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EARTH RESOURCES DATA SYSTEMS DESIGN
S192 INSTRUMENT MEASUREMENTS AND CHARACTERISTICS

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Prepared for
MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
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1.0 INTRODUCTION

This report is the first of several reports planned to be issued under MSC/TRW Task AA-51 Earth Resources Data Systems Design. The purpose of this task is to review and analyze the multispectral scanner data collection, handling, and processing system plans and procedures, and to determine their suitability for meeting user requirements by establishing a mechanism for MPAD through which they can systematically review, analyze and evaluate data collection, handling, and processing systems. This effort will aid MPAD in identifying and correcting deficiencies in the planned systems, and in defining tasks necessary to meet the requirements of principal investigators and other users of earth resources data.

This effort includes defining tasks to support the investigation of the system and to develop the necessary products to make the system operational such as software design documents, sensor requirements, etc. This task will initially consider scanner data from the S192 spacecraft instrument, Skylab aircraft underflights, and the MSC aircraft program.

This particular report introduces the S192 instrument and characteristics of its measurements, and how the data is generated onboard the spacecraft. The physical parameters influencing the data resolutions and electronics design are presented as well as calibration requirements and instrument operations. This report generally follows Section 1.0 of the initial task outline presented below and is based upon the discussions and notes from the task working group meetings. Additional detailed data will be generated and documented, as appropriate, generally following the outline.

TASK AA-51 INITIAL OUTLINE

S192 EREP OPERATIONS, DATA HANDLING AND ANALYSIS

1.0 S192 INSTRUMENT MEASUREMENTS

1.1 Measurement Characteristics

Data Quantities, Resolutions, Scan Frequency, ...

1.2 Preflight Calibration

Sensor Temperatures, Responses, Data Verification, Testing, ...

1.3 Operating Modes

Ground and Onboard Controls, Sequences, Constraints, ...

1.4 Time Tagging

References, Granularity, Accuracy, ...

2.0 ONBOARD DATA GENERATION AND AVAILABILITY

2.1 Data Recorded

Contents, Location, Timing, Amounts, Access, ...

2.2 Data Available in Real Time

Onboard, Ground, Type, Contents, ...

2.3 Data Formatting

Analog, Digital, Logged, Coding, Timing, ...

2.4 Data Available Post Flight

Analog, Digital, Logged, Formats, Contents, Correlations, ...

3.0 DATA COLLECTION PLANNING

3.1 Concurrent Operations

S/C, A/C, Ground, ...

3.2 Data Identification Requirements

Sources, References, Timing Tags, Calibration, ...

4.0 DATA COLLECTION FOR PASS PREPARATIONS

Calibrations, A/C, Ground, S/C

5.0 PREPASS OPERATIONS

5.1 Attitude Targeting

5.2 Inflight Calibrations

5.3 Pads

6.0 DATA COLLECTION MONITORING

Logging, Data Checks, Alternate Procedures, ...

7.0 NEAR REAL TIME POST PASS DATA REDUCTION AND EVALUATION

7.1 Instrument Field of View Computations

7.2 Pass Evaluations (Possibly Image Processing)

8.0 NEXT PASS PREPARATIONS

Data Taking Periods, Uplinking, S/C Preparation, Calibrations, Scheduling Concurrent Operations, ...

9.0 POST FLIGHT ONBOARD AND GROUND DATA HANDLING

9.1 Tape Preparation

9.2 Merging Data From Various Sources

9.3 Quick Look Imaging

10.0 POST MISSION ANALYSIS

10.1 Merging Support and Instrument Data

10.2 Data Smoothing

10.3 Data Conversions

10.4 Image Processing

11.0 PRINCIPAL INVESTIGATOR PRODUCT GENERATION

Tapes, Film, Printouts, Data Base, Correlated Data, ...

2.0 S192 MULTISPECTRAL SCANNER MEASUREMENTS

2.1 Introduction

The S192 Multispectral Scanner is one of 5 remote sensors in the Skylab Earth Resources Experiment Package (EREP). The Skylab EREP program is planned as part of, and in support of, already existing programs. These programs encompass multispectral sensing at ground level, by low and high level aircraft, by unmanned spacecraft, and the manned Skylab spacecraft. As a part of this overall program, ground truth data will be collected by ground and aerial survey from selected test sites to compare with the data obtained from the spacecraft sensors and for use in processing the spacecraft data. The S192 Multispectral Scanner is to be flown in the EREP program in order to obtain high spatial resolution, quantitative line scan imagery data of the radiation reflected and emitted by selected test sites in up to 13 spectral bands of the visible, near infrared, and thermal infrared regions of the electromagnetic spectrum.

2.2 Radiation Phenomena

Every object on the earth's surface reflects solar radiation and emits long wavelength infrared radiation in a pattern, characteristic of the object type, called the spectral signature of that object. In the ultraviolet, visible, and near infrared portion of the electromagnetic spectrum, radiation received from a scene is due primarily to the reflectance of solar illumination by the objects in the scene. In the thermal infrared region (wavelengths beyond about 4 microns), the energy received is predominately self-emission due to the temperature of objects in the scene. This radiation, either emitted or reflected, propagates upward from the scene in all directions. If an electromagnetic sensor intercepts part of this radiation and examines the radiation as a function of time, sensor angular motion, sensor translational motion, and/or wavelength, the radiation will supply information about the scene itself. In particular, the radiation received from a scene contains the spectral signatures of the constituents of the scene and may be used to identify objects or to discriminate between objects in the scene. Electromagnetic sensors which use radiation in only a single spectral band may obtain information about a scene in only that specific spectral band. Multispectral scanners offer advantages in certain applications in that they receive and discriminate radiance in many wavelength bands simultaneously, and the information received in each band may be used separately or in any combination to discriminate between object types in a scene. The spectral bands do not have to be limited to the photographic region (wavelengths shorter than about 1 micron), or even to a reflectance region, since thermal emission bands may also be included because electromagnetic detectors and not sensitive film may be used to record the electromagnetic data. One of the major attributes of the multispectral characteristics of multispectral scanners is the potential of automatic recognition of object types by their spectral signature using automatic computation and analysis, and in the advantageous selection of spectral bands to enhance contrast between object types for display purposes. One of the major disadvantages of multispectral scanners is that, compared to the most common and inexpensive electromagnetic sensors, photographic cameras, the multispectral scanners are relatively expensive and complex instruments. In addition, their spatial and spectral resolution is relatively poorer than that obtained with photography.

2.3 S192 Instrumentation and Optics

The S192 Multispectral Scanner is classified as an optical-mechanical scanner. The S192 instrumentation is mounted on the Skylab vehicle in such a way that during experiment operation the S192 experiment axis is pointed down toward the spacecraft nadir. The instrumentation scans an area normal to the spacecraft orbit plane with a conical line scan. Ground coverage parallel to the spacecraft ground track is provided by the spacecraft orbital motion. The spectral signatures of the area being spatially scanned are sampled and separated into 13 different spectral bands. These bands are then imaged onto arrays of electromagnetic detectors. The detector outputs are electrically processed and changed to digital form for recording on tape. The tapes are returned to earth manually for post-flight data processing.

S192 gathers data on the radiation reflected and emitted in the visible, near-infrared, and thermal infrared regions of the electromagnetic spectrum in the following 13 spectral bands.

BAND	DESCRIPTION	RANGE	SAMPLES/SCAN
3	Blue-Green	0.52 to 0.56μ	2480
4	Green-Yellow	0.56 to 0.61μ	2480
5	Orange-Red	0.62 to 0.67μ	2480
6	Red	0.68 to 0.76μ	2480
7	Infrared	0.78 to 0.88μ	2480
11	Infrared	1.55 to 1.75μ	2480
12	Infrared	2.10 to 2.35μ	2480
13	Thermal Infrared	10.2 to 12.5μ	2480
8	Infrared	0.98 to 1.03μ	1240
9	Infrared	1.09 to 1.19μ	1240
10	Infrared	1.20 to 1.30μ	1240
1	Violet	0.41 to 0.46μ	1240
2	Violet-Blue	0.46 to 0.51μ	1240
13	Thermal Infrared	10.2 to 12.5μ	1240
---	Housekeeping	20 analogs	1

The bands extend from the visible to the near-infrared and include much of the same electromagnetic spectrum as two other Skylab EREP experiments, the S190 Multispectral Photography Facility and the short wavelength portion of the S191 Infrared Spectrometer. Band 13 is the long wavelength radiation band. This band is in the thermal infrared portion of the electromagnetic spectrum and includes a part of the electromagnetic spectrum also covered by the long wavelength portion of the S191 Infrared Spectrometer. The similar spectral coverage of these Skylab instruments will allow post-flight correlation of data gathered by these instruments.

Absolute irradiance values may be established through the continuous in-flight calibration of the S192 data. Calibration in the visual and near infrared portion of the electromagnetic spectrum is obtained by scanning a tungsten lamp. Calibration in the thermal infrared region is obtained by using two thermally controlled black bodies.

