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Research on the improvement method of CAN bus based on CAN-FD

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Abstract. CAN bus fault diagnosis of new energy vehicles is the main factor affecting the maintenance efficiency of new energy vehicles, so a convenient and fast diagnosis method is particularly important. The CAN bus fault diagnosis of new energy vehicles has gradually become an important factor affecting the promotion of new energy vehicles in the post-market. CAN plays a crucial role in industrial application especially in automotive industry. For adapting the Big Bang of data, CAN need to be improved. CAN FD is a protocol which is raised to solve some shortages in CAN.This paper focus the way how to improve the CAN based on CAN-FD.By contrasting these two communication protocols ,this paper analyzes the way to improve CAN in four aspects which is include physical layer,the length of data frame, the rate of the data transmission and the way about error validation. In conclusion, the improvement of CAN, not only the rate and the data size in data transmission should be stipulated, also make some change in many ways to adapt the requirement so that the data can be transmitted rapidly and efficiently.

Keywords: controller area networks, controller area network with flexible data-rate, CRC.

1. Introduction

Nowadays, the controller area networks(CAN) are widely applied in many industrial aspects such as auto industry because its efficiency ,reliability and special design. The type of networks has over 30 years history which was put forward by BOSCH company and the J1939 protocol has become a general standard in trucks and carriage which was put forward by SAE(Society of Automotive Engineers) [1]. However, with the development of automotive industry, more and more data need to be transported. The rate should be faster and the data size should be larger the before. CAN only support speed with 1 M bits/sec and it only transport data as long as 64 bit.For improving these aspect, CAN-FD was put forward in 2012 by BOSCH company, the type aims to development the protocol of CAN. CAN FD can be compatible with CAN and widely used in some automobile company. This paper describe CAN generally include their architecture, protocol, and standards. This paper presents the difference between CAN and CANFD and tries to analyze the train of thought about how to improve CAN. This paper also explain the aspects that some methods how to improve CAN [2].

2. Characters of can and CAN-FD

2.1. Model and version

CAN and CANFD are based on Open System Interconnection Reference Model(OSI)which is proposed by International Standards Organization but the two protocols only define 4 layers: physical layer, transfer layer, object layer, and application layer [3].

CAN and CANFD has two different type of bit include dominant bit and recessive bit. The dominant bit expresses '0' and the recessive bit expresses '1'. The CAN uses serial data transmission and can operate at a rate of 1Mbit/sec over 40m of twisted pair cable or operate up to 10km with 5kbit/sec. Besides, CANFD can operate with flexible rate and the rate is up to 5 M bit/sec [4]. The major CAN versions are CAN 2.0A and CAN 2.0B. Compared with CAN 2.0A, CAN 2,0B has identifier with more bits to deal with the problem of insufficient number of identifiers. And CANFD also uses 11 bits or 21 bits for node identification.

2.2. The frame types

CAN have five type of frame include data frame, remote frame, error frame, overload frame and frame interval. And CANFD don't support remote frame to ensure compatibility with CAN [5].

2.2.1. Data frame

The data frame of CAN has 7 sections include SOF, Arbitration field, Control Field, DATA field, CRC Field, ACK Field, EOF Field.

SOF: This section only takes up one bit and it's a symbol of the beginning of data frame.

Arbitration field: If the version CAN 2.0A is used. The data frame is named standard data frame and the Arbitration field include 11 bits identifier and 1 bit RTR. If the version CAN 2.0B is used. The data frame is named extend data frame and the identifier divides into two parts. One part will take up 11 bit named standard ID, the other part have 18 bit which is named extended ID. The Arbitration field include 11 bits standard identifier, 1 bit SRR,1 bit IDE,18 bit extended ID and 1 bit RTR. RTR takes up one bit which is a symbol of difference between a DATA frame and a REMOTE frame. If the frame is DATA frame, this bit is a dominant bit("0").If the frame is REMOTE frame, this bit is a recessive bit("1"). IDE also takes up one bit which is used to differentiate between standard frame and extended frame. If the frame is stand frame, this bit is a dominant bit("0").If the frame is extended frame, this bit is a recessive bit("1") [6].

Control field: For standard frame, the field include IDE, r0 and DLC(Data Length Code).For extended frame, the field include r0, r1 and DLC. DLC takes up 4 bits and express the number of data. In CAN, "0000" to "1001" can be used in this field, and express the length of data from 0 to 8 byes. For r0 and r1, they are two dominant bits in CAN.

Data field: In data frame, the data field is used to load the data which is sent by the node. The length of this field depend on DLC.

