Research on Key Technologies of Detecting 1553B Avionics Data Bus Network

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Abstract

1553B avionics data bus network may fail due to vibration, temperature, humidity or human error. Therefore, the research on detection technology of 1553B avionics data bus network is an important subject. The key technologies are studied by analyzing the possible faults of the network, including four-wire DC resistance measurement method for conductors-to-shield short test and stub continuity test, equivalent impedance measurement of coupling transformer for main bus continuity test, polarity reversal test based on duty ratio measurement, attenuation measurement base on coupler model, and data path integrity test base on bit error rate calculation. Finally, the implementation methods of key technologies are researched, a portable integrated automatic test system of 1553B data bus network is constructed based on PC104 computer, and the hardware configuration and test process are especially designed.

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1. Introduction

The MIL-STD-1553B data bus was initially designed for aircraft. With the improvement of informatization level of military equipment, the MIL-STD-1553B data bus has been widely applied in various fields, especially in aerospace and military applications [1].

The MIL-STD-1553B data bus system is composed of data bus network and terminals. It has been used in communication and data transmission between avionics navigation system, task management system, and weapon system. It uses a half duplex data transmission with 1 Mb/s data rate in Manchester II code over twisted shielded pair (TSP) cable of which characteristic impedance is around 78 Ω. The data bus network includes main bus, stubs, couplers and termination resistors. The data bus network has the capability of connecting 31 terminals through the stubs. Three types of terminals including bus controller (BC), bus monitor (BM) and remote terminal (RT) are connected to the data bus network in either direct coupling method or transformer coupling method, as shown in Fig. 1. Only the transformer coupling method is required for airborne applications because it allows longer branches with high reliability. In Fig. 1, Z0 is used to represent the characteristic impedance of the cable, R1 and R2 are the isolation resistances of the coupler, R0 is the load resistance of the terminal. The turns ratio N2:N1 of coupling transformer is 1.41:1 with the higher number of turns on the side of isolation resistor.

2. Test requirements

The terminals or network may fail after the installation of 1553B avionics data bus system because of vibration,
temperature, humidity or improper operation. The faults are generally considered to be caused by the electronics and software, but the network has proved to be the root of the faults. The common faults of the network include:

1. main bus or stub conductor-to-shield short;
2. open or short of stub conductors;
3. short or open of main bus conductors, and wrong resistance of termination resistor;
4. polarity reversal of conductor of stub or main bus;
5. high insertion losses between stubs;
6. high bit error rate of data paths.

How to test and evaluate the network characteristics roundly and availably is an important subject if the network fails. Faults should be detected from the stub because it’s impossible to disassemble the data bus network after its installation in an aircraft. The key technologies of detection and the implementation methods will be researched in this paper.

3. Key technologies of detection

3.1. Four-wire DC resistance measurement method

DC resistance measurement is used for conductor-to-shield short test and stub continuity test.

In TSP cable the conductor-to-shield short might lead to a high data error rate [2]. Therefore the conductor-to-shield short should be detected. The conductor-to-shield short test is basically to measure a DC insulation resistance. The standard DC insulation resistance between shield and conductor must be more than 5000 Ω without short. If the resistance between any conductor and shield is less than 50 000 Ω, it is considered as short.

The DC resistance of the transformer winding between high and low conductors of the stub is between 1.0 Ω and 5.0 Ω. If the DC resistance of the stub is below 1 Ω, it is interpreted as stub short. If the resistance is above 5 Ω, it is interpreted as stub open. If the resistance is 1.0—5.0 Ω, it is interpreted as normal condition.

The four-wire resistance measurement method is used to measure DC resistance, which is also called voltage—voltage method. The measurement principle is shown in Fig. 2.

$U_i$ is the voltage of DC source. $U_s$ and $U_x$ are the voltages of resistor $R_s$ under measurement and known standard resistor $R_x$, respectively. The voltages $U_i$ and $U_s$ are amplified and converted to the digital values by AD conversion. The current $I$ in the circuit is

$$I = \frac{U_s}{R_s}$$

(1)

The resistance of $R_x$ under measurement is

$$R_x = \frac{U_x}{I} = \frac{U_i - U_s}{I}$$

(2)

3.2. Equivalent impedance measurement of coupling transformer

Equivalent impedance measurement of coupling transformer is to test main bus continuity, checking for the shorts or opens of the main bus conductors and the wrong termination resistor from a stub. Only two types of terminators (78 Ω and 3000 Ω) are in the network. The 78 Ω terminator is the right termination resistor on the main bus.

