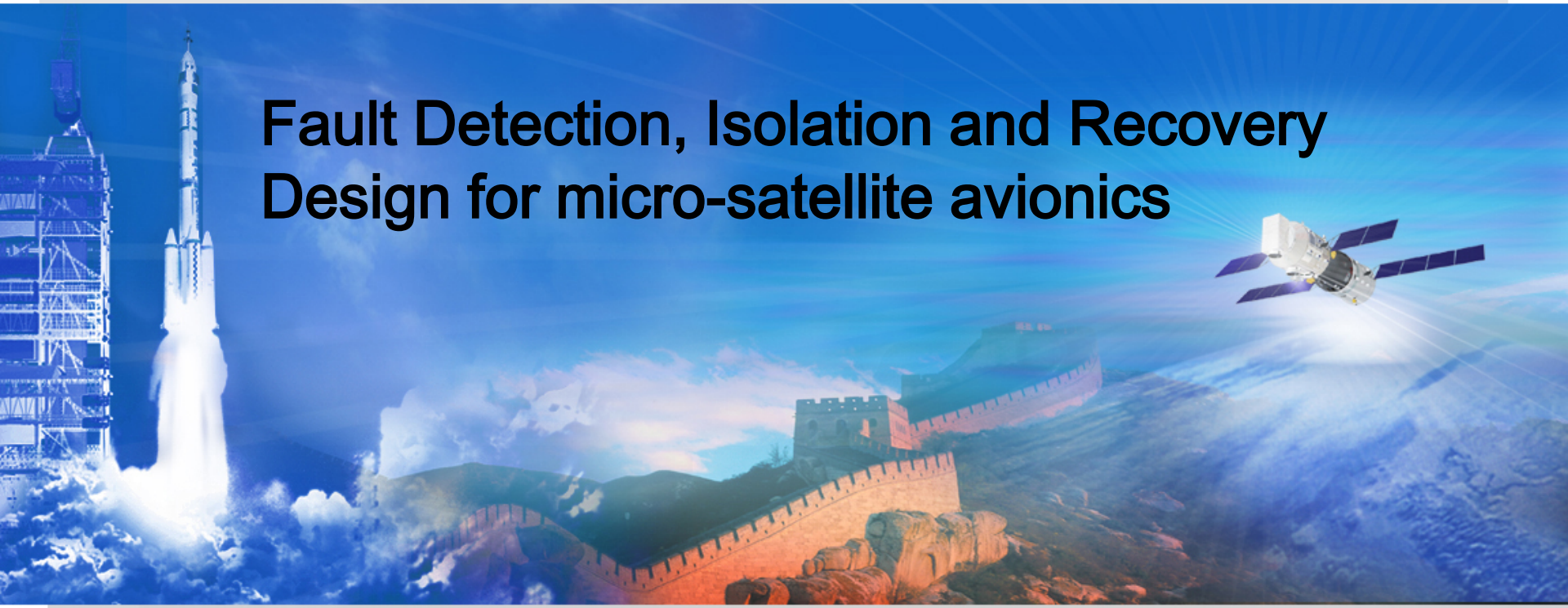


Fault Detection, Isolation and Recovery Design for micro-satellite avionics

The 9th ESA Workshop on Avionics, Data, Control and Software System(ADCSS),
October 20~22, 2015,ESA/ESTEC,Noordwijk, Netherlands

Jiang Lianxiang **Associate Head of the Department of microsatellite electronic Engineering,**
Shandong Aerospace Electronics Technology Institute, CAST, China
jianglianxiangcn@163.com

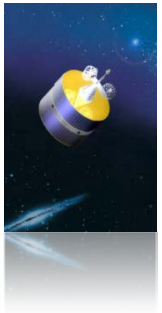
Agenda

- Introduction
- Background
- FDIR design for microsatellites
- Some ideas for further Research
- Conclusion

Organization

CAST
Key Member
of CASC

CALT



SAST

CASC

CASC

AASPT
AALPT
SCAIC
CAAET
…
…

CGWIC	Commercial Trading Company
ALIT	Defense Trading Company
CSCC	China's Sole Satellite Operator

