Spaceborne High Speed Data Link Design for Multi-Mode SAR Image Data Transmission

Young-Kil Kwag

Abstract

A high speed data link capability is one of the critical factors in determining the performance of the spaceborne SAR system with high resolution because of the strict requirement for the real-time data transmission of the massive SAR data in a limited time of mission. In this paper, based on the data link model characterized by the spaceborne small SAR system, the high rate multi-channel data link module is designed including link storage, link processor, transmitter, and wide-angle antenna. The design results are presented with the performance analysis on the data link budget as well as the multi-mode data rate in association with the SAR imaging mode of operation from high resolution to the wide swath.

Key words : data link, synthetic aperture radar, radar imaging mode, spaceborne payload.

Ⅰ. 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, and thus it is useful for both military surveillance and commercial remote sensing applications. Recently, 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. As the need for the high resolution image is demanding in the modern airborne and/or spaceborne SAR system, by the nature, a high speed data link capability is one of the critical factors in determining the performance of the SAR imaging system. It is due to the strict requirement for the real-time data transmission from a series of massive raw image data of spaceborne SAR to the ground station in a limited time of mission[1]. In order to provide the capability for transmission of the bulky radar imaging data in real-time from space to the ground receiving station, the data compression techniques such as BAQ (Block Adaptive Quantization) has been used for reducing the data rate [2], but the amount of the data acquired by the high resolution SAR is often exceeded by the limited data handling capability of the data link in the allowed time during mission operation. Therefore, the on-board storage is necessarily required in parallel with the data compression technique, particularly for the multi-mode SAR imaging system. Unlike the electro-optical sensor, it is important for SAR data to keep the accurate in-phase and quadrature-phase information for SAR image formation at the ground station. In practice, however, the data bit error due to the limited channel bandwidth and propagation losses when transmitted to the ground, affects on the quality and the resolution of the SAR image processed. In order to design the spaceborne data link reliably, it is required to analyze the requirements given by the SAR mission and system such as the amount of data to be transferred associated with the image mode and the data receiving performance of the ground station. Furthermore, the requirements including the mass, volume, and power consumption of the small SAR payload should be maintain with the data link performances when designing the whole satellite system.

In this paper, based on the data link model characterized by the spaceborne small SAR system, the high rate multi-channel data link module is designed including link storage, link processor, transmitter, and wide-angle antenna. The design results are presented with the performance analysis on the data link budget as well as the multi-mode data rate in association with the SAR imaging mode of operation from high resolution to the wide swath.

Ⅱ. Spaceborne SAR Data Link Model

The spaceborne data link model for designing link budget is shown in Fig. 1. The requirement for the data link is the capability to transfer the radar imaging data acquired from the spaceborne SAR in real-time to the ground station in a given data error rate, which include the altitude of the satellite,

Manuscript received February 28, 2002 ; revised April 15, 2002.
School of Electronics, Telecomm, & Computer Eng., Hankuk Aviation University, Seoul, Korea.

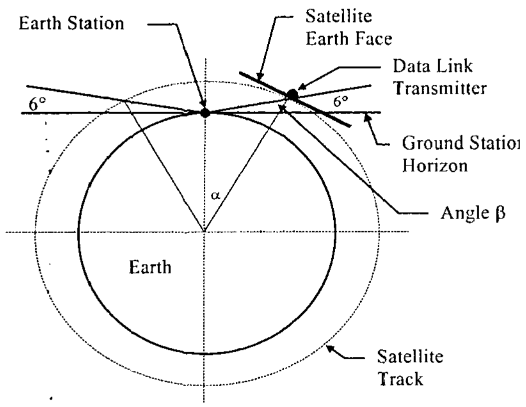

Fig. 1. Geometry for Spaceborne Data Link.

transmission coverage, data error rate, horizontal ground elevation. Based on the given spaceborne SAR system specification[3], the sun synchronous, dawn-dusk orbit with nominal altitude of 610 km at the equator is used with an orbit period of 14+16/19 orbits per day. The incidence angle ranges 15~46 degree for the wide access to achieve maximum 3 days of revisit to any part of the area of interest using dual sided looking. The SAR payload is limited by 450 Kg including margin. The required power is less than 2.3 kw at the full imaging mode. The data link coverage is within 2,000 Km in radius from the central ground station passing through the Korean peninsula. Considering the overall burden of the mass and volume characterized by the small SAR payload, the X band frequency is selected for both the SAR data acquisition and the data link, where the 8 GHz band of the data link frequency is separated from 9 GHz of SAR frequency. The elevation angle on the horizontal ground is 6 degree at the ground receiving station. The geometry for the spaceborne data link and SAR imaging is shown in Fig. 2.

