From Fig.2, we know that the tracking performance will be improved more as the bit rate ratio N increases. However, if we make N too large, it will result in a too long acquisition time from the requirement for $p_{L0}N\Delta$. So we choose N = 32 here. Letting $\Delta = 0.1$ μsec and $p_{L0} = 31$ rad/sec, we can satisfy the condition given by (11) (see Fig.3). Then from Eqs.(22) and (26), we get $n_L = 13$. Letting $p_{H0} = 1000$ rad/sec, we get $n_H = 18$ from Eq.(7). Then we get from Eqs.(5) and (6) that

$$\mathrm{Rmax} = 1.0 \times 10^{12} \text{ m (corresponding to the round trip time of 114 minutes at the speed of light)}, \tag{27}$$

$$\mathrm{Ta,max} = 2.4 \text{ min.} \tag{28}$$

If we assume $Ps/N_0 \gtrsim 69$dB, we get from Fig.2

$$\sigma_H = 0.83 \text{ nsec (corresponding to the range error of 0.12 m).} \tag{29}$$

We can calculate the performances of usual PN ranging systems under the same parameter values ; we get

$$\mathrm{Ta,max} = 2.4 \text{ min,} \tag{30}$$

$$\sigma = 0.83 \text{ nsec (for the phase-lock demodulation followed by video correlation system)}, \tag{31}$$

$$\mathrm{Rmax} = 3.9 \times 10^{6} \text{ m (corresponding to the round-trip time of 0.026 sec at the speed of light).} \tag{32}$$

Comparing Eq.(27) with Eq.(32), one can see that the maximum measurable range of the Dual Speed PN Ranging System is much larger than that of the phase-lock demodulation followed by video correlation system, while comparing Eqs.(28) and (29) with Eqs.(30) and (31), we see that the Dual Speed PN Ranging System has the same maximum acquisition time and the same tracking accuracy as those of the phase-lock demodulation followed by video correlation system.

5. Conclusions

We have proposed the Dual Speed PN Ranging System and analyzed its performances. The analysis shows that the maximum measurable range of this system becomes much superior to those of usual PN ranging systems, with no degradation of the maximum acquisition time. The analysis also shows that the tracking accuracy of this system for large SNR becomes the same as that of the phase-lock demodulation followed by video correlation system which is known to be the best among usual PN ranging systems.

Acknowledgment

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Operation Results of Communications Facilities at the Usuda Deep Space Center

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Abstract

Japanese Halley's Comet probes SAKIGAKE and SUISEI were launched respectively in January and August, 1985. The Usuda Deep Space Center(UDSC) was constructed to support these missions as its first task. This paper describes the outline of the communications system, the operation scheme of UDSC, and the operation results until the probes' encounters with Halley's comet in March, 1986.

1. Introduction

Halley's Comet returned close to the earth after an interval of 76 years. The European Space Agency, the U.S.S.R., the U.S.A. and Japan sent probes to gather complementary data on the comet. They all encountered the comet successfully in March, 1986(1).

The Usuda Deep Space Center (UDSC) was constructed in October, 1984 first to communicate with Japan's two missions in S-band. After the launches of probes, UDSC was turned into full operation(2). UDSC was also used for telemetry reception from America's cometary explorer ICE(3). As the operation of a deep space communications system was the first experience for ISAS, the operation scheme was determined carefully considering such factors as slant ranges, visible times for two missions and communications capabilities of both the probes and the UDSC.

2. Outline of Missions to be Tracked

One of Japan's probes SUISEI which was launched on August 19, 1985 is shown in Fig.1. The spacecraft is 1.4 m in diameter and 0.7 m high and is equipped with an ultra-violet camera and a solar wind detector. An offset parabolic antenna (HGA) is installed on the upper side together with a colinear array antenna (MGA) and a cross-dipole antenna (LGA) both under the lower side(4).

