Application of BeiDou/GNSS System in Spacecraft Autonomous Navigation

ZHANG Shuangna
China's Academy of Space Technology
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content

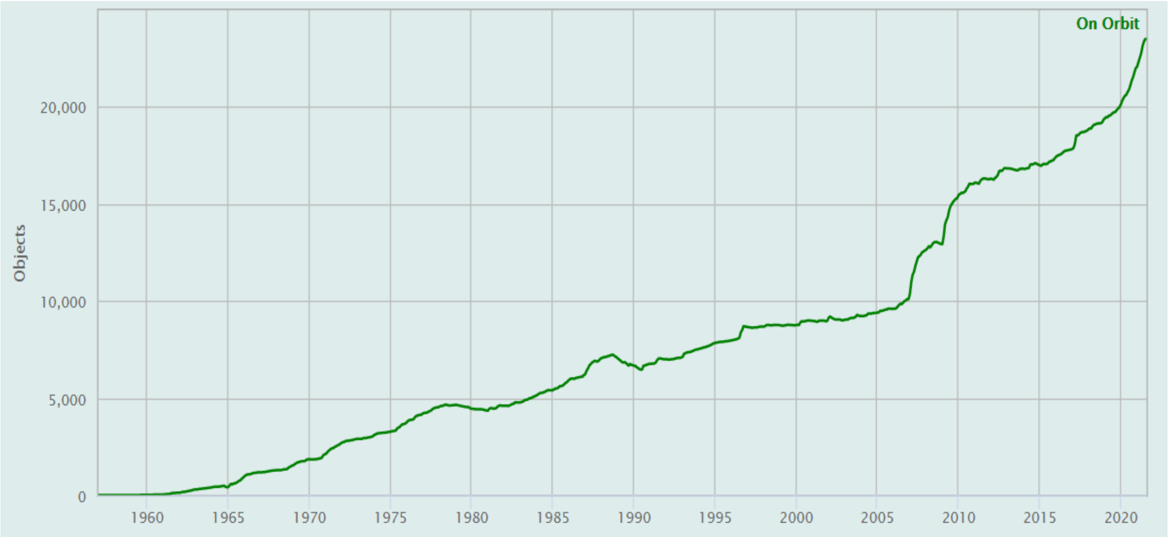
01

Aircraft Autonomous Navigation Requirements

1.Explosive Growth of the Spacecrafts

According to the Celestrak website, there were 7,937 satellites in orbit as of 2021 October 21. The number will increase at a phenomenal rate in the next coming years, due to the rise of Commercial Aerospace.

- SpaceX: Starlink plans to send 42000 satellites， with 1791 launched (Sep 14, 2021)
- Amazon: Project Kuiper plans to put 3236 satellites in orbit.

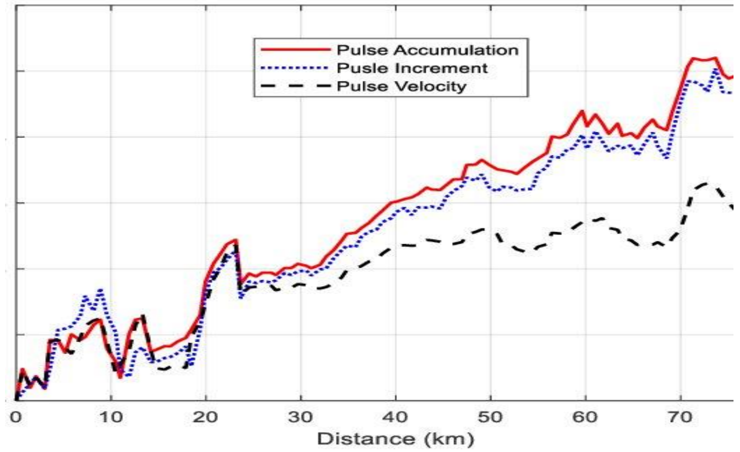


Statistics of on-orbit satellites from 1957 to 2021
（www.celestrak.com ）

2.Limitations of Traditional Spacecraft Measurement Methods

- **Ground/Sea-based spacecraft measurement and control network**
  - ✓ Large resource overhead and Long observation time
  - ✓ Difficult to support simultaneous measurement and control of many spacecrafts
- **Inertial navigation**
  - ✓ accumulated error
  - ✓ big challenge to achieve long-time high-precision navigation
- **Celestial navigation**
  - ✓ hard to acheive high precision
  - ✓ Small Angle Errors Cause Kilometer Level Position Deviations

