Early Robustness Validation of Automotive FlexRay Topologies through a Simulation-Based Method

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Overview

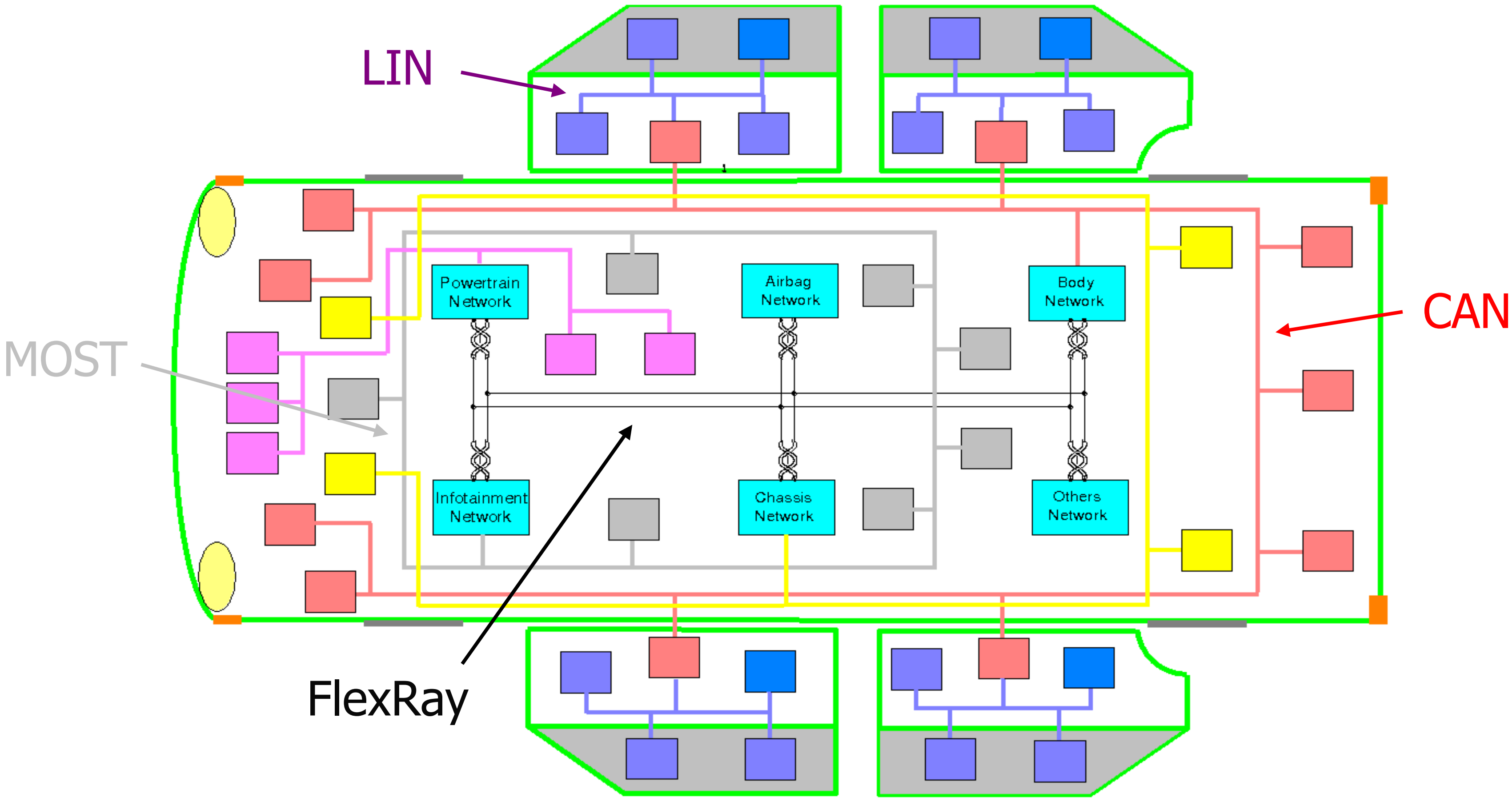
- Introduction & Motivation
- Robust Design Method & Models
- Critical Points of FlexRay‘s EPL
- Application Example
- Summary

Introduction
FlexRay Protocol

- New In-Vehicle Networking standard
- Developed for safety-relevant applications like x-by-wire and control systems
- Time triggered communication cycle (real time condition)
- High-speed transmission rate (10 MBit/s)
- Fault tolerant behavior (Dual channel)

Introduction

Future In-Vehicle Network Architecture



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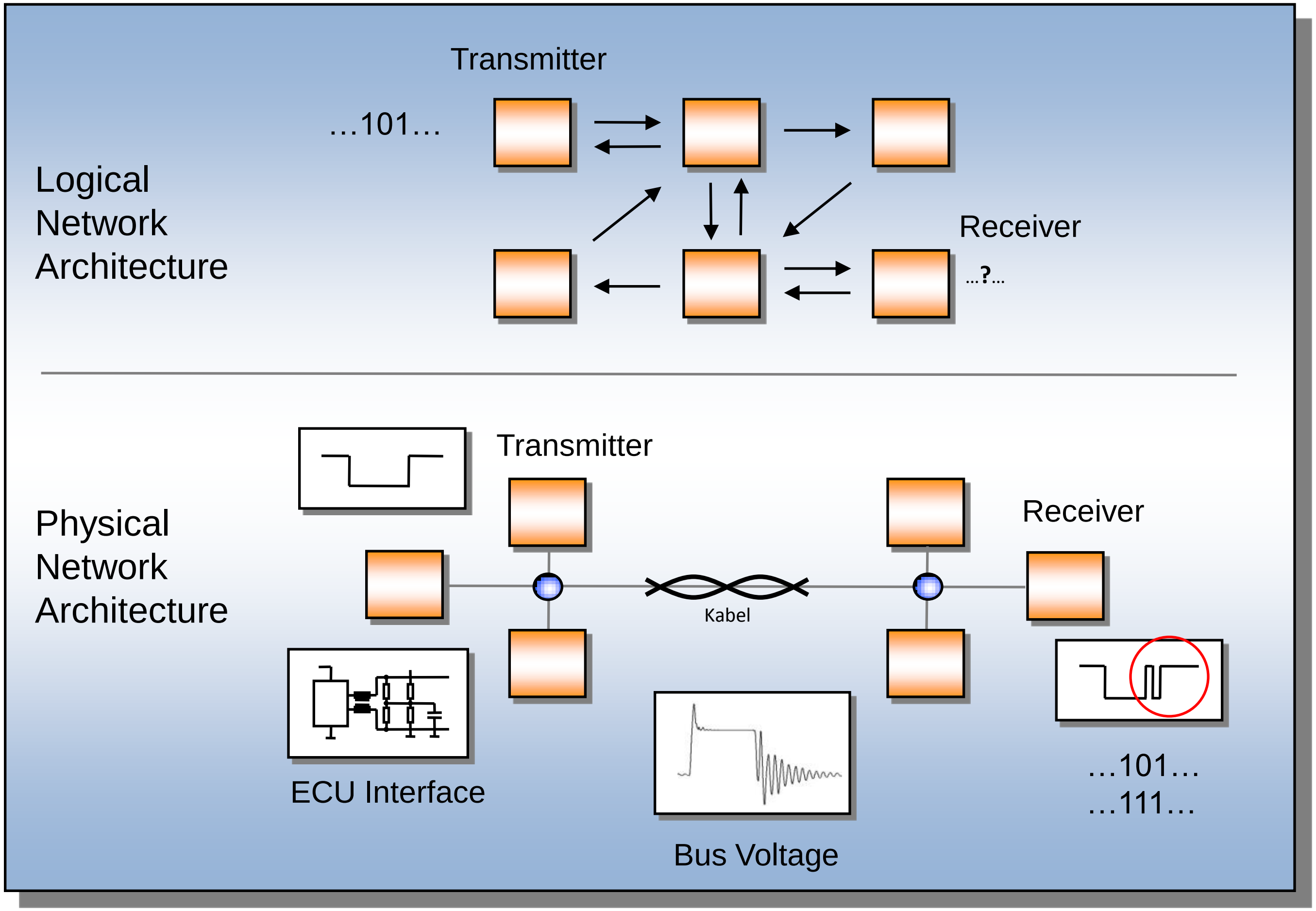
Basics

Logical vs. Physical Network Architecture



Motivation

FlexRay EPL Topology Challenges

- Topology guidelines
  - FlexRay‘s EPL specification provides rough guidelines
  - EPL spec kept flexible for system optimization
  - Analysis of EPL criteria requires the validation of the specific topology
- Different architecture compromises
  - Active/Passive star
  - Linear bus
  - Central/decentral termination
- Impact on signal integrity no longer predictable