The coupler is connected to the terminators $Z_1$ and $Z_2$ through the main bus, and connected to the terminals through the stubs. A simplified model of the coupler is shown in Fig. 3. The signal is transmitted from the terminal on the stub to the main bus through the coupling transformer in the coupler. The turns ratio of the transformer is $N_2: N_1$.

The load impedance $R_L$ at point $L$ is

$$R_L = \frac{Z_1Z_2}{Z_1 + Z_2} + R_1 + R_2$$

(3)

The equivalent impedance $R_L'$ from the bus to the stub due to the impedance transformation of transformer is:

$$R_L' = \left(\frac{N_1}{N_2}\right)^2 R_L = \left(\frac{N_1}{N_2}\right)^2 \left(\frac{Z_1Z_2}{Z_1 + Z_2} + R_1 + R_2\right)$$

(4)

When the network is normal, $Z_1 = Z_2 = Z_0$, the equivalent impedance $R_L'_{\text{normal}}$ is

Fig. 2. Principle of four-wire method.
When the main bus or the termination resistor is short, 
\( Z_1 = Z_0, Z_2 = 0 \), the equivalent impedance \( R'_{\text{L,short}} \) is:

\[
R'_{\text{L,short}} = \left( \frac{N_1}{N_2} \right)^2 R_{\text{L,short}} = \left( \frac{N_1}{N_2} \right)^2 (R_1 + R_2) = \left( \frac{N_1}{N_2} \right)^2 2.5Z_0 \tag{6}
\]

When the main bus or the termination resistor is open, 
\( Z_1 = Z_0, Z_2 = \infty \), the equivalent impedance \( R'_{\text{L,open}} \) is:

\[
R'_{\text{L,open}} = \left( \frac{N_1}{N_2} \right)^2 R_{\text{L,open}} = \left( \frac{N_1}{N_2} \right)^2 (Z_1 + R_1 + R_2) = \left( \frac{N_1}{N_2} \right)^2 2.5Z_0 \tag{7}
\]

When the main bus is connected to a wrong terminator, 
\( Z_1 = Z_0, Z_2 = 3000 \), the equivalent impedance \( R'_{\text{L,wrong}} \) is:

\[
R'_{\text{L,wrong}} = \left( \frac{N_1}{N_2} \right)^2 R_{\text{L,wrong}} = \left( \frac{N_1}{N_2} \right)^2 \left( \frac{Z_0 3000}{Z_0 + 3000} + R_1 + R_2 \right) = \left( \frac{N_1}{N_2} \right)^2 \left( \frac{Z_0 3000}{Z_0 + 3000} + 1.5Z_0 \right) \tag{8}
\]

The communication protocol of MIL-STD-1553B states that \( Z_0 = 70–85 \, \Omega \) [3]. The values of \( R'_{\text{L}} \) in different conditions change as \( Z_0 \) changes from 70 \( \Omega \) to 85 \( \Omega \), as shown in Fig. 4. If the value of \( R'_{\text{L}} \) is between 70 \( \Omega \) and 85 \( \Omega \), the main bus is normal; if it is below 65 \( \Omega \), the main bus conductors are short; and if it is above 87 \( \Omega \), the main bus conductors are open, or the main bus is connected to a wrong terminator.

3.3. Polarity reversal test base on duty ratio measurement

Duty ratio measurement can be used to check the polarity reversals of the main bus and the stubs. A signal receiver and a signal generator are used in the test. The generator is connected to one stub and emits 500 kHz pulse with duty ratio of 3/4. The receiver is connected to another stub for receiving the pulse. The duty ratios of pulses are different when the polarity of conductor is normal or reversal. In an ideal condition, the duty ratio of emitted pulse is 3/4, the duty ratio of received pulse is 3/4 in the case of normal polarity or 1/4 in the case of polarity reversal, as shown in Fig. 5.

