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PRINCIPAL CHARACTERISTICS OF A NATIONAL SATELLITE FOR EARTH OBSERVATION. PROJECT SPOT

Centre National D'Etudes Spatiales

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16. Abstract

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Table of Contents Page

1. INTRODUCTION /1

The rational management of the Earth's resources and environment cannot be imagined without the continuous flow of information on the atmosphere, geological information, geographic information, and ecological information. Space observation systems for Earth observation offer a particularly powerful means for obtaining this information in a systematic way, and with a sufficiently small delay. For this reason the development of remote detection methods from space for the observation of the earth's environment is one of the main tasks of the CNES space program.

In a general sense, the purpose of Earth observation is to obtain a quantitative and detailed knowledge about variations in the Earth environment. This is considered as a step required for developing a rational management plan for natural resources. In the long term, the following must be done:

- explore, establish and maintain an inventory of the limited resources or slowly-renewing resources in the ground, in the subsoil, in the atmosphere, and in the bodies of water;

- to observe the regional and time variation of the ecological processes, and also those which are initiated or modified by human activity: food production and utilitarian utilization of the soil, and the surface waters (agriculture, forests, animal breeding, fisheries...) contribute to the efficiency of essential activity;

- support of fishing, agricultural practice, detect, predict, and finally influence the evolutions of the following: oceanography, climatology, soil erosion, ground pollution;

- monitor natural and dangerious phenomena and activity: seismology, volcanic activity, meteorology (flooding, drought, storms), accidental pollution.

Such ambitious objectives can only be reached by carrying out a /2 research program including multidisciplinary studies and experiments. It will be supported by a number of additional ground measurements and by remote detection. Space remote sensing is an essential part of such a system.

It is in this context that the CNES conceived and proposed the SPOT (Earth Observation Probe System) program, which consists of an observation platform which is easily adaptable to future missions. The principal characteristics of the system were presented in the phase A report in March, 1977, and in the document CST/D/863 of October 31, 1977, entitled "Principal Characteristics of the National Earth Observation Satellite".

Based on this, the Economic and Social Committee on February 9, 1978, headed by the Premier Minister, decided to implement this system with a target date of 1984 for the satellite.

The committee asked CNES to list the applications of the SPOT platform, especially from the point of view of orbital corrections. The present document is a revision of the one published on October 31, 1977. This paper contains more details about the numerous subsystems.

2. OBJECTIVES AND CONCEPT OF THE SPOT SYSTEM /3

2.1 General Concept of the SPOT system.

The general objectives of Earth observation lead to a number of missions: exploration of the resources of our planet, detection and prediction of phenomena related to climatology and oceanography, monitoring of activities and natural phenomena, etc.

Remote sensing from space is a particularly fruitful tool for integrating a multi-disciplinary research, study and test program. It is assumed that the tool which we wish to develop will be adaptable to a large number of missions.

It was therefore in this context that the SPOT system was conceived. One of its essential elements, the satellite, includes a flexible platform capable of carrying different types of payloads for the different missions. The load capability of the European ARIANE launch vehicle is perfectly compatible with such a multi-mission platform.

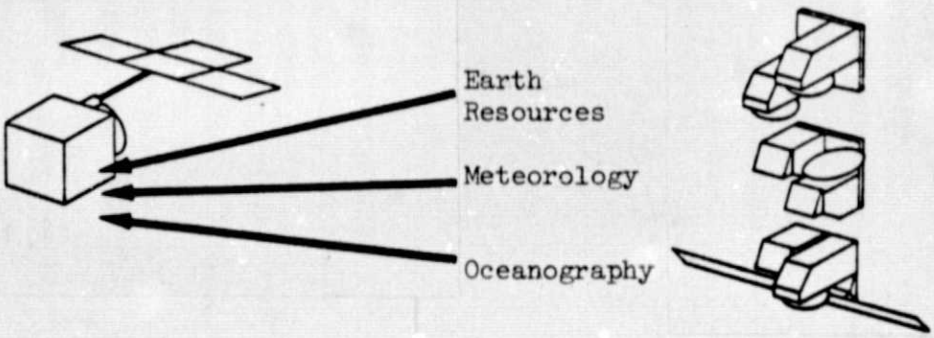

Figure 1: Standard Platform. Specific Mission Payloads.
• Earth resources • Meteorology • Oceanography

2.2 The First Mission

For the first SPOT satellite mission, we suggest the utilization of the territories as a theme. It has become apparent that large sectors of the economy which are in rapid growth are adjusting poorly because of the limited amount of statistical and cartographic conventional data, which is obtained with substantial delays. Public agencies wish to have available detailed localized information, which is frequently updated, regarding the utilization of an entire territory. The evolution of agricultural resources, forest resources, and grazing resources will depend heavily on this information. Also it will be used to evaluate and protect the quality of the environment.

Urbanization policies, for example, can be defined, promoted, and controlled more efficiently by repeated observation of the areas involved, which are undergoing rapid transformation.

At the present time, there is no information collection system which is sufficiently rapid and repetitive for observing vegetation cycles, evaluating the water content of soils, the amount and quality of water reserves, the progressive transformation of rural areas into urban areas, and the interactions between the oceans and the coast. A remote sensing satellite is particularly well-adapted to the study of these phenomena, and their interdependence.

SPOT program will provide additional information to the existing or planned civilian systems, and the information will respond to the requirements of European specialists, because of a finer ground resolution which is better adapted to the European surveys.

The first mission will carry two identical HRV (High Resolution Visible Range) instruments, which will each cover the visible and near IR (infrared) range inside a field of view with dimensions of 60 km, and with a ground sampling step of 20 m, or 10 m depending on whether /5 the instrument is operating in the multi-spectral (3 wavelengths) range or in the panchromatic mode. There is a mirror at the inlet of each instrument, which is oriented perpendicular to the satellite track. With it, one can change the viewing axis of each instrument within an angular range of ± 26°. This possibility will allow scientists to obtain stereoscopic pairs of the same ground area, and to reach areas which are quite far-removed from the satellite ground track (400 km to each side).

Assuming the above definition and assuming that the satellite is placed into a heliosynchronous orbit at an altitude of 822 km, the first mission can perform the following, depending on the utilization mode:

- a systematic global coverage of the Earth in 26 days
- accessibility of any point with an average access time of 2.5 days,
- production of stereoscopic pairs of the same area at close time intervals (per year, at the level of the EUROPE, there will be 84 opportunities of obtaining a given pair, one day apart).

2.3 Qualification of a Multi-Mission Platform

The concept which has been adapted allows re-utilization at minimum cost in future missions, with minimum delay, and re-utilization of a large part of the equipment developed for the first mission. In order to do this, the satellite has two parts; one is called the "platform", which includes the service unit (attitude control and orbital control systems, electrical power supply, on-board management system, remote measuring system and remote communications system) which can be re-utilized by most of the Earth observation systems. The other part is called the "payload" part, which includes specific equipment and instruments for the mission.

The objective of the SPOT program, in addition to the success of the first mission described above, consists of qualifying the multimission platforms for all of its tasks. Its parameters are defined by the following:

- heliosynchronous orbits with altitudes between 570 and 1200 km /6
- local time of ascending node, or descending node between 8 and 16 hours,
- weight of payload: 650 kg
- electrical power supplied by the solar generator can reach 1200 W,
- lifetime $\geq$ 2 years.

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3. DESCRIPTION OF SPOT SYSTEM

By relaxing the requirements for global optimization of the satellite, the concept allows the greatest possible autonomy of the instruments or equipment specific to the mission, with respect to the space vehicle proper.

The system includes the following:

- A satellite consisting of a payload and the standard platform,
- A ground complex consisting of an image station (oriented towards the payload) and a collection of control stations (oriented towards the platform). Additional image stations can be added later.

