Design of telemetry and telecommand subsystem of a micro-satellite based on industrial-level chips

Jie Liu, Hao Zhang, Wei Zheng, Liuguo Yin

***Abstract*—**Miniaturized satellites characterized with small size, low weight, cheap designs, short development period, and flexible launching way have been recognized as cost effective solutions for universities, Businesses and even individuals to develop satellites. However, the design of highly reliable subsystem based on commercial level or industrial level VLSI chips is the key challenging problem in micro-satellite production. In this paper, a redundant design scheme is proposed for designing the telemetry and telecommand (TTC) subsystem of a micro satellite based on industrial-level VLSI chips, and the reliability of the subsystem with the proposed design scheme is also analyzed. It is shown with analytical results that with redundant design scheme the reliability of a CAN Bus could be effectively improved, and the redundant CAN bus based on low-level VLSI chips could be applied to the TTC subsystem of a micro-satellite.

***Keywords*—**micro satellite, telemetry and telecommand subsystem, CAN bus, redundant design

I. Introduction

With the fast development of micro-computer technology and the satellite miniaturizing technology, researches on small satellite technologies have been a hot topic [1]. Compare with conventional large satellites, small satellites have smaller size, lower weight, cheaper designs, shorter development period, and more flexible launching way, which have made it possible for universities, Businesses and even individuals to develop satellites [2]. It has been recognized that small satellites can complement the services provided by the existing larger satellites, by providing cost effective solutions to specialist communications, remote sensing, and rapid response military missions. Miniaturized satellites also allow for the opportunity to test new hardware with reduced expense in testing. Furthermore, since the overall cost risk in the mission is much lower, more up-to-date but less space proven technology can be incorporated into micro and nanosats than can be used in much larger, more expensive missions with less appetite for risk.

However, there are many challenging problems in making small satellites. One of which is that small satellites are generally designed with VLSI chips of commercial or industrial level, and thereby electronics need to be carefully designed and rigorously tested to be ”space hardened” or resistant to the outer space environment (vacuum, micro-gravity, thermal extremes, and radiation exposure).

In this paper, a redundant design scheme for the telemetry and telecommand (TTC) subsystem of a micro satellite is introduced, and the reliability of the subsystem with the proposed design scheme is also analyzed. It is shown with analytical results that with redundant design scheme the reliability of the TTC CAN Bus could be effectively improved, and the redundant CAN bus based on low-level VLSI chips could be applied to the TTC subsystem of a micro-satellite.

The rest of this paper is organized as follows. In Section II, the TTC subsystem is introduced. Then in sectioin III, a redundant hardware design for the TTC subsystem is proposed. In Section IV, the software implementation issues of the redundant CAN bus is described in detail. After that, the reliability of the redundant TTC CAN Bus is analyzed in Section V. Finally, conclusions are draw in Section VI.

II. Hardware Structure of a TTC Subsystem

A TTC subsystem is made up of telecommand section and telemetry section. The hardware structure of a TTC subsystem is shown in Fig.1. The telecommand part consists of 4 microprocessors, all of which are Philips 87C51 microprocessors. 87C51 built-in central processing unit, 128 bytes of internal data memory RAM, 32 bidirectional input/output (I / O) ports, two 16-bit timer / counters, and five two interrupt structure, a full duplex serial communication mouth, on-chip clock oscillator circuit [3]. The fourth microprocessor is the backup of the other three. Telecommand module is responsible for receiving simple serial protocol telecommand data frame which comes form the RF receiver (a receiver could receive command frame that comes from ground station) on the satellite or other subsystems. After microprocessor decoding, the corresponding control command will be written to the latch area, each bit of the latch area corresponding to a switch on the micro-satellite, including the switch for the CAN bus.

The main chips of telemetry part are two Infieon C515C microprocessor, one Philips 87C51 microprocessor, two FPGAs and two AD converters. The 87C51 microprocessor, which functions as TLM0, is used for acquiring telemetry data from FPGA and sending framed telemetry data to the ground station, where operators could monitor the status of the satellite and send corresponding instructions to the satellite. The C515C processor, which functions as TLM1, could perform the same function as TLM0. And as an extension, TLM1 could also functions as providing telemetry data to other subsystems, telemetry data collecting from other subsystems and sending

