Full modeling of an encoder for real-time testing

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Outline

1. Key Takeaways

Key Takeaways

1. Model-Based Design achieves preservation, protection and sharing of Intellectual Property while softening the team learning curve.
2. MathWorks toolset extensibility and its comprehensive libraries support the integral modelling of complex products, even for those comprising communications in a distributed control system.
3. Investment in modeling and analysis pays off in subsequent validations when using automated model-to-code converters.
4. Selection of the right modeling guidelines is key to avoid costly rework when targeting a specific heterogeneous platform.

2. Overview of Organization and Business

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Overview of Organization and Business

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Business Units

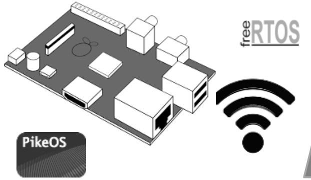
- **Electronics, Information and Communication Technologies**
- Advanced Manufacturing, Energy and Power Electronics

Knowledge Areas

- Hardware and Communication Systems
- **Dependable Embedded Systems**
- Industrial Cybersecurity
- Information and Communication Technologies

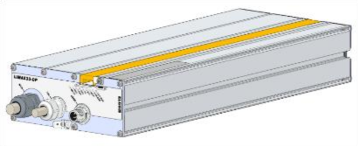
Specialisation Teams

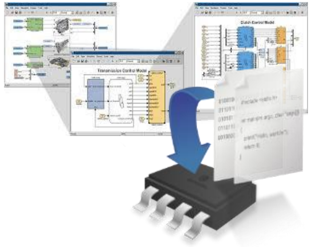
- **Real-Time Systems**
- Dependable Software



Partnership in Elevator Safety Project

- **Orona Group: Elevator manufacturer**
  - Distributed elevator control system
  - Elevator system concept and safety
  - Final integrator
- **Elgo: Safety sensor manufacturer**
  - Absolute encoder with integrated functional safety for elevators
- **Ikerlan: Technology partner**
  - MBD of real-time elevator simulator
  - Development of safety concept
  - Verification, Validation and Testing (VVT)





3. Innovation Challenges and Achievements

Context of the Project

Integration of new safety devices into an elevator controller

- Absolute position encoder with CAN bus and CANopen interface
- Encoder with safety functions
- Electronic Safety Gear

Fast pace of product updates

- Impact analysis eased if models of safety sensors and actuators can be integrated within an overall model of the safety concept

Limited availability and variability of test elevators and mockups

- Physical constraints on achievable elevator configurations
- Position encoding technology implies a lab mockup that requires CAM motion control that could accelerate sensor wearing down

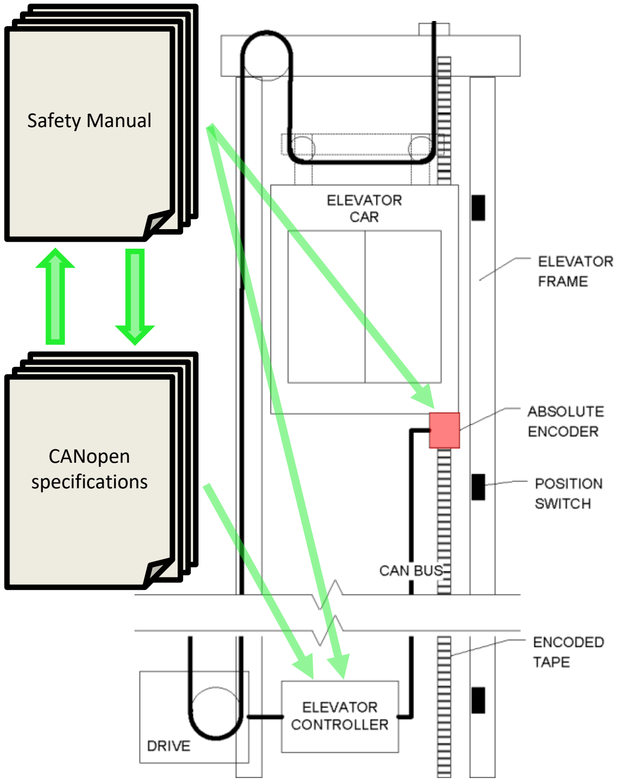
Challenges

Fast evolution of safety-devices

- Need to cope with evolving specifications
- Iterations with multiple prototypes

Compliance with specification models

- Multiple cross-referred document sources with potential mismatches
- How to plan and demonstrate the achievable safety rating?
- How to evaluate system modifications or replacement of obsolescent devices?



