MIL-STD-1553 Physical Layer for Time-Triggered Networks

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ABSTRACT

Time Triggered networking technologies such as TTP (Time Triggered Protocol) are beginning to be used in critical aerospace applications such as flight controls. While TTP provides stringent specifications for determinism and fault tolerance, it does not define a physical layer. TTP's "de facto" physical layer, RS-485, includes shortcomings in a number of areas. These include a relatively low minimum transmitter voltage, low receiver threshold, along with a lack of specificity in a number of areas. The latter include bus signal levels, transmitter zero-crossing distortion and receiver zero-crossing tolerance, isolation method, terminal output noise, common mode and noise rejection, and input impedance. MIL-STD-1553, which has been deployed in flight and mission critical military applications for decades, defines a highly proven and robust physical layer. This paper presents MIL-STD-1553's physical layer as a candidate for use with TTP.

INTRODUCTION

Physical layers represent important components for buses and networks used in flight critical applications, with tradeoffs involving topology, data rate, cable length, power, and cost. Time triggered technologies such as TTP (Time Triggered Protocol) and FlexRay use multiple topologies, including multi-drop buses, along with active and passive stars. TTP does not specify a physical layer, resulting in the deployment of multiple implementations rather than use of a common standard.

MIL-STD-1553's multi-drop bus physical layer operates in demanding applications such as flight control, mission computers, and weapons for fighter and attack aircraft. The maturity and technical characteristics of MIL-STD-1553's physical layer make it a strong candidate for use with time triggered networks.

MIL-STD-1553 defines a highly robust and proven physical layer. For use with time triggered technologies, 1553's 1 Mb/s data rate can be scaled to operate at 5 or 10 Mb/s by means of upgraded transceiver and transformer design, and use of 8B/10B encoding.

MIL-STD-1553's physical layer offers many advantages for time triggered networks. These include differential signaling, with a defined "idle" state to help prevent collisions between consecutive transmitters. MIL-STD-1553's use of transformer isolation and optional transformer bus coupling provide DC isolation, common mode rejection, and lightning protection, with series isolation resistors to protect against short circuit faults. The transformer bus coupling option increases stub impedance to enable increased stub lengths.

MIL-STD-1553's relatively high transmit voltages provide strong data rate/cable length performance, while 1553's specifications for rise and fall times limit EMI emissions. Additional 1553 specs include transmitter zero-crossing distortion, overshoot, ringing, droop, output noise, and output symmetry. MIL-STD-1553's output symmetry spec limits the amplitude and duration of "tails" at the end of a node's transmission.

MIL-STD-1553 also defines specs for "must ignore" and "must recognize" receiver voltages, plus requirements for zero-crossing distortion, common mode rejection, noise rejection, and terminal input impedance. MIL-STD-1553B also specifies voltage ranges delivered by the bus cable to all receiving nodes on the bus. The affect of these latter specs is to impose a maximum loss budget on the bus.

TTP and FLEXRAY -- PHYSICAL LAYERS

Time triggered networks such as TTP (Time Triggered Protocol) and FlexRay deploy multiple topologies. As shown in Figure 1, these include multi-drop bus, active star, passive star, and combinations thereof. Active stars entail penalties in the areas of component volume and weight, cable volume and weight, power, and cost. In these respects, the use of a multi-drop passive bus offers advantages over an active star.

TTP does not define a standard physical layer. This has led to the deployment of multiple physical layers for different implementations, rather than the adoption of a common standard. TTP's "de facto" physical layer, RS-485, includes shortcomings in a number of areas. These include relatively low values for required transmitter voltage and receiver threshold, along with a lack of specificity in a number of specs. The latter include transmitter and receiver zero-crossing distortion, isolation method, bus signal levels, terminal output noise, common mode and noise rejection, and input impedance.

For many decades, MIL-STD-1553 has provided proven and reliable operation in demanding applications such as flight control, mission computers, and weapons control for fighter, attack, and transport aircraft. MIL-STD-1553's maturity and technical characteristics make it a strong candidate as a physical layer for time triggered protocols such as TTP and FlexRay.

MIL-STD-1553 is defined for a 1 Mb signaling rate using Manchester encoding, and therefore a 1 Mb/s data rate. For use with time triggered technologies, 1553's physical layer specifications can be scaled for operation at signaling rates of 5 or 10 Mb.

A basic issue with a multi-drop topology involves the tradeoff between data rate and cable length. This involves loss budget, cable attenuation, stub and node impedances, the number of stubs, and stub lengths. To ensure low bit error rates, multi-drop buses must be defined to provide adequate levels of signal integrity to all receiving nodes.

MIL-STD-1553 defines differential signaling, with three voltage states: idle, active high, and active low. For use with time triggered technologies, the inclusion of an idle voltage level enables receivers to more easily determine "dead time", thereby indicating to the next node to transmit that the bus is "safe"; i.e., there won't be a collision with the preceding node's transmission. Further, the use of a differential, rather than single-ended bus provides advantages in the areas of common mode performance EMI, and lightning immunity. To preclude the possibility of a short circuit fault "taking down" an entire bus, MIL-STD-1553 includes a requirement for all nodes to include series isolation resistors.

DIRECT and TRANSFORMER COUPLING

As shown in Figure 2, MIL-STD-1553 provides two different configurations for coupling a node to a 1553 bus, direct coupling and transformer coupling. It is possible to include a mix of the two types of coupling methods on the same data bus.

MIL-STD-1553 requires the use of transformer isolation for both direct-coupled and transformer-coupled terminals. This provides robustness in the areas of DC isolation, survivability for lightning, and common mode rejection.

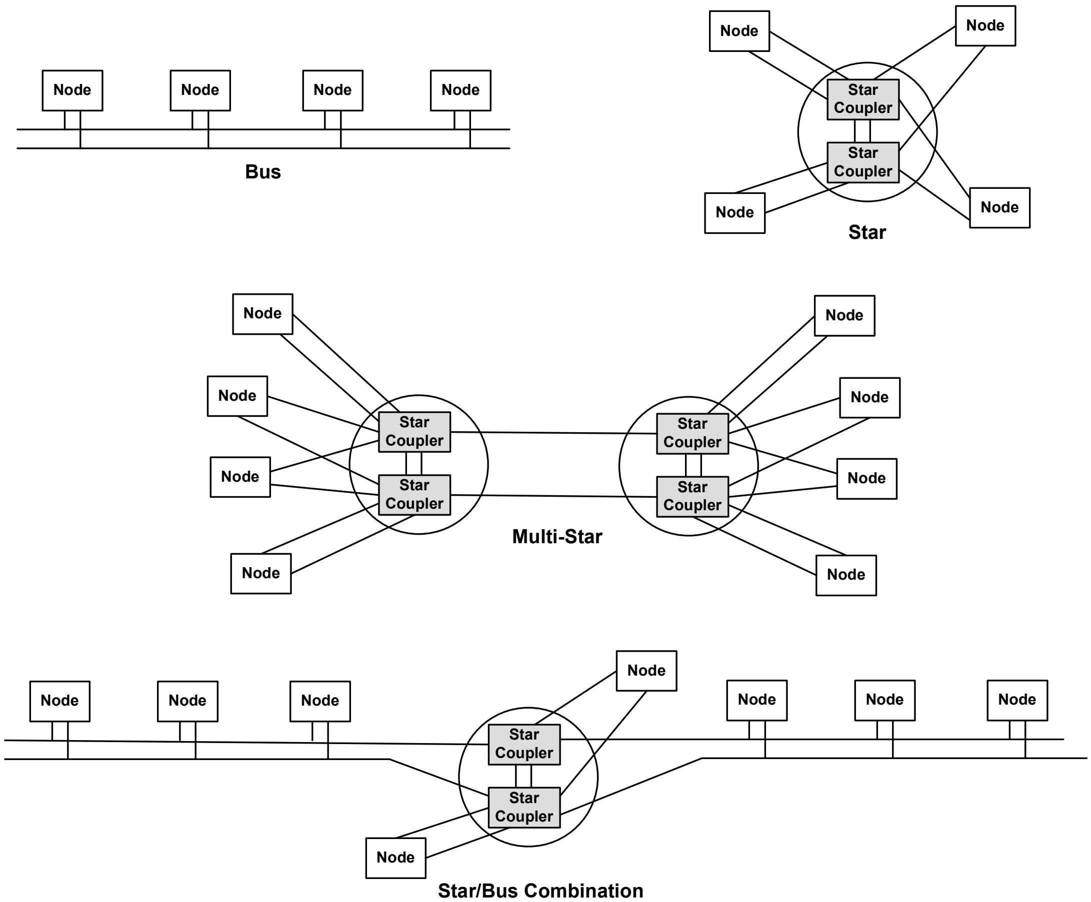


Figure 1. TTP Topologies: Bus, Star, Multi-Star, and Star/Bus Combination[1]

[1] Time-Triggered Protocol TTP/C High-Level Specification Document Protocol Version 1.1, page 21.

Direct coupling includes a requirement for 55 ohm isolation resistors in series with each leg of the isolation transformer. This provides protection in the case of a short circuit in a terminal's transformer or transceiver. If a short circuit occurs, the terminal will load the data bus with 110 ohms, rather than a dead short, allowing the remaining terminals on the bus to continue operation despite the fault. With direct coupling, the recommended maximum distance between the terminal and its connection to the data bus is one foot. The short stub length minimizes the possibility of a short circuit in the sub wiring, which is unprotected by the isolation resistors. In addition, this limitation also minimizes the loading of the data bus from the stub cable's capacitance.

Figure 2 also illustrates MIL-STD-1553 transformer coupling. Transformer coupling entails the use of a bus coupler to interface a terminal's stub to the data bus. As shown, the bus coupler consists of a coupling transformers and a pair of bus isolation resistors. Unlike for direct coupling, there are no isolation resistors in a transformer-coupled terminal. The value of these resistors is $0.75 \bullet Z_0$. These resistors provide protection against short circuit faults in the coupling transformer, stub, and the terminal's isolation transformer and transceiver.

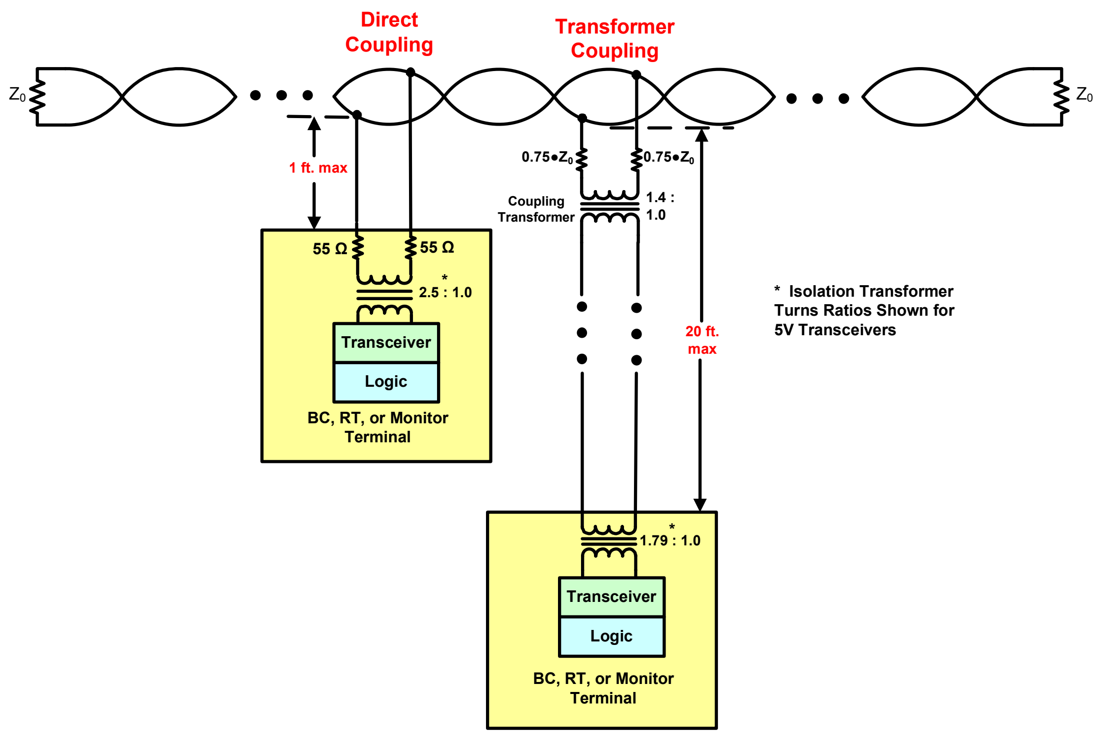


Figure 2. 1553 Direct and Transformer Coupling

MIL-STD-1553 specifies parameters for the coupling transformers, including:

- Turns ratio: 1.4 to 1.0, stepping down, from the bus to the stub.
- Open circuit impedance (on the bus side): ≥ 3,000 ohms, over 75 KHz to 1 MHz.
- Droop: ≤ 20%
- Ringing: ≤ 1 V_{pk}.
- Common mode rejection ratio: ≥ 45 db.

