SPACE SHUTTLE PAYLOADS SUPPORT CAPABILITY

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ABSTRACT

The NASA/Rockwell Space Shuttle with its highly versatile avionics and electrical provisions for use by the Shuttle payloads will provide an efficient system for future national space program activities and space program activities from foreign countries. This paper summarizes the avionics and electrical payload capabilities and interface characteristics. It includes a description of the command and data systems interface, the caution and warning system interface, and the aft flight deck accommodations; the electrical power distribution system; and the standard mixed cargo harness.

INTRODUCTION

The primary mission for the Space Shuttle is the delivery of payloads to earth orbit. In orbit, the Space Shuttle has the capability to carry out missions unique to the space program: to deploy payloads whose destination is high-altitude orbits; to retrieve payloads from orbit for reuse; to service or refurbish satellites in space; and to operate space laboratories in orbit. To accomplish these objectives, the Shuttle orbiter provides an avionic system that interfaces with payloads through the payload and mission specialist stations by means of hardwired controls and displays when the payloads are attached to the orbiter and through a radio link when the payloads are detached. The capability and interface characteristics of the avionics system that has been designed in support of payload operations and described in detail in NASA/JSC 07700, Volume XIV, are summarized in this paper.

The standard avionics provisions for payloads include communication, command, and data management interfaces with attached and detached payloads and electrical power and caution/warning interfaces for attached payloads. A functional block diagram of these standard avionics provisions is shown in Figure 1.

Orbiter transmitters, receivers, and signal structure are compatible with the established characteristics of NASA's space tracking and data network (STDN) and tracking and data relay satellite (TDRS), and the Air Force space-ground link subsystem (SGLS). The orbiter is equipped to communicate with ground stations, TDR satellites, and detached payloads at S-band frequencies and with the TDRS at Ku-band frequencies.

PAYLOAD COMMAND SYSTEM INTERFACES

Commands to attached or detached payloads can be forwarded from the ground or generated on-board. A block diagram of the command system interface is shown in Figure 2.

Payload Interrogator

The commands to detached payloads are via the payload interrogator, whose transmitter is capable of operating in three prime modes: STDN, deep space netork (DSN), and DOD. The transmit frequency channels available are as follows:

- STDN compatible payload - 808 channels from 2025.833333 to 2118.722328 MHz in 115.104 kHz increments (221/240 transmit/receive ratio).

- DSN compatible payloads - 29 channels from 2110.243056 to 2119.792438 MHz in 341.049 kHz increments (221/240 transmit/receive ratio).

- SGLS compatible payloads - 20 channels from 1763.721 to 1839.795 MRz in 4.004 MHz increments (205/256 transmit/receive ratio).

In the STDN and DSN modes, the interrogator accepts a 16-kHz subcarrier (PSK-modulated by command signals ranging from 125/16 to 2000 bps rate) and phase modulates the selected S-band carrier for RF transmission to the detached payload. In the DOD mode, the interrogator accepts a 65 ("S"), or 76 kHz ("0"), or 95 kHz ("1") subcarrier, amplitude-modulated by a 1-kHz or 2-kHz triangular wave from the user-provided signal processor in the payload station. The accepted signal phase modulates the selected RF carrier.

Payload Signal Processor (PSP)

In the STDN and DSN modes, the baseband signal is available to attached payloads via the PSP, which offers five differential outputs. Each output provides a 4 volt peak-to-peak (line-to-line), 16-kHz sinewave, PSK-modulated by the command data at data rates ranging from 125/12 to 2000 bps. The data waveform can be any one of the following: Bi-ϕ-L, -M, or -S; or NRZ-L, -M, or -S.

Multiplexer/Demultiplexer (MDM)

Serial digital and discrete commands are provided by the MDM. These commands can also be forwarded from the ground stations or generated on-board initiated via the keyboard. In the serial mode, the MDM command signal consists of a Manchester II biphase signal at a 1-mps burst rate. The true logic level is a nominal +4.5 Vdc, and the false logic level is a nominal -4.5 Vdc. The command signal channel includes word, message-in, message-out discretes, whose logic levels are nominally +3.5 Vdc and -3.5 Vdc for the true and false logic levels. The command message can include up to 32 16-bit data words. In the discrete output mode the MDM provides low-level and high-level discretes whose true/false logic levels are nominally +5/0 Vdc and +28/0 Vdc. Thirty-six high-level discretes (DOH) and thirty-two low-level discretes (DOL) are available.

Data Bus

For payloads requiring a greater number of commands, a data bus stub is provided to accommodate the installation of a payload-provided MDM.

Standard Switch Panel

Hardwired commands are provided by the standard switch panel (Figure 3) and the C3A5 panel located in the cockpit center console.

Ku-Band Signal Processor

The Ku-band signal processor provides the capability to forward 128 kbps of NRZ-L data plus clock. The true and false logic levels for this interface are +5 Vdc and -5 Vdc.

PAYLOAD DATA SYSTEM INTERFACE

The Shuttle orbiter avionics provides the capability to process payload data on-board, transmit data to the ground stations in real time, or record the data for later data dump to ground stations. A block diagram of the payload data system interfaces is shown in Figure 4.

Payload Interrogator

Data from detached payloads are via the payload interrogator, whose receiver is capable of operating in three prime modes: STDN, DSN, and DOD. The receive frequency channels available are as follows:

- STDN compatible payloads - 808 channels from 2200.000 to 2300.875 MHz in 125-kHz increments.
- DSN compatible payloads - 27 channels from 2290.185 to 2299.814 MHz in 370.37-MHz increments.
- SGLS compatible payloads - 20 channels from 2202.500 to 2297.500 MHz in 5-MHz increments.

In the STDN or DSN modes, the payload interrogator receives the selected RF carrier and detects a PCM/PSK-modulated 1.024-MHz subcarrier. The detected data are routed to other orbiter avionics line replaceable units for additional on-board processing and to be transmitted to ground stations.

In the DOD mode, the payload interrogator receives the selected phase-modulated carrier and detects the PSK-modulated 1.024-MHz subcarrier or the FM/FM-modulated 1.7-MHz subcarrier. The detected data are made available at the payload station where they can be accepted by the user-provided data processor.

The payload interrogator has the capability to select three predetermined sensitivity levels:

Sensitivity (dbm)	High	Medium	Low
Carrier acquisition	-108	-95	-75
Data			
16 kbps, PSK, BER 10^{-5}	-99	-86	-66
16 kbps, FM/FM, BER 10^{-6}	-86	-75	-56

Payload Data Interleaver (PDI)

Attached payload telemetry interface is via the PDI. The PDI also receives data from the payload signal processor (PSP), which processes data from detached payloads received via the payload interrogator. The programmable PDI can interface with up to five payloads and accept data simultaneously from four different payloads, then select and individually decommutate the data for storage in a buffer memory. The memory is accessible to the pulse code modulator master unit (PCMMU), which, after accepting the data from the PDI, formats the data into a serial digital stream for telemetry to the ground. A block diagram of the PDI is shown in Figure 5. The PDI provides the following capabilities to accommodate attached payload telemetry requirements: (1) seven input channel ports (five payloads, 1 each of two PSP) and capability to switch any of the seven inputs to any of four PDI channels; (2) capability to decommutate and process up to four asynchronous pulse code modulated data input channels simultaneously; (3) 64 kbps maximum input data rate for complete throughput of data; and (4) in-flight programmable PDI decommutators so as to be able to accommodate a change in payload data rate and format in flight. The PDI input telemetry format constraints are as follows:

- Bits per word - 8 or multiples of 8
- Words per frame - 8 to 1024
- Minor frame rate - 200 per sec maximum
- Minor frames per master frame - 1 to 256
- Minor frame synchronization - 8, 16, 24, or 32 bits
- Master frame synchronization - 8-bit unique pattern in first minor frame or 8-bit minor frame counter
- Format sample rate - 5 maximum

The PDI has a balanced differential input circuit. The minimum/maximum input voltage requirements measured line-to-line are 3/9 volts peak-to-peak. The PDI will accept NRZ-L, NRZ-M, NRZ-S, Bi-ϕ-L, Bi-ϕ-M, and Bi-ϕ-S data. The bit rate clock is required with NRZ codes.

