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Basics of MIL-STD-1553 Interconnect for Military Applications & Beyond

White Paper

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Introduction

The MIL-STD-1553 standard, also known as Milbus, was developed by the US Department of Defense (DoD), originally released in 1973. Since, there have been several revisions, currently MIL-STD-1553C released in 2018 is the latest version superseding MIL-STD-1553B from 1978. The longevity of this standard naturally spawns questions as to why it is still relevant in an age where there are hundreds of data bus communication standards. Though originally developed for US military aircraft applications, MIL-STD-1553 communication bus systems are used throughout civilian avionics, commercial aircraft, military aircraft, military vehicles, and even spacecraft data handling applications by NASA and international space agencies. Moreover, MIL-STD-1553 is used in industrial applications, transportation, and energy infrastructure applications. From its early beginnings as a data bus for the US Air Force's F-16 fighter jet, MIL-STD-1553 is now widely used by all branches of the US DoD, NATA, and a multitude of civilian, commercial, and industrial platforms.

The strength of the MIL-STD-1553 system is based on the dual redundant and balanced-line physical layer specification. This physical layer supports a differential network interface featuring time-division multiplexing (TDM), half-duplex, command/response data communications protocol with a maximum of 32 remote terminal devices. These specifications and features result in a communications bus that is deterministic, extremely reliable, and relatively simple to implement, especially considering the long history of implementation and diversity of platforms MIL-STD-1553 technology has been implemented on.

This whitepaper focuses on the basics of MIL-STD-1553 interconnect with some background on the communication bus operation. Further details regarding the various hardware elements of a MIL-STD-1553 system are also provided.

MIL-STD-1553 Bus Specifications & Operation: Features That Make Why MIL-STD-1553 Is Goings Strong for Nearly 50 Years

