SAE Aerospace
An SAE International Group

AEROSPACE INFORMATION REPORT

SAE AIR4013 REV. B

Issued 1987-08
Reaffirmed 1998-01
Revised 2005-09

Superseding AIR4013A

Multiplex Data Bus Networks for MIL-STD-1760 Stores

1. SCOPE:

This SAE Aerospace Information Report (AIR) will examine network aspects of open and shorted stubs, line reflections and bus loading due to network changes. Single network level is assumed, that is, no carriage store hierarchical levels. However, two passive network coupling variants called "branched bus" and "branched stub" will be introduced that possibly could be used in a stores management network.

This report assumes familiarity with MIL-STD-1553B.

1.1 Purpose:

This document summarizes the results of hardware tests on simulated weapon data bus networks utilizing MIL-STD-1760 (Reference 2.2.1).

Unique to this application is the fact that the network is reconfigurable by connecting together mission dependent MIL-STD-1553B (Reference 2.2.2) store remote terminals (RT)s at artificial network breakpoints. Further, during normal data bus operation the weapon RTs are physically removed from the network. That is, in-flight weapon separation from aircraft results in "open stubs" on the bus network. See Figure 1. All this gives rise to changing network conditions, stubs exposed to harsh environments (such as during rocket motor firing), noise interference, interoperable store requirements for US/NATO military services and controversy about the effect of "open stubs" on bus performance.

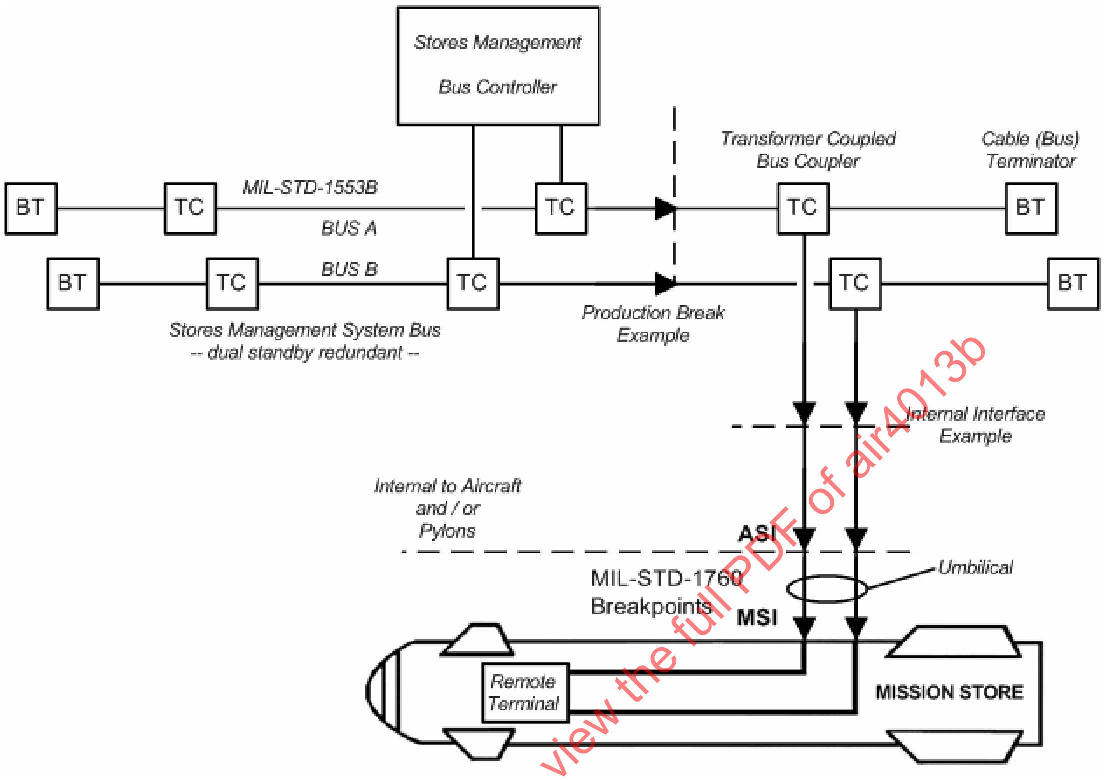

FIGURE 1 - Basic Stores Management System Bus Network

2. REFERENCES:

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Telephone: (724) 776-4841, Web address: http://www.sae.org