S-Band FM Link

Because of limited ground coverage, utilization of this link is restricted to ascent and landing phases after the tracking and data relay satellite system (Ku-band) is operational. Attached payload data can be patched to the FM signal processor at the payload station distribution panel. Payload data can time-share the FM link with the orbiter operational recorder dump, TV video, and main engine data. The FM signal processor will select one of the following payload inputs for transmission to the STDN at any time the FM link is not being used by the orbiter: payload recorder dump; wideband digital data (NASA payloads), 200 bps to 5 mbps; wideband analog data (NASA payloads), 300 Hz to 4 MHz; and digital data (DOD payloads), 250 bps to 250 kbps.

The FM signal processor has balanced differential input circuits. The digital data (DOD) channel will accept either biphase NRZ data. The input voltage requirement is 1 volt peak-to-peak. The digital data wideband channel receives Bi-ϕ-L or NRZ-L data (Bi-ϕ-L is limited to 2 mbps). The input voltage requirement is 5 volts peak-to-peak. The analog data channel input voltage requirement is 1 volt peak-to-peak.

Ku-Band Link

On orbit, the Ku-band system provides near continuous ground coverage. Attached payload data can be patched to the Ku-band signal processor at the payload station distribution panel. For downlink, the Ku-band system operates in two modes, quadrature phase shift key (QRSK, Mode 1) and FM (Mode 2), with three channels of input data in each mode. The Ku-band communication system is a combined system with the rendezvous radar. The system cannot be used in both modes at the same time. Ku-band service is provided only when the payload bay doors are open.

Two out of three channels in the Ku-band signal processor receive payload data. The interface characteristics are given in Table I.

Table I. Ku-Band Digital Processor Channel Interfaces

Channel	Mode 1	Mode 2
2	● 16 to 1024 kbps Bi-ϕ-L or 16 to 2000 kbps NRZ-L, -M, or -S ● Balanced differential ● 5 volts peak-to-peak ● TSP, 75 ±5 ohms	Same as Mode 1
3	Digital (analog input not used) ● 16 to 4000 kbps NRZ-L, -M, or -S ● Balanced differential ● 5 volts peak-to-peak Analog (digital input not used) ● Dc to 4.5 MHz ● Balanced differential ● 1 volt peak-to-peak ● TSP, 75 ±5 ohms	Digital only ● 2 to 50 mbps NRZ-L, -M, or -S ● Single ended ● 5 volts peak-to-peak ● Coaxial, 50 ± 5 ohms

In Channel 2, the payload timeshares the Ku-band system with the operational recorder dump, and the payload recorder dump. Mission planning is required to ensure that use of this interface is properly coordinated. Likewise in Channel 3, the Ku-band system is timeshared by the payload that is sending digital data, the payload that is sending analog data, and the orbiter TV downlink.

Payload Recorder

Payload experiment data recording is provided via the payload station. Predetermined payload station wiring permits digital data recording in parallel (up to 14 tracks) or in a combination of parallel and serial track sequences. Data rates from 25.5 to 1024 kbps can be selected from four tape speeds provided by premission wiring of recorder program plugs.

Analog data can be recorded on up to 14 tracks in parallel with frequency from 1.9 kHz to 1.6 MHz by premission program wiring. The payload recorder has the following record/playback capabilities:

Data Rate (kbps)	Freq Range (kHz)	Selectable Tape Speed (ips)	Time Per Tape Pass (min)
64 to 128	1.9 to 250	15	32
128 to 256	3.8 to 500	30	16
256 to 512	7.5 to 1000	60	8
512 to 1024	15 to 1600	120	4

The payload recorder interface characteristics are as follows:

	Digital Input (Bi- phase -L)	Analog Input
Signal level	3 to 9 volts peak-to-peak, line-to-line	1 volt rms
Coupling type	Direct coupled balanced differential	Transformer coupled
Cable impedance	75 ohms TSP	75 ohms TSP
Rise/fall time	10 percent of bit duration	-
Bit jitter	< 2 percent of bit duration (pulse-to-pulse)	

Multiplexer/Demultiplexer (MDM) Interface

The MDM is capable of receiving payload data in the form of 5-volt discretes (DIL), 0 to 5-volt differential analog inputs (AID), and serial data (up to 32 16-bit words) at a 1-mbps burst rate. Payload downlink telemetry originating at this interface may be substituted for PDI downlink data on orbit. Thirty-two DIL's, eight AID's, and four serial channels are available to the user as a standard service. The interface characteristics for these inputs are as follows:

- DIL's
  - Logic levels: 5 Vdc, True; 0 Vdc, False
  - TSP, 75 ohms

- AID's
  - Signal amplitude: differential +5.11 to -5.12 Vdc
  - TSP, 75 ohms

- Serial digital channel (4 lines)
  - Manchester II Bi-ϕ at 1 mps (burst)
  - Data line true/false logic levels (nominal): +4.5 Vdc/-4.5 Vdc
  - Word, message-in, message-out true/false logic levels (nominal): +3.5 Vdc/-3.5 Vdc

Master Timing Unit (MTU)

The MTU provides Greenwich Mean Time (GMT) and Mission Elapsed Time (MET) time code outputs in IRIG-B/modified code formats to payloads as a standard service. The voltage level of these signals is nominally 5 volts peak-to-peak. A 75-ohm TSP cable is used.

Payload Caution and Warning System Interface

Orbiter caution and warning is defined to include emergency, warning, and caution parameters. In the case of manned payloads, two identified orbiter emergency parameters require instinctive, immediate crew corrective action. They are fire/smoke and loss of cabin pressure. The caution and warning electronics unit will receive up to five hardwired-sensor dedicated payload warning parameters. The MDM will receive a total of 50 software-controlled payload caution inputs. They consist of 25 5-volt discretes and 25 0 to 5-volt differential analog inputs.

Safing commands can be generated by use of the five redundant switches on the C3A5 panel located at the commander/pilot center station. Use of these switches requires wire patching at the payload station distribution panel. The payload MDM's provide up to 36 safing commands consisting of 28-volt discretes. The commands can be initiated on board via the keyboard or on the ground via the uplink/forward link. Eighteen of the 36 safing commands require wire patching at the mission station distribution panel.

