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Design of Intelligent Body Networks

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ABSTRACT

With additional new or more intelligent functions emerging in the vehicle, engineers are facing new challenges in the design of the Automotive Electric/Electronic System. New ECUs, actuators and sensors have to be provided with information, energy and control signals. In order to limit the weight of the wiring harness and to guarantee the electrical supply of the components an improved design and architecture of the body network is required.

Communication is being handled by several bus systems which are connected via gateways. Sensors and actuators are getting smarter. The existing 12V electrical supply system will be supplemented or replaced by a 42V network. Several new functions (e.g. extended systems diagnostics) will be added without additional actuators but just by additional software, requiring more computing power in the vehicle.

All this will require a systems approach for the body networks resulting in an improved functionality and reliability keeping the costs and complexity of the system limited.

INTRODUCTION

Body electronics offer a variety of well-known and new functions:

- basic functions: external and internal lighting, wind-shield washing and wiping, signalling
- comfort functions: seat, mirror and steering wheel adjustment, power window control, sunroof adjustment
- vehicle security functions: central door locking, keyless entry, immobilizer, anti-theft system
- heating and climate control systems
- driver information systems: user interface, instrument cluster, navigation, communication, multimedia.

The Intelligent Body Network – as we understand it – provides the sensors and actuators of the vehicle body electronics with the required **intelligence** to utilize them in an optimum way, plus the infrastructure: **communication** and **power supply**.

Today several trends are changing the world of body electronics:

- System and module approach: the vehicle is subdivided into systems and modules, reducing the complexity for development and manufacturing.
- Distributed Intelligence: additional functions will not necessarily result in additional ECUs, intelligence will be distributed.
- Networking: more and more systems and components are communicating via several networks.
- Innovative power distribution: the power distribution system is getting more sophisticated, a new voltage level (42V) is going to be introduced.

1 SYSTEM APPROACH

The challenge in vehicle E/E design has shifted from optimizing individual components like ECUs, sensors, actuators, mechanical or electrical elements to the optimization of complete systems within the vehicle. Examples are: signal and power distribution system, vehicle security system (immobilizer, keyless entry/go, anti-theft control) and cockpit electronic system (instrument cluster, driving access, driver information system, HVAC, etc.). The base technology of these systems is multiplexing: the electronic control units (ECUs) distributed across the car body are interconnected by means of a bus system. The objective is to minimize the number of wires, connectors and contacts, so even for the cars' base equipment multiplexing can be introduced without additional costs. This is achieved by placing ECUs in those sections of a car, where electronics are required, e.g. dashboard, door, seat, roof and rear. Within a section sensors, actuators and switches are connected to the nearest electronic control unit, irrespective of the unit's function. The systems are characterized by the following features:

- Multiple functions are integrated into a single ECU. In order to amortize the electronics' costs multiple functions are integrated in a single ECU. Examples are functions like external and internal lighting, hazard warning control, front and rear wiper control, central door locking among others.

- Functions are distributed across multiple ECUs; for example the function “central door (un)locking via remote control” is typically realized by cooperation of the ECU in which the remote control receiver is integrated and the door electronic units integrating the lock function.
- Electrical distribution systems junction boxes are replaced by more expensive smart power distribution units (PDUs) including electronic functions and a bus interface. Additionally the distribution system is modularized by several PDUs into clusters. Each of these units add costs, but the cost reduction in the wiring harness and the easier handling of the system compensate these additional cost for the whole power distribution system.
- Smart sensors and actuators are naturally more expensive than simple ones, but they offer advantages in function (self-diagnostics, control), wiring and system availability, as several ECUs can utilize the same components. Actuators will include a power device, communication and maybe even intelligence. The smart actuator is reacting to the request of his „master ECU“ given by e.g. serial communication and is controlling his inner control circuit independently. Functions like current limitation etc. can be handled by the actuator itself. The intelligence may be incorporated directly into the actuator or in the connector. With less control outputs on the ECUs the system becomes more flexible. An addition of a smart component is much easier than an addition of a simple component as less additional connectors, terminals etc are required. Just the software in the „master ECU“ has to be adapted (control algorithm, CAN messages).
- Subsystems with sub-busses etc (e.g. doors, seats, cockpit) may include rather expensive ECUs and components, but reduce the complexity of the complete system and offer advantages in packaging.
- ECUs with rather high computing power will handle different tasks. The number of these multifunctional ECUs will be different in different cars. They will include software for „their“ sensors and actuators as well as software with no dedicated component like gateway, diagnostics, personal profiling, power management etc. Thus additional functions can be added just by adding software.

