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Utilization of the Usuda Deep Space Center for the United States International Cometary Explorer (ICE)

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Abstract

The comet Giacobini-Zinner (GZ) approached the Sun in September 1985 prior to Halley's comet. International Cometary Explorer (ICE) which had stayed at the Lagrangian point and measured the solar wind was sent using lunar swing-by techniques to observe comet GZ. The Usuda Deep Space Center (UDSC) was utilized to support the mission by enhancing the telemetry capability. This paper describes the outline of comet GZ observation project and the feasibility of the UDSC to the project.

1. Introduction

The International Sun Earth Explorer (ISEE-3) was launched in 1978. ISEE-3 spent the next five years in Earth orbit where its prime task was to measure the solar wind. In December 1983, using a Lunar swingby, the ISEE-3 spacecraft was sent on a new mission to intercept the comet Giacobini-Zinner (GZ) on 11 September 1985. The ISEE-3 spacecraft was renamed for the new mission, International Cometary Explorer (ICE). In January 1984, the ICE spacecraft went out of range of the 26-meter antenna which previously tracked it, and support from the Deep Space Network (DSN) 64-meter antenna was required for the remainder of the mission.

The ICE spacecraft is a 16-sided cylinder which is 1.61 meters tall and 1.74 meters wide. There are two bands of solar arrays above and below an equipment platform where most of its payload of scientific instruments is mounted (Fig. 1). The solar array provides for all of the power requirements of the spacecraft.

The spacecraft rotates around the central axis of the cylinder at a rate of approximately 20 revolutions per minute. The spin axis is maintained in an orientation perpendicular to the plane of the Earth's orbit around the sun. The spacecraft orientation sensor system consists of two fine sun sensors and a panoramic attitude scanner.

The ICE telecommunications links are two identical and independent systems. The two transponders operate on separate frequencies of 2217 mHz and 2270 mHz and can operate simultaneously. This fact was utilized by the DSN to design a system to effectively combine the two signals which allowed the ICE project to meet one of its goals of providing a high bit rate of information throughout the encounter. The combining of the two signals resulted in a 2.5 dB increase in the Telemetry Signal to Noise Ratio.

2. Mission Goals and Objectives

ICE was targeted to pass the anti-sunward side of Comet Giacobini-Zinner. ICE passed directly through the tail about 10,000 km downstream from the nucleus. The lack of a camera and other remote sensing devices gave the ICE Project scientists no other choice. The next decision was where in the tail from the nucleus, a value compatible with avoiding a comet wake region and still have a 99 percent or greater probability of intersection.

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The expected science return falls into three areas:

(1) The physics of the cometary bow shock: to evaluate the location, strength, structure, and related particle acceleration and to determine the extent of the foreshock.

(2) The physics of the interaction between the interplanetary magnetic field and the cometary plasma and an evaluation of the ionization phenomena and turbulence characteristics.

(3) The physics of the comet tail.

The orbit of Comet Giacobini-Zinner takes it around the Sun about once every 6.6 years. For a comet intercept mission, a precise orbit would have to be derived from previous sightings. To facilitate this, D. Yeomans of JPL and J. Brandt of GSFC collected GZ comet data and documented it in the Giacobini-Zinner Handbook.

Ultimately, a major trajectory maneuver was executed on June 5, 1985 after JPL (Yeomans) had updated the comet ephemeris from over two months of reliable worldwide observations. Two trim maneuvers were also made on July 9 and September 6 to correct for any burn errors. The final trim retargeted the spacecraft to a point 7815 km from the comet's nucleus, but kept the original intercept time of 11:04 UTC on September 11, 1985.

