Research Article

Study on Abnormal Transmission of Data Frames Based on PT-CAN Bus

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Received 27 January 2022; Revised 18 February 2022; Accepted 24 February 2022; Published 30 March 2022

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To research the problem of abnormal transmission, experiments were conducted under the conditions of the BMW F18 model. The real-time signal mutation value of PT-CAN was measured by the IBIM synthetic testing box, and the cause of abnormal transmission on the data bus was identified by the value of the signal mutation. Experiments compared and analyzed the signal waveform of PT-CAN under the conditions of normal data transmission, CAN_H to ground loaded with different resistance, CAN_H to battery loaded with different resistance, CAN_L to ground loaded with different resistance, CAN_L to battery loaded with different resistance, between CAN_H and CAN_L loaded with different resistance, when CAN_H or CAN_L was disconnected, and when CAN_H and CAN_L were interchanged. Experimental results indicate that abnormal data transmission may cause abnormal signal waveform of PT-CAN bus, and the different PT-CAN signal clutters have certain different forms and reasons. Experimental results were effective for the identification of abnormal data transmission.

1. Introduction

Power-transmission system controller area network (PT-CAN) can effectively enable real-time data to communicate and share control information, which is widely used in vehicle control systems. However, in the process of work, data bus abnormal transmission may occur due to various reasons, resulting in attenuation or distortion of the communication signal, which leads the control unit to stop working and malfunction, causing harm to the control unit [1–3]. Therefore, it is of great practical value to study the abnormal data frame exchange of bus systems among every control unit ECU and to analyze the transmission state of the communication signal by PT-CAN data conductor voltage.

Literature [4, 5] indicates that the data transmission state of the body network ECU can be directly monitored by the on-off state simulation of the CAN data conductor. Literature [6, 7] shows that it can improve the real-time and extended flexibility of information by reducing the CAN bus load of the body and verifying the delay test of CAN communication. Literature [8, 9] shows that the reliability of the delayed impact of the body system can be quantified by analyzing the communication characteristics of the controller LAN bus and ensuring the safety performance and omission factor of the broadcast authentication algorithm. Literature [10] shows that the key problems of the body network control system design can be analyzed by testing the whole-body CAN network communication system. Literature [11] indicates that the effective transmission of data communication protocol can be monitored through schedulable analysis, and the data transmission buffer response time is evaluated and analyzed.

At present, traditional forward testing is generally adopted in CAN bus, which cannot cover more abnormal testing environments. Most studies on the abnormal transmission of CAN data focus on real-time transmission performance [12, 13]. All of which have certain limitations. There is no much research on monitoring the data frame transmission state of communication line through PT-CAN BUS. In this paper, the PT-CAN bus with the data transmission rate of 500 kBit/s is used to measure the abnormal condition of high-frequency signal in the regional network.
of power system controller through the comprehensive test box of IBIM in real time [14, 15]. The error identification and processing of the voltage mutation value of the PT-CAN data conductor signal are carried out to determine the reason for the abnormal transmission of data frames.

2. Test Equipment and Methods

2.1. Test Equipment. The test subject is a BMW F18 vehicle, using Ethernet, FlexRay, K-CAN, K-CAN 2, MOST, PT-CAN, and PT-CAN2 as the main bus, while BSD, D-CAN, LIN, and Local-CAN are used as subbus. The main bus system is responsible for cross-system data exchange, including diagnosis, programming, and coding system. The subbus system is responsible for intersystem data exchange and is used to exchange relatively small amounts of data within a particular system. Since PT-CAN is used in the high-speed data network of power transmission and chassis which is the representative of data transmission signals, PT-CAN signals are selected for detection in this paper. The main parameters of the test vehicle are shown in Table 1.

