DSN Radio Science System Description and Requirements

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A new DSN data system has been created to collect the functions performed by the DSN in support of spacecraft radio science experiments. The system is described and some of its major functions are delineated.

I. Introduction

Until recently the Deep Space Network was functionally organized into five data systems, i.e., Tracking, Telemetry, Command, Test and Training, and Monitor and Control. These systems produced the major data types provided to flight projects, and also embodied all the functions and the equipment, personnel, and resources required to accomplish the functions which collected, processed, and delivered the data to the end user as a service to the flight projects.

The DSN has accepted a new role which is the production of spacecraft radio science data to meet flight project requirements. In the past these data types consisted of the conventional, radio metric data supplied to flight projects for navigation purposes and the use of special, R&D equipment for recording occultation data at certain Deep Space Stations. The requirements for the Voyager and Pioneer Venus missions specify new accuracy requirements on the conventional radio metric data types which exceed the navigational requirements and consequently impose new system requirements on the DSN. Also, the use of operational equipment for the collection of occultation data and other radio science related measurements is being implemented in the Network and must be identified as a new, sixth data system, the DSN Radio Science System, so that the functions which are unique to this System can be identified, and their corresponding requirements developed.

To develop DSN radio science functional requirements, meetings were held with radio scientists from the Voyager and Pioneer Venus Projects. This effort culminated in a review of these requirements on February 4, 1977 for these two flight projects. This article describes the System itself and provides at least an overview of some of the major functional requirements presently being considered for the System.

II. System Description

The requirements review began with a series of definitions; the first was the term "radio science" itself. The area of radio science is usually considered to include the measuring of phenomenon associated with radio wave generation and propagation, which includes those radio signals that originate from natural sources and from spacecraft sources. In the case where natural sources are involved, the object of the experiment is usually to study either the generation process or the propagation, and can be referred to as radio astronomy. Also, natural radio sources are used for very long baseline interferometry (VLBI).

When the spacecraft is the source of the radio signal, the investigation is usually related to phenomenon that occur along the ray path and affect the propagation of the radio wave. Some of these experiments concern celestial mechanics, planetary atmospheres investigations, interplanetary charged particle media investigations, the solar corona, measurements of planetary wind such as those made during the Pioneer Venus entry mission, and investigation of the rings of Saturn by the Voyager occultation. The material presented dealt only with spacecraft radio science and did not include requirements for receiving natural radio source signals. In the future, a presentation on VLBI requirements is planned that will cover the requirements for that system.

The DSN Radio Science System, intended primarily for use with spacecraft radio signals, can be divided into two major areas or data types. The first is radio metric or closed-loop receiver data, which generate doppler and ranging as principal data types. The second area is open-loop received data. The review was further limited to discussing only open-loop requirements. The closed-loop or radio metric data requirements will be the subject of another review in the near future. The reason for concentrating on the open-loop requirements is that these requirements need to be understood rather quickly so that the implementation of the new equipment planned in the DSN, which is dedicated solely to open-loop functions, can proceed. This is not to say that there are not many important open questions in the closed-loop area. However, the issue of the open-loop requirements, as was well documented by the review, could more than occupy time available for discussion in one day.

Figure 1 defines the various bandwidths discussed in the remainder of the review meeting. The scale of the horizontal axis is frequency either in MHz or kHz. The widest bandwidth, titled "allocated bandwidth," is intended to show the deep-space communication band, either at S- or at X-band, and allocated by international agreement, within which deep-space communication is conducted. Noting the break lines on the axis to indicate that somewhere within this 10- to 40-MHz band is an input bandwidth for the DSN Radio Science System that has been assigned to a particular mission. Consequently, the equipment must be able to be tuned anywhere within the allocated bandwidth but needs only to provide the requirements for a particular mission within the "input bandwidth," the bandwidth that the front end of the system must be capable of handling.

Within the input bandwidth is a system "output bandwidth," which implies that the DSN has performed some kind of bandwidth reduction. This bandwidth reduction can either be performed in real time, after the fact in nonreal time, or conceivably both. No requirement has been recognized for both however. This output bandwidth must contain the signal bandwidth that is intended to describe the actual instantaneous bandwidth occupied by the spacecraft signal.

Figure 1 shows the instantaneous bandwidths. The output bandwidth and signal bandwidth may move anywhere within the input bandwidth due to doppler excursions that must not exceed the input bandwidth.

