BMW – First Series Cars with FlexRay in 2006

BMW is the first car manufacturer that introduces FlexRay in series projects. Introduction starts in 2006, where a pilot application in the chassis domain will be implemented on five ECUs communicating via FlexRay.

The consequent next step is the introduction of FlexRay in 2008 where FlexRay forms a substantial part of the overall electronics architecture. The FlexRay network connects multiple ECUs that implement chassis, powertrain, and driver assistance applications.

FlexRay instead of CAN

Vehicle dynamics and driver assistance are essential for the BMW Group to differentiate the BMW brand on the market. Vehicle electronics, mechatronics, by-Wire-systems and the reliable control of the car network are vital for the future of the BMW Group. The increasing number of chassis control, convenience and safety functions leads to complex vehicle electronics with a fast growing number of ECUs, sensors, and actuators. Networking the various electronic modules with a high-performance data bus makes it possible to reduce the complexity of the wiring and to make multiple use of sensor data in order to integrate the individual functions in such a way that they form an intelligent overall vehicle.

Designated applications for powertrain and distributed closed loop chassis controls have high requirements concerning determinism, reliability, synchronicity, and bandwidth which can't be met by today's data communication systems. A CAN based network for future automotive requirements would have a large number of sub-buses, exceeding the acceptable level of network complexity and causing additional costs for gateways, system integration and warranty. Such a network would not have bandwidth reserves for future functional extensions, and the non deterministic behavior of CAN at high bus loads would lead to a poor performance quality of the electronic control systems (e.g. vehicle dynamics). The required short flash update time of all ECUs in a car cannot be fulfilled with CAN.

Recognizing these needs for a new communication system was an important reason for the BMW Group being one of the main driving forces in creating FlexRay and bringing it to life in series production cars. The FlexRay communication system is the right choice for the BMW Group, even if the car has no real by-wire applications (without mechanical fallback). The BMW Group designed innovative network architectures for future series production cars using FlexRay as a communication system for chassis, driver assistance and powertrain applications. The most important features for using FlexRay in future vehicle networks are bandwidth, data integrity and reliability, determinism, composability in the time domain, system integration and expandability, and standardisation in the automotive industry.

First Series Application

In order to keep the possible risks for the series introduction of a new protocol as low as possible, the BMW Group decided to start with a pilot application of FlexRay in a series car, using it in optional equipment of a closed loop chassis control system to network five nodes (**Figure 1**).

While the FlexRay standard offers a lot of enhanced features in order to support fault tolerant applications (e.g. dual channel communication, cascaded star topologies, etc), the first series introduction of FlexRay will utilize only a subset of these capabilities. Important features for the real series applications are the support of a gross data rate of 10 Mbps, determinism, and synchronization capabilities of tasks in distributed control systems. Therefore, single channel communication with single star and linear bus topologies is currently sufficient. This application makes it possible to test and qualify the silicon implementation of the FlexRay protocol (Freescale MFR4200A), the physical layer (Philips TJA1080 N1D2) and the use of the communication system in an automotive environment. Several test vehicles delivered already promising results and the

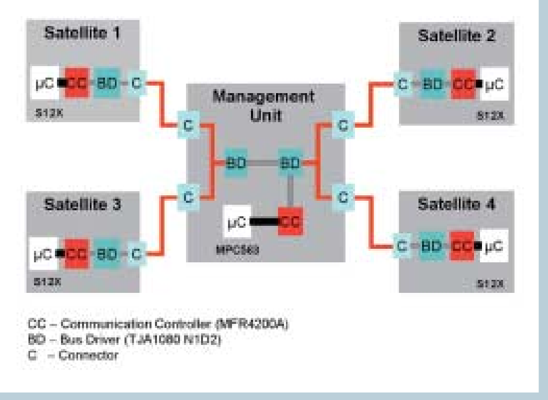

Figure 1: First Pilot application.

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first series production cars with FlexRay will hit the road in 2006.

