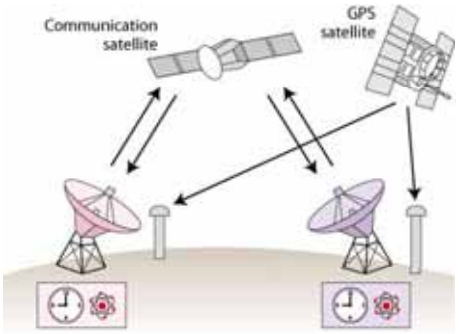
Time Transfer

Hideo Maeno: Japan Standard Time Project

Thomas Hobiger, Tadahiro Gotoh, Masanori Aida,
and Tingyu Li: Space-Time Measurement Project

2009/10/21



TP2009@NICT

Today's schedule

- 09:30 - 10:30 TWSTFT (Maeno)
- 10:30 - 10:40 Break
- 10:40 - 12:00 GPS (Hobiger, Gotoh)
- 12:00 - 13:00 Lunch
- 13:00 - 13:30 Training guidance (Maeno)
- 13:30 - 15:50 Tour & Practical Training (Maeno, Gotoh, Aida, Li)
- 15:50 - 16:00 Break
- 16:00 - 17:00 Q & A Time (Koyama, Maeno, Gotoh, Hobiger)

Two-way satellite time and frequency transfer (TWSTFT)

