# R&D for Satellite Navigation

NICT, JAXA and some institutes are working for R&D on satellite navigation.

NICT focuses the effort on T&F technology;

**ETS-Ⅷ** (Engineering Test Satellite 8), and

**QZSS** (Quasi Zenith Satellite System)

also possibe for highly-precise comparison between separated frequency standards

# Background of the project

- Is it necessary for Japan to develop own satellite positioning system ?

  1997 report from Space Activities Commission, Japan

  "research and development of following three technologies;

  ↓

  1. on-board atomic clock → small H-maser by NICT
  2. time management of the satellites

     → monitoring of on-board Cs clock of ETS-8 by JAXA & NICT,

     and precise time comparison experiment by NICT
  3. precise orbit determination → ETS-8 by JAXA

  ↓

● QZSS project has started since 2003

by the government (4 ministries) → positioning/navigation mission

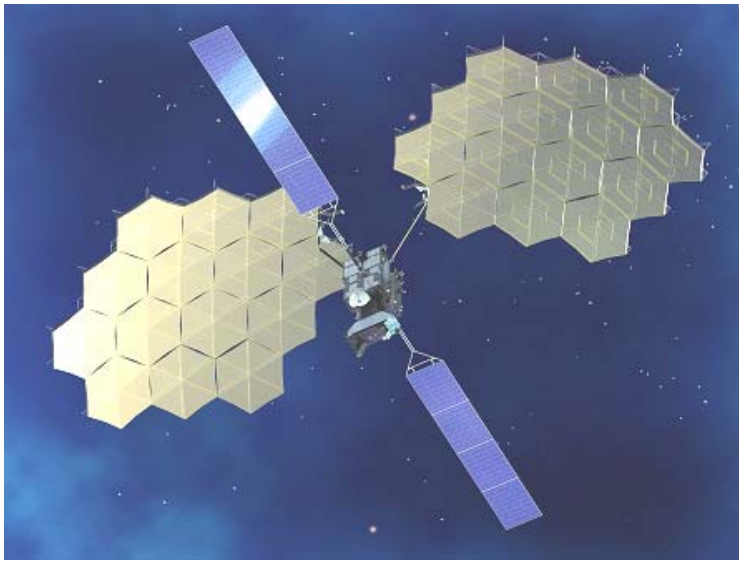
JAXA: Japan Aerospace Exploration Agency

# What is ETS-VIII ?



launched on Dec. 2006
has 2 on-board Cs clocks.

one of the main missions is;
establishing satellite navigation/positioning technology



**NICT's missions are;**

- Two-way T&F comparison between ETS-8 to the ground station for precise monitoring of the on-board clock

  Aimed sub-nano sec for code phase measurement,

  $10^{-11}$ order for carrier phase mearsurement

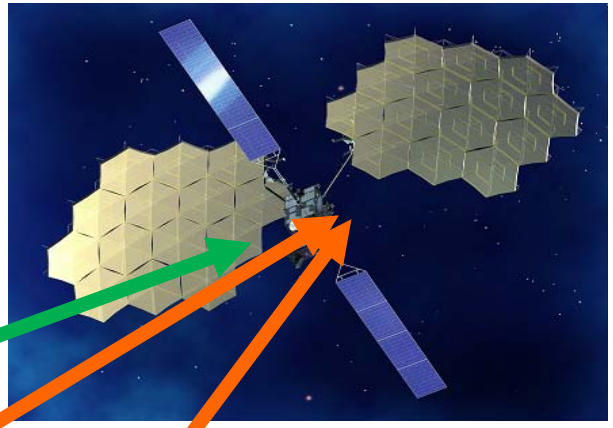
- Applying above method,
  precise ground-to-ground T&F comparison is also possible

# Equipments for ETS-VIII



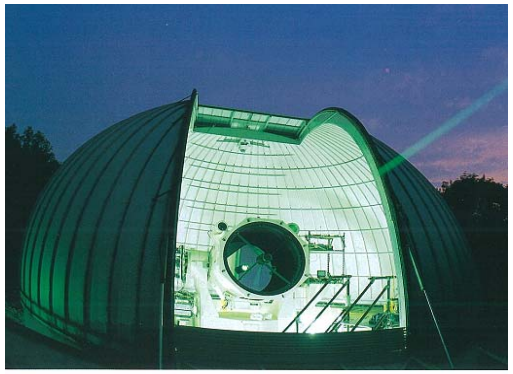
on-board precise time comparison equipment (TCE)

