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Communications

OCI and ROCSAT-1 Development, Operations, and Applications

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Abstract : This paper describes the development, operations, and applications of ROCSAT-1 and its Ocean Color Imager (OCI) remote-sensing payload. It is the first satellite program of NSPO. The satellite was successfully launched by Lockheed Martin's Athena on January 26, 1999 from Cape Canaveral, Florida. ROCSAT-1 is a Low Earth Orbit (LEO) experimental satellite. Its circular orbit has an altitude of 600km and an inclination angle of 35 degrees. The satellite is designed to carry out scientific research missions, including ocean color imaging, experiments on ionospheric plasma and electrodynamics, and experiments using Ka-band (20~30GHz) communication payloads. The OCI payload is utilized to observe the ocean color in 7 bands (including one redundant band) of Visible and Near-Infrared (434nm~889nm) range with the resolution of 800m at nadir and the swath of 702km. It employs high performance telecentric optics, push-broom scanning method using Charge Coupled Devices (CCD) and large-scale integrated circuit chips. The water leaving radiance is estimated from the total inputs to the OCI, including the atmospheric scattering. The post-process estimates the water leaving radiance and generates different end products. The OCI has taken images since February 1999 after completing the early orbit checkout. Analyses have been performed to evaluate the performances of the instrument in orbit and to compare them with the pre-launch test results. This paper also briefly describes the ROCSAT-1 mission operations. The spacecraft operating modes and ROCSAT Ground Segment operations are delineated, and the overall initial operations of ROCSAT-1 are summarized.

Key Words : Ocean Color Imager, Low Earth Orbit, experimental satellite.

1. Introduction

Based on the Fifteen-Year Plan for National Space Technology Development of Taiwan, ROC, the National Space Program Office was established in 1991 within the National Science Council. It will carry out a series of missions to build up Taiwan's space program and related industries. The mission objective of its first satellite, ROCSAT-1, is to develop, launch, and operate a low earth orbit satellite, and to conduct three scientific and technology experiments in the areas of ocean color imaging, space telecommunication, and solar-terrestrial physics.

The ROCSAT-1 spacecraft was developed jointly by TRW with a jointed team of TRW and NSPO engineers. The three on-board payload instruments are the Ocean Color Imager (OCI),

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the Experimental Communication Payload (ECP), and the Ionospheric Plasma and Electrodynamics Instrument (IPEI). The satellite operations are conducted from the ROCSAT Ground Segment (RGS) Mission Operation Center located in Hsinchu. The payload data and the spacecraft data are transmitted together in S-band link to the ground stations located in Cheng-li and Tainan. The received data are then sent through TI lines of the ground communication network to the control center for data processing. The processed science data are extracted and routed to the Science Data Distribution Centers for advanced processing and distribution.

Lockheed Martin's Athena I successfully launched the satellite from Cape Canaveral, Florida, to its final orbit on January 26, 1999. Following the initial check of the system, the satellite has been commanded to the Science Mode since February 1999. The satellite's performances have been fine. From spacecraft and instrument data obtained in the past few months of operations, many engineering and scientific studies have been conducted.

2. ROCSAT-1 Satellite System

ROCSAT-1 is a three-axis stabilized satellite. It weights 402kg and is hexahedron in shape with the width of 1.1m and the height of 2.1m. The satellite orbits the earth in a circular orbit at altitude of 600km and an inclination of 35 degrees. The satellite on this orbit communicates with either two TT&C ground stations in Taiwan for about seven 7.5 minutes duration contacts per day, assuming 10 degrees minimum elevation angle. Like most spacecraft, ROCSAT-1 is composed of six major subsystems: Structure and Mechanical Subsystem (SMS), Command and Data Handling/Tracking, Telemetry and Control Subsystem (C&DH/TT&C), Attitude and Determination and Control Subsystem (ADCS), Electrical Power Subsystem (EPS), Thermal Control Subsystem (TCS), and Reaction Control Subsystem (RCS).

The functional requirements of the ROCSAT-1 satellite directly influences the flight operations include the following:

A. Telemetry and Command conform to CCSDS standards and the data rate for real- time stream of SOH at 2.048Kbps or interleaved with recorder playback data at a composite rate of 1.39Mbps; command data rate for uplink at 2Kbps.