For transformer-coupled terminals, MIL-STD-1553 recommends a maximum distance between the bus and the terminal of 20 feet. Since stub impedance decreases as a function of stub length, the purpose of this recommendation is to limit the bus loading created by individual stubs.

Excessive stub loading increases transmission line reflections, resulting in waveform phase distortion. In addition, increased stub loading tends to reduce the bus voltage.

Transformer coupling enables longer stubs by doubling the stub impedance as “seen” by the main bus cable. In addition, it provides impedance matching for transmitters (the load on the transmitter = Z_0). Further, relative to direct coupling, transformer coupling provides improvements in DC and ground isolation, lightning protection, and common mode rejection.

DATA ENCODING and WAVESHAPING

Figure 3 and Figure 4 illustrate MIL-STD-1553’s basic data encoding and waveshaping specifications.

As shown in Figure 3, the encoding method specified by MIL-STD-1553 is Manchester II, or Manchester Biphase-L. For a 1 Mb/s data rate, Manchester encodes a logic ‘1’ as a 500 nS positive voltage, followed by a 500 nS negative voltage; and a logic ‘0’ as a 500 nS negative voltage, followed by a 500 nS positive voltage. In addition to its simplicity, another advantage of Manchester encoding is its transition density. Since Manchester provides a minimum of one signal transition per bit time, this helps to facilitate reliable clock recovery, and the use of oversampling decoding techniques. Further, Manchester encoding provides a balanced waveform with zero DC component, thereby enabling transformer isolation.

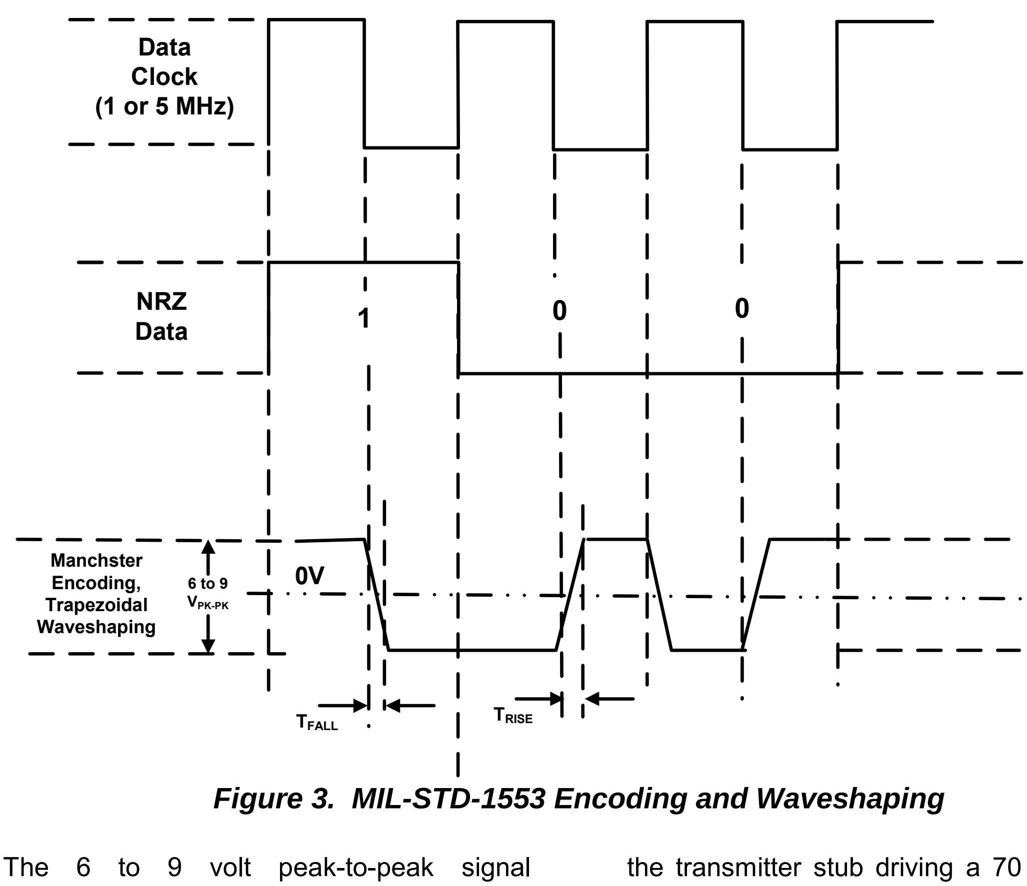


Figure 3. MIL-STD-1553 Encoding and Waveshaping

The 6 to 9 volt peak-to-peak signal amplitude spec shown in Figure 3 refers to the transmitter output for direct coupled terminals. For stub coupled terminals, MIL-STD-1553 specifies 18 to 27 volts across the transmitter stub driving a 70 ohm load. This results in approximately 6.36 to 9.54 volts peak-to-peak driven on to the bus.

As shown in Figure 3 and Figure 4, 1553 specifies trapezoidal waveshaping with a range of rise and fall times of 100 to 300 ns. These times are defined as the transition times between the 10% and 90% points of the peak-to-peak voltage. Trapezoidal, rather than sinusoidal waveshaping, results in simpler transmitter designs, including improved control over the important parameter of zero crossover timing.

The purpose of the lower limit on rise/fall times is to limit the harmonic content of the signal above 1MHz. This serves to minimize EMI and crosstalk, as well as transmission line reflections that can result in false zero crossings and possible decoding errors. Most transmitter designs tend toward the lower limit of the rise/fall time standard as a means of minimizing drive stage power dissipation.

As shown in Figure 4, MIL-STD-1553 limits the overshoot and ringing distortion of the differential transmitted voltage to less than ±300.0 mV peak for direct-coupling, and less than ±900.0 mV peak for transformer coupling. As shown, this spec is applicable for all rise and fall transitions during a transmission, as well following the end the last Manchester half-bit transmitted.

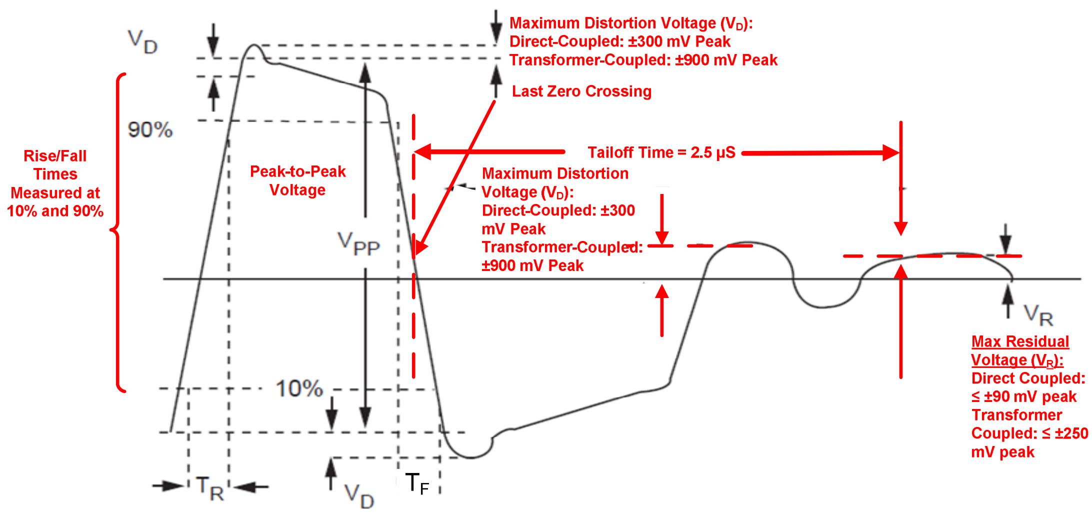


Figure 4. MIL-STD-1553 Transmit Waveform

MIL-STD-1553 includes an additional limit on the distortion at the end of a node's transmission. This spec, commonly referred to as "output symmetry" or "dynamic offset", provides a limit on the residual voltage or "tail". Specifically, this limits the voltage 2.5 μS after the mid-bit zero crossing of the last transmitted bit to less than ±90 mV for a direct-coupled transmitter, or less than ±250 mV for a transformer-coupled transmitter.

For a time-triggered network, this residual voltage spec helps to ensure a "dead bus" following one node's transmission prior to the start of transmission by the subsequent node. A related spec in this respect is that for maximum output noise from a non-transmitting terminal. MIL-STD-1553 limits this to less than 5 mV RMS for a direct-coupled terminal, or less than 14 mV RMS for a transformer-coupled terminal.

ZERO-CROSSING DISTORTION

Figure 5 illustrates another transmitter parameter, zero-crossing distortion. In other networking standards, this is referred to as jitter. Zero-crossing distortion has to do with the time between zero crossings of a Manchester encoded transmitted signal. The times t_{zcp} and t_{zcn} in Figure 5 represent the respective pulse widths of the positive and negative voltage pulses. For MIL-STD-1553 1 Mb/s Manchester encoded signals, the nominal times for t_{zcp} and t_{zcn} are 500 and 1000 nS. Per MIL-STD-1553, the maximum deviation from these nominal times is ±25 nS; that is, 500 ±25 nS, or 1000 ±25 nS.

In addition to specifying maximum zero-crossing distortion on the transmitting side, 1553 also specifies a minimum tolerance for receivers' zero-crossing distortion tolerance. For t_{zcp} and t_{zcn}, the minimum value of this parameter is ±150 nS. That is, a receiving terminal must accept as valid input signals with zero-crossing distortion of up to ±150 nS. This, together with the ±25 nS tolerance on the transmit side, allows a "zero-crossing distortion budget" of up to ±125 nS that can be introduced as the result of transmission line reflections from stubs, and from the bus cable.

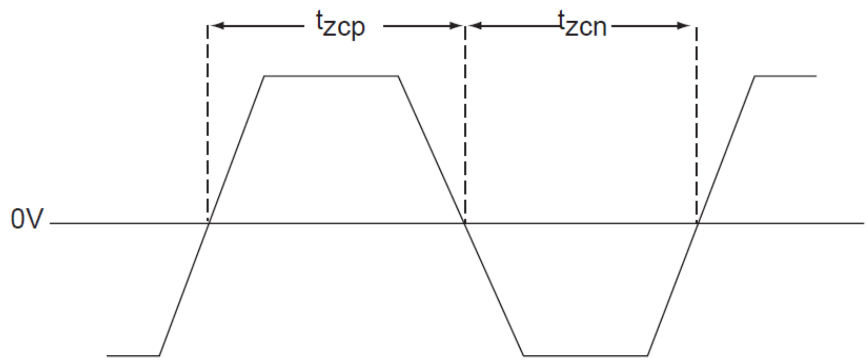


Figure 5. Zero-Crossing Distortion

DATA BUS and RECEIVER VOLTAGES

While MIL-STD-1553A specified a maximum length of 300 feet for the main bus cable, MIL-STD-1553B eliminated this restriction. In its place, as shown in Figure 6, 1553B specifies minimum and maximum voltages that a bus must deliver to all stubs. As shown, a MIL-STD-1553B bus must deliver 1.4 to 20 volts peak-to-peak to all direct-coupled stubs, and 1.0 to 14 volts peak-to-peak to all transformer-coupled stubs. This, in effect, mandates a maximum loss budget for the bus of slightly over 12.6 dB.