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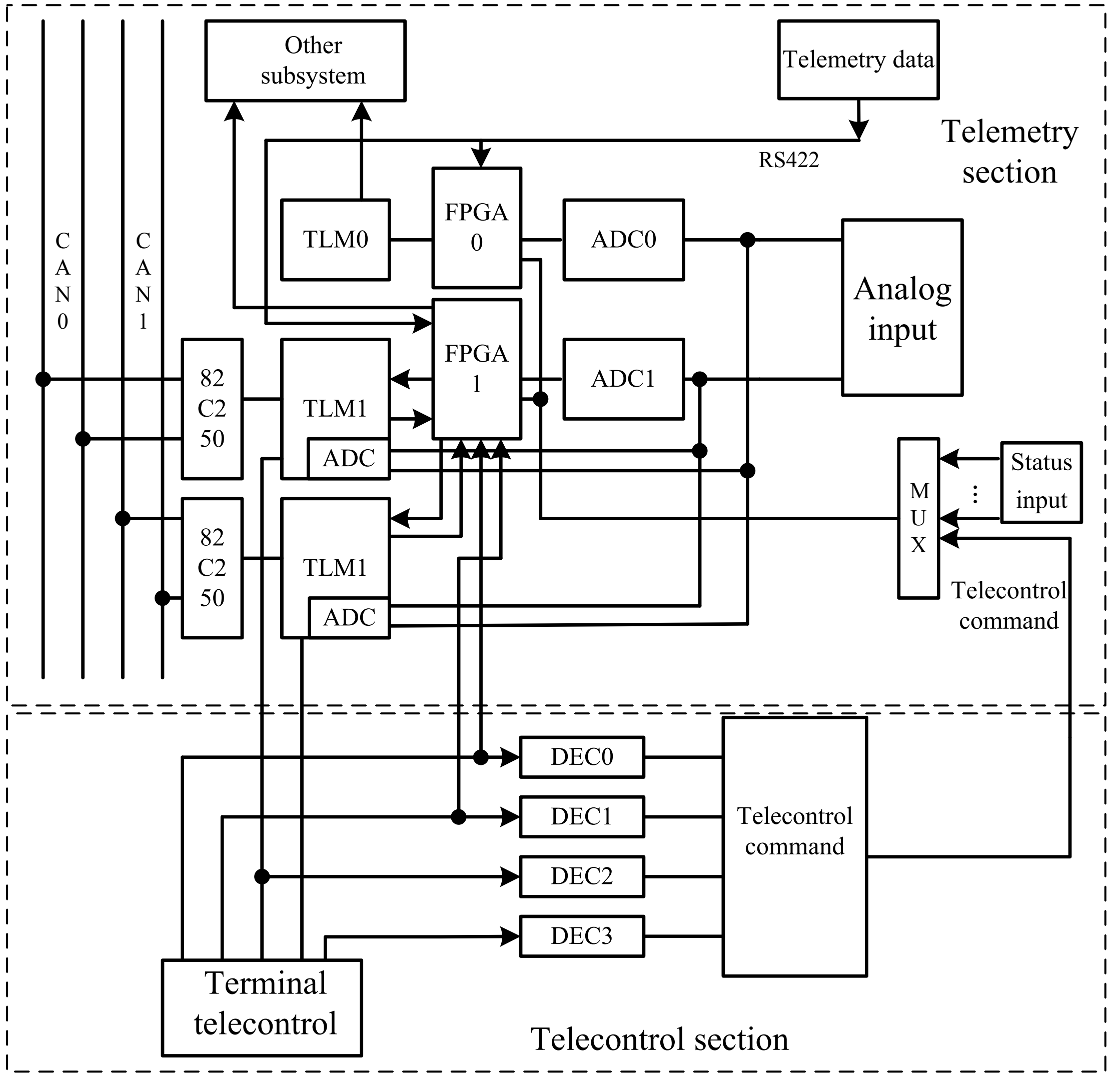

Fig. 1. block diagram of TTC

the telecommand subsystem commands. The C515C is an enhanced, upgraded version of the SAB 80C515A 8-bit microcontroller which additionally provides a full CAN interface, a SPI compatible synchronous serial interface, extended power save provisions, additional on-chip RAM, 64K byte of on-chip program memory, two new external interrupts and RFI related improvements. With a maximum external clock rate of 10 MHz it achieves a 600 ns instruction cycle time (1ms at 6 MHz) [4]. AD converters used to transform analog signals into digital signals which could be received by the FPGA, and the C515C microprocessor can read the data from the FPGA and frame the telemetry data, and then send the data frame. If the AD converter does not work, the other AD converter in the C515C microprocessor will be used. This switch could be implemented by a telecommand frame from the ground station.

