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GUIDE TO LOW AND MEDIUM SPEED DIGITAL INTERFACE STANDARDS FOR AVIONIC APPLICATIONS *

0 EXECUTIVE SUMMARY

This guide was commissioned by MoD through the Avionic Systems Standardisation Committee (ASSC). It compares the Def Stan 00-18 series of interface standards with several Electronic Industries Association (EIA) civil data transmission standards and two civil avionics data transmission standards developed by Air Radio Incorporated (ARINC) under the auspices of the Airlines Electrical Engineering Committee (AEEC), ARINC 429 and ARINC 629. The guide also includes a review of Time Triggered Protocol (TTP), Adaptive Standard PredictivE Network (ASPEN™), Universal Serial Bus (USB), IEEE 1394 - Standard for a high performance serial backplane bus, and the Controller Area Network (CAN) standard which originated in the automobile industry and WorldFIP Fieldbus which originated in the industrial & process control industry. The large difference in component cost between Def Stan 00-18 and EIA standards has been seen as an opportunity to save money by using these particular civil standards in military avionics systems. A suggestion in this vein has been made with particular reference to Def Stan 00-18 (Part 3), the Simplex and Half Duplex Serial Interface. This text is a careful technical summary of the issues involved so that there is a prepared position available.

The guide finds that Def Stan 00-18 and the several EIA standards are not comparable in function or fitness for purpose and that to transform the particular civil standards into a form fit for avionics purposes would incur very substantial costs and still not reach the same pedigree, acceptance or confidence. The text further demonstrates that a long established competitive market, supplying substantial numbers of Def Stan components, must converge on a price which is less than the price of a special. This is a fundamental economic principle. In other words requirements, public debate, competition and market forces have run their course and the price is the price.

Def Stan 00-18 and ARINC 429/629 components have been developed in a similar manner (standardisation committees) for use in a broadly similar application domain (avionics). The technical differences between these standards result from the different requirements in their application domains determined during their development. The level of maturity and therefore costs of components meeting these standards are similar.

The review concludes by noting that in current and future military projects the primary communication systems will tend towards 'Mil Spec' versions of more recent civil standards, e.g. FDDI and as Def Stan 00-18 is overtaken by newer technology.

A tabular comparison of the principal features of the various data transmission standards is appended to this report.

For details of higher speed bus standards refer to Guide to high speed interface standards (ASSC/120/2/77).

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1 INTRODUCTION

This review is a brief comparative summary of Def Stan 00-18 Parts 2, 3, 4 and the popular EIA 232, 422, 485 standards, often still referred to as RS 232, etc. The RS standards were created by the US Electronic Industries Association and RS has been replaced with EIA. Additionally, at the request of the ASSC Electrical Interfaces Working Group, the civil aviation ARINC 429 and 629 specifications have also been included. The guide also includes a review of Time Triggered Protocol (TTP), Adaptive Standard PredictivE Network (ASPEN™), Universal Serial Bus (USB), IEEE 1394 - Standard for a high performance serial backplane bus, and the Controller Area Network (CAN) standard which originated in the automobile industry and WorldFIP Fieldbus which originated in the industrial & process control industry. All of these standards support data communications between electronic devices and have a wide spread of applicability and purpose. The purpose of this review is to compare Def Stan 00-18 with the EIA commercial standards, and the ARINC standards and with CAN Bus with regard to use in military avionic systems. It is assumed that the reader has a reasonable degree of familiarity with the various standards discussed in this document.

It would be relatively easy to plunge into an extensive technical argument, however that is not deemed to be useful or justified. Instead this review begins with an abstract technical description of the lowest levels of a layered communication system. A specific description of each standard follows with identification of the basic properties, referencing the abstract discussion. Finally, there is a comparative summary.

It should be noted that EIA 232, whilst exceedingly useful and available, is actually intended for connecting telephone system modems to computing equipment, a different purpose from the other standards considered in this review.

2 ABSTRACT VIEW OF THE LOWEST LEVELS OF A LAYERED COMMUNICATIONS SYSTEM

All modern electronic data communications systems have layered architectures. The best known layered architecture is the International Standards Organisation (ISO) Open Systems Interconnect (OSI) model and it is appropriate to borrow some of its nomenclature to describe the systems under consideration. All the standards in scope use copper wire media, all use bit serial transmission and EIA 422, 485, ARINC 429/629 and parts of Def Stan 00-18 are similar in that the medium is twisted pair balanced transmission line. CAN uses either twisted pair or flat pair telephone cable. WorldFIP uses twisted pair balanced transmission line with a fibre optic option. To send information it is necessary to define a signalling element (symbol), a transmitter, a medium, a receiver and a framing protocol. The following text will elaborate on these issues in a general sense.

2.1 Symbol Signalling

The systems under consideration all use binary signalling (two levels). It is appropriate to call one level mark, the other space. To this we must add the concept of silence; in other words neither mark nor space. These three states are known as symbols.

To signal reliably the transmitted symbols have to be recognised by the receiver(s). This places constraints on the transmitter, symbol amplitude, media attenuation and the properties of the receiver such that all symbols (mark, space, silence) are recognised at all receivers. To send information it is necessary to send sequences of mark, space and silence. The length of mark, space and the transitions between is important and constitutes signalling rate. Obviously the faster the signalling rate the shorter the symbols and the rise and fall times.

The EIA standards, ARINC standards and to a lesser extent Def Stan 00-18 make reference to 'duplex'. This is a reference to direction of travel of the symbols. Duplex is synonymous with 'both ways'. Half duplex means both directions but only one direction at one time. Full duplex means both ways simultaneously while simplex means one way only. The terms are historical and come from telephone culture.

2.2 Medium and Configuration

A transmission line has a property called its characteristic impedance which is the impedance of an infinite length of the cable. A pulse applied at one end of an infinite cable will propagate indefinitely, at a velocity approaching the speed of light in the medium, attenuating as it travels. Practical transmission lines are low pass filters i.e. the high frequency energy attenuates faster than the low frequency energy. In other words, longer cable runs force lower bit rates.

If a terminating resistor equal to the characteristic impedance is placed at the end of a finite transmission line it absorbs all the energy in the pulse and ensures no reflection. Any discontinuity in the line (a stub, receiver or mismatched termination) causes a proportion of the pulse to be reflected distorting the symbol at other receivers.

Ideally the transmission line should be driven at one end with the receiver and terminating resistor placed at the other end. This configuration would behave in a very predictable fashion and have minimal reflections. However, that would allow only two parties to communicate. For economic reasons it is desirable that one cable serves multiple receivers along the cable, and minor mismatches (reflections) are tolerated. For the next logical step it is expedient to transmit from any location i.e. anywhere along the length of the cable rather than from the end. It is still a requirement that all transmitted symbols are unambiguously recognised at all receivers. Real systems also have to perform reliably in the presence of electro-magnetic noise coupled from other systems.

All of these considerations can loosely be called segment configuration rules and include symbol size, receiver impedance, stub lengths, rise times, etc. All the standards under consideration are subject to the same laws of physics which are well established, but that is not to say that computation of behaviour is either easy or economically practicable. To build high integrity systems it is invariably necessary to fix some properties e.g. speed and length and then attempt to optimise others e.g. rise time.

2.3 Sending Information (Framing and Media Access)

To send data it is required to associate symbols with bits. The naive way is to let mark be one and space be zero. This doesn't work well for several reasons. Primarily the data is not self-clocking, secondly the integrity of the receiver becomes data sensitive and the low frequency ac characteristics of the receiver amplifier become a potential problem. Finally, the resultant waveform cannot pass through a transformer. There are many ways that these issues can be addressed depending on circumstances.

Another issue is 'framing' which consists of a start delimiter, framing overhead, payload (the data) and end delimiter. This in turn can become complicated by 'in band' or 'out of band' delimiters. An in band delimiter has a specific pattern which might arise in the data. An out of band delimiter is a unique dedicated symbol or symbols.

Finally, there is the issue of who transmits, and when and whether the recipient sends an acknowledgement. This includes requirements for source addressing destination addressing and command/data. Loosely this issue is termed Media Access Control (MAC).

2.4 Electromagnetic Compatibility (EMC) Considerations

Electromagnetic compatibility is that property which permits a system to continue working in the presence of potentially interfering signals from other sources and without radiating compromising information or interfering with other aircraft systems. Interference from the aircraft environment into the cable which corrupts symbols will obviously jeopardise the performance or even survival of an aircraft. All data transmission systems will have a tolerance level beyond which performance is impaired. The need is to achieve an adequate and predictable level of performance. There are many obvious parameters such as cable screen efficiency but a much less obvious one is balance, on the part of the cable, transmitter and receiver since minor component unbalance may seriously compromise receiver common mode rejection resulting in unacceptable emissions. Signalling rate dictates the rise and fall times which need to be achieved, yet switching faster than necessary may lead to symbol distortion and greater energy radiation. Conversely slow rise and fall times may also result in symbol distortion. These are issues where consistency between components is vital. It is not enough to test a few components. Additional to testing is the requirement to specify the production tolerances and to test the performance of devices on that limit and in worst case combination.

3 OVERVIEWS

3.1 EIA 232 (RS232)

RS 232C is the oldest of the standards in this review and was completed in 1969. It is nearly unique in being an almost universal fitting on personal computers (PCs) and almost never used for the purposes for which it was designed. RS232C revised to RS232D is virtually identical to CCITT[1] (Comite Consultatif International Telephonique et Telegraphique) V24 when combined with V28. V24 defines the connectors, pin-out, etc., V28 defines the signalling levels.

