

SURFACE VEHICLE INFORMATION REPORT

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Survey of Known Protocols

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1. **Scope**—This SAE Information Report is a summary comparison of existing protocols found in manufacturing, automotive, aviation, military, and computer applications which provide background or may be applicable for Class C application (see Figure 1). The intent of this report is to present a summary of each protocol, not an evaluation. This is not intended to be a comprehensive review of all applicable protocols. The form for evaluation of a protocol exists in this paper and new protocols can be submitted on this form to the committee for consideration in future revisions of this report.

This report contains a table which provides a side-by-side comparison of each protocol considered. The subsequent section provides a more detailed examination of the protocol attributes. Many of the protocols do not specify a method for one or more of the criteria. In these circumstances 'user defined' or 'not specified' will appear under the heading.

Certain protocol specifics or details are omitted for the sake of brevity. Every attempt is made to provide the interested reader with the necessary references for further research.

- 1.1 **Background**—Three classes of vehicle communications have been identified by the SAE Vehicle Networking Subcommittee. These classes are defined as follows:

- a. Class A: A potential multiplex system usage whereby vehicle wiring is reduced by the transmission and reception of multiple signals over the same signal bus between nodes that would have been accomplished by individual wires in a conventionally wired vehicle (i.e., low-speed body wiring and control functions, for example, control of exterior lamps).
- b. Class B: A potential multiplex system usage whereby data is transferred between nodes to eliminate redundant sensors and other system elements (i.e., data communications, for example, sharing of vehicle parametric data).
- c. Class C: A potential multiplex system usage whereby high data rate signals typically associated with real-time control systems, such as engine controls and anti-skid brakes, are sent over the signal bus to facilitate distributed control and to further reduce vehicle wiring (i.e., high-speed real-time control, for example, distributed engine control).

These three classes describe the various applications of communication that are anticipated to exist within a vehicle. Each class is intended to be able to support the lower level Class applications. That is, Class A systems are designed for basic low level switch multiplexing. Class B introduces the aspect of parametric data sharing while still providing for Class A applications. Class C introduces the aspect of real-time control but still allows Class B and Class A tasks to be performed. Issues such as cost, reliability, and bus bandwidth will determine which link or combination of links are most appropriate for a given application.

For definition of other terms used in this report, please refer to SAE J1213.

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	Aircraft MIL STD 1553	ABUS	AUTOLAN	CAN	DDB	ETHERNET	HDLC/ SDLC	J1850	J1850	MINI-MAP	TOKEN RING	TOKEN SLOT DEVICE	VAN
AFFILIATION	Military Standard	VW	General Instrument	Proposed ISO Bosch	Philips	IEEE 802.3	ISO(HSLC) IBM(SDLC)	SAE J1850	SAE	IEEE	IEEE 802.5	GM	Proposed ISO
APPLICATION	Aircraft Network (fighter...)	Auto In-Vehicle	Auto In-Vehicle	Auto In-Vehicle	Audio/ Video	Lab and Business	Industrial	Auto In-Vehicle	Avionics	Factory Communications	Computer	Auto In-Vehicle	Auto In-Vehicle
TRANSMISSION MEDIA	Shielded TW, Pair Fiber Optic	Single Wire	Twisted Pair	Twisted Pair Fiber Optic	Twisted Pair	"Thick" Coaxial Cable		Single Wire Twisted Pair	Fiber Optic	Twisted Pair, Coax Fiber Optic	Dual Twisted Pair	Twisted Pair Fiber Optic	Twisted Pair
BIT ENCODING	Manchester II Biphase	NRZ	Alternate Pulse Inversion	NRZ With Bit Stuffing	PWM	Manchester	NRZ With Inversion And Zero Bit Insert	VPW PWM	Manchester	Phase Shift Keying (PCFSK, AMPSK)	Manchester	NRZ With Bit Stuffing	Manchester
MEDIA ACCESS	Master/ Slave or Token	Contention	Master/ Slave	Contention	Contention	Contention	Master/ Slave	Contention	Token Passing	Token Passing	Token	Token Slot	Contention
ERROR DETECTION	Parity	Bit Only	CRC	CRC	Parity	CRC	CRC	Optional CRC	CRC	Optional CRC	CRC	CRC	CRC
DATA FIELD LENGTH	2 Bytes Minimum	2 Bytes	2 Bytes	0-8 Bytes	2-128 Bytes	46-1500 Bytes	Any Number of Bytes	0-8 Bytes	32-65536 Bytes	2-256 Bytes	1-4 K Bytes	0-256 Bytes	0-8 Bytes
IN-MESSAGE ACK				Yes				Yes				Yes	
MAXIMUM BIT RATE	1 Mb/s	500 Kb/s	4 Mb/s	1 Mb/s	100 Kb/s	10 Mb/s	375 Kb/s 2.4 Mb/s	10 Kb/s 40 Kb/s	50 Mb/s	5.10.20 Mb/s	4 Mb/s 16 Mb/s	2 Mb/s	User Definable
MAXIMUM BUS LENGTH	Not Specified	Not Specified Typical 30 m	> 40 m	Not Specified Typical > 40 m	150 m	500 m		40 m	> 40 m	> 400 m	1500 m	Not Specified Typical 30 m	30 m
MAXIMUM NUMBER OF NODES	Not Specified	Not Specified Typical 32	127	Not Specified Typical > 16	50	1024		Not Specified	128	100	256	32 (Transmit Capability)	16
HARDWARE AVAILABLE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No

