The MIL-STD-1553B data bus: What does the future hold?

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ABSTRACT

Numerous military platforms (land, sea and air) feature serial data bus technology based on the US MIL-STD-1553B data bus standard for integration of their digital systems. Many of these platforms have 15-20 years of operational life remaining, but the installed 1553B data buses (data networks) having only a 1Mbit/sec transfer rate are unable to meet many of the future data networking requirements. Research into new, higher performance data networks has concentrated on modern alternatives with throughput increases of two to three orders of magnitude (100Mbit/sec to 1Gbit/sec). These are generally based on modern commercial-off-the-shelf (COTS) standards, good examples being Ethernet and Fibre Channel. Some are already being employed in military platforms having been ruggedised for the harsh physical and electro-magnetic environment. However these COTS systems while being a natural choice for new platforms may not be cost effective for upgrading older platforms. This paper plots the history of MIL-STD-1553, possibly the most successful military platform standard of all time, and discusses some of the options for increasing its performance and economically extending its life into the future.

NOMENCLATURE

AIR	air information report
AM	amplitude modulation
ASD	Avionics Systems Division
ASSC	Avionics Systems Standardisation Committee (UK)
ATD	advanced technology demonstrator
BC	bus controller
BER	bit error rate
CANbus	controller area network bus
CAP	carrier-less amplitude phase
COTS	commercial off the shelf
dc	direct current
DDC	Data Device Corporation
Def Stan	defence Standard (UK)
DISC	Digital Interfaces Sub Committee
DMT	discrete multi tone
DR	dual rate
DSL	digital subscriber line
DoD	Department of Defense (US)
EBR	extended bit rate

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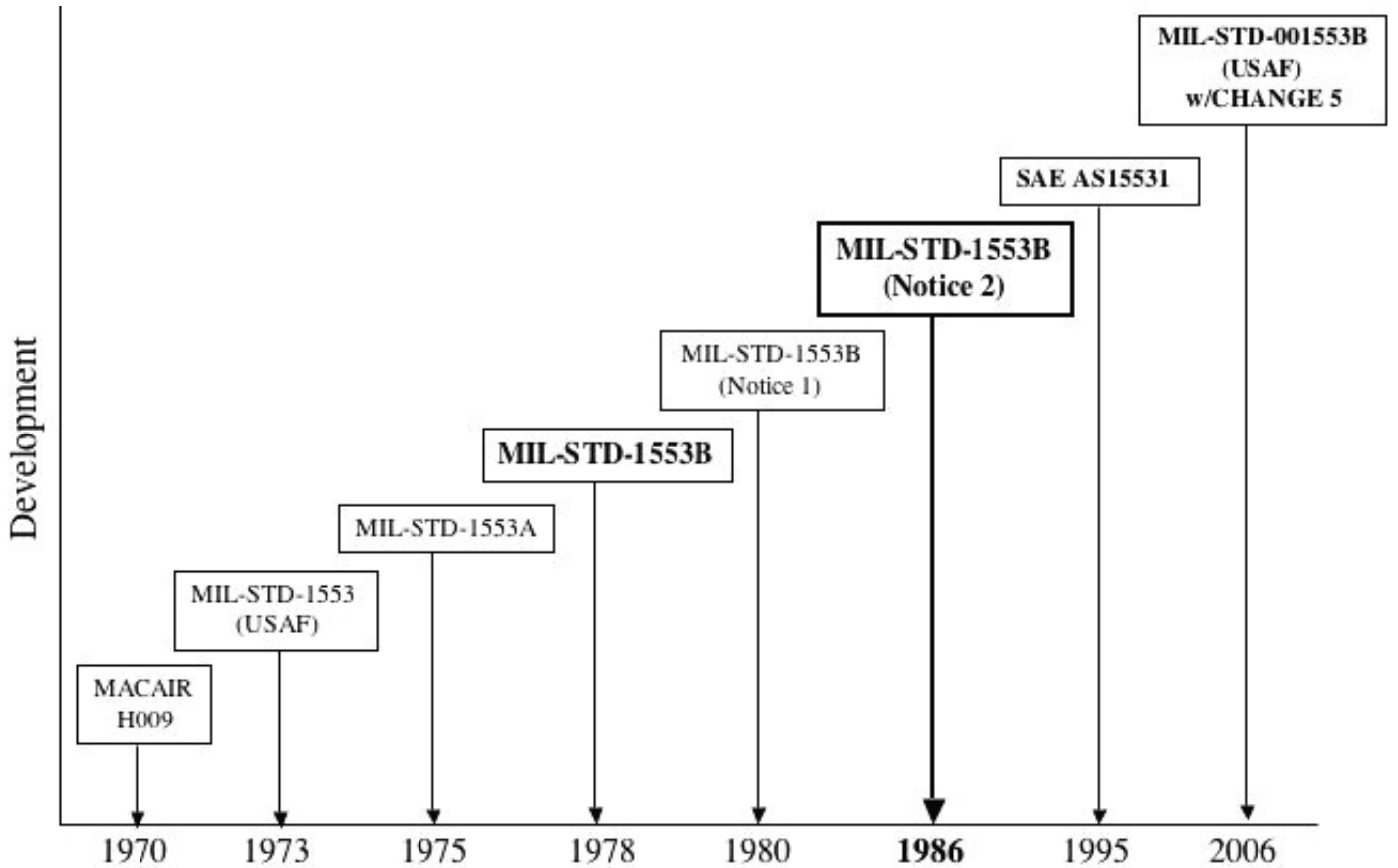


Figure 1. MIL-STD-1553B – History of main development.

EFA	European Fighter Aircraft
EFEX	EFAbus Express
EMC	electro magnetic compatibility
EMC&H	electro magnetic compatibility and hazards
EIA	Electronic Industry Association
FDM	frequency division multiplexing
FSK	frequency shift keying
HS	high speed
IPR	intellectual property rights
JDAM	joint direct attack munition
JTRS	joint tactical radio system
LS	low speed
Mbit/sec	megabits per second
MIL-STD	military standard (US)
MMSI	miniature munitions store interface
MSCS	miniature store carriage system
MoD	Ministry of Defence
NATO	North Atlantic Treaty Organisation
NEC	network enabled capability
NG	next generation
PREN	PReliminary European Norm
QAM	quadrature amplitude modulation
RAE	Royal Aircraft Establishment
RT	remote terminal
SAE	Society of Automotive Engineers
SEAFAC	systems engineering avionics facility
SMS	stores management system
STANAG	standardisation agreement (NATO)
UK	United Kingdom
USAF	United States Air Force
US	United States
WPAFB	Wright Patterson Air Force Base

1.0 INTRODUCTION

At present nearly all modern military platforms (land, sea and air) use serial digital data bus technology, mostly based on the US MIL-STD-1553B[1] data bus standard or its European equivalents such as UK Def Stan 00-18 (Part 2)[2] and NATO STANAG 3838[3], to interconnect the various on-board computing and electronic systems. The MIL-STD-1553B serial data bus, or 'bus' for short, usually provides the primary means of data transfer for all these systems and subsystems. Using a central bus controller concept the standard defines a means to programme all data transfers within a given system by providing deterministic message transactions for all operational modes of the system plus additional capabilities for bus management, message error detection and a degree of re-configurability.

The performance requirements defined in the standard provide for the reliable operation of buses in the harsh physical and electromagnetic environment of military platforms and the in-built design features provide a degree of protection and fault tolerance in the event of component failure and/or battle damage. For over three decades the 1553B data bus has provided a wholly dependable and deterministic means of communication between the on-board systems and sub-systems of military platforms particularly in military avionics systems for which it was originally designed.

While the system is highly dependable the 1Mbit/sec transmission rate is slow by modern standards and does not always provide sufficient data throughput for many current systems leading to bus loading problems. Furthermore it does not have anything like sufficient capacity for modern military platforms requiring on board systems and data networks capable of meeting the requirements for the modern electronic battlefield using network enabled capability (NEC).

A useful appendix has been added giving a brief introduction to those readers unfamiliar with the MIL-STD-1553B data bus.

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1.1 History of MIL-STD-1553B

MIL-STD-1553 was first introduced into military avionics systems in the early 1970s in the USA. It provided an unprecedented reliable, deterministic and high integrity data transfer service and quickly found use in many military computing applications. It became popular not only for aircraft but also land and sea based systems and because of its ruggedness also featured in some, non-aircraft related high integrity commercial applications.

As a military standard it has enjoyed phenomenal success and is now widely deployed in almost every military platform produced in the western world. Furthermore over the 30+ years of its existence it has remained largely unchanged and unchallenged as the on-board 'bus' of choice for new military systems. A brief history of the main milestones achieved during the development of MIL-STD-1553 are shown in Fig. 1.

The serial data bus concept first emerged in the USA in 1970 for the F-15 fighter programme using a McDonnell Douglas in-house company standard known as 'Macair H009'. It featured most of the basic concepts still found to this day in MIL-STD-1553B such as a half–duplex operation using a command-response communication protocol, 1Mbit/sec bit rate and the transmission of 1 to 32 word messages with each word consisting of 16 bits plus 1 parity bit. 1973 saw the first official publication of the standard known as MIL-STD-1553 (USAF) which as the name implies was at the time limited to United States Air Force (USAF) applications only.

The US Department of Defense (DoD) noticed that there were similar data bus developments also emerging from the US Army and Navy departments for their own programmes. They commissioned a special tri-service (Army, Navy, Air Force) committee to agree a joint (common) version of the standard for all three services. The result was MIL-STD-1553A published in 1975. This standard built on many of the basic features found in 1553(USAF) but added features that both the US Army and Navy felt were important for their own applications, the best example being the strong US Navy desire for direct coupled stubs and a broadcast capability.

By now industry, realising the potential of 1553, had taken a close interest in the emerging technology and formed a committee under the Society of Automotive Engineers (SAE) known as the A2K committee on multiplexing to develop the concept further. Supporting this initiative the US DoD commissioned the SAE/A2K to co-ordinate the development of the first major update of 1553 to the 'B' version of the standard with final decisions on its content being retained by the US military Tri-Service committee.

At this time serial data bus technology was also being researched in Europe, particularly in the UK by the then Royal Aircraft Establishment (RAE), part of the UK Ministry of Defence (MoD), for potential use in UK military aircraft. The RAE research programme quickly established that the 1553 concept was well suited to future UK programme needs and through its special relationship with the US Air Force at Wright Patterson Air Force Base (WPAFB) and its representation on the SAE/A2K committee quickly became involved with the ongoing development of 1553. This work contributed to the development of MIL-STD-1553B which was published in 1978. Following this publication there was a minor update in 1980 when the USAF published an amendment notice to the standard 'Notice 1 (USAF)' which limited the use of some of the options contained in 1553B when used for USAF programmes only.

