Fibre Channel:
Replacement for MIL-STD-1553
& Next Generation Military Data Bus

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The technologies poised to replace MIL-STD-1553B

While MIL-STD-1553 has long served as the backbone bus in avionics systems, more demanding data-intensive mission requirements including video, audio and data distribution, are pushing 1553 well beyond the limits of its bandwidth. Several high speed interconnect technologies, among them Fiber Distributed Data Interface (FDDI), Fibre Channel, ATM, IEEE 1394 (Firewire) and Fast Ethernet are competing to replace 1553. We will evaluate these technologies and discuss their suitability to the rigorous demands of future military platforms, concluding that Fiber Channel will be the eventual technology of choice for Vetronics and Avionics applications when deployed in the harshest of environments.

MIL-STD-1553 - Military Data Bus of Choice

MIL-STD-1553 is a deterministic, reliable data bus, well suited for the interconnect of mission critical computing modules with real time sensors and controllers. Over the last 20 years it has become the most widely deployed communication backbone in military platforms, including aircraft, land based vehicles and naval platforms. Its' longevity is attributable to its positive characteristics including:

- *Linear LAN network architecture*

  This topology makes '1553 ideally suited for connecting distributed devices in an aircraft or land vehicle. It reduces cabling required by point-to-point interconnections; thereby, reducing overall vehicle weight and conserving space. The linear topology also provides both system design and

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maintenance/support flexibility, allowing for ease of addition and removal of nodes on the network.

- *Capacity for redundancy*
  With its inherent dual bus approach, ‘1553 provides a level of fault tolerance with automatic switch between alternate channels which is transparent to mission software.
- *Support for dumb and smart nodes*
  ‘1553 provides support for non-intelligent remote terminals providing interfaces to sensors and actuators. It is ideally suited for linking intelligent, central computing modules with distributed slave devices.
- *High level of electrical confidence*
  With support for electrical isolation with transformer coupling, a node connected as a ‘1553 terminal can be safely isolated from the network; thereby, reducing the potential for damage to computing equipment.
- *Excellent component availability*
  ‘1553 silicon is widely implemented in extended temperature and military spec. off-the-shelf packages for deployment in harsh environments.
- *Guaranteed real-time determinism*
  Perhaps the most compelling reason systems designers have chosen MIL-STD-1553 for mission critical systems is its command/response protocol which guarantees real-time determinism.

Despite these positive features, future adoption of ‘1553 in more demanding military systems is limited because the serial transmission rate of the bus is only 1 Mbit/sec. While this data transmission rate remains suitable for more rudimentary functions such as control of landing gear and munitions, it is too slow to serve the increased peer-to-peer communications needed by avionics and vetronics applications in support of data, audio and video information exchange.

Military Vehicle Local Area Network Requirements

The growth in both type and volume of information transferred within modern military platforms is fueled by an attempt to maintain supremacy in an information war which is rapidly going digital. Imaging, Digital Signal Processing (DSP), target tracking and target recognition are typical of the applications which are contributing to the growth of information flowing through aircraft and tanks. System architectures are evolving to support the increased data flow, data storage and processing driven by these new and more demanding applications. Changes include:

- Sensor data is being converted to digital information earlier in the system while at the same time sample rates are increasing the information content (100+ M samples/sec).
- Sensor fusion requires data concentration in centralized high performance signal processors.
- There is growing demand for conversion of video from analog to digital.

We are primarily interested in how these changes define the need for new network technologies.

When selecting a technology for a harsh environment backbone networks, systems designers compare a long list of capabilities, including:

- *Standards Conformance*

  Conformance to an international standard helps to ensure that products from different manufacturers will be interoperable. It provides systems integrators with portability and reduces the affects of getting locked into proprietary solutions.
- *Commercial Following*

  Conformance to an international standard is of little value if it is not widely adopted and implemented by multiple manufacturers. Trends in technology adoption in the last decade demonstrate that military systems integrators are more likely to accept technologies which have a proven track record in the commercial arena. For this reason commercial adoption is a good indicator of the likely longevity of a LAN technology.

