

A SMALL LOW EQUATORIAL ORBITING SATELLITE - SSR FOR MONITORING THE AMAZON REGION

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ABSTRACT:

Frequent cloud cover over the Amazon region is the greatest limitation to monitor, via optical remote sensing systems, ongoing activities that are threatening the greatest rainforest of the world. Current optical remote sensing satellites do not have sufficient temporal and spatial resolution in order to be used as operational monitoring system. For instance, with the Landsat system it has been possible to cover the entire Brazilian Amazon with 229 cloud free scenes, only once a year. It is of high relevance to have an efficient monitoring system, from space, to assist the management of natural resources and to protect the Amazon environment. The SSR system presents an innovative solution through a small remote sensing satellite placed in a low equatorial orbit, providing synoptic images of the entire Amazon region, several times a day. The SSR will be a 400 kg satellite using the Brazilian multitemporal platform for small satellites, which is being developed under INPE's coordination and manufactured by the Brazilian industry. The SSR imaging system consists of a VIS/NIR sensor and a MIR sensor. The VIS/NIR sensor is a pushbroom CCD camera with three optical heads and five spectral bands: blue, green, red, NIR and an additional water vapor content band for atmospheric correction purpose. The MIR sensor is a pushbroom camera with two optical heads and one band in the 3.4 - 4.2 μm region. The spatial resolution at nadir should be 40 m for the VIS/NIR bands and 500 m for the MIR band.

1. INTRODUCTION

The Brazilian Remote Sensing Satellite (*Satélite de Sensoriamento Remoto Brasileiro* – SSR) is a small satellite which is part of the Brazilian National Space Activities Program. The Program has as main objectives: 1) to develop application satellites that fulfill Brazilian needs; and 2) to develop Brazilian technological knowledge and industry.

The Brazilian Amazon region is the greatest rainforest in the world, with an area close to 5 million km^2 which is comparable to the entire west Europe. The Amazon region is undergoing complex and fast changes influenced mainly by human activities (forest fires, deforestation, wood and mineral extraction) and natural events (rain, flooding and droughts).

It is of extreme importance to Brazil in ecological, economical and strategical terms to have an efficient monitoring system to manage the natural resources and to protect the environment of this region. Such a monitoring system must have the capability to provide a fast response to either natural or man made events, which leads to the demand of quick access to ready available data, acquired on a high rate basis, which are not available nowadays. One important factor that precludes the efficient monitoring of tropical regions is the severe cloud cover condition associated with the low revisit rate of the current available optical remote sensing satellite systems. Indeed, most satellites have sun-synchronous orbit, with a revisit period of 1 to 30 days, which is not adequate to monitor fast changing events such as ongoing fires and deforestations. For instance, with the revisit period of 16 days of the Landsat images it is common to have less than one cloud free scene a year in certain parts of the Amazon region. With the SSR it should be possible

to acquire cloud free images, either directly or via multitemporal composed images.

2. THE SSR

2.1 Mission Requirements

The SSR intends to solve the lack of available data for monitoring purposes in the Amazon region, through an innovative solution. Taking advantage of the geographic localization of the Amazon region, the SSR should be placed in a low equatorial orbit providing synoptic images of the entire region several times a day. The sensor should have an Earth surface swath of 2200 km able to image the entire planet region comprised between the latitudes of 9° North and 15° South (Figure 1). The images should be provided in 4 spectral bands in the visible-VIS (blue, green, red) and near infrared-NIR plus a mid infrared band-MIR. The spatial resolution at nadir should be 40 m for the VIS/NIR bands and 500 m for the MIR band.