The main elements of the SPOT system corresponding to the first mission are described in Figure 2.

Figure 3 shows a satellite corresponding to the first mission, consisting of a platform and a payload containing two HRV (High Resolution Visible Range) instruments. /7

SATELLITE

Payload	Standard Platform
- high resolution visible instrument #1	- structure
	- thermal control
- high resolution visible instrument #2	- power supply
	- attitude control
- image remote measurement	- orbital control
	- onboard management
	- TM - TC (telemetry, telecommand)
	- data collection unit (to be defined)

GROUND COMPLEX

Ground image part	Ground Control Part
- image remote measurement reception	- engineering remote measurement reception
- pretreatment	- telecommand transmission
- storage	- technical controls
- dissemination	- orbitography
- user service	- satellite programming and pretreatment programming.

Figure 2: General Structure. SPOT, first mission.

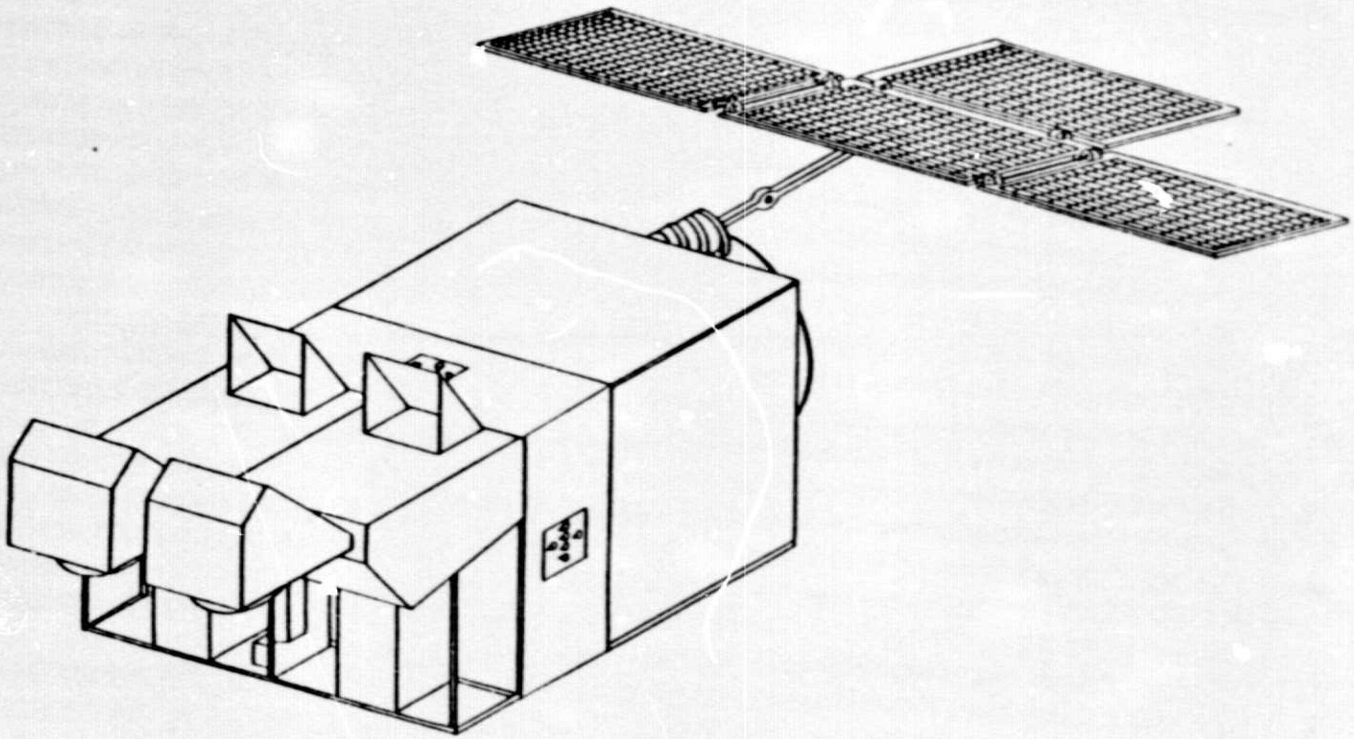

Figure 3: SPOT Satellite. First Mission

3.1 Description of the Multi-Mission Platform

The platform utilized for the first mission can be re-used for other Earth observation missions, as we have stated. Therefore, it is "polyvalent" in the sense defined previously in paragraph 2.3.

3.1.1 General Configuration

The proposed configuration is a result of the requirement for orienting the solar generator for the various possible satellite attitudes with respect to the sun. The platform configuration is compatible with a radiation-cooling system for the payload, for low circular heliosynchronous orbits and for local node passage times between eight hours and sixteen hours.

Figure 4 shows the design adapter.

The desired "polyvalence" (multi-use) and modularity for the platform dictate the following characteristics:

- the very distinct separation bewteen the vehicle and the payload allows the possibility of implementing the wide variety of payloads, with simple interfaces;

- nonsymmetric design of the solar generator on the vehicle, so that a good solar aspect coefficient is obtained, for any local hour angle of the considered heliosynchronous orbit. This design also allows complete protection against parasitic reflected light from the solar panel, which could deteriorate the performance of the payload (passive radiator for the thermal infrared range in particular).

The platform consists of two parts:

- The surface equipment compartment is a parallelepiped connected with the central tube, through which the forces are transmitted and in which the battery compartment is located. Each of the bases is dedicated to a platform subsystem and consists of a panel on a hinge, such that satellite integration operations are facilitated, and that all /11
equipment is easily accessible. The Earth side is reserved for the management subsystem equipment, as well as the remote sensing and remote command antennas.

The opposite face is used to support the solar panel in the launch configuration.

The other faces have the following equipment: equipment power supply subsystem, attitude and orbital control subsystem equipment,