Figure 6 shows a block diagram of the payload caution and warning system interface. The interfaces are keyed to the caution and warning signal characteristics in the following list:

1. Dedicated caution and warning electronics unit
   - 5 signal paths
   - Any combination of 5-Vdc discretes, 28-Vdc discretes, 0 to 5-V analog

2. MDM caution and warning inputs - direct to MDM
   - 12 analog differential input (AID) signal paths
   - Voltage range: +5.12 Vdc to -5.12 Vdc
   - 13 discrete input: low level (DIL) signal paths
   - Logic levels: True, +5 ±1.0 Vdc; False, 0 ±0.5 Vdc

3. MDM caution and warning inputs: via mission station
   - 13 analog differential input (AID) signal paths
   - Voltage range: +5.12 Vdc to -5.12 Vdc
   - 12 discrete input: low level (DIL) signal paths
   - Logic levels: True, +5 ±1.0 Vdc; False, 0 ±0.5 Vdc

4. MDM safing commands: direct from MDM
   - 20 discrete outputs: high-level (DOH) signal paths
   - Logic levels: True, +19.5 to +32 Vdc; False, 0 to 3 Vdc

5. MDM safing commands: via mission station
   - 18 discrete outputs: high-level (DOH) signal paths
   - Logic levels: True, +19.5 to +32 Vdc; False, 0 to 3 Vdc

6. C3A5 panel. switches
   - 5 redundant safing command signals consisting of switch closures

7. $\Delta P/\Delta T$ to Panel R13 A3
   - One differential analog signal
   - Voltage range: 0 to 5 Vdc

8. Master alarm light to payload
   - One witch closure to activate the master alarm light in the payload
   - No alarm: 20-megohm isolation
   - Alarm: ≤0.1-ohm contact resistance

9. Master alarm tone to payload
   - One tone: analog 1 Hz
   - Voltage: 2.2 V ±10 percent, dc isolated and balanced
     Fire/smoke: siren - ΔP/ΔT: klaxon - C&W: C&W tone

Aft Flight Deck Accommodations

The aft portion of the flight deck is an integrated crew station arranged for flight control, rendezvous and docking, payload manipulating, and payload operations. The design provides the flexibility and capability for the check out, monitor, command, and control of attached and detached payload operations. The aft flight deck crew stations (mission, payload, and orbit stations) are designed in a modular fashion to facilitate ground changeout and installation of Shuttle and payload-supplied display and control panels and associated equipment.

Figure 7 illustrates the aft flight deck stations. The panels that are cross-hatched are dedicated to payloads. Panels R-11, L-10, L-11, and L-12 are standard 19-inch wide panel spaces with required standardized electrical power connectors for accommodating user unique modules.

Two standard switch panels are provided as a service to users. They are located in L-12. One-half of a standard switch panel (SSP) has been allocated to each of four payloads sharing a Shuttle flight. One-half of an SSP provides twelve switches and twelve talkbacks.

Payload Electrical Power Distribution System Interface

DC power is available to payloads in the payload bay and to payload equipment in the aft flight deck during the ascent/entry and on-orbit mission phases. The on-orbit payload bay power level is 7 kW steady state, with a peak power of 12 kW available for up to 15 minutes once each three hours when the heat rejection kit is installed and all eight radiators are deployed. Without the additional heat rejection kit, total steady-state power drawn by all payloads in the payload bay is limited to 6 kW. During ascent and entry, the total power available to the payload is limited to a maximum of 1.0 kW. Auxiliary power is available to a maximum of 400 watts. The auxiliary power remains on in the event that the main power is interrupted. Use of the auxiliary power reduces the amount of power that may be used from the primary feeder by an equivalent amount. During emergency conditions, a maximum of 200 watts auxiliary power will be available for payload safing.

In the aft flight deck, the total on-orbit power level is 750 watts continuous, 1000 watts peak. Three-Phase ac power up to 0.69 kVA is also available and can be substituted for an equivalent amount of dc power. The ac power can be made available to the payload bay by doing some wire patching at the mission station. Power levels during ascent and entry are 350 watts continuous, 420 watts peak for two minutes.

The payload electrical power distribution system interfaces are shown in Figure 8. The maximum power available to payloads at the different interfaces is as follows:

- Mid-payload bay
  - Main power: 7 kW avg; 12 kW peak from dedicated fuel cell (with radiator kit)
  - Main power: 5 kW avg; 8 kW peak (orbiter shared) fuel cell
  - Auxiliary power*: 0.4 kW avg (continuous)

- Aft payload bay
  - Power: 1.5 kW avg; 2 kW peak each

- Aft flight deck** PS and MS distribution panels
  - DC power: 0.75 kW avg; 1 kW peak
  - AC power: 0.69 kVA (3-phase); 1 kVA (3-phase) from crbiter inverter
  - Auxiliary power*: 0.4 kW avg (continuous) (PS only)

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*0.4 kW total for combined interfaces
**AFD total, all sources, 0.75 kW; 1 kW peak

Standard Mixed Cargo Harness

The standard mixed cargo harness (SMCH) in the cargo bay provides the following to each of four payload sections: main dc power cable, control and signal wiring to AFD, GPC data bus (2), direct connection to an orbiter MDM, and control and signal wiring to GSE via T-0 umbilical.

Distribution to four payload sections in the cargo bay is effected by four functionally identical cable sets (Figure 9). The standard AFD harness permits connection of the control and signal wiring from the cargo bay to the orbiter's avionics services and to display and control panels on the AFD. This harness provides access to all standard avionics services, as described in the preceding sections of this paper, for each user, with some provisions for additional avionics services. It also provides both powered and unpowered switch functions and electromechanical status indicators from the standard switch panel. Figure 10 depicts the four SMCH sets that provide access to the signal and control avionics services. Figures 11 and 12 depict the nonstandard avionics services at the payload and mission stations that can be wire-patched to the payload interface using user-provided patch cables.

SUMMARY

The Shuttle avionics system provides a wide range of services to accommodate user payloads, including commands, data management, displays and controls, data recording, RF communications, electrical power, aft flight deck displays and controls panel space, and standard wire harnesses. The standard avionics and electrical provisions have enough flexibility to accommodate four major payloads per flight. The orbiter communication subsystem supports the transfer of payload telemetry and uplink data commands to and from the space networks. A payload recorder is provided for recording analog and digital data, which can be transmitted to ground stations via the orbiter communications system. A caution and warning subsystem is provided to monitor payload signals announcing a failure that could result in a hazard to the orbiter or crew. A standard switch panel is provided for generating hardwired commands to attached payloads. The payload stations in the orbiter cabin provide panel space for installing displays and controls unique to a specific payload. Standardized electrical interfaces are provided for payload power, monitoring, command, and control. Standard wire harnesses are provided for use in the payload specialist station and in the payload bay for connecting the standard avionics and electrical services to four payloads. Payloads can avail themselves of the nonstandard avionics services by use of nonstandard harnesses, which require user funding.

The design of the orbiter-to-payload avionics interfaces and accommodations has been optimized to provide an efficient and flexible system that will accommodate mixed cargo flight requirements and will require minimum changes between flights. This highly versatile avionics/electrical system for payload support, together with the flexibility of the Shuttle system, will offer foreign as well as national space programs an effective, viable system for future space activities.

