Life-Cycle Cost Analysis Task Summary

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The DSN life-cycle cost (LCC) analysis methodology has been completed. This article summarizes the LCC analysis methodology goals and objectives, the issues covered by the methodology, and its expected use and long-range implications.

I. Introduction

Development and implementation of the DSN life-cycle cost (LCC) analysis methodology has been completed. Policy, standards, guidelines, and procedures for performing LCC analysis are stated in Ref. 1, while background information and general guidance are supplied by the TDA document noted in Ref. 2.

The following is a summary of methodology goals and objectives, topics covered in the above documents, and expected use and implications of the methodology.

II. Methodology Goals and Objectives

Motivation for an LCC analysis methodology arose from the following conditions:

(1) The level of requirements levied on the DSN, relative to the budget, was greater than in the past.

(2) The probable cost of systems over their full lifetimes was often not available at the time of major planning decisions.

(3) NASA Office of Space Tracking and Data Systems needed stronger and stronger justification of budget items to obtain concurrence within NASA and the rest of the government.

(4) The cost of some items such as energy were increasing at a rate greater than the general inflation rate, and there was no mechanism by which to consider these relationships during the design phase.

(5) A technique, called LCC analysis, was developed by industry and the government that was capable of deriving the estimated cost of systems over their full lifetimes.

Thus, development of a DSN LCC analysis methodology was proposed. The goals of implementing and supporting the methodology were to minimize total future costs of existing and proposed DSN systems while still supplying required services, and to factor life-cycle cost predictions into decisions regarding the services provided.

The attending objectives were therefore as follows:

(1) To supply the methodology and motivation by which planning and design decisions:

  (a) become sensitive to estimated life-cycle costs.

  (b) consider cost relationships between components of a system.

(2) To provide a quantitative life-cycle cost analysis tool to help managers and engineers in planning and design decisions.

(3) To improve budgeting capabilities for the DSN as a whole.

III. Subjects Addressed

To meet the above goals and objectives, the two aforementioned documents (Refs. 1 and 2) were produced. Major topics covered in the documents are listed below:

(1) Definition of "life-cycle cost" and other terms.

(2) Criteria prescribing when an LCC analysis must be performed.

(3) Conditions under which an LCC calculation would be useful, though it is not required.

(4) Activities, roles, and responsibilities.

(5) Information needed before the analysis begins.

(6) Planning the LCC analysis.

(7) Gathering cost estimates.

(8) Calculation of the estimated life-cycle cost.

(9) Interpretation of the LCC.

(10) Reporting results.

(11) Examples.

IV. Use and Implications

The two LCC documents, together with the training package available from TDA Engineering, enables managers and engineers to perform and use LCC analysis. Consideration is also being given to follow-on tasks that might further enhance the effectiveness of LCC analysis within the DSN. Among these tasks are the following:

(1) Evaluation of the methodology in practice.

(2) Augmentation of existing cost data bases.

(3) Compilation of existing cost models and cost estimation techniques.

(4) Additional cost model development.

There are long-range implications of using life-cycle cost analysis to support planning in the DSN. Performance of cost trade-offs will become standard. The objective of minimum life-cycle cost will impact capabilities, specifications, and designs selected, and thus, the overall cost effectiveness of the DSN will continue to improve. Lastly, formal information exchange and feedback between implementing and operating organizations, as well as between levels of implementation, will increase.

References

1. *Life-Cycle Cost Analysis*, TDA Standard Practice 810-23. Jet Propulsion Laboratory, Pasadena, Calif., Sept. 15, 1980 (JPL internal document).

2. *DSN Life-Cycle Cost Analysis Handbook*, TDA Document 890-119. Jet Propulsion Laboratory, Pasadena, Calif., Oct. 1, 1980 (JPL internal document).

Voyager Mission Support (I)

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This article is a continuation of the Deep Space Network report on Tracking and Data Acquisition for Project Voyager, covering the period from May through July 1980.

I. Introduction

Both Voyager 1 and 2 continue in the Jupiter-Saturn Cruise Phase of the mission. Voyager 1 is scheduled to begin the Observation Phase on 22 August 1980 for the Saturn Encounter.