The S192 optical system is shown in Figure 1. Radiant energy from the earth's surface is collected by the spherical primary mirror and folded onto a scan mirror assembly. This assembly consists of an outboard and inboard scanning mirror mechanically coupled and rotated about an axis through the center of the inboard scanning mirror. It is the rotation of this scan mirror assembly, along with the spacecraft motion in its orbital plane which results in the spatial mapping of the earth's surface along the spacecraft ground track (Figure 2). The spherical primary mirror axis is offset 5.5-degrees from the main experiment axis, thereby extending the scan in lines along a 5.5-degree half-angle cone about the spacecraft nadir direction. The scan assembly rotates a full 360-degrees, but only the forward 120-degree portion of the scan produces data. The remaining 240-degrees is used for calibration and dead time. The calibration sources are placed in the field of coverage of the scan mirror such that they are scanned during the 240-degree scan, thus keeping the instrument calibrated automatically. The 120-degree conical line scan represents a 47-nautical mile ground swath along the spacecraft ground track, if the spacecraft altitude is taken as the nominal planned 235-nautical mile circular Skylab orbit.

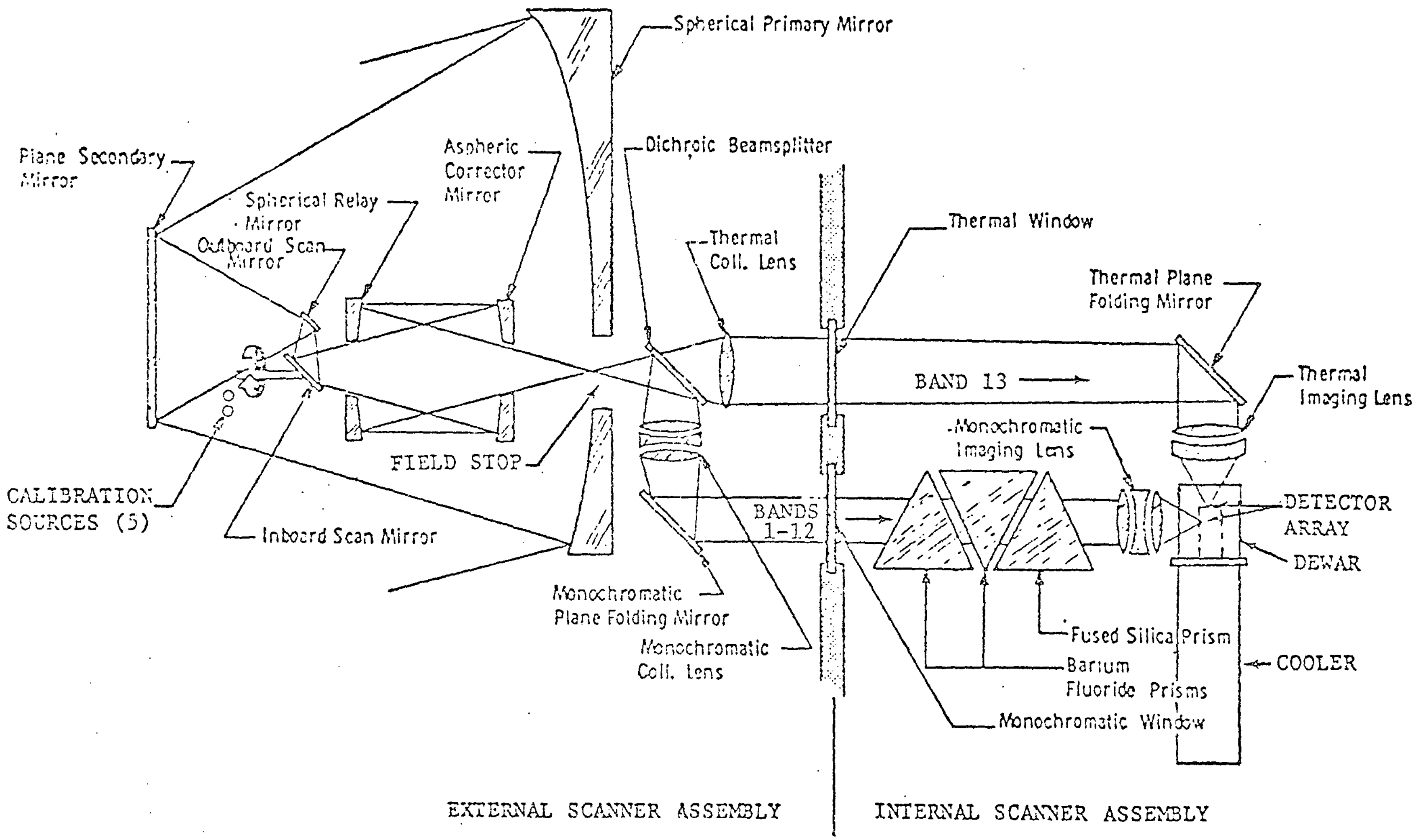

Figure 1. S192 Optical System

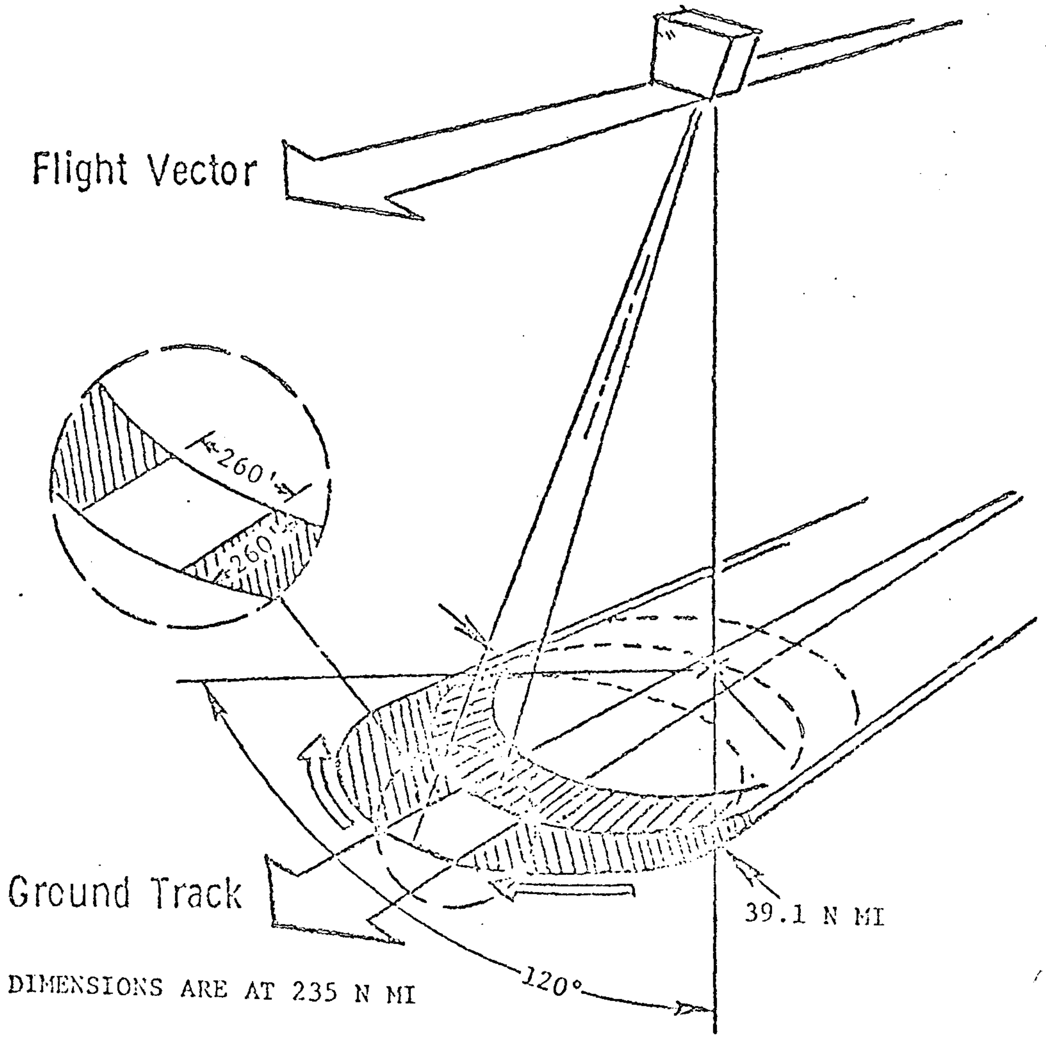

Figure 2. S192 Ground Coverage

After reflection from the scan mirror, the radiant energy is focused by a spherical relay mirror to a second image point where a field stop is located. This field stop defines the instantaneous field of view of the instrument as a 0.182 by 0.182 milliradian field of view. Again using the nominal 235-nautical mile Skylab orbit, this instantaneous field of view represents a 260 by 260 foot instantaneous field of view on the earth's surface, along the 120-degree conical line scan. A dichroic beamsplitter follows the field stop, and reflects the short wavelength radiation in the first 12 multispectral bands and transmits radiation in the thirteenth band. The short wavelength radiation is dispersed by a triple prism spectrometer and passed through a window into the spacecraft. The dispersed radiation is imaged onto a cooled mercury-cadmium-technetium (Hg Cd Te) detector array. The long wavelength radiation in band 13 is collimated by a simple lens, relayed through a second window, and folded to another cooled He Cd Te detector. The detector outputs are then electronically processed using analog video processing, an analog-to-digital converter, and multiplexer, and then recorded on tape for return to earth. The tapes are processed post-flight to obtain desired information. Consideration is being given to transmitting sample data to earth in near real time.

