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AVIRIS onboard data handling and control

Ronald E. Steinkraus and Roger W. Hickok

Observational Systems Division
Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive, Pasadena, California 91109

ABSTRACT

The timing and flow of detector and ancillary data for the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) are controlled within the instrument by its digital electronics assembly. In addition to providing detector and signal chain timing, the digital electronics receives, formats, and rate-buffers digitized science data; collects and formats ancillary (calibration and engineering) data; and merges both into a single tape record. Overall AVIRIS data handling is effected by a combination of dedicated digital electronics to control instrument timing, image data flow, and data rate buffering and a microcomputer programmed to handle real-time control of instrument mechanisms and the coordinated preparation of ancillary data.

1. INTRODUCTION

The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) instrument produces solar reflectance measurements in 224 spectral bands from 0.4 to 2.4 µm for each of 614 spatial footprints in a cross-track scan encompassing a 30-deg field of view. As the airborne instrument moves along its flight path, successive scan lines are recorded, forming a data base of 224 separate flight line images.

The cross-track scan mirror operates in a scan and flyback mode at a rate of 12 scans per second with a scan efficiency of 70%. Using the instrument's roll gyro, each scan line is corrected for changes in the aircraft's roll attitude within the range of ±1.5 deg. During each flyback period, a foreoptics shutter is cycled to provide detector background data for further ground processing. At the start and end of each flight line, an in-flight calibrator with a four-position filter wheel is activated to provide data on the radiometric and spectral stability of the instrument. Throughout the flight the foreoptics focus is continuously compensated for temperature.

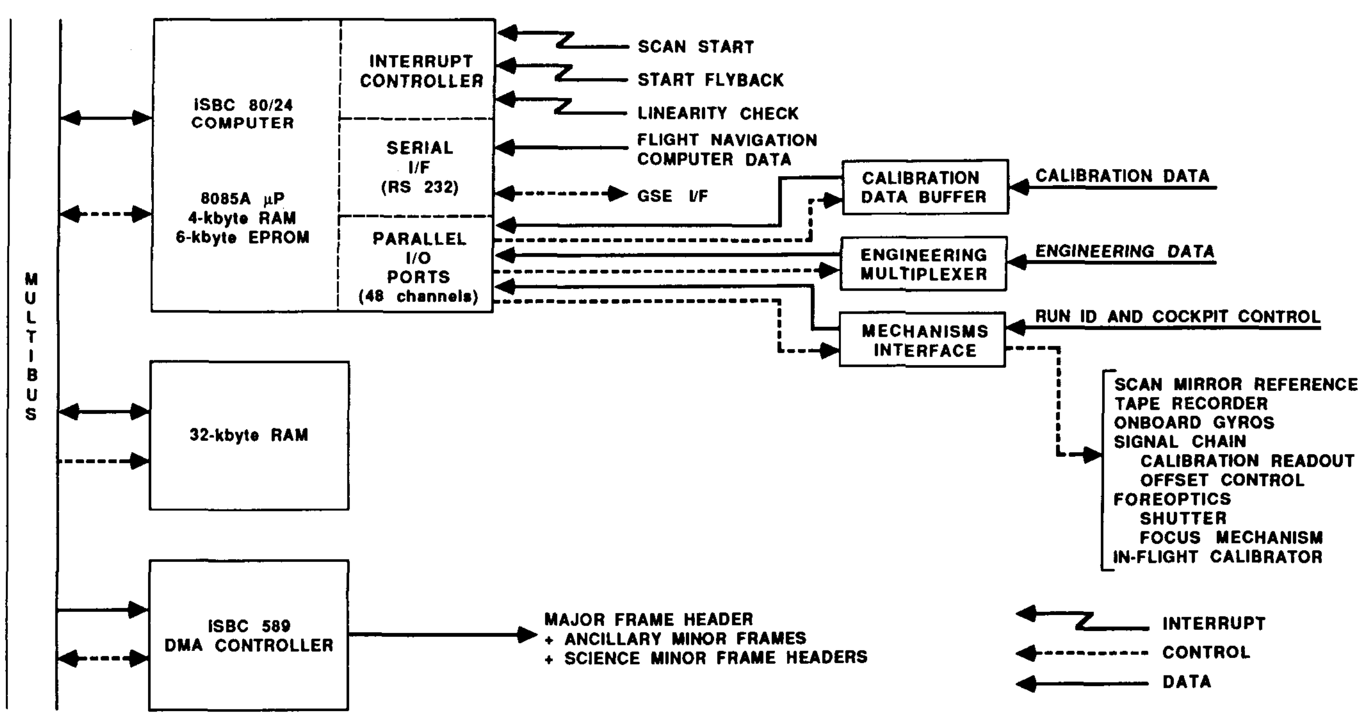

Figure 1. AVIRIS computer functionality block diagram.

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The instrument's digital electronics assembly orchestrates these mechanisms to gather the data, provides timing to process the data, and formats and buffers the data to the flight tape recorder.

2. INSTRUMENT CONTROL

AVIRIS instrument operation is designed for minimum human control. Pilot interfaces consist of instrument power on/off and tape recorder start/stop. Orchestration of all instrument functions to be described here is directed from the instrument's microcomputer (Figure 1).

