Aircraft Cable Fault Detection and Location Based on SSTDR
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Abstract. In the detection and positioning of aircraft cable faults based on Time Domain Reflectometry (TDR), due to the multiple cable connectors of the aircraft and in a severely noisy environment, the reflected signals are severely attenuated and waveform distortion exists, making it impossible to achieve accurate cable fault detection. In order to solve these problems, this paper designs the spread spectrum time domain reflectometry (SSTDR) for the characteristics of the aircraft cable, selects the m-code as the original signal, outputs the BPSK modulation with a modulation ratio of 0.5, and finally uses the correlation algorithm to obtain the fault type and distance. Using a signal source, an aircraft cable and an oscilloscope, an actual measurement system is used to test aircraft cables of different lengths. The test results show that SSTDR has high noise immunity and detection accuracy in actual tests.

Introduction
Aircraft cables are the hub between the various equipment of the aircraft, and are also an important part of the aircraft to provide power and transmit signals. Aircraft cables are widely covered in all corners of the aircraft. Due to the structural characteristics of the aircraft, there are high requirements for the volume and weight of the cables. Therefore, ordinary air wires with smaller diameters and thinner insulators are often used, and multiple wires pass through connectors[1-3]. Due to the long-term vibration, corrosion and aging of the aircraft during the mission, the cable has been open and short-circuited, which has caused great threats to the flight safety of the aircraft. Therefore, the research on fault detection and location technology of aircraft cables is becoming more and more urgent.

The method of cable fault detection and location from the initial bridge method to the reflection method after the last century has formed more positioning methods. Compared with the bridge method, the reflection method has the advantages of single end detection and simple realization of Gaohe. Reflection can be divided into Time Domain Reflection (TDR), Frequency Reflection (FDR), and High Low Reflection, depending on the transmission signal and signal processing method. LEHV, Extension Spectrum Time Domain Reflection (SSTDR), etc.[4-8]. At present, the most mature cable fault detection method is TDR, and the best detection effect is SSTDR. A lot of research has been done on cable fault detection and location technology based on TDR and SSTDR at home and abroad[9-11]. Wavelet transform and Hilbert transform are used to reduce noise to improve the test accuracy of TDR in cable detection. The detection accuracy of SSTDR is analyzed mainly from simulation. These studies mainly have the following shortcomings: (1) TDR technology is mainly used in power cable detection, the detection accuracy is low, and it cannot overcome the problem that the reflected signal cannot be obtained due to the attenuation, distortion, and electromagnetic environment interference caused by the transmission signal in the aircraft cable. (2) Most of the current research is based on the MATLAB simulation under ideal conditions, and there is no actual measurement of aviation cables. (3) The reasons for the strong anti-interference ability of SSTDR compared to Gaohe's detection accuracy are not explained in detail. In this paper, the SSTDR fault detection method is designed according to the characteristics of small test range, high precision requirement, more complex test environment and multiple transfer joints on the cable. The process of SSTDR detection is introduced in detail and the advantages of SSTDR compared to TDR in fault detection and location of aircraft cables are analyzed in detail.
SSTDR Fault Location Principle

SSTDR is a fault detection method based on spread spectrum technology. It is a new cable fault detection and positioning method developed on the basis of TDR. The SSTDR cable fault detection diagram is shown in Figure 1. The SSTDR test signal is a PN code modulated by sine wave BPSK. The test signal is injected into the tested cable as a transmitting signal, and the other signal is used as a reference signal. The transmitting signal encounters an impedance mismatch point (i.e., the fault point) in the cable and reflects the resulting mixed reflection signal through a filter. Filter filters out noise. The resulting signal is then cross-correlated with the reference signal for the delay time, and the maximum output value of the cross-correlator is changed by changing the delay time $\tau$.

The relevant results of the reflected mixed signal and the reference signal indicate the type and location of the failure. The first related peak is the autocorrelation peak, and the second peak is the cross-correlation peak, that is, the cross-correlation peak of the reflection signal and the reference signal; When the second peak is positive, the cable has an open circuit failure. When the second peak is negative, the cable has a short circuit failure. The time between the two related peaks is the fault delay time, from which the fault distance can be calculated. The difference from the TDR method is that the SSTDR method emits a pseudo-random sequence modulated by BPSK, and the TDR method emits a single pulse signal; At the same time, the SSTDR method needs to perform related processing on the reflection signal to obtain the fault information, and the TDR method can simply obtain the fault information through the filter wave. Compared with the TDR method, the main advantage of the SSTDR method is that the pseudo-random sequence approximates the characteristics of Gaussian white noise, and the on-line detection of aircraft cables can be achieved. At the same time, due to the excellent correlation of pseudo-random sequences, the signal attenuation and distortion have a small impact on the related results. It greatly enhances the anti-interference ability of cable fault detection.