RS 232 (now renamed EIA 232) originated in the telephone industry and was aimed at connecting a telephone circuit modem, known as the Data Communication Equipment, (DCE) to computing equipment, known as the Data Transmission Equipment, (DTE) so that two computers could communicate over the Public Switched Telephone Network (PSTN). The standard implies that the DTE and DCE are in relatively close proximity and that the signalling is done on discrete wires with a common return. A connection of less than a few metres was envisaged and there was no notion of transmission line parameters, impedance, or attenuation or such-like. In other words, EIA 232 is a communication standard for a short distance multi-wire interface. All the other standards within the scope of this review are aimed at driving long lines.

Initially, EIA 232 interfaces were fitted to computers for the purpose of communicating through modems. Computer users soon discovered that joining two DTEs together without all the modems, ringing, carrier, etc., worked well so long as the data rate is confined to less than about 20 kbit/s at one metre and 600 bit/s at 25 metres. As a result, EIA 232 is a very widely used option for connecting together computers which are physically close or connecting a computer to a slow data rate peripheral. Note that many 'EIA 232 compatible' equipment only implement that part of the standard needed by two DTEs and probably could not drive a modem!

3.2 EIA 422 (RS 422)

Without involving a telephone system, EIA 232 is not appropriate for joining together widely separated computers. EIA 422 was designed for this purpose. To quote the standard,

"..the interchange of serial binary signals...between point to point."

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[1] Note the CCITT is now re-titled ITU-TSS (International Telecommunication Union-Telecommunications Standards Sector)

EIA 422 is a point to point scheme which can signal at rates up to 10 Mbit/s over short distances and 10 kbit/s at one kilometre. EIA 422 does not define a rate or a distance but 'defines' cables, signalling levels, terminations, etc. and provides a table giving distance and maximum signalling rate which can be achieved. The word 'defines' needs some qualification. EIA 422 fails to define the cable other than a vague generalisation. This is not a criticism. EIA 422 is concerned with the general case and specific application requirements are properly left to 'the designer'.

EIA 422 defines transmitter and receiver characteristics and symbols. The rest is left to the implementor. Specifically in the matter of network configuration EIA 422 clause 4.2.4 states "....involves consideration of stub lengths data rate etc. is therefore beyond the scope of this standard."

In summary EIA 422 is a general scheme for signalling along twisted pairs with a simple network, ideally point to point but the standard does anticipate a single source multiple link system with up to ten receivers. At implementation time 'the designer' determines length, data rate, cable characteristic, etc. and then can calculate optimum device characteristics. All issues of framing, data representation, media access are not in the scope of the standard.

All of this is to say that for specific applications many details of a highly technical nature need to be determined in order to achieve a high integrity system.

3.3 EIA 485 (RS 485)

This standard is the evolution of EIA 422 to include multiple transmitters. It also increases the number of receivers (strictly Unit Loads) to 32. EIA 485 refines the generator and receiver characteristics of EIA 422, however it too is a generalisation of a serial communication system. The appendices to the standard (particularly A.2.3) emphasise that many technical decisions are left to 'the designer'. The optimum receiver/generator symbol design for signalling over 1 km at say 100 kbit/s is very different from the optimum design for 10 Mbit/s without regard for their matching to particular cables.

In summary EIA 485 is a general scheme for signalling along twisted pairs with a multi-point network. At implementation time 'the designer' determines length, data rate, cable characteristic, etc. and then can calculate optimum device characteristics. All issues of framing, data representation, media access are outside the scope of EIA 485.

3.4 Associated Standards

Given the technical discussion in Section 2 and the brief reviews of Section 3 it should be obvious that all three EIA standards only define mark and space symbols and provide general rules for designing a particular interconnection. The issues of bit representation, bit/byte order, framing and media access have to be provided by some other protocol, the most common being HDLC (High Level Data Link Control). This is an international standard and comprises two distinct parts. The LAPB (Link Access Procedure Balanced) subset of HDLC is the framing protocol for a balanced link and is commonly used to transfer data between two parties. There is a further subset called NRM (Normal Response Mode) which accommodates multiple transmitters. In the industrial world many proprietary communications systems are sold which are based on RS 485 and HDLC with enhancements and fixes, since the two fit by accident rather than intent. With sufficient investment and experiment workable systems can be produced.

Loosely speaking EIA 422 (or 485) combined with LAPB is similar to Def Stan 00-18 (Part 3) (Simplex and Half Duplex Serial Digital Interface Systems) whereas EIA 485 combined with an extended NRM and fixes for bit representation, has similarities to Def Stan 00-18 (Part 2) - Serial, Time Division, Command/Response, Multiplex Data Bus. Nevertheless, there are very substantial differences which are discussed below. EIA 485 and HDLC is 'serendipity', a happy accident which serves a useful purpose. It does not have the pedigree and integrity of Def Stan 00-18 which was designed to meet a specific set of requirements.

3.5 Def Stan 00-18 (Part 2) (US MIL-STD-1553B)

The scope of Def Stan 00-18 (Part 2) is wider than that of any of the three EIA standards discussed earlier. Not only is the scope wider, as will be shown, but more explicit and detailed. Where 422/485 is vague Part 2 is prescriptive. Consequently this section is somewhat longer than for the other standards.

Regarding the symbol signalling Part 2 defines mark, space, bit representation, symbol lengths, rise and fall time, bit rate, etc. This is to say that where 422/485 is generalised Part 2 is specific. The fixing of bit rate (1 Mbit/s) and bit representation allows detailed rules of configuration to be defined. Within these rules there is a clear high confidence route to high integrity systems.

It was said earlier that all such systems live with the same laws of physics and it could be said of Part 2 that the circumstances of 1 Mbit/s multiplexed signalling has been comprehensively studied and the results transformed into a detailed specification and configuration rules. Along the way numerous 'what ifs' were invoked regarding symbol signalling. An example is 'anti-jabber' but there are many more e.g. the accommodation of dual redundant media.

Def Stan 00-18 (Part 2) defines bit representation and uses Manchester II encoding. This is formally known as 1B2B for slightly different reasons but means that a bit is always sent as two complementary symbols. This breaks up the dc component that otherwise results from sending continuous sequences of mark or space and is self-clocking and capable of being transformer coupled, which brings further advantages. This is in contrast to EIA 422/485 which does not define how bits are represented. Part 2 permits up to 31 addressable attachments to the cable segment and any port can communicate symbols to any other.

Def Stan 00-18 (Part 2) defines the framing delimiters as out of band signals. These are unique symbols that are of longer duration than bit symbols, which means that by definition framing delimiters cannot be part of data. In the case of EIA 485 combined with HDLC frame delimiting and bit representation is not covered by either of the two standards. In practice in band delimiters are used, in other words data can have the same pattern as a delimiter. A scheme known as 'bit stuffing' is used to distinguish data from delimiters. Bit stuffing is rightly deprecated since it compromises error detection. A more elegant way of coding delimiter, framing, data sequences is that used on FDDI (and other modern standards). FDDI uses 4B5B i.e. four data bits are borne on five symbols. There are 32 possible symbol sequences for the 16 data nibbles leaving some patterns for framing and invalidating the continuous all mark or space patterns.

Def Stan 00-18 (Part 2) also includes a specific media access protocol which again is missing from EIA 422/485. It might consequently appear perverse to persist with a one sided comparison yet this matter is actually crucial to a deeper understanding of the fundamental problems for which Part 2 is a solution. The problem lies with 'latency' which is the time between committing some data at one port and receiving it at some other port.

To understand the factors contributing to latency consider the analogy of a railway with stations and trains. It is obvious that arriving just after the train has left is the worst time to arrive - the longest wait. Furthermore, it is possible that on arriving at the station there are numerous passengers or that trains arrive already full! In data communications these equate to a finite delivery service, variable loading, congestion and queuing. With a single (half duplex) cable, there is only opportunity for one transaction per unit time but many ports and potential queues into and out of the ports. It should be obvious that even with the 'perfect' scheduling algorithm latency is traffic dependent. A system in which latency is indeterminate may be adequate for transferring text files between computers, but is entirely inappropriate for use in a real time weapons system.

Def Stan 00-18 (Part 2) offers a deterministic traffic transfer but requires a different model of traffic. Imagine a pair of hosts each with a DMA memory between host and the data port. Part 2 offers a mechanism that will periodically move fragments of DMA memory from one port to another. Consequently the latency for crucial messages is guaranteed. The downside is poor efficiency but this is a result of fundamental differences between systems with overriding time constraints and 'best effort' systems. This is not to say that Part 2 cannot also operate queues. This property is almost unique to Part 2 but the same principles are being applied to industrial 'time critical' communication systems for essentially the same reasons. Which is to say that there are many control systems for which the application of a telephone culture mechanism simply does not serve.

3.6 Def Stan 00-18 (Part 3) and Part 4 Background

Def Stan 00-18 (Part 2) is essentially a rewrite of US MIL STD 1553B to which the UK made a substantial technical contribution. For the avionics purposes for which 1553B was designed there was, and still is, no comparable alternative. For lesser tasks, especially for simplex and discrete applications, 1553B would be over-kill, yet there is a great desire to regularise and harmonise the EMC aspects for all communications within aircraft. Part 3 and Part 4 were written to provide a harmonised set of standards such that the experience and pedigree of Part 2 could be used in lesser tasks, but at a lower cost.

