



# AUTOMOTIVE ELECTRONICS HANDBOOK

RONALD JURGEN



---

# AUTOMOTIVE ELECTRONICS HANDBOOK

---

**Ronald K. Jurgen** Editor in Chief

**McGraw-Hill, Inc.**

New York San Francisco Washington, D.C. Auckland Bogotá  
Caracas Lisbon London Madrid Mexico City Milan  
Montreal New Delhi San Juan Singapore  
Sydney Tokyo Toronto

**Library of Congress Cataloging-in-Publication Data**

Automotive electronics handbook / Ronald Jurgen, editor in chief.

p. cm.

Includes index.

ISBN 0-07-033189-8

1. Automobiles—Electronic equipment. I. Jurgen, Ronald K.

TL272.5.A982 1994

629.25'49—dc

94-39724

CIP

Copyright © 1995 by McGraw-Hill, Inc. All rights reserved. Printed in the United States of America. Except as permitted under the United States Copyright Act of 1976, no part of this publication may be reproduced or distributed in any form or by any means, or stored in a data base or retrieval system, without the prior written permission of the publisher.

1 2 3 4 5 6 7 8 9 0 AGM/AGM 9 0 9 8 7 6 5 4

ISBN 0-07-033189-8

*The sponsoring editor for this book was Stephen S. Chapman, the editing supervisor was Virginia Carroll, and the production supervisor was Suzanne W. B. Rapcavage. It was set in Times Roman by North Market Street Graphics.*

*Printed and bound by Arcata Graphics/Martinsburg.*

McGraw-Hill books are available at special quantity discounts to use as premiums and sales promotions, or for use in corporate training programs. For more information, please write to the Director of Special Sales, McGraw-Hill, Inc., 11 West 19th Street, New York, NY 10011. Or contact your local bookstore.

Information contained in this work has been obtained by McGraw-Hill, Inc. from sources believed to be reliable. However, neither McGraw-Hill nor its authors guarantee the accuracy or completeness of any information published herein, and neither McGraw-Hill nor its authors shall be responsible for any errors, omissions, or damages arising out of use of this information. This work is published with the understanding that McGraw-Hill and its authors are supplying information, but are not attempting to render engineering or other professional services. If such services are required, the assistance of an appropriate professional should be sought.

*This book is printed on acid-free paper.*



---

## CHAPTER 22

---

# ON- AND OFF-BOARD DIAGNOSTICS

---

**Wolfgang Bremer, Frieder Heintz, and Robert Hugel**

*Robert Bosch GmbH*

---

### 22.1 WHY DIAGNOSTICS?

---

The desire for greater safety, driving comfort, and environmental compatibility is leading to a rapid increase in electronic control units and sensors in upper class, medium-sized, and compact vehicles. Additional functions and their corresponding equipment in today's cars create a bewildering tangle of cables and confusing functional connections. As a result, it has become more and more difficult to diagnose faults in such systems and to resolve them within a reasonable period.

#### 22.1.1 Diagnostics in the Past and Today

On-board diagnosis has been limited thus far to a few error displays and fault storage achieved by relatively simple means. It has been left more or less to each manufacturer to decide to what extent diagnosis would be carried out. Diagnosis always means the working together of man and machine and consists essentially of three major components: registration of the actual condition, knowledge of the vehicle and its nominal condition, and strategy—how to find the smallest exchangeable deficient component by means of combining and comparing both the nominal and actual conditions.

All three points are inseparably connected. Only the means to the end have changed over time. The oldest and simplest method of diagnosis is that done with the help of our sense organs, but the limits of this kind of diagnosis are obvious. In fact, the objective in the development of diagnostic techniques is the extension of human abilities with the aid of diagnostic tools in order to be able to measure more precisely and more directly, to compare more objectively, and to draw definite conclusions.

The development of control techniques was essentially determined by the following items: the development of automotive engineering; the structure of workshops—that is, essentially the relation between the costs of labor and materials; and the development of electronics and data processing.

For a long time, motor diagnosis was limited to ignition control and timing. In the 1960s, new exhaust-gas measuring instruments for fuel injection adjustment were developed, but the mechanic still had to make the diagnosis. In the 1980s, the introduction of electronics in the vehicle was followed by a new generation of measuring instruments in the workshops. Not



control units and sensors are tied to a diagnostic connector which is plugged into the measuring instrument with a corresponding adapter for the respective vehicle. Because of the permanently increasing amount of electronic functions, it is necessary to develop connectors with more and more contacts. It is evident that this method soon will become too unwieldy.

Modern electronics in vehicles support diagnosis by comparing the registered actual values with the internally stored nominal values with the help of control units and their self-diagnosis, thus detecting faults. By interconnecting the measuring instruments, a detailed survey of the entire condition of the vehicle is available and an intelligent on-board diagnostic system is able to carry out a more precise and more definite localization of the defect.<sup>2</sup> With the help of an interconnection and standardization of the interface leading to the external tester, the many different complex and expensive adapters have become superfluous. Modern diagnosis will look like what is shown in Fig. 22.3.

