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SEASAT-A LAND APPLICATIONS DATA PROCESSING PLAN

Job Order 75-225

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Prepared By

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For

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ACRONYMS

ALT	Radar Altimeter on Seasat-A
CCT	Computer Compatible Tape
EDR	Experiment Data Record (raw data tape)
FNWC	Fleet Numerical Weather Central (Monterey, California)
GSFC	Goddard Space Flight Center
HDT	High Density Tape
HDDT	High Density Digital Tape
MOCS	Mission Operations & Control Subsystem (GSFC)
NASCOM	NASA Communications System
PDPS	Project Data Processing Subsystem
PDR	Processed Data Record
SAR	Synthetic Aperture Radar
SASS	Seasat-A Scatterometer System
SCAT	Microwave Scatterometer
SDPS	SAR Data Processing Subsystem
SMMR	Scanning Multifrequency Microwave Radiometer
STDN	Space Tracking and Data Network
TBD	To Be Determined
VIRR	Visible-IR Radiometer

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1.0 INTRODUCTION

This Technical Memorandum describes, in as much detail as possible at this time, the Seasat-A data products, formats and processing steps pertinent to a data processing plan for use of Seasat-A data in land applications studies at JSC.

The Seasat-A satellite which is to be launched in May 1978 will have five sensors. These include three active microwave sensors, one passive microwave sensor and one passive optical sensor:

	Sensor	Abbreviation	Type
(1)	Radar Altimeter	(ALT)	active microwave/non-imaging
(2)	Synthetic Aperture Radar	(SAR)	active microwave/imaging
(3)	Radar Scatterometer	(SASS)	active microwave/non-imaging
(4)	Scanning Multifrequency Microwave Radiometer	(SMMR)	passive microwave/non-imaging
(5)	Visible-IR Radiometer	(VIRR)	passive optical/imaging

The performance characteristics for these sensors are given in Table 1 and their surface coverages are illustrated in Figure 1. The major goal of the Seasat-A project, as a part of the NASA Earth and Ocean Dynamics Applications Program (EODAP) is to demonstrate the capabilities of a space system for monitoring global ocean dynamics. The five Seasat-A sensors have been chosen and designed to meet this goal. They will provide data for the calculation and monitoring of ocean currents, surface temperatures, waves, surface wind fields, sea ice, storms, etc. (Refs. 1-5).

The Seasat-A will orbit the earth fourteen times a day in a 790 km circular, retrograde polar orbit so designed that it will provide approximately global coverage every 36 hours. (See Figure 2). The following five Space Tracking and Data Network (STDN) stations are presently committed to provide telemetry, command and tracking support for Seasat-A.

(1) Fairbanks, Alaska (ULA)
(2) Goldstone, California (GDS)
(3) Merritt Island, Florida (MIL)
(4) Madrid, Spain (MAD)
(5) Orroral, Australia (ORR)

TABLE I.– SEASAT-A SENSOR CHARACTERISTICS

CHARACTERISTICS	SYNTHETIC APERTURE RADAR (SAR)	RADAR SCATTEROMETER (SASS)	SCANNING MULTIFREQUENCY MICROWAVE RADIOMETER (SMMR)	RADAR ALTIMETER (ALT)	VISIBLE INFRARED RADIOMETER (VIRR)
GENERAL					
Type	Imaging L-band	Fan Beam	Bidirectional Scan	Pulse/Precision	Scanning
System Contractor	Hughes/JPL	GE [2]	JPL	APL [3]/Johns Hopkins	SBRC [4]
Contracting Organization	JPL [1]	NASA/Langley	JPL	Wallops Flt. Ctr.	GSFC [5]
SPECIFIC					
Frequencies	1.275 GHz	14.6 GHz	6.6, 10.69, 18.0, 21.0 & 37.0 GHz	13.5 GHz	0.47 – 0.94 μm 10.5 – 12.5 μm
Spatial Resolution	25 m	50 km ±5%	Footprint axes: (6.6) 121 x 79 km (10.69) 74 x 49 km (18.0) 44 x 29 km (21.0) 38 x 25 km (37.0) 21 x 14 km	1.6 km diameter	Visible: 2 km Infrared: 4 km
Coverage	100 km (17 –23° or 230–330 km from nadir, one side)	High and low winds: ±25°–65°; 200–950 km near nadir roughness ± 70 km	638 km (±25° from nadir)	12 km (due to integration time)	2127 km
Polarization	H	VV & HH in sequences	dual linear	linear (antenna)	—
PRF [6]	1463, 1540, 1647 pps	38 pps	Non-applicable	1030 pps	Non-applicable
Data Rate	15.66 mbps	590 bps	2 kbps	8.15 kbps	(Vis) 6.28 kbps (IR) 3.31 kbps

1 Jet Propulsion Laboratory
2 General Electric
3 Applied Physics Laboratory
4 Santa Barbara Research Center
5 Goddard Space Flight Center
6 Pulse Repetition Frequency

NOTE: See JSC-11405. "Seasat-A Land Applications Program Plan" K. Krishen

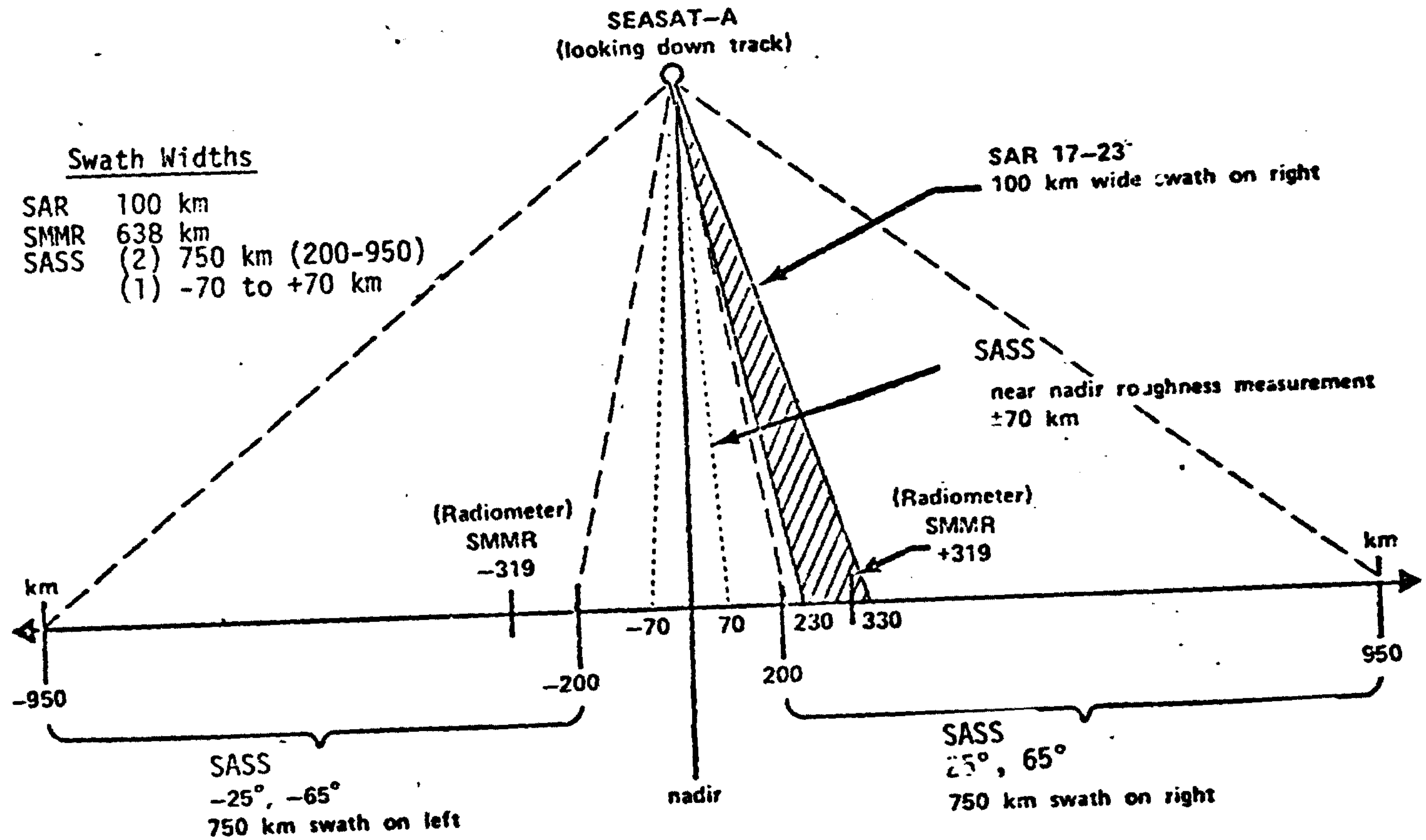


Figure 1. Seasat-A Sensor Coverage

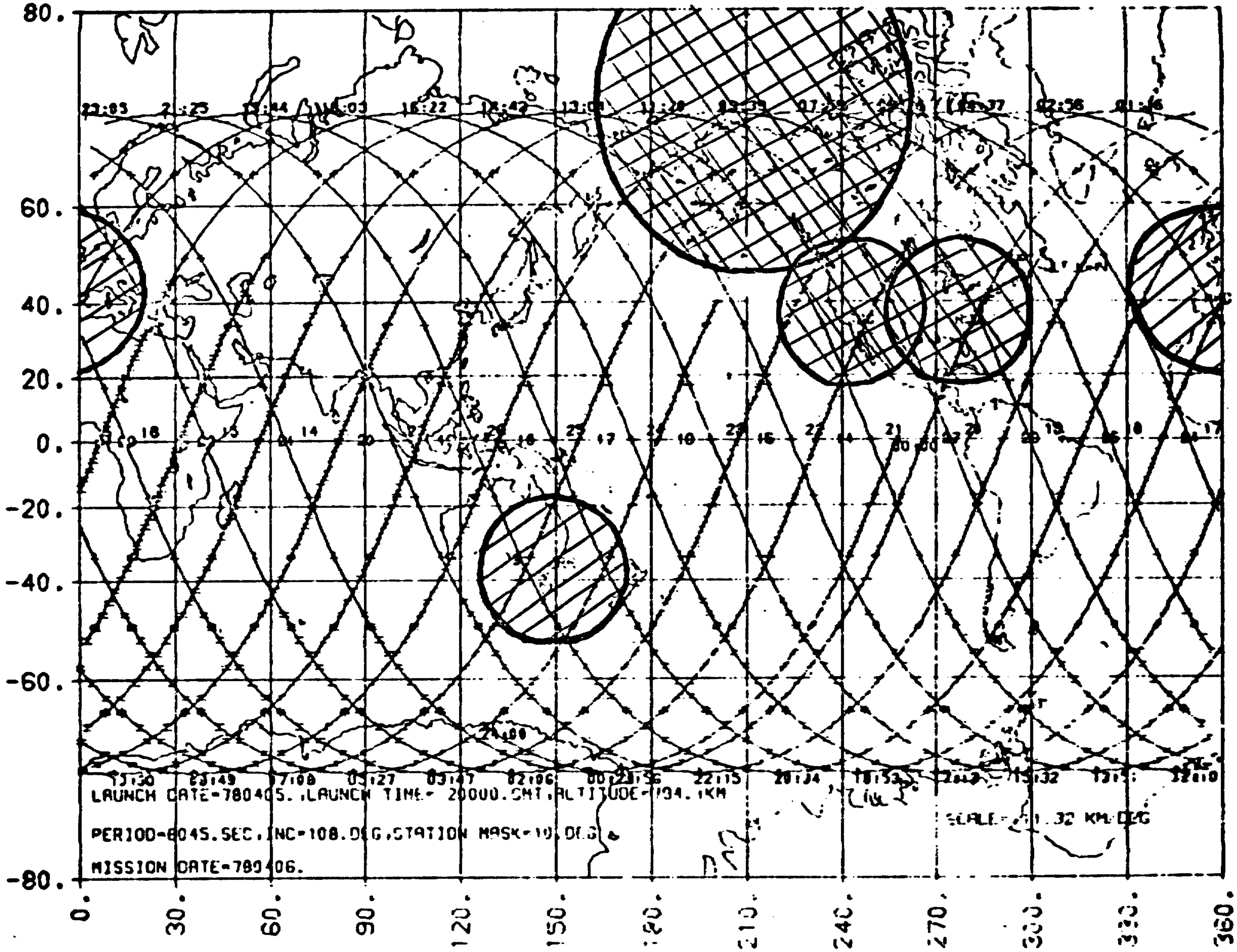


Figure 2. Seasat-A STDN Receiving Sites (Shaded) and Typical Ground Tracks
(Figure 4-10, Seasat-A Mission Plan; Ref. 6)

These STDN stations and their receiving areas are shown in Figure 2 with those areas covered by stations equipped for SAR data indicated with cross-hatching. The continental United States and its coastal waters are covered by the Goldstone (GDS) and Merritt Island (MIL) sites. The Fairbanks (ULA) site covers Alaska, western Canada and a large portion of the Arctic region of north of both. The Madrid (MAD) site covers the British Isles, Europe and northwestern Africa. The Orroral (ORR) site covers the southeastern half of Australia and the western edge of New Zealand.

