RADARSAT PROCESSING SYSTEM AT ASF

K. Leung, M. Chen, J. Shimada, A. Chu

Jet Propulsion laboratory
California institute of Technology
MS 300-243
4800 Oak Grove Drive, Pasadena, CA 91109, USA
Phone: (818) 393-9045
Fax: (818) 393-02.02
E-mail: kon.leung@jpl.nasa.gov

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Radarsat is a Canadian polar orbiting remote sensing satellite launched in November 1995. The only instrument is a synthetic aperture. radar (SAR) that is capable of operating in a number of imaging modes including the first operational ScanSAR in space. As one of the data reception, processing and archive facilities for Radarsat data, Alaska SAR Facility (ASF) has responded to its science users by establishing a Radarsat processing system to handle the data processing of all Radarsat modes. 'J'his task involves enhancements to the high-throughput, hardware-based Alaska SAR Processor (ASP) *to* handle standard mode Radarsat data; the addition of the new ScanSAR Processors (SSP) to process the Radarsat ScanSAR mode data; and the introduction of l'recision Processors (PP) to accommodate the special imaging modes such as fine resolution and wide swath. For raw data ingestion and distribution to the appropriate SAR processor a new Control Processor (CP) and Raw Data Scanner (RDS) subsystem are also incorporated.

This paper outlines the ASF Radarsat data processing requirements as driven by the science users and describes the Radarsat processing system design and implementation approach to meet the challenge of providing ASF with an integrated operational SAR image production facility. Design and implementation attributes that facilitate system growth in handling future SAR missions such as Envisat and HIROS are also addressed.

1 INTRODUCTION

The Alaska SAR Facility (ASF) situated at the University of Alaska Fairbanks (UAF) has been acquiring, processing, and archiving SAR data from a fleet of international polar orbiting satellites including the European ERS- 1 /2 and the Japanese JERS-1 since 1991 [1,2]. As onc of eight designated Distributed Active Archive Centers (DAAC) in the United States, ASF has

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also been selected to provide similar services for SAR data from the Canadian Radarsat which was launched in November, 1995. The Jet Propulsion Laboratory (JPL) was tasked in 1993 to upgrade the existing ASF with capability of handling all four operating satellites. in addition to upgrading the current facility to handle, process, and archive a 4-fold increase in data volume, ncw processing capabilities are also needed to deal with the novel ScanSAR mode and special beam mode data that are unique to Radarsat. Also, in order to keep the operations costs in check in the face of increased system complexity, operability and maintainability become important system design issues as well. The following sections provide an overview of the Radarsat data processing requirements levied on ASF and a perspective on the resulting increase in system complexity Major system design and implementation issues are then discussed followed by thorough descriptions of the SAR Processing System (S1'S) architecture and subsystem designs. A phased system delivery approach that minimizes the impact to on-going ASF operations is presented. 'l'his paper concludes with a brief summary of the development experience and a report on the current status of this activity.

11 RADARSAT PROCESSING REQUIREMENTS OVERVIEW

Radarsat is the first in a series of Canadian remote sensing satellites. Its single payload is a synthetic aperture radar (SAR) operating at C-band (5.3 GHz) with characteristics given in Table 1. In addition to operating in the customary continuous (strip) mode, Radarsat is unique in being the first operational spaceborne SAR system which also operates in a novel ScanSAR mode [3] which allows wide swath (up to 500 km) coverage over a single orbit pass. To fully exploit the capabilities afforded by Radarsat, a list of data processing requirements has been developed under the guidance of a team of science users [3]. General requirements applicable to all ASF systems, as well as throughput requirements for Radarsat, ERS-1/2, and JERS-1 are discussed in the following paragraphs.

Table 1. RADARSAT SAR Characteristics

incidence angle (degree	
RADAR frequency (GHz)	'L'"
polarization	HH
Pulse repetition frequency (Hz)	1200 - 1400
Chirp slope (KHz/us)	-721.4 -416.2 -2793
Transmit bandwidth (MHz)	30.299 17.48 11.731
Transmit pulsewidth (us)	42.0
Sampling frequency (MHz)	32.32 18.46 12.92

