# Battery Modelling for Future HEV and EV Product Development

Mike Dempsey

Managing Director

Claytex Services Limited

Software, Consultancy, Training

- Based in Leamington Spa, UK
  - Office in Cape Town, South Africa
- Experts in Systems Engineering, Modelling and Simulation
- Business Activities
  - Engineering consultancy
  - Software sales and support
  - Modelica library developers
  - FMI tool developers
  - Training services
    - Dassault Systemes Certified Education Partner
- Global customer base
 - Europe, USA, India, South Korea, Japan
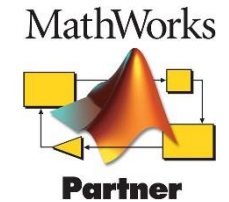
Multi-domain physical modelling to enable whole vehicle simulation

- Multi-domain physical modelling
  - Automotive products are complex systems covering many domains
    - Mechanical, Electrical, Hydraulic, Pneumatic, Thermal, Chemical, Control, Magnetic, …
  - No longer sensible to wait for prototypes to verify that all these systems interact in a good way
  - Consider all vehicle systems and how they interact with each other and the occupants
  - Need to use predictive models and not just functional ones to be able to start using simulation before a design is fixed

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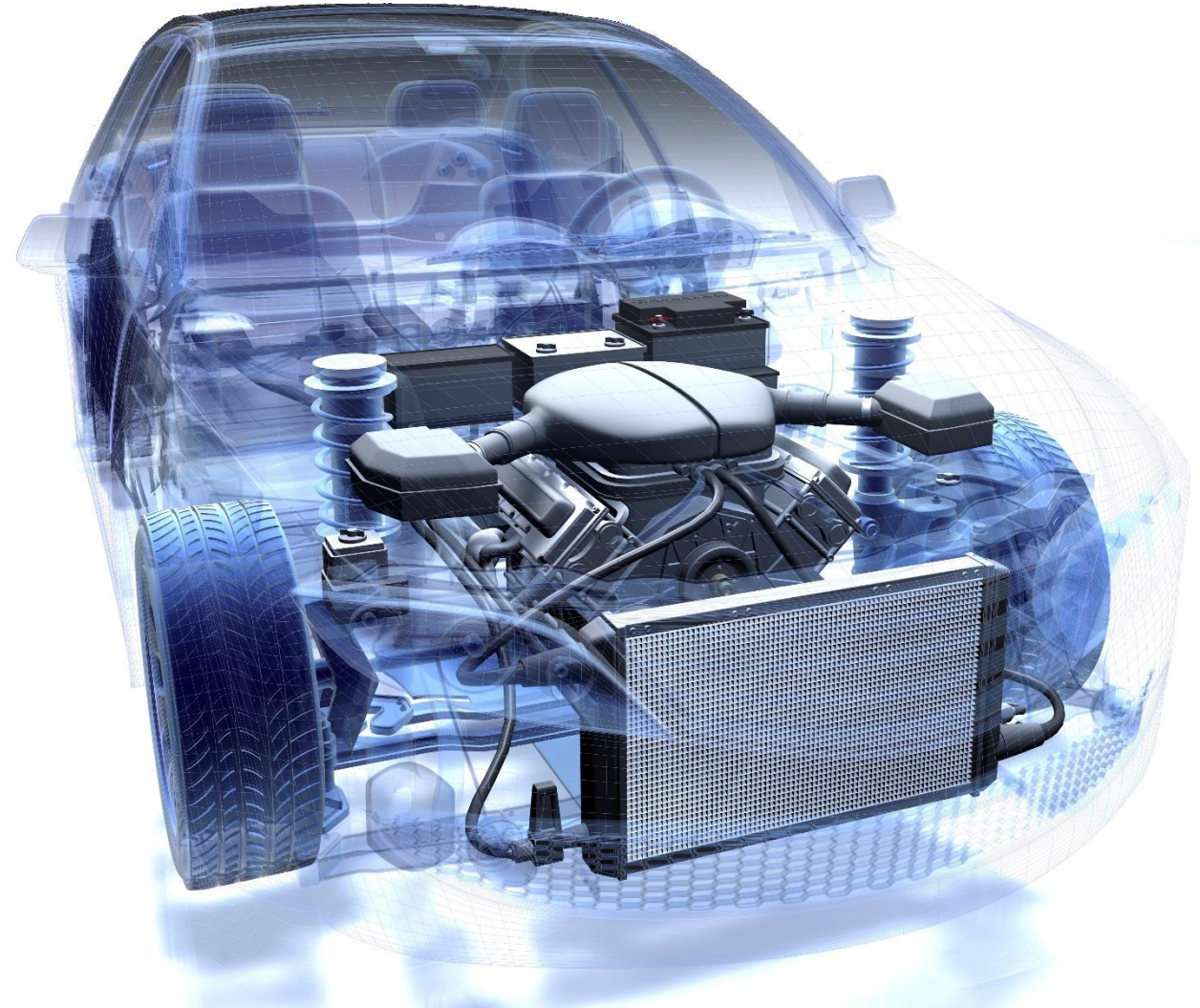
Functional and Predictive models