II. DSN Support

During the reporting period, the DSN continued to support routine and special activities with both spacecraft. Concurrently, implementation was being completed at the stations for the capabilities that would be required for the Saturn Encounter. Two of these capabilities, Real-Time Combining and Radio Science, are major additions to the stations and are described in detail.

III. Real-Time Combining and Antenna Arraying

During the Saturn Near Encounter Phase of the mission, an antenna arraying and data combining configuration at each DSN 64/34-m complex will be used to enhance the 29.8 or 44.8 kbps telemetry data. The real-time combined telemetry signal-to-noise ratio (SNR) improvement is dependent upon the SNR difference between the two supporting stations. Telemetry shall use the X-band TWTA at high power. The data rate strategy shall be based on the maximum data rate availability as shown in Fig. 1 at the 95 percent, 90 percent, and 80 percent confidence levels. The contrasting 64-m coverage for the same confidence ranges are shown in Fig. 2. The strategy specifically is based on the 90 percent confidence level for real-time data and the double digital tape recorder (DTR) playback of critical data and on the 95 percent confidence level for single DTR playback of noncritical data or for the real-time transmission of OPNAV frames. For the above strategy, the maximum number of hours available each day for the 44.8, 29.9, 19.2 and 7.2 kbps data rates are listed in Table 1.

The antenna arraying (real-time combining baseband signals) to be used for the Saturn Encounter is an upgrade of the previous subsystems. On 21 September 1974, the Goldstone stations were arrayed to improve the telemetry data received during the Mariner 73 Mercury Encounter. The current effort began in FY 78 with the objective of developing a permanent Real-Time Combiner (RTC) installation for the 64/34-m network. A prototype unit became available in November 1978 and was successfully used for the Voyager 2 Jupiter Encounter and for the Pioneer 11 Saturn Encounter. This prototype was the basis for the system presently installed at the three Deep Space Communication Complexes (DSCC). (See Ref. 1 for more detail.)

Figure 3 shows the RTC block diagram. Inputs to the RTC are from the telemetry receivers of the two supporting stations. The inputs are baseband data consisting of telemetry subcarrier plus data. In the RTC, the two signals are combined (added). Since the noise power is random in nature, the increase in signal power is greater than the noise power and results in an increase in SNR.

The baseband signals enter the RTC through low-pass filters. The signals then pass through AGC circuitry, which maintains equal amplitudes for both signals and sets the level for input to the Analog-to-Digital (A-to-D) converters. The A-to-D 10 MHz variable phase input clock is used to quantify the analog inputs into ten million samples per second. The phase variations of the input clocks, as controlled by the Central Processing Unit (CPU), act as a push-pull circuit so that if the phase of the 64-m signal input clock is advanced, and the 34-m signal input clock phase is delayed by an equal amount. The signals are then fed to the First-In-First-Out (FIFO) memory. The same input clock used by A to D is used to strobe the data into the FIFO. The FIFO inputs are strobed by the output clock, which is coherent to the input clock, but whose phase is fixed. The two signals are phase locked through use of the In-Phase and Quadrature Correlator (IP and Q Corr).

The 64-m signal IP and Q Corr has inputs from the 64-m FIFO and the 34-m FIFO. The correlation of the two signals is the average of their product. The IP correlator allows the CPU to adjust total phase tracking loop gain for optimum performance.

The Q correlator produces a count proportional to relative signal delay. This information is fed to the CPU, which creates an error signal used to correct the push-pull input clock phase. The signals are then routed to the Digital-to-Analog (D-to-A) converters, which are synchronized by the output clock, and then through low-pass filters to the summing amplifier (Σ amp). The input resistor values of the summing amplifier are selected so that the 34-m signal is six-tenths as great as the 64-m signal. The signals are, therefore, in phase and correctly proportioned for real-time combining. The CPU is interfaced via the Star Switch Controller to the Data System Terminal Assembly (DST) for control input and receipt of error messages. The 34-m TP and Q Corr is redundant and not used. These correlators may be hand switched in cases of anomalous operation.

Several improvements have been made to the antenna array subsystem, which were not available during Jupiter Encounter. Receiver lock and Automatic Gain Control (AGC) indications from the 34-m DSSs are now provided to the 64-m DSSs. These indications provide the 64-m DSSs with partial status of the 34-m station, and in the event of a problem, the 64-m DSS would be informed in real-time via these indicators.

