# Applications of Telemetry Arraying in the DSN

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*The individual large antennas at a DSN complex have been used in arrayed configurations to improve the telemetry return from very distant spacecraft. The technique has been applied to support critical spacecraft events when good telemetry is most important. An expanded array configuration, using the Parkes, Australia, Radio Astronomy Observatory will be provided to support the 1986 Voyager encounter with Uranus. This report reviews the development and use of arraying by the DSN for spacecraft mission support. Application of the experience to the 1986 design is discussed.*

## I. Introduction

For support of the 1986 Voyager 1 encounter with Uranus, the DSN is planning to array telemetry signals from the Parkes, Australia, Radio Astronomy Observatory 64-m antenna with those of the 64-m and two 34-m antennas of the Tidbinbilla DSN complex. During the process of assessing the array configuration system design for that application, the previous DSN operational experience with arrayed configurations was reviewed. The purpose of the review was to ensure that lessons from experience were not neglected.

The operational applications of arraying for telemetry reception by the DSN have been described in past TDA Progress Reports. The reporting covers all applications, except for the Voyager 2 Saturn encounter, which will be reported in a future issue. This material is an abstraction of those reports and of discussions with some of the authors. It also includes discussion of anticipated new factors involved with the integrated participation of the Parkes Facility for critical scientific deep space mission support.

## II. Arraying Phase 0

In 1970, conceptual levels of combining were described and their basic performance analyzed. The levels described were: carrier, baseband, bit stream, and processed data. Baseband and bit stream combining were configured with two 26-m antennas and demonstrated using the signals from the Pioneer 8 spacecraft. The results showed approximately 2.5 dB (vs 3 dB maximum possible) improvement with baseband and bit stream combining. Time delay tracking of the baseband signals was not required or used because of the low subcarrier frequency of the Pioneer signals. The work was done by the personnel of the Spanish complex using available station equipment and the DSS 61/62 26-m antennas (Ref. 1).

The next effort was demonstration of RT baseband combining of high-rate telemetry via microwave links of the signals from the DSS 12 and DSS 13 26-m antennas with the signal from DSS 14 (Ref. 2). The array was used to enhance the telemetry signals from the MVM spacecraft during its September 1974 second Mercury encounter. The system was designed, built, and operated by Advanced Systems Program personnel with support from Operations personnel. Installation and initial testing of the array system at Goldstone was straightforward. Array performance was evaluated using spacecraft signals from far encounter TV sequences. These tests indicated that the performance of the Subcarrier Demodulation Assembly (SDA) processing string, which was hard-wired to the array combiner signal stream, performed about 1/2 dB poorer than the string which was hard-wired to the 64-m-only signal stream. In the time available, it was not practical to alter or improve the situation. As a result, during the encounter pass, the arrayed signal stream was only 0.3–0.4 dB improved over the 64-m-only signal stream, rather than the ≈0.7 dB, which was in principle achievable. The ≈0.7 dB (vs 0.8 theoretical) was demonstrated by deleting briefly the 26-m antenna signals from the combiner input and observing the increase in image data bit error rate.

During a portion of the encounter pass over Goldstone, the spacecraft transmitted at maximum data rate (117 kbs vs 22 kbs), which was only supportable by the arrayed configuration. Although the full 0.7 dB capability of the array could not be exploited, the 0.3-0.4 dB improvement did significantly enhance the mission imaging data yield. The experience showed the difficulty in achieving full performance of an arrayed system, and the importance of a few tenths of a dB of performance.

## III. Arraying Phase I

The 1973-74 R&D demonstration project just described established technical feasibility of baseband arraying of very weak high-rate signals. In 1977, the DSN started to develop an operational arraying capability for the network. The first application was for Voyager encounters of Jupiter and Saturn. The first phase was providing a prototype system at Goldstone to be used for enhancement of the Jupiter encounters (Refs. 3, 4).

A prototype baseband real-time combiner (RTC) based on the analysis and design techniques developed by the earlier R&D activity was completed in the fall of 1978. It was designed to combine signals from DSS 14 and DSS 12. The signals from DSS 12 were sent to DSS 14 via the existing microwave link. The RTC was installed at the Compatibility Test Area (CTA 21) for initial testing. The tests were conducted in November and December 1978. The tests indicated that the RTC performed according to its analytical model. Conducting the test program at CTA 21 was surprisingly difficult and time consuming; finally, the equipment in the telemetry strings had to be carefully realigned and recalibrated and the test data taken at night to avoid electrical transients. Most of the problems encountered were external to the RTC–in the receiver/telemetry strings and test instrumentation.