This communication bus is based around relatively low data rate applications that require redundancy, reliability, and determinism. This means that 1553 bus communications are transmitted and reach their target within specified and predictable time periods. The high level of determinism of 1553 is ensured by supporting redundant communication lines and a centralized bus controller that strictly manages bus data transmission. In this way, the data transmissions from 1553 are precisely sent and delivered to each targeted device within the network with absolute predictability and no chance for access contention. These are major features of time-critical communications and data transfer, which is why 1553 is used for rapid and error-free data transmission for dynamic flight stability and other essential/critical and real-time communications. Examples of 1553 use also include sensor feedback for automated flight parameter adjustment, and unification schemes for consolidating data from GNSS, radar, and other navigation systems, such as inertial navigation sensors.
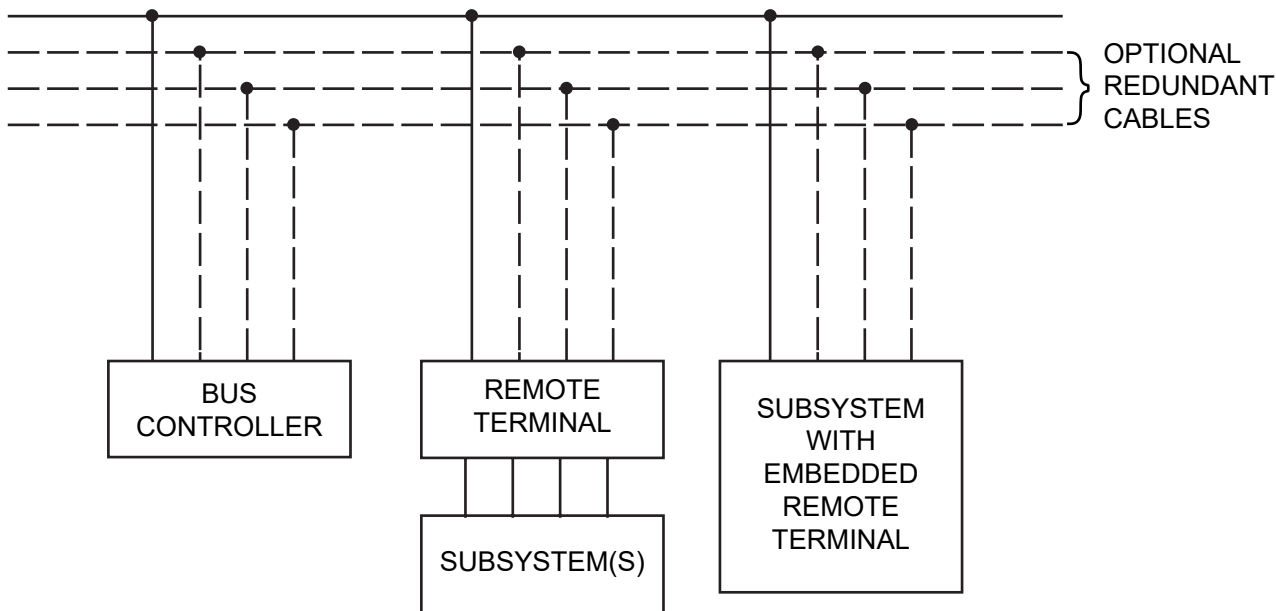
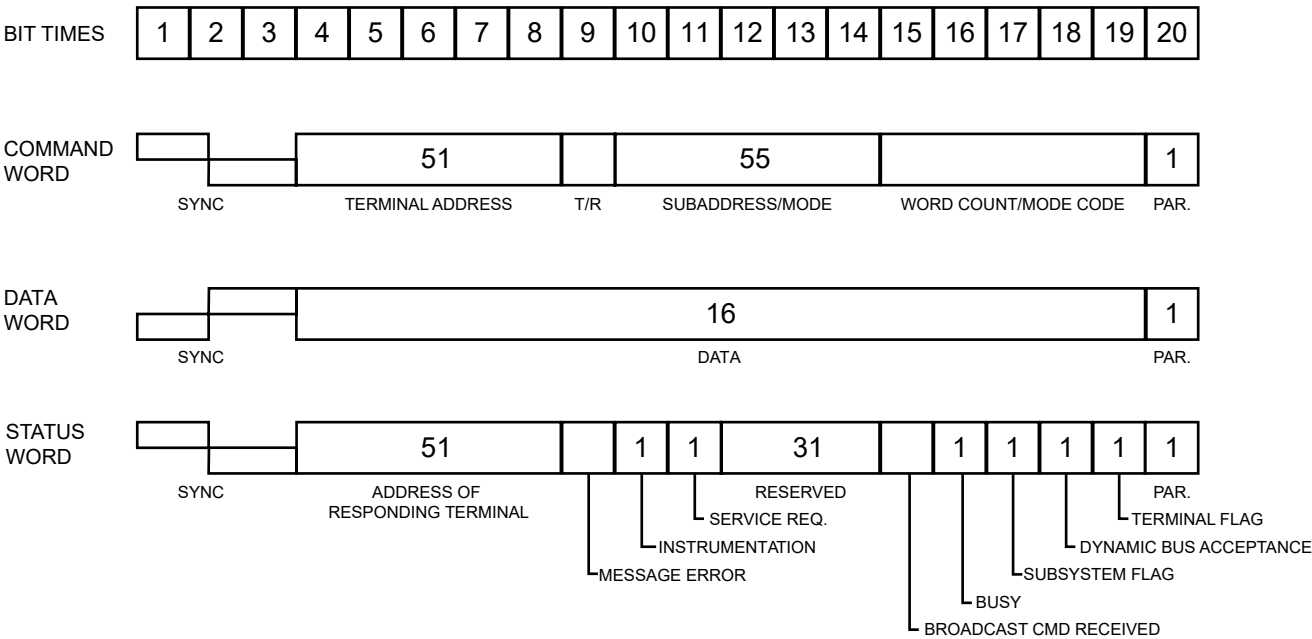Image: MIL-STD-1553 Sample multiplex data bus architecture Source [1]

Image: MIL-STD-1553 Word Format Source [1]