- A Functional model is one that captures the key function of the model

- A Predictive model allows us to predict the behaviour and explore it's characteristics
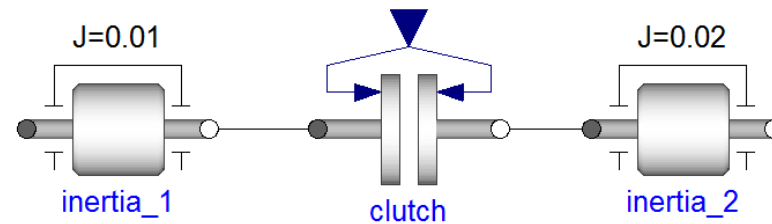
- The clutch is there to make sure the two inertias rotate at the same speed when engaged

- Functional model
  - Would reduce the relative speed across the clutch in a predefined manner
  - The controlling parameter would be the engagement time

- Predictive model
  - Would include a model for friction and the torque transfer would be a function of the clutch clamp load, relative speed, temperature, …
  - The parameters would include the geometry and friction characteristics
  - The engagement time could be predicted under different operating scenarios
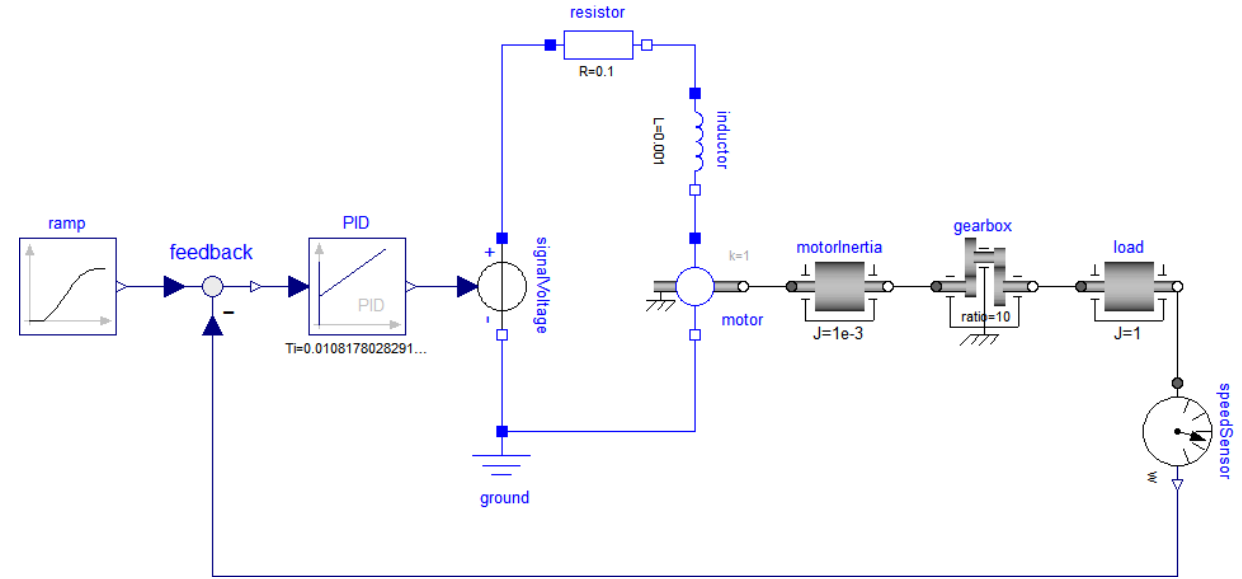
Battery Modelling

- Collaborative research project as part of the HVM Catapult with WMG and Jaguar Land Rover
  - 3 year project
- Aims to develop a Modelica library for modelling batteries from the cell level through to the complete battery pack based on research published by WMG and Jaguar Land Rover
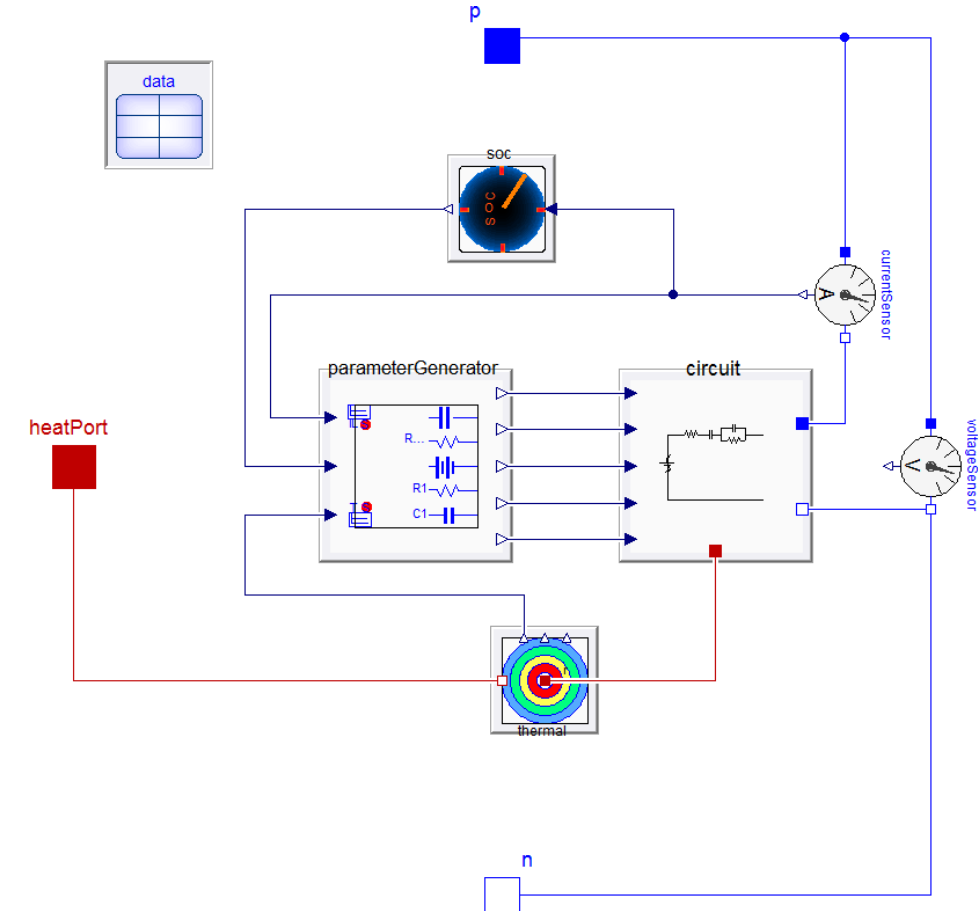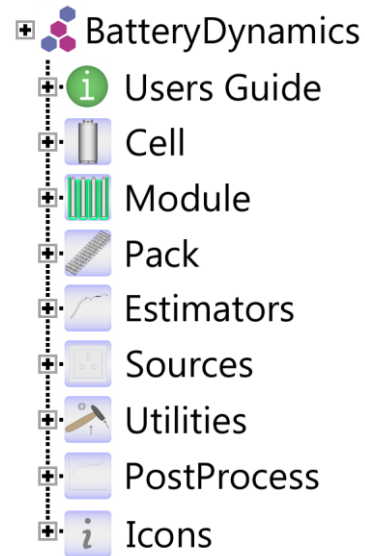
Multi-domain physical modelling