2.1 General Requirements

All subsystems within the ASF SAR Processing System (SPS) are required to follow the project-wide guidelines regarding subsystem interfaces, systems standards, coding standards, user interfaces, and error reporting [4]. The emphasis is on applying, to the greatest extent possible, Commercial Off-the-Shelf (COTS) hardware, software, standards, and technology. Communications between the control processor and the other SPS subsystems follows a client-server model, typically with the raw data conditioner and image generation processors acting as production servers to the control processor client. With the exception of the existing hardware-based Alaska SAR Processor (ASP), where additional new custom hardware is unavoidable, all other subsystems in the SPS are being implemented with commercial high-performance workstations and mini-supercomputers. Operating systems based on System V Release 4 (SVR4) UNIX are adopted in all cases. Compliance with POSIX (Portable Operating System Interface) is a requirement, as is compliance with the X/Open Portability Guide and X/Motif graphical user interfaces (GUIs) for those subsystems that have user interfaces. High-level programming languages such as ANSI C and FORTRAN have been selected for ease of implementation and maintenance. Error and informational messages generated by the various subsystems use the UNIX *syslog* facility to allow for a consistent and easily configurable policy for error reporting.

2.2 Radarsat Standard Beam Mode Processing Requirements

In addition to the ScanSAR and special beam modes of operation, the Radarsat can operate in any one of seven standard radar beam modes (ST1 - S"1'7), each covering ~100 km in swath and at incident angles ranging from 20 degrees to 50 degrees. ASF is required to process a total of 58 minutes of standard beam mode data from any combination of ERS-1/2, JERS-1, and Radarsat satellites within a 16-hour day.

2.3 Radarsat ScanSAR Beam Mode Processing Requirements

in the ScanSAR mode wide swath coverage on the order of 200 km to 500 km is achieved by sweeping the antenna beam electronically in the range dimension to generate multiple overlapping sub-swaths, each extending approximately 100 km in range. 'l'he resulting echo data for each subswath appears in the form of discrete 'bursts' of echo returns rather than a continuous sequence. Maximum swath width of -500 km can bc generated using a combination of 4 beams (covering 4 overlapping subswaths) with incidence angles of -20° at the near edge of the swath to 50° at far edge. in addition to four 4-bcam modes which generate 500 km swath coverages, Radarsat is also equipped with one 3-bcam mode which yields a -300 km swath and one 2-bcam mode which produces a -200 km swath as well. ASF is required to process 42 minutes of Radarsat ScanSAR data, all modes combined, in an 11 -hour day, including 8 minutes of 'quick turn-around' data for the National Oceanographic and Atmospheric Administration (NOAA).

2.4 Radarsat Special Beam Mode l'recessing Requirements

Radarsat is also equipped to operate 15 special beam modes that include 3 Wide Swath beams, 5 Fine Resolution beams, 6 High Incidence beams, and 1 Low Incidence beam. ASF is required to process at least 5 minutes of special beam mode data in a 5-hour day.

III ASF SPS OVERVIEW

3.1 ASF Overview

The Alaska SAR Facility (ASF) is a full service data processing and archiving organization, It can assume end-to-end SAR data processing and handling functions that include receiving and cataloging data ordering information from users, communicating data acquisition requests to respective flight agencies, collecting satellite downlink data, processing SAR data into various forms of data products, and archiving and distributing the respective products back to the individual users. To accommodate the added complexity associated with dealing with multiple satellites, ASF is undergoing a major upgrade to improve its capability and efficiency. Figures 2-a and 2-b arc block diagrams of ASF depicting its current versus the upgraded configurations.

