

speedgoat

熠速



基于Simulink的虚拟车辆模型在HIL仿真测试中的应用

王传东，上海熠速信息技术有限公司



2022 MathWorks
中国汽车年会

About Speedgoat



- **MathWorks联营公司**，于2006年由MathWorks前员工成立
- 总部位于瑞士首都伯尔尼，分部门位于美国（Natick）和德国（Hannover）
- 致力于提供专门针对MATLAB/Simulink环境的实时系统
- 与MathWorks联合开发，与MATLAB无缝兼容

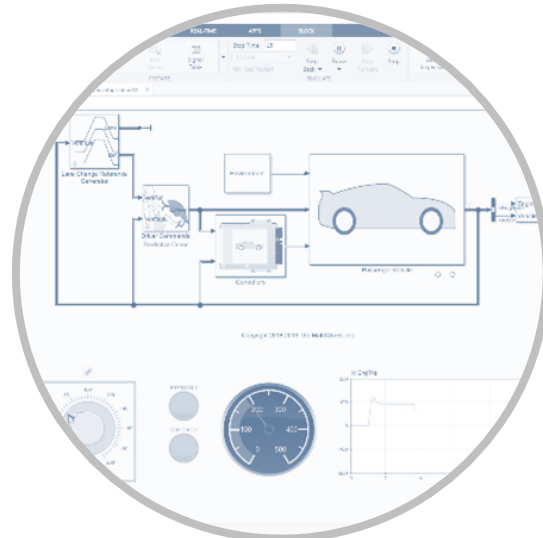


Part I



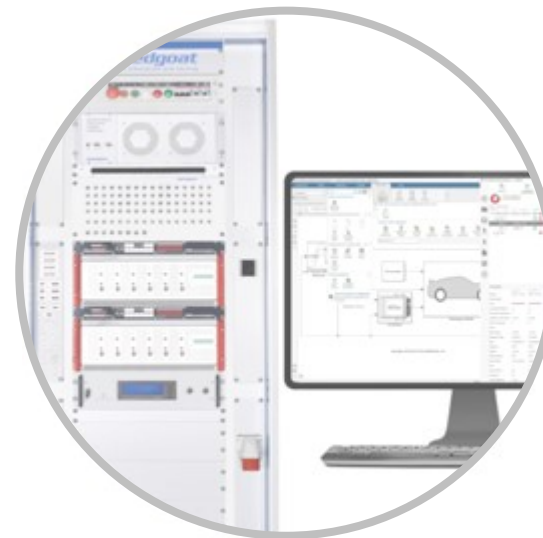
车辆HIL系统

Part II



虚拟车辆模型

Part III



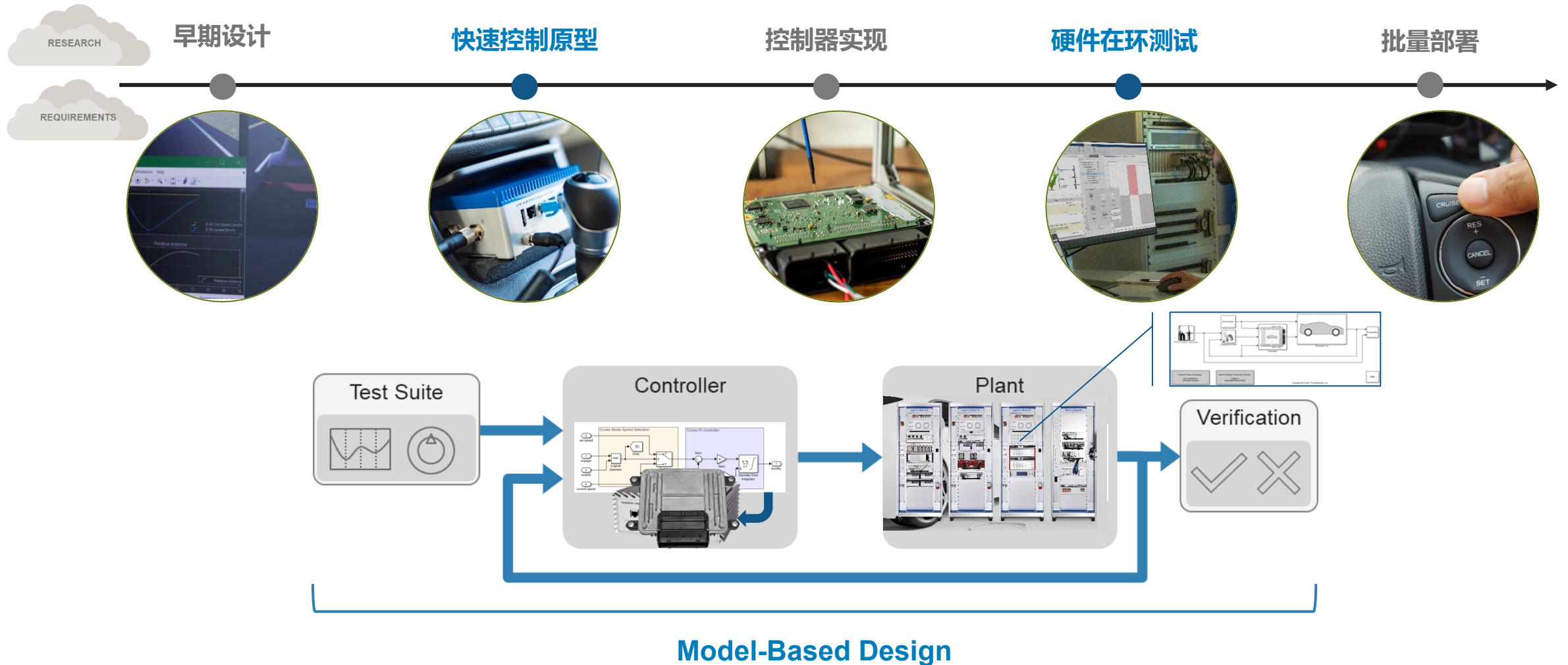
HIL测试实现

Part IV

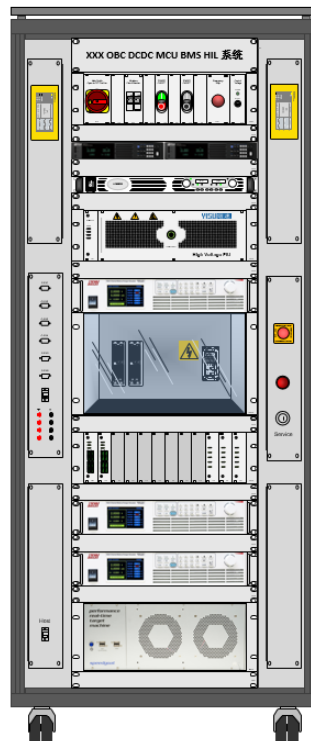


Q&A

基于模型的设计



基于Speedgoat 的汽车HIL系统



Speedgoat:

- Performance
- IO602/IO611
- IO144
- IO334
- IO3XX-21
- IO316
- IO715
- ...

All in Simulink



MathWorks:

- MATLAB
- Simulink
- Simulink Real Time
- XXX Coder
- Powertrain Blockset
- Vehicle Dynamic Blockset
- Simscape
- ...

XCU Controller

控制算法

IO及通讯接口

HIL测试台架

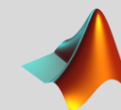
IO及通讯接口

实时机
虚拟车辆模型

信号调理
故障注入等

系统部件
接插件、供电等

上位机电脑



试验管理

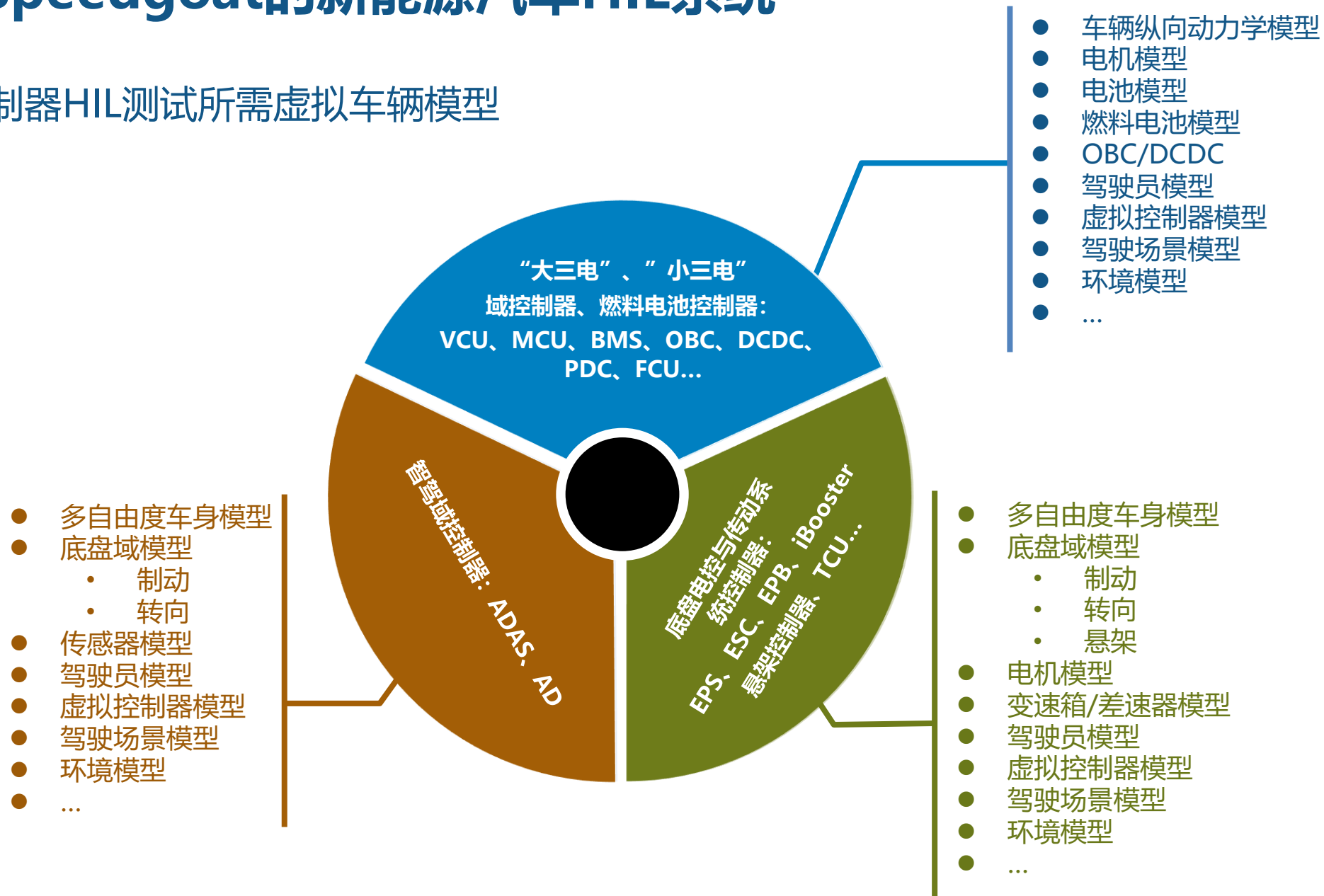
模型搭建

自动化测试

IO配置

基于Speedgoat的新能源汽车HIL系统

车载控制器HIL测试所需虚拟车辆模型

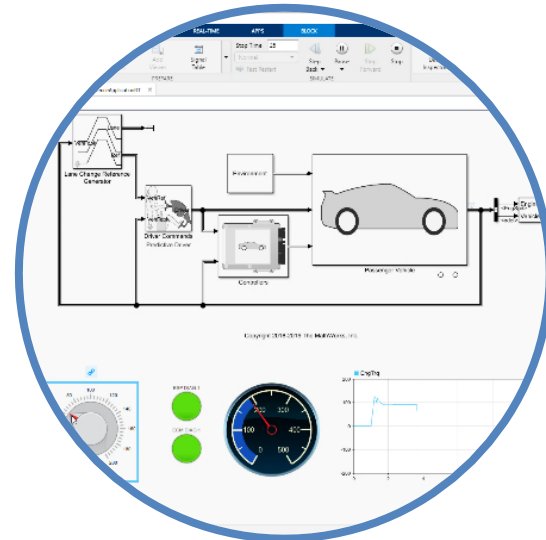


Part I



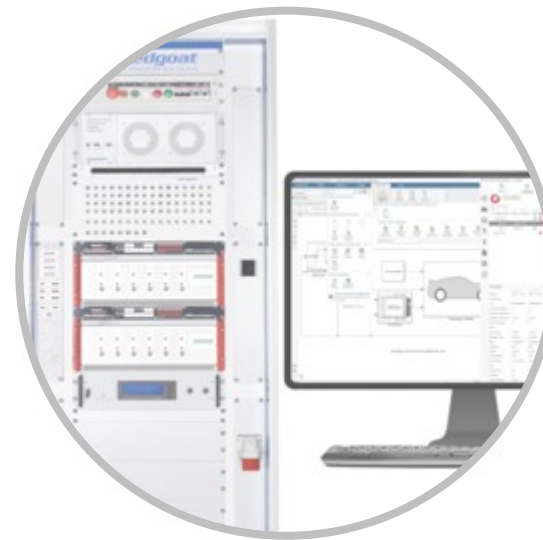
车辆HIL系统

Part II



虚拟车辆模型

Part III



HIL测试实现

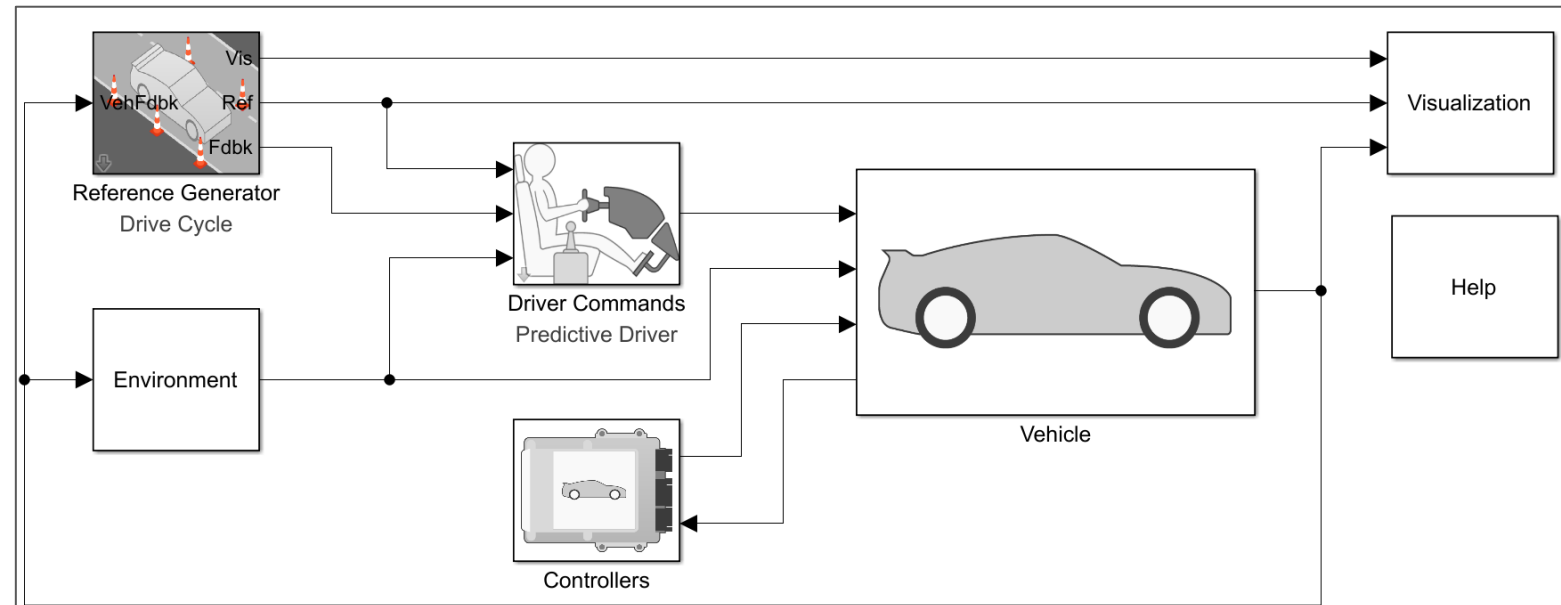
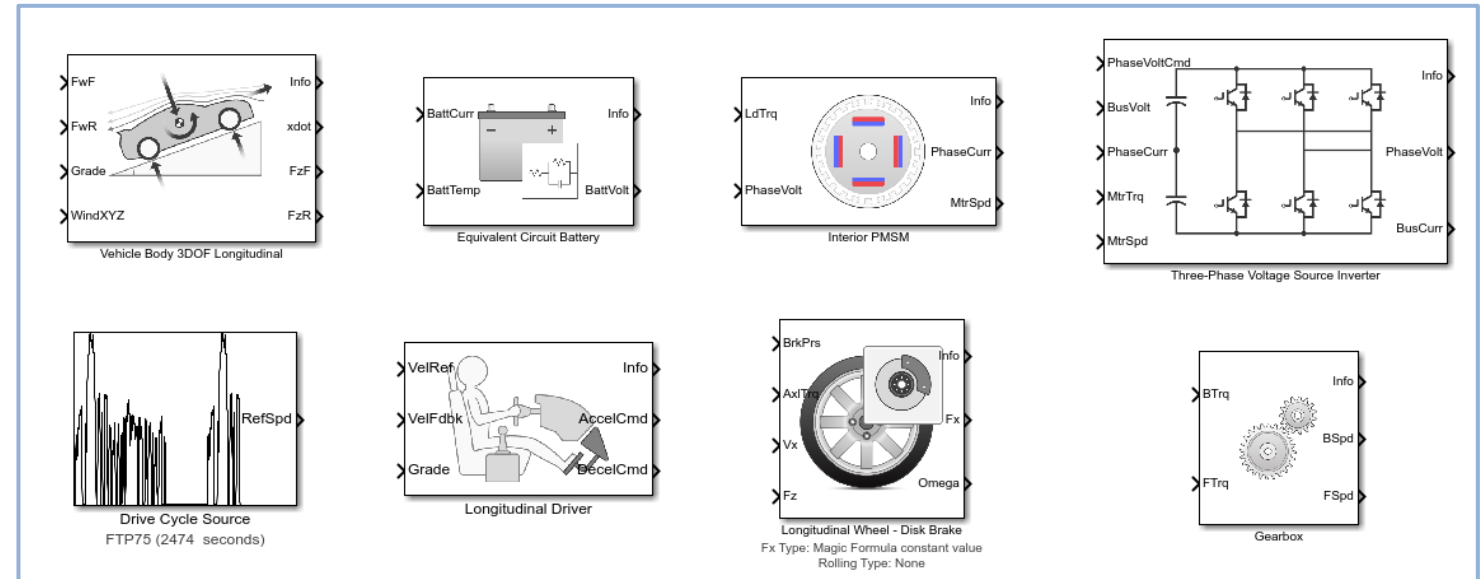
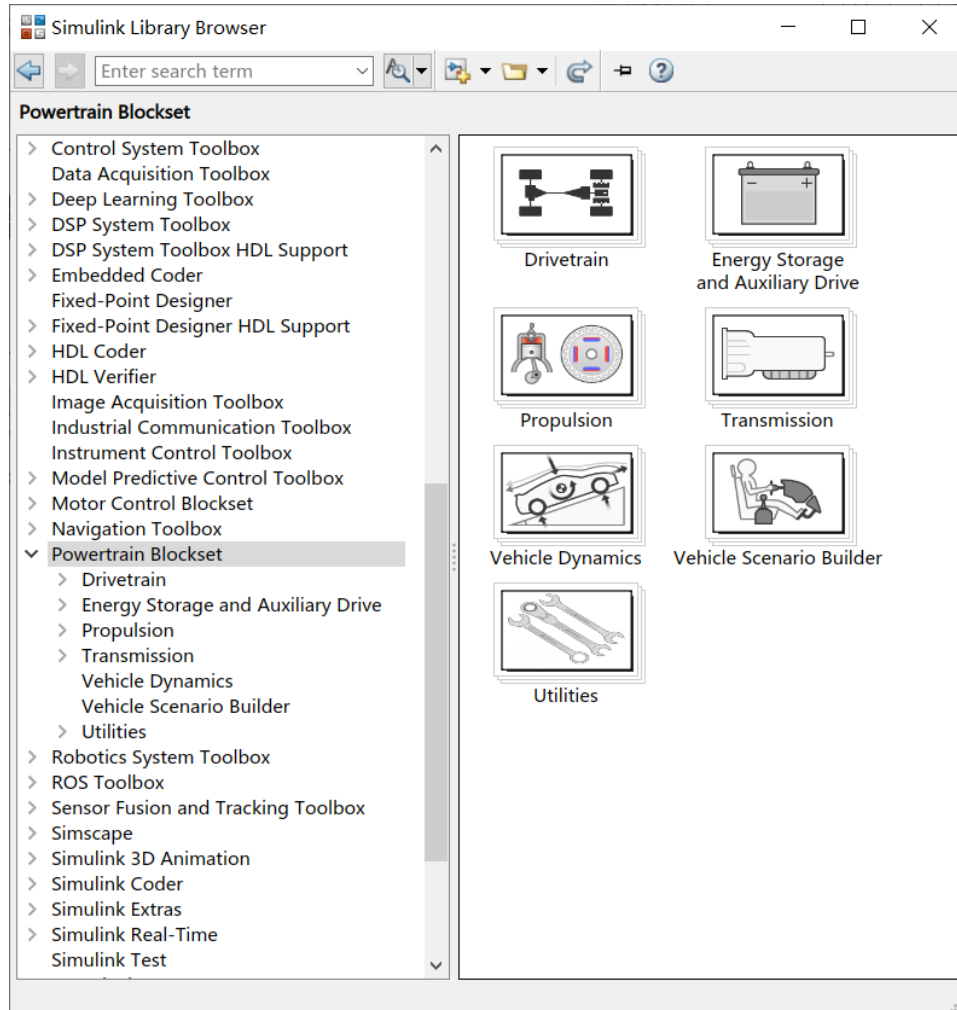
Part IV



