SPACE SHUTTLE PAYLOAD INTERROGATOR

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ABSTRACT

The payload interrogator (PI) for communication between the orbiter and detached DOD/NASA payloads is described. Salient features of the PI are discussed, including its capabilities and limitations.

For compatible operation in the orbiter's electromagnetic environment, the PI is equipped with a dual triplexer assembly. A limiter diode circuitry allows the PI to be safely exposed to high effective isotropic radiated power (EIRP) payloads at close range. A dual conversion PM short-loop receiver has a sufficient dynamic range for undistorted reception of near and distant payload signals. The PI acquires signals from compatible transponders within ±112 kHz of its center frequency. The center frequency can be set at 125-kHz steps for the spaceflight tracking and data network (STDN), 370 kHz for the deep space network (DSN), and 5 MHz for the space satellite control facility (SCF). The PI has false-lock-on protection capability to accommodate reliable acquisition of standard NASA and DOD payload transponders. The wideband phase detector demodulates baseband information, and by the use of AGC, provides three independent constant-level data outputs. Each of the 861 frequency channels is generated instantaneously by the receiver and transmitter synthesizers. The PM-modulated RF carrier transfers command information to the detached payloads. The RF output power is adjustable to assure reliable communication with payloads of various sensitivities (G/T). A wide and narrow carrier sweep capability is provided to accommodate any frequency uncertainty of payloads. The transmitter has an ON-OFF modulation control to avoid false-lock-on problems. The PSP command input modulation index is fixed, while the modulation index for the PS is a function of the input voltage. The PI receiver's complementary transmit channels are spaced 115 kHz for STDN, 341 kHz for DSN, and 4 MHz for SCF. The PI is compatible with the orbiter's configuration control equipment—GCIL, the PSP and PS for I/O data transfer, the Ku-band subsystem for "bent pipe" baseband telemetry transmission to ground, the MDM for the PI's telemetry transfer, and the RHCP/LHCP antenna

subsystem. Overall PI capabilities and limitations for communication with unique payloads are also presented.

INTRODUCTION

The Space Shuttle orbiter is equipped with a dedicated RF subsystem for two-way communications between the orbiter and detached payloads. Studies leading to the selection, design, and implementation were conducted in the early stages of the Space Shuttle development program. Consideration was given to NASA/DOD mission-dedicated payload equipments. There were approaches involving modular design, and a limited 40-channel-maximum configuration was a serious contender. However, in view of the fact that the Space Shuttle will handle the majority of payloads for the next decade, a maximum-capability, quick-reaction, NASA/DOD-integrated, RF mini-ground-station was selected for the orbiter. This configuration, in conjunction with the applicable on-board equipment, will support two major users (NASA and DOD), and it also has sufficient flexibility to support unique nonstandard payloads from private industry and foreign countries.

FUNCTIONS OF THE PAYLOAD INTERROGATOR

The primary function of the PI is to provide two-way duplex communications between the orbiter and the detached payloads. This allows the orbiter to control and monitor the deployed and/or to-be-retrieved cargo.

GENERAL DESCRIPTION

The PI consists of a dual triplexer, a receiver, a baseband, a synthesizer, a transmitter, and the necessary interface circuitry. A brief description of these major components follows.

Triplexer Assembly—The triplexer assembly comprises two triplexers and four coaxial switches to assure compatible, interference-free duplex operation in the orbiter's electromagnetic environment, an RF-limiting diode for receiver front-end protection, and an RF wideband preamplifier to provide sufficient signal level to the receiver mixer.

Receiver—The PI dual-conversion, PM short-loop receiver has a dynamic range of 120 dB for far and near range undistorted payload signal reception. It will acquire signals within ±112 kHz of its center frequency, which is selectable in steps of 125 kHz for STDN, 370 kHz for DSN, and 5 MHz for SCF. The receiver has also a false lock-on protection feature to provide reliable reception of telemetry links from standard NASA and DOD payloads. It acquires, with 0.9 probability, a -122.5 dBm minimum carrier signal.

Baseband—The wideband phase-detector-demodulated baseband information (up to 4.3-MHz bandwidth) is filtered and AGCed by the baseband channel for delivery to three independent outputs: the Ku-band, the PSP, and the PS. The PSP and the PS outputs are mutually exclusive.

