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JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

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OUTER PLANET PIONEER IMAGING COMMUNICATIONS SYSTEM STUDY FINAL REPORT

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16 December 1974

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

FOREWORD

The purpose of this study was to determine the effects of employing an improved imaging system with progressively more sophisticated data compression techniques on the Outer Planet Pioneer Spacecraft.

The effects measured were on:

1) Mission value,
2) The Imager,
3) The Spacecraft Data System,
4) The Spacecraft System,
5) The Telecommunications System,
6) The Deep Space Network (DSN),
7) The Mission Control and Computing Center (MCCC), and
8) The Image Processing System (IPS).

The data compression techniques analyzed were:

1) No compression,
2) Pixel editing, and
3) A proposed Advanced Imaging Communications System (AICS).

The findings of the study are presented in this report.

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GLOSSARY

AICS	Advanced Imaging Communication System
ASD	Angular semi-diameter
BER	Bit Error Rate
CCD	Central Command Decoder
CMOS	Complementary metal-oxide semiconductor
DSN	Deep Space Network
DSS	Deep Space Station
DSU	Data Storage Unit
DTU	Digital Telemetry Unit Data Transmission Unit
EDR	Experiment Data Record
EOM	End of Memory
GCF	Ground Communication Facility
GS&E	General Science and Engineering
HSD	High-speed data
HSDL	High-speed Data Line
IB	Image Buffer
IDB	Image Data Buffer
IDOB	Image Data Output Buffer
IP	Information Processing
IPC	Image Processing and Control
IPL	Image Processing Laboratory
IPP	Imaging Photopolarimeter
IPS	Image Processing System
LSB	Least significant bit
MCCC	Mission Control and Computing Center
MDR	Master Data Record
MMOB	Mass Memory Output Buffer
MOS	Mission Operations System
MRO	Memory Read Out
MSB	Most significant bit

MTBF	Mean time between failures
MTF	Modulation Transfer Function
Mw/s	Mega words per second
NRZ	Nonreturn to zero
OB	Output buffer
ODR	Original Data Record
OPP	Outer Planet Pioneer
OPPICSS	Outer Planet Pioneer Imaging Communications System Study
PE	Pixel Edit
PLSI	Pioneer Line Scan Imager
RAM	Radio Attenuation Measurement Project
RC	Rate Controlled
RM 2	Rice Machine No. 2
R-S	Reed-Solomon
SB	Source block
S/C	Spacecraft
S/E	Spacecraft to Earth
SNR	Signal-to-noise ratio
SPSG	Spin period sector generator
TTL	Transistor-transistor logic
WBDL	Wide band data line

STUDY REFERENCES

1) Reilly, T., Pioneer Line Scan Imager Functional Definition (a revised version will be issued early in 1975), Jet Propulsion Laboratory, Pasadena, Calif., July 12, 1974.

2) Rice, Robert F., Channel Coding and Data Compression System Considerations for Efficient Communication of Imaging Data, Technical Report 33-695, Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1974.

3) Rice, Robert F., RM2: Transform Operations, Technical Report 33-680, Jet Propulsion Laboratory, Pasadena, Calif., March 1, 1974.

4) Rice, R. F. and Plaunt, J. R., Adaptive Variable Length Coding for Efficient Compression of Spacecraft Television Data, IEEE Transactions on Communication Technology, Vol. COM-19, Part 1, December 1971, pp 889-897.

5) Odenwalder, J. P., Concentrated Reed-Solomon/Viterbi Channel Coding for Advanced Planetary Missions, Linkabit Final Report to JPL on Contract 953865, December 1974.

6) Odenwalder, J. P., Hybrid Systems Coding Study, Linkabit Final Report to Ames Research Center on Contract NAS 2-6722, September 1972.

7) Layland, J., A Model for Sequential Decoding Overflow Due to a Noisy Carrier Reference, Proceedings of the 1974 International Telemetering Conference.

PART 1

SUMMARY

A. BACKGROUND

Over the past several years, there have been three independent but mutually supportive advanced developments which have contributed to the initiation of the Outer Planet Pioneer Imaging Communications System Study (OPPICSS).

These developments have been:

1) The Advanced Imaging Communications System (AICS), an advanced data compression system for transmitting planetary images.
2) The Pioneer Line Scan Imager (PLSI), an advanced imaging device for the Pioneer spacecraft.
3) The Outer Planet Pioneer Spacecraft (OPPS), a functional design of an advanced Pioneer spacecraft.

The first of these advanced developments (AICS) deals with the compression of imaging data transmitted from unmanned planetary spacecraft. Since 1970 a research and development group[1] at the Jet Propulsion Laboratory (JPL) has been investigating the feasibility of reducing the data content of planetary images by factors of 1 to 32 while retaining varying degrees of information fidelity. After extensive analysis, the group had felt that it had developed a data compression and data transmission method which could significantly enhance future imaging mission returns with a minimal impact on other elements of the planetary data system. A brief description of AICS can be found in Appendix D, and a more detailed description in JPL TM 33-695.

[1]The Measurement Processor Development Group in the S/C Measurement Section (362).

Since 1973 this group has been specifically addressing the possible application of AICS to future Pioneer missions and has concluded that the development appears attractive enough to warrant a broader-based examination of the effects of AICS on other elements of the end-to-end data system. It was primarily this conclusion of the AICS group that led to the initiation of the OPPICS Study.

The second development which has influenced this study has been the developmental effort on the part of another group of researchers[2] at JPL who have been in the process of designing an improved imaging system for the Pioneer spacecraft. The Pioneer Line Scan Imaging system development, which was started in 1972, has reached a state of maturity comparable to that of AICS and, as such, it was felt that the PLSI would serve as a useful baseline imaging device for the OPPICS Study.

The third development having an influence on the conduct of this study was TRW's preliminary design of an improved version of the Pioneer spacecraft (sponsored by Ames Research Center) called the Outer Planet Pioneer Spacecraft. One of the major differences between the new design and Pioneer 10/11, is a significant improvement in telemetry, data handling, storage, and transmission rate capability of the OPPS. It was felt that this spacecraft was a likely candidate to carry an improved imager and as such was also used as a baseline spacecraft for the OPPICS Study.

The relative similarity in the state of development of the three activities listed above has naturally led to the establishment of a broader-based end-to-end data systems team (OPPICSS) whose purpose was to assess the impact of combining these developments on future Pioneer missions. The remainder of this report will describe in some detail the objectives, scope, progress, conclusions, and recommendations of the Outer Planet Pioneer Imaging Communications System Study.

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[2] A group in the Space Photography Section (821).

B. STUDY OBJECTIVES AND ASSUMPTIONS

1. Statement of Work

Based on a recommendation made by the AICS group, Ames Research Center (ARC) requested that the Jet Propulsion Laboratory, with support from TRW and ARC, conduct a study to determine the effects of different types of imaging data compression on the elements of the Pioneer end-to-end data system.[3]

Figure 1-1 is a summary of the OPPICS Study characteristics. A detailed statement of work is provided in Appendix A.

The phrase "progressively more sophisticated data compression techniques" was included in the statement of work by ARC in an attempt to determine what the driving functions are for value, complexity, and cost as a function of data compression level and technique.

2. Study Approach

It was recognized at the outset that the scope of the study, unless kept in bounds, would be so overwhelming as to preclude any definitive conclusions. In an attempt, therefore, to make the study task manageable, the following study approach was taken:

1) The end-to-end data system was defined to include all elements affected by imaging telemetry and imaging commands, and a representative from each of the affected areas was identified and made a member of the OPPICSS Team.

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[3] As referred to in this document, the end-to-end data system consists of:

1. The science instruments (the PLSI and other general science instruments)
2. The spacecraft system (the OPPS)
3. The telecommunications system
4. The Deep Space Network (DSN)
5. The Mission Control and Computing Center (at JPL)
6. The Mission Control Center (at ARC)
7. The Image Processing System (at JPL)
8. The Mission Operations System (at JPL and ARC)

PURPOSE: "...to perform a parametric end-to-end data system study to assess the overall value, effects, and implications of utilizing progressively more sophisticated imaging data compression techniques for the outer planet Pioneer spacecraft."

SPONSOR: Ames Research Center

PARTICIPATION: Ames Research Center, TRW, JPL

SCHEDULE: start: 10 June 1974, end: 31 October 1974 (5 mos.)

GUIDELINES: consider three imaging transmission methods:

1. No data compression (baseline)
2. Moderate data compression (bit or pixel editing)
3. AICS (study emphasis)

TEAM MEMBERSHIP:

Study Area	Org	Name
Study Leader	36	T. Gottlieb
Documentation	65	H. R. Baerg/J.Y. Pedigo
ARC Representative	ARC	L. Edsinger
Mission Design	39	A.M. Goldman
Pioneer S/C Systems	TRW	K. Heist/C. Renn
S/C Imaging & Science Value	82	T. H. Reilly
S/C Data Processing	36	R. Piereson
Telecom Systems	33	J.H. Yuen
DSN	41	A.J. Spear/E.C. Gatz
MCCC	91	R. Durstenfeld/J.R. Schoeni
MOS (ARC)	ARC	E. Levin
MOS (JPL)	29	D.C. Card
Image Processing	82	J.M. Soha

END-TO-END DATA SYSTEM: Science payload, S/C, telecom, DSN, MCCC, IPS, MOS (ARC & JPL)

Figure 1-1. Summary of OPPICSS Characteristics

2) A sample mission was selected in order to permit a more meaningful application of the different data compression techniques. The mission selected was a 1980 Saturn/Uranus mission with an entry probe at Saturn and including both planetary and satellite investigations at Saturn and Uranus. The sample mission was selected to: (a) be typical of a Pioneer class of missions, and (b) place emphasis on the imaging data transmission characteristics of the mission, i.e., Saturn at 10 AU, Uranus at 20 AU. A summary of the key mission characteristics is provided in Figure 1-2.

3) An attempt was made, through a number of tutorial sessions, to familiarize all of the team members with the salient features of the study. This was of particular concern in this study since most study team members were not familiar with the PLSI, AICS, or OPPS and, furthermore, were members of three different organizations (ARC, TRW, and JPL).

4) It was also recognized that because of the interdependence of the various elements of the end-to-end data system, a design team format was most desirable for the conduct of the study. In order to minimize the travel inconvenience of different members of the team, meetings were held once per week at JPL.

5) It was further agreed that the most desirable study procedure was to first consider the uncompressed data compression case, then the moderate data compression case, and finally the AICS case (placing study emphasis on the AICS case). A summary of the study plan, with achieved completion dates is presented in Figure 1-3.

3. Study Objectives Not Met

Although most of the objectives stated in the statement of work and many other unspecified objectives were met, there were two that were not. Their status is described below.

MISSION:	1980 SATURN/URANUS
LAUNCH DATE:	26 NOVEMBER 1980 TO 10 DECEMBER 1980
SPACECRAFT WEIGHT:	476 kg (1050 lb)
LAUNCH PERIOD:	15 DAYS
LAUNCH VEHICLE:	TITAN/CENTAUR TE-364-4
SATURN ENCOUNTER:	0224 GMT 5 JANUARY 1984 (3.1 yr)
SATURN ENCOUNTER RADIAL DISTANCE:	165,000 KM (2.73 R_S)
SATURN-EARTH DISTANCE AT ENCOUNTER:	10.30 AU (1.54 X 10^9 km)
EARTH OCCULTATION BY OUTER RING:	ENTER 0420 GMT, EXIT 0842 GMT (5 JAN '84)
EARTH OCCULTATION BY SATURN:	ENTER 0544 GMT, EXIT 0828 GMT (5 JAN '84)
SUN OCCULTATION BY OUTER RING:	ENTER 0410 GMT, EXIT 0744 GMT (5 JAN '84)
SUN OCCULTATION BY SATURN:	ENTER 0513 GMT, EXIT 0743 GMT (5 JAN '84)
SATURN PROBE SEPARATION:	2.42 X 10^7 KM (<400 R_S)
BUS-PROBE COMMUNICATION RANGE:	110,000 TO 160,000 km
URANUS ENCOUNTER:	1200 GMT 9 NOVEMBER 1987
URANUS ENCOUNTER RADIAL DISTANCE:	94,500 KM (3.5 R_U)
EARTH OCCULTATION:	ENTER 1346 GMT, EXIT 1519 GMT (9 NOV '87)
SUN OCCULTATION:	ENTER 1354 GMT, EXIT 1530 GMT (9 NOV '87)
URANUS-EARTH DISTANCE AT ENCOUNTER:	20.01 AU (2.995 X 10^9 km)

Figure 1-2. Summary of OPPICSS Mission Design Parameters

STUDY MILESTONE	PLAN	ACTUAL COMPLETION
1. DEFINE STUDY MISSION PARAMETERS	BY 1 JULY	28 AUGUST
2. ORIENT MEMBERS OF THE TEAM	BY 15 JULY	15 SEPTEMBER
3. COMPLETE BASELINE ANALYSIS	BY 1 AUGUST	15 AUGUST
4. CONDUCT MIDSTUDY REVIEW	BY 30 AUGUST	15 AUGUST
5. COMPLETE INTERMEDIATE ANALYSIS	BY 1 SEPTEMBER	1 SEPTEMBER
6. COMPLETE AICS ANALYSIS	BY 1 OCTOBER	15 OCTOBER
7. COMPLETE STUDY	BY 31 OCTOBER	31 OCTOBER
8. CONDUCT FINAL REVIEW	BY 31 OCTOBER	5 DECEMBER
9. COMPLETE DOCUMENTATION	BY 15 DECEMBER	15 DECEMBER (PROJECTED)
SUPPORTING DOCUMENTATION		
1. RM2 TRANSFORM	BY 15 MAY	1 MARCH
2. IMAGE COMMUNICATIONS SYSTEM REPORT	BY 1 JULY	15 JUNE
3. LINK-A-BIT STUDY REPORT	BY 15 JULY	DRAFT RECEIVED 31 OCTOBER
4. RM2 TECHNICAL DESCRIPTION	BY 20 SEPTEMBER	NOT DOCUMENTED DUE TO NEW TRW MEMORY IMPLEMENTATION (ORAL PRESENTATIONS PROVIDED)

Figure 1-3. Summary of OPPICSS Progress

1) It was initially intended that a science value study be performed as part of OPPICSS in an attempt to determine the acceptability and scientific value of different methods and levels of data compression. Because, upon detailed examination, this task was more ambitious than intially envisioned, it was not performed. A detailed description of the situation and a proposed plan for the execution of this study is presented in Appendix B.

   Although, as stated above, a rigorous science value study was not performed, a mission value estimate was made by the OPPICSS Team. It is expected that the science evaluation will establish the acceptable data compression ratios for various transmission systems but should not materially affect the mission value analysis performed in this study.

2) Prior to the study it was also assumed that ARC would provide Mission Control Center and Project Engineering support to the Study Team. Although representatives from these areas were provided, their participation in the OPPICS Study was limited due to higher priority support required for Pioneer 11 encounter preparations. Furthermore, the study support anticipated from JPL in the area of MOS also failed to materialize. As a consequence, the effects of the different forms of data compression on the MOS (at ARC and JPL) has not been treated. Certain necessary mission design assumptions were made, however, by the Study Team and reviewed by ARC (see Section D). An MOS study plan that can be carried out at some time in the future is presented in Appendix K.

4. Study Assumptions

In an attempt to realistically evaluate the effects of the three imaging transmission modes on each element of the end-to-end data system, a number of assumptions were made. These are summarized below.

a. General Assumptions

1) Mission lifetime and reliability considerations would be addressed outside of the OPPICS Study.

2) Adherence to NASA Telecommunications Standards format requirements would be handled outside of this study. Deviations from the standards would, however, be identified (see Appendix C).

b. Mission Related Assumptions

1) A 1980 Saturn/Uranus mission was assumed with a Saturn entry probe. A summary of the mission characteristics is presented in Figure 1-2, and a detailed explanation of the mission parameters is provided in Part 2, Section I, of this report.

2) The following science payload/experiments were assumed. A more detailed discussion of the payload is presented in Part 2, Section I.

Pioneer line scan imager (PLSI)
Ultraviolet photometer (UVP)
Ultraviolet spectrometer (UVS)
Infrared radiometer (IRR)
Infrared spectrometer (IRS)
Helium vector magnetometer (HVM)
Plasma analyzer (PA)
Charged particle detectors (CPD)
Cosmic ray telescope (CRT)
Geiger tube telescope (GTT)
Trapped radiation telescope (TRT)
Asteroid/meteoroid detector (AMD)
Meteoroid detector (MD)
Earth occultation
Celestial mechanics
Probe payload

3) It was assumed that a telemetry data rate of at least 256 bits/sec was required for general science and engineering for each phase of the mission.

c. End-to-End Data System Assumptions

The following assumptions relating to the end-to-end data system were made at the start of the OPPICS Study:

1) The baseline imaging device was the PLSI as described in Section II of Part 2 of this report. A summary of the PLSI characteristics is shown in Figure 1-4.
2) The baseline spacecraft was the Outer Planet Pioneer spacecraft with the following exceptions.

   a) A 23-watt X-band TWT was assumed.
   b) A Saturn probe support capability was assumed, as described in Section I of Part 2 of this report.

   A summary of the OPPS data system characteristics compared to Pioneer 10/11 is shown in Figure 1-5.
3) A summary of the assumed DSN characteristics is shown in Figure 1-6. A more detailed description of the DSN can be found in Part 2, Section VI.
4) A summary of the assumed MCCC characteristics is shown in Figure 1-7. A more detailed discussion of the MCCC may be found in Part 2, Section VII.
5) A summary of the assumed IPS characteristics is shown in Figure 1-8. A more detailed discussion of the IPS can be found in Section VIII of Part 2.
6) It was assumed that all MOS activities and ground data processing would be performed at ARC's Mission Control Center with the exception of (1) Tracking data processing and (2) Imaging data processing. Tracking data processing was not treated in this study.

Telescope	Catadioptric, 10-cm aperture, 22.9-cm length
IFOV	100 μr square per photodetector
Image Width	160 pixels/line at normal sample rate 80 pixels/line at low sample rate
Image Length	160 lines/CHIP (1, 2, or 3 overlapping CHIPS) 320 lines/CHIP (1 or 2 overlapping CHIPS) 640 lines/CHIP (single CHIP only)
Spectral Bands	Channel 1 600 - 1000 nm Channel 2 400 - 1000 nm Channel 3 400 - 500 nm
Calibration	Tungsten filament lamp, Solar diffuser
Sensors	Three CCD self-scanned line arrays operated in image motion compensation mode
Look Angle Range	2.88-radian range, 170 mr from antenna axis to 85 mr from anti-antenna axis
Look Angle Step	0.5-mr/step, 3 steps/sec slew rate, minimum increment of 4 steps
Output Data:	
Housekeeping	16 words, 8 bits/word
Video	160 word/line, 8 bits/word (normal rate) 80 words/line, 8 bits/word (low rate)
Engineering	10 analog test point voltages
Analog/Digital Conversion	8 binary bit/pixel, equal increment
Output Data Rate	8-bit parallel word output, 946 K word/sec max 59 K word/sec min
Data Quantity	Minimum frame size = 102400 bits /roll (low rate) Maximum frame size = 819200 bits/roll
Commands	67

Figure 1-4. Summary of Assumed PLSI Characteristics

SUBSYSTEM	CHARACTERISTIC	PIONEER 10/11	OUTER PLANETS PIONEER
COMMAND	Uplink Frequency	S-Band	S-Band
	Modulation	PCM/FSK/PM	PCM/FSK/PM
	Bit Rate	1 B/S	1 B/S
	Storage	5 Commands	32 Commands
	Spare Capacity	72 Commands	27 Commands
	Mechanized Spares	34 Commands	None
DATA HANDLING	No. of Bit Rates	8	8
	Highest Bit Rate	2048 B/S	16,384 B/S
	No. of Subcarriers	1	2
	Memory Capacity	49 KB	1.0 MB
	No. of Formats	23	23
	No. of Oper. Modes	3	3
COMMUNICATIONS	Telemetry Freq.	X-Band	S- and X-Band
	Primary Antenna	9 ft. Parabola	9 ft. Parabola
	Data Encoder	$K = 32$ $r = 1/2$	$K = 32$ $r = 1/2$
	S-Band Pwr. Output	8 W	8 W
	X-Band Pwr. Output	N/A	23 W
	Probe Telemetry	N/A	Yes

Figure 1-5. Summary of Assumed OPPS Data System Characteristics

- 64-m Subnet available for encounters and critical events during cruise
    - X-Band and S-Band Reception of Telemetry
    - S-Band Command
    - S/X-Band Radio Metric, Doppler and Ranging
    - Maximum Likelihood Convolutional Decoding (Viterbi Algorithm)
    - High Speed (4800 b/s) and Wideband (50 Kb/s) Ground Communications Circuits with error detection
- 26-m Subnet available for cruise
    - S-Band only
    - Maximum Likelihood Convolutional Decoding
    - High Speed (4800 b/s) Ground Communications Circuits with error detection

Figure 1-6. Summary of Assumed DSN Characteristics

Provide an Image Processing Capability based on current plans and technology which will include:

- Computer processing on Univac 1616 computers
- 64K word computer memories
- 200 Million bytes of mass storage to hold 1000 images
- 16 I/O channels
- 7 and 9 track tape system
- Displays
  - Volatile - CCTV compatible
  - Quick Look Hard Copy - Digifax and other devices
  - Film Recorders - 2 black and white, 1 color
- User Interaction
- Processing to include, but not be limited to
  - Filtering
  - Photometric correction and expansions
  - Rectifications
  - Special Projections

Figure 1-7. Summary of Assumed MCCC Characteristics

A. Image Processing Hardware

1. IBM 360/44 Computer with tape and disk peripherals
2. High speed convolution hardware
3. Interactive console with image displays
4. Digital tape to film conversion devices
    a. Video Film Converter
    b. Dicomed D-47
    c. Optronics International P-1500
    d. Perkin-Elmer PDS Scanner

B. Image Processing Software

1. "VICAR" image processing software monitor
2. Package of image processing applications programs

C. Support Services

1. Experienced image processing analysts
2. IPL photolab

Figure 1-8. Summary of Assumed IPS Characteristics

d. Uncompressed Imaging Data Case Assumptions

Although a number of viable alternatives exist for the simultaneous transmission of general science data and imaging data (see Part 2, Section IV), in this study, for the purpose of comparison, a single channel system was selected with a design point selected for a bit error rate of 10^{-4} for both imaging and general science data.

e. Moderately Compressed Imaging Data Case Assumptions

Based on a preliminary performance analysis, it appeared that pixel editing has higher performance characteristics than bit editing or delta modulation, with relatively little difference in implementation complexity. As a consequence, pixel editing was selected for a basis of comparison in this study. A more detailed description of pixel editing can be found in Part 2, Section III of this report.

f. Sophisticated Imaging Data Compression (AICS) Case Assumptions

It was assumed that the sophisticated imaging data compression case would be represented by AICS as described in Appendix D and References 2 through 7.

C. STUDY FINDINGS

1. Study Findings for the Uncompressed Case

In the course of the OPPICS study, a number of key issues were identified for the uncompressed case. A summary of these findings is listed below. Part 2 of this report provides a more detailed explanation of each, under the appropriate heading.

a. General:

1) It is expected that in the uncompressed case ~5000 images (160 x 640 pixels) will be returned from Saturn and ~600 from Uranus.
2) The uncompressed telemetry channel can support 3-color imaging of the planet every hour until ~E - 38 hours at Saturn and ~E - 33 hours at Uranus.
3) There is an incompatibility between the coding scheme utilized on the OPPS and the DSN's decoding support plans. The DSN does not intend to have sequential decoding capability for data rates higher than 2048 bits/sec. The estimated cost of implementing sequential decoding for the DSN for data rates between 2K bits/sec and 100K bits/sec is $530K. For this study it was assumed that the spacecraft would modify its encoding scheme to a K = 7, R = 1/2 convolutional code. The modification to the OPPS design is estimated to be minimal.

4) The command data rate for imaging only was expected to be 2 bits/sec with a 100% DSN duty cycle. Since this incompatibility was so fundamental, a redesign of the PLSI was performed during this study. The combined general science and imaging command data rate at Saturn is estimated to be 1 bit/sec with an ~73% DSN duty cycle, and will require an additional command decoder on the spacecraft.

5) There is an incompatibility between the BER requirements for general science data ($\sim 5 \times 10^{-5}$) and imaging data ($\sim 5 \times 10^{-3}$). If the PLSI is flown without data compression, then an appropriate transmission system will have to be selected. For this study a single-channel system with a BER of 1×10^{-4} was assumed.

6) The estimated cost of the modifications required (from the expected 1980 configuration except where otherwise noted) to the end-to-end data system is (see Part 2 of this report for a detailed breakdown):

PLSI	$5M (Assumed)
S/C	$X.X[4] (6.0 lb, 0.2 ft^3, 37.0 W increase to the OPPS)
DSN	$0.0
MCCC	$500K
MOS	$Unknown
IPS	$425K
TOTAL	$5.925 M + MOS Cost + P 10/11 to OPPS Conversion Cost

b. Imager Related:

Because the estimated cost of ground data processing for images containing 10 bits per pixel is expected to be twice that of 8 bits per pixel, the PLSI was redesigned to provide only 8 bits per pixel.

c. Spacecraft Related:

1) The OPPS data format sequence has to be modified to permit the transmission of one A or B format mainframe followed by 7 D format mainframes.

2) The estimated size of the OPPS memory has to be increased from 1 M to ~1.92 M bits.

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[4] $X.X represents the unknown cost of upgrading the Pioneer 10/11 spacecraft to the OPPS. The additional cost of upgrading the OPPS to the uncompressed data case of this study is estimated to be negligible.

3) A K = 7, R = 1/2 convolutional encoder must replace the K = 32 encoder.

4) A second command decoder has to be included in the design.

d. Telecommunications Related:

The error characteristics of sequential decoding and Viterbi decoding differ. Errors in sequential decoding results in missing data while errors in Viterbi decoding means that the decoded data is in error. The users of the data should be made aware of these differences.

e. DSN Related:

1) The uncompressed case has minimal impact on the DSN downlink.

2) The uncompressed case creates a severe command timing and command traffic load on the DSN uplink.

f. MCCC Related:

The uncompressed case has minimal impact on the MCCC.

g. IPS Related:

The uncompressed case has minimal impact on the IPS.

2. Study Findings for the Pixel Editing Case

In the course of the OPPICS Study, a number of key issues were identified for pixel edited case. A summary of these findings is listed below. Part 2 of this report provides a more detailed explanation of each, under the appropriate heading.

Since in the pixel editing case, a compression ratio of 1:1 must be retained, the findings attributed to the uncompressed case apply, with the following exceptions and/or additions:

a. General:

1) The scientifically acceptable data compression ratio using pixel editing is expected to be limited to 2:1.

2) Using a compression ratio of 2:1, the total number of images returned is expected to be ~6000 from Saturn and ~800 from Uranus.

3) For a data compression ratio of 2:1, the downlink telemetry channel can support 3-color imaging of the planet every hour until ~E - 17 hr for Saturn, and ~E - 16 hr for Uranus.

4) The combined general science and imaging command traffic at Saturn is expected to be ~ 1.5 bits/sec with a 100% DSN duty cycle.

5) The general science data and imaging science data BER incompatibility is reduced (because additional coding is required to quiet the channel) when data compression is used.

6) The estimated cost of modifications required (from the expected 1980 configuration except where otherwise noted to the end-to-end data system is (see Part 2 of this report for a detailed breakdown):

PLSI	$5.0M (Assumed)
S/C	$X.X + 20K (RS BB) + 270K (RS) (8.8 lb., 0.3 ft^3, 37.5 W increase to the OPPS)
DSN	$0
MCCC	$500K + 200K (RS) + 34K (+1200 images)
IPS	$425K + 34K (+1200 images)
MOS	$Unknown
TOTAL	$6.483M + MOS Cost + P10/11 to OPPS Conversion Cost

b. Imager-Related:

None

c. Spacecraft Related:

1) A Reed-Solomon encoder was included on the spacecraft.

2) Pixel editing logic has to be included on the spacecraft.

3) Steep performance codes like Reed-Solomon/Viterbi may require 1/2 to 1 dB bit rate switching steps.

d. Telecommunications Related:

It appears desirable to include a Reed-Solomon coder on the spacecraft to provide better telecommunications performance (~1.3 dB improvement). The study assumed the inclusion of the Reed-Solomon encoder.

e. DSN Related:

1) The pixel edit case has minimal impact on the DSN downlink.
2) The DSN command uplink situation is aggravated with 2:1 data compression.

f. MCCC Related:

1) In order to support the above, a Reed-Solomon decoding function has to be provided by the MCCC.
2) A pixel edit decompression algorithm has to be included in the MCCC. This addition is estimated to be minimal.
3) The cost of processing images will increase slightly.

g. IPS Related:

1) A pixel edit decompression algorithm has to be provided by the IPS. This edition is estimated to be minimal.
2) The cost of processing images will increase slightly.
3) Generally the pixel editing case has minimal impact on the IPS.

3. Study Findings for the AICS Case

In the course of the OPPICS Study, a number of key issues were identified for the AICS case. A summary of these findings is listed below. Part 2 of this report provides a more detailed explanation of each, under the appropriate headings.

Since, in the AICS case, a compression ratio of 1:1 must be retained, the findings attributed to the uncompressed case apply with the following exceptions and or additions:

a. General

1) The scientifically acceptable data compression ratio using AICS is expected to be ≤ 8:1.

2) Using a compression ratio of 5:1, (8:1 is not achievable due to the spacecraft roll rate) the total number of images returned from Saturn is expected to be ~ 8900. Using a compression ratio of 7.8:1, the total number of images returned from Uranus is expected to be ~1400.

3) For a data compression ratio of 5:1 at Saturn, the downlink telemetry channel can support 3-color imaging of the planet every hour until ~E - 16 hours, and at a compression ratio of 7.8:1 for Uranus until ~E - 8 hours.

4) The combined general science and imaging command data rate at Saturn is expected to be ~ 3.66 bits/sec with a 100% DSN duty cycle.

5) The general science data and imaging data BER incompatibility is significantly reduced with AICS.

6) The estimated cost of modification required (from the expected 1980 configuration except where otherwise noted) is (see Part 2 of this report for a detailed breakdown):

PLSI	\$5.0M (Assumed)
S/C	\$X.X + 200K (RM2 BB) + 20K (RS BB) + 1.105M (RS + RM2) (12.0 lb, 0.4 ft^3, 38.0 W increase to the OPPS)
DSN	\$0.0
MCCC	\$500K + 275K (RS + RM2) + 132K (+4700 images)
IPS	\$425 + 132K (+4700 images)
MOS	\$Unknown
TOTAL	\$7.789M + MOS Costs + P10/11 to OPPS Conversion Cost

b. Imager Related:

None

c. Spacecraft Related:

1) A data compressor (RM2) has to be included on the spacecraft.
2) A Reed-Solomon coder has to be included on the spacecraft to provide better telecommunications performance.

d. Telecommunications Related:

The inclusion of Reed-Solomon/Viterbi coding increases the performance of the telecommunications channel by 1.3 dB over the $K = 7$, $R = 1/2$ Viterbi channel.

e. DSN Related:

1) The AICS case has minimal impact on the DSN downlink.
2) The DSN command uplink situation is more seriously aggravated with 8:1 data compression.

f. MCCC Related:

1) A Reed-Solomon decoding function and an RM2 decompression function has to be provided by MCCC.
2) The cost of processing images will increase.

g. IPS Related:

1) The cost of image processing will increase.
2) The AICS case has minimal impact on the IPS.

D. STUDY CONCLUSIONS

A summary of the most significant conclusions reached by the OPPICSS Team is presented below. A more detailed description of each can be found in the appropriate section of Part 2 of this report.

a. General

1) It is expected that pixel editing data compression (from a science value point of view) will be limited to 2:1.
2) It is expected that RM2 data compression (from a science value point of view) will be limited to 8:1.
3) Imaging data compression is primarily a near encounter enhancement device. Some mission performance characteristics of the different cases considered are shown in Table 1-1.
4) Based on 3 above, AICS provides approximately a 2 to 4 fold increase, and pixel editing provides a less than 2 fold increase in imaging mission value.
5) The value of data compression is inversely related to the downlink telemetry bit rate.
6) The rolling characteristic of the spacecraft limits the selection of data compression ratios (an image can be acquired and transmitted only in an integral number of rolls).
7) Data compression might be used to perform acceptable Outer Planet missions at reduced downlink telemetry bit rates (at, say, ~2 kilobits/sec) thus allowing minimal changes to the Pioneer 10/11 spacecraft and data system.
8) There exists a command data rate and command timing incompatibility between the DSN and the type of mission examined in this study. These are:
   a) The inclusion of the PLSI on the OPPS creates two uplink problems independent of data compression.
      (1) It is anticipated that the DSN will have to transmit commands ~73% of the time from $\sim E_s$ - 38 hours to $\sim E_s$ - 2 hours (at the OPPS designed capability of 1 bit/sec).

Table 1-1. Selected Mission Performance Characteristics

Case	Saturn: Approximate number of pictures transmitted	Saturn: Time of down-link saturation[1] in hours	Saturn: Approximate resolution at saturation[1] in Km/pixel	Uranus: Approximate number of pictures transmitted	Uranus: Time of down-link saturation[1] in hours	Uranus: Approximate resolution at saturation[1] in Km/pixel
No compression	5000	E-38	191	600	E-33	170
Pixel edit (2:1)	6000	E-17	95	800	E-16	85
AICS (5:1 for S) (7:8 for U)	9000	E-16	90	1400	E-8	44

[1] Time of Downlink Saturation is defined here to mean the time when the downlink telemetry channel can no longer support 3-color imaging every hour.

(2) The PLSI requires real-time command support. The DSN cannot guarantee an uninterrupted real-time command capability during the critical near encounter portion of the mission.

b) For the assumed mission, the command data rate requirement is directly related to the data compression ratio. As an example, at Saturn it varies from ~0.73 bits/sec for a compression ratio of 1:1 to ~3.66 bits/sec for a compression ratio of 5:1.

c) The command data rate requirement is also directly related to the downlink telemetry data rate. For instance, for a data compression ratio of 1:1 at Uranus (~2 kilobits/sec) it is ~0.18 bits/sec while for Saturn (~8 kilobits/sec) it is 0.73 bits/sec.

9) Near-real-time telemetry data MOS requirements and data record requirements are not adequately understood.

10) The estimated costs for the three options examined in this study are shown in Table 1-2.

Table 1-2. OPPICSS Cost Summary

System	Option		
	Uncompressed (M$)	Pixel Edit (M$)	AICS (M$)
Imager	5. 0 (Assumed)	5. 0 (Assumed)	5. 0 (Assumed)
S/C	x. x (6. 0 lb, 0. 2 ft^3, 37. 0 W increase to OPPS)	x. x (8. 8 lb, 0. 3 ft^3, 37. 5 W increase to OPPS) 0. 020 (RS BB) 0. 270 (RS)	x. x (12. 0 lb, 0. 4 ft^3, 38. 0 W increase to OPPS) 0. 220 (RM2 + RS BB) 1. 105 (RM2 + RS)
DSN	0. 0	0. 0	0. 0
MCCC	0. 50	0. 500 0. 200 (RS) 0. 034 (+1200 images)	0. 500 0. 275 (RM2 + RS) 0. 132 (+4700 images)
IPS	0. 425	0. 425 0. 034 (+1200 images)	0. 425 0. 132 (+4700 images)
MOS	Unknown	Unknown	Unknown
TOTAL	5. 925 + x. x + MOS	6. 483+x. x + MOS	7. 789 + x. x + MOS

b. Imager Related:

1) The requirement for 10-bit pixels from the PLSI significantly increases the cost of ground data processing. Therefore, the PLSI data output was limited to eight bits per pixel.
2) It appears that the ground data processings costs may play a significant role in the determination of the number and types of pictures that will be returned from the spacecraft.

c. Spacecraft Related:

1) Inclusion of the PLSI or any other comparably performing imaging device necessitates significant modifications to the Pioneer 10/11 spacecraft with or without data compression.
2) The present OPPS design can accommodate design changes relatively easily. After implementation, however, the cost of even relatively minor changes will tend to become prohibitive. As a consequence,

   a design freeze should not be imposed until an end-to-end data system team has reviewed the requirements for the specific application needed.

d. Telecommunications Related:

1) Steep performance curve codes such as Reed-Solomon/Viterbi may need 1/2 to 1 dB step sizes for downlink bit rate changes.
2) The spacecraft's assumed capability of transmitting 8 kilobits/sec from Saturn and 2 kilobits/sec from Uranus is marginal.
3) Data compression can be used to preserve mission returns in the event of adverse weather conditions for X-band telemetry, or any other adverse tolerance telemetry conditions.

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[4] \$X.X represents the unknown cost of upgrading the Pioneer 10/11 spacecraft to the OPPS. The additional cost of upgrading the OPPS to the uncompressed data case of this study is estimated to be negligible.

4) The threshold for the downlink telemetry signal, using S-band with the 26-m net, is between 4 and 5 AU.
5) The threshold for the downlink telemetry signal, using S-band with the 64-m net, is ~10 AU.
6) X-band with the 64-m net is required to support downlink telemetry beyond ~10 AU.
7) Reed-Solomon/Viterbi coding should be considered for all high performance telecommunications systems.

e. DSN Related:

1) Pixel editing and AICS have minimal impact on the DSN downlink.
2) The 26-m DSN net, which is usually assigned to cruise science, will not be adequate beyond ~5 AU. Therefore, cruise science telemetry will require 64-m net support.

f. MCCC Related:

An analysis performed in this study indicates that the Reed-Solomon decoding should be performed centrally by the MCCC.

g. IPS Related:

The effect of data compression on the IPS is minimal.

h. AICS Related:

In general, the results of the OPPICS study agree with the preliminary system study performed by the AICS group in 1973.

E. STUDY RECOMMENDATIONS

A summary of the most significant recommendations reached by the OPPICSS Team is presented below. A more detailed description of each can be found in the appropriate sections of Part 2 of this report.

Data Compression Related—It is recommended that:

1) The science value study be performed as planned.
2) The MOS effects analysis be carried out (see Appendix K).
3) That the desirability of including the PLSI and AICS on an Outer Planet Pioneer Mission be determined and, in the event it is deemed desirable, that:

    a) A complete system verification of AICS be carried out.
    b) The RM2 data compressor be modified to incorporate the findings of this study.
    c) A breadboard effort of AICS be initiated.
    d) All elements of the data system be modified to incorporate the findings of this study.

General—It is recommended that:

1) The Pioneer Project Office study and resolve the incompatibility brought about by continuous time-critical commanding.
2) The Pioneer Project Office consider increasing the command data rate capability of the OPPS to 8, 16, or even 32 bits/sec (maximum bit rate capable of being supported by the DSN without modifications).
3) That an on-board computer/command sequencer be considered for inclusion on the OPPS as a possible solution to the continuous critical commanding problem.
4) A second command decoder be added to the OPPS.

5) Reed-Solomon/Viterbi coding be considered for all high-performance spacecraft telecommunications systems.

6) Consideration be given to incorporating 1/2 to 1 dB step changes for the OPPS downlink bit rate.

7) Consideration be given to the method of returning cruise science data from beyond ~5 AU.

PART 2

SECTION I
MISSION DESIGN AND ANALYSIS

A. INTRODUCTION

The purpose of the Outer Planet Pioneer Imaging Communications System Study (OPPICSS) is to assess:

1) The impact of an improved imaging device, the Pioneer line scan imager (PLSI).
2) Various coding and decoding techniques applied to imaging data and to general science and engineering (GS&E) data.
3) The application of various degrees of data compression to the imaging data.

The study includes several tasks:

1) Determination of the operational functions and their relative timing required to execute a typical planet encounter sequence.
2) Determination of the format, quantity, and rate of the downlink data.
3) Determination of the quantity and rate of uplink commands.
4) Determination of spacecraft data storage requirements.
5) Determination of system elements that limit system performance.

For this study, an example mission (not in NASA's proposed mission model) was selected. In 1980, an outer planet Pioneer (OPP) spacecraft will be launched towards Saturn and Uranus. The spacecraft will consist of a bus and an atmospheric entry probe to be deployed at Saturn.

The purpose of this section of the final report is to describe preliminary mission designs for interplanetary cruise and encounter periods at both planets. The impact of various degrees of data compression on the imaging data return from each planet, and on the required command load, is discussed. Spacecraft data storage requirements are estimated. Various constraints on the mission design are also included.

B. SPACECRAFT AND PROBE INSTRUMENTS AND EXPERIMENT OBJECTIVES

Table 1-1 presents a summary of the assumed spacecraft scientific instruments, experiments, and objectives, along with instrument weight and power consumption estimates.

The PLSI, which replaces the Pioneer 10/11 imaging photopolarimeter (IPP), is the only movable instrument on the spacecraft. Although image quality and resolution are improved by the PLSI, the type of photometric and polarization studies made by the IPP have been sacrificed.

Additional comments on Table 1-1 are as follows:

1) The UV spectrometer is the type to be flown on Pioneer/Venus in 1978.
2) If a lightweight IR spectrometer becomes available, it could be included in the payload.
3) The Earth occultation and celestial mechanics experiments utilize the spacecraft radio. Therefore, no weight is added, and no extra power is consumed.
4) The Geiger tube telescope and the trapped radiation telescope are included in case either Saturn or Uranus has a magnetic field strong enough to trap radiation.
5) Since all instruments except the PLSI are body-fixed, scanning is done either by movable mirrors inside the instrument or by spacecraft rotation.
6) All instruments, except as noted, have flown on Pioneer 10/11.
7) The spacecraft plus probe separated weight is 475 kg (excluding the 25-kg adapter).

Table 1-1. Outer Planet Pioneer Spacecraft Scientific Experiments

Instrument	Objective	Weight, kg	Power, W
Planet Atmospheres			
1. Pioneer Line Scan Imager	Obtain three-color imaging of planet atmosphere/surface and its satellites.	5.0	10.0
2. UV Photometer	Study interplanetary neutral hydrogen and planet atmospheric composition.	0.6	1.0
3. UV Spectrometer	Study interplanetary UV background emission and planet atmospheric composition.	2.7	?
4. IR Radiometer	Measure net thermal energy flux of planet and satellites.	2.0	1.3
5. IR Spectrometer	Make thermal map of planet and study atmospheric composition.	12.0	4.0
Solar Wind Studies			
6. Helium Vector Magnetometer	Measure interplanetary and planetary magnetic fields.	2.4	4.1
7. Plasma Analyzer	Study solar wind.	5.1	4.2
Cosmic Ray Astronomy			
8. Charged Particle Detectors	Study interplanetary cosmic radiation.	3.3	2.4
9. Cosmic Ray Telescope	Study solar and galactic cosmic radiation.	3.1	2.4

Table 1-1. Outer Planet Pioneer Spacecraft Scientific Experiments (contd)

Instrument	Objective	Weight, kg	Power, W
<u>Radiation Belt Observations</u>			
10. Geiger Tube Telescope	Survey energetic electrons and protons in planet magnetosphere.	1.6	0.8
11. Trapped Radiation Telescope	Delineate principal features of energetic corpuscular radiation trapped in planet's magnetic field.	1.7	2.2
<u>Meteoroid Astronomy</u>			
12. Asteroid/Meteoroid Detector	Measure parameters of asteroids and meteoroids in the asteroid belt and in interplanetary space.	2.4	1.7
13. Meteoroid Detector	Assess meteoroid hazard in the asteroid belt and in interplanetary space.	1.5	1.0
<u>Earth-Based Experiments</u>			
14. Earth Occultation	Obtain information on structure of planet (and possibly satellite) atmospheres and ionospheres.	0	0
15. Celestial Mechanics	Obtain improved estimates of planet and satellite orbits, masses, and gravity fields.	0	0
	TOTALS	43.4 kg	35.1+? W

The PLSI, IR radiometer, IR spectrometer, Geiger tube telescope, trapped radiation telescope, Earth occultation, and celestial mechanics experiments are primarily oriented towards the planets and their satellites. The plasma analyzer, charged particle detectors, cosmic ray telescope, asteroid/meteoroid detector, and the meteoroid detector experiments are oriented primarily towards interplanetary fields and particles. The remaining experiments (UV photometer and spectrometer and the magnetometer) are concerned with both regions.

Table 1-2 presents a summary of the probe scientific instruments, experiments, and objectives, along with instrument weight and power consumption.

The entire probe weighs 113 kg.

Table 1-2. Outer Planet Pioneer Probe Scientific Experiments

Instrument	Objective	Weight, kg	Avg. Power, W
Planet Atmosphere			
1. Pressure Sensor	Measure atmospheric pressure to 10 bars.	0.2	1.2
2. Temperature Sensor	Measure atmospheric temperature.	0.35	1.0
3. Accelerometer Triad	Measure atmospheric density.	0.3	2.0
4. Neutral Mass Spectrometer	Measure atmospheric constituents and cloud composition (for atomic masses from 1 to 40).	6.4	11.0
5. Nephelometer	Measure cloud structure and location using backscattered light.	0.5	1.0
	TOTALS	7.75 kg	16.2 W

C. MISSION MANEUVER PROFILE

Table 1-3 presents the nominal maneuver profile for a Pioneer Saturn/Uranus mission with a probe that is deployed at Saturn. A total of eight maneuvers is required. The first three occur with the probe attached to the spacecraft. The total required ΔV is 201 m/sec. The first maneuver, which occurs five days after launch, corrects for launch vehicle injection errors; this maneuver is the largest and requires 85 m/sec. A large pair of maneuvers occurs just after probe separation at Saturn encounter - 24 days. The spacecraft bus is deflected perpendicular to the Earth-line and is slowed slightly along the Earth-line. This assures proper bus-probe communications geometry and also prevents the bus from impacting Saturn. These two maneuvers together require 68.5 m/sec. Any errors that exist in the Saturn targeting required to continue on to Uranus will be greatly magnified during the Saturn flyby. About 40 days later, a 32-m/sec maneuver will be performed to restore the spacecraft to the desired trajectory to Uranus.

D. CRUISE SCIENCE AND DATA RETURN

The Pioneer family of spacecraft emphasizes the study of interplanetary fields and particles. During the cruise periods from the Earth to Saturn and from Saturn to Uranus, the PLSI and the probe are inactive. Also, the IR radiometer, IR spectrometer, Geiger tube telescope, trapped radiation telescope, Earth occultation, and celestial mechanics experiments are primarily encounter-oriented. Thus, during the cruise periods, which last for years, only GS&E data is taken, and it is transmitted at low rates. The data rate for all of the Pioneer 10/11 GS&E instruments combined is only 64 bits/sec. Dr. John Wolfe of NASA Ames Research Center has required that the A format mainframe data rate be not less than 256 bits/sec. (The data rate for the Outer Planet Pioneer GS&E payload is expected to be less than this rate.) This can be easily accommodated by the X-band telecommunications downlink during cruise. The cruise science data stream would consist of a series of A format mainframes with an occasional special D format mainframe devoted

Table 1-3. Nominal Maneuver Profile

Time	Maneuver	Probe	ΔV Direction	Equivalent ΔV, m/sec (I_{sp} = 225 sec)
Earth + 5 days	Launch Vehicle Correction No. 1	On	Any	85.0
Earth + 20 days	Launch Vehicle Correction No. 2	On	Any	3.0
Saturn - 26 days	Saturn Approach Trim	On	Any	7.5
Saturn - 24 days	Spacecraft Deflection Maneuvers	Off	Parallel to Earth-line	19.0
			Perpendicular to Earth-line	49.5
Saturn - 10 days	Saturn Approach Trim	Off	Any	2.5
Saturn + 40 days	Saturn Departure Trim	Off	Any	32.0
Uranus - 10 days	Uranus Approach Trim	Off	Any	2.5
			TOTAL	201.0 m/sec

to one or two of the GS&E instruments. No data compression would be required during cruise.

The spacecraft can transmit at either X- or S-band frequencies. The X-band TWTA has a power output of 23 watts. The S-band TWTA has a power output of 8 watts. The X-band TWTA frequency is 8400 GHz. The S-band TWTA frequency is 2290 GHz. The ratio of data rates, H, due to these two spacecraft changes is given by

$$\frac{H_x}{H_s} = \frac{P_x}{P_s}\frac{f_x^2}{f_s^2} = \frac{23\,(8400)^2}{8\,(2290)^2} = (2.875)\,(13.47) = 38.7$$

or, using decibel notation, we have

$$10 \log_{10}(2.875)\,(13.47) = 4.59 + 11.29 = 15.88 \text{ dB}.$$

However, the X-band performance may be degraded by adverse weather conditions. Most of the time, this weather degradation can be assumed to be no more than -3 dB. Therefore, the difference between X-band and S-band performance is closer to 15.88 - 3 = 12.88 dB.

Now recall that $10 \log_{10}(2) = +3$ dB and $10 \log_{10}(1/2) = -3$ dB. Rounding 12.88 dB down to 12.0 dB for simplification, we have

$$\frac{H_x}{H_s} = 12 \text{ dB} = (2)^4$$

At Saturn with X-band, the telecommunications down-link nominal performance is expected to provide a data rate of 8192 bits/sec = H_x. Therefore, at Saturn, if we were to transmit at S-band into the same 64-m Deep Space Station (DSS), the data rate would fall to

$$H_s = \frac{H_x}{(2)^4} = \frac{8192}{16} = 512 \text{ bits/sec}$$

Thus, if we desired, GS&E data, but not high rate PLSI imaging data, could be transmitted at S-band into a 64-m DSS at distances out to Saturn (10 AU), but not from greater distances. The purpose of the preceding discussion was to demonstrate the limited utility of using S-band as a backup to X-band for GS&E data return into a 64-m DSS.

The 64-m DSS can receive X- or S-band telemetry. In contrast, the 26-m DSS can receive only S-band telemetry. Furthermore, the S-band performance of the 26-m stations in terms of receiving antenna gain and equivalent noise temperature is about 10 dB less than that of the 64-m stations. Therefore, the 26-m stations will be useful only for receiving tracking data for navigation and GS&E data after launch and during the early cruise portion of the mission. For example, at Saturn where the S-band data rate into a 64-m DSS is 512 bits/sec, the communications distance is 10 AU. Now if we were to employ only a 26-m DSS receiving at S-band and to maintain a GS&E data rate of 256 bits/sec (+3 dB), the maximum communications distance would be R_{26}, given according to the inverse square law by

$$10 \log_{10}\left(\frac{R_{26}}{R_{64}}\right)^2 = 10 \log_{10}\left(\frac{R_{26}}{10 \text{ AU}}\right)^2 = -10 + 3 = -7 \text{ dB}$$

or

$$\left(\frac{R_{26}}{10 \text{ AU}}\right)^2 = \frac{1}{5}$$

or

$$R_{26} = \sqrt{20 \text{ AU}} = 4.48 \text{ AU}$$

E. IMAGING DATA COMPRESSION

A data cycle is assumed to consist of 1 A format mainframe containing general science and engineering plus probe data followed by 7 D format mainframes containing only imaging data. Thus, imaging data will be occupying 7/8 of the telemetry channel. At Saturn, imaging data will be returned at 7/8 (8192) bits/sec. At Uranus, imaging data will be returned at 7/8 (2048) bits/sec. It should be noted that these data rates are based upon expected nominal design performance of the telecommunications downlink.

Each formatted image frame contains 821024 bits including housekeeping and filler bits. The time required to empty one formatted image frame from storage at Saturn will be

$$\frac{821024 \text{ bits}}{7/8\,(8192)\,\frac{\text{bits}}{\text{sec}}} = 114.5 \text{ sec}$$

Now since the spacecraft is rolling once every 12 sec, the time required to return one formatted image frame may be expressed as

$$\frac{114.5 \text{ sec}}{12\,\frac{\text{sec}}{\text{roll}}} = 9.55 \text{ spacecraft rolls}$$

An image is taken when the spacecraft has reached a particular one of any of the 2048 angular spoke positions during a given roll. The next image cannot be taken until its selected spoke position is reached on the next roll. Thus, we must round up the 9.55 rolls to 10.0, the next integer roll. Now if the data were not compressed, the maximum number of images that could be returned in 1 hr from Saturn would be

$$\frac{3600\,\frac{\text{sec}}{\text{hr}}}{\left(10\,\frac{\text{rolls}}{\text{image}}\right)\left(12\,\frac{\text{sec}}{\text{roll}}\right)} = 30 \text{ images}$$

The first line of Table 1-4 presents the numbers that have just been discussed.

Table 1-4. Imaging Data Compression

Planet	Imaging Data Rate, bits/sec	Spacecraft Rolls Required to Empty One Image from Storage	Next Higher Integer	Effective Compression Ratio	Maximum Images Per Hour
Saturn	7/8 (8192)	9.55	10.00	1.00	30.0
Saturn	7/8 (8192)	5.00	5.00	2.00	60.0
Saturn	7/8 (8192)	2.00	2.00	5.00	150.0
Saturn	7/8 (8192)	1.00	1.00	10.00	300.0
Uranus	7/8 (2048)	38.20	39.00	1.00	7.7
Uranus	7/8 (2048)	20.00	20.00	1.95	15.0
Uranus	7/8 (2048)	5.00	5.00	7.80	60.0
Uranus	7/8 (2048)	1.00	1.00	39.00	300.0

Now suppose that it is desired to employ data compression in order to acquire and return more than 30 images/hr from Saturn. This would be equivalent to reducing the integer number of rolls required to return one image. Thus, we can define

$$\text{Effective compression ratio} = \frac{\text{integer rolls for uncompressed data}}{\text{integer rolls for compressed data}}$$

For Saturn, we have

$$\text{Effective compression ratio} = \frac{10.0}{\text{integer rolls for compressed data}}$$

Note that the effective compression ratio can take on any value between 1.0 and 10.0 at Saturn. Also note that the denominator, the integer rolls for compressed data, cannot be less than 1.0. (It takes at least one integer roll to acquire an image and to play it back.) Then at Saturn, we have

$$\text{maximum images/hr} = 30\,\frac{\text{images}}{\text{hr}} \times \text{effective compression ratio}$$

Table 1-4 contains four entries for data return from Saturn and four from Uranus. The two limiting cases for each planet (no data compression and maximum data compression) are shown plus two arbitrary cases. Between these limits, any effective compression ratio can be chosen as long as both the numerator and denominator in the expression are integers.

Three levels of data compression will be considered:

1) No compression,
2) Effective compression ratio $\cong 2$ (representative of moderate compression using PIXEL editing), and
3) Effective compression ratio between 5 and 8 (representative of strong RM2 compression while retaining good image quality).

F. DOWNLINK ANALYSIS FOR IMAGING FOR LOW, MODERATE, AND RM2 COMPRESSION NEAR ENCOUNTER

As the spacecraft approaches a planet, its angular diameter will increase with time measured relative to encounter, or hyperbolic periapsis passage. The time at which the PLSI is activated is somewhat arbitrary. However, the PLSI will be turned on well before the planet fills its 0.016 x 0.064 radian full frame field-of-view. At Saturn, the starting time was chosen as E - 600 hr, or 25 days before encounter when the angular diameter of Saturn plus its rings is 0.0114 radians (which is also just before the probe is separated from the spacecraft). At Uranus, the starting time was chosen as E - 120 hours, or 5 days before encounter when the angular diameter of Uranus is 0.009 radians.

The PLSI is composed of three charge coupled device arrays. Each array has a full frame field of view of 0.016 x 0.064 radians. The three arrays have different spectral filters: clear, red, and blue. (A green image can be synthesized on the ground by adding the red and blue images and subtracting the sum from the clear image.) In general, it is desirable to continue three-color imagery as long as possible. This depends upon the telemetry downlink channel capacity and the degree of data compression.

The Saturn imaging data plan is shown in Table 1-5. Effective compression ratios of 1.0, 2.0, and 5.0 are employed representing no compression, moderate compression (e.g., PIXEL editing), and strong compression (e.g., RM2). For an 8192 bit/sec downlink with 7/8 of it devoted to imaging data, the corresponding maximum image rates are 30, 60, and 150 per hour.

During the early approach phase to Saturn, three-color imagery can be accomplished with small numbers of PLSI frames. In fact, only 27 frames are required as late as E - 38 hr which is less than the 30 frame/hr telemetry channel capacity without data compression.

After E - 38 hr, subjective choices must be made depending upon the scientific desires and the degree of data compression. If Saturn plus its rings are to be imaged, rectangular arrays composed of many 0.016 x 0.064 radian PLSI full frames must be constructed such that the ratio of length-to-width of the rectangle is approximately 2.28 to 1.0, as the diameter of the outermost of Saturn's visible rings is 2.28 times the planet diameter. The number of PLSI full frames required to image in one color increases from 1 to 9 between E - 600 and E - 38 hours. After this time, the number of PLSI frames required to image in one color jumps to 38, 84, and 144 at E - 38, E - 16, and E - 10 hr, respectively. These numbers are conservative to allow for about 10% overlap between adjacent PLSI frames and to allow for modest pointing errors of the PLSI. After E - 7 hr, Saturn plus its rings can no longer be imaged in its entirety with an effective compression ratio of 5.0.

Table 1-5. Saturn Imaging Data Plan, Using Effective Compression Ratios of 1.0, 2.0, and 5.0

Time Interval Relative to Encounter, hr	Images/hr				Images In Time Interval
	Clear Filter	Red Filter	Blue Filter	Total	
	Effective Compression Ratio = 1.0				
-600 to -500	1	1	1	3	300
-500 to -420	1	1	1	3	240
-420 to -300	2	2	2	6	720
-300 to -200	2	2	2	6	600
-200 to -130	3	3	3	9	630
-130 to -95	4	4	4	12	420
-95 to -75	5	5	5	15	300
-75 to -60	6	6	6	18	270
-60 to -50	7	7	7	21	210
-50 to -43	8	8	8	24	168
-43 to -38	9	9	9	27	135
-38 to -17	15	15	0	30	630
-17 to 0	30	0	0	30	510
					5133
	Effective Compression Ratio = 2.0				
-600 to -38		same as	above		3993
-38 to -17	16	16	16	48	1008
-17 to -10	30	30	0	60	420
-10 to 0	60	0	0	60	600
					6021
	Effective Compression Ratio = 5.0				
-600 to -38		same as	above		3993
-38 to -16	38	38	38	114	2508
-16 to -10	75	75	0	150	900
-10 to 0	150	0	0	150	1500
					8901

On the other hand, after E - 38 hr, it may be desirable to concentrate on the disk of Saturn alone. In this case, square arrays composed of many 0.016 x 0.064 radian PLSI full frames will be required. The number of PLSI frames required to image in one color jumps to 16, 36, 64, 100, and 144 at E - 38, E - 17, E - 10, E - 7, and E - 5 hr, respectively. Again, allowance is made for overlap and pointing error. After E - 4 hr, the disk of Saturn can no longer be imaged in its entirety with an effective compression ration of 5.0.

Table 1-5 represents a compromise between (a) three-color imagery of all of Saturn plus its rings and (b) dual and single color coverage of portions of Saturn and/or its rings. For effective compression ratios of 1.0, 2.0, and 5.0, the total number of images obtained between E - 600 hr and encounter will be 5133, 6021, and 8901, respectively. No consideration was given to either the cost of processing this many images or to the number of images that scientists could practically analyze.

Table 1-6 presents the Uranus imaging data plan. Effective compression ratios of 1.0, 1.95, and 7.80 are employed. For a 2048 bit/sec downlink with 7/8 devoted to imaging data, the corresponding maximum image rates are 7.7, 15, and 60 per hour.

The starting time was arbitrarily chosen as E - 120 hr. Three-color imagery can be accomplished without data compression until nearly E - 22 hr. After E - 22 hr, subjective choices must be made. In the case of Uranus, the number of PLSI full frames required to image the disk in one color increases from 1 to 4 between E - 120 and E - 16 hr. Four PLSI full frames form a square array. However, because we are trying to image the disk of Uranus using square arrays, the number of PLSI full frames escalates rapidly to 4, 16, 36, and 64 at E - 22, E - 16, E - 8, and E - 5 hr, respectively. Again, allowance is made for overlap and pointing error. After E - 3 hr, the disk of Uranus can no longer be imaged in its entirety with an effective compression ratio of 7.80.

Table 1-6. Uranus Imaging Data Plan, Using Effective Compression Ratios of 1.0, 1.95 and, 7.80

Time Interval Relative to Encounter, hr	Images/hr				Images In Time Interval
	Clear Filter	Red Filter	Blue Filter	Total	
	Effective Compression Ratio = 1.0				
-120 to -66	1	1	1	3	162
-66 to -33	2	2	2	6	198
-33 to -22	3	3	1.7	7.7	85
-22 to -16	4	3.7	0	7.7	46
-16 to 0	7.7	0	0	7.7	123
					614
	Effective Compression Ratio = 1.95				
-120 to -66	1	1	1	3	162
-66 to -33	2	2	2	6	198
-33 to -22	3	3	3	9	99
-22 to -16	4	4	4	12	72
-16 to 0	15	0	0	15	240
					771
	Effective Compression Ratio = 7.80				
-120 to -66	1	1	1	3	162
-66 to -33	2	2	2	6	198
-33 to -22	3	3	3	9	99
-22 to -16	4	4	4	12	72
-16 to -8	16	16	16	48	384
-8 to -5	30	30	0	60	180
-5 to 0	60	0	0	60	300
					1395

Table 1-6 represents a compromise between three-color imagery of all of Uranus and dual and single color coverage of portions of the disk. For effective compression ratios of 1.0, 1.95, and 7.80, the total number of images obtained between E - 120 hr and encounter will be 614, 771, and 1395, respectively. It is seen that the use of the RM2 compressor can substantially increase the imaging science return at Uranus.

G. DSS COVERAGE REQUIREMENTS

Due to the competition between various interplanetary missions, the 64-m DSS net cannot be assigned full time to any one mission. Thus, the Outer Planet Pioneer missions can expect to be allocated 64-m DSS coverage for radio navigation tracking and for GS&E cruise science data return for perhaps one day per week. Of course, during Saturn and Uranus encounter periods, the 64-m DSS coverage can be assumed to be much more generous.

Referring to Table 1-3, we see that spacecraft maneuvers span the period from S - 26 days to S + 40 days at Saturn, and a maneuver may be required about 10 days before Uranus encounter. Before and after each maneuver, periods of intensive radio tracking coverage are required for maneuver computation and postmaneuver trajectory computation.

Referring to Tables 1-5 and 1-6, we see that image data transmission is assumed to begin about 600 hours before Saturn encounter at a rate of 3 images/hr. This increases to 30 images/hr at S - 38 hr, after which the assumed 7/8 (8192) bit/sec downlink is saturated for the no data compression case. From this point (S - 38 hr), continuous 64-m DSS coverage will be required until after exit from Earth occultation at S + 6.3 hr (see Figure 1-7).

At Uranus, imaging is assumed to begin about U - 120 hr at a rate of 3 images/hr. This increases to 7.7 images/hr at U - 22 hr, after which the assumed 7/8 (2048) bit/sec downlink is saturated for the no data compression case. From this point (U - 22 hr), continuous 64-m coverage will be required until after exit from Sun occultation at U + 3.5 hr.

H. EXAMPLES OF PLSI IMAGING

Figures 1-1 through 1-4 were generated by the SPINGEOM computer program developed at JPL. The program computes the projection of PLSI images onto a flat disk representing the planet. Figures 1-1 through 1-3 represent PLSI full frame images projected onto Saturn starting at E - 36 hr, E - 24 hr, and E - 12 hr, respectively. The sequences as shown required 8 min, 26 min, and 46 min, respectively, to complete. At these points along the Saturn approach trajectory, the planet is almost fully illuminated; the terminator is near the left edge of the disk. The planet equator is shown, and the north pole is denoted by the small letter N. The radial distance in planet radii from the spacecraft to the center of the planet is shown as well as the angular semi-diameter (ASD) of the planet as viewed from the spacecraft.

Figure 1-4 shows the projection of PLSI full-frame images onto Uranus beginning at E - 12 hr and ending 10 min later. Notice that the planet north pole is pointed roughly towards the approaching spacecraft. The planet appears to be fully illuminated at this time. The planet equator is near the right edge of the disk.