Q&A

虚拟车辆模型：Powertrain Blockset

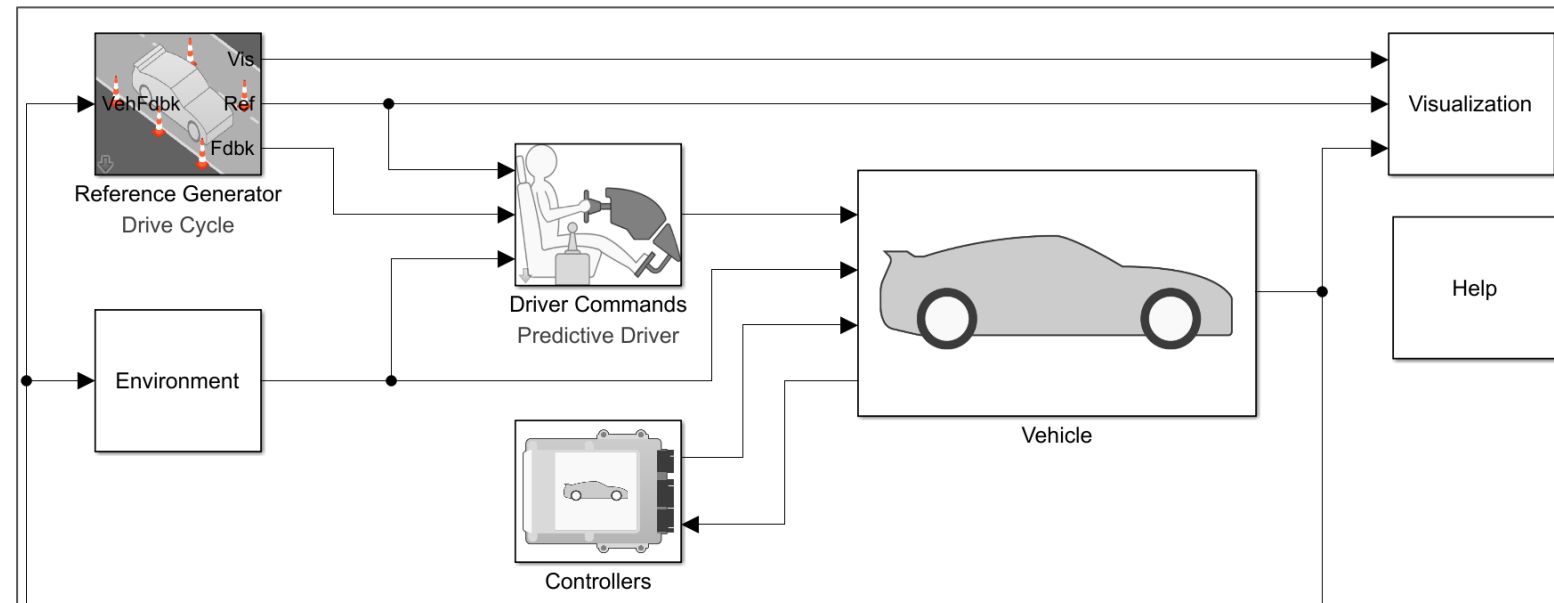
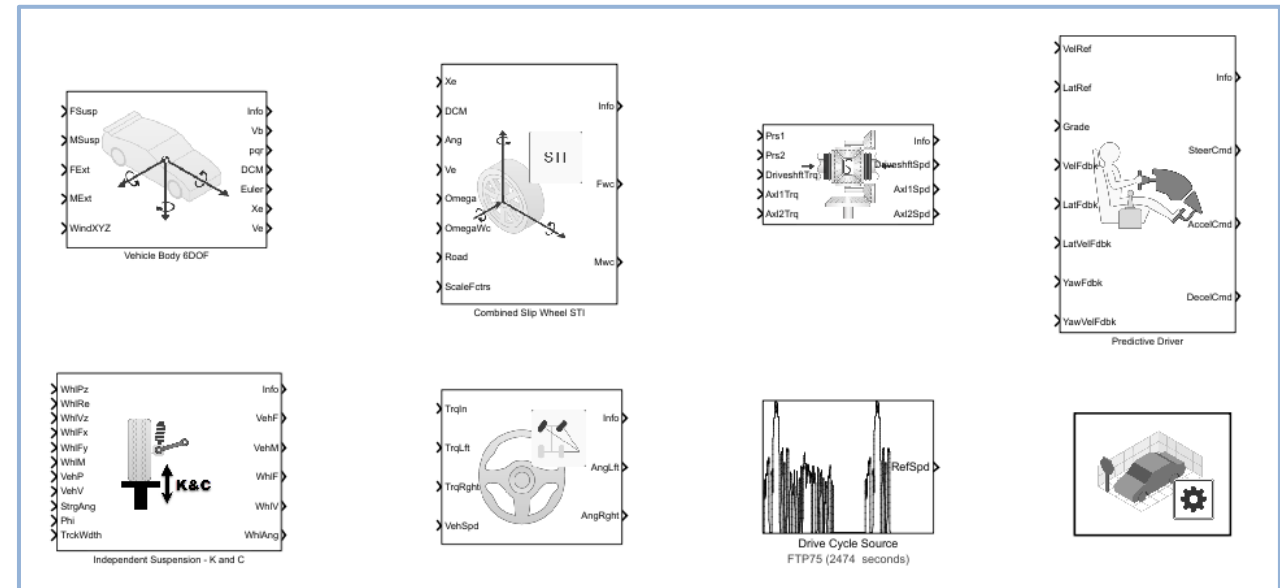
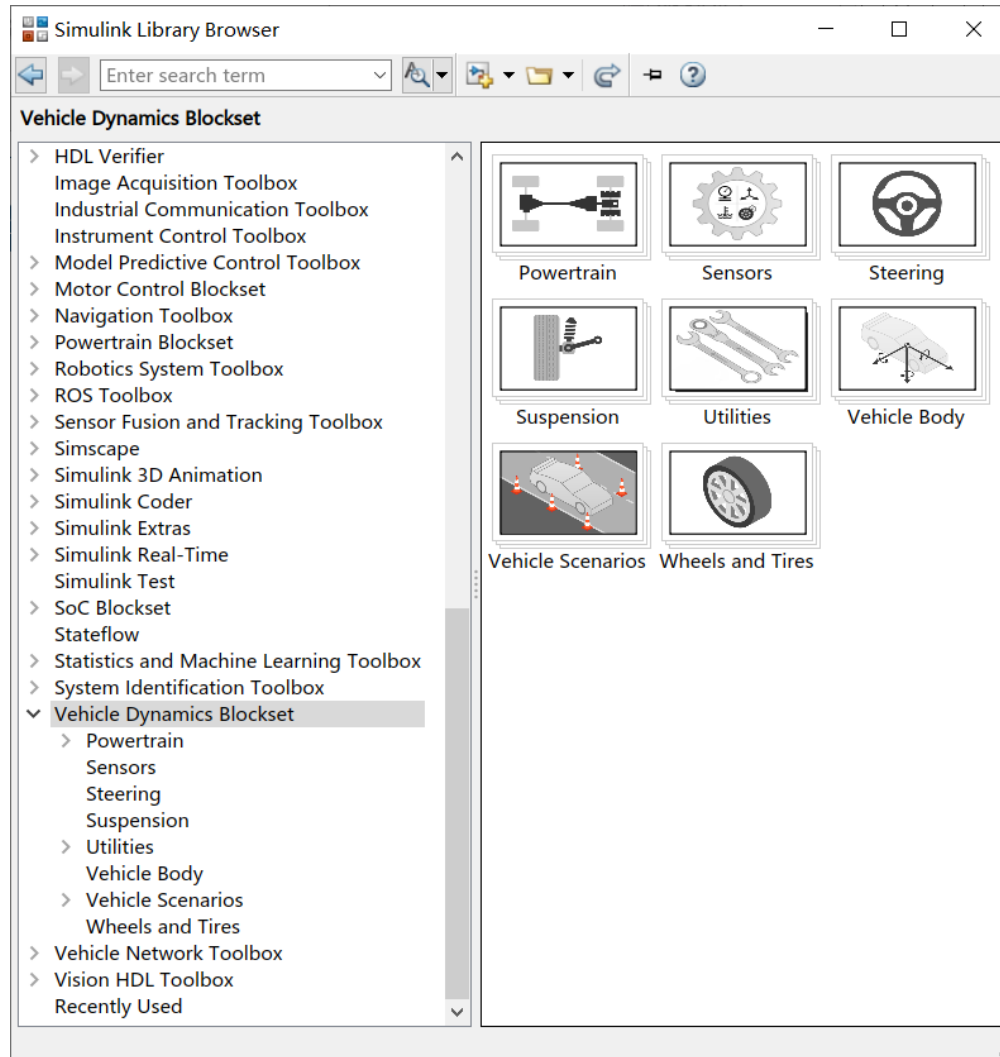
使用Powertrain Blockset模型库构建虚拟车辆模型



纵向动力学模型

虚拟车辆模型：Vehicle Dynamic Blockset

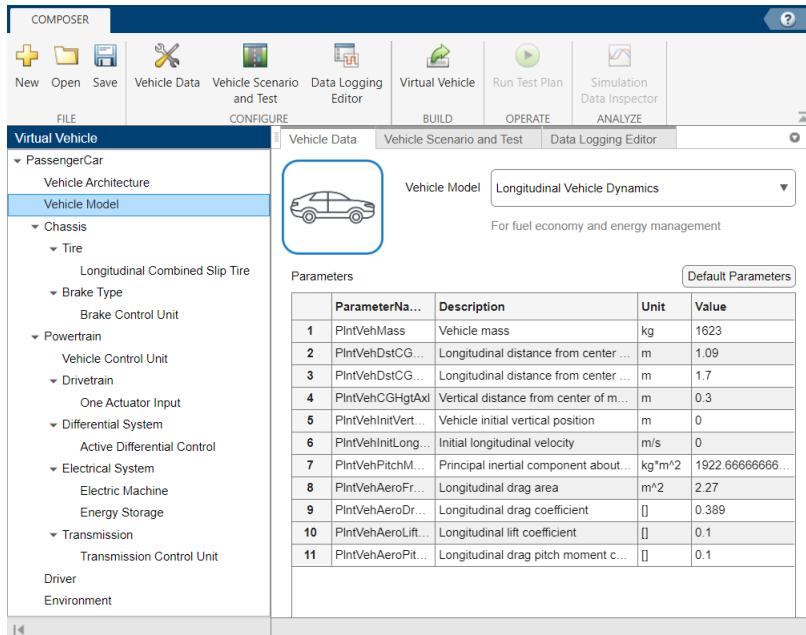
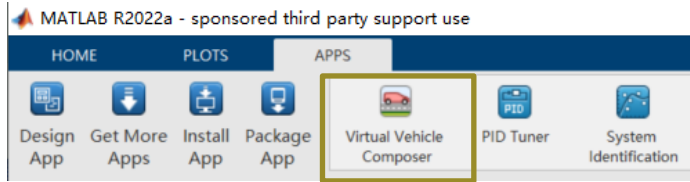
使用Vehicle Dynamic Blockset模型库构建虚拟车辆模型



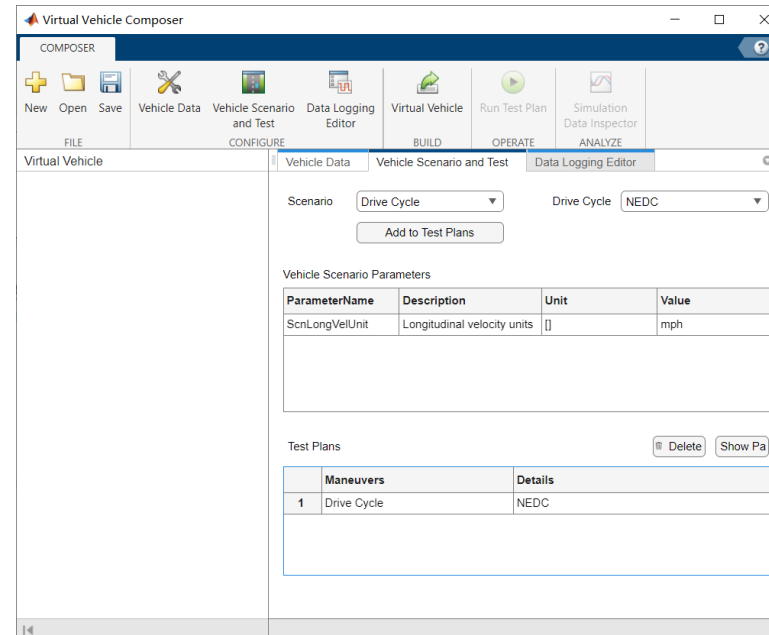
更多自由度动力学模型

虚拟车辆模型管理：Virtual Vehicle Composer

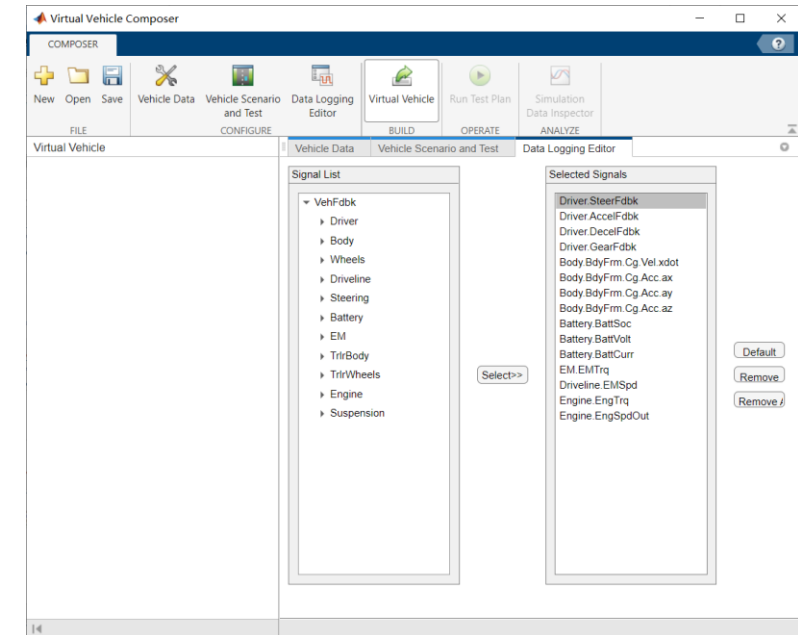
虚拟车辆模型的图形化、工程化、参数化管理与实现工具



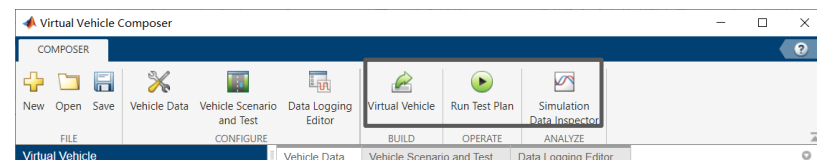
参数配置



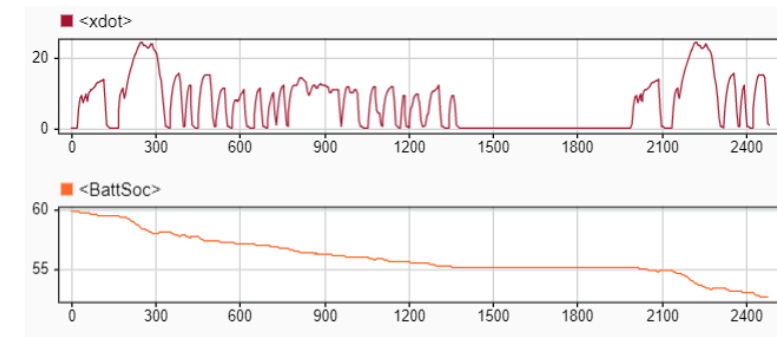
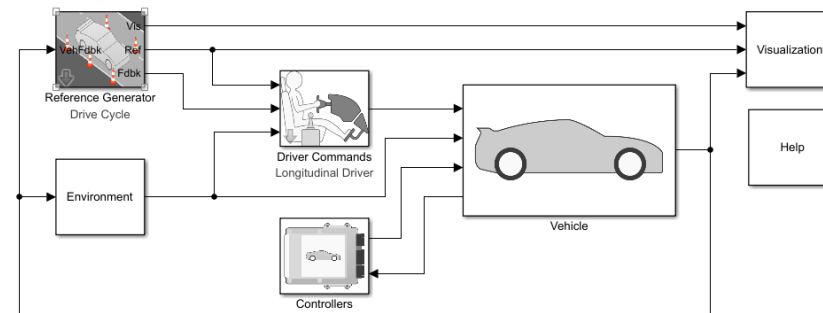
场景定义