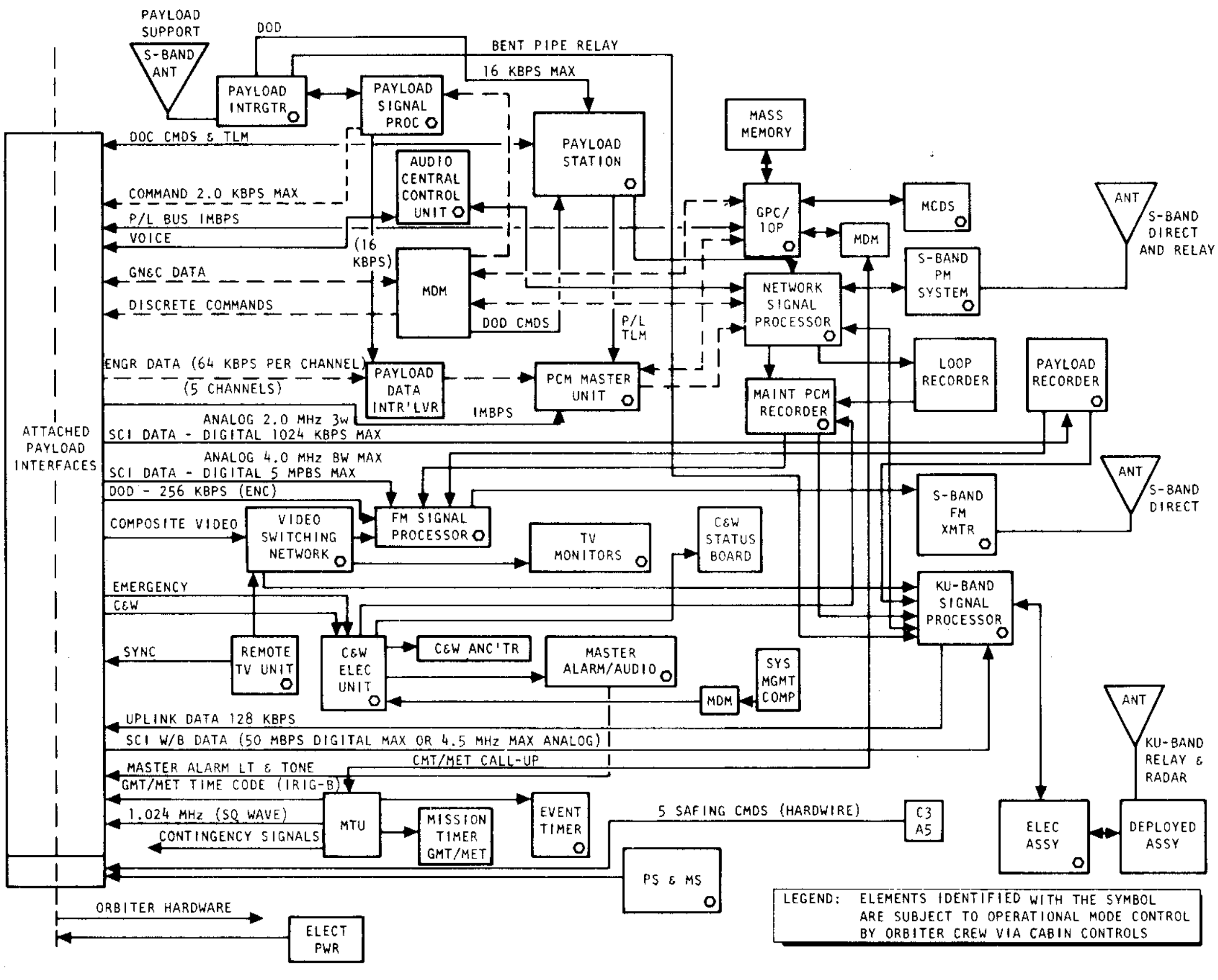


Figure 1. Standard Avionics Provisions for Payloads - Functional Diagram

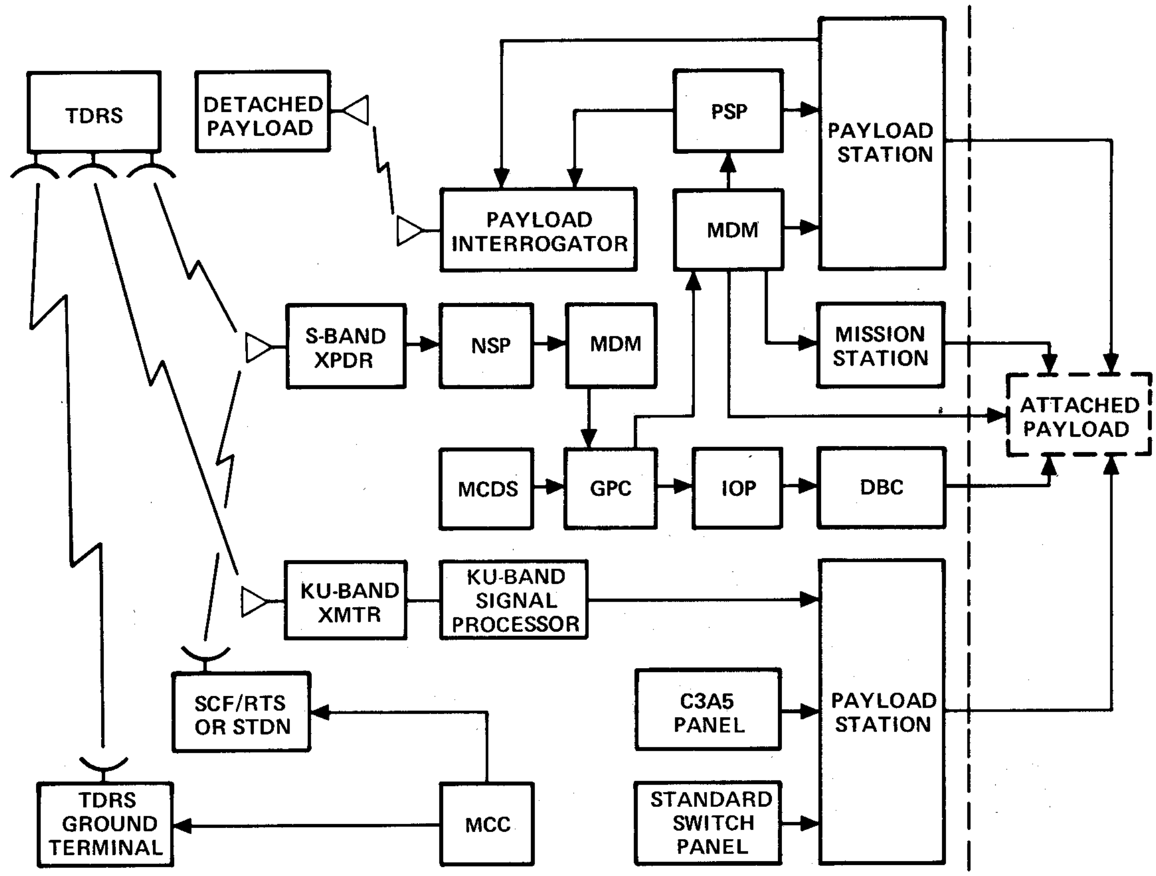


Figure 2. Payload Command System Interface Block Diagram

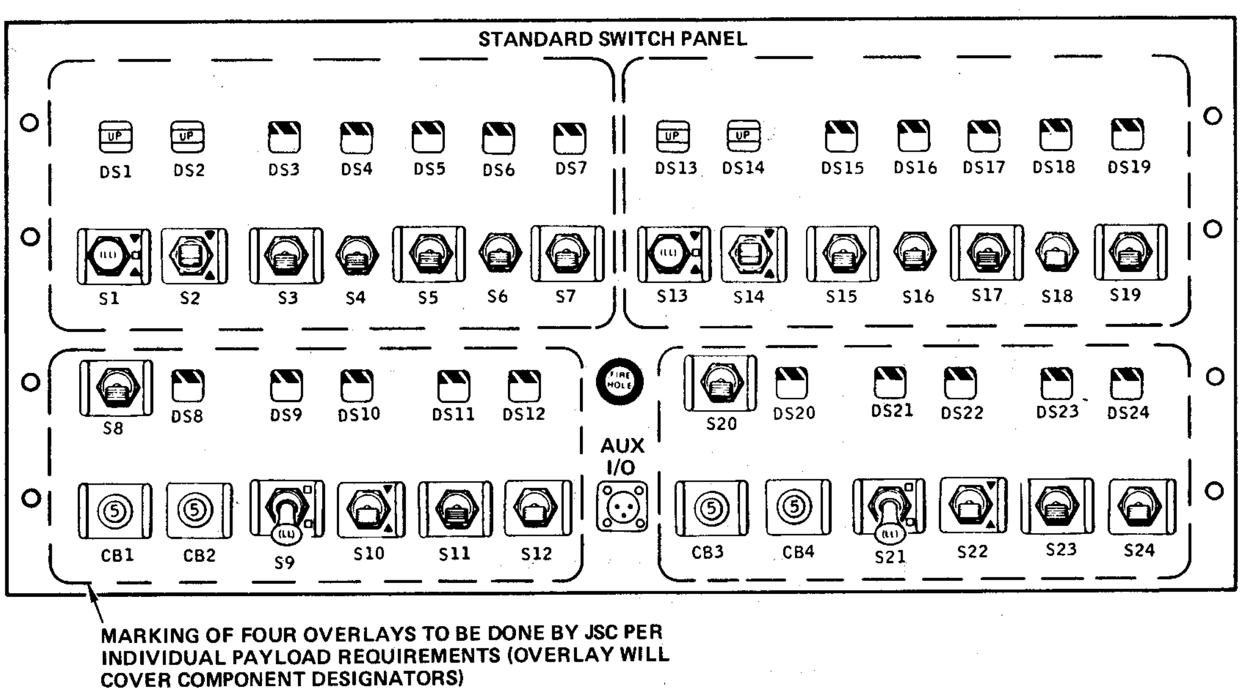


Figure 3. Standard Switch Panel Front Panel Layout

