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Imaging Mode Design and Performance Characteristics of the X-band Small SAR Satellite System

Young-Kil Kwag

Agency for Defense Development

Abstract : A synthetic aperture radar (SAR) system is able to provide all-weather, day-and- night superior imaging capability of the earth surface, and thus is extremely useful in surveillance for both civil and military applications. In this paper, the X-band high resolution spaceborne SAR system design is demonstrated with the key design performance for a given mission and system requirements characterized by the small satellite system. The SAR multi-mode imaging technique is presented with a critical parameter assessment, and the standard mode results are analyzed in terms of the image quality performances. In line with the system requirement X-band SAR payload and ground reception/processing subsystems are designed and the major design results are presented with the key performance characteristics. This small satellite SAR system shows the wide range of imaging capability with high resolution, and proves to be an effective surveillance systems in the light weight, high performance and cost-effective points of view.

Key Words : SAR, Small Satellite, Imaging Mode, Paylaod, Ground Processing

1. Introduction

A spaceborne SAR(Synthetic Aperture Radar) is a radar imaging sensor which can provide all-weather, day-and-night imaging capability over the wide areas of the earth surface. SAR offers some particular capabilities not available in optical systems such as penetration of cloud, dust and smoke, and interferometric processing to generate precise 3-dimensional images of the earth, and polarimetric processing for target identification. The major advantage of SAR observations is for disaster assessment or crisis monitoring, which are usually associated with adverse weather conditions which drastically reduce the effectiveness of optical sensors. SAR technique achieves the geometrical resolution comparable to, and possibly exceeding, the resolution of the optical systems. The resolution capability of the radar is limited by the size of the antenna aperture. High resolution images can be obtained by the synthetic aperture principle (Curlander, 1991 : Cantafio, 1989). A SAR has the unique property that the spatial resolution

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obtainable, normal to the antenna boresight, is independent of both wavelength and range for the given physical antenna size. This enables the possibility of high resolution imaging from a long stand off range in all weather, thus is extremely useful for military applications. Typical applications for SAR imaging include : a) imaging of the earth surface for geography, geology, oceanography, b) environmental monitoring for oil spills, deforest and regrowth of vegetation, c)agriculture for classification of vegetation, snow and humidity maps, d) disaster monitoring for floods, landslides, tropical storms, damage assessment, e) geophysics for earth quakes, volcanic activities, and f) military for surveillance, reconnaissance classification

Since the first spaceborne SAR Seasat in 1978, the typical spaceborne SAR systems have been launched, and operated in orbit for scientific and civilian applications : space shuttle based SIR-A/B/C/X-SAR, SRTM (NASA/JPL-USA), ERS-1/2 (ESA-European Union), Radarsat-1(CSA-Canada), and JERS-1 (NASDA-Japan). Most of existing spaceborne SAR systems may be characterized by a heavy mass, large volume, high power, multiple instrument, long development duration, high cost, and inflexibility. Due to the rapid advancement of the SAR technology, the new systems are now directing in a cost-effective approach employing simple and robust architecture, low technological risk, low mass and low power, reduced development plan (Cohen, 1998). This general trend is famously summarized by the "Faster, Better, Smaller, and Cheaper" motto. Thus, the small satellites in the range of less than 1000 Kg are characterized by the rapid, high performance, low-cost development scales when compared with the conventional space industry (Klemm, 1999: Ramongassie, 2000). The current technology trends are led by the multi-frequency, multi-polarization, spotlight, interferometry, on-board image processing, miniatured T/R module, and light antenna for the small SAR system.

In this paper, the high resolution, X-band small SAR system design is demonstrated as a part of the work carried out by the joint technology cooperation program with Matra Marconi Space-UK. Given mission and system requirements, the SAR system design parameters are evaluated in terms of the image performance, and the multi-mode imaging technique is presented with the design results on standard mode. In line with the mission and system requirements, the designed SAR payload and ground reception/processing subsystem present an X-band, wideband SAR capable of high performance multi-mode operation. The performances characteristics of the payload and ground processing were given with the key design results.

2. SAR Mission and System Design

The spaceborne SAR mission/system design process is a series of procedure for generating the system specification to be achieved for the given user's requirement. Generally, the customer requirement varies from the top level to the detailed informations such as type of target, imaging coverage, resolution, reflectivity, mode of operation, life cycle, application areas, and budget. Spaceborne SAR system mainly consists of the payload, platform, launch vehicle, and ground station. The SAR systems engineering design is preceded by the mission design process which broad-ranging customer requirements are translated to the system requirement element and subsystem requirement, particularly placed on a

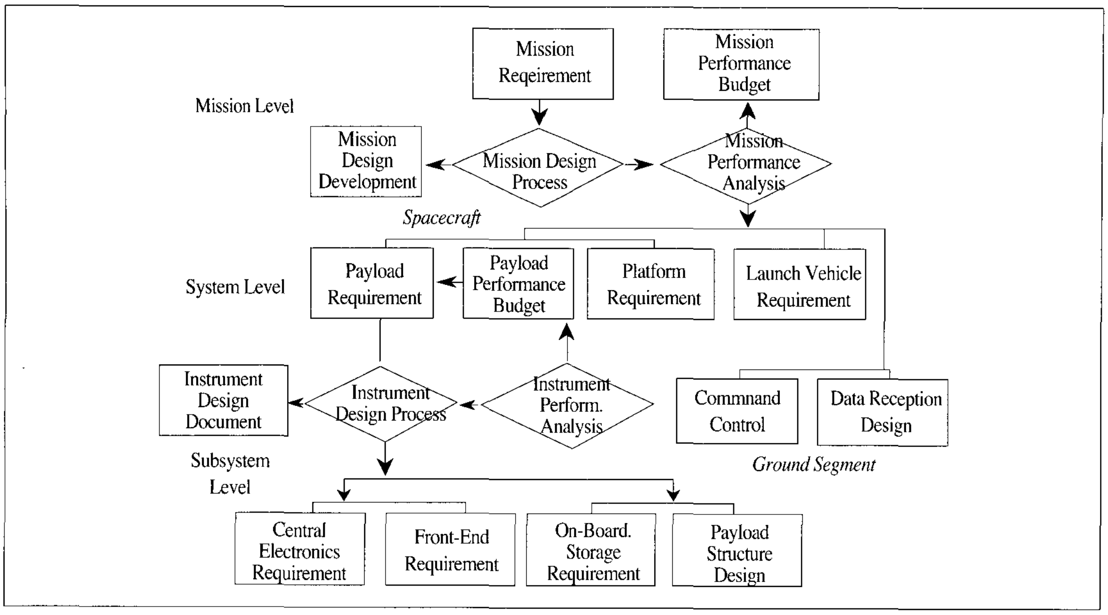

Fig. 1. Spaceborne SAR System Engineering

small SAR payload in this design process as shown in Fig. 1. In principle, the overall design of a spaceborne SAR system employs the top-down approach, but in areas where the technology mature has been identified in space, the concurrent execution of all engineering disciplines can give the advantages in establishing a coherent design, coherent interfaces and coherent performance in order to reduce the development cost and duration. The design flow of the SAR mission and system is summarized in Fig. 2. Critical system performance elements in designing the overall small SAR system are shown in Fig. 3. Constraints among those parameters are to be traded-off to give the priority of the design drives by taking into account the constraints imposed in the small SAR user's requirements of the mission, image performance, technology risk, and cost allowed. The key mission parameters include : wide coverage, frequent revisit, lower earth orbit, multi-mode swaths, fine resolution, wide incident angle, long life cycle, light mass, small volume, and lower power.