2.1.1 Aircraft/Stores Data Bus Networks, Paper Number 860842, SAE Aerospace Avionics Equipment and Integration Conference Proceedings P-179 (24 April 1986)

2.2 U.S. Government Publications:

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Telephone: (215) 697-2179, Web address: http://assist.daps.dla.mil/quicksearch/

2.2.1 MIL-STD-1760A through MIL-STD-1760D Aircraft/Store Electrical Interconnection System

2.2.2 MIL-STD-1553B Digital Time Division Command/Response Multiplex Data Bus

3. GENERAL COMMENTS:

The terms used in this report are consistent with MIL-STD-1760. The network is used for control and monitor of interoperable stores (missiles, bombs, pods) mounted either internal or external to aircraft. The current means for store control and status is through the use of MIL-STD-1553B.

3.1 Stores Management System (SMS) Bus Network:

Most of the MIL-STD-1553B SMS bus network is located internal to the aircraft as illustrated in Figure 1. To preserve bus integrity, the bus should cross as few internal aircraft separation planes as possible. The bus coupler and stub wiring to the Aircraft Station Interface (ASI) would be enclosed in the aircraft. However, unused ASI connectors and ASI to Mission Store Interface (MSI) umbilicals would be exposed to the separation event. Additionally, for externally mounted stores, the ASI to MSI path may be exposed to harsh environments over long time periods. The path from the MSI store connector to the remote terminal would be internal to the store. For example, in the AMRAAM missile (AIM-120) the internal cable length to the RT is about 2 feet.

3.2 Waveform Envelope:

MIL-STD-1760 defines the ASI output characteristics as a waveform envelope varying from a square wave to a sine wave with peak-to-peak, line-to-line amplitude between 1.4 and 14 volts. MIL-STD-1553B transformer coupled remote terminals must be able to operate with these signals as low as 0.86 volt peak-to-peak. This allows a margin of 0.54 volt peak-to-peak for possible signal attenuation and noise injection between the ASI and the store RT.

4. DISCUSSION:

Initial SMS network loading depends upon the number and type of stores connected to the network. Different missions may result in different initial bus loading. During mission operation, the network loading changes as stores are released. Normally, the network loading decreases as the stubs go open circuit (open); however, loading can increase considerably if the stubs become short circuit (shorted). Traditional MIL-STD-1553B avionic networks have constant loads and, therefore, are not subject to the dynamic environment of SMS networks.

4.1 Open Stubs:

Each loaded stub normally becomes an "open" stub when its store RT is disconnected from the network. This action results in a slight increase in signal amplitude at all other RTs still connected to the network. The resulting increase in signal amplitude does not degrade the performance of the network due to the fact that MIL-STD-1553B networks typically operate with signal amplitude considerably below the maximum acceptable level. In those situations where multiple RT stores are released and their stubs "open" simultaneously, the resulting increase in signal amplitude is still rather insignificant (typically less than 5%). Network radiated emissions and/or susceptibility caused by antenna effects of a stub "opened" at the MSI appear to be negligible due to the small size and coaxial arrangement of the inner and middle members of the triaxial contacts. The change in reflections at the coupler is also small. See the discussion on coupler spacing (see 4.5). The conclusion is that isolation techniques or resistor termination schemes after store separation do not seem to be necessary. The bus network will continue to operate with multiple open stubs.

4.2 Shorted Stubs:

If a transformer-coupled stub is "shorted" during the release of its store RT, additional loading is placed upon the network resulting in lower signal amplitude at all other RTs. If the signal amplitude had been only slightly above the threshold level of an RT before "shorting" of a stub, this action could result in word errors and/or missed words at the RT. Multiple "shorted" stubs can reduce the signal amplitude of the network significantly (typically greater than 20%). This amount of signal degradation could be devastating.

