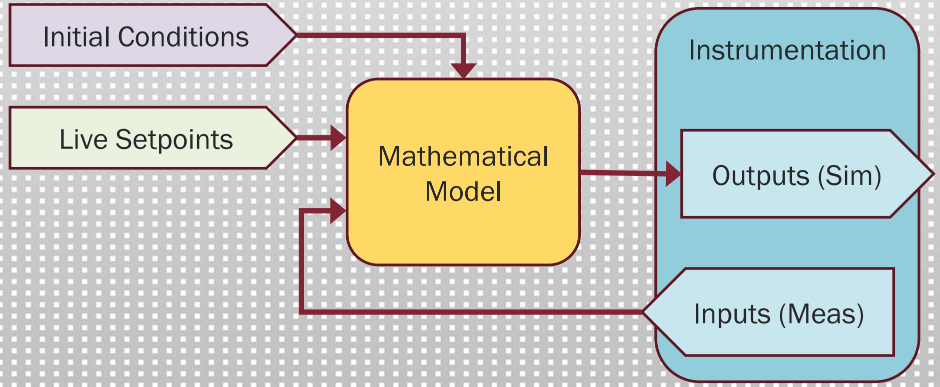
BLOOMY®

Demystifying BMS Hardware-In-the-Loop (HIL) Testing

Grant Gothing, Chief Technology Officer

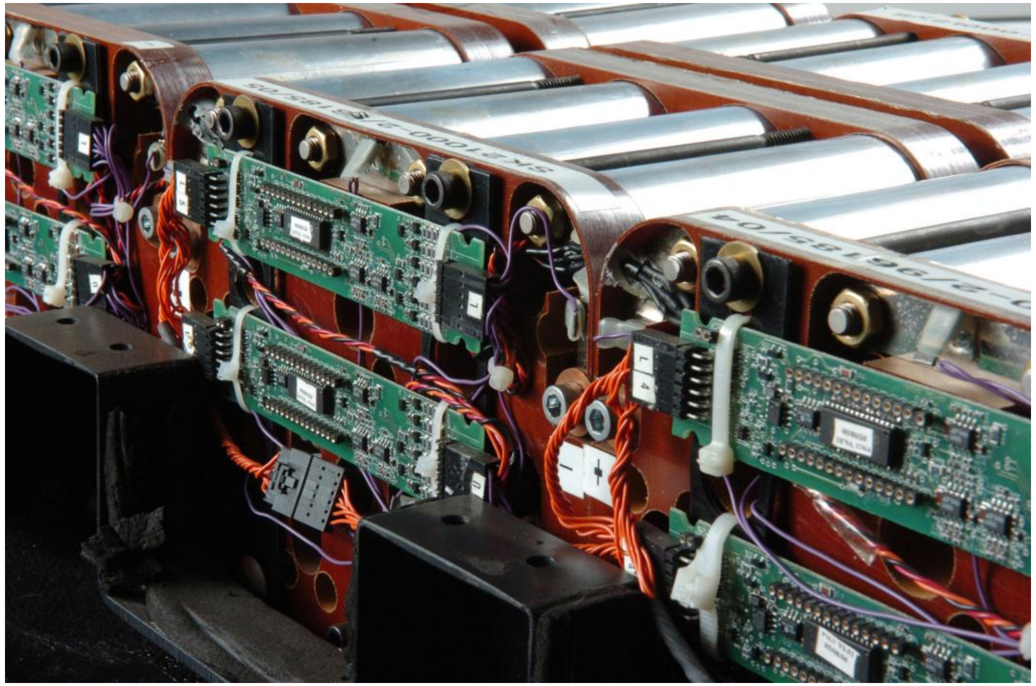
Peter Blume, President

June 26, 2020



Overview

- Introduction
- BMS HIL background
- Test methodologies
- Instrumentation and connectivity
- HIL test software for IO control
- User interfaces
- Test scripting & data logging
- BMS HIL test scenarios
- Q&A

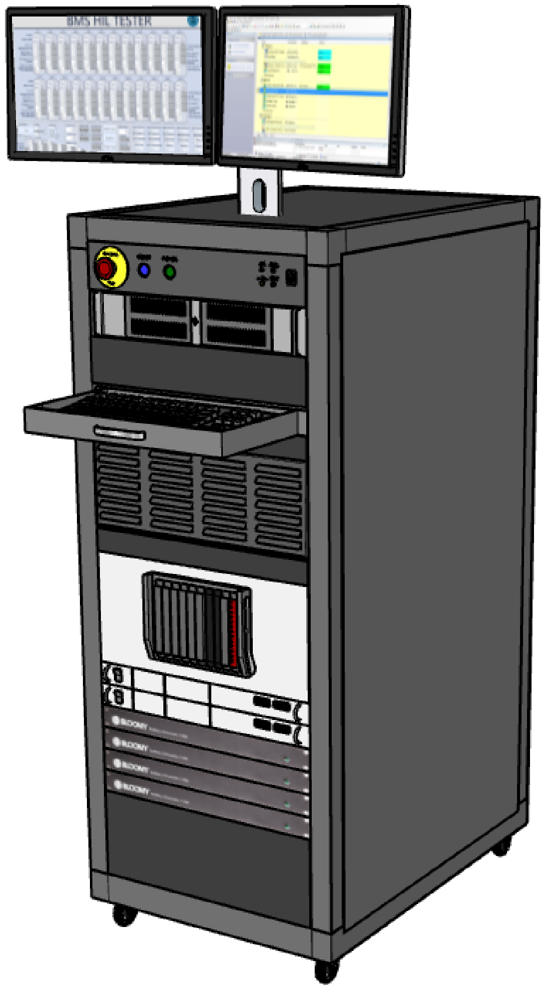


BLOOMY QUICK FACTS

- Founded in 1992
- Automated testing equipment
  - Battery test & simulation (BTS)
  - Trans/Aero/Def Simulation systems (SIMS)
  - Universal manufacturing electronics functional test (EFT)
- NI Platinum Alliance Partner
  - Published “The LabVIEW Style Book” © 2007, Prentice Hall
  - “BMS HIL Test System Helps JLR Shorten Time-to-Market” Graphical Systems Design Award in 2016

Bloomy BMS HIL Tester

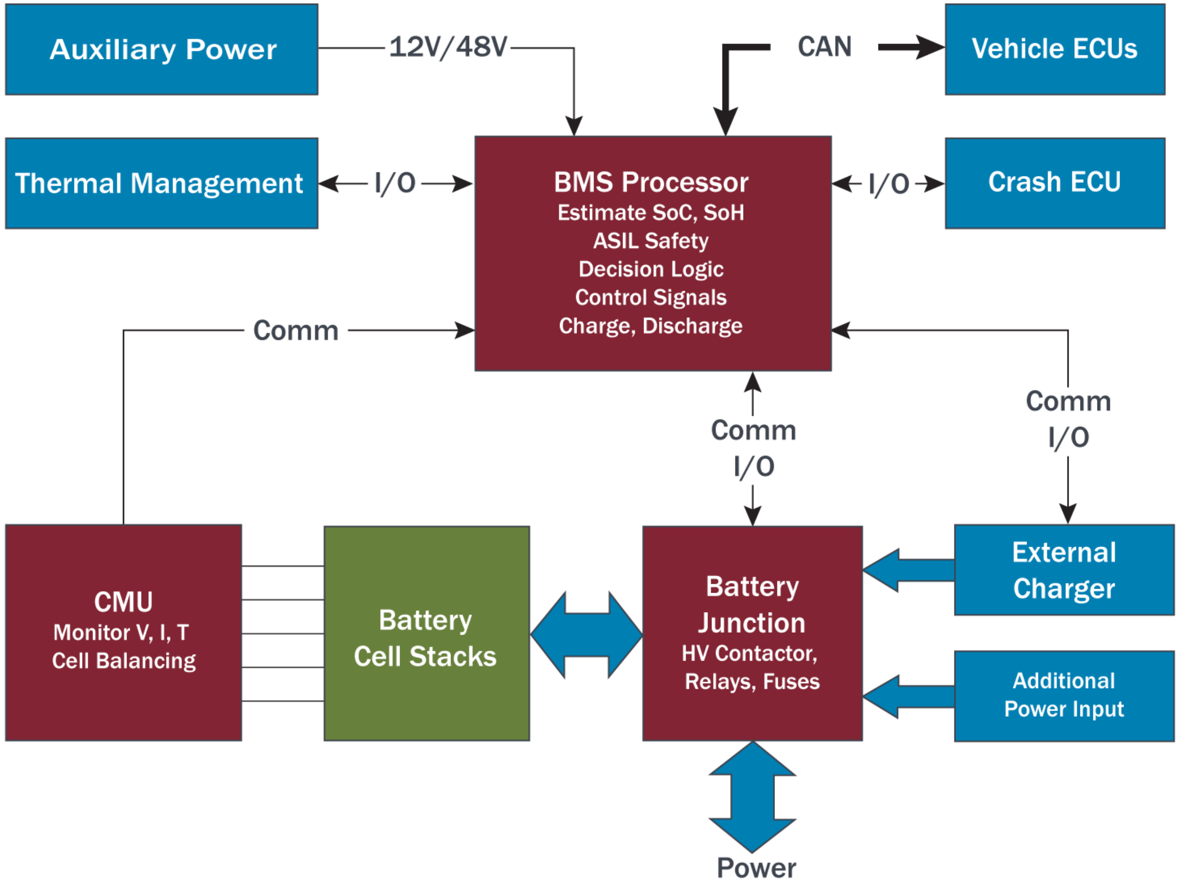
- Modular hardware and software
- <u>Open</u> platform
  - Based on COTS components
  - Bloomy BS1200 Cell Simulator
  - Maintainable & modifiable
  - Design documentation & source code provided
- Built on over a decade of BMS testing experience



What is the BMS?

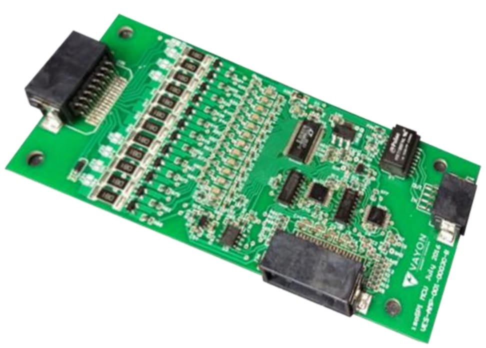
Battery Management System

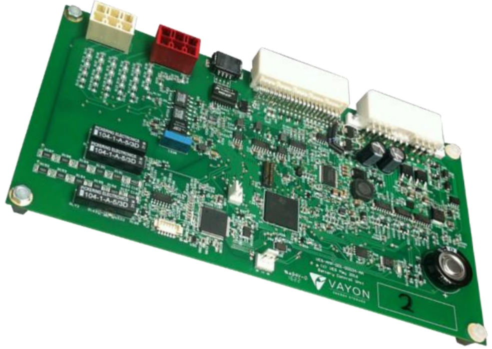
- Monitor cell V, I and T
- Estimating the SoC and SoH
- Controlling the rate of charging and discharging
- Cell balancing
- Monitoring alarm levels and pack voltage
- Managing critical safety functions
- Controlling the contactor(s)
- Communicating to the ECM and other ECUs



BMSs come in many different flavors

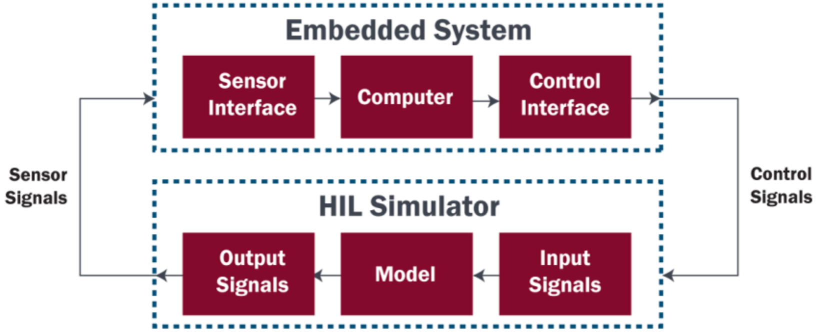
- Module and pack configuration
- Topology, series/parallel
- BMS optimized for end user profile
  - EV, grid, UPS, consumer electronics

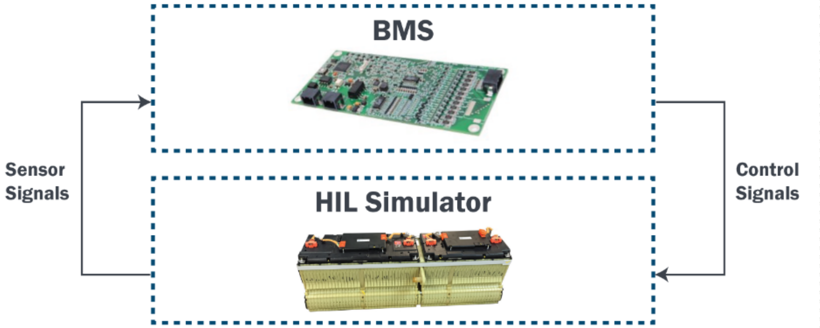




What is HIL testing?

- HIL = Hardware In the Loop
- Technique for development and test of embedded control systems
  - Mathematical model of processes
  - Simulation of sensor and control signals
  - Measurements fed back into model
- Facilitates testing electronic controls without the actual plant
- BMS HIL Simulator simulates battery and other EV subsystems
- Cell model is derived through characterization of real cells



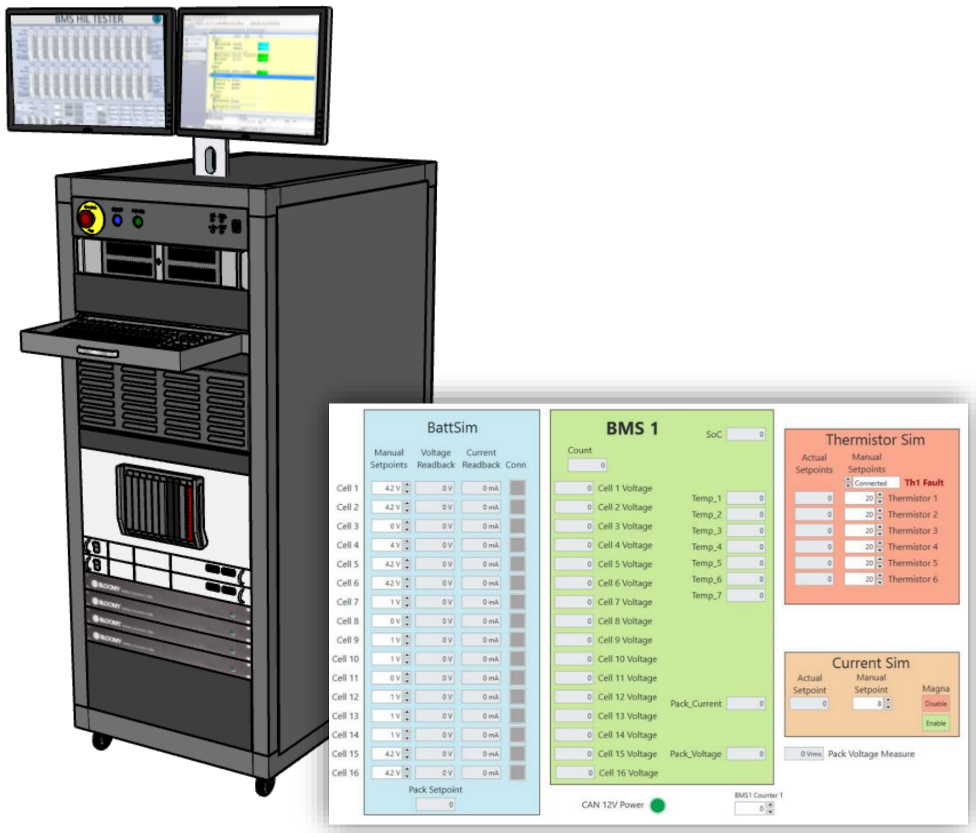


BLOOMY

What does a BMS HIL system consist of?