3. SAR Performance Parameters

The SAR system can be divided into space segment and ground segment. Each aspect of the system will have an impact on the quality of the final images. In order to achieve the system performance assessment, a series of parameters are defined as a means of assessing the in-orbit image quality.

1) System Impulse Response Function(IRF)

The IRF of the SAR system is defined as the two dimensional response in across and along track directions to an ideal point target in the final image. The key features of the scene can be expressed in terms of properties of the IRF such as

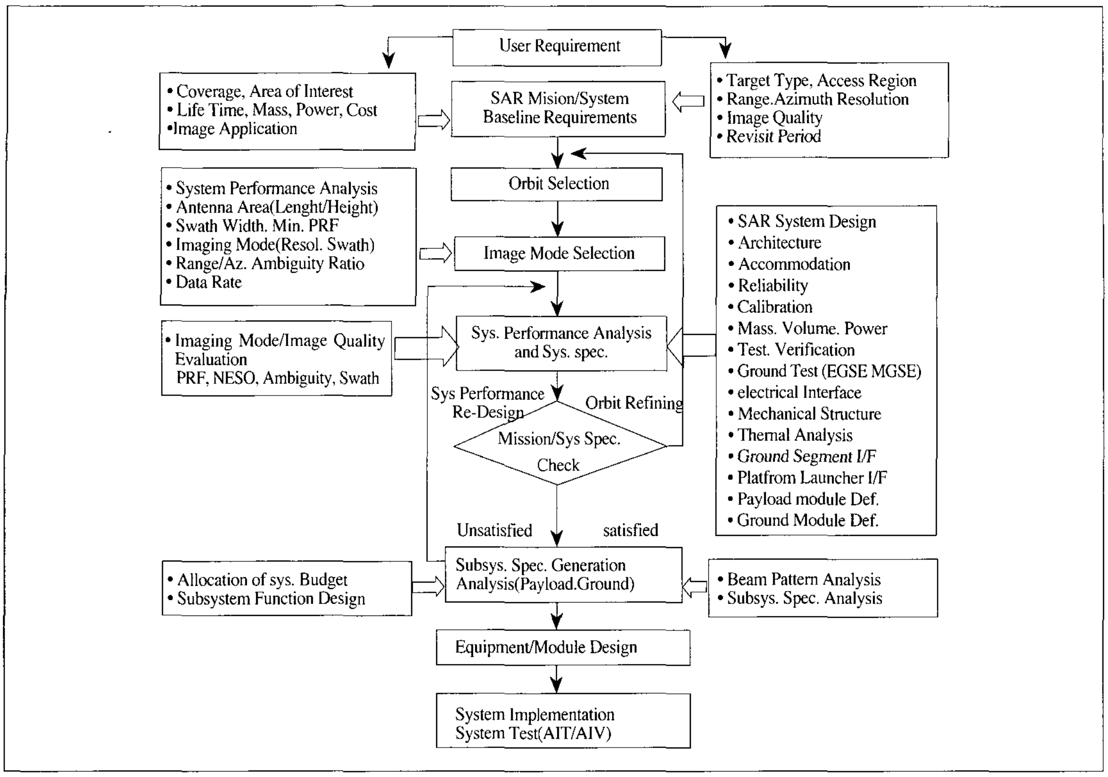

Fig. 2. SAR Mission/System Design Flow

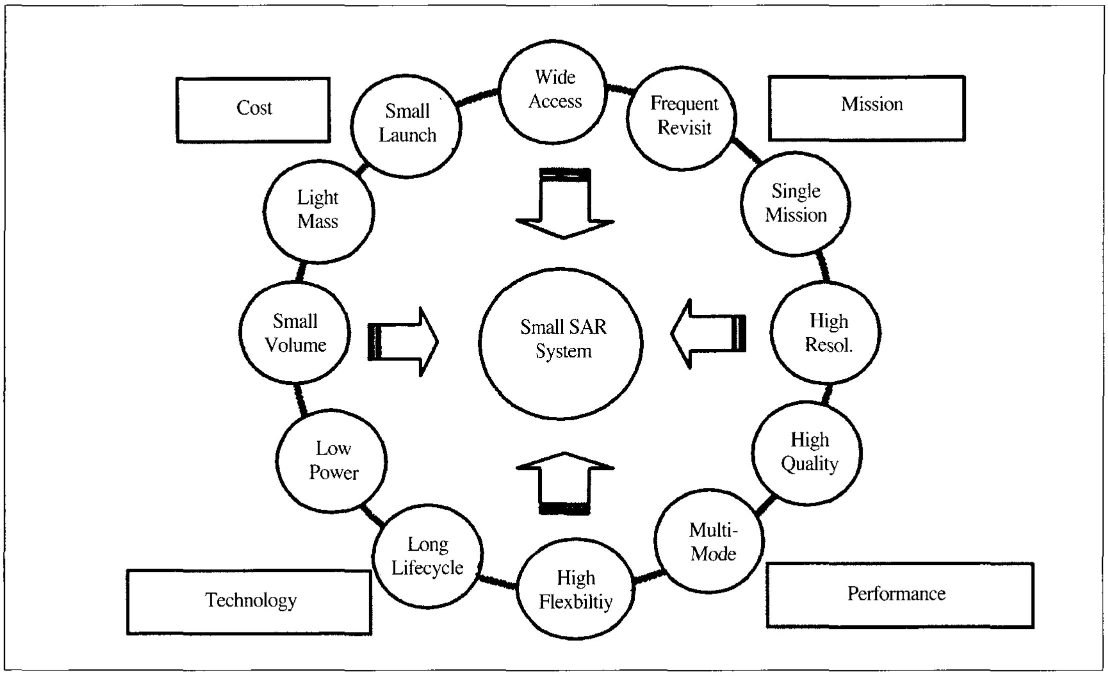

Fig. 3. Constraints of Small SAR System Performance Parameters

spatial resolution, peak sidelobe ratio, and integrated sidelobe ratio.

(1) Spatial Resolution

The spatial resolution of the SAR is the ability to distinguish small objects on the earth surface. This is defined as the half power width of the IRF is equal to the spatial resolution. In range direction, the spatial resolution is dependent upon the transmitted pulse bandwidth and the incidence angle at the imaged point on the earth surface. The azimuth resolution is determined by the Doppler bandwidth over the illuminated areas. Operating PRF has to be sufficiently large to adequately sample this spectrum, i.e. fine resolution demands a wide azimuth beam, which requires short antenna. Using the area illuminated within the half power points on the antenna footprint provides a balance between spatial resolution, signal to noise ratio and azimuth ambiguities.

(2) Integrated and Peak Sidelobe Ratios

All the energy within a single pixel in the final image would come from a single resolution cell on the ground, but energy from the adjacent resolution cells will inevitably appear in the image. To minimize the extent to which this effect occurs, two parameters are defined which control the relative energy distribution within the desired resolution cell to that lying outside. The peak sidelobe ratio defines that the ratio of the peak intensity in the mainlobe to that of the most intense sidelobe within a specified distance. The ratio of energy inside the IRF mainlobe to that outside this area is determined the integrated sidelobe ratio.

2) Ambiguity

The ambiguous energy is reflected transmit energy which enters the receiver, but does not come from the desired target region and whose properties are indistinguishable from those of the reflected energy from the target. Range ambiguities arise due to echoes arriving at the receiver simultaneously from different areas of the ground illuminated by previous transmit pulses. Antenna gain pattern is used to suppress the range ambiguities that occur from the areas beyond the imaged swath. Azimuth ambiguities arise due to the aliasing of high frequency Doppler returns by the pulse repetition frequency (PRF), and thus the ambiguous regions are located at the same slant range as the true target.