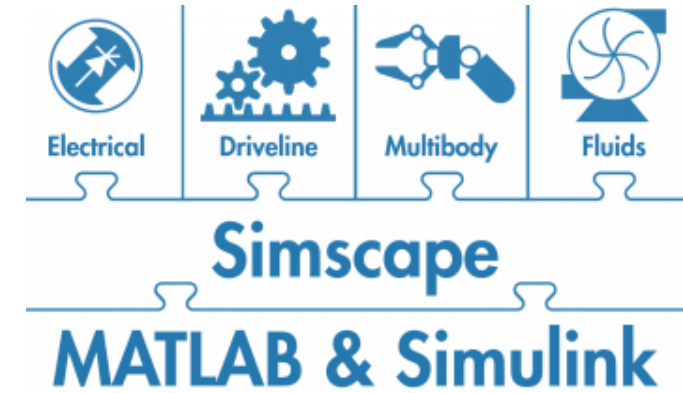
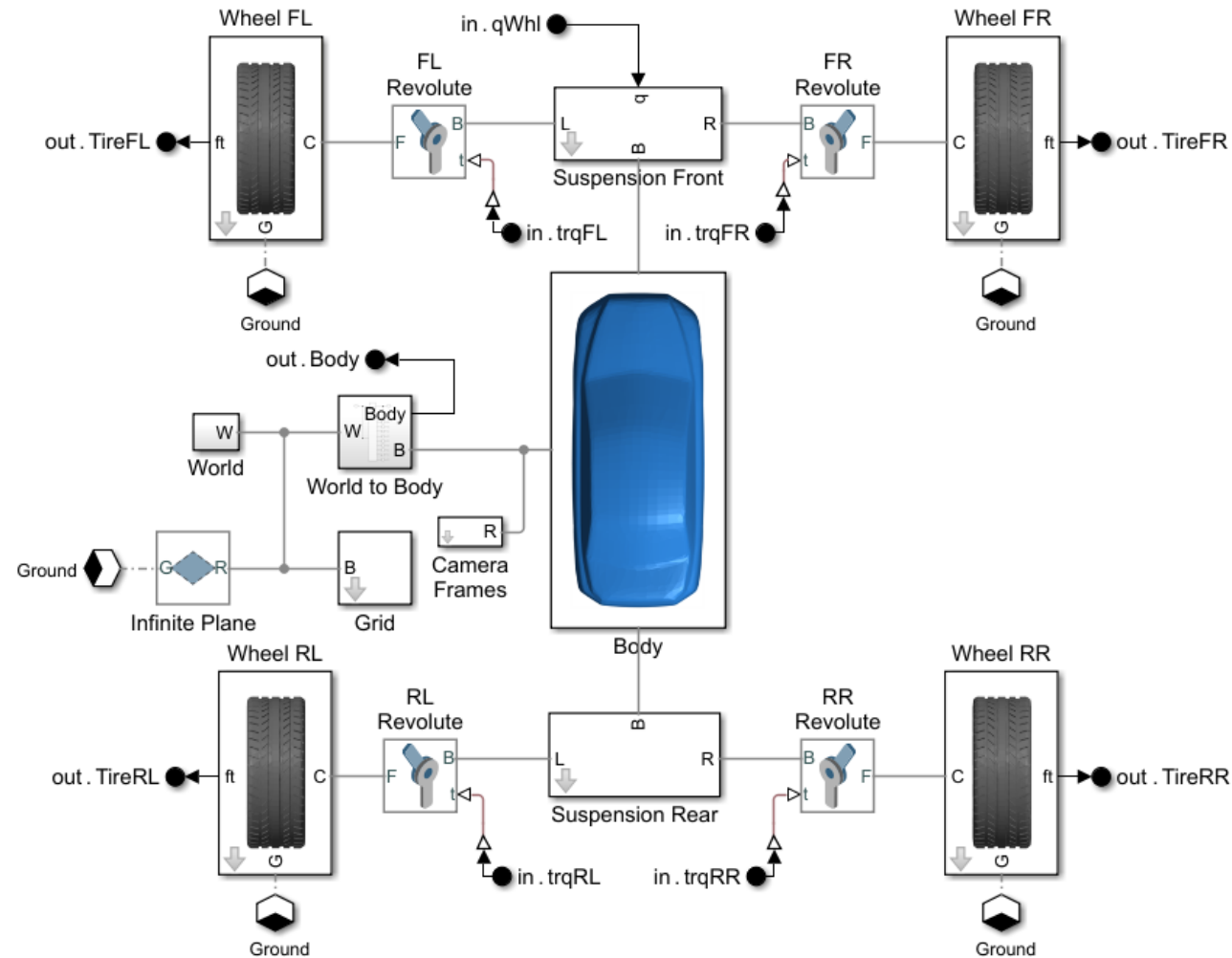
观测定义