The RTC was installed at DSS 14 in mid-December 1978. After checkout and alignment, the system was tested by receiving Voyager signals. Performance on the initial Voyager tests in December was inconclusive. After further off-line testing and alignment of the system, array gain on Voyager signals, ranging from 0.4 to 1.0 dB, was obtained in mid-February 1979. With intensive work by the design and operations personnel, the array system was brought on-line for the Voyager 1 Jupiter encounter during the first 10 days in March. It was brought up and used again for the Voyager 2 Jupiter encounter for two weeks in early July 1979.

The performance of the prototype array system during the Voyager Jupiter encounter operations was good. It provided approximately 1.0 dB S/N improvement vs the 64-m-only, with an availability of ≈0.95. The Voyager Project used the data from the array in preference to the on-line alternate 64-m-only stream for most of each tracking pass.

The prototype array system was next configured to provide enhanced support of the early September 1979 encounter of Saturn by the Pioneer 11 spacecraft (Ref. 5). Pioneer 11 had two important data rate options for the encounter/near encounter period, 1024 and 512 bps. The higher rate was greatly desired, but its support appeared marginal. To enhance the support capability, the DSN installed ultra-low noise listen-only front ends and selected the best performing of normally equal telemetry strings at the 64-m stations; also, it adapted the DSS 14-12 RT array for Pioneer S-band parameters.

At S-band, the S/N performance of the DSS 12 34-m system relative to the DSS 14 64-m system is poorer than at X-band. As a result, the potential arraying gain was only 0.5 dB for Pioneer vs approximately 1.0 dB for Voyager. Also, the DSS 12 Pioneer signals were so weak as to not support automatic tracking of their time delay by the RTC. The varying time delay between the DSS 14 and DSS 12 signals during a pass was calculated and input to the RTC (that open-loop mode was provided for in the prototype RTC design, and it worked satisfactorily on the relatively narrow baseband Pioneer signal).

The initial tests in early August of the array on the Pioneer signals were not successful. An intensive effort was required to resolve the performance problems with the array system. On August 25, the first day of planned mission support by the array, it worked well. It provided 0.4 to 0.5 dB performance improvement relative to the 64-m-only configuration and supported the 1024 bps rate. On the next pass, it was no better than the 64 m's. On the following pass, after inconclusive testing and diagnosis, it was back working properly.

The 10-day encounter sequence was hectic for the Pioneer Project and the DSN; unexpected solar noise and satellite RFI complicated the data rate strategy. The efforts to maximize imaging data (by using 1024 bps) was impacting non-imaging experiments when the rate was unsupportable. By two days before encounter, the array performance had stabilized fairly well. This allowed use of the 1024 rate during mid-pass over the Goldstone array; 512 was used at other times and places.

The experience on Voyager and Pioneer with the prototype RTC and array configuration showed the need for central control and monitoring of the array system, and again, the importance of having *all* elements of the array—receivers, antennas, instrumentation—operating completely correctly. Also, array performance testing on live spacecraft signals was next to impossible if the spacecraft and the ground stations were not in stable configurations dedicated to supporting the array tests—array testing on a noninterference basis was usually unproductive. This experience was applied to the design of the equipment and use procedures for the next phase of arraying system development.

## IV. Arraying Phase II

The objective of this phase was to provide operational arraying system configurations to combine the signals from the 64-m antenna and the 34-m antenna at each of the three DSN complexes. The arrayed systems were committed for operational support of the Voyager 1 (fall, 1980) and Voyager 2 (summer, 1981) encounters with Saturn (Ref. 6).

The design of the operational RTC's and arraying system was a direct upgrade of the Goldstone prototype just described. Modifications to the system and its operating procedures were based on the experience with the Goldstone prototype. The principal modifications to the system included:

(1) Displays of 34-m station receiver in-lock and AGC were provided at the 64-m stations.

(2) The Block IV receiver telemetry detectors were modified to improve performance and stability.

(3) A routine procedure for measurement of microwave link path delay was developed (DSS 12-14 use).

(4) Pretrack countdown time for the RTC's was reduced.

(5) The RTC was modified so that it could be restarted or accept new parameter inputs, without requiring reinitialization.

(6) The procedures for testing the array performance on spacecraft signals were improved.

(7) Simultaneous displays of symbol SNR for the 64-m-only, 34-m-only and the arrayed signals were provided at both the 64-m station and at the JPL network advisor's position.

The first operational RTC was installed at Goldstone in mid-May 1980. Testing of the DSS 14-12 array on Voyager signals was started on May 19. Eight performance tests and training sessions were conducted in the following month's time. Installation of the systems at the overseas stations was then done, followed by a similar test and training sequence. The process of bringing up the operational systems was difficult, but much easier than the previous experiences with the prototype system.