The number of PLSI full frame images displayed in Figures 1-1 through 1-4 is considerably less than the number suggested in the Imaging Data Plans presented in Tables 1-5 and 1-6. At Saturn, the Imaging Data Plan provided coverage of Saturn plus its rings, including small allowances for frame-to-frame overlap and PLSI pointing error. At Uranus, the Imaging Data Plan included small allowances for overlap and pointing error.

I. POSSIBLE X-BAND WEATHER DEGRADATION NEAR ENCOUNTER

The X-band telemetry is susceptible to severe degradation due to heavy concentrations of water vapor in the atmosphere near any Deep Space Station. The MJS'77 Project has estimated this degradation for each DSS location and for each season of the year. For our Outer Planets Pioneer example mission, the spacecraft arrives at Saturn in early January, 1984, and it arrives at

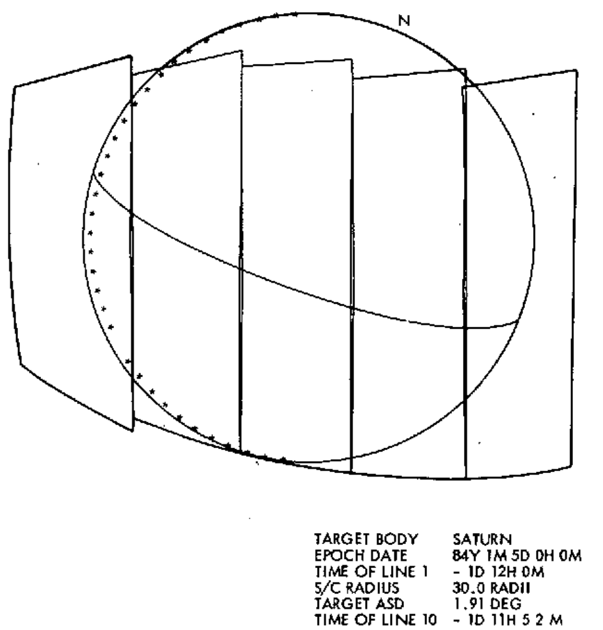


Figure 1-1. View of Saturn at E - 36 h

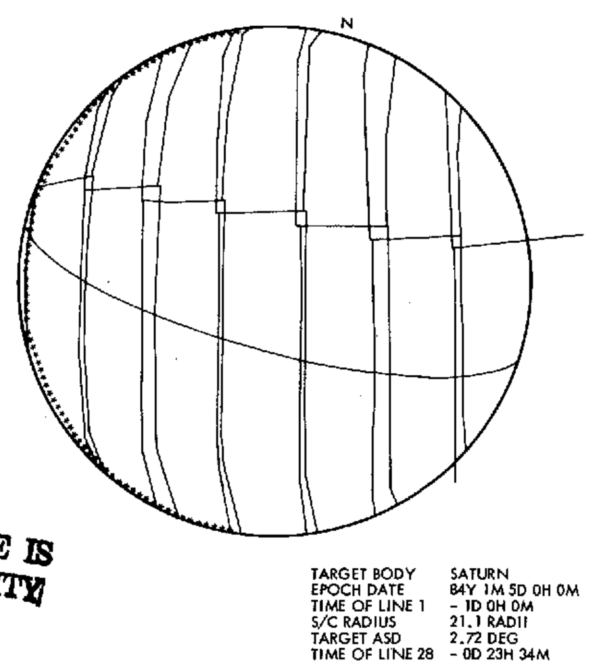
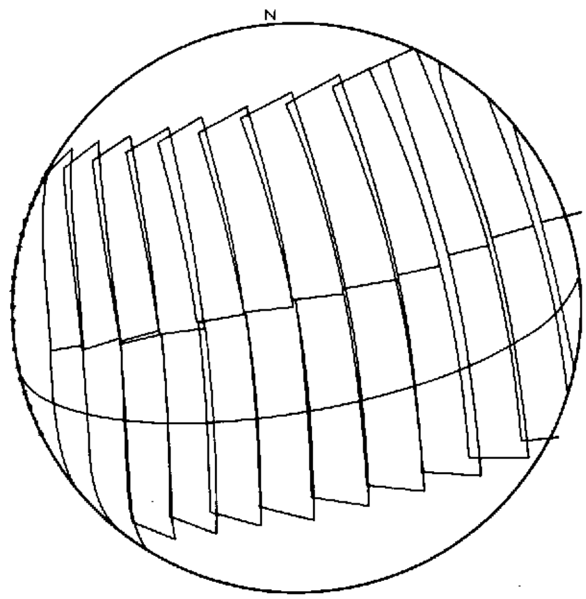
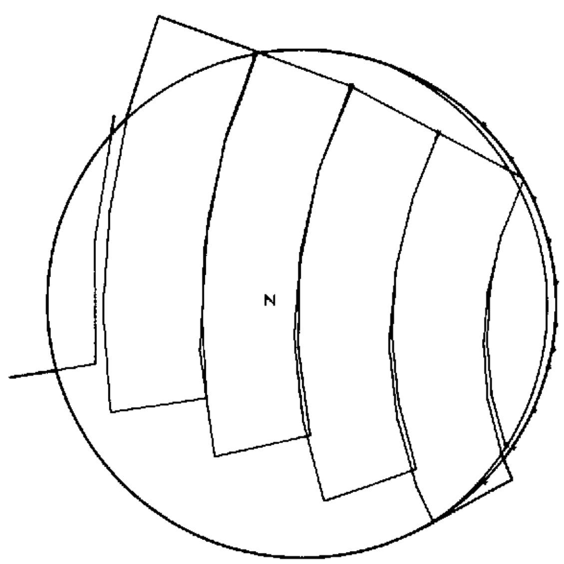


Figure 1-2. View of Saturn at E - 24 h



TARGET BODY SATURN
EPOCH DATE 84Y 1M 5D 0H 0M
TIME OF LINE 1 - 0D 12H 0M
S/C RADIUS 11.7 RADII
TARGET ASD 4.90 DEG
TIME OF LINE 48 - 0D 11H 14M

Figure 1-3. View of Saturn at E - 12 h



TARGET BODY URANUS
EPOCH DATE 87Y 11M 9D 0H 0M
TIME OF LINE 1 - 0D 12H 0M
S/C RADIUS 24.1 RADII
TARGET ASD 2.37 DEG
TIME OF LINE 12 - 0D 11H 50M

Figure 1-4. View of Uranus at E - 12 h

Uranus in early November, 1987. In either case, the worst weather can be expected at DSS 63 (Madrid). For example, the X-band weather degradation is estimated to be 3.5 dB at this 64-m DSS with an elevation angle of 15 deg for a cumulative probability of 80% of all expected weather conditions in the worst quarter of the year. The yearly average throughout the DSS net for the same elevation angle and cumulative probability will involve approximately a 2.5 dB X-band weather degradation. Assuming an average degradation of 3.0 dB, the X-band data rates at Saturn would be lowered from 8192 to 4096 bits/sec and at Uranus from 2048 to 1024 bits/sec. By lowering the data rate, the original bit error rate can be maintained.

An alternative to accepting the possible X-band weather degradation would be to switch the spacecraft to S-band and transmit into the 64-m DSS net. As previously discussed, the net difference in performance is about 12 dB. This difference represents approximately $(1/2)^4$ in data rate. Thus, at Saturn the data rate would fall to $(8192)(1/2)^4 = 512$ bits/sec, which is adequate for GS&E data but would essentially preclude the transmission of imaging data. At Uranus the data rate would fall to $(2048)(1/2)^4 = 128$ bits/sec, which is inadequate even for GS&E data. Of course, an alternative to lowering the data rate would be to allow the bit error rate to increase. However, this would be unacceptable, particularly for GS&E data.

Thus, it would appear that near planetary encounter times, it would be better to continue to operate at X-band and accept the statistical weather degradation rather than to switch to S-band. If necessary, the X-band data rate could be lowered to maintain the desired bit error rate. It appears that this approach would ensure at least some imaging capability at Saturn and Uranus, whereas a switch to S-band would preclude imaging.

The impact of X-band weather degradation on science sequence design will require planning for sudden reductions in data rate. This will affect the number of PLSI images that can be obtained. It will probably be best to plan redundant, repetitive sequences of images such that images of key planet features can be obtained serially when the spacecraft is in view of DSS 14, 43, and 63. In this way, the impact of a sudden drop in the data rate will be minimized.

It should also be noted that data compression could be used to soften the impact of adverse weather conditions. For example, if the X-band data rate had to be reduced from 8192 to 4096 bits/sec, the data compressor could be turned on and set to provide an effective compression ratio of 2.0. In this way, the total number of PLSI images taken would remain unchanged despite the weather-induced reduction in data rate. Also, at this low compression ratio, the image quality would not suffer noticeably.

J. UPLINK ANALYSIS FOR LOW, MODERATE, AND RM2 COMPRESSION NEAR ENCOUNTER

Each Pioneer command word is composed of 22 bits. The relationship between the command data rate and the command word rate is given in Table 1-7.

Table 1-7. Relationship Between the Command Data Rate and the Command Word Rate

Command Data Rate, bit/sec	Command Word Rate, commands/hr
1	163.7
2	327.4
4	654.8

On the average, each PLSI image is assumed to require 2 commands, as shown in Table 1-8.

The ratio of total commands to imaging commands varies throughout the mission. It will be assumed that this ratio does not exceed 2.0, as shown in Table 1-9.

Table 1-8. The Two Commands Required for Each PLSI Image

Planet	Effective Compression Ratio	PLSI Image Rate, images/hr	Imaging Command Word Rate, commands/hr
Uranus	1.0	7.7	15.4
↓	1.95	15.0	30.0
	7.80	60.0	120.0
Saturn	1.0	30.0	60.0
↓	2.0	60.0	120.0
	5.0	150.0	300.0

Table 1-9. Ratio of Total Commands to Imaging Commands

Imaging Command Word Rate, commands/hr	Total Command Word Rate, commands/hr	Required Command Data Rate for 100% Duty Cycle, bits/sec
15.4	30.8	0.18
30	60	0.36
60	120	0.73
120	240	1.46
300	600	3.66

It can be concluded that command data rates in excess of 2 bits/sec at Uranus and 4 bits/sec at Saturn will probably be required. This is within the present DSN command capability, but will require modification of the spacecraft command system.

Perhaps the greatest accommodation required to plan, transmit, and execute the sharply increased number of commands will be in the Mission

Operations System. In the case of Pioneer 10/11, commands are transmitted and executed in real time with men manually in the loop to verify each command with the plan just before transmission. With the Outer Planets Pioneer with a PLSI, this will no longer be possible. The increased number of commands will require removal of the men from the command loop. Furthermore, the command sequences will have to be loaded in advance into a computer memory for subsequent transmission automatically to the spacecraft. Also, the sequences will have to be designed with built-in redundancy in order that the PLSI sequencer can operate for brief periods of time without receiving ground commands. This will be necessary when the communications lines between ARC and a DSS suffer a temporary outage.

K. SOME TRAJECTORY CHARACTERISTICS

Figure 1-5 is a plan view of a typical trajectory for our example mission. The spacecraft is launched from the Earth in its orbit about the Sun on 26 November 1980. After arrival at Saturn of 5 January 1984, the gravity field of the planet sharply bends the trajectory towards Uranus. The spacecraft arrives at Uranus on 9 November 1987.

Figures 1-6 is a scale drawing of portions of the hyperbolic flybys of Saturn and Uranus. The planet is shown with a unit radius, and the spacecraft distance from the center of the planet is measured in planet radii. At Saturn periapsis, the spacecraft passes within 2.73 R_s. The Uranus periapsis distance is 3.5 R_u. True anomaly is the angle measured from the periapsis

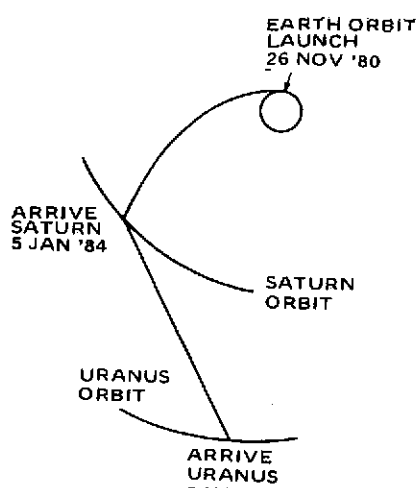


Figure 1-5. Trajectory Plan View

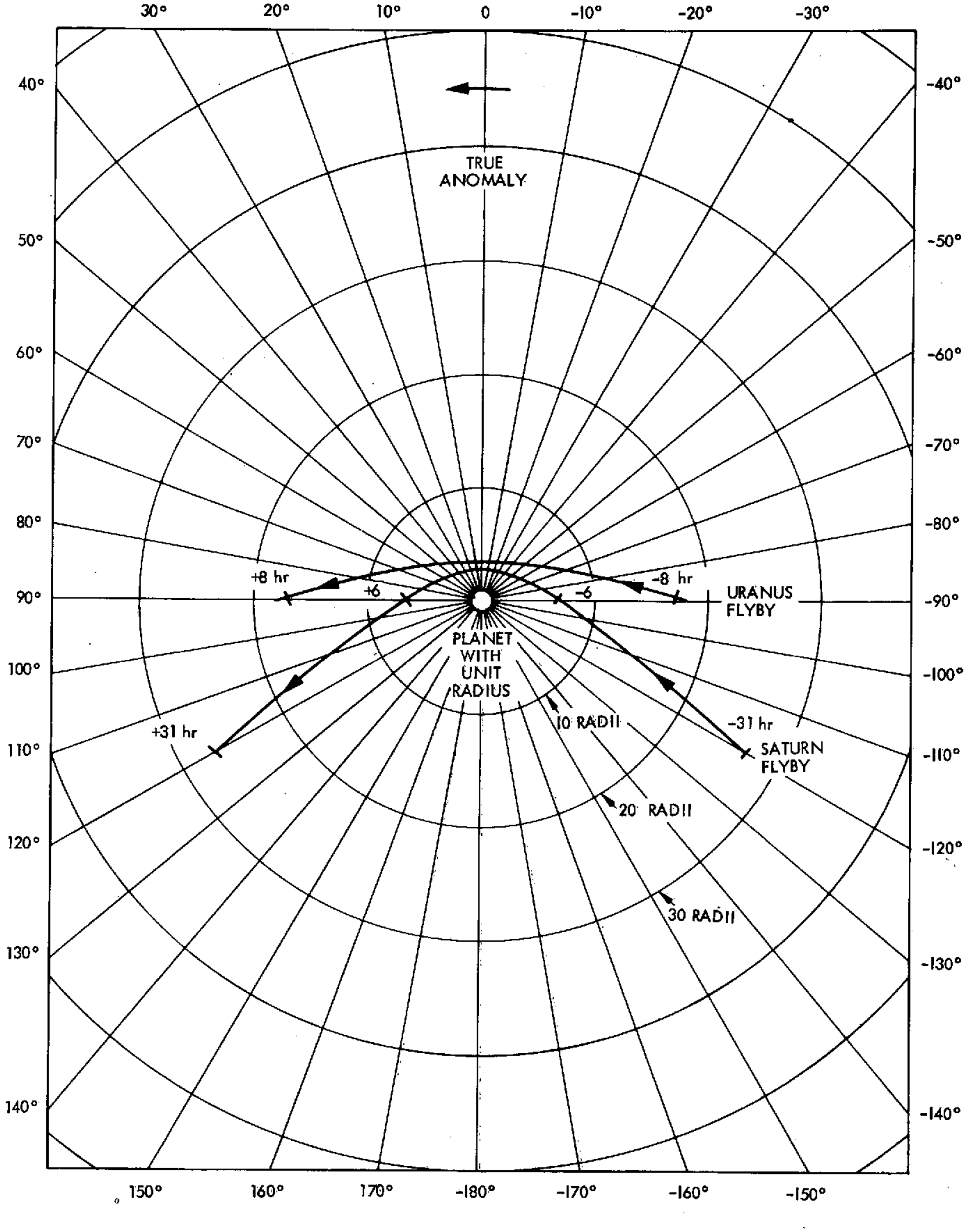


Figure 1-6. Hyperbolic Flybys

radius vector to the spacecraft radius vector at any point in time. At Uranus, the spacecraft passes from -90 deg to +90 deg of true anomaly in slightly more than 16 hr. At Saturn, the spacecraft passes from -120 deg to +120 deg in about 62 hr and from -90 deg to +90 deg in about 12 hr. The trajectory turning angle at Saturn is 84.6 deg, whereas at Uranus it is only 28.2 degrees. The turning angle at Saturn is larger for two reasons: the periapsis radius is less at Saturn, and the planet is 6.5 times more massive than Uranus.

The example trajectory passes through regions of Earth and Sun occultation after periapsis passage at both Saturn and Uranus as shown in Figure 1-7. The time after periapsis of occultation entry and exit is plotted against spacecraft true anomaly. Saturn's rings and disk both produce occultations shown along the solid curve. Uranus disk occultations are shown along the dashed curve.

As the spacecraft enters Earth occultation, the radio signal is first refracted and then extinguished by the planet's atmosphere. Upon exit from occultation, a similar effect occurs. By studying the characteristics of the

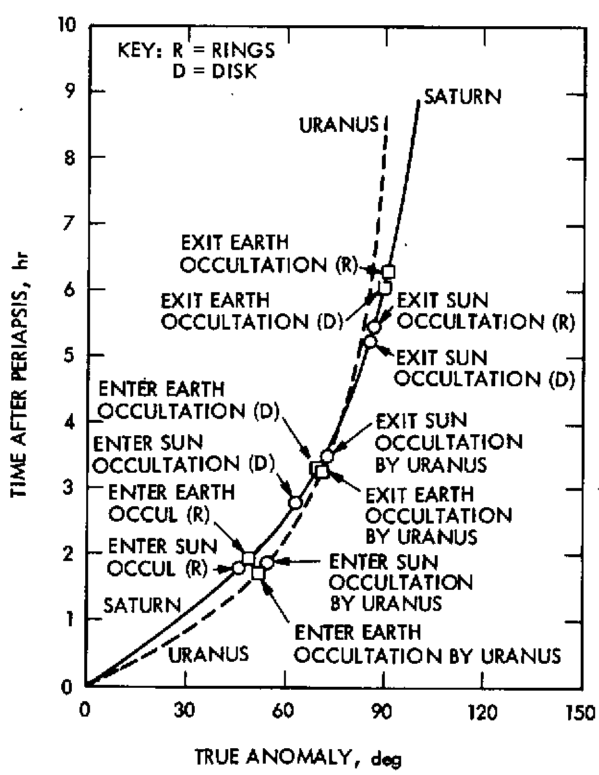


Figure 1-7. Occultations

radio signal, various properties of the atmosphere can be computed. During most of the occultation period, communication with the Earth is cut off. Therefore, all GS&E data acquired during this period must be stored for later playback.

Figure 1-8 presents the phase angle at the sub-spacecraft point on the planet surface for ±24 hr about peripasis. As the spacecraft is approaching either Saturn or Uranus, the planet appears to be nearly fully sunlit (low phase angle). Also, in both cases, the sub-spacecraft point crosses the terminator (phase angle = 90 deg) just before periapsis passage. It is assumed that PLSI imaging will end at periapsis. In both cases as the spacecraft recedes from the planet, it appears to be largely dark with only a thin lighted crescent.

Table 1-10 provides a brief summary of OPPICSS mission design parameters.

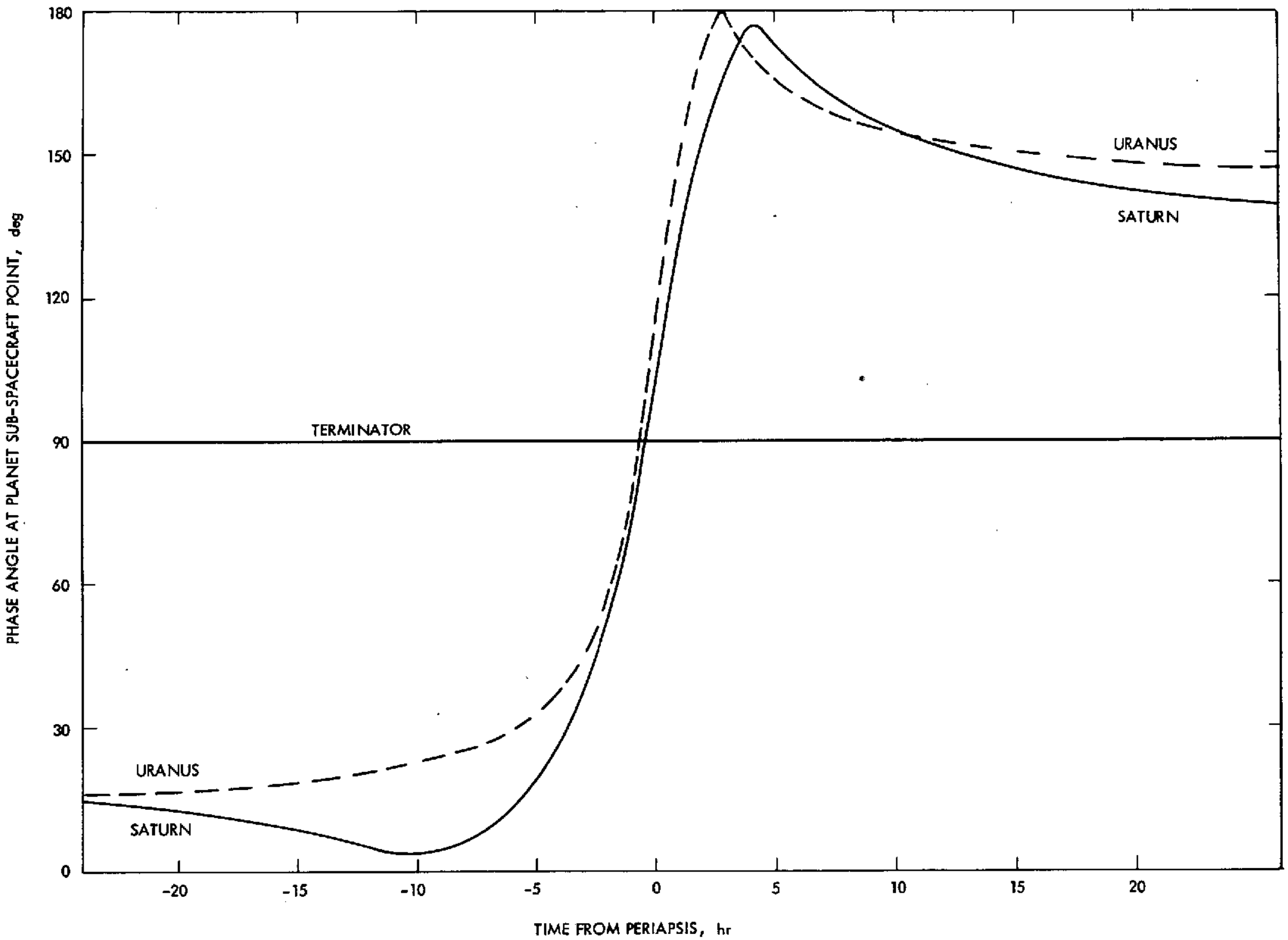


Figure 1-8. Phase Angle

Table 1-10. OPPICSS Mission Design Parameters

Mission:	1980 Saturn/Uranus	
Launch Date:	26 November 1970 to 10 December 1980	
Spacecraft Weight:	476 kg (1050 lb)	
Launch Period:	15 days	
Launch Vehicle:	Titan/Centaur TE-364-4	
Saturn Encounter:	0224 GMT 5 January 1984 (3.1 yr)	
Saturn Encounter Radial Distance:	165,000 km (2.73 R_s)	
Saturn-Earth Distance at Encounter:	10.30 AU (1.54 x 10^9 km)	
Earth Occultation by Outer Ring:	Enter 0420 GMT, Exit 0842 GMT	5 Jan. 1984
Earth Occultation by Saturn:	Enter 0544 GMT, Exit 0828 GMT	5 Jan. 1984
Sun Occultation by Outer Ring:	Enter 0410 GMT, Exit 0744 GMT	5 Jan. 1984
Sun Occultation by Saturn:	Enter 0513 GMT, Exit 0743 GMT	5 Jan. 1984
Probe Separation:	2.42 x 10^7 km (<400 R_s)	
Bus-Probe Communication Range:	110,000 to 160,000 km	
Uranus Encounter:	1200 GMT 9 November 1987	
Uranus Encounter Radial Distance:	94,500 km (3.5 R_u)	
Earth Occultation:	Enter 1346 GMT, Exit 1519 GMT	9 Nov. 1987
Sun Occultation:	Enter 1354 GMT, Exit 1530 GMT	9 Nov. 1987
Uranus Earth Distance at Encounter:	20.01 AU (2.995 x 10^9 km)	

L. SATURN ATMOSPHERIC ENTRY PROBE

Approximately 25 days before Saturn encounter the probe is separated from the spacecraft bus. The probe derives its spin stabilization from the spinning bus. After separation, the bus undergoes a two-component deflection maneuver at S-24 days as shown in Table 1-3. The Earth-line component retards the bus slightly behind the probe. The component perpendicular to the Earth-line deflects the bus and prevents it from impacting Saturn. This two-part maneuver assures good communication geometry between the bus and Earth and between the probe and the bus during entry. A final bus trim maneuver is made at S-10 days.

A schematic view of the Saturn encounter as seen from the Earth is shown in Figure 1-9. At the time of probe separation, the sub-spacecraft latitude is about 8.6 deg North. This will assure probe entry in the low to mid-latitudes in the Northern hemisphere of Saturn.

After separation, the probe cruises silently in formation with the bus towards Saturn. A more detailed view of the last 8 hr of the probe's flight is presented in Figure 1-10. Shortly before entry into the top of Saturn's atmosphere, the probe battery is activated and it starts to transmit data at 88 coded symbols/sec to the bus via a 400-MHz telemetry link. The bus in turn relays the probe data as part of an A format mainframe to the Earth at X-band. In addition to the real-time relay, the probe data is recorded in a separate data

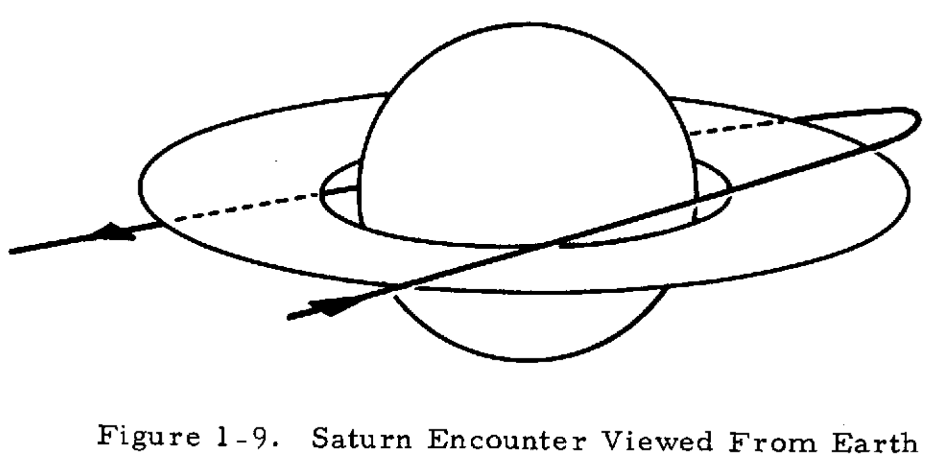


Figure 1-9. Saturn Encounter Viewed From Earth

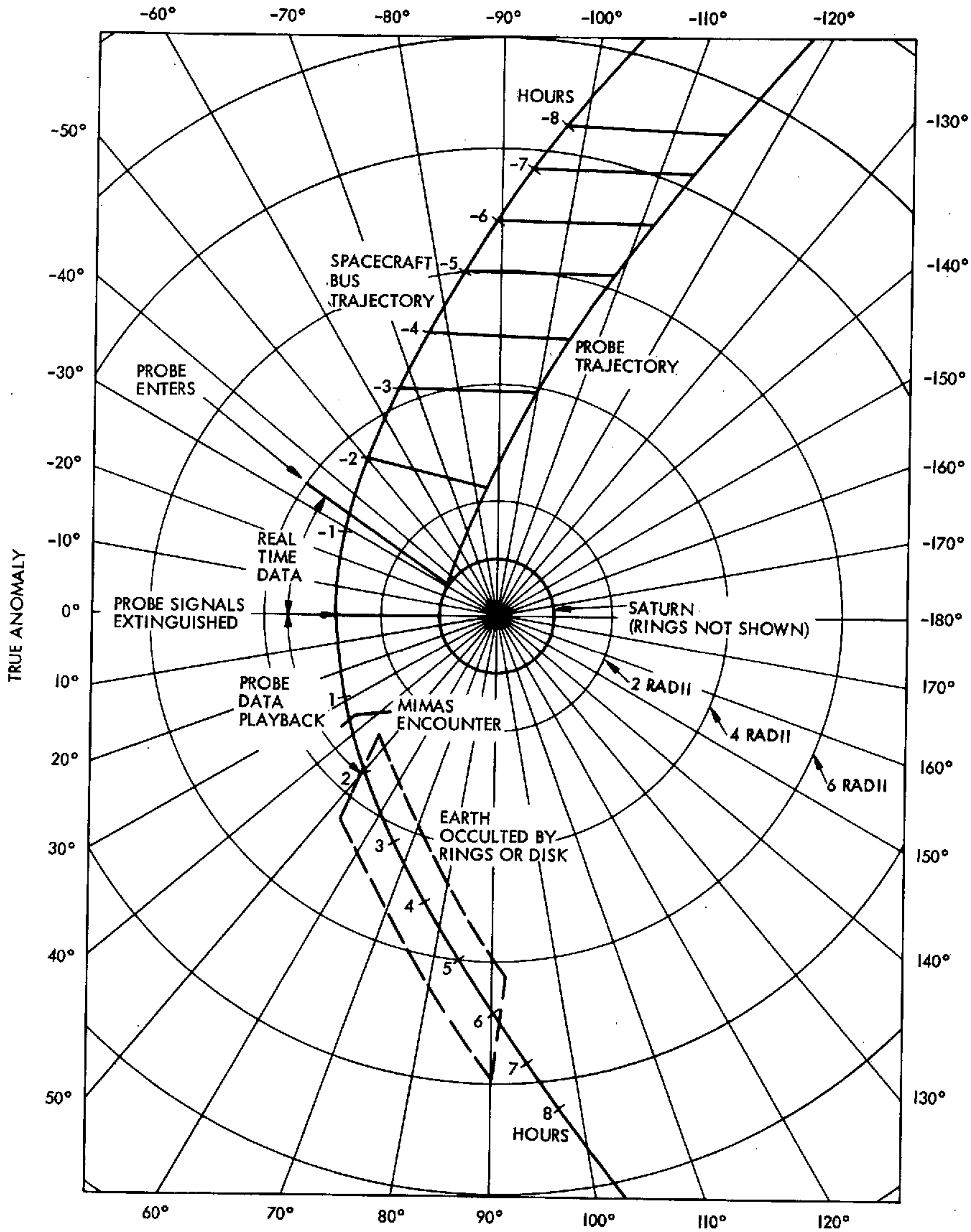


Figure 1-10. Probe Detail

storage unit (DSU) aboard the bus for later redundant playback to the Earth. This DSU should have a capacity of about 0.38×10^6 bits for probe data, as the probe will be transmitting for about 1.2 hr. It is hoped that during its 1.2 hr of active life, the probe will succeed in descending to a 10 bar (10 Earth atmospheres) pressure level. Below this level, it is assumed that either the probe will be crushed or its telemetry signal to the bus will be extinguished by attenuation in the atmosphere. The bus-probe relay geometry has been chosen such that the bus will approximately fly over the probe when transmission ends a little over an hour after probe entry. About this time, the bus will also have reached its hyperbolic periapsis. Since the bus will have previously crossed the planet terminator, it is assumed that the PLSI will no longer be taking images of Saturn.

After the spacecraft reaches periapsis, GS&E data will still be transmitted in real time together with readout from memory of the stored probe data. If desired, only A format mainframes could be transmitted at 8192 bits/sec. This could continue until the PLSI is reactivated prior to the Mimas encounter about 1.3 hr after periapsis. Each A format mainframe consists of 192 data bits, 24 of which are devoted to probe data. For an 8192 bit/sec data stream consisting of only A format mainframes, the probe DSU can read out once every

$$\frac{0.38 \times 10^6 \text{ bits}}{8192 \frac{\text{bits}}{\text{sec}} \times \frac{24}{192}} = 371 \text{ sec}$$

or 10 times in 1 hr 2 min.

Prior to encountering Mimas, the 8192 bits/sec data stream would revert to 1 A followed by 7 D3 format mainframes. Imaging of satellites, GS&E data, and probe data read-out (at a lower rate) could continue until the onset of ring Earth occultation about 1.94 hr after periapsis.

During Earth occultation, the spacecraft will continue to obtain GS&E, but not imaging data. The GS&E data can be stored in a separate memory similar to that provided for probe data. (The GS&E and probe DSU's receive data at low rates estimated to be 64 bits/sec and 88 bits/sec, respectively. The PLSI data memory receives data at very high rates of the order of 10^6 bits/sec; hence it is of a fundamentally different design.) The capacity of the GS&E memory can be estimated in the following way. The Saturn ring Earth occultation period lasts approximately 4-1/3 hr. If all of the general science instruments taken together are assumed to generate data at the rate of 64 bits/sec, then the GS&E data memory would require a capacity of 0.998×10^6 bits (excluding the allowance for engineering data), if this data were to be stored throughout the entire ring occultation period at Saturn.

After the spacecraft exits Earth occultation, the stored GS&E data can be read out, the probe data readout could be repeated, or imaging of satellites or the thin lighted crescent of Saturn could be resumed.

M. SATELLITE OBSERVATIONS NEAR ENCOUNTER

Saturn has ten natural satellites. The innermost seven have orbits outside the visible rings and in the planet's equatorial plane. Their periods vary from 0.75 to 15.95 days. In order to fly from Earth to Saturn to Uranus, the spacecraft approach geometry at Saturn is highly constrained. As the spacecraft approaches Saturn, the sub-spacecraft point is in the northern hemisphere, well above the satellite orbit plane. About 2.5 hr before hyperbolic periapsis passage, the sub-spacecraft latitude reaches its maximum value of nearly 30 deg. After this time, the trajectory is deflected sharply downward crossing the satellite orbit plane about 1.1 hr after periapsis at a distance of 3 Saturn radii (R_s) from the center of the planet.

Although the aiming point at Saturn is constrained, the spacecraft arrival time is a relatively free variable. The modest propulsive maneuvers shown in Table 1-3 at Earth + 20 days and Saturn - 26 days are used to adjust the Saturn aiming point as well as the arrival time. The arrival time at periapsis can be chosen such that when the spacecraft crosses the satellite orbit plane after periapsis it is phased to pass as close as possible to any one of the satellites. The closest passage could be made to Mimas at a distance of about 9400 km approximately 1.31 hr after periapsis. A summary of possible satellite close encounters is given in Table 1-11.

The sub-spacecraft point crosses the planet terminator about 0.4 hr before periapsis. At this time, the bulk of the PLSI imaging of Saturn will have been completed. Since the suggested satellite encounters are after planet periapsis, there should be relatively little scientific competition between Saturn and the satellites for control of the pointing direction of the PLSI. However, it should be noted that Earth occultation by Saturn's rings begins at E + 1.94 hr and ends at E + 6.31 hr, and Earth occultation by Saturn's disk begins at E + 3.33 hr and ends at E + 6.07 hr. Therefore, it will probably be best to phase the spacecraft arrival time to pass close to Mimas, as the other potential close satellite passages would occur when the spacecraft is in Earth occultation either by Saturn or its rings.

Uranus has five natural satellites orbiting in its equatorial plane; their periods vary from 1.41 to 13.46 days. The closest satellite is Miranda, whose mean distance is 129,800 km from the center of Uranus. The example trajectory from NASA Ames provides a posigrade Uranus flyby at a radial distance of 3.5 R_u or 94,500 km. Recall that the spin axis of Uranus is tipped

Table 1-11. Summary of Possible Satellite Close Encounters

Time Relative to Planet, Periapsis, hr	Spacecraft Radial Distance from Planet Center, R_s	Sub-spacecraft Latitude on Planet, deg	Satellite	Possible Closest Approach Distance to Satellite, km
1.31	3.11	-2.9	Mimas	9,400
2.87	4.15	-16.1	Enceladus	68,500
4.33	5.34	-22.0	Tethys	119,000
6.31	7.04	-25.7	Dione	183,000

over such that it lies nearly in the orbit plane of Uranus about the Sun. Thus, as the spacecraft approaches, Uranus and its satellites appear somewhat like a bull's-eye with revolving targets in a shooting gallery. As Uranus is the terminal planet for our example mission, considerable freedom is available in selecting the spacecraft aiming point as well as the time of arrival. Assume that a radial distance of 3.5 R_u is a reasonable compromise between high resolution for planet data and a reasonably close approach to the orbit of Miranda. Then the last two maneuvers in Table 1-3 can be used to adjust the Uranus aiming point and to time the spacecraft arrival such that it crosses the satellite orbit plane when Miranda is only 129,800 - 94,500 = 35,300 km away. The sub-spacecraft point crosses the Equator on Uranus about 1.02 hr before periapsis passage, and it crosses the terminator on Uranus about 0.36 hr later. Therefore, there should be only modest scientific competition between the planet and its satellites for control of the pointing direction of the PLSI. Earth occultation by the disk of Uranus begins at E + 1.77 hr and ends at E + 3.31 hr, so this will not interfere with satellite observations.

Throughout this discussion of satellite observations, we have emphasized opportunities occurring near or after the end of PLSI planet observations in order to minimize scientific conflicts between a planet and its satellites. It is entirely possible that the scientists may wish to reallocate some of the PLSI planet observations during the approach phase to the satellites, particularly at Uranus where the spacecraft trajectory is nearly normal to the satellite orbit plane at the instant of penetration.

N. SUMMARY AND CONCLUSIONS

The PLSI will provide an improvement in the number and quality of the images that can be obtained with an Outer Planet Pioneer spacecraft. Near planet encounters, when the PLSI is operating, data compression can be employed to increase the number of images that can be obtained. The total number of images to be obtained is likely to be limited by ground data processing costs and the ability of imaging scientists to absorb and interpret vastly increased quantities of data. Compression ratios from 2 to 8 appear to be of greatest interest, as most of the original image information can be preserved, and picture quality is expected to remain acceptable to the scientists.

For Outer Planet Pioneer missions it appears as if the spacecraft should transmit data at X-band frequencies using a TWT amplifier with a high power mode of at least 23 watts. The 64-m DSS will be required for receiving the data, as the 26-m DSS cannot receive X-band signals. Although X-band is susceptible to weather degradation, data compression can alleviate this problem by permitting a given number of images to be returned at a lower data rate while maintaining acceptable quality.

If the telemetry downlink can support a data rate of 8192 bits/sec or higher, and the channel coding schemes employed provide a sufficiently low bit error rate, then a very large number of images can be obtained without data compression. This is the situation for the Saturn encounter in our example mission. If, however, the data rate is considerably lower, data compression can be employed to increase the number of images, and, therefore, the scientific return. This is the case for the Uranus encounter in our example.

SECTION II

PIONEER LINE SCAN IMAGER

A. INTRODUCTION

The various subsystems considered during this study fall into two categories: existing components and those still under development. This is a very significant distinction. In the case of existing subsystems, any modification to the design involves tinkering with a tightly integrated, space qualified device. In the case of developmental subsystems, changes can usually be made using only a typewriter. The Pioneer Line Scan Imager (PLSI) is clearly in the developmental category.

Because modifications to a non-existent imager are relatively simple, many problems identified by the OPPICSS study have already been solved through paper redesign. In most instances, it has been possible to change from one design approach to another of similar cost and complexity. However, in order to understand the current baseline definition of the imager, it is necessary to review briefly the evolution of the PLSI during the course of OPPICSS.

The initial definition of the PLSI was completed prior to the start of OPPICSS. The imager was designed to be compatible with the Outer Planets Pioneer Spacecraft as defined in the Outer Planets Pioneer Spacecraft document. (NASA/Ames Research Center, 15 April 1974.) This spacecraft is an upgraded version of Pioneer 10/11, the major improvements being an X-band telecom channel and 10^6 bits of on-board data storage.

As the study progressed, three problem areas were identified:

1) The extremely high and variable data rate out of the imager made the interface with the spacecraft Digital Telemetry Unit impractical. Therefore, it was decided that the imager would interface directly with the Data Storage Unit, and the imager would provide the gating signals for transfer of data. The moderate data compressor (editor) operates on one-dimensional data and is fast enough to work at the

imager data rate. It can, therefore, be placed in series between the imager and the buffer storage. The RM2, however, requires two-dimensional data blocks and cannot match the imager data rate. This compressor, therefore, must operate on the data after it has been read into storage.

2) The original PLSI design called for encoding each pixel to 10 bits, and then truncating some combination of MSB's and LSB's to produce an 8-bit word. Because MSB truncation can disrupt the usual correlation within the image, this scheme is incompatible with sophisticated data compressors. Also, the ground data system is committed to a standard 8-bit word. If the truncated MSB's were restored on the ground, the resulting 9- or 10-bit words would each occupy two of the standard 8-bit words, thereby increasing processing costs. Because of these problems, the PLSI encoding has been changed to 8 bits, and some of the lost image flexibility was restored through a system of analog gains and offsets. Although this change was made quite late in the OPPICS study, it does not invalidate any of the analysis or conclusions based on the original scheme.

3) The real time command load during the Pioneer 10 Jupiter encounter was pronounced excessive by the DSN. With the original PLSI design, the required command load would be substantially worse (approximately 8 commands/frame). A redesign of the command scheme greatly lowered the total number of commands sent (2 per frame), but did not relieve the critical timing requirement on the remaining commands. The redesign of the command structure involved an expansion of the command dictionary and the addition of a simple sequencer in the imager.

Having reviewed the background leading to the present definition of the PLSI, it is now possible to state the first major conclusion of this section: the choice of data system (from among the three under study) has practically no impact on the hardware aspects of the imager. This situation is the result of two factors: first, the paper design of the imager was revised fairly late in the game to improve compatibility with the various data systems, and second, the buffer which stands between the imager and the rest of the data system can be used to reformat the data as well as lower the rate.

The conclusion that the data system has little effect on the imager design means that a single statement of operating mode, weight, volume, power, cost, etc. will serve for all three options. Although the hardware remains the same, the three data systems will result in different levels of performance for the PLSI.

B. PLSI DESCRIPTION

A detailed description of the PLSI is given in the document "Pioneer Line Scan Imager Functional Definition". The three changes listed above were made after the Functional Definition was published. The changes in the command scheme were defined in a supplement, "Alternate PLSI Command Structure".

C. UNCOMPRESSED DATA CHANNEL

With 7/8 of the uncompressed data channel assigned to imaging, one full frame can be acquired every 10 rolls at Saturn, every 40 rolls at Uranus. Under these conditions, it is possible to obtain between 15 and 20 thousand Saturn frames at better than Earth-based resolution. This is more frames than we could afford to process, so the compressor is not needed simply to boost the overall picture count.

A simple experiment profile has been proposed which allows us to measure the quantitative effect of using various data channels. With the uncompressed data channel, this profile calls for three-color full-disc coverage on an hourly basis until E-23h at Saturn, followed by 690 frames at resolution better than 120 km/pixel. The equivalent numbers at Uranus are E-31 h, 232 frames, and 232 km/pixel. Similar numbers are given in the next section for the compressed channel.

With an average of two commands per frame, imaging with uncompressed channel is within the capabilities of the Pioneer command system, although it consumes 36% of the uplink capacity at Saturn. Those two commands, however, are time critical, and this remains one of the major unresolved problems of the OPPICS study.

D. COMPRESSED DATA CHANNELS

The two compressed data channels will be tested together because, from the imager point of view, their similarities are greater than their differences. The differences will be considered first:

1) Image Quality — At equal compression ratios, the RM2 compressor will outperform the editor. The maximum useful compression ratio (beyond which the image quality is totally unacceptable) is higher for RM2 than for the editor. A quantitative comparison of image quality must await completion of the simulation study.
2) Nature of Telecom Channel Noise — With the moderate compression system, the channel errors will occur as rare large bursts. With the AICS system, the channel errors will cause rare deletions of blocks containing several thousand bits. (See Sections IIIB6, IIIC6, and IIID6 for more details.)
3) Relation to Storage Capacity — Since the editor can precede the buffer storage in the data system, it would be possible to increase the number of lines/frame by a factor equal to the compression ratio. Thus, with 2X editing, the storage would accommodate $2 \times 640 = 1280$ lines.

To make a crude comparison between the two compressors, an estimate is made of the maximum acceptable compression ratio for each. The estimate chosen by this author is 2X for the editor and 8X for the RM2 compressor. With this assumption, we can calculate the three figures of merit discussed for the uncompressed channel: the time at the close of full disc coverage, the resolution at that time, and the number of frames remaining before encounter. These numbers are:

Editor/Saturn	E-13h	75 km/pixel	1300 frames
Editor/Uranus	E-11h	59 km/pixel	275 frames
RM2/Saturn	E-10h	60 km/pixel	1500 frames
RM2/Uranus	E-8h	42 km/pixel	340 frames

The command problem is aggravated by the compressed channels. If we assume 2 commands per frame (at 22 seconds each), then the command system requires 4 spacecraft rolls (at 12 seconds each) between frames. At Saturn, this is a serious limitation on the effectiveness of the compressor, at Uranus it is not. Thus, at Saturn, compression factor greater than 3 may require use of the imager's automatic sequence feature. A more probable solution to the problem is an eventual change in the Pioneer command system.

E. CONCLUSIONS

1) X-band and data compressor technology seem to be maturing at about the same time. Taken together, these two advances result in a data channel whose efficiency places a major strain on the rest of the Pioneer system. In other words, the rest of the system needs to catch up to the proposed new channels.
2) The compressors are largely near encounter devices. This argument is made in detail in Appendix L.
3) Because ground processing costs place a limit on the total number of frames for a mission, the compression factors attainable by the compressor are not good figures of merit by themselves. When all factors are considered, the net improvements offered by the compressors are in the range from 2 to 4. Because of the drop in telecom rates with distance, compressors are more valuable at the further planets.
4) Given an opportunity, the scientist would like the freedom to trade the compressor off against other features of comparable size/weight/power. Some examples of this are an additional kilogram or two in the camera to permit a larger telescope or three full frame buffers instead of one. This latter feature would substantially improve color registration.

SECTION III

ANALYSIS OF SPACECRAFT ON-BOARD PROCESSING OF IMAGE DATA

A. INTRODUCTION

1. Image Data Compression Options

The OPPICSS study guidelines called for consideration of three system options. The first system option did not contain an image data compressor and was designated as the "OPPICSS Baseline System." The second system option was to contain an attractive data compressor for a system of "moderate" complexity. Based upon available simulation results from the previous OPP data compression study, "Pixel Editing" was selected for the moderate complexity system option. The third system option was specified to contain an RM2 data compressor in a system option employing the Advanced Imaging Communication System (AICS) configuration recommended in the previous OPP data compression study. The three system options are hereafter referred to as the "Baseline" option, the "Pixel Edit" option, and the "AICS" option, respectively.

2. Ground Rules of Special Importance to the Spacecraft Image Data Handling

a. Pioneer Line Scan Imager

The Pioneer Line Scan Imager (PLSI) was assumed as the imaging instrument. (See Ref. 1. Pioneer Line Scan Imager Functional Definition, July 12, 1974, for a detailed description of the PLSI.) The following list summarizes characteristics of the PLSI data which are especially important to the design of spacecraft data handling elements:

1) Picture Formats. Individual "image frames" were defined to comprise (160 pixels-per-line) × (160, 320, 480, or 640 lines-per-frame).

2) Maximum Time to Acquire a Picture. The maximum time to acquire a picture and deliver the data to the data storage unit was reported to be 1.75 seconds.

3) Pixel Intensity Resolution. Analog pixel values are linearly converted to 8 bits-per-pixel.

4) Modulation Transfer Function. The response of the PLSI instrument to spatial frequencies equal to one-half the pixel sampling rate is approximately 30% of the peak response.

5) Pattern "Noise" in Image Data. It is expected that the pattern noise will be dominated by an "offset" term which is added to each pixel value and which is dependent upon the position of each pixel within a line. (Corresponding pixels in successive lines exhibit the same offset.)

6) Random Noise in Image Data. Random noise content in the image data is limited to the least-significant-bit of the 8 bit-per-pixel representation.

b. Data Storage Unit

It was assumed that the spacecraft contained a data storage unit (DSU) which could store a complete 160 × 640 pixel picture with a pixel resolution of up to 8 bits-per-pixel. The basic storage element was assumed to be an LSI circuit which contained 8 parallel change-coupled-device (CCD) dynamic shift registers of 8192 bits each. It was assumed that the CCD-LSI memory element was able to store data for up to 50 ms before "refresh" was required, and that "refresh" circuits were provided at 50-bit intervals along each shift register. Thus data input/output was assumed to occur in word-serial fashion with 8 (parallel) bits-per-word. The maximum register clock rate was assumed to be $\sim 10^6$ Hz.

c. CMOS Integrated Circuits

It was assumed that CMOS integrated circuits of the kinds contained in the RCA CD-4000 line are acceptable in spacecraft hardware. It was also assumed that CCD memory chips of the kind planned for the DSU would be available for use in other elements of the system.

d. Maximum Data Transmission Rate

It was assumed that the maximum data transmission rate was 8,192 bits/sec and that all data rate changes would be in "3 dB" steps. It was assumed that general science and engineering data would be interspersed with imaging data on a single communication channel, and that the "general science" data required a bit error rate of $\leq 10^{-4}$.

e. Spacecraft Rate

It was assumed that the spacecraft roll rate had a constant value of approximately 5 rev/min. Also, it was assumed that no more than one image frame would be acquired during one revolution of the spacecraft.

3. Basic Format Structure of Image Data

As noted in the previous section, each uncompressed image frame contains 160, 320, 480, or 640 lines of 160 pixels each. It is convenient to define each 160 line × 160 pixel array of image data as an image subframe. Further, it is convenient to subdivide each image subframe into five 32 line × 160 pixel arrays and to call these arrays image source blocks. These definitions are illustrated in Figure 3-1.

The actual image data are combined with sync words, format identification (ID) words, PLSI housekeeping data, and data compressor housekeeping data to obtain a format structure which is suitable for transmission. The resultant image telemetry data format is illustrated in Figure 3-2.

The image data sync word is assumed to comprise 32 bits, and the format ID word is assumed to contain 8 bits. The decoding table for the format ID word is shown in Table 3-1.

The PLSI "housekeeping data" field comprises 256 bits in each system option. It is assumed that a "picture count" measurement would be contained in this data field.

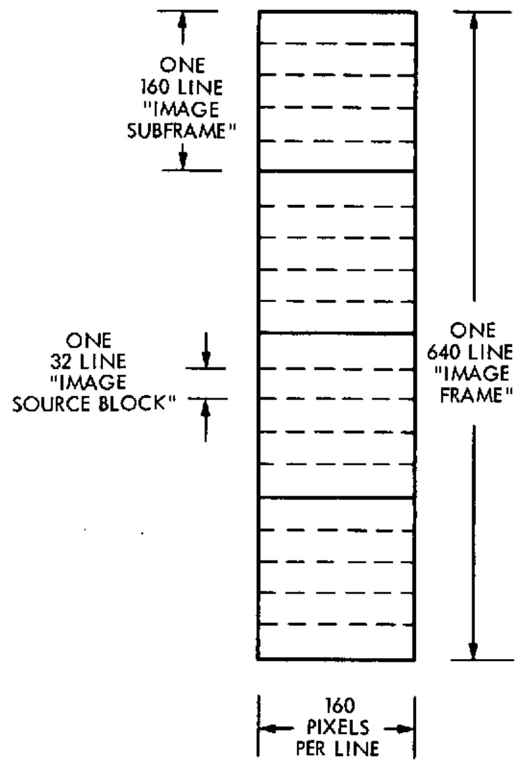


Figure 3-1. Image Source Blocks

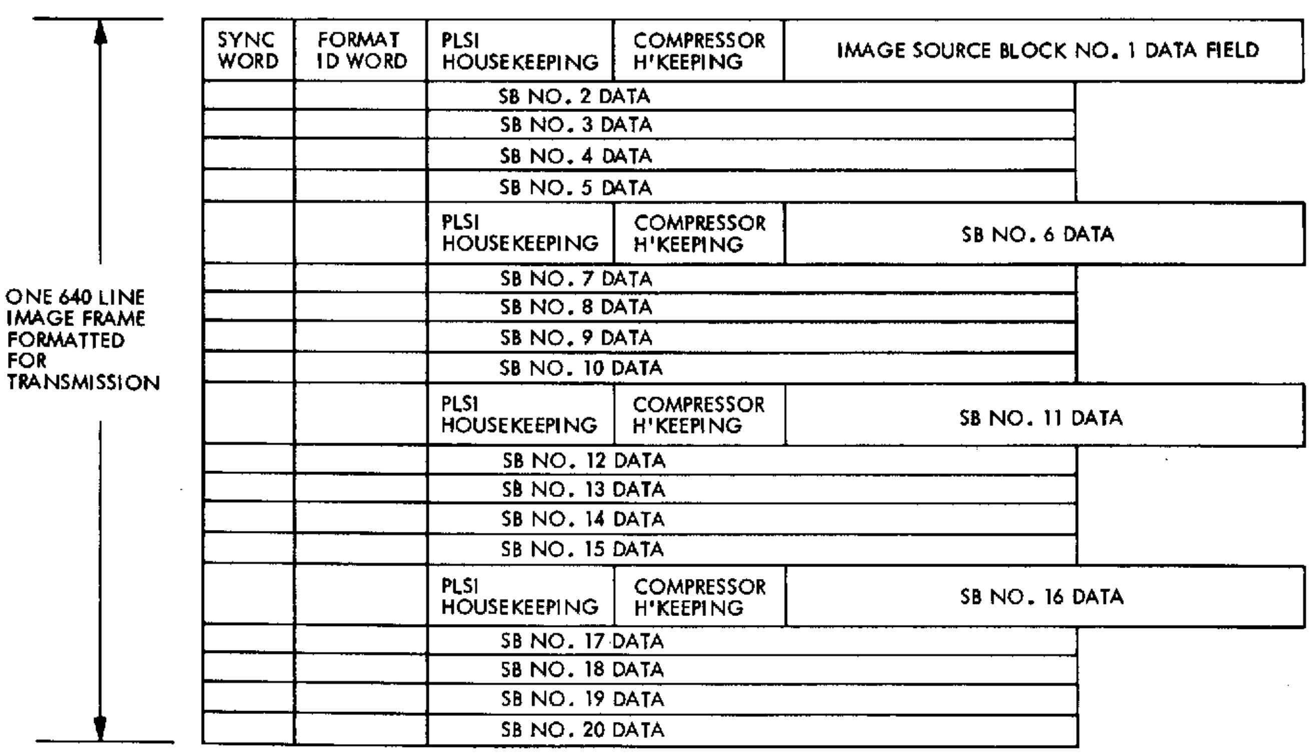


Figure 3-2. Image Telemetry Format

Table 3-1. Format Word ID Decoding

<u>First Five Bits</u>

Reports the number of the associated source block (1 to 20) in standard binary PCM code.

<u>Last Three Bits</u>

000: Uncompressed Image Data Format

001: 2:1 Pixel Edit Format

010: 4:1 Pixel Edit Format

011: 6:1 Pixel Edit Format

100: 8:1 Pixel Edit Format

101: RM2 Compressed Data Format

110: (Spare)

111: Filler Bit Format

No bits would be contained in the data compressor housekeeping data field for the Baseline system option or the Pixel Edit option. Approximately 32 bits would be required for the AICS system option.

Prior to actual transmission, the formatted image data are combined with formatted GS&E data on a time division multiplex basis. Specifically, following each 192 bit GS&E "main frame" ("A" or "B" format), a sequence of seven 192 bit "D3" main frames are transmitted which contain asynchronously imbedded image data which is in the previously described format. Each such set of 8 consecutive main frames is called a "data cycle." A representative "cycle" of imaging mode telemetry data is illustrated in Figure 3-3.

The normal ground processing sequence for these data would proceed as follows:

1) Find mainframe sync by locating the sync word imbedded in the A (or B) mainframe.
2) Separate the D3 mainframes from the A (or B) mainframes.

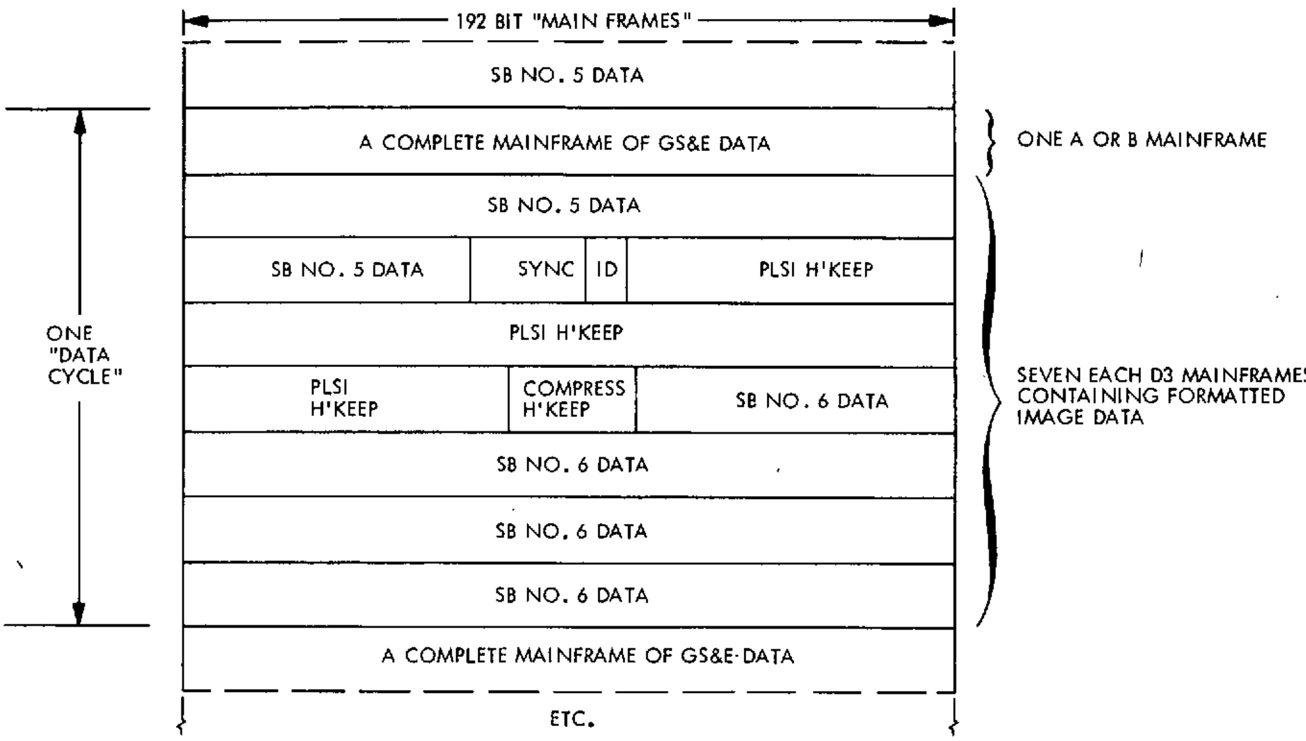


Figure 3-3. Representative Cycle of Imaging Mode Telemetry Data

3) Find an image data frame sync word in the data stream comprised of D3 mainframes.

4) Decode the source block ID word to determine where the associated pixels fit into the picture and to determine the next step in the image data restoration process.

B. ANALYSIS OF SPACECRAFT ON-BOARD PROCESSING OF IMAGE DATA IN THE BASELINE SYSTEM

1. Description of Compression Algorithm

There is no data compressor in the baseline system.

2. Basic Image Data Flow

The Basic Image data flow is shown in Figure 3-4.

The normal sequence of operations proceeds as follows:

1) Commands are sent to the PLSI and digital telemetry unit (DTU) to control image data acquisition and to establish the appropriate DTU operating mode.
2) Appropriate PLSI housekeeping data is transferred to the image processing and control unit (IPC).
3) The required image is acquired; the pixel data are transferred to the DSU in a period not exceeding 1.75 seconds.
4) The IPC causes formatted image data (including sync words, etc.) to be transferred to the OB in a manner which avoids output buffer (OB) overflow or underflow.
5) The DTU calls for data from the OB as required to assemble formatted data cycles for transmission at the commanded channel bit rate.

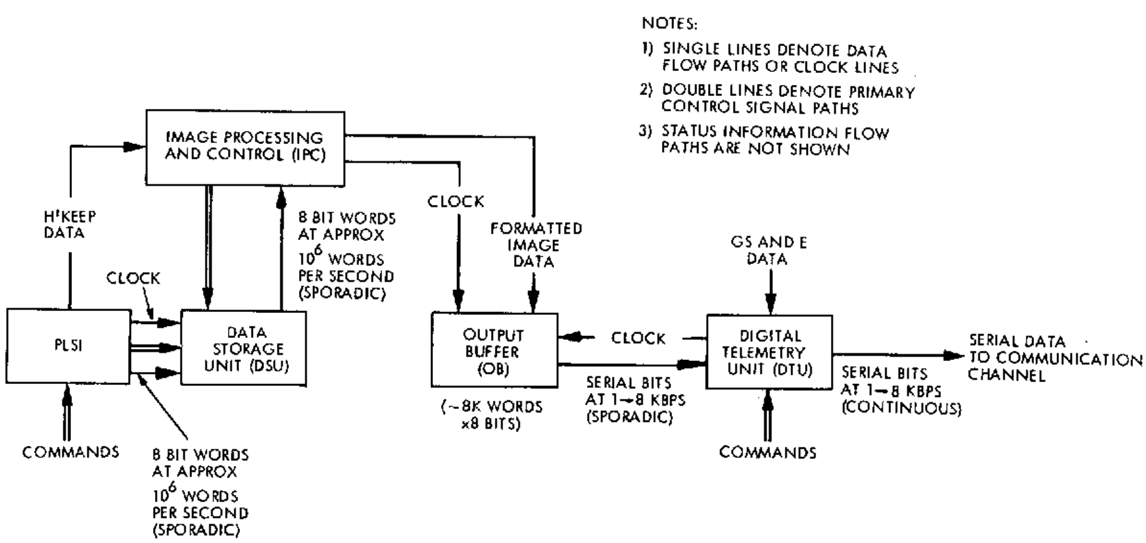


Figure 3-4. Basic Image Data Flow Diagram

3. Command Requirements for Data Compressor Control

No data compressor control commands are required in the baseline system.

4. Image Data Format Details

The principal parameters of formatted uncompressed image data are tabulated in Table 3-2.

If it were deemed desirable, filler bits can be added at the end of each image subframe to make each subframe correspond to exactly 153 data cycles. This would increase the on-board logic complexity slightly, but it may be preferred from a ground processing viewpoint.

The following Table 3-3 lists the number of spacecraft revolutions required to transmit uncompressed image frames as a function of the transmitted bit rate.

Table 3-2. Principal Parameters of Formatted Uncompressed Image Data

No. bits in first source block of each image subframe:	41,256
No. bits in second source block of each image subframe:	41,000
No. bits in third source block of each image subframe:	41,000
No. bits in fourth source block of each image subframe:	41,000
No. bits in fifth source block of each image subframe:	41,000
No. bits in each image subframe	: 205,256
No. bits in 640 line image frame	: 821,024
Average No. data cycles per 640 line image frame	: ~610.9

Table 3-3. Spacecraft Revolutions Per Image Frame

	Transmitted Bit Rate			
	8192 b/s	4096 b/s	2048 b/s	1024 b/s
160 × 160 frames	2.38 rev	4.77 rev	9.55 rev	19.09 rev
160 × 320 frames	4.77	9.55	19.09	38.18
160 × 480 frames	7.16	14.32	28.64	57.27
160 × 640 frames	9.55	19.09	38.18	76.36

Because the opportunities to take useful images occur at a specific spacecraft roll position, the time between image acquisitions must correspond to an integer number of spacecraft revolutions.