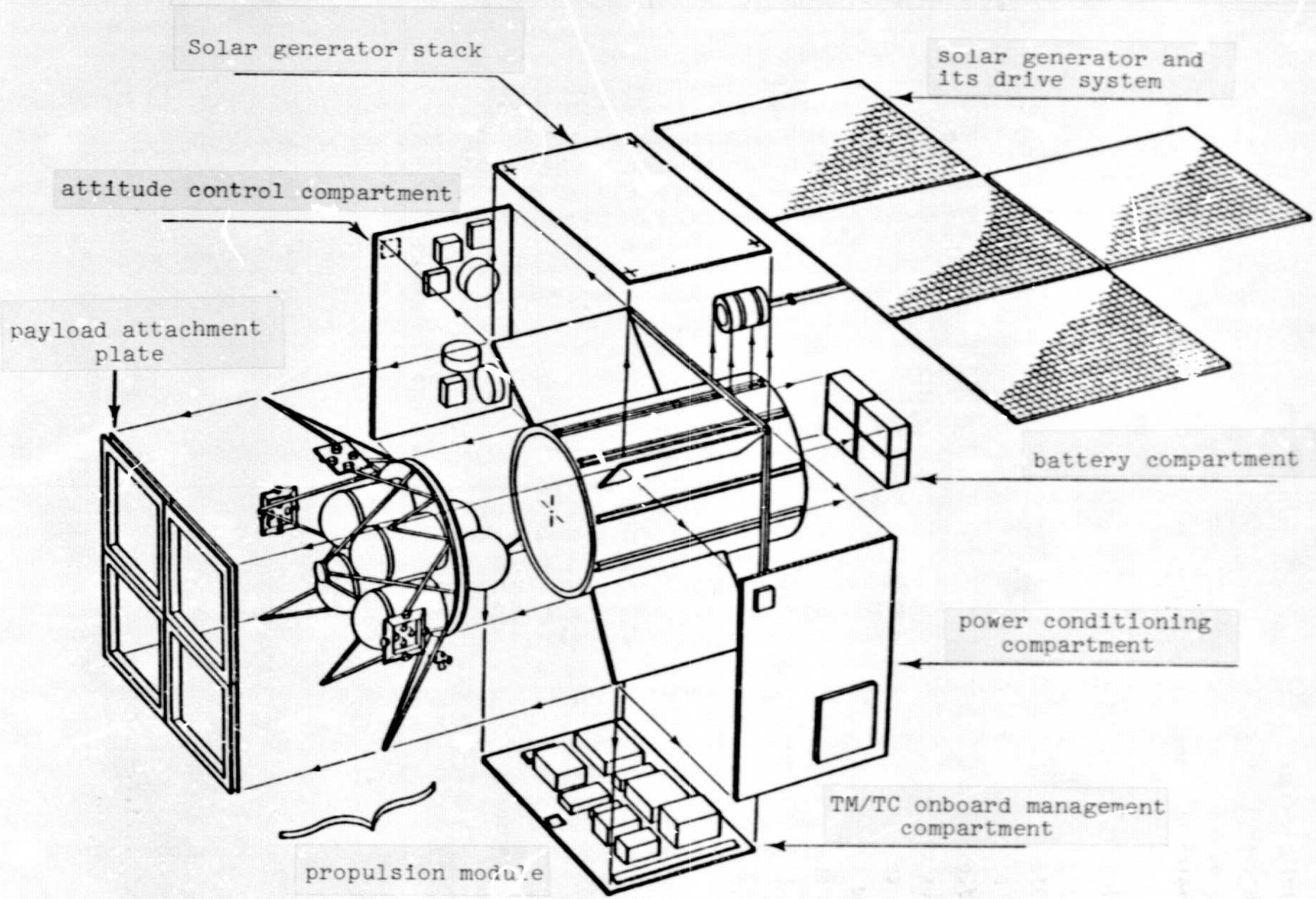

Figure 4: SPOT: Standard view of Platform.

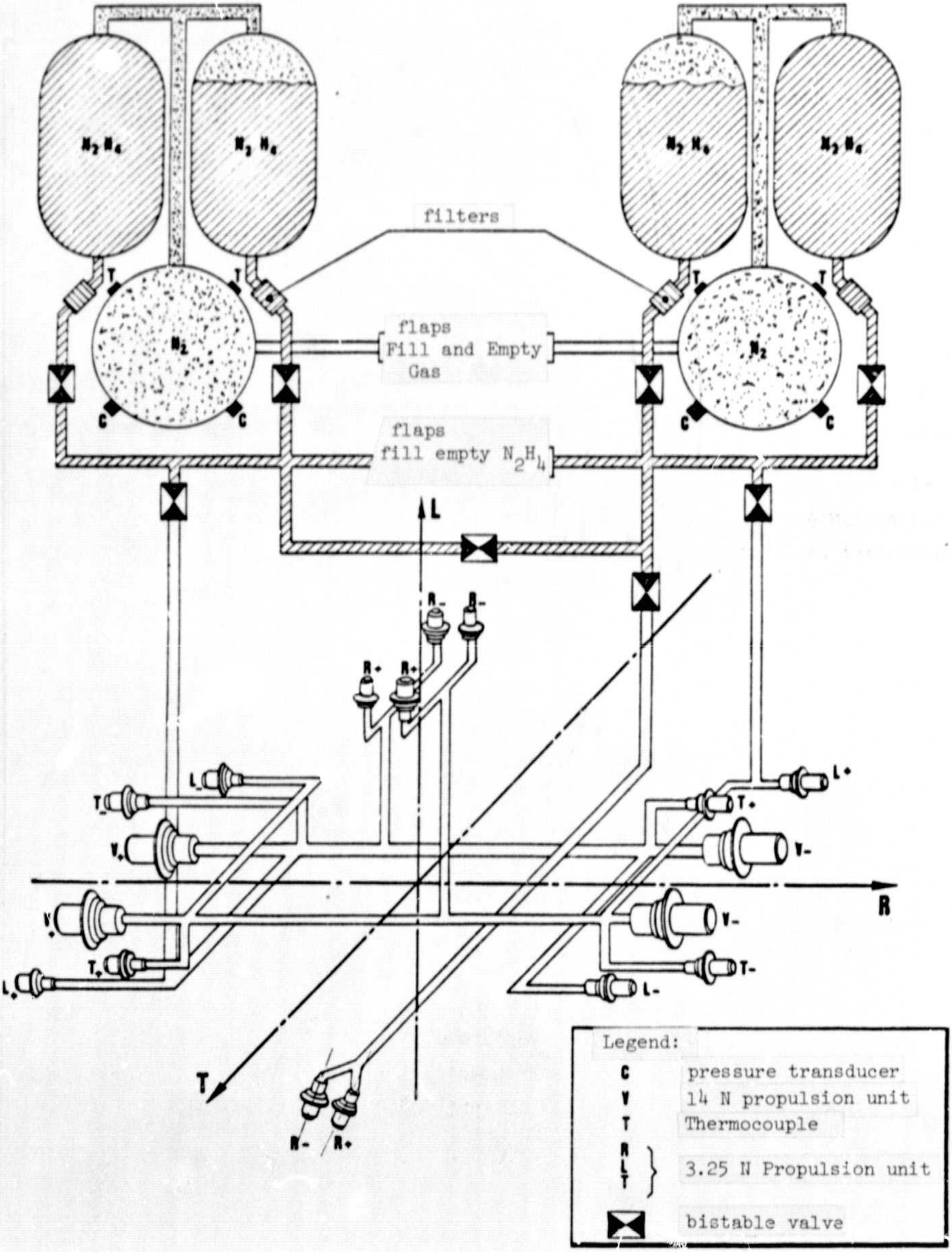

Figure 5: Synopsis of the "Hot Gas" System.

except for the attitude sensors, Earth sensors, and solar sensors, and the gyrometric block, which is connected to the payload plane so as to minimize the differential flextures. This will also eliminate severe position adjustment problems for this equipment, with respect to the payload instruments.

- the orbital control compartment includes reservoirs and attitude and orbital control lines. This complex is the "hot gas" system, sketched in Figure 5. It can be integrated separately, and is aligned with the extremity of the central tube. This compartment supports the payload platform, and has the dimensions 1,800 x 1,900 mm.

This configuration provides a distinct separation between the main functions (orbital control, attitude control, picture-taking, remote sensing). It satisfies all the requirements for the Earth observation platform, in particular there is a possibility of selecting the local time of picture-taking, or of installing an instrument which includes a radiation system for cooling the infrared detectors.

3.1.2 Control and Attitude Restitution Subsystem. /13

As far as the attitude control system is concerned, the requirement for the geometric relationships of the images is translated into relationships between angles and pitch, roll, and yaw angular rates. The main purpose of the attitude control system is to maintain the angles and the drift rates within narrow limits, which are the result of these relationships. This must be done over the picture-taking interval.

	Roll	Yaw	Pitch	Unit
Pointing accuracy	0.15	0.15	0.15	Degree (3σ)
Residual Rate	3×10^{4}	5×10^{4}	1.5×10^{-3}	Deg/sec(3σ)
Angle measurement	0.11	0.11	0.11	Degree (3σ)

The attitude control subsystem consists of transducers, actuators, and electronics which provide the commands to the actuators from information provided by the transducers (see Figure 6).

In order to obtain the requirement performance (the performance determines the quality of the multispectral images obtained), the transducers used for both control and measurement are classified into four categories:

- two infrared earth sensors with sweep for measuring roll and pitch angles. Their operation is independent of the orbital attitude.

