

A Robust Physical Layer for Aircraft Data Networks Based on MIL-STD-1553

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ABSTRACT

One of the current trends in aircraft system design is a shift from federated/centralized architectures towards a more distributed approach. The increased use of distributed processing in critical real-time control systems, such as flight control, engine control and power management systems, is creating a demand for reliable data communication networks. There are many commercially available data communication standards but very few of them will satisfy the stringent environmental requirements of an aircraft, such as lightning immunity.

MIL-STD-1553, which is well established in military aircraft, is a leading candidate for use in new commercial aircraft systems. [1] Airbus selected MIL-STD-1553 for use in the flight control system on the A-350XWB. MIL-STD-1553's physical layer was designed specifically for use in aircraft and as such it provides superior noise, EMI, and lightning immunity which are all essential elements of a reliable aircraft data network. [2]

This paper discusses the architectural benefits of 1 Mbps MIL-STD-1553 as it relates to an aircraft environment as well as extensions to MIL-STD-1553 which include faster data rates and its use with alternate protocols. The viability of a MIL-STD-1553 physical layer with an alternate protocol will be illustrated by technology demonstration hardware consisting of a TTP (Time Triggered Protocol) controller running with a MIL-STD-1553 physical layer at 4 Mbps.

MIL-STD-1553's robust physical layer combined with emerging high speed derivatives serve as an ideal set of building blocks for a variety of aircraft applications. The superior isolation performance of MIL-STD-1553 makes it an extremely attractive solution for applications with severe

EMI and lightning environments. Decades of in service flight history support the notion that MIL-STD-1553 is well suited for critical real-time systems such as flight controls. The use of MIL-STD-1553 on the A350 aircraft is a testament to 1553's effectiveness for use in real-time, high assurance systems. MIL-STD-1553 is a mature, field proven technology that provides an ideal solution for emerging commercial aerospace applications.

INTRODUCTION

The environmental requirements of aircraft systems create unique constraints on the implementation of a data communication network. The demanding EME (Electromagnetic Environment) requirements, specifically lightning and RF susceptibility are well beyond the limits of standard data communication interfaces. In addition the aircraft industry's shift from aluminum to composite airframes is increasing the significance of lightning susceptibility.

Most trade studies of industry standard data buses reveal that there are a large number of data bus technologies that are candidates for use in aircraft. Automotive data buses, such as CAN-bus and FlexRay, tend to provide low cost implementations due to the availability of mass produced processor chips with communication controllers for these protocols built in. These automotive data buses appear to be attractive solutions until the environmental requirements are evaluated. The long cable distances required on a large aircraft combined with the severe EME requirements put seemingly unrealistic demands on these data buses.

One megabit per second MIL-STD-1553 was designed explicitly for use in aircraft and has a long history of reliable usage. This paper will review some of the unique architectural features of MIL-STD-1553 that make it

appropriate for an aircraft environment and will explore the possibility of extending the data rate beyond one megabit per second. In addition a concept will be presented in which MIL-STD-1553's physical layer is used to supplement commercial data bus standards to make them appropriate for an aircraft environment.

ARCHITECTURAL OVERVIEW

MIL-STD-1553 utilizes a multi-drop bus topology to implement time division multiple access communication (refer to [Figure 1](#)). The shared bus acts as a broadcast medium between each of the communicating nodes. The connections to the shared bus are passive which results in a lower cost and lower complexity implementation when compared to active connections (such as a switched network). Access to the media is managed by MIL-STD-1553's command/response protocol.

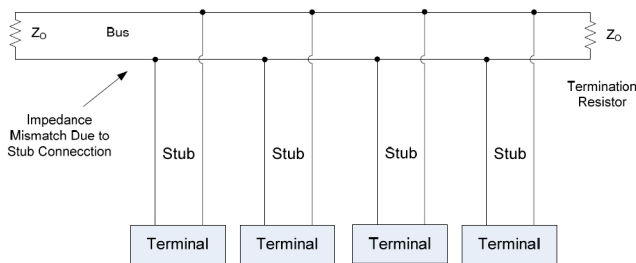


Figure 1. Multi-Drop Bus Topology

While a multi-drop bus topology has the advantage of lower complexity, it also presents a challenge in maintaining signal integrity on a transmission line that contains multiple stub connections. Each connection to a shared bus creates a mismatch in the characteristic impedance that results in reflections that cause distortion of the transmitted signal and in turn will impact the bit error rate of a receiver. MIL-STD-1553 utilizes a unique “transformer coupling” method to make connections to the shared bus. The use of transformer coupled connections results in reduced reflections, increased fault isolation, and better impedance matching which allows for longer bus lengths, longer stubs lengths, and more stub connections as compared to direct coupled connections.

MINIMIZING REFLECTIONS

A multi-drop bus consists of 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 2](#)). 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).

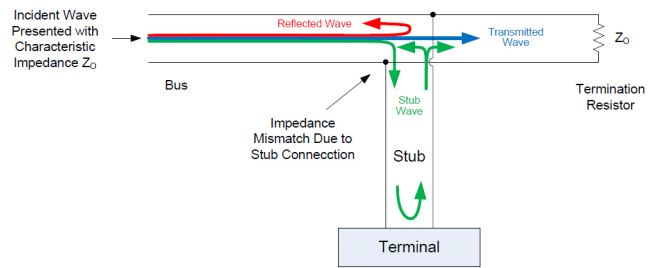


Figure 2. Reflections Caused by Impedance Mismatch

The stub wave, i.e. the portion of the wave that travels down the stub, will hit another point of discontinuity at the terminal (communication end system) due to the mismatch in impedance between the transmission line (Z_0) and the lumped impedance of the stub. The mismatch in impedance will result in a reflection of the stub wave back towards the bus. One option that could be considered would be to terminate the stub connection with a resistive value equal to the characteristic impedance at the terminal. Terminating the stub would eliminate the stub wave being reflected back onto the bus but would result in an attenuation of the transmitted signal because the stub wave portion of the transmitted signal would be dissipated into the termination resistor. The attenuation of the signal with terminated stub connections would significantly limit the number of nodes that could be connected to a bus.