The Block IV receiver telemetry detectors have been modified to reduce degradation, thus providing four possible paths for the 64-m output to the RTC. A procedural means of measuring the RF path delay has been formulated. The time required for RTC Pre-Track Preparation (PTP) has been reduced by deletion of some precal items and the streamlining of others. Operational equipment provides additional control statements and options. For example, the new RTC is able to be restarted without being reinitialized and parameters can be changed without reinitialization.

The RTC installation was completed at the Goldstone DSCC in mid-May 1980. Antenna arraying and RTC training and operational evaluation was started on 19 May. This training-evaluation consisted of a series of periods, during which both DSS 12 and 14 were scheduled simultaneously to track either Voyager 1 or 2.

The test activity allowed the station personnel to operate the RTC as they desired for the greater part of the scheduled period, but required them to maintain a standard configuration for a specified period of time. Under this concept, the noncombined telemetry data was transmitted to the project to meet the DSN commitment. The combined telemetry string was displayed via the monitor stream so that the advisors at JPL could monitor the station activity. During the standard configuration period, the symbol SNR was recorded for both the 64-m telemetry string and the 34-m telemetry string, and at both 29.8 and 44.8 kbps. This recorded data was the basis for operational evaluation.

It was generally found that the RTC operated within the specifications. However, some problems were experienced with the FIFO boards since some components were prone to fail. Likewise, it was found that the condition of the entire telemetry string, including all components, greatly influences the combiner performance. In order to measure the combiner performance, it is necessary to know the performance of the telemetry string to ±0.1 dB. This requires each component to be calibrated and within specs to ±0.1 dB. The SNR spread between the 34-m and 64-m stations was found to be greater than anticipated and part of the discrepancy is probably due to the telemetry string performance.

Eight array-RTC periods were conducted with DSS 12/14 prior to completion of the RTC installation at the overseas complexes. On 23 and 24 June, the first arraying period was scheduled for both DSS 42/43 and DSS 61/63. The same training-evaluation philosophy was observed during the subsequent tracking periods for these stations. The same findings and evaluation were made of the data from these DSCC as were made of the Goldstone complex. Variances were observed in the SNR spread between the stations and, in some cases, the spread was so great as to invalidate any combiner gain. Likewise, telemetry strings had problems in being locked up to the data, indicating marginal operation of some components.

The final conclusion from this testing is that a carefully calibrated, tuned, and stable telemetry string and RTC is a prerequisite to successful encounter operation. Training passes will continue to be scheduled to allow the stations to be properly prepared for critical encounter operation with this configuration.

IV. Radio Science

Radio Science is defined as the acquisition and extraction of information from spacecraft transmitted signals, which have been directly affected by passage through:

(1) Planetary neutral atmospheres

(2) Planetary ionospheres

(3) Planetary magnetospheres

(4) Solar corona (plasma)

(5) Gravitation (relativity)

(6) Planetary rings (particles)

and indirectly affected by forces acting upon the spacecraft:

(1) Gravity waves

(2) Gravitational fields

(3) Planetary atmospheric winds

(4) Solar radiation

The experimentation to be carried out during each Saturn Encounter by Voyager that requires the DSN Radio Science capability are:

(1) Voyager 1

- (a) Solar Corona
- (b) General Relativity Time Delay Measurement
- (c) Saturn System Celestial Mechanics
- (d) Titan Occultation
- (e) Rhea Mass Determination
- (f) Saturn Occultation
- (g) Saturn Ring Occultation
- (h) Saturn Ring Scatter

(2) Voyager 2

- (a) Saturn System Celestial Mechanics
- (b) Saturn Occultation
- (c) Saturn Ring Scatter

It is anticipated that the activities listed for Voyager 2 will expand as the results of the Voyager 1 Encounter are evaluated and as the Voyager 2 Encounter approaches.

A brief description of the DSN support requirement for each of these experiments follows.

A. Saturn System Celestial Mechanics

This experiment will require one-way (or TWNC) and two-way (or three-way) tracking in order to optimize data-taking for the various Celestial Mechanics investigations. Ground events will include normal tracking and ranging with selected doppler sample rates. Doppler and range data will be delivered to the project on tracking IDRs.