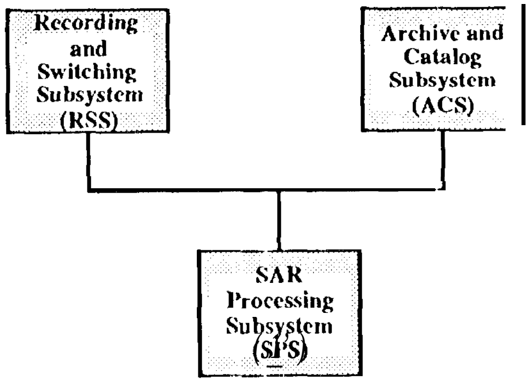


Figure 2-a, Current ASF Configuration

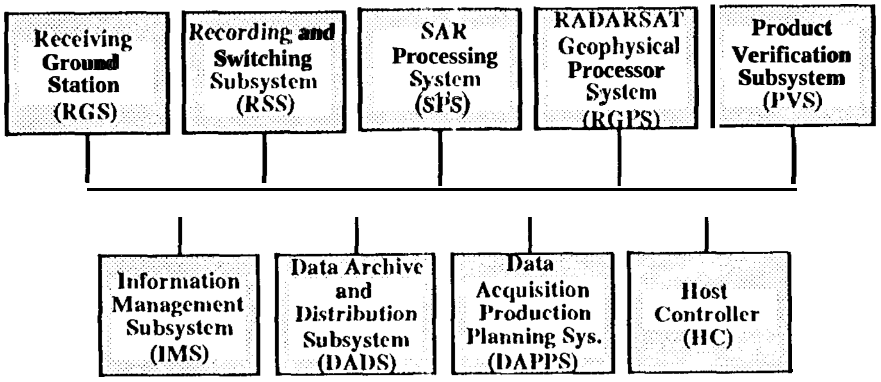


Figure 2-b. Ncw ASF Configuration

3.2 Current SPS Configuration

The SAR Processing System (SPS) at ASF is responsible for reducing the SAR raw data downlinked from satellite into various forms of image products. The current SPS (see Figure 3-a) consists of the Alaska SAR Processor (ASP) subsystem and the SAR Post Processor (SPP) subsystem. 'l'he ASP subsystem is a SAR data processor developed by JPL in the late 80's. It was commissioned in August of 1990 to support ERS-1 data processing. It underwent a modification in 1991 to accommodate JERS-1. To-date, 130,000 ERS-1 and JERS-1 image frames have been produced by ASF-SPS.

The ASP subsystem consists of a hardware correlator (AS]') and a control computer. The hardware based ASI' is a custom-built pipeline SAR correlator that executes the popular fast Fourier correlation technique [5] in both range and azimuth processing. A large corner-turn memory module is employed to facilitate data corner-turn between range and azimuth processing. The ASP is capable of processing strip mode SAR data at very high throughput rate; producing a. 100 km by 100 km ERS type scene in ~ 6 minutes. Processing control and processing parameter generation functions for the ASP subsystem arc provided by a MASSCOMP workstation. The ASP receives play-back SAR signal data from AMPEX DCRSi high density digital recorder (1 IDDR) via a Recorder Peripheral Interface (R]']) and a raw data deformatter. The raw data deformatter (EDFM for ERS data and JDFM for JERS data) decodes and conditions the downlink bit stream for ingestion by the ASP.

The SAR Post Processor (SPP) subsystem is hosted on a u-VAX, and provides data quality assurance and interface functions between the SPS and the Archive and Catalog Subsystem (ACS).

