

MIL-STD-1553 Goes Commercial



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Introduction

MIL-STD-1553 is a serial data bus that has been used as the primary command and control interconnect in military aircraft for the past three decades. MIL-STD-1553's robust performance, high level of interoperability, large installed base, and well established infrastructure of vendors has made MIL-STD-1553 the network of choice for military avionics systems around the world.

The use of MIL-STD-1553 is not limited to military aircraft. MIL-STD-1553's use is pervasive in military ground vehicles, military ships, UAVs, missiles, and satellite systems. More recently MIL-STD-1553 has been selected for use in the primary flight control system for a commercial aircraft(1). All of these applications share common requirements for a reliable, fault tolerant data bus that will operate in relatively harsh environments. Aircraft applications have unique environmental requirements such as lightning immunity, wide temperature range, high vibration, and high electromagnetic interference (from sources such as radar). MIL-STD-1553 was explicitly designed to operate in these demanding environments.

This paper explores some of the major attributes of MIL-STD-1553 and discusses why MIL-STD-1553 is an ideal choice for use in commercial aircraft systems.

Physical Layer

One of the key architectural features of MIL-STD-1553 is the use of transformers. Transformers are used for two fundamental purposes: galvanic isolation and impedance matching. Galvanic isolation is a major benefit in systems, such as aircraft, that have severe EMI and lightning requirements. Isolation is even more critical in new composite aircraft where the skin of the aircraft no longer provides an inherent Faraday shield as was the case with aluminum skinned aircraft.

MIL-STD-1553 defines the topology to be a multi-drop linear bus. Multi-drop buses tend to be lower cost, lower complexity, and lower weight than a switched fabric network. The challenge in implementing a multi-drop bus is to maintain signal integrity to all the receivers on the bus. One of the biggest impediments in a multi-drop bus is reflections. MIL-STD-1553's use of bus couplers is a unique architectural feature that reduces reflections and thus contributes to the performance of this robust physical layer.

Minimizing Reflections

A multi-drop bus starts with a main bus cable that has a characteristic impedance of Z_0 and is terminated into a resistive load equal to Z_0 . Transmissions will propagate down the bus and will be dissipated into the termination resistor. Stub cables are then used to connect terminals (communication end points) to the bus. Reflections will occur due to the mismatch in impedance on the main bus caused by the stub connection (refer to Figure 1). Part of the incident wave will be reflected (reflected wave), part will be transmitted up the stub cable (stub wave), and a portion will continue down the transmission line (transmitted wave).

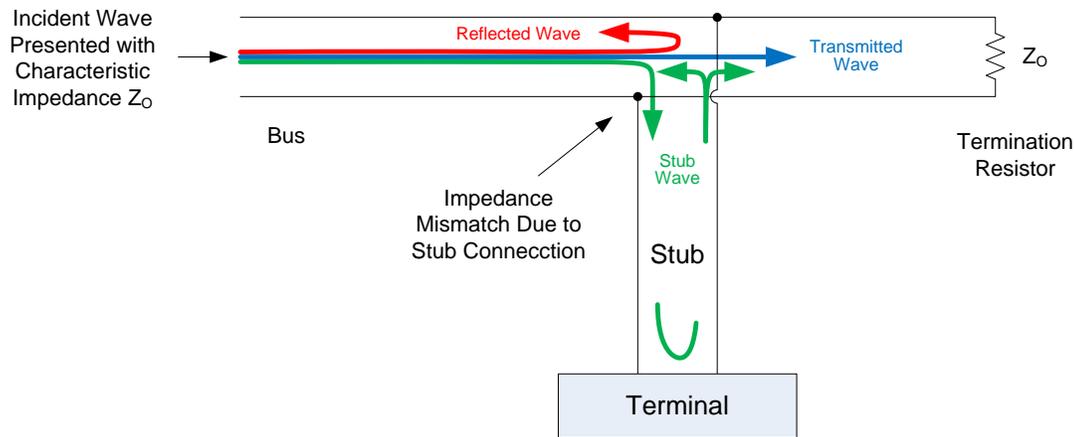


Figure 1. Reflections Caused by Impedance Mismatch

It may be expected that a stub cable be terminated with the characteristic impedance at the terminal interface, however, MIL-STD-1553 defines that the terminal must have a relatively high input impedance. The high input impedance of the terminal relative to the characteristic impedance will produce a large reflection coefficient at the terminal connection to the stub. The result of this high impedance is that most of the stub wave will be reflected back toward the bus and will add back into the incident wave with a phase shift due to the delay down the stub and back. If the terminal were terminated in the characteristic impedance then the signal would be attenuated at every stub connection, and would significantly limit the number of terminals that could be connected to the bus. Instead 1553 minimizes the attenuation due to the stub at the expense of a slight amount of phase distortion.