FIGURE 1—PROTOCOL DESCRIPTION

2. References

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest version of SAE publications shall apply.

- a. Aircraft Internal Time Division Command / Response Multiplex Data Bus (MIL-STD-1553): "MIL-STD-1553B Designer's Guide" published by ILC Data Device Corporation.
- b. Automotive Bit-serial Universal-interface System (ABUS):
 1. ABUS presentation by Volkswagen to SAE Class C Task Force 8/89.
 2. Press Information and data sheet by Telefunken Electronic 8/88.
- c. Auto Local Area Network (AutoLAN):
 1. John D. H. Harris, Nigel M. Bailey "General Instrument AUTOLAN - A High Speed Multiplexing System for Automotive Body Wiring Systems" SAE 890541
 2. "AUTOLAN CONTROLLER IC 616759 DRAFT 05-04-89"
- d. Class B Data Communication Network Interface (SAE J1850): Recommended Practice J1850, Revised 9/19/88.
- e. Controller Area Network (CAN):
 1. Intel 1989 Automotive Handbook
 2. SAE Information Report J1583
- f. Digital Data Bus (D2B): Philips Single-Chip 8-Bit Microcontroller User's Guide
- g. Ethernet (IEEE 802.3):
 1. IEEE 802.3 Summary by M.R. Stepper of the SAE Truck and Bus Control and Communications Subcommittee
 2. Intel 1989 Microcommunications Handbook
 3. Intel Local Area Networking (LAN) Tutorial
- h. Joint Integrated Avionics Working Group (JIAWG):
 1. James H. Nelson, Larry T. Shafer, Daryle B. Hamlin, James J. Herrmann "A Candidate for Linear Token-Passing, High-Speed Data Bus Systems" SAE 872494
 2. Draft "Standard Joint Integrated Avionics Working Group Linear Token Passing Multiplex Data Bus Protocol" DOCUMENT J88 - M5
 3. "Linear Token Passing Multiplex Data Bus Standard" Unisys Document 7340679
- i. Mini-Manufacturing Automation Protocol (Mini-MAP):
 1. "MiniMAP/MAP Controller/Carrierband Modem Interface" Motorola Inc. Rev. 1
 2. "MicroMAP1-7 Manufacturing Automation Protocol Software" Motorola Inc. Rev.1
 3. "IEEE 802.4 Token Bus"
- j. Synchronous Data Link Control/High-Level Data Link Control (SDLC/HDLC):
 1. Microcommunications Handbook, Intel, 1988
 2. Microprocessor, Microcontroller and Peripheral Data Volume II, Motorola, 1988
- k. Token Ring (IEEE 802.5):
 1. ANSI/IEEE std 802.5-1985, Token Ring Access Method
 2. ANSI/IEEE std 802.5-1985, Logical Link Control