![Figure 1. SSTDR cable fault detection diagram.](image)

SSTDR Key Technologies

**Transmission Signal Design**

**M Code Generation Principle.** SSTDR's emission signal requires that the relevant performance is good and the side flap of the related function is as small as possible, compared to the conventional Gold code, Barker code, Walsh code, and M code, in which the relevant function of the M code is theoretically binary, and its related function has peak peaks. Sharp and small side flap advantages, With strong anti-interference ability, it has a strong ability to identify the reflection signal with serious attenuation distortion in the aircraft cable.

The m-code can be generated by a multistage shift register or its delay element through linear feedback. If $n$ is the series of shift registers, there are $2^{n-1}$ states in addition to the full 0 state, which can produce a $2^{n-1}$ length m-code. Figure 2 is m-code generated. The principle frame diagram $C_0$, $C_1$ and $C_n$ are all feedback coefficients. If $C_i$ is 1, it indicates participating feedback. If $C_i$ is 0, it means not participating in feedback. $D_i$ indicates the status of n-bit registers. The feedback logic of $C_i$ in the form of a polynomial is:

$$G(x)=C_0 + C_1 x + C_2 x^2 + \cdots + C_n x^n$$

(1)
Where \( G(x) \) is \( n \) characteristic polynomials, \( C_i \) is a binary element, the value is 0 or 1, the power of \( x \) represents the position.

\[
\begin{align*}
X^n &\quad C_0 \\
X^2 &\quad C_1 \\
X^3 &\quad C_2 \\
\ldots &\quad C_{31}
\end{align*}
\]

Figure 2. M code generation principle box diagram

In this paper, we select a class 5 shift register to generate an m code with a length of 31. When \( n = 5 \), its feedback coefficient \( C_i = 45 \), according to the above principle, generates a length of 31 m code as shown in Figure 3(a) below, and then by finding its autocorrelation function as shown in Figure 3(b) below.

![Figure 3. M sequence and its associated graph.](image)

**M Parameter Selection.** According to the analysis of the relevant characteristics of the PN code, combined with the SSTDR measurement, when the signal processing system processes the reflected signal over one cycle of the PN code, two or more peaks will appear in the relevant result, and the fault waveform cannot be identified at this time, easy to confuse, Misjudgment. Therefore, after receiving the reflected signal, the signal processing system must complete the correlation operation in a PN code cycle to obtain the correlation peak. When the fault is very close to the test end, it will cause the peak of the related function of the transmitted signal and the reflected signal to overlap, resulting in the inability to range. In combination with the above two points, the corresponding test range can be determined based on the parameters of the emission PN code, ie:

\[
\frac{1}{2} \times T_c \times v \leq L \leq \frac{1}{2} \times N \times T_c \times v
\]

(2)

Among them, \( v \) is the propagation speed of the signal in the cable, \( \frac{c}{\sqrt{\varepsilon_r}} \) is the speed of light, and \( \varepsilon_r \) is the relative dielectric constant of the cable insulation material; \( T_c \) is the chip width of the PN sequence; \( T_m \) is the length of the PN sequence, that is, the cycle of the entire PN sequence. Aircraft cables generally do not exceed 100M. Aircraft cable fault detection requires small blind areas and high detection accuracy; Taking into account the characteristics of hardware
Implementation and fault detection of aircraft cables, the transmission signal selected in this paper is an M code with a chip width of 20 NS and a chip length of 31. Using this test signal blind area is only 2 m, and the test range can reach a maximum of 62 m. The test requirements are satisfied and the hardware is easy to implement.

