DSN Radio Science System, Mark III-78

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The DSN Radio Science System was created in February 1977, following a successful review of radio science requirements. This article describes the DSN Radio Science System, Mark III-78, as it has evolved in the eighteen months following its inception. Included in the article are the system definition, key characteristics, functional description, and functions of the Deep Space Stations, Ground Communications Facility, Network Operations Control Center, and Network.

Implementation of the "real-time bandwidth reduction," "wideband recording," and "non-real-time bandwidth reduction" capabilities in support of Pioneer Venus Orbiter, Voyager (Jupiter Encounter), and Pioneer Venus Multiprobe is nearing completion. Implementation of the "medium bandwidth recording" capability in support of Voyager (Saturn Ring Experiment) is under way, and is scheduled for completion in May of 1979.

I. Introduction

The DSN Radio Science System, Mark III-78, is one of eight DSN Data Systems which provide major data types and functional capabilities to the flight projects. In the broadest sense, the DSN Data Systems encompass the equipment, software, personnel, documentation, procedures, and resources necessary to deliver the required data to the flight projects. The Radio Science System was brought into existence on February 4, 1977, when the system requirements were reviewed and accepted by the Radio Science Review Board. The February 4, 1977 Radio Science Requirements Review has been described by Mulhall (Ref. 1).

This article describes the DSN Radio Science System as it has evolved in the eighteen months since its inception. Included in this article are the system definition, key characteristics, functional description, system configuration, testing, implementation status, and system schedule.

A. DSN Definition of Radio Science

The formal DSN definition of *Radio Science* is as follows:

> 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) Interplanetary media
>
> (7) Planetary rings (particles)

and indirectly affected by forces acting upon the spacecraft:

(8) Gravity waves

(9) Gravitational fields

(10) Planetary atmospheric winds (e.g., Pioneer Venus wind experiment)

(11) Solar radiation (solar sailing)

It should be noted that the DSN Radio Science System specifically *excludes* the often confused *Radio Astronomy* functions which are, according to the formal DSN definition, as follows:

The acquisition and extraction of information from signals emitted or reflected by natural sources (i.e., all sources other than spacecraft), such as:

(1) Planetary radar

(2) Planetary and lunar observations

(3) Discrete radio sources (pulsars, quasars, K-band, X-ray burst, etc.)

(4) Interstellar observations (formaldehyde, molecular lines, dark cloud recombination lines, etc.)

B. Origins of the DSN Radio Science System

The DSN Radio Science System traces its roots to the Pioneer Venus Mission, which includes two radio science experiments with major impact on the DSN. A brief description of these experiments and their resulting impact ensues.

In December 1978 the Pioneer Venus Multiprobe Mission Spacecraft will encounter the planet Venus. 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. 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 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. 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. The equipment which will perform "real-time bandwidth reduction"[1] and wideband recording was combined to form the DSS Radio Science Subsystem (DRS) at 64-meter subnet stations.

In addition, it was decided that non-real-time bandwidth reduction of the wideband radio science data (DLBI data) would be performed at the Jet Propulsion Laboratory, Pasadena. The necessary equipment was located at the Compatibility Test Area (CTA 21), and constitutes the CTA 21 Radio Science Subsystem (CRS).

It should be emphasized that although the initial implementation of the Radio Science System is geared toward the Pioneer Venus mission, the Radio Science System 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.

C. Flight Project Users of the DSN Radio Science System

Flight projects with active spacecraft which will be supported by the Radio Science System are as follows:

(1) Viking

(2) Pioneer Venus

(3) Voyager

(4) Pioneer Saturn

New or anticipated flight projects which can be expected to utilize the Radio Science System are:

(1) Galileo

(2) Solar Polar

[1]The expression "real-time bandwidth reduction" is 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.