Motivation

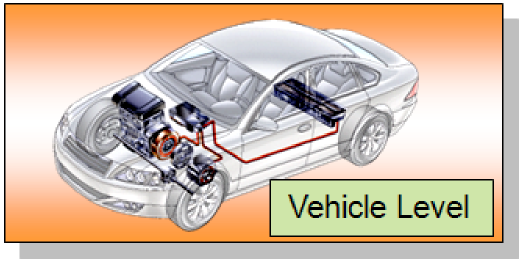
FlexRay EPL Topology Challenges (2)

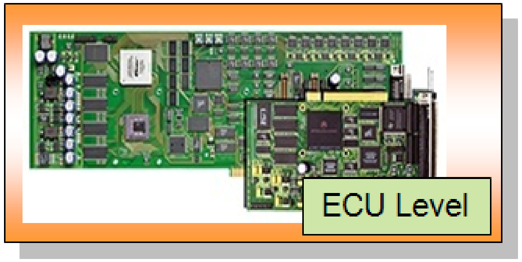
- Variants
  - Number of ECUs depends on vehicle equipment
  - Not all variants are available before Start Of Production (SOP)
- Changes
  - Cost intensive
  - Time consuming (critical when close to SOP)
- Simulation is the only choice to sufficiently evaluate topologies in the early development phase

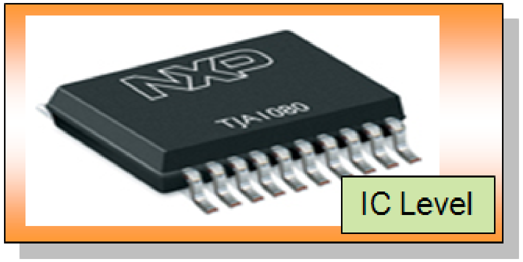
Basics

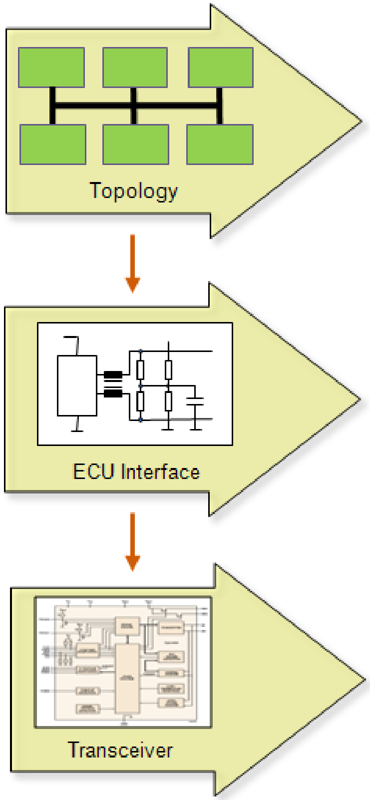
FlexRay Topology Verification

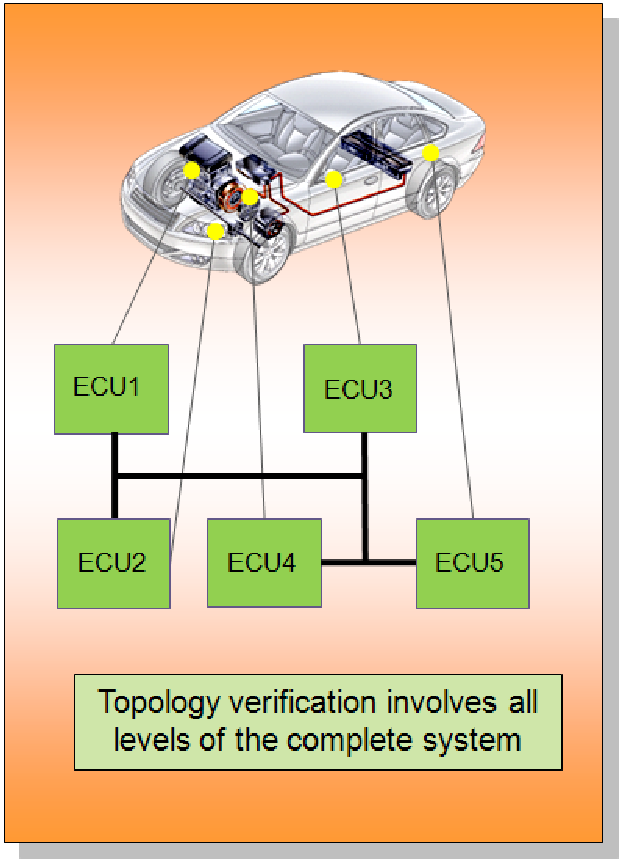
Aplication Level | Level Specific Abstraction | Physical Layer Topology Verification





