Satellite Data Transmitting Systems and In-Orbit Performance

By D.V. Ramana and Jolie. R

The system block diagram, specifications, qualification tests and link calculations of X-band data transmitting systems are discussed.

Abstract

An Indian Remote Sensing Satellite—Resoucesat-2—was launched successfully into a polar, sun-synchronous orbit on 20th April, 2011. It carries remote sensing payloads capable of operating in four spectral bands. The two types of payloads are Linear Imaging Self Scanning Sensors (LISSIV and LISSIII) and Advanced Wide Field Scanner (AWIFS). The payload data is transmitted through X-band data transmitters employing QPSK modulation. The modulated data is amplified using high gain Travelling Wave Tube Amplifiers (TWTAs) for downlink data transmission. The system block diagram, specifications, qualification tests, and link calculations of the X-band data transmitting systems are discussed. This paper also discusses the in-orbit performance of the X-band data transmitting systems.

Introduction

The space to earth communication link basically depends on the RF carrier frequency, modulation, data rate, figure of merit (G/T) of the ground station and onboard Effective Isotropic Radiated Power (EIRP). This would help in understanding the power level requirements of the data transmitters and gain of ground and onboard antenna systems for desired quality of data reception.

The X-band data transmitting system on Resourcesat-2 performs the following functions:

- Generates two X-Band carriers at 8125 MHz and 8300 MHz.
- Accepts data from the LISS-IV and LISS-III + AWIFS cameras.
- Modulates the above data on the two independent X-band carriers.
- Transmits the modulated carriers to ground after suitable amplification and filtering.

The data handling system is essentially built around two chains, the LISS IV chain and the LISS III chain, each handling 105 Mbps of data. The two chains are end to end independent.

X-Band Data Transmitter

The two chains of transmitters, LISS IV @ 8125 MHz and LISS III @ 8300 MHz, generate X-band carriers from Temperature Compensated Crystal Oscillators (TCXOs) at 270.833 MHz and 276.666 MHz, respectively. The two chains are operated simultaneously.

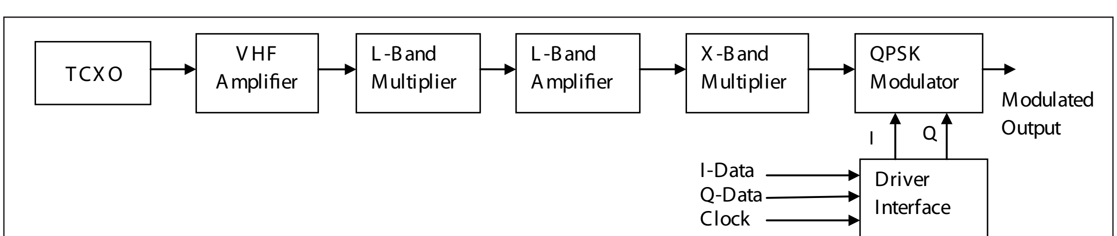

Figure 1 • Block diagram of the X-band data

Each transmitter has its own TCXO as a frequency source. The TCXO output is multiplied and amplified using two stages of frequency multipliers and amplifiers to obtain the X-band carrier. The payload data is modulated onto the stable carriers using QPSK modulation. A block diagram of the X-band data transmitter is shown in Fig. 1.

Direct QPSK modulation is carried out at X-band, with the formatted and encoded data (I, Q and Clock) provided by the base band data-handling system. The modulation is realized using two PIN diode based BPSK modulators—a 3dB hybrid and a Wilkinson power combiner. A driver interface circuit is used to convert the TTL inputs to bipolar levels suitable for biasing the modulator. The circuit also corrects any probable data asymmetry.

Data Transmitting System

The data transmitting system, consisting of the main and redundant data transmitters, TWTAs, filters, hybrids, isolators and switches, is shown in the block diagram in Fig. 2. For space systems, reliability is of prime importance, further strengthened with sufficient redundancy. Full cold redundancy is provided to the basic systems. The selection of basic system is done by powering only the selected chain. Selected modulated carriers are amplified to 40 watts each by separate TWTAs. Three 40 watts TWTAs are used, of which two are dedicated for LISS IV and LISS III chains. The third TWTA is kept as a spare and can take over any of the two normally operating TWTAs, in the event of a failure. The third TWTA is selected using one coaxial switch at the input and three waveguide switches at the output of the TWTAs as shown in Fig. 2. The TWTA consists of a Travelling Wave Tube (TWT) and an Electronic Power Conditioner (EPC). The EPC directly interfaces the TWT with the raw bus power and can operate from 28V to 42V. The modulated output amplified by the TWTA is filtered to restrict the bandwidth of the transmitted signal.

