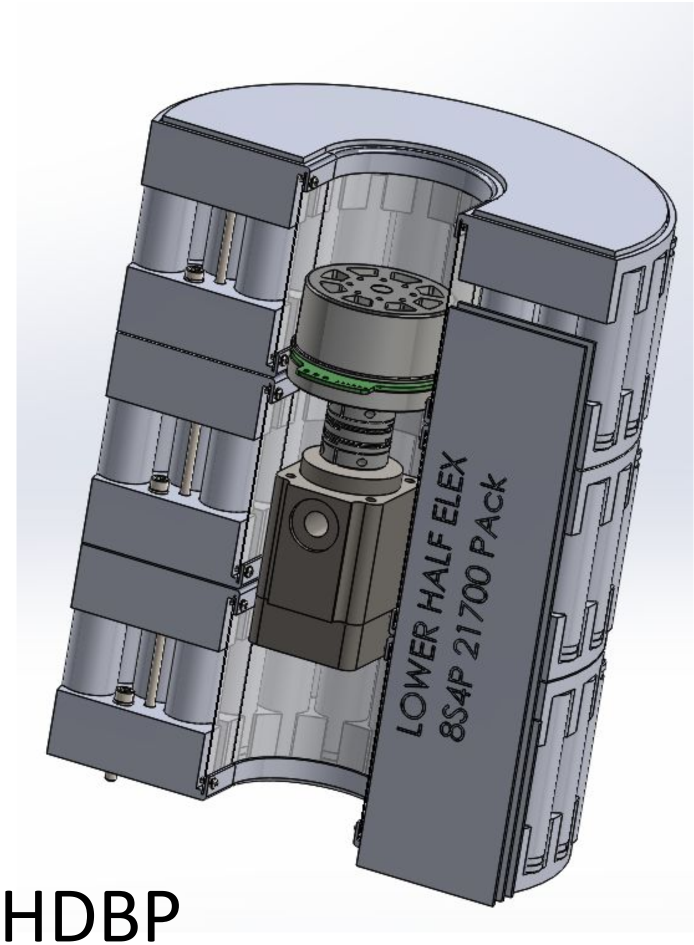
Coastal Profiling Float High Density Battery Pack Concept Design Review

Monterey Bay Aquarium Research Institute

5 May 2021



The HDBP

Goals

- Make sure the CPF HDBP design is “safe”
  - Define what tests, analyses, etc. we need to do to verify we’re safe
- Ensure the current conceptual/preliminary design for the CPF HDBP makes sense before changes become expensive
- Review the MBARI battery pack design guidelines to ensure we can design “safe” packs for this and future applications

Agenda

- System overview
- Requirements and best practices
- Mechanical
- Electrical
- Battery Management System
- Software
  - Embedded software
  - External charger
- Review Action Items

Request: If your comment or question requires a follow up, please make sure you put a note in the chat box of your meeting window so I can make sure it gets followed up.

CPF Team

Chad Kecy - Electrical: Battery management system

Eric Martin - Software

Gene Massion - Project Manager, System Engineer, Mechanical

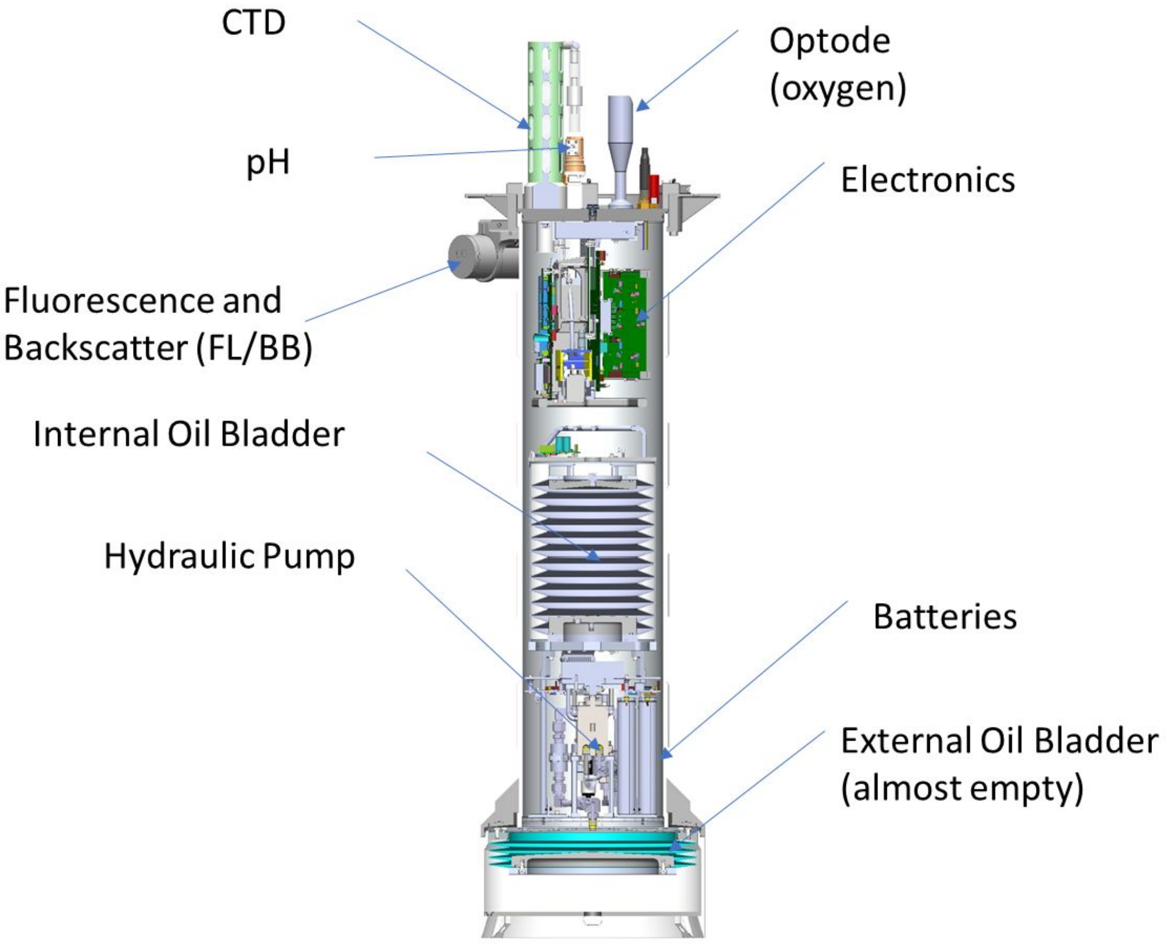
Ed Mellinger - Electrical: Lower Half Elex CCA; Battery Safety Committee

Note: Everyone has expertise in Mechanical, Electrical and Software. Everyone contributes in all 3 disciplines

Executive Overview (Gene)

- Motivation: Maximizing battery pack energy density is crucially important to many MBARI development projects
- The CPF is the first project to pursue a "high density" Li-ion battery pack (HDBP) design here at MBARI
- Personnel safety is priority 1
- We need to find the right balance between safety and energy density
  - For example, burning up a pack in the ocean *<u>might</u>* be acceptable, hurting someone is not

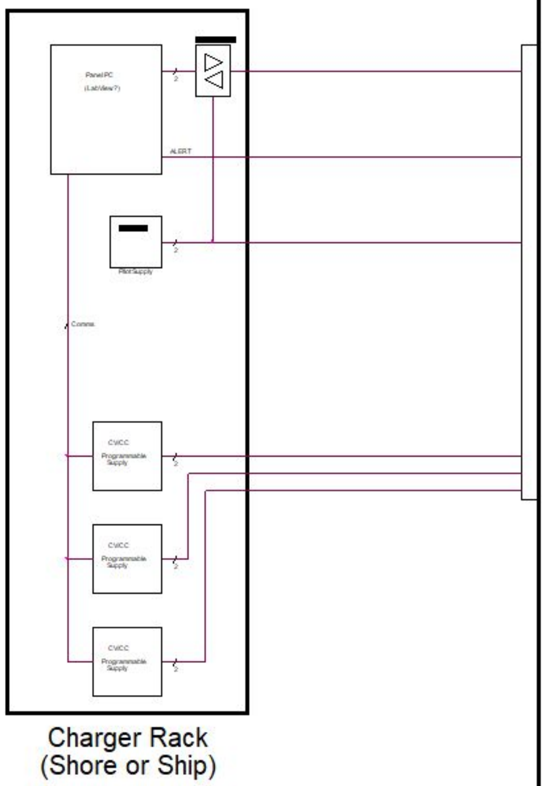
"high density" = lots of Joules/cm^3, Joules/kgf, not necessarily Joules/$

