THE NEW GENERATION SPOT SATELLITES SPOT 4 AND 5

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ABSTRACT

This paper presents the main characteristics of the new generation SPOT 4 and 5 satellites, the improved version of a series of high resolution imaging remote sensing satellites constituting the SPOT family. The main objectives of the SPOT 4/5 mission concern :

i) the continuity of the SPOT 1/2/3 services and products,
ii) the extension of the high resolution mission, in particular, through the addition of a new band in the middle infrared region,
iii) the development of a new optical instrument called Vegetation, characterized by a wide field of view and a high radiometric resolution, for the purposes of agricultural forecasts and environmental studies,
iv) the extension of the satellite life duration,
v) the capability to offer an embarkment to new passengers, and
vi) the reorganization and new development of the ground segment.

1. INTRODUCTION

The SPOT 1 satellite, the first of a series of high resolution imaging remote sensing satellites, has been successfully launched by the ARIANE launcher on February 22, 1986. After more than 2 years of operation, the SPOT 1 operational behaviour appears quite satisfactory, at the exception of some anomalies in the tape recorder operations which resulted in a definitive failure of one of the two tape recorders in July 1986. Moreover the SPOT 1 image quality fulfills the original system specifications as explained in Ref. 1. General information about the SPOT 1 system may be found in Refs. 2 to 5.

The basic mission of the SPOT program being to establish a continuity of the SPOT data and services, it has been decided :

- to produce two recurrent models named SPOT 2 and SPOT 3 ;

at the time of writing (may 1988), SPOT 2 has completed its integration phase and is planned to be launched in early 1989. The industrial phase of SPOT 3 has already started and SPOT 3 should be ready to be launched in early 1990.

- to develop 2 improved satellites named SPOT 4 and SPOT 5.

The design phase (phase A) of SPOT 4/5 is over, and its preliminary industrial definition phase (phase B) will be completed at the end of 1988. The industrial development and realization phases (phases

C and D) will start in early 1989, the goal being to be ready to launch SPOT 4 at the beginning of 1993 and SPOT 5 in 1995.

The main objectives of the SPOT 4/5 mission are the following :

- provide the continuity of the SPOT 1/2/3 services,

- ensure the extension of the high resolution mission, essentially through the addition of a new spectral band in the middle-infrared region and the on-board registration of the 10m/20m resolution channels in the high resolution instruments HRVIR,

- add a new payload named Vegetation, a wide field of view, low spatial resolution instrument for high repetitivity observations in the visible and middle infrared range,

- increase the life duration of the satellite,

- offer new possibilities of embarkment of passengers,

- improve the ground segment.

This paper describes these objectives, the main technical choices adopted for the space and ground segments, and their evolution relative to the SPOT 1 system.

2. CONTINUITY OF THE SPOT PROGRAM SERVICES

The SPOT 4/5 system must provide the continuity of the SPOT services up to the year 2000 at least.

The SPOT 4/5 system appears as an extension of the SPOT 1/2/3 system, hence the main system parameters have remained unchanged. Thus the orbit parameters, the local time and the main high resolution instrument characteristics (spatial resolution, swath, spectral bands in the visible and near infrared region, etc...) have not been modified.

The continuity of the SPOT 4/5 system is also apparent at the ground station interface level. The ground stations belonging to the SPOT 1/2/3 system will be able to receive and process the SPOT 4/5 telemetry emission without any other modification than proper equipment adjustment. In other words, it will be possible to program the SPOT 4 satellite in a mode compatible with the SPOT 1 modes with a telemetry format identical to that of SPOT 1 (see also section 3.3.).
Moreover the preprocessing of raw data as well as the use of system parameters to elaborate higher level products will be made possible with minor modifications with the type of hardware and software currently used in the ground stations belonging to the SPOT 1/2/3 system.

