X-SAR, A Spaceborne Synthetic Aperture Radar Instrument

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ABSTRACT

X-SAR is a Shuttle-borne imaging Synthetic Aperture Radar (SAR) operating in X-Band (9.6 GHz). It is being developed and operated in a joint venture between Germany and Italy. Integrated together with the L-Band (1.25 GHz) and C-Band (5.3 GHz) Radar SIR-C of NASA/JPL, X-SAR will become part of a multifrequency/multipolarisation SAR Facility, called Shuttle Radar Lab (SRL). SRL will be operated for approximately 50 hours during each of the envisaged flights. The first 9-days mission is scheduled for September 30, 1993, the second one for December 1994 and the third one for spring 1996; this flight sequence allows monitoring of seasonal changes.

KEY WORDS: Earth Observation, Microwave Sensor, Synthetic Aperture Radar, Multifrequency, Multipolarisation, Shuttle Mission, SAR Data Processing

1. INTRODUCTION

X-SAR is a cooperative space project between Germany and Italy in the field of Earth Observation from space. The German Space Agency (DARA) and the Italian Space Agency (ASI) have delegated the management of the joint project to an X-SAR Joint Project Office comprising DARA and ASI personnel. The X-SAR project comprises the following elements:

- o Synthetic Aperture Radar Instrument developed under Dornier as a prime contractor with ALENIA as a co-contractor;
- o Mission Planning and Operation System (MPOS) developed under ALENIA as a prime contractor with the Quicklook Processor developed by Dornier;
- o Off line SAR Processing Systems including Survey Processing of all acquired data under ASI responsibility and Precise processing of 10% of the survey processed data equally shared between ASI and DARA.

After integration of the X-SAR onboard instrument with SIR-C, being developed by NASA/JPL, which comprises an L-Band and C-Band SAR, X-SAR will become part of the Shuttle Radar Lab (SRL). This integrated Radar Facility will be the first multifrequency, multipolarization and multiple-incidence angle Synthetic Aperture Radar (SAR) to be flown in space.

Shuttle Radar Lab will be operated for approximately 50 hours during each of the envisaged missions. Presently three missions are planned, a fourth is under discussion. Each mission has a duration of 9 days. The first one is scheduled for end of September 1993 and subsequent reflights will be performed at time intervals allowing monitoring of seasonal changes on the Earth surface.

From a scientific point of view a significant extension of our knowledge and understanding of conditions and dynamic processes on the Earth surface is expected from evaluation of the SRL SAR data. This will contribute to a more precise and more reliable recording and monitoring of the renewable and non-renewable resources of the Earth.

A further important objective is to contribute, in the framework of international cooperation, to the design and specification of future generation (pre-operational) multifrequency SAR systems to be flown on polar-orbiting environmental monitoring satellites. In this context the SRL data will be used to set and refine the technical requirements on future spaceborne SAR instruments in terms of sensitivity, resolution, image quality and other essential system parameters.

2. SHUTTLE RADAR LAB SYSTEM DESIGN

The Shuttle Radar Lab system design, as shown in Fig. 1, consists of an antenna structure housing the three antenna arrays, the X-SAR electronics, and the SIR-C electronics which are located in the Shuttle cargo bay. The digital data routingelectronics and the three payload high rate recorders are located in the Shuttle crew cabin. The data acquired during a mission will be about 130 tape cassettes each holding 3.2×10^{11} bit of digital data. The data acquired during a mission will be digitally processed on the ground after the mission, for X-SAR all data transmitted during missions via the Shuttle Ku-Band link will also be processed in real-time.

The SIR-C and X-SAR systems are designed to operate in synchronism. Both systems transmit pulses simultaneously and their data quantization is controlled by a common clock. In this manner, the output products can be made to overlay each other on pixel to pixel basis.

Table 1 gives an overview on the most essential SRL system requirements in terms of frequencies, polarisations and image quality parameters.