The material presented at the review has taken a fairly novel and unprecedented approach to specify requirements in the purest sense as opposed to design parameters. Frequently, experimenters have stated their needs in terms of an assumed design (e.g., sample rates and bits per sample). If design parameters are used as a starting point, the design is unnecessarily constrained, preventing life-cycle cost analysis, trades, and minimization. The constraints will also very likely inhibit a design that is multimission, since each experimenter is likely to conceive a different design and use somewhat different design parameters to specify his needs. Consequently, the presentation was intended to get back to basic, fundamental requirements and to deal with them further in a top-down approach.

The basic requirements are first, to acquire the radio signal; second, to maintain system linearity through the various steps in handling the signals, namely acquisition, recording, and reproduction; and third, a new commitment by the DSN, to perform bandwidth reduction consistent with the requirements for acquisition and linearity. The reason that the DSN has accepted requirements for bandwidth reduction, either real-time or nonreal-time, is that performing this first step in one facility removes the requirement on each flight project for this first data processing step and, consequently, does not have to be reinvented for each flight project. The reason for this was the overwhelming costs to the Pioneer Venus Orbiter occultation data reduction which, if performed in real time, could vastly reduce the overall agency cost for this experiment. It was recognized that this capability was really a multimission capability. Minimization of system life-cycle costs is also a first-level requirement.

Figures 2 and 3 show functions and major system interfaces at the Deep Space Stations, CTA-21, and the Network Operations Control Center (NOCC). The Transmitter and Frequency & Timing Subsystems form part of the system since, even though data is being received open loop, an uplink may still have been established in at least some cases. Consequently, system requirements need to be levied on these subsystems.

Two new subsystems, the DSS Radio Science Subsystem (DRS) and the CTA-21 Radio Science Subsystem (CRS) were proposed as a means of identifying the equipment at the stations, and at CTA-21, which is dedicated to radio science data acquisition and processing. Functions of these subsystems are shown in Fig. 4.

Radio frequency requirements were then discussed (see Table 1). The need for signal presence indication by all projects was strongly voiced. The requirement is not only for an indicator for the station operator, but also for a signal presence indication within the radio science Mission Support Area. This latter requirement will require some study since a design that minimizes system life-cycle costs may not be feasible.

The signal power and system noise temperature measurements were also discussed. The data are required as calibrations of the system rather than experimental observational data.

Data handling requirements were presented for both real and nonreal-time bandwidth reduction. The requirement for backup recording was discussed at length. The first few occultations of an orbiter are extremely important since the uncertainty in the doppler signature for these first few events will limit the amount of real-time bandwidth reduction that can be performed until the signature is well enough in hand so that the remaining occultations can be performed with more bandwidth reduction to reduce nonreal-time processing costs.

Suitable backup recording will be provided for orbiters as well as flyby missions.

In the process of performing bandwidth reduction, linear ramps are used to sweep the local oscillator frequency to track out some of the doppler excursion. It is required that the history of the ramps used be provided to the experimenters. In addition, the deviation of the mixer frequency from the nominal model must be less than 0.005 Hz. The programmed oscillator will deliver this accuracy even for extremely high doppler rates, one kHz per second, which is greater than any anticipated.

Table 2 provides more detailed requirements; it addresses the subject of the characteristics of the spacecraft signal, the system requirements on the input bandwidth previously defined, and the requirements on the output bandwidth (after bandwidth reduction process).

By developing Table 2 and filling in the requirements, the most stringent requirement in each of the four cases can be identified. These four cases are the Pioneer Venus Entry and Orbiter radio science experiments, and the Jupiter and Saturn encounters by Voyager. When the most stringent requirement in any one line item is found, then a multimission system can be designed to meet that requirement and also satisfy the less stringent requirement at the same time. Missing from these charts are the requirements for the Pioneer 11 occultation of Saturn, which occurs in 1979. These requirements will be included prior to publication of the functional requirements document.

In Table 2 where an S is followed by a diagonal slant and an X, the corresponding numbers refer to the S-band or the X-band requirement.

In the input bandwidth requirements, constraints are listed that include the range over which the doppler can cause the input frequency to shift, the uncertainty in the doppler shift, and the spectral broadening of the carrier, which is fairly pronounced for the rings of Saturn occultation.