Hardware

- Computing
  - Real-time
  - Windows
- Instrumentation
  - Simulation
  - Measurements
  - Comms



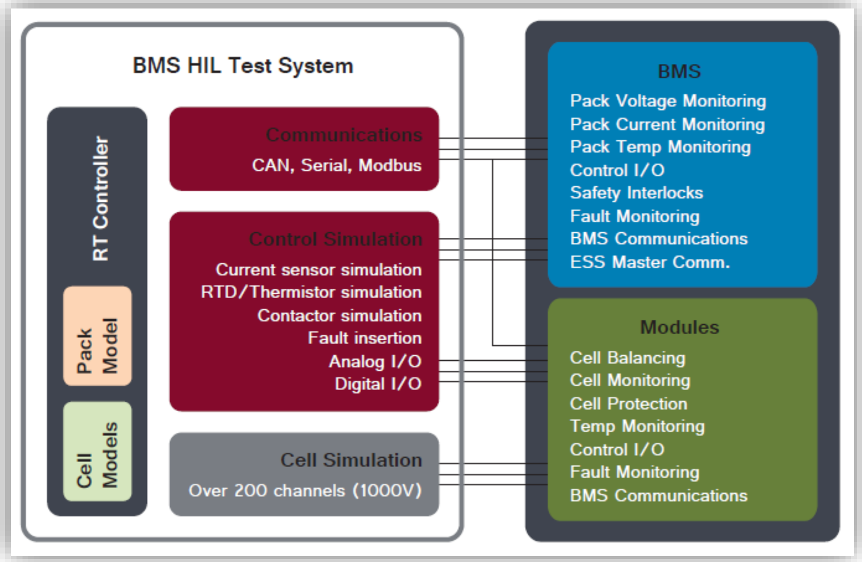
Software

- Real-Time deterministic
  - IO & comms control
  - Model execution
  - High speed data logging
- Windows
  - Configuration
  - User Interfaces
  - Test Scripting

BMS HIL Test Objectives & Benefits

Objectives

- Validate functionality
  - Hardware & Firmware
- Tune algorithms
- Ensure BMS safety
- Check response timing
- Test edge cases



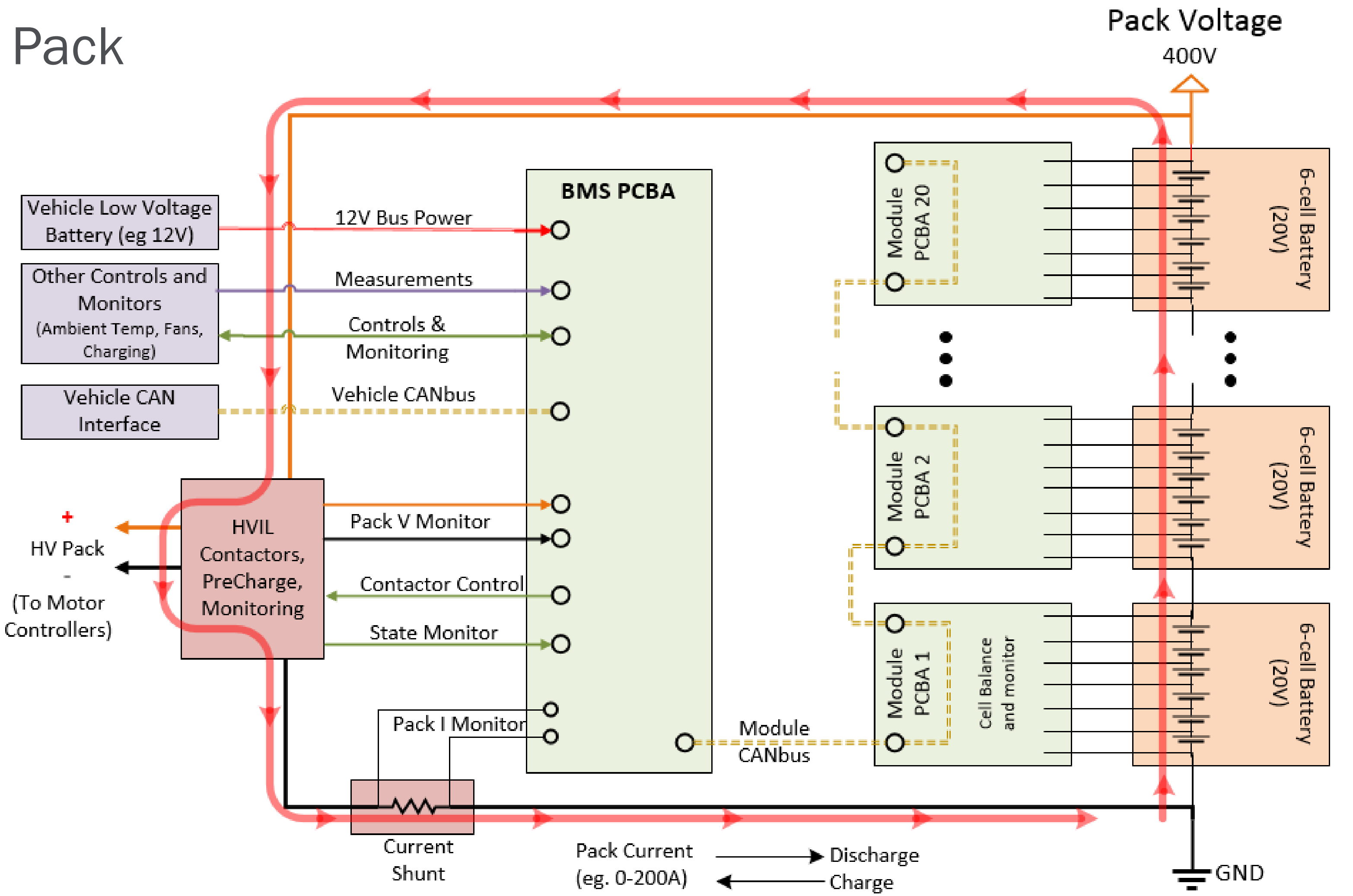
Benefits

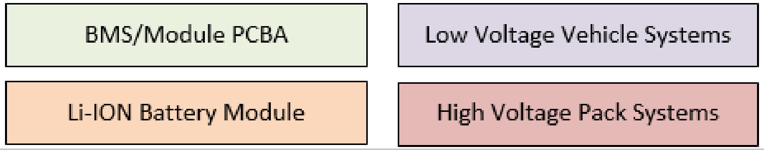
- Operator & product safety
- Explicit repeatability
- Reduced test time
- Extended test coverage
- Faster time to market

BMS HIL METHODOLOGY

BMS and Module Interaction

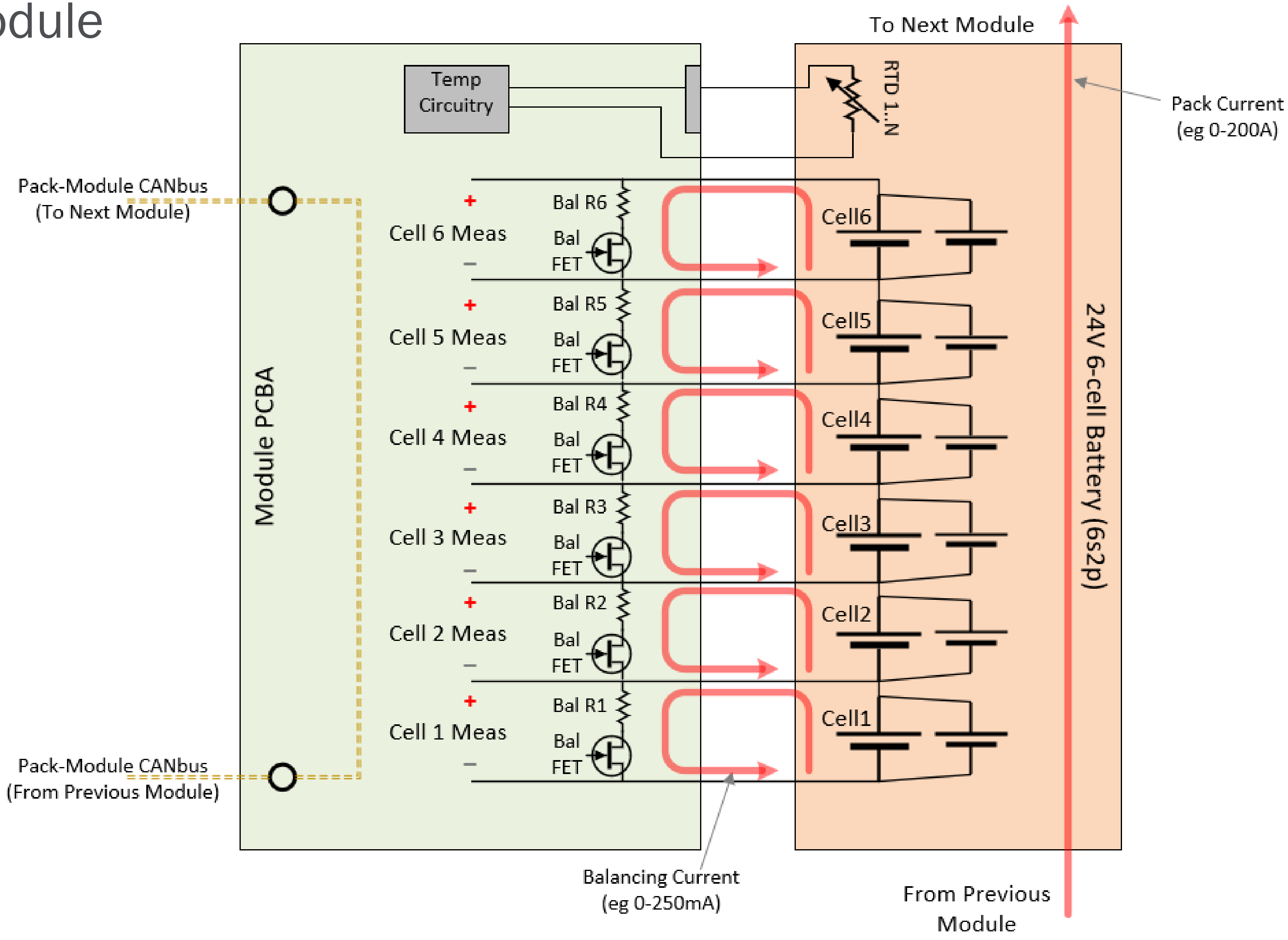
"Real World" Pack





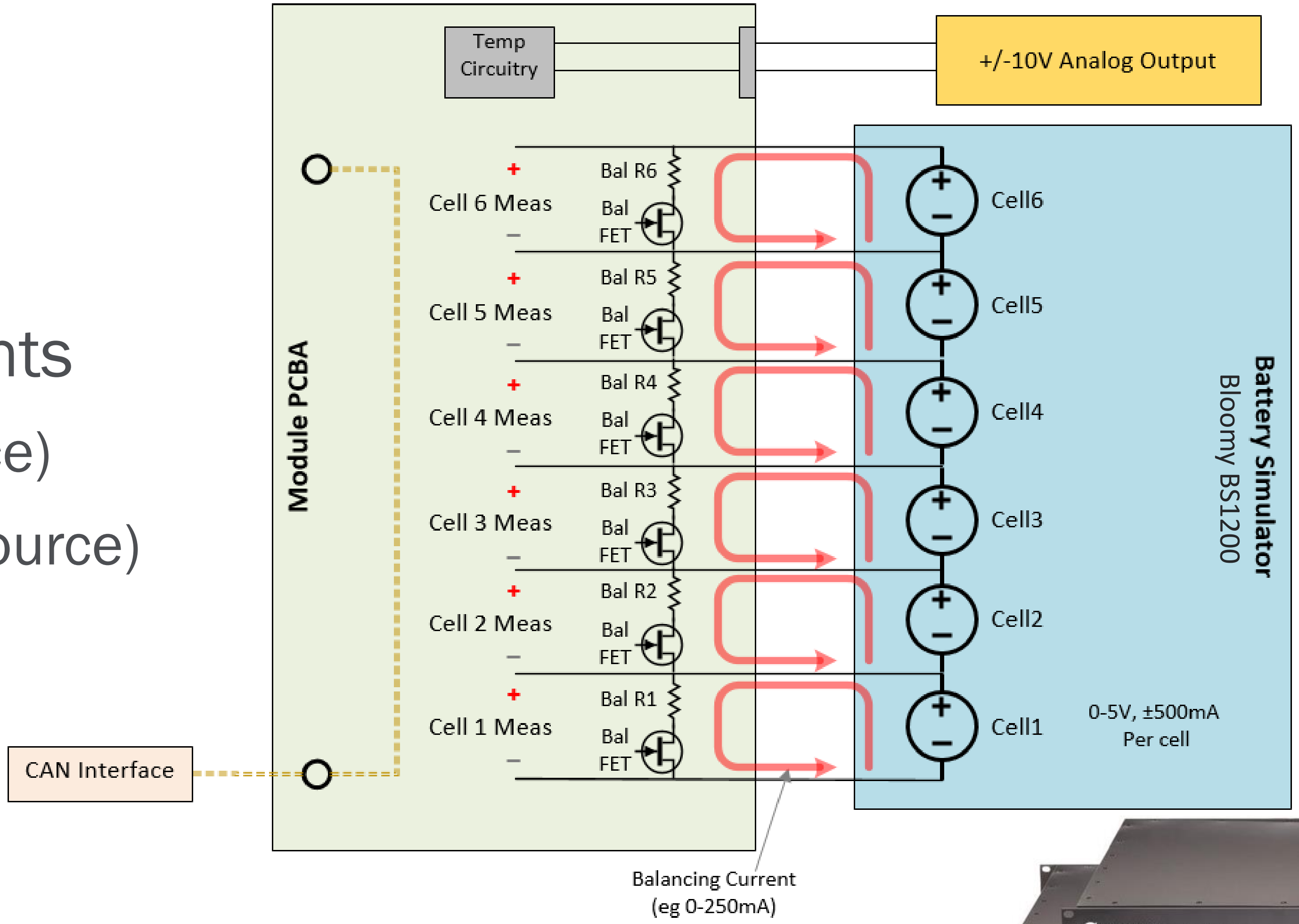
BMS and Module Interaction

"Real World" Module



HIL Testing at the Module Level

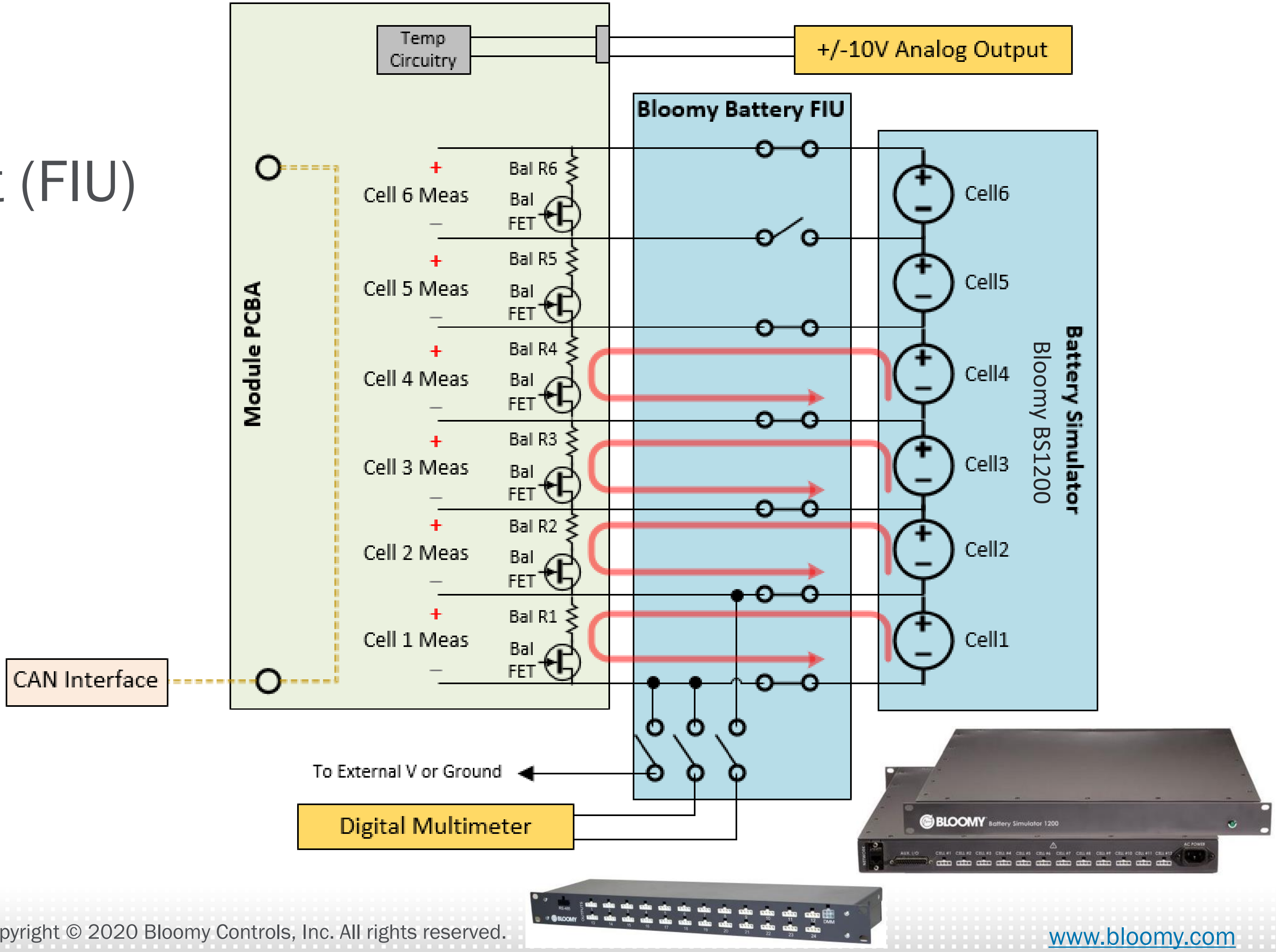
- Simulate series cells
- Output cell voltages
- Provide balancing currents
  - Passive balancing (source)
  - Active balancing (sink/source)
- Simulate thermistors