3. EXTENSION OF THE HIGH RESOLUTION MISSION HRVIR PAYLOAD

The SPOT 4/5 system will allow an improvement of detailed thematic inventories through the addition of a new band in the middle infrared region (this is why the HRV instruments have been renamed HRVIR, standing for High Resolution in the Visible and Infrared Range) and the ability to register on-board the 10 meter resolution and the 20 meter resolution channels.

3.1 Use of a middle infrared band (MIR) 1.58-1.75 microns

In agronomy and natural vegetation studies, the MIR band will permit an estimation of the ground humidity and will improve agricultural inventories, particularly those of cereals. The objective in this latter domain is to increase the performance of cultures identification with a monotemporal of multitemporal set of data, first, by bringing an information on the differences of water content in the vegetation cover either in time or between different parcels of a given agricultural zone, and second, by offering a better sensitivity than that of the near infrared channel B3 to the covering rate of the ground by the vegetation.

In hydrography, it will be possible with the MIR band to perform a detailed cartography of the snow mantle (since this band discriminates easily snow and clouds) and to inventory the various types of snow.

In geology, the 1.58-1.75 microns band can improve significantly the possibilities of discrimination between various types of minerals ; it can also give an access to the notion of ground humidity, and indirectly to anomalies of metal content of the ground.

3.2. Registration of 10m resolution and 20m resolution channels

The panchromatic 0.49-0.73 microns SPOT 1 band operating at 10 meter resolution has been replaced on SPOT 4 by the B2 band (0.61-0.68 microns). The 10m resolution channel is of strong interest in urbanism, forestry, small parcels inventory, texture analysis, etc... Many applications of the 10m resolution channel require its combination with the 20m data. The adoption of the same band B2 for the 10m and 20m resolution channels has made possible an instrument concept where both channels are registered on-board, which is most convenient in the production of data for such applications.

3.3. Main characteristics of the HRVIR payload

The HRVIR payload contains two identical HRVIR instruments. As those of SPOT 1, the instruments are pointable in the across track direction up to $\pm$ 27° ($\pm$460 km on ground) to provide accessibility and stereo coverage capability. The HRVIRs operate independently with the capability to produce monospectral (M), multispectral (X), and/or SPOT 1 compatible multispectral (XS) images whose swath width is 60 km at Nadir.

In the monospectral mode, the HRVIR generates a black and white image in the B2 band with a ground resolution of 10 meters by 10 meters.

In the multispectral mode, the HRVIR generates a multispectral image in 4 bands B1, B2, B3, MIR whose ranges are 0.50-0.59, 0.61-0.68, 0.79-0.89, 1.58-1.75 microns respectively at 20 meter resolution.

In the SPOT 1 compatible multispectral mode XS, the HRVIR generates a multispectral image in 3 bands B1, B2, B3 at 20m resolution.

The X and M data are compressed on-board using Delta Pulse Code Modulation techniques (8-5-5-8), while the XS mode is not compressed on-board. The pixel is restituted on ground on 8 bits.

Each HRVIR can deliver two 25 megabits /sec. data streams corresponding to the monospectral (M) and multispectral (X or XS) modes. Only two among the 4 bit streams available are transmitted to the ground or recorded on-board, the total telemetry data rate being 50 megabits/sec. The recording capability of each of the two tape recorders has been increased from 20mn (SPOT 1) to 40 mn on SPOT 4. The transmitted data are ciphered on-board.

The radiometric and geometric image quality criteria are listed in TABLE 1. Note that the instrumental radiometric resolution and dynamic range are obtained from the TABLE 1 ground reflectance data and from the assertion that the solar incidence angle be in the range 15°-60°. Note also that while the localization and length alteration criteria apply to rectified images using system corrections only (no ground control point), the photogrammetric restitution criterium applies to the processing of stereo pairs with the use of ground control points.