CAST industrial footprint

Beijing
16036 people

Inner Mongolia
583peeople

Tianjin
1257 people

Lan Zhou 1809 people

Yantai
1196 people

CAST Xi' an
2672 people

Shen Zhen
133 people

15 subsidiaries in 7 cities
3 Representative Offices Abroad

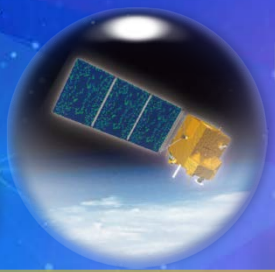
Core Business

CAST

Space

Spin-off

Telecommunications



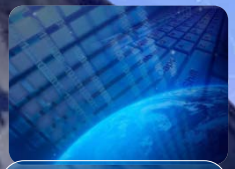
Remote Sensing

Navigation

Science Exploration

Manned Spaceflight

Satellites Application



Elelctronic Information Systems

Civilian Engineering Systems and Equipment

Space Segments

➢ **We design, build and deliver end-to-end space systems:**

◆**168 spacecrafts delivered**

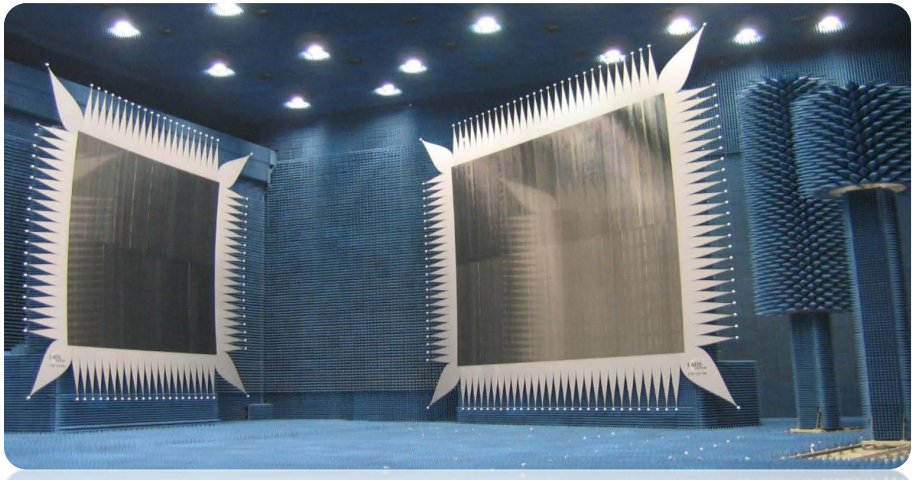
◆**88 spacecrafts in orbit**

Providing worldwide customers with full range of space to ground solutions

Telecommunications

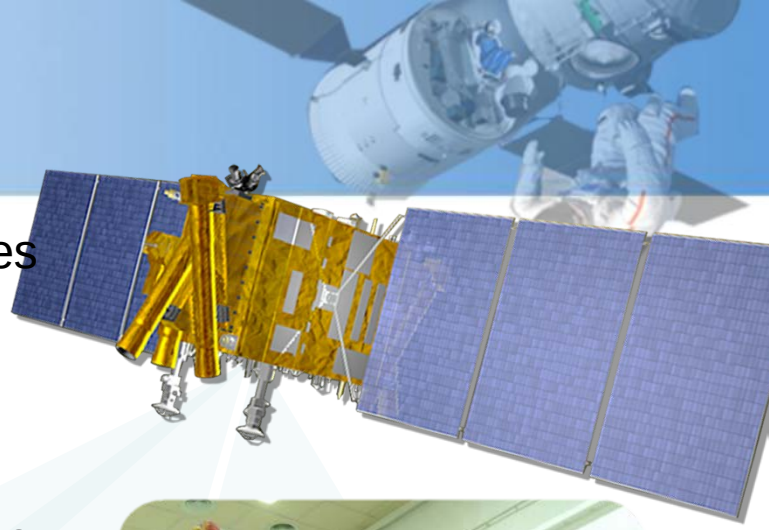
Prime contractor for over 30 telecommunications satellites

- **Turnkey Solutions**
  - **Consultation**
  - **Orbit Frequency Coordination Support**
  - **System Design & Integration**
  - **Satellite Manufacture**
  - **Launch and In-orbit Operation Support**
  - **KHTT**
- **Mature DFH platform series for telecommunication, broadcast and customized missions**
- **Reliable and customized payloads**



Remote Sensing

Core Player for over 80 Remote Sensing Satellites



Space to Ground turnkey solutions

Versatile LEO/SSO/GEO satellites and constellations

High performance and innovative bus & payloads

Reliable ground application system

Navigation

Prime constructor of China's Beidou Navigation Satellite System

- **The 1st generation: 4 satellites**
- **The 2nd generation:**

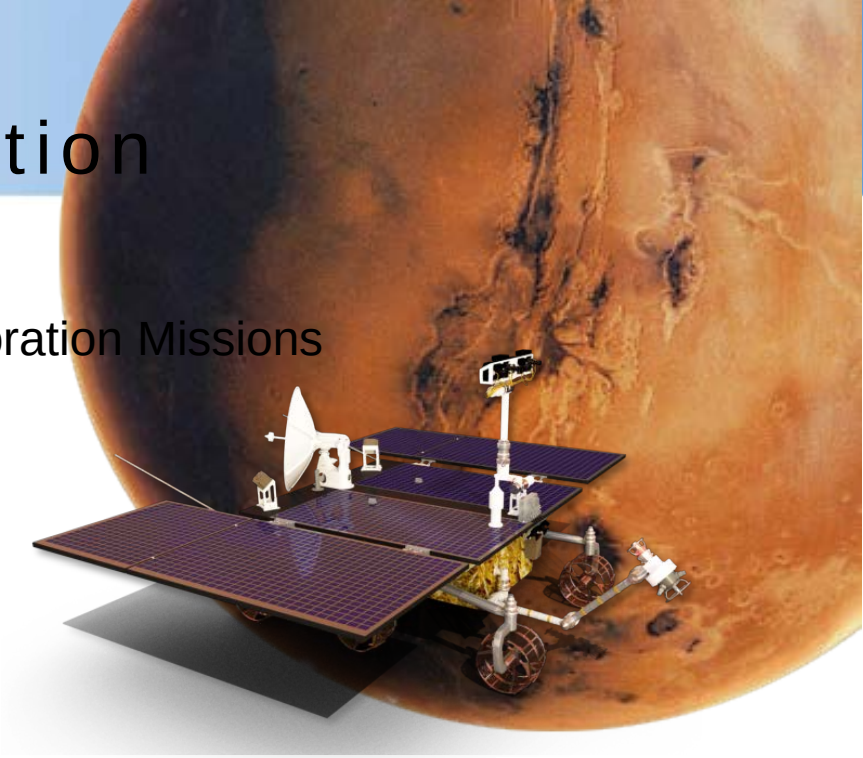
  16 satellites offers regional services for Asia-Pacific area by 2012.

  35 satellites will offer global coverage by 2020.

Beidou navigation satellite applications

- **Intelligent transportation**
- **Disaster Relief**
- **Emergency Command & Control**
- **National security**
- **Precise Timing**

Space Science Exploration



A prime role in China's Space Science Exploration Missions by delivering over 15 satellites

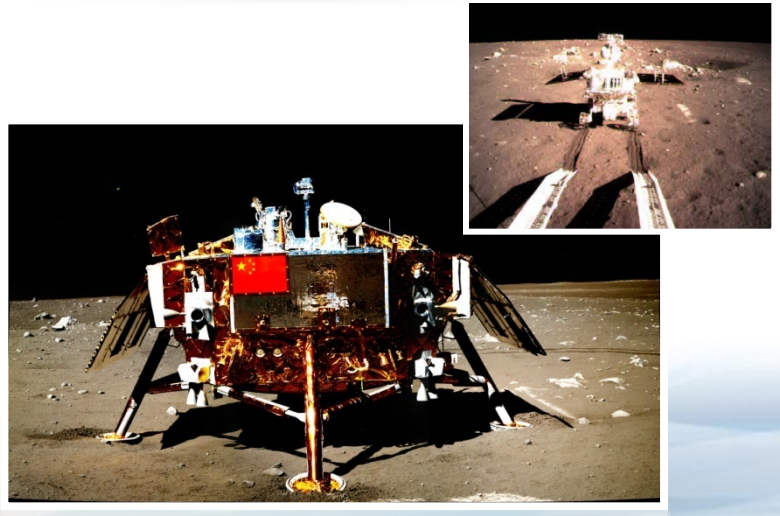
Prime contractor of China's Lunar & Mars Exploration Program

CAST carries out lunar exploration by three steps.

Orbiting
Orbiting around the moon

Landing
Soft-landing on the moon surface

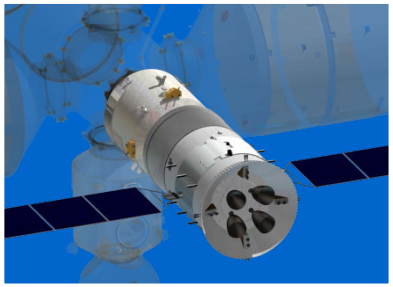
Returning
Sample collection of moon surface and returning to the Earth



Human Space Flight

Founder of China's Manned Space Program
Successfully launched 10 Shenzhou spaceships and 1 Space Lab, will build China's first space station

China's Manned Space Program is implemented by three steps.