It can be determined through test whether the polarities of conductors connecting the signal generator and receiver with the network are normal or reversal. If the duty ratio of the received pulse is below 1/2, the polarities of the conductors are reversal; if it is above 1/2, they are normal.

If any failure is detected in polarity reversal test, it is necessary to find out which part of the main bus and which stubs are involved in the failure problem. The first step is to connect the generator to any stub and emit the pulses. The receiver is connected to the next stub for polarity reversal test. If the receiver indicates “test pass”, then the polarities on both stubs and the main bus between them are normal. If the receiver indicates “test fail” in one or few stub locations with respect to the generator, the polarity reversal is on those stubs where the receiver shows “fai” indication. If the receiver indicates “test fail” on all the stubs with respect to the generator, then the polarity reversal is on the stub which the generator is connected to.

3.4. Attenuation measurement base on coupler model

The attenuation measurement is used to test the insertion losses between two stubs. A signal receiver and a signal generator are used in the attenuation measurement. The attenuation is the ratio of the voltage emitted on one stub to the voltage received on another stub. The attenuation is measured with 1 MHz sine wave.

A simplified coupler model is used to measure the attenuation in the network. The coupler model is divided into two categories. The first model is to suppose that the signal generator connected to the coupler transmits a signal, as

![Fig. 3. Simplified model of coupler.](image)

![Fig. 4. \( R'_{L} \) values in different conditions.](image)

![Fig. 5. Duty ratio of received pulse.](image)
shown in Fig. 6. The second model covers the case where the signal receiver receives a signal, as shown in Fig. 7.

When the signal generator transmits a signal, the voltage ratio is

\[
\frac{V_2}{V_1} = \frac{N_2}{N_1} \left( \frac{Z_0}{Z_0} \right) \frac{R_1 + R_2}{R_0} \frac{R_2}{N_2} \frac{1}{N_1} \frac{1.5Z_0}{R_0} \]

\( (9) \)

When no defect is present, where \( R_1 = R_2 = 0.75Z_0 \), the voltage ratio of \( V_2 \) and \( V_1 \) is

\[
\frac{V_2}{V_1} = \frac{N_2}{N_1} \frac{0.5Z_0}{0.75Z_0 + 0.75Z_0} = \frac{N_2}{N_1} \frac{1}{4} \]

\( (10) \)

Fig. 7 shows a simplified DC model of the coupler when the signal receiver receives a signal. The voltage ratio of \( V_2 \) and \( V_3 \) is

\[
\frac{V_2}{V_3} = \frac{N_2}{N_1} \left( \frac{R_1 + R_2}{R_0} \right) \left( \frac{R_2}{N_2} \right) \left( \frac{1}{N_1} \right) \left( \frac{1.5Z_0}{R_0} \right) \]

\( (11) \)

When no defect is present, where \( N_2:N_1 = 1.41:1, \)
\( Z_0 = 78 \Omega \) and \( R_0 = 3000 \Omega \), the attenuation is

\[
A = 20 \log \left( \frac{V_1}{V_3} \right) = 12 \text{ dB} \]

\( (12) \)

Based on the simplified coupler model, the attenuation between any two stubs is 12 dB in a perfect network. However, in practice, the connectors and cables of the network have the insertion loss, so the attenuation varies from 12 dB to 17 dB and depends on the network configuration since the cables have a specified loss of 0.0492 dB/m [4]. The number of stubs in the network and the lengths of the main bus and stub should be considered in the attenuation measurement.

3.5. Integrity test of data path base on bit error rate calculation

This integrity test of data path is to check the working condition of Mil-Std-1553B data bus network by calculating bit error rate. All possible paths from BC to RT are combined in the network. Each path should be tested for 10,000 times of data receiving and transmitting test in both directions between stubs. 32 data words should be contained in each test, which are random numbers in 1553B format. The network passes the integrity test only when the bit error rate is zero [5].

4. Design of automatic test system

The most important work is to research the implementation methods of key technologies to design an automatic test system (ATS) for 1553B data bus network.

