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Development and Testing of the Data Automation Subsystem for the Mariner Mars 1971 Spacecraft

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
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PREFACE

The work described in this report was performed by the technical divisions of the Jet Propulsion Laboratory under the cognizance of the Mariner Mars 1971 Project.

ACKNOWLEDGMENT

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CONTENTS

ABSTRACT

The data automation subsystem designed and built as part of the Mariner Mars 1971 program sequences and controls the science instruments and formats all science data. This report includes a description of the subsystem with emphasis on major changes relative to Mariner Mars 1969. In addition, it describes the complete test phase.

I. INTRODUCTION

The data automation subsystem (DAS) serves as the data handling subsystem for the science payload. It provides basic timing and commands to control the instrument's modes and sequences. The instrument data is formatted for transmission to Earth in real-time via the telemetry channel or stored on the tape recorder for playback in non-real-time.

This report describes the design, fabrication, and test of the Mariner Mars 1971 (MM '71) DAS. Major changes are discussed relative to the Mariner Mars 1969 (MM '69) Project. For background material, see Refs. 1 and 2.

II. MISSION IMPACT

The requirements that necessitated a new DAS design for MM '71 are found in Ref. 3. The infrared spectrometer (IRS) instrument on the MM '69 spacecraft was removed and an infrared interferometer-spectrometer (IRIS) instrument was substituted for the MM '71 spacecraft. Control of TV shuttering and filter wheel stepping by the DAS was added. Also, logic was included to automatically step through a picture sequence as a function of commands received. The capability was added to delay TV camera readout to allow fine control of TV shutter times. A 512-bit core memory was added to buffer high-rate data and to allow mechanization of a non-volatile time count not affected by power turn-offs. A serial ground command was added to control instrument modes and to set parameters for fixed operation (Ref. 4).

The design was accomplished within the guidelines established in Ref. 5.

III. DESCRIPTION

A. Physical Characteristics

The MM '71 data automation subsystem (DAS) (Fig. 1) includes a power converter subassembly (16.76 × 15.24 × 5.08 cm), an interface subassembly containing mostly discrete components (16.76 × 35.56 × 4.17 cm), and two logic subassemblies (16.76 × 35.56 × 2.69 cm). The subsystem weighs 6.96 kg, has a total volume of 7100 cm^3, and consumes 21.5 W of power under nominal conditions. It contains 1143 discrete parts and 858 logic IC circuits. Four analog-to-pulse-width (A/PW) converters using "ramp comparison" and one high-speed analog-to-digital converter (A/DC) using "successive approximation" were furnished to the science instruments. These units were packaged in the science instruments and are remotely controlled by the DAS.

B. Interfaces

Figure 2 shows the interfaces between the DAS and other spacecraft subsystems. The major inputs are data from the science instruments, commands from the ground (flight command subsystem [FCS]) and the onboard computer (central computer and sequencer [CC&S]), and 2.4-kHz ac power provided by the power subsystem. The major outputs are instrument control signals and data to telemetry (frequency and timing subsystem [FTS]) and the tape recorder (data storage subsystem [DSS]). Umbilical and direct access lines used for testing are not shown.

C. Data Streams

The DAS produces three data streams simultaneously and continuously (Table 1). They have a fixed sync relationship and are in sync every 84 s at the beginning of a TV A camera readout cycle.

The REAL-TIME SCIENCE 1 data format shown in Fig. 3 contains DAS status, TV and IRIS engineering data, all IRR data, and ultraviolet spectrometer (UVS) LYMAN ALPHA data. It is sent to FTS and imbedded in both higher rate science data streams.

The REAL-TIME SCIENCE 2, 8.1 kbps data format shown in Fig. 4 contains mostly UVS and IRIS spectral and engineering data. The 16.2 kbps format shown in Fig. 5 provides a back-up to the TV picture data recorded on the tape recorder. It includes approximately every eighth TV pixel.

The format of data stored on the tape recorder is shown in Fig. 6. It contains all the science status information, all spectral data, and all TV pixels.

D. Command Structure

The DAS receives ground commands (DCs and CC20s) and commands from the onboard computer (CC&S) to control payload modes and sequences. Critical commands are redundant and can be initiated from either source.

The structure and definition of the 18-bit serial command, CC20, are shown in Fig. 7. CC20s are received at 1 bit/s with a minimum spacing of 30 s between commands. Each command must contain a leading "one," odd parity, and a valid subaddress (6, 9, or 12). All bits are permanent action except those designated "single action" (S/A) which initiate action and are reset.

The DAS received discrete commands are listed in Table 2. All are single events except 20H and 20J, which are latching switch closures that must be reset.

E. Instrument Sequencing and Control

The major sequencing function of the DAS is controlling those parameters involved with taking and recording TV pictures. The TV shuttering and filter stepping, picture counting, and tape recorder start and stop functions are controlled by the "sequence logic" (Fig. 8). When commands are received to record TV pictures, the DAS steps through the appropriate states controlling the functions listed in the order shown in the blocks.

The "fixed mode" or "algorithm mode" of shutter control can be independently selected for each TV camera. In the fixed mode, one of 12 shutter intervals (Table 3) is selected by coded command. In the algorithm mode, the last shutter interval and the "pixel average" from that exposure are used to determine the next shutter interval. Figure 9 shows the algorithm operation with the pixel average given in decimal.

TV filter wheel stepping can also be controlled in two modes. In the "fixed mode," the position is determined by coded command. In the "nominal stepping" (automatic) mode, the filter is stepped twice on even-numbered positions when a picture is to be recorded.

The IRIS IMCC enable and stow functions, the TV calibrate and beam on functions, the TV A frame start time, and the DAS RTS 2 data rate are also set by commands received.

IV. DESIGN

The functional design and basic architecture of the DAS began at JPL prior to the selection of a subcontractor to do the detail design, fabrication, and testing. The basic goals of implementing a design to be completely synchronous and have a high degree of functional independence were achieved. This resulted in a reliable design that is easy to understand and, therefore, easy to analyze and operate. A functional block diagram is shown in Fig. 10.

Litton Systems, Inc., Guidance and Control Systems Division, was selected as the DAS subcontractor and supplied the personnel to do the detail design under JPL direction. A breadboard was built and tested to verify the design.

The TV ADC functional and detailed design was performed by JPL. The completed design was delivered to the contractor and the hardware fabricated as part of the DAS contract.