- Modelica
  - Open source, generic modelling language
  - Designed from the beginning to support a component orientated, physical modelling methodology
  - Developed by an independent, international organisation called the Modelica Association
    - Formed in 1996
- Dymola
  - Modelling and Simulation tool that uses Modelica
  - Extensive range of libraries built using Modelica covering all aspects of automotive products
  - Part of CATIA from Dassault Systemes and also available on the 3DEXPERIENCE platform

Modelling approach

- Modelica models are built from components that are defined from 1st principles
  - Modelica uses an equation based approach
  - Enables automated model code optimisation (_not tabularisation!_) through symbolic manipulation
    - Reduction in simulation time with no loss of accuracy
- The components are combined to define devices
  - Physical connections between components
- From devices and components we create subsystems
  - Often using templates that make it easy to swap the model fidelity
- From subsystems we create the whole vehicle model
  - Model architecture can be defined independently to promote reuse of subsystem models

```
model Inertia
  extends Interfaces.Rigid;
  parameter SI.Inertia J=1 "Moment of Inertia";
  SI.AngularVelocity w "Angular velocity";
  SI.AngularAcceleration a "Angular acceleration";
equation
  w = der(phi);
  a = der(w);
  flange_a.tau + flange_b.tau = J * a;
end Inertia;
```
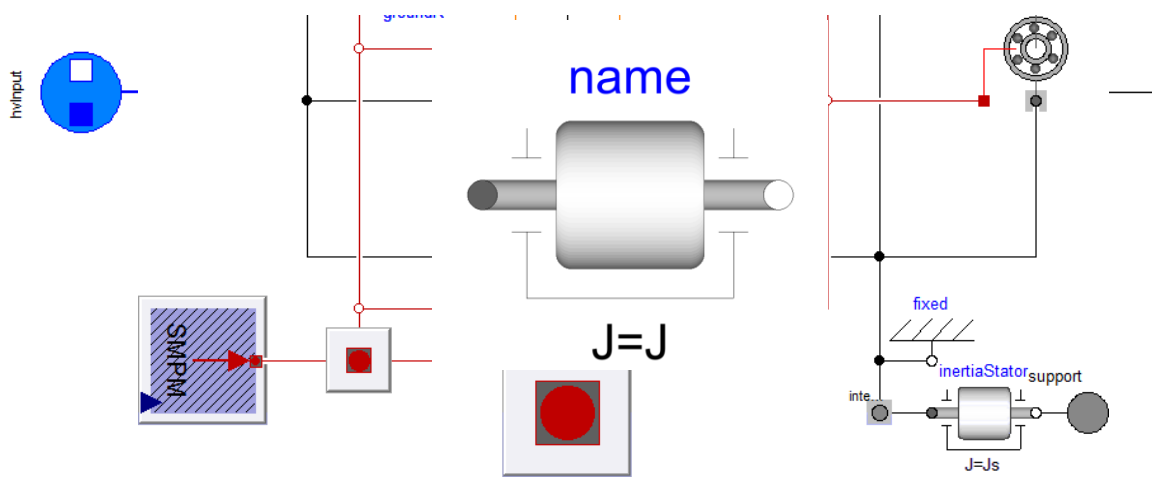
Model Reuse

