SCIENCE AND APPLICATIONS SPACE PLATFORM COMMUNICATIONS AND DATA MANAGEMENT SYSTEM[*]

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ABSTRACT

The development of space platforms represents the next logical step in the exploration and utilization of space. Such platforms promise cost-effective means for performing both scientific and applications missions, such as surveys of Earth resources, for example, in low Earth orbit.

Payloads mounted on these platforms can perform missions for longer periods of time than are currently available to payloads mounted in the Shuttle's payload bay. In addition, these platforms can provide a variety of services, including a centralized power source, command and data acquisition, communications, pointing and environmental control, as well as periodic Shuttle visits for performing maintenance tasks, replenishing consumables, and replacing payloads.

These platforms must be able to provide data and communications services to groups of payloads consisting of individual payloads that may or may not have common objectives and operating characteristics, and where the payload mix on a platform changes periodically during the orbital life of the platform.

Appropriate data systems can be provided to support a platform development program and modest extensions of existing technology will allow these platforms to accommodate the evolution of payloads foreseen through the 1980's.

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INTRODUCTION

Science and Applications Space Platforms (SASPs), resulting from a conceptual design study conducted by the McDonnell Douglas Astronautics Company in 1980[1] and illustrated in Figure 1, promise cost-effective means for performing scientific and applications missions, e.g. , surveys of Earth resources, in low Earth orbit.

Payloads using these platforms can perform missions of longer duration than currently available to payloads mounted in the Shuttle's bay, and with a mix of objectives and operating characteristics, as well as where the payload mix on a platform changes periodically during the orbital life of the platform. These platforms will supply a centralized power source, command and data acquisition, communications, pointing and environmental services, and periodic Shuttle visits for maintenance work, replenishing consumables, and replacing payloads. The 1980 McDonnell Douglas Astronautics Company study of SASPs[1] projected the evolution of these platforms to proceed in two steps.

The first-order platform (Figure 2) provides both S- and Ku-band command and data links compatible with the Tracking and Data Relay Satellite System (TDRSS). The onboard command and data management system (CDMS) provides centralized data gathering and storage for high-rate scientific data compatible with Spacelab experiments. CDMS also provides centralized MACRO scheduling of payload experiments and monitoring of housekeeping data.

The second-order platform (Figure 3) grows to accommodate more and bigger payloads. In the area of communications and data management, the second-order platform provides the same S- and Xu-band capability, but has centralized data multiplexer and storage capability that is more responsive to the forecast requirements of future users and that uses the TDRSS in a more cost-effective manner. The latest developments in the technology are incorporated to provide improved ancillary data.

At that same time that platforms are expected to become a basic part of the Space Transportation System, payload sensors are expected to have increasingly larger bandwidths and hence will be capable of producing data at higher and higher rates. Figure 4 shows the past and projected growth in data acquisition for National Aeronautics and Space Administration (NASA) programs, with certain data-intensive payloads/ programs shown. This chart was presented by Dr. William P. Raney of NASA Headquarters at a recent conference of the American Institute of Aeronautics and Astronautics. The data projected for two possible SASP payload groups, identified as SASP-A8 and SASP-F5, have been added to the figure.

The SASP End-to-End Data System Study[2], Figure 5, was initiated to study the implications that science and applications space platforms might have regarding data, and to achieve the following three principal objectives:

1. Evaluate the capability of present technology and the TDRSS to accommodate the requirements of SASP payload users.

2. Optimize the SASP onboard command and data. management system (CDMS) to provide the maximum service to the user.

3. Assess the ability and availability of new technology to accommodate the evolution of SASP payloads.

The approach selected to meet these objectives was to start with results generated by earlier Marshall Space Flight Center (MSFC) studies and (1) survey industry and government to determine the status of and projections for key data system hardware elements, (2) configure a SASP data system based on current and near-term technology, (3) evaluate the performance of that data subsystem in support of two selected candidate SASP payload groups using the MSFC Data System Dynamic Simulator Facility, and (4) make recommendations for optimizing the system and for developing data system technology to support an evolving SASP program.

Two payload groups were selected for analysis on the basis that they were representative of an early first-order platform payload group and a late 1980's second-order platform group. Each group was selected because it appeared to present stressing requirements to the SASP data system. The payload groups, designated A8 and F5, were originally defined in the SASP Payload Accommodations Study[3]. The A8 payload group had a peak composite data rate of approximately 90 Mbps; F5's peak composite rate exceeded 200 Mbps.

USER REQUIREMENTS

During the study, the data requirements for 80 Spacclab payloads were examined to provide an envelope of peak downlink data rates. A set of 16 design reference missions (DRMs) from the NASA/MSFC Phase B Power Systems Study was also reviewed for downlink peak rate requirements. These requirements are summarized in Figure 6, which shows the cumulative percentage distribution of peak downlink data rates for the 80 individual payloads as well as for the 16 Power System DRMs.

The median data rate for the individual payloads is approximately 200 Kbps, the 90 percentile level is 30 Mbps, and the highest data rate is 120 Mbps (two synthetic aperture radar payloads). For the Power System DRMs, the peak data rate for any DRM was defined as the sum of the peak data rates for the individual payloads in the worst-case (from a data rate standpoint) payload group in that DRM. The mcdian DRM peak data rate is seen to be approximately 10 Mbps and the highest DRM peak rate is just less than 100 Mbps. The DRM included only some of the 80 individual payloads. This is why the highest DRM data rate is less than the highest individual payload data rate.

Command rates are of concern because of Spacelab experience, where you have a large mix of experiments requiring command uplinks, and because of the scheduling constraints associated with TDRSS forward links. However, examination of the SASP payload data base showed that most payload command requirements are for rates in the 1- and 2-Kbps range, with the highest rate defined as 25 Kbps (see Figure. 7).

Command error-correcting and verification requirements will tend to increase the effective channel bit rate that is needed. In addition, because SASP will carry several payloads and TDRSS forward link time may be a scarce resource, the SASP CDMS has baselined a 300-Kbps command channel for payload usage. Figure 7 also shows how time division multiplexing could be used to provide, in effect, a dedicated port with some fraction of the 300-Kbps capability. The payload’s use of this channel would be constrained only by TDRSS channel scheduling and overall platform command compatibility restrictions.

Figure 6 also shows the peak data rates for the A8 and F5 payload groups (Figures 8 and 9), which were the focus of this study. To allow data flow simulations for these two groups it was necessary to define operating timelines for each payload in each group. Figures 10 and 11 show the resulting timelines for A8 and F5, respectively.

Most of the data timelines are driven by predictable target occurrences (e.g., land, sunlit land, oceans). However, Solar Optical Telescope (SOT) is a notable exception in that the data rates are event driven; that is, the data rate is higher during a particular event of interest, a solar flare, which of course cannot be scheduled.

Figure 12 depicts the Reference Power System[4] CDMS as modified for this study. Modifications to the Reference Power System concept were made to accommodate the payload data requirements envelope and include the following changes:

1. Increase the KSA channel downlink data rate from 226 Mbps to 300 Mbps to match the maximum TDRSS data rate capability.

2. Add one, two, or three Spacelab-type high-data-rate recorders to provide a scientific data storage resource for payloads.

3. Substitute a current-technology high-rate multiplexer for the Spacelab HRM included in the Reference Power System CDMS. This last change was suggested because of the requirement to accommodate several payloads with rates at or exceeding 50 Mbps.

A conceptual design of the current-technology multiplexer was performed to ensure feasibility. The input-output requirements are shown in Figure 13. The multiplexer uses a two-tiered multiplexing scheme to accommodate the wide range of input data rates. Format flexibility is provided by using microprocessor control of the multiplexer operation. Formats are defined by instructions in the microprocessor memory, which can be a combination of ROM and RAM, allowing for both predefined formats and on-orbit format changes.

DATA SYSTEM ANALYSES

A8 Payload Group

The payload data outputs were assigned to the SASP high-rate MUX and low-rate MUX inputs as shown in Figures 14 and 15. Simulation ground rules were established that defined a TDRSS timeline generation methodology and the SASP data recorder operating rules.