Hideo Maeno

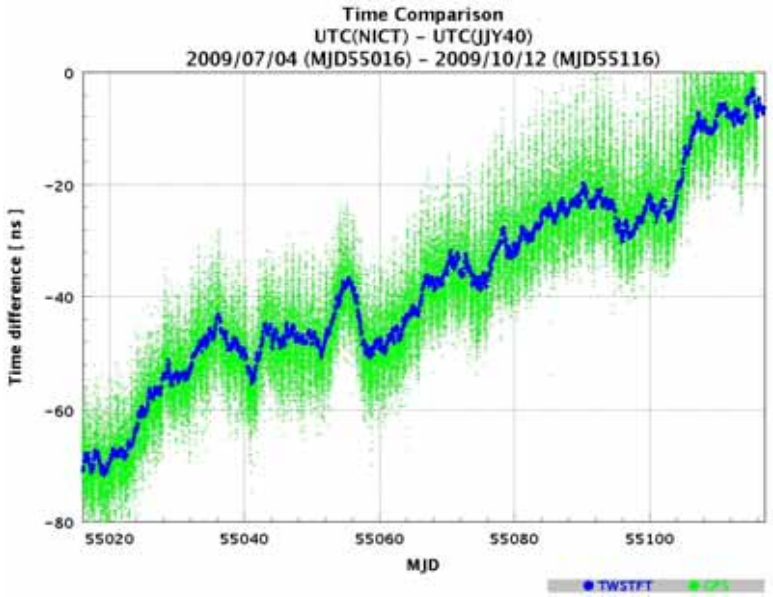
Japan Standard Time Project

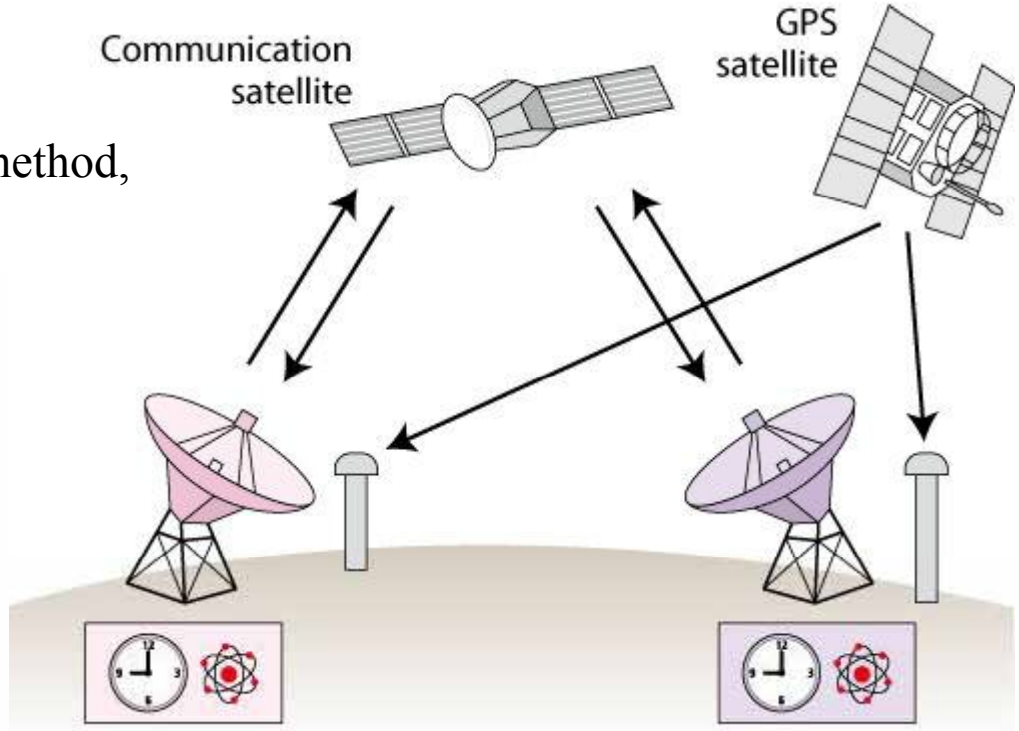
2009/10/21

TWSTFT and GPS

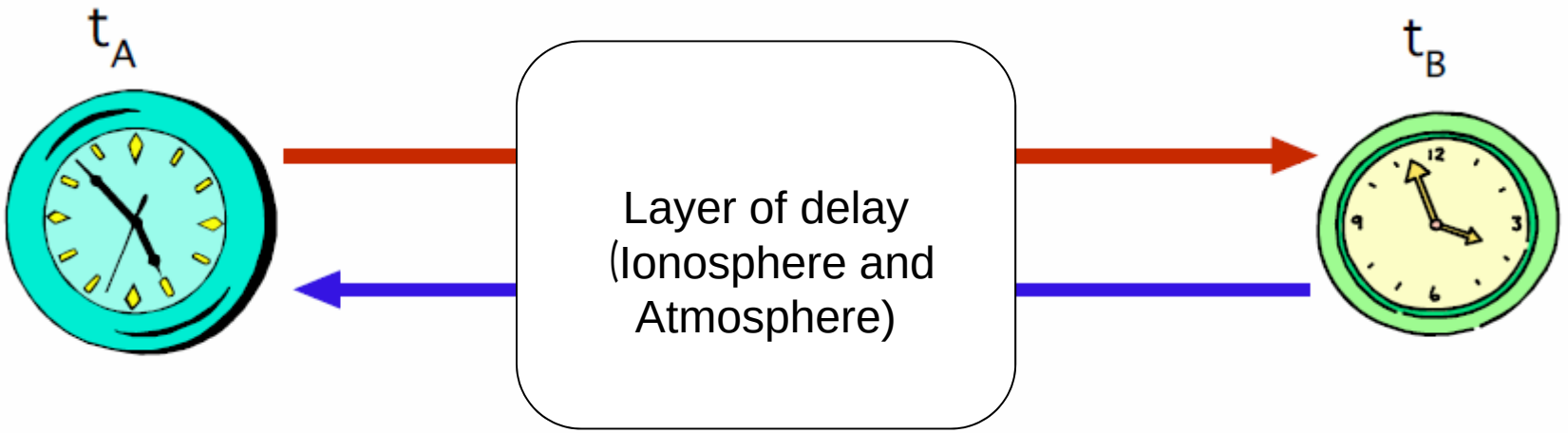
TWSTFT
Using Communication (Stationary) Satellite
Ku-band (up 14GHz, down 12GHz) ,or X, C-band
High performance (uA $\leqq$ 0.5 ns), High cost

GPS
Using GPS Satellite, L-band (1.2GHz) ,
Performance (uA$\geqq$0.7 ns) , All in view method,
Low cost