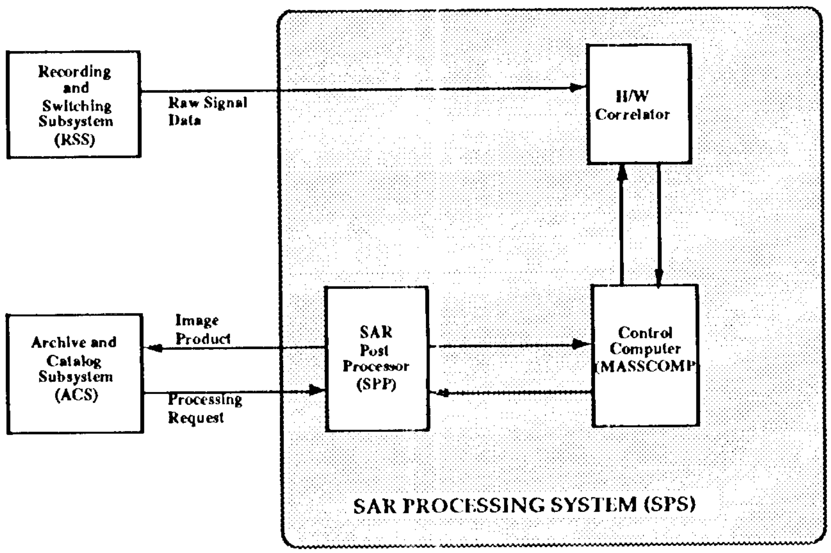


Figure 3-a. Current S1% Configuration

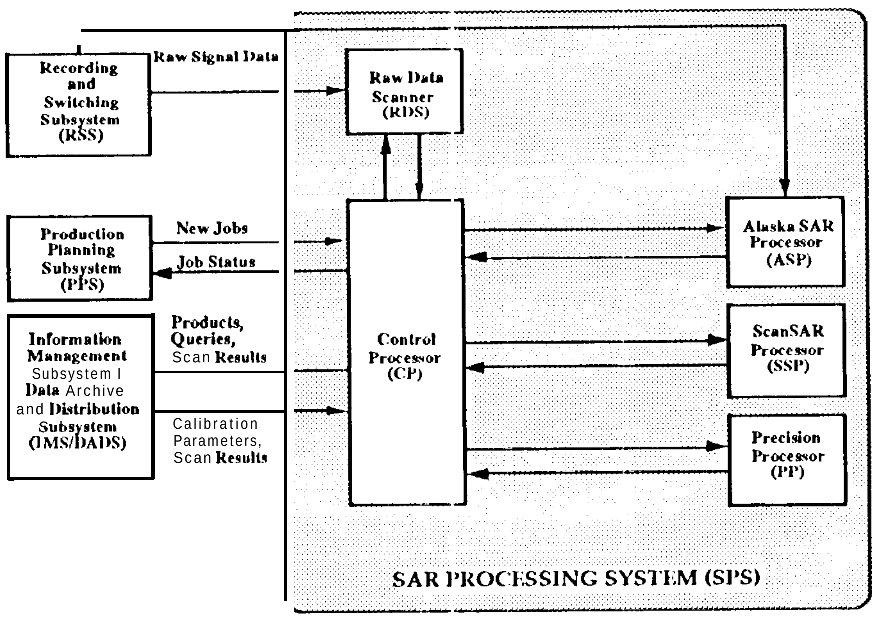


Figure 3-b. New SPS Configuration

3.3 SPS Configuration in the Radarsat Era

To accommodate Radarsat and to allow for easy expansion to include future satellites, the S}'S is being reconfigured and upgraded using an integrated system approach. As depicted in Figure 3-b, it consists of a Control Processor (CP), a Raw Data Scanner (RDS), and a number of SAR processors including the upgraded Alaska SAR Processor (ASP), the new ScanSAR Processors (SSP), and the new Precision Processor (1'1').

3.3. System Design Approach

The design of the new S1'S has been driven not only by numerical throughput requirements, but also by the ASF project directives and overall goals of expandability and ease of use. To those ends, the following elements have been incorporated into the S1'S:

- Resource management is centralized at the Control Processor (CP). in particular, the CP houses a large disk array for temporary storage of decoded raw data files and completed image products. The other SPS subsystems such as the SAR data processors and data conditioners, have only enough local storage to meet their processing requirements for one job request. Placing most of the disk space at the CP reduces the need to have large amounts of storage distributed at each subsystem and reduces the software development costs associated with having to manage distributed data stores.

- Centralized control of SPS operations through the Cl' means that the SPS operator can monitor operations from a single location and user interface development for the SPS is almost completely confined to the CP. 'l'his also greatly simplifies the addition of new SAR processors,

- Because a phased rapid development approach [6] is being adopted for the deliveries of the ASF subsystems, subsystems both inside and outside the S1'S can exist in various stages of operability. In particular, the SSP will not reach its final 3-platform configuration until its mid-1 996 delivery. To allow for a variable number of ScanSAR Processor (SS1') platforms and to allow for normal S1'S operations (to the greatest extent possible), in the event that a subsystem needs to be taken down for maintenance, the SPS has been designed to allow easy reconfiguration of the particular machines to bc used for SPS operations at a given time.

- As described earlier, the SAR data processors (ASP, PI', and SSP) and data conditioner (RDS) all behave as product servers to the client CP. The CP uses an identical communications protocol with each of these servers to send and receive job information and send control messages for subsystem initialization and shutdown. To implement this protocol, a common library of functions for message handling has been developed for usc on the CP/RDS platform (a Silicon Graphics, Inc. Challenge X1.), the ASP platform (a Digital Equipment Corp. Alpha), the SS1' platform (IBM SP-2's), and the PPS platform (Sun SPARCstations (running Solaris 2.x)). Development of the library has been greatly aided by the fact that the operating systems on all these platforms are based on SVR4 UNIX and are POSIX-compliant. However, the library docs violate one of the project directives in that it is not based on Distributed Computing Environment (DCE) remote procedure calls [4]. This exception was made because of the lack of timel y availability y of DCE on the SGI.

- The ASP, PP, RDS, and SSP also use a common error-handling mechanism with the Cl'. Each of the former subsystems is essentially stateless in its job handling, i.e. if it is asked to redo a partially completed job, it completely restarts the processing rather than resuming it from its previous stopping point. 'l'his approach was deemed prudent when a slight loss in throughput efficiency is balanced against a substantial reduction in development costs.

3.3.2 New System Description

The new SPS configuration is shown in Figure 3-b. It consists of five subsystems:

- an upgraded version of the current Alaska SAR Processor (ASP) that handles, in addition to the current ERS-1 and JERS-1, also ERS-2 and Radarsat data
- new ScanSAR Processors (SSP) for handling ScanSAR-mode data from Radarsat

- new Precision Processors (PP) for handling Radarsat special beam modes, as well as processing of all strip mode data into high-precision image data products
- a new Raw Data Scanner (RDS) for reading and deformatting raw signal data from the various satellites for ingestion by the SSP and PP, and for determining raw data availability
- a new Control Processor (Cl') for coordinating all SPS processing controls and int erfaces.