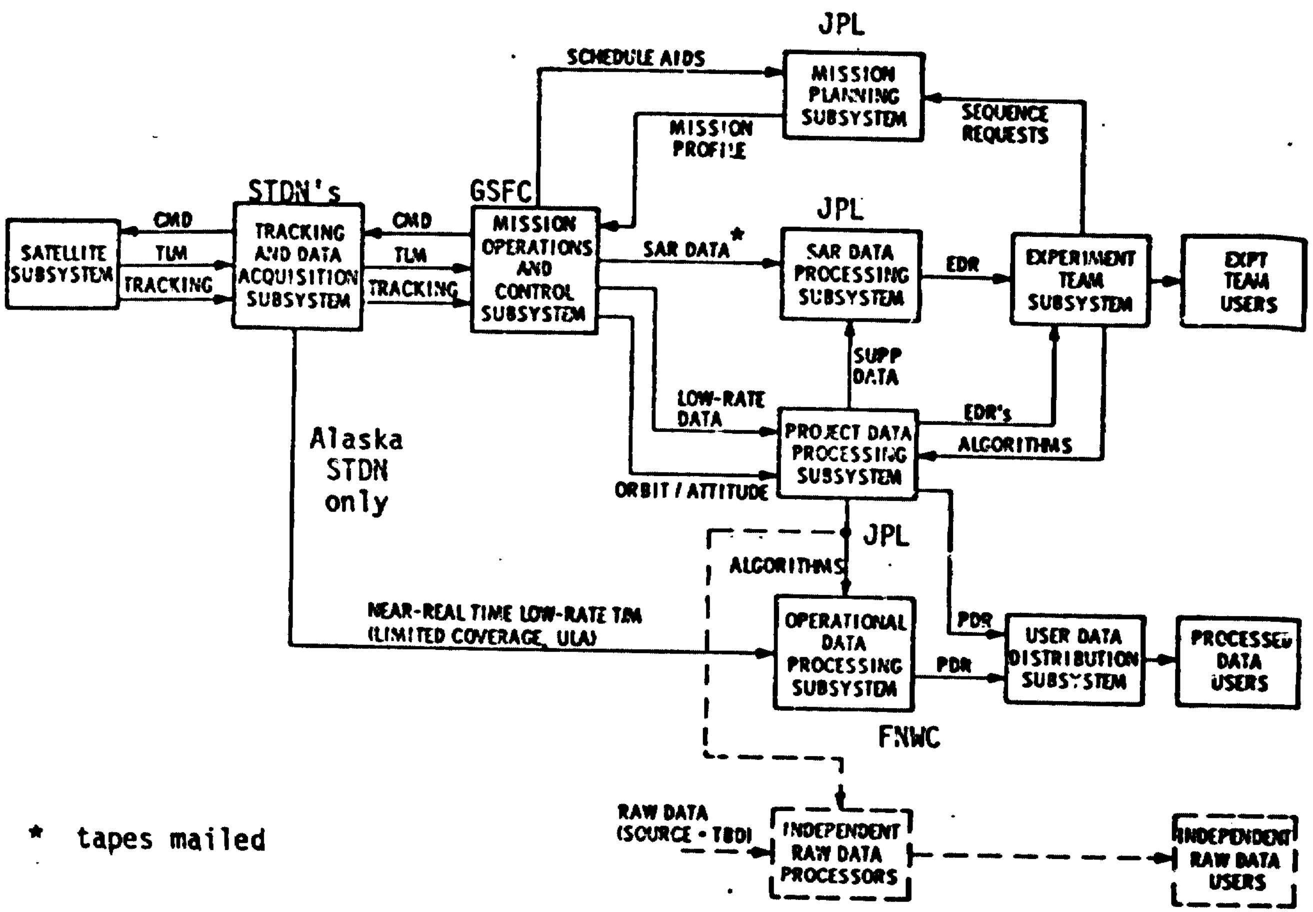
The first three of these STDN stations (ULA, GDS and MIL) will be equipped to receive and record the real time SAR data transmissions. The sites at Madrid (MAD) and St. John's, Newfoundland may eventually be added to these.

The following STDN sites are under consideration, to provide additional support to Seasat-A:

Ascension Island	(ACN)
Santiago, Chile	(AGO)
Quito, Peru	(QUI)
Guam	(GWN)
Hawaii	(HAW)
Bermuda	(BDA)
Canary Islands	(CYI)

2.0 OVERALL SEASAT-A DATA FLOW

The overall Seasat-A data flow is shown in the general block diagram of Figure 3. The satellite command, data telemetry and tracking are performed by the NASA Tracking and Data Acquisition Subsystem (TDAS). This consists of the five STDN stations presently committed to supporting Seasat-A (see section 1.1) and the NASA Communication (NASCOM) lines which link these STDN sites to the Mission Operations and Control Subsystem (MOCS) at GSFC. The 56 kb/s NASCOM lines will be used for all but the SAR data, i.e., the low data rate ALT, SASS, SMMR and VIRR data will be transmitted to GSFC in real to near-real time. The raw SAR data will be mailed to JPL in the form of digital tapes from those STDN sites especially equipped (see section 1.1) to receive, digitize and record the SAR data. A special high data link will provide the Operational Data Processing Subsystem of the Navy's Fleet Numerical Weather Central (FNWC) with low rate (non-SAR) data from the Fairbanks, Alaska STDN site. These data are then processed in near real time by the FNWC and made available to NOAA and other outside users.



* tapes mailed

Figure 3 Overall Seasat-A Data System (from Fig. 4-12, Ref. 4)

All of the low rate (non-SAR) sensor data are processed at JPL by the Project Data Processing Subsystem (PDPS) and the SAR data are processed by the SAR Data Processing Subsystem (SDPS). The PDPS outputs include both experiment data records (EDR's) for use by experiment teams and processed data records (PDR's) of geophysical data for the users. As indicated in Figure 3 the experiment teams will use the EDR data to develop algorithms which will in turn be used by the PDPS to generate the PDR's. The SDPS consists of specialized equipment for processing the SAR data into EDR's in the form of imagery and tapes. More details in the functions and operation of the SDPS and PDPS are given in sections 3.0 and 4.0 respectively.

The User Data Distribution Subsystem (UDDS) provides PDR's from the FNWC's Operation Data Processing Subsystem and the PDPS to those processed data users not part of the Ocean Experiments Team (see Figure 3). Note that the independent raw data (non-SAR) users have access to the processing algorithms used by the PDPS. These raw data users can thus perform their own processing using either their own algorithms or the ones developed with the PDPS.

The Mission Planning Subsystem (MPS) provides the means for scheduling the sensor operations required by the experiment teams.

The overall Seasat-A sensor and engineering data flow are shown in Figure 4 along with the approximate time periods anticipated for each step. The steps and time required to process the low-rate (non-SAR) data (through JPL and also the Navy's FNWC) and the SAR data are listed in Table 2.

3.0 SAR DATA PROCESSING

The very high data rate of the Seasat-A SAR will preclude recording it on-board for playback when in range of a receiving station. The SAR data must therefore be transmitted in real time, i.e., it can only be taken when it is in range of a receiving station equipped to record its data. Three of the Space Tracking and Data Network (STDN) sites participating in the Seasat-A Project will be equipped to receive and record the raw SAR data during the first year. These sites are as follows:

(1)	Fairbanks, Alaska	(ULA)
(2)	Goldstone, California	(GDS)
(3)	Merritt Island, Florida	(MIL)

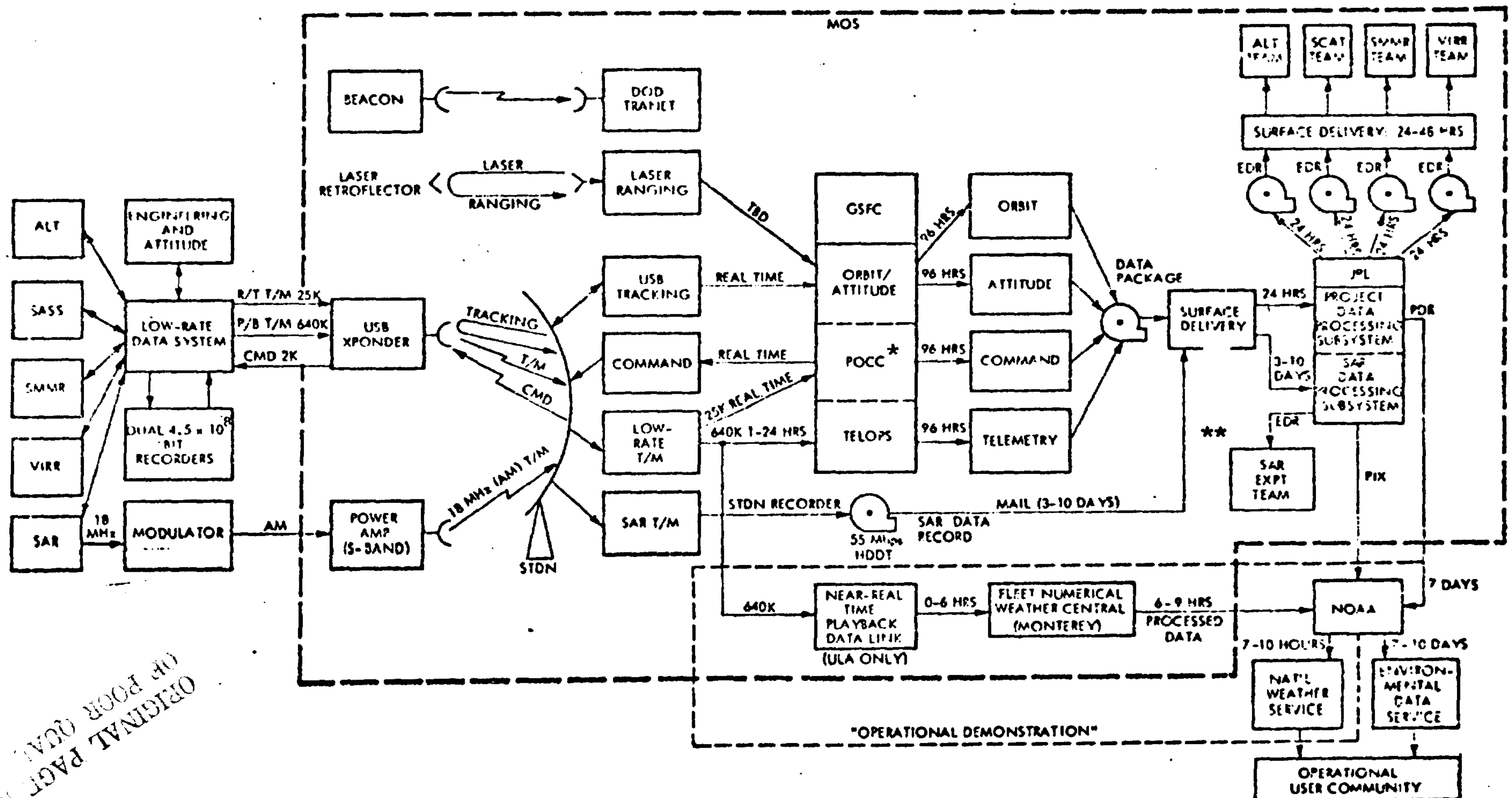


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Figure 4. Seasat-A Downlink Data Flow

*Project Operations Control Center

**Ref. 7 specifies less than 10 days for film imagery after acquisition and 20 days for digital image data.

TABLE 2 SEASAT-A DATA SCHEDULES

Data Flow Steps	SAR	Non-SAR Sensors	
		JPL	Navy FNWC
Receipt from STDN site	3 - 10 days	5 - 6 days	0 - 6 hours
Generation of EDR's	1 day	1 day (PDPS)	
Delivery, EDR's to Teams		1 - 2 days	
Subtotal, STDN to Teams	10 days for film 20 days for tapes*	7 - 9 days	
Processed Data to NOAA		7 days	6 - 9 hours
Subtotal, (non-SAR data to NOAA)		12 - 12 days	6 - 15 hours
NOAA to National Weather Service		7 - 10 hours	7 - 10 hours
Subtotal, Non-SAR to NWS			19 - 34 hours
NOAA to Environment Data Service			7 - 10 days
Subtotal, Non-SAR to EDS			8 - 11 days

*Ref. 7 calls for film products available 10 days after data acquisition and the digital image data within 20 days of request.

