The DSS Radio Science Subsystem—Real-Time Bandwidth Reduction and Wideband Recording of Radio Science Data

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New radio science experiment requirements levied by the Pioneer Venus Project have resulted in the development of a multimission radio science subsystem at the 64-m subnet. Major functional capabilities of the DSS Radio Science Subsystem (DRS) are real-time bandwidth reduction and wideband recording of radio science data. This article provides a functional description of the key characteristics, requirements, and operation of the DRS.

I. Introduction

The Pioneer Venus Mission, with launches scheduled in May 1978 (Pioneer Venus Orbiter) and August 1978 (Pioneer Venus Multiprobe) has two radio science experiments with major impact on The Deep Space Network (DSN). In December 1978 the Pioneer Venus Multiprobe Mission Spacecraft will encounter the planet Venus, and at that time, the Differential Long Baseline Interferometry (DLBI) experiment will attempt to measure wind velocities in the atmosphere of Venus as four probes descend through the atmosphere (Ref. 1). Also starting in December 1978, the Pioneer. Venus Orbiter will undergo daily occultations by Venus for a period of approximately three months. In addition, a smaller period of occultations occurs in May 1979.

As the Pioneer Venus Mission planning evolved, it became clear that the DLBI experiment would require that the signals from the four descending probes and the (spacecraft) bus be received on one high phase stability, wideband (~2 MHz) open loop receiver, and that the output of this receiver be recorded on a high precision, very high rate recorder. In addition, it was also clear that costs associated with processing approximately 100 S- and X-band occultations of the Pioneer Venus orbiter by previously used techniques would be quite burdensome (Ref. 2). To reduce these costs, the idea was conceived of driving the open loop receiver first local oscillator with the predicted (atmospherically refracted) frequency, so that only a very narrow open loop receiver output bandwidth would need to be recorded. Since processing costs are approximately linear with recorded bandwidth, this procedure would be expected to result in substantial savings.

As a result of these new radio science experiment requirements, it became apparent that it would be appropriate for the DSN to create a Radio Science System (Ref. 3). The equipment at the 64-meter subnet which will perform the "real-time bandwidth reduction"[1] and the wideband recording was combined to form the DSS Radio Science Subsystem (DRS). This article describes in detail the functional operation of the DSS Radio Science Subsystem. It should be emphasized that although the initial implementation of the DRS is geared toward the Pioneer Venus mission, the DRS provides multimission radio science capabilities, and will be extensively utilized in fulfillment of the radio science requirements of other projects, such as Viking, Voyager, Galileo, etc.

II. Functional Description of the DSS Radio Science Subsystem

A. Definition

The DSS Radio Science Subsystem, a dedicated and integral element of the DSN Radio Science System, performs the following functions:

(1) Receives programmed oscillator (PO) frequency predictions and uses an error detection algorithm to verify correctness of predictions transmission.

(2) Reduces required open-loop receiver bandwidth via automatic control of a programmed oscillator which centers the open-loop receiver about the predicted frequency profile.

(3) Digitizes and formats for high-speed data line (HSDL) transmission the narrowband open-loop receiver data and programmed oscillator data (radio science data).

(4) Digitizes and records wideband open-loop receiver data and associated timing information (wideband radio science data) on magnetic tape.

DSS Radio Science Subsystem functions and interfaces are presented in Fig. 1, while Fig. 2 presents functions and data flow.

B. Key Characteristics

The key characteristics of the DSS Radio Science Subsystem are listed below for functions of the Occultation Data Assembly (ODA) and the Digital Recording Assembly (DRA).

1. Real-time bandwidth reduction (ODA) key characteristics.

(1) Hardware and software compatibility with DSN Mark III configuration.

(2) Programmed oscillator frequency predictions reception via HSDL; transmission verification by an error detection algorithm.

(3) Frequency predictions conversion to frequency rates for automatic control of programmed oscillator that drives S- and X-band open-loop receivers.