- two fine solar sensors, whose position depends on the local time adapted for taking pictures. It is used to calibrate the gyrometers.

- a triaxial gyrometer block which detects yaw and measures the rotation components around each of the three roll, yaw, and pitch axes.

- a collection of solar sensors with a wide field of view for attitude acquisition.

For controlling attitude, we have the following actuators:

a) During the picture-taking phase,

- three reaction wheels mounted on the magnetic beams with a maximum kinetic moment of $\pm$ 10 Nms;

- two magnetic coils (or magneto couplers) used for desaturation of the reaction wheels.

b) For the first acquisition and controlling attitudes during orbital maneuvers, there is an additional hydrazine actuator.

Piloting is of the numerical type, and is controlled by the programmable on-board computer.

3.1.3 Orbital Control Subsystem

This subsystem is indispensable for acquiring and maintaining a heliosynchronous orbit with a correct phase, and provides the following four main functions:

- acquisition and maintenance of the nominal attitude just after satellite orbit insertion and during orbital maintenance operations;

- fine acquisition of nominal orbit

- maintenance of the orbit (maintenance of the phase relationship);

- modification of the semimajor axis of the orbit, if necessary, in order to modify the phase relationships of the ground tracks.

The hydrazine system used allows one to perform corrections in the orbital plane, as well as corrections perpendicular to the orbital plane (maintenance of the heliosynchronous condition, and the adapted local time). The stress levels are two Newtons and 14 Newtons, at the beginning of the mission.

Up to 300 kg o' stored hydrazine can be loaded in four pressurized reservoirs. /16

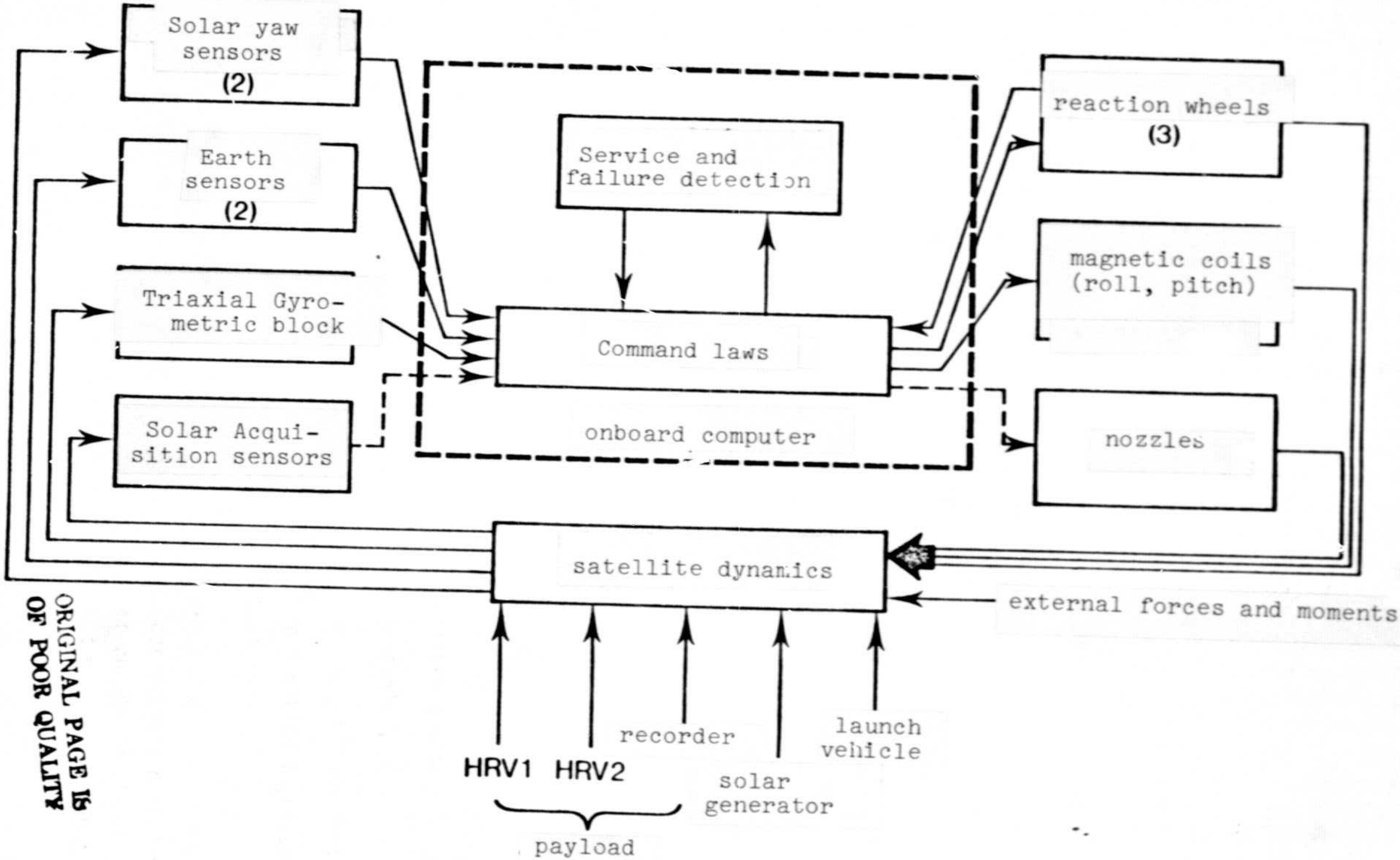

Figure 6: Attitude and Orbital Control Subsystem

3.1.4 Service Telemetry, on-board Computer, and Remote Command Subsystem.

The purpose of the service remote measuring system is to transmit information on the operation of the satellite. In contrast to the payload telemetry data rate, the data rate is small; less than 2 kbits per second.

The service telemetry measurement system (engineering telemetry system) consists of an S band antenna, and its lobe is formed such as to attenuate the gain variations observed on the ground. A helicoidal antenna provides a link to the ground in a cone with a half-angle at the apex of 66°. A transmitted power level of less than 0.5 W is sufficient, which means that a traveling wave tube does not have to be used. The information to be transmitted is formatted by an on-board computer. An auxiliary antenna provides coverage in the case of loss of nominal attitude.

The remote programmable on-board computer provides management of the entire satellite operations, in particular, the following functions:

- management of the payload activity over seven orbits (or fourteen orbits): upon remote programming instructions from the control station, picture-taking initiation, calibration sequences, orientation of the viewing axis of the HRV instrument, etc., are implemented.

- adaptation of the command laws such as to compensate for deviations between flight values and predicted values, and also to consider the real behavior of the satellite (thermal control, orbital maintenance);

- Adaptation of the command laws to the subsystems, as a function of their natural aging condition (residual contents of reservoirs, output of solar collectors). /17

- adaptation of the telemetry format to the control functions to be carried out, which varies depending on the operational phases: attitude and orbital acquisition phase, picture taking phase;

- maintenance of an on-board data log and accounting of any incidents, particularly any incident which occurs outside the visibility zone of the control station.

Under normal conditions, the remote command function provides loading for the on-board computer. In the case of a computer failure, the remote command system could directly command the main operations in the satellite. The operating frequency is in the 2025-2120 MHz band.

Figure 7 shows the layout of the subsystem.

3.1.5 Power Supply Subsystem

This subsystem (see Figure 8) is designed to adapt to the particular conditions of each mission: variation of the average (power) consumption depending on the payload used, variation of the incident solar radiation condition depending on the orbit and the local time used for picture-taking. The observation platform has a solar generator made up of a wing consisting of four panels, which are folded during launch. The delivered power at the beginning of the mission is 300 W for each panel.

