SAE INTERNATIONAL

SURFACE VEHICLE INFORMATION REPORT	J2057™-4	DEC2022
	Issued 1993-06 Reaffirmed 2006-09 Stabilized 2022-12 Superseding J2057-4 SEP2006	

Class A Multiplexing Architecture Strategies

RATIONALE

This document has been determined to contain basic and stable technology which is not dynamic in nature.

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FOREWORD

There are generally three classes of multiplex application requirements within the vehicle. To cover these applications two prevalent multiplex architecture strategies have developed. The most popular is the Single Network Architecture. This architectural strategy sizes the network hardware to meet the requirements of the highest level application while maintaining the capability, where possible, of handling the lowest level application. The second strategy, Multiple Network Architecture, is to develop as many types of specialized network hardware components as required to efficiently handle each application and then gateway them together to have only one diagnostic service port. These two differing strategies are studied in detail and presented in this SAE Information Report.

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1. SCOPE

The subject matter contained within this SAE Information Report is set forth by the Class A Task Force of the Vehicle Network for Multiplexing and Data Communications (Multiplex) Committee as information the network system designer should consider. The Task Force realizes that the information contained in this report may be somewhat controversial and a consensus throughout the industry does not exist at this time. The Task Force also intends that the analysis set forth in this document is for sharing information and encouraging debate on the benefits of utilizing a multiple network architecture.

1.1 Three Classes Multiplex Networks

The Vehicle Network for Multiplexing and Data Communications (Multiplex) Committee has defined three classes of vehicle data communication networks.

1.1.1 Class A

Low-Speed Body Wiring and Control Functions, e.g., Control of Exterior Lamps

1.1.2 Class B

Data Communications, i.e., Sharing of Vehicle Parametric Data

1.1.3 Class C

High-Speed Real Time Control, e.g., High-Speed Link for Distributed Processing

1.1.4 Interrealtionship of Classes A, B, and C

The Class B Network is intended to be a functional superset of the Class A Network. That is, the Class B Bus must be capable of communications that would perform all of the functions of a Class A Bus. This feature protects the use of the same bus for all Class A and Class B functions or an alternate configuration of both buses with a “gateway” device. In a similar manner, the Class C Bus is intended as a functional superset of the Class B Bus.

2. REFERENCES

2.1 Applicable Publications

The following publications form a part of the specification to the extent specified herein. Unless otherwise indicated, the latest revision of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J1850 Class B Data Communication Network Interface

SAE J2057-1 Class A Application/Definition

SAE J2058 Chrysler Sensor and Control (CSC) Bus Multiplexing for Class 'A' Applications

SAE J2178-1-2-3-4 Class B Data Communication Network Messages

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this document.

Thomas R. Wrobleski, "A Multiplexed Automotive Sensor System," Sensors Magazine dated February 1989, Volume 6, No. 2

Thomas R. Wrobleski, "A CSC Bus Multiplexing Technique for Sensors and Actuators Which Allows Common Vehicle Electronic Control Modules," Paper #89123, 20th International Symposium on Automotive Technology and Automation, Florence, Italy, May 1989

3. DEFINITIONS

3.1 Event-based

The attribute of transmission of data on a manually triggered event or on change of parametric value.

3.2 Event-driven

The attribute of event-based network protocol.

3.3 Response-Type Messages

Messages that require Acknowledgement.

3.4 T-tap

A splice in a wiring harness forming a "T" connection. Sometimes this configuration is associated with automated insulation displacement type connection at a connector.

3.5 Time-based

The attributes of repetitive parametric data in a Class B Multiplex Network.

4. MULTIPLEX WIRING SYSTEM ARCHITECTURE STRATEGIES

It is a well-known fact that the cost of electronics is decreasing. More functions can now be integrated into fewer modules. The availability of Class B multiplexing now avails the automotive system designer with many new architecture partitioning options. The availability of customer-specific ICs to accomplish a function at a substantially lower cost is becoming a reality. On the other side of the equation is rising wiring and labor costs. Vehicle manufacturers have, in some instances, gone to off-shore or other countries to offset these labor-intensive assembly costs. However, the growth in size and complexity of wiring harnesses causes an ever-increasing investment in assembly facilities that overshadows these cost-containment efforts. These basic trends are projected to apply in the future and become our base assumptions.