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

EIA 485 evolved as a multi-drop symbol signalling system from a point to point system. Part 3 evolved the other way around. Def Stan 00-18 (Part 3) is essentially a sub-set of Part 2 and uses the same electrical components and consequently the same configuration rules. It follows that any references to physical layer or EMC characteristics of Part 2 apply equally to Part 3.

The standard covers simplex operation, from one source to one or more receivers and half duplex operation between two parties. The standard also includes the notion of full duplex using two reversed simplex links. This standard enables the use of existing components in a simple system where the complexity of Part 2 is not necessary, yet the excellent EMC performance of Part 2 is required.

3.8 Def Stan 00-18 (Part 4) - Discrete Signal Interfaces

There are many situations where the status of a Boolean function such as a micro-switch, have to be led from the actuator to a computer port. Conversely there are many situations where a Boolean decision, taken in a computer have to be conveyed to the actuator. In a modern aircraft there are hundreds of such signals, of varying lengths and criticality. It is the purpose of Part 4 to lay down a standard for such discrete signalling. Previously, unique designs appeared in every project, creating problems with support and spares, etc. This was seen to be inefficient and needlessly complicated design and validation. Standardisation also underwrites inter-working of different vendors equipment and provides a known EMC capability.

Part 4 is in four parts; critical timing, non-critical timing, low power switching, and fault detecting non-critical timing signalling. Low power switching is a special case of signalling where the signal is also the actuator power supply e.g. a lamp or solenoid. Power switching is a function for which the EIA standards are wholly unsuited.

3.8.1 <u>Critical Timing</u>

The critical timing subset is for signalling along screened twisted pairs. Strictly speaking signalling here is simply 'state', (on/off) rather than serial data. The levels are similar to those of EIA 422 and the similarity is not coincidence. At the time that Part 4 was created there was no MoD policy or standard covering discrete signalling, and unsuitable commercial standards such as EIA 422 were being considered. At that time the components offered as compliant with EIA 422 were demonstrably inadequate especially with regard to EMC performance. Part 4 was written around EIA 422 to tighten aspects of the 422 specification such that compliant components would have an EMC performance comparable to that of Part 2, especially as both are required to endure the same environment.

3.8.2 Non-critical Timing

This subset is a simple standard providing Boolean signalling on unbalanced wire for non-critical applications. It regularises how these systems shall be implemented such that ad hoc solutions may be avoided.

This is an application for which there might be a temptation to use devices such as EIA 422 drivers and receivers. However, as is demonstrated below the real benefits of such an approach are at best questionable.

3.8.3 Low Power Switching

This subset of Part 4 is for those applications where the Boolean signalling system is also the actuator power source. As with the non-critical system this text is to regularise the situation and is simply good practice written down to head off ad-hoc solutions.

3.8.4 Fault Detecting Non-critical Timing

This interface is intended for high integrity application and its distinctive feature is an ability to detect a variety of fault conditions in either the transmitting element or the interconnecting media.

This is achieved by using a two state switched resistive element as the transmitter, this is fed with a dc constant current from a source in the receiver, or sensor unit. In normal operation, the sensor unit senses voltages corresponding to the two states of the transmitter. In a fault condition (e.g. a short or open circuit in the connecting medium) a voltage is produced which is outside the range occurring in normal operation, and the fault condition is detected by the sensor unit. This approach also allows faults within the transmitter to be detected.

3.9 Def Stan 00-18 (Part 7) - Utilities data bus standard

With the recent developments in modular avionic systems, it has become apparent that there is a need for the application of data bus technology to low level utility functions such as simple proximity detectors, on/off discretes, indicators, relay and electrical load controls, etc. which still exist in modular systems. These demand high integrity operation in the harsh avionic environment but must be provided at a lower cost to connect.

The bus system defined in this standard is designed to meet the above requirement by providing a high integrity, low cost solution based on the proven technology of Def Stan

00-18 (Part 2)/MIL-STD-1553B. It retains centralised control, command/response philosophy and use of transformer isolated terminals coupled to a shielded, twisted pair, medium but operates at 250 kbit/s with an addressing limit of 126 terminals. In practice the actual number of terminals and maximum bus length is constrained by the electrical parameters of the implementation.

Even with the use of this standard, subtle differences may still exist between Utilities data buses used in different applications due to the options allowed in the Standard; systems designers must recognise this fact. These designer selected options must exist to allow the necessary flexibility to assemble a custom Utilities data bus system from the functionally standard parts. Alternative coupling methods are defined in supplements to this Standard.

The purpose of this standard is to establish uniform requirements for multiplex data system techniques which will be used to control and monitor utilities based equipment. This Utilities data bus will enable the integration of, and promote standard system interfaces for, associated Utilities sub-systems. The standards also defines the concept of operation and information flow on the bus along with the electrical and message formats to be employed.

The physical layer of the interface specified in Def-Stan 00-18 (Part 7) is compatible with those of Def Stan 00-18 (Part 2). The interface specified in Supplement A of Def-Stan 00-18 (Part 7), makes use of the same bus structure. It does, however, aim to allow increased bus length and/or numbers of Remote Terminals while reducing the cost of implementation. This is achieved by increasing the terminal impedance and choosing line levels that can be achieved with a single logic power supply voltage standard and standard Def Stan 00-18 (Part 2) transformers.

3.10 ARINC specification 429-14 Mark 33 Digital Information Transfer System (DITS)

This specification, generally known as ARINC 429, has some similarities to Def Stan 00-18 (Part 3). It describes a data transmission system based on the use of a single data source and reception of that data by up to 20 sinks or receivers. The maximum number of receivers permitted for connection to a source is limited by the specified minimum receiver input resistance, ARINC 429 specifies an 8 bit destination address implying that 256 different addresses may be used. The medium is shielded twisted pair and transmission is in one direction only (simplex) on one length of cable. If bi-directional data transmission is required then this is achieved by a second simplex link in the opposite direction to the first.

The modulation technique is return to zero bipolar giving three states of 'HI', 'NULL' and 'LO'. These are represented by a differential voltage between the two wires of the cable. 'HI' is represented by a received level between +6.5 and +13V, 'NULL' by +2.5 to -2.5V and 'LO' by -6.5 to -13V. A drawback associated with this modulation technique is that transmission data with unequal numbers of 'HI' and 'LO' bits can result in a transfer of electrical energy into reactive elements of the bus, i.e. the bus may become 'charged' resulting in end of message distortion and ringing.

Two ranges of transmission rate are defined. 'High Speed' at 100 kbit/s ±1% and 'Low Speed' in the range 12 to 14.5 kbit/s. In the commentary to the standard implementors are 'warned off ' certain bit rates which could interfere with commonly used aircraft navigation systems.

ARINC 429 organises data in 32 bit words. There are five application domains for this data and the word and message formats used depend upon the application domain and the specific data which is transferred. There are, however, some common word format features. Bit 32 is the parity bit, bits 31 and 30 are sign/status bits. Bits 1 to 8 form a data label which identifies the type of data being transferred.

ARINC 429, with its mass of attachments, appendices and supplements, sets out to exhaustively define detailed requirements for implementation of a range of applications. In so doing it descends into depths of application related detail which Def Stan 00-18 leaves to the system designer (ably assisted by the Def Stan 00-18 Guide and MIL-HDBK-1553). ARINC 429 has become a large mass of detailed requirements and thus lacks the relative clarity of Def Stan 00-18 Part 2.

3.11 ARINC specification 629-2 Multi-transmitter Data Bus

This standard is generally known as ARINC 629, and has been developed by the ARINC Data Bus Subcommittee. The standard has four parts; part one is the technical description, part two is the application guide, part three describes the standard format of data and part four is the part one test plan. The standard as a whole defines a digital communications system in which avionics Line Replaceable Units (LRUs) or sub-systems may transmit and receive digital data using a standardised protocol. A linear topology is used and sub-systems are coupled to the bus by terminals located in each sub-system. Media access is by a Carrier-Sense Multiple Access/Collision Avoidance (CSMA/CA) scheme. Bus access control is distributed amongst all participating terminals each of which autonomously determines its transmission sequence. This is achieved by the use of bus access timers which monitor bus quiet time and are different for each terminal on the bus. When this timer (known as the terminal gap) has elapsed the terminal can access the bus. A further timer known as the synchronisation gap timer is used to determine terminal malfunction and allow resynchronisation of terminals. There are two operating modes known as Basic Protocol and Combined Protocol. The former allows either periodic or aperiodic data to be transmitted on the bus with the ability to switch between these modes. The latter allows both types of data to be transmitted over the bus within a single frame.

Three terminal to bus coupling methods are currently defined. These are current mode coupling, voltage mode coupling, and optical mode coupling (defined in Supplement 3 of ARINC 629). Only current mode coupling is defined to a level where components are available. Current mode coupling has been criticised on noise immunity grounds and a fibre optic option is being developed which will give better noise immunity. Great efforts are being made in support of this development. A data rate of 2 Mbit/s is defined and up to 120 terminals are allowed on the bus. 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. These data words are assembled into word strings which contain a label word with channel information and data labels for addressing. This may be followed by a further word containing the word count.

