

# Digital Networks in the Automotive Vehicle

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Nothing stands still for long in the world of electronics. The automotive industry is party to this phenomenon and is fast becoming a breeding ground for binary electronic life forms. Today's vehicles include a complex symbiosis of intelligent electronic systems and integrated mechanical structures. The rapid growth of the computer industry has spawned a host of modern solutions and opportunities for automotive systems. It could be argued that the electronics revolution of the past two decades is the single biggest driving force behind the evolution of the motor car. Today, electronic components and systems account for over 20% of the cost of a high-end passenger car, and this percentage figure is increasing rapidly.

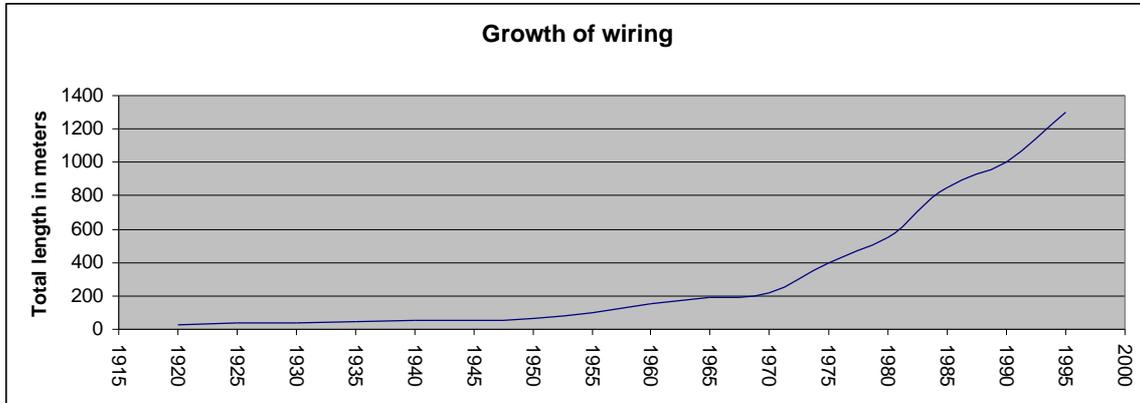
The customer is demanding more and more sophisticated features at an affordable price. The automotive manufacturers are competing to meet such customer demands within the market price envelope. New regulatory safety and fuel related standards (emissions, fuel efficiency etc.) are presenting further challenges to the manufacturers. Electronic systems now provide the technology to enable the manufacturer to deliver new features and to meet the mandatory regulation requirements in a cost-effective manner. Vehicle electronic systems are now common place and are growing in terms of both quantity and complexity. In this paper we take a glimpse under the hood of the modern vehicle to provide an insight into the world of automotive electronics, with special emphasis on the networking aspects of these electronic systems.

## Developments in automotive networks

Up until recently the in-vehicle communication between simple devices such as switches and actuators was achieved using point-to-point wiring; resulting in bulky, expensive, and complicated wiring harnesses which were difficult to manufacture and install. With the expanding number of features within the vehicle the amount of wiring grew to a stage where the volume, reliability and weight became a real problem. Figure 1 shows the growth of vehicle wiring requirements for Volvo passenger cars over nearly eight decades<sup>1</sup>. The problems associated with the vast amount of vehicle wiring can be summarised as follows:

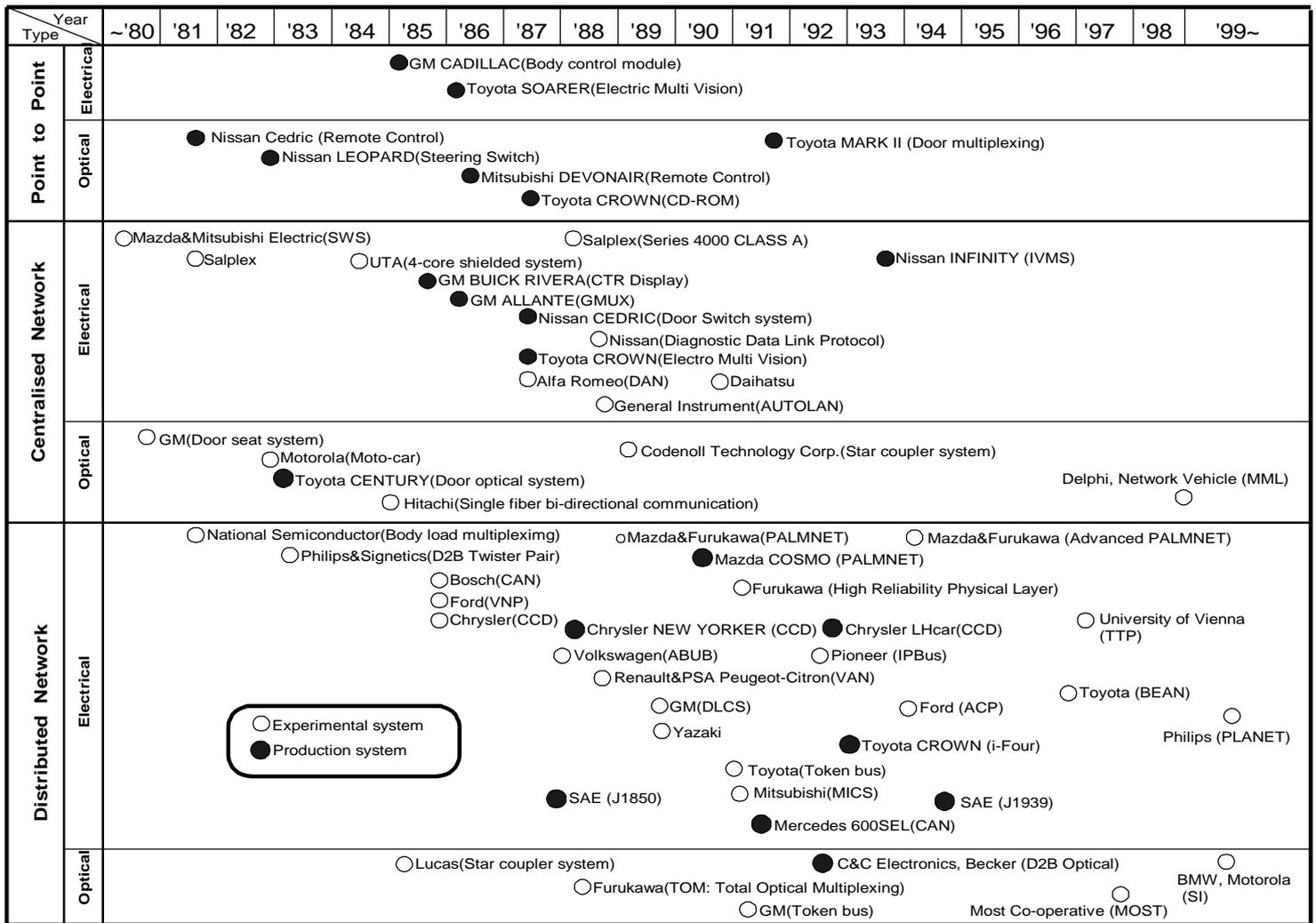
- shrinking layout space
- manufacturing and assembly difficulties
- deterioration of serviceability
- the cost/benefit ratio, does not encourage when adding additional functions at the expense of extra wiring