The principal function of the output buffer is to match the high data rate of the DSU to the low data rate of the channel. Having this structure, however, also enables the final bits of a prior image frame to be transmitted at the same time that a new image is being acquired and loaded into the DSU. Even with this feature, however, it is likely that many situations will occur in which all previously acquired image data will be transmitted before the next image acquisition can be completed. In this case, it is planned to insert "filler bits" (an alternating one-zero pattern) until the next image data becomes available.

5. Spacecraft Data Compressor and Error Correction Coder Hardware

The baseline system contains no data compressor nor error correction coder.

6. Effect of Communication Errors on Received Image Quality

The principal communication error sources which have been identified are the Spacecraft-to-Earth (S/E) channel and the Ground Communication Facility (GCF) lines.

For the baseline system it is planned to employ a K=7, rate 1/2 convolutional code for the S/E channel. Further, it is planned to operate this channel at a Bit-Error-Rate (BER) of $\leq 10^{-4}$ in order to satisfy general science data accuracy requirements. At this operating point, the channel errors tend to occur in short bursts wherein the average number of bits-per-burst is approximately 5 and the average number of bit-errors-per-burst is approximately 3. Consequently, at a BER of 10^{-4}, approximately 0.05% of the pixels in each picture would contain one or more bit errors. This is substantially better than the stated requirement for image data accuracy.

It has been stated that the GCF can always deliver nearly error-free data in "non-real-time." Further, up to 5,000 b/s can be delivered nearly error-free in "near-real-time." The only condition when GCF errors are a potential problem is when >5000 b/s is required in near-real-time. In this condition, it is estimated that the GCF can deliver approximately 99.5% of the 2400 bit "GCF blocks" in error-free form. Each 2400 bit GCF block can convey 2136 bits of telemetry data. Consequently, approximately 440 GCF blocks are required to deliver one complete 640 line image (including the interspersed GS&E data). Thus one would expect an average of approximately 2.2 "flaws" in a typical near-real-time picture where each "flaw" constituted deletion of approximately 1-2/3 lines of the image. (As noted previously, nearly perfect images could be produced in non-real-time.) It is assumed in this analysis that the frame sync algorithm will take advantage of knowledge of which GCF blocks are missing and thereby maintain proper frame sync in the presence of missing GCF blocks.

7. JPL Support of ARC/TRW Spacecraft Data System Development Activities

No JPL development activities would be required to support ARC/TRW development of spacecraft image data processing elements for the baseline system option. (The PLSI subsystem is not considered to fall within the scope of the above statement.)

2-2

C. ANALYSIS OF SPACECRAFT ON-BOARD PROCESSING OF IMAGE DATA IN THE PIXEL-EDIT SYSTEM

1. Description of Data Compression Algorithm

Pixel-edit (PE) data compression involves transmission of a subset of the original pixels such that the transmitted pixels cover the original image area with near uniform spacing. Estimated values for the deleted pixels are then derived on Earth by computing a weighted mean based on the values of nearby pixels which were transmitted. At a compression ratio of 2:1, the restored images are usually of acceptable quality because the values of adjacent pixels in an image are usually highly correlated. Available picture simulations using vidicon images indicated that higher PE compression ratios will often produce excessive degradation of image quality. Further, the degradation at a given PE compression ratio would probably be worse for image data from the PLSI because the PLSI exhibits an unusually high response at spacial frequencies equal to one half the normal pixel sampling rate.

PE compression ratios of 1:1 (uncompressed), 2:1, 4:1, 6:1, and 8:1 were selected for the PE system option. The pattern of transmitted pixels for each of these compression ratios is illustrated in Figure 3-5.

2. Basic Image Data Flow Diagram

The Basic Image Data Flow diagram is shown in Figure 3-6.

The normal sequence of operations is the same as for the baseline system except that compression ratio control commands are required to be sent along with those required for PLSI and DTU control. In the PE system, a Reed-Solomon error-correcting code is concatenated with the convolutional Viterbi channel code because it increases channel rate capability by approximately 35% for a small increase in system complexity.

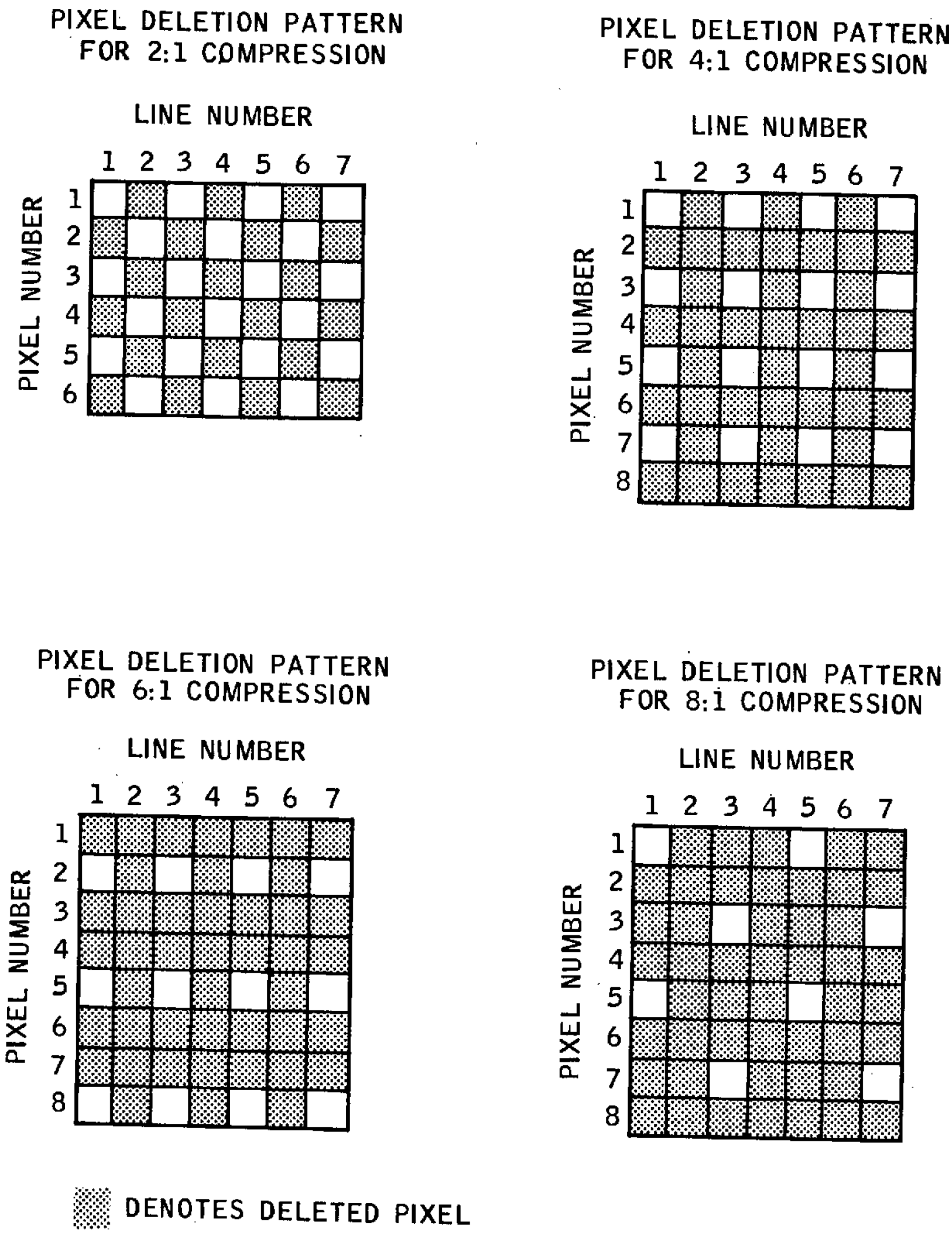


Figure 3-5. Pattern of Transmitted Pixels for Each Compression Ratio

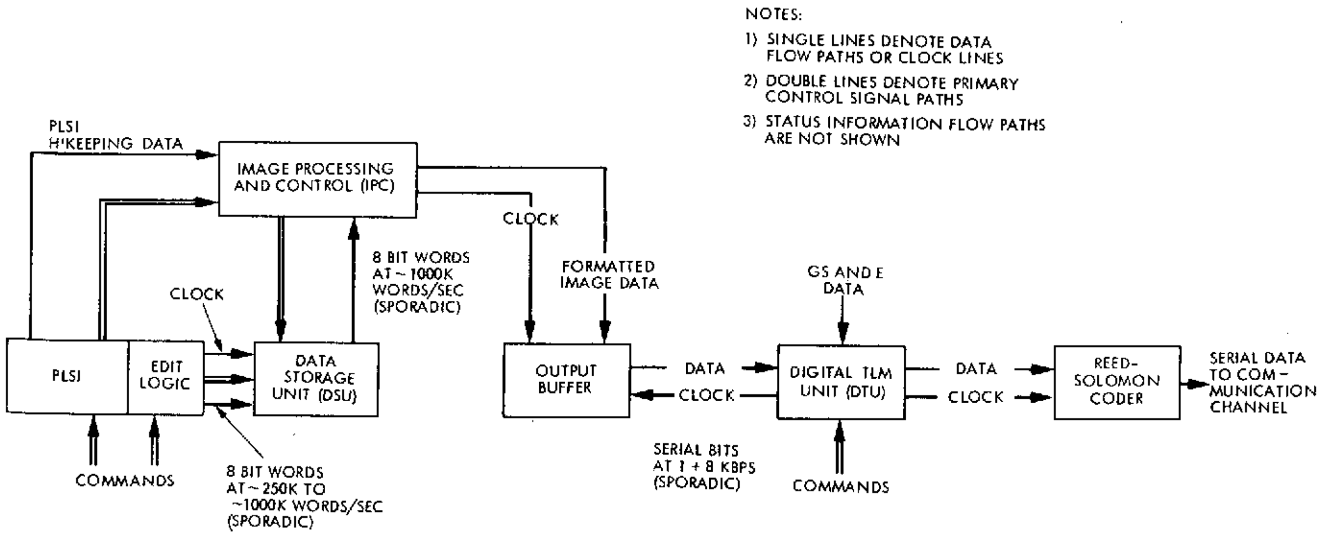


Figure 3-6. Basic Image Data Flow Diagram

3. Command Requirements for Compressor Control

The following five compressor control commands are proposed:

1) 1:1 compression ratio.
2) 2:1 compression ratio.
3) 4:1 compression ratio.
4) 6:1 compression ratio.
5) 8:1 compression ratio.

With these commands, the desired compression ratio can always be established with a single command.

4. Image Data Format Details

The principal parameters of formatted PE compressed image data are illustrated in Table 3-4.

As in the case of uncompressed data, it would be possible to add filler bits at the end of each subframe to make each subframe correspond to an integer number of data cycles.

Table 3-4. Principal Parameters of Formatted PE Compressed Image Data

	Compression Ratio				
	1:1	2:1	4:1	6:1	8:1
No. of Bits 1st SB of subframe	41,256	20,776	10,536	7080	5416
No. of Bits 2nd SB of subframe	41,000	20,520	10,280	6824	5160
No. of Bits 3rd SB of subframe	41,000	20,520	10,280	6824	5160
No. of Bits 4th SB of subframe	41,000	20,520	10,280	6824	5160
No. of Bits 5th SB of subframe	41,000	20,520	10,280	6824	5160
No. of Bits each subframe	205,256	102,856	51,656	34,376	26,056
No. of Bits 640 line image frame	821,024	411,424	206,624	137,504	104,224
Average No. Data Cycles per 640 line image	~610.9	~306.1	~153.7	~102.3	~77.5

Table 3-5 illustrates the tabulation lists for the number of spacecraft revolutions required to transmit PE compressed image frames for several different values of the data transmission rate. The table treats only the 160 × 640 pixel image frames. The values for other image frame sizes can be obtained by a linear scaling process.

The significance of these figures to channel utilization efficiency is, in principle, the same as for the baseline system.

Table 3-5. Spacecraft Revolutions Required to Transmit PE Compressed Image Frames

	Transmitted Bit Rate			
	8192 b/s	4096 b/s	2048 b/s	1024 b/s
1:1 Compression Ratio	9.55 rev	19.09 rev	38.18 rev	76.36 rev
2:1 Compression Ratio	4.78	9.57	19.13	38.26
4:1 Compression Ratio	2.40	4.80	9.61	19.22
6:1 Compression Ratio	1.60	3.20	6.39	12.79
8:1 Compression Ratio	1.21	2.42	4.85	9.69

5. Spacecraft Data Compressor and Error Correction Coder Hardware

The preliminary implementation plan calls for the PE logic to be contained in the PLSI subsystem. Additional logic is required in the Image Processing and Control (IPC) unit to implement the different image data formats including their effect on DSU output control logic. The logic designs were not investigated in detail, but it is unlikely that the associated hardware will exceed 0.2 kgm or 0.5 watt.

The PE system option also includes a Reed-Solomon error correction coder to enable higher data transmission rates at the required BER of 10^{-4}. It has been estimated that this coder would require approximately 0.2 kgm and 0.2 W assuming CMOS logic circuits.

Also, the DTU is required to supply new clock frequencies in addition to those required in the baseline system. The minor effect of this requirement on the DTU implementation is covered in Section IV of this report.

6. Effect of Communication Errors on Received Image Quality

The effects of communication errors in the PE system are quite different from those observed in the Baseline system. The principal difference lies in the fact that the Reed-Solomon (R-S) Convolutional-Viterbi coding used in the PE system results in relatively infrequent, but relatively large, error bursts. The effect of such errors on compressed data is discussed extensively in Section

VI of TM 33-695 ("Channel Coding and Data Compression System Considerations for Efficient Communication of Imaging Data", Robert F. Rice, June 15, 1974) Ref. 2. With the simplest R-S interleave procedure, a single R-S word error can seriously affect many pixel values contained in the 28,416 bits of a R-S block. Also, the nature of the PE reconstruction procedure causes "blossoming" of errors in transmitted pixels.

An analysis of communication error effects was made based upon pessimistic assumptions regarding error distributions. The results of this analysis is summarized in Table 3-6.

Table 3-6. Analysis of Error Distributions

Pixel Edit Compression Ratio	Probability That a Received Image is Damaged by a S/E Channel Error	Probability That a Non-Real-Time Image is Damaged by a GCF Error	Probability That a Near-Real-Time Image is Damaged by a GCF Error When the GCF bit rate is ≤5000 b/s	Average Number of Image Lines Missing from Near-Real-Time 640 line Images when the GCF bit rate is >5000 b/s
1:1	0.0054	0.0051	0.0051	53. lines
2:1	0.0028	0.0025	0.0025	55.
4:1	0.0015	0.0013	0.0013	56.
6:1	0.0010	0.0009	0.0009	56.
8:1	0.0008	0.0007	0.0007	56.

Notes:
(a) R-S word error rate assumed to be 10-5 and R-S word errors are assumed to be statistically independent.

(b) The rate of imperfect GCF blocks for the non-real-time case and near-real-time at ≤ 5000 b/s case is assumed to be 1×10^{-5}.

(c) The rate of imperfect GCF blocks for the case of near-real-time data at ≥ 5000 b/s is assumed to be 5×10^{-3}.

(d) Imperfect GCF blocks are assumed to be completely obliterated.

(e) Each image is assumed to contain 640 lines.

The number of flaws-per picture is inversely proportional to the compression ratio, but the average size of an image flaw is directly proportional to the compression ratio.

The near-real-time images are needed only to confirm proper system operation. The predicted near-real-time performance, even for data rates exceeding 5000 bits/sec, would seem to be adequate for that purpose. Because data rates in excess of 4000 bits/sec are required only for approximately 2 days near Saturn encounter, the most practical approach may be to return only a 5/8 of those data to the MC^3 in near-real-time. That way, the GCF rates would never exceed 5000 bits/sec, the delivered near-real-time data would be virtually error free, and the GCF costs would be reduced because all data could be returned via high-speed data lines (as opposed to wide-band data lines). If better quality near-real-time data is desired at rates exceeding 5000 bits/sec, there are a number of attractive technical approaches to improving near-real-time performance.

7. JPL Support of ARC/TRW Spacecraft Data System Development Activities

No JPL development activities would be required to support ARC/TRW development of spacecraft image data processing elements for the PE data compression system option. However, it may be advantageous to obtain support on the Reed-Solomon Coder from Linkabit Corporation.

D. ANALYSIS OF THE SPACECRAFT ON-BOARD PROCESSING OF IMAGE DATA FOR THE AICS SYSTEM

1. Description of the Data Compression Algorithm

The RM2 data compressor has two basic modes of operation. In the "information-preserving" (IP) mode, the RM2 compressor achieves compression ratios typically in the range of 2:1 to 4:1, and yet enables exact reconstruction of the original image data. In the "rate-controlled" (RC) mode, the RM2 compressor will achieve specified compression ratios in the range of 2:1 to 32:1 with surprisingly small distortion in the restored pictures. The OPP version of the RM2 data compressor operates sequentially on image data source blocks comprising 32 lines of 160 pixels each. In the RC mode, the actual compression ratio may vary slightly from one source block to the next, but an internal servo loop adjusts internal parameters so that the average compression ratio over the whole image is very close to the specified value.

A basic block diagram of the RM2 compressor is presented in Figure 3-7.

There are three basic process steps to the RM2 compression algorithm in the RC mode:

1) Iterative application of a basic 2×2 Hadamard transformation.
2) Application of an approximation (quantization) process to Hadamard coefficients to reduce their entropy to a level compatible with the specified compression ratio.
3) Application of an adaptive, information-preserving, variable length encoding procedure to the modified Hadamard coefficients.

The Hadamard related transform operations employed in the RM2 compressor are described in Ref 3, JPL Technical Memorandum 33-680. ("RM2: Transform Operations" by Robert F. Rice, dated March 1, 1974.)

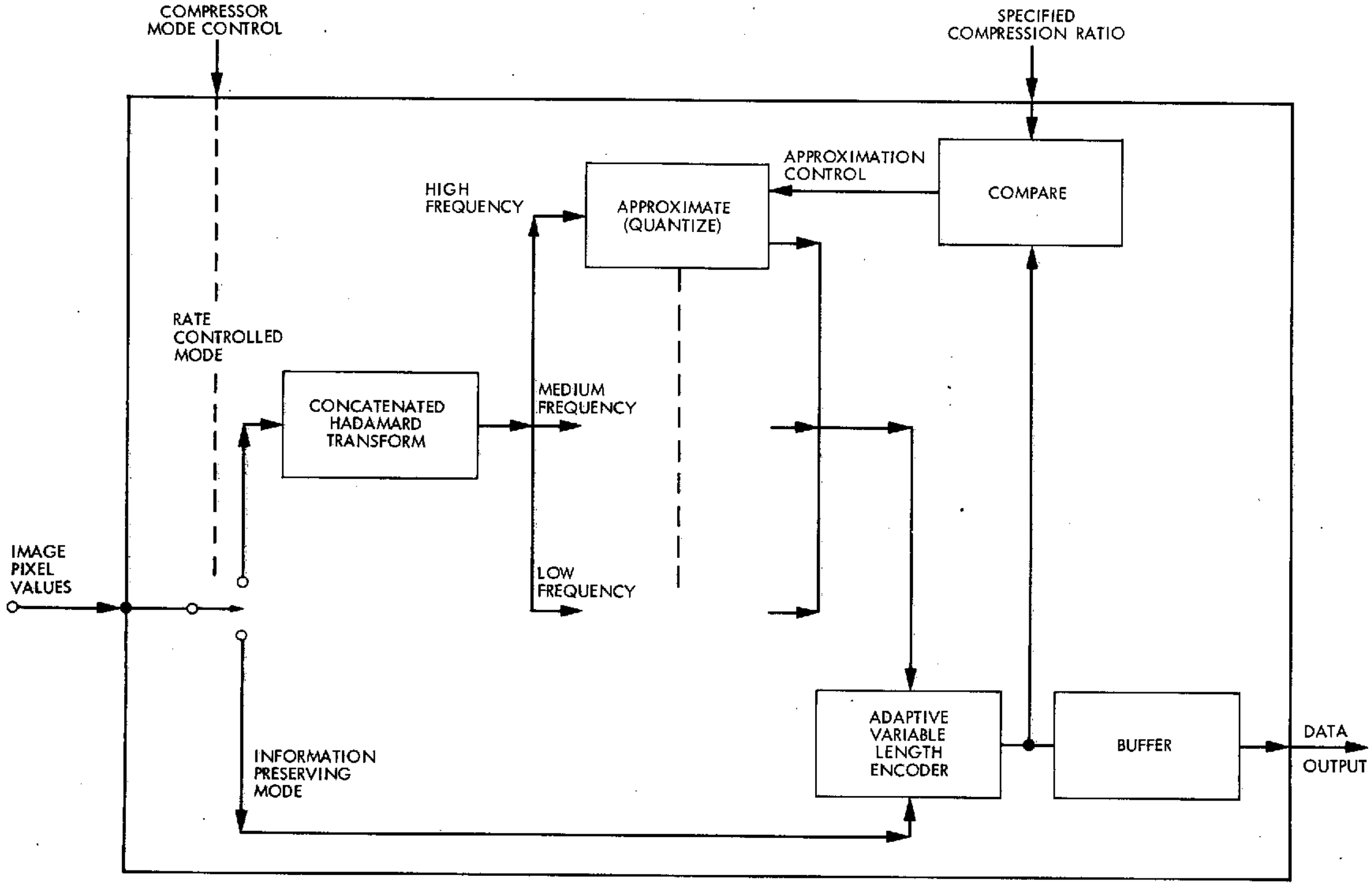


Figure 3-7. RM2 Compressor Block Diagram

Alternative processes for reducing the entropy of Hadamard coefficients include (a) a multiply by $2^{\pm i}$ operation for one of several alternative integer values of i (accomplished by shift-left or shift-right operations in a data register) followed by truncation to the integer part of the product, and/or (b) "thresholding" to transform near-zero coefficients to the zero state, and/or (c) coarse-quantizing to transform unusually large coefficients to the nearest "available value."

The basic principles of the adaptive variable length encoding process are described in Ref 4.

"Adaptive Variable Length Coding for Efficient Compression of Spacecraft Television Data" by R. F. Rice and J. R. Plaunt, IEEE Transactions on Communication Technology, Vol. COM-19, Part 1, December 1971, pp 889-897.

The process for recovering estimated values for the original image pixel values proceeds as follows:

1) Decode the variable length code to recover the approximate values of the Hadamard coefficients.
2) Iterative application of an adaptive inverse transform process (accounting for the various operations which were used to reduce the entropy of Hadamard coefficients within the RM2 compressor) to estimate original image pixel values.

The OPPICSS study indicated that the primary mission interest was concentrated in compression ratios of 10:1 or less. Also, considerable emphasis was placed on minimizing the command load during mission operations. Consequently, the number of operating modes of the Pioneer version of the RM2 compressor was reduced to those listed in Table 3-7.

The non-integer compression ratios were chosen to cause picture transmissions to correspond to an integer number of spacecraft revolutions at the nominal roll rate of 5 rpm.

Table 3-7. RM2 Operating Modes

Mode Number	RM2 Mode Description
1	Uncompressed Image Data
2	2.4:1 RM2 RC Compression
3	3.2:1
4	3.8:1
5	4.8:1
6	6.4:1
7	9.7:1
8	RM2 Information Preserving Compression

2. Basic Image Data Flow Diagram

See Figure 3-8.

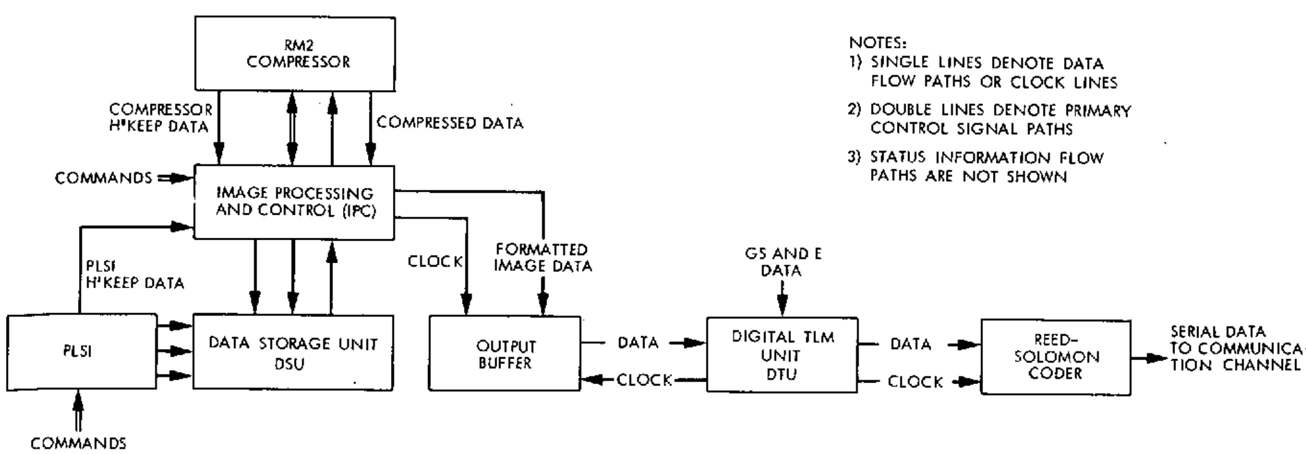


Figure 3-8. Basic Image Data Flow Diagram

The normal sequence of operations proceeds as follows:

1) Commands are sent to PLSI and DTU as in the baseline case. Also commands are sent to control the data compressor mode.
2) The PLSI and Compressor housekeeping data are transferred to the IPC.
3) The specified image is acquired and the pixel values are transferred to the DSU within 1.75 seconds.
4) Upon completion of the DTU load cycle, a signal is issued to initiate the compression process. Successive source blocks are compressed and then transferred to the output buffer along with appropriate sync words, etc.
5) The IPC regulates the data transfer processes to prevent OB data overflow or data underflow.
6) The DTU calls for data from the OB as required to assemble formatted data cycles for transmission at the commanded bit rate.

As in the case of the other system options, the final bits of a prior image can continue to be transmitted at the same time that a new image is acquired and loaded into the DSU. This is especially useful in the AICS system option because the RM2 compressor can automatically make fine adjustments to the compression ratio to prevent cumulative effects from leading to a OB overflow or underflow condition.

3. Command Requirements for Data Compressor Control

The following eight commands are sufficient for compressor control:

1) 1:1 compression ratio
2) 2.4:1 compression ratio
3) 3.2:1 compression ratio
4) 3.8:1 compression ratio
5) 4.8:1 compression ratio
6) 6.4:1 compression ratio
7) 9.7:1 compression ratio
8) Information preserving compression

With these commands, the desired compression ratio can always be established with one command.

4. Image Data Format Details

The principal parameters of formatted RM2 compressed image data are tabulated in Table 3-8. It should be noted that these are average values. There will be small variations from source block to source block (and image frame to image frame). However, servo controls internal to RM2 will cause the averages to converge to the values shown.

Table 3-8. Principal Parameters of Formatted RM2 Compressed Image Data

	Compression Ratio						
	1:1	2.4:1	3.2:1	3.8:1	4.8:1	6.4:1	9.7:1
No. Bits in 1st SB	41,288	17,436	13,136	10,984	8,832	6,684	4,532
No. Bits in 2nd SB	41,000	17,145	12,844	10,694	8,544	6,393	4,243
No. Bits in 3rd SB	41,000	17,145	12,844	10,694	8,544	6,393	4,243
No. Bits in 4th SB	41,000	17,145	12,844	10,694	8,544	6,393	4,243
No. Bits in 5th SB	41,000	17,145	12,844	10,694	8,544	6,393	4,243
No. Bits in Subframe	205,288	86,013	64,512	53,760	43,008	32,256	21,504
No. Bits in 640 lines	821,152	344,064	258,048	215,040	172,032	129,024	86,016
Avg No. Data Cycles per 640 lines	611.0	256.0	192.0	160.0	128.0	96.0	64.0

Table 3-9 lists the number of spacecraft revolutions (at 5 rpm) required to transmit RM2 RC mode compressed data for several different values of the data transmission rate. The table treats only 160 × 640 pixel image frames. The values for other frame sizes can be obtained by a linear scaling process.

Note that most of the above values are integers. This fact, coupled with the RM2 servo controls on compression ratio, make it possible to more fully utilize the available data transmission rate. That is, image acquisition timing consideration seldom make it necessary to insert filler bits in the data stream with the AICS system option.

5. Spacecraft Data Compressor and Error Correction Coder Hardware

The image data processing hardware on the spacecraft is similar to the pixel-edit system except for the following items:

1) The pixel-edit logic is deleted from the system.
2) More complex control logic is required in the IPC to implement the additional compressor modes.
3) The RM2 data compressor must be added to the system.

Table 3-9. Spacecraft Revolutions Required to Transmit RM2 Compressed Data

RM2 Compression Ratio	Transmitted Bit Rate			
	8192 b/s	4096 b/s	2048 b/s	1024 b/s
Uncompressed	9.55 rev	19.09 rev	38.19 rev	76.37 rev
2.4:1	4.0	8.0	6.0	12.0
3.2:1	3.0	6.0	12.0	24.0
3.8:1	2.5	5.0	10.0	20.0
4.8:1	2.0	4.0	8.0	16.0
6.4:1	1.5	3.0	6.0	12.0
9.7:1	1.0	2.0	4.0	8.0

A detailed logic design study was not performed on either of the first two items, but it is estimated that those two items will balance out so that there is no net change in hardware complexity.

A study of the RM2 data compressor implementation resulted in an estimate that it would require approximately 340 CMOS circuits. It was also estimated that the RM2 compressor would require approximately 1.0 kgm and 1.5 watts.

6. Effect of Communication Errors on Received Image Quality

The effect of Reed-Solomon/Convolutional-Viterbi channel errors on compressed imaging data was extensively analyzed in Section IV of TM 33-695, Ref 2: ("Channel Coding and Data Compression System Considerations for Efficient Communication of Planetary Imaging Data", Robert F. Rice, June 15, 1974). The effects of communication errors in the AICS system are quite similar to those in the PE system.

An analysis of communication error effects was made based upon pessimistic assumptions regarding error distributions. The results of this analysis is summarized in Table 3-10.

It may be of interest to note that the number of flaws-per-picture is inversely proportional to the compression ratio, but the average size of an image flaw is directly proportional to the compression ratio.

It is assumed that near-real-time images are needed only to confirm proper system operation. The predicted near-real-time performance, even for data rates exceeding 5000 bits/sec, would seem to be adequate for that purpose. Because data rates in excess of 4000 bits/sec are required only for approximately 2 days near Saturn encounter, the most practical approach may be to return only a 5/8 of those data to the MC^3 in near-real-time. That way the GCF rates would never exceed 5000 bits/sec. That way the delivered near-real-time data would be virtually error-free, and the GCF costs would be reduced because all data could be returned via high-speed data lines (as opposed to wide-band data lines). If better quality near-real-time data is desired at rates exceeding 5000 b/s, there are a number of attractive technical approaches to improving near-real-time performance.

Table 3-10. Communication Error Effects

RM2 Compression Ratio	Probability That a Received Image is Damaged by a S/E Channel Error	Probability That a Non-Real-Time Image is Damaged by a GCF Error	Probability That a Near-Real-Time Image is Damaged by a GCF Error When the GCF bit rate is ≤5000 b/s	Average Number of Image Lines Missing from Near-Real-Time 640 line Images when the GCF bit rate is >5000 b/s
1:1	0.0054	0.0051	0.0051	53. lines
2.4:1	0.0024	0.0021	0.0021	88.
3.2:1	0.0018	0.0016	0.0016	80.
3.8:1	0.0015	0.0013	0.0013	75.
4.8:1	0.0013	0.0011	0.0011	70.
6.4:1	0.0010	0.0008	0.0008	66.
9.7:1	0.007	0.0005	0.0005	61.

Notes:

(a) R-S word error rate assumed to be 10^{-5} and R-S words are assumed to be statistically independent.

(b) The rate of imperfect GCF blocks for the non-real-time case and near-real-time at $\leq$ 5000 b/s case is assumed to be 1×10^{-5}.

(c) The rate of imperfect GCF blocks for the case of near-real-time data at > 5000 b/s is assumed to be 5×10^{-3}.

(d) Imperfect GCF blocks are assumed to be completely obliterated.

(e) Any error in a compressed image source block is assumed to destroy the whole source block.

(f) Each image is assumed to contain 640 lines.

7. JPL Support of ARC/TRW Spacecraft Data System Development Activities

The first appropriate activity (now in process) is to produce simulation pictures to enable assessment of the effect of RM2 data compression on the science value of images representative of those which would be obtained from a PLSI camera during a Saturn-Uranus mission. This activity is expected to be completed in the spring of 1975.

The second appropriate activity would be to complete all aspects of a computer simulation of a Pioneer version of the RM2 data compressor. Concurrently, it would be advisable to proceed with development of a breadboard version of this compressor. It is estimated that these activities would take approximately one year and cost approximately $200, 000. Because there are other possible mission applications for the RM2 compressor, it is possible that this activity could be jointly funded by two or more different sponsors.

The third appropriate activity would be to build a breadboard version of the Reed-Solomon error correction coder. It is estimated that this could be accomplished in approximately 6 months and would cost approximately $20, 000.

The fourth appropriate activity would be to participate in a complete end-to-end test of the complete system including the following elements:

1) Pioneer Line Scan Imager
2) RM2 Data Compressor
3) Reed-Solomon Coder
4) Convolutionally coded, Viterbi decoded communication channel
5) Reed-Solomon Decoder
6) RM2 Decoder
7) Image Enhancement and Display

Finally, if all activities continue to indicate the advisability of using the AICS approach on outer planet Pioneer missions, work should proceed to facilitate design and construction of flight prototypes of the RM2 compressor and the Reed-Solomon coder by the Pioneer system contractor.

E. GENERAL OBSERVATIONS AND CONCLUSIONS

1. Details Regarding the Pioneer Line Scan Imager

During the course of the OPPICSS study, many more details of the PLSI became known. The image frame format (160 pixels/line 160, 320, 480, or 640 lines/picture) prompted a change in the definition of the image data source block for the Pioneer version of the RM2 compressor. (The definition of a source block was changed from a 64 × 64 pixel array to a 160 × 32 pixel array.) Also, preliminary information is becoming available regarding the random and pattern noise characteristics of PLSI data. Based upon this preliminary information, it appears that a simple process step can be added to the RM2 compressor to overcome possible adverse effects of pattern noise on RM2 compressor performance. The characteristics of the PLSI coupled with the assumed trajectory lead to a conclusion that data compression ratios in the range from 2:1 to 10:1 are of most interest for the assumed PSU mission. Refinements could be made to internal RM2 parameters to optimize performance over this range of compression ratios.

2. Pioneer Spacecraft Data Storage Unit

The Pioneer spacecraft data storage unit was originally intended to be based upon CMOS technology. Consequently, early RM2 implementation studies assumed a "static" memory with random access capability. Later in the OPPICSS study, it was decided by TRW that the DSU would be implemented with digital CCD technology. The "dynamic" nature of CCD memory devices dictated a serial DSU memory organization. This in turn dictated a change in the organization of the RM2 data compressor. The RM2 implementation studies indicated that the choice of a CCD DSU had no significant effect on the RM2 complexity. However, the basic organization of the RM2 compressor is sensitive to the DSU organization. An RM2 compressor breadboard designed to interface with a CCD DSU may not be appropriate for use with a CMOS DSU.

3. Data Quality Requirement

There was no clear definition of the data quality requirement for near-real-time data to support mission operations. It has been reported that approximately 0.5% of the near-real-time GCF blocks will be extensively damaged when the GCF data rate exceeds 5000 b/s. The effect of such GCF block "deletions" is analyzed in this report. If the predicted near-real-time image quality is not acceptable, there are a number of attractive technical approaches which could be taken to improving performance. Note the following examples:

1) Implement "automatic recall" on the wide band data lines (WBDL).
2) Transmit each GCF block twice and implement a merging process at the Network Operations Center based upon the error detection code already contained in the GCF Blocks. (Twice the 8 kilobits/s OPP data rate still fits within the WBDL capacity of ~50 kilobits/s.)
3) Operate the S/E channel at a slightly higher SNR (~+0.3 dB) and reduce the number of telemetry bits per GCF block. The interleaved R-S code could then enable correction of most near-real-time GCF Block errors.

4. Use of Advanced Imaging Communication System to Achieve Objectives Other Than Mission Value Enhancement

The primary emphasis of the OPPICSS consideration of the effect of AICS on mission design was to investigate how the mission science value could be enhanced. Other objectives of interest include the following:

1) The ability to accommodate the effect of adverse weather on X-Band channel performance.
2) The ability of reducing ground operations costs by enabling near-real-time production of final data records. This would eliminate costs associated with double processing at MC^3; once to meet near-real-time requirements and again in non-real-time to meet

the quality requirements which apply to final data records. This could be facilitated by using image data compression to achieve scientific objectives while limiting data transmission rates to 4000 bits/sec. The data could then be returned to MC^3 in nearly error-free form over high-speed-data-lines (HSDL). Also, GCF costs are lower if the project can meet its needs with a HSDL rather than a WBDL. Further, one could consider using image data compression to achieve scientific objectives at a maximum transmission rate of 2,000 bits/sec. It might then be possible to use the Pioneer 10/11 channel coding method. (A K=32 convolutional code with sequential decoding.) The system question then revolves on whether the various cost savings associated with image data compression more than offset the costs associated with the image data compressor and the image data decoding operations at MC^3. This area requires further study.

5. RS/Viterbi from a Multi-Mission Point of View

The implementation of the AICS channel coding system employing an interleaved Reed-Solomon algebraic code concatenated with Viterbi decoded convolutional codes has clear long term multi-mission benefits.

a. High Rate Applications

A primarily serial hardware decoder implementation for the principal candidate RS code assumed in this study (J=8, E=16, I=16) can be built to operate at 100 kilobits/sec. A similar serial decoder for a second code with E=8 gives up about 0.2 dB in performance but reduces parity overhead by 50% and could operate at around 200 kilobits/sec. Further a decoder with both options could be built with little increase in complexity or cost. Such decoding rates may not be critical to immediate Pioneer applications, but would have long term benefits to later Mariner and Pioneer missions.

b. Inner Code Changes

An inner K=7, R=1/2 convolutional code was emphasized in OPPICSS because of the desire to provide the simplest baseline OPP. However, Viterbi decoders for both the K=7, R=1/2 code and K=7, R=1/3 code are expected to be available at the DSN stations. As predicted in TM 33-695 ("Channel Coding and Data Compression System Considerations for Efficient Communication of Planetary Imaging Data") (Ref 2) and verified in the recent Linkabit Study (Ref 5), a R=1/3 inner code will provide a performance increase in the RS/Viterbi system of about 0.5 dB. For future missions employing RS/Viterbi, this gain is obtained at essentially no cost. For OPP it is obtained at the expense of a redesign of Pioneer 10/11 on-board oscillators, perhaps a worthwhile endeavor for the system of moderate complexity assumed by OPPICSS, or AICS.

c. Receiver Imperfections, Low Data Rates

Receiver imperfections could become an issue in multi-planet missions and low data rates. It has been shown in many places that Viterbi decoded systems are not very sensitive to such receiver imperfections as imperfect AGC measurements and imperfect phase tracking at high bit error rates ($P_b \geq 5 \times 10^{-3}$) associated with uncompressed imaging.

1) It was noted in TM 33-695 and verified by simulation in the Linkabit study that losses due to imperfect AGC measurements are the same for RS/Viterbi or Viterbi alone.

2) Also noted in TM 33-695 and verified by simulation in the Linkabit study that increases in S/N necessary to maintain a RS/Viterbi system at a "virtually error free" operating point when a receiver is imperfectly tracking phase is no worse than a Viterbi system alone operating at $\overline{P}_b = 5 \times 10^{-3}$. Such losses are small.

d. Principal Advantage

RS/Viterbi systems offer performance advantages in future planetary missions even if data compression is not involved. However, the principal advantage offered is that any data compression, be it applied to imaging or GS&E data, could be used in future missions without having to first give up significant transmission rate in order to achieve a clean channel. As noted above, these advantages apply to a very wide range of data rates and therefore to a broad spectrum of future planetary missions.

As clearly indicated in TM 33-695, the motivation behind AICS imaging data compression research was to provide data compression which would give the User almost unlimited flexibility to trade-off image coverage and image quality along with similar and varying requirements for non-imaging data (which, of course, could also be compressed). Such flexibility was intended for a multi-mission, multi-planet, multi-data class environment.

Much of the potential flexibility to adjust User priorities exhibited by preliminary RM2 results has not been considered for the initial OPP missions for quite reasonable practical reasons. Later missions with different constraints and goals might make more use of the inherent flexibility in an AICS based communication system, providing further increases in effective rate of information return.

SECTION IV

PIONEER SPACECRAFT SYSTEM ANALYSIS

A. INTRODUCTION*

The Outer Planets Pioneer (OPP) spacecraft which is the payload carrier for the OPPICSS mission is a derivative of the Pioneer 10 and 11 vehicles. The definition of the OPP configuration was based on a set of broad requirements imposed by a typical flyby mission. The OPP payload was defined to include an imaging instrument, although no specific design is reflected in the reference document. The basic OPP spacecraft did not include a probe and hence this feature of the OPPICSS mission is not covered. Appendix F has been prepared to summarize the interfaces of a probe with the basic Pioneer configuration. These data have been extracted from the Outer Planet Pioneer Spacecraft description (TRW publication).

A functional block diagram of the three major subsystems of interest to the OPPICS study is given in Figure 4-1. The major subsystems are 1) the communications subsystem, the command subsystem, and the data handling subsystem. A brief description of the operation of these subsystems and of the proposed OPP modifications is given in Appendix E.

The OPP spacecraft defined in Section 4 of the Outer Planet Pioneer Spacecraft document has certain deficiencies as a baseline for measuring hardware impacts. Since the OPP is a paper configuration, it was deemed more reasonable to evaluate changes involving weight, power, volume, and cost relative to Pioneer 10/11 rather than to OPP.

*During the last month of the OPPICSS study, it was decided to change the PLSI pixels from 10 bits to 8 bits. It was not practical to revise all the study results affected by that change. Consequently, some of the material in this section still reflects the original assumption of 10 bits-per-pixel.

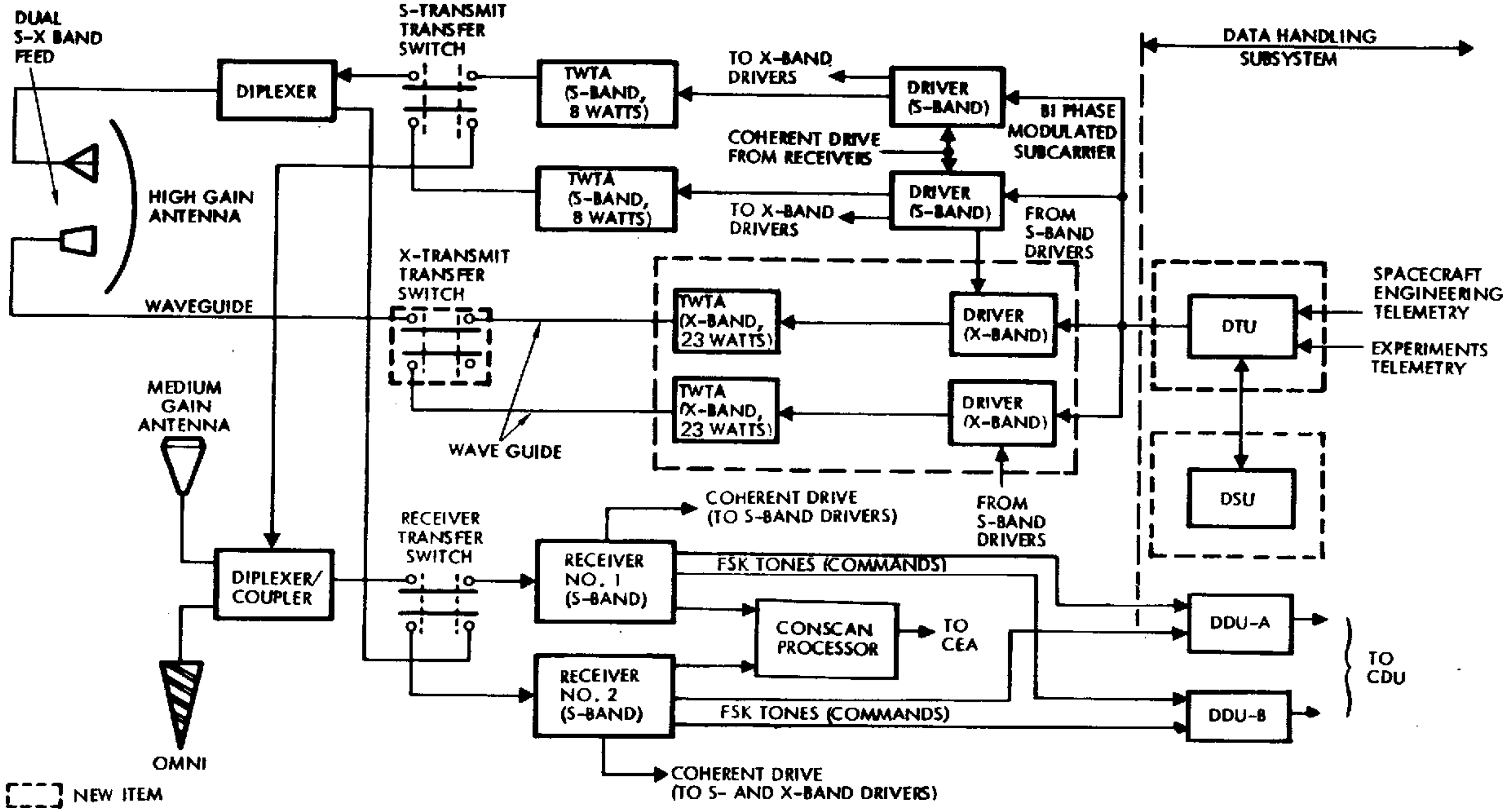


Figure 4-1. Communication Subsystem Functional Block Diagram

The OPPICSS mission includes handling the following categories of data:

1) Science and Engineering Data

   a) A, B, C, D, E formats
   b) Variable downlink bit rates from 64 bits per second to 32,768 bits per second

2) PLSI Imaging Data

   a) Multiple D formats
   b) 1.1×10^6 words per second.

3) Probe Data

   a) Science format for real time transmission
   b) Storage for delayed transmission in D format
   c) 88 bits/s

The mission periods of interest for these categories of data are discussed in Appendix C. Each type of data will need mass memory as indicated in Table 4-1.

Table 4-1. Mission Mass Memory Requirements

Data Type	Cruise Mode	Planet Approach	Occultation**	Post-occultation Cruise
Science & Eng*	No	Yes	Yes	No
PLSI	Yes	Yes	No	Yes
Probe	No	Yes	Yes	No

*Science and Engineering based on currently available requirements.

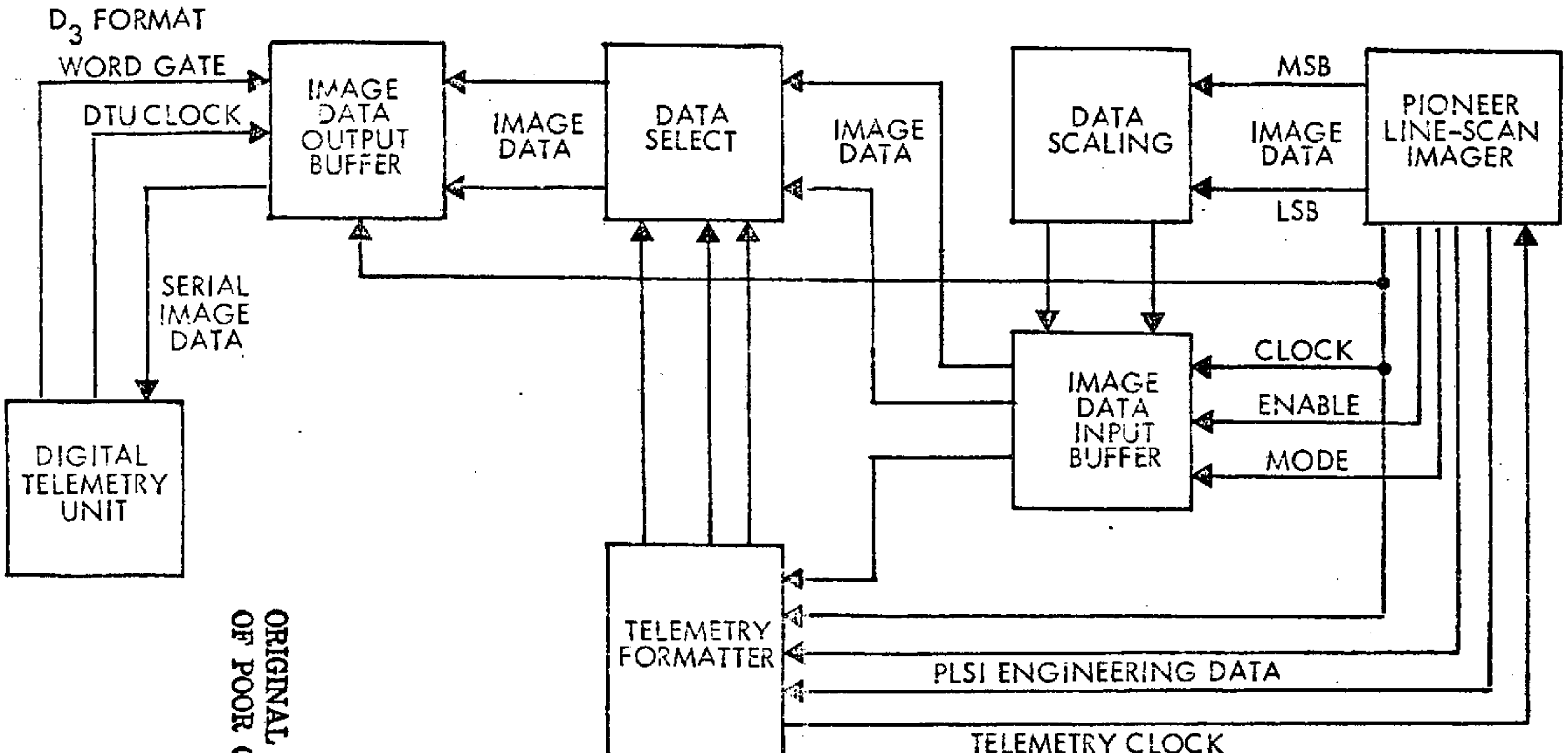
**Occultation requirements include immediate post-occultation memory dump.

B. UNCOMPRESSED DATA ANALYSIS

1. General

The Pioneer Line Scan Imager (PLSI) will interface directly with the Digital Telemetry Unit (DTU) and the Data Storage Unit (DSU) as shown in Figure 4-2. In addition, the PLSI will require a command interface, and indirectly will require certain format changes in the DTU. These format changes are basically derived from the desire to allocate an appreciable fraction of the downlink data rate to imaging data. On the Pioneer 10/11 and in the proposed OPP configuration, the DTU limits the amount of image data which can be transmitted to 50 percent of the telemetered data. For the OPPICS Study, the General Science and Engineering (GS&E) data was assumed to be limited to approximately 256 bits/sec. This is only 13 percent of channel capacity at a bit rate of 2048 bits/sec. Since GS&E data is nominally transmitted in either an A or B format and the imaging data in the D format, a new DTU format configuration was devised to satisfy the OPPICSS ground-rules. This new format consisted of sending one A format followed by a multiple number of D formats. For all configuration options except option 2 (see Section 2 below) the specific format chosen for analysis was one A (or B) format followed by seven D formats. As noted in Appendix E, the D formats do not contain any fixed words. Consequently the reconstruction of PLSI images must relay on the A format data for synchronization and identification of image data or such fixed words must be provided external to the DTU.

The DTU contains a circuit known as the spin period sector generator (SPSG). This device, operating from a selected sun or star sensor pulse, measures the spacecraft spin period, divides this period into equal increments, and outputs these as roll reference pulses. The SPSG in the OPP can provide pulses at a rate of 512 pulses per revolution corresponding to an angular resolution of 360/512 or 0.7 deg. This is much too coarse for the PLSI and



760-115

Figure 4-2. OPPICSS Data System Functional Block Diagram, Uncompressed Data hence the SPSG for the OPPICSS mission will be modified to provide 2048 pulses per spacecraft revolution corresponding to 0.18 degrees.

Appendix F discusses the expanded command dictionary required for a typical OPP flyby/probe mission. Whereas Pioneer 10/11 had some 55 - 65 spare commands, the table in Appendix F shows that 45 additional commands can be identified for the new spacecraft and mission configuration. This leaves a maximum of 20 spare commands available for the PLSI and related equipment. This was not considered acceptable for the OPPICSS mission since the PLSI requires at least 32 commands for operation. Instead, a new secondary command decoder, utilizing one of the two spare command routing addresses, will be incorporated as a modification of the OPP. This new unit could be physically located as an extension of the OPP Command Distribution Unit or it could become part of the new Data Storage Unit. The diagrams which follow show this item as part of the DSU or Data Storage Group.

Transfer of PLSI data from the instrument to the DSU is accomplished in parallel via ten data lines. Clocking and gating of the image data is under control of the instrument. The DSU will provide an End-Of-Memory (EOM) signal back to the PLSI. This signal can be used to inhibit picture taking/ data transfer until the data already in memory is read out. Between the PLSI and the image data storage mass memory is a data scaling function which selects, by command, one of three eight bit groups of data, deleting either the 2 MSB, the 2 LSB or the MSB and LSB. The entire block of image data is stored in the image data buffer in parallel eight bit words. For a 160 pixel by 640 line picture the maximum storage requirement is:

$$^{*}\frac{8\ \text{bits}}{\text{pixel}} \times \frac{160\ \text{pixels}}{\text{line}} \times \frac{640\ \text{lines}}{\text{picture}} = \frac{819,200\ \text{bits}}{\text{picture}}$$

*As will be shown later, all 10 bits of the PLSI data were assumed to be stored and processed by the RM2 before the word is reduced to 8 bits.

When the PLSI signals the mass memory/buffer that an image is being transferred, the telemetry formatter is also signalled and the PLSI parallel digital housekeeping data is routed through the data select block to the image data output buffer. When the image data is loaded into the 820 K buffer it is readied for downlink transmission in 65 K bit segments which are word-by-word loaded into the image data output buffer.

This output memory accepts and stores 8-bit parallel data and reads it out in serial form when interrogated by the DTU D3 format. This 65 K bit memory is necessary to assemble the data out of the circulating mass memory into a continuous serial data stream under DTU control. The timing for the operation of the image buffering is presented in Figure 4-3. The DTU format for the imaging data is one A format followed by seven D 3 formats repetitively alternating.

The image data output buffer accepts and stores 8-bit parallel data and reads it out in serial form when interrogated by the DTU D3 format. This 65 K bit memory is necessary to assemble the data out of the circulating mass memory into a continuous serial data stream under DTU control. The timing for the operation of the image buffering is presented in Figure 4-3. The DTU format for the imaging data is one A format followed by seven D3 formats repetitively alternating.

Figure 4-3 depicts the timing of two critical periods of the image data process:

1) Startup period, comprising the storage of image data in mass memory, sampling of telemetry data, and beginning of image data transmission at the end of an A format.
2) Mass memory output buffer loading period, which involves mass memory search time to next segment of data, loading that segment of data into its output buffer, while continuing downlink data transmission without gaps in the data.

The startup period is initialized by the receipt of the PLSI Data Enable pulse, which is true during the load cycle. The time period

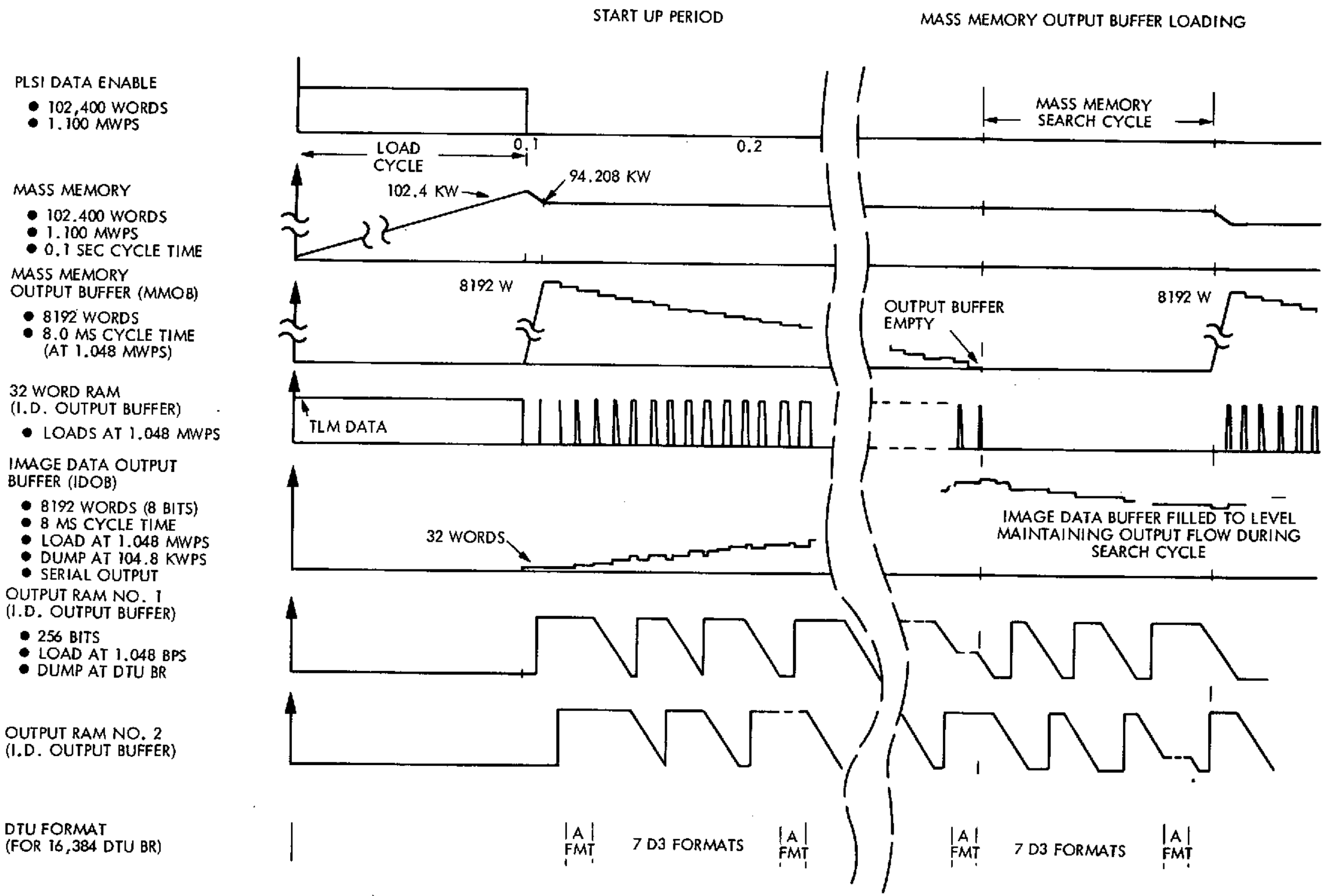


Figure 4-3. Timing for Image Data Buffering - Noncompressed Data

for image data transfer from the PLSI to the image data buffer mass memory is 1.75 seconds.

When the PLSI enable signal is received PLSI telemetry buffers are interrogated and the telemetry data is loaded into the Image Data Output Buffer 32 word input RAM to be readied to precede the image data in downlink transmission. At the end of the PLSI pulse (and the load cycle), the beginning of the first block of 8192 words has reached the output of the mass memory and is loaded into the mass memory output buffer (MMOB) (an 8192 word CCD) at 1.048 mw/s and the telemetry is shifted into the image data output buffer (IDOB) (an 8192 word CCD) at 1.048 mw/s. At the end of the cycle time of the two buffers (which is approximately coincident) their contents are transferred. The telemetry data in the IDOB is transferred serially to output RAM No. 1 at 1.048 mb/s (104.8 kw/s) and 32 words of data in MMOB is transferred through the 32-word RAM into IDOB. The process of data transferral from MMOB to IDOB is continued in this fashion. At the end of the next A format when the RAMs are both loaded RAM No. 1 is dumped downlink in Format D3 at the DTU bit rate. When it is emptied then RAM No. 2 is dumped, continuing the data stream, while RAM No. 1 is filled from the IDOB at the appropriate time of its circulation cycle. At the end of seven D3 formats, the next A format occurs and the transmission of imaging data is interrupted for 192 bits. This alternating or RAMs and formats continues until the entire mass memory is dumped. It is seen from Figure 4-3 that the data in the IDOB is increasing because it is loaded at a higher rate than that at which it is being unloaded. Also the data in MMOB is being dumped at a constant rate as long as the IDOB is not filled. As the cycle times of MMOB and IDOB vary (because the IDOB dumps at 100 kwps) the 32 word RAM (IDOB) has an ever increasing delay between load and dump until they will be coincident, meaning the MMOB waits until the next cycle time. The example shown is for 16,384 b/s, the bit rate for which the output buffering was sized. For lower bit rates there is even more time margin between loading and dumping of the output RAMs, hence the IDOB is filled quicker.

The mass memory output buffer (MMOB) loading period is critical in that it highlights the requirement for the IDOB for the noncompressed mode. When the MMOB is empty it accesses the mass memory for a new block of data. It may take up to 0.1 sec. for the mass memory to circulate at 1.024 Mw/s to the desire data location, during which time the IDOB must have sufficient data to continue to feed the output RAMS. For data rates lower than 256/0.1 sec or 2560 b/s an IDOB may not be necessary as one full output RAM may be sufficient to be backup during the MMOB loading period. For rates above 2560 b/s the IDOB is necessary.

Referring again to Figure 4-3, the peak power requirements can be noted. While average power of the CCD memories is low because power at the standby frequency of 1 KHz is very low, the peak power during read-in/readout at 1 MHz is high. The peak power for each image CCD memory portion is noted in Table 4-2.

The maximum peak power requirement is during the search mode of the MMOB loading period when both the mass memory and the IDOB are operating for a total peak power of 7.0 watts for 0.1 sec. The longest peak power time is during the dump of the first block of data in the MMOB when both MMOB and IDOB are continually cycling at 1.048 MHz. This time is 2.048 sec. and the power is 1.0 watt.

Table 4-2. Peak Power for Each CCD Memory Portion

Memory Portion	No. Chips	Read-In Rate MHz	Pwr/Chip @ Read-In Rate (w)	Peak Pwr Read-In (w)	Read Out Rate MHz	Pwr/Chip @ Readout Rate (w)	Peak Pwr Readout (w)
Mass memory	13	1.1	0.5	6.5	1.024	0.5	6.5
MMOB	1	1.048	0.5	0.5	1.024	0.5	0.5
IDOB	1	1.048	0.5	0.5	1.024*	0.5	0.5

*The IDOB reads at 102.4 KHz but cycles at 1.024 MHz between read-in and/or readout during heavy duty cycles.

2. Alternative Options and Their Implications

Table 4-3 summarizes the weight, volume, power and relative cost of the six options for the no data compression system configuration. The deltas for Option 1 are referenced to the Pioneer 10/11 configuration; all other deltas are referenced to Option 1. Figure 4-4 identifies the various operations.

The Pioneer 10/11 DTU consists of nine separate circuit boards. Modification of this unit affects seven of these boards for the reasons shown in Table 4-4, and hence the DTU modification for either OPP or OPPICSS has been characterized as "substantial."

