Usuda Deep Space Center Support for ICE

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TDA Mission Support and DSN Operations

This article summarizes the planning, implementation and operations that took place to enable the Usuda, Japan, Deep Space Center to support the International Cometary Explorer (ICE) mission. The results show that even on very short notification our two countries can provide mutual support to help ensure mission success. The data recovery at the Usuda Deep Space Center contributed significantly to providing the required continuity of the experiment data stream at the encounter of the Comet Giacobini-Zinner.

I. Introduction

An agreement between the National Aeronautics and Space Administration (NASA) and the Japanese Institute of Space and Astronautical Science (ISAS) for the instrumentation and operation of ISAS's Usuda Deep Space Center in support of the International Cometary Explorer (ICE) mission was signed in early 1985. This agreement made the Jet Propulsion Laboratory (JPL) responsible for implementing, maintaining, and operating all equipment temporarily installed in the Usuda configuration which was required for support of ICE. ISAS was responsible for the operation and maintenance of the Usuda facility.

ISAS is a Japanese government institute which was established in 1981 by reorganizing the Institute of Space and Aeronautical Science of the University of Tokyo. One of the tasks ISAS was chartered to do was research and development of interplanetary probes and the tracking of those probes. In support of this element of their charter, they built the 64-m antenna at Usuda, Japan.

The Japanese space program is divided into two general classifications. ISAS is the central institute in organizing scientific space research while the National Space Development Agency (NASDA) is in charge of development of application programs.

The ISAS Deep Space Center at Usuda, Japan, consists of a new 64-m antenna which uses wheel and track drives with an elevation over azimuth configuration. The antenna has a shared main and sub-reflector with a beam waveguide feed system. The Usuda antenna is located about 160 km northwest of Tokyo in a mountainous region at an elevation of 1074 m. The approximate longitude is 138°E and a latitude of 36°N.

The location of the Usuda antenna made it a candidate for improving data recovery return from the longitude. The southern hemisphere DSN complex at Canberra, Australia, had a very low elevation ground station to spacecraft look-angle compared to Usuda in approximately the same longitude.

II. Task Goals

The primary goal of the Usuda support for the ICE task was to provide telemetry data at an acceptable signal-to-noise ratio (SNR) to supplement the DSN Australian complex during Giacobini-Zinner encounter (see Refs. 1 and 3). A non-realtime telemetry interface would be sufficient. Other secondary goals were: to provide a demonstration of symbol stream recording which would be used with another site's recordings for non-realtime symbol stream combining (see Ref. 2); to gain experience with beam waveguides; and, finally, to demonstrate the advantages of international cooperative work.

III. Planning

The first step in planning the ICE support from the Usuda Deep Space Center was a feasibility study by a group from JPL under the direction of the Office of Telecommunications and Data Acquisition. This group found that the Usuda antenna and drive system, the receiver, and general facility were compatible with project requirements. The Usuda front-end amplifier, which was a cooled paramp, would not be adequate for the expected Giacobini-Zinner encounter signal level; therefore, a different front end would be required. Table 1 indicates the parameters of the Usuda installation. Figure 1 shows the Usuda block diagram. The telemetry processing that the Usuda site used did not deliver a product compatible with the DSN so either changes at JPL or different telemetry processors at Usuda would be needed.

At this point an implementation team was formed to determine the equipment required, its source, and an implementation and test schedule. The low-noise amplifier (LNA) selected was an ultra-low-noise MASER developed by the Radio Frequency and Microwave Subsystems Section with the advanced Systems Program Resources; the MASER had many years of reliable service including a lengthy installation period at DSS 14. This MASER, with its long performance history, made an excellent baseline measurement device to compare the conventional waveguide installation at DSS 14 with the beam waveguide installation used at Usuda. This comparison would be a valuable experience for future DSN antenna feed designs. It was decided that the most cost effective implementation would be to use DSN telemetry processing equipment at Usuda. The telemetry equipment selected consisted of two strings of the DSN Mark III configuration, which were available after DSS 12 was taken down for implementation into Mark IV-A. Timing equipment to supply Mark III reference pulses and time code was assembled from Mark III surplused equipment and some items from CTA 21 spares. A high level block diagram of the Usuda site modified for ICE support is shown in Fig. 2.