4.1 Multiple Network Architecture Background

Initially, the Vehicle Network for Multiplexing and Data Communications Committee recognized the three different requirements for vehicle networking. A chart of these three vehicle multiplex networking typical characteristics is shown in Figure 1. This chart was presented late in 1986 to the SAE Truck and Bus Committee as the state of consensus by the Multiplexing Committee.

The chart shown in Figure 1 does not mean that three networks are needed to cover the multiplexing requirements, but that there are three different characteristic requirements within the vehicle that must be considered. Some of the entries in the chart such as “Status” and “Data Consistency” were not totally understood as noted by the missing entry under Class A. For example the “Status” entry was eventually recognized as the need for acknowledgement in a Class A Network. Some entries had slightly different meanings between committee members and, therefore, further development was dropped. The purpose of this document is not to explain all the characteristic requirements of vehicle networking, but to focus on the Class A and Class B interrelationship and, therefore, there will be no further discussion on Figure 1.

The decision to pursue a multiple network architecture strategy requires a careful study of the alternatives. This investigation of multiple network architectures begins with the assumption that a lower total vehicle system cost would result if one network were optimized around a data communications requirement and other networks were optimized around the sensor and control requirements.

Consider first the ramifications of optimizing a network around the data communications requirements, i.e., Class B multiplexing. Class B multiplexing interconnects intelligent modules such as the engine controller, body computer, vehicle instrument cluster, and other electronic modules. It normally does not affect the base vehicle wiring such as lighting, but it does affect wiring in that it may reduce the connections between sensors and modules. Class B Multiplexing in this case provides an intermodule data communications link for distributed processing. The parametric data shared between modules is almost exclusively repetitive in nature and rarely do these modules require handshaking or acknowledgement of data with other modules. Therefore, a network can be optimized around functional addressing. This is the result of handling the dominance of repetitive data and only a small amount of response type data, e.g., diagnostic data. It is consistent with this strategy to define a multiplex application so optimized by handling the dominance of time-based data communications requirements (see SAE J1850).

When physical addressing is required in a data communication optimized network, usually for vehicle diagnostics, it can be handled without reducing efficiency. The amount of safety type data that a data communications optimized network has to handle is negligible and can be very effectively handled by other means such as discrete hard wiring. Hard wiring of sensitive functions is considered an advantage because it is consistent with the present conservative method of handling these functions.

When the encumbrance of handling safety type data and most Class A (sensor and control multiplexing) functions are eliminated from the network requirements, a significantly simpler data communications network is the result. This multiple network architectural philosophy also results in a simpler and more effective method of handling sensor and control multiplexing.

The logistical size and complexity of the vehicle manufacturers' systems organization is another factor to be considered. The multiple network architecture is better suited to development and production by multiple sources: a situation that may be important to some vehicle manufacturers. The multiple network architecture requires only a moderate systems organization to insure compatibility because fewer messages would be supported by the data communication network. The sensor and control subsystem requirements can be handled by the product development organization with less direction from the system engineering group. This direction is possible because most of the subsystem would interface with their relevant sensors via their own dedicated Class A Network.

The multiple network architecture strategy should not be a hindrance to multiplex standardization because the Class B Network would be used to support diagnostics.

REQUIREMENTS OF VEHICLE NETWORKS			
	Class A	Class B	Class C
Repetitive	Allowed	Yes	Yes
Bursty	Yes	Yes	Yes
Handshaking	Yes	Yes	Yes
Status	------	Yes	Yes
Data Consistency	------	Allowed	Beneficial
Number of Nodes	> 100	> 10	> 10
Reliability	Better	Better	Better
Open	Truly	Qualified	Qualified
Priority	Allowed	Yes	Yes
Latency	< 50 ms	< 50 ms	~< 5 ms
Hardware Level	Complete	Flexible	Independent
EMC	*	*	*

TYPICAL ATTRIBUTES OF VEHICLE NETWORKS			
	Class A	Class B	Class C
Bus Rate	1 K bits/sec	10 K bits/sec	1 M bits/sec
Trans. Media	Single Wire	Dif Twist Pr	Coax/Fib Opt

* Note: Use SAE test methods to insure compatibility with automotive environment.