See the shaded regions in Figure 2 for the coverage areas of the first two of these STDN sites.

JPL will award the digital processing contract for the SAR data in January 1977. It will go to either Hughes, IBM or Westinghouse, the three companies which responded to the JPL proposal and the corresponding SAR Data Processing Sybsystem (SDPS) specifications. The SDPS will process the raw SAR data into imagery data and provide as output products both digital image data tapes and film imagery. The SAR data processing will be conducted in two steps (Ref. 7). The "first pass" processing will convert the raw data into image data and perform basic geometric corrections. The "second pass" processing will include finer corrections, image enhancement techniques, scaling, mosaicing, etc. The requirements for the "second pass" processing are yet to be determined.

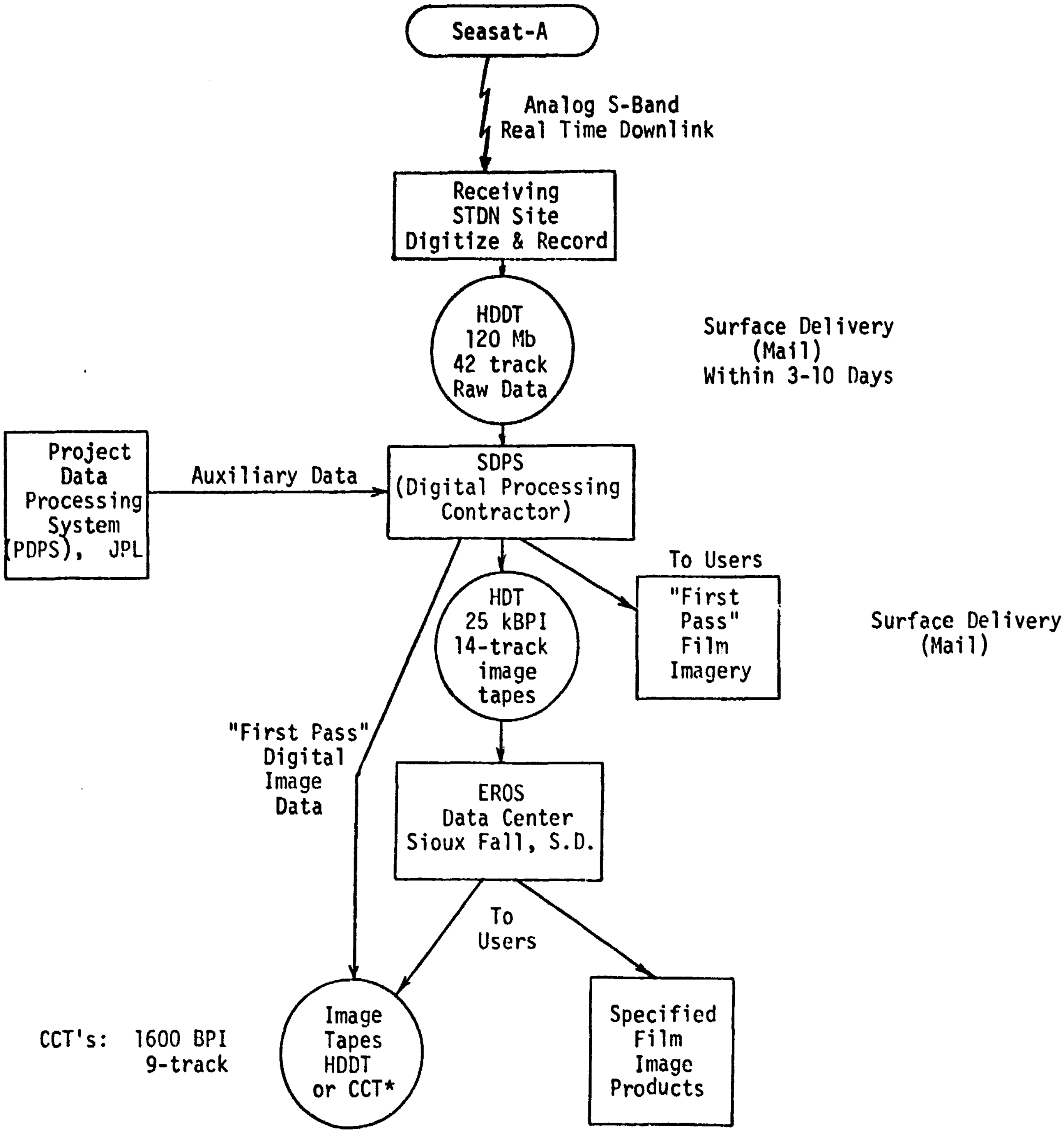
The "first pass" SAR film requirements specify that film imagery shall be block formatted, just as the digital image data shall be, in 100 km x 100 km blocks with 10% overlap. The processed resolution shall be 25 m in range and 7 m in azimuth. The images shall be geometrically corrected such that the range and azimuth scales are equal. The "first pass" SAR imagery shall be on negative transparency film with the optical transmissivity varying linearly with the logarithm of the radar cross section (Ref. 7), such that the stronger returns are more opaque. The imagery shall be produced at a 2,000,000 : 1 scale on 9 inch film. Annotation on the film will include a header with identifiers and calibration gray scales, "start" and "end" marks, time marks (GMT), range reference lines, and latitude/longitude grids. See Ref. 7 for details on the annotation requirements.

The "first pass" SAR digital data requirements specify 9-track, 1600 BPI computer compatible tapes (CCT's), with only one frame (100 km block) per CCT. The annotation shall be the same as that on the film imagery. Table 3 lists the SAR film and digital tape "first pass" data requirements.

The SAR data processing flow from receipt at the STDN sites to the users is diagrammed in Figure 5. The raw SAR data will be digitized and recorded in real time at the receiving STDN site with a 120 Megabit, 42 track tape recorder. The resulting High Density Digital Tapes (HDDT's) will then be mailed to the SAR digital processing site (i.e., the SDPS) within 3-10 days of recording.

TABLE 3. SAR "FIRST PASS" DATA REQUIREMENTS

	Digital Tapes	Film Imagery
Format	CCT's = 1600 BPI 9-track	9 inch block formatted (100 km x 100 km)
Processed Resolution	range - 25 m azimuth - 7 m	range - 25 m azimuth - 7 m
Frame Overlap	10%	10%
Scale	--	2,000,000 : 1
Data Discontinuities (stripes, dropouts, etc.)	$\leq$ 2% of image area	$\leq$ 2% of image area
Overall Bit Error Rate	≤ 1 in 10^5	——



*Formats by April 1977: The CCT handling has not yet been decided.

Figure 5 Seasat-A SAR Data Flow

The SDPS, using auxiliary data from the Project Data Processing Subsystem (PDPS) at JPL, will correlate the raw SAR data into image data in both digital tape and photographic film form. The digital image data will be recorded on 25 kBPI, 14-track High Density Tapes (HDT) which will then be sent to the EROS Data Center in Sioux Falls, South Dakota. EROS will be responsible for distributing the digital image data and generating film imagery on a frame-by-frame basis for users. The projection or cartographic grid used in producing this imagery will be chosen and specified by the data requesters. There are as yet no plans for handling the Computer Compatible Tapes (CCT's) although these will probably also be handled through EROS.

Both the HDT and CCT formats will not be finally determined until April 1977. (Ref. 8) In addition, the overall pixel location accuracy (i.e., latitude and longitude) is yet to be determined. However, a TBD portion of the 260 SAR passes (these vary from 6 to 12 minutes; typically 4000 km long, 100 km wide) planned for digital processing will be processed to a 50 meter pixel location accuracy. The image data produced with this degree of accuracy must be limited because it requires the GSFC to calculate the precise altitude and orbit of the Seasat-A satellite during the data takes. This is both difficult and time consuming, taking about two weeks. Any processing of SAR data beyond the specified 260 passes will be handled directly through the SAR data processing contractor.

Optical processing had originally been considered as a secondary or backup means of processing the raw SAR data into imagery. Selected STDN sites would be equipped to record the raw SAR data directly onto film. This film would then be delivered to the optical processing site where it would be optically processed for viewing and/or filming. The optical processing approach offers relative simplicity, speed and reliability compared to the much more complex and time consuming digital processing approach. For example, 10 minutes of the SAR data will require approximately 16 hours with a special purpose digital processor. The optical approach is limited only by the time required to develop a film recording of the imagery or the time required to electronically scan the image plane, digitize and record the data.

Unfortunately, however, the optical approach was experiencing funding problems as of November 1976. If problems develop with the digital approach, e.g., an inability to maintain the required volume of processing, then the optical approach may receive strong attention.

Sesat-A SAR data users at JSC have three basic options that might be considered for obtaining processed SAR image data. These are as follows (Ref. 24):

(1) Have raw SAR data processing performed at JPL,

(2) Contract the data processing outside

(3) Develop means at JSC of processing the raw SAR data.

The first of these is obviously desirable and should be utilized if possible. However, if this approach is not able to meet the primary Seasat-A SAR data users demands then the other options will have to be considered.

The second option is the next most attractive since the SAR processing capabilities will have been developed by those companies competing for the JPL processing contract.

The third option, that of developing raw SAR data processing capabilities at JSC would require designing, procuring and operating a very complex system. The amount of time and money required for this appear to obviate it as an option.

It has been recommended (Ref. 24) that the Seasat-A raw SAR data processing be either contracted to JPL or directly to one of the companies involved in the JPL processing contract or its competition.

Finally, it should be noted that SAR image data obtained through JPL will be nine (9) track 1600 BPI tapes. If no special arrangement can be made for JSC to obtain 800 BPI tapes then provisions must be made for converting the received 1600 BPI tapes to 800 BPI for use in applications data processing at JSC.

4.0 NON-SAR DATA PROCESSING STEPS

The overall non-SAR (ALT, SASS, SMMR, VIRR) data flow is included in Figure 6. These steps and the approximate times required for each one listed in Table 2.