Spacecraft Tracking Antenna



Inertial navigation accumulative error

3 .The Advantages of GNSS system in Space Application

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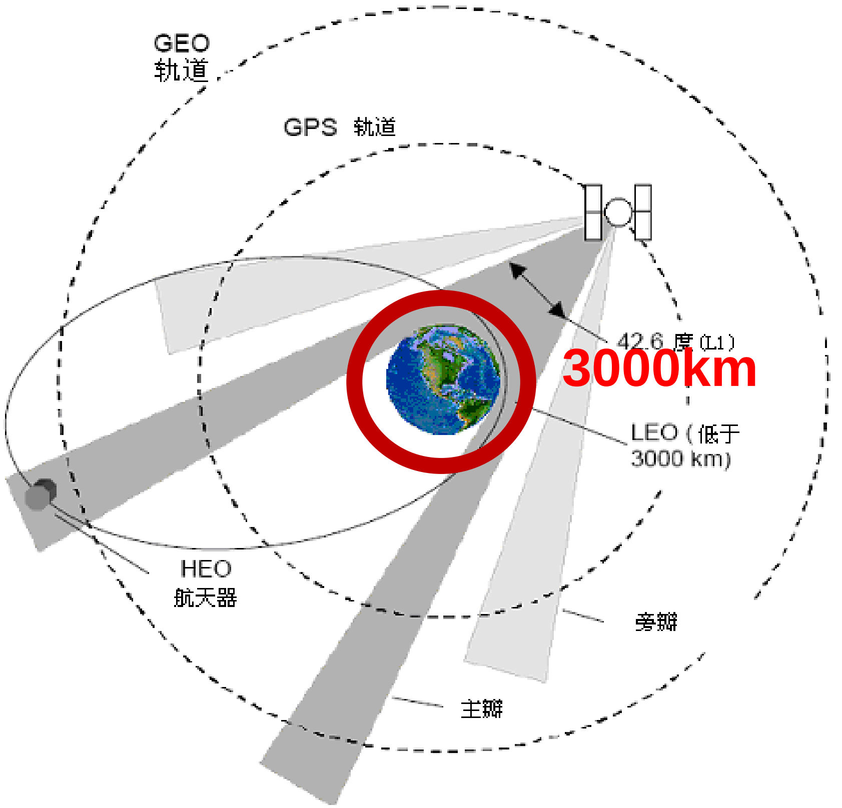
The satellite-borne GNSS receiver realizes the satellite autonomous orbit determination and position maintenance, effectively reduces the dependence on the ground station, and greatly improves the satellite on-orbit autonomous survival ability and usability.

- **LEO satellite(less than 3000km)：Location, velocity measurement, orbit determination**
  - ✓ Reduces the burden of ground TT&C networks and reduces the cost
  - ✓ High precision & real-time positioning and orbit determination
  - ✓ Autonomous GNC on satellite



GNSS service area division

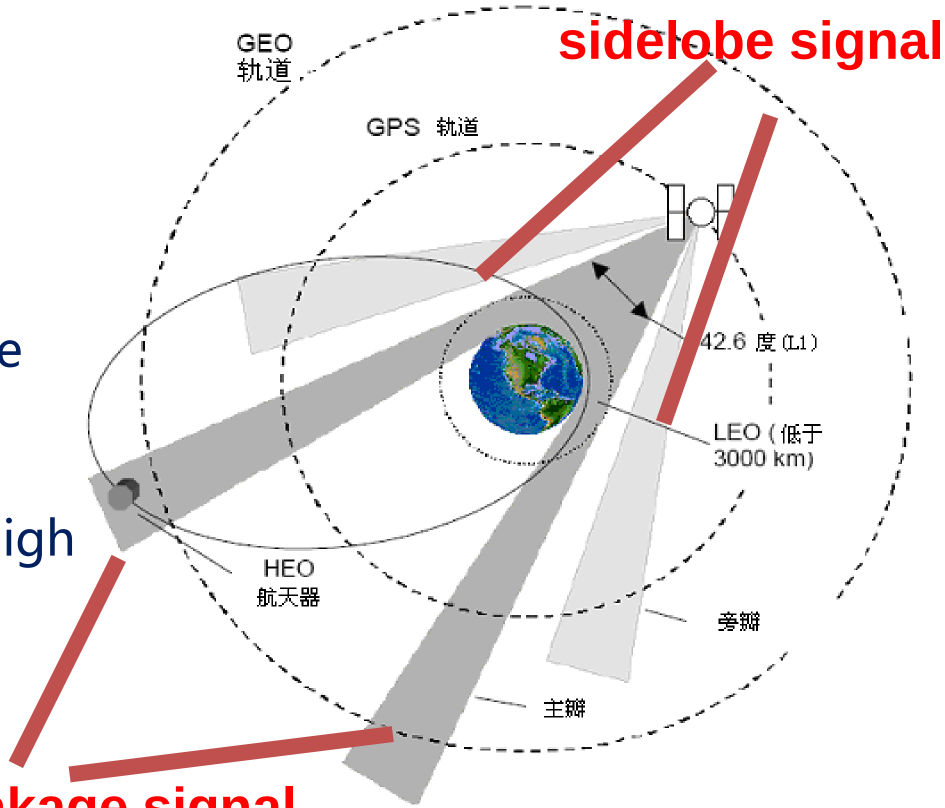
3 .The Advantages of GNSS system in Space Application

- The satellite-borne GNSS receiver realizes the satellite autonomous orbit determination and position maintenance, effectively reduces the dependence on the ground station, and greatly improves the satellite on-orbit autonomous survival ability and usability.

