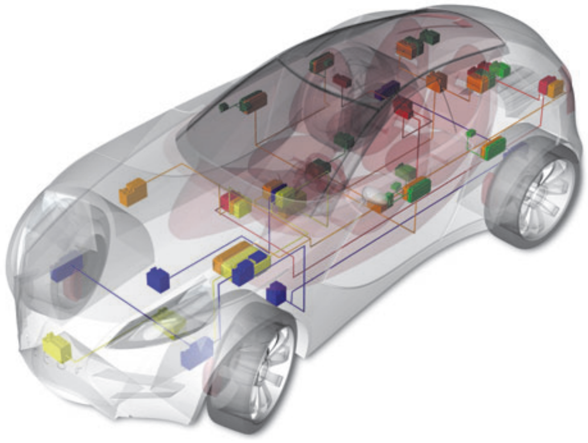
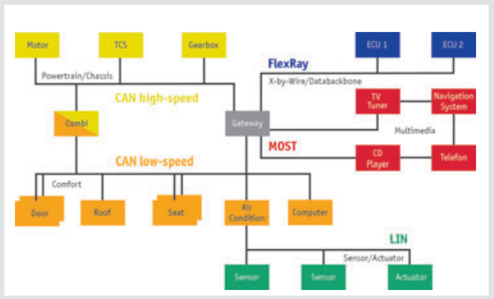
Serial Bus Systems in the Automobile

Part 1:

Motivation, advantages, tasks and architecture of serial bus systems in the automobile

The share of electronic components in the automobile is growing from year to year. Electronics plays a decisive role, not only in satisfying primary customer wishes for better driving safety and comfort, but at the same time to achieve better fuel economy and reduced exhaust emissions. Another aspect that should not be underestimated is the contribution by numerous serial bus systems in the automobile. Many functions would not even be possible without data exchange between electronic components. This article offers some initial insights into the world of serial bus systems in the automobile.





Motivation and advantages of serial bus systems in the automobile

Recent history of the automobile is characterized by intensive electronification. The driving force for this originates primarily from customer expectations of a modern automobile which are becoming increasingly demanding. Moreover, legislators are continually placing stricter requirements on exhaust emissions. The rising competitive and cost pressures of globalization also produce constant innovative pressure. Automotive OEMs have found electronics to be a way to meet this multiple challenge. Particularly this is reflected in the migration of electronic control units (ECUs) into the automobile which began at the end of the 1970s.

At that time, the first embedded electronic systems still performed their tasks fully autonomously. However, very early it was recognized that by coordinating applications placed in different ECUs, it would be possible to increase vehicle functionality immensely. This was the motivation for integrating communication systems in the automobile.

Ahead of everything else, at that time it was electronic driving dynamics control that dominated advanced development. However the intensive wiring effort utilizing individual dedicated lines only permitted limited data exchange. As a way out of this dilemma, bit-serial data exchange via a single communication channel came into question. This single communication channel integrates all individual communication channels and is referred to as a bus. Using this bus and associated serial interfaces it is possible to join all ECUs together into a network refer to as a serial bus system (Figure 1). In this context, ECUs are referred to as bus nodes.

Since the introduction of serial bus systems, the complex and often divergent types of wire harnesses in the automobile have become a thing of the past. Bus systems not only simplify project design and installation, but also reduce the weight and space required for wiring. Moreover, the lower

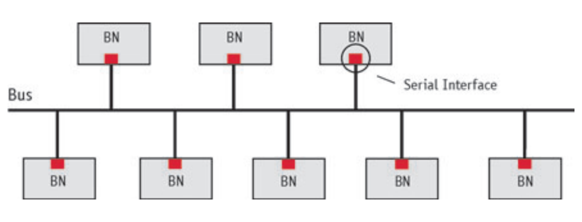


Figure 1:
Bus networking: All electronic control units (Black: Bus nodes) are joined into a system network, the serial bus system, by means of a bus and related serial interfaces.

number of connectors reduces the susceptibility to failure significantly. These many advantages face numerous communication tasks that must be mastered by the serial bus system. The most important communication tasks are discussed in the following.

