

Research on Frequency Domain Detection Method for 1553B Bus Based on Dual-Coaxial Mechanism

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Abstract—As modern warfare becomes more informational, the reliability of communications in weapon systems is critical. As a data bus commonly used in weapon systems, there is an urgent need to explore an efficient and accurate detection method for the 1553B bus. Based on the current situation of 1553B bus detection, this paper analyzes the application limitations and shortcomings of existing detection methods. On this basis, a new dual-coaxial detection method in frequency domain for 1553B bus based on TDR technology is proposed, besides the detection strategy, application difficulties and solutions are described in detail. Measured results show that the scheme has high feasibility and good diagnostic accuracy, which provides an important reference value in engineering for reducing the difficulty of electrical fault detection for 1553B bus.

Index Terms—1553B bus, fault detection, TDR

I. INTRODUCTION

The full name of the MIL-STD-1553B bus is "time division command/response multiplex data bus", which has the advantages of simple and flexible connection between devices, real-time transmission and reliable communication. Since the 1990s, it has been widely used in various combat aircraft and extended to other system platforms such as vehicles and ships [1]. As the link of data exchange between devices, the reliability of bus is crucial for the internal information sharing and integrated control of the system. Therefore, how to detect the 1553B bus effectively, locate and diagnose fault accurately and provide maintenance advice timely has become an urgent problem to be solved.

The existing detection methods for 1553B bus mainly focus on the tests of static electrical continuity when the cable is shipped, waveform distortion during signal transmission, bit-error rate of messages based on techniques such as expert library, fault tree, and fuzzy petri net when the 1553B bus topology network works [2]-[5]. The above mainly ensures that the 1553B bus works normally at the communication level [6]. However, due to the special environment inside the aircraft, some cables will be bent, and operated at a high temperature, which makes the cables in the aviation system age faster than characteristics is the premise of normal

communication of 1553B bus, as well as the basis of the application of the above detection methods.

The 1553B bus has a dual redundant backup mechanism to ensure its communication reliability. In the case of single redundancy, although the devices can communicate normally, the bus belongs to a hidden fault state. It is also necessary to check the fault and replace the components promptly. At present, there are two common methods for detecting electrical characteristics of the 1553B bus: one is manual multi-point measurement, which has the disadvantages such as high error rate and low efficiency, but it is still used for cable detection in factory because of its low cost and easy operation. The other method, Time Domain Reflectometry (TDR), is relatively efficient [7]. It only needs to inject a step signal at one end, and then observe the reflected signal to judge the fault type and calculate its distance based on experience. However, this method requires strict rise time of the injected signal. If the rise time is too long, the resolution of the TDR system will be insufficient, which means that some feature points will be hidden, and the fault cannot be diagnosed. In order to ensure a faster rise time, the use of the protection circuit must be minimized as much as possible, which results in the sampling probe being extremely susceptible to electrostatic breakdown or EOS overwork damage caused by charge accumulation. Therefore, this paper designs a frequency domain method to avoid this problem and realize the detection for the 1553B bus.

II. PROBLEM DESCRIPTION

The normal working frequency of 1553B bus is around 1MHz. According to $\lambda=c/f$, the wavelength of the electromagnetic wave transmitted in the 1553B cable is estimated to be 300m. Transmission line theory states that when the ratio of the geometric length of the transmission line to the wavelength of the transmitted electromagnetic wave (electrical length) is greater than or close to 0.05, it is called a long line. It is known from the length of the actual application that the 1553B bus belongs to a long line. Because the wavelength is relatively short, the cable can no longer be regarded as a node. Which means that the voltage and current values distributed in the cable are inconsistent at any time and the lumped parameter theory is no longer applicable. What's more, the voltage, current,

related impedance and admittance parameters are difficult to abstract, so the reflection and transmission modes in the electromagnetic field theory are needed to analyze the cable. The scattering parameter (S parameter) is a network parameter based on the relationship between the incident wave and the reflected wave, and can express the characteristics of long-line transmission well. This scheme is to realize the detection of 1553B cable based on the measurement and analysis of S parameters.