There is a common denominator of all these features and examples: not an individual component is optimized (costs, packaging...), but a whole system. The optimized system may consist of non-optimum components.

Putting all these characteristics together, the most likely E/E architecture of the future is a hierarchical system, as shown in Figure 1.

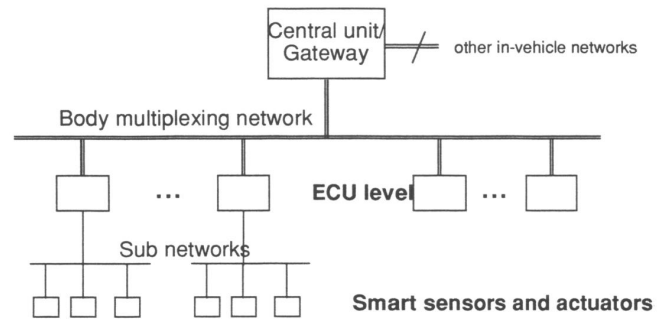


Figure 1. Hierarchical electronics architecture

Dependent on the vehicle type, packaging, equipment and the OEMs philosophy the functions are implemented in different ECUs and integrated in a vehicle- or OEM-specific electronic architecture. This poses a major challenge to the suppliers requiring a lot of flexibility. They have to develop their software in a way that it can be transferred between different ECUs at a rather late state of a project. Even during the lifetime of a product major changes may occur caused by added features in the vehicle. And a full system supplier has to be able to include software developed and tested by another supplier or the OEM. This results in the following requirements:

- Clear decoupling of ECU hardware and software by means of a layered software architecture. The OSEK/VDX open architecture – comprising real-time operating system, communication protocols (intra-ECU and inter-ECU) and network management – is the fundamental basis for future ECUs software architecture and is the prerequisite for the introduction of software techniques and tools that support portability, reuse, software sharing and code generation. Figure 2 shows as an example a typical future ECU software architecture, including OSEK/VDX and additional hardware encapsulation software components like I/O, flash programming and diagnosis drivers.
- The functions and thus the software have to be structured in a modular way with very easy interfaces allowing easy reuse in different configurations. For this purpose Bosch has developed the CARTRONIC® approach. CARTRONIC® is an ordering concept for all vehicle control systems. The concept comprises modular expandable functions, safety and electronics architectures. Fundamental architectural structuring and modeling rules are established in order to organize networked systems independently of a special hardware topology from a functional point of view. The rules define components, their permitted interactions and patterns for recurring tasks independent from a special function. This means that the

rules and patterns are a “common language” for engineers to analyze functions in the entire vehicle from the same view. CARTRONIC® is providing a consistent methodology to handle the challenges that arise by increasing system interconnections starting from the abstract level of function analysis [1, 3].

- Tools have to be available to enable software design independent of the hardware architecture. A step in this direction is the TITUS approach which was developed in a joint project of DaimlerChrysler and IBM [5]. TITUS uses the client/server model for the structuring of distributed applications. The TITUS architecture defines an application software framework with 6 different types of components which communicate with each other by use of well-defined interfaces and protocols. During the SW design phase ECU implementation aspects are not taken into account; the application software can be developed without knowledge of the target hardware configuration. The implementation phase is supported by code generators which generate the application (control) and the communication software based on the OSEK/VDX system software infrastructure. The TITUS approach makes a simple and tool-supported integration of software components possible. The software architecture is the basis to design software components which can be reused for different vehicle model lines.

2 NETWORKING

Most new vehicles nowadays offer at least one bus system for ECU communication and diagnostics.

Table 1. Characteristics of in-vehicle networks

Network	Interconnection of	Data transfer rate	Network features	Data transfer mechanism	Example
Powertrain network	Engine Man., ABS, TCS, VDC, Transm., Suspen., ACC, etc.	Typ. 500 Kbit/s	Multi-master bus, twisted pair line	Asynch., mess. priority based bus access, cyclic and event driven transfer	CAN High Speed
Body network	Door ECU, Seat ECU, Instrum. cluster, Climate control, Keyless go, etc.	< 125 Kbit/s	Multi-master bus, twisted pair line, fault-tolerant physical layer	Asynch., mess. priority based bus access, cyclic and event driven transfer	CAN Low Speed (Europe) J1850 (US)
Multi-media network	Navigation, Video, Audio receiver, Audio amplifier/HMI panels, Displays/CDC, Mobile phone	5 – 100 Mbit/s	Plastic optical fiber, Ring topology	Synchr. transfer of audio and video data, Asynch. transfer of control data	D2B optical MOST (Media Oriented Systems Transport) MML (Mobile Media Link)
X-by-wire network	x-by-wire ECUs, e.g. brakes, steering	1 Mbit/s, 2 Mbit/s	Fault tolerant physical layer, 2 wires	Time-triggered (TDMA), Static mess. scheduling, Global time	TTP/C