3) Radiometric Resolution and Noise Equivalent Sigma Naught

The radiometric resolution of the radar is the ability to distinguish between close values of a point target radar reflectivity. In the SAR image the speckle noise can be reduced by averaging several independent observations at the expense of spatial resolution. This is related to the number of independent looks and the signal to noise ratio of each observation.

Noise Equivalent Sigma Naught (NEσ_0) is defined as that value of reflectivity from a distributed target which produces a receiver output SNR of unity. This provides a measure of the sensitivity of the SAR instrument.

4) Radiometric Accuracy

Radiometric accuracy is defined as the accuracy to which the SAR is able to measure the value of the radar reflectivity of a feature within the image. If this measurement is repeated many times then the variance of these measurements is determined by the radiometric stability of the instrument. Radiometric stability is a measure of the gain stability of the SAR system as corrected by any calibration process, with contributions from instabilities due to the instrument, spacecraft pointing errors and the ground processor.

4. SAR Imaging Mode Design

1) Imaging Modes

A big advantage in operating SAR sensor is to be able to implement the various imaging mode by using a single antenna and instrument hardware. The primary imaging modes envisaged for this system are : a) Standard mode, b) Fine Resolution mode, and c) Wide Swath mode, as shown in Fig. 4.

• **Standard mode** is the conventional SAR imaging technique in which a single continuous swath of imagery is acquired, normally denoted the stripmap technique. Provision is included for steering of the antenna beam pattern in the elevation direction so that the relative location of the swath with respect to the subsatellite ground track can be adjusted, thereby enabling the acquisition of image strips over a wide access range.

• **Fine Resolution mode** also uses the stripmap technique but spatial resolution is enhanced and swath width is reduced. Operation using the snapshot imaging technique is simply a subset of the stripmap technique in which discrete images are acquired by operating the radar for relatively short durations, thereby generating scenes which are typically of a similar length to the swath width. This can be especially advantageous when specific regions of interest can be selectively targeted.

• **Wide Swath mode** makes use of the ScanSAR technique. This is an imaging technique in which the elevation beam is rapidly repointed in order that a number of different swaths are cyclically illuminated. These subswaths are configured so that they marginally overlap to provide broad coverage. This capability facilitates instantaneous coverage of a wider region with the same antenna configuration, thereby reducing the nominal revisit times to any specified location.

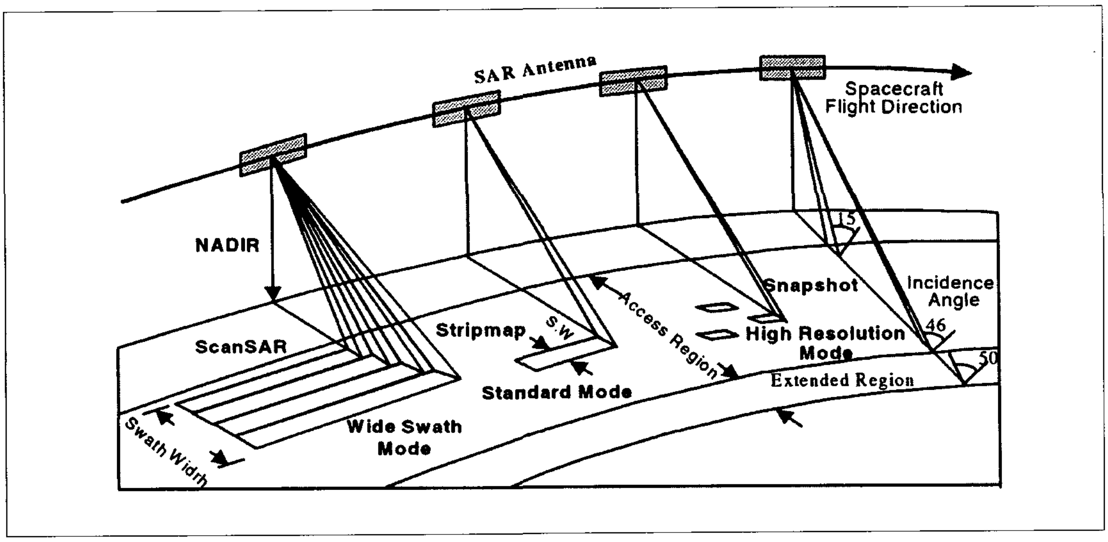

Fig. 4. SAR Imaging Modes Configuration

2) Design Procedure

The altitude and incidence of the satellite are determined by the geometry of the SAR system to be designed as shown in Fig. 5. Given the required resolution, the minimum area of the antenna is derived and the antenna length and height are calculated. The minimum PRF of the system is determined by the azimuth resolution and the ground speed of the spacecraft platform. The swath selection is used to produce a set of swaths to cover the access region, based on the mission requirement and diamond diagram given as a function of the PRF and the swath area of the access region. The design steps are described below.

(1) Antenna Size

The SEA software(SEA, 1995) is used to investigate the possible orbit configurations capable of satisfying the mission requirement of frequent revisit. The output from this software is the spacecraft altitude and the incidence angle range required for complete coverage of the area of interest. The incidence angle range and altitude requirement are used to calculate the minimum antenna area, A, given by

$$A = \frac{4v_s R\tan(\theta_i)}{f} \quad (1)$$

where v_s is the satellite speed, R is the slant range to the far swath, θ_i is the maximum incidence angle, and f is the RF frequency. The antenna length, d, is calculated from :

$$d = \frac{2v_s 0.885(\delta_a)}{f_a v_g} \quad (2)$$

where fa is the broadening of the impulse response function due to Hamming weighting for the sidelobes reduction of the impulse response function and phase/ amplitude errors, v_g is the velocity of the beam across the ground, δ_a is the finest azimuth resolution required of the instrument

The antenna height requirement can be calculated as h = A/d. A quantization of the possible height is necessary to allow for row height which is typically ~0.74 of the RF wavelength in order to avoid the Grating Lobe in the area of interest. Antenna beam synthesis may refine this height in accordance with the various ambiguity performance.

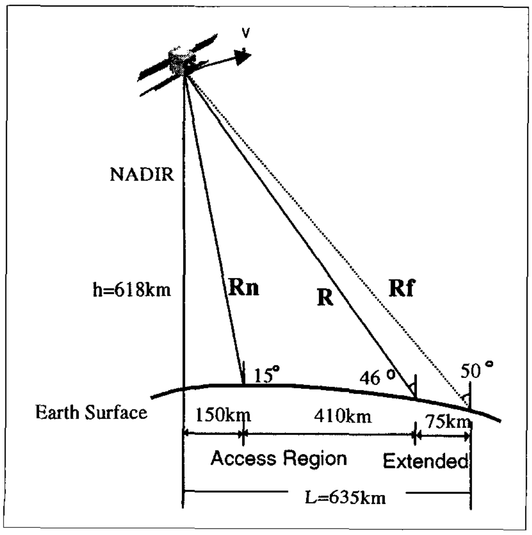

Fig. 5. SAR Mode Design Geometry

(2) Minimum PRF

The Doppler bandwidth required to achieve the azimuth resolution is given by:

$$B = \frac{f_a v_{g_{max}}}{\delta_a} \quad (3)$$

where $v_{g_{max}}$ is the maximum ground speed of the satellite at the minimum incidence angle. This bandwidth can be increased by typically 5% to allow for phase and amplitude errors which will broaden the impulse response function, and the beam broadening factor of 1.05 is applied for the Hamming weighting of 0.72. Therefore, the minimum PRF for the desired azimuth resolution is given by

$$PRF_{\min} = 1.15 \times 1.05 \times B \tag{4}$$

where the oversampling factor of 15% is typically applied. The Doppler bandwidth is sampled each pulse repetition interval (PRI). In order to satisfy the Nyquist Criterion the PRF must equal the Doppler bandwidth. Hence, some oversampling is used to suppress the azimuth ambiguities.