Principle

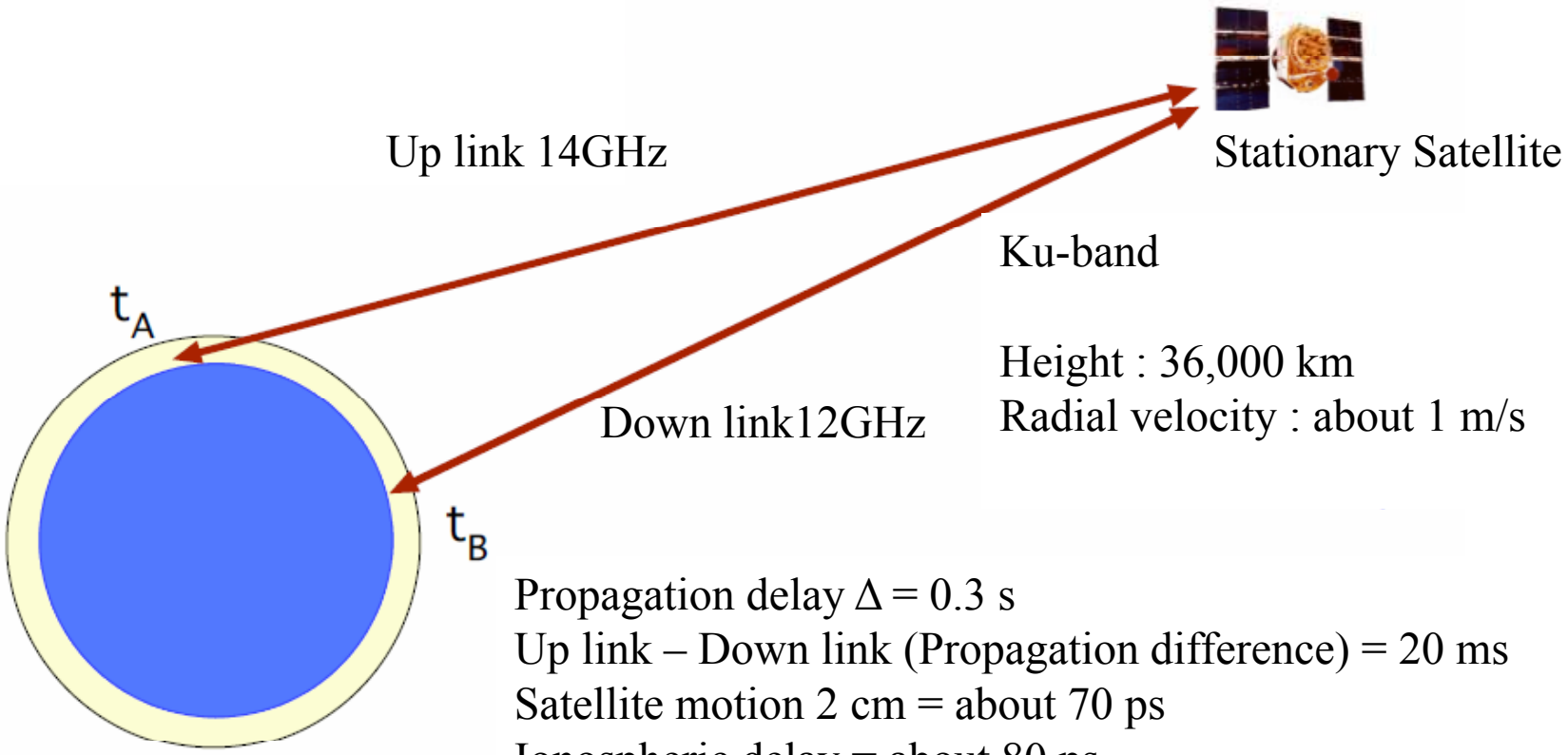


Propagation delay Δ = distance + delay by layer

$$\left.\begin{aligned} \rightarrow &= t_A + \Delta - t_B \\ \leftarrow &= t_B + \Delta - t_A \end{aligned}\right) \quad \rightarrow - \leftarrow = 2(t_A - t_B)$$

Measuring at the same timing is important.