MIL-STD-1553B receiver voltage specs are based on the concept of a threshold; that is, the voltage above which a node must consider a received 1553 message to be valid. For direct-coupled terminals, the maximum threshold is 1.2 V peak-to-peak, while for transformer-coupled terminals, the maximum threshold is 860 mV. Relative to the minimum voltage level that must be provided by the bus, this provides a minimum margin of 200 mV peak-to-peak for direct-coupled terminals, and 140 mV for transformer-coupled terminals.

In addition to the maximum threshold voltage, 1553B also specifies minimum "no respond" voltages. That is, received signal levels below this value *must not* be considered to be valid. For direct-coupled terminals, the minimum "no respond" voltage is 280 mV peak-to-peak, while for transformer-coupled terminals, the "no respond" voltage is 200 mV. These "no respond" voltages specify a definitive "dead zone", allowing a node to determine that no other nodes are transmitting. In addition, they provide an inherent degree of noise immunity.

COMMON MODE REJECTION

MIL-STD-1553 specifies a minimum level of common mode rejection for all terminals. Common mode rejection is partially a characteristic of the terminals' isolation transformers, and is a form of noise disturbance commonly encountered in avionics.

As shown in Figure 7(a), for the common mode test for a transformer-coupled terminal, the common mode signal is applied between the center tap of the bus coupling transformer on the "stub" side and ground. As shown in Figure 7(b), for a direct-coupled terminal, the common mode signal is applied between the junction of two "half-termination" resistors ($0.5\bullet Z_0$ each) and ground.

For the terminal common mode rejection test, the minimum signal level of 860 mV peak-to-peak transformer-coupled, or 1.2 V direct-coupled is used. The common mode signal applied includes ±10 VDC, and a ±10 V (peak) AC voltages whose frequency is swept from 1 Hz to 2 MHz. To pass, the terminal must accept all messages received.

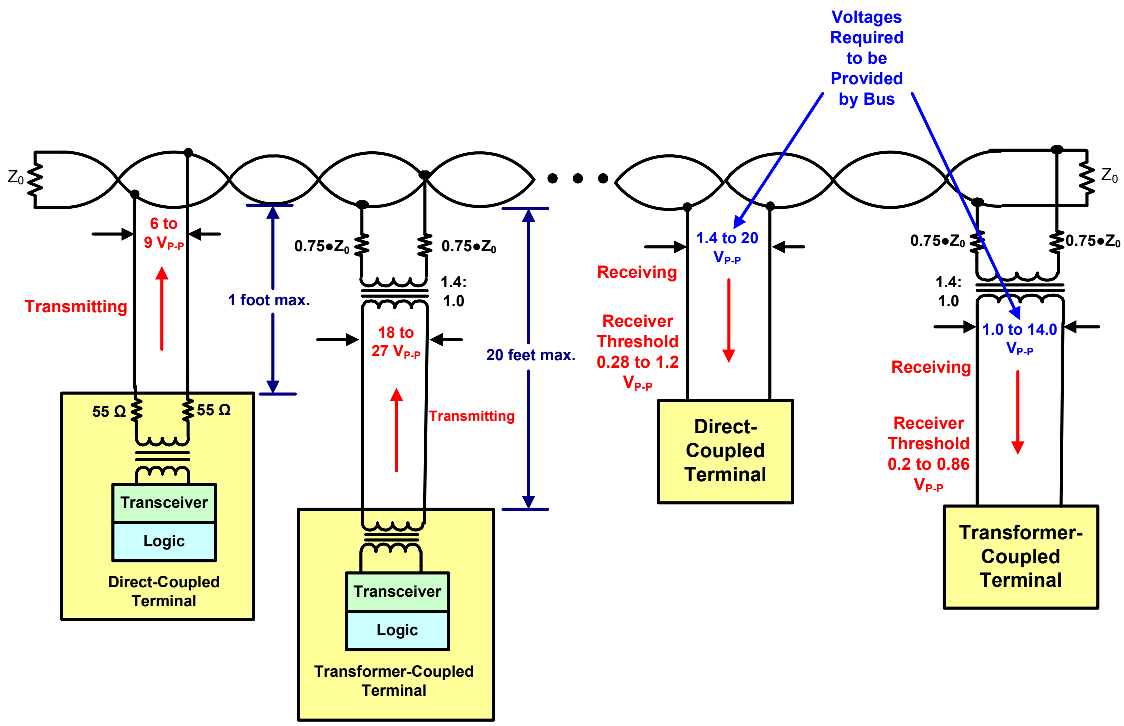


Figure 6. MIL-STD-1553 Bus, Stub, and Receiver Voltages

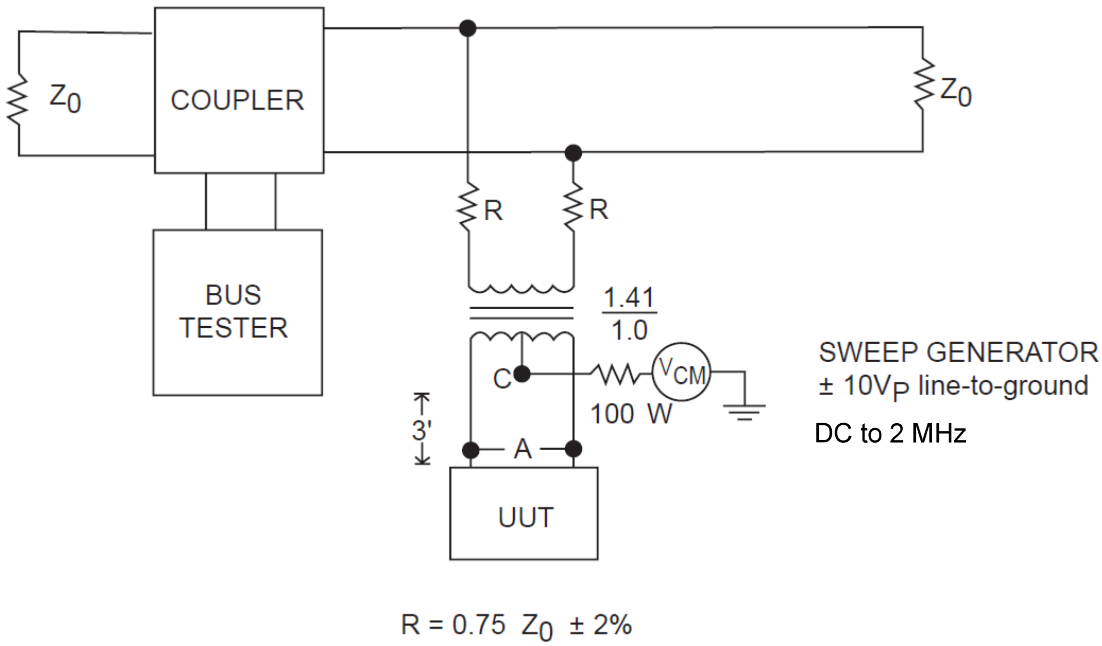
INPUT IMPEDANCE

Another 1553 physical layer spec is terminal input impedance. The importance of input impedance is that it effects the loading on the main bus. Excessive stub loading increases transmission line reflections, resulting in waveform phase distortion, and tends to reduce the bus voltage. MIL-STD-1553 specifies a minimum terminal input impedance over the frequency range of 75 KHz to 1 MHz. This represents the range of fundamental frequencies for 1553 signals.

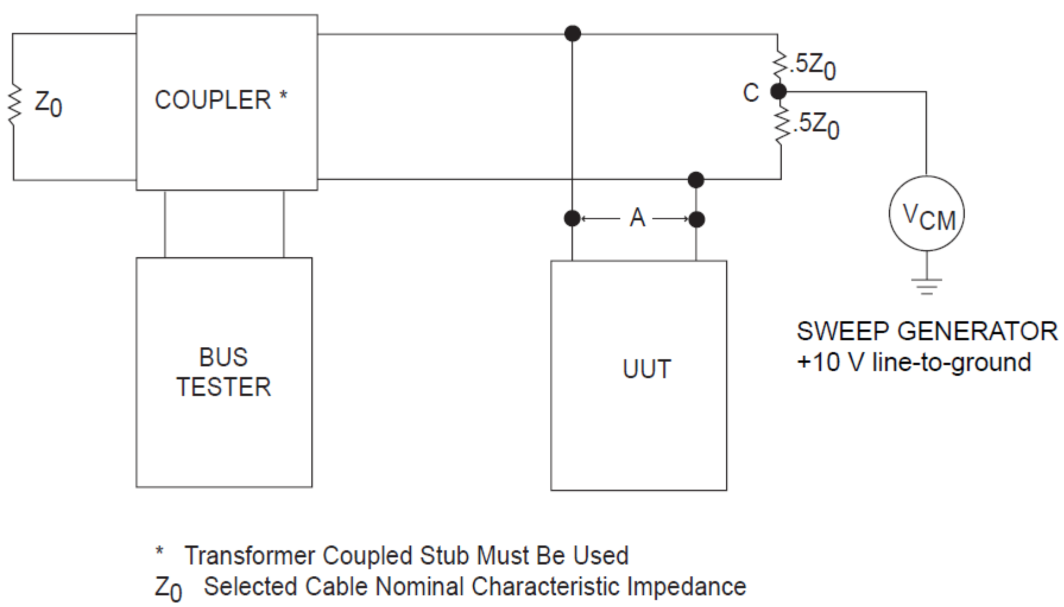
For direct-coupled terminals, the terminal input impedance must be a minimum of 2,000 ohms, while for transformer-coupled terminals, the terminal input impedance must be a minimum of 1,000 ohms. The reflected impedance of transformer-coupled terminals to the main bus is doubled by the 1.4 to 1.0 turns ratio of the bus coupling transformer.

NOISE REJECTION (BIT ERROR RATE)

Another spec for 1553 terminals is noise rejection, or bit error rate testing. MIL-STD-1553B defines a test for terminals to be able to receive messages in the presence of white, Gaussian noise applied differentially across the data bus or stub. This test, which is defined within the 1553 standard, provides a figure-of-merit test criteria for operating in an environment including switching power supplies, radios, radar, electromechanical switching, and other sources of EMI.



(a)



(b)

Figure 7. MIL-STD-1553B Common Mode Rejection Test: (a) Transformer- coupled; (b) Direct-coupled[2]

[2] SAE AS4111; Validation Test Plan for the Digital Time Division Command/Response Multiplex Data Bus Remote Terminals; Figure 6A, page 60; and Figure 6B, page 61.

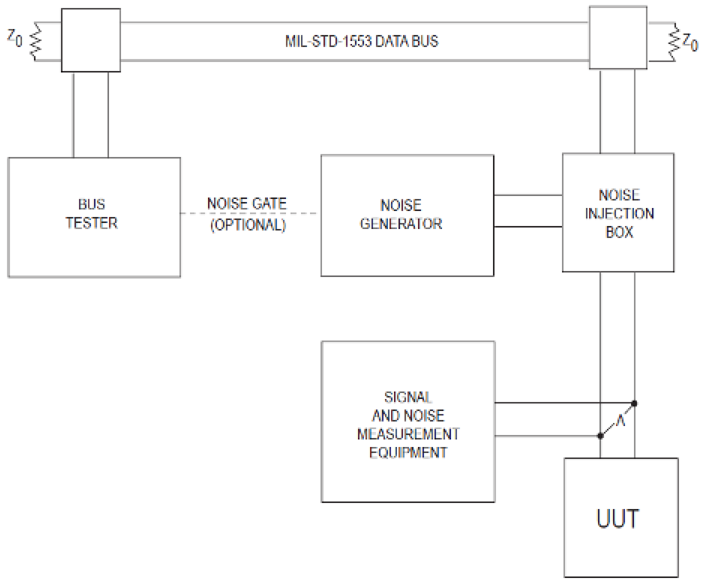


Figure 8. Noise Rejection (Bit Error Rate) Test

The 1553 noise test specifies signal and noise levels, with a signal-to-noise ratio of approximately 16.6 dB. For direct-coupled terminals, the test entails the use of a signal level of 3.0 volts peak-to-peak and a white Gaussian noise source of 200 mV RMS distributed over 1.0 to 4.0 MHz. For transformer-coupled terminals, the test specifies a signal level of 2.1 volts peak-to-peak and a white Gaussian noise source of 140 mV RMS.

