3-9 High Accuracy Clock (HAC)

NODA Hiroyuki, SANO Kazuhiko, and HAMA Shin'ichi

To obtain the basic technology of satellite positioning system, NASDA will conduct the experiments of ETS-VIII high accurate orbit determination and time synchronization, satellite navigation signal relay, user positioning by ETS-VIII combined with GPS satellites. High Accuracy Clock (HAC) generates and transmits L/S-band navigation signal synchronized with high stability frequency signal from Cs atomic clock on board, and conducts coherent relays of navigation signal transmitted from ground station. Positioning experiment system consists of the satellite segment of ETS-VIII, GPS satellite and the ground segment of satellite monitor stations receiving navigation signal and generating ranging data, master control station processing the ranging data, navigation signal transmitting station and laser ranging stations.

Keywords
Satellite positioning experiment, High Accuracy Clock, Satellite positioning experiment system, ETS-VIII

1 Introduction

Remarkable recent developments in satellite positioning applications have quickly become essential to science, industry, commerce, and everyday life. Satellite positioning systems include GPS and GLONASS, as well as new systems like the Galileo Project in Europe. Given this broad trend, there would be clear value in acquiring basic positioning system technologies and developing a system unique to Japan, beginning with a consideration of various approaches to maximize accuracy and functionality. Against this backdrop, the National Space Development Agency of Japan (present Japan Aerospace Exploration Agency) has decided to acquire basic positioning system technologies by launching a broad experimental development effort addressing both satellite systems and ground systems. This project will be known as ETS-VIII. This paper describes a satellite positioning experiment planned for ETS-VIII that will involve a high accuracy clock (HAC) and an experimental satellite positioning system.

2 Satellite positioning experiment

The ETS-VIII satellite positioning experiment will involve the following components. Fig.1 illustrates the concepts underlying the experiment.

(1) Highly accurate orbit determination and time synchronization

The goal is to achieve the highly accurate orbit determination and time synchronization technology essential for a positioning satellite. Located much farther from Earth than medium-orbit GPS satellites and varying only slightly in position relative to the ground station, geostationary satellites are associated with a plethora of difficulties, including the difficulty of highly accurate orbit determination and highly accurate time synchronization. Establishing this area of the technology is one of the major goals of the experiment.

The determination technique is based on a reverse GPS system that uses ETS-VIII navigation signals, and plans call for achieving high accuracy by referencing high-accuracy time and ranging data acquired in time comparison and SLR operation modes.

The following general approach will be applied to establish this technology: first, analysis of results will be used to extract and correct errors typical of positional systems, and secure the accuracy of ETS-VIII orbit determinations and time synchronization; finally, real time analysis will be used to improve determination accuracy. Targeted accuracies for orbit determination and time synchronization were set to 30 m or less and 10 ns or less (post analysis); and to 100 m or less and 30 ns or less (real time analysis), respectively.

The specifics of the experiment in each mode are given below.

(a) Atomic clock mode experiment

Ranging data between the satellite and ground stations (four stations) will be acquired using the ETS-VIII navigation signals, and a satellite position and the time error between an atomic clock on board the satellite and a ground reference atomic clock will be derived analytically (reverse GPS system).

(b) Time comparison mode experiment

Using time comparison equipment (TCE), ETS-VIII navigation signals are communicated between the ground station and the satellite bi-directionally to detect time errors between the atomic clock on board the satellite and the ground reference atomic clock. Since this method results in almost immediate cancellation of propagation delays in navigation signals, extremely high error detection accuracies, on the order of sub nanoseconds, can be obtained (Note: The TCE on board the satellite and ground equipment for the time comparison experiment were developed by CRL).

(c) SLR operation mode experiment

Laser ranging will be conducted between the satellite and the ground station. Highly accurate orbit determination of the satellite will be conducted based on high-accuracy ranging data on the order of centimeters.

(2) User positioning experiment by a combination of the positioning satellite and GPS satellites

After ETS-VIII orbit determination and time synchronization technology is established experimentally (1), user positioning by a combination of GPS and the ETS-VIII will be performed to confirm the effectiveness of the geostationary satellite as a complementary system during periods when positioning accuracy based on GPS satellites alone declines.