TWSTFT by Stationary Satellite

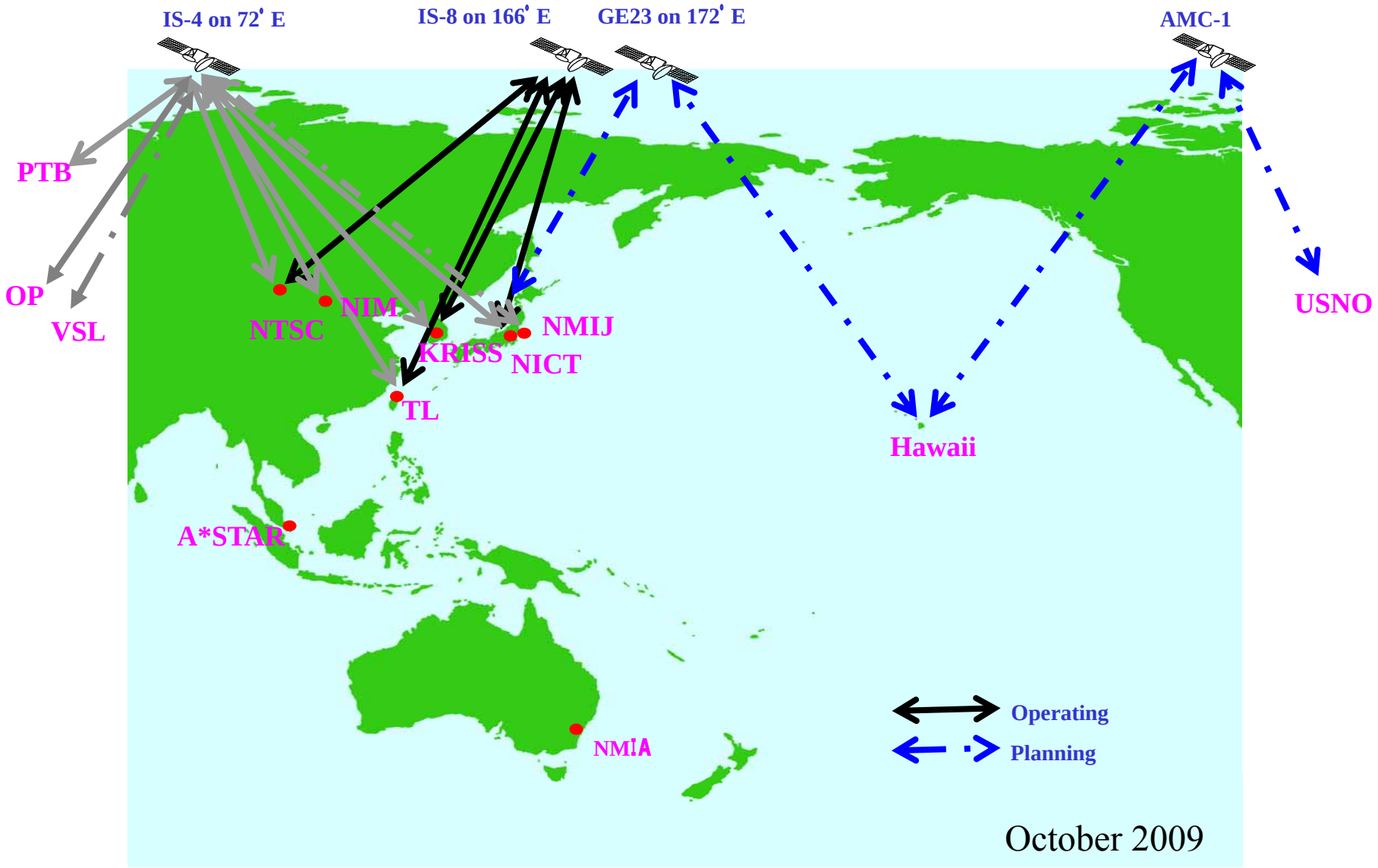


Earth
Radius 6,400 km
Ionosphere 200-1000 km

Propagation delay $\Delta = 0.3$ s
Up link – Down link (Propagation difference) = 20 ms
Satellite motion 2 cm = about 70 ps
Ionospheric delay = about 80 ps