(4) Availability of four analog-to-digital (A-D) conversion channels capable of being configured to digitize open-loop receiver data in the following channel vs maximum sample rate combinations:

(a) One channel at 80 k samples/second

(b) Two channels at 40 k samples/second

(c) Four channels at 20 k samples/second

(d) One channel at 60 k samples/second; one channel at 20 k samples/second

(5) Availability of 8-bit quantization level of digitized open-loop receiver data for the maximum rate; 12-bit level otherwise.

(6) Temporary storage of radio science data on magnetic tape at the DSS for subsequent transmission to the NOCC via HSDL.

2. Wideband recording (DRA) key characteristics.

(1) Hardware compatability with DSN Mark III configuration.

(2) A-D conversion of wideband open-loop receiver data with 3-bit quantization.

(3) Provision for 18-bit parallel user input interface.

(4) Provision for data recording at any discrete rate between 175 k bits/second and 50 M bits/second.

(5) Provision for data recording on magnetic tape at nominal tape speeds of 19.05, 38.1, 76.2, 152.4, and 304.8 cm centimeters/second.

(6) Provision for time-tagging of recorded data to one microsecond or better resolution.

(7) Provision for full reproduce capability (shared between two transports).

(8) Provision for tape copying capability.

(9) Provision for 18-bit parallel user output interface.

(10) Eighty-minute record capability at 76.2 centimeters/second (12.5 M bits/second).

(11) Internal monitoring of recording performance.

(12) Provision for final output in analog form for monitoring purposes.

[1]The expression "real-time bandwidth reduction" is here defined as the process of driving the open loop receiver local oscillator with frequency predictions, and subsequently filtering, digitizing, and recording a narrow bandwidth containing the (mixed) signal.

C. Functional Operation

1. **Real-time bandwidth reduction.** Frequency predictions that include planetary atmospheric effects are generated by the Network Control (NC) Support Subsystem PREDIK software program. Transmitted in the form of S-band frequencies at the programmed oscillator (PO) level, they reach the DRS via HSDL and are verified for correctness of transmission by an error detection algorithm before storage for subsequent use.

When initialized, the Occultation Data Assembly converts the time-tagged frequencies to frequency rate commands for the programmed oscillator control assembly; the programmed oscillator functions to drive narrowband S- and X-band open-loop receivers. Narrowband open-loop receiver data are received by the DRS, digitized, formatted, and stored on magnetic tape. Concurrently the programmed oscillator frequency is counted by the DRS, formatted, and stored on magnetic tape. Similarly, the ODA frequency rates to the Programmed Oscillator Control Assembly (POCA) and POCA frequency commands to the PO are received by the DRS, formatted, and stored on magnetic tape.

During DRS operation, manual inputs are made via the DSS Monitor & Control Subsystem (DMC), and, similarly, the DRS is monitored from the DMC.

The digitized open-loop receiver data and the various programmed oscillator frequency data are transmitted from the DSS to the NOCC via HSDL in nonreal time or via tape shipment. Users gain access to the radio science data via Intermediate Data Records (IDR) written by the Ground Communications Facility (GCF) Data Records Subsystem. Figure 3 presents a functional block diagram of the Occultation Data Assembly.

2. **Wideband recording.** Wideband open-loop receiver data from the Multimission Open-Loop Receiver (MMR), which may contain multiple probe signals and receiver calibration tones, are received by the Digital Recording Assembly. These data are digitized at a quantization level of 3 bits and are recorded on 18 tracks of magnetic tape at a nominal tape speed of 76.2 centimeters/second (12 M bits/second). Concurrently, timing information received from the Frequency and Timing Subsystem (FTS) is recorded on two additional tracks. During recording, performance is monitored internally within the DRA.

The DRA simultaneously records on two separate transports. Subsequent to these recordings, duplicate copies may be produced on the DRA. The recorded wideband tapes are subsequently shipped to the Compatibility Test Area (CTA 21) Radio Science Subsystem via Network Information Control (NIC).