Figure 3-b shows the external interfaces of the S1'S with the Recording and Switching Subsystem (RSS) which houses the high-density digital recorders (I II)DRs) used for nominal raw signal data input, the Production Planning Subsystem (PPS) which is a subsystem of the Data Acquisition and Planning Subsystem (DAPPS), and the information Management/ Data Archive and Distribution Subsystems (l MS/DADS).

IV '1'1 IE ASF SPS SUBSYSTEMS

4.1 The Alaska SAR Processor

in the new SPS configuration, the ASP becomes just one of the many SAR data processors within the S1'S. The main function of the Alaska SAR Processor (ASP) is to continue to provide a high throughput strip mode data processing capability for SPS by augmenting its system to accommodate ERS-2 and Radarsat in addition to the current ERS- 1 and JERS-1. The new ASP subsystem will continue to be based on the existing hardware correlator (ASP) which will be fed by three data deformatters, the existing EDFM and JDFM for ERS and JERS, respectively, and a new RDFM for Radarsat strip mode data. A number of modifications arc also implemented to enhance system performance and maintainability and to allow it to conform to the new project mandated client-server interface protocol. With that, the ASP processing control will be moved to the CP. The new ASP configuration is expected to yield a 50% increase in processing throughput generating a 100 km by 100 km scene within 4 minutes. Similar to the current data processing options available for ERS-1/2 and JERS-1, the ASP can produce any of the four user selected image products for Radarsat: standard low-resolution (LOW), standard full-resolution (FUI .), complex

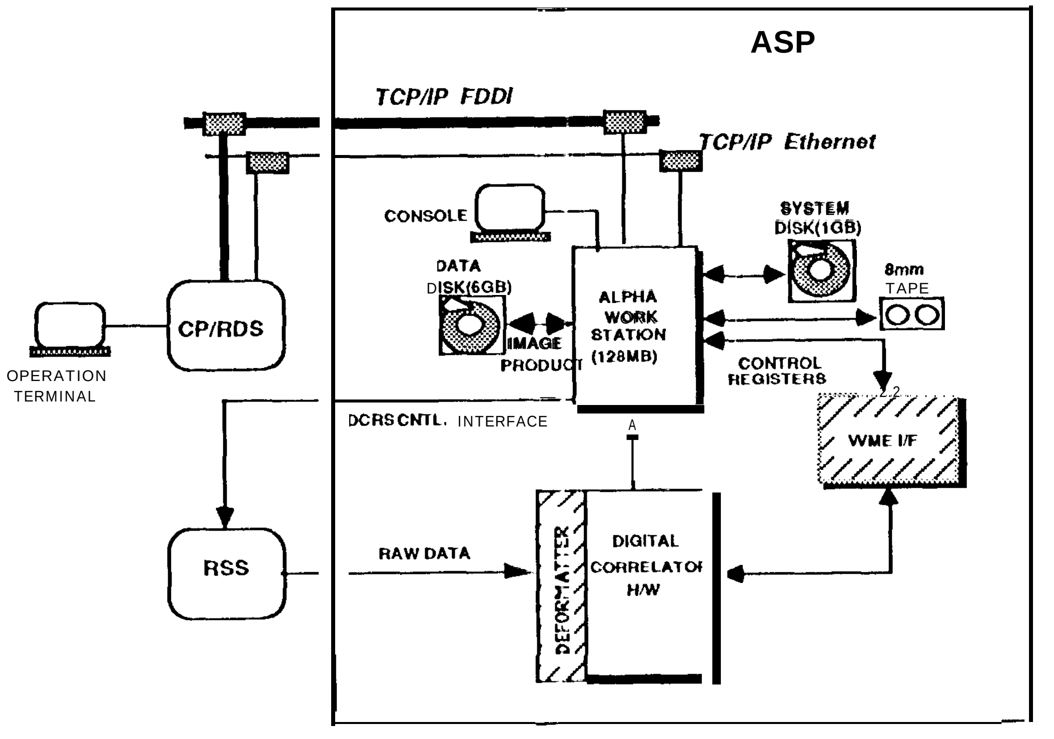
(CPX), and computer compatible signal data (CCSD). Brief specifications for these four products are shown in Table II.