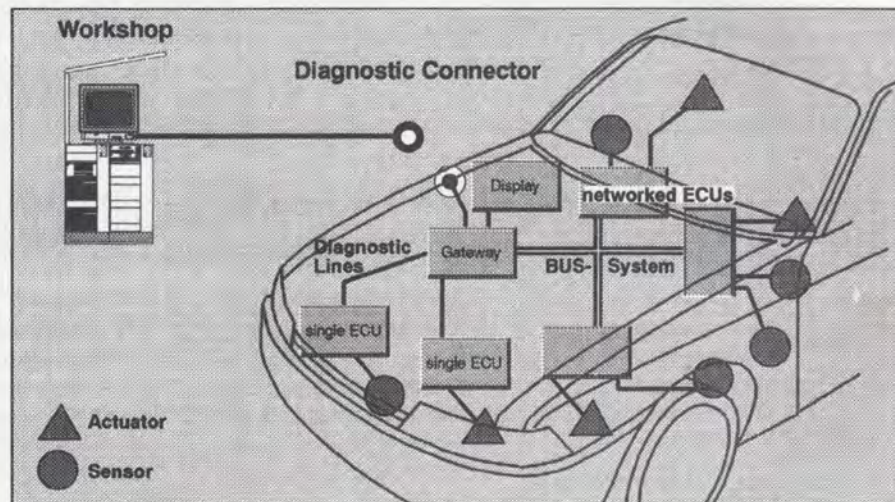


FIGURE 22.3 Future diagnostic connector installation in a vehicle.

Instead of a multiplicity of adapters there is only a single standardized interface, provided by the diagnostic processor. By means of interconnection, the diagnostic processor is provided with all available data and the condition of the vehicle is known. With the help of the diagnostic processor, the external measuring instrument has access to the measuring and diagnostic values of the sensors and is able to directly reach the actuator for measuring purposes.<sup>3</sup>

Such a diagnosis also demands a certain change in the functional structure of a vehicle. Corresponding hierarchical models have already been presented.<sup>4</sup>

### 22.1.2 Reasons for Diagnostics in Vehicles

Which are the most important reasons for diagnostics as demanded and desired in today's vehicles?

**Existing Diagnostic Problems.** A number of diagnostic problems must be resolved:

- Early diagnostic information was related only to single components and control units. In case of a defective comprehensive system, every unit, component, sensor, and connecting



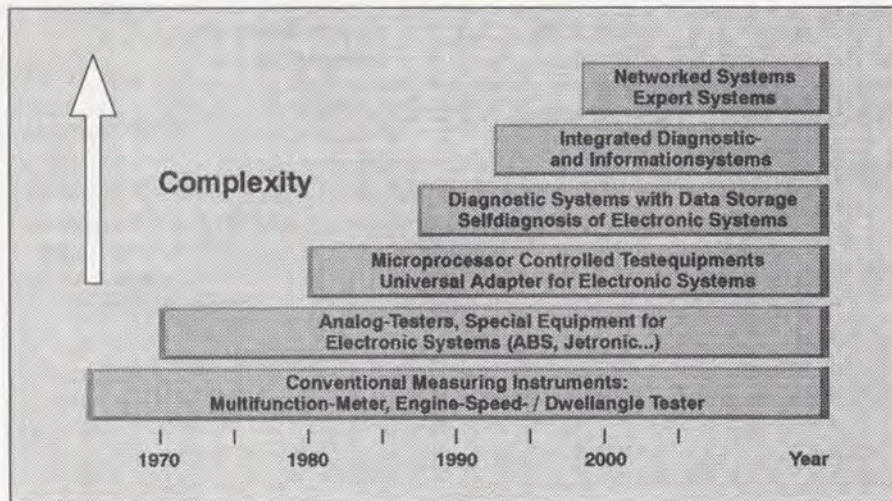


FIGURE 22.1 Evolution of diagnostic test equipment.

only were separate measurements combined with comprehensive test procedures, but also the information about the nominal condition of the vehicle was stored in a data memory.<sup>1</sup> A view of the development is shown in Fig. 22.1.

As more and more electronic systems were added to cars, the more difficult it became to determine the actual condition in case of a defect. Soon a multitude of connecting cables and adapters were required to reach the necessary measuring points. Moreover there was an increasing amount of information needed to make an effective diagnosis. In the majority of workshops, diagnosis is carried out as shown in Fig. 22.2. The most important test points of

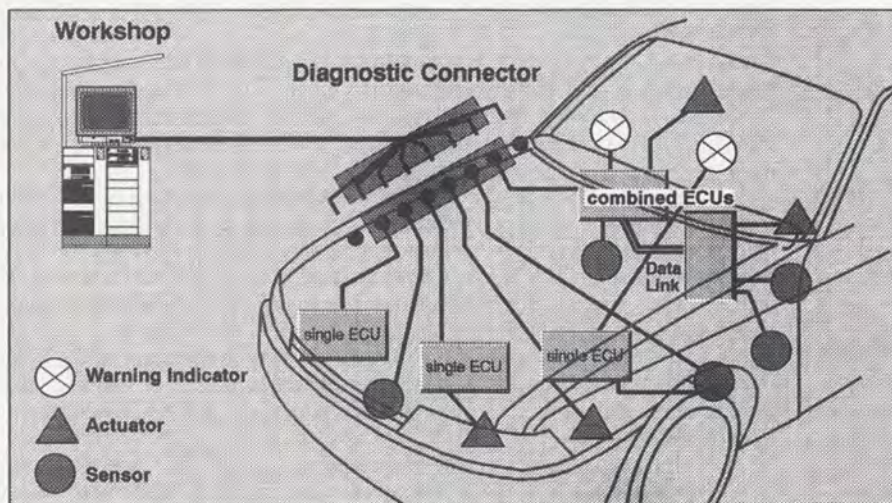


FIGURE 22.2 Present-day diagnostic connector installation in a vehicle.



cable of the system had to be tested and controlled. This was a very time consuming and expensive process.