模型创建、运行、结果观测



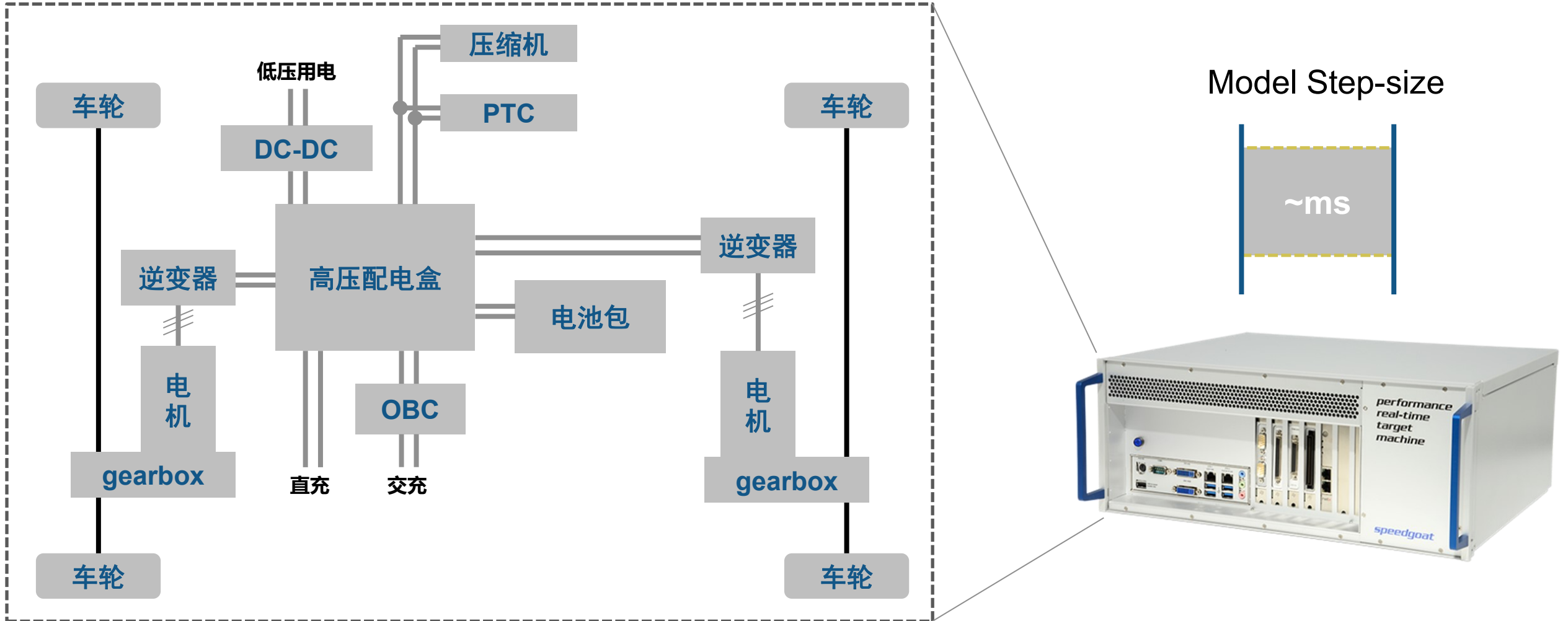
虚拟车辆模型: Simscape



- 多物理域
- 模型更加精细
- DAE求解器
- 适用于汽车机械、电气、流体类部件建模

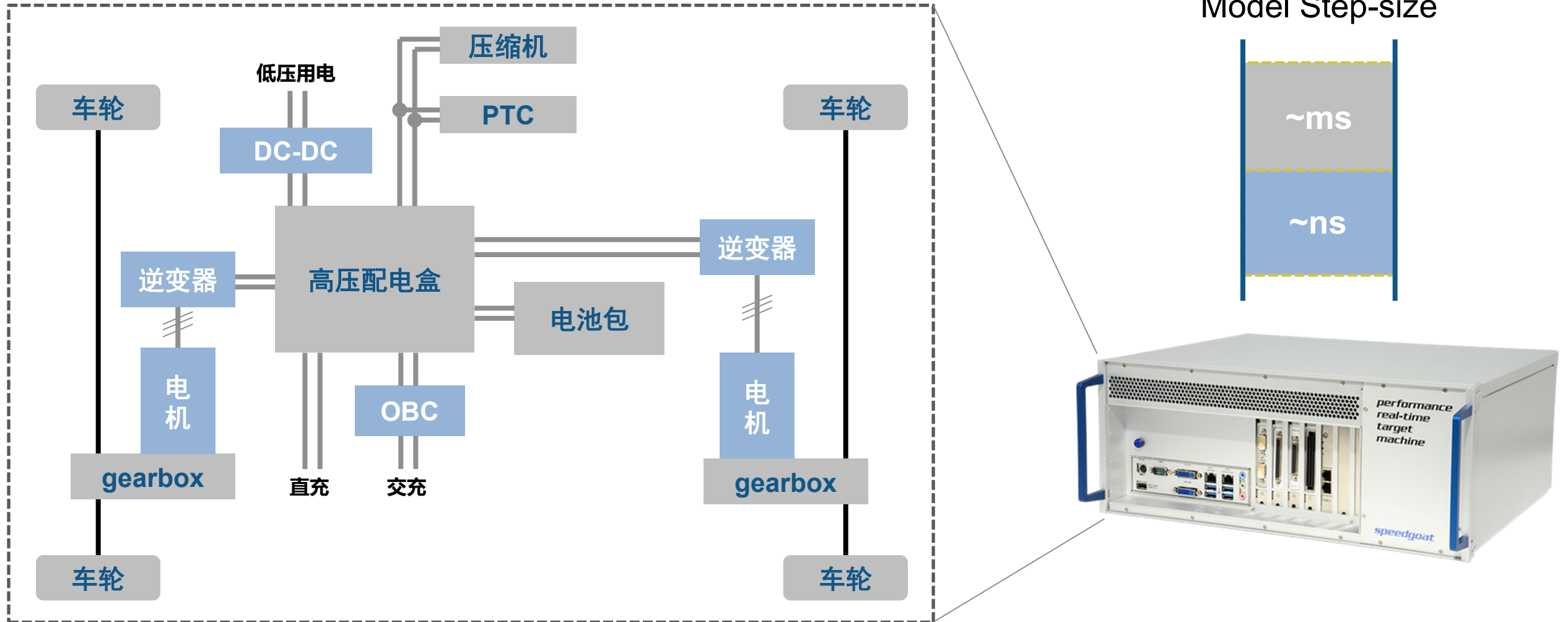
HIL中的虚拟车辆模型实时性要求

VCU、BMS、底盘域等非电驱或电力电子控制器HIL测试的实时性要求：~ms



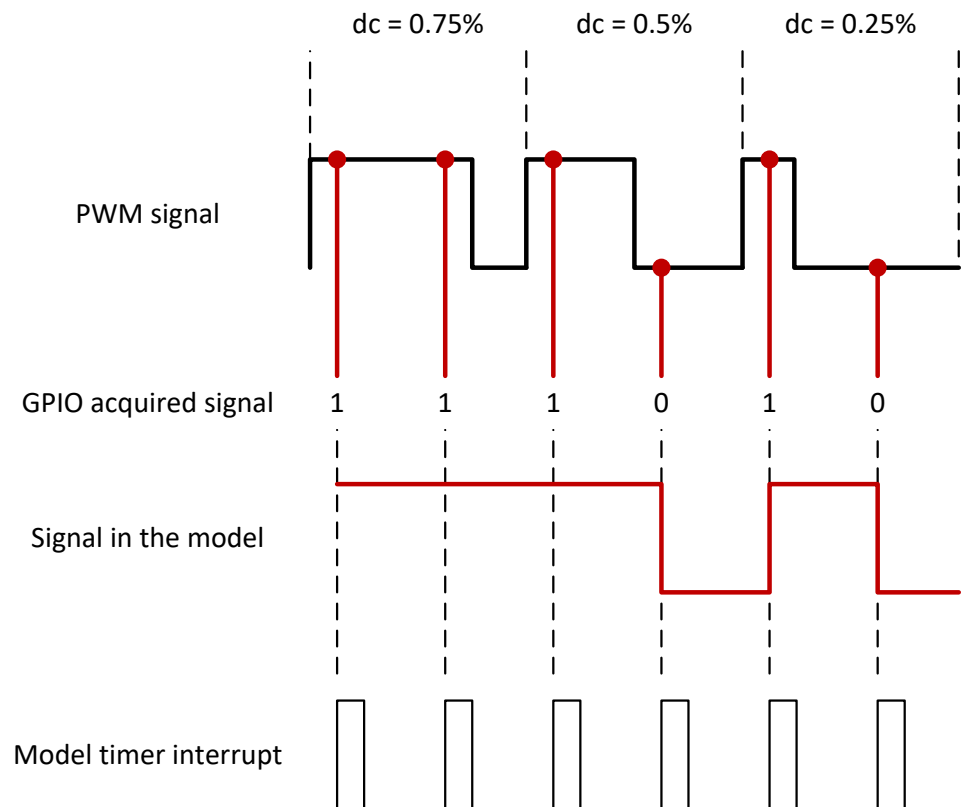
HIL中的虚拟车辆模型实时性要求

MCU等电驱或电力电子控制器HIL测试的实时性要求: $\sim ns$

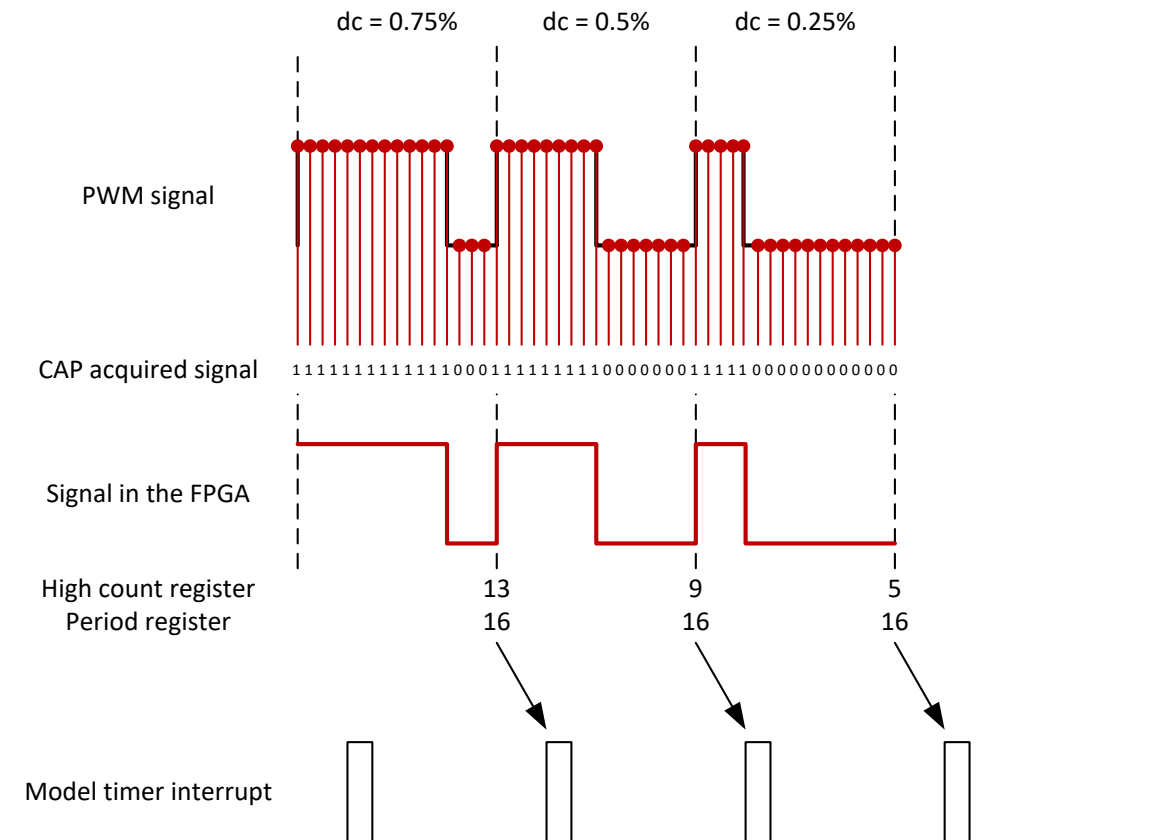


HIL中的虚拟车辆模型实时性要求

电力电子及电驱动系统仿真的特殊性



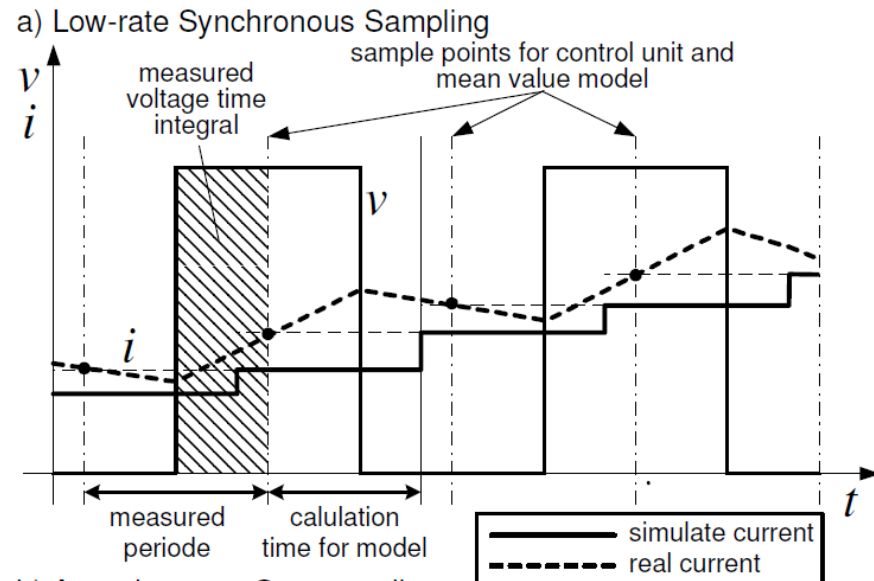
低速率同步采样



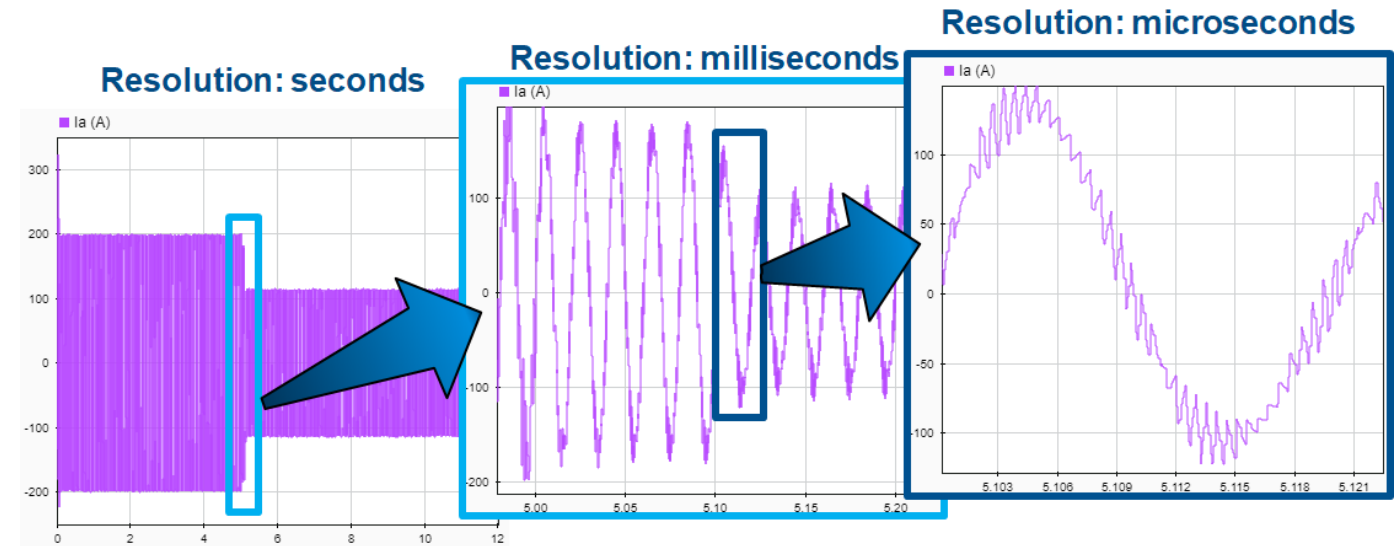
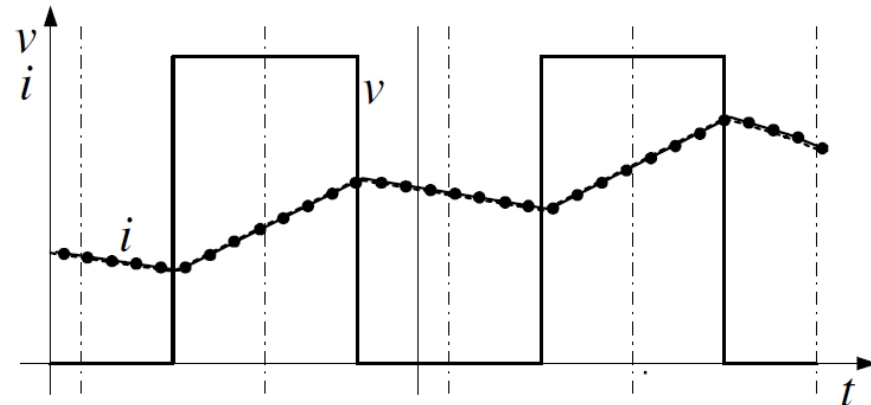
异步过采样

HIL中的虚拟车辆模型实时性要求

电力电子及电驱动系统仿真的特殊性



b) Asynchronous Oversampling:



低速率同步采样

- 仿真步长: 25~50 μs
- 延迟大: 25~50 μs
- 开关频率较高时仿真结果不精确

异步过采样

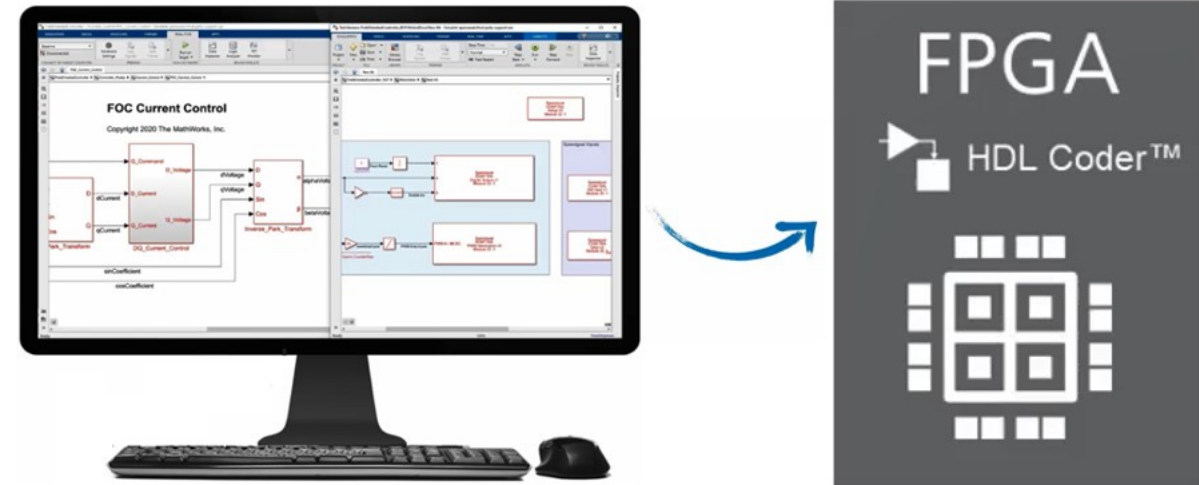
- 仿真步长: 10~100 ns
- 延迟小, 100~500 ns
- 开关频率较高时仿真结果仍然精确

电力电子及电驱系统HIL仿真策略: 基于FPGA的异步过采样

基于HDL Coder进行FPGA建模的先进技术路线

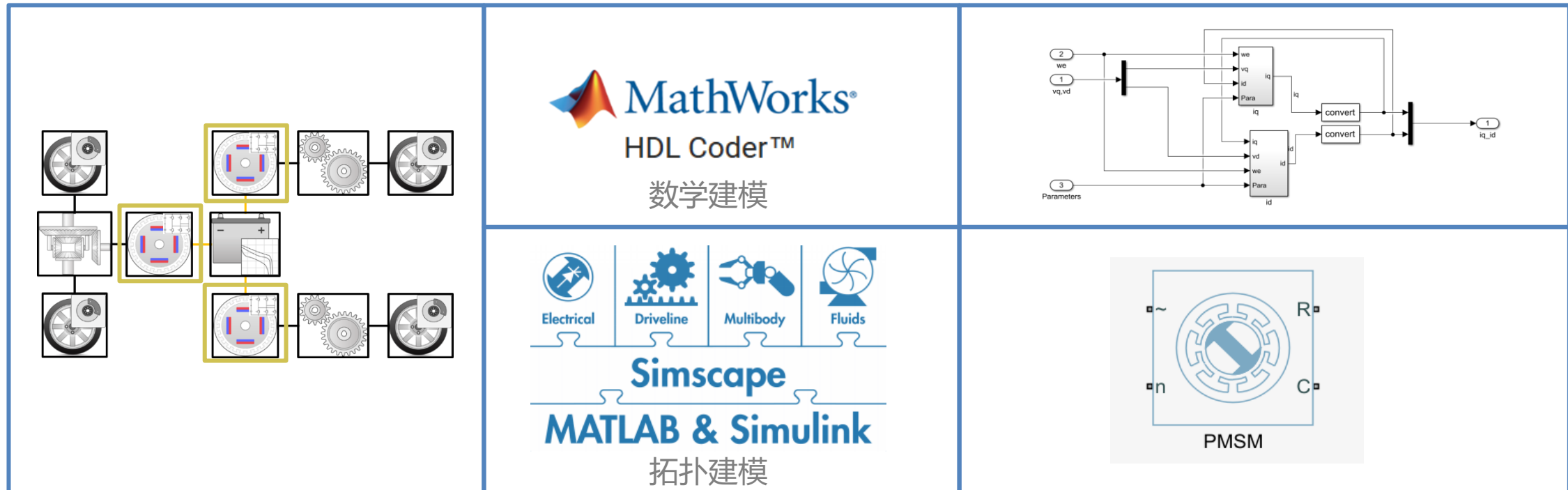
从桌面式基于Simulink的FPGA算法开发到Speedgoat的FPGA实时验证

- 所有流程均在Simulink图形化开发环境中完成。结合MATLAB的FPGA代码生成工具HDL Coder，将Simulink模型转化成FPGA代码。
- 开发人员无需了解FPGA开发的硬件和逻辑知识，只需会使用Simulink即可。
- 工具不仅支持定点运算，还支持原生浮点运算，无需担心FPGA模型运算精度问题。
- 按钮式操作，全自动化的工作流程：从模型到FPGA代码实现及时序分析，并生成位流文件。
- 支持将Simscape电路模型转化为FPGA实时模型。
- 模型可读性好，便于用户二次开发。



纳秒级电力电子与电驱系统模型

电力电子及电驱动系统建模方式



All from Simulink

纳秒级电力电子与电驱系统模型：数学建模

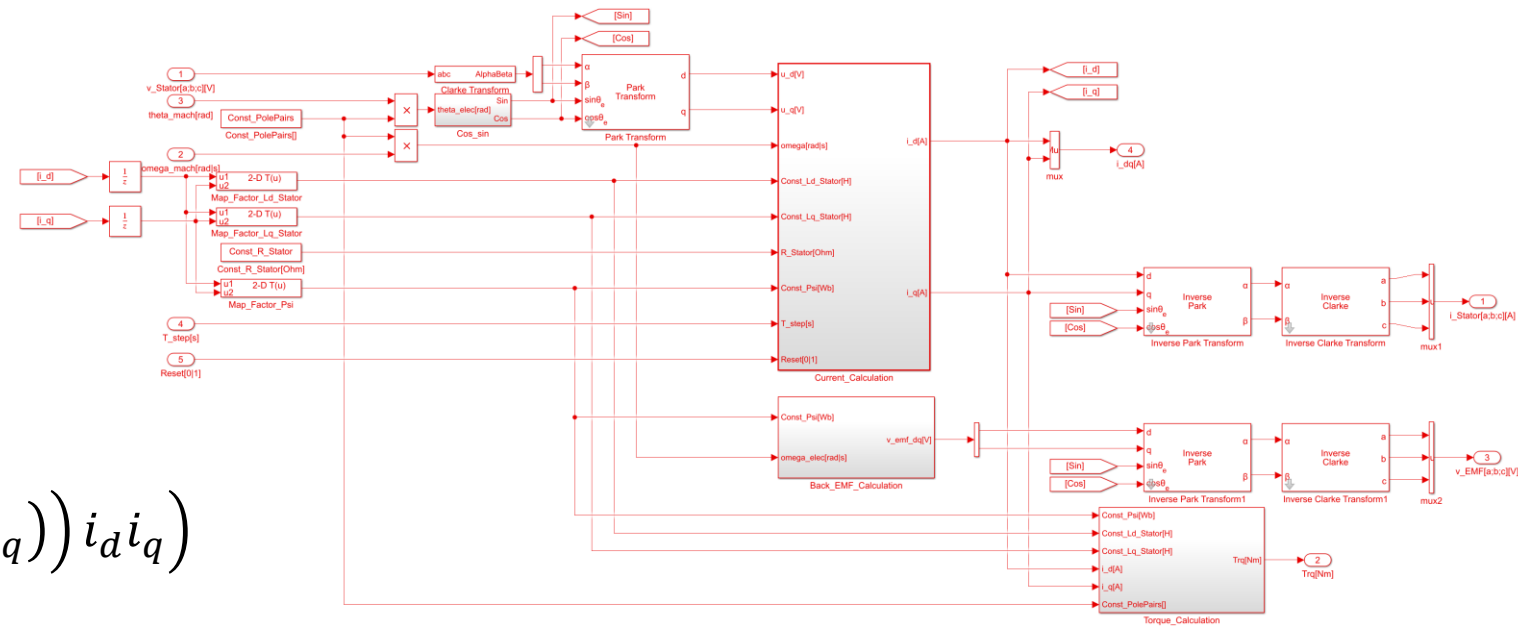
电机模型

基于数学方程采用HDL Coder搭建FPGA模型

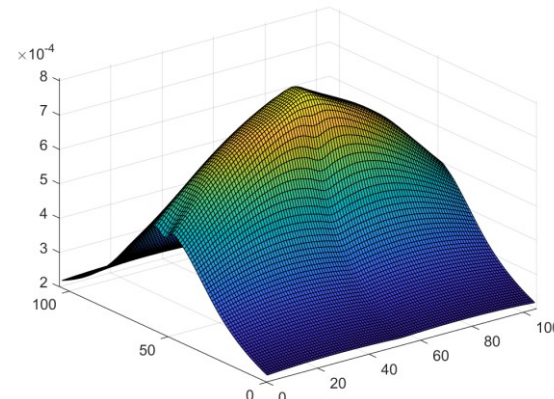
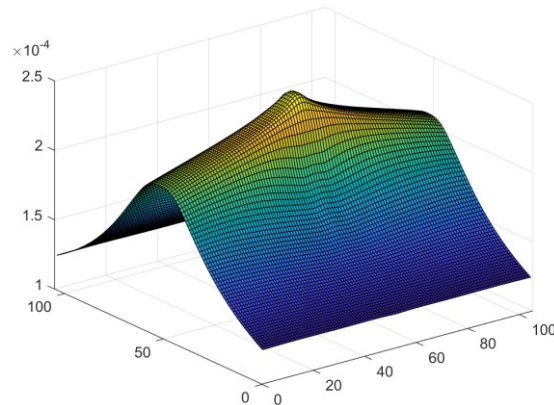
$$\begin{cases} u_d = R_s i_d + \frac{d\varphi_d}{dt} - \omega \varphi_q \\ u_q = R_s i_q + \frac{d\varphi_q}{dt} + \omega \varphi_d \end{cases}$$

$$\begin{cases} \varphi_d = L_d(i_d, i_q) i_d + \varphi_M(i_d, i_q) \\ \varphi_q = L_q(i_d, i_q) i_q \end{cases}$$

$$T_e = \frac{3}{2} p \left(\varphi_M(i_d, i_q) i_q + \left(L_d(i_d, i_q) - L_q(i_d, i_q) \right) i_d i_q \right)$$



基于HDL Coder的非线性电机模型



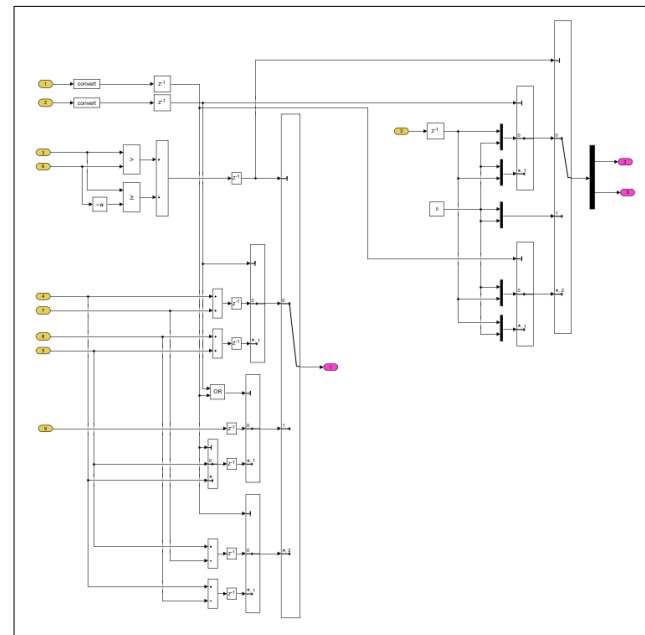
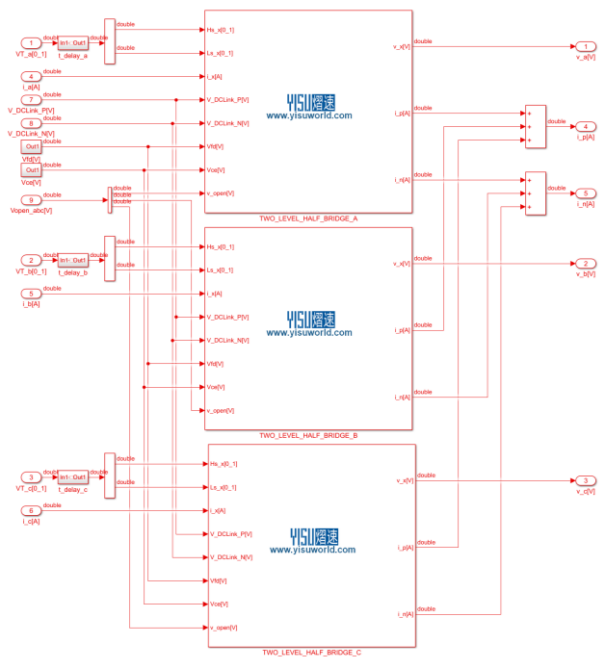
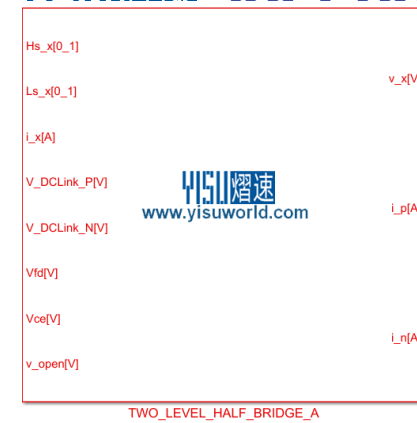
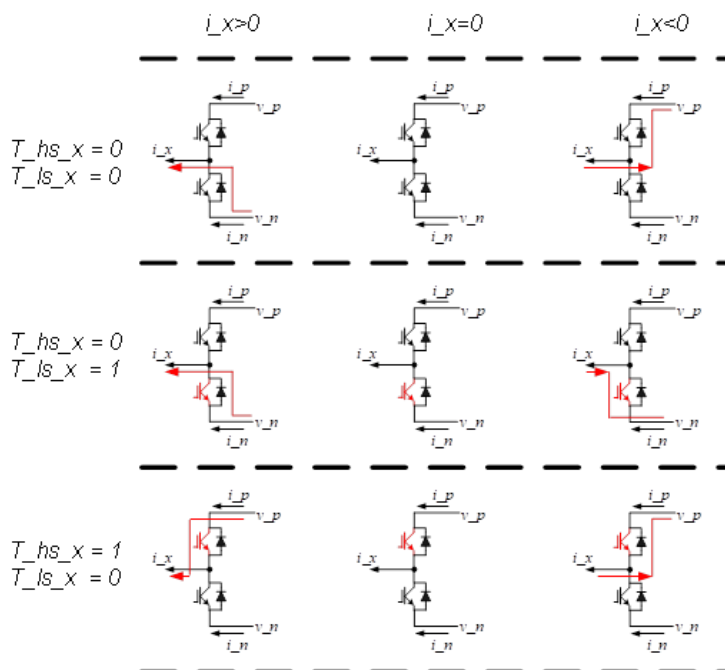
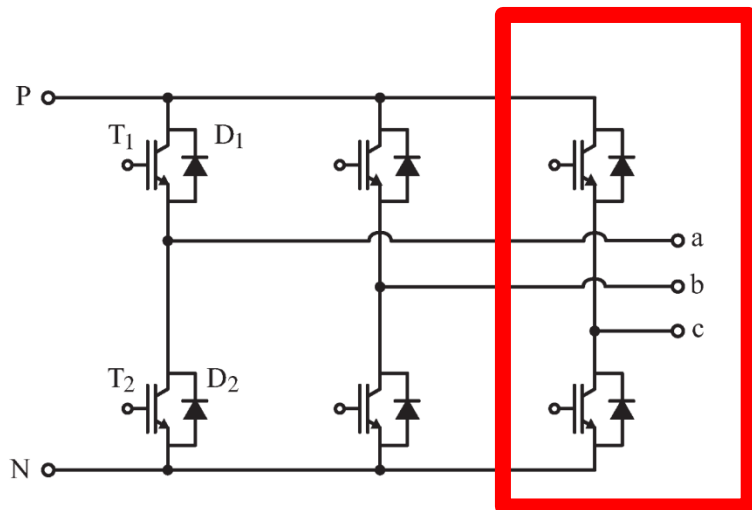
更多电机建模原理细节：