(3) Satellite navigation signal relay experiment

Experiments (1) and (2) involve a system of generating navigation signals at the ground station and relaying these signals via the ETS-VIII, followed by verification of system effectiveness.

Since the navigation signal generation component of this system is ground-based, this system features high operability and maintainability, as well as cost-effectiveness thanks to use of ground-based components as key components, such as the atomic clock.

Verification of the effectiveness of this system represents a significant step toward realizing an effective positioning system based on geostationary satellites.

(4) Chip rate alteration experiment

This experiment will help determine an optimal chip rate by altering the chip rates of pseudorandom noise (PRN) included in the navigation signal and verifying the dependence of the chip rate on user positioning accuracy (code positioning, in particular).

(5) Evaluation of operability of experimental

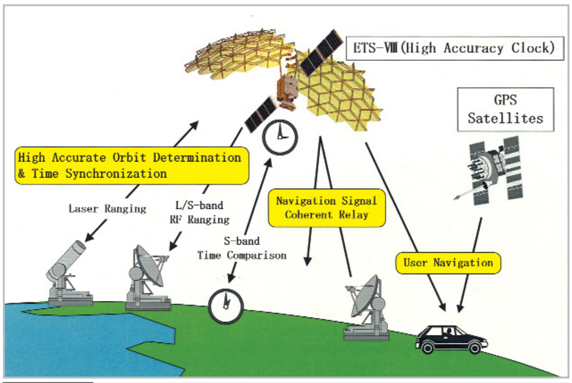

Fig.1 Conceptual diagram of the ETS-VIII satellite positioning experiment

positioning system

The experimental positioning system will be operated continuously over a predetermined period to extract and resolve problems related to availability, integrity, and continuity, aspects critical to a practical positioning system.

3 High Accuracy Clock

3.1 Functions, specifications, and appearance

Functions of the HAC required to execute the experiment of 2 are shown below.
Table 1 and Fig.2 give specifications; while Fig.3 provides an illustration.

(1) Generating a highly stable standard frequency
(2) Generating a time standard signal from the standard frequency
(3) Transmitting the time standard signal to the ground.
(4) Performing coherent relay of the time standard signal generated on the ground and returning it to the ground.
(5) Performing command reception and telemetry transmission
(6) Reflecting a light signal from ground to ground.
(7) Receiving an uplink signal for the experiment that uses TCE, distributing it to the TCE, and distributing a clock signal to the TCE

3.2 Design overview

The main points of the design overview are given below. As a reference, Fig.4 shows the functional block.

(1) Atomic clock mode

The reference signal generated by the atomic clock is entered into a synthesizer (SYNTH), which performs the following operations: generating a frequency f1 (20.46 MHz) and outputting it to a base band processing unit (BPU); generating a frequency f4 (1595.88 MHz) as an L-band carrier and outputting it to the L-band modulation amplifier (LMPA); and generating a frequency f5

Table 1 *HAC subsystem specifications*

Item	Specification		
Atomic Clock			
Type	Cesium Frequency Standard		
Frequency	10.23MHz-5.52328E-3Hz(Relativistic Correction)		
Frequency Stability	1E-11(1.0s<τ<3.6s) / 1.89E-11/√τ (3.6s<τ<1E5s) / 6E-14(1E5s<τ<1E6s)		
	Drift:<1E-14/day / Temperature Sensitivity:<1E-13/degC(|T-25℃|<10℃)		
	Magnetic Sensitivity:<1E-12(|B|<1[Gauss]) / Voltage Sensitivity:<1E-12(|V-28V|<4V)		
Navigation Signal	L-band Signal(D/L)	S-band Signal(D/L)	S-band Signal(U/L)
Modulation	BPSK	BPSK	BPSK(Navigation Signal) / CW(Pilot)
Frequency	1595.88MHz±7.5MHz	2491.005±7.5MHz	2656.39±1.39MHz(Navigation Signal)
			2659.8MHz(Pilot)
EIRP	more than 26.6dBW (-3dB Area)	more than 28.0dBW (-3dB Area)	G/T:more than -8.4dB/K (-2dB Area)
Polarization	Right Hand Circular	Left Hand Circular	Left Hand Circular
Data Rate	50bps		
PRN Code	Chip Rate:1.023M / 1.705M / 3.410M / 5.115Mbps		Chip Rate:1.023Mbps
	Code Length:1023, Code Type:Gold Code(#12)		
Antenna			
Type	Reflector:Centre Feed Parabolic Antenna(1.1mϕ) / Feeder:L/S-band Common-use Patch antenna		
Signal	L-band Signal(Transmission)	S-band Signal(Transmission)	
Gain	more than 16.9dBi(-3dB Area)	more than 21.3dBi(-3dB Area)	
Beam Width	more than 11.3deg.	more than 6.9deg.	
Axial Ratio / VSWR	less than 2.0dB / less than 1.5	less than 2.5dB / less than1.5	
Service Area	shown in fig.2		
LRRA			
Type	Prism Array Type(Array Number:36pcs.)		
Wave Length	532nm (2nd harmonic of Nd : YAG Laser)		
Optical Characteristics	Photon Reception Probability:more than 0.1 / Reflection Coefficient:more than 0.75		
Weight	less than 130kg		
Electrical Power Consumption	less than 440W		