CRC field: This field include 2 fields. One is CRC(Cyclic Redundancy Check) which is a 15 bits field as a check code in data frame. It can be used to confirm whether there are some errors in the process about the sent massage which the received node receives. The other is CRC Delimiter which is a recessive bit("1") used to separate CRC field and ACK field. The value of CRC is calculated in the following range: SOF field, Arbitration Field, Control Field, Data Field

ACK field: ACK Field is composed of an ACK Slot bit and an ACK Definer .The ACK Field of the sending unit is composed of 2 recessive bits, and the ACK Field of the receiving unit is composed of 1 dominant bit and 1 recessive bit. The field is used to confirm that the data receive normally.

EOF field: EOF Field consist of 7 recessive bits which is a symbol of the end of the data frame. Between SOF~CRC Field, five-bit stuffing pattern is used in data frame. For sending node, the data , if the same bit lasts for 5 bits, in the next bit (6th bit) then 1 bit with the inverse bit of the first 5 bits should be inserted. For receiving node, if the same level lasts for 5 bits, the next bit needs to be deleted

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before receiving it. If this 6th bit has the same level as the previous 5 bits, it will be considered as an error and an error frame will be sent [7].

2.2.2. Remote frame

Compared with Data Frame, Remote Frame doesn't have Data Field and in Remote Frame the RTR bit is a recessive bit. The frame is used by receiving node to request data from other source. The DLC is a symbol of the length of the data requested.

2.2.3. Error frame

The frame is used to detect errors and inform errors when receiving and sending messages. This frame consists of an error flag and an error definer. For error flag, it includes active error flag and passive error flag. Active error flags consists of 6 dominant bits and passive error flags consists of 6 recessive bits. The error definer consists of 8 recessive bits [8].

2.2.4. Overload frame

The frame is used to inform the receiving node that there are not ready to receive data. The frame consists of overload flag and overload definer. The overload flag has same composition with active error flag and the overload definer has the same composition with the error definer.

2.2.5. Frame interval

The frame is used to separate data frame and removed frame and the frame can't be interleaved before Overload Frame and Error Frame. For comparability of CAN, Removed Frame is removed in the protocol of CANFD. And the Data Frame is similar to that in CAN.D ata Frames of two types have same construction and there are some improvement in CANFD: Because Remote Frame isn't supported in CANFD, the RTR bit is replaced by the SRR bit which is a dominant bit all time. To differentiate Data Frame of Can, the FDF(FD Format) bit is added after the RRS. If the FDF bit is a dominant bit, the frame is a classical CAN's Data Frame and if the FDF bit is a recessive bit the frame is Data Frame of CANFD. FD means flexible data rate. To arrive the goal, a BRS(Bit Rate Switch) is used in the end of Arbitration Field. The bit is recessive bit   indicates rate switching, the transmitting node will switch to the baud rate of high-speed transmission in the BRS bit, and other receiving nodes must also switch the corresponding baud rate.At the sampling point of the CRC definer, the baud rate of all nodes then switches back to the baud rate of the arbitration field; when the BRS bit is a dominant bit ”0” indicates that no rate switching is performed. DLC is extended, from "1001" to "1111" can be used to express more length of data which is transported. CRC Field also is different than which is in CAN,so that the probability of dew inspection can be decreased and the reliability of data transmission can be increased. In ACK Field, Data Frame in CANFD support 2 bits ACK identifier. Across these improvement CAN FD can have flexible and faster data rate and it can transmit more data one time [9].

2.3. Arbitration

CAN is a structure of multiple node which means there can be more than one node operate meanwhile. As long as the bus is free, any node can start transmitting messages. If there are two or more nodes starting transmitting messages at the same time, then there is a bus access conflict. To solve the conflict, bit-by-bit arbitration of identifiers is used [10]. During arbitration, each transmitter monitors the bus and if the transmit and receive levels are the same, the node can continue sending messages. It has two characters, one is that multiple nodes on the bus send both dominant and recessive levels at the same time, and the bus level is expressed as an dominant level, the other is The CAN controller monitors the bus level status even while transmitting data, that when in arbitration, when the controller sends a recessive level but detects a dominant level on the bus, the node arbitration fails and switches to the receiving node. Across the way, in CAN, Data Frame is transmitted preferentially compared with Remote Frame because their RSR bits is arbitrate before ID.

3. Improvement in physical layer

In CAN, the physical layer defines how the signals are actually sent, the bit timing, how the bits are encoded and the steps for synchronization. Specifically, however, signal levels, communication speed, sampling points, electrical characteristics of the driver and bus, and connector morphology are not defined. These must be determined by the user according to the system requirements. The physical layer of CAN communication is divided into an open-loop bus and a closed-loop bus. The open-loop bus is used for low-speed communication and is suitable for long-distance communication. The closed-loop bus is used for high-speed communication and is suitable for close-range communication. In CAN, differential signals are usually used for transmission, and shielded twisted pair cable is used for networking and wiring to reduce the impact of external interference on bus communication. Then the paper will introduce some direction in improvement the physical layer [11].