III. Functional Requirements of the DSS Radio Science Subsystem

A. Functional Requirements for Real-Time Bandwidth Reduction

1. **Programmed oscillator frequency predictions.** The ODA shall accept via HSDL and store programmed oscillator frequency predictions in the form of time tagged S-band frequencies at the programmed oscillator level (~46 MHz).

2. **Prediction error detection.** The ODA shall include an error detection algorithm in conjunction with the NC Support Subsystem PREDIK software program. This shall be for the purpose of verifying prediction consistency from generation through the ODA.

3. **Programmed oscillator frequency control.** The ODA shall convert time-tagged frequency predictions to frequency rates, and provide the results to the Programmed Oscillator Control Assembly (POCA) for programmed oscillator control of narrowband S- and X-band open-loop receivers.

4. **Signal presence and ODA operation verification.** The ODA shall provide a reconstructed analog receiver signal to the Spectral Signal Indicator for real-time verification of signal presence in the receiver bandwidth and verification of ODA operation.

5. **Occultation data processing and storage.** The ODA shall receive, digitize, and store time-tagged narrowband S- and X-band open-loop receiver output. The following are mission period requirements:

(1) Pioneer Venus Orbiter

Channels: 1 S-band, 1 X-band
Bandwidths: 1 kHz S-band, 3 kHz X-band
5 kHz S-band, 15 kHz X-band
Quantization: 8-bit

(2) Pioneer Venus Orbiter (solar corona)

Channels: 1 S-band, 1 X-band
Bandwidths: 1000 Hz S- and X-band
500 Hz S- and X-band
100 Hz S- and X-band
Quantization: 8-bit

(3) Voyager (first Jupiter encounter)

Channels: 1 S-band, 1 X-band
Bandwidths: 2.5 kHz S-band, 7.5 kHz X-band
10 kHz S-band, 30 kHz X-band
Quantization: 8-bit

(4) Voyager (second Jupiter encounter and Saturn encounter)

Channels: 2 S-band, 2 X-band
Bandwidths: All channels 100 kHz
Quantization: 8-bit

6. **Timing information and accuracy**. The ODA shall time-tag data with the following timing accuracies:

(1) Time synchronization with station time shall be accurate to less than 10 microseconds.

(2) Sampling rate accuracy shall be within 3×10^{-10}

(3) Sampling jitter shall be less than:

(a) Two microseconds at 10-kHz bandwidth

(b) Twenty microseconds at 1-kHz bandwidth

7. **Programmed oscillator frequency recording.** The ODA shall time-tag and record the programmed oscillator frequency output as follows:

(1) The programmed oscillator frequency shall be counted and recorded at one-second intervals on the integer second.

(2) The recorded programmed oscillator frequency shall be accurate to 0.5 Hz at S-band (RMS).

Additionally, the ODA shall record:

(1) The POCA-commanded PO frequency at one-second intervals on the integer second.

(2) The ODA-commanded PO initial frequency, and subsequent frequency rates, at one-second intervals on the integer second.

8. **Original Data Record (ODR) data content specification.**

a. Systematic Data Errors. The ODR shall have a 99% probability of containing error-free data (exclusive of Paragraph *b* below) during any span of ODA operation up to 300 minutes duration.

b. Random Data Errors. The ODR bit error rate shall be less than 1×10^{-6}, exclusive of tape flaws.

9. **Block I VLBI requirements (ODA).** The Block I VLBI system requirements on the ODA are as follows:

(1) 8 channels multiplexed.

(2) 250-kHz bandwidth/channel.

(3) One bit/sample.

(4) 500 k bits/second data rate.

(5) 500 M bits data volume.

(6) 1×10^{-6} bit error rate.

(7) 2 nanosecond maximum sampling jitter of any bit with respect to station reference.

(8) 10-microsecond time tag accuracy.

B. Functional Requirements for Wideband Recording

1. **Digitization and recording.** The DRA shall accept, digitize, and record wideband open-loop receiver data.

2. **Reproduction, tape copying, and recording continuity.** The DRA shall provide:

(1) Full reproduce capability.