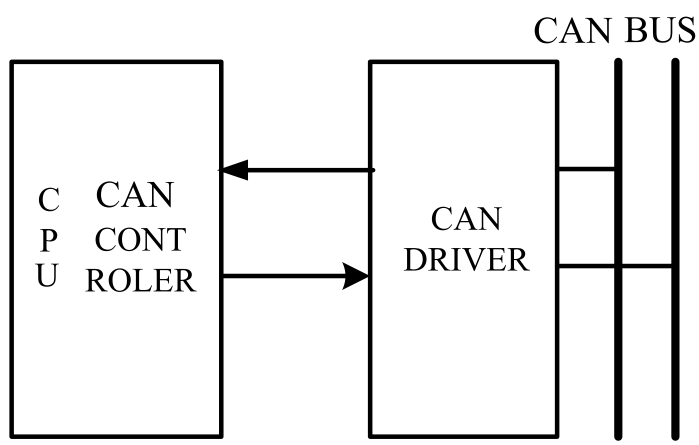

Fig. 2. non-redundant CAN bus

III. Hardware Design of Redundant CAN Bus

A CAN node is generally consists of CAN-bus controller, CAN-bus driver, microprocessor [5]. A traditionally non-redundant CAN bus architecture is shown in Fig.2. Currently, redundant CAN-bus patterns can be summarized as the following forms [6]: 1) backup in CAN-bus driver 2) backup in CAN-bus controller 3) system-level backup. It is easy to see

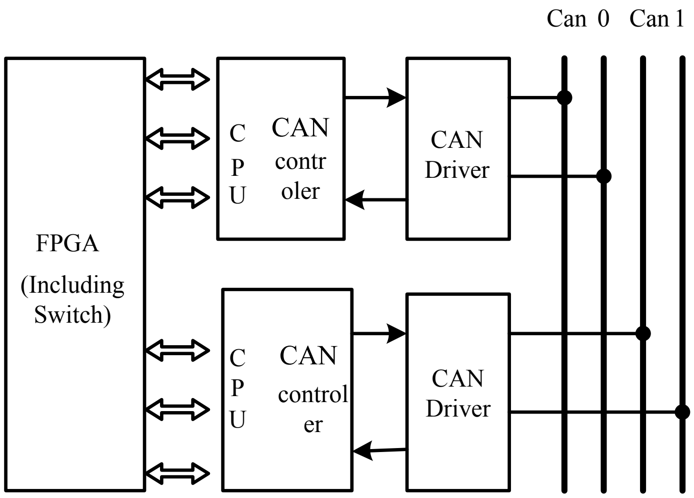

Fig. 3. redundant CAN bus

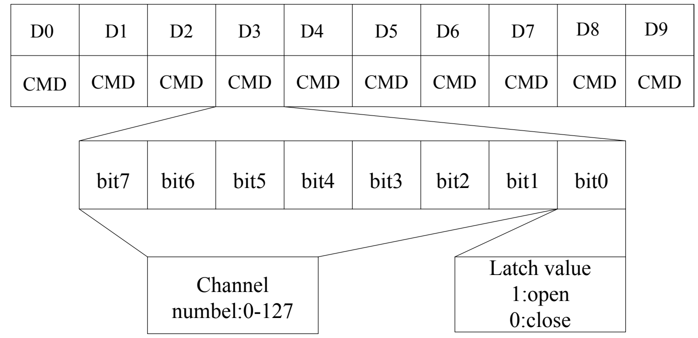

Fig. 4. the structure of telecommand command data

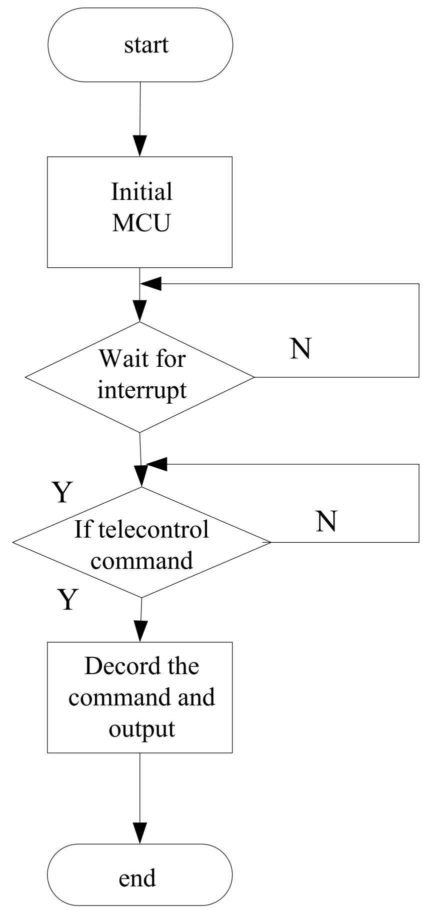

Fig. 5. the flow of processing telecommand command

that system-level backup may have the highest reliability level. In our research we take system-level backup in the design of the CAN-bus architecture, as shown in Fig.3. In fig. 3, a C515C microprocessor is selected for data processing, in which a CAN-bus controller is embedded. On the selection of backup strategy, there are two manners for selection: cold backup and hot backup [7]. The so-called cold backup denotes that the backup system will not be powered up until the main system can not operate properly. The drawback of this manner is that the real-time performance is not good enough for the application in TTC subsystems. The hot-backup manner means that both the two systems work simultaneously, but only one output is selected to sent to the receiver. Once the selected output is detected to be improper by the ground state, a telecommand frame will be sent to the TTC subsystem to switch to the other system output.