ETS-VIII



S-band: two-way (up and downlink)
L-band: downlink

Ionospheric delay can be compensated by using two frequencies

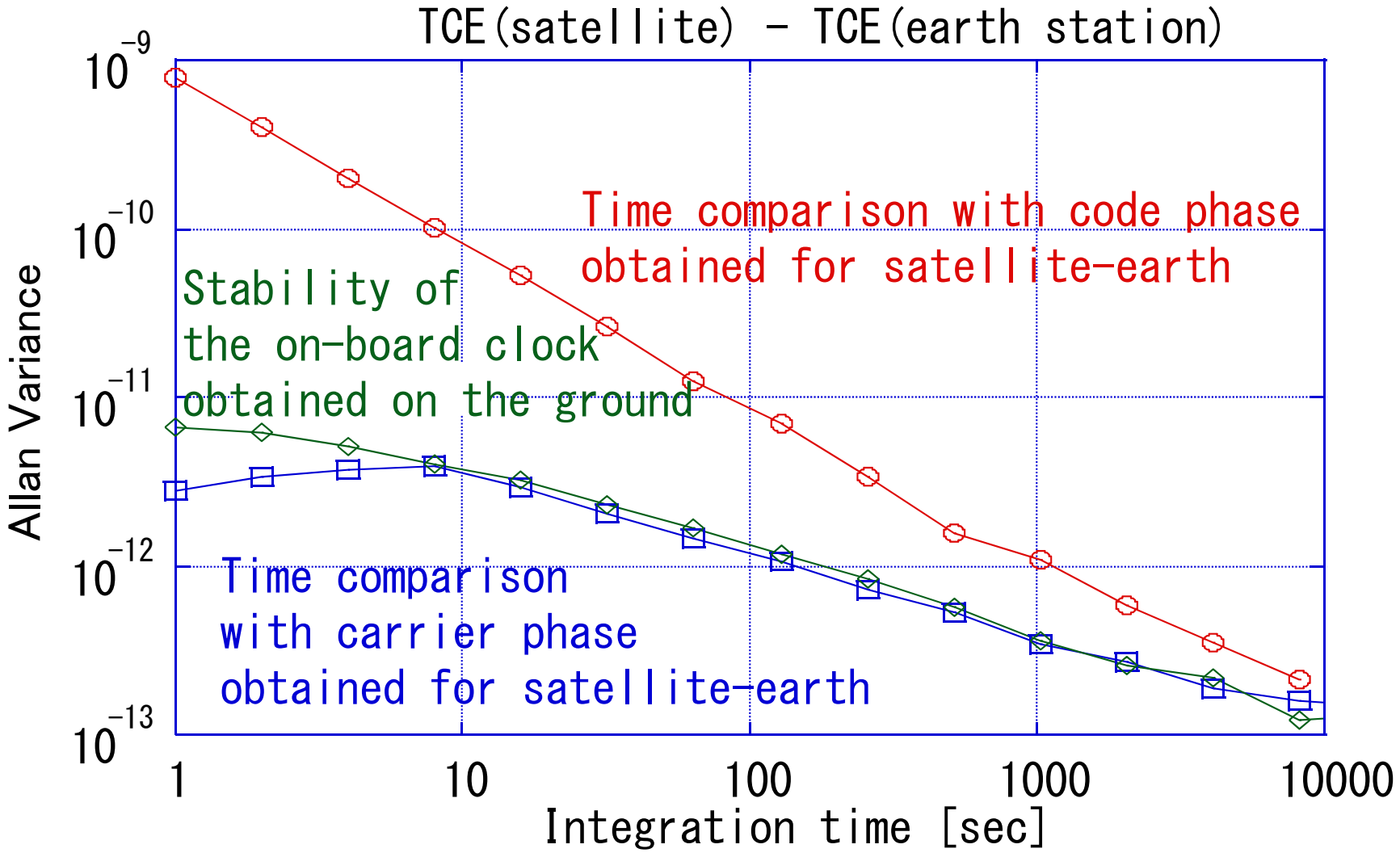


SLR
(Satellite Laser Ranging)