Since stubs can be "shorted" during the release of a store due to metallic particles from rocket motor exhaust plumes and/or melted connector pins, it is strongly recommended that the network design be tested with the maximum number of anticipated "shorted" stubs - not just the one "shorted" stub required by MIL-STD-1553B. During this abnormal operation of shorting stubs while stores are releasing from the network, the bus controller protocol may require special processing (such as more retries or inhibit transmission) so that other RTs on the bus are not faulted.

4.3 Store RT Output:

To improve the performance of SMS bus networks, MIL-STD-1760 requires a minimum transmitted output of 20 volts peak-to-peak for all store remote terminals measured at the MSI (MIL-STD-1553B requires a minimum of 18 volts peak-to-peak). This higher output voltage helps to overcome the signal attenuation associated with large, heavily loaded networks.

4.4 Transceiver Types:

At present, there are two types of MIL-STD-1553B transceivers: constant current and constant voltage. Both have worked well in systems encountered to date. However, the advent of MIL-STD-1760 is changing the nature of MIL-STD-1553B networks from small static to large dynamic loads. Constant current transceivers will not handle varying loads as well as constant voltage transceivers. The output voltage of a constant current transceiver varies inversely with the changing load. This could lead to signal amplitude problems on heavily loaded SMS bus networks. Built-in current limiting is advisable for either type of transceiver for overall protection.

4.5 Bus Coupler Spacing:

Classical transmission line theory states that impedance mismatches on a transmission line generate reflected waves. The mismatches caused by couplers in a MIL-STD-1553B network produce reflections which affect the shape of the signal waveform. As coupler spacing decreases, the leading edge of the waveform becomes distorted but the signal amplitude is not reduced. Therefore, coupler spacing (evenly distributed versus lumped together, up to 7 in Reference 2.1.1) appears to have little effect on bus performance.

System implementation may make it desirable to collocate the couplers (lumped) to handle multiple store stations in the confines of a pylon or rotary launcher.

4.6 Unique Configurations:

SMS network configurations are more complicated than fixed avionics networks due to physical limitations of aircraft volume constraints and interface requirements of removable components such as rotary launchers and pylons. In addition, lower level multiple store stations such as multiple carriage bomb racks, may require communication from a single ASI. Several solutions and the ramifications of each are discussed below.

4.6.1 Hierarchical Bus Structure: The hierarchical bus structure (or sub-bus) uses a “bridge” which acts as a remote terminal on the aircraft bus and a bus controller on the lower level bus connected to the mission stores. While providing electrical isolation, this architecture introduces complexities in message routing from aircraft to mission stores. The aircraft is not able to “talk to” mission stores on a sub bus in the same manner as when these same mission stores hang on the parent pylon. A message routing protocol must be established for messages going through the multiple carriage bomb racks to the mission stores. These routing protocols have the potential to introduce significant data delays in the system.

4.6.1 (Continued):

Most routing protocols handle Receive type messages (aircraft to store) with minimal throughput delay. Delays in data transmission are more severe with Transmit messages (store to aircraft). Many protocols require two messages from the aircraft to get the desired data from a store for a particular subaddress. The first message (a Receive message) would direct the bridge controller to get the required information from the selected store. Sometime later (minimum is the fetch time for the bridge design), a second transmit would then be able to get the desired data from the bridge remote terminal.

4.6.2 Bus Repeater: In this concept, a bi-directional electronic repeater is connected between the SMS bus and the lower bus. When a transmission from the aircraft is sensed, the repeater activates and retransmits the signal through to a lower level RT. The RT response is received by the repeater and echoed back to the main bus. The primary benefit of this approach is to electrically isolate the aircraft bus from stub generated reflections and stub variations by fixing the electrical length of the stub to the distance between the main bus and the repeater bus input. The repeater presents a single remote terminal electrical load on the aircraft bus.