As hinted at in these statements, 1553 also includes built in error-checking mechanisms, aided by the standard dual-data lines. The transmission protocol for 1553 is time-division multiplexing (TDM), which means that data communications are transmitted and received in discrete packets of time along the network, which allows for multiple devices (up to 32) to operate on the same bus network. The communication protocols for 1553 also require acknowledgement and status upon initiating a data transfer, either between the bus controller (BC) and remote terminals (RTs) or terminal to terminal communications. Manchester encoding is used to include timing and data in single transmission without the need for a dedicating timing path. Each 1553 data transmission can have up to 32x 16-bit words. Within a single 1553 bus there may be as many as 32 remote terminals, with each remote terminal having up to 32 potential sub-addresses.
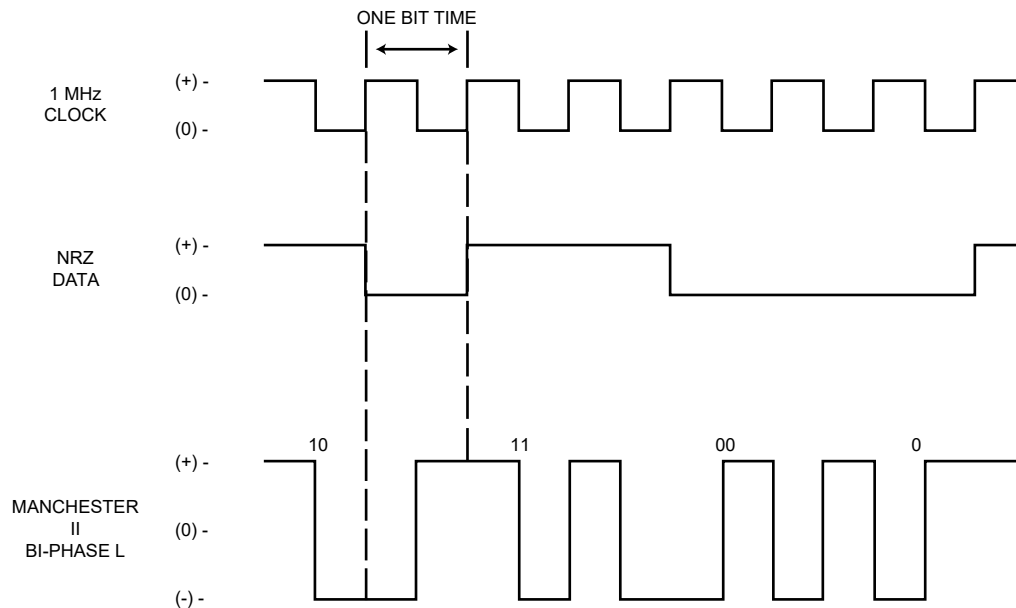
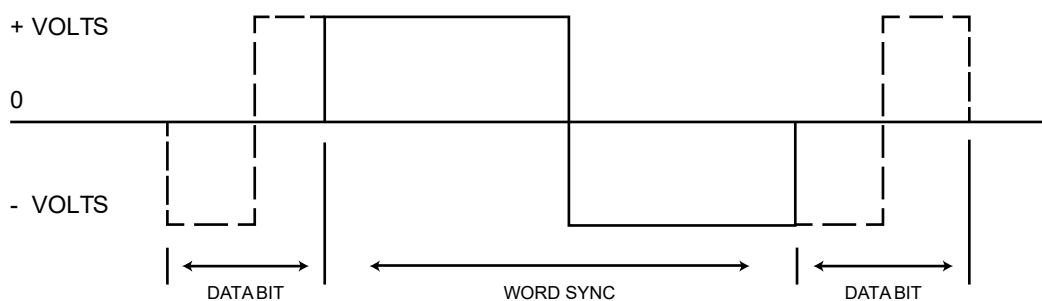Image: MIL-STD-1553 data encoding Source [1]

Image: MIL-STD-1553 command and status sync. Source [1]