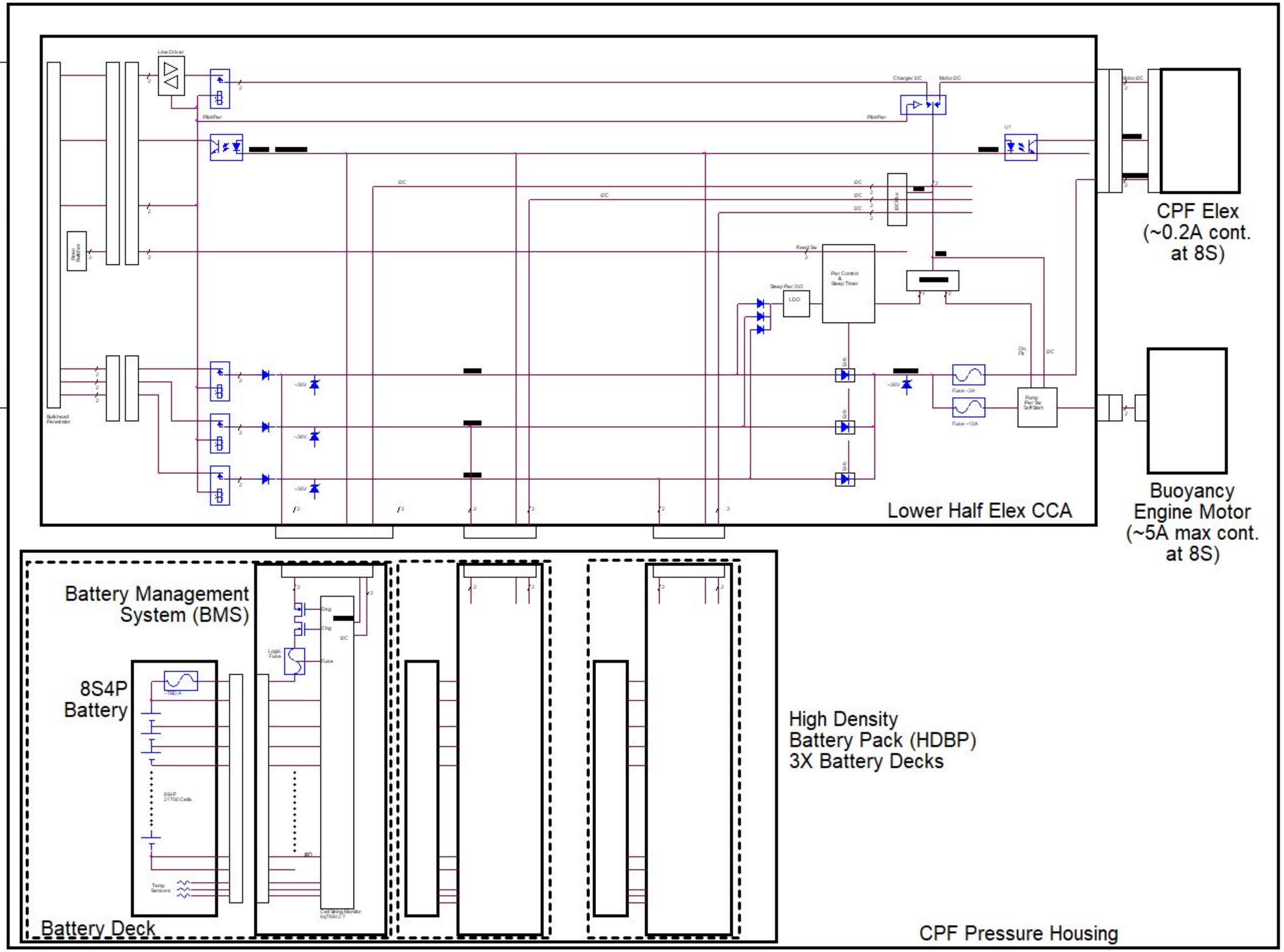


Typical mission scenario

1. Verify 1-N CPFs ready for deployment on shore
2. Load CPFs onboard, verify operations
3. Transit to first deployment site, verify operations (Bluetooth and e-mails), heave CPF over the side
4. CPF descends to park depth or seabed, whichever comes first
5. Park or anchor for 0-6 hours, sometimes 1 or more days, start acquiring science data
6. De-anchor if necessary and ascend
7. Surface and transmit science and engineering data to shore

CPF Block Diagram (emphasis HDBP)





1 battery **pack** = 3 **decks**
1 **deck** = 1 8S4P **battery**
1 8S4P **battery** = 32 **cells**

HDBP Starting Point

- We’ve been deploying a CPF with 3 different kinds of COTS battery packs for several years
  - The BMS and HDPB packaging is new
  - The LHE is an iteration of the current design
- Available volume is driven by other CPF subassemblies
- 8S (24-33.6VDC) was a reasonable compromise for bus voltage
  - ICs, chargers, DC/DC converters, etc. are reasonably available
  - <48VDC (Safe Level)
  - High enough to keep pump motor current <~10A
  - 8S4P 21700 packages nicely, 8S6P 18650 is problematic but possible, densities are roughly similar
  - So, 8S4P 21700 it is (for now)
- Guidance from Judy Jeevarajan (NASA, UL): 2mm radial spacing, firebreak between decks, no PTC up to 4P