- increased emphasis on fuel efficiency and performance (acceleration, deceleration) requires reduction in vehicle weight
- sensor/input data being inefficiently distributed by multiple discrete signal channels
- the numerous connectors lead to unreliable operation; each link reducing the mean time between failure



**Figure 1 Growth of Automotive Wiring**

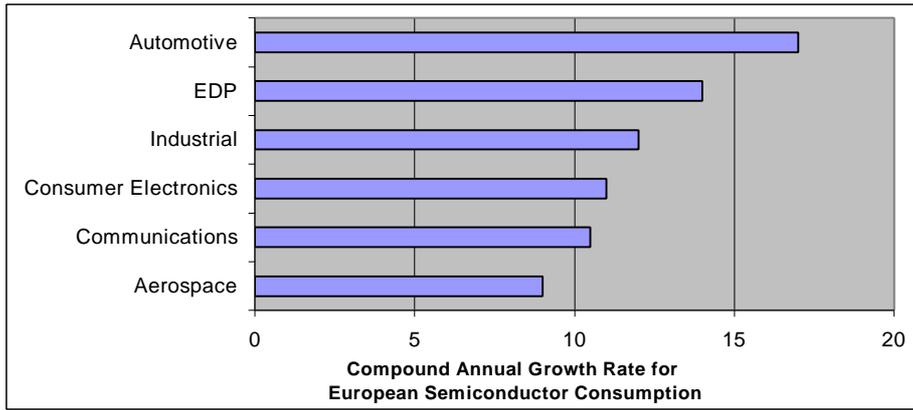
The need to reduce the vehicle wiring content and to improve the distribution of control and monitoring functions within the vehicle became apparent over the years and solutions for vehicle networking started to emerge during the 1980s. Figure 2 charts this historical progression and shows many of the early and current vehicle networking solutions<sup>ii</sup>. Many of the technical concepts for vehicle networking were borrowed from developments in the area of computer data networks but vehicle communication requirements are driven by control strategies rather than by classical data transfer strategies.



**Figure 2 Automotive Network Development**

In the early days of vehicle networking development there was little interest in devising common networking standards. Many of the early networks made use of custom circuits and generic UART (Universal Asynchronous Receiver/Transmitter) devices to provide simple serial communication links. This approach was acceptable at the time, as then most manufacturers were vertically integrated and not as highly dependent on external suppliers, as they are today. As confidence grew and the benefits of adopting a standardised networking approach became more apparent, external suppliers were commissioned to develop increasingly more sophisticated modules which finally resulted in a move away from proprietary interfaces in favour of industry-wide standardised protocols. The standardisation of protocols helped facilitate the integration of systems developed by different suppliers, leading to a type of ‘open architecture’, and added a degree of composability to the system design process. In-vehicle networking was initially introduced in high end luxury class models (as with all leading-edge technology), but the standardisation efforts which followed helped to support the economy of scales necessary for its introduction into the mid-range and standard class

vehicle. Today networked electronic subsystems are a vital element in all classes of vehicle and as can be seen from Figure 3<sup>iii</sup> this electronics presence in vehicles is growing rapidly.



**Figure 3 Semiconductor Consumption Compound Annual Growth Rate**

In the US the SAE (Society of Automotive Engineers) has published a series of documents describing recommended practices for vehicle networking. The SAE has also formally classified vehicle networks based on their bit transfer rates, Table 1 illustrates these categories. Specific standards exist for Class A, Class B and Class C networks, but the SAE have not yet defined specific standards for Class D networks. However networks which exceed a data rate of 1Mb/s are often referred to as Class D networks.

