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GUIDE TO AVIONICS DATA BUSES *

0 EXECUTIVE SUMMARY

This document details the study undertaken by ERA for the ASSC High Speed Data Transmission working group; the objective of which was to detail the functions and applications of various data buses for use in an avionics system. The data buses under consideration were selected by the working group and consist of the following:

Def Stan 00-18 (Part 2)	Serial, Time Division, Command/Response Multiplex Data Bus Standard (US MIL-STD-1553B)
Def Stan 00-18 (Part 3)	Simplex and Half Duplex Serial Digital Transmission Interface Systems
prEN 3910	High Speed Data Transmission under STANAG 3838 or fibre optic equivalent control
prEN 3758	Simplex High Speed Data Transmission System
AS 4074	SAE Linear Token Passing Bus Standard (LTPB)
AS 4075	SAE High Speed Token Passing Ring Bus Standard (HSRB)
ANSI FDDI	Fibre Distributed Data Interface
ARINC 629	Multi-transmitter data bus
IEEE 802.3	Carrier Sense, Multiple Access with Collision Detection (CSMA/CD)
IEEE 802.4	Token Bus
IEEE 802.5	Token Ring

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This report takes each data bus in turn and outlines the structure of each protocol, their strengths and weaknesses and proposes the types of system for which each data bus is most applicable. Each data bus tends to have been developed for specific application areas which may limit their use in other applications. This document can therefore be used as an aid when matching a data bus to a specific application.

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1 INTRODUCTION

1.1 Background

During the 1950s and 1960s, the electronics used on aircraft were fairly basic. Communication, navigation and weapon aiming systems were almost exclusively provided by analogue devices. Connections within systems were largely analogue voltage, switch contact or synchro-resolver in nature. Inter-system connections were kept to an absolute minimum because they were, in general, too difficult, complex and expensive to engineer.

During the 1970s, the application of digital computers to avionics offered increased computational capability and simplicity. Sensor inputs and systems receiving information from the computers, however, were still mainly analogue in nature and this led to the classical configuration of a small number of centralised computers (usually only one or two) being interfaced to the other avionic systems by complex, heavy and expensive analogue to digital and digital to analogue converters together with the necessary dedicated connections.

As systems on aircraft became progressively more digital in nature there was a consequent reduction in analogue to digital and digital to analogue conversion and, with the advent of cheaper, smaller digital computers, most, rather than some, of the systems now had a digital capability and a digital interface. Greater overall system benefits could be gained by providing one subsystem with the information contained in another, with the information passed from one to another in a digital form. Serial rather than parallel transmission of data was used to reduce the number of interconnections and the number of driver-receiver electronics, but this was still not sufficient to allow really effective connections between a number of subsystems. It became apparent to avionics designers that a multiplexed bus system was required to enable all subsystems to be connected by only one set of wires.

1.2 Need for standard interfaces

Over the last decade a rapid increase in the function, size and complexity of avionic systems led to the development of numerous non-standard data transmission interfaces for each new project. The escalating costs and development timescales associated with this approach to data transmission highlighted the need for standardization in this area.

The advent of digital avionics made this aim possible as the data transmission requirements could be more easily rationalised, enabling a common electrical interface and standard message exchange protocol based on the serial multiplex data bus technique.

Standardization was finally achieved in the UK by the adoption of US MIL-STD-1553B - Aircraft Internal Time Division Command/Response Multiplex Data Bus as Def Stan 00-18 (Part 2). In addition to the serial data bus, other classes of data transmission were identified as candidates for standardization such as the simplex and half duplex applications, discrete signal interfaces and the definition of an analogue video transmission system. These form the remaining Parts of the Defence Standard 00-18 series of Standards.

Def Stan 00-18 thus forms a complementary family of Standards covering the majority of avionics applications. Work has been undertaken to evaluate the performance of the interfaces so that potential users will have confidence that the application of one or more of these standards will result in both functional and electromagnetic compatibility (interfaces procured from independent sources should be compatible with each other and the aircraft electromagnetic environment).

Many data transmission systems are also in use within the commercial world, connecting PCs, workstations etc to shared resources like printers and file servers. These have the characteristics of standard interfaces to allow 'open' access to the resources by any equipment connected to the data transmission system. However, such systems have less emphasis placed on the timing of transfers; but more emphasis is provided on the fair allocation of resource access for all users.

Avionic systems, on the other hand, place greater emphasis on the reliable and timely transfer of information, such that greater care is taken over the connection to and specification of operation on the data transmission system. Thus, although readily available 'open' standards may be used, to ensure interoperability, the resulting systems are 'closed' to general connection. This is covered further in the Handbook of System Data Communications (Ref 1).

1.3 Objective

It is now widely recognised in the field of military avionics that as processing power increases and sub-systems evolve, there is thus an increasing need to transmit more data on the data bus which will be a key element in future avionics architectures. It will also be necessary to ensure that latency values for the data transmission are within the required deadline, and that failure to meet such a deadline is considered a system fault which may result in the failure of the mission. Many data bus protocols have been defined, some of which are intended specifically for military avionics applications. Each of these data buses have their own strengths and weaknesses, thus making some better suited than others to certain system configurations.

The aim of this report is to highlight the different factors associated with each of the data buses and to identify applications for which they are most suitable. The report can thus be used to aid the process of choosing the appropriate data bus for a particular application. The work has been funded by AES15d under the ASSC contract No AWL12C/2758 for the High Speed Data Transmission Working Group. Eleven data buses are detailed in this report; Def Stan 00-18 (Part 2), Def Stan 00-18 (Part 3), prEN 3910, prEN 3758, SAE LTPB, SAE HSRB, FDDI, ARINC 629, IEEE 802.3 (Ethernet), IEEE 802.4, IEEE 802.5. Table 1 lists the data buses under consideration and other common names by which they are known. References to these standards in this document will use the title shown in the first column.

Not all systems will benefit from higher rate data buses either because the architecture used may reduce the total amount of data that is transmitted over the system or because no increase in the total data is perceived during the lifetime of the system. Factors which must therefore be taken into consideration when determining which data bus is best suited to the intended application include the performance of the data bus; implementation issues such as cost and complexity; and the expectation that established data buses will require less development time than a data bus that operates an entirely new protocol. As processing and memory requirements become even greater, so too do the requirements associated with the data bus to ensure throughput remains at the level required by the system.

The layout of this report is such that a general overview of each of the data buses is given, followed by a section giving details of the strengths and weaknesses of each. Also included is a section describing the main applications of each data bus. Appendix 1 containing a table which summarises the main features and differences of the protocols is given at the end of the report. The description given for each data bus is that of its conventional usage. It is noted that all data buses can be modified to meet particular system requirements (eg through the addition of protocols which use the data bus transfers), but doing so may result in transfer inefficiencies, incompatibility with other systems using the same data bus and problems not previously encountered which may make commissioning as difficult as for a new data bus.

2 DESCRIPTION OF DATA BUSES

2.1 Def Stan 00-18 (Part 2) - Serial, Time Division, Command/Response Multiplex Data Bus

2.1.1 Background

Def Stan 00-18 (Part 2) (Ref 2) defines both the electrical and protocol features of a 1 Mbit/s serial data bus system. It was initially conceived to reduce the complexity of earlier avionics systems which consisted of a series of point-to-point links. By using a common mechanism whereby all information is transmitted over a single serial link, the overall complexity of implementation is minimised. The standard was initially developed by the U.S. Air Force but this was subsequently revised by the three services (U.S. Army, Navy and Airforce), the Society of Automotive Engineers (SAE) and UK participation, leading to the issue of US MIL-STD-1553B in 1978. The standard has now been widely adopted and many suppliers offer a range of equipment which meet the MIL-STD-1553B specification. The standard has subsequently been adopted as a UK Defence Standard. Def Stan 00-18 (Part 2) is technically the same as US MIL-STD-1553B but adopts accepted British terminology. US MIL-STD-1553B has also been adopted as a NATO standard (STANAG 3838AVS) and an Air Standardization Coordinating Committee (ASCC) Standard (Air Standard 50/2).

2.1.2 Description

The standard consists of a 1 Mbit/s serial data bus (a signalling rate of 2 Mbaud since Manchester II biphase coding is used) which provides communication between Remote Terminals (RTs) or between the Bus Controller (BC) and the RTs. The Medium Access Control (MAC) mechanism is described as command/response time division multiplexing (TDM), as access to the bus is only allowed by commands issued by the BC at predetermined times. The BC is responsible for the sequencing and timing of all information transfers and several techniques have been developed to determine the sequence used, generally referred to as bus transaction tables. The data to be sequenced usually consists of either regular (periodic, cyclic) traffic or irregular (aperiodic, acyclic) traffic. The rate of transmission of cyclic data is chosen to ensure that subsystems receive the data at the required update rate but also to avoid transferring data which has not yet been updated. The organisation of the bus transaction tables for the particular system must be carefully designed since it must efficiently transfer all data, thus preventing any one RT from being polled either too often or too little.

The complexity of the bus transaction table depends on the number of RTs, and the amount of data to be transferred. Some examples of typical bus transaction tables are outlined as follows.

1. Round Robin. Here each RT is polled in turn, the sequence being predetermined by the BC. A slot is allocated to each RT with spare allocation being made for growth (figure 1).
2. Binary Interval. The RTs here are polled at different intervals thus allowing for different cyclic rates for each terminal. Unoccupied polling slots are retained for expansion (figure 2).
3. Rolling Piano Key. Different polling frequencies are allocated to different functions, staggered in turn for successive RTs (figure 3).
4. Control and Service. This is a more complex polling scheme that enables RTs to be commanded to transmit only when they require service. A fast, regular control poll is made for each RT to give a status report and from this a service poll is made to undertake the service for each terminal, for instance to input or output data transfers. This complex polling scheme offers the facility to provide end to end flow control as well as error correction facilities but the additional overhead associated with the transfer of control messages leads to a reduced utilisation of the bus bandwidth for data transfers.

