The DSN VLBI System, Mark I-79

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The DSN VLBI System has been established as a new Network System. This article describes the system and discusses the system functional requirements.

I. Introduction

Very long baseline interferometry is a new capability being implemented in the Network to support flight project navigation requirements and provide station frequency standard stability monitoring of sufficient accuracy to effectively validate hydrogen maser performance.

In order to manage this major new implementation, the DSN VLBI System was established, and a review of the system functional requirements was held on 24 February 1978. A description of the system and the phases of its implementation follow.

II. Definition

Very long baseline interferometry is a method of measuring the time of arrival of a radio signal at two locations very distant from each other on the Earth's surface. From the measurement of difference in time of arrival, the position of the radio source and/or several other parameters of the problem can be determined. These other parameters include Universal Time One (UT1) (the instantaneous rotational angle of the Earth), polar motion, the relative position of the two stations, and the time offset and rate of change of the clocks at the two stations.

III. System Characteristics

The DSN VLBI System can be characterized as a new implementation in the 64-meter subnet and the Network Operations and Control Center. The implementation modifies existing station equipment; implementation of the 34-meter subnet is planned later (e.g., the multimission open-loop receivers, the occultation data assembly, and the digital recorder assembly). New hardware and software will be implemented in the Network Data Processing Area at JPL Pasadena.

VLBI requires at least two stations and a central facility for correlation and estimation processors.

The station diagram consists of an antenna pointed at the signal being used to make the measurement, low-noise microwave amplifiers, and receivers for receiving the signal and converting it to zero offset. At this point, analog-to-digital converters and multiplexers convert the data to digital form and direct them to the appropriate device for recording. The diagrams show various implementation phases. These are Block 1 (Phase 1, 2, and 3) and Block 2.

Block 1 handles data differently than does Block 2. As shown in Fig. 1, the Block 1 system records the data on computer-compatible tape for playback and transmission to the Ground Communications Facility (GCF) wideband data lines.

The DSS configuration for Block 1, Phase 1 is shown in Fig. 3. GCF transmission capability will be achieved by July 1979 by employing the Block IV receiver and DSN Advanced System IF to video converters to provide data to the DSS Radio Science Subsystem. By July 1980, the multimission open-loop receiver will be transferred. This configuration (Fig. 4) is called Block 1, Phase 2. The Block 1 configuration is completed with Phase 3 by the addition of the Block 1 processor (Fig. 6).

The Block 2 interferometer (Fig. 2) requires such large volumes of data and is used so relatively infrequently that the data are recorded on a digital instrumentation recorder, the digital recorder assembly. These tapes are then shipped or transported to the correlation facility. Figure 3 shows the DSS configuration with the Block 3 Monitor and Control Subsystem, which centralizes the collection of configuration and calibration data.

The correlation facilities are also divided by Blocks 1 and 2 in Figs. 1 and 2. These two processor facilities employ the same design and equipment, special-purpose hardware for correlation, control computer, and correlation software. However, as before, the method of providing data to the correlator is significantly different for Block 1 than for Block 2. In the case of Block 1, the computer edits the data received over wideband data lines and provides two serial streams of bits representing the information recorded at the two separate stations. These data are accepted by the correlator and the cross-correlation is performed. This facility serves only DSN operational functions, and consequently, will be located in the Network Data Processing Area (NDPA).

In the case of Block 2, the same correlator design is employed; however, the data are provided by playback from the digital recorder assembly. This facility will be located outside of the Network Operations Control Center (NOCC) at another location within JPL, Pasadena.

IV. DSS Configuration

The DSS configuration (Figs. 3, 4, and 5) includes the portions of the Ground Communications Facility (GCF) that exist at the station. The configuration at both VLBI stations is identical.

The signal is received and passes through the Antenna Microwave Subsystem. In this subsystem, the phase calibrator tones generated by the Receiver-Exciter Subsystem are injected as high up, as near the front end, as possible. These tones provide a calibration of any drift between the injection point and the analog-to-digital converters. The Antenna Microwave Subsystem also provides water vapor radiometer data to the DSS Monitor and Control Subsystem for logging.

The signal next passes to the Receiver-Exciter Subsystem, where the signal is converted from RF to 300 MHz IF. The signal is then divided into eight IF-to-video converters. These IF converters are in turn interfaced to the A-to-D converters in the DSS Radio Science Subsystem. At this point the data either go through a multiplexer to the occultation data assembly for recording for Block 1 functions or the digital recording assembly for Block 2 functions. After the observation, if Block 1 configuration is in use, the data are played back from the real-time record, blocked up in GCF blocks, and provided to the station wideband data assembly for transmission. If Block 2 functions are being used, the recording on the digital recording assembly is shipped back to the correlation facility.

