

Design of Redundant CAN Bus for Telemetry and Telecommand Subsystem of a Micro-Satellite

Jie Liu
Hebei University
School of EIE
BaoDing City, 071002
CHINA
liujieaaa@tom.com

Hao Zhang
Tsinghua University
School of Aerospace
Beijing, 100084
CHINA

Wei Zheng
Hebei University
School of EIE
BaoDing City, 071002
CHINA

Liuguo Yin
Tsinghua University
School of Aerospace
Beijing, 100084
CHINA

Abstract: 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 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.

Key-Words: micro satellite, telemetry and telecommand subsystem, CAN bus, redundant design

1 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 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 TTC subsystem of a micro-satellite.

The rest of this paper is organized as follows. In Section 2, the TTC subsystem is introduced. Then in section 3, a redundant hardware design for the CAN bus of the TTC subsystem is proposed. In Section 4, the software implementation issues of the redundant CAN bus is described in detail. After that, the reliability of the redundant CAN Bus is analyzed in Section 5. Finally, conclusions are draw in Section 6.

2 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 87C51. 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 oth-

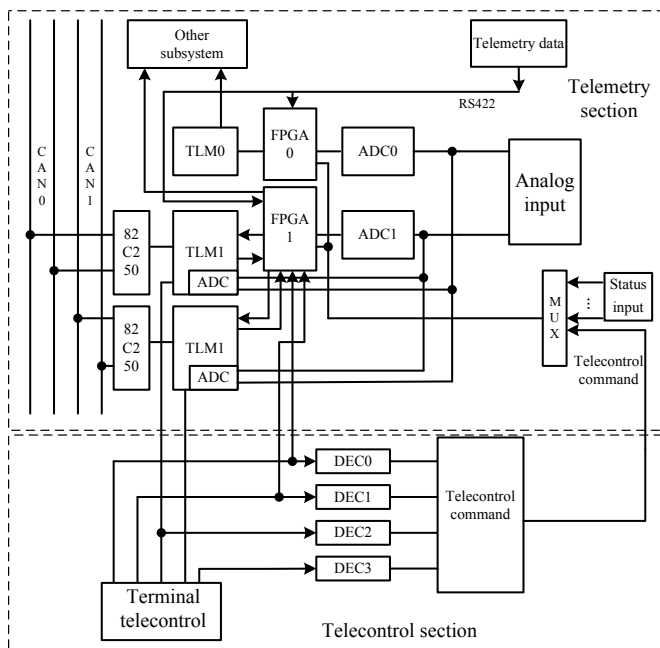


Figure 1: block diagram of TTC

er 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 Infineon 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 the telecommand subsystem commands. 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.

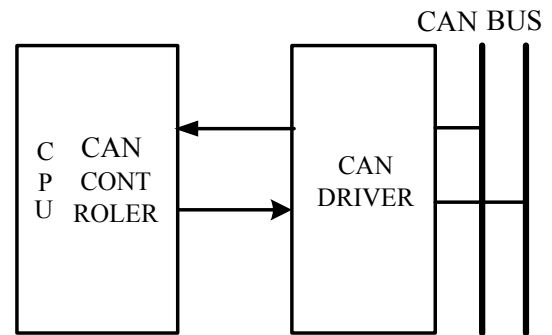


Figure 2: non-redundant CAN bus

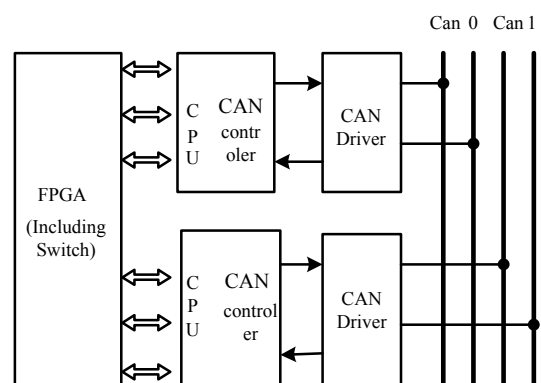


Figure 3: redundant CAN bus

3 Hardware Design of Redundant CAN Bus

A CAN node is generally consists of CAN-bus controller, CAN-bus driver, microprocessor [3]. A traditionally non-redundant CAN bus architecture is shown in Fig.2. Currently, redundant CAN-bus patterns can be summarized as the following forms [4]: 1) backup in CAN-bus driver 2) backup in CAN-bus controller 3) system-level backup. It is easy to see 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 [5]. 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 out-