B. Payload experiments data under the constraints of on-board storage (2Gb), downlink channel capability (1.39Mbps), and contact time between the satellite and the ground stations. The mission planning will allocate these resources based on the requests and priority of the experiments.

C. 2Gb Solid State Recorder is not partitioned for OCI, IPEI, or SOH. These data are stored interleaved without any pre-defined allocations. Thus proper mission planning is important.

D. Commands are uplinked to the spacecraft on a daily basis. Both the spacecraft and instruments activities are planned and scheduled in advance and uplinked in the previous day.

E. The spacecraft maintains three-axis stabilization to within 0.5 degree (3 sigma) in all directions. This pointing accuracy requirement is driven from OCI.

The characteristics and functions of the payloads are described here. The IPEI carries four sensors: an Ion Trap, Horizontal and Vertical Drift Meters, and a Retarding Potential Analyzer. These sensors measure ion concentration, ion temperature, and cross-track ion velocity. From the sensors, major ion composition can also be derived. The processing unit can control the sampling rate adaptively and transition between the normal mode (low rate sampling) and the fast mode (high rate sampling) so that both the global data and local detail plasma structures called bubbles, can be studied without overloading the data storage or transmitting capabilities. The unique feature of this mode allows the scientist to investigate spatial structures with scale sizes as small as 16 meters. They will provide important ion characteristics at the 600km altitude within the latitude band of +/−35 degrees along the ROCSAT-1 orbit.

The objective of the ECP project is to study implementation techniques of the low earth orbit Ka-band satellite communication systems and to conduct Ka-band satellite communication experiments to study the performance of the video/voice/data/fax transmission and Ka-band propagation effect. The ECP consists of ground, space, and science segments. The ground segments consists of a fixed ground terminal and a transportable terminal. The space segment provides a bent-pipe transponder and a downlink beacon transmitter. The uplink and downlink frequencies are 28.25GHz and 18.45GHz respectively, while the downlink beacon operates at 19.5GHz.

3. Ocean Color Imager

The OCI, as shown in Fig. 1, is the first push-bloom type spectral-radiometer for measuring radiance from ocean surfaces and atmospheric scattering for doing research subjects in:

- mapping the photosynthetic pigment distribution in the low-latitude oceans and generating surface spectral data,
- studying marine productivity and the dynamics of meso-scale eddies, and

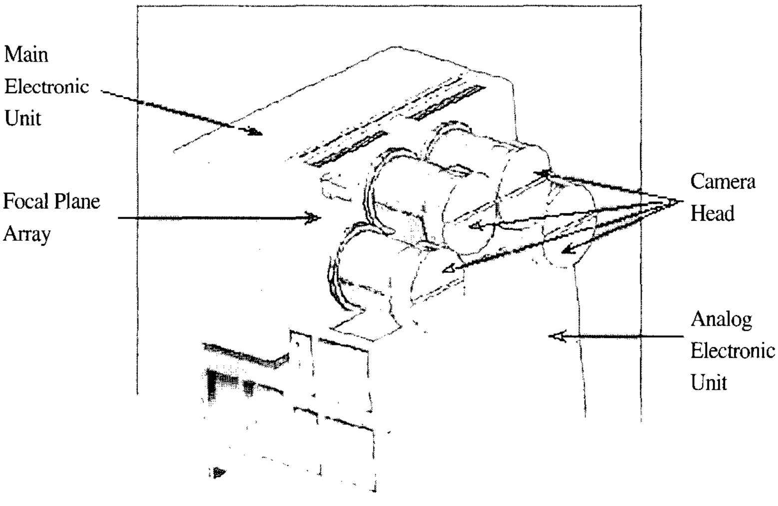

Fig. 1. Ocean Color Imager

- investigating the influence of atmospheric aerosols in remote sensing.

Besides a redundant 555nm band, the OCI has six different visible and near IR spectral bands (Table 1) that are similar to, but fewer than the SeaWiFS. Since there is little water-leaving radiance from the ocean surface in the spectral regions near 670nm and 869nm, B5 and B6 are mainly for measuring atmospheric ally scattered light with the measured data to be used for atmospheric correction. The acquired data of the other bands are from both atmospheric scattering and reflectance from ocean surface. After correction by subtracting the estimated radiance of atmospheric scattering, water leaving radiance values can be obtained and used to compute the pigment distribution near the ocean surface by using the validation and calibration algorithms developed by the science team.