The Monitor and Control Subsystem has the functions of configuring the stations and collecting various calibration and configuration data. These calibration and configuration data are provided to the digital recording assembly for logging and transmission over wideband lines with the actual VLBI data or they are provided over high-speed lines for monitoring purposes. If Block 2 data are being recorded, then the computer recorder on the occultation data assembly is used for collecting the calibration and configuration data and providing them with the digital recording assembly tape. The Monitor and Control also receives predicts from the Network Operations and Control Center, which are disseminated to the appropriate subsystems, including Antenna Mechanical, for pointing the antenna.

V. Ground Communications Facility and Network Operations and Control Center Configurations

Figures 6 and 7 show the entire GCF, including the station portion and the NOCC configuration. The NOCC configuration is further divided between the equipment in the network data processing terminal and the network data processing area. The network data log provided by the GCF can be used for collecting the VLBI and the calibration and configuration data for Block 1. The VLBI real-time monitor collects configuration and calibration data to verify the performance of the network in real time.

The VLBI data are replayed and metered out to the VLBI correlator assembly that is under the control of the VLBI processor assembly, a computer with the correlation program running in it. The two data streams are cross-correlated and the resulting fringes are recorded by the VLBI processor assembly. After the correlation process, the post-correlation tape is replayed through the same computer and post-correlation and estimation processing are performed. The final product is clock sync, UT1, the polar motion.

The Block 2 correlator does not employ the GCF transmission, and consequently, the tapes of the digital recording assembly and occultation data assembly are brought to this facility, where the correlation process is quite similar using the same design correlator and identical software except for additional features and functions required of Block 2 over Block 1 capability.

The Display Subsystem provides station configuration data to the network operations and, from this area, controls are sent to the station. In the Support Subsystem, the VLBI predicts program is used to generate the sequence of events for the station, including the antenna pointing angles, which are then transmitted through GCF for Blocks 1 and 2 data acquisition.

VI. Block 2 VLBI Future Requirements

The future of the Block 2 VLBI processor beyond the DSN requirements for radio source catalog maintenance are being studied and defined. The evolutionary growth of this facility, so that it can serve the radio astronomy community and the National Geodetic Survey requirements as well as the DSN needs, is briefly described.

Table 1 shows the evolutionary steps for the processor for radio astronomy applications. The columns list the number of stations or radio telescopes which can be simultaneously correlated, the number of BWS channels that can be correlated in parallel, and finally, the need dates for the expanded capability. The first step would be the two-station, 8-channel correlator capability. This capability employs digital instrumentation recorders with 24 tracks, which are capable of extension to 28 tracks. In order to reduce tape usage, the eight BWS channels are blocked up after A and D conversion and written across the 24 tracks. This requires deskewing upon playback.

The first step in increasing capability would be to add Mark II compatibility for system validation and for processing of Mark II tapes, which will still be in use when the processor becomes operational. The need for this Mark II capability could be as early as 1979, even though the processor is not operational at that time. At the same time, capability should be provided to read eight tracks of data directly off the tape and provide each track to the respective correlator channel so that the processor would be capable of performing Mark III processing with multiple passes through the tape. The capability for parallel reading without deskewing could also be used as early as 1979.

The second step would be either to expand to three stations and three baselines with eight channels or expand the two telescope processors to 28 channels, all of which would be read directly off independent tracks of the 28-track recorder. The expansion from eight to 28 tracks increases processor thruput by a factor of 3.5 if all 28 tracks are parallel BWS channel recordings. On the other hand, going from two to three stations increases thruput by a factor of 3 (three baselines versus one). This latter step is considerably more expensive, since an additional tape drive is required.

By 1981, a third step could be justified in terms of the needs of the radio astronomy community. This third step would be to provide three baseline correlators with 28 BWS channels per station. At this time, a decision point is reached. For the ultimate capability, the number of radio telescopes in the radio astronomy network needs to be identified. Presently, there are four, perhaps five, radio telescopes in the United States which will shortly be equipped with Mark III instrumentation. By 1981, we should be able to say if the number of radio telescopes in the Network Users Group will increase to eight or possibly ten.