2.2. Test Method. PT-CAN is a regional network of power train controller. The physical interface of a high-speed data bus adopts ISO11898 standard and has a linear topology structure. The transmission speed of PT-CAN is 500 kBit/s, and the two terminal resistors at the end of the bus are 120Ω. It is in the form of a twisted-pair wire with an additional wake-up lead. The test device of the PT-CAN data bus is shown in Figure 1. Waveform signal acquisition equipment is a BMW-specific IMIB (AT772CN) comprehensive test box produced by the AVL DITEST Vehicle Diagnosis Co., Ltd., Austria. It is connected to the red probe (channel 1) to test the voltage signal of CAN_H communication data and connected to the black probe (channel 2) to test the voltage signal of CAN_L communication data. For the convenience of comparison, all signal test data are obtained at an idle state. Through CAN_H and L wires loaded with different resistors, the correlation changes of high and low signals are compared and analyzed, and the change rules of communication data signals are identified and judged.

2.3. Detection Principle of Bus Transmission Data

2.3.1. Transmission (Bit) Rate. The voltage level on the PT-CAN data wire switches in rhythm according to the binary value to be transmitted, numerically which is equal to the number of bits transmitted per second that constitute the data code, which is

$$I = \frac{1}{T} \times \log_2 N,$$

where $T$ is the width (full width code) or repetition period (zero return code) of a digital pulse (symbol) signal, and the unit is second; and $N$ is the number of effective discrete values taken by a symbol, also called modulation. $N$ is generally taken to the integer power of 2.

$$1 \times \begin{cases}1 \frac{1}{R_1} + \frac{1}{R_2}, \end{cases}$$

where $R_1$ is the terminal resistance of the engine electronics system (DME) and $R_2$ is the terminal resistance of the electronic fuel pump control system (EKPS).

Signal steepness: It is expressed in volts per unit of time, which must be observed with a high-resolution IMIB (AT772CN) integrated test box. The signal edges are cut at 40% and 60% of the K-CAN signal level, and the steepness of the signal edge to be checked is interpolated.

$$\alpha = \tan^{-1} \left( \frac{U_{40\%} - U_{60\%}}{T_{40\%} - T_{60\%}} \right),$$

where $\alpha$ is signal steepness, $U_{40\%}$ is the signal voltage value at 40%, and $U_{60\%}$ is the signal voltage value at 60%.

2.3.3. Differential Signal. PT-CAN data lines are subject to network voltage fluctuations or ground offset and do not affect the differential signal level, which can eliminate the interference voltage and improve the system’s transmission reliability.

$$U_{diff} = U_{CAN_H} - U_{CAN_L},$$

where $UCAN_H$ is the signal voltage value of CAN_H and $UCAN_L$ is the signal voltage value of CAN_L.

3. Boundary Condition Influence to Bus Data Transmission

3.1. PT-CAN Bus Data Transmission Signal Waveform. The normal operation of the PT-CAN waveform is shown in Figure 2. The upper and lower waveforms correspond to the CAN_H and CAN_L signals, respectively, in a vertical symmetry. The level switches back and forth between the
dominant state and the recessive state without interference. In the dominant state, the voltage value of the CAN_H signal is about 3.5 V, and the voltage value of the CAN_L signal is about 1.5 V. In recessive state, the recessive levels of CAN_H and CAN_L signals are both 2.5 V. The collected CAN network messages are in normal communication condition without error frames. The signal level value may fluctuate in the range of several hundred millivolts depending on the bus load.

3.2. Influences on Bus Data Transmission When PT-CAN_H Is Loaded with Different Resistance to Ground. When PT-CAN_H loads different resistors to the ground, the change comparison of its waveform is shown in Figure 3. It can be seen that with the decrease of the loading resistance, the dominant signal level of CAN_H decreases from 3.5V to 0V. The recessive signal level changes from 2.5V to 0V, and the switch state of signal can not be observed in the data conductor from the dominant state to the recessive state. Due to the buffering effect of the PT-CAN termination resistance, the CAN_L signal level change has a certain delay to the CAN_H to ground loading resistance and decreases more slowly, but the overall pattern of change is consistent with CAN_H. This is because with the decrease of the load resistance value, the short-circuit tendency of CAN_H conductor to ground increases, and the influence of the short-circuit voltage to ground on the dominant and recessive signal levels increases, and gradually, the oscillation jump decreases. The CAN_L signal level is affected likewise and has the same tendency as CAN_H.