Manned Space Flight

STEP 1

STEP 2

EVA, Space lab rendezvous & docking

STEP 3

70-ton Space station

Spacecraft Subsystems and Equipment

Reliable supplier of spacecraft subsystems and equipment
100% subsystem and more than 90% equipments design and manufactured by CAST

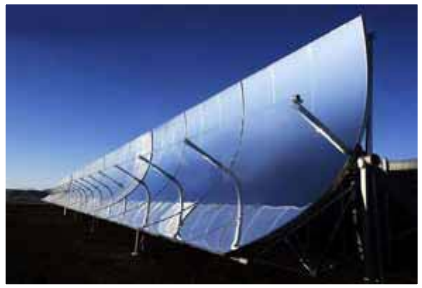
- **High performance orbit control and propulsion subsystems**
- **More than 90% self-manufactured Optical Camera**
- **All types of Antennas**
- **Reliable Self-developed Robotic Arm**

Space Technology Applications

- **Satellite Applications**
- **Electronic Information Systems and Products**
- **Civilian Engineering Systems and Equipment**

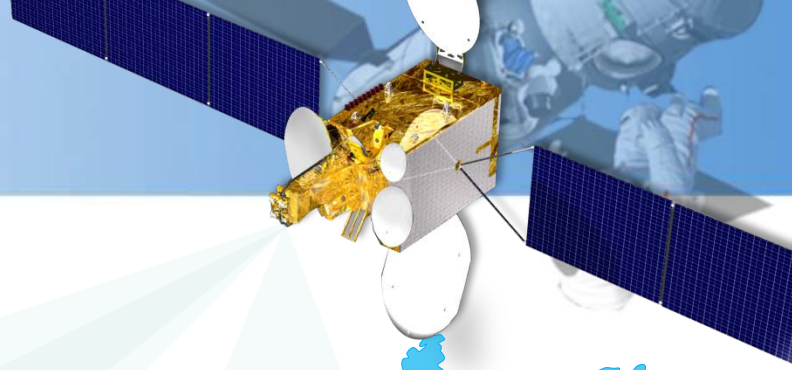
Satellite Applications

Electronic Information Systems and Products



Civilian Engineering Systems and Equipment

Global Partners of CAST



CNES
ISS
DLR
ESA
Eutelsat
SSC

SES
TAS
ADS
Turksat

MDA
COM DEV
ITL

SUPARCO
Arabsat
NTS
BASARNAS
LAPAN
BAKAMLA
GISTDA
MOSTI
KACST
Supremesat

ASAL
NASRDA
NARSS
Nigcomsat

ABE
ABAE
INPE
CONAE

Introduction-what we do

Shandong Aerospace Electronics Technology Institute is one of 15 subsidiaries of CAST. It deal with the space data system application , integrated avionics, computer application、TM&TC、Power control and distribution is several key filed.

Part of products:

Integrated RTU

Transceiver

TMR OBC

Power Control Unit

current limit protector

Pneumatic discharge pressure valve

Introduction

Yantai city lies in Shandong province of China, it's a seaside city. It is famous for its sea food, wine(Zhangyu) and fruits(apple, pear, cherry, etal.)

Agenda

- Introduction
- Background
- FDIR design for microsatellites
- Some ideas for further Research
- Conclusion

Background

- microsatellite widely used in communication, remote sensing, reconnaissance, mobile internet, etc. more and more microsatellites are sending into space in the recent years.
- quicker, better, cheaper guidelines for microsatellites
- more autonomy, operate with some intelligence, operation state self-awareness ;
- flying in formation or constellation, on-board task scheduling, becoming more reliable and fault tolerant.

FDIR technology could provide fault(failure) detection, isolation and recovery mechanism in time. It makes satellites know their health state, so the satellites need less ground station's intervention and control and lower the operation cost. FDIR could provides the quick testability, which accelerates the on-board test.

Here, I would like to share some experience with the FDIR design and development for avionics of microsatellites.

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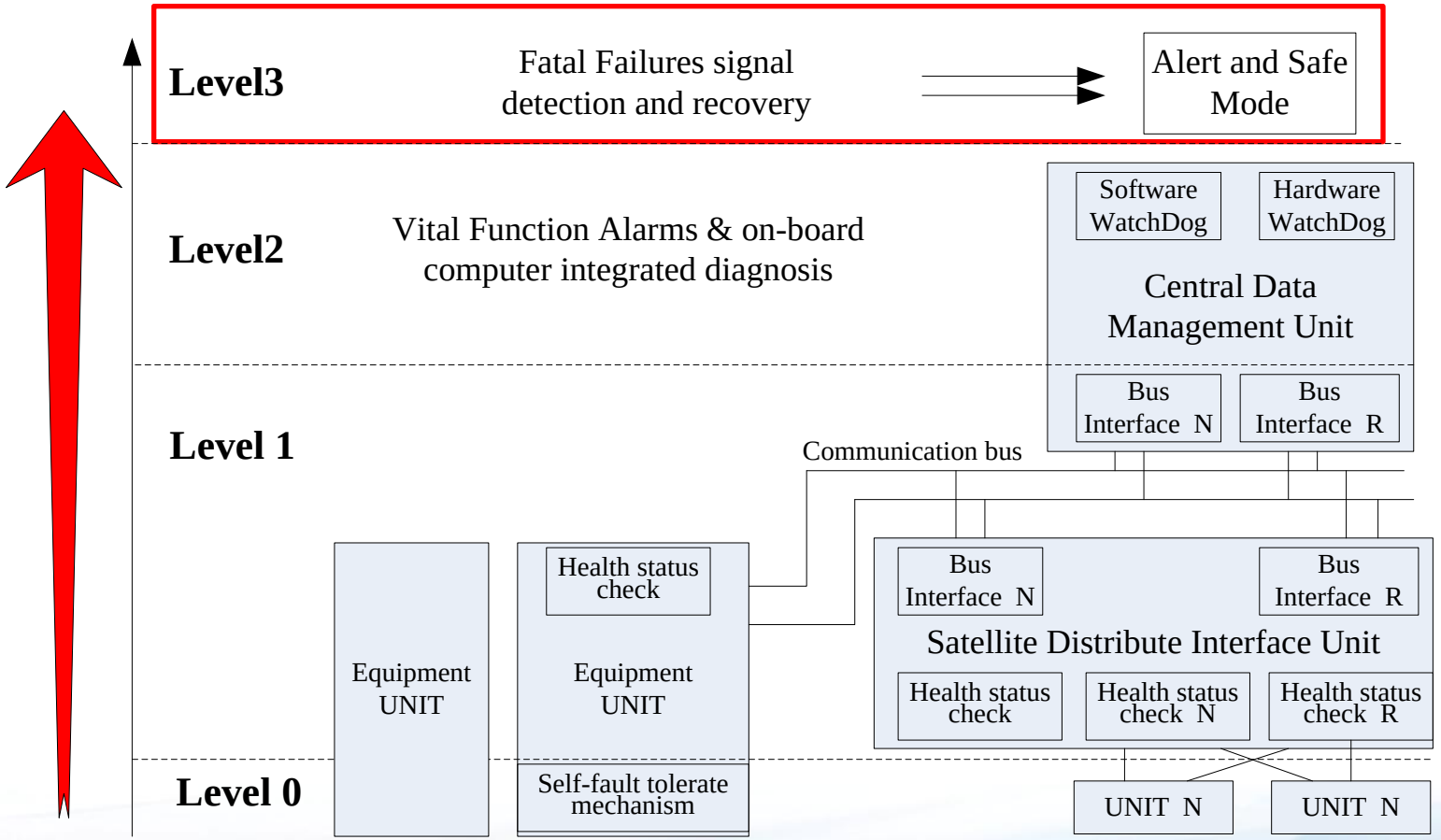
FDIR design for microsatellites