Network Classification	Speed	Application
<b>Class A</b>	<10 kb/s	Convenience features
	Low Speed	e.g. trunk release, electric mirror adjustment
<b>Class B</b>	10 – 125 kb/s	General information transfer
	Medium Speed	e.g. instruments, power windows
<b>Class C</b>	125 kb/s – 1 Mb/s	Real time control
	High Speed	e.g. power train, vehicle dynamics
<b>Class D</b>	> 1 Mb/s	Multimedia applications
		e.g. Internet, Digital TV
		Hard real time critical functions e.g. X-by-Wire applications

**Table 1 Classification of automotive networks**

A typical motor vehicle represents an extremely hostile environment for electronic equipment, subjecting this equipment to adverse conditions such as: mechanical vibration; temperature swings from  $-40\text{ }^{\circ}\text{C}$  to  $+80\text{ }^{\circ}\text{C}$ ; splashes from oil, petrol and water; ice; strong electromagnetic fields (automotive field strengths can be  $> 200\text{ V/m}$ , domestic is

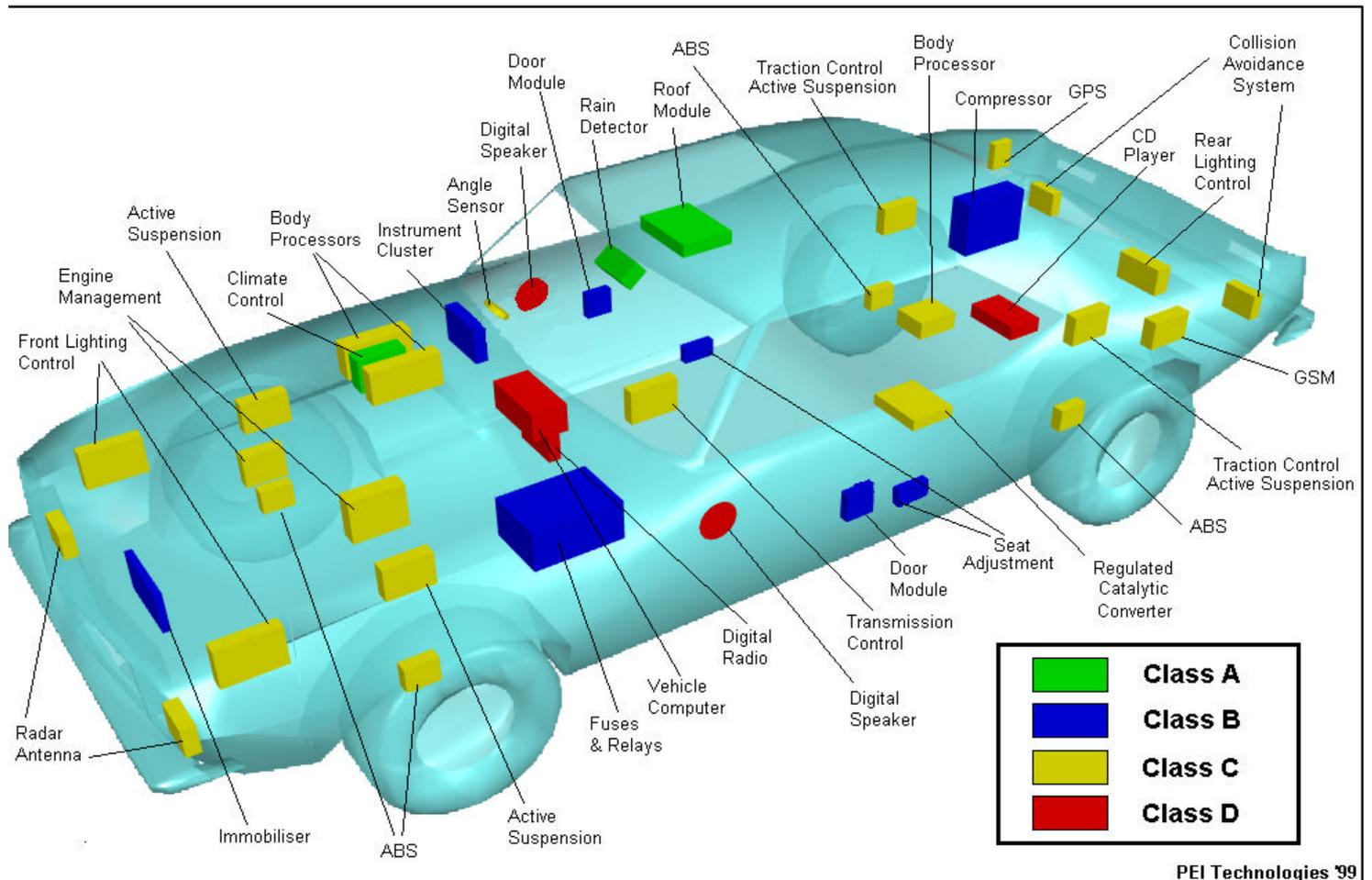
around 3 V/m and industrial 10 V/m ); electrical spikes/transients of both polarities ( $> \pm 100\text{V}$ ); load dumps; jump starts; high humidity; dust; sand storms; and potential mis-wiring of electrical systems (e.g. short circuits to ground or positive, reverse battery, etc.).

Along with the environmental considerations, automotive network solutions require some special design considerations, such as:

- **High integrity**                      The probability of an undetected error must be negligible for the life span of the vehicle
- **Bounded determinism**            A guaranteed upper threshold on message latency time for control problems
- **EMC compliance**                    Both emitted radiation levels and the tolerated absorption levels must be met
- **Low interconnection count**      Each additional connector increases the probability of a potentially life endangering fault
- **Compact connectors**                The connector is often the largest component on an automotive electronic module
- **Low cost**                                Costs are critical. A saving of a few pennies on a component is substantial in high volume production
- **Network composability**          Variations across models and after market extras require a network which is easily expand and modified
- **Fault Tolerance**                      Communication must be restored when faults are removed and redundancy is becoming important

## **The typical vehicle will have more than one network system**

Electronic equipment is distributed throughout a modern vehicle supporting a host of functions as illustrated in Figure 4. The functionality for a given automotive system is often distributed to span more than one network system. For example, the interplay between an engine management system network and the traction control system network needs to be carefully defined where, for instance, a reduction in engine torque is necessary to reduce drive wheel slippage, through fuel and engine timing adjustment. Another example is an intelligent auto-routing function, which might require information from a number of systems, gathering variables such as ABS wheel position data, steering wheel angle, GPS satellite data, and the radio RDS-TMC (Radio Data System - Traffic Message Channel) information.