Synthesizer—The 861 frequency channels of the PI are generated instantaneously by the receiver and transmitter synthesizers, which use phase-lock loops with programmable dividers in the feedback circuits.

Transmitter—To assure reliable communication with a great range of G/T payloads, the RF output power is adjustable. In addition, the transmitter is equipped with a wide and narrow carrier sweep range and with a modulation ON-OFF function. The PSP command input modulation index is fixed; whereas the modulation index for the PS is a function of the input voltage.

Interface Circuitry—The PI has compatible, independent I/O interfaces with the payload signal processor (PSP) and the payload station (PS). For the Ku-band "bent pipe," only an output is provided. All controls for the PI are discretes coming from the GCIL, while health and status telemetry is fed to the MDM. The PI RF output port is connected to the orbiter payload antenna subsystem.

The following sections present detailed descriptions of the PI modules and their functions, with emphasis on their salient features. For completeness, the PI electrical interfaces are also briefly treated.

TRIPLEXER ASSEMBLY

To assure a compatible, interference-free operation with the orbiter's S-band subsystems, two triplexers were selected for use with the PI. The high-frequency one will operate with the network's low frequency channels, while the low frequency one will operate with the network's high frequency channels. Both triplexers use 7- to 10-pole Chebychev-type band-pass filters. The transmit filter's very stringent design parameters were based on a maximum 0.1 -dB degradation of the sensitive orbiter/TDRS link and on the required false lock protection of the PI receiver from the PI spurs. These requirements, coupled with the physical constraints (size, weight), resulted in less than optimum transmit channel attenuation, which in turn called for a higher power generation for the specified EIRP (+37 dBm minimum). The appropriate triplexer filter pair required for the PI duplex operation is selected by three out of four single-pole-double-throw (SPDT) magnetically latched RF coaxial switches. Figure 1 presents the dual triplexer block diagram and its frequency response. To avoid additional losses and to enhance the receiver noise figure, the coaxial limiter and the RF preamplifier assembly package were made an integral part of the dual triplexer. The coaxial limiter network protects the PI receiver from damage by accepting RF input signals of up to plus 36 dBm without performance degradation. This very important feature allows a safe and reliable PI communication with high EIRP payloads in the immediate proximity of the orbiter.

RECEIVER

The antenna RF signal is filtered by the applicable triplexer channel, limited when above a certain level, then amplified for the injection into the first mixer. It is then combined with the local oscillator (LO) input to feed the first IF amplifier. The LO signals are generated by a synthesizer to provide a 215-MHz IF. The LO frequency is fixed for each channel, and it is selectable in specified steps. The selection of the first LO frequency is the only variable in the receiver, which otherwise is identical for each of the operating modes. The frequency range of the dual-conversion, short-loop PM receiver is 2,200 MHz to 2,300 MHz; and while sweeping ($f_c \pm 112$ kHz), it requires a minimum carrier power of -122.5 dBm for 0.9 acquisition probability. The 215-MHz down-converted signal is routed to the AGCed amplifiers, filtered, then again AGC-amplified and mixed with the second LO for a 31-MHz output. This output is fed into the second IF AGCed amplifier, followed by appropriate filtering and division into the wideband data channel and the 300-kHz crystal filtered carrier acquisition channel. The 31-MHz signal in the carrier acquisition channel is fed to the phase detector and the coherent amplitude detector (CAD). Simultaneously, a highly stable reference signal (31 MHz) is applied via a 90-degree hybrid to both detectors. The CAD provides an output dc voltage which is fed to the threshold detector and the coherent AGC loop-filter amplifier. When the CAD voltage exceeds the preset threshold voltage, the sweep circuit is disabled and the phase detector’s error output voltage is applied to the phase-lock-loop, which controls the frequency of the VCXO (18.4 MHz). The VCXO output is multiplied by 10 for injection as a second LO into the second mixer, thus closing the tracking loop; i.e., when phase lock is established, the second LO follows frequency changes of the received signal (assuming a highly stable first LO).