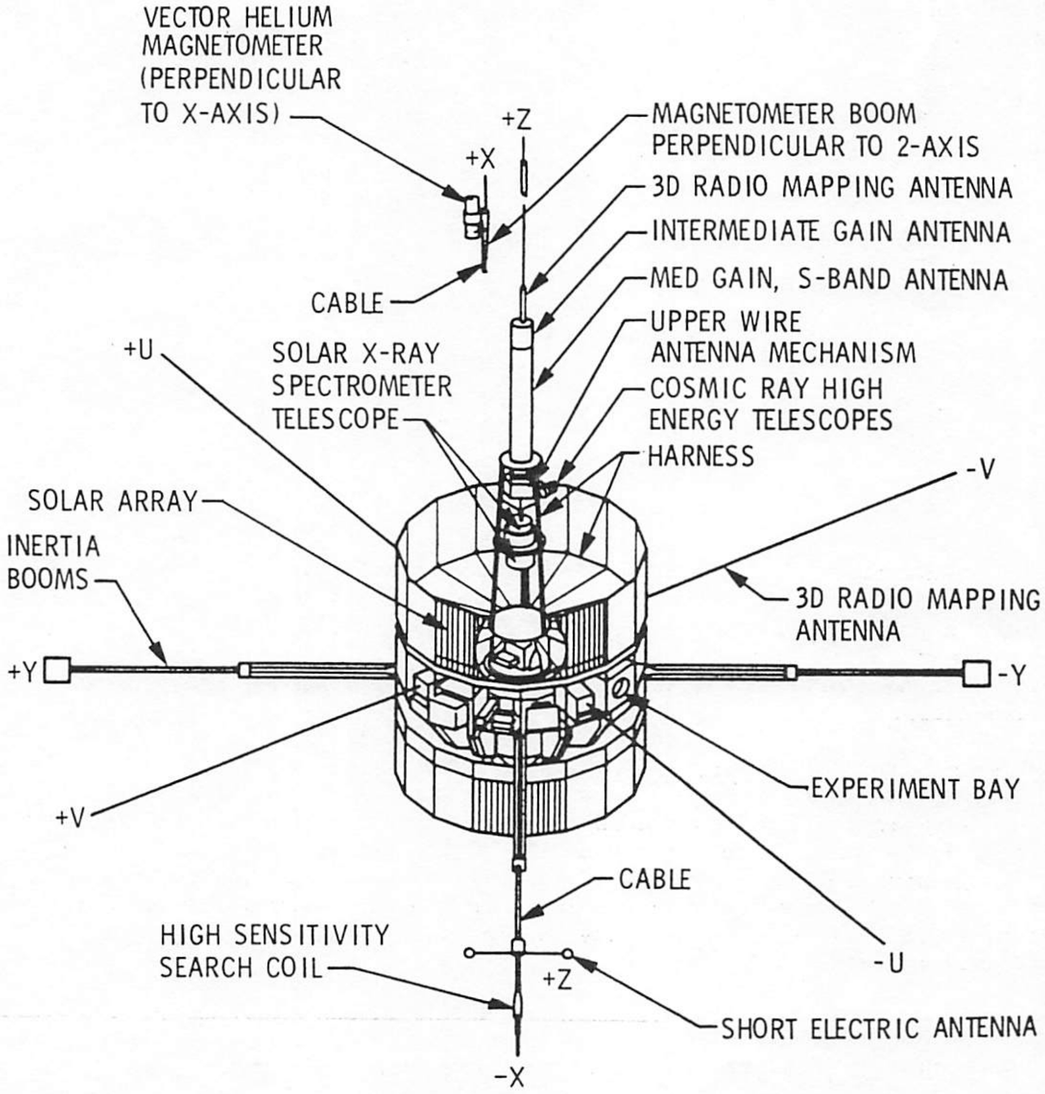

Fig. 1 Drawing of ICE Spacecraft

3. Worldwide Observation System of Comet GZ and ICE

The DSN's plan for supporting the ICE encounter required telemetry arraying at the three DSN tracking complexes located at Goldstone, California, Madrid, Spain and Canberra, Australia. Each site used a 64-meter antenna which had special low-noise amplifiers (masers) covering the frequency range of both ICE transponders (Channel A was 2270 mHz and Channel B 2217 mHz). The spacecraft was configured so that both channels had identical telemetry modulation. The two channels were summed at the ground stations and this output was combined with the single Channel A output of a 34-meter antenna at both Canberra and Madrid. At Goldstone the 64-meter signal was combined with two 34-meter stations, each of which demonstrated the Channel A signal only. Even with telemetry array from multiple antennas at each site the link margin was small. Therefore, additional support was obtained by using the Usuda, Japan 64-meter antenna and the 305-meter antenna of the Arecibo Radio Observatory at Arecibo, Puerto Rico (Fig. 2).