https://mp.weixin.qq.com/s/36R6qE_SDt_YP_ckeBBzTA



纳秒级电力电子与电驱系统模型：数学建模

电力电子模型

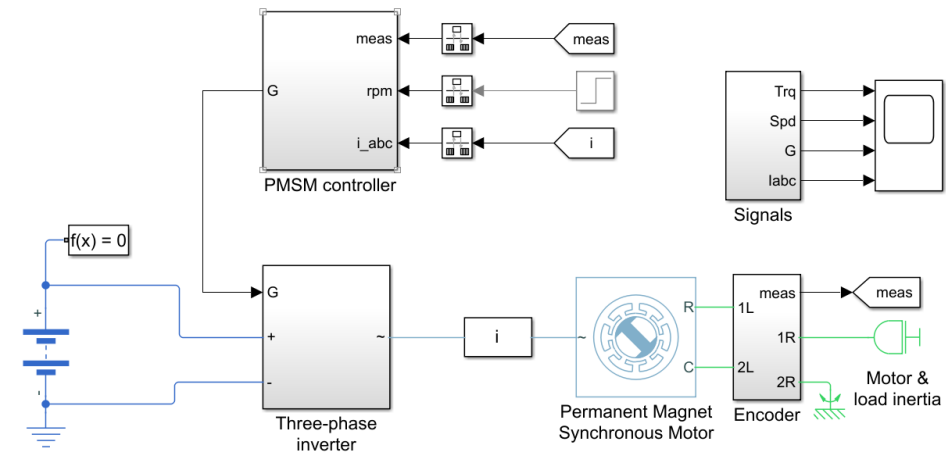


基于HDL Coder的半桥模型

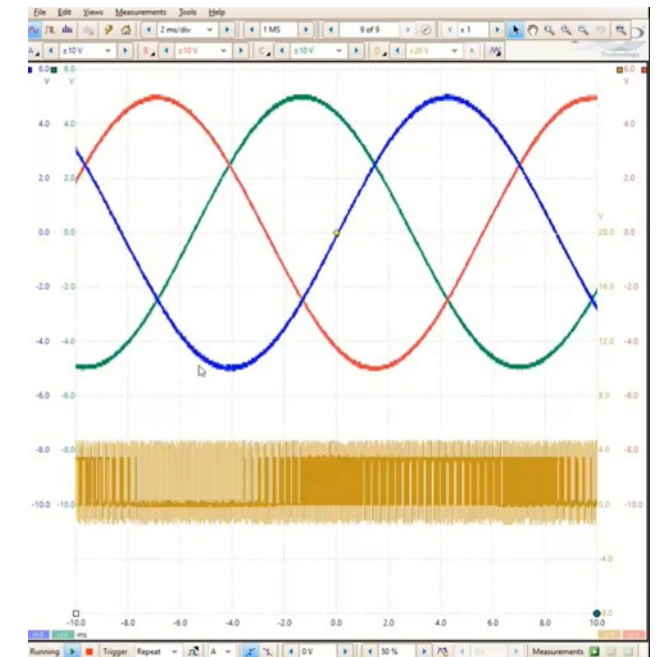
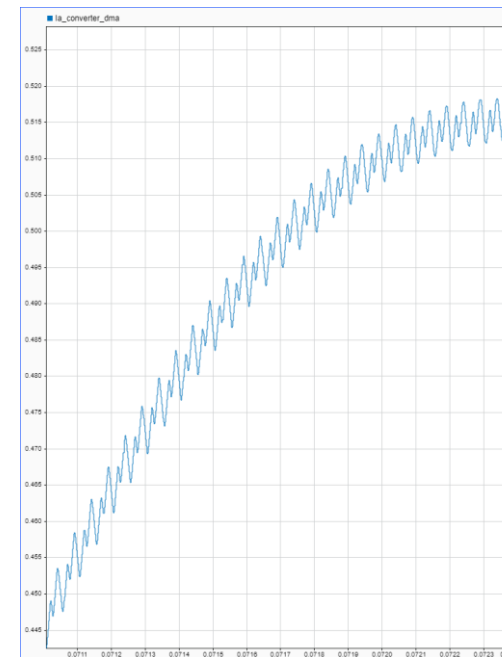
更多电力电子建模原理细节：
<https://mp.weixin.qq.com/s/bU1TzB2NMWpq66J1U0xZ-Q>



纳秒级电力电子与电驱系统模型：拓扑建模



- 使用Simscape Electrical搭建电力电子与电驱系统模型并部署到FPGA
 - 先将 Simscape electrical 物理模型转换为状态空间模型
 - 再将状态空间模型生成HDL代码
- ~1us仿真步长
 - 可模拟高达数百kHz的开关动态特性
 - PWM开关分辨率可达4ns级别



更多物理模型实现细节：<https://mp.weixin.qq.com/s/F1jZb27a6BSfRV0bOfB5qQ>

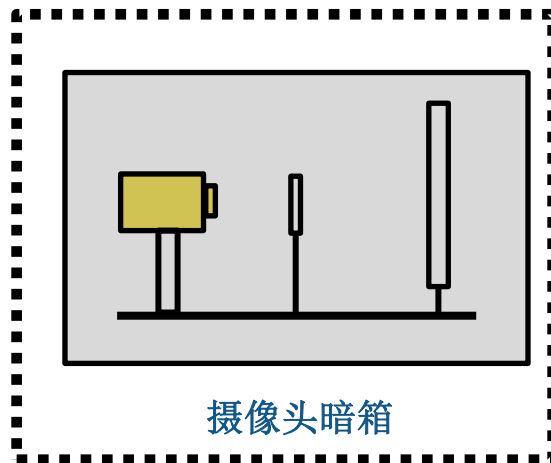
ADAS HIL系统：场景与传感器模型



- **Automated Driving Toolbox**
 - 毫米波雷达
 - 摄像头（常规相机、鱼眼相机）
 - 激光雷达
- **Roadrunner**
 - 3D场景搭建
- **Ureal Engine**
 - 环境仿真与渲染

Driving Scenario
驾驶场景模拟

Sensor Models
传感器模型



Ethernet

Vehicle info



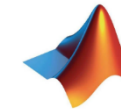
Object list

Lane marking

speedgoat



Vehicle Model
车辆模型



- **Powertrain Blockset**
- **Vehicle Dynamic Blockset**

Control Signal



Vehicle info
Object list
Lane marking

CAN

Object list

Lane marking

CAN



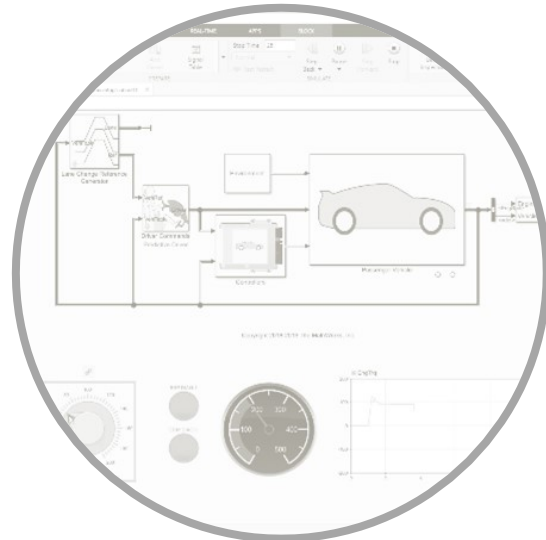
ADAS控制器

Part I



车辆HIL系统

Part II



虚拟车辆模型

Part III



HIL测试实现

Part IV



Q&A

Speedgoat实时仿真系统工具链

桌面式离线仿真——无缝衔接到——HIL实时仿真测试

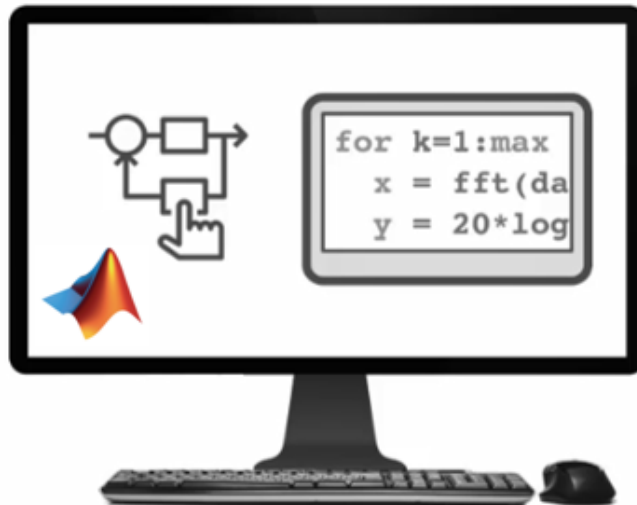
离线设计、仿真与测试

控制算法开发

被控对象模型仿真

逻辑功能验证

测试及分析



All in MATLAB/Simulink



HIL实时仿真与测试

实时操作系统

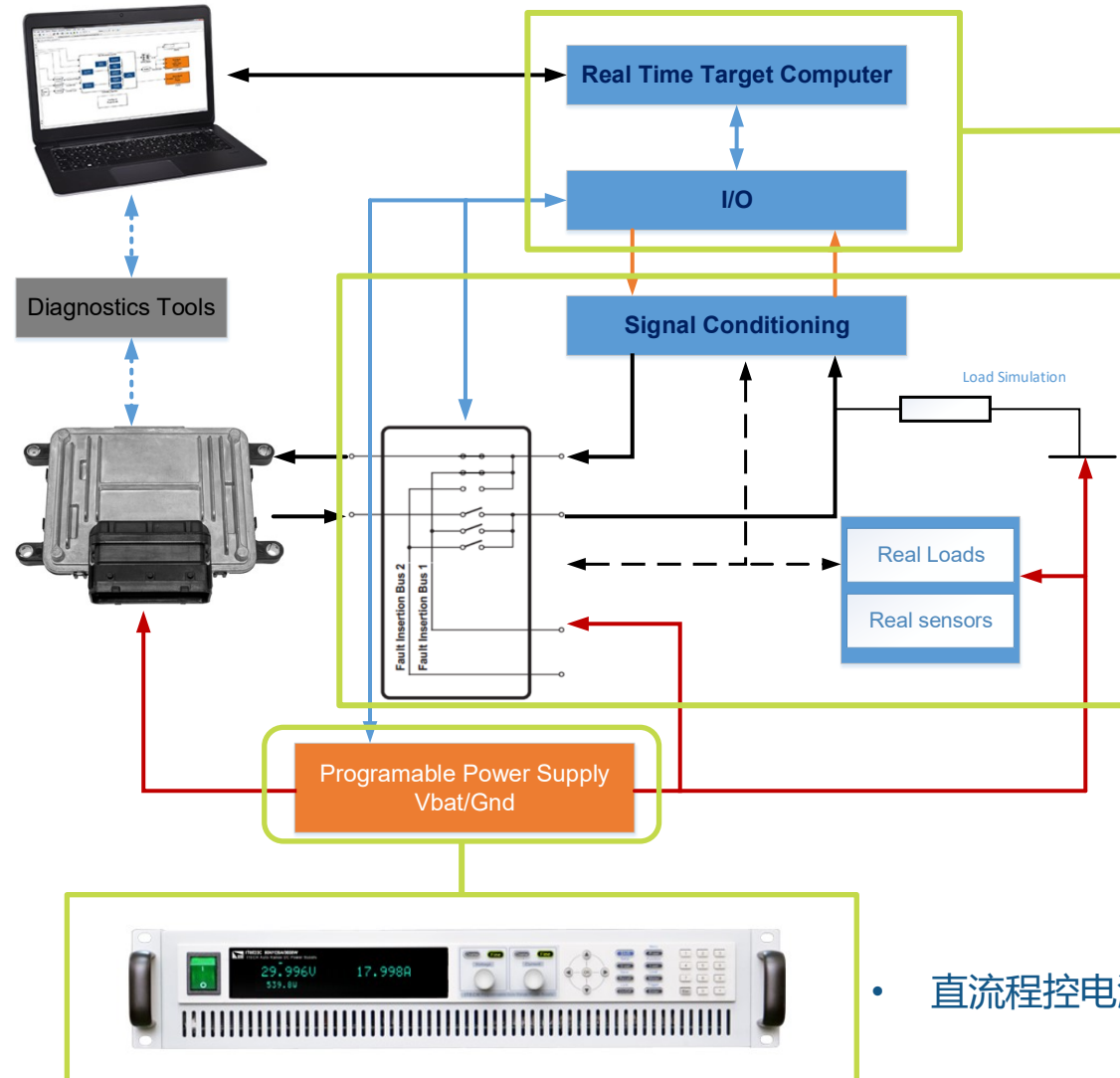
IO配置

试验管理

自动化测试



HIL系统的硬件: Speedgoat Real Time System



- Speedgoat Performance实时仿真主机
- IO板卡



- 信号调理板卡
- 故障注入单元
- 负载仿真
- ...

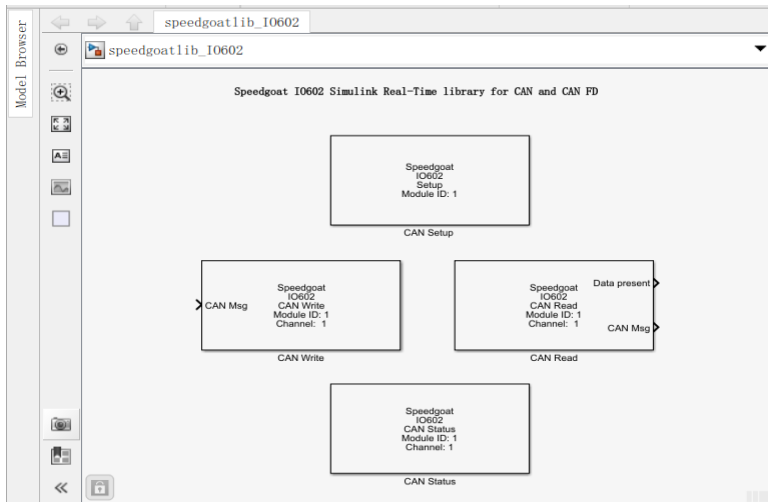
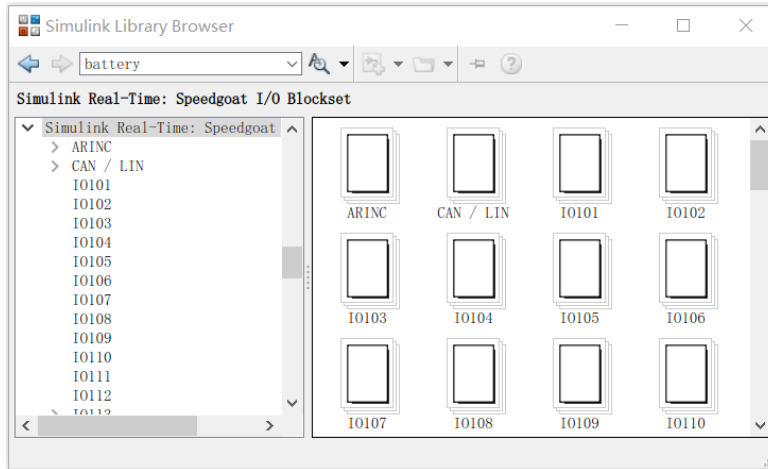