IV. Implementation

For implementation of the equipment, personnel were provided by the DSN Operations and Engineering Support Section, who were responsible for the implementation of the Telemetry Strings, their testing, and for the overall System Performance Test (SPT). The Radio Frequency and Microwave Subsystems Section provided a person for installation and test of the LNA. DSN Operations and Engineering Support personnel also assisted in the installation and test of the LNA in order to help train them for the maintenance and operation of the LNA during the operational phase of the task. The personnel left for Japan on March 29, 1985. Equipment was shipped from JPL on March 13, 1985 with JPL responsible for U.S. export license, customs clearance, and transportation to Tokyo, Japan. ISAS was responsible for customs clearance in Tokyo and transportation to Usuda. The shipment arrived at Usuda on April 1, 1985. Equipment was uncrated, inspected, and inventoried. The only physical damage to the equipment was to a door hinge on one of the magnetic tape units, which was repaired on site.

The LNA was installed on the second floor of the antenna equipment building. Figure 3 is a drawing of the antenna structure. This room rotates in azimuth but is stationary in elevation. Negotiations between JPL and ISAS gave responsibility to ISAS to produce a listen-only feed horn assembly to interface the JPL-supplied LNA to the beam waveguide system, and to provide adequate space, power, and air conditioning for the JPL-supplied equipment. The LNA was mounted on its side to allow for the installation of the horn with the shortest possible waveguide transition. The beam waveguide is a feed method where the propagation does not depend on the boundary conditions of the walls. A system of mirrors is used to move the focal point to a convenient location. Figure 4 indicates an example of this technique. A tube encloses the mirror/focusing system just to ensure nothing penetrates the beam. The listen-only system noise temperature measured after the implementation was approximately 15.5 K with the antenna at zenith.

The telemetry processors were installed in the control room. Power had to be adapted by ISAS from 200 Vac, 60 Hz, to 117 Vac, 60 Hz. A series of transformers were used for this purpose. The control room was air conditioned and had a computer floor, but the floor was primarily solid with removable panels only along a few cable run areas. Since the removable panels did not coincide with the allocated layout of JPL equipment installation, small stands (25 cm × 61 cm × 71 cm) were built by ISAS to set the racks on. This allowed for cable entry through the bottom of the rack and for cold air flow entry into the racks.

The implementation process proceeded according to plan. Some small technical problems occurred but nothing which wouldn't be encountered at any other site. LNA cooldown, system noise temperature measurements, star tracks, and SPTs were all completed on schedule.

Measurements of system noise temperatures at 2295 MHz is summarized in Table 2. The Usuda antenna aperture efficiency is 79% ±1% (1.05 dB higher than DSS 14). For low-noise communications at 30-deg elevation, the Usuda system sensitivity (antenna gain divided by system temperature or *G/T*) in dB is 1.58 dB better than DSS 14 in the comparable low-noise configuration. For ICE tracking at 2270 MHz the Usuda *G/T* was 2.2 dB more than DSS 14 because DSS 14 was configured to operate in the diplexed mode. The data clearly show that the Usuda beam waveguide system does not degrade the overall system noise temperature.

V. Operations

The negotiations between JPL and ISAS developed a schedule for ICE support by Usuda for the following three periods of time:

May 15 – June 29, 1985
September 8 – September 12, 1985
October 28 – November 6, 1985

The first tracking period helped alleviate a heavy workload at the Australian complex. The second period covered the Giacobini-Zinner encounter, and the third period covered the first Halley radial by ICE.

ISAS had a Halley Comet project with two spacecraft. One of the spacecraft, which was called MST5 prior to its successful injection and now called Sakigake, was already on its way to measure the environment prior to the Halley Encounter. The second spacecraft was successfully injected between the first and second periods of ICE support at Usuda. The second spacecraft, known as Planet A prior to successful injection and now called Suisei, will encounter Halley's Comet. The view periods for Sakigake, Suisei, and ICE unfortunately had quite a bit of overlap so scheduling became a tough problem. Complicating the problem was the single crew staffing at Usuda. The end result was that the majority of the scheduled passes for ICE was from 4-1/2 to 5 h long. During the first support period these blocks of time were starting near the horizon and terminated with an antenna elevation of about 49 deg.

Antenna pointing was accomplished using predicts generated by ISAS from state vectors supplied by JPL. The Navigations Systems Section supplied the state vectors periodically during the time Usuda was tracking ICE. The state vectors were generated at JPL and sent by Telex to ISAS in Tokyo, where the computer that generated the predicts was located.