- l. Token Slot Protocol: SAE Information Report J2106 "Token Slot Network for Automotive Control"
- m. Vehicle Area Network: VAN Specification, Version 1.2, ISO/TC22/SC3/WG1

3. **Definitions**—The descriptions of the protocol subsections follow. These descriptions appear in the order in which they are discussed for each protocol.
- 3.1 **Intent of Protocol Subsections**—The following describes the intent of the various subsections of the protocol characteristics.
- 3.2 **Application/Affiliation**—The application section briefly identifies the applications for which the protocol was designed to serve (e.g., military, aircraft, industrial, land vehicles, trucks). The affiliation section identifies the organization(s) that originally developed or specified the protocol or which now endorse the protocol.
- 3.3 **Transmission Media**—The transmission media section describes the physical medium generally associated or required by the given protocol (e.g., single wire, dual (parallel) wire, twisted pair, twisted pair with shield, dual twisted pair, fiber optics).
- 3.4 **Physical Interface**—This section describes the basic circuitry used to connect the nodes to the network. In some cases the schematic of a typical interface may be shown. In others, a reference to a generally known interface technique may be made. This section may also include additional data about aspects of the interface not readily shown. An example would be that receiver nodes synchronize to the signal from a transmitting node, or that receiver nodes adjust their receiver clock to the received data signal.
- 3.5 **Bit Encoding**—The bit encoding section describes the way in which the logical bits, 1's and 0's, are translated into signals on the transmission medium by the physical interface (e.g., NRZ, PWM, MANCHESTER).
- 3.6 **Network Access**—The network access section describes the method used to award the communication network to one of the nodes for the transmission of a message (e.g., master slave, token passing, CSMA/CD).
- 3.7 **Message Format**—The message format section describes the fields that make up the basic message(s) used in the protocol. This includes the order, name, and size of the fields.
- 3.8 **Handshaking**—The handshaking section describes the interaction of nodes within a network in order to effect a transfer of data. This may include such things as negative and positive acknowledgement, and in-message acknowledgement.
- 3.9 **Error Detection Management**—The error detection management section describes the types of errors the protocol detects and recovery techniques it uses (e.g., wrong message length, CRC).
- 3.10 **Fault Tolerance**—The fault tolerance section describes the ability of the protocol to continue operation, possibly at a degraded level, when various parts of the physical layer or medium of the network on which the protocol is operating fails (e.g., node connections are broken, bus wires are opened, bus wires are shorted to ground or to vehicle battery voltage).
- 3.11 **Data Rate**—The data rate section identifies the maximum data rate supported by the protocol.
- 3.12 **Framing Overhead**—The framing overhead section briefly shows the amount of non-data overhead (i.e., framing overhead) associated with the given protocol. If possible the calculation of overhead is shown. Because some protocols offer significantly different message formats and/or message sizes several overhead calculations may be necessary to give an accurate picture of the range of the protocol's overhead requirements.
- 3.13 **Latency**—The latency section describes the factors that affect the delay between the availability of a message to be transmitted and the beginning of the reception of that message by the intended receiver.



3.14 Power Reduction Mode—The power reduction section has general information about any modes of operation that require less power than normal operation. As a minimum, this section identifies the lower power level(s). It also includes a brief description of the criteria used in transitioning to the lower power mode(s) and to return to normal power mode. Some of this information may be device version specific and will be so identified.

3.15 Selected References—The selected references section identifies the source of the information used to create the summary of a given protocol (e.g., manuals, standards, presentations).

3.16 Contributors—The contributors section recognizes the person(s) who supplied information on the particular protocol and/or who reviewed the information.

4. Protocol Technical Summary

4.1 Aircraft Internal Time Division Command/Response Multiplex Data Bus (MIL-STD-1553)

4.1.1 APPLICATION/AFFILIATION—Military standard (presently in Revision B). Used in aircraft (fighter jet, other) and tank networks. One of the basic tools used by the Department of Defense for integration of weapon systems. In the future, it is intended to be used to integrate flight controls, to integrate propulsion controls, and to store management subsystems.

4.1.2 TRANSMISSION MEDIA—Standard defines specific characteristics for a twisted pair shielded cable. Other media may be used. A related protocol, MIL-STD-1773, supports fiber optics. A summary of Data Bus and Coupling Requirements may be found in Table 1.