(2) Tape copying capability.

(3) Continuous recording (no gaps) capability.

3. **Bit error rate.** Exclusive of tape flaws, the DRA bit error rate shall be less than 1×10^{-6} at all required tape speeds.

4. **Timing information and accuracy**. The DRA shall time-tag recorded data with the following timing accuracies:

(1) Time synchronization with station time shall be less than 10 microseconds.

(2) Timing information shall have a resolution of one microsecond or better.

5. **Analog Signal Regeneration and Delivery**. The DRA shall regenerate an analog signal from the recorded input data and deliver the signal to the Spectral Signal Indicator of the DSS Receiver-Exciter Subsystem.

6. **Pioneer Venus Recording.** For the Pioneer Venus Multiprobe mission, the DRA shall record wideband data at a sample rate of $\geqslant$ 4-1/6 M samples/second with the following accuracies:

Sampling rate accuracy: 3×10^{-12}
Sampling jitter: $\leqslant$ 10 nanoseconds RMS
Quantization: 3-bit

The recording capability shall be continuous for a minimum of 80 minutes at a data rate of 12.5 M bits/sec.

7. Block II VLBI Requirements (DRA). Block II VLBI system requirements on the DRA are as follows:

(1) 8 channels.

(2) 2-MHz bandwidth/channel.

(3) 1 bit/sample.

(4) 32 M bits/second data rate.

(5) 10^{11} bits data volume.

(6) 1×10^{-6} bit error rate.

(7) 2 nanosecond maximum sampling jitter of any bit with respect to station reference.

(8) 5-microsecond time tag accuracy.

IV. DRS Planned Implementation Schedule

The planned implementation dates for the various DRS capabilities are presented below:

Digital Recording Assembly

DSS 14 . . . . Feb. 15, 1978
DSS 43 . . . . Feb. 15, 1978
DSS 63 . . . . Feb. 15, 1979

DSS Radio Science Subsystem

DSS 14 . . . . July 1, 1978
DSS 43 . . . . July 1, 1978
DSS 63 (ODA only) . . . . Dec. 1, 1978

Programmed Oscillator Monitor

DSS 14 . . . . Oct. 1, 1978
DSS 43 . . . . Oct. 1, 1978
DSS 63 . . . . Dec. 1, 1978

Very Narrow Bandwidth Capability

DSS 63 . . . . Dec. 1, 1978
DSS 14 . . . . April 1, 1979
DSS 43 . . . . April 1, 1979

Four-channel Capability (Saturn Ring Experiment)

DSS 14 . . . . April 1, 1979
DSS 43 . . . . April 1, 1979
DSS 63 . . . . April 1, 1979

Spectral Signal Indicator Display Processing

DSS 14 . . . . July 1, 1979
DSS 43 . . . . July 1, 1979
DSS 63 . . . . July 1, 1979

DMC Interface

DSS 14 . . . . July 1, 1979
DSS 43 . . . . July 1, 1979
DSS 63 . . . . July 1, 1979

Wideband Interface

DSS 14 . . . . July 1, 1979
DSS 43 . . . . July 1, 1979
DSS 63 . . . . July 1, 1979

References

1. Berman, A. L., and Molinder, J. I., "The CTA 21 Radio Science Subsystem – Non-Real-Time Bandwidth Reduction of Wideband Radio Science Data," in *The Deep Space Network Progress Report 42-41,* Jet Propulsion Laboratory, Pasadena, California, October 15, 1977.

2. Berman, A. L., "Planetary Atmosphere Modeling and Predictions" in *The Deep Space Network Progress Report 42-42,* Jet Propulsion Laboratory, Pasadena, California, December 15, 1977.

3. Mulhall, B. D. L., "DSN Radio Science System Description and Requirements" in *The Deep Space Network Progress Report 42-39,* Jet Propulsion Laboratory, Pasadena, California, June 15, 1977.