Earth stations
Fixed station Transportable station

# Measurement performance was confirmed

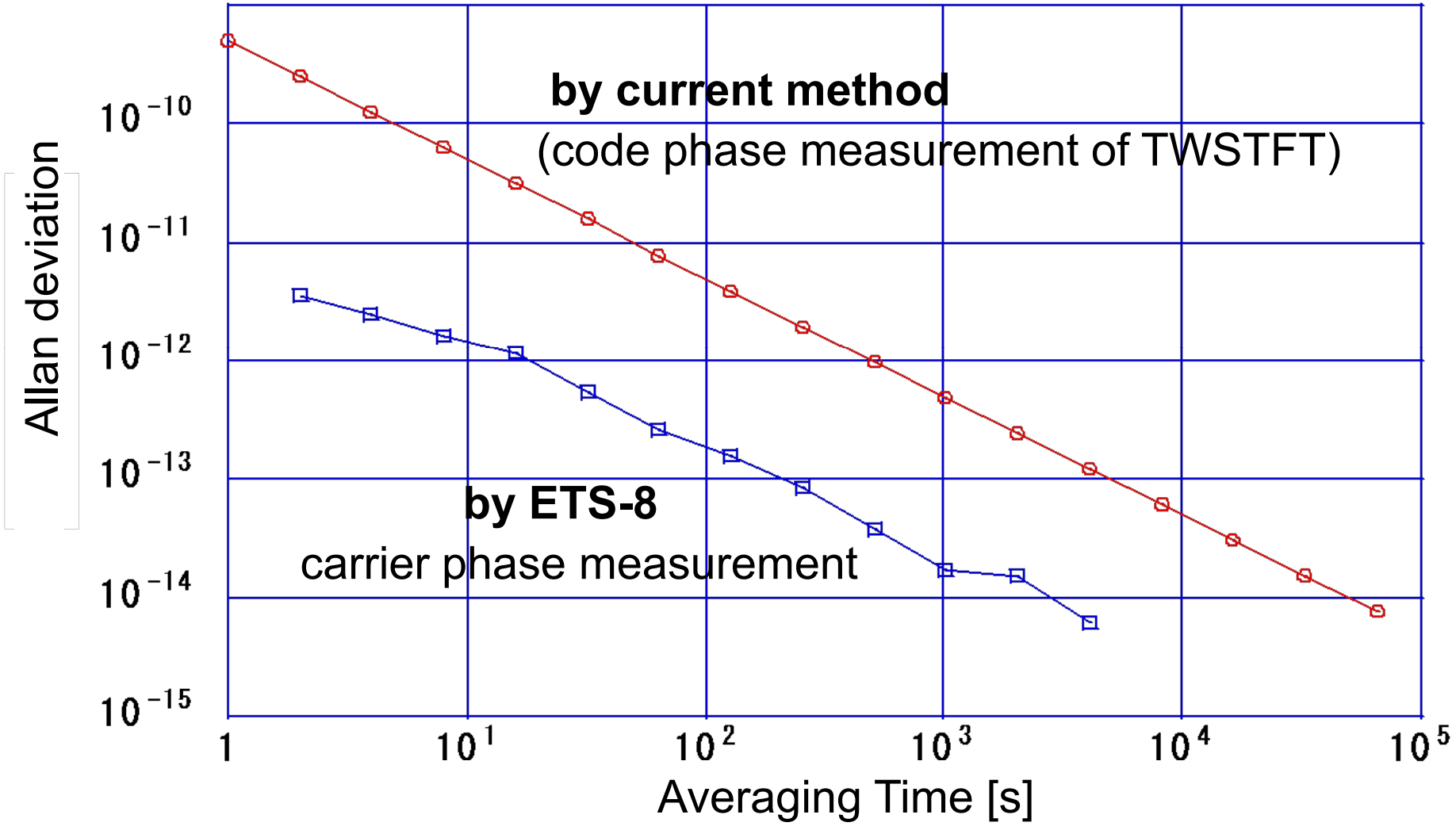




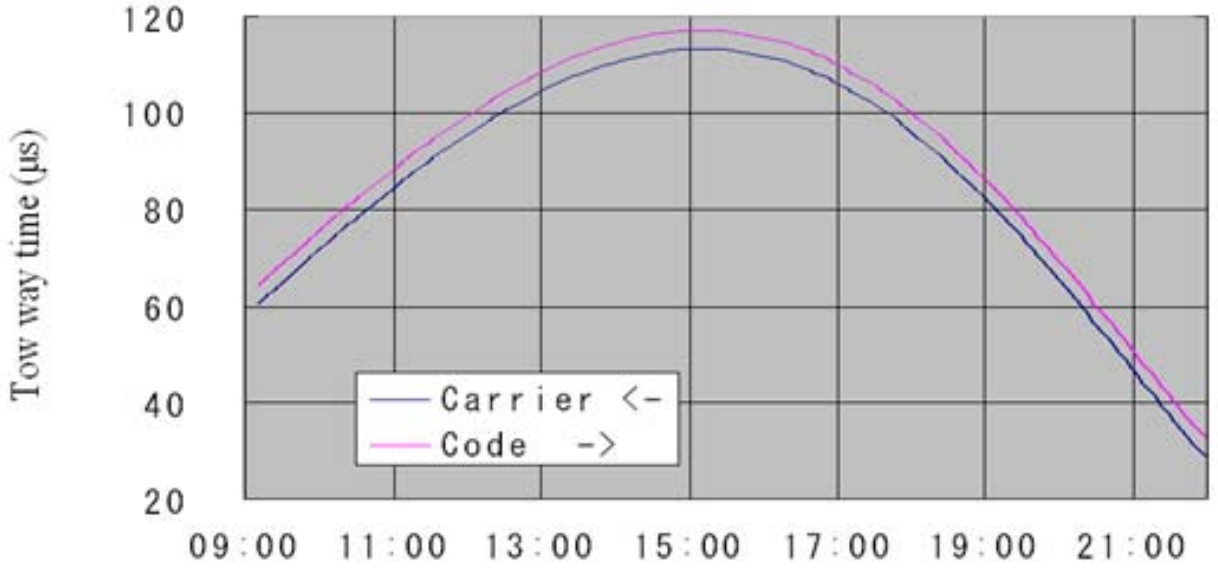

- 0.7ns@1s for code phase mearsurement
- $3 \times 10^{-12}$@1s for carrier phase mearsurement

# Example of gGround-to-ground comparison

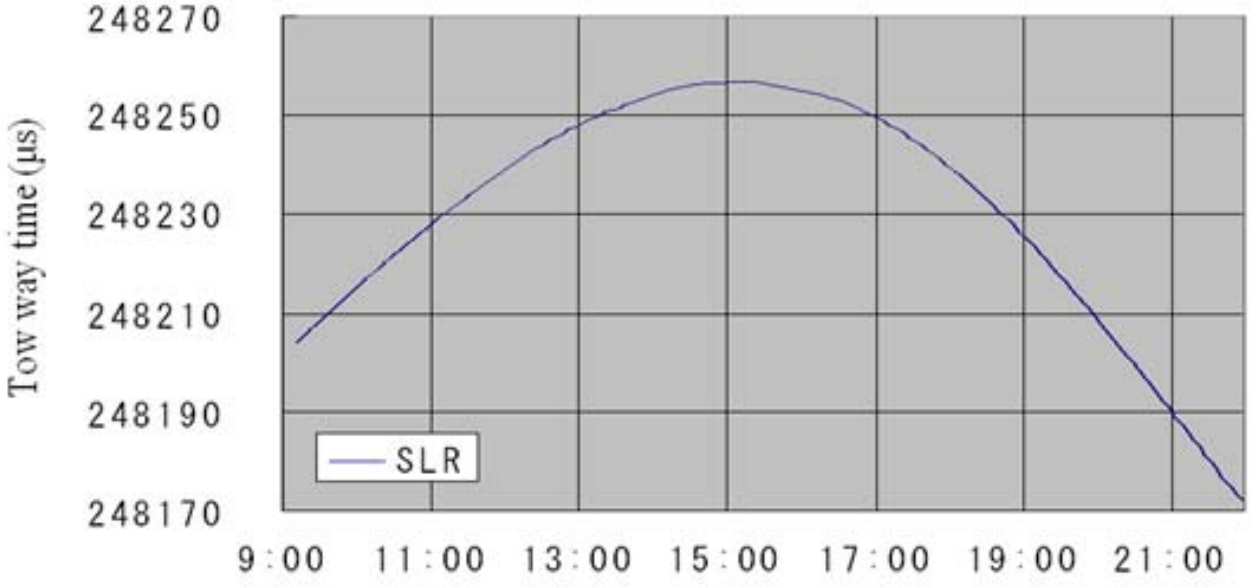
- station A to ETS-8 + ETS-8 to station B = station A to station B
- 2 order improvemnt compared to the ccurrent method
- can be used for comparison of precise atomic clocks



# Ranging measurement (ETS-8 to the ground)




measured by ETS-8
(relative values)




measured by SLR

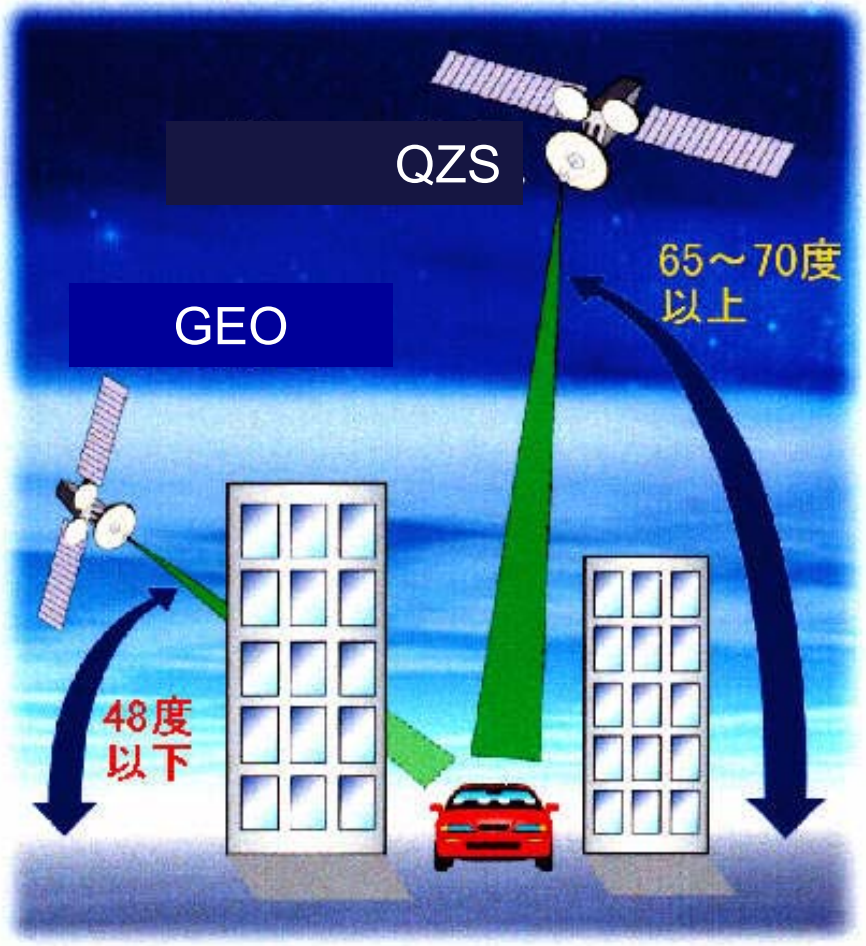
The RMS of the fluctuation of the difference (ETS-8 vs SLR) is within 1m