- **HEO Satellites (orbit altitude between 5000 to150000 km):**

Positioning Verification Based on GNSS Sidelobe Signal

  - ✓ High Sensitive Signal Receiving Using Sidelobe or Mainlobe Leakage Signal
  - ✓ Autonomous Navigation Measurement and Control with High Efficiency



GNSS Navigation using leakage signal

02

Challenges of Spaceborne GNSS Navigation

1. Precision

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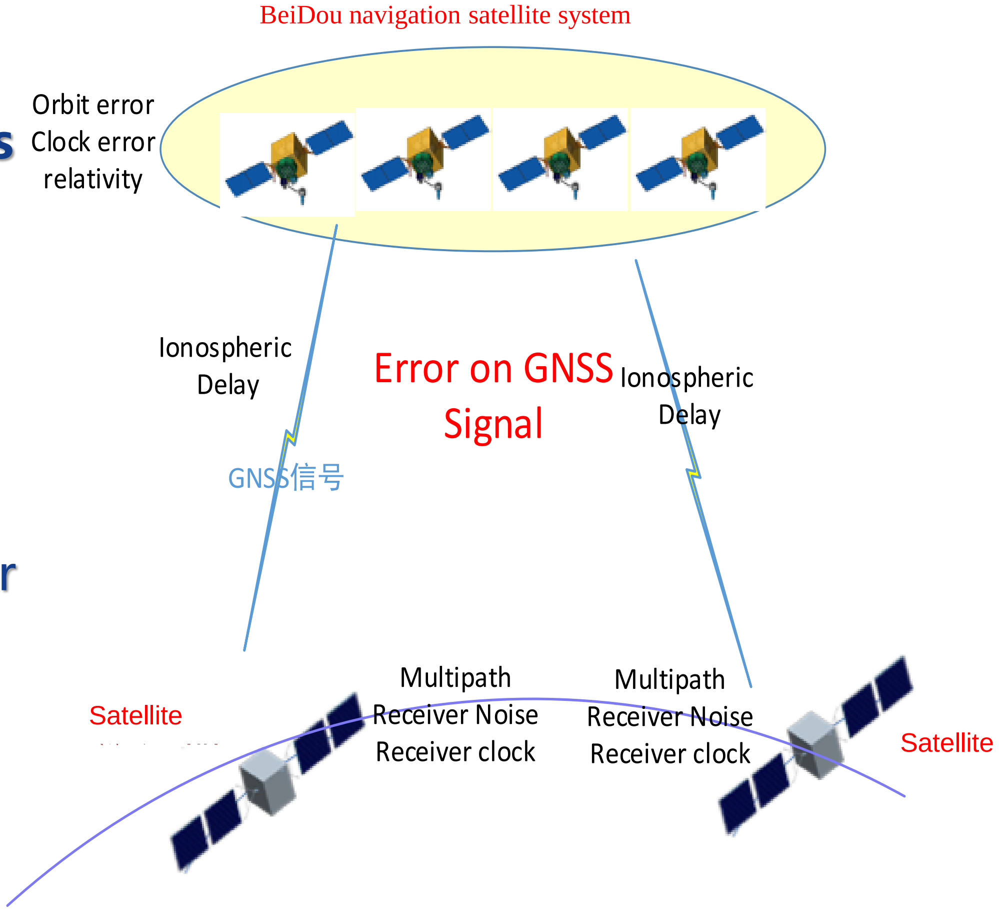
● Challenges

- ✓ **Space ionospheric effects**
- ✓ **Orbit error、Satellite clock error （Precise ephemeris is difficult to obtain)**