3.12 Controller Area Network (CAN) Bus

Controller Area Network, commonly known as CAN Bus is a serial data communications bus which originated in the mid eighties in the German car industry, and has since been adopted world-wide for automobile data communications. The principal needs which drove the development of CAN were identical to those which spawned avionic data buses i.e. to provide real time data communication, with reduced cabling size and weight, and normalised I/O specification. More recently CAN has been adopted for use in a wide range of areas including manufacturing, process control, marine control and navigation, agricultural machinery, medical systems and, significantly, avionics. Avionic applications include engine control, and there is also a 72 k/bit/s 'general aviation' variant of CAN known as Light Aircraft Multiplexed Bus (LAMBus^{TM}).

In contrast to the small, and shrinking, military semiconductor market the automotive semiconductor market is huge and rapidly expanding. It is claimed that 5.5 million CAN chips alone were sold in 1995, with projected cumulative sales of 140 million by 1999. This massive volume coupled with fierce competition drives prices down to levels which are a tiny fraction of those traditionally met in the military field. One source reports CAN controllers at $10 (about £6) in small quantities, while another rumours simple devices for less than $1 (about £0.6).

A wide range of CAN devices and board level products is readily available at low cost from a number of major silicon and equipment suppliers. It is also claimed that CAN is supported by 'a huge range of support tools' including development boards, debuggers and software drivers.

The severity of the automotive environment approaches that found in military aircraft. Hence, CAN devices are available with a -40 to +125°C operating temperature range, and there are reports of devices planned capable of operating at +200°C. However, there may be a problem with applications requiring the ability to operate at the extreme end of the military temperature range between -40 and -55°C.

CAN has been formalised in two ISO standards. ISO 11898 for high speed applications and ISO 11519 for low speed. CAN standards define requirements for the Data Link layer and the Physical Layer (Electrical only) of the ISO seven layer model only. A variety of protocols (some still emerging) are used to between the CAN Data Link layer and various Application layers, e.g. the Allen-Bradley DEVICEnet™.

CAN uses Non Return to Zero (NRZ) encoding on a terminated differential two wire bus made up of screened or unscreened twisted pair. Flat pair telephone cable is also used at the expense of degraded EMC performance.

The maximum bit rate is 1Mbit/s for a 40m bus and lower bit rates are used for longer buses e.g. 100 kbit/s for 500m.

The ISO11898 standard recommends that bus interface devices should be designed to function with either of the two wires in the bus broken, or either wire shorted to power or to ground, albeit with degraded performance. However it is understood that many commercial devices do not meet this requirement. Some fault tolerant devices are available but generally at the expense of maximum transmission rate (typically 250 – 500 kbit/s max). It is claimed that if both wires are severed the parts separated by the break may still function as separate buses.

Messages transmitted on a CAN bus do not contain terminal addresses. Instead the data content of the message is indicated by a unique identifier, and receiving terminals examine the identifier to determine if the data is required by the terminal.

The identifier also defines the priority of the message. The lower the numerical value of the identifier, the higher the priority. Higher priority messages are guaranteed bus access. Lower priority messages are re-transmitted subsequently.

To determine the priority of messages, CAN uses Carrier Sense, Multiple Access with Collision Resolution (CSMA/CR). Collision resolution is by non-destructive bit-wise arbitration in which a dominant state (logic 0) overwrites a recessive state (logic 1). A higher priority terminal, having a lower value identifier, transmits a logic 0 before a lower priority terminal. Transmitting terminals monitor their own transmissions hence a competing lower priority terminal finds one of its logic 1 bits overwritten to a logic 0, it then terminates its transmission and waits until the bus is free again.

Non-destructive bit-wise arbitration is said to allocate bus access on the basis of need, providing efficiency benefits not achievable with fixed time schedule allocation (e.g. 1553) or destructive bus allocation (e.g. Ethernet). Outstanding transmission requests are dealt with, in their order of priority, with minimum delay, and with maximum possible utilisation of the available capacity of the bus. It is claimed that, unlike Ethernet, CAN will not lock up because no bandwidth is lost in collisions. However low priority messages can be permanently locked off the bus.

CAN protocol version 2.0A supports messages with 11 bit identifiers, the extended CAN protocol version 2.0B supports both 11 bit and 29 bit identifiers. The number of unique identifiers available to users, on a 2.0A network, is 2,032. The number available on a

2.0B network exceeds 500 million. A Remote Transmission Request (RTR) bit provides a means of requesting data from a remote node.

CAN implements five error detection mechanisms: Cyclic Redundancy Checks (CRC); Frame Checks; Acknowledgement Error Checks; Bit Monitoring; Bit Stuffing. A residual (undetected) error probability of 10^{-11} is claimed.

CAN provides an error confinement mechanism which is claimed to be unique. This discriminates between temporary errors and permanent failures using error count registers within each terminal, a faulty device will cease to be active on the bus, but communications between the other nodes can continue unhindered.

3.13 Time Triggered Protocol (TTP)

3.13.1 Overview

Time Triggered Protocol (for safety critical applications) (TTP/C) has been developed over the last fifteen years specifically for applications that need high-integrity safety critical data buses. A TTP network consists of a number of nodes connected together to create a *cluster*. The nodes in such a cluster communicate over a dual redundant broadcast data bus, implemented in a TTP/C Controller chip. A synchronised global time base is maintained throughout the clusters by the Controller chips, which is isolated from the host Central Processing Unit (CPU) by a firewall (implemented in dual-port RAM). This synchronised time base allows a deterministic Time Division Multiple Access (TDMA) scheme to be implemented where each node in a cluster can transmit once in a TDMA round. This is a static scheme determined at design time, which is stored in each controller in a data structure called a Message Descriptor List (MEDL). Each node can only transmit in its pre-determined slot, which is protected by a bus guardian in the controller – thus preventing babbling nodes. The synchronised time base also means that the protocol carries a very low overhead, as no message identification information needs to be sent – the receiving node can calculate which message has been received by using the synchronised time and the information stored in its MEDL.

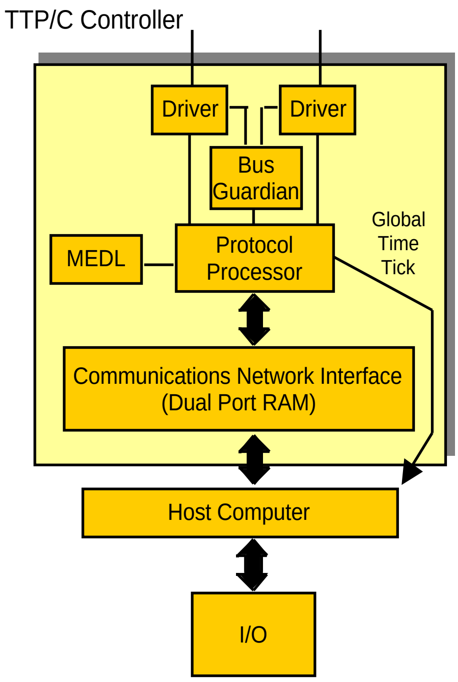

Figure 1: TTP/C controller

Each node can transmit 1 to 16 bytes in each TDMA slot, where the TDMA slot length of all slots is set to the duration of the longest slot. Each data packet is preceded by a 4 bit header and protected by a 16 bit Cyclic Redundancy Check (CRC). After each message there is a Interframe Gap, where the Controller chip performs its processing on the received data and updates the Communications Network Interface (CNI) (implemented in dual port RAM) with the received data.

Data is transmitted periodically in what is called a Cluster Cycle. A Cluster Cycle can consist of 2, 4, 8 or 16 TDMA rounds. This limitation can significantly affect the length of the cluster cycle, depending on the number of messages that need to be transmitted by each node. It is therefore well suited to utility systems with small message sizes. However, it must also be noted, that TDMA slots can be shared between nodes, so less critical nodes can send information less often, therefore maximising the potential usage of the bus.

The TTP services include Membership information, where each node connected to the bus knows (with a small delay) which other nodes have membership to the bus. If a node transmits faulty / null information then it looses its membership to the bus and has to re-integrate, likewise if it is the only node to receive faulty / null information (for example in the case of link failures). As part of this membership service an Implicit acknowledgement scheme is also implemented.

The bus can currently operate at speeds of 0.5 / 1.0 / 2.0 Mbit/s, although these speeds are purely an implementation restriction and not a protocol restriction. There is a possibility of future implementations operating at speeds in excess of 100MBit/s.

The maximum number of nodes that can be connected in a cluster is 64, however this can be extended by using multi-cluster systems connected by gateways. Currently there is no TTP/C controller chip facility to synchronise the time base between clusters.

One of the main perceived benefits of TTP is what is called *composability*. This means that various components of the system can be developed independently and integrated at a late stage. This is due to the strict design rules that give a pre-defined interface and guarantees temporal behaviour. This characteristic of TTP should reduce the testing and certification costs of a system.

3.13.2 Implementation

The Inter-frame gap for this chip is currently 100 μs, which has an impact on the design of the system and the length of the Cluster cycle, but it is hoped to improve on this timing, by increasing the clock speed and reducing the complexity of the chip. The volume cost of the Controller is expected to be less than $10.

Microcontrollers with built-in TTP/C Controllers are proposed similar in concept to the MPC555 microcontroller, based around the PowerPC architecture, which has a CAN interface [EET]. The MPC555, with a CAN interface will be less than $30 in volume by the year 2000. A similar price is expected for the TTP implementation, which should be produced by Q4 2000.

3.13.3 Media

The bit encoding is based on Modified Frequency Modulation (MFM). The physical media is not specified since TTP/C is media independent (the protocol does not depend on the detection of bus contention). It has been successfully run on shielded twisted pair using CAN and RS485 line drivers. It has also been run on optical fibre.