SUISEI has a sister spacecraft named SAKIGAKE which was put into orbit on January 8, 1985. They are very similar except for the fact that SAKIGAKE's scientific instruments are a plasma wave probe with two 5 m long antennas, a ring-core flux-gate magnetometer with a 2 m long boom and a solar wind detector(5).

The communications facilities at UDSC are designed to complement the restricted communications capacity of spacecraft.

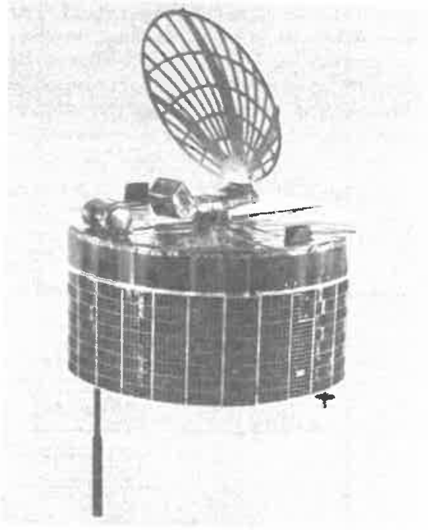

Fig.1 Spacecraft SUISEI

3. Outline of UDSC and its related facilities

UDSC is composed of equipments shown in Fig.2. Low noise amplifiers(LNA), high power amplifiers (HPA) and first and second IF stages of a heterodyne receiver are installed in the building below the antenna. Other equipments are installed in another building about 100 meters apart from the antenna.

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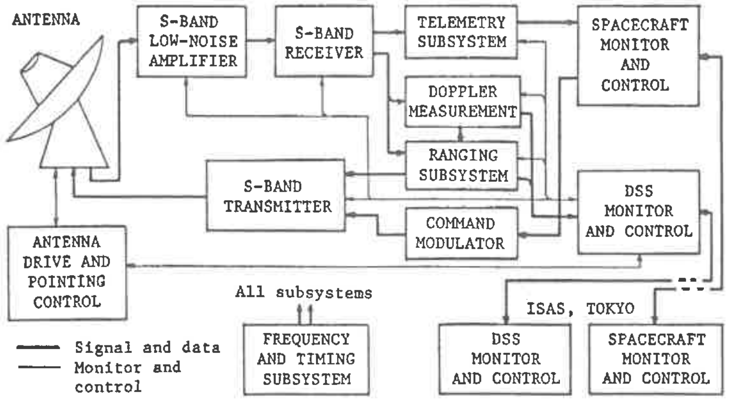


Fig.2 Functional block diagram of the Usuda Deep Space Center

The antenna is a cassegrain type with a 64 m diameter main dish. It is fed through a beam waveguide system which enables LNA and HPA to be fixed on the floor and makes the maintenance and operation very convenient. Its characteristics are summarized in Table 1. The generated noise by HPA in reception bandwidth is strictly limited to prevent the interference to LNA as well as direct leakage power to LNA in transmission bandwidth. The details of the design principle and performances of other equipments are described in another paper(6).

Table 1 Characteristics of Usuda 64m antenna

Frequency	S-band (2.1~2.3 GHz) X-band (7.1~8.5 GHz)
Antenna gain	62.6dB (2293MHz)
Aperture efficiency	77% (S-band)
Noise temperature (at the zenith)	12K (antenna alone) 22K (with diplexer)
Polariation	RHC or LHC
Half power beamwidth	0.13deg. (S-band)
Pointing accuracy	0.003deg.RMS

From the viewpoint of operation, each equipment has following peculiarities. The equivalent noise bandwidth 2BL can be changed between 3Hz and 1 KHz depending on radio link conditions. The output of HPA can be changed between 200 w and 40 kw. The transmit frequency is swept in order to establish synchronization of a phase lock loop in the spacecraft for coherent communications.