The encounter was planned to take place when the spacecraft was in view of the Madrid, Arecibo, and Goldstone complexes to ensure good encounter data. Realtime communication links were established to ensure realtime encounter data to the ICE Project. The Usuda antenna's data was recorded with expedited air shipment of magnetic tapes to JPL for post-encounter processing.

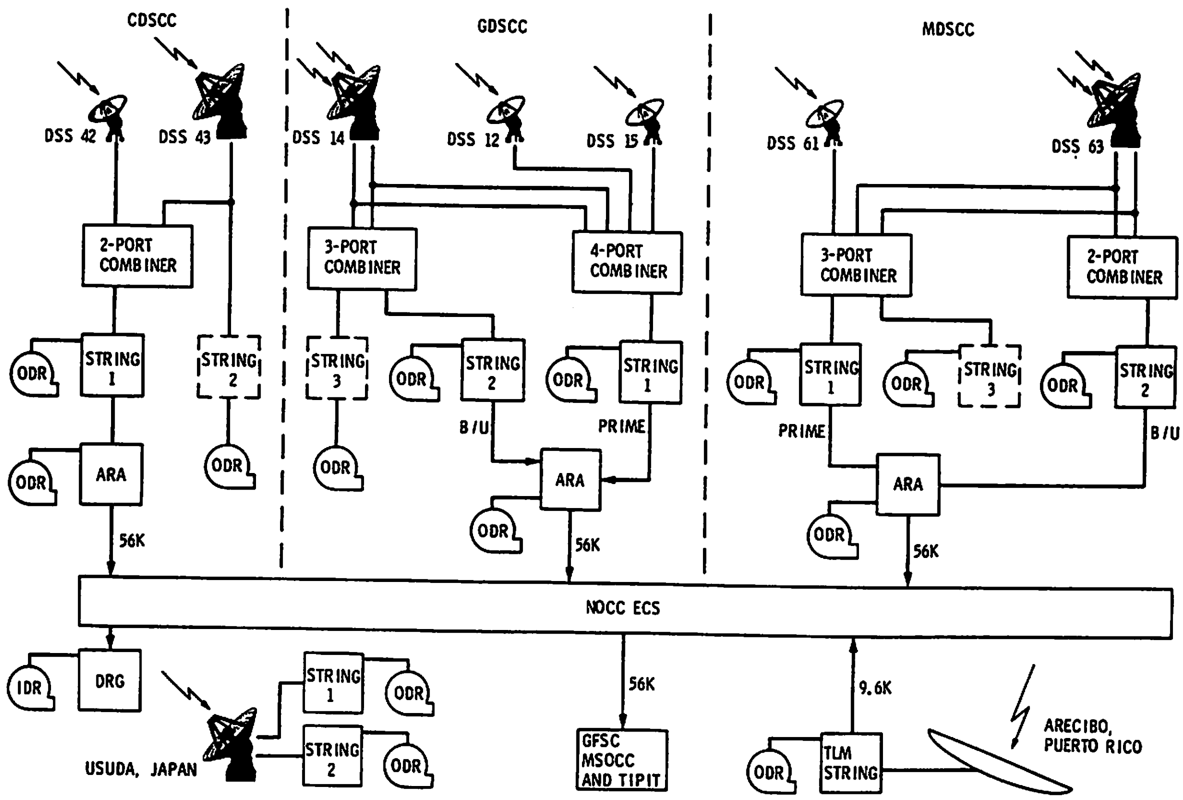

Fig 2 ICE Encounter Support Configuration

4. Role of Maser and its Constitution

ICE mission support requirements dictated that a maser low noise amplifier be used to achieve the highest signal-to-noise ratio possible. The Deep Space Network (DSN) Advanced Systems Program supplied the maser system, consisting of a traveling-wave maser (TWM) contained in a 4.5 degrees kelvin closed-cycle helium refrigerator, helium compressor, rack-mounted control instrumentation and power supplies, cables, gas lines, and support equipment. A block diagram