Over the last few years, automotive electronics have increasingly defined the driving experience of modern vehicles. Starting in engine management and car audio, electronics have now penetrated all major systems in the vehicle, ranging from power train, body and chassis to driver-assistance systems and active and passive safety systems.

The trend to network these systems started in the mid-1980s with the introduction of the controller-area network (CAN). At that time, every electronic control unit (ECU) still represented an autonomous functional unit in the vehicle. As the number of ECUs has increased along with the technical abilities that electronic control can provide, the trend has shifted from networked ECUs to distributed systems where functions are spread across multiple ECUs.

To address the increasing demands of this trend, the automobile’s communications network needs to provide not only high-speed data transfer, but also data transfer that is deterministic and fault-tolerant--and, thus, capable of supporting advanced distributed-control systems. Over the last few years, an industry consortium of more than 120 companies has developed the FlexRay communications system, a time-deterministic protocol with a data rate of 10 Mbits/second for advanced control systems in vehicles.

The development of FlexRay started in 2000 in the context of an industry consortium founded by four companies: carmakers BMW and DaimlerChrysler, and chip makers Philips Semiconductors (now NXP) and Motorola (now Freescale Semiconductor). By 2003 Robert Bosch, GM and Volkswagen had joined, bringing the roster of core partners to its current number of seven. The consortium quickly attracted numerous other members throughout the automotive industry, bringing its membership numbers beyond 120 by the end of 2005.

FlexRay is configured in recurring communication cycles at a data rate of 10 Mbits/s. Each communication cycle contains a static communication segment, a dynamic communication segment and the network idle time, which is a communication-free period that concludes each communication cycle. In addition, each communication cycle can contain an optional symbol window that can be used to run-time-test an ECU’s interconnection to the physical network.

**Closed loop**
In a typical FlexRay communication cycle, the static communication segment accommodates data communication that requires bounded-latency and small-latency jitter. In order to achieve this, the static communication segment utilizes a TDMA-based communication scheme based on static communication slots. In combination with a static schedule that is calculated off-line during the design of the system, FlexRay is able to address highly deterministic distributed applications, such
as closed-loop control applications where the control loop is closed over the network.

In the static segment, the progression of static communication slots occurs in lockstep on both channels. ECUs may send frames with the same or with different content on each of the two channels within the same static communication slot. It is also possible to allocate the channels to different ECUs within one and the same static communication slot or to leave slots empty. In the dynamic segment, the pattern of dynamic communication slots unfolds independently on the two channels depending on whether dynamic communication slots are used or left empty.

The temporal characteristics of the FlexRay communication cycle are defined at design time and stored statically in each ECU. ECUs that require greater bandwidth and those that need shorter update intervals for messages are assigned more slots than those that require less bandwidth or that allow for longer update intervals for messages.

The communication cycle utilizes an arbitration grid to provide collision-free communication in the static and in the dynamic segments. The arbitration grid consists of "macroticks." The macrotick represents the smallest synchronized granularity unit of the global time that is synchronized across all ECUs by means of a clusterwide clock-synchronization algorithm.

This synchronization ensures that the macroticks between different ECUs are synchronized such that all macroticks are kept in sync with one another within a defined precision. The precision describes the worst-case deviation between the corresponding macroticks of any two synchronized ECUs in the network.

This fault-tolerant clock synchronization is the key mechanism of the communications protocol that drives the communication cycle. To support fault tolerance, the decision was made to deploy a fault-tolerant distributed clock-synchronization algorithm as a clusterwide clock-synchronization algorithm. In contrast to a master-slave synchronization algorithm, the fault-tolerant distributed clock-synchronization algorithm will continue to operate even in the event that an ECU fails in the systems. The clock-synchronization algorithm is executed autonomously by the protocol state machine within each ECU without any interaction of the host processor.

**Ensuring success on road**

Key factors determining the success of FlexRay technology are the availability of semiconductor components implementing the FlexRay protocol and their deployment in automotive-series applications. Throughout the development of the FlexRay protocol, Freescale Semiconductor Inc. was able to provide the BMW Group with FlexRay communication controllers.