As the operational date of May 15, the start of the first support period, approached the LNA warmed up. There was evidence that the refrigerator had massive contamination of the engine circuit. During the first support period there were several warmups by the LNA. The drive unit displacer was changed. Leaks were repaired. The compressor was replaced. None of the attempted fixes seemed to cure the problem. Although the LNA made it through the other two support periods without any loss of support to scheduled tracking passes, the problem persisted. It took a great deal of coordination between JPL personnel at the site and the Radio Frequency and Microwave Subsystems Section personnel to keep the LNA going as well as it did.

Table 3 indicates the performance during the first support period. On DOY 143 the Earth–spacecraft distance was approximately equal to what it would be at Giacobini-Zinner encounter. On this day the spacecraft was switched from its normal data rate of 512 bps coded to the encounter rate of 1024 bps coded. The objective was to demonstrate the network data recovery capability in the encounter environment. The Usuda performance on that day was very encouraging; the telemetry decoding string locked up near the horizon with a symbol SNR of –0.1 dB and it peaked at the end of the track support at +1.25 dB with an antenna elevation of 40 deg.

During the first support period for Usuda there were the three LNA refrigerator problems referred to earlier. On the days the LNA was not available, the ISAS-cooled paramp was used, and the symbol SNR was approximately 3 dB lower than when the DSN LNA was used. This still gave acceptable data at 512 bps coded but would not have been an adequate configuration for the Giacobini-Zinner encounter at 1024 bps coded. The second telemetry string at Usuda was for redundancy in case of a failure on the prime string. When both strings were operational, which turned out to be the case on all passes except the next to last pass of the third support period, the second telemetry string was used for making symbol stream recordings.

The tapes from both the telemetry decoding string and the tape from the symbol stream recording were retained at Usuda until approximately a 10-day quantity had accumulated and then were shipped back to JPL in a single shipment. At JPL an Original Data Record (ODR) to Intermediate Data Record (IDR) conversion was made by the Network Data Processing Area (NDPA) and the IDR data was electrically transmitted to the project.

For the second support period of the Giacobini-Zinner encounter, the scheduled track times for ICE were at better elevation angles; the tracks were scheduled from 1900Z to 0100Z daily which corresponded to elevation 57 deg at the beginning of the scheduled support increased to 77 deg and by end of the pass was 40 deg. The ground station support during the encounter period was without incident and the symbol SNRs were higher than on the test day, DOY 143, due to the better elevation angles. Table 4 indicates the performance on a pass basis. The tapes for this period were sent to JPL on a daily basis. During practice sessions several modes of tape delivery were tried but the only one which got us tapes within 24–30 h of end of pass was an express handling service called DHL. The decoded telemetry tapes were expedited to NDPA for transmission to the project. The symbol stream recordings were delivered to the Communications Research Section for processing (see Ref. 2).

The third support period, for the first Halley radial the times scheduled for the ICE support, gave better antenna elevation angles than the first period and the symbol SNR for the 512 bps coded averaged 3.6 dB to 6.0 dB during a pass. Results are indicated in Table 5. The only abnormal event was that both telemetry strings were not available on October 31 so no symbol stream recording was made. The problem was in a Symbol Synchronizer Assembly (SSA), which was repaired after the pass and both strings were available again for the next pass, which was the last one. Tapes for the third support period were consolidated into one batch shipment for return to JPL.

After the November 1 pass the JPL equipment was disconnected and prepared for shipment. The Japanese customs broker/exporter picked up the equipment on November 10 and by December 9, 1985 the equipment had cleared customs in Los Angeles and was returned to JPL.

VI. Summary

The objectives of the task were all met. The Usuda Deep Space Center supported as negotiated, and the data supplied sufficiently enhanced the data recovery from that longitude. A demonstration of non-realtime symbol stream combining was accomplished by combining recordings from Usuda and Goldstone. The beam waveguide feed system was analyzed and considered to have many advantages over conventional waveguide systems. The experience with the Usuda beam waveguide will be useful in the decision-making process for future DSN designs. The practicality of our two countries sharing the use of scientific facilities was shown to be mutually advantageous and very cooperative.