Four design changes were made to the DAS after the flight units were delivered to JPL. Three were changes in the payload requirements, and the fourth was to correct a problem not previously noted.

The mechanical design was similar to the MM '69 DAS. A single 15.25 × 35.6 cm board was used rather than two boards approximately 15.25 × 15.25 cm to accommodate additional ICs. The packaging density was 1.97 ICs/cm^2, as compared to 1.22 on MM '69. A pin limitation problem on the logic subassemblies caused by higher packaging density and the use of the fewer connectors was solved by using two 30-lead flexible circuit cables to feed lines between boards on opposite sides of a subassembly. This reduced the number of lines going through the connectors and harness, leaving enough pins to satisfy the subassembly needs.

Several new components with little or no past flight history were used in the MM '71 DAS. These include flatpack resistors, dual and quad flatpack transistors, flatpack diodes, some analog ICs, and fixed trim resistors. These components were qualified during the subsystem level testing and some special environmental testing conducted using a DAS subassembly prior to building the flight hardware.

V. FABRICATION

Three DAS units in flight configuration were built by the contractor. The power converter used one single-layer printed circuit board. The remainder of the subsystem used multilayer printed circuit boards. The two boards for discrete interface circuits each have four layers, the one memory board has eight layers, and the three logic boards have fourteen layers each. The planar layout multilayer printed circuit board approach was used to obtain the packaging density required, and it allows changes to be made with relative ease after the hardware has been built.

Artwork for the multilayer boards was generated using design automation techniques. This method of layout and the tooling used throughout the fabrication process provided the means of maintaining the registration required for large multilayer boards.

VI. TEST

All testing of the DAS as a complete subsystem was performed using an automatic checkout system. A PDP-7 computer was used with special interfacing equipment to simulate, under program control, all spacecraft subsystems that mate with the DAS. This provided closed-loop control on all DAS functions and enabled a thorough dynamic test while all DAS outputs were being monitored.

The PDP-7 checkout system design, fabrication, checkout, and programming was completed in time to be used for the design verification of the DAS breadboard. This significantly reduced the total time required for this phase, compared to the time needed on past programs, when manually operated bench checkout equipment (BCE) was used. The problems normally associated with design verification were quickly identified and resolved.

Initial testing of the DAS in the flight configuration was performed at the contractor at the subassembly level. This provided a reasonable check of each subassembly, and most failed components and fabrication errors were identified at this point. Next, the hardware was checked as a complete subsystem on the PDP-7 checkout system at JPL. This was again a departure from past programs, inasmuch as BCE was used, requiring several days to complete these tests. The hardware was received, tested, and returned to the contractor within the same day. The hardware fabrication was then completed and the hardware delivered to JPL.

Voltage/temperature margin tests were conducted using the PDP-7 checkout system. Each flight unit was characterized by noting the point where functions cease to operate as the voltage is reduced at temperatures of -10, 0, and +65°C. Operation was also verified at +40% voltage settings at these temperatures.

These tests were run when the units were received from the contractor, after flight acceptance environmental testing, and after spacecraft level testing prior to shipment to AFETR. The results were carefully compared looking for indications of degradation. No significant changes were noted, indicating stable operation.

Subsystem level testing was completed with few problems. An average of 350 hours had been accumulated by each of 3 flight units (1 proof-test model plus 2 flight units) when spacecraft level testing began. Marginal components and design errors not previously noted were removed and corrected.

DAS operation during spacecraft level testing was error-free. Not a single problem was noted on the three spacecraft during several hundred hours of operation.

The A/PW converters and the TV A/DCs were subassembly level tested and delivered to the science instrument area. They were built into each subsystem and tested during the test program for that particular instrument. Only one problem was identified with these units during the entire test cycle: a noise problem between ground layers in the TV A/DC caused the least significant bit of each conversion to be a one. This situation was corrected by a minor change in the DAS where the A/DC timing signals are generated.

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1. "Mariner Mars 1969 Final Project Report: Development, Design, and Test," Technical Report 32-1460, Vol. I, Jet Propulsion Laboratory, Pasadena, California, November 1, 1970.

2. "Data Automation Functional Requirements," JPL Internal Document M69-4-2020B, Jet Propulsion Laboratory, Pasadena, California, January 10, 1968.

3. "Mariner Mars 1971 Mission Specifications and Plans," JPL Internal Document 610-16, Rev. A, Jet Propulsion Laboratory, Pasadena, California, August 8, 1969.

4. "MM'71 DAS Functional Requirements," JPL Internal Document M71-4-2020A, Jet Propulsion Laboratory, Pasadena, California, October 23, 1970.

5. "Mariner Mars 1971 Spacecraft Characteristics and Restraints," JPL Internal Document M71-3-100A, Jet Propulsion Laboratory, Pasadena, California, August 31, 1971.

Table 1. DAS data streams

Data line	Data rate	To	Data format
Real-time science 1	50 bps	FTS	Orbital science
Real-time science 2	8.1 kbps	FTS	Spectral science
Real-time science 2	16.2 kbps	FTS	Selected video
Science data to DSS	132.3 kbps	DSS	Recorded science

Table 2. DAS discrete commands

Command No.	Function	Source
DC-36	Initiate TV mapping	FCS
DC-83	Change RTS 2 rate	FCS
20B	Change RTS 2 rate	CC&S
20C	Initiate TV mapping	CC&S
20D	Take a TV picture pair	CC&S
20G	Reset orbit logic	CC&S
20H	IRIS IMCC enable	CC&S
20J	TV beam on/off	CC&S

Table 3. TV shutter times

Bits	N	Nominal shutter interval, ms[a]
0000	0	3
0001	1	6
0010	2	12
0011	3	24
X100	4	48
X101	5	96
X110	6	192
X111	7	384
1000	8	768
1001	9	1,536
1010	10	3,072
1011	11	6,144

[a]The nominal time is computed using 3.0×2^N ms.

The actual shutter interval is $2.96296 \times 2^N + 2.006$ μs.