CYCLE	TIME SLOTS				
	1	2	3	4	5
1	RT 1 TX	RT 2 TX	RT 3 TX	RT 4 TX	SPARE
2	RT 1 TX	RT 2 TX	RT 3 TX	RT 4 TX	SPARE
3	RT 1 TX	RT 2 TX	RT 3 TX	RT 4 TX	SPARE
4	RT 1 TX	RT 2 TX	RT 3 TX	RT 4 TX	SPARE

Figure 1 Round Robin polling scheme

The RT status word can provide information about the condition of an RT. On receipt of the previous command, for example, there are flags which can be used to indicate whether there is a fault in the subsystem or a terminal.

The protocol is highly suitable for systems where the generation and transfer of data is regular in nature. The benefits of implementing a common system data bus include increased reliability, flexibility, interopretability and reduced cost.

The theoretical maximum data transfer rate is 735 kbit/s, whilst a more reasonable assessment would be 680 kbit/s.

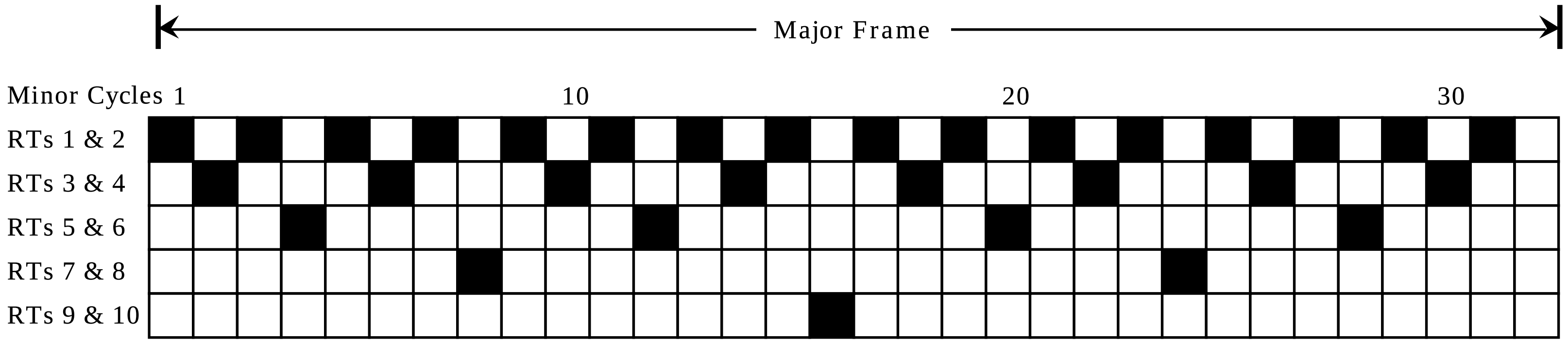


Figure 2: Binary Interval Sequencing

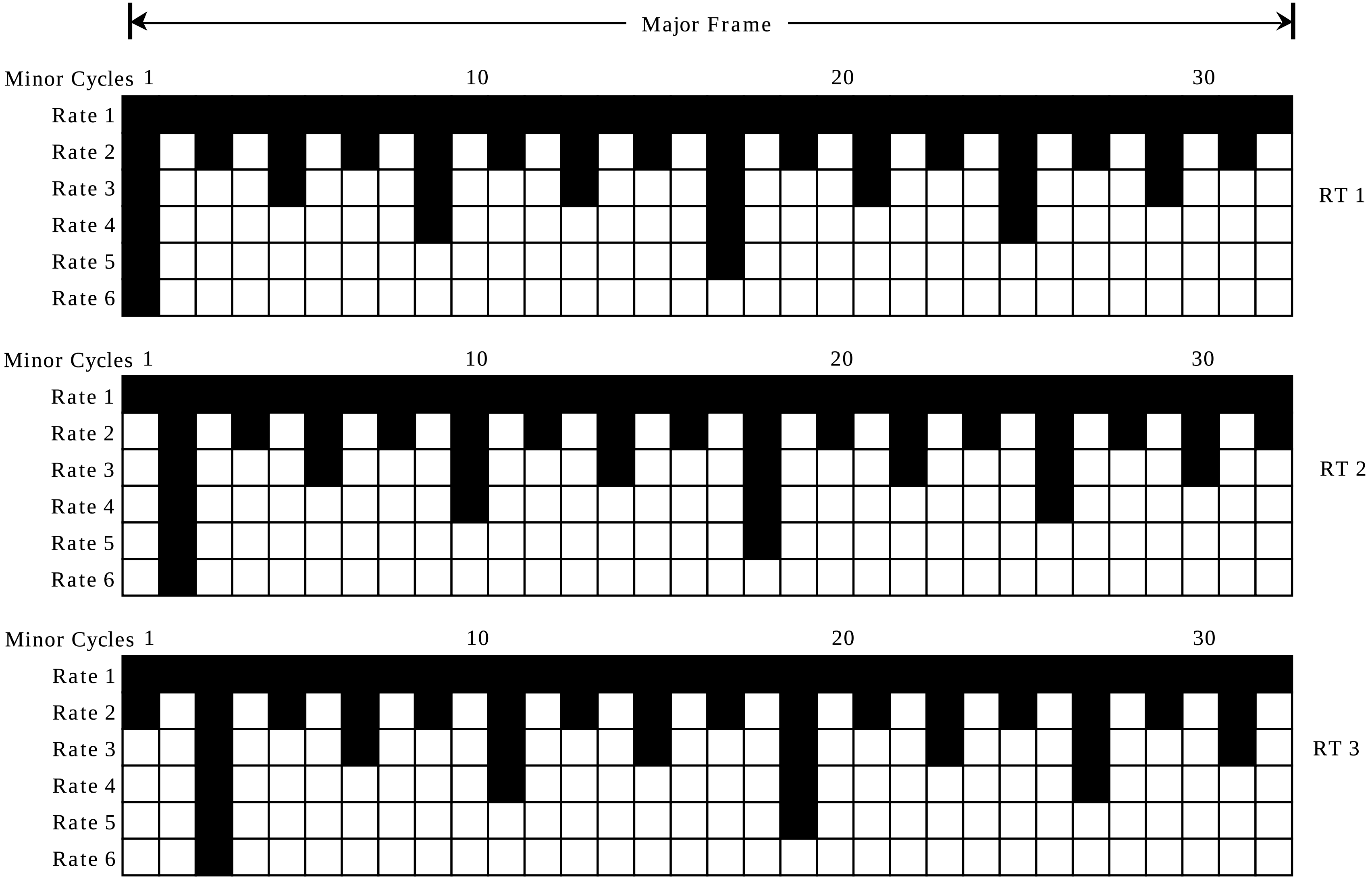


Figure 3 : 'Rolling Piano Key' Sequencing

2.2 Def Stan 00-18 (Part 3) - Simplex and Half Duplex Serial Digital Transmission Interface Systems

Def Stan 00-18 (Part 3) (Ref 3) defines a 1 Mbit/s, digital data transmission interface (a signalling rate of 2 Mbaud) in which data is broadcast from a single transmitter to one or more receivers. A point-to-point half duplex interconnection is also defined in order to provide a two way communication capability.

Part of this standard is fully compatible with Def Stan 00-18 (Part 2) since the electrical and word format characteristics are not changed. The significant difference is that data transmission is from a single source only.

The theoretical maximum data rate is 760 kbit/s, whilst a more reasonable assessment would be 725 kbit/s.

2.3 prEN 3910 - High Speed Data Transmission under STANAG 3838 or fibreoptic equivalent control

2.3.1 Background

prEN 3910 (Ref 4) is a data transmission system operating under STANAG 3838 AVS (technically identical to Def Stan 00-18 (Part 2) and US MIL-STD-1553B) control. For certain applications, STANAG 3838 AVS does not allow enough data throughput and prEN 3910 was therefore conceived to overcome some of the throughput inadequacies, whilst maintaining MIL-STD-1553B compatibility. By developing the new protocol based on existing technology and experience, development time and cost has been reduced. It should be noted that this document (Ref 4) is still in the study phase. The European Standard is being developed by Association Européenne des Constructeurs de Matériel Aérospatial (AECMA) C2/GT9 committee which will be adopted as STANAG 3910 AVS as soon as its development is completed. UK participation in this development is through the ASSC High Speed Data Transmission Working Group and BSI Technical Committee ACE/6/9.

2.3.2 Description

prEN 3910 is made up of two data buses as shown in figure 4, a high speed fibre optic or electrical bus operating at 20 Mbit/s (a signalling rate of 40 Mbaud) and a low speed electrical or optical bus operating at 1 Mbit/s (2 Mbaud). prEN 3910 uses a centralised control mechanism, in the form of a bus controller, which controls access to the high speed channel via the low speed STANAG 3838 channel. Both data buses use a broadcast medium but only stations whose address matches the destination address on the message header can copy the message. Thus data may be transmitted to many stations simultaneously leaving the bus lightly loaded, increasing the overall efficiency of the system.

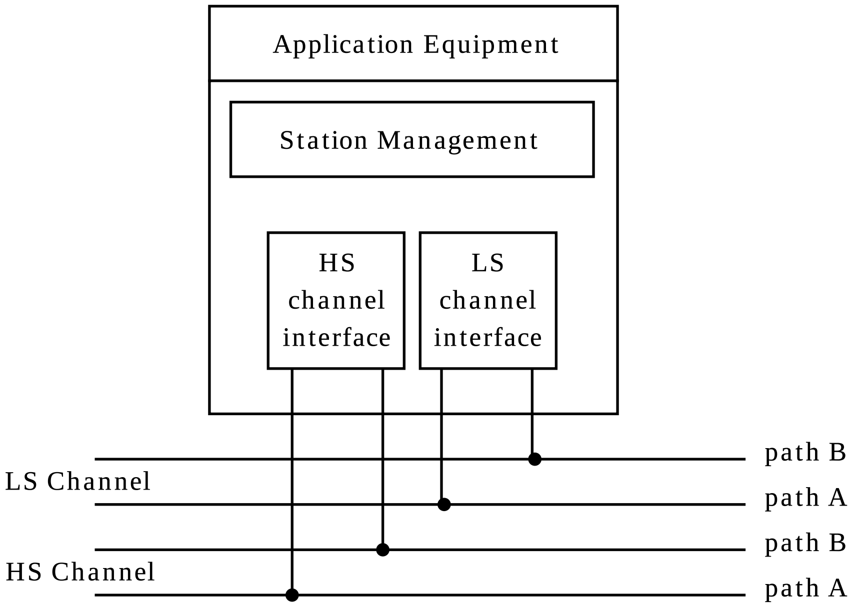


Figure 4 **High speed bus terminal diagram for prEN 3910**

There are a number of options by which message transactions can be initiated, the most efficient of which is to initiate each message transaction over the high speed bus to begin just after the previous message transaction is complete. This can be implemented by allowing sufficient time for the message transaction based on knowledge of the message size. Another option would necessitate 'listening' for activity on the high speed channel before initiating a message transaction. This will be less efficient due to the greater overhead associated with this function. In these ways, as with Def Stan 00-18 (Part 2), prEN 3910 is operated using a message transaction table, all data transfers being known in advance to make effective use of the available bus bandwidth.