In both cases, the terminal must demonstrate a word error rate of less than 10^{-7}., equivalent to a bit error rate of $2\bullet10^{-9}$.

BUS ISOLTION

To ensure independence for redundant buses, MIL-STD-1553 specifies a minimum isolation of 45 dB between buses.

VALIDATION TESTING

One of the keys to MIL-STD-1553's long-term success in military use is its defined and publically available criteria for validation testing. This delineates a rigorous suite of tests, to which a terminal must demonstrate compliance to. This test includes all of the physical layer parameters discussed in this paper, along with comprehensive protocol testing. As a result, while MIL-STD-1553 has been implemented by many dozens of different designers over the years, it has historically *not* encountered issues with interoperability.

CABLE

MIL-STD-1553's cable specifications include the use of twisted/shielded cable, with a defined characteristic impedance, maximum attenuation, shielding coverage, capacitance, twists per foot, and EMC. Table 1 lists MIL-STD-1553's cable characteristics.

Table 1. MIL-STD-1553 Cable Characteristics

Property	Value

Type	Twisted-shielded pair
Characteristic impedance (Z_0)	70 to 85 ohms at 1.0 MHz
Attenuation	1.5 dB/100 ft at 1.0 MHz, maximum
Shielding Coverage	75% minimum
Length of main bus	Not specified
Capacitance (wire to wire)	30 pF/ft, maximum
Twist Four per foot	0.33/in, minimum
EMC	Per MIL-E-6151

COMPARISON: MIL-STD-1553 vs. RS-485

Like MIL-STD-1553, RS-485 is based on the use of differential signaling. However, in many respects, RS-485 is a less robust standard than 1553. For example, RS-485's minimum bus voltage is 1.5 volts peak (3.0 volts peak-to-peak), which is half of the MIL-STD-1553 minimum bus voltage of 6.0 volts peak-to-peak. Similarly, in order to provide a degree of noise immunity, 1553 specifies higher voltages for receiver threshold than RS-485, including (in effect), "must reject" voltages.

For rise and fall times, in order to control EMI emissions, MIL-STD-1553 specifies both a minimum and maximum, while 485 specifies only a maximum. In addition, while MIL-STD-1553 provides a clear delineation of bus "dead time", RS-485 does not.

Further, 1553 defines specs in a number of areas for which RS-485 is "silent" about. These include isolation method and options for either direct or transformer coupling; ranges for bus voltages delivered to receivers (loss budget); transmitter limitations and receiver tolerances for zero-crossing distortion (jitter); noise rejection (bit error rate); and terminal input impedance.

Table 2 provides a comprehensive comparison of MIL-STD-1553's physical layer relative to RS-485.

Table 2. Physical Layer Comparison: MIL-STD-1553 vs RS-485

Characteristic	MIL-STD-1553	RS-485	Advantage/Benefit
Type of Signaling	Differential	Differential	**Even.** Both MIL-STD-1553 and RS-485 use differential signaling.
Signal Encoding Method	Manchester Bi-Phase	Not specified.	**N/A**
Transmit Voltage	Direct Coupled: 6.0 to 9.0 $V_{PK\text{-}PK}$ Transformer Coupled: 18.0 to 27.0 $V_{PK\text{-}PK}$	Differential voltage = 1.5 to 5.0 volts = 3.0 to 10.0 $V_{PK\text{-}PK}$	**MIL-STD-1553.** For both direct and transformer-coupled configurations, MIL-STD-1553 provides a higher minimum bus voltage: 6.0 $V_{PK\text{-}PK}$ direct-coupled, or 6.36 $V_{PK\text{-}PK}$ transformer-coupled.
Rise/Fall Times (10% to 90%)	100 to 300 nS	≤0.3●UI	**MIL-STD-1553.** For MIL-STD-1553, a stream of all Manchester "1"s or "0"s results in rise/fall times in the range of 0.2●UI to 0.6●UI. For alternating "1"s and "0"s, the corresponding rise/fall times are 0.1●UI to 0.3●UI. MIL-STD-1553's upper limit is equivalent to that for RS-485. MIL-STD-1553's lower limit of 100 nS serves to minimize EMI and over/undershoots.
Transmitter Zero-Crossing Deviation	≤ ±25 nS	Not specified	**MIL-STD-1553.** MIL-STD-1553 specifies an upper bound on transmit jitter, thereby providing increased margin for distortion introduced by bus cabling and stubs.
Non-Transmitting Output Noise	Direct Coupled: ≤ 5 mV RMS line-to-line Transformer Coupled: ≤ 14 mV RMS line-to-line	Defines a maximum offset voltage in the range of -1.0 to +3.0 volts.	**MIL-STD-1553.** MIL-STD-1553's more stringent requirement for non-transmitting output voltage guarantees a lower maximum level of interference from inactive (non-transmitting) nodes.
Output Symmetry – Residual Voltage	Direct Coupled: ≤ 90 mV peak, line-to-line Voltage 2.5 µS after last mid-bit crossing Transformer Coupled: ≤ 250 mV peak, line-to-line Voltage 2.5 µS after last mid-bit crossing	Maximum common mode voltage is -3.0 to +1.0 volts. Maximum difference between positive and negative peak voltages must be ≤ 0.2 volts.	**MIL-STD-1553.** MIL-STD-1553's requirement for a maximum residual (or "tailoff") voltage 2.5 µS following the end of a transmission ensures non-interference with the subsequent transmission on the bus. In addition, RS-485's allowance for a DC offset voltage complicates the use of transformer isolation.
Node isolation.	Isolation transformers are required for all MIL-STD-1553 terminals.	Isolation is not required.	**MIL-STD-1553.** MIL-STD-1553's requirement for transformer isolation ensures a high degree of ground isolation, and lightning and common mode rejection.
Bus-to-Bus Isolation	≥ 45 dB	None	**MIL-STD-1553.** MIL-STD-1553 limits crosstalk between redundant buses.
Fault Isolation	Direct Coupled: 55 ohm Series Resistors in Each Terminal Leg	None	**MIL-STD-1553.** The requirement for isolation resistors prevents a short-circuited terminal or stub from taking the entire bus out of operation.

Characteristic	MIL-STD-1553	RS-485	Advantage/Benefit
	Transformer Coupled: $0.75 \bullet Z_0$ Series Resistors in Each Stub Leg		
Bus Coupling Transformer	Turns Ratio: 1.4 to 1.0 (step-down, bus to stub) Open Circuit Impedance: ≥ 3,000 ohms, over 75 KHz to 1 MHz Droop: ≤ 20% Ringing: ≤ 1V peak Common Mode Rejection: ≥ 45 dB	N/A	**MIL-STD-1553.** The option for transformer coupling provides increased stub impedance, matched transmitter impedance, improved ground isolation, and provides a higher degree of lightning immunity.
Signal Level Delivered By Bus to Stub	Direct Coupled: 1.4 to 20 V_{PK-PK}, line-to-line Transformer Coupled: 1.0 to 14 V_{PK-PK}, line-to-line	Not specified	**MIL-STD-1553.** MIL-STD-1553A specified a maximum cable distance of 300 feet. While MIL-STD-1553B dropped this requirement, it requires a minimum (and maximum) voltage to be presented to each terminal and/or stub on the bus. This forces implementers to design terminals, buses and stubs in such a way to ensure reliable network operation.
Receiver Signal Range	Direct Coupled: 1.2 to 20 V_{PK-PK}, line-to-line Transformer Coupled: 0.86 to 14 V_{PK-PK}, line-to-line	-0.2V (peak) ≤ threshold voltage ≤ +0.2V (peak). This implies a receiver “threshold” of 0.0 to 0.4 volts peak-to-peak.	**MIL-STD-1553.** MIL-STD-1553 allows higher receiver thresholds than RS-485, thereby providing a lower bit error rate. Further, MIL-STD-1553 receivers must provide a “dead zone” of 0.28 V V_{PK-PK} = ±0.14 V_{PK} (direct coupled), or 0.2 V V_{PK-PK} = ±0.1 V_{PK} (transformer coupled), thereby providing improved noise immunity. In addition, this improves the capability for a 1553 receiver to be able to determine the end of a received signal transmission. For TTP, this enables shorter gap times between transmissions by individual nodes. RS-485’s minimum receiver threshold of 0V can result in receiver output jitter when there is no received signal.
Receiver “No Response” Range	Direct Coupled: 0 to 0.28 V_{PK-PK}, line-to-line Transformer Coupled: 0 to 0.2 V_{PK-PK}, line-to-line		
Receiver Zero-Crossing Distortion Tolerance	≥ ±150 nS	Not specified.	**MIL-STD-1553.** This 1553 requirement provides tolerance for phase shifts introduced by transmitters, bus cabling and stubs.
Receiver Common Mode Rejection	± 10 V_{PEAK}, line-to-ground, DC to 2 MHz	Receivers must operate over a common mode voltage range of -7V to +12V	**MIL-STD-1553.** MIL-STD-1553’s common mode range is slightly higher, ±10V_{PK} = 20 V_{PK-PK} vs. RS-485’s of +12/-7 V_{PK} = 19 V_{PK-PK}. In practice, MIL-STD-1553’s requirement for transformer isolation

Characteristic	MIL-STD-1553	RS-485	Advantage/Benefit
	For transformer-coupled stubs, coupling transformers must have a common mode rejection ratio greater than 45.0 dB at 1.0 MHz.		provides a greater common mode rage than $\pm10V_{PK}$. In addition, MIL-STD-1553's option for transformer coupling with a common mode rejection ratio of 45 dB for coupling transformers provides a further improvement in overall common mode rejection.
Noise Rejection (Word Error Rate)	Direct Coupled: ▪ 3.0 V_{PK-PK} Signal Level ▪ 200 mV RMS White Gaussian Noise, 1.0 to 4.0 MHz ▪ Word Error Rate < 10^{-7}	No specified	**MIL-STD-1553.** MIL-STD-1553's noise rejection (bit error rate) test ensures the implementation of receiver filtering, thereby providing reliable operation in the presence of differential noise.
	Transformer Coupled: ▪ 2.1 V_{PK-PK} Signal Level ▪ 140 mV RMS White Gaussian Noise, 1.0 to 4.0 MHz ▪ Word Error Rate < 10^{-7}		
Terminal Input Impedance	Direct Coupled: ≥ 2,000 ohms, over 75 KHz to 1 MHz Transformer Coupled: ≥ 1,000 ohms, over 75 KHz to 1 MHz	Defines the concept of "unit load", in which a receiver's, transmitter's, or transceiver's DC resistance is approximately 8.7 KΩ to 12 KΩ. A receiver's, transmitter's, or transceiver's overall input impedance, including reactive (i.e., capacitive) components, is not specified. In addition, the input resistance can be either less than, equal to, or greater than one "unit load".	**MIL-STD-1553.** MIL-STD-1553's minimum values for terminal impedance provide a limitation of the bus voltage loading by individual terminals, and minimize distortion resulting from transmission line reflections.