In Table 2 are two items titled "Linearity." The first one, under the phase response across the system input band, is for phase linearity and impacts the work required for data reduction since nonlinear phase requires more calibration. The other Linearity entry refers to harmonic distortions (which is not believed to be a problem) and allowable saturation. This latter item has not been developed fully enough to show the specific items of importance and the units or the quantities that need specification. However, it was included since it is the subject for further study and may or may not survive to be incorporated in the requirements documents.

The requirements of the bandwidth reduction process are also outlined in Table 2. The constraints on the real-time bandwidth reduction include Doppler shift uncertainty, spectral broadening, and time of onset of the doppler shift. Real-time bandwidth reduction is limited by the a priori knowledge of these parameters. These requirements will be extended to the Jupiter encounters since real-time bandwidth reduction for this event appears to be quite feasible.

Also in Table 2 nonreal-time reduction is discussed. Here the constraints are not as severe since the data has been recorded and more than one attempt can be made at bandwidth reduction. Nonreal-time bandwidth reduction will probably be required for the Saturn encounter since the real-time system will not be capable of accommodating the bandwidths for this event.

The general system requirements were also discussed and the requirement for minimal life-cycle cost was modified to show that for the temporary installations for the Pioneer Venus entry mission, the normal 10-year life cycle will not be used. Instead, the actual time that the equipment is maintained in the Network will be used for the life-cycle period.

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Table 1. Radio frequency requirements

Parameter	Pioneer Venus 78		Voyager	
	Entry	Orbiter	Jupiter encounter	Saturn encounter
Frequency bands	S	S and X	S and X	S and X
Polarization	RCP	RCP	RCP or LCP	RCP and LCP
Signal presence indicator	Required	Required	Required	Required
Signal power measurement			Required	Required
System noise temperature measurement			Required	Required

Table 2. Open-loop requirements

Requirement	Pioneer Venus 78		Voyager	
	Entry	Orbiter	Jupiter encounter	Saturn encounter
Signal parameters				
Amplitude measurement				
Precision			0.1 dB over any 10-dB range 0.5 dB over any 40-dB range	
Calibration			1.5 dB	1.5 dB
Phase measurement				
Absolute phase at receiver input frequency, S/X			36 deg/132 deg	
Differential phase				
Across band, S/X	1 deg/not applicable (NA)			
Between S- and X-band (S-3/11 X)		To be supplied (TBS)	10 deg (1 deg design goal)	
Between receivers tuned to same frequency at one DSS				1 deg
System				
System input bandwidth, S/X	2 MHz/NA	TBS	600 kHz/2 MHz	600 kHz/2 MHz
Constraints				
Doppler shift range	TBS	TBS	TBS	TBS
Doppler uncertainty	TBS	TBS	TBS	TBS
Spectral broadening			1 kHz	20 kHz
Placement of system bandwidth within total allocated band	Adjustable within entire S- and X-band allocation			
Amplitude response across system input bandwidth				
Calibration			0.2·dB	0.2 dB
Stability (over 1 hour)			0.2 dB	0.2 dB
Uniformity			±3 dB (±1 dB desired)	
Phase response across system input bandwidth				
Calibration				
Real-time, S/X				
Nonreal-time, S/X	0.5 deg/NA		0.5 deg/0.5 deg	
Stability				
Real-time, S/X				
Nonreal-time, S/X	0.5 deg/NA		0.5 deg/0.5 deg	
Linearity				
System noise spectral density				
Calibration precision			1%	1%
Accuracy (1 sample/10 s)			2%	2%
Stability			10%	10%
Amplitude dynamic range				
Linearity				

Table 2 (contd)

Requirement	Pioneer Venus 78		Voyager	
	Entry	Orbiter	Jupiter encounter	Saturn encounter
Bandwidth reduction				
Real-time bandwidth reduction				
Input bandwidth, S/X	NA	80 kHz/300 kHz	TBS	NA
Constraints				
Doppler uncertainty				
Spectral broadening				
Time of onset				
Amplitude degradation	NA	< 0.5 dB	TBS	NA
Phase degradation				
Absolute, S/X	NA	< 5 deg/< 20 deg	TBS	NA
Differential				
Output bandwidth	NA	1 kHz to 40 kHz	TBS	NA
Nonreal-time bandwidth reduction				
Input bandwidth	2 MHz	NA	NA	TBS
Amplitude degradation	<2 dB	NA	NA	TBS
Phase degradation				
Absolute	< 2 deg	NA	NA	TBS
Differential between signals on one recording	< 5 deg	NA	NA	TBS
Output bandwidth	1 kHz to 10 kHz	NA	NA	TBS