- *Fault Tolerant*

  Due to the mission criticality of these systems, the backbone network of choice must provide some level of tolerance to minimize the affects caused by a break in connection between communicating nodes. Ideally, an alternate network technology will provide fault tolerance features similar to the built-in dual redundant capability inherent to MIL-STD-1553.
- *Iscochronous Video*

  Deterministic video transfers are required to support low latency, real-time imaging.
- *Low Maintenance*

  The network technology must support the removal and addition of nodes on the network to support maintenance.
- *High Bandwidth*

  The growing appetite for more bandwidth is driven by the need to move data, video and audio between computing components. Competing network technologies must offer between 100 Mbit/sec and 1 Gbit/sec (100 MB/sec) data throughput.
- *Real Time Deterministic Behavior (Low Latency)*

  High throughput is just part of the requirement. Competing technologies must also provide low latency transfers to support deterministic, real-time response required by military mission computers.
- *Support for Harsh Environments*

  Due to the nature of the environments in which these military systems are deployed, the network technology must be capable of operating in temperature extremes while sustaining severe shock and vibration.

LAN Options: The Big List

There are numerous open standard LAN options in use in commercial and consumer markets. Figure 1 identifies some of the more popular choices showing where they fall within the interconnect spectrum. This spectrum ranges from Wide Area Networks (WANs) at one end, covering global connections, to very tightly coupled bus and processor based interconnections at the opposite extreme. WANs and Metropolitan Area Networks (MANs) provide more global capabilities than is appropriate for a vehicle backbone network. System Area Network (SAN) options, which include I/O and Bus interconnects are also inappropriate because they are intended for more tightly coupled systems which are typically located within very close proximity. Those technologies which fall in the Local Area Network window are the best candidates to be considered as the backbone network of choice: Fibre Channel, FDDI, Ethernet, Firewire/IEEE 1394, ATM, and Universal Serial Bus (USB).