Based on the ultimate number of potential telescopes, the decision can be made to proceed to increase the processor to four, possibly five, stations, leaving room for ultimate expansion to the final number. At this point also, the existing hardware correlator assembly probably needs to be repackaged to make room available for cabling to interconnect all the other station correlators so that in Step 4, when expansion is made to four or five telescopes, the repackaging would leave enough room for additional cabling and modules to allow all the necessary cross-correlations to be performed in parallel.

The expansion in BWS channels beyond 28 may also be required, but this decision can probably be made later. The increase in hardware for expansion in channels goes by n, while the increase for expansion in telescope goes by n^2, and consequently the ultimate number of stations to be processed simultaneously is a more critical decision than the ultimate number of BWS channels.

Table 2 shows the growth of processor capability required primarily for geodetic but also for geodynamic (UT1-polar motion) applications. Some differences between these requirements and the astronomy requirements are:

(1) BWS channel widths for radio astronomy range from 0.125 MHz to 2 MHz (possibly both narrower and

wider widths will be required), while geodesy requires 2 MHz to 25 MHz channel bandwidth.

(2) Radio astronomy requires independent track recording, while geodesy requires maximum tape efficiency while keeping the ability to speed up or slow down the data rate during the observation, depending on the source strength. This requires blocking the data and writing across all tracks regardless of the tape speed.

The immediate impact of these Block 2 processor plans is the design requirement to be able to expand the correlator to multiple baseline. The Block 1 processor is not affected since it will remain a two-station device.

Table 1. Radio astronomy applications

Step	Number of telescopes	Number of BWS channels	Date needed
0	2	8 (blocked and written over 24 tracks)	
1a		(Mark II compat.)	1979
1b	2	8 (parallel, each track recorded independently)	1979
2 }	3	8	
2 }	2	28	
3	3	28	1981
(Decision points for ultimate number of telescopes)			
4	4 (5?)	28	1983

Table 2. Geodetic and/or geodynamic applications

Step	Number of antennas	Number of BWS channels	BWS channel width	Date needed
1	2	2	2 – 25 MHz	1981
2	2	6	2 – 8 MHz	1981
3	6	6	2 – 8 MHz	1982/3