Related Algorithms

There are many kinds of related algorithms for signals, such as primary correlation algorithm, secondary correlation algorithm, Hilbert conversion algorithm, etc.. Because the m-code has good self-correlation performance, this paper adopts the most easily implemented primary correlation algorithm. The detailed principles are as follows:

\[
\begin{align*}
    x(n) &= s(n) + n_1(n) \\
    y(n) &= \sum a_i s(n-d) + n_2(n)
\end{align*}
\]  

(3)

Among them, \(x(n)\) is Launch signal, \(y(n)\) is a reflection signal, \(n_1(n)\) and \(n_2(n)\) are noise, \(d\) is the delay of the signal in the cable, and the intercorrelation of \(x(n)\) with \(y(n)\) is:

\[
R_{xy}(\tau) = E\left[\left(s(n) + n_1(n)\right)\sum a_i s(n-d) + n_2(n)\right]
\]

\[
= \sum a_i R_{as}(\tau-d) + \sum a_i R_{as}(\tau-d) + R_{ns}(\tau) + R_{ns}(\tau)
\]

(4)

If the noise is all additive noise, the noise is not related to the signal. The above formula can be reduced to:

\[
R_{xy}(\tau) = \sum a_i R_{as}(\tau-d)
\]

(5)

From the above formula, it can be seen that when the correlation function obtains a maximum value at time \(d\), the value is a delay time, from which the cable fault distance can be calculated.

SSTDR Cable Measurement

The test results of SSTDR and TDR for a certain length cable in different noise environments were compared, and the detection accuracy of SSTDR and TDR for different length cables was compared.

Comparison of SSTDR & TDR Anti-interference

Select TRX316 with a length of 30m to compare the test results of SSTDR and TDR in different noise environments. In the TDR test, the signal source generates a single pulse signal with a pulse width of 10ns and an amplitude of 5V. It chooses to test without external noise and adds 20% of external noise. The results of the oscilloscope test are introduced into MATLAB as shown in Figure 6 below.
It can be seen from the above figure that when no additional noise is added, the TDR reflection wave is more obvious, but after adding a small amount of noise, the reflection wave is completely covered by noise and cannot achieve cable fault detection and positioning.

In the SSTDR test, a code with a width of 20 NS and a length of 31 is selected, and the modulation ratio selector $\beta = 0.5$ is the same as the TDR test environment. The result is shown in Figure 7 below.

As can be seen from Figure 5, the test results of SSTDR are basically not affected by noise, and the relevant peaks of open circuit and short circuit are obvious.

### Comparison of SSTDR and TDR Detection Precision

Select TRX316 with a length of 15M, 23m, 37m, and 49m as the test cable. At this time, the signal source output signal does not add noise. The number of oscilloscope sampling points is 1400, and the time axis range is 700ns, and the single point sampling interval is 0.5ns; The spacing between each sampling point is 0.05 m.

Table 1 shows the detection results of SSTDR and TDR for four lengths in the open circuit.

<table>
<thead>
<tr>
<th>the length of cable (m)</th>
<th>result of open fault test of TDR (m)</th>
<th>result of open fault test of SSTDR (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>14.80</td>
<td>14.90</td>
</tr>
<tr>
<td>23</td>
<td>22.80</td>
<td>22.90</td>
</tr>
<tr>
<td>37</td>
<td>36.70</td>
<td>36.85</td>
</tr>
<tr>
<td>40</td>
<td>48.65</td>
<td>48.80</td>
</tr>
</tbody>
</table>

Table 2 shows the detection error rate of SSTDR and TDR for four lengths in the open circuit.
Table 2. TDR & SSTDR cable open circuit test error rate.

<table>
<thead>
<tr>
<th>the length of cable (m)</th>
<th>the error rate of open fault test of TDR (%)</th>
<th>the error rate of open fault test of SSTDR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>1.33</td>
<td>0.67</td>
</tr>
<tr>
<td>23</td>
<td>0.87</td>
<td>0.43</td>
</tr>
<tr>
<td>37</td>
<td>0.81</td>
<td>0.41</td>
</tr>
<tr>
<td>40</td>
<td>0.71</td>
<td>0.41</td>
</tr>
</tbody>
</table>

Table 2 shows the detection error rates of SSTDR and TDR for four lengths in the case of short circuits. From tables 1 and 2, it can be seen that the SSTDR error in the four length cable tests is within 0.2 M, the error rate is within 0.7 %, the TDR error is within 0.5 M, and the error rate is within 1.4 %; The detection results of SSTDR are more accurate than TDR.

Summary

Aiming at the shortcomings of TDR in fault detection and positioning of aircraft cables, the method of cable fault detection and positioning based on SSTDR is introduced in detail, and the effect of SSTDR and TDR in fault detection and positioning of aircraft cables is compared through the actual measurement of cables. The experimental results show that SSTDR has stronger anti-interference ability and higher detection accuracy than TDR. In the complex environment of the aircraft, SSTDR is more suitable for cable fault detection and positioning.

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References