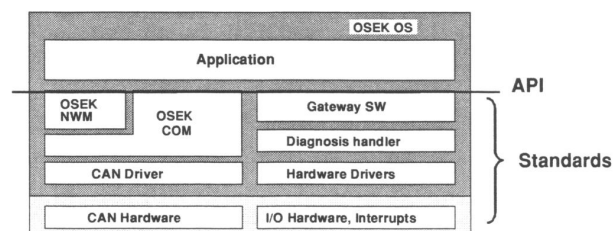


Figure 2. Structure of future ECU architecture

2.1 IN VEHICLE NETWORKS – The requirements with respect to data transfer rate, protocol mechanism, reliability, fault tolerance and costs are dependent of their applications and have lead to the development and introduction of different network types (see Table 1). Network technology is further pushed by standards like CAN and OSEK/VDX [Kie98]. With OSEK/VDX, protocols and services in the areas of network communication, network management and ECU operating system have been specified and will be used from 2000 on in production cars by several European car manufacturers. The use of the OSEK/VDX standards simplifies significantly the development of network-based distributed applications and the integration of ECUs and software coming from different suppliers.

In future cars the communication across network limits will increase. Functions like HMI, user profile, power supply management, tele-diagnosis, etc. will require integrating all ECUs in a global vehicle network. This global network is the interconnection of the different vehicle networks by means of special gateways.

2.2 GATEWAYS – A gateway node is an ECU which is connected to at least two different networks. Its function is to transfer data from one network into another network and vice versa. Basically, there are two approaches for gateway architectures: a distributed system with several point-to-point gateways with each gateway connecting two networks, and a central multipoint gateway with all networks connected to a central ECU. A special case of a distributed gateway is the gateway bus, where each network is connected via a gateway node to the gateway bus, so that information can be exchanged between all networks via the gateway bus.

Distributed gateway – In a distributed gateway system several gateway nodes are implemented to achieve a global network. Typically the gateways are no standalone ECUs but integrated with other functions in a multifunctional ECU. To enable data exchange between each pair of N networks at least $N-1$ gateways are required. To have a minimum distance of 1 between all N networks, $N*(N-1)/2$ gateways are necessary. In this case each network is directly connected with each other network by means of a gateway.

Central gateway – In a central gateway a single ECU integrates the gateway function. The microprocessor of the central gateway has access to several networks and is responsible for exchanging data across the different networks. Compared to the solution discussed above the central gateway realizes a minimum distance inter-network communication with the minimum amount of hardware.

Gateway bus – The gateway bus solution is a special case of a distributed gateway system. Each network has access to the gateway bus via its own gateway node. In case of N networks, N nodes with a gateway function are required. The distance between two arbitrary networks is always 2.

Besides the general solutions described above, there are a lot of specific hybrid solutions which result from partitioning a set of networks into different clusters where each cluster is interconnected according to one of the described architectures.

Comparison – The central gateway has clear advantages in terms of system costs and latency time. However, in case of a gateway failure the corresponding networks are isolated. Fault-tolerance could be achieved by redundancy in form of additional gateway units or a central gateway with a multi-processor architecture.

The gateway bus is a very flexible solution, if new networks or messages are to be added; however it is a costly solution as an additional bus is required.

The distributed gateway system is feasible for a small number of networks. In case of a single gateway failure only a single network is isolated.

For more details see [6].

2.3 SUB-NETWORKS – Driven by semiconductor technology there is a continuous trend to integrate electronics into sensors, actuators and switch panels. The communication interface of smart sensors and actuators is rather simple compared to multiplexing networks like CAN. In most cases a low-cost SCI or UART-based master-slave communication scheme is used. The communication line is typically a single wire, the signal levels correspond to the 12V ISO 9141 physical interface (k-line), data transfer rate is 9.6 Kbit/s. Examples of such sub-busses are described in [7] and [8]. Application areas for sub-networks are for example:

Area	Sensors, actuators
Cockpit	Switch panels, steering wheel column stalk, radio satellite, air conditioning motors, displays, etc.
Door	Switch panel, lock, window lift motor, mirror (see Fig. 3)
Seat	Seat adjustment motors, switch panel
Roof	Sensors, roof adjustment motor, interior lighting control
Others	Alternator, headlamps, headlamps adjustment, smart wiper etc.