X-Band Data Transmitter Specifications

Carrier Frequency	8125 MHz for LISSIV
	8300 MHz for LISS III+ AWIS
Carrier Frequency Stability	± 2 ppm
(Over operating temperature range)	
Tx Power output	0 dBm
Power @ TWTA output	+ 46 dBm
Harmonics	30 dBc
Spurious	50 dBc
Modulation	QPSK
Data Rate	2 x 52.5 Mbps
Data Input Level	TTL
Phase Accuracy	± 5°
Amplitude Imbalance	± 1 dB
Carrier suppression	20 dBc
Operating Temperature	–10°C to +50 °C
DC power (typ)	3.5 W

TWTA Specifications

Frequency of operation	8 - 8.4 GHz
RF output power, EOL	40 Watts (min)
Gain @ saturation	58 dB (typ)
DC power consumption	90 Watts @ 28 - 42 V (max)

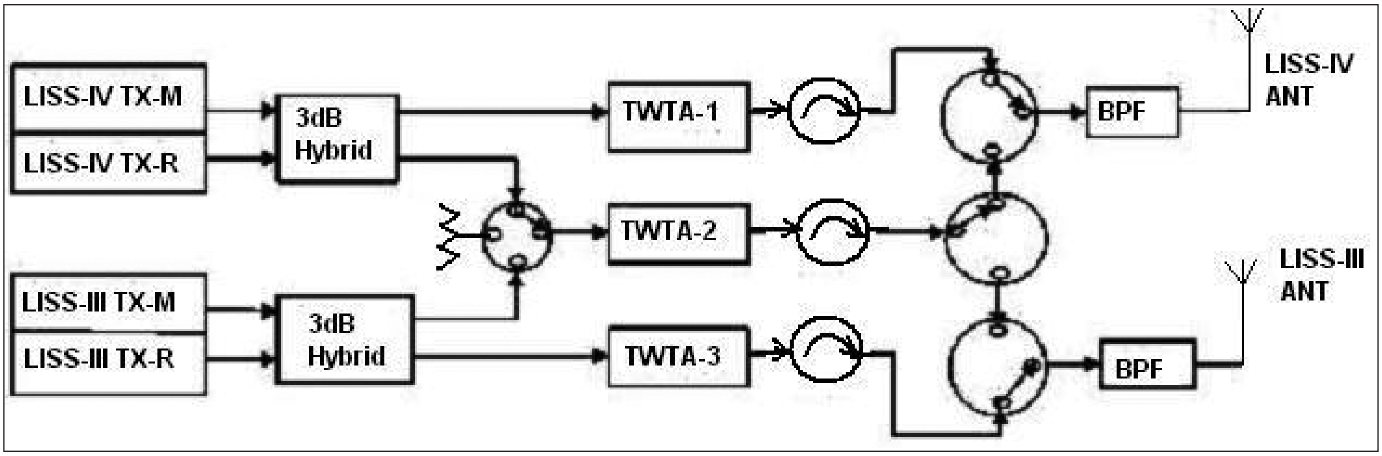

Figure 2 • Block diagram of the X-band data transmitting system.

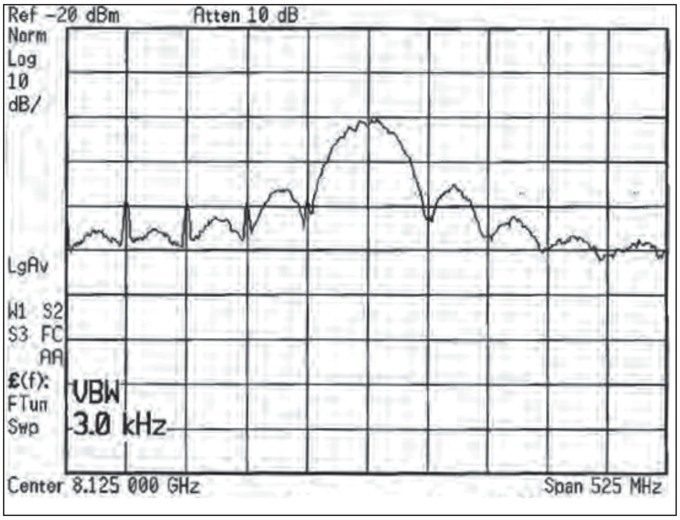

Figure 3 • PRBS spectrum in cold cycle.