Following the formal publication of MIL-STD-1553B there followed a period of intense technical development of the standard over a number of years largely co-ordinated by the SAE committee culminating in the publication of the Tri-service 'Notice 2' version of the standard in 1986. Those involved included all interested parties from government and industry sources including valuable input obtained from a number of US program offices that were by now using earlier versions of the standard in a number of projects. There was also considerable input from research work taking place in Europe, particularly from the UK where a whole range of 1553B compatible hardware including interface 'chip-sets', cables, couplers and transceivers, etc, were under development.

The activities leading to publication of Notice 2 were overseen by the Systems Engineering Avionics Facility (SEAFAC) at WPAFB. SEAFAC co-ordinated the update process taking technical inputs and recommendations from the SAE/A2K, project offices, academia and other agencies throughout the world which after technical vetting were then submitted to the Tri-service committee for authorisation resulting in the second and most significant update of 1553B known as MIL-STD-1553B 'Notice 2'. This is the definitive version of the standard which is still in use today. There have been more recent change notices published, 'Notice 3' (1993) and 'Notice 4 '(1996) but these are non-technical in nature and were published for administrative purposes only.

However a brand new version of MIL-STD-1553B[4] officially known as MIL-STD-001553B(USAF) w/CHANGE 5, but commonly referred to as '1553C' or '1553B Notice 5' was published in February 2006. This is a major upgrade of the standard offering an entirely new capability of ≥100Mbit/sec transmission rate on standard 1553B bus wiring harnesses. At the time of writing the contents of this standard were subject to US Department of Defense export restrictions and was not available in the UK. However, more about this new standard and its potential impact on the future of 1553B later.

2.0 BACKGROUND

Although MIL-STD-1553B enjoys widespread application in thousands of military platforms on land sea and air the standard was originally designed for the integration of military aircraft avionics. From the very beginning the use of serial data bus technology made a huge impact on the design, reliability and ease of maintenance of these systems by substantially reducing the on-board wiring mass and offering single point access for test equipment. It was inevitable that the industry would build on its success and the following section looks at closely related developments to 1553B.

2.1 Developments

Over the years a number of different and related versions of the standard have been produced mainly in the USA, UK and by the North Atlantic Treaty Organisation (NATO). Figure 2 identifies the most significant of these divided into three categories – different versions, related standards and recent developments. The diagram shows the relationship of these various other standards and documents to the core MIL-STD-1553B standard.

The 'different versions' area mainly identifies additional national and international versions of MIL-STD-1553B together with the well known 'MACAIR' McDonnell Douglas Aircraft Company standards. In particular UK Def-Stan 00-18 (Part 2) and NATO STANAG 3838 are the main publications which are technically identical to 1553B except for a minor relaxation in prohibition of the use of broadcast messages for data transfers. The UK Def-Stan standard version has also been Anglicised with changed wording to enhance interpretation and uses Metric rather than the US preferred units contained in 1553B. AS15531 is the SAE 'enhanced' version of 1553B and NATO STANAG 7155 is simply the NATO version of SAE/AS15531. The SAE version does contain some minor differences compared with 1553B which are identified in a UK Avionics Systems Standardisation Committee (ASSC) document[5]. Finally the MACAIR standards are company in-house standards used by McDonnell Douglas for aircraft such as the F-15, F/A18, AV8B and Harrier GR7, etc. The two most popular versions are shown being MDC A5232 based on 1553A and MDC A5690 based on 1553B. Functionally the MACAIR standards are almost identical to their 1553 counterparts. The main difference is that the MACAIR standards call for centre tapped to ground bus coupling transformers

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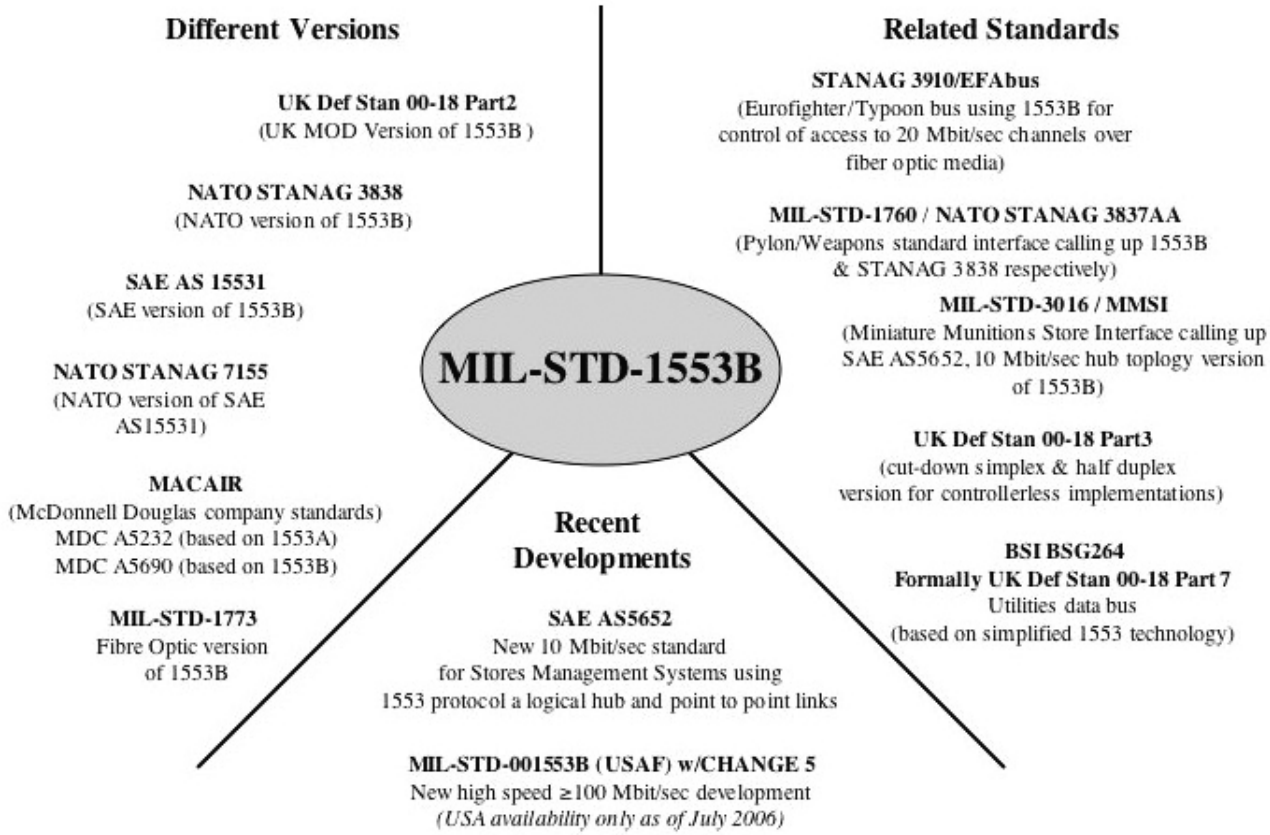


Figure 2. MIL-STD-1553B – different versions, related standards and recent developments.

and a different sinusoidal waveform transmitted on the bus. This has enabled the company to run data bus cables within ordinary aircraft wiring looms with pigtailed screens through bus and bulkhead connectors without impairing the electro magnetic compatibility (EMC) performance of the aircraft. Most 1553B component vendors offer bus transceivers compatible with both 'standard' 1553B and the MACAIR versions through pin selection.

The 'related standards' area shows a list of standards that either call up the use of 1553B in some way or where 1553B was used as a source for the definition of a wholly new standard. In the first category NATO STANAG 3910/EFAbus call up the use of NATO STANAG 3838 to control access to high speed (HS) 20Mbit/sec channels as defined in NATO STANAG 3910. MIL-STD-1760 and its NATO equivalent STANAG 3837AA (aircraft pylon/weapons interface standard) call up the use of 1553B and STANAG 3838 respectively. MIL-STD-3016 the miniature munitions store interface (MMSI) standard currently under development will call up SAE AS5652 the SAE's new 10Mbit/sec hub topology data bus which uses some of the protocol features of 1553B but being specifically designed for aircraft armament applications and is known as Extended Bit Rate (EBR) 1553.

UK Def-Stan 00-18 (Part 3) is a simple, fixed message format, point-to-point, single source, multiple sink data transmission system (no bus controller required) based on 'cut down' 1553B technology. Finally UK British Standards Institute (BSI) BSG264 is a simplified 'low cost to connect' utilities data bus based on 1553B concepts but using a slower 250Kbit/sec transmission rate but supporting up to 128 addressable terminals (compared with only 31 for 1553B systems).

The 'future developments' area shows the new AS5652 developed by the SAE and also MIL-STD-001553B w/CHANGE 5 the new standard sponsored by the USAF to define a •100Mbit/sec service capable of being transmitted on existing 1553B data bus harness wiring.

2.2 The need for higher speed

Modern advances in electronics and processing technologies together with their attendant increased functionality and performance requirements have made the 1Mbit/sec operating speed of 1553B a limiting factor for new system designs. This limitation has been recognised for many years and mostly overcome by using multiple 1553B buses and dedicated point-to-point links to form the hierarchical system architectures seen in the majority of present day military systems. While this strategy has been largely successful for new platforms when first in service, the ability to conduct subsequent upgrades has been compromised by there being little or no bus bandwidth left for increased data traffic.

The constant efforts to improve the performance and capability of legacy military platforms would be significantly aided by the introduction of higher speed data transmission between the on-board systems. Small improvements in speeds over the standard 1Mbit/sec of 1553B to perhaps between 2 and 5Mbit/sec would provide some relief to older systems currently suffering from high 1553B bus loading. This could possibly be achieved by simply increasing the bit rate of the standard 1553B protocol. However, to accommodate new military requirements, particularly for network enabled capability (NEC), there is a need for at least two orders of magnitude increase in speed to at least 100Mbit/sec. This is needed to cater for requirements such as transmission of real time uncompressed digital video for target identification, real time imaging for target damage assessment and the system wide transfer of large on-board data bases such as map and terrain information. This kind of performance increase cannot be achieved by simply increasing the bit rate of standard 1553B systems.

In order to meet these new requirements research into newer more capable data networks for military platforms has concentrated on developing alternatives to 1553B which will yield the required

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performance. Solutions are generally based on well established commercial off the shelf (COTS) standards suitably ruggedised for the military environment. However retrofitting or upgrading legacy platforms in this way requires labour intensive activities including the removal of old wiring and terminal hardware, etc and the installation of new data network cabling. The latter for aircraft involves de-skinning the structure which is a lengthy and costly process.

The incorporation of new COTS based data networks makes sense for new build weapon system platforms and may at first sight seem attractive for upgrading legacy systems by offering such a huge increase in performance. However, for these systems the benefits must be traded off against the relatively high cost of implementation, the problems of technology mismatch and overall life of platforms that are often heading towards the end of their service lives. It may for example be more appropriate and cost effective to consider using some form of enhancement to the MIL-STD-1553B systems that already exist on the platform rather than removing the existing 1553B hardware and re-wiring for a new COTS based alternative.