CONCLUSION

Currently, TTP (Time Triggered Protocol) does not specify a physical layer standard. The physical layer defined by MIL-STD-1553 is a strong candidate for use with time triggered networking technologies such as TTP and FlexRay. In particular, MIL-STD-1553 provides higher transmit voltages and receiver thresholds relative to RS-485. In addition, 1553 provides detailed specifications in a number of areas which are not defined by RS-485, including transmitter zero-crossing distortion and receiver zero-crossing tolerance, isolation method, terminal output noise, common mode and noise rejection, and input impedance.

MIL-STD-1553's higher bus voltages and other specs make it highly suitable for use in a passive, multi-drop topology. Use of a passive, multi-drop topology reduces or eliminates the need for active star couplers, thereby leading to reductions in the associated total cable length, cost, power, weight, and volume.

MIL-STD-1553 Physical Layer (PHY) for TTP – Test Results

Introduction

Time Triggered Protocol (TTP) is emerging as a strong candidate for use in real-time distributed processing control systems in commercial aircraft. Early implementations of TTP in commercial aircraft have faced challenges meeting the environmental requirements of an aircraft, especially lightning and HIRF. RS-485 has been the de facto physical layer for TTP yet a detailed analysis found RS-485 to be lacking is several key areas. RS-485 suffers from a low transmit signal, low receiver threshold, inadequate isolation method, short stub length and is non-specific in many areas (interoperability issues).(1)

MIL-STD-1553 is a 1 Mbps deterministic serial data bus that has been in use in real-time critical systems in military aircraft for over 30 years. MIL-STD-1553 was designed specifically for use in an aircraft environment and as such provides robust performance in terms of isolation and noise immunity. MIL-STD-1553 is an ideal physical layer for use with TTP.

This report summarizes characterization testing that was performed on MIL-STD-1553 as a physical layer for Time Triggered Protocol (TTP). A 1553 physical layer board (1553 PHY) was developed by Data Device Corporation. The 1553 PHY was designed to be installed on a TTP development board (refer to Figure 1).

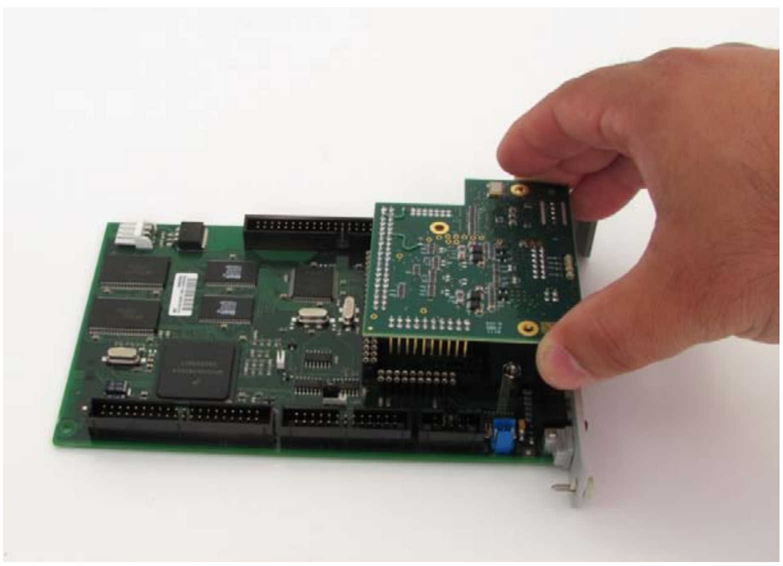


Figure 1. DDC's 1553 PHY Board for TTTech's Powernode TTP Controller Board

DDC's 1553 PHY board contains two MIL-STD-1553 transmitter/receivers (transceivers). The transceivers on the 1553 PHY board were designed to operate at data rates up to 5 Mbps. The TTP controller on the Powernode boards operates at 4 Mbps.

Test Equipment Used

Tektronix TDS5034B Oscilloscope
Tektronix P6246 Differential Probe
Tektronix 1103 TekProbe Power Supply
HP4396A Network / Spectrum Analyzer
HP85016A S-Parameter Test Set
Micronetics NOD-5107 Noise Source
Lambda LPT-7202-FM Power Supply
MIL-STD-1553 cables of various lengths
North Hills NH12826 MIL-STD-1553 Bus Couplers
North Hills 0101BB Baluns (50 ohm unb to 75 ohm bal)
Trompeter TNG-1-78 Terminators (78 ohm)
70 ohm Resistive Load
Kay Elemetrics Corp Model 432D Attenuator

Transmitter Characteristics

Setup

The setup for the 1553 PHY board transmitter measurements is shown in Figure 2. The 1553 PHY board contains DIP switches which can be used to enable test modes of operation. An external power supply was used to supply 5V and 3.3V to the 1553 PHY board. The DIP switches on 1553 PHY board were configured such that the board transmitted a fixed test pattern. The transmit test pattern consisted of a MIL-STD-1553 word that included a Sync plus 17 Manchester encoded bits at a data rate of 5 Mbps with a 25% transmit duty cycle. An oscilloscope was used to measure the output of the transmitter across a resistive load.

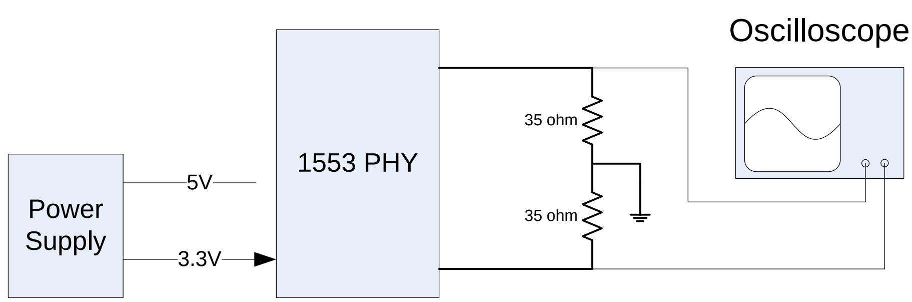


Figure 2. Transmitter Test Configuration

Measurements

Amplitude

MIL-STD-1553 specifies amplitude of the transmitter to be in the range of 18 to 27 V_{PP} across a 70 ohm resistive load. The amplitude of the 1553 PHY board was measured differentially across a 70 ohm resistive load. The transmit amplitude was 24 volts peak to peak (within the MIL-STD-1553 specification).

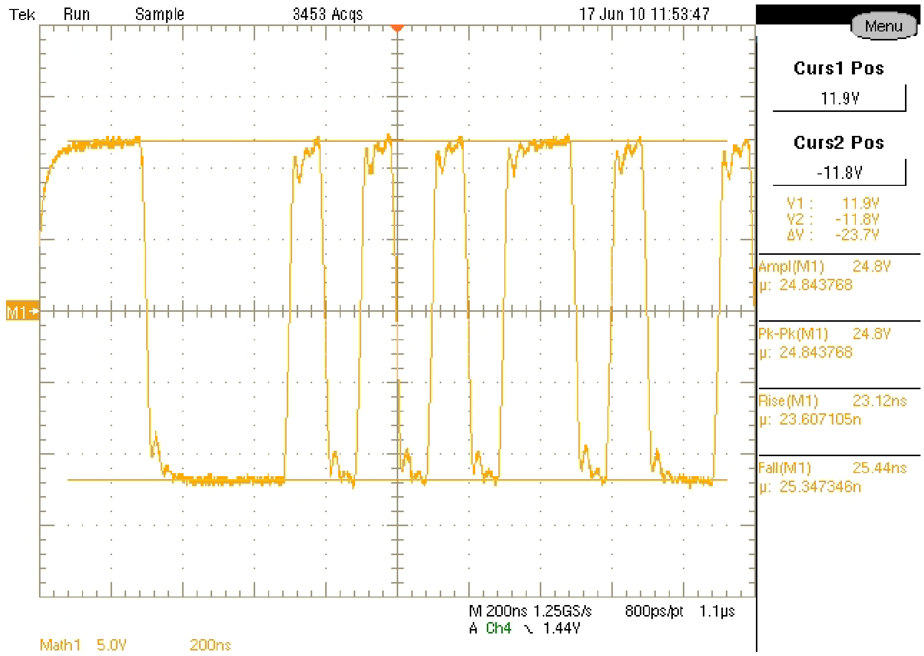


Figure 3. Transmit Waveform Showing Amplitude

Risetime/Falltime

MIL-STD-1553 specifies a transmitter to maintain a rise and fall time within the range of 100 to 300 ns for a 1 Mbps data rate. The 1553 PHY board is designed to run at 5 Mbps so the rise/fall time of the waveform needs to be scaled accordingly (i.e. 20 to 60 ns). The rise and fall time of the 1553 PHY board was measured to be 23 ns (refer to Figure 4).

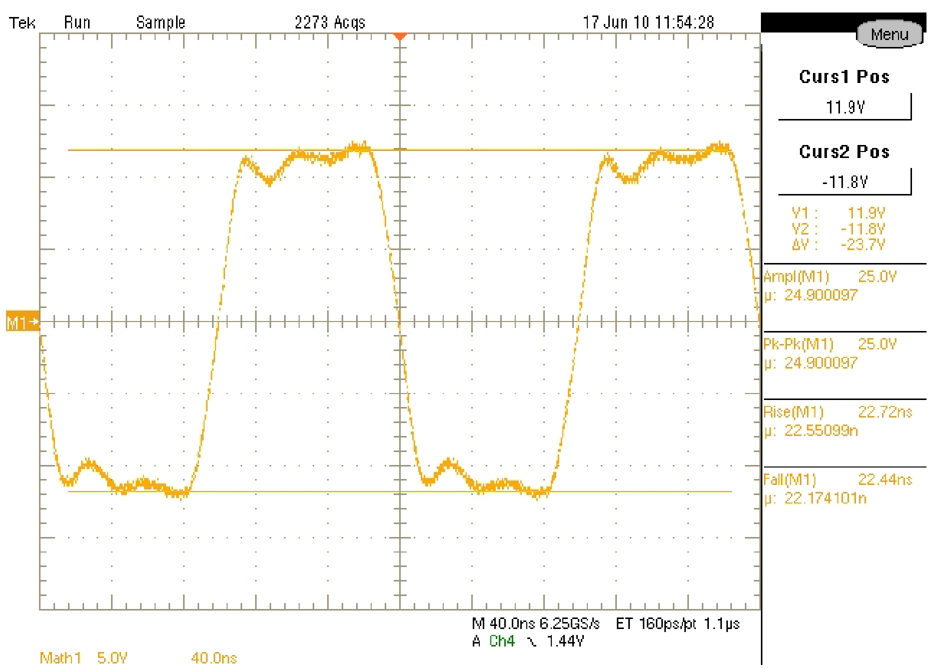


Figure 4. Transmit Waveform Showing Rise/Fall Time

Zero Crossing Stability

A Manchester line code produces a series a pulses in which the zero crossing points will be at multiples of the baud rate (i.e. multiples of 500 ns for 1 Mbps MIL-STD-1553). MIL-STD-1553 specifies that a transmitter must maintain a specific tolerance, referred as zero crossing stability, on the timing between subsequent transitions. The zero crossing tolerance for 1 Mbps MIL-STD-1553 is +/- 25 ns (5% of the baud time). The 1553 PHY board is designed to run at a Manchester coded data rate of 5 Mbps, which utilizes a 100 ns baud time. The proposed zero crossing stability for a 5 Mbps data rate is 5% of 100 ns or +/- 5 ns. Figure 5 shows the timing between consecutive zero crossings to be 98.96 ns, which is well within the proposed tolerance of 100ns +/- 5 ns. Note the zero crossing shown in Figure 5 is the first transition following the 1553 “sync” field. The large difference in frequency content between the sync pulse (consisting of pulse that is 3 baud times wide) and a data bit pulse (1 baud time wide) generally causes a large zero crossing error. In this case the zero crossing stability is well within spec.