IV. Software Design of the Redundant CAN Bus

A. Implementation of the CAN bus switching

In order to switch the CAN bus system, sending telecommand command frames could quickly switch. Telecommand command control the output status (0 or 1)of telecommand access of TTC, to open or close a switch in a subsystem.

The telecommand frame which the telecommand microprocessor receive consists of label and valid data[8]. In the protocol, we add the marker in front of valid data. For example, in the label, the leading word is used for synchronizing serial interface; pattern word is used to characterize the data frame content, etc. When in telecommand frame decoding stage, first of all, distinguishing telecommand frame based on these markers, and then examining if the telecommand frame contains 10 repetition bytes of valid instruction. If not, discarding the frame, waiting for retransmission. This action will ensure the reliability of telecommand data[9].

Protocol provides for telecommand frame contains 10 repetition of the instruction bytes, each byte contains a number of channels to control and sets the control value information. Definition of each byte show in Fig.4. Bit7 - Bit1 said channel number: 0 to 127. Bit0 said the latch data values (1 or 0) corresponding to the switch to open or close. In order to switch the CAN bus, the telecommand frame should contain the right label which could represent that it is the telecommand frame and the valid instruction byte could set the right channel number. The flow of processing of the telecommand microprocessor as follows(Fig.5):

B. Can bus protocol design

1) The Can bus protocol: Follow CAN 2.0A specification of Bosch, we use the data frame structure shown in Fig.6, and use the 11bit identifier [10](address of can node). Frame start bit,

