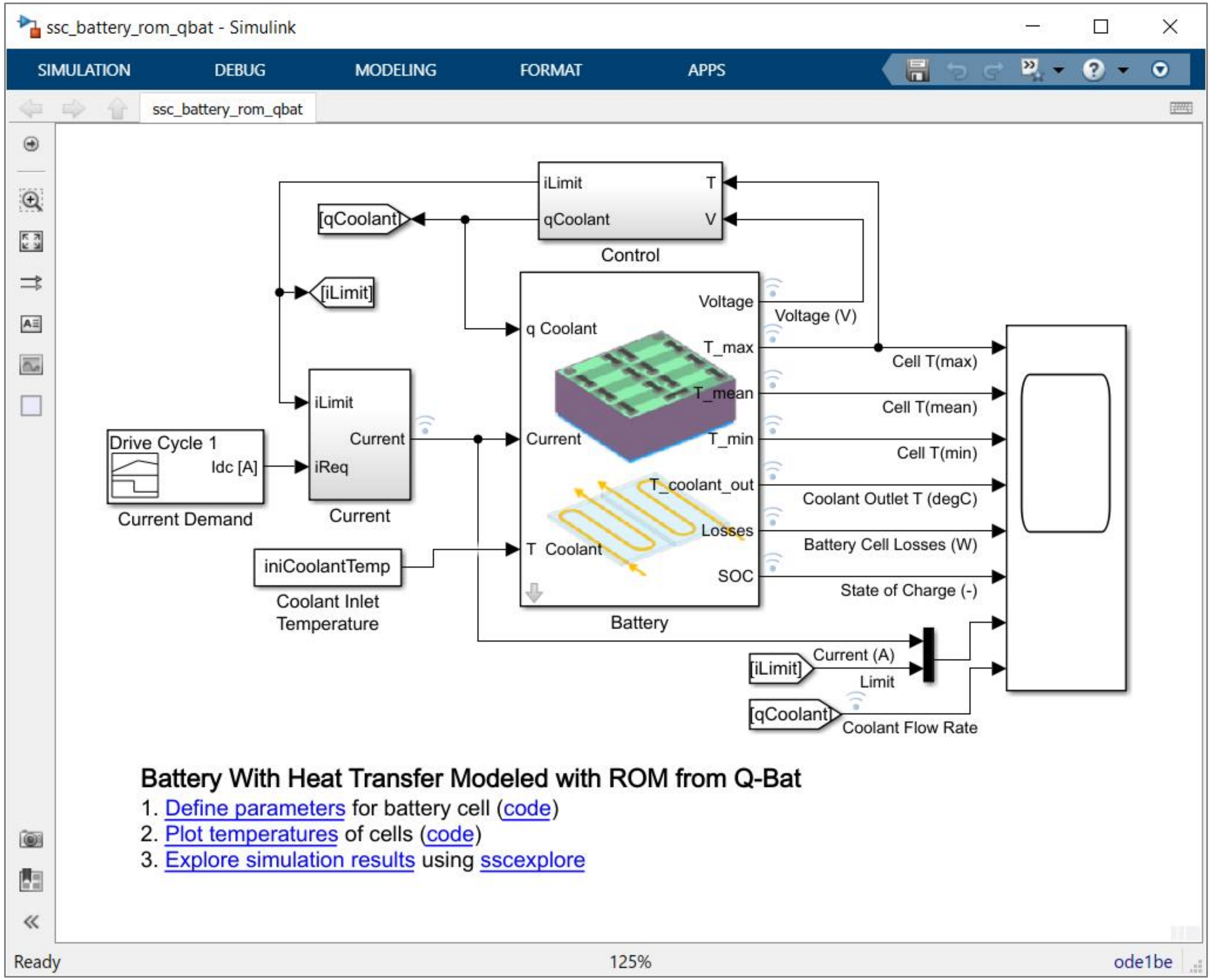
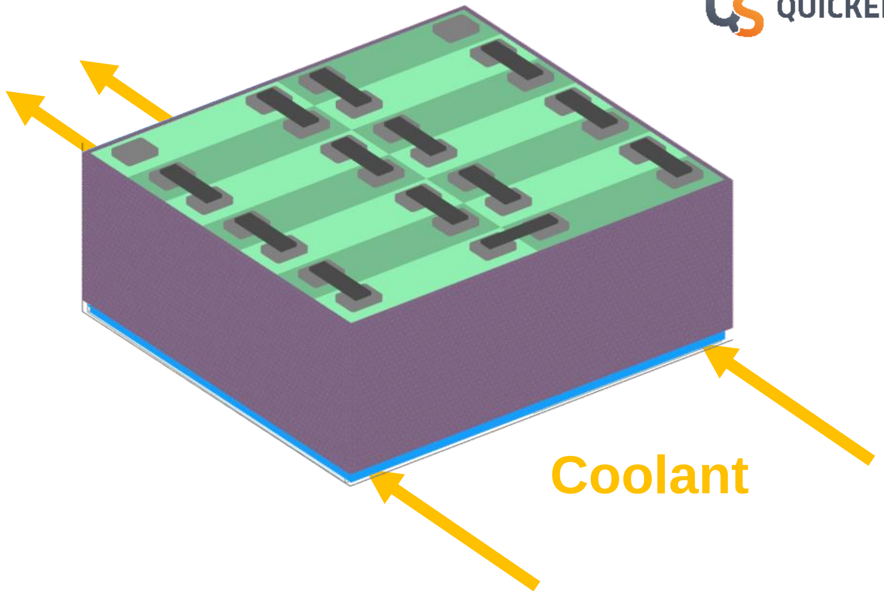
