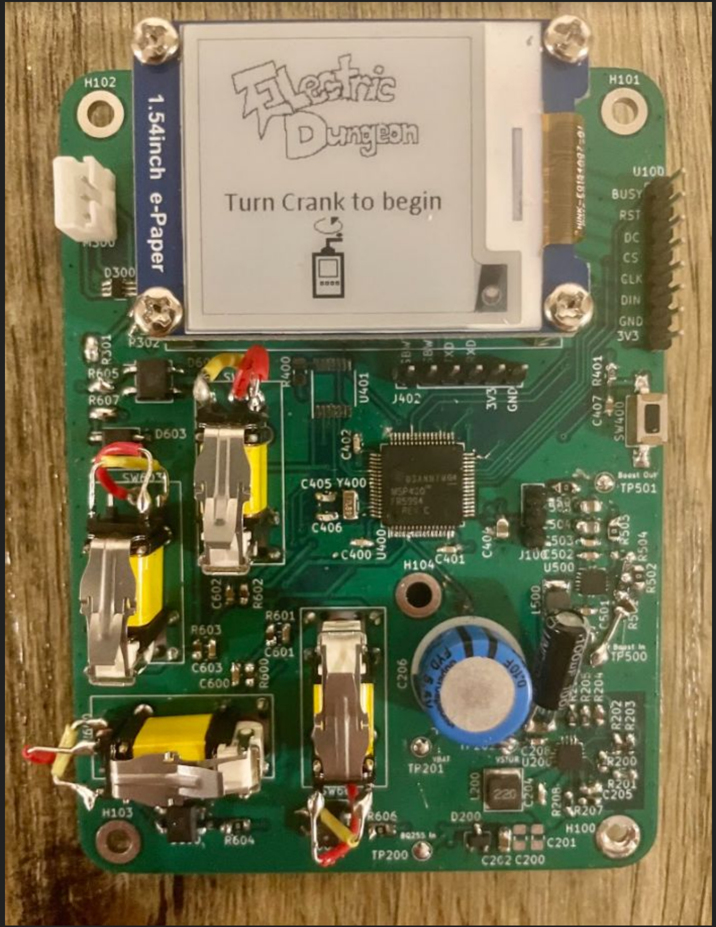
Software Game Implementation

- Synchronous Software Development
  - Modular in order to accommodate easy conditional changes to gameplay
  - Design based around making refactor time as short as possible
- Compute through power loss API
  - Used to save initialization settings for all programed modules of the MCU
  - Faster start up after brown out
- State Change Progression
  - main() function simply manages game state and associated function calls
  - Interrupt Service Routines (ISR) used with low power modes when waiting for user input



Final PCB

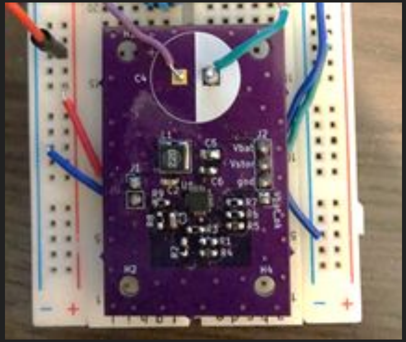
- Consolidated all block into single system
  - Power production
  - Power storage
  - Boost Regulator
  - Integrated uC
  - E-ink Display
  - Software
- Testing
  - Zero Ohm Resistors
  - Test Points