2.4 Uses of Data

The data obtained from the S192 Multispectral Scanner will be used in the following ways:

(1) To obtain quantitative radiance values simultaneously in 13 spectral bands over the selected test sites.

(2) To evaluate the usefulness of spacecraft multispectral data in crop identification, vegetation mapping, land use determination, soil moisture measurement, identification of contaminated areas in large bodies of water, and surface temperature mapping.

(3) To evaluate and determine the feasibility of using automatic processing spectrum matching techniques for the identification of earth features from space.

(4) To compare the results of automatic processing techniques with direct photo interpretation of scanner imagery generated from the different spectral bands.

(5) To compare the imagery from the four spectral bands closest to the S190 Multispectral Camera bands with the photography obtained from the S190 camera.

(6) To investigate the use of atmospheric temperature profiles and water vapor concentrations obtained with the S191 Infrared Spectrometer to correct for the effect of atmospheric attenuation on the radiance measured in space with the Multispectral Scanner.

One of the most interesting potential uses of the data obtained by the S192 Multispectral Scanner is the evaluation of the application of automatic computer processing to discriminate between and to identify object types by using their spectral signatures. The spectral signatures of object types on the earth are represented by sets of data in each of the 13 multispectral bands. By using ground truth data collected by multispectral sensing, using ground or aerial surveys, or by positively identifying object types in the multispectral data by using photographs or other spacecraft sensor data, the spectral signatures of object types may be determined and provided to a computer for use in classifying object types in the multispectral data. By comparing these reference spectral signatures to the spectral data in wavelength bands in the multispectral scanner data, the computer can recognize the same object types in the multispectral scanner data, and can display the objects in an easily recognized form such as false color recognition maps. To eliminate computer confusion in recognition only those channels are used for which the target object radiance is different from the radiance of other objects to be mapped.

Because of the availability of radiance data in many spectral bands, only those bands need to be used which will enhance contrast between object types. Although an overall simplification of the data processing requirements, this example serves to show the type of data processing required and points out how automatic computer data processing is feasible for identifying object types using multispectral scanning data.

3.0 MEASUREMENT CHARACTERISTICS

The section describes the data quantities and characteristics produced by the S192 instrument. Details of the onboard electronics and physical parameters are presented along with discussions of coding techniques and recording formats. The information presented herein is for the purpose of introducing the onboard data generation process and separate documentation will be issued covering the details of the data recorded, data formatting, and data availability in real time and post flight.

3.1 Data Quantities and Characteristics

The radiometric and geometric resolution of the scanner are determined primarily by the basic characteristics of the optical configuration, the detectors and the signal processing electronics (Figure 3). The following are parameters related to system sensitivity and operation.

Radius of Scan Circle on Earth (at 235 nm altitude)	22.6 nm
Information Rate per Line per Detector	Coarse Resolution 1.24×10^3 samples/line Fine Resolution 2.48×10^3 samples/line
Total Bit Rate per Line	1.024×10^4 bits/line
Orbital Period	93.2 min/orbit
Orbital Velocity (earth sweep)	3.9044 nm/sec
V/H	1.66×10^{-2} rad/sec
Number of Lines Required Continuous at 235 nm	91.3 lines/sec
Number of Lines Required to Meet Underlap Spec at 215 nm	94.8 lines/sec
Nominal Line Rate	100 lines/sec (scan/sec)
Data Generation	During 1/3 of a Scan Period
Nominal Samples/Second	Coarse res. 1.24×10^5 Fine res. 2.48×10^5

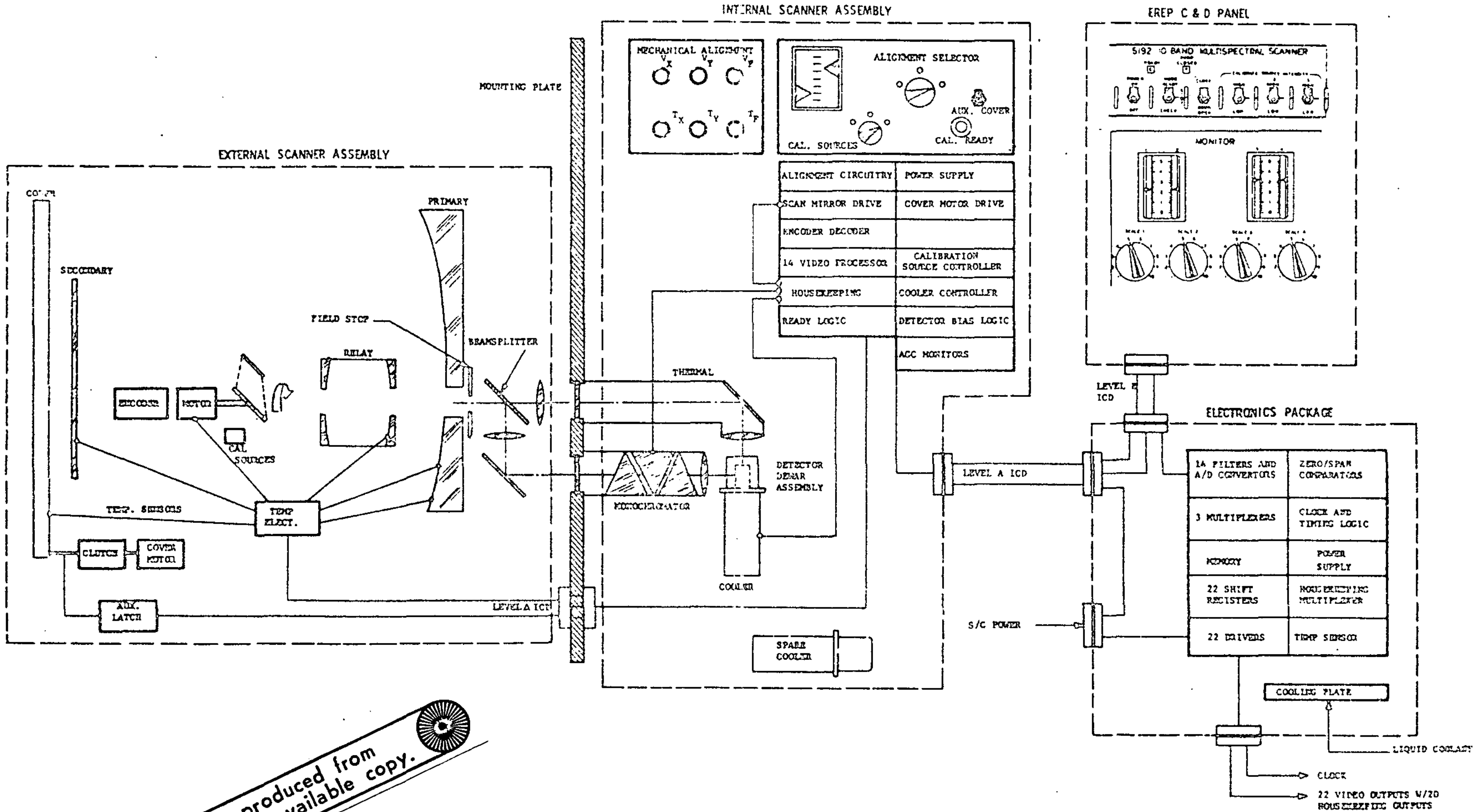

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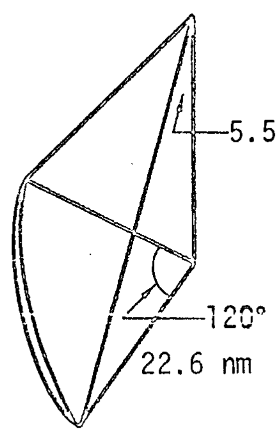
Figure 3. System Block Diagram

Based upon the above parameters and the scan pattern, the instantaneous field of view has been selected to be 0.182 square milliradians. This translates to a 260 square foot area at 235 nm which allows for contiguous area coverage along the flight path and also along the scan line (by establishing the proper sampling rate). One second of S192 operation generates radiance data from approximately a 4 x 47 nautical mile area on the earth's surface. The sampling rates have been selected to provide an overlap to account for tolerances in the optics, scan motor, electronics, and spacecraft nominal orbital parameters. This overlap is determined as follows from the basic geometry:



Scan Circle Radius = 235 sin 5.5 = 22.6 nm

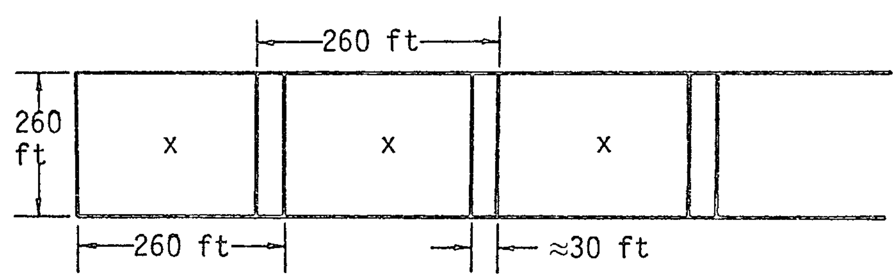
Scan Arc (S) = RO = 22.6(2.094) = 47.2 nm

Samples/sec = 1240 (low resolution)
2480 (high resolution)

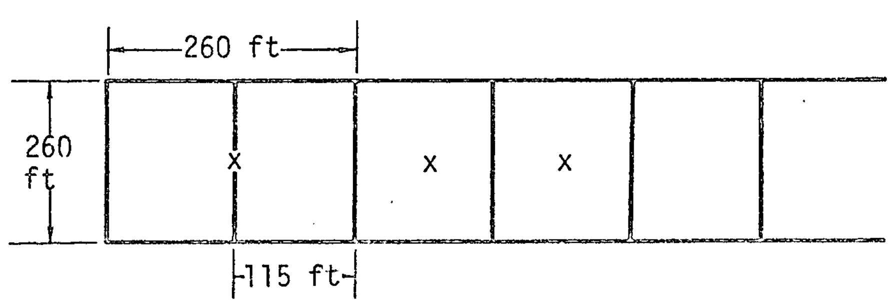
Feet/sample = $\frac{6076 \times 47.2}{1240}$ = 230 ft/sample (low resolution)

and = $\frac{6076 \times 47.2}{2480}$ = 115 ft/sample (high resolution)

The overlap is 12% for the low resolution sampling and 55% for the high resolution sampling as shown below:

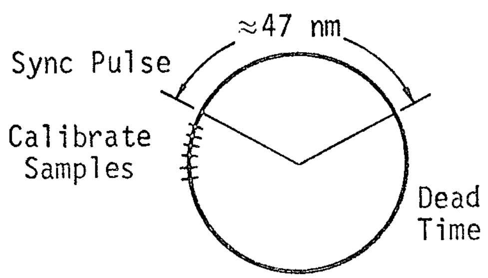


Low Resolution Sampling
12% Overlap



High Resolution Sampling
55% Overlap

Along the flight path (at 235 nm): $4.1 \times \left(\frac{3440}{3440+235}\right) \times .01$ sec/scan $\times$ 6076 ft/nm = 236 ft/scan. Therefore, the overlap in this direction is ≈ 9.3%. Each scan line (data taking) begins upon a signal from an encoder on the scan motor shaft and ends at preset interval which represents 120 degrees of arc as indicated below.



Scan Rate = 100 scan lines/second

3.2 Analog/Digital Conversion and Buffer Design

The ground resolution desired dictates sampling rates of 1240 and 2480 samples per scan line based on the geometry of the orbit. Each sample is an 8-bit word and the sampling rates provide the inputs to the electronics design to provide the analog digital and buffering electronics for eventual digital recording on magnetic tape. There are 14 detector channels; 8 channels requiring a sampling rate of 1.37 usec per sample and 6 channels requiring 2.74 usec per sample. The samples have to be buffered before being read out on 22 tracks of high density magnetic tape. Figure 4 is a block diagram showing the data flow through the electronics which are sized as follows:

READ-IN SPEED:

$$(1/3 \text{ scan}) \left(\frac{1}{100}\,\frac{\text{sec}}{\text{scan}}\right) \left(\frac{8 \text{ wds}}{1.37\times10^{-6} \text{ sec}} + \frac{6 \text{ wds}}{2.74\times10^{-6} \text{ sec}}\right) \simeq 26760 \text{ wds/scan}$$

READ-OUT SPEED:

$$\text{Time} = \left(\frac{22 \text{ wds}}{26{,}760 \text{ wds/scan}}\right) \left(\frac{1 \text{ sec}}{100 \text{ scans}}\right) \simeq 8.24 \times 10^{-6} \text{ sec}$$

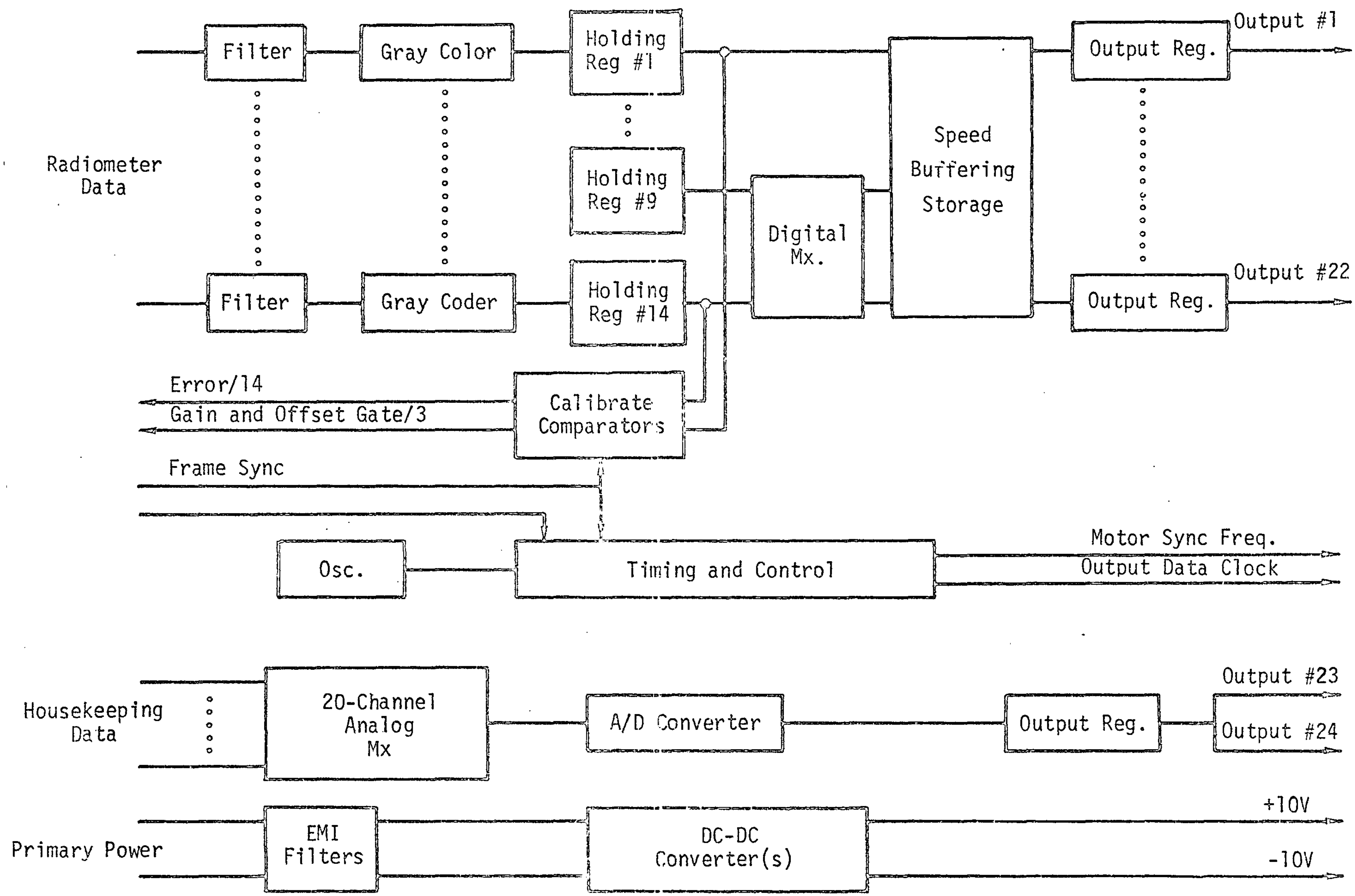


Figure 4. Digital Processing Electronics, Block Diagram

BUFFER SIZE:

8 Bands Read-in at 2560 wds/scan line } Equivalent to 11 bands at
6 Bands Read-in at 1280 wds/scan line } 2560 wds/line

At 8 bits/wd size is (8x11) by (2560 x 2/3) = 88 bit by 1707 words

NOTE: (Reading out begins at same time as reading-in. Need memory buffer at 3/3 - 1/3 = 2/3 of read-in rate.) ∴ Use (2) 88 bit x 1024 word memories