A secondary benefit is that data delays are much lower with this "immediate repeat" concept when compared to the "store and forward" technique of a hierarchical bus. The aircraft is able to “talk to” the mission stores as if they were attached to the main aircraft bus thereby significantly reducing the software impact to the aircraft for carriage of multiple mission stores from a single ASI when compared to the hierarchical architecture.

The primary disadvantage lies in the repeater design trade-off between round trip transmission delay and system noise immunity. As time available for repeater signal processing is increased, the repeater can conduct more checks on the received signal to reduce probability of repeating illegal or distorted signals. For repeaters with little filtering, the propagation delay through the repeater includes contributions from the receiver, transmitter and the intervening logic. Typical one-way propagation delays can range from 600 ns to over a microsecond. If, for instance, sync pulse validation is required, propagation delays would be increased by 1.5 to 3.0 microseconds. The primary deterrent to high delays, several microseconds, is the "no response time out" feature of MIL-STD-1553 bus controllers. If the aircraft designer selects a bus controller with a "long" no response time out, the designer can then increase the repeater processing for improved signal quality.

NOTE: There is no allowance in MIL-STD-1553B for any delay induced by active repeaters. Analysis of the system (i.e., actual no-response timeout of the bus controller) must be completed and verified before the use of a repeater.

4.6.3 Branched Stub: A seemingly convenient method for servicing multiple remote terminals from a single transformer coupled stub is shown in Figure 2. Those familiar with MIL-STD-1553B may feel that this configuration will work given the proven robustness, but discussed here are some of the ramifications of this simple arrangement.

4.6.3.1 Input Impedance: With multiple terminals attached to a single transformer coupled stub, there is a high probability of violating the non-transmitting and off state terminal input impedance limit of 1000.0 Ω over the frequency range of 75.0 kHz to 1.0 MHz (MIL-STD-1553B 4.5.2.1.2.3). While MIL-STD-1760C allows for a 300 Ω limit for carriage stores which technically allows the configuration shown in Figure 2, the following should be noted.

In a recent test of a branched stub, problems appeared in a system which previously operated successfully; data errors and signal corruption were exhibited when there was a change in vendors for the transceivers in one of the two remote terminals in a branched connection. The errors appeared in the communicating remote terminal when the offending terminal was unpowered. Figure 3A shows normal communications from one of the two branched terminals (the other terminal is unpowered). Figure 3B shows large distortion in data. The only change in the test setup between Figure 3A and Figure 3B is a change in the vendor of the transceiver of the unpowered remote terminal.

4.6.3.2 Fault Tolerance: With multiple terminals attached to a single transformer coupled stub, a failure in one terminal will adversely affect the other remote terminals connected to the branch thereby defeating the fault tolerance built into the MIL-STD-1553B architecture.

4.6.4 Branched Stub With Additional Isolation Resistors: In an effort to minimize the effects depicted in Figure 3 and to enhance Fault Tolerance to shorted terminals, isolation resistors could be added to the branched terminals as shown in Figure 4. However, relative to the system requirements that serve as the technical thresholds for MIL-STD-1760 interoperability, the following factors make this design alternative non-viable.