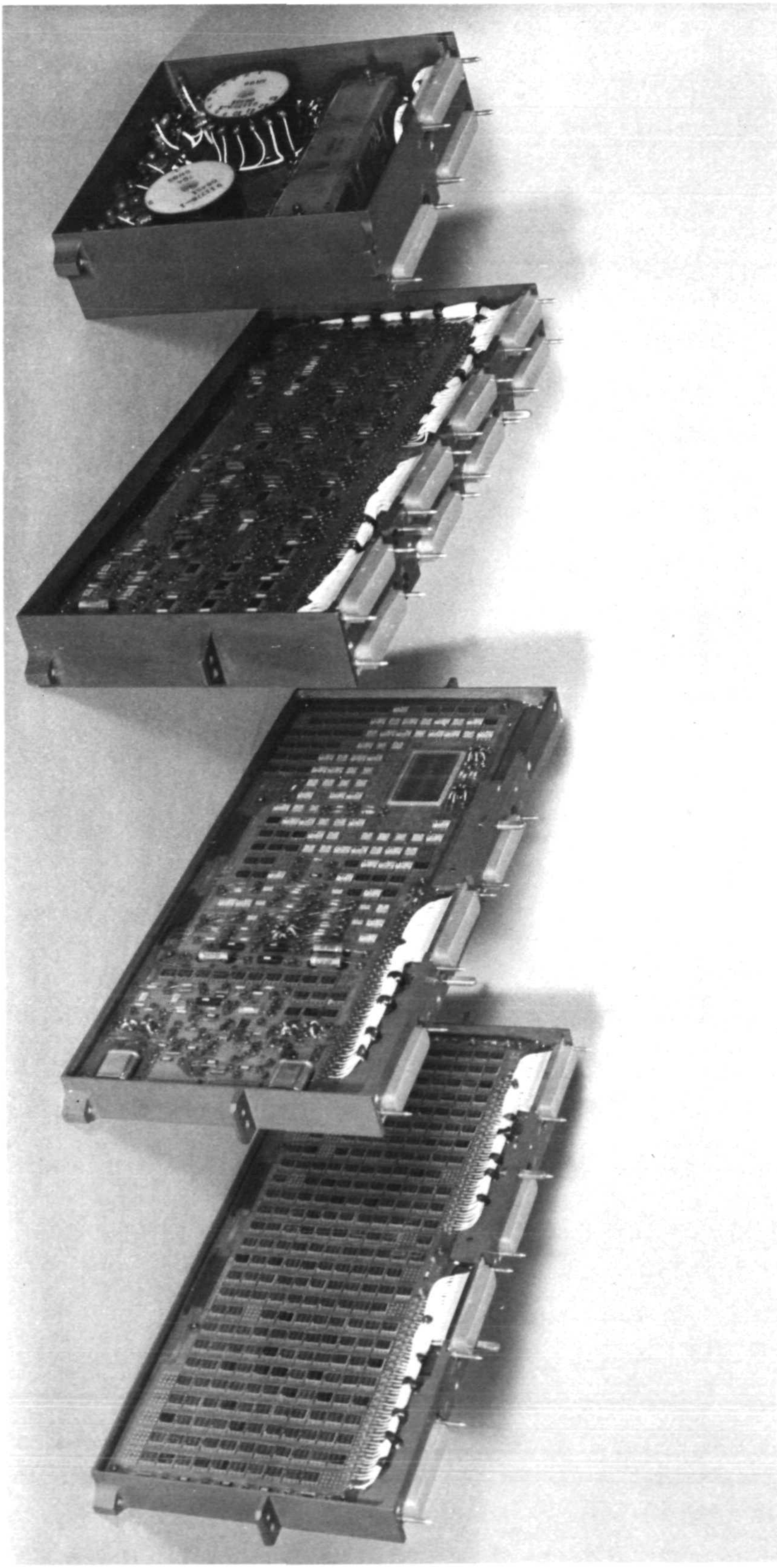
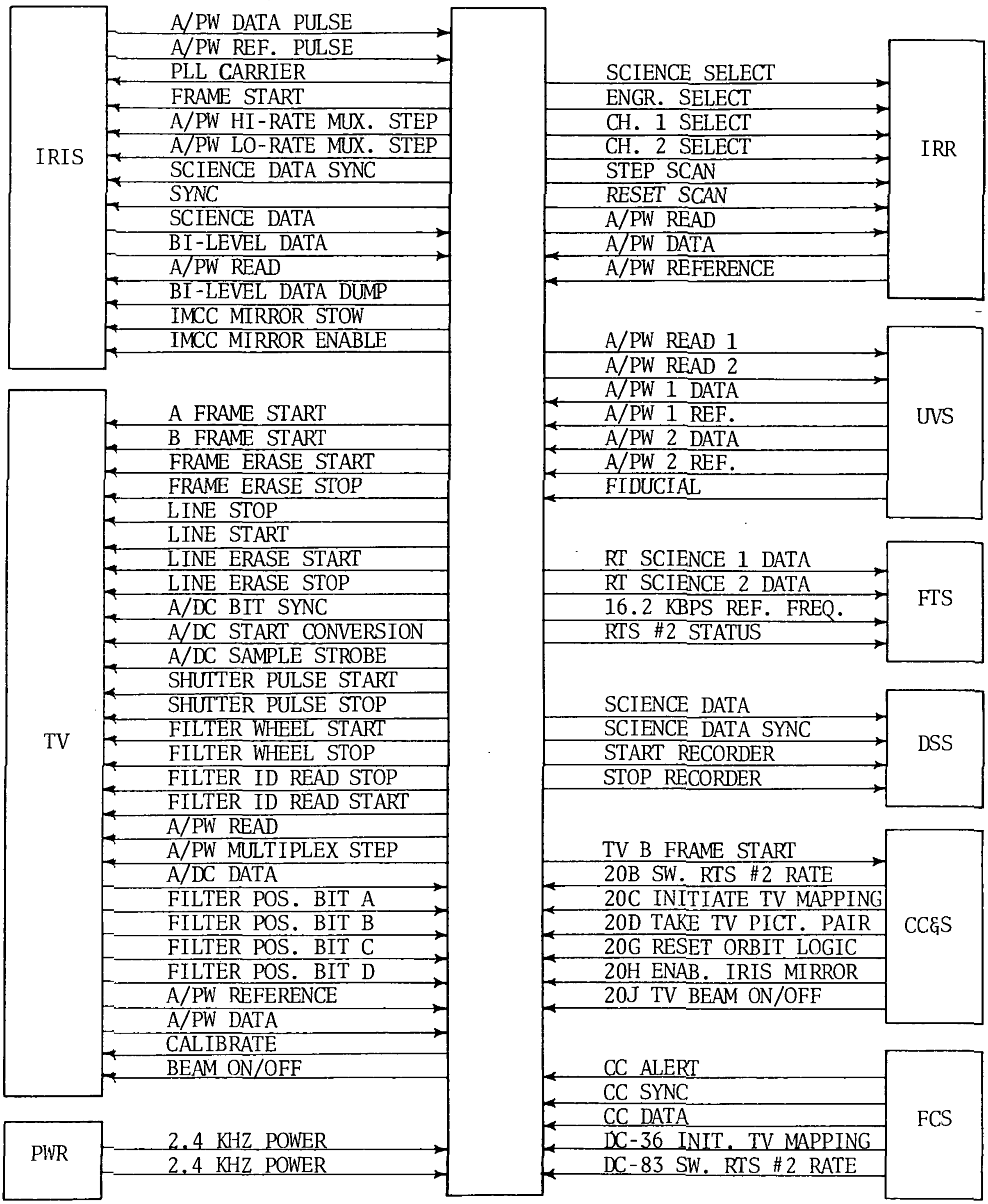