FIGURE 1 - CHART OF TYPICAL VEHICLE MULTIPLEXING CHARACTERISTICS

This multiplexing strategy does have many other advantages. For example, the software required for system control is simplified because it is not required to support timers, counters, or other response types of communications or control. The interfacing hardware is simplified and a less-complex microcomputer is normally required. The data communication rates are consistent with SAE J1850 single wire interfacing, which also supports a lower-cost solution. Data communication multiplexing requirements are consistent, and tend to be associated with the cost-proven technique of integration of body feature modules.

As system designers choose between 4-bit, 8-bit, and 16-bit microcomputers and apply them to their requirements, one would similarly think that Class A is most likely to be bit oriented, Class B is likely to be byte oriented and Class C is likely to be message oriented. The multiple network architectural philosophy also conforms with the reasoning where a number of optimized and simpler solutions can be developed to handle the many and differing requirements of the vehicle multiplex spectrum.

4.2 Single Network Architecture Background

The single network architecture strategy alternative that meets the requirements of both Class A and B classifications leads to a more complex and costly solution. In order to handle data communications or time-based type messages (which are repetitive in nature) and control-type messages (which are event-driven by nature), the control-type message dominates in hardware and software complexity. Control-type messages, such as turn headlights on, are easily understood as event-based. A more complex situation is where parametric data such as vehicle speed, which is defined to be time-based type messages must transmit only on change in parametric value, e.g., change in vehicle speed from 45 to 46 mph to represent an event for transmission as an event-based message.

In this event-based protocol a loss of message is much more critical than a loss of a message in a time-based protocol where the data is naturally repetitive for the message being transmitted is generally current status. The addition of an acknowledgement to the protocol is a possible solution and the following complexity ramifications should be considered:

a. RAM is required to save message(s) and control data for messages.

b. Messages may need to be saved while they await acknowledgement.

c. Timer data associated with a given message may need to be maintained while messages wait for acknowledgement.

d. A retry counter data associated with a given message may need to be maintained while messages await acknowledgement.

In a time-based protocol, acknowledgement of data may add unnecessary complexity. This condition can be easily understood by considering the situation where a given copy of a message is not received, for whatever reason, and another more current copy will be coming shortly. There is no reason to keep a copy of the current message so that it can be retransmitted if the previous transmission is not acknowledged.

Generally, there is nothing that a module can do if one of its messages is not acknowledged aside from the exception of possibly creating a fault condition indication. There are exceptions where modules may be carrying on a particular dialogue, but these are the exception and not the general rule. The correct acknowledgement response may enhance the probability of detecting message corruption, but basic network communications capability is not improved by acknowledgement techniques. It remains the transmitting module's responsibility to transmit its messages and should register a fault if it is unable to do so. The modules that receive messages should monitor whether they are correctly receiving them and, if not, should register a fault. Acknowledgement techniques do not generally improve this capability.

Unlike the time-based optimized protocol where only the functional broadcast-type messages strategy can be effectively used, an event-driven protocol may need other message types to be most effective. For example, an event-driven protocol needs response-type messages, and the use of in-message response as the acknowledgement mechanism does not change the basic scenario. Distinct from functional broadcast-type messages that do not care where they came from or where they are going, the event-driven protocol does sometimes care.

5. ROLE OF CLASS A MULTIPLEXING

Class A Multiplexing is most appropriate for low-speed body wiring and control functions. The example most often used to illustrate the benefits of Class A Multiplexing is the base exterior lighting circuit. However, this example is the hardest function to cost justify. The base exterior lighting system is extremely simple and very low cost. A multiplex network applied to this lighting system could result in increased wiring complexity and cost. Data integrity in the lighting system can be a stringent requirement for Class A Multiplexing, e.g., a single bit error that results in Headlights “Off” when they should be “On.” Adequate data integrity in a Class A Multiplex network is a constraint and bit error checking may be required.

In the future, the results could change if new features such as low current switching or lamp outage warning became a requirement or new lamp technology such as smart bulbs became a reality. In general the addition of new features, as just illustrated, will play a major role as to when and how multiplexing will become a costeffective solution.