B. Rhea Mass Determination

The DSN will acquire two-way tracking data near Rhea encounter to determine the mass of Rhea to within ±5 percent. A ten sample-per-second doppler rate will also be required. Data will be delivered on tracking IDRs.

C. Radio Occultation of the Solar Corona

This experiment will require alternating periods of S-X differential ranging (two-way) and scintillation (one-way or TWNC) for Sun-Earth Probe (SEP) angles of less than 15 degrees. The DSN will provide open- and closed-loop dual frequency one-way doppler and ODA data during TWNC-ON periods. Closed-loop dual frequency ranging will be required during TWNC-OFF periods. Tracking IDRs will provide doppler and range data, with ODA data being delivered on ODA DODRs.

D. General Relativity Time Delay Measurement

The acquisition of ranging data for 15 hours before and after minimum SEP angle will be required. This will enable the measurement of the General-Relativistic Time Delay induced in the communication link by the sun's gravity field. The DSN will provide continuous ranging during the period of interest. Data will be delivered on tracking IDRs.

E. Titan Radio Occultation

The requirements here are to perform ingress and egress measurements at fixed high-gain antenna (HGA) offset angles with respect to Earth. The ingress is optimized for ionosphere and upper atmosphere studies, and the egress will be for measurements as deep as several atmospheres. The DSN will provide closed-loop doppler data at ten samples per second, open-loop medium-band recording, and use of special frequency predicts. Tracking IDRs will provide doppler data to project and the open-loop data will be delivered on ODA DODRs.

F. Saturn Radio Occultation

A limb-tracking maneuver will continuously be performed throughout Earth occultation except for a 20-minute period where maneuvering will cease in order to accommodate the ultraviolet spectrometer sun-occultation exit. The DSN will support with one sample-per-second closed-loop doppler data, open-loop narrow bandwidth recording, and special frequency predicts. Also, a station transfer from DSS 43 to DSS 63 will occur during occultation. Doppler data will be supplied to project via IDRs, and the open-loop data via ODA DODRs.

G. Radio Occultation of Saturn's Rings

This experiment will occur with the High-Gain Antenna (HGA) pointed at Earth from Saturn Earth Occultation Exit (EOE) through "F" ring EOE. The DSN will provide one sample-per-second closed-loop doppler data, open-loop medium bandwidth recording, and special frequency predicts. Doppler data will be supplied via tracking IDRs, and open-loop data will be delivered via medium bandwidth computer compatible tapes produced at CTA 21 from DRA recordings.

H. Radio Scattering by Saturn's Rings

This experiment will be accomplished by obtaining radio scattering data by tracking an area of the "A" ring with the HGA for approximately 100 minutes after "F" ring EOE and for approximately 30 minutes during Earth occultation. Again, the DSN will provide one-per-second closed-loop doppler data, open-loop medium bandwidth recording, and also special frequency predicts. Doppler data will be supplied to project via tracking IDRs, and open-loop data will be via medium bandwidth computer-compatible tapes from CTA 21.

The key characteristics of the DSN Radio Science System to be used to support these experiments are:

(1) Acquires left and right circularly polarized spacecraft signals at S- and X-band frequencies.

(2) Digitizes and bandwidth-reduces up to four open-loop receiver channels simultaneously by means of an automatically controlled programmed oscillator.

(3) Digitizes and records wide bandwidth open-loop receiver output.

(4) Generates programmed oscillator frequency predictions that incorporate effects due to planetary atmospheres.

(5) Performs real-time system performance monitoring and provides system performance data in real-time to the project.

(6) Transmits quick look radio science data from Deep Space Stations (DSS) to Network Operations Control Center (NOCC) via High-Speed Data Line (HSDL).

(7) Performs non-real-time bandwidth reduction of wide bandwidth radio science data.

(8) Provides radio science data to the project via computer-compatible magnetic tape.

The following paragraphs describe these capabilities.

1. Wide bandwidth recording and subsequent non-real-time bandwidth reduction. Spacecraft signals are acquired by the wide bandwidth (2 MHz) multi-mission open-loop receiver (MMR). These signals are digitized and recorded on a high-rate, high-precision digital recorder (the Digital Recording Assembly, or DRA). The DRA recordings are shipped via Network Information Control (NIC) to CTA 21, where the (radio science) data bandwidth is processed and reduced by the NWK Radio Science Subsystem (WRS). The digitized, bandwidth-reduced data are supplied to the project on computer compatible magnetic tape.