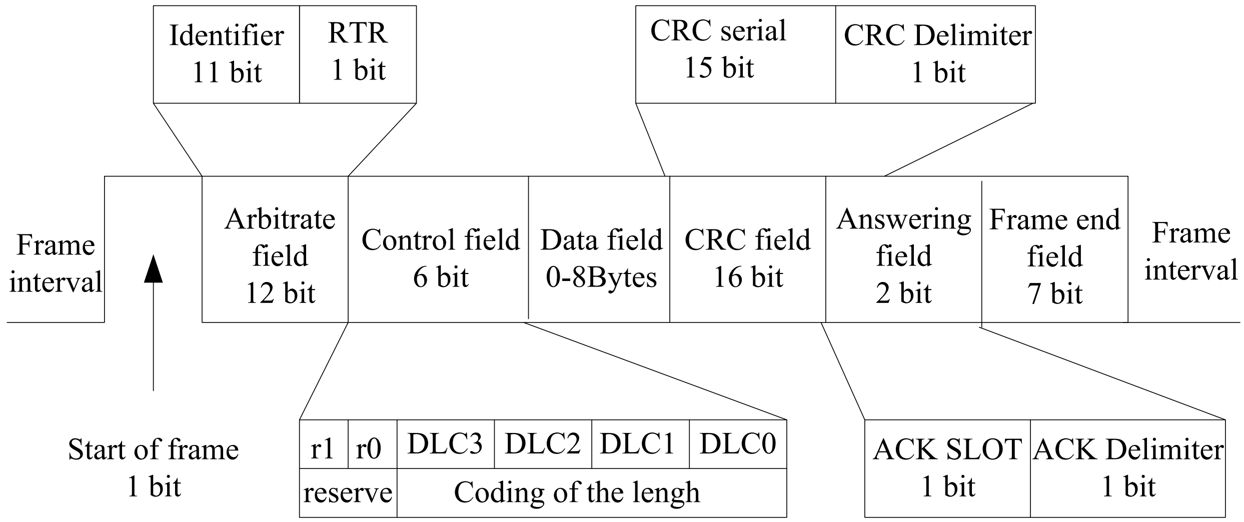

Fig. 6. The structure of CAN data frame

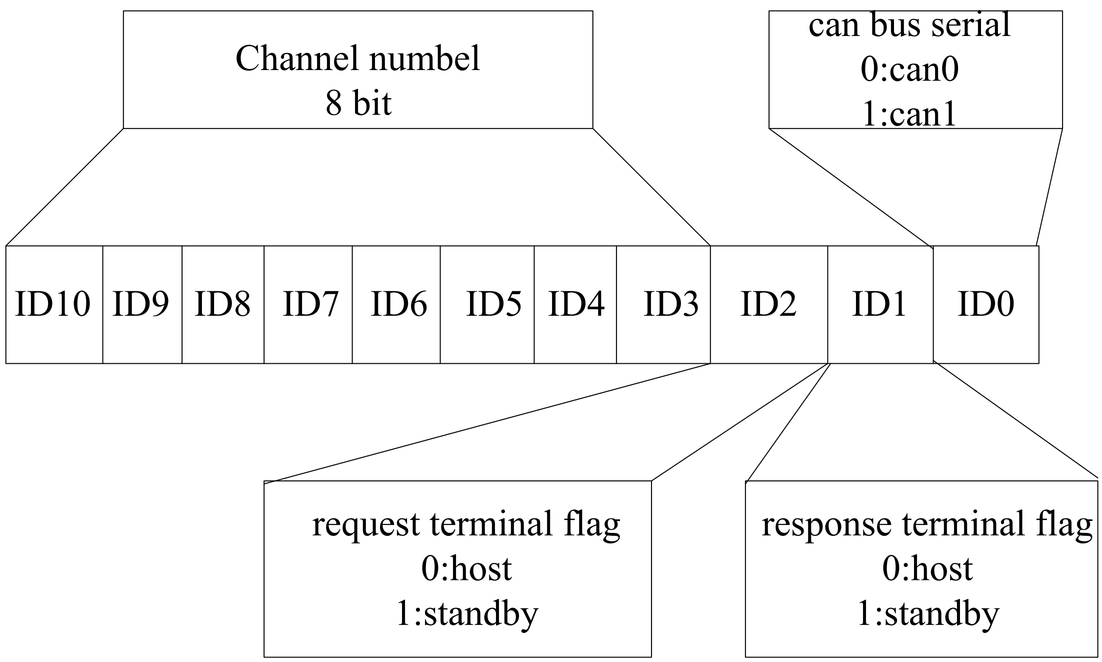

Fig. 7. The define of can node address

a reserved bit in control field, CRC field, answering field and frame end bit directly is generated by the CAN controller. The information including identifiers (11bit), remote transmission request bit (RTR, 1bit), the control data field length encoding (DLC, 4bit) and 0 to 8 bytes of data fields [11] need to be written into CAN controller by application software.

The 11bit identifier in this paper, also known as the CAN node address, the protocol provide that dividing the CAN node address of 11 bits into the channel number, the flag of host or standby in the request terminal,the flag of host or standby in response terminal and the serial number of CAN bus, For the TTC , the flag of host or standby is always 0.As shown in Fig.7. CAN 2.0A specification defines a high 7 ($ID10 - ID4$) can not be all 1.

CAN bus communication protocol on the satellite is based on CAN bus 2.0A protocol, but using only the data packets. Using a custom communication node address allocation and packet structure, shown in Fig.8. As CAN commands have many species,using a command word to indicate the meaning of the accepted command. For different command word, address word has different meanings. Specific communication node address allocation is not described in detail here.

2) Main functions design of the redundant CAN bus: TTC in Micro-satellite need to achieve many tasks, due to limited space in this article, can not do everything. Here only with CAN bus related applications are introduced.

CAN bus complete the following main functions: a) telemetry function to achieve: Various subsystems determine their own telemetry logic and complete telemetry process. Telemetry

