NASA DEEP SPACE NETWORK PERFORMANCE ANALYSIS

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ABSTRACT

Network performance analysis is an essential element in the operation of the NASA Deep Space Network. The primary function of the Deep Space Network is to support the communication, radio navigation and radio science needs of the flight project users. As a part of Network Control Center Operations, it is the task of the Performance Analysis Group to provide the Network with the analysis support required to assure that actual Network performance meets or exceeds committed levels throughout the mission.

The Performance Analysis Group provides time-critical monitoring and analysis for the Tracking, Telemetry and Command Systems of the Deep Space Network. The group is organized into units that are specialized to provide the functional requirements of each system. It provides failure analysis to determine causes of Network failures and data outages, as well as providing technical assistance to the operations organization for recovery from failures. It generates the predictions used to point the antennas, acquire the radio frequency, and to validate the monitored Network performance. Also, it provides technical interfaces with the user projects as required for the smooth running of the operation. As a result of this specialized expertise, complex and time-critical problems that arise receive an immediate decision-making response.

INTRODUCTION

Every flight project utilizing the Deep Space Network must perform certain telecommunications system activities. Telecommunications can be thought of as a service provided to the flight project. To obtain optimal scientific return from each mission, the telecommunications system must perform in an efficient and predictable manner. This requires the effective coordination of many technical disciplines both on-board the spacecraft and on the ground.

The Deep Space Network can be characterized as the tool which provides the telecommunications service. It is a scientific instrument which uses an uplink and a downlink carrier, in combination with a coherent spacecraft transponder, to perform high-precision radio tracking while simultaneously transmitting uplink command and receiving downlink telemetry. Its primary task is to support the communication, radio navigation, and radio science needs of the flight project. This support is currently provided by a state-of-the-art network consisting of three Deep Space Communication Complexes. The Network Operations Control Center coordinates and directs the Deep Space Network from its headquarters at the Jet Propulsion Laboratory in Pasadena, California providing the interface by which the flight project utilizes the Deep Space Network. This facility contains the computers and displays necessary for network control functions and the analysis of system performance, as well as for the control of mission operations. (2)

PERFORMANCE ANALYSIS

As part of the Control Center Operations, the Performance Analysis Group is responsible for the performance validation of all committed Deep Space Network support to the various user projects. The Performance Analysis Group provides the Network with the analysis support required to assure that actual Network performance meets or exceeds committed levels throughout the mission. Validation is accomplished as the signals are received in real-time by monitoring the data streams and comparing the data quality against predicted values and established performance standards and tolerance limits.

The Tracking, Telemetry and Command Systems are monitored on a continuous basis by the Network Analysis Team of the Performance Analysis Group. Tracking System performance is analyzed by monitoring radiometric data in the data streams. Telemetry System performance is analyzed by monitoring ground system configuration, spacecraft configuration, and status parameters, such as receiver lock, signal strength, signal-to-noise ratio (SNR), and bit error rate. The Command System performance is analyzed by monitoring system displays of control functions to confirm nominal status or to respond to alarm conditions. Trend logs of performance and a daily log of real-time activity are maintained for each system. With this information the Network Analysis Team keeps the Network Operations Control personnel apprised of the system status as it may affect flight project support.

Extensive nonreal-time research and analysis support the real-time validation effort. The Performance Analysis Group develops the reference models used to acquire and compare received data, and supplies the expertise to analyze problems that arise. The Performance Analysis Group is organized into functional units for the specific purpose of accomplishing these tasks.

One major function is to generate the predictions used to point the antennas, acquire the radio frequency, and to validate the monitored Network performance. Tracking, radio science, and polarizer angle predictions are the responsibility of the Tracking Unit of the Performance Analysis Group. Predict production requires that the Tracking Unit establish an interface with Project Telecommunications and Navigation Teams to facilitate the exchange of pertinent information. The Tracking Unit then acts as the single point of contact for all other units requiring trajectory-related predictions or view periods. As a subtask, the Tracking Unit also provides the observation source schedule predictions for Very Long Baseline Interferometry (VLBI) analysis. The VLBI System provides the capability to accurately measure internetwork clock synchronization offsets.

Telemetry predictions are the responsibility of the Telemetry/Command Unit of the Performance Analysis Group. Coordination with the Project Telecommunications Team and the Telemetry System Cognizant Operations Engineer provides the capability to maintain and update all of the telecommunications parameters required in the generation of predicts. This task provides sufficient information to allow for the application of biases to the Telemetry predictions in response to real-time configuration changes.