Acknowledgments

As in any task there are many people to thank and no one wants to forget anyone, but I will still attempt to acknowledge some outstanding efforts. In the planning, there were R. Clauss of the TDA Technology Development Section and R. Bolan of the DSN Operations and Engineering Support Section. In the implementation, S. Petty, D. Neff, M. Britciffe, and all of the Radio Frequency and Microwave Subsystems Section were responsible for the installation test and repair of the LNA. The people who kept the JPL site equipment working and did a great job interfacing with the Usuda site personnel were C. Hoynes and R. Spear of DSN Operations and Engineering Support Section and N. Williams of Goldstone Operations. In Japan two people without whose assistance we would never have met our commitments were Dr. T. Nishimura and Dr. T. Takano of ISAS.

References

1. Layland, J.W., "ICE Telemetry Performance," *TDA Progress Report 42-84,* this Issue.
2. Hurd, W.J., "Symbol Stream Combining for ICE," *TDA Progress Report 42-84,* this Issue.
3. Fanelli, N.A., and Morris, D.G., "ICE Encounter Operations," *TDA Progress Report 42-84,* this Issue.

Table 1. Usuda system characteristics

Characteristics	For ICE Mission	For Planet-A Mission
Antenna type	Cassegrain antenna fed by 4-ref. beam-waveguide	Cassegrain antenna fed by 5-ref. beam-waveguide
Antenna mount	Azimuth-elevation mount with wheel and track	
Antenna drive	DC motor anti-backrush drive	
Tracking mode	Manual and program	Manual, program and monopulse
Angular travel and maximum drive speed	AZ: ±270° (Rf. T.N.), 0.5 deg/s EL: 5° to 92°, 0.5 deg/s	
Pointing accuracy	0.01° rms for S-band use	
Angle readout resolution	0.001° rms	
Frequency range	Receive: 2.2 to 2.3 GHz	Transmit: 2.11 to 2.12 GHz Receive: 2.29 to 2.30 GHz
Antenna gain at feed horn throat	62.0 dB at 2.25 GHz	61.2 dB at 2.1 GHz 62.0 dB at 2.3 GHz
Antenna noise temperature with feed loss	19 K (EL $\geqslant$ 20°) [Feed loss $\leqslant$ −0.08 dB]	30 K (EL $\geqslant$ 20°) [Feed loss $\leqslant$ −0.25 dB]
Wide-angle radiation pattern	Equivalent to CCIR Rec. 465-1	Equivalent to CCIR Rec. 465-1
Beam-alignment between RHCP and LHCP	±2% of beamwidth	±3.5% of beamwidth
Axial ratio	---	No more than 2 dB
VSWR	No more than 1.1 at feed horn	No more than 1.3
Isolation between transmit and receive	---	No less than 100 dB
Power handling capacity	---	40 kW (CW) nominal

Table 2. Usuda 64-m antenna noise comparison (low-noise configurations at 2295 MHz)

Element	DSS 14		Usuda	
	Zenith	30° EL	Zenith	30° EL
Maser	2.5 K	2.5 K	2.5 K	2.5 K
Feed components*	4.4 K	4.4 K	3.9 K	3.9 K
Antenna (spillover)	4.5 K	6.7 K	4.0 K	4.9 K
Sky (cosmic + atmos)	4.6 K	6.5 K	4.6 K	6.5 K
Totals	16.0 K	20.1 K	15.0 K	17.8 K

*Feed components at DSS 14 include: calibration coupler, switch, transmit filter, orothomode junction, polarizer, rotary-joints, feedhorn and 2 reflex feed reflectors.

Feed components at Usuda include: calibration coupler, switch, orothomode junction, polarizer, mode generator, feedhorn, and 4 beam waveguide reflectors.