(3) Swath Width Selection

Given the minimum PRF and the access requirement, the swath selection or diamond diagram can be drawn using the Swath Selection Design Module (SSD) software(Newey, 1997). This software plots on a graph of ground range versus PRF keep out the regions due to coincidence of echo return with transmission pulse and nadir return. Swaths can then be selected to avoid these regions. The diamond diagram allows the guard time of 5 s and the duty factor of 7%. The swath selection criteria is summarized in Table 1.

(4) Peak and Integrated Sidelobe Level

The range peak sidelobe (PSLR_R) and the azimuth peak sidelobe (PSLR_A) are calculated by finding the maximum value from all i off the main lobe of the impulse response function (IRF), but less than 20 times the unit resolution cell, respectively.

$$PSLR\_R = \max IRF[t_{Range}(i)] \tag{5}$$

$$PSLR\_A = \max IRF[t_{Azimuth}(i)] \tag{6}$$

From these two functions, the integrated sidelobe ratio (ISLR) can be calculated.

$$\text{ISLR}=10\ \log_{10}\left[\frac{outer\text{-}inner}{inner}\right] \tag{7}$$

where *outer* is the signal power in dB for an area of 20 range resolution by 20 azimuth resolutions, and inner is the signal power for an area of one range resolution by one azimuth resolution.

(5) Azimuth Ambiguity Ratio

In azimuth, the only contribution to the peak value of the target IRF are the ratio of the ambiguity signal and the target signal. The distributed ambiguity ratio is given by

$$AAR = 10\log_{10}(\Sigma P_A/P_T) \tag{8}$$

where ambiguity signal P_A and target signal P_T are defined as

$$P_A = \sum_{\substack{j=-N \\ j\neq 0}}^{N} \left(\frac{1}{L_A} \cdot \sum_{k=1}^{L_A} \cdot a_k \cdot \beta_k\right) \tag{8-a}$$

$$P_T = \frac{1}{L_A} \cdot \sum_{k=1}^{L_A} a_k \cdot \beta_k) \tag{8-b}$$

where L_A is the number of azimuth looks, N is the number of ambiguities considered on each side of the target, $a_k \beta_k$, are the look summation weights and the k^{th} look energy, respectively.

(6) Data Rate

The data rate is given by

$$\text{DR} = \text{PRF x Nb x CADU} \tag{9}$$

where Nb is the number of bits per swath window which is given by Nb = 2WSQ+h, where S is the sampling frequency, Q is the quantization level,

Table 1. Swath Selection Criteria

Mode	Wide Swath	Standard Mode	Fine Mode
Swath Width	> 120Km	> 30 Km	> 10Km
Resolution (Rg x Az)	30m x 30m	10m x 10m	□ x □ m
Overlap Width	> 5 Km	> 5 Km	> 5 Km
PRF	Min. PRF	Min. PRF	Min. PRF
Data Rate	< 210 Mbps	< 210 Mbps	< 210 Mbps
Range Ambiguity	< -20 dB	< -20 dB	< -20 dB

W is the window length, the difference in return time between the near and far edge of the swath. A CADU is a channel access data unit which is an additional data in the packet.

(7) Antenna Mask and Beam Pattern

Antenna patterns are generated to satisfy this mask for swath selected. The software Range Ambiguity Ratio Module is used to give a numerical analysis of beam performance by calculating the range ambiguity ratio across the swath. The directivity calculated in generating the antenna beam are input into the link budget along with initial estimates of losses, transmit powers, geometry, number of looks and reflection coefficient.

(8) Range Ambiguity Ratio

The range ambiguity is given by

$$RAR = 10\log_{10}(\Sigma P_A/P_T) \qquad (11)$$

where P_T is the target strength and ΣP_A is the combined ambiguity strength:

$$P_T = \frac{G_{TT} \cdot G_{RT} \cdot \sigma_{0T}}{R_T^3 \sin\theta_T} \qquad (11\text{-a})$$

$$P_A = \frac{G_{TA} \cdot G_{RA} \cdot \sigma_{0A}}{R_A^3 \sin\theta_A}. \qquad (11\text{-b})$$

(9) Sensitivity

Noise Equivalent Sigma zero is calculated from

$$NE\sigma_0 = \frac{(4\pi)^3 R^3 N_f L_s L_p k T_0 B_m v_s \sin(\theta)}{P_t G_T G_R L_B^2 \lambda^3 c f_a} \qquad (13)$$

where R is slant range, N_f is noise figure, L_s is system loss, L_p is ground processor loss, k is Boltsmann's constant, T_0 is 290K, vs is satellite speed, θ is incident angle, P_t is the mean transmitter power in a single look, GT, GR is transmit and receive antenna gain, L_B^2 is one way beam shape loss, λ is free space wavelength, c is speed of light, and f_a is azimuth broadening factor.

(10) Radiometric Resolution

The radiometric resolution is given by

$$\gamma = 10\log_{10}\{1 + \frac{1}{\sqrt{N_L}}(1 + \frac{1}{SNR})\} \qquad (14)$$

where L is the number of Look, and SNR = $(\sigma_0/NE\sigma_0)$.

5. Design Results and Performance Analysis

The SAR imaging modes have been designed and analyzed with respect to the various image performances. The design results of the standard mode has been presented in detail below.

1) Design Results

- The X-band frequency was selected through the various trade-offs under the constraints of small satellite. The sun-synchronous polar orbit was designed with the repeat cycle of 19 days at the altitude of 618km. The incidence angel was decided to steer the beam over the range of 15-46 degree for the wide access of the region.

- The minimum antenna size was calculated by 2.737m^2 using Eq.(1), and the antenna length was given by 5.52m. The number of antenna row was obtained by 21.7, but was adjusted to 24 by considering the number of power divider which can be splitted into 3 branches. The minimum PRF is selected as 2910Hz under the consideration of the finest resolution achievable.

- The swath width was selected using the diamond diagram to produce an initial set of swaths to cover the access region. A 5 μs guard time and a 7% duty cycle were assumed in calculating the nadir and transmit keep out regions. The swath selection was then refined using the following criteria: swath width wider than 40 km in standard mode, size of overlap greater than 5 km, a total 20 swaths in the access region over the range of 150km–640 km. The range of PRF was 2910–3900Hz. The resultant swath width was shown in Fig. 6. The azimuth ambiguity in the standard mode was obtained as low as –25.9dB for the point target, and –21.7dB for the distributed one, respectively which is satisfied with the requirement of –20dB.

-The overall data rate was obtained in the range of 132.08-317.39 Mbps, It was identified that the date rate, which exceeds the allowable maximum rate of 210Mbps were occurred in the 1st, 2nd, and 4th swath width. In this case, the excess data can be stored into the on-board storage, and transferred to the ground station without loss of data in the next pass.

- The antenna will electronically steer the beam so that it points at swaths lying between 15 and 46 degree incidence. The antenna boresight was 27.2 degree so that optimum performance is obtained consistent with satellite configuration. An antenna mask and beams were drawn using the Elevation Mask and Beam Design Module software (Newey, 1997). The results of the mask and the elevation beam pattern are shown in Fig. 7 in case of the swath No.12 in standard mode. This figure shows that most of the sidelobes exist outside the region of the range ambiguity of the mask pattern, but, some sidelobes override the mask pattern. For the full 20 swaths, the range ambiguity ratio was obtained in Fig. 8 using the land/sea clutter model of ESA. The figure shows that the range ambiguity ratio is less than –20dB for Taylor weighting antenna pattern, and that Swath 15 and 16 have high ambiguity ratio at the beam edge.