4. Why did we opt for MathWorks?

Why did we opt for MathWorks?

Hardware-in-the-Loop Elevator Simulator (HiLES)

- Cornerstone tool for integration and regression testing of controllers
- Up to 4 generations of simulators based on different RT platforms
- Each generation added complexity and platform-specific optimizations
- More accurate timing of simulated signals lead to heterogenous HIL HW
- Reverse engineering of SW-coded functionality became impractical

Model-based re-design with Simulink/Stateflow

- Decouple functionality from platform to ease migration to new HW
- Eases unit testing and stepwise integration
- Facilitates composition with new simulation capabilities
- Optimize for target HIL platform later once functionality is stated
- Highly automated model-to-code transformation

5. Adopted Solution

Incremental Approach to MBD

1. **Simulink modeling of conventional position sensors**
   - ✓ Position switches
   - ✓ Quadrature encoder (HDL synthesizable, FPGA deployment)
2. **Simulink modeling of an absolute encoder with CAN interface**
   - ✓ Simulate an Elgo LIMAX 02 device
   - ✓ Compliant to CiA 301 and CiA DP 406 CANopen standards
   - ✓ HDL Coder synthesized and deployed on FPGA. CAN timing accuracy: 1 µsec
3. **Simulink modeling a safety abs. encoder with CAN interface**

   Ongoing
   - Simulate an Elgo LIMAX 33 CP device with safety functions
   - CiA 301, CiA DP 406 and manufacturer-specific object dictionaries

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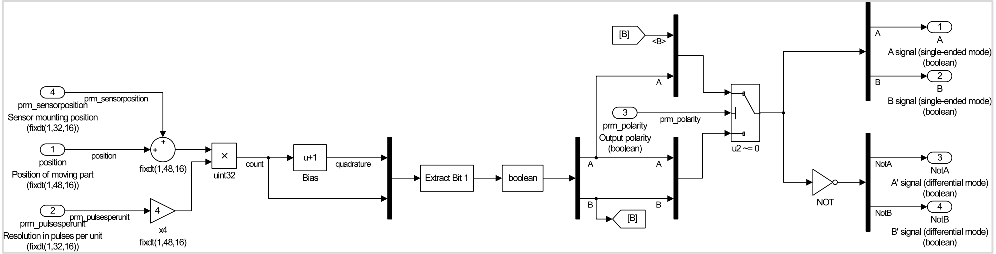
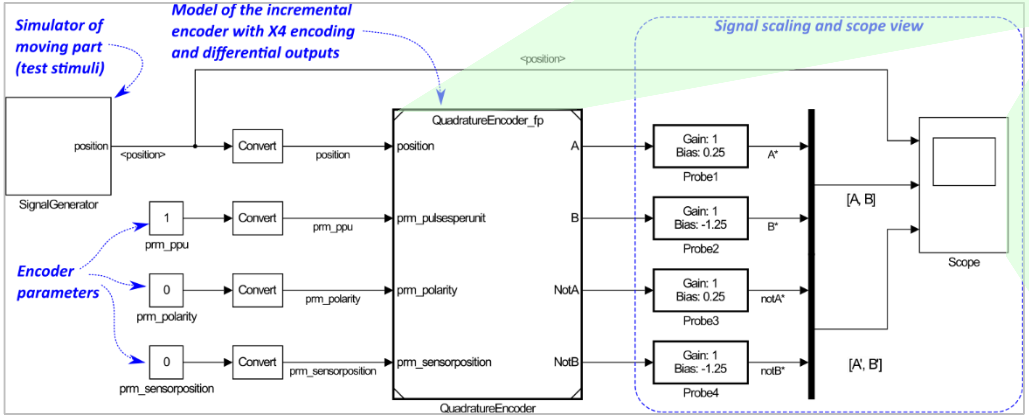
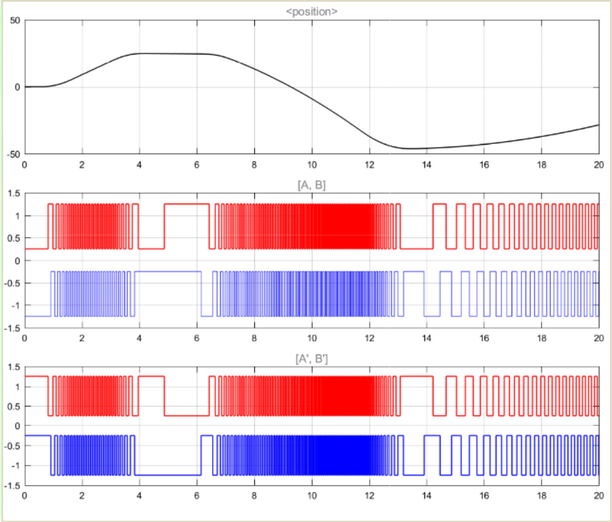
Conventional Elevator Position Sensors