Currently there are activities driven by Motorola and European car manufacturers to establish an international standard for in-vehicle sub-networks. For more details, see [4].

Sub-networks will be connected to the entire vehicle network by means of gateways, which are integrated in the ECUs of the multiplexing bus, so that the resulting network is a hierarchical system (see Figures 1, 3). In a hierarchical electronics architecture, the smart sensor/actuator level components provide clearly defined functions and services which can be accessed by the higher levels in order to implement ECU- and cross-network functions.

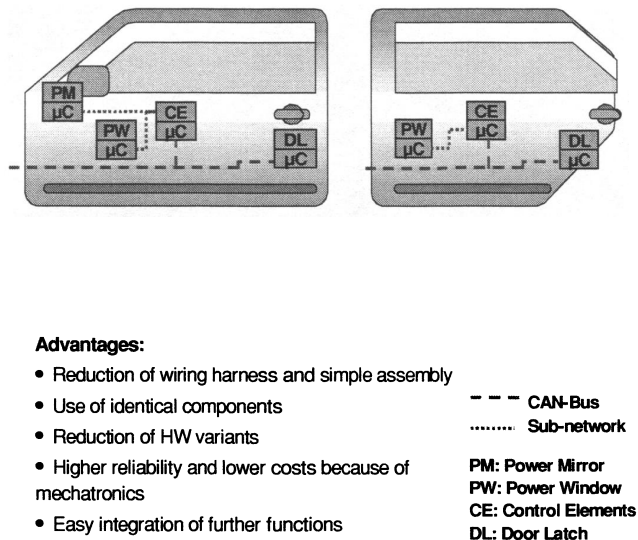


Figure 3. Sub-network within the door (example)

3. POWER DISTRIBUTION SYSTEM

With more and more functions being requested in upper class vehicles the power demand is increasing rapidly. Additionally efforts to reduce fuel consumption and emissions lead to the tendency of replacing direct drives by electronically controlled drives. This increases the demand of electrical power while reducing the demand of „mechanical power“ – thus fuel. As the conventional 12V power supply system is hardly able to provide the required currents, the industry is discussing the introduction of a 42V PowerNet.

3.1 INTRODUCTION SCENARIO – Potential high power electric consumers include:

- Front window defroster
- Auxiliary electric heating
- Electromagnetic valve control
- Electric power steering
- Electromechanical brakes
- Electromechanical suspension control
- Heated catalyst
- Integrated starter/alternator
- Rear window defroster
- Electric pumps (ABS, cooling, water..)
- Electric motors (power seats..).

The introduction scenario of 42V will be different for each vehicle manufacturer. Main motivations are:

- Some loads require a higher voltage level (e.g. front window defroster).
- The current 12V (14V) system cannot supply the power requested by new loads (e.g. heated catalyst) anymore.

- Wiring harness or power dissipation are reduced.
- The redundant 12V/42V power supply is used for safety critical systems (e.g. electric steering/braking/locking)
- The integrated starter/alternator is utilized as auxiliary drive to reduce emissions and fuel consumption.

With a great number of 12V loads already introduced in today's vehicle, a complete conversion to a pure 42V car is not likely. So a dual voltage power supply will be the common architecture for the next several years. The major additional costs (DC/DC converter) and the additional failure modes (shortcut between 14V and 42V) will in the long run drive automotive manufacturers and suppliers to a complete conversion to 42V. The new 42V PowerNet will then display 42V as the only common voltage level with some locally available lower voltages (12V, 5V..).

3.2 POWER DISTRIBUTION ECU – Back bone of the Power Distribution System are the wiring harness and the smart junction boxes or Power Distribution Units (PDU). The PDUs as the active part protect, switch and control the electric consumers and provide communication. Additionally they divide the E/E-system into smaller clusters reducing complexity of the system and the handling of the wiring harness (s. figure 4).