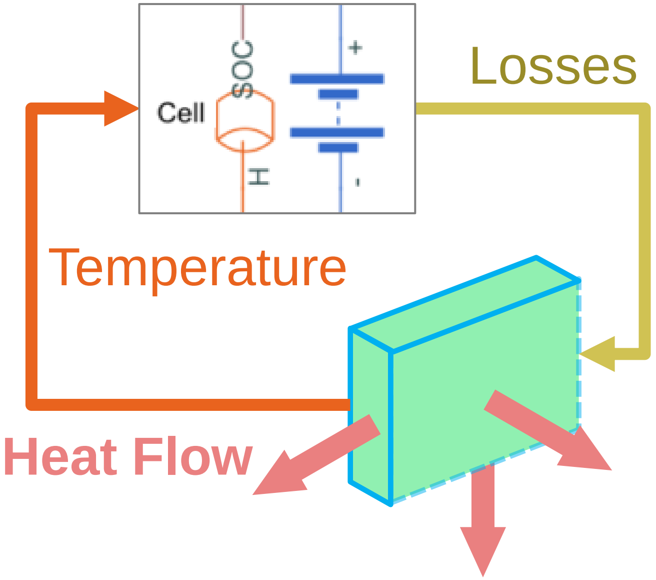
Overview of Model