4 levels kinds of fault are defined and divided as follows:

- **Level 0: model level fault, such as single event upset of SRAM, these faults could be detected by the BIT design and recovered by inner redundancy design.**
- **Level 1: equipments' level fault; it could be detected by the BIT design of equipments;**
- **Level 2: system level fault, including CMU hardware or software fault and subsystem's primary parameters abnormal;**
- **Level 3:system safety level fault, such as primary power bus abnormal, which will affect the satellites' safety, these faults will be detected by direct alert signals and generate reconfigurable instructions directly by the FDIR hardware model.**

FDIR design for microsatellites

FDIR design architecture



BIT, Fault-redundant design , watch dog etal is widely used in the FDIR design for Level 0 ~ Level 2.

FDIR design for microsatellites

FDIR Level 3 design

The functions of the FDIR module is as follows:

(1)Detection of the system alarm signal, including discrete signal (such as OBC or RTU's watch dog signal) and analog signal such as primary power bus, payload current etal.

(2)Generate instructions for fault recovery when enabled, the instruction is reconfigurable.

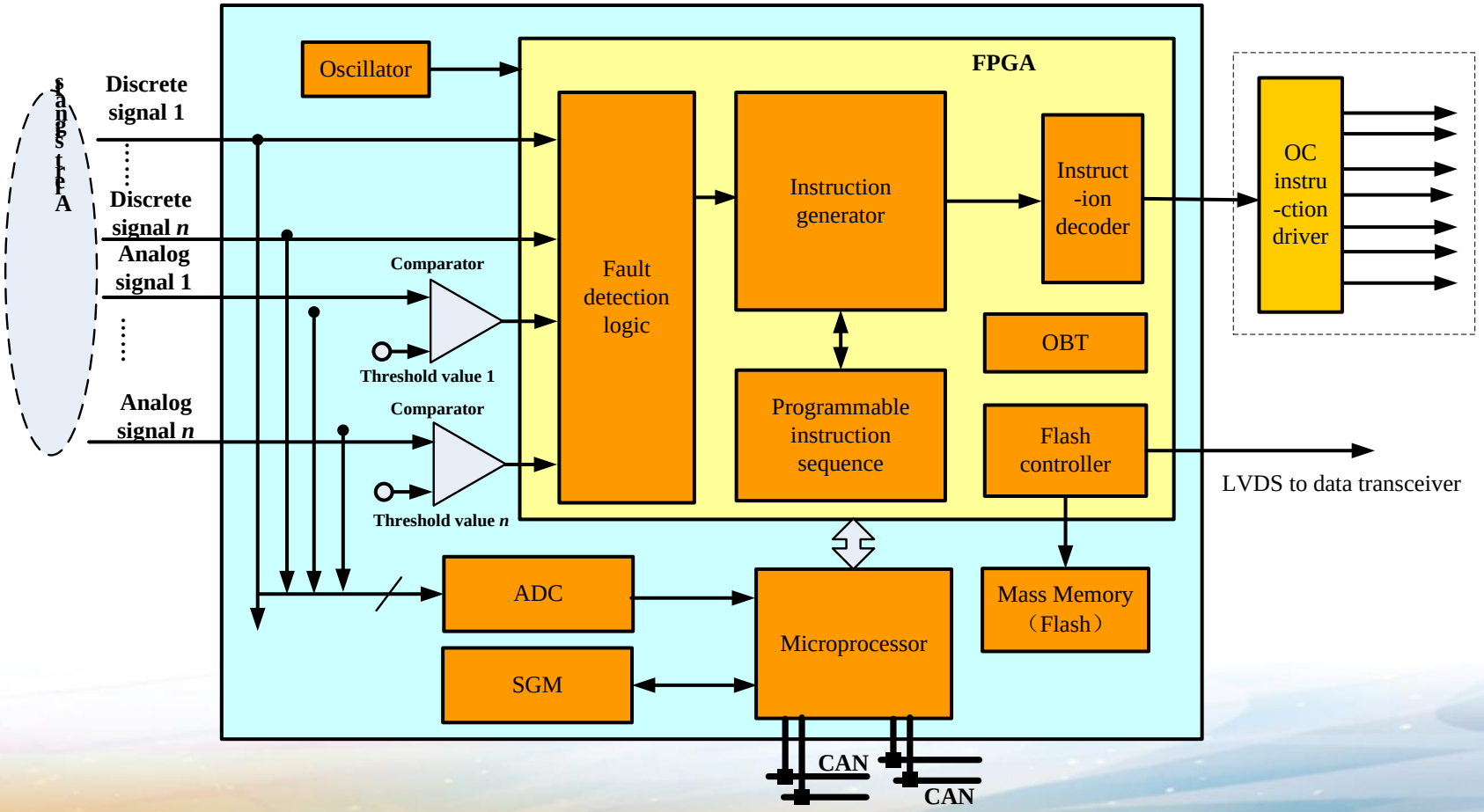
(3)Safe Guard Memory: store the important operation parameters of satellites avionics, such as uploading instructions, on-board time, when the backup OBC or RTU switches on, it can get the current operation parameters;

(4)On-board timer, it works as the backup on-board timer;

(5)Mass memory, monitor and store the CAN bus data, provide LVDS interface(10Mbps) to data transceiver. These data is very useful for ground engineer to analyze the satellites on-board operation state, especially for fault isolation.

