Arecibo Observatory Support of the U.S. International Cometary Explorer Mission Encounter at Comet Giacobini-Zinner

D. D. Gordon
TDA Engineering Office

M.T. Ward
Flight Mission Support Office
Goddard Space Flight Center

The Arecibo Observatory in Puerto Rico participated in the support of the U.S. International Cometary Explorer (ICE) mission when the ICE spacecraft passed through the tail of comet Giacobini-Zinner on September 11, 1985. The Arecibo Observatory is a research facility of the National Astronomy and Ionosphere Center (NAIC) operated by Cornell University under contract to the National Science Foundation (NSF). Coverage of the encounter involved the use of the observatory's 305-m (1000-ft) radio reflector antenna and RF and data system equipment fabricated or modified specifically for support of the ICE mission. The successful implementation, testing, and operation of this temporary receive, record, and data relay capability resulted from a cooperative effort by personnel at the Arecibo Observatory, the Goddard Space Flight Center, and the Jet Propulsion Laboratory.

I. Introduction

The Arecibo Observatory in Puerto Rico provided support to the U.S. International Cometary Explorer (ICE) mission when the ICE spacecraft passed through the tail of the comet Giacobini-Zinner (G-Z) on September 11, 1985. The Arecibo Observatory is a research facility of the National Astronomy and Ionosphere Center (NAIC) operated by Cornell University under contract to the National Science Foundation (NSF). The support involved the use of the observatory's spherical radio reflector antenna (Fig. 1) having a diameter of 305 m (1000 ft) and the installation of telemetry receiving and recording equipment designed to handle the ICE spacecraft telemetry signal. The Arecibo facility does not normally receive modulated signals, and the frequency of the ICE spacecraft signal is slightly below the observatory's S-band receive capability. Observations of the comet at Kitt Peak Observatory in April 1984 made it possible to target the ICE spacecraft for the encounter coverage by the Arecibo Observatory.

The ICE spacecraft, formerly designated the International Sub-Earth Explorer-3 (ISEE-3) consistent with the objectives of its earlier mission, was launched on August 12, 1978. For that mission the NASA Ground Spaceflight Tracking and Data

Network (GSTDN), managed and operated by Goddard Space Flight Center (GSFC), provided telecommunication and data acquisition support for the spacecraft. After the spacecraft was diverted from its earlier orbit and placed on an intercept path with the comet Giacobini-Zinner (Ref. 1), it soon traveled out of range of GSTDN stations and support responsibility was transferred to the NASA Deep Space Network (DSN) operated by the Jet Propulsion Laboratory (JPL).

Early DSN link margin calculations, which took into consideration the 70 million-kilometer communication distance and the desired 1024-bps telemetry data rate, indicated that a signal-to-noise ratio margin of 1.0 ± 0.5 dB would be experienced at encounter. However, it was recognized that there was a potential for signal strength degradation and, therefore, a loss in science data return due to the effects of cometary dust. Use of the Arecibo facility to enhance the capability for data recovery at encounter was deemed to be advisable in order to increase the confidence in achieving a successful ICE mission.

Goddard Space Flight Center had responsibility for implementation and testing of the modified telemetry receiving and recording system. GSFC also provided personnel to assist the observatory staff in the operation of the NASA-supplied equipment.

II. ICE Mission Support Requirement

The Arecibo Observatory was requested to provide coverage for approximately 2 h each day for the 8-day period bracketing the ICE spacecraft encounter at the comet. This support required the installation of RF and data system equipment to provide a receive and record capability compatible with the ICE spacecraft transponder A telemetry signal, and activation of a real-time data quality circuit between the observatory and GSFC.

The ICE spacecraft transponder A downlink characteristics are as follows:

(1) Transponder A, link 2, 2270.4 MHz

(2) Convolutionally coded PCM

(3) 1024-bps telemetry rate

(4) Split phase modulation code

(5) PM modulation

(6) 1.08 modulation index

III. System Implementation

Studies at JPL and GSFC indicated that the most expedient and cost effective approach to implementing a temporary receive, record, and data relay capability at the Arecibo facility included: (1) fabricate a circularly polarized antenna feed and cryogenically cooled low-noise amplifiers (LNAs) to accommodate the 2270.4-MHz downlink signal from the ICE spacecraft transponder A; (2) make use of existing RF and data processing hardware borrowed from GSFC; and (3) arrange through NASCOM for the lease of a data quality circuit for transfer of data from the Arecibo Observatory to GSFC.