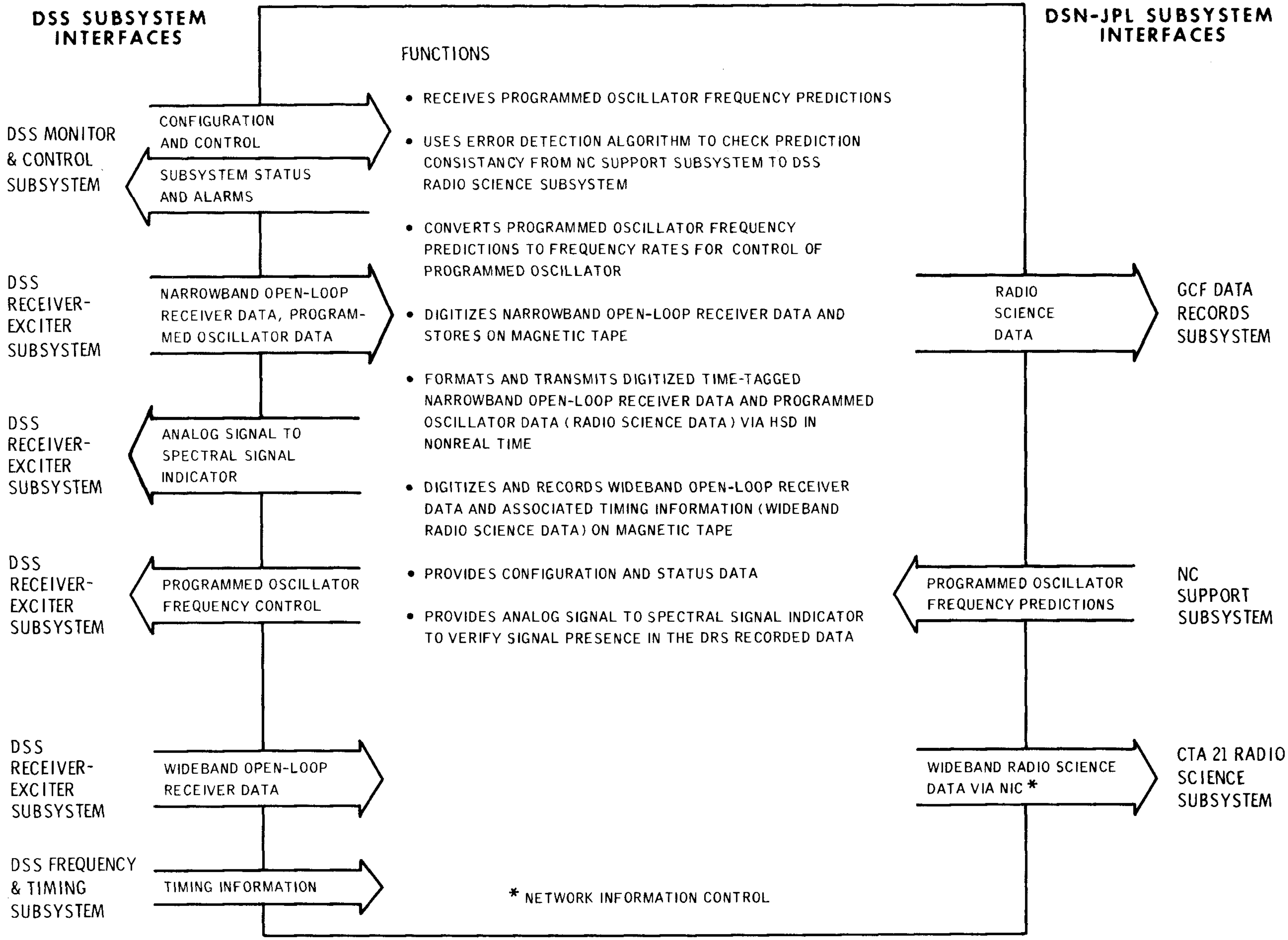

Fig. 1. DSS Radio Science Subsystem functions and interfaces