The rest of this paper explores the various options for higher performance 1553B that are either known to exist or to be under development with the objective of helping system designers choose an appropriate strategy when faced with system upgrade decisions.

3.0 ENHANCEMENT OPTIONS

There has been no shortage of ideas for extending the capabilities or improving throughput performance of 1553B data bus systems. These range from simply dealing with some of the perceived shortcomings within the existing standard to the study of new higher performance systems using different technologies. The committees under the SAE/AS1 have been the main industry focus for most of these activities and they have spent a great deal of time and effort looking at ways of improving the performance of 1553B. Their activities are known to have included: compiling an 'issues' document on the existing version; publishing the SAE's own version of 1553B known as AS15531; developing dual-rate versions of both 1553B and a little used fibre optic version of 1553B known as MIL-STD-1773; developing the new 10Mbit/sec 'EBR1553' for the miniature munitions store interface (MMSI) and investigating requirements for higher speed versions of 1553B under the 'next generation (NG)1553' initiatives.

Most of the proposed enhancements to 1553B fall into three main categories listed below:

1. Simply running the existing 1553B bus faster by increasing the clock speed (i.e. over-clocking).
2. Increasing performance by using technologies and/or features of standard 1553B enhanced or modified in some way.
3. Alternative schemes that can use already installed 1553B bus wiring to support much higher speed data transmission services.

Some developments have been a mixture of the above, for example there have been proposals in the past for the transmission of high speed (burst) data during the inter-message and response-time gaps times defined in the basic 1553B protocol and for the use of 'speeded up' 1553B communication protocols unmodified within the channels of higher performance COTS based data network systems such as Fibre Channel. There has also been successful development work on dual-rate systems where the bus is operated alternately at both the standard speed of 1Mbit/sec and a higher speed in order to retain compatibility with existing 1Mbit/sec terminal hardware. However many of these concepts were never developed beyond their initial proof of concept stages. In contrast some developments in the three main categories listed above have led to practical and documented demonstrations or new standards such as NATO STANAG 3910 and most recently MIL-STD-001553B (USAF) w/CHANGE 5.

3.1 Faster clocked versions

This method of enhancing the performance of 1553B relies on simply increasing the clock frequency (or overclocking) of the bus terminal hardware to increase data throughput.

The main problem with this approach is caused by the electrical dynamics of the bus harness as the 1553B bus network essentially forms a low pass filter with a usable bandwidth somewhere between 500Khz and 10 MHz. Another problem is that different 1553B bus harnesses can exhibit very different overall bandwidths due to the dominant effect of the bus coupling transformers whose bandwidth can and does vary significantly. The bandwidth limitation at the high frequency end strips the higher order harmonics of the waveform slowing rise and fall times to the point where the overall amplitude of the signal is reduced at faster clock frequencies. On top of this capacitive reactance and signal reflections from stubs on the bus become more of a problem with increased clock speed compromising waveform integrity eventually leading to receiver decoding errors.

Another issue for faster clocked versions is that the existing remote terminal (RT) response times and bus controller (BC) generated inter-message gap times may have to be retained at their current values (as for the 1Mbit/sec version) and not made proportionally smaller with faster clock rates. These gap times are needed to guarantee decay of residual energy stored in the bus network which has a time constant as a function of the distributed capacitance and inductances present in a particular bus wiring harness. This causes, as the clock speed is increased, an ever increasing loss of throughput efficiency.

However, despite all the above problems a number of different and successful approaches to faster clocking have been tried over the years with some 'one off' customised designs having being implemented in projects. In the past the main work of interest in this area has been conducted by the SAE with the development of dual rate (DR) systems and in the UK with the work of the ASSC on faster clocking of conventional 1553B which took place during the late 1990's.

3.1.1 SAE developments

The SAE developments included a DR approach where both 1 and 2Mbit/sec systems co-exist on a single bus with operation at either of the two rates at different times determined by either two bus controllers synchronised together or a single dual-rate bus controller. This approach offers several advantages for system designers who are looking for particularly low risk upgrade paths for their systems as follows:

1. The 2Mbit/sec is a conservative increase in speed that would work on most existing 1553B bus hardware with minimum modification.
2. The approach allows for a theoretical doubling of the number of RT addresses from 32 to 64 on a single bus with 'same' addresses on the 1 and 2Mbit/sec systems being transparent to one another. Note there may be a practical limit to the number of RTs that can be physically attached to a single bus below the maximum 64 due to electrical loading limitations.
3. Timing requirements for the 2Mbit/sec operation are simply scaled up from the standard 1Mbit/sec operation for simplicity.

Another DR approach jointly developed by the US Navy and the SAE was a DR version of MIL-STD-1773 this standard being the 'fiber optics mechanisation' of MIL-STD-1553B published in 1988. DR1773, as it was known, was a further development of 1773 and supported both 1Mbit/sec and 20Mbit/sec operation. Unfortunately neither of the above approaches found widespread application as their benefits were largely overtaken by the promise of more capable systems such as EBR1553 and 1553B 'Notice 5' that were also being developed at the same time. However these systems do represent a class of low risk enhancements to 1553B that have been tried and tested which could be realistically considered for use in projects requiring relatively modest levels of improved performance.

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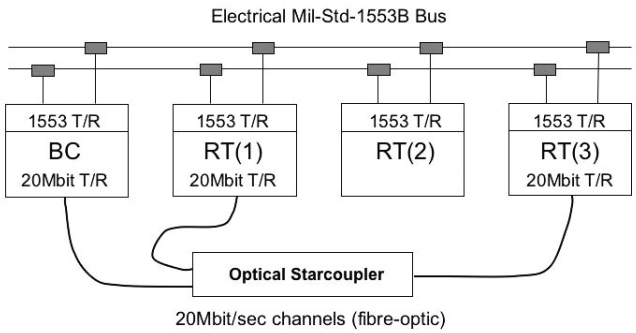


Figure 3. STANAG 3910 Type A configuration.

3.1.2 ASSC faster clocked 1553B studies

Turning to the work of the ASSC in the UK, it was felt there would be benefits from running conventional 1553B systems faster in situations where high bus loading was becoming a problem with current systems and where modifications must be kept to a minimum. With this in mind the ASSC supported by the UK MoD conducted a four phase programme of investigation and development during the period 1997 to 2000 under the guidance of the ASSC Data Interfaces Sub Committee (DISC)

The first phase investigated the feasibility of faster clocked approaches. This involved studying previous work using the technique, testing 'real' 1553B compatible hardware to determine maximum achievable bit rates, studying the effects on throughput of changing word and message lengths and conducting an analysis of the maximum theoretical capacity of 1553B bus networks.

The second phase involved a practical study undertaken to examine the extent to which bit rate could be increased using industry standard protocol devices together with transceivers having minimal modifications to accommodate the higher frequencies and faster rise and fall times of bus waveforms. A number of internationally recognised 1553B component suppliers supplied test hardware for investigation into this phase of the programme.

The third phase investigated the effectiveness of improved protocol device clocking arrangements, the performance of different bus configurations using components from different suppliers and the constraints on enhanced bit rate operation imposed by the dynamics of the bus harness and, in particular the coupling transformers.

The fourth phase investigated the electro magnetic compatibility (EMC) aspects of faster clocked 1553B data buses under the guidance of the ASSC Electromagnetic Compatibility and Hazards (EMC&H) working group. This work concluded that in general there was no significant worsening of the EMC performance of 1553B data buses either for radiated interference or susceptibility up to a data rate of 3Mbit/sec. All the 1553B configurations tested at these higher bit rates effectively passed the industry standard EMC tests in use at the time for avionic systems.

The experience gained from conducting the above programme was used in collaboration with the SAE/ASD to produce a draft Air Information Report (AIR) 5591[6] to support the use of SAE AS15531 buses (the SAE version of 1553B) at enhanced bit rates.

Overall the ASSC work clearly demonstrated that modest increases in bit rate over 1Mbit/sec were feasible with no modification to an existing bus network and with only minor changes required to terminal hardware. However, it should be noted that differences in bus configuration and the performance of components (in particular coupling transformers) from different suppliers caused variation in the maximum bit rate achievable but for most practical purposes speeds somewhere between 2 to 5Mbit/sec could reliably be achieved with minimum modifications and no adverse affects to the EMC performance. All the ASSC work on fast clocked 1553B systems is available (at the time of writing) as a single report[7] from the ASSC website at http://www.era.co.uk/assc/databus.asp.

3.2 Increased performance examples

This category of system obtains increased performance by borrowing technologies and/or features of standard 1553B that are either partly used, enhanced or modified in some way to produce a new bus system specification. There are two significant developments in this category that have lead to new standards widely recognised by the industry. The first is NATO STANAG 3910 that uses standard 1553B to control access to faster (20Mbit/sec) communication channels and the second is SAE AS5652 a 10Mbit/sec hub based topology version of 1553B.

3.2.1 STANAG 3910

NATO STANAG 3910[8] was produced in Europe and also has the status of a PReliminary European Norm standard as (PREN) 3910. This standard was developed primarily for the Eurofighter Typhoon programme and the version used in this programme is known as 'EFAbus'.

This approach relies on using special 1553B messages transmitted at 1Mbit/sec on the 1553B bus to instruct high speed (HS) capable terminals to communicate on separate HS channels (at 20Mbit/sec using separate fibre optic or wire media). Messages transmitted on the HS channels are similar in construction to standard 1553B messages in that they define BC to RT, RT to BC and RT to RT messages using HS command and HS status words. The standard has four basic options for choice of media as follows:

Type A	low speed (LS) channel	1553B electrical data bus
	high speed (HS) channel	fibre optic data bus
Type B	LS channel	fibre optic equivalent of 1553B
	HS channel	physically separate fibre optic data bus
Type C	LS channel	fibre optic equivalent of 1553B
	HS channel	wavelength division multiplexed with the standard 1553B LS channel onto a common fibre optic medium
Type D	LS channel	1553B data bus
	HS channel	physically separate wire data bus

'EFAbus' as used in the Eurofighter conforms to a type 'A' version of the STANAG using standard electrical 1553B (LS) and optical 20Mbit/s (HS) channels. The French Rafael fighter uses a type 'D' configuration using electrical 1553B (LS) and electrical 20Mbit/sec (HS) channels. Figure 3 shows the general configuration of a type 'A' system as used for the Eurofighter using an optical reflective star coupler and point to point fibre optic links to support the HS channels.

This type of system enhances the capability of 1553B by simply adding additional higher speed services on an alternative bus medium to the 1553B bus used for access control using standard 1553B message formats. The message protocol on the HS channel is similar to 1553B therefore much of the experience and knowledge gained from using conventional 1553B systems in the past has been translated to the definition of the HS side of the system leading to a generally lower risk and potentially more cost effective upgrade path.