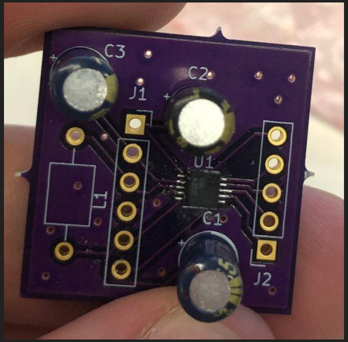


Hardware Testing

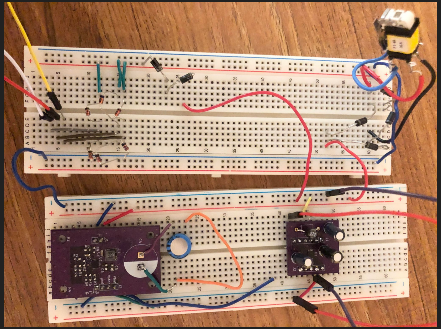
- Unit Testing
  - Breakout boards
  - Ensure functionality via lab equipment
- Integration Testing
  - Power production to power storage
  - Power storage to power regulation
- System Testing
  - Entire gameplay loop

Unit Testing

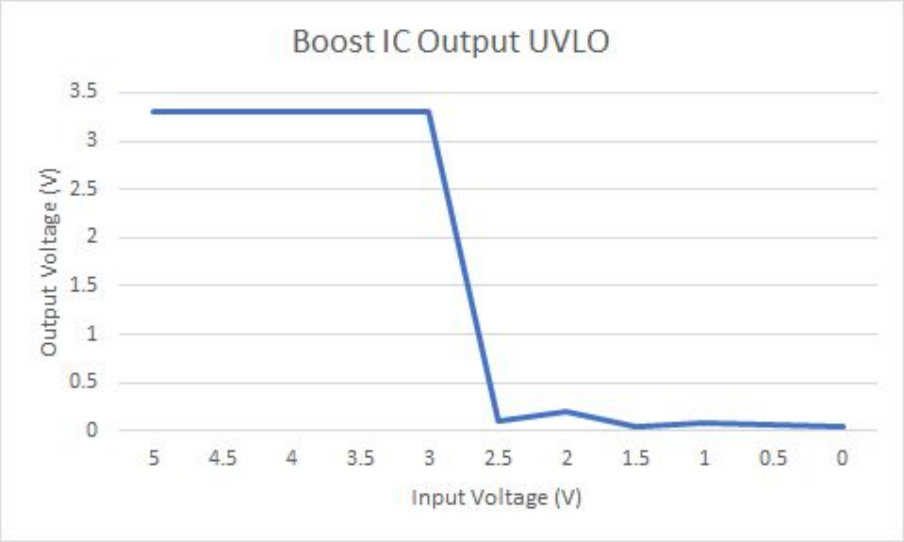




Integration Testing



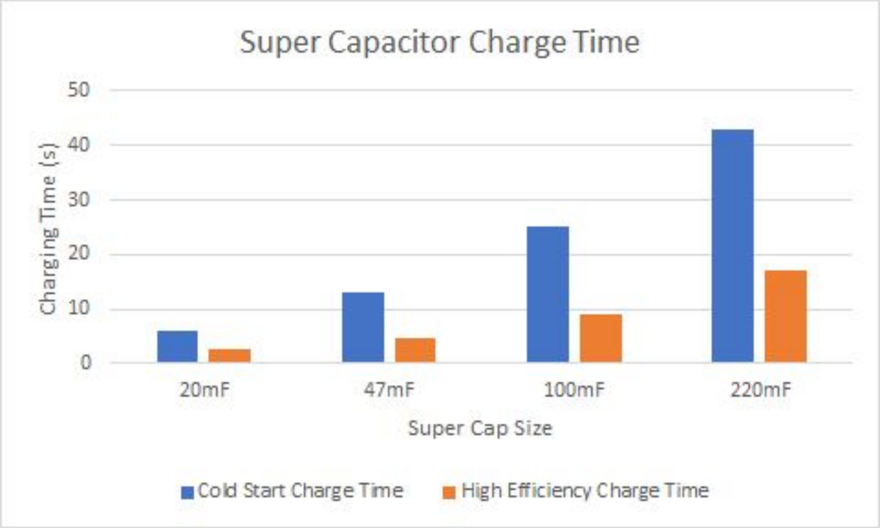
Unit Testing - Boost IC



- Boost UVLO at 2.52V
- Test Setup
  - Boost Breakout Board
  - Lab Voltmeter and Power Supply
- Expectation:
  - Output remains @ 3.3V until input drops below 2.52V