Housed in a multibus chassis, the microcomputer consists of an Intel SBC 80/24 single-board computer, an Intel SBC 589 direct memory access (DMA) controller board, a 32-kbyte RAM board, a custom-built engineering data multiplexer, and a custom-built mechanism control interface. The SBC 80/24 board provides an 8085A-2 microprocessor, 12 kbytes of PROM, 4 kbytes of RAM, a multi-counter programmable interval timer, an 8-level interrupt controller, one serial RS-232 interface, and six 8-bit parallel I/O ports. The DMA controller board provides direct multibus memory access for high-rate 16-bit parallel data transfers. The two custom interface boards provide for direct mechanism control and engineering data retrieval via the computer's parallel I/O ports. The computer's serial port facilitates the collection of aircraft navigation data in flight or provides full-duplex communications with the AVIRIS ground support equipment (GSE) during laboratory testing.

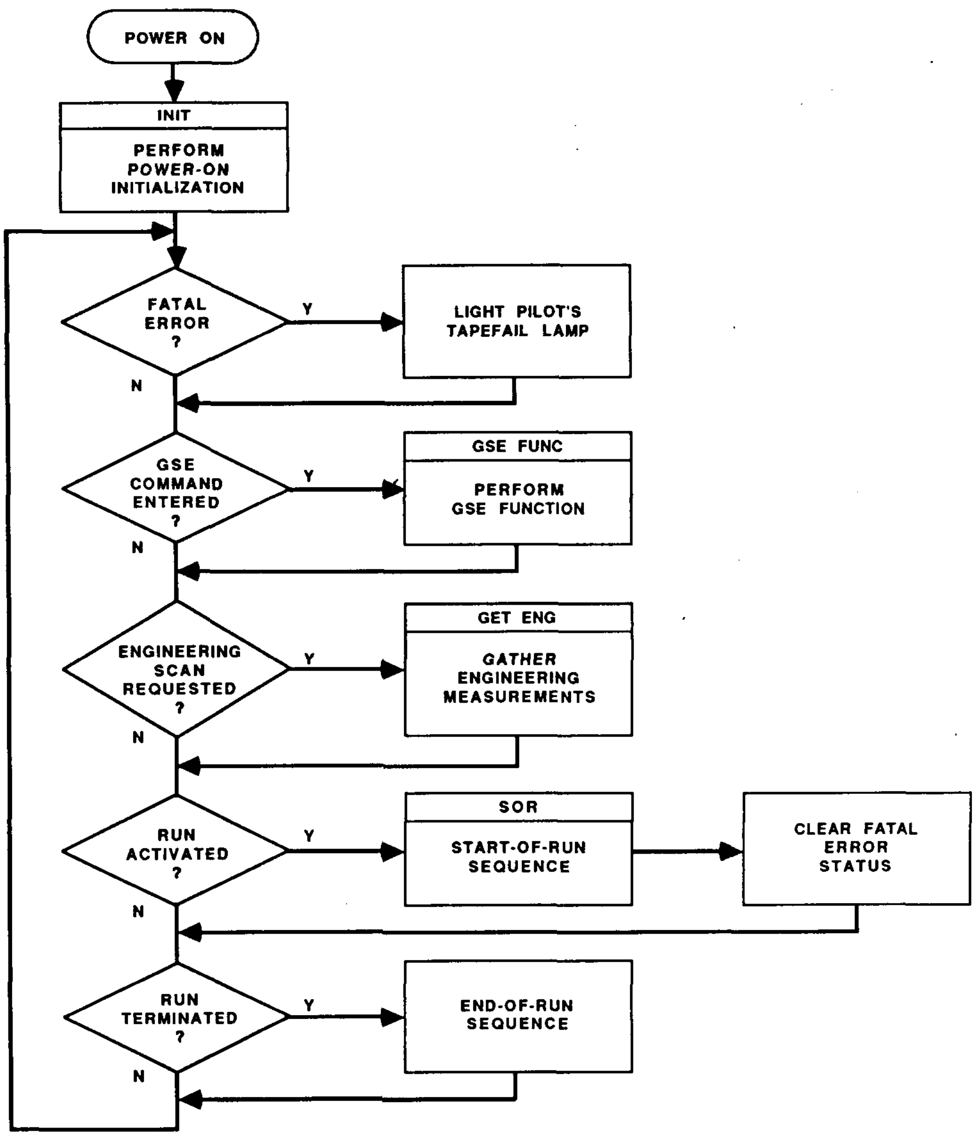

Figure 2. AVIRIS main program flowchart.

The AVIRIS firmware (Figure 2), programmed in three 2716 EPROMs, contains the instructions required to direct the instrument's operation. The main program becomes active at instrument power-on, executing an initialization routine that clears the onboard RAM (including the Run ID), initializes the onboard support chips, programs one interval timer to produce a continuous 23.4-Hz square-wave timing reference to the foreoptics scan motor, rotates the calibration filter wheel to its dark position, withdraws the focus mechanism to its reference position, powers up the tape recorder, and initializes the instrument gyros. Thereafter, the mainline firmware enters its normal top-level idle loop, where it checks for and handles occurrences of fatal mechanism errors (lighting the failure indicator on the cockpit control panel for any error), engineering minor frame requests (causing all engineering data to be read once per mirror scan), GSE commands (performing GSE functions as requested), and record start/stop commands from the cockpit control panel (performing start-of-run/end-of-run sequences as requested).