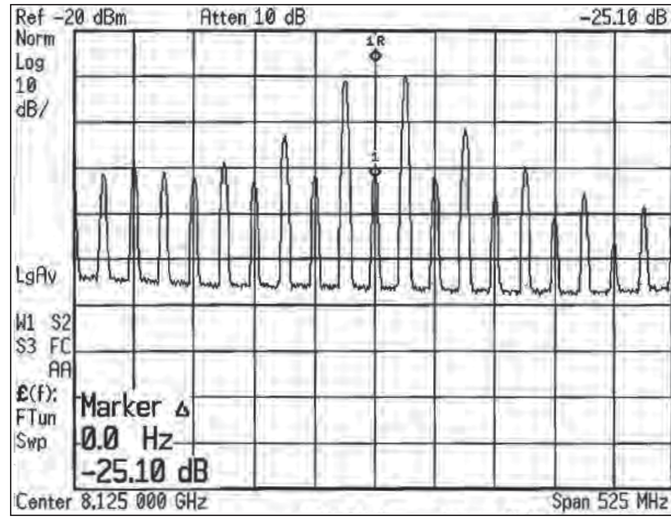

Figure 4 • 4 1010…. spectrum in cold cycle.

The filtered QPSK signal is transmitted through a shaped-beam antenna. The transmitting antenna is basically a circular waveguide with a shaped sub-reflector. The antenna is mounted on the earth viewing side of the satellite and transmits the modulated carrier to ground using Right Hand Circular Polarization (RHCP). The two carriers are transmitted by separate iso-flux antennas. Hence, the power amplifiers (TWTAs) can be operated near saturation to obtain the best possible efficiency.

Qualification Tests

The data transmitters were initially aligned in ambient to meet all electrical specifications over the operating temperature range and were later subjected to various qualification tests. The following are the test sequence and levels for which the systems were qualified. The test levels are based on the levels the spacecraft would experience during flight and in its orbital period.

Hot and Cold Operational Test

The data transmitters were subjected to acceptance temperature limits of -10°C and +50°C. The test evaluates the electrical performance of the systems under extreme temperatures.

EMI/EMC Test

The data transmitters were qualified for EMI/EMC tests as per MIL standards MIL-STD-461C. Radiated Emission, Conducted Emission, Radiated Susceptance, and Conducted Susceptance tests were carried out.

Vibration Test

The data transmitters were also qualified for vibration levels in all the three axes as dictated by the launch vehicle specifications. The subsystem was subjected to sinusoidal vibration and random vibration tests. The vibration levels depend on the weight of the transmitter package and its location on spacecraft. The test brings out any mechanical defects or workmanship problems in the package.

Thermovac Test

The transmitter packages were loaded in a thermo-vacuum chamber along with their respective DC-DC Converters. Thermo-vacuum test was carried out and the performance of the transmitters was verified to meet all the electrical specifications under the following environmental conditions.

Temperature	:	-10ºC and +50ºC, 24 hrs duration
Pressure	:	1×10^{-5} Torr

The test simulates the in-orbit test conditions and the performance of the systems is checked. The test also helps in detecting multipaction, corona discharge and hot spots, if any, in the system. Figs. 3 & 4 show the spectrums for pseudo random bit sequence (PRBS) and 1010 type of data patterns, respectively, at cold temperature (-10ºC) and Figs. 5 & 6 show the corresponding spectrums at higher temperatures (+ 50ºC).

Link Calculations

The performance of any communication system depends on numerous link parameters. RF link estimation is actually a relatively simple addition and subtraction of gains and losses within the link. When these gains and losses of various components are determined and assumed, the result is an estimation of end-to-end system performance in the real world. To arrive at an accurate figure, factors such as the satellite onboard power amplifier gain, advanced modulation techniques, coding

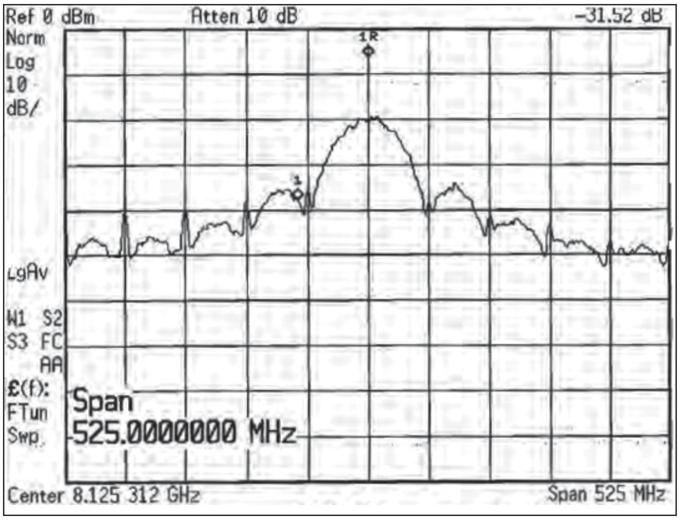

Figure 5 • PRBS spectrum in hot cycle.