CAN line drivers are limited to 1 Mbit/s with a bus length of 40m, which is unacceptable for most aerospace applications. RS485 drivers can support 32 nodes at 2 Mbit/s, with a bus length of 100m.

Specific line drivers for TTP/C are expected by the end of 2001.

3.13.4 Tools

Basic low level TTA tools have been produced which have now been enhanced to include a suite of software to develop TTA based systems.

Under new funding an integrated TTA toolset will be developed, which shall allow system simulation (including "hardware in-the-loop" simulation) and testing, before downloading to the host hardware. This shall be performed by using the existing low level tools and integrating them with high level COTS tools, for example Matlab/Simulink.

3.13.5 Standardisation

The TTP Forum was set up (first meeting June, 1998, Munich) to disseminate the TTP technology and to address any issues, such as conformance testing and standardisation. Talks have been continuing between Technical University of Vienna and SAE over the past few years and the specification should be submitted to the SAE sometime this year (1999).

The specification (currently in a draft form) can be freely requested from TTTech's website. A copy of the specification is sent to you via E-mail in .pdf format.

3.13.6 References

[TUV]	Technical University of Vienna	http://www.vmars.tuwien.ac.at/frame-projects.html
[TTT]	TTTech	http://www.tttech.com
[MOT]	Motorola	http://www.mot-sps.com /news_center/press_releases/PR980713B.html
[EET]	EETimes Article	http://www.techweb.com/wire/story/RWB19980421S0011
[DCS]	Dependable Computer Systems	http://www.decomsys.com

3.14 Adaptive Standard PredictivE Network (ASPEN) (also SAE AS 5370)

The primary requirement for any aircraft data bus is the support of real-time, critical control messages. The data bus must have a media access protocol, which provides for guaranteed message latency, and which supports error detection and fault tolerant mechanisms to ensure the reliable delivery of application messages and the reliable detection of corrupted messages.

The Adaptive Standard PredictivE Network (ASPEN) is a multi-transmitter, bi-directional, fibre optic data network which is suitable for use in critical aircraft applications, and employs a distributed media access technique. ASPEN is a derivative of the Echelon LONWORK technology that has been modified and thoroughly analysed to verify the protocol's suitability for aircraft applications.

LONWORKS technology is a set of commercial open standard and techniques for implementing distributed control network systems. These networks consist of intelligent devices or nodes that interact with their environment, and communicate with one another over a variety of communications media using a common, message based control protocol.

There are several significant differences between ASPEN and the LONWORK technology which serve to enhance the protocol's suitability for the aircraft environment. These differences include a patented media access mechanism, a certifiable, safe system image, stringent configuration management controls, and a patented fibre optic transceiver type. Although tailored for fibre optic transceivers, ASPEN may also be employed with traditional wire-based transceivers.

ASPEN includes a new media access mechanism which layers a deterministic time slot, by specific values, allocation protocol over the existing contention based protocol, thereby providing a mechanism by which message latencies may be bounded. ASPEN is capable of certification under the guidelines specified in RTCA/DO-178B. ASPEN uses a reduced functionality version of the standard protocol that has been analysed for safe system operation. Certain original protocol features which are either unused or undesirable for aircraft applications have been deleted from the protocol. ASPEN is also controlled under a stringent configuration management program which ensures that errors found in either the ASPEN version or the base version of the protocol are identified, corrected, and forwarded to the proper authorities. A deterministic fibre optic transceiver has been developed which is compatible with either the base protocol or the ASPEN protocol.

The simplicity and low-cost of fibre-based ASPEN networks brings new levels of safety, economy, and reliability to a broad range of civilian aircraft - from single engine trainers to business jets, regional airliners, and large civil transport aircraft.

The ASPEN protocol is currently controlled by Raytheon is now standardised as SAE AS-5370. The structure of a 4-node CBL system is shown in the diagram.

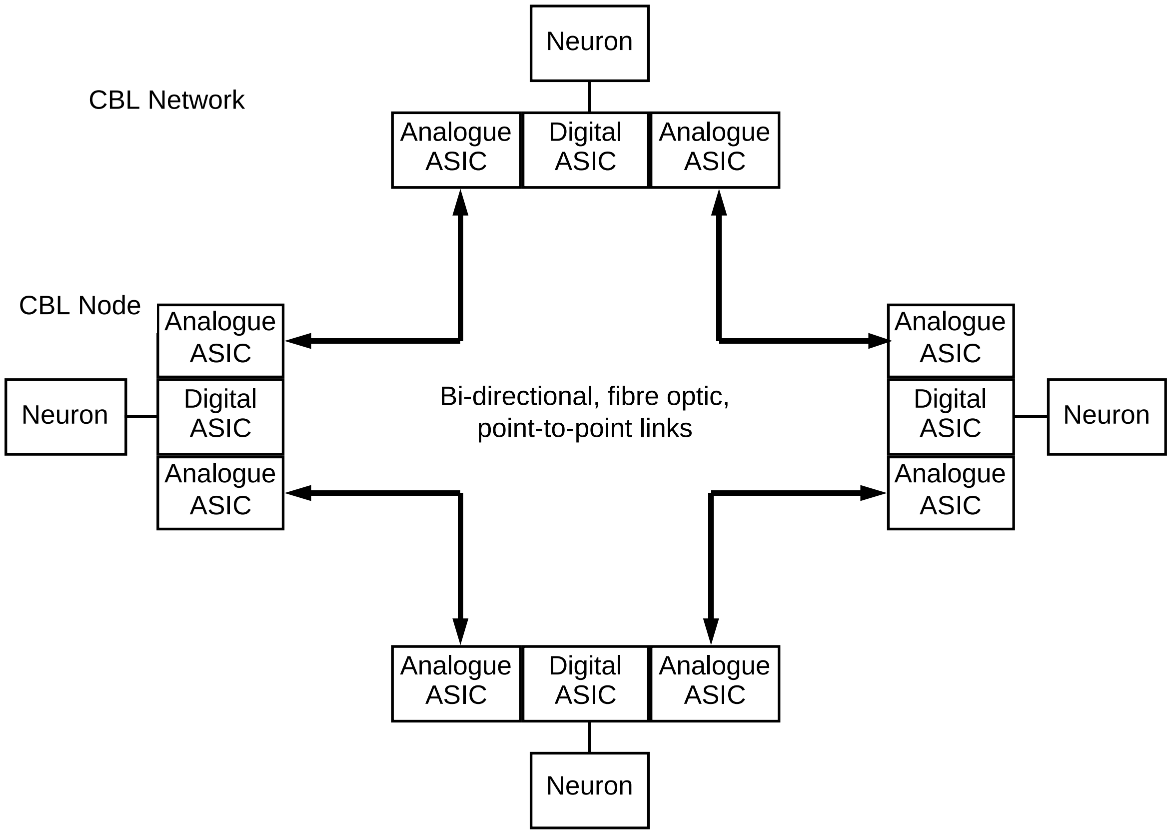

Figure 2: The structure of a 4-node CBL system

A CBL node is comprised of a LonWorks 'Neuron' processor, a digital ASIC and two analogue ASIC's. Nodes are connected together by bi-directional, point-to-point, fibre optic links. The analogue ASIC's are fibre-optic transceivers, but also perform fault monitoring on the databus such as weak, jammed or failed link detection. All messages pass around the ring in both directions simultaneously under the control of the digital ASIC's. This results in the dual redundant, counter-rotating flow of data around the ring.

The digital ASIC, and modified firmware in the Neuron, implement the remainder of the ASPEN protocol. The Neuron firmware is currently reprogrammed by Raytheon, although it is proposed this will be licensed to third parties interested in developing CBL nodes. The Neuron provides all seven layers of the ISO model and contains a dedicated 8-bit processor for applications software. Alternatively the Neuron can be interfaced in host mode to a higher performance processor.

Bit encoding is Manchester biphase. The maximum bit rate for a standard system is 1.25MBps, although 2.5MBps and 5MBps implementations are under development. Total bus lengths of several kilometres are possible with several hundred meters per fibre-optic link.

The ASPEN protocol is Time Division Multiplexed (TDM). Timing is maintained by receipt of a periodic ‘beacon’ message, which can be generated by any node. Time slots are allocated to nodes on a static basis nodes during software design.

ASPEN software is developed using the LonWorks, LonBuilder development suite, although certain features of LonWorks are not allowed to increase the determinism of the system. If the 8-bit processor of the Neuron is to be used LonBuilder provides all tools required for software development and network configuration. If a more powerful host is required, LonBuilder is used for network configuration and to configure the appropriate Neurons into host mode.

An ASPEN chip-set, comprising a reprogrammed Neuron plus the three ASIC’s, was intended to be around the £50. Standard CBL products, packaged for various aerospace applications, are available from Raytheon. These applications include, fuel monitoring, data acquisition and actuator control. All products can be certified to RTCA/DO-178B.

The web page has now moved to www.control-by-light.com

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3.15 Universal Serial Bus (USB)

Two major new interface technologies are appearing for desktop personal computers which due to their very low cost and widespread industry support may well appear in future avionics systems applications. These interfaces are the Universal Serial Bus (USB) and IEEE 1394 otherwise known as "Firewire".

The USB is intended to replace the older 'RS' series of serial interface standards such as RS232,422,485 and the 'Centronics' parallel ports for serving low speed peripherals such as mouse, keyboard, scanner and printing devices. The IEEE 1394 interface is intended to replace SCSI interfaces for higher speed devices such as hard disks, CD-ROM's, digital video, etc.