Table 3. Usuda ICE performance May 15–June 30, 1985

DOY 1985	Length of pass, *h*	Bit rate, bps/coded	Peak symbol SNR, dB	Comments
134	4 1/2	512	1.1	Maser red Used paramp
135	4 1/2	512	4.3	Maser green
136	4 1/2	512	4.3	
137	8	512	4.3	
138	8	512	4.3	
139	4 1/2	512	4.3	
140	4 1/2	512	4.3	
141	4 1/2	512	4.3	
142	4 1/2	512	4.3	
143	4 1/2	1024	1.25	
144	4 1/2	512	4.3	
146	4 1/2	512	4.2	
147	4 1/2	512	1.3	Maser red Used paramp
148	4 1/2	512	1.3	Maser red Used paramp
149	4 1/2	512	1.3	Maser red Used paramp
150	4 1/2	512	1.3	Maser red Used paramp
151	4 1/2	512	1.3	Maser red Used paramp
153	4 1/2	512	1.3	Maser red Used paramp
154	4 1/2	512	1.3	Maser red Used paramp
155	4 1/2	512	4.2	Maser green
156	4 1/2	512	4.2	
157	4 1/2	512	4.2	
158	4 1/2	512	4.1	
160	4 1/2	512	4.1	
161	4 1/2	512	4.1	
162	4 1/2	512	4.0	
163	4 1/2	512	4.0	
164	4 1/2	512	4.0	
165	4 1/2	512	4.0	
167	4 1/2	512	4.0	
168	4 1/2	512	4.0	
169	4 1/2	512	4.0	
170	4 1/2	512	4.0	
171	4 1/2	512		Missed pass ISAS predict computer problem
172	4 1/2	512	4.0	
174	4 1/2	512	1.0	Maser red Used paramp
175	4 1/2	512	4.0	
176	4 1/2	512	4.0	
177	4 1/2	512	4.0	
178	4 1/2	512	4.0	
179	4 1/2	512	4.0	Last pass this period

Table 4. Usuda ICE performance for Giacobini–Zinner encounter support

DOY 1985	Pass	UTC	Bit rate, bps/coded	Symbol SNR, dB	Elevation, deg	Comments
251	794	1900–0100Z	1024	1.8 – 2.0–1.6	57–77–40	
252	795	1900–0100Z	1024	1.7 – 2.0–1.6	57–77–40	Decoding string had varying SNR
253	796	1900–0100Z	1024	1.9 – 2.1–1.4	57–77–40	Heavy rain storm towards end of track
254	797	1900–0100Z	1024	1.8 – 2.15–1.6	57–77–40	RCVR momentarily dropped lock 0040Z; cause unknown
255	798	1900–0100Z	512	4.8 – 5.0–4.5	57–77–40	

Table 5. Usuda ICE performance for Halley first radial support

DOY 1985	Length of pass, h	Bit rate, bps/coded	Peak symbol SNR, dB	Comments
300	4	512	6.0	
301	4	512	6.0	
302	4	512	5.8	Heavy rain
303	4	512	5.8	Fog and rain
304	4	512	5.8	SSA failure No symbol stream recording Drizzling
305	4	512	6.0	