- A physical modelling approach allows a high degree of model reuse
  - Same subsystem model, different types of analysis e.g. forward dynamic or inverse dynamic
  - Reuse the models in different system architectures
- Dymola supports plug-and-play changes in the subsystems to make it easy to configure the model for different tasks
  - Easily swap the power electronics between power balance and detailed switching models without changing any other parts
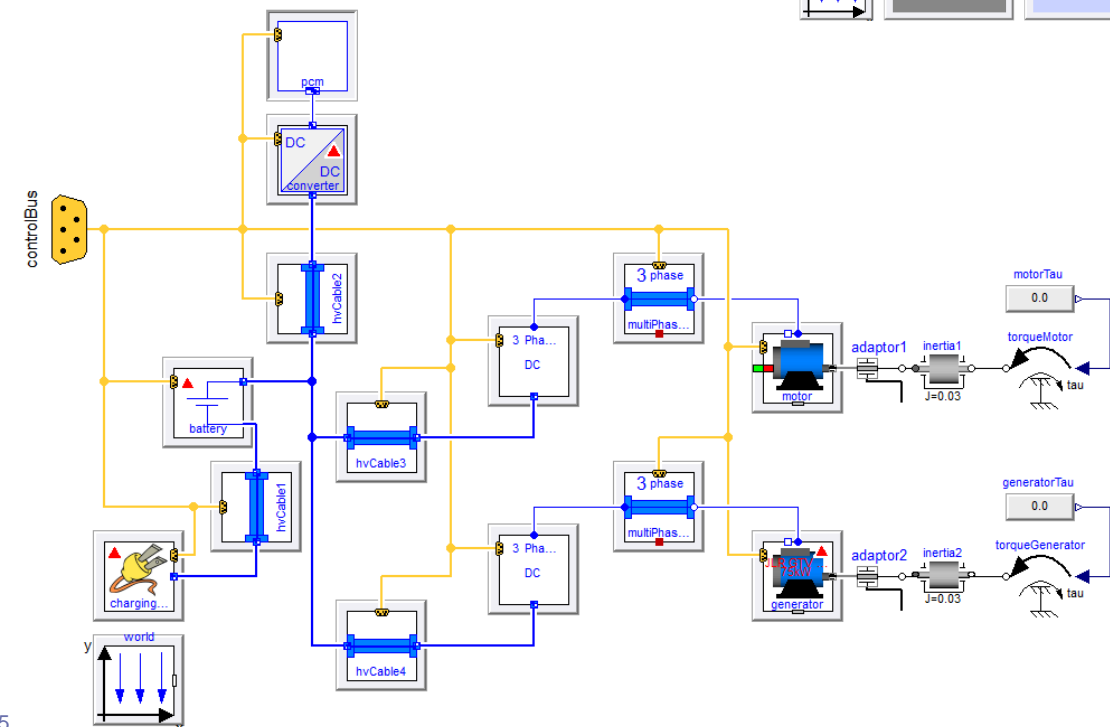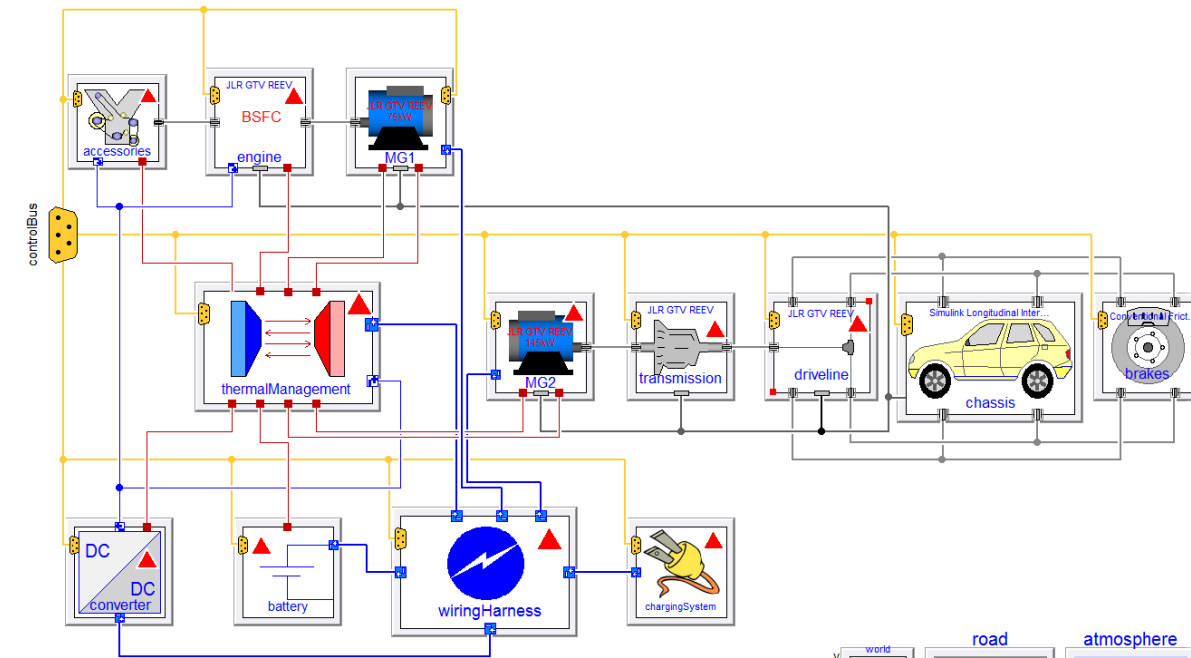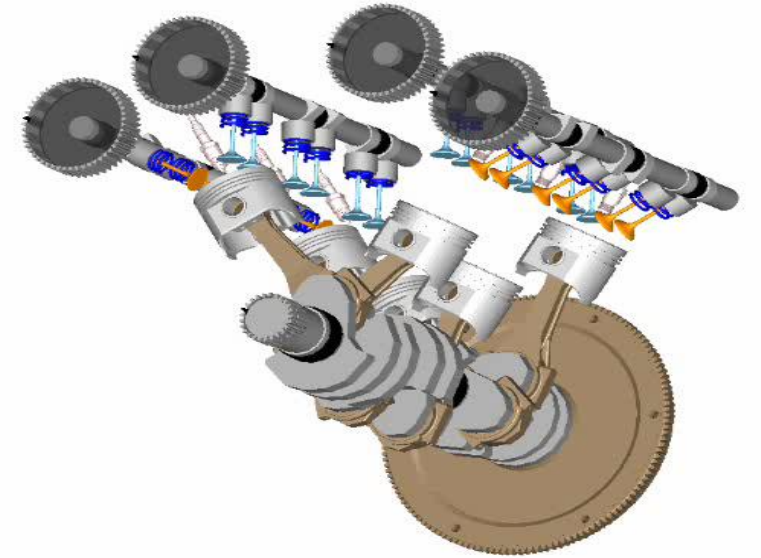
Automotive Application Libraries
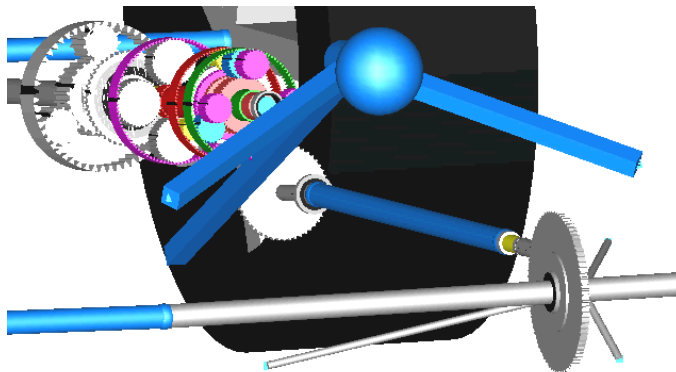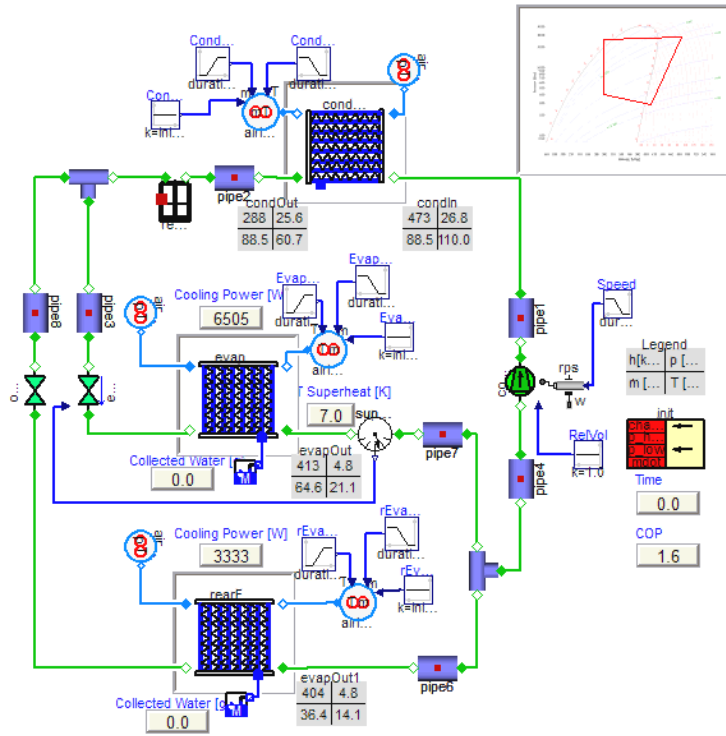
- Air Conditioning
- Belts
- Batteries
- Engines
- E-Drives
- FlexBody
- Fuel Cell
- Heat Exchanger
- Human Comfort
- Hydraulics
- Liquid Cooling
- Pneumatics
- Powertrain Dynamics
- Simulator
- Smart Electric Drives
- SystemID
- TIL Suite
- Vapor Cycle
- Vehicle Dynamics
- VDLMotorsports
- XMLReader