Table 1 Shuttle Radar Lab System Requirements

Parameter		Requirement
Frequencies		L,C, and X-Band
Polarisation	L-Band C-Band X-Band	HH, HV, VH, VV HH, HV, VH, VV VV
Cross Polarisation Isolation		25 dB or greater
System Noise Equivalent Sigma Zero	L-Band C-Band X-Band	-40 dB -35 dB -22 dB
Spatial Resolution-Azimuth		30 m
Impulse Response Integrated Sidelobe Ratio		-12 dB
System Ambiguity Ratio		- 20 dB total
Data Acquisition		50 hours/ channel/mission

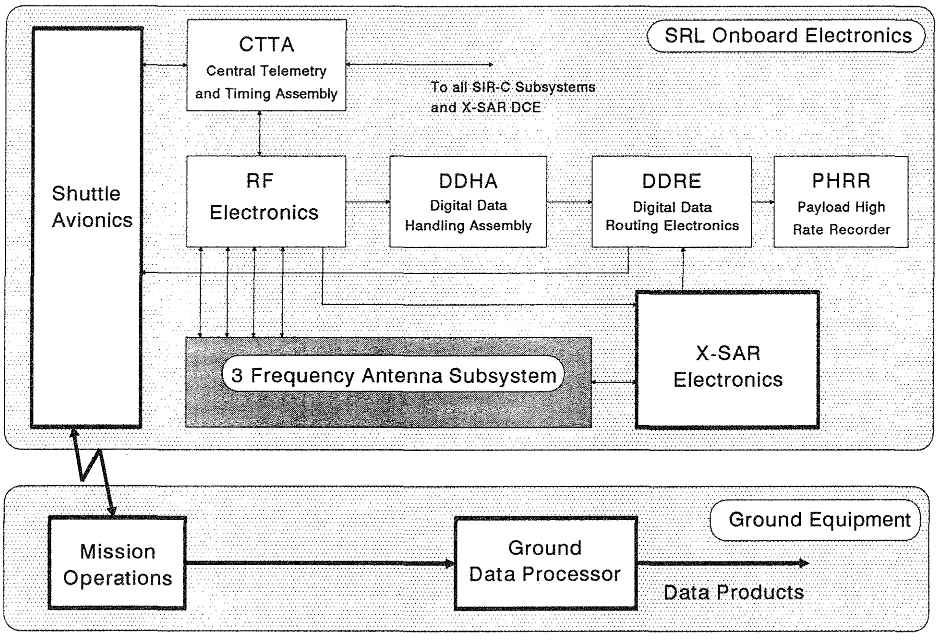

Figure 1 Shuttle Radar Lab System Block Diagram

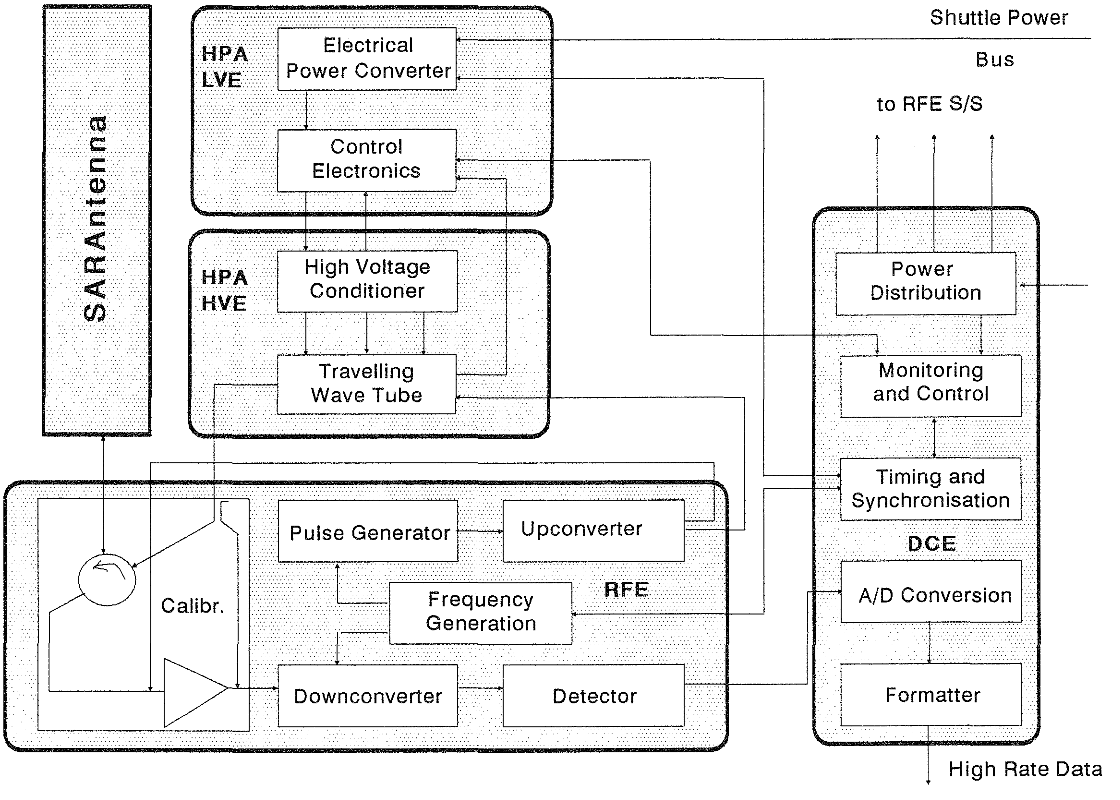

Figure 2 X-SAR Instrument Block Diagram

3. X-SAR SPACE SEGMENT DESIGN

The X-SAR Space Segment consists of the following major elements, called the X-SAR Instrument:

- o The X-SAR Instrument Electronics including the interfaces to SIR-C and to the Space Shuttle. The electronics are mounted on a standard Shuttle Pallet.
- o The X-SAR Antenna, which is mounted on a tiltable structure attached by hinges to the fixed SIR-C antenna truss.
- o The Receive and Transmit Waveguide including a Rotary Joint as connecting link between the Electronics and the Antenna.

Fig. 2 shows a blockdiagram of the X-SAR Instrument with the essential subsystems and their main functions. They are described in more detail below.

The X-SAR flight equipment is in an advanced development status. The antenna has been ready for flight since October 1990. For the onboard electronics a complete Engineering Model has been integrated and tested, the Flight Model integration and acceptance testing will be finalized until September 1992.

The test data attained give high confidence that all essential system performance requirements will be met during missions. Table 2 shows a comparison of X-SAR image quality vs. relevant requirements.

Tables 3 and 4 show the X-SAR mass and power budgets, which also demonstrate a good margin of measured data vs. requirements.

Table 2 X-SAR System Performance Parameters

System Parameter	20^{o}	50^{o}	Requ.
Point Target			
Range - Slant Resolution (m)	9.6 (F)	18.0 (C)	<10 (F) <20 (C)
- ISLR (dB)	12.1	12.2	>11