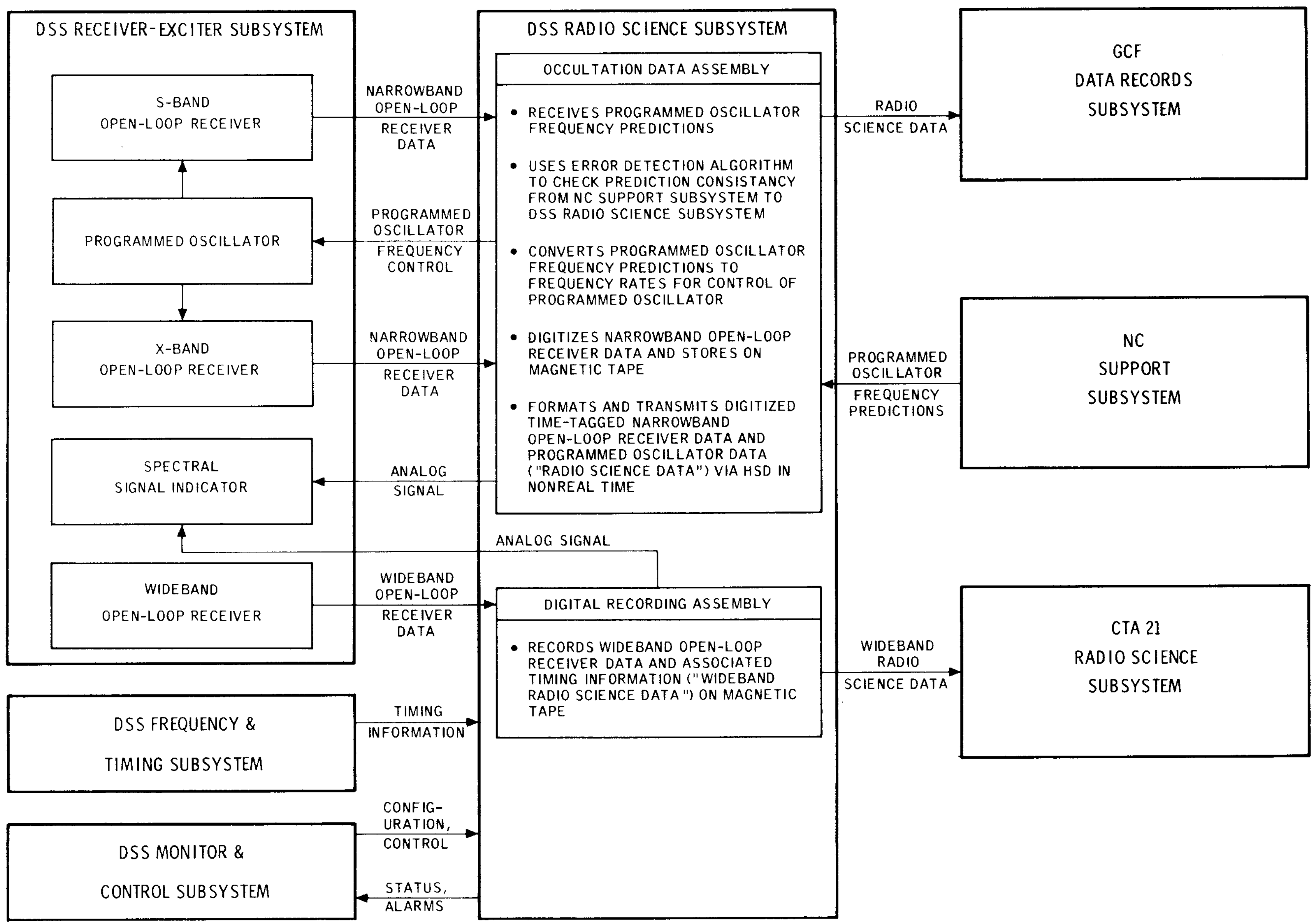

Fig. 2. DSS Radio Science Subsystem functions and data flow