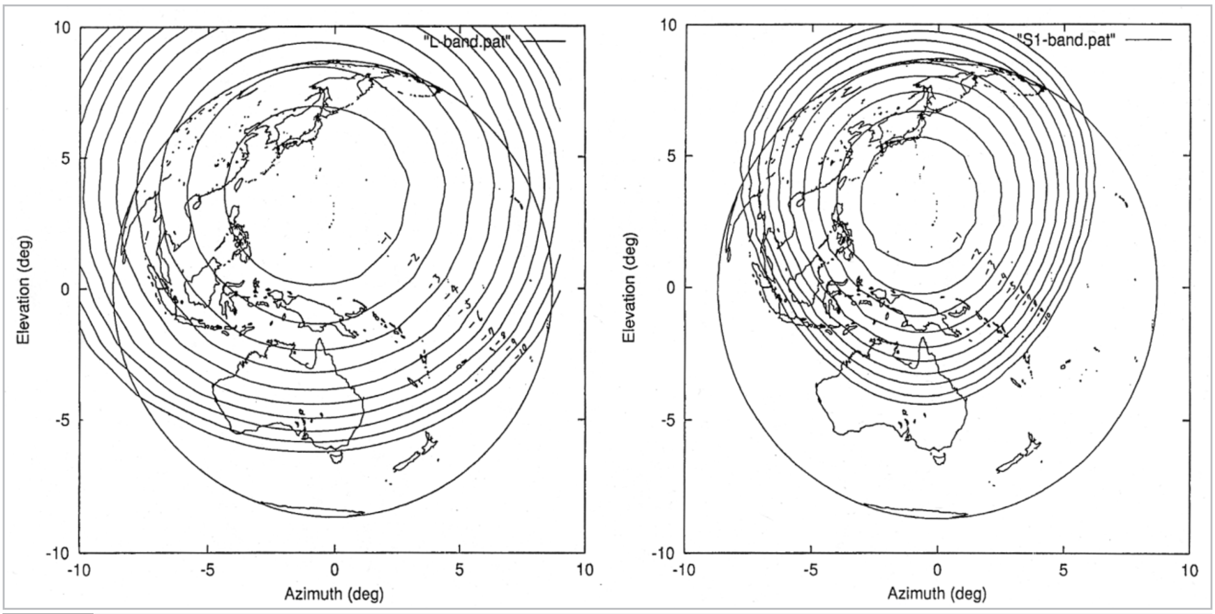

Fig.2 *Navigation signal service area*

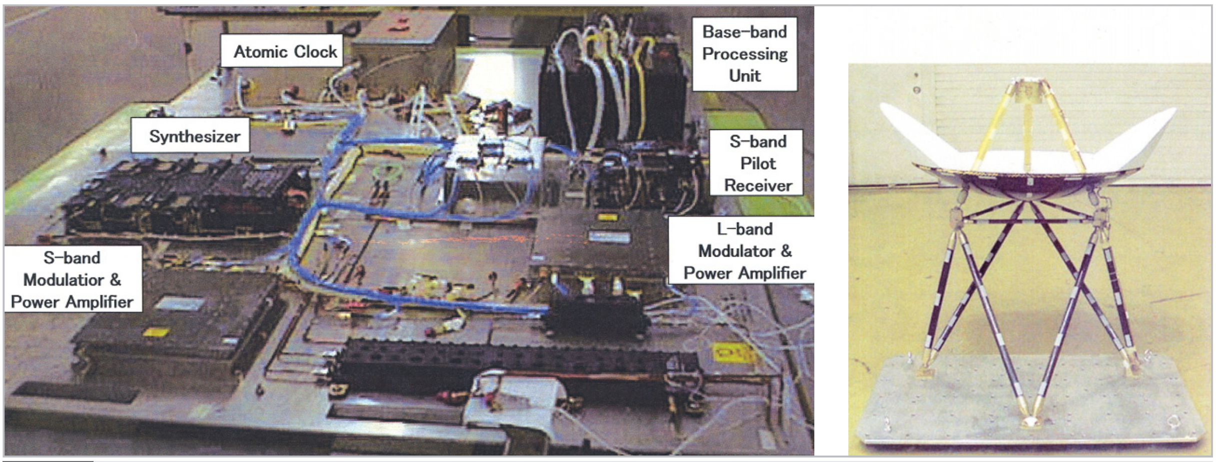

Fig.3 *Appearance of the HAC subsystem*

(2491.005 MHz) that will serve as an S-band carrier and outputting it to the S-band modulation amplifier (SMPA). The BPU divides the frequency f1 and generates a PRN code and navigation message. The navigation message is in the same format as for GPS, but also contains ETS-VIII-specific information. In addition, the PRN code is prepared in three chip rates, except the C/A code (chip rate: 1.023 Mcps). The PRN code is output to the LMPA and the SMPA, wherein the L- and S-band carriers are subjected to BPSK with the PRN code, subsequently amplified by a 18W class SSPA, and transmitted through the HAC-ANT.

(2) Time comparison experiment mode

At the time of the TCE experiment, the signal received from the ground and a calibration signal entered from the TCE are combined with an S-band coupler (SCPL2) to form a signal, which is amplified by an LNA in an S-band receiver (SBPR) and output to the TCE. Moreover, an S-band transmit signal (chip rate: 1.023 Mbps) generated in the HAC using the atomic clock as a reference is transmitted to the ground, and at the same time is demultiplexed by an S-band coupler 1 (SCPL1) in an S-band diplexer and output to the TCE. Furthermore, the reference signal of the atomic clock is demultiplexed by the SYNTH and output to the TCE, while the 1 kpps signal is simultaneously output to the TCE based on an instruction from the BPU.