Electrothermal Integration

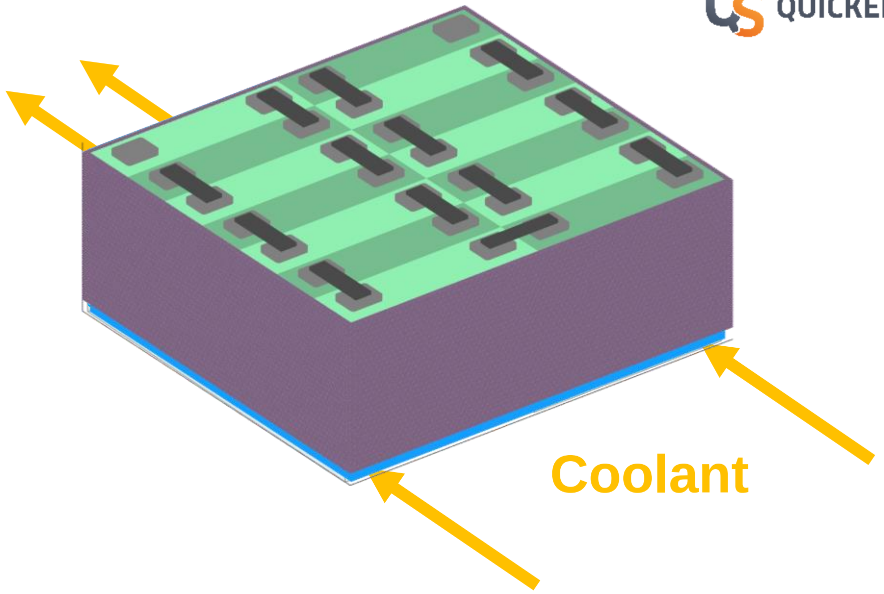
- Electrical model
  - Calculates losses per cell in electrical model
  - Losses determine heat generation in thermal model
- Thermal model
  - Heat generated uniformly across cell volume
  - Mean cell temperature determines electrical behavior
- Boundary conditions
  - Battery is surrounded by perfect insulator
  - Heat leaves system only via coolant in coolant channel

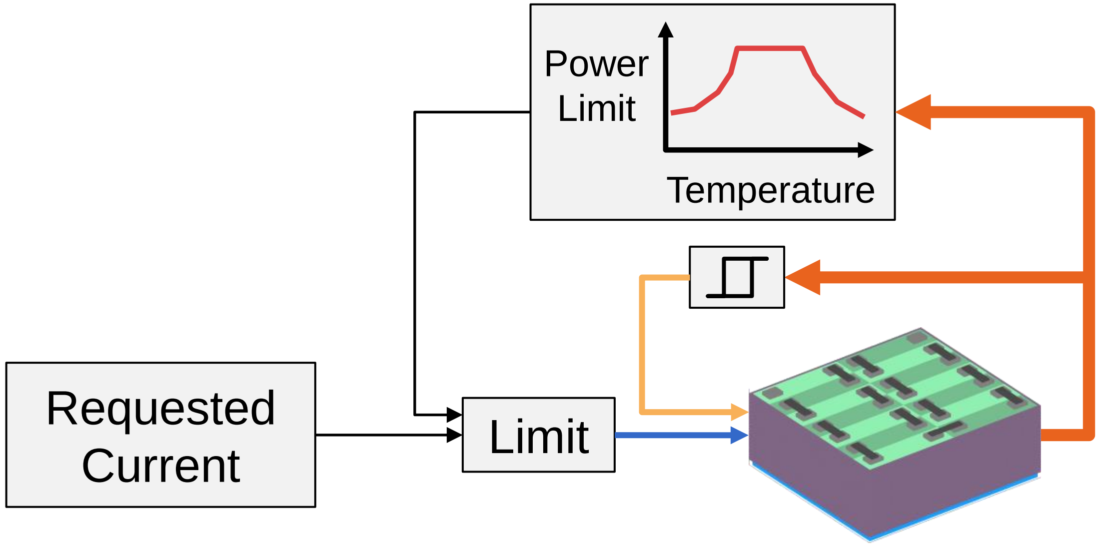


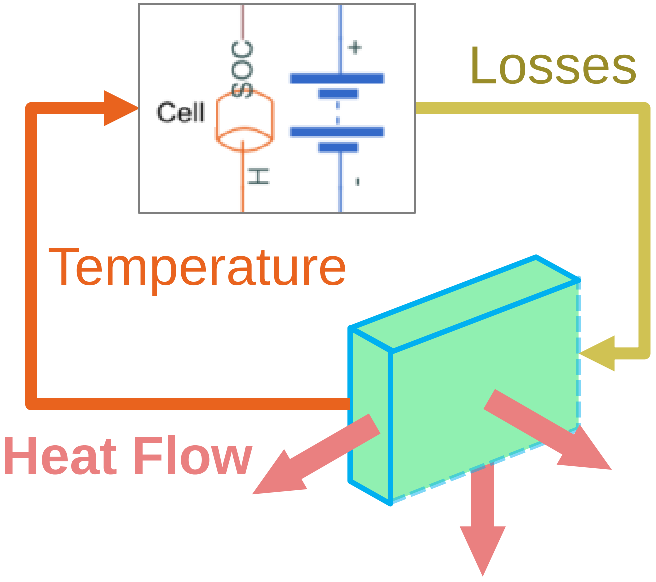


Electrothermal Controls

- Keep battery in desired temperature range
  - Derating: Limit battery power
  - Active cooling: Increase coolant flow