The S parameters are usually measured using a Vector Network Analyzer (VNA). The VNA measures the frequency-dependent S parameters by scanning frequency of the input signal, and it also has a directional coupler to separate the incident energy and the reflected energy. Among the S parameters, S_{11} and S_{22} are reflection coefficients, representing the return loss, that is, the energy reflected back to the source. S_{12}/S_{21} is the inverse/forward transmission coefficient, which represents the transmission gain, that is, the energy transmitted to the destination. It is known that the fault affects the impedance of the cable, and when the instantaneous impedance of a certain point is mismatched with the characteristic impedance of the cable, the reflection characteristics will change. Therefore, for the detection of the 1553B bus, the fault information will be reflected in the change of S_{11} and S_{22} parameters directly. By converting this frequency domain information into time domain information with the mathematical method, the problem that TDR sampling probe is easy to be burned out is solved, and the purpose of locating faults in the time domain is also achieved. Therefore, a vector network analyzer is selected as the detection instrument of this scheme.

The vector network analyzer is used as a dedicated device for testing the components with the coaxial interface. When it is applied to detect the twisted-pair cable, such as 1553B bus, there are two problems, that is, the mismatched characteristic impedance and the unpaired connectors between the detecting device and the cable to be tested. By analyzing the requirements of detecting electrical faults of the bus, working mechanism of vector network analyzer and conditions of matching connectors, a scheme for 1553B bus detection based on dual-coaxial mechanism is proposed. In the scheme, an appropriate method for impedance matching is selected and the corresponding adapter is designed to solve the above application problems. The next section will introduce the design and implementation of detection scheme for the 1553B bus in detail.

III. THE DETECTION SCHEME FOR 1553B BUS BASED ON DUAL-COAXIAL MECHANISM

A. Analysis of 1553B Cable Structure

The structure of the 1553B bus cable belongs to the shielded twisted-pair symmetrical type. The cable is made up of two symmetrical insulated cores twisted together, with a shielding layer woven on the outside and finally a sheath to protect all of them. It has the

characteristics of high and low temperature resistance, aging resistance, flame retardancy, small diameter, light weight and excellent mechanical toughness, which makes it especially suitable for the systems with harsh working environments such as aviation. The structure of the 1553B cable is shown in Fig. 1.

The connector of 1553B cable is a dedicated three-coaxial connector, such as the PL75-47. Its physical and appearance are shown in Fig. 2.

In the figure, the central metal pin and the outer two metal layers are in turn, the blue line, the white line, and the shielding layer in Fig. 1, and the metal casing is electrically connected to the shielding layer of the cable. The characteristic impedance of the connector is 75 ohms.

B. Impedance Matching

It is known that the characteristic impedance of the 1553B cable to be tested is 75 ohms, while the standard connector of the network analyzer has an impedance of 50 ohms. Therefore, in order to make the change of reflection coefficient as much as possible reflect the impedance change caused by the fault, the problem of impedance mismatch between the cable and the network analyzer needs to be solved. An easy solution to this problem is to introduce an impedance converter that adjusts the impedance from 75 ohms to 50 ohms into the test loop. Although this way can achieve impedance matching, a typical 75Ω - 50Ω converter has a loss of about 6dB. However, for the ideal situation of cable transmission, the loss is required to be less than 20dB within the working frequency, which means that the application of such two impedance converters will result in a severe attenuation of the signal, and the source of the reflected signal is unclear. In order to avoid the above disadvantages, the method adopted in this paper is to test the cable by considering its characteristic impedance as 50 ohms, and then convert the measured S-parameter with a characteristic impedance of 50 ohms into the one with 75 ohms. Next, taking S_{11} as an example to illustrate the conversion method of S parameters under different impedances.