At the start-of-run, the tape recorder is started and allowed to come up to speed. The signal chain offset correction feature is updated by closing the foreoptics shutter, temporarily disabling the offset correction, and writing dark current calibration data to the offset correction buffer. The foreoptics shutter is then reopened and the offset correction reenabled. The instrument gyros are reset, the Run ID incremented, and the Major Frame Count is reset. A standard calibration sequence is activated which collects detector data for each of four in-flight calibrator filters. This is accomplished by closing the foreoptics shutter and rotating the calibration source filter wheel through its four positions (low-level broadband, spectral-line, high-level broadband, and dark), capturing a full scan line of data at each position. When the filter wheel has returned to the dark position, the shutter is then reopened and image data collection commences with the next mirror scan.

Thereafter, by means of scan-driven interrupt handling, the firmware closes the foreoptics shutter at the beginning of the scan mirror flyback period, collects a minor frame of offset corrected dark current data, and reopens the shutter prior to the start of the next scan. During the flyback period, the foreoptics focus temperature compensation algorithm may move the focus mechanism one step if the foreoptics temperature change since the last correction exceeds 0.3 deg Celsius. Initial flight data indicate that this temperature may vary as much as 5 deg Celsius during a three-hour flight, but only 0.3 deg Celsius during a flight line lasting five minutes. During each active scan interval, 11 scan mirror linearity-check and gyro engineering readings are made based on evenly spaced scan "linearity check" interrupts, and all other engineering data are gathered once per scan as a main program background activity. An additional ongoing interrupt-level firmware function (but asynchronous to the scan timing) is the processing of flight navigation data received serially from the aircraft's navigation computer at 9600 baud in bursts of 28 characters every five seconds.

At the end-of-run, the standard calibration sequence involving the in-flight calibrator is repeated and the tape recorder is stopped. The main program resumes its normal top-level idle loop until the next tape recorder start command is received from the cockpit or until the instrument's power is turned off.

Table 1. Firmware Mechanism Control Summary

Activity	Timing
Scan motor reference signal generation	Continuous
Instrument gyro initialization	Once per flight
Tape recorder power up	Once per flight
Tape recorder start/stop	Once per run
Signal chain offset correction update	Once per run
Instrument gyro reset	Once per run
In-flight calibration filter wheel rotation	Twice per run
Foreoptics shuttering	Once per scan
Foreoptics focus correction	Maximum of one step per scan

Table 2. Firmware Data Acquisition Summary

Activity	Timing
Aircraft navigation data received	Every 5 seconds
Calibration offset data read	Once per run
Four in-flight calibration data frames read	Twice per run
Calibration dark current data read	Once per scan
All engineering data sampled	Once per scan

A summary of firmware mechanism control and data acquisition responsibilities may be found in Tables 1 and 2.

To facilitate laboratory test and calibration activities, the AVIRIS GSE may utilize the flight navigation computer serial interface, enabling GSE mode commanding of the instrument. In the GSE mode, the instrument's firmware allows scan operations to continue, but disables automatic scan-driven mechanism control (i.e., shutter, focus, and in-flight calibrator mechanisms). Instead, each mechanism may be individually controlled by GSE operator command. In addition, the firmware will perform simple EPROM, RAM, and DMA controller confidence tests upon command. When exiting the GSE mode of operation, the firmware will resume normal flight operation, having first returned all GSE-moved mechanisms to their appropriate positions.

3. ANCILLARY DATA FORMATION

Ancillary data, composed of aircraft navigation data, instrument engineering data, offset data, and calibration data, are acquired as previously described via the microprocessor's parallel and serial ports. These data are buffered and formatted by the firmware according to the format described in Figure 3 in preparation for DMA output to the

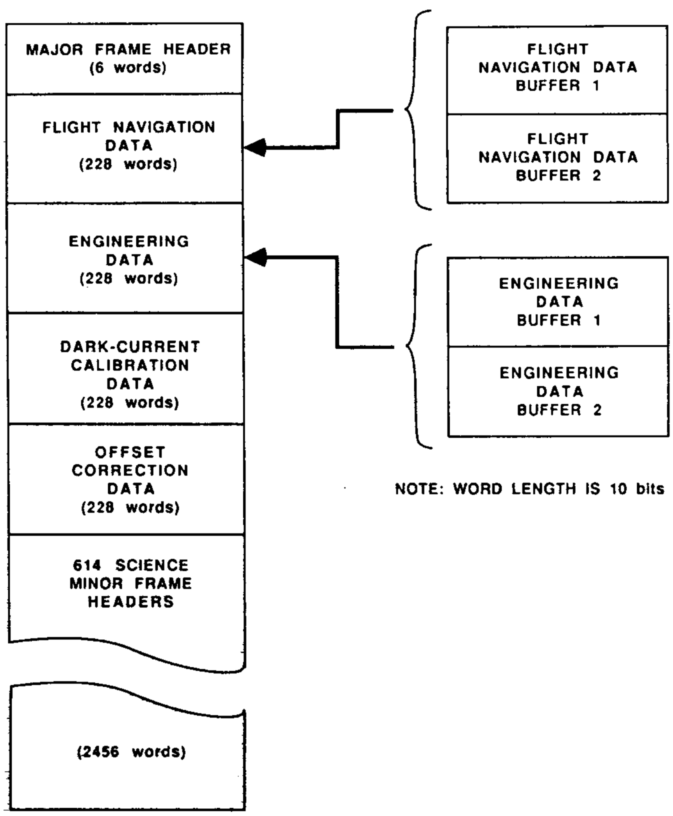

Figure 3. AVIRIS ancillary data buffer organization.