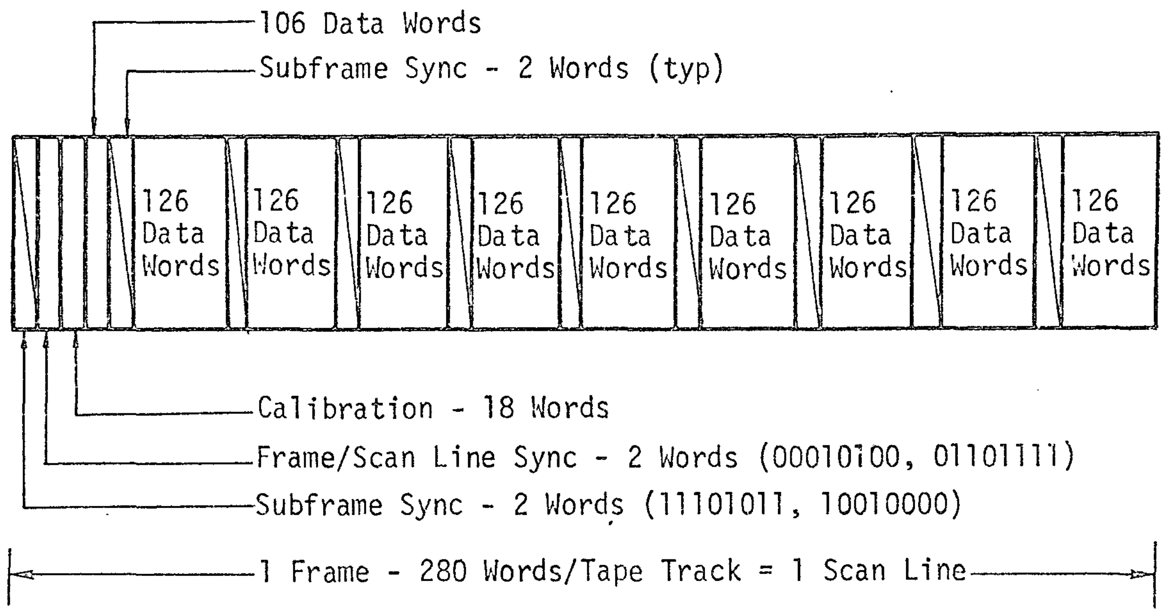
Additional memory capacity is used for sync and calibrate words. Note that the six low resolution channel data words are placed into the buffer memory every other 1.37 usec reading time period. However, the buffer readout arrangement on the 22 tape tracks is such that each of the 6 low resolution channels is read out. The difference is that every data sampling period the high resolution channels require 2 tracks, that is twice as many data words as low resolution tracks. This means that you do obtain data for each of the 14 channels every sampling period. A further analysis and discussion of the relationship between the geometry, data samples, timing, and tape storage arrangement will be presented in part 2.0 - Onboard Data Generation and Availability, of the task outline.

3.3 Coding and Recording Formats

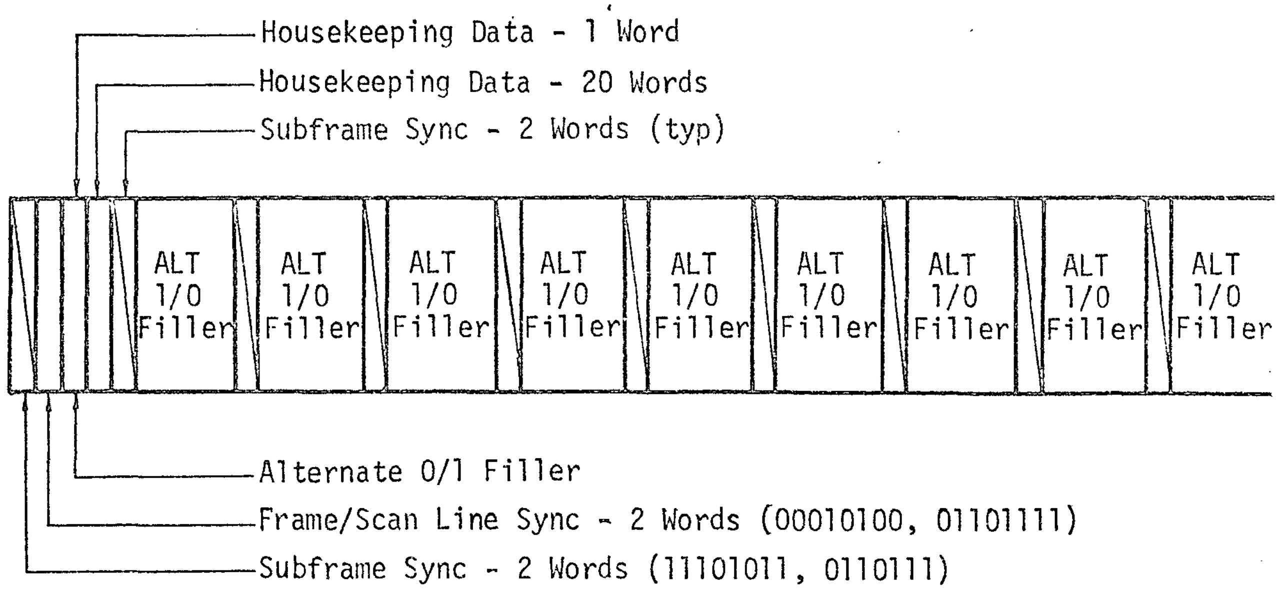
A brief summary of onboard data formatting and coding is provided here to complete this discussion of measurement characteristics. The S192 scientific data format are as follows:

- -- 8 bits/word (255 counts maximum)
- -- 1280 words/frame
- -- PCM encoding: Miller, 970.67 KBPS 5 Bits/second
- -- 94.792 Frames/second
- -- Scientific data including calibration source data, is recorded on T/R tracks 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, and 26.
- -- Housekeeping data is recorded on T/R tracks 1 and 27 (redundantly).

Scientific Data Format



Housekeeping Data Format



Word Assignments Scientific Data

Tape Tracks (Except Track 25)

Word	Subframe 1	Subframe 2 - 10
1	Sync - subframe	Sync - subframe
2	Sync - subframe	Sync - subframe
3	Sync - frame	Data
4	Sync - frame	Data
5 - 10	One Fill	Data
11 - 16	Visible Lo Ref	Data
17 - 22	Visible Hi Ref	Data
23 - 128	Data	Data

Tape Track 25

Word	Subframe 1	Subframe 2 - 10
1	Sync - subframe	Sync - subframe
2	Sync - subframe	Sync - subframe
3	Sync - frame	Data
4	Sync - frame	Data
5 - 10	Thermal Hi Ref	Data
11 - 16	Thermal Lo Ref	Data
17 - 22	Visible Lamp	Data
23 - 128	Data	Data

Word Assignments Housekeeping Data

(Redundantly Recorded on Tracks 1 and 27)

Word		Subframes 2 - 10
1	Sync - subframe	Sync
2	Sync - subframe	Sync
3	Sync - frame	Alternate (1/0)
4	Sync - frame	
5-62	Alternate (0/1)	
63	Data Acquisition Delay	
64-108	Alternate 0/1	
109	Cal 1 Temp 1 (Hot BB Temp Sensor 1A)	
110	Cal 2 Temp 1 (Cold BB Temp Sensor 2A)	
111	Cal 3 Current (Lamp 1 Current Monitor)	
112	Cal 4 Temp (Redundant BB Temp Sensor 3A)	
113	Cal 5 Current (Lamp 2 Current Monitor)	
114	Array Temp 1 (Detector Array Temp Sensor A)	
115	Optic Temp 1 (Prim Mirror Temp Sensor 1)	
116	Optic Temp 2 (Secondary Mirror Temp Sensor)	
117	Optic Temp 3 (Prim Mirror Temp Sensor 2)	
118	Optic Temp 4 (Aspheric Mirror Temp Sensor)	
119	Optic Temp 5 (Cover Temp Sensor)	
120	Optic Temp 6 (Scan Motor Temp Sensor)	
121	Optic Temp 7 (Cooler Motor Sensor)	
122	Optic Temp 8 (Scanner Elect Temp Sensor)	
123	Optic Temp (Monochromator Temp)	
124	D.P.E. Temp (Digital Electronic Temp)	
125	Array Temp 2 (Digital Electronic Temp)	
126	Cal 1 Temp 2 (Hot BB Temp Sensor 1B)	
127	Cal 2 Temp 2 (Cold BB Temp Sensor 2B)	
128	Cal 4 Temp 2 (Redundant BB Temp Sensor 3B)	