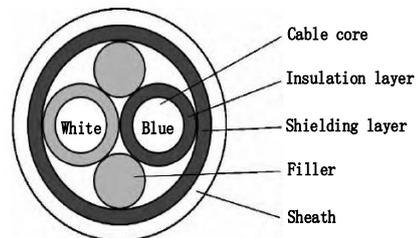


Figure 1. 1553B cable structure.



Figure 2. Diagram of the connector of the 1553B cable.

$$S_{11} = \frac{Z_{IN} - Z_{01}}{Z_{IN} + Z_{01}} \quad (1)$$

where, Z_{IN} is input impedance, $Z_{01} = 50\Omega$.

$$Z_{IN} = Z_{01} \left(\frac{1 + S_{11}}{1 - S_{11}} \right) \quad (2)$$

where, S_{11} is the complex number and $S_{11} = R + jX$. Substituting it into (2), obtain

$$Z_{IN} = Z_{01} \left(\frac{1 + R + jX}{1 - R - jX} \right) \quad (3)$$

When the characteristic impedance of the measured object is 50 ohms. The real part and imaginary part of the input impedance Z_{IN} are respectively

$$Z_{IN} (REAL) = Z_{01} \left(\frac{1 - R^2 - X^2}{(1 - R)^2 + X^2} \right) \quad (4)$$

$$Z_{IN} (IMAGINARY) = Z_{01} \left(\frac{j2X}{(1 - R)^2 + X^2} \right) \quad (5)$$

Similarly, when the characteristic impedance of the measured object is 75, there is

$$S'_{11} = \frac{Z_{IN} - Z_{02}}{Z_{IN} + Z_{02}} \quad (6)$$

where, $Z_{02} = 75\Omega$, S'_{11} is the S parameter with a characteristic impedance of 75 ohms. Z_{IN} is the input impedance calculated from (3) and $Z_{IN} = Z_{INR} + jZ_{INI}$. Substituting it into (6), obtain

$$S'_{11} = \frac{Z_{INR} + jZ_{INI} - Z_{02}}{Z_{INR} + jZ_{INI} + Z_{02}} \quad (7)$$

By processing the above equations, the real part and imaginary part of S'_{11} can be respectively denoted as

$$S'_{11} (REAL) = \frac{Z_{INR}^2 - Z_{02}^2 + Z_{INI}^2}{(Z_{INR} + Z_{02})^2 + Z_{INI}^2} \quad (8)$$

$$S'_{11} (IMAGINARY) = \frac{j2Z_{INI}Z_{02}}{(Z_{INR} + Z_{02})^2 + Z_{INI}^2} \quad (9)$$

According to this conversion, the influence caused by impedance mismatch between 1553B cable and network analyzer can be minimized to make the test result more accurate.

C. Connector Matching

The standard connector of the vector network analyzer belongs to the coaxial type (SMA/N), so the most common application to the cable is the detection of coaxial line. As you can see from Section 3.1, the use of a network analyzer to detect the 1553B cable introduces the other problem, that is, how to connect the three-coaxial connector of the 1553B cable to the coaxial connector of the vector network analyzer. Since the detection of the electrical characteristic for the cable mainly focuses on the continuity characteristic, the coupling characteristics between the two lines can be temporarily ignored. Based on the premise, this paper proposes a dual-coaxial

mechanism for detecting 1553B cable, that is, combining two signal lines of 1553B cable with the shielding layer, forming a "coaxial line" respectively, and then according to the method for the coaxial line, the detection for the 1553B cable is realized by detecting these two coaxial lines sequentially. By analyzing the detection mechanism, an adapter cable was designed to convert a three-coaxial connector (T-type) to two coaxial connectors (SMA), thereby solving the problem of connector mismatch. The physical and structure of the adapter are shown in Fig. 3.

To verify whether the 1553B cable with the adapters meets the transmission requirements of the coaxial line. Taking the blue line (A line) as an example, by connecting the two SMA connectors corresponding to this line to the network analyzer respectively, the transmission coefficient S_{21} is obtained as shown in Fig. 4.