Communication tasks

A precondition for trouble free serial data exchange is the unique allocation of the data to be sent to the bus nodes. Essentially a distinction is made between sender-selective and receiver-selective allocation (addressing). In case of sender-selective addressing the sender identifies the desired receiver by a unique bus node address. In contrast, in case of receiver-selective addressing the data to be sent are addressed. This means in principle that all data are available for any node to receive (Broadcast). Therefore all bus nodes have the task of filtering out data that are relevant to them. This is accomplished with the help of the address referred to here as identifier.

In order that the receiver acquire the data and address as one unit, the sender packs both of them together as a frame. A typical frame encompasses the address and data with a start and end recognition, which are primarily used to synchronize senders and receivers. A “frame” is also referred to as a “message”.

The most pressing tasks of a serial bus system include real-time communication and data integrity. A distributed system can only fulfill its intended purpose if all data reach the destination node in time and without errors. A serial bus system’s performance and field of application in the automobile substantially depend on the degree with which it can avoid, reject, detect and correct errors, and can guarantee timely data transport.

Data integrity

Quantitatively data integrity can be described as the residual error probability. This is a statistical measure of data integrity violation. Residual error probability is understood as the product of probability A that the transmitted data are corrupted and probability B that the corrupted data remain undetected. The data integrity of a serial bus system therefore depends first on the extent to which it avoids the corruption of data, and second on the degree to which it can detect corrupted data.

Various interactions related to electrical, capacitive or inductive coupling, as well as electromagnetic fields, come into consideration as potential causes of data corruption in the automobile. Specific sources responsible for corruption might be actuators, fan motors, high-frequency signals generated by the commutation process in DC motors and fast da-

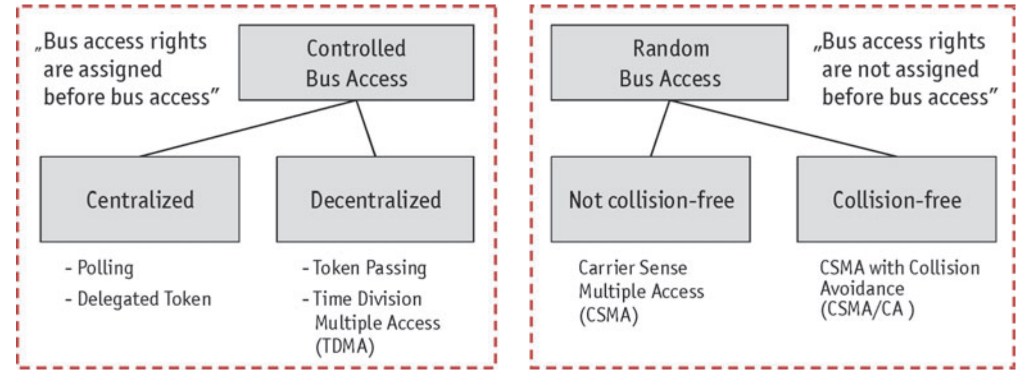


Figure 2: Controlled and random bus access.

ta transmissions or reflections at the ends of buses. The more successfully these causes can be eliminated, the greater the noise immunity and more reliable the data transmission.

To enhance the noise immunity of a serial bus system, certain important measures are necessary. Besides shielding the transmission medium, as well as all electrical and electronic components, it is important to provide sufficiently large distances between data and power transmission lines and between electrical and electronic components. Furthermore, it is important to limit the data transmission frequency and number of data signal edges and their steepness, to apply the principle of differential signal transmission and finally to terminate bus ends with the characteristic impedance of the transmission medium. Even with optimal physical system design transmission errors cannot be eliminated entirely. Error detection mechanisms are therefore essential. Among the most frequently utilized methods is the checksum method, wherein the sender computes a checksum from the data block to be sent by a defined algorithm. It then sends this checksum at the end of the data block. Using this checksum the receiver is able to verify the received data block. The more clever the algorithm, the shorter the data block to be protected and the longer the checksum, the better the algorithm's error detection ability. However, due to limited bandwidth and time requirements, a compromise must be reached between error detection ability and the ratio between data block and checksum size (transmission efficiency). Furthermore one must consider that the checksum itself is not immune to disturbances during transmission.