Table 11. Radarsat Standard Mode Product Specifications

PRODUCT	Number of Looks	Pixel Spacing (Resolution) (m)	Pixel Format	**Swath (km)**
LOW	256	100 (240)	Byte Amplitude	100 X 100
FUL	4	12.5 (30)	Byte Amplitude	100 X 100
CPX	1	natural (10)	16I/16Q	40 x 50
CCSD	NA	NA	8I/8Q	NA

ASP Implementation

The new ASP subsystem (see Figure 4) uses a DEC-Alpha in place of the MASSCOMP as the control computer. The DEC-Alpha acts as a server to CP responding to CP'S processing requests. It also generates processing and control parameters for the hardware correlator and buffers image data to the CP storage disks. For ingestion of Radarsat data from RSS a new deformatter, RDFM, is added to the front end of the ASP hardware correlator. The RDFM is designed to decode and descramble the downlinked data from Radarsat into engineering data to be used for processing parameter generation by the control computer and echo data for processing by the hardware correlator. A new VME bus interface is also introduced to serve as a control signal interface between the DEC-Alpha and the hardware correlator.



Figurc 4: New ASP System Configuration

in addition to hardware modifications the ASP software is also upgraded. Pre-processing software for generating proper processing parameters is enhanced to handle the various Radarsat standard beams. A fixecl-scene-ccntcr scheme is adopted for absolute location of image frames, thereby simplifying users' ordering procedures and allowing users to order image frames based on latitudes instead of data start and stop times. An efficient 2D-FFT pre-processing algorithm is also implemented for Doppler estimation to further enhance processing throughput. All ASI' image products will be formatted to conform to CEOS specifications with a CEOS image file and an associated CEOS leader file.

4.2 ScanSAR Processor

The function of the ScanSAR Processors (SSP) is to provide SPS with a capability of processing Radarsat ScanSAR mode data. '] 'he implementation of the ScanSAR Processor is divided into two phases. Under Phase 1, a prototype processor is built for the evaluation of ScanSAR processing algorithms. This final version of the prototype shall meet all image performance requirements.

Its throughput rate is projected to be approximately one three-hundredth real-time or one 500 km by 500 km ScanSAR image frame in about 6 hours. 'l'his prototype is also expected to participate in initial Radarsat downlink validation at ASF. Phase 2 involves the implementation of high throughput ScanSAR processors that arc capable of processing 42 minutes of ScanSAR data inan 11-hour day (or approxim atcly onc fifteenth real-time). Various types of ScanSAR image products produced by the SSP include a number of standard products, a 'quick-look' product for NOAA , and special products for internal system calibration support. Table III lists the characteristics of these ScanSAR data products.

Table 111. Radarsat ScanSAR Product Specification

PRODUCT	Number of 1 ooks	Pixel Spacing (Resolution)	Pixel Format	Swath (km)
Standard - Geocoded	8-28	50/100/400 (75 / 150/ 600)	*Byte* Amplitude	"512/ 307.2
Standard - Terr-corr'd	8-28	50/ 100/400 (75 /150 / 600)	Byte Amplitude	'512/307.2.
NOAA-AT/CT	8 - 28	50 (75)	Byte Amplitude	512 / 307.2,
Special - Single-look	1	100 (150)	Byte Amplitude	3
Special - Mulit-look	8 - 28	100 (150)	Byte Amplitude	512.

SSP Implementation

The Phase 1 prototype processor is cohosted with CP and RDS on a Silicon Graphics Challenge XI. computer with four processing elements as shown in Figure 5-a. Processing control is initiated by the CP in accordance with a client-server model. The ScanSAR processing algorithm selected [7-12] capitalizes on the burst nature of the data by processing a burst at a time. Each burst is first range compressed using the familiar FFT correlation approach. The resulting data burst is then corner-turned followed by azimuth processing which utilizes an efficient deramp-FFT algorithm. The resulting burst is then geometrically rectified and radiometrically compensated. At this point, data from adjacent bursts arc merged in a final multi-look overlay and image projection process forming the final ScanSAR image.

For phase 2, three IBM S1'-2 mini-supercomputers, two equipped with 8 processing nodes and onc with 4 nodes, are used [13]. Each SP-2 is expected to operate independently as a server to the CP processing upward of 17 minutes of ScanSAR data in an 11-hour day. The SP-2 is a distributed memory machine well suited for the burst mode nature of the ScanSAR data and its processing algorithm with each processing node handling integral data bursts efficiently without the need for frequent 1/0. The phase 2 processors will inherit the proven core processing code from the prototype unit with massive parallclization employed to achieve high throughput. The IBM SSP-2 platform configuration is depicted in Figure 5-b.