II. Radio Science System Definition

The DSN Radio Science System is defined as follows:

> The DSN Radio Science System generates radio science data (digitized amplitude samples) from spacecraft signals which are both left circularly polarized (LCP) and right circularly polarized (RCP) and are at S-band and X-band frequencies. The radio science data bandwidth is reduced in either real-time or non-real-time via differencing with a predicted signal profile. Bandwidth reduced radio science data are delivered to the project via computer compatible magnetic tape (Intermediate Data Record).
>
> The DSN Radio Science System additionally provides graphical displays in real-time of both radio metric and radio science data.

It should be noted that radio metric data (Doppler, Range, etc.) constitutes prime radio science information. However, all radio metric data is and will continue to be delivered by the DSN *Tracking* System.

Figure 1 presents the Radio Science System functions and interfaces. The Radio Science System functional block diagram is presented in Fig. 2. Note that Fig. 2 also includes DSN Tracking System functional capabilities which deliver the closed-loop radio science (radio metric) data. Finally, Fig. 3 presents the Radio Science System functions and data flow.

III. Radio Science System Key Characteristics

The key characteristics of the DSN Radio Science System, Mark III-78, are as follows:

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

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

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

(4) Generates programmed oscillator frequency predictions which 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) Provides transmission of radio science data from Deep Space Station (DSS) to Network Operations Control Center (NOCC) via High-Speed Data Line (HSDL).

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

(8) Provides wideband back-up of all unique radio science events.

(9) Provides radio science data to the project via Intermediate Data Record (IDR).

IV. Radio Science System Functional Description

Major functional capabilities of the DSN Radio Science System, Mark III-78, can be conveniently categorized as follows:

(1) Wideband recording and subsequent non-real-time bandwidth reduction (Pioneer Venus DLBI Experiment).

(2) Real-time bandwidth reduction (planetary occultations and solar corona operations).

(3) Medium bandwidth recording (planetary ring operations).

(4) System performance validation.

These are described in detail below.

A Wideband Recording and Subsequent Non-Real-Time Bandwidth Reduction

Multiple probe signals are acquired by the Wideband (~2 MHz) Multimission 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 recorded tapes are shipped via Network Information Control (NIC) to CTA 21, where the (radio science) data bandwidth is reduced via CTA 21 Radio Science Subsystem (CRS) processing. The final digital, bandwidth-reduced data are supplied to the project on computer compatible magnetic tape ("Wideband Radio Science" IDR). References 2, 3, and 4 describe in detail the MMR, DRA, and CRS, respectively.

B. Real-Time Bandwidth Reduction

Real-time bandwidth reduction starts with provision of a spacecraft state vector 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) Support Subsystem software program "PREDIK." The output of PREDIK is radio science formatted downlink frequency predictions, which are transmitted to the appropriate 64-m DSS via High-Speed Data Line (HSDL). 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 in a two-channel open-loop receiver (either the Block III OLR at DSSs 14 and 43, or the new narrow bandwidth MMR at DSS 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 data are validated via usage of the Signal Spectrum Indicator (SSI). After data acquisition is complete, the ODA formats the data for HSDL transmission to the GCF Data Records Subsystem (GDR). The real-time bandwidth reduced data are supplied on computer compatible tape ("Radio Science" IDR) to the appropriate flight project.

Radio science predictions are further described in Ref. 5, while Ref. 3 describes ODA operations in detail.

C. Medium Bandwidth Recording

Generation of radio science predictions and subsequent handling by the ODA, POCA, and PO are the same as described in Subsection B. In this case, however, four spacecraft signals (permutations of LCP and RCP, and S- and X-band) are acquired by the four-channel Narrow 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 via use of the SSI. Subsequent to data acquisition, the ODA reformats the DRA recorded data and re-records it on computer compatible tape. The data are finally provided to the project via computer compatible tape ("Medium Bandwidth Radio Science" IDR).

D. 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 HSDL 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 experimentors. Additionally, the NRS provides displays of the DRS status and configuration.

Display of radio science data and radio science equipment status is described in greater detail in Ref 6.