Unit Testing - Super Capacitor

- Charging & Discharging Timing
- Cold Start vs High Efficiency State
- Test Setup:
  - Power IC Breakout Board
  - Use Crank Crank to generate power
  - Use voltmeter to measure output
- # E-ink Full Refreshes
  - 220mF: ~10
  - 100mF: ~5
  - 47mF: 2-3



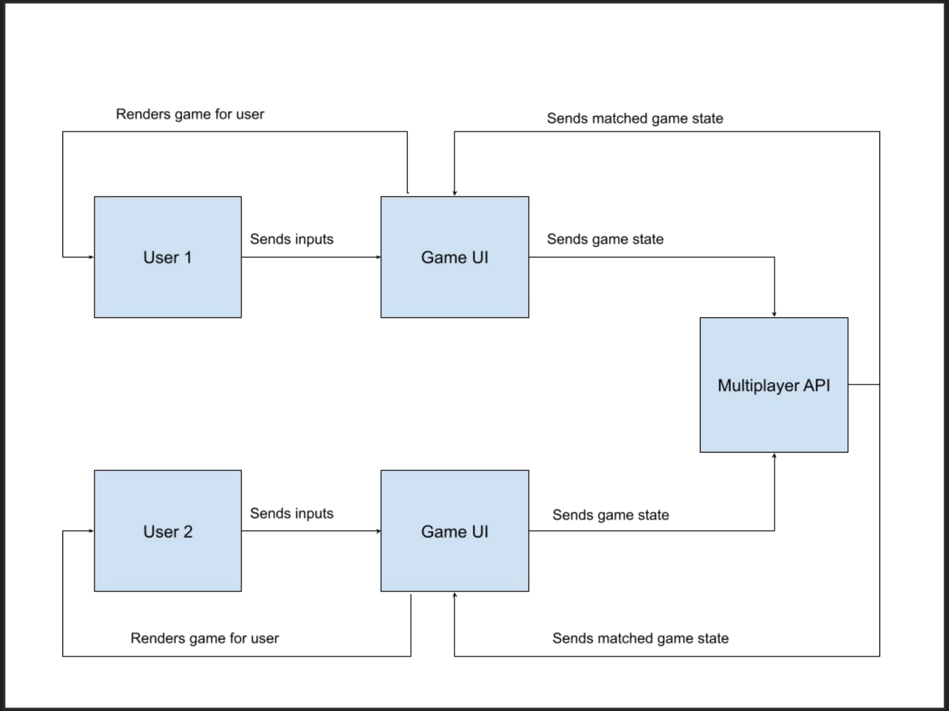
Risks & Mitigation

Risk	Mitigation
Certain modules on the final PCB do not function as expected	• Add zero Ohms in critical places • Add testpoint for easy debugging
Final PCB does not function	• Breakout modules of each major piece • If necessary breadboard breakout modules together to obtain a functioning design
Software memory requirements exceed the MCU onboard memory available.	• Utilize SD card memory storage • Reduce the software complexity

Hardware/Software Technology Platforms

- Software
  - Code Composer Studio
  - CLion
- Hardware
  - KiCAD

Future Implementations



- Multiplayer Functionality
- Utilize 2nd FRAM module
  - Additional Screens
  - High Address Space
- Implement Partial Refresh
- Increase Game Complexity
- Better Handling of Coldstart on BQ25504
- Coverage testing