The Radio Frequency Interference (RFI) Unit of the Performance Analysis Group investigates and analyzes the impact of suspected RFI events. This requires coordination with many external government agencies in order to obtain information about the many satellites currently orbiting the Earth. Analytical models are used to develop operational procedures from which predictions are generated to minimize RFI impact on supported projects.

Another function performed by the Performance Analysis Group is that of anomaly investigation. Responsibility for the investigations is divided along system lines and assigned to the appropriate units for corrective action. This troubleshooting activity may include software analysis or the conducting of special tests in order to resolve a problem. The results are documented and retained for long-term trend analysis of overall Network performance. The specialized expertise of each unit provides the Performance Analysis Group with the capability to respond rapidly to critical anomalies with a recommended procedure for recovery. In this respect the nonreal-time personnel serve as technical advisors to the Operations Control Team.

Integral to the validation effort is the support task of generating and maintaining performance standards and tolerance limits for each flight project. These are the criteria against which actual Network performance is judged. Because these criteria are imposed upon the Network systems, it is the responsibility of the Performance Analysis Group to assure that the Standards and Limits files remain responsive to real-time changes affecting the Network while maintaining data quality.

Long-term trend analysis is a major function of the Performance Analysis Group. Data records are collected and maintained for this purpose. Residual values resulting from comparing predicted versus actual Doppler and Range data are examples from the Tracking System records. The Telemetry System records contain residual SNR values, downlink signal levels and uplink signal levels, to name a few. The Command System records keep track of the cummulative number of commands transmitted during the mission and the number of commands aborted by the spacecraft. These records along with the histories of anomaly investigations yield a multitude of results. Trend analysis allows the Performance Analysis Group to define, implement and execute operations support procedures which improve the ability to accomplish the validation task. It allows the development of improved analytical models which increase the accuracy of predictions. It is a source from which the requirements for operation analysis are drawn for future mission support planning activities. Performance trend analyses provide inputs to the design activity of System Engineering.

ORGANIZATIONAL STRUCTURE

All of the functions performed by the Performance Analysis Group are applied to the Tracking, Telemetry and Command Systems. But each system is so different and the breadth of technology between the systems is so great that similar functions require vastly different types of technical expertise for support in each system. For this reason the Performance Analysis Group is subgrouped into units along system lines. Specialized technical talents are assembled together to provide the depth of understanding necessary for each unit to entirely support its system.

On the surface, the Performance Analysis Group is broadly divided into two categories: real-time personnel and nonreal-time personnel. The real-time personnel comprise the Network Analysis Team (NAT). Their primary role is to support real-time operations by monitoring the incoming data streams on a continuous basis. The real-time task requires time-critical decision-making analysis in the Control Center environment.

Because real-time operations hardware and displays are organized by system, it is logical and efficient to separate the monitoring tasks based upon systems. As a result there are two positions on the Network Analysis Team: NAT Track and NAT Telemetry/Command. The NAT Track position monitors all Tracking System functions. The NAT Telemetry/Command position monitors all Telemetry and Command Systems functions. Although there were two separate positions in the past for the Telemetry and Command Systems, recent economic conditions necessitated the combination of these tasks into one position. Combining two functions demands a greater technical knowledge from an individual. It does represent an increased risk of data loss to the project since less time is spent on monitoring each system. But to date the transition has been successful.

The nonreal-time personnel are grouped into the Tracking, Telemetry/Command and RFI Units of the Performance Analysis Group (again the separate Telemetry and Command Units of the past were combined under economic pressure). The units provide all of the support required for the performance of the Network Analysis Team. The importance of data transference has cultivated a close operational interface between the Network Analysis Team and the Tracking and Telemetry/Command Units. As such, the Network Analysis Team positions can be functionally regarded as subgroups of the Tracking and Telemetry/Command Units.

Even though the three units all perform the functions of predict generation, anomaly investigation and trend analysis, it is appropriate to organize by system rather than by function in order to best respond to the systemized arrangement of operations. The criticalness and complexity of the problems that arise in the real-time environment demand a timely response. The nonreal-time personnel maintain this capability to deliver a quick response by concentrating in a system-oriented thinking mode. Although the normal forty hour work week is sufficient to handle most problems that occur, the nonreal-time personnel remain available around the clock and often provide support for critical events.