- The NEσ_0 margin by using Taylor weighting antenna pattern is plotted in Fig. 9 against incidence angle for each swath, using the increased rainfall and atmospheric attenuation values. The margin at the outer swaths using the specified attenuation values does not meet the requirement, but at the inner swaths up to incidence angle of 46 degree, the sensitivity performance is well met with the requirement.

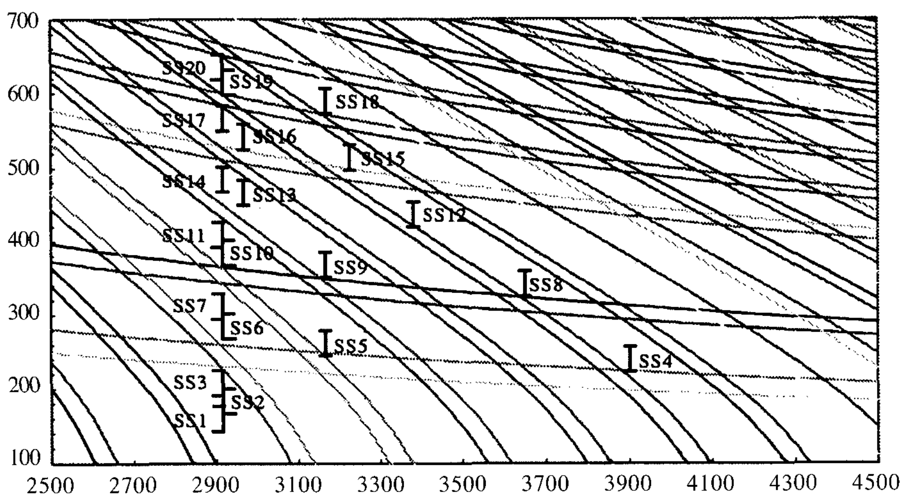

Fig. 6. Diamond Diagram for Swath Selection

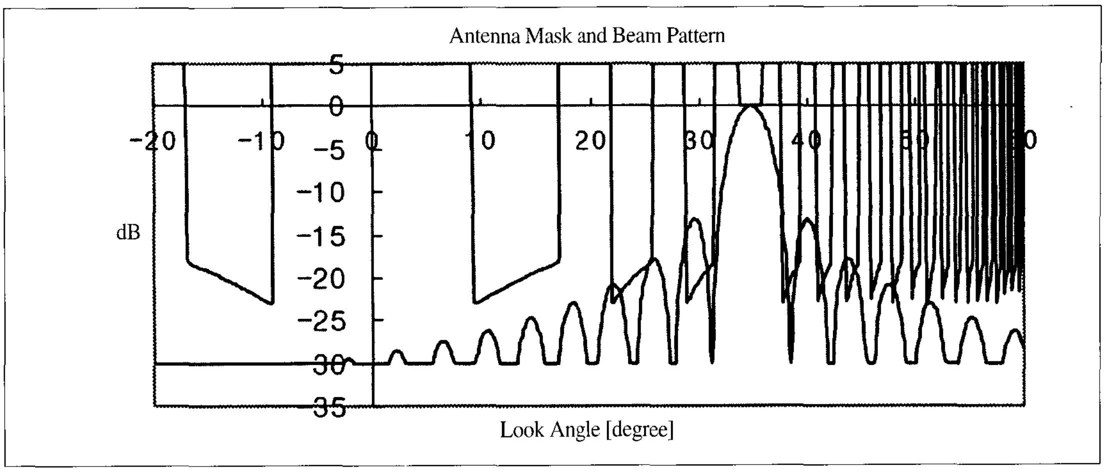

Fig. 7. Antenna Beam Mask and Pattern

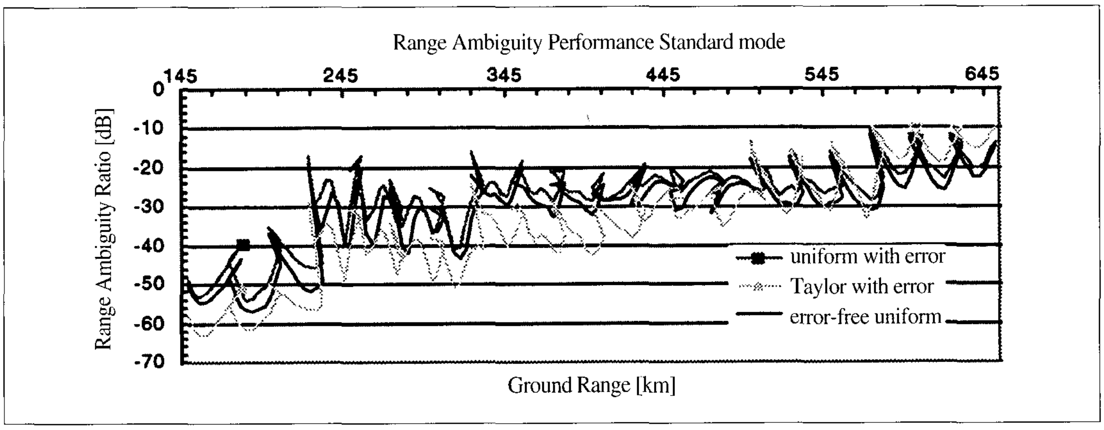

Fig. 8. Range Ambiguity in Std Mode

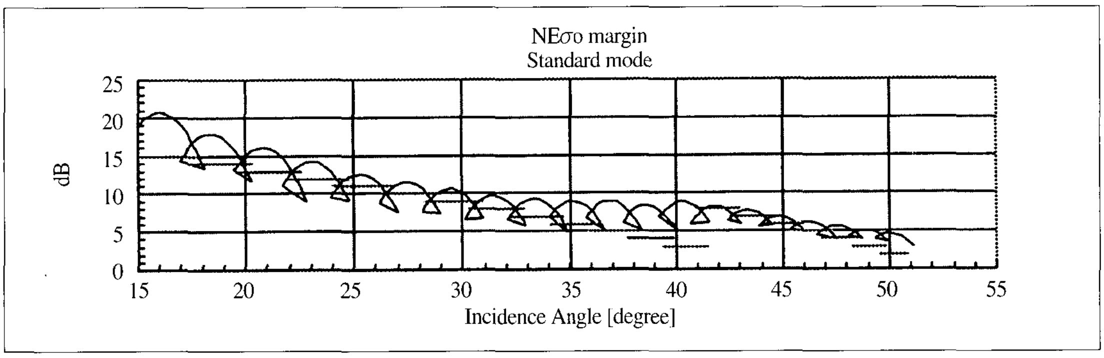

Fig. 9. Sensitivity NEσ_0 of Std Mode

The radiometric resolution performance is shown in Fig. 10, based on the NEσ_0 achieved. The results shows that the performance of the resolution lies in the range of 1.9–2.34 dB, which outperforms the requirement of 2.5 dB.

