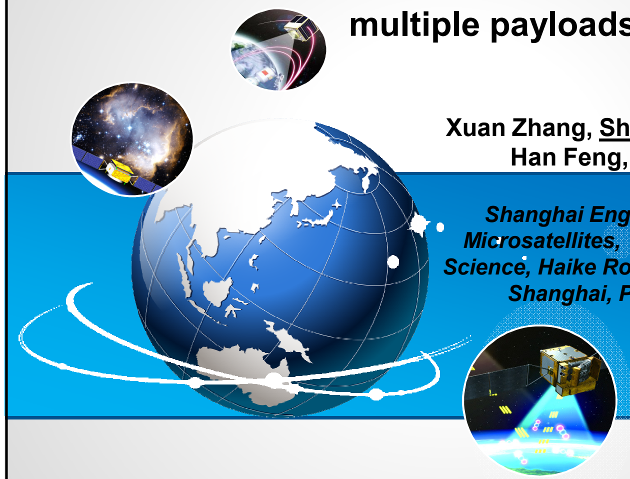
Design and implementation of multiple payloads on CubeSat



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SECM microsat

- Shanghai Engineering Center for Microsatellites
- Founded by Chinese Academy of Science (CAS) and Shanghai City Government
- Located in Pudong of Shanghai
- Has a capability to manufacture 20+ satellites simultaneously

SECM microsat

Missions

Navigation | Micro/Nano satellite | Science | Others

Nav-1 (2015)
[ca.900kg]
Nav-2 (2016)

BX-1 (2008)
STU-2 (2015)
[3U,2U CubeSat]
BX-2 (2016)
[50kg]

TanSAT(2016, 600kg)
DMaHS(2016, 1800kg)
QUESS (2016, 500kg)

Over past 14 years, SECM has launched into orbit 9+ micro/small satellites, accumulated 30+ orbit-year of satellite operation.

STU-2 Mission

microsat

Two 2U CubeSat and One 3U CubeSat

- Monitoring sea ice status in polar regions
- Gaining the maritime traffic information via AIS receiver
- Monitor civil aircraft traffic information via ADS-B receiver
- New technology demonstration & validation of Micro-propulsion, dual-band GPS-BD receiver, and Gamalink
- Demonstration of autonomous rendezvous (RVD) flight

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STU-2 Mission

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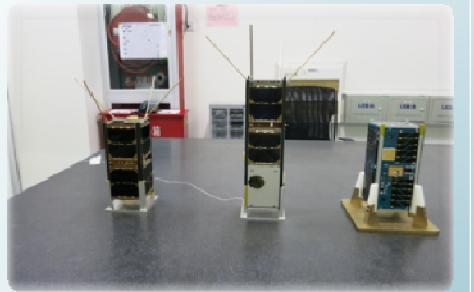
- 3 Cube Satellites to carry different payloads
- 2 Ground Stations in Shanghai and Nanjing of China
- Orbit: SSO, 480km, 8:00am
- Launch: Sept 25th 2015
  Jiuquan, China



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STU-2C

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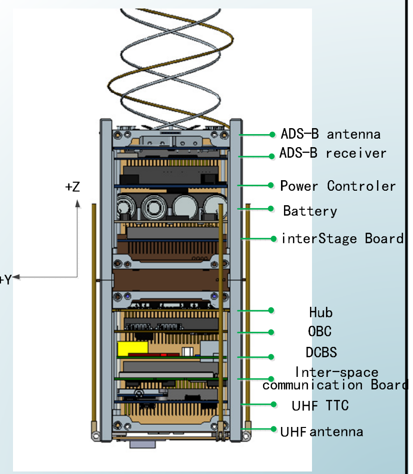
- ❑ Platform: OBC, ADCS, Structure, Power Controller and Battery, and TTC.
- ❑ Payloads:
  - ❑ **SoC dual-band GPS/BD2 receiver**
  - ❑ **a minimized magnetometer**
  - ❑ **a multi-channel inertial sensor**
  - ❑ ADS-B receiver
  - ❑ Inter-space communication Board
- ❑ Only **one year** for the team to develop the satellite
- ❑ Payloads are very limited in terms of the physical space available due to the extremely restricted size.