Staffing levels within the Performance Analysis Group tend to follow the activity of the on-going projects. During critical mission periods the staff is at its largest size. Staffing levels decrease, however, under the reduced activity of a mission cruise phase. This occurs through careful advanced planning and natural attrition. An example of the organization of the Performance Analysis Group staff during cruise phase is illustrated in Figure 1.

ANALYSIS OF THE REAL-TIME COMBINER

An actual example of an analysis is appropriate at this point to illustrate how the validation effort impacts data quality. This particular example involves the Telemetry System of the Deep Space Network. It was the task of the Performance Analysis Group to verify that the performance of the Real-Time Array Signal Combiner was operating within its design specifications for the Voyager Mission encounter with Saturn in November of 1980.

The Real-Time Combiner hardware allows improved signal reception through station arraying. The significant factor that makes the technique of station arraying possible is the fact that a spacecraft signal received simultaneously at several Deep Space Stations is affected by independent noise contributions at each station. An improvement in the signal-to-noise ratio (SNR) of the spacecraft signal is achieved by combining the outputs from various receiving locations in an appropriate manner to reinforce the coherent spacecraft signal while cancelling out incoherent noise from the stations (see Figure 2). Once the signals are combined by the Real-Time Combiner, they are transferred to the rest of the Telemetry chain for processing in the normal manner.

During the Voyager Mission, each Deep Space Communications Complex used a 64-meter diameter antenna together with a 34-meter diameter antenna to form an array. The design of the Real-Time Combiner specified a signal degradation of no more than 0.2 ± 0.05 dB from the theoretical combined gain. The task of the Telemetry Unit was to analyze actual gain data to verify that the system-induced degradation was within the theoretical accuracy range of the system design.

The 64-meter and 34-meter uncombined SNR averages were used to calculate the theoretical combined SNR value. At optimal performance the combined SNR is maximized to a theoretical value of

$$SNR_s = SNR_{64} + SNR_{34} \quad (1)$$

$$= SNR_{64} (1 + (SNR_{34}/SNR_{64})) \quad (2)$$

where

$$A_{th} = 1 + (SNR_{34}/SNR_{64}) \quad (3)$$

is the theoretical gain over the uncombined 64-meter signal alone. The actual gain is calculated from the measured data

$$Ac = SNR_s - SNR_{64} \text{ (SNRs in dB)} \quad (4)$$

and the residual difference between the theoretical and calculated values is

$$\text{Residual} = A_{th} - A_c \text{ (Gains in dB)} \quad (5)$$

These residual values were used to demonstrate the performance capabilities of the Real-Time Combiner.

A statistical analysis of the residual gains reduced from data collected from all of the arrayed Deep Space Stations during the Saturn encounter period is presented in Figure 3. The data encompasses residual gains as affected by the change in antenna elevation throughout the tracking viewperiod, causing the bell-shaped distribution. The distribution illustrates that the statistical means of 0.22 dB was within the designed operating range of the Real-Time Combiner and thus validates its performance.

Additional manipulation of the data also revealed that the actual improvement in the signal-to-noise ratio of the combined signal was an average of 0.62 ± 0.15 dB over the 64-meter signals alone. This value may initially seem of little significance for the amount of effort behind the hardware design and implementation. But an improvement of less than 1 dB is significant to the resolution of a signal that has traveled the distance from Saturn to Earth. To understand the extent of this significance, examine the visual difference between the pictures in Figure 4. On November 7, 1980, the Australian complex received the Saturn pictures in Figure 4 while under heavy cloud cover and snowfall. The clarity of the arrayed pictures compared to the unarrayed pictures is striking, particularly in the face of such adverse weather conditions. The Voyager Mission data demonstrated that the Real-Time Combiner was operating within design specifications, and the pictures illustrate the performance extension achieved with array technology.

CHALLENGES FOR THE FUTURE

The Performance Analysis Group has been described as it functions to validate committed Deep Space Network support to the user flight projects. Its task is well defined, yet it must remain adaptable to the changing environment in order to accomplish this task. The unique characteristics of each mission, mission loading schedules and advancing system technology are just some of the factors to which the Performance Analysis Group must remain responsive. Planning for the future is a necessity in order to maintain the technical expertise required to do the job.