- Because of the single component and control unit checks, it was impossible to analyze all the additional data correlated with a particular defect.
- In the case of a defect in single sensors or units, the car was often inoperable. Taking into consideration all available information about the vehicle, it is possible to use alternative parameters and procedures in order to achieve at least a so-called limp-home function and sometimes continue the use of the vehicle under only slightly limited operating conditions.
- Usually there was only a global error display with an often ambiguous warning light available for the driver. Drivers desire more detailed information and especially guidelines for what procedures should be followed.
- The multitude of adapter cables, plugs, diagnostic equipment, and communication interfaces in a workshop has become so complex that the effectiveness decreased dramatically, with the repair costs increasing disproportionately.

**New Legal Proposals.** Worldwide new legal proposals and governmental regulations [e.g., California Air Resources Board (CARB), On Board Diagnostics II (OBDII), Environmental Protection Agency (EPA)] are forcing manufacturers and subcontractors to seek more profitable, effective, and convincing diagnosis of vehicles.

**Serial Data Networks.** New serial data networks for the connection of control units and vehicle body components, installed in the vehicle, offer the possibility of absolutely new optimum approaches and even anticipate maintenance and diagnosis up to the introduction of autodidactic data processing systems and external data bases.<sup>5,6,7,8</sup>

**International Initiatives for Standardization.** Initiated by legislative and governmental demands for better diagnostics in the area of emission control, initiatives for standardization in the entire diagnostic field in vehicles were launched during recent years to achieve worldwide standardization of tools, interfaces, connectors, and protocols.

### 22.1.3 Diagnostic Tasks in Vehicles

In order to minimize the number of defects or even to completely avoid them, a vehicle requires regular checks. In case of an inevitable defect, a clear and directed diagnosis is required and has to be followed by a prompt, reliable, and inexpensive repair. Therefore appropriate diagnostic systems are being developed considering the following targets: simplification of maintenance, fault indication in time, guidelines for the driver in case of a defect, and safer and faster repairs with the help of a specific fault indication.

In addition to technical considerations, environmental aspects are now being taken into consideration as reflected in the diagnostic concepts. In the future, only perfect systems will be accepted, in order to keep environmental pollution to a minimum. It is understandable, therefore, that legislators insist on increased monitoring standards, particularly for exhaust-related components.

As an example of the new monitoring standards, consider the requirements of CARB and EPA in the United States and the resulting consequences for diagnosis. At the moment, the extent of such a detailed monitoring has to be a compromise between the different requirements and the possible technical and economical solutions, but the environmental aspects will gain more and more importance. The increased amount of available data will certainly permit a considerably higher rate of in-depth fault localization and will also allow clear fault identification without interactive outside intervention. Having knowledge of the functional interrelationships and access to all essential data, a picture of the defect can be created with the help of individual pieces of information. The driver and the workshop can



then be provided with appropriate instructions. In this context, on-board expert systems are being considered.

For an effective and successful diagnosis today and in the future the following tasks and targets can be defined.

**Fault Storage with Boundary Conditions.** A very important aspect of modern diagnosis is the clear and reliable analysis of the respective fault. During the self-diagnosis, it is absolutely necessary to store not only the respective fault information but also all relevant marginal parameters in the control unit, e.g., ambient temperature, velocity, engine speed, engine knock, and so on. The additional data can be stored when a defect occurs as well as during specified intervals around the moment of a defect. Such additional data is called "freeze frame" data.<sup>9</sup>

**Fault Localization.** Mechanics must be able to locate a defective control unit quickly and then determine which component of that control unit is at fault so that it can be replaced.

**Data Correlation, Recognition of Imminent Faults.** A large amount of data useful for the analysis of a vehicle is now available and even more will be available in the future. These data will have to be evaluated and compared with the help of modern data processing techniques, including fuzzy logic, neural networks, autodidactic systems, and expert systems. These techniques will not only enable the diagnosis of the actual condition of the vehicle but will also determine future maintenance needs. As a result, the reliability and availability of a vehicle will be increased and the possible consequences of a defect kept to a minimum. The driver can also be forewarned about imminent problems and can then take appropriate steps before starting on a trip.

**Parameter Substitution.** The breakdown of a sensor in modern diagnostic procedures is not necessarily followed by a lack of the respective information. After having diagnosed a fault, the diagnostic computer—with the aid of the available information—is often able to compute an auxiliary parameter to replace the original one. As a result, either a limp-home condition is possible or else the nominal function can be assured but under slightly limited conditions. Simple examples for such a calculated parameter are vehicle speed (considering the gear and the synchronous speed, or the antilock braking information, or the data of the navigation system), motor temperature (considering the outside temperature and the operating time), and the amount of remaining fuel (considering the last actual fuel content and the calculated consumption).

**Providing Guidelines.** As mentioned earlier, a diagnostic system has to provide clear information to the driver in case of a defect. A global warning indication is not sufficient. The driver needs to learn the extent of the defect and its consequences by appropriate text, graphics, or synthetic voice. In addition, the driver needs to be told the steps that have to be taken (e.g., "refill cooling water," "minimum speed to the next service station, risk of engine breakdown," "stop, brake system out of order").<sup>10</sup>

The diagnostic monitoring system can also be used, if there is no service station nearby, as a substitutional off-board system. The defect is then localized by an interactive working together of the indicating system and an appropriate input medium.