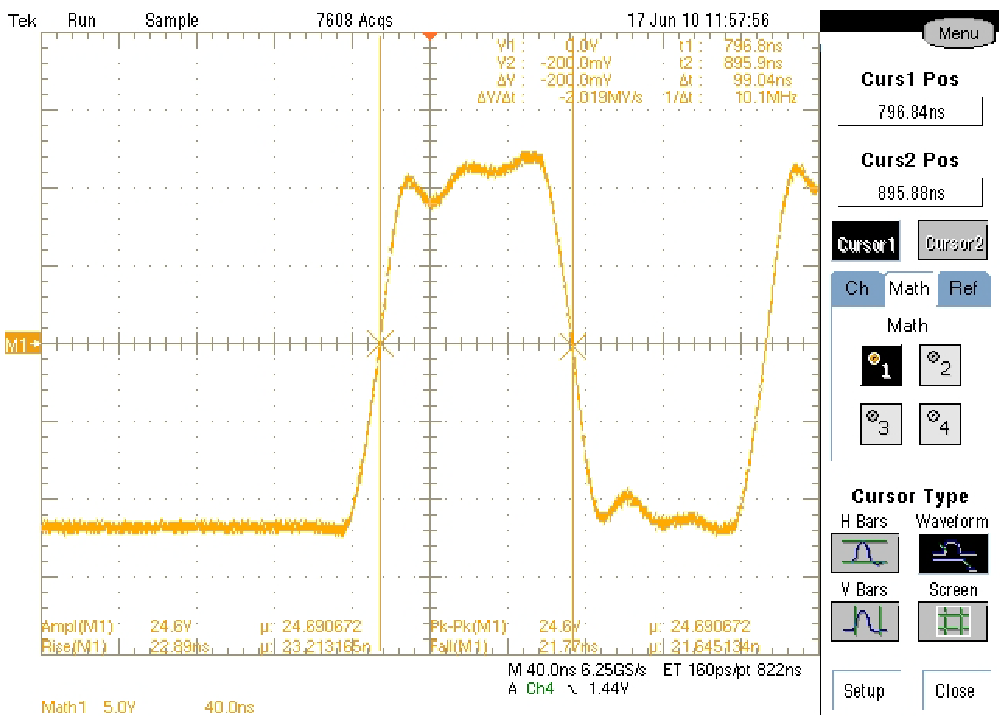


Figure 5. Zero Crossing Stability of 5 Mbps Manchester Coded Data

Analysis

A MIL-STD-1553 data bus will introduce both amplitude and phase distortion. Amplitude distortion will be in the form of attenuation while phase distortion will have the effect of changing the width of the transmitted pulses (i.e. shift the zero crossing points on the waveform). In order to bound the performance of the network it is necessary to specify both the transmitter and receiver with regards to amplitude and phase distortion. They two key transmit characteristics are amplitude and zero crossing tolerance.

Receiver Characteristics

Receiver Threshold

The receiver threshold on the 1553 PHY board was tested by plugging the 1553 PHY board into a test connector on a BU-65590F PMC card. The BU-65590F PMC card was loaded with custom FPGA firmware that would utilize transceivers on the 1553 PHY board and would implement MIL-STD-1553 protocol running at 5 Mbps.

Channel 1 on the BU-65590F PMC card was configured as a 1553 Bus Controller (BC) utilizing transceiver channel A on the 1553 PHY board while channel 2 on the PMC was configured as a Remote Terminal utilizing channel B on the 1553 PHY board. A pair of baluns and a programmable attenuator was used to decrease the amplitude of the BC signal to determine the receiver threshold of the RT (refer to Figure 6).

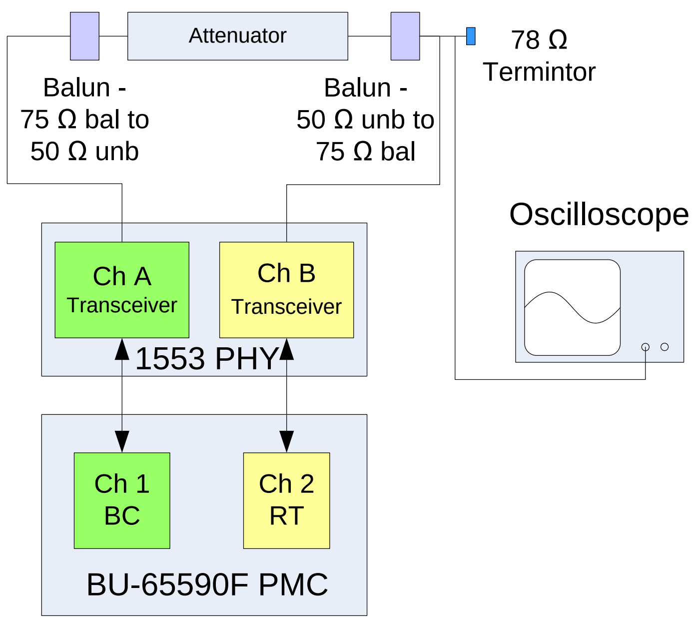


Figure 6. MIL-STD-1553 Receiver Threshold

The BU-65590F PMC and 1553 PHY boards were installed in a computer and custom software was written to run the BC and RT while displaying total message count along with an associated error count. The test was started with no attenuation (0 dB). The Bus Controller was setup to continuously send messages. The RT response was observed on the oscilloscope and was confirmed on the computer display (total messages increasing with zero errors). The attenuator was then used to decrease the amplitude of the BC signal until the RT stopped responding and the resulting signal level was measured on the oscilloscope (see Figure 7 for a sample waveform).

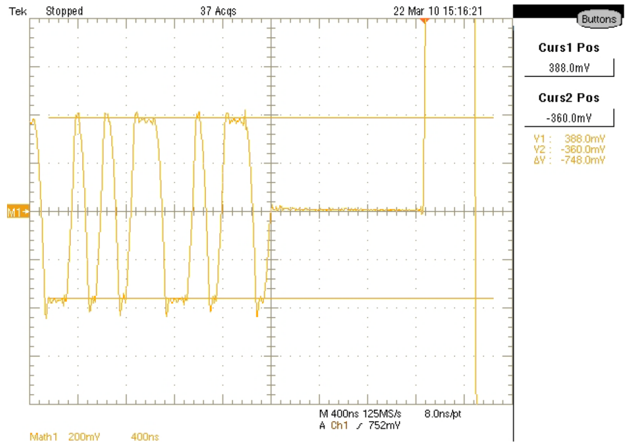


Figure 7. Attenuated BC Signal and RT Response

On channel A it was determined that the RT would not respond to a BC signal of 530 mV and would respond to a BC signal of 600 mV. On channel B the no response threshold was also 530 mV while the response threshold was 595 mV.

Receiver Filter Frequency Response

The frequency response of the receiver filter on the 1553 PHY board was characterized using an HP4396A Network Analyzer with an HP85016A S-Parameter Test Set (refer to Figure 8). A balun was connected to port 1 on the network analyzer. The purpose of the balun was to convert the unbalanced output from the network analyzer to a balanced signal and to convert the impedance from 50 ohms to 75 ohms. Port 2 on the network analyzer was connected to a receiver test point on the 1553 PHY board (i.e. the output of the receiver filter).

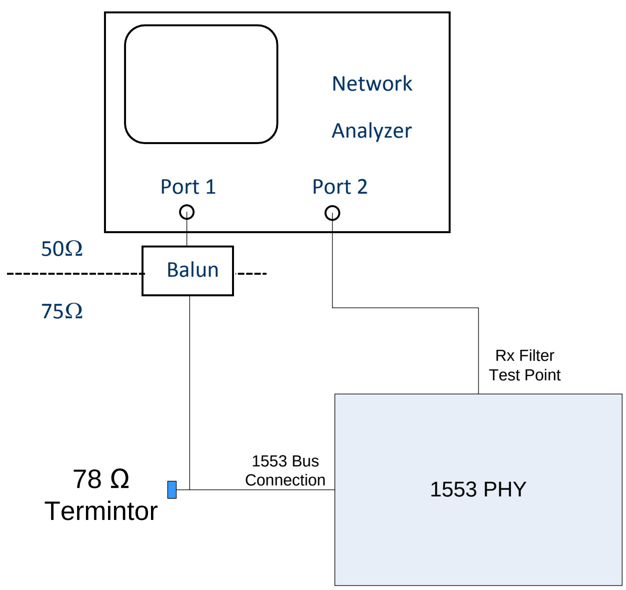


Figure 8. Receiver Filter Frequency Response Measurement

The network analyzer was programmed for a sweep frequency from 300 KHz to 20.3 MHz. The magnitude and group delay for the S21 (forward gain) are shown in Figure 9.

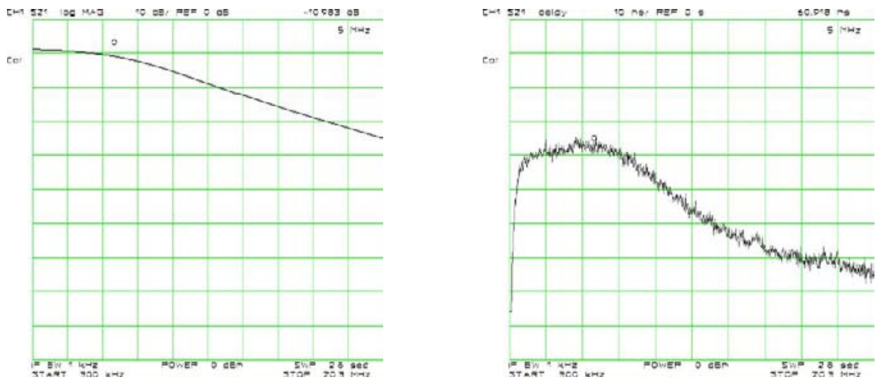


Figure 9. Gain Magnitude and Group Delay of Receiver Filter

Receiver Zero Crossing Distortion

A Manchester coded signal will consist of consecutive pulses with a width equal to the baud rate (500 ns for 1 Mbps 1553 and 100 ns for a 5 Mbps data rate). Phase distortion in the channel (i.e. on the bus) will have the effect of increasing or decreasing the width of each pulse (i.e. shifting the zero crossing point between consecutive transitions). The receiver needs to be designed to tolerate this phase distortion. MIL-STD-1553 specifies that a receiver must be able to decode a waveform with a zero crossing error of up to 150 ns (30% of the baud time) for a 1 Mbps data rate. The proposed limit for a 5 Mbps rate is 30% of 100 ns or 30 ns.

The zero crossing performance of a receiver is dependent on the combination of the analog receiver and the digital decoder. The analog receiver will convert the received signal into a series of digital pulses. The decoder will recover the embedded clock and convert the digital pulse stream into a serial data stream. The 1553 PHY board implements the analog receiver function while the TTP controller on the Powernode implements the decoder function.

Testing the receiver zero crossing distortion of a receiver requires specialized test equipment. For MIL-STD-1553 companies such as DDC provide MIL-STD-1553 test equipment that has the ability to transmit signals to a receiver under test with a programmable zero crossing error. It is our understanding that this type of equipment does not exist for TTP. TTP is also a more complicated protocol so it appears that a simple pattern generator cannot be used to test the receiver. A true test of the receiver will require a specialized tester that implements the TTP protocol.

The receiver filter characterization in the Receiver Filter Frequency Response section shows that the amplitude and group delay of the 1553 receiver is consistent over the proposed pass band, which implies that the receiver will not induce additional amplitude and phase distortion and thus the performance of the receiver in terms of tolerance to zero crossing distortion will be determined primarily by the digital decoder within the TTP controller. A more detailed understanding of the operation of the TTP controller will be required to assess the zero crossing performance of the decoder.

Analysis

The receiver threshold of the 1553 PHY is consistent with the values defined in MIL-STD-1553, thus the loss budget between a transmitted and received signal will be similar to that of MIL-STD-1553 (amplitude distortion). Although the receiver zero crossing distortion was not tested it is believed that the performance should be similar to 1 Mbps 1553. The analog receiver was shown to maintain the amplitude and phase of the received signal and the same decoder algorithm used in MIL-STD-1553 could be used with TTP (assuming that the decoder in the TTP controller is found to be deficient).