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**Figure 4 Electronic equipment in a modern motor car**

## Automotive Network Solutions

Table 2 shows a selection of automotive network solutions. There is a wide range of automotive networks reflecting defined functional and economic niches. High bandwidth networks are used for vehicle multimedia applications, where cost is not excessively critical. Reliable, responsive networks are required for critical real-time control applications such as powertrain control, and vehicle dynamics. In such demanding control applications the functional needs dominate over the economic ones and it is sometimes necessary to implement networks incorporating fail-safe redundancy.

Comfort electronic systems such as power windows, adjustable seats and some instrumentation require only modest response times which only just surpass human perception times. Comfort systems are far more cost sensitive and the associated networks and modules are highly tuned to be cost effective. Certain vehicle functions may be implemented on a very minimalist network, supporting simple features, such as: trunk release and central locking, where delays in the order of a second are acceptable. Often single wire networks running at 10 kb/s are suitable here.

<b>Protocol</b>	<b>Affiliation</b>	<b>Application</b>	<b>Media</b>	<b>Bit Encoding</b>	<b>Media Access</b>	<b>Error Detection</b>	<b>Data Field Length</b>	<b>MAX. Bit Rate</b>
<i>ABUS</i>	VW	Control	Single wire	NRZ	Contention	Bit only	16 bit	500 kb/s
<i>APC</i>	Ford	Audio	Twisted pair	NRZ	CSMA/CA	Checksum	64 bit	9.6 kb/s
<i>AUTOLAN</i>	General Inst.	Control	Twisted pair	API	Master/slave	CRC	0 – 64 bit	4 Mb/s
<i>BEAN</i>	Toyota	Control	Single wire	NRZ	CSMA/CD	CRC	8 – 88 bit	10 kb/s
<i>CAN</i>	Bosch	Control	Twisted pair	NRZ & Stuffing	Contention	CRC	0 – 64 bit	1 Mb/s
<i>CCD</i>	Crysler	Sensor Mux.	Twisted pair	NRZ	CSMA/CR	CRC	Un-limited	~7.8 kb/s
<i>CSC</i>	Crysler	Sensor Mux.	Twisted pair	Voltage	Polling / Addressing	—	1 bit	~1kb/s
<i>D2B</i>	Optical Chip Consortium	Audio / Video	Fibre Optic	PWM	Contention	?	?	12 Mb/s
<i>DAN</i>	Alfa Romeo	Dash Board	Twisted pair	NRZ	Master/slave	CRC	8 bit	9.6 kb/s
<i>DSI</i>	Motorola	Sensor Mux.	2 wire	Voltage & Current	Master/slave	CRC	16 bit	= 5 kb/s
<i>IVMS</i>	Nissan	Control	Twisted pair	PWM	Polling	Parity	16 bit	~27.8 kb/s
<i>J1850 PWM</i>	SAE	Control	2 wire	PWM	CSMA/CR	CRC	8 – 64 bit	41.6 kb/s
<i>J1850 VPW</i>	SAE	Control	1 wire	VPW	CSMA/CR	CRC	8 – 64 bit	10.4 kb/s
<i>J1939</i>	SAE	Control	Twisted pair	NRZ & Stuffing	Contention	CRC	0 – 64 bit	1 Mb/s
<i>MML</i>	Delphi	Multimedia	Fibre Optic	NRZ	Master/slave	?	= 2048 bit	110 Mb/s
<i>MOST</i>	Most Co-op	Multimedia	Fibre Optic	?	?	?	?	25 Mb/s
<i>PALMNET</i>	Mazda	Control	Twisted pair	NRZ	Contention	CRC	32 or 64 bit	1 Mb/s
<i>TTP</i>	TTTech	Real Time Control	2 channel	MFDM	TDMA	CRC	128 bit	2 Mb/s, 4 Mb/s soon
<i>VAN</i>	Renault & PSA	Control	Twisted pair	Manchester	Contention	CRC	0 – 64 bit	~250 kb/s

**Table 2 A selection of automotive networks**

Gateways and bridges are devices employed to interconnect multi-network architectures. Gateway devices can connect dissimilar networks whereas bridges are used to connect networks which have common data link layer protocols.

Gateways and bridges can filter data passing between functionally independent network segments, allowing only the messages required by a module on another network segment to pass through. For example, if the trip computer requires the fuel tank level data in order to determine the optimum refuelling point, it can receive data, which may have originated on a Class A network node. This data may have travelled via a bridge to a Class B network and then via a gateway to a Class D network. Often diagnostic interfaces are optimally placed on gateway or bridge nodes for strategic traffic monitoring.