The traditional manual detection of 1553B data bus network needs a lot of instruments, including ohmmeter, continuity tester, signal generator, oscillograph and time domain reflectometry (TDR). As all the instruments are connected to every stub, the test process is complex, difficult, and
Table 1
Test result of 1553B data bus network.

<table>
<thead>
<tr>
<th>Order</th>
<th>Test item</th>
<th>1553B data bus network ATS</th>
<th>S2476N data bus network tester</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test result</td>
<td>Test data</td>
<td>Fault</td>
</tr>
<tr>
<td>1</td>
<td>Conductor-to-shield short test</td>
<td>Pass/green</td>
<td>DC resistance: &gt; 50 kΩ</td>
</tr>
<tr>
<td>2</td>
<td>Stub continuity test</td>
<td>Pass/green</td>
<td>DC resistance = 1.99Ω</td>
</tr>
<tr>
<td>3</td>
<td>Main bus continuity test</td>
<td>Pass/green</td>
<td>Equivalent impedance = 76.03Ω</td>
</tr>
<tr>
<td>4</td>
<td>Polarity test</td>
<td>Pass/green</td>
<td>Duty ratio 0.74 &gt; 0.5</td>
</tr>
<tr>
<td>5</td>
<td>Attenuation test</td>
<td>Pass/green</td>
<td>Attenuation = 14.759 dB</td>
</tr>
<tr>
<td>6</td>
<td>Integrity test</td>
<td>Pass/green</td>
<td>Error rate = 0.0%</td>
</tr>
</tbody>
</table>

4.1. Hardware configuration design

ATS is used to check whether the 1553B data bus network operates properly, detect the possible failures, and locate the faults. A signal generator and a signal receiver are used in polarity reversal, attenuation and integrity tests. The 1553B data bus network ATS is divided into host unit and generator unit. The generator unit is connected to one stub and the host unit is moved from one stub to another stub during testing, as shown in Fig. 8.

The host unit and generator unit are constructed based on a PC104 computer operating on Windows XP, an 8 in. touch screen and 27 V lithium battery. Both the units communicate through WiFi or RS-485 to perform all tests.

In the host unit, an oscillograph card with a sampling rate of 1 GSa/s is used for measuring resistance and voltage and analyzing the signal waveforms in detail; a Mil-Std-1553B communication card is used to simulate RT for receiving 1553B data words in integrality test.

In the generator unit, a 40 MHz signal card is used to generate the excitation signals; a Mil-Std-1553B communication card is used to simulate BC for transmitting 1553B data words in integrality test.

The test data is displayed on the screen of host unit. The virtual light indicates the test results, the green light indicated “Pass”, and the red light indicates “Failed”. The test data and results can be printed and registered through USB interface.

4.2. Test process design

The host unit is used for the short detection of conductors and shield, the continuity test of stub and the continuity test of main bus. Both host unit and generator unit are used for polarity reversal test, attenuation measurement and integrity test. The test sequence in Fig. 9 should be followed during detection.

It is important to perform the test in sequence. The subsequent items under detection can be detected only after a failed item is repaired so that the effect of failed item on the subsequent items under detection is avoided.

5. Conclusions

1553B data bus network ATS was used to detect 1553B data bus network of some type aircraft. The results from ATS are compared with the results from S2476N data bus network tester made by BCF Designs Ltd in England. The test results are listed in Table 1.

Compared to S2476N data bus network tester, 1553B data bus network ATS has an integrity test function. ATS not only shows test result, but also shows test data and has higher accuracy in measuring attenuation. If faults occur in the data bus network, the 1553B data bus network ATS can pinpoint the cause and location of a failure.

The key technologies of detecting avionics 1553B data bus network from the stubs were discussed, with emphasis on the hardware configuration and test process in designing a portable automatic test system based on PC104 computer.

The application showed that the 1553B data bus network ATS can detect the network roundly, and locate any fault with a very high level of confidence in a short time. The test process is carried out automatically, the test reports are displayed clearly and unambiguously, and the detection efficiency and reliability are improved greatly.

Acknowledgements

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References