When CAN_H loads resistance to the ground with 250 Ω, the data of CAN_H and CAN_L become irregular distorted waveforms, and the signal level can not be normally transmitted, causing difficulties in PT-CAN communication and the vehicle starting, which shows the message “CD840 A: DME, PT-CAN communication fault”. When CAN_H loads to the ground with 37 Ω, CAN_H and CAN_L line data signal levels suddenly change to ground voltage, the transmission is further deteriorated, the communication difficulty of PT-CAN is aggravated, and the vehicle can not start, warning CAN_H signal failure; when CAN_H is short circuit to the ground, the signal level of CAN_H decreases to 0V, and the signal electric average value of CAN_L conductor decreases to about 900 mV. There is no signal level transmission of the CAN_H data conductor, and the measured waveform is a straight line of 0V without state change. The measured waveform of CAN_L data wire is an average 900mv oscillation curve. In this case, the error frame is triggered, and the PT-CAN communication is interrupted.

3.3. Influence on Bus Data Transmission When PT-CAN_H Is Loaded with Different Resistance to Battery. PT-CAN_H
loads different resistors to battery supply, and the change comparison of its waveform is shown in Figure 4. It can be seen that with the decrease of the load resistance value, CAN_H dominant signal level changes from 3.5v to the battery supply voltage, experiencing a higher oscillation jump, and the recessive signal level changes from 2.5v to battery supply voltage, undergoing with higher oscillation jump, where the signals switch state cannot be observed from the dominant state to the recessive state. Due to the buffering effect of PT-CAN terminal resistance, the change of CAN_L signal level has a certain delay to CAN_H to battery loading supply, and the increase is more slowly. However, the overall variation rule is consistent with that of CAN_H. This is because with the decrease of the load resistance, the short-circuit tendency of the CAN_H wire to the battery supply increases. The dominant and recessive signal levels are affected by the battery short-circuit voltage, and the gradual oscillation jump rises. The CAN_L signal level is affected by the same effect and has the same tendency as CAN_H.

When CAN_H loads to battery with 500 Ω, the data signal level of CAN_H and CAN_L is abruptly changed to over 5v, and the dominant and recessive states can not be distinguished effectively, resulting in difficulties in PT-CAN communication and vehicle start, which indicates CAN_H signal failure. When the battery supply is 150 Ω, the data signal level of CAN_H and CAN_L line has suddenly changed to the battery supply voltage, and the communication difficulty of PT-CAN becomes worse, and the vehicle cannot start, warning CAN_H signal failure. When CAN_H is short to battery, the voltage level of the CAN_H signal rises to 12V, and the voltage level of the CAN_L conductor rises to 12V. There is no signal level transmission of CAN_H and CAN_L data conductors, and the measured waveform is a straight line of 12V without changing trend. In this case, the error frame is triggered, and the PT-CAN communication is interrupted.

3.4 Influences on Bus Data Transmission When PT-CAN_L Is Loaded with Different Resistance to Ground. PT-CAN_L loads different resistors on the ground, and the change comparison of its waveform is shown in Figure 5. It can be seen that with the decrease of the load resistance, the dominant signal level of CAN_L changes from 1.5V to 0 voltage after oscillating and decreasing jump, while the recessive signal level changes from 2.5v to 0V, experiencing oscillating and decreasing jump where the signal switches can not be observed from the dominant state to the recessive state. Due to the buffering effect of PT-CAN terminal resistance, the change of CAN_H signal level has a certain delay to CAN_L to ground loading resistance, reducing more slowly. However, the overall variation rule is consistent with that of CAN_H. This is because with the decrease of the
load resistance value, the short-circuit tendency of CAN_L conductor to ground increases, the influence of the short-circuit voltage to ground on the dominant and recessive signal levels increases, and the gradual oscillation jump decreases. The CAN_L signal level is affected by the same effect and has the same tendency as CAN_H.