In practice the only down side of defining the EFAbus/STANAG 3910 standard was difficulties experienced in the early days with the development of fibre optic components capable of meeting the full military environment which took much longer than expected however this is no longer a problem. Now with mature components readily available and with STANAG 3910 in use both in the Eurofighter Typhoon (fibre optic HS media) and the Rafale (electrical HS media) the standard has become firmly established, reliable and well proven. A more recent development of the EFAbus standard can be found in EFAbus Express (EFEX) where the option exists to use 20Mbit/sec channels without having to use the 1553B bus for access control.

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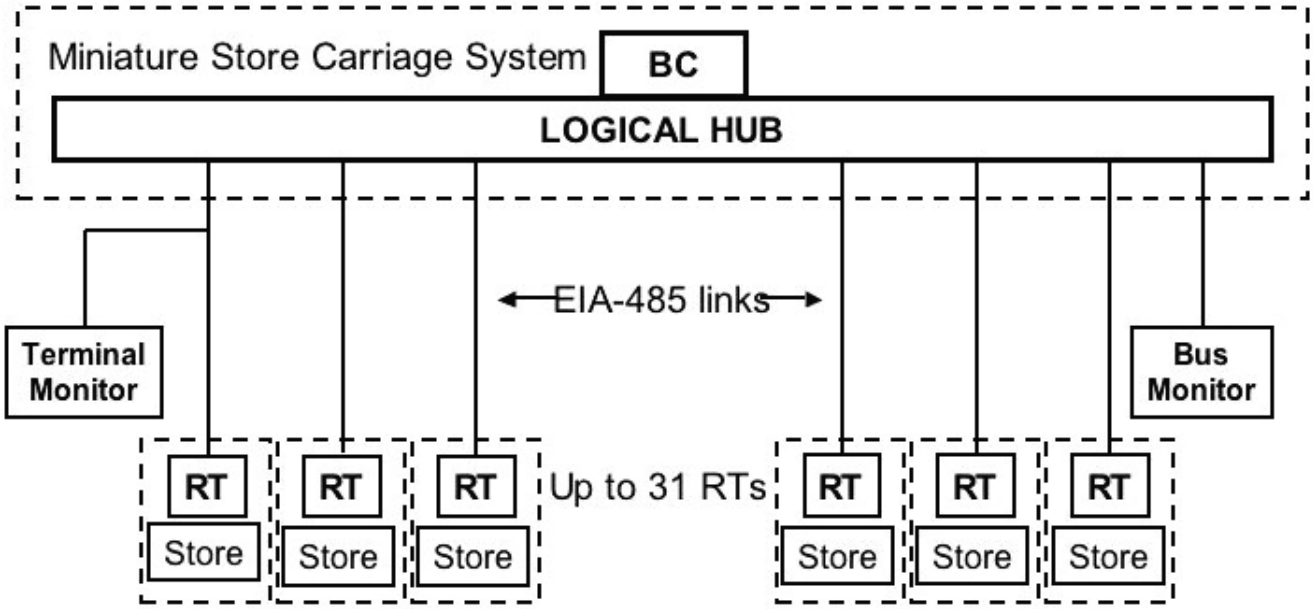


Figure 4. AS5652 general configuration.

3.2.2 SAE AS5652

This is a new development from the SAE intended to provide a higher performance version of 1553B for the miniature munitions store interface (MMSI) standard MIL-STD-3016 currently under development for the aircraft armament community. Also known as EBR1553 the standard offers a full 10Mbit/sec operation. The general configuration is shown in Fig. 4.

The standard uses the same command/response protocol as defined in 1553B with some limitations but the linear, multi-drop serial bus harness is replaced by an active logical hub located in the miniature store carriage system (MSCS) with physical point-to-point links conforming to the commercial EIA-485 standard connecting to the RTs. This facilitates the use of low cost commercial EIA-485 transceivers throughout the system.

The scheme supports both monitoring of the whole bus using a special output from the logical hub or individual dedicated terminal monitors. There is also an extension defined in the standard to increase the usable address range from 31 to 255 by using a 'supporting' controller area network bus (CANbus) interface to provide extended addressing capabilities.

It is understood the SAE are continuing development of this standard and looking at ways of offering a serial multi-drop topology option in the future.

3.3 Alternative schemes

For the various faster clocked schemes to improve the performance of MIL-STD-1553B described above the laws of physics eventually prevail limiting maximum bit rate for faster clocking on legacy 1553B buses to around 5Mbit/sec depending on bus layout and the bus components used.

The next opportunity for improving the throughput performance of 1553B is by using the increased performance schemes by either changing the topology and media used as in AS 5652 operating at 10Mbit/sec, or by using 1553B to control access to higher speed services such as that used in STANAG 3910 at 20Mbit/sec. While these methods offer good improvements in performance over the standard 1Mbit/sec of 1553B they still have their own limitations. For example AS 5652 specifies the use of EIA-485 links where 10Mbit/sec is the maximum transmission speed and STANAG 3910 uses standard 1Mbit/sec 1553B to control access to its HS channels. While the speed of the HS channels can theoretically be increased there is still the fundamental limitation of a lower speed system controlling access to a higher speed system with its attendant inefficiencies whose effects get worse as the HS transmission speed is increased.

None of the schemes discussed so far can address the need for bandwidths greater than 100Mbit/sec for NEC platform requirements. A fundamental re-think was therefore needed to address the problem of upgrading legacy systems currently using 1553B to be capable of supporting these significant increased levels of data transmission throughput.

3.3.1 A new approach

In the late 1990s, particularly from the need identified by the USAF and the work conducted within the SAE/ASD, it was apparent that a radical new approach was required to significantly increase the performance of 1553B systems. Ideally it was felt that being able to transfer data at high speed on existing 1553B wiring harnesses as an additional service would be the most cost effective and efficient way forward for upgrading legacy systems. Most military platforms are integrated using 1553B so overlaying an additional service would be a nearly ideal solution. Figure 5 shows how this capability might be used in a military aircraft avionics example.

In this example several key equipments associated with sensing and receiving target imagery are integrated using a standard dual redundant 1553B data bus. It can be seen that higher data rates are required to export data from the radar receiver, to transfer data in and out of the Mission/SMS computing and bulk memory units, and to convey image data from the joint tactical radio system to the rest of the units. The new capability would support all these higher speed data transfers without the need for additional wiring.

Seeking a technical solution for this type of high speed data transfer the SAE turned to the telecommunications industry where new techniques had been developed to support broadband data transmission along standard telephone lines. For these applications a

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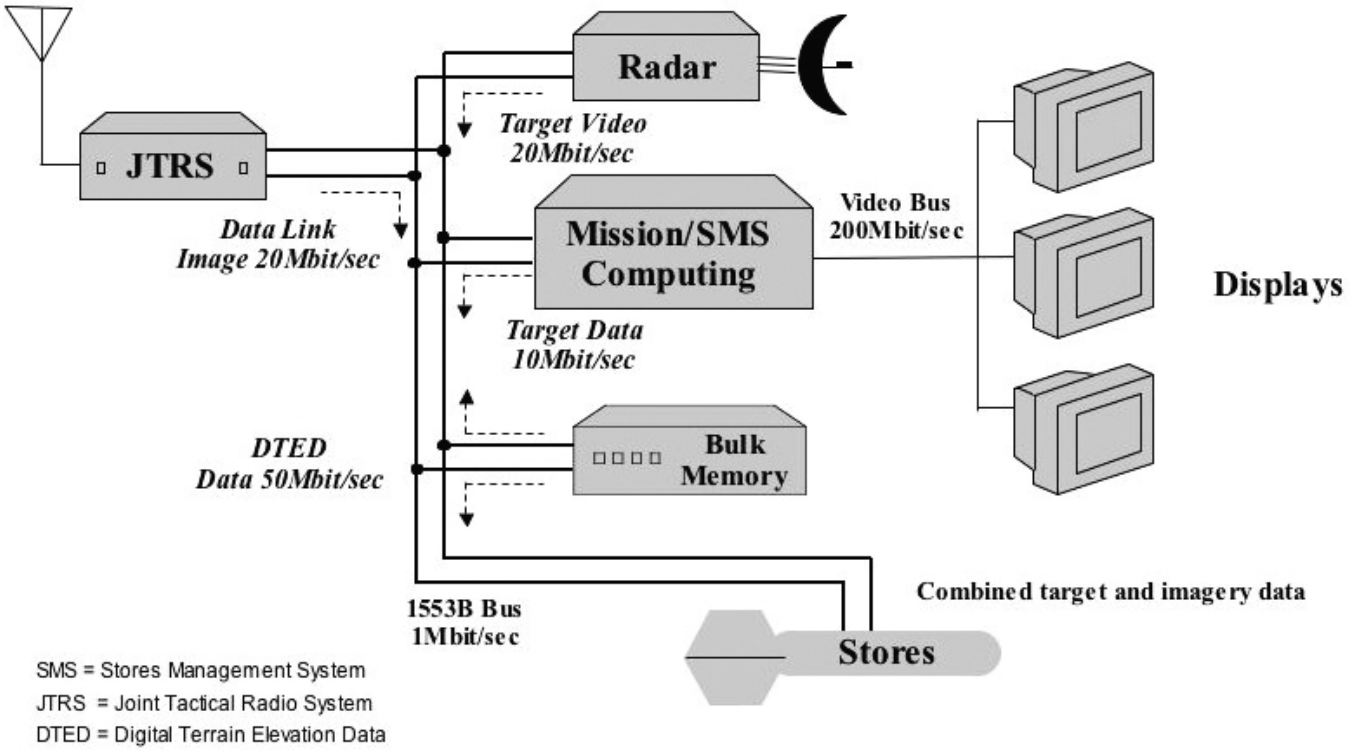


Figure 5. Example of mixing standard 1Mbit/sec and higher speed transmissions on the same 1553B wiring harness.