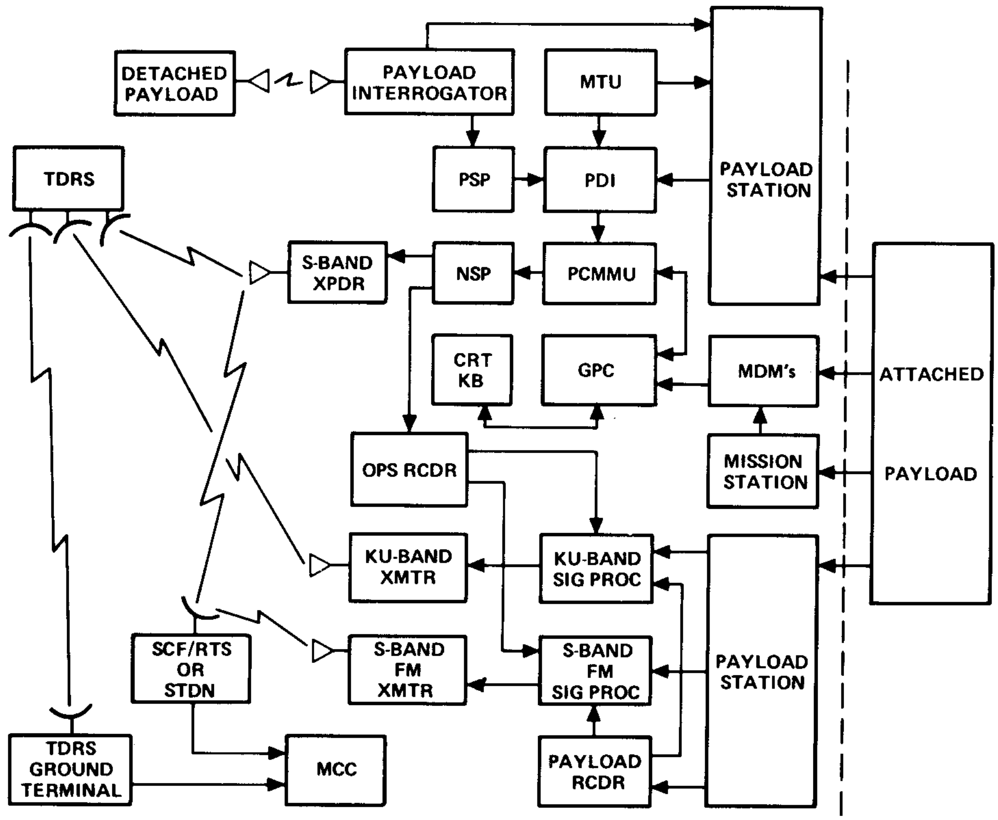


Figure 4. Payload Data System Interface Block Diagram

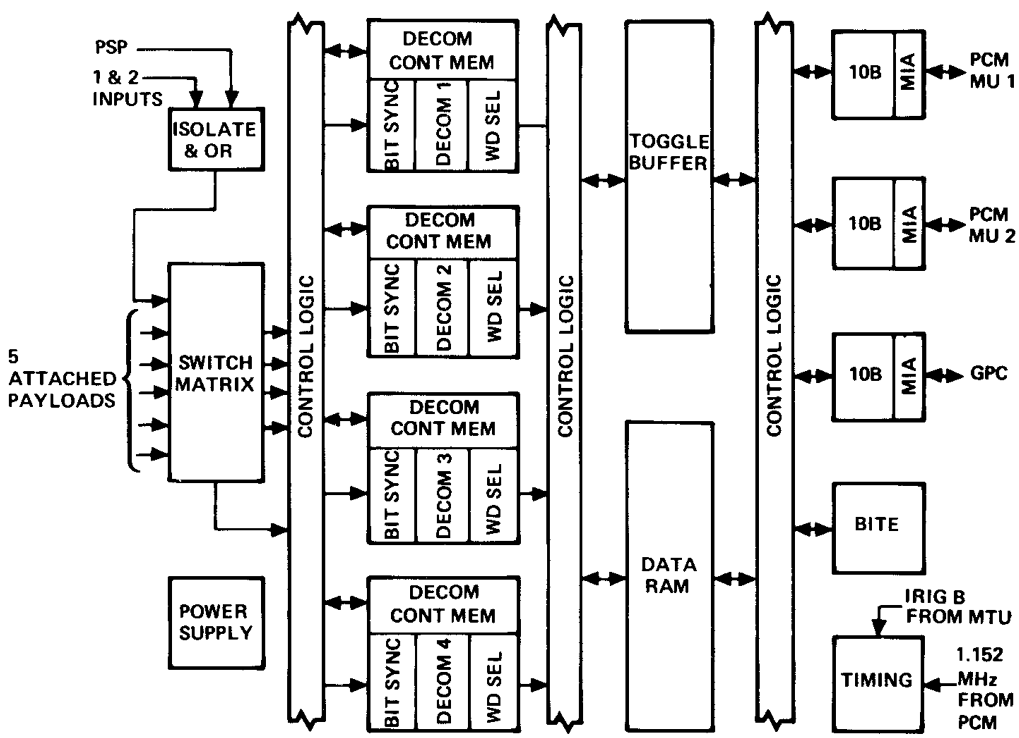


Figure 5. Payload Data Interleaver Block Diagram

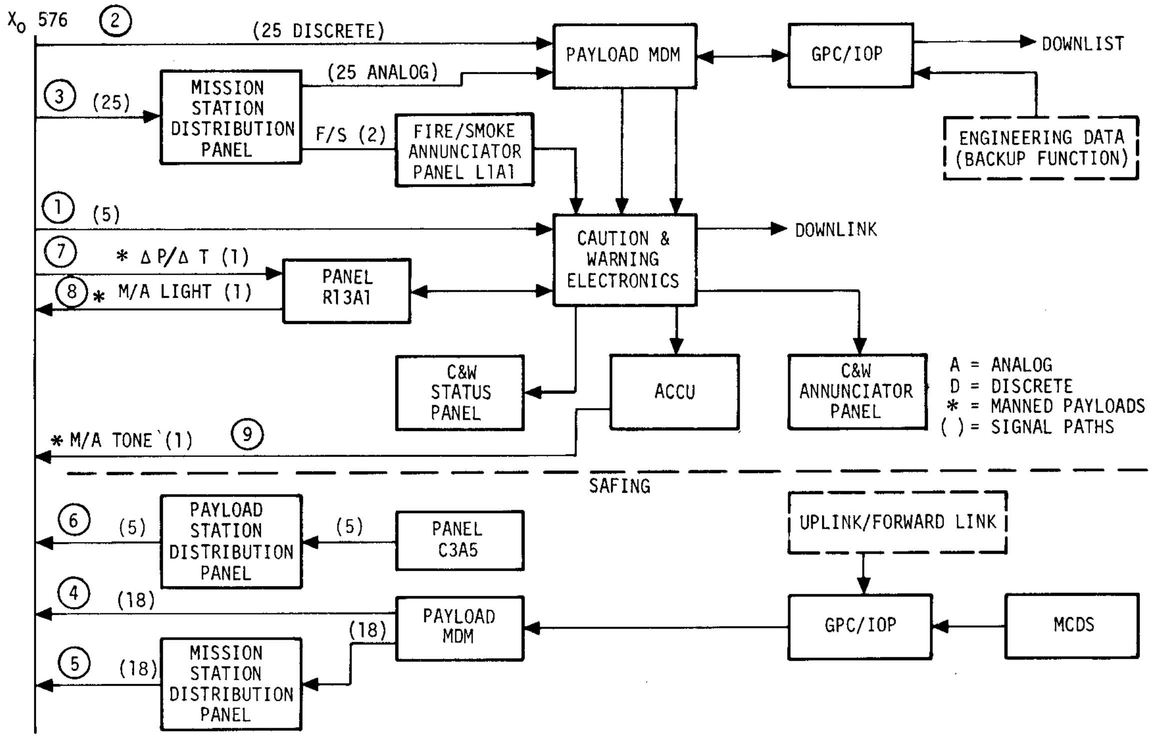


Figure 6. Payload Caution and Warning System Interface