5.1 Other Driving Forces

The design of vehicles to minimize manufacturing complexity is a major force that will lead to architecture partitioning development. The properly developed multiplex architecture can be very effective in reducing the number of parts in the assembly plants and built-in diagnostics can substantially reduce build test time.

5.2 Example Class A Systems

To illustrate how a Class A Multiplex Network could be used to simplify the vehicle wiring situation, first consider the Vehicle Theft Alarm system shown in Figure 2. Although this example does not represent the epitome in theft alarm features, it does illustrate the nonmultiplexed condition. The horn actuator and the sensor switches are all wired directly to the theft alarm module. The module is then armed by activating the Dash Arm Switch. The module can be disarmed by either the driver door key switch, passenger door key switch, or the trunk key switch. The horn is sounded when either the hood, door, or trunk is tampered with when the module is armed.

The Vehicle Theft Alarm system shown in Figure 3 illustrates a near optimal configuration of a Class A Network. The sensors and actuators are integrated with the multiplexing electronics so that they can communicate over a single wire to the theft alarm module. The integration of electronics into the sensors and actuator improve sensor diagnostics because the sensor status and condition can be reported back to the controlling module. The integrity of the sensor status/condition can be linked to the mechanical operation of the sensor. This level of switch integrity cannot be achieved with normal switch biasing methods. In a theft alarm system there is an added benefit: the sensor condition can be used to set off the alarm and foul the tampering of a would-be thief.

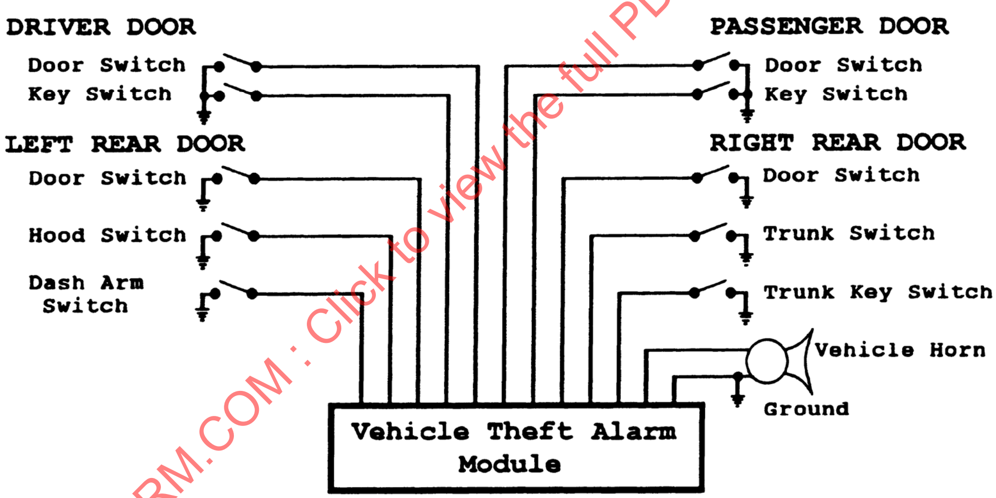

FIGURE 2 - EXAMPLE VEHICLE THEFT ALARM SYSTEM

The I/O requirements support T-tap connections which can be highly automated in the production of wiring harnesses, reduce bundle size, and eliminate dual crimps. The configuration also supports the concept of adding sensors or actuators as the option requires without changing the Theft Alarm Module configuration to support the optional features. This expandability feature allows the cost of the option to drive the system cost.

To show how this configuration is flexible and easily expandable consider the example condition where some versions of Theft Alarms are built as originally described, but an upscaled version is offered as an option where the unit is armed by the driver locking the doors. To support this option the Dash Arm Switch would be eliminated and the Driver Door Lock Switch would be configured with the integrated switch multiplex at a different address. The same Theft Alarm Module's software could then reconfigure itself without hardware modifications.

Statistically speaking, there are approximately seven sensors to every actuator in a real vehicle body system (See SAE J2057 Part 1). This Theft Alarm System is typical with ten sensors (switches) to one actuator (horn).