HIL Testing at the Module Level

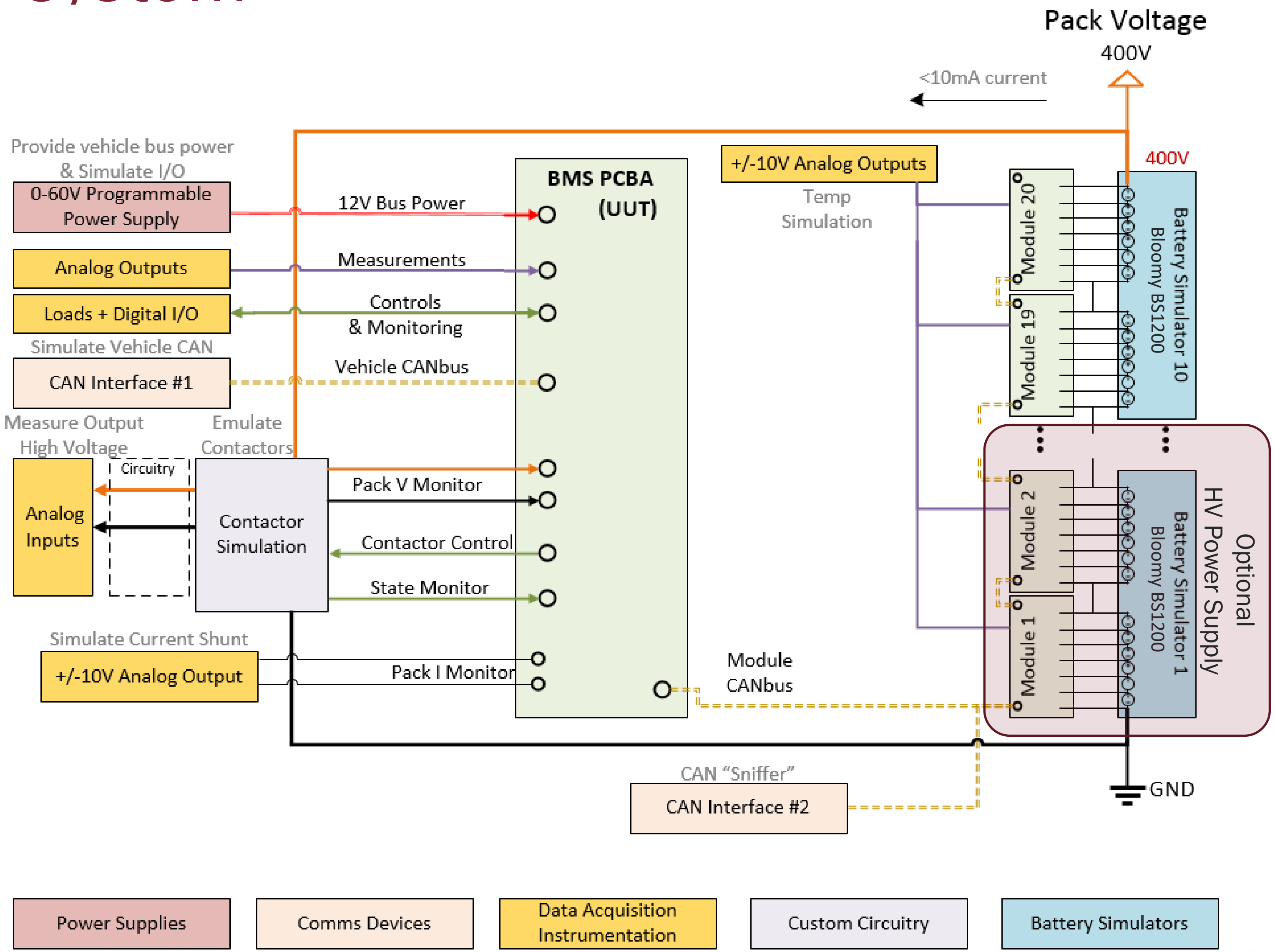
With Fault Insertion

- In-line Fault Insertion Unit (FIU)
- Open/broken wire faults
- Short to rail faults
- Connect to DMM
- Shorted cell (BS to 0V)



HIL Testing of the entire system

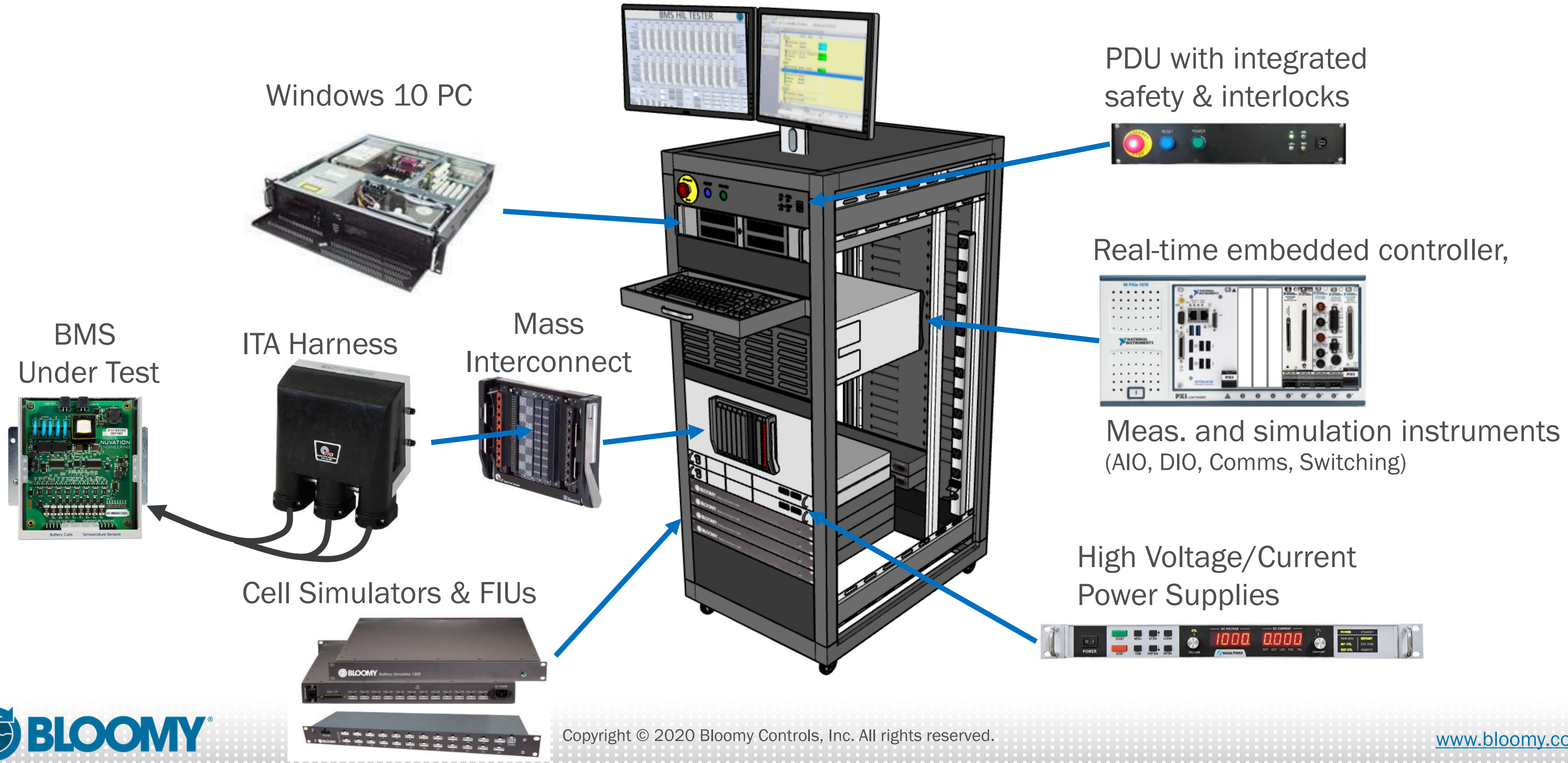
- BMS in the "real world"
- Simulate/monitor all IO
  - Cells
  - Pack V & I
  - Contactors
  - Environmental
  - Vehicle/system
  - Communications
- Low power, inherently safe



