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Tsinghua Micro/Nanosatellite research and it's application

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Abstract

With the development of Micro-/Nano-technology, Micro-/Nano-satellite are paid great attention and developed rapidly. Tsinghua Space Research Center(TSRC) has planed to develop their Microsatellite and Nanosatellite with the cooperation of Surrey Space Center (SSC). The Tsinghua-1 Microsatellite is new generation 3-axis stabile Microsatellite in 50 Kg. It is used as technical demonstration of Microsatellite constellation for globe disaster forecast net. The main Payloads include Multi-Spectral Earth Image System (MEIS) which have a 50 meters ground resolution and the cameras will be mounted 15 degrees off Z-axis of the satellite to meet the 400 kilometre ground swath requirement, Date Transmit Experiment payload which is used to survey the radio frequencies interference and GPS receiver. The THNS-1 is a Nanosatellite in 5Kg. One micro magnetometer, three micro 2-d sun sensor, a micro GPS receiver and MIMU is employed to determine the attitude of Nanosatellite. A small gravity-gradient boom is used as basic stabilization of satellite. The main payload is a micro Multi-Spectral Earth Imaging system (MEIS). Three on chip CMOS CCD Cameras providing 250 meter ground sampling in 3 spectral bands with an 75 km field of view capable of providing detailed information on Earth resources, land use and environmental haze pollution and etc. The other Micro-Mechanical-Electric-system (MEMS) devices are as experimental payloads also.

1, Introduction

Tsinghua University is a comprehensive and State key university having disciplines of science, engineering, management and social science with engineering as its main focus. As one of the important national bases for higher learning and for scientific research and technological development. At present, Tsinghua University consists of 6 schools, 31 departments, and 44 research institutes, 9 engineering research centers and 163 laboratories including 15 national key laboratories. Tsinghua Space Research Center (TSRC) was set up in Oct. of 1998. A goal of TSRC is to integrate the scattered space researches in Tsinghua University and build spacecraft in future. With the cooperation of Surrey space center, TSRC is building the Tsinghua-1 Micro-satellite which is first Micro-spacecraft in Tsinghua and starting to design the THNS-1 Nanosatellite

2, Tsinghua-1 Microsatellite

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Tsinghua-1 Microsatellite is new generation 3-axis stabile Microsatellite in 50 Kg. It is used as technical demonstration of Microsatellite constellation for globe disaster forecast net. The main Payloads include Multi-Spectral Earth Image System(MEIS) which have a 50 meters ground resolution and the cameras will be mounted 15 degrees off Z-axis of the satellite to meet the 400 kilometre ground swath requirement , Date Transmit Experiment payload which is used to survey the radio frequencies interference and GPS receiver. The design life of Tsinghua-1 is above 3 years. It will be launched in the end of 1999 in schedule.