**External Diagnostic Access.** For off-board diagnosis, the diagnostic system of the vehicle has to provide a standardized access to all relevant components, control units, and stored information. This standardized access might also be used by the vehicle manufacturer, legisla-



tor, application engineer, and the end-of-the-line programmer. The access itself has to be controlled with the help of an appropriate mechanism to prevent possible abuse.<sup>11</sup>

**Logbook Function.** The control unit or the diagnostic computer of the vehicle is supposed to store every repair that has been carried out in the format of a logbook. It should contain the time and name of the workshop, every exchanged and newly installed element, every inspection carried out, and so forth.

## 22.2 ON-BOARD DIAGNOSTICS

The more complex automobiles became, the greater the number of electronic systems and the more difficult became the registration of the actual condition in case of a defect. To reach the necessary measuring points, many connecting cables and adapters were required. In addition, much data about the different systems and their working together was needed to allow a system-specific diagnosis. Modern electronics with self-diagnosis supports the service mechanic by registering the actual values, comparing them with the nominal values, and diagnosing faults that are stored for repair purposes. Actually, the internal functions are checked whenever an ECU is turned on.

First, the checksum of the program memory is checked together with its function and the correct version. Then a read and write test of the RAM cells is performed. Special peripheral elements (e.g., AD converters) are also checked within this test cycle. During the entire operating time of the vehicle, the ECUs are constantly supervising the sensors they are connected to. With the help of an adequate interpretation of the hardware, controllers are able to determine whether a sensor has a short circuit to ground or battery voltage, or if a cable to the sensor is interrupted. By comparing the measured values and the stored technical data, a controller is able to determine whether the measured values exceed the limits, drift away, or are still within the tolerable limits. The combination of information provided by other sensors allows the monitoring for plausibility of the measured values.

Sensors are tested similarly to the way actuators are monitored for short circuits or interruptions of cables. The check is carried out by measuring the electric current or reading the diagnostic output of intelligent driver circuits. The function of an actuator under certain conditions can be tested by powering the actuator and observing the corresponding reaction of the system. If discrepancies to the nominal values are diagnosed, the information is stored in an internal fault memory together with relevant outside parameters, e.g., the motor temperature or the engine speed. Thus, defects that appear once or under certain conditions can be diagnosed. If a fault occurs only once during several journeys, it is deleted. The fault memory can be read later in the workshop and provides valuable information for the mechanic.

In case of a detected defective sensor, the measured values are replaced by nominal values or an alternative value is formed using the information of other sensors to provide at least a limp-home function.

With the help of an appropriate interface, a tester can communicate with the ECUs, read the fault memory and the measured values, and send signals to the actuators. In order to be able to use self-diagnosis as universally as possible, manufacturers aim at the standardization of the interface and the determination of appropriate protocols for data exchange.

Another task of self-diagnosis is the indication of a defect to the driver. Faults are mostly indicated by one or more warning lights on the dashboard. Modern developments aim at more comprehensive information using displays for text and graphics, which provide priority-controlled information for the driver. Legal regulations concerning exhaust-gas gave rise to an essential extension of self diagnosis. The control units have to be able to control all exhaust-relevant functions and components and to clearly indicate a defective function or the exceeding of the permissible exhaust limits. Some of the demanded functions require an enor-



---

## CHAPTER 26

---

# MULTIPLEX WIRING SYSTEMS

---

**Fred Miesterfeld**

*Chrysler Corporation*

---

### 26.1 VEHICLE MULTIPLEXING

---

Production and proposed passenger vehicle multiplexing and data communications network systems will be thoroughly examined in this chapter. The systems covered are those methods that are relevant to the electronic engineer who has the assignment of applying multiplexing techniques to high-volume production. In passenger vehicle design, cost is the universal method of determining whether or not a design will be put into production. If a multiplex network design can be applied while delivering functional improvements at a system-cost saving, then this design is the most likely network design to be accepted.

The SAE Vehicle Network for Multiplexing and Data Communications (Multiplex) Committee has defined<sup>1</sup> three classes of vehicle data communication networks:

*Class A.* A potential multiplex system usage where vehicle wiring is reduced by the transmission and reception of multiple signals over the same signal bus between nodes that would have ordinarily been accomplished by individual wires in a conventionally wired vehicle. The nodes used to accomplish multiplexed body wiring typically did not exist in the same or similar form in a conventionally wired vehicle.

*Class B.* A potential multiplex system usage where data (e.g., parametric data values) are transferred between nodes to eliminate redundant sensors and other system elements. The nodes in this form of a multiplex system typically already existed as stand-alone modules in a conventionally wired vehicle.

*Class C.* A potential multiplex system usage where high data rate signals, typically associated with real-time control systems, such as engine controls and antilock brakes, are sent over the signal bus to facilitate distributed control and to further reduce vehicle wiring.

The Class B network is intended to be a functional superset of the Class A network; i.e., 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.

Generally, this section will deal only with the requirements for the lowest three layers of the seven-layer ISO open system interconnects (OSI) model (Ref. ISO 7498). These layers in descending order are the network layer, data link layer, and the physical layer.



26.1.1 Background of Vehicle Network Architectures

A wide variety of network topologies<sup>2</sup> can be envisioned by network designers. The message structure described in this section is very flexible and useful in exchanging information between network nodes. The following discussion describes two network architectures which are likely configurations that can use this message definition set: a single-network architecture and a multiple-network architecture.