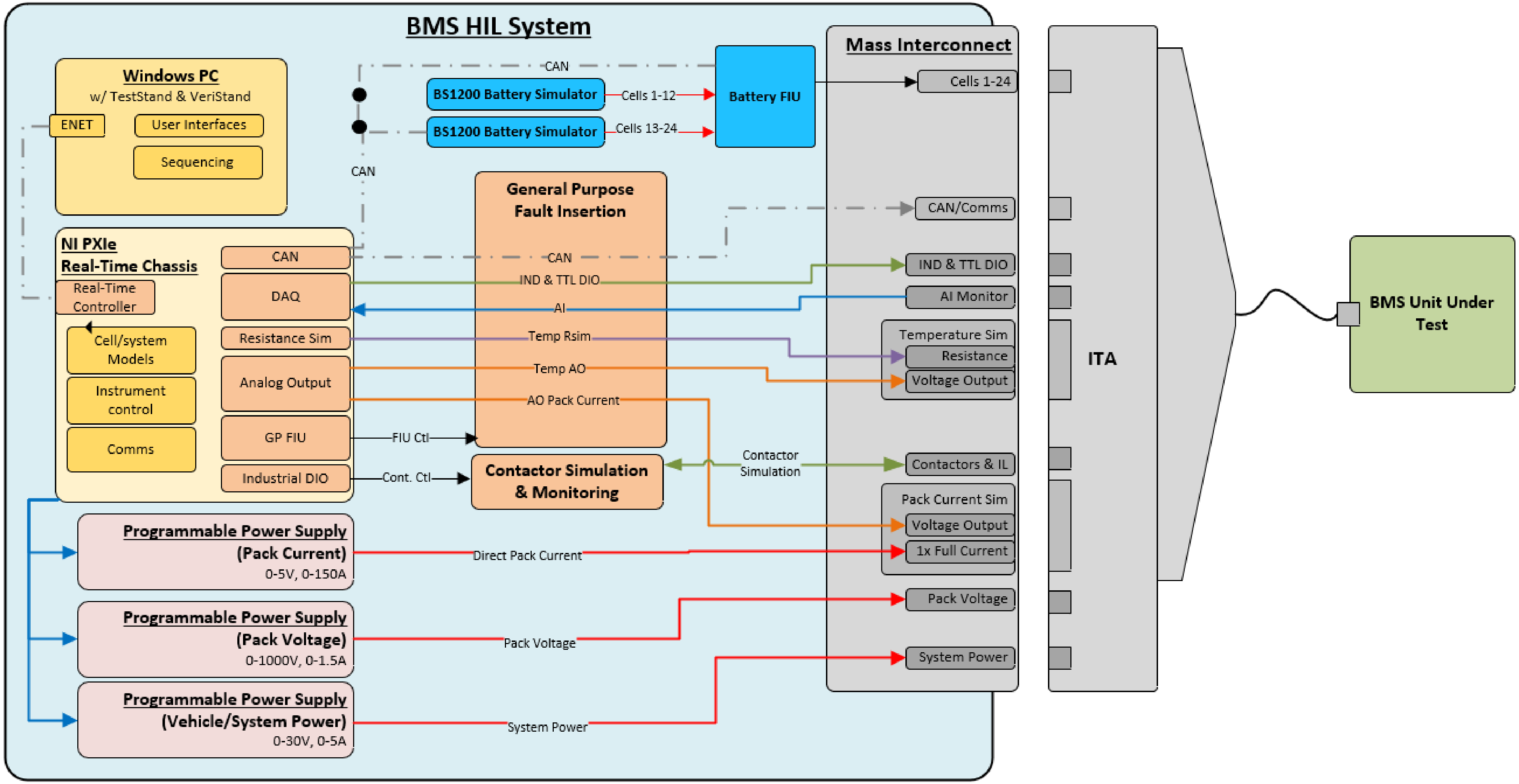
BLOOMY

BMS HIL INSTRUMENTATION AND CONNECTIVITY

BMS HIL Instrumentation Overview



BMS HIL Hardware Block Diagram

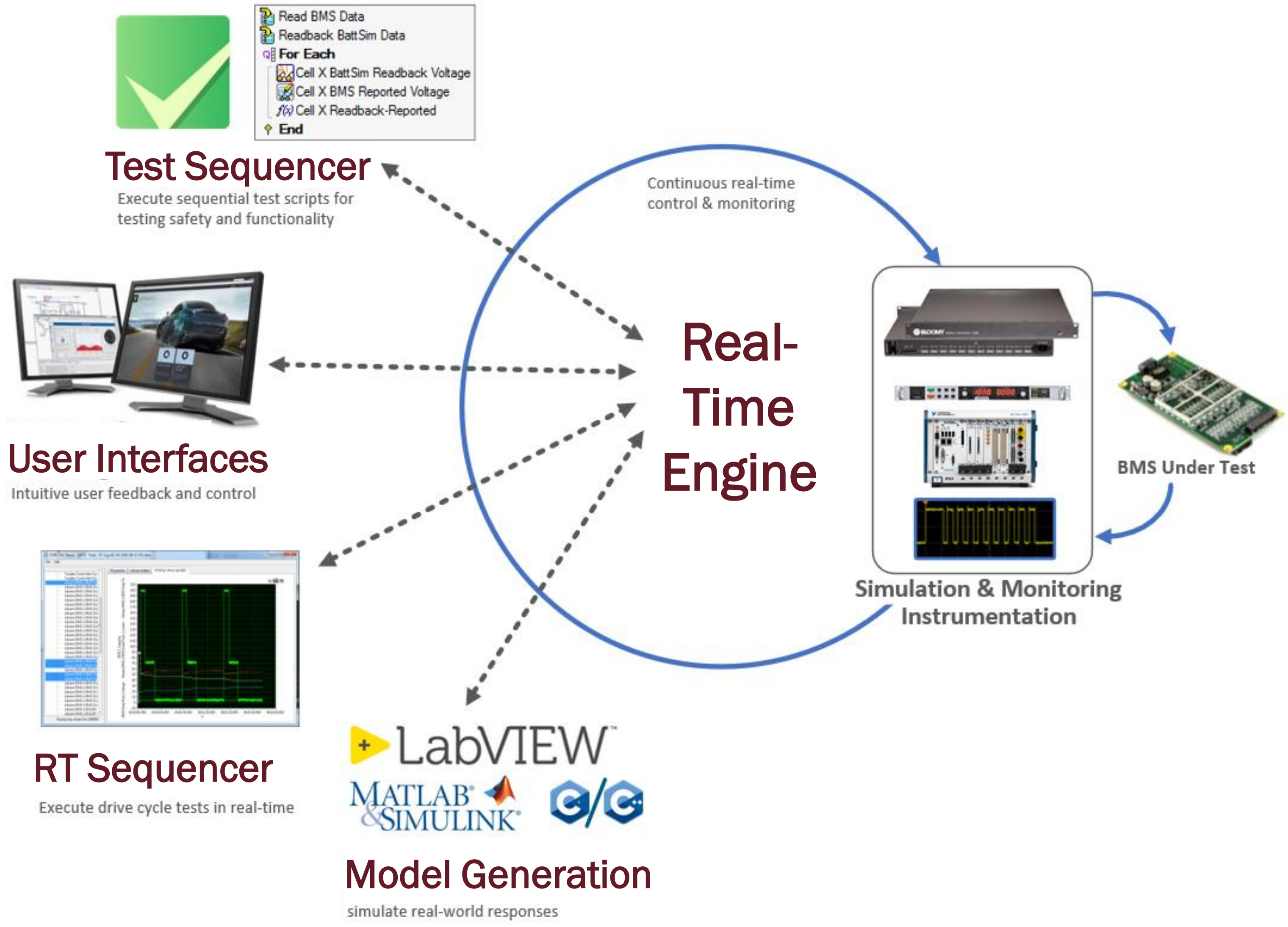


BMS HIL Signals

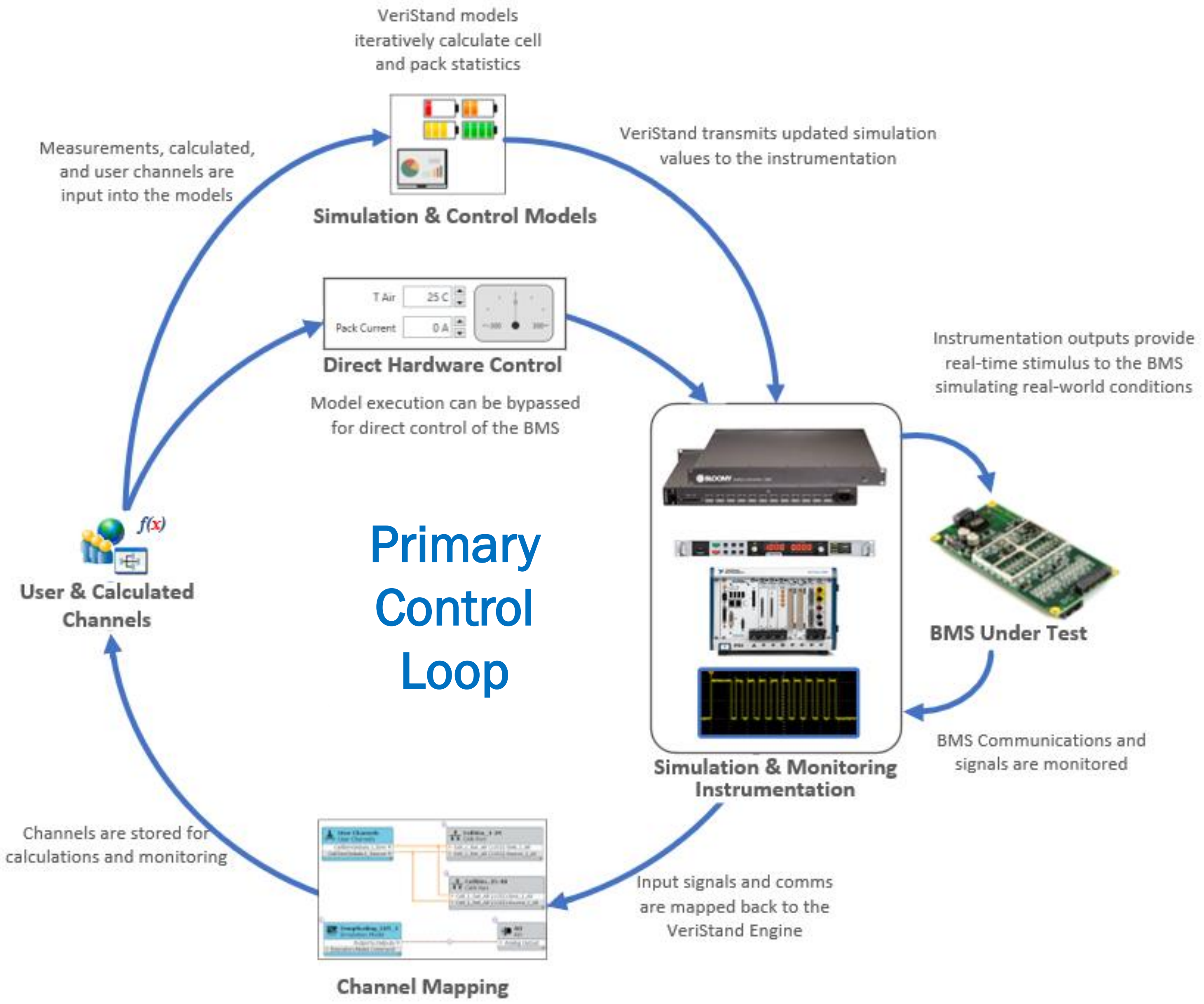
Signal Type	Qty	Description	Details
Vehicle/CAN power & interlocks	1-3	12V or 24V main power	Programmable Power Supply
Cell Simulation	12-200	Simulation of individual cells	0-5VDC Sink/Source 500mA
Temperature Simulation	8-32	Simulation of cell/pack temperatures	Analog Voltage (+/-10V) Resistance (0-65kΩ)
Pack Current Simulation	1	Simulation of full pack current (eg 400A)	Analog Voltage (+/-10V) Programmable PS (up to 150A)
Vehicle Discretes	2-4	Controlling ignition, interlock, enable, CAN power	Fixed power supply with industrial digital output control
Comms	1-4	BMS-Vehicle, Module, etc	CAN, LIN, Serial, IsoSPI
Contactors	2-4	Simulation of contactors to verify BMS control	Fixed resistance with industrial digital inputs for monitoring
Insulation Resistance sim	1-2	Simulating HV resistance to test BMS monitor circuits	Fixed resistors with high voltage switching
Misc BMS IO	4-12	Misc analog/digital inputs and outputs to/from BMS	Analog/digital inputs and outputs for simulation/monitoring

BMS HIL SOFTWARE

BMS HIL Software Components

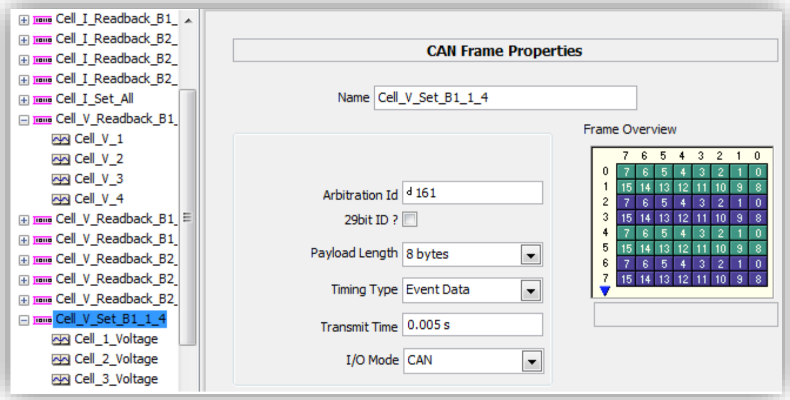


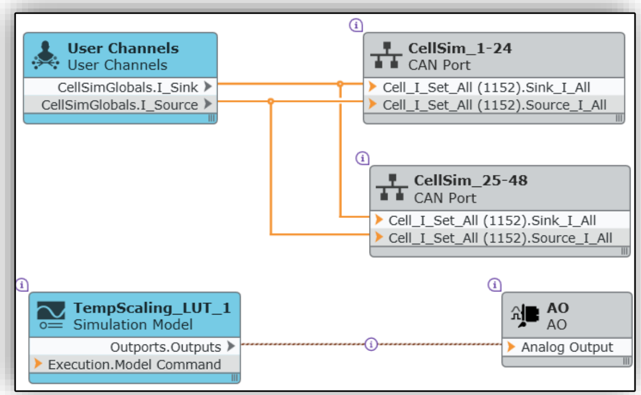
BMS HIL Software – Real-Time Engine Execution

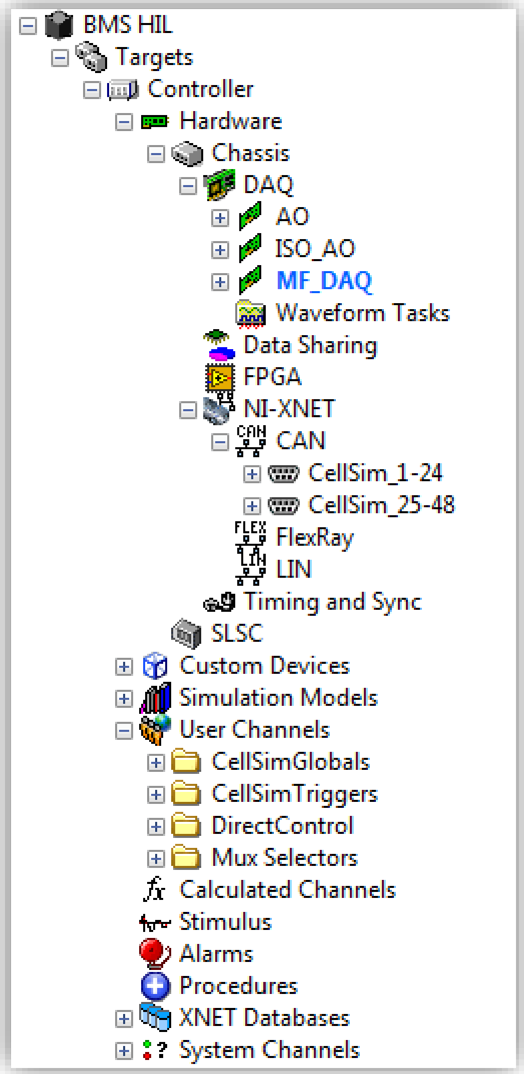


BMS HIL Software– Real-Time Engine Configuration

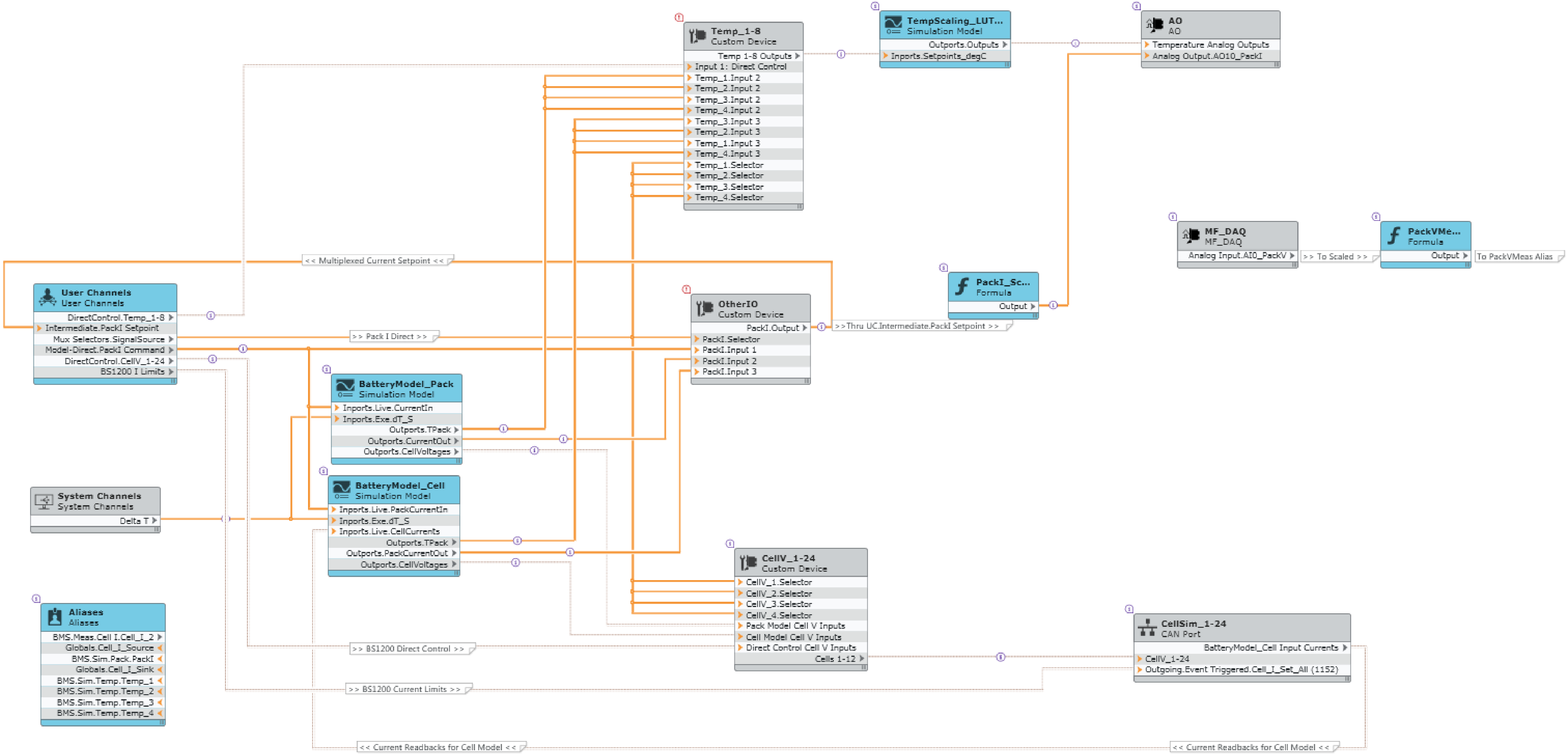
- Instrumentation Interfaces
  - DAQ, BattSim, FIU
  - Switching, Power Supplies
- User and calculated channels
- BMS Communications
  - Serial, CAN Databases
- Models
  - Cell, vehicle, contactors
- Procedures
  - Startup, alarm, safety
- Channel mapping





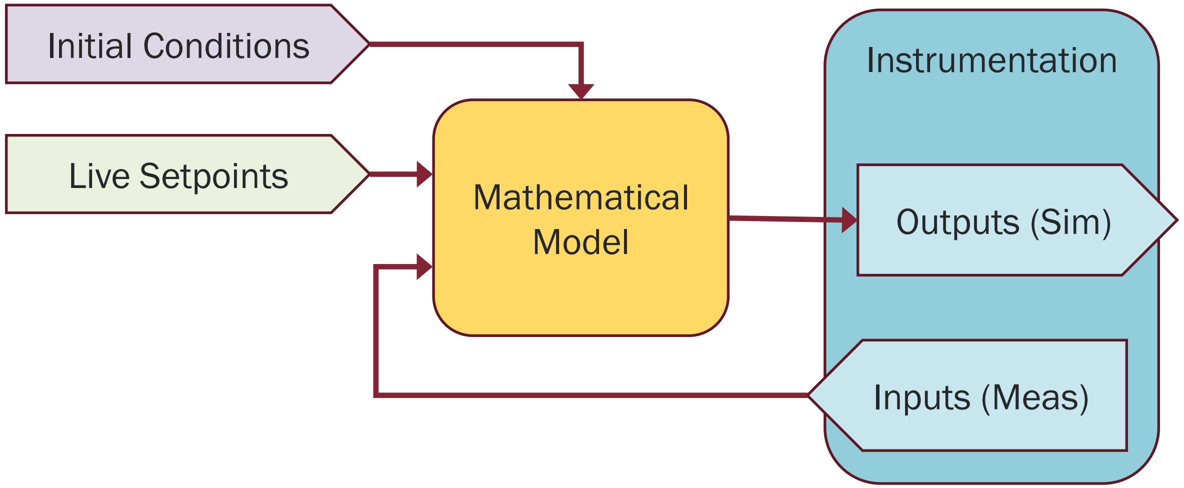


User & System Channels | Battery Models | Channel Multiplexing | Output Scaling | Instrumentation IO | Input Scaling



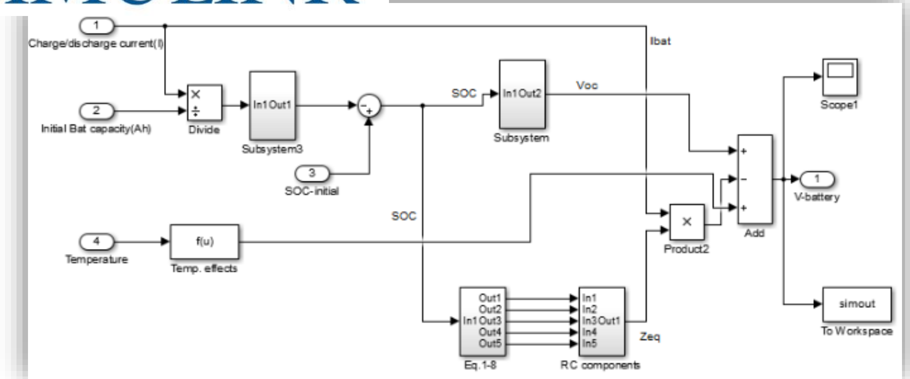
BMS HIL Software – Model Integration

- Models define behavior of outside world
  - Cells, thermal, pack
  - Contactors, vehicle/system
- Models close the loop
- Provide “real world” testing
- Mimic the response of real batteries
- Tune algorithms and response of BMS



Model Development Options

MATLAB & SIMULINK

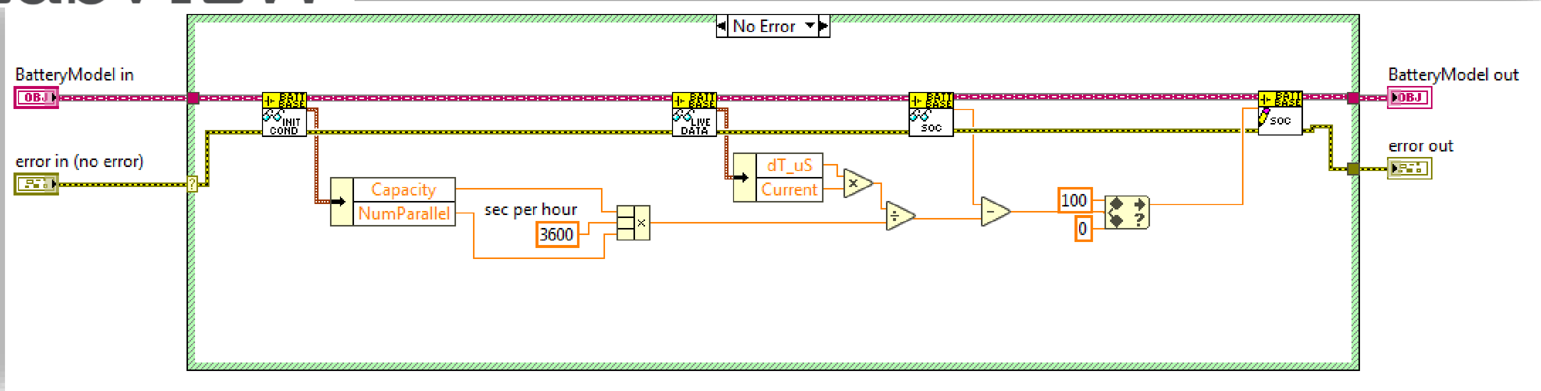


Sheikh, Muhammad & Baglee, David & Knowles, Michael & Elmarakbi, Ahmed & Al-Hariri, Mohammad. (2015). A Novel Approach for Predicting Thermal Runaway in Electric Vehicle Batteries When Involved in a Collision. 10.1115/IMECE2015-51781.