1. Conventional Sensors

- Position switches
- Quadrature encoder
- Synthesizable
- Valid for $v_{elevator}$ < 10 m/sec







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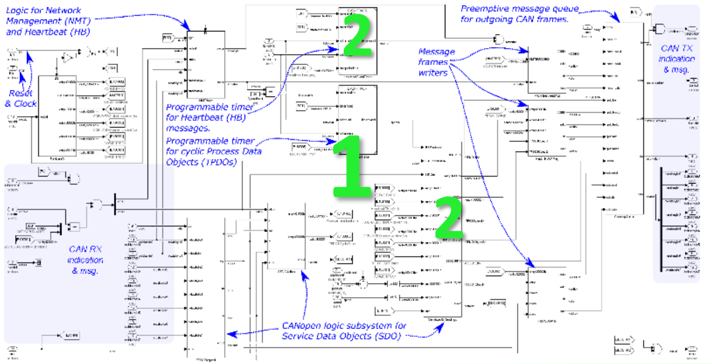
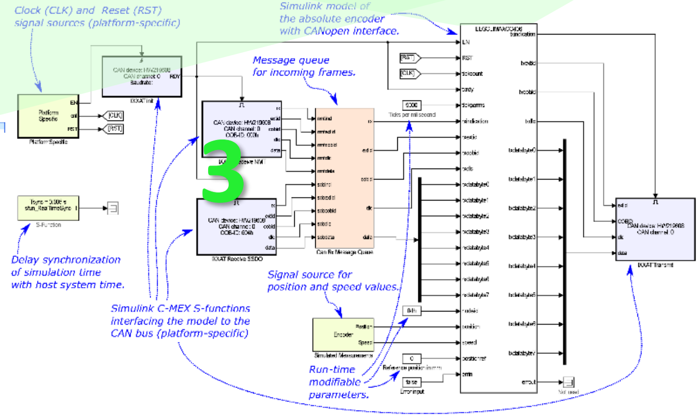
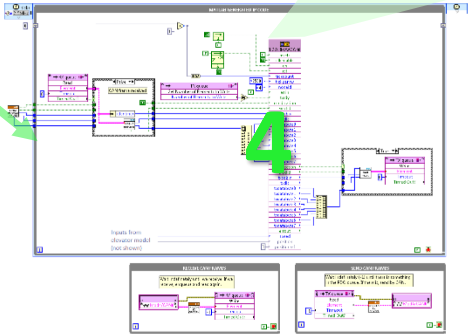
Absolute Encoder with CANopen Interface

2. Elgo LIMAX 02 encoder

- Sensor and communication functions modelled in Simulink (1)
- Standard CANopen CiA 301 and CiA DP 406 profiles implemented (2)
- First validation by host simulation in Model-in-the-Loop and real CAN (3)
- Model coded with HDL Coder, synthesized and deployed to FPGA (4)







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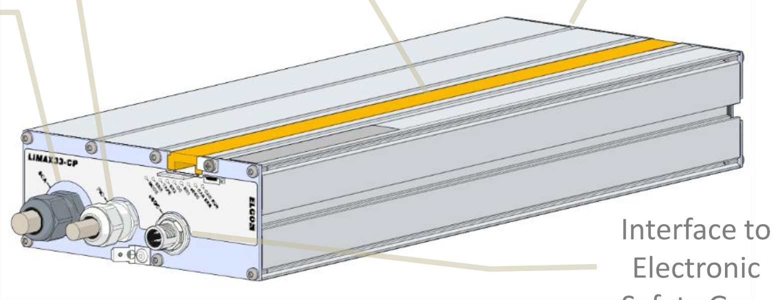
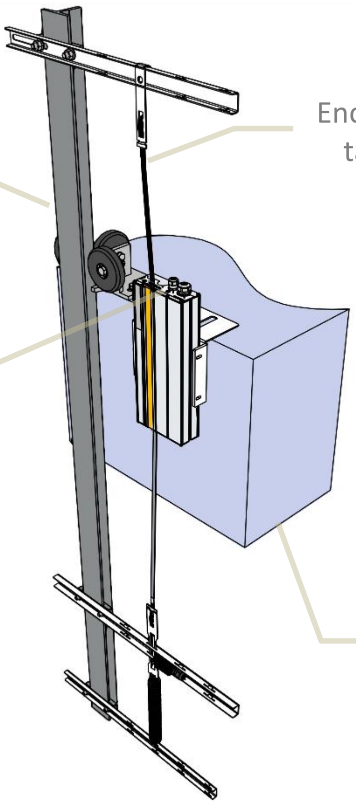
Absolute Encoder for Safety Elevator Applications