The selection would be application-specific and, thus, it is the system designer's choice as to which network architectures to use. It should be noted that the hardware that supports these two message structures is generally not interchangeable. It is recommended that care be taken in choosing which message definition to use, because the selection is generally irreversible because of hardware limitations.

**Header Selection.** The header field (header) is a one-, two-, or three-byte field within a frame and contains information about the message priority, message source, target address, message type, and in-frame response. The multiple network architecture is usually associated with the single-byte header protocol. Figure 26.1 (1) illustrates the header byte as the message identifier (ID), which is primarily used for functional "broadcast"-type messages and implicitly defines all the required information about the message. It is unnecessary to specify the source or destination of functional-type messages. Reception becomes the exclusive responsibility of the receiving node. Figure 26.1 (2) also illustrates header bytes, which are primarily used for physical-type messages, and has two bytes: the first is the ID and the second is the target address.

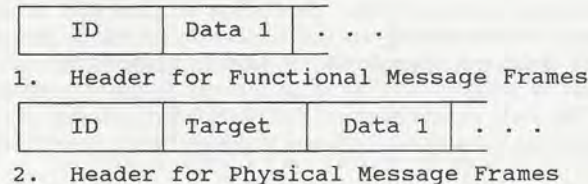


FIGURE 26.1 Single-byte header protocol.

The single-network architecture is usually associated with the multiple-byte header protocol, shown in Fig. 26.2. The first byte of the frame defines the priority and message types, functional or physical.



FIGURE 26.2 Multiple-byte header protocol.

**Architecture Selection.** Consideration must be given by the network designer as to whether a single-network architecture or a multiple-network architecture is preferable for an application. For example, a multiple-network architecture could be based on one network optimized around data communication (Class B) protocol requirements, and another network optimized around sensor type (Class A) multiplexing requirements. The Class B network may be characterized such that low latency is a significant requirement of the protocol and where the short functional type of messages can most effectively be used. A Class A network could handle the vehicle's event-driven multiplexing requirements. See the next section on Class A networking for more information on Class A multiplexing considerations.



Without regard to either the header or architecture selection, in Class B communications the network consists of the interconnection of intelligent nodes such as an engine controller, a body computer, a vehicle instrument cluster, and other modules. Such a network normally does not significantly reduce the base vehicle wiring but provides an intermodule data communications capability for distributed processing. The data shared between modules may be repetitive in nature and sometimes requires handshaking between modules or acknowledgment of data reception. As a result of handling the repetitive data and response-type data, a network can be optimized around functional addressing. Functional addressing sends data on the network, which can be received by one or more nodes without regard to the physical location of the module but only by their "interest" in those specific functions. In general, the transmitting node does not care which, if any, nodes receive the data it is sending. When physical addressing is required in a data communications network (Class B), it is usually for vehicle maintenance purposes and can be easily handled without reducing network bandwidth.

The nature of Class A multiplexing requires the interconnection of limited intelligence nodes, often simply sensors or actuators. These Class A networks can significantly reduce the base vehicle wiring as well as potentially remove redundant sensors from the vehicle. The data shared between nodes in this case are generally event-driven in nature. In most vehicles, the number of event-driven signals predominates, but they are only needed infrequently. The message to "turn headlamps on," for example, can be easily seen as event-driven. Because these messages are infrequent (only sent once when the signal changes) they generally require acknowledgment, either within the same message or a separate handshake/response message.

The single-network architecture carries both the Class A and Class B messages on one network and the multiple-byte header has the advantage of having more bits available for use in assigning message identifiers, priorities, message types, etc. The characteristics of both time-critical and event-driven messages must be accommodated on a message-by-message basis. In general, this level of complexity will need the flexibility of the multiple-byte header structure. It should be clear that both network architectures must be cost effective for the application and the specific nodes on each network.

The multiple network architecture tends to separate the Class A messages from the Class B messages and optimize each network and node interface for the specific characteristics of each network class. The time-critical messages could be exchanged on one network, while the event-driven messages are sent on another. For example, the data communication (Class B) repetitive messages can be handled on one network and the sensor and control (Class A) multiplexing requirements on another network. This architecture requires both networks to work together to achieve the total vehicle network requirements. If information is needed between the multiple networks, care must be exercised to meet the needs of each of the networks. This concept of multiple networks is not limited to two, but can be extended to several separate networks if desired.

**Class A Network.** Class A multiplexing<sup>3</sup> 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 will play a major role as to when and how multiplexing will become a cost-effective solution.



*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 and built-in testability can substantially reduce vehicle build test time.

*Example Class A Systems.* To illustrate how a Class A multiplex network could be used to simplify the vehicle wiring situation, consider the vehicle theft alarm system shown in Fig. 26.3. 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. When the module is armed, the horn is sounded when the hood, door, or trunk is tampered with.

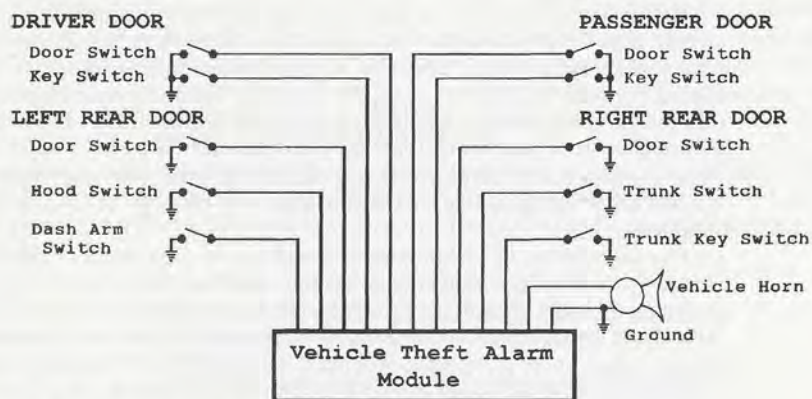


FIGURE 26.3 Vehicle theft alarm system.