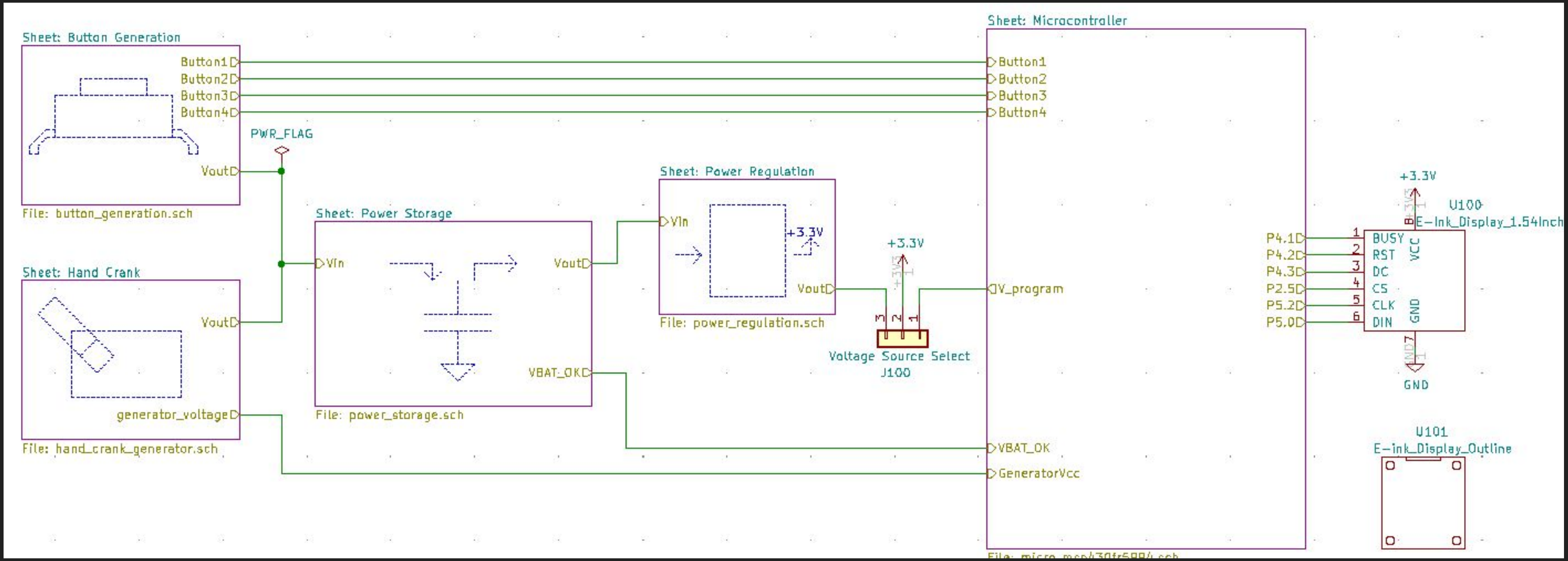
Task Responsibilities and Contributions

- John Brose
  - Chief Engineer- Power Systems
  - Meeting Facilitator
- Jake Larimore
  - Chief Engineer- Integration
- Franklin Bates
  - Chief Engineer- Microcontroller
  - Meeting Scribe
- Daniel Lamar
  - Test Engineer
  - Report Manager
- Shivam Vashi
  - Chief Engineer- Software

Final Product - It works!

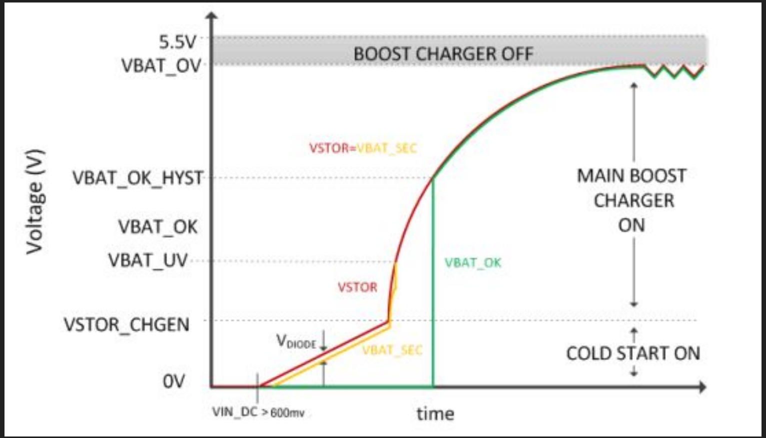
Any Questions?