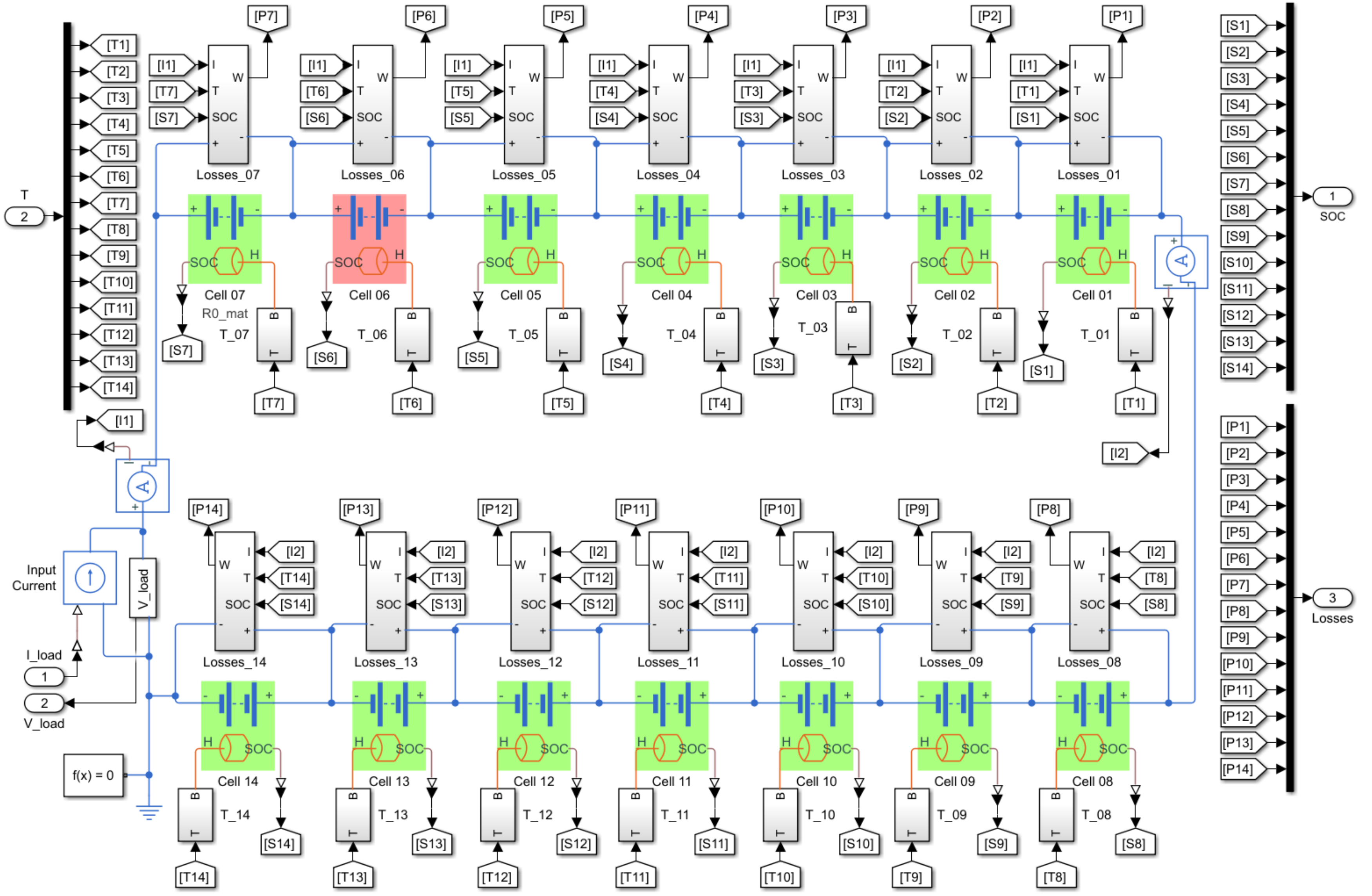






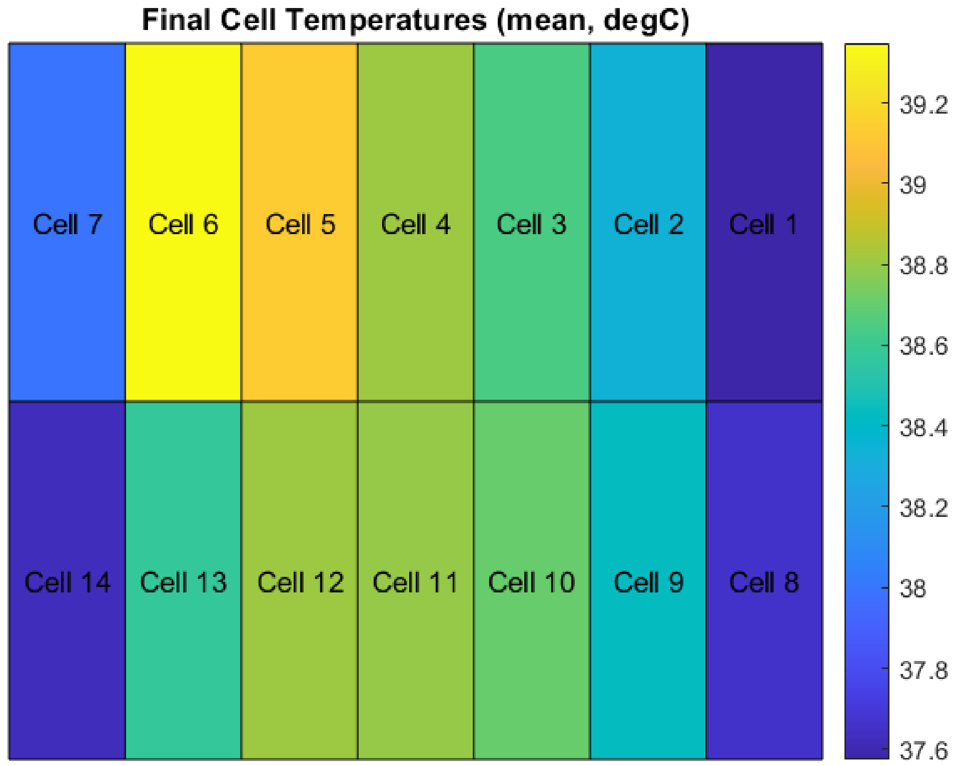
Electrical Model

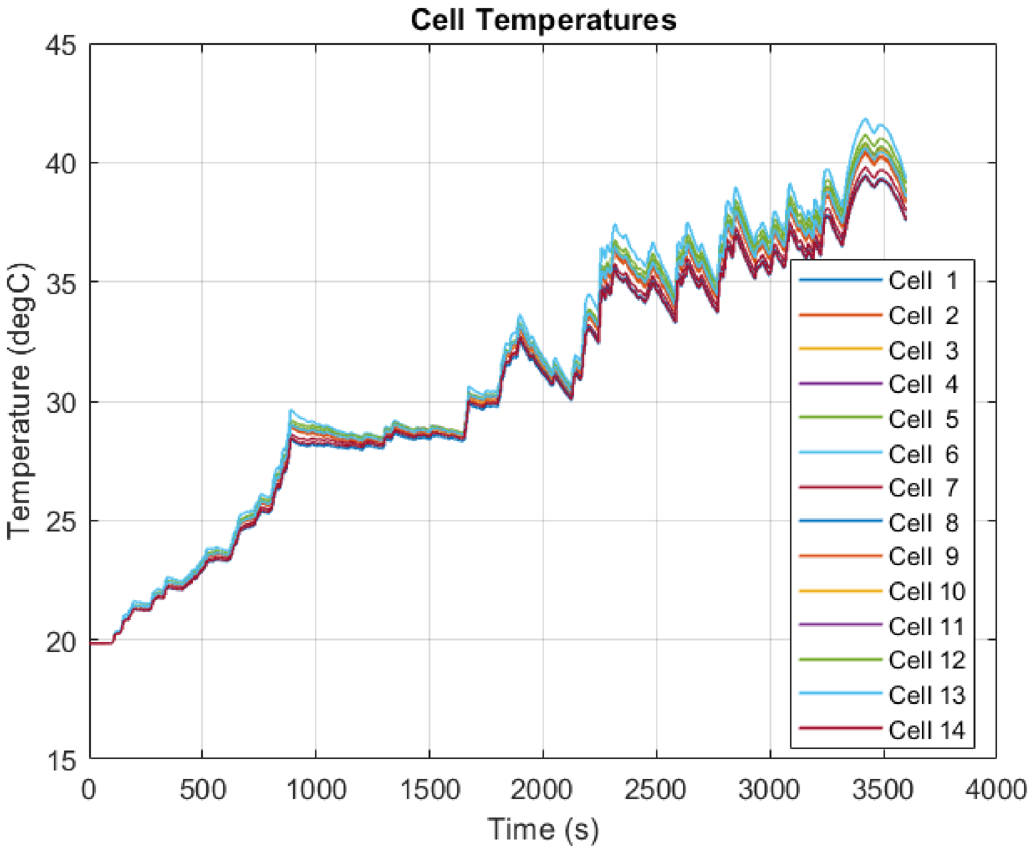
