

Multi-Channel High Speed Data Link Design for Small SAR Satellite Image Data Transmission

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Abstract: 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.

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, 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. In practice, 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. 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.

2. 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, 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 data link coverage is within 2000 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 9GHz of SAR frequency. The elevation angle on the horizontal ground is 6 degree at the ground receiving station

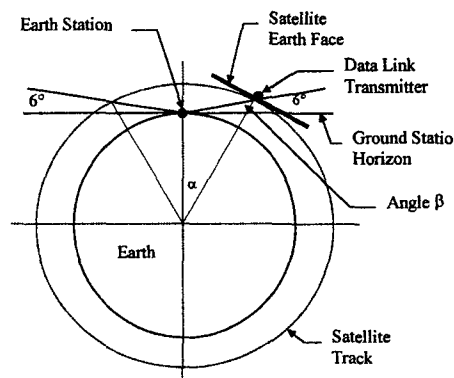


Figure 1. SAR datalink geometry

3. 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 gives equation (1).

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

where, L_{LFS} = 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 data link budget analysis, the transmission data rate of 105Mbps is set within the transmission coverage of maximum line of sight of 2276 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 . 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

Parameter	Unit	Data
Carrier Frequency	MHz	8325
Bit Error Rate	-	10 ⁻⁵
Required Eb/NO	dB	9.5
Data Rate	BPS	105000000
Boltzmann's Constant	J/K	1.38x10 ⁻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 Eb/NO	dB	11.5
EIRP	dBW	19.1
Gain of On-Board Ant.	dB	> 8.5
Tx Power/Channel	dBW	10.605

4. Data Rate in Imaging Mode

4.1. SAR Imaging Mode

The SAR imaging modes for this system are operated in three modes [3]: Standard mode, Fine Resolution mode, and Wide Swath mode. The Standard mode is the SAR imaging technique in which a single continuous swath of imagery is acquired, normally denoted the stripmap technique. The nominal resolution and swath width of this mode are 10m and 30Km, 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 3m and 10Km, 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 30m 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).

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

where, N 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. W is given by the function of pulse length and slant range. The SAR data rate was calculated using the SAR design module [5], which requires the satellite orbit data and swath width data in accordance with the image mode.

5. Data Link Design

5.1 Structure of Data Link

The SAR satellite payload consists of radar instrument and data link as shown in Fig. 2. The radar instrument is dividend into antenna, transmitter, receiver, central electronic subsystems [3]. 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 105Mbps unit channels and one redundant channel in order to satisfy the mission system requirement of data transmission rate of 210Mbps

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

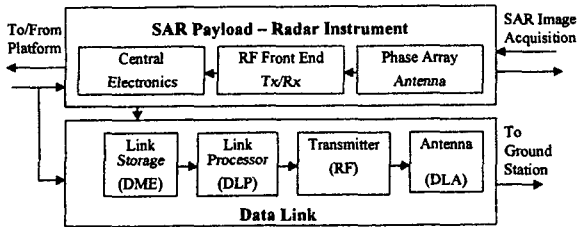


Figure 2. SAR payload and datalink

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. 3, the link storage consists of input router, buffer memory, output router and output channel. The input router receives 32-bit formatted 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.

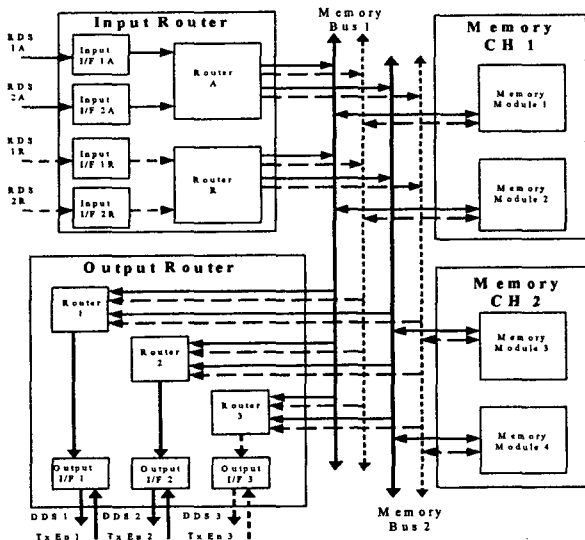


Figure 3. Data storage structure

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. 4, 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 controlling and monitoring is carried out by on-board data link software which is situated within the data link processor.

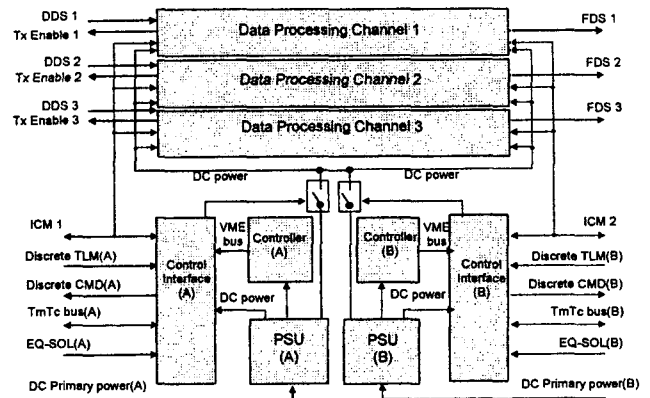


Figure 4. Data processor structure

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. 5 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 8025 MHz to 8400MHz, and the each channel bandwidth is 52.5MHz, 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.

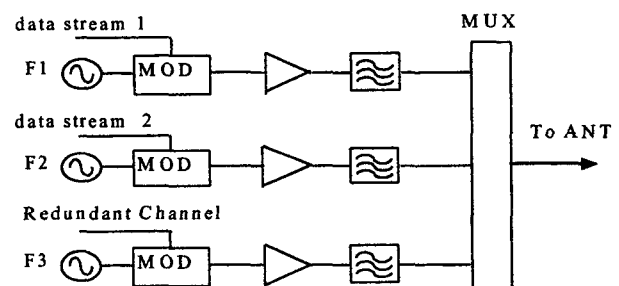


Figure 5. Data link transmitter

5.5 Data Link Antenna

The requirement criteria for data link antenna is to cover 2000Km in radius centered at the ground receiving station

and, in order to maintain the elevation angle of 6° from ground 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. 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.

6. 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 8024 ~ 8400 MHz which accommodate 3 data channels for 210Mbps data rate. The centre frequency for data channel is 8125, 8225, 8325 MHz, each with 105Mbps. For the type of modulation, 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.6.

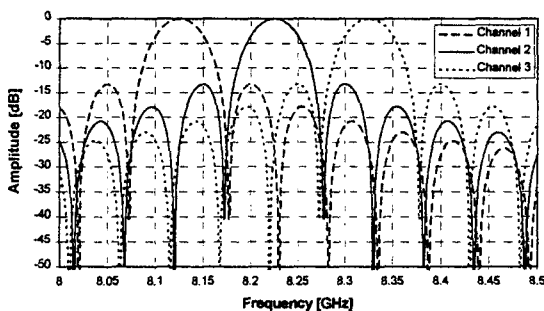


Figure 6. Frequency response of 3-ch modulator

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. In case of wide swath mode with 30m

resolution, where sampling frequency of 30MHz 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

7. 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 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.

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