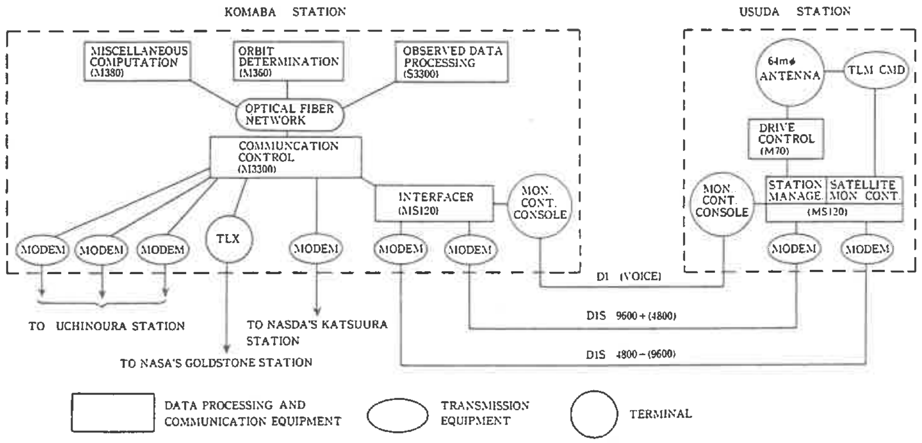


Fig.3 Functional diagram of the data communication and processing system

The conditions or the operational modes of UDSC, probes and radio links are checked out through the monitor and control consoles at both of UDSC and Komaba Deep Space Center (KDSC) in Tokyo. The operation is supported by super-computers at KDSC and a data processing and communication system shown in Fig.3.

4. Operation planning

The visible time of a probe from UDSC is determined mainly by the probe's location in space and the attitude of the earth. The computed results are shown in Fig.4 as for two Japan's probes and the America's cometary probe ICE whose signal was received from May to November in 1985 occasionally. The actual visible time is further reduced due to the skyline of mountains surrounding the big dish. UDSC tracks plural probes sequentially in a day to satisfy the demand from each mission and the spacecraft maneuvering. To accomplish this, the time overlaps of probes shown in Fig.4 should be managed.

The conditions of radio links are dominated by the probe-earth slant range, the kind of a space-borne antenna in use and the spacecraft's attitude. The slant ranges were predicted as Fig.5 which agree quite well with measured values. In the near range the higher speed telemetry mode of 2 kbps can be utilized using a well-pointed high gain antenna. Otherwise only the lower speed mode is feasible.

Table 2 Link parameters of SUISEI
・Telemetry ・At the encounter with Halley's comet

Item		Value	Note
Spacecraft	Output	37.4dBm	5.5w
	Antenna gain	23.1dB	High gain antenna
	Pointing error	− 0.2dB	Less than 1.5deg.
	Feeder loss	3.2dB	
Space	Free space loss	263.8dB	160 million km
	Propagation loss	0.3dB	Rain, Polarization conv.
Earth station	Antenna gain	62.4dB	64m diameter
	Pointing error	− 0.2dB	
	Feeder loss	0.3dB	
(SUM) Received power level		− 145.1dBm	
Modulation loss		2.1dB	Modulation index=0.9rad.
Radio loss,etc.		1.6dB	Radio loss, Syanh. loss Wave distort., Cct loss
Data rate		18.1dBHz	64 b/s
Receiver noise power density (El=20deg.)		− 182.9dBm / Hz	antenna =18k diplexer=10k, LNA=9k
(SUM) Eb/No		16.0dB	
Coding gain		5.1dB	BER $=10^{-5}$、 Viterbi decod.
Required Eb/No		9.6dB	BER $=10^{-5}$、 BPSK, Synchronous det.
(TOTAL SUM) Margin		11.5dB	