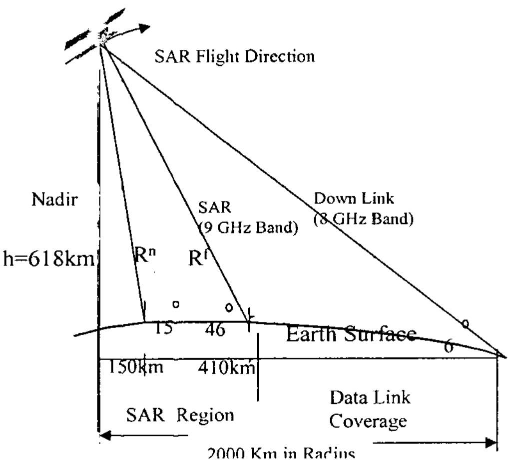

Fig. 2. Geometry of Data link and Spaceborne SAR imaging.

Ⅲ. Data Link Budget

In order to analyse the data link budget between the spaceborne and ground station using the SAR data link model above, a data link equation is introduced [3], [4]. Representing EIRP as the ratio of received energy-per-bit-to-noise density E_b/N_o gives equation (1).

$$EIRP = \frac{E_b}{N_o} - L_{FSP} - L_{SYS} - G_{RX}/T_{RSYS} - 228.6 + 10Log_{10}R \quad (1)$$

where, L_{FSP} =free space path loss, L_{SYS} = transmission path loss, G_{RX} = receive antenna gain, T_{RSYS} =receive effective system noise temperature, R = data rate. In this date link budget analysis, the transmission data rate of 105 Mbps is set within the transmission coverage of maximum line of sight of 2,276 Km from the ground receiving station. Taking into account the mass and power consumption constraints imposed by the hardware of the small satellite, the on-board antenna with light mass and low power transmitter are desired, instead selecting relatively large ground receiving antenna in order to optimize overall data link budget to meet the required data error rate of 10^{-5}. Table 1 shows the resultant link budget analysis. The required transmit power is determined as 10.6 dBW per channel.

Table 1. Link budget analysis for spaceborne SAR.

Parameter	Unit	Data
Carrier frequency	MHz	8325
Bit error rate	–	10^{-5}
Required E_b/N_o	dB	9.5
Data rate	BPS	105000000
Boltzmann's constant	J/K	1.38×10^{-23}
Propagation path length	km	2276.35
Free Space prop. loss	dB	177.99
System loss	dB	10.5
Ground receiver G/T	dB/K	> 32.5
System margin	dB	2.0
Received E_b/N_o	dB	11.5
EIRP	dBW	19.1
Gain of on-board ant.	dB	> 8.5
Tx power/channel	dBW	10.605

Ⅳ. Data Rate in Imaging Mode

4-1 SAR Imaging Mode

The SAR imaging modes for this system are operated in three modes [3],[5]: Standard mode, Fine Resolution mode, and Wide Swath mode as shown in Fig. 3. The Standard mode is the SAR imaging technique in which a single continuous swath of imagery is acquired, normally denoted the stripmap technique.

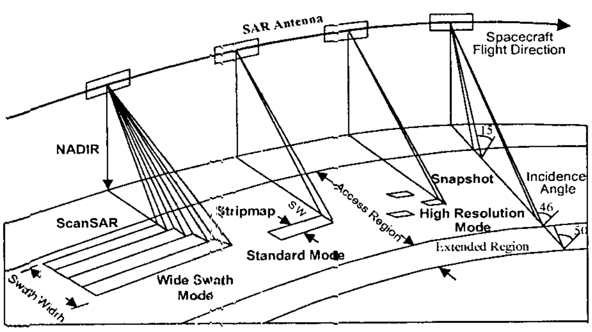

Fig. 3. SAR imaging mode.