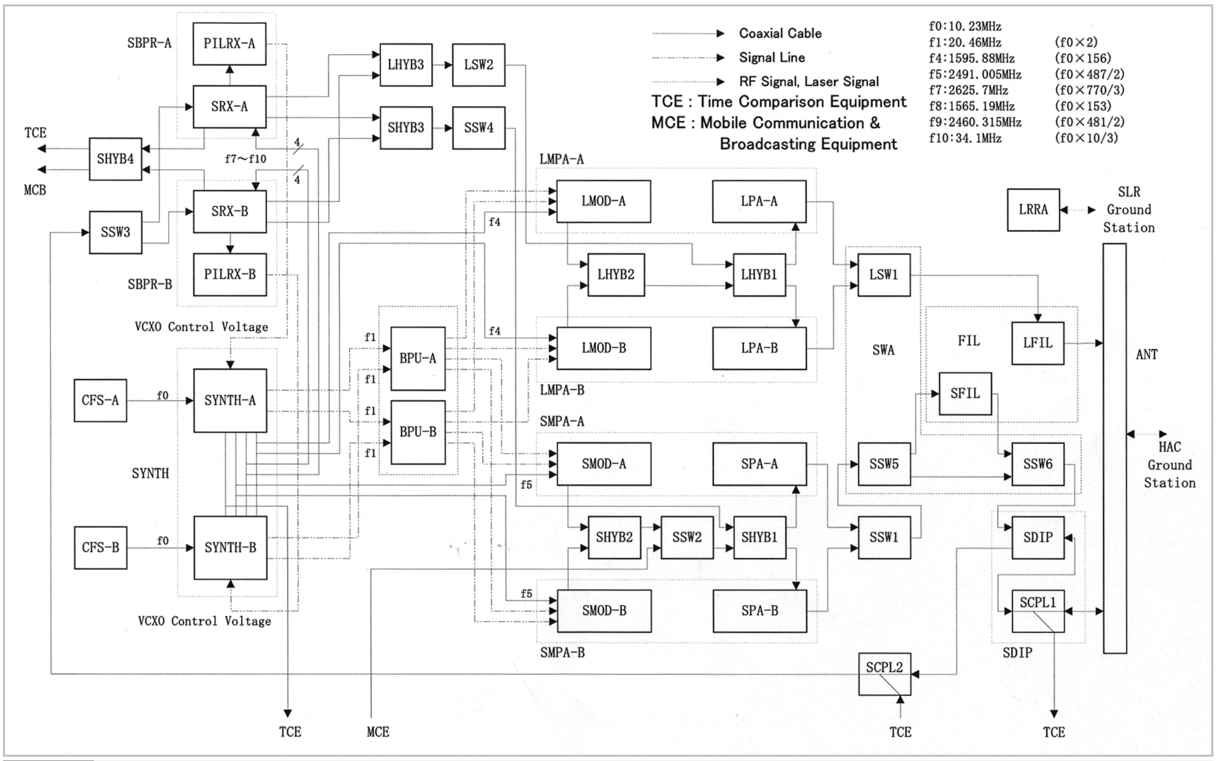

Fig.4 HAC functional block

(3) Navigation signal relay experiment mode

In relay experiment mode, the HAC receives a pilot signal transmitted from the ground and conducts operations using a 10.23 MHz signal generated from this signal as a reference signal. The pilot signal is received by the SBPR, converted into 34.1 MHz using a local signal f7 (2625.7 MHz) output from the SYNTH, and subjected to phase comparison with a signal f10 (34.1 MHz) similarly output from the SYNTH to generate a phase error signal, which is then output to the SYNTH. The SYNTH has an internal VCXO of 10.23 MHz, controls the frequency of the VCXO using phase error signals from the SBPR, generates a signal f10 whose frequency is 10/3 times the frequency of the VCXO, and outputs it to the SBPR. The overall system of the SYNTH and the SBPR constitutes a PLL, which generates a signal in synchronization with the pilot signal. In this mode, the S band receiver receives a pilot signal and navigation signal and converts their frequencies into those for the L- and S-band, respectively, which are amplified by the SSPA and returned to the ground source, as with (2).

(4) SLR operation mode

A laser ranging signal transmitted from the ground SLR station is reflected back to the ground by a laser retroreflector array (LRRA). The LRRA(s) is composed of 36 prism arrays (each 5 cm-Φ) having an effective reflector cross section of 1.0×10^8 m^2 facing and normal to the axis of signal transmission. Analysis showed that photon reception probability when measuring one or more photon counts was 0.9 or higher to each of the SLR stations: Koganei (CRL); Mt. Stromlo, Australia; and Heleakala, U.S.

(5) Atomic clock thermal control design