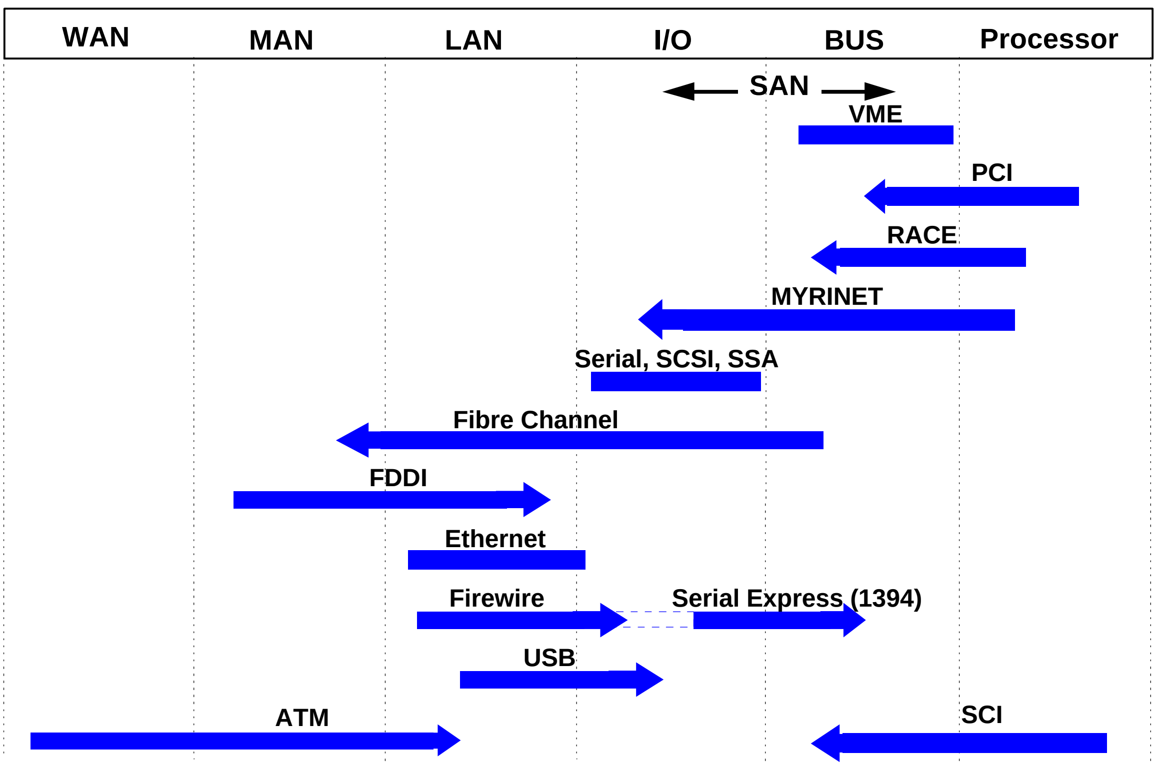

Figure 1: Interconnect Technology Spectrum

Technology Adoption/Maturation: Reducing the Big List

Equally important as technical considerations in the selection process is the technology adoption and maturation status which determines the viability and fit of a technology to the deployment window of potential opportunities. Analysis of the technology adoption and maturation status for the military system LAN options is shown in Figure 2. All technologies lie between introduction and obsolescence on this curve. The options appearing early in the curve have not reached sufficient maturity to be considered for use in next generation military systems. Others have matured and are now in a decline with respect adoption in new programs. For example, for reasons identified earlier, MIL-STD-1553 is beyond maturity and is in decline; whereas, Fibre Channel has been accepted by early innovators and is showing signs of being adopted as a mainstream technology. Still, some options are scaleable and hence more likely to withstand 'aging'. We will refer to the maturation curve as we compare competing technologies in more detail.

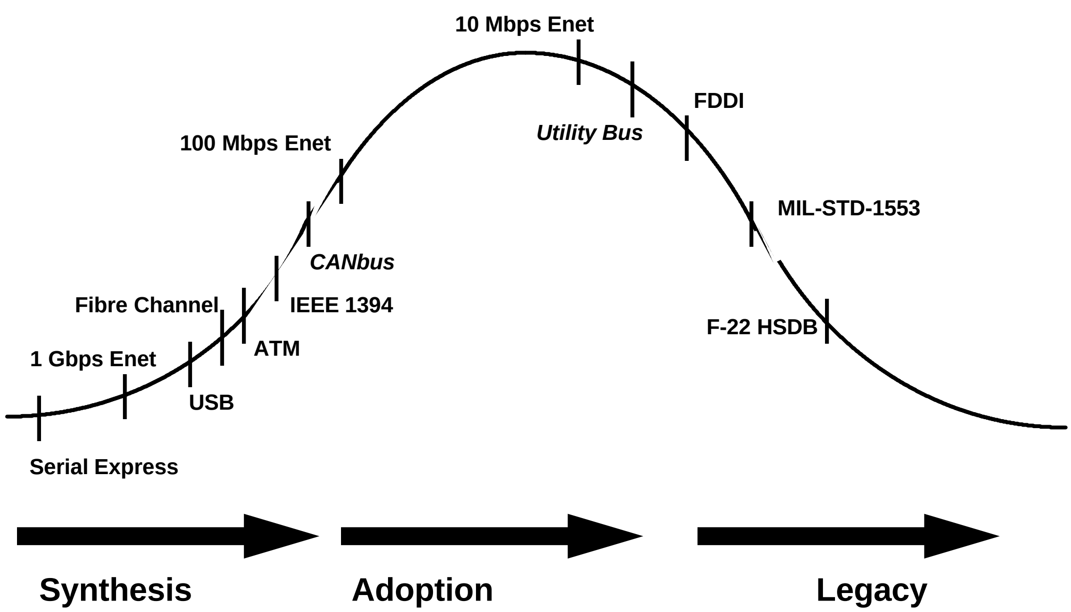

Figure 2: LAN Technology Adoption/Maturation Status

As depicted, there are several newly emerging interconnect standards not proposed for further consideration, due to lack of available silicon and/or inadequate fit. They include:

- IEEE 1394 (also called Firewire)

  This standard high-speed (100 Mbit/sec to 400 Mbit/sec), peer-to-peer peripheral serial bus has yet to see wide implementation; however, a broad cross-section of PC and consumer electronics vendors have adopted the standard and we expect to see systems support for this technology emerging over the next 12 months. Particular strengths of 1394 include its support for hot swapping of devices and plug-and-play compatibility, as well as isochronous audio/video support.