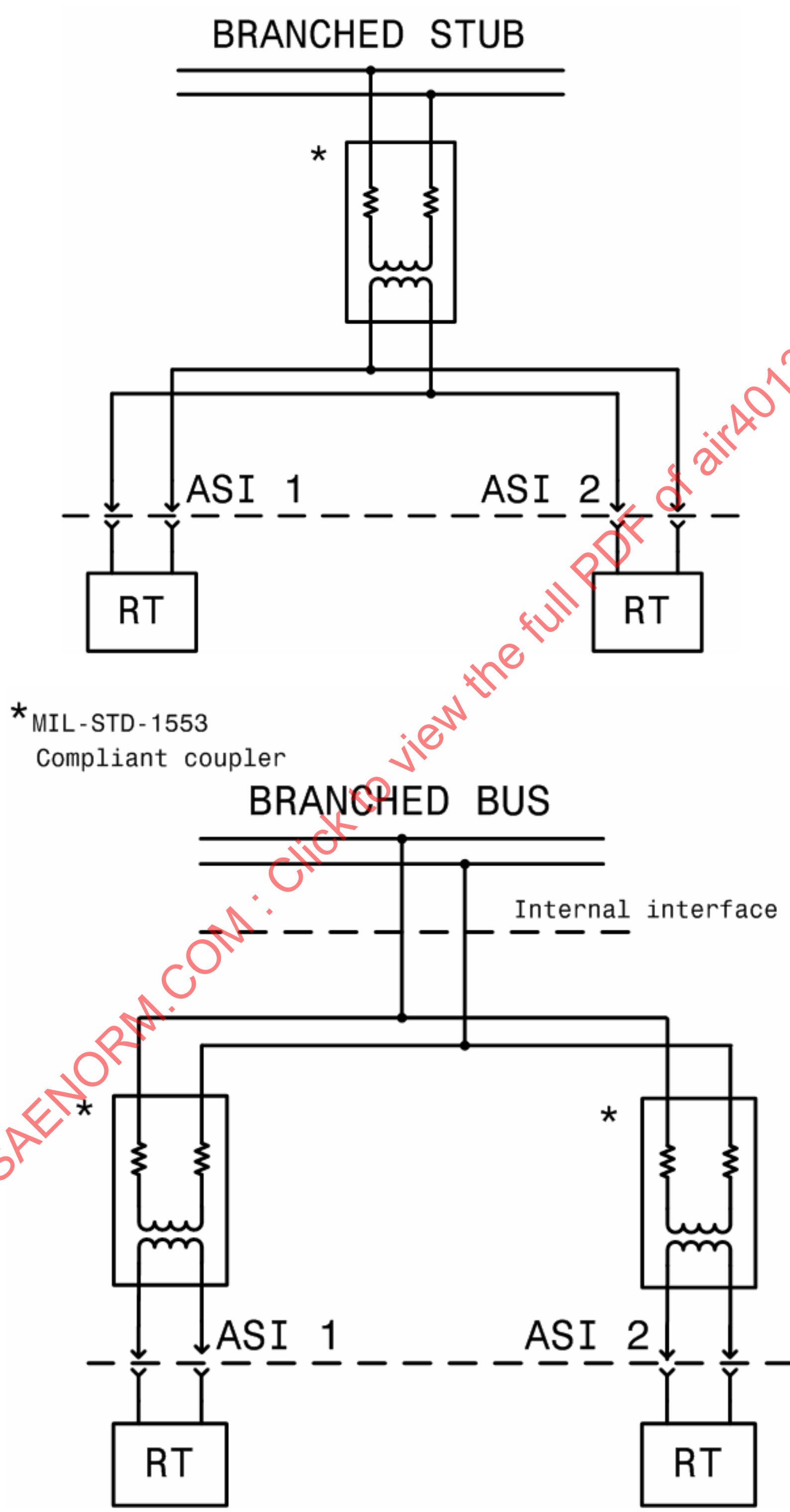

FIGURE 2 - Unique Configurations (Not Recommended)