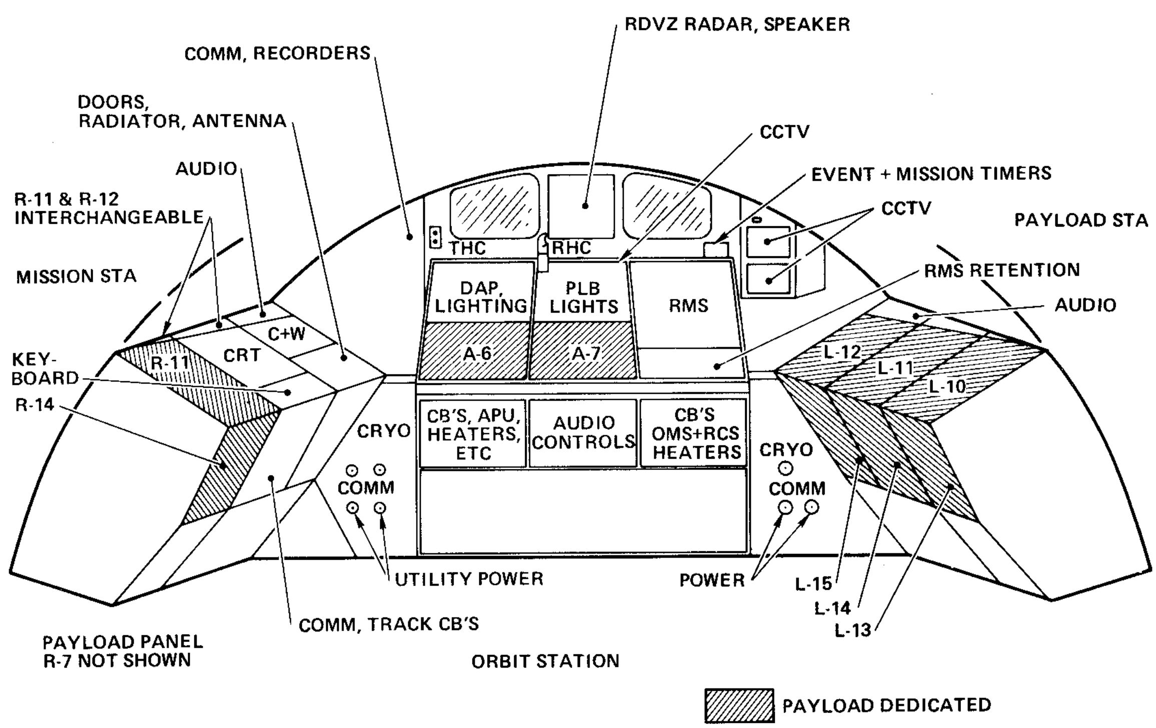


Figure 7. Aft Flight Deck

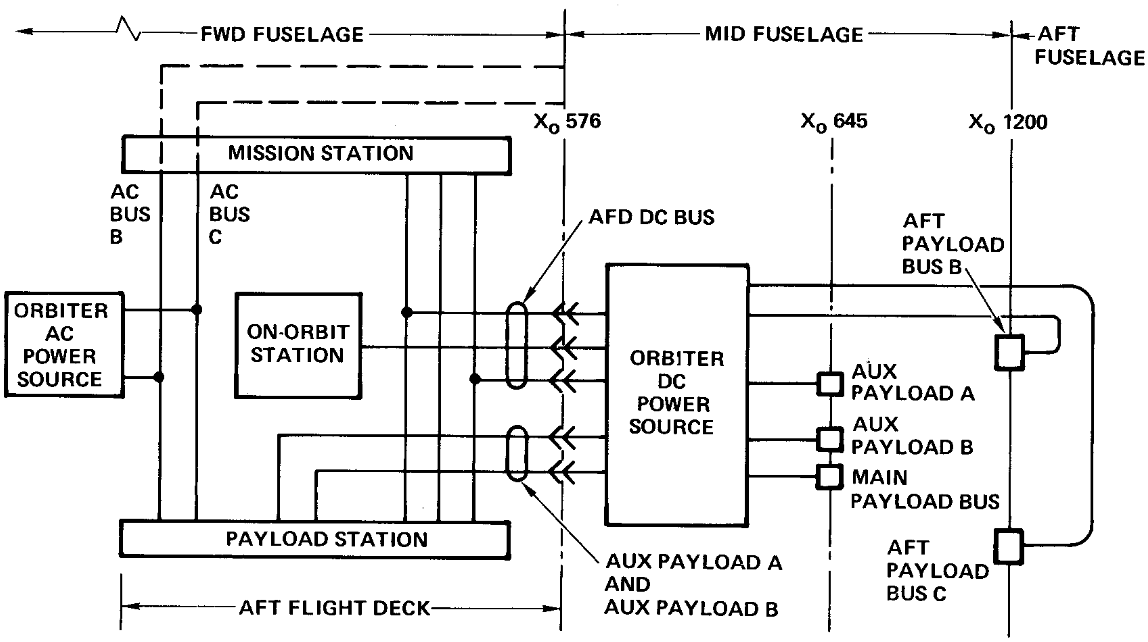


Figure 8. Payload Electrical Power Distribution System Interface

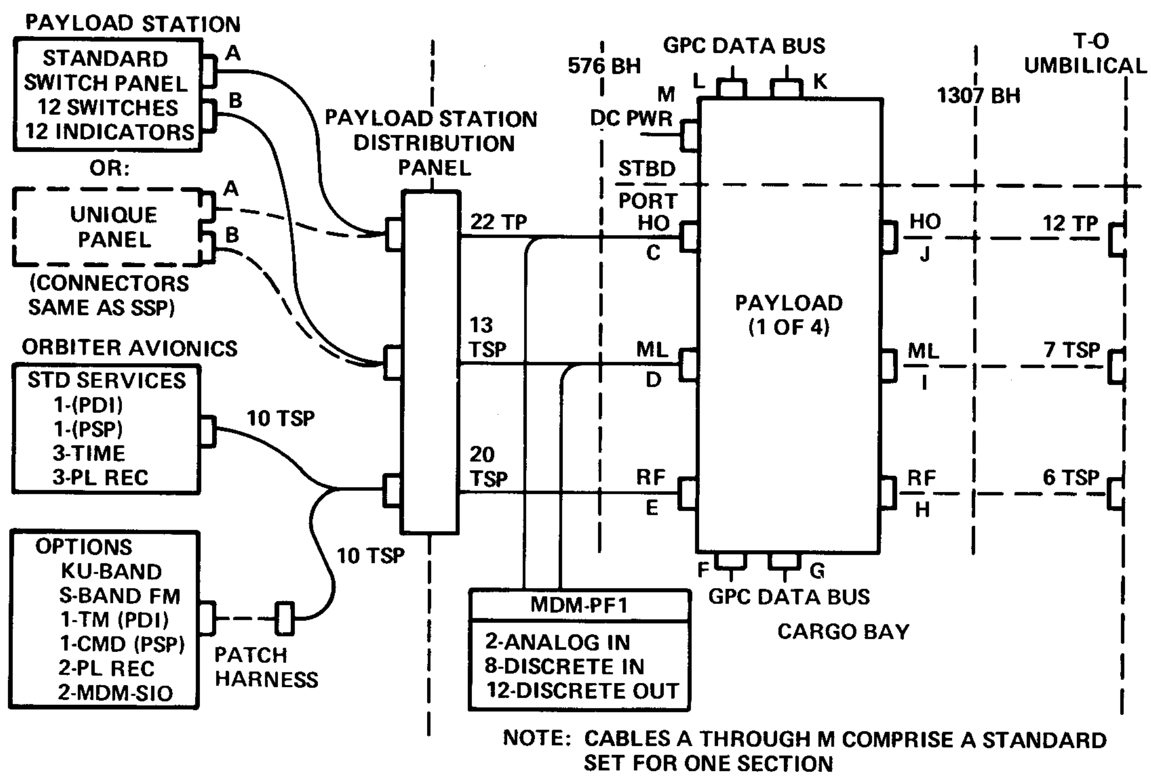


Figure 9. Standard Payload Cables for Shared Cargo Showing Services for One of Four Users

