

Use of a 2.3-GHz Traveling-Wave Maser on the Usuda 64-Meter Antenna

D. Neff

Radio Frequency and Microwave Subsystems Section

A 2.3-GHz traveling-wave maser/closed-cycle refrigeration system was installed on the 64-m antenna at Usuda, Japan. This was done to evaluate the beam-waveguide antenna noise performance, and to support the International Cometary Explorer's (ICE's) comet flyby mission. System noise temperature at 2270 MHz was measured to be 15 K, including the maser noise contribution of 2.5 K. Maser installation and noise performance are described. The Usuda 64-m antenna is of high quality with a system operating noise temperature better than the DSN 64-m antennas.

I. Introduction

The Institute of Space and Astronautical Science (ISAS), a Japanese agency that is similar in function to NASA, completed construction of a 64-m cassegrain antenna in October 1984 at Usuda, Japan, approximately 180 km west of Tokyo. This antenna is a more modern design than the DSN 64-m antennas, the first of which was completed in 1966. The Usuda antenna uses shaped main and subreflector surfaces, a beam-waveguide feed system, automatic subreflector positioning, extensive digital control systems, very modern receiver equipment with fiber optics interface to the antenna, and automated station control with remote monitor and control capabilities from Tokyo.

NASA's interest in the antenna's beam-waveguide noise temperature performance and a decision to use the antenna for tracking the International Cometary Explorer (ICE) [1] prompted an agreement to ship, install, and operate a 2.3-GHz traveling-wave maser (TWM) and closed-cycle refrigerator (CCR) system to support the ICE Giacobini-Zinner comet

flyby. This article describes the preparation, installation, testing, and operation of the TWM-CCR system in support of these objectives.

II. Preparation

Starting in August 1984, new equipment was ordered and existing equipment was assembled for the planned TWM-CCR installation at Usuda. The equipment required for the installation, operation, and maintenance of the system had to be supplied from JPL to the site. A TWM developed in 1973 [2] was available, as well as a compressor and helium purifier from the JPL and DSN inventory. The balance of the system was borrowed from several other projects to reduce costs (all equipment was returned to JPL when the task was completed). The TWM was tested at JPL on the roof of Building 238 in March 1984, and the results were virtually identical with the noise data taken in 1974 at 2295 MHz (Table 1). The total system noise operating temperature (T_{op}), measured at 2270 MHz (10.2 K), was quite acceptable, so the TWM components were shipped in March 1985 via air freight.

III. Site

The antenna (Fig. 1) is located in a forest preserve on the side of a mountain at a 1074-m elevation ($N = 36^{\circ}07'49''$, $E = 138^{\circ}22'03''$), approximately 15 km from the town of Usuda in the Nagano prefecture. Standard access to Usuda is by train via Komora from Tokyo Ueno Station. Travel time is 3 to 4 hours, depending on transfer connections at Komora. Equipment must be transported by truck from Narita Airport (80 km west of Tokyo) over generally good roads. The last 8 km are over a maintained dirt road. Access in the winter is sporadic due to heavy snow at various times. Rain is a common occurrence the rest of the year and varies from clouds and mist to heavy precipitation. A dormitory building has recently been completed to reduce travel requirements for personnel working at the site.

IV. Installation and Layout

Mitsubishi Electric Company (MELCO) installed a 2.3-GHz feedhorn in a low-noise configuration for use with a TWM (Fig. 2). The antenna feedhorn, complete with polarizer and orthomode transducer, terminates in an air-conditioned room, allowing easy access to equipment. The maser equipment rack (Fig. 2) was located adjacent to the maser, requiring only a 3-m cable run. The compressor is in another room where temperatures can vary between -20°C and above 35°C (Fig. 3). Earthquakes are a constant threat in Japan, and therefore everything was braced and securely bolted in place to the antenna structure.