Staffing for future needs is one of many challenges to be faced. There is the problem of retaining personnel under ever-increasing workloads. There is the challenge of finding new people with sufficient technical knowledge when higher activity demands a larger staff. The need for training new personnel and updating the general knowledge pool with new advances in hardware and software remains an ongoing task.

Of impact to the immediate future is the support of the forthcoming High Earth Orbiter (HEO) Missions. Modifications to the Deep Space Network have been undertaken to adapt the Network to the near-earth environment. A shift in emphasis away from the Deep Space Flight Projects has required the assembling of many skills to coordinate the phases of planning, design and implementation for a smooth transition. The response to the challenge of the HEO Missions will not be completely tested until 1984 when the first HEO Mission is scheduled for launch.

By far the most challenging situation to be faced is that of economics. It is a constant endeavor to develop the means to perform under less funding. So far, the challenge has been met by combining functions to reduce staffing levels. However, the answer to one problem has created others. Personnel are overloaded by a greater mental workload which demands a broader technical capability. It creates specialized positions that are difficult to fill.

Decreasing economic funding generally means increased risk to the supported projects. There will be a risk of losing data, losing hardware, or losing the spacecraft if the Deep Space Network is unable to respond to an emergency situation. Of course, the major planning efforts are directed at minimizing these risks. But the greatest challenge for the future to the Performance Analysis Group, as well as to the entire Deep Space Network, will be to assess the impact of all future trends and determine the point at which the returns from our efforts are no longer greater than the investment.

BIBLIOGRAPHY

1. Bartok, C. D., “Performance of the Real-Time Array Signal Combiner During the Voyager Mission” Telecommunications and Data Acquisition Progress Report 42-63, Jet Propulsion Laboratory, Pasadena, CA, June 15, 1981, pp 191-202.

2. Chafin, R. L., “NASA Deep Space Network Operations Organization.” Proceedings of the International Telemetry Conference, ITC/82, San Diego, CA, September28-30, 1982.

3. Edelson, R. E. (Editor), “Telecommunications System Design Techniques Handbook,” Technical Memorandum 33-571, Jet Propulsion Laboratory, Pasadena, CA, July 15, 1972.

4. Layland, J. W., “Noisy Reference Effects on Multiple Antenna Reception,” JPL Deep Space Network Progress Report 42-25, Jet Propulsion Laboratory, Pasadena, CA, February 15, 1975-, pp 60-64.

5. Renzetti, N. A. (Editor), “A History of the Deep Space Network.” Technical Report 32-1533, Volume I, Jet Propulsion Laboratory, Pasadena, CA, September 1, 1977.