During the course of the OPPICSS study, the DSU implementation for the Outer Planets Pioneer was re-evaluated. The alternatives considered were C-MOS and CCD. Comparisons of the two show the size, weight, and power advantage using the CCD memory. Further definition of the DSU design is given in Appendix G.

Option 2 requires an additional secondary command decoder (which could use the last remaining routing address) plus a series of new format generators. These 256 new format generators would require a change in the DTU volume and/or footprint.

Providing 16-bit rates in the DTU instead of 8-bit rates requires modification of the DTU command decoding logic which requires the addition of one standard transistor-transistor logic (TTL) integrated circuit (average density of 2/in.^{2} to the main-frame multiplexer board. In addition, six TTL integrated circuits are added to the bit rate select logic located on the programmer board. These changes add nothing to the size and weight of the DTU but increase the power by 0.3 watts.

Table 4-5 shows in the first column the current binary countdown chain steps derived from the 4.194-MHz crystal oscillator down to 64 b/s, the lowest baseline rate. The second column shows ideal values for the -1.5 dB steps

Table 4-3. Summary of Alternatives Using No Data Compression

Option	Components Affected	Reason for Change	Weight Δ (lb)	Volume Δ (in.^{3})	Power Δ (W)	Relative Δ Cost
1	Digital Telemetry Unit (DTU)	New data formats New encoding parameters New SPSG output for PLSI	no change		+0.8	
	Data Storage Unit (DSU)	Increase capacity to accommodate simultaneous storage of probe, imaging data, and DTU data.	+4.6	+238	+0.44	baseline
	Command Distribution Unit (CDU)	Additional commands for PLSI; existing spares marginal hence new secondary decoder required	+2.0	+96	+1.0	
2	DTU	Add 256 format generators to provide A_n D_m and B_n E_m formats where $1 \le N \le 8$ and $1 \le M \le 16$	no change	no change	0.12	
	CDU	Add new secondary decoder for 256 new commands	2.0	+96	1.0	
3	DTU	Modify countdown clock and bit rate select logic to provide 16 bit rates in 1.5 db steps Modify DTU command decoder logic to provide 16 bit rate commands	no change	no change	0.3	
4	DTU	Add GOLAY coding logic	1.0	48	0.1	
	CDU	Provide GOLAY coding bypass command	no change	no change	no change	
5	*DTU	Add Reed-Solomon coding logic Modify countdown clock	2.8	154	0.4	
	CDU	Provide Reed-Solomon coding bypass command	no change	no change	no change	
6	*DTU	Provide separate modulators, format generators, and subcarriers for 2 channel operation	0.4	29	0.5	
	CDU	Provide separate commands for 2 channel operation	no change	no change	no change	

*Will require new footprint or greater volume

Option 1

General: GS & E bit rate = $\sim$ 64 b/s
GS & E channel allocation $\geq$ 256 b/s
GS & E BER $\leq 10^{-4}$ bits, imaging BER $\leq 10^{-4}$ bits
Max. bit rate at Saturn = 8, 192 b/s
Max bit rate at Uranus = 2, 048 b/s

S/C: OPP S/C with the following modifications:
Line Scan Imager
1.2×10^6 bit memory instead of 1×10^6 bits
Variable B & D formats (e.g., 1B1D, 1B4D, 1B8D)
K = 7, R = 1/2 conv. coder instead of K = 32, R = 1/2

Option 2

Same as Option 1 with the following modifications:
1) Variable B&D formats as described in AI 36.

Option 3

Same as Option 1 with the following modifications:
1) Sixteen bit rates at 1.5 dB steps

Option 4

Same as Option 1 with the following modifications:
1) Golay outer code, K = 7, R = 1/2 inner code

Option 5

Same as Option 1 with the following modifications:
1) Reed-Solomon outer code with K = 7, R = 1/2 inner code

Option 6

Same as Option 1 with the following modifications:
1) Two channel telemetry link. S-band for GS & E @ a BER $\leq 10^5$ and X-band for Imaging and GS & E @ a BER $\leq 5 \times 10^{-3}$

Figure 4-4. No Data Compression System Configuration Options

Table 4-4. DTU Modifications

Reason for Change	Boards: MF MUX 1	Prog 2	S.W. Gen. 3	Analog SF 4	Output Logic 5	Dig SF 6	Power
*1) 32.768 kilobits/sec bit rate	X	X		X	X	X	X
*2) Change 8-bit rates		X					
*3) Two sub-carriers		X			X		
4) Conv. Code Gen mods					X		
5) Multiple D formats, A/C_1 D_1 D_1 D_1 D_1 B/D_1 D_1 D_1 D_1 D_1		X					
*Incorporated in OPP Design							

between the normal bit rates below 32,768 b/s. The next three columns show three different approximations for the 1.5 dB steps. These are derived by dividing an upper frequency by uneven integers to obtain numbers near 23,170.5 b/s, the -1.5 dB step from 32.768 b/s, and successively dividing down by 2. The error, hardware impact, and power for each approach is noted. The changes noted would impact the Programmer board in the DTU, the most densely packed board in the unit.

The addition of either a Golay (Option 4) or Reed-Solomon (Option 5) outer code to the Option 1 configuration will require some circuitry (weight, volume, power) outside the DTU as well as modifications to the DTU itself.

Table 4-5. Comparison of -1.5 dB Bit Rate Implementations

Normal Countdown Chain (*Baseline Bit Rates) bits/sec	Ideal -1.5 dB Steps bits/sec	Synthesized -1.5 dB Steps, bits/sec		
		I	II	III
4,194,304				
2,097,152				
1,048,576		1,048,576 ÷ 45 =		23,302
524,288				
262,144	262,144 ÷ 11 =		23,831	
131,072				
65,536	65,536 ÷ 3 =	21,845		
⊛ 32,768				
	23,170	21,845	23,831	23,302
⊛ 16,384				
	11,585	10,923	11,916	11,651
⊛ 8,192				
	5,793	5,461	5,958	5,825
⊛ 4,096				
	2,896	2,731	2,979	2,913
⊛ 2,048				
	1,448	1,365	1,489	1,456
⊛ 1,024				
	724	683	745	728
512				
	362	341	372	364
⊛ 256				
	181	171	186	182
⊛ 128				
	91	85	93	91
⊛ 64				
	45	43	47	46
% Error		-5.7%	+2.9%	+0.5%
Hardware Impact (Added Parts)		4 FP	4 FP	6 FP
Power		0.2 W	0.2 W	0.3W

The use of two separate telemetry channels for GS&E and imaging data (Option 6) requires:

1) That GS&E data at Uranus can be limited to 32 b/s
2) That additional sync word generators will be provided for the imaging data
3) That a new subcarrier, channel encoder, and modulator be provided
4) That additional commands (for example the remaining unused routing command) be available for this configuration.

Implementing this option requires a new box or redesigned DTU to provide the two channel capability. This new unit will provide the sync words and the secondary command decoder noted above. In addition, it must supply a modulator and a separate channel encoder for the X-band system. Figure 4-5 shows this new unit in block diagram form.

C. MODERATE DATA COMPRESSION ANALYSIS

1. Introduction

The specific form of moderate data compression selected for analysis - namely, pixel editing - has a minimal impact on the OPP configuration. If this editing can be accomplished by a symmetrical scheme of pixel deletion, then no on-board data processing will be required. Instead, a compression command would be issued to one or more buffer registers in the DSU, and the editing would be accomplished by gating the appropriate elements in the output buffer. Some simple examples of how this could be accomplished are given in Figure 4-6. For this study it has been assumed that the output data buffers and the mode select logic would be provided as part of the DSU. As a consequence, the only additional demand on the OPP required to support

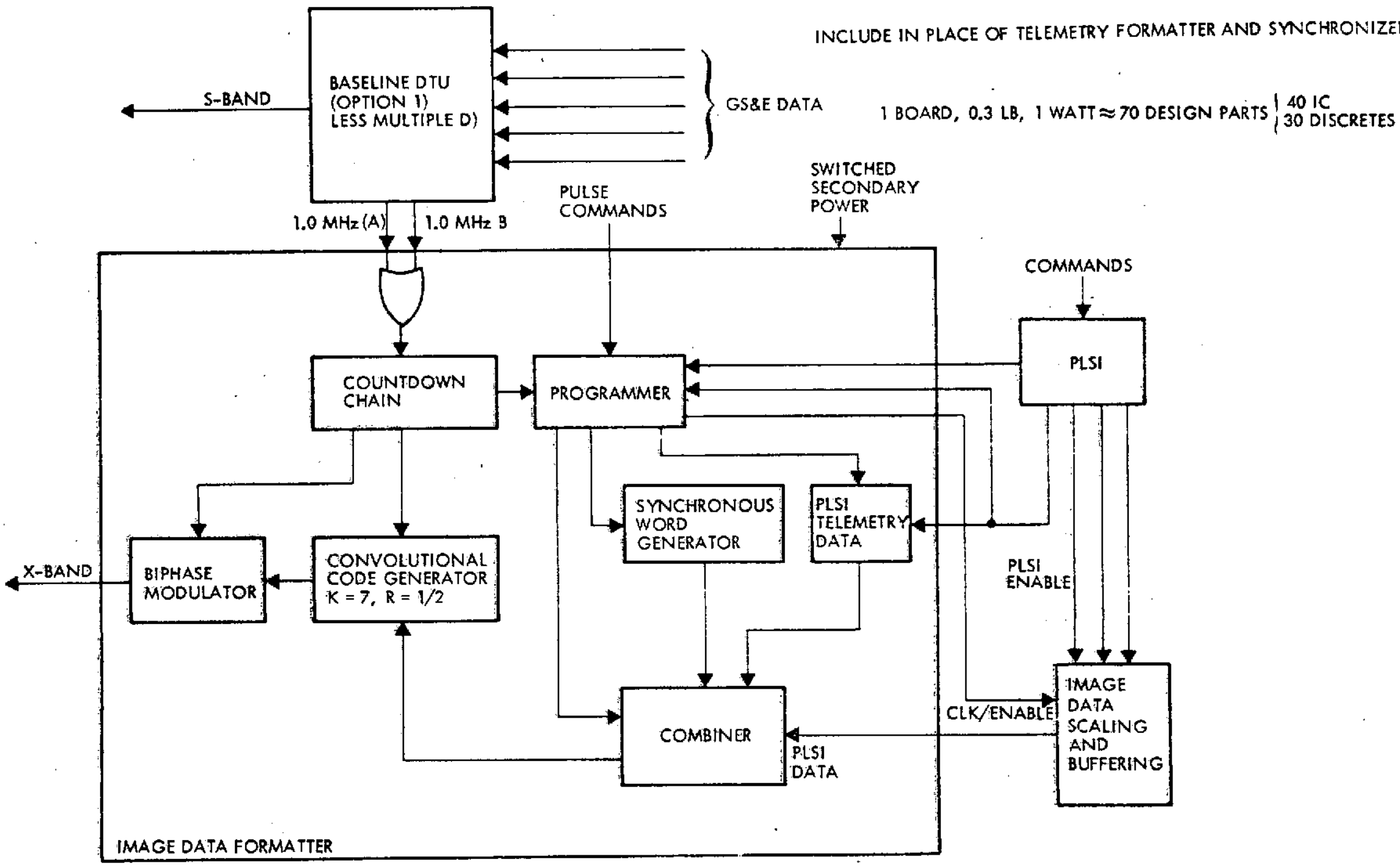


Figure 4-5. Dedicated X-Band Imaging Channel

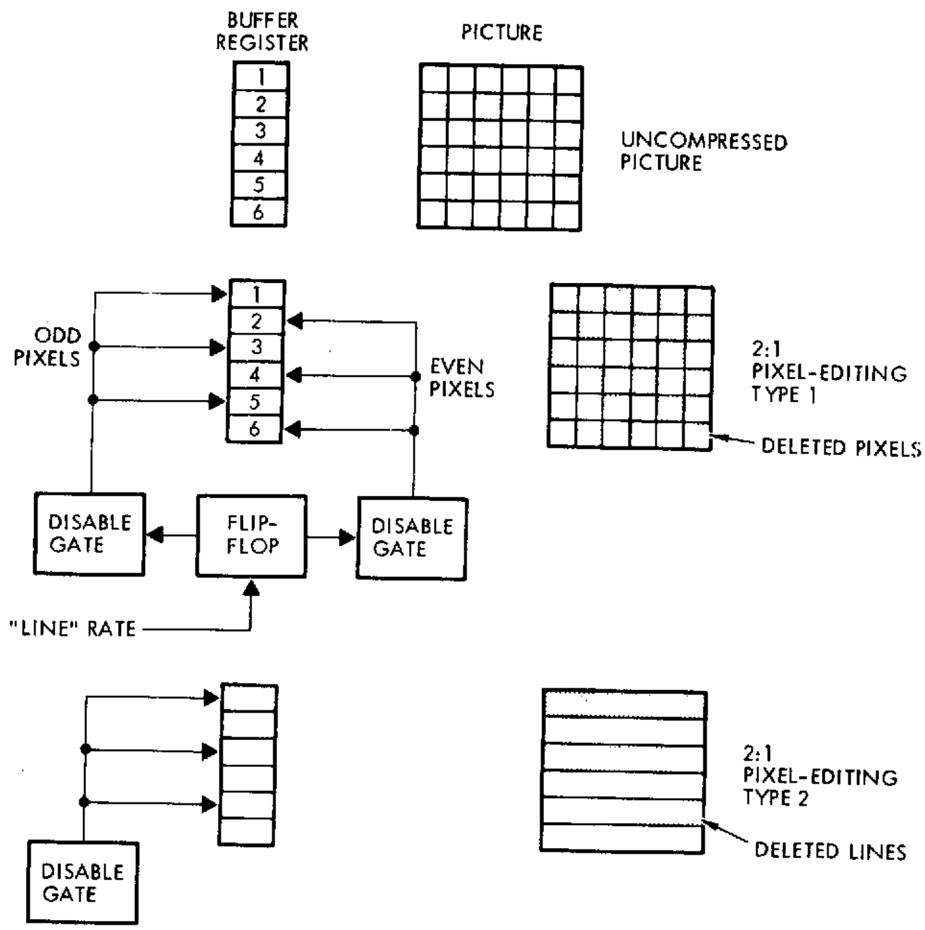


Figure 4-6. Forms of Pixel Editing

pixel editing would be for compression set commands. If two types of pixel editing are required, and if the allowable compression ratios are limited to 4:1, then a maximum of eight commands would be required to accommodate moderate data compression. Note that data compression does not reduce the data storage capacity since the 1:1 or no compression capability will always be retained.

2. Alternative Options and Their Implications

Other methods of achieving moderate data compression such as delta modulation and bit editing were discussed but not analyzed during the OPPICSS study. In general these alternate schemes would require some small additional hardware which could be located in the DTU or the DSU.

3. Summary and Conclusions

The addition of Reed-Solomon encoding to the moderate data compression case is the most significant impact of this configuration. Several additional commands will be required to accommodate this type of compression:

1) Compression value (1)
2) Compression value (n)
3) Compressor bypass.

D. AICS ANALYSIS

1. General

The spacecraft configuration for the AICS includes mass memory image data buffing for the PLSI, RM2 data compressor interface control logic, a Reed-Solomon (RS) encoder, and eight telemetry bit rates (32.768 b/s, 16.384 kb/s, 8192 b/s, 4096 b/s, 1024 b/s, 256 b/s, 128 b/s and 64 b/s) as depicted in Figure 4-7. The PLSI and RM2 data compressor require expansion of the baseline OPP command capability in addition to modification of the DTU downlink data format for image data to one A or B format followed by seven D3 formats. The RM2 data compressor accesses the image buffer in up to 20 source blocks per image. The image data is formatted by source block for downlink transmission through the image data output buffer at the selected downlink telemetry. For the AICS configuration the DTU data is enclosed with Reed-Solomon code and K = 7, R = 1/2 inner code.

In Figure 4-7 the data system functional block diagram is presented, showing the PLSI, DTU, RM2, image data buffering, Probe/DTU data storage, RS encoder, and remote command decoder.

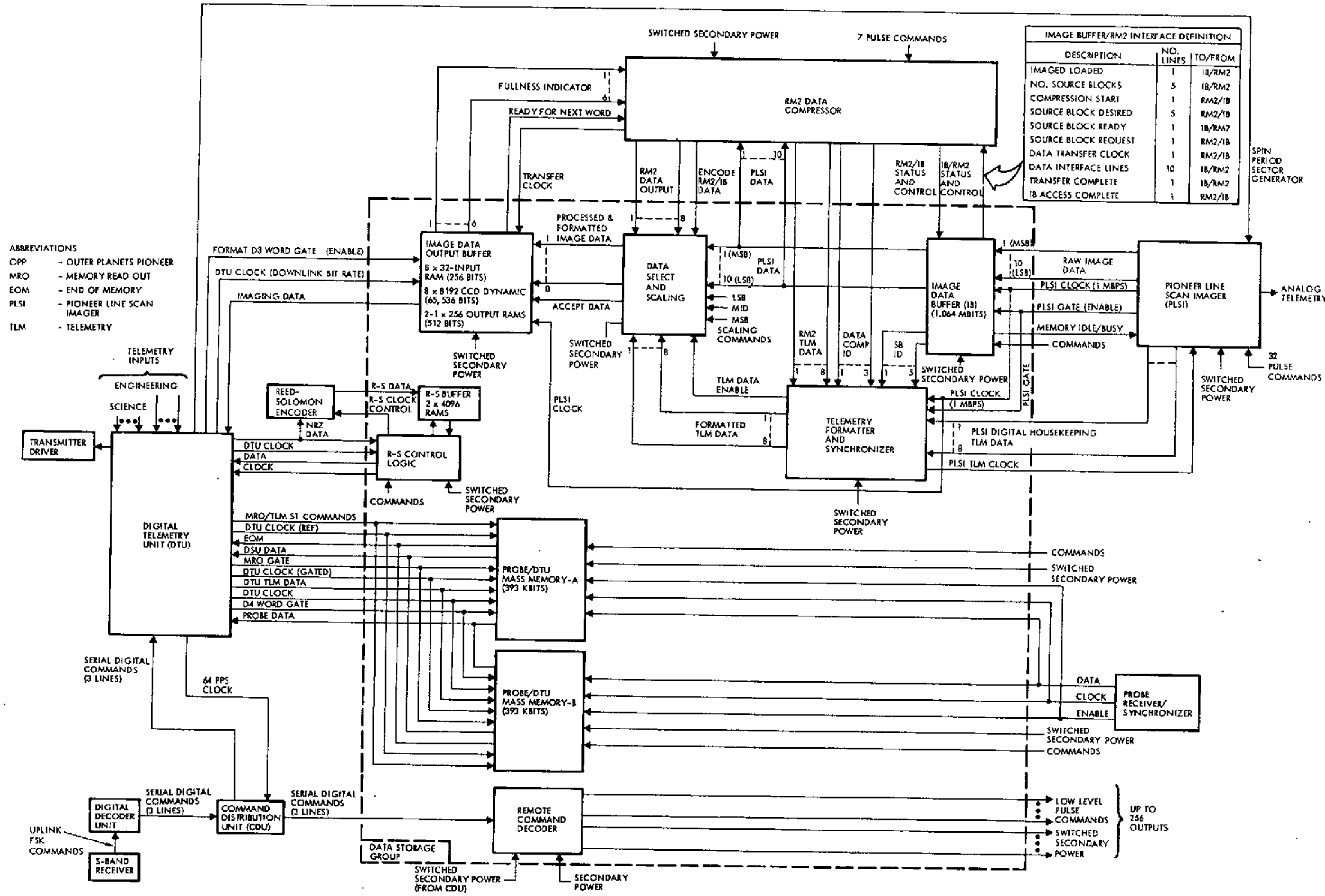


Figure 4-7. AICS Data System Block Diagram

2. Operational Description

a. Electrical Interfaces

These redundant memories provide storage for the DTU in the same manner as the OPP DSU. Data is input during TLM store mode and accessed during MRO mode. The TLM ST, MRO reference clock, gated clock, EOM (end of memory), DTU data and DSU data interfaces are the same as for OPP.

The probe data is input from the Probe Receiver/Synchronizer at 88 b/s in a continuous data stream. This interface includes a probe bit rate clock, an enable line (tone when data is gated in) and the data line. The DTU accesses the data from memory in a D4 format. The interface includes the probe data line, DTU clock (BR $\leq$ 4096 b/s) and the D4 format word gate.

Additional interfaces include switched secondary power, which powers the memories only during appropriate periods of the mission, pulse commands, which select which memory is used for DTU and probe, and telemetry of the status of the memory.

(1) Pioneer Line Scan Imager (PLSI)

(a) Image Data Buffer. The data transfer includes the following:

1) Raw Image Data: Ten parallel lines to transfer 102,400 words of raw image data at 1.1 Mw/s.
2) PLSI Enable: Goes true during the period of data transfer to enable the memory to receive the data.
3) PLSI Clock: 1.1 MHz clock from PLSI, synchronous with data word stream.
4) Memory Idle/Busy: gives indication of status of data buffer for PLSI picture taking coordination.

(b) Telemetry Formatter and Synchronizer. PLSI digital housekeeping telemetry data is sampled at the beginning of even/source block of data.

1) Telemetry Data - 16 8-bit words, sampled at 1.048 Mw/s at the beginning of each source block.
2) PLSI TLM Clock - 1.048-MHz clock
3) PLSI TLM Enable - True during the telemetry sample period to gate the current data from the PLSI telemetry buffer.

(c) Remote Command Decoder (RCD)

1) Switched Power - PLSI power switched on for picture taking periods, diagnostic periods only.
2) Pulse Commands - 32 pulse commands for ground control of PLSI.

(d) Digital Telemetry Unit (DTU)

1) Analog Telemetry - Analog telemetry data for the DTU science subcommutator.
2) Spin Period Sector Generator - Pulse train providing sector divisions of the spacecraft spin status for PLSI images timing.

(2) RM2 Data Compressor

(a) Assumptions:

1) Image Data Buffer (IDB) - Twenty image source blocks of 160×32 pixels can be randomly accessed and nondestructively read out in parallel 10-bit/pixel words at a rate of 1,048,576 words per second.
2) The Image Buffer (IB) is assumed to have a one source block holding register which can be read by RM2 simultaneously with the Camera loading of the IB. The IB must be able to ready a source block of

data for RM2 access within 0.11 sec, and must be able to commence read out of the block, thereafter, within 10 ms.

3) The RM2 output to the Data Select and Scaling Block will be 8-bit parallel words with the RM2 waiting for a ready indication before blocking each word.

4) If the Image Data Output Buffer (IDOB) is less than 99% full, then the IDOB must be ready to accept RM2 output data at a minimum average rate (over 100-ms intervals) of 24 kb/s, and the IDOB must be ready to accept consecutive 8-bit words with not more than 10 ms delay between any two words.

5) The IDOB is assumed to be at least 64 K bits in size, and must supply RM2 with a buffer fullness signal of at least 6-bit resolution.

(b) Image Data Buffer (IDB)

1) (1 Bit)
Image loaded indication from the IDB to RM2 indicates that PLSI data is loaded into IDB and is ready for compression.

2) (5 Bits)
Number of source blocks/image from the IDB to RM2 indicating how many source blocks to compress. This signal is coincident with signal (1).

3) (1 Bit)
RM2 compression start to the IDB from RM2 indicates that RM2 has begun compression.

4) (5 Bits)
Source block desired by RM2 to the IDB from RM2 will access. The IDB begins readying this source block after (3), and after each Transfer Complete Signal (9) which the IDB initiates.

5) (1 Bit)
Source block access ready from the IDB to RM2 and indicating the desired source block is available for start of transfer to RM2 within 10 ms of request by RM2.

6) (1 Bit)

Source block access request from RM2 to the IDB indicating that RM2 wants the 10-bit parallel word source block data as soon as it can get it. The timing requirements for IDB response to (6) is given in (7).

7) (1 Bit)

Data transfer clock from the IDB to the RM2 performs the clocked transfer of the source block data from the IDB to RM2 over the Data Interface Lines (8). This is the 1, 048, 576-Hz IDB clock and clocks exactly 5120 10-bit words, with the first 10-bit word being the first picture element of the source block and all other 10-bit words ordered in the same manner in which they were acquired from the camera. The Data Transfer Clock (7) signal must respond to the Source Block Access Request (6) in not more than 10 ms.

8) (10 Bits)

Data interface lines provide consecutively all the data in the source block. The data is to occur on these lines in 10 bit parallel (1 picture element/10-bit word) synchronously with the Data Transfer Clock (7).

9) (1 Bit)

Transfer complete comes from the IDB to RM2 and indicates 5120 10-bit words have been transferred to RM2. This signal must occur concurrently with the last clocking of the Data Transfer Clock (7).

10) (1 Bit)

IB access complete from the RM2 to the IDB indicating when RM2 accessing of the IDB is completed for the current picture. This signal is reset by RM2 whenever an Image Loaded Indication (1) is received from the IDB.

(c) Telemetry Formatter and Synchronizer

1) RM2 Telemetry Data - Eight bilevel outputs sampled when the PLSI telemetry data is enclosed.

2) Data Compression ID - 3 bilevel bits indicating one of eight compression modes.

(d) Data Select and Scaling

(101) (8 Bits)
Output transfer lines from the RM2 to the Image Data Output Buffer (IDOB).
8-bit words will be consecutively provided by the Output Transfer Lines (101) to the IDOB synchronously with the Output Buffer Transfer Clock (103).

(e) Image Data Output Buffer (IDOB)

(102) (1 Bit)
Ready for next word from the IDOB to the RM2 and indicating the IDOB is able to receive another 8-bit word. RM2 will not clock out its data until (102) has been reset and then set again.

(103) (1 Bit)
Output buffer transfer clock from RM2 to the IDOB, occurring when RM2 output data is ready. The IDOB to synchronously clock in the 8 bits of data on (101).

(104) (6 Bits)
Output buffer fullness from the IDOB to RM2, providing an indication of the IDOB fullness to 1 part in 64.

(3) Digital Telemetry Unit (DTU)

(a) Image Data Output Buffer (IDOB). The IDOB data is transferred under the multiple D3 format utilizing the D3 word gate, DTV clock (downlink bit rate) and the imaging data line. This is a standard D format interface.

(b) Reed Solomon (R-S) Encoder/Control. The interface to the RS encoders are data from the DTU combines and the DTU bit rate clock. The interface from the RS control logic is R-S data and clock (if R-S is selected) or normal DTU data and clock (if R-S is by-passed) into the DTU convolutional code generator.

b. Functional Blocks

(1) Image Data Buffer Memory (IDB). The IDB provides a high-speed mass memory for up to 102, 400 words of 10-bit PLSI data. Figure 4-8 presents a functional block diagram for the memory. Two memory segments are indicated, both using the CCD memory technology and design discussed in Appendix F. In addition to the memory segments are control logic for modes and source block selection and identification and clock control.

The mass memory comprises 13 CCD memory elements which are 10 10 parallel 8192-bit paths each for a total capacity of 106, 496 10-bit words. The requirement for PLSI data is up to 20 source blocks of 5120 words or 102, 400 words. The mass memory operates at 1, 048 MHz for read-in or readout and at 1, 024 Hz during standby or storage modes to save power. The data in the register is recirculated when not being read in and data readout is also recirculted, providing a nondestruct feature. The mass memory pointer counter is indexed to zero when the first word is read in and repeats the count when that data reaches the output of the memory. An adjunct 5-bit source block counter and logic keeps track of the 5120-word source block segments so the current source block can be telemetered and so a specific source block of data can be accessed by the RM2. The cycle time of the mass memory at 1, 048, 576 MHz is 106, 496/1, 048, 576 = 0. 1016 sec. This is the maximum time required to load data and to access a specific source block. Once acquired the source block can be transferred to the mass memory output buffer (MMOB) in 5120 words/1, 048, 576 words/sec = 4. 88 ms.

The MMOB is one CCD memory element providing 8192 10 bit-words of storage for a source block of data (5120 10-bit words). This buffer is necessary as RM2 requires the next block of data to be ready for readout in 10 ms or less. So as RM2 is processing the current data, it will indicate the next source block which can be accessed from MM and loaded into the MMOB. The MMOB is organized with recirculating data and a pointer counter which is indexed each

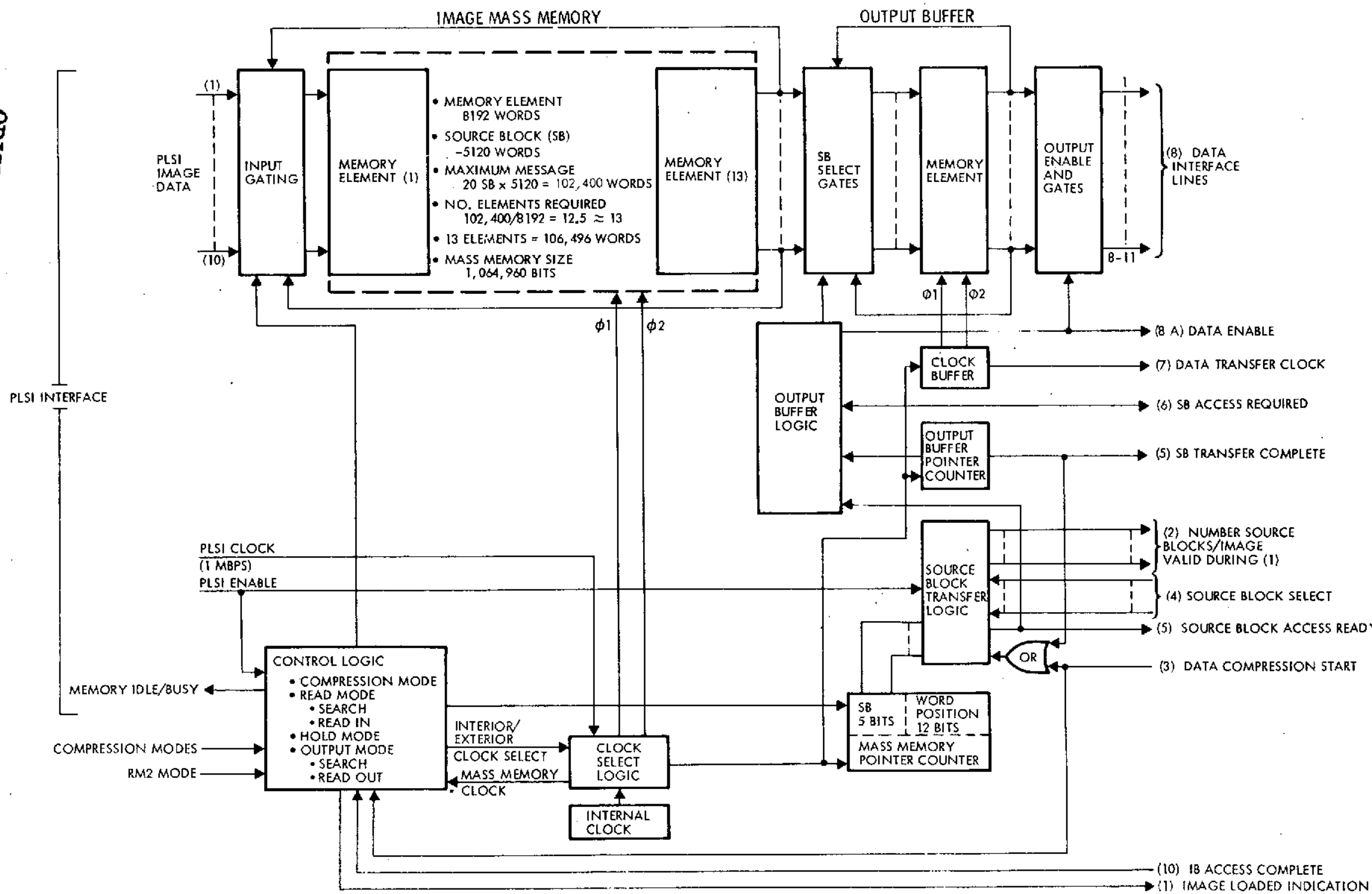


Figure 4-8. Image Data Buffer Memory Functional Block Diagram

time a new batch of data is read in. The MMOB reads in, reads out and searches at 1.048 MHz, and circulates during standby at 1.024 Hz. The read-in/readout time for a source block of data is 4.88 ms and the circulation (access) time is 8192/1,048,576 = 7.82 ms, which meets the RM2 10 ms or less requirements to commence source block read out.

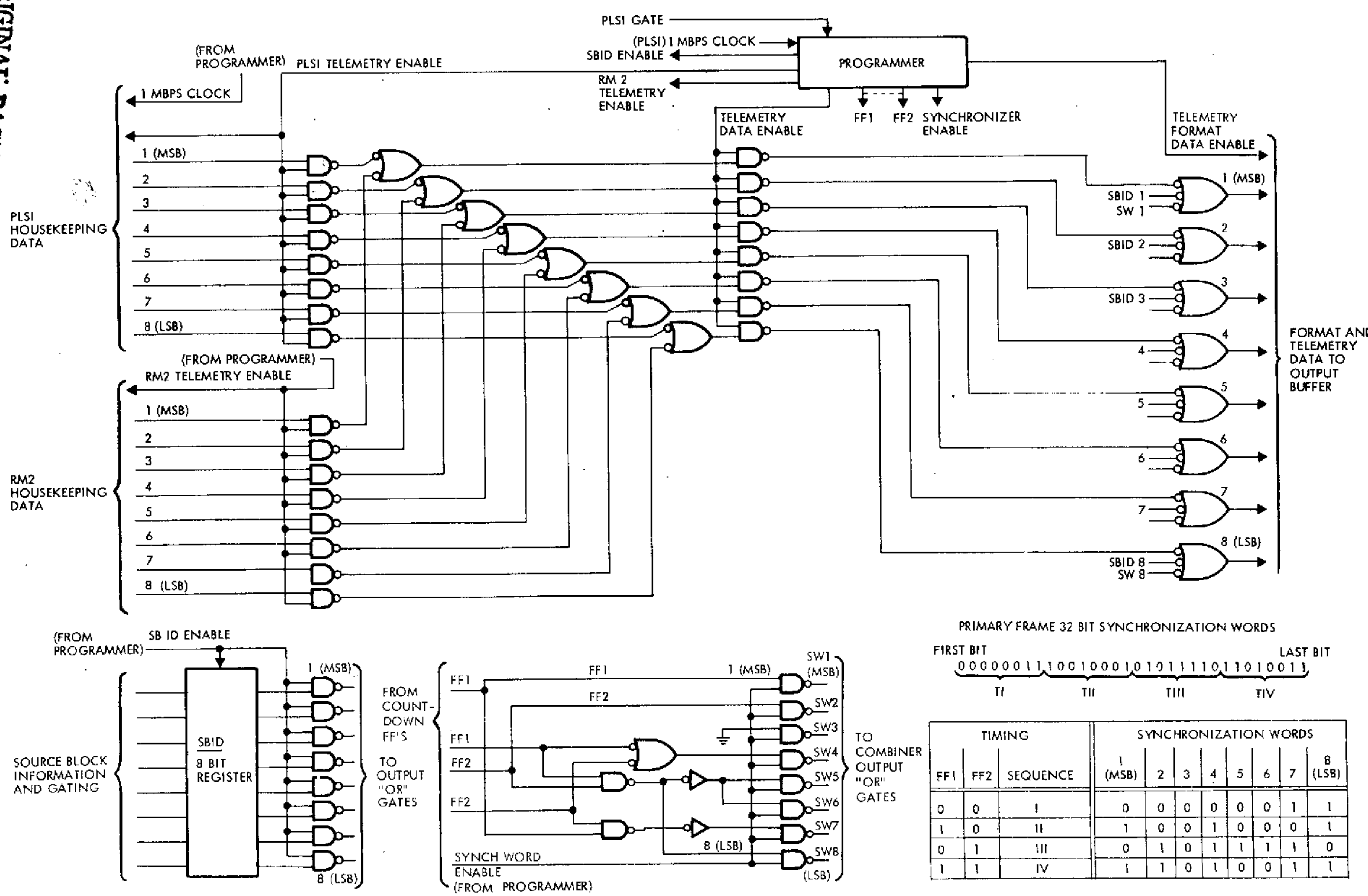
(2) Telemetry Formatter and Synchronizer. Telemetry data from PLSI, IDB and RM2 are collected and formatted to precede each source block.

The compressed imaging data will be formatted into the multiple D3 format alternating seven D3 blocks with either the A or B main frame format. Imaging data transmitted downlink may be either raw data or compressed data. The data transmitted will be assembled asynchronously with the main data formats. An asynchronous scheme of formatting imaging data proposed by JPL (IOM 3621-74-047 "Image Data Source Blocks for a Pioneer RM2 Compressor," from R. Piereson, dated 13 September 1974) shows how the image data and housekeeping data can be folded into the D3 format. This approach assumes partitioning the image data into five source blocks per 160 × 160 pixel subframe with up to 20 source blocks used. Each source block would be prefaced by a 32-bit synchronizing word and housekeeping data. This formatting can be performed as part of the RM2 data compression function.

For the noncompressed or moderately compressed modes, the raw data will be transmitted in the D3 format with no additional formatting.

Figure 4-9 presents a block diagram for the telemetry formatter and synchronizer block. The programmer synchronizes the operation of the block with the image data handling using the source block ID and PLSI clock. The data collected is the PLSI digital housekeeping data (16 8-bit words, 128 bits), RM2 telemetry (8 bits), source block ID (8 bits) and the 32-bit synchronization word. The synchronization word is generated in four 8-bit words according to the truth table and mechanization shown in Figure 4-9.

At the beginning of each source block, the programmer timing starts the synchronization word generator and the telemetry format data enable goes



TIMING			SYNCHRONIZATION WORDS							
FF1	FF2	SEQUENCE	1 (MSB)	2	3	4	5	6	7	8 (LSB)
0	0	I	0	0	0	0	0	0	1	1
1	0	II	1	0	0	1	0	0	0	1
0	1	III	0	1	0	1	1	1	1	0
1	1	IV	1	1	0	1	0	0	1	1

Figure 4-9. Block Diagram of the Telemetry Formatter and Synchronizer Block

true, enabling data to the output buffer. After four state times the source block ID, PLSI telemetry and RM2 telemetry are gated out in turn to the output buffer. At the end of the telemetry data the telemetry format data enable goes false.

(3) Data Select and Scaling. The telemetry data, RM2 data and raw image data are selected in this block. Figure 4-10 shows the data sources for this block. Figure 4-10 gives the mechanization. The priority of data is shown below:

1) Telemetry data
2) RM2 data
3) Raw image data buffer.

This priority is determined by the logic shown. All outputs are designated "or" to go to the input of the Image Data Output Buffer (IDOB).

An additional feature of this block is the scaling of raw image data received from the IDB on the uncompressed mode. This scaling is accomplished where the MSB, mid-bits or LSB 9-bits are selected by command.

(4) Image Data Output Buffer. The Image Data Output Buffer (IDOB) (see Figure 4-11) is a one chip CCD memory with 10 parallel 8192-bit paths. The input data is in 8-bit words so only 8 paths are used for a capacity of 65,536 bits. To facilitate word-by-word data transmission when the memory is filling a 32 × 8-bit word, Ram is used for input buffering. The RAM is loaded under the control of available input data and dumped into the next IDOB address when it becomes available. Read-in and readout of the RAM are at 1.048 Mw/s.

The CCD memory operates on a random read/write basis which utilizes the pointer counter to give last read-in and last readout addresses. In addition, RM2 requires a fullness indicator to one of 64 accuracy. This is accomplished with an up/down counter which is incremented for read-in word counts and decremented for readout counts. As the memory fills (because the data

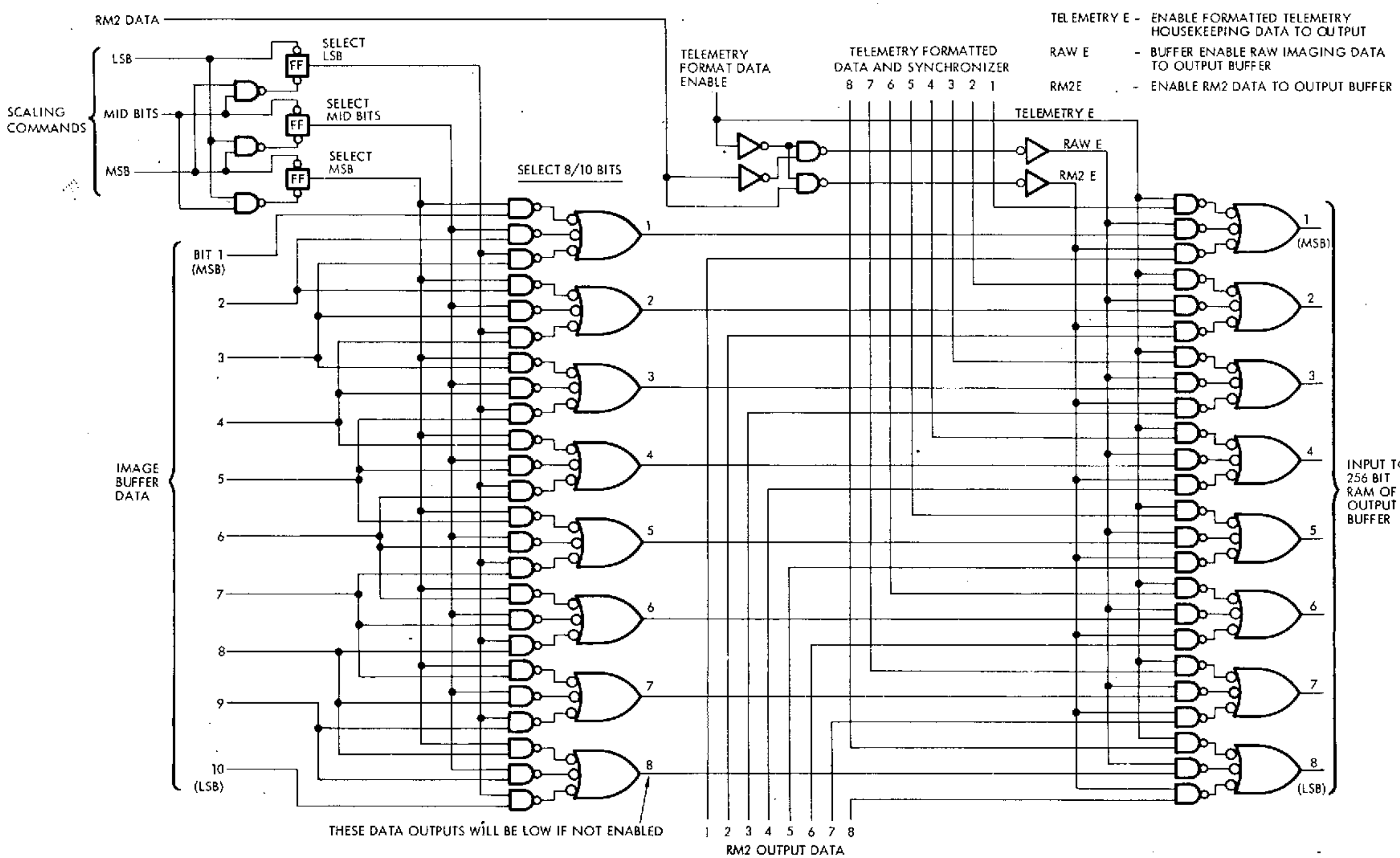


Figure 4-10. Data Select and Scaling

transmission rate is less than the data availability rate) the six msb of the "fullness" counter are routed to RM2.

The output of the IDOB interfaces with the DTU and must present data available for continuous serial downlink transmission under control of the DTU A/DDDDDDD format. Additional output RAM buffering is provided to accomplish this. The output of the IDOB is parallel to serial converted and shifted alternately into either RAM-A or RAM-B at 1.048 mb/s which means that the data is shifted out of IDOB at 104.8 kw/s. When both RAMs are full or busy the IDOB recirculates at 1024 Hz.

(5) Reed-Solomon Encoding. Figure 4-11 shows the DTU NRZ data output interfacing with a Reed-Solomon (R-S) encoder. The data flow with R-S encoding would be as shown in Figure 4-12. The data and clock from the DTU can be either routed to the R-S encoder for processing prior to convolutional coding or directly to the convolutional code generator, bypassing the R-S encoder. As shown in Figure 4-12 there is a requirement for a R-S data buffer at the R-S encoder output.

(6) Probe/DTU Mass Memory. Figure 4-13 presents the Probe/DTU mass memory mechanization. The basic memory is six CCD chips with input/output logic selecting one of eight paths to give a total serial memory capacity of $6 \times 8 \times 8192 = 393,216$ bits. The probe data requirement is for 88 bps up to 1.2 hours or

$$88 \frac{\text{bits}}{\text{sec}} \times 1.2 \text{ hours} \times 1.2 \text{ hours} \times 3600 \frac{\text{sec}}{\text{hours}} = 380,160 \text{ bits.}$$

The proposed memory capacity meets the probe requirement. It is assumed that the DTU requirement is met by this capacity.

The input/output RAMs provide serial buffers for the low input/output data rates with the CCD mass memory. The characteristic features of the memory are noted in Figure 4-13.

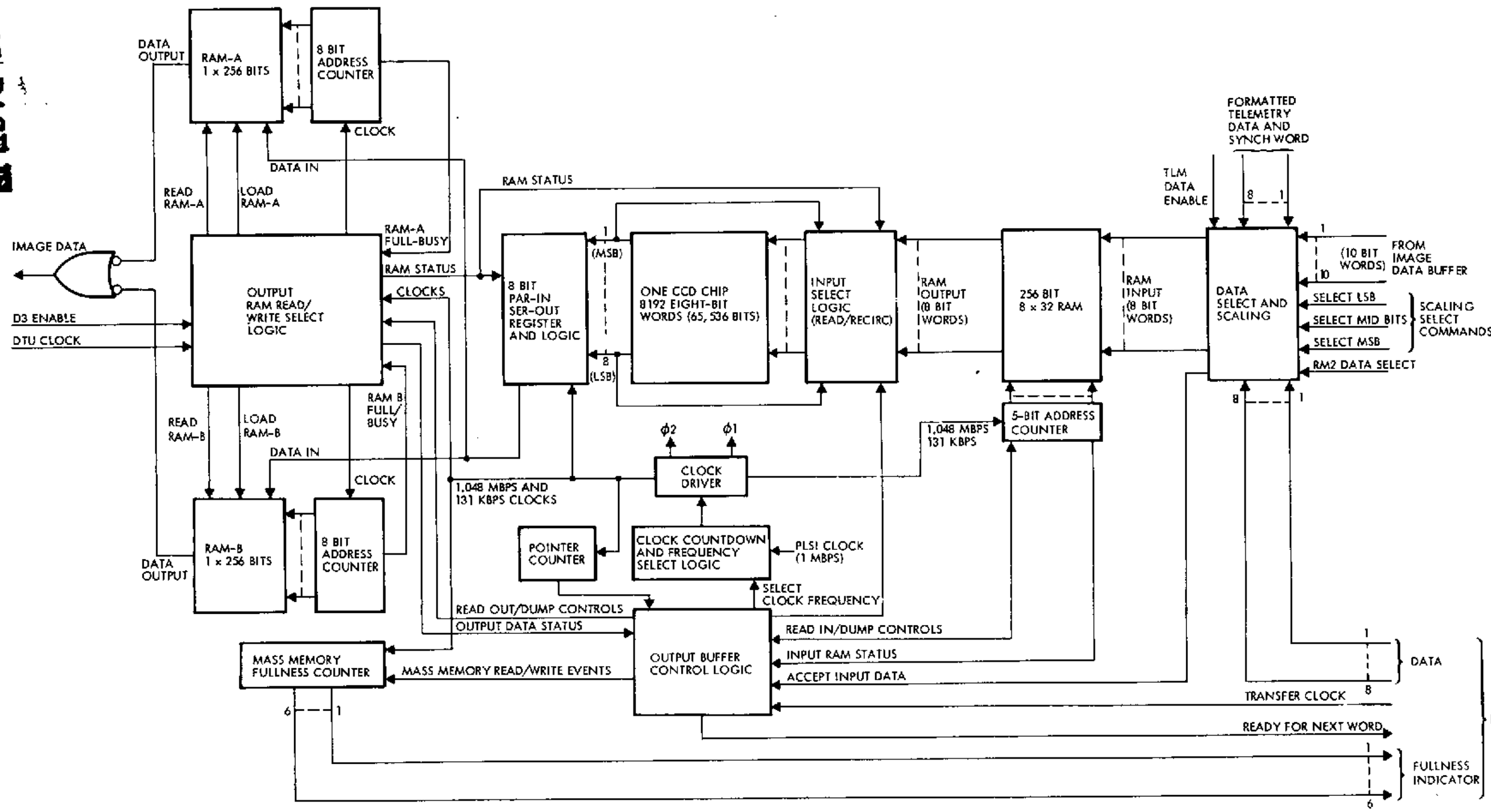


Figure 4-11. Image Data Output Buffer

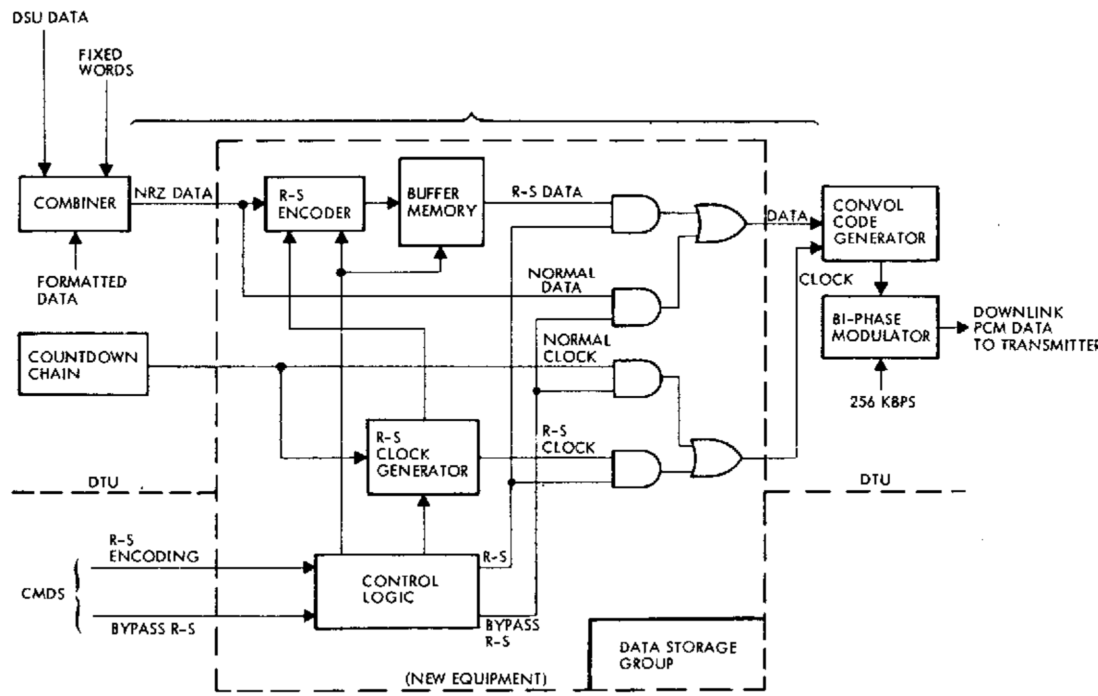
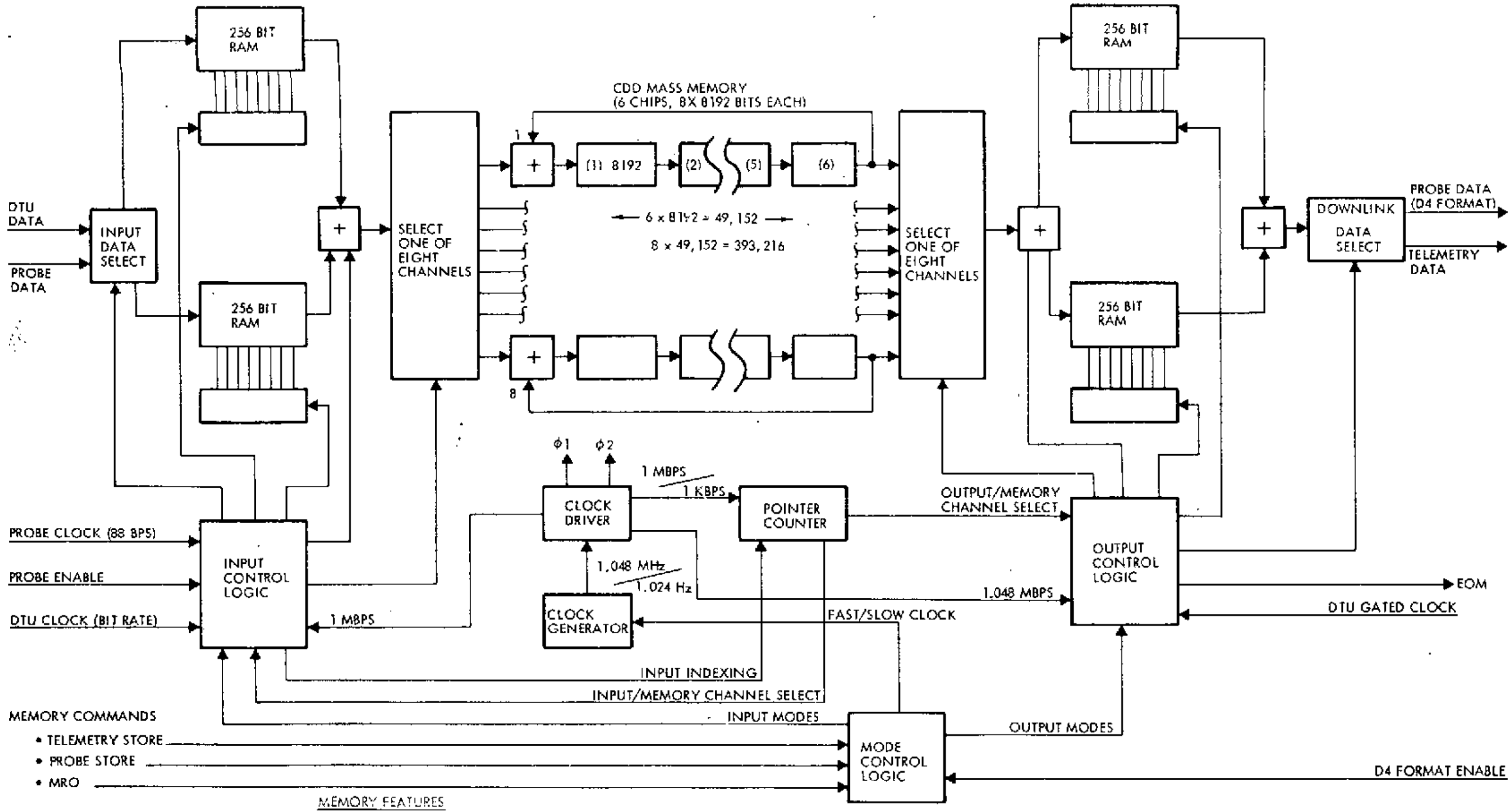


Figure 4-12. Reed-Solomon Encoder and Interfaces



MEMORY FEATURES

MEMORY ELEMENTS

- CCD MASS MEMORY 393,216 BITS OF STORAGE
  - 8 PARALLEL PATHS, 6 x 8192 = 49,192 BITS EACH, LOADED SEQUENTIALLY UNTIL FILLED OR END OF DATA
  - FIRST IN/FIRST OUT OPERATION
    POINTER INITIALIZED AT INPUT FOR SINGLE MASS LOADING
  - 2 MEMORY SPEEDS - 1.048 MEG BIT/SEC READ IN/READ OUT MODES
    1.024 KBIT/SEC STORAGE MODE
  - CYCLE TIME - 0.045875 SEC, READ IN/READ OUT MODES (1.048576 MBPS)
    - 5 SEC - , STORAGE MODE (1024 BPS)
- 256 BIT RAM BUFFERS
  - 2 INPUT BUFFERS
    - POWERED ON DURING INPUT MODE ONLY
    - READ DATA IN ALTERNATELY AT INPUT DATA RATES

      DTU BIT RATE $< \frac{256}{\text{MASS MEMORY CYCLE TIME}} = \frac{256}{47\ \text{MS}}$ 5450 BPS
    - LOAD MASS MEMORY ALTERNATELY AT 1.048576 MBPS
  - 2 OUTPUT BUFFERS
    - POWERED DURING OUTPUT MODE ONLY
    - READ DATA OUT ALTERNATELY AT TLM DOWNLINK BIT RATE
      MAXIMUM DOWNLINK RATE ≤ 5450 BPS
    - LOAD FROM MASS MEMORY ALTERNATELY A 1.048576 MBPS
- CLOCK GENERATOR/DRIVER
  - 2 INTERNALLY GENERATED FREQUENCIES: 1.048576 MHz, 1024 Hz
  - 2 PHASE CLOCKS FOR MASS MEMORY ELEMENT
  - CLOCK FOR MASS MEMORY POINTER COUNTER
  - HIGH SPEED CLOCK FOR MASS MEMORY/RAM INPUT/OUTPUT TRANSFER
- CONTROL LOGIC
  - PUTS MEMORY INTO PROPER MODES ON EXTERNAL COMMAND
  - COORDINATES INPUT/STORAGE/OUTPUT FUNCTIONS WITH INTERFACING EQUIPMENT

Figure 4-13. Probe / DTU Mass Memory Mechanization

c. Equipment Summary

Table 4-6 presents a summary of size, weight, power, parts count and redundancy for modified and new required equipment to accommodate an OPPICS mission.

Table 4-6. OPPICS Equipment Impact

Equipment	Size (in.) (in.^{3})	Weight (lb)	Power
Digital telemetry unit (DTU)	N/C	N/C	1.0
Remote command decoder (RCD)	2 × 6 × 8 (96)	2.0	1.0
Probe/DTU mass memory -A	1.6 × 6 × 8 (77)	1.3	0.2
-B	1.6 × 6 × 8 (77)	1.3	0.2
Image data buffer	1.6 × 6 × 8 (77)	1.5	0.5
Control logic	1 × 6 × 8 (48)	1.0	0.1
R-S implementation	1.6 × 6 × 8 (77)	1.4	0.25
Control logic	1.6 × 6 × 8 (77)	1.4	0.25
Output buffer	1.6 × 6 × 8 (77)	1.4	0.12
RM2 compressor	4 × 6 × 8 (192)	3.2	0.5

E. SUMMARY AND CONCLUSIONS

The preceding study results show that an imaging mission consisting of the OPP spacecraft and the PLSI imager is feasible. For uncompressed data, the PLSI interface with the OPP is largely with the new DSU although some changes to the DTU are required.

A significant result of this study is the level of detailed definition between the PLSI, the probe receiver, and the DSU which has been developed. The identification of separate (and simultaneous) storage requirements for probe data and for imaging data represents a new mission requirement.

Another important study results has been the formulation of a plan to format imaging data using the existing DTU. The use of multiple D formats will allow imaging data to occupy a significant fraction of the downlink channel capacity.

The need for a new secondary command decoder to expand the available command dictionary for imaging missions has been established in this study.

The support requirements for the general science payload (bit rates, command, storage) on a flyby mission such as the OPPICSS mission have not been defined. Hence it is possible that future definition of these requirements could impact the results of the OPPICSS study.

The changes to Pioneer 10 and 11 hardware required to accommodate the OPPICSS mission are substantially the same order as the changes required by the OPP definition.

The effort spent on analyzing the six options for the no compression case was largely directed toward increasing downlink bit rate. First, it is open to question whether such an increase is necessary. Second, it may be that some other parameter such as the allowable error rate, the PLSI field-of-view, the total storage capacity, or the spacecraft spin rate should be changed or would better enhance mission science than increased downlink bit rate. Until the imaging science data requirements have been analyzed and stated in meaningful terms, further tradeoffs on mission options are of doubtful value.

SECTION V

TELECOMMUNICATIONS SYSTEM ANALYSIS

A. INTRODUCTION

This section explores the telecommunications system performance and channel characteristics for an Outer Planets Pioneer Saturn / Uranus mission and describes the effects of various proposed data compression schemes on the telecommunications system.

The characteristics of mission design, Spacecraft System (S/C), Deep Space Network (DSN), Mission Control and Computing Center (MCCC), Mission Operations Systems (MOS) and Image Processing System (IPS) and data compression schemes are discussed in detail in appropriate sections elsewhere in this report. Here telecommunications system performance and channel coding/decoding necessary to support various data compression schemes are discussed.

For the purpose of providing a basis of comparison, the baseline system is that of no data compression case.

B. BASELINE

The baseline system is essentially that of OPP spacecraft with short constraint convolutional code, Viterbi decoding instead of long constraint convolutional code, sequential decoding. Viterbi decoding scheme is assumed since Viterbi decoder is available at DSN, and DSN sequential decoding capability cannot support high data rates required in OPPICS. A constraint length $K=7$ and rate $R=1/2$ is used in this study. The performance of Viterbi decoding is illustrated in Figure 5-1.

The X-band frequency transmission with 64-m antenna at DSN is assumed. X-band frequency transmission can support substantially higher bit rates than S-band at a given transmission power. Theoretically, an 11.3 dB link performance gain improvement occurs from increasing the downlink frequency

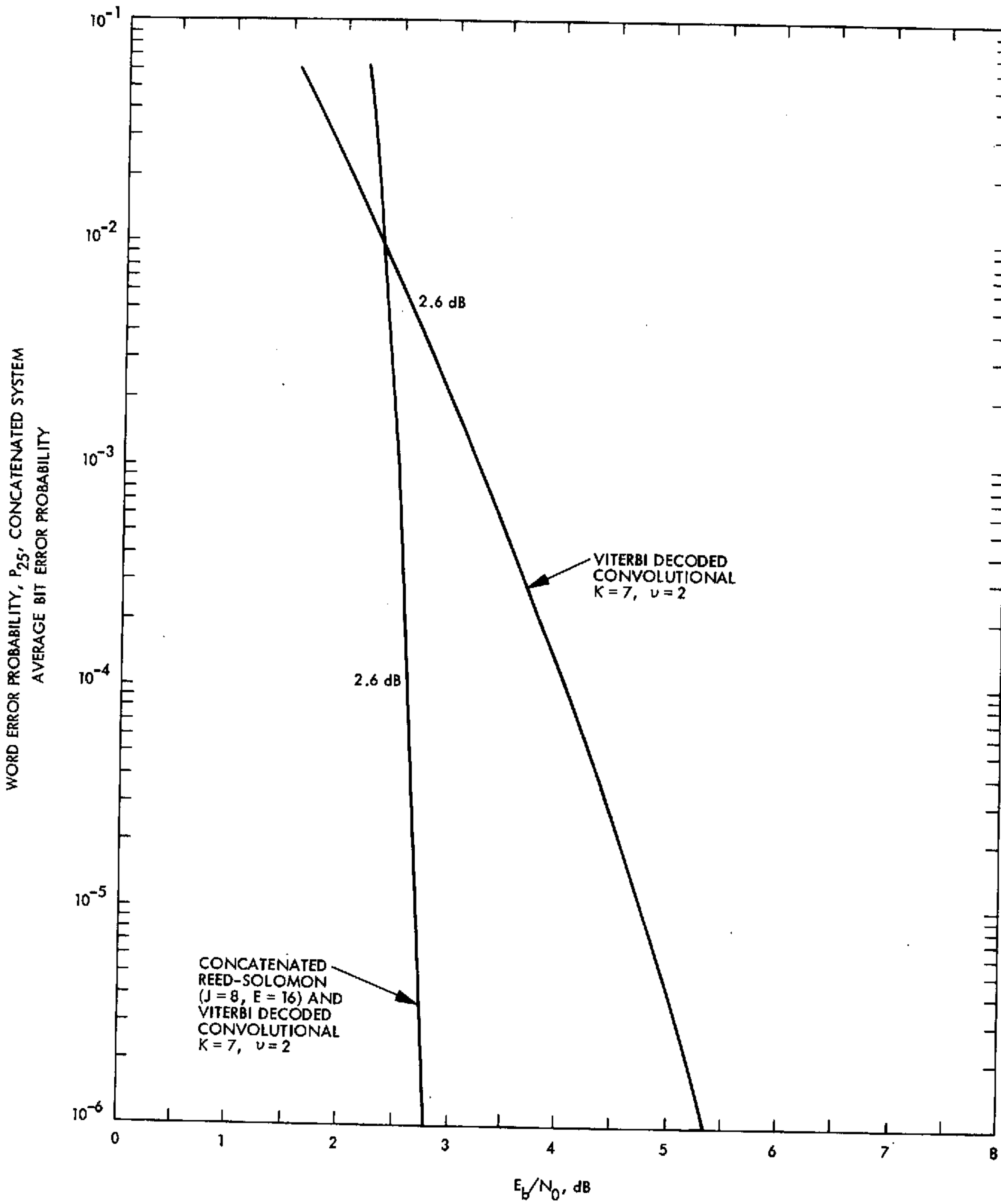


Figure 5-1 Performance Curves

from 2.3 GHz to 8.4 GHz. Practical limitations (e.g., higher antenna pointing losses and atmospheric attenuation) restrict this improvement to approximately 8.5 dB or a factor of 7 in data rate. Further, X-band propagation is weather dependent. Cloud cover or rain can introduce losses ranging from tenths of dB's to several dB's, depending on the density of the cover.