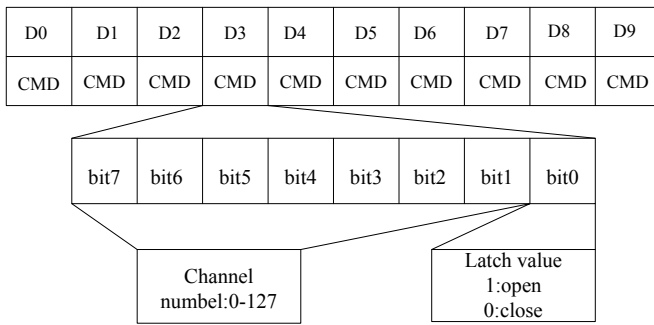


Figure 4: the structure of telecommand command data

put 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.

4 Software Design of the Redundant CAN Bus

4.1 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. 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.

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):

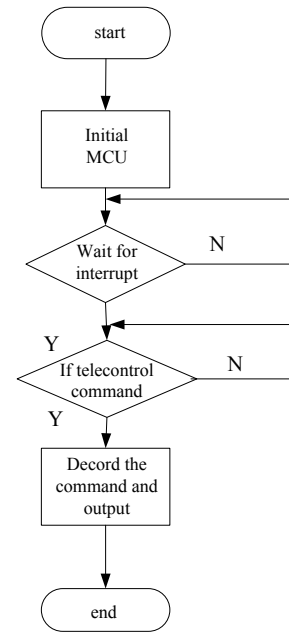


Figure 5: the flow of processing telecommand command

4.2 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 communication protocol on the satellite is based on CAN 2.0A specification of Bosch [6].

CAN bus complete the following main functions: a) telemetry function to achieve: Various subsystems determine their own telemetry logic and complete telemetry process. Telemetry 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.6. In the main program implement telecommand function

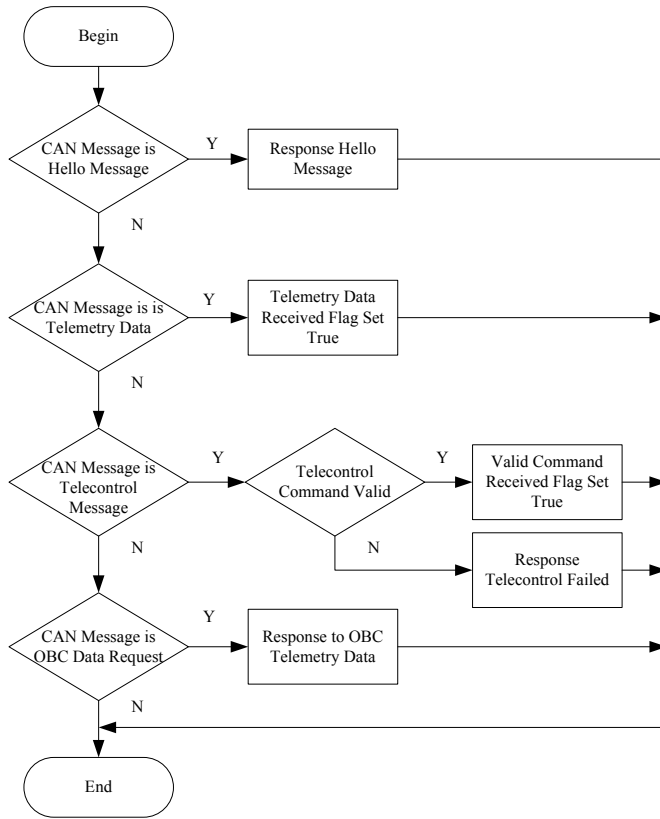


Figure 6: The flow of interrupt processing

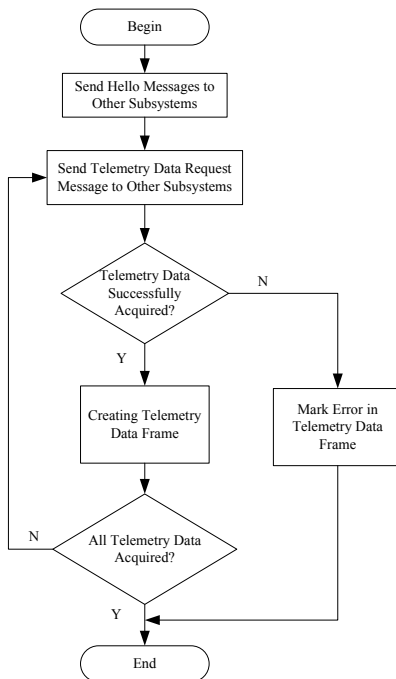


Figure 7: The flow of CAN telemetry processing

and telemetry function, the process shown in Fig.7 and Fig.8.