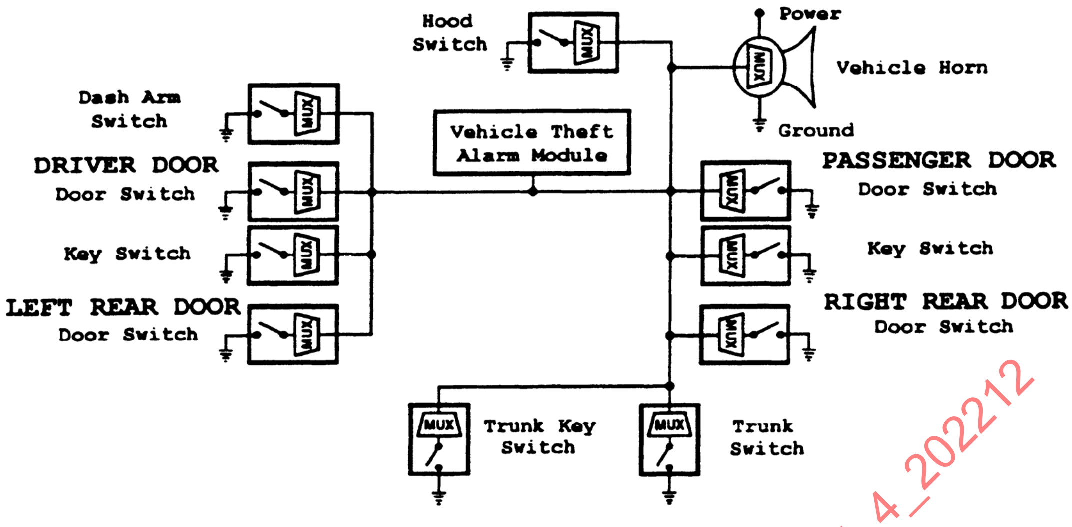

FIGURE 3 - MULTIPLEXED THEFT ALARM SYSTEM

The sensors and multiplexing electronics can be integrated into the switch component. This configuration eliminates separate wiring and mounting of the multiplex module. Some component manufacturers have even been working on two wire (signal and ground) sensors where the power to run the sensor has been supplied by the multiplex signal (for an example component see SAE J2058). These sensors have been designed to include the multiplex circuit integrated with the Hall Effect Device in the same TO92 size package. The multiplexer portion is very small and requires approximately 300 logic gates.

The actuator driver and multiplexer can similarly be integrated into the horn or motor. This configuration also reduces wiring and mounting complexity. Actuators normally require more power than sensors and, therefore, usually require three wires: signal, power, and ground. Refer to SAE J2058 for an example component. However, some manufacturers are developing a method to eliminate one of these wires by placing the signal on the power wire.

Cost is perhaps the biggest factor and criteria of judgment as to whether a Class A Multiplexing Network will be successful. Ideally the cost of the sensor or actuator component should be less than or equal to the part it replaces. This cost requirement should not be too big a challenge for the aggressive sensor/actuator supplier. (For an explanation see Appendix A.)

Even with all the advantages of the Class A Network, the overall system cost must be competitive. The cost of the sensors is controlled by their mature volume. With many different sensors being required, the logistics involved with developing each part can significantly affect the final price. An effective means of programming the distinct address on a common part must be available.

6. PROPOSED VEHICLE ARCHITECTURE

The vehicle system designer now has many architecture partitioning options. A strategy of when to integrate many features into a module or when to employ a dedicated node is a prime example. Care must be taken or the partitioning strategy may not achieve optimal results. The issue is much more complex when vehicle multiplexing is involved in this partitioning strategy. The most popular networking strategy is the Class B Single Network Architecture. However, Class B Multiplexing does not always result in an optimal solution.

A hypothetical vehicle will be described to illustrate this point. Figure 4 illustrates the part of a Data Communications Network that contains a Body Computer, an Instrument Cluster, and a Message Center. In this example all the sensors that feed the network enter through the Body Computer.