Figure 16 depicts the TDRSS timeline simulation for 6 hours of the A8 simulation. The TDRS-E and TDRS-W line-of-sight (LOS) timelines for the A8 orbit were generated by the MSFC Resource Scheduler computer program. An A8 schedule block for TDRSS was placed within each LOS timeline block at a fixed time after initiation of LOS and with a fixed duration. For the A8 simulation, each scheduled TDRSS timeline block started 10 minutes after the start of LOS and lasted for 10 minutes. The TDRS-E and TDRS-W timeline allocations were combined to define the total TDRSS timeline allocation for A8. This resulted in two 10-minute blocks for typical orbits.

Figure 17 shows the nature of the simulation and some of the results of a 24-hour mission. The experiment MUX function combined the time-varying data streams from the payloads to produce a composite data stream with a mean rate of 15. 6 Mbps and a peak of 93.5 Mbps. The switch (SW) function routes the composite data stream directly to the output MUX and then to TDRSS when TDRSS is available (during a TDRSS schedule block). When TDRSS is not scheduled, the data stream is routed to a rate switch function. This function compares the data stream peak rate to the onboard recorder peak record rate (32 Mbps in this case). If the data stream rate exceeds the recorder rate, the data represented by the excess rate is considered to be lost; the data at 32 Mbps or less is routed to the tape-recorder function.

The data quantity going to the tape recorder is monitored by the simulator program. If the data quantity exceeds the recorder capacity, that excess data is considered lost. When TDRSS schedule blocks occur, the tape recorder is dumped to the output MUX simultaneously with real-time data at the maximum recorder output rate, and the data quantity currently stored on tape is reduced accordingly.

As shown in Figure 17, 19% of the A8 payload group data in a simulated 24-hour mission was transmitted in real time. Seven percent of the data was lost because it was acquired when TDRSS was not scheduled and at a rate in excess of the 32-Mbps storage capability. Another 12% of the data was lost because the tape recorder capacity was not sufficient. Sixty-two percent of the data was stored and dumped by the onboard tape recorder.

A review of the nature of the lost data indicated that it consisted almost totally of SOT payload data. SOT has a primary objective - the collection of data during solar flares. The SOT data output was modeled at 50 Kbps continuous output, a 5-Mbps output for 15 minutes before and 15 minutes after a solar flare, and a 50-Mbps output for 15 minutes during the flare event (see Figure 18). The simulation was set up to generate simulated solar flares at random times at an average rate of three every 24 hours. During the A8 simulation, three simulated flares occurred, none of which coincided with a TDRSS schedule block. Since the onboard storage system was not sized to handle this data, the data was lost.

Figure 19 summarizes the assessed data system performance for the A8 payload. The peak data rates were well within the SASP data and communication capabilities and are also well under the TDRSS KSA channel capacity. Data loss for the A8 payload group could be eliminated by either (1) TDRSS scheduling that ensures TDRSS availability during peak data acquisition periods, or (2) providing a modest improvement in onboard storage rate and capacity.

F5 Payload Group

The payload data outputs were assigned to the SASP high-rate multiplexer inputs, as shown in Figures 20 and 21. Figure 20 also shows the peak data rate produced by each payload. The processor (PROC) block was added to represent the data rate increase that may result due to source packetization of the data. It was assumed that the rate increase would be approximately 10%.

Figure 22 defines the parameters used in each of five simulations for the F5 payload group. The onboard storage record and dump rate, storage capacity, and the TDRSS timeline availability were varied as shown. In configuration C, the Ocean Synthec Aperature Radar (OSAR) payload was deleted on the basis that such an applications-oriented, high-data-rate, high-data-quantity payload may be more effective with its own dedicated data and communications system, thereby bypassing and offloading the SASP data and communications system and the TDRSS. Configuration D simulated the effect of reducing the OSAR and thematic mapper peak rates by a factor of 4 by the use of onboard data compression and reduction techniques.

Figure 23 summarizes the statistics for the five F5 simulations. As in the A8 case, peak data rates are within the SASP data system and the TDRSS capability. The total quantity of data produced by F5, however, proved to be stressing to the data system. Because of the total expected to be placed on the TDRSS resource, users will have to minimize their requirements for TDRSS time. This will require onboard data storage that can be dumped to TDRSS in a short time period, i.e., at a high data rate. For payloads like the OSAR and the thematic mapper in the F5 group, onboard data processing and reduction and compression techniques will be needed to prevent the large amounts of data from swamping the SASP data system, the TDRSS, and the ground data networks.

CONCLUSIONS

As can be seen from the results of the simulation on F5, new technology requirements include multiplexers and onboard storage and/or signal processing. The A8, although less stressing, also identified the need for increased onboard storage and larger multiplexing capability and, to a lesser degree, onboard signal processing would have helped. The primary driver behind this was the limited access to the TDRSS for single-access channels, which means that there will be long periods of time when it will not be possible to downlink data >50 Kbps. The reason behind the limited access is obvious in that the few number of channels must be shared with all spacecraft in low Earth orbit plus the Shuttle. In this regard, the SASP would help to alleviate the problem if the technology were available to support the desired configuration. Data compression (onboard signal processing) allows the useful and processed data to be stored for long periods of time, and then, when the TDRSS is accessible, a high storage reproduce rate will take maximum advantage of the TDRS bandwidth. This is illustrated for both F5 and A8 in Figures 24 and 25. Combining the candidate multiple payloads into an optimum data stream results in less TDRSS access time being required than if there were individual free-flyer payloads; this was considered to be one of the most significant advantages of the SASP.

For the technology items identified, our surveys show that the hardware will or could be available in the time frame considered to support the SASP-type of groupings; this will depend however, on the resources applied to the development of these items for onboard applications. The onboard storage devices currently being developed could be adapted for A8 usage with minimal cost and risk. To support the F5 type of data rates, a new, bigger onboard storage device would be required. The high-rate multiplexer on board is considered well within the state-of-the-art for onboard implementation, and minimal development should be needed to adapt existing DoD technology to the SASP requirements. Onboard signal processing is considered payload unique in its application, but for many of the candidate sensors the technology is being developed that could support data compression and editing onboard the SASP.

In addition to providing the advantages identified for the SASP, onboard signal processing solves another part of the end-to-end data system problem by eliminating large signal processing tasks at the ground stations and providing a more timely access to the data.

Data systems can be provided to support a SASP program. Modest extensions of existing technology will allow the SASP to accommodate the evolution of payloads foreseeable through the 1980s. However, careful system planning and extensive coordination are needed to ensure that the SASP data system evolves to meet user needs in a cost-effective manner.

ACKNOWLEDGEMENT

I would like to express my appreciation to my fellow workers who supported this efforts; P. R. Crawford and E. M. Nishikawal plus H. Golden, J. E. Mabry, and W. H. Funston, who supported us at Marshall Space Flight Center, and F. A. Wulff, at NASA Headquarters. I would also like to acknowledge the encouragement and support received from the Contracting Officer Representatives (OR's) at MSFC M. E. Nein, W. C. Snoddy and C. C. Priest. The total effort is documented in Reference 2.

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- MDAC Report - MDC G9372, "Science and Applications Space Platform (SASP) End-To-End Data System Study", Final Report. dated April 1981.

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- NASA Technical Memorandum - NASA TM- 78212 "25kW Power Module Updated Baseline System", December 1978 prepared by Marshall Space Flight Center.