As a rule, after detecting a transmission error, error correction is needful, e.g. by means of an error-correcting checksum. However, unlike simple error detection that would require an explicit longer checksum. For efficiency reasons error-correcting checksums are not implemented in the automobile. The error correction happens by repeating the message: caused either by an error flag set by the bus node detecting the error, or automatically in the case of periodic message transmission.

Real-time capability

A system with real-time capability must be able to guarantee transmission of all data to be exchanged between the various bus nodes within a defined time window. Key factors

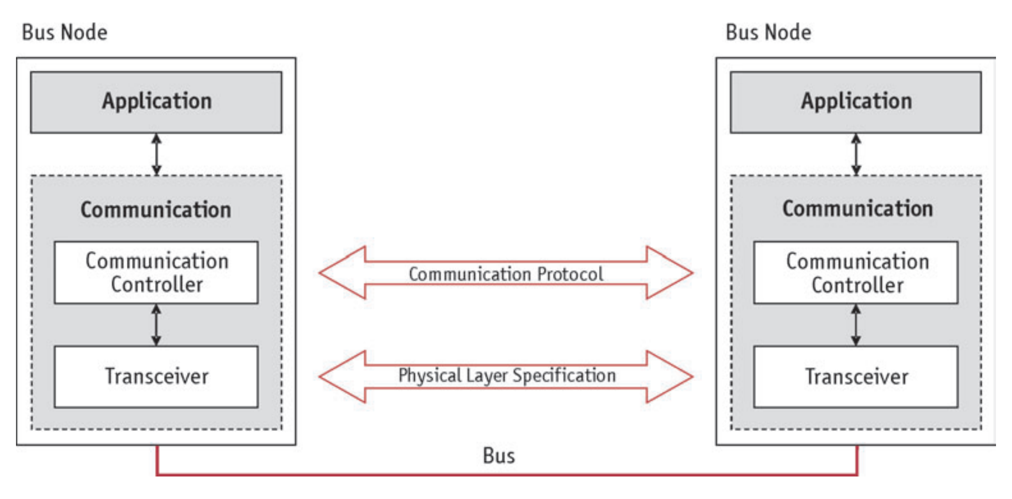


Figure 3: Simplified architecture of serial bus systems.

here are the number and sizes of messages, the available bandwidth, and especially the type of bus access. In the latter case a fundamental distinction is made between controlled and random bus access (Figure 2).

In serial bus systems with controlled bus access, bus access rights are already clearly defined before the bus access. Such systems offer deterministic message traffic as an important precondition for attaining real-time capable serial bus systems. However, since the entire communication sequence is executed according to a schedule and cannot be influenced, serial bus systems with controlled bus access are characterized by poor dynamic behavior.

This disadvantage does not apply to bus systems with uncontrolled bus access. Each bus node has the right to occupy the bus at any time, e.g. in response to an event that just occurred. This produces very fast bus access; however there is the inherent risk of more or less acute collisions, depending on the event density, message sizes and the available data rate. These are not good conditions for achieving real-time capable data transmission.

Monitoring of the bus by bus nodes wishing to send significantly reduces the risk of collision. It can be prevented entirely by introduction of message priorities. However, these bus access methods based on bus monitoring and message priorities cannot guarantee timeliness. It is possible, that low-priority messages will be delayed unreasonably long.

Architecture of serial bus systems and bus nodes in the automobile

Based on the reference model for data communication specified by ISO (International Standardization Organization), the serial interface of a bus node in the automobile is typically subdivided into two (communication) layers: A lower layer (Physical Layer) and a layer above it (Data Link Layer).