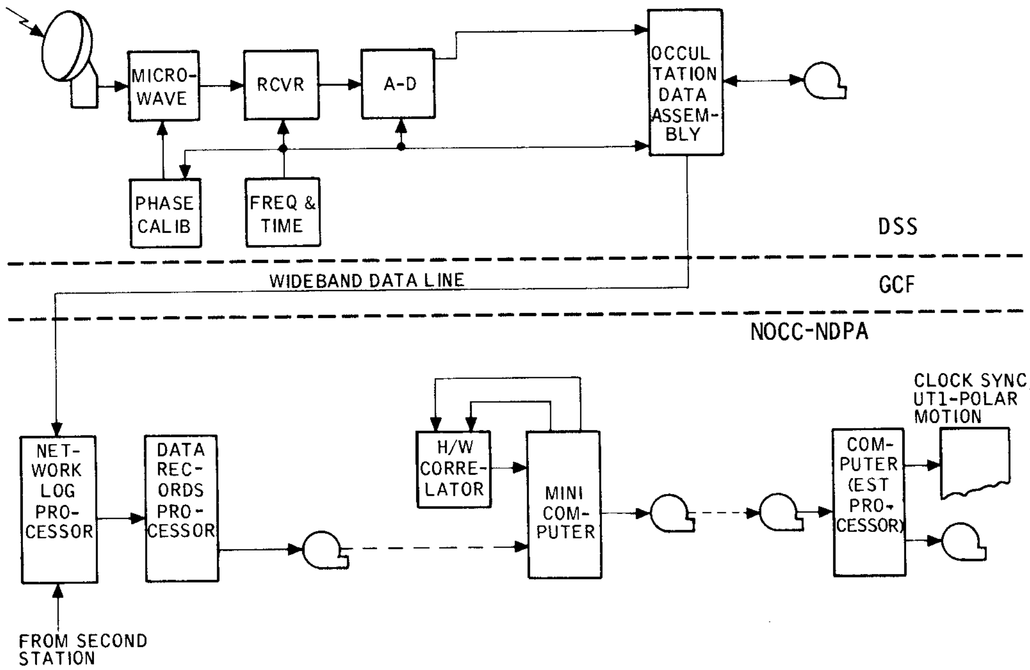

Fig. 1. Block 1 configuration

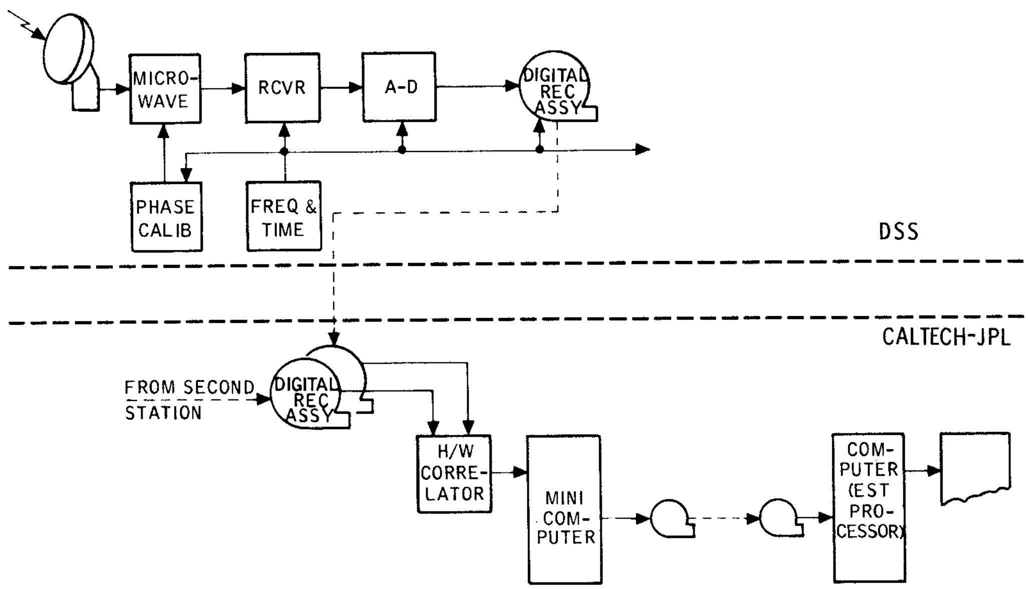