C/C++

```
int32_t state_normal(double timestamp) override {

    static double current[currentLen];
    static int loop;
    switch((ModelMode)(inports->Mode)) {
        case FIXED_CURRENT:
            {
                double cellVoltage[16] = {0};
                int numCells = inports->Num_Series;
                double PackV = 0;
                double TPackFactor = 0;
                bool thresholdreached = false;

                //update SoC based on pack current
                signals->SoC = ((((signals->SoC/100.0)*inports->Capacity)-(
                inports->Current*1e-5))/inports->Capacity)*100.0;

                //Limit SoC to 0-100
                signals->SoC = (signals->SoC < 100) ? signals->SoC : 100;
                signals->SoC = (signals->SoC > 0) ? signals->SoC : 0;

                //update cell voltages based on SoC
                for (int i = 0; i < 16; i++) {
                    if(i <= numCells-1){
                        cellVoltage[i] = -2e-7*std::pow(signals->SoC,4)+5e-5*std
                        ::pow(signals->SoC,3)-0.004115*std::pow(signals->SoC,2)+
                        0.1335*signals->SoC+2.5;
```

LabVIEW



Model Integration into HIL Environment

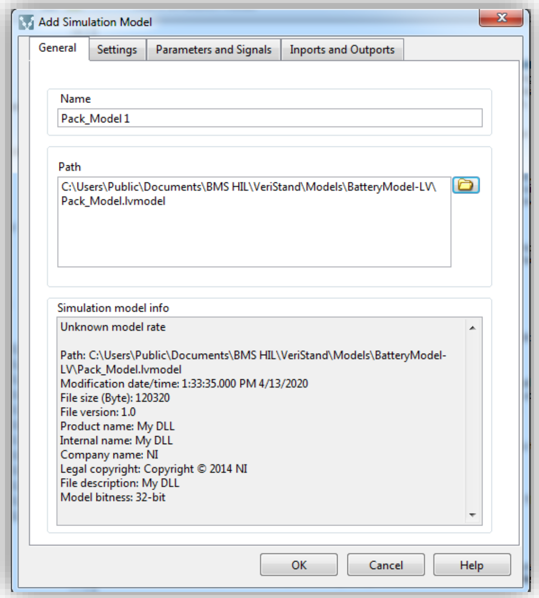
Develop & compile model

MATLAB® & SIMULINK®

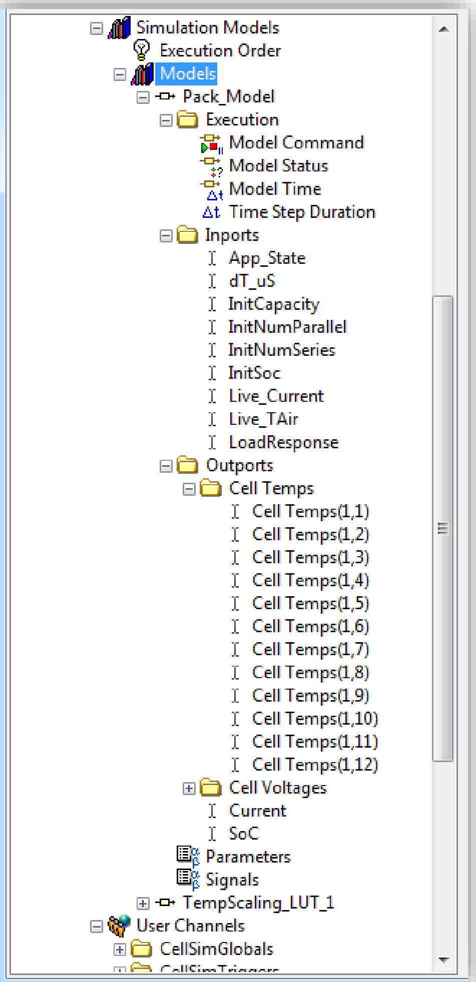
C/C++

LabVIEW™

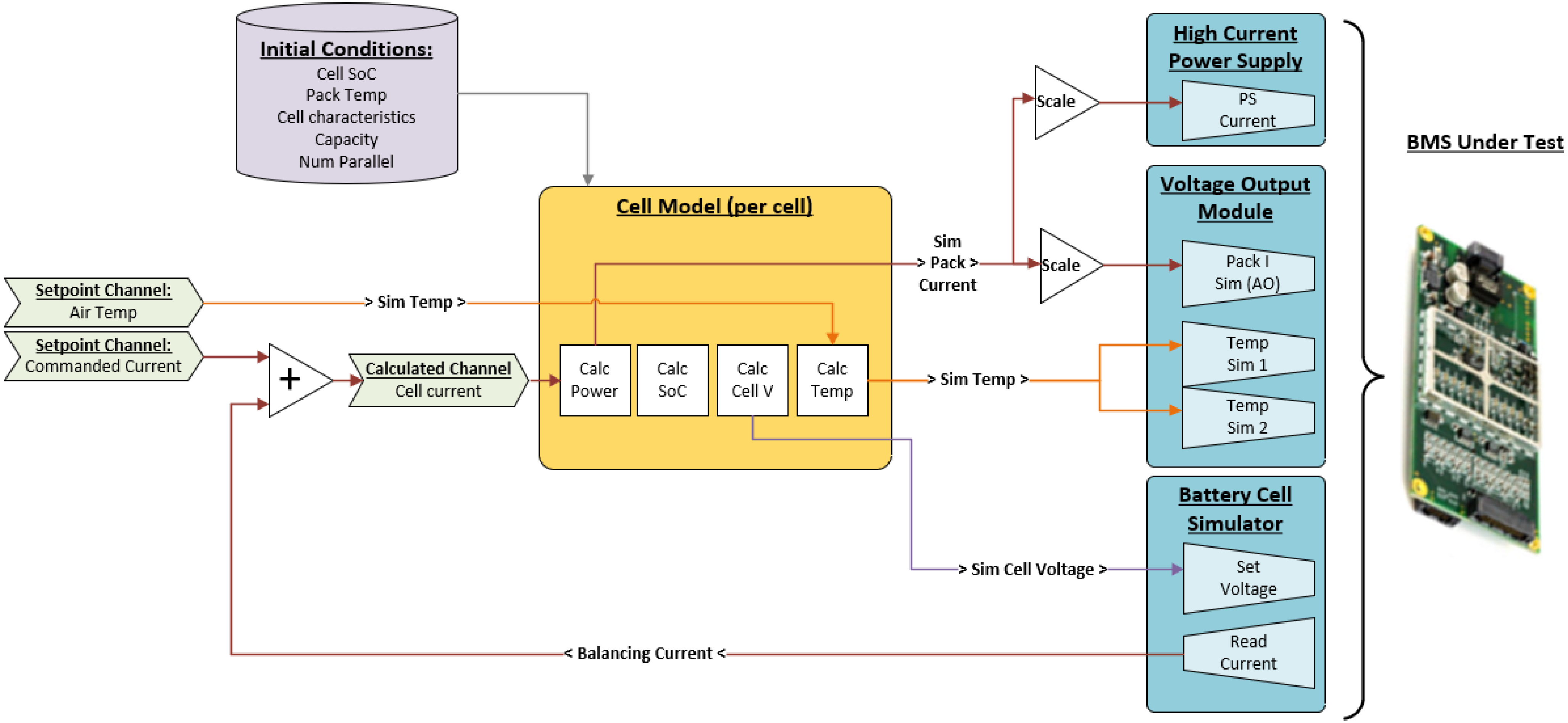
Load into environment



Map channels

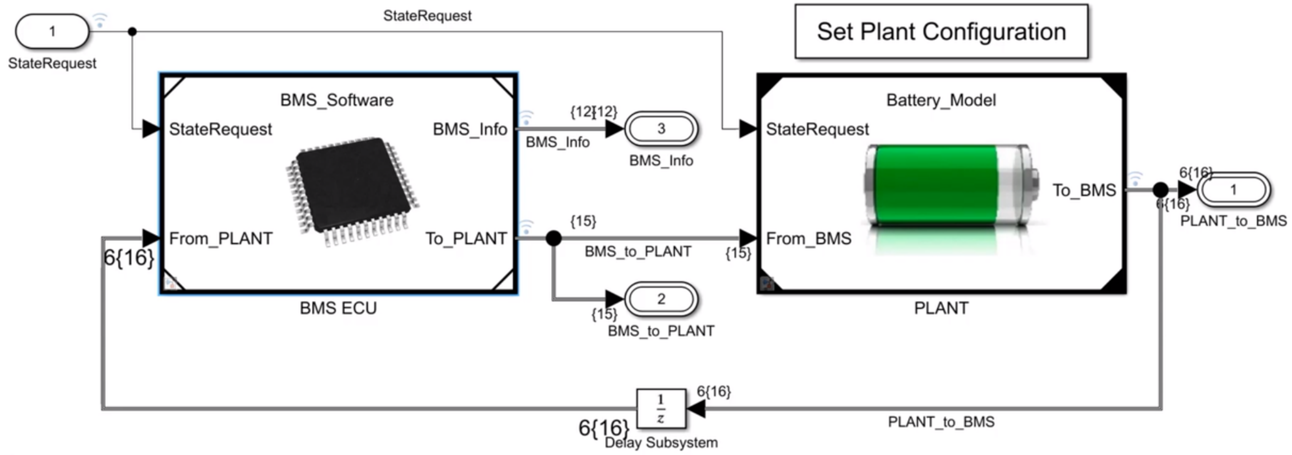


BMS HIL Software – Cell Model Example



Advantages of Model-Based BMS Testing

- Evaluate different cell chemistries/suppliers
- Evaluate different BMS architectures and tune algorithms
- Incorporate interaction with other vehicle systems
- Repeatably test real-world and edge condition scenarios
  - Impossible, impractical, too dangerous, or too expensive



https://www.mathworks.com/solutions/power-electronics-control/battery-models.html

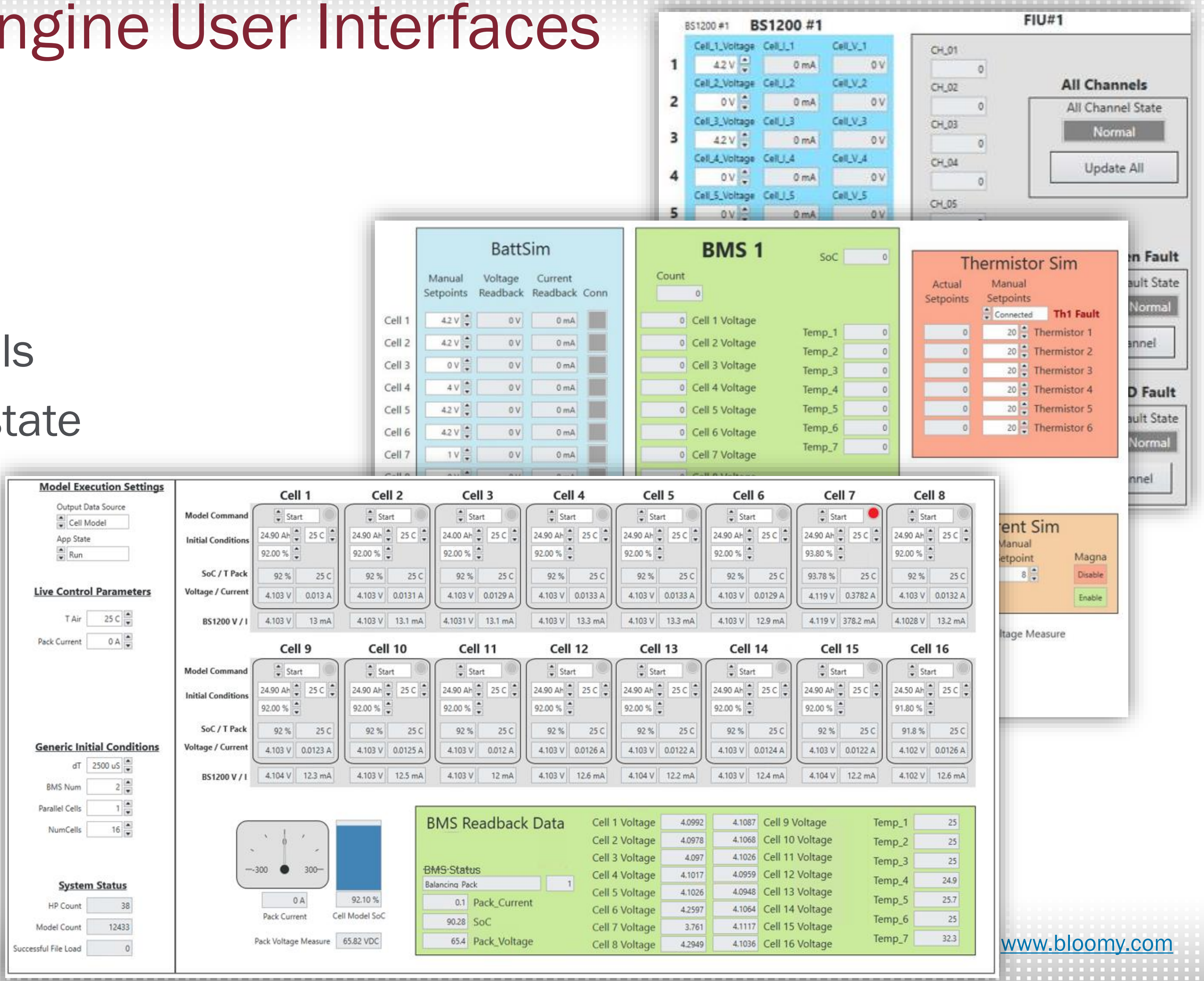
BMS HIL USER INTERFACES

BMS HIL Software – Engine User Interfaces

Engine User Interfaces

- Windows-side client
- Socket into RT execution
- Peek/poke system channels
- Intuitive view into system state

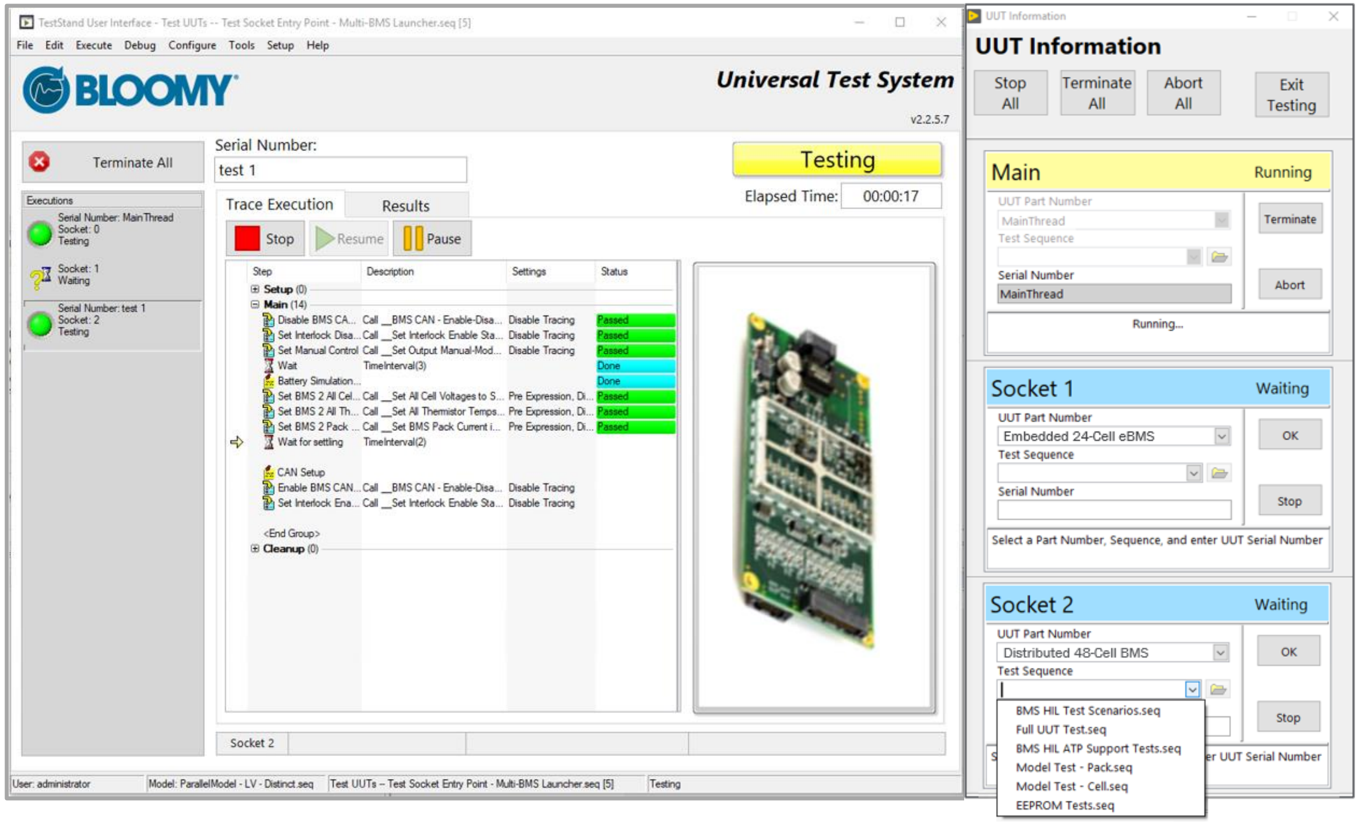
- Direct hardware control
- BMS interface control
- Model-based control