When CAN_L loads 75Ω to ground, the data of CAN_H and CAN_L are irregular distorted waveform, the signal level changes to ground voltage, and the data can not be transmitted normally, causing difficulties in PT-CAN communication and the vehicle starting, warning CAN_L signal failure. When CAN_L loads 30Ω on the battery supply, the data signal level of CAN_H and CAN_L wires increases, the influence of the short-circuit voltage to ground on the dominant and recessive signal levels increases, and the gradual oscillation jump decreases. The CAN_L signal level is affected by the same effect and has the same tendency as CAN_H.

When CAN_L loads 150Ω, the data signal level of CAN_H and CAN_L changes abruptly to above 5V, and the dominant and recessive states can not be distinguished effectively. The communication of PT-CAN is difficult, and the vehicle shows difficulty, thus warning CAN_L signal failure. When CAN_L is short circuit to the ground, the signal level of CAN_L is reduced to 0V, and the signal electric average value of CAN_H conductor is reduced to about 900mV. CAN_H and CAN_L data conductors have no signal level transmission, and the measured waveform is a straight line of 0V and 900mV without state change. In this case, the error frame is triggered, and the PT-CAN communication is interrupted.

3.5. Influence on Bus Data Transmission When PT-CAN_L Loaded with Different Resistance to Battery. When

![Figure 4: Signal waveform of PT-CAN_H to battery loaded with different resistances. (a) PT-CAN_H load resistance to battery with 2.5kΩ. (b) PT-CAN_H load resistance to battery with 500Ω. (c) PT-CAN_H load resistance to battery with 150Ω. (d) PT-CAN_H load resistance to battery with 0Ω.](image-url)
further, and the voltage value of CAN_L signal increases steeply to 8V and then remains at about 8V after a series of oscillations. The voltage value of CAN_H signal increases steeply to 6V and then remains at about 6V after a series of oscillations. The voltage value of CAN_H and CAN_L signal is much higher than the normal CAN_L voltage, where PT-CAN communication is interrupted, and the vehicle cannot start, warning CAN_L signal failure. When CAN_L loads 0Ω resistance value on the battery supply, the level voltage of CAN_L wire rises to 12V, and the signal level voltage of CAN_H rises to 9V. There is no signal level transmission between CAN_H and CAN_L data wire, and the measured waveform is a straight line with almost no trend of change. In this case, the error frame is triggered, and the PT-CAN communication is interrupted.

3.6. Influences on Bus Data Transmission Loaded with Different Resistors between PT-CAN_H and L. When different resistors are loaded between PT-CAN_H and L, the change comparison of the waveform is shown in Figure 7. It can be seen that with the gradual decrease of load resistance from 75Ω to 0Ω, the dominant signal level of CAN_L gradually increases from 1.5V to 1.8V, 2V, 2.2V, and 2.5V, while the recessive signal level remains at 2.5V. The dominant signal level of CAN_H gradually decreases from 3.5V to 3.2V, 3V, 2.8V, 2.5V, while the recessive signal level remained at 2.5V. CAN_H and L signal level amplitudes are reduced from the normal 1V to 0V. This is because the signal level transmitted by CAN_H and L wires is opposite in polarity and equal in amplitude and is symmetrically arranged up and down. With the decrease in the loading resistance value, the mutual interference trend of CAN_H and L signal levels increases. Finally, the dominant state mutually offsets for 2.5v, implicit state constant for 2.5v.

When 15Ω is loaded between CAN_H and L, the dominant signal level of CAN_L increases from 1.5V to 2V, and the dominant signal level of CAN_H gradually decreases from 3.5V to 3V. CAN_H and CAN_L wire data signal levels have no regular cycle, which makes data signal transmission and PT-CAN communication difficult. Therefore, the vehicle starts difficultly, warning CAN_L signal failure. When 0Ω is loaded between CAN_H and L, the two voltage signals overlap each other, and the curves are the same. There is no signal level transmission on the data lines. The measured waveform is a 2.5v straight line with almost no trend. CAN_H, L data wire with error frame exists, and the data cannot be transmitted normally. PT-CAN communication is interrupted.