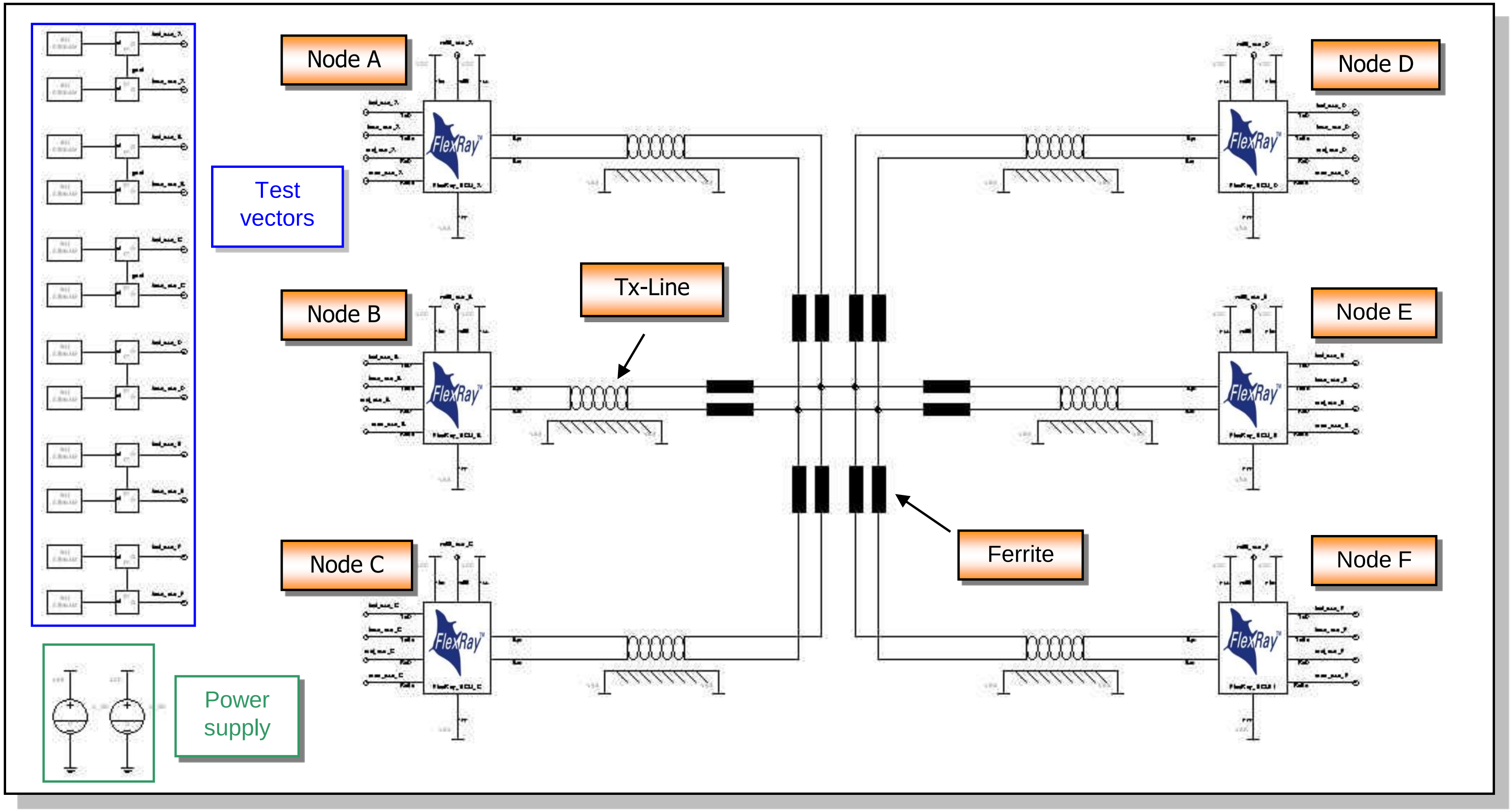






Basics

Overall Goal – FlexRay Physical Layer



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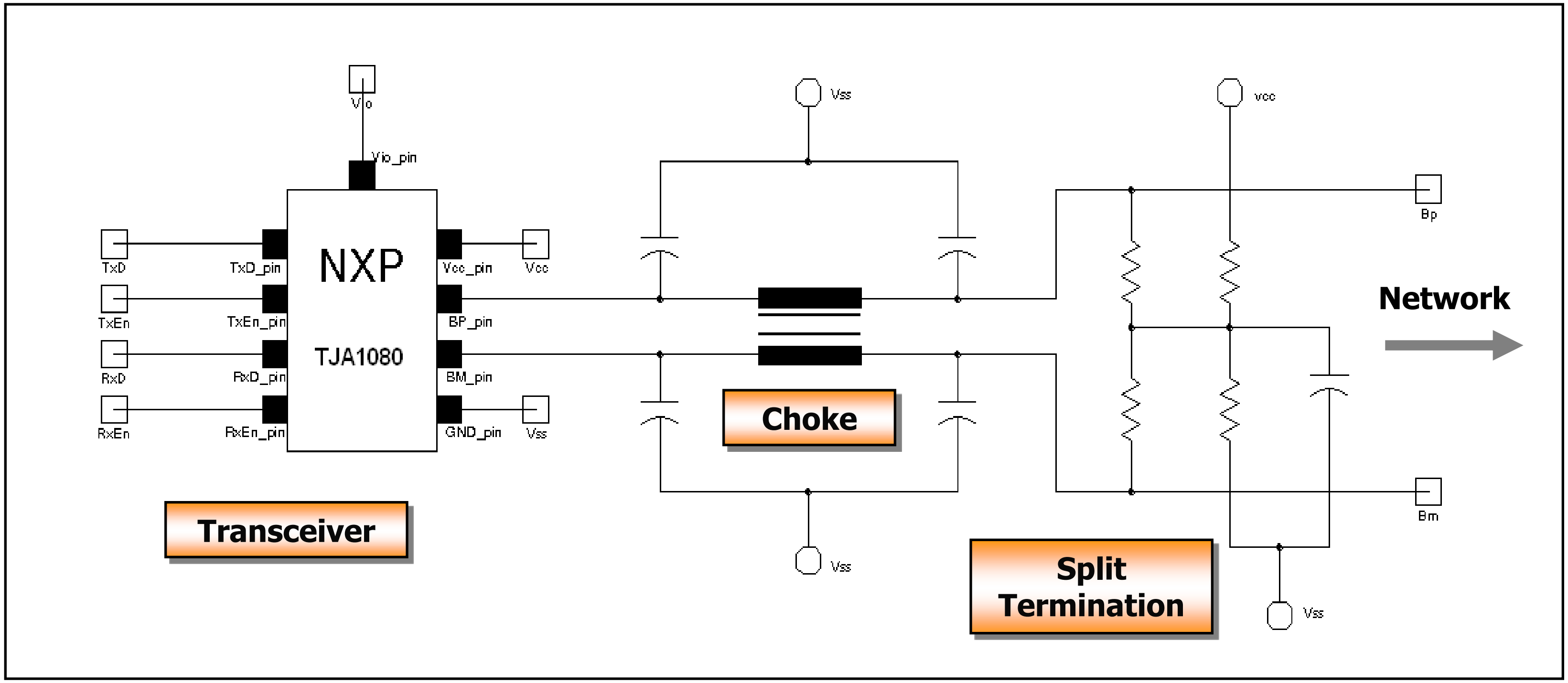
Simulation

Simulation Environment & Models

- FlexRay network simulated in Saber
- Required simulation models
  - ECU
    - Bus interface (analog)
    - Transceiver
    - Common mode choke
  - Transmission line
  - Ferrites
- Models based on MAST Hardware Description Language (HDL)

Simulation

ECU Interface Model



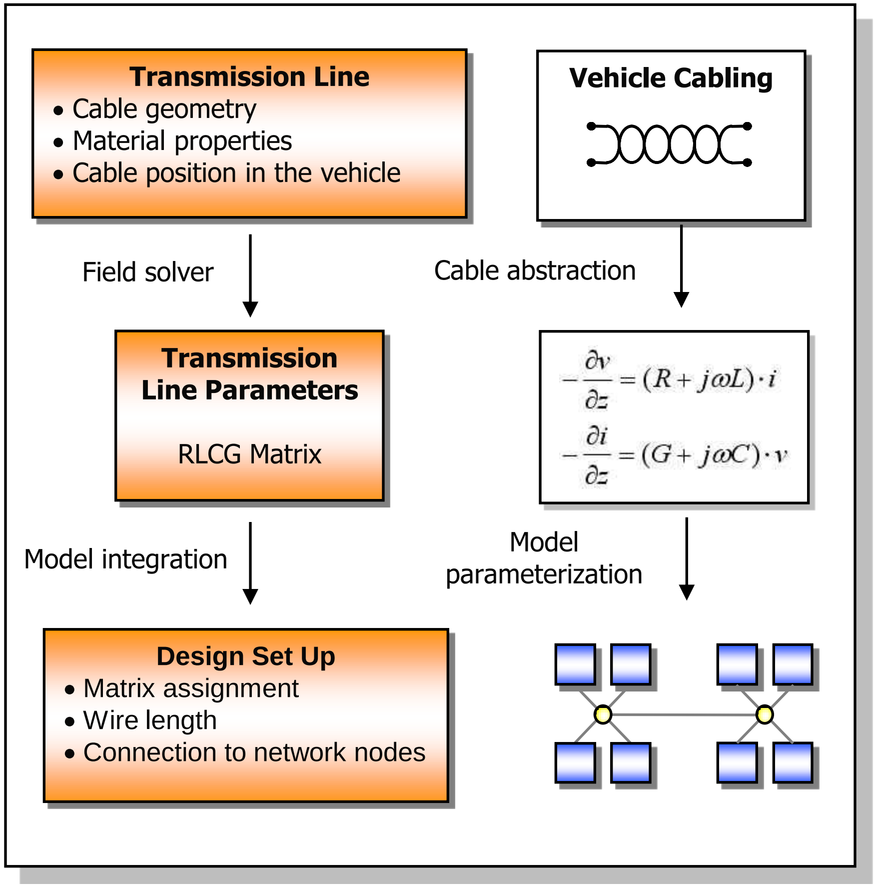
Simulation
FlexRay Transceiver Model

- TJA1080 FlexRay transceiver
  - Developed by IC manufacturer (NXP Semiconductor)
- Behavioral model according to data sheet
  - Mode transitions
  - Analog behavior at connection pins
  - Transmitter and receiver asymmetries
- Support of worst case behavior
- Specially developed for system simulation

Simulation

Transmission Line Model

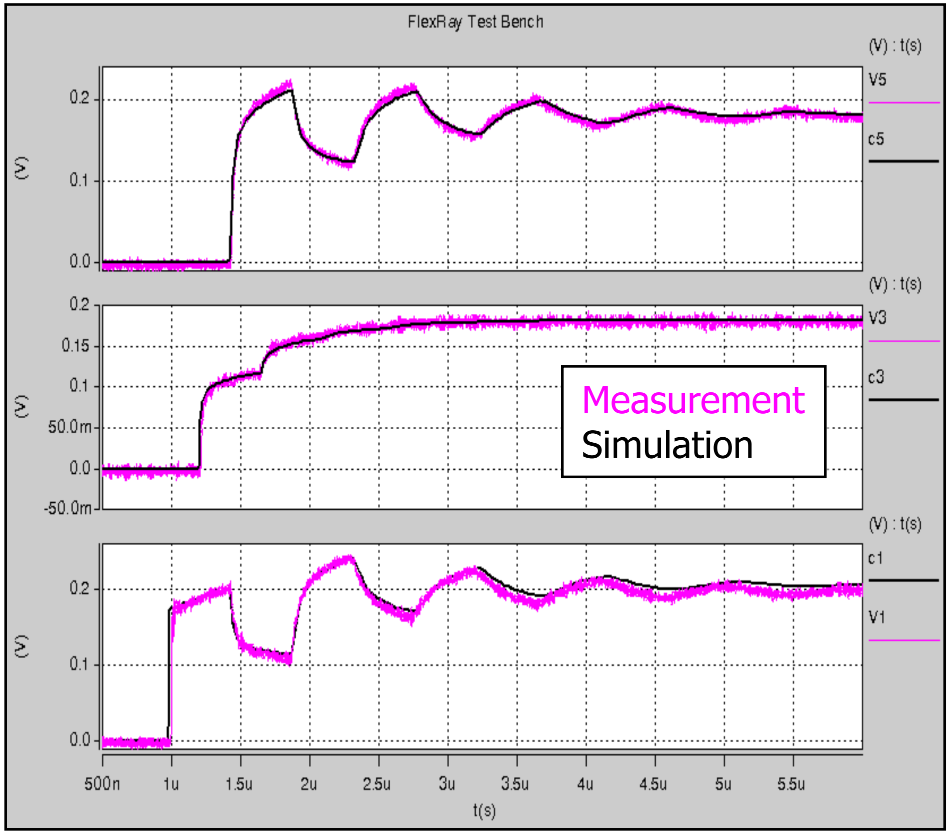
- Developed based on spec from FlexRay EPL working group
- Equations defined in frequency domain
- Wire length as model argument
- Skin Effect
- Support of both differential and common mode
- Validated by measurements