Both these new interface technologies feature common characteristics to support modern 'hot insertion and removal' and 'plug and play' capabilities. The USB features Asynchronous and Isochronous modes of operation over a simple common cabling scheme which also provides the capability of distributing power to peripherals within the standard cable. The IEE 1394 interface is covered in section 3.16. The main features of USB are as follows.

USB provides support for up to 127 logical devices connected via a tiered star topology (Christmas tree) using multi-way 'hubs' of up to six tiers. The system supports both 1.5 and 12Mbit/s operation with control being dedicated to one USB host, normally in the host computer/PC. 'Hot' insertion and removal of peripheral devices is managed by automatic re-configuration software/firmware within the host.

The physical layer consists of 2-wire differential signalling along a twisted pair at CMOS 3.3V levels. Transmitters are controlled to have rise and fall times between 4 to 20 nsec to minimise RFI and signal skew. The twisted pair is combined with 2 power conductors to form standardised interconnection cables consisting of shielded cable assemblies of up to 5 metre lengths terminated in standardised 4 pin shielded (blind mating) connectors at each end. The twisted pair has a line impedance of 90 Ohms and the power conductors are rated for the supply of 5 Volts at up to 500mA.

The USB system topology consists of three basic elements:-

(1) The Host Controller which is responsible for centralised command and control of the network being most typically found in the host computer PC/workstation.

(2) The Hub which is a router/repeater device for providing the connectivity for the peripheral devices. Every hub has one "upstream port" and one or more "downstream ports". In personal computer applications keyboards and monitors often provide the USB hub function and typically support at least *four* downstream ports.

(3) The Peripheral Interface is the actual interface providing USB support for the attached devices and they come in two forms, the Low-Speed Peripheral Interface (LSPI) for 1.5Mbit/s operation and the Full-Speed Peripheral Interface (FSPI) for 12Mbit/s operation.

The USB system supports a number of different data transfer types to suit the varying real-time requirements of the attached peripherals. These are primarily in the form of data or control exchanges between the host and peripheral devices either as uni or bi-directional transfers. Communication is set up between the host and either single or multiple endpoints and such associations in USB terminology are called 'pipes'.

There are four main transfer modes consisting of *Isochronous* mode for delivery of real time messages at a guaranteed rate, *Interrupt* mode for delivery of data no slower than a peripheral device specifies, *Control* mode for configuration of peripheral devices when they are first attached to a USB network and *bulk* mode for delivery of large blocks of data requiring high bandwidth but at infrequent intervals.

Transfers are controlled by*token* packets which are only issued by the USB host to allow for *in* , *out* and *setup* type transactions. The data field may range from 0 to 1023 bytes which must be an integral number of bytes. The data bits within each byte are transmitted LSB first. *Handshake* packets are transmitted to report the status of data transactions and can return values indicating successful reception of data, flow, control and stall conditions. *Start of frame* packets are issued by the USB host at a nominal rate of 1msec and consist of a packet ID followed by a 11 bit frame number field. Both the token, data and start-of-frame packets are protected with 5 bit CRC fields.

In many ways the centralised control philosophy of the USB together with the transfer modes described above resemble the well accepted command/response philosophy of the Mil-Std-1553B (Def-Stan 00-18 (part 2)) avionics data bus. This would make the USB, as a modern COTS derivative, attractive for potential avionics system use. However at the time of writing the USB is only just becoming widespread in the personal computer world and there are no known avionic applications (although some avionics related research projects feature its use). Therefore before use in an avionics environment uncertainties about the robustness of USB, particularly for EMC, as well as the limitation of the tiered star topology would have to be evaluated for avionics system use. However the shear size of the market for USB will make components very cheap and readily available which will in turn encourage its use for avionics system applications and hence its inclusion in this guide.

3.16 IEEE 1394 - Standard for a high performance serial backplane bus

The original IEEE 1394 called ‘Serial bus’ (also called ‘Firewire’ by Apple).

The 1394 Trade Association (http://www.1394ta.com) has separated the extensions into individual study groups.

IEEE 1394.1 is the supplement to 1394
IEEE 1394.2 is the gigabit extension
IEEE 1394.3 is the definition of bus bridges

The following information has been obtained from the 1394 Trade Association from an article titled ‘IEEE 1394, the A/V Digital Interface of Choice’ by Gary A Hoffman, Technologist.

IEEE 1394 is an international standard, low-cost digital interface that will integrate entertainment, communication, and computing electronics into consumer multimedia. Originated by Apple Computer as a desktop LAN and developed by the IEEE 1394 working group, IEEE 1394 is:

* A hardware and software standard for transporting data at 100, 200, or 400 megabits per second (Mb/s).
* A digital interface-there is no need to convert digital data into analogue and tolerate a loss of data integrity.
* Physically small-the thin serial cable can replace larger and more expensive interfaces.
* Easy to use-there is no need for terminators, device IDs, or elaborate set up.
* Hot pluggable-users can add or remove 1394 devices with the bus active.
* Inexpensive-priced for consumer products.
* Scaleable architecture-may mix 100, 200, and 400 Mb/s devices on a bus,

* Flexible topology-support of daisy chaining and branching for true peer-to-peer communication.
* Inexpensive-guaranteed delivery of time critical data reduces costly buffer requirements.
* Non-proprietary - There is no licensing problem to use for products.
* Serial Bus Management provides overall configuration control of the serial bus in the form of optimising arbitration timing, guarantee of adequate electrical power for all devices on the bus, assignment of which IEEE 1394 device is the cycle master, assignment of isochronous channel ID, and notification of errors. Bus management is built upon IEEE 1212 standard register architecture.

There are two types of IEEE 1394 data transfer: asynchronous and isochronous. Asynchronous transport is the traditional computer memory-mapped, load and store interface. Data requests are sent to a specific address and an acknowledgement is returned.

In addition to an architecture that scales with silicon technology, IEEE 1394 features a unique isochronous data channel interface. Isochronous data channels provide guaranteed data transport at a pre-determined rate. This is especially important for time-critical multimedia data where just-in-time delivery eliminates the need for costly buffering.

Much like LANs and WANs, IEEE 1394 is defined by the high level application interfaces that use it, not a single physical implementation. Therefore as new silicon technologies allow high higher speeds, longer distances, and alternate media (wireless?), IEEE 1394 will scale to enable new applications.

Perhaps most important for use as the digital interface for consumer electronics is that IEEE 1394 is a peer-to-peer interface. This allows for example not only dubbing from one camcorder to another without a computer, but allows multiple computers to share a given camcorder without any special support in the camcorders or computers.

<u>IEEE 1394 in the Industry</u>

Initially IEEE 1394 will be the computer attachment of digital cameras and digital video applications. IEEE 1394 is the lowest-cost digital interface available for audio/video applications. New audio/video applications such as digital television, Multimedia CDROM (MMCD), and home networks are the first market for IEEE 1394.

IEEE 1394 has been accepted as the standard digital interface by the Digital VCR Conference (DVC). This standard has been proposed to the IEC to publish as an international standard. The EIA 4.1 subcommittee has voted for IEEE 1394 as the point-to-point interface for digital TV as well as the multi-point interface for entertainment systems. The European Digital Video Broadcasters (DVB) have endorsed IEEE 1394 as their digital television interface as well. Several of these companies have proposed IEEE 1394 to the VESA (Video Experts Standards Association) for the digital home network media of choice.

From a video editing point of view IEEE 1394 enabled cameras removes the need for costly analogue video computer frame buffers to capture digital video. The video is converted to its digital form when captured at the camera. DVC Camcorders not only delivers Beta SP quality at a fraction of the camera cost, but professional computer interfaces at the price of a 100Mb Ethernet adapter.

Later IEEE 1394 will gradually have application opportunities to improve upon existing interfaces such as SCSI. IEEE 1394 offers higher speed, lower cost, and is more user friendly than most existing interfaces. SCSI products such as scanners, CD-ROMs, disk drives, and printers are examples of devices that would be enhanced by migrating to IEEE 1394.

The 1394 Trade Association also is working with other standards groups and electronics associations as IEEE 1394 becomes useful for them. The American National Standards Institute (ANSI) has defined Serial Bus Protocol (SBP) to encapsulate SCSI-3 for IEEE 1394. Several TA companies have proposed IEEE 1394 to the VESA Home Network working group as the preferred digital home network medium.

In the 1394 Trade Association and the IEEE 1394.1 study group many new extensions to IEEE 1394 are being mapped out. Extensions include:

* Gigabit speeds for cables
* 100Mb for backplane implementations
* Longer distance cables using copper wire and plastic fiber
* A/V command and control protocols
* 1394 to 1394 bus bridges
* IEEE 1394 gateways to communication interfaces, such as ATM.

<u>IEEE 1394 Future</u>

Based on the initial success of the Sony camcorders, other A/V products are expected to be introduced in 1996 and 1997. These introductions may include: DVD for television using the DVC HD format (MPEG2), DVD as a CD-ROM, desktop cameras, and colour printers.

ATM (Asynchronous Transfer Mode) and IEEE 1394 will drive each other's markets. ATM will become the world-wide voice/video/data public switched networks. However, ATM is too expensive for devices such as disk drives, cameras, and desktop computers. Therefore IEEE 1394 is a complementary interface as the device interface for ATM.