A. Functional Description

The implemented operational configuration is represented in Fig. 2. The functions depicted in Fig. 2 are as follows:

(1) LNAs receive and amplify ICE spacecraft signal at 2270.4 MHz.

(2) Down convert (D/C) the 2270.4-MHz signal to 260 MHz.

(3) Up convert (U/C) the 260-MHz signal to 670 MHz.

(4) Input the 420-MHz signal to the multi-function receivers (MFRs, R_x).

(5) MFR video output to bit synchronizers.

(6) Hard decision output of bit synchronizers to frame synchronizers.

(7) Soft decision output of frame synchronizers to sequential decoders.

(8) Output of decoders to tape recorders and communication data formatters (CDFs).

(9) Output of the CDFs through a modem to the NASCOM line.

B. NSF/NAIC Fabricated Equipment

NAIC designed the circularly polarized antenna feed and low-noise amplifier (LNA) to be compatible with the ICE telemetry signal at 2270.4 MHz. These items were fabricated at NAIC's engineering laboratory at Cornell University and shipped to the observatory in May and June 1985 for installation in the carriage house suspended over the antenna (Fig. 3). NAIC also provided down converters at the output of the LNA for conversion of the received signal to a 260-MHz intermediate frequency.

The LNA was designed with two channels to accommodate reception and amplification of both left-circular polarized and right-circular polarized signals. This allowed some redundancy, as one channel could substitute for the other in the event of a failure. The right-circularly polarized channel was the prime supporting channel, as that is the polarization of the ICE downlink signal. There was no on-line operational redundancy in the remaining components of the LNA; however, spare parts had been procured and were on hand for replacement of components considered to be candidates for failure.

NAIC development of these devices was funded by NASA specifically for support of the ICE mission, but are to be retained at the observatory for use by NAIC in future scientific applications.

C. NASA/GSFC-Supplied Equipment

GSFC provided the additional RF and telemetry data processing equipment required to complete the ICE spacecraft compatible link at the Arecibo Observatory. In order to increase the probability of successful data capture, redundant equipment was installed for all operational functions:

(1) Multi-function receivers: 2

(2) Analog tape recorders: 2

(3) Up converters: 2

(4) Bit synchronizers: 2

(5) Frame synchronizers: 2

(6) Sequential decoders: 2

(7) Time code generators: 2

(8) Communication data formatters: 2

(9) Signal generator: 1

(10) Cables for the above equipment

All of the above equipment was assembled and tested at GSFC prior to shipment. It was delivered to the observatory pre-assembled in equipment racks for installation and integration at the observatory. This equipment was provided on loan from GSFC specifically for support of the ICE mission and was returned to GSFC following the comet encounter.

D. Communications Link

After the implementation task was underway, approval and funding became available for a communications circuit to provide the real-time transfer of telemetry data from the Arecibo Observatory to the Multi-Satellite Operations Control Center (MSOCC) and the Telemetry Processing Facility (TPF) at GSFC. NASCOM procured a commercial link for this purpose. The link was composed of several segments, principally a satellite link to an Earth station in Puerto Rico and microwave links from there to the observatory. The operational employment of this circuit routed data through JPL's Network Operations Control Center, which maintained overall operations control of communications circuits in support of the ICE mission.

IV. Test and Training

The test and training for the Arecibo support (NASA/GSFC document[1]) was composed of two basic parts: (1) a series of engineering tests, and (2) a series of operations tests, with the latter including operations training.

Initial testing began with the completion of the equipment link implementation at GSFC prior to its shipment to the observatory. A series of tests were conducted at GSFC to verify the functional integrity of the link and its interface with the MSOCC and TPF facilities. The results of these tests were satisfactory except for a timing interface problem between the link and the TPF. This problem was discovered early in the testing and survived through several tests until isolated in the Communications Data Formatter firmware. Upon its discovery the problem was promptly corrected, and the system was declared ready for shipment to the observatory.

Prior to shipment of the GSFC equipment to Arecibo, NAIC personnel installed the feed and LNA in the carriage house suspended over the antenna and performed preliminary tests of these units. After arrival of the GSFC equipment, an engineering test of the entire link was possible for the first time.