- PSLR (dB)	21.9	21.9	>20
Azimuth - Ground Resolution (m)	27.5	27.4	<30
- ISLR (dB)	15.47	15.5	>11
- PSLR (dB)	21.9	21.9	>20
Distributed Target			
Ambiguity Ratio (dB)	19.4	19.4	>18
Image Signal to Noise Ratio (dB)	8.7	7.7	---
Radiometric Resolution (m)	2.1	2.1	<2.75
Dynamic Range (dB)	32.9	36.8	>20
Swath Width (km)	30.4	32.0	>15

Note: F=Fine Resolution, C=Coarse Resolution

Table 3 X-SAR Mass Budget

Element	act.(kg)	spec.(kg)
Antenna	43.6	<53.3
Rx/Tx Waveguide	8.3	<11.5
Electronics	156.3	<161.5
Total Mass	**208.2**	**<226.3**

Table 4 X-SAR Power Budget

Operating Mode	actual (W)	spec. (W)
Standby	58.8	<69.0
Pause	181.2	<199.0
Transmit		
- PRF=1240 Hz	758.0	<1409.0
- PRF=1830 Hz	1060.0	<1409.0

3.1 Antenna Subsystem

The X-SAR Antenna is a planar slotted waveguide array antenna with a total size of 12 m length and 0.4 m width. It consists of three mechanical leaves, each divided into four electrical subpanels. Each of these electrical subpanels has fourteen resonant waveguides with 42 displaced radiating slots. The waveguides are manufactured from metallized Carbon Fiber Reinforced Plastic material in order to achieve the required phase and amplitude stability over a large operating temperature range and to survive also the worst case temperature conditions of a range from $+100^{o}$ C to -150^{o} C. Furthermore this material gives the necessary mechanical stiffness and low mass for such a large structure.

The feeding network on the backside of the panels consists also of CFRP waveguides. Distribution to the radiating waveguides is performed by 14-way couplers, power distribution to the subpanels uses 3 dB couplers. Exact Phase trimming between panels and subpanels can be performed by mechanical adjustment of distance bushing waveguides. Power distribution to the three mechanical panels is performed by a Three Way Power Divider.

Results from acceptance testing of the flight antenna give a beamwidth of 5.5 degrees in elevation and 0.14 degrees in azimuth with an overall gain of 44.5 dBi. In order to achieve the required sidelobe reduction in elevation for a good suppression of nadir echos a taper is used.