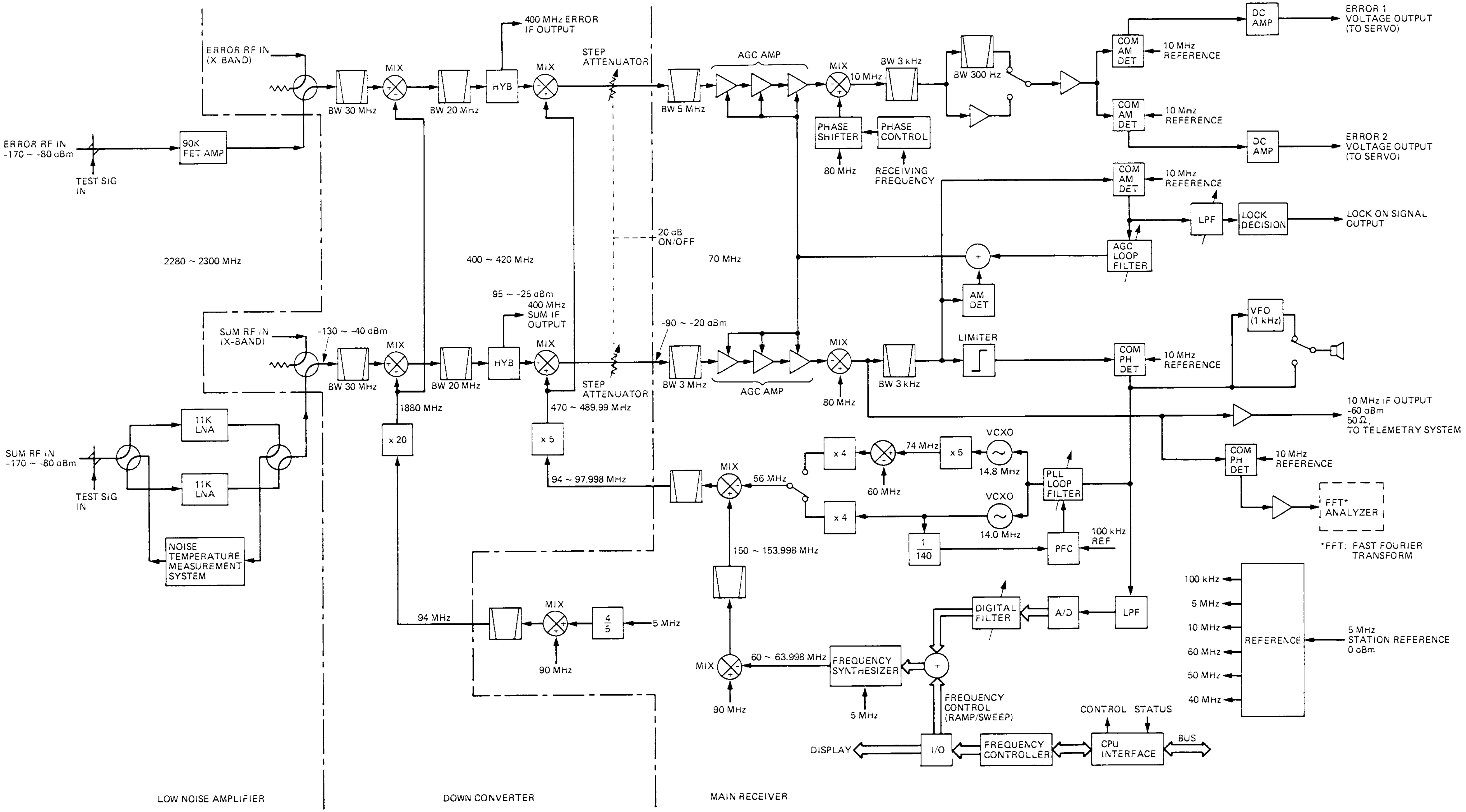


Fig. 1. Usuda block diagram