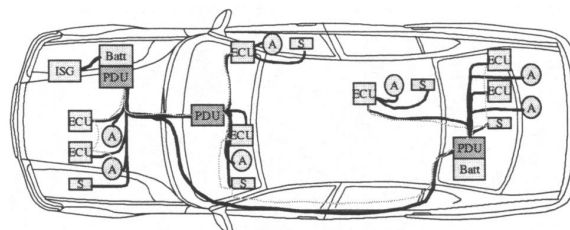


Figure 4: Clusters created by different PDUs

The transition from junction boxes to PDUs offers the chance to add intelligence to the Power Distribution System:

- improved diagnostics, including system diagnostics
- fail safe functions, keep alive functions
- personal profiling
- load management and management of the quiescent current.

Improved systems diagnostics will only partly be incorporated into the PDUs as they require a lot of computing power. But by diagnosing their subsystem and providing „meta-information“ the PDUs ease the task of a central body computer responsible for system diagnostics and

the proper communication with driver and garage. With improved on-board-diagnostics the PDUs identify defect actuators and sensors, and drive the system into a safe state or replace the defect function by a similar feature without adding cost to the original actuators. So a defect low beam lamp function may be replaced by pulse width modulating the high beam lamp; and with a detected failure of the lamp switch all lights may be turned on guaranteeing a safe vehicle.

Personal profiles allow to adapt comfort functions to the individual driver or passenger of the vehicle. The stored characteristics of the users are transferred to the respective actuators which are set to the predefined status.

Load management and management of the quiescent current shall prevent discharge of the battery and allow reduction of battery and alternator by taking better advantage of their abilities.

3.3 DUAL VOLTAGE SYSTEM ARCHITECTURE – Up to now no standard architecture for a dual voltage network has been established. Some alternatives are:

- 42V alternator, DC/DC converter
- Alternator with dual voltage output
- 42V alternator, 12V alternator.

Most alternatives include a 36V as well as a 12V battery. Instead of a starter battery a “supercap” may be used as well. The approach with a DC/DC converter may incorporate several DC/DC converters to generate local distribution networks. The other approaches may include a (small) DC/DC converter as well for improved flexibility and jump starting.

Power generation by 42V alternator and DC/DC converter may be the best solution for a system with low power demand on 12V. If with the introduction of 42V only a small number of loads is on 42V and the majority stays on 12V, the DC/DC converter has to provide lots of power, creating a rather costly solution. In this case the introduction of two different alternators becomes an attractive solution.

The power distribution system is divided into several clusters by the addition of several PDUs. A very attractive solution appears to be the combination of PDU and DC/DC converter. The combination of a central PDU/Converter offers advantages in costs and failure handling, while the combination of local PDUs with DC/DC converters allows the reduction of the wiring harness and a very easy system approach (s. figure 5).

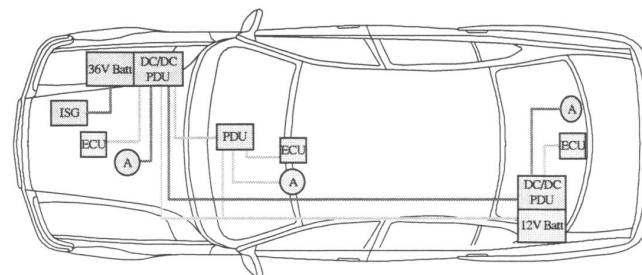


Figure 5: Dual voltage architecture with combined PDU/Converter

3.4 FAILURE HANDLING – A new technical problem will be the potential shortcut between the 14V and the 42V voltage levels. Shortcuts are an issue in every electrical network, but the automotive dual voltage network displays a special problem. Whenever a shortcut between 42V and a 14V device switched by a MOS switch occurs, not only this 14V device, but the whole 14V network is connected to the 42V level. This is due to the unavoidable reverse diode of MOS switch S1 (s. figure 6).

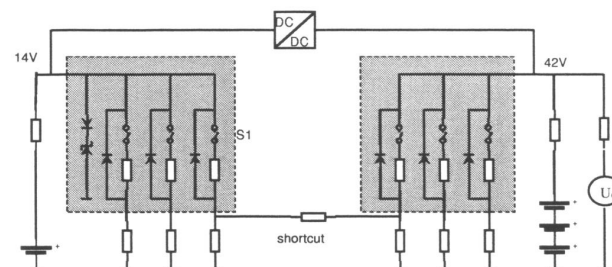


Figure 6: Shortcut between 14V and 42V

The most effective way to protect the 14V loads is detecting the “driving” 42V load and turning it off as soon as possible. In order to switch off the source of the short cut current unprotected 42V lines have to be avoided. In a very common architecture (see figure 7) the powerlines between starter/alternator, battery, DC/DC converters and PDUs can only be protected by switching off the smart battery post disabling the whole vehicle.