- 14 cells in series
- Temperature dependent behavior
- Losses calculated and passed to thermal model
- Degraded cells can be modeled



Simulation Results

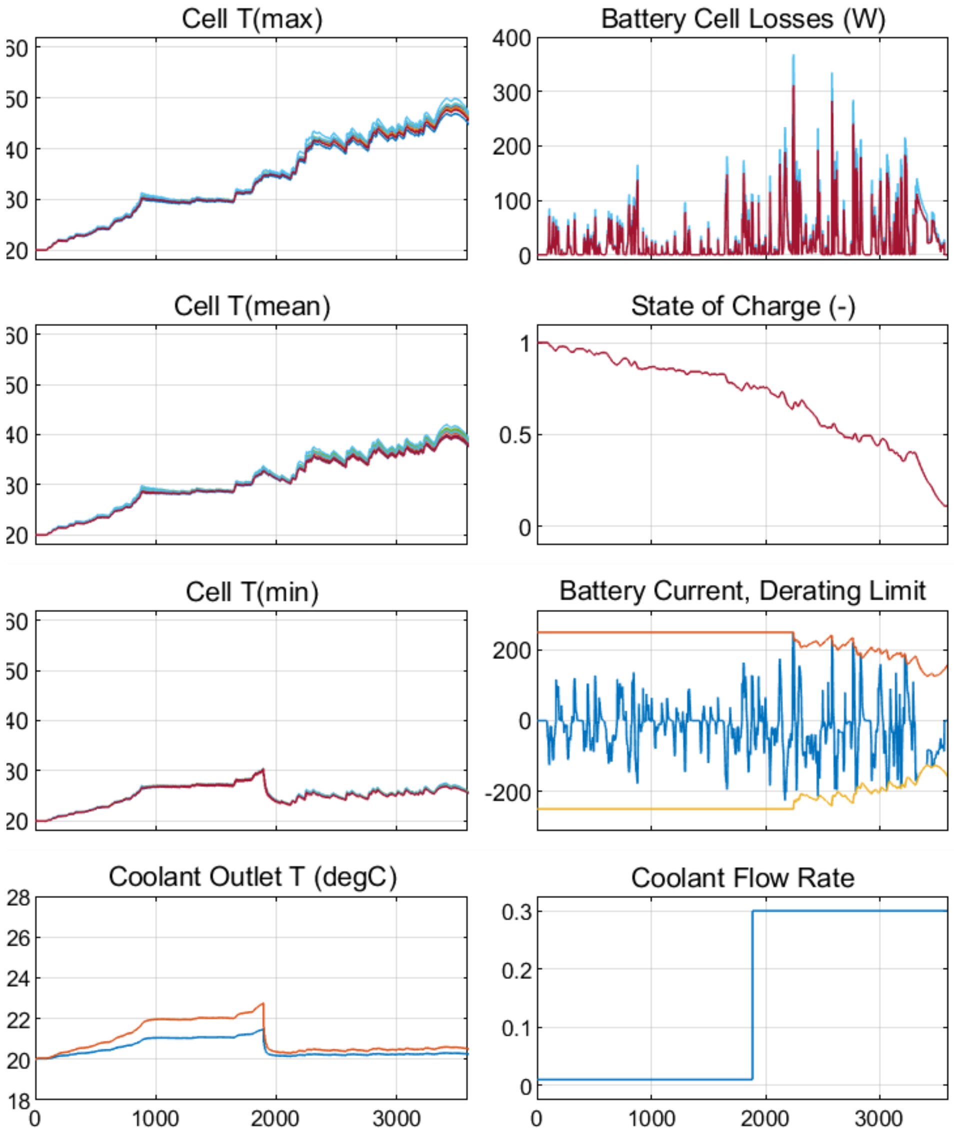
- Mean temperature of cells
  - Cell 6 is degraded