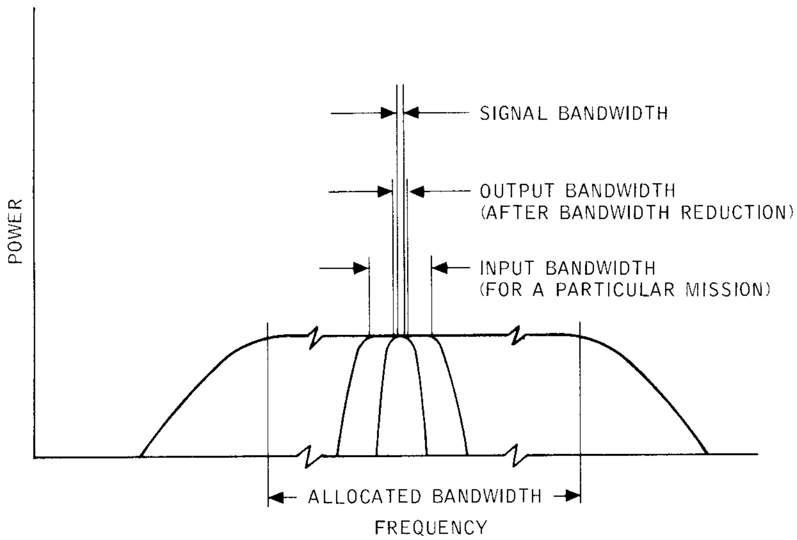

Fig. 1. Bandwidth definitions

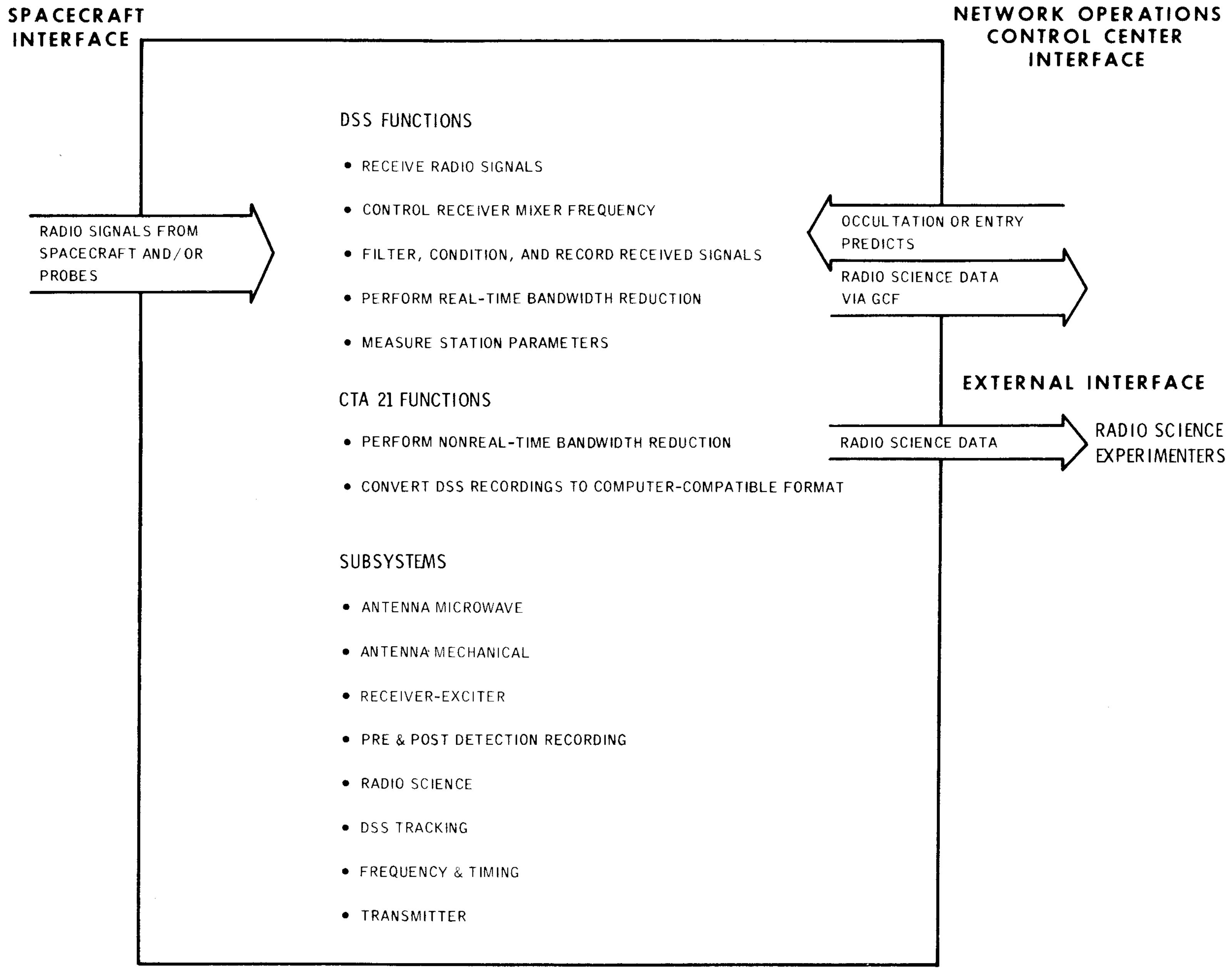