RADIOMETRY			GEOMETRY	
Ground reflectance resolution	$Ne\Delta\rho$	$5\ 10^{-3}$	Localization	1500m rms 4500m max
Ground reflectance dynamic range	ρMIN	0	Length alteration on image $\frac{\Delta l}{l}$	10^{-3} rms $3\ 10^{-3}$ max
	ρ^{MAX}	0.5(B1) 0.5(B2) 0.7(B3) 0.6(MIR)	Sampling regularity	0.1 pixel rms
Calibration accuracy	absolute band to band multitemporal	10% max 3 % max 10% max	Multispectral registration	0.3 pixel max
M T F	at Nyquist frequency	>0.3	Photogrammetric restitution (planimetry/ altimetry)	10m rms

TABLE 1 - HRVIR IMAGE QUALITY

We mention finally two interesting improvements of the SPOT 4/5 system relative to SPOT 1. First, it will be possible to program each HRVIR independently regardless of any possible motion of the pointable mirror of the other HRVIR, whereas on SPOT 1 such motion on one HRV invalidates the image acquisition of the other HRV due to pointing inaccuracies, resulting in significant programming difficulties. Second, there will exist at any time 3 operational analog gains per spectral band and per HRVIR ; the SPOT 4/5 mission center will program the appropriate gain out of the 3 gains available on different segments of a given orbit from criteria elaborated in advance with an histogram data base made of all histograms of cloud free scenes acquired by SPOT 1/2/3. Such a measure should be most appropriate in bands B1 and B2 where the scene radiometric dynamic range may vary significantly with season, latitude and the type of scene considered (sand, vegetation, etc...).

4. A NEW PAYLOAD : VEGETATION

4.1. The VEGETATION mission

The HRVIR instruments provide very detailed images of the Earth surface but their repetitivity of observations is sometimes insufficient for applications relative to renewable resources or environmental studies.
The Vegetation instrument, named also VGT, is conceived as a high radiometric resolution instrument with a wide field of view, with consequently a high repetitivity observation capability allowing a continuous monitoring of evolutive phenomena. The first priority objective of VGT is the worldwide operational monitoring of evolutions of crops and natural vegetation for the purposes of agricultural forecasts and environmental studies. The second priority objective of VGT is the observation of oceans mainly for scientific purposes. These two objectives are detailed hereafter.

4.1.1. Estimate of crops and natural vegetation monitoring

The possibility to estimate crop yields relies on the capability of VGT to monitor temporal evolutions of the ground reflectance. Hence the VGT instrument will deliver data which will eventually permit :

i) to retrace at any point the evolution of biomass and of the vegetal cover structure to detect possible growth anomalies or hydrous stresses,

ii) to cartography the disparities of evolution, in a given agricultural or climatic zone, by a multidate measurement over this entire zone,

iii) to provide an indication of the amount of biomass at its maximum.

The VGT data will also permit, besides the biomass evaluation, the estimation of the proportion of given species in large homogeneous regions. Such estimate, wherever possible, should be performed through a spatial extension of detailed classifications elaborated from HRVIR data.

These various informations will be obtained with a combination of the VGT informations at any point in the bands B1, B2, B3, MIR, the same bands as those of HRVIR.

4.1.2. Oceanography

The addition of a "blue" band B0 (0.43-0.47 microns), centered on the main absorbtion band of phytoplankton pigments, makes possible the monitoring of the amount of vegetal biomass in water, with the following potential applications :

i) cartography of spatio-temporal variations of the distribution of phytoplankton and archive,

ii) quantitative estimation of worldwide primary production of phytoplankton,

iii) climatologic and biogeochemical studies (carbon fixation, CO_2 cycle),

iv) use of biomass as a tracer of the dynamics of superficial water masses,

v) assistance to fishing by fast localization of zones of high phytoplankton concentration.

The bands B1 and B2 can also be used, in addition to B0, to perform a mesoscale monitoring of water turbidity, in particular along the coast lines. All these applications require careful atmosphere corrections which will be taken care of by the system.

4.2. The VGT operations

The VGT instrument can generate 2 channels at 500 kbits/sec. data rate each.