TABLE 1—SUMMARY OF DATA BUS AND COUPLING REQUIREMENTS

Parameter	MIL-STD-1553B
Transmission line	
Cable type	Twisted-shielded pair
Capacitance (wire to wire)	30 pF/ft, maximum
Twist	Four per foot (0.33/in), minimum
Characteristic impedance (Z_0)	70 to 85 Ω at 1.0 MHz, maximum
Attenuation	1.5 dB/100 ft at 1.0 MHz, maximum
Length of main bus	Not specified
Termination	Two ends terminated in resistors equal to $Z_0 \pm 2\%$
Shielding	75% coverage minimum
Cable coupling	
Stub definition	Short stub < 1 ft Long stub > 1 to 20 ft (may be exceeded)
Coupler requirement	Direct coupled - short stub; transformer coupled - long stub (ref. Figure 1-1.7)
Coupler transformer	
Turns ratio	1:1.41
Input Impedance	3000 Ω , minimum (75 kHz to 1.0 MHz)
Droop	20% maximum (250 kHz)
Overshoot and ringing	± 1.0 V peak (250 kHz square wave with 100 ns maximum rise and fall time)
Common mode rejection	45.0 dB at 1.0 MHz
Fault protection	Resistor in series with each connector
Stub voltage	equal to $(0.75 Z_0) \pm 2.0\% \Omega$ 1.0 V to 14.0 V p-p, 1-1, minimum signal voltage (transformer coupled); 1.4 V to 20.0 V, p-p, 1-1, minimum signal voltage (direct coupled)

- 4.1.3 **PHYSICAL INTERFACE**—Direct coupling and transformer coupling based on length of connected stub.
- 4.1.4 **BIT ENCODING**—Valid Manchester II biphase encoding. Zero crossing deviation of ± 23 ns and rise and fall time of greater than or equal to 100 ns specified. 1-1/2 bits positive volts, 1-1/2 bits negative volts for Command and Status Words, the opposite for Data Word. Valid Manchester II for bits other than the word sync.
- 4.1.5 **NETWORK ACCESS**—In the “stationary master bus control system,” MIL-STD-1553 operates as Master/Slave with respect to the bus controller and the remote terminal. The bus controller is in control of all communication and it is the sole device allowed to transmit command words. All messages are initiated by the bus controller using command word(s). The network implements “Internal Time Division Command/Response” to control access between the bus controller and the remote terminals.

In the “non-stationary master bus control system,” multiple bus controllers may (one at a time) control the single data bus system. The protocol provides a method for issuing a bus controller offer, allowing a potential bus controller to accept or reject control via a bit in the returning status word. Two methods have been used: time based and round robin.

- 4.1.6 **MESSAGE FORMAT**—There are 10 message types (see Figure 2). The 10 message types may be broken into 2 groups - “information transfer formats” and “broadcast information transfer formats.”

Each message consists of 3 primary sections or “words.” They are the “Command Word,” the “Data Word,” and the “Status Word” (see Figure 3).

- 4.1.7 **HANDSHAKING**—Message acknowledgement is provided by the “Status Word.” For a single receiver, the structure is shown in Figure 3. The broadcast message format requires the receiving remote terminals to suppress their status responses. Therefore, to analyze the status word after a broadcast message has occurred requires a mode code message to a unique terminal to be sent (and the message must be transmitted before any other transmission to that unique terminal).

All accesses to the bus are controlled through the bus controller. For transmissions to a specific remote terminal, the remote terminal address is used. For broadcast messages, the bus controller transmits commands using a remote terminal address of “31 hex.”

Acknowledgement is provided by the command/response philosophy, which requires that all error-free messages received by a remote terminal be followed by the transmission of a remote terminal status word.