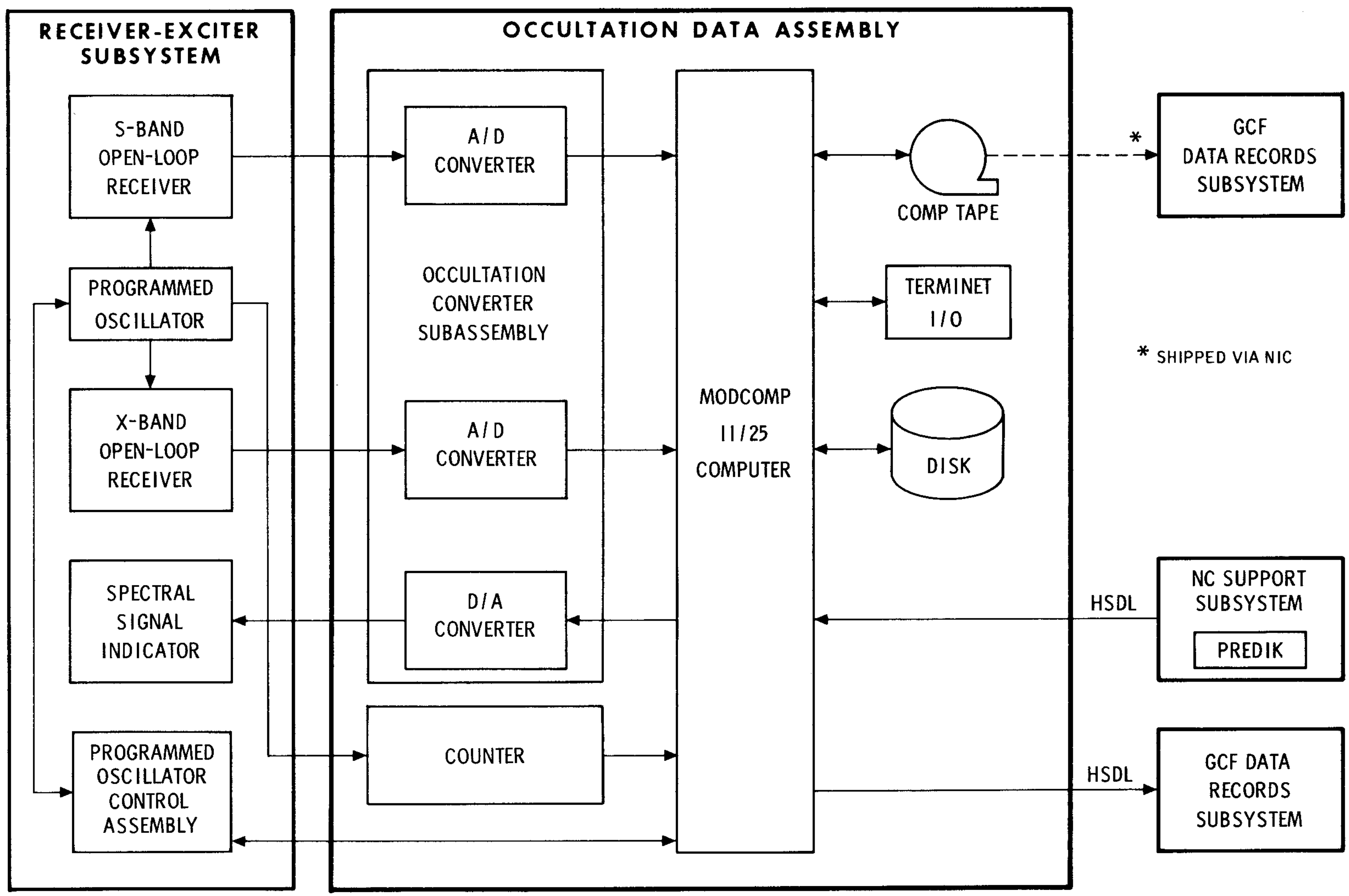

Fig. 3. Occultation Data Assembly functional block diagram