Beginning in mid-August 1980, the arrayed configurations were used at all stations at regular intervals for Voyager 1 Saturn far-encounter operations support, and for DSN test and training. For the near-encounter period, the arrayed configuration was used for all passes (Ref. 7).

During the first several days of the period the array performance of the complexes was only "fair". At that point (November 1, 1980, 12 days before encounter) a procedure for assessing array system performance at regular frequent intervals was established. The procedure was: at 1-hour intervals the JPL network advisor computed a 10-minute average of the symbol SNR from the 34-m, the 64-m, and the arrayed signal streams of the active DSN complex.

The "observed" arraying gain was calculated as SNR (array)/SNR (64-m); the "theoretical" or "loss-free" arraying gain was calculated as 1+ SNR (34-m)/SNR (64-m). If the ratio of the two gain numbers exceeded 0.3 dB, the nominal combining loss plus tolerance, the DSN complex was alerted to look for possible system problems. That procedure was used on all remaining passes through encounter, and good stable array performance was achieved. The average array gain for the encounter period was 0.62 ±0.15 dB relative to the 64-m-only and the array availability was approximately 0.95 (Cf. Ref. 7).

In preparation for the late August 1981 Voyager 2 Saturn encounter, array system test and training was started by the Network in early April (Ref. 8). The work went fairly smoothly. It was supported by arrayed stream, 64-m-only stream, and 34-m-only stream symbol SNR performance monitoring in real-time at the complexes and at JPL.

All complexes supported the beginning of the observatory phase on June 5, 1981, in the arrayed configuration, with very good results. Array training and performance validation tracks on the Voyager signals were conducted at regular intervals until the start of near-encounter operations.

During the 30-day near-encounter period, the arrayed configuration was used extensively. The procedure of hourly collection of 10-min average symbol SNRs and calculation of the combining loss was used throughout the 30-day period. It was the basic procedure developed during the Voyager 1 Saturn encounter. To reduce operations staffing required, the 10-min averages were automatically calculated in the station Telemetry Processor Assemblies (TPAs) and reported verbally to the Network Analysis Team at JPL. Also, the near-real-time (within 10 minutes) image display at the stations was found to be useful in keeping the arraying performance near optimum at all times.

The results during the Voyager 2 Saturn encounter were very satisfactory, clearly the best yet achieved. The *network* average of observed array gain relative to 64-m-only was 0.8 dB with a standard deviation of 0.2 dB. The *network* average combining loss was 0.2 ±0.05 dB. Those results are consonant with the design predictions/specifications. Out of a total of 79 passes scheduled for arraying support during the near-encounter operations, satisfactory array capability was provided for 75 of them, giving an availability of ≃0.95. These above results are from a preliminary analysis of operations data.

The experience with the operational RTC and 64-m–34-m arraying systems for the Voyager 1 and 2 Saturn near-encounter operations showed the following:

(1) The array system works methodically according to its design principles.

(2) Array availability data are sparse and subject to interpretation, but some conclusions can be drawn. Downtimes are the sum of the 64-m string, the 34-m string and the combining system downtimes in that order of contribution, a logical result. The availability of the total array from about 7 weeks of encounter operations is ≃0.95, not a super good result, but probably representative of the present system capability.

(3) Extensive real-time visibility into the performance of the individual strings and the total system has been provided by the operations organization during the evolution of the use of the arrayed configurations. It is concluded that was done because it was needed.

(4) Bringing up and validating a new array configuration is difficult but can be systematically accomplished, culminating with 6-10 scheduled spacecraft live data exercises.

## V. Arraying Phase III and Beyond

The next application of DSN arraying will be support of the Voyager 2 Uranus encounter in January 1986. At the Australia and Goldstone complexes, the 64-m and two 34-m's will be arrayed; at Madrid, the 64-m and the single 34-m will be arrayed. Also, at Australia, it is planned to array the Parkes 64-m with the DSN complex. The Parkes facility is about 280 km distant from the DSN Tidbinbilla complex.

The design and the operational use planned for the 1985-86 arraying system for the DSN complexes is based on the previous configurations. It will be baseband with RT-only combining at the DSN complexes. The combining method, RT-only, NRT-only or hybrid, for the Parkes signals is being reviewed—the current baseline design includes both RT and NRT.

A new Baseband Assembly (BBA) is being designed for the DSN complexes. The BBA will provide the functions of the RTC, the SDA, and the Symbol Synchronizer Assembly (SSA) in a single integrated unit. The new design is expected to improve the operational performance, stability, and monitor capability of the combiner/telemetry channel.