2.1 Tsinghua-1 platform

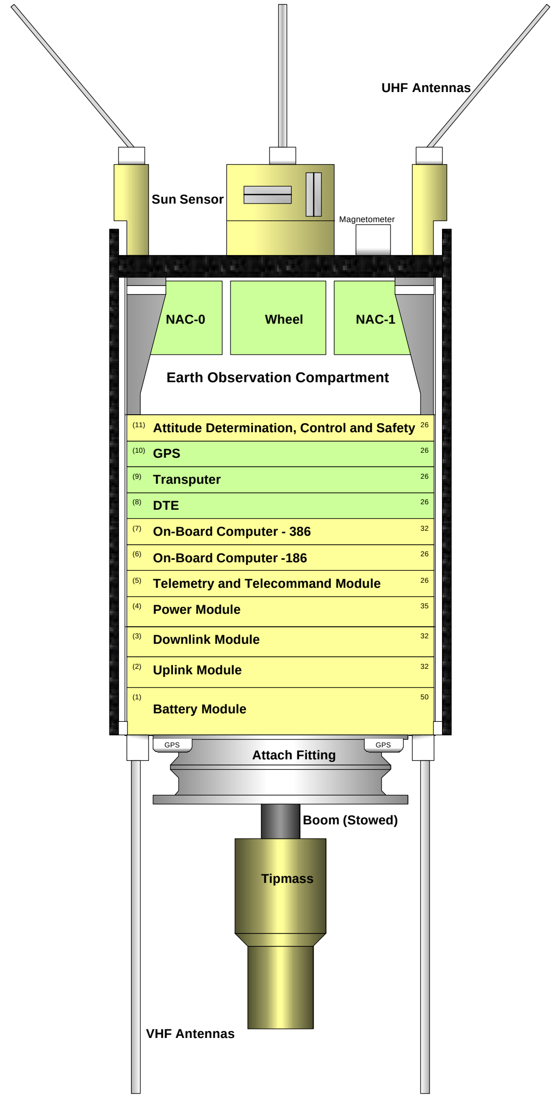
2.1.1 Spacecraft configuration

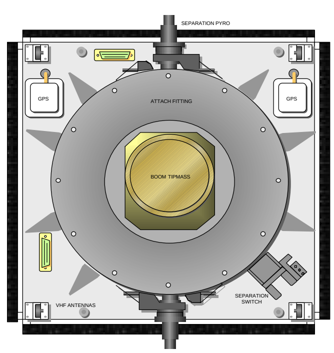
The spacecraft configuration has been developed and is illustrated below. The spacecraft mass is approximately 50kg measuring 350x350x640mm (excluding flexible antennas). Module trays carry the standard platform modules, and payloads and experiments. Three payload modules include the GPS, Transputer, and DSP/DTE. The cameras and wheels are accommodated in the Earth Observation Compartment. Two GPS antennas are accommodated on the space facing facet.

Tsinghua-1 Configuration is shown in Tab.1. The Layout of Tsinghua-1 is shown in Fig.1.

Tab.1 Tsinghua-1 Configuration Table

Physical Characteristics		
Envelope	330 mm X 330 mm X 640 mm (approx.)	
Mass	50 kg (approx.)	
Primary Platform Subsystems		
Attitude Control	Magnetorquer-assisted gravity gradient, nadir pointing; 3 axis Reaction wheels	≈ ±0.3° roll/pitch nadir pointing ≈ ±0.3° yaw pointing accuracy ≈ ±15° roll nadir off-pointing
Solar Panels	GaAs ≈35 W per panel (BoL)	4 fixed body-mounted panels
Batteries	7 Ah NiCd	SSTL qualified
On-Board Computing	80C186 + 16 Mbytes 80C386 + 64 Mbytes	Primary OBC Secondary OBC
	2 ×T805 Transputer +32Mbytes	
On-Board Data Network	9.6 kbps serial bus High speed CAN bus	Single network Dual network
Communications links	9.6 kbps VHF uplink	3 single channel receivers, 2 synthesised receivers
	9.6 - 38.4 kbps UHF downlink	2 synthesised transmitters