An alternative arrangement, is for the bus controller to poll each terminal in the polling cycle to establish whether any terminal has data to transmit before instructing the terminal to send data. This data bus is not a token passing system (cf LTPB) since the bus controller will poll each terminal in a pre-set polling cycle instructing each terminal polled to transmit data, ie it uses similar techniques to STANAG 3838 AVS, but in effect, this does superimpose a logical ring onto the linear transmission medium (figure 5). If a terminal has data to transmit, then the bus controller will schedule the message on the high speed channel for transmission once any previous message transmissions are complete and poll the next terminal in the polling cycle. If the data takes less time to be transmitted than the time to poll the next terminal, then the high speed channel is not fully utilised since there will be a gap in transmission. If the time for message transmission is greater than the time to poll the next terminal, then messages may be continuously transmitted on the high speed channel.

A version of prEN 3910 called the EFAbus is currently being implemented on the European Fighter 2000. The main difference between these two standards is the transmission of data, which on the EFAbus is restricted to multiples of 32 words whereas prEN 3910 allows the transmission of a final block of 1-32 words. This will have an affect on overall efficiency of the data bus system but this will be minimal if the number of very short messages is small.

The theoretical maximum data rate is 19.6 Mbit/s, whilst a more reasonable assessment would be 3.2 Mbit/s.

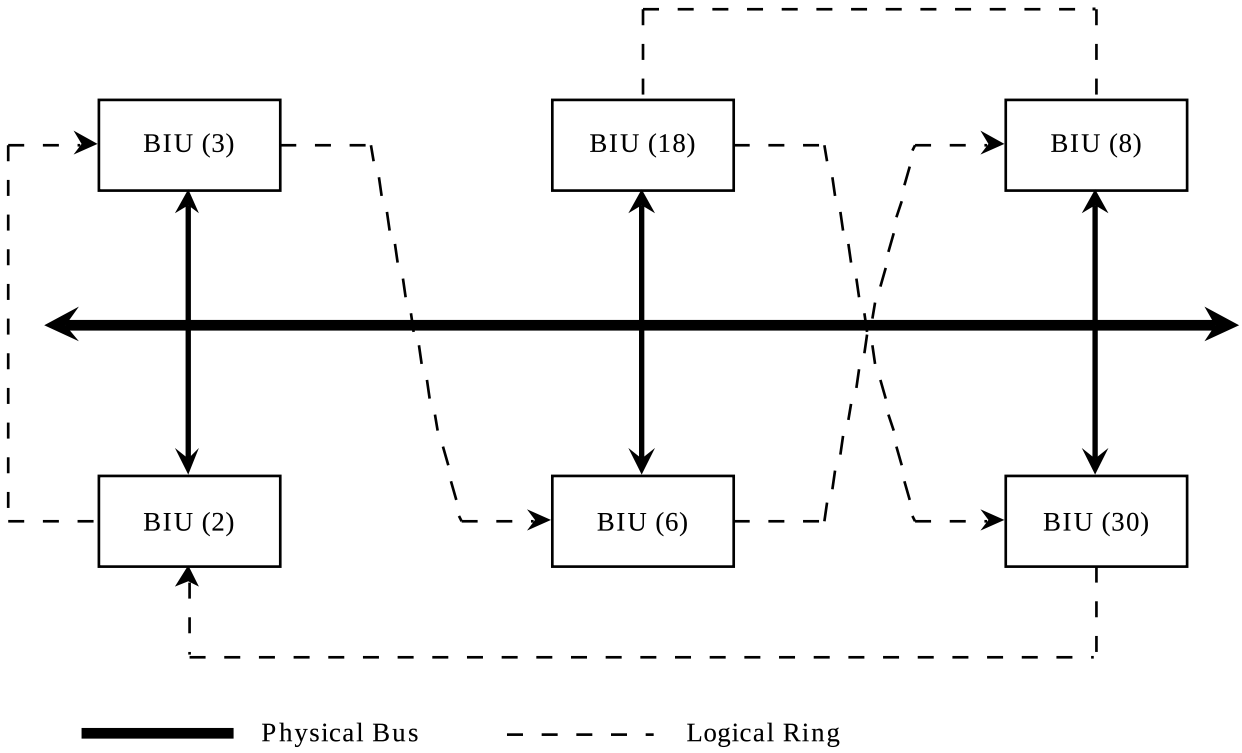


Figure 5 **SAE Linear token passing bus**

2.4 prEN 3758 - Simplex High Speed Data Transmission System

prEN 3758 (Ref 5) specifies the characteristics and requirements of a system which consists of one fibre optic or wire interconnect for data transmission from a single source. This document originated from the need to produce a separate standard for the single source option of prEN 3910; subsequently, all mention of the single source option in prEN 3910 has then be removed. prEN 3758 is being developed by AECMA C2/GT9 in the same way as for prEN 3910. The Standard adopts the paragraph numbering and wording of prEN 3910 as far as practical. NATO is to adopt the standard when development is complete as STANAG 7040 AVS.

The prEN 3758 system is intended to operate at 10 Mbit/s (20 Mbaud) or greater (initially defined as 20 Mbit/s) with only one terminal being able to transmit data to one or more other terminals on a single fibre optic or wire interconnect. Unlike prEN 3910, where the bus controller has control of the system, it is the single transmitting terminal that has control of the system. However many of the functions of prEN 3910, including fault tolerance parameters such as frame check sequence and message frame validation, are contained within prEN 3758.

The maximum theoretical data rate is 19.9 Mbit/s, whilst a more reasonable assessment would be 11.6 Mbit/s.

2.5 SAE Linear Token Passing Bus (LTPB)

2.5.1 Background

In the late 1970s, it was perceived by some members of the SAE that systems based on the use of a command/response TDM protocol would not meet the needs of new architectures being conceived for future avionics systems where more data would be transmitted via the data bus. Available civil standards that were considered included the IEEE 802.3 and 802.4 standards but none of these met stated requirements. A document developed by the SAE High Speed Bus Applications and Requirements task group (HART) was subsequently prepared which detailed the requirements for such a bus. Following this two task groups were formed, both tasked with defining data bus standards which adhered to the HART requirements document, the SAE LTPB being one of the standards which was defined.

2.5.2 Description

The SAE Linear Token Passing Bus (Ref 6) is a 50 Mbit/s (a signalling rate of 100 Mbaud since Manchester II biphase coding is used) , low latency, fault tolerant data bus suitable for real-time military and commercial applications. The standard can be applied to both wire or fibre optic implementations. A bus topology is normally assumed for a wire implementation and a transmissive star topology for a fibre optic implementation, utilising either a passive or active coupler.

The SAE LTPB uses a broadcast transmission medium, as shown in figure 5, in which all stations can receive messages transmitted on the bus. However, only stations whose address matches the destination address on the message header can copy the message. Superimposed on the linear transmission medium is a token passing path (figure 5) known as the logical ring. Unlike the token passing protocol on a physical ring, the token cannot just be placed on the bus and expect to find the next station on the logical ring. A free token is passed around the logical ring on the medium from the lowest physical address to the highest physical address and then back to the lowest. Any station which has a message to send claims the free token and transmits the message. Token passing on the SAE LTPB is handled through a "Brother's Keeper" concept; that is, each station is responsible for maintaining a valid token successor. Thus when station i has finished transmitting its message, or if it has no message to send, it must generate the token on which it appends the address of the current active successor (say, station i+j) and passes it to the latter. Stations i and i+j need not be physical neighbours. Thus the SAE LTPB protocol is similar to the IEEE 802.4 token passing bus, but has been optimised to achieve higher throughput at the given medium data rate. It also has a simple station insertion and error recovery mechanism; made possible by the fact that the maximum number of stations is limited to 128.

The Medium Access Control (MAC) protocol selected for the SAE LTPB provides bounded delay transmission for real-time applications, by means of timer controlled priority mechanisms. The protocol involves a Token Holding Timer (THT) and three Token Rotation Timers (TRT). The THT not only ensures an upper bound for the overall system token rotation time but also acts as a TRT for the highest priority messages. The TRTs are used to authorise and bound the transmission of lower priority messages from a station. Together these timers permit a station to implement a total of four message priority levels. During normal operation, each station resets its THT to the pre-programmed maximum value when it receives the token; this value determining the amount of time a station may use the transmission medium on each token visit. After a station has serviced its highest priority messages, and if time still remains on the THT, then for each priority class in turn the station loads the remaining time on the TRT (if it has not already expired) to the THT and this value is used to limit the message transmission at this priority level. The TRTs are reset to the maximum values after loading into the THT.

There will be occasions when heavy increases in network traffic cause messages in the lower priority classes to be deferred due to TRT expiration. The TRTs affected will be reset to their maximum value upon checking by the station, thus giving the opportunity for lower priority messages to be transmitted on the next token cycle. Thus the TRT scheme has the characteristics of deferring lower priority traffic corresponding to TRTs and only transmitting high priority traffic.

The theoretical maximum data rate is 49.9 Mbit/s, whilst a more reasonable assessment would be 30.3 Mbit/s.