The amount of reflection on the main bus will be based on the impedance mismatch caused by the stub (refer to Equation 1). The impedance at the stub connection (Z_L) will be a result of the cable's characteristic impedance in parallel with the impedance of the stub. A higher stub impedance will produce a higher Z_L and result in a lower reflection coefficient (C_R).

Equation 1. Reflection Coefficient

$$C_R = \frac{Z_L - Z_0}{Z_L + Z_0}$$

Increasing the impedance of the stub will reduce the amount of reflections on the main bus. The impedance of the stub will be based on the combination of the input impedance of the terminal and the distributed impedance of the cable. Figure 2 illustrates the first –order magnitude calculation of the impedance of the stub as a function of stub length. The figure shows that a 20 foot direct coupled stub with a terminal input impedance of 2000 ohms will result in a stub impedance of less than 300 ohms.

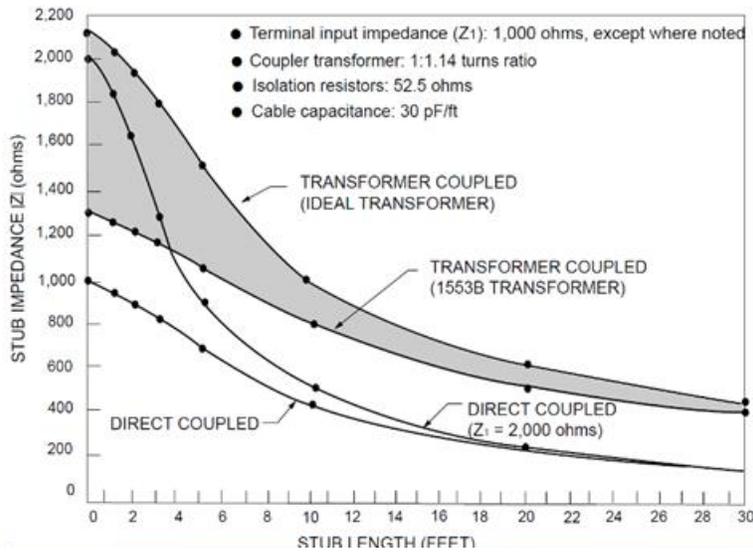


Figure 2. Stub Impedance Versus Stub Length

MIL-STD-1553 defines the option for a transformer coupled connection which utilizes a bus coupler to increase the input impedance of the stub and thus reduce reflections on the main bus. The bus coupler contains a transformer with a turns ratio of 1:1.41 (refer to Figure 3). The transformer will increase the effective impedance of the stub by the turns ratio squared (i.e. by a factor of 2 to 1).

Referring to Figure 2, a transformer coupled terminal will have an input impedance of 1000 ohms. With a stub length of zero the impedance of the terminal will be increased by factor of two (plus the 52.5 ohm series resistors), resulting in an effective stub impedance of 2105 ohms (assuming an ideal transformer). Figure 2 also illustrates the more realistic case using an actual transformer, which will provide an effective stub impedance of approximately 1300 ohms for zero stub length. The real benefit of the transformer coupled connection can be seen with longer stubs lengths. The impedance of a 20 foot stub using transformer coupling will be almost twice the impedance of a direct coupled stub.