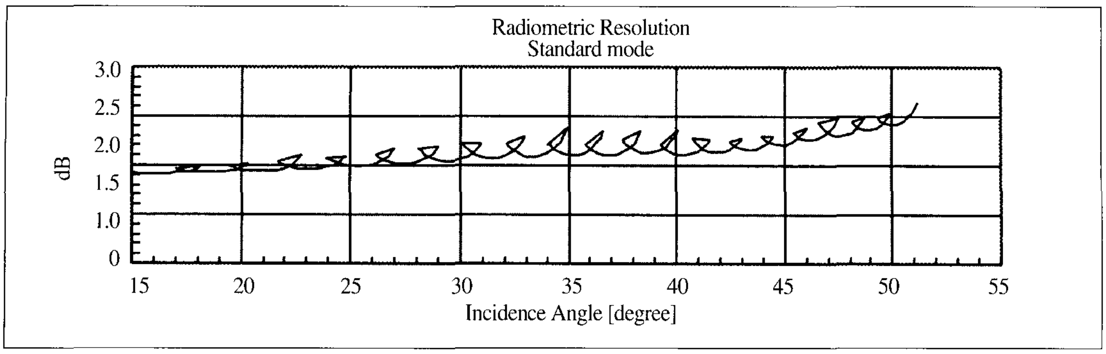

Fig. 10. Radiometric Resolution of Std Mode

2) Performance Simulation and Analysis

The performance simulation results for the designed three imaging modes are shown in Table 2. The range resolution at the near edge of each swath has a discontinuity as a result of the change in pulse bandwidth. At near incidence the 50MHz bandwidth of a single receive chain is not sufficient to achieve 10 m. A resolution of 10m could be achieved using 65MHz. This would give a NEσ_0 improvement at near incidence of 1.2 dB taking the margin to >16dB. As the incidence angle increases the pulse bandwidth required to achieve 10m resolution decreases. The ambiguity performance in this small SAR system is a marginal at the beam edge of the far swath (ROK-SAR, 1997a).

Table 2. Imaging Mode Performance Parameters

Parameter	Wide Swath Modet	Standard Mode	Fine Resolution Mode
Resolution - Range - Azimuth	 ≤ 30 m ≤ 30 m	 6.3 ~10 m ≤ 10 m	 □ m □ m
Peak Sidelobe - Range - Azimuth	 ≤ -23.3 dB ≤ -23.3 dB	 -23.3 dB -23.3 dB	 -23.3 dB -23.3 dB
Integrated SL	≤ -12.0 dB	-14.0 dB	-14.0 dB
Ambiguity Ratio - Range - Azimuth	 ≤ -19.5 dB ≤ -22.7 dB	 ≤ -20 dB < -20 dB	 -20.5 dB -21.6 dB
NEσ_0 margin*	10.2 - 25.8dB	8 ~ 22.3 dB	3.9-22.5 dB
Radiometric Resolution	2.33 - 2.59 dB	1.9~ 2.34 dB	3.02-3.8 dB
Swath Width	≥ 120 km	30 km	□ km
Overlap Width	5 km	8 km	-
Incidence Angle -Normal Access	15°~ 46	15°~ 46	15°~ 46°
Radiometric Accuracy	0.94 dBc	0.94 dB (1σ)	0.94 dB(1σ)
Bandwidth	5-25MHz	25-65MHz	□ MHz
PRF(Hz)	2667-4133	2910-3900	2910-3900
No. of Beam	4	20	36

It is important to note that the performance of the designed small SAR system is comparable to that of the large system such as Radarsat and ERS in terms of the image resolution and quality, except for the limited swath width. The best ambiguity and sensitivity performances were achieved with the small SAR system having less than half size of antenna compared to the large system. The wide bandwidth is available only in X-band frequency allocation. In addition to the advantages of antenna size in achieving a small SAR system, an X band frequency gives the good performance advantages in both the reflectivity of the echoes and high resolution achievement

7. SAR System Design Demonstration

The X band spaceborne small SAR system has been designed and demonstrated for the

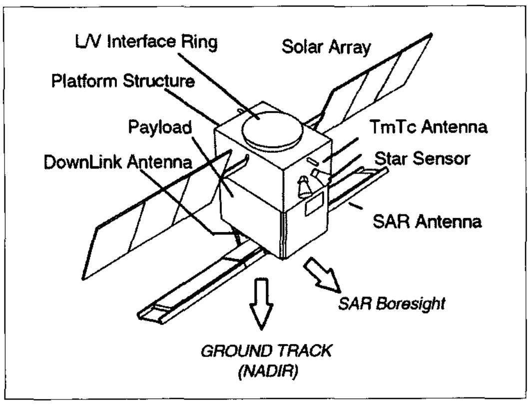

Fig. 11-a. Deployed SAR Spacecraft

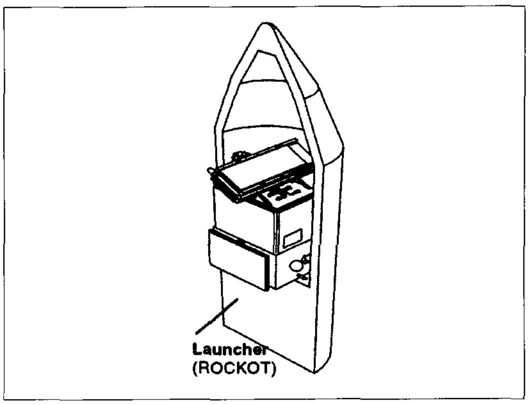

Fig. 11-b. Launcher

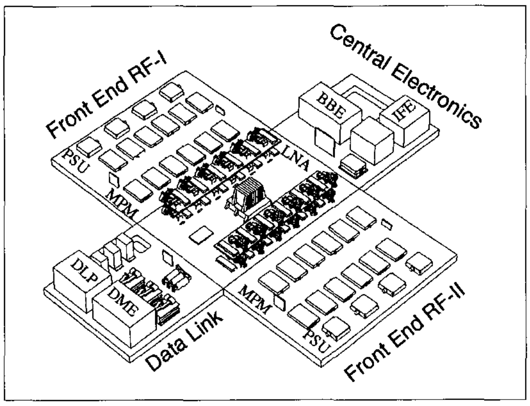

Fig. 11-c. SAR Payload Accomodation

applications to the resource management, environment and crisis monitoring. The spaceborne SAR system can be subdivided into the space segment, the ground segment, and launcher vehicle. The operational configurations of the designed SAR system is shown in Fig. 11. The deployed spacecrafts configuration shows the X band antenna for the SAR image data, S band antenna for telemetry and telecommand, star sensor, sun sensors, and solar arrays. The dimension of the payload is 1m × 1.45m × 1m, which can be accommodated in the fairing constraints of the small launcher compatible with the mass budget of the Rockot launcher. The sun synchronous, dawn-dusk orbit with nominal altitude of 610 km at the equator were selected with an orbit period of 14+16/19 orbits per day. The detailed analysis was taken into account as key factors: system performance requirement, mission size of the small launcher and platform constraints, sufficient swath overlap to accommodate orbit prediction errors, and incidence angle ranges to achieve access in maximum 3 days of revisit to any part of the area of high interest using dual sided looking (ROK-SAR, 1997b).

The SAR payload is limited by 450kg including margin. The required power is less than 2.3Kw at the full imaging mode. As a part of the mission plan, a priority level of operation is to be defined as urgent, priority, and normal modes as shown in Fig. 12. In operate mode, the SAR operates according to command to acquire Standard, Fine resolution, or Wide Swath image and simultaneously down-links the data to the ground receiving and processing center located in the customer site of the Korean peninsula. A motion compensation of the platform is generally negligible in the spaceborne system, rather the calibration of the SAR paylaod instrument is sensitive to the image quality. Two schemes of internal calibration and external calibration are