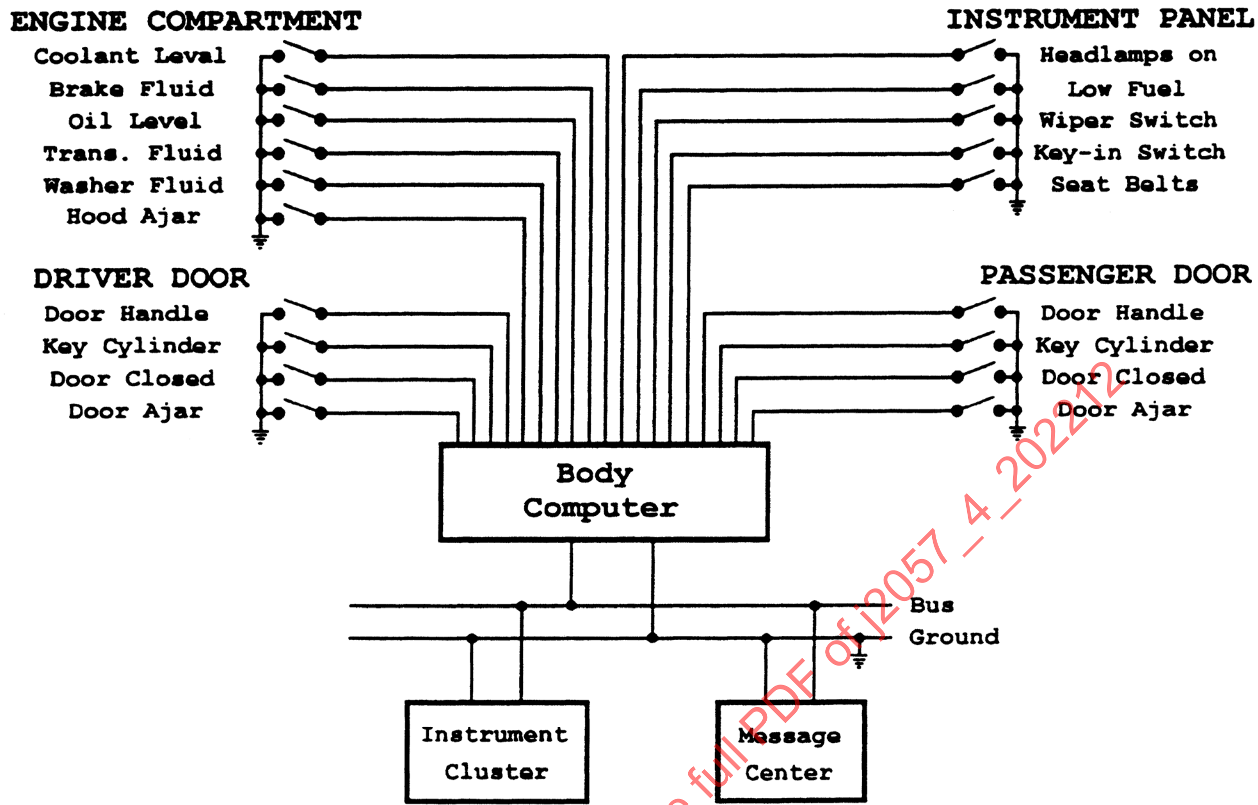

FIGURE 4 - DATA COMMUNICATIONS NETWORK WITH BODY COMPUTER, INSTRUMENT CLUSTER, AND MESSAGE CENTER

As illustrated in Figure 4, all sensors are wired directly to the Body Computer. This example shows that a base vehicle with only a small amount of electronic content, where all the sensors are directly wired to the body computer, the wire bundle size, and number of connector pins is attainable. As additional features are made standard, either by consumer demands or government regulations, it becomes more and more difficult to implement the required system. This added complexity is due to the tremendous number of interconnecting wires from sensors to the modules. The build complexity and trouble-shooting problems make this option a limited solution for this partitioning strategy.

The Class B Single Network Architecture strategy would solve this complexity problem by adding a sensor node and reduce the number of interconnecting wires. By this strategy conventional sensors are connected directly to the node which serves as a gateway to the other modules over the Class B data link. Figure 5 illustrates the dramatic reduction in the number of circuits required. This method is effective in reducing the number of sensor wires connected through “crunch points” such as the bulkhead or door hinge. However, this reduction in wiring is obtained at the expense of three added sensor nodes.