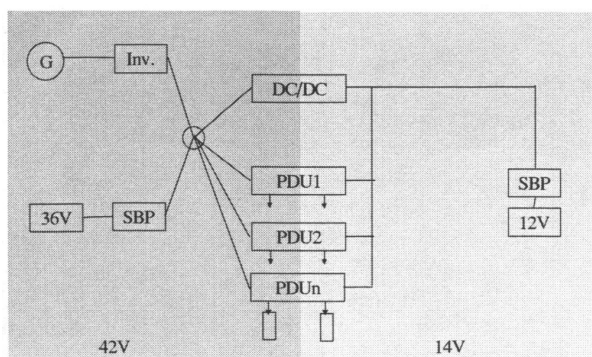


Figure 7: common architecture

To reduce the possibility of this major fault, some general rules should be applied:

- combine DC/DC converter and one PDU to a “Master-PDU/converter”
- mount Master-PDU close to battery
- mount battery close to starter/alternator.

Additionally

- protect all “satellite-PDUs” by the Master-PDU
- protect all 42V loads in PDUs
- minimize unprotected 42V lines
- avoid neighboring 14V and 42V lines.

To reduce the effect of the shortcut to the 14V loads, basically two different methods are possible. The first alternative avoids switches with a reverse diode, separating the shortcut from the 14V net. The 14V net is saved, but major problems may appear detecting the fault and the driving 42V switch, as the additional current through the 14V device may be small compared to the standard current through the 42V source.

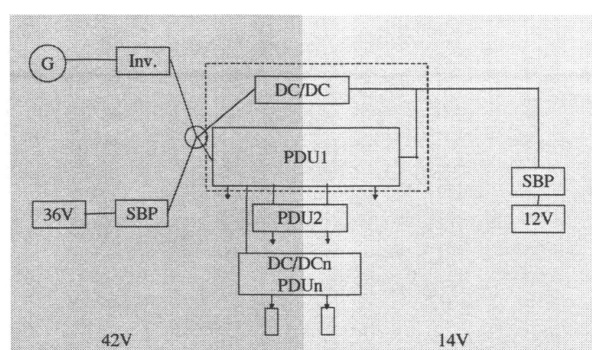


Figure 8: Proposed architecture

The second alternative is installing a “sacrificial device” on the 14V level. This device has to accept the whole current from the short cut reducing the overvoltage in the system and protecting the 14V loads until the short cut is detected. It has to stand currents close to 1000A and to limit the system voltage to a level of approximately 24V, still allowing the 14V and the 42V components to work. With this high current the source on the 42V level can easily be detected and turned off.

Different sacrificial devices are currently under investigation.

Both strategies turn off the minimum number of components or subsystems in case of a failure and protect all but one 14V device. Proper architectures, devices and strategies have to ensure the detection is fast and no device is destroyed by the current through short cut and other devices.

3.5 TECHNOLOGY – With the introduction of 42V using semiconductors is getting more (cost) attractive. Relays (with fuses) may be replaced by solid state relays, and fuses may be replaced by solid state relays or polyswitches. Tables 2 and 3 show some advantages, disadvantages and features of the different alternatives.

Table 2. Comparison of solid state and mechanical relays

Solid State Relays	Mechanical Relays
Current sensing, diagnostics	-
PWM control possible	-
-	Complete blocking, no reverse current
-	Different control and load circuits
Reliable	Robust (against overload)
Low control power	No quiescent current
Advantages in ECU construction	Easy servicing
Cheaper with small currents	Cheaper with high currents

Table 3. Comparison of fuses, solid state relays and polyswitches

Fuses	Solid State Relays	Polyswitches
-	Additional functionality	-
-	Self healing	Self healing
Low power dissipation	Medium power dissipation	High power dissipation
-	Quiescent current required, Load management possible	-
High currents	Medium currents	Low currents
Low costs	High costs	Medium costs

It is expected that most relays (especially for low power devices) will be replaced by semiconductors, while fuses will still be prominently displayed in PDUs. Small loads may be protected by polyswitches while solid state relays will only be used for fusing in special cases.

CONCLUSION

In an effort to enhance the vehicles' comfort, safety and efficiency the electronics are getting more and more complex: huge software modules, a large number of ECUs, and different voltage levels are the flip side of the continuous evolution of the automobile.

A consequent systems approach is introduced in order to control the complexity of body electronics. Intelligent Body Networks organize the intelligence, communication and power supply in a novel way and open the door for more innovation and customer satisfaction.

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