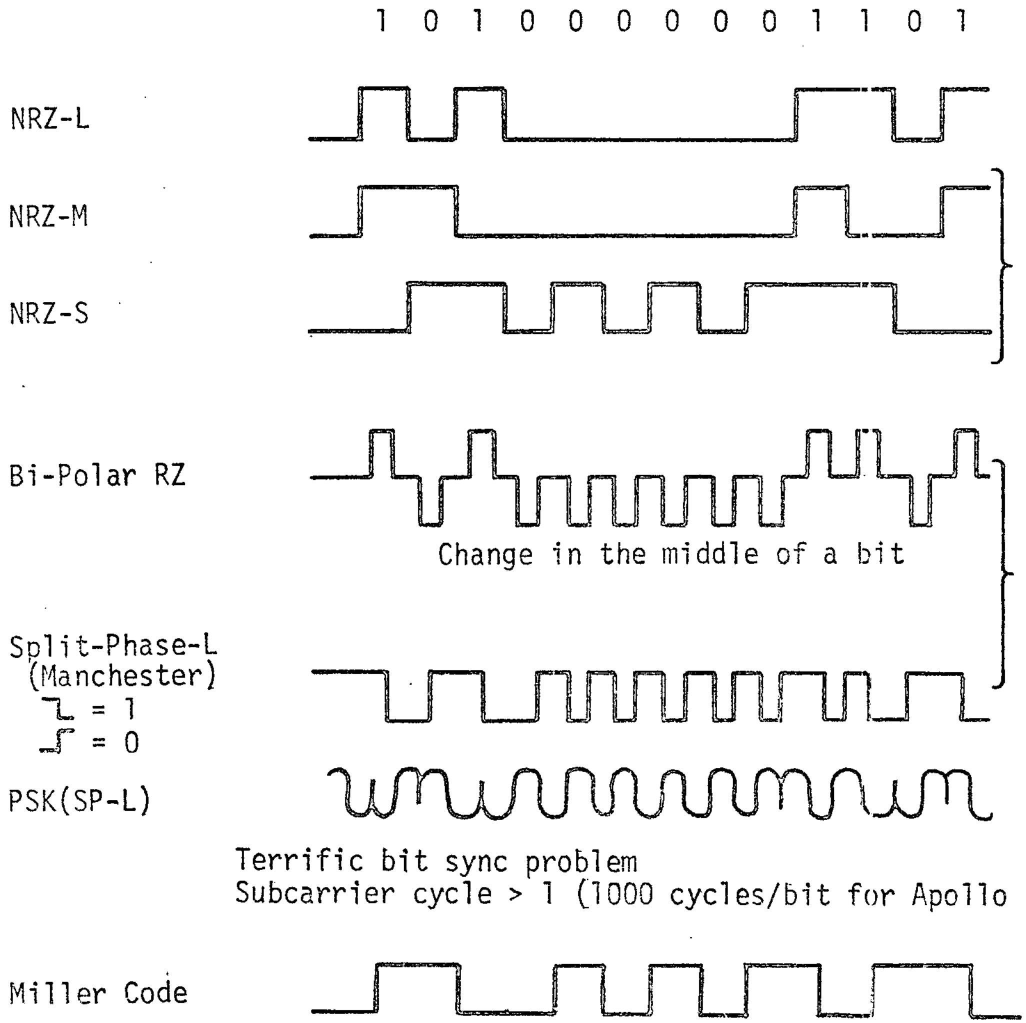
PCM Techniques

The PCM coding technique used onboard is the Miller encoding scheme. Restrictions to recording PCM signals due to the basic characteristics of longitudinal recorder systems are bandwidth, time base stability and system signal linearity. NRZ codes (see Figure 5) have two major limitations; the requirement for d-c response and susceptibility to time base errors. The packing density for NRZ codes is limited to about 6K bit/in/channel with bit error reliability of 1 in 10^6.

Manchester codes (split-phase L or bi-phase) do not require d-c response and do not have timing problems due to jitter. However, the bandwidth requirement is high. Packing densities are as much as 12K bit/in/channel with bit error reliability of 1 in 10^6.

The Miller coding (a proprietory scheme developed by Ampex) provides the advantages of NRZ and Manchester codes with none of the disadvantages. Bit packing densities are about 20K bit/in/channel with an error reliability of better than 1 in 10^6. The maximum bit rate that can be recorded is limited by the recorder bias frequency of 7.7 MHZ. To ensure that no unwanted signals will occur the encoder should be limited to a maximum bit rate of 4.0 Mb/sec. The maximum reproduce bit rate is limited by the decoder and should not exceed 3.6Mb/sec.

Miller encoding will require conversion to NRZ codes to be compatible with ground computers. This requirement will be covered in another report.



NRZ-L: Denotes ones and zeroes.

Easy to obtain 100% bit errors with inversions. This coding is not used in communications.

NRZ-M, NRZ-S:

NRZ-M - transition every time a one occurs

NRZ-S - transition every time a zero occurs

Polarity not a factor; only changes count. Allows short term stability.

Bi-Polar RZ, Split-Phase-L (Manchester):

No. of transitions a function of bit stream.
May have a polarity ambiguity problem but no sync problem.
All have a non-zero d-c component which causes baseline walk or creep and therefore detector problems.

RZ requires twice as much bandwidth as NRZ.
Never has a d-c offset problem because spends equal time above and below ref.

PSK(SP-L):

Terrific bit sync problem
Subcarrier cycle > 1 (1000 cycles/bit for Apollo PSI)

Miller Code:

A one causes a transition in the middle of the bit.
A zero causes a transition at the beginning.
A one followed by a zero is coded as no transition.
A zero followed by a zero is coded as a transition at the end of the first bit period.
No baseline offset problems.
Easy synchronization - at least one transition every other bit.
Bandwidth comparable to NRZ but does not have low freq. components (death for tapes).

Clock causes a pulse at the edge of a bit

∴As tape speed fluctuates without transitions location of bits would not be known

Bit synchronizer reconstructs signals into nice up and down bits. Clock defines bit boundaries (Requires a 101 bit pattern for proper clock phasing)

Requires narrow spectral band occupancy ∴more bits/inch

Figure 5. PCM Coding Examples

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4.0 CALIBRATION AND ALIGNMENT

The S192 scanner produces calibration data during operations to allow later evaluation and possible correction of the experiment data. There are two sets of calibration data recorded on the EREP tape; 1) radiometer detector response characteristics to premeasured radiation sources, and 2) housekeeping data consisting of optics, array, and detector temperatures. Alignment procedures for the onboard electronics using the internal scanner alignment panel (Figure 3) are essential to producing the calibration data.

4.1 Detector Preflight Calibration

Radiometric fidelity of the detector is defined as the accuracy of the video output as a representation of target radiance, neglecting random type errors such as electrical noise. The radiometric fidelity is dependent on the initial external calibration of the system, the internal calibration update (during flight) and any effects not corrected by the calibration (such as motor variations, shaft flexing, AGC circuit stability, blackbody temperature stabilities). The visible and near infrared detector channels are calibrated preflight using a highly precise known source of radiation (a standard lamp and a specially painted reflecting surface). The detector response to the known source is estimated to be accurate to about 0.4%. The thermal detector channel is initially calibrated with a precision blackbody reference with a known temperature accurate to $0.1^{\circ}K$ and an emissivity to an accuracy of 0.005. The resultant uncertainty in the initial calibration will be less than $0.2^{\circ}K$.

4.2 Inflight Calibration

During scan dead time each of the 14 channels are automatically calibrated. The gain of each video channel is updated once per scan line by the AGC circuitry and the sensing of the internal calibration sources. This compensates for the effects of various gain drifts in the electronics. If the AGC system is "perfect" and the internal calibration sources are stable then the video outputs will always be correct (radiometrically faithful) even though preamplifier gain and detector responsivity should drift. For the visible channels the calibration source is a well-regulated tungsten lamp with radiance stability of about 1% over the mission time. Control circuits are expected to have short term stability (15 minutes) to better than 0.1% in each video channel. For the thermal channel, blackbody sources are used for the zero and span references. The stabilities of these blackbodies will be better than $1^{\circ}K$ over 15 minutes or $0.02^{\circ}K$ over one minute with a temperature measurement accurate to better than $0.1^{\circ}K$.

The other sources of error are the timing of the calibration pulses during the scan, the AGC electronics, and the movement of the optics and scan motor, and variations in the reflectance of the optics. These are expected to have negligible effect. However, if there are significant variations in the optical element properties they may be determined by the data recorded on the EREP tape and their effects as a source of error removed.

There are two factors which affect the stability of the spectral bands, 1) location of the detector bands, and 2) vibration due to the detector cooler assembly. An alignment capability is provided onboard to allow realignment to less than 0.0005 inch, or approximately one-quarter of a spectral band width. Tests indicate that the vibration will be less than 0.025 micron but further tests are to be made.

4.3 Onboard Calibration Sources

Five radiometric sources (minature calibration lamps) are used to provide the inflight calibration. Three blackbody sources are available for thermal calibration (two primary and one redundant). One primary is hot ($295^{\circ}K$, $320^{\circ}K$) and the other is cold ($260^{\circ}K$, $295^{\circ}K$). They provide the "zero" reference and the span reference. Calibration data during each scan is placed in the memory buffer and read out as 18 words at the beginning of each frame (scan line). There are six words of thermal high reference, six words of thermal low reference, and six words of visible lamp reference data (further details about the format, location and content of the data words will be presented in a future report).

4.4 Housekeeping Data

The buffer electronics required for the various housekeeping functions will provide an analog 0 to +5v d-c output. There are twenty housekeeping functions which go to the digital electronics for permanent record on magnetic tape during system operating conditions. The twenty channels of low speed housekeeping analog data are multiplexed into one PAM line fed to an encoder. Each channel is sampled once per frame and the 8-bit digital data are read out redundantly on two tape tracks. The housekeeping data consists of calibration sensor temperatures, optics temperatures, and array temperatures as listed below.