Fig. 2. DSS and CTA 21 open-loop functions and interfaces

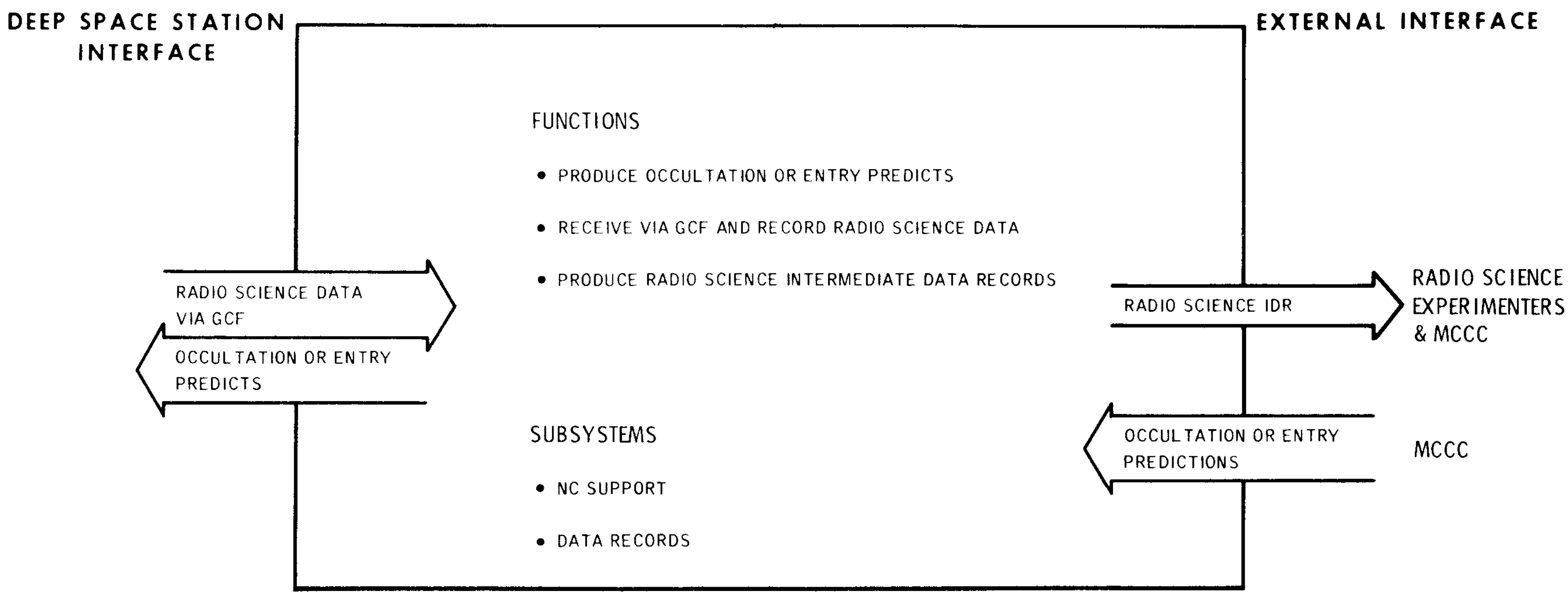

Fig. 3. NOCC functions