The normal working frequency of 1553B bus is around 1MHz, therefore, the swept-frequency signal in the range of 300kHz-300MHz is used to test the cable. It can be seen from the Amplitude-frequency and phase-frequency curves of S_{21} representing the transmission characteristics that the total attenuation of forward transmission is within 2.5 dB, which means that most of the energy is transmitted to the destination end, and the A-line regarded as a coaxial line has good transmission characteristics in this frequency range. In order to explain the influence of the adapter cable on the transmission characteristics of the 1553B cable visually, the reflection coefficients of the A and B lines are converted by the IFFT respectively, and the TDR curves of these two lines are obtained as shown in Fig. 5 and Fig. 6.

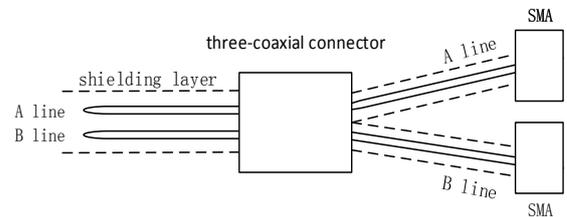


Figure 3. Diagram of the adapter cable.

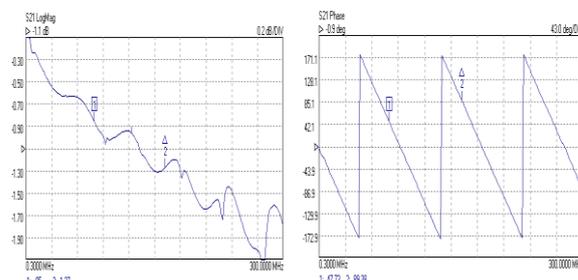


Figure 4. Transmission characteristics of A "coaxial line".

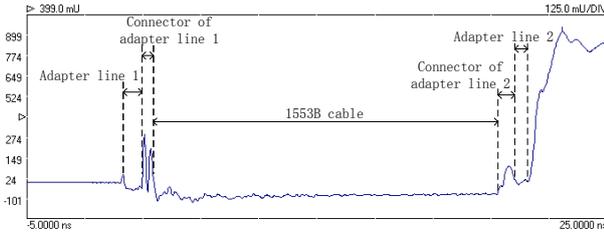


Figure 5. TDR of A "coaxial line".

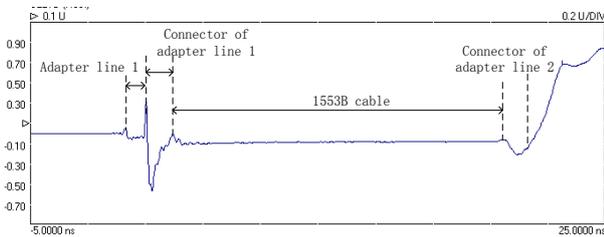


Figure 6. TDR of B "coaxial line".

In order to obtain more obvious reflection characteristics, the end of the cable to be tested is opened, so that all signals are reflected back to the source, which can be concluded from the end of the curves in Fig. 5 and Fig. 6. It can be seen from the figure that the impedance between blue line and shielding layer is inductive, making TDR curve in Fig. 5 rise at the connector; while the impedance between white line and shielding layer is capacitive, and the TDR curve in Fig. 6 falls at the connector, which conforms to the transmission characteristics for differential signals of the 1553B bus.

In the detection, the length of the adapter cable should be as short as possible to reduce its influence on the main cable. At the same time, the relationship between the frequency range of the signal and the number of sampling points should be adjusted to avoid hiding the feature points of the adapter cable in the TDR due to the low sampling resolution. As can be seen in the Fig. 5 and Fig. 6, in the detection environment constructed in this scheme, the 1553B cable between the two adapters can be located clearly to realize its detection.