3. Elgo LIMAX 33 CP encoder

- Simplifies elevator installation
- Reduces system start-up time
- SIL3 certification achievable



Elgo LIMAX 33 CP encoder (detail)



Encoder mounting example

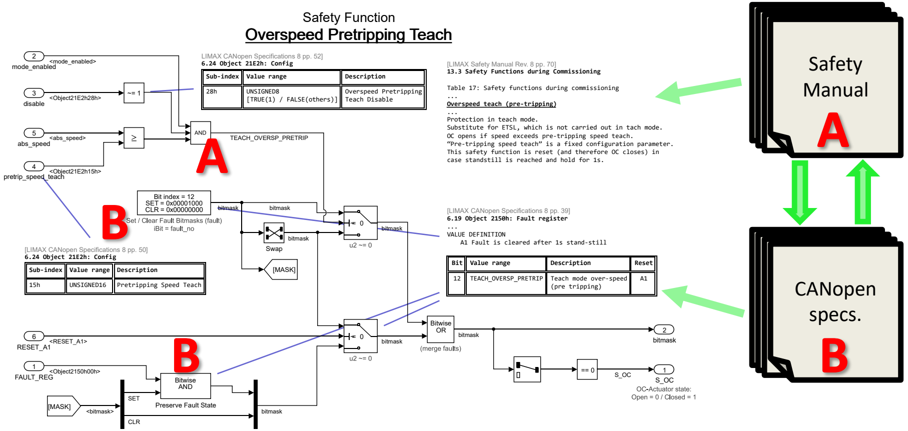
Absolute Encoder for Safety Elevator Applications

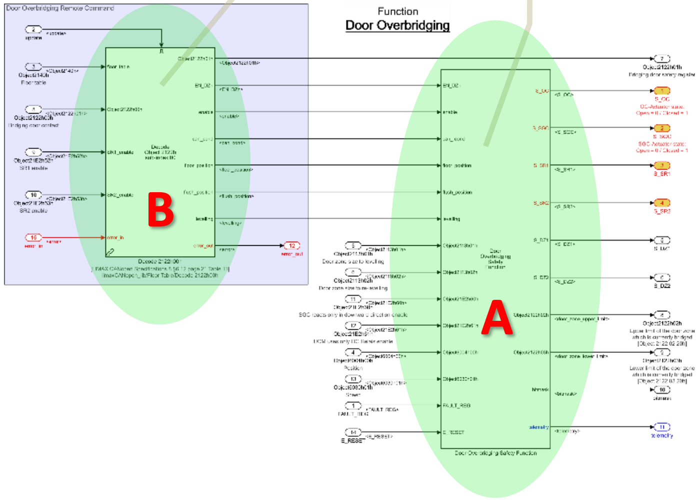
3. Elgo LIMAX 33 CP encoder

- Two coupled models: Safety and Communications
- Extended communication object dictionary (circa 1k variables)→Deployment hampered by FPGA constraints!

CAN event-driven fcn.
(from CANopen library)

Discrete-time safety fcn.
(from safety library)