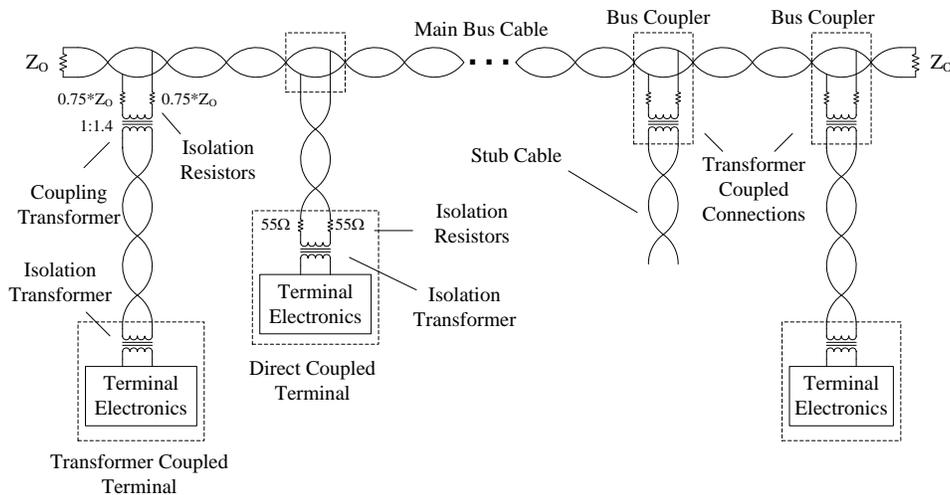


Figure 3. Bus Topology

MIL-STD-1553's transformer coupled connections enable the use of relatively long stubs (up to 20 feet or longer) while still maintaining reasonable transmission line characteristics on the main bus (i.e. minimizing reflections and attenuation).

Fault Isolation

MIL-STD-1553 provides the benefit of fault isolation through the use of series resistors in the path between stubs and the main bus. The fault isolation resistors will allow the network to continue operating even in the presence of a short circuit on one of the stub connections.

Impedance Matching

The values of the isolation resistors and the turns ratio of the coupling transformers are specified such that a matched impedance is presented on the stub input to a bus coupler which helps reduce signal distortion due to secondary reflections on the stub. Refer to Figure 4. A direct coupled terminal will be presented with a bus impedance Z_B which is equal to $Z_0/2$ at the end of the stub. A transformer coupled terminal will be presented with a reflected impedance Z_R through the coupling transformer. The bus impedance for the transformer coupled configuration consists of $Z_0/2$ (termination resistors) in series with two isolation resistors with a value of $0.75 * Z_0$. Therefore the bus impedance Z_B for a transformer coupled terminal will be $Z_0/2 + 2 * 0.75 * Z_0 = 2 * Z_0$. The impedance reflected through the transformer (Z_R) will be increased by the turns ratio squared. $Z_R = Z_B/(1.41)^2 = Z_0$. The net effect of the bus coupler is that the impedance from the stub looking into the bus coupler is equal to the characteristic impedance Z_0 which means that the stub is presented with a matched impedance, which will reduce reflections on the stub.

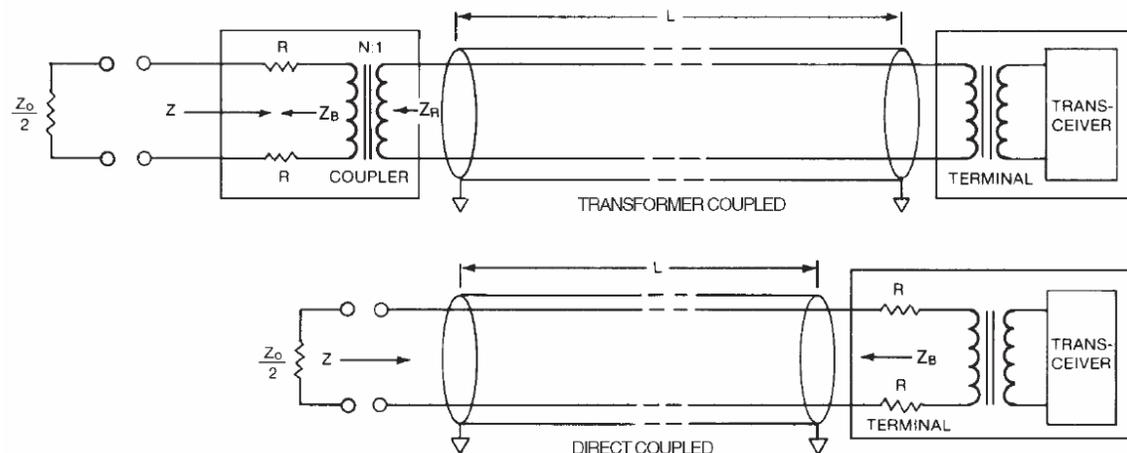


Figure 4. Transformer and Direct Coupled Stubs

MIL-STD-1553 combines stringent transmitter and receiver specifications with a generous link budget to produce a robust data bus that is extremely tolerant to various channel conditions based on bus length, number of nodes, and environmental conditions (such as noise, EMI, and lightning).