2.6 SAE High Speed Ring Bus (HSRB)

2.6.1 Background

Like the SAE LTPB, the SAE HSRB (Ref 7) was developed from the HART requirements to meet the needs of systems requiring more bandwidth than available from a command/response TDM protocol. Available civil standards such as IEEE 802.5, FDDI, and other were considered but none met the stated requirements. The HSRB is a high bandwidth, low latency, fault tolerant real-time data communication standard based on a counter-rotating ring topology with a token passing access method providing distributed access control. It is possible to operate the protocol at any data rate since the protocol is not data rate dependent; current slash sheets define a fibre optic implementation operating at a data bit rate of 80 Mbit/s. A 4B/5B encoding scheme is used as the method of encoding data transmissions. This incurs a 20% increase in the required bit rate (i.e. signalling rate of 100 Mbauds for fibre optic media) as opposed to the 100% increase for the Manchester II coding scheme used on the SAE LTPB.

2.6.2 Description

The SAE HSRB consists of a set of stations connected by point-to-point links in a closed loop topology. Data are transmitted in messages from one station to another along each point-to-point link in a unidirectional manner around the physical ring (figure 6). Starting from the sending station (i.e. the token holding station), the message passes through the remaining stations until it returns to the sending station which removes it from the ring. The station then issues a free token. Note that when a station claims a free token, it changes it into a claimed token and appends its message behind the token as it is repeated through the stations. No additional protocol is required to control the token passing operation since token passing is sequential around a physical ring. This feature has implications not only for the time required for the token to circulate around the complete system but also for message priorities; the overhead in allowing a token to pass through stations with low priority messages to reach a station with a high priority message is negligible. This is in contrast to the SAE LTPB which uses a shared medium token protocol which must include overheads to set-up and maintain a logical ring.

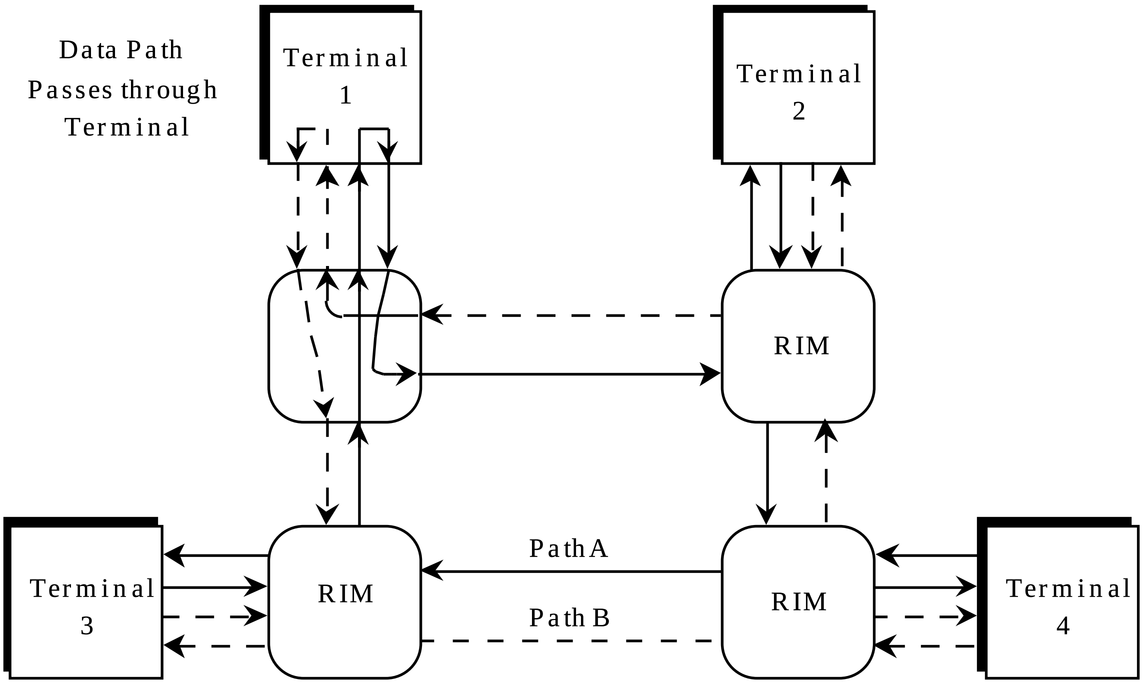
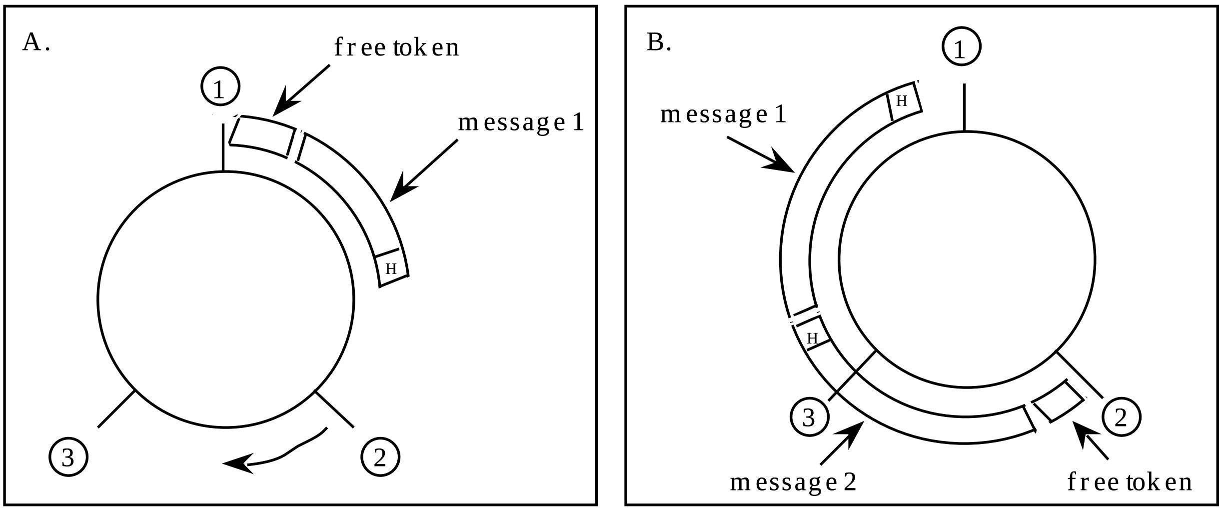


Figure 6 Dual redundant HSRB topology

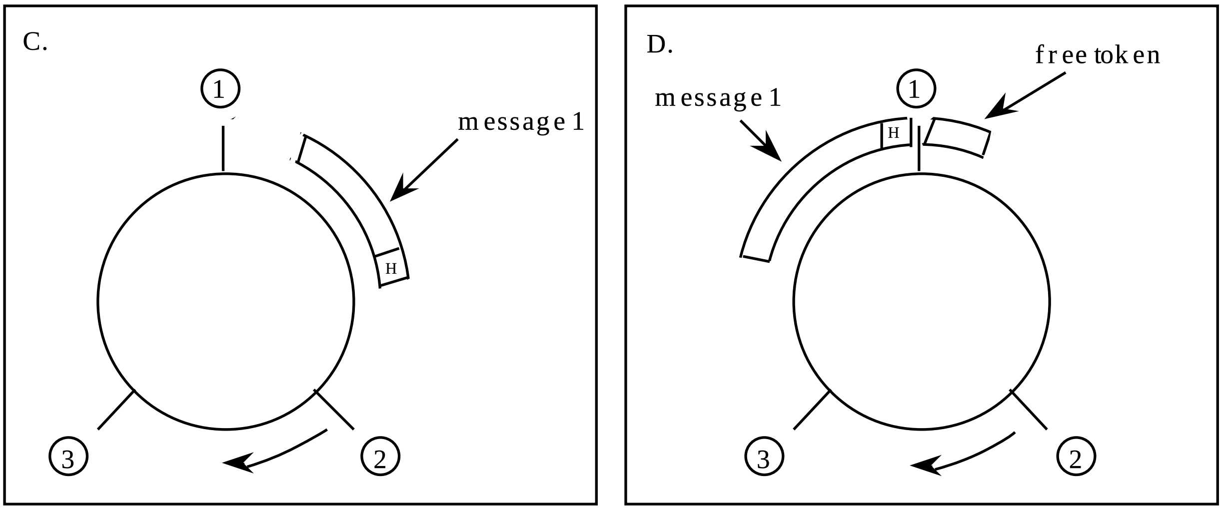
The SAE HSRB protocol use a reservation priority mechanism which allows the allocation of up to eight levels of message priority. The token format contains a reservation field indicating the next free token's priority. Stations which have messages to send can reserve the priority of the rotating token by setting its priority in the reservation field only if the station's message priority is greater than or equal to the priority in the reservation field. This ensures that the next free token is transmitted at the highest priority of any generated message on the ring (with the exception of any higher priority messages which arrive on the ring after the reservation field has been set). When a station receives the free token, only one message whose priority is equal to or greater than that of the token may be transmitted. Thus the SAE HSRB protocol operates a true message priority access method in which higher priority messages are transmitted before lower ones. This form of priority mechanism is very similar to that used in the IEEE 802.5 token ring standard, with one major difference; with the SAE HSRB protocol, priority operation is allowed to be interrupted for the transmission of up to 16 consecutive "short messages" when the Short Message Protocol (SMP) option is selected.

A short message is defined as a message transmission time which is less than or equal to the Ring Rotation Time (RRT); the RRT being made up of the transmission delay on the media together with station delays that are in the direct path of the ring. Thus transmission of a short message will be completed before the message header (with its reservation field in the claimed token) returns to the originating station for the issue of a free token as shown in figure 7. In this case waiting for the return of the claimed token before issuing a free token will waste available bandwidth. The solution adopted is to allow a station to issue a free token immediately after transmitting its short message. The cost of such a scheme is that if a station does not wait for its own message header to return before issuing a free token then the issued token cannot allocate a priority. As a compromise the SMP option is allowed to interrupt the strict priority protocol by allowing up to 16 consecutive short messages on the ring before priority order is enforced again. Thus the selection of the SMP option allows an increase in throughput of short messages at the cost of priority order while not significantly affecting latency times. As the number of active stations in the ring increases, messages become shorter with respect to the ring length, and longer short messages will be transmitted by the SMP protocol. Similarly, if higher data rates are used, short messages will become more numerous because the effective ring size increases.