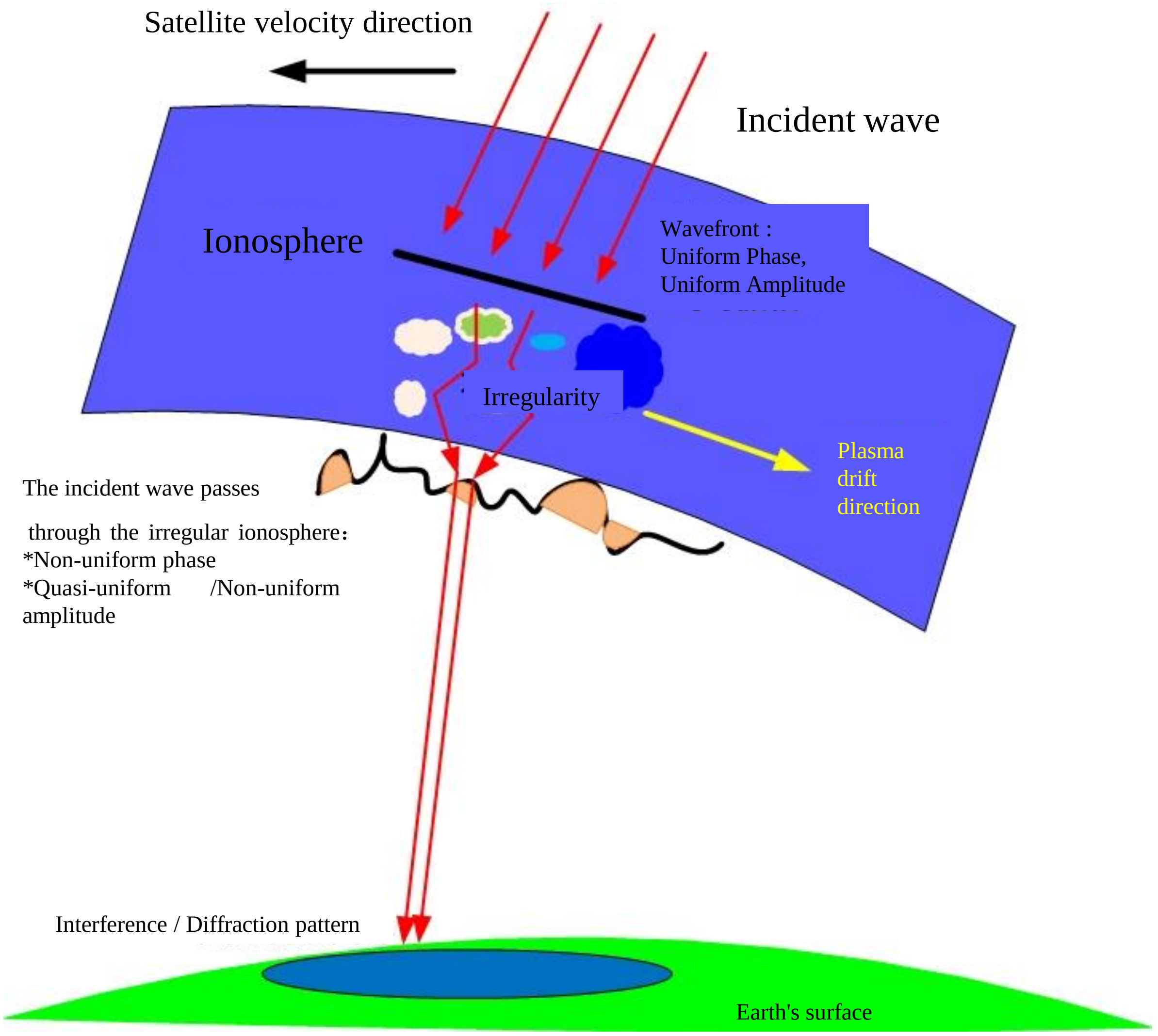
● Key Technologies

- ✓ **Orbit Determination Technology**: Orbital Dynamics Model, the positioning accuracy reaches meter level or decimeter level in real time, while it reaches centimeter level in post-processing.
- ✓ **Differential Measurement Technology**: Eliminating Error by Difference， the baseline measurement accuracy can reach centimeter level in real time and millimeter level in post-processing.



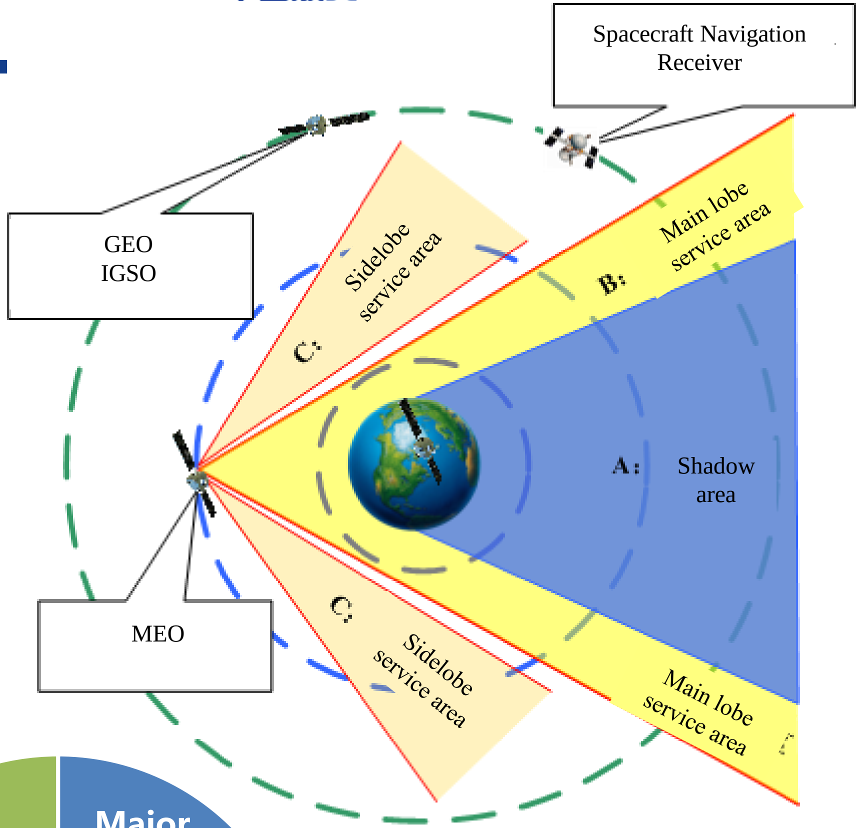
2. Reliability

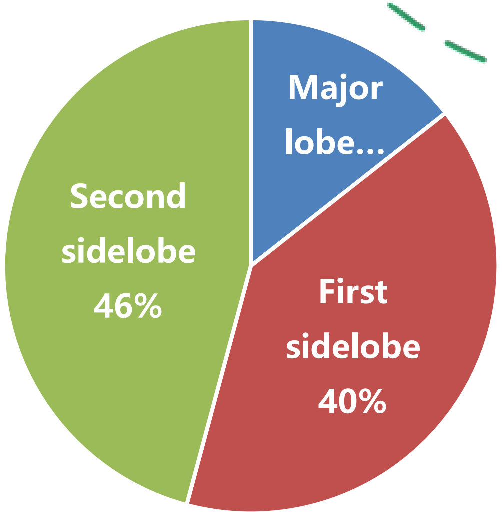
- **Challenges**
  - ✓ **Ionospheric Disturbance**
  - ✓ **Space radiation effects**
- **Key Technologies**
  - ✓ **Ionospheric Interference Suppression Technology**
  - ✓ **Autonomous integrity detection and recovery**
  - ✓ **Anti-space radiation design**