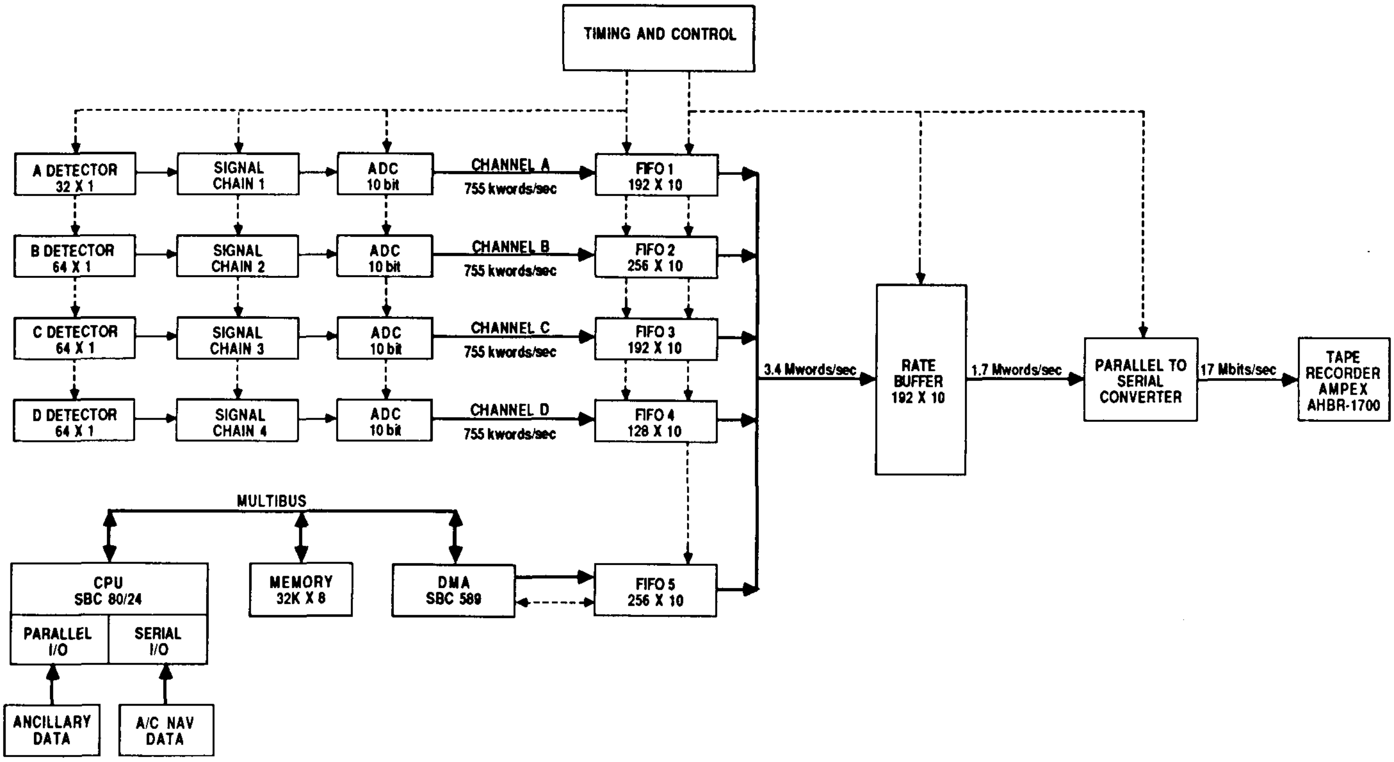

Figure 4. AVIRIS data flow block diagram.

instrument's data buffers (Figure 4) and subsequent tape recording. Included with these data are all major and minor frame headers generated directly by the firmware.

At the start of the scan mirror flyback period, a DMA operation is initiated to transfer the 3,374 (10-bit) words of ancillary data and frame header information from the ancillary data buffer to the first-in-first-out (FIFO) buffer. Transfer of 256 words is accomplished prior to the start of the next mirror scan, with subsequent transfers occurring throughout the scan line on an as-needed basis to refill the FIFO buffer. The process remains active until all words have been transferred and is reinitiated during each scan mirror flyback period.

Since new engineering and flight navigation data may be received during the DMA transfer operation, a double buffering scheme is employed for these two data types. At the start-of-flyback, the latest complete buffers of engineering and flight navigation data are copied to their places in the ancillary data buffer by the DMA controller itself, as a prelude to the output DMA transfer operation.

Because mechanism positioning and tape recorder warm-up/stop periods are required at the start and end-of-run, the synchronous nature of the tape recorder causes a number of "throwaway" frames to be recorded with the run's calibration frames on the tape. These occur prior to and immediately following the run's full sequence of image frames. Such frames are marked as "throwaway" by the firmware, and the data they contain are not normally subject to any later processing. Data frames recorded while in the GSE mode are also marked as having been produced while in the GSE mode and may be later interpreted for test or calibration purposes.