Cell modelling

- The cell models are equivalent electrical circuits with integrated thermal models
- Table based parameters are derived from cell tests
  - 2D and 3D look-up tables for temperature, current and state of charge
- Parameter estimation functions to define the cell models from test data capturing electrical, thermal and ageing effects
  - Automated procedures use optimisation routines to generate the tables that drive the model
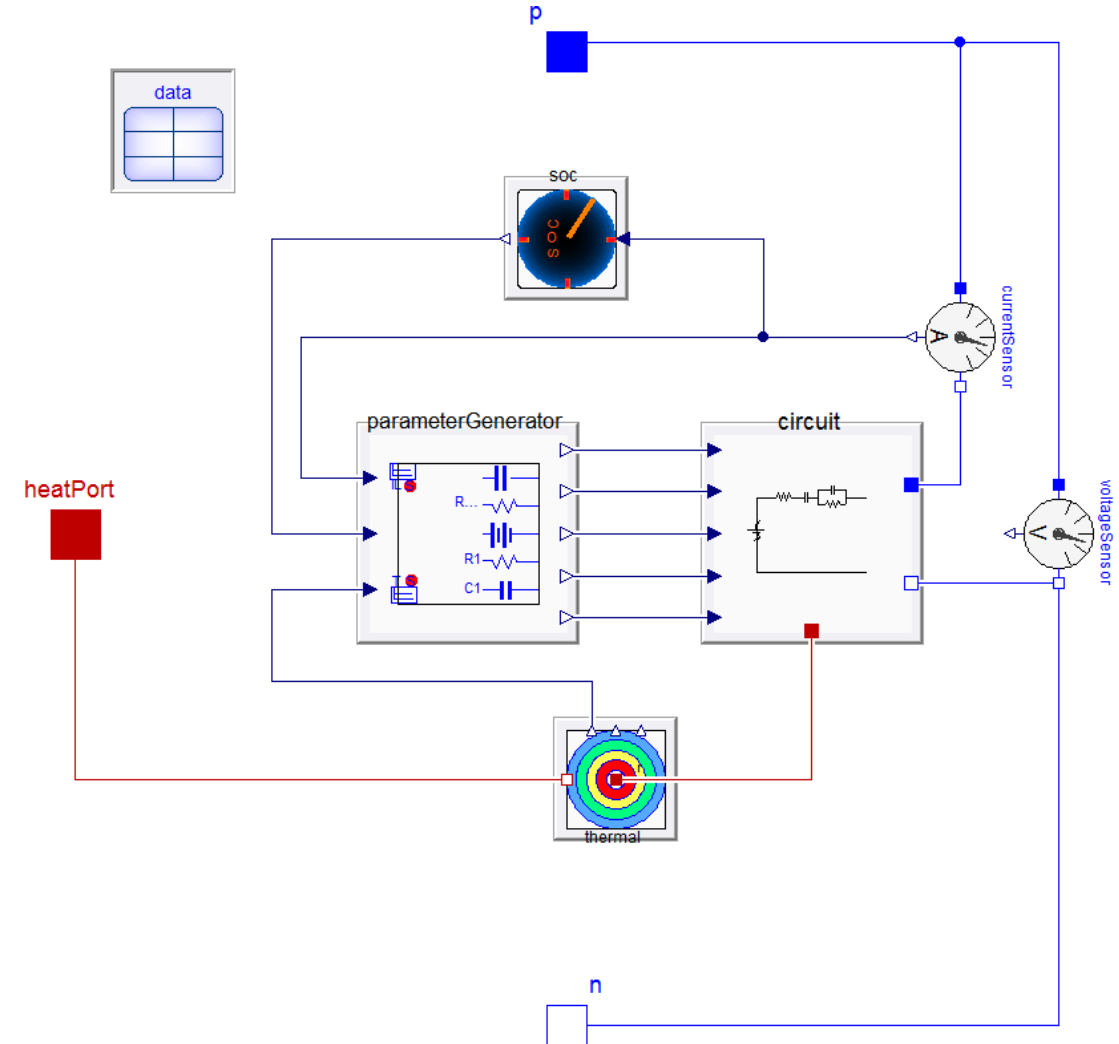
Cell model parameterisation and validation

- Several measurements are needed for parameterisation of the cell models
  - Capacity tests from full charge and discharge cycle
  - Open Circuit Voltage at a range of states-of-charge during charging and discharging
  - High power pulse characterisation tests
- Each test is used to tune different parameters in the electrical and thermal model
  - Plots compare the cell voltage during these tests
  - Blue is the measurement result and red is the cell model after calibration
- Separate validation tests are used to verify the cell model is behaving well