Fig. 2. Block 2 configuration

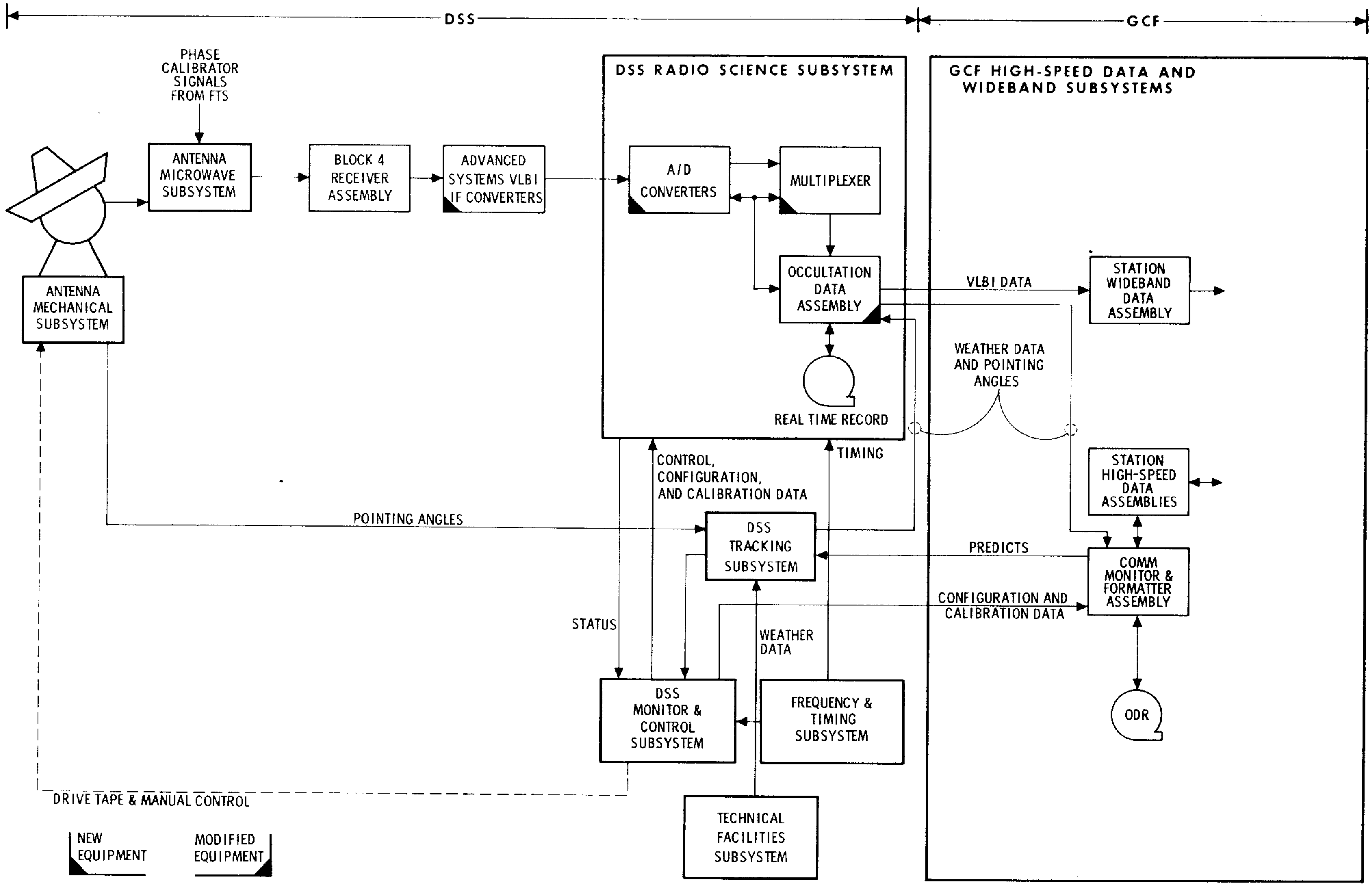

Fig. 3. DSS-GCF block diagram, Block 1, Phase 1