Simulation

TxLine – Simulation vs. Measurement

- Validation test benches defined by FlexRay EPL working group
- 96m cable length
- High/Low impedance terminated branches
- Unterminated branches
- Perfect matching between simulation results and measurements



Critical Points of FlexRay's EPL

Validation Criteria

- Critical aspects of the signal integrity of a FlexRay™ network
  - Signal propagation delay
  - Asymmetric delay
  - Bit deformation due to ringing and reflections
  - Truncation of transmission start sequence (Transition idle to active)
  - Frame Stretching due to ringing after last bit (Transition active to idle)

Critical Points of FlexRay's EPL
Propagation Delay

- Propagation delay → Synchronization precision relevant
  - Time lapse between the falling edges of transmitter and receiver nodes in the network
  - Depends mainly on the topology of the path
    - Bus load
    - Temperature
    - Supply voltage variations

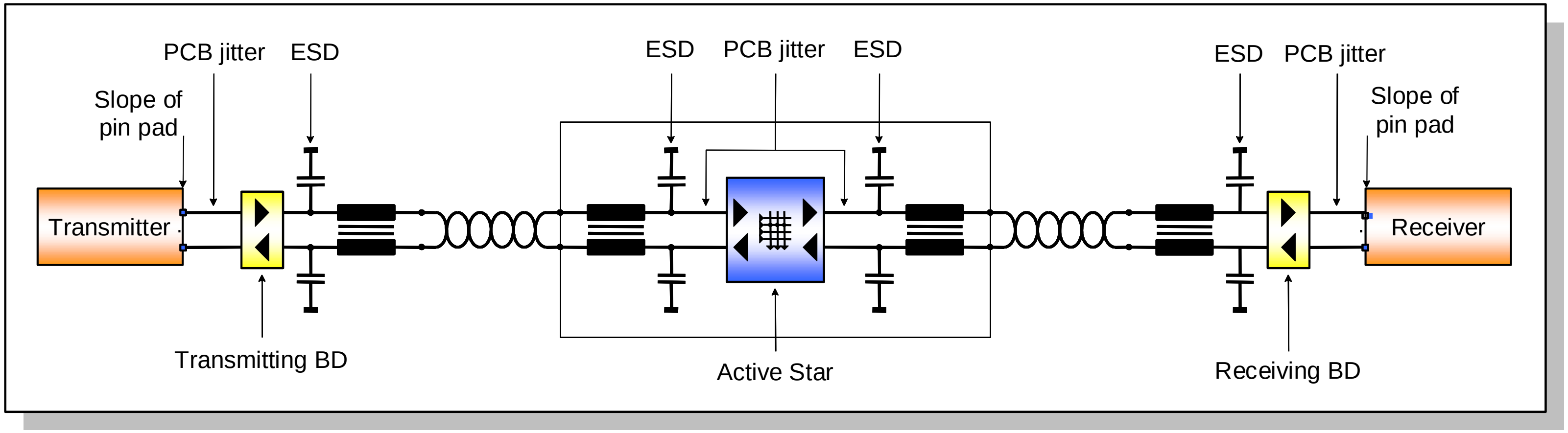
    → **Simulation is the only choice for investigation!**
- The FlexRay protocol defines a constraint for the propagation delay between two nodes n and m

$$dPropagationDelayM,N \leq cPropagationDelayMax$$

Critical Points of FlexRay's EPL

Asymmetry

- Relevant for correct signal decoding
- Mismatching between negative and positive edge propagation delays of the bus drivers and active stars
- Non-symmetric split termination networks
- Non-balanced ESD protection elements
- The greater the total asymmetry of the topology path the lower the robustness against injection of EM fields



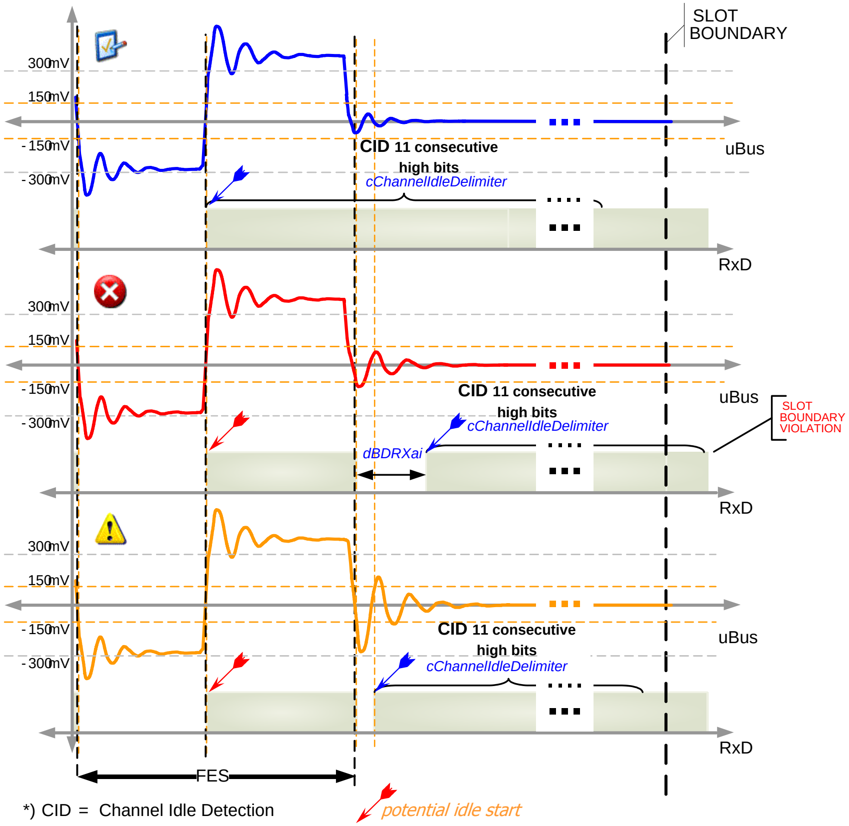
Critical Points of FlexRay’s EPL
Truncation of TSS

- Each communication element starts with the so called Transmission Start Sequence (TSS)
- Relevant for the transition from bus idle to bus active
- During the transition from bus idle to active the sequence of data can be shortened
  - Activity detection in the receiver BDs and Active stars
  - Filter time for activity detection plus internal logic
- Sufficient TSS length depends on the topology

Critical Points of FlexRay's EPL

Transition Active to Idle

- Frame stretching due to ringing after last frame bit
- The channel idle recognition point (CHIRP) is shifted
- Critical problem especially beyond cascaded active stars
- A static slot may be corrupted, boundary violation may appear
- The scenario may lead to an error in dynamic segment



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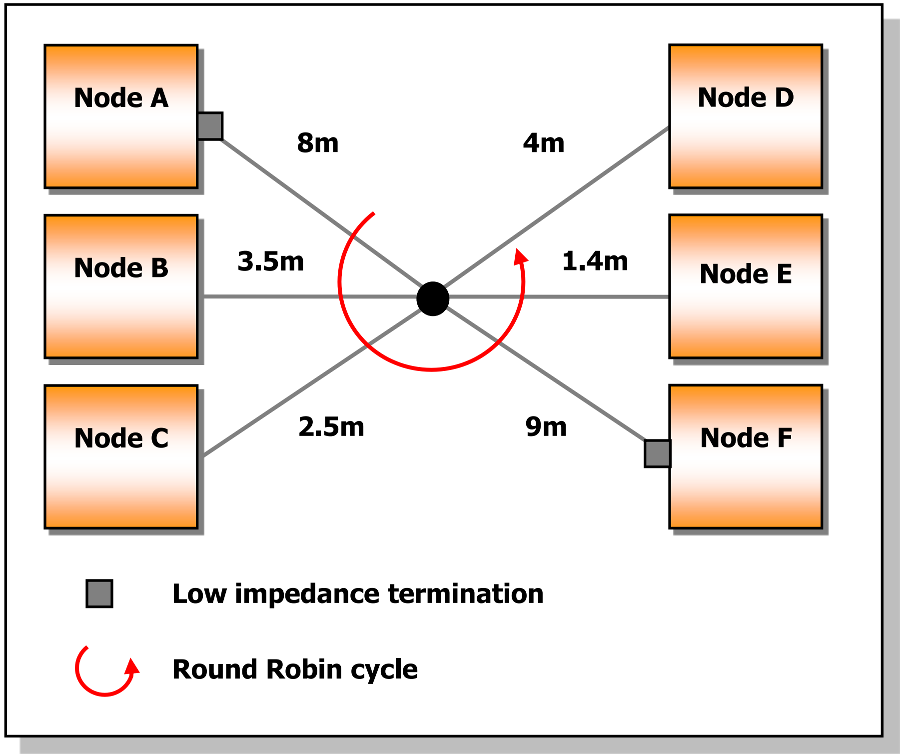
Application Example