- 直流程控电源

HIL系统的软件: All in MATLAB/Simulink

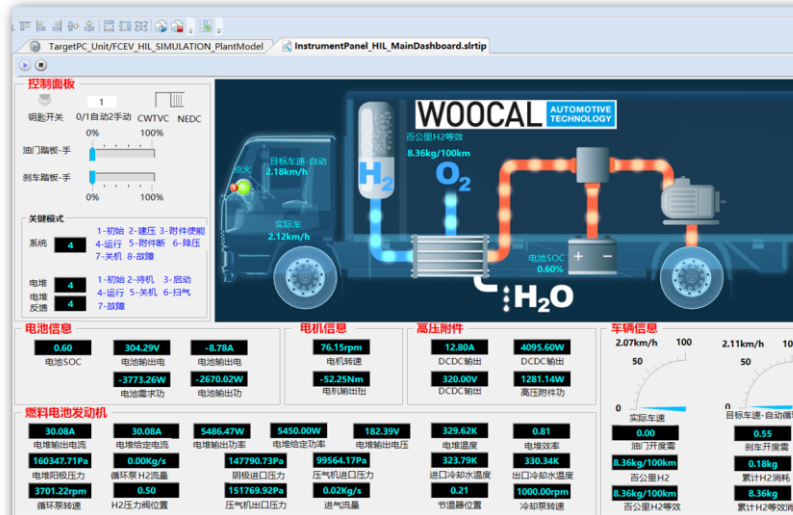
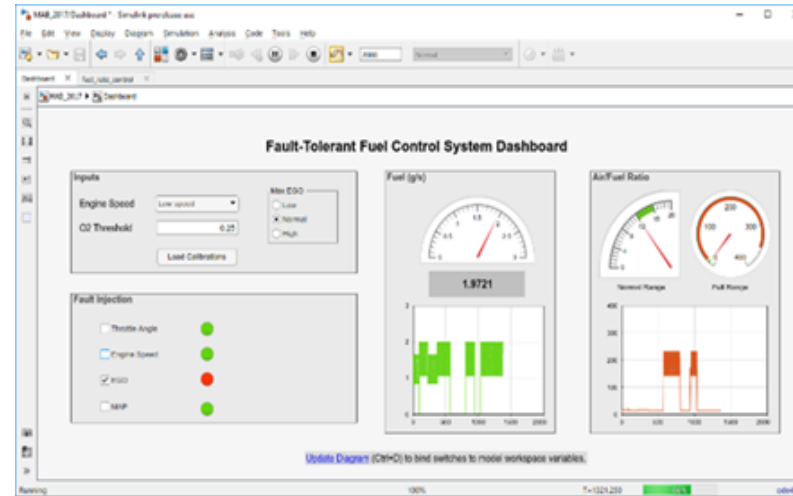
IO配置

Speedgoat I/O Blockset



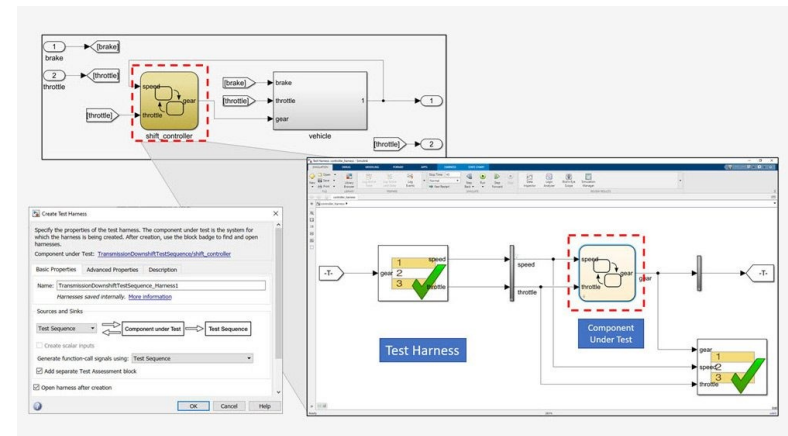
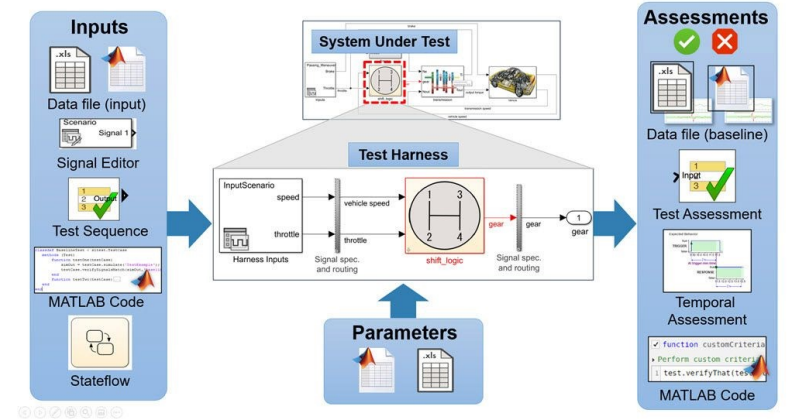
试验管理

Simulink Real-Time

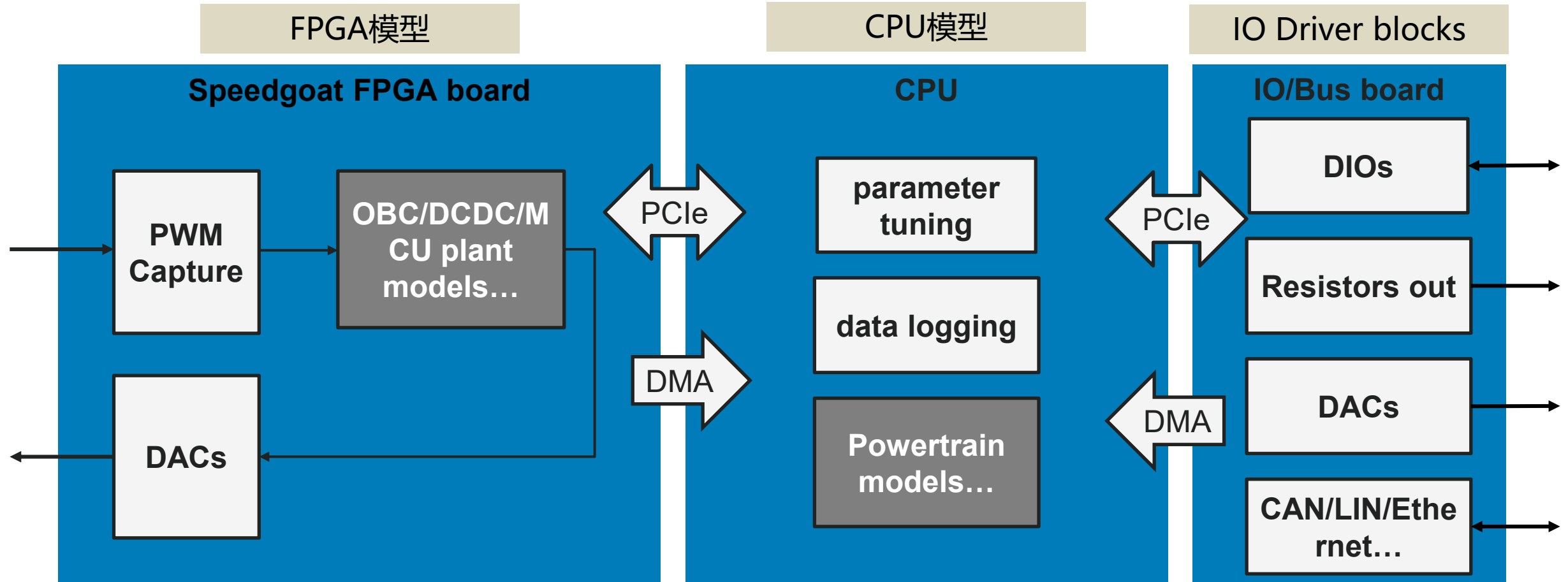


自动化测试

Simulink Test



基于Speedgoat HIL系统的实现



高速电力电子及电驱系统模型：~ns级

- HDL Coder

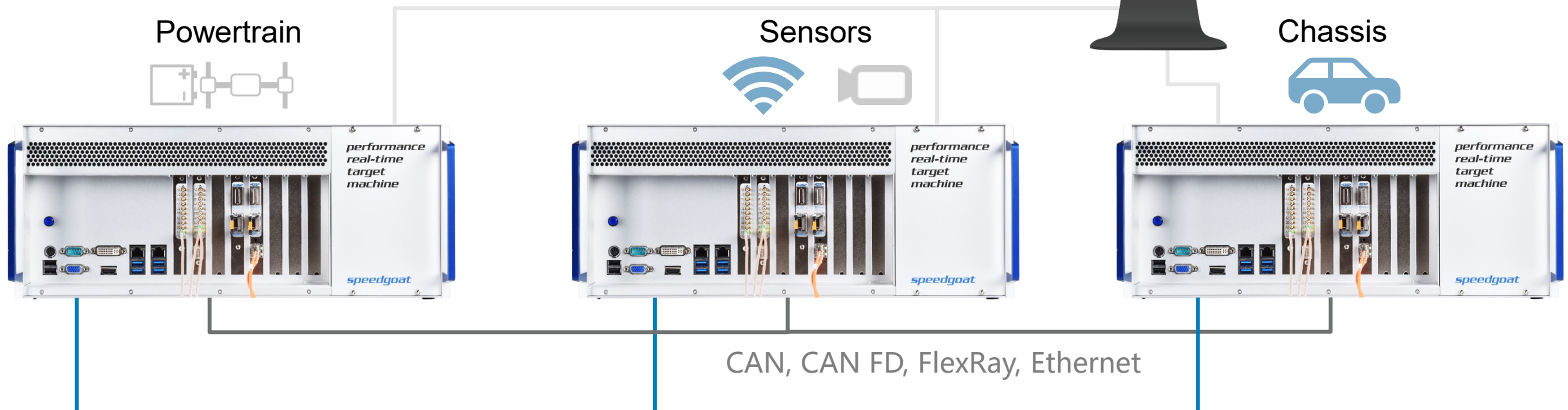
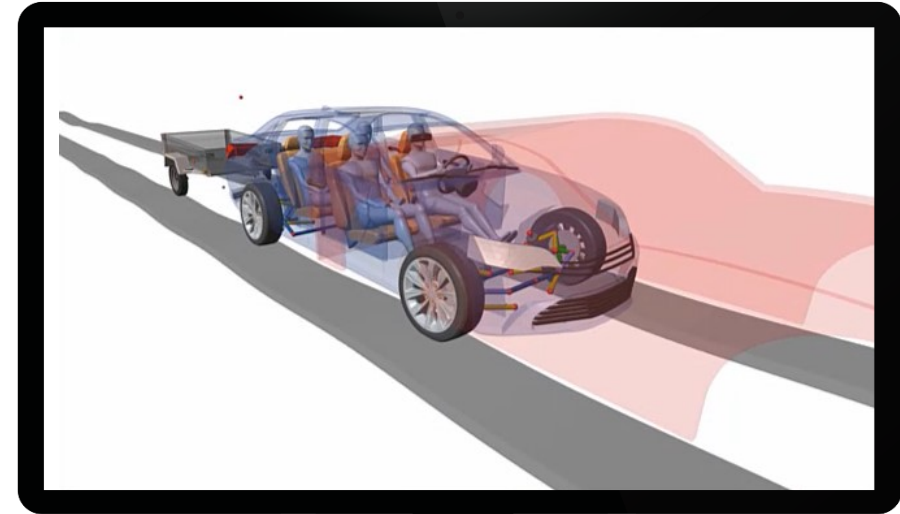
慢速整车模型模型：~ms级

- Powertrain Blockset
- Vehicle Dynamic Blockset
- Simulink Real Time

慢速IO信号和总线信号

基于Speedgoat HIL系统的实现

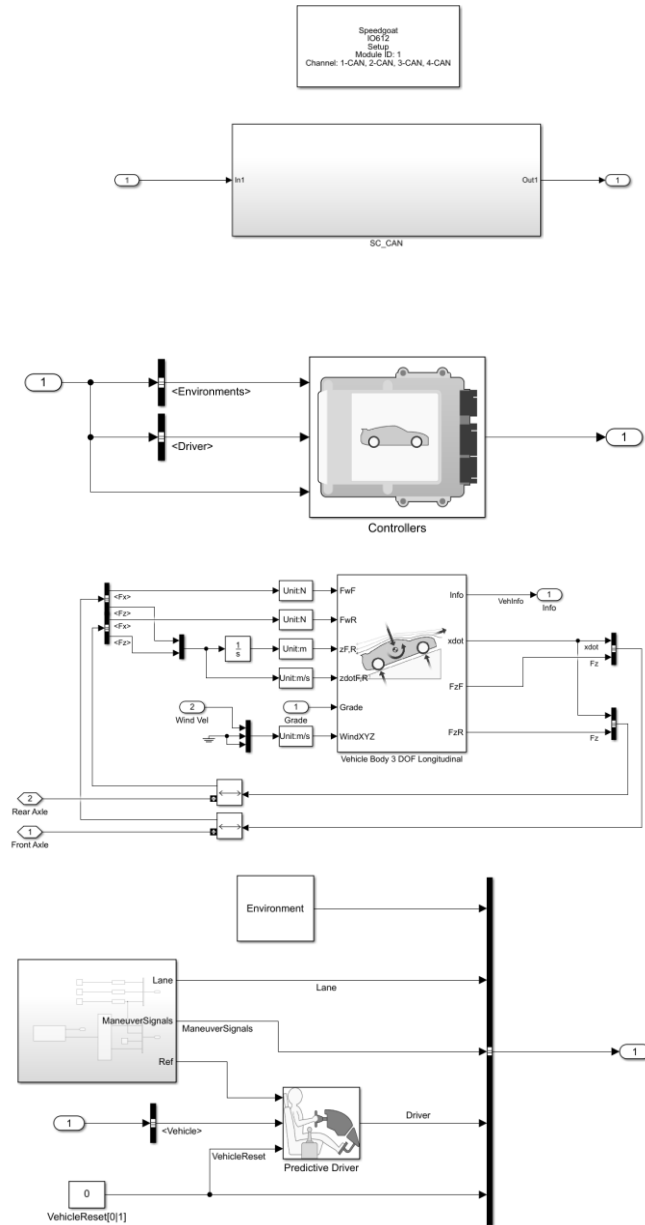
Virtual Vehicle 模型分布式仿真



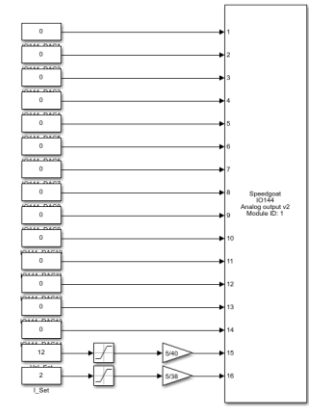
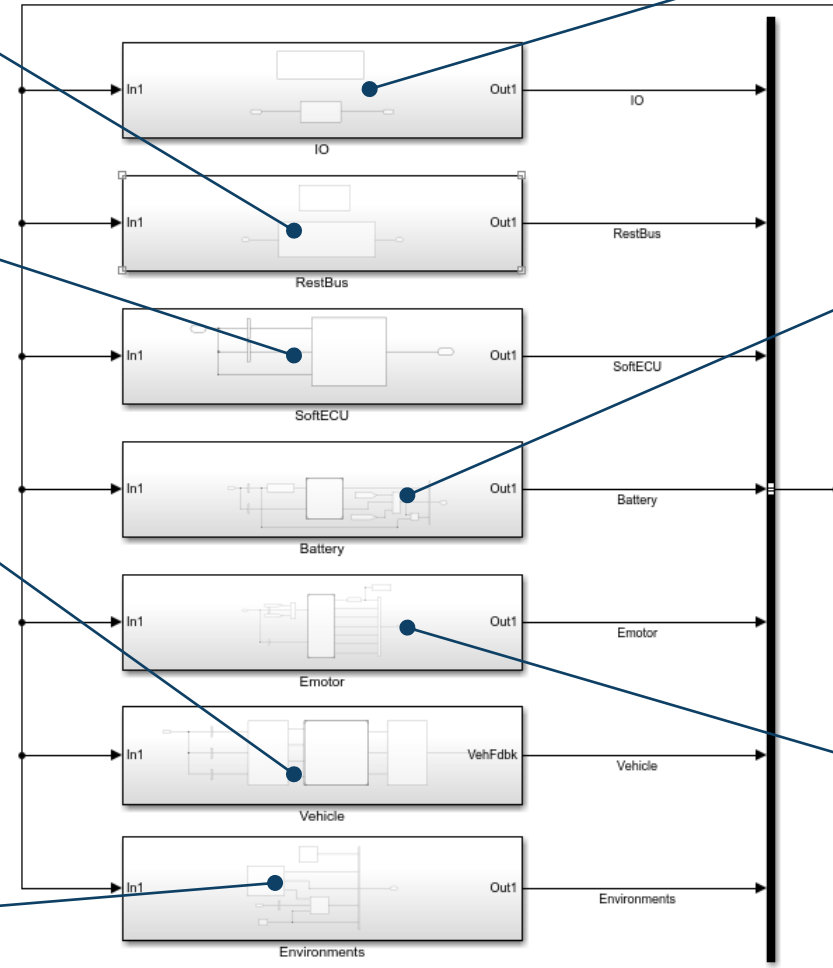
同步方式: Clock, Triggers (Shared Memory, PTP, GNSS, IRIG, PPS)

MCU HIL测试的虚拟车辆模型

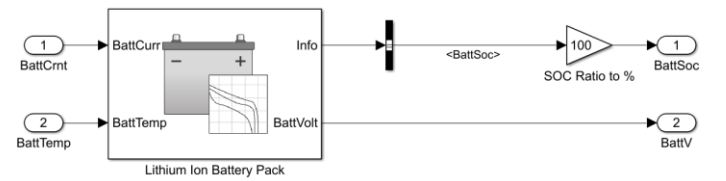
Powertrain blockset
Powertrain blockset
Powertrain blockset