The theoretical maximum data rate is 79.8 Mbit/s, whilst a more reasonable assessment would be 47.4 Mbit/s.



HSRB with SMP/FDDI



HSRB without SMP/802.5

Key

A. Station 1 transmits message 1 followed by free token.

B. Station 2 claims free token and transmits message 2 followed by free token

C. Station 1 transmits message.

D. On receipt of header of message 1, Station 1 issues a free token.

H. Header.

Figure 7 The Ring message protocols

2.7 ANSI Fibre Distributed Data Interface (FDDI)

2.7.1 Background

The FDDI is a high data rate (100 Mbit/s) fibre-optic token ring standard for second generation Local Area Networks (Ref 8). It has been developed primarily as a commercial standard by the ANSI X3T9.5 Committee which mainly consists of representatives from mainframe computer and workstation users. Similarly to the SAE HSRB, the FDDI topology is a counter-rotating ring with connections between stations being implemented as point-to-point links (figure 8). It also uses the 4B/5B data coding in conjunction with Non-Return-to-Zero-Invert (NRZI) modulation. Since this encoding scheme is 80% efficient, the FDDI 100 Mbit/s data rate will translate into a 125 Mbaud signalling rate implementation. Unlike the SAE HSRB and the SAE LTPB, the standard was designed solely to operate on fibre-optic media. However, a wire implementation of the protocol is feasible and is being investigated by a number of companies.

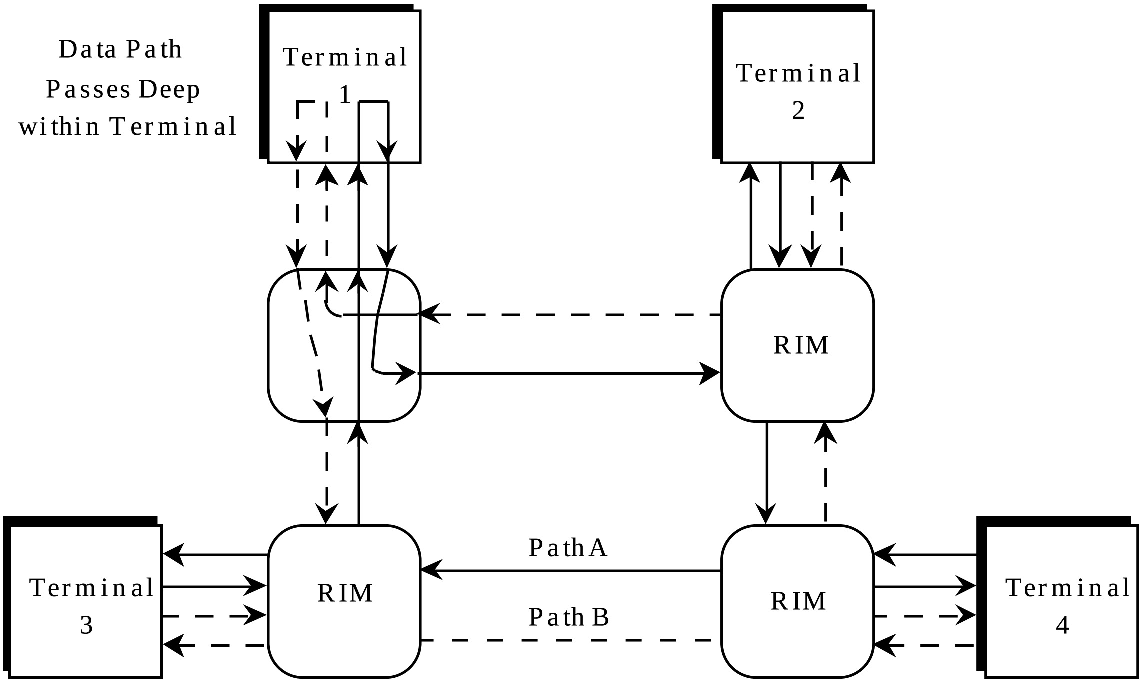


Figure 8 Dual redundant FDDI topology

2.7.2 Description

FDDI can support 500 stations over a 200 km ring length as compared to 128 stations over 3 km for the HSRB. This difference indicates that these two buses were developed for different target applications. The FDDI token ring protocol was not designed with real-time applications specifically in mind and this can be seen in the priority scheme discussed later. The protocol is in fact designed to offer bandwidth sharing in which timers within each station co-operatively attempt to maintain a specified token-rotation time by selectively regulating the amount of time a station may transmit depending on how rapidly the token progressed around the ring on the previous cycle. In this respect, FDDI allows a far greater number of stations and a larger area coverage on a single ring. Token capturing also means the complete reception of a token and its removal from the ring, followed by separate transmission of a message frame. This method of token capture is obviously less efficient (due to high station delays) than the corresponding SAE HSRB method which modifies it "on the fly", but it is easier to implement at high data rates. In the case of the SAE HSRB, the smaller number of stations and shorter ring is designed to allow the reserved priority scheme to operate effectively with station delays intentionally kept to a maximum of only 6 bits per station (with the exception of 40 bits delay at the master station) to reduce message latency. The FDDI standard allows up to 94 bits delay for each station on the ring.

This difference in station bit delay will result in higher ring rotation times for FDDI. This means that more messages will be "shorter" than the ring so than priority reservations cannot be made in the message header without severe performance penalties. Thus, as soon as message transmission is complete, the token is transmitted (figure 7A). Instead of reserving the next token priority, the FDDI protocol uses a timer controlled priority mechanism similar to that used in the SAE LTPB. The only exception is that the SAE token bus has four priority levels while FDDI has no protocol-defined upper limit on the number of priorities. FDDI operates a scheme that allows multiple message transmission per token hold in order to gain increased bandwidth advantages; this is similar to the SAE LTPB. The methods used to handle message priorities have a profound effect on the operation of the FDDI within a real-time system. FDDI uses a bandwidth sharing protocol in which token rotation timers are used to control the transmission of two distinct types of network service classes; synchronous and asynchronous. Synchronous service supports applications that have stringent requirements on message delivery time, such as real-time control and voice or video transmissions. Asynchronous service supports applications which do not have such stringent medium access requirements, or at least have time constraints which are measured in units that are large relative to the token rotation time.

Using a negotiation process, stations in an FDDI network choose a target token rotation time (TTRT). Generally TTRT is chosen to be sufficiently small that responsiveness requirements at every station will be met. The right to ring access for high priority synchronous messages is allocated among the stations in a manner such that it is guaranteed that the network capacity is not exceeded. Consequently, the token rotation time for FDDI is bounded; this bound is a function of a ring parameter, known as T_Opr, which specifies the expected token rotation time. To maintain a bounded token rotation time, the protocol forces the token to circulate with sufficient speed that all stations receive their allocated fractions of capacity for synchronous traffic. This is achieved by simply determining whether the token has rotated sufficiently fast that it is ahead of schedule (or early) with respect to the target token rotation time. An early token indicates that the ring is lightly loaded and therefore time is available for the token holding station to transmit lower priority asynchronous messages. When the free token is late, the ring is heavily loaded and lower priority messages will be deferred until the next token cycle. Thus access is guaranteed for synchronous traffic while asynchronous traffic is transmitted only if the load on the ring is light enough to support it. It is also important to note that FDDI (in a similar way to the SAE LTPB) does not operate a true priority scheme, since the order of message transmission will depend on the location of the transmitting station as well as its priority.

When the HART document was completed, the emerging FDDI protocol was examined to determine if it met the requirements and could therefore be adopted as a standard. There were several failings in the protocol at the time, particularly in reference to fault tolerance. It was therefore rejected by the SAE committee. The FDDI standard has been subsequently modified to meet some of the HART requirements for fault tolerance but no further comparisons have been made.

The basic FDDI standard provides packet-oriented services only. The extended version, FDDI-II provides an additional connection-oriented service. The time sharing of an FDDI-II ring can be sub-divided into up to 16 wideband channels for the connection-oriented service, with a capacity of 6.144 Mbit/s each. A fixed frame structure is used for this purpose; every 125 µs, a new frame is inserted by a station called a bus master. The main purpose of the FDDI-II standard is to combine voice and data onto one bus. The standard is nearing completion but there is no implementation in silicon or otherwise. FDDI-II can be considered as the FDDI protocol which defines the bus access mechanism with the additional transfer layer protocol which defines the type of connection used. It is not yet clear whether this is a limiting factor for certain applications since there are a number of transfer protocols specifically aimed at applications where there are critical latency deadlines and which may be better suited. Hence by using the basic FDDI protocol the user has a greater choice over which transfer protocol is used.

2.8 ARINC 629 - Multi-transmitter data bus

2.8.1 Background

ARINC Specification 629 (Ref 9) was developed for use in civil aircraft including use in flight control systems. It defines a digital communications system in which avionics Line Replaceable Units or sub-systems may transmit and receive digital data using a standard protocol. The standard is being developed in four parts. Part 1 is the basic OSI Physical and Data Link Layer specifications plus some information on the upper layers. Part 2 of the specification is the applications guide. Part 3 defines data standards for ARINC 629 systems and Part 4 is the test plan.

2.8.2 Description

Sub-systems are coupled to the bus by terminals which are located in each sub-system. A linear topology is used with a Carrier-Sense Multiple Access/Collision Avoidance (CSMA/CA) scheme. Bus access control is distributed amongst all participating terminals, each of which autonomously determines the transmission sequence. This is achieved by the use of bus access timers (known as the terminal gap) which are different for each terminal on the bus. These are reset and started whenever the bus goes quiet. Each terminal also has a Transmit Interval timer which limits the minimum period within which a terminal can transmit. This is reset and started when the terminal starts to transmit. When both these timers have elapsed, the terminal can access the bus. A further timer, common to all terminals, known as the synchronisation gap is used to allow resynchronisation of terminals and to determine terminal malfunction.

There are two operating modes known as Basic Protocol and Combined Protocol. The former allows either periodic (TI defines) or aperiodic (total set of transfers defines) terminal access to the bus with the ability to switch transparently between modes. The latter allows both periodic and aperiodic data to be transmitted over the bus in successive Frames.