A block diagram of the antenna microwave front end and TWM system is shown in Fig. 4. The front end consists of the following:

- Main 64-m shaped surface
- Shaped cassegrain subreflector
- Four beam waveguide reflecting surfaces [1]
- S-band antenna feedhorn
- RCP/LCP orthomode polarizer
- WR 430 waveguide switch
- WR 430 waveguide
- 33-dB directional coupler
- TWN/CCR assembly

The beam-waveguide system uses a movable mirror as a switch to connect to other feeds. A separate feedhorn with angle tracking and diplexed transmitter and receiving ability can be used for two-way communications with spacecraft at S-band.

V. Problems

Maser testing at the site was delayed a week because of a CCR warm-up problem during the test period allocated by MELCO. The station ran on a rather fixed and predetermined schedule because of the ongoing antenna work and acceptance testing being performed by MELCO. The TWM system testing was later restricted to brief periods before and after actual tracking periods.

The TWM experienced warm-up problems about every 4 to 6 days when first installed. Troubleshooting was difficult because the station was not manned 24 hours a day and failures often occurred during the night. The warm-up problems were believed to be caused by helium gas contamination, either from the compressor or from the helium supply source. The helium gas purity at the station was checked and found to be at least 99.999 percent pure. It was next suspected that the problem might be associated with the CCR drive cylinder system. The drive was changed with no improvement. Finally, the helium compressor was replaced with a spare unit. This contamination problem was not observed again, and the TWM operated normally during tracking periods for the ICE spacecraft. The suspect compressor was returned to JPL, where it was found to exhibit the same symptoms with a second refrigerator as those observed at Usuda. This compressor has subsequently been found to have an oil breakdown problem not observed in other compressors. The exact failure mechanism is not yet known, but an overheated component in the 440 three-phase motor or head assembly is suspected.

VI. Test Results

The first T_{op} measurement was made on April 29, 1985 using the cold sky/ambient load Y -factor technique. During clear sky conditions with the antenna at zenith, T_{op} measured 15.7 K at 2270 MHz and 15.0 K at 2295 MHz. After additional TWM tuning experience was obtained at Usuda, T_{op} final measurements of 15.0 K at 2270 MHz and 15.0 K at 2295 MHz were obtained. The net maser gain was between 45 and 50 dB, and instantaneous bandwidth (at -3 dB points) was approximately 20 MHz.

A tipping curve from 10-deg elevation to zenith was made and is plotted in Fig. 5. Data from a typical DSN antenna is shown for comparison. The subreflector support is a tripod rather than the quadripod structure used in the DSN and results in less blockage and lower ground noise. The improved noise performance, compared to the DSN data, varies from 1.5 K at the zenith to 4.5 k at the 10-deg elevation angle. The system noise temperature performance comparison between an existing operational DSN S-band antenna and the Usuda antenna is shown in Table 2 (from [1]).

VII. Beam-Waveguide System

The fact that the system noise temperature remained normal during heavy rain and did not increase is due to the design of the beam-waveguide system, since the horn window is protected from rain and is heated to prevent water condensation.

The beam-waveguide system (shown in [1]) consists of an approximately 3.5-meter-diameter tube with the necessary reflectors to refocus the microwave energy to the feedhorn. The feedhorn is a Potter dual mode sheet metal type [3], and is about 7 meters in length. The length (which is about twice that of DSN feedhorns) is required to reduce phase error at the horn aperture—a requirement of the beam waveguide system. The antenna in its present configuration has provisions for other antenna feedhorns, either at the same frequency or at other frequencies.

VIII. Summary

The ISAS Usuda 64-m antenna is a modern beam-waveguide antenna of superb quality with operating noise temperature performance better than the DSN 64-m antennas. The most outstanding feature from a hardware point of view is the ability to quickly install and maintain large pieces of equipment. The beam waveguide allows flexibility for multiple feed systems, multiple frequency bands, and expansion for future programs without compromising the performance of any existing front end system.

All goals of the ICE Giacobini-Zinner comet encounter involving the installation of the 2.3-GHz TWM were met, and much was learned about the new ISAS 64-m antenna. Future DSN antenna construction should consider the features and merits of the Japanese design.