To suppress variations in the standard frequency due to the temperature dependence of the atomic clock, a heat pipe embedded in a panel in the region where the atomic clock is mounted in the system mission panel will be eliminated, heat exchange with other components will be blocked with an MLI cover installed specifically for the atomic clock, and the atomic clock will be equipped with a dedicated heater and thermal sensor, which are controlled by the BPU, thereby maintaining the atomic clock at +25±10℃.

4 Satellite positioning experiment system

The satellite positioning experiment system consists of a satellite segment (ETS-VIII and GPS satellites) and a ground segment described belowSee Fig.5 for an illustration of the system configuration.

(1) HAC experimental ground system

This system consists of four satellite monitoring stations (Koganei; Tanegashima; Bangkok, Thailand; and Brisbane, Australia), one user station (Tsukuba); and one master control station (Tsukuba). The satellite monitor station receives both a navigation signal from the ETS-VIII and navigation signals from GPS satellites, and generates ranging data to the satellites. Basic user station functions are virtually identical to those for the satellite monitor stations. However, the user station is made to be a portable station and used as a station that simulates a user. The master control station acquires, analyzes, and evaluates ranging data from the satellite monitor stations, the user station, and the SLR stations, and manages the overall experimental system.

(2) HAC transmission system

This is a facility for generating and transmitting a navigation signal on the ground for the satellite navigation signal relay experiment.