## **Automotive control networks**

Conventional automotive control networks are widely used in control systems for applications such as engine management, door control, etc. These networks operate at moderate data rates (SAE Class B or Class C). The automotive system design engineer must consider the functional requirements in terms of information flow, network bandwidth and response times. The following issues will require specific consideration:

- Worst case network traffic load which includes: inter-network traffic; diagnostic data; etc.
- Individual message priority assignment
- Physical and Logical distribution of data sinks and sources
- Network expansion capacity for an entire range of vehicle models
- Error probability and its effects on traffic latency
- System level FMEA (Failure Mode & Effect Analyses) and fault tree analyses results
- Physical length constraints for network segments
- Fault tolerance behaviour and possible redundancy
- Optimum placement of bridges and gateways
- Network management control schemes and associated traffic

Fortunately, the automotive industry has created and are adopting market-wide standards for vehicle control networks; in order to minimise production costs, through mass production. A global consensus on methods and implementations enhances the total product development cycle, ultimately impacting on the final cost to the consumer. CAN and J1850 are currently two of the most successful standards for vehicle control networks.

## CAN – Controller Area Network

In Europe the dominant vehicle control network is CAN (Controller Area Network). This protocol was developed by Robert Bosch GmbH in the mid 1980's and was first implemented in a Mercedes Benz S-class car, in 1991. CAN has since been adopted by most major European automotive manufacturers and a growing number of US companies are now using CAN. In the US, in 1994, the SAE Truck and Bus Control and Communications subcommittee selected CAN as the basis for the J1939 standard (a Class C network for truck and bus applications). The ISO standardised CAN as an automotive networking protocol: ISO 11898 and ISO11519-2.

Many of the world's major semiconductor companies now offer CAN implementations. It is estimated that there are already over 140 million CAN nodes installed world-wide. [Although CAN was developed as a vehicle network standard, it is interesting to note that, currently, the majority of CAN applications exist outside of the automotive industry, employed in numerous other applications ranging from farm machinery to photocopiers.] CAN may be implemented as a Class A, Class B or Class C network.

### *J1850*

In the US, the SAE adopted J1850 as the recommended protocol for Class A and Class B networks. This protocol was the result of a co-operative effort among the 'Big Three' car companies: GM, Ford, and Chrysler. The protocol specification is a combination of GM's Class 2 protocol and Ford's SCP (Standard Corporate Protocol). Emissions legislation was highly influential in the standardisation of J1850. The OBD-II (On Board Diagnostics II), created by CARB (California Air Resources Board) requires the implementation of diagnostic tools for emission-related systems. It specifies that stored fault codes should be available through a diagnostic port via a standard protocol, namely J1850 and the European standard, ISO 9141.

## **High bandwidth automotive networks**

Formula One competitions are not the only races in the automotive arena. The race to introduce an automotive multimedia network standard is well under way. It is just a matter of time before networked in-car PCs will become options or standard features in motor cars. Such PCs will provide a host of additional functionality for entertainment, navigation and business applications. A number of companies such as Microsoft, Saab, Mecel, Intel, Clarion and others are working on their vision of the street-computer for in-vehicle use, and have demonstrated their work in the Personal Productivity Vehicle. Meanwhile, IBM, Delco, Netscape and Sun Microsystems are developing the Network Vehicle which uses Java as its operating environment. The development of such in-car personal computers will support features such as:

- Voice activated control for many functions
- Internet access from the car
- Text to speech e-mail reading while you “drive and listen”
- Voicemail
- Auto-route planner with real-time updates using the traffic reports from your radio’s RDS or the Web
- Advanced interactive digital audio and video features
- Computer games and in-car-entertainment systems for the back seat passengers

The emerging technology will allow the vehicle to become a true mobile office or a sophisticated gaming arcade, at the press of a button. However, the question of driver distraction and the associated effects on safety has yet to be resolved.

A new class of vehicle network is emerging to connect the forthcoming in-car personal computers and their peripherals. The Optical Chip Consortium has specified a network called D2B (Domestic Digital Bus) which is a fiber optic based solution offering approximately 12 Mb/s of bandwidth. This network is currently used in the new Mercedes S-Class. Oasis Silicon Systems have developed the MOST (Media Orientated Systems Transport) solution, again with a fiber optic physical layer, giving a transfer rate of 25 Mb/s. Delphi Automotive Systems provide a solution in the form of MML (Mobile Media Link). Fiber optic based MML has an impressive transfer rate of 110 Mb/s.

Toyota, GM, Ford, Daimler, Chrysler and Renault founded AMIC (Automotive Multimedia Interface Collaboration) in October 1998<sup>iv</sup>. AMIC represents a global project to standardise the vehicle multimedia architecture for the 21<sup>st</sup> century. The plug-and-play ‘infotainment’ specification will encompass software interfaces for vehicle systems, connectors and network implementations. Critical to this architecture are gateways and firewalls, preventing PC software (viruses, etc.) or malfunctions from interfering with the vehicle’s other control and data networks. There is a clear incentive for companies to have their technologies incorporated into the vehicle multimedia standards and Microsoft is making a significant effort with the Windows CE based Auto PC, unveiled in 1998. However, the automotive giants are determined to remain in the driving seat, and it is unlikely that they will uncharacteristically tie themselves to a single supplier from the onset. From a network perspective it is probable that an IDB-C (Intelligent Data Bus-CAN) solution will become one of the adopted standards. IDB-C is based on CAN’s physical and data link layers, but will be complemented by a higher speed multimedia bus, almost certainly based on fiber optic media, similar to the MOST or MML solutions. The in-car PC is expected to have a USB connection and a standard IrDA (InfraRed Data Association) port, leaving ample room for peripheral expansion and after market upgrades.