In the coherent AGC filter amplifier, a reference voltage is used to maintain the CAD dc output at a constant level when the coherent AGC is closed. The noncoherent AGC control voltage is provided by an AM detector. The AGC action is such that above the tracking threshold, the noncoherent AGC is active before acquisition, and the coherent AGC is active after acquisition. The coherent AGC dc voltage is added to the noncoherent AGC dc voltage to provide a feedback to the IF amplifiers, thus closing the AGC loop. To accommodate maximum received signal variation due to range or payload attitude changes, the first IF has a dynamic range of 110 dB. To allow for payload antenna switching and/or momentary signal dropouts due to drastic antenna nulls, the receiver is equipped with a 50- to 90-millisecond memory before the sweep is activated. The very critical false-lock-on protection is incorporated by a unique design. The noncoherent AGC works on noise from the highly selective 300-kHz crystal filter; when a carrier appears with sidebands, within the 300 kHz, which are lower than the carrier, the noncoherent AGC will set the IF amplifiers to the strongest signal level, so that only the high carrier signal will be visible for lock-on and coherent AGC tracking. The false-lock-on protection is also enhanced by a very high sweep rate (approximately 750 kHz/sec). As a result, the PI receiver will not false-lock when a discrete spur or a sideband component level is 29 dB below the unmodulated carrier in the $f_c \pm 242$ kHz frequency range. This false-lock-on protection capability satisfies the telemetry conditions from standard NASA and DOD payloads.

Any unique payloads must comply with these power spectral distribution requirements to avoid dangerous false locks and thus assure reliable telemetry transmission to the PI receiver. The receiver functional block diagram is shown in Figure 2.

BASEBAND CHANNEL

The wideband phase detector coherently demodulates PM signals, which are filtered and AGCed over a 50-dB dynamic range to maintain a constant output at the PSP/PS and Ku-band interfaces. The demodulated subcarrier signal level at these 75-ohm differential outputs is 2 ± 0.4 volts rms. The Ku-band output for the Ku-band bent-pipe transmission is always active, while only one of the two remaining outputs is on at any time. The PSP or PS output can be selected from the PS.

SYNTHESIZER

The 861 frequency channels of the PI are generated through the use of phase-lock loops (PLL) with programmable dividers in the feedback circuits. The frequency division of a very stable temperature-compensated crystal oscillator (TCXO) provides the minimum frequency separation of adjacent selectable channels. This signal is then used as a reference to the phase detector, while the other input comes from a VCO which is down-converted and then divided by N. This N divider represents the selected operation channel. The phase detector drives a loop filter which in turn drives the VCO until a phase coherence is achieved. This VCO output (755 ± 50 MHz) is upconverted, using a fixed 1,280-MHz source, to provide the required first local oscillator signal in the 2,035 ± 50-MHz frequency range, which is always 215 MHz below the selected receive frequency. The $f_{LO} \pm 50$ MHz covers the STDN channels in 125-kHz steps, the DSN channels in 370-kHz steps, and the SCF in 5-MHz steps. The transmitter synthesizer uses the same phase-lock-loop principle as the receiver synthesizer. Here, however, the frequency is determined by the use and modification of the receiver synthesizer's downconverted VCO signal to provide the required turnaround ratio (STDN/DSN: 221/240; SCF: 205/256), and thus generate the complementary, but noncoherent transmit frequency for each selected receive frequency. Here again, the VCO output is upconverted using fixed 1,280-MHz source to provide the transmit signal of 2,075 ± 50 MHz for STDN/DSN and 1,800 ± 40 MHz for SCF. The minimum transmit frequency separation between the channels is 115 kHz for STDN, 341 kHz for DSN, and 4 MHz for SGLS. The STDN, DSN, and SCF modes, and the high- or low-frequency bands, are automatically selected by binary coded decimal control. And here again, the unique feature of the PI design is the use of minimum external controls for instantaneous selection of the frequency channels in the required mode. The functional block diagram of the synthesizer is shown in Figure 3.

TRANSMITTER

The selected transmitter carrier frequency is generated by the up-conversion of the synthesized channel frequency with a fixed 1,280-MHz source. It is then amplified, filtered, and fed via exciters to the power amplifiers, where external controls set the RF output power to high, medium, or low level. This wide range of output power setting will allow reliable communication with a great range of G/T payloads at far and near distances.

The modulated or unmodulated carrier is then fed to the appropriate triplexer filter for duplex operation with the complementary receive signal. Two independent exciter and power amplifier channels are used to satisfy the required 365-MHz amplification bandwidth, one for STDN/DSN and the other for SCF.