Network Characteristics

Setup

A test network was assembled consisting of a main bus length of 430 feet with 10 stub connections (refer to Figure 10). Each stub connection utilizes a standard MIL-STD-1553 bus coupler consisting of a coupling transformer and a pair of isolation resistors (as defined in MIL-STD-1553). Powernode cards with 1553 PHY boards installed on them (referred to as 1553 Powernodes) were connected to seven of the stubs on the bus. The other 3 stubs were terminated in a simulated load of 2000 ohms.

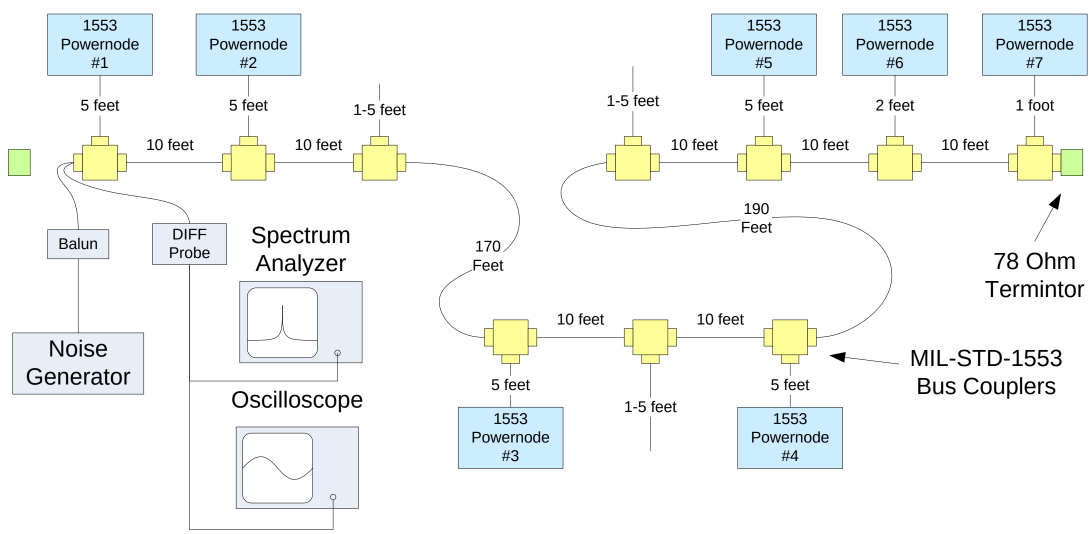


Figure 10. 430 Foot Test Bus

The terminator on one end of the bus (near 1553 Powernode #1) was removed and the end of the bus was connected to an NOD-5107 noise generator for bit error rate testing. A balun was used to convert the 50 ohm unbalanced output impedance of the noise generator to a 75 ohm balanced impedance (to match the 78 ohm impedance of the 1553 bus). The NOD-5107 outputs random noise from 100 Hz to 100 MHz with a maximum output power of -70 dBm/Hz.

Each 1553 Powernode contains custom firmware that implements a cluster cycle consisting of 2 rounds with a 4 ms cycle time. Each 1553 Powernode will send a 240 byte X-Frame in each of the two rounds (each X-Frame contains 16 bytes of TTP status information such as the membership vector plus 224 bytes of actual data). The payload data consists of a cyclic pattern of 256 * 224 bytes of pseudo-random data (data is updated on each round). This firmware also displays bit error rate statistics on the console port every 10 minutes (total frame count along with error frame count and missing frame count). The TTP controller on the Powernode was configured to run at 4 Mbps. Note that the 1553 PHY board was designed to run at 5 Mbps but the Powernode firmware does not provide an option for running at 5 Mbps.

The network illustrated in Figure 10 was constructed to test multiple aspects of the bus including attenuation and phase distortion. The path from 1553 Powernode #1 to 1553 Powernode #7 is expected to provide the largest attenuation and the largest phase distortion due to dispersion (i.e. group delay of the channel). The path from 1553 Powernode #1 to Powernode #2 is expected to provide the smallest amount of attenuation, minimal dispersion and largest phase distortion due to reflections.

Eye Diagrams

The cluster was powered up and the waveforms were measured using the oscilloscope. Figure 11 shows an eye diagram measurement for Powernode #7 measured at the opposite end of the bus (as illustrated in Figure 10). The eye diagram clearly shows the difference in attenuation between 2 MHz and 4 MHz components of the Manchester waveform. The 2 MHz component of the waveform has been attenuated to 4.9 V_{PP} while the 4 MHz component has been attenuated to 3.3 or 2.8 V_{PP} (~ 4 to 5 dB difference). The amplitude of the received signal is well above the defined maximum defined receiver threshold of 1.2 V_{PP}.

The waveform in Figure 11 also shows jitter on the zero crossing points of the waveform. An ideal crossing will be in multiples of the baud time. A 4 Mbps Manchester line code consists of a series of 125 ns pulses so all the zero crossing points on the waveform should be multiples of 125 ns (baud time). MIL-STD-1553 defines that a receiver must tolerate a zero crossing error of up to +/- 30% of the baud time (i.e. +/- 150 ns for a 1 Mbps data rate). Scaling the receiver zero crossing tolerance to 4 Mbps yields a tolerance of +/- 37.5 ns. The received signal in Figure 11 contains a maximum zero crossing error of +12 ns (well within the proposed performance limit of +/- 37.5 ns).

The receiver threshold (1.2 V_{PP}) and zero crossing distortion (+/- 37.5 ns) specifications were used to form an eye mask, which is superimposed on the receive waveform in Figure 11.

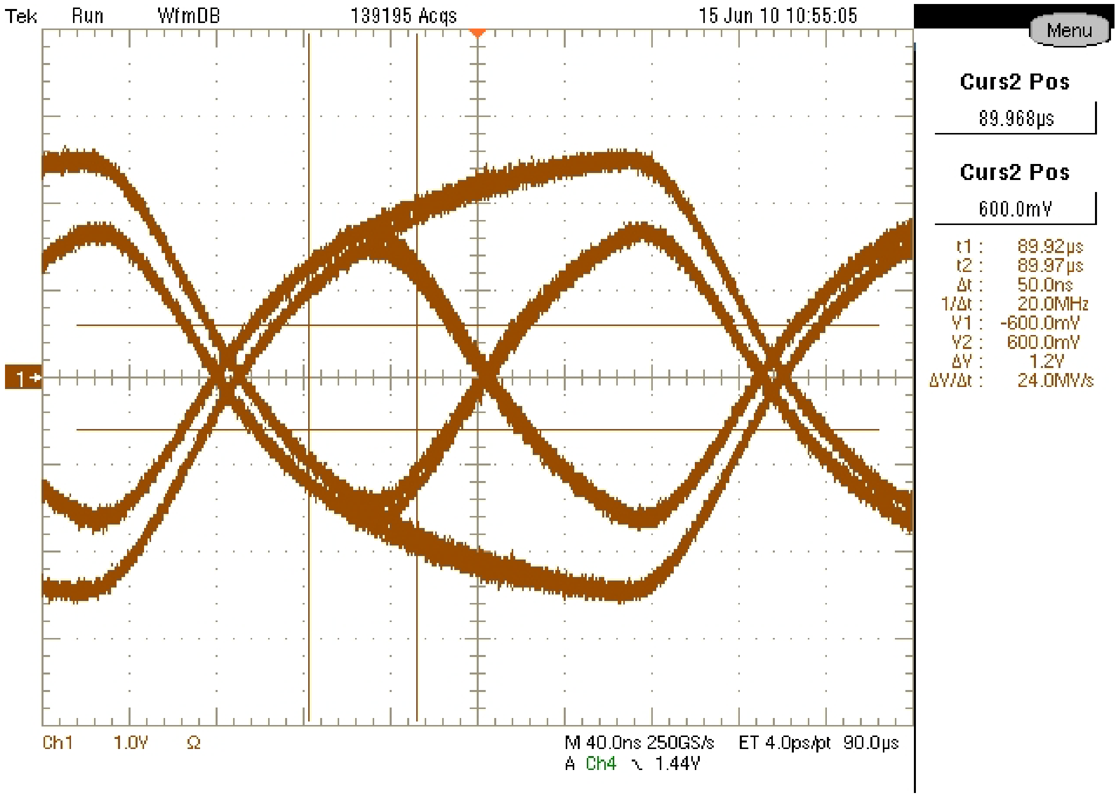


Figure 11. Eye Diagram for 1553 Powernode #7 on 430 Foot Bus with No Noise

Figure 12 shows an eye diagram measurement for 1553 Powernode #7 with the addition of -78 dBm/Hz of noise. This figure includes the same eye mask that was presented with Figure 11. This measurement shows that even in the presence of a very large noise source a stable eye pattern exists. The effectiveness of the eye mask will be substantiated later in this report when bit error rate testing is performed on this setup.

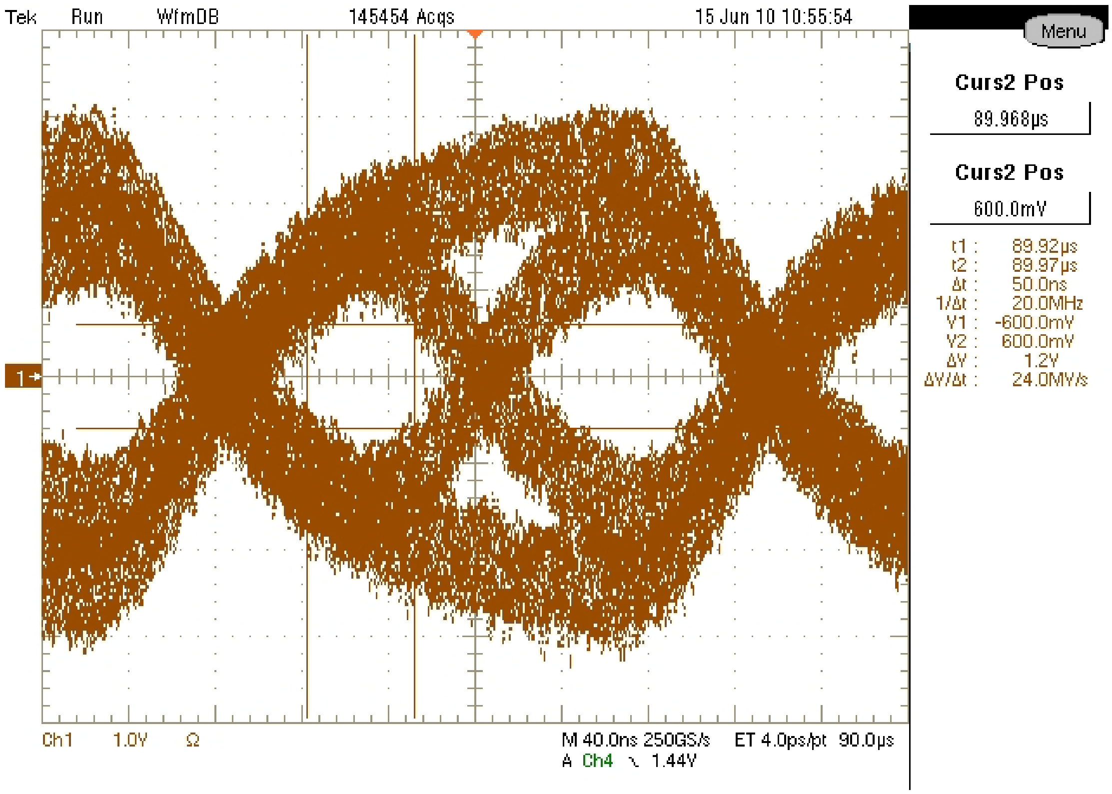


Figure 12. Eye Diagram for Powernode #7 on 430 Foot Bus with -78 dBm/Hz Noise

Insertion Loss Measurements

An HP4396A Network Analyzer with an HP85016A S-Parameter Test Set was used to measure the insertion loss through the bus from 1553 Powernode #7 to the other end of the bus (refer to Figure 13). Port 1 on the network analyzer was connected to the stub connection in place of 1553 Powernode #7 while port 2 was connected to the end of the bus (in place of one of the termination resistors. Baluns were used to convert the 50 ohm unbalance impedance of the network analyzer to a 75 ohm balanced impedance that is compatible with the characteristic impedance of the 1553 bus. The network analyzer was programmed for a sweep frequency from 300 KHz to 20.3 MHz.