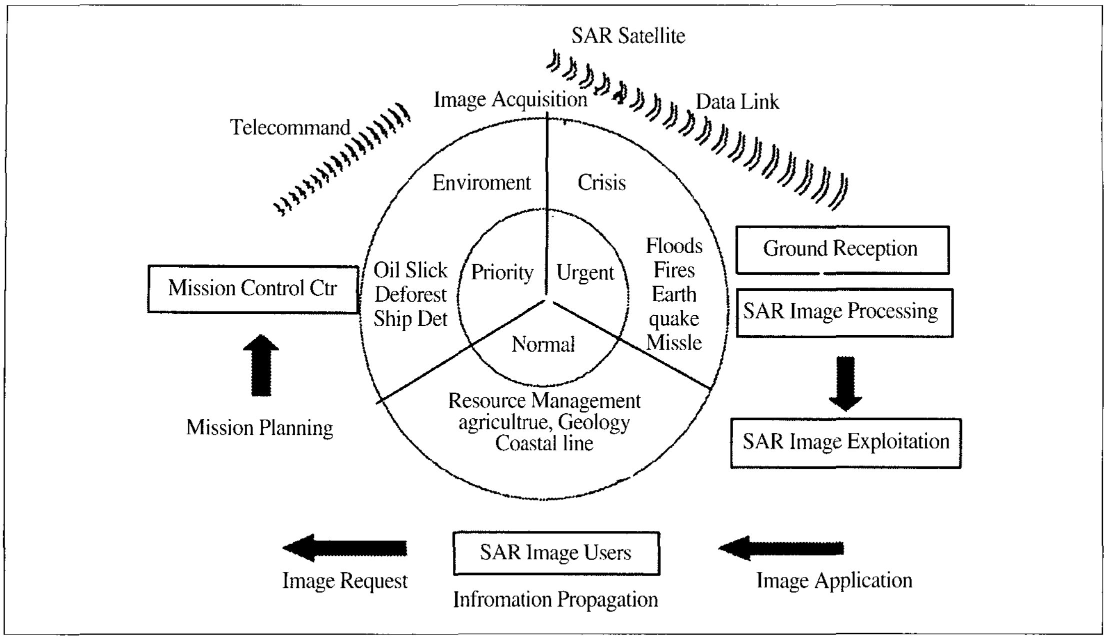

Fig. 12. SAR Operation Concept

processed in the ground center. In the special case of antenna beam characterization, the image over the Amazonian rain forest is stored within the instrument for download on the next pass over the ground station. The mission and system performance are summarized in Table 3 and 4, respectively

1) SAR Payload

The SAR payload comprising a radar instrument and a data link has been designed for achieving the given system performance requirement in the payload hardware and software (ROK-SAR, 1999 : Kwag et al, 1999). Major performance characteristics of the designed SAR payload can be characterized by the followings : X-band frequency for fine resolution

Table 3. SAR Mission Performance

Altitude	618 km
Orbit	Sun-Sync. (Dawn-Dusk)
Inclined	97.8 deg
Period	97min (14 + 16/19/ day)
Repeat Cycle	19 days (282 times)
Revisit	0.5 - 2.5 days
Mode	Wide, Standard, Fine Mode
Incidence	15 - 46 deg (Normal)
Angle	46 - 50 deg (Extended)
Total Mass	< 950 Kg
Total Power	< 2.5 Kw

Table 4. SAR System Performance

Frequency	X band (9 GHz band)
Mass	< 450kg
Power	< 2.3 kw
Life Time	3 - 5 Years
Size	1x1.45x1 m
Polarization	HH
PRF	2900-3500Hz
Tx Power	160W/MPM x 24 Ch
Antenna Size	5.52 x 0.56m
Beam width	0.27(Az) x Max 3 deg(El)
Pulse Width	10% of PRF
Bandwidth	5 - 85MHz
Data Speed	210MBps (2 Ch)
Storage	10 Gbits
BER	10-5

imaging, horizontal polarization for land observation, phased array antenna steering for multi-mode imaging, wideband chirp generation for high resolution achievement in a processor known as chirp stitching technique, on-board high speed date storage for data buffering, redundant module for life-time reliability, and precise calibration for the good image quality. The key payload performances are summarized in Table 5.

The functional diagram of the payload is shown in Fig. 13. The SAR payload consists of the phased array antenna(PAS), front end electronics(FES), central electronics (CES), and data link(DLS). The PAS comprises the SAR antenna including the radiating slotted waveguide array, feed network, supporting structure, deployment mechanisms and hold down and release mechanism. The

Table 5. SAR Payload Subsystem Parameters

Antenna	
Type	Slotted Waveguide Array
Size	5.52m(L)×0.56m(H)
Beam Width	0.27°(Az)x3°(El-Variable)
Gain	42 dBi
Front end RF	
Tx Power(Peak)	160W/MPM×24 Ch
Pulse Width	10 % of PRF
Phase Control	360o/6 Bit
Amplitude Control	20dB/6 Bit
Central Electronics	
Pulse Bandwidth	25 - 85 MHz
Sampling Rate	8 Bits, 61 MHz
Data Compression	BAQ, 128 Block
Gain Control	8dB/Tx, 32dB/Rx
Data Link	
Data Rate	210 Mbps
Frequency	X band (8 GHz)
Storage	10 Gbits
Bit Error Rate	10^{-5}

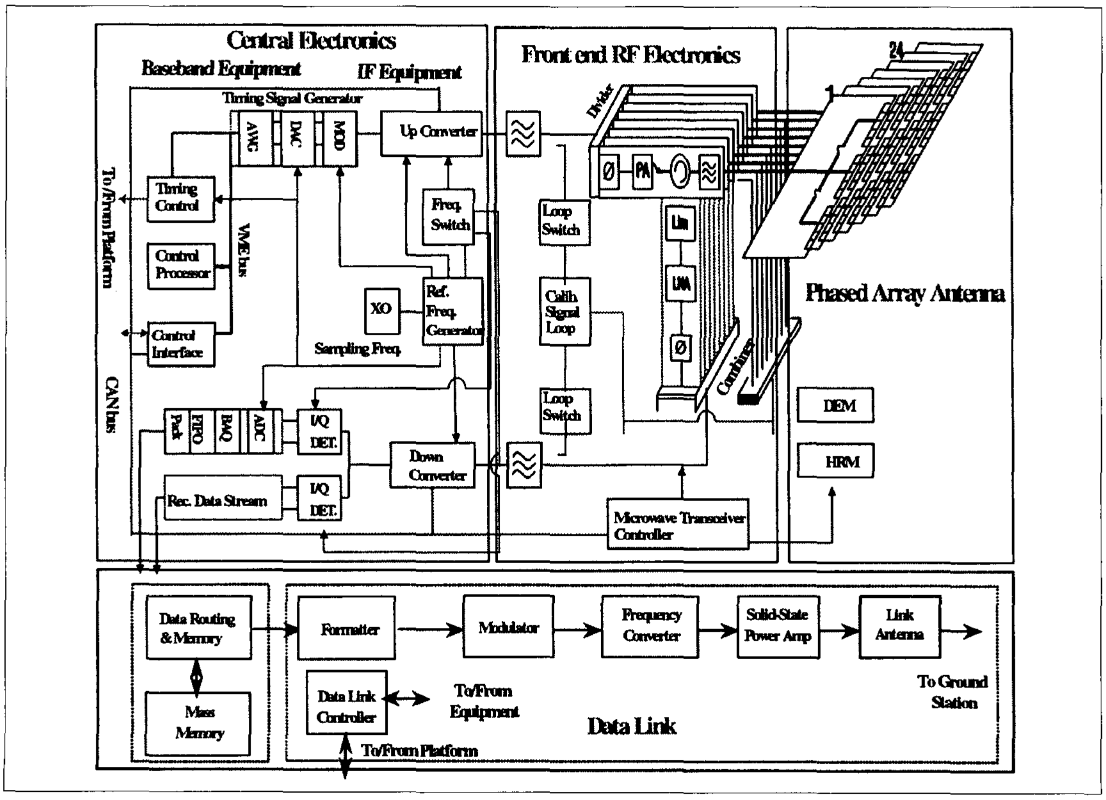

Fig. 13. SAR Paload Subsystem Functional Diagram

antenna consists of three panels with three sub-arrays per row per panel, which is interconnecting hinges that allow the full 5.5m length to be folded into a stack for launch. The radiators are made of aluminium waveguide with alternately inclined slots cut in the narrow wall, supported on an aluminum honeycomb backing structure. This configuration produces horizontally polarized radiation. The azimuth beam width is 0.27 degree, and the elevation beam can be steered up to 3 degree for wide range of swaths.