Acknowledgment

The author would like to acknowledge the many people at Usuda for their help, cooperation, and patience, particularly Dr. T. Nishimura and Dr. T. Takano for making things happen, often under a very difficult schedule. Special thanks are due Clarence Hoynes and Richard Spear for their help in troubleshooting and repairing the TWM, and to Mike Britcliffe for diagnosing and correcting the problems with the cryogenic system. Thanks also to R. Clauss for performing the tipping curve comparison and his many helpful discussions.

References

- [1] J. P. Goodwin, "Usuda Deep Space Center Support for ICE," *TDA Progress Report 42-84*, October–December 1985, pp. 186–196, Jet Propulsion Laboratory, Pasadena, Calif., February 15, 1986.
- [2] R. Clauss and E. Wiebe, "Low-Noise Receivers: Microwave Maser Development," *JPL Technical Report 32-1526, Vol. XIX*, November–December 1973, pp. 93–99, Jet Propulsion Laboratory, Pasadena, Calif., February 15, 1974.
- [3] P. D. Potter, "A New Horn Antenna with Suppressed Sidelobes and Equal Beamwidths," *Microwave Journal*, Vol. 6, pp. 71–78, 1963.

Table 1. The comparison of system noise temperatures

Frequency, MHz	T_{op} , K	TWM, K	T_{op} , Switch and Coupler, K	Year
2295	8.3	2.1	N/A	1974
2295	8.3	2.2	8.5	1985
2270	9.1	3.0	10.2	1985

Table 2. System comparison

Components	DSS 14, K*		Usuda, K*	
	Zenith	30-deg Elevation	Zenith	30-deg Elevation
TWM	2.5	2.5	2.5	2.5
Feed Components†	4.4	4.4	3.9	3.9
Antenna (spillover)	4.5	6.7	4.0	4.9
Sky (cosmic + atmos.)	4.6	6.5	4.6	6.5
Totals	16.0	20.1	15.0	17.8

* Low-noise configuration, 2295 MHz.

† Feed components at DSS 14 include: calibration coupler, switch, transmit filter, orothomode junction, polarizer, rotary joints, feedhorn and two reflex feed reflectors. Feed componets at Usuda include: calibration coupler, switch, orothomode junction, polarizer, moder generator, feedhorn, and four beam-waveguide reflectors.