Top Level Schematic

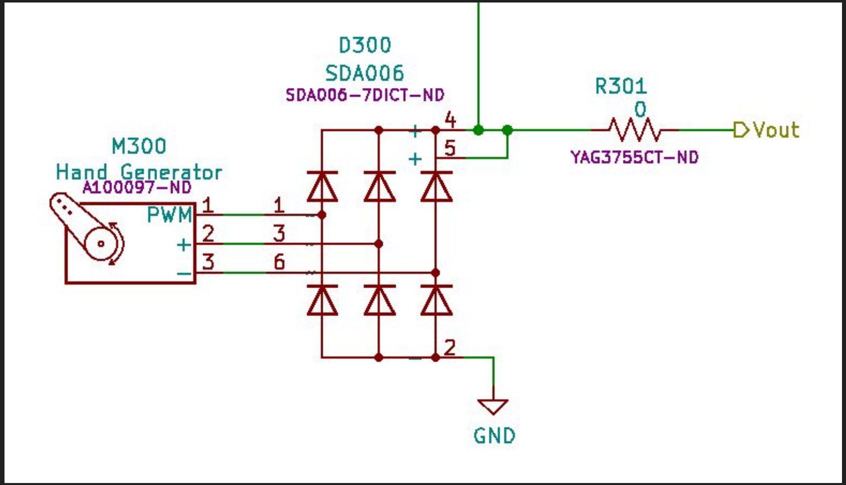


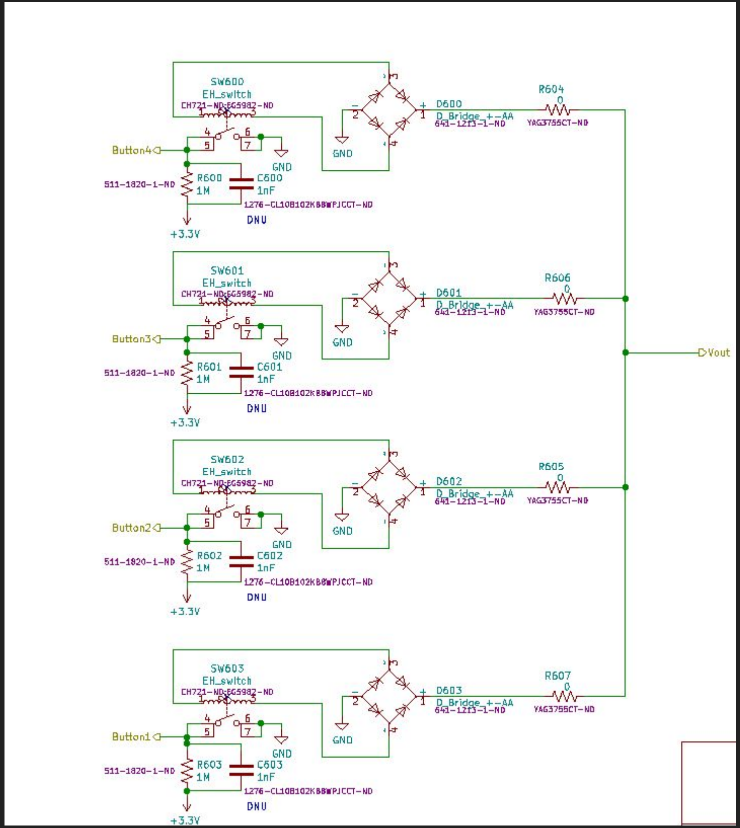
BQ25504 - Coldstart

- Clamped to 600mV during coldstart
- Use PFet on output of module that is controlled by vbat_ok which would attach the load after cold