Model calculation error = about 100 ps

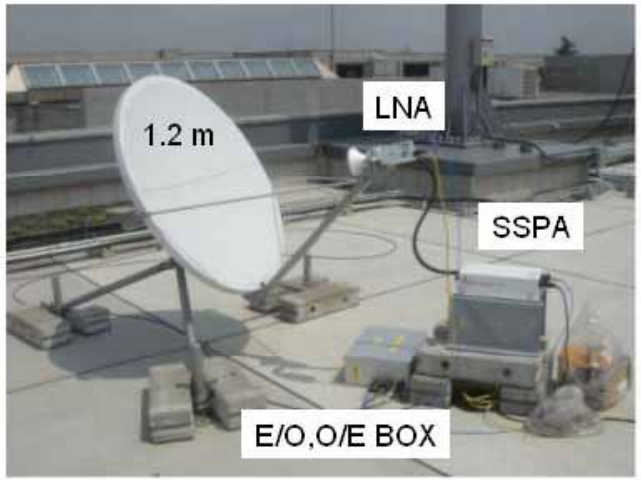
TWSTFT network in Pacific rim

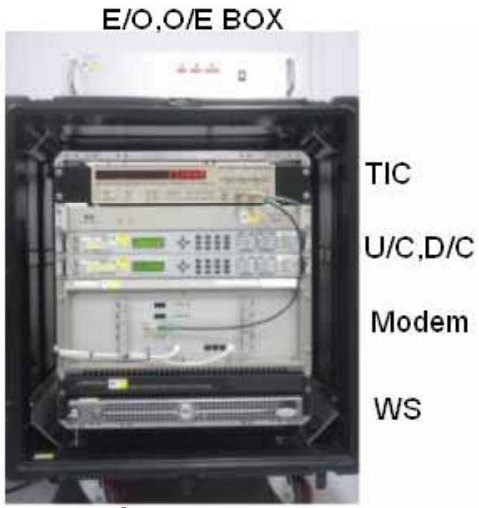


Equipment and Antenna

NICT Stations

Asia and Domestic (LF St.) link





Portable Station

Eu-Asia link

Block Diagram

SSPA

Up-Converter

70 MHz

NICT Modem

14GHz

10 MHz

12GHz

LNA

Down-Converter

70 MHz

1PPS

LAN Cable

SATRE Modem (Include Control PC)

70 MHz

10 MHz

1PPS

PC Linux (Data)

Internet

Control PC @NICT

Modem

- NICT modem
  - Multi-channel (8 ch or 2 ch)
  - Simultaneous measurement
  - Operation at a master station and other slave stations is fully automated.
  - 2.0475 MChip

- SATRE modem
  - 3 ch (Max)
  - MITREX modem Compatible
  - Usually, it is used by time sharing.
  - 0.5, 1, 2.5, 5, 10 and 20 MChip

Data Analysis

TWSTFT Modem
- Measurement

↓

Work Station
- Save raw data

↓

PC
- Data Analysis
- Make data with ITU-R format

RECOMMENDATION ITU-R TF.1153-2

↓

Upload to either BIPM ftp site or Local site
- tai.bipm.org (ftp site)
- http://www3.nict.go.jp/w/w114/data/TWSTFT/