The in-orbit antenna performance depends to a large extent from the stability of the antenna truss structure, on which the X-SAR antenna will be mounted. This truss structure is presently being designed and manufactured by JPL and will be available for integration in December 1992.

3.2 Radio Frequency Electronics Subsystem

The Radiofrequency Electronics subsystem performs the basic function of generating linear FM modulated transmit pulses with a selectable bandwidth of 9.5 MHz or 19.0 MHz. The chirp signals of 40 μsec length are produced by Surface Acoustic Wave (SAW) devices, upconverted and are used to drive the High Power Amplifier.

For calibration purposes the transmit signal from the High Power Amplifier is coupled out and routed back to the RFE, which contains also the Transmit-Receive Switch. The receive signal from the antenna is amplified in a Low Noise Amplifier, downconverted and finally detected. The I and Q signals are routed to the Data and Control Electronics.

The RFE contains two loops for calibration of the onboard electronics. The first loop routes an attenuated transmit signal to the downconverter. This loop is mainly used for transmit signal calibration. The second loop uses the upconverted chirp signal and injects a fraction into the Low Noise Amplifier. This loop allows calibration of the receive chain.

The implementation of the RFE uses Surface Mounted Components in order to achieve a high packing density.

3.3 High Power Amplifier Subsystem

The High Power Amplifier (HPA) consists of a Low Voltage Electronics performing the conversion from the 28 V DC Shuttle Power Bus to a 200 V AC intermediate power bus, which drives the High Voltage Electronics. It also performs control and protection functions and interfaces with the RFE and the DCE.

The High Voltage Electronics is housed in a sealed container at a nominal pressure of 1000 Hectopascal (1 atmosphere). The chirp signal from the RFE is amplified by a Travelling Wave Tube to an output power of 3.3 kWatt peak. The HPA has an overall efficiency of 28% due to use of highly efficient power converters and of a multistage Travelling Wave Tube.

3.4 Data and Control Electronics

The Data and Control Electronics performs mainly the X-SAR control and data handling functions as well as power conversion and distribution. Furthermore it interfaces both with Shuttle and with SIR-C concerning commanding, telemetry and synchronization.

The analog I/Q data from the RFE are converted to digital form with either 4 Bit or 6 Bit by A/D Converters. After time expansion and formatting the SAR raw data are routed to the SIR-C Digital Data Routing Electronics and from there either to the onboard tape recorders or to the Shuttle Ku-Band System for transmission to ground.

Commands are received via SIR-C from the Shuttle command link, stored in a command memory and checked for validity before execution. Housekeeping data from the X-SAR subsystems are collected by the DCE and monitored, formatted and transmitted to the Shuttle telemetry system as well as inserted into the High Rate Data stream.

As a particular feature a data window position monitor has been built in, which allows to check the imaged swath on-ground. The same data are also used on-board to derive a programmable gain control for gain setting of the X-SAR receive chain.

An essential interface with SIR-C is the timing and synchronization performed by the DCE on the X-SAR side. All X-SAR frequencies are derived from the SIR-C 90 MHz Ultrastable Oscillator. Command execution and mode switching is performed exactly on a one second time tick, which is derived from this oscillator as well.

3.5 Receive and Transmit Waveguide

The Receive and Transmit Waveguide System provides the RF power link from the High Power Amplifier to the Radiofrequency Electronics and from there via a Rotary Joint to the tiltable X-SAR Antenna.

In order to achieve this function and to decouple from mechanical misalignments of the electronic boxes on the Shuttle Pallet as well as dynamic movement of the Pallet versus the Shuttle Cargo Bay, development and space qualification of mechanically highly flexible waveguides with very high electrical performance was necessary. The total length of this waveguide system composed of a series of fixed and flexible pieces is now more than 4.8 meters with a total loss of less than 1.7 dB.