Baseline telecommunications link performance at Saturn and Uranus encounters are summarized in Tables 5-1 through 5-3. It is seen that at design value, no data compression baseline system is capable of supporting 8 kb/s at Saturn encounter and 2 kb/s at Uranus encounter as required. However, in an adverse situation, data rates must be lowered to achieve quality data.

C. MODERATE DATA COMPRESSION

Moderate data compression consisting of pixel editing would have little effect on the channel. Performance gain is realized from the pixel editing ratio. For example, an 8-to-1 pixel editing would increase the data rate 8 times provided reconstructed pictures are of acceptable quality. In order to provide a low error rate channel, Reed-Solomon/Viterbi concatenated decoding scheme of reasonable complexity is recommended. This scheme uses a maximum likelihood-decoded (Viterbi decoding) inner code and a Reed-Solomon outer code, best decoded by generalized minimum distance decoding. The performance of this coding scheme is shown in Figure 5-1.

The performance of the telecommunications link with moderate data compression using Viterbi decoding alone (as that in the baseline case) and using RS/Viterbi decoding are summarized in Table 5-1 and Tables 5-4 and 5-5. It is seen that RS/Viterbi gives 1.3 dB improved performance.

D. AICS-RM2 DATA COMPRESSION

In order to obtain high data rate at low-error rate, the RS/Viterbi decoding scheme is recommended to support data system using RM2 data compression. Its channel performance gain is summarized in Tables 5-4 and 5-5.

E. CONCLUSIONS AND DISCUSSIONS

The Telecommunications System is capable of supporting an OPP Saturn/ Uranus mission with encounter data rates of 8 kb/s and 2 kb/s at bit error rate 10^{-4} at designed operation point. The Reed-Solomon/Viterbi channel coding scheme is recommended regardless of having data compression or not. This channel coding/decoding scheme gives about 1.3 dB improvement over the baseline in channel performance in the sense of achieving higher data rates and/or lower bit error rates.

If system design is based on adverse design value, then even with RS/Viterbi channel coding scheme, the telecommunication system will not be able to support the data rates required at Saturn and Uranus encounters. The application of data compression scheme is one of the methods that can be used to meet design requirement at the adverse situation. Data compression schemes such as pixel editing and RM2 with compression ratio of 5 to 1 will be necessary and sufficient to meet design requirement.

Since Viterbi decoding capability will be available for OPP missions, the only addition required in a RS/Viterbi channel is a RS decoder which can be installed in MCCC for cost-effectiveness considerations. Brief investigation also indicates that the sequential decoder can also be implemented for only slightly higher cost. A preliminary attempt has been made to assess the performance of sequential decoding vs Reed-Solomon/Viterbi decoding on simulated RM2-compressed data at selected compression ratio. It is found that RS/Viterbi decoding is 1/2 to 1 dB superior to sequential decoding; but further studies are needed to make sure that the improvement of sequential decoding at lower bit rates does not out-perform RS/Viterbi. Also, extensive studies are needed to be carried out for all expected data compression ratios, photograph formats, and data rates. We also note that R=1/3 convolutional codes are expected to have about 1/2 dB performance gain over R=1/2 convolutional code which has been assumed in OPPICSS.

Both RS/Viterbi decoding and Sequential decoding algorithms have steep performance curves (P_E vs E_b/N_o). The steepness of performance curves indicates that it is a very sensitive system with respect to system parameters such as receiver tracking loop bandwidth, coherent-phase noisy reference loss, acquisition and cycle-slipping characteristics, etc. These must be investigated further to ensure operation success. Also data rates should be occurring at small dB steps such as 1/2 to 1 dB steps. Spacecraft operational flexibility and mission return benefits due to many data rates in small dB steps need to be traded-off against added ground operation complexity.

From an overall system standpoint, results indicate that RM2 does offer improvement in data rate provided pictures reconstructed from compressed data are of acceptable quality. Picture quality dictates the acceptable data compression ratio. RM2 is an excellent idea which could substantially increase the performance of Deep Space video systems at a relatively modest cost; but, of course, convincing proof that RM2 achieves high compression ratios at an acceptable picture quality loss must be via intensive studies of its performance on actual photographs.

In the OPPICSS, results have been based on theoretical analysis. Results must be validated via a complete end-to-end system simulation or test such as shown in Figure 5-2. In addition, simulation studies can provide answers to issues that can't be treated analytically.

Table 5-1. Performance Summary

	P_E	Maximum Data Rate (KBPS)			
		Saturn Encounter		Uranus Encounter	
		Baseline	RS/Viterbi	Baseline	RS/Viterbi
Design Value	10^{-4}	8.55	12.08	2.14	3.02
	10^{-5}	7.28	11.80	1.82	2.95
Adverse Value	10^{-4}	1.96	2.76	0.49	0.69
	10^{-5}	1.67	2.70	0.42	0.67

Table 5-2. OPPICS Telemetry Design Control Table

No Data Compression Baseline, Saturn Encounter		
Transmitter Parameters	Design Value	Adverse Tolerance
Trans. Power (23W) dBm	43.62	-0.5
Circuit Loss, dB	-0.5	-0.1
S/C Antenna Gain	44.1	-0.5
Pointing Loss	-0.5	-0.2
Path Parameters		
Space Loss	-294.45	0
Freq. = 8413 MHz		
Range = 10 AU		
= 1.496×10^9 km		
Receiver Parmeters		
Antenna Gain	71.7	-0.7
Elevation Angle = 25°		
Wind Speed = 20 mph		
Polarization Loss		

Table 5-2. OPPICS Telemetry Design Control Table (contd)

No Data Compression Baseline, Saturn Encounter		
Receiver Parameters	Design Value	Adverse Tolerance
Signal Attenuation (Weather)	-0.4	-1.90
Elevation Angle = 25°		
Confidence level = 90%		
Pointing Loss	-0.2	-0.3
Total Received Power	-136.73	-4.3
P = Σ (1 thru 9)		
Noise Spectral Density	-181.95	0.9
Total Received Power-to-Noise Spectral Density	45.22	-5.2
P/N_o = (10-11)		
<u>Carrier Tracking Performance</u>		
Carrier Modulation Loss	-7.8	-0.1
Carrier P_c/N_o	37.42	-5.3
Carrier Loop Threshold BW	4.77	0.4
3 Hz ± 0.3 Hz $2B_{LO}$		
Carrier Loop Threshold SNR	19.5	0
Carrier Margin at 10 AU	13.15	-5.7
(14-15-16)		
<u>Telemetry Data Performance</u>		
Data Modoulation Loss	-0.8	-0.8
(Mod. index = 1.15 radians		
Data SNR (S/N_o)	44.42	-6.0
(12 + 18)		
Waveform Distortion	-0.2	-0.1
Radio Loss	0.6	-0.1
Subcarrier Demod. Loss	-0.1	-0.1
Symbol Synch Loss	-0.1	-0.1

Table 5-2. OPPICS Telemetry Design Control Table (contd)

No Data Compression Baseline, Saturn Encounter		
Telemetry Data Performance	Design Value	Adverse Tolerance
Required E_b/N_o (Viterbi decoding)		
a. $P_E = 5 \times 10^{-3}$	2.6	0.
b. $P_E = 10^{-3}$	3.2	0.
c. $P_E = 10^{-4}$	4.1	0.
d. $P_E = 10^{-5}$	4.8	0.
Maximum Data Rate (19-20-21-22-23-24)		
a. 12.08 kb/s	40.82	-6.4
b. 10.52 kb/s	40.22	-6.4
c. 8.55 kb/s	39.32	-6.4
d. 7.28 kb/s	38.62	-6.4
Maximum Data Rate (Taking Adverse Tolerances into Account)		
a. 2.76 kb/s	34.42	
b. 2.41 kb/s	33.82	
c. 1.96 kb/s	32.92	
d. 1.67 kb/s	32.22	

Table 5-3. OPPICS Telemetry Design Control Table

No Data Compression Baseline, Uranus Encounter		
Transmitter Parameters	Design Value	Adverse Tolerance
Trans. Power (23W) dBm	43.62	-0.5
Circuit Loss, dB	-0.5	-0.1
S/C Antenna Gain	44.1	-0.5
Pointing Loss	-0.5	-0.2
<u>Path Parameters</u>		
Space Loss	-300.47	0
Freq. = 8413 MHz		
Range = 20 AU		
= 2.992×10^9 km		
<u>Receiver Parameters</u>		
Antenna Gain	71.7	-0.7
Elevation Angle = 25°		
Wind Speed = 20 mph		
Polarization Loss	-0.1	-0.1
Signal Attenuation (Weather)	-0.4	-1.9
Elevation Angle = 25°		
Confidence level = 90%		
Pointing Loss	-0.2	-0.3
Total Received Power	-142.75	-4.3
$P_T = \Sigma$ (1 thru 9)		
Noise Spectral Density	-181.95	0.9
Total Received Power-to-Noise Spectral Density	39.20	-5.2
P_T/N_o = (10-11)		

Table 5-3. OPPICS Telemetry Design Control Table (contd)

No Data Compression Baseline, Uranus Encounter		
Carrier Tracking Performance	Design Value	Adverse Tolerance
Carrier Modulation Loss	-7.8	-0.1
Carrier P_c/N_o (12 + 13)	31.40	-5.3
Carrier Loop Threshold BW	4.77	0.4
3 Hz ± 0.3 Hz $2B_{LO}$		
Carrier Loop Threshold SNR	19.5	0
Carrier Margin at 10 AU	7.13	-5.7
(14-15-16)		
Telemetry Data Performance		
Data Modulation Loss	-0.8	-0.8
(Mod. index = 1.15 radians)		
Data SNR (S/N_o)	38.40	-6.0
(12 + 18)		
Waveform Distortion	-0.2	-0.1
Radio Loss	-0.6	-0.1
Subcarrier Demod. Loss	-0.1	-0.1
Symbol Synch Loss	-0.1	-0.1
Required E_b/N_o		
(Viterbi decoding)		
$P_E = 5 \times 10^{-3}$	2.6	0.
$P_E = 10^{-3}$	3.2	0.
$P_E = 10^{-4}$	4.1	0.
$P_E = 10^{-5}$	4.8	0.
Maximum Data Rate		
(19-20-21-22-23-24)		
3.02 kb/s	34.80	-6.4
2.63 kb/s	34.20	-6.4
2.14 kb/s	33.30	-6.4
1.82 kb/s	32.60	-6.4

Table 5-3. OPPICS Telemetry Design Control Table (contd)

No Data Compression Baseline, Uranus Encounter		
Telemetry Data Performance	Design Value	Adverse Tolerance
Maximum Data Rate (Taking Adverse Tolerances into Account)		
0.692 kb/s	28.40	
0.602 kb/s	27.80	
0.489 kb/s	26.90	
0.417 kb/s	26.20	

Table 5-4. OPPICS Telemetry Design Control Table

Data Compression RS/Viterbi Saturn Encounter		
Transmitter Parameters	Design Value	Adverse Tolerance
Trans. Power (23W) dBm	43.62	-0.5
Circuit Loss, dB	-0.5	-0.1
S/C Antenna Gain	44.1	-0.5
Pointing Loss	-0.5	-0.2
Path Parameters		
Space Loss	-294.45	0
Freq. = 8413 MHz		
Range = 10 AU		
= 1.496×10^9 km		
Receiver Parameters		
Antenna Gain	71.7	-0.7
Elevation Angle = 25°		
Wind Speed = 20 mph		
Polarization Loss	-0.1	-0.1
Signal Attenuation (Weather)	-0.4	-1.9
Elevation Angle = 25°		
Confidence level = 90%		
Pointing Loss	-0.2	-0.3
Total Received Power	-136.73	-4.3
$P_T = \Sigma$ (1 thru 9)		
Noise Spectral Density	-181.95	0.9
Total Received Power-to-Noise Spectral Density	45.22	-5.2
P_T/N_o = (10-11)		

Table 5-4. OPPICS Telemetry Design Control Table (contd)

Data Compression RS/Viterbi Saturn Encounter		
Carrier Tracking Performance	Design Value	Adverse Tolerance
Carrier Modulation Loss	-7.8	-0.1
Carrier P_c/N_o (12 + 13)	37.42	-5.3
Carrier Loop Threshold BW 3 Hz ± 0.3 Hz $2B_{LO}$	4.77	0.4
Carrier Loop Threshold SNR	18.0	0
Carrier Margin at 10 AU (14-15-16)	14.65	-5.7
<u>Telemetry Data Performance</u>		
Data Modulation Loss (Mod. index = 1.15 radians)	-0.8	-0.8
Data SNR (S/N_o) (12 + 18)	44.42	-6.0
Waveform Distortion	-0.2	-0.1
Radio Loss	-0.6	-0.1
Subcarrier Demod. Loss	-0.1	-0.1
Symbol Synch Loss	-0.1	-0.1
Required E_b/N_o (RS/Viterbi decoding)		
a. $P_E = 10^{-4}$	2.6	
b. $P_E = 10^{-5}$	2.7	
Maximum Data Rate (19-20-21-22-23-23-24)		
a. 12.08 kb/s	40.82	-6.4
b. 11.80 kb/s	40.72	-6.4
Maximum Data Rate (Taking Adverse Tolerances into Account)		
a. 2.76 kb/s	34.42	
b. 2.70 kb/s	34.32	

Table 5-5. OPPICS Telemetry Design Control Table

Data Compression RS/Viterbi Uranus Encounter		
Transmitter Parameters	**Design Value**	**Adverse Tolerance**
Trans. Power (23W) dBm	43.62	-0.5
Circuit Loss, dB	-0.5	-0.1
S/C Antenna Gain	44.1	-0.5
Pointing Loss	-0.5	-0.2
<u>Path Parameters</u>		
Space Loss	-300.47	0
Freq. = 8413 MHz		
Range = 20 AU		
= 2.992×10^9 km		
<u>Receiver Parameters</u>		
Antenna Gain	71.7	-0.7
Elevation Angle = 25°		
Wind Speed = 20 mph		
Polarization Loss	-0.1	-0.1
Signal Attenuation (Weather)	-0.4	-1.9
Elevation Angle = 25°		
Confidence level = 90%		
Pointing Loss	-0.2	-0.3
Total Received Power	-142.75	-4.3
$P_T = \Sigma$ (1 thru 9)		
Noise Spectral Density	-181.95	0.9
Total Received Power-to-Noise Spectral Density	39.20	-5.2
P/N_0 = (10-11)		

Table 5-5. OPPICS Telemetry Design Control Table (contd)

Data Compression RS/Viterbi Uranus Encounter		
Carrier Tracking Performance	Design Value	Adverse Tolerance
Carrier Modulation Loss	-7.8	-0.1
Carrier P_c/N_o (12 + 13)	31.40	-5.3
Carrier Loop Threshold BW	4.77	0.4
3 Hz ± 0.3 Hz $2B_{LO}$		
Carrier Loop Threshold SNR	18.0	0
Carrier Margin at 10 AU	8.63	-5.7
(14-15-16)		
<u>Telemetry Data Performance</u>		
Data Modulation Loss	-0.8	-0.8
(Mod. index = 1.15 radians)		
Data SNR (S/N_o)	38.40	-6.0
(12 + 18)		
Waveform Distortion	-0.2	-0.1
Radio Loss	-0.6	-0.1
Subcarrier Demod. Loss	-0.1	-0.1
Symbol Synch Loss	-0.1	-0.1
Required E_b/N_o		
(RS/Viterbi decoding)		
$P_E = 10^{-4}$	2.6	0
$P_E = 10^{-5}$	2.7	0
Maximum Data Rate (19-20-21-22-23-24)		
3.02 kb/s	34.8	-6.4
2.95 kb/s	34.7	-6.4
Maximum Data Rate (Taking Tolerances into Account)		
0.692 kb/s	28.4	
0.676 kb/s	28.3	

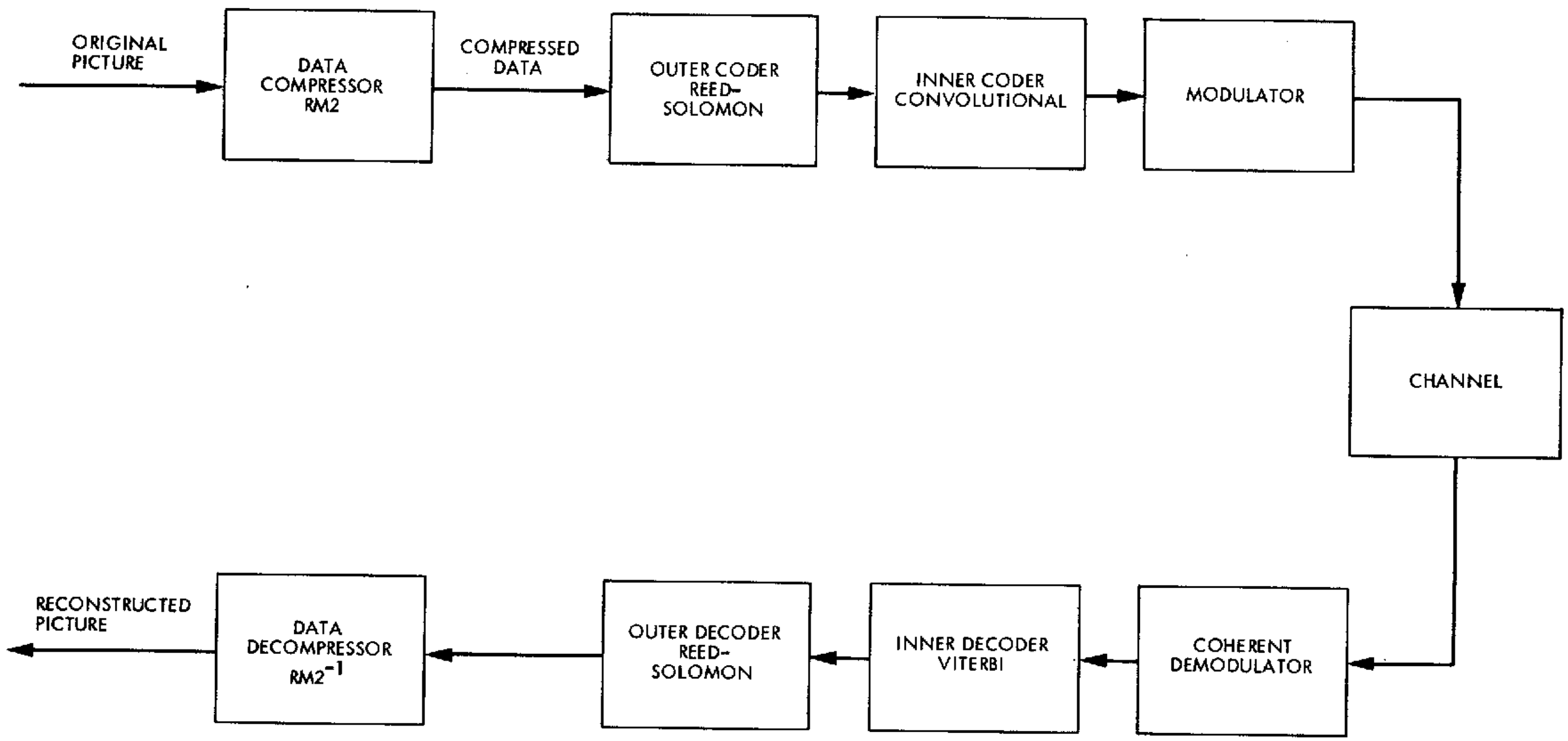


Figure 5-2. OPP Imaging Communication System Block Diagram

SECTION VI

DEEP SPACE NETWORK SYSTEM ANALYSIS

A. INTRODUCTION

This section provides an analysis of the impact on the Deep Space Network of the Outer Planets Pioneer Imaging Communications System. This impact analysis is concentrated in two areas: Telemetry and Command Systems. The DSN also provides radio metric data, derived from the DSN Tracking System, and participates in Mission simulation using its Test and Training System, but these are outside the scope of this study which is restricted to the impacts of imaging and data compression configurations.

The central assumptions underlying the following analyses and relating to the Deep Space Network are:

1) Encounter: (E - 30 days to E + 5 days) and Maneuvers

   a) X-Band Carrier
   b) 8 kb/s or higher at Saturn
   c) 2 kb/s or higher at Uranus
   d) 64-m DSS Support
   e) Data includes imaging and General Science and Engineering

2) Cruise:

   a) S-Band Carrier primarily, some X-Band
   b) Lower bit rates, whatever the link will support
   c) 26-m DSS Support primarily, some 64-m
   d) Primary General Science and Engineering Data

B. BASELINE TELEMETRY

1. Configuration

The planned Telemetry configuration for the 1977 era is shown in Figure 6-1. This indicates the principal equipments and shows the prime string which would be used for the OPP imaging data. A second string for backup is indicated. This is the 64-m DSS configuration; the 26-m configuration is identical except that there is no X-Band, nor wideband GCF capability. Not shown is a second channel on each Telemetry Processor which can accommodate a low rate (< 2000 bits/sec), uncoded or sequentially decoded, engineering stream. This channel is provided for MJS project requirements and is not critical to the present analysis. The configuration shown is considered a baseline in that major elements are already installed; the following are budgeted and planned for installation before MJS77:

1) X-Band Microwave and Receiver
2) Maximum-Likelihood Convolutional Decoder (Viterbi Algorithm)
3) Telemetry Processor Assembly (replaces present equipment)
4) Communications Monitor and Formatter

2. Key Characteristics

The key functions and capabilities of each element of the system are defined below.

a. Antenna Microwave

Provides illumination of the dish, polarization control, low-noise amplification. Operates both S- and X-Band simultaneously, with backup masers at each frequency. New equipments are maser upgrades and X-Band backup.

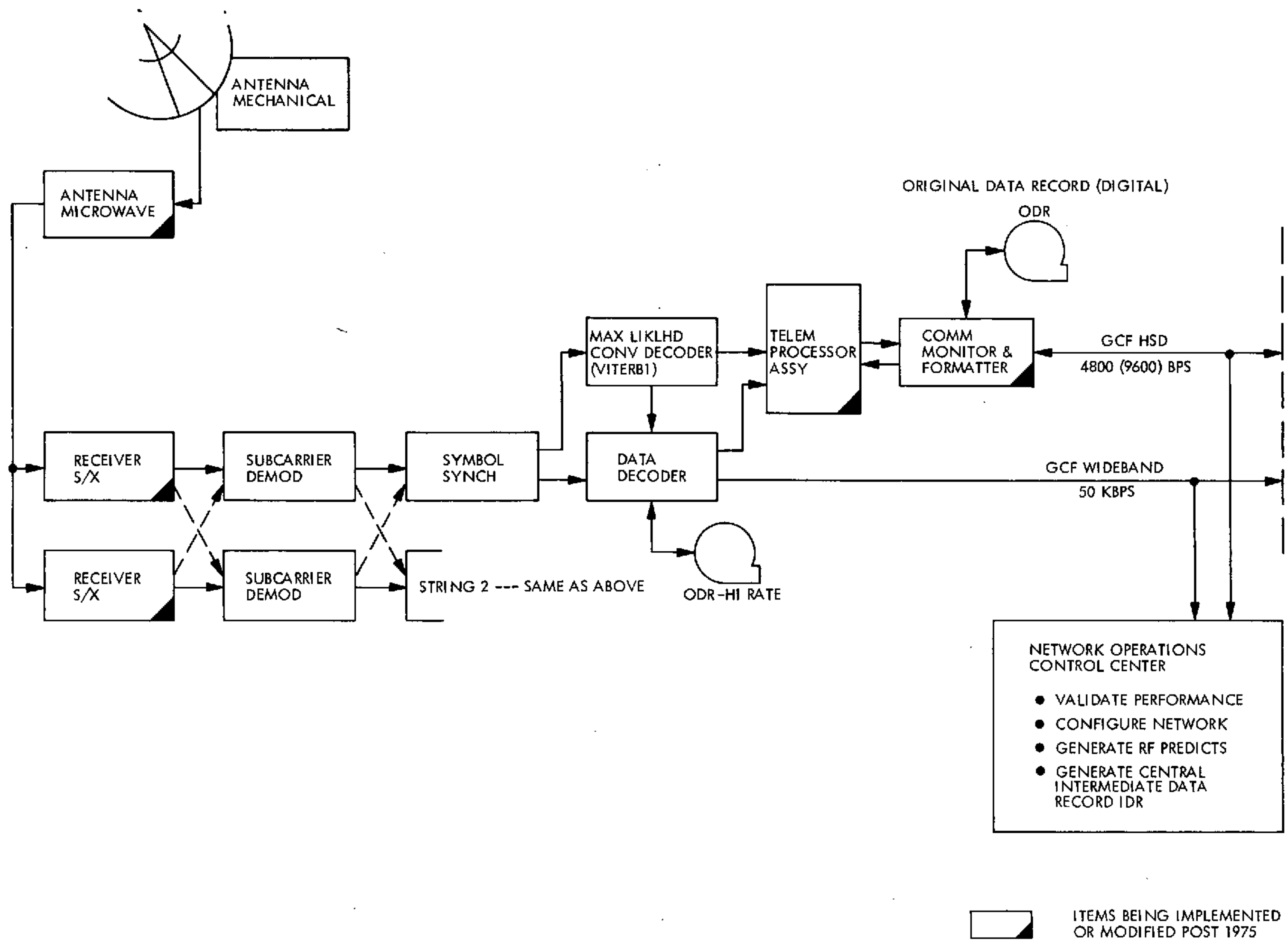


Figure 6-1. Deep Space Network Telemetry Configuration 64-Meter Station 1977

b. Receiver

Provides both S- and X-Band RF carrier reception. Multiple receivers are provided for backup, and for dual frequency operation.

c. Subcarrier Demodulator

Existing equipment accommodates subcarrier frequencies for 500 Hz to 1 MHz, and symbol rates from 5 sps to 500, 000 sps.

d. Symbol Synchronizer

Existing equipment detects symbols for sps to 250, 000 sps.

e. Maximum Likelihood Convolutional Decoder

New equipment is being installed to provide decoding of short constraint length (k = 7) convolutionally encoded data, utilizing the Viterbi algorithm. The decoder will handle rate 1/2 and 1/3 codes and accept input symbols at rates from 20 sps to 500 Ksps for rate 1/2, and from 30 sps to 750 Ksps for rate 1/3. It will provide decoded output data at rates from 10 b/s to 250 kb/s for either code.

f. Data Decoder

Existing equipment provides the following functions:

1) Sequential Decoding (Fano algorithm), 8 to 2048 b/s output data rate
2) Formatting of high rate data (2 kb/s — 50 kb/s) for wideband data lines
3) Control of high rate Digital Original Data Records from 2 kb/s to 130 kb/s, and control of playback at GCF rate up to 50 kb/s.

g. Telemetry Processor Assembly

New equipment is being installed to replace existing computers. This assembly provides control and configuration data for all the symbol synchronizing, decoding and processing equipments. It also formats the data for the GCF HSD lines.

h. Communication Monitor and Formatter Assembly

This new equipment will provide interface and control to the GCF communications circuits and allow for continuous central monitoring of line status. It will provide the ODR record and replay functions for all data transmitted via HSD lines. In combination with similar equipment at the Central Communications Terminal, it will provide automatic error detection and retransmission. This is planned to virtually eliminate all HSD errors, except for bursts exceeding about 8 seconds. Note this error control is planned only for HSD use. The wideband circuits will continue with error detection, but no automatic real time retransmission. Wideband errors can be filled by replay of the ODR after a pass. Provision is included for both high rate and low rate ODR replay automatically in response to request messages from the Network Operations Control Center.

HSD current (1974) rate is 4800 b/s. This is expected to be increased to 9600 b/s by 1976 or 1977. At that rate, the Telemetry data transmission rate will be only about 6-7 kb/s, because of circuit overhead, and other data (e.g., command and radio metric) requirements on the same line.

3. Outer Planet Pioneer Impact

The DSN Telemetry System described above can accommodate the assumed Outer Planet Pioneer Telemetry stream with uncompressed imaging data with no difficulty. This assumes that the X-Band data is convolutionally encoded with a short constraint code, compatible with the standard Maximum Likelihood Decoder. Higher rate data at Saturn encounter would be returned in real time via wideband circuits. At Uranus encounter, the data can probably be accommodated completely on HSD lines.

Because of the limited number of 64-m stations in the Network (3 total, one at each of 3 longitudes) it is recommended that only the encounter period require 64-m support. All cruise periods should be designed to be supported by 26-m Deep Space Stations. This implies S-band only, and relatively low rate during cruise. Of course, the 64-m antennas may be available for special purposes, but should not be depended on during cruise because of limited DSN resources and competition from other flight projects.

C. MODERATE DATA COMPRESSION ANALYSIS

The use of moderate data compression, which for this study is defined as bit and pixel editing on the spacecraft, has no first order impact on the DSN Telemetry System described in Paragraph B. Second order effects (i.e., very small, possibly trivial) are a slight increase in the number of Telemetry modes and more reference to Telemetry records. These items may have some operational effect, but nothing significant for this study is identified. The incorporation of a Reed-Solomon outer code is considered in detail in Paragraph D. It has minimal impact here assuming decoding is implemented outside the DSN. As identified below, there is some slight additional communications overhead.

D. ADVANCED IMAGING SYSTEM ANALYSIS

1. Introduction

For the purposes of this study, advanced imaging means sophisticated data compression, which is analyzed elsewhere in this report. The implication on the DSN is that a high rate, low error (because of sensitivity of compressed data to channel errors) channel is required.

To date (through the Mariner-Jupiter-Saturn 77 and Pioneer Venus missions) mission requirements have indicated a need for two types of spacecraft-to-earth communications channels.

Channel	Rate	Bit Error Rate (BER)	Use	Implementation
1	Medium to High $\leq$250 kb/s	Medium to High 5×10^{-3} to 5×10^{-2}	Imaging and Engineering	Uncoded, Block-Coded Viterbi Decoded
2	Low to Medium 8 to 2048 b/s	Medium to Low $\leq 1 \times 10^{-4}$	General Science	Uncoded, Long Constraint Sequential Decoded, or Golay/Viterbi codes

For compressed imaging, and for high rate General Science or future missions, a third type of channel is now identified:

3	Medium to High	Low	Compressed Imaging	a. Reed-Solomon/ Viterbi
		$\leq 1 \times 10^{-5}$		b. Long Constraint Length Sequential
	2048 b/s to 100 kb/s		General Science	c. Viterbi
				d. Other

Use of a straight Viterbi channel (option 3C) as an implementation for a low-BER channel appears to require an additional 3 dB relative to theoretical performance for either Reed-Solomon/Viterbi or Long Constraint Length Sequential Decoding. But this is an option requiring no additional channel design or implementation above what is being accomplished for MJS. If an effective imaging gain, of say, 10 dB due to data compression was expected for a mission under study, then use of a straight Viterbi channel would yield a net gain of (10-3) = 7 dB which may be attractive because of the lesser channel complexity and cost.

In regard to option 3d., (other codes), at the present time there appears to be no other code on the horizon yielding major performance breakthroughs.

2. Alternative Options and Their Implication

An implementation cost comparison of the principal remaining options is shown in Table 6-1.

It was assumed that both R.S/Viterbi and long constraint sequential have nearly the same performance. This may be a good baseband, theoretical assumption. However, noisy reference loss and/or practical implementations designs may further separate performance for medium to low data rates. Performance with data interleaving needs to be compared for both codes.

No theoretical analytical model exists for either the R.S/Viterbi or long constraint sequential process. R.S/Viterbi simulations are underway and in the process of validation. In terms of lending itself to complete analysis, it appears that the block coded case has had the most complete analysis. Viterbi decoding is less well analyzed, followed in order by Long-Constraint and Reed-Solomon/Viterbi.

A better understanding is needed of the impact of GCF wideband errors on the Low BER/High Rate data transmitted from the tracking stations. Low BER requirements (Command and General Science) for the HSDL have resulted in plans for HSDL error detection and retransmission as described in Paragraph B., above. Wideband lines in the past communicated primarily uncompressed imaging with medium BER requirements. Errors and outages are corrected in non-real time by playing back station records. Present implementation plans, described in Paragraph B. are for increased HSDL transmission rates, and error detection and transmission. For the Pioneer Outer Planet Spacecraft and mission under study, this might accommodate the data without severely constraining the data return. However, imaging data, even compressed imaging data, might be expected for many other missions to exceed the HSDL rate. A real time requirement for such data would most likely force wideband line error detection and retransmission. For current wideband channels, this is estimated to involve about $750,000 in implementation, not currently budgeted.

Table 6-1. First Cut at a Cost Comparison of R.S./Viterbi vs Long Constraint Length Sequential

Number	Channel Implementation	Pioneer S/C Costs	Ground Costs K$				
			Dev	Unit	Added GCF Costs	Other	Total[6]
1	Long Constraint Length Sequential	0	210	320 (8 units)[3]	0	Additional Maintenance Costs	530 + Maint
2	R.S./Viterbi[1] Central Processing	?	200	100 (4 units)[4]	Note[5]	Additional Maintenance Costs (Lower than 1 and 3)	300 + GCF Costs + Maint
3	R.S./Viterbi[2] Local Station Processing	?	200	200 (8 units)[3]	0	Additional Maintenance Costs	400 + Maint
4	Viterbi	0	0	0	0	0	0

1. R.S. decoding done at a central site, say in MCCC at JPL. R.S. places an approximate 12% overhead on the total data stream. This option requires an additional 12% GCF data rate.
2. R.S. decoding done at each Deep Space Tracking station. Reduces GCF data rate requirement by 12% relative to option 2.
3. Two decoder units for each of three stations, plus two for Compatibility Test Areas.
4. Viterbi decoder (implemented for MJS) costs are not included. Assumes that DSN NOCC R.S. decoding is necessary for data validation in addition to project/R.S. decoding in MCCC. 4 units = 2 in NOCC + 2 in MCCC.
5. Could cost upwards to 60K/MOS for an additional GCF wideband line. The probability of incurring this high an additional cost is low. Depends on data rate.
6. Maintenance and operations costs of long constraint length Sequential and R.S./Viterbi equipments are assumed about equal. Option 2. is lower solely because of fewer equipments required.

A better understanding of GCF cost due to R.S. overhead is needed. Assuming a 12% overhead and the GCF wideband cost data given in Table 6-1, then for mission data rates up to 44 kb/s, no additional GCF costs are incurred with the overhead. If the mission data rate requirement happened to exist between 44 and 50 kb/s, then the R.S. overhead would require a fraction of, or an additional wideband line – costing up to $60K/MOS. For the Pioneer Outer Planet spacecraft under study, the data rates are ≤44 kb/s and one wideband line is sufficient. However, GCF costs due to R.S. overhead may be a factor considering the rate requirements of other missions.

3. Conclusions

The implementation of R.S/Viterbi channel with centralized processing appears cheaper overall, unless implementation of R.S. encoding on the spacecraft costs as much as $130 to 230K. This channel has least impact to the DSN, assuming the predicted performance is achieved. It has maximum impact on the spacecraft (implementation of R.S. encoding) and on the MCCC (assuming they implement the R.S. decoding).

Additional work is required in the following areas.

1) Additional code comparison analysis as mentioned in Paragraph D.2., above.
2) Validation of R.S./Viterbi hardware performance.
3) Validation of long constraint decoding hardware performance.
4) Assessment of multi-mission needs of a Low BER/High Data Rate channel.
5) Detailed cost and performance trades factoring in performance validations and better understanding of GCF performance requirements and cost.

E. COMMAND SYSTEM ANALYSIS

1. Baseline Configuration

The DSN Command System configuration for the baseline 1977 period is shown in Figure 6-2. The System provides for the modulation and transmission, at S-Band, of commands received from the flight project (at MCCC or at some other remote location) via GCF HSD lines. The System provides for both: 1) Verification messages back to the project, acknowledging receipt of commands to be transmitted; and 2) Confirmation messages indicating that a specific command has been sent (or aborted, if that unlikely event occurs).

The configuration is identical for both 64-m and 26-m stations except for the second Exciter and High Power Transmitter at 64-m stations. All equipment is backed up, with the exception of transmitters at 26-m stations, and the antenna structures and pointing equipment at all stations.

The new Command Processor, being implemented in 1976 and 1977, replaces the current processor, which is shared with Telemetry processing functions. This new processor, dedicated to Command functions, is intended to increase the utility and reliability of the DSN Command System.

The DSN Command System is designed for multiple-mission and multiple-rate operations. The system is transparent to Command message format, being capable of handling any sequence of bits desired. The Transmitter, Exciter, Command Modulator, and the interface to the Command Processor can handle any bit rate from 1 b/s up to 1 kb/s. The design of the Verification, Confirmation, and Command messages handled by the Command Processor and the MCCC limit that part of the system to about 30 b/s. This is adequate for all projects through MJS 77 and can be redesigned if higher rates are required.

2. Outer Planet Pioneer Impact

As described above, the DSN Command System can handle Outer Planet Pioneer Command rates and formats with no impact. However, the total

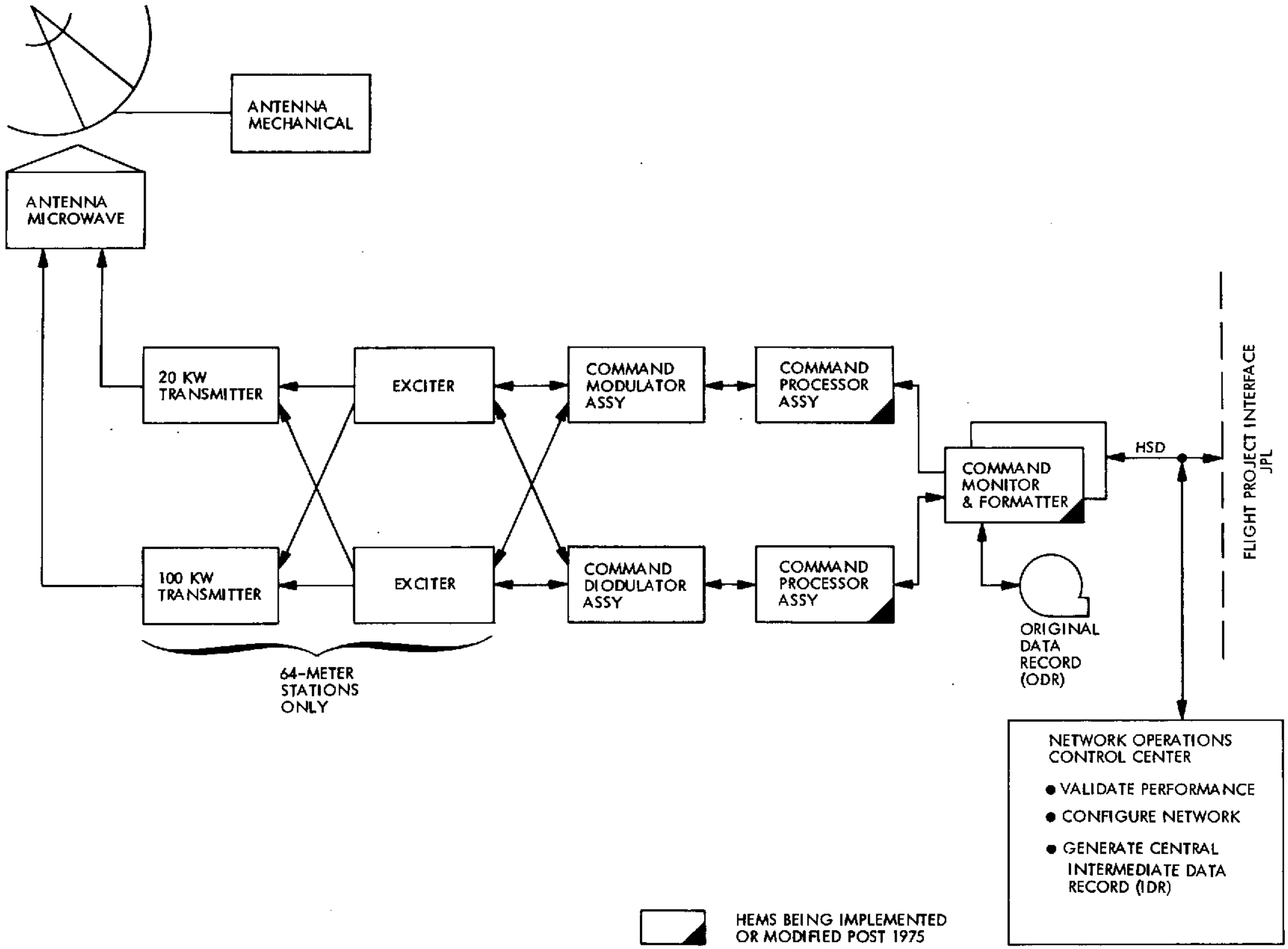


Figure 6-2. Deep Space Network Command Configuration 1977

Command traffic impact is severe. Current estimates are for nearly continuous commanding at 1-2 b/s during the entire encounter operations (E-30 to E+5 days). Increasing the bit rate to 4-8 b/s would reduce the total command time and duty cycle, but would not alleviate the requirement for many time-critical commands.

The significance of this impact is discerned by reference to the configuration diagram (Figure 6-2). The failure of any element (except the antenna) can be covered by replacement with backup equipment, but such replacement requires about 15 minutes, and unavoidably results in interruption of commanding and delay of time-critical commands. Note that there is no known practical method of replacing this type of equipment on a bit-coherent basis. Note further the contrast to telemetry, for example, where it is feasible to operate two strings in parallel; when one fails, all data may still be recovered from the other with no loss.

Therefore, it must be pointed out that requirements for continuous or time-critical commanding must be tempered by expectations of failure and interruption. Current, typical reliability experience is listed in Table 6-2. It can be expected that the Command Processor MTBF will be improved with the new, dedicated equipment, but the message is still clear, that some Command interruptions are inevitable. This impact is not sensitive to the degree of data compression used. More pictures implies more Commands, but the problem exists in all options.

F. CONCLUSIONS AND RECOMMENDATIONS

Conclusions for DSN Analysis are as follows:

1. Recommended Methods to Accommodate Data Compression

The recommended method to accommodate data compression is the Reed-Solomon/Viterbi channel, with the Reed-Solomon decoding done in the MCCC (or Pioneer Control Center). This option has little impact on the Network for the following reasons.

Table 6-2. DSN Command System
Mean Time Between Failures[1]

Transmitter/Exciter	254 ± 7 hours
Antenna[2]	242 ± 6 hours
Command Processor/Command Modulator	142 ± 2 hours
Communications Equipment	72 ± 0.5 hours
Deep Space Station Total (excluding GCF)	66 ± 0.5 hours

Notes:

1. Data are based on Pioneer 10/11, January to July 1974. Data accumulated over more than - 9000 total tracking hours.
2. Antenna failures include operational failures in tuning, leading to loss of communication, as well as failures causing antennas to go off point.

1) Viterbi decoding is already being implemented.

2) The Reed-Solomon decoding is implemented outside the Network. (It could be done in the Network, but at somewhat higher cost to the Project.)

3) Communications overhead would be small.

2. Compressed Imaging Data

Compressed imaging data which exceeds the Network high-speed rate must be transported via wideband data circuits. It is currently planned to incorporate error correction (by real-time automatic re-transmission) on the high-speed circuits, but not on the wideband. If real-time wideband error correction is required (this is not clear) the impact is significant; about 750K$ for 3 64-m Deep Space Stations.

3. Uncompressed and Moderately Compressed Imaging Data Options

Uncompressed and Moderately compressed imaging data options do not impact the Network, assuming the planned Viterbi decoding capability is adequate.

4. Network Command Function Impact

The impact on the Network Command function is important. All imaging options imply a requirement for near-continuous commanding throughout the encounter period of several days. Further, it is implied that many time-critical commands be sent. The very nature of the Network Command System (and the Mission Control and Computing Center Command System, too) is such that failures cause interruption of Command traffic. Backup and redundant equipment are provided to minimize outage time, but there is no way to prevent a failure from interrupting the Command stream. The Mission Sequence and Operations Plan must be designed to consider such interruptions.

5. Future Study

The following items are not fully understood and should be the subject of future study:

1) Validation of Reed-Solomon/Viterbi hardware performance. This should be compared with validation of long-constraint sequential decoding hardware. Both should consider the effects of imperfect channels, carrier reference errors, and acquisition and sync problems (if any).
2) Assessment of impact of GCF wideband errors, and requirements for real-time error correction.

SECTION VII

MISSION CONTROL AND COMPUTING CENTER SYSTEM ANALYSIS

A. INTRODUCTION

The JPL Mission Control and Computing Center (MCCC) is prepared to support an Outer Planet Pioneer Mission for imaging through the use of the MCCC Image Processing System. This system includes the processing hardware and software, volatile and hardcopy display equipment, image storage and limited user interaction with image data as well as the required operations staff (see Figure 7-1). Imaging data record production (imaging MDR/EDR's) and associated bookkeeping normally included within the scope of the Image Processing System are not included in the analysis and costing below due to unknowns in the OPP Mission Operations and Plans.

The analysis below covers uncompressed data analysis, (see Figure 7-2), and AICS analysis. The baseline design assumptions, provided in Section B, apply equally to the uncompressed, moderately compressed, and AICS analysis. The moderately compressed analysis is not covered below as a separate topic. The only modifications required for moderate data compression over AICS are the elimination of the RM2 decoder (see Figure 7-3) and the addition of a small routine (of insignificant cost) needed to replace the edited pixels. The design for AICS is somewhat more complex and is described in Section C.

Costs are provided, where appropriate. They are predicated on receiving approximately 6000 images from Saturn and Uranus (baseline), 160 × 640, 8 bit pixels per image.

It has been noted in Reference 9 that the proposed OPP telemetry data words and formats violate certain Telemetry Standard. Only one of these violations appears to adversely affect the MCCC in its ability to process the data, namely a 10 bit pixel instead of an 8 bit pixel (i. e. a 10 bit word is a

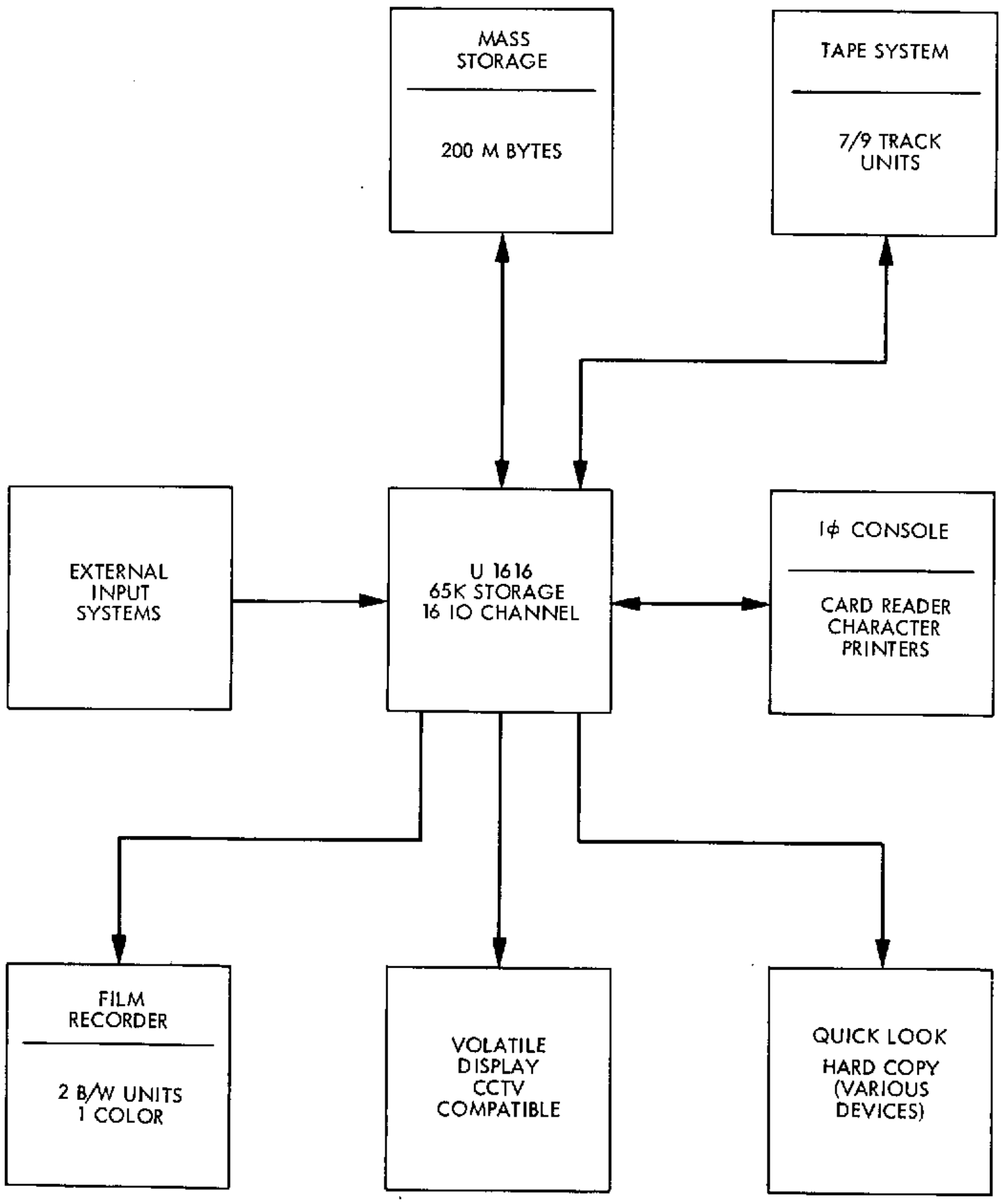


Figure 7-1. MCCC Imaging System Hardware

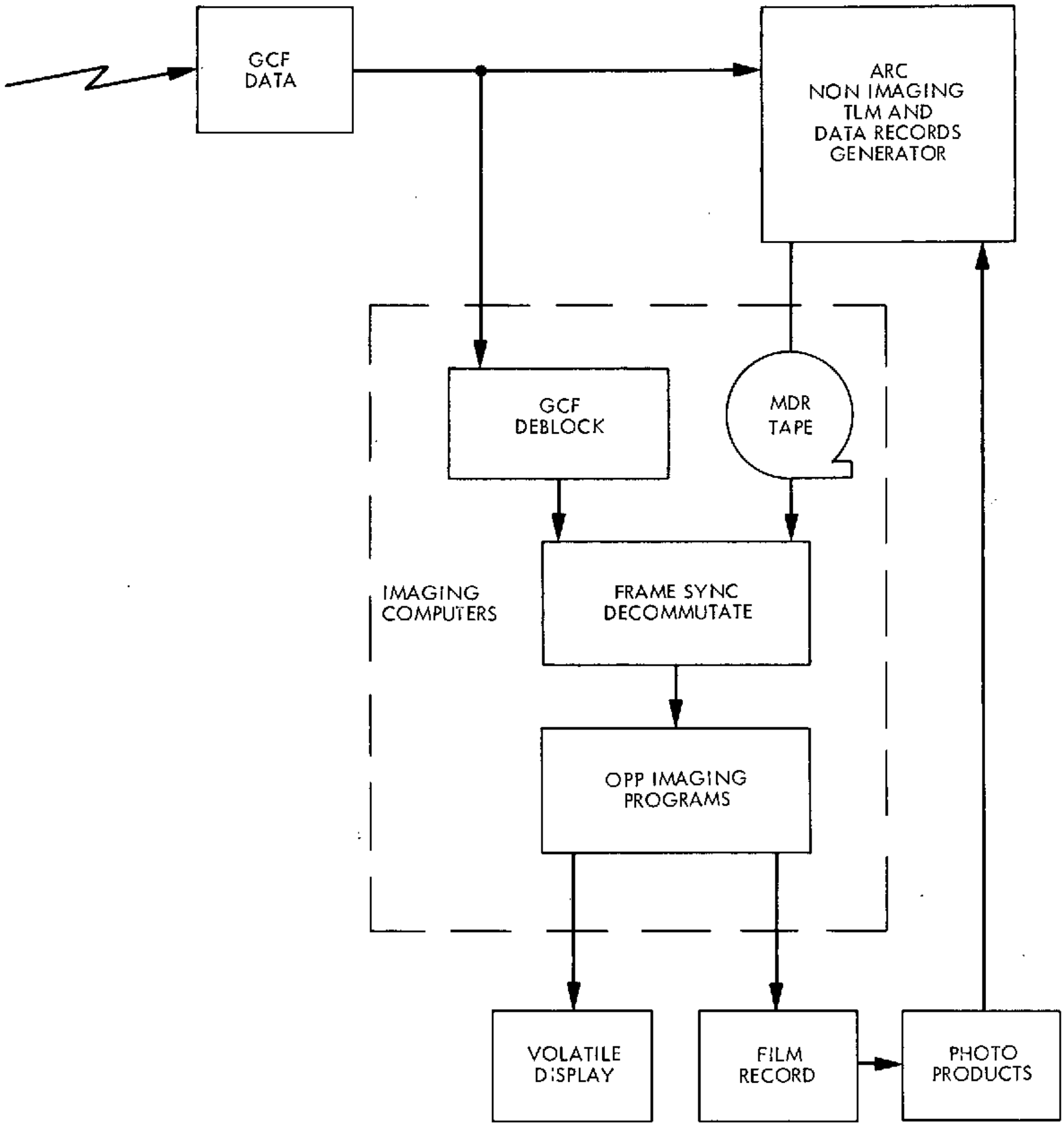


Figure 7-2. MCCC Uncompressed Imaging System — Data Flow

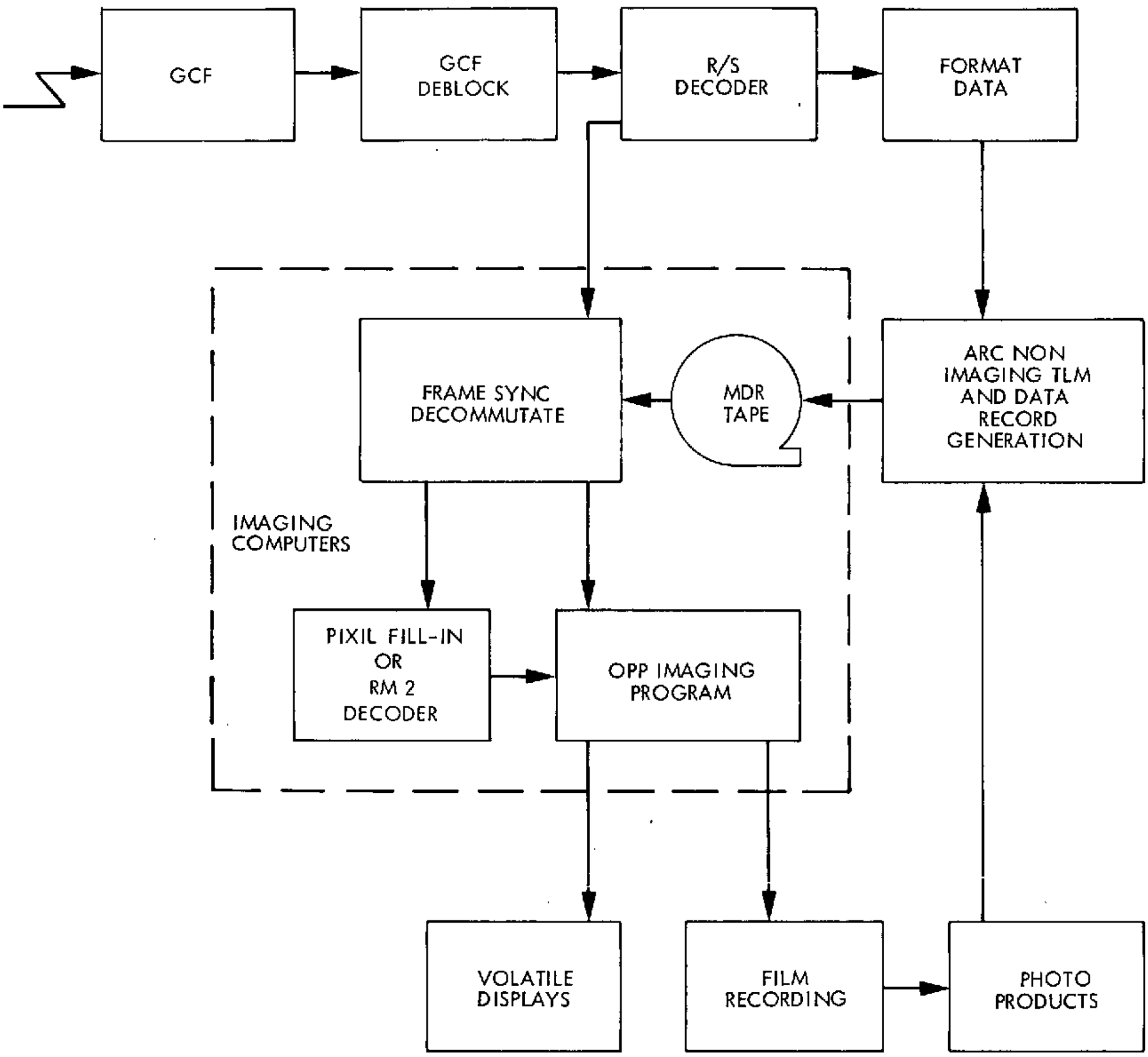


Figure 7-3. MCCC Compressed Imaging – Data Flow

Telemetry standard violation). This topic is discussed in greater detail in Section B2.

B. UNCOMPRESSED DATA ANALYSIS

1. Introduction

The MCCC baseline image design includes the following assumptions. All non-IPL image processing is to be performed in the MCCC. Imaging MDR/EDR's will not be part of the imaging system. The basic hardware and software will be similar to the MJS system and the basic costs will be institutional. Real time support will be available during encounter periods with selected volatile and hardcopy displays. Two hardcopy versions of each received image will be produced in non-real time. A reasonable number of photo products will be made of each image frame (approximately 10). This system will not be used during system test nor will it be available for test until encounter minus six months. All the GCF data will be shipped to Ames Research Center (ARC), so that they can perform the non-imaging data processing and MDR/EDR generation. During imaging sequences, the imaging data will be routed in parallel to Ames and the MCCC Imaging System. See References 1) through 4) used in support of this section.

2. Discussion

The MCCC MJS imaging capability was chosen for this study as it appeared to have all the required elements for Outer Planets Pioneer Image Processing. The MCCC imaging system was sized to perform the OPP image data processing on one shift, 5 days a week operation. Other modes of operation i. e., (all data processed in real-time) were acknowledged but not considered in this study, due to the uncertainty of the requirements and the high cost associated with a 24 hour, 7 day real-time operation. These high costs are due primarily to the need for backup hardware and the 4 to 5 people required for each operational position to fully staff that position.

One spacecraft option that affected the MCCC was the question of 10-bit versus 8-bit image data. Since the Mariner Jupiter Saturn (MJS) system that is being used as a base is 8 bit, it appears that 10-bit data would have a major cost impact and should not be used. A first order assessment of this impact places the hardware and software cost for processing 10-bit pixels beyond the funds currently allocated for the forthcoming design of the MCCC.

The processing of uncompressed data by the MCCC will be performed using current hardware types (Univac 1616 computers, 200 million bytes of on-line storage, volative and permanent hardcopy display devices). The cost to the Project for this equipment is basically the cost of operation and maintenance during the period of commitment to the OPP Project. This system should be available for use by the OPP Project approximately 6 months before Saturn encounter for testing and training purposes. It will take approximately 5 months following Saturn encounter to complete the processing of all the images. This procedure is expected to cost approximately $500K based on FY'75 figures.

This MCCC data processing design calls for all data to be sent to ARC for telemetry processing and data records generation. Only during imaging sequences will data also be sent directly to the MCCC in real-time. The MCCC will develop the capability to process ARC MDR data files so that the imaging data can be processed. All the data storage internal to the MCCC imaging system will be on a large disk system. This system will hold approximately 1000 OPP images on line for processing and display. All images will be stored on the disk as they are received in real-time from the GCF, and MDR tapes will be used to update and correct the data on the disks. The image data will be available to the investigators for display and processing during prime shift activity. Using the current mission sequence, it is anticipated that until encounter minus one week all processing can be performed on a daily basis.

3. Summary and Conclusion

In summary, the basic MCCC imaging system design can process all the OPP images during a 12-month period centered about the Saturn encounter.

C-3

The Uranus encounter is so far in the future that it is hard to predict what the processing capabilities may be. But if the Saturn system is still available, it would take only about three months of one shift, 5 days a week operation to complete the processing of Uranus data. The conclusion of the MCCC is that this imaging task could be performed with only minor changes to the planned MCCC Imaging System. It is not reasonable at this time to try to attach dollar figures to operations costs for a three month operational period which will not occur until 1987.

C. AICS ANALYSIS

1. Introduction

The following additional assumptions were made with regard to the AICS system. The Reed-Solomon decoder will reside in the MCCC. At least three such units will be required to support dual station telemetry and provide back up capability. The RM2 decompression will be performed by software using an MCCC image computer. Due to the increased complexity of this system, additional time will be required for integration and testing over the baseline requirements. See References 5) through 13) used in support of this Section.

2. Discussion

The AICS adds three features to the ground data processing system, namely; a channel decoder, an RM2 decompressor, and the generation of a greater number of images from the spacecraft. The basic image processing system will remain the same and only these additions will be discussed. The fact that the data stream is coded, and Reed-Solomon coding is assumed, changes the method by which the data is handled on the ground. A central R-S decoder should be developed by and located at the MCCC. Only decoded data will be sent to ARC and to the MCCC imaging system. A subsystem to decode the R-S coded data can be developed in either new software or new hardware.

After a study of the R-S algorithms a software/hardware combination appears preferable for early processing. This part of the system will use standard general purpose computers to perform the GCF deblocking required prior to decoding, and for the reformatting of the decoder output, which is to be forwarded both to the ARC and to the imaging system. Special purpose hardware will be used to perform the actual R-S decoding algorithm. (See Figure 7-3). This approach appears cost effective as the special purpose hardware is less expensive than a large general purpose computer which would be required for R-S decoding by software methods.

The next item added to the system is the RM2 decompressor. After some study it was concluded that this can be best accomplished through software residing in one of the image processor computers. This creates a potential problem insofar as the data to be routed to ARC for data records generation is compressed data. Therefore, the MDR will be generated using compressed data, making future processing somewhat more difficult.

The costs of adding the R-S decoders and the RM2 decompressor to the basic OPP imaging system should be approximately $275K ($200K & $75K respectively). This figure includes the hardware, software, and additional operations and maintenance required for these additions. The cost of additional images, that are generated by virtue of the compressor, is about one month of additional operations (approximately $28K) for each 1000 additional images.