The nominal resolution and swath width of this mode are 10 m and 30 Km, respectively. The fine resolution mode also uses the stripmap technique but spatial resolution is enhanced and swath width is reduced. This can be especially advantageous when specific regions of interest can be selectively targeted. The nominal resolution and swath width of this mode are less than 3 m and 10 Km, respectively. The 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. The nominal resolution and swath width of this mode are about 30 m and 100 Km, respectively.

4-2 Data Rate

The data rate of the spaceborne SAR data link, which is the maximum data speed for transmitting the raw SAR imaging data acquired at the area of interests to the ground receiving station, is a function of the PRF (Pulse Repetition Frequency), swath width, and both range and azimuth resolution, which is given by eq. (2).

$$D_R = PRF \times N_R \times CADU \quad (2)$$

where, N_R is the number of data bit per window of the echo signal received from the direction of range in the areas of interest, respectively. CADU is channel access data unit, which is an additive data to the packet. N_R is given by the size of the swath width and range resolution, which is represented by eq. (3).

$$N_R = 2WSQ + h \quad (3)$$

where, Q is the quantization level, h is data head length, S is the radar sampling rate depending on the range resolution, δ_r, given by the function of the pulse bandwidth in eq. (4).

$$\delta_r = \frac{c}{2B\sin\theta_i} \quad (4)$$

where c=light velocity, B=pulse bandwidth, θ_i =incident angle. In eq.(3), W represents the swath width window time which is the length per PRI unit due to the time difference between the near and far ranges. W is given by the function of pulse length and slant range as shown in eq. (5).

$$W = \tau_p + 2\frac{(R_f - R_n)}{c} + g_t \quad (5)$$

where, τ_p = pulse width, g_t = guard time, θ = incident angle, R_f and R_n are the slanted far and near ranges from the antenna of the satellite, respectively. The SAR data rate was calculated using the SAR design module[6], which requires the satellite orbit data and swath width data in accordance with the image mode. The analysis results are summarized in Table 3.

V. Data Link Design

5-1 Structure of Data Link

The SAR satellite payload consists of radar instrument and data link as shown in Fig. 4. The radar instrument is dividend into antenna, transmitter/receiver, central electronic subsystems [3],[7]. In order to meet the requirement of the link budget and data rate of the image modes, the data link subsystem is designed including link storage, link processor, transmitter, and antenna modules. The major functions of the data link are to directly transfer the data acquired by the SAR to the ground, and to store them into the on-board storage in a given data rate. In this design, the data link is implemented by two 105 Mbps unit channels and one redundant channel in order to satisfy the mission system requirement of data transmission rate of 210 Mbps

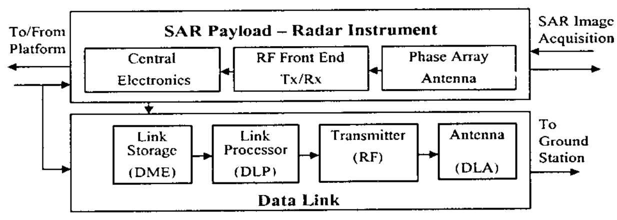

Fig. 4. SAR Payload and data link structure.

5-2 Link Storage

The link storage is used for storing the SAR image data as well as the SAR calibration data according to the imaging mode of operation. The link storage consists of input router and memory block where memory block stores image data in packet units. The input/output router has two main functions: one is to input packetized image data which are acquired from the various channels of central electronics subsystem, and the other is to transfer packet data from memory block to the data link processor at the ground transmission speed. As shown in Fig. 5, the link storage consists of input router, buffer memory, output router and output channel. The input router receives 32-bit formated data from 4 serial data channels and the buffer memory is 12 Gbits DRAM where data is stored in the form of source packet. The output router is to transfer data from the buffer memory to the output channel sequentially. Taking multi-channel extension into account, two active memory channels and one redundant memory channel are applied for the reliability during life time.