The OCI's hardware was built by the NEC Corporation and consists of three modules: the Optical Unit (OU), the Analog Electronic Unit (AEU), and the Main Electronic Unit (MEU).

The OU consists of four camera heads with seven focal planes each with a Thomson TH7811 linear array CCD device for detecting the input radiance. Two focal planes (B1/B3, B2/B4, or B5/B6) share a camera head that has an eight-lens telecentric telescope subsystem with 19.5mm focal length and 60.7° field of view (FOV) to give 702km swath width at 600km altitude. B7 uses a stand-alone camera head with a lens subsystem similar to that of the others.

The TH7811 linear CCD device has 1728 cells each with a 13μm × 13μm photosite that can transform optical radiance into electric current. The cells in each device are arranged to give 832 double cell pixels plus 64 single cell pixels in the center region of the array. At 600km altitude and with 19.5mm focal length, 6.9km/sec ground track speed and 115.8milli-second integration time, the nadir-looking push-broom mechanism will give ~800m × 800m ground resolution for the double cell pixel and ~400m × 800m ground resolution for the single cell pixel.

Table 1. Major Parameters of the Ocean Color Imager

Band Number	1	2	3	4	5	6	7
Center Wavelength (nm)	444	492	512	555	670	869	555
Band Width (nm)	20	20	19.6	18.5	18.5	40.3	18.5
Mean Radiance*	84.1	65.6	56.4	45.7	24.6	10.9	45.7
Signal To Noise Ratio	751	779	782	657	777	671	700
MTF @ Nyquist Frequency	0.53	0.55	0.52	0.52	0.53	0.47	0.51
Ground Resolution	800 m						
Swath Width	702 km						
Orbit	600 km altitude, 35° inclination						
Radiance Accuracy	5%, absolute						
Mass	15.2 kg						
Size	37.9cm × 34.9cm × 34.2cm						
Power Consumption	33 W Peak, 17.4 W Standby						

*Units of W/(Sr-m^2-μm)

4. Operations of ROCSAT-1 and OCI

The RGS consists of six functional subsystems. Mission Operations Center (MOC) is the central control authority for the RGS. Tracking, Telemetry, and Command Stations (TT&C) provides direct access to the ROCSAT-1 satellite for tracking, telemetry collection, and satellite commanding. Flight Dynamics Facility (FDF) performs orbit and attitude determination and control computations, ephemeris data management, and mission planning support. Mission Control Center (MCC) provides the capability to support ROCSAT-1 policy decisions and mission planning. Science Control Center (SCC) is responsible for science instrument planning and scheduling, data processing, archive, and distribution; Ground Communication Network (GCN) provides the communications among the RGS subsystems, and between the RGS and external elements. The RGS has communication interfaces with the other ground segment elements which supporting on-orbit operations. The elements include two Science Data Distribution Centers (SDDCs) for OCI and IPEI instruments planning and science data processing & distribution; the ECP Ground Station and ECP SDDC for Ka-band experiments; Remote Tracking Stations at Banglore and Maritius (supported by DLR/GSOC) for emergency backup support.

The spacecraft has six modes: Launch, Standby, Sun, Maneuver, Science, and Safe Hold. Of which only the last four modes are used in the on-orbit operations. Upon separation from the Athena, the ROCSAT-1 wakes up in Maneuver mode and begins autonomous operations. When the satellite itself passed the initial deployment checkout, it is commanded by stored command from Maneuver mode to Sun Mode. After entering Sun mode, thrusters provides attitude control for acquiring the sun and maintaining sun pointing based on data from Coarse Sun Sensors. Once sun pointing, the satellite waits for all the preparation being finished, then the command from the RGS are sent to perform earth search then enter into Maneuver mode. Since the Athena has successfully launched the ROCSAT-1 into its operational orbit within the required tolerances, there is no needs to perform any further orbit adjust burns. Therefore, while the satellite has been maintained in LVLH attitude and high rate telemetry mode, all spacecraft subsystems checkout have been conducted directly at Maneuver mode. After completing the spacecraft activation, checkout, and preparation for entering Science mode, the ROCSAT-1 has been successfully configured to Science mode in February, 1999. Since then, instrument activation and checkout were performed and science experiments commenced.

Mode transition can be enacted by a ground command, by the ADCS software mode transition logic, or by a command issued from the fault triggered monitoring software. However, without any special purposes, the satellite will be maintained in Science mode for Normal Operations during the lifetime of the satellite.