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Payloads

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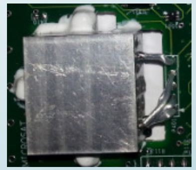
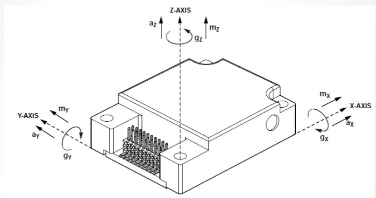
- ❑ The Ten degrees of freedom inertial sensor (ADIS16448)
  - ❑ a triaxial gyroscope
  - ❑ a triaxial accelerometer
  - ❑ a triaxial magnetometer
- ❑ Size：24.1 mm × 37.7 mm × 10.80 mm
- ❑ used for platform stabilization and control in the ground.

magnetometer





ADIS16448

- ❑ The custom made magnetometer (23 mm×21.5 mm×17 mm) is a trial for miniaturization based on traditional magnetometer design.
- ❑ High precision is not expected in this case, but in-orbit data may help the improvement in future mission.

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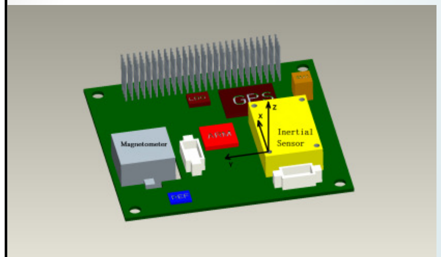
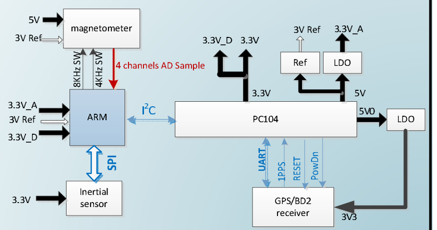
DCBS

- To save space in the STU-2C, we decide to integrate the three payloads into one electronic circuit board, called DCBS. The principle of the design is to **provide independent interface of power and data for each payload and take advantage of the shared mechanical and electronic interface** provided by the PC104 stack connector.
- An ARM is used to manage the system control and data collection of the board, mainly for the inertial sensor and magnetometer.
  - STM32F103RET7
  - the processing centre of the DCBS





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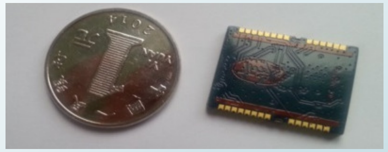
SoC GPS/BD2 receiver

- Dual band receiver : GPS L1 (1575.42MHz) and BD2 B1 (1561.098MHz)
- small size (22.4 mm×17mm×2.2 mm)
  - a 28-pins chip-sized module
  - weight : 4 g
- Low power consumption
  - (less than 0.5 W itself)
- COTS components
  - Originally optimized for terrestrial operation
  - the software algorithms embedded in the devices are tuned to accommodate the large variations in Doppler frequencies and the rapid changes in satellite visibility that accompany with the orbital motion



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SoC GPS/BD2 receiver

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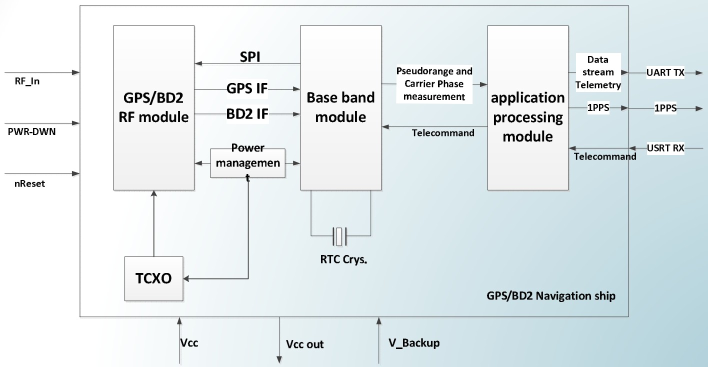
The 'chip' has integrated with necessary components already, even a RF module inside with LNA, Mixer and IF filter, which makes it can process signal from antenna directly.