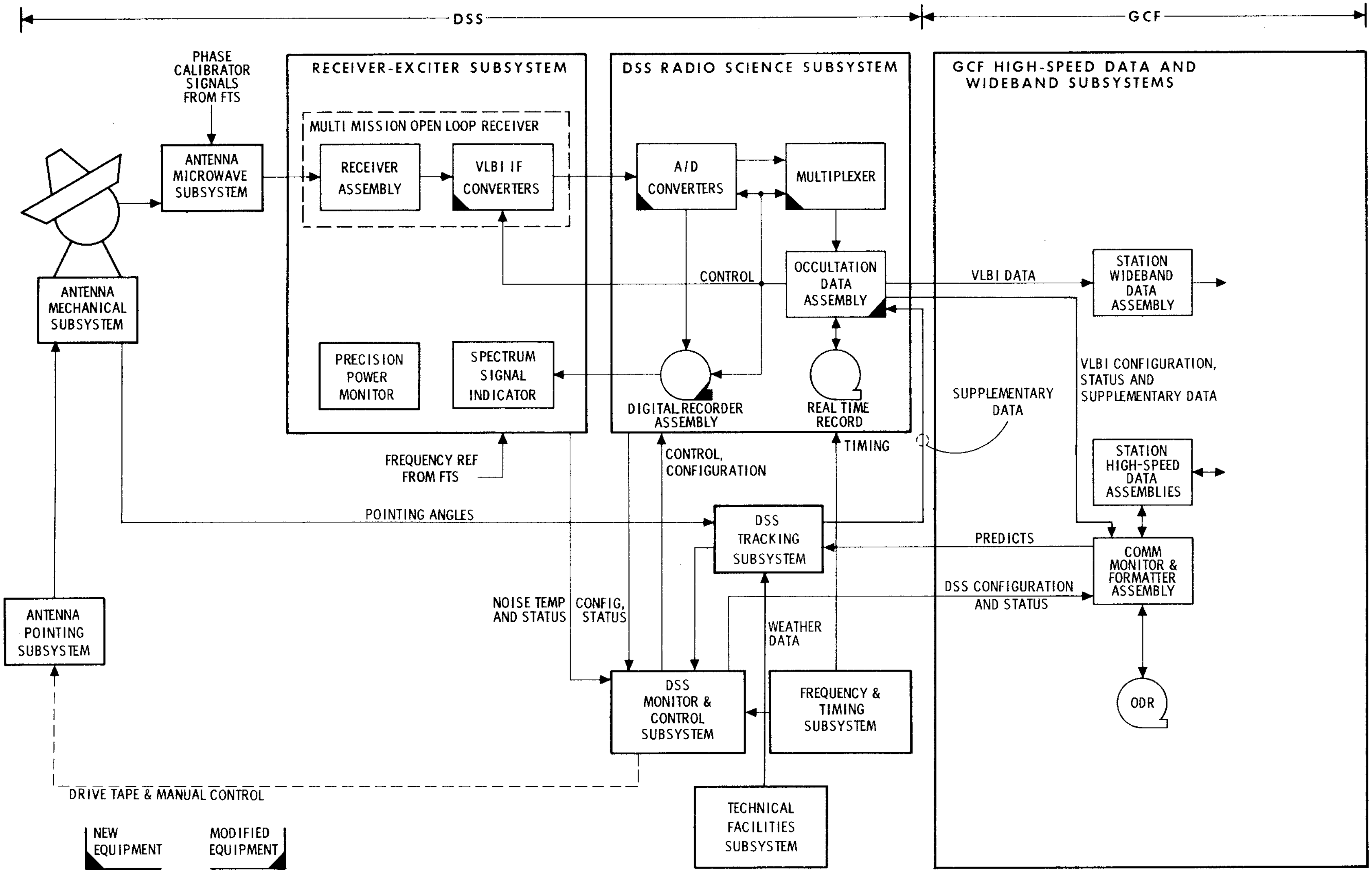

Fig. 4. DSS-GCF block diagram, Block 1 and 2 VLBI configuration before Block 3 DMC