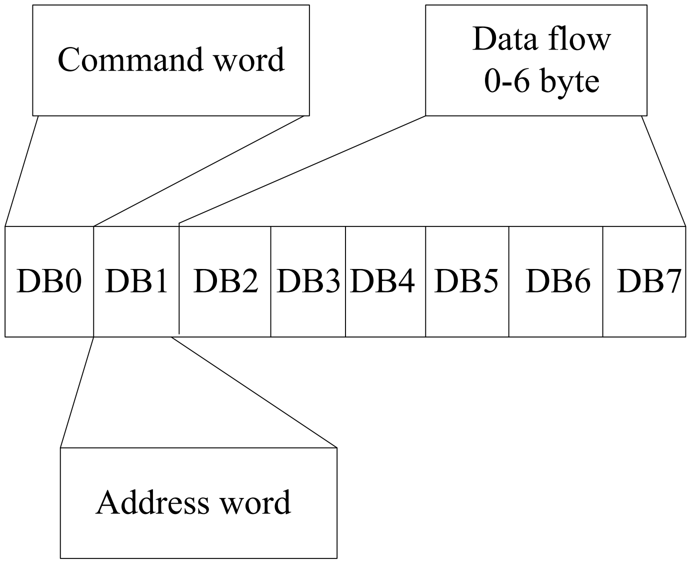

Fig. 8. The structure of CAN data packet

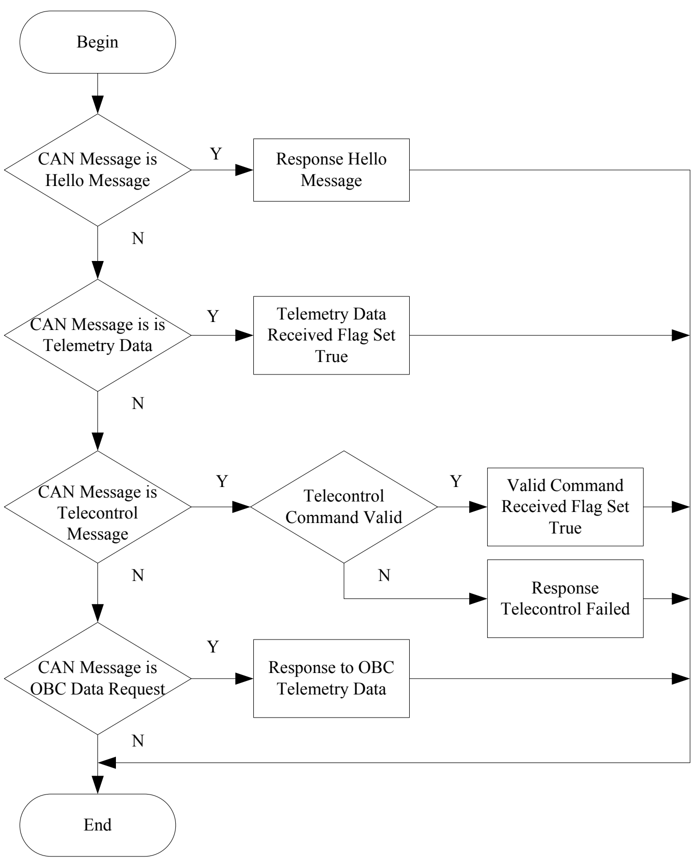

Fig. 9. The flow of interrupt processing

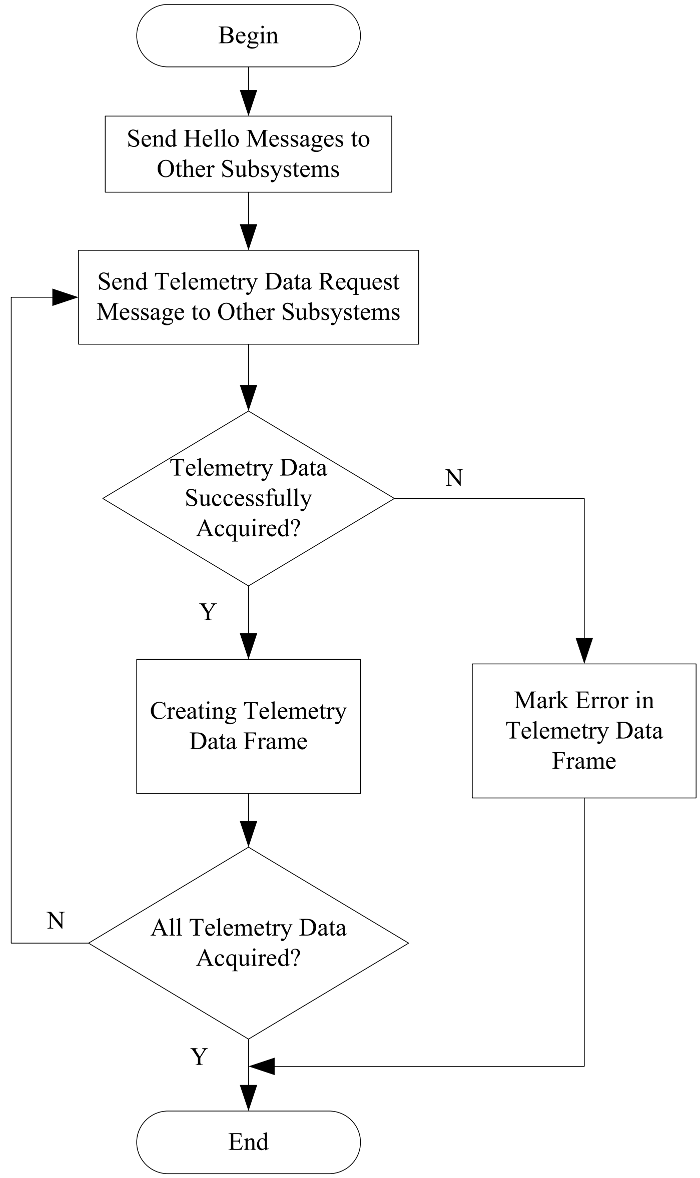

Fig. 10. The flow of CAN telemetry processing

data stored in the buffer. CAN master node (TTC)send the telemetry require command and wait for the response of other node,if TTC receive the response from other node and then obtain telemetry data from the node and issue the telemetry data to the ground station. b) telecommand function to achieve: On board computer subsystem(OBC) sends telecommand command frame through CAN bus, the C515C MCU in the TTC subsystem receives it and transforms the command frame into the frame that the telecommand MCU could receives. Finally, the telecommand MCU decode and output it.