Protocol Layer

MIL-STD-1553's use of a command/response protocol enables highly deterministic communication making it ideal for real-time command and control functions, which typically require the transfer of data at a periodic rate (isochronous communication). Every transfer on the bus is initiated by a central bus controller (BC). The centralized bus controller allows the scheduling of data transfers with microsecond accuracy and very low jitter.

Reliable Link Layer

MIL-STD-1553 combines error detection with acknowledgement to implement a reliable link layer protocol. All data transfers on the 1553 bus start with a command word from the BC and include a status response (acknowledgement) from a Remote Terminal (RT). The RT is required to respond to the command within 12 usec. The BC will wait a minimum of 14 usec for the RT response before considering the message to have timed out. Following a timeout the BC has the option of retrying the message either on the same bus or on the redundant bus. 1553's short response timeout value (14 usec) and relatively small payload size (64 bytes max) allow for efficient retransmissions. 1553 also includes support for dual redundancy making it an ideal choice for high availability systems.

Time Synchronization

Many distributed processing systems require time synchronization. MIL-STD-1553 provides the facility for a Remote Terminal to synchronize their local time through the use of the "synchronize" and "synchronize with data" mode codes (protocol specific messages). The synchronize mode code is generally used to reset a local free running counter within the MIL-STD-1553 controller chip while the synchronize with data mode code is used to load the local free running counter within MIL-STD1553 controller with a specific value. Most controller chips, such as DDC's ACE series of components, implement the synchronize mode codes autonomously (without host processor intervention) which enables accurate distribution of time with minimal impact on processor bandwidth. The synchronize mode codes facilitate time partitioning and just in time delivery of data.

Test Plans (Certifiability / In-service History / Maturity)

One of the hallmarks of MIL-STD-1553's success over the years has been the high level of interoperability between MIL-STD-1553 interfaces in different boxes. Interoperability is a fundamental requirement for integration of complex systems. Compliance to MIL-STD-1553 is ensured through a suite of validation and production test plans (refer to Table 1). These test plans are published by the Society of Automotive Engineers as Aerospace Standards.

Table 1. Summary of MIL-STD-1553 Compliance Test Plans	
AS4111	Validation Test Plan for Aircraft Internal Time Division Command/Response Multiple Data Bus Remote Terminals
AS4112	Production Test Plan for Aircraft Internal Time Division Command/Response Multiple Data Bus Remote Terminals

Table 1. Summary of MIL-STD-1553 Compliance Test Plans	
AS4113	Validation Test Plan for Aircraft Internal Time Division Command/Response Multiple Data Bus Bus Controllers
AS4114	Production Test Plan for Aircraft Internal Time Division Command/Response Multiple Data Bus Bus Controllers
AS4115	Test Plan for the Digital Internal Time Division Command/Response Multiplex Data Bus System

In addition to a rigorous suite of compliance test plans MIL-STD-1553 also has millions of flight hours of in-service history to attest to its reliable operation in an aircraft environment. DDC has estimated that one of their MIL-STD-1553 controller chips has over 65 million flight hours of in-service history. Validation testing and in-service history are important contributors to the design assurance level of systems, especially aircraft systems that will ultimately need to meet the requirements of DO-178 and DO-154.

Conclusion

Why consider a new, unproven technology for use in a flight environment when a mature technology like MIL-STD-1553 is available? The reliability and robustness of MIL-STD-1553 has been proven based on decades of flight history. In addition, MIL-STD-1553 is more cost effective than most people realize. A common misconception is that a 1553 interface is very expensive when in reality the cost of a MIL-STD-1553 node has consistently decreased in price over the last 10 years. MIL-STD-1553 is a natural choice for use in commercial aircraft systems.

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Data Device Corporation is recognized as an international leading supplier of high-reliability data interface products for military and commercial aerospace applications since 1964 and MIL-STD-1553 products for more than 25 years. DDC's design and manufacturing facility is located in Bohemia, N.Y.

References

1. **Data Device Corporation.** 2010 Press Releases. *Data Device Corporation Web Site.* [Online] Data Device Corporation, March 2, 2010. [Cited: March 10, 2010.] http://www.ddc-web.com/News/Press/DDC_Airbus.aspx.



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Industry documents used to support DDC's certifications and Quality system are: AS9001 OEM Certification, MIL-STD-883, ANSI/NCSL Z540-1, IPC-A-610, MIL-STD-202, JESD-22, and J-STD-020.





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