The vehicle theft alarm system shown in Fig. 26.4 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 and 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 foil the tampering of a would-be thief.

The I/O requirements support T-tap connections, which can be highly automated in the production of wiring harnesses, reducing the wire bundle size and eliminating 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 in which some versions of theft alarms are built as originally described, but an upscaled version is offered as an option in which 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.

There are approximately seven sensors to every actuator in a real vehicle body system. This theft alarm system is typical with 10 sensors (switches) to one actuator (horn).



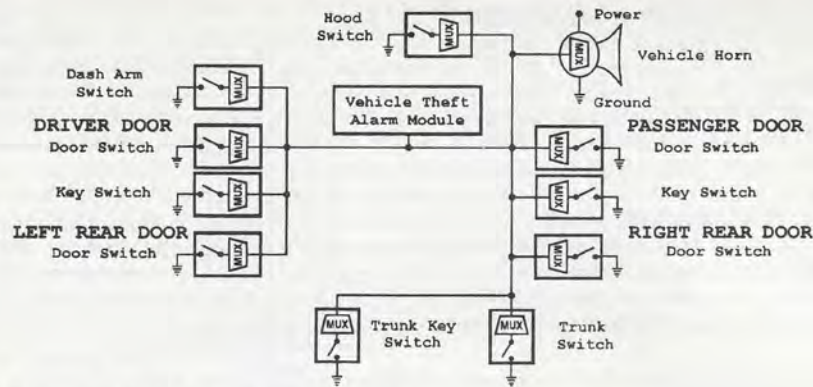


FIGURE 26.4 Multiplexed vehicle theft alarm system.

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 in which the power to run the sensor has been supplied by the multiplex signal. For an example component, see Sec. 26.3.7. 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 usually require three wires; signal, power, and ground. However, some manufacturers are developing a method to eliminate one of these wires by placing the signal on the power wire.

**Class B Data Communications.** The vehicle system designer now has many architecture partitioning options. A prime example is when to integrate many features into a module or when to employ a dedicated node. 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, this architectural strategy does not always result in an optimal solution.

A hypothetical vehicle will be described to illustrate this point. Figure 26.5 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.

As illustrated in Fig. 26.5, all sensors are wired directly to the body computer. This example shows that for 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 troubleshooting problems make this option a limited solution for this partitioning strategy.

The Class B single-network architecture strategy would solve this complex problem by adding a sensor node and reducing the number of interconnecting wires. Conventional sensors are connected directly to the node which serves as a gateway to the other modules over the Class B data network. Figure 26.6 illustrates the dramatic reduction in the number of cir-



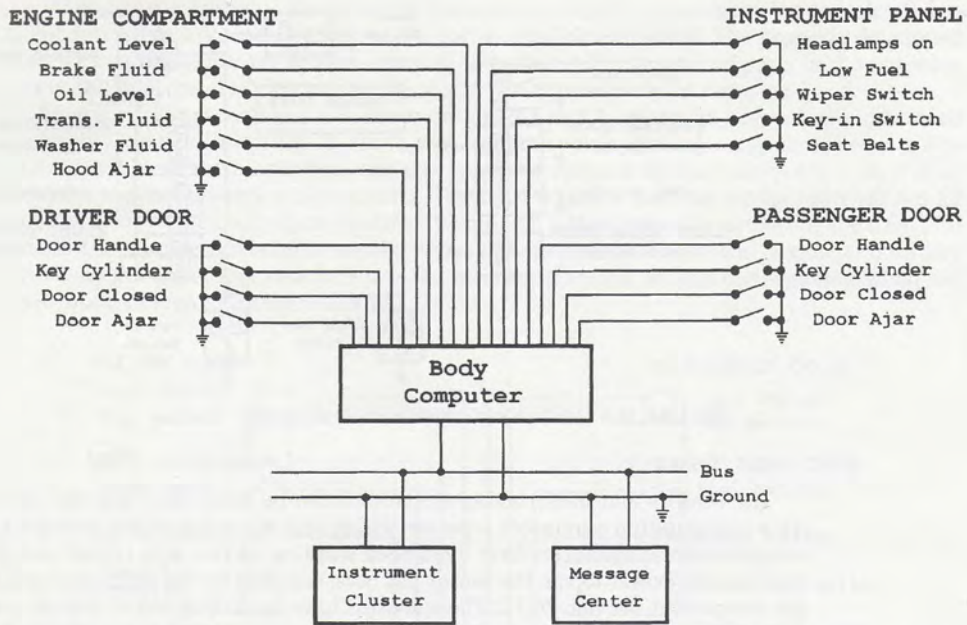


FIGURE 26.5 Data communications network with body computer, instrument cluster, and message center.