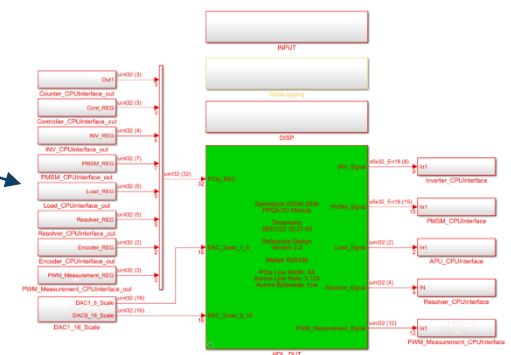
Speedgoat IO driver blockset



Speedgoat IO driver blockset



Powertrain blockset

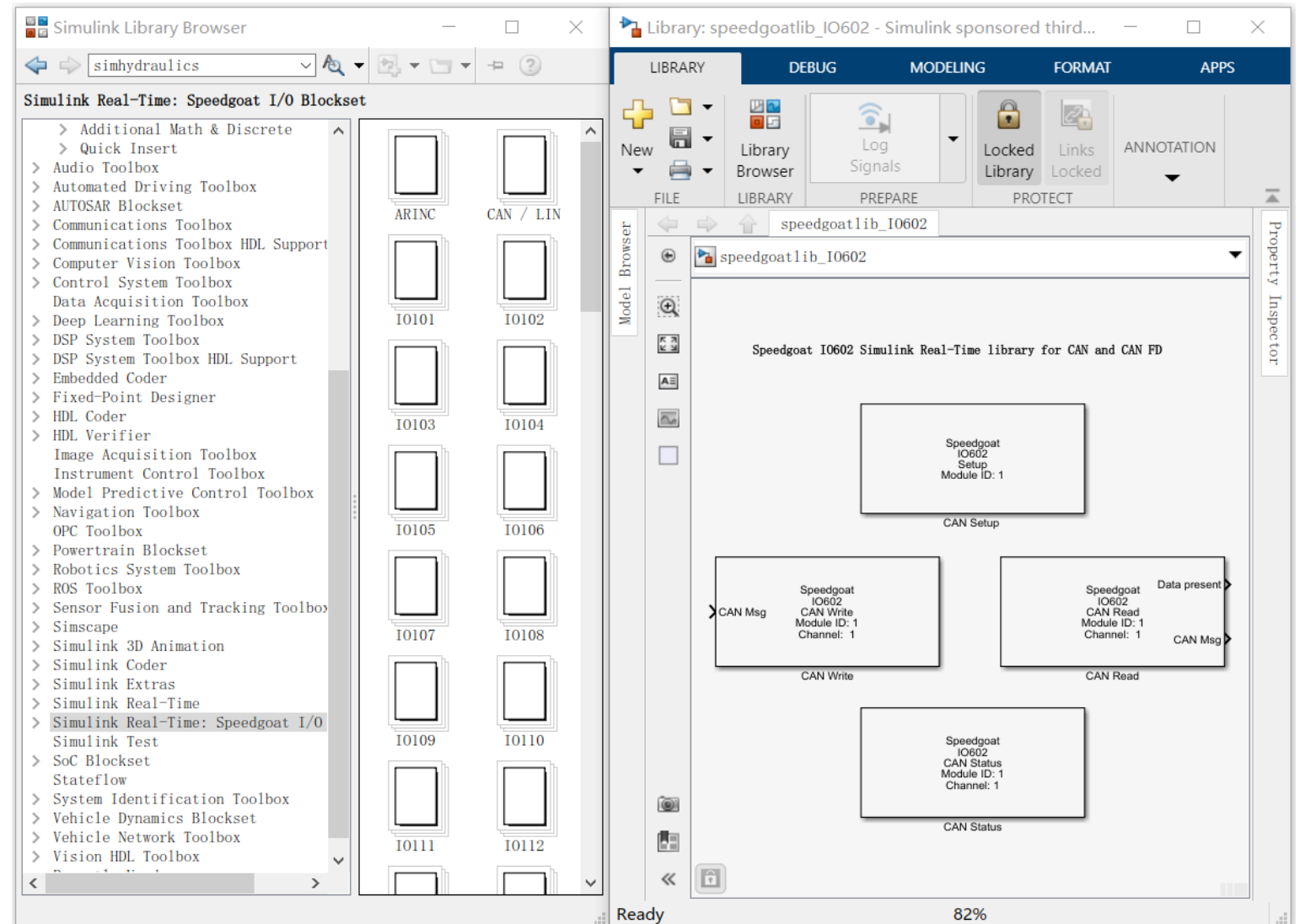


HDL Coder
Speedgoat HDL Coder Integration Package

IO配置: Speedgoat I/O Blockset (驱动库)

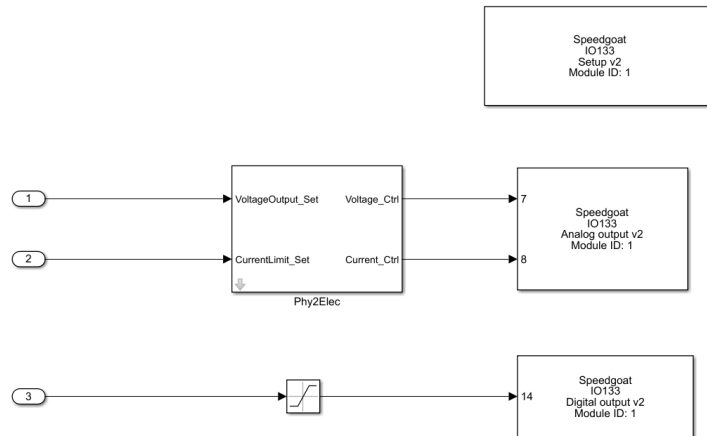
Simulink工具箱形式

- 硬件通道图形化
- 嵌入到Simulink的工具箱
- 没有license限制, 不限电脑
- 支持最新版MATLAB
- 拖拽方式引入到Simulink模型
- IO通道配置
- CAN、LIN、以太网等通讯配置

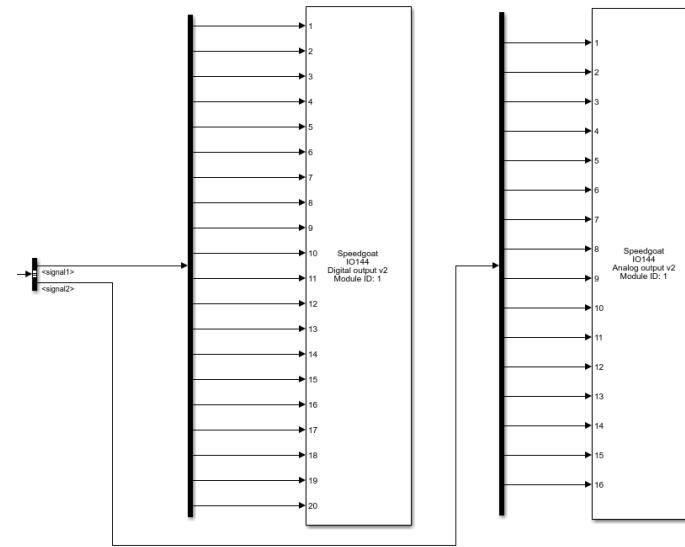


使用Speedgoat驱动模块将车辆模型与硬件通道关联

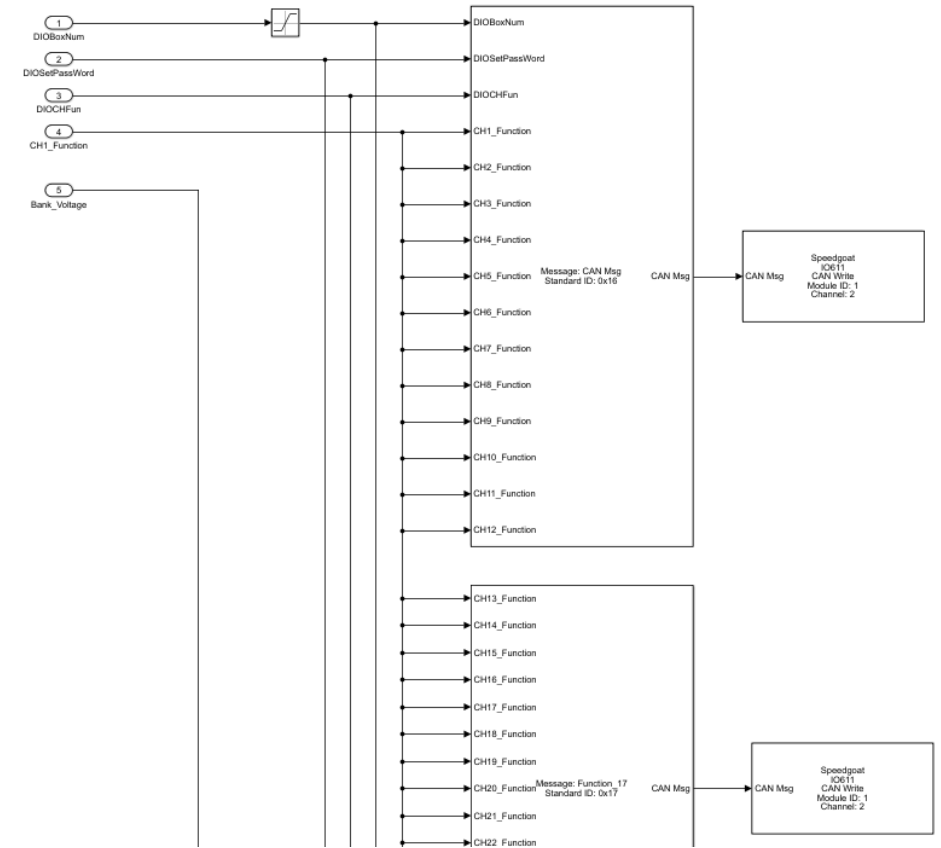
在Simulink环境下将车辆模型与控制器接口进行映射



程控电源控制模型



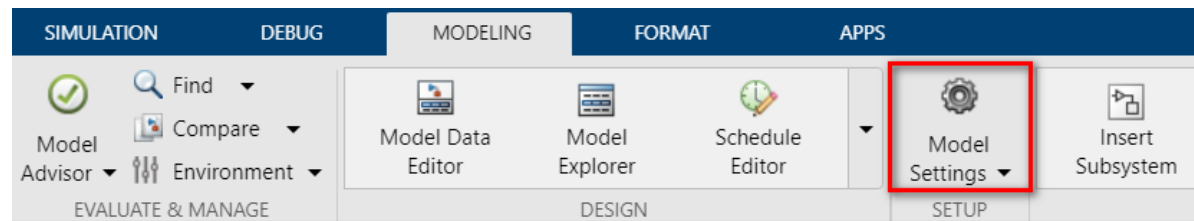
IO模型



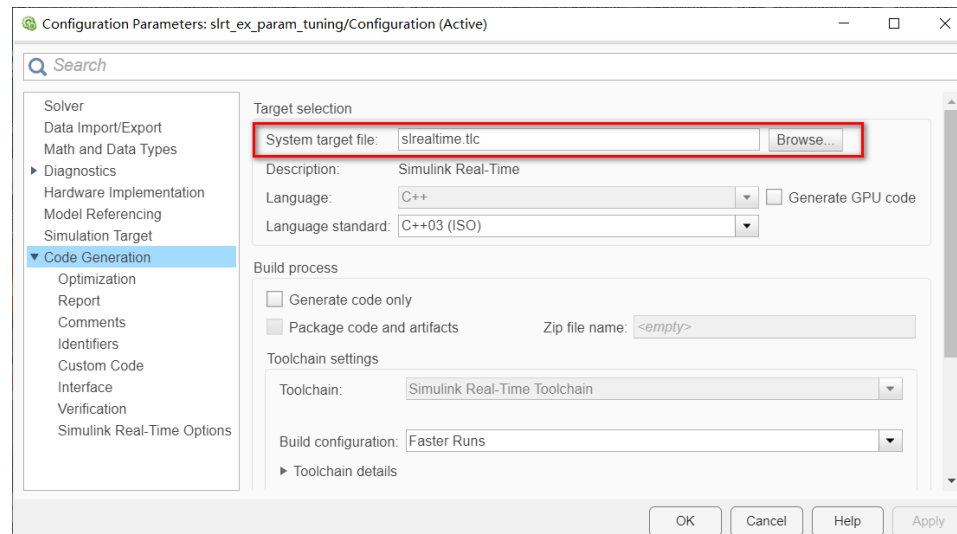
Restbus 模型

将HIL模型部署到Speedgoat实时系统中

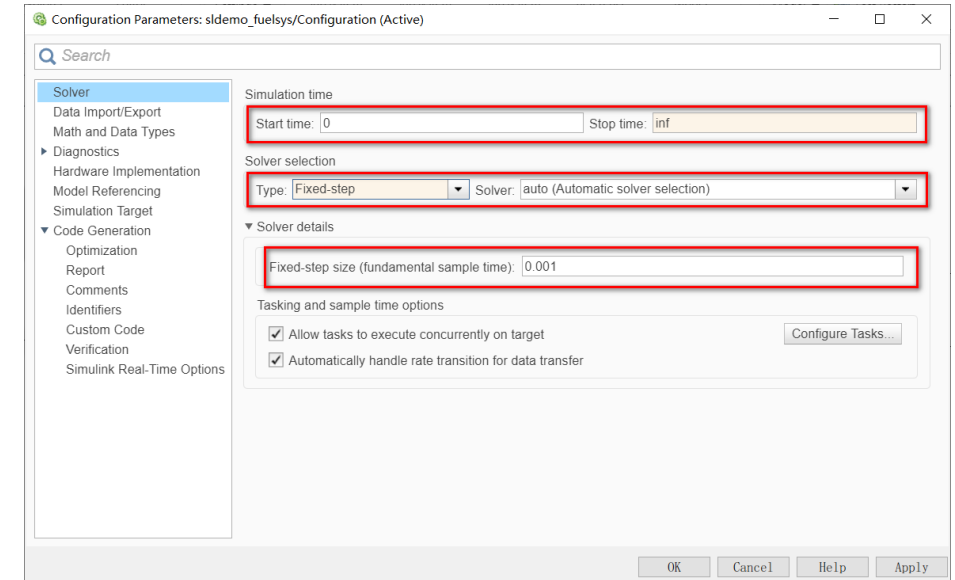
使用Simulink Coder/MATLAB Coder将模型生成代码



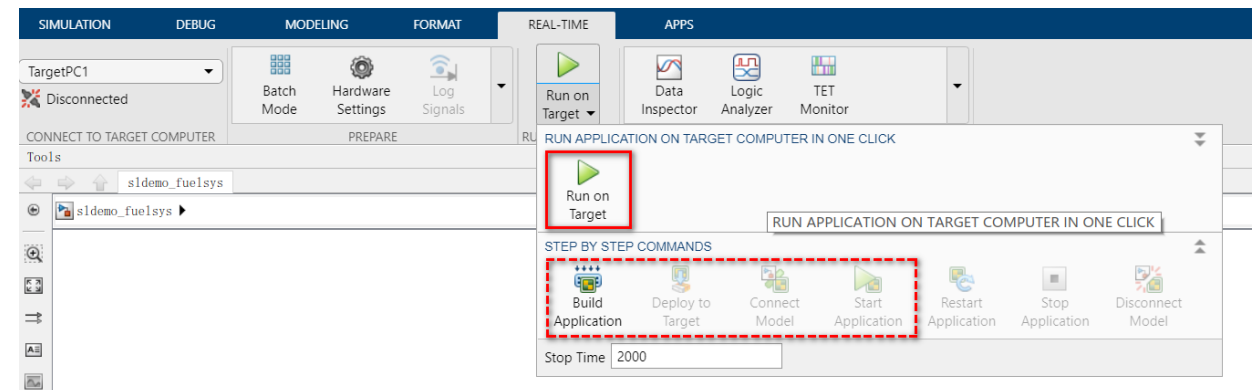
1. 打开模型参数配置界面



3. Code Generation配置



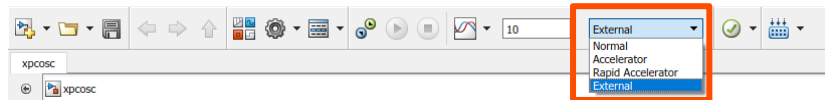
2. Solver配置



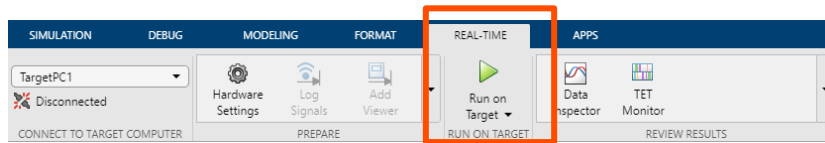
4. 模型编译和下载

试验管理方式1: Simulink External Mode (Real-Time Mode)

直接在Simulink模型中进行试验管理

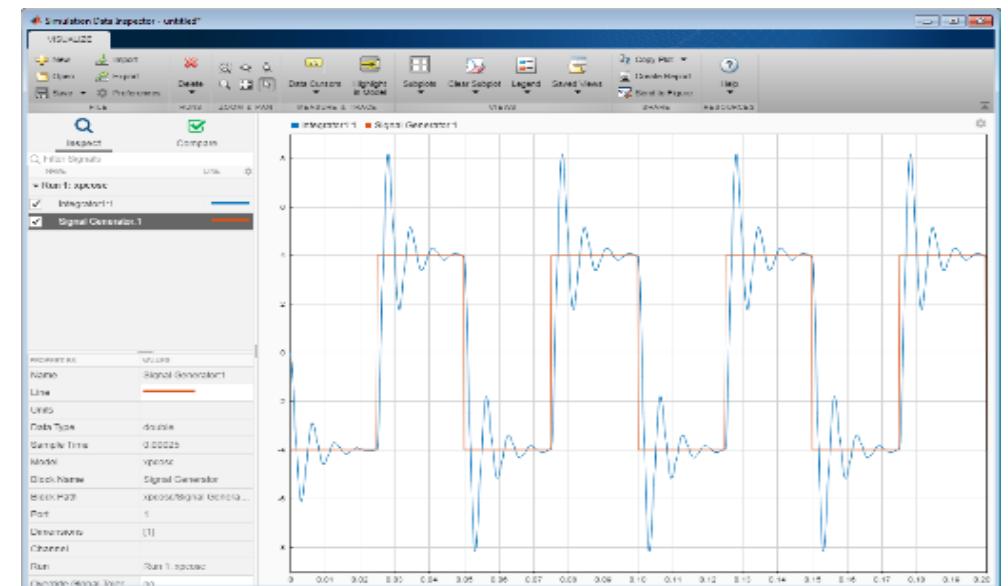
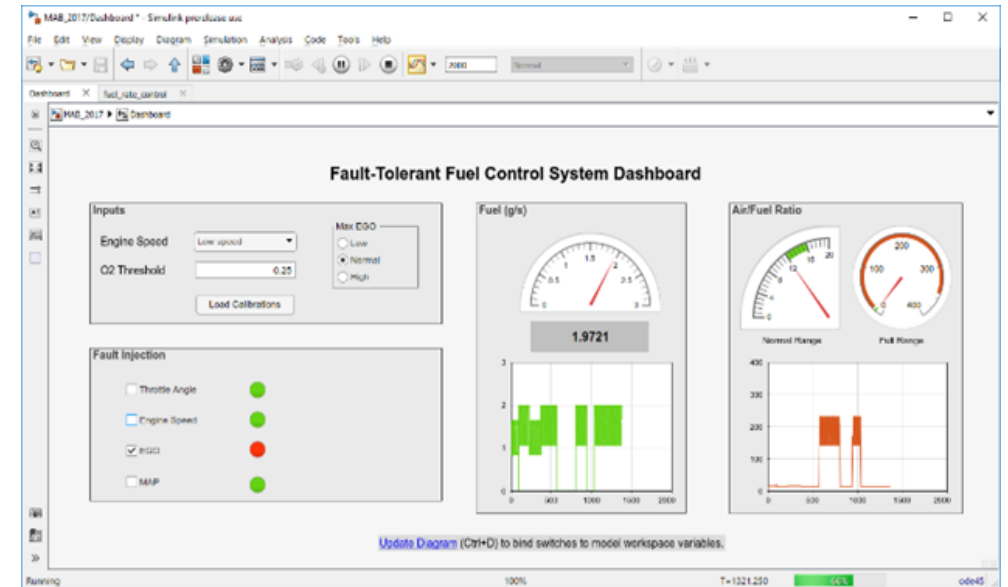