There are three transmission media options are currently defined. These are current mode, voltage mode and fibre optic technology. A data rate of 2 Mbit/s (4 Mbaud using Manchester encoding) is defined for current mode operation and up to 120 terminals are allowed on the bus. As in Def Stan 00-18 (Part 2) the basic information element is the word which is twenty bit times in length. Data uses sixteen of these bits, three are used as a sync pulse and the final bit is used as a parity check. Words are assembled into wordstrings which contain a label word with channel information and data labels for addressing. This is followed by an optional word containing a word count; there is no word count facility at the lowest level. The specific formats of the message structure are defined in Part 3, 'Data Standards' of the specification.

2.9 IEEE 802.3 - Carrier Sense Multiple Access/Collision Detection (CSMA/CD) standard

This standard (the same as ISO 8802/3) is a carrier sense multiple access/collision detection (CSMA/CD) local area network. If a station wants to transmit data, it first 'listens' to the data bus to determine whether there is any activity. If the data bus is busy, the station must first wait until it goes quiet before transmission, otherwise the station can transmit immediately. If two or more stations simultaneously begin transmitting on an quiet data bus, the messages will collide. All stations transmitting the colliding messages reinforce the situation by sending a 'jam' command, then terminate their transmission, wait a random time, and repeat the process of transmission again. Ethernet is a standard for a 10 Mbit/s CSMA/CD data bus whereas IEEE 802.3 covers a whole family of systems, running at speeds from 1 to 10 Mbit/s on various media.

The prime limitations of this data bus for use in an avionics environment is that media access is not deterministic. In effect this means that a station wanting to transmit data does not know when it will gain access to the data bus. When lightly loaded (<20%), this does not prove to be a problem, since the terminal is likely to be able to transmit at its first opportunity. However, as the loading increases, more collisions occur and a terminal may 'back off' more than once. There is no priority mechanism in the protocol, however it may be possible to adapt the 'back off' time when there is a collision of messages. Messages with a higher priority can be given a shorter wait time.

2.10 IEEE 802.4 Token Bus standard

This standard (the same as ISO 8802/4) is a token bus system in which all stations are physically attached to a linear bus with each station knowing the address of the next station and the previous station in the logical token ring (see figure 5). As with the SAE LTPB, each station can only transmit data when it is in possession of the free token. Once a message has been sent, the token is passed to the next station in the logical ring. The data bus is a broadcast mechanism, thus each station receives each message, discarding those not addressed to it. This protocol has up to four priority levels, access of each priority message is dependent on timers. The operation of this priority system may limit the usefulness of this protocol for real-time systems but many of the features of this standard are included in the SAE LTPB. Standards are defined for 1 - 10 Mbit/s.

2.11 IEEE 802.5 - Token Ring standard

The protocol of this standard (the same as ISO 8802/5) has similarities with the SAE HSRB Both are a series of point-to-point links connected to form a ring. A station may transmit a message when it has the free token in its possession. When the station has completed its message it passes the token to the next station on the ring once the message header has returned (see figure 7D). The station can hold the token and transmit data for the 'token holding time' before it must release the token. The protocol defines a scheme for handling priorities which is similar to the SAE HSRB without SMP. Stations make a reservation in the token header if the header is of a lower priority. The station that makes the reservation must then lower it when it has claimed the token. The protocol contains a number of features which allow the data bus to reconfigure in the event of station failure or a lost token.

This Standard has been adopted as a ISO Standard 8802/5 and has been used as the basis of the IBM token ring and SAFENET I standards. The ISO standards define data rates of 1 and 4 Mbit/s, whilst SAFENET defines data rates of 4 and 16 Mbit/s.

3 STRENGTHS AND WEAKNESSES

Each of the data buses considered in this report were developed with particular types of application in mind; only some of which were avionic. When designing an avionic system, the strengths and weaknesses of each data bus must be considered before any decision can be made regarding the most suitable candidate. One critical factor is whether the performance of the data bus meets the specification for the system. This may not be simply the peak performance of the data bus but may consider whether the data bus operation is adequate to enable the system to perform within given margins.

Other criteria which may need to be considered include: latency determination, interface power dissipation, interface size, data transmission system weight, system operation (periodic/event driven), fault tolerance, failure modes, growth capability, cost, VLSI interface availability, previous experience, EMC performance and fibre vs copper considerations.

Def Stan 00-18 (Part 2), prEN 3910, Def Stan 00-18 (Part 3), prEN 3758 and ARINC 629 have been designed for application in multi-sink systems where data transmission is primarily regular (periodic) in nature. Much of the data is also predictable in advance, hence the bus transaction tables can be designed to enable highly efficient use to be made of the available bus time.

Def Stan 00-18 (Part 2) has been widely implemented both in the field of military avionics and industrial applications. This protocol therefore has the advantage that it has been extensively tested and equipment is available from many different suppliers.

Def Stan 00-18 (Part 2) and Def Stan 00-18 (Part 3) both have the lowest bit rate, 1 Mbit/s. Additionally, the protocol of Def Stan 00-18 (Part 2) only has limited extensibility because of the operation of a fixed (small) address structure. Therefore, as the requirements imposed on the system become greater this protocol will only be of limited use.

prEN 3910, is being developed as a means for growth from Def Stan 00-18 (Part 2) to overcome the data rate and size of message. prEN 3910 operates using a broadcast bus with the Def Stan 00-18 (Part 2) protocol for control enabling current technology and equipment already developed to be used. As with Def Stan 00-18 (Part 2), this standard does require a message transaction table; terminal access is allocated prior to system start up. It is possible to allocate some time to message transactions which have not been pre-allocated but this will incur additional overheads through the use of the Def Stan 00-18 (Part 2) control bus. prEN 3910 only has limited extendibility since access to the high speed channel is limited by the use of the Def Stan 00-18 (Part 2) protocol. Increasing the speed of operation of either channel will have only limited effect since the overheads associated with the command/response protocol will predominate.

The SAE LTPB, SAE HSRB and FDDI operate at much greater data rates than Def Stan 00-18 (Part 2) and prEN 3910, thus making them more appropriate to systems in which there is a need to transmit increased amounts of data on the data bus. The two SAE buses were conceived for application to military real time avionics, particularly those systems where hard message deadlines exist. These two data buses therefore offer a priority scheme where data considered more vital to the success of a mission will be given greater access to the data bus. The token reservation protocol makes it possible for the SAE HSRB to operate a true priority scheme where messages with the highest priority are transmitted ahead of those messages with lower priorities. The SAE LTPB also offers a priority scheme, but because of the nature of the bus structure true priority separation is not achieved, due to the dependence on timers to allocate bus access. Hence the situation may arise where many messages with a lower priority are transmitted ahead of messages with a greater priority. The priority scheme used by the SAE LTPB is limited by the use of timers. With this priority scheme, it is evident that a station which has a high priority message to send cannot prevent the transmission of lower priority messages from stations ahead of it in the logical ring, except when the maximum throughput level of the lower priority has been reached. Thus the SAE LTPB priority scheme is inherently inconsistent (or non-deterministic). That is, the strict ordering of priority levels is not maintained, unless the network is heavily loaded but latencies can be limited. The same is true for FDDI.

The SAE LTPB, SAE HSRB and FDDI have the disadvantage that none of them have been used as part of any military programme and chip sets are only just becoming available, thus limiting the amount of equipment available for these protocols that meets military specifications. The SAE LTPB protocol uses a broadcast bus structure, thus allowing knowledge gained in implementing this type of system to be used here. This has the advantage that it is similar in concept to Def Stan 00-18 (Part 2) and STANAG 3910 and would therefore allow a more natural progression to these much higher rate data buses. It is noted that the prEN 3910 frame structure is the same as for the SAE LTPB.

There are also high overhead problems associated with the linear token bus network. High overheads arise from the management of a logical ring and the control of token passing. Every station is required to generate and pass the token whether it has a message to transmit or not. This high overhead may affect the delay and throughput performance of the network. However, this will only be a problem if it results in data failing to achieve the required target latency value. Additional overhead problems relate to the network reconfiguration and station insertion procedures and the token regeneration procedure considerably affects the network response time and destroys the upper-bound transmission delay property. When a station passes a token to its successor it must listen to the channel for a predefined transmission time. If no transmission is received after the time-out period, the station is required to repeat the transmission. If no transmission is received after the second time-out period, the station passes its token to the station following its successor in the logical sequence. Furthermore the use of timers which govern the token hold time poses additional problems associated with setting them and the affects of timers when the total load on the system changes.

FDDI is currently defined to operate at the greatest data rate of all the data buses under consideration. As with the SAE LTPB protocol, it uses a timer mechanism to control access to the data bus. In FDDI, data is either synchronous or asynchronous. Asynchronous data can be sub-divided further giving some bandwidth allocation to make priorities, but this will make the setting of timers and priority allocation of messages more difficult. As with the SAE LTPB protocol, the use of timers does have an affect on the overall throughput and efficiency of the system when the data loading is changing. It may be necessary in an avionics system to be able to have different timer settings for different phases of the mission, but this has not yet been tried.

ARINC 629 has been specifically developed for applications involving civil aircraft where the emphasis on the features of the data bus are different from those in a military avionics data bus. For example the data rate on ARINC 629 is only 2 Mbit/s compared with 50 and 80 Mbit/s used by the SAE high speed data buses. The fault tolerance mechanism on ARINC 629 is limited; there are no explicit provisions for a dual redundant data bus system. If multi-redundancy is required, a practical method is to implement two or more data buses which carry out all transactions simultaneously. Redundancy issues are a higher system level consideration. In a civil aircraft, most data is regular in nature and there is less need to be able respond to a critical message within a very short period. In a military environment, failure to respond to a high priority message with a set deadline may result in mission failure. However, no co-operation is required between the terminals in order for a terminal to determine when it should transmit (autonomous operation). ARINC 629 also considers the reliable operation of the terminals as imperative such that dual monitored protocol engines are part of the definition. For these reasons, it is considered a prime candidate for flight control systems.

ARINC 629 only has a limited implementation of priorities. The protocol requires a predefined table which specifies all the message transactions that are to take place from each terminal. Some data can be transferred without prior arrangement, but this reduces the efficiency and increases latency values of the data.