# Why QZSS ?



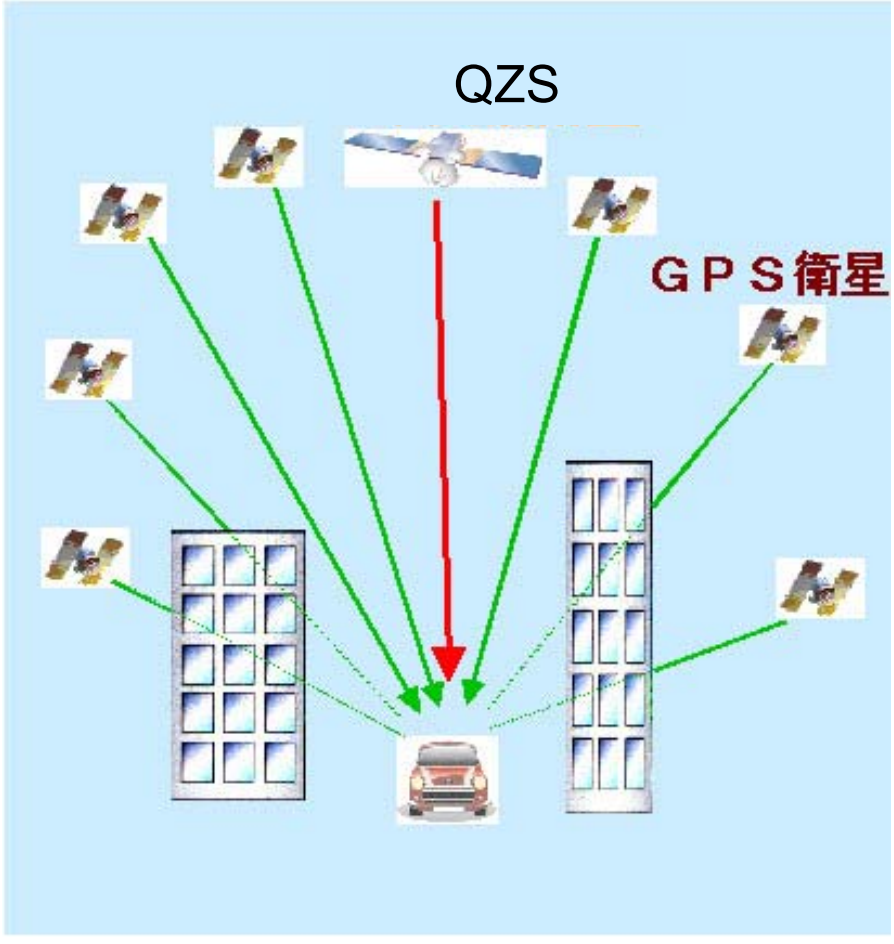
## Broadcast, Communication, Navigation service from overhead

### Broadcast & Communication




avoid blocking & shadowing

### Navigation & Positioning




improve visibility & GDOP

# What does NICT do ?

## ➢ Time management for satellite navigation

- Precise delay measurements
  - – between the satellite and the ground stations
  - – between on-board atomic clocks
  - – between the L-band navigation signals (L1, L2C, L5)
- New TWSTFT method using Bent-pipe function
- on-board Hydrogen Maser

(Engineering Model (EM) was developed to show that the EM endures space environment test)

↓

## ➢ Interoperability with GPS

# QZSS orbit

period：23 hours 56 minutes
(geosynchronous)
inclination：43±4 degrees
eccentricity：0.075±0.015
（preference for Japan）
orbital planes：3 (spacing 120º)
central laltitude：135±5 deg.E