4. X-SAR GROUND SEGMENT

4.1 Overview on Mission Planning and Operation System

For mission planning and mission operations X-SAR is developing the Mission Planning and Operations System (MPOS). As shown in Fig. 3 it consists of the following major elements:

- o Planning and Analysis System (PAS) which has two important functions. It is firstly a comprehensive mission timelining system, which will be used prior to the mission to plan the complete sequence of mission events; during the mission it will be used to update this sequence according to the latest available information. It is secondly a powerful tool for analysing data take information and deriving corrections to radar settings in realtime. The PAS will have read-access to SIR-C data tables, enabling the compilation of the joint SIR-C/X-SAR mission timeline.
- o Telemetry System (TS) which will decode and display the X-SAR S-Band telemetry data providing information on the status of the onboard subsystems, the actual running data take, the radar echo and the uplinked commands.
- o Command System (CS) which will be used to transmit individual command blocks or series of commands to the Mission Control Center (MCC) for uplink to the onboard instrument; during standard operations, the CS will regularly uplink sequential portions of the X-SAR Command Plan to the 16 kByte onboard DCE command memory; additional commanding will be required in response to replanning or contingency operations requiring realtime changes. In the synchronous mode X-SAR and SIR-C commands will be output to a single queue for transmission to the MCC.
- o SAR Processing System (SPS) which permits real-time multi-look processing of the downlinked High Rate Data of 45 Mbit/sec; the quicklook processed images will primarily be used as a powerful tool for optimizing data take parameter setting. Beside the basic application the SPS provides auxiliary tools for the monitoring of health status of all the devices involved in the data acquisition chain.

4.2 X-SAR Quicklook Processor

A realtime SAR data processor has been developed and tested for use on the ground to support the X-SAR mission operation team in selecting the radar parameters, to monitor proper function and performance of the flight instrument and to verify whether the radar beam really hits the selected target area. Because of the mechanical deflections in the Shuttle, the misalignments and inaccuracies of the Shuttle attitude and orbit data, a correct prediction of the antenna pointing is not possible. Real time digital processing of the two-dimensional X-SAR raw radar data transmitted via the Shuttle Ku-Band link to the ground station is performed at a rate of 45 Mbit/sec. The processed SAR image is displayed on a 1024 x 768 pixel high resolution monitor either full swath reduced resolution or reduced swath with full resolution. The expected image performance is for the azimuth resolution to be 16 m to 60 m with an integrated sidelobe ratio better than -12 dB and a resolution of 12 m or 21 m for fine or coarse mode in range. The resolution depends on the FFT length and number of looks selected for data processing. The baseband mean Doppler estimated accuracy shall be +/- 80 Hz and the FM rate accuracy +/- 150 Hz/sec. Fig. 4 shows the architecture of the X-SAR Quicklook Processor. It mainly consists of a pipeline processor chain applying integer FFTs and two levels of control. The whole equipment fits into two standard 19" racks.

The X-SAR Quicklook Processor development was completed in August 1990. Integration into the MPOS-SPS is planned for summer 1992. A SAR processor of similar design is already in use for ERS-1 data since 1991.