Using the experience from this pilot application the BMW Group will launch another series car with up to 15 FlexRay nodes in 2008. In this application FlexRay will network powertrain, driver assistance, and chassis systems.. It is a single channel, single star and linear bus topology, using 10 Mbps with unshielded twisted pairs in a conventional wiring harness. Beyond the already stated features of FlexRay for the current series projects, future applications will additionally require composability in the time domain, the flexible use of bandwidth, easy expansion capability, reserves for future functional extensions and the possibility to implement future real drive-by-wire functions without mechanical back-up.

BMW - the Driving Force for the Commercial Exploitation of the FlexRay Standard

Together with the semiconductor companies, clear roadmaps have been established for the commercial availability of FlexRay stand-alone communication controllers as well as integrated into microcontrollers and physical layer devices to meet the SOP requirements for BMW series cars. Furthermore, the BMW Group has initiated the development of low-cost transceivers and cost-effective physical layer star devices that integrate multiple physical layer connections into a single device.

It is obvious that the introduction of a new technology with higher performance results in additional costs. Integrating the communication controller in a microcontroller and using a low-cost transceiver will save up to 5 Euro per node compared to today's existing solutions. Due to a larger silicon area, FlexRay silicon of a single device will always be a bit more expensive than CAN. Nevertheless, the business case has to be done on system level comparing the same functionality implemented using CAN vs. FlexRay. Replacing several CAN sub-buses, cables, gateways, redundant sensors, and partitioning effort, the FlexRay system will have approximately the same cost as a CAN system, offering at the same time higher performance, extensibility and lower complexity. On a long term basis (lifecycle), business case calculations based on overall system costs show clear commercial benefits of a FlexRay architecture compared to a multiple CAN scenario. These business case calculations served as a fundamental decision criterion for the early introduction of FlexRay in BMW series cars.

Interoperability of FlexRay Communication Controllers

There are two IP providers for a FlexRay communication controller available today: Freescale Semiconductor, Inc. and Robert Bosch GmbH. Both IPs will be used in the 2008 series scenario. Additionally to the conformance tests that are developed by the FlexRay consortium in the course of 2005, the BMW Group established a project to ensure interoperability of different FlexRay devices in the particular BMW series configuration.

The interoperability tests focus on the 2008 series configuration, where stand alone as well as integrated FlexRay devices from different semiconductor manufacturers will be used.

The tests started with an evaluation platform based on FPGA and stand-alone silicon versions from Freescale and Bosch that implement the V2.1 protocol specification.

Additionally to the evaluation boards based on FPGA, any other board or series ECU can be integrated into the test setup in order to perform regression tests with updated versions during series development. For the test setup an OSEKtime operating system and a FlexRay software stack is used based on the BMW standard core. The test execution is performed in two major steps.

Hardware tester: for each new FlexRay device a fundamental CHI function test is performed to check the principle operation of the device before integrating it into the

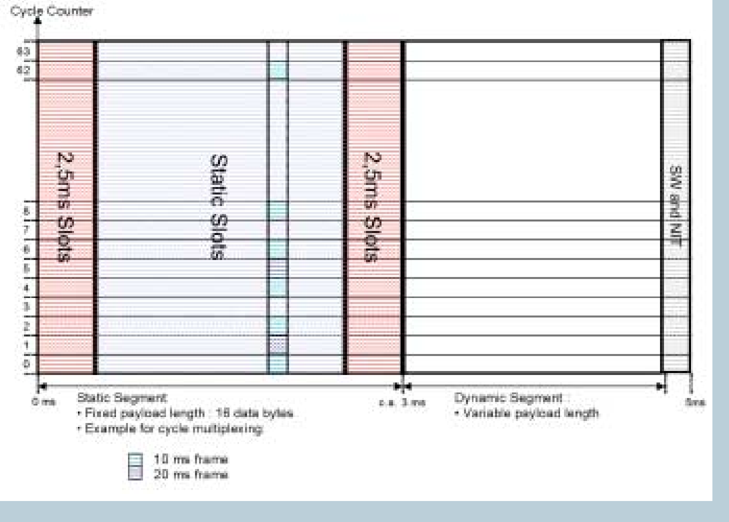

Figure 2: FlexRay system parameter overview.