OCV Charging Test

OCV DischargingTest

HPPC Test

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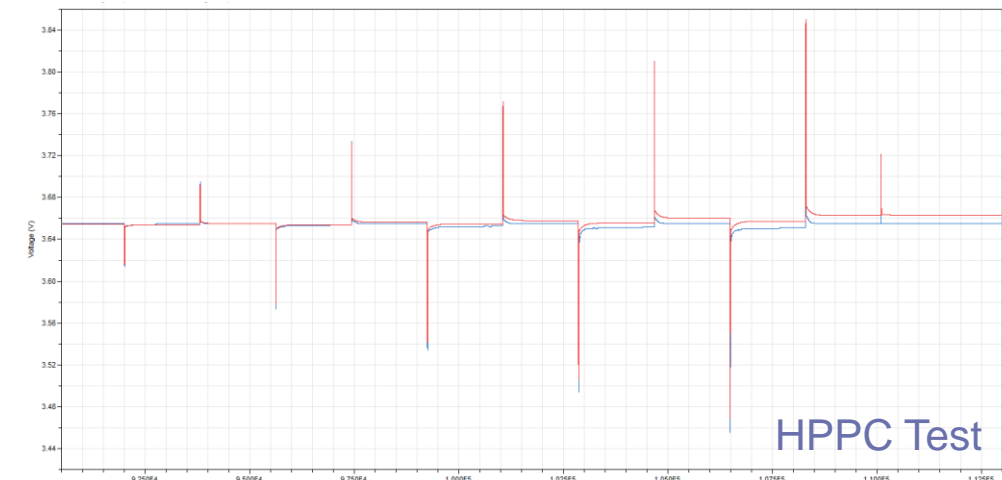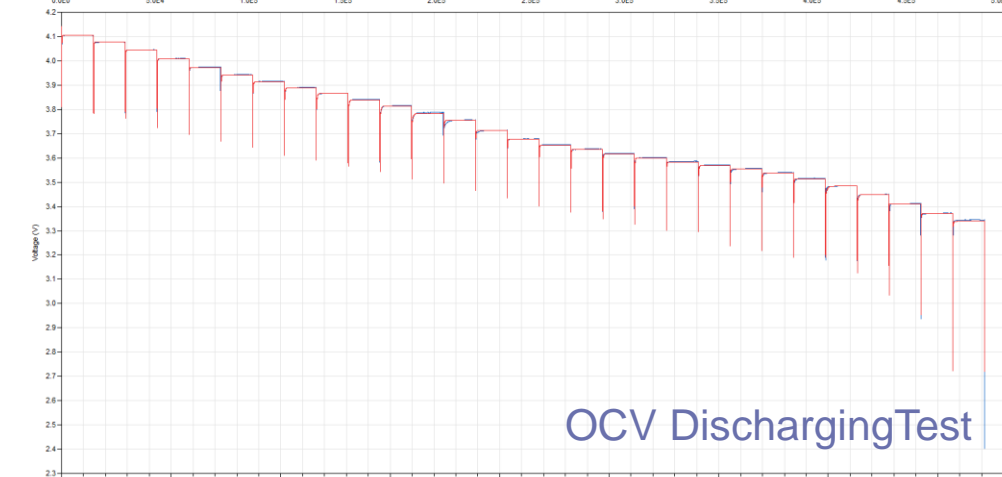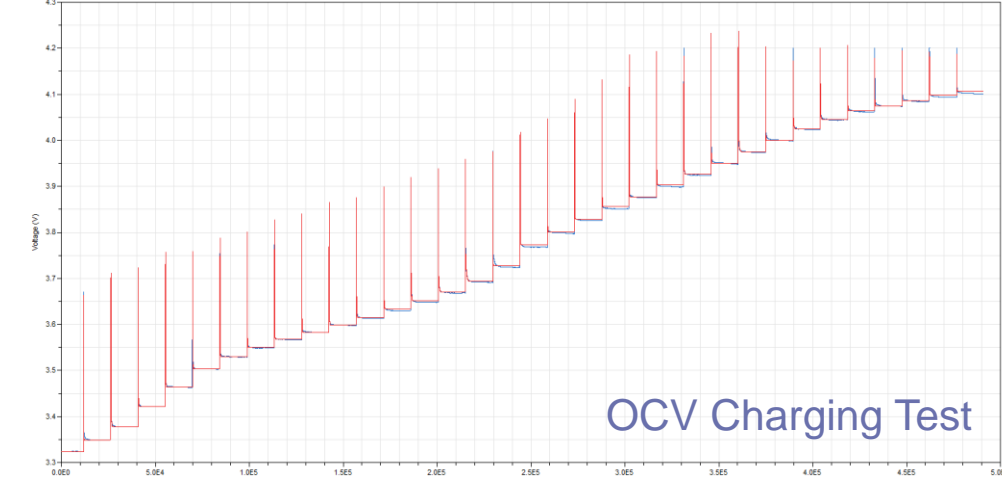
Pack and Module

- Modelica has a concept of component arrays that allows us to easily scale a single cell model to define a complete pack
  - Electrical connections do not have to follow geometric layout
  - Thermal connections between individual cells and cooling system
    - Can use 1D thermofluid cooling systems
- Cells can be identical or have variations in parameters
  - Supports investigation of effects related to under performing cells
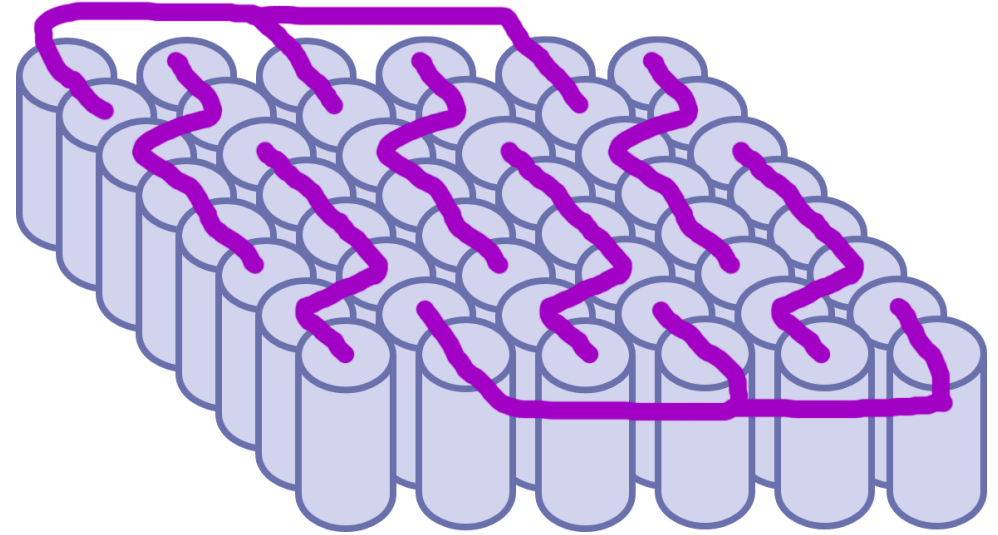
Integration into whole vehicle model