4. DATA PROCESSING

The image data flow originates with readouts from four linear focal plane arrays (Figure 4). Each is housed in its own spectrometer and measures a separate part of the 0.4- to 2.4-μm spectrum. Although three of these arrays contain 64 detector elements and the fourth 32, the readout process for each is identical. A start pulse, in conjunction with a two-phase clock supplied to the array multiplexer (Figure 5), initiates the process. As this pulse shifts through the multiplexer, FET switches successively connect each detector to a common video bus. The resultant signal is amplified by an external preamplifier and passed along to the signal chain for further processing and digitization.

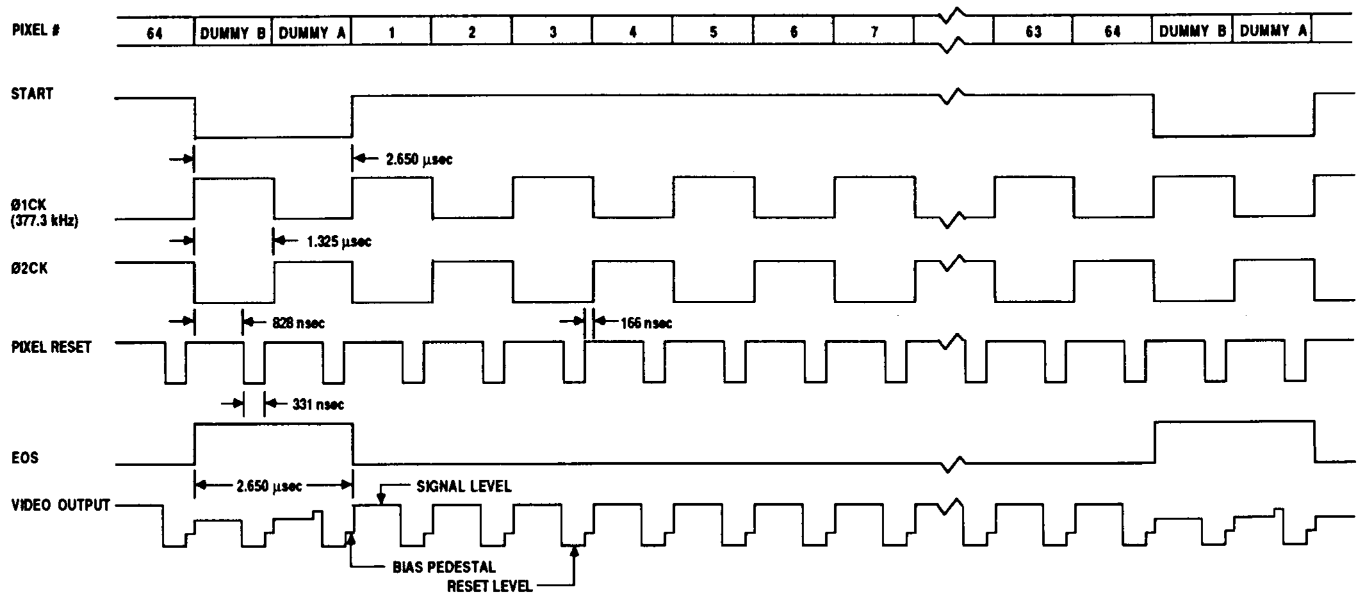

Figure 5. AVIRIS focal plane array readout timing.