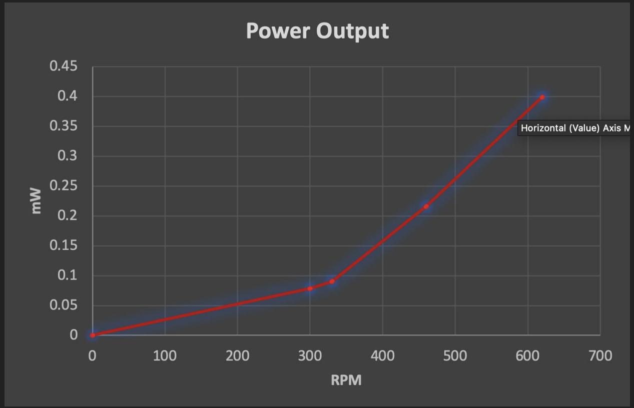
Hand Crank and Button Schematics

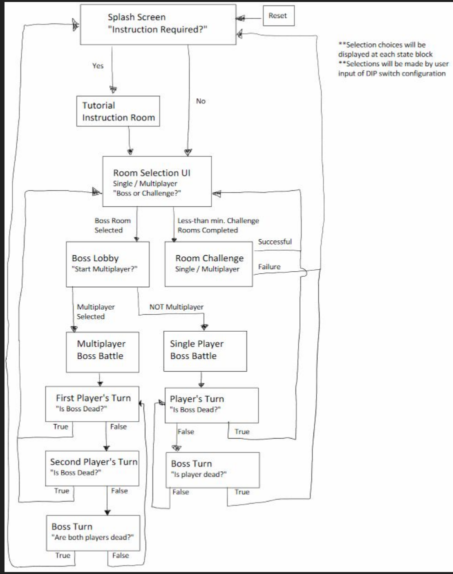




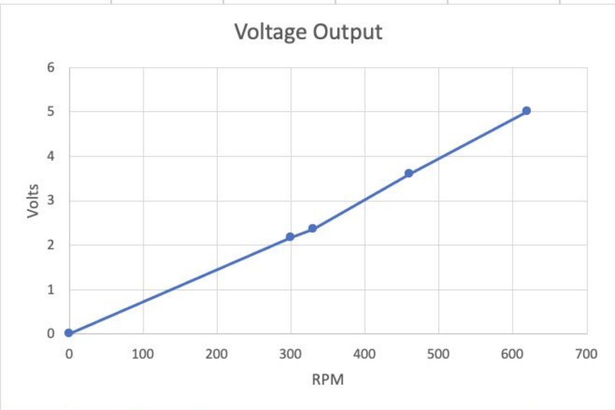
First Semester Recap

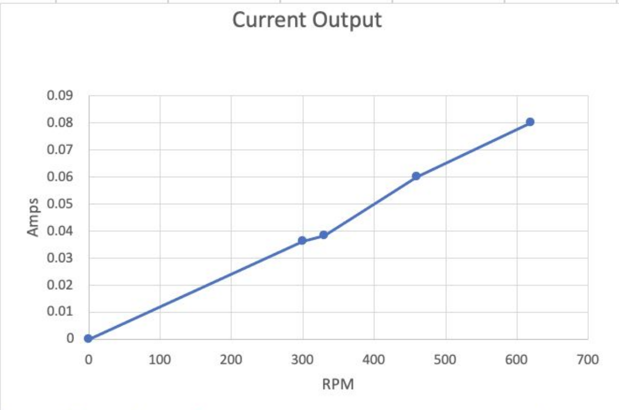
- Tested power output of the generator at varying RPMs and verified
- Designed preliminary power storage and regulation system
- Compared power output of energy devices to power requirements of E-ink/Microcontroller to prove feasibility
- Developed the concepts and framework for the gameplay progression