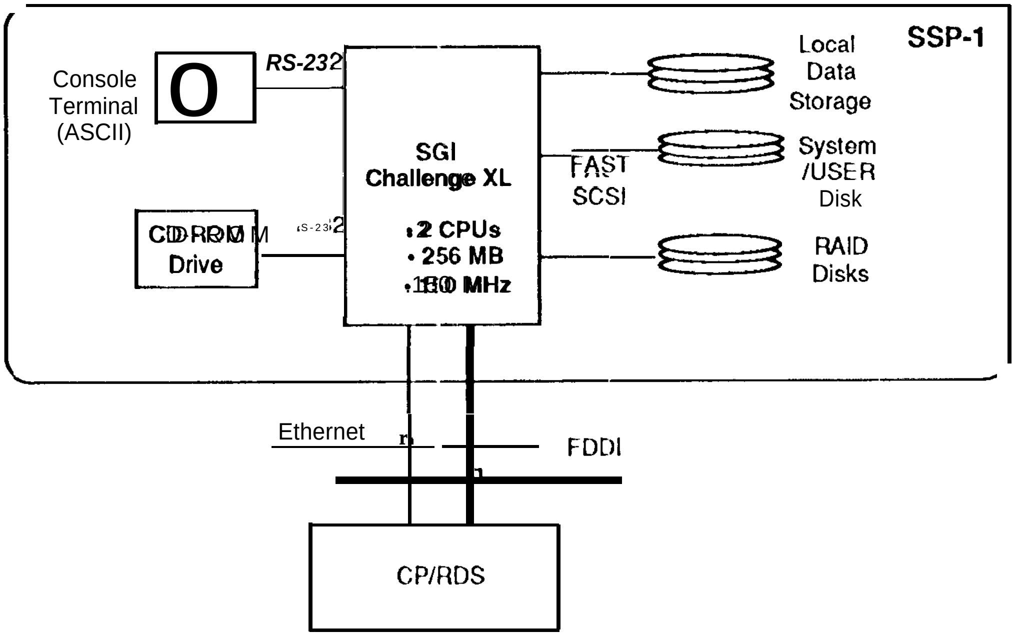


Figure 5-a: SS1'- 1S ystcm Configuration

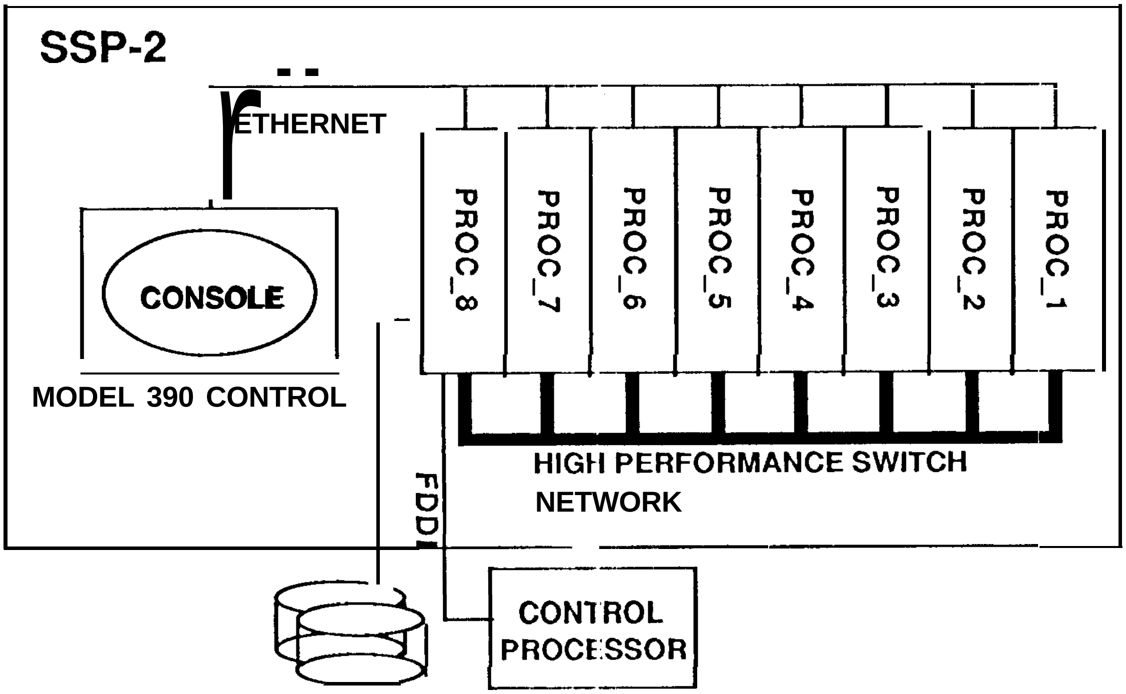


Figure 5-b: SS1'-2 System Configuration

4.3 Precision Processor

The main function of the Precision Processors is to provide a processing capability to handle the Radarsat special beam mode data. It is also designed to be flexible so that modern SAR processing algorithm technology can be implemented efficiently with relative case. Current throughput is expected to bc on the order of processing 5 minutes of nominal 100 km swath strip-mode data per 5-hour day.

1'1' Implementation

The Precision Processors will be cohostcd on the IBM S1'-2's that also process ScanSAR data (see Figure 5-b). It is expected that each 8-node SP-2 will be capable of processing ~2.5 minutes of data in 5 hours.

4.4 Raw Data Scanner

The main function of the Raw Data Scanner (RDS) is to deformat and decode raw signal and ancillary (ephemeris and engineering) data that arc embedded in the high-rate data stream from each satellite. The decoded SAR signal data and ancillary data arc then fed to either the SSP or the PP for image generation. (Note that the ASP has its own raw data decoding and scanning capability.) A second function of the RDS is to provide an efficient scanning capability to determine how much of the downlinked data can actually be processed into image products. The results of a scan arc returned to the CP which then stores this information in the information Management Subsystem (l MS) database for usc by the subsystems that handle user orders. The RDS is expected to scan 200 minutes of data and supply the SSP and PP with 54 minutes of reformatted and decoded data during each 16-hour day.

Implementation

A Silicon Graphics Challenge XL computer has been chosen as the host platform for the RDS software (see Figure 5-a). This system has four Ml PS R4400 CPU's and 256 MB RAM memory. An Ampex VME interface has been included to provide access to the Ampex DCRSi HDDR's at the Recording & Switching Subsystem (RSS). The RDS software has been implemented as a single multithreaded application capable of taking its input from either DCRSi tape or from disk.

The delivery of the RDS has been staged so that the appropriate capabilities are available to support each new processor as it comes online. Future capabilities include support for other HDDR's such as the *Sony* ID-1's.

4.5 Control Processor