Fig. 1. Mariner Mars 1971 data automation subsystem



IMCC = IMAGE MOTION COMPENSATION AND CALIBRATION
RT = REAL-TIME
RTS = REAL-TIME SCIENCE

Fig. 2. DAS interfaces

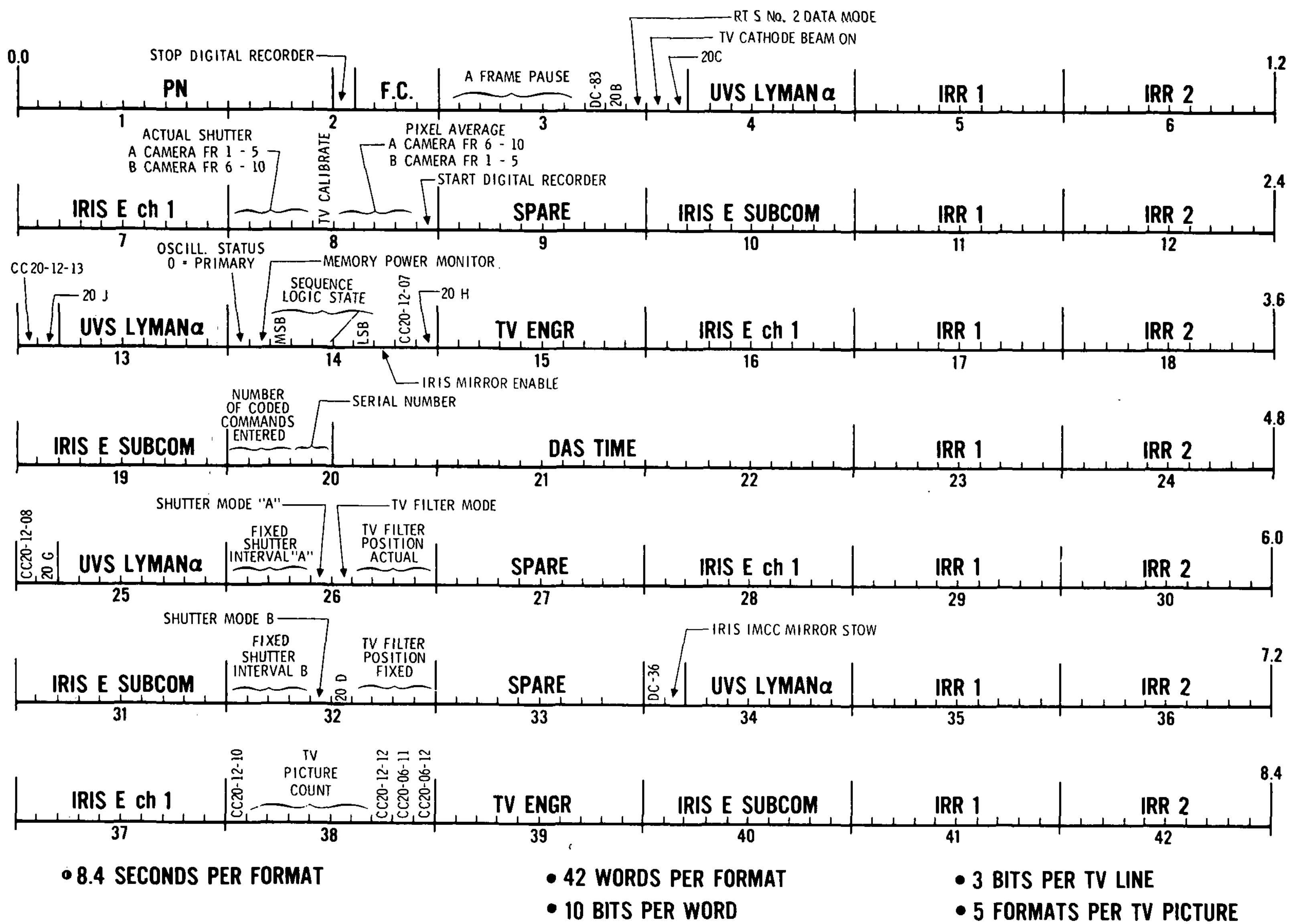


Fig. 3. Orbital science format (50 bps)