Class B Multiplexing is a very useful technique for reducing many of the problems encountered by the automotive system engineers. However, this report will demonstrate that in many situations the multiplex strategy, shown by Figure 5, leads to a less than optimum system architecture. It is highly desirable to have a multiplexing architecture which would:

a. Permit the use of smaller module connectors

b. Reduce the number of wires crowding through the congested areas

c. Accomplish without introducing more modules to mount, wire, and service

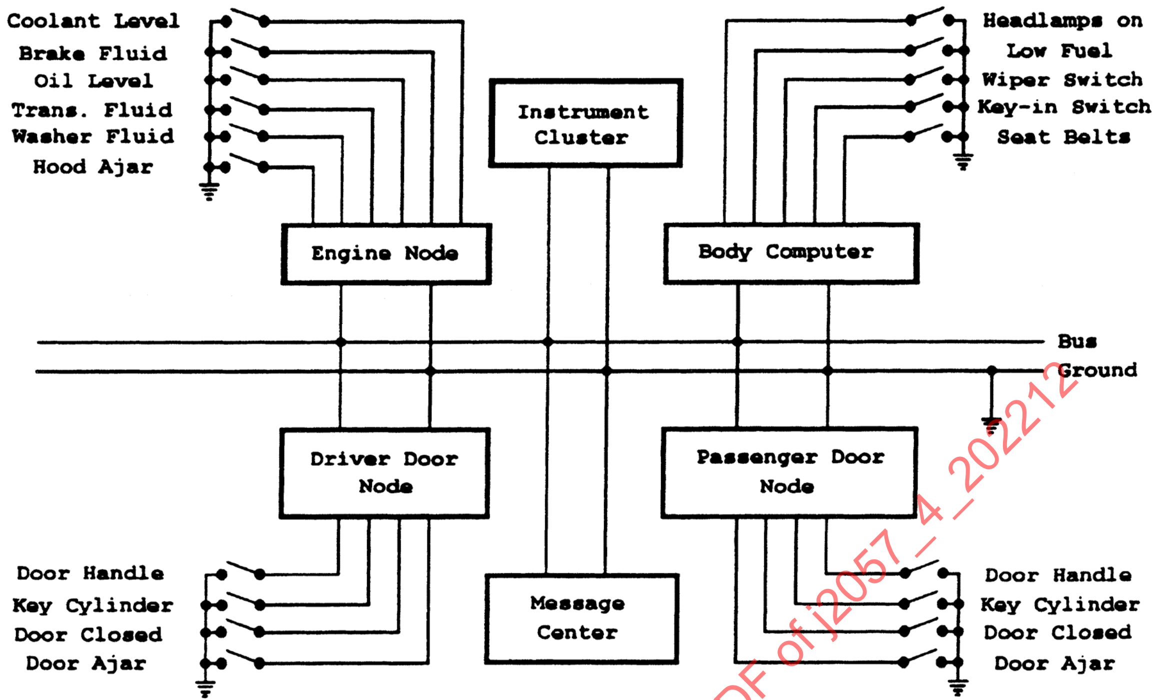

FIGURE 5 - DATA LINK WITH BODY COMPUTER, INSTRUMENT CLUSTER, MESSAGE CENTER AND THREE SENSOR NOTES

6.1 Engine Compartment Node

In this hypothetical example it may be desirable to integrate the node with the Engine Controller Module. This operation would reduce module count and wiring circuits at the same time. The integration solution is not possible because the Engine Controller already has an uncontrollably large module connector and would add a separate part just to cover an option. Reference Figure 6 for an illustration of this connector wiring complexity.

6.2 Door Nodes

In this hypothetical example the best location for the door node would be inside the door (see Figure 7). By placement inside the door, the number of circuits through the door hinge is minimized but without making further improvements the same wiring complexity inside the door still exists. These further improvements generally could integrate the electronics and mechanics into a single package.

6.3 General Node Concerns

a. In order to achieve minimum cost, nodes tend to become application specific and not generic because they usually can cover only one feature product.

b. To cover more than one product, nodes tend to become intelligent and employ a microcomputer and may negatively impact the system cost and complexity.

c. Using conventional sensors remote from the node does not normally improve sensor diagnostics, e.g., the node cannot tell if the sensor switch is off or if the wire is disconnected. Refer to 5.2 for a discussion on switch integrity.

d. The Door Node illustrated in Figure 7, and nodes in general, can be effective in some wire bundle size and weight reductions but further improvements are possible with Class A Sensor/Actuator Networking. The number of connector pins for the system can also be reduced with Class A Networking.