V. Deep Space Station Functions

A. DSS Antenna Mechanical Subsystem (ANT)

The DSS Antenna Mechanical Subsystem points the antenna at spacecraft via NOCC generated tracking predictions, and collects and focuses spacecraft signal energy at S- and X-band frequencies.

B. DSS Antenna Microwave Subsystem (UWV)

The DSS Antenna Microwave Subsystem performs low noise amplification of left and right circularly polarized signals at both S- and X-band frequencies.

C. DSS Receiver-Exciter Subsystem (RCV)

The DSS Receiver-Exciter Subsystem acquires via open-loop receivers left and right circularly polarized signals at both S- and X-band frequencies. The signals are hetrodyned down to baseband via use of automatically controlled Programmed Oscillators, filtered, and provided to the DSS Radio Science Subsystem (DRS). The RCV displays DRS provided signals on the Spectrum Signal Indicator (SSI) for purposes of validation of DRS operations.

D. DSS Radio Science Subsystem (DRS)

The DSS Radio Science Subsystem digitizes, bandwidth reduces and records radio science data, and digitizes and records wideband radio science data. The DRS receives radio science predictions from NOCC, configuration and control data from the DSS Monitor and Control Subsystem, and signals from the DSS Receiver-Exciter Subsystem. The DRS provides radio science data and wideband radio science data to NOCC, status and configuration data to the DSS Monitor and Control Subsystem, and Programmed Oscillator frequencies to the Receiver-Exciter Subsystem.

E. DSS Monitor and Control Subsystem (DMC)

The DSS Monitor and Control Subsystem provides control data to the DRS, receives and displays DRS status data, and transmits DRS status data to NOCC.

VI. Ground Communications Facility (GCF) Functions

A. High-Speed Data Subsystem (HSDS)

The High-Speed Data Subsystem transmits radio science predictions from the NOCC to the DSS and CTA 21, and radio science data from the DSS to NOCC.

B. GCF Data Records Subsystem (GDR)

The GCF Data Records Subsystem generates and provides to the flight projects radio science Intermediate Data Records (IDRs).

VII. Network Operations Control Center Functions

A. NC Radio Science Subsystem (NRS)

The NC Radio Science Subsystem generates open- and closed-loop radio science DTV graphics displays, and DRS status and configuration displays.

B. NC Display Subsystem (NDS)

The NC Display Subsystem provides NRS generated radio science displays to the Network Operations Control Area (NOCA) and project radio science areas, and provides control data to the NRS.

C. NC Support Subsystem (NSC)

The NC Support Subsystem generates radio science predictions for transmission to the CTA 21 and DSS Radio Science Subsystems.

VIII. Network Functions

A. CTA 21 Radio Science Subsystem (CRS)

The CTA 21 Radio Science Subsystem bandwidth reduces wideband radio science data recorded at the DSS. The CRS receives digital wideband radio science data from the DSS Radio Science Subsystem and provides bandwidth reduced radio science data to the flight projects via wideband radio science Intermediate Data Records (IDRs).

IX. Radio Science System Performance Testing

Radio Science end-to-end system performance testing will be accomplished by comparing open-loop frequency data generated by the Radio Science System to closed-loop frequency data generated by the Tracking System. These tests are described in detail in Ref. 7.

X. Implementation Status

The real-time bandwidth reduction and wideband recording capabilities have been implemented at DSSs 14 and 43, and NOCC. Non-real-time bandwidth reduction capability has been implemented at CTA 21. Major (planned) implementation milestones in the coming year are as follows:

(1) December 1, 1978
Real-time bandwidth reduction at DSS 63.

(2) February 1, 1979
Wideband recording at DSS 63.

(3) May 1, 1979
Four channel open-loop receiving capability at DSS 14, medium bandwidth recording capability at DSSs 14, 43, and 63, and remote spectrum display in NOCC.