A. Engineering Tests

The engineering test series at Arecibo tested the link's capability to process ICE telemetry signals. During the first tests, simulated and pre-recorded signals were injected into the system. After successful conclusion of these tests, the link successfully tracked the ICE spacecraft, and the recorded data was shipped to the GSFC for verification by the TPF. At this point the link was declared operational and operations tests began, although the communications circuit remained to be tested since it was not yet available from the vendor.

B. Operations Tests

The operations tests consisted of a series of simulations to exercise equipment and procedures under conditions simulating those of the encounter support. These tests were conducted using both live spacecraft and recorded data sources with the participation of Arecibo, JPL, and GSFC. The tests concluded with an Operational Readiness Test conducted on September 6 after the communications circuit was available.

[1] "Space Tracking and Data Network ICE Network Test Plan," STDN No. 403/ICE, NASA/GSFC document, June 1985.

V. Operations

Encounter operations support at the observatory (Refs. 2 and 3) began on September 8, 1985, and continued through September 14, three days following the transit through the comet tail on September 11. The daily support consisted of an approximately 2-h period, the maximum coverage time available at the observatory during which telemetry data was received, transmitted to the MSOCC and TPF at GSFC, and recorded on station for possible playback. Operations at the observatory were supported by a team of NAIC personnel and GSFC personnel who operated the GSFC equipment. The overall operations control, integrating the Arecibo support operations with that of the DSN complexes at Madrid and Goldstone, was carried out by the JPL Network Operations Control Center.

The Arecibo Observatory performance profile is represented in Fig. 4. The telemetry equipment performed very well during the encounter, achieving solid lock with good data delivered at 72 deg of elevation. The effective threshold corresponds to an AGC reading of –154 dBm. At higher elevations, and for at least one-half hour of the time of comet tail crossing, the SNR was about 3.5 dB above this threshold value.

References

1. Farquhar, R., Muhonen, D., and Church, L. C., "Trajectories and Orbital Maneuvers for the ISEE-3/ICE Comet Mission," *Journal of Astronautical Sciences*, Vol. 33, No. 3, pp. 235–254, July–Sept. 1985.