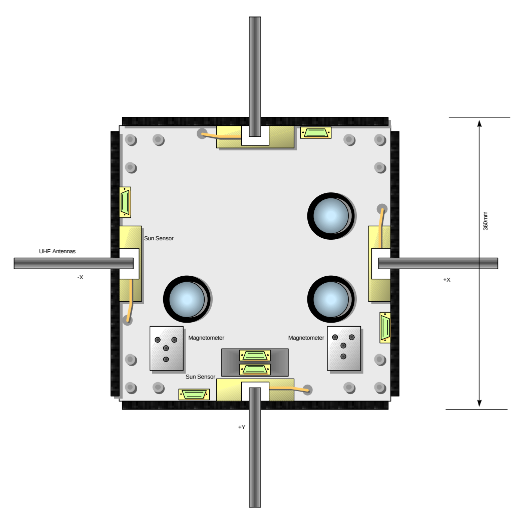


Fig.1 the Layout of Tsinghua-1

2.1.2 **Spacecraft system block diagram**

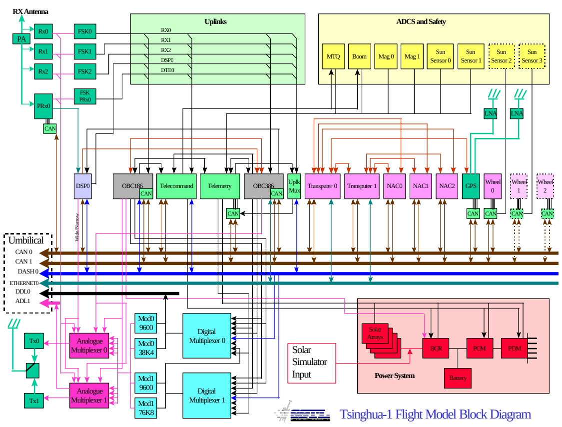


Fig.2 The spacecraft system block diagram

The spacecraft system block diagram is shown in Fig.2 .The Controller Area Network (CAN) is a standard widely adopted in the automotive and process-control industries for distributed telemetry and telecommand and medium-rate data transfer with a data rate of 1.0Mbps. The CAN provides a standard physical and data-link layer interface, above which SSTL has defined application protocols for spacecraft data transfer. Any payload with a CAN interface and on-board software implementing the SSTL application protocol can be connected directly into the Microsatellite CAN bus. In Tsinghua-1 there are two CAN bus as the primary and the secondary.
On board the spacecraft telemetry and telecommand, bootloading and file transfer protocols are implemented, with typical net data transfer rates of 32kbps. This is more than adequate for these functions, and where experiments such as the imaging system and DSP/DTE require higher rates, dedicated point-to-point links are employed.
The imaging system includes 20Mbps links to transfer data from the cameras to the transputer. A 10Mbps Ethernet link exists between the OBC386 and transputers for bulk data transfer, supporting net data transfer rates up to 8Mbps.
A dedicated serial point-to-point link will be included between the OBC386 and DSP/DTE.
The inclusion of transputer link between the OBC386 and transputer will be a new development.

2.1.3 **Attitude Control and Determination**

The attitude control system is designed in order to provide nadir pointing for the Earth Observation Platform (EOP). This is achieved via a gravity gradient boom, magnetorquers and magnetometers. The Tsinghua-1 is also to carry sun sensors, wheels and additional software. In order to meet the desire to image targets point accuracy ±0.3 degrees, the full three-axis control to be used , tested and validated with a safe fallback mode.

The primary operational attitude modes envisaged are

- 3-axis control with GG boom stowed
- 3-axis control with GG boom deployed
- Yaw control with GG boom deployed
- Yaw spun with GG boom deployed

In the three axis modes, the satellite is to be controlled to perform fast slew maneuvers within +/-15 degrees about the roll-axis or +/-180 degrees about the yaw-axis, and then to keep an accurate off-nadir pointing for a required period of up to half an orbit. This can be performed at lower risk with the gravity gradient boom deployed.
The imaging mode will be gravity gradient with yaw control. The cameras are mounted at 15 degrees from nadir, so that the yaw angle can be selected to offer the required off-pointing angle (±15°) from nadir.
The nominal mode will be gravity gradient control with yaw spin, in order to maintain the optimum thermal environment for the mission.

2.2 Tsinghua-1 payloads

In tsinghua-1, the Payloads include :

50m Multispectral imaging system
Wide band range DSP/DTE
GPS
3-axis experiment

Now the main payload---Multi-Spectral Earth Imaging System is introduced.
In 800 km low Earth orbit, the MSEIS provides high quality 50-metre ground sampling multi-spectral images in 3 spectral bands using 1024x1024 pixel 2-dimensional CCD array detectors digitized to 8 bits radiometric resolution (256 levels). The image swath width is 80km and each imager can collect 4 images contiguously along the flight path. The MSEIS carries out on-board autonomous histogram analysis to ensure optimum image quality and dynamic range. After this images are processed and can be compressed using advanced scene-dependent software compression techniques using the T805 Transputers and then stored on-board the Microsatellite OBCs and RAMDISKs for later transmission to ground via digital packet error-controlled links at UHF. The OBCs can also be employed to carry out autonomous on-board cloud editing & high-compression “thumb-nail” image previews.

The configuration of MEIS is shown in Tab.2. The block diagram of Transputers and camera inter-connections is shown in Fig.3. The block diagram of the Kodak camera sensor board is shown in Fig.4 .The simulating performance of Tsinghua-1 MEIS with 50m ground resolution is shown in Fig. 5.