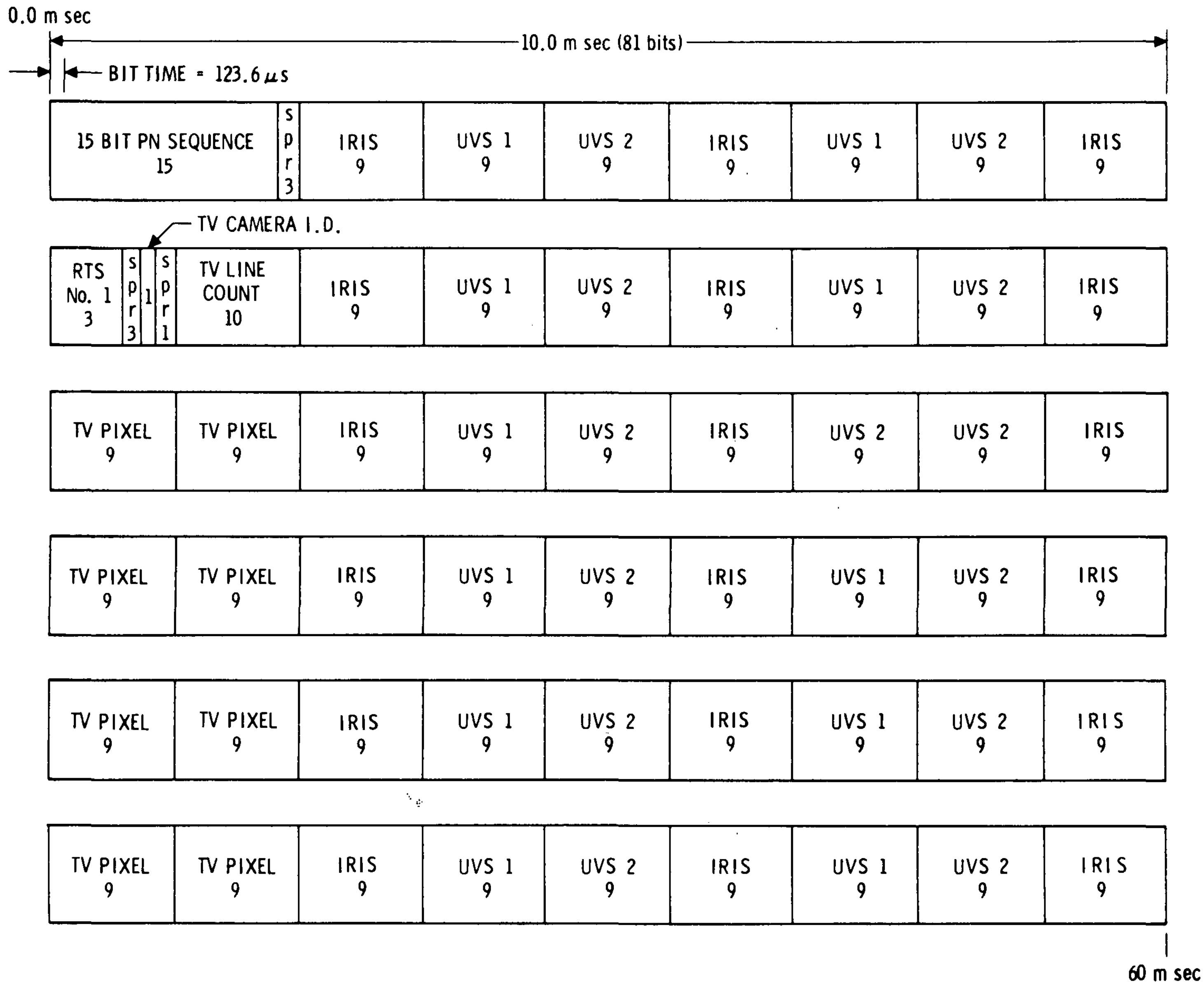


Fig. 4. Spectral science format (8.1 kbps)

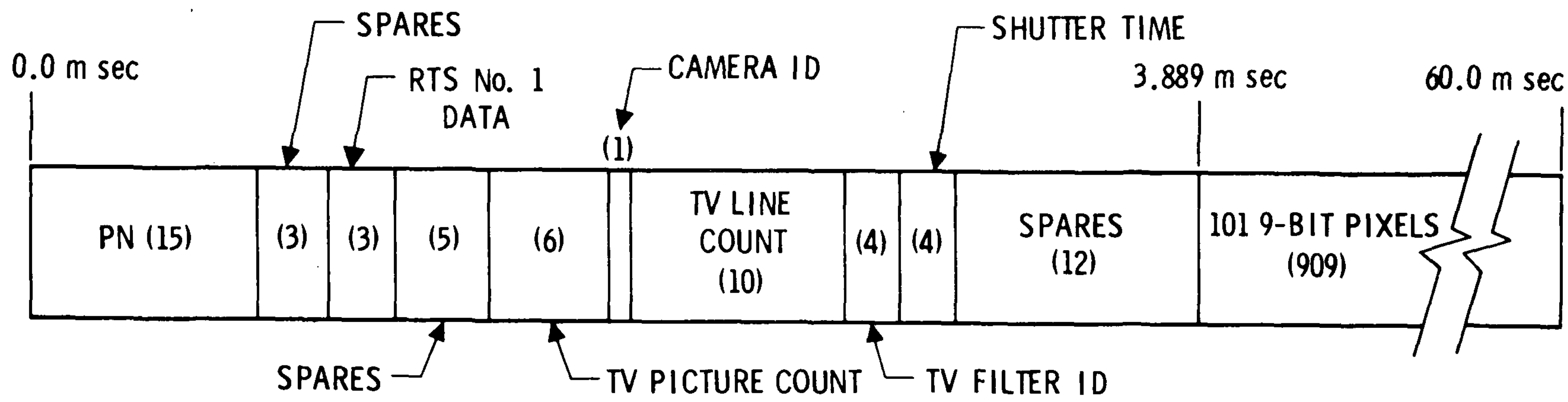


Fig. 5. Selected video format (16.2 kbps)