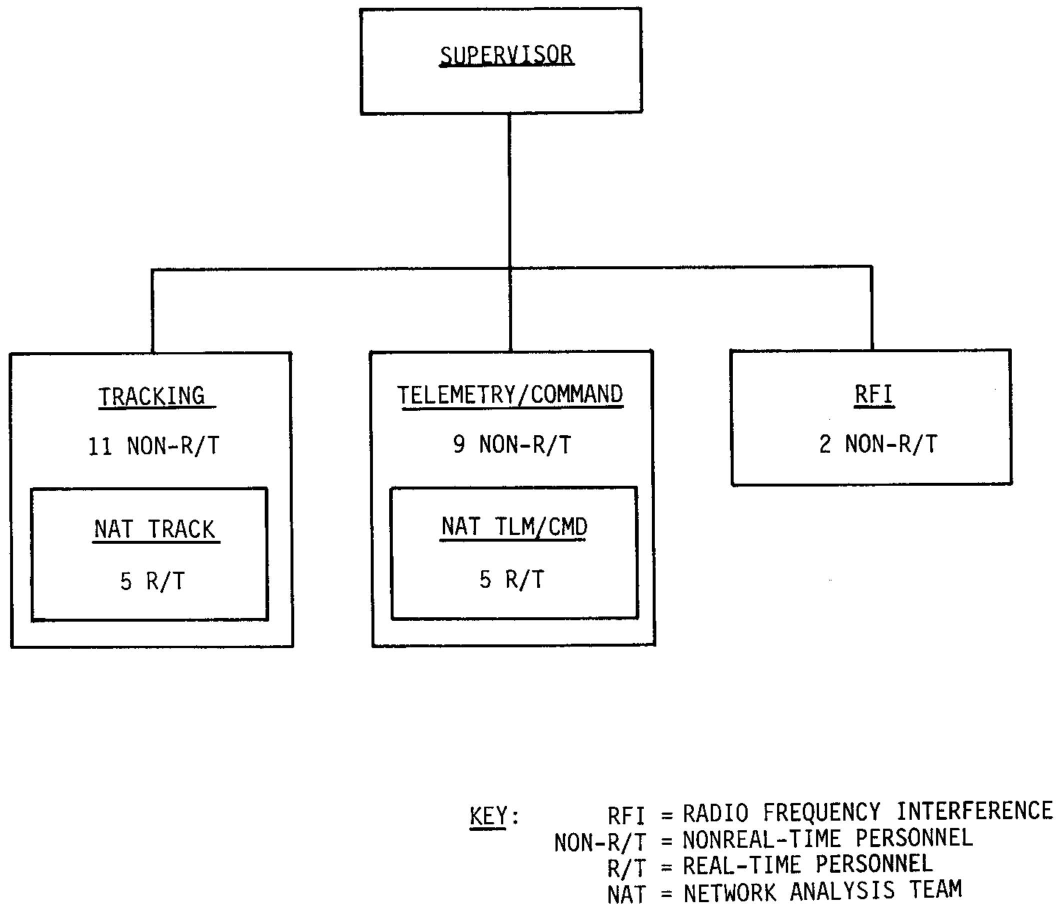

FIGURE 1. PERFORMANCE ANALYSIS GROUP STAFFING ORGANIZATION WHILE IN CRUISE PHASE OF VOYAGER MISSION

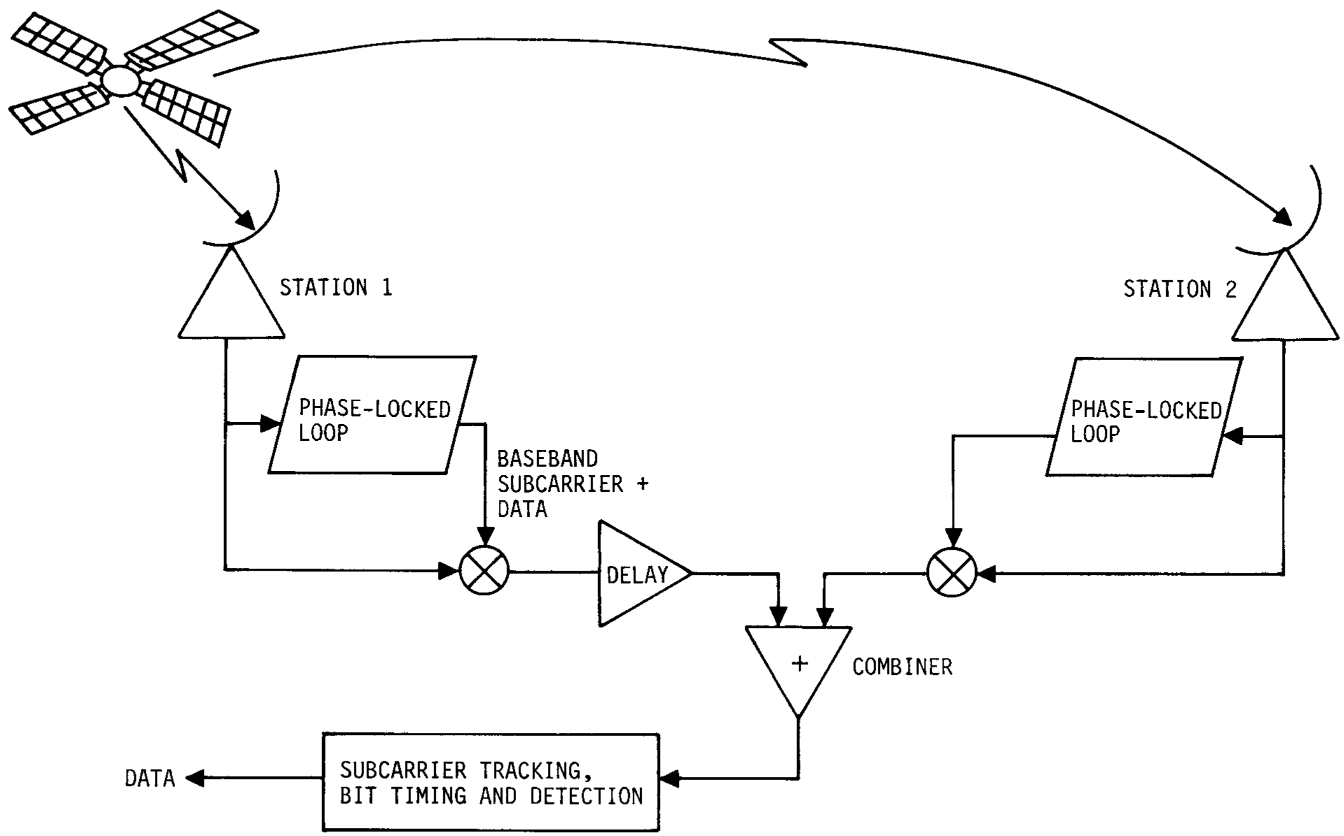