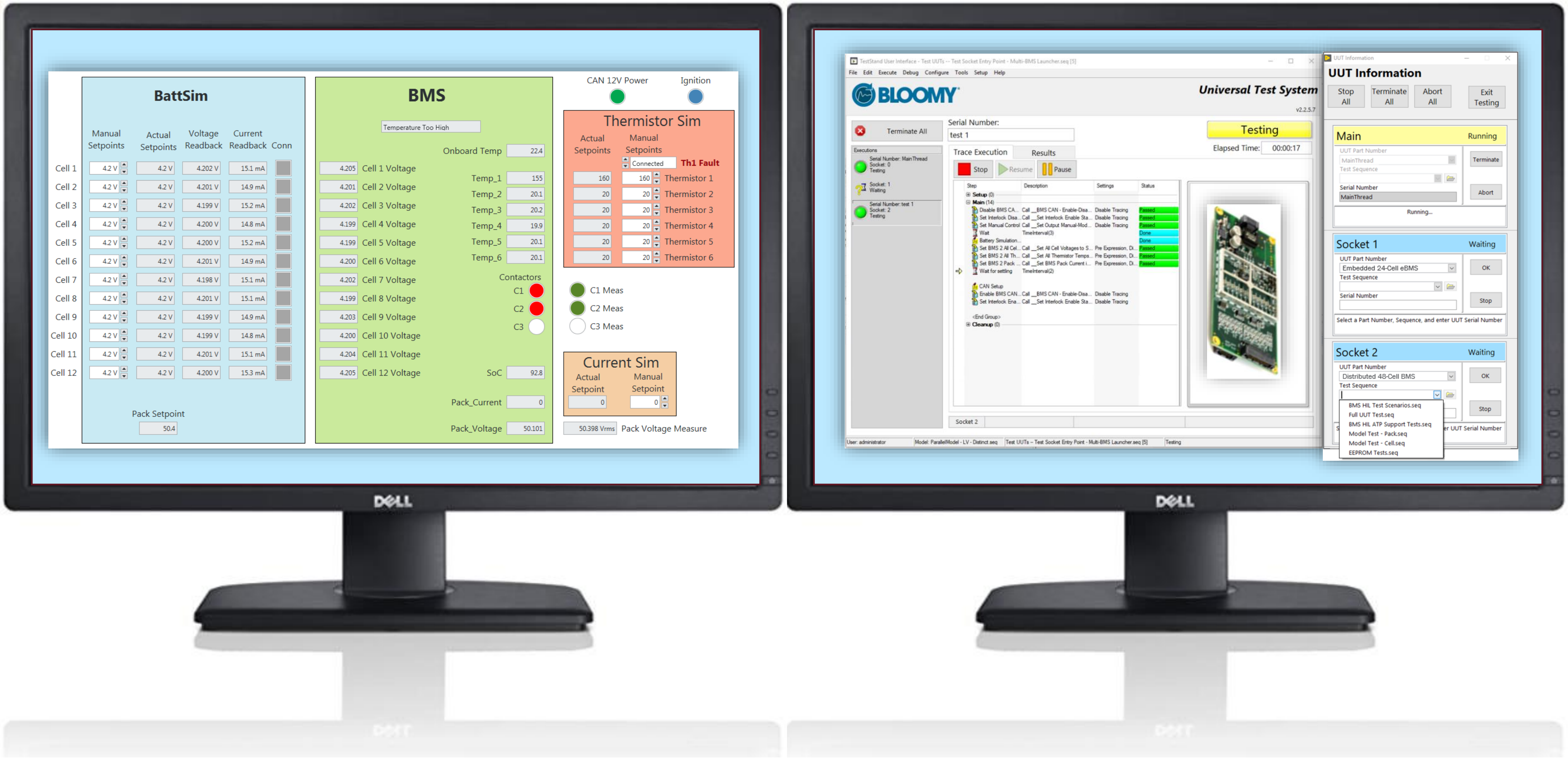


BMS HIL Software – Automated Test Operator Interfaces

Automated Test User Interface

- Windows-side client
- Intuitive automated test selection
- Simplifies test execution
- Trace execution
- Advanced debugging
  - Single stepping, looping
  - Pause, terminate



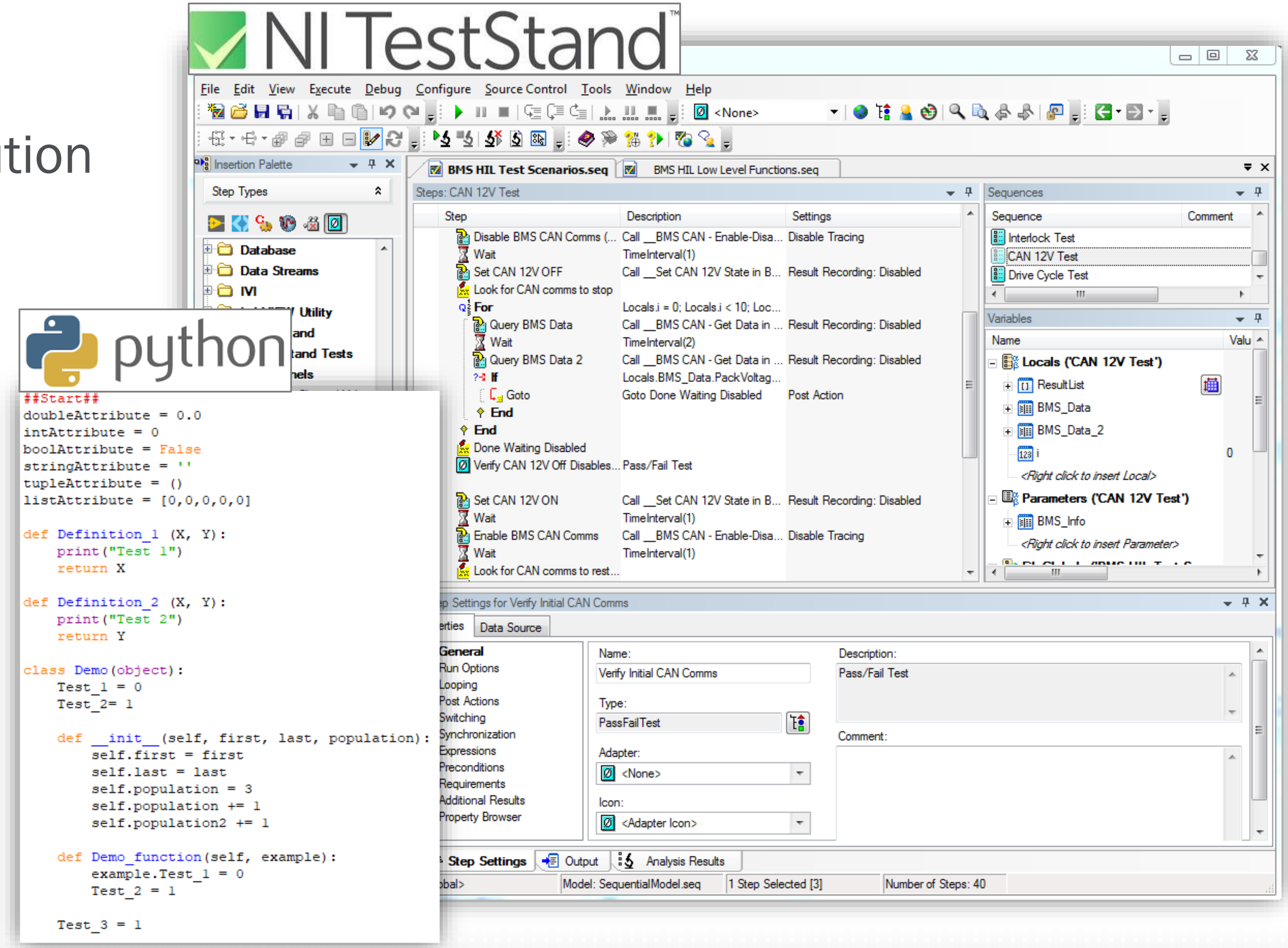


www.bloomy.com

BMS HIL TEST SCRIPTING AND DATA LOGGING

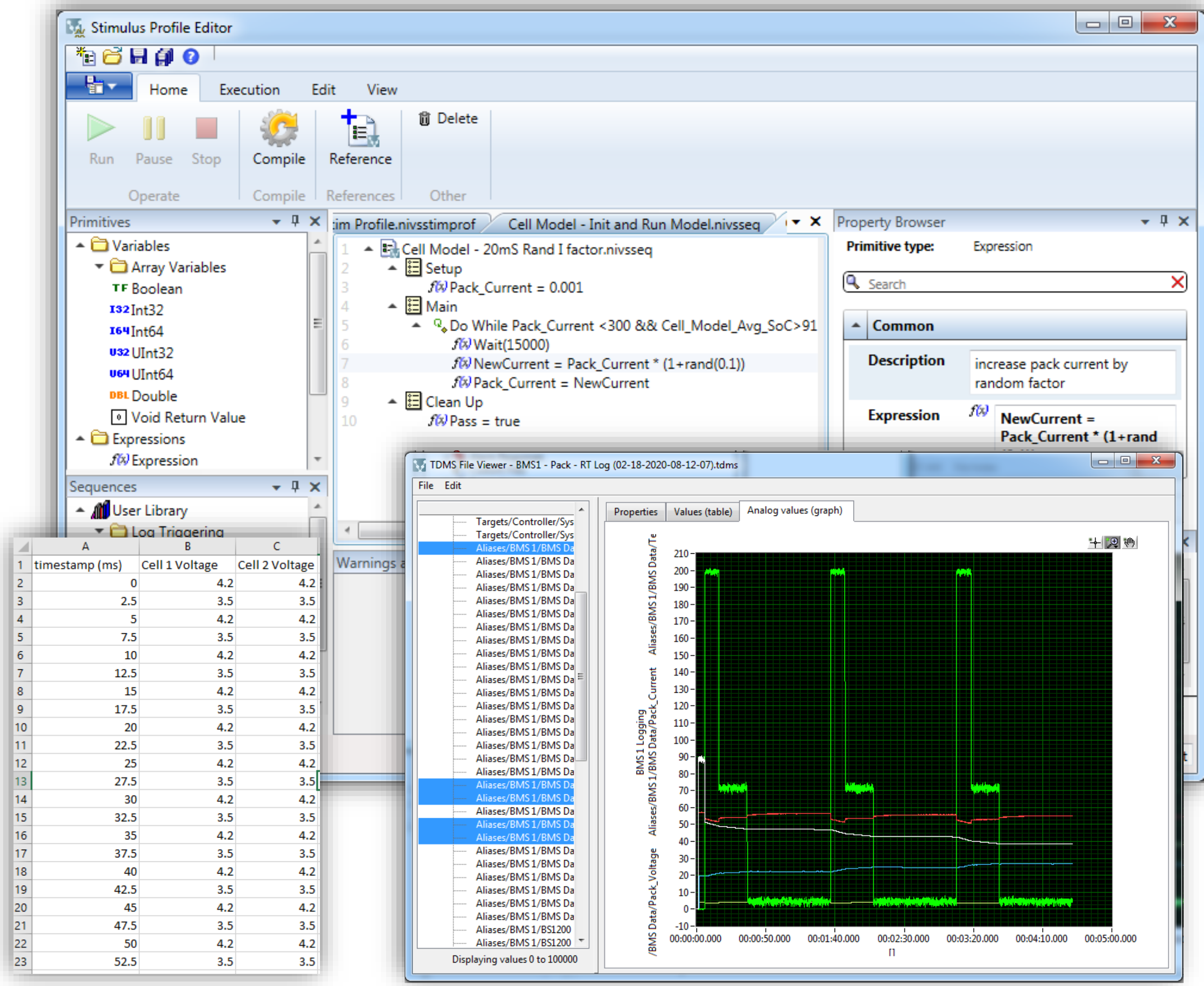
BMS HIL Software – Automated Sequencing

- Python, NI TestStand, etc
- Test script development & execution
  - Sequential scripts, flow control
  - Pass/fail determination
  - Results collection
- Interact with real-time system
  - Get/Set channel values
  - Control model setpoints
- Automate common tasks/tests
- Tests are non real-time



BMS HIL Software – Real-Time Sequencing

- RT engine-based
- Stimulus profiles
  - High speed drive cycle playback
  - CSV-based channel control
- Real-time sequencing
  - Set/read channels
  - Pass/fail determination
  - Flow control
- Execute in Real-Time
- High-speed channel data logging



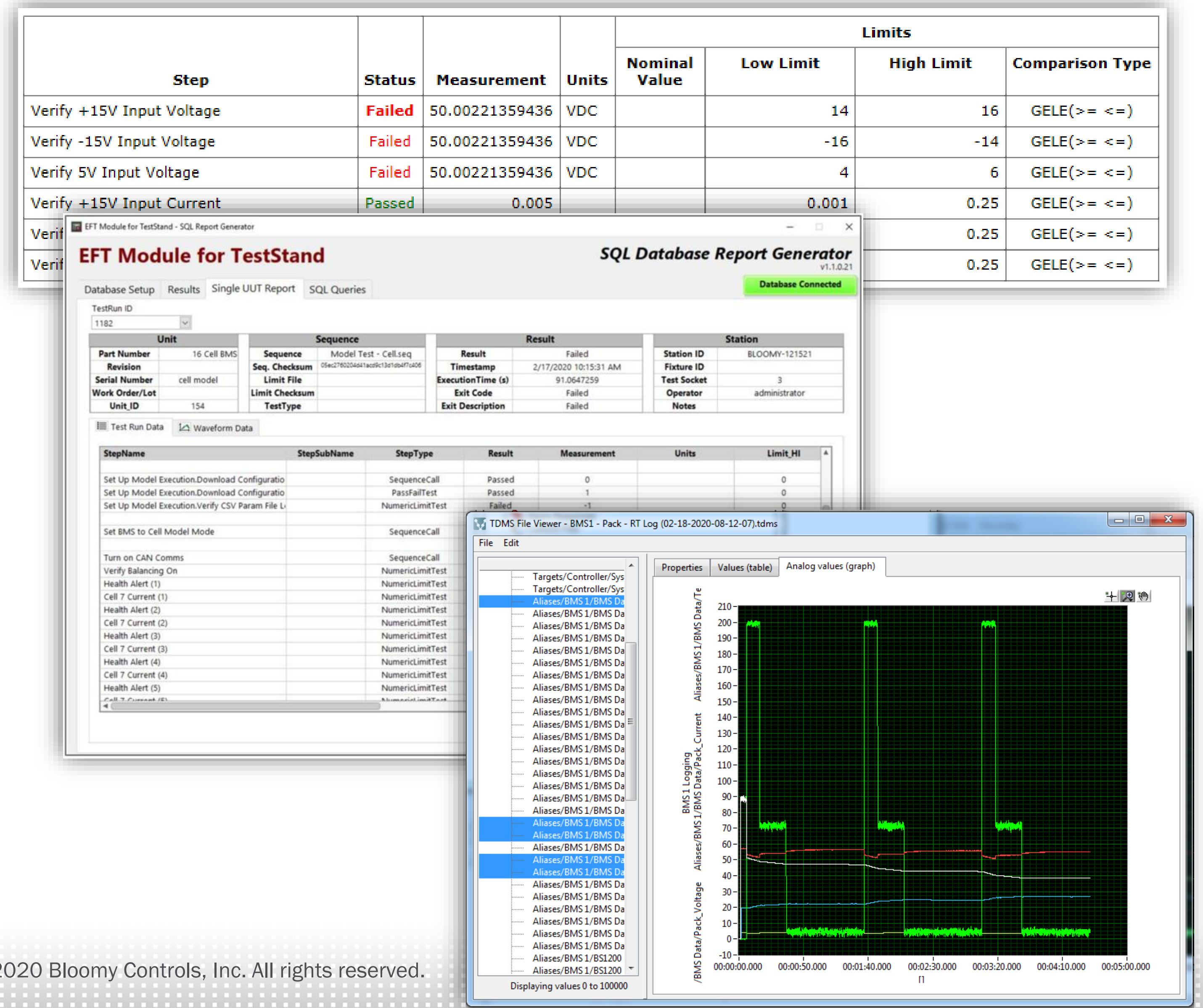
BMS HIL Software – Data Logging

Automated test script results

- Discrete measurements
- Pass/fail data
- XML, CSV, or Excel files
- Database storage

Real-time channel logging

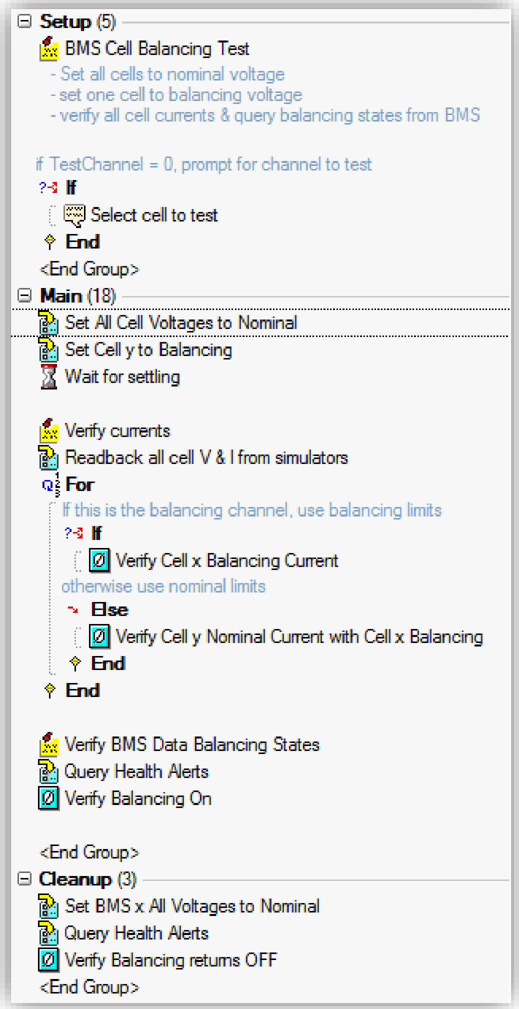
- At PCL rate (400 – 1000Hz)
- Any real-time channel
- CSV, Excel, TDMS