2. Real-time bandwidth reduction (narrow bandwidth). Real-time bandwidth reduction (narrow bandwidth) is initiated when a spacecraft state vector is supplied to the "POEAS" software program. The output of the POEAS program is a Polynomial Coefficient Tape (PCT), which includes the frequency-independent, planetary atmosphere-refracted spacecraft observables. The PCT is input to the Network Control (NC) Tracking Subsystem software program "PREDIK." The output of PREDIK consists of radio science formatted downlink frequency predictions, which are transmitted to the appropriate 64-m DSS via high-speed data line. The predictions are received by the Occultation Data Assembly (ODA) of the DSS Radio Science Subsystem (DRS). The ODA processes the predictions and provides them to the Programmed Oscillator Control Assembly (POCA). The POCA drives a Programmed Oscillator (PO), the output of which is multiplied up to S-band and X-band frequencies in a two-channel open-loop receiver (either the Block III OLR at DSS 43, or the new narrow bandwidth MMR at DSS 14 and 63) and mixed with the two (S- and X-band) spacecraft downlinks. The open-loop receiver filters the baseband product(s) of the mixing, and provides the filtered signals to the ODA. The baseband signals are digitized and recorded on magnetic tape along with the counted output of the PO. During actual operations, the ODA-recorded signals are validated (singly) via usage of the Signal Spectrum Indicator (SSI). After data acquisition is complete, the ODA formats the data for WBDL transmission to the GCF Data Records Subsystem (GDR). The real-time bandwidth-reduced data are supplied on computer-compatible tape to the appropriate flight project.

3. Real-time bandwidth reduction (medium bandwidth). Generation of radio science predictions and subsequent handling by the ODA, POCA, and PO are the same as described in the preceding paragraphs. In this case, however, four spacecraft signals (permutations of LCP and RCP, and S- and X-band) are acquired by the four-channel medium bandwidth MMR, and mixed with appropriate PO frequencies. The mixed product(s) are filtered and provided to the DRS. Within the DRS, the signals are digitized and recorded on the DRA. During data acquisition, the recorded signals are verified (singly) by the SSI. Subsequent to data acquisition, the DRA-recorded data and the various PO data recorded on computer-compatible tape by the ODA are shipped to the NWK Radio Science Subsystem (WRS). The DRA-recorded data are processed and rewritten on computer-compatible tape by the WRS and provided to the project.

4. Real-time system performance validation. Digital spectrum (radio science) data from the Spectral Signal Indicator (SSI) are provided to the Occultation Data Assembly (ODA), where they are formatted for WBDL transmission to the NOCC. The digital spectrum data are routed to the NC Radio Science Subsystem (NRS), which processes the data to form a replica of the original (SSI) spectral display. The NC Display Subsystem (NDS) displays the spectra in the Network Operations Control Area (NOCA) and, additionally, provides the displays to the appropriate project area(s) for viewing by radio science experimenters. Additionally, the NRS provides displays of the DRS status and configuration.

a. Predicts. The open-loop receiver POCA predicts will be generated at JPL and transmitted to the Occultation Data Assembly (ODA), where the predicts will be stored on disk and used to drive the S/X-band open-loop receiver POCA. Time of Earth occultation may vary by several seconds with no predict bias changes required, but if the timing error is too large, time or frequency deltas will be provided.

b. Open-loop recording.

(1) The DODR recording will begin prior to the start of occultation. It is necessary to collect baseline data prior to and after occultation. The Project SOE will provide the time to turn on the ODA recording, and will also provide the turn off time. Approximately four hours of recording are anticipated. The ODA narrow band or medium band will be prime for occultation, dependent upon special requirements.

(2) ODA narrow band open-loop backup recording will be provided by the medium band or wide-band (150/300 kHz) Open-Loop Receiver (OLR) and its Digital Recorder Assembly (DRA) (see Fig. 4).