The transmitter carrier is phase-modulated at a preset modulation index of 1 radian peak when a 16-kHz PSK-modulated subcarrier is applied by the PSP. However, for PS input, the modulation index is set by the incoming command signal voltage with a linear response from 0.3 to 2.5 radians, and with a flat frequency response of up to 200 kHz.

In addition, to accommodate a wide family of payload transponders, the transmitter is equipped with a wide and narrow carrier sweep function, and with a modulation ON-OFF capability. The sweep will allow operation with transponders of high-frequency uncertainty, while the removal of the modulation will prevent the very undesirable false-lock-on problem. The functional block diagram of the transmitter is shown in Figure 2.

INTERFACES

The payload-dedicated RF communication subsystem is fully redundant; but at any one time, only one of the two RF strings can be energized. Its implementation requirements and the resultant performance parameters were presented to enhance understanding of the capabilities and/or limitations of the interrogator. A brief description of its electrical interfaces, as shown in Figure 4, and major performance parameters, as listed in Table 1, will be of assistance.

Ku-Band (Bent Pipe)—The Ku-band communications subsystem continuously accepts the PI baseband data from “standard” and “unique” payloads. This telemetry information can then be transmitted to ground via TDRS, as required.

Payload Station—The PS is located in the aft forward deck of the crew compartment, where standard electrical DOD interfaces are provided, including access to the PI for command transmission and telemetry reception. For the unique, nonstandard payloads, provisions are made for power, I/O to PI, and access to the payload station distribution panel (PSDP). However, the payload-unique signal processor or unique wiring will have to be supplied by the user.

Payload Signal Processor (PSP)—The PSP provides standard NASA I/O interfaces with the PI; i.e., command transmission of up to 2,000 bps on a 16-kHz subcarrier, and reception of up to 16 kbps telemetry on a 1,024-MHz subcarrier.

Ground Control Interface Logic (GCIL)—The GCIL provides configuration control of the PI from the ground via the S-band network and the Ku-band subsystems. The same functions can also be performed by the crew from the displays and controls (D&C) via the GCIL.

Multiplex Demultiplex Unit (MDM)—The MDM accepts PI health and configuration status telemetry for storage and/or real-time transmission to ground.

Antenna Subsystem—Left- and right-hand circular polarization antennas are provided. The antenna gain is 2.5 dB in a radiation cone of 80 degrees.

Table 1. Transmitter and Receiver Major Parameters

Transmitter Major Parameters

- Frequency Plan

Mode	**Number of Channels**	**Frequency**
STDN	808 in 115-kHz increments	2,025.8 to 2,118.7 MHz
DSN	29 in 341.039-kHz increments	2,1 10.1 to 2,119.7 MHz
SCF	20 in 4.004-MHz increments	1,763.7 to 1,839.7 MHz

- Key Parameters
  - RF pwr out; • High ≥ 37 dBm • Medium ≥ 27 dBrn • Low ≥ 4 dBm
  - Frequency sweep

	Wide		Narrow	
	NASA	DOD	NASA	DOD
Range (kHz)	±75	±55	±33	±33
Rate (kHz/sec)	10	10	0.25	0.25

- Carrier Phase Noise: 8° rms max (steady state)

	Commands
NASA	Up to 1,000 bps on 16 kHz subcarrier; β = 1 rad fixed
DOD	1 or 2 k-baud: subcarrier ternary FSK/AM: 65.76 or 95 kHz β = 0.3 to 2.5 rad

Receiver Major Parameters

- Frequency Plan

Mode	**Number of Channels**	**Frequency**
TDN	808 in 125-kHz increments	2,200 to 2,300.875 MHz
DSN	27 in 370.37-kHz increments	2,290.18 to 2,299.81 MHz
SCF	20 in 5-MHz increments	2,202.5 to 2,297.5 MHz

- Key Parameters
  - NF ≤ 6 dB
  - Acquisition: F_{cs} ± 80 kHz, 5 sec (0.9 probability)
  - Max Doppler: ± 87 kHz; Doppler rate = 17 kHz/sec
  - Dynamic range: -3 dBm to -122.5 dBm
  - No damage input: + 36 dBm max
  - Post-detection 3-dB bandwidth: 1 kHz to 4.3 MHz