References

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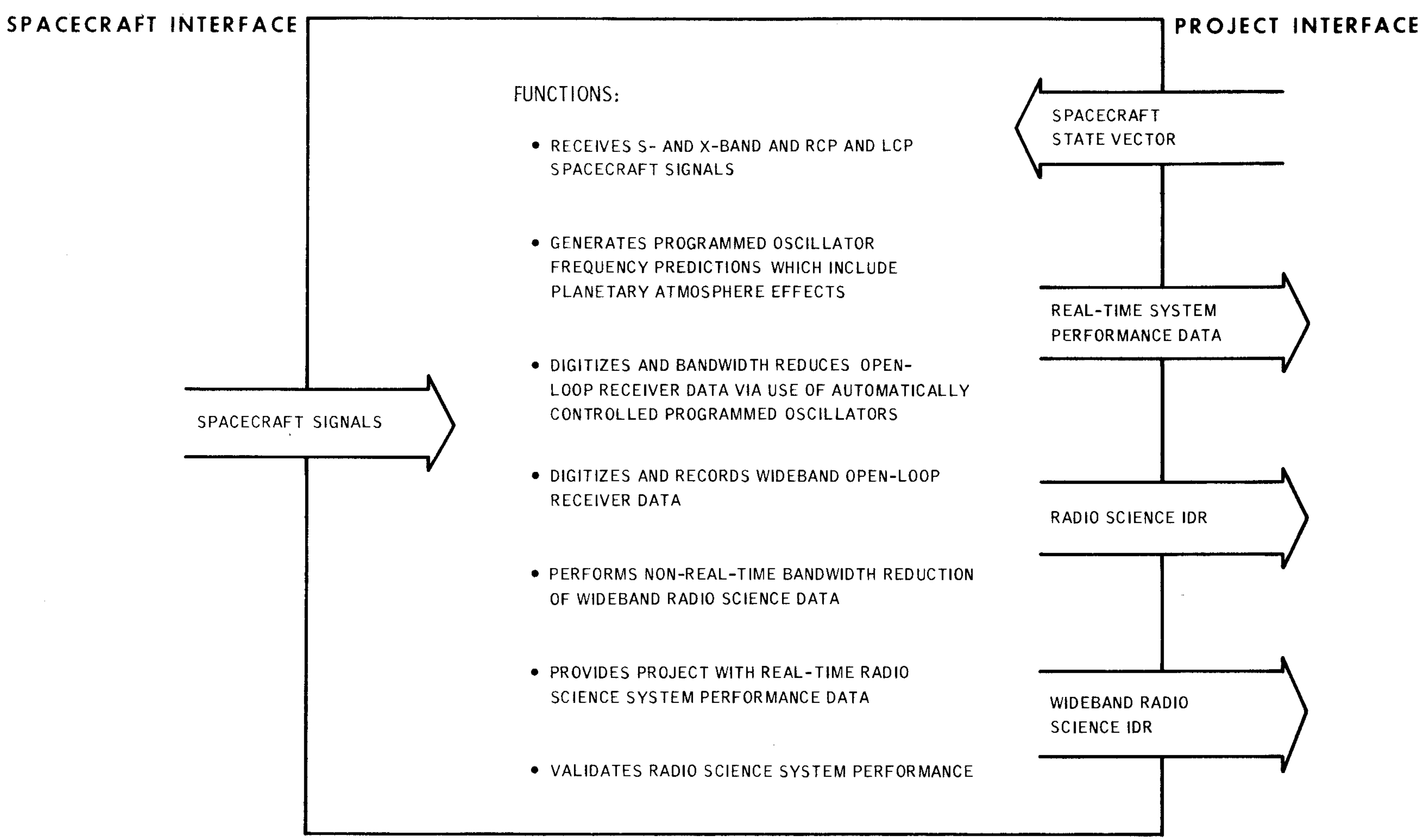