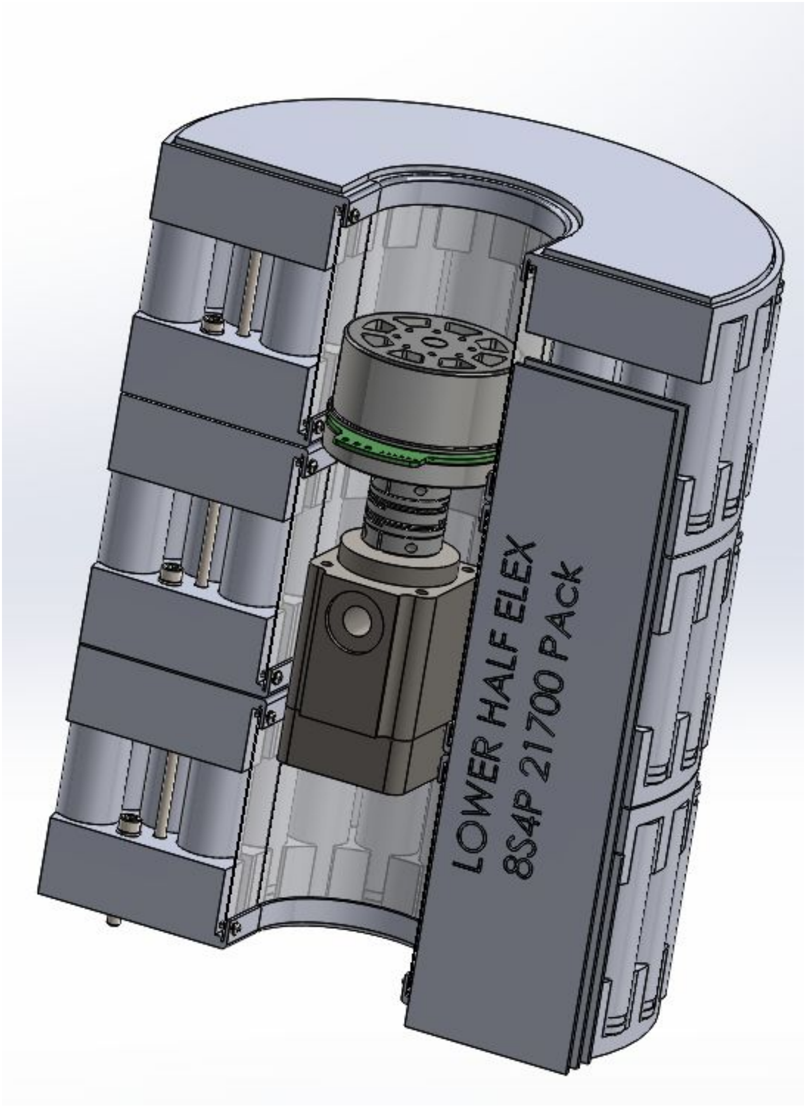
MBARI Li-Ion Best Practices Summary

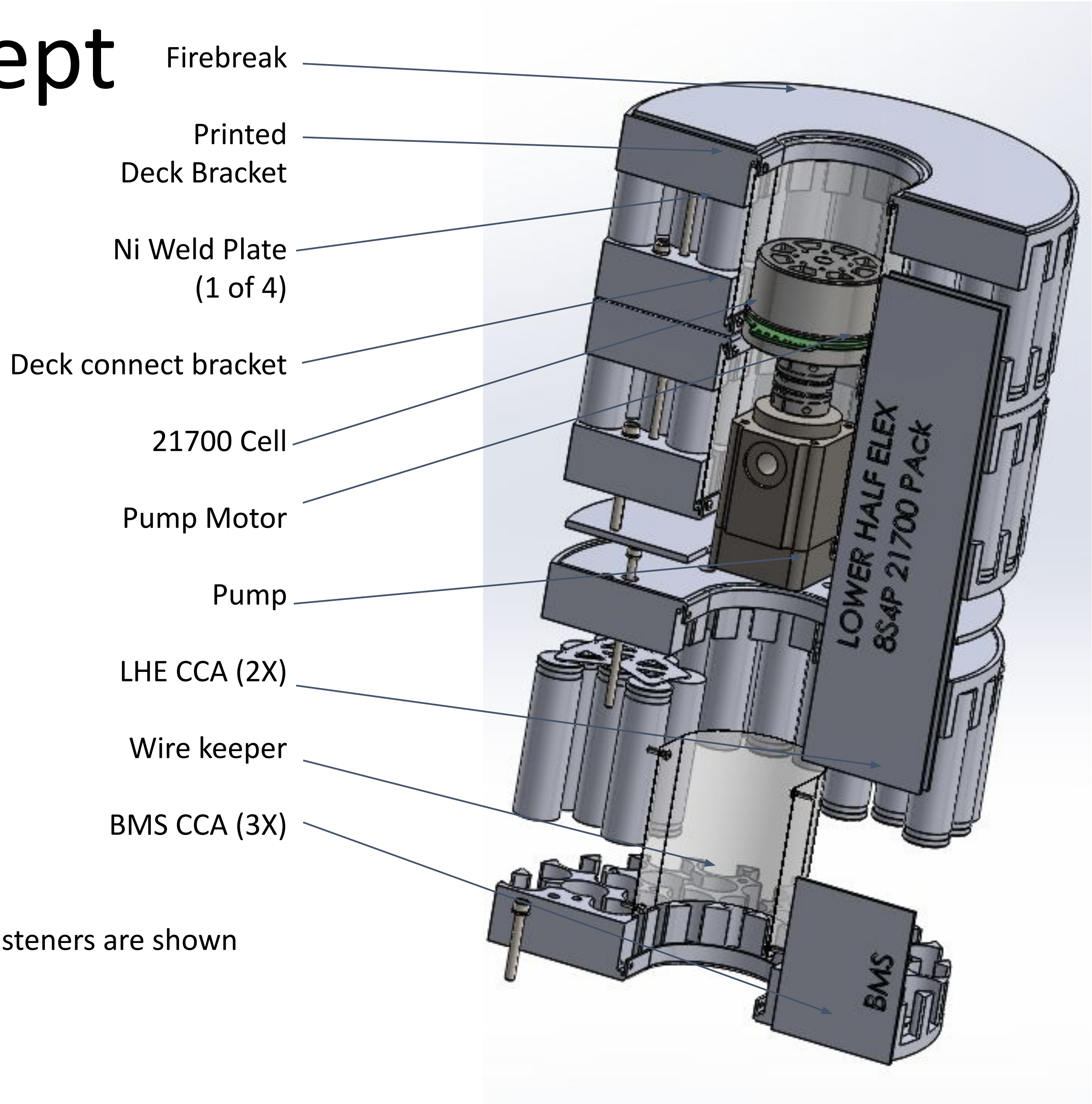
- Use qualified cells (UN38.3 or UL1642), qualified vendors and qualified assemblers.
    - Current QPL = Sanyo/Panasonic, LG, Samsung. Others?
- Airgap between cells for thermal isolation, default 2mm.
- Place thermal barrier material in cell rupture/vent paths
- Pressure release (manual or automatic) on battery pressure housings
- Monitor voltage of every cell.   Cease charge/discharge on over/under voltage.
- Monitor current in every string.   Reduce or shutdown on overcurrent.
- Redundant string voltage monitor.   Permanent disconnect on over/under voltage.
- Charge with CC/CV charger tailored to pack voltage and C rate.
- Monitor pack temperature.   Adjust charge rate accordingly.
- Monitor temperature distribution within pack to identify hot spots.
- Fuse parallel cell groups, with more than 4 cells, with inter-cell fuses
- Fuse each cell string, the pack charge input, and the pack output,
- When on charge, provide outside-world alarm signal(s), and designated watch stander.
- UN38.3 testing or certification of the pack, for transportation.

CPF HD Battery System Performance Requirements

- Ambient operating limits 0-50 C discharge, 10-40 C charge.
- 1.5 g any axis shock, shipboard vibe TBD, 20-99% RH, filtered salt air.
- Desired energy ~1.5 kWh (5.4e+6 J), available space will determine.
- 8S voltage, 24 - 33.6 V operating
- Discharge profile, deployed: 10 min @ 5 A, 1 hr @ 0.2 A, 5 hr @ <0.001 A.
- Max discharge current 11 A, with 2 of 3 decks installed.
- Charge time 8 hr max, 3 hr desired. Cell balancing desired, rate < 0.0025 C.
- Fuel gauging desired. Cycle life >100 desired.
- I2C interface, to Charger when present, to Mobo/Micro when not
- System outputs: V_{batt} @ 3 A to Mobo/Micro, Switched/ECB V_{batt} @ 8 A to VB Pump
- On/off control, via endcap reed switch and programmable Sleep Timer ~1 hr
- Assembled floats will eventually need to be air shipped.