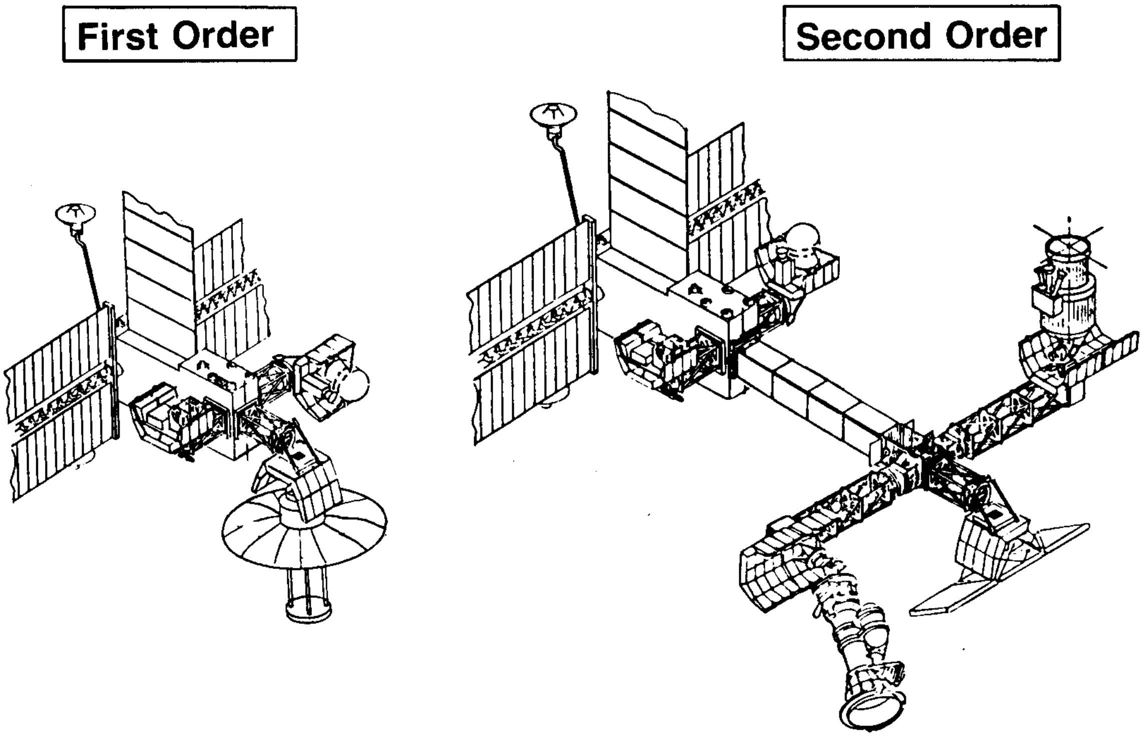


Figure 1. Basic Platform Family

COMMUNICATIONS AND DATA HANDLING

- TDRSS CAPABILITIES WITHIN PS LIMITATIONS
- SPACELAB EQUIVALENT MULTIPLEXING AND DATA STORAGE
- PS COMPUTERS PROVIDE EXECUTIVE CONTROL

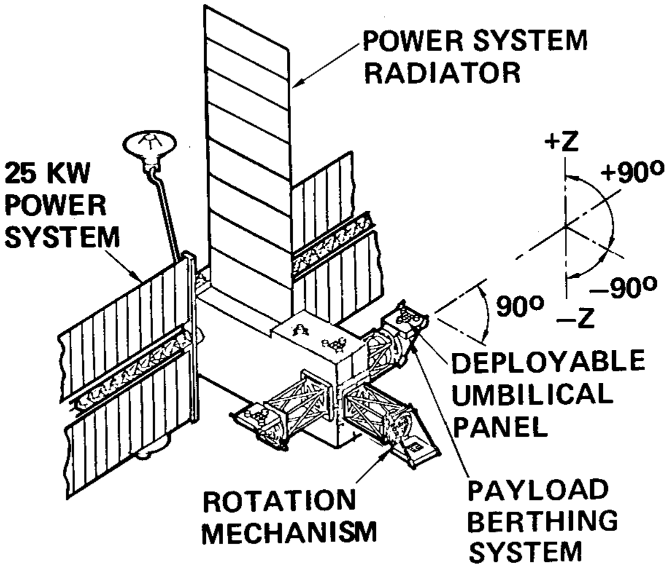
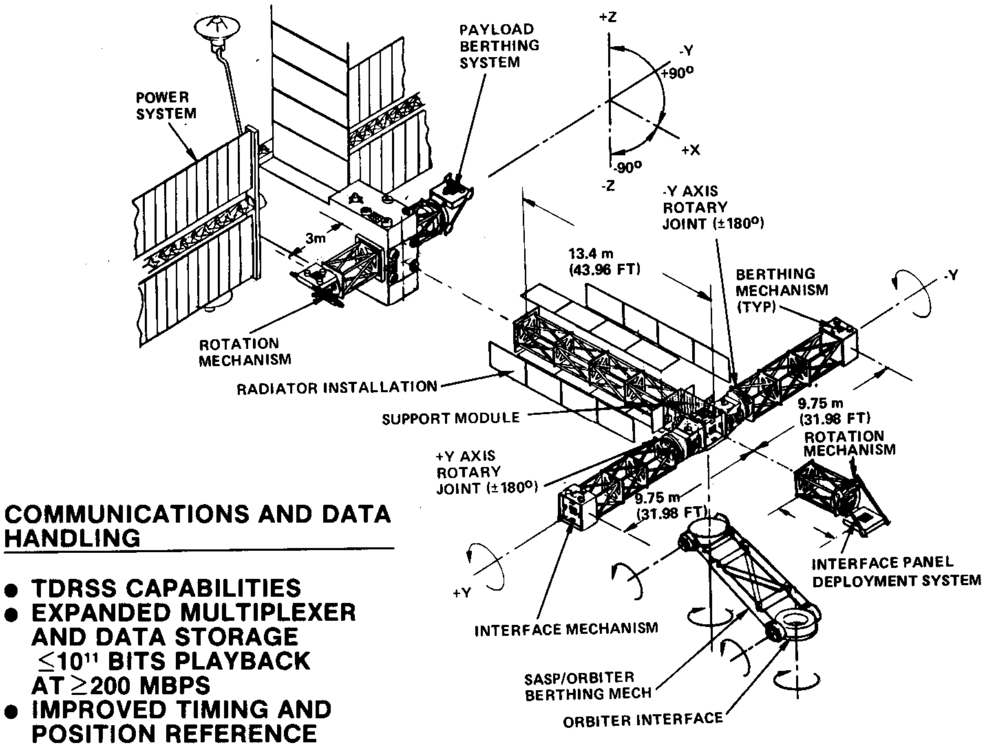


Figure 2. First-Order Platform



COMMUNICATIONS AND DATA HANDLING

- TDRSS CAPABILITIES
- EXPANDED MULTIPLEXER AND DATA STORAGE $\leq 10^{11}$ BITS PLAYBACK AT $\geq$200 MBPS
- IMPROVED TIMING AND POSITION REFERENCE