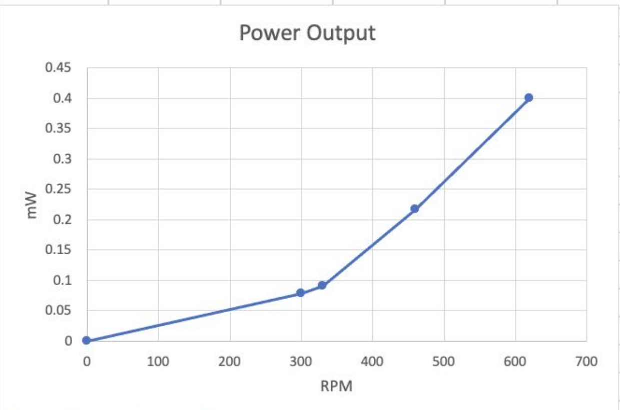


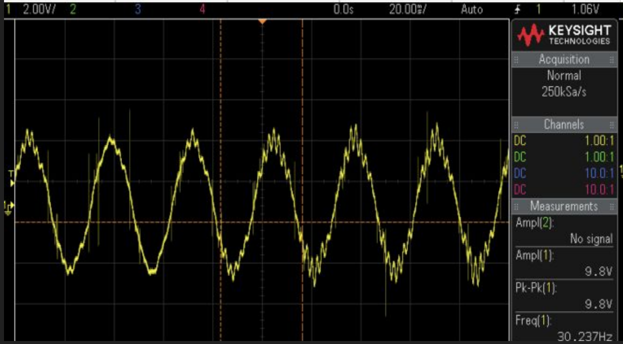


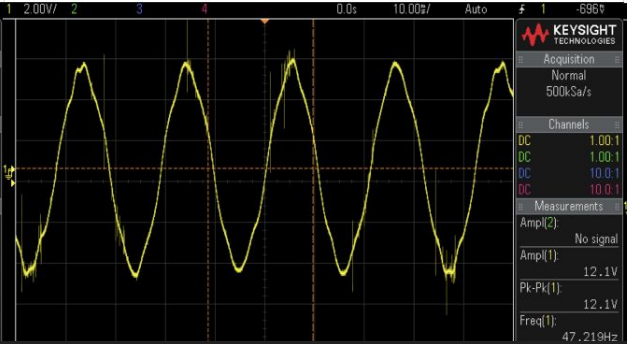
Generator Testing

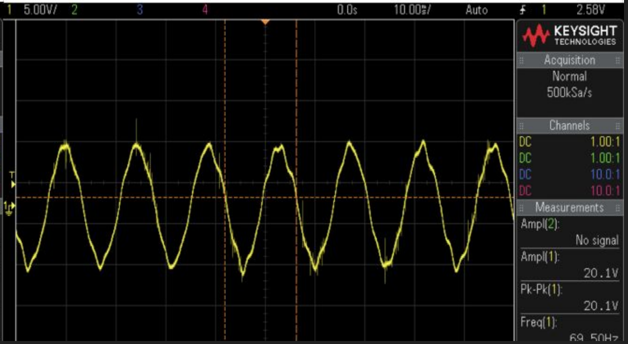












Button Testing

Trial Number	Capacitance(uF)	Initial Voltage(mV)	Final Voltage(V	Time(s)	Energy(mJ)	Power(mW)
1	2000	10	2.52	5	6.3001	1.26002
2	2000	20	3.8	10	14.2884	1.42884
3	2000	20	4.06	20	16.3216	0.81608
4	4000	10	1.65	5	5.3792	1.07584
5	4000	5	2.47	10	12.15245	1.215245
6	4000	10	3.51	20	24.5	1.225
7	4000	2	1.46	5	4.251528	0.8503056
8	4000	2	2.28	10	10.378568	1.0378568
9	4000	2	3.07	20	18.825248	0.9412624
10	6000	12	1.15	5	3.885132	0.7770264
11	6000	10	1.88	10	10.4907	1.04907
12	6000	2	2.58	20	19.938252	0.9969126