Several applications to monitor and study the Amazon region are being proposed with the SSR images, such as: a) quantitative evaluation of deforested areas; b) detection of burning and burned areas; c) characterization and classification of vegetation cover; d) natural vegetation regrowth; e) phenology of vegetation; f) agricultural activities; g) flooding and inundation; and h) mining activities. Since not only the Amazon region will be covered by the SSR images but also the whole equatorial belt around the world, as shown in Figure 1, other useful information should be provided by the SSR to: a)

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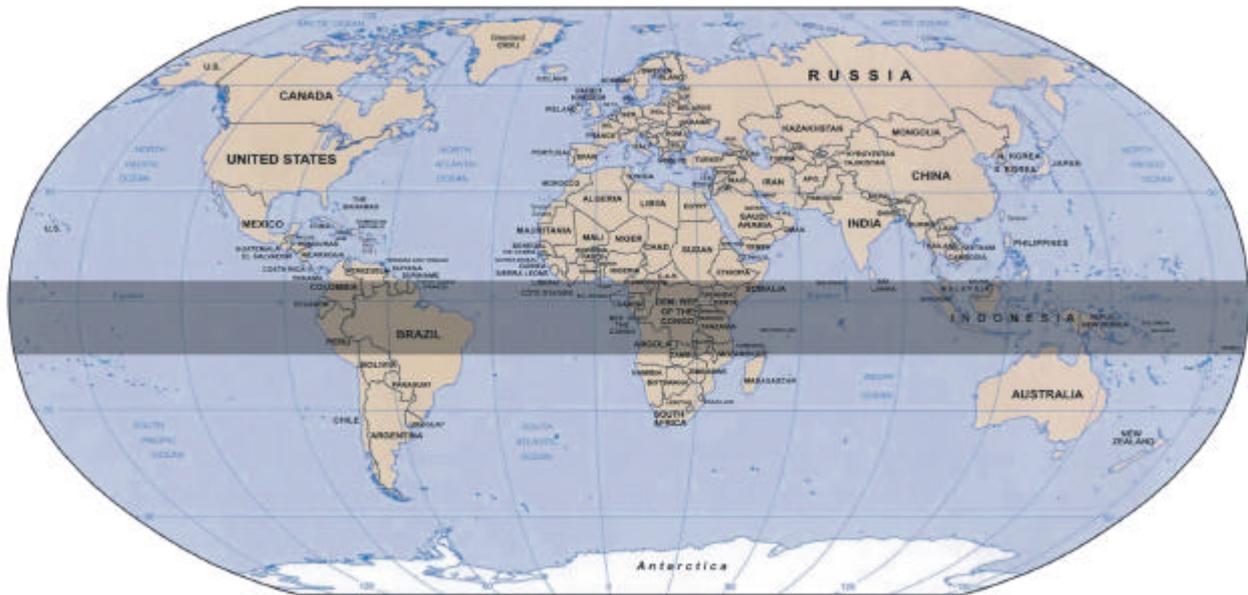


Figure 1. SSR World Coverage Area

desertification studies; b) oceanography; c) geology; d) solar radiation, among others (Rudorff et al., 1996). The SSR mission aims to provide relevant data to both scientific community and governmental agencies.

To reduce the latent time in data distribution, besides the standard centralized mission center, the system should also have the capability to distribute the SSR data directly to users in a near real time basis, via small and low cost stations. The SSR system will consist of the satellite and its ground segment as shown in Figure 2.

2.2 Mission Constraints

The SSR payload shall be modular and compatible with the Brazilian multimission platform and existing Ground Segment. The following constraints apply for the SSR payload module: a) mass is limited to 100 kg; b) average power shall be less than 140 W; c) down link bit rate shall be less than 150 Mb/s; and d) mission lifetime in orbit shall be 4 years.

2.3 Mission Peculiarities

Due to its unusual orbit and large swath width, this system brings some difficulties and challenges compared to usual systems with satellite in sun-synchronous orbits.

One peculiar characteristics is the wide variation range of solar incidence angles over the target. In an equatorial orbit, during a 12 minutes pass the satellite will span 3 time zones. This means that in a single image, the local time in one extreme will be 3 hours less than the local time in the other extreme, with great changes not only in illumination conditions but also in the size and direction of shadows. Besides that fact, the satellite should pass over a region several times a day (approximately every 100 min) and, therefore, solar azimuth will vary greatly for the different passes.