Figure 3. Second-Order Platform

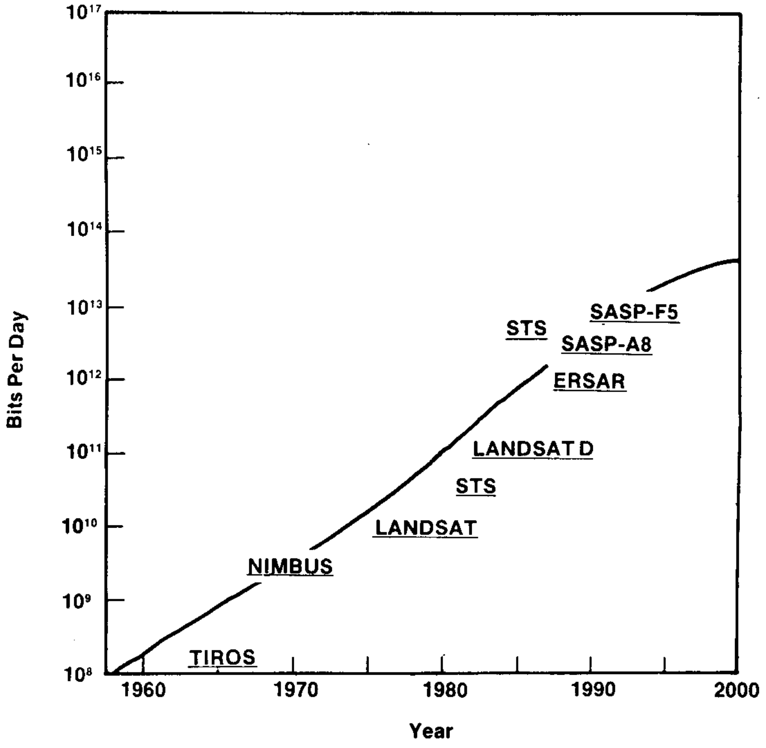
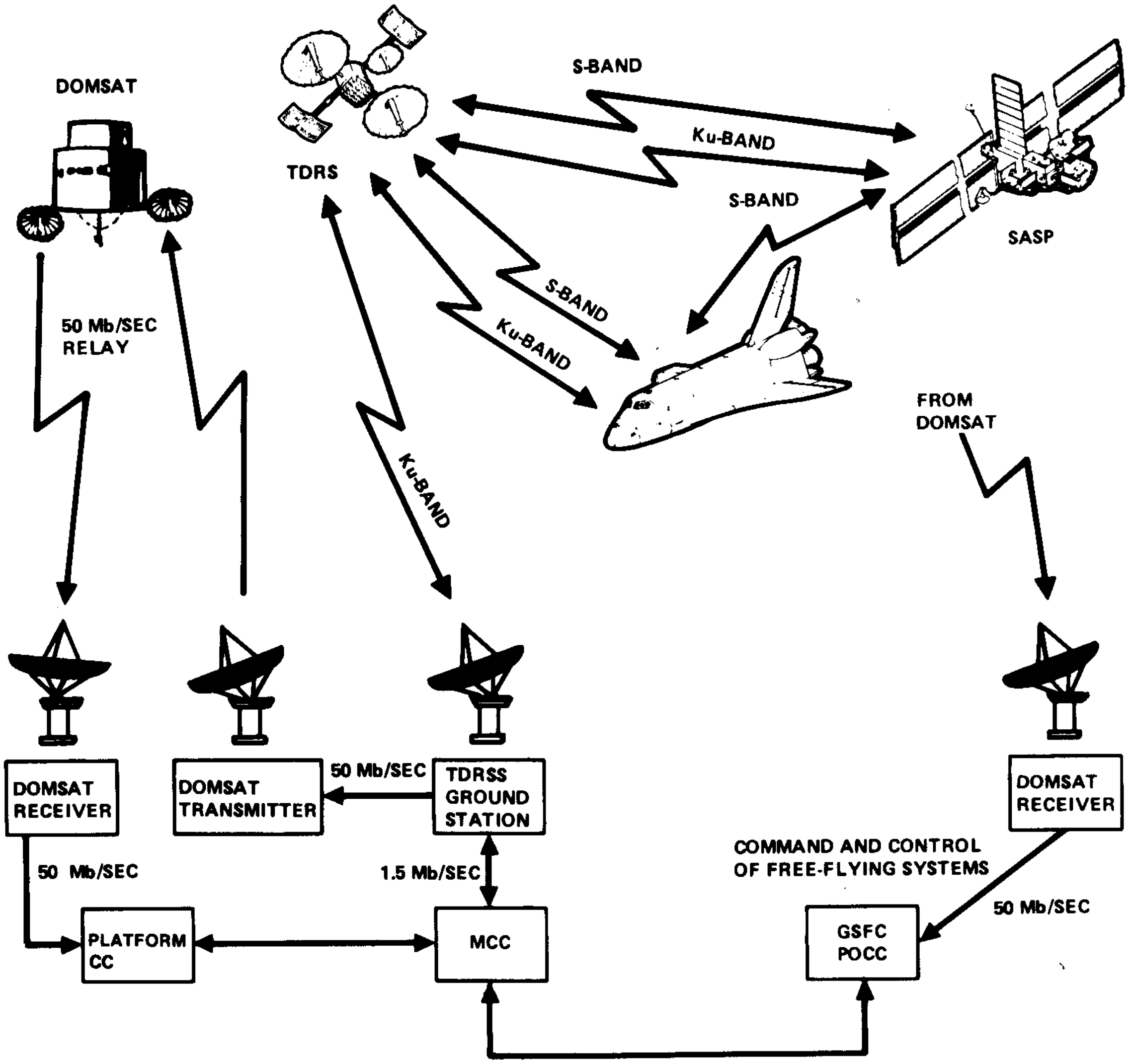


Figure 4. Data Acquisition Growth



Objectives

- Evaluate Capability of Present Technology and TDRSS to Accommodate SASP Payload Users Requirements
- Optimize SASP Onboard Command and Data Management System to Provide the Maximum Service for Users
- Assess the Ability and Availability of New Technology to Accommodate the Evolution of SASP Payloads

Figure 5. SASP Study Add-On: End-To-End Data System Study (Funded by Office of Space Tracking and Data System)

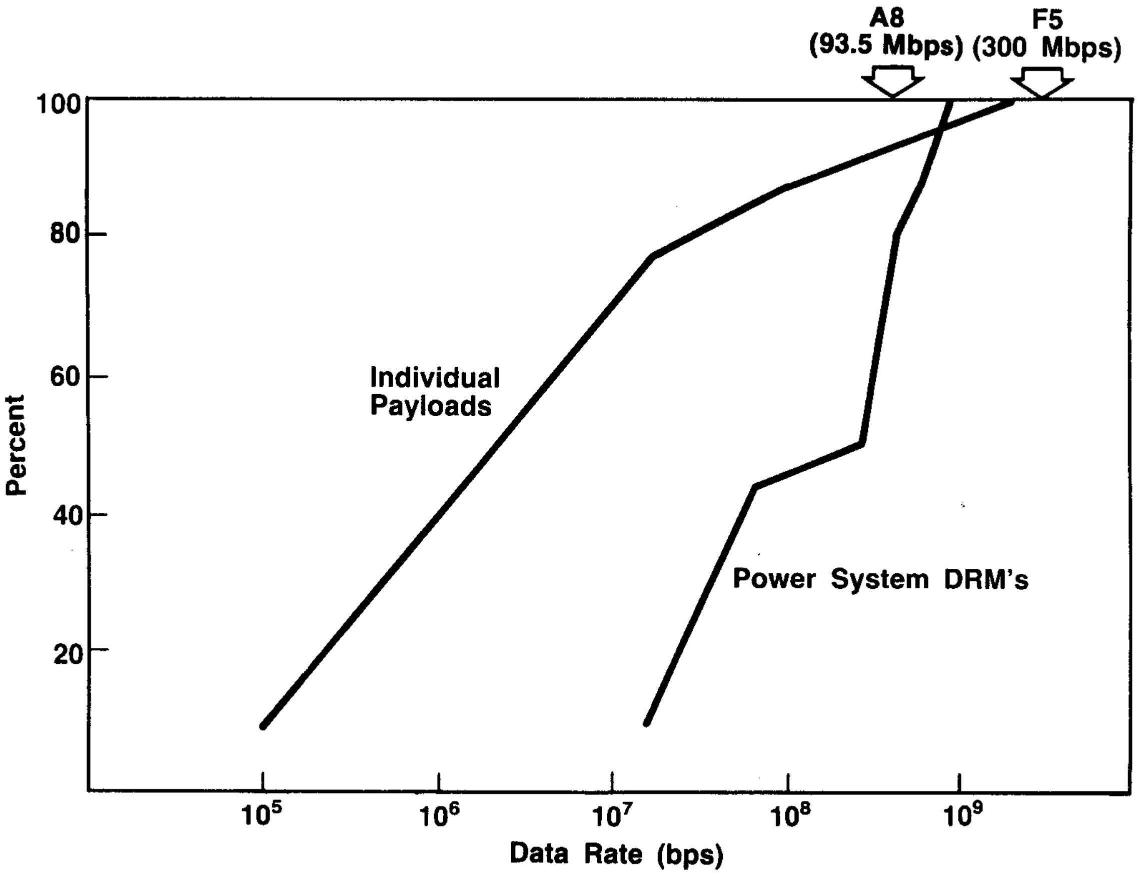


Figure 6. Distribution of Peak Data Rates

- SASP Payload Data Base
  - — Most Defined Requirements are in 1-2 Kbps Range
  - — Highest Rate Identified is 25 Kbps
- Need to Consider Simultaneous Command Requirements
- Ample Bandwidth Available
  - — TDRSS MA 10 Kbps
  - — TDRSS SSA 300 Kbps
  - — TDRSS KSA 25 Mbps
- Suggest Time Multiplexed Sharing of 300 Kbps SASP Command Link