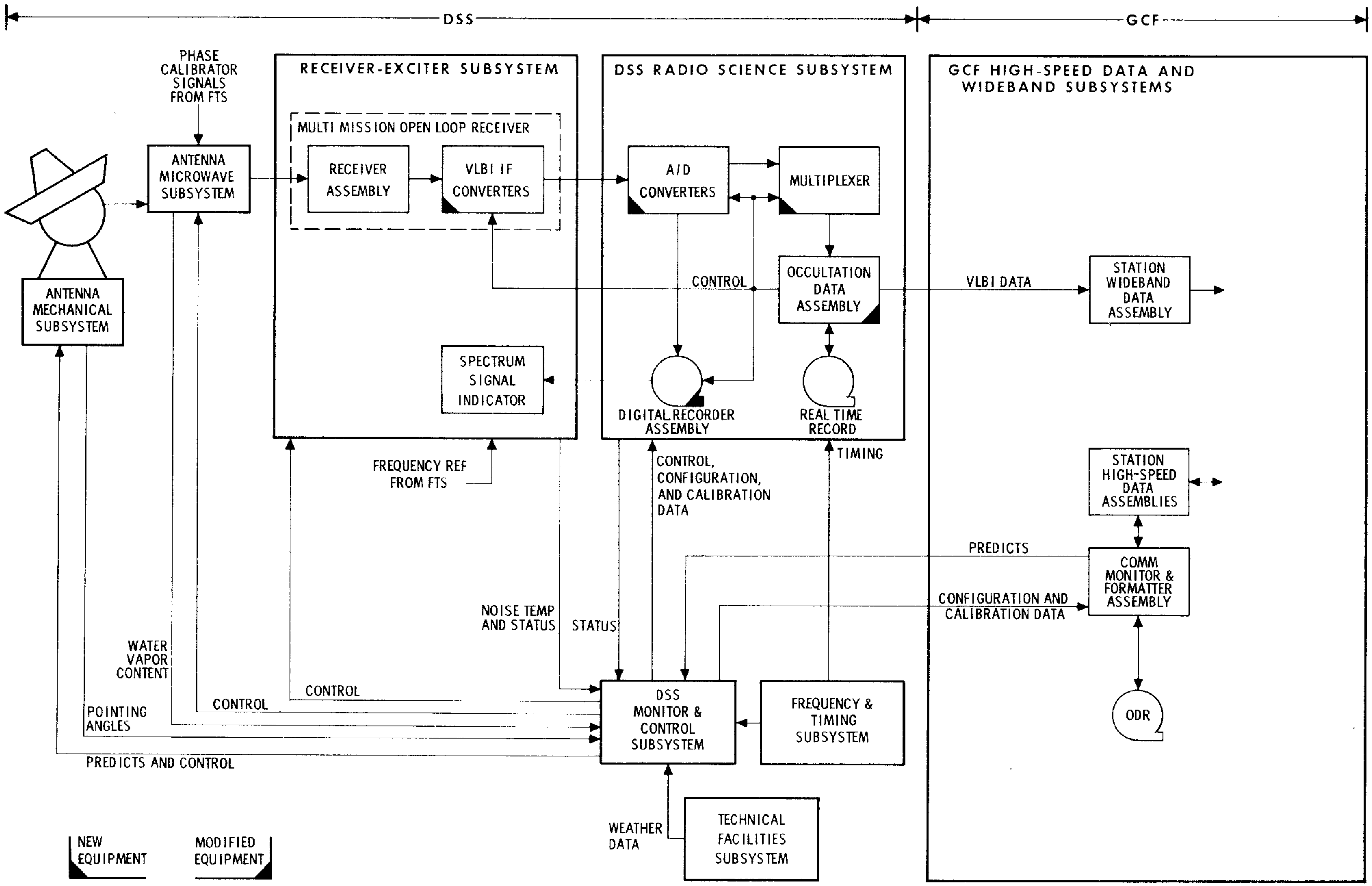

Fig. 5. DSS-GCF block diagram, with Block 3 DMC

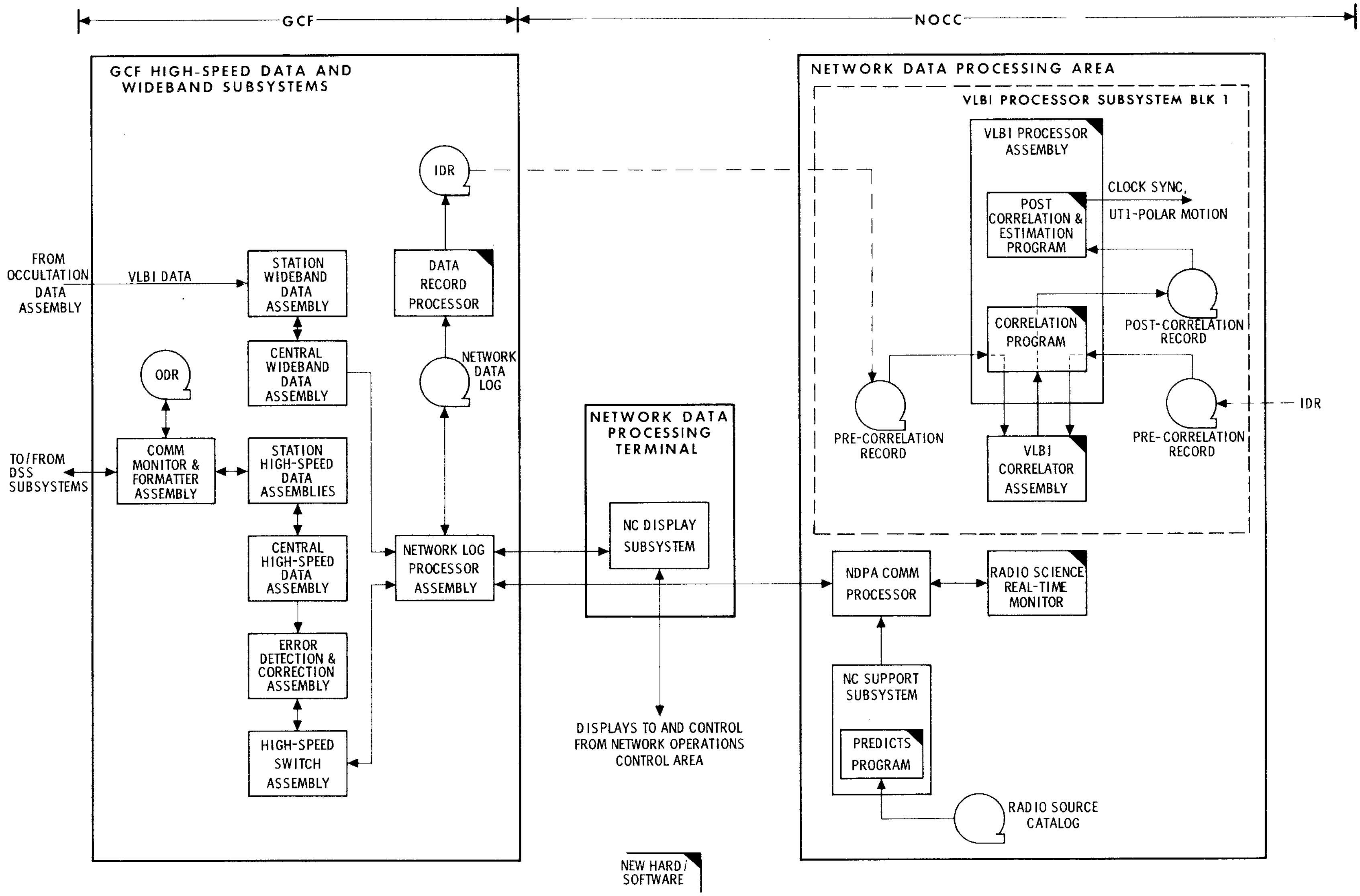