ITU-R TF.1153-2 p.16 Computation of clock differeces

UTC(LAB1) – UTC(LAB2) =

$+0.5(TW_1 + ESDVAR_1) + REFDELAY_1$ Data line lab 1

$-0.5(TW_2 + ESDVAR_2) - REFDELAY_2$ Data line lab 2

$+CALR$ Data line lab 1

ITU-R format data

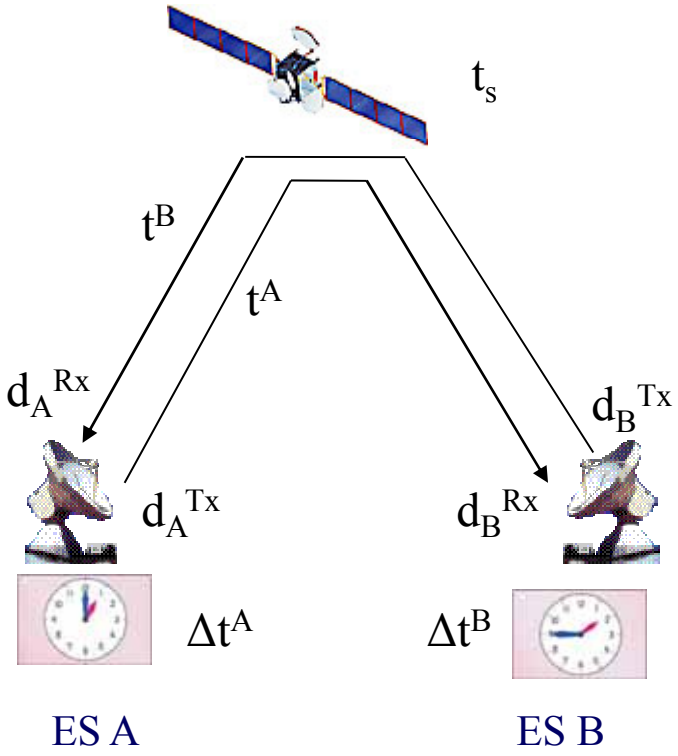
```
* TWNICT54.921
* FORMAT    01
* LAB       NICT
* REV DATE  2007-06-21
* ES NICT01 LA: N  35 42 28.194      LO: E 139 29 16.527   HT:    93.76 m
* REF-FRAME GRS80
* LINK   10 SAT: JCSAT-1B            NLO: E 150  0  0.000  XPNDR: 999999999 ns
*           SAT-NTX: 12306.0000 MHz  SAT-NRX: 14054.0000 MHz
* CAL   207 TYPE: PORT ES REL        MJD: 54116  EST. UNCERT.: 99999999 ns
* CAL   206 TYPE: PORT ES REL        MJD: 53826  EST. UNCERT.:    1.148 ns
* CAL   004 TYPE: CIRCULAR T         MJD: 53663  EST. UNCERT.: 99999999 ns
* CAL   005 TYPE: UNCALIBRATED       MJD: 99999  EST. UNCERT.: 99999999 ns
* LOC-MON   NO
* MODEM     NICTmodem
* COMMENTS
*
* EARTH-STAT  LI  MJD  STTIME NTL       TW       DRMS SMP ATL     REFDELAY     RSIG  CI S    CALR     ESDVAR   ESIG TMP HUM PRES
* LOC    REM          hhmmss  s         s         ns   s   s         s           ns             ns       ns      ns degC  %   hPa
NICT01 KRIS01 10 54921 000000 299  0.249873755920 0.478 300 299  0.000000477955 9.999 207 1     7.708 99999.999 9.999    8  52 1013
NICT01   TL01 10 54921 000000 299  0.248659394241 0.487 300 299  0.000000477955 9.999 206 1    89.288 99999.999 9.999    8  52 1013
NICT01   SG01 10 54921 000000 299  0.251113703855 0.353 300 299  0.000000477955 9.999 004 1   -93.086 99999.999 9.999    8  52 1013
NICT01 NTSC01 10 54921 000000 299  0.252657433827 0.327 300 299  0.000000477955 9.999 005 9 99999.999 99999.999 9.999    8  52 1013
NICT01 KRIS01 10 54921 010000 299  0.249868289294 0.482 300 299  0.000000477955 9.999 207 1     7.708 99999.999 9.999    9  50 1012
NICT01   TL01 10 54921 010000 299  0.248653820826 0.453 300 299  0.000000477955 9.999 206 1    89.288 99999.999 9.999    9  50 1012
NICT01   SG01 10 54921 010000 299  0.251107801078 0.362 300 299  0.000000477955 9.999 004 1   -93.086 99999.999 9.999    9  50 1012
```

Caliblation (Principle of TWSTFT)

- Time difference

$$\Delta t^A - \Delta t^B \quad 1/2[(t^A - t^B) + (d_A^{Tx} - d_A^{Rx}) - (d_B^{Tx} - d_B^{Rx}) + t_s]$$

t_s ：delay by Sagnac effect
d^{Tx} ：delay of uplink in earth station
(up-converter, SSPA, cables etc…)
d^{Rx} ：delay of downlink in earth station
(LNA, down-converter, cables etc…)
Δt：time difference
t ：reception time



Differential delay calibration is necessary!

- Absolute value ⇒ by Portable station (uB = 1.1 ns) or GPS (uB = 5.0 ns)
- Relative variation⇒ by delay measurement system

Calibration method by portable station

- Time transfer between ES A and PS

$$(d_A^{Tx} - d_A^{Rx}) - (d_p^{Tx} - d_p^{Rx})_A = -(t^A - t^P) \quad ①$$

- Time transfer between ES B and PS

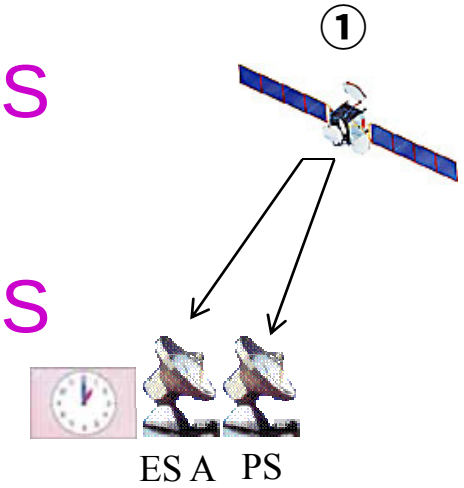
$$(d_B^{Tx} - d_B^{Rx}) - (d_p^{Tx} - d_p^{Rx})_B = -(t^B - t^P) \quad ②$$