Fig. 1. DSN Radio Science System functions and interfaces

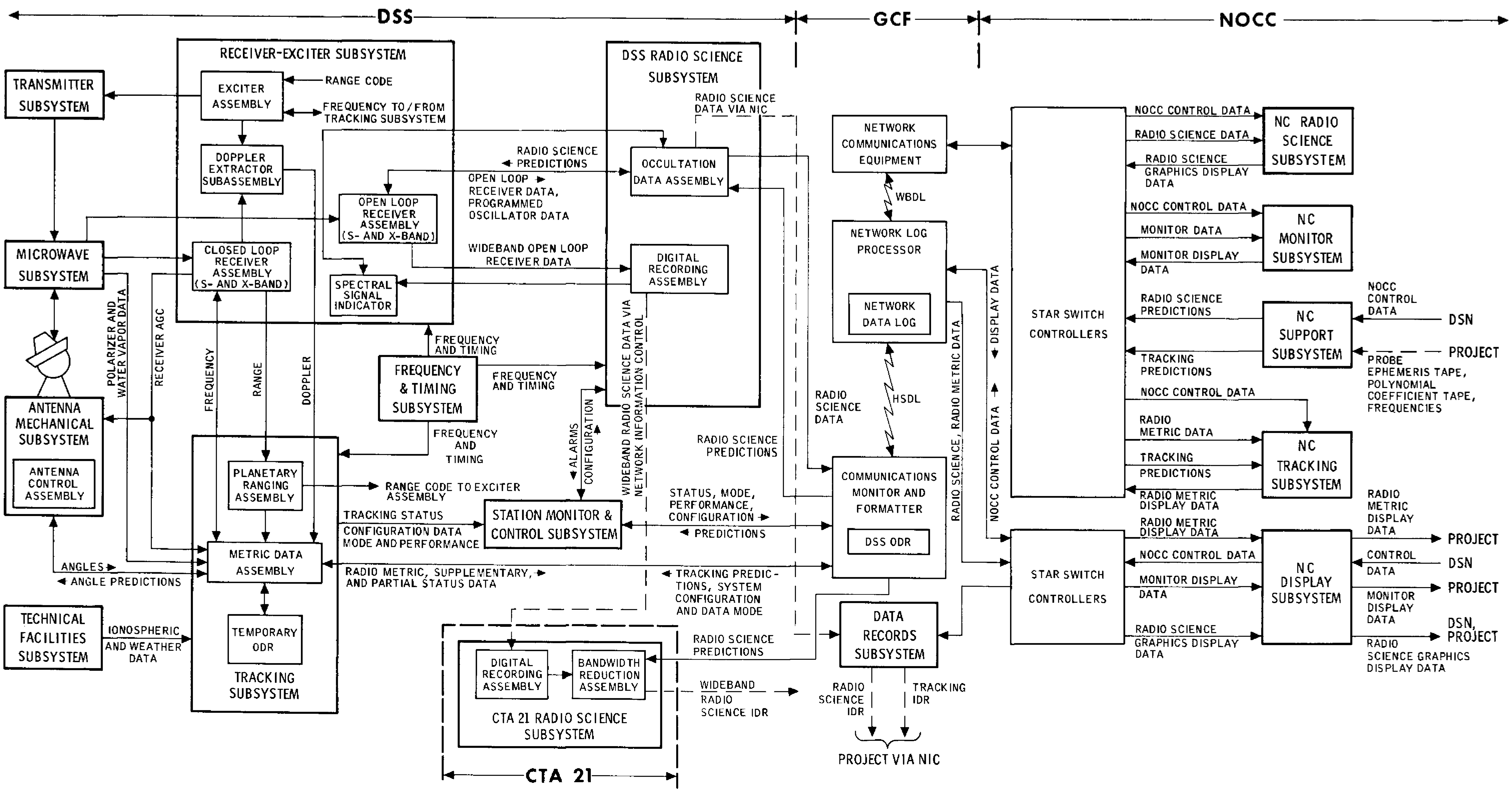

Fig. 2. DSN Radio Science System