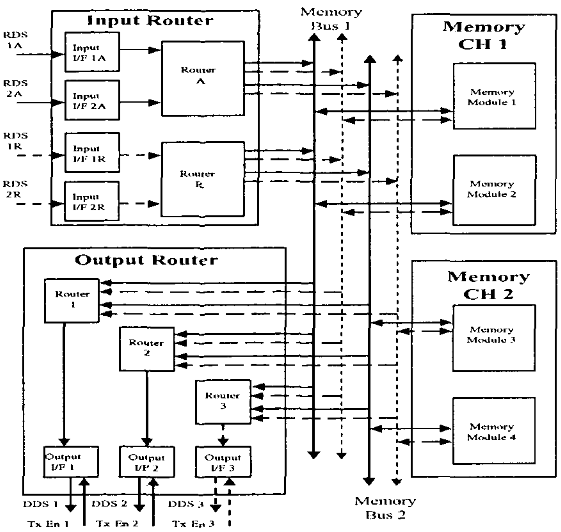

Fig. 5. Data storage structure.

5-3 Data Link Processor

The data link processor provides interface between satellite platform and data link, and it is through this interface where the link software macro commands are transferred to and/or from the remote sensing data. The structure of data link, as shown in Fig. 6, consists of data processor channel module, control module, control interface module and power supply. The main functions are to format the received data into a frame unit according to the communication protocol set by the Consultative Committee for Space Data System (CCSDS) and to spread the signal spectrum using standard signal in order to restore the data efficiently in the ground station. In addition, the link processor controls all the functions of the data link in accordance with the command transferred from platform through telemetry and telecommand interface. These controling and monitoring is carried out by on-board data link software which is situated within the data link processor.

5-4 Data Link Transmitter

The data link transmitter is to modulate RF radar signal composed of unit frames received from link processor and to provide sufficient power for meeting the link budget required. Fig. 7 shows the structure of three channel transmitter. The primary functions are the transmitting frequency up-conversion and the amplification of the formatted input data in order to meet the required EIRP(Effective Isotropic Radiated Power), allowing bit error rate (BER) of 10^{-5}. As shown in Table 1, for the spaceborne SAR system requirement, the minimum EIRP is 19.1 dBW and the bit energy-to-noise ratio is 9.5 dB in case of the QPSK modulation. The transmitting band ranges from 8,025 MHz to 8,400 MHz, and the each channel bandwidth is 52.5 MHz, considering the efficiency of the spectral spread and the limited DC power consumption. The data link transmitter has two active channels and one redundancy channel with each of 105 MHz data rate, and the central transmitting frequency per each channel is divided into 8125, 8225, and 8325 MHz separated by 375 MHz band.

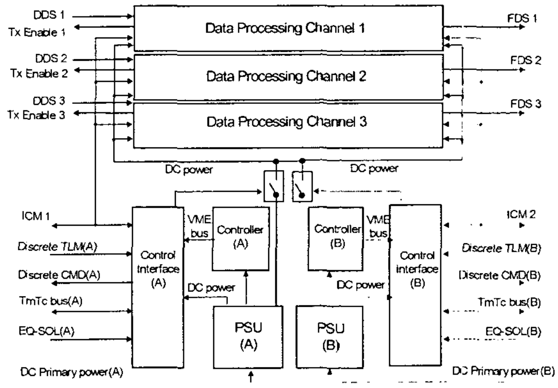

Fig. 6. Data link processor.

5-5 Data Link Antenna

The requirement criteria for data link antenna is to cover 2,000 Km in radius centered at the ground receiving station and, in order to maintain the elevation angle of 6° from ground

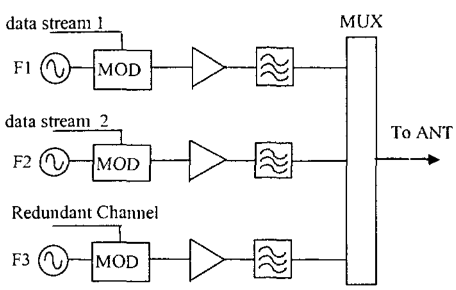

Fig. 7. Structure of data link transmitter.