For details, see “IS-QZSS” in
http://qzss.jaxa.jp/is-qzss/index_e.html

proposed orbit

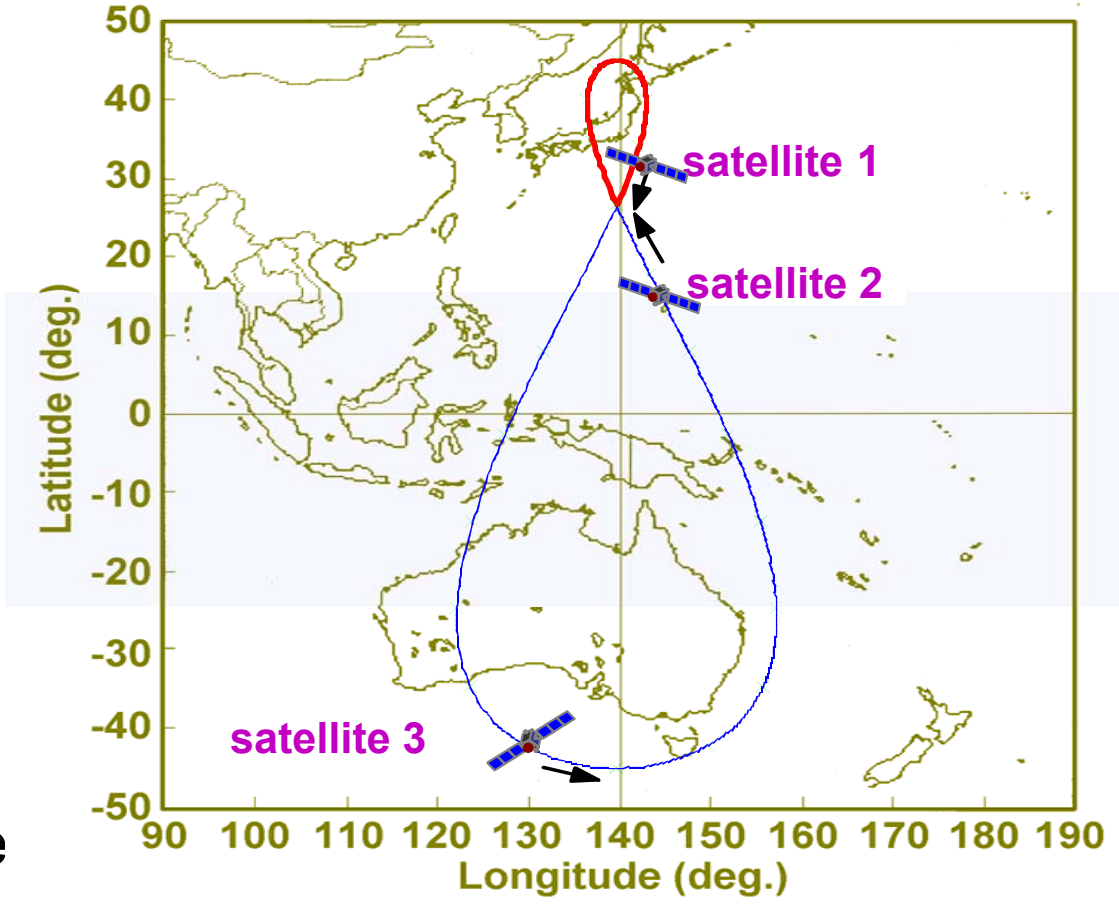
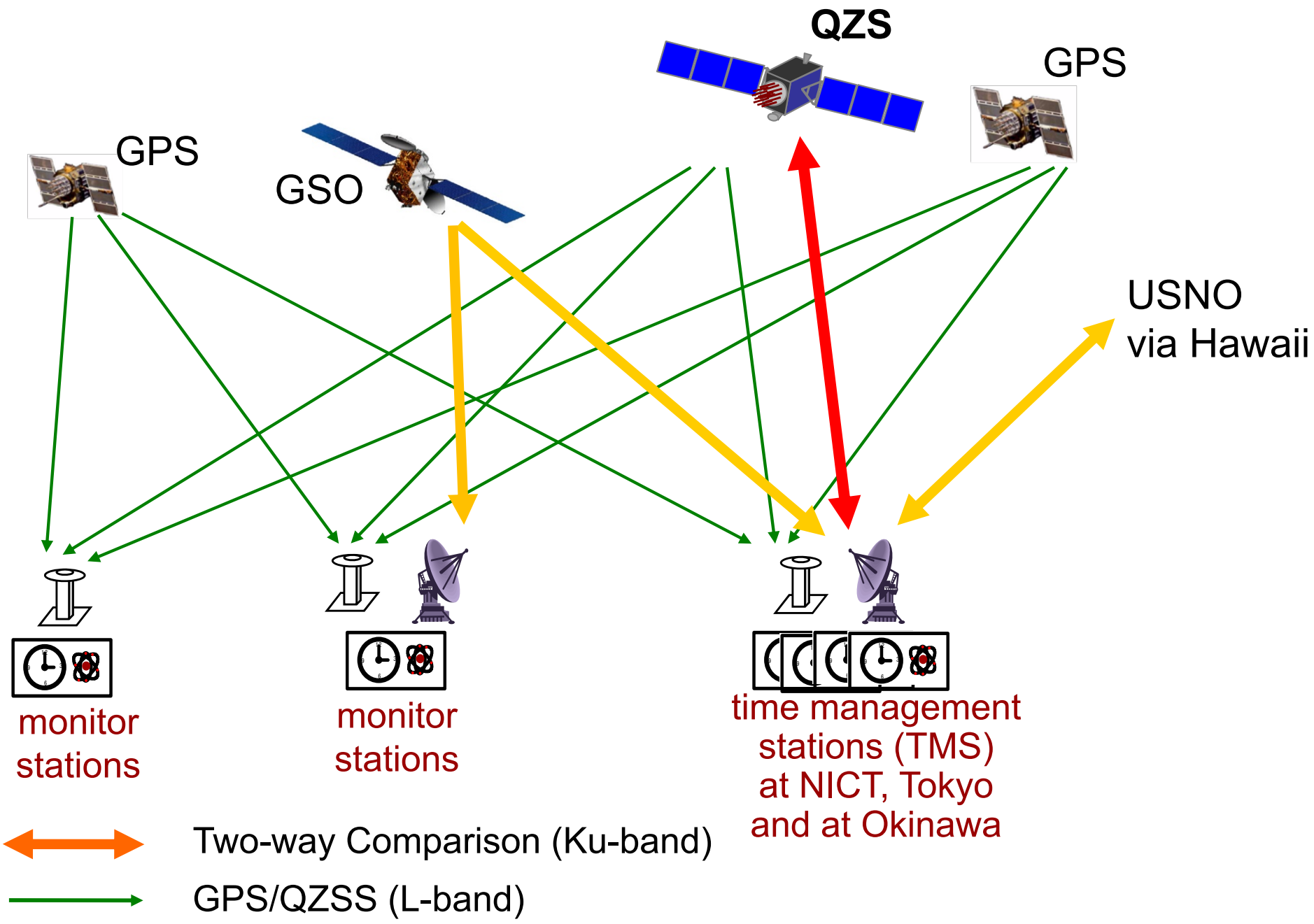



Figure “8”