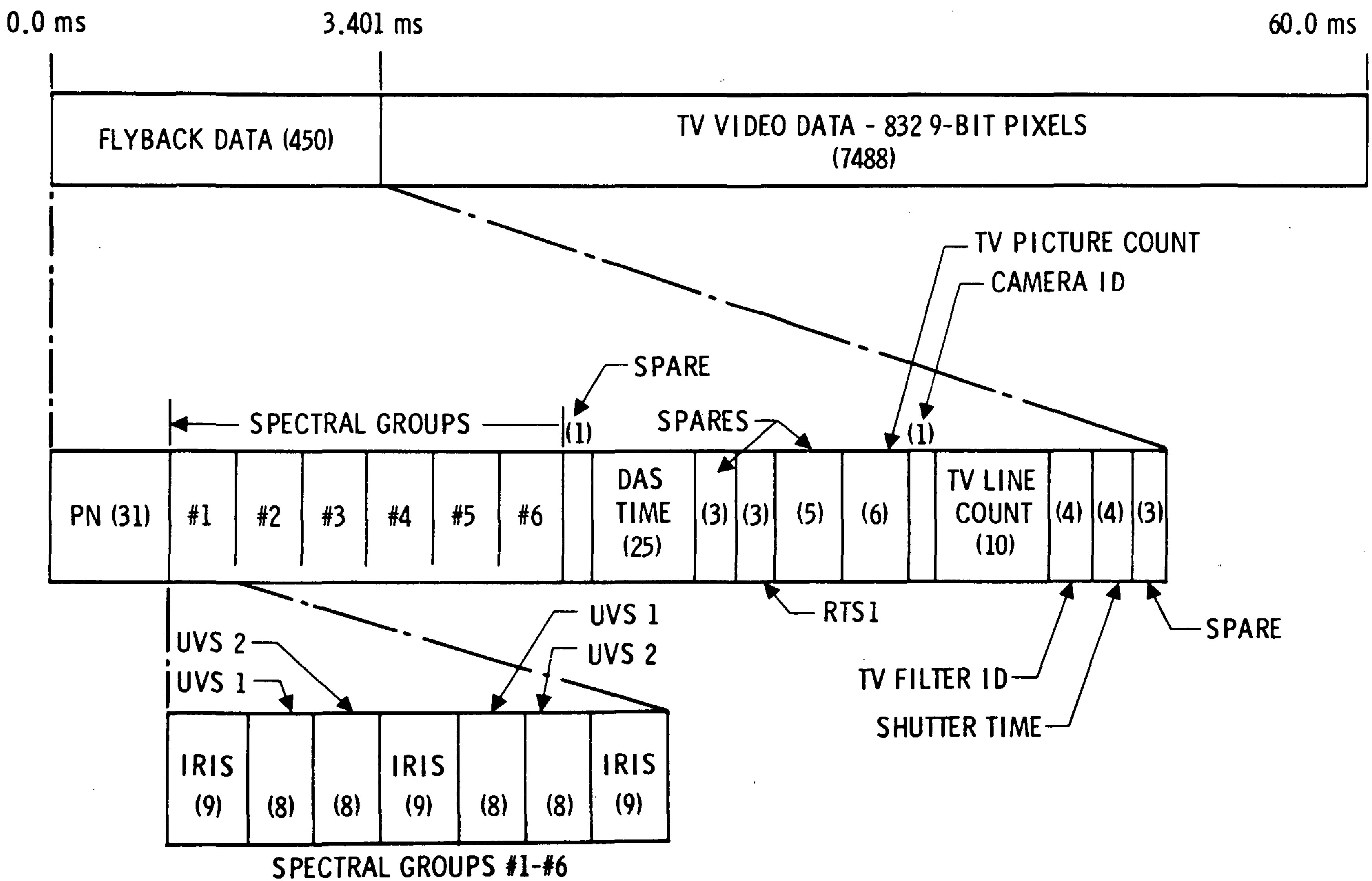
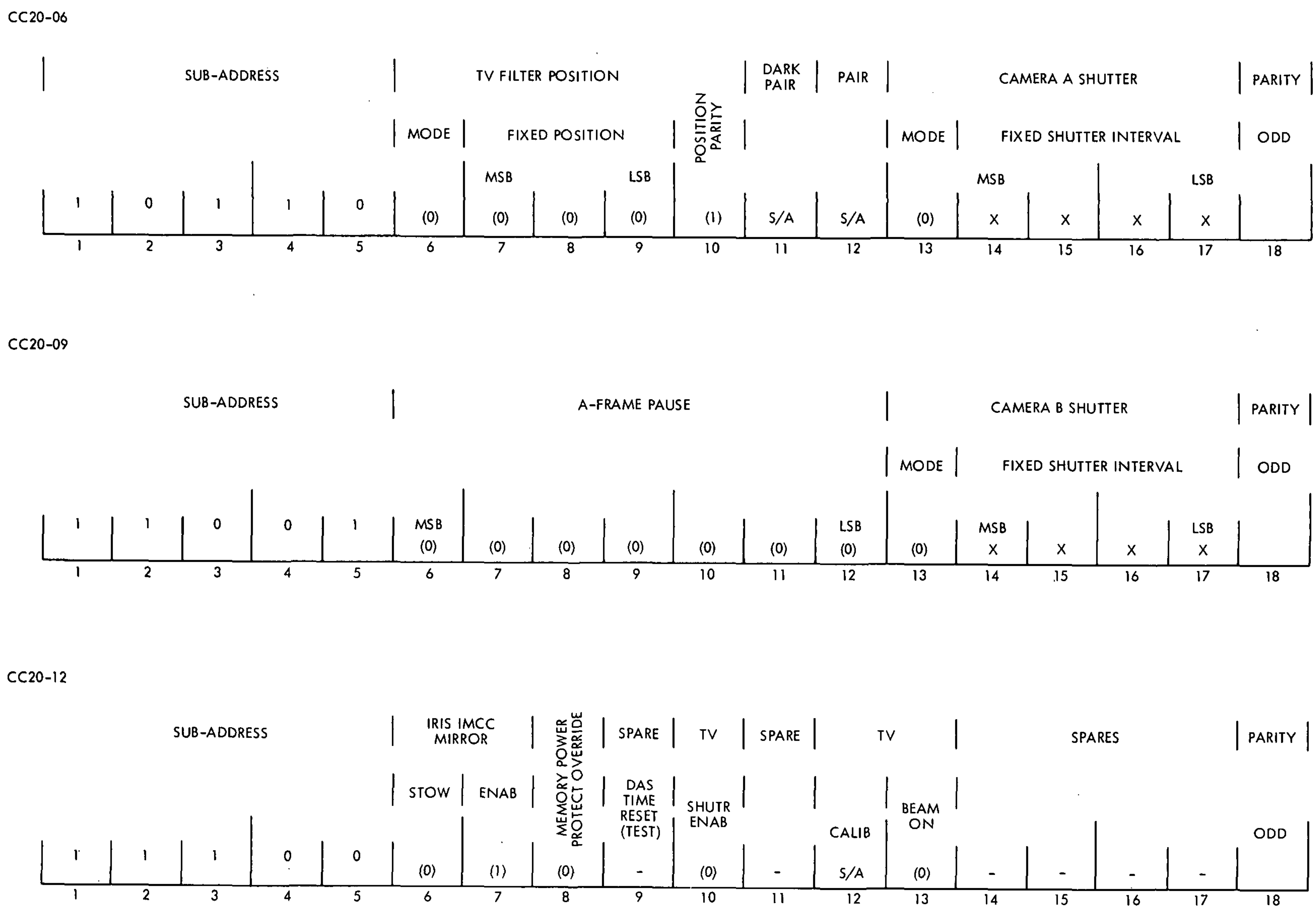