The IEEE data buses are all designed for either industrial or commercial applications; one major weakness in applying them to military avionics platforms are their fault tolerant capabilities which are limited; in the case of IEEE 802.5, this limitation has been addressed by the development of SAFENET I. Further, data transfers are not deterministic in thatthe priority schemes do not guarantee latency times of messages. It should be noted that the French Navy have developed a deterministic Ethernet protocol which does offer some guarantee of data transfer but this protocol has never been ratified as a standard. They do, however, offer commercial support, all three data buses are widely used in the commercial and industrial field.

4 APPLICATIONS AND TIME SCALES

Def Stan 00-18 (Part 2)/US MIL-STD-1553B is currently being implemented widely in military avionics systems and there are many items of equipment available which meet the standard. A version of prEN 3910 is being used on EF 2000 since it offers a greater throughput than Def Stan 00-18 (Part 2). Although FDDI also has a greater throughput than Def Stan 00-18 (Part 2), it was not possible to use this protocol when EF 2000 was initially being developed because it was believed that the implementation of FDDI would not meet the timescale of EF 2000. It was considered that prEN 3910 could be developed within the required timescale and would meet the performance criteria required by EF 2000 since it offers a high speed channel for data transfers.

The SAE LTPB cannot be considered as a current technology data bus since it has not yet been used on any military platforms. This standard forms the basis of JIAWG (Joint Integrated Avionics Working Group) data bus standard. The standard is being used on the US F-22 aircraft and the RAH-66 Comanche helicopter programme. A single contractor is supplying components for both programmes but components for the LTPB are also being developed by others.

Unlike the SAE LTPB, the SAE HSRB has not been proposed for any military programme. A chipset was developed in the US to comply with the standard, but the programme has been beset with delays and the outcome is still uncertain. The current slash sheets offer a fibre optic implementation of 100 Mbaud but, due to the ring structure used by this protocol, the data rate can be increased. Slash sheets for 250 and 400 Mbaud have also been proposed. This standard therefore has an attractive development route to higher performance variations and, as processors become more sophisticated and the requirements on the data bus increase, this protocol could emerge as an effective solution.

The ANSI FDDI protocol is principally a commercial standard and has been adopted in at least 3 commercial applications, particularly for the interconnection of local networks. Chipsets have been developed and although they implement most features of the standard, the implementation of the asynchronous priority mechanism does not allow subdivision into any lower priorities.

Unlike the majority of the data buses which have been developed specifically for avionics systems, FDDI has been developed primarily as a commercial standard and as such has been biased towards transmitting large volumes of data between mainframe computers and workstations. FDDI chipsets are being built to meet military specifications and the standard has been adopted by the US Navy as part of the SAFENET II programme. It is also being examined as part of a feasibility study by the UK Navy for use on-board submarines.

FDDI does have a high throughput with guaranteed latency values, but its applicability to military avionics will be limited in situations where there are many events in the system and a number of these events are critical; for example in a battle situation it will be necessary for the aircraft to be able to deploy weapons as well as manoeuvre the aircraft.

ARINC 629 is currently being developed as a standard to enable implementation of a data bus on civil aircraft to take place in the near future. This data bus is not considered applicable to military platforms due to its rigid message schedule. In a military environment there may be changes in operational mode which require urgent and unscheduled attention eg due to battle damage, missile warnings, etc necessitating different sets of data to be transferred.

IEEE 802.3 is widely used in commercial applications for the interconnection of systems in a technical or office environment. IEEE 802.4 and 5 are used in industrial environments. These data buses have not been developed for military applications and therefore to not have the necessary fault tolerant features required for military applications in which there exist critical events.

Table 2 provides an indication of the use of the standards in current systems. Table 3 gives an overall summary of the applications of each data bus.

Interface standard	Application
Def Stan 00-18 (Part 2) technically identical to US MIL-STD-1553B and STANAG 3838 AVS	Torando, Harrier GR5 & 7, M1A1 tank, B1-B, AH-64A, F-16, F-18, C-17A, EH101, EF 2000, Lynx Mk8, Rapier, Challenger tank, and universal applications across western military avionics projects and on the US space station
Def Stan 00-18 (Part 3)	EF 2000
prEN 3910	EF 2000, Rafale
prEN 3758	EF 2000
LTPB	Similar on F-22 , RAH-66, and on the US space station
HSRB	Unknown
FDDI	Numerous commercial, non-avionic naval platforms, and civil aircraft on-board LAN
ARINC 629	Boeing 777 and other civil aircraft projects
IEEE 802.3	Numerous commercial but non-avionic
IEEE 802.4	Numerous commercial but non-avionic
IEEE 802.5	Numerous commercial but non-avionic

Table 2 Indications of interface standard application to current systems

Databus	**Applications**
Def Stan 00-18 (Part 2) technically identical to US MIL-STD-1553B and STANAG 3838 AVS	Systems in which data is principally of a regular and/or periodic nature and having a relatively low overall capability of less than 1 Mbit/s.
prEN 3910	Systems in which data is principally of a regular and/or periodic nature and having a relatively low overall capability of less than 10 Mbit/s.
SAE Linear Token Passing Bus Standard (LTPB)	Systems where the data may not be regular but for which the data transfer must be fully deterministic. Data capacity less than 50 Mbit/s.
Fibre Distributed Data Interface (FDDI)	For commercial business systems. Data capacity is less than 100Mbit/s.
SAE High Speed Token Passing Ring Bus (HSRB)	Systems where data may not be regular but for which the data transfer must be fully deterministic. Data capacity less than 80 Mbit/s.
ARINC 629	For civil airline systems. Has similar throughput capabilities to Def Stan 00-18 (Part 2). Data capacity less than 2 Mbit/s. No bus control as control is distributed among terminals
IEEE 802.3	For commercial business systems. Data capacity less than 10 Mbit/s.
IEEE 802.4	For industrial and commercial business systems. Data capacity less than 10 Mbit/s.
IEEE 802.5	For industrial and commercial business systems. Data capacity less than 4 Mbit/s.

Note: The effective throughput of data is typically 50% of the given data rate of the bus.

Table 3 : Applications for which data buses are designed

5 CONCLUSIONS

The non-exhaustive collection of data buses that have been described in this report are all considered to be applicable to avionics applications. Def Stan 00-18 (Part 2), Def Stan 00-18 (Part 3), prEN 3910 and prEN 3758 are all current technology protocols and are presently being incorporated in aircraft projects where data loading in the bus is expected to be at least 500 kbit/s. The SAE LTPB and SAE HSRB are not considered as current technology protocols since they all operate at much greater data rates and are therefore prime candidates for future generation of aircraft where it is conceived that as processing speeds increase so too will the requirements on the data buses. The critical feature of future generations of aircraft will be the ability of data to meet hard deadlines. Therefore the requirement to transmit data in real-time rather than in quantity will be an important factor. Def Stan 00-18 (Part 2), Def Stan 00-18 (Part 3) and ARINC 629 are generally considered to be low speed protocols since the first two operate at 1 Mbit/s and ARINC 629 at 2 Mbit/s. Increasing the data rate on these protocols will only provide limited increase in throughput due to the nature of the protocol and the overheads associated with data transfer. ARINC 629 has been included in this report because it is a data bus which, although originally developed for civil avionics applications, could conceivably be used for military applications. prEN 3910 offers increased bandwidth by using a 20 Mbit/s high speed channel. Although performance of this protocol is much greater when compared to Def Stan 00-18 (Part 2), this increased data transmission rate provided is subject to restrictions due to the need for Def Stan 00-18 (Part 2) protocol to control access the high speed channel.

The SAE LTPB and SAE HSRB were both developed for military real-time avionics systems. Both protocols offer extensive redundancy and fault tolerance mechanisms and high data rates. The SAE HSRB offers greater throughput and efficiency characteristics than the SAE LTPB. This may be critical for situations where the data bus is being fully utilised; for example in an emergency situation when parts of the system become damaged. The priority mechanism operated by these two protocols is also quite different; the bus structure of the SAE LTPB protocol uses a timer mechanism to control access to the bus, whereas the ring structure of the SAE HSRB protocol enables a round robin approach to be taken where a priority reservation scheme is used. This prevents messages of a lower priority from being transmitted ahead of messages with a greater priority.

The FDDI protocol was developed as a commercial standard intended for use principally in resource sharing applications. Due to its very high data rate, fault tolerance facilities and priority implementation, it has been adopted for use in military programmes for the US and UK Navies. The protocol does have higher overhead values associated with token passing when compared with the two SAE buses, a factor which generally increases latency values.

The IEEE 802.3,4 and 5 protocols are all principally designed for industrial or commercial applications. They have lower data rates (less that 10 MBit/s) than the data buses specifically designed for military avionics use (for example the SAE LTPB which has a data rate of 50 MBit/s). While they are less robust as they fail to relate how to handle fault tolerance, this does not preclude their use in multi-redundant systems for applications requiring a high degree of fault tolerance .

From this discussion of the advantages and disadvantages of the various data bus systems, it must be concluded that the application requirements must determine the data bus to be used; a single data bus cannot be recommended which is the best choice for all systems. Limiting the scope of data bus choice to those previously used or being considered by others goes a long way towards the benefits of a single choice (interoperability), whilst maintaining the ability to choose a data bus commensurate with the system requirements (ie no gold plated sledgehammers to crack nuts). Ultimately, the choice of the network may be driven more by technology intangibles, such as cost, failure rates and weight, than by the theoretical means and rate of data transfer.

6 GLOSSARY

6.1 Definitions

4B5B Encoding	An encoding method whereby four information data bits are encoded into five-bit symbols.
Bandwidth	The carrying capacity of a network, usually measured in bits per second for digital circuits, or Hertz for analogue circuits.
Connectionless service	One in which the data and parameters for the transfer are provided by the user for each transfer.
Connection oriented service	One in which the parameters for a series of transfers are given before any data is passed and thereafter the user provides data only.
Data rate	The speed at which bits are transmitted and received, usually measured in bits per second.
Deterministic	Property of an item to which the future behaviour can be predicted precisely.