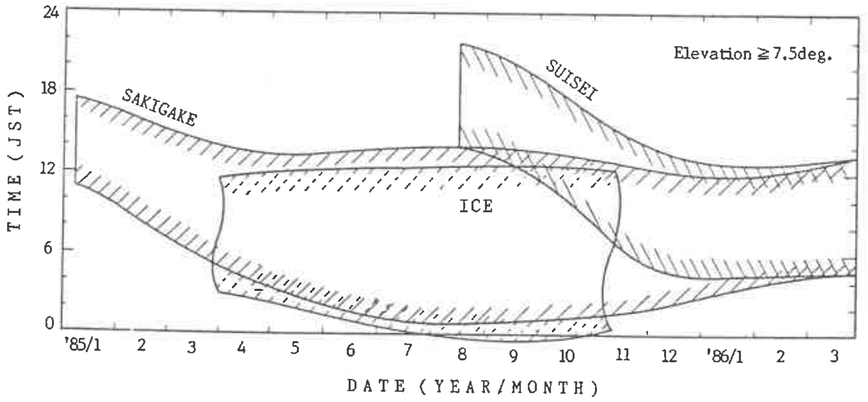


Fig.4 Visible time of the probes from UDSC

The telemetry system has the smallest margin compared with other radio systems such as a command system or a ranging system. At the encounter with Halley's comet the link parameters of the lower speed telemetry are shown in Table 2. The margin of 11.5 dB is expected.

5. Operation results

(1) Operation sequence

Main events concerning communication after the launches are summarized for SUISEI in Table 3. Space-borne antennas were switched according to the probe's attitude. Transmission levels of the probe and UDSC were also changed depending on the slant range. After January 14, telemetry mode was kept in lower speed. The status parameters of the receiver at UDSC were changed in accordance with these operations, though they are not described in Table 3.

(2) Transmission and reception

Typical change of received carrier level is shown in Fig.6 for SUISEI during a day. At the time of Acquisition Of Signal (AOS), the level increases gradually for 20 minutes after the time when the probe's elevation angle coincides with the skyline angle. At the time of Loss Of Signal (LOS) the level remains finite for 2.5 minutes after the intersection time of the probe elevation with the skyline. The time constants of the change at AOS and LOS are different each other, and seem dependent on the hight and distance of ridges blocking radio waves from the probe(7).

The level for a period from AOS to LOS changes according to probe-earth slant range. Figure 6 also shows results of maneuvers of attitude control and spin-down, and a ranging operation.

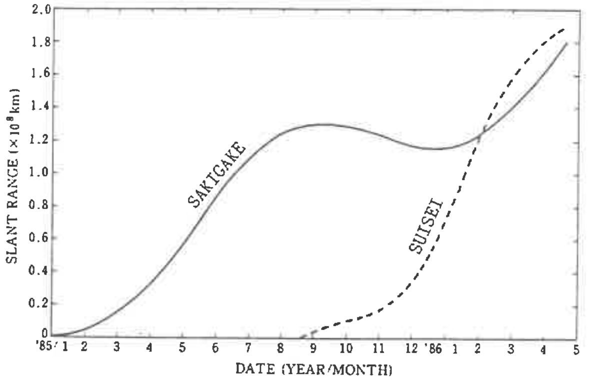


Fig.5 Daily changes of slant range

Table 3 Operational events of SUISEI

1985 Aug. 19	Launch, Spacecraft transmission level = 70mw→5w, UDSC transmission level =200w, Spin rate =29→6.5rpm, Attitude control
Aug. 20	Attitude control, Antenna =LGA → MGA
Aug. 23	UDSC transmission level =200w→2kw
Aug. 24	Antenna =MGA → HGA, Despin start
Sept. 2	Solar wind observation start
Sept. 4	Spin check of 0.2rpm
Sept. 7	UV imaging start
1986 Jan. 5	UDSC transmission level =2kw →20kw
Jan. 14	Telemetry mode=high speed→low speed
Mar. 12	JPL Madrid Station receiving, Eucounter with Halley's Comet, JPL Goldstone Station receiving