(3) Voyager will not make use of the HSDL to get open-loop ODA data to JPL, except for preliminary quick-look data, because the number of station hours to replay data via HSDL is prohibitive. The prime method of getting data to JPL is to ship the open-loop DODRs to JPL.

(4) DODR recording for Voyager will use six DODR tapes per hour, five DODRs per hour for the narrow band MMR/ODA subsystem, and approximately one DODR per hour for the medium band or wide band OLR/DRA subsystem.

(5) New or once used digital tape, at least 2300 feet in length for ODA and 9,200 feet in length for DRA, must be used for recording open loop data, to insure optimum data return.

c. Spectral Signal Indicator. Station personnel will use the Spectral Signal Indicator (SSI) to verify that occultation data are actually being recorded onto the DODR. The SSI will provide recording status for the narrow band, medium band, and wide band recording subsystems. The narrow and medium bands are used for the prime data and will require more monitoring by the DSS operator than the wide band subsystems. The DSS will report signal status to the NOC at least every 15 minutes, more often if requested, if the signal disappears or is marginal.

Testing of the Radio Science System, particularly the recording of open-loop receiver data, is relatively easy as compared to real-time combining because any spacecraft X-band data can be used. The stations have been making such recordings for training and testing purposes. In addition, two ORTs have been conducted. The first ORT was a preliminary training exercise since much of the equipment had not been installed at the stations. ORT-2 was likewise considered unsuccessful because the SSI, PPM, backup Multi-Mission Receiver

(MMR) at DSS 63 and MDA OP-E software were not available (not installed or not functioning) for test support.

Mission Configuration Tests (MCTs) were conducted by the DSN as the new equipment was installed. A successful ORT was conducted with DSS 43 on 24 July 1980; however, the DSS 63 portion was canceled due to X-band Maser problems at the station. ORT-3 is scheduled to be conducted concurrently with the Near Encounter Test to be conducted in August 1980.

Reference

1. Simon, N. K., and Hoynes, C., "Preliminary Telemetry Operations Experience With the Real-Time Combiner: 1 November 1978 to 1 November 1979," in *The Deep Space Network Progress Report 42-55*, pp. 90-96, Jet Propulsion Laboratory, Pasadena, Calif., February 15, 1980.

Table 1. Maximum number of hours per day of telecom capability, 64/34-m array, during VGR-1 NE

44.8 kbps 90%	29.9 kbps 95%	29.9 kbps 90%	19.2 kbps 90%	7.2 kbps 90%
15.1	18.1	22.1	23.6	24

7.2 kbps @ 90% - GS-2 (rec), GS-4 (rec), IM-2 (rec), GS-3, OC-1
19.2 kbps @ 90% - IM-12, plus all of the above
29.9 kbps @ 90% - IM-9, IM-11, plus all of the above
29.9 kbps @ 95% - PB-3, plus all of the above
44.8 kbps @ 90% - IM-7, PB-2, plus all of the above