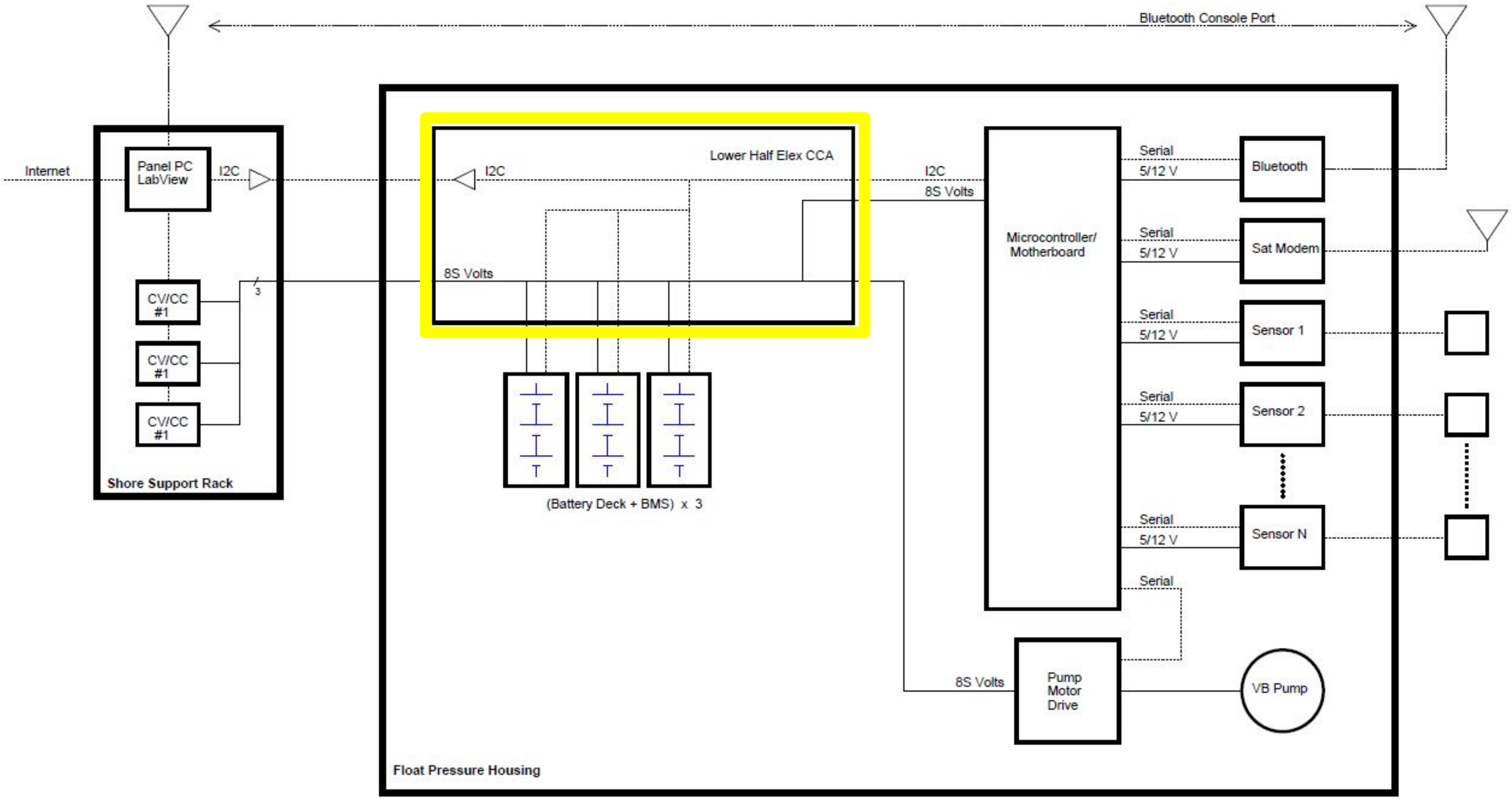
HDBP Mechanical Concept





Note:
Not all fasteners are shown

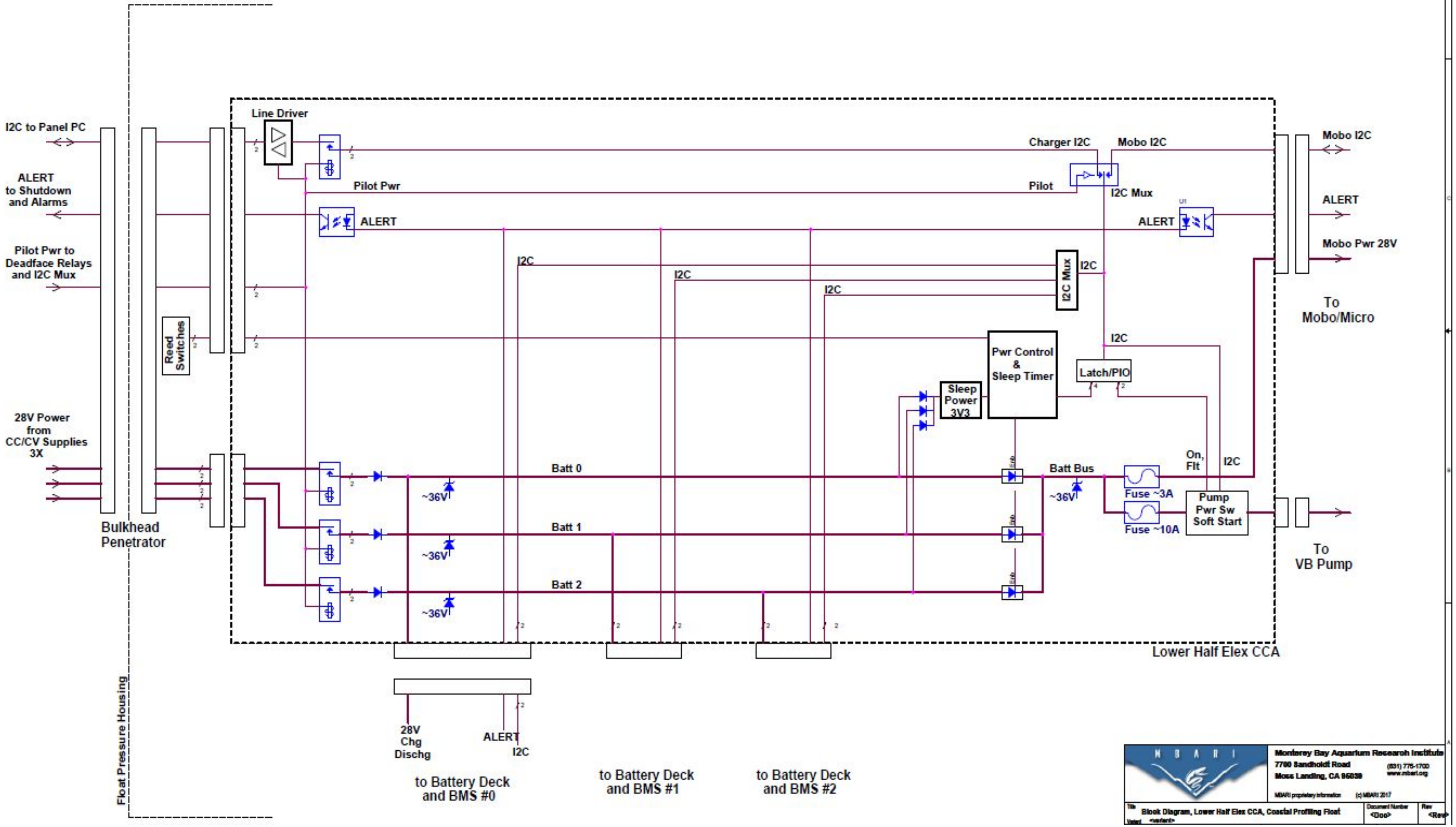
Lower Half Electronics ('LHE') CCA



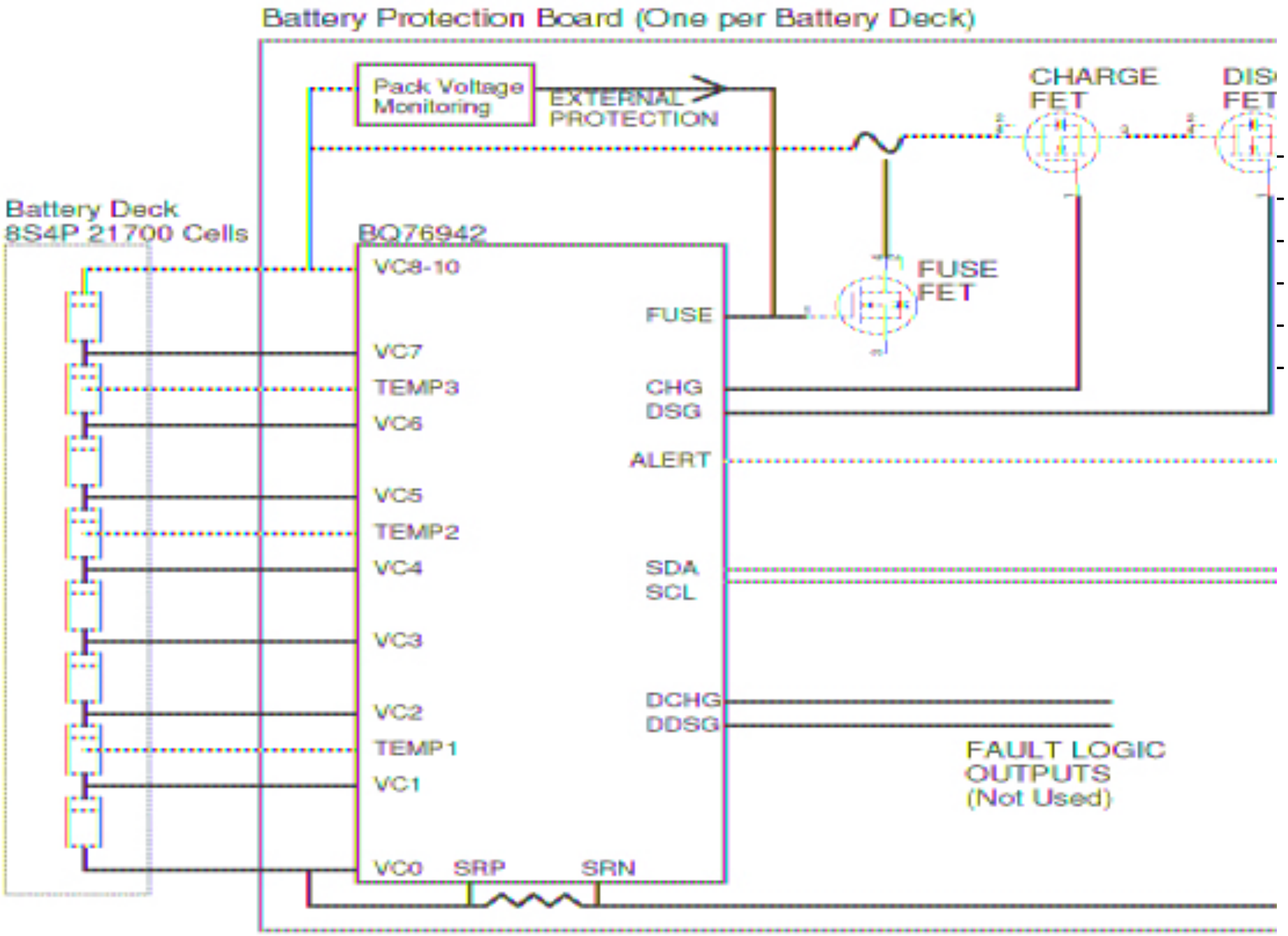
LHE Requirements

- Interconnect power and communications between Charger, HD Battery Decks, and Float Payload Electronics
- Deadface or isolate all seawater-facing connections when deployed
- Support 3 HD Battery Decks at 24-33.6 V, 11 A discharge, 6 A charge
- Provide I2C Comms and ALERT signal path to Charger and Mobo/Micro
- Provide fused Load Power of 3 A Mobo/Micro (always-on) and 8 A Pump Drive (switchable, with soft start and ECB)
- Provide load power disconnect with Endcap Reed Switches and 1-64 minute Sleep Timer
- Use < 5% of pack capacity on 1-year standby (about 100 uA)
- Size ~10” x ~3”? x ~1.2”

Lower Half Elex (LHE) CCA



BMS Concept



- One BMS board per battery deck (3)
- Signals fed to LHE
- FUSE FET used as a Permanent Failure option
- BQ76942 registers control bulk of protections
- Eval Module of BQ76942 being tested now
- No true fuel gauging right now, should we?

Registers - Primary Protections