Beyond the dual-balanced line bus that 1553 supports, there is also the ability to enhance the redundancy of a 1553 connection to RTs, bus controllers, and subsystems. As seen in the following figure, it is possible to pair two bus controllers with their own dedicated communication line, to ensure that data transferred on the 1553 bus is received. Moreover, it is possible to use dual RTs for a cluster of subsystems. This ensures that if there is a bus line failure or RT failure, that the subsystems have redundant access to communications. Another approach is to have an RT that has access to both buses, or subsystems that have embedded RT capability.
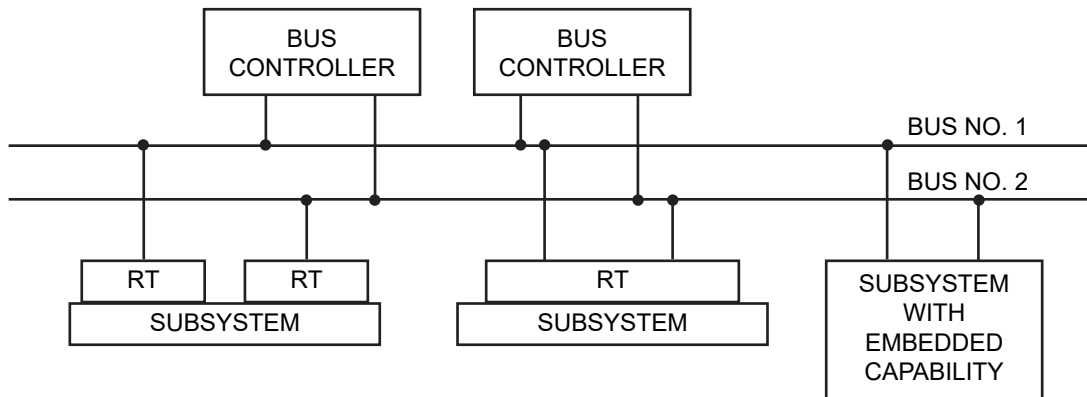
Image: MIL-STD-1553 illustration of possible redundancy configurations Source [1]

The tests for noise rejection in the 1553 standard are incredibly stringent. The specification for a terminal is to exhibit less than 1 in 10^7 word error rate when subjected to additive white Gaussian noise of a 140 mV RMS amplitude over a 1 kHz to 4 MHz bandwidth. Moreover, a minimum of 45 dB of isolation between data buses is required by the standard. This requirement means that each bus line is separated from the other bus lines by substantial isolation in addition to the shielding requirements for the entire wire pair.
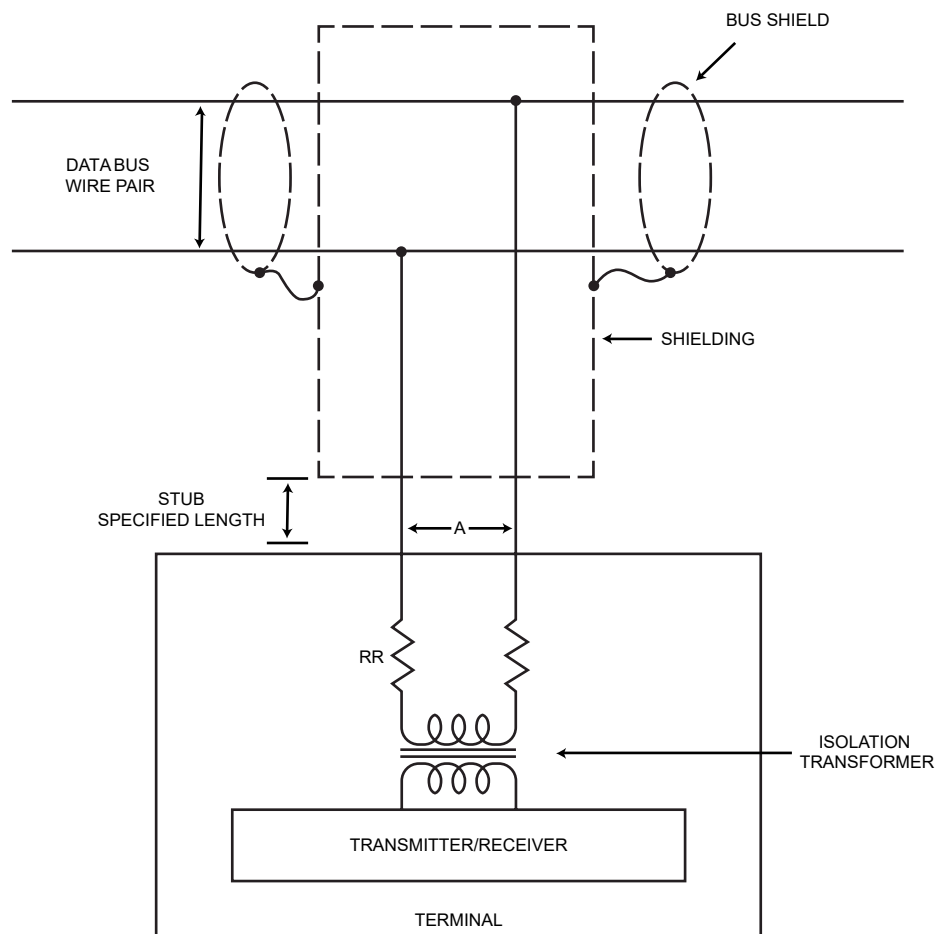

Image: MIL-STD-1553 data bus interface using transformer coupling Source [1]

An isolation transformer is used between the connection of the bus lines to a terminal in 1553. This aids to ensure the isolation between the bus lines. Moreover, the additional business shielding and shielding of the interconnect between the bus and terminal is also highlighted. The continuous shielding for coupling transformers and isolation resistors in this standard are specified to provide a minimum of 75 percent coverage and are specified to be placed as close to the junction of the stub to the main bus as possible.