FIGURE 2. THE TECHNIQUE OF STATION ARRAYING (4)

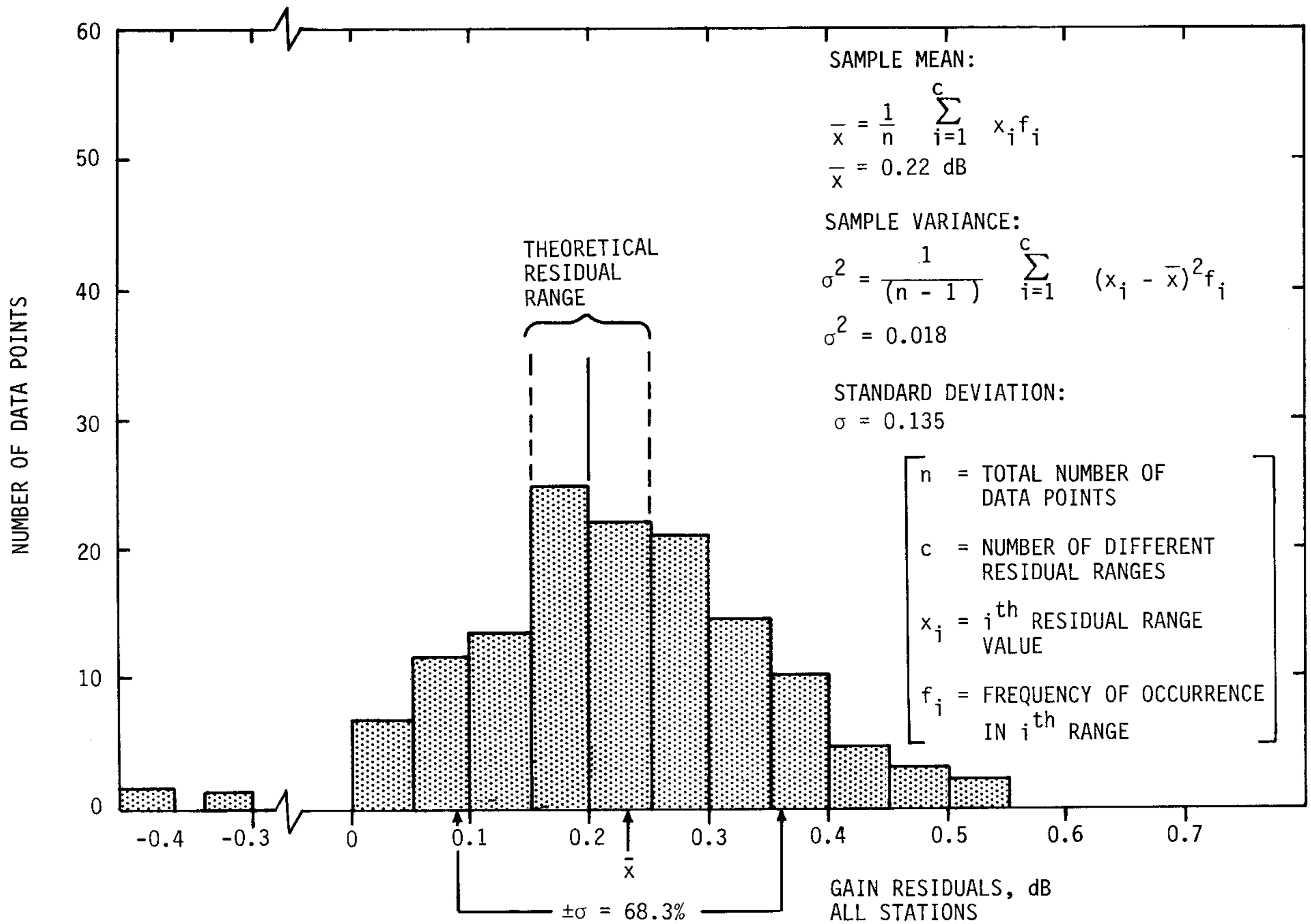

FIGURE 3. REAL-TIME CONBINER RESIDUAL ARRAY GAIN DATA DISTRIBUTION (1)