- 4.1.8 **ERROR DETECTION MANAGEMENT**—The message error bit is the only required status bit and it is used to identify messages which do not pass the word or message validation tests. This bit is set if a message fails to pass the tests and the status word is suppressed (i.e., not transmitted). All messages that are not error-free will not have a responding status word—allowing the bus controller to time-out on the no status response, alerting the bus controller of a failure condition. Parity is used at the end of each word. Odd parity is established for all words based on the 16 bits of data plus parity.

a. The word validation includes:

1. word begins with a valid sync field
2. bits are a valid Manchester II code
3. word parity is odd

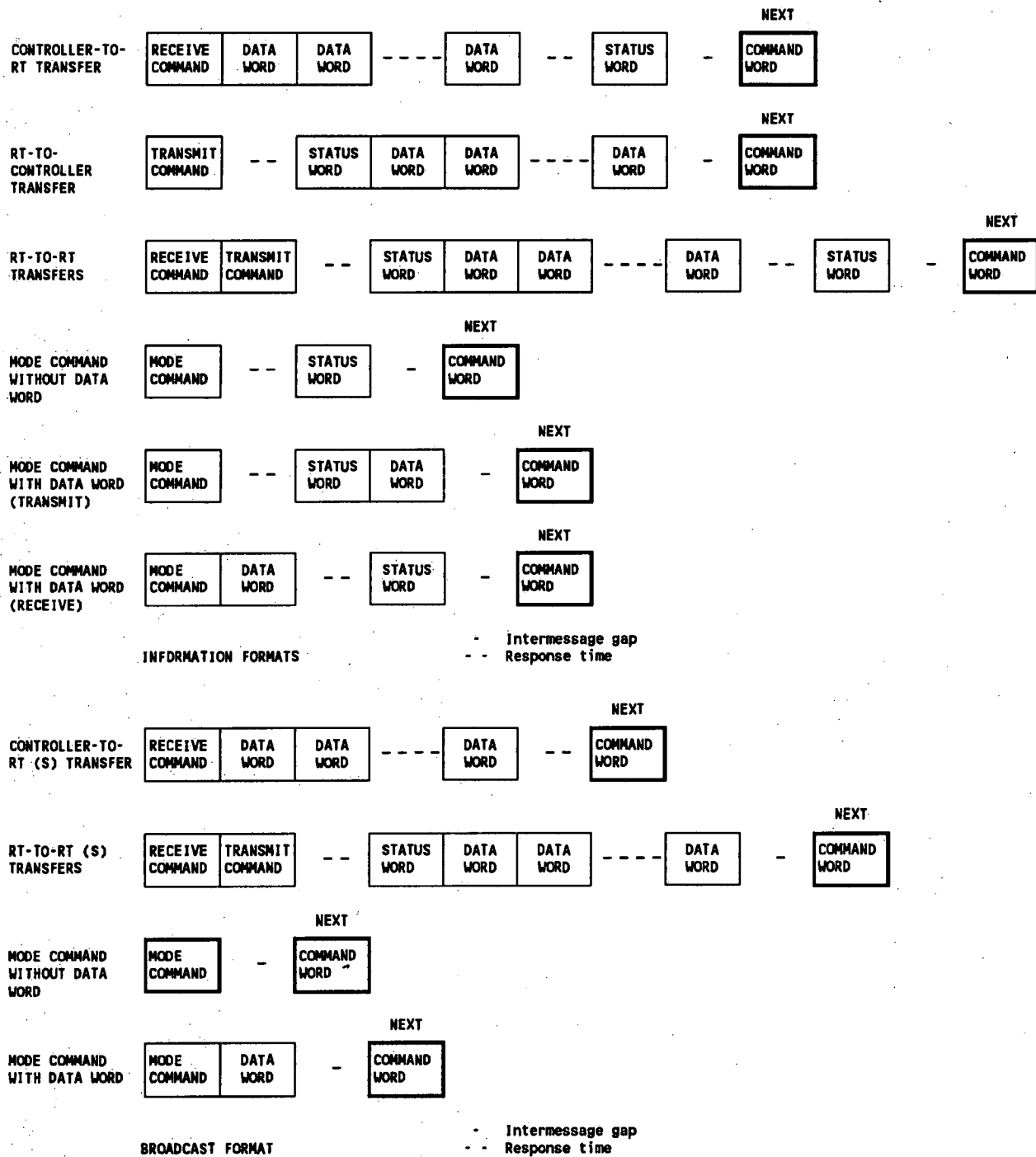


FIGURE 2—TRANSFER FORMATS

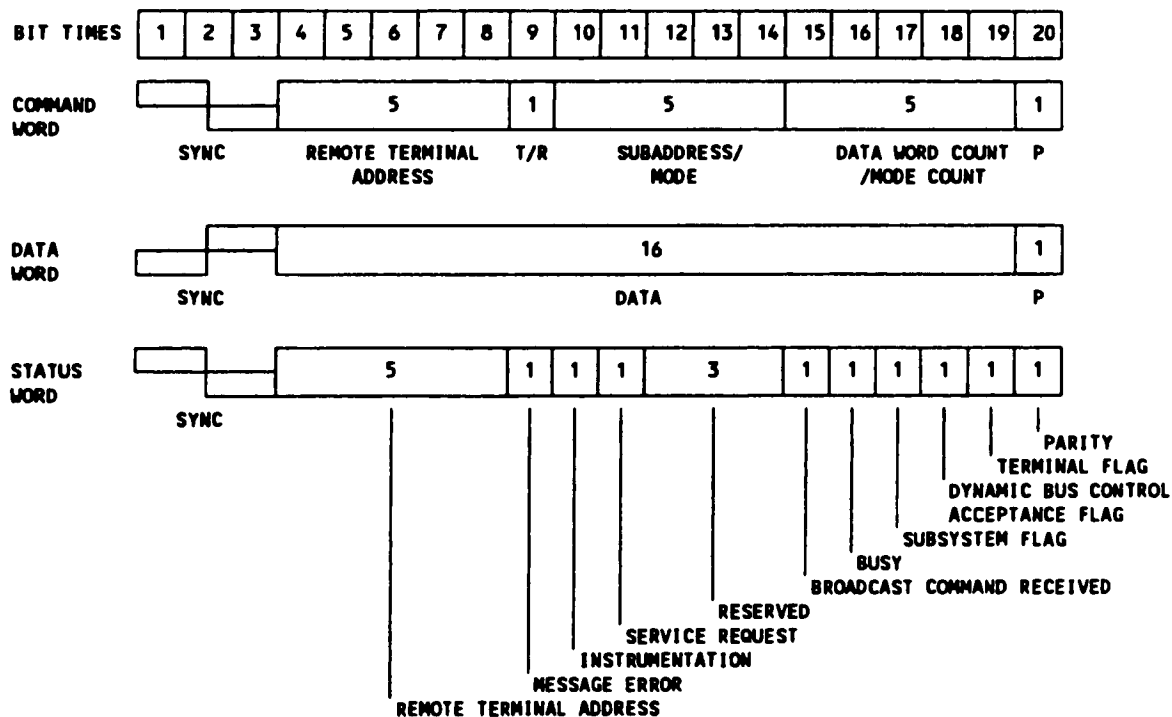


FIGURE 3—THREE PRIMARY SECTIONS OR WORDS

- b. The message validation includes—The message is contiguous. This is taken to mean within words (Command, Data, Status). The bus controller shall provide a minimum gap time of 4.0 μ s between messages, and the remote terminal will respond within a maximum response time (i.e., the remote terminal shall respond to a valid command word within the time period of 4.0 to 12.0 μ s).
- c. Additional errors identified are:
1. Message error
 2. Busy
 3. Subsystem flag
 4. Terminal flag
 5. Parity error (incorrect odd parity)
 6. Improper sync
 7. Invalid Manchester
 8. Improper number of data bits and parity
 9. Discontinuity of data words
 10. No status word response

4.1.9 FAULT TOLERANCE—Not specified.

4.1.10 DATA RATE—Maximum specified bit rate is 1 Mb/s.

4.1.11 FRAMING OVERHEAD—Message length (see Figures 2 and 3) appears to be at least 60 bits in addition to the time between Control, Data, and Status Words (which allows 4 to 12 μ s). Data Words allow 16 bits each and multiple Data Words may be used within a message. Each Data Word is 20 bits. Using the formula: $\text{OVERHEAD/MESSAGE} = \text{FRAMING} / (\text{FRAMING} + \text{DATA})$ approximate framing overhead per message calculated is $60/(60+40)=60\%$.