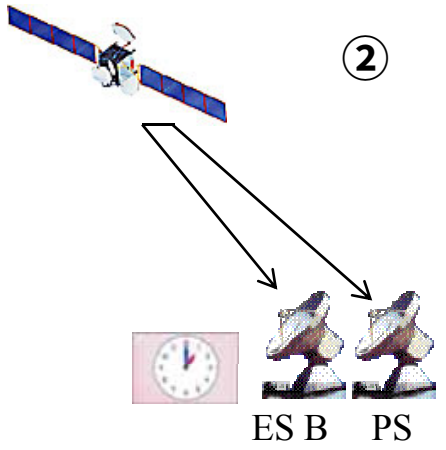
- ① - ② ＝ Differential delay

$$(d_A^{Tx} - d_A^{Rx}) - (d_B^{Tx} - d_B^{Rx}) = -(t^A - t^P) + (t^B - t^P)$$

But, $(d_p^{Tx} - d_p^{Rx})_A = (d_p^{Tx} - d_p^{Rx})_B$

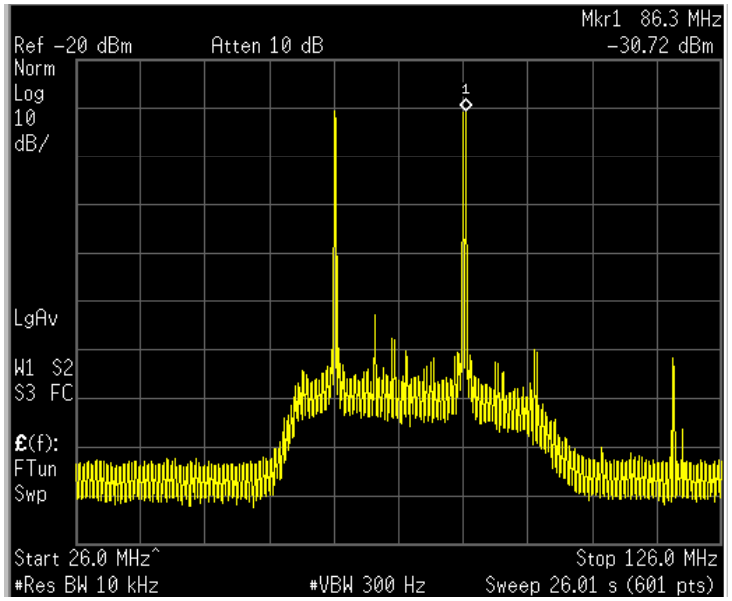
Variation of differential delay in PS should be small!
The transponder of a satellite must be one!





Future of Modem (Dual PRN)

Signal generator (right)
and Sampler (left)



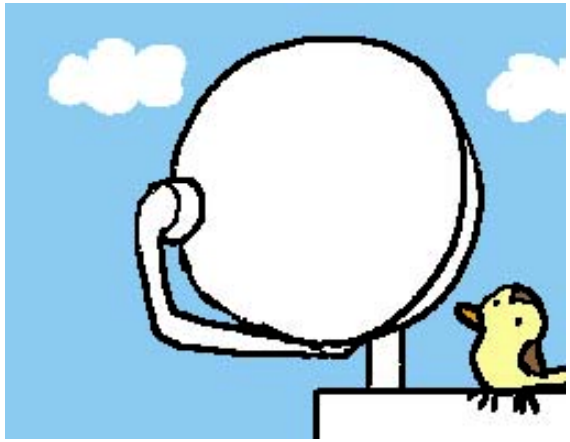
Dual PRN signal
Frequency separation : 20 MHz
BW : 200 kHz each

Simple hardware & software processing
Modulation part: Wave-form generator (WFD)
Demodulation part: A/D convertor (ADC)
Most of the data processing: processed in a personal computer
☞ Low cost & easy reconfiguration, Short term stability < 50 ps

Conclusion

- The error by propagation delay, delay of a station, and motion of a satellite are canceled.
- Satellite is far → High Power Amp. and Big Parabolic Antenna (Ku-band：1.8-2.4 m, C-band：≧4 m) are necessary
- Link fee (2.5MHz Bandwidth is about 20,000 $/month)
- Strong radio wave Transmit → Radio license is required
- Reduction of a measurement error is important. A multi-pass has no problem. A system noise and delay change are important.
- Future → We are going to use DPRN (≦50 ps) or ETS-VIII (Atomic-clock on boarded satellite: ≦10 ps) .

Thank you for your attention !



