FlexRay – A Communications Network for Automotive Control Systems
WFCS 2006

Rainer Makowitz
Automotive Systems Engineering, EMEA
FlexRay is the next generation automotive bus to provide

- High-speed communication
- Deterministic communication
- Fault-tolerant communication

FlexRay System Components released by the FlexRay Consortium in 2005:

- FlexRay Communications System Protocol Specification Version 2.1, May 2005
- FlexRay Communications System Electrical Physical Layer Specification 2.1, May 2005
- FlexRay Bus Guardian Specification Version 2.1, December 2005
In addition:

- FlexRay Executable (Reference) Model, Version 2.1.0.2 available today from FSL
  - certified by TUEV
  - SystemC based
  - Unambiguous reference for FlexRay IP providers and tool makers

Evolution of Vehicle Networks
Evolution of Vehicle Networks (1)

• CAN
  - 1st car use 2002; widely adopted in automotive products
  - CAN-B (ISO 11898-3): 125kbps, VUL=1.5V, VUH=3.5V
  - CAN-B (SAE J2411): 33kbps, VUL=0V, VUH=4.1V
  - CAN-C (SAE J2284): 500kbps, designed limit of 1 Mbps rarely implemented today

• Byteflight
  - 1st car use for airbag in 2004
  - 10Mbps
  - Time-triggered + Flexibility

• FlexRay
  - 1st car use for Chassis application in 2006
  - 10Mbps
  - Time-triggered + Flexibility + safety concept
Byteflight Data Transfer Overview

- Master clock
- Cycle starts with Sync symbol
- Fixed time slots for high priority communication
- Rest of bandwidth is allocated to low priority communication

- Frame format: 6bit Sync, ID Byte, 12 message Bytes, 2 CRC Bytes
FlexRay Data Transfer Overview

- 254 bytes, 8 Bytes overhead (5 header incl. header CRC, 3 frame CRC) plus start/stop bits
FlexRay Data Transfer Overview

Communication cycle

Static segment – TDMA based MAC
(bounded latency and small latency jitter communication, deterministic communication static bandwidth requirements)

Dynamic segment – flexible TDMA based MAC
(ad-hoc communication, varying bandwidth requirements)

Example of a FlexRay communication cycle showing the static and the dynamic segment.
Evolution of Vehicle Networks: Issues Resolved

CAN → byteflight → FlexRay

- Unpredictable latency
- TDMA + Bandwidth Allocation Flexibility
- TDMA + Bandwidth Allocation Flexibility + Fault tolerance concept
### Evolution of Vehicle Networks (Overview)