  Based on the PC market support, IEEE 1394 could become the standard peripheral bus in the desk-top computer market; however, commercial acceptance of this technology may not ensure similar success as a military backbone network. A limitation of IEEE 1394 is that its network is in the form of a tree topology with limited distance (10's of meters), which complicates both cabling and maintenance when used as a vehicle backbone network. Additionally, popular support for 1394 is largely restricted to the consumer electronics market whose needs for long term reliability and support for harsh environments do not necessarily compare with those of military system integrators.

- Serial Express

  This is a high-speed (1 Gbit/sec) serial bus based on IEEE 1394 but with support for higher speeds and longer distances. Because it is a fairly new technology as indicated by its position on the maturation curve it is too early to predict it's place in military systems.

- Universal Serial Bus (USB)

  USB is a 12 Mbit/sec desktop peripheral interconnect bus intended to replace existing interfaces such as RS-232C serial ports, the PC parallel port, MIDI ports and the monitor port. It is an ideal complement for 1394 on a desktop

PC, but because it is too slow and has an inappropriate tree topology structure, it will not be considered for detailed comparison with competing backbone technologies.

- Fast or Gigabit Ethernet

  Gigabit Ethernet is seeing adoption in the networking industry; however, due to its point to point topology it complicates vehicle connections as well as maintenance. Additionally, the inherent non-deterministic, collision rich nature of Ethernet makes it unreliable for the type of real-time, guaranteed, deterministic communication required in avionics and vetronics applications.

Competing Backbone Technologies: The Short List

The only interconnect technologies available today which meet the needs of a high performance, harsh environment, backbone communications bus which supports data, audio, and video distribution are:

- Fibre Distributed Data Interface (FDDI in copper version @ 100 Mbit/sec)
- Fibre Channel Arbitrated Loop (FC-AL copper version operates in loop mode - 100 Mbit/sec scaleable to 1 Gbit/sec)
- Asynchronous Transfer Mode (ATM - copper at 155 Mbit/sec scaleable to optical 622 Mbit/sec)

Table 1 provides a comparison of these technologies and shows how they compare to MIL-STD-1553:

Table 1: Interconnect Technology Comparison

Parameter	ATM	FDDI	FC-AL	1553
Projected Cost (material $ per redundant node in a rugged implementation)	8000 (1)	2500	2500	1000
Data Rate (Mbit/sec > may be available)	155	100	100	1
Data Latency (usec worst case)	300	36	30	60
Deterministic Delivery (no=1 yes=10)	1	1	10	10
Bus Initialization Time in ms	10.0	10.0	1.0	0.1
Number of Nodes (practical)	16	16	16	32
Cable Length (copper)	100M	100m+	50m	30 (4)
Intelligent nodes required	Yes	Yes	Yes	No
Thermal Environment span in degrees C	70	130	145	180
Size in square inches	20	12	12	4
Galvanic Isolation	No	No	No	Yes Trsfr
Adoption in harsh environments	No	Navy	Air Force	Many
Physical Layer	STP	Twinax	Twinax	Tri-ax
Guaranteed Delivery (ACK) no 1, yes 10	1.0	10.0	10.0	10.0
Suitable for real-time control	1	6	5	10
Redundancy Management	1 (1)	8 (3)	4 (2,3)	10
Second Source (ext. temp. suppliers)	Unknown	Some	+VHDL	4
Maturity	3.0	6.0	3.0	10.0
Power, maximum in Watts	25 (1)	12.5	10	3
COTS availability	5	8	4	10
Growth	10	1	7	1

Notes:

1. ATM inherently requires a star physical and switch architecture so includes 16 port switch overhead for 8 redundant nodes.
2. ATM or Fibre Channel use dual node adapters to achieve redundancy/fault tolerance.
3. FDDI or Fibre Channel could use a star physical arrangement with a simple cross-bar switch to solve the inherent single point failures of a loop architecture.
4. 1553 cable length is total linear bus length vs. point to point of others.