- Cell Over Voltage
- Cell Under Voltage
- Short Circuit in Discharge
- Over Current in Charge
- Over Current in Discharge (1,2,3)
- Host Watchdog
- Precharge Timeout
- Load Detection
- Over Temperature in Charge
- Over Temperature in Discharge
- Over Temperature FET
- Internal Over Temperature
- Under Temperature in Charge
- Under Temperature in Discharge
- Internal Under Temperature

Note: Verification of all this functionality winds up in the test plan

Registers - Secondary Protections

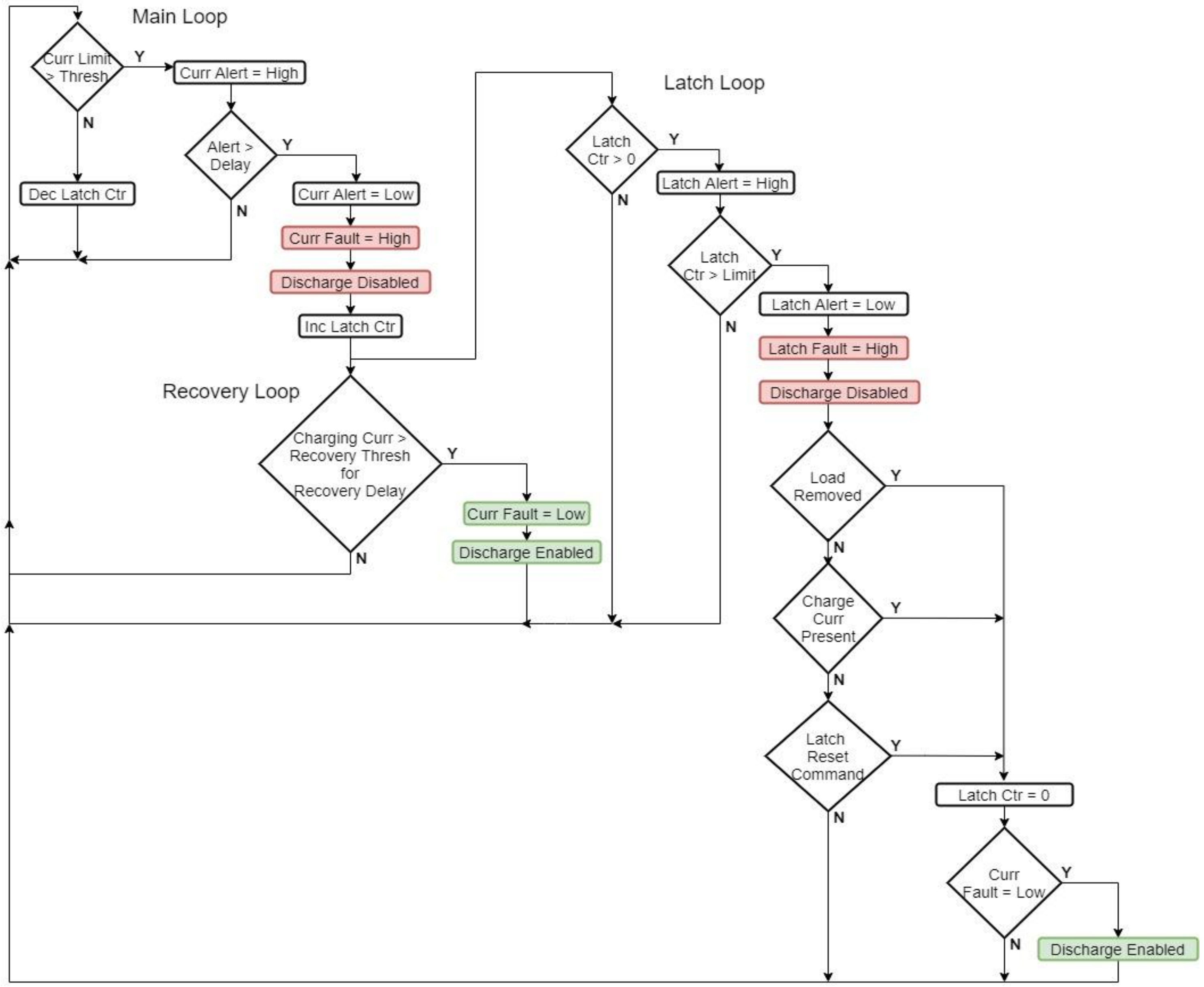
Secondary Protections are all Permanent Failures (PF)

- Copper Deposition
- Safety Under Voltage
- Safety Over Voltage
- Safety Over Current in Charge
- Safety Over Current in Discharge
- Safety Cell Over Temperature
- Safety FET Over Temperature
- Charge FET
- Discharge FET
- Secondary Protector
- Voltage Imbalance in Relax
- Voltage Imbalance in Active

- Short Circuit in Discharge Latch
- OTP Memory Signature
- Data ROM Memory Signature
- Instruction ROM Memory Signature
- LFO Oscillator
- Voltage Reference
- VSS
- Protection Comparator MUX
- Commanded PF
- Top of Stack Measurement
- Cell Open Wire