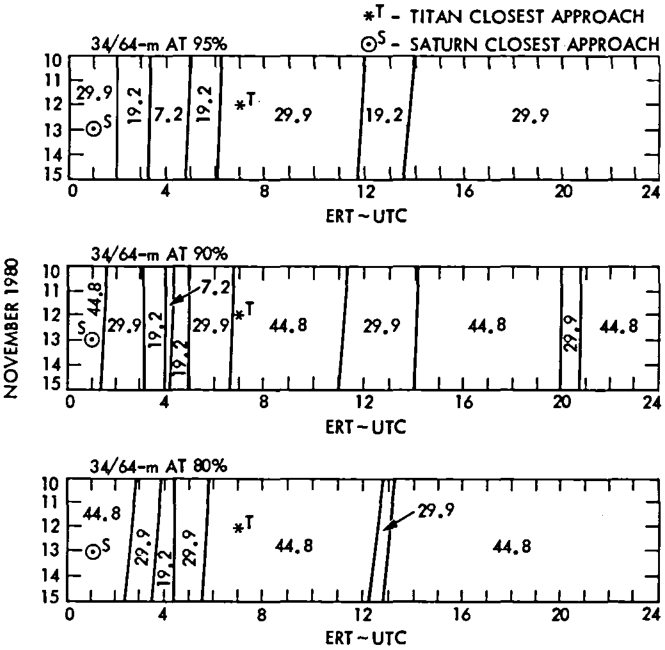

Fig. 1. VGR-1 NE 34/64-m telecom performance maximum kbps envelope

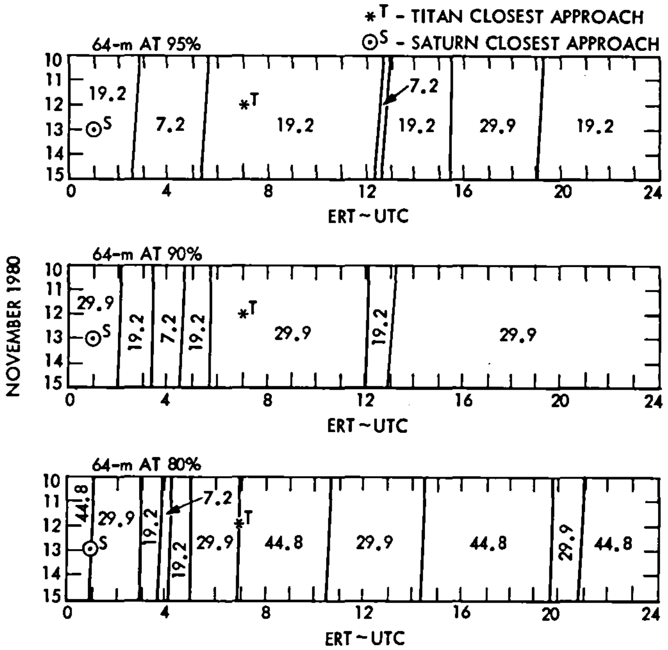

Fig. 2. VGR-1 NE 64-m telecom performance maximum kbps envelope