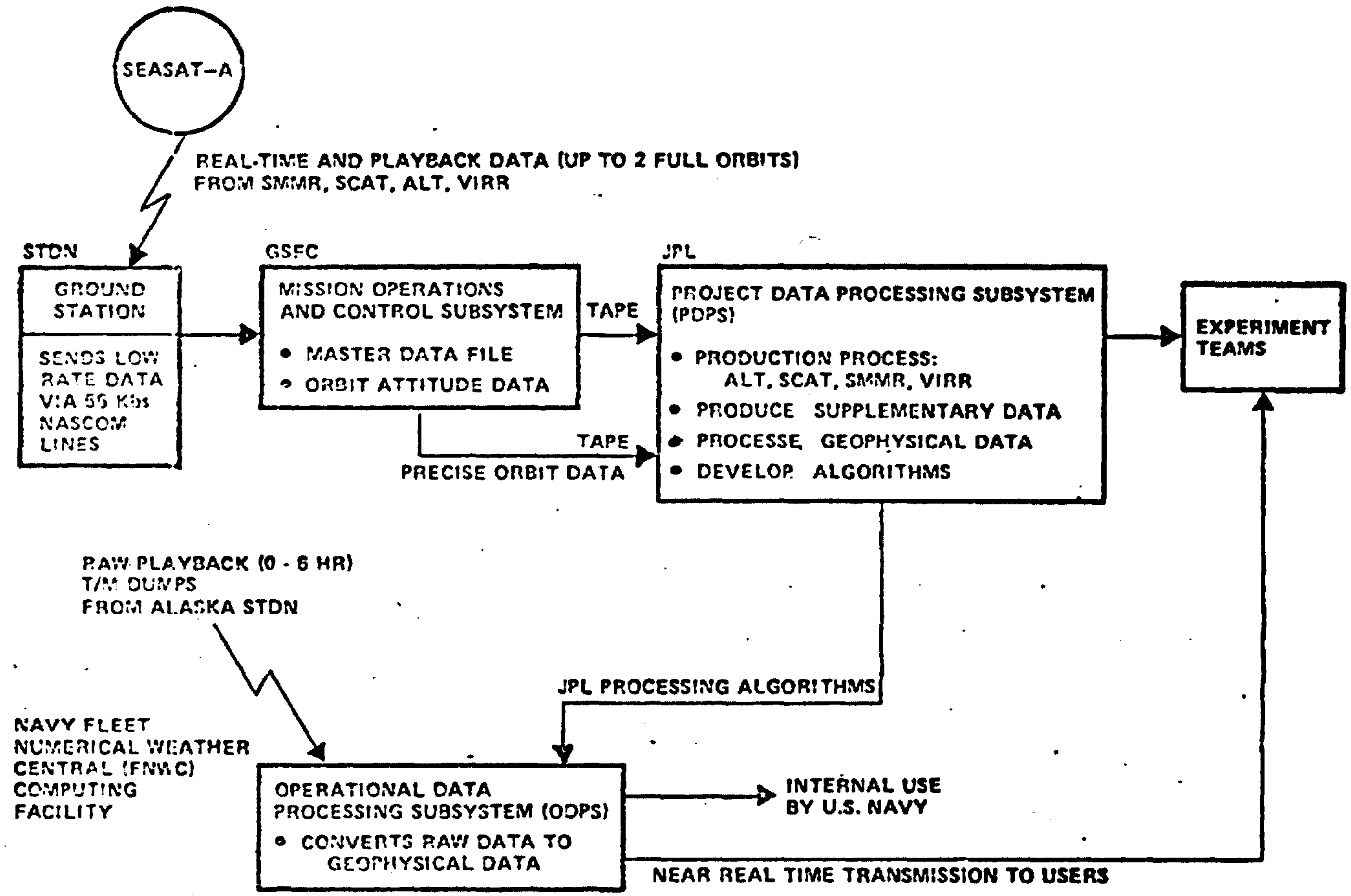
The low rate data are transmitted from the Seasat-A satellite in real time and/or playback mode. The latter is good for up to two orbits of data. The STDN receiving stations send these data via 56 Kbs NASCOM lines to the Missions Operations and Control Subsystem at the GSFC where they are put into master data files. Orbital and attitude data are computed and sent in tape form to the Project Data Processing Subsystem (PDPS) at JPL. The PDPS provides production processing of the low rate data, produces supplementary data and allows investigators to develop algorithms for obtaining geophysical measurements from the sensor data. Both the sensor data and algorithms are then distributed to the Experimental Teams.

As indicated in Figure 6 there is another, near real time processing path. Raw data received at the Alaska STDN station can be recorded and then transmitted to the Navy's Fleet Numerical Weather Central (FNWC) Computing Facility at Monterey, California. The Operational Data Processing Subsystem (ODPS) at FNWC coverts the sensors data into geophysical parameters using algorithms developed and provided by JPL. These near real time geophysical data are then made available for internal use by FNWC and outside users, e.g., NOAA.

The following subsections of this section briefly describe the non-SAR sensor characteristics and ground coverages. Information on their respective output data and data formats is included wherever possible.

4.1 RADAR ALTIMETER

The Seasat-A Radar Altimeter (ALT) concept of operation was proven with the Skylab S-193 and on the GEOS-3. The 13.5 GHz, 1500 pps, precision chirp pulse altimeter will measure the altitude to ± 10 cm. over a 1.6 - 12 km. wide swath at nadir. In addition, the altimeter data will also provide information on the ocean surface roughness and significant wave heights.



*NON-SAR = SMMR, SCAT, ALT, VIRR

Figure 6.— Non-SAR data processing steps.

Significant wave height, $H_{1/3}$, is defined as the highest one-third of waves present in an area of the sea (p. 182, Ref. 9). Chapter 3 of this reference contains detailed information on the theory and use of radar altimetry data over the oceans. The use of radar altimetry data for measurement of $H_{1/3}$ is also discussed by Pierson (p. 248, Ref. 10). The Seasat-A radar altimeter will enable measurement of $H_{1/3} \sim 1$ m over a 1.6 km. diameter area centered at nadir and of $H_{1/3}$ up to ~20 m over a similar 12 km diameter area. The real time, once per second measurement accuracy will be ±10% or 0.5 m, whichever is greater (Ref. 4), for $H_{1/3}$ = 1-20 m. Therefore, the accuracy will correspondingly range from 0.5 to 2 m.

The radar altimeter will produce data samples at a rate of 10 per second. The measurements made during each 0.1 second "frame time" are listed in Table 4 (Ref. 11). Note that the total of 782 bits is per frame time and that the average data rate, excluding a frame ID, is 7820 bits per second.

4.2 SEASAT-A SCATTEROMETER

The Seasat-A Satellite Scatterometer (SASS) is an active microwave sensor which will produce data for calculating the wind speed and direction at the ocean surface. Studies with aircraft (e.g., NASA/JSC 13.3 GHz) and orbital scatterometers (e.g., Skylab S-193) (Refs. 12, 13, 14) have shown a relationship between the radar backscatter coefficient and windspeed for winds from 3 to 20 m/sec and for incidence angles greater than about 25°. For these conditions the radar backscatter is primarily determined by the capillary waves which are comparable in size with the radar wavelengths.

The SASS will operate at 14.6 GHz, in the Ku-band, a band for which the wind speed sensitivity has been proven with the JSC 13.3 GHz and Skylab 13.9 GHz S-193 scatterometers. The level of technology and hardware development in the Ku-band was another important factor in selecting the operating frequency for the SASS. For a more thorough discussion of this and other design specifications of the SASS to be covered below, see Reference 15.

A fixed, fan beam antenna geometry was chosen for the SASS. The fan beam footprints are shown in Figure 7. The four main beams are spaced 90° apart, with two forward and two aft beams as indicated. The aft beams will provide data from areas covered by the forward beams, the 90° difference in azimuth (See Figure 8) enabling the wind direction to be calculated. These beams are associated with the "Mode I" operation of the SASS. They will have incidence angles at the ocean surface ranging from around 25° to 65° and will

TABLE 4 RADAR ALTIMETER SCIENCE DATA*

Measurement	Quantization (bits)	No. of Words	Total Bits
Altitude (H)	22	1	22
Altitude Enor (ΔH)	5	1	5
Altitude Rate (H)	10	1	10
Waveform Samples**	10	63	630
Sea State ($\overline{H}$ 1/3)	10	1	10
Interpretive Data	10	10	100
Acquisition Step	5	1	5
Total			782

*from Table 4-3, Ref. 11

**in an optional mode these data may be deleted, enabling a lower data rate.

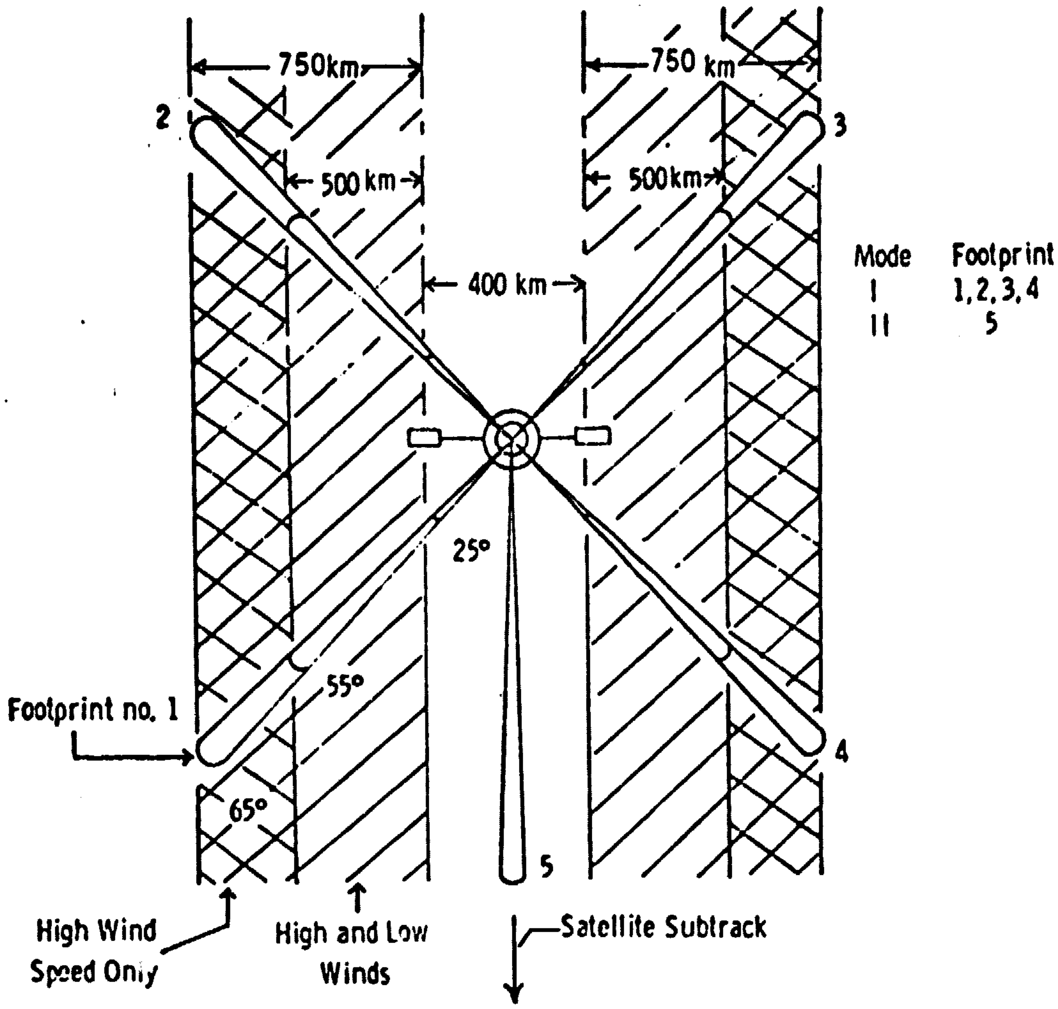
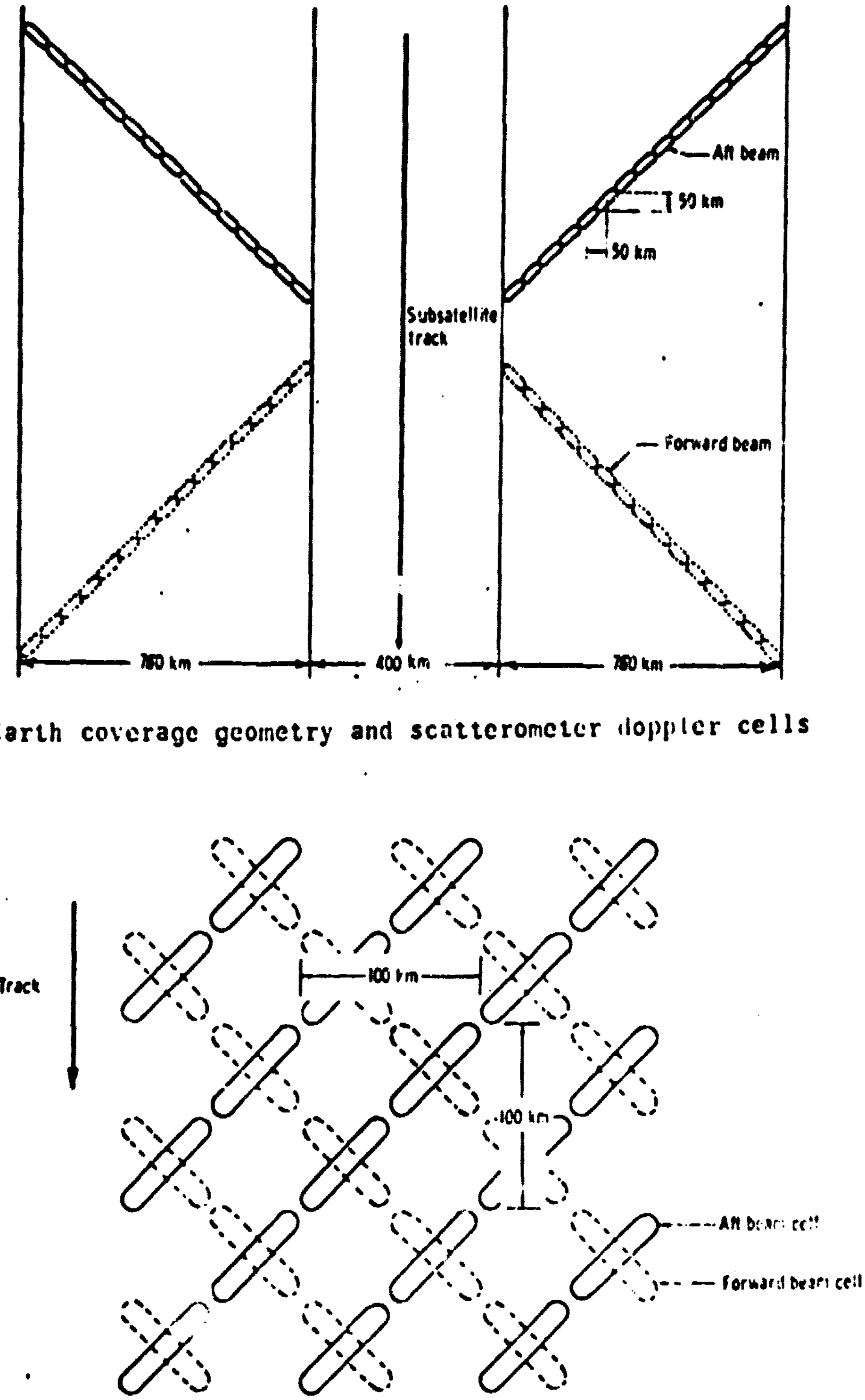