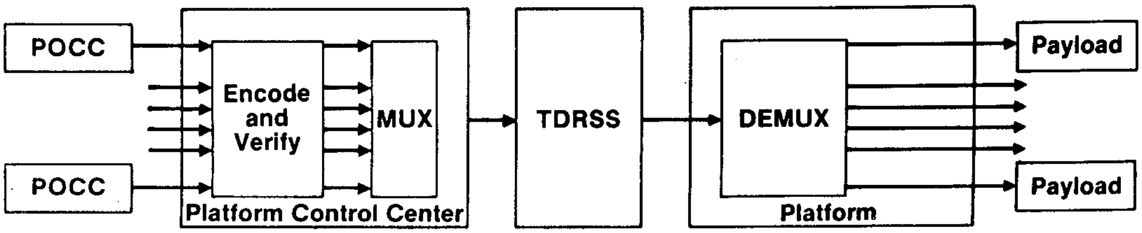
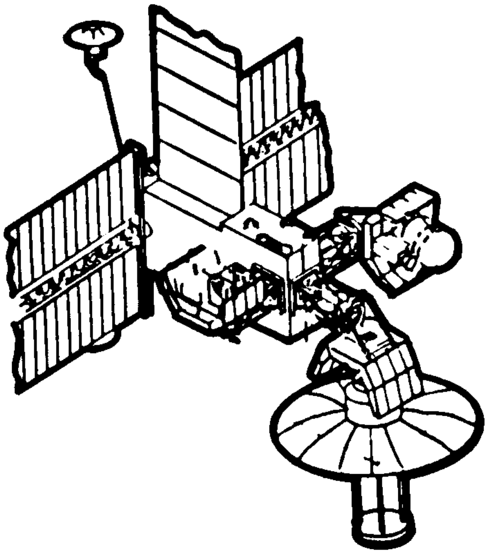
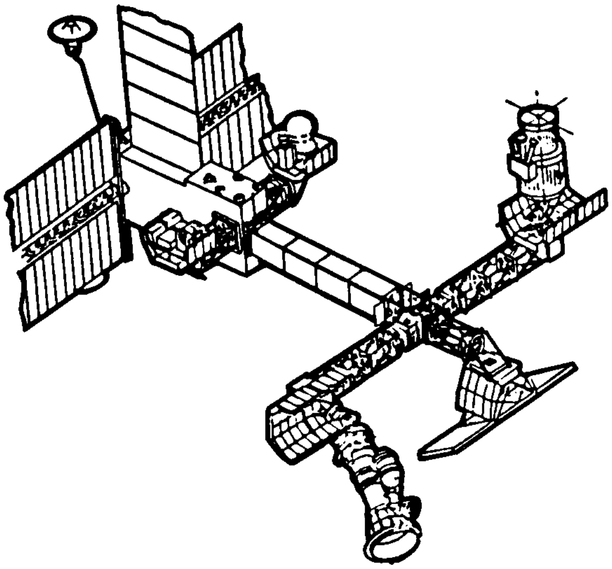


Figure 7. Command Link Data Rates



- First Order Platform
- 57°, 400 km Orbit
- Multidisciplined
  - Solar Physics
  - Resource Observations
  - Environmental Observations
  - ISPM Science Support
- 1987 Flight
- Payload Grouping Includes
  - EO-1
  - EO-2
  - RO-2
  - SOT
  - UARS

Figure 8. A8 Payload Group



- Second Order Platform
- 98°, 705 km Orbit
- 1989 Flight
- Applications Platform
- Payload Group Includes
  - RO-1
  - SMR-PA
  - LFS
  - MMIRI
  - UARS
  - OSAR

Figure 9. F5 Payload Group

EO-1	Target: Sun Operates Continuously Except During South Atlantic Anomaly. Instrument is Off When Electrons are >3 MeV With a Flux >10 Particles/cm^2
UARS	Target: Earth Takes 20 Minutes of Data When Activated. 50 Percent Duty Cycle Over Entire Orbit
RO-2	Target: Earth — Daylight Portion of Orbit 20 Kbps of Housekeeping Data Continuously; Additional 320 Kbps Data During Daylight Portion of Orbit
EO-2	Target: Earth 20 Kbps and 4.6 Mbps Continuous Data. 16 Mbps Data has 50 Percent Duty Cycle Over Entire Orbit at 20 Minute Intervals.
SOT	Target: Sun 50 Kbps Continuous; 5 Mbps has 4 Percent Duty Cycle (Sun Only). High Rate Data (60 Mbps) is Random Event Driven Occurring 3 Times a Day. 30 Minutes of 60 Mbps Data for Each Event.

Figure 10. A8 Data Timelines

RO-1
Thematic Mapper — Target: Earth
Data Rate: 85 Mbps
Duty Cycle: 2 Percent
Maximum Delay For Data Dump: Realtime if Possible or 1 Orbit
Specific Targets: Land Mass Over Continental U.S.

Spectroscopic Imaging System — Target: Earth
Data Rate: 32 Mbps Plus 2 Kbps (Housekeeping at 100 Percent)
Data Cycle: 17 Percent
Maximum Delay for Data Dump: 2 Orbits
Specific Targets: Land Mass on Sunlit Side

Multispectral Resource Scanner — Target: Earth
Data Rate: 30 Mbps
Data Cycle: 17 Percent
Maximum Delay for Data Dump: Realtime if Possible or 1 Orbit
Specific Targets: Sunlit Land Masses

Fraunhofer Line Discriminator — Target: Earth
Data Rate: 50 Kbps
Data Cycle: 21 Six Minute Observations at 10:00 am to 2:00 pm
(Standard Time of Nadir Observations)
Maximum Delay for Data Dump: No Restriction — Anytime
Specific Targets: Continental U.S. Land Mass

Figure 11-1. F5 Data Timelines

- SMR-PA
  - Target: Earth
    - Data Rate: 8 Kbps
    - Duty Cycle: 100 Percent
    - Maximum Delay for Data Dump: Realtime with 2 Orbits (Max.)
    - Specific Targets: Earth with Land Calibration
- LFS
  - Target: Earth
    - Data Rate: 100 Kbps
    - Duty Cycle: 32 Percent
    - Maximum Delay for Data Dump: 2 Orbits
    - Specific Targets: Dark Side Oceans
- MMIRI
  - Target: Earth
    - Data Rate: 30 Mbps
    - Duty Cycle: 50 Percent
    - Maximum Delay for Data Dump: Realtime if Possible or 1 Orbit
    - Specific Targets: All Land Masses
- UARS
  - Target: Earth
    - Data Rate: 50 Kbps
    - Duty Cycle: 61 Percent
    - Maximum Delay for Data Dump: 2 Orbits (Max.)
    - Specific Targets: Limb Solar Occulation and Earth
- OSAR
  - Target: Earth
    - Data Rate: 120 Mbps
    - Duty Cycle: 25 Percent
    - Maximum Delay for Data Dump: Realtime If Possible or 1 Orbit
    - Specific Targets: Oceans and Artic Ice, Anytime (Day or Night)