Mark III-78 functional block diagram

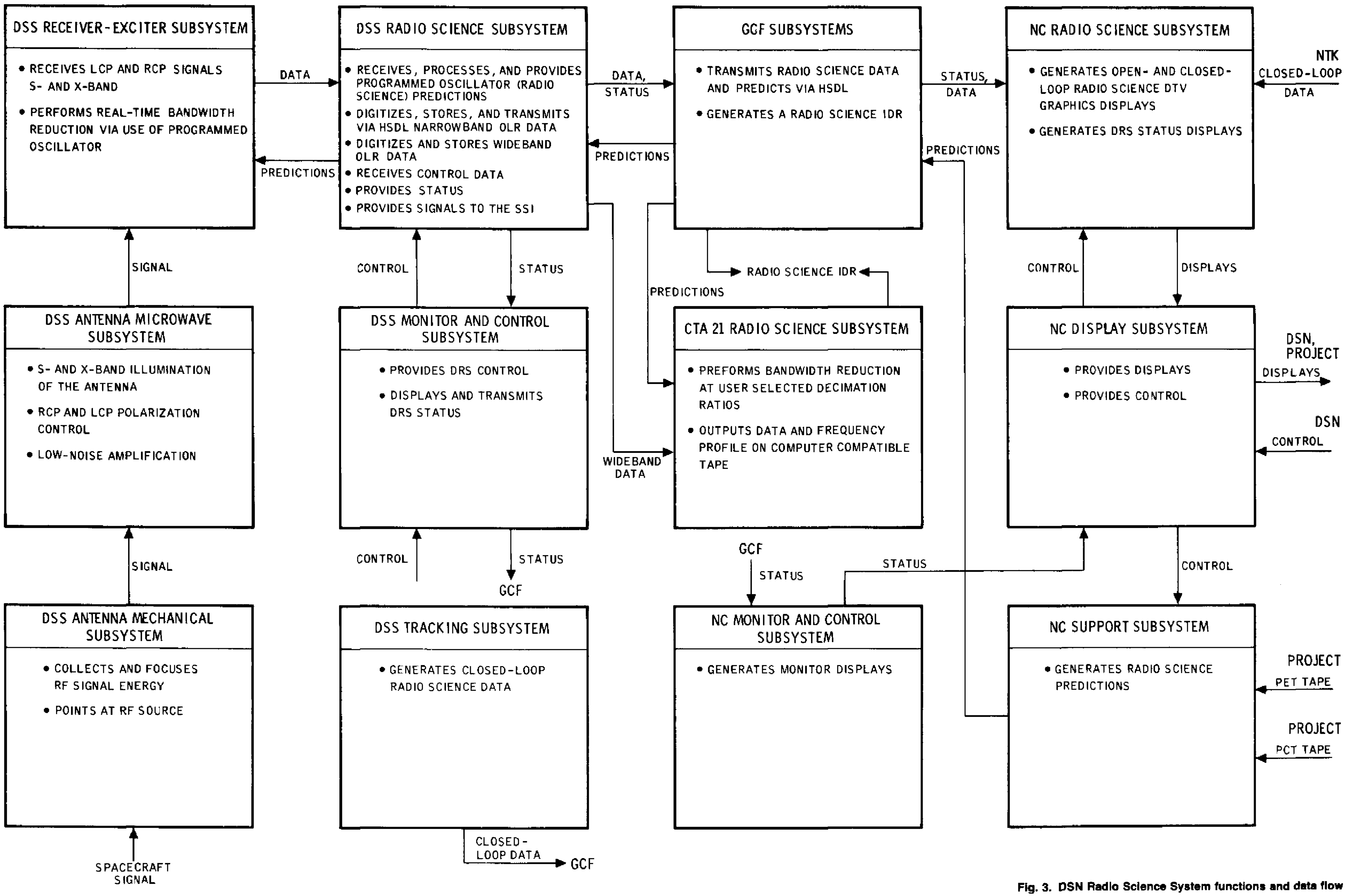

Fig. 3. DSN Radio Science System functions and data flow