Figure 7. Scatterometer fan beam geometry.
(Fig. 14 from Ref. 15)



(a) Earth coverage geometry and scatterometer doppler cells

(b) Expanded view of forward and aft footprint crossings - 100 km grid

Figure 8. Orthogonal doppler cell crossings for forward and aft antenna beams (Mode I)

(Fig. 19 from Ref. 15)

cover 750 km swaths either side of nadir, at ranges from 200 to 950 km. Each of these swaths will be divided into two regions. The regions from 200 to 700 km will yield both low and high wind data while the remaining 700 to 950 km regions will yield high wind data only. The inner edge of these swaths is set at an incidence angle of 25° due to the wind speed accuracy requirement for the SASS of ± 2 m/sec or ± 10% (whichever is greater). This is due to the fact that at incidence angles less than 25° the corresponding radar cross section measurement requirements exceed the state of the art. Furthermore, the radar backscatter-wind speed relationship also depends on sea state for incidence angles less than 25°. The 55 - 65° incidence angle range will be used for high winds only since for this range the return from lower wind speed conditions will be too low.

A fifth fan beam will be pointed directly ahead of the satellite (see Figure 7) and is associated with the "Mode II" operation of the SASS. It will cover a swath ± 70 km around nadir at incidence angles from 0° (straight down) to 65°. It will provide a possible means of measuring the effect of sea state on scatterometer data, especially for incidence angles less than 25°. In addition, it also will provide wind speed data over a wider incidence angle range and at a different azimuth angle (straight ahead as opposed to 45° and 135°). The latter is also required to supplement the other wind speed data. Another difference with Mode II is that all four possible polarization combinations will be available for radar scattering cross section measurements (i.e., HH, HV, VH, VV) whereas only the HH and VV combinations are utilized for Mode I. These two modes and other mode options are listed in Table 5. Modes III through IX in this table represent possible alternatives which may or may not be achievable in reality on Seasat-A. However, these illustrate the flexibility which could be included in the sensor design. Modes III, IV, IX and X, for example, provide data from all five antennas by reducing the overall number of polarization measurements made. This may prove quite useful if early data shows either a preference for some polarization data or no need for obtaining more than one or two polarizations. The remaining modes (V through VIII) simply represent the four possible variations on Mode I for obtaining higher resolution data by using only one swath (right or left) and one polarization (HH or VV).

Mode Identification	Antenna Polarization		Swath Width	Comments
	Antenna no. 1, 2, 3, 4	Antenna no. 5		
I	σ^o_{VV}, σ^o_{HH}	–	1000 Km	Mode for taking operational data
II		σ^o_{VV}, σ^o_{HH}, σ^o_{VH}, σ^o_{HV}	NA	Research mode for evaluating instrument limits
III	σ^o_{VV}	Any two pol.	1000 Km	Gives user req'd wind speed and direction plus wind speed along the satellite subtrack
IV	σ^o_{HH}	Any two pol.	1000 Km	Gives user req'd wind speed and direction plus wind speed along the satellite subtrack
V	σ^o_{VV} antennas 1 and 2 only	–	500 Km	Improves σ^o measurement accuracy for V_{pol} operational data
VI	σ^o_{VV} antennas 3 and 4 only	–	500 Km	Improves σ^o measurement accuracy for V_{pol} operational data
VII	σ^o_{HH} antennas 1 and 2 only	–	500 Km	Improves σ^o measurement accuracy for H_{pol} operational data
VIII	σ^o_{HH} antennas 3 and 4 only	–	500 Km	Improves σ^o measurement accuracy for H_{pol} operational data
IX	σ^o_{VV}	σ^o_{VV}	1000 Km	Efficient mode for taking operational data including wind speed along subtrack
X	σ^o_{HH}	σ^o_{HH}	1000 Km	Efficient mode for taking operational data including wind speed along subtrack

Note: It may not be possible to get all four polarization measurements made for all incidence angles at the instrumented test site during one satellite pass. 1st priority should be given to providing all incidence angles at each polarization, then to providing differential σ^o measurements at a given angle between polarizations.

Table 5.- Representative Mode Options for Scatterometer.

(Fig. 21 from Ref. 15)

The time difference between the coverage of a particular area by a forward antenna resolution cell and the corresponding aft one increases from 1 minute at 200 km range to 4 minutes 47 seconds at the maximum 950 km range. This is assuming a nominal ground speed of 6.61 km/sec. The fifth (Mode II) antenna will be used to obtain data at 100 km spacings for various incidence angles, and the timing will be adjusted accordingly.

The data will be taken from the four Mode I beams (see Fig. 7) in the sequence 1, 4, 2, 3, i.e., first the forward beams, right and left, then the aft beams, right and left. In this sequence the data taken with the aft beams will correspond to data and resolution cells in preceding forward beam scans. In each step polarization data are taken in the sequence first VV then HH.

The SASS electronic data format is summarized in Figure 9 and Table 6. It is comprised of 82 10-bit words which report the engineering and operational status of the SASS, including sync bits, channel gains, system temperatures, mode selections, etc.

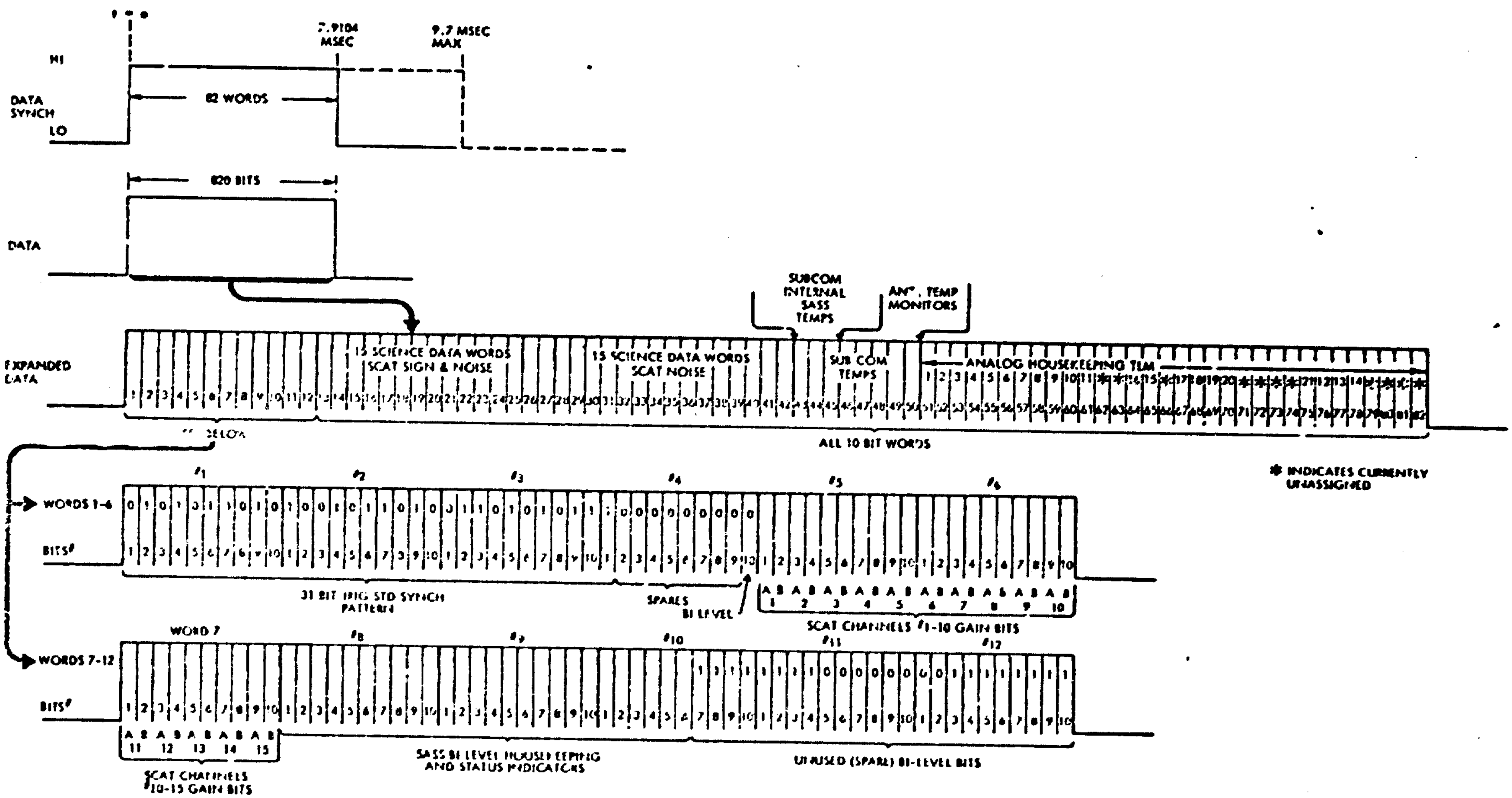


Figure 9.- SASS Electronics Data Format (Ref. 16)

WORD #	BIT NO.	FUNCTION	
1	1 to 10	Synch Word #1 (Pattern = 0101011010)	
2	1 to 10	Synch Word #2 (Pattern = 1001011010)	
3	1 to 10	Synch Word #3 (Pattern = 0110101011)	
4	1	Synch Bit #31 (1)	
4	2 to 9	ALL ZEROS (Spare Bits)	
4	10	SLO LO Frequency Select (0 = LO)	
5	1 & 2	Scat Channel #1 Gain Bits A & B Respectively	
5	3 & 4	Scat Channel #2 Gain Bits A & B Respectively	
5	5 & 6	Scat Channel #3 Gain Bits A & B Respectively	
5	7 & 8	Scat Channel #4 Gain Bits A & B Respectively	
5	9 & 10	Scat Channel #5 Gain Bits A & B Respectively	
6	1 & 2	Scat Channel #6 Gain Bits A & B Respectively	
6	3 & 4	Scat Channel #7 Gain Bits A & B Respectively	*Note
6	5 & 6	Scat Channel #8 Gain Bits A & B Respectively	
6	7 & 8	Scat Channel #9 Gain Bits A & B Respectively	
6	9 & 10	Scat Channel #10 Gain Bits A & B Respectively	
7	1 & 2	Scat Channel #11 Gain Bits A & B Respectively	
7	3 & 4	Scat Channel #12 Gain Bits A & B Respectively	
7	5 & 6	Scat Channel #13 Gain Bits A & B Respectively	
7	7 & 8	Scat Channel #14 Gain Bits A & B Respectively	
7	9 & 10	Scat Channel #15 Gain Bits A & B Respectively	

*NOTE:

Bit A	Bit B	Gain Select	Gain Curve No.
0	0	Highest Gain	1
1	0	2nd Highest Gain	2
0	1	3rd Highest Gain	3
1	1	Lowest Gain	4

(Bit A is the least significant bit.)