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interoperability test setup.
Frame tester: this test is based on a distributed application for test control, test execution and test evaluation in the specific series environment. The physical topology and cable lengths used for the frame tester simulate the corner case scenario of the 2008 series topology.
The frame tester consists of generic software modules that are assigned to each ECU. During test execution the end-to-end communication of all ECUs within the cluster is checked and diagnosis information is passed to a PC.
Corner case tests: in order to perform corner case tests two additional hardware modules have been developed to inject variations in the quartz drift as well as line delays and bit distortions. With the clock drifter module tolerances, aging and temperature effects of quartzes can be simulated by manipulating of the clock drift in the range of +/-1500 ppm. The delay and distortion boards can perform propagation delays and pulse distortions in the signal path to simulate the behavior of the physical layer, e.g. by extending the high or low phases of a bit cell. It is also possible to create variations in the TSS (transmission start sequence) length of FlexRay.
Results: First results show interoperability between the FPGA solutions of both IP providers. Future regression tests based on real silicon devices will show the interoperability of the series devices as soon as the silicon devices are available.

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FlexRay Series Configuration

Even if FlexRay is a new technology, the development of systems with FlexRay must fit into the existing development process. This requirement is fulfilled by an early freeze and verification of the series parameter set and an enhanced scheduling strategy that decouples application task schedules from FlexRay communication schedules. Following consequently this strategy, a carry over support of ECUs is easily possible for future series projects. A FIBEX based tool chain supports the configuration process in order to perform automatic updates of FlexRay schedule for each integration step.
The configuration process shall be deterministic, i.e. repeatable, and the generated FlexRay schedule shall be reproducible. Therefore, the bus schedule shall be based on an open and simple algorithm in order to meet these requirements. The generated schedule shall be (partially) freezable, i.e., incremental modifications shall be possible without any impact on the previously frozen parts of the schedule. This is an important feature to support a stable configuration during the development phase of a vehicle model and the reuse of ECUs across different platforms. In general, ECU local requirements changes shall have as little impact as possible on the global configuration. The requirements changes initiated by one supplier shall not change the entire bus schedule, but only the affected ECUs.
In order to meet the above mentioned requirements, some key parameters are fixed for all planned series projects: these parameters include a communication cycle of 5 ms, partitioned into a 3 ms static and a 2 ms dynamic segment length (see **Figure 2**). The 3 ms static segment length allows for a signal period of 2.5 ms by scheduling frames twice in one communication cycle (one time at the beginning of the static segment and another time at the end of the static segment).
The bus schedule algorithm is based on signal windows. The signal period defines the window, where it is scheduled, i.e., all signals with the same period are scheduled in the same window (see **Figure 3**). The exact position of the signal in the signal window is not relevant for the application tasks, because they shall be synchronized on the signal window start and end point. During the signal window of a signal the application shall avoid read and write access to the signal.

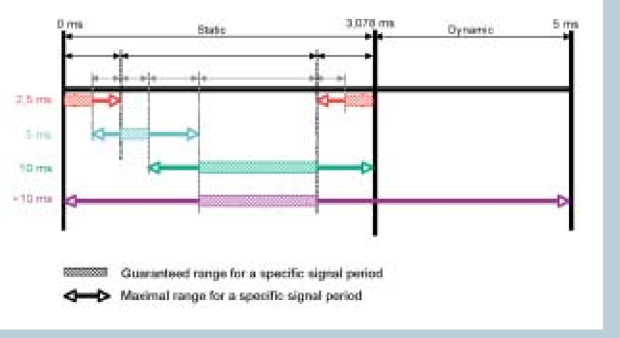

Figure 3: Signal window in one cycle.

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In addition to the hardware development, the BMW Group is actively working on the specification, implementation, and standardization of FlexRay software modules. The BMW Group meets the challenge between early availability of a FlexRay stack (software drivers, interface, network management, transport layer, etc.), and the standardization activities of AUTOSAR. While some software modules are already based on fully AUTOSAR compliant implementations (e.g. network management), others are based on commonly agreed requirements in order to allow migration towards AUTOSAR as soon as the implementations are available.

Next Steps

By the early decision to introduce FlexRay in a pilot application, the BMW Group is the driving force for early availability of automotive qualified FlexRay silicon as well as tools and software that fulfill series requirements. Based on this experience FlexRay will be rolled out in future BMW vehicle models including backbone architectures.

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