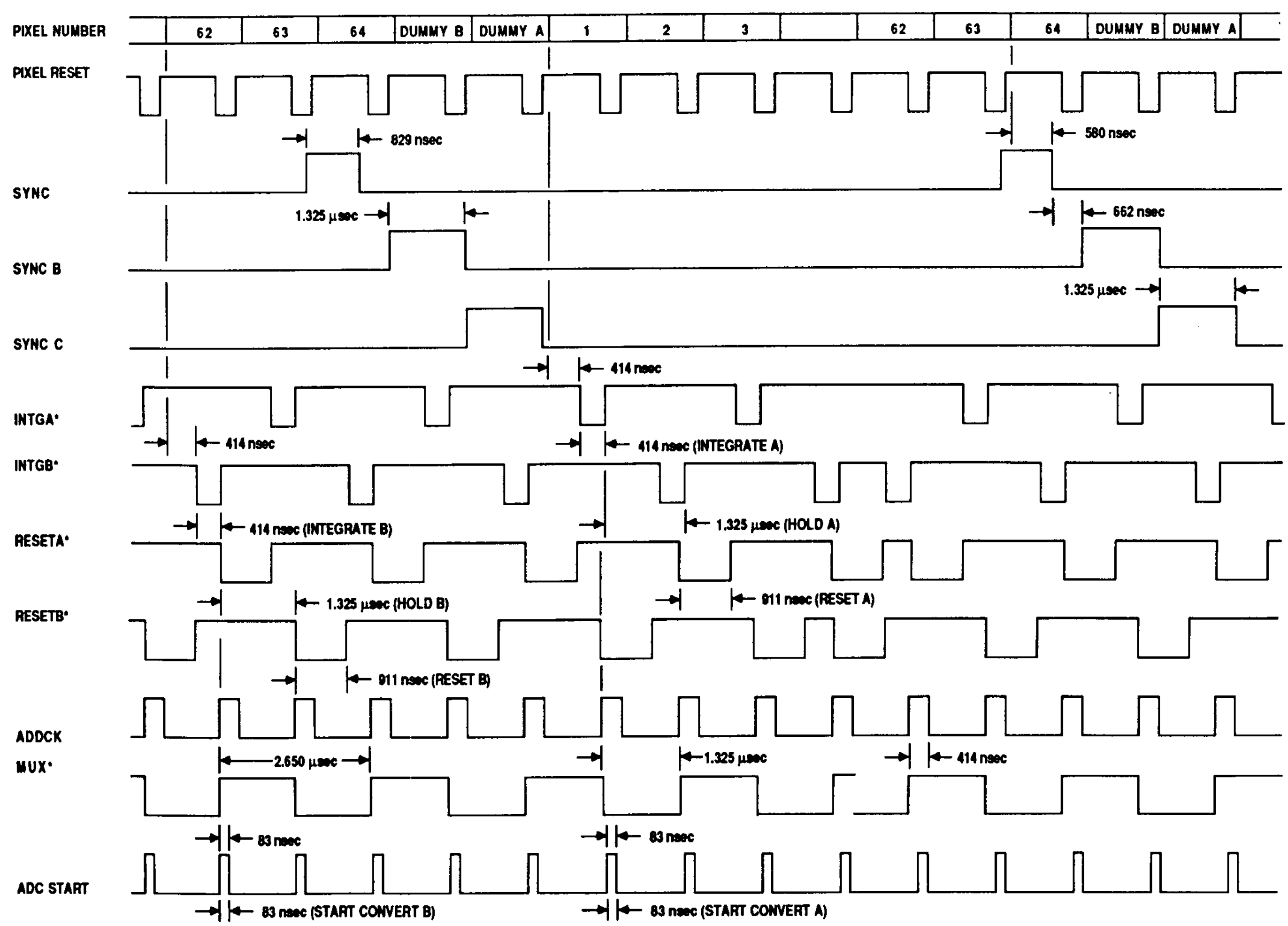

Figure 6. AVIRIS signal chain timing.

The two-phase clock, common to all four arrays, operates continuously at 377 kHz, enabling readout from each array at a rate of 7.55 X 10^5 detectors per second. Start pulses nominally occur at 87.45-μsec intervals, defining the detector integration time. Only at the start of each scan line are more frequent pulses issued to facilitate synchronization to the scan mirror motion. The digital subsystem also provides the capability to make fine adjustments to the spatial correlation between spectral data by controlling the phase relationship of start pulses issued to each array.

A dedicated signal chain and analog-to-digital converter (ADC) for each array enable the parallel processing of detector data. Preamplifier signals are further amplified, integrated, and digitized to ten bits. Timing and control signals (Figure 6), provided by the digital subsystem, are common to all signal chain channels.

Of special note is the process of offset subtraction occurring just prior to signal integration. Early in the AVIRIS system design it was noted that small changes in the detector's temperature could give rise to offset signals equal to the predicted full-scale image signal. Removal of this signal to keep the desired image signal on scale is accomplished by offset subtraction. At the start of each flight line, the foreoptics shutter is closed and the resultant offset signal is processed, digitized, and stored in an onboard memory. The shutter is reopened, and as image signals are processed, the memory data are synchronously recalled, converted to analog form, and subtracted from the appropriate detector data.

The data processing operations discussed to this point occur continually, independent of the validity of the data. Screening of invalid data such as those taken during the flyback of the scan mirror is accomplished by gating the write strobes to the FIFO buffers that receive the ADC outputs. Further data manipulations occur within these buffers, which is the subject of the next section, Data Formatting.

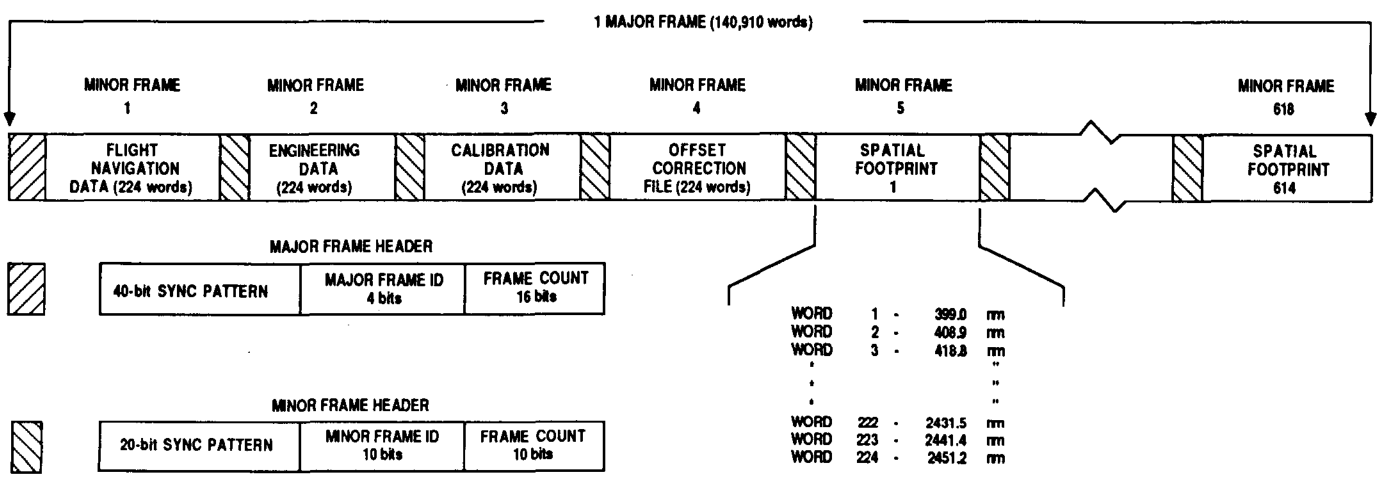

Figure 7. AVIRIS data format.