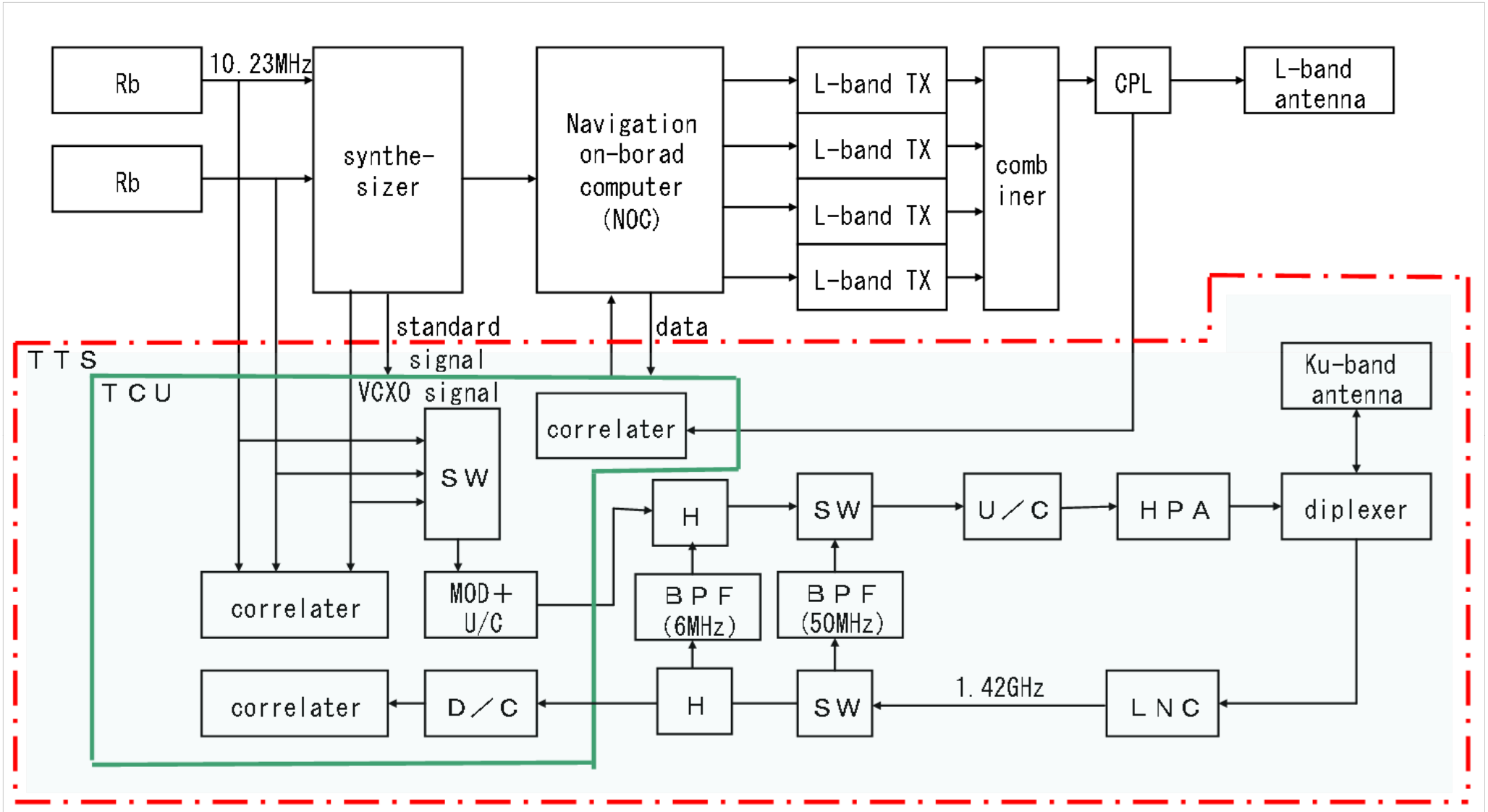
3 satellites are needed for 24 hr service

The 1st QZS is to be launched in 2010.

# QZSS configuration



# Block Diagram of the On-board Equipment



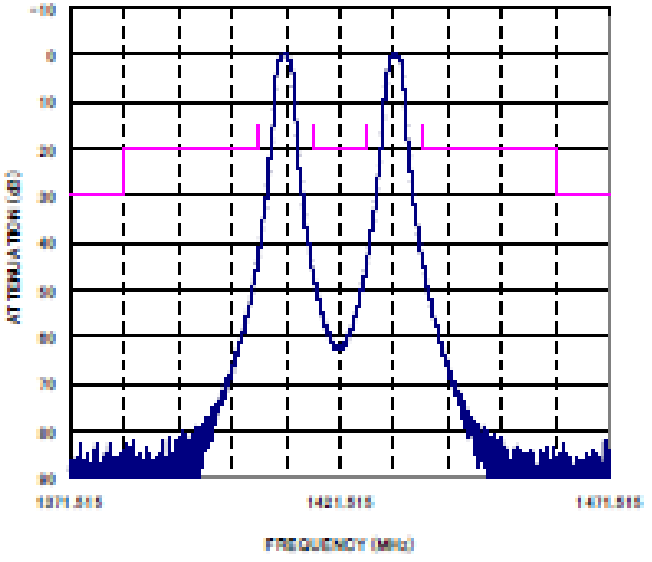

TTS : precise Time Transfer Subsystem by NICT, TCU: Time Comparison Unit
HPA : High Power Amplifier, LNC : Low Noise Converter

**developed by NICT**

# Bent pipe Function

- Two types of bent pipe (BP) function for TWSTFT using a non-GEO satellite

| | narrow band BP * | wide band BP |
|---|---|---|
| Bandwidth (99% power) | 6 MHz x 2 (20.46 MHz separated) | 50 MHz |
| Chip rate | 2.046 Mcps x 2 BOC(10,2) | 10.23 Mcps |
| spectrum overlap with regular signal | not overlapped | overlapped |
| comment | equivalent to a wideband | conventional |
| BPF (@1.4GHz band) | coaxial interdigital | microstrip |