Using these components, BMW engineers pioneered FlexRay technology in the X5 family. Production vehicles began coming off the assembly line in September, with a pilot application implemented in the chassis domain of the latest revision of the X5. The carmaker plans to expand this use to include a substantial part of the overall electronics architecture based on a FlexRay network connecting multiple ECUs implementing chassis, power train and driver-assistance applications from 2008 onward.

To minimize the risks associated with introducing a new communication technology, the BMW
engineers decided to introduce FlexRay technology as part of an optional application in the X5 chassis domain. In this instance, a FlexRay network interconnects five ECUs of an electronic damper (shock absorber) control system. The key aspects of the FlexRay network utilized in this application are the gross data rate of 10 Mbits/s, the time-deterministic collision-free data transfer and the capabilities to synchronize various tasks within the distributed closed-loop control system.

The application is implemented using a communication cycle of 5 milliseconds partitioned into a static segment of 3-ms duration and a dynamic segment of approximately 2-ms duration. Using this cycle layout, it is possible to provide not only data update periods of 5 ms but also data update periods of 2.5 ms, by transmitting data twice per communication cycle. Or, by making use of the cycle-multiplexing capability provided by the FlexRay protocol, where data is transmitted only in specific predetermined communication cycles, it is possible to provide data update periods of 10 ms, 20 ms and 40 ms.

The dynamic segment is used to communicate frames with larger cycle times, event-triggered messages, network-management and diagnosis messages, frames used for flash download and calibration data (XCP on FlexRay). In this application, the ECUs are interconnected by a single communication channel that is designed as single star combined with a linear bus topology.

Implementing FlexRay net
Multiple technical criteria can be applied in deciding whether to implement a FlexRay network. Key criteria are bandwidth, deterministic communication, specific system-integration properties and the provision of fault-tolerance capabilities. These criteria are outlined in the table above and compared with CAN.

The intention of the FlexRay Consortium was to develop technology to complement established LIN and CAN networks by enabling the design of new applications (and not to substitute for these established networks). That could be done only by providing lower cost.

It is obvious, however, that introducing new technology with higher performance and increased capabilities results in higher costs. Ultimately, the comparison of business cases has to be done on a comparable level of functionality. Looking at the CAN system, for example, replacing several CAN sub-buses, cables, gateways and redundant sensors, and considering the partitioning challenges and the system integration effort, the FlexRay system is considered to have comparable costs.

At the same time, however, the FlexRay system offers higher performance, more extensibility and lower complexity. Considering the system life cycle, the business-case calculations based on overall system costs show clear commercial benefits of a FlexRay architecture compared with a multiple-CAN scenario. These business-case considerations served as a key decision criterion in introducing FlexRay technology early in BMW-series cars.

Cross-industry linkage
In recent years, the FlexRay communications system has become part of a broad range of activities and initiatives. In 2003 the Automotive Open System Architecture (Autosar) Development Partnership was founded to develop and establish a de facto open industry standard for automotive architecture to serve as a basic infrastructure for the management of functions within future applications and standard software modules.
Autosar defines software application programming interfaces that abstract the details of communication while utilizing the key properties of the protocol. Autosar complements FlexRay by providing a standardized run-time environment that encapsulates communication from higher-level software components in a very flexible way through Autosar interfaces.

In the future, it will be possible to provide innovations on the hardware level of the system hierarchy--by adding, for example, more controller host interface services to FlexRay or by incorporating a user-programmable coprocessor on a low level of the system hierarchy--ideally, in a way that is fully transparent to higher software layers.

**Conclusion**
When the FlexRay Consortium set out to develop the FlexRay protocol, it envisioned its ultimate objective as "industrywide recognition of a new standard for a deterministic automotive network which shall be open to use and development by third parties." Today, with the first automotive applications of FlexRay technology on the road, a key milestone has been accomplished toward this vision.

With the decision to introduce FlexRay technology in a pilot application, BMW has established itself as a driving force in the protocol's development. By ensuring early availability of FlexRay silicon qualified for use in automotive systems, Freescale has demonstrated the capability of bringing FlexRay to the market.

While these two companies chose to go first, it must be appreciated that the success of FlexRay technology as a whole is also a story of more than 120 companies deciding to invest, develop and move forward in the same direction. n

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