Also, the Mark IVA DSN will incorporate improvements in the antenna pointing system and monitor and control of the station equipment. Without these kinds of improvements, the availability of the planned three-element DSN arrays would clearly be less than the ≃0.95 of the present two-element configurations. The design availability for the Mark IVA Australian DSN complex 64-m – 2 × 34-m array is ≃0.97, an ambitious objective.

In the baseline design for the planned Parkes-Tidbinbilla array, both RT and NRT combining configurations are provided. At critical times they would be used in parallel. The basic function of the NRT capability is for backup or fail-soft protection to the RT microwave link failure node. The basic technical specification on the NRT configuration is to provide records from Parks and Tidbinbilla which can be played into the RTC with degradation ⩽0.2 dB. That is the same performance specification as for the RT link.

The DSN is developing a recording and playback system to meet the specification in a station environment. It uses the Mark III data acquisition terminals (DATS) with special signal processing electronics to accommodate the weak telemetry signals. The Mark III DATS is used by the DSN and many radio observatories for VLBI recording.

DSN engineers have had experience in the development and application of sophisticated recording systems (e.g., VLBI recording and playback and the recording and playback systems for the Pioneer Venus multiprobe and DLBI wind experiment support); there is high confidence in the NRT telemetry system development. A software simulation of the output spectrum reconstruction electronics has been successfully run. That is an important accomplishment. The recording system will be demonstrated in the fall of 1983. Output combining of two recorder systems through an RTC will be demonstrated in the spring of 1984; field demonstration at Goldstone will be in the summer of 1984.

The plan to include Parkes with the Tidbinbilla array presents new technical and managerial challenges to the DSN. Compared to the Goldstone DSS 14-12 configuration, Parkes is truly remote from the Tidbinbilla complex. Its expected contribution to the array performance is next in significance to the DSN 64 m. Its availability, as currently predicted, will be significantly less than for a DSN array element, so that its proper operational use is expected to be more difficult. The use of Parkes will be the DSN's first experience with a non-NASA owned facility tightly coupled with critical mission support. Hence, the operational procedures and interfaces will be relatively immature compared to those that have been brought to bear on past arrayed mission support operations.

The GIOTTO Project will use the Parkes facility for prime support of its mission, and it will use the DSN Tidbinbilla complex for backup support. The GIOTTO spacecraft encounter with Halley's Comet occurs in mid-March 1986, following the Voyager 2 Uranus encounter by less than two months. This is perceived as an advantage (perhaps an enabler due to shared facility and equipment use at Parkes), and at the same time, an operational complication in the use of Parkes for Voyager support. While there does not appear to be mutual conflict of critical project schedules at Parkes and Tidbinbilla during late 1985 and early 1986, they are interlaced without much contingency during January and February. However, if the two spacecraft and the ground systems behave reasonably well during that period, the continuous usage of the ground facilities under tight configuration management could benefit both projects and the DSN.

## References


1. Urech, J. M., "Telemetry Improvement Proposal for the 85-Foot Antenna Network," *Space Programs Summary 37-63, Vol. II*, Jet Propulsion Laboratory, Pasadena, Calif., May 31, 1970.

2. Winkelstein, R. A., "Analysis of the Signal Combiner for Multiple Antenna Arraying," *DSN Progress Report 42-26*, Jet Propulsion Laboratory, Pasadena, Calif., pp. 102-118, April 15, 1975.

3. Simon, N. K., and Hoynes, C., "Preliminary Telemetry Operations Experience With the Real-Time Combiner: 1 November 1978 to 1 November 1979," *DSN Progress Report 42-55*, Jet Propulsion Laboratory, Pasadena, Calif., Feb. 15, 1980.

4. Howard, L. D., "Prototype Real-Time Baseband Signal Combiner," *TDA Progress Report 42-60*, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 15, 1980.

5. Miller, R. B., "Pioneer 11 Saturn Encounter Mission Support," *DSN Progress Report 42-54*, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 15, 1979.

6. Fanelli, N., and Nance, H., "Voyager Mission Support (I)," *DSN Progress Report 42-60*, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 15, 1980.

7. Bartok, C. D., "Performance of the Real-Time Array Signal Combiner During the Voyager Mission," *DSN Progress Report 42-63*, Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1981.

8. Fanelli, N., and Nance, H., "Voyager Mission Support," *DSN Progress Report 42-64*, Jet Propulsion Laboratory, Pasadena, Calif., Aug. 15, 1981.