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Current Vehicle Network Architecture Trends – 2000

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ABSTRACT

Vehicle network architectures are migrating toward the use of multiple vehicle networks. Cost, application differences, lessons learned, and industry experiences have pushed aside the original philosophy of using the single vehicle-wide network that was attached to J1850. This paper discusses the current state of vehicle network architectures, the rationale behind the use of multiple vehicle networks, and discusses the current business and technical issues.

PULLING THE PLUG ON J1850

In the beginning, there was only one concept and it was "only one network protocol is needed". And amazingly because this basic philosophy originated at each automotive company independently and at slightly different times, a very large assortment of vehicle network protocols has been created over the past ten years. Several companies even made more than one protocol. Some companies continue such internal protocol development activities to this day.

Each of these reasonably powerful, well-designed, small area network (SAN) solutions represented major corporate investment. The resources used to engineer a near-perfect protocol, to design the protocol chips, to develop a physical layer, to write the protocol software, to create the messaging database, to educate the application developers, to create the protocol tools, and to continue managing the protocol became excessive. So excessive that for some companies "the plug was pulled".

While several American car and truck programs continue to be based on J1850 because of corporate inertia, the funeral is basically over, only the official announcement that "J1850 is dead" is missing.

Based on few technical reasons and primarily on key business reasons, the leading small area network solution has emerged to be the CAN protocol. While the technical debating continues to this day, few are listening and even fewer understand the atomic details of any of today's protocols. Since there is no higher technical authority when it comes to small area networks, most decisions are essentially made at the business level.

THE INDUSTRY SHIFT

The question is not which protocol - but which architecture. Is it really the case, that the CAN protocol has dominated all of the other small area network solutions? As one carefully examines this industry-wide experience, one discovers that it was not a protocol vs. protocol question, but an architecture vs. architecture question that has motivated the major shift to CAN.

The industry's experience-based system-level answer is the multiple vehicle network architecture.

REQUIREMENTS CHANGED – As the vehicle level requirements began to change, the architectural choice of the single vehicle wide network began to lose its following.

DEMAND FOR MORE FEATURES – The demand for new features increased as vehicle networking helped to fuel the proliferation of more and more body electrical functions. Even when early voice recognition systems were experimentally interconnected to network-based body electrical subsystems several years ago, the concept people began to see an ever expanding universe of features with amazing possibilities.

DEMAND FOR MOTION CONTROL FUNCTIONS – Designers became more interested in distributing motion control functions. Why not make a separation between the engine and transmission? Why not consider changing the throttle control from mechanical to being electronic?

Questions like these coupled with the positive experiences with J1850, redirected a portion of the electrical and electronic systems effort. Networking applied to vehicle motion control functions seemed quite possible, but many new issues were raised. A higher speed network solution also seemed necessary.

CONCERN WITH CRITICAL FUNCTIONS – A concern grew when system designers realized that grouping critical functions with non-critical functions might be inappropriate. Is mixing human-controlled audio volume information with ABS or traction control data on the same network a good idea?

DEMAND FOR LOWER COST NETWORKING – The desire to lower the cost per node also played a major role.

Early J1850 solutions were expensive. Each of the big three attempted to lower costs by funding their own protocol chip development. But these three different chip architectures severely limited the opportunity to obtain an industry-wide high volume low-cost solution. Instead, three medium-cost solutions were the best that could be achieved.

In some cases, the multiple vehicle network architecture provided an opportunity to employ a second low-cost network solution instead of the usual J1850 solution. Ford's Audio engineering (now Visteon) developed ACP, a UART-based protocol, as a suitable alternative. In this experience, the business goal of lowering overall system cost was met by utilizing more than one vehicle network.

The demand for more features, the demand for distributed motion control functions, the concern about mixing critical and non-critical functions, and the demand for lower-cost networking solutions all influenced the migration towards multiple vehicle network architectures.