Built firmly on a base of low cost implementations IEEE 1394 will become a high volume consumer electronics interface. Consumer electronics interfaces tend to be very long lived, plain old telephone (POTS) as we know it is over 100 years old, and audio/video coax interfaces date from World War II. Therefore with ability to span media and maintain software compatibility, IEEE 1394 should enjoy a very long life. If ATM, the next telephone system, lasts at least 100 years then IEEE 1394 will be there with it.

Such a high volume interface that is fundamentally available to computers will enable many new applications. Not only will A/V data be available for computers to manipulate, but a use friendly command and control interface will span home, vehicle, office, and factory products. Barriers that exist will gradually be shattered by growth of IEEE 1394 roots.

3.17 WorldFIP Fieldbus

WorldFIP (FIP = Factory Instrument Protocol”), often just called “FIP”, originated in France 12 years ago for industrial & process control and has since become a European Standard and is used World-wide in industries such as power generation, mass transportation, marine, discrete manufacturing and process control. The principal needs which drove the development of WorldFIP were the need for standardised real-time networked communication with the increasing number of intelligent controllers, sensors and actuators in industrial and process automation. A particular stress was industries with very expensive plant and/or high safety requirements. The WorldFIP bus therefore has high EMC immunity and redundancy features, using a physical layer which owes a lot to 1553B. It has therefore now found applications in the nuclear industry and in naval defence applications.

Approximately 500,000 WorldFIP nodes are installed world-wide with a continuing growth in installations. WorldFIP controller chip prices range from $10 (about £6) for the simplest chip to $20 (about £12) for the most complex. A line driver and transformer are also needed to complete the interface.

The WorldFIP protocol is supported by the WorldFIP organisation, a non-profit making “club” of companies interested in developing, supporting and exploiting the protocol. Two main ranges of WorldFIP chips are available, developed by Schneider Electric and Alstom Technology. A wide range of board level products, associated development tools and software is available through the WorldFIP organisation. The cost of development tools ranges from under $1000 up to $10000.

The severity of the WorldFIP industry sectors, particularly rail transportation, has required the development of chips with temperature ranges up to –20 to +125 degrees Celsius.

WorldFIP has recently been formalised as a European Standard: EN 50-170. The WorldFIP physical layer is the IEC Fieldbus Standard: IEC 61158-2, which has been in place for over 4 years. WorldFIP Standards completely define the Physical, Data Link and Application layers and associated network management functions. A set of WorldFIP Interoperability Guides further define how the protocol is to be used for different classes of product.

WorldFIP uses Non return to zero inverted (NRZI) encoding on a terminated differential two wire bus (shielded twisted pair). Transmission is half-duplex. The highest specification cable uses metal tape shield although cable with woven screen is often used (IBM type 6). Connection to each node is isolated, usually by a transformer.

The bit rates allowed are 2.5Mbit/s, 1Mbit/s or 31.25Kbit/s. At 2.5Mbit/s the maximum distance is about 500m. At 1 Mbit/s it is about 1.2 km. The possibility of higher speeds is under consideration during 1999, of the order of 20Mbit/s.

Fault tolerance features at the physical layer includes anti-jabber inhibit in the chips. The chips support multiple data paths.

Data transmitted on the WorldFIP bus is of three explicit types:

Cyclic data: (Known as “periodic variables”): Used for time critical control loops.

Event data: (Known as “aperiodic variables”): Used for time critical alarms & events

Message data: (Known as “messages”): Used for non time critical configuration and diagnostics.

Cyclic data is always transmitted on time regardless of other traffic (deterministic). Event data is the second priority (within this level there are two priorities of events) and is itself not affected by the lowest priority, the non time critical “message” data.

Access to the bus is controlled by a function called the “bus arbiter”, often referred to in the USA as an “active link scheduler”. This acts like the conductor of an orchestra, allocating time for cyclic, event and message data appropriately. This means that there are never any collisions. The bus arbiter has a fixed schedule of cyclic data to be transmitted and maintains queues of events and messages which are processed in order of receipt (FIFO) As a potential single point of failure, the bus arbiter can be multiple redundant, existing in more than one node of the network. The active bus arbiter is monitored by the inactive ones, which will pick up control of the bus in the event of failure.

Data communication is peer-to-peer using the producer-consumer model for the time critical cyclic and event data. Time critical data packets are identified using logical identifiers, not physical addresses. To maintain the deterministic nature of the cyclic data, there are no retries in the event of data corruption. The next value to arrive simply overwrites the last value. There are logical flag “freshness” and “promptness” which can optionally be used by the application to manage cyclic data. Transmission of message frames (which contain a source and destination physical address) can include retries. A recent development is the creation of an “IP socket” interface to the WorldFIP Data link layer to allow transparent connection to other networks using TCP/IP.

Up to 64000 variable identifiers can be supported on one WorldFIP network (a small number are pre-allocated for management functions.). Variables cannot be bridged to other networks (because of loss of determinism) but messages can be bridged to up to 8 other WorldFIP networks.

WorldFIP implements cyclic redundancy checks (CRC16), frame checks, acknowledgement error checks as well as time outs on node and bus arbiter responses, jabber inhibit and freshness and promptness indication for time critical data. Dual redundant cable is frequently used in high integrity applications. Statistics of failures are maintained in the node sand accessible to network management.

4 SUMMARY

This review was commissioned to compare Def Stan 00-18 with certain justifiably popular and seemingly lower cost civil standards. A comparison of Def Stan 00-18 and ARINC 429/629 was also included for completeness. At the request of the ASSC Data Interfaces Subcommittee, the review has now been expanded to include the CAN bus standard. The objective is to compare the features of these various standards in a technical manner and to cite the primary purpose of each standard for educational reasons and 'for the record'. Underlying all this purpose is the matter of cost, particularly the comparison of EIA 485 with Def Stan 00-18 Part 2. As at February 1998 the cost of a military specification Def Stan 00-18 (Part 2) chipset was of the order of £700, and that of an ARINC 629 serial interface module around £400, whereas EIA 485 parts cost just a few pounds. As already stated CAN bus parts cost are available for about £6, and WorldFIP parts from £6 to £12. It is reported that avionic device prices have recently become much more sensitive to volume than previously, with reductions to around 50% for thousand off volumes. It would be ideal at this point to cite formal Life Cycle Cost (LCC) models and enter the parameters with which to compute the true cost of each route. Unfortunately such an option is not available. Models exist but are quite inappropriate to the scale of the task. Consequently the matter has to be argued in words.

The issues involved are purpose, specification, durability, connectivity, certification and an attribute which might be called maturity. In the following discussion most of the comments on Def Stan 00-18 are applicable to the ARINC standards.

Taking purpose first, it should be clear from the above description that Def Stan 00-18 (Part 2) is much more than EIA 485. For example the media access method is defined in the former and is completely absent in the latter. To create a comparable resource based on EIA 485 considerable effort would have to be expended. The work required to create a system with the integrity and utility of Part 2 would be considerable and time consuming. If Part 2 took say as little as 10 man years of specialist international effort then some large fraction of that effort would be required to create an alternative based on EIA 485. CAN bus however, provides functionality comparable with Def Stan 00-18 (Part 2), including a media access mechanism, addressing, framing and CRC error detection.

With regard to specification, production tolerances become an issue. The spread of components which are compliant with a loose specification would yield a spread of performance which is unacceptable in an avionics environment. Selection is sometimes economic but more often the only certain course is to specifically make the high specification component.

Durability is the next issue and it should be obvious that 'mil spec' components, of whatever type, require shock, temperature and vibration specifications which are not available with inexpensive commercial parts. Since price is a function of volume seeking higher specification devices drives up the price in a very non-linear manner. It should be obvious that a competitive market in Def Stan 00-18 (Part 2) components from several suppliers will drive the price down compared with a lower volume 'special to project' production run. This is simply as result of 'market forces' all matters of durability being equal. To this one must add the matter of quality assurance. Each component must be traceable and calibrated, etc. and such specialisation is costly. Having said all this it must be recognised that CAN, coming from the automotive industry with its harsh environment and high reliability requirements, is likely to provide a degree of robustness approaching that required of military avionics. The uptake of CAN by the car industry suggests that high levels of reliability are being achieved.

Connectivity (or interoperability) is the next issue. In avionics and military vehicles, etc. within NATO Def Stan 00-18 (Part 2) (ie STANAG 3838 AVS) is such established practice as almost to guarantee inter-connectivity between terminals from different suppliers. Established practice also brings an infrastructure of test equipment and a high level of technical expertise regarding maintenance and repair. Choosing some other arbitrary communication system will provoke a non-linear escalation of costs to any avionics building block and a corresponding cost for maintenance. The extent to which connectivity (particularly between different vendors products) is assured by CAN is not clear. However, it is hard to believe that the car industry would tolerate interoperability problems, given its propensity for multiple sourcing of components. The, justifiable, claims made for Def Stan 00-18 (Part 2) concerning support in terms of test equipment and widespread expertise are echoed by CAN supporters, albeit that these virtues exist in a different domain.