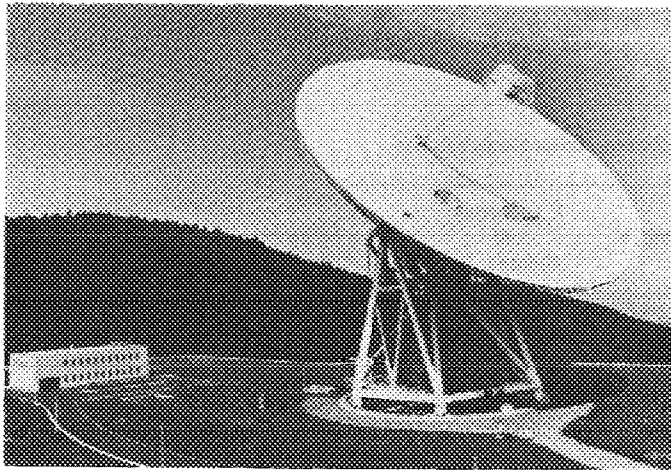


Fig. 1. Usuda antenna

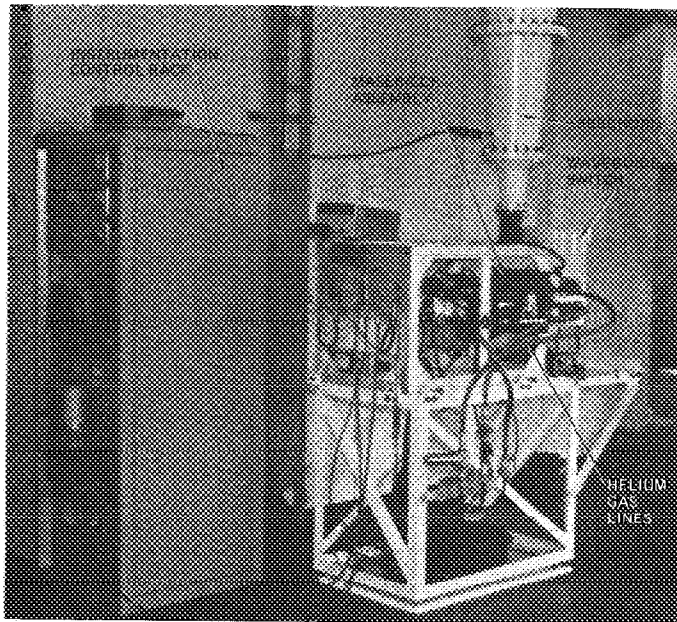


Fig. 2. Maser and instrumentation equipment

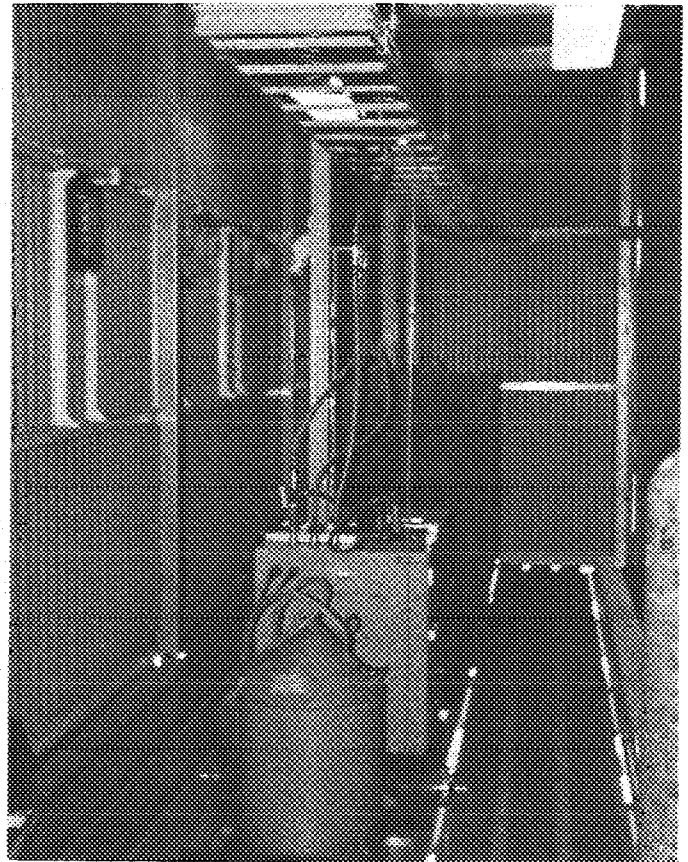