MIL-STD-1553 Hardware

There are several key hardware elements of a MIL-STD-1553 system, which include the bus controller (BC), remote terminals (RTs), a bus monitor (BM), and the interconnect hardware. As indicated in the following diagram, BCs and RTs are necessary elements, where additional redundant cables, subsystems, BMs, etc. are optional though often included in a real system. Essentially, any system that connects to the 1553 bus is defined as a terminal by the standard.
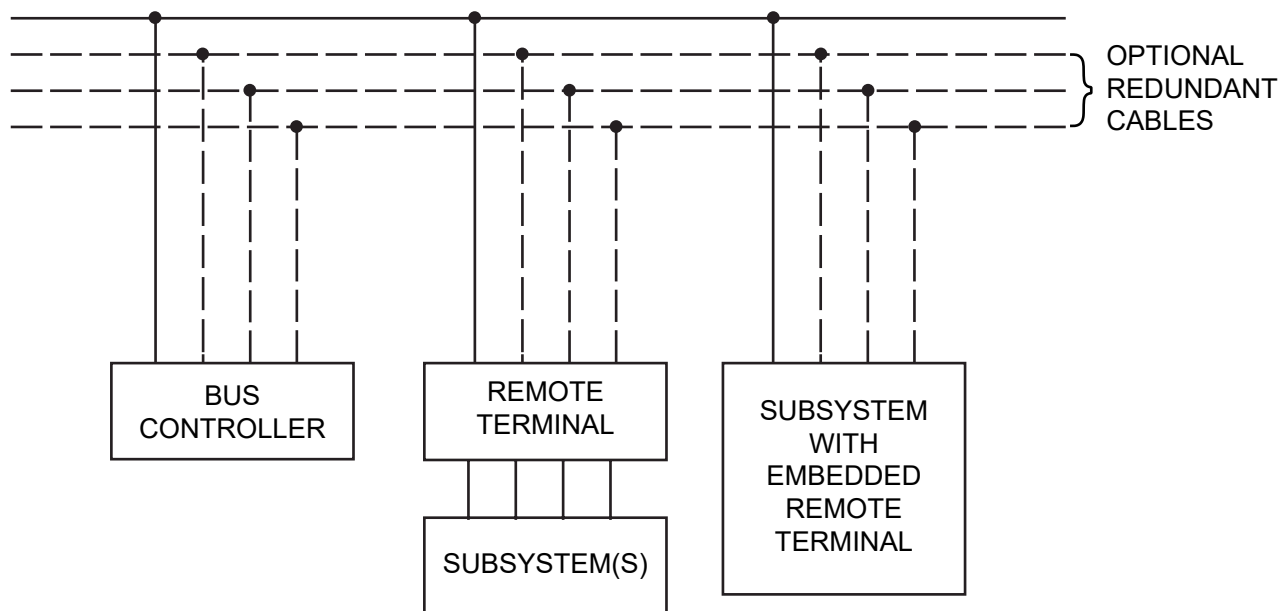

Image: A MIL-STD-1553 sample multiplex data bus architecture Source [1]

Bus Controller (BC)

In a 1553 system, there is only a single Bus Controller operating at a time on bus, possibly with redundancy. The purpose of the bus controller is to initiate all messages on the bus. The bus controller also determines on which line the messages are sent along. Furthermore, the bus controller services any requests by the RTs, detects and recovers from errors, and logs a history of errors.

A backup bus controller can be implemented, where a backup bus controller (BBC) may accept a handover of the system control if the initial controller fails or in response to external handover commands from an outside source connected to the bus. A discrete connection is generally needed between the BCs and BBCs in order to initiate a handover due to a fault or failure condition. The BBC may also be monitoring the bus in case a prolonged quiescence could indicate a BC failure and self-initiate a handover.