5. DATA FORMATTING

AVIRIS data are formatted according to the description in Figure 7. A major frame is equivalent to the data produced during one cross-track mirror scan. It is composed of a major frame header, containing a sync pattern, frame count, and ID, and 618 minor frames, which contain ancillary data (4) or image data (614). A minor frame consists of a four-word header, containing sync and ID, and 224 words of data. (Words are ten bits in length.) An image data minor frame organizes spectral information from the shortest wavelength measurement to the longest wavelength measurement for a specific footprint in the cross-track scan.

While this format presents the image data in a straightforward and orderly fashion, it is far from the chronological order in which the data are collected. A consequence of the AVIRIS optical design allows each spectrometer to view a different spatial footprint at any given time in the cross-track mirror scan (Figure 8). Data at the output of the ADCs, therefore, are not only spectrally misordered, but also spatially misaligned. Control of the write/read timing to the FIFO buffers is used to sort the data and place them in the required order, as illustrated in the following description.

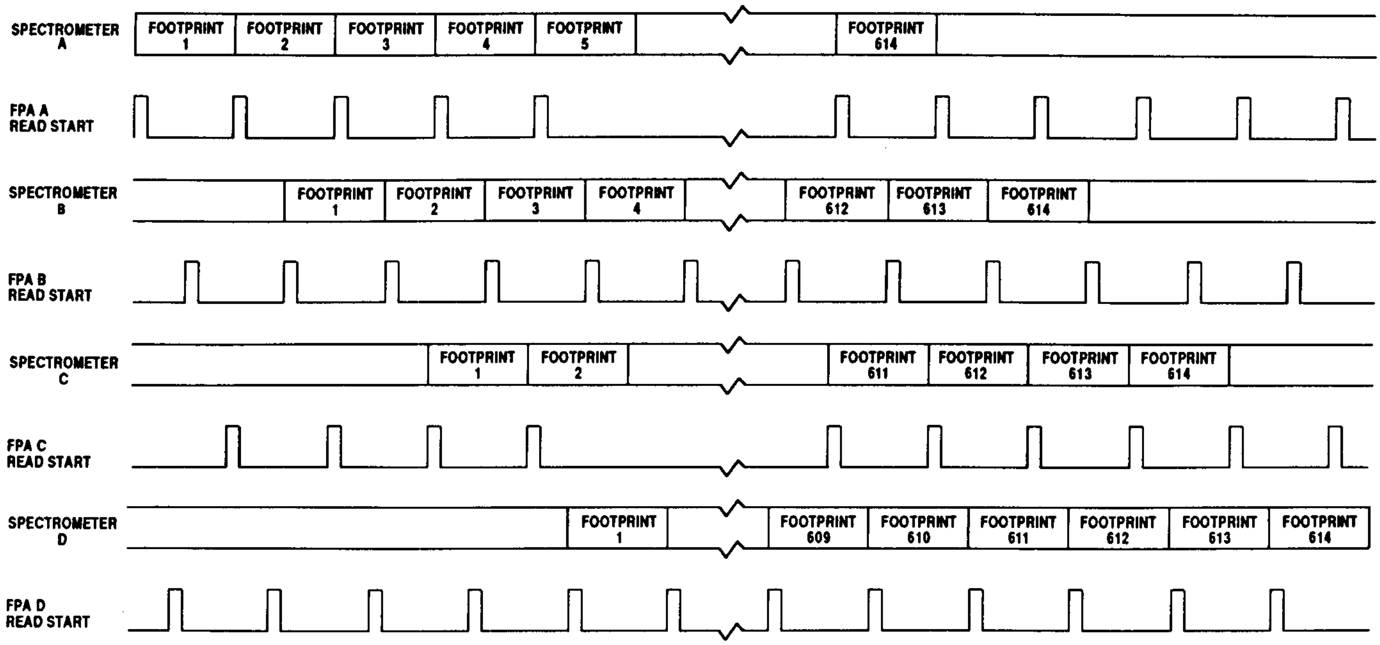

Figure 8. AVIRIS cross-track scan spatial footprint skew. This figure illustrates when each spectrometer views a particular spatial footprint. The array readouts are timed to coincide with these viewing times.