Another important factor is the extreme view conditions to image regions between latitudes of 10°S and 15° S. For instance, at 15°S the viewing geometry has an off-nadir angle of 56° and target view angle of 20° above horizon, as shown in Figure 3.

This will cause a significant increase of the length of the path through the atmosphere, introducing fading and distortions that will require special atmospheric correction techniques and procedures. In addition, the spatial resolution will be degraded from 40 m at nadir to 200 m at 15°S.

In order to assess the technical feasibility of the payload a study for the SSR payload was performed by DLR-*Deutsches Zentrum für Luft- und Raumfahrt*, in the frame of scientific and technological cooperation with INPE (DLR, 2001). The objective of this study was to demonstrate the capability to meet the requirements, to assess image quality in the extremes of the coverage and to show the compatibility with the Brazilian multimission satellite platform. As part of this study an airborne flight campaign was performed in the Amazon region using the HyVista hyperspectral camera-HyMap (Cocks et al., 1998).

In the next item the main results of this payload study is being presented .

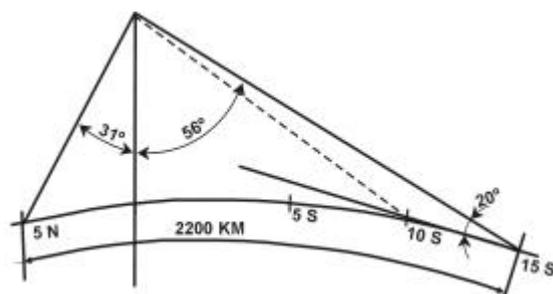


Figure 3. SSR-1 viewing geometry

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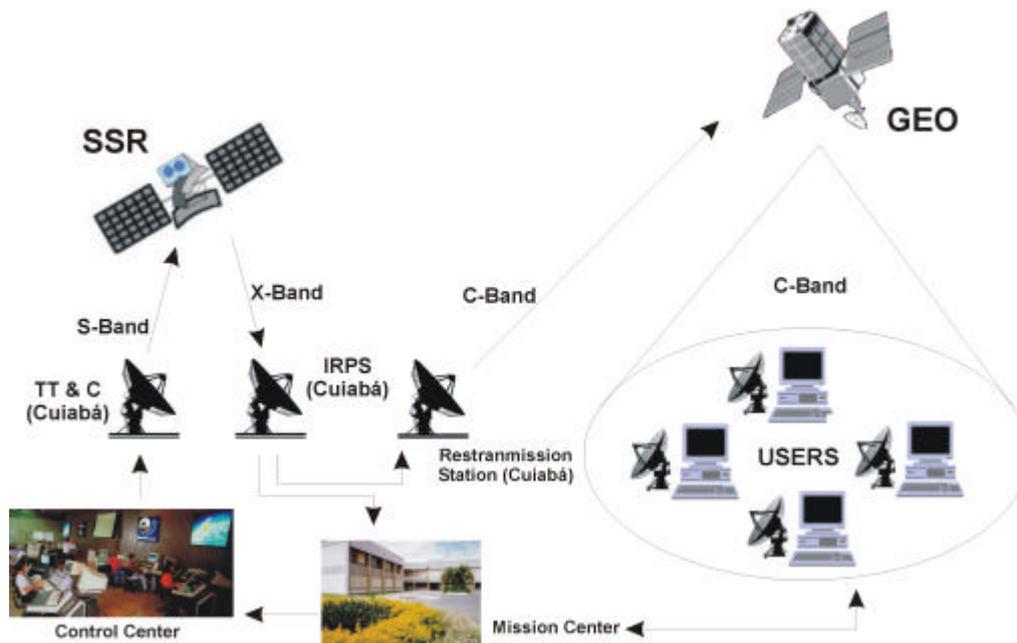


Figure 2. SSR-1 System

3. PAYLOAD CONCEPT

The study presents a payload concept that can fulfill the majority of the requirements and constraints. The payload design has taken into account the following principles: a) well-proven technology; b) small size; c) low power; and d) low cost. The baseline SSR imaging system consists of a VIS/NIR sensor unit, a MIR sensor unit, a Digital Data Processing and Control unit, and a RF unit. The overall payload configuration is shown in Fig. 4.