Table 6. SASS Data Format (Ref. 16)

WORD #	BIT NO.	FUNCTION
8	1 to 3	Analog HK Subcommutator I.D. Bits
8	4	Calibration Status (1 = cal)
8	5	Input Current Trip (1 = Trip)
8	6	Pol. Circulator Status Bit (1 = CW)
8	7	L/R Circulator Status Bit (1 = CW)
8	8	F/A Circulator Status Bit (1 = CW)
8	9	Receiver Protect Circulator Status Bit (1 = CW)
8	10	Undervoltage Trip (1 = Trip)
9	1	Body Current Trip (1 = Trip)
9	2	Noise Diode ON/OFF (1 = ON)
9	3	Mode 1 Selected (0 = Mode 1 Selected)
9	4	Mode 2 Selected (0 = Mode 2 Selected)
9	5	Mode 3 Selected (0 = Mode 3 Selected)
9	6	Mode 4 Selected (0 = Mode 4 Selected)
9	7	Mode 5 Selected (0 = Mode 5 Selected)
9	8	Mode 6 Selected (0 = Mode 6 Selected)
9	9	Mode 7 Selected (0 = Mode 7 Selected)
9	10	Mode 8 Selected (0 = Mode 8 Selected)
10	1	Continuous Calibration Mode Selected (0 = Selected)
10	2	Standby Mode Selected (0 = STDBY)
10	3	HVPS On Cmd (from S/C) (1 = ON)
10	4	SLO HI Freq Select (0 = HI Freq 208 MHz)
10	5	SLO Looplock Status ("1" = Lock Loss)
10	6	XMIT Looplock Status ("1" = Lock Loss)
10	7 to 10	ALL ONES
11	1 to 4	ALL ONES
11	5 to 10	ALL ZEROS
12	1 & 2	ALL ZEROS
12	3 to 10	ALL ONES

Table 6. SASS Data Format (Continued)

WORD #	BIT NO.	FUNCTION	
13 thru 27	1 to 10	Scat Channel #1 Accumulated S+SN Data thru Scat Channel #15 Accumulated S+SNGData	(MSB First) (MSB First)
28 thru 42	1 to 10 / 1 to 10	Scat Channel #1 Accumulated SN Data thru Scat Channel #15 Accumulated SN Data	(MSB First) (MSB First)
43	1 to 10	0 to +5 Analog HK Group #1	Subcommutated SASS Internal Temps
44	1 to 10	0 to +5 Analog HK Group #2	
45	1 to 10	0 to +5 Analog HK Group #3	
46	1 to 10	0 to +5 Analog HK Group #4	Subcommutated Antenna Temps (40)
47	1 to 10	0 to +5 Analog HK Group #5	
48	1 to 10	0 to +5 Analog HK Group #6	
49	1 to 10	0 to +5 Analog HK Group #7	
50	1 to 10	0 to +5 Analog HK Group #8	
51	1 to 10	0 to +5V AHK Channel #1	DC/DC Conv. +5 Out
52	1 to 10	0 to +5V AHK Channel #2	DC/DC Conv. +15 Out
53	1 to 10	0 to +5V AHK Channel #3	DC/DC Conv. -15 Out
54	1 to 10	0 to +5V AHK Channel #4	SLO Power Monitor
55	1 to 10	0 to +5V AHK Channel #5	Mod Power Monitor - 200 MHz
56	1 to 10	0 to +5V AHK Channel #6	TWT Cathode Voltage
57	1 to 10	0 to +5V AHK Channel #7	TWT Cathode Current
58	1 to 10	0 to +5V AHK Channel #8	TWT Body Current
59	1 to 10	0 to +5V AHK Channel #9	ION Pump Current
60	1 to 10	0 to +5V AHK Channel #10	TWT Input Current
61	1 to 10	0 to +5V AHK Channel #11	Transmit Power
62	1 to 10	0 to +5V AHK Channel #12	Unassigned (Grounded if not used)
63	1 to 10	0 to +5V AHK Channel #13	Unassigned (Grounded if not used)
64	1 to 10	0 to +5V AHK Channel #16	Xmit Channel Power Monitor (SSS/LO)
65	1 to 10	0 to +5V AHK Channel #15	DC/DC Conv. 28V

Table 6. SASS Data Format (Continued)

WORD #	BIT NO.	FUNCTION
66	1 to 10	0 to +5V AHK Chan 26 - Unassigned (Grounded if not used)
67	1 to 10	0 to +5V AHK Chan 17 - DC/DC Conv. -6V Out
68	1 to 10	0 to +5V AHK Chan 18 - DC/DC Conv. +6V Out
69	1 to 10	0 to +5V AHK Chan 19 - Thermistor Reference Voltage 'A'
70	1 to 10	0 to +5V AHK Chan 20 - Thermistor Reference Voltage 'B'
71	1 to 10	0 to +5V AHK Chan 25 - Unassigned (grounded if not used)
72	1 to 10	0 to +5V AHK Chan 22 - Unassigned (grounded if not used)
73	1 to 10	0 to +5V AHK Chan 23 - Unassigned (grounded if not used)
74	1 to 10	0 to +5V AHK Chan 24 - Unassigned (grounded if not used)
75	1 to 10	0 to +5V AHK Chan 21 - Upconverter Diode Bias
76	1 to 10	0 to +5V AHK Chan 12 - TDA Stage 1 Bias
77	1 to 10	0 to +5V AHK Chan 13 - TDA Stage 2 Bias
78	1 to 10	0 to +5V AHK Chan 14 - TDA Stage 3 Bias
79	1 to 10	0 to +5V AHK Chan 29 - Unassigned (grounded if not used)
80	1 to 10	0 to +5V AHK Chan 30 - Unassigned (grounded if not used)
81	1 to 10	0 to +5V AHK Chan 31 - Unassigned (grounded if not used)
82	1 to 10	0 to +5V AHK Chan 32 - Unassigned (grounded if not used)

Table 6. SASS Data Format (Continued)

4.3 SCANNING MULTIFREQUENCY MICROWAVE RADIOMETER

The Scanning Multifrequency Microwave Radiometer (SMMR) is being developed for the Nimbus-G and will also be used on the Seasat-A satellite. It will operate at five frequencies (6.6, 10.69, 18, 21, and 37 GHz) and provide data over a 638 km wide swath symmetrical about the nadir ($\pm 25^{\circ}$). The footprint sizes, which are listed in Table 1, range from around 20 x 14 km to 120 x 80 km. The antenna is pointed downward at about 45° and scans are ahead of the spacecraft at $\pm 35^{\circ}$ in azimuth. The scanning pattern (see Fig. 10) is bidirectional with horizontal and vertical polarization data being taken on alternate swaths for the 6.6, 10.69, 18 and 21 GHz channels. Data for both polarizations are taken simultaneously for the 37 GHz channel. The overlap from scan to scan varies with channel and position within the scan.

The SMMR frequencies were chosen for performance in the following three primary applications:

(1) Measure wind speeds from about 10 m/sec to perhaps 50 m/sec (beyond the upper limit of the scatterometer data)

(2) Measure sea surface temperature, accurate to 2° C

(3) Determine atmospheric water and water vapor contents, for use in weather forecasting models and for corrections of the precision radar altimeter data.

In addition, the SMMR will also provide low resolution coverage of ice fields. The technical and performance characteristics for the Seasat SMMR are listed in Table 7 which was derived from the Seasat-A Project Plan (Ref. 4).

The surface wind speed is correlated with the ocean surface roughness and foam, which in turn is related to the microwave thermal emission. The emission measurements primarily in channels 2, 3 and 5 (10.69, 18 and 37 GHz) will be used to derive or measure surface wind speed data. The dual polarization data should be useful in separating and cancelling out atmospheric effects.

Sea surface temperature measurement will be made primarily with channel 1 (6.6 GHz, λ = 4.5 cm.) data since the sensitivity of microwave emission from the sea to the surface temperature shows a broad peak around a wavelength of 5 cm. (Ref. 17).

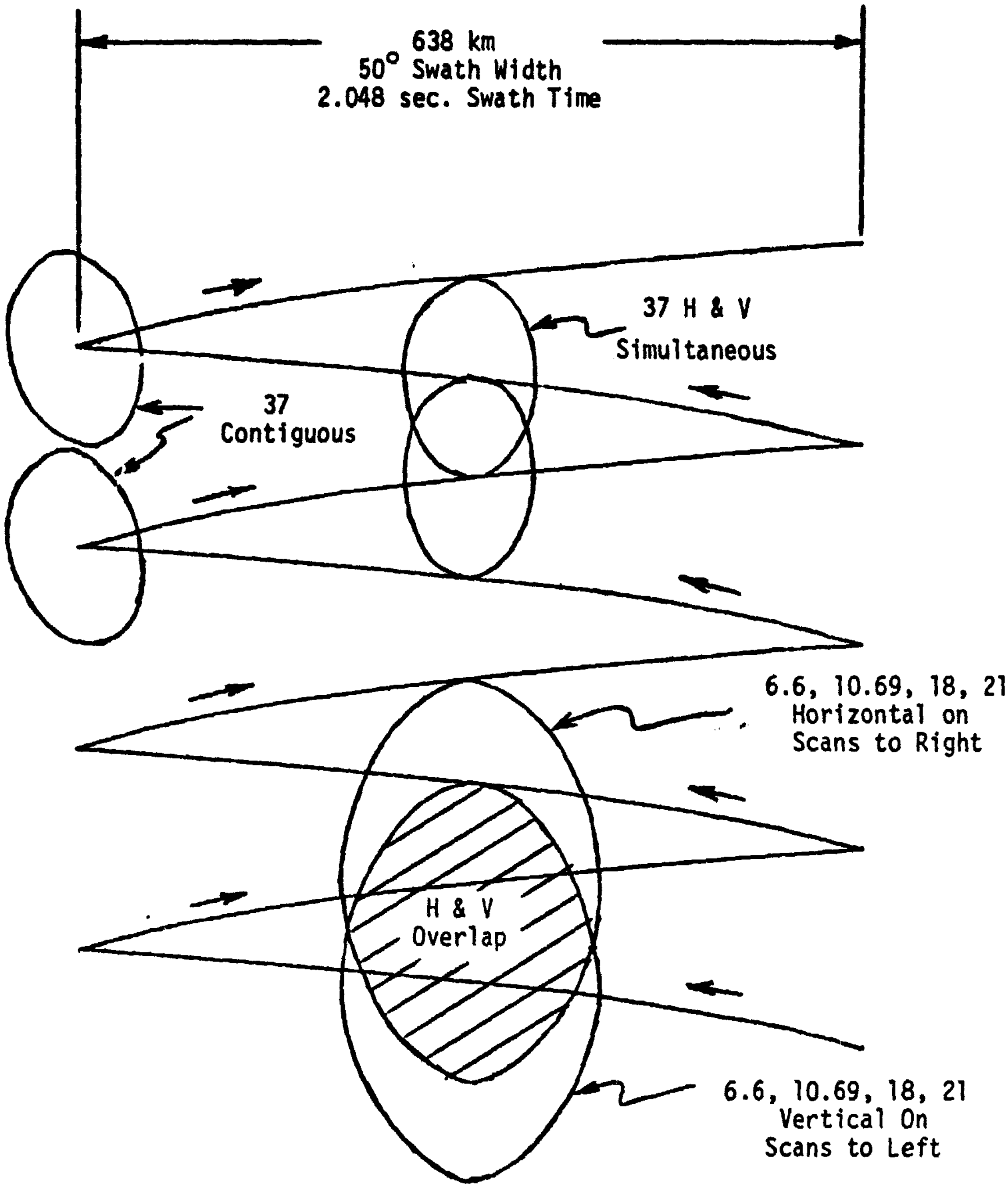


Fig. 10 SMMR Scan Pattern (Ref. 4)