Figure 11-2. F5 Data Timelines

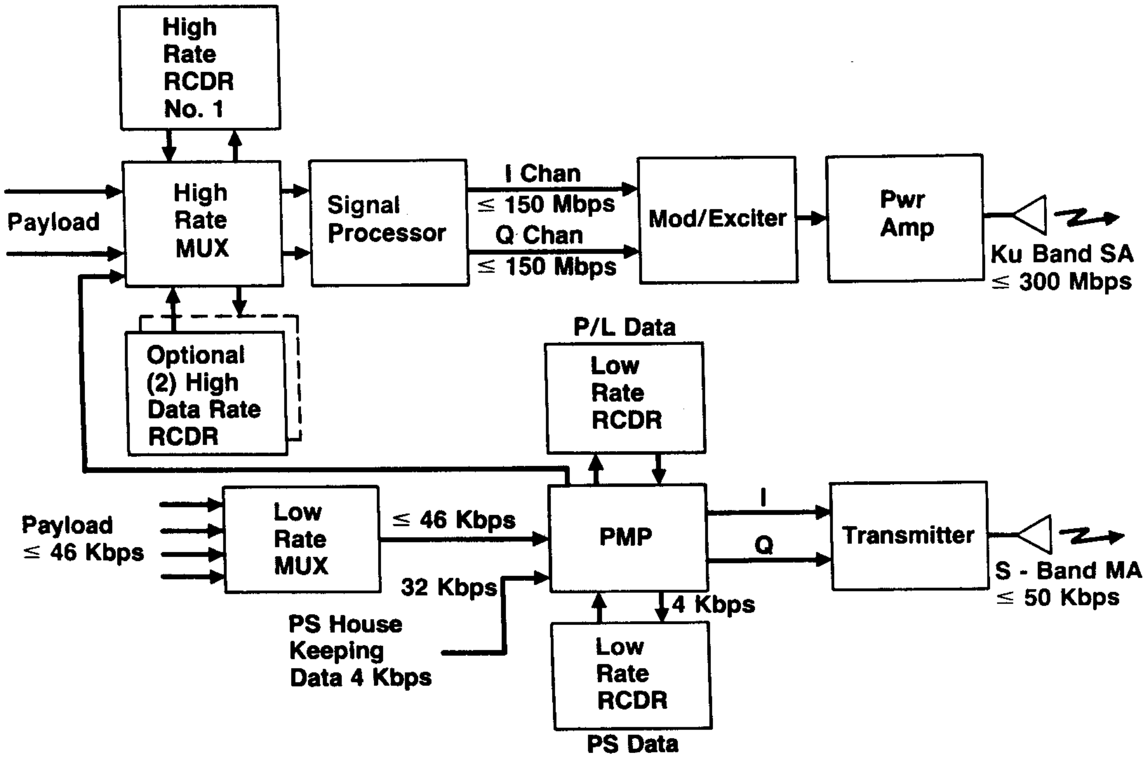


Figure 12. Modified NASA Reference Power System Data Subsystem

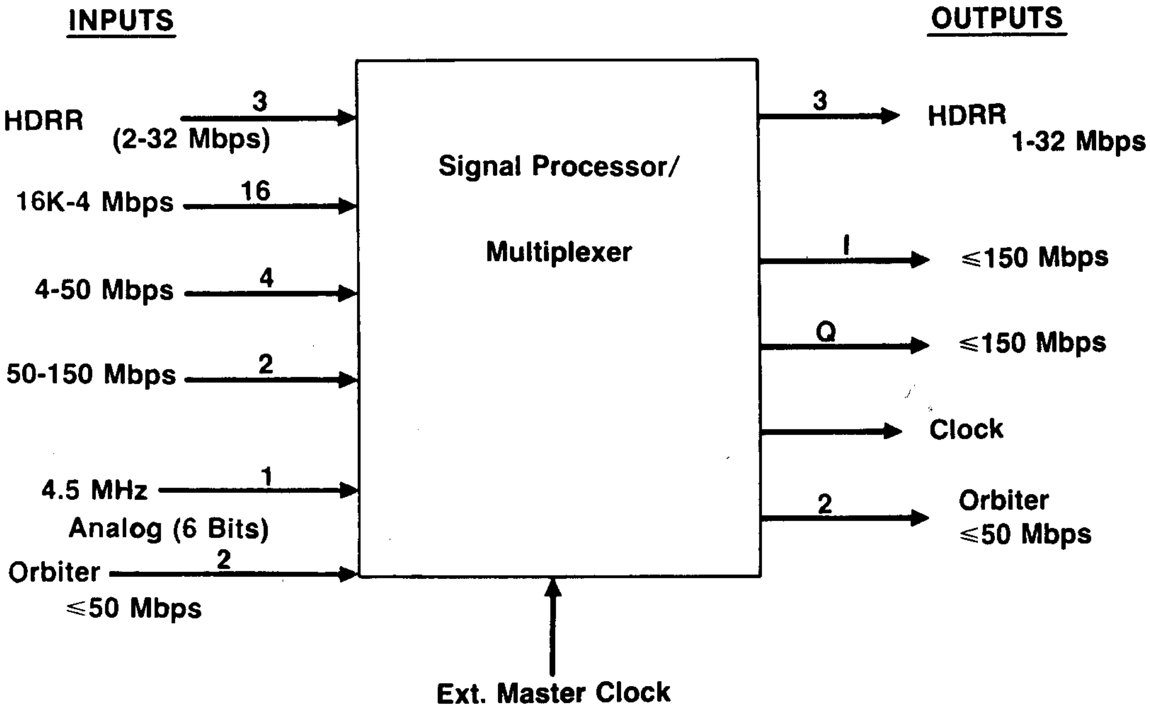


Figure 13. Simplified Multiplexer Diagram

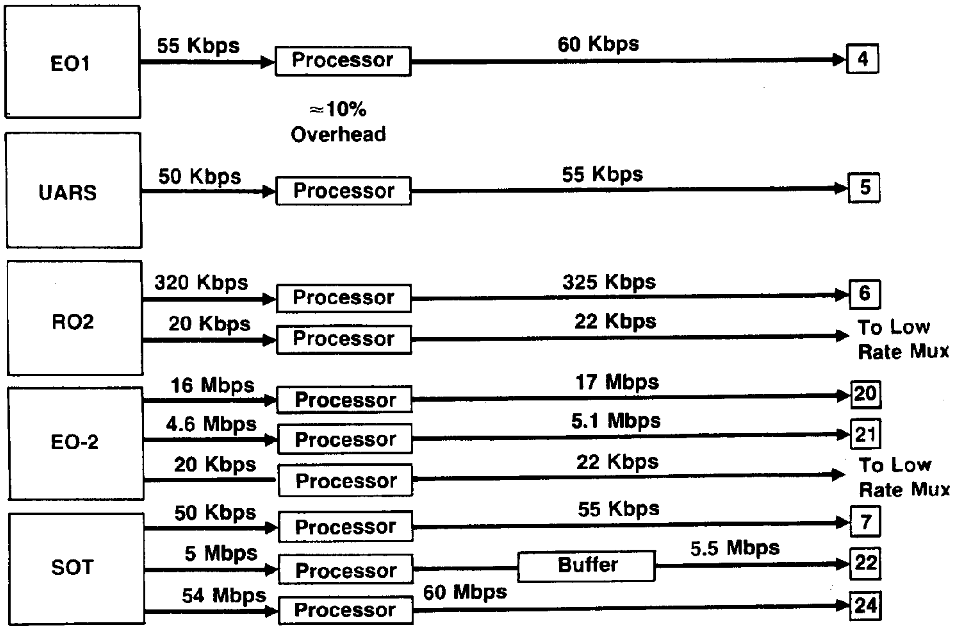


Figure 14. A8 Configuration Maximum Data Rates

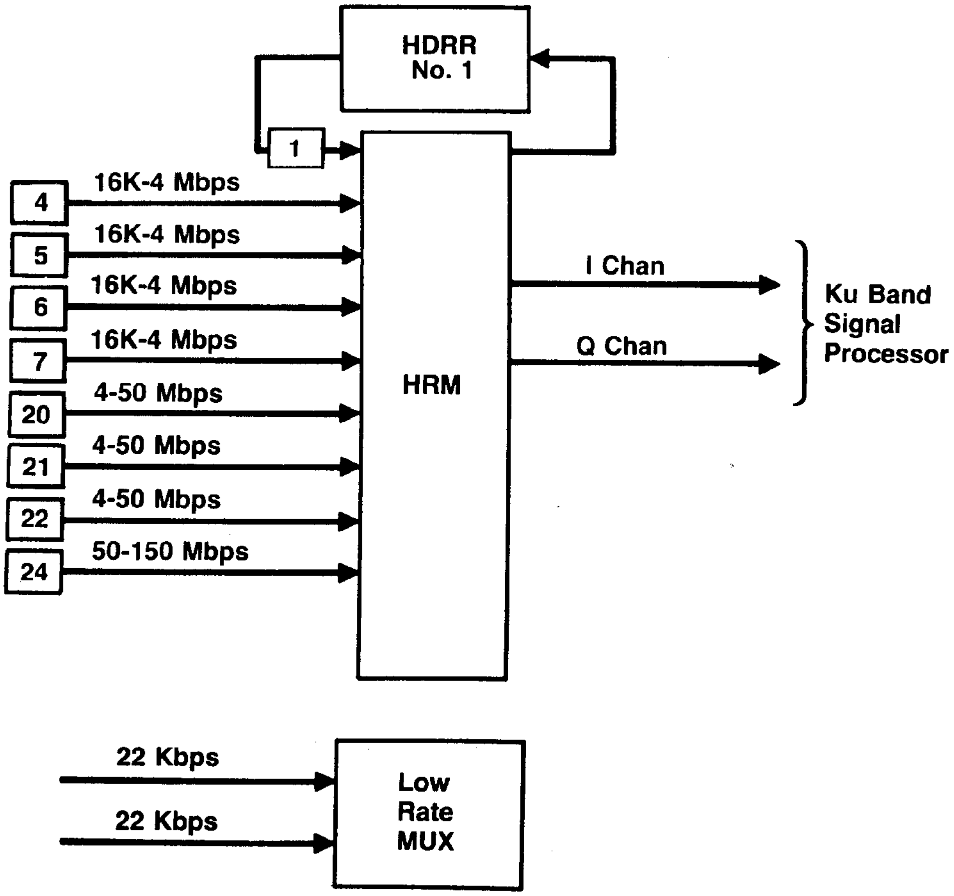


Figure 15. MUX Configuration for A8 Payload Group

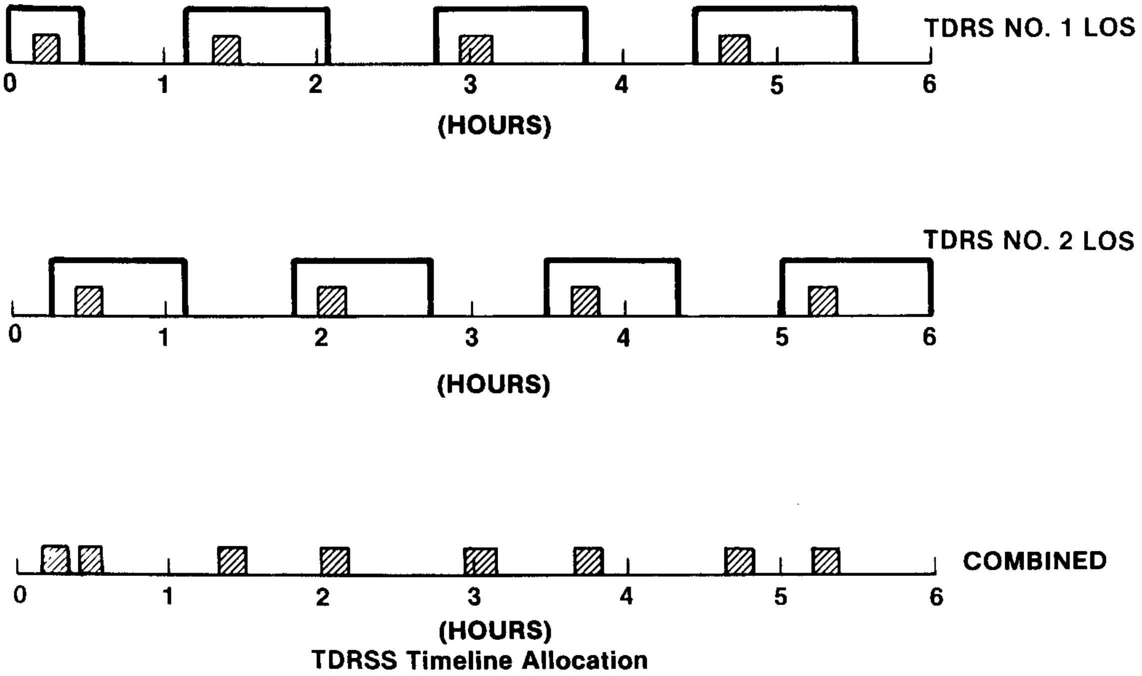