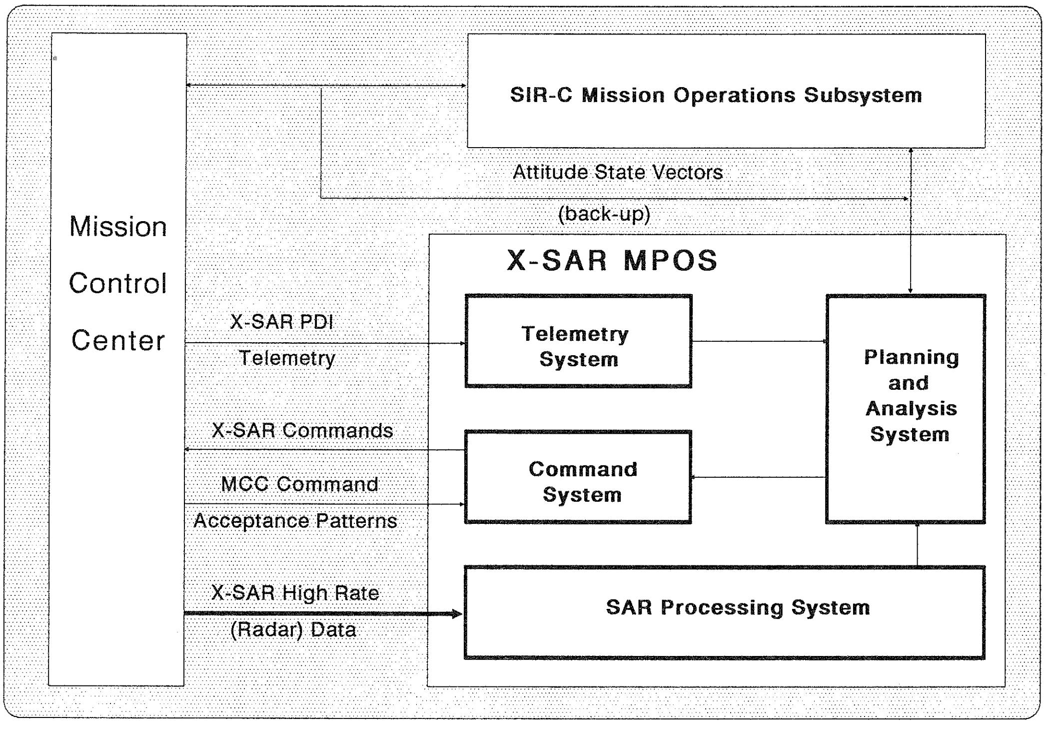

Figure 3 X-SAR Mission Planning and Operation System

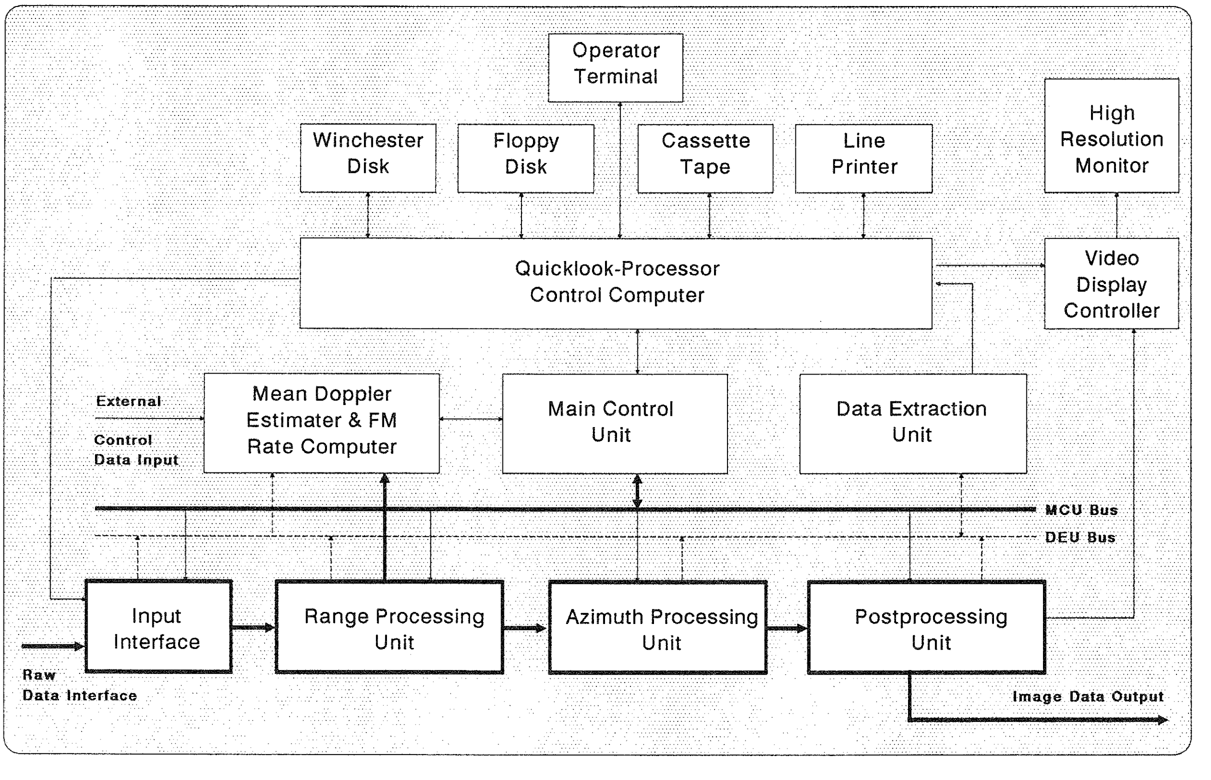

Figure 4 X-SAR Quicklook Processor Blockdiagram

5. SUMMARY

The joint SIR-C/X-SAR system represents a state-of-the-art radar sensor which will be flown in several missions on Space Shuttle from 1993 onwards. This system incorporates the features of all previous space borne radar sensors and those on aircraft. The outstanding new feature is the ability to acquire simultaneous radar data at three frequencies from space with polarimetric data at L and C-Band. The system will establish a new reference for future spaceborne multifrequency/multipolarisation SAR systems.

6. REFERENCES

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