Table 7 - SMMR Technical and Performance Characteristics (Ref. 4)

Technical Characteristics

o Clock inputs - 1 Hz, 10 kHz, 1.6 MHz, satellite time					
o ENG and SCI data rate - 2 kbps					
o Frequency, GHz	6.6	10.69	18	21	37
o Antenna diameter, m	←		0.79		→
o Antenna beamwidth, half-power, deg	4.02	2.48	1.47	1.26	0.72
o Polarization	←		Dual Linear		→
o Footprint Dimensions Major axis, km	121	74	44	38	21
Minor axis, km	79	49	29	25	14
o Full swath angle, deg	←		50		→
o Full swath width, km	←		638		→
o Incidence angle of beam center at surface, deg	←		48.8		→
o RF bandwidth, MHz	←		250		→
o Noise figure (mixer + IF AMP), DSB, dB	4	4	5	5	5
o System noise temperature DSB, K (referred to feed aperture)	606	606	838	891	947
o Predetection bandwidth, MHz	←		100		→
o Integration time constant, milliseconds	126	62	62	62	30
o Temperature resolution, K (1σ)	0.34	0.48	0.67	0.72	1.09
o Absolute temperature accuracy, K (1σ)	←		2		→
o Dynamic temperature range, K	←		10-330		→

Performance

- o Ocean surface wind speed from 7 m to 50 m/sec ±2 m/sec OR ±10%, whichever is greater
- o Ocean surface temperature to within ±2°C absolute and ±0.5°C relative
- o Wind and temperature resolution - 121 km
- o Ice field maps. Resolution - 21 km
- o Measurement of integrated atmospheric water vapor and liquid matter in a column along the signal vector
- o Measurement of rain drop size and distribution in a column along the signal vector

The atmospheric liquid water content measurements will be made using data from channels 2, 3 and 5 (10.69, 18 and 37 GHz), the same ones that will be used for wind speed determinations. The atmospheric water vapor content determinations will be made using data from channel 4 since its 21 GHz frequency coincides with a resonance line of water vapor.

The sea ice mapping studies will utilize channel 5 (37 GHz) data because it has the best spatial resolution (14 x 21 km).

In addition to the above oceanographic applications, soil moisture measurement studies will find use for the Seasat-A SMMR data, especially at the longer wavelengths. A study with data from the Nimbus-5 Electronically Scanning Microwave Radiometer (ESMR), a predecessor to the design of the SMMR, showed indications of soil moisture sensitivity at the sensor's 19.3 GHz frequency (Refs. 18 and 19). The latter is between the SMMR's 3rd and 4th channels (18 and 21 GHz). Another study, in 1971 (Ref. 20), used aircraft radiometer coverage of 200 fields near Phoenix, Arozona to examine the utility of data at 1.42, 19.35 and 37 GHz. The results of this study indicated potential use for 19.35 GHz data for soil moisture greater than 15 percent and for 1.42 GHz data in the 0-35 percent range. The 37 GHz data showed poor soil moisture sensitivity. These results lend further support for using the SMMR's 3rd and 4th channels in soil moisture studies.

The SMMR data format (Ref. 21) will consist of master frames of 32 blocks with 16 words each (see Fig. 11). Each master frame is 4.096 seconds in length and has 512 16 bit words. Eight master frames are required to communicate all 64 engineering words. The radiometric data will use 12 bits of each 16 bit data word. Three of the remaining bits are used on each four consecutive data words to record the antenna position. The most significant bit (MSB) is used for word synch. A typical data word is shown at the top of Figure 12. The second line in this figure shows the six bits used for the status word which notes the scan set, the scan power on and the frame count. The second, third and fourth words (block 0) are shown next with the format for recording the time and date information. The lower half of this figure shows the eight engineering data blocks corresponding to block number 16 of eight consecutive master frames.

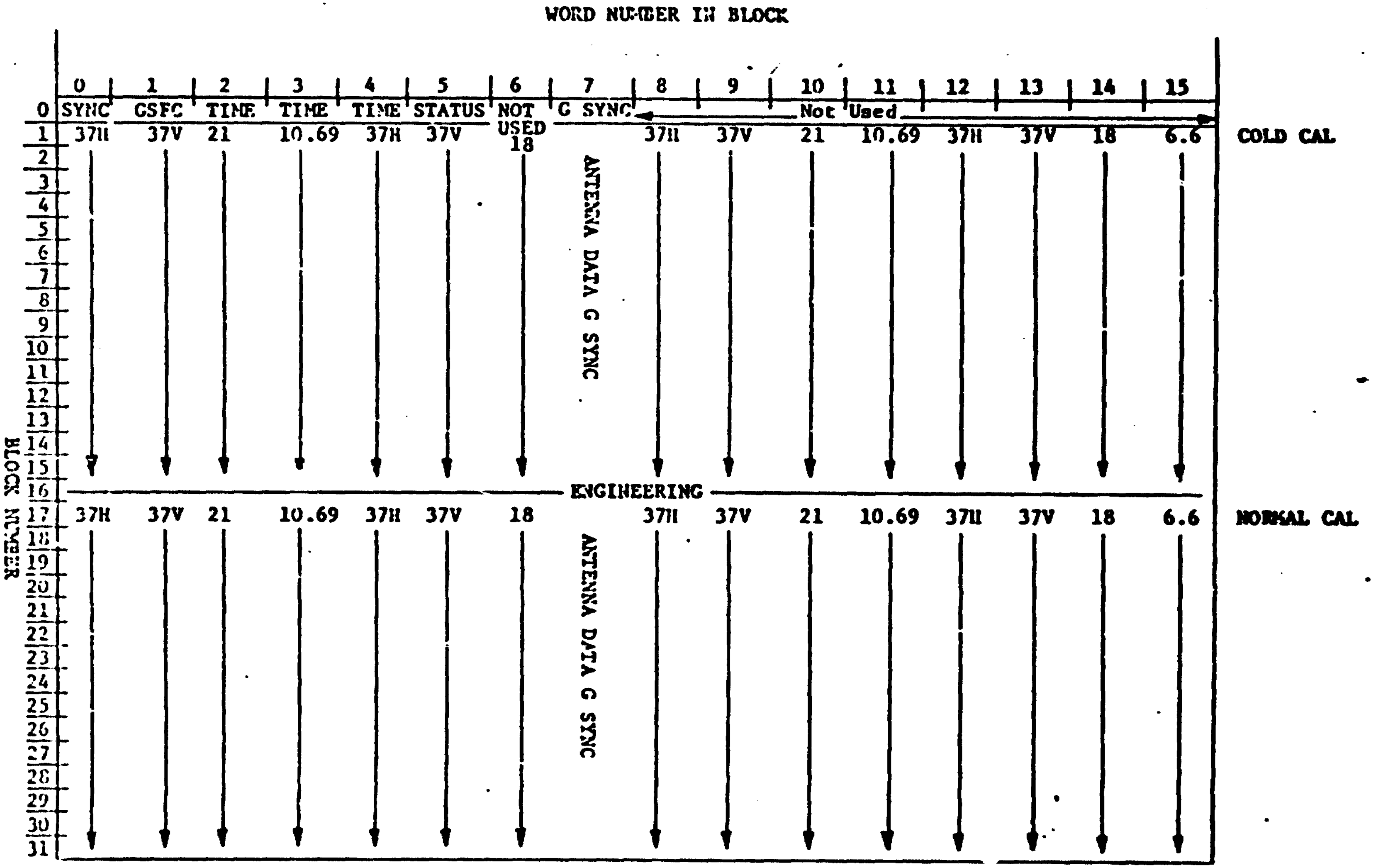


Figure 11.- SMMR Data Format.
(From Ref. 21)

DATA WORD (TYP)

MSB															LSB
1	A	A	A	D	D	D	D	D	D	D	D	D	D	D	D

SEE NOTE 4

STATUS WORD (WD 5 BLOCK Ø)

1	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	P	R	C	C	C

← NOT USED → (bits 2–11)

TIME (WD 2 BLK Ø)

1	Ø	Ø	Ø	Mt	Mu	Mu	Mu	Mu	St	St	St	Su	Su	Su	Su

TIME (WD 3 BLK Ø

1	Ø	Ø	Ø	Du	Du	Du	Du	Ht	Ht	Hu	Hu	Hu	Hu	Mt	Mt

TIME (WD 4 BLK Ø

1	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Dh	Dh	Dt	Dt	Dt	Dt

SEE NOTE 3

BLOCK 16A	WD1	WD1	WD2	WD2	WD3	WD3	WD4	G SYNC	WD5	WD5	WD6	WD6	WD7	WD7	WD8	WD8
BLOCK 16B	WD9	WD9	WD10	WD10	WD11	WD11	WD12	G SYNC	WD13	WD13	WD14	WD14	WD15	WD15	WD16	WD16
BLOCK 16C	WD17	WD17	WD18	WD18	WD19	WD19	WD20	G SYNC	WD21	WD21	WD22	WD22	WD23	WD23	WD24	WD24
BLOCK 16D	WD25	WD25	WD26	WD26	WD27	WD27	WD28	G SYNC	WD29	WD29	WD30	WD30	WD31	WD31	WD32	WD32
BLOCK 16E	WD33	WD33	WD34	WD34	WD35	WD35	WD36	G SYNC	WD37	WD37	WD38	WD38	WD39	WD39	WD40	WD40
BLOCK 16F	WD41	WD41	WD42	WD32	WD43	WD43	WD44	G SYNC	WD45	WD45	WD46	WD46	WD47	WD47	WD48	WD48
BLOCK 16G	WD49	WD49	WD50	WD50	WD51	WD51	WD52	G SYNC	WD53	WD53	WD54	WD54	WD55	WD55	WD56	WD56
BLOCK 16H	WD57	WD57	WD58	WD58	WD59	WD59	WD60	G SYNC	WD61	WD61	WD62	WD62	WD63	WD63	WD64	WD64

A = Ant Pos Data
D = Radiometer Data
C = Frame Count Number
R = 1 = Scan Pwr Off
P = 1 = Scan Set to Ø

Su = Seconds Units
St = Seconds Tens
Mu = Minutes Units
Mt = Minutes Tens
Hu = Hours Units

Ht = Hours Tens
Du = Days Units
Dt = Days Tens
Dh = Days Hundreds

Figure 12.- SMMR Word Formats (Ref. 21)

4.4 VISIBLE-IR RADIOMETER (VIRR)

The Seasat-A VIRR is identical to the Scanning Radiometer (SR) of the ITOS-J weather satellite (Ref. 22). See Table 7 for a summary of its performance characteristics. The VIRR will have two channels, one in the visible (0.47 - 0.94 μm) and one in the thermal infrared (10.5 - 12.5 μm). It will unidirectionally scan a 2127 km wide swath, centered about nadir, with closely spaced, but non-contiguous scan lines (See Figure 13). The visible channel will have a resolution or pixel size of 2 km and the infrared channel will have a pixel size of 4 km. As can be seen in the figure the gap between successive scan lines will be much greater for the visible channel. This gap is greatest at nadir with 3.3 km for the visible scan lines and 1.3 km for the IR ones.