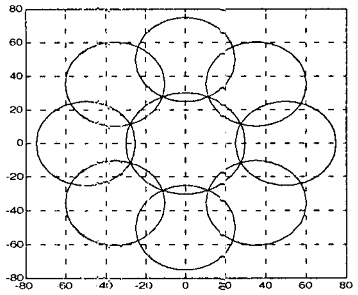

Fig. 8. Nine-switched horn antenna cluster beam.

horizon, it is designed so that it can transmit data at the antenna look angle of ± 65°. In order to compensate the propagation losses due to transmission slant range and incident angle, the requirement of the antenna beam pattern which has low gain at the center and high gain at the edge has been considered. Thus, the trade-off of antenna structure between the switched horn cluster and the mechanically steerable horn antenna was made in the aspects of coverage performance, power consumption, mass, and reliability of the SAR payload. The selected antenna structure is the nine-switched horn cluster which can switch the antenna sequentially when the satellite passes through the area of interest. The antenna structure consists of 8 RF switches, 9 polarizers and 9 horn antennas. The cluster antenna beam width, as shown in Fig. 8, needs to have 60° for switched horn cluster at the center and 50° for 8 corrugated conical horn antenna at the circumference so that it can cover a wide area.

Ⅵ. Performance Analysis

The X-band frequency was chosen as transmitting frequency for data link, considering the burden of the volume and mass of the small satellite payload. Furthermore, 8 GHz band which suits for WARC regulation was used to avoid interference from the SAR radar frequency. The frequency band range is 8,024 ~ 8,400 MHz which accomodate 3 data channels for 210 Mbps data rate. The centre frequency for data channel is 8,125, 8,225, 8,325 MHz, each with 105 Mbps. For the type of modulation,

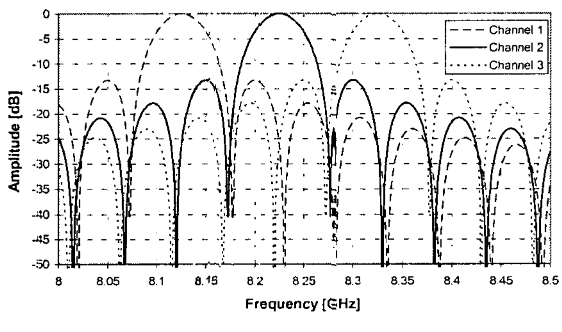

Fig. 9. Frequency response of three-channel modulator.

QPSK was chosen for the efficiency of power and spectrum. In the aspect of RF power amplifier, instead of single wideband data channel, multi-channel structure was applied using solid-state power amplifier which has lower DC power and small light weight. For this reason, two active channels of 105Mbps are used to meet 210Mbps data transmission and one redundancy channel is used for reliability. The characteristics of 3 channel frequency is shown in Fig. 9.

To make the data transmission become possible at the ground horizontal elevation angle of 6°, it is designed so that the data link antenna look angle is within ± 65° range. The design performance of the center and outside switched horn antenna is given in [3].

The data transmission rate was analysed according to the satellite orbit data and image mode. The data sampling was done in the given band width of 20 % of design margin and 4-Bit BAQ is applied to data compression. As shown in Table 2, in case of wide swath mode with 30m resolution, where sampling frequency of 30 MHz is used, the given transmission speed is adequate, but, in case of high resolution mode with 75 ~ 85 MHz, most of swath widths occurs as the data limit of 210 Mbps is exceeded. In such case, the exceeded data is stored in the data link storage in real time according to the imaging mode and thus the exceeded data is transmitted to the ground receiver during the ready-mode before and/or after the satellite enters the mission area. It is noted in Table 2 that the notation of SS in the No. of swath width represents the sub-swath width of the given image modes.

Table 2. Data rate of SAR imaging modes.