- Dymola is a multi-domain modelling and simulation tool making it possible to build a complete model of the vehicle
  - The model can include the mechanical, electrical, thermal, fluid and control aspects of the system
- Explore battery behaviour in the context of whole vehicle operation
  - Energy efficient operation
    - When to use the engine, motors
    - When to run the AC system
  - Whole vehicle thermal management
    - How to manage the waste heat from the engine, motors, batteries under different ambient conditions
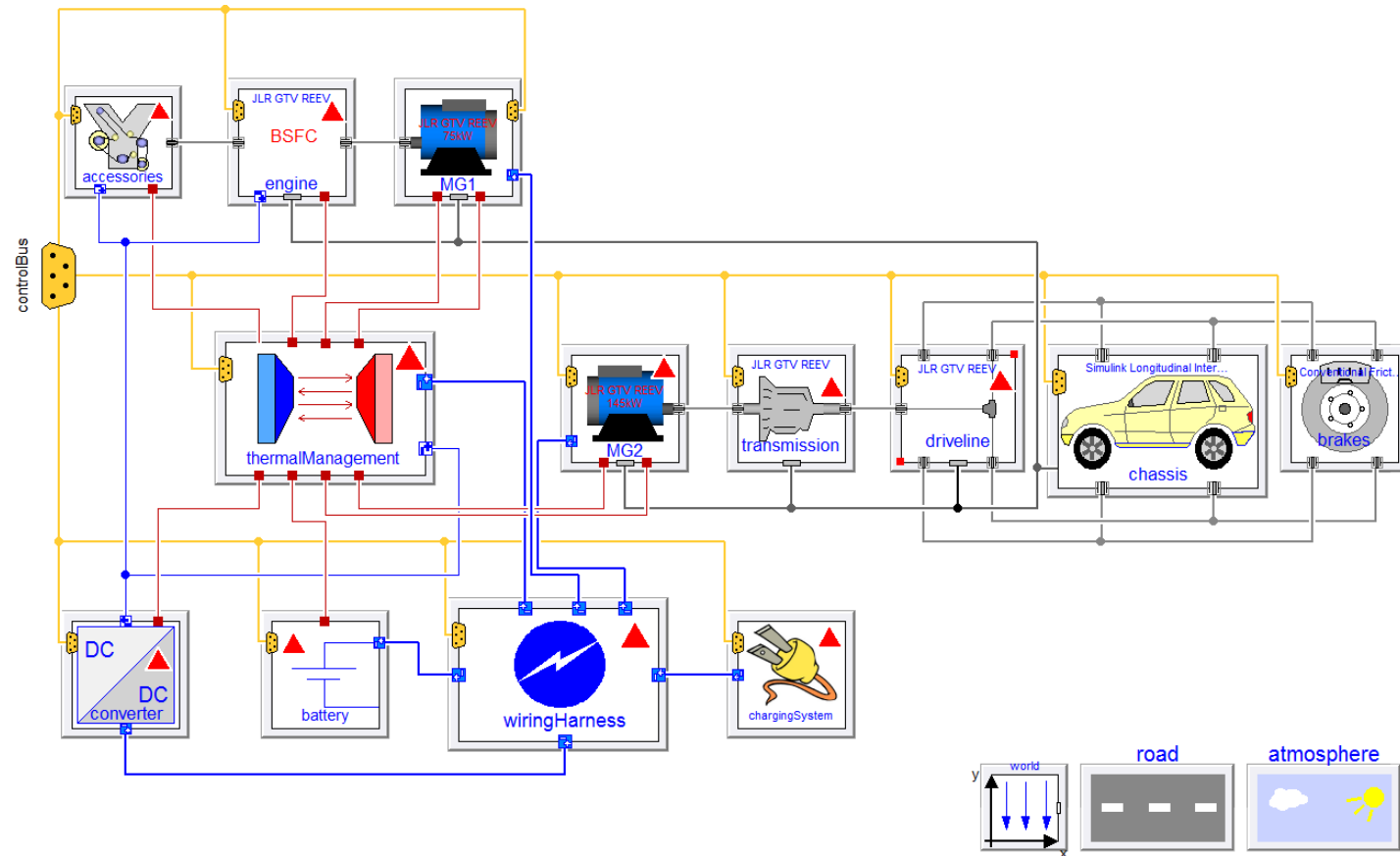
Benefits of physical modelling

- Models are built from first principles and are therefore predictive
- Powerful concepts for defining system architecture and then plugging in models of different fidelity to suit each analysis
- Modelling activities can start in the concept phase
  - Functional models can be used together with Predictive models for sizing studies and to make sure targets are compatible

- Dymola uses a component orientated approach based on Modelica
- Modelica is an open modelling language designed for modelling multi-domain systems
- The extensive range of libraries available for Dymola can model the whole vehicle
  - Provide an open and extendible base to start modelling your vehicle or subsystem

- Using Dymola and Modelica we can create models that include all the vehicle systems and we can optimise the behaviour of the whole system

Thank you

For more information visit our stand C2-32

Mike Dempsey

mike.dempsey@claytex.com

+44 1926 885900

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