3. Summary and Conclusions

There are two areas of concern with regard to the planned method of implementing the R-S decoder. They are the lack of knowledge as to the actual performance of the R-S decoder, as regards its operation and reliability and what appears to be a current requirement to operate the MCCC (at least for decoding) during the entire mission.

It should be noted that based on our current knowledge of the RM2 decompressor, neither its implementation nor its execution time appear to be of any particular concern to the MCCC. Based on our current knowledge of the RM2 compressor algorithm (which is not yet firm), software decompression should take approximately 6 seconds (with the degree of compression causing only a small variation) utilizing a digital computer with a 1 microsecond average instruction time. No additional storage requirement is anticipated for decompression beyond that already available for standard processing functions.

In conclusion the AICS will necessitate some additions to the MCCC. These should be straightforward and present no problems. The addition of the AICS to the OPP mission should not be constrained by any MCCC changes or additions.

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2) MCCC Baseline Support for OPPI

    a) Data Systems Functional Requirements Book — Video Processing 22 July 1974.

    b) Tracking Functional Requirements M76-4-300 July 1974.

3) MCCC Imaging — MCCC'76 Vu Graphs for Presentation July 1974.

4) IOM 916.25/34, re Effects of new imaging format structure, 14 August 1974.

5) IOM 916.25/34, Response to Action Item 33 and attached IOM's 916.25/7, 916.25/6, 917.31/021 re 1 and 2 channel telemetry, 1 channel with Golay or Reed-Solomon Outer code, multiple bit rates and bit rate steps, 14 August 1974.

6) IOM 916.25/36, Reed-Solomon Decoder IOM 916.22/81 attached, 24 September 1974.

7) Presentation Data on the updated Pioneer Ground Command System R. Malm, Minutes of the 16th Meeting OPPICSS, 3 October 1974.

8) Presentation Data on the Affects of AICS on the MCCC — J. Schoeni, Minutes of the 16th Meeting OPPICSS, 3 October 1974.

9) IOM 916.25/38, "OPP Violations of Telemetry Format Standards", 2 October 1974.

10) IOM 916.25/40 — Action Item 63 — No impact re T.R. Command modifications.

11) IOM 916.25/41, "Viewgraphs for RM1/RM2," 16 October 1974.

12) IOM 916.22/84 "Computation Time Requirements for Reed-Solomon Decoder Part II, 14 October 1974.

13) IOM 916.31/087 reissue, addition to action item 18 and replies to OPPICSS Action Items 50, 59, 69, 70, 71, 73 and 75, October 29, 1974.

SECTION VIII

IMAGE PROCESSING SYSTEM ANALYSIS

A. INTRODUCTION

Defined below are the probable image processing requirements for an Outer Planets Pioneer mission with a Pioneer line scan imager and the effects of the proposed data compression alternatives on the Image Processing System (IPS) are discussed. For the purpose of this study, the Image Processing Laboratory (IPL) of the Jet Propulsion Laboratory is the model for the IPS installation (see Figure 8-1). This defines an existing level of capability to which the particular requirements of an Outer Planets Pioneer mission can be added. Many of the assumptions regarding science objectives, processing requirements and computer time are based on previous Mariner experience.

The Image Processing Laboratory consists of a nucleus of hardware and software developed over more than a decade of image processing activity, from Ranger and Mariner 4 to the Mariner 10, Viking and Earth Resources work going on today. Computer processing is performed on an IBM 360/44 computer, with disk and tape I/O and a quarter million bytes of core storage. An interactive console, with keyboard and displays, facilitates "on-line" image processing. This capability is particularly useful for activities requiring frequent "turn-arounds", such as registration and comparative processing of a pair of images, and for the optimization of processing parameters in the early phases of post-encounter data analysis. Conversion of processed images from magnetic tape to film can be accomplished on any of several digital to film conversion devices: a Video Film Converter, a Dicomed D-47, and Optronics International P-1500 or a Perkin-Elmer PDS Scanner. Images having up to 8000 picture elements per line can be played back on these devices, exposing film of up to 8 x 10 inches in size. The IPL photolab develops exposed film and produces high quality prints as required.

More significant than the hardware is the image processing software which has been developed and refined through the past several years. The

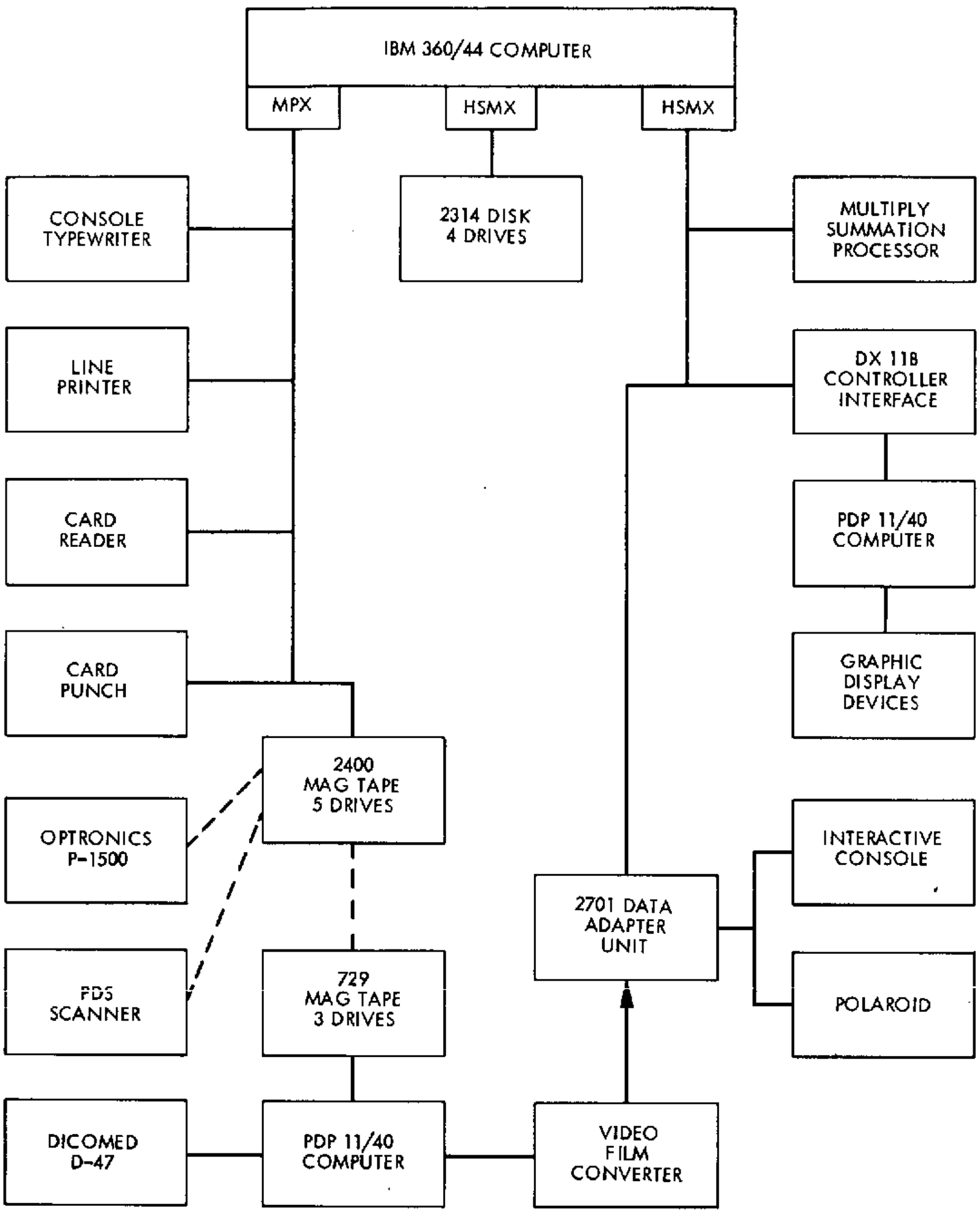


Figure 8-1. IPL Facility Functional Block Diagram

system consists of a monitor program, VICAR, and a package of image processing application programs, currently numbering over 200, each of which performs, under parameter control, a specific set of picture processing tasks. The VICAR monitor is in effect a high level user-oriented language, specifically designed for image processing, which permits an analyst to easily allocate system resources and specify a sequence of application programs to be executed. VICAR also provides a framework which simplifies the coding of new application programs.

Of equal importance are experienced image processing analysts. It is essential that these analysts have a familiarity with the capabilities of the installation and of the software, permitting them to utilize these resources effectively in the accomplishment of practical image processing tasks. They must have an understanding of the objectives of the experimenters, and the ability to find image processing solutions to their problems, either through the use of existing capabilities, or, when necessary, through the design and implementation of new software.

An environment such as that described above, with experienced analysts utilizing an established set of basic image processing software in an installation providing the necessary hardware facilities, is the most cost effective means of providing the required IPS. Such a system was assumed as the basis for the cost estimates which follow.

B. BASELINE IMAGE PROCESSING SUPPORT REQUIREMENTS (NO DATA COMPRESSION)

Before assessing the nature and costs of image processing for a Pioneer Outer Planets mission, one important qualifying statement must be made. The cost of image processing support depends largely on the scientific objectives of the imaging experiment, and the nature of the processing required to support those objectives. At this point, these scientific objectives are undefined, and are likely to remain so until an imaging team is assembled. In the absence of well defined requirements, estimates will be based on previous Mariner experience, together with the predicted characteristics of the Pioneer imaging system.

The participation of the IPS in an imaging experiment should begin long before launch. The IPS should certainly be involved in the experiment definition phase of the mission, that is in the discussion and design of the particular investigations to be undertaken as a part of the imaging experiment. The role of the IPS in this effort should consist of providing an understanding of image processing capabilities and techniques, and helping to determine the additional processing capability that will be required to support the particular objectives of the Pioneer imaging experiment. During this period, image processing support for camera development and calibration is required, both to monitor and analyze camera performance as calibration data is taken, and, where necessary, to construct data files for use in the later decalibration of flight pictures. Another aspect of image processing responsibility during the pre-flight and pre-encounter period is the development and testing of new computer software required to support post-encounter data analysis, including both decalibration of images and processing support for particular imaging investigations.

IPS participation with the imaging team in experiment definition activity is very important to ensure productive image processing support later in the mission. Interaction with the experimenters is clearly necessary to provide an IPS which is responsive to their needs. Planning to ensure best use of available resources, plus the design of any additional processing capability which may be needed, must begin during this period. Decisions may also be made at this time which will affect the level of image processing calibration support which is required.

Several areas in which calibration support activity will probably be required can be identified now. Light transfer sequences of flat field targets will be required to define the radiometric characteristics of the camera. Temperature of the sensor may be included as a variable in this analysis. If a calibration lamp is built into the camera, the response of the camera to this lamp must be characterized. Dark current non-uniformity (or pattern noise) will be a function of sample position on the sensor, and must be determined. Blemishes may exist on the sensors which will affect their response. Monitoring of random and any spacecraft induced noise levels may also be desirable. Another area of possible calibration activity is the analysis of the Modulation Transfer Function (MTF) characteristics of the overall camera system. Of particular interest would be the effect of the variable vertical sampling rate due to spacecraft rotation, and the degree of aliasing present. There should be no geometric distortion in the arrays themselves, but image processing support may be useful for checking the relative positioning of the three sensors.

Computer programming to remove geometric distortion in images caused by spacecraft spin will certainly be required during the pre-launch (or at least pre-encounter) phase of the mission. A reformatting program will be required to convert the picture data from the format received from IPS's data source (presumably MCCC) to the format required by the image processing applications programs. A modification to an existing program might be necessary to correct for dark current non-uniformity and non-linearity in the camera system response. Other additional software development work might be necessary to support particular imaging investigations.

As stated previously, the nature of the image processing performed during the post-encounter image analysis phase of the mission depends to a great extent on the specific objectives of the imaging experiment and the interests and preferences of members of the imaging team. In spite of the current uncertainty regarding ultimate team preferences, however, several areas of probable image processing activity can be anticipated. Reformatting (or "logging") of data received from MCCC will certainly be required. Random noise introduced by the data link should be "removed" and radiometric decalibration should be performed on most frames processed, to assure removal of pattern noise and to facilitate picture to picture comparison and mosaicking. Geometric restoration will probably be required for most, but not necessarily all, frames processed. Mosaicking of the relatively small Pioneer images will probably be a common procedure. Standard image enhancement procedures, such as high pass filtering and contrast stretching, will inevitably be frequently used. Registration of images, both for study of variable features and for color reconstruction and analysis, are likely activities.

Not knowing what mix of these image processing activities will ultimately develop, or what additional types of processing may prove to be needed, estimates of cost must be based on the experience of recent Mariner missions. The present cost of using the IPL facility is $100 per hour of computer time. Approximately eight hours of analyst time are required to support one hour of 360/44 computer processing. Combining these factors yields an overall total cost of $250 per computer processing hour (based on FY75 rates). This price includes all supplementary activities such as digital tape to film conversion and photolab processing. Estimating about 8 minutes of computer time, on the average, for each sequence of image processing operations on a Pioneer image results in an average estimated cost of $30 to $35 per picture processing sequence. A "picture processing sequence" means a set of image processing tasks performed on one picture at one time to satisfy a specific processing objective. If the same picture must be processed again later in pursuit of a different objective, this would constitute a second picture processing sequence. The number of times that a given picture will be processed depends too much on the scientific objectives of the imaging experiment team to be reliably estimated at this time, but the correct figure probably lies somewhere between one and two.

Assuming approximately 6000 picture processing sequences (or the processing of somewhere between 3000 and 6000 different images), a total cost of the order of $400,000 to $450,000 for the Image Processing System is probably reasonable, of which 40% to 50% would support calibration and software development, and 50% to 60% would be used for post encounter image processing. These figures are consistent with the basic goal of keeping the cost of Pioneer missions below those of Mariner missions.

C. EFFECTS OF MODERATE DATA COMPRESSION ON IPS

Moderate data compression consisting of pixel editing would have little effect on the IPS. The reformatting (logging) program would probably need to be somewhat more complex to accommodate several data modes, but this is not a major cost item. Software and computer time would also be required to decompress images, but these are not large factors.

In terms of cost per picture processed, moderate data compression would increase costs slightly, but would only be significant if it produced a requirement to process more images.

D. EFFECTS OF AICS ON THE IPS

Assuming that all decoding is done upstream of the IPS, the effects of AICS would also be relatively minor. The use of AICS would require a change in the logging program, but would probably make it no more complex. Back-up decompression software would be desirable, and might also be useful during calibration. Since the data should be cleaner, random noise processing should not be required, which results in a slight savings. By far the greatest impact is likely to be a greater number of pictures of scientific interest for which image processing is desired. On a per picture basis, however, the impact of AICS on the IPS is minimal.

28 May 1974

APPENDIX A

OUTER PLANET PIONEER IMAGING COMMUNICATIONS SYSTEM STUDY

STATEMENT OF WORK

A. PURPOSE

The purpose of the Outer Planet Pioneer Imaging Communications System Study (OPPICSS) is to perform a parametric end-to-end data system study to assess the overall value, affects and implications of utilizing progressively more sophisticated imaging data transmission techniques for the Outer Planet Pioneer Spacecraft.

The study will consider the affects of imaging data transmission techniques on the Spacecraft System (S/C), Deep Space Network (DSN), Mission Control and Computing Center (MCCC), Mission Operations Systems (MOS)[1], and Image Processing System (IPS).

For each of the above areas a determination will be made regarding any modifications required to support the specified imaging data transmission methods in terms of functional and operational impact, hardware, software, special test or other facilities required, and their related cost and staffing requirements (recurring and non-recurring).

B. SPONSORSHIP AND PARTICIPATION

The study is to be performed for Ames Research Center (ARC) with participation by JPL and TRW.

1. MOS will include Ame's Mission Control Center (MCC) and JPL's Space Flight Operations Facility (SFOF)

4. Determination of the spacecraft data processing and storage requirements.
5. Determination of the changes required to the existing Outer Planet Pioneer Spacecraft design.
6. Determination of the changes required to the planned multimission equipment and software of the Deep Space Net, Mission Control and Computing Center, and Mission Operations System to meet the requirements of the functional designs.
7. Determination of the ground computer processing time and storage capacity required for each system.
8. Determination of the changes required to the JPL image processing system.
9. Determination of the system elements that limit performance of the systems.
10. Identification of attractive alternative mechanizations in any element of the system for further study.
11. Identification of unresolved questions, problems, and characteristics that require further analysis or experimental verification.
12. Identification and performance of tests to determine image quality and science value as a function of data compression and operational flexibility.
13. Determination of the resource requirements for the S/C System, DSN, MCCC, MOS and IPS to support the various imaging communication systems analyzed.

C. GUIDELINES

The following guidelines apply to the conduct of the study.

1. Information regarding the S/C is to be provided by TRW.
2. Information regarding the Imaging System, DSN, MCCC, and IPS is to be provided by JPL.
3. Information regarding the MOS will be supplied jointly as required by Ames and JPL.
4. For the purpose of providing a basis of comparison, three imaging data transmission methods will be considered. They are:
   a. utilizing no data compression (to be used as a baseline).
   b. utilizing moderate data compression (such as pixel editing, bit editing or delta modulation).
   c. utilizing various options of a recently proposed Advanced Communications Imaging System (AICS) technique (this area is to receive particular study emphasis).

D. SPECIFIC TASKS

The study will include, but not be limited to, the following specific tasks:

1. Determination of the operational functions and decisions required to operate each system in a typical planet encounter sequence, and a determination of the relative timing of these functions.
2. Determination of the type, quantity, and quality of telemetry data required to support the operational functions.
3. Determination of the type, quantity, rate, timing, and criticality of commands required to support the operation.

E. REPORTING

The following will constitute the minimal reporting for the study.

1. A final written report (25 copies) on the results of the study.
2. A midterm and a final oral report.

F. SCHEDULE

The study will begin on 10 June 1974 and be completed by 31 October, with the final documentation delivered to ARC no later than 16 December 1974.

A detailed study schedule is shown in Figure A-1.

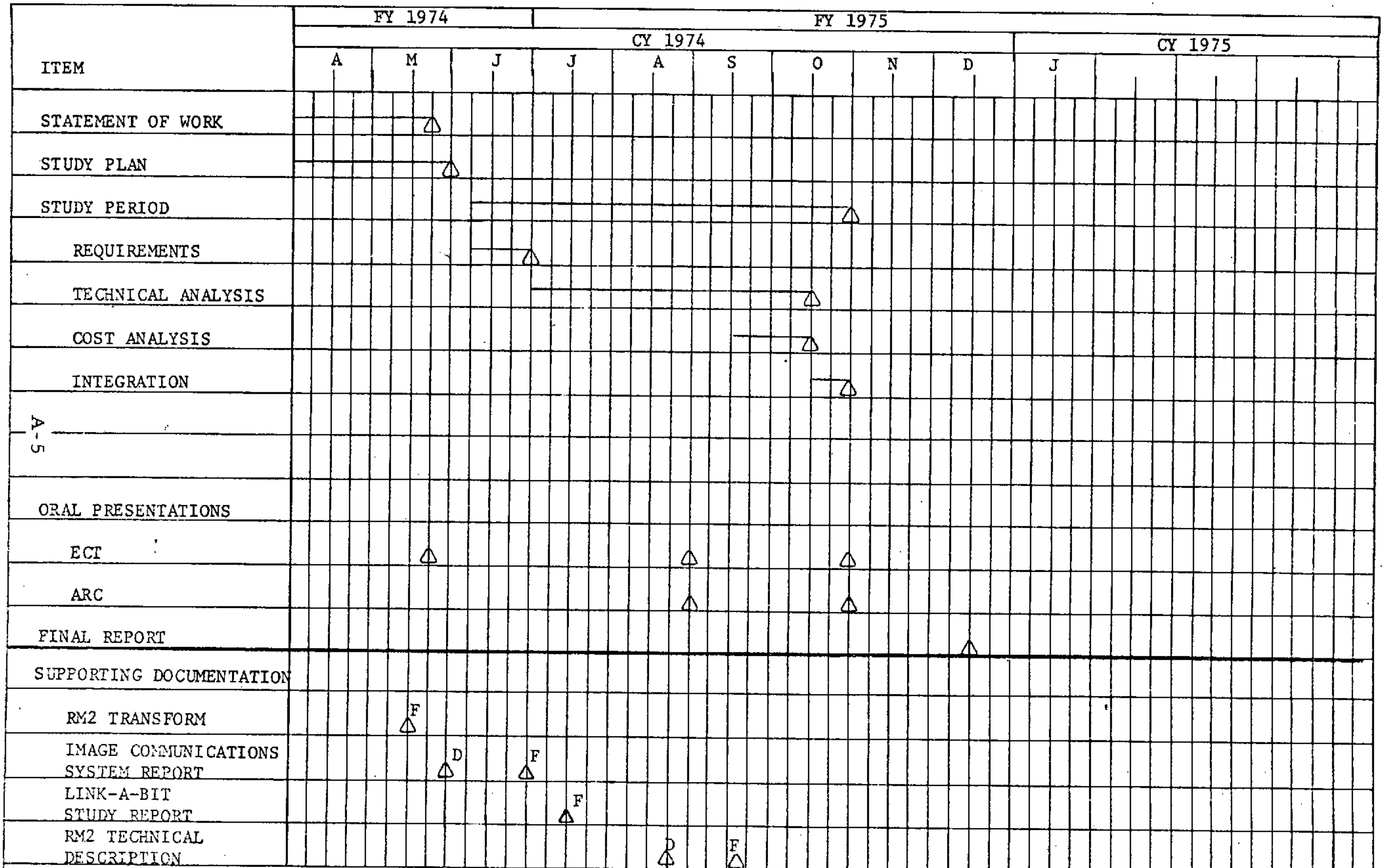
G. PRESENTATIONS

Periodic presentations (as shown in Figure A-1) will be provided to ARC and the Planetary Data System Engineering Coordination Team (ECT).

H. SUPPORT PLAN

Figure A-2 shows the study resource plan including the level and sources of funding.

Figure A-1. OUTER PLANET PIONEER IMAGING COMMUNICATIONS SYSTEM STUDY SCHEDULE



D = Draft
F = Final

PREPARED BY:	DATE:
T. Gottlieb	10 May 1974
APPROVED BY:	DATE:

1 YEAR SCHEDULE

2947-5 MAY 67

Figure A-2. Outer Planet Pioneer Imaging Communications System Study

Resource and Support Plan

TASK	Support Plan	
	MM	$K
Study Leader	4	12
Systems Engineering	2	6
Mission Design	2	6
S/C Imaging Analysis		TBP1
S/C Data Processing Analysis		TBP2
Telecommunications Analysis	4	12
DSN Analysis	4	12
MCCC Analysis	4	12
MOS Analysis	4	12
Image Processing Analysis		TBP2
Science Value Analysis		TBP3
TOTAL	24	72

TBP1 = Support to be provided from Solid State Spin Scan Camera Study (Div. 82).

TBP2 = Support to be provided from AICS Effort (Div. 36).

TBP3 = Support to be defined at a later date.

RECEIVED

OCT 30 1974

TOM GOTTLIEB

JET PROPULSION LABORATORY

INTEROFFICE MEMO

3621-74-061

TO: T. Gottlieb

29 October 1974

FROM: R. Piereson R. Piereson

SUBJECT: OPPICSS AI #45

The plan reported in T. Reilly's memo, attachment (1) is still the basic plan for providing science evaluation data to T. Reilly.

Attachments (2), (3), and (4) describe some refinements to the plan. Attachment (5) gives a preliminary outline of the engineering report on this effort.

The work is somewhat behind schedule at this time. Also, there is considerable interest in completing the variable length coding element of the RM2 simulation prior to conducting compression and decompression processing on the test images. The RM2 simulation must also be modified to accommodate recent changes in the PLSI pattern noise model. These factors could delay completion of the science evaluation by as much as three months. Policy and schedule decisions will be made within the next two weeks.

RGP:cj

Attachment 1: T. H. Reilly's memo dated 7-30-74, "Simulations for Science Value Study."

Attachment 2: "Preliminary Plans Regarding the Pioneer Picture Simulation Task," prepared by R. Piereson, 9/18/74.

Attachment 3: "Candidate Photoproducts List for Each Test Scene," prepared by R. Piereson, 9/18/74.

Attachment 4: T. H. Reilly's memo dated 9/18/74, "Test Images for Pioneer Simulation."

Attachment 5: Preliminary Outline of Engineering Report for Picture Simulation Effort, prepared by R. Piereson, 9/18/74.

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Attachment #1

JET PROPULSION LABORATORY

INTEROFFICE MEMO

30 July 1974

TO: OPPICSS Distribution

FROM: T. H. Reilly

THR

SUBJECT: Simulations for Science Value Study

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NOTE: Section 362 - Spacecraft Data Processing
Section 821 - Space Photography
Section 824 - Image Processing Laboratory

Representatives from Sections 362, 821, and 824 have met to discuss plans for producing simulated image data. The major points of agreement are listed below.

1. A list was drawn up showing the major tasks in chronological sequence. A rough estimate of completion date was made for each task. The list is attached.

2. It was agreed that all three organizations will participate in every phase of the effort. However, one section was assigned principal responsibility for each task. Any other OPPICSS Team member with an interest in this work is invited to participate.

3. A representative from each section has agreed to determine the scope of his assigned tasks, to obtain management approval to undertake these tasks, and to inform T. Gottlieb if any additional resources are needed.

4. Tasks 4, 5, 7, 8, and 9 require the use of a computer. In each case, the responsible section will supply both the machine time and the operator.

5. For the purpose of defining tasks 7 and 8, estimates were made of the number of different cases to be simulated. For task 8, it appears that a satisfactory job can be done with fewer than 300 simulated frames. An exhaustive job, however, could require up to 600 frames. The IPL has agreed to price out the effort at both levels.

6. The production of hard copies under task 9 will be limited to a small number (2-3). If it is later determined that a wide distribution of first-generation picture products should be made, the Team Leader should so inform R. Piereson who will then include the added cost of this distribution under task 10 (the Report).

THR:ski

SIMULATION TASK ASSIGNMENTS

FOR IMAGING SCIENCE VALUE STUDY
T. H. Reilly

	TASK	RESPONSIBILITY	COMPLETION DATE
1.	Overall Technical Coordination	362 (R. Piereson)	
2.	Arrange Study Contract with Scientist	821	September 9
3.	Select Test Images	821	September 30
4.	Convert Test Images to IPL Tape Format	824	October 7
5.	Adjust Test Images to Desired Dimensions, MTF, Noise, and Contrast	824	October 21
6.	Characterize Test Image MTF, Noise, Contrast, and Scene Activity	824	October 28
7.	Process Test Images to Simulate Data Compressor and Communication Channel	362	November 25
8.	Enhance and Annotate Simulated Images	824	January 13
9.	Convert Video to Film and Produce Hard Copy	824	January 20
10.	Coordinate Report on Simulation Effort	362	February 17
11.	Final Report by Outside Scientist	821	April 21

-14-

THR
30 July 74

Attachment #2

R. Piereson
9/18/74

Preliminary Plans Regarding the Pioneer Picture Simulation Task

1. Test images (in digital form) will be produced for > 5 test scenes. The test images will be representative of those which would be produced from the Pioneer Line Scan Imager (PLSI) being developed under the direction of T. Reilly. In particular, the MTF, pattern noise, and random noise of the test images will be representative of PLSI data.

2. Each test image will comprise a 512 x 768 rectangular array of 8 bit pixels.

3. The following two types of image data compressors will be included in the simulations.

   (a) Pixel Editing

   (b) RM2 Compression

4. The following two types of communication channels will be included in the simulations:

   (a) A channel employing a K=7, rate=½ convolutional coder in conjunction with a Viterbi decoder. The operating point will correspond to a bit-error-rate of 10^{-4}. (The required E_b/N_0 is approximately 4.1 db.)

   (b) A channel which employs a Reed-Solomon J=8, E=16, I=16 error-correcting-code concatenated with the convolutional/Viterbi code described in (a). The operating point will correspond to a Reed-Solomon word-error-rate of 10^{-6}. (The required E_b/N_0 is approximately 2.8 db.)

(Note: For the specified operating points, the type (b) channel can provide a data rate approximately 35% greater than that which can be provided with the type (a) channel.)

5. The following characterizations shall be produced for each test image:

   (a) Histogram of pixel values.

   (b) Histogram of difference between adjacent pixels along the "lines" and normal to the "lines" of the test image.

   (c) Histogram of the "random noise" contained in the pixel values.

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(d) A quantitative description of the pattern noise contained in the test images. (Example - a listing of the average offset between adjacent pixels due to "pattern noise".)

(e) A plot of the spectral composition of the video signal produced when the image is read-out serially (pixel-by-pixel along successive "lines").

6. The test images will not contain "artificial" changes in adjacent pixel values due to deletion of one or more "significant" MSB's from the pixel values. A pixel MSB is "significant" if it changes value during the image.

7. Although an RM2 compressor designed for use with the PLSI would probably employ "source blocks" which were 160 x 32 rectangular arrays of pixels, the subject simulations will use 64 x 64 pixel source blocks so that an adaptation of an existing RM2 simulation can be used for this study. It is believed that the picture quality using existing RM2 simulation will be nearly identical to that which would be obtained in a simulation employing 160 x 32 pixel source blocks.

Attachment #3

Candidate Photoproducts
List for Each Test Scene*

Image Data Compression Ratio	Type of Data Compression	Compressed/ Reconstructed Pictures with Different Enhancements				"E1" Enhanced Comp./Reconst. Pictures with Different Types of Channel Errors		Enhanced Difference Pictur[illegible] (Comp. Reconst. [illegible])
		E0	E1	E2	E3	C1	C2	E4
1:1	None	X	X	X	X	X	O_1	
2:1	Pixel Edit		X	X	X	X	O_2	X
4:1	↓		X	X	X	X	O_4	X
8:1	↓		X	X	X	X	O_8	X
2:1	RM2		X	X	X		O_2	X
4:1	↓		X	X	X		O_4	X
6:1	↓		X	X	X		O_6	X
8:1	↓		X	X	X		O_8	X
12:1	↓		X	X	X		O_{12}	X
16:1	↓		X	X	X		O_{16}	X
24:1	↓		X	X	X		O_{24}	X
32:1	↓		X	X	X		O_{32}	X

Key

X = photograph

O_n = "worst-case blemish" overlay for n:1 data compression ratio

* Note: Total Products Assuming 5 "Test Scenes":
(52 pictures/scene) x 5 scenes = 260 pictures
O_1, O_2, O_4, O_6, O_8, O_{12}, O_{16}, O_{24}, & O_{32} = 9 Blemish Overlays

Enhancement Codes:

E0 = No Enhancement
E1 = "Standard" Stretch
E2 = (TBD)
E3 = (TBD)
E4 = "Hard" Stretch

(Different enhancement process parameters can be selected for different scenes, but those parameters will be held constant for all compression ratios of the same scene.)

Channel Codes:

C1 = Convolutional (K=7, rate=½) Channel Code with Viterbi Decoding

C2 = Reed-Solomon (I=8, E=16, I=16) Error Correcting Code concatenated with "C1" channel code.

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R. Piereson
9/18/74

Attachment #4

RECEIVED

SEP 2? 1974

R.G. PIERESON

JET PROPULSION LABORATORY

INTEROFFICE MEMO

18 September 1974

TO: Distribution

FROM: T. H. Reilly THR

SUBJECT: Test Images for Pioneer Simulation

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In selecting a format for the test images, the following factors must be considered:

1. The Pioneer Line Scan Imager (PLSI) format is 160 pixels by 640 lines. An image of this size does not contain very many features, so it would be desirable to simulate a small mosaic of frames covering adjacent areas of the scene.

2. The RMII compressor algorithm now exists in software. As presently coded, the algorithm operates on blocks of 256 pixels by 256 lines. This block size is not fundamental to the operation of the compressor, but to change it for the purpose of this simulation would require additional programming work in Division 36.

3. Pictures obtained by recent Mariner spacecraft are expected to be a prime source of test images for this simulation. The format of these images is 700 x 832.

The attached diagram shows how these various requirements can be reconciled. First, a Mariner image is cropped to 512 x 768. As shown by the heavy lines, this reduced format contains exactly six of the RMII compressor blocks. The entire image is then processed as a unit by IPL and Division 36. After completing the enhancement processing, the IPL would divide the image into three PLSI frames as shown by the fine lines.

The question arises as to whether the data compressor obtains an unfair advantage (or disadvantage) by operating on a format other than the one planned for the PLSI. Division 36 points out that the performance of RMII depends primarily on the data correlations within a block of 64 x 64 elements. Correlations over a distance of 256 pixels are much less significant to the compressor efficiency. Therefore, we believe that doing the simulation as outlined above would not introduce a significant error in the assessment of RMII capabilities. It should be pointed out that if the AICS were advanced to the hardware stage, it would be an easy matter to reconcile the camera and compressor formats by changing either or both.

A more serious problem arises from the need to modify characteristics of the test images other than the format. It is now estimated that the CCD images will have higher resolution, less random noise and more pattern noise than vidicon images. The simple way to handle this is to average 2 x 2 pixels in a Mariner image, thereby improving resolution and random noise at the pixel level. The CCD pattern noise will probably be additive, and therefore can easily be imposed on the test image. The difficulty is that the averaging process also reduces the image format by a factor of two in both dimensions. Thus, to obtain a suitable end product, we need to start with a vidicon image of 1024 x 1536 elements, substantially larger than anything flown to date.

Some possible solutions to this problem are listed below.

1. Obtain a computer mosaic (as distinct from a cut and paste mosaic) of Mariner images. Jim Cutts will look into this.

2. Obtain the test images from a source other than Mariner flight data. Possibilities include Apollo, ERTS, and Pioneer 10. T. Reilly will look into this.

3. Modify the test images by means other than averaging.

4. Do the averaging and settle for a test image whose format is too small.

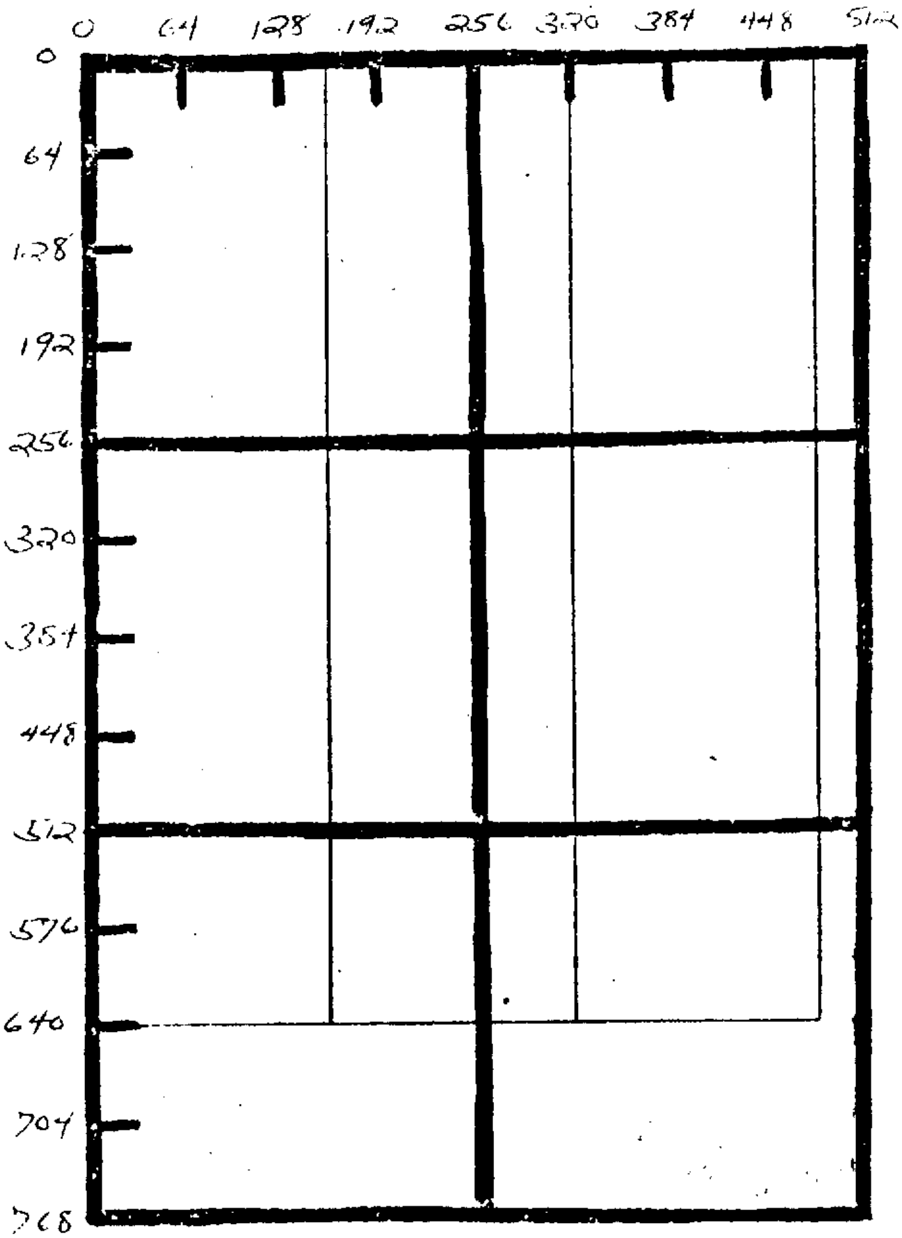
5. Maintain the format size and settle for incorrect noise and resolution characteristics.

THR:ski

Distribution
J. Cutts
E. Hilbert
D. Lynn
R. Piereson
R. Rice
G. Root

TEST IMAGE FORMATS

FOR PIONEER SIMULATIONS



Attachment #5

R. Pierson
9/18/74

A simulation task is planned to enable evaluation of scientific implications of alternative image communication systems for Outer Planet Pioneer missions. A two volume engineering report on the "Pioneer Image Communication System Simulation" (PICSS) task is planned.

Volume 1: A Description of the PICSS Task

Volume 2: PICSS Technical Products

A preliminary outline of Volume 1 is contained in the attachment. Volume 2 would contain copies of all photoproducts produced as a part of the PICSS task and copies of other technical products when feasible. (It would be impractical to include massive computer listings of pixel values, etc.)

Preliminary Outline of Volume 1
of the PICSS Engineering Report

1. Introduction
   (Including brief description of the assumed Outer Planet Pioneer mission and references to OPPICSS, the PLSI development program, the Pioneer Data Compression Study (and AICS), the TRW OPP spacecraft study activity, and the OPP imaging science value study.)

2. Description of the Pioneer Line Scan Imager (PLSI)
   (Including picture formats, MIF, pattern noise, and random noise characteristics.)

3. Description of process by which (digital) test images representative of PLSI are produced from other data sources.

4. Characterization of the test images and the processes used to produce the characterization (pixel value histogram, etc.).

5. Description of data compression and decompression algorithms used in the study.
   (Include brief rationale for selection of these algorithms and rationale for any "short cuts" employed in the simulations.)

6. Description of the error characteristics of the alternative communication channels and the process by which pictures (and blemish overlays) were produced to enable assessment of the effect of channel errors on image science value.

7. Description of the process used to produce photographic prints and characterization of the fidelity of this process.

8. Description of technical products (other than those treated above) and the process by which they were produced.

9. A complete index of all technical products produced as a part of the PICSS task.

10. Brief description of significant problems incurred in the conduct of the PICSS task and suggestions regarding related future tasks.

Appendix C

Deviation from NASA Telecommunication Standards

JET PROPULSION LABORATORY

INTEROFFICE MEMO
916.25/38
2 October 1974

TO: T. Gottlieb

FROM: R. Durstenfeld

SUBJECT: O.P.P. Violations of Telemetry Format Standards (ACTION ITEM 55)

REFERENCE: Figure 5-11 and Telemetry Format Standards Attached

1) Basic Format Structure (Sec. 2.3.2) vs figure 5-11
2) Frame Length (Sec. 2.3.2.1 second bullet) 192 bits vs.360(20 x 18 bits)
3) Frame synchronization word (Sec. 2.3.2.2) note for 2 and 3 above, the frame synch word shown in 5-11 is 18 bits.
4) Word length (Sec. 2.3.3.1) 8 bits vs. 3 bits.
5) Multiplex structure (Sec. 2.3.6)
6) Data sequence is probably violated? (Sec. 2.3.6.3)

Also

An original issue of the telemetry standards contained a paragraph which stated:

Data Compression

Fixed length data compression techniques shall be permitted. The criteria for selecting a compression technique is yet to be determined. Variable length data compression techniques shall be prohibited.

The above paragraph does not appear in the attached (i.e. latest version) of the Telemetry Standards. I include it only for information - not necessarily as a violation.

RD:ml
Attachment

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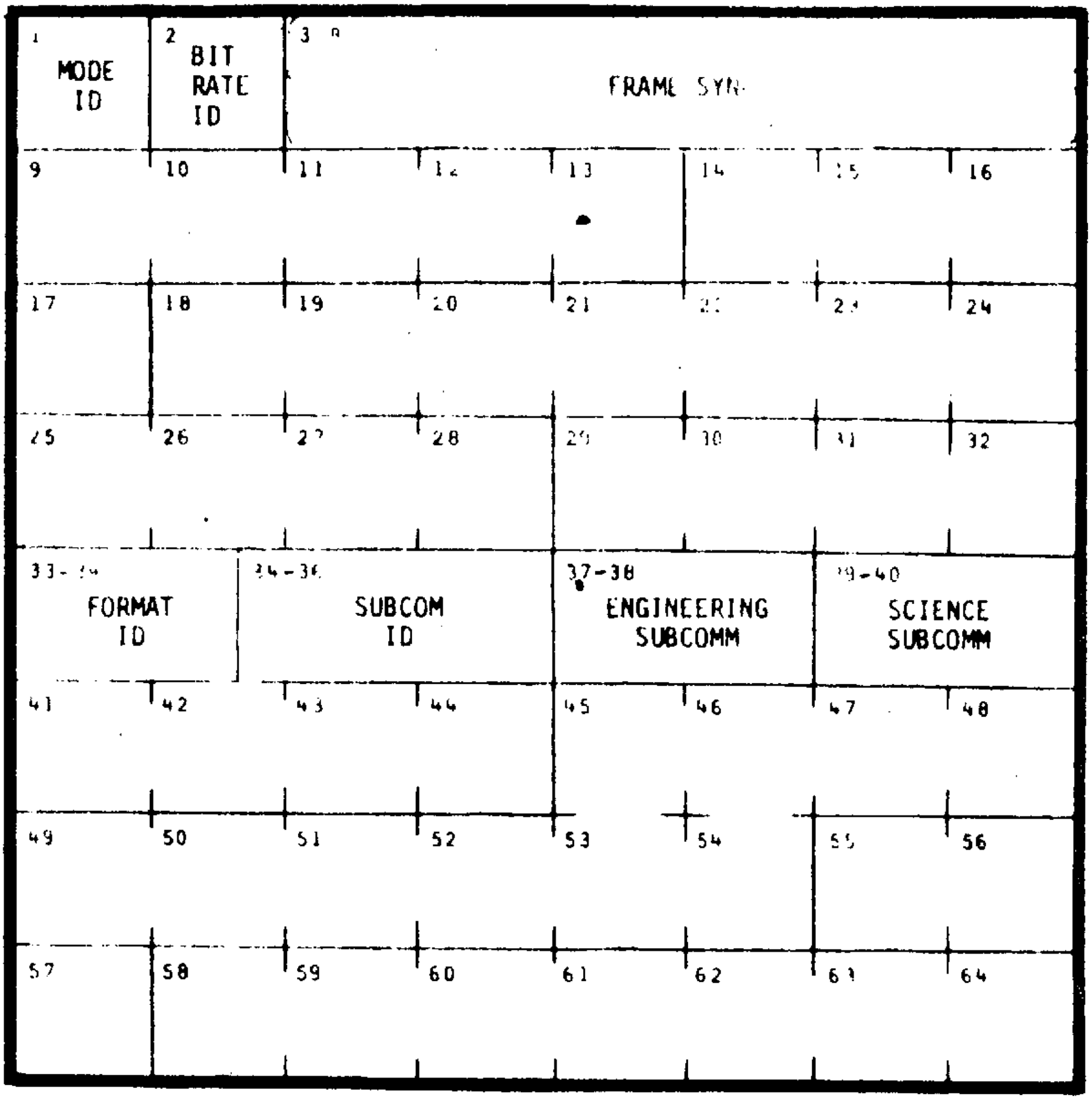

NOTES:
1. Formats A and B are the basic scientific formats with a word size of 3 bits.
2. Subcom ID = Subcommutator Identification.
3. Each blank word slot denotes a serial digital word slot. Formats A and B are both independently patchable in the data portion of the mainframe. Each of these two formats handle a maximum of 12 digital input channels.
4. Each mainframe word slot is sampled at a rate of BR/192, where BR = bit rate.

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Figure C-1. Mainframe Organization

Encl 9

TRW
SYSTEMS GROUP

INTEROFFICE CORRESPONDENCE 8140.8.7-48

TO T Gottlieb
JPL

CC

DATE 28 October 1974

SUBJECT Action Item 55, 33(A)

FROM C. W. Renn

BLDG R5 MAIL STA. 1271 EXT. 62310

Action Item 55

The following comments were received from Tim Bridges relative to the deviations of the Pioneer 10/11 from the Telemetry Standards, and indicate areas where Pioneer 10/11 does not comply with the Standards:

1) Paragraph 2.2.1.4 - Subcarrier Frequency Stability
2) Paragraph 2.2.1.5 - Subcarrier Phase Stability
3) Paragraph 2.3.2 - Frame Format (Structure)
4) Paragraph 2.3.2.1 - Frame Length
5) Paragraph 2.3.2.2 - Frame Sync Word
6) Paragraph 2.3.3 - Word Format
7) Paragraph 2.3.3.1 - Word Length
8) Paragraph 2.3.4 - Format Changes

These deviations by Pioneer 10/11 may persist in the OPP spacecraft, although it would be possible to easily correct some of them since a substantial redesign of the DTU is required.

Action Item 33(A)

This response amends the previous answer to the above action item. In order to comply with the telemetry standards, a specific subcarrier and synchronization mechanization is defined. This will require a separate portion of the DTU for the X-band system (see attached).

C. W. Renn

C. W. Renn

CWR:bfm

Attachment as stated

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APPENDIX D

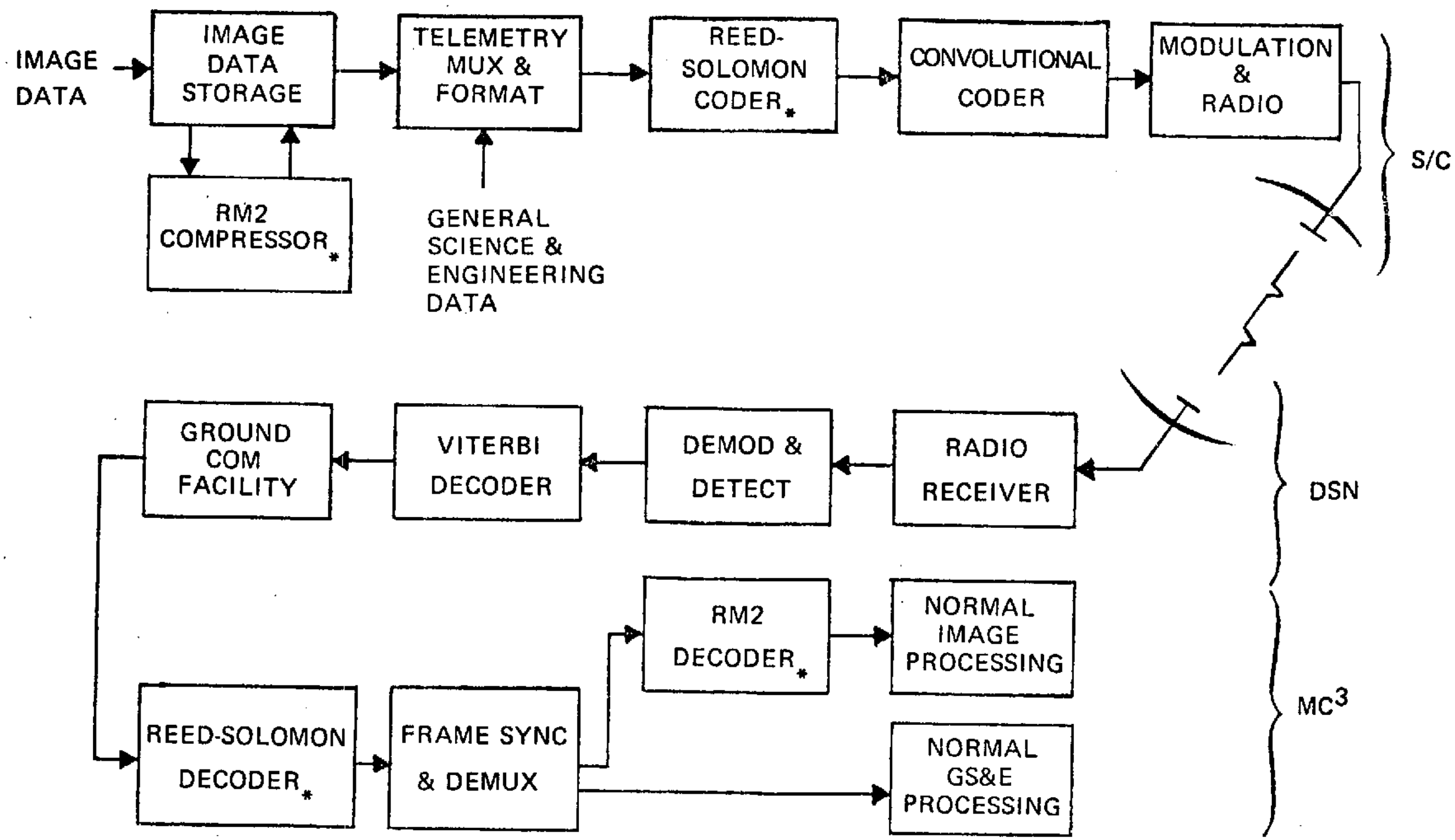
THE ADVANCED IMAGING COMMUNICATION SYSTEM

The Advanced Imaging Communication System (AICS) was developed to provide a substantial improvement in capability to transmit image data from planetary spacecraft. The development was guided by end-to-end system considerations pertaining to performance, cost, and compatibility with existing communication system elements. Figure D-1 illustrates the principal system elements:

It is of interest to note that all system elements are like those of existing Pioneer and Mariner systems except for the addition of the elements marked with asterisks. The added system elements comprise an RM2 image data compressor and its associated decoder plus a Reed-Solomon error-correcting coder and its associated decoder. Consequently, the AICS approach can be implemented without extensive impact to existing system elements.

The basic characteristics of the RM2 compressor are described in section III, paragraph D.1, of this report. Computer simulations indicate that RM2 can reduce the number of bits required to transmit a picture by any factor up to 32:1 and yet provide image quality which is substantially superior to any other known approach which may be feasible in a space application. The operational flexibility of the RM2 compressor makes it especially attractive for multi-planet missions and as a multi-mission design.

FIG. D-1 AICS SYSTEM BLOCK DIAGRAM



The development status of the RM2 compressor is as follows: A computer simulation of an earlier compressor (RM1 - Reference 4) proved the concept of the variable-length coding technique planned for RM2. A partial computer simulation of RM2 has been developed which incorporates all aspects except for the variable length coding element discussed previously. Also, a computer simulation of the RM2 decoder (except for the variable-length decoder) has been developed. These simulations were used to produce pictures which show that RM2 can accomplish large data compression factors with surprisingly small effect on image quality.

The Reed-Solomon (R-S) error-correction code is concatenated with an existing convolutional-Viterbi (C-V) channel code to enable the error requirements of compressed data (and general science data) to be met without requiring a reduction in data transmission rate.

Details regarding the structure and characteristics of communication systems employing concatenated Reed-Solomon/Viterbi channel coding are provided in references 2, 5 and 6. Extensive analysis and simulation results are interrelated with the fidelity requirements of GS&E and imaging data (compressed or uncompressed) along with constraints imposed by DSN structure and projected capabilities.

Some of the topics covered include coder/decoder implementation complexity and rate capabilities, RS code block synchronization, interleaver depth requirements, methods of interleave, optimization of RS and convolutional code parameters, parity overhead and burst error correcting capabilities, buffer zones for uncertainties in S/N, and the determination of performance degradations under imperfect receiver operating conditions.

The most fundamental and rewarding performance characteristic of an RS/Viterbi system indicated by these studies is simply that channel errors can be virtually eliminated without requiring any significant reduction in data transmission rate. Furthermore the system appears quite feasible. Advantages and conclusions looked at from a multi-mission viewpoint are given in Section 3-E-5.

It is important to note that these conclusions and results are based on extensive simulations which in Ref. 5 include a phase-locked-looped receiver in addition to interleaved RS decoders and Viterbi decoders. An observation of particular interest; test results indicate that the R-S/C-V channel is substantially more tolerant of imperfect radio receiver operation (noisy carrier reference and imperfect AGC) than is a channel using a convolutional code in conjunction with sequential decoding (Ref. 7).

APPENDIX E

DESCRIPTION OF SELECTED OPP SUBSYSTEMS

1.0 COMMAND SUBSYSTEM

The command subsystem provides the capability of controlling the operating modes of the spacecraft equipment and scientific instruments from information received in rf transmission to the spacecraft and from signals generated on-board at discrete events. The command subsystem consists of two command decoders (DDU) and a command distribution unit (CDU). Figure E-1 is a block diagram of the subsystem.

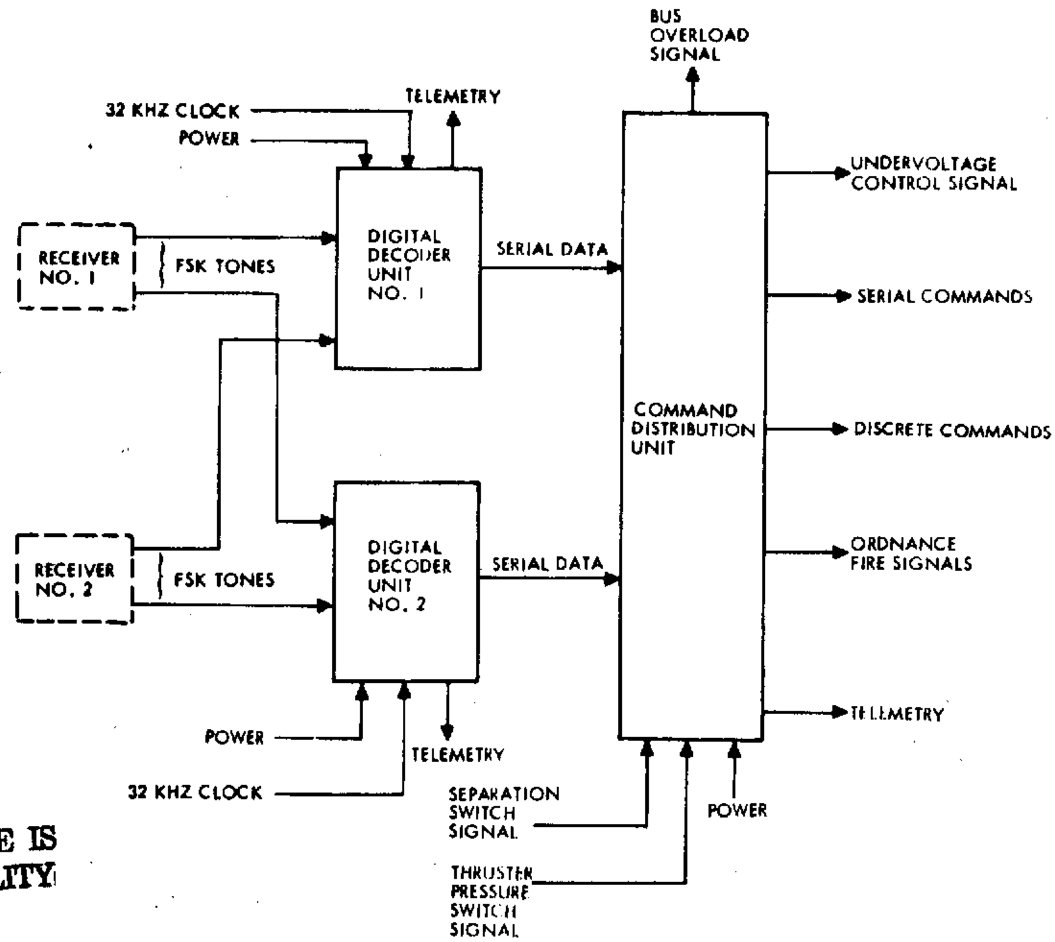


Figure E-1. Command Subsystem Block Diagram

The commands are transmitted to the spacecraft with a PCM/FSK/PM modulation of the uplink S-band carrier signal at a rate of 1 bit per second. Twenty-two bits are transmitted from the ground for a single command message. Two bits are used for selecting the decoder, 3 bits are used for command rcuting, and 8 bits for command information. The remainder are used for processing and verification of the command. The activated spacecraft receiver demodulates the carrier and provides the frequency shift key (FSK) tones to the command decoders. The addressed decoder converts the FSK tones to digital data and performs a verification operation with the command message to reduce the probability of executing wrong commands. The decoder forwards the routing address, command message and, if the command is properly verified, an execute pulse to the CDU. If the command is not properly verified by the DDU, the execute pulse is inhibited and the CDU does not act on the command message.

The CDU processes and distributes all commands to the spacecraft equipment and scientific instruments. Two basic types of command output are provided. One type is a serial data output to a specified user. The routing portion of the command message identifies the user and the 8 bits of command information provide the serial data. The other output is a signal applied to any one of 255 discrete lines for initiating specific functions. The routing portion of the message signifies this discrete type of output and the 8 bits of command information identify the particular one of the possible 255 discrete commands. The CDU also has the capability of being programmed by the routing and command messages to store up to 5 discrete commands for sequential execution at a later time and to store the time delay between sequence enable and sequence execution and between each command of the sequence. This feature permits the commands to be sent and verified by telemetry before execution and is particularly useful when the communication time is great. In addition, special functions required by the spacecraft separation signal, ordnance firing, signal conditioning, and sequential turnoff of power to various subsystems in the event of an undervoltage condition of the primary bus.

For redundancy, two DDU's are provided for selective operation by an address in the transmitted command message. Each decoder is capable of receiving FSK signals from either receiver. The units are interconnected by a resistance cross-strap network to protect against a single failure in either decoder or receiver from totally disabling the processing of commands.

The major change to the Pioneer F/G command subsystem is the increased requirement for power, telemetry, and command-controlling functions associated with growth of the science payload and the inclusion of X-band communication equipment. Command distribution unit (CDU) expansion is possible but it can be tailored to accommodate specific mission requirements since it is capable of processing 255 discrete commands whereas less than 190 have been implemented on Pioneer F/G. Thirty-four of the unused discretes are available without further modification; the remainder can be made available by the addition of integrated circuits. Cabling harnesses will, of course, require substantial redesign.

The command memory implementation in the CDU is a significant departure from the Pioneer F/G concept. Based on C-MOS memory chips identical to those selected for the DSU, the new design can accommodate 32 stored commands for delayed execution (up to 36 hours) with timing resolution of

2 seconds. Moreover, commands may be executed in a sequence different from that in which they were stored, simplifying and increasing the flexibility of ground operations.

The existing redundant digital decoder unit (DDU) is capable of demodulating and verifying a maximum of 255 discrete commands. Therefore, no changes to this unit are contemplated.

2.0 DATA HANDLING

The data handling subsystem time multiplexes and formats science and engineering data into a coded or uncoded data stream suitable for modulating the telemetry transmitter. Timing and operational signals are provided to the scientific instruments and spacecraft subsystems. The data handling subsystem will also store and read out formatted data upon command. The data handling subsystem consists of a digital telemetry unit and a data storage unit. The data handling subsystem has three modes of operation, 8 commandable bit rates from 16 to 2048 bits/sec in binary increments, and 11 data formats. Figure E-2 is a functional block diagram identifying key input/output interfaces.

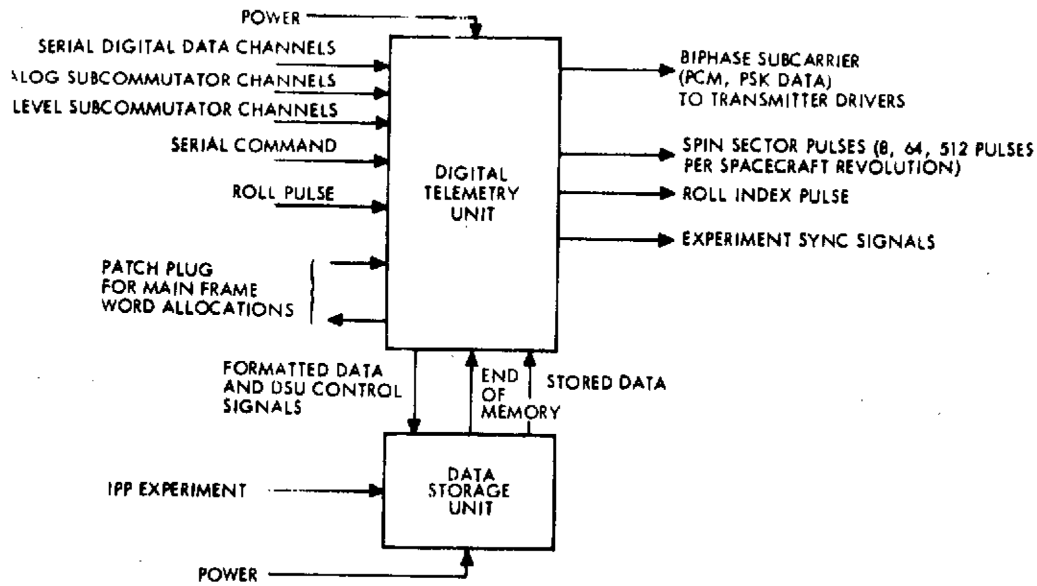


Figure E-2. Data Handling Subsystem Block Diagram

2.1 Operating Modes

The three operational modes are: real-time, telemetry store, and memory readout.

a) Real-Time. Sampled data are processed, formatted, convolutionally coded upon command, and transmitted directly, without intermediate storage, at a bit rate selected by ground command.

b) Telemetry Store. Data are stored and transmitted simultaneously and continuously until either the DSU is full or the data subsystem is commanded to the real-time mode. The DSU can be partially filled and data stored at a later time beginning at the memory location of the last previously stored data. When the telemetry storage mode is terminated by ground command, or when the DSU is filled, the data handling subsystem will automatically switch to the real-time mode in the format and bit rate used during the telemetry storage mode. In this mode it is possible to sample and store data at a more rapid rate than can be received on the ground. The stored data then can be transmitted later at the prevailing bit rate.

c) Memory Readout. Data are read out from the DSU and transmitted at a bit rate selected by ground command. When memory readout is completed, the data handling subsystem will automatically switch to the real-time mode and the format used before memory readout, and remains in the bit rate used during memory readout.

2.2 Formats

The formats are divided into science and engineering groups. The science group includes two basic science formats and three special purpose science formats for science main frame data and two science formats that are subcommutated in the main frame. The basic science formats each contain 192 bits which includes 144 bits assigned to the scientific instruments, 6 bits to subcommutate the engineering formats, 6 bits to subcommutate the science subframe, 18 bits for frame synchronization and the remainder for identification of the subcommutated data, telemetry mode, bit rate and format. One of the basic science formats is arranged for use primarily during interplanetary flight and the other during encounter. The three special purpose science formats each contain 192 bits of digital data from only one or two scientific instruments (there are no subcommutated or identifying words) and are transmitted only in conjunction with one of the basic science formats, alternating every 192 bits. These special formats provide the capability to sample data from certain scientific instruments at a high rate at the expense of reducing the amount of data from the other instruments by one-half.