Image mode	No. of swath	PRF (Hz)	Ground range		Pulse BW (MHz)	Res (m)	Data rate (Mbps)
			Near (Km)	Far (Km)			
Std mode	SS1	2910	149	182	65	9.5	292.7
	SS5	3165	249	282	50	7.8	205.8
	SS10	2910	374	407	41	6.9	240.0
	SS15	3225	499	532	24	9.7	150.1
	SS20	2910	624	652	25	8.3	132.1
Fine mode	SS1	2910	149	168	85	7.2	210.1
	SS7	3900	241	258	85	4.7	293.4
	SS14	3400	339	356	85	3.6	314.7
	SS20	3400	423	440	85	3.0	347.3
	SS30	2910	549	564	75	2.9	316.3
Wide mode	SS1 − a	3107	149	189	30	24.5	87.5
	SS1 − c	4154	217	257	30	17.4	136.7
	SS2 − a	3118	278	318	30	14.1	125.2
	SS2 − d	3911	383	423	30	11.8	181.0
	SS3 − a	3419	418	458	30	10.4	168.7
	SS3 − c	2700	485	525	30	9.5	148.3

Table 3. Performance of SAR data link.

Parameter	Performance	Remark
Coverage	2,000 Km	Radius centered at ground station
Frequency	X-Band	8,025~8,400 MHz
Data rate	210 Mbps	Maximum Limit
Bit error rate	10^{-5}	Per Channel
Data rate	105 Mbps	Per Channel
No. of data channel	2 Channel	Active 210 Mbps
	1 Channel	Redundancy
Storage size	10 Gbits	End of life
	12 Gbits	Begin of life
Mass	61 Kg	DME+DLE
Power	194 W	DME+DLE
Reliability	0.965	3 yrs of life cycle

The key design performance of data link is summarized in Table 3. Data link structure is designed in 105 Mbps unit channel module so that extension can be made with ease. Furthermore, data link storage, whose size is 10 Gbits at the end of life, is designed to utilize high speed semiconductor memory in order to meet the SAR mission requirement which is the small, light weight, and high reliability during the life cycle of 3 years in orbit.

Ⅶ. Conclusion

In this paper, based on the data link model characterized by the spaceborne small SAR system, the high-rate multi-channel data link module is designed for handling the high speed SAR image data, and the design results are presented with the architecture of link storage, link processor, transmitter, and wide-angle antenna. The performance analysis on the data link budget is also presented with the multi-mode data rate in association with the SAR imaging mode of operation from high resolution to the wide swath. The designed multi-channel architecture can be effectively used for the increase of the data rate by 105 Mbps unit modular expansion for accommodating high resolution SAR data transmission in real-time. The resultant data link designed for 210 Mbps data rate requirement has two data channels and one redundant channel for reliability. The overall performance of the data link including the mass and power constraints imposed by the small SAR satellite was verified to be well met with the system requirements. The designed data link module architecture can be effectively used for the spaceborne and airborne applications which requires to expand the high speed data link capability.

The author, who was a program manager, would like to acknowledge the research engineers of SAR team, Agency for Defense Development and the Matra Marconi Space-UK who participated in the spaceborne SAR design project.

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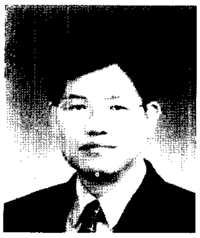
Young-Kil Kwag



received the B.S. degree from National Aviation University in 1976, M.S. degrees from Korea Advanced Institute of Science and Technology in 1981, and Ph.D degree from Ohio University, Ohio, USA in 1987, respectively. From March 1976 to March 2001, he had worked with the Agency for Defense Development (ADD) as a principal researcher and a research division head in the areas of radar systems and radar signal processing, spaceborne synthetic aperture radar systems. He was an adjunct professor at the KAIST from 1992 to 1993. He was a program manager at the Matra Marconi Space in UK for spaceborne SAR program from 1997 to 1999. Since March 2001, he has been a faculty member in the School of Electronics, Telecomm., and Computer Eng., and the Director of Aerospace and Aviation Electronics Research Center, Hankuk Aviation University, Seoul, Korea. His research interests include radar and adaptive signal processing, spaceborne SAR system and SAR image processing, aeronautical communications and surveillance, data link, avionics-CNS/ATM, DSP applications to radar and communications.