3.1 VIS/NIR Sensor

The VIS/NIR sensor is a pushbroom CCD camera with three optical heads, combined to achieve the FOV and geometrical resolution requirements. Each focal plane assembly has 5 parallel CCD lines, one for each spectral band. This design is based on the DLR High Resolution Stereo Camera (HRSC) heritage. The five spectral bands are blue, green, red, NIR and an additional channel (B5) for the estimation of the water vapor content, that will be used in an atmospheric correction procedure (Table 1). Table 2 shows the main characteristics of the three lenses. The detectors are Thomson THX 7834C linear CCD image sensor with 12000 pixels. The ground sample distance achieved with this configuration is shown in Figure 5. The output of the CCD detectors is converted to digital by a 14 bits A/D converter. This high resolution

| Bands | Wavelength | |
|-------|-------------|------------------------------|
| B1 | Blue | 0.447 to 0.502 μm |
| B2 | Green | 0.518 to 0.566 μm |
| B3 | Red | 0.636 to 0.682 μm |
| B4 | NIR | 0.786 to 0.890 μm |
| B5 | Water Vapor | 0.814 to 0.844 μm |

Table 1. VIS/NIR Spectral bands

| | North Lens | Middle Lens | South Lens |
|------------------------|------------|-------------|------------|
| Focal Length (mm) | 137 | 137 | 190 |
| F Number | 4.85 | 4.85 | 4.85 |
| FOV (degrees) | 31.8 | 31.8 | 23.1 |
| Aperture (mm) | 115 | 115 | 100 |
| Orientation from nadir | +15° | -17° | -44.5° |

Table 2. VIS/NIR Optical characteristics

A/D converter will allow to accommodate the whole signal dynamic range and to operate in all illumination conditions without gain switching. The estimated raw bit rate for this camera is 252 Mbps. Due to the limited downlink rate of 150 Mb/s, data compression will be employed. The selected method is online compression, using Constant Rate Wavelet based Image Compression (CWIC).

3.2. MIR Sensor

The MIR sensor is a pushbroom camera with two optical heads with 32° FOV, combined to increase the total FOV. Each optical head has one focal plane assembly with two staggered 512 pixels HgCdTe line detectors. A stirling type split cooler will be used to refrigerate the detectors, which shall operate at the temperature of 80 K. This design is based on the DLR BIRD heritage. Due to the high power consumption and the degradation of the geometrical resolution at high latitudes, it was decided not to cover the whole swath width of 2200 km with this sensor. The MIR sensor will cover the swath between 5°N and 5°S, with a GSD varying from 500 m to 700 m.

The MIR sensor shall cover the mid infrared spectral band from 3.4 to 4.2 μm and the output of the detectors is converted to digital by a 14-bit A/D converter. Since this dynamic range is not enough to avoid saturation, the sensor performs real-time processing to detect high illuminated pixels and reacquire those portions of the image with smaller integration time. The MIR

sensor shall have a Noise Equivalent Temperature Difference better than 0.5 K.

In order to improve the performance of fire detection in the presence of smoke, the inclusion of a TIR sensor was recommended by DLR.

3.3. Mechanical Design

All payload items are mounted on a dedicated panel, which provides the interface with the platform, as shown in Figure 6. This solution simplifies the interface definition, assembly, integration and test activities. The camera heads are mounted in a common optical bench to meet the co-alignment requirements.