The first channel is called "direct" or "regional" channel and transmits data in real time with a spatial resolution at nadir of about 1 km. This operating mode is called "Regional Observation" and provides information from the region in which the station (Toulouse or another ground station) is located. The working zone for the Regional Observation is subject to the condition that the sun incidence angle be lower than 60°.

The second channel is called "recording" or "worldwide" channel and transmits data which have been recorded at 4 km resolution at nadir. The 4 km resolution is obtained by agglomerating onboard 4x4 neighbouring image elements at 1 km resolution. The production of 4 km resolution recorded data is called "Worldwide Observation" and can be obtained only at the Toulouse station. The working zone for the Worldwide Observation is nominally located between 60° North and 40° South.

A very high repetitivity of observations is achieved, taking into account the orbit characteristics, by a wide field of view of the instrument (± 50°) corresponding to a swath width of 2200 km. With this configuration, a given point on ground is seen every day by VGT above a latitude of 35°, and seen 3 days out of 4 at the Equator.

4.3. The VGT instrument

The VGT instrument contains a radiometer made of 5 objectives (one for each spectral band B0, B1, B2, B3 and MIR) and an electronic chain which amplifies and codes on 10 bits the signal.
An array of 1728 CCD detectors is located in the focal plane of each objective.

The main characteristics of the VGT payload are displayed in TABLE 2, while the VGT geometric and radiometric image quality criteria are listed in TABLE 3.

Weight	160 kg
Volume	0.7 x 1 x 1 m^3
Power	200 watts
Data rate	2 x 500 kbits/sec.
Pixel coding	10 bits
Telemetry frequency	8.2 GHz
Recording memory	256 Megabits

TABLE 2 - VGT MAIN CHARACTERISTICS

RADIOMETRY			GEOMETRY	
Ground reflectance resolution	NeΔρ	10^{-3}(B0) 1 to 3 10^{-3} (other bands)	Localization	2400m rms 5000m max
Ground reflectance dynamic range	ρMIN	0	Local distorsion on image	0.3 pixel rms 0.6 pixel rms
	ρMAX	0.1(B0) 0.5(B1) 0.7(B3) 0.6(MIR)		
Calibration accuracy	absolute band to band multitemporal VGT/HRVIR	10% max 3 % max 10% max 3% max	Multispectral registration	0.3 pixel max
M T F	at Nyquist frequency	>0.3	Localization VGT/HRVIR	1500m rms

TABLE 3 - VGT IMAGE QUALITY

Note in TABLE 3 that the local distorsion on an image remains sufficiently small that 2 images taken at different dates be superimposable to a 1 pixel rms accuracy and to within a translation of an integer number of pixels (less than 5 by virtue of the localization performance).

5. EXTENSION OF LIFE DURATION AND MODIFICATIONS OF THE SATELLITE

A number of improvements have been inserted in the satellite design, in order to improve its performances and increase its life duration from 2 years (SPOT 1 concept) to 5 years.

The increase of life duration will be ensured by an appropriate choice of elementary components and by a new thermal design in order to lower the average operating temperature and hence reduce the failure rate of the electronic components.

The flexible solar arrays of the solar generator have been replaced by a solar array with rigid panels, a concept both simpler and more reliable, and the available power end of life has been extended from 1100 watts (SPOT 1) to 1800 watts. Moreover the 3 x 24 A.h batteries have been replaced by 4 x 40 A.h batteries to accomodate to a higher demand of power and to provide a reduced depth of discharge.

The mechanical concept has been changed by adding an "equipment case" between the platform and the payload. Such equipment case is needed to accomodate the new tape recorders and to provide a mechanical support to the HRVIRs and VGT payloads as well as to a number of passengers of the SPOT 4/5 platform.

The in orbit configuration is shown on FIGURE 1.