Figure 14 shows example video analog waveforms for the two channels plus related timing or sync signals. The video signals will be negative-going analog voltages with the dc re-established. The bandwidths are 0-600 Hz for the IR channel and 0-1200 Hz for the visible channel. The voltage calibration signals will be the same for both channels and will consist of five voltage level steps (See Figure 14) of 10±5 msec duration each. These voltage levels are (Ref. 22):

Level	Voltage (volts)
1	-6.0 ± 0.06
2	-4.8 ± 0.05
3	-3.6 ± 0.03
4	-2.4 ± 0.02
5	-1.2 ± 0.02

In addition to these voltage calibration signals each channel will have two radiometric calibration signal levels. The infrared channel will view deep space for a low end (cold) point and a blackended housing cavity for a warm source. The visible channel will also view deep space establishing a black level. Note in Figure 14 that the voltage calibration signals follow the video signal portions. The radiometric signals then follow with the deep space looks occurring at instrument zenith. The 1.25 second period is produced by the rotating (48 rpm) single surface mirror. The IR channel gain will be set such that -5.75 ± 5% volts will correspond to a 320°K target

Table 7 VIRR Technical and Performance Characteristics (Ref. 4)

TECHNICAL CHARACTERISTICS	VISIBLE CHANNEL	THERMAL CHANNEL
o Scan Rate	48 RPM	
o Scan Angle	100 Degrees	
o IFOV (-6 dB Points)	2.8 ± 0.3 mr	$5.3^{+0.5}_{-1.1}$ mr
o Samples per FOV	1.4	
o Data Rate	6.26 kbps	3.31 kbps
o Quantization	9 bits per sample	
o Spectral Region (-6 dB Points)	0.47 ± 0.05μm 0.94 ± 0.05μm	10.5 to 12.5μm Nominal
o Data Rate (Field of View per Scan) x (Scan Rate) x (Samples per Field of View) x (Quantization per Sample)	6.26 kbps	3.31 kbps
o NEI (Over Operating Temperature Range) for Extended Target Source	4.1×10^{-10} W/cm^2	4.2×10^{-10} W/cm^2
o NETD (At Indicated Target Scene, Over Operating Temperature Range) for Extended Target Scene		1.0°K at 300°K 4°K at 185°K
o Output Voltage Range (Nominal)	05.9 to -0.3 Vdc	-0.25 to -6.1 Vdc
o Maximum Output Voltage Range Over Temperature For Maximum Calibrated Target Scene	-1.0 to +0.1 Vdc (100% Albedo; 25°C SR Temperature Reference)	-6.1 to -5.0 Vdc (320°K Target)
o DC Restore Level	-5.9 to -0.3 Vdc	0.25 ± 0.05 Vdc
o Operating Temperature	-5°C to +45°C	-5°C to +40°C
o Jitter (Scan line-to-scan line, Long Term)	<2 msec	
o Feature Location	5 km	

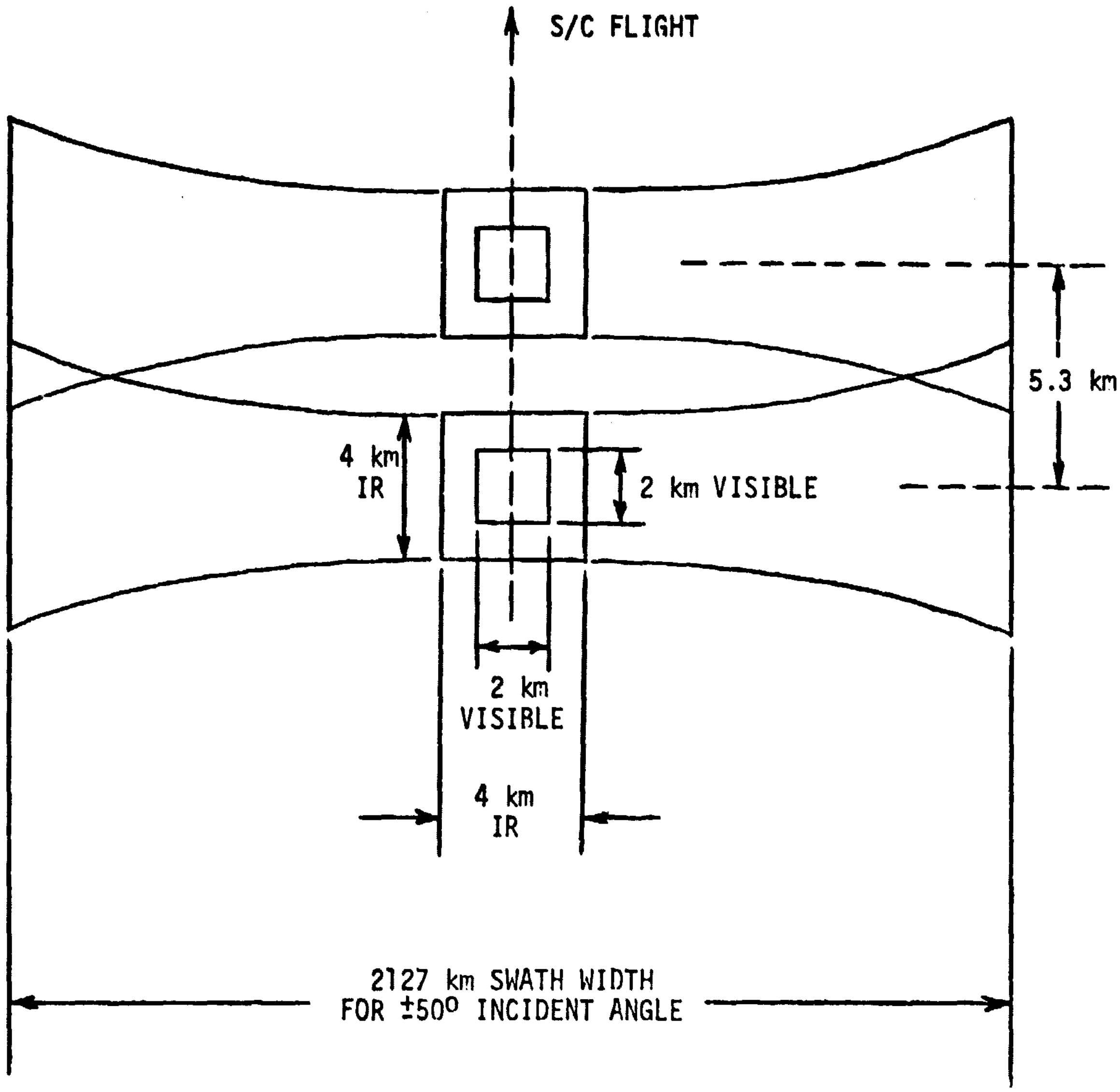


Figure 13. Seasat-A VIRR Scan Coverage

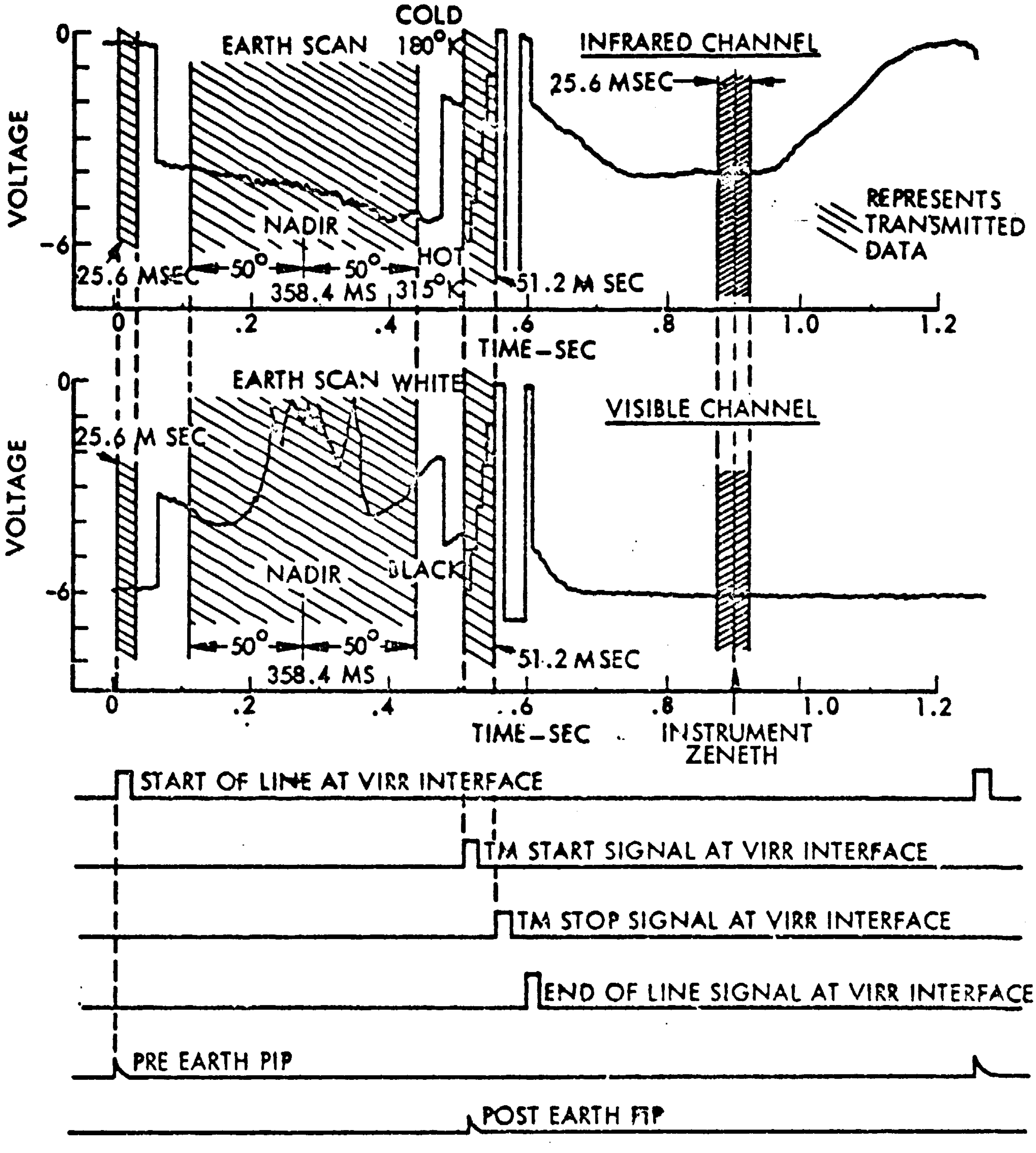


Figure 14. Analog Data Waveforms and Timing Signals (Ref. 23)

temperature. The visible channel signal level of -0.30 $\pm$ 0.10 volts will correspond to a target brightness of 100% albedo (Ref. 22).

The sensitivity of the VIRR is specified in terms of the Noise Equivalent Irradiance (NEI) or the irradiance at the entrance aperture which will produce a signal equal to the rms noise of the sensor. The NEI design goal for the infrared channel will be 2.9 x 10^{-10} watt cm^{-2} with a level of 4.2 x 10^{-10} watt cm^{-2} acceptable.

With this sensitivity in its thermal channel the VIRR will have the temperature measurement capability indicated in the Noise Equivalent Differential Temperature (NEΔT's) listed below (Ref. 22):

Scene Temperature (°K)	NEΔT (°K)
185	4.0
300	1.0

The sensitivity in the visible channel is specified at a NEI of 4.1 x 10^{-10} watt cm^{-2}.

The VIRR will be boresighted with respect to external mirrors on the spacecraft to an accuracy of $\pm$0.05°. The optical axes of the visible and infrared channels will be aligned to within 2.7 milliradians of each other. At the nominal spacecraft altitude (794 km) this maximum channel alignment error will correspond to a distance of 2.14 km. If this error was to occur in the across scan or along scan directions then the center of the 2 x 2 km visible resolution cell would occur outside the 4 x 4 km infrared visible cell. This error could therefore be quite significant for investigators using the two channels and concerned with the registration.

5.0 RESOURCES

The funding and manpower resource requirements for the major elements of a Seasat-A land application program at JSC have been presented in Reference 24. These resource data are given for fiscal years 1977 through 1980. Table 8 shows the man-year effort (MYE) figures from Table 8 of Ref. 24. Note that the contractor and civil service support (MYE) levels will rise sharply in 1978 and remain high in 1979. The final report in 1980 will then close the program.

Table 8. Manpower Resource Requirements

CS = civil service, CO = contractor

Program Element	FY 1977	FY 1978	FY 1979	FY 1980
Program management	CS 0.7	CS 1.5	CS 1.5	CS 0.7
Applications analysis and requirements study	CS 0.3 CO 1.0			
Aircraft data collection and processing		CS 3.0 CO 8.0	CS 2.0 CO 4.0	
and Ground data collection and processing		CS 0.5 CO 3.5	CS 0.5 CO 1.5	
Data processing/dissemination and investigator evaluation		CS 0.5 CO 1.0	CS 0.5 CO 1.0	
Analysis techniques development		CS 0.5	CS 0.5	
Applications investigations		CS 3.0	CS 2.0	
Total:	CS 1.0 CO 1.0	CS 9.0 CO 12.5	CS 7.0 CO 6.5	CS 0.7 CO 0

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24. Krishen, K., "Seasat-A Land Applications Program Plan," Rev. A, JSC-11405, August 1976.