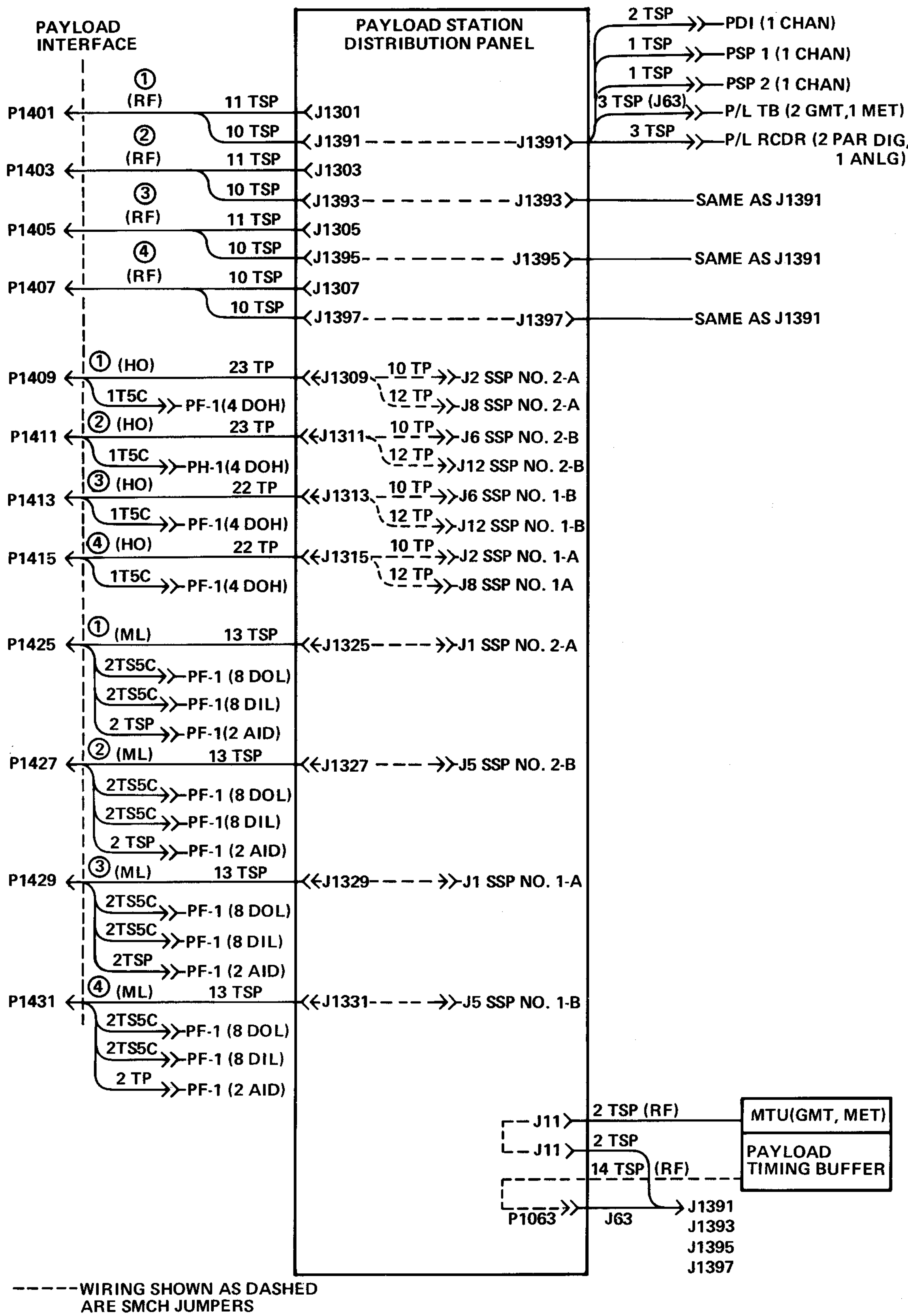


Figure 10. Standard Mixed Cargo Harnesses

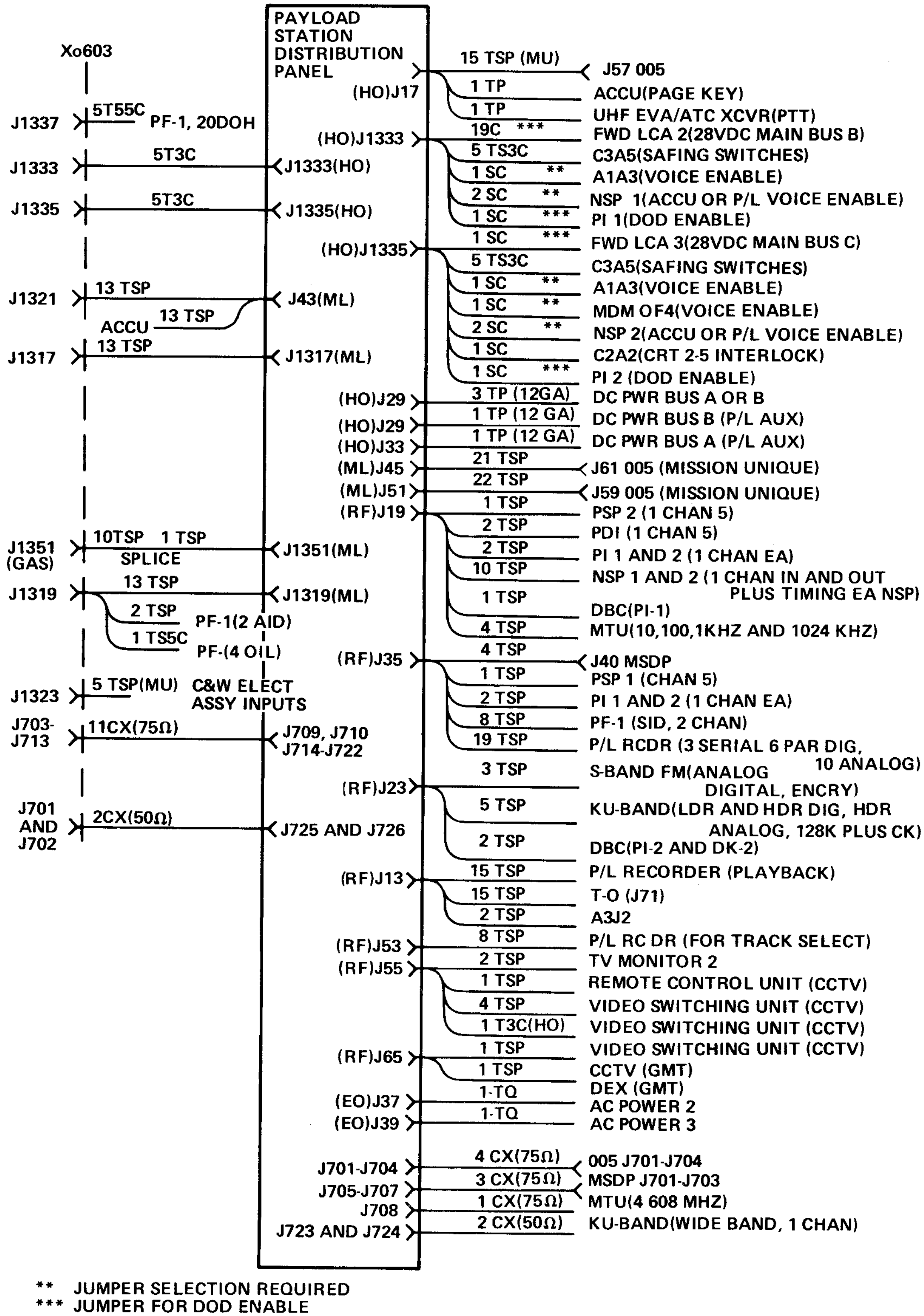
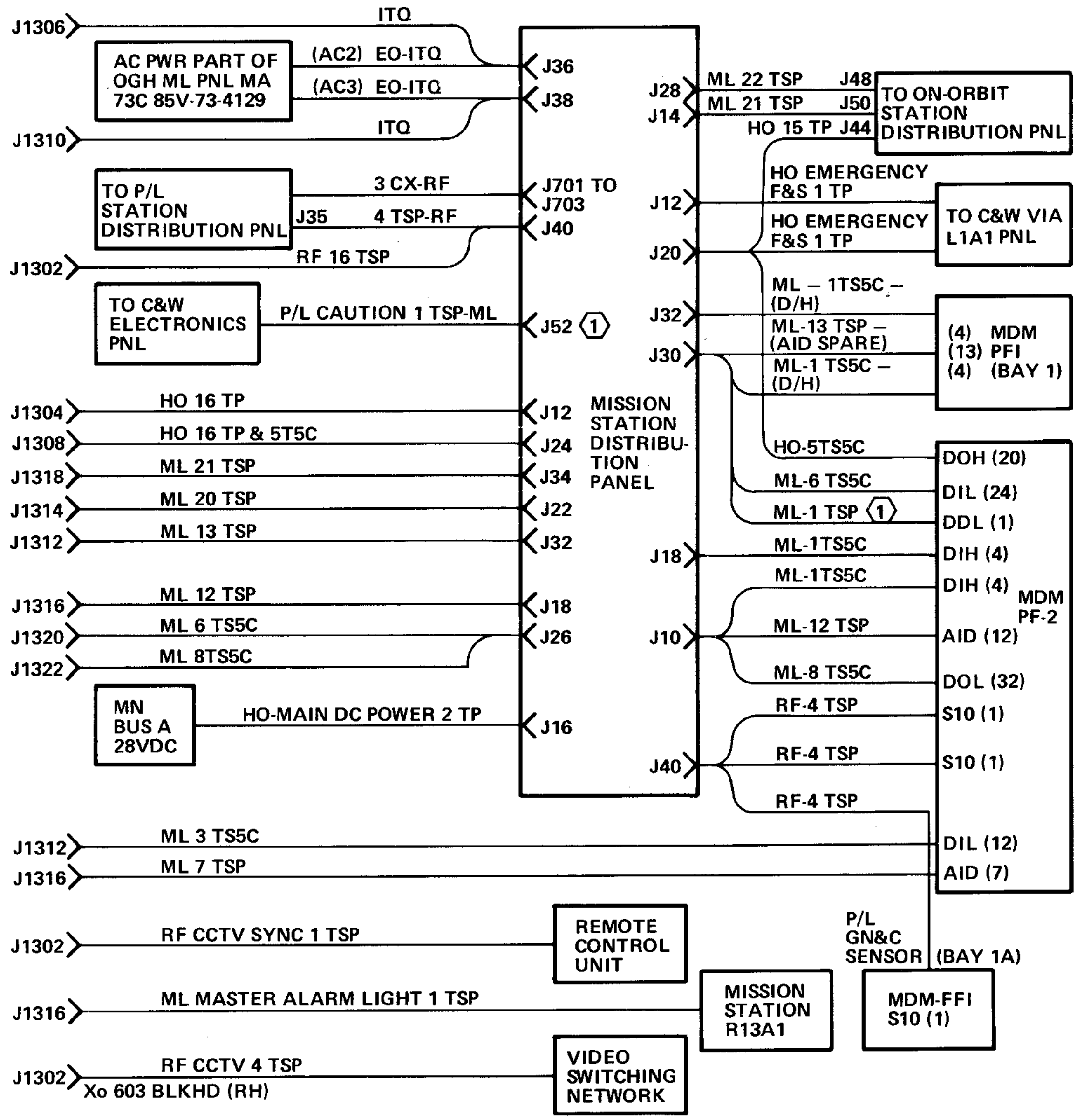


Figure 11. Nonstandard Avionics Services, Payload System



(1) PATCH J30 TO 30J52 WHEN FUNCTION IS UTILIZED – JUMPER TSP INPUT TO RETURN AT 30J52 WHEN FUNCTION IS NOT UTILIZED

Figure 12. Nonstandard Avionics Services, Mission Station