FIFO BUFFER 1

INPUT

SPECTRAL BAND 32 -	FOOTPRINT 614
•	•
•	•
SPECTRAL BAND 2 -	FOOTPRINT 2
SPECTRAL BAND 1 -	FOOTPRINT 2
SPECTRAL BAND 32 -	FOOTPRINT 1
•	•
•	•
•	•
SPECTRAL BAND 4 -	FOOTPRINT 1
SPECTRAL BAND 3 -	FOOTPRINT 1
SPECTRAL BAND 2 -	FOOTPRINT 1
SPECTRAL BAND 1 -	FOOTPRINT 1

OUTPUT

FIFO BUFFER 2

INPUT

SPECTRAL BAND 96 -	FOOTPRINT 614
•	•
•	•
SPECTRAL BAND 34 -	FOOTPRINT 2
SPECTRAL BAND 33 -	FOOTPRINT 2
SPECTRAL BAND 96 -	FOOTPRINT 1
•	•
•	•
•	•
SPECTRAL BAND 36 -	FOOTPRINT 1
SPECTRAL BAND 35 -	FOOTPRINT 1
SPECTRAL BAND 34 -	FOOTPRINT 1
SPECTRAL BAND 33 -	FOOTPRINT 1

OUTPUT

FIFO BUFFER 3

INPUT

SPECTRAL BAND 160 -	FOOTPRINT 614
•	•
•	•
SPECTRAL BAND 98 -	FOOTPRINT 2
SPECTRAL BAND 97 -	FOOTPRINT 2
SPECTRAL BAND 160 -	FOOTPRINT 1
•	•
•	•
•	•
SPECTRAL BAND 100 -	FOOTPRINT 1
SPECTRAL BAND 99 -	FOOTPRINT 1
SPECTRAL BAND 98 -	FOOTPRINT 1
SPECTRAL BAND 97 -	FOOTPRINT 1

OUTPUT

FIFO BUFFER 4

INPUT

SPECTRAL BAND 224 -	FOOTPRINT 614
•	•
•	•
SPECTRAL BAND 162 -	FOOTPRINT 2
SPECTRAL BAND 161 -	FOOTPRINT 2
SPECTRAL BAND 224 -	FOOTPRINT 1
•	•
•	•
•	•
SPECTRAL BAND 164 -	FOOTPRINT 1
SPECTRAL BAND 163 -	FOOTPRINT 1
SPECTRAL BAND 162 -	FOOTPRINT 1
SPECTRAL BAND 161 -	FOOTPRINT 1

OUTPUT

Figure 9. AVIRIS FIFO buffer fill sequence.

At the start of a scan line, the microprocessor sets up a DMA block transfer to FIFO 5 (Figure 4) containing all ancillary data and frame header information in the order defined by the AVIRIS data format. Since the data block contains more information than can be stored in the FIFO at any given time, the DMA operation continues to refill the buffer as the format routine empties it. Meanwhile, the image data processing operations have

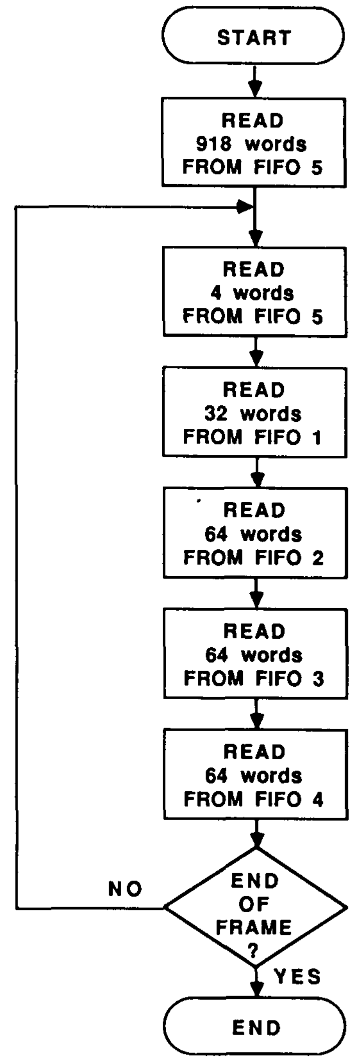

Figure 10. AVIRIS FIFO buffer read algorithm.

synchronized themselves to the scan mirror motion and begin filling FIFO buffers 1-4 with spectral information from spatial footprint one. The data in each buffer are arranged in ascending wavelengths for their respective spectrometer measurement bands (Figure 9).

As data become available at the buffer outputs, the FIFO buffer read/rate buffer write controls begin transferring data to the rate buffer (Figure 4). The process selectively moves data from FIFO buffers 1-5, as defined in Figure 10, to successive memory locations in the rate buffer, effectively building an image of the required AVIRIS format. The process continues until data from all 614 spatial footprints are collected.

The rate buffer contains enough memory to hold one major frame of data. Its purpose is to lower the continuous flow data rate to the tape recorder to an average of 17.0×10^6 bits per second from the instantaneous rate of 23.6×10^6 bits per second occurring during a cross-track mirror scan. At the averaged rate and with the data converted to a serial stream, an AVIRIS data tape will hold approximately 40 minutes of data.

6. CONCLUSIONS

The requirements for the onboard data handling and instrument control electronics created several design challenges. Among these were the need to manipulate large amounts of data at high instantaneous data rates, maximize the data storage efficiency of the tape recorder, and provide full instrument control with a minimum of pilot interface. The success of the design in meeting these challenges is demonstrated by the problem-free completion of many hours of laboratory testing and calibration as well as the successful data return from the U2 missions flown to date.

7. ACKNOWLEDGMENT

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