## Control by wire networks

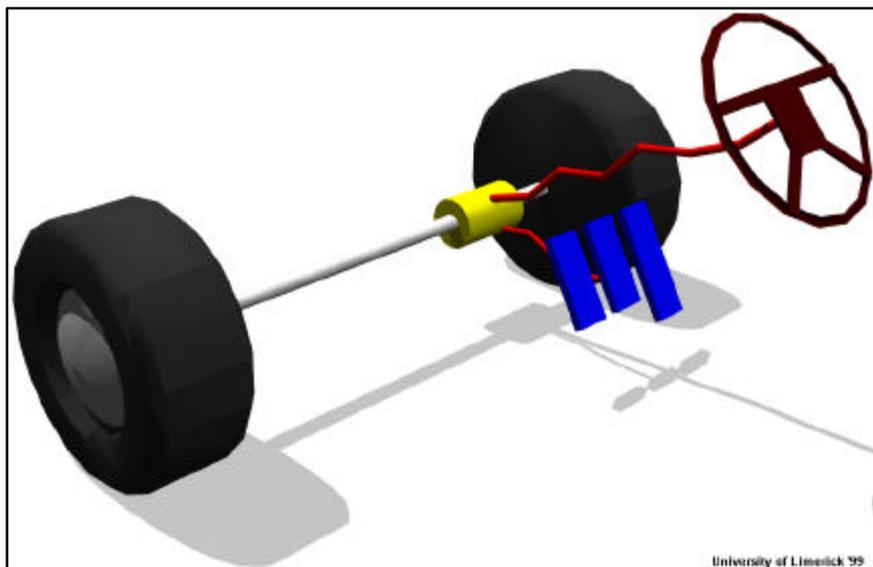
Networked electronic modules are replacing the equivalent mechanical systems! Electrical and electronic systems are eliminating power steering pumps, hoses, hydraulic fluid, drive belts, pulleys, and brake servos. Systems like E-Steer (Steer-by-wire) from Delphi Automotive Systems will be seen in high volume European vehicles later this year<sup>v</sup>.

X-By-Wire is an EU-funded BRITE-EURAM research project (contract number BRPRCT95-0032), which has resulted in the design of a novel computer architecture, TTA (Time-Triggered Architecture), which is based on time-triggered technology for fault-tolerant distributed embedded real-time systems. Fundamental to this strategy is the communications protocol TTP<sup>vi</sup> (Time-Triggered Protocol), where channel access control is based on a TDMA (Time Division Multiple Access) scheme, derived from a fault tolerant common time base. Prof. Hermann Kopetz at Vienna University of Technology is the authority on this extremely well designed protocol, which has a bright future, not only in the automobile but also in the aerospace and rail industries. TTP it is extremely reliable and deterministic but somewhat less flexible than most other automotive control networks.

TTA has defined a network architecture to replace the fore-mentioned mechanical systems, Figure 5 illustrates the concept. The replacement of mechanical systems with electronic solutions potentially offers several advantages:

- Less expensive in volume production
- Simplifies manufacturing of left hand drive and right hand drive vehicles
- Simplifies the general assembly of vehicles
- Intelligent self diagnosing systems, offering enhanced reliability and dependability
- Less mass, thus enhancing vehicle performance
- Environmentally compatible, no fluid necessary
- More compact
- Simplifies integration of auxiliary systems like active collision avoidance and cruise control systems

The drive-by-wire concept is perhaps a little daunting at first, however, when one considers that we have been travelling in fly-by-wire controlled aircraft for many years now, drive-by-wire does not seem to be such a big step.