Tab.2 The configuration of MEIS

Imaging sensor	1024x1024 pixel Eastman-Kodak KAI-1001 non-interlaced scientific sensor
Optics	colour-corrected Nikon lenses 150mm
Ground Sampling Distance	50x50 metres
Swath width	50 km, contiguous frames
Spectral bands (selectable)	0.81-0.89µm NIR, 0.61-0.69 µm red, 0.5-0.59 µm; green
Exposure control	electronic integration time & gain (1000:1)
Radiometric resolution	8-bit (256 levels) - video digitization is synchronized with pixel stream producing 8-bit quantisation (9-bit linearity)
Signal-to-noise	better that 35dB at 100% (~2000:1)
Image raw data size	1 Mbyte per spectral band per frame
Image compression	scene-dependent compression 3:1 to 5:1 (using Transputer software adaptive moment preserving block truncation coding techniques)
On-board processing	2xT805 20MHz Transputers + 32Mbytes SRAM
On-board storage	150 compressed multi-spectral images
On-board data handling	dual CAN-bus (ISO 11898 & ISO 11519-1) 20 Mbps INMOS serial point-to-point link 9600 bps asynchronous duplex (UART)

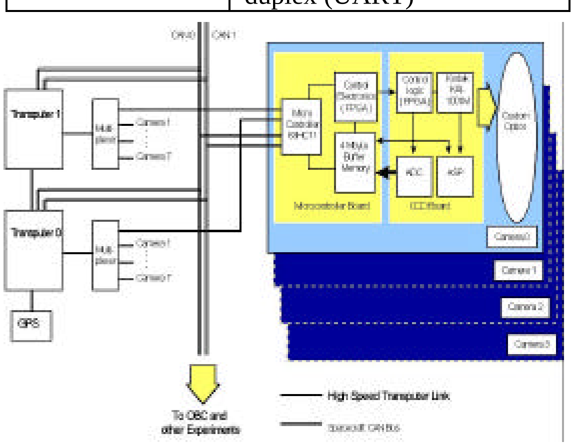


Fig.3 The block diagram of Transputers and camera interconnections

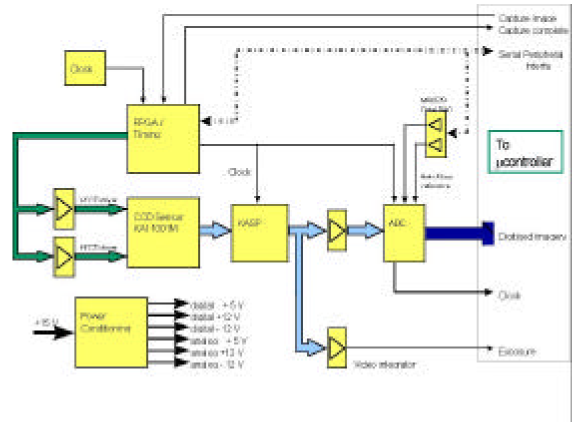


Fig.4 The block diagram of the Kodak camera sensor board.

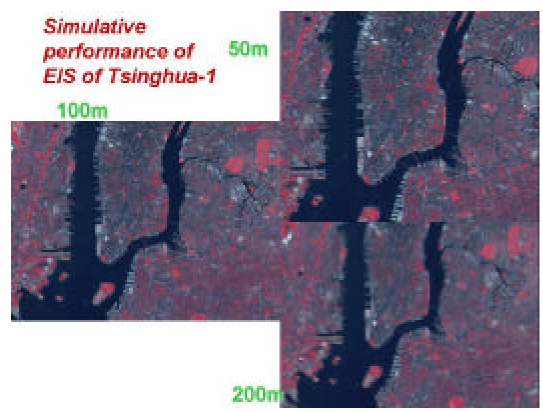


Fig. 5 The simulating performance of Tsinghua-1 MEIS with 50m ground resolution.

3, THNS-1 Nanosatellite

The THNS-1 is Nano-satellite in 5Kg. One micro magnetometer, three micro 2-d sun sensor, a micro GPS receiver and MIMU is employed to determine the attitude of Nanosatellite. A small gravity-gradient boom is used as basic stabilization of satellite. The main payload is a micro Multi-Spectral Earth Imaging system(MEIS). Three on chip CMOS CCD Cameras providing 250 meter ground sampling in 3 spectral bands with an 75 km field of view capable of providing detailed information on Earth resources, land use and environmental haze pollution and etc. The other Micro-Mechanical-Electric-system (MEMS) is as experimental payloads also.

3.1 THNS-1 platform

The configuration of THNS-1 is shown in Tab.3. The general view of THNS-1 is shown in Fig.6. The structure of THNS-1 is shown in Fig.7. The Earth image platform (EOP) of THNS-1 is shown in Fig. 8. The module box of THNS-1 is shown in Fig.9.