Subframe	Word	Measurement Name	
1	109	Cal 1 Temp 1	Hot blackbody sensor "1A"
1	110	Cal 2 Temp 1	Redundant blackbody temp sensor "3A"
1	111	Cal 3 Temp 1	Cold blackbody temp sensor "2A"
1	112	Cal 4 Temp	Lamp 1 current monitor
1	113	Cal 5 Temp	Lamp 2 current monitor
1	114	Array Temp	Detector array temp sensor "A"
1	115	Optics Temp 1	Primary mirror temp sensor number 1
1	116	Optics Temp 2	Primary mirror temp sensor number 2
1	117	Optics Temp 3	Secondary mirror temp sensor
1	118	Optics Temp 4	Aspheric mirror temp sensor
1	119	Optics Temp 5	Scan motor temp sensor
1	120	Optics Temp 6	Cover temp sensor
1	121	Optics Temp 7	Monochromator temp
1	122	Optics Temp 8	Scanner elect temp sensor
1	123	Optics Temp 9	Cooler motor temp
1	124	D.P.E. Temp	Digital electronic temp
1	125	Array Temp 2	Detector array temp "B"
1	126	Cal 1 Temp 2	Hot blackbody temp sensor "1B"
1	127	Cal 2 Temp 2	Redundant blackbody temp sensor "3B"
1	128	Cal 3 Temp 2	Cold blackbody temp sensor "2B"

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5.0 OPERATING MODES

This section summarizes some of the operational procedures for the S192 instrument especially in terms of calibration, checkout, and operate modes. A more detailed description of the onboard and ground control operations and their effects on data generation and collection will be made in a separate report.

5.1 Prepass Planning

Site selections are made nominally 5 days in advance of a pass. The orbital characteristics of the spacecraft indicate near ground track repetition every 5 days within about 1 degree. The pass plans are updated daily based on the following criteria:

Ground Track - at least 30° of data taking
Sun Angle > 30°
Beta Angle < $\pm 50^{\circ}$
Experiment Field of View
Weather Conditions
Cloud Cover
Target Priorities
Aircraft Availability for Simultaneous Coverage
Truth Site Status
Communications Reliability
EREP Sensor Priorities
Pointing Data
EREP and Spacecraft Systems Status
Scientific Data Requirements

At T-1 day before the pass target selections are finalized and the detailed timeline uplinked at T-8 hours includes:

Time of Z-LV maneuver
Checkout and warmup times of EREP equipment
AOS and LOS of targets
Pointing requirements

Swtiching procedures for the various modes of operation

The T-8 hours PAD message is uplinked in three parts; 1) EREP setup, 2) EREP operate (checklist and timeline), and 3) Viewfinder Tracking System operations which include site ID numbers, cloud cover indices, map and lead-in graphics ID, and GMT and gimbal angles for locating the target.

5.2 S192 Scanner Operating Procedures

Checkout Procedure

Prior to the data taking pass, the operator must set the internal calibration switches to the prescribed settings, set the scanner mode switch to the standby position, and set the power switch to the "on" position.

A period of twenty minutes is allowed for stabilization of the scanner temperatures.

The operator will then set the mode switch to the check position. He will check the scanner for proper operation by displaying the relevant signals (calibration source temperatures and currents, dewar temperature, and detector agc voltages) on the meters of the C&D panel. In the event of indicated malfunction, the operator will undertake one of the contingency procedures described below.

Contingency Procedures

Blackbody calibration source replacement: In the event that the temperature of one of the blackbodies is out of the specified temperature range that blackbody will be replaced. The operator will open the internal scanner assembly cover to expose the internal scanner control panel. If the "hot" blackbody source has failed, the operator will turn the source replacement switch to the "hot cal source replace" position. If the cold blackbody has failed, the operator will turn the source replacement switch to the "cold cal source replace" position.

Visible channel calibration source replacement: If a failure of the visible calibration source is indicated (by the display of current) that source will be replaced. This is accomplished by changing the visible calibration switch (on the EREP C&D panel) from the low position to the high position, or vice versa as appropriate.

Replacement of detector-dewar-refrigerator assembly: In the event that the indicated temperature of the detector-dewar is out of the acceptable range, the dewar-refrigerator assembly will be replaced. The operator will open the internal scanner assembly cover; this exposes both the spare assembly and the failed assembly. The operator will release a set of fasteners holding the failed assembly and then remove that failed assembly from its supporting bracket. He will then place the spare assembly against the supporting bracket, and attach it with the appropriate fasteners.

Alignment of detectors: In the event of a detector dewar replacement, or in case the detector agc voltages are unacceptably low, the detector assembly will be aligned (or realigned). The operator will go to the internal scanner. There are six alignment knobs; three knobs align the thermal channel in the x, y, and z directions; the three other knobs align the visible channels in x, y, and z.

During the alignment of the thermal channel the operator will monitor one of the two needles on the "alignment meter" which is also located on the internal scanner control panel. The operator will first set the select switch for thermal channel alignment.

He will then manipulate the x and y thermal alignment knobs so as to "peak" the meter output. Specifically, the operator will first move the y knob over its full excursion with the x knob set at one of its extremes; he will then index the x knob by a small increment; he will repeat this procedure until the meter needle moves appreciably and he has "found" the detector. This procedure results in a detector search pattern. The operator will then "peak" the meter by making small movements of the x and y knobs. Finally, the operator will manipulate the z control knob to appropriately peak the meter reading.

The alignment of the visible detectors is performed in a manner similar to that just described. In this case, however, the outputs of detectors 1 and 9 are presented by the two needle meters. Prior to this alignment, the selector switch is set for visible channel alignment. The x, y, and z knobs for the visible channel are then manipulated as described above to peak both of the meter needles. Note that if one needle has been properly peaked, the other should also be near its peak value.

"Operate" Procedure

After the appropriate checkout and contingency procedures have been completed the scanner will be ready for operation.

The operator will switch on the "cover opening" switch. If the cover fails to open (as indicated by a light on the EREP C&D panel) the operator may activate an auxiliary cover opening mechanism by a three position switch on the internal scanner control panel; the operator will turn the switch from the "off" to the "arm" position, and then to the "fire" position.

The operator will then set the mode switch in the "ready" position. This causes the EREP tape to run at 60 ips and data is written on the tape as discussed previously.

After data taking, the mode switch will be set in the "standby" or "off" position as appropriate. If the "off" mode is initiated, the aperture cover of the scanner should be closed.