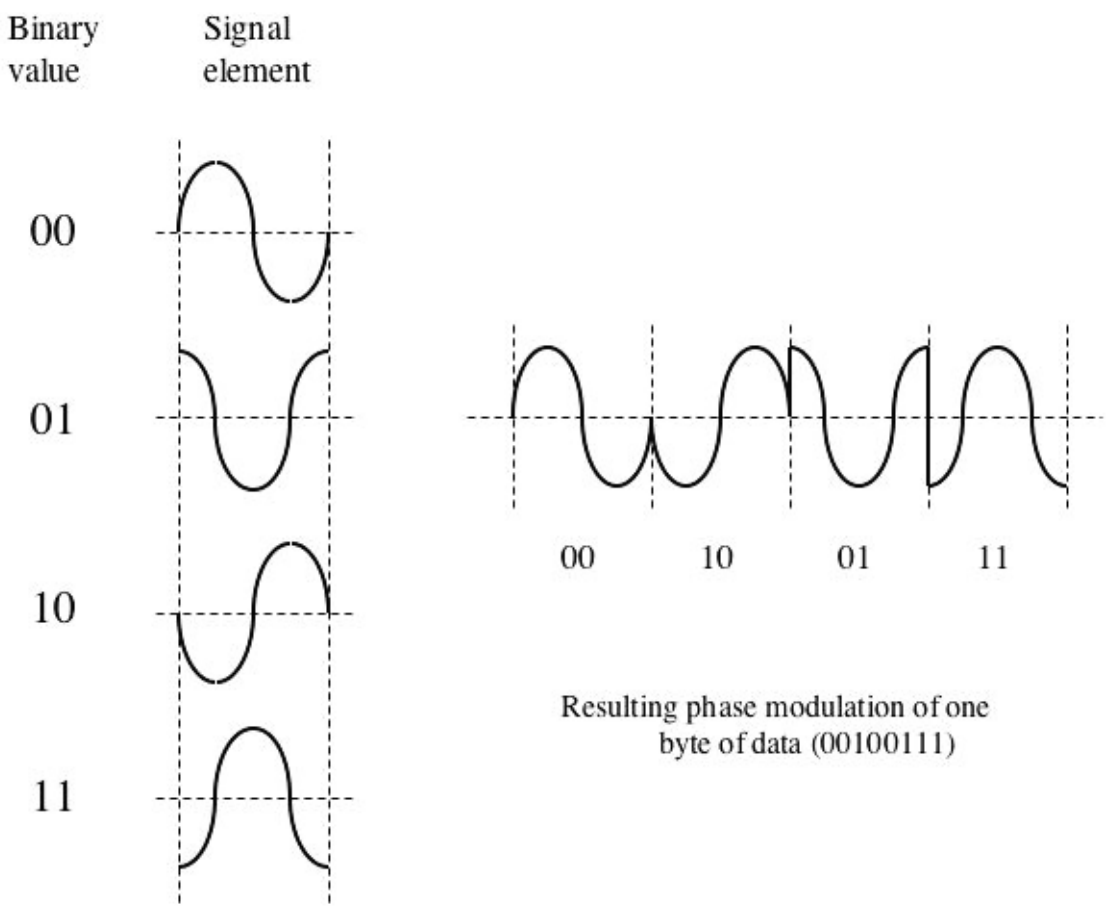


Figure 6. Code gain method using phase modulation.

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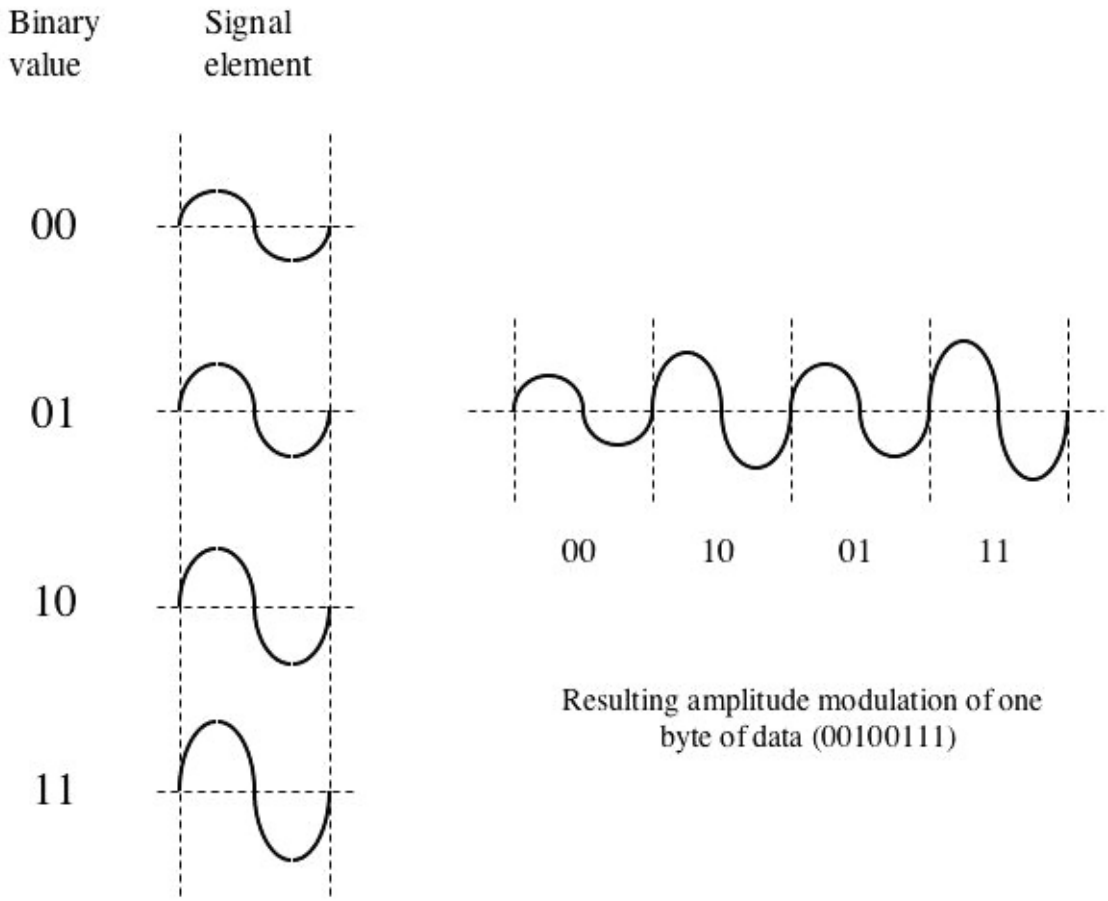


Figure 7. Code gain method using amplitude modulation.

concept known as 'code gain' is used to transmit high rates of digital data far in excess of the analogue bandwidth of the transmission channel used. This concept offered an opportunity to break free from the classic bandwidth limitations associated with standard 1553B wiring harnesses which limited simple faster clocked solutions to around 5Mbit/sec.

The most promising 'code gain' technologies identified were the rapidly developing digital subscriber line (DSL) family of standards. They use advanced coding methods such as frequency division multiplexing (FDM), phase shift keying (FSK) and amplitude modulation (AM) combined in various ways to achieve novel line coding methods. At the time of the study the two main coding techniques identified were discrete multi tone (DMT) and carrier-less amplitude/phase (CAP). The DSL family is constantly being developed to support higher data throughputs with more limited channel bandwidths.

To give a brief understanding of how code gain is achieved Fig. 6 illustrates how phase modulation can be used to encode one byte of data into four signal elements.

It can be clearly seen how the phase of the signal element is adjusted to achieve the desired encoding and the resulting waveform for the example of a single byte of data (00100111).

Figure 7 illustrates how amplitude modulation can also be used to encode one byte of data into four signal elements. Again it can be clearly seen how this time a variation in amplitude of the signal is used to encode the data and the resulting form of the example single byte of data (again 00100111).

Figure 8 shows how both phase and amplitude modulation can be added together to transmit four bytes of data using only four signal elements. This is representative of the well known quadrature amplitude modulation (QAM) technique commonly used in

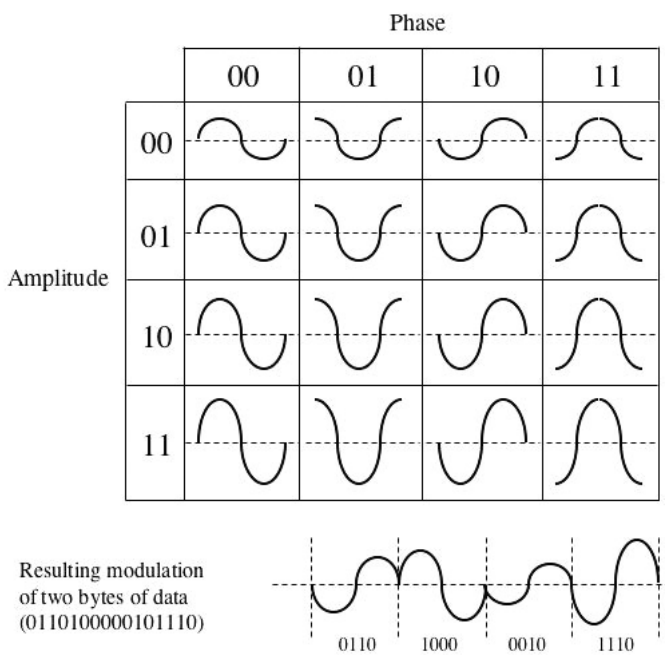


Figure 8. Quadrature amplitude modulation (QAM) example.

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carriers called sub-channels which for DMT are independently modulated and transmitted simultaneously thus multiplying the code gain achieved by QAM by the number of sub-channels used. So within the limited bandwidth of telephone wiring we have hundreds of sub-channels each carrying QAM modulated data thus providing a data throughput many times that of the analogue bandwidth of the system.

These techniques have been established in the telecommunications industry for some time and they enable the transmission of broadband data along standard telephone wires to carry many Mbit/sec of data traffic both for uplinks and downlinks while still allowing the simultaneous use of analogue voice channels by not having data sub-channels in the spectrum occupied by the analogue voice service.

As the bandwidth of a 1553B wiring harness is greater than that of telephone wiring there is considerable scope for DSL based techniques to offer data throughputs significantly greater than that currently achieved for telephone based broadband services.

Could such techniques therefore be used successfully on existing 1553B wiring harnesses to achieve a major new capability for upgrading existing systems and accommodate the new NEC driven data transfer speed requirements discussed above? The answer is yes with two major developments in the USA having achieved major milestones in 2006. Technically both these developments have been kept very much under wraps (presumably for intellectual property rights (IPR) reasons) but they are both believed to employ variations of the DSL techniques discussed above suitably refined and engineered for the military environment.

3.3.2 USAF sponsored development

The USAF has long defined its need for high performance 1553B systems and was behind the original US Tri-Service request to the SAE to investigate the development of such techniques back in the late 1990's. The USAF's interest peaked in 2002 when after running a competition Edgewater Computer Systems (Canada) was chosen to develop a practical solution and help with the development of a new standard (at that time mostly referred to as 1553C) plus supporting handbook.

In December 2004 the USAF published a pre-solicitation document[9] identifying the key technical requirements for potential suppliers of the enhanced performance 1553B technology into their future programmes. This document was the best indication we had in the UK of the likely capabilities that would feature in the new standard and some of the key requirements stated in the document are listed below:-

1. Ultimate data throughput to be in excess of '200 megabits per second (Mbit/sec)'
2. No data compression allowed
3. For use over "existing aircraft wiring"
4. Adhere to a 1×10^{-12} bit error rate (BER) performance, the same as conventional 1553B
5. Backward compatibility to the existing MIL-STD-1553B protocol
6. Concurrent operation of both standard 1Mbit/sec and high speed data transfers required

Development work was led and backed by significant investment over a number of years from the USAF. Little is known publicly about the technical solutions employed in this development and the resulting standard US MIL-STD-001553B (USAF) w/CHANGE 5[4] published in February 2006 is restricted to US nationals and companies only and not yet (at the time of writing) available in the UK. It is however understood the UK MoD are making representations for its release so that UK industry can become more actively involved with its further development.