2. Fanelli, N. A., and Morris, D. G., "ICE Encounter Operations," *TDA Progress Report 42-84*, this issue.

3. Layland, J. W., "ICE Telemetry Performance," *TDA Progress Report 42-84*, this issue.

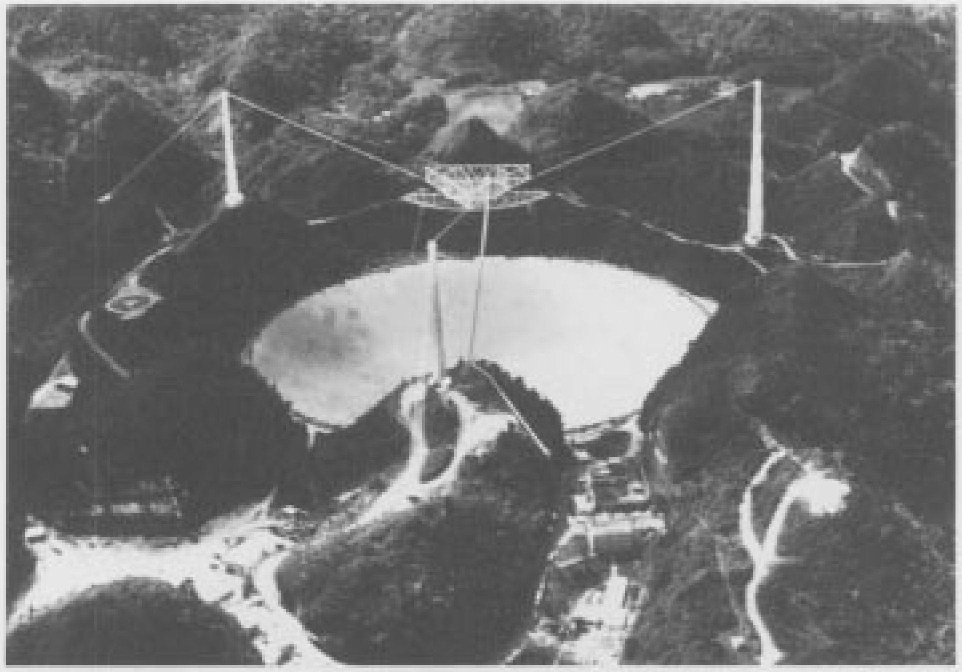

Fig. 1. Arecibo Observatory 305-m (1000-ft) diam radio reflector antenna

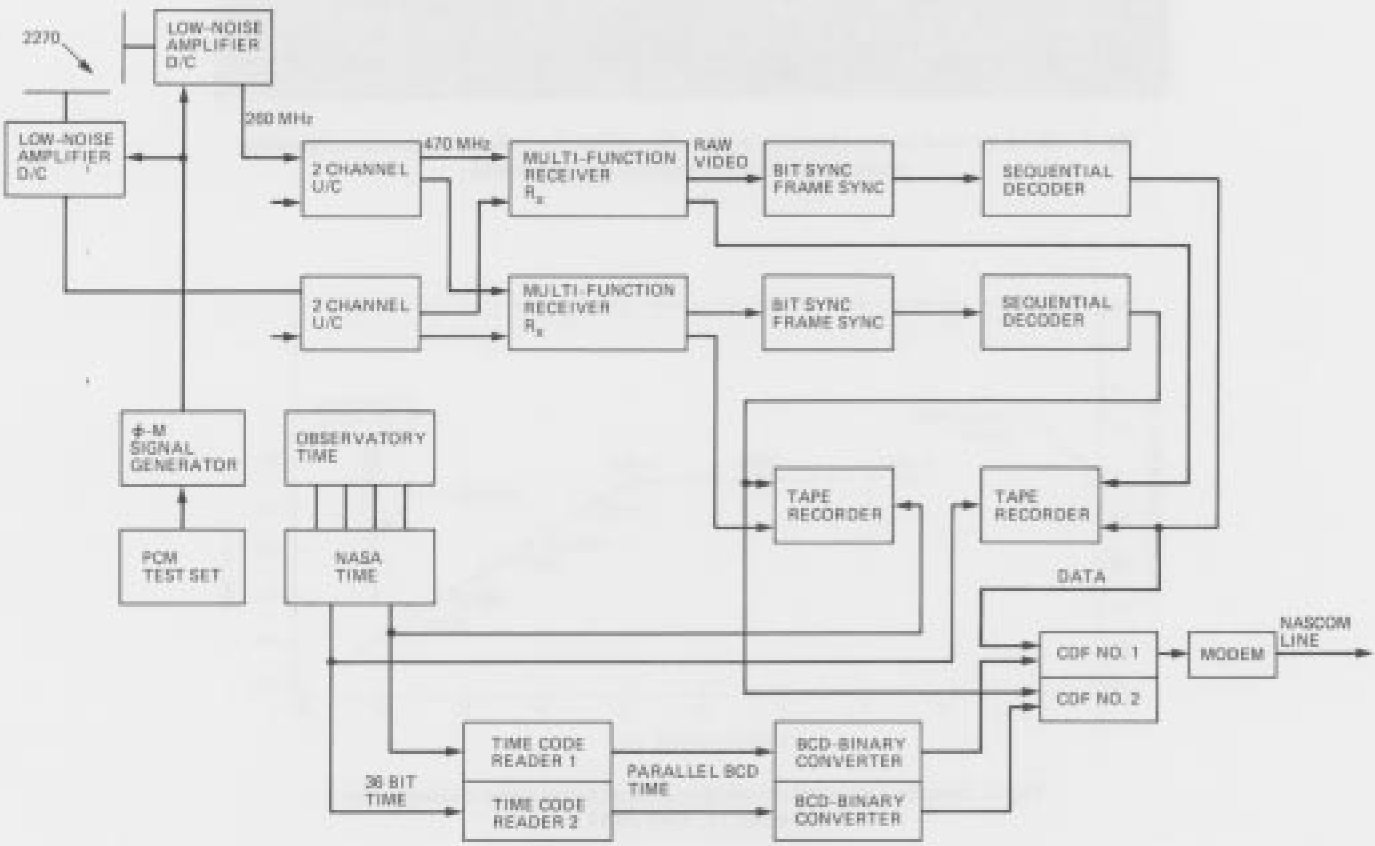