TOTAL SYSTEM-LEVEL REQUIREMENTS

From the simple to the complex, vehicle system-level requirements continue to impact the vehicle network architecture. At the system level, the vehicle network architecture and its supporting protocol(s) must satisfy the following list of requirements –

- all vehicle subsystem functions including motion control and human control
- all critical vehicle functions including brakes, cruise control, air bag deployment
- the worst case vehicle electrical and physical environment
- the entire volume and traffic rate of all vehicle network data
- the entire range of network speeds up to the maximum bit rate requirement
- all required control methods including real-time, peer-to-peer, master/slave, and TDM
- all required forms of conversation including event, periodic, and conditionally periodic
- all operational modes including normal operation, diagnostic, and manufacturing

Satisfying the entire list of requirements with a single vehicle-wide network creates the need for a network solution pushed to the extreme in both maximum technical robustness and maximum cost per node. However, for a multiple network architecture, the ability to partition the system provides an opportunity to lower the overall system cost while maintaining the necessary level of robustness on a per subsystem basis.

J1850 CANNOT COVER ALL REQUIREMENTS – The original 'one network fits all' approach and its burdensome responsibility of satisfying all requirements became the Achilles Heel of the single network architecture. Detroit's three proprietary versions of J1850 are not capable of handling today's complete list of vehicle system-level requirements.

J1850 VS. CAN – For today's multiple vehicle network architectures the leading protocol choice is CAN.

System Coverage – CAN provides one of the best solutions for today's multiple vehicle network architectures. While lacking some of the protocol advances made during the development of J1850, the older CAN protocol is still more than adequate. CAN's error handling strategy which virtually guarantees data consistency across the network one of its most robust features.

Flexibility – CAN may be used for high speed (up to 1 MBPS) , medium speed, or low speed functions. Its relative independence from network speed and physical layer make CAN a flexible protocol.

More Available Physical Layers – Several CAN-based physical layers, each with substantial industry experience, are available. High-speed transceivers, medium speed transceivers with fault-tolerant capability, and new single wire transceivers provide a wide range of interconnection choices.

Large Accessible Knowledge Base – CAN knowledge is available through many sources. Corporations can choose to build their own internal knowledge base or use the existing industry infrastructure to get information. CAN tool companies, industry standards groups, consultants, and a variety of other sources are available.

More Available Silicon – The number of semiconductor companies that are supporting the CAN protocol continues to grow. Even though the old "11 bit only" parts are being retired, the replacement and new silicon, all CAN 2.0 B compliant, give the industry a wide range of choices.

From low-end 8 bit micros up to 32-bit high-performance processors with multiple integrated CAN controllers, the semiconductor industry continues its commitment to this leading small area network solution.

More Tools – A wide variety of off-the-shelf CAN tools are available. Developers have choices that range from low-cost tools with limited features up to programmable high-performance tools with oscilloscope-like graphical interfaces.

Even the distributed system designers have powerful tools capable of node emulation. Vector's CANoe tool which was co-developed with DaimlerChrysler, allows

complete system-level evaluation with any number of nodes being real or virtual. Tools like this provide developers the opportunity to do simultaneous engineering and have dramatically decreased the time to market for CAN-based product architectures.

Another important development in the tool arena has been the emergence of CAN-based calibration tools. With an existing CAN network connection, this type of tool provides an opportunity to do module development, test, and evaluation while the module is resident in the vehicle. Changing parameters and evaluating the results while driving down the road is now possible. Module software development no longer needs to be confined to the engineer's desk or lab. What has provided this opportunity has been the CAN Calibration Protocol or CCP. Developed by the European standards group known as ASAM, CCP (also known as ASAP1a) looks like a high-powered monitor program that includes the capability of flash programming.

CURRENT MULTIPLE VEHICLE NETWORK ARCHITECTURES

Many OEMs are currently using multiple vehicle network architectures, especially for some of their high-end vehicle platforms. Figure 1 shows an example of a typical vehicle network architecture that uses three separate networks.