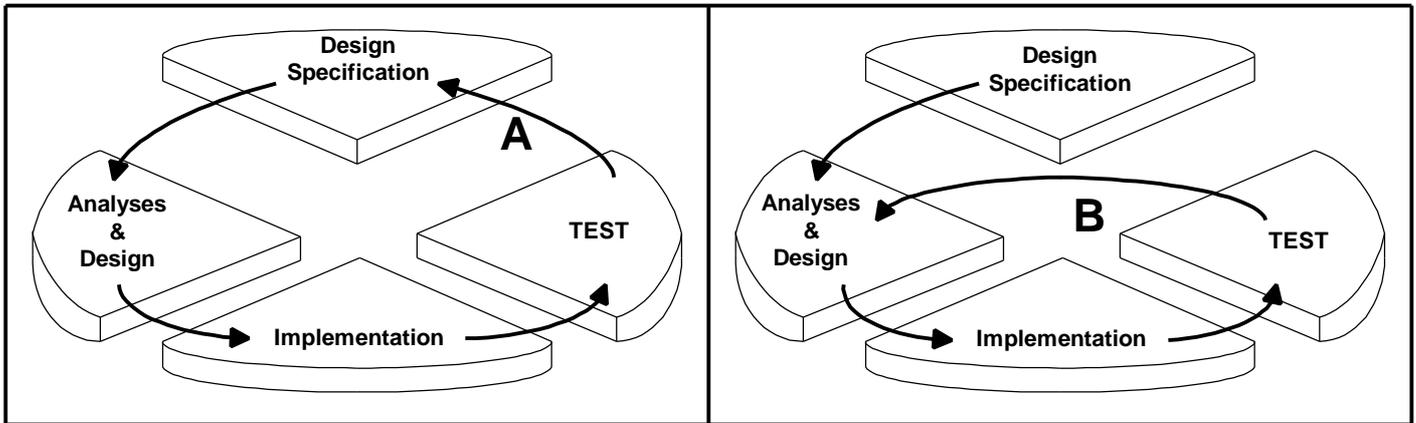


**Figure 5 Drive-by-wire**

## **Distributed software development for automotive systems**

The development of distributed real-time control software is a challenge for any engineering design team. The combined hardware and software solution needs to be arrived at in a cost-effective manner, which requires a formalised approach to design, prototyping and testing. To this end rapid prototyping methods are now being introduced into the development cycle for vehicle electronics. The emerging rapid prototyping based development cycle is initiated with the generation of a requirement analysis specification for the proposed system. A CASE (Computer Aided Software Engineering) tool assists in this analysis and leads into a computer aided design phase. The software design approach is moving towards an object oriented model and the challenges of creating large-scale distributed applications can be approached by using visual modelling tools such as UML (Unified Modelling Language). The output of such tools can be cross-linked to the engineering documentation activity so that both code implementation, textual specifications and system diagrams are combined as different views of the same system. As Figure 6 illustrates the conventional approach of path B is being replaced by the interactive method, path A. Automatic code generation from the specification representations of the system is now possible, often leading to pre-production quality software code. The resulting code must be tested in a hardware environment. Here perhaps the most powerful advances are being made. The prototype software can be executed on a variety of development platforms such as a VME hardware rack, Power PC platforms, PCs, or the actual target hardware. Configurable and scaleable operating systems allow the hardware requirements to be accurately assessed and quantified early in the design cycle. In fact, software development can be completed before the

final hardware is completely designed. HiL (Hardware in the Loop) implementations are possible where the real time simulation is comprised of one or more components which exist as real hardware, while other components are simulated as mathematical models using tools such as Matlab or Simulink.



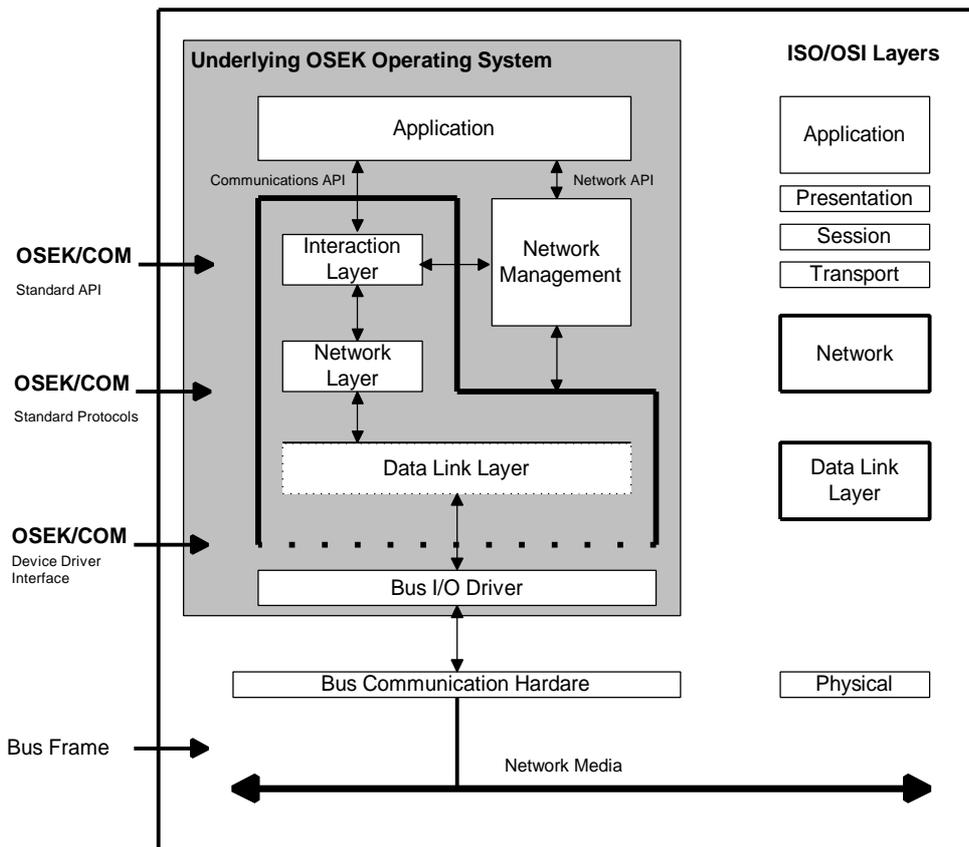
**Figure 6 Software development cycle**

Software testing of the prototype implementation, using automated test sequences, dramatically cuts down on the otherwise repetitive testing which hitherto may have required actual trials in the car. Based on the evaluation of the implementation performance the loop iterates until ready to proceed directly to early target resident executable code.

Because software has now been assigned such an important role in automotive systems, standardised software layers are being defined for vehicle networks. Such layers offer functionality such as operating systems, communication interface systems and network management systems. The recent developments in the area of OSEK/VDX provide a good example of such an approach.

## **OSEK/VDX**

In May 1993, OSEK was initiated as a joint project by a number of companies within the German automotive industry. OSEK aims to achieve a standard open-ended architecture for distributed control units within vehicles. OSEK is an abbreviation for the German term “Offene Systeme und deren Schnittstellen für die Elektronik im Kraftfahrzeug”. The English equivalent is: “Open Systems and the Corresponding Interfaces for Automotive Electronics”. The French car manufacturers PSA and Renault were working on a similar project, the VDX-approach (Vehicle Distributed eXecutive), and they joined OSEK in 1994, giving rise to the OSEK/VDX standard. OSEK/VDX aims to specify a standardised interface to allow the gelling together of hardware modules, network protocols and application software in a coordinated and intelligent fashion.