The software is as follows: C515C microprocessor can receive data frame and generate interrupt, according to the different data frame adopt different treatment in the interrupt. As shown in Fig.9. In the main program implement telecommand function and telemetry function, the process shown in Fig.10 and Fig.11.

V. Subsystem reliability Analysis

The evaluation of CAN bus system performance, mainly measure the reliability of the system, reliability is the probability the system can still work under certain conditions in given time interval[12]. In this paper, FPGA, C515C MCU(including CAN controller), PCA82C250(CAN driver) are the main components which affect the reliability of CAN-bus

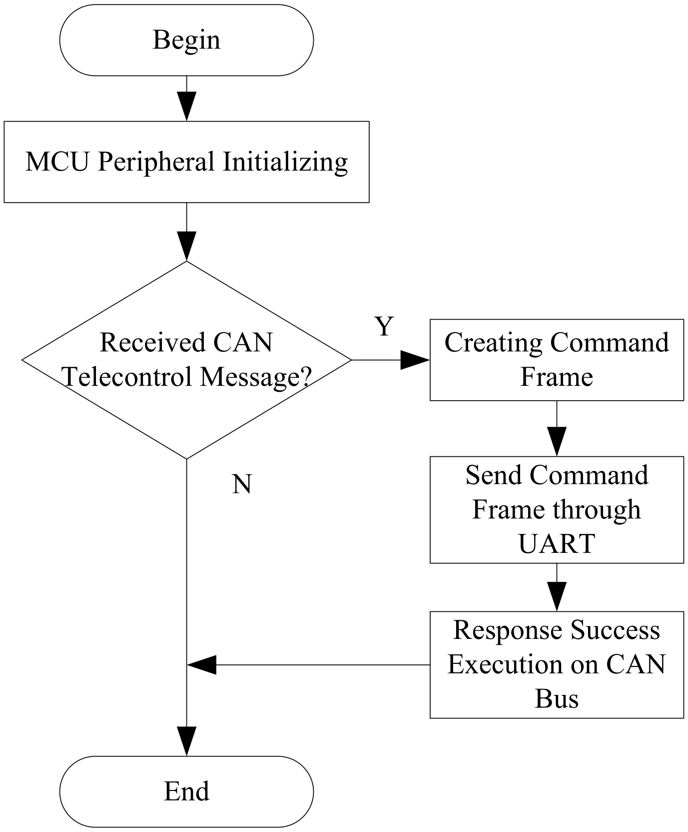

Fig. 11. The flow of CAN telecommand processing

system.The FPGA in this paper which is produced by ACTEL company is antifuse.In the past decade, Actel antifuse FPGA has been successfully applied to more than 300 space program, these applications prove the reliability of Actel's FPGA is beyond doubt.We just put C515C MCU and PCA82C50 into account[13]. Assuming N samples take experiment through time t under the same conditions, the number of samples still work is S(t), the number of failures is the F(t), the component reliability is:

$$R(t) = \frac{S(t)}{N} = \frac{N - F(t)}{N} = 1 - \frac{F(t)}{N} \tag{1}$$

$$\frac{dR(t)}{dt} = -\frac{1}{N}\frac{dF(t)}{dt} \tag{2}$$

Define the failure rate Z(t) is the number of failures per unit time with the ratio of the number of normal work :

$$Z(t) = \frac{1}{S(t)}\frac{dF(t)}{dt} \tag{3}$$

Failure rate of components set constant P, from (3) can be obtained:

$$\frac{dR(t)}{dt} = -P\frac{S(t)}{N} = -PR(t) \tag{4}$$

Of type (4) both sides of the integral transformation can be obtained:

$$R(t) = e^{-Pt} \tag{5}$$

Set CPU failure rate of P_1, CAN bus driver PCA82C250 failure rate of P_2, CAN bus controller failure rate of P_3, the establishment of non-redundant CAN bus system reliability model.The model shown in Fig.2. Non-redundant CAN bus system model is the series system reliability model, available non-redundant CAN bus system reliability is:

$$R_{non}(t) = e^{-(P_1+P_2+P_3)t} \tag{6}$$

The establishment of system-level reliability of redundant CAN bus system model shown in Fig.3. CAN bus system model is redundant parallel system reliability model, available redundant CAN bus system reliability is:

$$R_{redu}(t) = 2e^{-(P_1+P_2+P_3)t} - e^{-2(P_1+P_2+P_3)t} \tag{7}$$

It is obvious that redundant R(t) minus the non-redundant R(t) is greater than 0, redundant CAN bus system reliability is greater than the non-redundant CAN bus system, indicating the reliability enhancements. Of course, in practice the reliability of measurement is more complicated, but still be seen in parallel model the reliability of system is increased.