With the USAF's firm operational requirements and continued need to upgrade fleets of legacy aircraft for NEC it can be safely assumed that the new standard will see significant development and application in the coming years. With the sheer number of military systems currently using conventional 1553B a potentially large market exists for all developers able to produce solutions compliant with the new standard. It is also hoped that the new standard will be opened up into Europe and the NATO community for application within European programmes.

3.3.3 Data Device Corporation (DDC) development

DDC a long time developer and leading supplier of 1553B hardware recognised the potential of high performance 1553B systems some years ago and instigated their own in-house research and development programme to engineer a solution. They too have developed a solution based on DSL technologies but unlike the Edgewater development DDC has published a number of papers and given numerous presentations on the progress of its developments particularly in relation to theoretical studies looking at typical 1553B bus harness configurations, noise performance and maximum channel capacity[10].

During 2005 and 2006 DDC demonstrated prototype hardware both in the USA and Europe using 'real' 1553B bus hardware and demonstrated simultaneous 1553B and concurrent high speed data transfers at 40Mbit/sec without errors.

In January 2006 they announced a successful flight trial of their concept on the Boeing F15E1 Advanced Technology Demonstrator (ATD) aircraft flown from St Louis in December 2005. The test configuration used transmitted digital imagery between equipment mounted in the forward avionics bay and a modified joint direct attack munition (JDAM) mounted on a wing pylon using the high speed capability. DDCs circuit cards were hosted on Honeywell general purpose processors at each end of the interface. During the trial a sustained 40Mbit/sec data rate was achieved simultaneously with the transmission of standard 1Mbit/sec 1553B traffic. Both 80 and 120Mbit/sec throughputs were achieved on the same 1553B wiring harness without the standard 1Mbit/sec 1553B being operational.

DDC has named its high performance 1553B development HyPer-1553™. With the publication of the new USAF standard DDC have stated their desire to make HyPer-1553™ compatible with it as soon as possible.

The DDC development along with the USAF backed Edgewater Systems approach is evidence of advanced development activities designed to meet the growing need for enhanced performance 1553B systems, using DSL technologies and operating at speeds far in excess of that achievable using conventional 1553B designs.

4.0 CONCLUSIONS

The MIL-STD-1553B data bus standard has been in use for over three decades and during that time has formed the main backbone for on-board data communications on thousands of land sea and air based military platforms worldwide. Despite its low bandwidth by modern standards its inherent integrity, reliability, dependability and widespread implementation and support still make it a first choice for many system designers and also despite its age is still being specified for installation into new military equipment.

However over the years the requirements for platform data networking have grown and in recent years accelerated much more rapidly with the introduction of NEC compatibility requirements for military platforms. To meet these requirements data transfer speeds of 100Mbit/sec or higher are required for on-board systems which for legacy systems are beyond the scope of simply speeding up standard 1553B buses or using alternatives such as Stanag 3910 or AS5652. Either entirely new high performance COTS based systems are needed, which for aircraft require costly and lengthy

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reworking of the airframes, or new/alternative technologies must be developed that can make economic use of already installed wiring (i.e. existing 1553B harnesses) to carry these higher speed services.

New enhanced performance technologies now exist that can make use of existing 1553B wiring harnesses in the form of the USAF supported development of MIL-STD-001553B w/CHANGE 5 by Edgewater Computer Systems and the Data Device Corporation's HyPer-1553™ development. These solutions, and perhaps others that may appear in the future, are set to offer the military community a powerful and cost effective method of upgrading the on-board data network systems of legacy military platforms in order to meet the requirements of NEC.

For new build military platforms it is accepted that the introduction of modern COTS based systems is entirely appropriate. There are many options for data networks with improved performance over 1553B and two examples that have already been used successfully in the civil and military aircraft environment are Ethernet and Fiber Channel. It is likely that conventional MIL-STD-1553B will also continue to be used for some time in new systems where its bandwidth limitation is not a problem or where integration is required with older equipment.

For older military platforms that only require minor system upgrades or those that are only suffering issues of high bus loading practical options exist to use faster clocked versions of 1553B up to about 5Mbit/sec to deal with these issues. For performance above 5Mbit/sec there are solutions such as the SAE AS5652 at 10Mbit/sec or STANAG 3910 at 20Mbit/sec both of which requiring different bus media.

As always the system designer makes the final choice and must assess the advantages and disadvantages of the various approaches for both designing new and/or upgrading legacy systems. However this paper has demonstrated there is a range of viable choices for enhanced 1553B solutions and the continued development and use of these options will take MIL-STD-1553B and its related developments well into the future.

ACKNOWLEDGEMENTS

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APPENDIX A

A.1.0 A BRIEF INTRODUCTION TO THE MIL-STD-1553B DATA BUS

A.1.1 Introduction

For those unfamiliar with the concept of a serial data bus and the contents of the MIL-STD-1553B standard this appendix is intended to give a simple overview of the main concepts, features and intended application of the standard.

MIL-STD-1553B is a US military standard defining a serial, time division, multiplex data bus widely used throughout the world. For those in the UK and Europe the same standard also exists as Def-Stan 00-18 (Part 2) and NATO STANAG 3838 respectively.

Serial data buses provide digital data communication between the complex computing and electronic systems found in modern weapon system platforms. In the case of aircraft the line replaceable units (LRUs) or 'black boxes' will nowadays almost always communicate using such serial data buses. Figure A1 shows an example military avionics system using several such bus systems.

This design approach is very common for most modern military weapon systems, not just for aircraft, and is known as a hierarchical system architecture. In this example there are five separate bus systems all of which would probably be dual redundant (for clarity only the main avionics bus is shown as dual redundant, Bus A and Bus B). Each system requires its own bus controller which is usually embedded in one of the sub-system enclosures, or LRUs. Of interest are the equipments which have two or more bus connections forming a 'bus bridge' for the exchange of information between different bus systems and in this case the different avionics sub-systems. For example the weapons system control box would probably contain bus controllers for both the weapons and stores buses and also interface to the avionics bus.

As all these data bus interfaces are common throughout the system the aerospace industry benefits by using a military standard for the definition of such interfaces, the most widely used currently being MIL-STD-1553B.

The standard defines all that is necessary to build a serial data bus system and contains information specifying the physical requirements of the data bus (wiring, couplers and stubs), the protocol (the means by which data is permitted to access the bus, where it comes from and where its going) and the electrical specifications (bus voltages, waveforms, impedances, etc).

The standard does not define how the bus is actually implemented within a particular project this being the responsibility of the system designer. Typical examples of what needs to be specified would be number of buses used, physical configuration, bus layout, use of optional features, number of terminals, redundancy levels, bus controller programming, error management philosophy, etc, etc.

The following section provides a brief description of the main contents of the standard.

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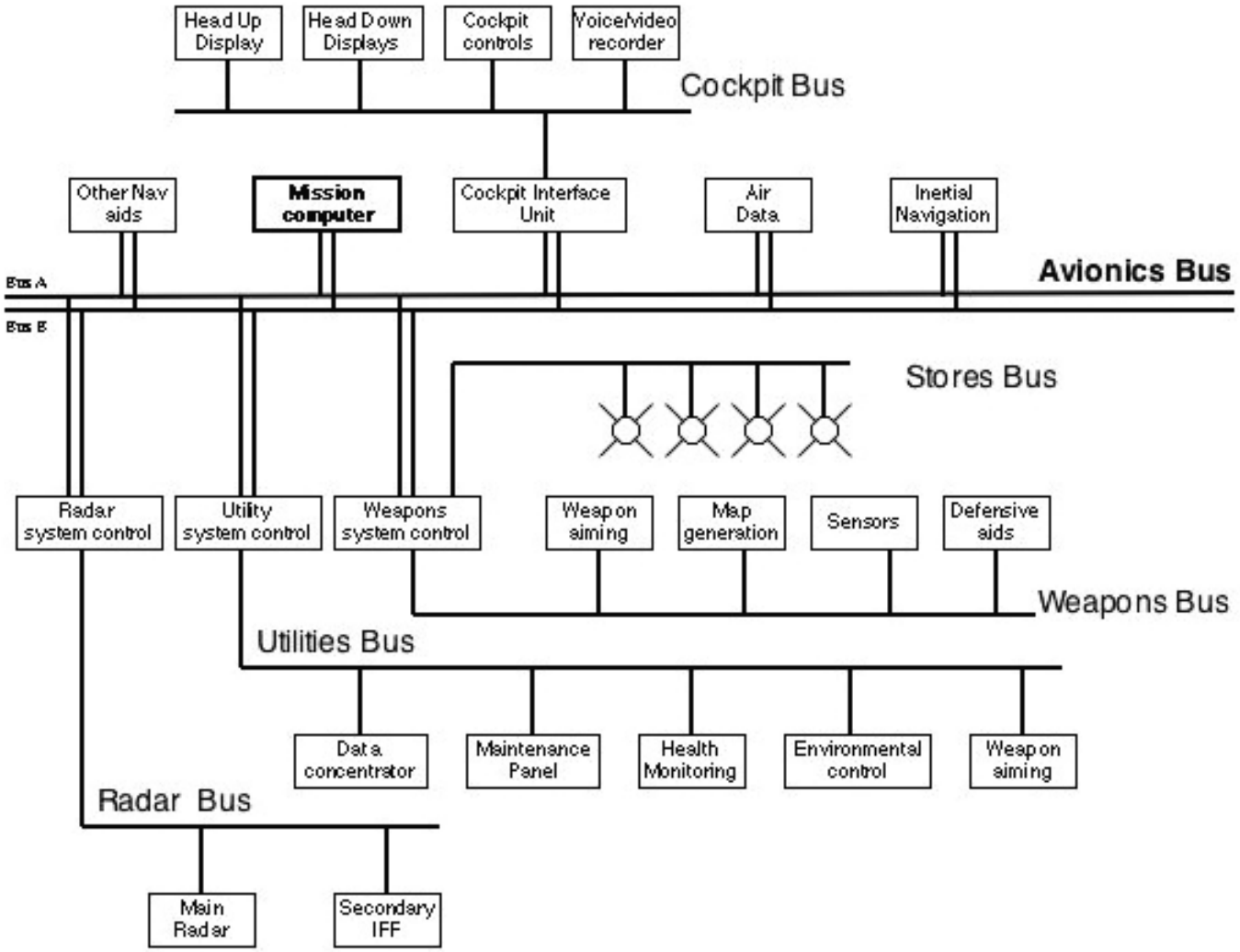


Figure A1. Avionics system example.