R2019a External Mode
and older



R2019b Real-Time Mode
and later

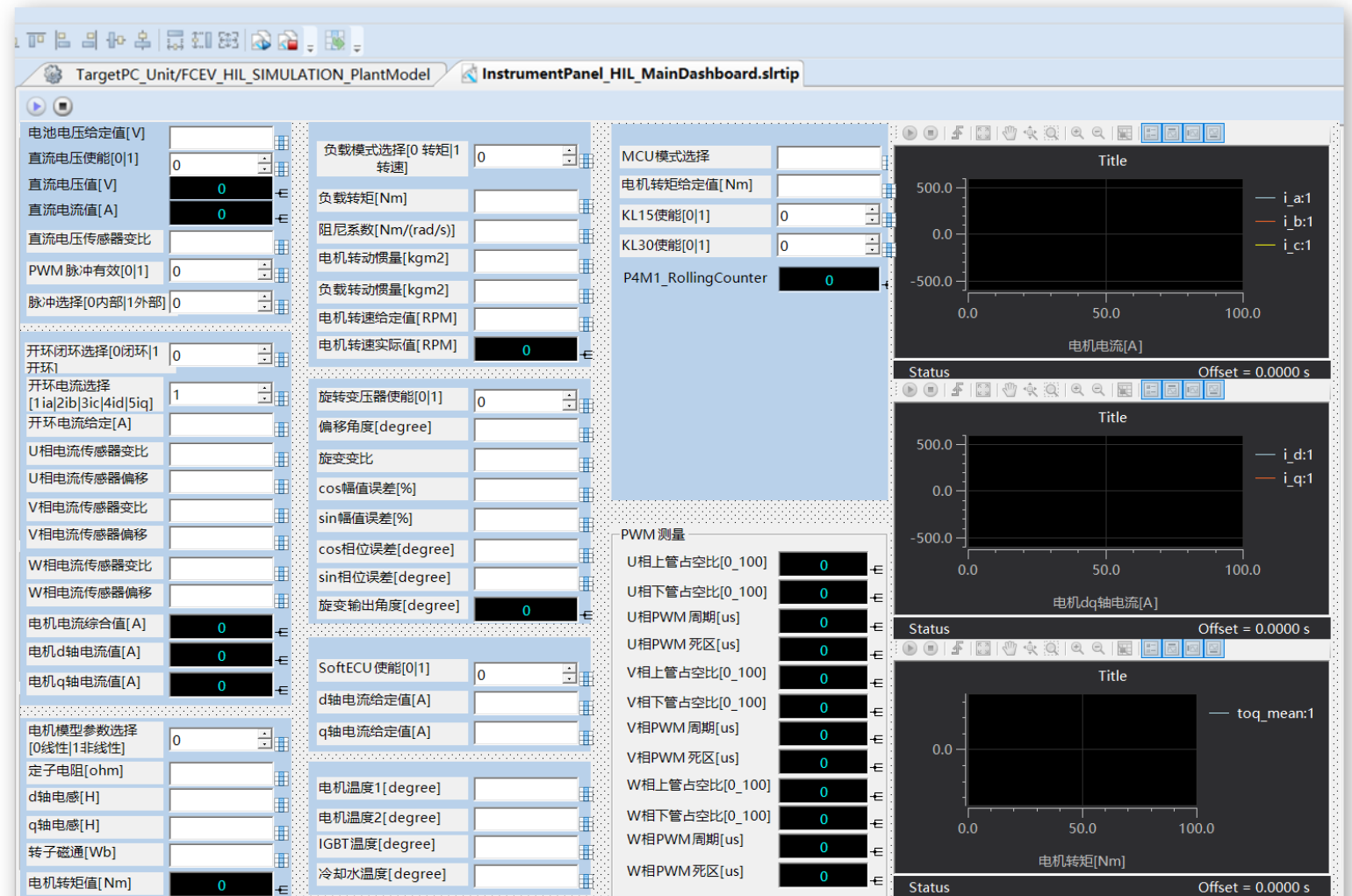
- 纯Simulink操作
- 在Simulink模型中实时调整模型参数
- 通过Simulink的Scope和数据Inspector实时观测模型信号
- 支持Simulink的dashboard工具箱搭建仪表化界面



试验管理方式2: Simulink Real-Time Explorer (R2020a及以前)

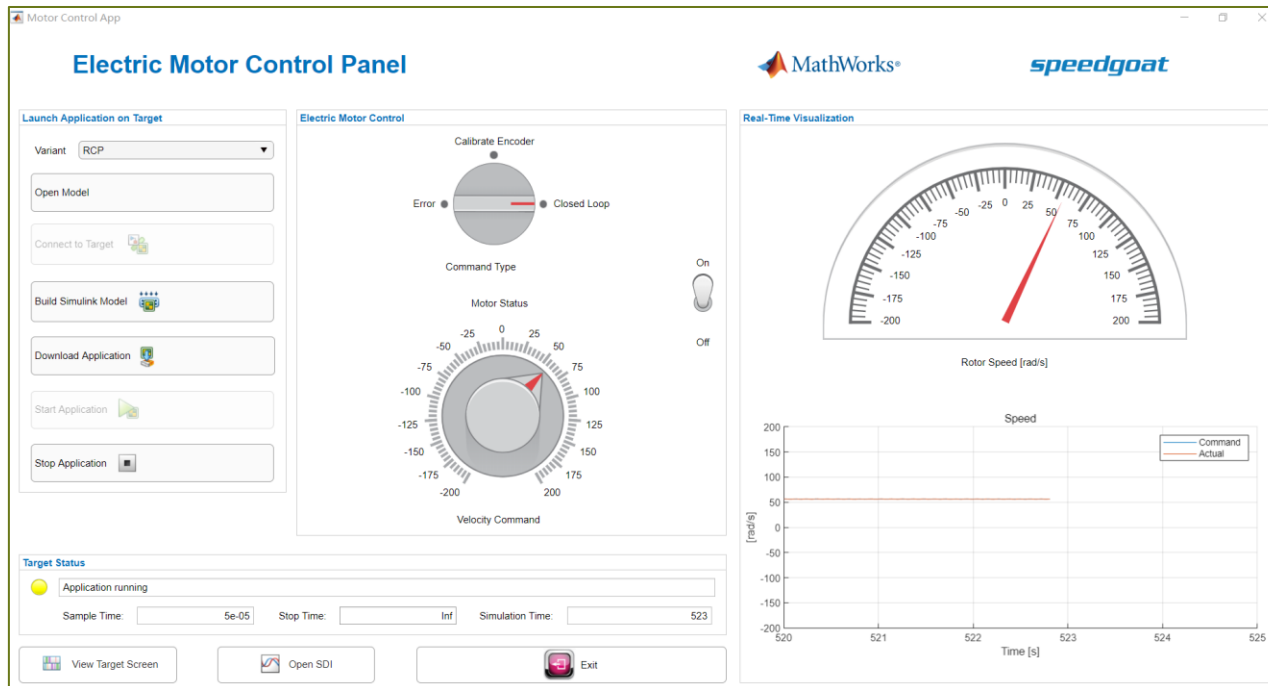
MATLAB自带的试验管理软件

- 包含于Simulink Real-Time工具箱
- 支持创建图形化界面
- 实时调整模型参数
- 实时观测模型信号
- 保存模型运行数据
- 支持导出可执行的exe文件

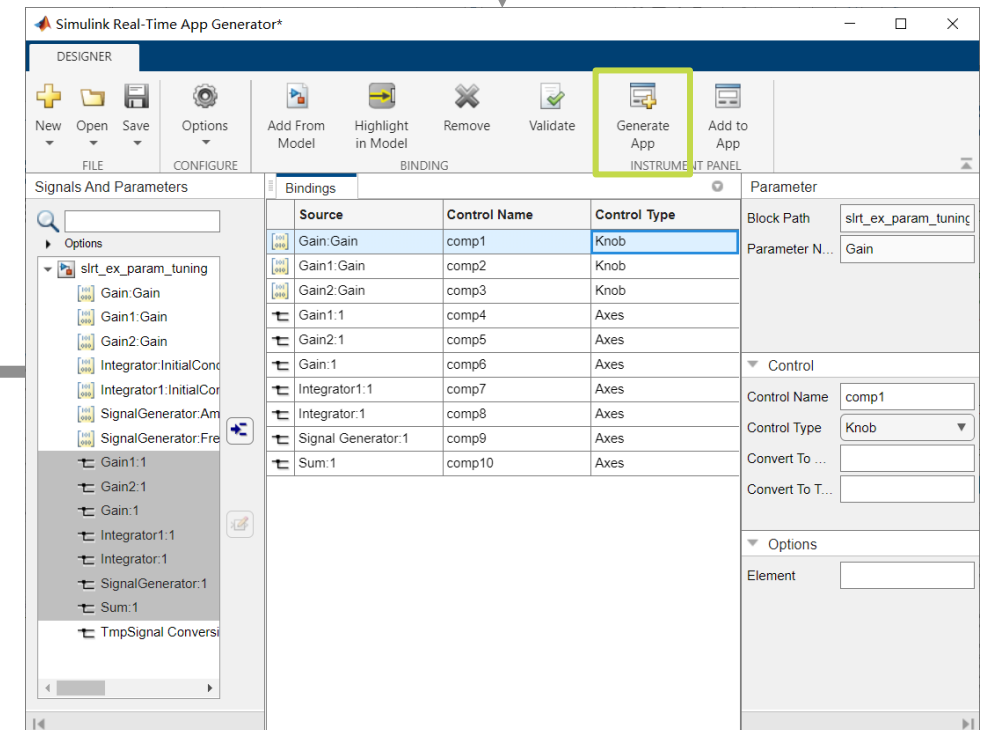
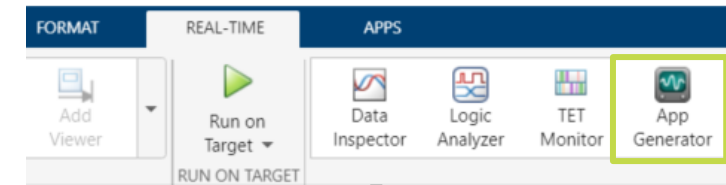


试验管理方式3: MATLAB App Designer

定制个性化试验管理界面

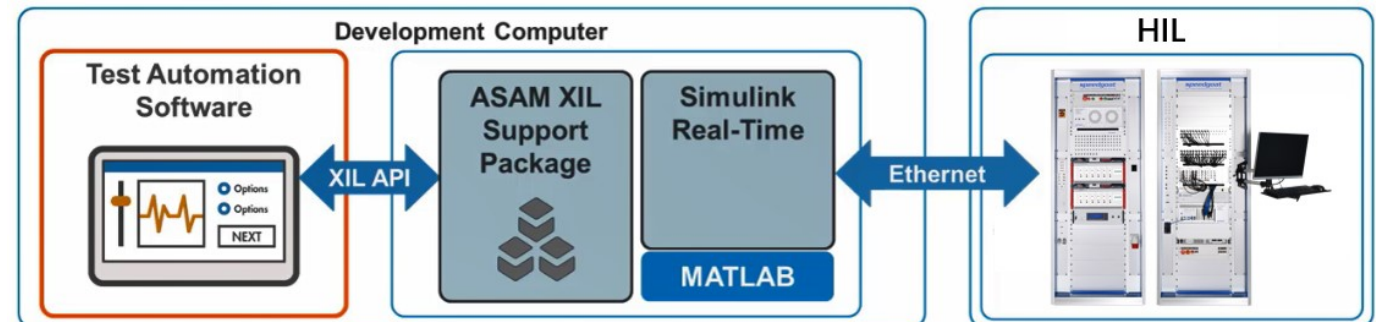
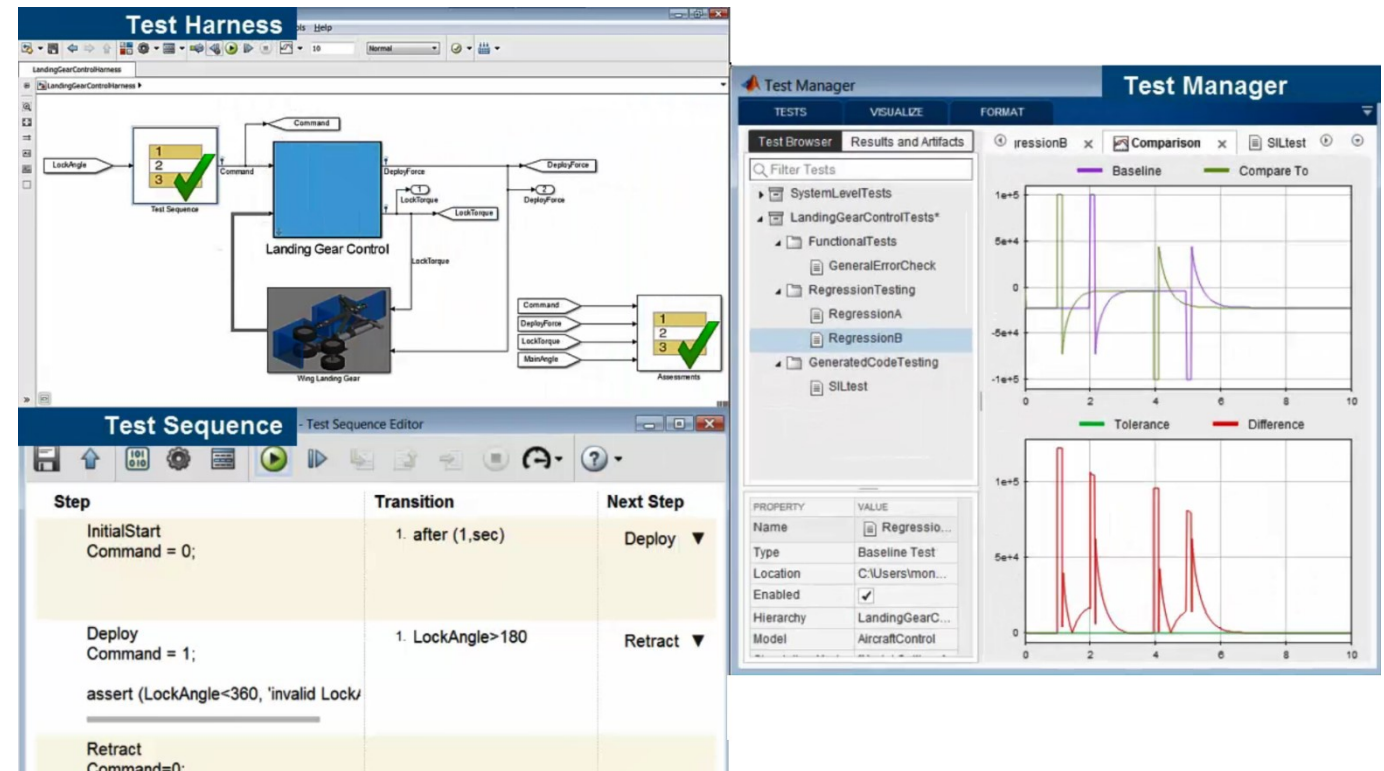
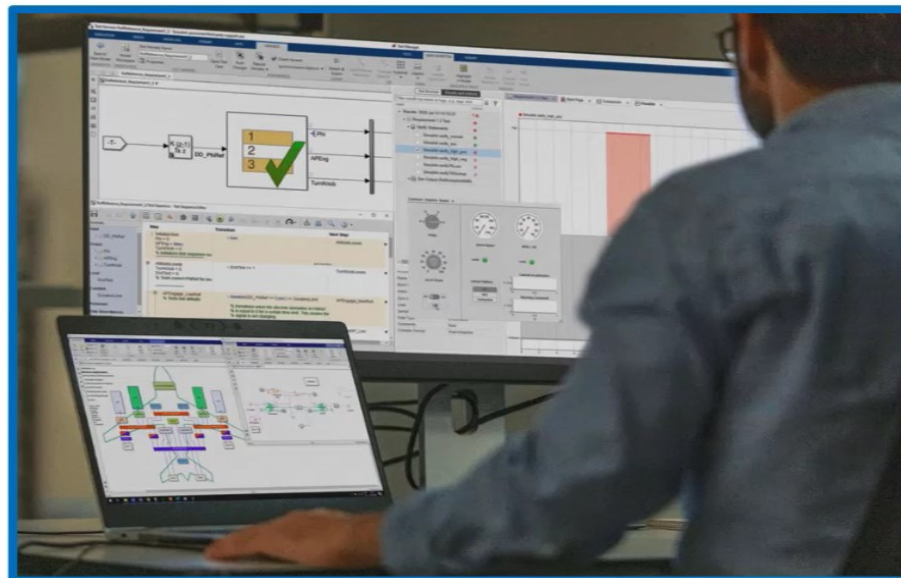
MATLAB App Designer
(standalone supported with MATLAB Compiler)



自动化测试: Simulink Test

MATLAB的自动化测试软件

- 支持MIL、SIL、HIL, 复用测试用例
- 支持ASAM XIL API
- 支持Python、C#、m语言等
- 支持Excel编写测试用例
- 自动生成Word、PDF、HTML格式的测试报告

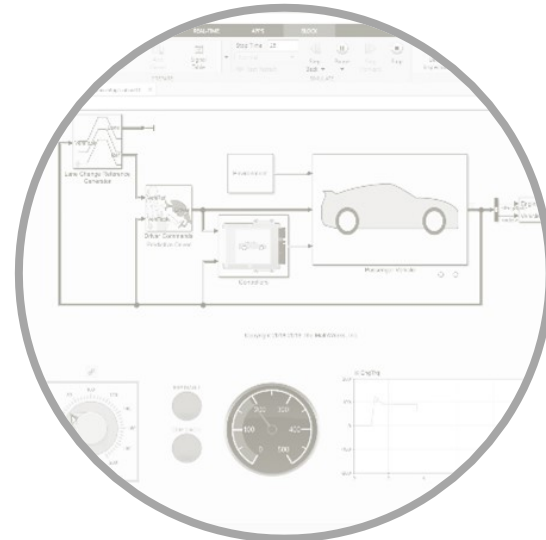


Part I



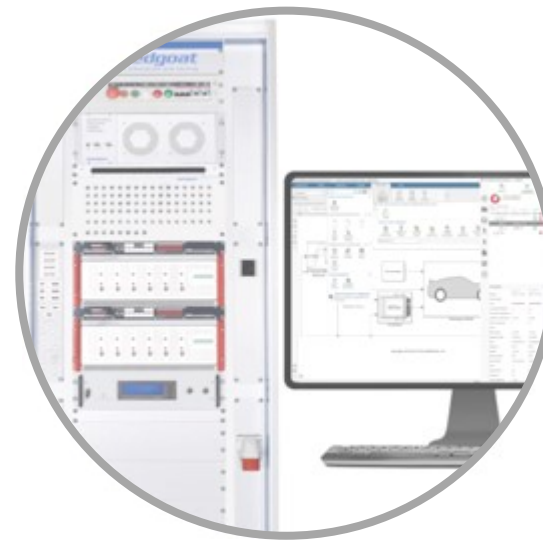
车辆HIL系统

Part II



虚拟车辆模型

Part III



HIL测试实现

Part IV



Q&A

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Thank you



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