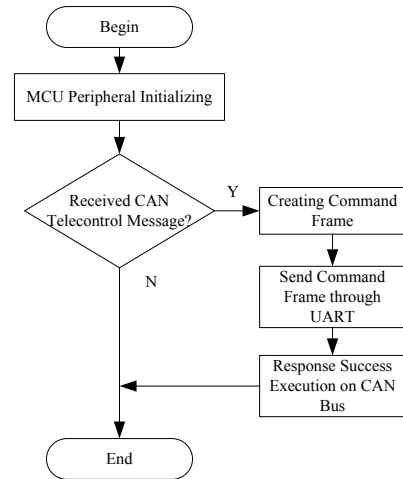


Figure 8: The flow of CAN telecommand processing

5 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[8]. 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:

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

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

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

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

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

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

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

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

Set CPU failure rate of P_1 , CAN bus driver P-CA82C250 failure rate of P_2 , CAN bus control failure rate of P_3 , the establishment of non-redundant

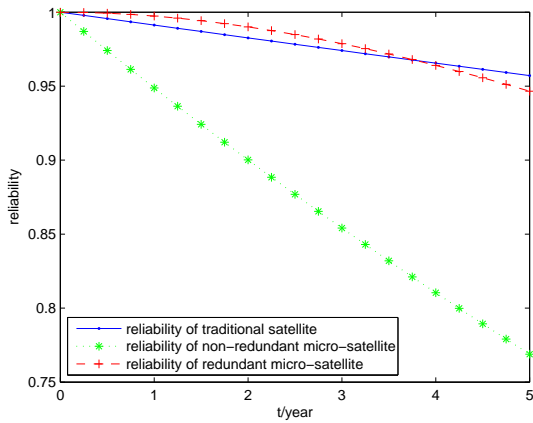


Figure 9: the reliability of different systems in different years

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:

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

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:

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

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[8], 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 the results can be calculated as shown in Table I. Micro-satellites redundant bus system can achieve a reliability of 0.99 within five years, which meets the micro-satellite systems reliability requirement.

6 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.

Acknowledgements: This work was supported in part by National Natural Science Foundation of China (No. 61021001) and Program for New Century Excellent Talents in University (NCET).

References:

- [1] ZHAN Ya-feng, MA Zheng-xin, CAO Zhi-gang, "Technology of Morden Micro Satellite and Its Development Direction[J]." *ACTA ELECTROICA SINICA*, vol.28 NO.7, pp.102-106, 2000.
- [2] WANG Xi-ji, LI Da-yao, "Design Of Satellite." *Shanghai Science Technology Publishing Company*, 1997.
- [3] Rao Yun-tao, Zhou Ji-jun, Wang Jin-hong, Zheng Yong, "Theory of the can field bus and its application technology." *Beihang University Publishing Company*, 2003
- [4] Yu Chun-lai, Xu Hua-long, Liu Gen-wang, Hou Xiao-lin, "Research of the Redundant Methods of CAN.[J]" *The Technology Of Metry And Control*, 200322(10), pp.28-30.
- [5] Zhang Xin-fu, "Investigation on Reliability of CAN and its application of light control system.[D]" *Haerbing Engineering University*, 2009.
- [6] Bosch Robert. CAN specification, Version 2.0[Z]. 1991.
- [7] Wang li-ying, "Research on Redundant CAN Bus in Marine engine Control System[D]." *Haerbing Engineering University*
- [8] Jiang Lian-xiang, Yang Gen-qing, Li Hua-wang, Hu Wei-shen, Xu Pei-pei, "Reliability research and design of on-board computers of micro-satellite[J]" *System Engineering And Electronics*, 2009, 31(1):238-240.