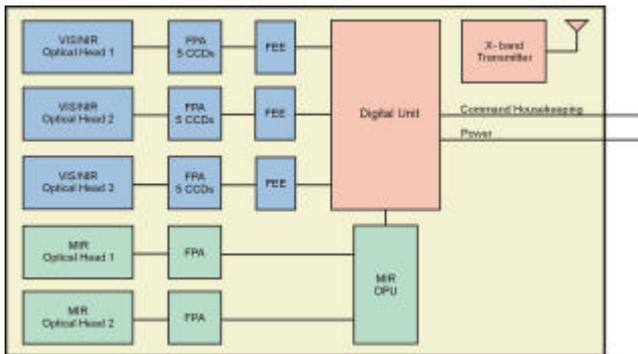


Figure 4. Payload block Diagram

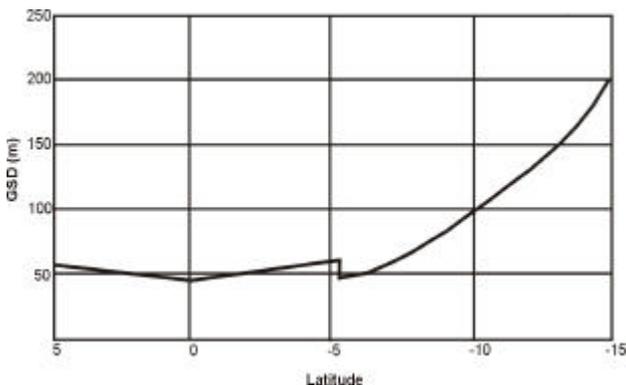


Figure 5. SSR-1 Ground Sample Distance (GSD) as a function of latitude.

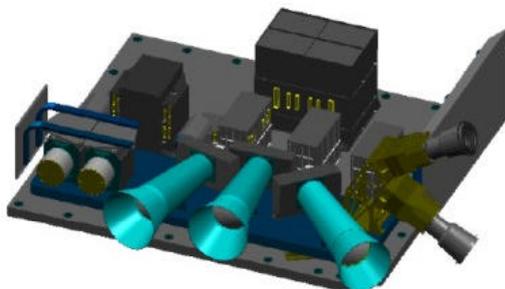


Figure 6. Mechanical Layout

The payload module key parameters are: a) mass of 95 kg; b) volume of 1084 x 1130 x 322 mm; and c) power of 375W / 97W (without heater).

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4. ACCOMPLISHMENT OF REQUIREMENTS

The accomplishment of the mission requirement was demonstrated using data from a flight campaign in order to simulate SSR-1 data and performing computer simulations to assess the performance of the sensor in different conditions. The flight campaign was carried out using the HyMap sensor (Cocks et al., 1998) in April 2000 over Amazon rain forest in the State of Acre, Brazil. To simulate the SSR-1 data the following scenarios were addressed: a) varying solar illumination condition over daytime; b) varying viewing geometry over wide angle; and c) target and atmospheric characteristics.

To simulate the varying solar illumination condition it was planned to acquire HyMap images every two hours from 8:00 AM to 4:00 PM. However, due to intense cloud cover conditions during the period allowed for the flight campaign (two weeks) data were acquired only for one favorable day around 8:00 and 10:00 AM. For the 8:00 AM path data were acquired at both nadir and off-nadir (up to 65°) by banking the airplane in order to simulate the viewing geometry over a wide angle (Figure 7). The targets were typical Amazon rain forest and deforested areas with pasture for cattle raising.