Tab.3 THNS-1 system configuration

Physical Characteristics		
Envelope	100 mm hexahedron with 200mm height (approx.)	
Mass	<5 kg (approx.)	
Primary Platform Subsystems		
Attitude Control	Magnetorquer-assisted gravity gradient, nadir pointing; Yaw-mini-Reaction wheels	≈ ±1° roll/pitch nadir pointing ≈ ±3° yaw pointing accuracy ≈ ±15° roll nadir off-pointing
Solar Panels	GaAs ≈5 W	6 fixed body-mounted panels
Batteries	4.5 Ah NiCd	
On-Board Computin g	StrongARM SA1100 + 12 Mbytes RAM or RISC 80960 + 12 Mbytes RAM	
On-Board Network	9.6 kbps serial bus	
Communi cations	9.6 kbps VHF uplink	2 single channel receivers
	9.6 - 38.4 kbps UHF downlink	2 synthesised transmitters
Payloads		
Digital Store-&-Forward Communications	Function provided by Platform On-Board Computer software	
MIMU Experiment	Micro-accelerometer & microgyro	
Multi-spectral Earth Imaging System	250-m ground sampling distance, 3-band MSEIS using 320x240 pixel CMOS CCD arrays	
GPS receiver	Experimental receiver for orbitdetermination	

Fig.6 The general view of THNS-1

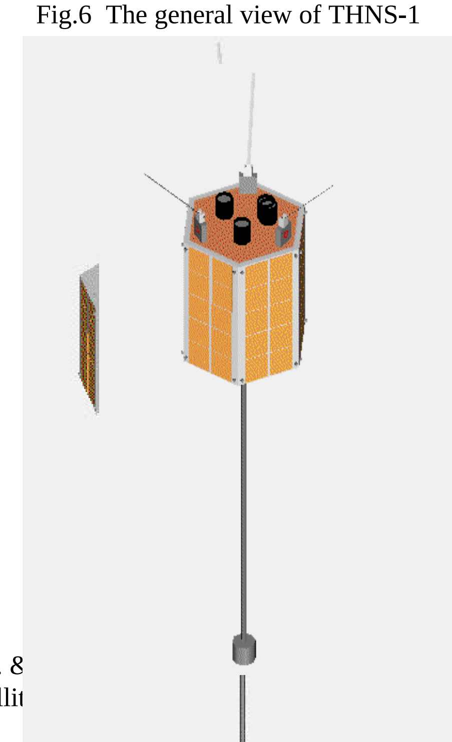


Fig.7 The structure of THNS-1

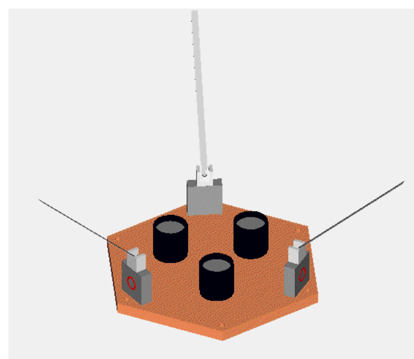


Fig.8 the EOP of THNS-1

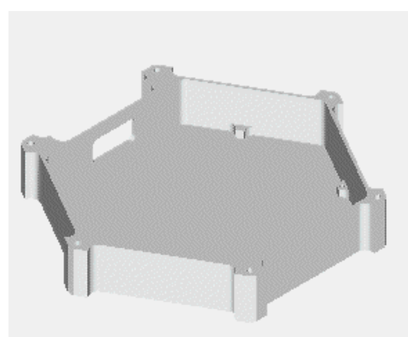


Fig.9 The module box of THNS-1

3.2 Mechanical structure

The configuration of mechanical is based on that of Tsinghua-1 Microsatellite. The standard hexagonal module box is used to each subsystem. The payloads , such as mini-reaction wheel, COMS

CCD camera, MIMU and etc. are located in the top of module stack. Six solar panels are fixed the body of THNS-1. The mass budget is shown in Tab.4 . So the total mass of THNS-1 is about 4830 and less than 5kg.