Fig. 6. GCF-NOCC block diagram, Block 1 processor

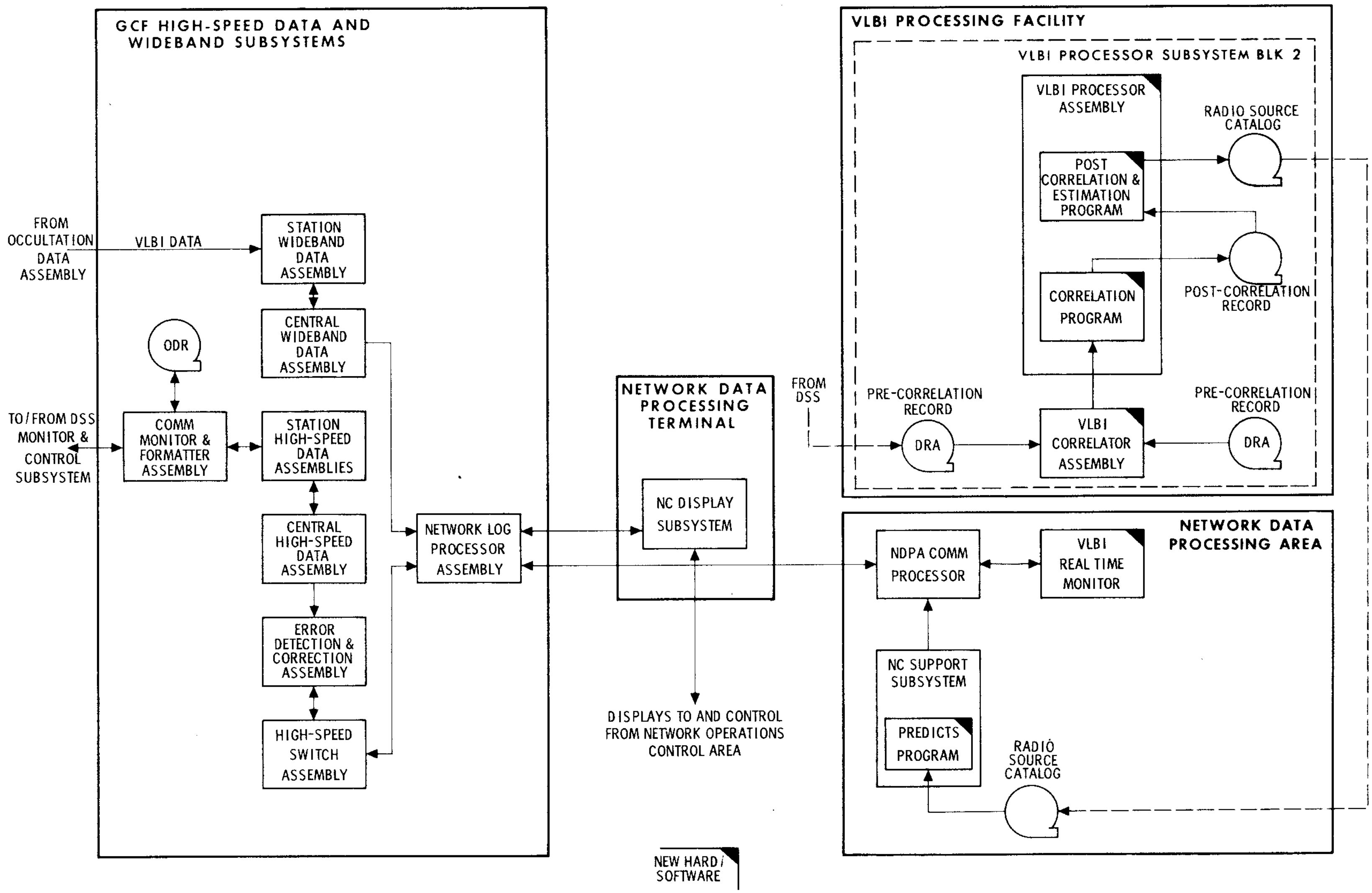

Fig. 7. GCF-NOCC block diagram, Block 2 processor