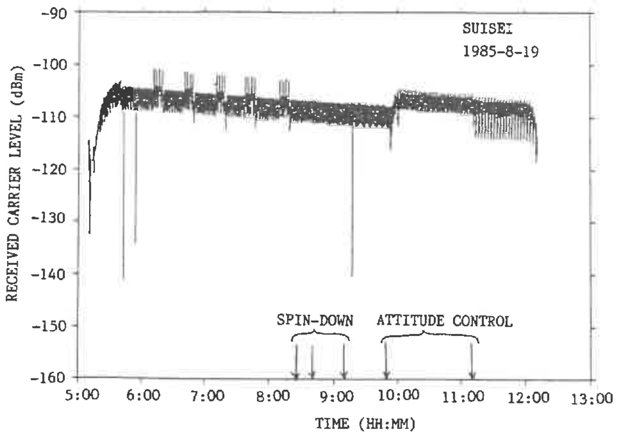


Fig.6 Received power level variation in a day

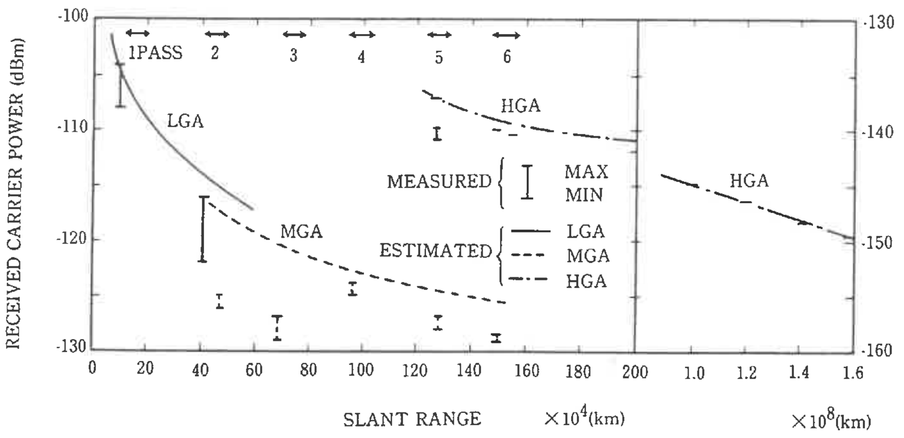


Fig.7 Slant range versus received power level (SUISEI)

Received carrier level for telemetry is plotted against slant range in Fig.7. It is seen that space-borne antennas were switched from LGA to MGA in the second pass and finally to HGA in the fifth pass. In the case of LGA the variation of the received level reached 7 dB, probably because the non-uniformity of the antenna pattern appeared significant due to an offset spin-axis from the earth.

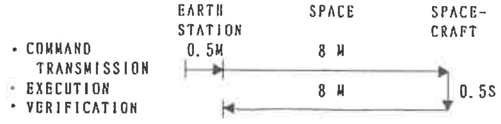
In the fourth pass the received level increase abruptly as MGA pointed to the earth after attitude control. At the encounter the carrier was received at -149 dBm. Theoretical curves in the figure are derived from Table 2 adding the correction for slant range and carrier reduction due to modulation (4.1 dB). The theoretical values and the measured values agree well each other, as is the verification of satisfactory performances of communications subsystems. The Eb/No at the encounter was 17 dB which corresponds to the estimated value in Table 2.

The uplink which is used for command or ranging can be monitored through housekeeping data in the telemetry. The transmitted data of the link agrees well with estimated values.

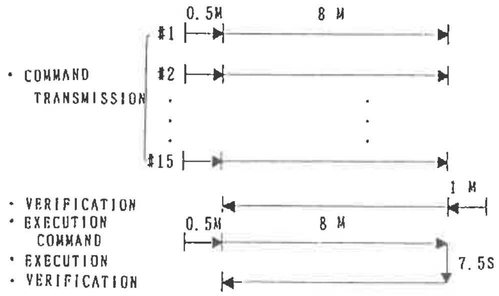
(3) Remarkable operations

Communication between UDSC and a probe was possible only during visible time. The data for invisible time were stored first in a probe and were sent to UDSC during visible time. Around the encounter the data were also received by Deep Space Network Stations of JPL, NASA.