	Data (T/M)
NASA	Up to 16 kbps on 1.023 MHz subcarrier; β = 1 rad
DOD	Up to 256 kbps on 1.024 MHz or 1.7 MHz subcarrier β = 1 rad or 0.3 rad
Ku-Band	As NASA, DOD above, or 1 kHz to 4.3 MHz

CONCLUSIONS

This ambitious undertaking of designing, developing, and implementing a dedicated, highly diversified RF subsystem for detached payload communication on the orbiter was very successful. As the NASA/DOD integrated “mini-station,” the PI supports not only STDN, DSN, and SCF compatible payloads, but also unique scientific, commercial, or foreign payloads which use up to a 4.3-MHz baseband and up to 200 kHz for command transmission.

The PI’s quick-setting response for any mode and configuration selected, makes the PI, with minimum external controls very easy to operate. This capability allows its operation by the flight crew (manually) and/or ground (remotely) with minimum impact on the mission. A unique false-lock-on protection feature is provided. However, to assure reliable signal acquisition, the payloads must comply with the specified power spectral distribution of their RF transmission. The PI accommodates a wide range of EIRP and G/T payloads, including the ones with high-frequency uncertainty. In conclusion, it can be stated that all PI requirements to support two-way duplex communication with detached standard NASA and DOD payloads were met and in many instances exceeded.

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3. Panter, P. F., Modulation, Noise, and Spectral Analysis, McGraw-Hill, 1965.