3. Availability

- **Challenges**
  - ✓ Weak signals，receiving earth opposite satellite signals or sidelobe signals
  - ✓ Few visible satellites、 poor DOP、 available arc segments are fragments
  - ✓ Dynamic signal changes
- **Key Technologies**
  - ✓ High-sensitivity signal acquisition and tracking technology
  - ✓ High-reliability orbit determination technology of high-orbit satellite





signal source

03

Space Application Cases of BeiDou System

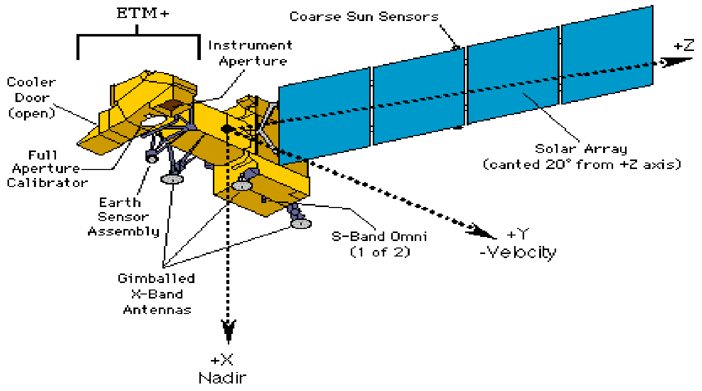
1. History of GNSS Navigation in Aerospace

In 1982, the Landsat-4 firstly validated on orbit is based on GPS service;

In 1995，high-precision GPS receiver was first used in Microlab-I by NASA;

In 2008，China’s first spaceborne BeiDou-1 receiver was applied；

In 2011，the first multisystem (supporting BeiDou) spaceborne receiver was carried by TG-1 space laboratory.



2. Application of BeiDou in LEO Orbit Determination

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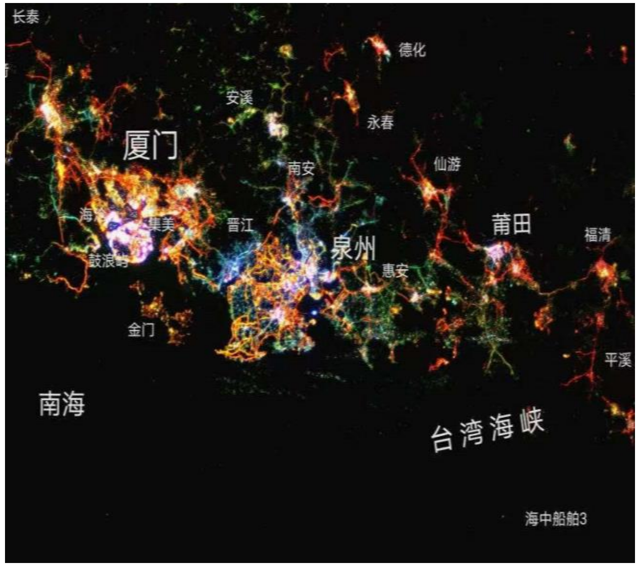
Application of Orbit Determination

Posterior Centimeter- Level Orbit Determination

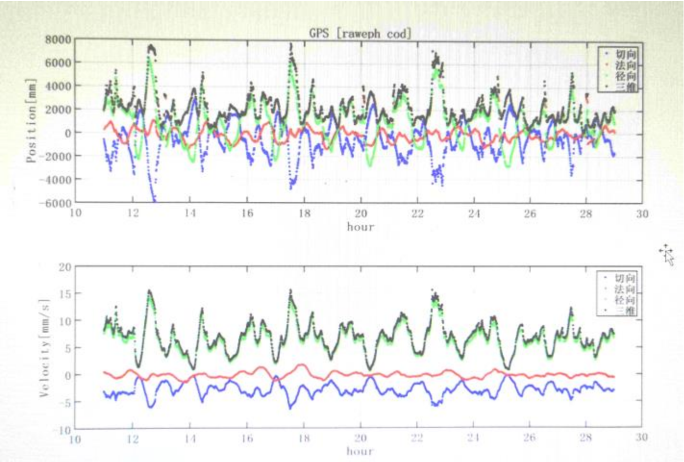
Combining the dynamic model with GNSS observations， Real-time meter-level orbit determination and posterior centimeter-level orbit determination can be realized, which is used in many fields such as Earth Observation, Communication and Retranslator Satellite.



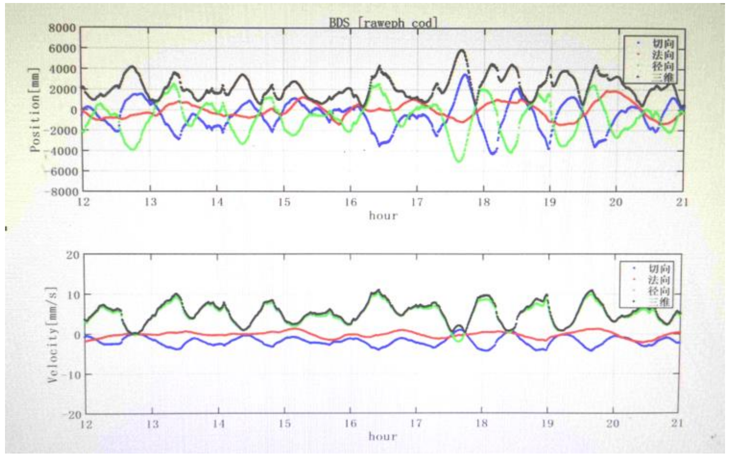
2. Application of BeiDou in LEO Orbit Determination