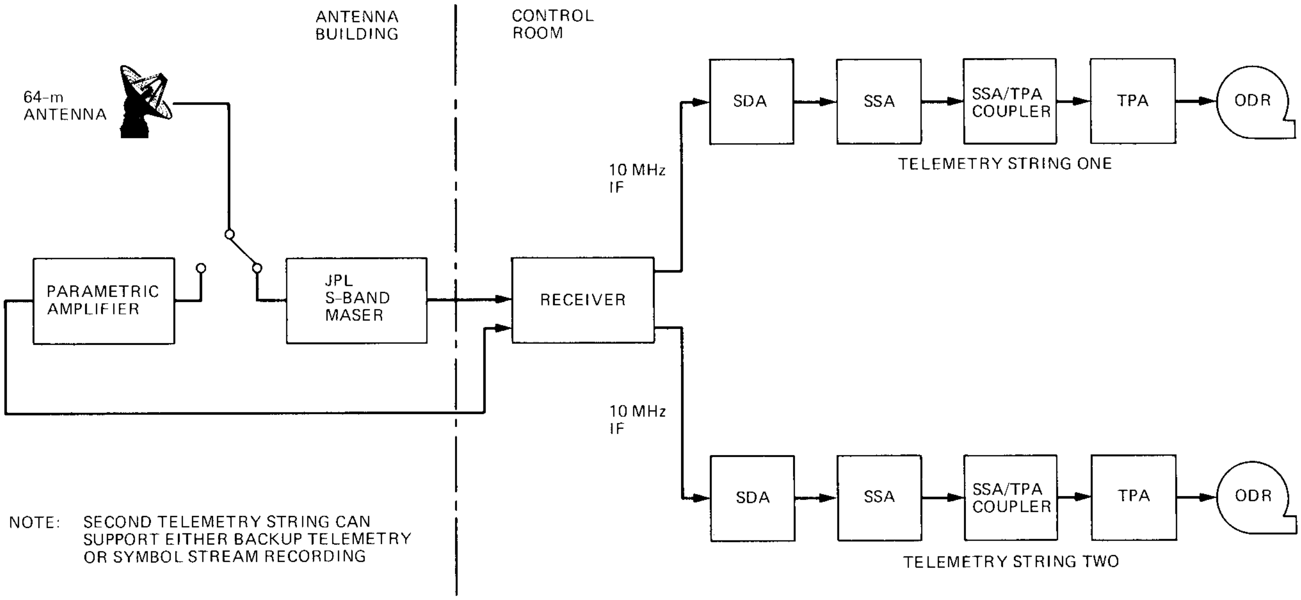
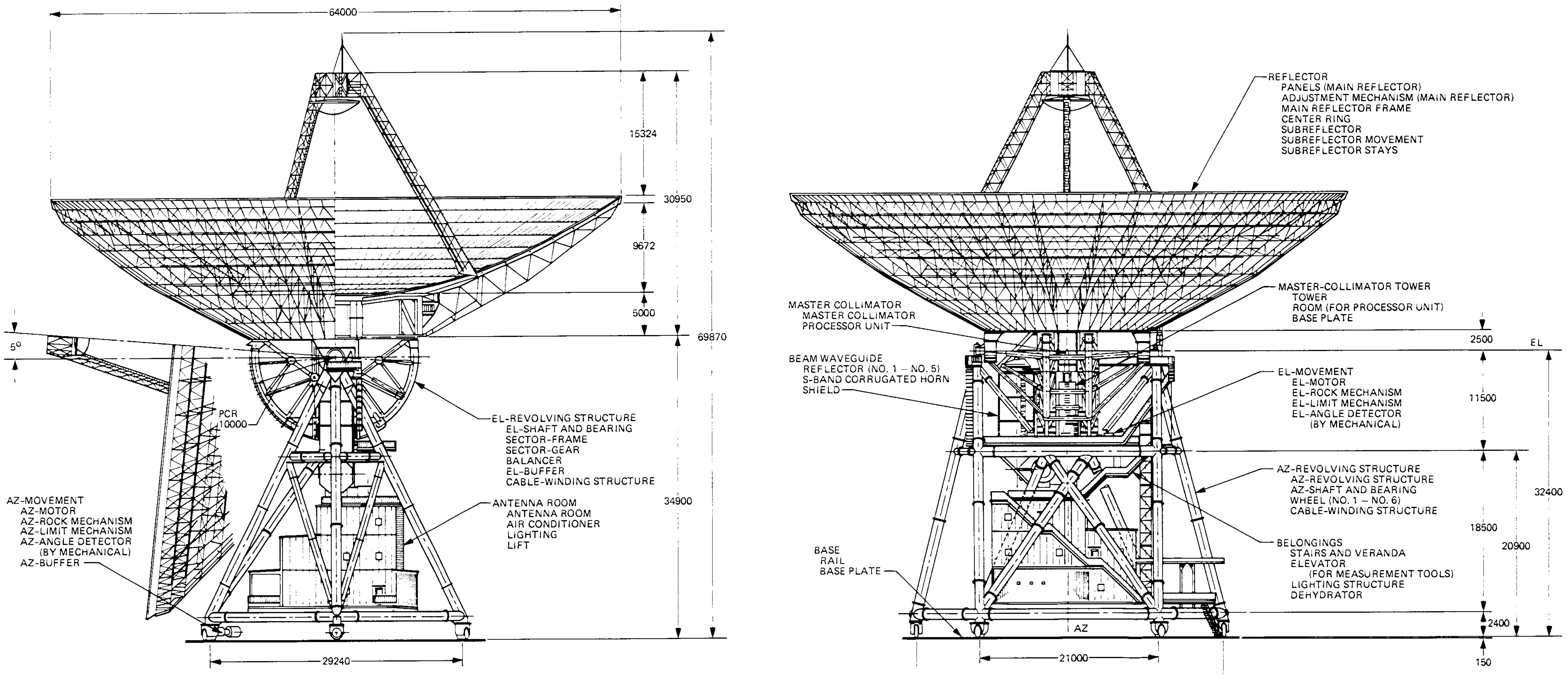