(3) SLR station

The station performs laser ranging to the ETS-VIII. The use of two domestic stations (Koganei (CRL) and Tanegashima (NASDA)) and three overseas stations (Heleakala, Hawaii, U.S.; Mt. Stromlo, Australia; and Kunming, China) is planned.

(4) TCE ground station

The station receives a navigation signal for the time comparison experiment.

5 Concluding remarks

The foregoing discussed an ETS-VIII satellite positioning experiment, an on-board high-accuracy clock for the satellite, and a satellite positioning system. The HAC has already passed an electric performance test and an environmental conditions test conducted in the latter half of fiscal 2002. Its integra-

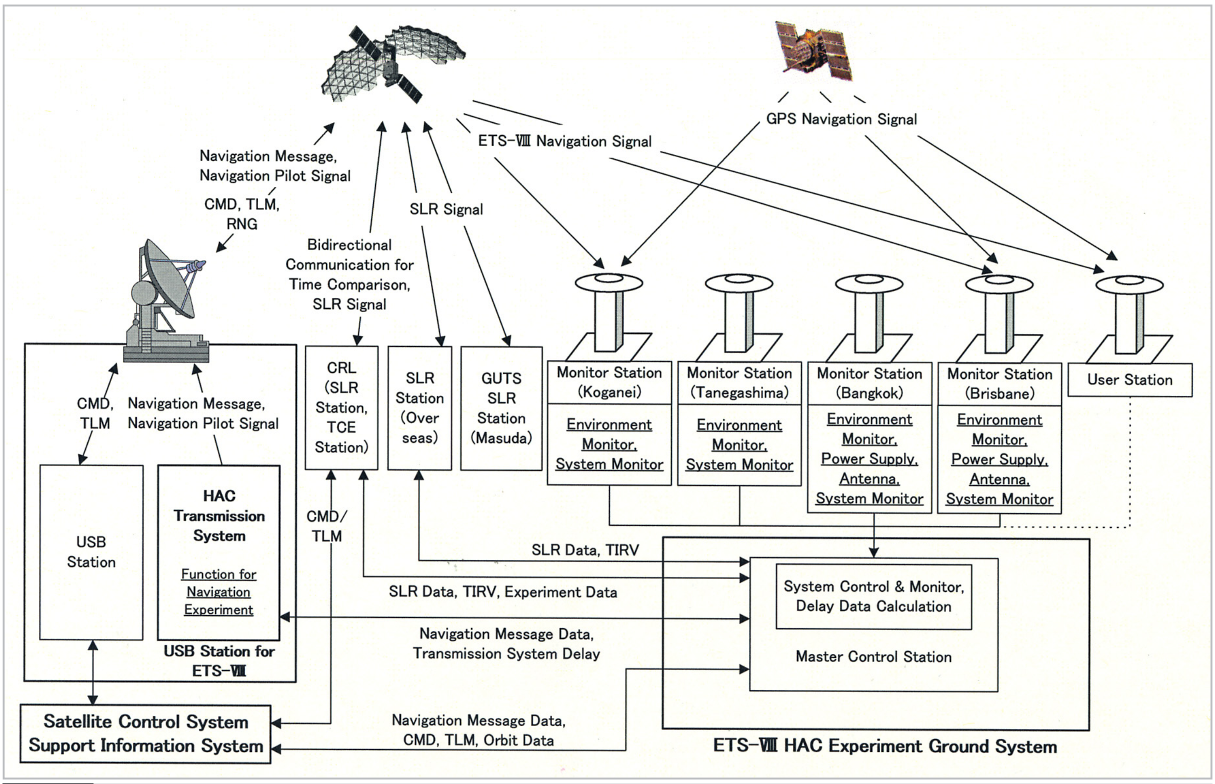

Fig.5 *ETS-VIII satellite positioning experimental system*

tion into the satellite system was complete as of August 2003.

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NODA Hiroyuki

Japan Aerospace Exploration Agency

Development of the Satellite Positioning Experiment System

SANO Kazuhiko

Japan Aerospace Exploration Agency

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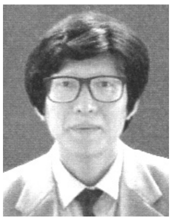

HAMA Shin'ichi

Leader, Quasi-Zenith Satellite System Group, Applied Research and Standards Division

Satellite Communication, VLBI