- **The precision of BeiDou spaceborne receiver is equivalent to that of GPS spaceborne receiver.**

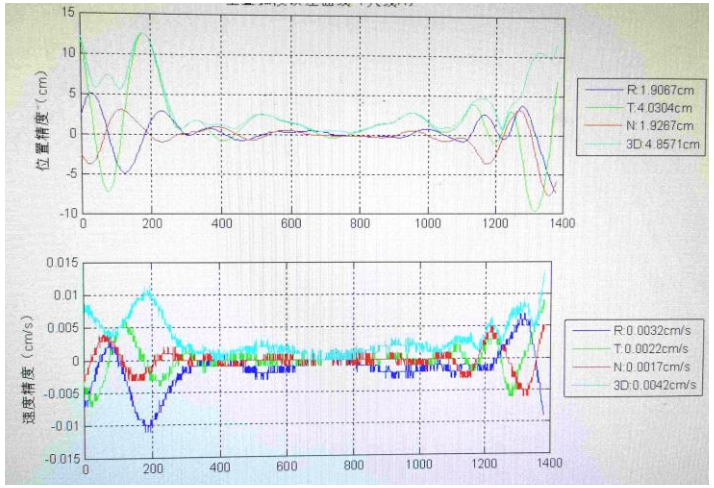
GNSS System	Posterior Orbit Determination	Real-time Orbit Determination
BDS	4.4cm~6.3cm	2.6m~5.0m
GPS	4.8cm~5.9cm	2.4m~4.7m



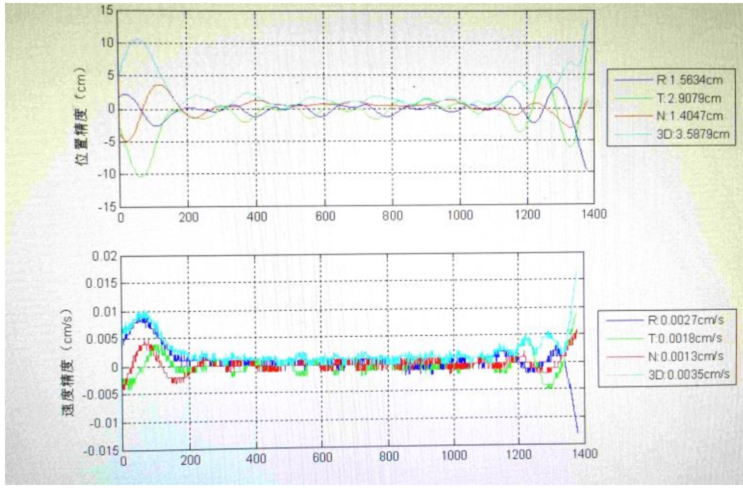
GPS real-time OD



BDS real-time OD



GPS Posterior OD



BDS Posterior OD

3. Space Relative Measurement

Rendezvous of Space Station

Relative Measurement High-precision Synchronization

- **Name:** Relative Measurement GNSS Receiver
- **Function:** Relative position and relative velocity measurement with high-precision and high-reliability
- **Key technology:** Carrier phase relative measurement with moving baseline
- **Applications**: Docking of TianHe space station with cargo spacecraft

  Pseudo-range accuracy: 0.5m (rms)

  Carrier phase accuracy: 0.0027m (rms)