- 4.1.12 LATENCY—The total length for the frame is network latency which is dependent on several system factors. Framing overhead constants are included in Table 2.

TABLE 2—FRAMING OVERHEAD CONSTANTS

Constants	Bits
Command word	20
Status word	20
Response time	2-10
Intermessage gap	2-30
Mode codes without data words	20
Mode codes with data words	40
Data words	20
Non-stationary master bus controller passing	48 min

Stationary versus non-stationary bus controller systems may see different latency results.

The bus access method used may be either Master/Slave or a form of Token. In either case there are latency factors to be considered. In a master/slave system all communication goes through the master, effectively doubling overhead and/or latency. In a token system, latency is dependent in part on the number of nodes and the additional message traffic required for non-stationary master controller passing. Additionally, if the token is "lost" or nodes drop from the network, additional overhead is required for reconstructing the token ownership and/or the token passing path. Systems may be optimized through the construction of multiple paths for the token, i.e., a "fast loop" for high-priority nodes followed, by a "slow" loop which includes all nodes, followed by another "fast" loop for high-priority nodes again.

- 4.1.13 POWER REDUCTION MODE—Not specified.

4.2 Automotive Bit-Serial Universal-Interface System (ABUS)

- 4.2.1 APPLICATION/AFFILIATION—Designed for automotive applications by Volkswagen AG.
- 4.2.2 TRANSMISSION MEDIA—Not specified. Single wire suggested.
- 4.2.3 PHYSICAL INTERFACE—Not specified.
- 4.2.4 BIT ENCODING—NRZ with eight samples / bit, which means each sample is 1/8 the length of the bit. A valid bit has to have either four or six samples the same (see Figure 4). The requirement of either four or six required common samples is user selectable.



- BUS IDLE** **NC/DAT**

1	1	11	16	2
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START **IDENTIFIER** **DATA** **STOP** **BUS IDLE**

ID10	ID9	ID8	ID7	ID6	ID5	ID4	ID3	ID2	ID1	ID0
------	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

IDENTIFIER FIELD

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
-----	-----	-----	-----	-----	-----	----	----	----	----	----	----	----	----	----	----

DATA FIELD

START BIT **STOP FIELD**

STP0 **STP1**

FIGURE 5—MESSAGE FORMAT

4.2.7 **HANDSHAKING**—Negative acknowledgement by receiver after error is detected. Any receiving device that notices a protocol error notifies all other bus members by pulling down the STP1 bit. If the STP1 bit is low, the message is regarded as invalid by all members. There is no required or dedicated positive acknowledgement.

4.2.8 **ERROR DETECTION MANAGEMENT**—The transmitter and receiver monitor the bus for errors. The transmitter reads its own message back from the bus and compares it with the message that it intended to send. The receiver detects code errors by sampling the bus and by comparing the samples. Four different types of errors are monitored:

- a. **Start-bit Error**—it has not been possible to generate a start bit at the beginning of the transmission process.
- b. **Transmit Error**—during transmission the value read back was not equal to the value sent out Y times consecutively between the arbitration and STP1 bit.
- c. **Receive Error**—during reception an error has been detected X times consecutively prior to the STP1 bit.
- d. **Short Circuit**—no logical “1” has been read for a period of 256 clock pulses after a high to low transition.

NOTE—X and Y are programmable values (to 8, 16, and 32). In the present implementation these error occurrences are stored in a status register and cause an interrupt. Before they are recognized as an error, the sender tries to send a message for 8 to 32 times.

4.2.9 **FAULT TOLERANCE**—Not specified.

4.2.10 **DATA RATE**—Maximum specified bit rate = 500 Kb/s.

4.2.11 **FRAMING OVERHEAD**—The message length is 31 bits, 16 of these are data. To transmit 4 bytes of data, 2 messages must be sent. Using Equation 1:

$$\text{OVERHEAD/MESSAGE} = \text{FRAMING}/(\text{FRAMING} + \text{DATA}) \quad (\text{Eq. 1})$$

Approximate framing overhead/message calculated is: $(15+15)/((15+16)+(15+16))=48\%$.