Round-Robin Communication

- Six ECU nodes
- Passive star architecture
- Round-Robin communication
- Low impedance split termination → nodes with the largest distance
- Ferrites as passive filter elements in the center of the star



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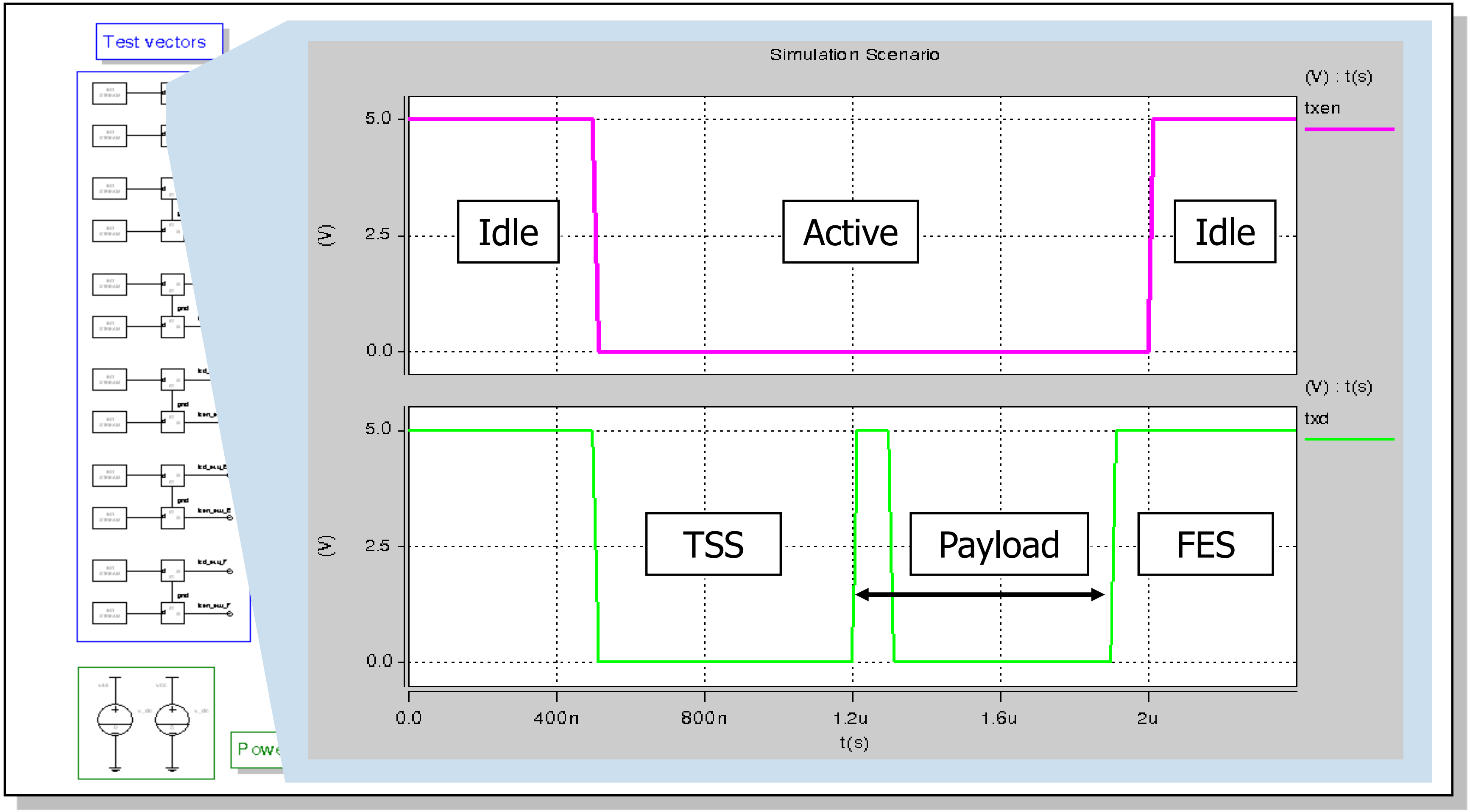
Application Example

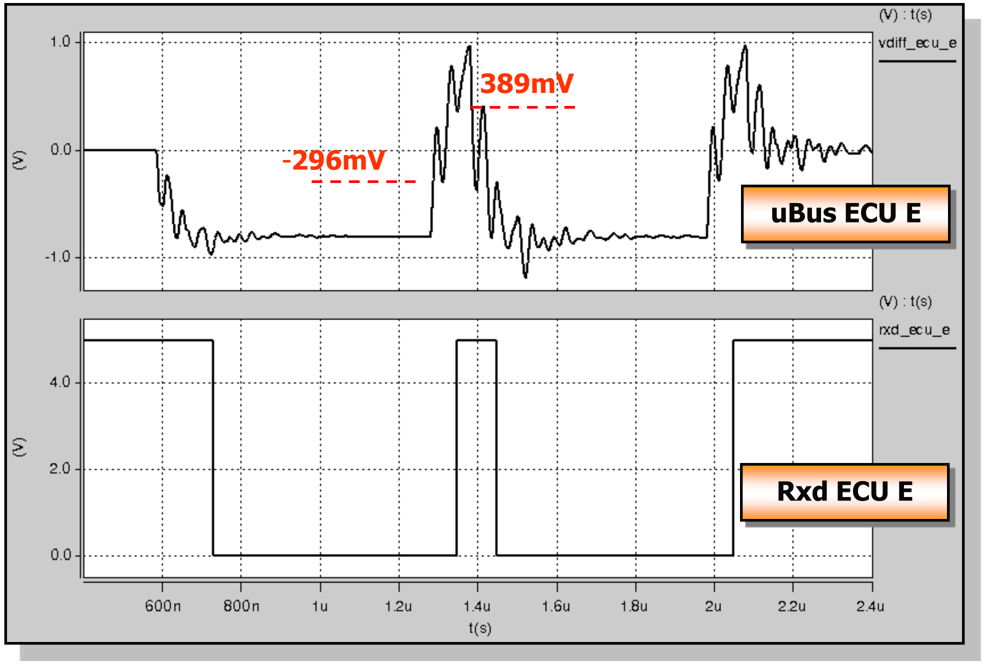
First Scenario - Test Bench



Application Example

First Scenario - Signal Quality

- Voltage peaks magnitudes in the range of -296mV and 389mV
- Transceiver nominal input threshold (±225mV)
- Peaks are filtered through low pass filter
- Considering worst case threshold (±150mV) this may result in multiple switching of the Rxd signal



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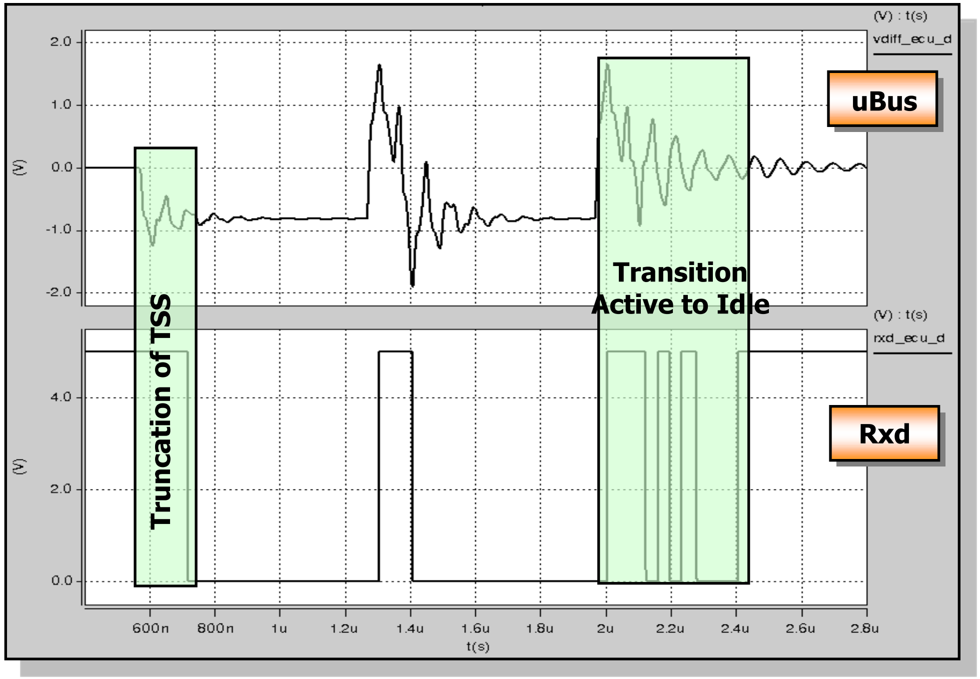
Application Example