Remote Terminals (RTs)

RTs are any other system or host of subsystems on a 1553 bus. Generally, RTs are used as an interface between the 1553 bus and attached subsystems, or as a bridge between two different MIL-STD-1553 buses. Of the 32 maximum allowed RTs on a 1553 bus, an RT or RT subsystem may be as simple as a switch that controls a light, or as complex as automated flight equipment.

Bus Monitor

A bus monitor is without means to transmit messages over the MIL-STD-1553 bus. However, the BM may be used to monitor and record bus interactions, clearly without the potential to interfere with the bus communications. A BM may be used to record and store bus communications for later analysis or may specifically be triggered by errors as a diagnostic tool. BMs may also record, and store messages algorithmically based on some desired criteria. A BM may also be used in conjunction with a BBC to allow for the BBC to accept a handover and immediately begin operation based on prior communications over the bus that were recorded and stored by the BM and transferred to the BBC when it becomes initialized.

Stubs

A stub is the interconnect between the bus and an RT, BC, BM, or other bus connected systems. A stub is the connector interface and the cabling, ideally the same as the bus, which connects the bus to the bus element. A stub may be either a transformer coupled stub or direct coupled stub. Though more complex, transformer coupled stubs are often preferred due to their higher fault tolerance and better matching to bus impedance than direct coupled stubs. Better impedance matching with the bus results in reduced reflections from mismatch and improves the interconnect of the stub and bus in general. Transformer based stubs also generally provide DC isolation between the stub and bus, enhance the common-mode rejection, and provide additional fault isolation between the stub and terminal. In the case of direct coupled stubs, they should generally be avoided, according to the standard, as any faults with a direct coupled stub could degrade the bus or cause wide failure of the bus.

Transformer coupled stubs have increased in preference, as with composite aircraft, the outer material of the aircraft no longer provides shielding from electromagnetic or electrical interference. An example of this could be lightning strikes, which could be directly coupled to a 1553 bus by a direct coupled stub.

Bus Couplers

1553 bus couplers are coupling boxes that can provide one or more stub connections. These couplers are required to meet the shielding specifications of the MIL-STD-1553 standard and also may contain the coupling transformers and isolation resistors for the stubs. A simple bus coupler consists of at least two connectors for which the bus feeds through, and one or more external connections for stub connections. When not in use, it is important to leave the matching resistors unterminated using blanking caps unless the bus coupler is at the end of the bus cable.

1553 Cables, Connectors, & Adapters

The MIL-STD-1553 standard does not specify the type of connectors that should be used or how the interconnect should be planned. The one exception to this is the shielding requirement of the cable and individual bus lines and the isolation specifications that must be maintained. Within laboratory, test, or automation environments, twinax bayonet style connectors are often used for 1553 connectors and twinax cabling, such as TRB connectors. This type of cabling and connectors are likely to easily provide safe margins on shielding and noise immunity for the 1553 bus. With aircraft applications, common MIL-DTL-5015 and MIL-DTL-38999 circular connectors are commonly used.

The most common characteristic impedance for MIL-STD-1553 applications is 78 Ohms, which is why there are a variety of 78 Ohm interconnect available that meet 1553 specifications. 100 Ohm and 75 Ohm are also relatively common. Though it generally isn't advised to interconnect systems with different characteristic impedance cabling, it is possible through adapters and impedance matching components.

Cable Terminators

Both ends of the 1553 bus must be terminated in the characteristic impedance of the bus within a couple of percent of the nominal characteristic impedance of the 1553 bus. This ensures the 1553 terminations will absorb bus signal energy that reaches them instead of reflecting the signals back to the bus, potentially causing waveform distortion or other interference from standing waves.

Conclusion

Even with over a half-century of life, the MIL-STD-1553 bus is still widely used and integrated into new projects. The prevalence of 1553 is also leading to advancements in the standard and hardware to make the bus even more prolific and viable for higher data-rate applications. It is likely as electrification of previously mechanical or hydraulic systems, that more sensors and actuators will need to be controlled and communicated with along highly reliable buses. The 1553 bus is uniquely suited to harsh applications where reliability, redundancy, and robustness is key.

References

1. http://everyspec.com/MIL-STD/MIL-STD-1500-1599/MIL-STD-1553C_55783/