Traditional satellite systems using space-level devices[14], the main device failure rate could reach roughly 10^{-7}, under the harsh operating environment of micro-satellites,the P could be 10^{-6}. According to the tests of the device available in a micro-satellite system, the failure rate generally reached $6 * 10^{-6}$, therefore, we can obtain traditional satellite and micro-satellite CAN bus system reliability in different years. After

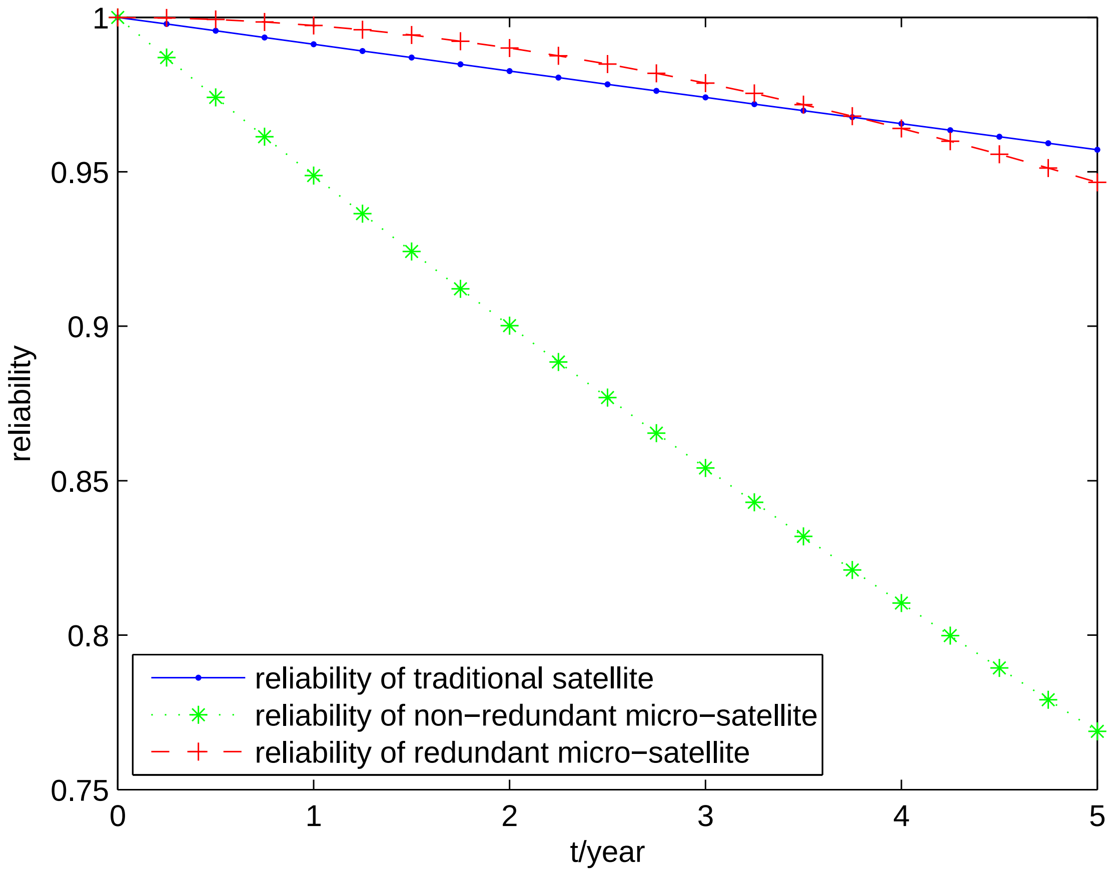

Fig. 12. the reliability of different systems in different years

TABLE I
THE RELIABILITY OF DIFFERENT SYSTEMS

time(year)	traditional satellite(non-redundant)	micro-satellite(non-redundant)	micro-satellite(redundant)
0.5	0.9957	0.9744	0.9993
1	0.9913	0.9488	0.9974
2	0.9826	0.9002	0.9900
3	0.9741	0.8541	0.9787
4	0.9656	0.8104	0.9640
5	0.9571	0.7689	0.9466

the results can be calculated as shown in Table I. In order to facilitate performance analysis, drawing as shown in Fig.12. Figure analysis can be drawn within five years, micro-satellites redundant bus system can achieve a reliability of 0.99, which meets the micro-satellite systems reliability requirement.

VI. Conclusions

In this paper, a redundant design scheme for the CAN-Bus of the telemetry and telecommand (TTC) subsystem of a micro satellite is introduced, and the reliability of the subsystem with the proposed design scheme is also analyzed. It is shown with analytical results that with redundant design scheme the reliability of a CAN Bus could be effectively improved, and the redundant CAN bus based on low-level VLSI chips could be applied to the telemetry and telecommand subsystem(TTC) of a micro-satellite.However, we can consider from the software design to improve overall system reliability. For example, the redundancy approach can also be applied to software design[15].

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