First Scenario - Ringing → Active to Idle

- Repeated switching on the digital RxD pin
- The potential idle start event is delayed significantly, in this case 0.4 us
- The channel idle recognition point (CHIRP) is shifted

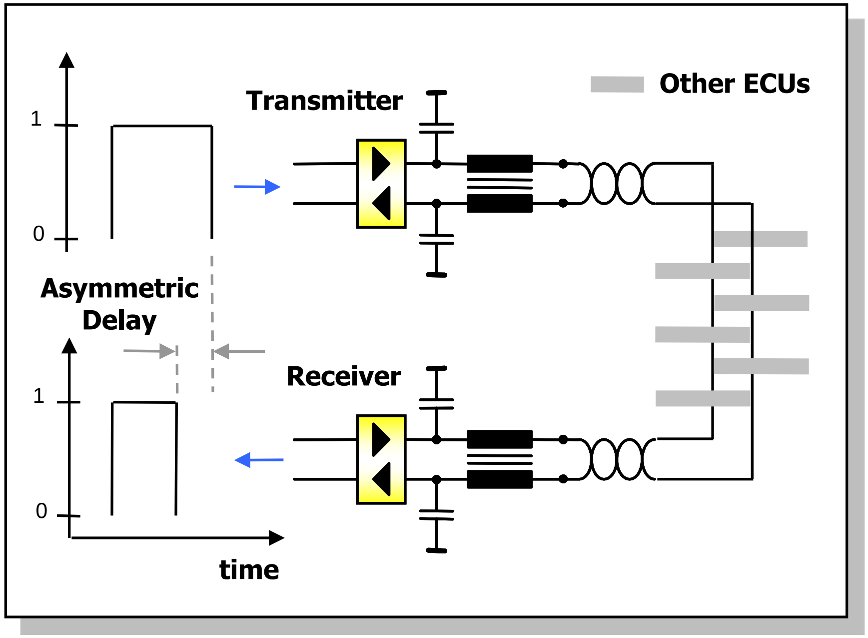


The maximum allowable duration of this effect will be prescribed in the physical layer specification.

Application Example

First Scenario - Asymmetric Delays

- Limits for asymmetric delays defined in FlexRay EPL Spec
- Need to be evaluated for complete Round Robin communication and each ECU
- Manual evaluation could be very time consuming
- Automated approach is used to generate Matrix written in Excel



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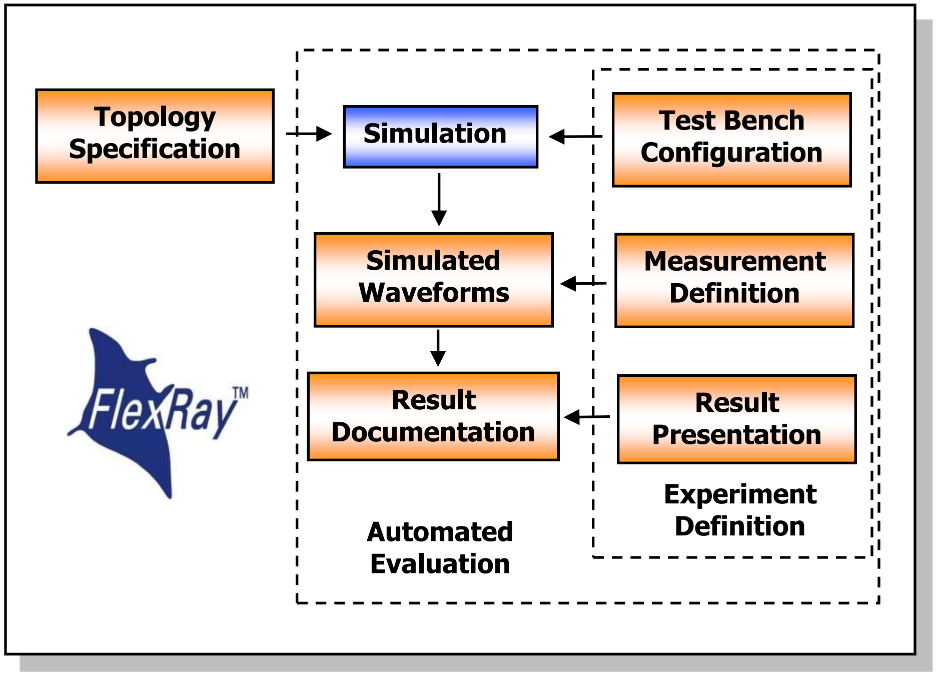
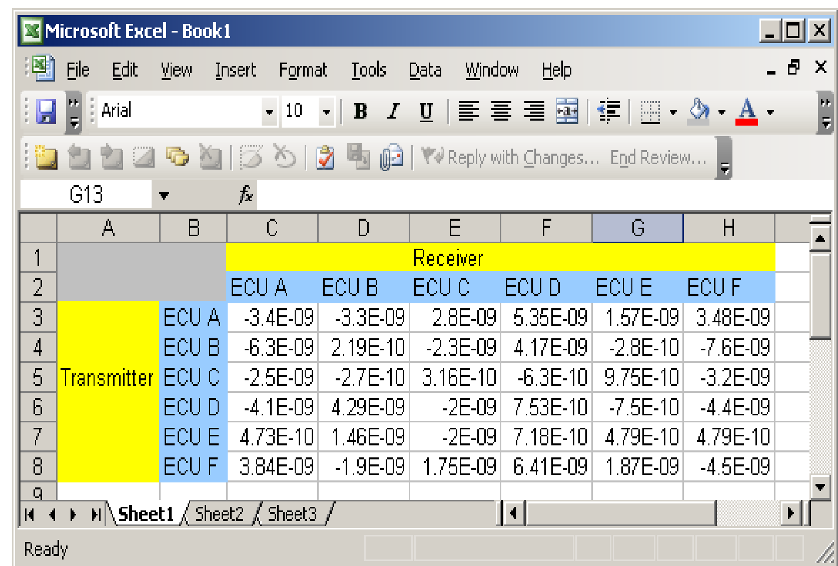
Application Example

Asymmetric Delays – Automation



One button solution

Output Report



	A	B	C	D	E	F	G	H
1			Receiver					
2			ECU A	ECU B	ECU C	ECU D	ECU E	ECU F
3	Transmitter	ECU A	-3.4E-09	-3.3E-09	2.8E-09	5.35E-09	1.57E-09	3.48E-09
4		ECU B	-6.3E-09	2.19E-10	-2.3E-09	4.17E-09	-2.8E-10	-7.6E-09
5		ECU C	-2.5E-09	-2.7E-10	3.16E-10	-6.3E-10	9.75E-10	-3.2E-09
6		ECU D	-4.1E-09	4.29E-09	-2E-09	7.53E-10	-7.5E-10	-4.4E-09
7		ECU E	4.73E-10	1.46E-09	-2E-09	7.18E-10	4.79E-10	4.79E-10
8		ECU F	3.84E-09	-1.9E-09	1.75E-09	6.41E-09	1.87E-09	-4.5E-09
9								