3.7. Influence on Bus Data Transmission When Wire Conductors of PT-CAN_H and L Are Disconnected. As can be seen from Figure 8(a), the voltage level value of CAN_H signal is about a 2.5V straight line, the dominant voltage value of CAN_L signal is 1.5V, and the recessive voltage
Figure 6: Signal waveform of PT-CAN_L to battery loaded with different resistances. (a) PT-CAN_L load resistance to battery with 2.5kΩ. (b) PT-CAN_L load resistance to battery with 150Ω. (c) PT-CAN_L load resistance to battery with 30Ω. (d) PT-CAN_L load resistance to battery with 0Ω.

Figure 7: Continued.
value is 2.5V, which can be determined that CAN_H conductor is disconnected. As can be seen from Figure 8(b), the voltage level value of CAN_L signal is about a 2.5V straight line, the dominant voltage value of CAN_H signal is 3.5V, and the recessive voltage value is 2.5V which can be determined that CAN_L conductor is disconnected. For PT-CAN can not be "fault-tolerant", when any network cable is disconnected, the network system will send an error frame, and the communication is interrupted.

3.8. Influence on Bus Data Transmission When PT-CAN_H and L Are Interchanged. Pt-Can_H and L wires of Digitale Motor Elektronik (DME) are interchanged, and the change of waveform is shown in Figure 9. It can be seen that CAN_L dominant signal level is 3.5v, recessive signal level is maintained at 2.5v, CAN_H dominant signal level is from 1.5v, and the recessive signal level is maintained at 2.5v. CAN_H and L signal levels are just opposite to the normal transmission level signals. This is because when CAN_H and L conductors are interchanged, the signal level is also interchanged for transmission, resulting in data disorder, where data signals can not be transmitted normally, and PT-CAN communication is interrupted. The waveform shows similar variation when CAN_H and L of each electronic module on PT-CAN wires are interchanged.

Figure 7: Signal waveform between CAN_H and L loaded with different resistances. (a) Loading 75Ω between PT-CAN_H and L. (b) Loading 37Ω between PT-CAN_H and L. (c) Loading 15Ω between PT-CAN_H and L. (d) Loading 0Ω between PT-CAN_H and L.

Figure 8: Signal waveform under the conditions of CAN_H or L being disconnected. (a) PT-CAN_H wire open circuit. (b) PT-CAN_L wire open circuit.

Figure 9: Signal waveform under the conditions of CAN_H and L being interchanged.
4. Conclusion

(1) With the decrease of the resistance value of the ground loading, the dominant and recessive signal levels gradually decreased to 0V through the oscillation reduction and jump. When CAN_H loads 250Ω to the ground, the data of CAN_H and CAN_L wires become irregular distorted waveforms, and the signal level cannot be transmitted normally, resulting in the PT-CAN communication difficulty.

(2) With the decrease of the resistance of Pt-Can_h to the battery supply, the dominant and recessive signal levels gradually rise to the battery supply voltage, experiencing signal levels oscillation increase and jump. When CAN_H loads 500Ω to the battery supply, the data signal level of CAN_H and CAN_L wire cannot distinguish the dominant state from the recessive state effectively, causing PT-CAN communication difficulty.

(3) With the decrease in the resistance value of ground loading, dominant and recessive signal levels of PT-CAN_L decreased to 0V gradually, experiencing oscillations. When CAN_L loads 75Ω to the ground, the data of CAN_H and CAN_L conductors become irregular distorted waveforms, and the signal level changes to the voltage to the ground, where the data cannot transmit normally, causing PT-CAN communication difficulty.

(4) With the decrease of the resistance value to the battery supply, dominant and recessive signal levels gradually rise to the battery supply voltage with oscillation and jump. When CAN_L loads 150Ω on the battery supply, the data signal level of CAN_H and CAN_L wires changes to more than 5V, and the dominant and recessive states cannot be distinguished effectively, resulting in PT-CAN communication difficulty.

(5) As the load resistance decreases between PT-CAN_H and PT-CAN_L, the dominant and recessive signal levels of CAN_L coincide at 2.5V, and the dominant and recessive signal levels of CAN_H coincide at 2.5V. When 15Ω is loaded between CAN_H and L, the data signal level of CAN_H and CAN_L changes irregularly, resulting in the difficulty of the data signal transmission and PT-CAN communication.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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