Efficiency	The percentage ratio of the number of data bits to the total number of transmission bits (including overhead).
Fault Tolerance	Capability of the system to endure component errors and/or failures without causing total system failure. Actions range from ignoring it, to retrying action, to complex actions of fault isolation and then taking positive action to continue operation without the failed component.
Flow control	The ability to limit the rate at which a terminal can transmit data.
Full duplex communications	A simultaneous, two-way communications path.
Half duplex communications	An alternating transmission path, two ways, but only one direction at a time.
Latency	A measure of time delay.
Manchester II encoding	A way of encoding to get a zero-DC binary waveform. In this encoding scheme, half of the bit interval is transmitted with a positive signal and the other half is transmitted with a negative signal.
Overhead	Non-data bits or characters necessary for transmission, error detection or for use by protocol.
Packet	A block of data, including addressing, routing and numbering information. Very long messages may be segmented into packets for transmission over the data transmission path.
Protocol	A set of related rules describing specific processes or activities.
Signalling rate	The speed at which data bits and overhead bits are transmitted sometimes referred to as Baud rate.
Simplex communications	A one direction communications path.
Throughput	A measure of the effective network transmission speed, it is the net bandwidth of a network.

7 REFERENCES

1. Society of Automotive Engineers (SAE), Handbook of System Data Communications (AIR4271).
2. Def Stan 00-18 - Avionic Data Transmission Interface Systems (Part 2) - Serial, Time Division, Command/Response Multiplex Data Bus Standard
3. Def Stan 00-18 (Part 3) Simplex and Half Duplex Serial Digital Transmission Interface Systems.
4. prEN 3910 High Speed Data Transmission under STANAG 3838 AVS or fibre optic equivalent control.
5. prEN 3758 -Simplex High Speed Data Transmission System.

6. Society of Automotive Engineers (SAE), Linear Token Passing Multiplex Data bus Standard (AS4074).

7. Society of Automotive Engineers (SAE), High Speed Ring Bus Standard (AS 4075).

8. Draft International Standard ISO/DIS 9314-1 3 parts Information Processing System - Fibre Distributed Data Interface (FDDI).

9. ARINC Specification 629 Multi-transmitter data bus.

10. IEEE 802 Standards
    - 802.1 High level interface
    - 802.2 Logical link control
    - 802.3 Carrier Sense, Multiple Access with Collision Detection (CSMA/CD)
    - 802.4 Token bus
    - 802.5 Token ring

11. Further information that is available for interface standards

Def Stan 00-18 (Part 2)	Def Stan 00-18 (Part 1) Section 2 - Guide to the Serial, Time Division, Command/Response Multiplex Data Bus Standard US MIL-HDBK-1553A
Def Stan 00-18 (Part 3)	Def Stan 00-18 (Part 1) Section 3 - Guide to the Simplex and Half Duplex Serial Digital Transmission Interface Systems Standard
prEN 3910	Handbook for prEN 3910
prEN 3758	None
LTPB	SAE Aerospace Information Report (AIR) 4288
HSRB	SAE AIR 4289
ARINC 629	None
IEEE 802	None

A review of data interface standards for avionic applications
(ASSC publication ASSC/110/2/42)

Data bus	FDDI	ARINC 629	802.3	802.4	802.5
Media	FO (maybe wire)	FO	wire	wire	wire
Access Mechanism	token	CSMA/CA	CSMA/CA	CSMA/CA	CSMA/CA
Data rate (Mbit/s)	100	2	1 - 10	1 - 10	1, 4
Bandwidth share mechanism	timers	pre-set and using timers	NONE	timers	timers
Encoding	4B 5B	Manchester II	Manchester II	Manchester II	Manchester II
No. of terminals Max.	500	120	7×10^{13}	7×10^{13}	
Max no of words	4096	64000	1500	8182	
Word size	16	20	8	8	
Level(s) defined	Physical, media access and station management	Physical and media access only	Media access	Media access	Media access

Appendix 1 : Main features of the data bus protocols

APPENDIX 2 DATA RATE DETAIL

The following indicate how the 'theoretical' and 'reasonable' data rates were arrived at. The approach is based on defining how long it takes to transmit a maximum length message or 16 words (reasonable assessment), including overheads of command words, token transmission etc. (Note that the detail for the IEEE and FDDI Standards is not included.)

A.2.1 Def Stan 00-18 (Part 2) - Serial, Time Division, Command/Response Multiplex Data Bus

This makes use of 20 bit Command, Status and Data words, a 12 µs terminal response and a 4 µs intermessage gap.

$$\text{Time to transmit Max data} = \frac{20 + 33\text{x}20}{1\ \text{Mbit/s}} + 12 + 4 = 696\ \mu\text{s}$$

$$\text{Max Rate} = \frac{32\text{x}16}{696\ \mu\text{s}} = 735\ \text{kbit/s}$$

$$\text{Time to transmit Reasonable} = \frac{20 + 17\text{x}20}{1\ \text{Mbit/s}} + 12 + 4 = 376\ \mu\text{s}$$

$$\text{Reasonable Rate} = \frac{16\text{x}16}{376\ \mu\text{s}} = 680\ \text{kbit/s}$$

A.2.2 Def Stan 00-18 (Part 3) - Simplex and Half Duplex Serial Digital Transmission Interface Systems

This makes use of 20 bit Tag and Data words and a 12 µs intermessage gap.

$$\text{Time to transmit Max data} = \frac{33\text{x}20}{1\ \text{Mbit/s}} + 12 = 672\ \mu\text{s}$$

$$\text{Max Rate} = \frac{32\text{x}16}{672\ \mu\text{s}} = 760\ \text{kbit/s}$$

$$\text{Time to transmit Reasonable} = \frac{17\text{x}20}{1\ \text{Mbit/s}} + 12 = 352\ \mu\text{s}$$

$$\text{Reasonable Rate} = \frac{16\text{x}16}{352\ \mu\text{s}} = 725\ \text{kbit/s}$$

A.2.3 prEN 3910 - High Speed Data Transmission under STANAG 3838 or fibreoptic equivalent control

This makes use of a 40 bit LS Control/Action sequence, 70 bit HS frame overhead and a 24 µs Transmit timeout (reduced by 1/2 a control bit and 2 data bits due to the measurement points).

$$\text{Time to transmit Max data} = \frac{40}{1\ \text{Mbit/s}} + \frac{70 + 4096\text{x}16}{20\ \text{Mbit/s}} + 24 - (0.5 + 0.1) = 3343.7\ \mu\text{s}$$

$$\text{Max Rate} = \frac{4096\text{x}16}{3343.7\ \mu\text{s}} = 19.6\ \text{Mbit/s}$$

$$\text{Time to transmit Reasonable} = \frac{40}{1\ \text{Mbit/s}} + \frac{70 + 16\text{x}16}{20\ \text{Mbit/s}} + 24 - (0.5 + 0.1) = 79.7\ \mu\text{s}$$

$$\text{Reasonable Rate} = \frac{16\text{x}16}{79.7\ \mu\text{s}} = 3.2\ \text{Mbit/s}$$

A.2.4 prEN 3758 -Simplex High Speed Data Transmission System

This makes use of a 40 bit Preamble, a 70 bit frame overhead and a 4 µs intermessage gap (reduced by 4 data bit due to the measuring points).

$$\text{Time to transmit Max data} = \frac{40 + 70 + 4096\text{x}16}{20\ \text{Mbit/s}} + 4 - 0.2 = 3286.1\ \mu\text{s}$$

$$\text{Max Rate} = \frac{4096\text{x}16}{3286.1\ \mu\text{s}} = 19.9\ \text{Mbit/s}$$

$$\text{Time to transmit Reasonable} = \frac{40 + 70 + 16\text{x}16}{20\ \text{Mbit/s}} + 4 - 0.2 = 22.1\ \mu\text{s}$$

$$\text{Reasonable Rate} = \frac{16\text{x}16}{22.1\ \mu\text{s}} = 11.6\ \text{Mbit/s}$$

A.2.5 SAE Linear Token Passing Bus Standard

This makes use of 70 bits overhead, a 72 bit token and a 0.5 µs terminal response time.

$$\text{Time to transmit Max data} = \frac{70 + 4096\text{x}16 + 72}{50\ \text{Mbit/s}} + 0.5 = 1314.06\ \mu\text{s}$$

$$\text{Max Rate} = \frac{4096\text{x}16}{1314.06\ \mu\text{s}} = 49.9\ \text{Mbit/s}$$

$$\text{Time to transmit Reasonable} = \frac{70 + 16\text{x}16 + 72}{50\ \text{Mbit/s}} + 0.5 = 8.46\ \mu\text{s}$$

$$\text{Reasonable rate} = \frac{16\text{x}16}{8.46\ \mu\text{s}} = 30.3\ \text{Mbit/s}$$

A.2.6 SAE High Speed Token Passing Ring Bus

This makes use of 176 overhead bits (includes token).

$$\text{Time to transmit Max data} = \frac{176 + 4096\text{x}16}{80\ \text{Mbit/s}} = 821.4\ \mu\text{s}$$

$$\text{Max Rate} = \frac{4096\text{x}16}{821.4\ \mu\text{s}} = 79.8\ \text{Mbit/s}$$

$$\text{Time to transmit Reasonable} = \frac{176 + 16\text{x}16}{80\ \text{Mbit/s}} = 5.4\ \mu\text{s}$$

$$\text{Reasonable rate} = \frac{16\text{x}16}{5.4\ \mu\text{s}} = 47.4\ \text{Mbit/s}$$

A.2.7 ARINC 629 - Multi-transmitter data bus

This makes use of 20 bit Message Identifiers and Data words, a 12 µs TG, a 16 µs SG and a 4 µs inter-wordstring gap.

$$\text{Time to transmit Max data} = \frac{20 + 256\text{x}20}{2\ \text{Mbit/s}} + 4 = 257\ \mu\text{s}$$

$$\text{Max Rate} = \frac{256\text{x}16}{257\ \mu\text{s}} = 1.6\ \text{Mbit/s}$$

$$\text{Time to transmit Reasonable} = \frac{20 + 16\text{x}20}{2\ \text{Mbit/s}} + 4 + 12 + 16 = 200\ \mu\text{s}$$

$$\text{Reasonable rate} = \frac{16\text{x}16}{200\ \mu\text{s}} = 1.3\ \text{Mbit/s}$$