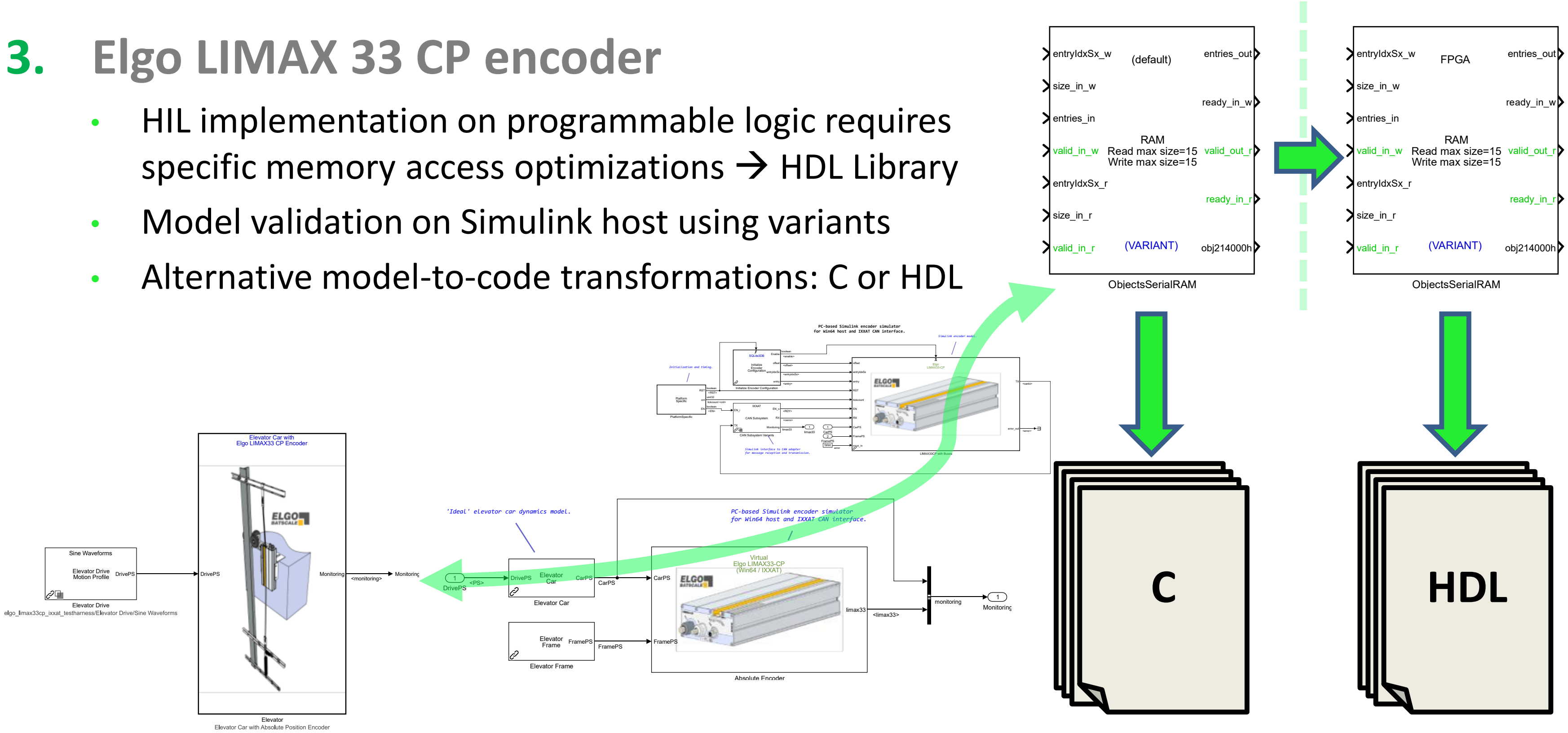




Absolute Encoder for Safety Elevator Applications

3. Elgo LIMAX 33 CP encoder

- HIL implementation on programmable logic requires specific memory access optimizations → HDL Library
- Model validation on Simulink host using variants
- Alternative model-to-code transformations: C or HDL



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Achievements using MBD

Reusable assets for what-if scenarios

- Adaptation to changing specifications while components evolve
- Enable exploration of alternative solutions

“Survival-kit” for long-term maintenance

- Reference for safety-critical system with expected operation life-term > 20 yr
- Eases the evaluation of system modifications or replacement of obsolescent devices

MathWorks Toolset
MATLAB
Simulink
Simulink Coverage
Stateflow
Simulink Coder
Embedded Coder
HDL Coder
HDL Verifier

6. Concluding Remarks

Best Practices and Lessons Learnt

Best Practices

- Develop models and simulation model harnesses concurrently
- Get system and FPGA experts in-touch as early as possible
- Test frequently for correctness of models
- Test models for model-to-code transformation after modelling a new feature

Lessons Learnt

- Model partitioning from a system viewpoint can lead to models unfeasible for real-time FPGA implementations
- Hardware and timing constraints for real-time implementations shall be considered in advance to address performance bottlenecks or optimize the hardware resources required to compute the functionality in time

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Forward-looking Plans

1. **Integrate communications and safety models**
   - Verify correctness of the assembled model throughout MIL / SIL
   - Synthesize with HDL Coder and check satisfiability of resource and timing constraints for the Programmable Logic
2. **Deploy to real-time heterogeneous HIL testbench**
   - If necessary switch to fallback solution using Embedded Coder to deploy communications on a Processor
3. **Use Simulink & Stateflow to refine the elevator safety concept**
   - Support extended analysis with executable specification models
   - Ease future product evolution of the safety system

THANK YOU

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QUESTIONS

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