Fig. 2. ICE Arecibo support capability functional block diagram

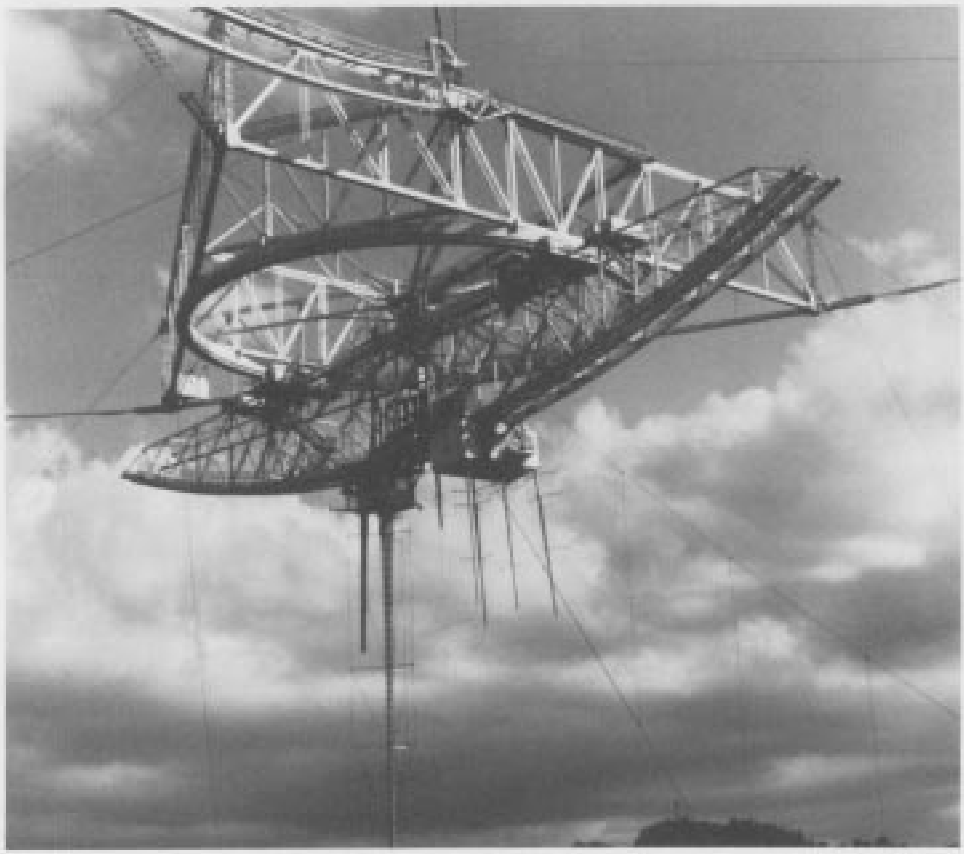

Fig. 3. Close-up view of the structure suspended above the reflector antenna supporting two carriage houses and the antenna feeds

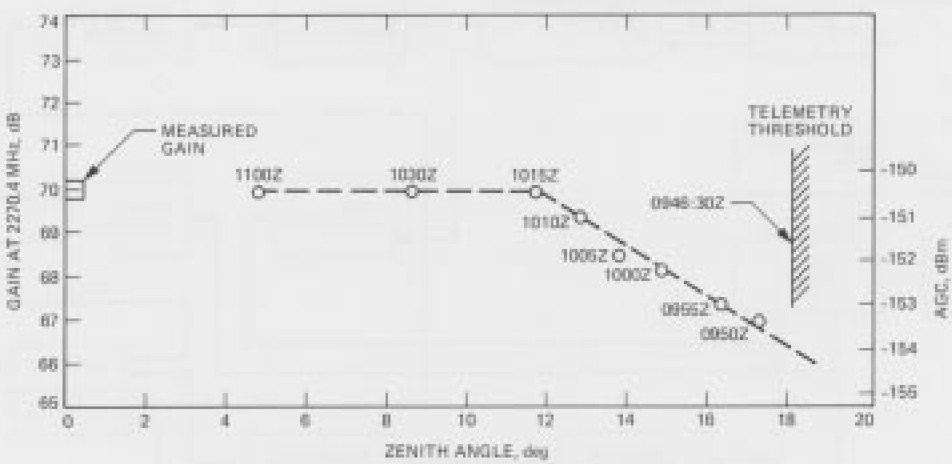

Fig. 4. Arecibo Observatory performance at ICE mission encounter on September 11, 1985 (DOY 254)