Note: Verification of all this functionality winds up in the test plan also

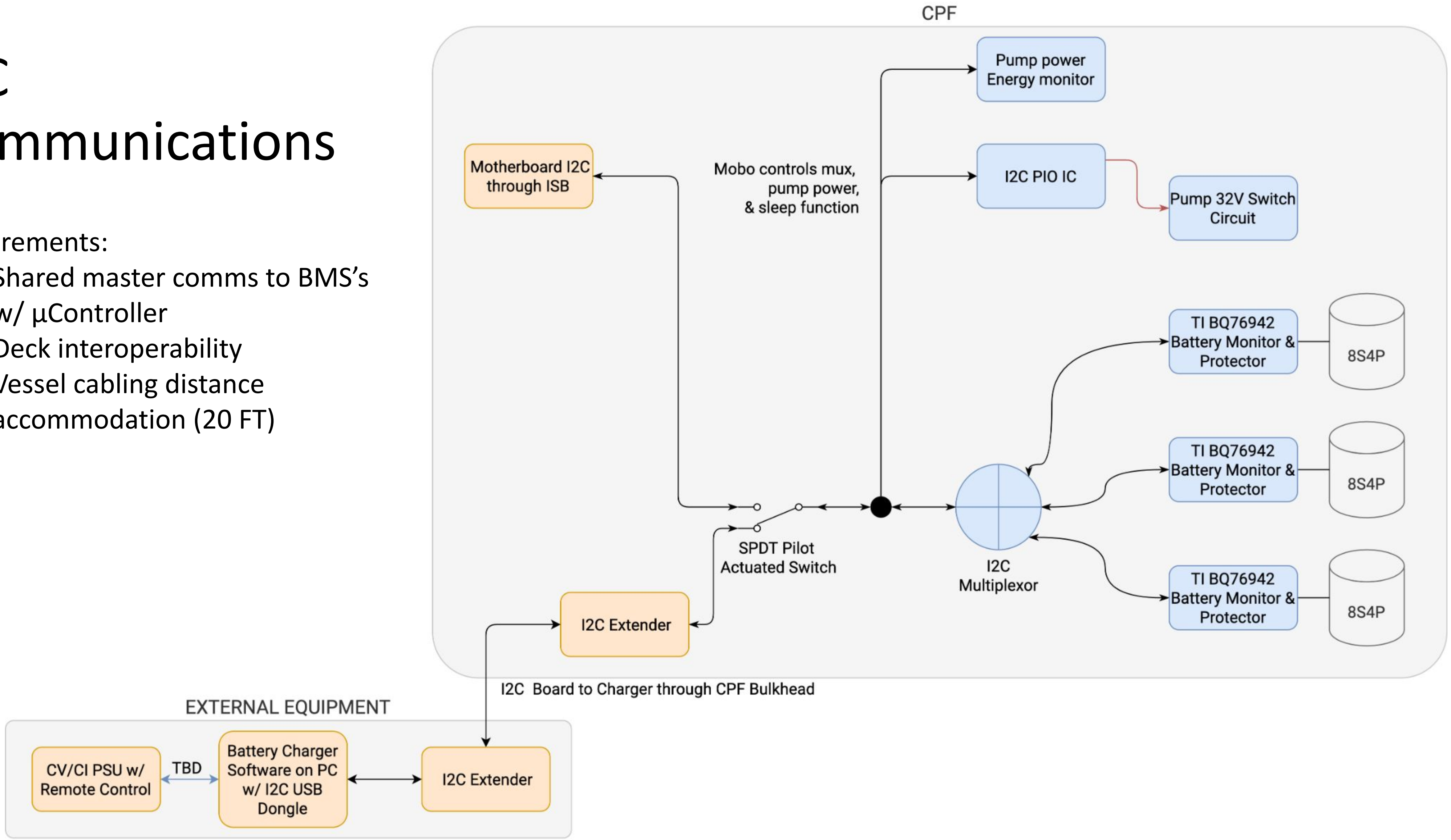
Overcurrent in Discharge Flowchart



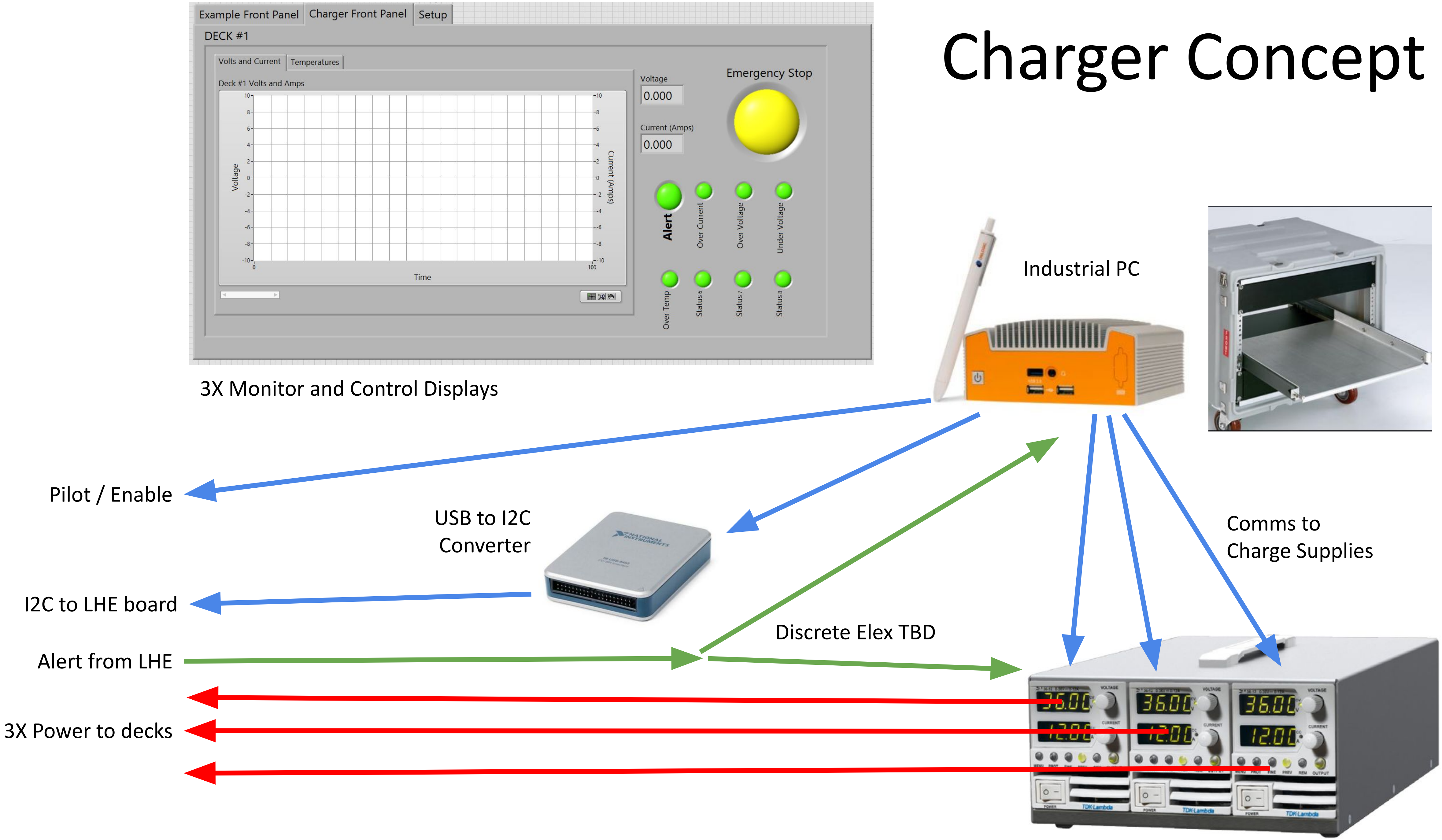
I2C Communications

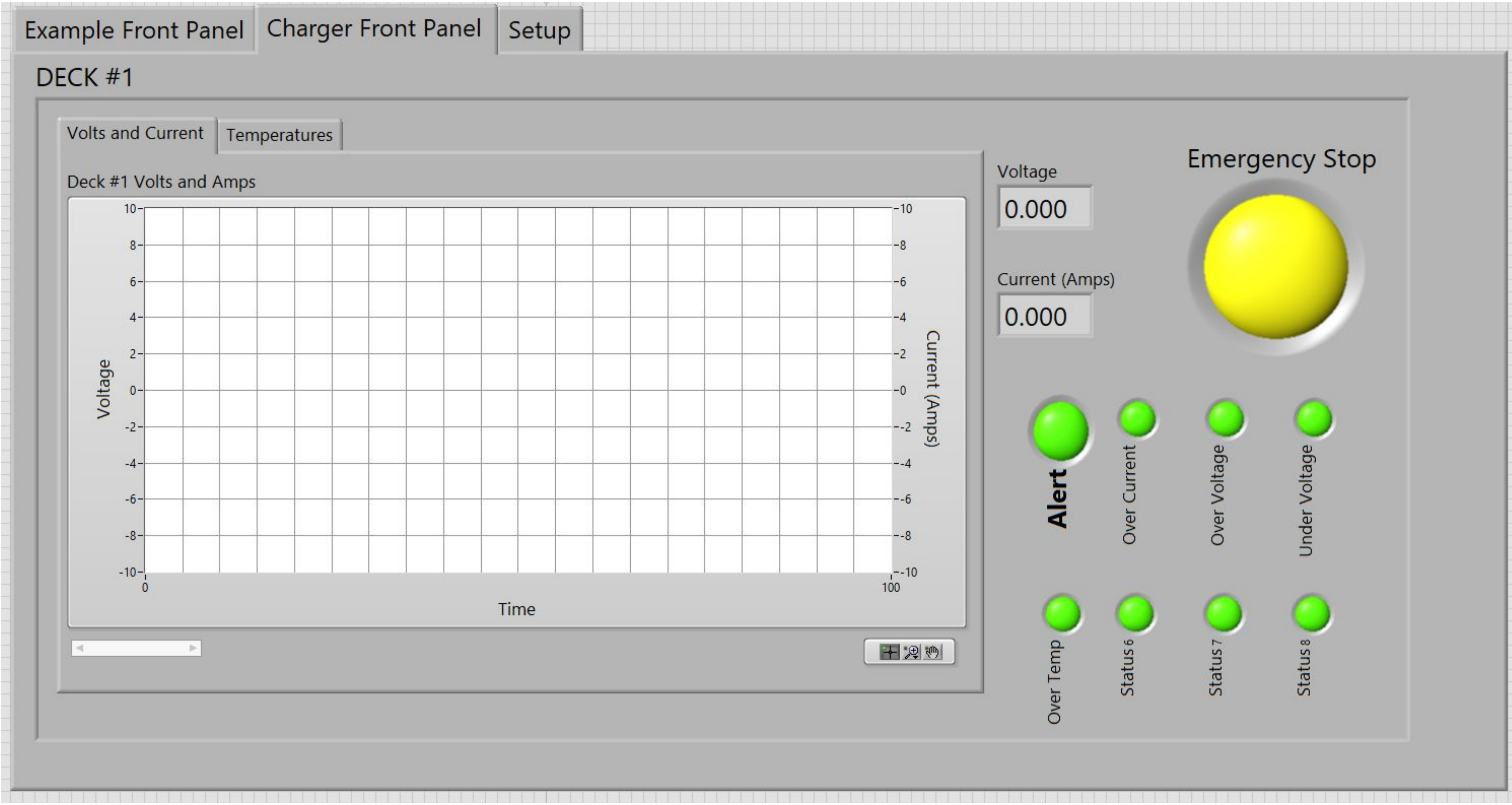
Requirements:

- Shared master comms to BMS’s w/ µController
- Deck interoperability
- Vessel cabling distance accommodation (20 FT)

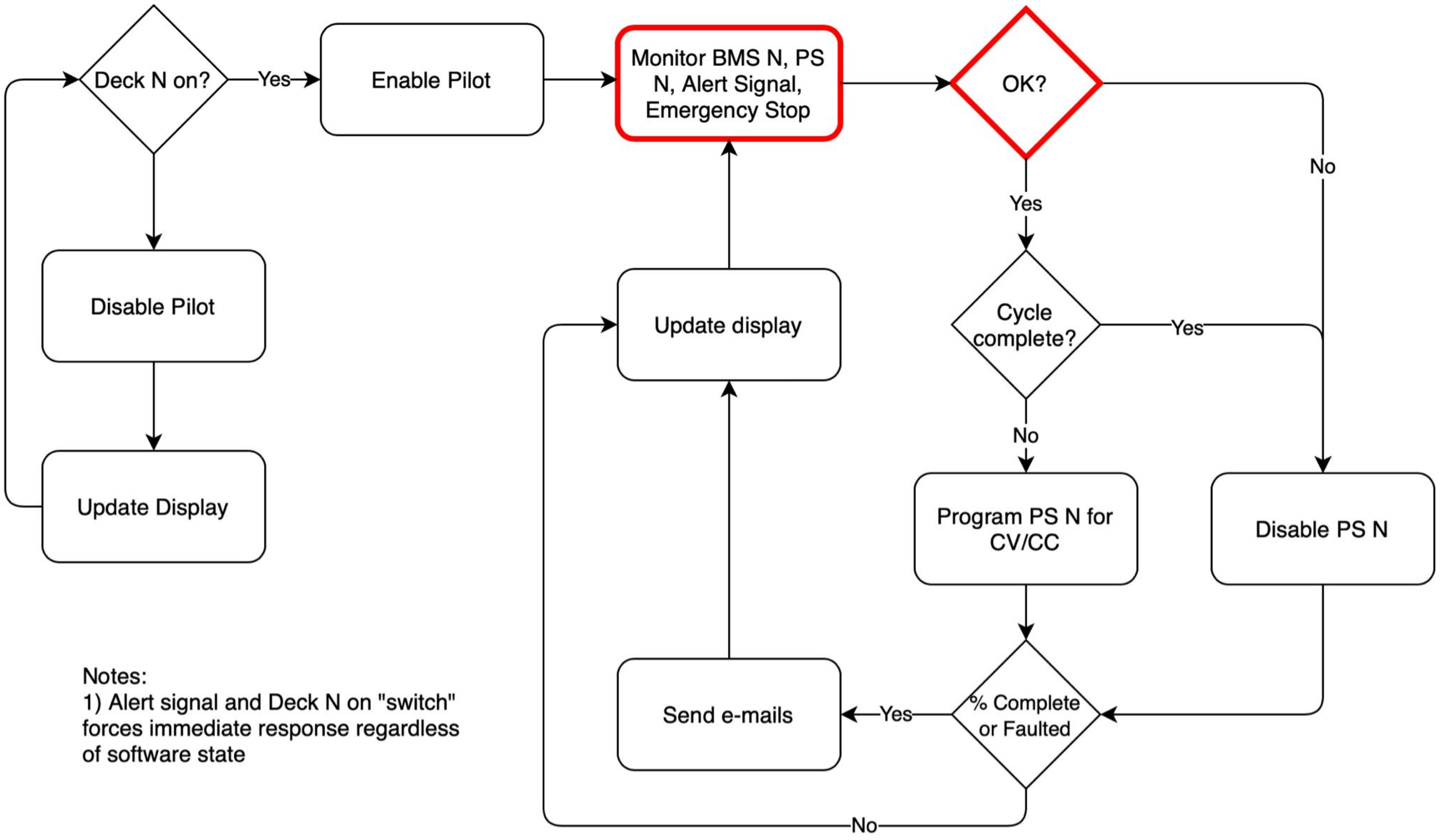


Charger Concept




Example Front Panel
Charger Front Panel
Setup
DECK #1
Volts and Current
Temperatures
Deck #1 Volts and Amps
Voltage
Current (Amps)
Time
Voltage
0.000
Current (Amps)
0.000
Emergency Stop
Alert
Over Current
Over Voltage
Under Voltage
Over Temp
Status 6
Status 7
Status 8

Charger software flow chart



Next Steps

- Address issues from this review, provide report
- Do an appropriate Failure Mode Analysis
- Finalize pack integrator choice, solicit input
- Finish the design, develop test plan and procedures
- Battery Safety Committee review (?)
- Address BSC review issues, report
- Build first article with selected pack integrator
- Test first article
- Build 3-5 packs

Action Items

- Verify no fusible link in the 4P cell groups is acceptable.
- Verify 2mm spacing is acceptable.
- Understand how BSC recommendations affect the AUV, LRAUV, and others.
- Do PTCs as fusible link between cells make sense since they are temporary and require current to stay open
- Ensure the design does not put too much axial/radial pressure on cells. Same for shear on the tabs/welds
- Should cell venting gases be ‘directed’ to a specific location?
- Check on exit path for venting from cells… make sure firebreaks/brackets does not prevent vent from venting.
- Check for stress to the cell sidewalls in case of lateral load to battery pack during shipping horizontally.
- Need to understand cell temperature rise during 8h and 3h charge rates (thermal modeling or test or ???)
- We need to make sure we terminate change at temperature (40C?) much lower than when any risk for thermal run-away would arise
- Do we need a sense line added to the cabling or bulkheads for better CV/CC control?
- verify condition for mismatched packs so damaging inrush current doesn't occur from mismatched packs
- Investigate feasibility of running CPF from only 1 deck.
- Investigate what happens when plugging a fully charged deck into 1 or 2 other decks
- Get a list of common industry risks/failure/law suits
- Need better definition of non-mbari tests that need to be in the test plan, e.g. thermal cycling, shock, vibe, safety and abuse