of the system is shown in Fig. 3 and a photograph of the equipment installed in the antenna is shown in Fig. 4. The maser and instrumentation rack were installed on the second floor of the antenna equipment building. The Usuda beam waveguide feed system provides a place for feeds, low noise amplifiers, and transmitters that rotates in azimuth but is stationary in elevation, thus providing for easy access to the equipment even during tracking periods.

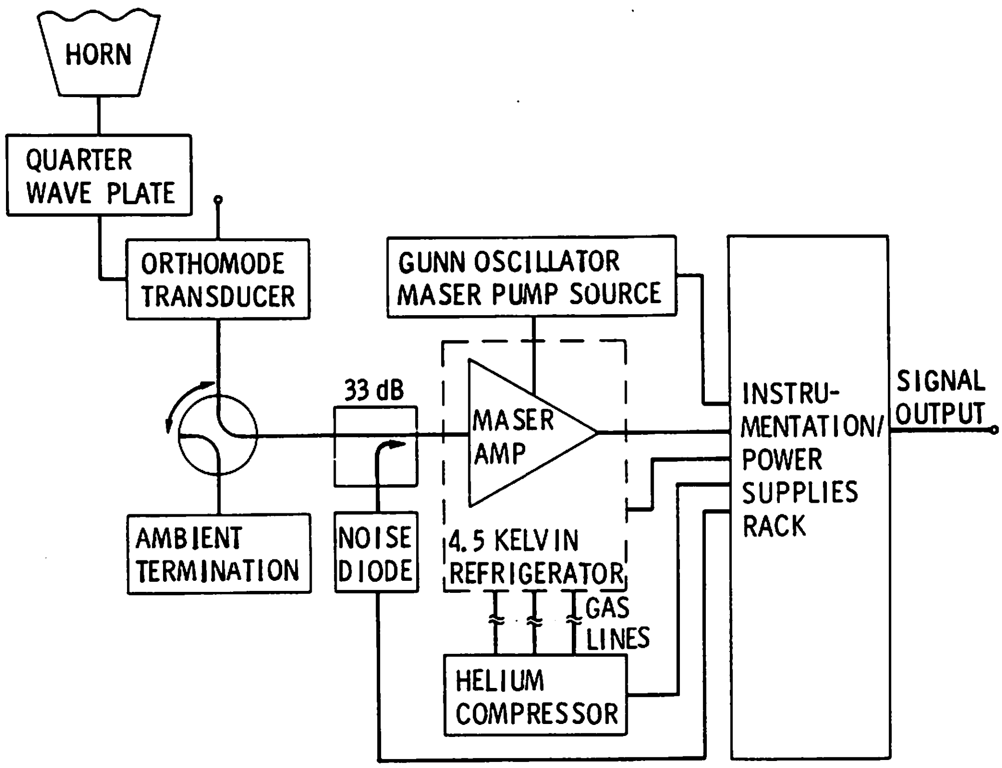

Fig 3 Block Diagram of Waveguide Feed Components and Maser Amplifier System

This maser/refrigerator assembly was first installed in the Deep Space Network's DSS-14 64m antenna at Goldstone, California in 1974 (Refs. 1, 2) and was used there for ten years. It is designed to operate in any position (unlike the Usuda antenna, DSN antennas have a cassegrain feed configuration with the maser/refrigerator system mounted in a feedcone above the elevation axis).