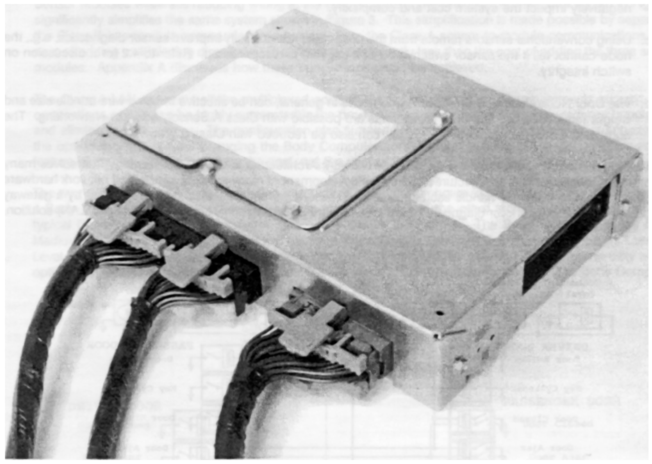

FIGURE 6 - ENGINE CONTROLLER CONNECTOR AND WIRE BUNDLE

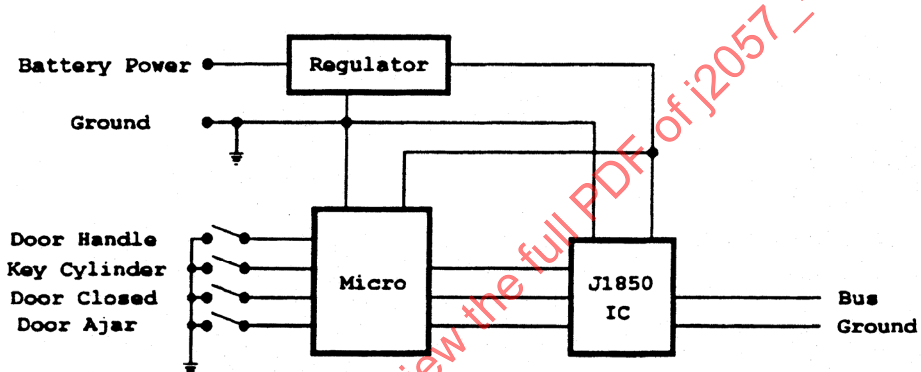

FIGURE 7 - ILLUSTRATION OF A DRIVER DOOR NODE

6.4 Multiple Network Architecture

The Multiple Network Architecture is the second strategy that solves many of these concerns. This architecture requires the development of many types of specialized network hardware components to efficiently handle each application. These components are connected together by a gateway on the Class B Network for diagnostics purposes. Figure 8 illustrates this Local Area Network (LAN) solution.

Multiple network architecture strategy requires the integration of electronics into the sensors, actuators, and motors so that they can communicate over a single wire into the module that utilizes them. Since the sensor and actuator components contain the added multiplex electronics the separate installation and wiring of the multiplex module is eliminated. Unlike the single network architecture strategy the integration of electronics into the sensors, actuators, and motors normally does improve sensor diagnostics because the sensor status and condition can be reported back to the controlling module. Also, the method makes use of a Class A LAN without adding components to the vehicle system.

Figure 8 shows that the Class A LAN eliminates the need for the Engine Compartment Node and two Door Sensor Modules while still reducing wiring at the crunch points. The Multiplex Architecture shown in Figure 8 significantly simplifies the same system shown in Figure 5. This simplification is made possible by separating the Class B intermodule communications network from the Class A sensor-to-module communications. The cost of adding multiplexing directly to the sensors is significantly less than the cost of adding the three sensor modules. Appendix A discusses how these conclusions could be achieved.

The Class A LAN connects all the multiplexed components in parallel. The I/O requirements support T-tap connections, which can be highly automated in the production of wiring harnesses. This reduces bundle size and eliminates dual crimps. The configuration also supports the concept of adding sensors or actuators as the option requires without changing the Body Computer configuration to support the option. This add-on feature allows the option to dictate the cost, not the cost of the added node dominating.