From its successfully launched to the orbit, the ROCSAT-1 has orbited the Earth for more than 4,000 revolutions by now. The overall performance in the Science mode of the ROCSAT-1 has been as good as expected. The satellite attitude errors are controlled to within 0.2 degrees in all three axes. EPS, TCS, and C&DH/TT&C are all performed as expected.

Since the satellite has configured to Science mode and finished all the comprehensive checkouts in February, payload instruments have been performed well also. IPEI has been turned on and data collected successfully in three different modes. OCI has been operated under various combinations of its operating modes and gain settings. The imaging area has covered all oceans of the world within the +/− 35 degrees latitude limitations. Some dark current data are also collected for noise characterization. By now, more than 8,000 minutes of image time have been taken and 1300 image of OCI data has been obtained and successfully processed by the OCI SDDC.

When the OCI is observing an oceanic region without cloud and sun-glint, its total input radiance can be expressed as follows

$$L_t = L_r + L_a + t\,L_w \qquad (1)$$

Where, L_r, L_a and L_w represent Rayleigh scattering, aerosol scattering and water-leaving radiance, respectively and t is diffuse transmittance of the atmosphere. The value of L_w will be used to estimate the amount of pigment in the ocean and it is desirable to calculate this value by removing the atmospheric components, i.e., Rayleigh scattering and aerosol scattering, from the total input radiance.

Before launch the OCI was calibrated with a standard light source and the signal chain of the calibration process could be expressed as follows,

[Radiance from the Standard Light Source] → [OCI] → [Digitized Output Signal]

where, the light source was a well calibrated integrating sphere with 97% absolute accuracy and 99.5% uniformity.

Unlike other space-borne ocean observation instruments, such as CZCS, OCTS, and SeaWiFS that utilized rotating mirror architecture with only one photodetector to measure the input radiance for each spectral band, the OCI has 896 CCD pixels (detectors) to measure the input radiance for each spectral band.

Since L_w generally constitutes less than 20% of L_t, small uncertainty in the calibration parameter due to non-uniformity of the standard light source could cause big impact in computing L_w, and, moreover, degrade the image quality of the pigment distribution significantly because the relation between L_w and the pigment concentration is largely logarithmical. Specifically, we have found that 0.5% uncertainty due to non-uniformity of radiance from the standard light source would lead to ~2.5% uncertainty in the computed L_w, and eventually ~15% uncertainty in the computed concentration of pigment, such as chlorophyll-a. As a result the image quality would be degraded by non-periodic vertical stripes arise from uncertainty of the derived pigment concentration originated from inaccuracy of relative calibration among the CCD pixels due to non-uniformity of radiance from the standard light source.

This phenomenon, the presence of non-periodic vertical stripes originated from non-uniformity of radiance from the standard light source, has not been found in ocean color imagery of any other space-borne ocean observation instruments because they have, instead of several hundred CCD pixels, only one photodetector for each spectral band. The phenomenon has not been seen in images provided by any space-borne land observation instruments including those with push-bloom scanning mechanism, such as SPOT and IRS, because data processing of land imagery is much less sensitive to uncertainty of L_t than that of ocean imagery.

It is therefore a task with unprecedented challenge to improve the OCI's image quality by modifying the calibration parameters to eliminate the non-periodic vertical stripes. We have very carefully analyzed many post-launch data taken by the OCI over regions with uniform radiance and used the results to modify the original calibration parameters. The modified parameters, with less than 0.2% inaccuracy of relative calibration among the CCD pixels, would lead to ~1% uncertainty in L_w computation and ~5% uncertainty in pigment concentration computation. The processed image, with better quality and much less visible stripes by using the modified parameters, is illustrated in Fig. 2.

Blooming and Sun-Glint Effects

When the OCI is used for observation, some objects such as land and cloud are much brighter than the ocean. Anti-blooming is a CCD feature that can effectively reduce the charge spill over to the neighborhood when some CCD cells are illuminated by extremely bright incident light. By setting the saturation voltage at 6.5V on TH7811 CCD chips, significant anti-blooming feature as well as very high response linearity over the desired dynamic range both were achieved. The anti-blooming performance for each spectral band was measured by using a bright stripe as the observation object with 20(IFOV width and brightness that provided 6 times the saturation radiance. The results showed that blooming effects were limited to only $\leq 5 \times$ IFOVs, or ≤ 10 CCD cells.