FDIR design for microsatellites

FDIR Level 3 design



FDIR design for microsatellites

FDIR module performance:

■Processing ability: ≥2MIPS

PROM：32KB

EEPROM：32KB

SRAM：32KB

■Alarm signal input channels:8

■OC instruction output：16

■Enable: controlled by instruction；

■SGM：256KB；

■Bus Interface: CAN 2.0B

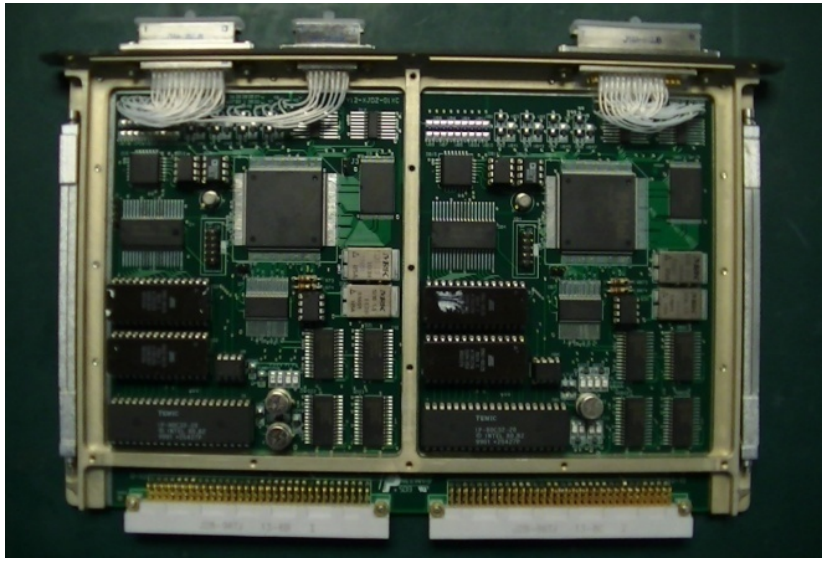
■LVDS interface: 10Mbps

■On-board timer: Sec:32bit,SubSec:16bit

■Mass Memory: 2GB

■Mass：≤ 0.6kg

■Power：≤1.5W



FDIR design for microsatellites

Built-in-test(BIT) helps to implement fault detection and isolation.

I. Module level BIT

BIT should be able to carry out real-time monitoring of the key parameters of the product, including work voltage and current. Generate and send the corresponding fault code.

(1) Power up BIT

- ROM memory check

The boot program and the application program is stored by three copies, the three copies are compared with each other before running.

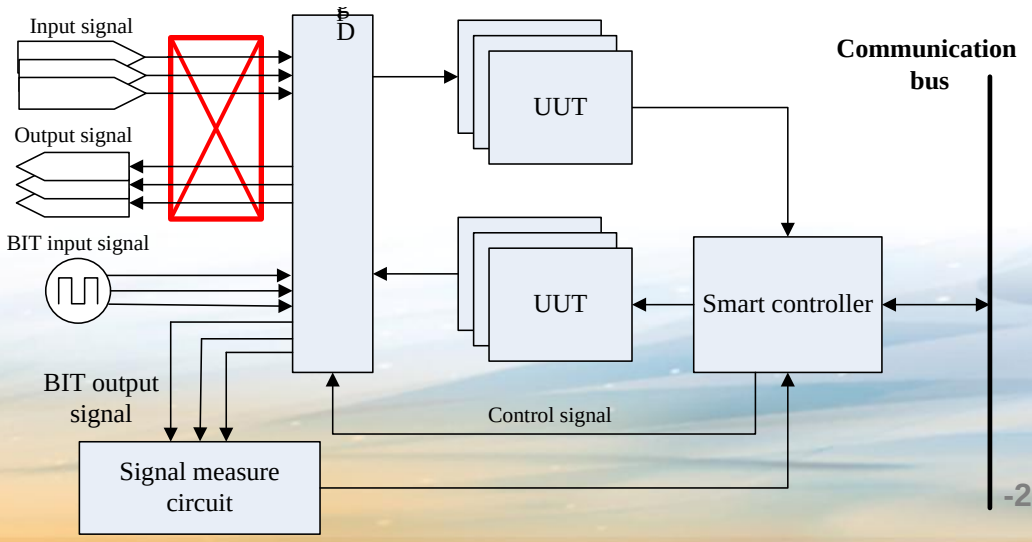
- SRAM memory check
- Inner voltage signal check

(2) Periodic BIT

- external interface monitoring, such as CAN, RS422, etal;

OBC monitors the periodic communication with other nodes

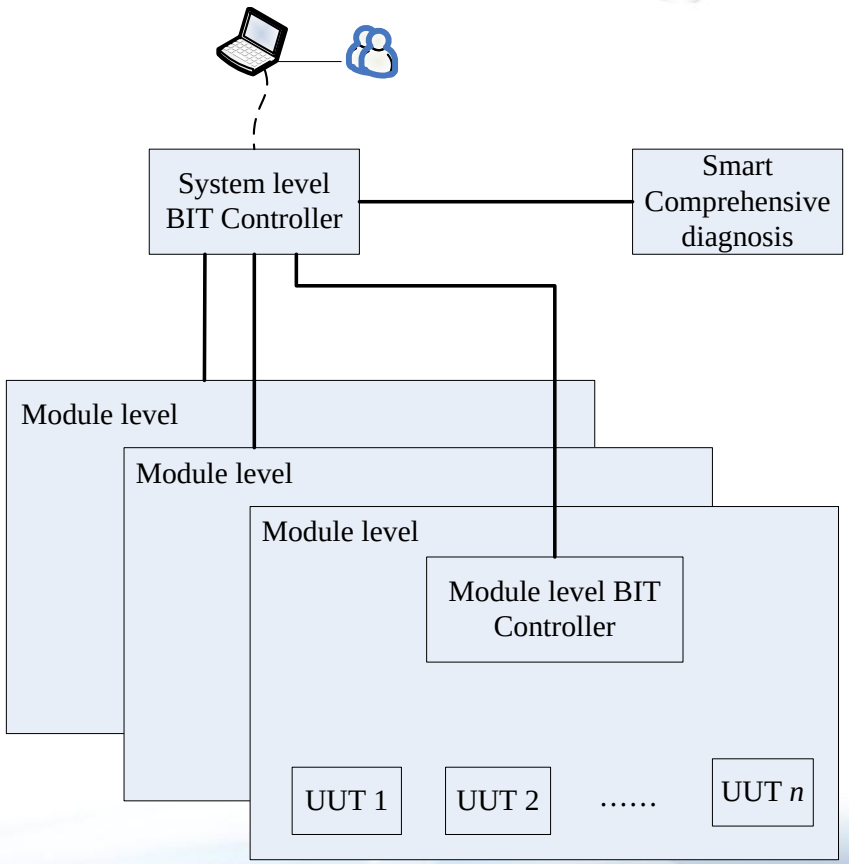
- SRAM memory check
- Inner voltage signal check



FDIR design for microsatellites

II. System Level BIT

System level BIT is a fast system level test when system integration or on-board test. System level BIT is mainly realized by the hierarchical design and based on the underlying module BIT design. The on-board computer act as the system level bit sponsors and organizers, and is triggered into test mode by the system level BIT instruction. In the test mode, OBC sends test instruction to other module and carry out the module level test one by one. The system BIT controller collects each module level test data and develop fault detection, localization and comprehensive diagnosis.