A.1.2 MIL-STD-1553B description

The standard defines a command/response, multiplex, serial, linear, multi-drop, digital data bus. Figure A2 illustrates the basic bus layout for a 1553B system showing the main interface elements of bus controller (BC), remote terminals (RTs) and a bus monitor (BM). These three types of interface elements, more generically known as terminals, could be stand alone units but most commonly nowadays are small electronic modules embedded in the circuit boards of the host equipment. Also shown are two optional redundant buses however the standard can support many more up to a theoretical but impractical limit of 2^{16} buses. In practice the most common format used for real systems is dual redundant.

A.1.3 Physical layout

The main bus (serial, linear element) and stubs (multi-drop elements) comprise twisted pairs of wires used to carry the signalling waveforms, and transformers to couple terminals to the bus. The bus and stubs are electrically shielded to prevent radiation of interference from the bus and to stop external electrical interference getting onto the bus. At each end the twisted pairs are terminated with resistors equal to the characteristic impedance of the bus cabling (normally 78 Ohms). These provide impedance matching and essentially prevent signals being reflected back along the bus causing corruption of the bus signal waveform. Figure A3 illustrates the basic electrical configuration of the bus showing both 'direct' and 'transformer' coupled stubs as defined in the standard.

The various equipments that use the bus are all connected via terminals using stubs which either connect directly to the main bus with a stub of up to 1 foot (max) in length or via the more preferred transformer coupling method of up to 20 feet (max) in length. In fact, as can be seen in the diagram, both methods actually employ a transformer within the terminal to connect to the stub. Stubs use the same shielded twisted pair cable as used for the main bus which itself can be as long as 300ft depending on the size of platform the bus is used.

In practice for the transformer coupled stub a coupling transformer with its associated isolation resistors (R) are placed as close to the main bus as possible often spliced into the main bus cable. A second transformer will be required inside the terminal enclosure at the other end of the stub as part of the electrical transceiver assembly. For the direct coupled stub there is only one transformer and its associated isolation resistors (R) which will be placed inside the terminal enclosure also as part of the electrical transceiver assembly. In this case however remember there is only a very short stub allowed of ≤1 foot.

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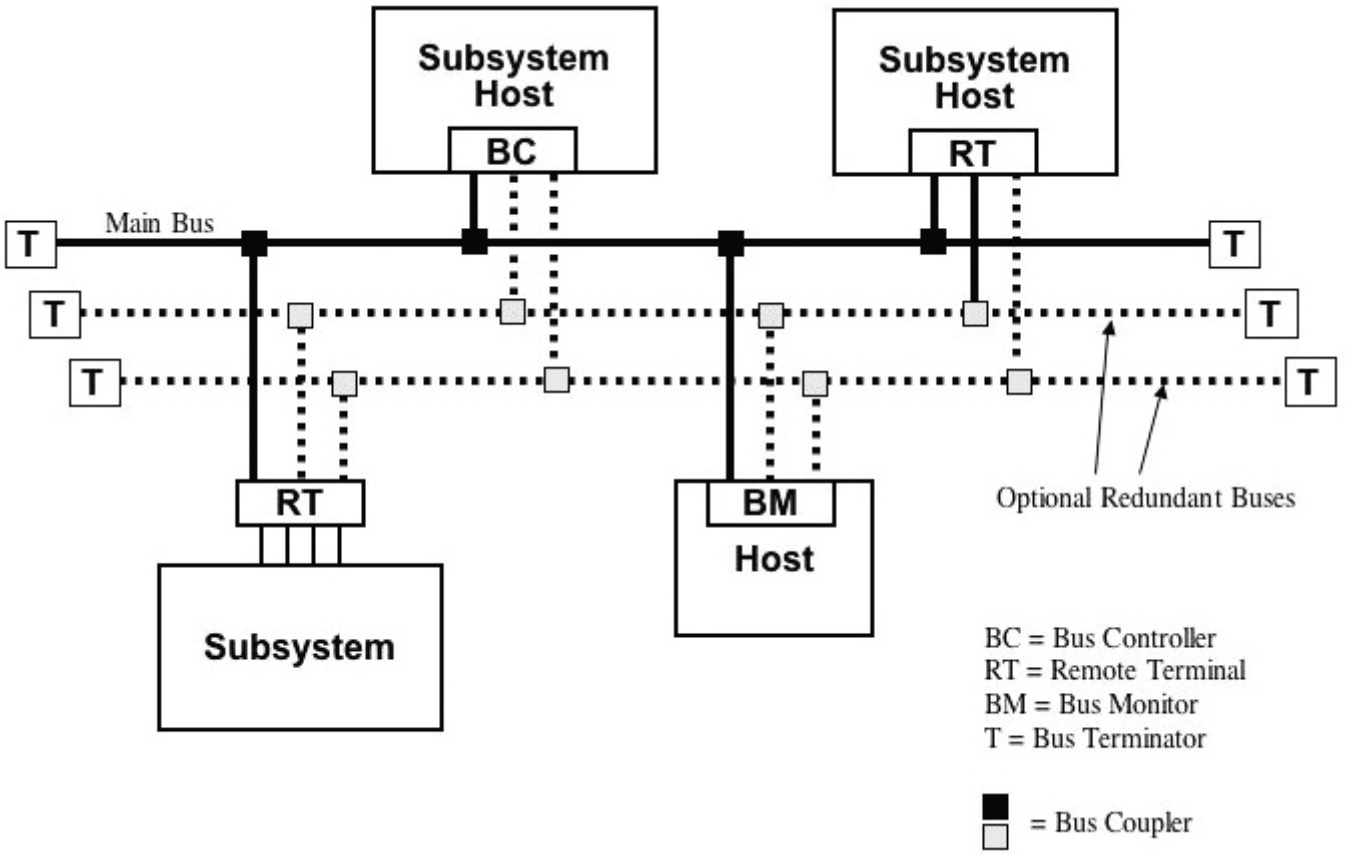


Figure A2. Basic bus configuration.

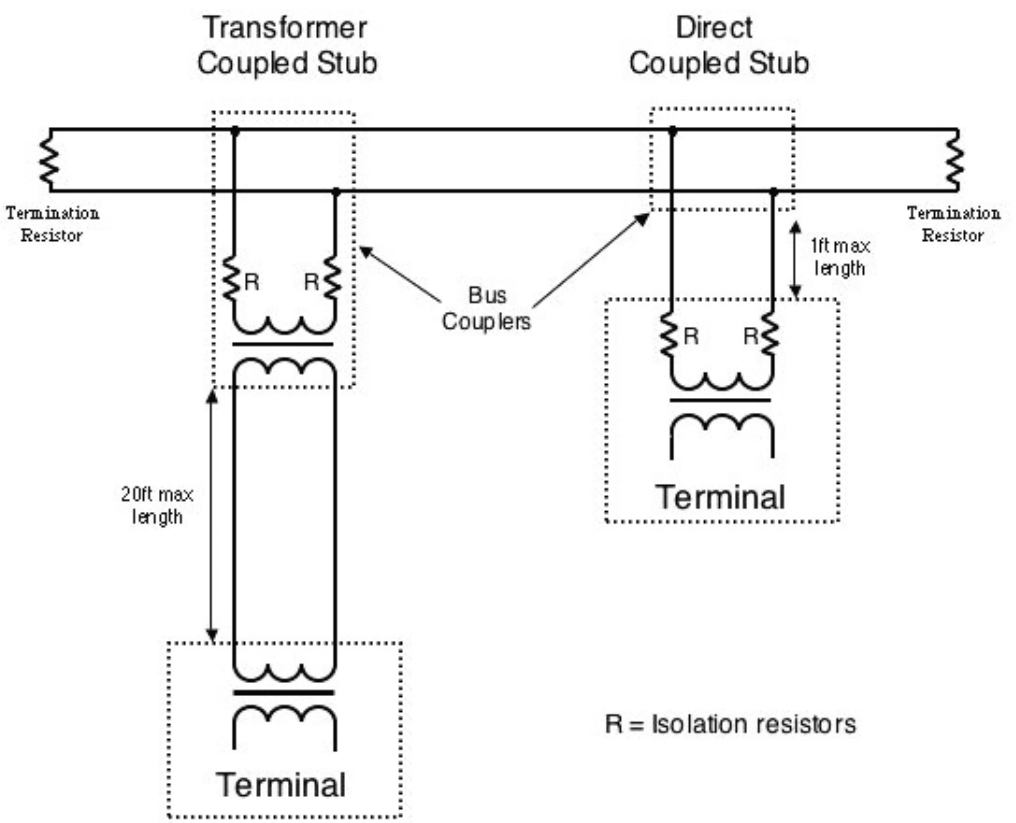


Figure A3. Basic electrical configuration.

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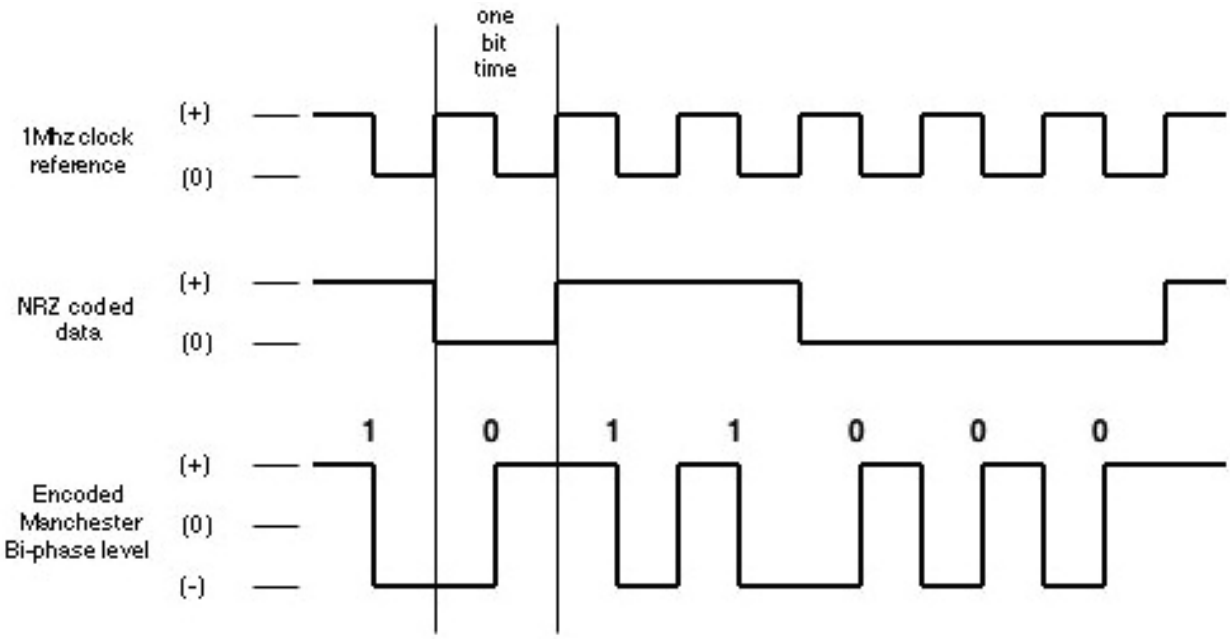


Figure A4. Signal encoding – Manchester II Bi-phase level.