Block diagram of GPS/BD2 receiver module

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SoC GPS/BD2 receiver

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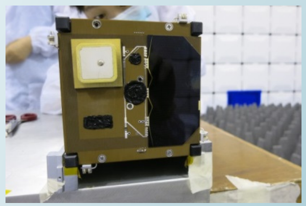
- The chip can only work with suitable peripheral circuits which provide it with power and data interface with outside. Chip-sized design significantly save the space in satellite. And users can custom the peripheral circuits design to fulfill different navigation system requirements on different systems.

Parameters	Values
Position accuracy	< 5 m
Velocity accuracy	< 0.2 m/s
1PPS output accuracy	30 ns
Sensitivity	< -140 dBm
Update rate	1Hz
TTFF	< 5min
Power consumption	< 0.5 W
Orbit	100~1000 Km LEO
Operation temperature	-40℃~85 ℃

- A type of micro strip antenna is chosen in this mission.
- No deployment is required and it makes integration easier.
- it can ensure a gain up to -1 dBi when the elevation is up to 30 degree



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EMC

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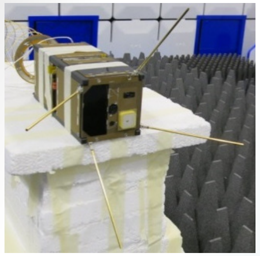
- Avoiding the influence from signals emitted from other transmitter should be a critical issue worthy to be considered at the very beginning of the circuit design since that the inside design of the module, which can ensure a high sensitivity to weak L band navigation signal, may also make the amplifier easy to be saturated or be damaged.



- a UHF band (435-438MHz) transceiver, which outputs beacon (1 W) every 10 seconds.
- an omni-directional TTC antenna placed very close to the GPS/BD2 antenna in STU-2C
- -45 dB isolation （GPS/BD2 antenna to TTC signal）

The second stage LNA or SAW in the GPS/BD2 module could be easily damaged when the radio is on.

As a result, proper filter and LNA have been added in the peripheral circuits of flight model of DCBS in STU-2C. A SAW chip (SF1186B) with an absolute attenuation above 50 dB @ 450 MHz and a LNA chip (SPF-5043Z) which can acquire 14.4dBi gain @1.5GHz is suitable for the system. Subsequent tests have confirmed the effectiveness of the amelioration.

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DCBS

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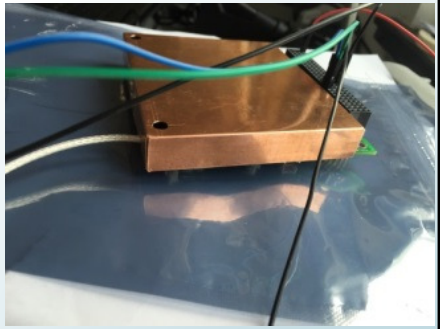
Flight model of DCBS



DCBS with a mental shell

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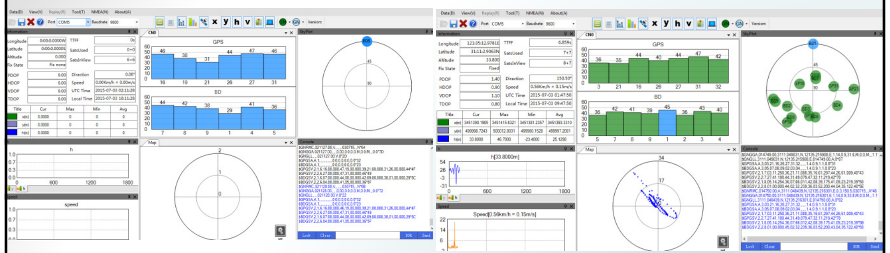
Ground test of SoC GPS/BD2 receiver



Software with friendly visual window is developed to facilitate the upcoming ground test.