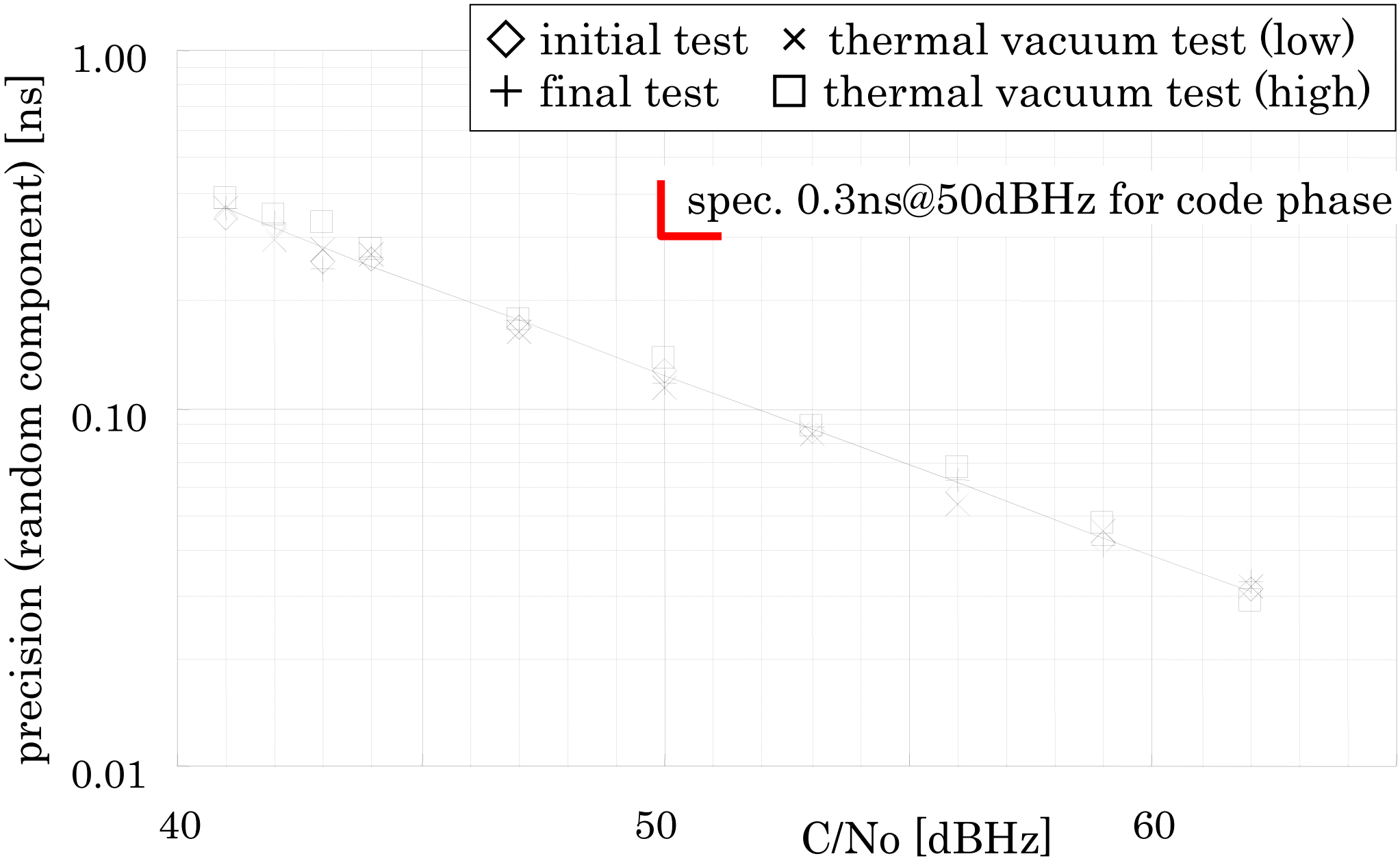
frequency response of the narrow band BPF

* see Amagai, ATF 2008

BOC: Binary Offset Carrier

# C/No vs. two-way precision (time comparrison unit)





# Ground Segment design

- System design includes;
  Configuration, functions, operation of the ground stations
  Data communication with master control station (MCS)
  Studying time link to GPST and UTC(USNO)
  Emergency operation management
  Link cessation to meet RR

- Development
  Install TMS Koganei and Okinawa
  TWSTFT in some monitor stations
  (Two domestic, one in Hawaii)
  Joined JPL realtime GPS network

TMS antenna at Koganei

# Domestic ground stations



Sarobetsu
monitor station

Okinawa
(26.5N, 127.9E)

QZS is visible
for 24 hours

Koganei, NICT
(35.5N, 139.5E)

maintain UTC(NICT) with
18 Cs clocks

ChiChi-jima
monitor station

# Functions of the ground stations

| Location | | Japan | | | | USA | | Australia | Thailand | India |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Koganei | Okinawa | Sarobetsu | Chichijima | Hawaii | Guam | Canberra | Bangkok | Bangalore |
| TMS | Ku-band Two-way | O | O | | | | | | | |
| L-band Monitor | | O | O | O | O | O | O | O | O | O |
| TWSTFT (GEO) | | O | O | O | O | O | | | | |

* MCS is installed at Tsukuba, Japan by JAXA

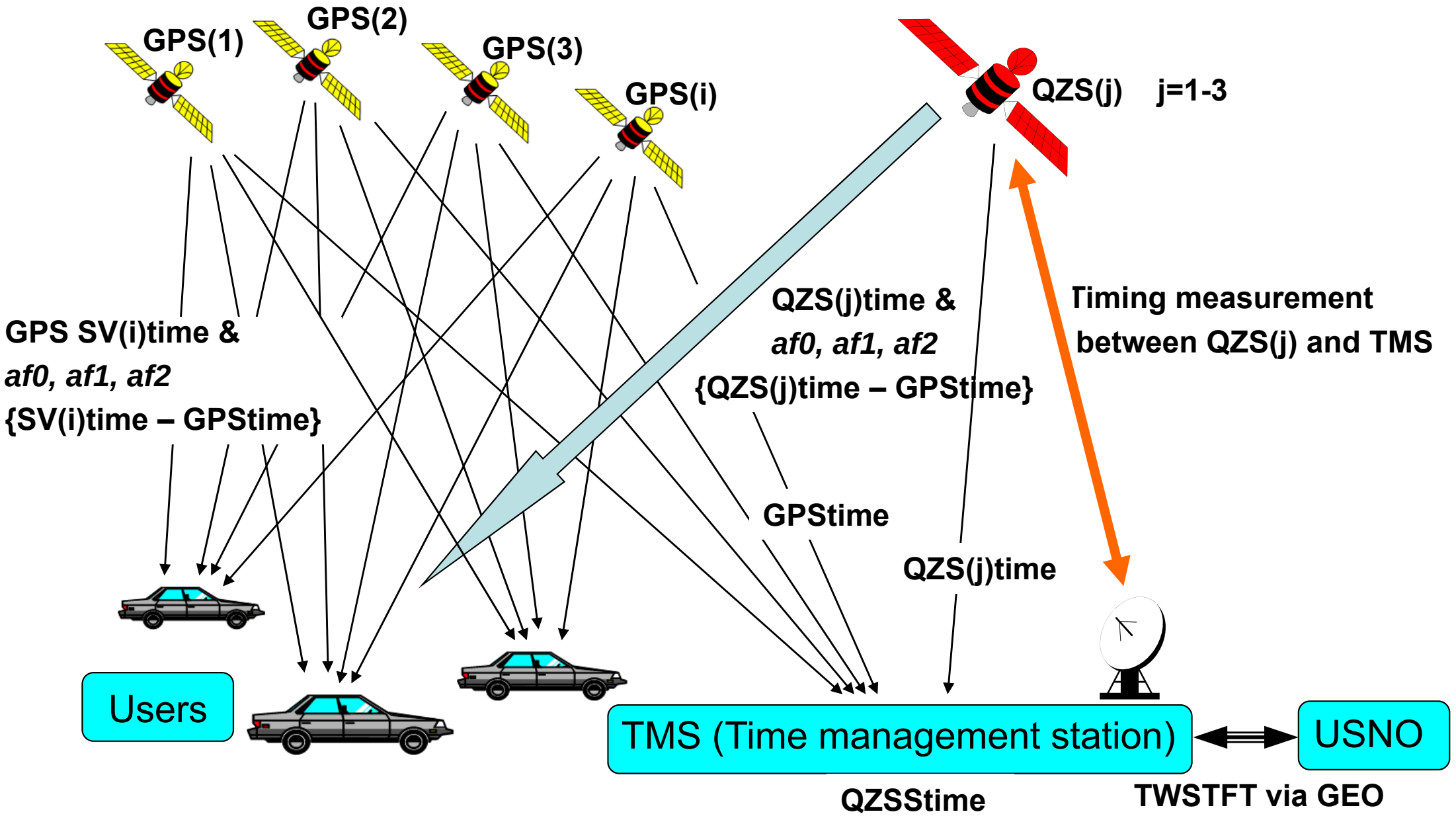
** TTC station is installed at Okinawa, Japan also by JAXA