The TWM structure consists of a copper comb-line slow-wave structure which contains bars of single crystal ruby. This structure is placed in a 2.5 kilogauss persistent-mode superconducting magnet. The TWM and magnet are mounted on the 4.5 degrees (K) station of a 1 watt closed-cycle helium refrigerator. A low-noise input transmission line, which couples the room temperature WR430 waveguide input port to the TWM, contributes less than 0.5 kelvin to the maser noise temperature. This is achieved by cooling the entire center conductor of the coaxial input line to 4.5 degrees (K) and providing a low loss quartz vacuum window. A vacuum housing and radiation shields provide thermal isolation for the cooled components.

The TWM is designed to provide optimum operation in the 2270-2300 MHz frequency range; it is tuneable from 2250 MHz to 2400 MHz. The equivalent input noise temperature of the maser package at the room temperature waveguide input flange is 2.5 degrees (K), and the resulting antenna system noise temperature at zenith measured 15 degrees (K). The maser was operated at approximately 50 dB net gain with an instantaneous bandwidth of 20 mHz.

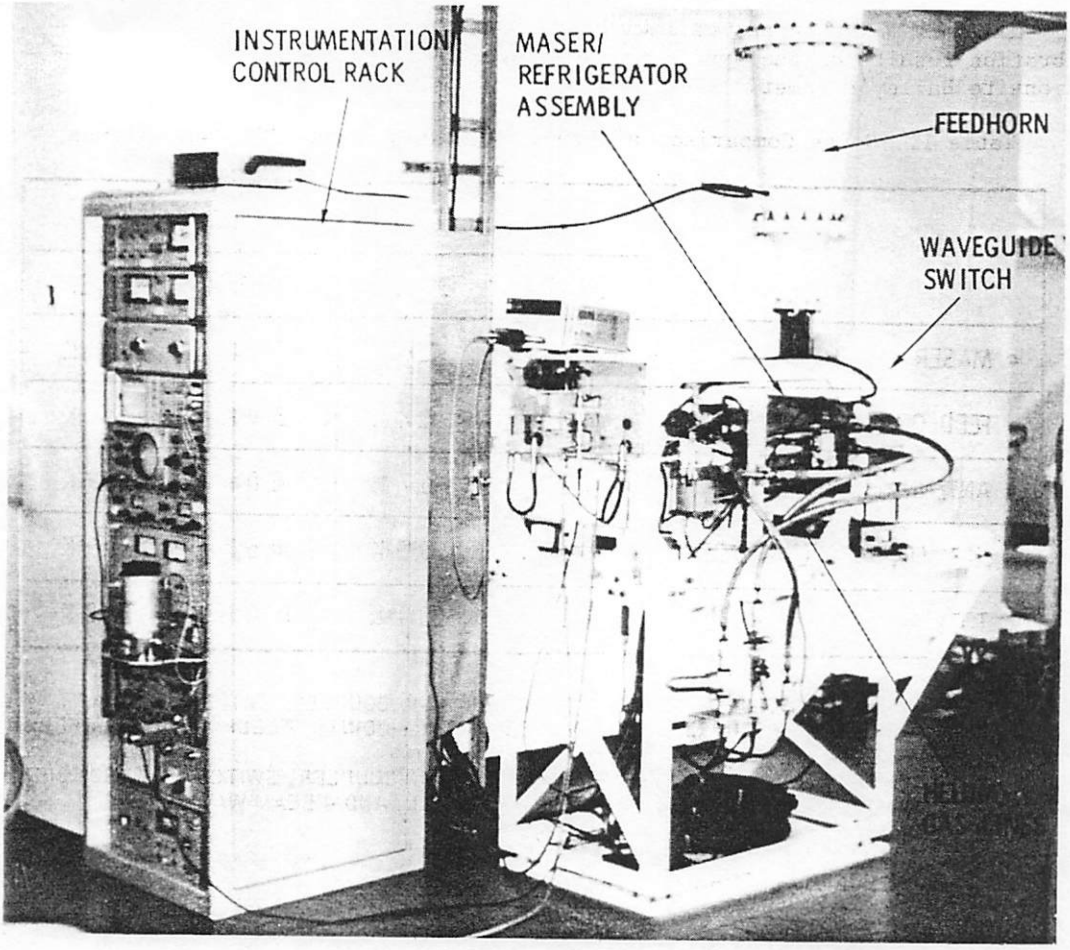

Fig 4 Maser System Installation (Helium Compressor located in another room)