- ❑ display basic information like state of signal tracking and locking, time, positions, speed, TTFF, numbers of satellites used, numbers of satellites in view.
- ❑ provide graphical display like height, speed, trajectories and Carrier-to-Noise Ratios (c/no).
- ❑ Once the receiver capturing satellites in view, the blue chart indicating c/no in the middle of the window will turn to green to sign the validity of the satellite tracking

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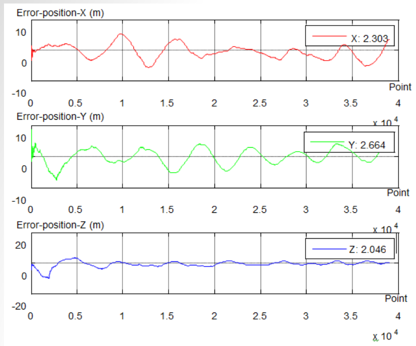
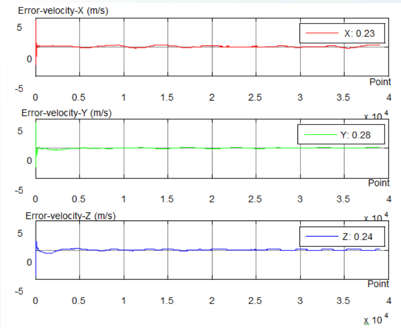
Ground test of SoC GPS/BD2 receiver





- ❑ The analysis of performance is based on a simulation lasting 4 hours (15000 points) with Spirent STR6560.
- ❑ The position error is better than 3m and the velocity error is better than 0.3 m/s

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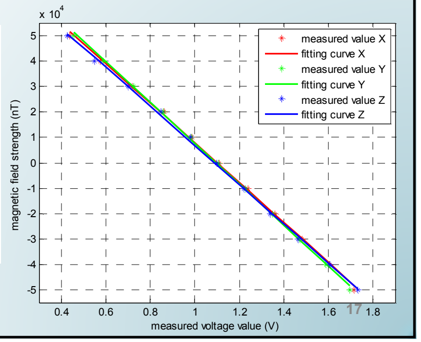
Calibration of magnetometer

- The in-house made magnetometer is an analogy one.
- So the magnetic value should be calibrated in standard magnetic environment before flight to figure out the linear relationship between measured voltage and the magnetic field intensity.
- Fitting formula can be concluded from known true magnetic value and measured voltage
- The measurement range is from -50000 nT to 50000 nT, but the precision of the magnetometer is over 1100 nT when the measured voltage is around the top or bottom boundary.

Setted magnetic value（nT）	Measured Voltage of X (V)	fitted magnetic value（nT）
50000	0.4384	51738.47
-50000	1.715	-48315.4
40000	0.5753	41008.89
-40000	1.6024	-39490.4
30000	0.7201	29660.15
-30000	1.4799	-29889.4
20000	0.8604	18664.09
-20000	1.3591	-20421.7
10000	0.9868	8757.454
-10000	1.238	-10930.4
0	1.1085	-780.82
Fitting formula: Magnetic strength(nT)= -78375.3 * Voltage(V)+ 86098.2		



The calibration result of x axis

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In orbit result

- The GPS/BD2 subsystem of STU-2C is operating as expected.
- We compare the in-orbit result with the propagated orbit based on TLE to give us a general estimation of the in-orbit performance
- The precision of TLE is around of hundred meters, and the precision deteriorates when the TLE epoch is too far from the propagating time.