# QZSS time and UTC(NICT)

for interoperbility between GPS and QZSS,

- QZS broadcasts “SV time - GPST”
- QZS broadcasts “SV time - UTC(NICT)”
- UTC(NICT) is intended to meet UTC +10/-10 ns
- UTC(NICT) is to be compared to UTC(USNO) by TWSTFT (via Hawaii)
- QZSST is defined at some point in TMS Koganei, and will be defined as an ensemble time in the future

# Image of interoperability with GPS



# Thank you for your attention.

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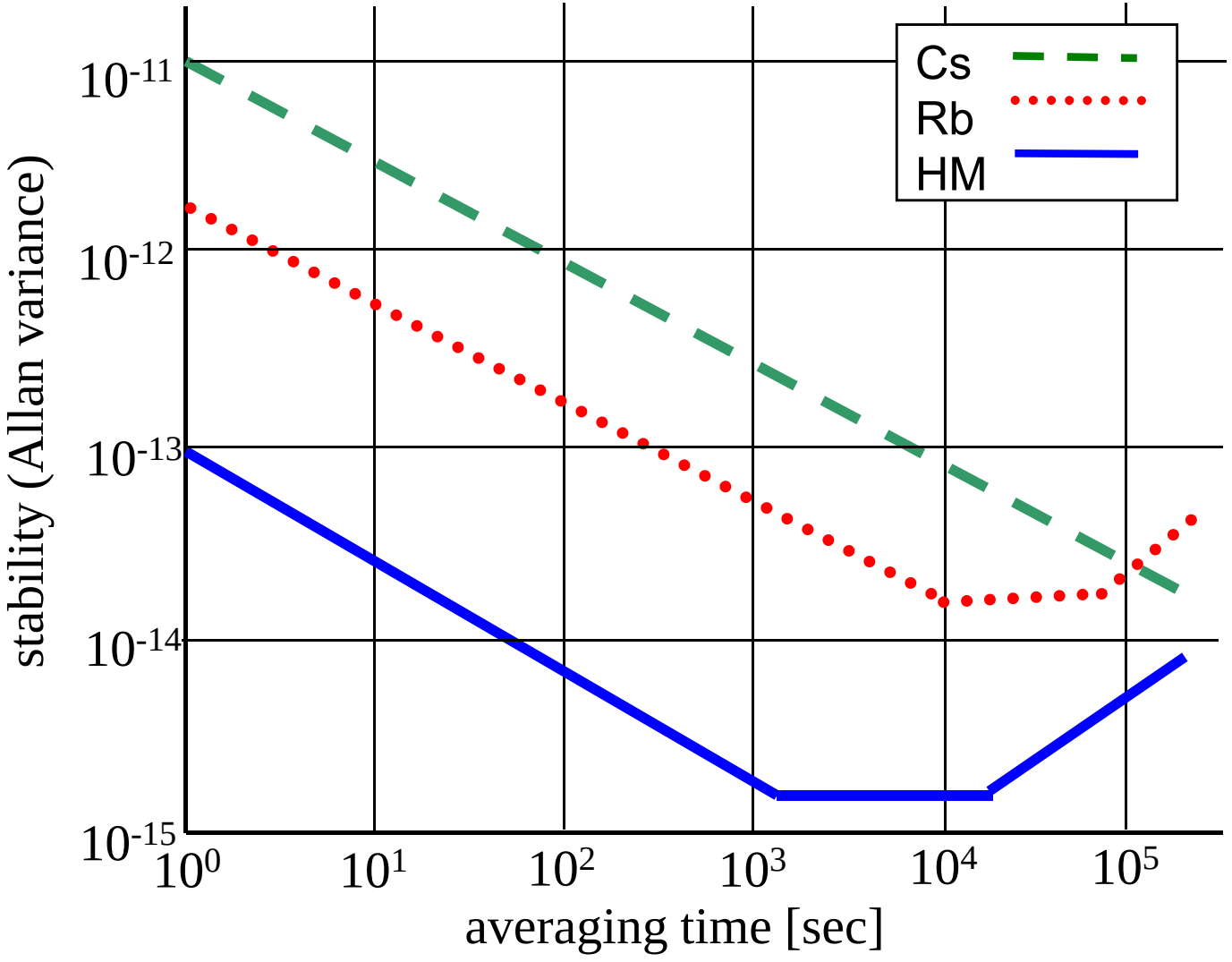
# Stabilities of typical atomic clocks






HM (hydrogen maser) is adopted as an experimental atomic clock for QZSS.
Rb clocks are used for practical use.

# Issues to achieve the specs of the HM



- Developed a BBM in 2003 to study how to achieve the specs

  - Downsizing (＜80kg)
    combine the cavity into the resonator,
    optimize the thickness of the magnetic shields
  - Life time (＞10 years)
    improve the pumps and efficiency of the H beam
  - Anti vibration and shock (＜20G)
    prevent frequency shift, H beam tilt, breakdown of parts
  - Adapt to the space environment (＜$1X10^{-14}$/K)
    improve the characteristics
    for changes of temperature and magnetic field

BBM: bread-board model

# Engineering model (EM) 2004～06

- two models (3.3 *l* & 2.07 *l*)
  physics part of the 2.07 *l* model : 36.5 kg → 30 kg
- improvement of materials and construction:
  stiffness : 90 Hz → 144 Hz
- confirmation of re-start of ion-pump after 1 week break
- update for more compact electronics part
- Environment tests
  such as vibration, thermal-vacuum, radiation, ..

# Ionosphere effect

Ionospheric delay $\propto 1/f^2$

0.24ns (EI = 90°) at Okinawa
during solar maximum
($10^{18}/m^2$)
(> 1 ns if elevation is low)

but, can be estimated