The power supply subsystem consists of the following four major components:

- the solar generator already mentioned;
- the tracking system around the pitch axis which provides permanent pointing of the panel towards the sun over the part of the orbit in the sun;
- a power conditioning electronic unit;
- two to four batteries, each having 23 elements of 23 Ah each.

The 50 a.h. elements will not be qualified for the first plat- /20
form, but could be developed and utilized for the following platforms.

The rotation motion of the panel, which continuously follows the direction of the sun, is provided by a stepping motor which is commanded synchronously. The attitude control performances given above take into account the perturbations due to this drive system.

The power supply possibilities delivered by the platform to the payload will be discussed in paragraph 3.5.2.

3.1.6 Thermal Control Subsystem

This sybsystem is designed for multimission operation for the platform. The thermal control principle is based on the temperature stability of the side facing the earth. The other faces are partly protected by superinsulation coverings: there are spaces in these coverings so as to provide windows for thermal control.

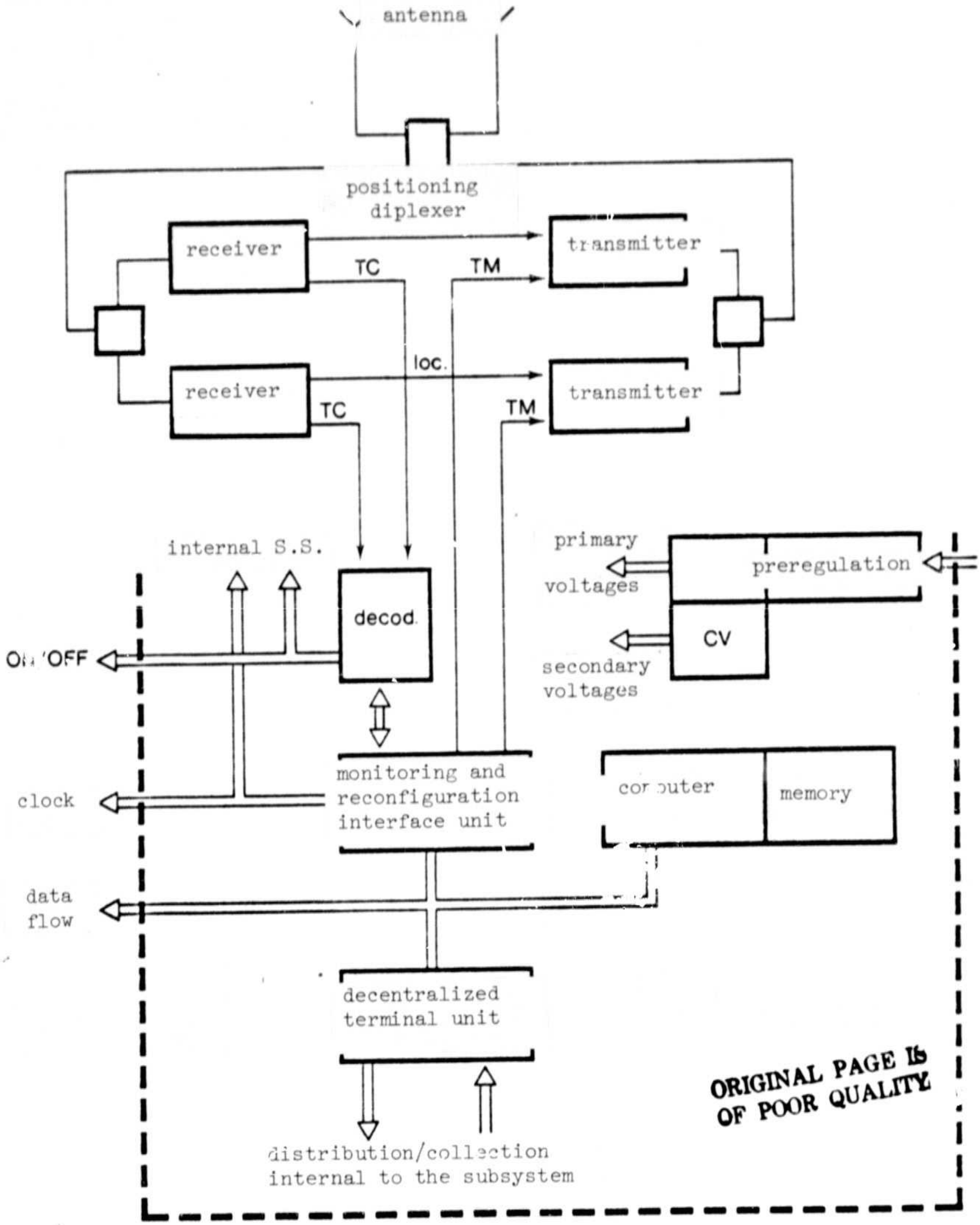

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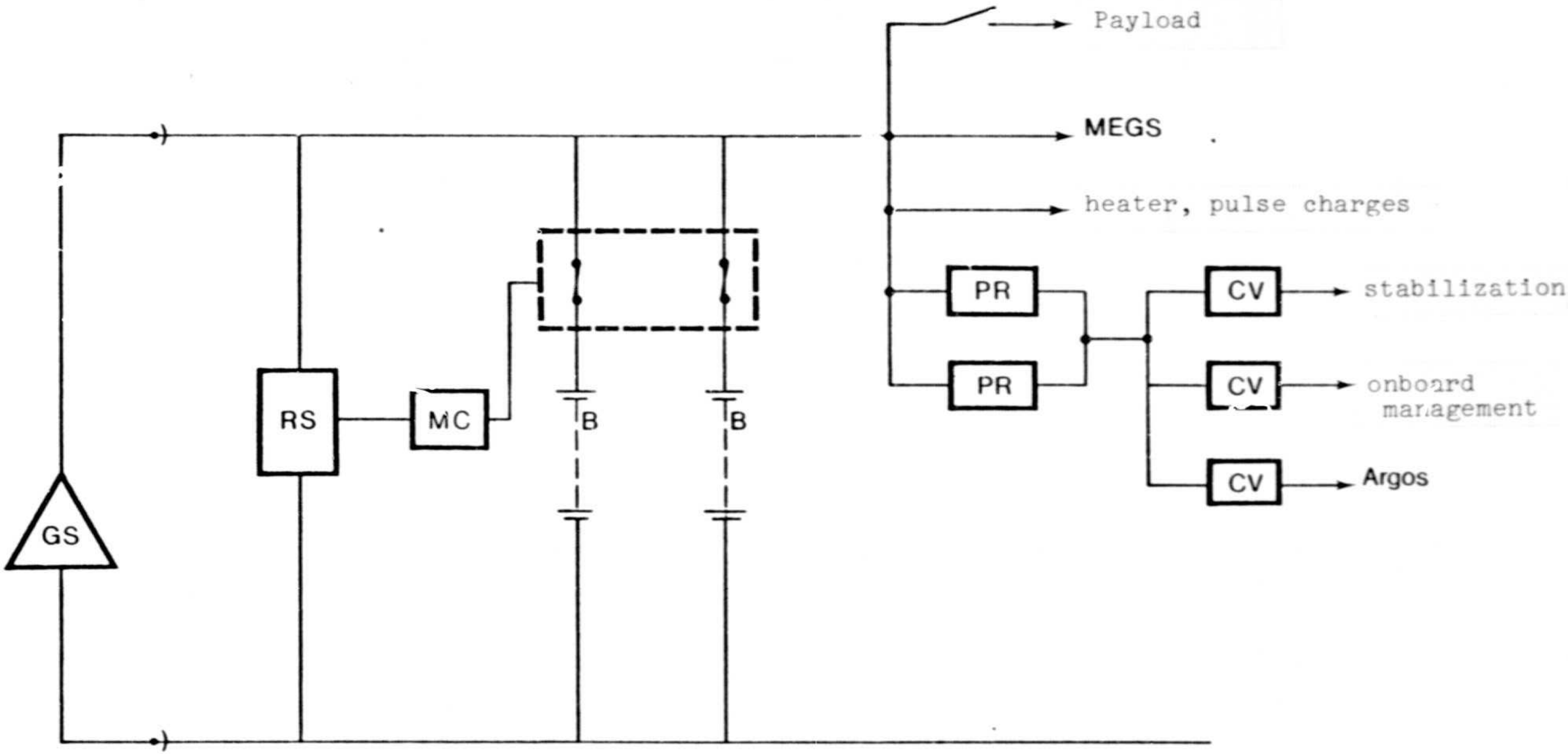
Figure 7: Telecommunication and On-board Management System.