3.1. Transmission medium

In CAN and CANFD, shielded twisted pair cable is widely used in the transmission of data. However CAN bus network in the harsh environment of industrial field communication using twisted pair long-distance transmission signal susceptible to electromagnetic interference. To solve this problem, new medium can be used in the transmission of data. Fiber optic communication has the advantages of long relay distance, large transmission capacity and good transmission quality. Especially, it has the advantages of anti-electromagnetic interference not affected by high voltage and high current. So some scholars try to apply fiber optics to replace twisted pair [12]. The key of the way is how to realize the mutual conversion of optical and electrical signals. If the CAN signal can transform to optical signal, the data can be transmitted in fiber optic.

3.2. Terminal resistance

In high-speed communication of CAN, the terminal resistance is applied in CAN_H line and CAN_L line so that the level goes into recessive state quickly and improve the quality of the signal.Different from the traditional CAN network terminal resistance 120Ω empirical matching method, people have found that it is difficult to ensure that all nodes can participate in communication properly when different resistors such as 120Ω, 60Ω, 30Ω or a combination of them are arranged in different locations. So how to chose the suitable resistance is the key to realize the terminal-matching. Normally, people use enumerative approaches to find the suitable resistance. However the resistance can be chosen by some optimistic algorithm. Some people come up with using particle swarm-based parameter optimization algorithm to solve this problem. By establishing quantitative evaluation criteria for bus signal quality, the algorithm is verified that it can improvement the quality of communication.

3.3. CAN transceiver design

The CAN bus transceiver essentially implements the level conversion and is the interface between the CAN controller and the physical bus, which is the main factor affecting the safety, reliability and electromagnetic compatibility of the network system. The ISO standard 11898-2/-5/-6 defines the requirements for CAN high-speed transceiver design. The CAN transceiver which is is up to the ISO standard should be design so that the data can be transmitted stably and accurately. For the improvement in CAN, the parameters which are used to design CAN transceiver should be different with that before.

4. Improvement in CAN data frame

When the physical layer is supported faster data rate and more data size in one time data transmission. The protocol should be changed to inform the receive node the length of data which will be sent and the rate of data transmission. Besides check mode should be defined in the protocol. The data frame is the most important frame in CAN data transmission.This paper will illustrate three aspect about the improvement based on CANFD.

4.1. The length of data

In CAN, the DLC is used to inform receiving node the length of the sending data. However in CAN Data Frame, the length of Data Field is 64 bits at most.So, the maximum effective data transfer efficiency is near 60 percent. With the length of Data Frame except Data Field consistent,if Data Frame has longer Data Field effective data transfer efficiency will be higher. Based on CANFD,the length of data field can be 512 bits and the effective data transfer efficiency is near nine tenth. In CANFD,the DLC also consists of 4 bits but the protocol define more correspondence between the DLC and the length of Data Field as shown in table 1.

Table 1. CAN&CANFD DLC code table.

DLC	CAN Data Length(byte)	CANFD Data Length(byte)
0(0000B)	0	0
1(0001B)	1	1
2(0010B)	2	2
3(0011B)	3	3
4(0100B)	4	4
5(0101B)	5	5
6(0110B)	6	6
7(0111B)	7	7
8(1000B)	8	8
9(1001B)	/	12
10(1010B)	/	16
11(1011B)	/	20
12(1100B)	/	24
13(1101B)	/	32
14(1110B)	/	48
15(1111B)	/	64

In the table,the shortage about the DLC in CANFD is that though Data Frame can take data up to 64 bytes,the data length isn’t be chosen flexible.For example,the CAN DATA whose length is 9 bytes isn’t allowed to be transmitted.If Data Frame can transmit more types of length,the DLC should consist of more bits.However,with the data length increase,too much DLC bits will decrease effective data transfer efficiency.It is crucial to keep the balance in the DLC and the Data Field.The congruent relationship between DLC and length of Data Field isn’t too tight or loose so that too much useless data is transmitted.