Some of the tasks handled by the Data Link Layer are addressing, framing, bus access, synchronization and error detection and correction. These tasks are defined by a communication protocol. The Physical Layer specification, on the other hand, covers all aspects of the Physical Layer, from the physical bus interface to physical signal transmission over the bus.

Generally the physical bus interface is implemented with the help of a transceiver. A communication controller covers the Data Link Layer. If all of the bus nodes within the system follow the same communication protocol and the same Physical Layer specification, then the fundamental preconditions for trouble-free data exchange between the bus nodes are satisfied.

In serial communication the sender's application passes to the communication controller the data block to be sent. The communication controller in turn adds the address and checking and synchronization information to the data block, thereby creating a frame. The transceiver now transmits the frame over the bus. In the automobile the physical interconnection structure is generally the line topology, which is very easy to manage due to the passive bus interface. On the receiver side the transceiver accepts the frame and passes it to the communication controller, which evaluates the information transmitted to it and in case of correct data reception routes the data block to the application.
This results in a hierarchical and therefore transparent communication flow. This is guaranteed by completion of the communication tasks assigned to the layers, and by the communication protocol and definition of the Physical Layer (Figure 3).

For some tasks such as bus management (including Sleep and Wake-Up functionality) or diagnostics and configuration of bus nodes, the communication functionality provided by the Data Link Layer is insufficient. By definition higher layers respectively higher communication protocols the communication functionality can be expanded.

CAN, LIN, MOST and FlexRay

Intensified competition is contributing toward more and more safety and convenience functions in the automobile. This not only results in a permanent increase in the number of electronic components in vehicles, but also a substantially greater degree of networking with rapidly escalating data volumes, since most new automobile functions cannot do without data exchange any longer. To keep the growing complexity of automotive electronics manageable, automotive OEMs create different standards on the system, functional and communications levels. On the system or functional level, "AUTOSAR" (Automotive Open System Architecture) is expected to provide the necessary transparency in the future. Non-proprietary communication standards such as CAN, LIN, MOST and FlexRay provide greater transparency on the communications level.

CAN (Controller Area Network) is used primarily in the powertrain, chassis and convenience areas. LIN (Local Interconnected Network) serves to achieve simple and cost-effective data transmission in the sensor/actuator area. MOST (Media Oriented System Transport) is implemented in infotainment to transmit video and audio signals. Finally, FlexRay enables the most challenging communication in safety-critical distributed applications. Figure 4 shows an example of ECU networking with serial bus systems in a modern automobile. In contrast to CAN, LIN and MOST, however, FlexRay must first become established in the automobile. This fall the first FlexRay production application will hit the streets. The Munich automotive producer BMW is introducing the innovative bus system in an active suspension control system on its new X5 automobile.

CAN was developed in the early 1980s by Robert Bosch GmbH, and in 1994 it became an international standard (ISO 11898). Three of Vector's executive directors played key roles in its development, and in 1988 they founded Vector Informatik GmbH. LIN, MOST and FlexRay emanated from non-proprietary organizations: The LIN Consortium (www.lin-subbus.org), MOST Cooperation (www.mostcooperation.com) and FlexRay Group (www.flexray.com). Although they have not been officially standardized, they can be considered de-facto standards.

Reliable partner for ECU networking and data exchange

The specialists at Vector support automotive OEMs and suppliers in CAN, LIN, FlexRay and MOST networking with a universal tool chain of design and development tools as well as software components and base software for AUTOSAR ECUs. Advising, consulting services and tools for process management supplement the application areas. Its services are complemented by a broad-based training program on Vector tools, software components and serial bus systems.

For entry-level work in automotive ECU networking or data exchange the Stuttgart-based company offers the one-day seminar "Serial bus systems in the automobile". Fundamentals seminars on CAN, LIN, FlexRay and MOST are best suited as introductions to the various development activities related to automotive electronics. Additional information and schedules one can find on the Internet: www.vector-informatik.com

Outlook

Parts 2-5 of this series address the serial bus systems CAN, LIN, FlexRay and MOST in detail.

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