MIL-STD-1553, recognizing the limitations of terminating stubs, specifies that each terminal on the bus must maintain a relatively high impedance thus creating a mismatch in impedance relative to the characteristic impedance. The mismatch will produce a large reflection coefficient which will result in most of the stub wave being reflected back towards the main bus where it will be added back into the incident wave. The effect of maintaining a high input impedance on the terminal will be a reduction in the attenuation of the transmitted signal on the main bus. The reflection of the stub wave back on the bus will however result in phase distortion of the transmitted signal due to the round trip delay time down the stub cable and back to the bus. The amount of phase distortion can be controlled by limiting the length of the stub cables.

The reflection coefficient on the main bus will be based on the impedance mismatch caused by a stub connection (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 value of Z_L that approaches Z_0 and will result in a lower reflection coefficient (C_R). [3]

$$C_R = \frac{Z_L - Z_0}{Z_L + Z_0} \quad (1)$$

The stub impedance includes both the impedance of the terminal as well as the distributed impedance of the cable. The effective stub impedance presented at the connection to the bus will decrease as the length of the stub cable is increased. Figure 3 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 1000 ohms will result in a stub impedance of less than 300 ohms. It is also interesting to note that if the terminal input impedance were doubled from 1000 ohms to 2000 ohms the resulting input impedance through a 20 foot stub cable would still be approximately 300 ohms implying that stub length is a dominant factor in determining the resulting reflection coefficient for a direct coupled stub connection. [4]

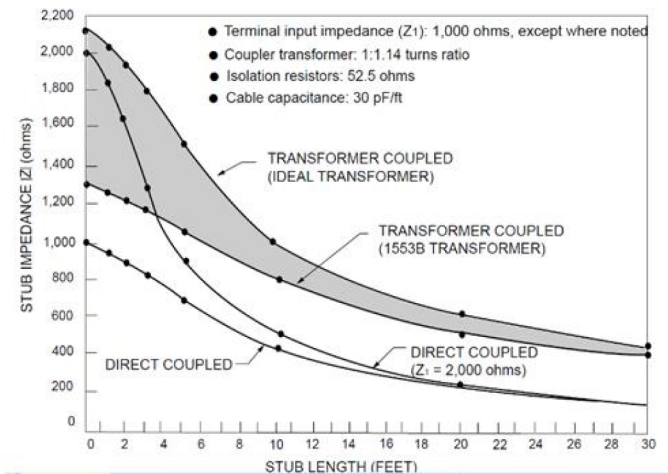


Figure 3. Stub Impedance Versus Stub Length

MIL-STD-1553 includes an option for what is referred to as “transformer coupled” connections, which defines the use of bus couplers at the connection between a stub cable and the main bus. The bus coupler contains a transformer with a step up turns ratio of 1:1.41 from the stub to the bus (refer to Figure 4). The transformer will increase the effective impedance of the stub by the turns ratio squared (i.e. by a factor of 2 to 1), which will decrease the resulting reflection coefficient and in turn will reduce the amount of phase distortion of the transmitted signal due to the stub connection.

Referring to Figure 3, assume that a terminal has an input impedance of 1000 ohms. The effective impedance through an ideal transformer with a ratio of 1.41:1 would be 2000 ohms plus the impedance of the isolation resistors (which will be discussed in more detail later). A real transformer will include parasitics that will result in a slight reduction in the effective input impedance as compared to an ideal

transformer. 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.

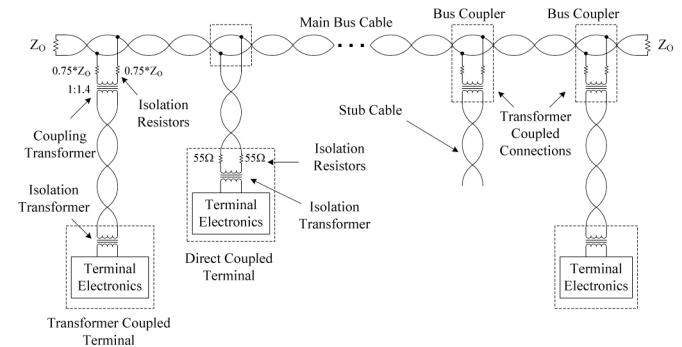


Figure 4. Bus Topology

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

Fault isolation is an important consideration in the implementation of a critical data bus. Unlike a switched network, in which the links to each node are physically isolated, a multi-drop bus, such as that defined within MIL-STD-1553, could be susceptible to a single failure disabling communication between all nodes. MIL-STD-1553 requires the implementation of a transmitter watchdog timer, which is an independent circuit, within a communication terminal, intended to detect a fault within the terminal in which the device transmits continuously (a babbling transmitter). The transmitter watchdog timer is required to disable the transmission in the event that the transmission exceeds a maximum allowable length.

MIL-STD-1553 also 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. Fault isolation is an important consideration for a broadcast medium to ensure that a single fault condition does not result in total loss of communication on the bus. For example suppose that a faulty transmitter on one of the nodes presents a dc voltage into its isolation transformer. The dc voltage will result in magnetic saturation of the transformer core and the secondary winding will effectively short out the stub. The isolation resistors in the bus coupler will allow the bus to tolerate this fault condition in which one of the stubs is shorted.