The engineering data are separated by subsystem into four formats as follows:

1) Data handling

2) Electrical

3) Communications

4) Orientation and propulsion

With a science main frame the engineering formats are subcommutated sequentially in 6 bits of the basic science format. With an engineering main frame the four engineering formats can be transmitted sequentially or each engineering format can be transmitted individually with all four engineering formats subcommutating sequentially at the main frame rate. The separation of the engineering data into formats by subsystem provides high data rates for launch phases, critical maneuvers and diagnostic purposes. The subcommutating science formats, each 192 bits long, also subcommutate 6 bits in the engineering formats at the main frame rate.

2.3 Digital Telemetry Unit (DTU)

The DTU is the heart of the data handling subsystem and processes analog, digital and bilevel (discrete) science and engineering data into a serial time-multiplexed PCM signal which modulates the transmitter. Nearly all elements in the DTU are redundant and selectable by command. A stable, crystal controlled clock and countdown chain generates the timing signals needed throughout the spacecraft and for transfer of data to the DTU. Utilizing timing signals and the roll reference pulse provided by the attitude control subsystem, a spin period sector generator within the DTU generates an accurate roll-index pulse and spin period sector pulses corresponding to 512, 64, and 8 sectors per spacecraft revolution for the scientific instruments and spacecraft subsystems. This information is also used to determine roll position in relation to the telemetered data and spin rate. A 6-bit analog-to-digital converter is used to encode analog inputs into binary words and is continually checked by encoding three reference voltages. The output of the DTU to the transmitter is in the form of a NRZ-L biphase-modulated 32.768 kHz square-wave subcarrier. The DTU has a patch plug which allows for rearrangement of the two main science formats without disassembly and rewiring of the DTU.

The convolutional coder, packaged as part of the DTU, codes the formatted data to increase the telemetry efficiency. The telemetry data can be either coded or uncoded by command. The convolutional coder has a multiple-bit shift register and data are shifted in and out of the register at the data bit rate. Logic is provided for generating a pair of parity bits, based on the data in the shift register, for each incoming data bit. Thus, the parity bits are generated and transmitted at twice the data rate. In error-free data, the bits of a pair provide an unambiguous representation of the original data bit. With errors in the data, a decoding process on the ground utilizing a sequence of parity pairs provides reconstructed error-free data well beyond normal acceptable error limits without the coding.

2.4 Data Storage Unit (DSU)

The DSU is controlled by the DTU except when buffering IPP data in which case the instrument controls the store operations and the DTU controls the readout operations. 1 The storage and readout of data need not be continuous; they may be interrupted and resumed later by command, if required.

2.5 OPP Modifications

The baseline configuration for the Outer Planets Pioneer incorporates a modified DTU based on the Pioneer F/G concept and technology, and a new DSU with substantially increased capacity (from 49 kilobits to 1 megabit). A summary list of the requirements differing from the Pioneer F/G DTU is given below.

a) Increase the maximum bit rate from 2048 bps to 16,384 bps, implementing the following information bit rates: 32, 64, 128, 256, 1024, 4096, 8192, and 16,384 bits per second

b) Provide an increased subcarrier frequency for bit rates exceeding 4096 bps

The requirement for the increased bit rate is predicated on the anticipated requirements imposed by a visual imaging system, e.g., a line scan camera experiment. It is desirable to minimize the time required to transmit a picture which is inversely related to the telemetry bit rate. However, 16,384 bps is the maximum rate which can be supported by the baseline X-band communications system, described in Section 4.3.5, at the range of Jupiter, the closest planet of interest.

To increase the bit rate to 16 kbps, the following modifications must be made to the Pioneer F/G DTU design:

a) Replace the analog-to-digital converter with a faster circuit, potentially available from another program

b) Redesign the programmer logic

c) Increase the speed of the main frame and subcommutator multiplexers

d) Increase the subcarrier frequency from 32,768 Hz to 131 kHz for bit rates exceeding 4,096 bits per second.

In summary, substantial redesign of the DTU impacts each of the nine existing boards, an additional board for the expanded science subcommutator, enlargement of the chassis, and additional connectors. However, the Pioneer F/G footprint area, 83 square inches, would be unchanged.

In order to size the capacity of the DSU, a typical imaging system was considered to be the primary driver requirement. One megabit storage affords considerable flexibility in meeting the varied formats of this class of instruments. One way that this capability could be allocated assumes an imaging sensor comprising 390 detector elements. The dimension along the array is accommodated electronically, while scanning normal to the array is automatically provided by the rotation of the spacecraft. The required storage capacity is, therefore, 390 TV lines x 390 data samples/TV line x 6 bits/sample encoding level or 0.9×10^6 bits. The DSU stores the data acquired during one revolution of the spacecraft until it can be transmitted to the ground. Using half the telemetry at the highest bit rate, 16,384 bps, a picture can be transmitted every 110 seconds. Of course other formats and applications can easily be accommodated.

3.0 COMMUNICATIONS

The increased data rate requirements, dictated primarily by an increased imaging capability envisioned for most of the contemplated missions, justify seeking a significantly increased downlink telemetry bit rate capability. Therefore, the approach taken to configuring the communications subsystem was to achieve the highest possible bit rate consistent with retaining as much of the simplicity, reliability, and technology of Pioneer F/G as possible and constrained by the available electrical power. The inclusion of an X-band transmission capability to provide the prime telemetry support is the most straightforward solution, within the constraints cited, which can provide the desired improvement in link gain.

Retention of an S-band downlink capability is imperative, however, because it:

a) Supports tracking and telemetry operations during launch, ascent, and initial Deep Space Station acquisition phases of the mission

b) Provides continuous communications during off earth-pointing maneuvers

c) Permits routine data acquisition from the DSN 26-meter diameter antenna network

d) Serves as a back-up data link (at reduced bit rate) for the X-band system

e) Provides increased assurance of continuous telemetry coverage in the event that the spacecraft attitude "drifts" beyond the X-band beamwidth.

A functional block diagram of the communications subsystem for the Outer Planets Pioneer baseline configuration is shown in Figure E-3. It differs from Pioneer F/G in the following areas:

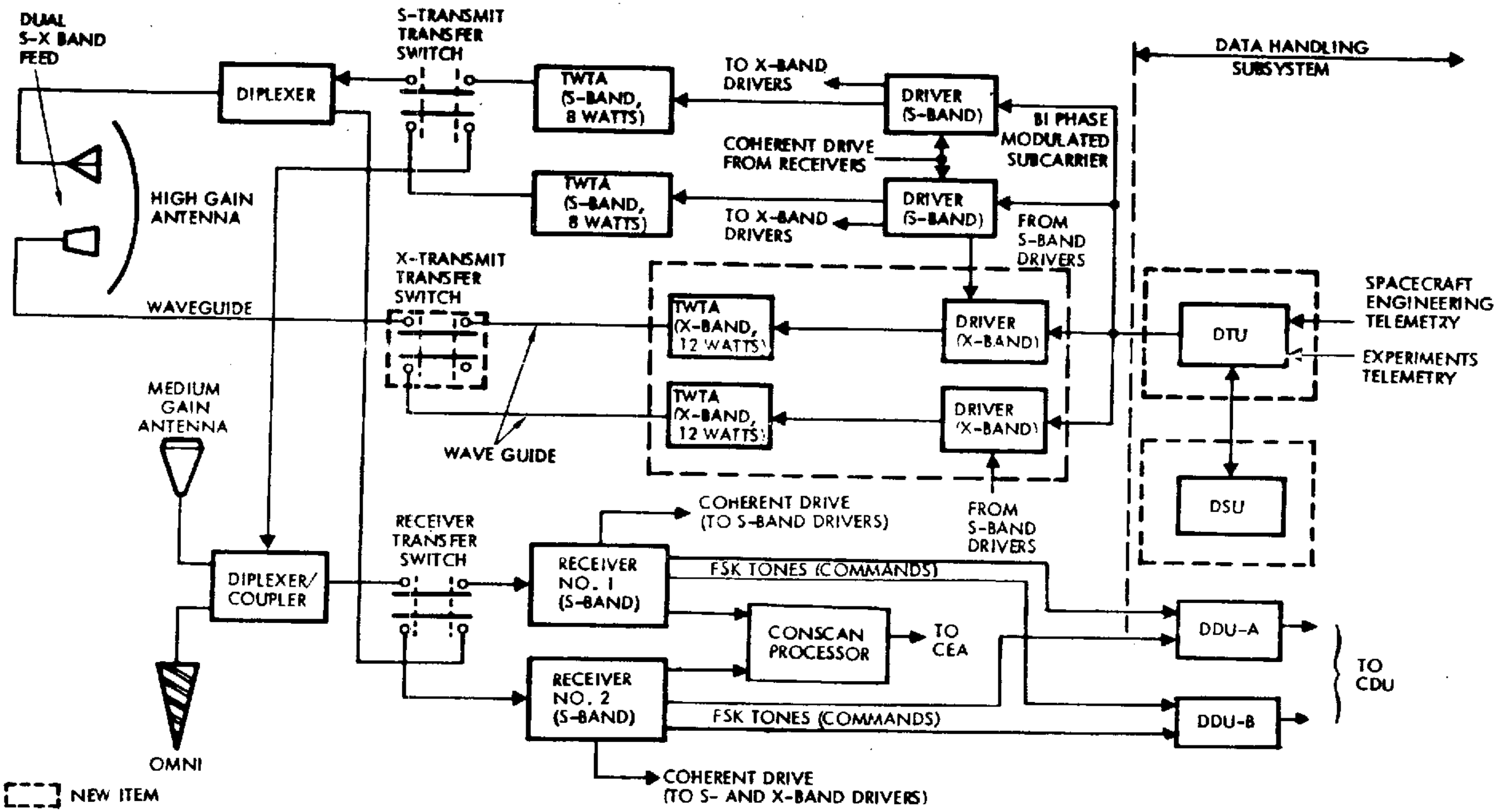


Figure E-3. Communication Subsystem Functional Block Diagram

a) The existing S-band transmission system has been augmented with an X-band capability comprised of redundant TWTA's (each providing 12 watts RF output) and driver amplifiers. The option for the X-band downlink to be phase coherent with the S-band uplink carrier is implemented by command, just as it is for the S-band downlink on Pioneer F/G.

b) An X-band transfer switch, utilizing waveguide ports, has been included to permit selection, by ground command, of either X-band TWTA/driver pair.

c) The high-gain antenna S-band feed and associated feed movement mechanism is replaced with a fixed dual S- and X-band feed. Ridged waveguide horns are used for this application. The S-band horn is permanently off-set from the reflector focal point to squint the beam and produce a -2dB gain crossover. The X-band horn is positioned in one of the S-band waveguide ridges and is coincident with the focal plane axis.

Table E-1 summarizes the essential differences between elements of the Pioneer F/G communication subsystem and the Outer Planets Pioneer baseline configuration.

Table E-1. Communication Subsystem Modifications

Unit	Pioneer F/G	Outer Planets Pioneer Baseline Configuration
High-gain antenna	Nine-foot paraboloid; focal point feed	Unchanged
High-gain antenna feed	Cavity-backed, crossed dipole S-BAND	Dual S- and X-band
Feed movement mechanism	Thermal actuator	Deleted
Medium-gain antenna	Corrugated horn	Unchanged
Omni antenna	Log conical spiral	Unchanged
S-band transfer switch	Procured from Teledyne Microwave	Unchanged
X-band transfer switch	Not applicable	New item
Diplexer	Procured from Wavecom	Unchanged
Diplexer/coupler	Procured from Wavecom	Unchanged
X-band transmitter	Not applicable	New item 12 watt RF output
X-band driver	Not applicable	New item
S-band transmitter	Eight watt TWTA; procured from Watkins/Johnson	Unchanged
S-band driver	50 mw power output	Unchanged
Receiver	Phase lock loop; 20 Hz threshold loop bandwidth	Add coherent drive to X-band drivers
Conscan processor	Digital maximum likelihood estimator	Unchanged
RF transmission lines	Coaxial (semirigid and flex)	Coaxial and waveguide

APPENDIX F

SATURN URANUS PROBE IMPACTS ON OPP

1.0 COMMAND REQUIREMENTS

A review of the command and data handling requirements was made to determine what modifications of Pioneer F/G would be necessary to meet the Saturn/Uranus mission objectives. Changes in the command subsystem are required primarily as a result of:

- enhanced communications performance of the system, i.e., the addition of X-band communication equipment;
- additional data handling and storage requirements;
- accommodation of probe housekeeping, test and telemetry requirements by the bus; and
- accommodation of the modified bus science payload complement.

Table F-1 lists the additional command functions accruing from these requirements. These additions are partly offset by elimination of some of the baseline Pioneer F/G equipment from the spacecraft. These deletions are also listed in Table F-1.

The required expansion of functions to be performed by the command distribution unit (CDU) is possible without a major design change since the CDU can be tailored to accommodate the specific requirements of the spacecraft. The CDU is capable of processing 255 discrete command whereas less than 190 have been implemented on Pioneer F/G. Thirty-four of the unused discretes are available without further modification; the remainder can be made available by the addition of integrated circuits. Cabling harnesses will, of course, require substantial redesign.

The preliminary estimate given in Table F-1 of 45 additional command (taking the deletions into account) is within the functional capacity of the existing CDU design and still leaves a margin of 20 unused discrete commands.

The specific command requirements of the new bus science instruments are not defined at this point. However, the addition of three new instruments in the list of science experiments specified by Ames Research Center is offset by the elimination of five others of the present Pioneer F payload. This change can be accommodated by redistribution of commands

Table F-1. Additional Command Requirements (Preliminary)

Subsystem	Command	Number of Commands Added	Number of Commands Deleted
Electrical Distribution	Select register	5	
	Probe separation pyro actuation	6	
	Probe operations pyro actuation	8	
	Probe battery charge	4	
	Probe test commands	4	
Communication	S-band transmitter	4	
	TWTA to high gain antenna	2	
	L-band receiver/data synchronizer on/off	2	
	S-band feed offset		4
Attitude Control	SPSG roll reference input	4	
	Reference set	2	
	SCT pair select	1	
	Pulse length	6	
	Image system gimbal angle register	2	
	Image system gimbal rotation execute	2	
	Star mapper gimbal angle register	2	
	Star mapper gimbal rotation execute	2	
Data Handling	DSU control logic	2	
	Probe data buffer	2	
Propulsion	Radial thruster	6	
Electrical Power	Bus battery control		7
Science	Added instruments (3), estimated	6	
	Deleted instruments (5), estimated		10
	Deleted IPP mode and angle control		6
	Total Added	72	
	Total Deleted	27	
	Net Total Increase	45	

that are now being used in the baseline spacecraft. Six of the present Pioneer F/G instruments can probably be retained with only minor changes.

The command memory feature of the Pioneer F/G CDU, providing the capability of storing command messages and their associated time delay periods for later sequential execution, is retained. The command memory capability may be essential for execution of certain time-dependent functions such as controlling scientific experiments when the spacecraft is occulted by the planet. Other operational procedures such as probe release sequences, instrument calibration and mode selection may be greatly simplified with the command memory.

2.0 PROBE DATA LINK

The data acquired by the probe must be transmitted to the bus for subsequent retransmission to the earth. Direct transmission of these data from the probe to the earth is not feasible within the established program constraints. Elements of this link which are located on the bus include an antenna, receiver, data synchronizer, and data buffer. These components are shown interconnected in Figure F-2.

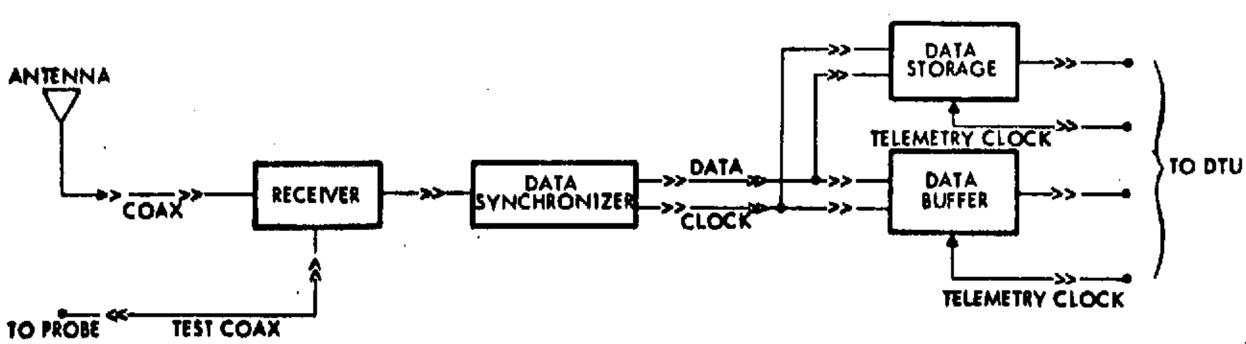


Figure F-2. Probe-Bus Data Link Block Diagram

3.0 DATA HANDLING AND STORAGE

As shown in Figure F-2, probe data may be introduced into the bus receiver via the RF link or, while the probe is still attached, via the hardlined coax. In either case, a digital bit stream will be produced by the data synchronizer. (Note that on-board decoding of probe data is not part of the synchronizer functions.) This probe data leaves the synchronizer as a steady stream at 88 bps. Since this bit rate is asynchronous with the spacecraft DTU bit rate, some form of storage or buffering of the probe data is required prior to folding the probe data into the bus format.

In addition to the quasi real-time transmission of probe data via the bus telemetry link, the bus must store the entire probe message for subsequent retransmission in case of problems with the real-time data. This establishes a requirement for a digital storage unit (DSU) with a capacity of 88 bps times 4320 seconds or 380,160 bits.

APPENDIX G

DATA STORAGE UNIT

1. STORAGE REQUIREMENTS

The demands for data storage used in the OPPICSS study originate from various sources (PLSI, probe, General Science instruments, RM2). Data storage may be used to buffer high bit rate data (PLSI), to store data during occultation periods (GS&E), to preserve mission critical data (probe), or to support data compression (RM2). In addition to these functions, small buffer storage units are required to support the asynchronous operation of the DTU and the probe communication link, the DTU and Reed-Solomon encoder and the DTU and the RM2. Expansion of the OPP command storage beyond the 32 commands identified in Reference 5 was not investigated during this study.

Probe data storage requirements are described in Appendix G. These data must be retained throughout the occultation period because it is not possible to receive the data on the ground, analyze the data, and then send a command to the spacecraft to read out or clear this memory prior to occultation by the planet (see Figure G-1). The probe storage capacity may be used <u>prior</u> to the encounter and <u>after</u> the encounter but must be dedicated during the encounter and occultation periods. The apparent occultation by the rings of Saturn shown in Figure G-1 would occur prior to receipt of all the real-time data. However, the encounter trajectory could be shaped to preclude this event. Table G-1 summarizes the probe storage requirements.

Storage requirements for General Science and Engineering instruments were not specifically defined for this study. It is assumed that the requirements of Pioneer 10 and 11 will be retained and probably will be increased. Since the IPP operation will coincide with the operation of PLSI, and since the IPP does require buffer storage, it is apparent that this instrument cannot share the PLSI storage. Therefore some additional storage capability must be provided for the General Science payload. In addition to buffering the IPP data, it may be desirable to store GS&E data during the occultation period. This requirement could be satisfied by the PLSI data buffer. The

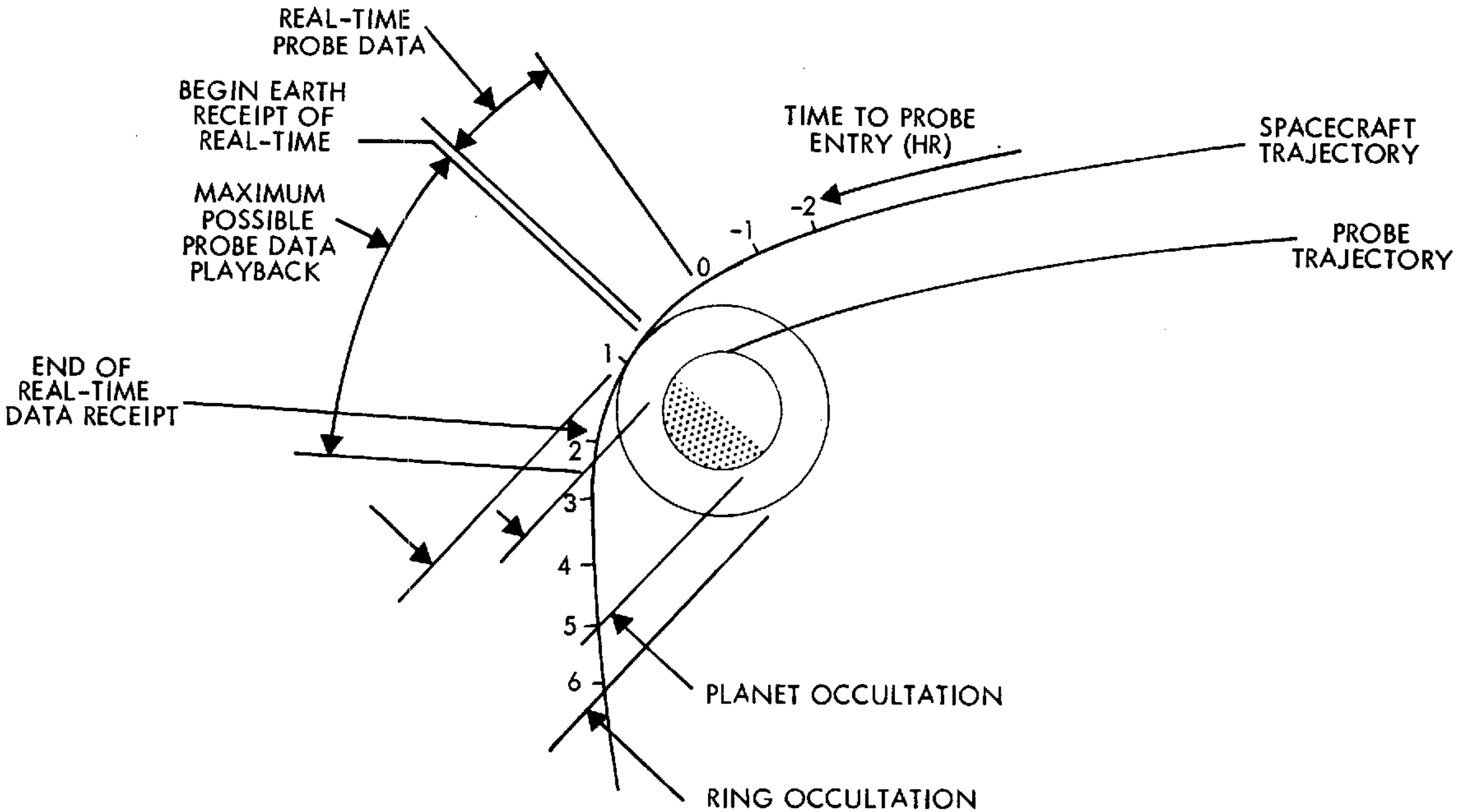


Figure G-1. Saturn Encounter Geometry

major problem in providing this capability comes from the large difference in input data rates. The PLSI data rate is approximately 9 to 11 Mbit/sec on 8 to 10 parallel lines whereas the GS&E data would be closer to 64 bit/sec; a dynamic range of 60 dB. Using the PLSI storage capacity of 0.82×10^6 (see derivation below) and the occultation periods contained in Table G-2, the typical occultation data storage rates at Saturn are:

$${}_1 = \frac{0.82 \times 10^6}{164 \times 60} \qquad 83.5 \text{ bit/sec (planet occultation)}$$

$${}_2 = \frac{0.82 \times 10^6}{262 \times 60} \qquad 52 \text{ bit/sec (ring occultation)}$$

Buffer storage for the PLSI may be dictated by several factors. For the OPPICSS study, the storage capacity is determined by the PLSI detector (160 pixels), the allowable aspect ratio (4:1), and the number of quantization levels. This latter parameter may vary from 8 to 10 bits per pixel, although in any case only 8 bits will be transmitted. Hence the minimum PLSI storage capacity will be (160) x (160 x 4) x (8) or 820,000 bits. The pertinent features of PLSI data storage requirements are given in Table G-3.

Table G-1. Probe Data Storage Requirements

Variable	Value	
Input bit rate	88 bps (nominal)	
Output bit rate	64 bps - 32.7 kbps (set by DTU)	
Maximum data storage	0.38×10^6 bits (set by Saturn entry)	
Input data form	Serial (write/erase)	
Output data form	Serial (non-destructive)	
Output buffer	(TBD) bits	
Interface signals	Input clock Input data Output clock	Output data Input power
Commands	Power on Power off	Register reset Begin readout

Table G-2. OPPICSS Mission Design Parameters

Mission:	1980 Saturn (Titan)/Uranus	
Launch Date:	26 November 1980 to 10 December 1980	
Spacecraft Weight:	476 kg. (1050 lb.)	
Launch Period:	15 days	
Launch Vehicle:	Titan/Centaur TE-364-4	
Titan Encounter:	0403 GMT 4 January 1984	
Titan Encounter Radial Distance:	333,000 km	
Saturn Encounter:	0224 GMT 5 January 1984 (3.1 yrs.)	
Saturn Encounter Radial Distance:	165,000 km (2.73 R_s)	
Saturn-Earth Distance at Encounter:	10.30 A.U. (1.54×10^9 km)	
Earth Occultation by Outer Ring:	Enter 0420 GMT, Exit 0842 GMT	5 Jan '84
Earth Occultation by Saturn:	Enter 0544 GMT, Exit 0828 GMT	5 Jan '84
Sun Occultation by Outer Ring:	Enter 0410 GMT, Exit 0744 GMT	5 Jan '84
Sun Occultation by Saturn:	Enter 0513 GMT, Exit 0743 GMT	5 Jan '84
Probe Separation:	4.23×10^7 km (<700 R_s)	
Bus-Probe Communication Range:	110,000 to 160,000 km	
Uranus Encounter:	1200 GMT 9 November 1987	
Uranus Encounter Radial Distance:	94,500 km (3.5 R_u)	
Earth Occultation:	Enter 1346 GMT, Exit 1519 GMT	9 Nov '87
Sun Occultation:	Enter 1354 GMT, Exit 1530 GMT	9 Nov '87
Uranus-Earth Distance at Encounter:	20.01 A.U. (2.995×10^9 km)	

Table G-3. PLSI Data Storage Requirements

Variable	Value
Input word rate	1.1×10^6 words/sec
Input data rate	8.8×10^6 bps ($11\ 0 \times 10^6$ bps)[1]
Output data rate	see Note 2
Maximum data storage	0.82×10^6 bits (1.024×10^6 bits)
Input data lines	8 parallel lines (10 parallel lines)
Output buffer	see Note 2
Interface signals	Word gate PLSI data Enable gate End-of-memory Housekeeping data
Input data form	Parallel (write/erase)
Output data form	see Note 2 (non-destructive)
Commands	see Note 2

Notes:

1. Values in parentheses based on storing 10 bit words.
2. Depends on the interface - whether with the DTU or the RM2.

2. TECHNOLOGY CONSIDERATIONS

2.1 General

Mass memories with bit capacities exceeding one-million bits utilized in a space environment in recent times have taken by default the form of tape recorders. Until recently, no suitable substitutes had been developed. With the advent of large scale integration (SI) and associated emerging technologies, a viable medium-capacity tape recorder substitute is becoming reality. This application of solid-state mass memory technology is particularly important from the standpoint of improved reliability and reduced weight, size, and power from that attainable with the conventional electro-mechanical devices currently employed in spacecraft systems.

The statement, "tape recorders are the most failure-prone component in U.S. spacecraft," provided the impetus for study of the feasibility of replacing tape recorders with a solid state mass memory. The projected mission time frame is 1978-1980 for anticipated required applications. A study of solid-state memories was conducted by TRW in December 1973.[1] The objective of this study was to provide a detailed state-of-the-art design for a solid state memory data storage unit meeting specified requirements and performance characteristics with special consideration given to maximizing reliability and bit capacity while minimizing cost, weight and power.

The mass memory study began by reviewing applicable solid state technologies that had potential in the projected time frame. The prime contenders were reduced to charged coupled devices (CCD) and complementary metal oxide semiconductor (CMOS), both of which had high bit capacity per chip and very low power dissipation per bit. A conceptual design using each technology was generated, with a resultant recommendation of further development of the CCD mass memory. Subsequently, a preliminary mass memory unit design was developed, providing a better definition of unit functions and characteristics.

The emerging very high density solid-state technology of CCDs offers many attractive features which make it a leading candidate for mass memory applications. For the time frame of interest, CCD memories have projected bit capacities in the range of 50 to 128 thousand bits per chip (or integrated circuit) with power dissipation in the range of 10 to 50 nanowatts per bit. TRW microelectronic center (MEC) has built and tested devices with 4096 bits per chip and currently plan to design, fabricate and test chips with bit densities up to 128K bits/chip by end of 1975. Simplicity in device fabrication and projected upper clock rates of 10 to 50 MHz are other CCD attributes. Although a relatively "young" technology, being about four year old at present, the basic fabrication technology and device physics are all derived from the well known MOS

[1] Solid State Mass Memory Study, TRW report 7331.2-052R, S.K. Ogi and M. Garaway dated 26 December 1973

technology that has been around since the mid-sixties. As the popular literature notes, many firms are actively pursuing device development in the CCD field. This implies good availability and alternate sources.

The CCD construction is a P-MOS type of the same technology which has been used successfully in the Pioneer 10 DTU multiplexer in the radiation environment of Jupiter. It is anticipated that the radiation effects on the CCD memories will be of the same level of susceptability as for the DTU on the Pioneer 10/11 missions.

2.2 Comparison of CMOS and CCD

CMOS and CCD configurations differ fundamentally in their mode of operation and bit density per chip.

The CMOS memory can operate as a Random Access Memory (RAM) with access times of 4 μsec or less while the CCD memory operates as a serial register so the access time is a function of the memory cycle time which is governed by bit rate and register length.

The bit density for a CMOS RAM is 256 bits/chip with up to 8 chips contained in one standard integrated circuit flat pack (1/4" x 1/4") for 2048 bits/flat pack. Considering leads and circuit etch paths the packaging density for these flat packs is about 2 flat packs/sq. in. This gives a bit density of:

$$\text{Bit density (CMOS)} = 2048 \text{ bits/fp} \times 2 \text{ fp/in}^2 = 4096 \text{ bits/in}^2$$

The bit density for CCD chips for the 1975 time frame is estimated by TRW's micro-electronics center to be up to 128K bits/chips where each chip is 0.4 in x 0.4 in. The OPPICSS study considered a density of 81,920 bits/chip. For a package of 6 chips the estimated size of the hybrid integrated circuit is 1.5 in x 2 in. Allowance for leads and circuit etch results in a density per package of one fp per 2 square inches or a bit density of:

$$\text{Bit density (CCD)} = 81{,}920 \text{ bits/chip} \times 6 \text{ chips/fp} \times 1\text{fp/5in}^2 = 98.3\text{K bits/in}^2$$

It is evident that for larger memory requirements the CCD has a bit density advantage while its access time disadvantage increases. The access time for the CCD can be improved with input/output buffering of segments of the mass memory; however this addes to the complexity and degrades the effective bit density.

A comparison is made in Table G-4 for CMOS and CCD mechanizations for the image data buffering required to support the AICS system. The CCD image data buffer and output buffer contains necessary internal buffering to provide access time necessary to interface with RM2 for source block transfers and with the DTU for continuous downlink data transmission. Figure G-3 shows the AICS interfaces for RM2, PLSI, DTU and the image data buffering. The trade does not include the data select and scaling and telemetry formatter and synchronizer which are necessary for either mass memory mechanization.

The data for the CCD mass memory is based on the mechanization presented in paragraph C3. The data for the CMOS is based on a previous TRW CMOS memory study[2].

Table G-5 shows a tradeoff of the Probe/DTU memory for CMOS and CCD technologies.

The comparisons in Table G-4 and G-5 show that the CCD image data buffering and Probe/DTU memories provide a significant advantage over the CMOS configuration.

3. DESCRIPTION OF SELECTED DESIGN

3.1 Approach

The requirements for storage for image data, probe data, and DTU data are different in rates and parallel/serial modes; however, with proper data buffering a common memory element can be used for the mass memory requirements minimizing development and fabrication costs.

The approach for the noncompression and AICS application is the same. The building block memory element is a CCD chip with several 8192-bit parallel registers which can be clocked together for word storage or separately or selected for serial storage. For the noncompressed data

[2] CMOS Memory Study by S.K. Ogi dated 30 November 1973.

Table G-4. CCD/CMOS Configuration Trade
(AICS Mission - Image Data Buffering)

	CMOS			CCD		
Parameter	Mass Memory	Output Buffer	Total	Mass Memory	Output Buffer	Total
Capacity (bits	1.024M	40,960	1,064,960	1.024M	81,920	1,105,920
Parts (total	850	200	1050	167	145	312
IC	670	100	770	77	65	142
Discrete	180	100	280	90	80	170
No. boards	12	2	14	2	2	4
No. slices	4	1	5	1	1	2
Size (in.)	8 x 6 x 8	1.6 x 6 x 8	9.6 x 6 x 8	1.6 x 6 x 8	1.6 x 6 x 8	3.2 x 6 x 8
Weight (lb)	6	1.4	7.4	1.4	1.4	2.8
Power (watts)	5	0.6	5.6	0.28[1]	0.12	0.40
				0.50[2]	0.12	0.62

[1] Downlink bit rate = 16.4 kbps

[2] Downlink bit rate = 8.2 kbps

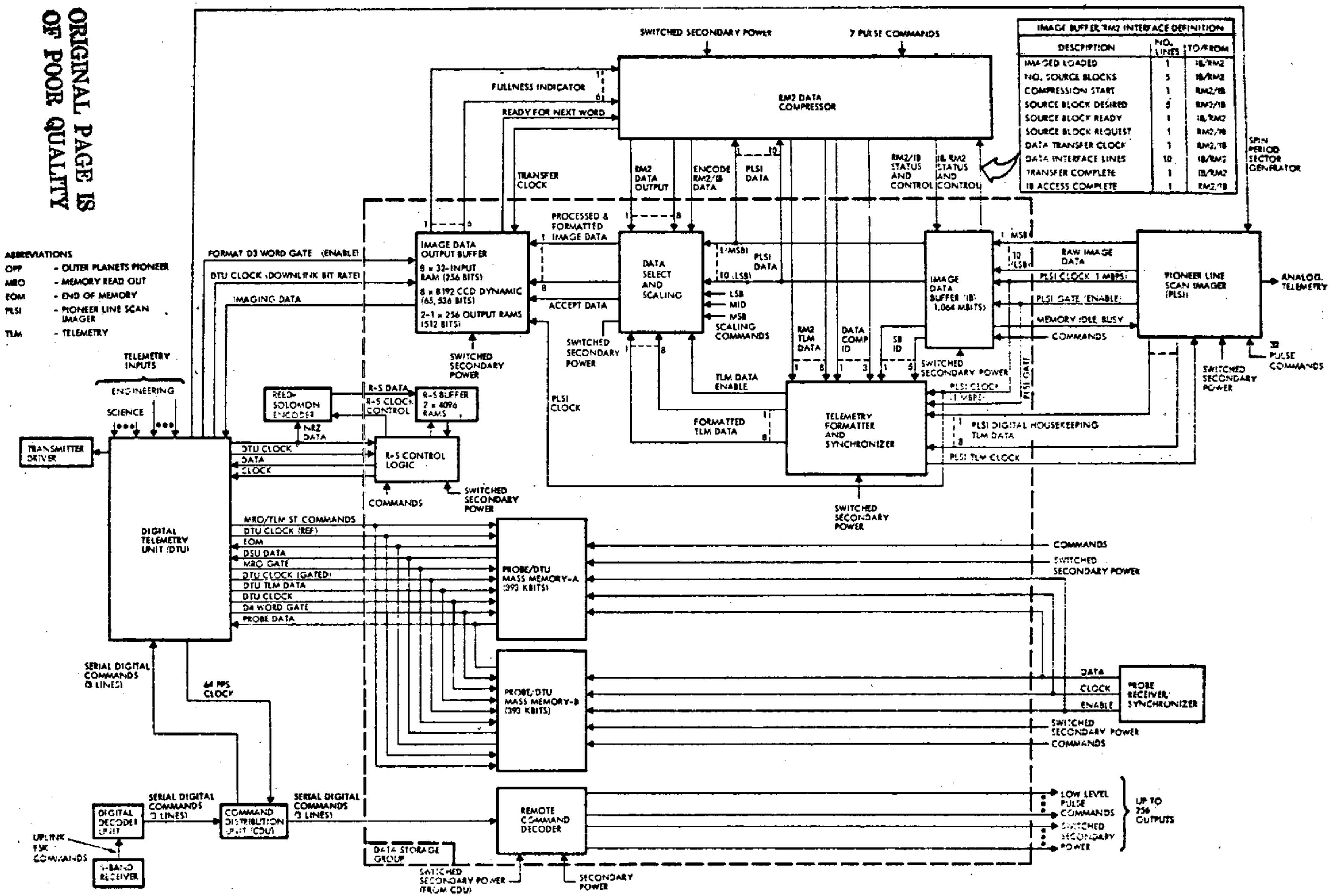


Figure G-2. AICS Image Data Block Diagram

Table G-5. Probe/DTU Memory

Parameter	CMOS	CCD
Capacity	393 21b bits	393,216 bits
Bit rate		
in/out internal	88 bps/imbps up to 1 mbps	88 bps/16,384 bps up to 10 mbps
Parts (total)	390	137
IC DISC	290 100	60 77
No boards	5	2
No slices	2 (2-board, 3-board)	1
Size	3" x 6" x 8"	1.4" x 6" x 8"
Weight (lb)	2.5	1.3
Power (watts)	2	0.15

or moderately compressed data application, eight parallel paths (65,536 bits) are required; for the AICS application, 10 parallel paths (81,920 bits) are required. The chip size will be about 400 x 400 mils. Up to six chips can be mounted in a hybrid integrated circuit package (1.5 x 2 inches. Almost all of the power dissipated in the memory is due to the clock driver input capacitance. This power varies approximately linearly with frequency according to Table G-6.

Table G-6. Operating Power Versus Frequency

Frequency	Power Per Chip (MW) 8-Parallel Bits (65,526 bits)	 10-Parallel Paths (81,920 bits)
1 kHz	0.58	0.72
10 kHz	5.0	6.3
100 kHz	50.0	62.0
1 MHz	500.0	620.0

The mass memory and buffer memory requirements are noted in Table G-7 indicating number of chips for each one and number of six integrated circuits and/or single-chip integrated circuits would be required. The AICS case is given as the number of chips for either system is the same.

Table G-7. AICS Memory Requirements

Memory	Capacity Requirement	Number of Chips	Number of IC 6 Chip	1 Chip
Image data Mass memory	1.024 Mbit (102,400 words)	12.5	2	1
Mass memory Output buffer	51,200 bits (5120 words)	1	-	1
Image data Output buffer	51,200 bits (5120 words)	1	-	1
Probe/DTU data Mass memory	380,160 bits	6	1	-

3.2 Operational Description (Adapted from Mass Memory Study)[1]

There are certain inherent characteristics of CCD memories that require special design consideration. Since the device is dynamic, a standby internal clock, which automatically takes over in the event of an external clock failure, is necessary. Also, synchronization circuits are required to ensure first in – first out (FIFO) storage.

After considering the above constraints, the following design guidelines are submitted:

- Redundant internal clocks as backup
- FIFO data storage
- Record followed by reproduce cycles only
- Serial structure for the memory devices
- Status telemetry outputs
- Continuous clock availability; internal or externally provided.

Basic to the operational philosophy of the memory system are the record-reproduce cycles. Once a record command has been received,

1) ibid

data will be stored in the CCD shift registers until the entire memory has been filled or an inhibit (stop) signal is decoded.[2] When a reproduce command is received, data is gated out of the memory in a FIFO fashion.

Because data storage is dynamic, a pointer counter system indicates the instantaneous position of the data. Forcing the pointer counter to a predetermined state at the beginning of a record cycle allows the first data bit to be correlated to a state of the counter. When a reproduce command is received, the system waits until the pointer indicates that the selected data bit is at the end of the loop, and then enables the output circuits.

Commanding multiple record cycles will require that the pointer be preset to the last address each time the command is received.

3.2.1 Clock Operation

In the event that the external clock is lost, it is imperative that an internal clock continue circulating the CCD memory; therefore, redundant low- and high-speed internal clocks are provided to minimize the probability of clock loss. The fast internal clock is provided so that there will be a minimum delay before data is available at the output. Either internal clock may be enabled by command. The clock frequencies used are the 1.048 MHz, 100 kHz (image data output buffer only), and 1 kHz with the high-speed clocks used for quickly moving data to the end of the memory system and read-in/read-out mode, and the 1 kHz clock used for low-power slow-speed operation in the storage or standby modes.

3.2.2 Shift Registers

The configurations of memories require both parallel and serial operation of the CCD registers. A configuration was chosen which can be compatible with both types of requirements with external logic mechanization. The operation of each CCD memory is still the same whether shifting data into one or 10 (eight for non-AICS) paths at once.

---

2) Original start up of the memory system requires a start command prior to a record or reproduce command. Also, a start command is required to override a previous inhibit command.

A CCD shift register presents a capacitive load to the data and clock drivers. Based on P-MOS shift register experience, nine CCD shift registers can be driven by one clock driver.

Output data from the CCD shift registers is level shifted to CMOS levels and passed on to the output. The output data is feed back to the input for recirculation and gated out when enabled by the control logic.

3.2.3 Control Logic and Pointer Counter

The memory applications for probe/DTU and image data buffering require intermittent read/write capabilities. Therefore, the control logic must properly decode commands and other logic inputs to put the memory into search, read-in/read-out, standby (storage), or power off modes for short spurts of time.

The pointer counter must have a main register that is initialized when the memory is first loaded and counts the memory clock to give a continual position indication of the circulating registers. An auxiliary register must remember the last address read in (for sporadic read in) and another must remember the last address read out. For the mass memory, a source block select register is also required to allow selection of specific blocks of data for readout.

Appx H

TRW

Appendix H

H L Moy

H. L. Moy

RM-2 and Reed-Solomon Encoder Cost Analysis

7331.9-010

TO: C. W. Renn

CC:

DATE: 8 November 1974

SUBJECT: OPPICSS RM2 & RS Encoder SWAG Cost Estimate

FROM: F. P. Hall

BLDG. R6 MAIL STA. 1118 EXT. 61944

To support JPL's costing effort for the OPPICSS Study this SWAG cost estimate is submitted, derived from the preliminary parts count informally received from JPL (Hilbert and Rice) 23 October 1974. In order to understand JPL/TRW responsibility for technical integrity, packaging, testing, and manufacturing, this estimate comprises the following elements which are included as attachments:

1. Ground Rules and Assumptions
2. Parts Count
3. Packaging (size, weight, power)
4. Cost Breakdown

Summary

1. The RM2 and R-S Encoder would be developed and tested through breadboard stages by JPL and translated into production flight hardware by TRW.

2. Parts Count:

	Total	IC	Discretes
RM2	485	385	100
R-S Encoder (Non-Redundant)	115	70	45

3. Packaging:

	Package	Size (inch.)	Weight (lb)	Power (w)
RM2	2-3 Board Slices	4 x 6 x 8	3.2	0.5
R-S Encoder	1-2 Board Slice	1.6 x 6 x 8	1.4	0.25

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Page 2

4. Cost:

	Engineering		Manufacturing
* RM2 (INCL. EM)	$397 K		
Test Equip. & Software	100 K		
3 Production Units			$146 K
RM2 Total		497 K	
* R-S Encoding (INC. EM)	99		
Test Equip. & Software	37		
3 Production Units			69 K
R-S Enc. Total		136 K	
* SPM/WPM (INCL. SKILL CENTER)		100 K	75 K
SEPARATE TOTALS		$733 K	$290 K
		290 K	
Product Integrity		82 K	
GRAND TOTAL		1105 K	

F. P. Hall

F. P. Hall

FPH:mls

EM - ENGINEERING MODEL

SPM - SUBPROJECT MANAGER

WPM - WORK PACKAGE MANAGER

Attachment 1
7331.9-010
November 8, 1974

GROUND RULES AND ASSUMPTIONS

1. JPL develops algorithms and performs conceptual design of RM2 and R-S encoding function considering applications for OPPICSS equipment.

2. JPL designs, builds, and tests breadboards for both RM2 and R-S encoder. The purpose of this activity is to prove the design visualized by JPL. The final activity of this stage would be a conceptual design review of the functions as implemented thus far.

3. JPL provides to TRW a data package documenting their efforts through breadboard tests and conceptual design review including:

   a) Functional description of RM2 algorithm and R-S encoder.

   b) Detailed logic design and analyses performed to implement breadboard.

   c) Trade-offs performed in the breadboard design phase.

   d) Detailed breadboard logic diagrams and schematics.

   e) Detailed breadboard parts list, recommending part types for production equipment.

   f) Breadboard test report.

   g) Results of the conceptual design review.

4. TRW engineering to utilize the concept developed by JPL and adapt it to hardware interfacing with AICS mission equipment.

5. The TRW engineering tasks for electrical and product engineering are identified below:

   5.1 <u>Electrical Engineering</u>

   a) Prepare detailed schematics and parts lists for hardware implementation of RM2 and R-S encoder.

   b) Perform worst-case analyses covering the following topics.

      - Logic Fan-Out
      - Logic Timing
      - Circuit Design
      - Component Power Dissipation
      - Component Application and Derating
      - Unit Power Profile

   c) Perform interface study to develop AICS requirements for RM2 and R-S encoder.

5.1 (continued)

d) Prepare equipment specifications for RM2 and R-S encoder based on the adapted JPL concept and AICS hardware interface.

e) Develop engineering model test plan, perform tests and submit an engineering model test report.

f) Design and fabricate engineering model and factory test equipment.

g) Development of test software (programs and procedures) for engineering models, qualification models and production equipment.

h) Prepare design review packages for:

- TRW Preliminary Design Review of hardware design concept (approximately 6-months after go-ahead).
- TRW Critical Design Review of engineering model analysis and test results (12 to 15 months after go-ahead).

i) Provide reliability analyses.

j) Prepare requirements and procedures for environmental tests required for electromagnetics, radiation, and thermal vacuum.

5.2 Product Engineering

a) Provide drawings, schematics and parts lists for engineering models and flight equipment.

b) Fabricate engineering models.

c) Stress, thermal and trade studies concerning packaging concept.

d) Design special test fixtures for environmental and acceptance testing.

e) Provide manufacturing liason engineer.

5.3 Component Engineering

a) Review parts application and provide necessary specifications for new parts that may be required.

b) Coordinate development of any new parts such as special printed-circuit boards or hybrid integrated circuits.

6. TRW manufacturing to provide management and skill center support to produce the following equipment:

	Qual	Flight	Spare	Total
RM2	1	1	1	3
R-S Encoder	1	1	1	3

Attachment 2
7331.9-010
November 8, 1974

PARTS COUNT

JPL submitted to TRW preliminary parts count by type which are listed below. The count is assumed to be a "preliminary actual" and includes no discretes. To provide for growth, power control and input/output buffering the JPL totals will be increased by 20% and an estimated number of discretes will be added. The total parts including the increased IC's and added discretes are the number of "design parts" upon which the engineering and manufacturing costs are based.

1.0 RM2 Parts List

Device Type	No. Flat Packs (Integrated Circuits)
Counters	16
Mux (Gates)	70
Demux (Gates)	12
RAM (64 x 4)	10
RAM (8 x 4)	10
ROM (8 x 256)	2
ROM (64 x 4)	3
Compare	25
Gates	90
SI/PO-PI/PO Registers	23
Add	37
Accumulator	20
CCD	3
JPL Total	321
+20%	64
	385
+ Discretes	100
Total Parts/Unit:	485

2.0 R-S Encoder Parts List

Parts Type	No. Flat Packs
RAM (512 x 1)	4
ROM (2)	2
ROM	2
PI/PO, SI/PO, PO/SI	6
Counter (4-Bit)	8
Mux (Gates)	4
EX-OR	2
Add	2
Gates	28
JPL Total	58

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2.0 (continued)

JPL Total	58
+20%	12
	70
+ Discretes	45
Total Parts/Board	115
Total Parts/Unit (2-Boards)	230

PACKAGING

The sizing for the units can be found with the following formula:

$$\text{No. of P.C. Boards} = \frac{1}{\text{Area/Board}}\left(\frac{\text{No. of IC}}{\text{IC Density}} + \frac{\text{No. of Disc}}{\text{Disc Density}}\right)$$

Area/Board = 34 in^2/Board (Parts on both sides if required)

IC Density = 2.25 IC/in^2

Disc Density = 6 Disc/in^2

1.0 RM2

$$\text{No. of P.C. Boards} = \frac{1}{34\ \text{in}^2/\text{Board}}\left(\frac{385\ \text{IC}}{2.25\ \text{IC/in}^2} + \frac{100\ \text{Disc}}{6\ \text{Disc/in}^2}\right)$$

$$= 5.52\ \text{Boards}$$

RM2 packages in 2 - 3 board slices.

	Size (inch)	Weight (lb)	Power (w)
Per Slice	2 x 6 x 8	1.6	-
Both Slices	4 x 6 x 8	3.2	0.5

2.0 R-S Encoder

$$\text{No. of P.C. Boards} = \frac{1}{34\ \text{in}^2/\text{Board}}\left(\frac{70}{2.25\ \text{IC/in}^2} + \frac{40}{6\ \text{Disc/in}^2}\right)$$

$$= 1.14\ \text{Boards}$$

R-S encoder packaged in 1 - 2 board slice (includes two identical redundant boards)

Size:	1.6 x 6 x 8 inches
Weight:	1.4 pounds
Power:	0.25 watts

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COST BREAKDOWN

1.0 Engineering Costs

		Electrical		Product Design
RM2 (485 Des. Parts)	1)	$ 195K	2)	$ 97K
Test Equipment & Fixture		40K		10K
Test Software		50K		-
Engineering Model ($70/Part)		-		35K
Component Eng.		25K		10K
Support To Mfg		10K		15K
Totals:		320K		167K
		167K		
RM2 Eng. Total (EE + PE)		$ 497K		
R-S Encoder (115 Des. Parts)	1)	$ 46K	2)	$ 23K
Test Equipment & Fixtures		15K		2K
Test Software		20K		-
Engineering Model (Non-Red.)		-		10K
Component Eng.		10K		-
Support to Mfg		5K		5K
Totals:		96K		40K
		40K		
R-S Encoder Eng. Total (EE + PE)		136K		
SPM/WPM		100K		
Total Engineering:		$ 733K		

2.0 Manufacturing Costs

Mfg Quantities:	Qual	Flight	Spare	Total
RM2	1	1	1	3
R-S Encoder	1	1	1	3
(Internally Redundant)				

RM2 (485 Production Parts) - 3 Units	3)	$ 146K
R-S Encoder (230 Production Parts) - 3 Units		69K
Total Production:		215K
Manufacturing Management & Skill Center		75K
Total Manufacturing Costs		$ 290K

3.0 Product Integrity (8% of total) 82K

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Notes:

1) EE design costs @ 400/design part (ELECTRICAL ENGINEERING)
2) PE design costs @ 200/design part (PRODUCT/PACKAGING ENGINEERING)
3) Mfg recovering costs @ 100/production part

Encl 10

TRW
SYSTEMS GROUP

Appendix I

Telecommunications System AICS as an Element of the Spacecraft

TO T. Gottlieb
JPL

CC:

DATE 29 October 1974

SUBJECT Action Item 76

FROM: C. W. Renn

BLDG R5 MAIL STA. 1271 EXT. 62310

As I understand this action item, the question can be paraphrased as follows:

What economies could be realized (weight, power, cost) and what other factors are involved (mission science, reliability, etc.) if the RM2 was established a priori as an element of the OPP spacecraft telecom system?

As a basis for answering this question, the simplified block diagram of the OPPICSS telecom system will be useful as a reference (see Figure I-1).

First, it should be noted that a data compression option does not reduce the required image data storage capacity. The primary effects of data compression are to reduce the telecom channel bit rate and possibly to reduce the information content of the image data.

Second, any (scientifically) acceptable compression ratio will not permit deletion of the X-band link on OPP. Per Figure I-2, the 8 watt S-band capability operating with the 64 meter ground antenna network can support nominal bit rates of 30 and 300 bits per second at Uranus and Saturn respectively. These bit rates might not provide acceptable imaging data, especially at Uranus. Further, the X-band system has other mission functions such as occultation science, telecom redundancy, and dual frequency tracking which may preclude the deletion of this channel.

Third, there are reasons in addition to the above, which mitigate against deletion of the S-band system. These include the requirement to utilize the Johannesburg station (no X-band capability) for injection plus the wider antenna beamwidth of the S-band system which alleviates tracking and maneuvering constraints. In any case, the S-band up-link is required for the command function.

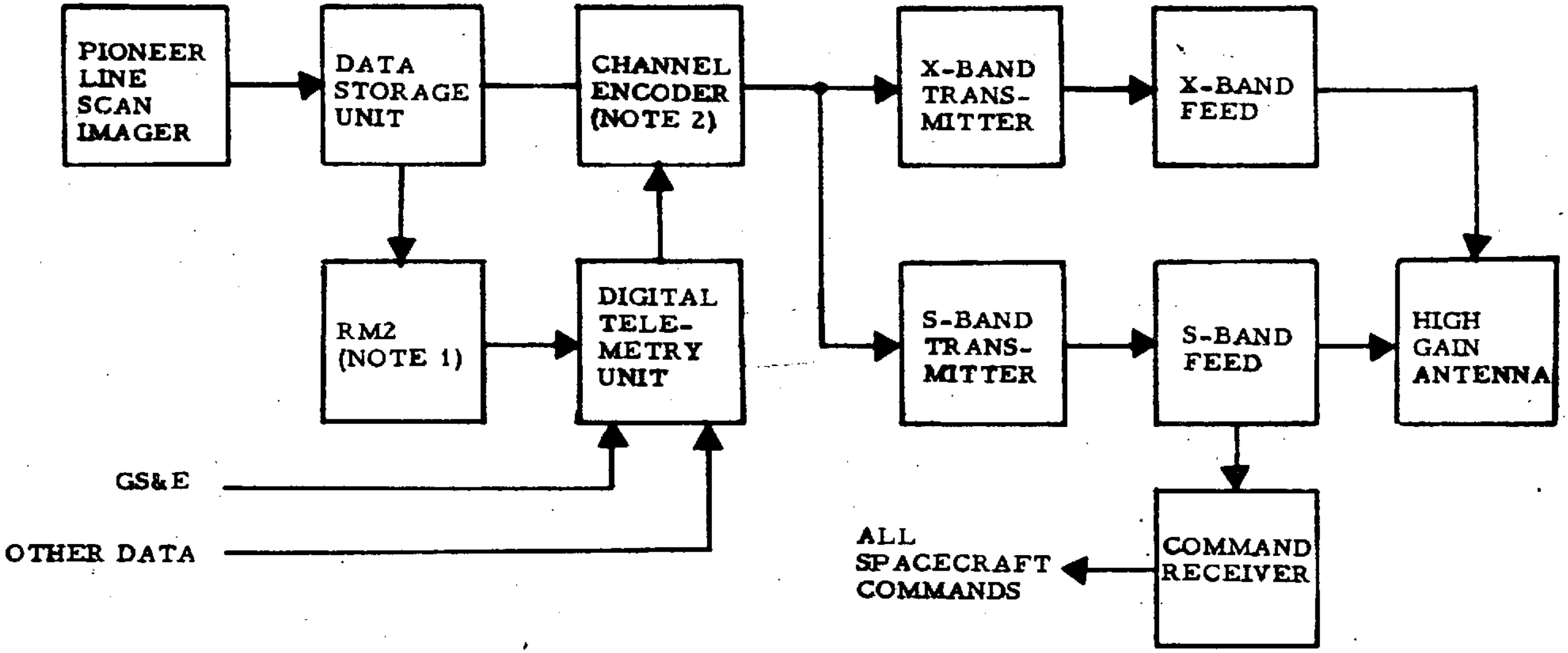
For this discussion, it will be assumed that a compression ratio is selected which will permit a 10 db reduction in EIRP. This reduction in EIRP would permit a reduction in antenna size from a 9-foot diameter to a 3-foot diameter with a potential weight saving of 15 to 20 pounds but no reduction in RTG power required. Obviously such a reduction in antenna size would have a serious impact on the S-band link and in particular on the command uplink.

Alternatively, the output power of the X-band link might be reduced from 20 watts to 4 watts as shown in Figure I-2. This in turn would allow a weight reduction of 10-15 pounds and a reduction in power of approximately 50 watts. The reduction to 4 watts instead of 2 watts is due to the receiver detection degradation at the lower bit rates. The power reduction is dramatic and could be the single most important benefit to be derived from the in-line use of data compression.

Table I-1 summarizes the various options and impacts.

C. W. Renn

C. W. Renn



NOTES:
1. COMPRESSION RATIO VARIABLE UPON COMMAND.
2. REED-SOLOMON/VITERBI.