4.2. The data rate

When the data size has increased, the rate should be increased to keep the time used in transmitting data short normally, which means the system using CAN bus can process information fast and the system can be useful. In Classical CAN,the data rate keeps a fixed number such as 1Mbit/sec and 5kbit/sec. For faster data rate and compatibility of CAN,the flexible data rate can be used.The receiving node should be informed that which one rate will be used in transmitted.The Data Frame can be add to a flag bit as a symbol of the data rate.Based on CANFD,the BRS(Bit Rate Switch) is used to express bit rate conversion and it also is a delimiter about the section with flexible data rate.Variable rate from the BRS bit in the control field up to the ACK field (including the CRC divider), the rest is the rate used by the classical CAN bus.In practical application,The system is capable of rate switching by changing the cycle length of the smallest time unit in the constituent bit.Meanwhile the CAN FD protocol uses a secondary sampling point to solve the sampling problem of the sending node in the data domain, and stipulates that the interval between the secondary sampling point and the sending point should be delay+offset, offset is the compensation value, which is generally the length of half a bit in the data domain. If there are more different data rate used in

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transmission of Data Frame,the flag bits should takes up more bits.If BRS consist of n bits,the number of rates used in transmission will be 2^n.Certainly, if more types of data rate are used,the sending point is more difficult to decide and the physical layer should be more accurate.Now,CAN FD realizes the switch in 1M bits/sec and 5M bits/sec and efficiently rise the data rate.

4.3. Check mode

To ensure that data can be transmitted correctly,some check modes will be applied in transmission.In CAN,CRC(Cyclic Redundancy Check) is the main way to check. CRC code is a linear, grouped system code [13]. Using CRC check is to add a CRC Field after the data bits to help with the checksum, the calculation is performed by not rounding modulo 2 division, and the result is found to be comparable to the result of a per-bit hetero-dyne operation.The result of the algorithm is the remainder of the transfer polynomial divided by the adopted generating polynomial.In CAN,the adopted generating polynomial is x^15+x^14+x^10+x^8+x^7+x^4+x^3+x^0. Besides CAN uses five-bit stuffing pattern, so if receiving node receives 6 same bits, it’s easy to find error in the transmission. If more data will be transmitted,check mode should have less residual error rate.By text,the residual error rate in CRC is higher than the indicators of Bosch and for a 500 Kbps CAN bus system, assuming a bus utilization of 40% and a frame length of 135 bits, the CAN system will have one missed frame in 9.96 hours [14]. So check mode should be improved to decrease the residual error rate and keep the system safe.Based on CAN FD,there are some aspects ways to improve the check mode. The simple way is that new check modes can be added in Data Frame such as parity check,padding check.Compared with CAN,the bit-suffering count which consist of 3 bits and parity check about the count which consist of 1 bit are added before the CRC Field. The value represented by the 3-bit bit-suffering count is the result of modulo 8 of the actual fill bit count and is displayed in Gray Code.Besides the parity bit checks the bit-suffering count for parity, i.e. when the number of 1's is odd, the value of the parity bit is 1, and vice versa is 0. On the other hand, the generate polynomials can be changed in CRC.More item number is used in generate polynomials,the residual error rate will be less,because item number decides the type of congruent polynomial and the chance that the right data and the error data have the same result of taking the remainder of the generated polynomial.In CAN FD,if the DLC is from “0000” to “1010” i.e. the length of Data Field is less than or equal to 10 bit,CRC-17 will be applied and the generating polynomial is x^17+ x^16+ x^14+ x^13+ x^11+ x^6+ x^4+ x^3+ x^1+ 1. Besides is the DLC is from “1011” to “1111”,CRC-21 will be applied and the generating polynomial is x^21+ x^20+ x^14+ x^11+ x^7+ x^4+ x^3+ x^1+ 1, because the length of data field has dramatic increased. Finally,five-bit stuffing pattern is an important mechanism.The pattern also is applied in error detection. Normally CRC checks would have detected all odd errors, and multi-bit errors of less than 5 bits can be detected, but if there are pairs of padding errors, the additional odd errors can also be missed, and the additional multi-bit errors can also be missed.To solve the problem,a efficient way is that the suffering bits is added in the transfer polynomial in other words When the transmitting node sends a message, it first suffers the message with bits according to the five-bits suffering pattern, and then does the CRC calculation. In CAN FD,this way is applied in CRC calculation. What’s more there are fixed suffering bits in CRC Field following the rule that there will be a reverse bit inserted in the next bit.

5. Conclusion

To improve a complete communication protocol, not only the protocol of data transmission should be considered,but the suitable physical device should be designed.This paper introduces CAN and CAN FD and give some ways about improvement of CAN. In physical layer,the medium,the way of terminal resistance and the CAN transfer have some ways to improve to suit the protocol. In protocol, the paper analysis some positive change between CAN and CAN FD and explain the reason why make difference in DLC, BRS and CRC Field. In CAN FD,the data can be transmitted faster,more accurately and with bigger size. This paper sum up some experience in improvement in CAN and can be a reference in how to improve a communication protocol.In future, there will be a more perfect protocol used in daily life based on these modified ways.

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