Power Storage Design (BQ25504)

	A	B	C	D	E	F
1	User Input	VBIAS	1.25	V		
2	Fixed					
3–5		Comparator threshold for VSTOR maximum. Typically the max storage element voltage, e.g. 4.2V for LiIon battery				
6		2.5V ≤ VBAT_OV ≤ 5.25V				
7	Desired					
8	Desired	RSUM[1]	10	Mohm		
9	Desired	VBAT_OV	5	V		
10						
11						
12				closest 1% resistor[1]		
13	Computed		Exact	<	>	
14	Computed	ROV1	3.750	3.740	3.830	Mohm
15	Computed	ROV2	6.250	6.190	6.340	Mohm
16	Computed	VBAT_OV	→	4.978	4.979	V
17	Computed					
18						
19	Selected	ROV1	4.53	Mohm		
20	Selected	ROV2	5.62	Mohm		
21	Selected		↓			
22						
23	Typ voltage	VBAT_OV(typ)	4.201	V	-19.01	% diff
24	Typ voltage					

	H	I	J	K	L
3–5	Comparator threshold voltages indicating when VSTOR has risen above VBAT_OK_HYS or fallen below VBAT_OK				
6	VBAT_OV ≥ VBAT_OK_HYST ≥ VBAT_UV				
7	RSUM[1]	11	Mohm		
8	VBAT_OK	2.3	V	> VBAT_UV	
9	VBAT_OK_HYST	2.5	V	> VBAT_OK	
11			closest 1% resistor[1]		
12		Exact	<	>	
13	ROK1	5.500	5.490	5.620	Mohm
14	ROK2	4.620	4.530	4.640	Mohm
15	ROK3	0.880	0.866	0.887	Mohm
16	VBAT_OK	→	2.281	2.282	V
17	VBAT_OK_HYST	→	2.479	2.479	V
19	ROK1	5.62	Mohm		
20	ROK2	4.53	Mohm		
21	ROK3	1	Mohm		
22		↓			
23	VBAT_OK (typ)	2.258	V	-1.88	% diff
24	VBAT_OK_HYST (typ)	2.480	V	-0.81	% diff

	N	O	P	Q	R
3–5	Comparator threshold for VSTOR minimum. Typically the min storage element voltage, e.g. 2.5V for LiIon battery				
6	2.2V ≤ VBAT_UV ≤ VBAT_OV				
8	RSUM[1]	10	Mohm		
9	VBAT_UV	2.258	V		
12			closest 1% resistor[1]		
13		Exact	<	>	
14	RUV1	5.536	5.490	5.620	Mohm
15	RUV2	4.464	4.420	4.530	Mohm
16	VBAT_UV	→	2.256	2.258	V
19	RUV1	5.62	Mohm		
20	RUV2	4.53	Mohm		
22		↓			
23	VBAT_UV(typ)	2.258	V	-0.02	% diff

	T	U	V	W	X
3–5	Maximum power point threshold, e.g. ~0.7-0.8 of solar panel's open circuit voltage				
6	MPPT				
7	RSUM[1]	20	Mohm		
8	VIN_DC(OC)	1	V	Open Circuit Volts	
9	VREF_SAMP	0.8	V	MPP voltage	
11			closest 1% resistor[1]		
12		Exact	<	>	
13	ROC1	6.000	5.900	6.040	Mohm
14	+10MEG[2]	10.000	10.000	10.000	Mohm
15	ROC2	4.000	3.920	4.020	Mohm
16	+10MEG[2]	0.000	0.000	0.000	Mohm
17	VREF SAMP	→	0.802	0.800	V
19	ROC1	6.04	Mohm		
20	+10MEG[2]	10.000	Mohm		
21	ROC2	4.02	Mohm		
22	+10MEG[2]	0.000	Mohm		
23		↓			
24	VREF_SAMP	0.800	V	-0.05	% diff