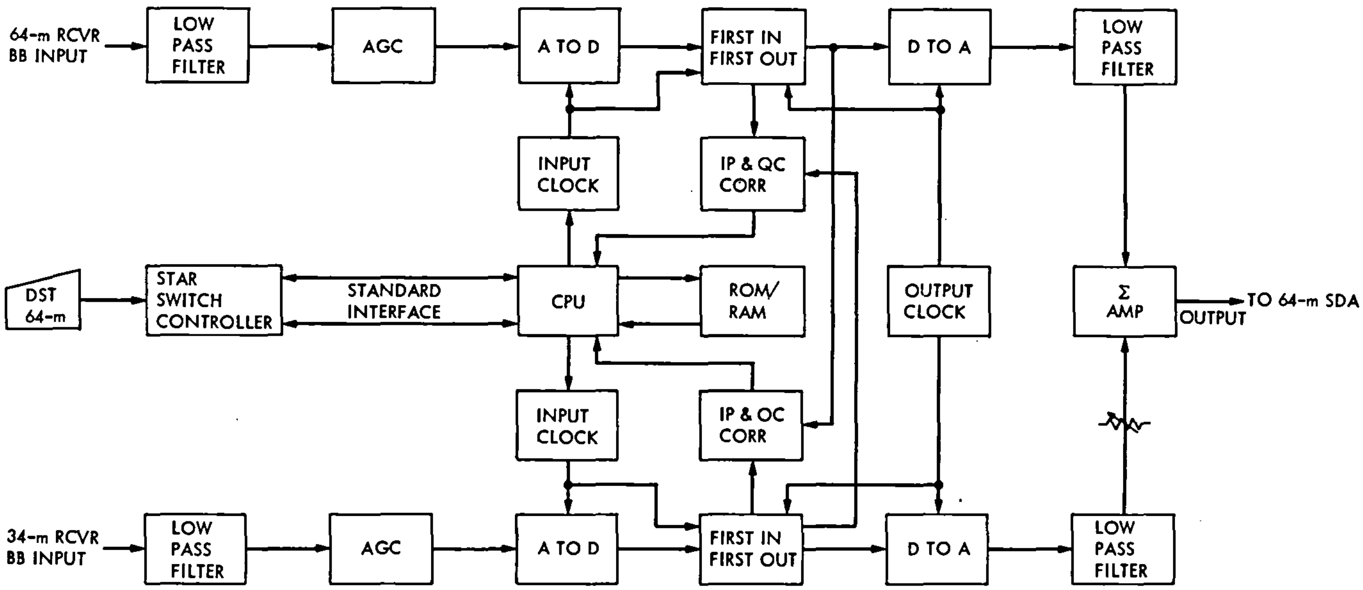

Fig. 3. Real-time combiner configuration

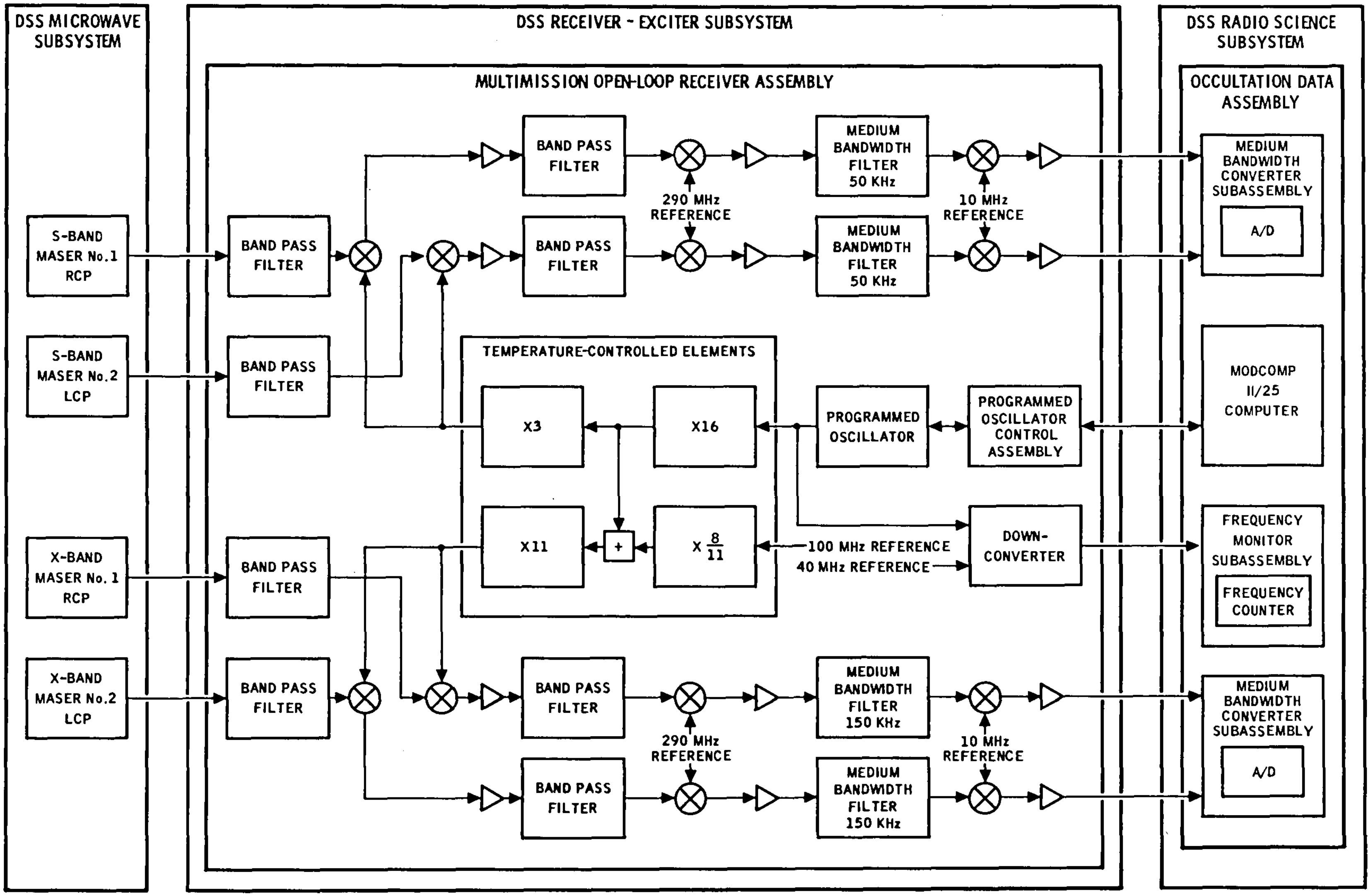

Fig. 4. Voyager open-loop receiver configuration