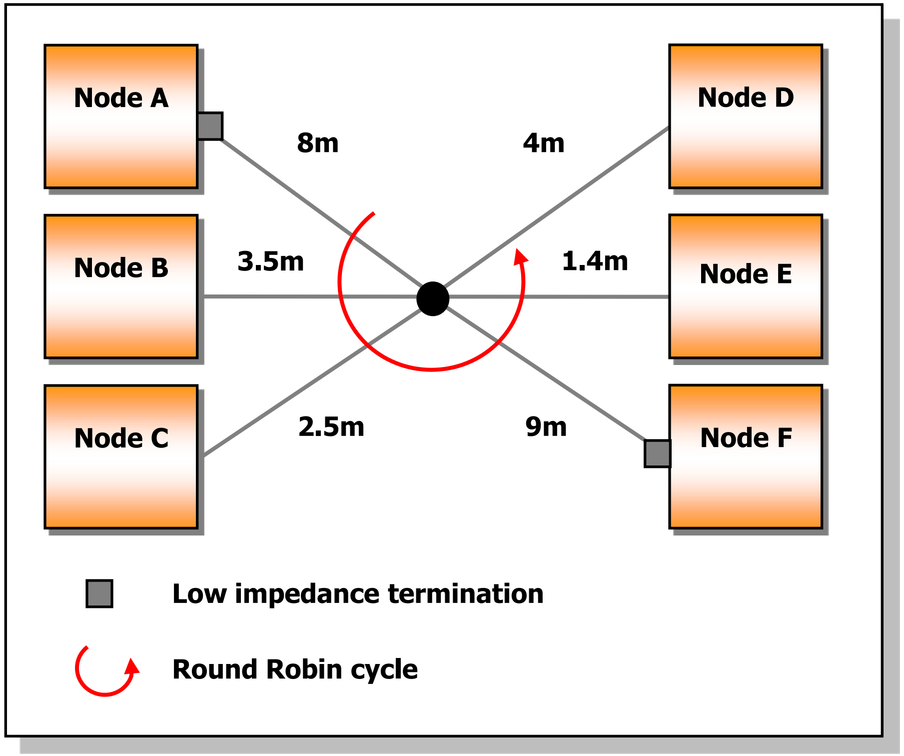
Application Example

Component Tolerances

- Only the nominal case was analyzed so far but...
  - All components are associated with tolerances
  - Impact of signal integrity can be significant
- Transceiver tolerances have significant impact on overall signal integrity
  - Differential input voltage thresholds
  - Detection of logical levels (correct signal decoding)
  - Differential output voltage levels
  - Signal propagation delays through transceiver
- May have a great impact in case of larger reflections
- Very important for the evaluation of the asymmetric delays

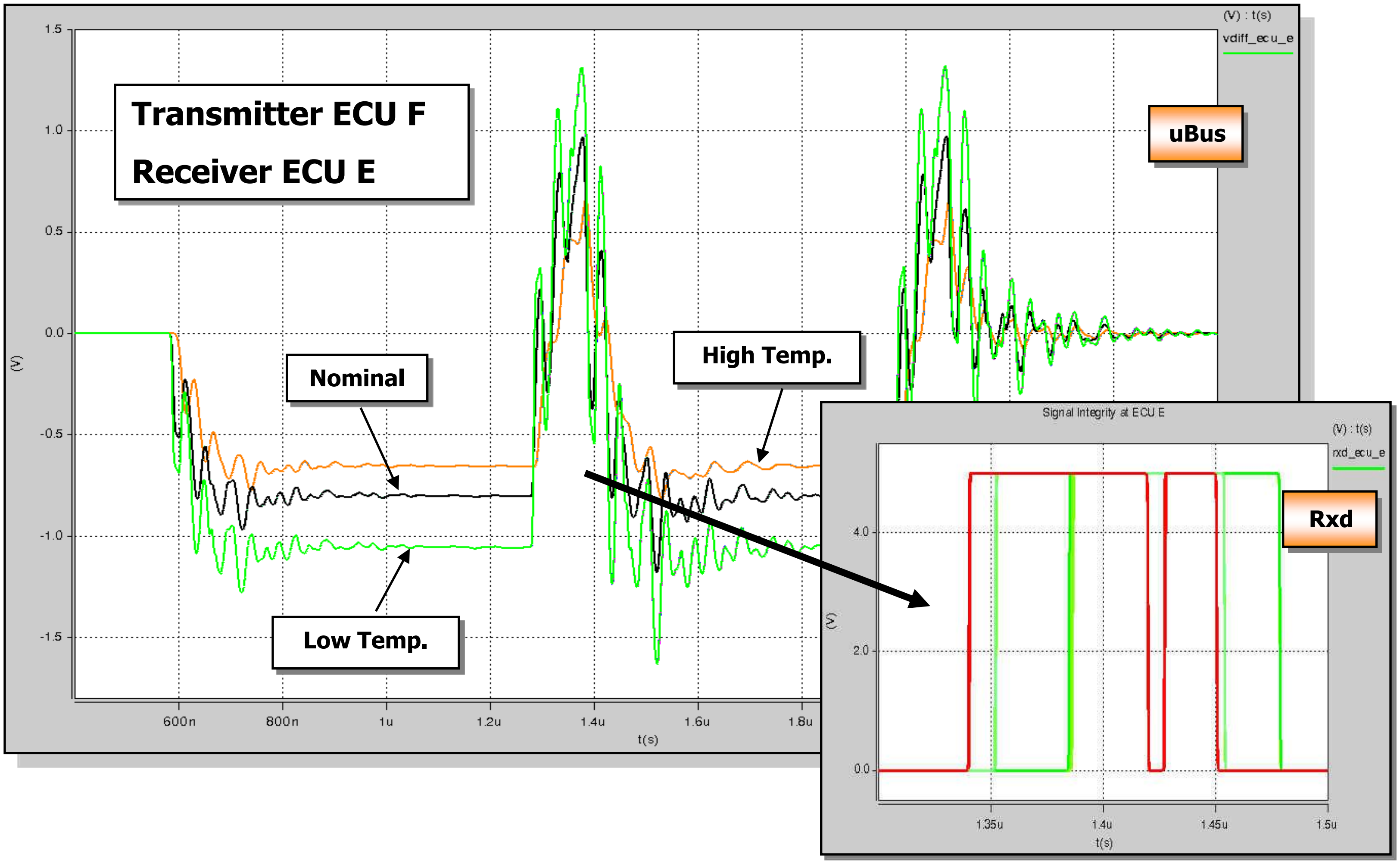
Application Example
Second Scenario – Nested Simulation

- Same Round Robin communication as before
  - Same transmission rate as before
  - Same bit pattern
- Transceiver tolerances
- Nested looped simulation runs