GS: Solar generator (maximum 4 panels)
RS: shunt regulator
MC: control module
B : battery (1 to 4)
PR: preliminary regulator
CV: converter

Figure 8: Power Supply Subsystem

SUMMARY OF THE MAIN CHARACTERISTICS OF THE MULTI-MISSION PLATFORM /21

Dry weight	700 kg
Weight of Hydrazine Transported	300 kg
Payload Transported:	
- mass	650 kg
- static moment	700 m-kg
Lifetime	2 years
Electrical Power of Solar Generator	1,200 W at the beginning of service
Service Remote Commands:	
- frequency band	2025/2120 MHz
- number of commands	510
Service Remote Measuring	
- frequency band	2200/2300 MHz
- emission power	$\leqslant$0.5 W
- number of transmitted words	256, 8 words each
- TM rate	2 kb/s

Figure 9

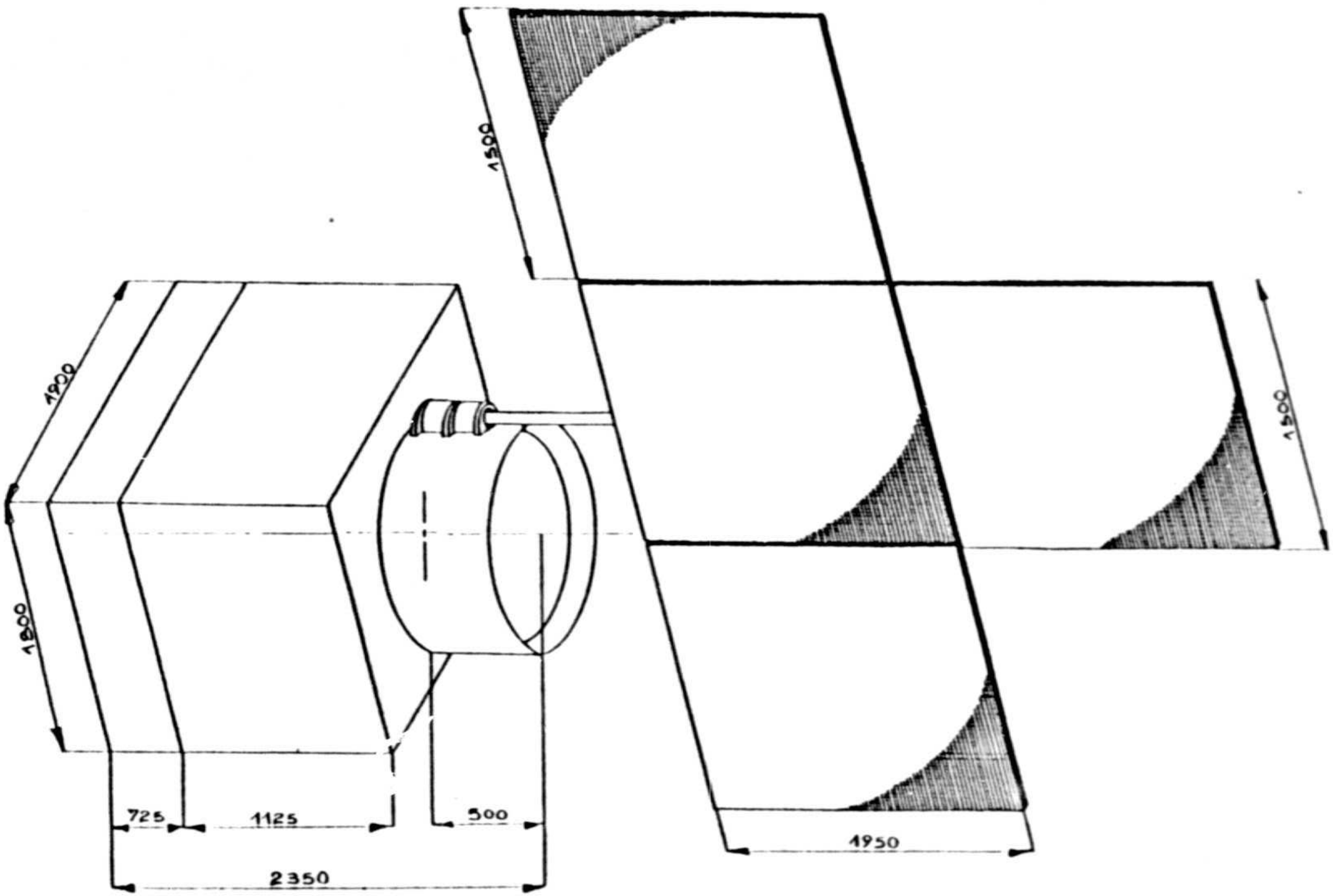


Figure 10: Dimensions of the Platform

The thermal control of the payload is uncoupled from the platform thermal control.

3.1.7 Data Collection Subsystem

To be defined and probably is optional.

3.2 Description of the First Satellite /23

3.2.1 The Orbit

The observation of natural resources from space requires a linear ground resolution on the order of 10 to 100 m, especially for the European area , where utilization of the data is very highly structured. For this application, the geostationary space observations are beyond technical states of the art. Consequently, we specified a low circular orbit, which alone will provide the required degree of resolution, obviously at the expense of intermittent regional coverage. The orbit is in a quasipolar plane, which allows the satellite to fly over all areas of the globe.

Consequently, it is important that successive operations from space are obtained as much as possible under the same illumination conditions, which means that the satellite should always have over a given region the same solar time. If there are no perturbations, the orbital plane will remain fixed with respect to a sidereal reference, such that the sun-earth direction will turn almost 1° per day (exactly 360° in 365.24 days). Celestial mechanics tells us that the oblateness of the earth perturbs the motion of a low altitude satellite and produces a precession of the orbital plane. By appropriately selecting the inclination of the orbital plane with respect to the equator, we can very exactly obtain the precession of almost 1° over 24 hours, which is required to exactly maintain the same geometric relationship between the orbit and the sun-earth direction.

Such an orbit is called heliosynchronous: a satellite placed in this heliosynchronous orbit will always pass over a given latitude at the same solar time. The selection of the time is indifferent from the point of view of celestial mechanics, but it obviously is very important for the quality of the observations.

On the other hand, one wishes to have the maximum number of /24 stereoscopic pairs obtained one day apart, with a viewing angle which is sufficient so that the two images of a landscape on the ground are relatively stable. The possibility of pointing the viewing axis of the instruments means that one has to take into account the case of ecular reflections of the sun on water surfaces, when selecting the loc.. time period (of picture-taking). This selection is made by taking into account the previous arguments, and by maximizing the period during the year when the zenith elevation of the sun (θs) is greater than 60°.