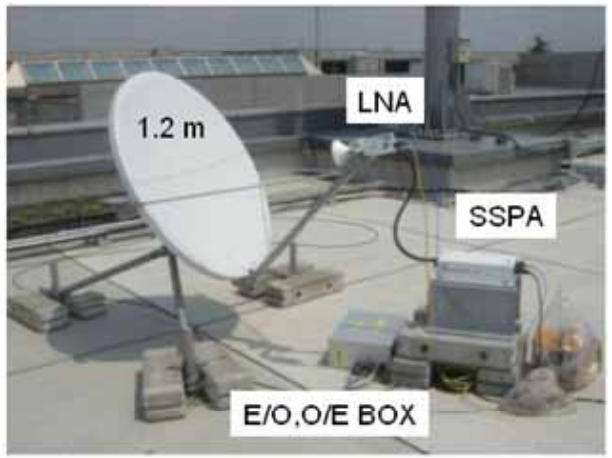
Training Guidance

Tour:

- GPS (@3F & rooftop)
- TWSTFT (@4F & rooftop)

Practical Training using Portable Station Antenna:
(@rooftop)

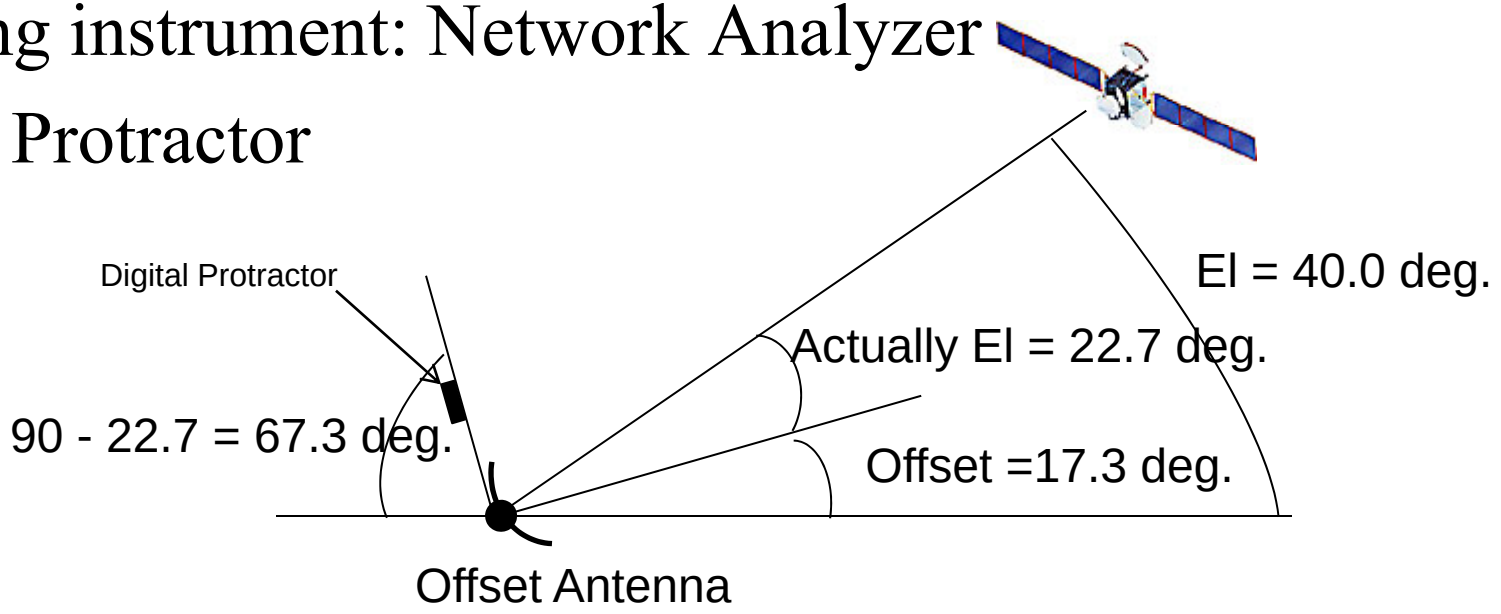
- Antenna disassembly
- Antenna assembly
- Direction adjustment (Az., El., Pol.)
- Reception of a satellite beacon signal
- Fine adjustment of an antenna



Direction adjustment

- Reception Satellite: IS-8
- Az = 139.5 deg. El = 40.0 deg. @NICT 35.70N, 139.49E
- Beacon 12747 MHz (H) 12748 MHz (V)
- Observation Frequency12422.75MHz (H)
- Equipment: Portable Station Antenna and LNA
- Measuring instrument: Network Analyzer

and Digital Protractor



Reception Satellite IS-8 Beacon