5. Characteristics of the UDSC System and Observed Results

Table 1 shows the total system temperature measured at Usuda and DSS-14 at zenith and 30 degrees elevation angle using the same TWM. The individual contributors to system temperature vary in origin: (1) The maser was measured separately, (2) the sky noise was estimated based on atmospheric attenuation and cosmic background data published by others, (3) the spillover was estimated by antenna engineering calculations, and (4) the feed components were deduce by subtracting the other individual contributions from the totals. Accuracy of the total system temperature is determined by the accuracy of the power ratio measurement when switching between an ambient reference load and the antenna feed, the knowledge of the reference load temperature and the system linearity. It can be shown that the error in total system temperature is less than +/- 0.5K.

The tipping curve shown in Fig. 5 compares the Usuda and DSN 64m antenna noise temperature increase as a function of elevation angle. It is important to know the noise temperature as a function of antenna elevation angle in order to predict link performance during entire spacecraft tracks.

The received power level, signal-to-noise ratio (SNR), symbol-error rate (SER) were monitored in operation. SER is computed from the coded signals and the number of needed corrections. SNR and SER are highly dependent on weather and circumstances, and their changes with time are shown in Fig.6. Immediately after the acquisition of signal (AOS), the noise from the ground degrades the SNR. SER decreases from 5.6% to the stable value of 1.2%, as is accurately correspondent to the change of SNR. The variation of SER is far less than that of SNR.

At the encounter of ICE with comet GZ, the carrier power of -144 dBm was received. This value agrees well with the estimated level considering the calibration results of the system which is designed at the frequency of Japan's missions to Halley's comet.

Table 1. Noise Comparison of Usuda 64M Antenna with DSN 64M Antenna

	DSS 14[2]		USUDA[2]	
	ZENITH	30^0 EL	ZENITH	30^0 EL
• MASER	2.5 K	2.5 K	2.5 K	2.5 K
• FEED COMPONENTS[1]	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