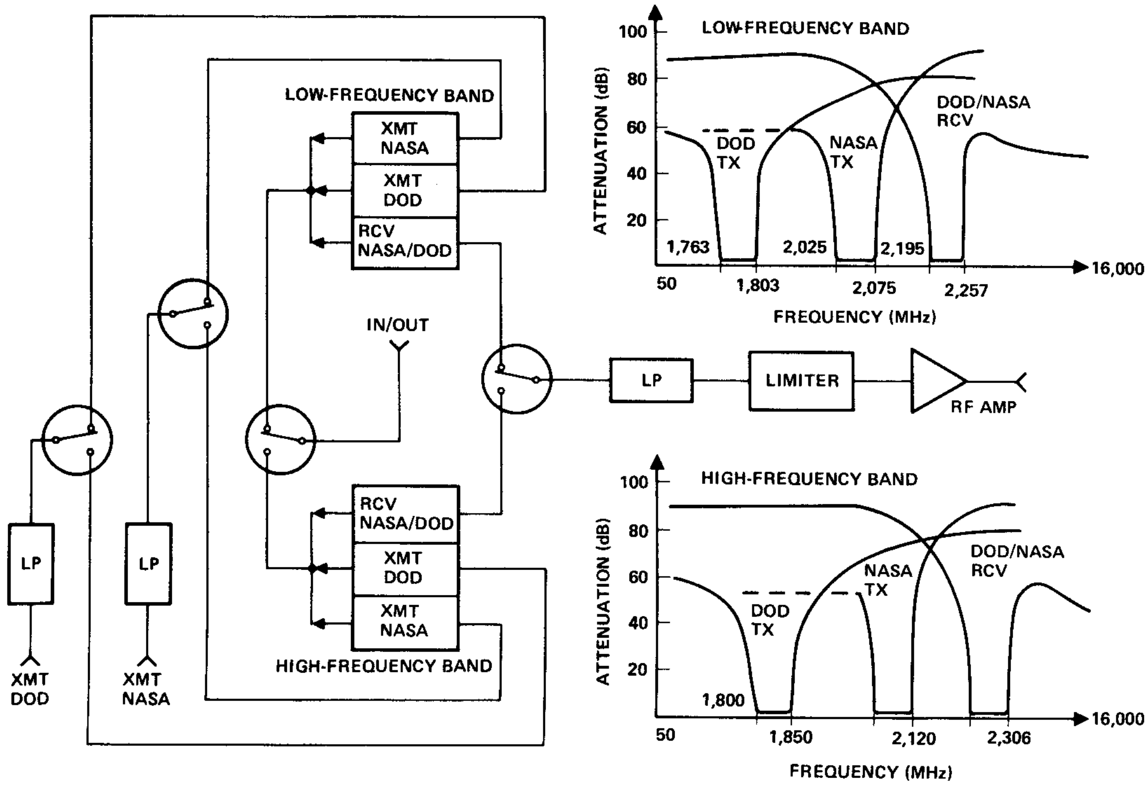

Figure 1. Dual Triplexer Block Diagram and Its Frequency Response

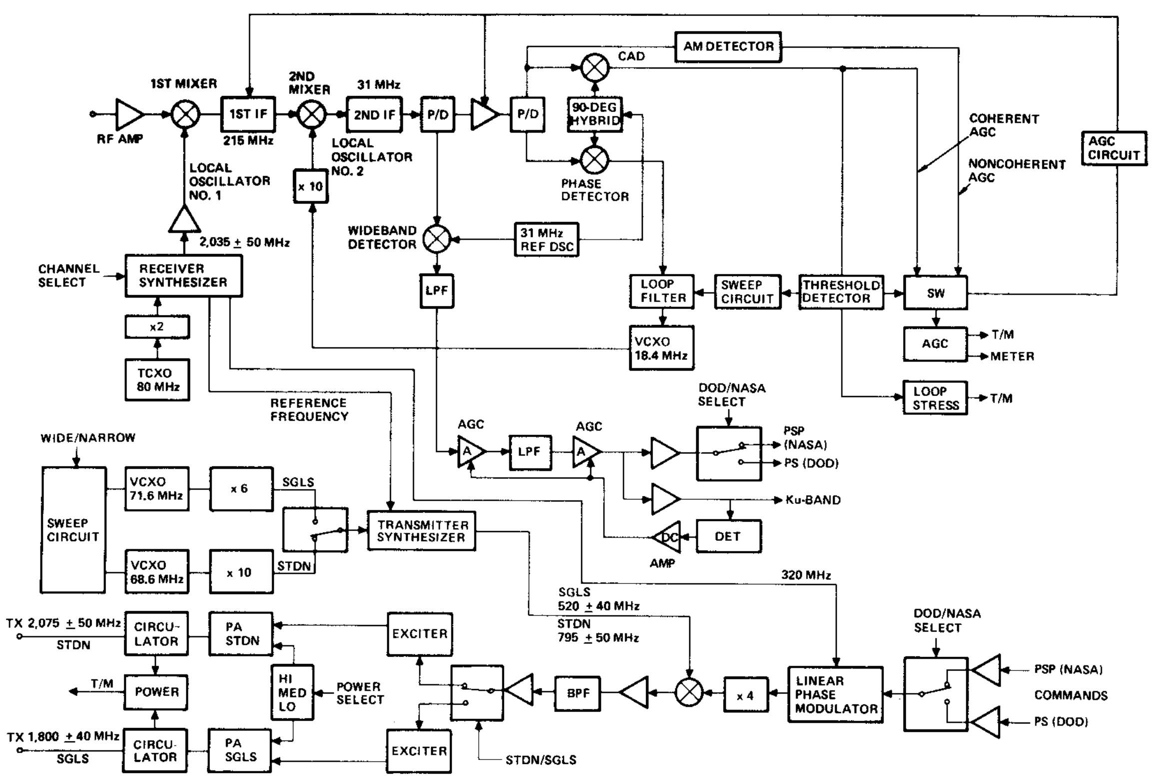

Figure 2. Payload Interrogator Receiver and Transmitter Functional Block Diagram