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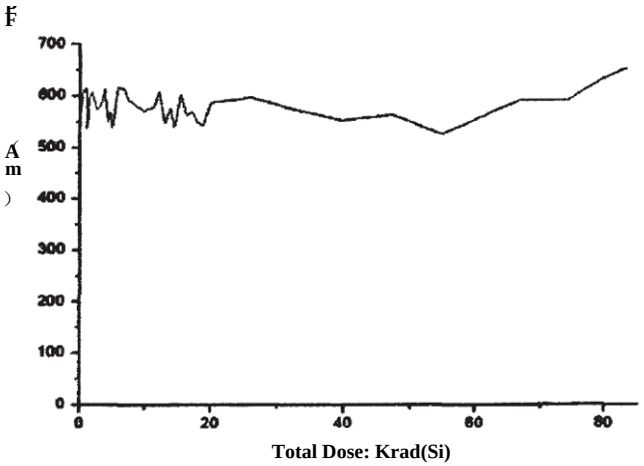
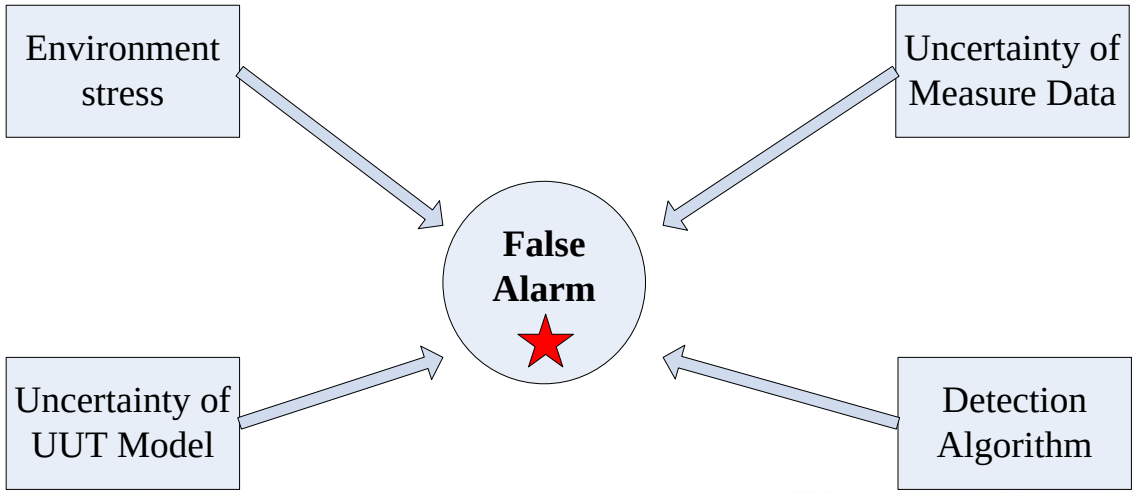
Some Ideas for Further Research

How to lower the false alarm rate during BIT design

BIT is widely used in the aircraft and automobile avionics design, now we employ BIT design in the on-board avionics. With the high reliability and rigorous space environment, We have to solve the false alarm problem.

Firstly, the reason for false alarm is summarized here:



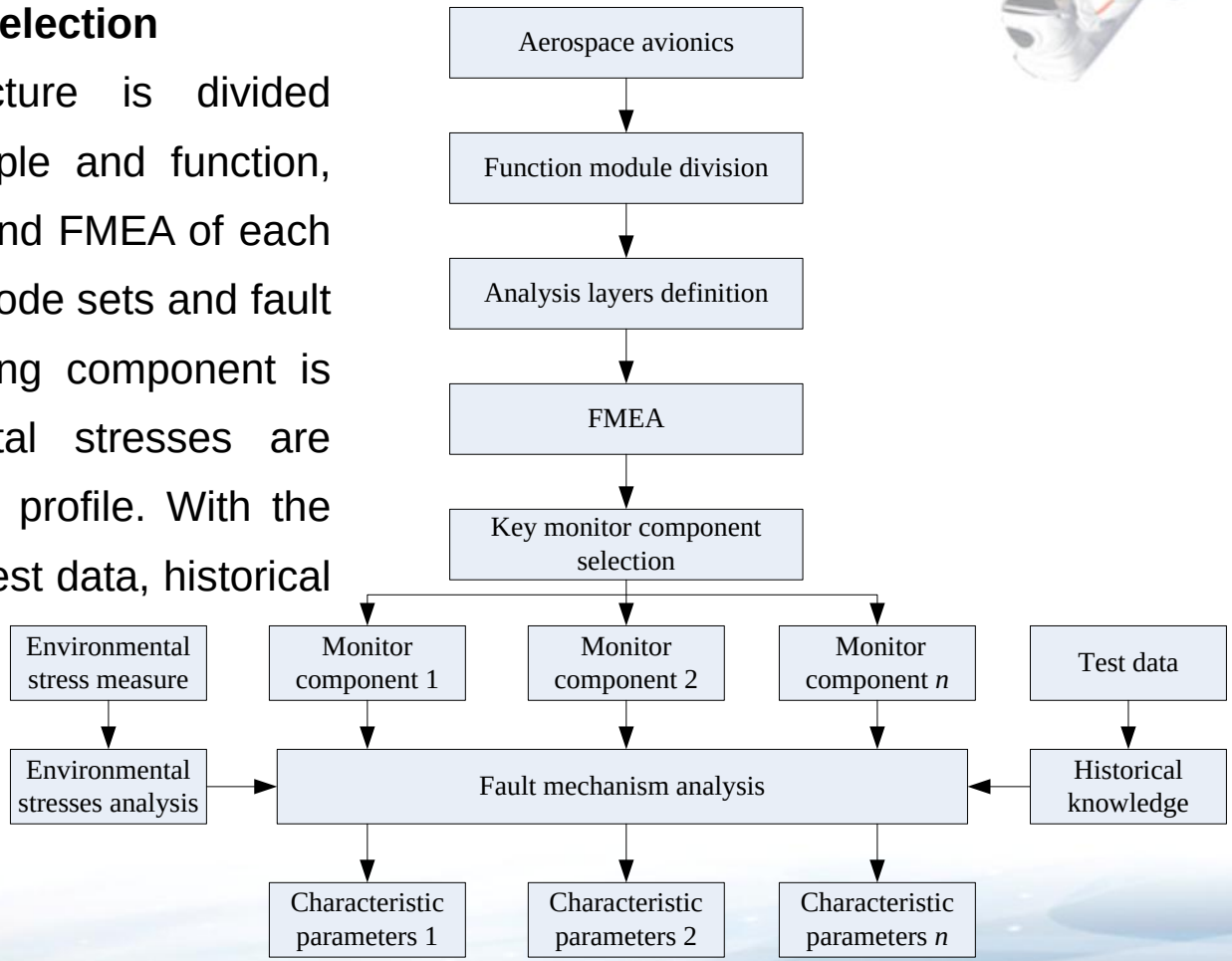


Several measures will be adopted in the following research:

Some Ideas for Further Research

I. Characteristic parameters selection

Firstly, the equipment structure is divided according to the operating principle and function, and the analysis layer is defined and FMEA of each module is carried out to get fault mode sets and fault attributes. Then the key monitoring component is selected. Secondly, Environmental stresses are analyzed based on environmental profile. With the help of prior information, such as test data, historical knowledge, and failure analysis, fault mechanism is analyzed and summarized. Finally, according to the failure physics model of components, Key Characteristic Parameters can be selected and its exact model could be setup.

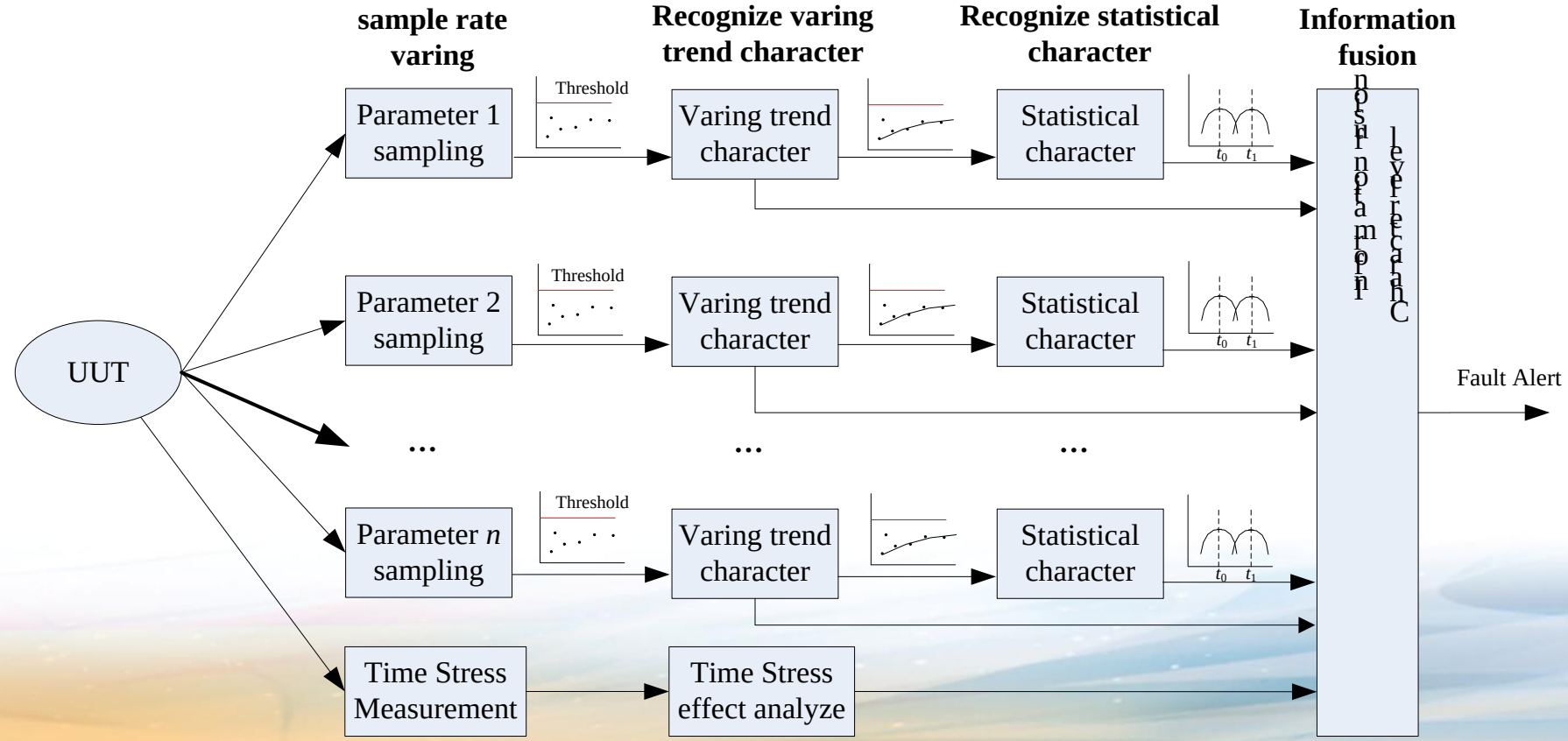


Some Ideas for Further Research

II. Fault detection methods:

Character level information fusion is proposed to use in the fault detection process.

Threshold check, varing trend character and statistical character is fused to make the decision—fault or not.