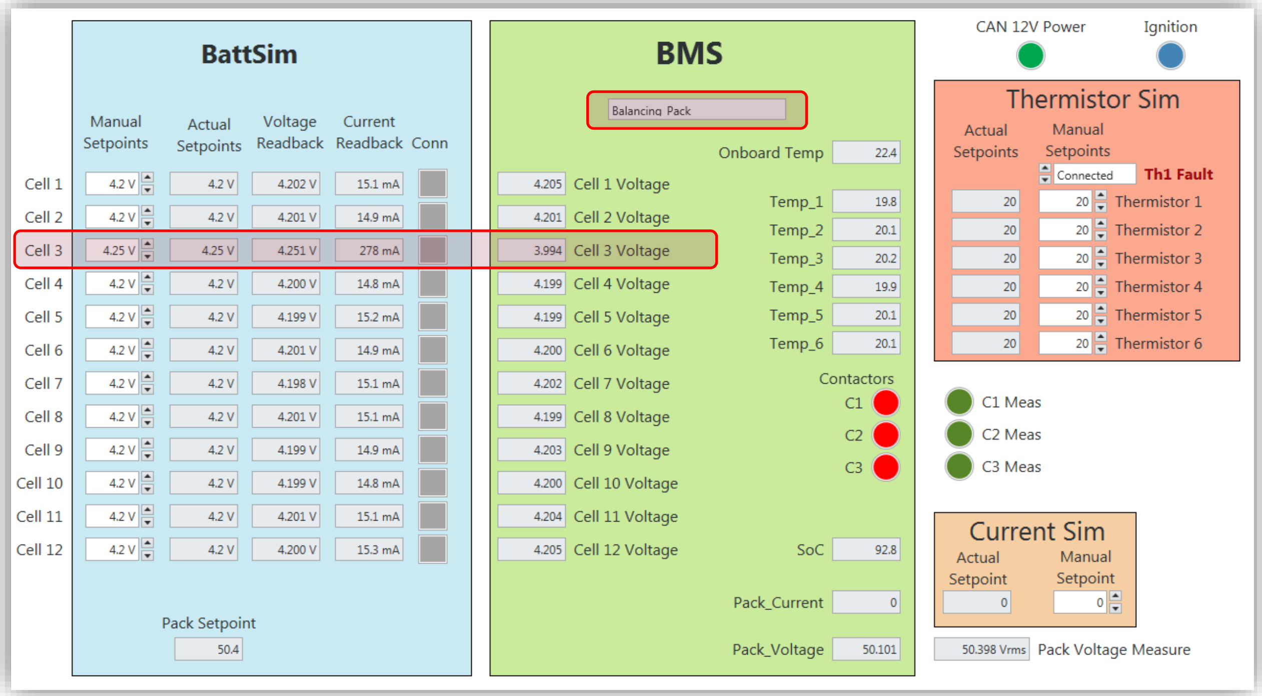
BLOOMY

BMS HIL TEST SCENARIOS

Cell Voltage Verification and Balancing Test

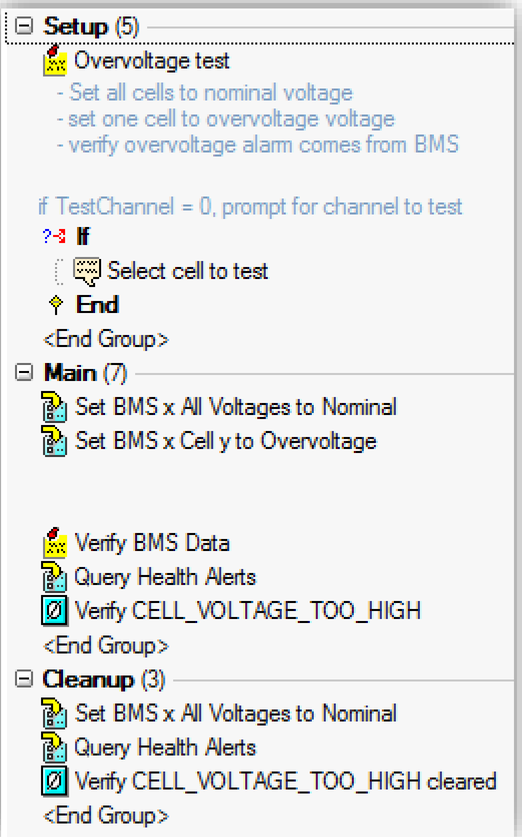


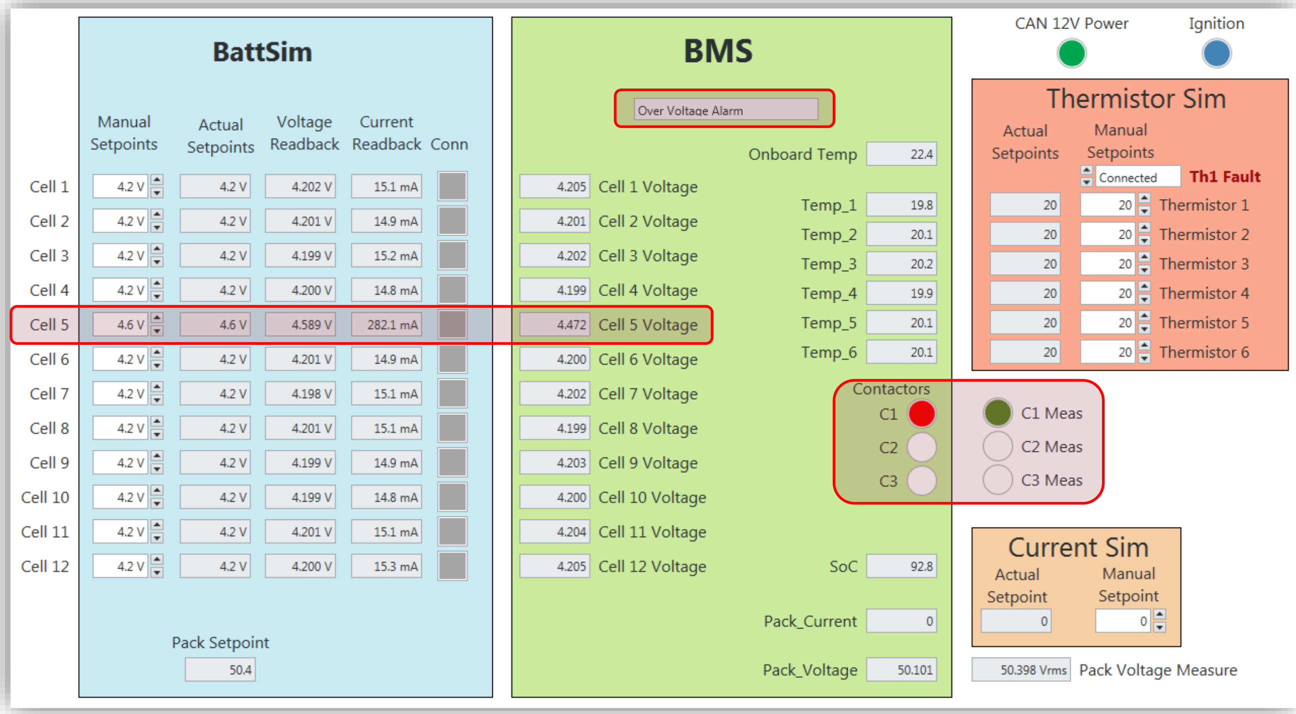
- Set one cell at a time to balancing voltage
- Verify Balancing V & I from BS1200
- Verify BMS response (status & meas)



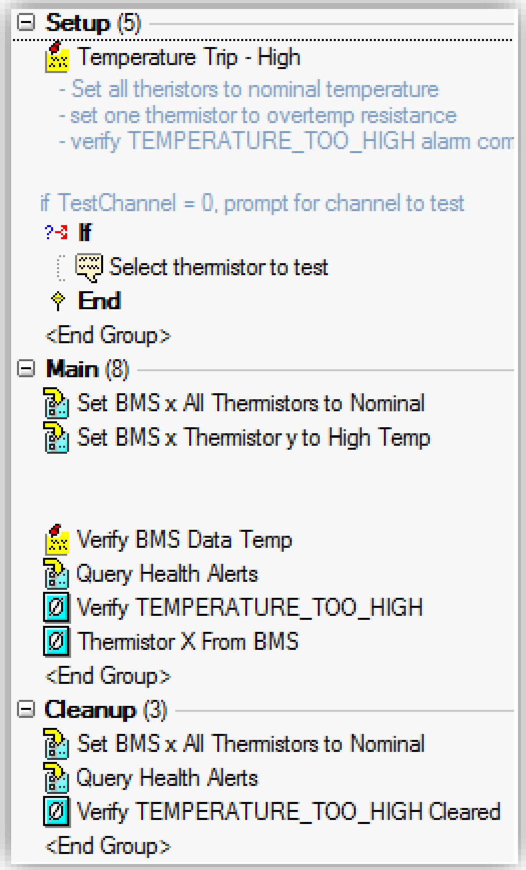
Over/Under Voltage Protection Test

- Set one cell at a time to over/under voltage
- Verify BMS contactor outputs
- Verify BMS response (status & meas)

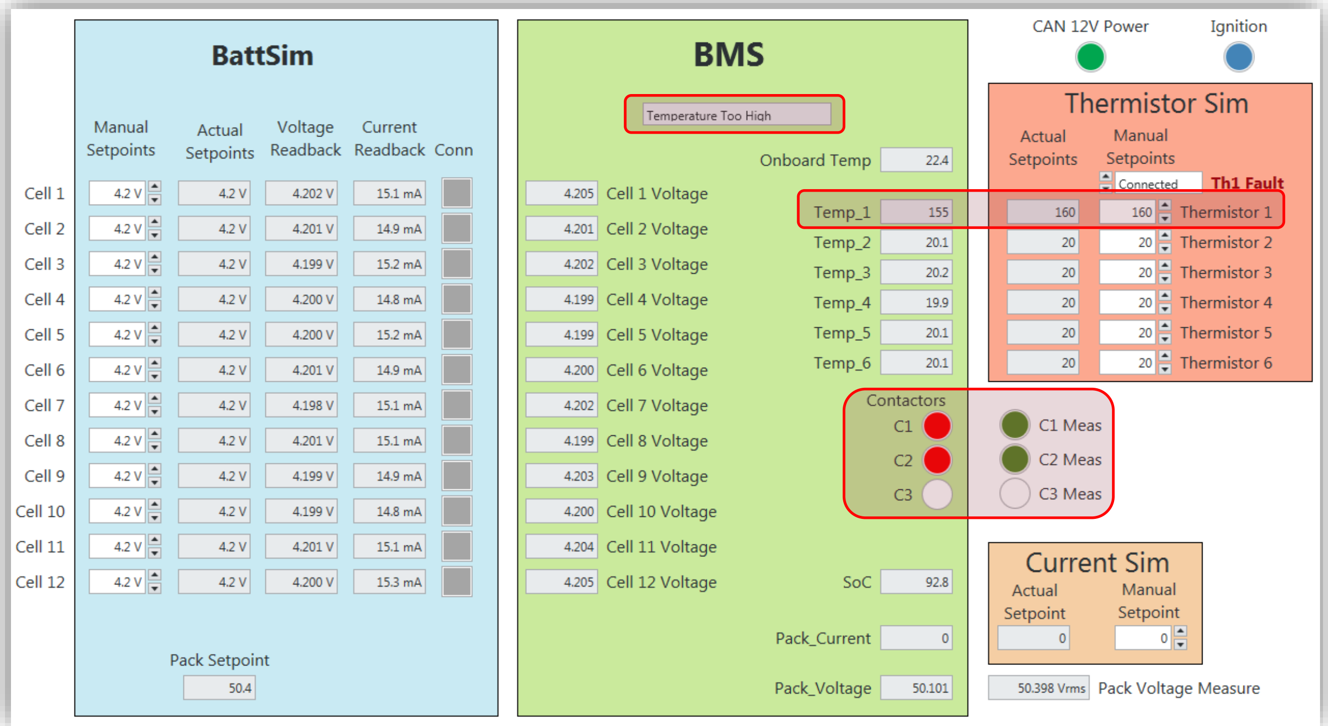




Temperature Trip Test

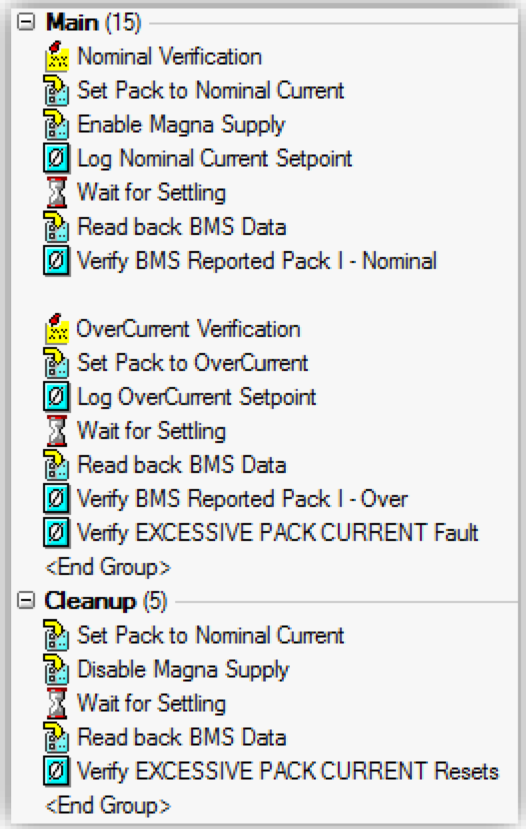


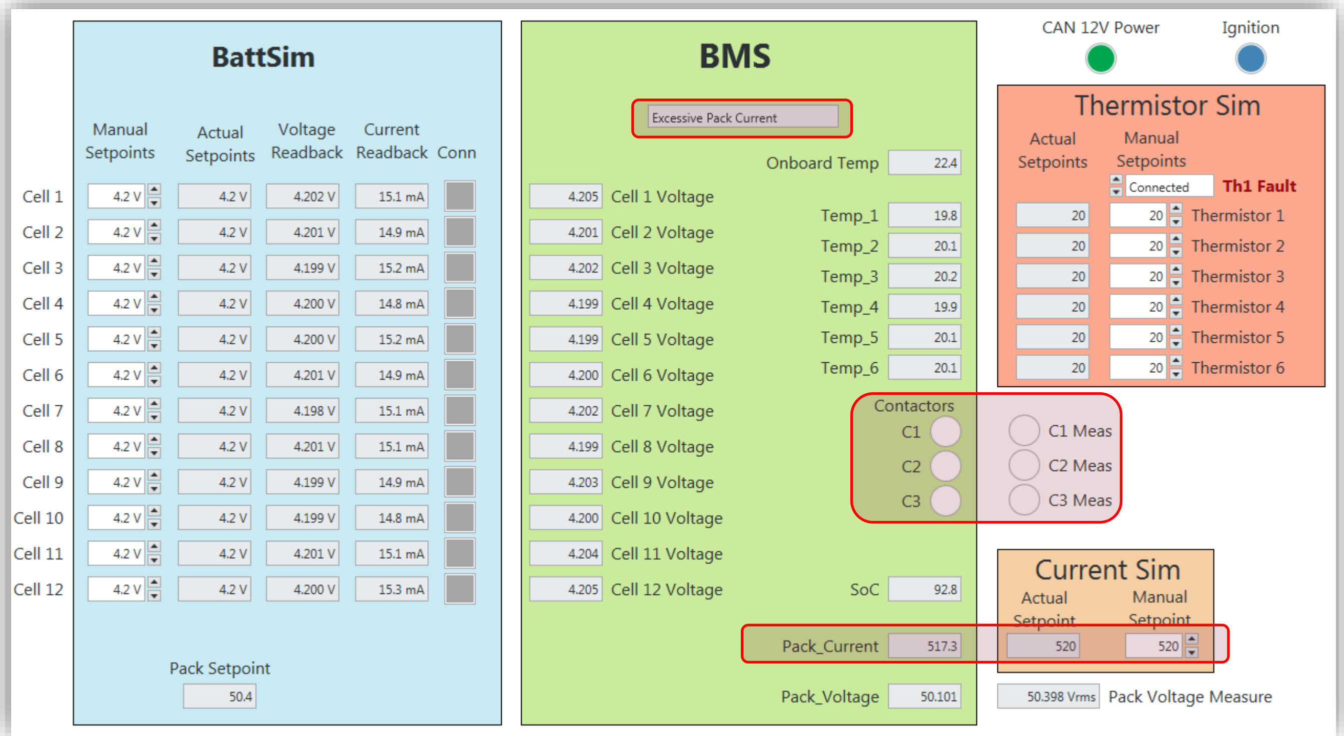
- Set one thermistor at a time to over/under Temp
- Verify BMS contactor outputs
- Verify BMS response (status & meas)