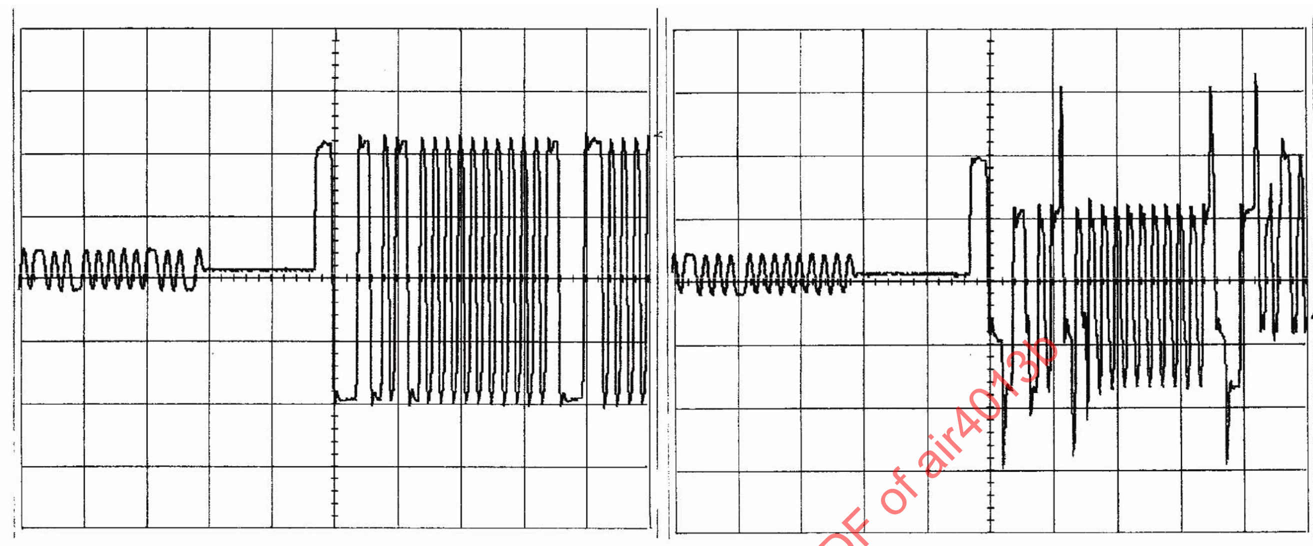

FIGURE 3A - (left) No Distortion on Transmit Message

FIGURE 3B - (right) Large Distortion on Transmit Message

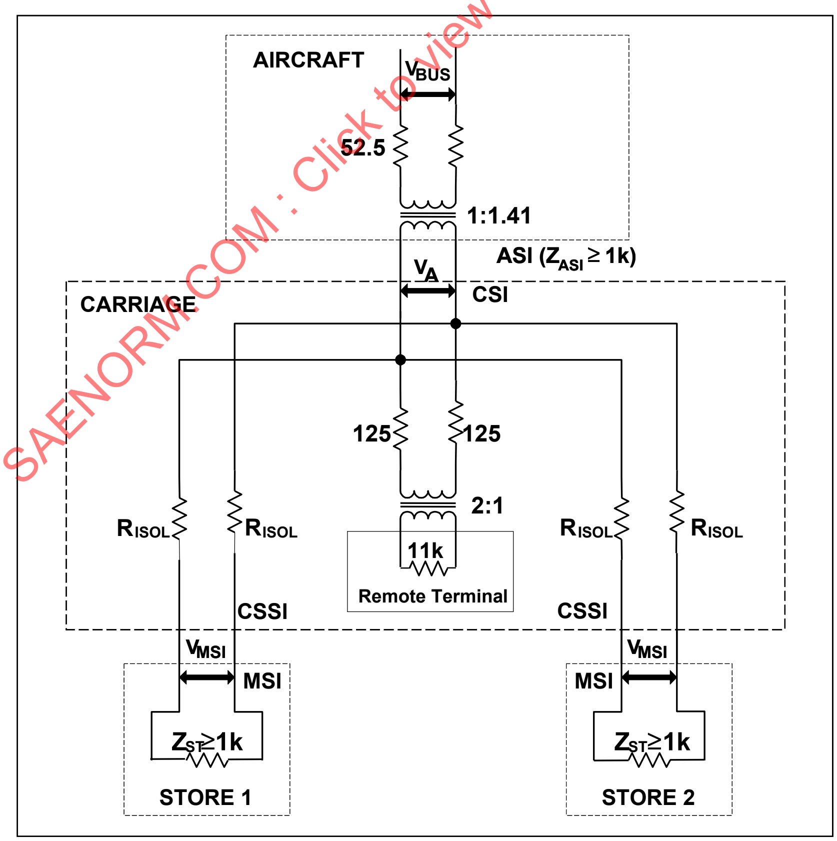

FIGURE 4 - Branched Stub with Isolation Resistors