Fibre Distributed Data Interface (FDDI)

The FDDI standard is the oldest among the competing technologies on our short list and therefore the most technologically mature.

One of the key advantages of FDDI as a replacement for MIL-STD-1553 is its built in dual redundancy feature which automatically (transparent to the application layer) bypasses a downed station. Unfortunately, it rates poorly with respect to deterministic data communication as FDDI is a token ring in which communicating nodes gain access to the network when an active node releases a shared token. It is difficult to simulate the time division multiplex, command response protocol of ‘1553 with a token ring without placing artificial limitations on the media and reducing overall bandwidth.

FDDI has failed to capture a significant share of the commercial networking market since silicon was first introduced over 7 years ago. With the rapid growth in competing communication standards it is extremely unlikely that it ever will. Its primary success, though limited, has been in the large computer backbone networking market previously served by proprietary solutions. Its maximum data rate of 100 Mbit/sec, while at the upper end when FDDI was first introduced, is now a limitation, with 1 Gbit/sec technologies becoming common place. Additionally, the high cost of each node adapter (~$2500) has been a road block to mass deployment. The growth in this market will likely migrate to Fast Ethernet and Fibre Channel.

While its maturity brings the advantage of extended temperature range FDDI chip sets that have been implemented, the long term availability is uncertain as commercial interest in FDDI drops off . Additionally, while extended temperature chips are available, they are at a premium with a costs at over $1000 per node compared to commercial implementations at less than $150. The military has adopted FDDI for some Naval ship board applications in benign environments not likely to see temperature extremes, such as command and control rooms.

For example, FDDI is currently being used on, or in consideration for, Navy programs, including Trident, ARCI, NSSN and SQQ-98. It should be noted that many of these applications are now being targeted for Fibre Channel or ATM implementations.

Asynchronous Transfer Mode (ATM)

ATM has popular support in the telecom world where it has become a preferred wide area digital interconnect. While this should help to reduce the cost point over time, ATM remains an emerging technology whose general adoption as a mainstream product has been hampered by delays in both hardware and software standardization. This slower than projected adoption of ATM has resulted in the loss of some of its initial momentum as a general data bus. ATM has yet to penetrate the desktop connection market and is now competing with Fast Ethernet and soon Gigabit Ethernet. It remains to be seen whether ATM will ever migrate from the telecommunication switch world to desktop solutions.

With its roots in telecommunications, the ATM protocol was primarily designed for voice transmission and is a lossy protocol. For voice and video the ‘on-time, in-order’ but non-reliable attributes of ATM were ideal. They are less suitable for data communications which require reliable, error-free transmissions without information loss. Although loss of a packet in a voice transmission may be undetectable to the human ear, serious inefficiencies arise if a packet is dropped from a data block. Enhancements to ATM protocols to support data have come slowly and thereby have also been an impediment to desktop adoption.

Another handicap to ATM adoption as a military data bus is the lack of low-latency switches and interfaces, and software driver overheads which further compound network latency. Unlike the telecom world which may be able to withstand 100 microsecond latencies, mission critical, military applications require more responsive control.

There are no known commercially available extended temperature range ATM node adapter chip sets. The link level implementations have been developed in VHDL such that ASICs or future high speed FPGAs could be used to develop extended temperature implementations. Like FDDI but to a lesser extent, ATM has seen some use in ship-board environments, where the environment has been fairly benign and sheltered from temperature extremes.