We analyzed the OCI's post-launch imaging data and found that radiance of B6 from land and cloud was 20 and 30 times stronger than the specified mean radiance if image acquisition time was at noon. As a result, even with anti-blooming feature, blooming effect could not be easily suppressed for B6 in noontime images, especially in the right neighborhood of a large piece of cloud or land.

Because the OCI is always viewing in the nadir direction, it is not easy to avoid sun-glint, solar radiance directly reflected from the ocean surface. And its image quality is hence often degraded by this effect if image acquisition time is around noon, i.e., between 10:30 AM and 1:30 PM local time. It is nevertheless possible to significantly reduce this effect provided the imaging schedule is carefully planned.

Validation of OCI Data with SeaWiFS

There is no on-board solar calibrator on OCI. Since the orbit does not pass over the North Pole, to implement solar calibrator would require a mechanism to swing a solar diffuser into the optical aperture so that the reflected sun light can enter the optical train. Such mechanism cannot be accommodated with the tight payload adapter space allocation.

Procedures of cross calibration have been developed by the science team. Some initial comparisons of chlorophyll a concentration derived from OCI with that derived from SeaWiFS were made. The correlation coefficients of 0.6~0.83 were obtained initially.

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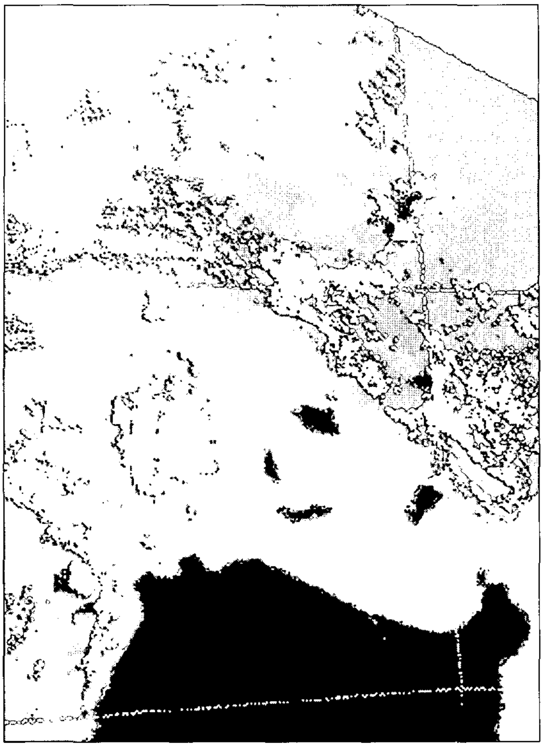
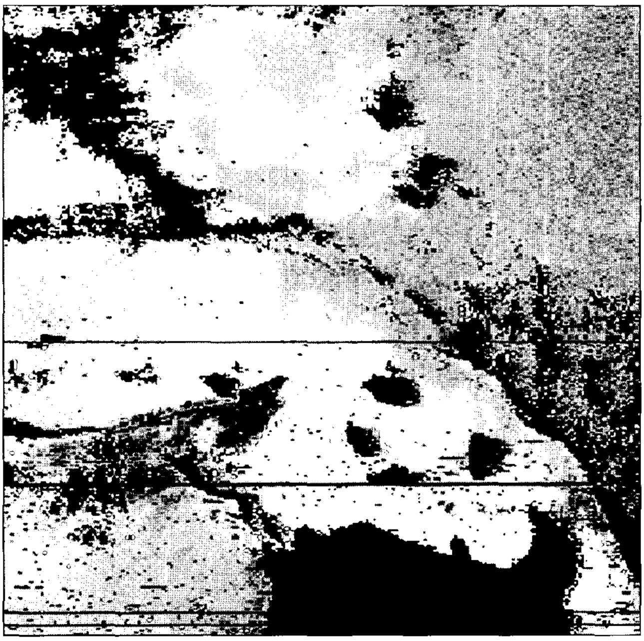


Chlorophyll-a imagery of the OCI



Chlorophyll-a imagery of SeaWiFS

Fig. 2. Image of OCI and SeaWiFS

their outstanding effort in building and testing the instrument within a very tight schedule. OCI science team, under the direction of Professors H-W Li and C-T Liu, has provided much valuable and useful advice during the course of the project. The project has been supported by the National Science Council of the Republic of China.

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