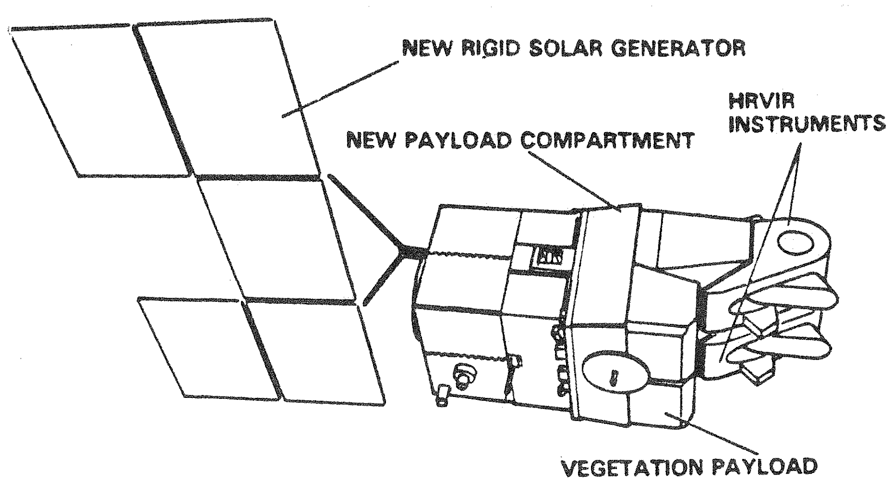

FIGURE 1 - SPOT 4 IN ORBIT CONFIGURATION

6. THE SPOT-4 PASSENGERS

The extended capabilities of the SPOT 4 satellite allow to embark the following additional experiments :

- PASTEC (PASsager TECnologique) which is a group of experiments for studying orbital environment,

- DORIS (Doppler Orbitography and Radiopositionning Integrated by Satellite) which will be used for precise orbit determination and localization of ground platform,

- a Radar Transponder which will be used to calibrate the ground radar of the Guyana Space Center and to train the operators,

- PASTEL (PASsager Spot de TELecommunication Laser)

The PASTEL package is part of an European Space Agency program for the experimentation of an optical link between a low orbit spacecraft (SPOT 4) and a geostationnary satellite. This optical link will be used for transmitting the SPOT 4 payload data stream at a rate of 2 x 25 Mb/sec.
These data will demonstrate the feasibility and performance of optical communication and will be used on a pre-operational basis to relay image data.

Using these facilities will bring about a fundamental change in the capabilities and management of the system. As an example, Figure 2 shows the visibility on earth between SPOT 4 and a geostationary satellite located at 19°E. As seen in Figure 2 the visibility is restricted mainly by the Earth and the SPOT 4's body which may obscure the optical link.

The operational SPOT services will still use the tape recorder and ground station network, while the optical link will be used to extend image transmission capabilities in the event of lack of tape recorder capability or failure.