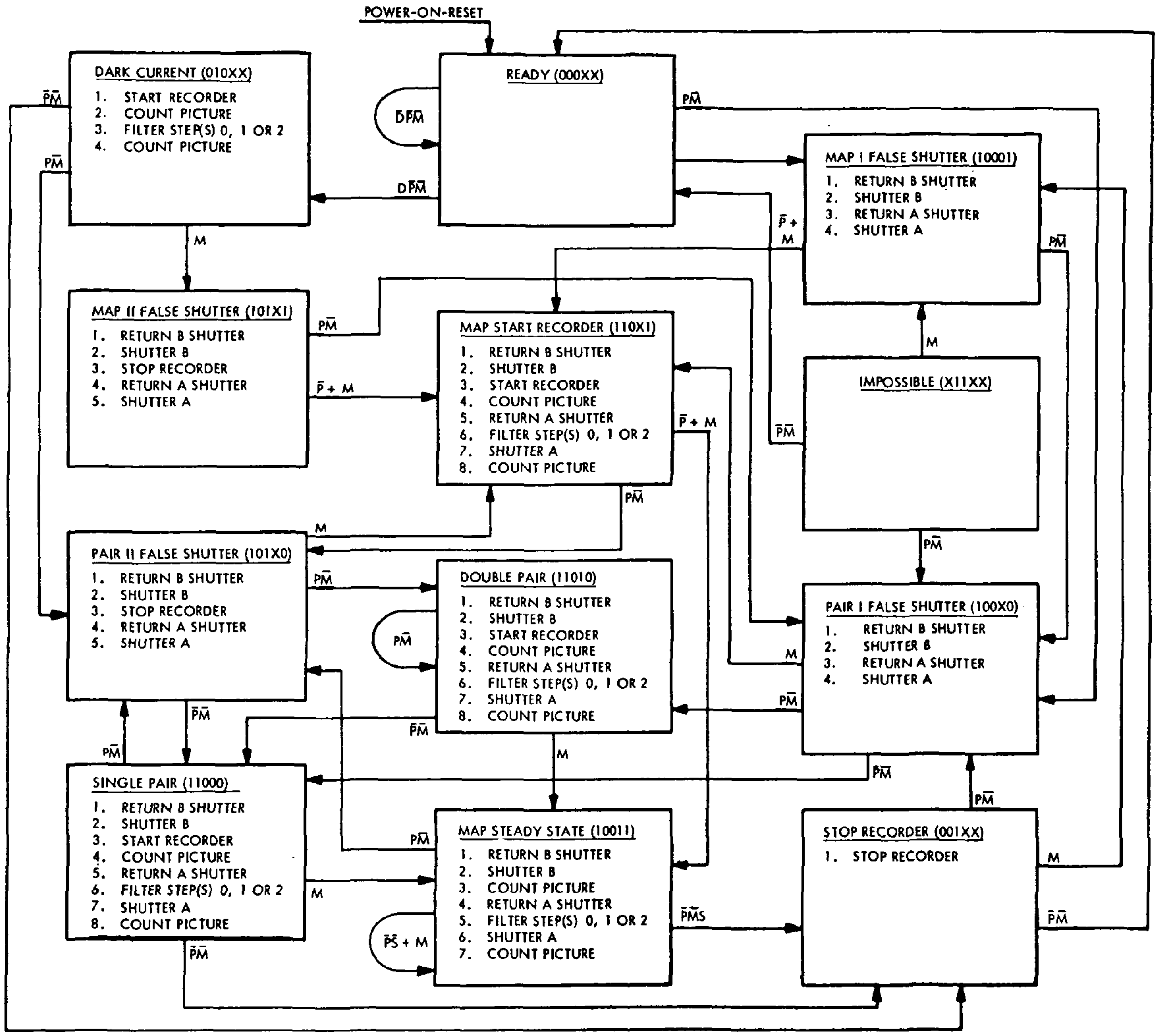