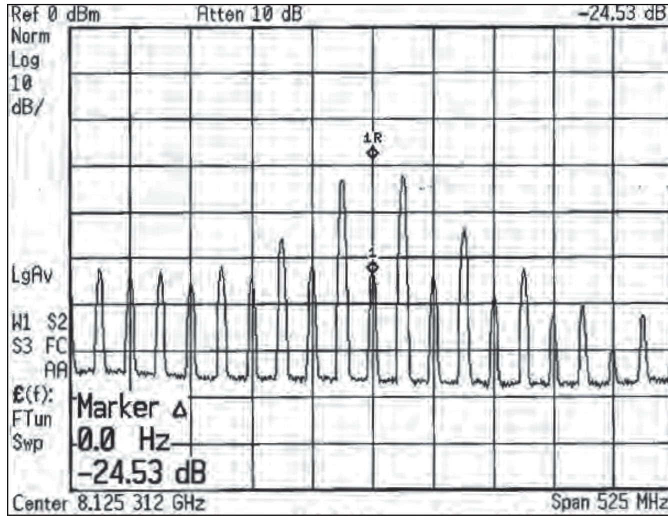

Figure 6 • 1010… spectrum in hot cycle.

schemes, transmit antenna gain, slant angles and corresponding atmospheric loss over distance, receive antenna and amplifier gains and noise factors, cable losses, interference levels and climatic attenuation factors must be taken into account. In order to accommodate the known performance deviations and also unknown effects of various parameters in the RF link chain, onboard power is suitably increased to provide comfortable system margin (> 3dB) for receiving the data with acceptable Bit Error Rate (BER= 1×10^{-6} for space links).

Transmitter frequency	8125/ 8300 MHz
Modulation	QPSK
Data rate	2 X 52.5 Mbps
Transmitter output power	16.0 dBW
Onboard loss	2.0 dB
On-board antenna gain	5.0 dBi
EIRP	19.0 dBW
Orbit height	817 Kms
Elevation	5°
Slant Range	2820.6 Km
Path loss	179.8 dB
Miscellaneous loss	1.0 dB
Ground Station G/T	31.0 dB/°K
Received CNDR	97.8 dB-Hz
E_b/N_o available	17.6 dB
Required E_b/N_o	10.8 dB
Implementation margin	2.0 dB
Margin available	4.8 dB

TABLE 1 • Link Estimate

Table 1 gives the link calculation for data transmission in the X-band. The link has been designed to ensure a BER better than 1×10^{-6} for an elevation angle of 5º. For the Resourcest-2 satellite, in a near circular orbit with an altitude of 817 km, the maximum slant range for 5º elevation is 2820 Km. An EIRP of 19 dBW has been found adequate to provide sufficient link margins.

The theoretical value of E_b/N_0 required for achieving a bit error rate (BER) of 1×10^{-6} is 10.8. The received carrier to noise density ration (CNDR) is 97.8 dB-Hz. The available E_b/N_0 works out to be 17.6 dB leading to a link margin of 4.8 dB taking 2 dB implementation margin. The implementation margin takes into account link impairment parameters such as amplitude imbalances in the modulator, clock instability, data asymmetry, rise time, filtering, group delay distortion in amplifier and

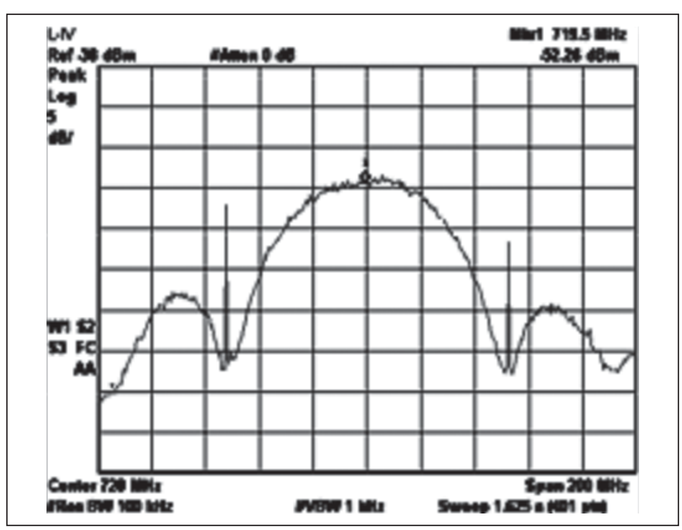

Figure 7 • LISS III PRBS spectrum.

receivers, carrier and oscillator instability, matched filter mismatch, timing errors etc.