Figure 16 . A8-TDRSS Scheduling Simulation

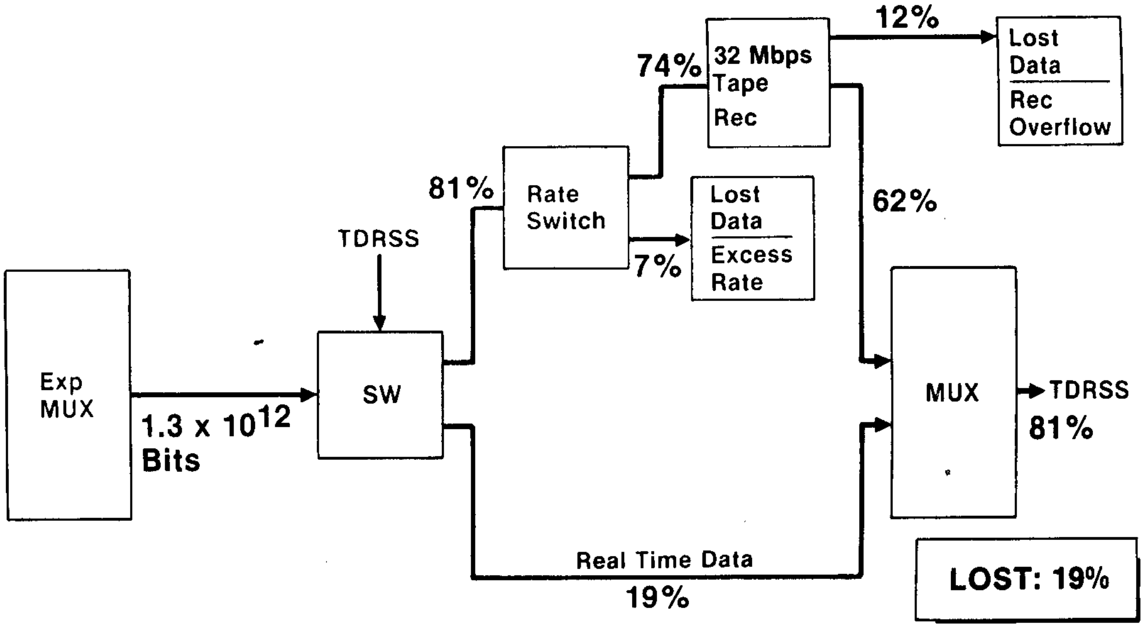


Figure 17. A8 Simulation (10 Min/Orbit TDRSS Time)

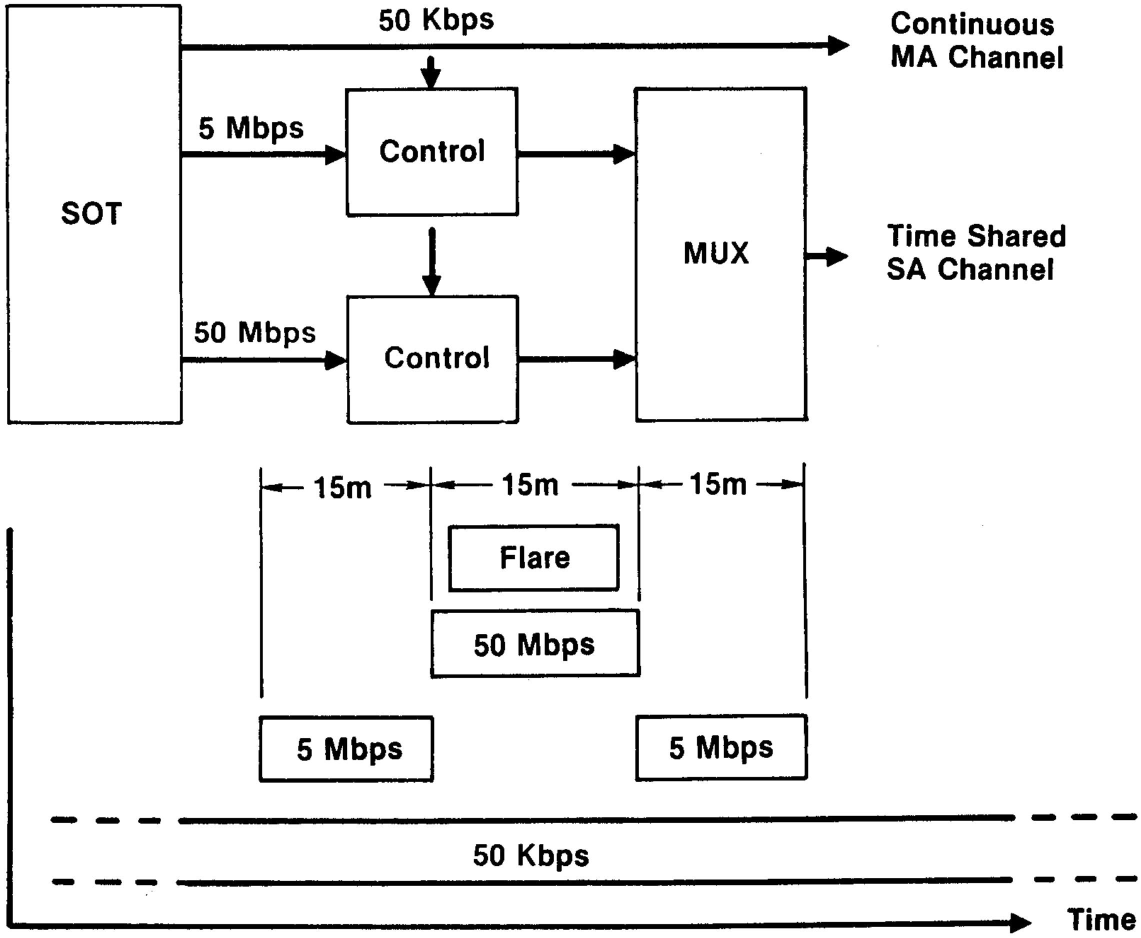


Figure 18. SOT Solar Flare Data Handling

- Peak Real-Time Data Rates Are Within SASP Data System Capability

- Data Loss Can Be Eliminated By

  - Improved Scheduling of TDRSS Access, Or
  - Modest Improvement in Recorder Capability