The assembly of the main bus and stubs is generally known as the bus harness and is replicated as a whole to provide the required level of bus redundancy throughout a given system.

A.1.4 Bus signalling

Information for transmission on the data bus is encoded using a signalling format called Manchester II Bi-phase Level. Figure A4 illustrates how this is achieved. The top waveform is just a clock reference waveform and the second is representative of a data sequence (1011000) required to be transmitted on the bus but shown in non return to zero (NRZ) format. The third waveform shows how this sequence will actually be transmitted on the bus. For each bit a '1' is indicated by a high to low transition in the middle of a bit time and a '0' is indicated by the converse. The resulting waveform is described as self clocking because the reference 1Mbit/sec clock can easily be extracted by receivers. Furthermore the minimal direct current (dc) content of the waveform allows transformer coupling to be used providing a strong noise rejection feature.

A.1.5 Terminals

All 'terminals' specified in 1553B perform the necessary electrical interfacing between the bus and the equipment connected by providing such functions as bus transceivers, protocol, message handling, error detection and built-in-test functions.

As shown in Fig. A2 above three types of terminal are defined; these are known as a bus controller (BC), remote terminal (RT) or bus monitor (BM).

1. There can only be one active BC per bus system and this is the only terminal allowed to initiate message transfers. The BC is also responsible for monitoring and managing the general health of the bus.
2. There can be up to 31 separately addressable RTs per bus system which interface the user equipments to the bus.
3. BM terminals can be used where necessary to interface equipment for off-line monitoring of bus traffic.

A.1.6 Bus protocol

For the bus to operate there has to be a mechanism for allowing equipments orderly access to the bus known as media access control. For this reason a 'bus protocol' is defined which establishes the rules for bus access and for 1553B this is achieved by using central control and a command/response philosophy. The BC transmits a command to an addressed RT (multiplex, command/response element) which performs the required task and responds with a status word after which the BC issues a command for the next message and so on until the required message sequence is built up. Messages are formed using only three types of digital 'words' as defined in the standard. These are known as command, data and status words.

1. Command words only ever transmitted by a BC are sent to an addressed RT on the bus (one of 31 addressable RTs) instructing it to either receive or transmit data.
2. Data words contain the actual information to be transmitted, each data word contains 16 information bits. Messages can contain from 1 to 32 data words.
3. Status words only ever transmitted by RTs in response to valid commands from the BC contain useful information about the mode and health of the RT and its host user equipment.

In summary for normal operation the BC issues a 'command' to an addressed RT on the bus which is then expected to 'respond' by performing the required action (transmitting or receiving data) and then sending a status word back to the BC. The status word contains information for the BC to check that the message transfer has been successfully completed.

There are only three basic message formats defined in 1553B as shown in Fig. A5.

1. BC to RT — in this case the BC sends a 'receive' command to a single addressed RT on the bus followed by the required number of data words (from 1 to 32) after which the addressed RT responds by transmitting its status word back to the BC.
2. RT to BC — in this case the BC sends a 'transmit' command to a

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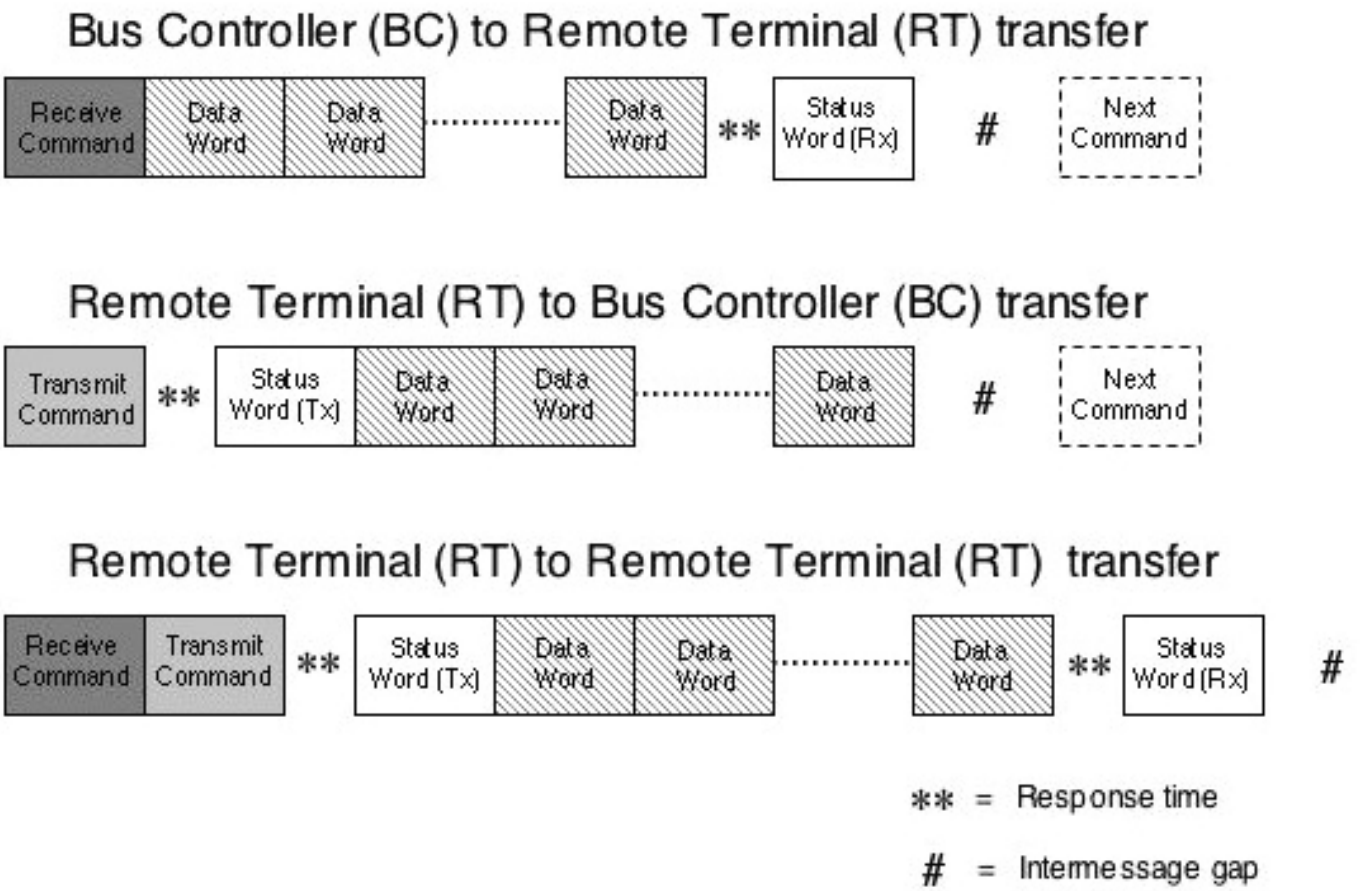


Figure A5. Basic message formats.

single addressed RT on the bus and the RT is required to respond by transmitting its status word followed by the required number of data words (again from 1 to 32) back to the BC.

3. RT to RT – in this case the BC sends a 'receive' command to one addressed RT on the bus followed by a 'transmit' command to another addressed RT on the bus for the required number of data words. The message transfer will then take place between the two addressed RTs with the BC checking the status word responses from both the transmitting and receiving RTs.

These three basic message types are used by the system designer to form the data communications required for the overall system and are established by the programming of the BC. In addition the standard contains a capability to broadcast messages to multiple RTs.

A.1.7 Bus management and robustness

BCs can be very simple just sequencing fixed and often repetitive lists of messages or much more complex changing the message lists dynamically for different operational modes of the system. Either way only the BC can transmit command words which RTs on a given bus must process and respond to with the appropriate action. All these message formats are subject to timing requirements defined in the standard for things like transmission rate stability (for the 1MHz clock frequency), response times for RTs to respond to commands and the definition of a minimum intermessage gap times before a BC can issue a new command.

The protocol described above is fine if everything is working correctly. However, in the harsh environment within military platforms this can lead to component failure and of course there is the ever present threat of battle damage. The standard contains a number of features which are designed to provide continued operation in the presence of faults (ie fault tolerance) and damage. The following is list of the main features providing this robustness.

1. Shielded twisted pair cabling provides good balanced transmission line for bus signalling effectively attenuating common mode interfering signals and providing good electro magnetic compatibility (EMC) with external systems
2. Resistive terminations of main bus at each end prevents reflections from corrupting the bus waveform
3. Transformer coupled stubs and isolation resistors provide good common mode rejection of interfering signals, electrical isolation and survival of damaged stubs
4. Redundant buses provide alternative paths for communication if one is damaged
5. Error detecting circuitry in all receiving terminals at bit level (checking for correct Manchester Bi Phase encoding, at word level (checking for 16 bits plus parity) and message level (checking that the correct number of words were transmitted and/or received in a message) These measures give an estimated undetected bit error rate performance of 1×10^{-12} which is stated in the standard.

In addition to the built-in features listed above there is an extensive list of mode commands which the BC can use to

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'manage' the bus. These mode commands are used to instruct RTs to perform management tasks, such as reset RT, transmit status word, transmit last command, perform transmitter shutdown on redundant buses, etc. These mode commands are used by the BC in conjunction with monitoring information provided in the status responses from RT's to provide continuous real-time management of the bus system. Examples of bus management actions are re-transmitting failed messages or switching to redundant bus transceivers if failure occurs.

A.1.8 Conclusion

This brief overview has given a flavour of the main capabilities and features of the MIL-STD-1553B data bus standard. It has described the basic configuration and operation of the bus, shown a typical example of how it might be used in a military aircraft system and given some indication of the more advanced features available.

For a more in depth discussion of MIL-STD-1553B it is recommended that the reader consults one of the numerous handbooks and guides readily available from the internet or attends a specialist tutorial on the subject.

For those in the UK an excellent source of 'official' information is the UK Avionics Systems Standardisation Committee (ASSC) recently updated guide to 'US MIL-STD-1553B/UK Def-Stan 00-18 (part 2)/NATO STANAG 3838 – serial, time division, command/response multiplex data bus standards, ASSC/110/4/41 Issue 2, July 2006'. At the time of writing this document is available on the ASSC website at http://www.era.co.uk/assc/index.asp.

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