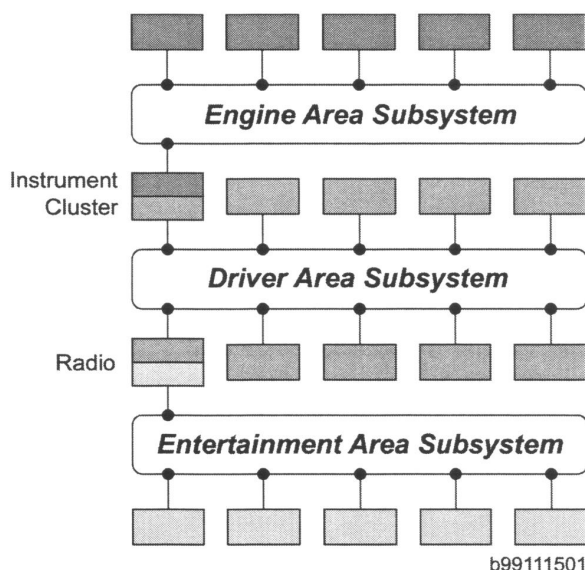


Figure 1. Typical Multiple Vehicle Network Architecture

Using this organization, high speed motion control requirements have been distinctly separated from medium speed human control requirements. A third bus is used to separate the driver (body electrical) functions from the audio/entertainment subsystem.

The module that supports the instrument cluster functions is typically a gateway between the motion control network and the driver area network. Information

sharing requirements for the instrument cluster might include moving selected engine information onto the driver area network. For example, the feature of "automatic door locking" will typically involve receiving the vehicle speed from the motion control network and retransmitting this data onto the driver area network so that modules related to door locks can handle the function.

The radio is typically used as a gateway between the driver area network and an audio/entertainment subsystem network.

While many German multiple vehicle network architectures use the CAN protocol for both the motion control and driver control networks, some are considering using other high-speed data plus audio network solutions to support the audio/entertainment subsystem.

KEY ARCHITECTURAL INFLUENCES

Some of the major influences that have redirected the system toward multiple networks include –

- Current Types of Vehicle Subsystems
- Spectrum of Low End to High End Vehicles
- Reusable Network Strategies

CURRENT VEHICLE SUBSYSTEMS – From the system's point of view, the vehicle is a integrated set of mechanical, electrical, chemical, and energy conversion functions or subsystems.

Today's electrical-related vehicle subsystems can be divided into three major functional areas –

- Engine Area Subsystems
- Driver Area Subsystems
- Entertainment Area Subsystems

While some functions such as electrical power distribution and climate control may cross subsystem boundaries, such partitioning does not create too difficult of a problem for the distributed systems engineer.

Engine Area Subsystems – The major engine area subsystems of engine, transmission, brakes, and vehicle dynamics essentially handle vehicle motion functions. This area's harsh underhood environment includes wide temperature extremes, shock, vibration, repetitive high energy spark events, and corrosive elements. The engine area includes module and network design requirements substantially more stringent when compared to most other vehicle subsystems.

For the engine area subsystems, two key networking requirements emerge –

- The processing data rate must be relatively fast to support motion control. If such data is placed onto a network, the relative communication speed will be much faster than that required of the driver area.

- The harsh engine area environment requires additional consideration and usually requires higher performance components.

Driver Area Subsystems – Driver Area Subsystems support driver and passenger functions. Typically these functions directly interface with the customer, using human activated commands. In general, the vehicle's option content heavily influences what collection of functions are implemented.

Typical driver area functions include –

- Window and mirror controls
- Door access controls
- Climate control
- Interior and exterior lighting
- Seat controls
- Window wiper controls

The operation of many of the driver area subsystem functions is rather slow and the expected response time from human input to function activation need only match the customer's expectation.

For the driver area subsystems, three key in-vehicle networking requirements are –

- The data rate is relatively slow to support human actuated control functions when compared to motion control. The approximate 100 millisecond "human expected response time" is appropriate for most of the driver area functions.
- The total number of humans interacting with all driver area subsystems is limited. The driver and a possible front seat passenger are the two prime input sources.
- The primary initiator of network-related conversation for most driver area functions is the human.

Entertainment Area Subsystems – While the audio subsystem can be easily considered a driver area subsystem, many vehicle designers are recognizing that this functionality can be separated. The use of dedicated networks to support distributed audio/entertainment subsystems is becoming more common. Some automotive manufacturers use independent entertainment area networks. Such system partitioning is relatively easy to accomplish, especially when an entertainment module can also be used as a gateway to provide information sharing. The response of the Audio subsystem to input command must also match the "human expected response time" and acceptable response times range from approximately 60 to 100 milliseconds.