IV. SCHEME VERIFICATION

Considering the continuity of the cable and the insulation between the signal line and the shielding layer, the typical faults of the 1553B cable can be divided into the following four types: single-line open circuit, single-line short circuit, dual-line open circuit, dual-line short circuit. The structure diagram of the four types of faults is shown in Fig. 7.

According to the dual-coaxial detection mechanism mentioned previously, four 1553B cables simulating the above types of fault are tested to verify the scheme. It is necessary to connect two SMA connectors corresponding to one "coaxial line" to the network analyzer and avoid mixing the SMA connectors of different lines. The detection device of this experiment is a dual-port VPN, which means that each 1553B cable with fault needs to be tested twice to obtain the reflection coefficient of 4 ports. Then the IFFT method is used to transform this frequency

domain information into time domain information representing the fault location. As a result, the four TDR curves of the 1553B cable with fault are obtained as shown in Fig. 8.

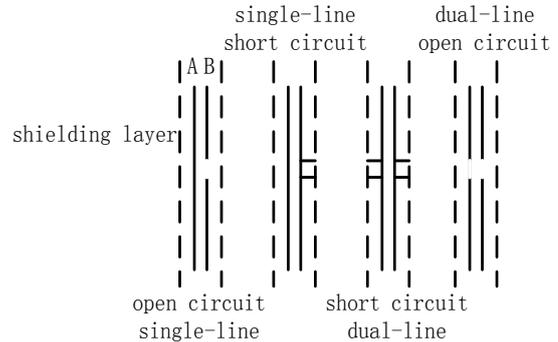
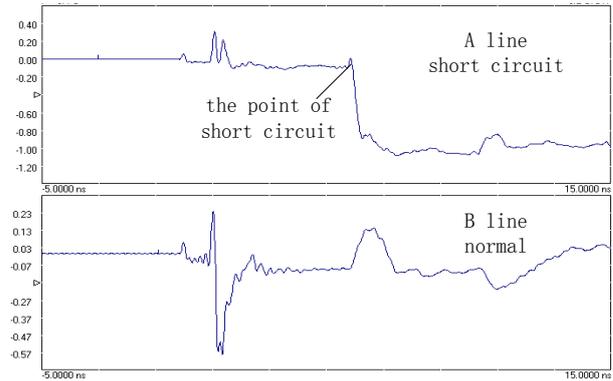
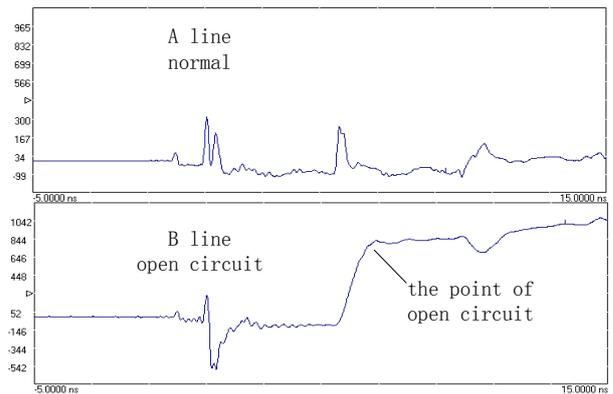


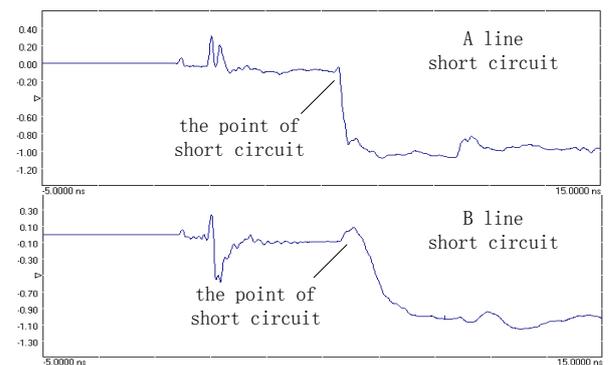
Figure 7. Diagram of typical fault of 1553B cable.