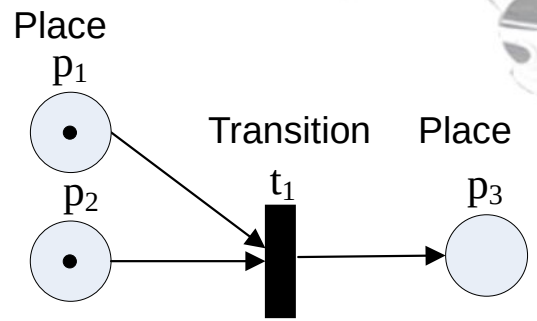
Some Ideas for Further Research

III. Fault Isolation methods:

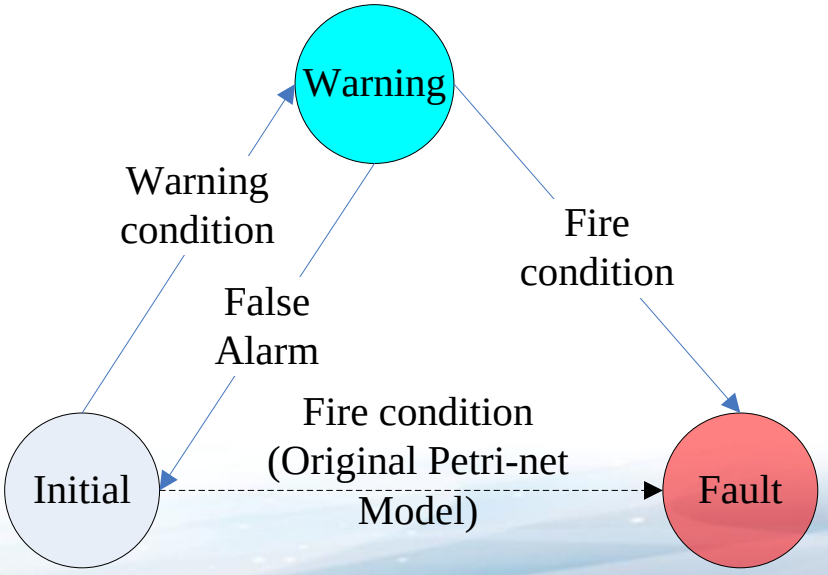
As we all know, faults can transmit from one to another, a system level fault may be accused by a sub-layer fault. If the system level fault is detected, we should find the initial fault that reduced the detected fault.

Petri nets (PNs), coined by Carl Petri , are an adaptive, versatile, and yet simple graphical modeling tool for representing dynamic systems. PNs have successful applications in the reliability modeling of various systems. Petri-net is selected to model the fault relationship among faults and the transmitting character of fault.

But, Petri-net couldn't describe the transient state, which may cause false alarm. So we propose to add a Warning state in the Petri-net model to describe transient state.



Petri-net Model



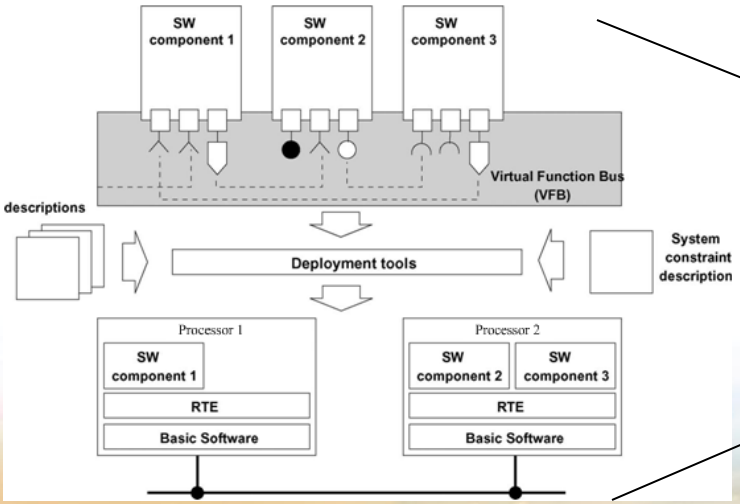
The Proposed new Petri-net Model

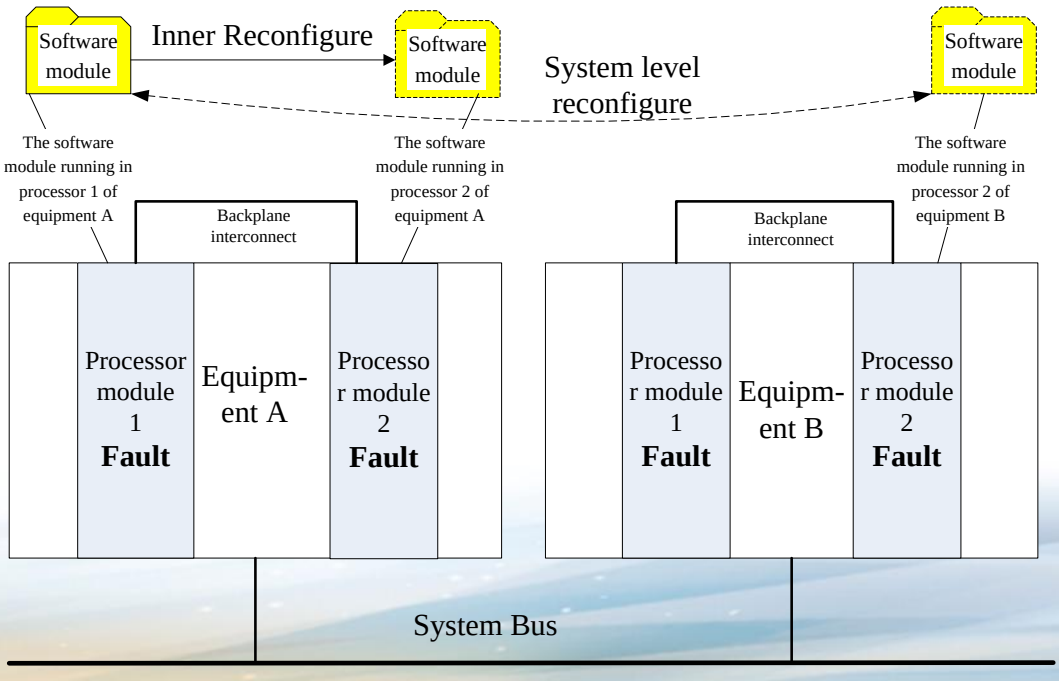
Some Ideas for Further Research

IV. Fault Recovery:

Reconfiguration is one of the most important solution for fault recovery. But now, the reconfiguration is very limited for on-board avionics. Generally speaking, the on-board avionics is a distributed processing system.

if the OBCs have powerful processing ability, the software component could be deployed on different OBC dynamically, which will provide flexible reconfiguration ability. The software component running on a failed OBC could be deployed on another one, so the failed OBC don't affect the system's function.





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Conclusion

In the development of the avionics for microsatellites, we proposed a hierarchical FDIR architecture and the FDIR hardware module was developed for the fatal fault detection and recovery. It also store the vital operation parameters for state recovery when the OBCs switch on or off. It also monitor and store the CAN bus data and provide a high speed channel to the transceiver, so that more data could be transmit down to ground-station.

some ideas for the next following research is proposed:

- parameters selection based on FMEA
- character level information fusion for fault detection
- a new Petri-net model is proposed for transient state modeling
- reconfiguration based on software component dynamic deployment

Thanks for attention!

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