Finally, it is desirable to compare successive images of the same region obtained precisely for the same viewing angles. This is not possible unless the satellite orbit periodically passes over the same place, after an even number of days which constitute an orbital cycle. This assumes an exact relationship between the revolution period around the planet and the earth's rotation rate. This relationship is called the phase in this present study. It is obtained for certain discrete values of altitude and inclination of the orbit. Among the discrete values we have selected the following orbital characteristics:

- quasipolar circular orbit
- average altitude 822 km
- inclination 98.7°
- revolution duration: 101 minutes
- orbital cycle: 26 days
- local time at descending node: 10 h 30

3.2.2 The Payload

The first payloads consist of two identical high resolution visible range (HRV) instruments. The data from these instruments are transmitted to the ground by a specific telemetry panel.

3.2.2.1 The HRV instrument.

The resolution is one essential characteristic of this mission: one could not obtain it using a mechanical sweep system.

The instrument takes pictures without any moving parts; sweep mirror, shields or modulating discs. It is obtained using a mixed sweep mode:

- the formation of a line of the image is the result of a line of detectors in the focal plane of the instrument, and the sweep of the line is done electronically;
- the succession of the image lines results from the motion of

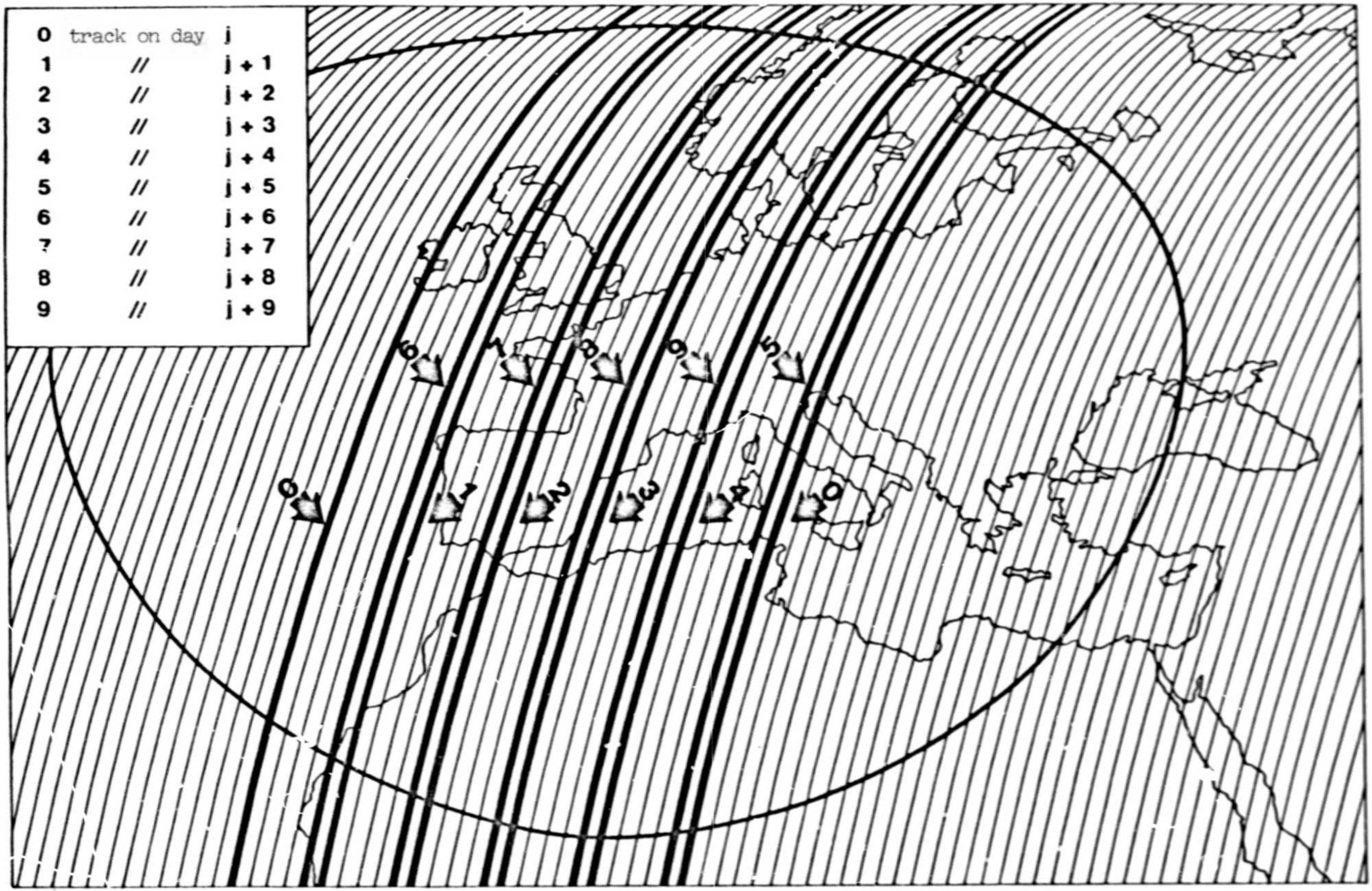


Figure 11: Descending Orbits Over Europe.

the satellite on its orbit (Figure 12).

Therefore, we have the following two important factors:

- maximum picture-taking interval for each point of the landscape;
- great mechanical simplicity, which has also the advantage of giving an excellent geometrical quality to the image, due to the designs.

In order to realize this sweep mode, one must have a line of detectors in the focal plane of the instrument, which represents a collection of 3000 detectors, in the case of a sampling step of 20 m over a 60 km field. There are 6000 detectors in the case of a 10 m sampling over the same field. The detectors selected are charge transfer detectors, (DTC), arranged in bars, each containing more than 1000 discrete detectors.

For each bar, a sequential transfer device along the register /28
means that only a single amplifier is necessary for formating the signals of the entire bar.

The following table summarizes the main characteristics of the images of each HRV:

INSTRUMENT FIELD	60 km
Spectral bands	(XS) .5 - .59 μm; .61 - .69 μm; .79 - .90 μm (20 m)
	(P) .5 - .9 μm (10 m)
Orientation of the viewing axis	$\pm$ 26° in steps of 0.6°
Displacement rate of the viewing axis	4°/s
Coding	8b linear (XS) : 24 Mb/s 6b (P) : 24 Mb/s
Radiometric resolution (multispectral)	$\simeq$ 0.5 for $\theta_s \leq 60°$ θ_s = zenith elevation.

The sensitivity of the instrument allows the detection of the ground reflection variations on the order of 0.5 degrees, for good illumination conditions (sun more than 30° above the horizon, that is, $\theta_s = 60°$).