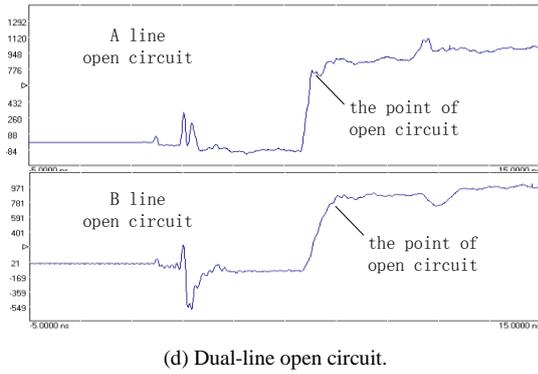
(a) Single-line short circuit.



(b) Single-line open circuit.



(c) Dual-line short circuit.



(d) Dual-line open circuit.

Figure 8. TDR of four types of 1553B cable with fault.

As can be seen in the figure, in the case of single-line fault, the line with fault will affect the normal one to produce an inductive impedance, which is reflected in the fact that the TDR curve of the normal line rises instantaneously at the position corresponding to the fault of the other line.

According to $S_{11} = \frac{Z - Z_0}{Z + Z_0}$, when there is a fault of

open circuit in the cable, Z becomes larger, the reflection coefficient is close to 1, and more energy is reflected back to the source. The vertical axis of the TDR curve represents the amplitude of the reflected voltage, so the fault of open circuit is reflected in the TDR curve rising after the open point. However, when there is a fault of short circuit in the cable, Z is close to 0, the reflection coefficient is around -1, and the energy reflected back to the source reduces, which means that the TDR curve falls after the short point. In the figure, the fault characteristics of the 1553B cable between the two adapters are obvious so that the type of fault can be judged easily.

The time difference from the fault point to the source can be obtained through the TDR curve, and then the fault can be located according to the TDR positioning theory $L = v \frac{\Delta t}{2}$. Taking single-line open circuit and short circuit as examples, the positioning results are shown in Table I.

The results show that the fault location is accurate. In summary, the feasibility of the frequency domain detection method based on the dual-coaxial mechanism for the 1553B bus is verified.

Compared with the TDR method, the scheme not only increases the safety, but also expands the number of faults that can be detected in one test and improves the efficiency of detection. If there are multiple faults on the single line of the 1553B cable, when measuring the S-parameter of a "coaxial line", the reflection coefficient of both ends can be obtained at the same time, and then the mathematical methods can be used to get the information of the first fault of each end. However, if it is implemented by the TDR method, signals need to be injected into the two ends respectively to perform two detections. By analogy, for one detection of the 1553B cable, up to four fault can be found, which makes sense for efficient detection of two/multi-line cables. The

efficiency of this method will continue to increase by using the four-port network analyzer, but the device is quite expensive, therefore, a compromise between detection cost and efficiency is needed.

TABLE I. RESULT OF FAULT LOCATION

Fault types	Time difference (ns)	Fault distance (m)	True fault distance (m)
Single-line short circuit	5.9482	0.5249	0.5
Single-line open circuit	5.9516	0.5246	0.5

V. CONCLUSION

Based on the current situation of 1553B bus detection, a frequency domain method based on dual-coaxial mechanism for the diagnosis of electrical faults of 1553B cable is proposed. The scheme uses the vector network analyzer to measure and process the S-parameter of the 1553B cable, obtain the required information of fault, and solve the problems of impedance mismatch and connector mismatch between the device and the 1553B cable. Finally, the detection of four 1553B cables with common faults is carried out to verify the feasibility of the scheme. The experimental results show that the method proposed in this paper can improve the efficiency and safety under the premise of ensuring the accuracy of diagnosis, which provides certain practical reference value for the detection of 1553B and other multi-line cables.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Tingting Du conducted the research and wrote the paper; Qingzhong Jia guided the research. All authors had approved the final version.

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