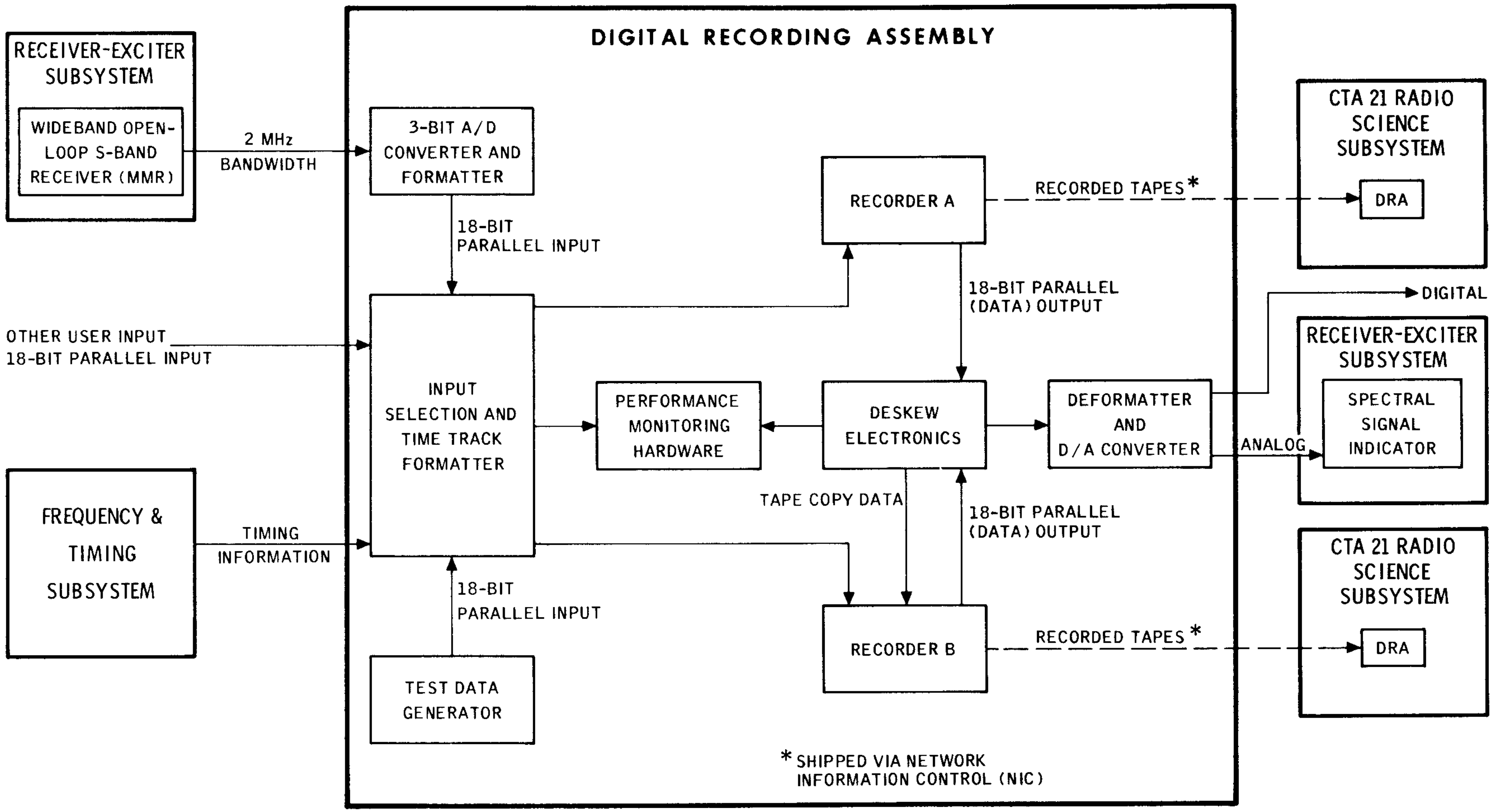

Fig. 4. Digital Recording Assembly functional block diagram