ARRAY PERFORMANCE - VOYAGER 1 SATURN ENCOUNTER
AUSTRALIAN COMPLEX NOVEMBER 7, 1980

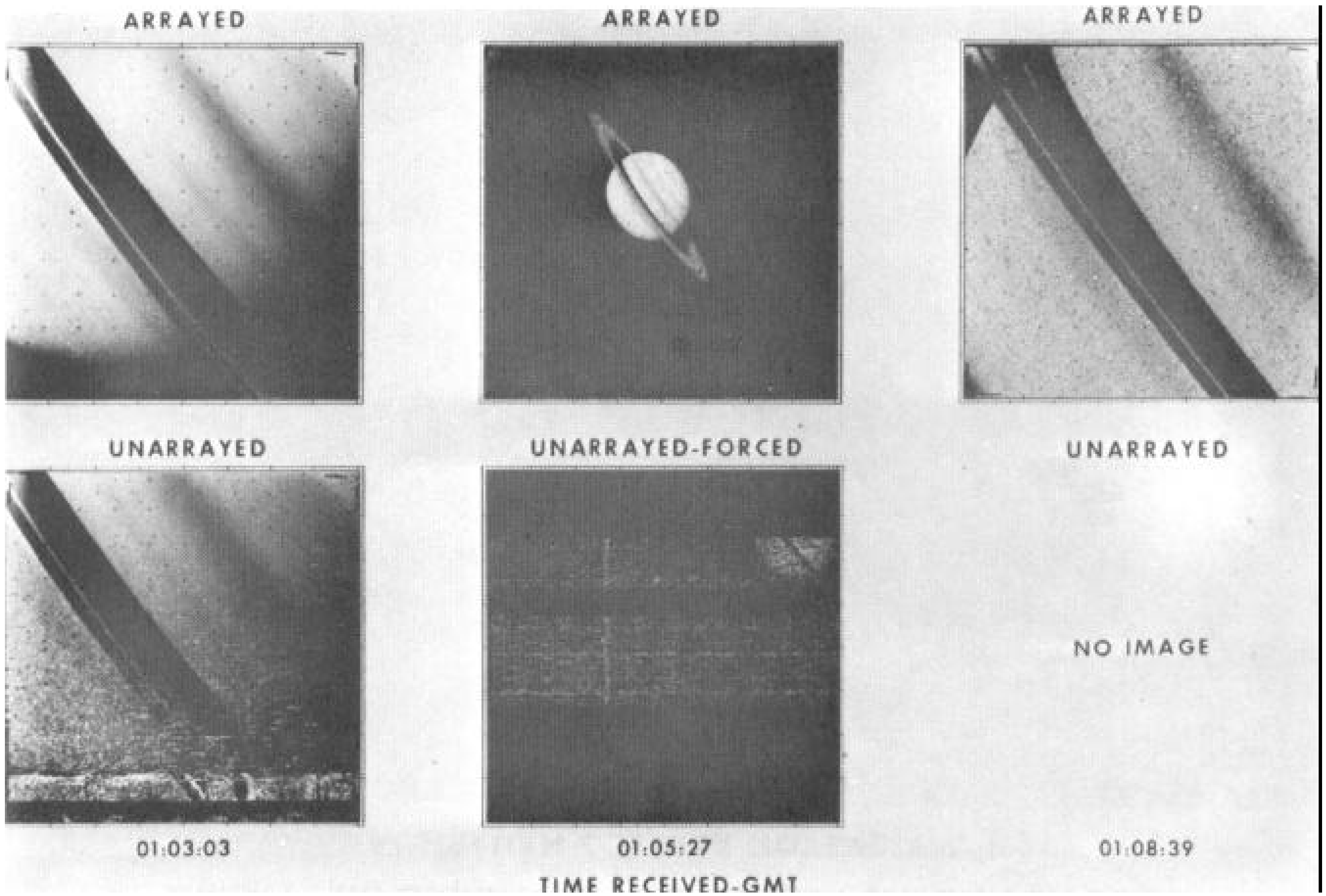

Figure 4a