and interfaces

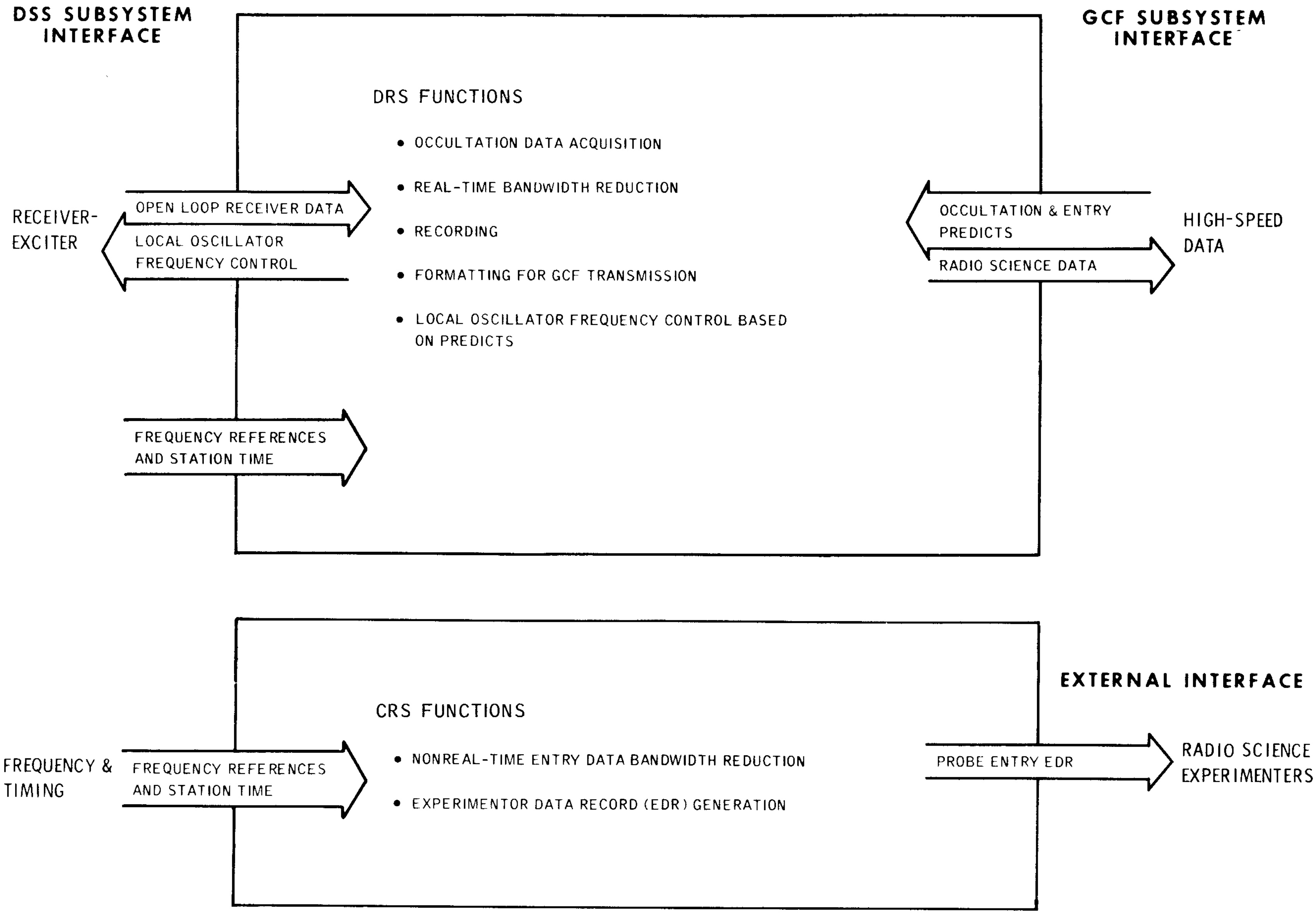

Fig. 4. Radio science subsystems functions and interfaces