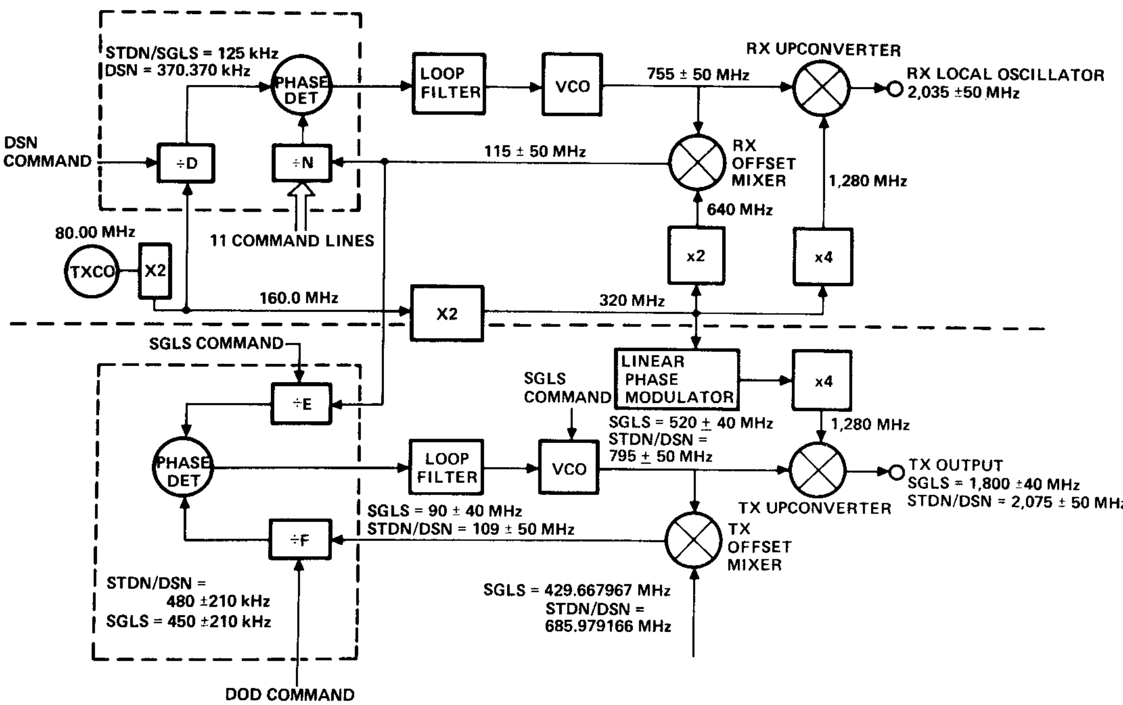

Figure 3. Synthesizer Functional Block Diagram

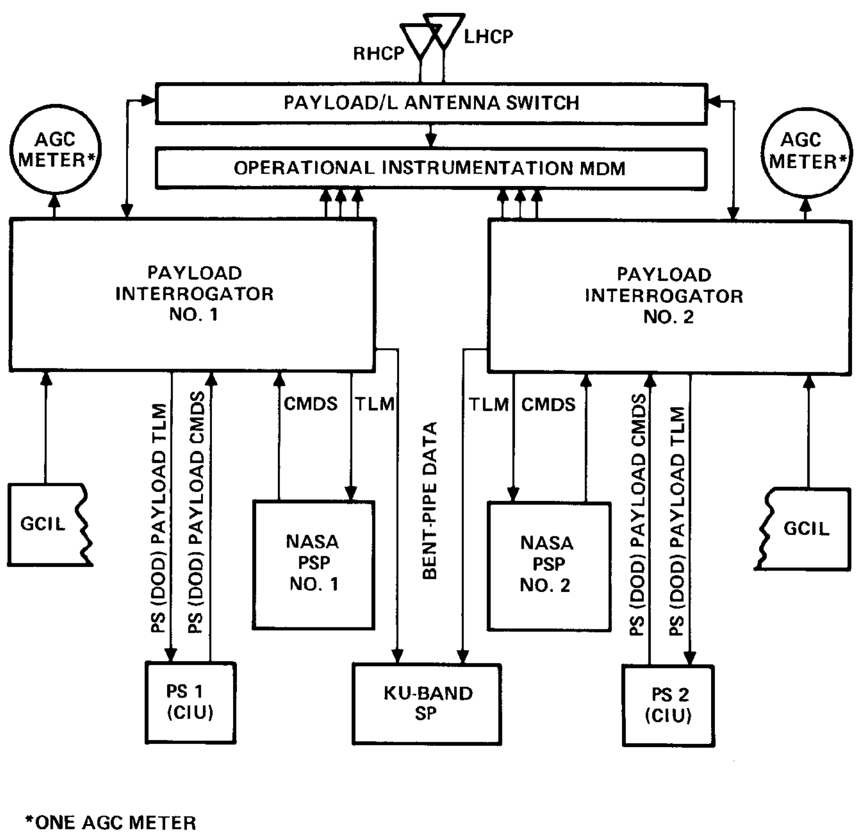

Figure 4. Payload Interrogator Electrical Interfaces