4.2.12 **LATENCY**—The ABUS protocol uses nondestructive bitwise arbitration in contention to determine bus access. In the case of two or more nodes beginning transmission simultaneously, the message with the highest priority will win the arbitration and continue transmission. As a result, the maximum latency for the highest priority message is the number of bits in the maximum length message multiplied by the time per bit. A 31-bit message will require 64 ms at 500 Kb/s. Lower priority messages may encounter additional delay in the event that they lose arbitration. Their latency may be determined based on a statistical analysis of the system (bus load, priority, other).

4.2.13 **POWER REDUCTION MODE**—The power consumption of the ABUS IC can be reduced by using the sleep mode. In this mode, the oscillator is turned off and the power consumption is reduced to 10 to 100 μA . The sleep mode is initiated by the host microprocessor. The IC will wake up either by a reset or by bus activity, but will go through a reset in either case. After the reset it will take about 50 ms for the oscillator to work properly, e.g., the first message works as an “alarm clock”—which implies it is not received completely.

4.3 Auto Local Area Network (AutoLAN)

4.3.1 **APPLICATION/AFFILIATION**—General Instrument's Transportation Electronics Division designed AutoLAN for transportation applications.

- 4.3.2 **TRANSMISSION MEDIA**—The transmission media is a dual twisted pair. One pair carries data and idle bits from the Master to all Slaves. The second pair carries data from the Slaves to the Master.
- 4.3.3 **PHYSICAL INTERFACE**—The Physical Interface utilizes a custom 68 pin PLCC package operating at 5 V (± 0.5 V).
- 4.3.4 **BIT ENCODING**—Alternate Pulse Inversion which is a combination of Pulse Width Modulation and Pulse Inversion. Pulse Width Modulation was not used solely because a varying DC component (in the resulting signal) would not work with a transformer coupled system. See Figure 6.

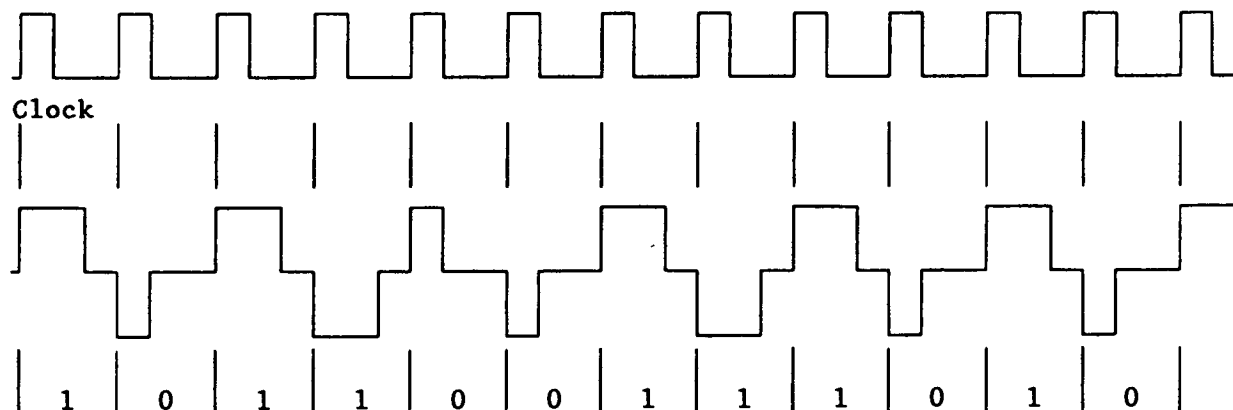


FIGURE 6—ALTERNATE PULSE INVERSION BIPOLAR DATA

- 4.3.5 **MEDIA ACCESS**—MASTER/SLAVE
- 4.3.6 **MESSAGE FORMAT**—See Figure 7. All messages have the same format.

START (1)	POLL/COMMAND (1)	ADDR (7)	DATA (16)	CRC (7)	STOP (1)
--------------	---------------------	-------------	--------------	------------	-------------

START : Unique signal
P/C : Message Type, Poll or Command
ADDR : Global or Node address
DATA : Input or Output Data, 16 inputs / 16 outputs
CRC : Cyclic Redundancy Check
STOP : Unique signal

FIGURE 7—MESSAGE FORMAT