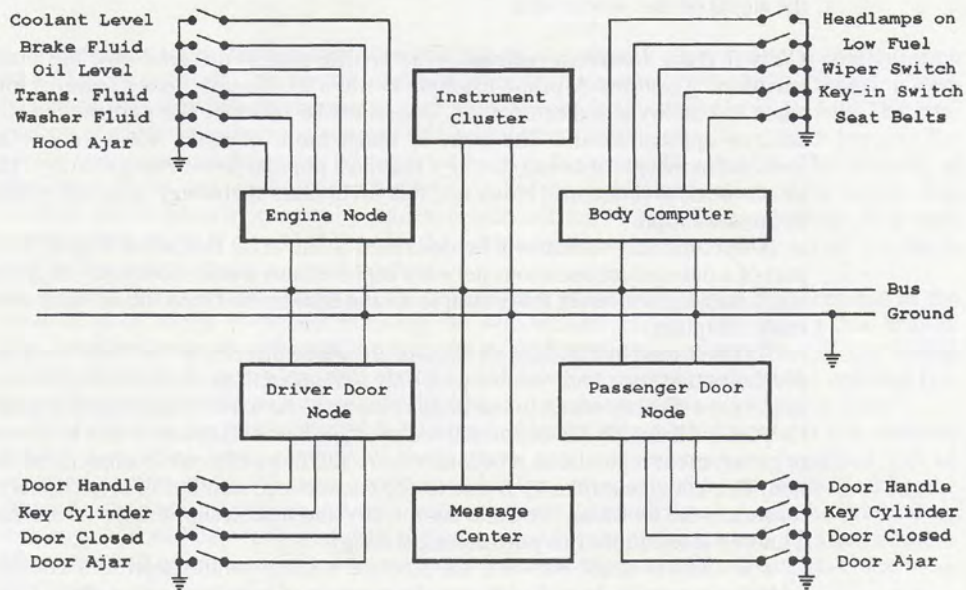


FIGURE 26.6 Data link with body computer, instrument cluster, message center, and three sensor nodes.



cuits required. This method is effective in reducing the number of sensor wires connected through "crunch points" such as the bulkhead or door hinge. This reduction in wiring, however, 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. This section will demonstrate that in many situations the multiplex strategy, shown by Fig. 26.6, leads to a less than optimum system architecture. It is highly desirable to have a multiplexing architecture which would permit the use of smaller module connectors, reduce the number of wires crowding through the congested areas, and attain a solution without introducing more modules to mount, wire, and service.

*Engine Compartment Node.* In this hypothetical example, it may be desirable to integrate the node with the engine controller module, which would reduce module count and wiring circuits at the same time. The integration solution is not always possible because the engine controller already has an uncontrollably large module connector and would add a separate part just to cover an option.

*Door Nodes.* In this hypothetical example, the best location for the door node would be inside the door (See Fig. 26.7). 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.

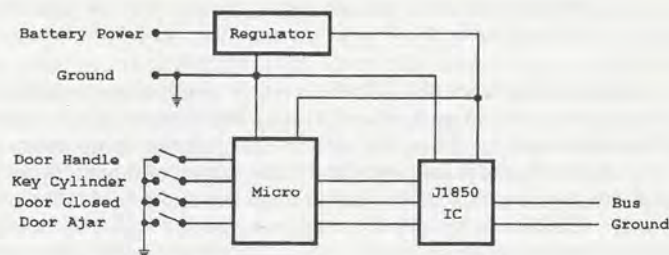


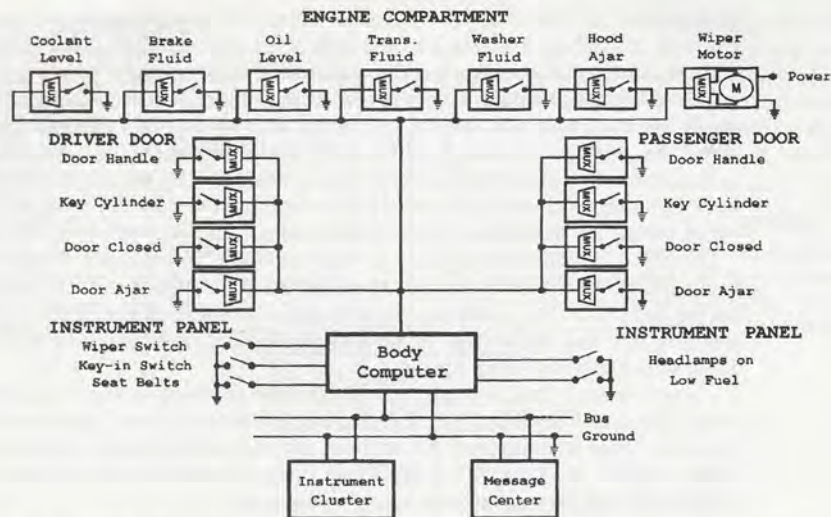
FIGURE 26.7 A driver door node.

*General Node Concerns.* General node concerns include the following:

- In order to achieve minimum cost, nodes tend to become application-specific and not generic because they usually can cover only one feature product.
- To cover more than one product, nodes tend to become intelligent and employ a microcomputer, and may negatively impact the system cost and complexity.
- 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 the previous section, "Example Class A Systems," for a discussion on switch integrity.
- The door node illustrated in Fig. 26.7, and nodes in general, can be effective in some wire bundle size and weight reduction 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.

*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 26.8 illustrates this local area network (LAN) solution.





**FIGURE 26.8** Data link with body computer, instrument cluster, message center, and Class A network for sensors.

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. This method makes use of a Class A LAN without adding components to the vehicle system.