Simulation Results

- Basic control logic
  - Derating: reduces current demand as battery reaches high temperatures
  - Coolant flow rate is increased as battery reaches high temperatures

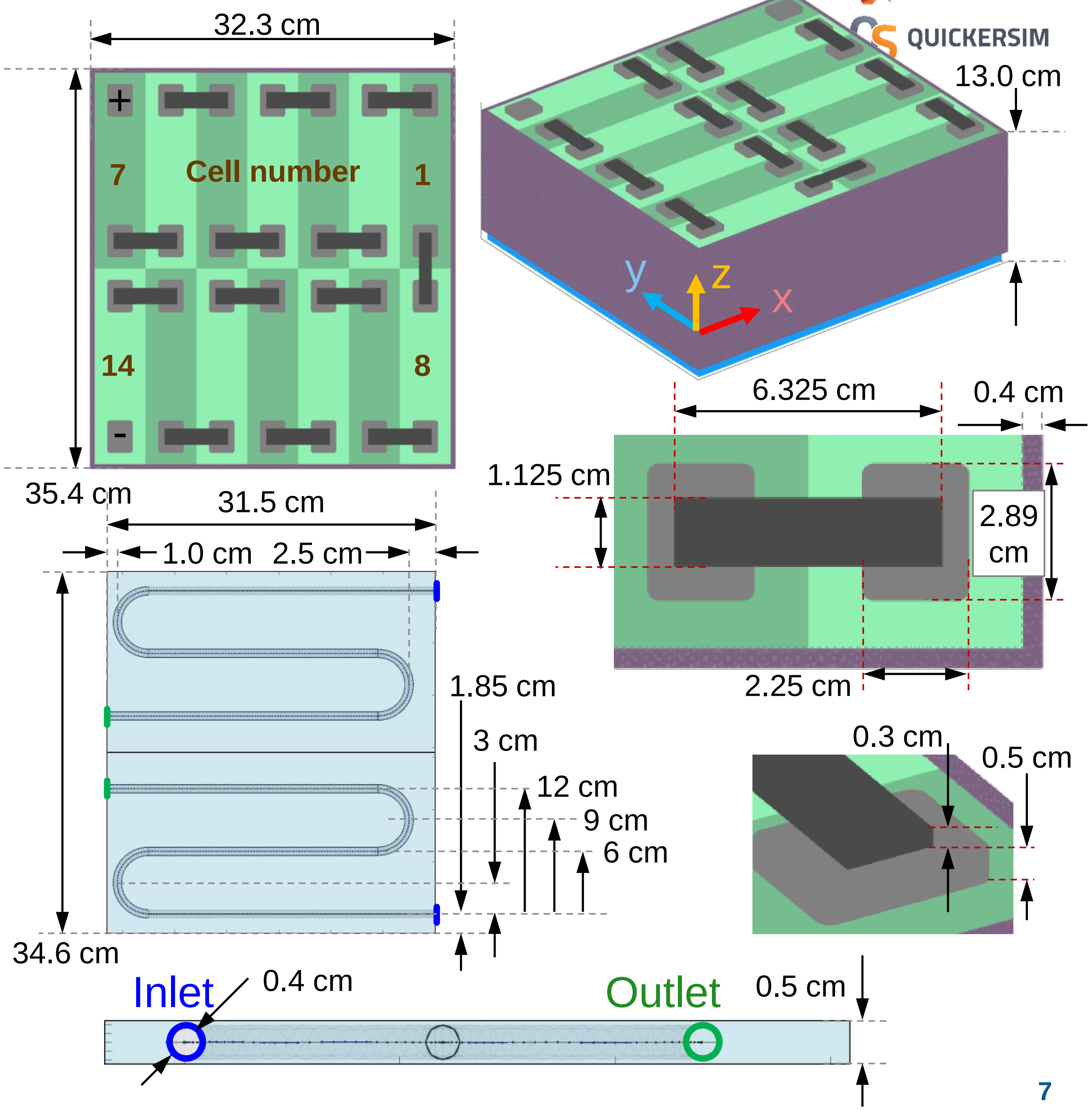


Battery Dimensions

Part	Material	rho	λ_x	λ_y	λ_z	cp
Casing	Aluminum	2690	238	238	238	901
Cell		2670	12	3	14	500
Plate	Aluminum	2690	238	238	238	901
Tabs	Copper	883	397	397	397	448
Terminal	Copper	883	397	397	397	448

Coolant water glycol

T	rho	Cp	λ	nu	mi
-40	1108	3040	0.416	1.00E-04	1.11E-01
-20	1100	3110	0.409	2.50E-05	2.75E-02
0	1092	3190	0.405	9.50E-06	1.04E-02
20	1082	3260	0.402	4.50E-06	4.87E-03
40	1069	3340	0.398	2.40E-06	2.57E-03
60	1057	3410	0.394	1.50E-06	1.59E-03
80	1045	3490	0.390	1.00E-06	1.05E-03
100	1032	3560	0.385	7.00E-07	7.22E-04



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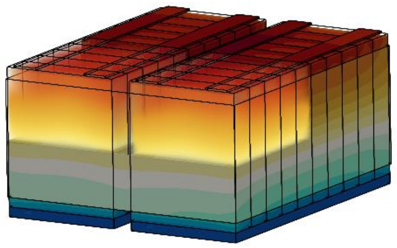

- Simscape™ is used to model the electrical behavior in this example. Simscape enables you to rapidly create models of physical systems within the Simulink® environment and leverages MATLAB® technology.
  - Multidomain Schematics
  - Comprehensive Libraries
  - Intuitive Modeling Language
  - Efficient Simulation

- To learn more:
  - Electrical modelling: https://www.mathworks.com/products/simscape-electrical.html

- For a free trial license, visit MathWorks website https://www.mathworks.com/campaigns/products/trials.html

- Q-Bat is a MATLAB-based product for real-time battery thermal simulation in 3D with CFD-like accuracy. Its main features are:
  - Near real-time execution
  - Accurate 3D data of battery temperature distribution
  - The capability of exporting the model to the Simulink
  - Fast model definition via dedicated GUI and TUI.

- To learn more:
  - QuickerSim https://emobility.quickersim.com/
  - Q-Bat product page https://www.mathworks.com/products/connections/product_detail/quickersim-q-bat.html

- For a free Q-Bat lite license, visit QuickerSim licensing website https://licensing.quickersim.com/