In-Orbit Performance

The in-orbit performance of the data transmitter has been evaluated and a link margin better than 3 dB is observed for LISS IV chain and 4 dB for LISS III chain against a calculated figure of 4.8 dB. The difference in link margins for the two chains may be due to small variation in the onboard antenna gain, G/T value of the ground station and variation in the performance of the two demodulator chains. No errors were observed during reception due to the availability of good link margins. Table 2 gives the CNDR received at the ground station during a satellite pass. Figs. 7 & 8 show the down converted (720 MHz IF) PRBS spectrums at the ground station, for the LISS III and LISS IV payloads, respectively.

Conclusion

The X-band data transmitting systems were fabricated, tested and qualified for the Resourcesat-2 mission. Redundancy has been provided for the transmitter and the TWTAs. The main or redundant data transmitters and the third TWTA can be selected by ground command. The data reception centre receives data from the LISS IV, LISS III and AWIFS payload cameras onboard the Resourcesat-2 spacecraft. The earth station is able to receive good signal levels with expected link margin of better than 3 dB.

Elevation(deg)	LISS-3	LISS-4
5	97	96
6	96	96
7	96	96.5
8	96	96.8
10	97	98
15	98	99.6
20	99.5	101.6
30	102	104.4
50	102	104.4
62.44	103.5	103.9
50	103	103.5
40	102	102
30	102	101
20	99.5	100.4
15	98	99
10	97.7	97.7
8	95	97
6	95.8	96
5	95.3	97.3

TABLE 2 • CNDR.

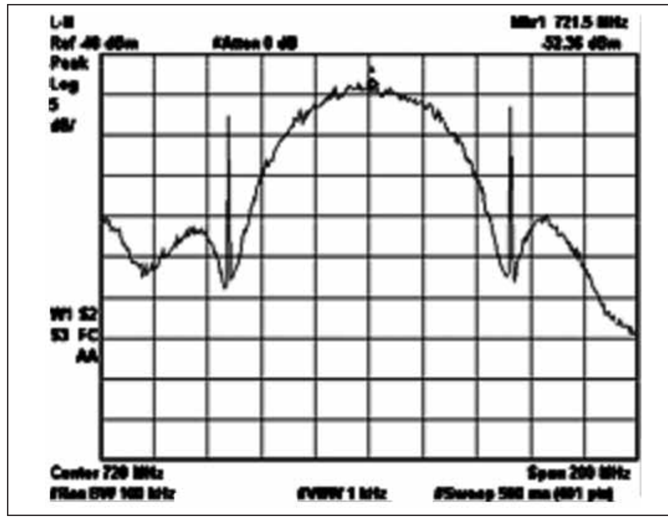

Figure 8 • LISS IV PRBS spectrum.

About the Authors:

Dr. D. Venkata Ramana received his Ph.D. from the Indian Institute of Science, Bangalore, in 2005 and his M.Tech degree from the National Institute of Technology, Surathkal, in 1989. He joined the ISRO Satellite Centre, Bangalore, in 1983 and has been associated with the Communications Systems Group. He is involved in the design and development of high bit rate data transmitters and advanced modulation schemes for various Indian Remote Sensing Satellites. He has published papers in various national and international journals. He is a Senior Member of the IEEE, Fellow, IETE, and Fellow IE, LM-IMAPS.

Mrs. Jolie. R received her M.Tech from the Cochin University of Science and Technology in 1996. She obtained her B.Tech from the University of Kerala in 1992. She joined the ISRO Satellite Centre, Bangalore, in 2000 and is a design engineer for data transmitting systems for IRS satellites. Her work includes the development of high bit rate modulators, data transmitters at X and Ka-bands, and research in the area of spectrally efficient data transmission system for space communication links. She is currently registered for her Ph.D. at VTU, Bangalore, and is a Life Member of IMAPS.