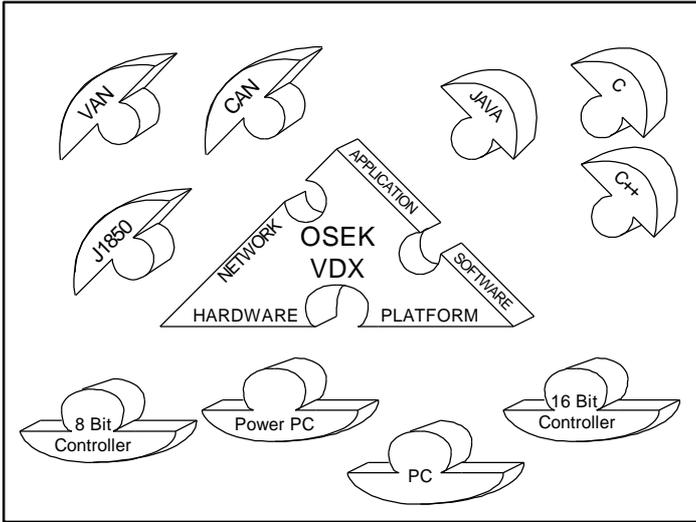


**Figure 7 OSEK/VDX structural overview**

OSEK/VDX specifies a series of interfaces, which allows for the development of software components, which are portable and reusable. Figure 7 shows a structural overview of OSEK/VDX<sup>vii</sup>. The software application interface specification is abstracted from the hardware and the network involved. This concept is illustrated in Figure 8.

Functionality is both configurable and scaleable, enabling optimum tuning of architecture and application. The specification facilitates functional verification and validation. Because the API (Application Programming Interface) is standardised, development on various platforms without the need to learn a new tool set is possible, resulting in a clear saving on development time. Software from different suppliers can now co-habitate within a single microcontroller.

For the first time the potential for real co-operation between the various system suppliers is made possible, where traditionally products were developed independently, and rivalry rather than co-operation was the order of the day. Now those who hold the purse strings are changing the rules somewhat.



**Figure 8 OSEK/VDX: Independence of the network, hardware and applications**

OSEK/VDX realises a distributed operating environment within the vehicle; based on the same principles used to implement distributed operating environments within large data networks. OSEK/VDX's ultimate goal is to reduce costs by enabling the creation of re-usable embedded application software. The PC industry has shown that once an adopted operating system standard is in place, products become far more commercially competitive.

However, it is worth noting that the flexibility offered by the OSEK/VDX approach has some cost implications in terms of additional ROM, RAM and processor overhead. If OSEK compliant software implementations demand higher specification processors, then cost saving, in terms of software reuse, in the short term may be more than offset by additional hardware costs accrued over millions of units<sup>viii</sup>. Never the less, future silicon prices will decrease, and the benefits of reusable, mature and validated software, in the long term, is probably worth the initial investment.

It is interesting to note that the aerospace industry has expressed considerable interest in the OSEK/VDX developments, viewing it as a potential solution to their similar problem set.

## **Conclusions**

Vehicle networks were invented by necessity to resolve the problems associated with bulk wiring harnesses. However, the coming of automotive networks has opened up new opportunities for the industry. Control networks are now well established in high-end vehicles and are quickly filtering down to all vehicle classes.

Whereas control networks operate behind the scenes, as far as the driver and passengers are concerned, it is the high bandwidth multimedia networks, which will have the biggest impact on customer perceptions; offering new concepts in in-vehicle work and entertainment features.

Control-by-wire solutions will provide new engineering solutions and challenges, where car users will need to trust electronics to guarantee their safety in the absence of the tried and tested mechanical systems. The service and maintenance industry and the average car enthusiast will have to find room in their toolbox's for a PC!

Software development is becoming as important as engine design or chassis design in the automotive design process. Soon we should expect to see the emergence of automotive specific software suppliers and a possible redirection of emphases within existing supplier companies.

Automotive related industries should benefit from the standardisation of vehicle network architectures and software environments. At the end of the day the ultimate winner will be the consumer.

## **Acknowledgements**

The assistance of PEI Technologies, University of Limerick, is greatly appreciated.

# Representative vendors and organisations for Automotive Technologies

## Networking

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## Operating Systems

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**IIIT**  
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<http://www.alphaworks.ibm.com/networkvehicle/t-drive/index.htm>

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[http://www.mecel.se/html/expanding\\_areas.htm](http://www.mecel.se/html/expanding_areas.htm)

## Development Tools

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(Mathcad)  
6 Business Centre West,  
Avenue One,  
Letchworth, Herts  
SG6 2HB, UK  
01462 480055  
fax 01462 480213  
[www.adeptscience.co.uk](http://www.adeptscience.co.uk)

**The MathWorks Inc.**  
(Simulink, Mathlab, Stateflow)  
24 Prime Park Way  
Natick, MA 01760-1500  
508-647-7000  
fax 508-647-7101  
[www.mathworks.com](http://www.mathworks.com)

**ETAS GmbH & Co.KG**  
(LabCar)  
Borsigstrasse 10  
D-70469 Stuttgart  
49 (711)8 96 61-102  
fax 49 (711)8 96 61-106  
[www.etas.de](http://www.etas.de)

## Others

**PEI Technologies**  
(Design & analyses)  
Foundation Building  
University of Limerick  
Ireland.  
353-61-202607  
fax 353-61-334925  
[www.ul.ie/~pei](http://www.ul.ie/~pei)

**Surge-Transport**  
(Transportation Group)  
7 Allée des Hetres,  
F95570 Bouffémont,  
France.  
Fax 33-1-39359751  
[www.surge-europe.com](http://www.surge-europe.com)

**ERTICO**  
(Intelligent Transport)  
326 avenue louise  
1050 Brussels  
32 2 4000 700  
fax: 32 2 4000 701  
[www.ertico.com](http://www.ertico.com)

**SAE**  
(Society of Automotive Engineers)  
[www.sae.org](http://www.sae.org)

**ITS America**  
(Intelligent Transport)  
400 Virginia Avenue,  
SW., Suite 800  
Washington, D.C. 20024-2730  
202 484 4847  
fax: 202 484 3483  
[www.itsa.org](http://www.itsa.org)

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