[1] 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

[2] LOW NOISE CONFIGURATION, 2295 MHz

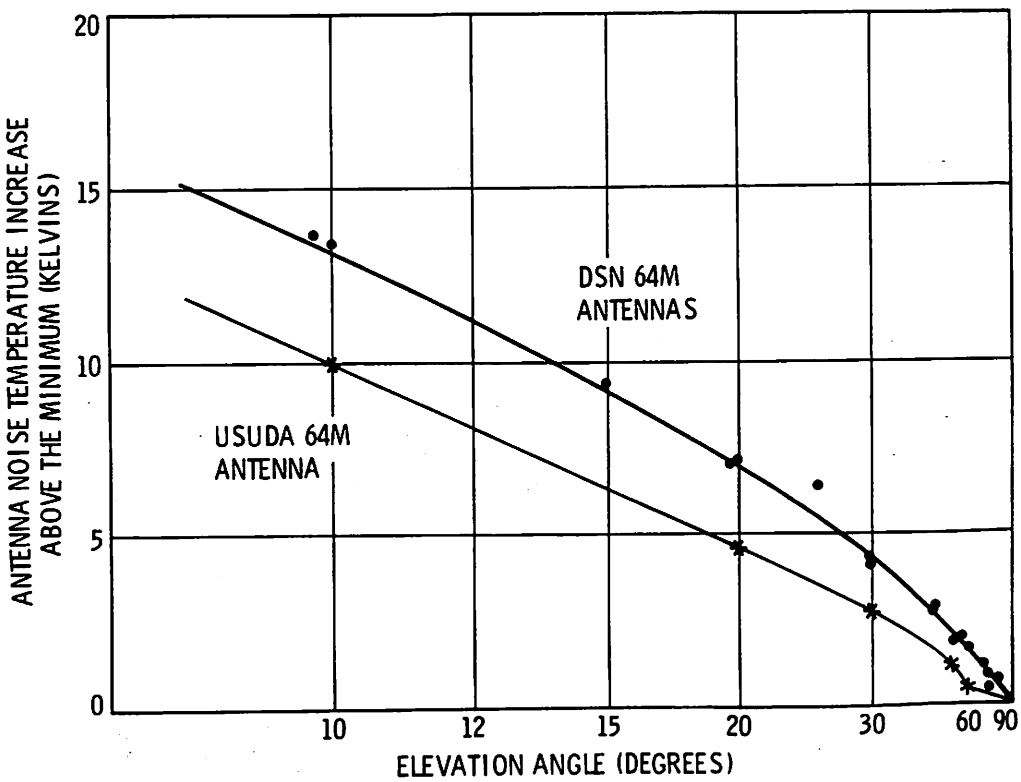

Fig 5 Tipping Curve Comparison of Usuda and DSN 64m Antennas

Comet dust model predictions estimated that about 0.5 to 1 dB signal level variation could be expected due to GZ comet dust interaction with the ICE spacecraft as the spacecraft crossed the comet's tail. No signal level variation occurred during ICE GZ comet tail crossing and the ICE Project reported that no detectable dust damage occurred.

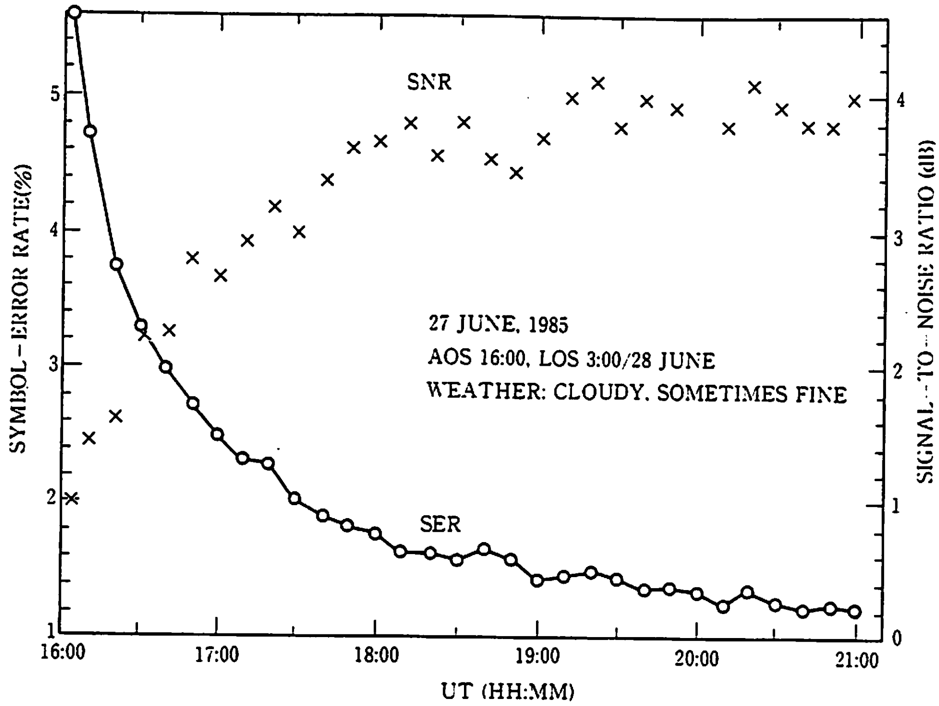

Fig.6 Symbol-Error Rate and Signal-to-Noise Ratio Changes with time

6. Conclusion

Usuda performance with one receiver channel was comparable to, or slightly in excess of, that of the Goldstone 64-m antenna with the two channels combined. The contributors to this were a higher antenna efficiency (62.4 dBi gain), and lower system temperature (14.5 K) in a listen-only configuration. These factors combined to make the Usuda effective performance about 2.7 dB stronger than that of the Goldstone 64-m single channel diplex configuration, or comparable to that of the Goldstone two-channel.

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 faciliities was shown to be mutually advantageous and very cooperative.

Acknowledgments

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