- Solar Flare Data Requires Special Consideration

  - Real Time Monitoring and Fast Response TDRSS Scheduling, Or
  - Onboard Data Evaluation and Capture

Figure 19. A8 Assessment

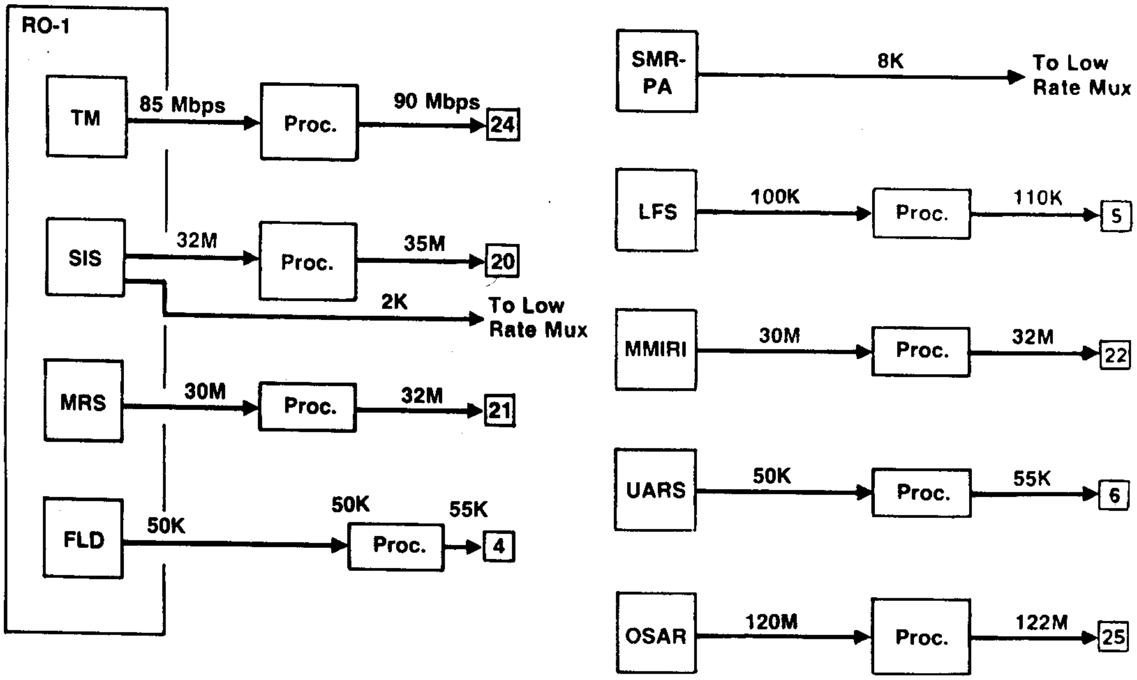


Figure 20. F5 Configuration Maximum Data Rates

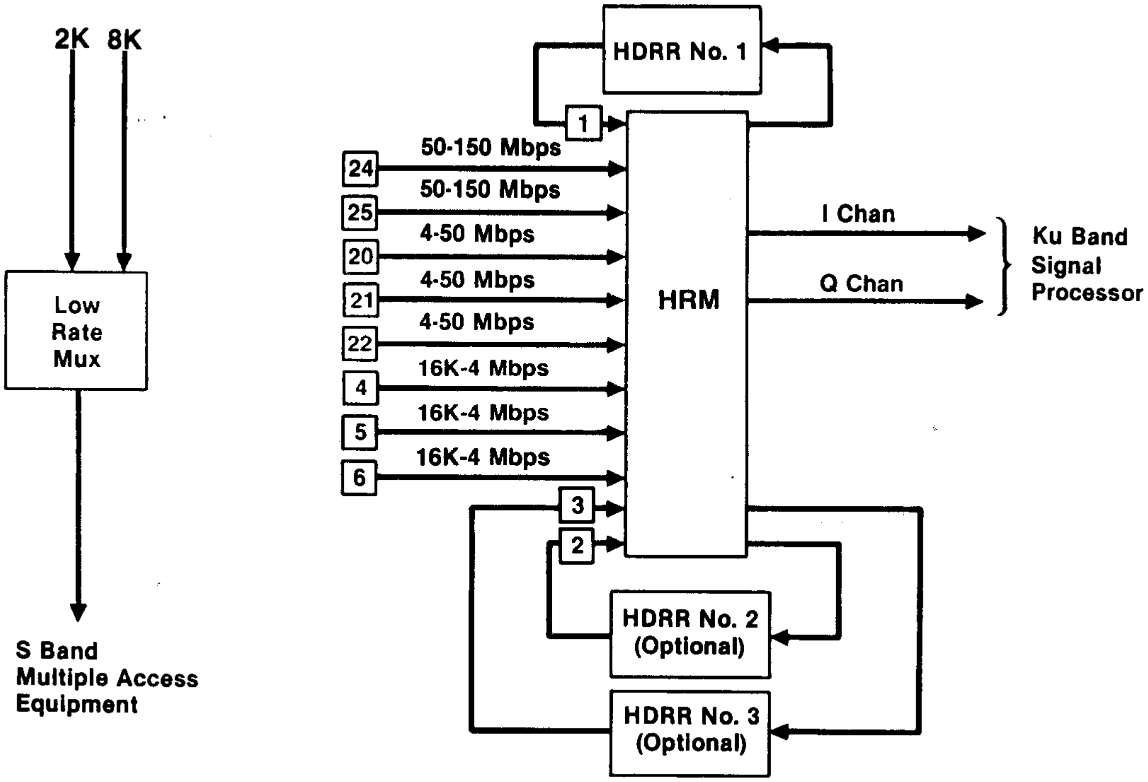


Figure 21. MUX Configuration for F5 Payload Group

Config-uration	Record/ Dump Rate	Record Capacity	Data Compression	TDRSS Available	P/L Configuration
Baseline	32 Mbps	3.8×10^{10}	—	20 Min	Full F5
A	64 Mbps	3.8×10^{10}	—	10 Min	Full F5
B	100 Mbps	3.8×10^{10}	—	7 Min	Full F5
C	100 Mbps	3×10^{11}	—	15 Min	Delete OSAR
D	100 Mbps	3×10^{11}	Reduce Pk Rates TM = 22.5×10^6 OSAR = 30.5×10^6	15 Min	Full F5

Figure 22. F5 Trade Studies

	Total Data Acquired (24 Hr)	% Transmitted In Real Time	% Recorded And Dumped	% Data Lost
Baseline F5	9.4×10^{12} Bits	36%	11%	53%
A	9.4×10^{12} Bits	20%	11%	69%
B	9.4×10^{12} Bits	12%	10%	78%
C	1.3×10^{12} Bits	38%	62%	0%
D	3.2×10^{12} Bits	31%	69%	0%

Figure 23. F5 Simulation Results

	Free Fyers (No Storage)	Free Flyers (With Storage)	SASP (32 Mbps (Storage)	SASP (100 Mbps Storage)
Data Transfer Time (Min/Day)	2295	682	594	329
Acquisition Time (Min/Day)	134	102	70	38
Total SA Time Req'd (Min/Day)	2429	784	664	367

Figure 24. SA Channel Utilization. A8 SASP versus Free-Flyers

	Free Flyers (No Storage)	Free Flyers (With Storage)	SASP (32 Mbps (Storage)	SASP (100 Mbps Storage)
Data Transfer Time (Min/Day)	1699	1259	480	308
Acquisition Time (Min/Day)	192	162	64	64
Total SA Time Required (Min/Day)	1791	1421	544	372

Figure 25 . SA Channel Utilization. F5 SASP N/O OSAR) versus Free- Flyers