Fig. 3. Compressor room

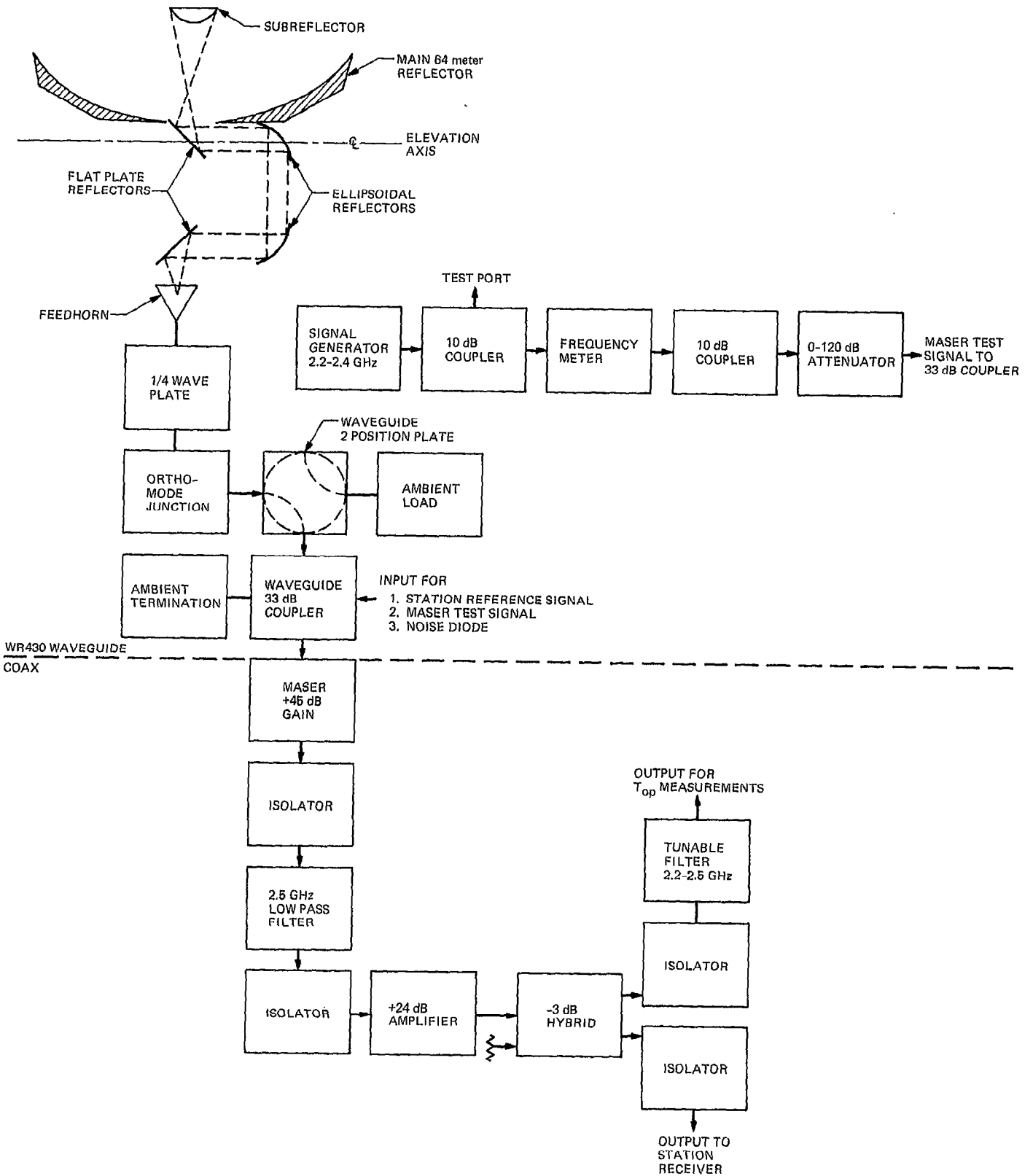


Fig. 4. RF block diagram

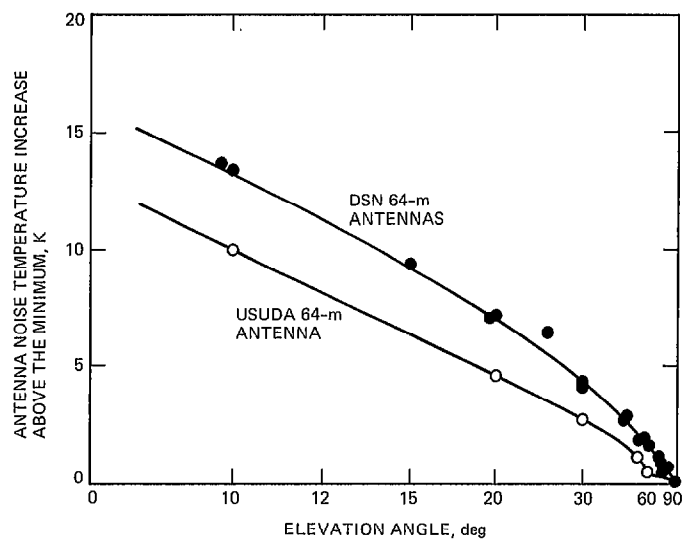


Fig. 5. Tipping curve