ARRAY PERFORMANCE - VOYAGER 1 SATURN ENCOUNTER
AUSTRALIAN COMPLEX NOVEMBER 7, 1980

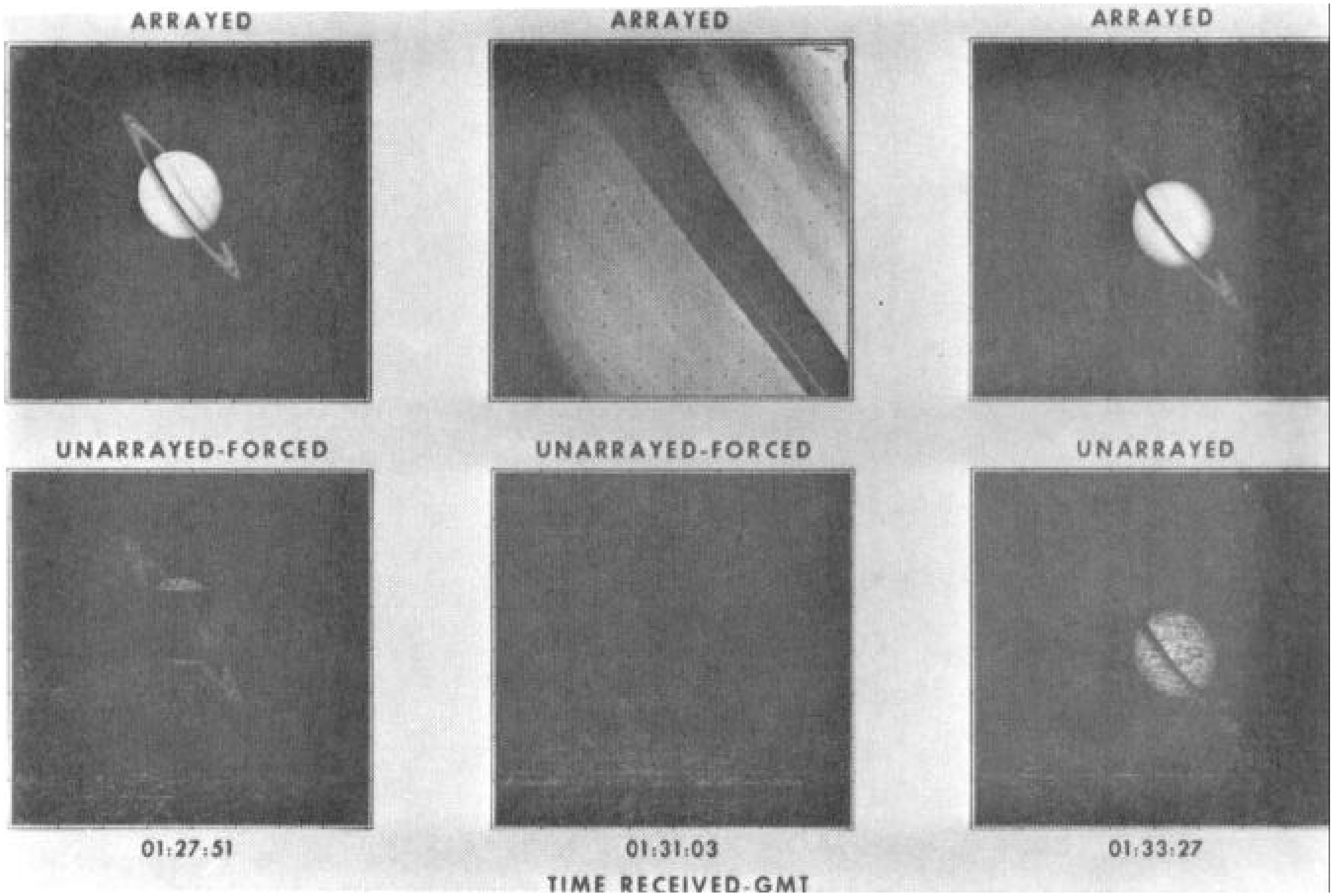

Figure 4b