<table>
<thead>
<tr>
<th>Feature</th>
<th>CAN</th>
<th>TTP</th>
<th>byteflight</th>
<th>FlexRay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Message transmission</td>
<td>asynchronous</td>
<td>synchronous</td>
<td>synchronous and asynchronous</td>
<td>synchronous and asynchronous</td>
</tr>
<tr>
<td>Message identification</td>
<td>message identifier</td>
<td>time slot</td>
<td>message identifier</td>
<td>time slot</td>
</tr>
<tr>
<td>Data rate</td>
<td>1 Mbps gross</td>
<td>2 Mbps gross</td>
<td>10 Mbps gross</td>
<td>10 Mbps gross</td>
</tr>
<tr>
<td>Bit encoding</td>
<td>NRZ with bit stuffing</td>
<td>modified frequency modulation (MFM)</td>
<td>NRZ with start/stop bits</td>
<td>NRZ with start/stop bits</td>
</tr>
<tr>
<td>Physical Layer</td>
<td>transceiver up to 1 Mbps</td>
<td>not defined</td>
<td>optical transceiver up to 10 Mbps</td>
<td>10Mbps with differential signalling</td>
</tr>
<tr>
<td>Clock synchronization</td>
<td>not provided</td>
<td>distributed, in μs range</td>
<td>by master, in 100 ns range</td>
<td>distributed, in μs range</td>
</tr>
<tr>
<td>Temporal composability</td>
<td>not supported</td>
<td>supported</td>
<td>supported for high priority messages</td>
<td>supported</td>
</tr>
<tr>
<td>Latency Jitter</td>
<td>bus load dependent</td>
<td>constant for all messages</td>
<td>constant for high priority messages according t_cyc</td>
<td>constant for all messages</td>
</tr>
<tr>
<td>Error containment</td>
<td>not provided</td>
<td>provided with special physical layer</td>
<td>provided by optical fiber and transceiver</td>
<td>provided with special physical layer</td>
</tr>
<tr>
<td>Babbling idiot avoidance</td>
<td>not provided</td>
<td>only by independent bus guardian</td>
<td>provided via star coupler</td>
<td>provided via star coupler or bus</td>
</tr>
<tr>
<td>Extensibility</td>
<td>excellent in non-time critical applications</td>
<td>only if extension planned in original design</td>
<td>extension possible for high priority messages with effect on bandwidth</td>
<td>separation of functional and structural domain</td>
</tr>
<tr>
<td>Flexibility</td>
<td>flexible bandwidth for each node</td>
<td>only one message per node and TDMA cycle</td>
<td>flexible bandwidth for each node</td>
<td>multiple slots per node, dynamic</td>
</tr>
</tbody>
</table>
Fault Tolerance
FlexRay and Functional Safety

• Safety requirements
  ▪ Depend on application area (brake, steering, driver assist)
  ▪ Lead to redundancy of system components
  ▪ Degree of redundancy must be calibrated by field data on failure probability

• FlexRay provides the infrastructure to design reliable (safety-critical) communications systems
  ▪ Deterministic System Design
  ▪ Static Segments
  ▪ Dual channel - scalable system fault-tolerance
  ▪ Bus Guardian
  ▪ Interconnect topologies: centralized or bus
Fault-Tolerance Overview

Topological flexibility (single versus dual channel, mixed connectivity)

Scalable fault-tolerance to support fault-tolerant and non fault-tolerant systems

Fault-tolerant clock synchronization also usable in a non fault-tolerant way

Conceptual separation of functional and structural domain
## Topological Flexibility

<table>
<thead>
<tr>
<th>Optional BG</th>
<th>Bus</th>
<th>Multiple star</th>
<th>@ 10MBit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Single channel</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>reduced wire-harness, experience, cost</td>
</tr>
<tr>
<td><strong>Dual channel</strong></td>
<td></td>
<td></td>
<td>tolerates one faulty channel</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>electrical &amp; optical physical layer</td>
</tr>
<tr>
<td><strong>mixed topologies</strong></td>
<td>passive medium, most experience, cost efficient</td>
<td>allows for high data rates, increases error containment</td>
<td></td>
</tr>
</tbody>
</table>

- Optional BG: mixed topologies
- Bus: single channel
- Multiple star: dual channel
• Exchanging Deviations
  ▪ Implicit exchange of clock deviations via exchange of (sync) frames

• Reference clock
  ▪ No single physical reference clock exists
  ▪ Each node calculates deviation in respect to a virtual reference clock
  ▪ Virtual reference clock established using distributed fault-tolerant clock synchronization algorithm (fault-tolerant midpoint)
  ▪ Combined use of offset correction and rate correction
Separation of Functional & Structural Domain

Communication cycle
(driven by synchronized time base)

Static segment – TDMA based MAC
(bounded latency and small latency jitter communication, deterministic communication static bandwidth requirements)

Dynamic segment – flexible TDMA based MAC
(ad-hoc communication, varying bandwidth requirements)

Channel A
1 2 3 4 5 6 7 8 9
3a 1a 3c 4a 1c 4b 3d

Channel B
1 2 3 4 5 6 7 8 9
3b 1b 2a 3c 1c 3e 1d 2b

Example of a FlexRay communication cycle showing the static and the dynamic segment.
Functionality Beyond FlexRay