Application Example

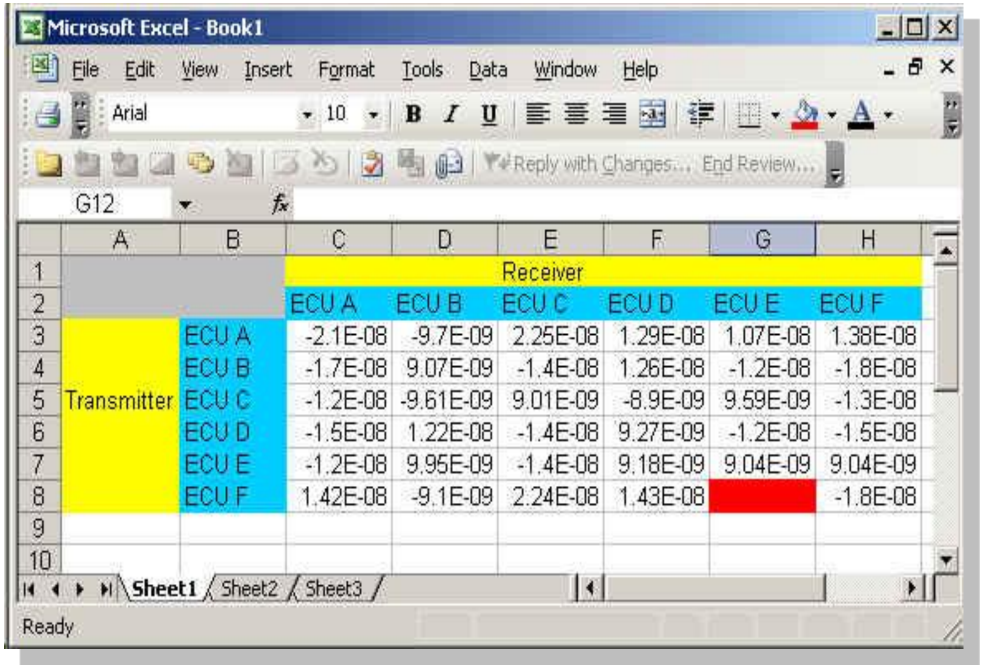
Second Scenario - Signal Quality



Application Example

Second Scenario – Asymmetric Delays

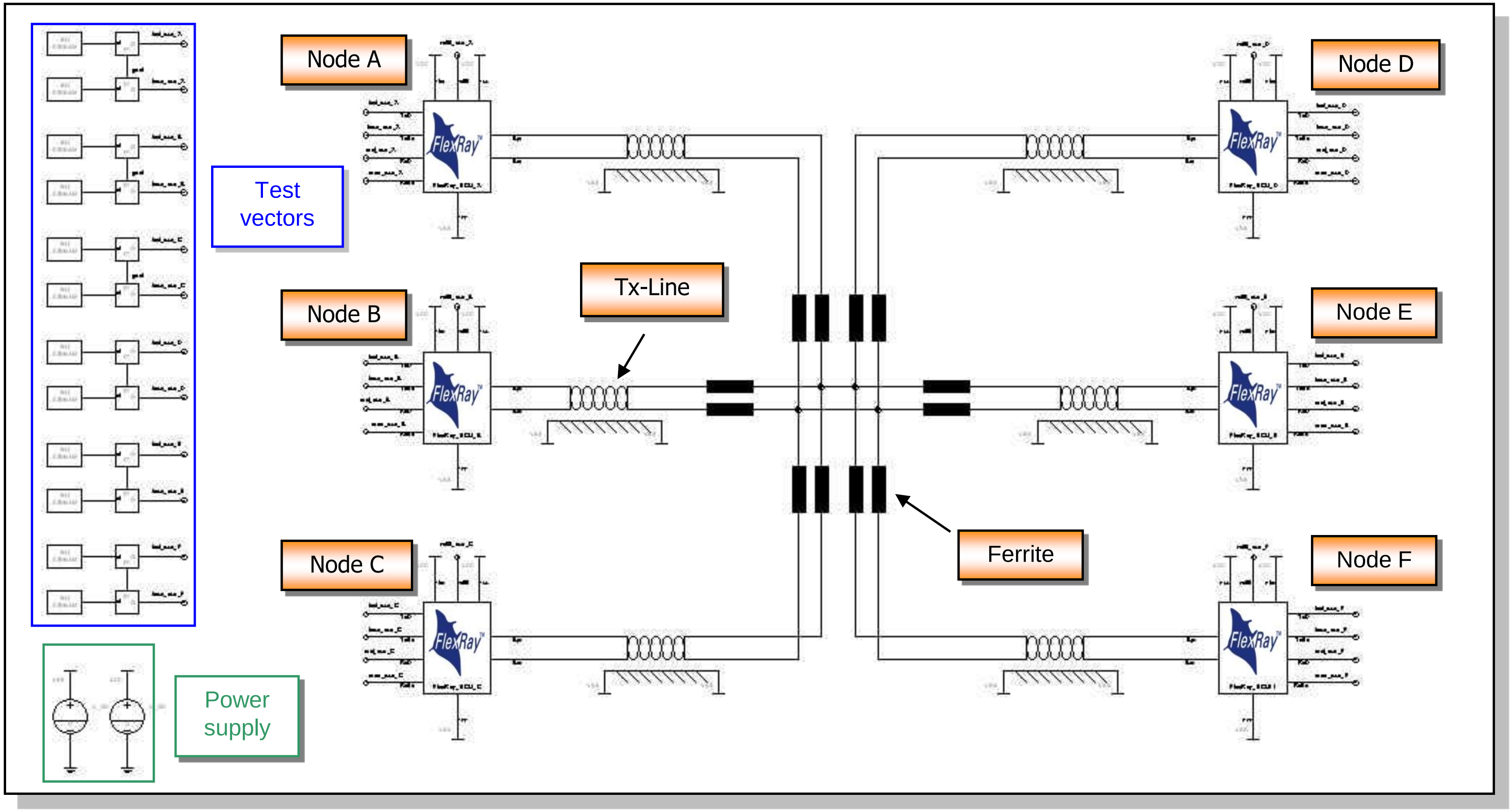
- Tolerances impact asymmetric delays significantly
- Maximum value is now 22.5ns
- 3x larger compared to nominal case (-7.6ns)
- Considering RF reserve the topology is close to its limit ($\pm$30.75 ns)



		Receiver					
		ECU A	ECU B	ECU C	ECU D	ECU E	ECU F
Transmitter	ECU A	-2.1E-08	-9.7E-09	2.25E-08	1.29E-08	1.07E-08	1.38E-08
	ECU B	-1.7E-08	9.07E-09	-1.4E-08	1.26E-08	-1.2E-08	-1.8E-08
	ECU C	-1.2E-08	-9.61E-09	9.01E-09	-8.9E-09	9.59E-09	-1.3E-08
	ECU D	-1.5E-08	1.22E-08	-1.4E-08	9.27E-09	-1.2E-08	-1.5E-08
	ECU E	-1.2E-08	9.95E-09	-1.4E-08	9.18E-09	9.04E-09	9.04E-09
	ECU F	1.42E-08	-9.1E-09	2.24E-08	1.43E-08		-1.8E-08

Application Example

Third Scenario - Ferrites as Filter



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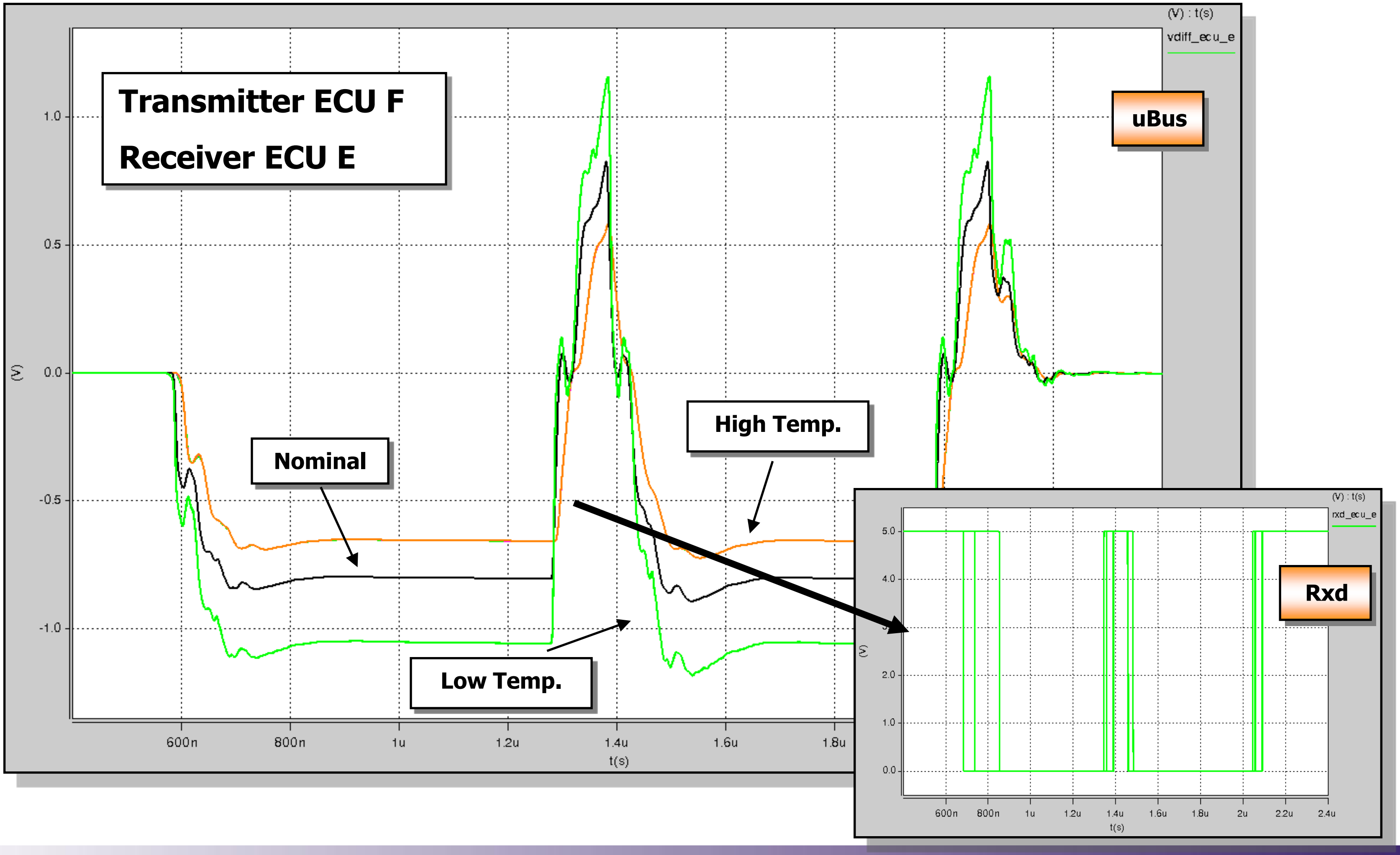
Application Example

Third Scenario - Signal Quality



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Summary

- Verification of concepts in the early stage of the design process before real network is available
- Improved quality of network topology against possible issues
- System simulation allows to reduce development time through a partially automated evaluation process
- Deep system understanding

Thank you for your attention!