The term maturity has been used here to refer to the accumulated experience of successfully producing, integrating, testing and operating Def Stan 00-18 components and systems. It might with some justification be argued that the various EIA standards under consideration have an equally long history and much greater installed base than Def Stan 00-18 (or US MIL-STD-1553B). However, the EIA standards have been used in very different applications and environments from Def Stan 00-18 and their maturity is therefore at best only partially relevant. The quality of the maturity of Def Stan 00-18 owes much to the relatively close nature of the western world's military avionics data communications community revolving around such axes as the UK Avionic Systems Standardisation Committee (ASSC), the US Society of Automotive Engineers (SAE) and the Air Standardisation Co-ordinating Committee (ASCC - Australia, Canada, New Zealand, United States and United Kingdom). Evidence of this maturity exists in the form of the US MIL-HDBK-1553A, which might be described as a distillation of the US experience in implementation of MIL-STD-1553B and in the UK Guide to Interface Systems [Def Stan 00-18 (Part 1)], which gives extensive guidance on application of Def Stan 00-18 (Parts 2 – 4). Furthermore, a comprehensive range of validation and production test plans has been produced by SAE and ASSC. The Def Stan 00-18 (Part 2)

Remote Terminal Production Test Plan produced by ASSC has been subjected to extensive practical evaluation procedures. As for CAN bus, which first appeared in the mid nineteen eighties, it is likely that its supporters would claim for it a significant degree of maturity. Although CAN lacks a pedigree quite as long as MIL-STD-1553B it has been used in much greater volumes in a wide range of industries and applications and so would be expected to have a significant body of experience behind it.

Finally, under the heading of maturity and specifically related to Def Stan 00-18 Parts 2 - 4, mention must be made of the comprehensive programme of validation and EMC testing performed on implementations of these standards in the early 1980s by ERA Technology Limited on behalf of ASSC. This testing programme demonstrated the ability of interfaces and data buses designed in accordance with Def Stan 00-18 to meet the stringent requirements of military avionic EMC standards. As part of that programme lengthy consideration was given to the desirability of adopting EIA 422 for time critical discrete signal applications. Tests were performed on commercial EIA 422 devices and a careful comparison of the requirements of Def Stan 00-18 (Part 4) and EIA 422 was undertaken. This exercise concluded that the Part 4 critical timing interface standard covers a number of important areas not addressed by EIA 422. These include definitions of transmitter common mode pulse voltage, transmitter output impedance balance, transmitter internal fault effects, receiver hysteresis and receiver ac common mode rejection. It was concluded that for avionic applications the more stringent requirements of Def Stan 00-18 should apply.

Certification is the last hurdle. In the limit who wants to be identified with a contributory cause of the loss of an aircraft? If there is a system which has been certified already and for which there is extensive operational experience then choosing an unproven and economically dubious alternative should be viewed with suspicion. Creating the confidence and supporting evidence for an alternative could be a very costly exercise.

5 CONCLUSION

In conclusion the component cost of Def Stan 00-18 (Part 2) and of ARINC 429/629 appears high but the issue is whether there is a comparable alternative which can become less costly when all factors are taken into consideration. ARINC 629 and 429 are standards which are of a similar pedigree to the Def-Stan 00-18 (Parts 2 and 3) and are aimed at performing tasks which are basically similar. It might therefore appear that they could be interchanged. However, in cost terms this would provide little benefit since the costs of components meeting these standards are similar. Furthermore the ARINC standards (429 in particular) have been tailored specifically to civil aviation needs. Significant modification, or at least stripping away of civil application requirements, would be essential to make these standards suitable for military use.

Previous versions of this guide pointed out that there are industrial application which are as onerous as avionics. It was suggested that 'in a few years' similar civil systems with superior performance to Def Stan 00-18 (Part 2) would be available and high volumes would will drive the cost down to the few pounds level. CAN has achieved dramatic reductions in cost compared to traditional avionic systems and may have overcome the connectivity problems. However, CAN only offers a transmission rate similar to systems like Def Stan 00-18 (Part 2) and ARINC629. There is mounting evidence that military avionics is urgently seeking much higher bit rates than either CAN or Def Stan 00-18 (Part 2) provide. Having said all this, it should be recognised that for applications where bit rates below 1Mbit/s are sufficient CAN has a major cost advantage and may be able to offer adequate robustness. Further careful investigation of the potential for application of CAN in military avionics will be needed to determine its suitability.

6 TABULATED COMPARISON OF STANDARDS

Table 1 is a tabulated comparison of the principal features of the standards considered in this guide. The 'Environmental Specification' entries are intended only to give an indication of common areas of application. Component cost values are of necessity very approximate.

	Def Stan 00-18 Part 2	Def Stan 00-18 Part 3	Def Stan 00-18 Part 4	ARINC 429	ARINC 629	EIA 232	EIA 422
Modulation	ManchesterBi Phase II	ManchesterBi Phase II	N/A	Return to Zero Bipolar	Manchester Bi Phase II	Non Return to Zero	N/D
Transmission Rate	1 Mbit/s	1 Mbit/s	N/A	100 kbit/s 12-14.5kbit/s	2 Mbit/s	20 kbit/s max	10 Mbit/s max
Word Length (Information)	16 bits	16 bits	N/A	31 bits	16 bits	7 or 8 bits	N/D
Error Detection	Parity	Parity	N/A	Parity	Parity, Checksum/CRC	Parity	N/D
Message Formats Defined?	Yes	Yes	N/A	Yes	Yes	No	No
Media Access Control	CMAC	CMAC	N/A	RTS/CTS	CSMA/CA	RTS/CTS	N/D
Max No. of Terminals	31	31	2	20**	120	2	2
Terminal-Bus Isolation	Yes	Yes	No	No*	Yes	No	No
Environmental Spec.	Military Avionics	Military Avionics	Military Avionics	Civil Avionics	Civil Avionics	Commercial /Industrial	Commercial /Industrial
Approx. Component Cost per Terminal	£600	£300	£50	£500	£400	£10	£10

Table 1: Comparison of Standards

Notes:
* Opto isolated receiver under investigation for ARINC 429
1. N/A = Not Applicable
2. N/D = Not Defined
3. CRC = Cyclic Redundant Character Check

** 256 addresses, see section 3.9
4. CMAC = Central Media Access Control
5. RTS/CTS = Request to Send/Clear to Send
6. CSMA/CA = Carrier Sense Multiple Access/Collision Avoidance
7. CSMA/CR = Carrier Sense Multiple Access/Collision Resolution

	EIA 485	CAN Bus	WorldFIP	TTP	ASPEN	USB
Modulation	N/D	Non-return to Zero Bipolar	Manchester biphase NRZI	Modified Frequency Modulation	Manchester Biphase	NRZI with Bit Stuffing
Transmission Rate	10 Mbit/s max	1 Mbit/s max	1& 2.5Mbit/s 5Mbit/s optical	0.5 / 1.0 / 2.0 Mbit/s	1.25Mbit/s available 2.5/5Mbit/s proposed	1.5 & 12Mbit/s
Word Length (Information)	N/D	Up to 8 bytes	Variable up to 128/256	1 to 16 bytes (Message Length)	Up to 228 bytes	8 bits
Error Detection	N/D	CRC	CRC16	16 bit CRC	CRC	CRC16
Message Formats Defined?	No	Yes	Yes	No	Yes	Yes
Media Access Control	N/D	CSMA/CR	Redundant CMAC	None required ‡	TDM	Token/Handshake
Max No. of Terminals	32	>30	256	64	32000	127
Terminal-Bus Isolation	No	No	Yes	Yes – Bus Guardian	N/A Point-to-point	No
Environmental Spec.	Commercial/ Industrial	Automotive	Industrial/Marine/ Rail	Industrial/ Automotive/ Rail/ Aerospace	Aerospace	Commercial /Industrial
Approx. Component Cost per Terminal	£10	£6	Chip only £6-£12 Total: £14-£21 Redundant:£24-34	Controller should be < $10 (automotive)	£50	£5-£10

Table 1: Comparison of Standards (continued)

Notes: see above

‡ There should be no bus contention as system is synchronous. TTP standard does not specify physical layer CAN & RS485 (copper) and optical media have been used. Philips are developing a TTP specific line driver.

7 WEB SITES OF POSSIBLE RELEVANCE TO THE DATA INTERFACES SUBCOMMITTEE

The following provides details of Web sites with URLs possibly of relevance to the Data Interfaces Subcommittee.

Site	Outline of content	URL (http://)
US MIL-STD-1553B	Information of vendors	www.navmar.com/vendorlist.htm#Matrix
CAN	Useful information on CAN bus	www.omegas.co.uk/CAN/ www.mfuniversity.com
IEEE-1394 Trade Association	Up-to-date detail of IEEE 1394 information from the Trade Association	www.1394ta.com
IEEE-1394-95	Useful information on Firewire	www.firewire.org
IEEE-1394-95	Texas Instruments 1394 page	www.ti.com/sc/docs/msp/1394/1394.htm
IEEE-1394-95	Technical papers and news articles	www.skipstone.com/info.html
WorldFIP	UK WorldFIP club site	www.worldfip.org
WorldFIP applications	Applications page	www.worldfip.org/practice.html
SAE	SAE web page	www.sae.org/techcmte/aasd
ASPEN		www.raytheon.com/re/adc/ctlbylight/aspen.html
CBL		www.raytheon.com/micro/ctlbylight/cbl.html
USB	Universal Serial Bus (USB)	
D. Stan	Defence Standards	www.dstan.mod.uk
TTA/TTP	Time Triggered Protocol	www.vmars.tuwien.ac.at/projects/carmodel; www.daimler-benz.com/presse/tech.htm; www.tttech.com; www.vmars.tuwien.ac.at/frame-projects.html
	multiple links to other data bus sites	www.actionio.com/hotlinks.html ireland.iol.ie/~readout/fieldbus
Swiftnet	Swiftnet plus other general information	www.shipstar.com