Figure 26.8 shows that the Class A LAN eliminates the need for the engine compartment node and two-door sensor module while still reducing wiring at the crunch points. The multiplex architecture shown in Fig. 26.8 significantly simplifies the same system shown in Fig. 26.6. This simplification is made possible by separating the Class B intermodule communications network from the Class A sensor-to-module communications.

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 configuration 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 and not the cost of the added node dominating.

The two different Class A networks using multiplexed sensors are shown in Fig. 26.8 and Fig. 26.9 and illustrate a body computer flexibility trait that is not available in the other architectural approaches. The typical base vehicle using the Class A network is shown in Fig. 26.9. The body computer in the base, medium, and premium vehicle systems all have the wiper switch, seat belt switch, headlamps on, low fuel level, key-in ignition switch, Class A interface, and the Class B multiplex interface. This trait across option rates allows additional inputs to be connected without modifying the hardware in the body computer.

Unlike this hypothetical situation just used for illustration purposes, a real vehicle will have several actuators as well as sensors connected to the body computer. As it was previously discussed, there are approximately seven sensors to every actuator in a real vehicle body system. For illustrative purposes, 14 sensors and one actuator (wiper motor) were shown in this example. The principles shown, however, apply similarly to any number of actuators.



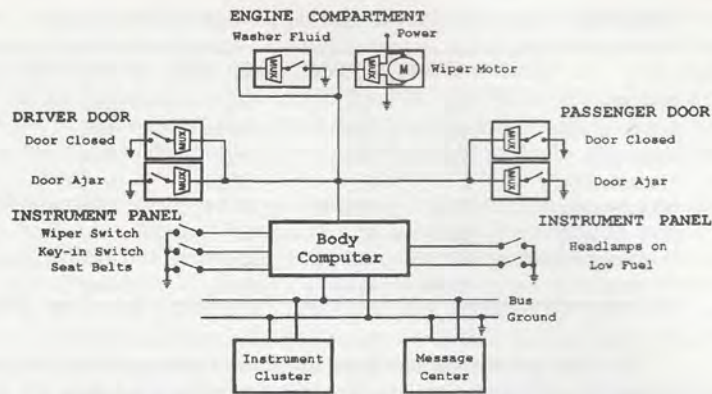


FIGURE 26.9 Base vehicle with Class B data link, body computer, instrument cluster, message center, and Class A network for sensors.

**Class C Real-Time Control.** The Class C network is the least mature network, and consensus of opinion on requirements does not yet exist. Experts cannot agree on many facets and many of the requirements are controversial. Many automotive engineers believe that an adequate statistical latency achievable with a bit-by-bit arbitration-based media access protocol is sufficient for real-time distributed Class C multiplexing. Others believe a token-passing media access protocol is required because a maximum latency is guaranteed, because with an arbitration-based media access only a statistical maximum latency is achievable. There are still others who argue that both the arbitration-based and token-passing media access is not good enough for tightly looped distributed processing because both methods have too great a variation in latency time. They argue that a time-triggered media access method is required because the network variations in latency should not affect tightly looped processing times. Other factors such as required data rates and the physical media type also remain open. It is clear that more research and development is required to resolve these questions.

## 26.2 ENCODING TECHNIQUES

The data encoding technique<sup>4</sup> has a significant effect on the radiated EMI. In order to achieve the highest possible data rate, it is important to choose a data-encoding technique that has the fewest transitions per bit with the maximum amount of time between transitions and bit-synchronized so that invalid bit testing can be effective. PWM, for example, has two transitions per bit with  $\frac{1}{2}$  bit times between transitions. NRZ has a maximum of one transition per bit but is increased to provide for synchronization. Some of the disk drive encoding techniques such as modified frequency modulation (MFM) are synchronous with fewer than one transition per bit. (See Table 26.1 for a comparison chart of a selection of encoding techniques used in vehicle multiplexing.)

The variable column in the table describes an attribute whereby the transmission time for data byte is a variable quantity depending on the data value. VPWM and Bit-Stuf NRZ both have variable byte repetition rate (*data variability*).

Some of the bit-encoding techniques synchronize on transitions that fall on or within the bit boundaries. 10-bit NRZ, Bit-Stuf NRZ, and E-MAN all employ added transitions for synchronization (*clock synchronization*).



*The most comprehensive, authoritative reference  
on automotive electronics ever published*

# AUTOMOTIVE ELECTRONICS HANDBOOK

Electronic devices and systems are transforming the automotive industry. In fact, it's a reasonable estimate that soon about 15 percent of every car's value will reside in its electronics alone.

The time is ripe for this comprehensive handbook. Inside, you'll find contributions from a virtual "who's who" of experts from the world's premier companies—including Chrysler, Bosch, Honda, Nissan, and others—offering the kind of in-depth engineering details never before available in a single source. There's up-to-the-minute information on virtually every electronic system and component currently in use—along with many that are only just emerging—including:

- Each of the individual sensors and actuators that make a car's major control systems possible
- New technologies being utilized in electric cars, intelligent-vehicle highway systems, and noise cancellation
- The latest advances in instrument panel displays, computer systems, safety features, antitheft devices, and more

No matter what your area of expertise or interest, this landmark reference on automotive electronics is one you've long needed ... and one you'll surely be consulting for many years to come.

ISBN 0-07-033189-8



9 780070 331891

Cover Design: Lerner Communications, Inc.  
Cover Photo: SuperStock, Inc.

**McGraw-Hill, Inc.**  
Serving the Need for Knowledge  
1221 Avenue of the Americas  
New York, NY 10020