Fibre Channel

Fibre Channel is an ANSI standard which defines a family of protocols which provide low latency, high bandwidth connections. Unlike other networking candidates we have considered, Fibre Channel supports both host-to-peripheral channels and host-to-host network connections. It supports scaleable throughput rates (133 Mbit/sec to 4 Gbit/sec) with data integrity and high reliability provided through its 8-bit/10-bit encoding scheme. Despite the name, Fibre Channel is implemented with multiple physical serial media, including copper coax, twisted pair, or optical fiber. The Fibre Channel standard defines three topologies: a fabric switch topology, point-to-point, and an Arbitrated Loop (FC-AL) which offers a high-performance low-latency network with scaleable growth. FC-AL topology allows up to 127 ports, connected serially, or loop-fashion and offers good electrical characteristics, meaning higher data rates. Unlike ATM, Fibre Channel does not require a concentrator which will result in a lower cost than ATM's switched topology. Where guaranteed performance characteristics must be provided, point-to-point connections can be combined with a basic loop.

The status of extended temperature range Fibre Channel chips is a mixed story. A Fibre Channel node adapter copper implementation consists of high speed buffer memory, a protocol chip, an 8-bit/10-bit encoder/decoder chip and transceivers. An encoder/decoder and transceivers are available in industrial grade. Several military contractors have developed their own protocol chips meeting military environmental requirements. Although these may not be appropriate implementations for the general market they do indicate that single chip harsh environment implementations are possible. An alternative approach is to use a commercial implementation of the protocol with screened parts.

The FC-AE (Fibre Channel Avionics Environment) working group is developing an operational profile of the existing Fibre Channel standard for use in military and in particular avionics environments. The working group is defining a set of real-time constructs to augment Fibre Channel to provide the deterministic latency and bandwidth needed by mission critical applications. The focus is on the definition of real-time arbitrated loop extensions, real-time priority preemption within a fabric, and a real-time isochronous loop. The intent is to enforce fixed size packets and guaranteed access to the loop so as to provide bounded latency and deterministic response; thereby, approaching the deterministic behavior seen with ‘1553 but in a 1 Gbit/sec interface.

Fibre Channel is gaining market share in the commercial world and is supported by all major vendors of workstations and servers including HP, Compaq, IBM and Sun. Additionally, most major server companies are members of the Fibre Channel Association and plan to use Fibre Channel to interconnect servers and storage systems. It is also gaining popularity within the military and has been adopted in avionics upgrades including AWACS Extend Sentry, B-1 Lancer strategic bomber, and F/A-18 Hornet fighter bomber. On the Navy F-18 tactical area moving map capability (TAMMAC) the interconnect between the program load device (PLD) and the map generator will be Fibre Channel. On the B1-B mission computer upgrade, Fibre Channel will be used to interconnect the mission computers and mass storage units while on the AWACS, Fibre Channel is being used to interconnect some 15-20 workstations to the main radar data distribution system. Additionally, it is being evaluated to provide high speed interconnects between complex sub-systems on the US/UK next generation tactical Joint Strike Fighter (JSF).

Summary and Recommendation

We have looked at several high speed interconnect technologies as competing choices to replace MIL-STD-1553 as the data bus of choice for military systems. There are a number of interesting technologies such as IEEE 1394, Fire Wire and USB which are beginning to see acceptance in the consumer electronics world but which for reasons of maturity or fit are not appropriate for military systems. The three technologies which made our short list for detailed evaluation included FDDI, ATM and Fibre Channel.

FDDI is a mature technology which has seen military deployment; however, it has failed to gain popular acceptance and is unlikely to see significant future growth. While it provides built-in redundancy, it does not fair well as a real-time deterministic interconnect and its maximum data rate is slow in comparison.

ATM remains an emerging technology which has popular support in the telecommunications switch market but has failed to become a mainstream technology. With its less than reliable lossy protocol and lack of extended temperature components it has some challenges to overcome before it can be used as a reliable backbone for harsh environment computing networks.

The Fibre Channel Arbitrated Loop (FC-AL) copper implementation offers a high performance low latency network that has scaleable growth. It has been adopted in the commercial arena and a Fibre Channel profile is being developed for the avionics world.

After evaluating each of these technologies and comparing them in terms of suitability to the rigorous demands of future military platforms, the recommended choice for an avionics and vetronics local area network based on open industry standards and new emerging scaleable technology is the Fibre Channel Standard.

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