- Low Protocol Overhead
  - Services to support application safety are left to the application software (e.g., membership services)
  - AutOsar must complement FlexRay link layer (in the controller)

Application related fault-tolerance (such as message agreement)

Application related error handing (such as system diagnosis)

-> Functional or structural view

Communication rel. fault-tolerance (such as clock-synchronization)

Communication rel. error handing (loss of synchronization)

Error signaling to application

-> Functional view
Applications
Application Domain Examples

- Powertrain
- Chassis
- Backplane
- By-wire systems

- High-speed CAN replacement

- 2006
- 2008
- 2012
Example: Chassis Applications

- Adaptive Suspension System
  - Distribution of control algorithm between 4 wheel nodes and 1 control unit
  - Passive star topology @ 10Mbps
  - Single channel
  - Fail silent strategy

FlexRay ECU based on MPC563 and MFR4200.
Trends in Chassis Electronics

• Current state:
  ▪ Longitudinal dynamics only (ABS and Traction control)

• Future:
  ▪ Networking of Longitudinal & Lateral Dynamics & Driver Assistance

• Challenge:
  ▪ Flexible architecture w/
    > ABS, DSC in basic configuration
    > Active Steering, electric brake management, ACC as options
  ▪ FlexRay provides a feasible backbone w/ separation of structure and function
    > No change of ECU code at change of option package
    > All ECUs have FlexRay slots assigned according to platform plan
Example: X-by-Wire

- European funded project SPARC (Secure Propulsion Using Advanced Redundant Control)
  - Execution layer (steering system, braking system, power pack (engine & transmission), energy system) uses FlexRay as bus architecture
  - Implementation of steer-by-wire system, brake-by-wire system, shift-by-wire system, engine-by-wire system, load separation module and energy management
  - The platform is equipped with two independently working FlexRay Buses, each consisting of two channels. One is assigned to the communication between the HMI and the DCS, the other bus is used for communication between the PTC and the execution (mechatronic) layer, i.e. the lower part of the hourglass.
SPARC Architecture

**Truck**
- Camera, GPS Radar
- Joystick A
- Joystick B
- Brake A1
- Brake A2
- Brake A3
- Power Module A
- Power Module B
- Star
- Central ECUs
- Brake B1
- Brake B2
- Brake B3
- Star
- Central ECUs
- Brake B1
- Brake B2
- Brake B3

**Car**
- Camera, GPS Radar
- Joystick A
- Joystick B
- Brake A1
- Brake A2
- Power Module A
- Power Module B
- Star
- Central ECUs
- Brake B1
- Brake B2
- Star
- Central ECUs
- Brake B1
- Brake B2
FlexRay
Product History
FlexRay Implementations Roadmap

FlexRay Protocol Specifications

- PS V0.4.3
- PS V0.6
- PS V1.0
- PS V1.9
- PS V2.0
- PS V2.1A

FlexRay Consortium founded

2000 2001 2002 2003 2004 2005 2006

Integrated MCUs w/ FlexRay from many vendors

Freescale Semiconductor Communication Controllers

- FPGA V4
- FPGA V5
- MFR 4100
- MFR 4200
- MFR 4300

FPGA

Philips Semiconductors Physical Layer Bus Driver

- TJA1080

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Summary

• FlexRay is the next generation communication backbone for automotive applications
  - Qualified Controller and Physical Network Interface products exist
  - Automotive mass-production SOP 2006
  - Reference Model to explore systems architecture
• Safety critical applications like by-wire systems will use mechanisms built into FlexRay to support fault tolerance
  - No technical limits for state-of-the-art systems
  - Full flexibility for emerging systems architectures for ‘affordable’ safety in vehicles
• FlexRay market will develop in non-safety-critical application first
Thank you for your attention

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