3. Space Relative Measurement

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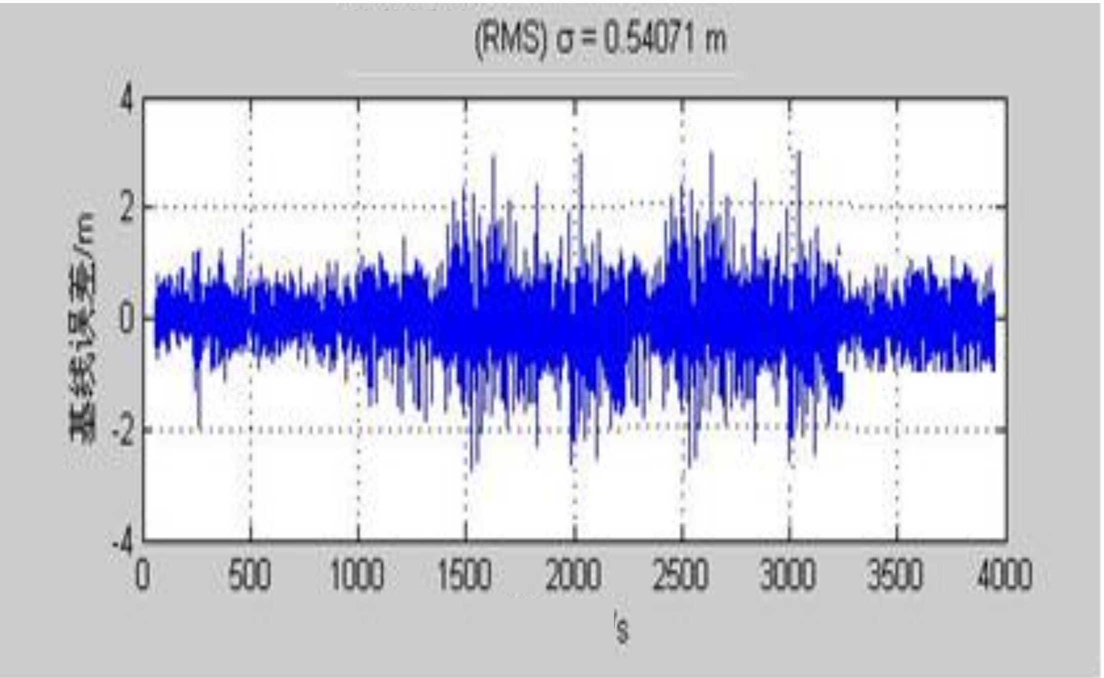
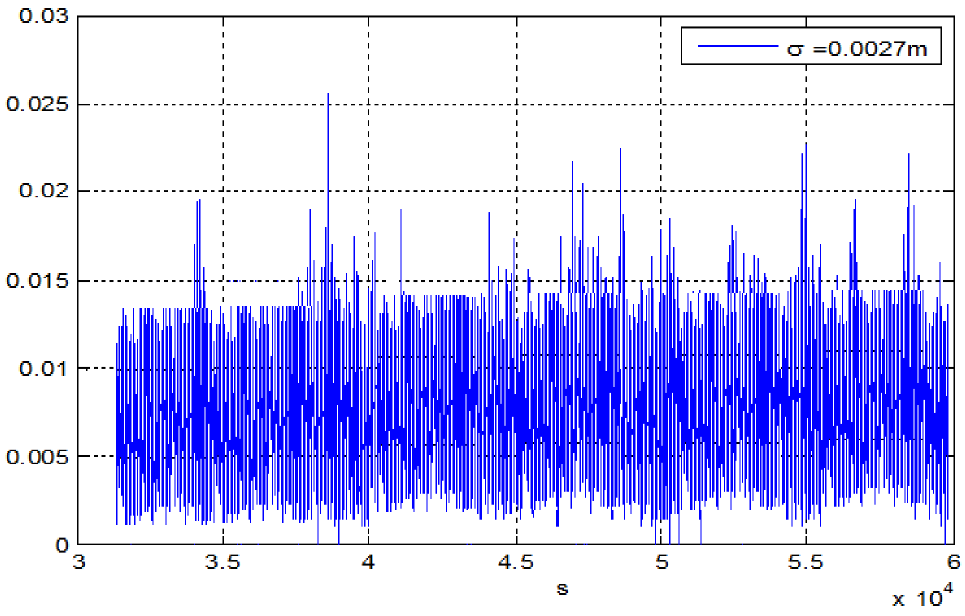
- **Analysis of Relative Measurement Accuracy based on BeiDou.**

Pseudo-Range Difference



Carrier Phase Difference



4. Navigation for High Earth Orbit

High Earth Orbit / Lunar GNSS Receiver

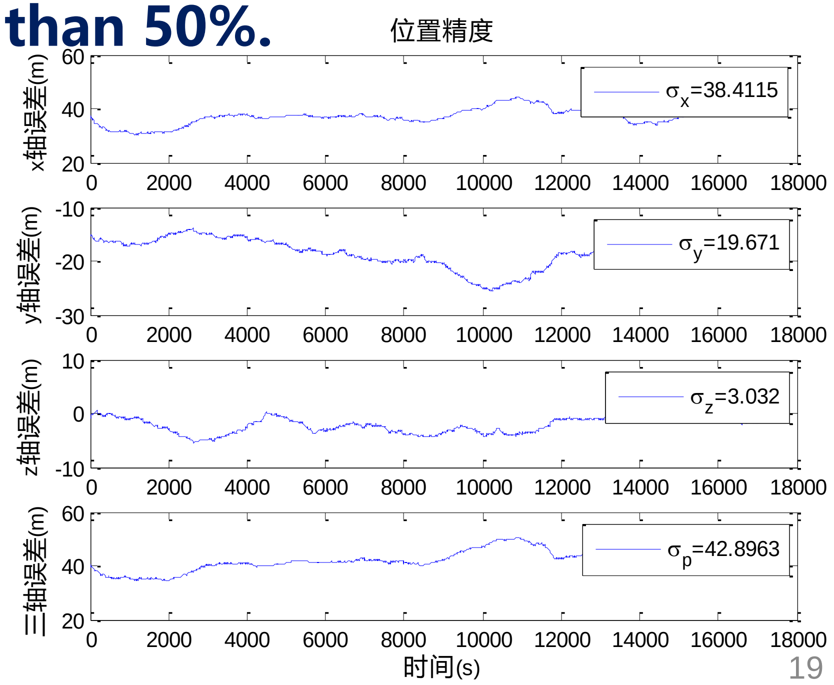
- **Name:** Weak Signal GNSS Receiver
- **Function:** Orbit determination of high orbit spacecraft
- **Key technology:** Weak signal receiving technology for GNSS sidelobe
- **Applications:** High-orbit communication satellite, High-orbit remote sensing satellite, lunar exploration, etc..