For the operation of scientific instruments on board, many commands should be sent to probes sequentially to change the instruments' parameters. For saving operational troubles, the non-execute discrete commands which can simplify verification process as shown in Fig.8 was quite effective as well as the block command which can send 8 bit data simultaneously.



(a) EXECUTE DISCRETE COMMAND



(b) NON-EXECUTE DISCRETE COMMAND

SLANTRANGE = 1.6×10^8km , COMMAND RATE = 16 BPS , TELEMETRY RATE = 64 BPS

Fig.8 Command operation sequence and the time required

6. Conclusions

The operation results of communications facilities in UDSC which supported the Halley's comet exploration is described in this paper. The operation of UDSC was quite successful and the communications facilities showed satisfactory characteristics as well as those of two Japan's probes.

As those facilities are precious tools for engineering and science, the availability for other missions such as space-VLBI are being proposed .

Acknowledgement

The operation of UDSC has been carried out by many persons of ISAS and contractors, to whom we express our sincere gratitude. We also thank Miss Y.Kawada for preparing the manuscript.

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Ground Facilities for Satellite Broadcasting Service Using Broadcasting Satellite BS-2

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Abstract

The first operational satellite broadcasting in Japan using BS-2a has been promoted since 1980, reflecting the performance of the BSE experiences1) and the results of International Radio Regulations adopted at WARC-BS 1977. National Space Development Agency of Japan (NASDA) is responsible for developing the satellite under contract with Toshiba/GE, entrusted by NHK and Telecommunication Satellite Corporation of Japan (TSCJ). BS-2a was launched by NASDA in January 1984 from its Tanegashima Space Center by N-II launch vehicle. TSCJ is responsible for satellite control in operational phase. NHK has been operating broadcasting since May 1984 using one-channel transponder available. Back-up satellite BS-2b was launched in February this year and has been under initial check out for the two-channel broadcasting service.

NHK installed a main earth transmitting station, sub-earth transmitting station, mobile and transportable earth stations, retransmitting stations and reception monitoring stations. Using these earth stations, NHK has accumulated 2.0 year experiences of operating BS-2a satellite broadcasting system in collaboration with TSCJ and NASDA.

1. Introduction

NHK has devoted to develop satellite broadcasting systems since 1965, and various experiments have been carried out using the Medium-scale Broadcasting Satellite for Experimental Purpose (BSE) launched in 1978. Based on the results, NHK decided to introduce operational satellite system (BS-2) to eliminate reception difficulties in rural areas such as mountainous areas and remote islands.

BS-2 project was started in 1980 by NHK, National Space Development Agency (NASDA) and Telecommunications Satellite Corporation of Japan (TSCJ). NASDA is responsible for the development of spacecraft and launch vehicles, launching, establishing a geostationary orbit and initial check-out. TSCJ is responsible for in-orbit operation control during lifetime of the satellite. BS-2a was launched by NASDA in January 1984 from its Tanegashima Space Center by N-II launch vehicle. NHK has started television broadcasting since May 1984 using one-channel transponder available. Back-up satellite BS-2b was launched in February this year and has been under initial functional check-out for the two-channel service to be started this year.

NHK has prepared several types of feeder-link earth stations and some ground facilities to operate BS-2 system effectively and flexibly. Feeder-link earth stations consist of a main earth station, sub-earth stations, mobile earth stations and transportable earth stations. In the following sections outlines and design features of these facilities will be presented.

2. BS-2 satellite broadcasting system

2.1 Outline of BS-2 system

Operational satellite broadcasting system using BS-2 in Japan is mainly intended to serve the whole area of the country, including mountainous areas and remote islands, in order to solve problems of reception difficulty in terrestrial television broadcasting. In addition, the system provides effective measures for broadcasting in case of disaster and emergency, to establish outside broadcast link almost anywhere in the nation, to serve radio-shadowed areas in cities and other places and to establish technical criteria for new services such as HDTV, digital sound, facsimile, scrambling etc. In order to achieve this goal, BS-2 has a capability of transmitting

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