The FES contains the transmit and receive chains. The transmit chain is required to provide sufficient power amplification to meet the mission needs. The transmit chain receives the signal from the calibration and phase shift assembly via 24 coaxial cables and performs amplification to the RF output of 160w using 24MPMs. On receive the 24 channel, low noise amplification and amplitude control are provided to maximize the signal to noise ratio and to provide the amplitude tapering needed for the antenna patterns. To carry out the calibration function, coupled signals to/from the FES are passed into a divider/combiner network. for three calibration pulse type.

The CES provide the control, signal generation and processing functions which form the heart of the radar instrument. The signal is down-converted into two stages within the IF chain to about 1GHz, and is then passed to the demodulator where it is divided into two channels. For wide bandwidth operation, both channels are utilized with demodulation by two LO signal separated by 50 MHz. For wideband chirps, the BBE implements a chirp stitching and segmentation function which operates in up to 50 MHz blocks. The signal is then I/Q detected and passed through anti-aliasing filters to reduce the noise aliased into the passband of 25MHz. A 8 bit analog to digital converter is used and the sampling rate for the echo is around 60MHz. The I/Q samples are passed to a data compression using block adaptive quantization(BAQ) scheme to produce either 4 or 3 bit output samples. The data is then placed into CCSDS packets.

Overall control of the instrument includes communication with the platform/ground via commands and telemetry on the TmTc bus as well as internal control. This commands schedule the required modes and the characteristic parameters needed for the requested performance. These data includes parameters related to timing, pulse characteristics, antenna beam coefficients, data handling functions and instrument equipment.

The DLS comprises the on-board storage, data link processor, and data link RF and antenna. The SAR science data enters the data link as quantized source packets with one packet per receive channel per sample window, and buffered into the buffer memory of 10 Gbit at the end of life. The X band antenna consists of 9 horns, configured to provide coverage over the whole required viewing area. The maximum data rate of 210 Mbps is splitted on two standard 105Mbps channels.

The payload structure is made as a box from five honeycomb panels, where are attached to each other by a series of cleats along their edges. The panel are constructed using CFRP and a lightweight aluminum alloy honeycomb core. The payload thermal design is suitable for dual sided looking operation in order to protect the internal instrument of the payload box from the severe temperature changes in space.

2) Ground Reception and Processing

The ground segment provides a wide range of facilities for controlling the satellite as well as processing the data from the SAR into products for delivery. The ground reception/processing station comprises the receiving antenna, data ingest, SAR image processing, and image interpretation and applications, as shown in Fig. 14. The X band ground receiving antenna system receives the bit stream data transmitted from the satellite, and pass to the data ingest and preparation subsystem for the formatted baseband data recovery. The ingested output is a single data structure accessible to the raw data archive and the image processor. In the SAR image formation processor, the various level of the data processing is performed. The level 1 image types are radiometrically and geometrically calibrated, and level 2 images are terrain corrected and geocoded. The processed level 2 SAR image is shown in Fig. 15 for Seoul area captured by Radarsat with the resolution of 10m, as an example of standard mode. For high resolution SAR image implementation, particularly, the point target image were simulated by combining the segmented lower and upper chirp data channels into the stitched original wideband signal. The various SAR image applications to

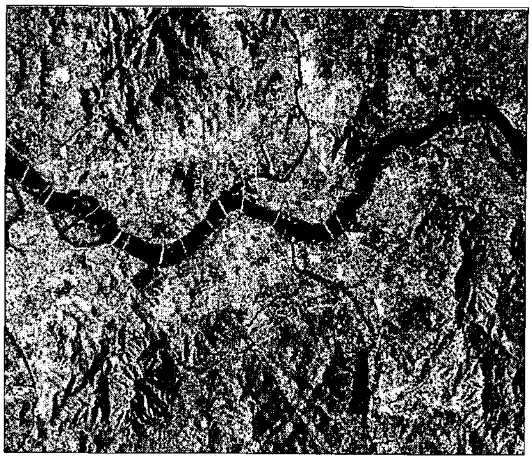

Fig. 15. SAR Image Processed for Standard Mode with 10m Resolution Around Han River in Seoul

Table 6. SAR Ground Processing Subsystem Performance Characteristics

Antenna Size	>10m
Sensitivity	>32.5dB/K G/T (6o in El)
Frequency	8 GHz Band
Data Rate	210Mbps
Archive	56GB/ day
Pre-processing	Real Time
Image Proc.	Near Real Time
Application	Change Detection
	Target Identification
	Interferometry, Stereo Image

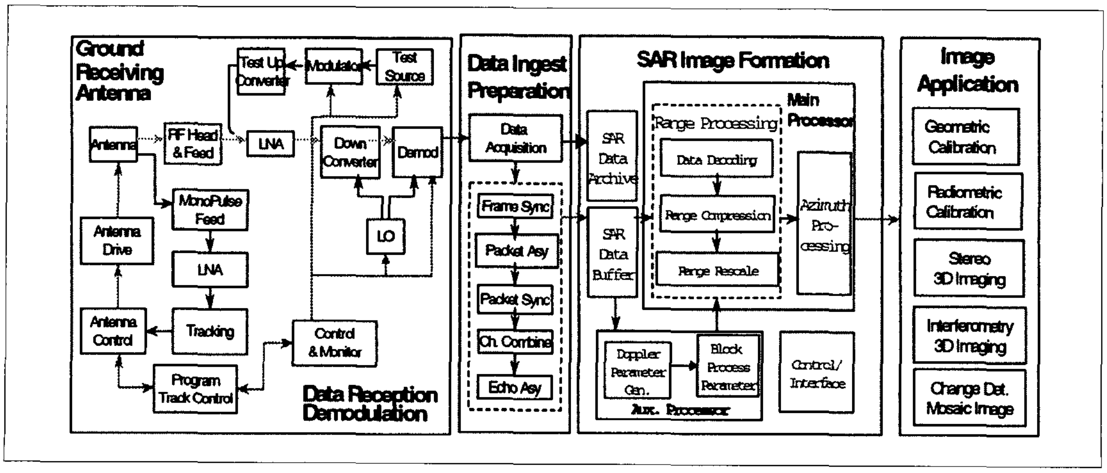

Fig. 14. SAR Ground Reception/Processing Subsystem Functional Diagram

classification and change detection were performed. The key performance characteristics of the ground processing is listed in Table 6.

8. Conclusion

In this paper, the spaceborne X-band SAR system was designed, and the given SAR mission and system performances were evaluated in terms of image quality to compromise the constraints imposed by a small satellite SAR launcher and platform size. As a results of the SAR imaging mode design, the performance of the designed small SAR system is comparable to that of the previous large satellite system, excepted for the limited swath width in the moderate resolution. For the SAR system design demonstration, the X band SAR payload and ground subsystems were presented with the key performance characteristics, which show the X-band frequency for fine resolution, beam steering for multi-mode imaging, wideband chirp generation on-board and ground processing for high resolution achievement. This small satellite SAR system provides the wide range of imaging capability, and proves to be an effective surveillance systems in light weight, high performance, and cost-effective points of view. The achieved ROK-SAR system is well met with the mission requirements of the small satellite, and is expected to be contributed for both civil and military applications to the crisis monitoring, resource management, and environment monitoring.

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