SPECTRUM OF LOW END TO HIGH END VEHICLES – Although both the engine area and driver area subsystems are common to all vehicles, the feature content of these subsystems varies across the

manufacturer's car platform spectrum from "low-end" vehicles to "high-end" vehicles. Across the entire spectrum from the "low-end" vehicle to the "high-end" vehicle the range of variability in subsystem functionality is wide. Thus, one additional requirement of a vehicle network architecture is to handle this diversity.

REUSABLE NETWORK STRATEGIES – Many companies now use reusable software building blocks to contain their system-specific network strategy. Starting with simple common protocol drivers, the industry is seeing many network-related tasks moving away from the application and into the network software. For example, early implementations had periodic message timing activities handled by the application software, but now many new network software implementations include this repetitive message functionality.

OSEK – OSEK is another of the new reusable network strategies. Although its roots began in Europe, OSEK has now entered the U.S. automotive scene as a small portion of DaimlerChrysler and General Motors network strategies. While OSEK's Communication (COM) and Network Management (NM) blocks establish essential network related requirements, it is the OSEK Operating System (OS) that provides a task management architecture to handle both the application and network territory.

GMLAN – Using its experience with J1850, General Motors has created a comprehensive multi-network strategy called GMLAN to handle its new designs based on the CAN protocol. The GMLAN strategy encompasses both a J2284-compliant high-speed motion control network and its new J2411 Single Wire CAN network used for body control functions. The GMLAN systems strategy requirements have been implemented in software for a variety of microcontrollers and these implementations are given to module suppliers for integration with their application software.

Other Varieties – In Europe, DaimlerChrysler has also been using a vehicle network strategy that has been implemented in software. These software implementations are also given to its module suppliers for integration into the module software.

THE CASE FOR THE MULTIPLE VEHICLE NETWORK ARCHITECTURE

But the CAN protocol with its advantages and flexibility, the knowledge base, the available silicon, and supporting tools do not make the case for the multiple vehicle network architecture. While the choice of a particular architecture is motivated by both business and technical reasons, the decision primarily focuses on a comparison of the advantages to the disadvantages.

ADVANTAGES OF THE MULTIPLE VEHICLE NETWORK ARCHITECTURE – Moving toward a multiple vehicle network architecture provides several business and technical advantages, including lowering costs and reducing complexity.

Lower average node cost per vehicle possible – The multiple vehicle network architecture provides an opportunity to lower the average node cost per vehicle. Rather than an attachment to an expensive network solution for each and every node, alternate low cost solutions may be suitable for a portion of the vehicle's functionality. The addition of another network may reduce costs. Of course, it's also possible to add another network that increases costs. Using sound system engineering principles with heavy emphasis on the business cost issues has helped several car companies to reach their economic targets.

Easier to manage speed requirements – The multiple vehicle network architecture makes it easier to manage speed requirements. The opportunity to partition by speed requirements is possible; high speed motion control-type functions may be separated from slow human events. Even the choice of utilizing a high-speed data network with integrated audio capability is a new opportunity when embracing the multiple network architecture.

Opportunity to partition by functional area – The multiple vehicle network architecture provides the opportunity to partition by functional or geographical area. Most German car companies already have two CAN-based vehicle networks, one to support engine and another for the driver area (referred to in Europe as the body bus).

Opportunity to partition by data criticality – The multiple vehicle network architecture provides the opportunity to partition by data criticality. Perhaps a braking control subsystem should not share the same communication channel as an audio entertainment subsystem. This data criticality issue is the main concern motivating a new industry-wide effort to create an air bag bus separate from the existing vehicle networks.

Opportunity to partition by control architecture – The multiple vehicle network architecture provides the opportunity to partition by control architecture or by communication method. While CAN's use of peer-to-peer communications is adequate for most vehicle functions, perhaps the same communication method found in TTP (Time Triggered Protocol), that is time-division multiplexing will be found to be more appropriate for the control of high speed distributed functions.