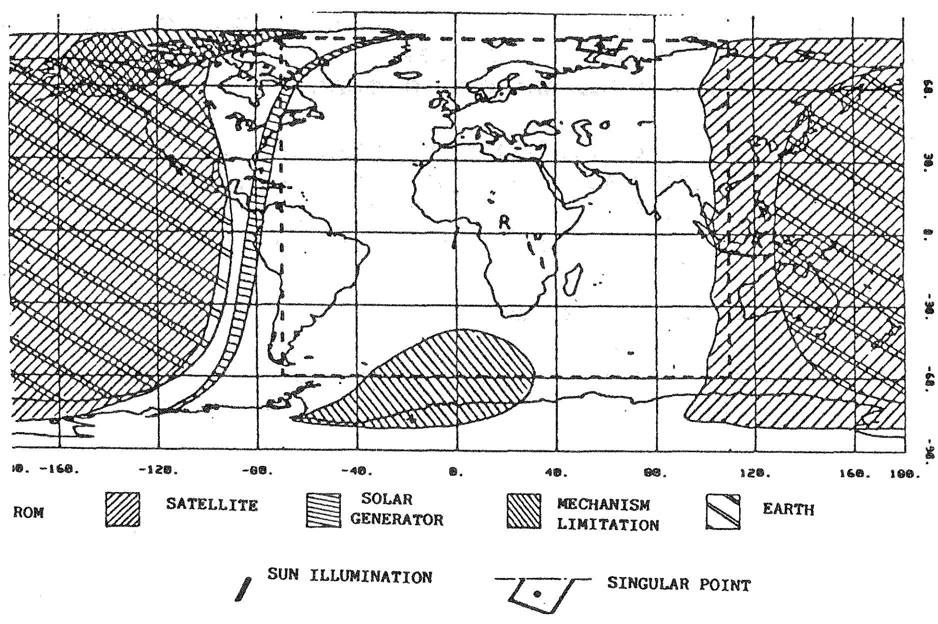

FIGURE 2 - PASTEL GROUND COVERAGE

7. THE GROUND SEGMENT

7.1. The image ground segment - Products

Two stations -TOULOUSE and KIRUNA- will be used to ensure a large direct and playback transmission capacity of the HRVIR data. Night passes and some day passes will be used to collect recorded VEGETATION data on the TOULOUSE station.

Apart from these stations direct read-out X band stations can be implemented worldwide to acquire HRVIR and VGT data.

The Toulouse and Kiruna stations contain an HRVIR Archiving and Preprocessing Center which archives all the HRVIR data and processes level 0 and level 1 products. These centers are also capable to process images issued from the SPOT 1/2/3 archive.
The level 0 product is an exchange level product with geographically arranged pixels and a raw radiometry.
The level 1 is a radiometrically corrected (level 1A) and geometrically corrected (level 1B) product. Only system corrections are applied to perform the geometric rectification. Note that contrary to SPOT 1 the level 1B scenes can be mosaïqued along the track without further processing and centered upon request at any point along the track. Note also that the cloud cover notation at the inventory step (catalogue) of the image processing will be significantly improved relative to the SPOT 1 system, by the addition of automatic and semi-automatic analysis methods (analysis of the reflectance and reliability, graphics facilities,etc...).

The Toulouse station includes also a Preprocessing Center of VGT images which produces and archives level 1 data. The level 1 VGT product is characterized by radiometric and systematic geometric corrections, as well as a systematic correction of atmospheric effects. The VGT level 1 product contains also reduced data such as the vegetation or turbidity indexes, and a simplified classification map (snow, cloud, water, ground).

The products delivered by the Toulouse VGT Center will be available within 8 hours in the Regional Observation mode, 36 hours in the Worldwide Observation mode after their acquisition by the satellite, as soon as VGT enters its fully operational phase.

7.2. Organization of the ground segment

In the operational phase, after the post launch assessment, the responsabilities will be shared between the various entities as follows.

The satellite operator (CNES) will be in charge of the Control Center and the Platform and Payload Management Center. These centers perform all satellite management functions, monitor the satellite operations, generate the necessary commands and determine the orbital parameters.

The commercial operator (SPOT IMAGE) has the exclusive license to organize the promotion, the distribution and sale of SPOT data. It will be in charge, moreover, of the Mission Programming Center and of the Toulouse image ground segment. The Mission Programming Center is responsible for mission management regarding the HRVIR and VGT payloads. It programs the on-board image acquisition and storage in accordance with user requirements, and also sends the data necessary for image acquisition and processing to the ground stations.

8. CONCLUSION

CNES has undertaken an ambitious earth observation and data distribution program. This ambition is obviously already apparent since SPOT 1 has been giving most satisfactory results for more than 2 years of operational life, and since the following satellites SPOT 2 and SPOT 3 have been either built or fully decided. The aim now is to ensure a continuity and an improvement of the SPOT services and products up to the year 2000 and beyond.
The SPOT 4/5 system has been designed to fulfill this requirement. This generation of satellites represents a technological challenge (in particular, the development of CCDs in the MIR band, the wide field of view objectives with CCD arrays of Vegetation, the development of a new polar platform) and widens the field of potential applications of earth remote sensing, especially through the use of the new payload Vegetation.

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