The main function of the Control Processor (CP) is to provide overall control of all the other SPS subsystems through a single operator interface. This interface allows the SPS operator to initialize and shut down the various subsystems without having to physically log onto each subsystem's host platform. The CP has been designed to automate the SAR processing to the greatest extent possible. Incoming, jobs from the PPS are automatically routed to the appropriate subsystem or subsystems and completed image products arc delivered to the IMS/DADS with minimal intervention required from the operator. The CP also hosts the image data quality control functions for the SPS providing completed products to bc checked at a centralized location prior to delivery.

implementation

The CP subsystem software shares the SGI Challenge XL with the RDS (see Figure S-a). A DigiData Z9000 RAID-3 subsystem with 128 GB of storage serves as temporary local storage for the reformatted data files used by the SSP and PP and for the completed image products prior to their delivery to the IMS/DADS. To better enable fast transfer of large volumes of data within the SPS and to the DADS, the SGI utilizes two separate FDDI connections. Two Tektronix X-terminals hosted from the SGI are used by the SPS operator to monitor the processing through the main operator interface and for image quality control. The main application is a multithreaded program that manages the various processing jobs within the SPS and allows the operator to monitor and control the processing through an X/Motif graphical user interface (GUI). Multiple threads of execution allow parallel processing of X events and input and output messages to and from the subsystems that interface with the CP. The other CP applications are used for the quality control functions and for interfacing with external subsystems such as PPS and IMS/DADS. These applications also utilize X/Motif GUI's and/or threads as appropriate.

As with the RDS, the delivery of the CP has been staged so that the appropriate capabilities arc available to support each new processor as it comes online.

V SUMMARY& STATUS

This paper provided a comprehensive overview of the new SAR Processing System at ASF with special emphasis on its processing capabilities and accommodation of the various operating modes of Radarsat. The upgraded ASP and the prototype ScanSAR Processor have been undergoing testing using test data modified from SIR-C as well as test data sets supplied by the Canadian Space Agency (CSA). The new ASF-SPS for the Radarsat era is approaching its major delivery to ASF at Fairbanks in May of 1996. By then all SPS subsystems and capabilities described in this paper will be operational with the exception of the Precision Processor (PP) which is to be delivered in October of 1996.

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