Opportunity to partition by subsystem – The multiple vehicle network architecture provides the opportunity to partition by subsystem. Perhaps an audio subsystem should always be separated from the remaining vehicle

networks in order to allow the OEM the opportunity to obtain complete audio subsystems from their suppliers.

Rather than buying the individual audio-based network modules and managing the subsystem integration, partitioning by subsystem may allow the OEM a business opportunity to purchase a complete audio subsystem without attending to the complexity of its supporting network.

DISADVANTAGES OF THE MULTIPLE VEHICLE NETWORK ARCHITECTURE – While the advantages are quite significant, it is important to list and consider the business and technical disadvantages.

The architecture of multiple vehicle networks has disadvantages which include –

- Additional resources are required
- May need to support different protocols
- Increased complexity to share information across different networks
- Usually requires gateway functionality
- Servicing may be more difficult

Additional resources are required – Additional resources are required to support each different network. The systems engineering design, development, integration and system-level validation effort plus the support for production and diagnostics may require adding engineering staff for each vehicle network.

May need to support different protocols – Each network may use a different protocol. This can also add another layer of complexity which requires more resources to manage. Multiple protocols require multiple knowledge bases, multiple message and database tools, and multiple protocol tools.

Increased complexity to share information across different networks – The sharing of information between multiple networks adds complexity. One of the biggest advantages of the single vehicle network architecture was the ability to easily access virtually any piece of information across the network. In some instances, the shift to a multiple vehicle network architecture may remove this advantage and create a potential need for moving information from one network to another.

Usually requires gateway functionality – The sharing of information across different networks may easily increase system requirements such that a gateway will be required. Gateway (or bridge) functionality typically becomes an additional burden for one of the vehicle electronic modules above and beyond the module's normal set of application requirements. Supporting two network connections while handling network-to-network message timing requirements makes gateway implementation complex. Late changes to the vehicle

system functionality might even be impossible if sufficient micro-controller resources are not available.

Servicing may be more difficult – With the single vehicle network architecture, a single diagnostic method and strategy could be used. But the multiple vehicle network architecture will likely cause diagnostics and the servicing of the different buses to become more complicated.

CURRENT TECHNICAL ISSUES

Many of the current technical issues facing multiple vehicle network architectures are carryovers from the earlier single network solutions. Continuing issues include –

- EMC
- physical layer
- network speed and bandwidth
- data criticality
- the mixing of information with control functions
- continuous demand for new vehicle features

New issues that require attention include how to flash program modules, how to partition functions across multiple networks, how to handle information sharing across multiple networks, and how to address the diagnostics issues that grow with the increasing number of networks.

THE INFLUENCE OF CHANGING REQUIREMENTS –

Requirements for vehicle network architectures are not stable. Once requirements change to a significant enough extent such that a change in the architecture is needed, the choice between a new architecture or re-partitioning the existing system must be revisited. And how often are requirements changing? Continually. Vehicle system complexity continues to increase with the demand for more features and functions. This creates a never-ending discussion of architecture versus architecture and forces the technical/business analysis to be examined on a recurring basis.

Do changing requirements further the case for multiple vehicle network architectures? To a large extent it does, using a multiple network solution provides more opportunity to manage change.

CURRENT BUSINESS ISSUES

The current business issues that surround MVNA can be concentrated into 4 key areas –

- human resources
- time to market
- cost
- cross company variation

HUMAN RESOURCES – To manage a multiple vehicle network architecture requires additional resources. While supporting multiple networks does not necessarily carry twice the resource burden, resource expenses are much higher when standard " off-the-shelf" protocols are not used. If each vehicle network uses the same or similar network implementation, the resource drain can be highly minimized.

Electrical engineering, systems engineering, test engineering, and management are all necessary to handle a company's multiple vehicle networks. A maintained knowledge base is also necessary.

TIME TO MARKET – Time to market may be of little interest to the engineering side of vehicle networking, but to management it is an important issue. When examining the product development time associated with implementing a multiple vehicle network architecture, one recognizes that the time to market –

- increases if each OEM perpetuates its own unique network solution
- increases when cross industry variation increases
- increases when standardization is avoided
- increases when companies need to make their own tools

When each electronic module supplier must develop special circuitry or software for each OEM's unique network solution, the overall industry time to market increases. One major tier 1 supplier reports the need to support over 30 different protocols to satisfy its entire customer base. Even if this supplier is managing several of its own proprietary protocols, this number is staggering.