Set	TLE orbit epoch (UTC)	Time start of in orbit data (UTC)	Data interval (s)	Num of points
1	2015/10/27 10:30:20	2015/10/27 11:39:20	8	2000
2	2015/10/30 2:37:19	2015/10/30 10:18:09	8	2000

Set	RMSE of position (m)	RMSE of velocity (m/s)
1	X: 199.7 Y: 266.7 Z: 473.8 3-axis: 579.22	X:0.693 Y:0.599 Z:0.268 3-axis: 0.954
2	X: 1072.1 Y: 1274.1 Z: 2131.9 3-axis: 2705.13	X:1.600 Y:2.100 Z:1.100 3-axis: 2.86

Result:

- set 1: The accuracy of position is around 579 m and the accuracy of velocity is 0.95m/s
- set 2: The accuracy of position is around 2.7km and the accuracy of velocity is 2.86 m/s

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In orbit result

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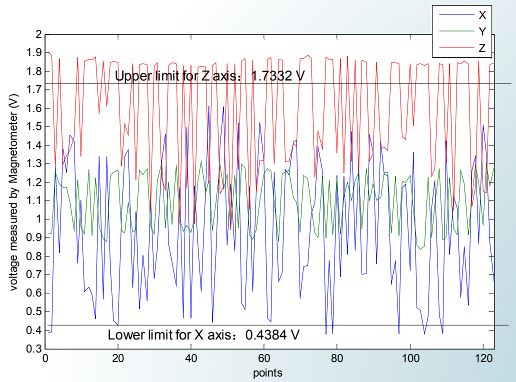
- Some data collected from magnetometer in DCBS are values out of the supposed measure range
- This can be seen from the figure below and this may be caused by the poor precision of over 1500 nT as the ground test result indicates



Voltage measured by magnetometer
(recorded in STU-2C during 22:06:20~0:25:05, 2016/1/25)

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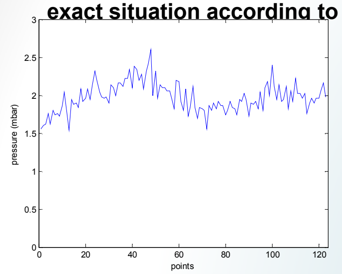
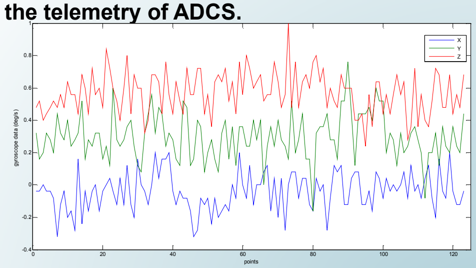
In orbit result

microsat

- the inertial sensor has displayed relatively stable performance in the orbit.
- The measured pressure in the 481km height is about one thousandth of 1 atm, which is quite consistent with the real situation in the space.
- The gyroscope data indicates the CubeSat is spinning with a rotation rate around 0.6 deg/s along Z axis during January 2016, which is the exact situation according to the telemetry of ADCS.



Pressure measured by the inertial sensor



Gyroscope data measured by the inertial sensor

recorded in STU-2C during 2016/1/25 22:06:20 ~ 2016/1/26 0:25:05 UTC)

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Discussion

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Young team members obtain millions of experience after this CubeSat mission. Here's some lessons learned:

- A System on Chip design or minimized improvement for former manufacture could significantly save the space in satellite and more issue should be considered to keep its independence and operation performance when share some interactions with other components in a system.
- Reconfigurable design for software or even hardware design could be greatly helpful to avoid unexpected problems occurring in the development.
- EMC issue is a critical thing in satellite design especially for CubeSat. A sensitive receiver may also sensitive for interference. If considering proper RF design at the very beginning of the mission, the rework could be avoided. And additional mental shell sometimes may be helpful to get rid of the interference.
- COTS components or devices could also be well operated in space, but component screening is critical for the performance after launch.
- TLE is an important source for CubeSat teams to determine orbit, however orbit information with higher precise is needed for better valuation of sensitive GPS receiver in space.

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