Tab.4 Mass budget

Module	Mass(g)		
	Mechanic	Electric	Sum.
Platform			
ADCS	120	150	270
OBDH	120	200	320
RF	120	350	470
Batt. and Power	120	200	320
Solar panels	900		900
Reaction wheel	220	30	250
Sun sensor			300
Magnetometer			200
Connector	300		300
GG boom	250		250
Total			3580
Payloads			
CMOS camera	300	300	600
GPS receiver	50	100	150
MIMU	200	300	500
Total			1250
Total Mass(g)			
4830<5kg			

3.3 The Power system

The power system is comprised 6 solar panels, battery packs, Battery Charge Regulator (BCR), Power Condition Module (PCM). The peak output power from the solar panels is 5 watts and average output power is about 3 watts. 6 NiMH battery cells Are employed in battery packs and the output of battery packs is 4.5 watt-hours. The ±5V and +9 V are supplied by the power system.
According the following assumptions, effective factors and parameters such as:

(1) the needed power (power budget) Pn
(2) the efficiency of power system: E (75%)
(3) the power margin : M(30%)
(4) sunlight factor: Is (caused by the eclipse time, typical 1/3)
(5) illumination factor: Ii (typical value is 0.7)
(6) degradation rate: $e^{-fn.}$ N is the life time, the typical value of f is 0.025
(7) efficiency of solar cells: U(GaAs=18%)
(8) packing factor: Pa (78%)
(9) illumination density: I ($1353W/m^2$)
(10) equal section area: T (1.7A, A is the area of one solar panel's surface)

We can get the power of solar panel generate Ps:

$$Pn*(1+M)/E=Ps*Ii*Is*e^{-fn.}$$

And the effective solar area:

$$A*1353*U=Ps$$

So the area of each panel:

$$A = \frac{p}{1353 \times Ii \times Is \times e^{-fN} \times T \times Pa}$$

If the power need is 3W, the area of each solar panel $A=0.022m^{2.}$ Actually, the area of each solar panel, which we used, is $0.025m^2$.

Tab.5 Power budget

	V/v	I/mA	P/W	e %	P_I/W
Platform					
Power	5	20	0.10	81	0.12
TTC	5	15	0.075	67	0.11
	5	15	0.075	67	0.11
RX	5	50	0.25	67	0.37
	5	30	0.15	70	0.22
TX	5	123	0.615	86	0.92
OBC	5	40	0.20	73	0.27
Wheel	5	80	0.40	73	0.54
Mag.M	5	15	0.075	67	0.11
Mag.T	5	150	0.65	81	0.92
Total/w	2.14				
Payloads					
GPS	5	250	1.25	66	1.8
MEIS	5	270	1.35	85	1.6
MIMU	5	300	1.5	85	1.7

In the Tab.5, e is efficiency of power in the different location.

3.4 Attitude Determination and Control System

The block diagram of attitude determination and control system is shown in Fig.10. The attitude will be determined by micro-magnetometer, mini-sunsensor and Micro inertial Measurement Unit (MINU). The GG boom, magnetorquers , mini-reaction wheel is used as actuator of attitude controlling.

The THNS-1 platform has an autonomous attitude control system managed by the Housekeeping OBC. In the baseline configuration, the satellite is *gravity-gradient* stabilized with the +Z facet pointing toward the Earth.

The Earth-pointing gravity-gradient stabilizing torque is supplied by a 3-m boom topped by a 0.5 kg tip mass. This torque is insufficient by itself to stabilize the satellite completely, consequently, the Housekeeping OBC uses Electro-magnets (magnetorquers) in a control system to provide attitude control. The satellite has dual-redundant magnetorquers in all three axes, and dual-redundant three-axis magnetometers to measure the Earth's magnetic field for the control loop.

The autonomous, computer controlled gravity-gradient/Magnetorquer system has been used by to provide nadir (Earth) pointing within ±3°. In the baseline configuration, the Housekeeping OBC also imparts a slow rotation about the satellite's Z-axis (yaw) with a period of approximately 10 minutes to minimize thermal gradients.

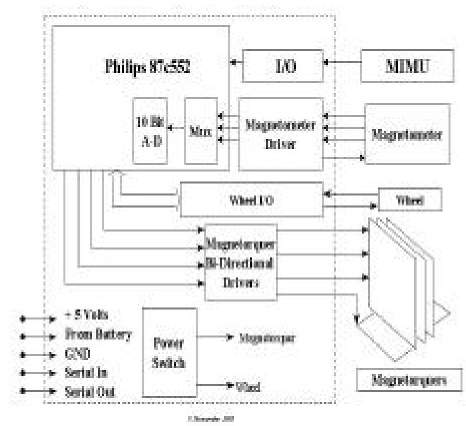
Many missions require precise attitude knowledge for data analysis. Generally, sophisticated ground-based algorithms operating on magnetometer measurements stored simultaneously with the experiment data derive this knowledge. The attitude restitution software for the standard bus. can provide attitude information accurate to 1° in all three axes.