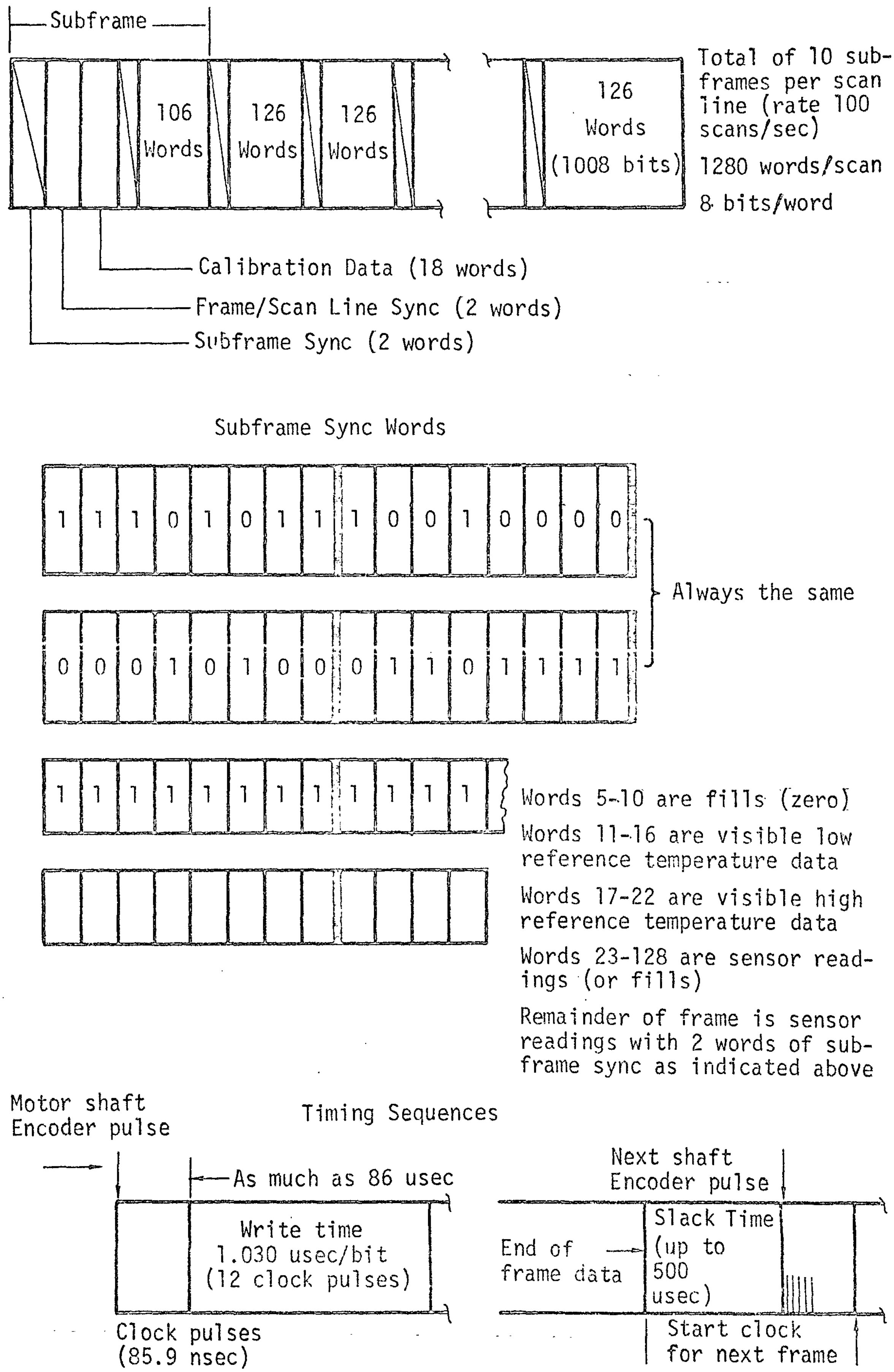
6.0 TIME TAGGING AND REFERENCES

There are no direct time tags or references placed on the 22 tracks of S192 data nor on the 2 tracks of housekeeping data associated with the S192 instrument. However, if any part of the S192 data can be time correlated, then the S192 frame rate and internal electronic circuit time characteristics for reading and writing data could be used to time tag each data word. The subject of time tagging S192 data can be considered in two parts: 1) internal timing, and 2) referencing the data to a standard GMT.

6.1 S192 Internal Timing Characteristics

An S192 frame is randomly started, but once a data taking run begins the frame rate is nominally constant at 10 msec with 1280 words per scan line. It should be noted that time tagging a single 8-bit data word within a frame requires adjustment because of the difference in read-in and read-out times (1.37 and 8.24 usec) and more important because of the ambiguities at the beginning and end of a frame. The scanner circuitry synchronizes the motor shaft encoder to the read-in and read-out pulses of the buffer memory (and to the sampling and A/D conversion operations). The circuits are also designed to ensure that a frame ends with an 8-bit word. All of the internal pulse counters are synchronized immediately following the occurrence of the frame synchronization signal from the shaft encoder. There is a maximum ambiguity of 86 usec between the pulse and the start of read-out from the buffer onto the EREP tape (refer to Figure 6). There is a built-in 500 usec time window as slack time at the end of the frame in the event of motor speed variations. At the 8.24 usec readout rate this becomes about 60 words of margin. The motor speed variation for a single scan is negligible and this slack or margin is designed to account for long term speed variations. This design allows about a 4.7% $\left(\frac{60 \times 100}{1280}\right)$ speed-up in the motor without loss of data. Motor slowdown is compensated for by the circuits which adjust the sampling rates accordingly.

Figure 6. S192 Recorded Data



Motor speed variations are expected to be minimal, and the amount of the actual slack window per scan is recorded on the housekeeping data word 63 (8 bits near the end of a scan redundantly recorded on EREP tracks 1 and 27). This allows a check on motor speed variations.

If an 8-bit dataword is to require accurate time tagging it may be preferable to wait until rectification (conversion from a conical scan line to a straight scan line). Time tagging individual words within a frame can be accomplished with microsecond accuracies and the errors (if one understands the process) are negligible compared to the inaccuracies of time tagging to a ground reference time.

Time tagging or correlating a frame of S192 data to a GMT reference is accomplished by using the time tag furnished to the S190 data on tracks 14 and 15 of the EREP tape. However, the basic problem here is that the S192 and S190 initial data frames start randomly and their frame rates differ. S190 has a frame rate of 15.625 msec and S192 has a 10 msec frame rate. The time tag was originally established to accomodate S190 data by having a basic time increment of 1/64th of a second to correspond to the S190 rate of 64 frames per second. This means that the GMT tag for S190 data can be determined to a granularity of 122.0703125 usec (the read time per bit) by counting the bit periods between S190 frame updates. It should be noted that this time tag (see Figure 7), placed at the end of a frame of S190 data (composed of 16 8-bit words), is the time tag for the beginning of the S190 frame.

All this indicates that the beginning of a single S192 frame could be time tagged with an error of up to 15.625 msec when attempting to correlate an S190 frame to an S192 frame (assuming it is possible to correlate one-to-one between single time frames). The time reference accuracy of the S190 data to a ground reference time was not included here and is discussed separately in the next section. The 15.625 msec error could also be interpreted as an error in time tagging S192 frames up to 1-1/2 scan lines.

GMT

Bit No.	1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40
Ex.	0 1 1 0 0 1 0 1	0 1 1 0 0 0 0 1	1 0 1 0 1 1 1 0	0 1 0 0 1 0 0 1	1 0 0 1 0 0 0 0

Bit Wt.	2 1	8 4 2 1	8 4 2 1	2 1	8 4 2 1	4 2 1	8 4 2 1	4 2 1	8 4 2 1	500 250 125 62.5 31.25 15.625	Always Zero
Bit Content	Hun Day	Ten Day	Unit Day	Ten Hrs	Unit Hrs	Ten Min	Unit Min	Ten Sec	Unit Sec	Milliseconds	Not Used

Example = 195 days, 21 hours, 57 min, 12 sec, 390.625 millisec

Figure 7. S190 GMT Time Word

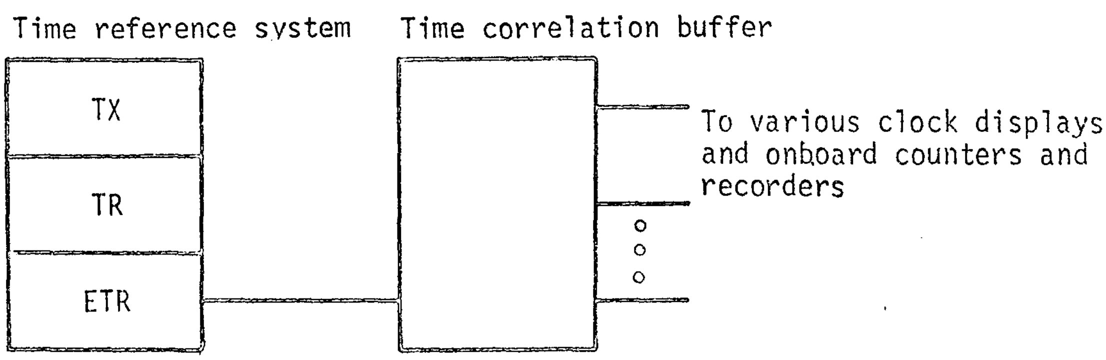
6.2 Referencing the Onboard Time Tag to a Standard Time (GMT)

This is a preliminary discussion of onboard time tagging with reference to a standard time reference. A more complete discussion will be presented in a later document covering the conversion and processing of S192 data on the ground. The onboard Time Reference System (TRS) is essentially the same equipment used on the Gemini program. For Skylab, additional hardware called a Time Correlation Buffer (TCB) was designed to provide time references for various onboard clocks and displays including the EREP Control and Display Panel. The TRS consists of a primary and secondary electronic timer, two time correlation buffers, a digital clock, two digital display units, and a portable timer. The TRS provides: 1) onboard displays of elapsed time; 2) elapsed time data to the instrumentation system and earth resources experiments; and 3) two time dependent control switching functions to the DCS. The time characteristics are:

Input voltage range	18 to 30 Vdc
Accuracy	$\pm$ 3.125 sec/day
Stability	$\pm$ 0.875 sec/day at $77^{\circ} \pm 18^{\circ}$F

The time tags generated by the TRS are also downlinked in the telemetry stream every 2.4 seconds as a 24 bit word. Within the 2.4 second telemetry frame rate there is a "fine" time sample generated 10 times per second. This time word has a granularity of 1/8 second which means the time word changes 8 times within the 10 readings. This would seem to indicate that if the onboard timing mechanism and ground references are perfect (no biases or drifts) data could be time tagged to within 125 msec (which is orders of magnitude higher than the time tagging discussed above for the internal S192 timing system). PCM telemetry time tagging will be covered in another report.

The TRS onboard consists of three registers: the TX and TR registers which are decremental counters and the ETR which is an incremental counter (Figure 8). The TX register can cound down up to 2 hours, 16 minutes and is used to zero the ETR to GMT midnight within 125 milliseconds. The procedure is to correct the ETR once every 24 hours. The TCB drives various clocks and displays and provides a 24-bit BCD word which is placed in a 36-bit register in the TCB. The TCB (from its circuits) adds 6 bits binary to provide the 1/64 second granularity. Additional bits are added manually (by the astronaut) to denote time in days. In actual operation the TCB synchronized to the TRS produces a 32 pps square wave used for display on the EREP Control and Display whose circuits actually place the time words onto the EREP tape. Further details and analysis of this timing situation will be documented at a later date as this task progresses according to the task outline.



Note: The TCB is always in sync with the ETR

Figure 8. Onboard Time Reference System

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