COST – For each OEM and module supplier, the business cost of developing and managing multiple vehicle network architectures is a key issue. However, with no industry cost figures available and few accountants assigned to examine this area, little is known about this issue. While the engineering staff adequately handles the various networking technical tasks, their expertise does not cover the cost issue. Perhaps when upper management understands the business issues in managing vehicle network engineering, the cost issues will be carefully scrutinized.

Several factors affect the issue of cost. When developing and managing multiple vehicle network architectures, cost –

- increases when cross company variation increases
- decreases when using off-the-shelf solutions
- decreases through standardization

Because there is no general overseer of industry costs for this vehicle networking area, this business issue will continue to remain in the dark.

Some of the factors that influence this lack of attention to cost include –

- management not knowing of the problem
- the engineering staff's inexperience in handling business issues
- the inability to recognize the overall system and business environment that affects cost

CROSS COMPANY VARIATION – When one examines the spectrum of multiple vehicle network architectures across the industry, one sees considerable cross company variation. Each company's vehicle network implementation differs. The CAN protocol may be the only thing that is common. Whether based on technical reasons or an interest in creating local fiefdoms, this variation in vehicle network implementations increases complexity for all module suppliers.

While J2284 establishes requirements for a CAN-based high-speed 500K BPS bus, each car company still requires its own different implementation. For each module supplier a circuit change is necessary and this does not reduce the time to market.

The medium or low speed CAN bus used to accomplish driver area functions will be another area of major cross company variation. The chance that DaimlerChrysler, GM, and Ford will each deploy a different CAN network solution seems a certainty.

Even though J1850 has been abandoned and many OEM's have converged to the CAN protocol, each OEM still continues to do whatever it wants. Each OEM has essentially created a company-specific CAN-based network solution that is different from the other OEMs. At one time, we had three versions of J1850, and now, we have at least three different versions of CAN.

Yes, this has also happened in Europe.

But the issue closer to home is - what does this say about our automotive electronics industry?

Could it be the case, that engineers who get control of new technologies that management does not understand will continue to fight like Saturday afternoon college football teams regardless of the business consequences. With no referees to call fouls and no impartial judges to help guide the way, our standardization efforts continue at a snail's pace.

Cross company variation can only be stopped through the efforts of industry standardization. Someday in the future, vehicle networking, just like tires, will become a complete off-the-shelf item. This will happen at an unbelievably slow rate regardless of the number of engineers standing in the way.

CONCLUSION

From a system's point of view, the migration toward multiple vehicle networks has provided the means to lower the overall vehicle networking cost and has helped to manage the increasing complexity that faces the automotive electronics industry.

The development and maintenance of proprietary protocols is a waste of company resources when suitable "off-the-shelf" solutions exist.

It will be the new requirements that will influence the future of vehicle networking architectures.

It is the vehicle networking architecture that establishes the requirements for small area network protocols.

While many of the past vehicle networking decisions were based on reasonably sound technical reasoning, it will be primarily business decisions that determine the future direction of vehicle networking architectures.

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ADDITIONAL SOURCES

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To contact ASAM, visit the ASAM website at: <http://www.asam.de>.

The CCP CAN Calibration Protocol V2.1 can be found using the link: http://www.asam.de/Asap_Gen.htm

CONTACT

The author has over 20 years of distributed embedded system engineering experience with both proprietary and "off-the-shelf" protocols and may be contacted at emaus@vector-cantech.com.

DEFINITIONS, ACRONYMS, ABBREVIATIONS

ASAP: Arbeitskreis zur Standardisierung von Applikationssystemen (Standardization of Application/Calibration Systems)

ASAM: Association for Standardization of Automation and Measuring Systems

CAN: Controller Area Network

CCP: CAN Calibration Protocol

ECU: Electronic Control Unit

UART: Universal Asynchronous Receiver Transmitter