Mainlobe Signal
Sidelobe Signal

4. Navigation for High Earth Orbit

The Latest Application of BeiDou in HEO Spacecraft

BeiDou service has been successfully applied to several communication satellites, and the application field is extended from below 1000km to more than 36000km, realizing GEO satellites' autonomous positioning and timing. The orbit measurement efficiency is increased by more than 50%.

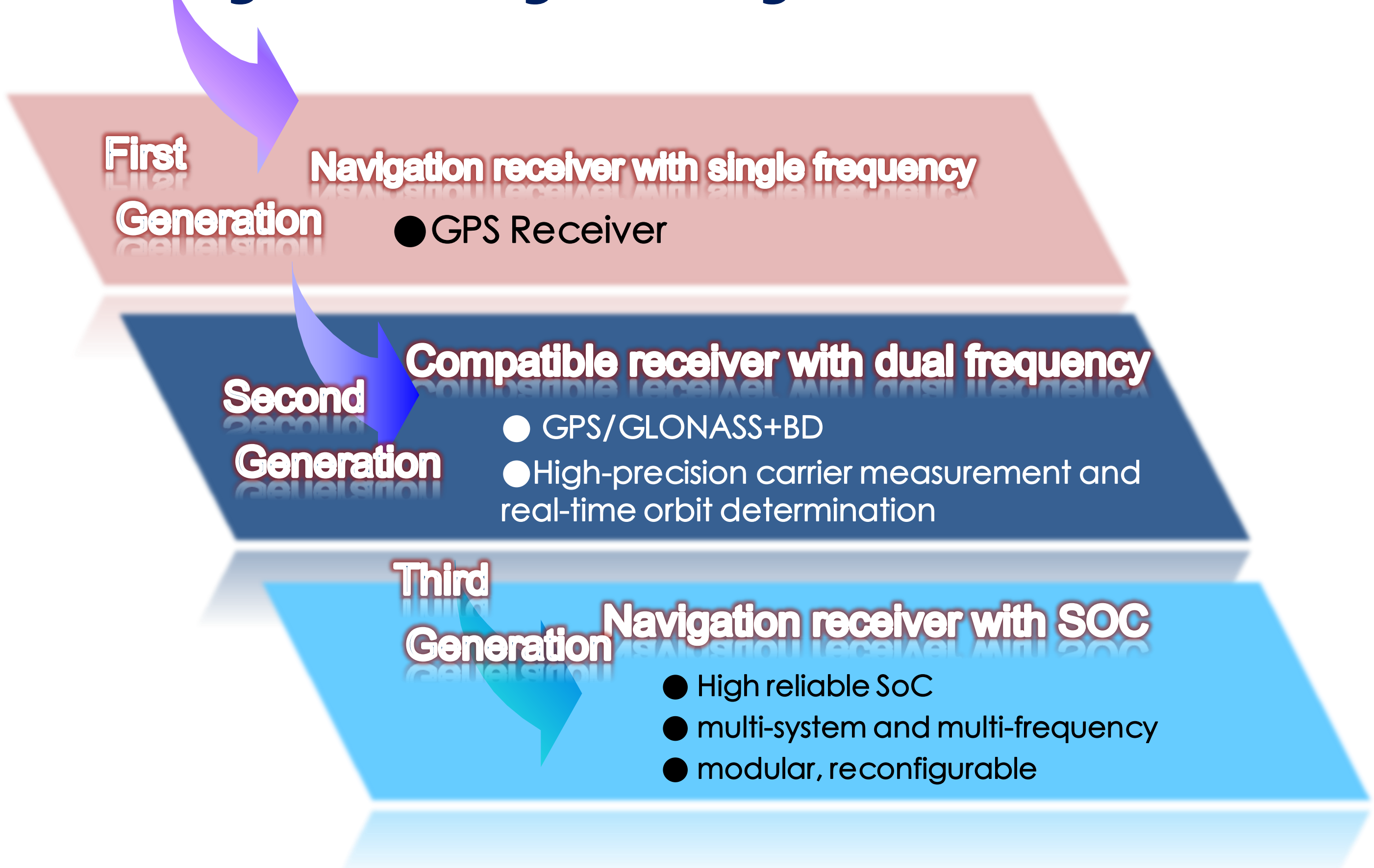


- **Technical Index:**
  - ✓ Position accuracy: 50m
  - ✓ Velocity accuracy: 0.1m/s

5. Development of China's Space Navigation Products

After 24 years of development, China Spaceborne Receiver has developed into many kinds of products according to different uses. Three typical satellite receiver products include navigation, measurement and orbit determination. The development of spaceborne receiver has gone through three generations.

- Navigation
- Measurement
- Differential Positioning



04

Anticipation of the Future

Anticipation of the Future

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- **Accuracy improvement – 60,000 km space provides autonomous navigation services better than 100 m**
  - ✓ The antenna gain increases 3 ~ 5dB.
  - ✓ Multi-mode GNSS receiver guarantees the performance of high-orbit space service.
  - ✓ A-GNSS information assistance technology to enhance signal acquisition and tracking sensitivity.

- **Satellite Communication + RNSS - Integrated Navigation,Positioning,Measurement and Control Transmission**
  - ✓ Autonomous navigation of aircraft.
  - ✓ Bidirectional transmission of measurement and control data.
  - ✓ There is no need to build overseas stations to achieve global measurement and control.


Thanks for Your Attention!