The mini-reaction wheel is used for attitude experiments. It can be used to do the ±15° off-pointing. The block diagram of attitude determination and control system is shown in Fig.10 . The whole system is controlled by a the controlling software can be uploaded in orbit.

3.5 The Multi-Spectral Earth Imaging System (MSEIS)

In 800 km low Earth orbit, the MSEIS provides high quality 250-metre ground sampling multi-spectral images in 3 spectral bands using 320x240 pixel 2-dimensional COMS CCD array detectors digitized to 8 bits radiometric resolution (256 levels). The image swath width is 10km and each imager can collect 3 images contiguously along the flight path. The MSEIS carries out on-board autonomous histogram analysis to ensure optimum image quality and dynamic range - after which images are processed, compressed using advanced scene-dependent software compression techniques and then stored on-board the OBCs and RAMDISKs for later transmission to ground via digital packet error-controlled links at UHF.

Fig.10 The block diagram of attitude determination and control system



Imaging sensor	320x240 CMOS CCD
Optics	colour-corrected lenses 50mm
Ground Sampling Distance	250x250 metres
Swath width	75 x75 km, contiguous frames
Spectral bands (selectable)	Magenta, cyan, yellow
Exposure control	electronic integration time & gain (1000:1)
Radiometric resolution	8-bit (256 levels)
Signal-to-noise	better that 42dB at 100% (~2000:1)
Image raw data size	76.8kbyte per spectral band per frame
Image compression	scene-dependent compression 3:1 to 5:1
On-board processing	OBC+ 4 Mbytes SRAM+4 Mbytes Ram
On-board storage	50 compressed multi-spectral images
On-board data handling	9600 bps asynchronous

Tab.6 The image sensor specification

The OBCs also carry out autonomous on-board cloud editing & high-compression "thumb-nail' image previews. The image sensor specification is shown in Tab.6. The block diagram of MEIS is shown in Fig.11.

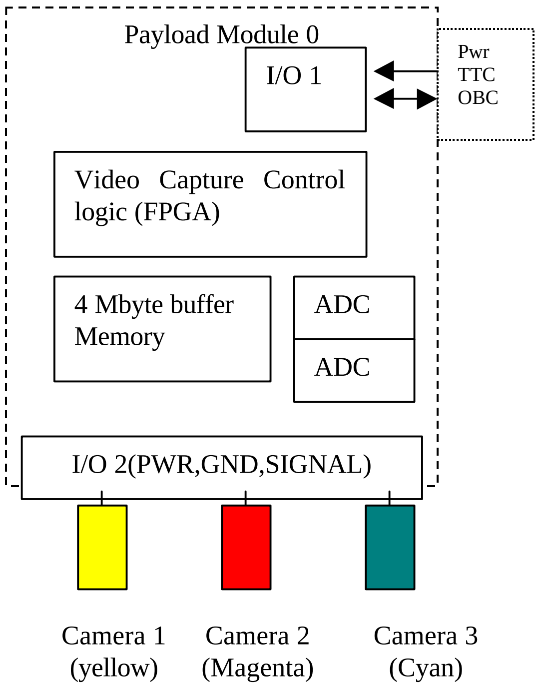


Fig.11 The block diagram of MEIS

4, Conclusion

In this paper, the Tsinguha-1 Microsatellite and THNS-1 nanosatellite are introduced. As it is mentioned in the start, Tsinghua-1 and THNS-1 micro/nano spacecraft are built for demenstationof advanced technology and space research in Tsinghua. The best thing for space research is to build the spacecraft by themselves.

Finally the authors would like to thank SSTL Tsinghua-1 responsible engineers and Tsinghua TT team members for their great contribution for these researches.

6, References

1. Tsinghua TT Team, "Tsinghua-1 Microsatellite Mission Defintion Report", 1999.3
2. You zheng and etc., "THNS-1 nanosatellite General Design Report",1999.5