Action items Day 2

- Is there a way to remove single point of failure when overload in one point could bring down all 3 decks?
- In external rack charger config, there should be an option to charge to partial state, say 60% or 16V, which would be important for testing and storage; then just before deployment to top to 100% charge
- Clear charge profiles need to be identified for software V/I Control algorithms
- Need an MBARI approved statement about UN/UL/??? testing or certification
- Investigate SAE J2464 or other battery testing spec
- We could use some suggestions about appropriate shock and vibe and other specs from Kevin. I only know about the mil-spec shipping specs (and a few others)
- Probably could use better definition about what's in the document we're hoping to get from Kevin 1) specific to the CPF application and 2) of more generic use to the BSC

Thanks very much

Safety Checklist (based on Best Practices doc)

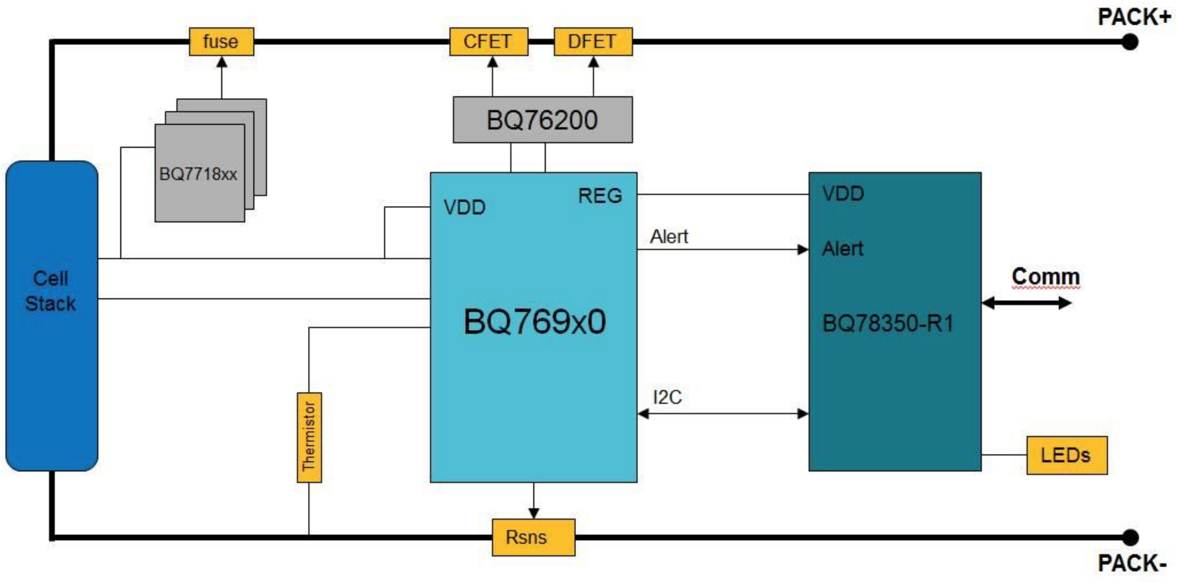
- Where cell voltages are monitored; response to OV/UV including software elements
- Where string current is monitored, response to OC/UC including software elements
- Where temperature is monitored, etc
- Charging operations plan -- watchstander, notifications

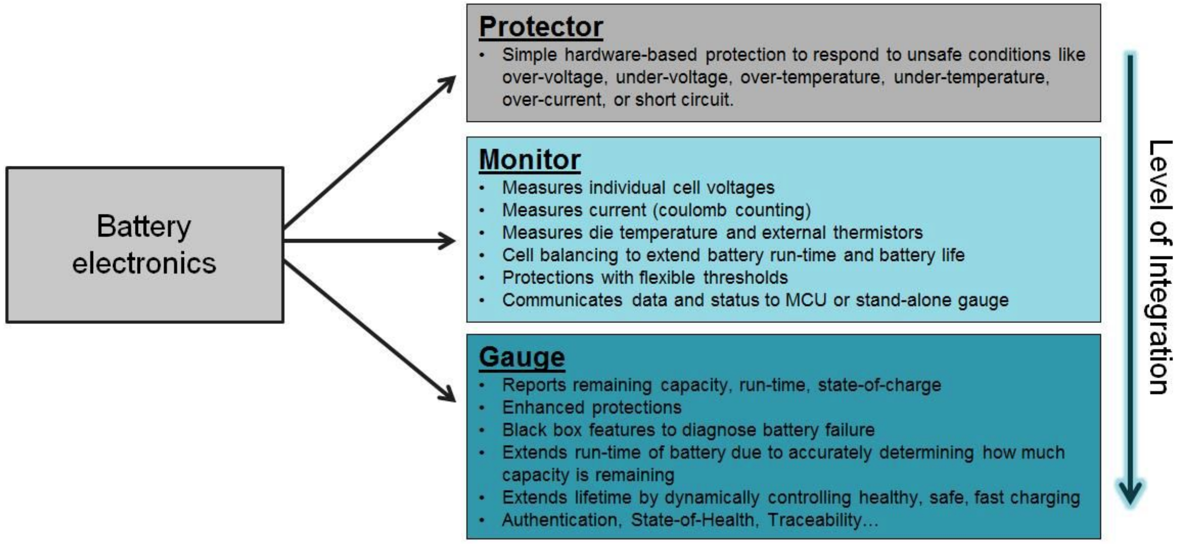
From Me to Everyone: 02:30 PM
test message from Gene
From Eric Martin to Everyone: 02:41 PM
https://drive.google.com/file/d/1dbuosVW0YyoFSfWq_SDlV19mvaUm0uvN/view?usp=sharing
From Me to Everyone: 03:53 PM
For Alana: Need to confirm no PTC for 4P configuration is acceptable.
From Gene: Need to make sure that we understand how the BSC recommendations affect the AUV, LRAUV and other projects.
From Gene: Need to understand shipping regulations for HDBP decks and CPFs with HDBP in them with knowledge of the 100 pack/year prototype "exemption"
From Denis Klimov to Everyone: 04:18 PM
Are PTC between cell groups make sense? Would not prevent discharge of cell group in case of shorted cell
Would standoffs between brackets help prevent too much axial pressure on cells?
From Kevin Konecky to Everyone: 04:18 PM
should cell venting gases be 'directed' and 'guided' into a specific location?
From Ed to Everyone: 04:19 PM
Check on exit path for venting from cells... make sure firebreak does not prevent vent from venting.
From Denis Klimov to Everyone: 04:29 PM
Check for stress to the cell sidewalls in case of lateral load to battery pack during shipping horizontally
From Doug Pargett to Everyone: 04:30 PM
Ensure any motion or loads is not transferred thru the batter terminals, electrical welds or bus.
From Ed to Everyone: 04:40 PM
Need thermal modelling to investigate cell temperature rise during 8h and 3h charge rates
From Denis Klimov to Everyone: 04:43 PM
Meshing of a note, Inspired Energy modules would terminate change at temperature (40C?) much lower than when any risk for thermal run-away would arise
From Eric Martin to Everyone: 04:52 PM

Design Trades for Full SMBus inline gauge

Feature	**A: Switched I2C**	**C: SMBus Gas Gauge**
Part Count	Medium	High
Hotel Current Per Cell	Low (286uA/pack) + Logic	High (286+650 uA/pack
Software Complexity	High (2 sets of code)	Medium (already done and COTS SMBus, but CEDV info needs programming)
Standalone Operation	Needs logic on pcb	Best
Gas gauge/CEDV	No	Yes

Scenario C: BQ78350-R1 Concept





https://e2e.ti.com/blogs_/b/powerhouse/archive/2019/06/13/protector-monitor-or-gauge-selecting-the-correct-battery-electronics-for-your-system