The main conclusions for the accomplishment of the mission requirements can be summarized as follows:

- 1) the noise equivalent reflectance of 1% for the blue channel can be fulfilled under a standard atmosphere (10 km meteorological range) for up to 8°S; further south this can be fulfilled only under good atmospheric conditions (23 km meteorological range);
- 2) at the southern extremity of the swath (15°S) the slant view shading effects may pose problems; for instance, at the latitude of 15°S, a tree with an height of 40 m will project a shade of 115 m;
- 3) strong view angle effects can be corrected taking into account turbidity, water vapor content and wavelength dependence of the aerosol scattering;
- 4) the influence of view angle on water vapor column content proved to be systematic and should be correctable
- 5) due to radiometric effects, in combination with the slant view shading and cloud shadows, the number of useful images are strongly restricted, despite of the high data acquisition rate
- 6) although much less HyMap data were acquired than initially planned they proved to be very useful not only to simulate illumination and viewing conditions but also to define the band characteristics;
- 7) interpretation of the HyMap data showed that even under extreme view angles important data products like the NDVI and water vapor path content can be extracted; and
- 8) future studies are necessary to develop standard methods adapted to the special characteristics of the SSR-1 images influenced by both sensor and target.

5. CONCLUSION

The preliminary results of the study show that the majority of the SSR requirements can be fulfilled with a payload composed by two instruments: a VIS/NIR and a MIR camera. It was concluded that due to power and mass limitations of the small satellite, it will not be possible to meet the geometric resolution and the swath width for the MIR camera. It was also found that

a significant loss in the image quality will occur for latitudes between 13°S and 15°S. Nevertheless, due to its high revisit rate, images from these region can be useful for certain applications.

The introduction of a TIR camera was recommended due to its suitability to perform accurate fire detection during daylight in the presence of smoke.

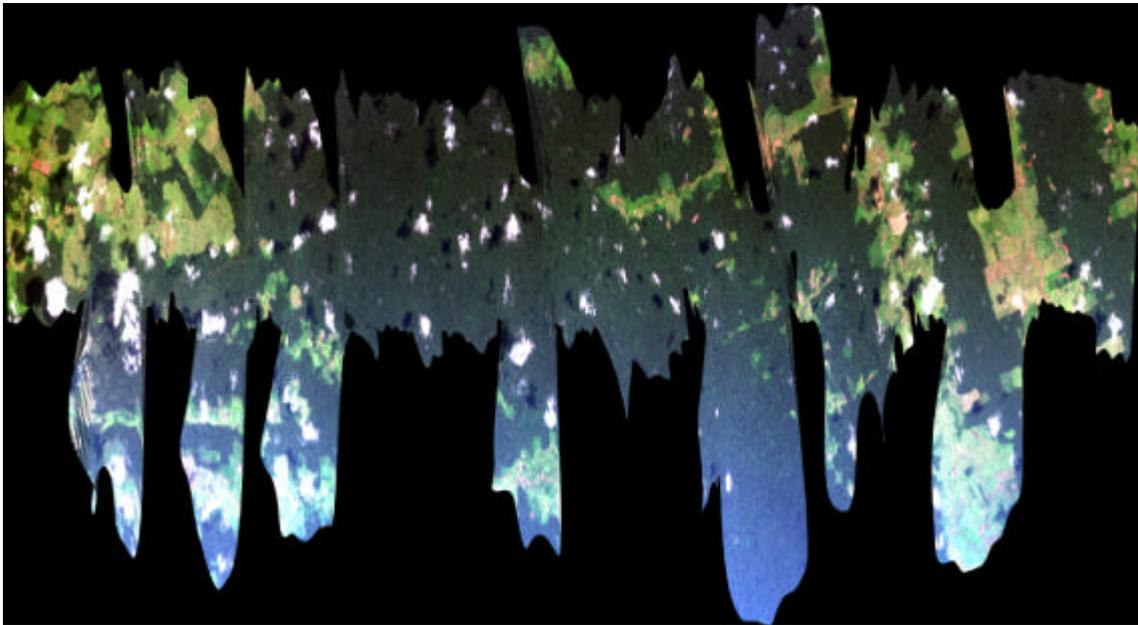


Figure 7. True color HyMap image (bands 15, 10 and 5) of the partially banked flight line over the study area in the State of Acre, Brazil.

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