Fig. 2. Usuda Deep Space Center ICE configuration



DIMENSIONS IN MILLIMETERS

Fig. 3. Usuda 64-m antenna

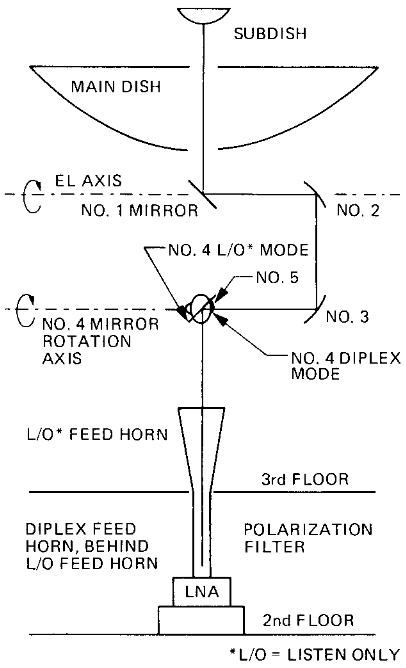


Fig. 4(a). Beam feed configuration

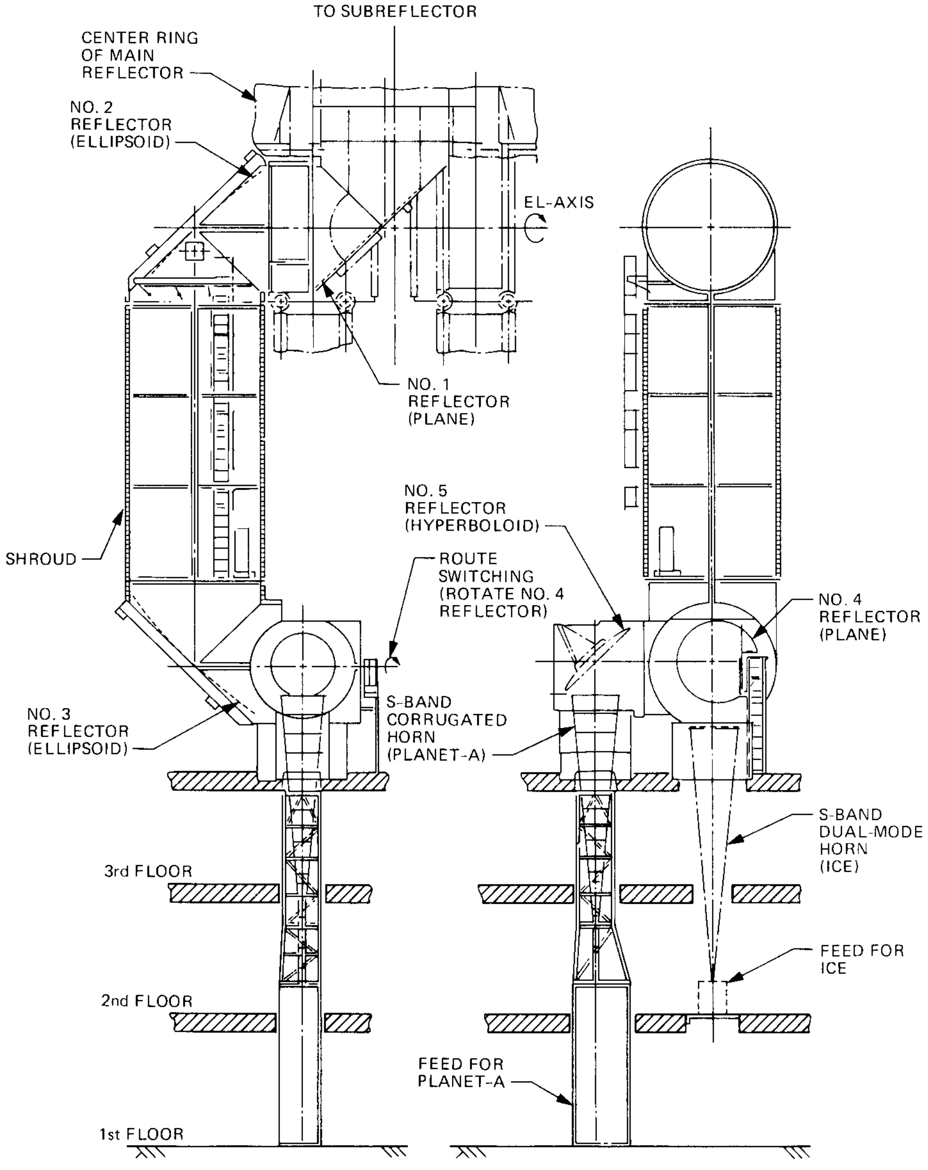


Fig. 4(b). Feed system of Usuda 64-m antennas