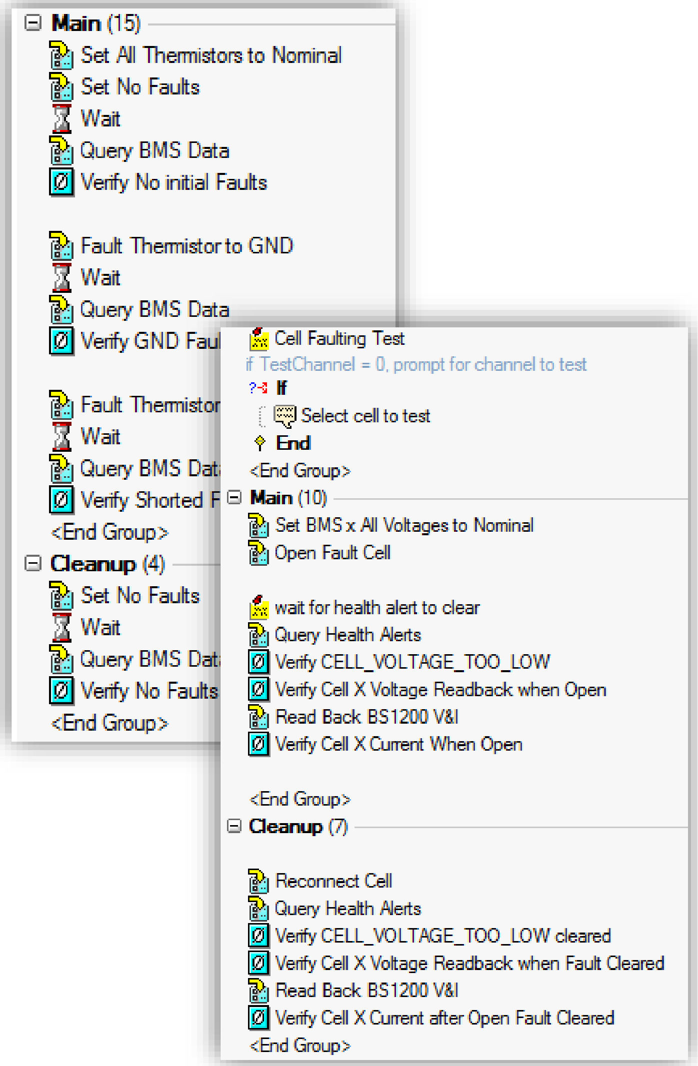
Pack Current Trip Test

- Set pack current over threshold
- Verify BMS contactor outputs
- Verify BMS response (status & meas)



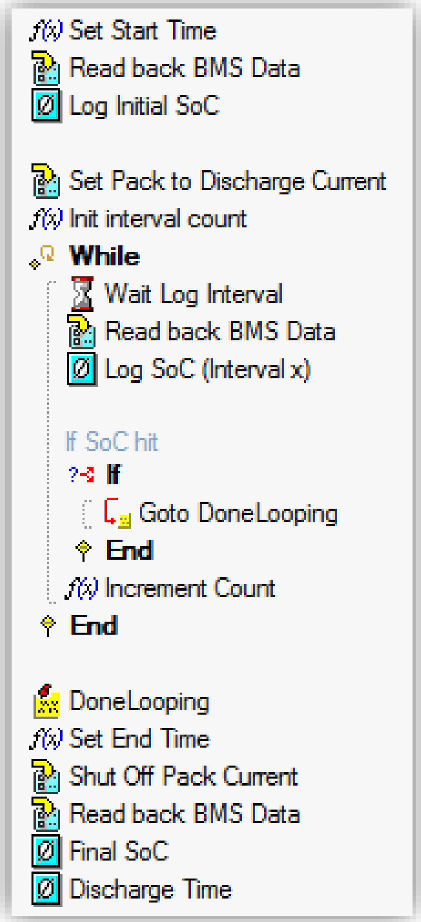


Fault Response Tests

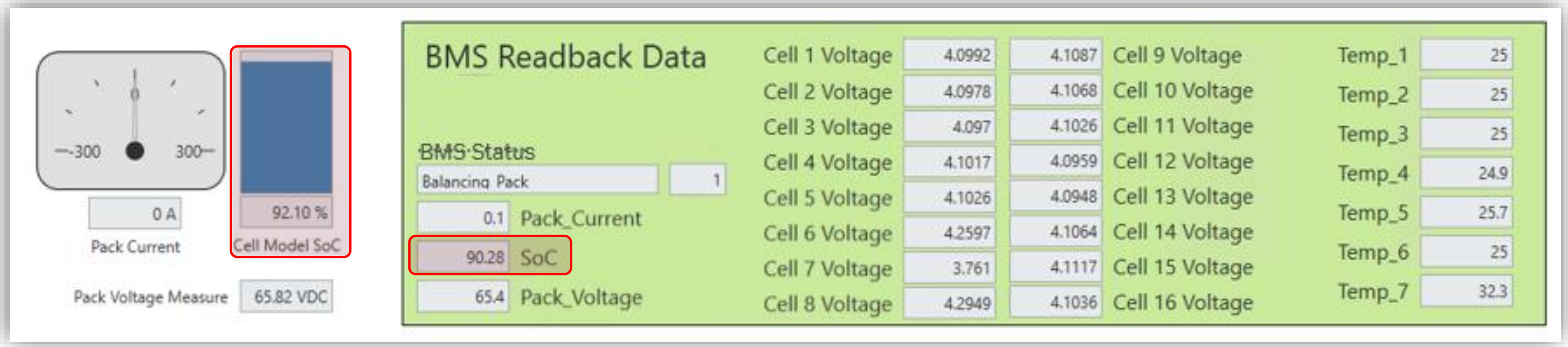


- Inject hardware faults
- Verify BMS response (status & meas)
- Verify contactor outputs
- Faults include:
  - Cell (open, short, short to rail/gnd)
  - Thermistor (open, short, short to rail/gnd)
  - Comms (bad data, short to rail/gnd)
  - Insulation resistance

Charge/Discharge Test

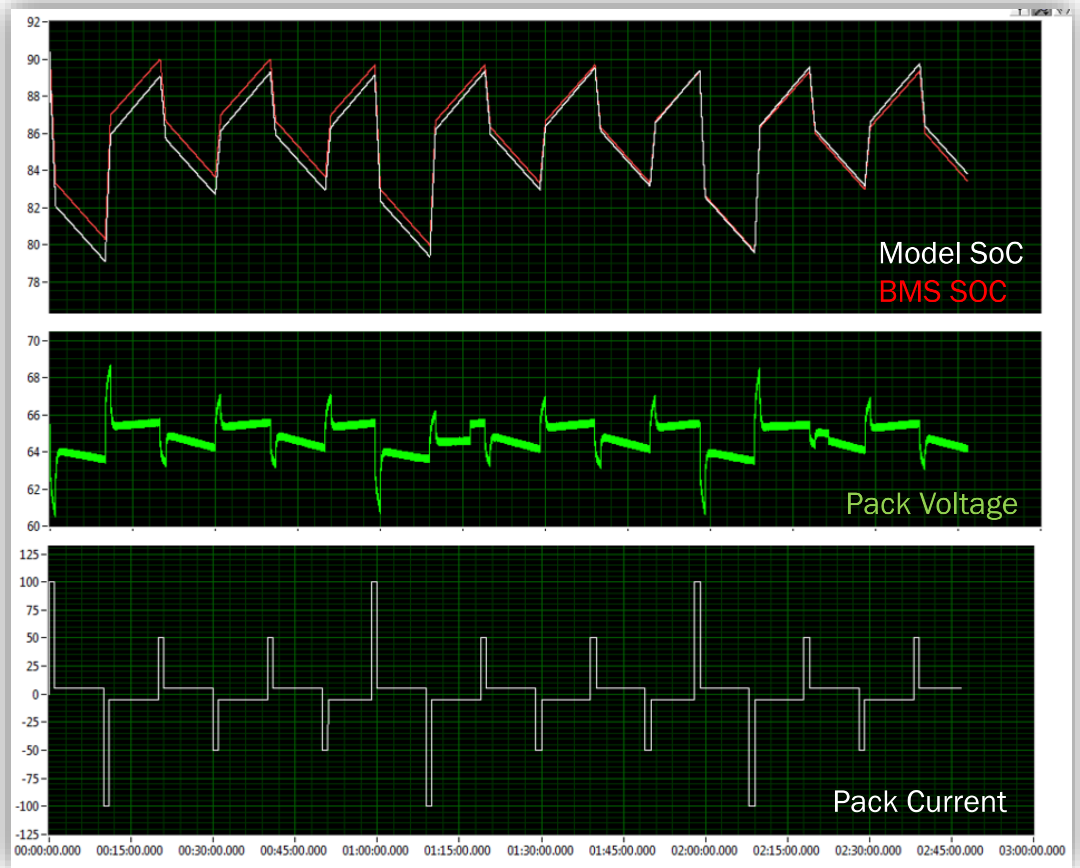


- Ideally with model in the loop
- Set pack current to 1C, 2C, 3C, etc
  - Discharge, then charge
- Monitor BMS from 95% → 5% → 95% SoC
- Compare against model/expected SoC
- Monitor BMS outputs and alarms



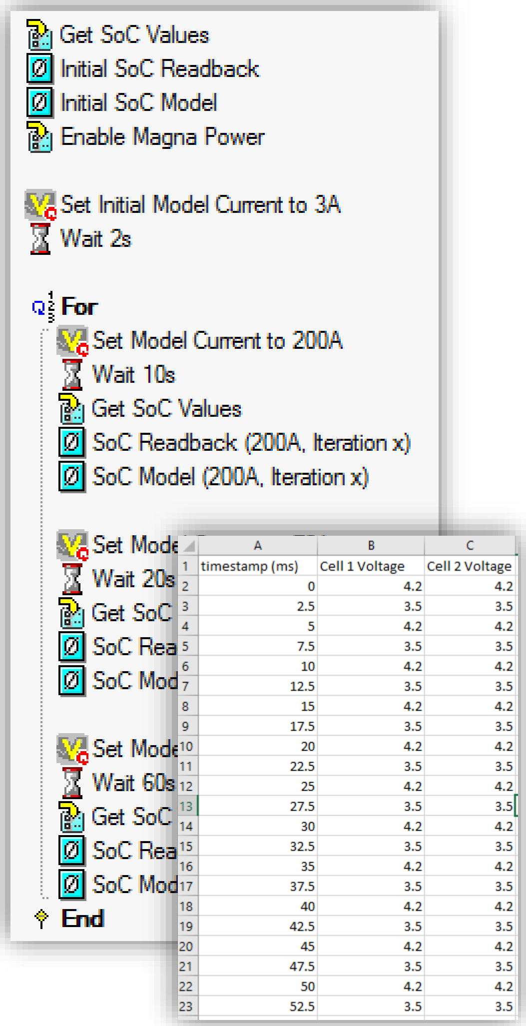
SoC Estimation Tuning

- Control pack current through drive cycle test
- Compare model output SoC with BMS algorithm

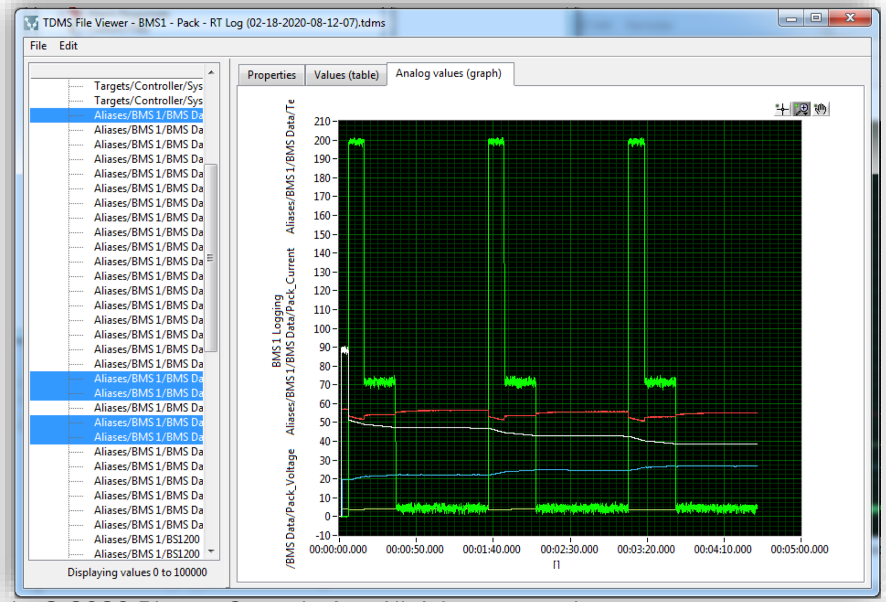


Drive Cycle Testing

- Real-time CSV or TestStand-based
- Model in the loop
- Control & log parameters, measurements, BMS response in real-time
- Verify BMS response to driving personas
- Playback of actual test track data



	A	B	C
1	timestamp (ms)	Cell 1 Voltage	Cell 2 Voltage
2	0	4.2	4.2
3	2.5	3.5	3.5
4	5	4.2	4.2
5	7.5	3.5	3.5
6	10	4.2	4.2
7	12.5	3.5	3.5
8	15	4.2	4.2
9	17.5	3.5	3.5
10	20	4.2	4.2
11	22.5	3.5	3.5
12	25	4.2	4.2
13	27.5	3.5	3.5
14	30	4.2	4.2
15	32.5	3.5	3.5
16	35	4.2	4.2
17	37.5	3.5	3.5
18	40	4.2	4.2
19	42.5	3.5	3.5
20	45	4.2	4.2
21	47.5	3.5	3.5
22	50	4.2	4.2
23	52.5	3.5	3.5



BMS HIL CASE STUDIES

LG xEV BMS SOFTWARE VALIDATION

LG Chem Power Inc.

- Proprietary BMS software algorithms developed, tested, validated by LG

- Simulate a wide range of battery systems
  - 500V packs for EV
  - 200-300V full hybrid, PHEV
  - 48-200V micro, mild hybrids
  - 12V start-stop systems

- Able to reconfigure HIL simulator for different xEV programs without new capital appropriations

JAGUAR LAND ROVER

- Evaluated 3 cell chemistries
- Validated 4 BMS architectures
- Accelerated firmware validation from more than 1 month to less than 1 week

"Major BMS firmware releases can now be rolled out within one week with good confidence of success, whereas similar projects in the past used to take well over a month, and with substantially less confidence."
Miguel Angel Gama-Valdez, Principle Engineer, Jaguar Land Rover

- Download whitepaper

https://www.bloomy.com/support/resources/white-paper/bms-hil-test-system-helps-jaguar-land-rover-shorten-time-market-hybrid

SUMMARY

Battery Management System HIL Testing

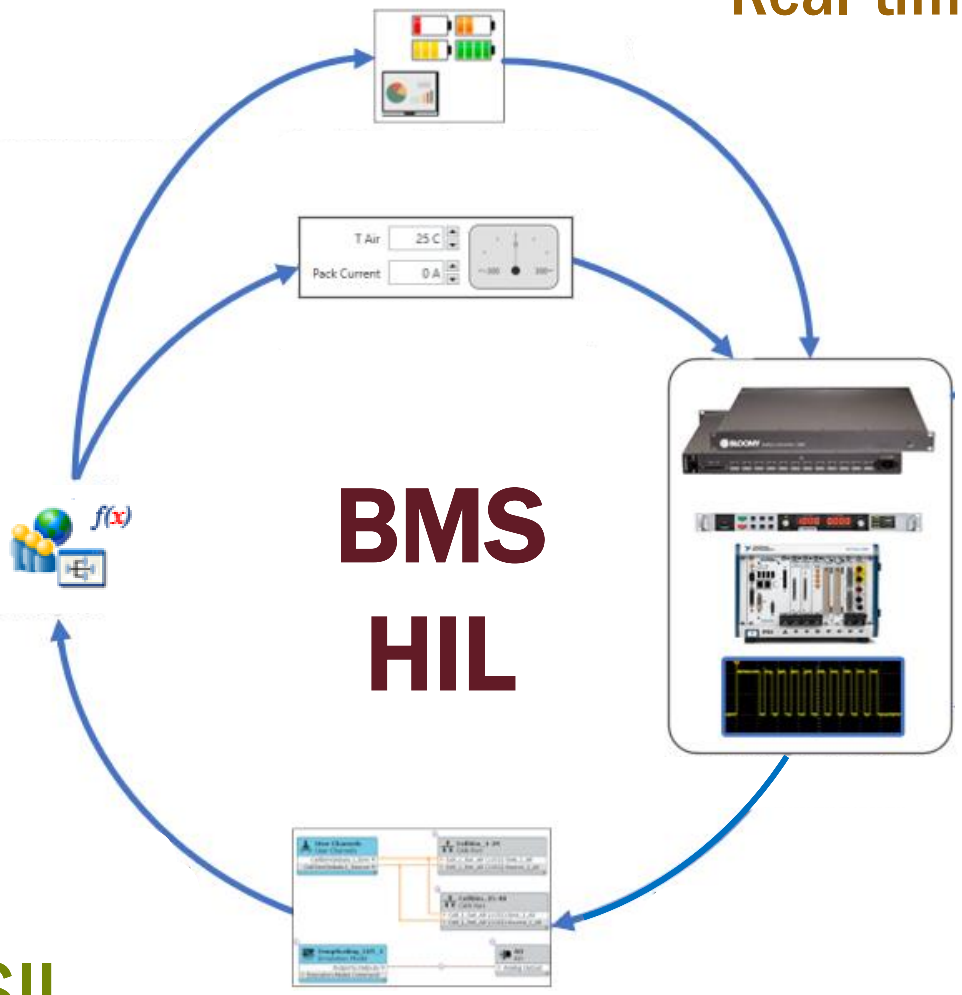
Safety

Repeatable

Eliminate defects

Time to market

ASIL



Real-time

Throughput

Coverage

Extremes

Tune Algorithms

Reduce cost

MORE INFORMATION

Grant Gothing

grant.gothing@bloomy.com

Peter Blume

peter.blume@bloomy.com

www.bloomy.com