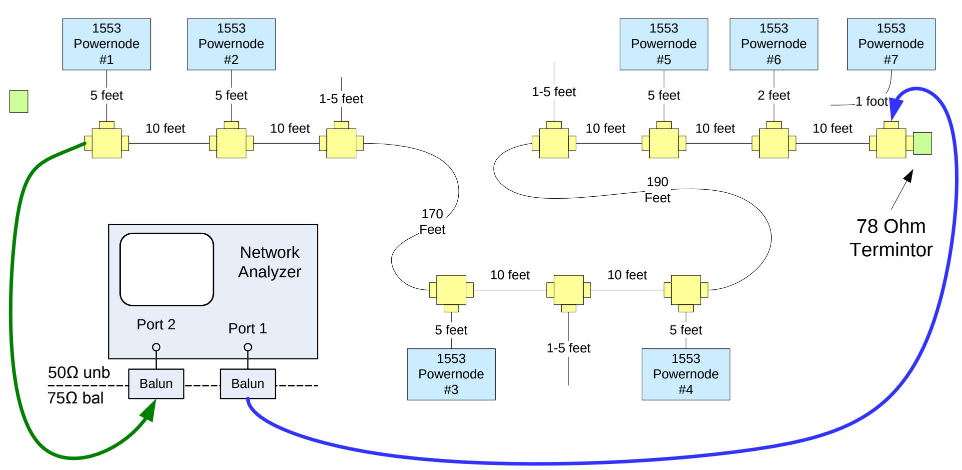


Figure 13. Insertion Loss Measurement Setup

Figure 13 illustrates the insertion loss measurement (i.e. the magnitude for the S21 forward gain) for the channel from the stub connection for 1553 Powernode #7 to the opposite end of the bus (on the bus near 1553 Powernode #1). The measurement shows the insertion loss to be -17 dB at 2 MHz and -21 dB at 4 MHz (a 4 dB difference). Note that this is fairly consistent with the voltage measurement in Figure 11 which shows a 4 to 5 dB difference between the 2 and 4 MHz Manchester pluses.

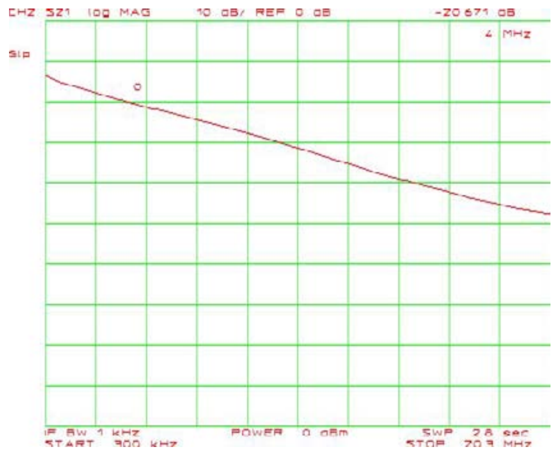


Figure 14. Insertion Loss from 1553 Powernode #7 to End of Bus

Bit Error Rate Measurements

Bit Error Rate (BER) testing was performed using the setup illustrated in Figure 10 (430 foot bus with 10 stubs). The console port on 1553 Powernode #1 was used to view the error rate statistics which are collected by the embedded processor on the Powernode card. The embedded processor displays total frames, error count, and missing frames every 10 minutes. Once the cluster is up and running the processor verifies the presence of a frame in every slot. If a frame is missing then the missing frame counter is incremented. If a frame is received with an error (i.e. a CRC failure) then the error counter is incremented.

BER testing was run with three different noise levels. The first test was run to calculate the BER of the network with nominal “laboratory” noise levels (external noise source turned off). The lab noise environment test was run over a long period of time (over 25 days) in order to achieve a high statistical confidence level in the BER. Additional testing was performed with higher noise levels to perform an “accelerated noise test”. Note that MIL-STD-1553 also makes use of an accelerated noise test in order to be able to run BER testing in a reasonable amount of time. The power spectral density (PSD) of the noise used in the accelerated BER testing was -84 dBm/Hz and -78 dBm/Hz.

Figure 15 shows the spectrum analyzer measurements for both the receive signal (blue trace) and the injected noise (black trace). Note that 20 dB needs to added to the traces in Figure 15 to account for the use of a 10x scope probe. The measurement shows that the signal to noise ratio for this noise level (-78 dBm/Hz) is approximately 18 dB at 4 MHz. Note that an SNR of approximately 15.5 dB is required for a BER of 10^{-9}.(2)

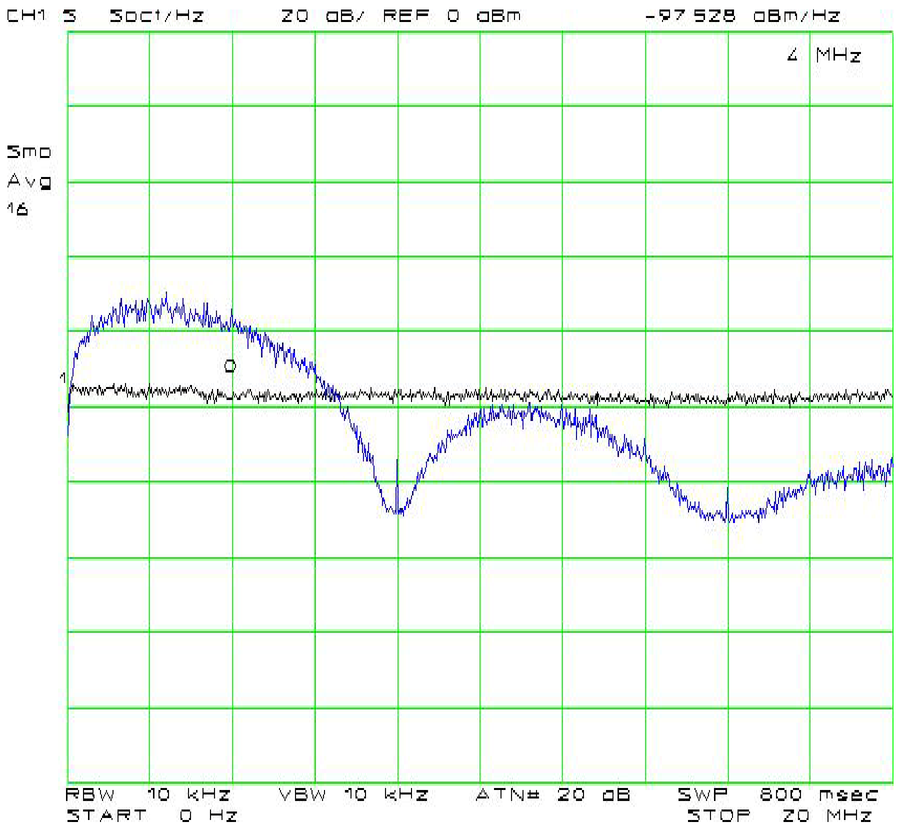


Figure 15. Spectrum Measurement of Receive Signal and Noise

The results of the BER testing, summarized in Table 1, represent the number of frames and associated bits that were received with zero errors. In addition the table provides a statistical confidence level for various bit error rates, based on the number of error free bits that were received.(3)

Table 1 - BER Test Results (with zero errors)

Noise Level (dBm/hz)	Total Frames	Total Bits	Time	Confidence Levels for Various Bit Error Rates			
				10^{-9}	10^{-10}	10^{-11}	10^{-12}
None	3.9×10^{9}	7.4×10^{12}	25.6d	100.0%	100.0%	100.0%	99.9%
-84	88.2×10^{6}	169×10^{9}	14h	100.0%	100.0%	81.6%	15.6%
-78	7.4×10^{6}	14.1×10^{9}	1.2h	100.0%	75.6%	13.2%	1.4%

Analysis

The test configuration used in sections 5.2 through 5.4 was constructed to provide a test bed that represents a demanding data bus configuration. The eye diagram measurements showed that the receiver contains significant margin. An eye mask was constructed based on the defined receiver characteristics. The eye mask predicted that the receive signal with a high noise level shown in Figure 12 had significant margin that the receiver should be able to decode the waveform. The BER testing in section 5.4 confirmed the eye mask by showing that the BER for the configuration was less than 10^{-9}.

Phase distortion was kept to a minimum on the network (12 ns of zero crossing error for 125 ns pulses). The low phase distortion is attributed to the use of bus couplers as defined in MIL-STD-1553. Bus couplers have the effect of matching the impedance of the stub looking into the bus and increasing the effective impedance presented by the stub connection to the bus which results in a lower reflection coefficient and thus less phase distortion on the bus.(4)

Noise testing was performed with power levels that are far above those expected to be present in an aircraft environment. Past measurements conducted by DDC on an F-15 aircraft showed the PSD of background noise on a real MIL-STD-1553 bus to be approximately -120 dBm/Hz, which is significantly lower than the noise levels used in the accelerated BER testing.(5) The 1553 Powernodes showed superior BER performance even in the presence of abnormally high noise.

Conclusion

Testing has shown that 4 Mbps TTP utilizing a 1553 PHY provides robust performance while maintaining the key architectural benefits of MIL-STD-153 including galvanic isolation. Interoperability was shown between a commercially available TTP controller and a 1553 PHY. This technology demonstration establishes a performance baseline for TTP 1553 and highlights the robust performance that makes it an ideal solution for demanding applications such as commercial aircraft systems.

References

1. *MIL-STD-1553 Physical Layer for Time-Triggered Networks.* **Glass, Mike.** Seattle : SAE, 2009. Document Number: 2009-01-3147.

2. **Proakis, John G.** *Digital Communications Fourth Edition.* s.l. : The McGraw - Hill Companies, Inc., 2001.

3. **Redd, Justin.** Calculating statistical confidence levels for error-probability estimates. *Lightwave Magazine.* April, 2000.

4. *MIL-STD-1553 – A Robust Data Bus For Commercial Aircraft.* **Hegarty, Michael.** Farmingdale : IEEE, 2010. Long Island Systems, Applications and Technology Conference.

5. *High Performance 1553 F-15E Mux Bus Capacity Study Prepared for the Boeing Compnay.* **Data Device Corporation.** Bohemia : s.n., 2004.

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As the world's largest supplier of Solid-State Power Controllers (SSPCs) and Remote Power Controllers (RPCs), DDC was the first to offer commercial and fully-qualified MIL-PRF-38534 and Class K Space-level screening for these products. DDC's complete line of SSPC and RPC boards and components support real-time digital status reporting and computer control, and are equipped with instant trip, and true I^2T wire protection. The SSPC and RPC product line has been field proven for military markets, and are used in the Bradley fighting vehicles and M1A2 tank.

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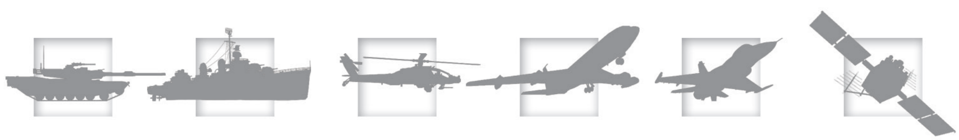
Certifications

Data Device Corporation is ISO 9001: 2008 and AS 9100, Rev. B certified.

DDC has also been granted certification by the Defense Supply Center Columbus (DSCC) for manufacturing Class D, G, H, and K hybrid products in accordance with MIL-PRF-38534, as well as ESA and NASA approved.

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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