FIGURE I-1. REFERENCE TELECOM CHANNEL

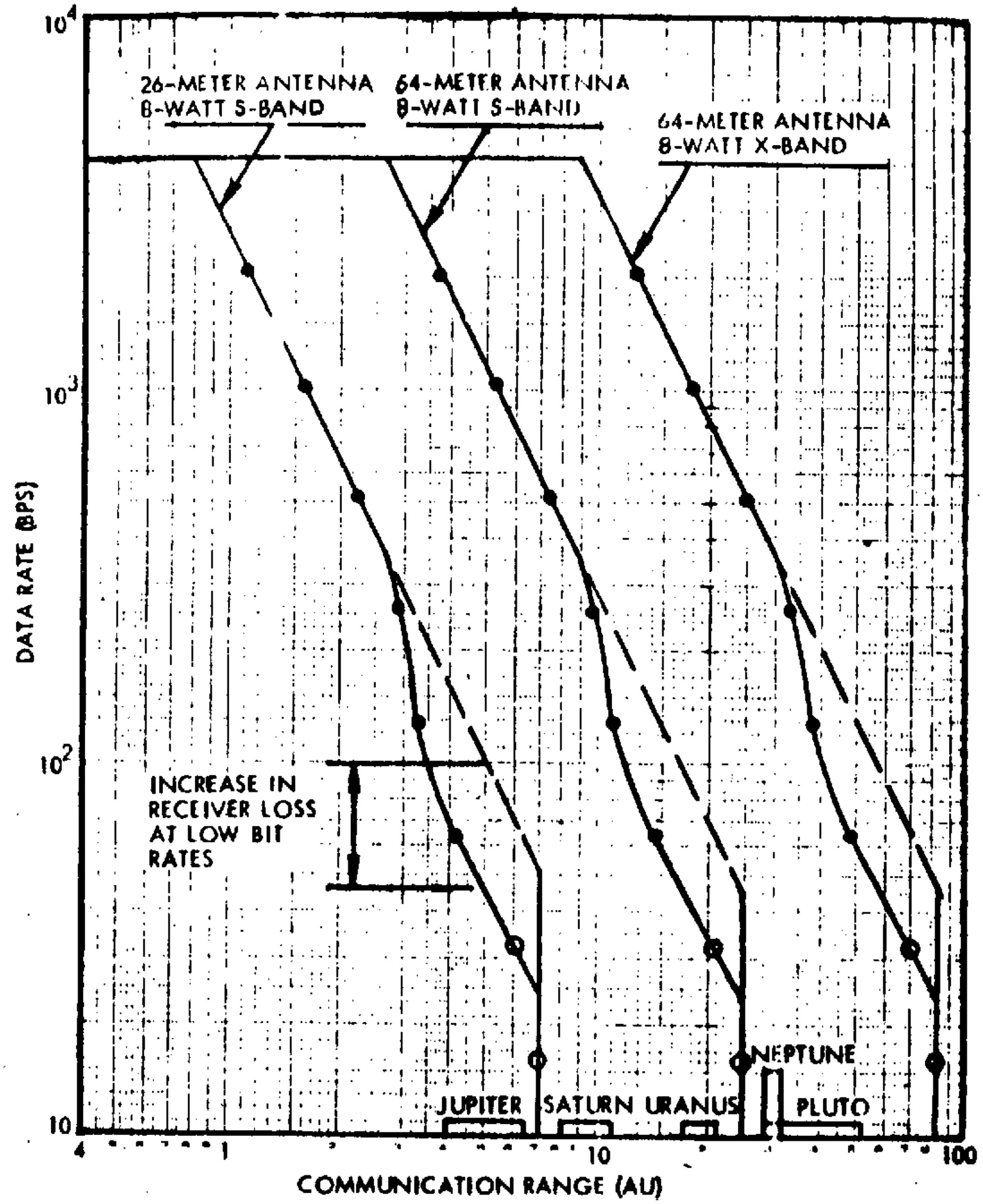


Figure I-2. Telemetry Bit Rate vs Range Profile

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Table I-1. Options Available When Using RM2

ASSUMPTIONS:

1. RM2 is added to the telecom channel per Figure 1 (3.2 lb 0.5 watts)
2. A compression ratio is selected to reduce EIRP by 10 db
3. Cost impacts are relative to OPPICSS no compression (option 1) configuration

OPTION		SPACECRAFT IMPACT			REMARKS
		WEIGHT (LB)	POWER (WATTS)	RELATIVE COST	
1.	Reduce high-gain antenna size	15-20 (Reduction)	—	Significant increase	Represents a substantial spaceccraft MOD; reduces uplink capability - probably unacceptable
2.	Reduce X-Band output power	10-15 (Reduction)	50 (Reduction)	Slight decrease	Reduction of RTG load is significant and may be required for the OPPICSS mission
3.	Delete X-Band system	20 (Reduction)	65 (Reduction)	Significant decrease	Reduces GS&E bit rate; impacts occultation experiment; reduces tracking capability; probably unacceptable
4.	Delete S-Band downlink	15 (Reduction)	30 (Reduction)	Slight decrease	Impacts injection, tracking, uplink capability, occultation; probably unacceptable

Appendix J

OPPICSS ACTION ITEM LIST

4 Dec '74

NO	ACTION ITEM	DUE		STATUS	COMMENT/RESOL
1	PROVIDE TEAM MEMBERS WITH OUTER PLANET PIONEER SPACECRAFT REFERENCE DOCUMENTATION.	KH	6/19	C 6/27, OPP S/C BOOK DISTD.	N/A
2	PROVIDE TEAM MEMBERS WITH MISSION DESIGN DOCUMENTATION	BS	6/19	C 6/19, NASA TM X-2824 AND IOM 392.1-14-AMG DISTD.	N/A
3	PROVIDE TEAM MEMBERS WITH AICS DOCUMENTATION.	RP	6/19	C 7/3, TM 33-695 DISTD.	N/A
4	PROVIDE TEAM MEMBERS WITH IMAGING DOCUMENTATION.	TR	7/10	C 6/27, TALK AND DOCU. DISTD.	N/A
5	PROVIDE A MEMO DESCRIBING THE TYPE AND SOURCE OF INFORMATION REQUIRED BY YOU TO BE ABLE TO RESPOND TO THE STATEMENT OF WORK.	ALL	6/19	C 7/3, ALL RESPONSES RECEIVED AND DISTD.	
6	REVIEW ATTACHED DISTRIBUTION LIST AND PROVIDE ADDITIONAL NAMES IF APPROPRIATE.	ALL	6/19	C 6/19	N/A
7	BRING A SUMMARY OF PRESENTATION TO BE INCLUDED IN THE MINUTES.	ALL	AT TIME OF OF PRESENTATION.	C 10/15.	N/A
8	PROVIDE TEAM MEMBERS WITH TM 33-584, TRACKING AND DATA SYSTEM SUPPORT FOR PIONEER 10. N/A	LP	7/3	C 7/3, TM DISTD.	N/A
9	CHECK BLANKS AND UNDERLINED PART OF OPPICSS MISSION DESIGN PARAMETERS, A TABULARIZED SUMMARY OF H. SWENSON,S 19 JUNE PRESENTATION.	AG	7/3	C 7/9, IOM 392.1-15-AMG, DISTD. M5/E3	1980 SAT/URAN MISSION PARAMETERS SUMMARIZED
10	DETERMINE WHAT FRACTION OF COMMUNICATIONS CHANNEL SHOULD BE PROVIDED TO IMAGING SCIENCE, GENERAL SCIENCE, AND ENGINEERING AS A FUNCTION OF MISSION PHASE.	LE	7/10	C 8/14, REV. 1 IOM 392.1-16AMG. M10/E2	GS E NEEDS AT LEAST 256 BITS/S DURING ENTIRE MISSION.
11	PROVIDE AN ESTIMATE OF THE TOTAL INPUT DATA RATE THAT THE SPACECRAFT MUST ACCOMMODATE AS A FUNCTION OF TIME DURING THE MISSION. ESTIMATE THE SCIENCE SEQUENCE REQUIREMENTS.	AG	7/17	C 7/22, IOM 392.1-16-AMG, M7/E2,M10/E2	GS E = 64BPS PROBE=88BPS MEM CAP=1.2 X 10(6)BITS FORMAT=187D 13,200 PIX AT SATURN (7.9 PIX/HR. 503 PIX AT URANUS(7.9

					PIX/HR.
12	RESOLVE THE APPROACH TO BE USED FOR ASSESSING THE IMAGING SCIENCE VALUE FOR THE VARIOUS FORMS OF DATA TRANSMISSION BEING CONSIDERED IN STUDY.	TR	7/17	C 8/14, M10/E3	NEW SCIENCE EVALUATION PLAN PROPOSED COMPLETION DATE ABOUT 3 FEB 75
13	UPDATE THE OUTER PLANET PIONEER SPACECRAFT CHARACTERISTICS FOR THE SATURN/URANUS MISSION.	KH	7/10	C 7/10, M4/E1	23 W TWT 32 TO 16K BPS 8K BPS AT 10 AU
14	RESOLVE THE QUESTION OF WHICH BASELINE PIONEER S/C AND SUPPORTING CONFIGURATION TO USE FOR THIS STUDY.	TG	7/17	C 7/17 BY B. PADRICK	POP S/C WILL BE BASELINE.
15	DEFINE THE PROJECTED DSN COMMAND BIT RATE CAPABILITY.	AS	7/10	C 7/17, M6/E	UP TO 32 BPS
16	DETERMINE AND DOCUMENT WHAT MODIFICATIONS NEED TO BE MADE TO THE OPP S/C TO SUPPORT NON-COMPRESSED IMAGING SCIENCE, INCLUDE FUNCTIONAL BLOCK DIAGRAM, WEIGHT, POWER, SIZE, LOCATION, RESOURCE REQUIREMENTS, AND ANY PROBLEMS ASSOCIATED WITH THE ABOVE.	CR	7/31	C 8/26 M9/E4 M14/E6	MODIFIED CODER(K=7, R=1/2), PROGRAMMER (1B7D BIT RATES (32 TO 33.76 KBPS FORMAT (10 PLSI ENG MSRMTS), SUB-CAR.FREQ. (32.768KHZ, 262.144KHZ), MEMORY (0.98M TO 1.2M BITS)
17	DETERMINE AND DOCUMENT WHAT MODIFICATIONS NEED TO BE MADE TO THE PLANNED DSN TO SUPPORT NON-COMPRESSED IMAGING SCIENCE, INCLUDE FUNCTIONAL BLOCK DIAGRAM, POWER, SIZE, LOCATION, RESOURCE REQUIREMENTS, AND PROBLEMS ASSOCIATED WITH ABOVE.	AS	7/31	C 8/6 M9/E2, M9/E3	CANNOT PERFORM HIGHER HIGHER THAN 2 KBPS SEQ. DECODING, CANNOT SUPPORT HIGH UPLINK TRAFFIC REQUIREMENT.
18	DETERMINE AND DOCUMENT WHAT MODIFICATIONS NEED TO BE MADE TO THE PLANNED MCCC TO SUPPORT NON-COMPRESSED IMAGING SCIENCE, INCLUDE FUNCTIONAL BLOCK DIAGRAM, POWER, SIZE, LOCATION, RESOURCE REQUIREMENTS, AND PROBLEMS ASSOCIATED WITH ABOVE.	RD	7/31	18 C 7/31 M8/E3 C 10/21 M18/E3	NO EFFECT EST. COST = $645K FOR 15K PICTURES.
19	DETERMINE AND DOCUMENT WHAT MODIFICATIONS NEED TO BE MADE TO THE PLANNED IPS TO SUPPORT NON-COMPRESSED IMAGING SCIENCE, INCLUDE	JS	7/31	C 10/22 M18/E5	MINOR REPROGRAMMING. EST. COST = $425K FOR

	FUNCTIONAL BLOCK DIAGRAM, POWER, SIZE, LOCATION, RESOURCE REQUIREMENTS, AND PROBLEMS ASSOCIATED WITH ABOVE.			APPROX. 6K PICTURES.
20	DETERMINE AND DOCUMENT WHAT MODIFICATIONS NEED TO BE MADE TO THE PLANNED MOS TO SUPPORT NON-COMPRESSED IMAGING SCIENCE, INCLUDE FUNCTIONAL BLOCK DIAGRAM, POWER, SIZE, LOCATION, RESOURCE REQUIREMENTS, AND PROBLEMS ASSOCIATED WITH ABOVE.	EL 7/31	NOT RESOLVED.	RESPONSE IN PROCESS.
21	SUBMIT A MEMO DESCRIBING IMAGE QUALITY AS FUNCTION OF BIT ERROR RATE.	TR 7/17	C 6/19 IOM SUBMITTED M7/E4	GS AND E BER LTE 5X10(-5) IM BER LTE 5X10(-3)
22	IDENTIFY THE DOCUMENT DESCRIBING THE GCF ERROR CHARACTERISTICS.	AS 7/24	C 7/31	IOM BY ODU ADAYEMI
23	IDENTIFY THE DOCUMENT DESCRIBING DSN STATION DATA PROCESSING ELEMENTS.	AS 7/17	C 7/24, M8/E4	TM 820-15 AND M8/E4
24	DETERMINE THE PROJECTED GCF HIGH-SPEED DATA LINE BIT RATE CAPABILITY.	AS 7/17	C 7/24	7200 BPS TO BE IMPLEMENTED FOR MJS.
25	VERIFY WITH ARC THE CONSEQUENCES OF FIXED S- AND X-BAND MOD INDEXES FOR THE OPP S/C DESIGN.	LE 7/24	C 8/28	STUDY TO ASSUME FIXED MOD INDEXES.
26	RESOLVE THE INCOMPATIBILITY BETWEEN POP S/C CODE AND DSN SUPPORT PLAN.	TG 7/17	C 7/12 SEE IOM 3395-74-074M6/E6	UNCOMPRESSED CASE WILL ASSUME K=7, R=1/2 CONVOLUTIONAL CODE
27	DETERMINE THE IMPLICATIONS OF CODING SCHEMES AND BIT ERROR RATE ON THE NON-IMAGING SCIENCE, IS A 10(-4) BIT ERROR RATE ACCEPTABLE FOR POP S/C SYSTEM.	LE 7/24	C 8/7	GS E BER OF LTE 10(-4) IS ACCEPTABLE.
28	DETERMINE THE PERFORMANCE OF K=7 VITERBI DECODING, AND ALSO THE PERFORMANCE OF K=32 SEQUENTIAL DEC.	JY 7/24	C 8/7 SEE M9/E2	THEY HAVE DIFFERENT ERROR CHAR. PERFORMANCE ABOUT SAME.
29	BE PREPARED TO DISCUSS TR S IOM, -DATA SYSTEM SIMULATIONS-.	ALL7/24	C 7/24	SEE M6/E5
30	DETERMINE THE IMPACT OF SEQUENTIAL DECODING ON THE DSN FOR DATA RATES GREATER THAN 2048 BITS/SEC.	AS 8/16	C 9/20 IOM AJS 74-25 M15/E8	$300K FOR UP TO 100K BPS.

31	PROPOSE A METHOD FOR PRODUCING VARIOUS NECESSARY PICTURE SIMULATIONS FOR ANALYSIS BY AN IMAGING SCIENCE CONSULTANT UNDER CONTRACT TO EVALUATE VARIOUS CANDIDATE DATA COMMUNICATION SYSTEMS FOR POP MISSIONS.	RP 7/31	C 8/21 REFER TO M10/E3	
32	SUPPLY DESIGN CONTROL TABLES ON THE TELECOMMUNICATIONS LINK TO KH.	JY 8/7	C 8/7 M14/E2	DESIGN CONTROL TABLES ON TELECOM DELIVERED.
33 (A)	FOR THE RESPECTIVE SYSTEMS, DETERMINE THE EFFECTS AND IMPLICATIONS OF (A) SUPPORTING A 2-CHANNEL TELEMETRY LINK, IMAGING ON X-BAND, GENERAL SCIENCE AND ENGINEERING ON S-BAND. (B) SUPPORTING 1-CHANNEL TELEMETRY CONCATENATED WITH, GOLAY OUTER CODE, K=7,R=1/2 INNER CODE, - REED SOLOMON OUTER, K=7, R=1/2 INNER CODE. (C) SUPPORTING 1.5-DB BIT RATE STEPS (D) SUPPORTING MORE THAN 8 BIT RATES, SAY 16 RATES.	CR 8/14	C 10/12 TRW 8140.8.7-40 M11/E2,M14/E6 M19/E9	A. WILL REQUIRE A SEPARATE PORTION OF THE DTU FOR X-BAND. B. MINOR MOD C. 6FP, 0.3W D. 7FP
33 (B)	FOR THE RESPECTIVE SYSTEMS, DETERMINE THE EFFECTS AND IMPLICATIONS OF (A) SUPPORTING A 2-CHANNEL TELEMETRY LINK, IMAGING ON X-BAND, GENERAL SCIENCE AND ENGINEERING ON S-BAND. (B) SUPPORTING 1-CHANNEL TELEMETRY CONCATENATED WITH, GOLAY OUTER CODE, K=7,R=1/2 INNER CODE, - REED SOLOMON OUTER, K=7, R=1/2 INNER CODE. (C) SUPPORTING 1.5-DB BIT RATE STEPS (D) SUPPORTING MORE THAN 8 BIT RATES, SAY 16 RATES.	AS 8/14	C 9/17 M14/E10	A. NO EFFECT. B. NO EFFECT (PRELIMINARY) C. AND D. NO EFFECT (SLIGHT OPERATIONAL COMPLEXITY).
33 (C)	FOR THE RESPECTIVE SYSTEMS, DETERMINE THE EFFECTS AND IMPLICATIONS OF (A) SUPPORTING A 2-CHANNEL TELEMETRY LINK, IMAGING ON X-BAND, GENERAL SCIENCE AND ENGINEERING ON S-BAND. (B) SUPPORTING 1-CHANNEL TELEMETRY CONCATENATED WITH, GOLAY OUTER CODE, K=7,R=1/2 INNER CODE, - REED SOLOMON OUTER, K=7, R=1/2 INNER CODE. (C) SUPPORTING 1.5-DB BIT RATE STEPS (D) SUPPORTING MORE THAN 8 BIT RATES, SAY 16 RATES.	JY 8/14	C 9/12 IOM 33-95-74-30 M16/E8	WILL BE ABLE TO SUPPORT.
33 (D)	FOR THE RESPECTIVE SYSTEMS, DETERMINE THE EFFECTS AND IMPLICATIONS OF (A) SUPPORTING A 2-CHANNEL TELEMETRY LINK, IMAGING ON X-BAND, GENERAL SCIENCE AND ENGINEERING ON S-BAND. (B) SUPPORTING 1-CHANNEL TELEMETRY CONCATENATED WITH, GOLAY OUTER CODE, K=7,R=1/2 INNER CODE, - REED SOLOMON	RD 8/14	C 9/12 IOM 916.25/34 M10/E4,	A. NO EFFECT. B1. MINOR EFFECT(3K WORDS 1/10 OF U1616). B2. 0.12 SEC/ BLOCK, 64K

	OUTER, K=7, R=1/2 INNER CODE. (C) SUPPORTING 1.5-DB BIT RATE STEPS (D) SUPPORTING MORE THAN 8 BIT RATES, SAY 16 RATES.			BYTE CORE, OR 0.22 SEC/ BLOCK, 0.5K BYTE CORE. (8 BIT) BYTES C.NO EFFECT D.NO EFFECT
33 (E)	FOR THE RESPECTIVE SYSTEMS, DETER- MINE THE EFFECTS AND IMPLICATIONS OF (A) SUPPORTING A 2-CHANNEL TELEMETRY LINK, IMAGING ON X-BAND, GENERAL SCIENCE AND ENGINEERING ON S-BAND. (B) SUPPORTING 1-CHANNEL TELEMETRY CONCATENATED WITH, GOLAY OUTER CODE, K=7,R=1/2 INNER CODE, - REED SOLOMON OUTER, K=7, R=1/2 INNER CODE. (C) SUPPORTING 1.5-DB BIT RATE STEPS (D) SUPPORTING MORE THAN 8 BIT RATES, SAY 16 RATES.	EL 8/14	NOT RESOLVED.	
33 (F)	FOR THE RESPECTIVE SYSTEMS, DETER- MINE THE EFFECTS AND IMPLICATIONS OF (A) SUPPORTING A 2-CHANNEL TELEMETRY LINK, IMAGING ON X-BAND, GENERAL SCIENCE AND ENGINEERING ON S-BAND. (B) SUPPORTING 1-CHANNEL TELEMETRY CONCATENATED WITH, GOLAY OUTER CODE, K=7,R=1/2 INNER CODE, - REED SOLOMON OUTER, K=7, R=1/2 INNER CODE. (C) SUPPORTING 1.5-DB BIT RATE STEPS (D) SUPPORTING MORE THAN 8 BIT RATES, SAY 16 RATES.	DC 8/14	NOT RESOLVED.	
33 (G)	FOR THE RESPECTIVE SYSTEMS, DETER- MINE THE EFFECTS AND IMPLICATIONS OF (A) SUPPORTING A 2-CHANNEL TELEMETRY LINK, IMAGING ON X-BAND, GENERAL SCIENCE AND ENGINEERING ON S-BAND. (B) SUPPORTING 1-CHANNEL TELEMETRY CONCATENATED WITH, GOLAY OUTER CODE, K=7,R=1/2 INNER CODE, - REED SOLOMON OUTER, K=7, R=1/2 INNER CODE. (C) SUPPORTING 1.5-DB BIT RATE STEPS (D) SUPPORTING MORE THAN 8 BIT RATES, SAY 16 RATES.	JS 8/14	C 10/22 M18/E5	NO EFFECT.
33 (H)	FOR THE RESPECTIVE SYSTEMS, DETER- MINE THE EFFECTS AND IMPLICATIONS OF (A) SUPPORTING A 2-CHANNEL TELEMETRY LINK, IMAGING ON X-BAND, GENERAL SCIENCE AND ENGINEERING ON S-BAND. (B) SUPPORTING 1-CHANNEL TELEMETRY CONCATENATED WITH, GOLAY OUTER CODE, K=7,R=1/2 INNER CODE, - REED SOLOMON OUTER, K=7, R=1/2 INNER CODE. (C) SUPPORTING 1.5-DB BIT RATE STEPS (D) SUPPORTING MORE THAN 8 BIT RATES, SAY 16 RATES.	TR 8/14	C 9/14 M14/E7	A. NO EFFECT B. REED-SOLO- MON PREFERRED C. BENEFICIAL D. BENEFICIAL

34 DETERMINE AND DOCUMENT THE UPLINK REQUIREMENTS FOR BASELINE MISSION.	AG 8/14	C 8/14 IOM 392.1-18-AMG,M10/E5	UPLINK REQUIREMENTS = ABOUT 2 BPS CONTINUOUS COMMANDING FOR IMAGING ONLY.
35 EVALUATE AVAILABLE CODING SCHEMES FOR MODERATE DATA COMPRESSION, AND MAKE A RECOMMENDATION FOR A BASELINE OPPICSS MISSION.	JY 8/14	C 8/4 BY A PRESENTATION. M14/E2 ALSO RICE/HILBERT IOM 3621-74-041. M11/E4	RECOMMENDED REED SOLOMON/VITERBI
36 (A) FOR THE BASELINE ANALYSIS, INCLUDE THE EFFECTS OF THE FOLLOWING FORMAT STRUCTURE, A(1)A(2)..A(N)..AND D(1)D(2)...D(M) B(1)B(2)..B(N)..AND D(1)D(2)...D(M) WHERE N=1 TO 8, AND M=1 TO 16.	CR 8/7	C 8/20 TRW 8140.8.7-39 M11/E2	IMPACT IS SUBSTANTIAL. RECOMMEND A1DN WHERE N LTE 7 WITH MIN. IMPACT
36 (B) FOR THE BASELINE ANALYSIS, INCLUDE THE EFFECTS OF THE FOLLOWING FORMAT STRUCTURE, A(1)A(2)..A(N)..AND D(1)D(2)...D(M) B(1)B(2)..B(N)..AND D(1)D(2)...D(M) WHERE N=1 TO 8, AND M=1 TO 16.	AS 8/7	C 9/17 M14/E11	NO EFFECT
36 (C) FOR THE BASELINE ANALYSIS, INCLUDE THE EFFECTS OF THE FOLLOWING FORMAT STRUCTURE, A(1)A(2)..A(N)..AND D(1)D(2)...D(M) B(1)B(2)..B(N)..AND D(1)D(2)...D(M) WHERE N=1 TO 8, AND M=1 TO 16.	RD 8/7 JS	C 8/14 M10/E4	NO EFFECT IF FORMAT INFORMATION IS AVAILABLE.
36 (D) FOR THE BASELINE ANALYSIS, INCLUDE THE EFFECTS OF THE FOLLOWING FORMAT STRUCTURE, A(1)A(2)..A(N)..AND D(1)D(2)...D(M) B(1)B(2)..B(N)..AND D(1)D(2)...D(M) WHERE N=1 TO 8, AND M=1 TO 16.	EL 8/7	NOT RESOLVED.	
36 (E) FOR THE BASELINE ANALYSIS, INCLUDE THE EFFECTS OF THE FOLLOWING FORMAT STRUCTURE, A(1)A(2)..A(N)..AND D(1)D(2)...D(M) B(1)B(2)..B(N)..AND D(1)D(2)...D(M) WHERE N=1 TO 8, AND M=1 TO 16.	DC 8/7	NOT RESOLVED.	
36 (F) FOR THE BASELINE ANALYSIS, INCLUDE THE EFFECTS OF THE FOLLOWING FORMAT STRUCTURE, A(1)A(2)..A(N)..AND D(1)D(2)...D(M) B(1)B(2)..B(N)..AND D(1)D(2)...D(M) WHERE N=1 TO 8, AND M=1 TO 16.	AG 8/7	C 9/17 M15/E17	PROVIDES A WIDE VARIETY OF DATA RATES

36 (G)	FOR THE BASELINE ANALYSIS, INCLUDE THE EFFECTS OF THE FOLLOWING FORMAT STRUCTURE, A(1)A(2)..A(N)..AND D(1)D(2)...D(M) B(1)B(2)..B(N)..AND D(1)D(2)...D(M) WHERE N=1 TO 8, AND M=1 TO 16.	JS 8/7	C 10/22	NO EFFECT.
37	PROVIDE TELECOMMUNICATION PERFORMANCE CURVES FOR THE NO-DATA-COMPRESSION BASELINE CASE.	JY 8/14	C 9/4 M14/E2	
38	DETERMINE AND DOCUMENT WHAT MODIFICATIONS NEED TO BE MADE TO THE OPP S/C TO SUPPORT MODERATELY COMPRESSED IMAGING SCIENCE, INCLUDE FUNCTIONAL BLOCK DIAGRAM, WEIGHT, POWER, SIZE, LOCATION, RESOURCE REQUIREMENTS, AND ANY PROBLEMS ASSOCIATED WITH ABOVE.	CR 8/28	C 10/23 WITH FINAL REPORT M19/E5	
39	DETERMINE AND DOCUMENT WHAT MODIFICATIONS NEED TO BE MADE TO THE PLANNED DSN TO SUPPORT MODERATELY COMPRESSED IMAGING SCIENCE, INCLUDE FUNCTIONAL BLOCK DIAGRAM, WEIGHT, POWER, SIZE, LOCATION, RESOURCE REQUIREMENTS, AND ANY PROBLEMS ASSOCIATED WITH ABOVE.	AS 8/28	C 9/17 M14/E9	NO FIRST ORDER EFFECT.
40	DETERMINE AND DOCUMENT WHAT MODIFICATIONS NEED TO BE MADE TO THE PLANNED MCCC TO SUPPORT MODERATELY COMPRESSED IMAGING SCIENCE, INCLUDE FUNCTIONAL BLOCK DIAGRAM, WEIGHT, POWER, SIZE, LOCATION, RESOURCE REQUIREMENTS, AND ANY PROBLEMS.	RD 8/28 JS	C 9/12 M15/E4 M18/E3	MINOR EFFECT. RS DECODER PIXEL DE-EDIT TOTAL COST = 845K FOR 15K PICTURES
41	DETERMINE AND DOCUMENT WHAT MODIFICATIONS NEED TO BE MADE TO THE PLANNED IPS TO SUPPORT MODERATELY COMPRESSED IMAGING SCIENCE, INCLUDE FUNCTIONAL BLOCK DIAGRAM, WEIGHT, POWER, SIZE, LOCATION, RESOURCE REQUIREMENTS, AND ANY PROBLEMS ASSOCIATED WITH ABOVE.	JS 8/28	C 10/23 WITH FINAL REPORT M18/E12	
42	DETERMINE AND DOCUMENT WHAT MODIFICATIONS NEED TO BE MADE TO THE PLANNED MOS TO SUPPORT MODERATELY COMPRESSED IMAGING SCIENCE, INCLUDE FUNCTIONAL BLOCK DIAGRAM, WEIGHT, POWER, SIZE, LOCATION, RESOURCE REQUIREMENTS, AND ANY PROBLEMS ASSOCIATED WITH ABOVE.	EL 8/28	NOT RESOLVED.	
43	RESOLVE AND PROVIDE THE RATIONALE FOR THE QUESTION OF WHETHER PIXEL EDITING SHOULD BE DONE IN THE IMAGING INSTRUMENT OR IN THE S/C DATA SYSTEM.	CR 8/14	C 8/20 TRW 8149.8.7-38 M11/E2	RECOMMENDED THAT IT BE DONE IN THE INSTRUMENT.

44	DETERMINE WHETHER OR NOT PIXEL AVERAGING WILL BE REQUIRED FOR THE MODERATE DATA COMPRESSION CASE.	TR 8/21	C 9/4 M14/E4.	PIXEL AVERAGING WILL NOT BE REQD.
45	PREPARE A NEW PLAN FOR PROVIDING SCIENCE EVALUATION DATA TO T.REILLY.	RP 8/9	C 10/30 M18/E8	
46	DETERMINE THE IMPACTS OF CODING/DECODING SCHEMES ON MODERATE DATA COMPRESSION FOR POP IMAGING.	RP 8/9	C 8/14. RICE/HILBERT IOM 3622-74-041. M11/E	R-S/VITERBI RECOMMENDED.
47	USE NOISY IMAGING DATA SIMULATION TAPE TO VALIDATE NOISY CHANNEL MODEL.	EH 9/4 JY	C 11/6	TAPE NOT REQD WILL HAVE PRELIMINARY VERSION OF DOC.BY 4 NOV.
48	DETERMINE AND DOCUMENT WHAT MODIFICATIONS NEED TO BE MADE TO THE PLANNED OPP S/C TO SUPPORT AICS RM2, INCLUDE FUNCTIONAL BLOCK DIAGRAM, SIZE, WEIGHT, POWER, LOCATION, RESOURCE REQUIREMENTS, AND ANY PROBLEMS.	CR 9/25	C 10/2 M16/E3	REQUIRED CHANGES LISTED (4,6.2 X6X8 IN SLICES, 6.2 LB, 4.25 W).
49	DETERMINE AND DOCUMENT WHAT MODIFICATIONS NEED TO BE MADE TO THE PLANNED DSN TO SUPPORT THE AICS RM2, INCLUDE FUNCTIONAL BLOCK DIAGRAM, SIZE, WEIGHT, POWER, LOCATION, RESOURCE REQUIREMENTS, AND ANY PROBLEMS.	AS 9/25 EG	C 10/16 M17/E1	MAY REQUIRE ERROR CONTROL ON GCF WIDEBAND.
50	DETERMINE AND DOCUMENT WHAT MODIFICATIONS NEED TO BE MADE TO THE PLANNED MCCC TO SUPPORT THE AICS RM2 INCLUDE FUNCTIONAL BLOCK DIAGRAM, SIZE, WEIGHT, POWER, LOCATION, RESOURCE REQUIREMENTS, AND ANY PROB-	RD 9/25 JS	C 10/21 M18/E3	WILL HAVE TO INCLUDE A R/S DECODER AND RM2 DECODER MODULE (APP. TOTAL COST = $920K FOR 15K PICTURES,4 SEC ADTL PROCESSING/PIX).
51	DETERMINE AND DOCUMENT WHAT MODIFICATIONS NEED TO BE MADE TO THE PLANNED IPS TO SUPPORT THE AICS RM2, INCLUDE FUNCTIONAL BLOCK DIAGRAM, SIZE, WEIGHT, POWER, LOCATION, RESOURCE REQUIREMENTS, AND ANY PROBLEMS.	JS 9/25	C 10/22 M18/E5	MINOR REPROGRAMMING, NO ADDITIONAL COST.
52	DETERMINE AND DOCUMENT WHAT MODIFICATIONS NEED TO BE MADE TO THE PLANNED MOS TO SUPPORT THE AICS RM2, INCLUDE FUNCTIONAL BLOCK DIAGRAM, SIZE, WEIGHT, POWER, LOCATION, RE-	EL 9/25	NOT RESOLVED.	

SOURCE REQUIREMENTS, AND ANY PROBLEMS.

53	SHOULD THE REED SOLOMON OUTER-LEVEL DECODING BE DONE, IN THE DSS, AS OPPOSED TO THE MCCC.	AS 9/25	C 10/16 M17/E	RECOMMEND IT BE DONE IN MCCC FOR COST EFFECTIVENESS
54	DOCUMENT THE TV GAINS OBTAINED FROM THE AICS RM2 RELATIVE TO THOSE FROM MODERATE DATA COMPRESSION OR FROM THE POP BASELINE FOR SATURN AND URANUS.	TR 10/9	C 11/5 M19/E9	THE COMPRESSOR IS PRIMARILY A NEAR ENCOUNTER ENHANCEMENT DEVICE.
55 (A)	IDENTIFY DEVIATIONS FROM TELEMETRY STANDARDS FOR THE POP S/C,	CR 9/25	C 10/30 M19/E2	DEVIATIONS LISTED.
55 (B)	IDENTIFY DEVIATIONS FROM TELEMETRY STANDARDS FOR THE DSN	AS 9/25	NOT RESOLVED.	
55 (C)	IDENTIFY DEVIATIONS FROM TELEMETRY STANDARDS FOR THE MCCC	RD 9/25 JS	C 10/2 M16/E6	DEVIATIONS LISTED.
55 (D)	IDENTIFY DEVIATIONS FROM TELEMETRY STANDARDS FOR THE MOS	DC 9/25	NOT RESOLVED.	
55 (E)	IDENTIFY DEVIATIONS FROM TELEMETRY STANDARDS FOR THE IPS	JS 9/25	NOT RESOLVED.	
56	ANALYZE THE AICS RS/VITERBI TELECOMMUNICATIONS CHANNEL PERFORMANCE.	JY 10/2	NOT RESOLVED.	A.I. 62 MUST BE COMPLETED FIRST.
57	DOCUMENT THE POP S/C ROLL AND OVERHEAD LIMITATIONS ON DATA COMPRESSION GAIN.	TR 9/25	C 9/4 M14/E3	OVERHEAD IS VARIABLE, BUT TYPICALLY APPROXIMATELY 20 PERCENT.
58	PREPARE A DETAILED FUNCTIONAL INTER FACE DIAGRAM FOR POP S/C DATA SYSTEM INCLUDING THE RM2 COMPRESSOR, THE RS CODER, BUFFER, AND ADVANCED LINE SCAN IMAGER. RESOLVE THE FOLLOWING (A) RM2 S USE OF THE MAIN BUFFER VS USING AN INTERNAL 35K MEMORY WITHIN THE RM2. (B) INTERFACE BETWEEN LINE SCAN IMAGER, RM2, AND BUFFER. (C) RS CODER/BUFFER INTERFACE. (D) SEQUENTIAL VS PARALLEL RM2 PROCESSING. (E) DATA FORMAT AND SYNCH. (F) MAIN BUFFER STRUCTURE (G) DATA COMPRESSION RATIOS.	CR 9/13 W EH 10/2 TR AG JS	C 10/2 M16/E4	N/A
59 (A)	RESOLVE THE COST PER PICTURE FOR POP S/C LINE SCAN IMAGER,	9/25 JS	C 10/31 WITH FINAL REPORT	$28K/1000 PICTURES

				M18/E12	
59 (B)	RESOLVE THE COST PER PICTURE FOR POP S/C LINE SCAN IMAGER,	JS	9/25	C 10/22 WITH FINAL REPORT M18/E5	$28K/1000 PICTURES
59 (C)	IDENTIFY THE PRICING STRUCTURES, THE TYPE, SIZE AND TIME OF PICTURES.	TR	9/25	C 10/28 M19/E4	CANNOT RE-SOLVE AT THIS TIME. NEED MORE DETAILED ANALYSIS.
60	REVIEW AND ASSES THE FUNCTIONAL OPERATION OF RM2 BASED ON WORK DONE TO DATE. MAKE RECOMMENDATIONS AS TO WHAT ADDITIONAL WORK IS NEEDED TO VALIDATE THE RM2 ALGORITHM, ABOVE, WHAT IS PLANNED FOR RM2 SIMULATIONS, IF ANY.	RM	9/25	C 9/12 M15/E	RECOMMEND DIV. 36 PROVIDE MORE CREDIBLE PER-FORMANCE DATA. LOOKS PROMISING.
61	WRITE A MISSION DESCRIPTION (A SCIENCE SEQUENCE) FOR EACH OF THE SATURN/URANUS ENCOUNTERS. DESCRIBE THE IMAGING RETURN AS A FUNCTION OF TIME AT EACH ENCOUNTER (FAR AND NEAR ENCOUNTERS) FOR THE BASELINE, MODE-RATE DATA COMPRESSION, AND AICS SYSTEMS. DEVELOP THE COMMAND SEQ-UENCE FOR EACH SYSTEM, AND DESCRIBE THE GENERAL SCIENCE RETURN. (SUP-PORT FROM TR.)	AG	10/15	NOT RESOLVED.	
62	ANALYZE THE IMPACT OF USING THE R.S. OUTER CODE ON THE VITERBI CHAN-NEL OPERATION (DSN RECEIVE AND SUB-CARRIER DEMODULATION, DECODING AND DETECTION IN THE 10(2) BER REGION). FOR INSTANCE, DOES OPERATING THE VITERBI CHANNEL A BER EGT 10(2) HAVE ANY PECULIAR EFFECT ON DSN DECODING. COMPARE PERFORMANCE AND IMPLEMENTA-TION (COST TRADEOFFS) IMPLICATIONS OF R.S. /VITERBI AND SEQUENTIAL DE-CODING. ARE THERE OTHER CODING SCHEMES UNDER DEVELOPMENT THAT SHOULD BE CONSIDERED FOR HIGH QUA-LITY - HIGH VOLUMES CHANNELS (LOW BER/HIGH DATA RATE). WHAT IS THE RECOMMENDED CODE/DECODE SYSTEM FOR THIS TYPE OF CHANNEL.	JY WI TH HE LP FR OM RM JL DL	10/2	C 10/22 M18/E4	R-S/VITERBI WITH R-S DECODING AT MCCC RECOM-MENDED. TOTAL COST TO DSN = $300K + MAINTENANCE.
63 (A)	ASSESS IMPACT AND DESIRABILITY OF IMPLEMENTING TR S SUGGESTED COMMAND MODIFICATIONS.	AG	10/2	C 10/10 M18/E9	
63 (B)	ASSESS IMPACT AND DESIRABILITY OF IMPLEMENTING TR S SUGGESTED COMMAND MODIFICATIONS.	AS	10/2	C 10/16 M17/E	TRAFFIC CON-FLICT REMOVED REAL TIME

				CMD REQUIREMENT STILL INCOMPATIBLE WITH DSN. (SEE AI 77)
63 (C)	ASSESS IMPACT AND DESIRABILITY OF IMPLEMENTING TR S SUGGESTED COMMAND MODIFICATIONS.	RD 10/2 JS	C 10/16 M17/E	NO IMPACT.
63 (D)	ASSESS IMPACT AND DESIRABILITY OF IMPLEMENTING TR S SUGGESTED COMMAND MODIFICATIONS.	JS 10/2	C 12/4 BY TG	NO IMPACT.
63 (E)	ASSESS IMPACT AND DESIRABILITY OF IMPLEMENTING TR S SUGGESTED COMMAND MODIFICATIONS.	DC 10/2	NOT RESOLVED.	
63 (F)	ASSESS IMPACT AND DESIRABILITY OF IMPLEMENTING TR S SUGGESTED COMMAND MODIFICATIONS.	EL 10/2	NOT RESOLVED.	
63 (G)	ASSESS IMPACT AND DESIRABILITY OF IMPLEMENTING TR S SUGGESTED COMMAND MODIFICATIONS.	CR 10/2	NOT RESOLVED.	
64	PROVIDE AN UPDATED VERSION OF THE POP G.S. REQUIREMENTS, 1. PAYLOAD 2. MIN/MAX RATES. 3. BER. 4. STORAGE FACTOR IN THE MJS AND PIONEER VENUS GENERAL SCIENCE SELECTION PROCESSES.	LE 10/3	C 9/30 M16/E7	
65	FOLLOWS UP ON TAPE STATUS FOR A.I.47	RP 9/18	C 11/8 BY TG REPORT PRESIDED TO JY M18/E7	TAPE NOT REQD WILL HAVE PRELIMINARY REPORT ON 4 NOV.
66	DEFINE THE S/C MEMORY CAPACITY REQUIREMENTS FOR EACH OF THE THREE DATA TRANSMISSION CASES (NO) COMPRESSION, PIXEL EDITING, AND AICS).	AG 9/25	C 9/23 M15/E12	1.2M BITS FOR EACH PLUS 64K BITS FOR RM2.
67	IS THE COST FOR SEQUENTIAL DECODING LOWER FOR BIT RATES BELOW 100 KBPS (E.G. 16 KBPS.)	AS 10/9	C 9/25	NOT SIGNIFICANTLY.
68 (A)	REVIEW AND COMMENT ON THE FINAL REPORT OUTLINE (INCLUDE THOSE ITEMS THAT YOU FEEL OUGHT TO BE INCLUDED FROM YOUR AREA BASED ON THE STATEMENT OF WORK, AND YOUR OPINION, AND PROVIDE AN UPDATED OUTLINE OF YOUR SECTION.)	AG 9/30	C 9/30 M18/E9	SATISFACTORY AS IS.
68 (B)	REVIEW AND COMMENT ON THE FINAL REPORT OUTLINE (INCLUDE THOSE ITEMS THAT YOU FEEL OUGHT TO BE INCLUDED FROM YOUR AREA BASED ON THE STATE-	TR 9/30	C 9/30	SATISFACTORY AS IS.

	MENT OF WORK, AND YOUR OPINION, AND PROVIDE AN UPDATED OUTLINE OF YOUR SECTION.)			
68 (C)	REVIEW AND COMMENT ON THE FINAL REPORT OUTLINE (INCLUDE THOSE ITEMS THAT YOU FEEL OUGHT TO BE INCLUDED FROM YOUR AREA BASED ON THE STATEMENT OF WORK, AND YOUR OPINION, AND PROVIDE AN UPDATED OUTLINE OF YOUR SECTION.)	JY 9/30	C 9/30	CHANGE CHAPTER. NO.
68 (D)	REVIEW AND COMMENT ON THE FINAL REPORT OUTLINE (INCLUDE THOSE ITEMS THAT YOU FEEL OUGHT TO BE INCLUDED FROM YOUR AREA BASED ON THE STATEMENT OF WORK, AND YOUR OPINION, AND PROVIDE AN UPDATED OUTLINE OF YOUR SECTION.)	CR 9/30	C 9/30	SATISFACTORY AS IS.
68 (E)	REVIEW AND COMMENT ON THE FINAL REPORT OUTLINE (INCLUDE THOSE ITEMS THAT YOU FEEL OUGHT TO BE INCLUDED FROM YOUR AREA BASED ON THE STATEMENT OF WORK, AND YOUR OPINION, AND PROVIDE AN UPDATED OUTLINE OF YOUR SECTION.)	AS 9/30	C 10/7	SATISFACTORY AS IS.
68 (F)	REVIEW AND COMMENT ON THE FINAL REPORT OUTLINE (INCLUDE THOSE ITEMS THAT YOU FEEL OUGHT TO BE INCLUDED FROM YOUR AREA BASED ON THE STATEMENT OF WORK, AND YOUR OPINION, AND PROVIDE AN UPDATED OUTLINE OF YOUR SECTION.)	RD 9/30 JS	C 10/7	SATISFACTORY AS IS.
68 (G)	REVIEW AND COMMENT ON THE FINAL REPORT OUTLINE (INCLUDE THOSE ITEMS THAT YOU FEEL OUGHT TO BE INCLUDED FROM YOUR AREA BASED ON THE STATEMENT OF WORK, AND YOUR OPINION, AND PROVIDE AN UPDATED OUTLINE OF YOUR SECTION.)	JS 9/30	C 10/31 M18/E15	WILL ADD A SECTION ON COMMAND INDEPENDENCE.
68 (H)	REVIEW AND COMMENT ON THE FINAL REPORT OUTLINE (INCLUDE THOSE ITEMS THAT YOU FEEL OUGHT TO BE INCLUDED FROM YOUR AREA BASED ON THE STATEMENT OF WORK, AND YOUR OPINION, AND PROVIDE AN UPDATED OUTLINE OF YOUR SECTION.)	DC 9/30	NOT RESOLVED.	
68 (I)	REVIEW AND COMMENT ON THE FINAL REPORT OUTLINE (INCLUDE THOSE ITEMS THAT YOU FEEL OUGHT TO BE INCLUDED FROM YOUR AREA BASED ON THE STATEMENT OF WORK, AND YOUR OPINION, AND PROVIDE AN UPDATED OUTLINE OF YOUR SECTION.)	EL 9/30	NOT RESOLVED.	

68 (J) REVIEW AND COMMENT ON THE FINAL REPORT OUTLINE (INCLUDE THOSE ITEMS THAT YOU FEEL OUGHT TO BE INCLUDED FROM YOUR AREA BASED ON THE STATEMENT OF WORK, AND YOUR OPINION, AND PROVIDE AN UPDATED OUTLINE OF YOUR SECTION.)	RP 9/30	C 9/30	SOME MODIFICATIONS.
69 (A) WHAT CONCLUSIONS CAN YOU DRAW (FOR YOUR AREA OF RESPONSIBILITY) FROM THE OPPICSS STUDY.	AG 10/18	C WITH FINAL REPORT	
69 (B) WHAT CONCLUSIONS CAN YOU DRAW (FOR YOUR AREA OF RESPONSIBILITY) FROM THE OPPICSS STUDY.	TR 10/18	C 10/25 M18/E2 M19/E4	CONCLUSIONS DOCUMENTED.
69 (C) WHAT CONCLUSIONS CAN YOU DRAW (FOR YOUR AREA OF RESPONSIBILITY) FROM THE OPPICSS STUDY.	JY 10/18	C 10/25 M18/E14	
69 (D) WHAT CONCLUSIONS CAN YOU DRAW (FOR YOUR AREA OF RESPONSIBILITY) FROM THE OPPICSS STUDY.	CR 10/18	C 10/31 WITH FINAL REPORT M19/E5	
69 (E) WHAT CONCLUSIONS CAN YOU DRAW (FOR YOUR AREA OF RESPONSIBILITY) FROM THE OPPICSS STUDY.	AS EG 10/18	C 10/31 M18/E15	
69 (F) WHAT CONCLUSIONS CAN YOU DRAW (FOR YOUR AREA OF RESPONSIBILITY) FROM THE OPPICSS STUDY.	RD JS 10/18	C 10/31 WITH FINAL REPORT M18/E12	
69 (G) WHAT CONCLUSIONS CAN YOU DRAW (FOR YOUR AREA OF RESPONSIBILITY) FROM THE OPPICSS STUDY.	JS 10/18	C 10/22 WITH FINAL REPORT M18/E5	
69 (H) WHAT CONCLUSIONS CAN YOU DRAW (FOR YOUR AREA OF RESPONSIBILITY) FROM THE OPPICSS STUDY.	DC 10/18	NOT RESOLVED.	
69 (I) WHAT CONCLUSIONS CAN YOU DRAW (FOR YOUR AREA OF RESPONSIBILITY) FROM THE OPPICSS STUDY.	EL 10/18	NOT RESOLVED.	
69 (J) WHAT CONCLUSIONS CAN YOU DRAW (FOR YOUR AREA OF RESPONSIBILITY) FROM THE OPPICSS STUDY.	RP 10/18	C 11/4 WITH FINAL REPORT M19/E10	
70 (A) WHAT RECOMMENDATIONS DO YOU HAVE (FOR YOUR AREA OF RESPONSIBILITY) BASED ON THE ABOVE CONCLUSIONS.	AG 10/18	C 10/23 WITH FINAL REPORT M19/E3	
70 (B) WHAT RECOMMENDATIONS DO YOU HAVE (FOR YOUR AREA OF RESPONSIBILITY) BASED ON THE ABOVE CONCLUSIONS.	TR 10/18	C 10/25 M18/E2 M19/E4	EXTEND DESIGN COMMONALITY TO THE S/C.
70 (C) WHAT RECOMMENDATIONS DO YOU HAVE (FOR YOUR AREA OF RESPONSIBILITY)	JY 10/18	C 10/31 M18/E14	

BASED ON THE ABOVE CONCLUSIONS.

70 (D)	WHAT RECOMMENDATIONS DO YOU HAVE (FOR YOUR AREA OF RESPONSIBILITY) BASED ON THE ABOVE CONCLUSIONS.	CR	10/18	C 10/31 WITH FINAL REPORT M19/E5	
70 (E)	WHAT RECOMMENDATIONS DO YOU HAVE (FOR YOUR AREA OF RESPONSIBILITY) BASED ON THE ABOVE CONCLUSIONS.	AS EG	10/18	C 10/31 M18/E15	
70 (F)	WHAT RECOMMENDATIONS DO YOU HAVE (FOR YOUR AREA OF RESPONSIBILITY) BASED ON THE ABOVE CONCLUSIONS.	RD JS	10/18	C WITH FINAL REPORT	
70 (G)	WHAT RECOMMENDATIONS DO YOU HAVE (FOR YOUR AREA OF RESPONSIBILITY) BASED ON THE ABOVE CONCLUSIONS.	JS	10/18	C WITH FINAL REPORT	
70 (H)	WHAT RECOMMENDATIONS DO YOU HAVE (FOR YOUR AREA OF RESPONSIBILITY) BASED ON THE ABOVE CONCLUSIONS.	DC	10/18	NOT RESOLVED.	
70 (I)	WHAT RECOMMENDATIONS DO YOU HAVE (FOR YOUR AREA OF RESPONSIBILITY) BASED ON THE ABOVE CONCLUSIONS.	EL	10/18	NOT RESOLVED.	
70 (J)	WHAT RECOMMENDATIONS DO YOU HAVE (FOR YOUR AREA OF RESPONSIBILITY) BASED ON THE ABOVE CONCLUSIONS.	RP	10/18	C WITH FINAL REPORT	
71 (A)	WHAT ISSUES REMAIN UNRESOLVED IN YOUR AREA WHICH YOU FEEL SHOULD BE PURSUED AT A LATER TIME.	AG	10/18	C WITH FINAL REPORT	
71 (B)	WHAT ISSUES REMAIN UNRESOLVED IN YOUR AREA WHICH YOU FEEL SHOULD BE PURSUED AT A LATER TIME.	TR	10/18	C 10/25 M18/E2 M19/E4	IMAGE GROUND DATA PROCESSING COST SAVINGS.
71 (C)	WHAT ISSUES REMAIN UNRESOLVED IN YOUR AREA WHICH YOU FEEL SHOULD BE PURSUED AT A LATER TIME.	JY	10/18	C 10/31 M18/E14	
71 (D)	WHAT ISSUES REMAIN UNRESOLVED IN YOUR AREA WHICH YOU FEEL SHOULD BE PURSUED AT A LATER TIME.	CR	10/18	NOT RESOLVED.	
71 (E)	WHAT ISSUES REMAIN UNRESOLVED IN YOUR AREA WHICH YOU FEEL SHOULD BE PURSUED AT A LATER TIME.	AS EG	10/18	C 10/31 M18/E15	
71 (F)	WHAT ISSUES REMAIN UNRESOLVED IN YOUR AREA WHICH YOU FEEL SHOULD BE PURSUED AT A LATER TIME.	RD JS	10/18	NOT RESOLVED.	
71 (G)	WHAT ISSUES REMAIN UNRESOLVED IN YOUR AREA WHICH YOU FEEL SHOULD BE PURSUED AT A LATER TIME.	JS	10/18	NOT RESOLVED.	

71 (H)	WHAT ISSUES REMAIN UNRESOLVED IN YOUR AREA WHICH YOU FEEL SHOULD BE PURSUED AT A LATER TIME.	DC	10/18	NOT RESOLVED.	
71 (I)	WHAT ISSUES REMAIN UNRESOLVED IN YOUR AREA WHICH YOU FEEL SHOULD BE PURSUED AT A LATER TIME.	EL	10/18	NOT RESOLVED.	
71 (J)	WHAT ISSUES REMAIN UNRESOLVED IN YOUR AREA WHICH YOU FEEL SHOULD BE PURSUED AT A LATER TIME.	RP	10/18	NOT RESOLVED.	
72	REVIEW AND COMMENT ON COSTING GUIDELINES DATED 1 OCT 1974	LE	10/9	NOT RESOLVED.	
73	WHAT AFFECT DOES THE 8 OUT OF 10 OR 10 OUT OF 10 BIT IMAGING DATA HAVE ON THE MCCC.	JS	10/18	NOT RESOLVED.	DIFFICULT TO ASSESS. IS EXPECTED TO DOUBLE SOFT-WARE COSTS.
74	HOW CAN WE ELIMINATE THE 8 OUT OF 10 OR 10 OUT OF 10 BITS SITUATION FROM THE IMAGER.	RP	10/18	C 10/1 M16/E11	
75	IS THE MCCC COST ANALYSIS BASED ON MARINER PICTURES (800X800) OR PIO-NEER PICTURES (160X640).	RD JS	10/18	C 10/16	BASED ON PIO-NEER PICTURES
76	FOR THE OPP S/C CONSIDER THE TRADE-OFF OF DATA COMPRESSOR AS AN ELEMENT OF THE S/C TELECOM SYSTEM.	CR	10/30	C 10/30 M19/E10	POSSIBLE TRADE-OFFS DESCRIBED. MAY BE USED TO REDUCE X-BAND FROM 20 TO 4 WATTS
77	THE OPP S/C HAS BEEN DESIGNED TO EXECUTE REAL TIME COMMANDS. WHAT IS THE DSN S POSITION IN SUPPORT OF THIS CAPABILITY.	EG	10/23	NOT RESOLVED.	
78 (A)	COMPLETE FINAL REPORT PER OUTLINE OF M15/E16.	AG	10/23	C 11/14 M19/E3	ROUGH DRAFT PROVIDED.
78 (B)	COMPLETE FINAL REPORT PER OUTLINE OF M15/E16.	TR	10/23	C 11/7 M19/E13	ROUGH DRAFT PROVIDED.
78 (C)	COMPLETE FINAL REPORT PER OUTLINE OF M15/E16.	RP	10/23	C 11/4 M19/E10	ROUGH DRAFT
78 (D)	COMPLETE FINAL REPORT PER OUTLINE OF M15/E16.	CR	10/23	C 10/31 M19/E5	ROUGH DRAFT PROVIDED
78 (E)	COMPLETE FINAL REPORT PER OUTLINE OF M15/E16.	JY	10/23	C 11/6 M19/E11	ROUGH DRAFT PROVIDED.
78 (F)	COMPLETE FINAL REPORT PER OUTLINE OF M15/E16.	EG AS	10/23	C 10/31 M18/E13	ROUGH DRAFT PROVIDED.

78 (G)	COMPLETE FINAL REPORT PER OUTLINE OF M15/E16.	RD JS	10/23	C 10/31 M18/E12	ROUGH DRAFT PROVIDED.
78 (H)	COMPLETE FINAL REPORT PER OUTLINE OF M15/E16.	JS	10/23	C 10/22 M18/E5	
78 (I)	COMPLETE FINAL REPORT PER OUTLINE OF M15/E16.	DC	10/23	NOT RESOLVED.	
78 (J)	COMPLETE FINAL REPORT PER OUTLINE OF M15/E16.	EL	10/23	NOT RESOLVED.	
79 (A)	CONSIDER HOW AICS CAN BE UTILIZED TO ACHIEVE COST EFFECTIVENESS IN YOUR AREA OF COGNIZANCE.	AG	10/30	NOT RESOLVED.	
79 (B)	CONSIDER HOW AICS CAN BE UTILIZED TO ACHIEVE COST EFFECTIVENESS IN YOUR AREA OF COGNIZANCE.	TR	10/30	NOT RESOLVED.	
79 (C)	CONSIDER HOW AICS CAN BE UTILIZED TO ACHIEVE COST EFFECTIVENESS IN YOUR AREA OF COGNIZANCE.	RP	10/30	NOT RESOLVED.	
79 (D)	CONSIDER HOW AICS CAN BE UTILIZED TO ACHIEVE COST EFFECTIVENESS IN YOUR AREA OF COGNIZANCE.	CR	10/30	NOT RESOLVED.	
79 (E)	CONSIDER HOW AICS CAN BE UTILIZED TO ACHIEVE COST EFFECTIVENESS IN YOUR AREA OF COGNIZANCE.	JY	10/30	NOT RESOLVED.	
79 (F)	CONSIDER HOW AICS CAN BE UTILIZED TO ACHIEVE COST EFFECTIVENESS IN YOUR AREA OF COGNIZANCE.	AS	10/30	NOT RESOLVED.	
79 (G)	CONSIDER HOW AICS CAN BE UTILIZED TO ACHIEVE COST EFFECTIVENESS IN YOUR AREA OF COGNIZANCE.	RD JS	10/30	NOT RESOLVED.	
79 (H)	CONSIDER HOW AICS CAN BE UTILIZED TO ACHIEVE COST EFFECTIVENESS IN YOUR AREA OF COGNIZANCE.	JS	10/30	NOT RESOLVED.	
79 (I)	CONSIDER HOW AICS CAN BE UTILIZED TO ACHIEVE COST EFFECTIVENESS IN YOUR AREA OF COGNIZANCE.	DC	10/30	NOT RESOLVED.	
79 (J)	CONSIDER HOW AICS CAN BE UTILIZED TO ACHIEVE COST EFFECTIVENESS IN YOUR AREA OF COGNIZANCE.	EL	10/30	NOT RESOLVED.	
80 (A)	PROVIDE UPDATED DRAFTS OF FINAL REPORT.	AG	11/20	C 11/25	
80 (B)	PROVIDE UPDATED DRAFTS OF FINAL REPORT.	TR	11/20	C 12/4	

80 (C)	PROVIDE UPDATED DRAFTS OF FINAL REPORT.	RP 11/20 C 12/4
80 (D)	PROVIDE UPDATED DRAFTS OF FINAL REPORT.	CR 11/20 C 12/2
80 (E)	PROVIDE UPDATED DRAFTS OF FINAL REPORT.	JY 11/20 NOT RESOLVED.
80 (F)	PROVIDE UPDATED DRAFTS OF FINAL REPORT.	EG 11/20 C 11/27
80 (G)	PROVIDE UPDATED DRAFTS OF FINAL REPORT.	RD JS 11/20 C 11/27
80 (H)	PROVIDE UPDATED DRAFTS OF FINAL REPORT.	JS 11/20 C 11/20
80 (I)	PROVIDE UPDATED DRAFTS OF FINAL REPORT.	DC 11/20 NOT RESOLVED.
80 (J)	PROVIDE UPDATED DRAFTS OF FINAL REPORT.	EL 11/20 NOT RESOLVED.

C = CLOSED
M = MINUTES
E = ENCLOSURE
LTE = LESS THAN OR EQUAL TO
10(N) = 10 TO THE N TH POWER
IM = IMAGING

JET PROPULSION LABORATORY

INTEROFFICE MEMORANDUM

5 December 1974
295-74-2208

Appendix K

TO: T. Gottlieb

FROM: J. Holladay Jah

SUBJECT: OPPICSS Effects on Mission Operations

The purpose of this memo is to provide comments on the mission operations implications of adding imaging to the Outer Planet Pioneer missions as analyzed in the Outer Planet Pioneer Imaging Communications System Study (OPPICSS).

Based on the information developed in the OPPICS study, the addition of imaging to the Outer Planet Pioneer missions would have a significant impact on mission operations, primarily because of the requirement to generate and transmit large numbers of commands to the spacecraft. This impact is largely independent of the use of data compression. The major effect of adding pixel editing or AICS is to further increase an already heavy command traffic load by increasing the number of images to be taken. The following paragraphs provide more detailed comments on these and other areas which are potentially affected.

Commanding

The basic problem is the requirement for large numbers of time-critical ground commands. This is true for all options studied, although the problem increases as the number of images increases. Large numbers of time-critical ground commands create problems not only for the DSN but for the entire ground command system and for the flight operations team.

To reduce the dependence on timed ground commands, an increase in on-board command storage should be provided to at least the level planned for Pioneer-Venus. A cost/benefit analysis for various sizes of on-board storage should be a part of any follow-on study in order to determine the minimum useful size for this storage.

This on-board storage capability need not have very complicated logic - it could consist of an on-board "command-stack" in which a series of spacecraft commands and time deltas would be executed in the order they are loaded in the stack. Initiation of the sequence should be via an on-board clock; if a time-dependent execute command is required from the ground, the interval before the first stack command will be executed should be sufficient to allow confirmation in ground telemetry (2½ to 3 RTLT recommended).

It is strongly recommended that the command bit rate be increased in order to reduce the "duty-cycle" or percentage of available time that commands are actually radiated.

It should be noted that the "store and forward" mode being planned for the 1977-era ground command system will alleviate some of the operational difficulties associated with large volumes of commands.

Command Generation

Generation and management of the large number of commands required means that new mission-dependent software must be developed. This software would have the following functions:

1) Generate commands based on desired observation parameters;
2) Validate the commands generated to determine that they will produce the desired observations;
3) Keep track of spacecraft status.

In Pioneer 10 much of the validation and checking has been done by a man in the loop, but as command volume and spacecraft complexity increase, much of this work must be automated.

Keeping track of spacecraft status is required because the camera commands are deltas from the previous state. There is also a command to reset the camera to a known state which would have to be used periodically to minimize the effect of rejected commands.

Development of the command generation software will require additional resources for cognizant engineering and programming support. In addition, if this program is to be run at Ames, there will probably be a significant impact on computer resources required.

Telemetry

Minimal flight operations impact in the telemetry area is foreseen as long as sufficient GS and E data is available in real time. In addition, some fraction of the images received must be processed in near-real-time to verify that the S/C and the ground data system are functioning properly.

The effects of transmitting compressed and coded data via GCF lines should be analyzed more thoroughly. In particular, the effects of HSDL and WBDL dropouts on Reed-Solomon decoding and on RM2 decompression should be examined in terms of data gaps/outages to be expected, and in terms of throughput times for the ground data system.

In order to perform this analysis, the project requirements for completeness of real-time or near-real-time data must be defined. As a general comment, the effects of burst errors, even fairly long ones, on mission operations should not be too severe as long as a good frame of telemetry is received periodically. However, loss of an entire Reed-Solomon Code block (32768 bits) would mean a data outage of 16 min (at 2 kbps), and this would no doubt be considered unacceptable.

Specific requirements for data completeness for both real-time data and for data records should be supplied by Pioneer Project mission operations personnel.

There is an additional GCF requirement imposed by the plan to produce all MDRs, including video, at Ames. This would require that the JPL to Ames communication circuits have the same data rate capacity and quality as the circuits from JPL to the Deep Space Stations. The implication is that if Wideband Data Lines are used to bring video data to JPL, then a WBDL circuit would be needed from JPL to Ames. If no video processing other than MDR generation is done at Ames, then it is recommended that a cost tradeoff be made to determine whether these MDRs should be made at Ames or at JPL.

Flight Operations

Although no conceptual approach to flight operations has been defined by Pioneer, the addition of an imaging experiment would certainly require additional operations personnel. These personnel would be required because there would be more sequence planning, more command sequence generation, and a more complex spacecraft to keep track of.

Assuming that real-time project operations, including command and control, would be done from Ames, there is a potential coordination problem if all video processing is done at JPL. Some project personnel would have to be located at JPL to analyze the video results and coordinate with the sequence planning functions in mission control.

Simulation

Simulated spacecraft data streams are required for both ground data system testing and for operations team training. For complex spacecraft the simulation costs can be significant. Future study work should include simulation requirements and the effects of adding data compression.

Conclusions

Future study efforts should include the following work in the mission operations area:

1) Define a flight operations conceptual approach and estimate personnel requirements.

2) Study command generation software requirements. A comparison should be made with Pioneer 10/11 command volumes and method of generation.

3) Perform a cost/benefit study of on-board command storage and determine the minimum useful size of such storage.

4) Define completeness requirements for real-time data and for data records.

5) Perform an analysis of the effects of GCF errors on Reed-Solomon decoding and on RM2 decompression.

6) Determine simulation requirements to support the proposed mission.

JAH:hw

cc: N. E. Ausman
D. Card
N. Sirri
G. F. Squibb

JET PROPULSION LABORATORY

RECEIVED
NOV 05 1974
TOM GOTTLIEB

INTEROFFICE MEMO

4 November 1974

TO: OPPICSS Distribution

FROM: T. H. Reilly

SUBJECT: Action Item 54 - Mission Value of a Data Compressor

I. SCOPE

The net value of using an image data compressor is determined by a trade-off among three factors:

1. The added cost and complexity of the required hardware. This factor is being assessed by the OPPICSS Team.
2. The loss of image quality, at least for the higher compression ratios. This factor will be assessed by the science value study of simulated images.
3. The increased number of pictures returned from the flight or from some critical segment of the flight. This third factor is the subject of the present memo.

Having restricted our attention to the quantity of images returned, it is not possible to differentiate between the pixel editor and RM2. The editor can be operated at any compression ratio attained by RM2, thereby producing the same picture count. Under these circumstances, however, we would expect poorer image quality from the editor. A proper comparison of the editor with RM2 requires that we evaluate the two devices at equal rate/unequal quality or at equal quality/unequal rate. Therefore, this memo addresses only half the question; the other half is addressed by the simulation study. In the following discussion, a generalized compressor is characterized by its compression ratio only.

II. EXPERIMENT PROFILE

To determine the increase in picture count resulting from use of the data compressor, it is necessary to construct a simple experiment profile. The profile chosen is the same for both Saturn and Uranus, and consists of dividing each encounter into four segments.

Segment 1 - Period prior to the time when the target planet fills a single frame (i.e., the planet subtends 160 pixels). Although useful pictures can be taken, the science value of this segment is less than for later segments. A principal activity during this period is engineering tests of the instrument to calibrate the pointing and select the operating mode. The amount of data acquired during this segment will not tax the telecom channel.

Segment 2 - Starting when the planetary disc first fills a single frame, this segment consists of repeated full disc mosaics in three colors on one hour centers. The repeated global coverage is needed for the study of cloud dynamics, and the color gives clues to the cloud composition. The constantly improving resolution reveals the cloud structure at different scales. Segment 2 ends when it is no longer possible to cover the disc on one hour centers.

Segment 3 - The period between the close of Segment 2 and encounter. During this segment, illumination angles and the position of the spin axis vector are the principal considerations in selecting targets of opportunity.

Segment 4 - Post encounter. During this period, the illumination angles are not favorable, and useful imaging will be restricted to a small area of the planet. Fewer pictures are needed, and so this segment does not place heavy demands on the telecom channel.

In the above description, full disc coverage of Saturn includes coverage of the rings.

Satellite coverage has not been mentioned. In the trajectory used for this study, the satellite encounters are of poor quality, and satellite coverage does not have much impact on the picture budget. Titan is encountered at E-20h, and even at closest approach, full color coverage can be obtained with the equivalent of four frames. Better satellite encounters can certainly be found, but it does not appear that their inclusion in the experiment profile would change the conclusions of this memo.

III. EFFECT OF COMPRESSOR

Since the normal X-band channel will probably be sufficient to handle the data generated during Segments 1 and 4, we look to Segments 2 and 3 to see the real value of the data compressor.

The three-color, full-disc coverage obtained during Segment 2 is intended to be all inclusive, i.e., when everything that is visible has been photographed hourly through every spectral filter, there is nothing left to do. Coverage beyond this level becomes redundant, and the cost of ground processing argues against large scale redundancy. Therefore, the value of the compressor during Segment 2 lies not in a simple increase in frame count, but rather in the extension of this comprehensive coverage pattern to a later point in the mission.

In Segment 3, we can no longer photograph everything in sight, so an increased frame count becomes very important. During this segment, the net compression ratio is a fair measure of the compressor's value.

The attached table summarizes the effect of the compressor at Saturn and Uranus. Since the images must be separated in time by an integral number of spacecraft rolls, this number is listed first. The second column shows the net compression ratio required to obtain the specified frame timing.

C-4

EFFECT OF COMPRESSOR AT SATURN AND URANUS

	Rolls Between Successive Frames	Nominal Compression Ratio	Time at End of Segment 2 (in hours before encounter)	Resolution at End of Segment 2 (in kilometers per pixel)	Number of One-Color Frames in Segment 3
SATURN	10	1.00	23	120	690
	5	2.17	17	95	1,020
	3	3.66	13	75	1,300
	2	5.96	10	60	1,500
	1	16.0	7	46	2,100
URANUS	40	1.00	31	158	232
	20	2.00	14	75	210
	12	3.34	11	59	275
	8	5.00	8	44	300
	4	10.0	7	38	525

There are two circumstances in which the compressor would be more valueable than indicated in the summary table: a particularly good satellite encounter and operation of the X-band channel under adverse weather at the ground station. The first circumstance will be difficult to assess until a good satellite encounter is found, and this could require a substantial mission design effort.

In the second case, the X-band channel performance has been calculated on the basis of 95% weather, i.e., we can expect the channel to operate at half the quoted rate about 5% of the time. Under these conditions, Segment 2 would end earlier and Segment 3 would be longer. The compressor would be operated at peak efficiency for a greater period. A very crude way to look at this is to say that the compressor will be twice as valuable about 5% of the time, so the table understates the compressor's value by 2 X 5% = 10%. The scientist, of course, would take a much different view if the 5% weather occurred right at encounter.

IV. CONCLUSIONS

A few generalizations can be drawn from the attached table:

1. The compressor is primarily a near encounter booster. Even if we add a little pad, it appears that the full value of the compressor is realized only during the last 36 hours prior to encounter. (For reference, Segment 2 starts at E-400 hours at Saturn.)

2. Based on the figures of merit considered in this memo, the compressor provides a 2-4 fold increase in mission value. The validity of the higher figure depends on whether the higher compression ratios yield acceptable image quality.

3. The compressor will probably not be used to increase the total picture count for the flyby. It now appears that ground processing costs rather than the data system will determine the picture budget. What the compressor will do for us is permit a concentration of the allotted frame sin the last few days of the encounter when resolution is best.

4. At Saturn, the integral-number-of-rolls requirement means that compression ratios above 6 will not be very practical. (A discussion of this problem is given in the response to OPPICSS Action Item 57.).

THR:ski