Fig. 6. Recorded science format (132.3 kbps)



( ) = BITS AT POWER-ON-RESET

Fig. 7. Mariner Mars 1971 DAS coded commands



EACH 84 sec (AT THE "DECISION TIME"), THE FOUR BINARY VARIABLES BELOW ARE EVALUATED AS FUNCTIONS OF EVENTS OCCURRING OVER THE PAST 84 sec. BASED ON THE PREVIOUS SEQUENCE STATE AND THE FOUR VARIABLES, THE NEXT SEQUENCE STATE IS ENTERED

M = MAP (DC-36 OR 20C) COMMAND RECEIVED DURING PAST 84 sec
P = PAIR (CC20-06-12 OR 20D) COMMAND RECEIVED DURING PAST 84 sec
D = DARK CURRENT (CC20-06-11) COMMAND RECEIVED DURING PAST 84 sec
S = PICTURE COUNT EQUAL TO 00_8 DURING PAST 84 sec

Fig. 8. DAS sequence logic states

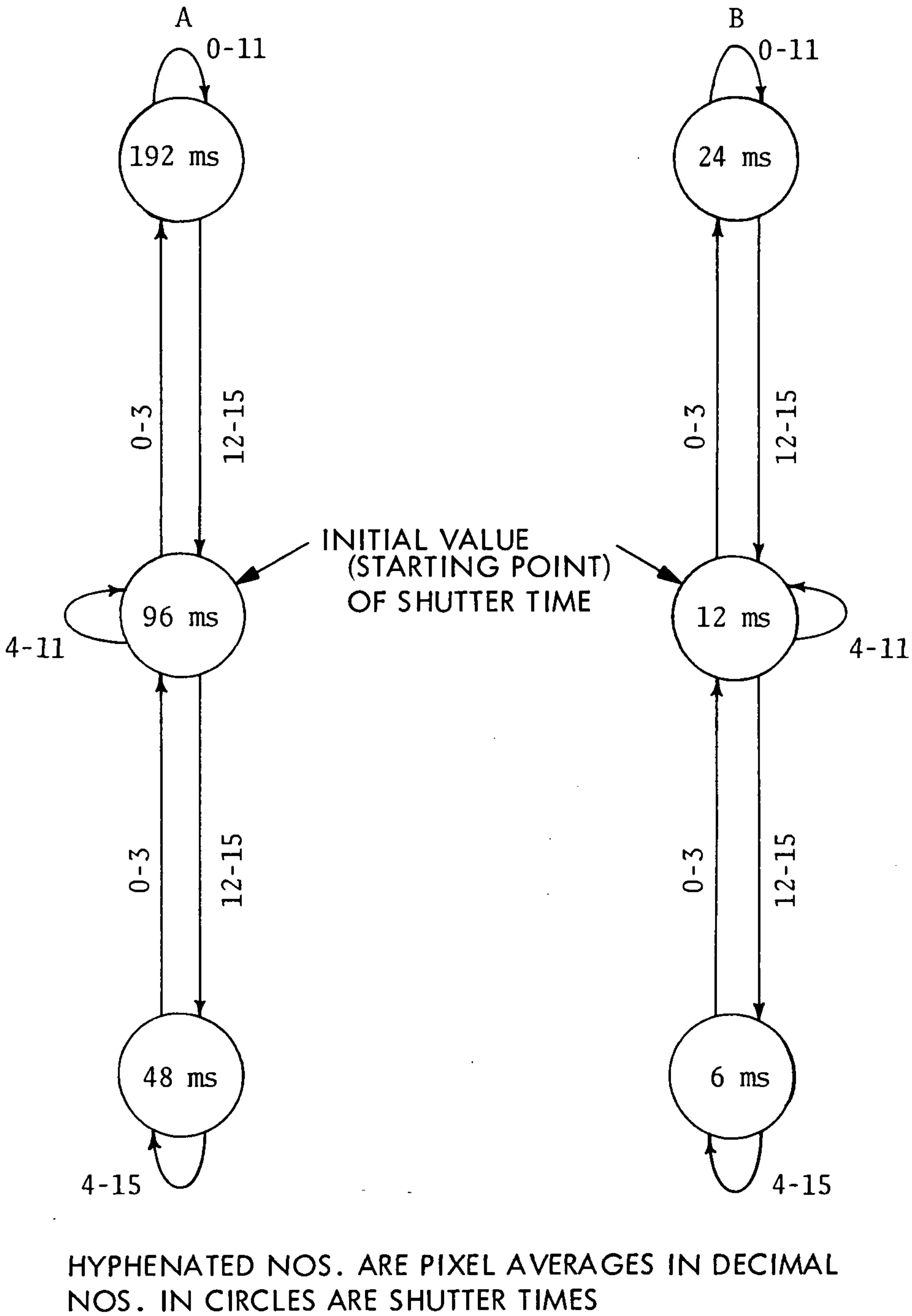


Fig. 9. TV shutter algorithm

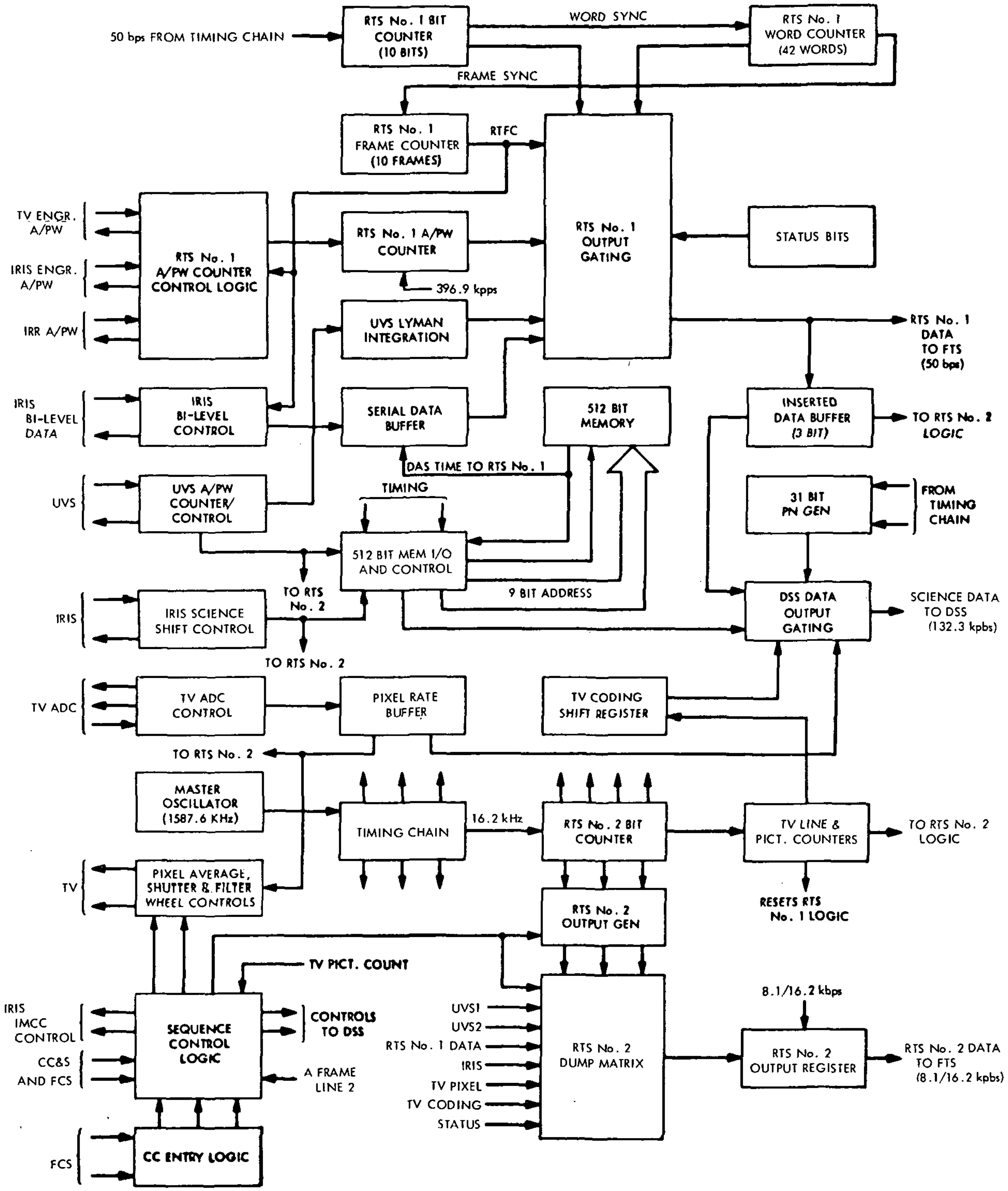


Fig. 10. Mariner Mars 1971 DAS functional block diagram

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