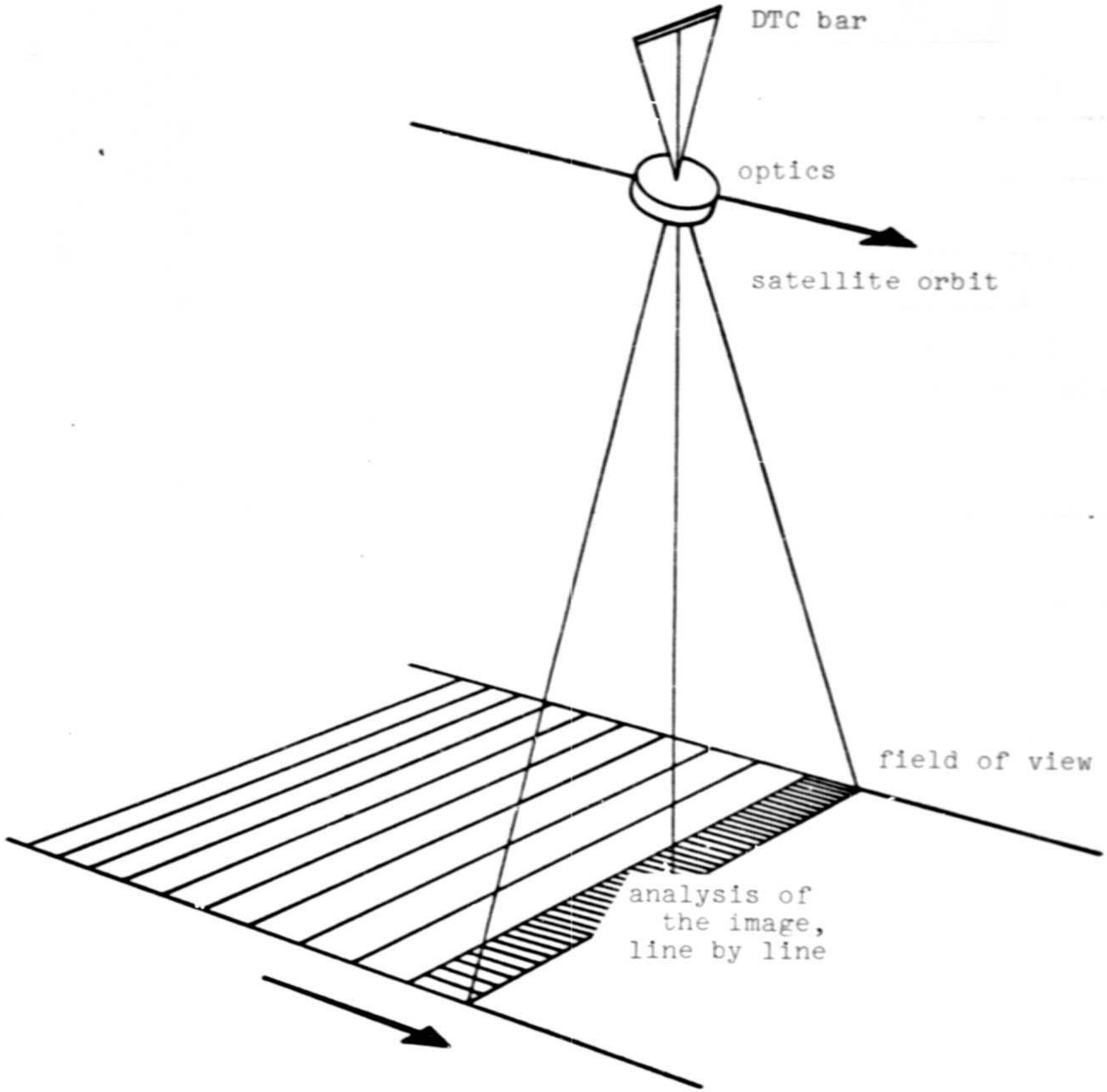


Figure 12: Illustration of the PUSH BROOM sweep

/27

One fundamental quality desired for multispectral observation is the capacity to place images of the same landscapes observed under different spectral bands with an accuracy of several tenths of the image /29 element, with point-by-point coincidence. By separating with a dichroic prism, we can obtain point-by-point coincidence on the rough image, and this was also used for the colored bands. The panchromatic track is separated from the multispectral track within the instrument field.

Optical System

Of course, this is a critical element considering the excellent quality to be maintained over an extended field. The HRV instrument (see Figure 13) consists of a telescope with a focal length of 1,082 mm and an aperture of f/3.5. Three dichroic prisms placed in the focus provide spectral separation perpendicular to the satellite track. At the head of the telescope there is a flat mirror which can be oriented so as to displace the viewing angles. By using two instruments, we can obtain stereoscopic pairs from one orbit to the next, as shown in Figure 14.

Detectors

For each spectral band, a collection of detector bars transforms the luminous signal into a sampled video signal. By adjusting the gain by remote control, we plan to obtain the best possible usage of the coding dynamics as a function of the solar incidence conditions.

The concept for this optical system is based on the use of DTC bars, which are made up of elementary 13 μm detectors.

In this configuration, certain numbers of innovations must be studied and validated in a very rigorous fashion. This is why two aircraft systems operating according to the "push-broom" principle were developed, and which respectively used 500 and 1,728 points. /32

The models were studied and were built in the CENTRE SPATIAL DE TOULOUSE (Toulouse Space Center Laboratory). The first tests took place in the spring of 1976, and the instruments were flown on a B-17 aircraft of the National Geographic Institute, at the end of July, 1976. The photograph on the following page was taken in October, 1977, in the Amiens region.

The results obtained in the laboratory and the experiments carried out recently lead us to believe that such a remote detection unit will be successful.

3.2.2.2 Telemetry from the Payload

For the mission, each of the two instruments can operate in the multispectral mode (XS) or the panchromatic (P). The two modes among the four possible ones are transmitted by the payload telemetry system. The data rate of the payload is two times 24 Mb/s, which is 48 Mb/s. Regulations regarding authorized frequencies allow a telemetry transmission in the X-band (8,025 to 8,400 GHz). Use of this band requires technology, the development of which is straightforward, both for payload equipment and ground equipment. Considering the two instruments for picture-taking, the payload telemetry system consists of two independent information chains (one for each instrument, and simultaneous transmission of the two numerical trains is obtained by frequency multiplexing).

In addition to the images, a small amount of additional information on the payload or the platform (calibration, synchronization) are multiplexed and transmitted by the payload telemetry system. Also, the information required for pretreatment is located in the same image data reception station.

Each payload telemetry emission chain consists of a quadriphase /34 8 GHz modulator, a nominal 20 W power transmitter, a collection of filters for limiting the occupation of the spectrum of frequencies, and a fixed antenna which covers the complete visibility cone of the earth.

Two recorders will store picture-taking data and will restitute it during the passage of the satellite over the Toulouse image station. The storage capacity of each recorder is 30 minutes.

The synoptic layout for telemetry is shown in Figure 15.

3.2.2.3 SPOT and other Earth observation systems

The characteristics of the optical instruments proposed for the first SPOT mission must be close to those of the instruments of LANDSAT 1, 2, and 3, which are presently in orbit, as well as LANDSAT D which will be launched in 1982 (see following table).

3.2.3 The Platform

The platform used for the first mission is the multimission standard platform described in paragraph 3.1, with the following remarks supplied:

- solar generator consisting of four panels will only have cells on three panels. The supplied power (900 W) is sufficient. Nevertheless, the four panels will be placed in orbit in order to qualify the deployment sequence.

- the amount of hydrazine used on the first mission will be one-half of the carrying capacity of the platform (two reservoirs will be orbited out of four); effectively, this is amply sufficient for the requirements of the mission. In the course of the development of the first platform, we will qualify the two configurations, with two and four reservoirs.

- the on-board computer program is specific to the first mission for the models of the payload.

3.2.4 The Ground Complex

The ground complex provides a link between the SPOT satellite and the user. It consists of three parts, which provide the following three functions: Management proper of the satellite using the ground control segment, which monitors the satellite functioning state, which generates the remote command and which determines the orbit flown; the production of the images transmitted by the satellite is provided by the ground image complex; the management of the entire complex and in particular the planning of the picture-taking and the image treatment as a function of the user requirements are performed by the mission control center. Figure 18 shows the general organization of the ground complex.

3.2.4.1 The ground control complex

The ground control complex consists of servicing stations which transmit remote commands, receive platform telemetry, and provide positioning measurements. During the operational exploitation phase, a /42
single station located at Toulouse is sufficient. The crew station will provide redundant back up in the case of failure of maintenance operations. During the launch phase and orbital acquisition phase, other stations from the NASA or ESA network will be added.

A communications network from the servicing stations to the

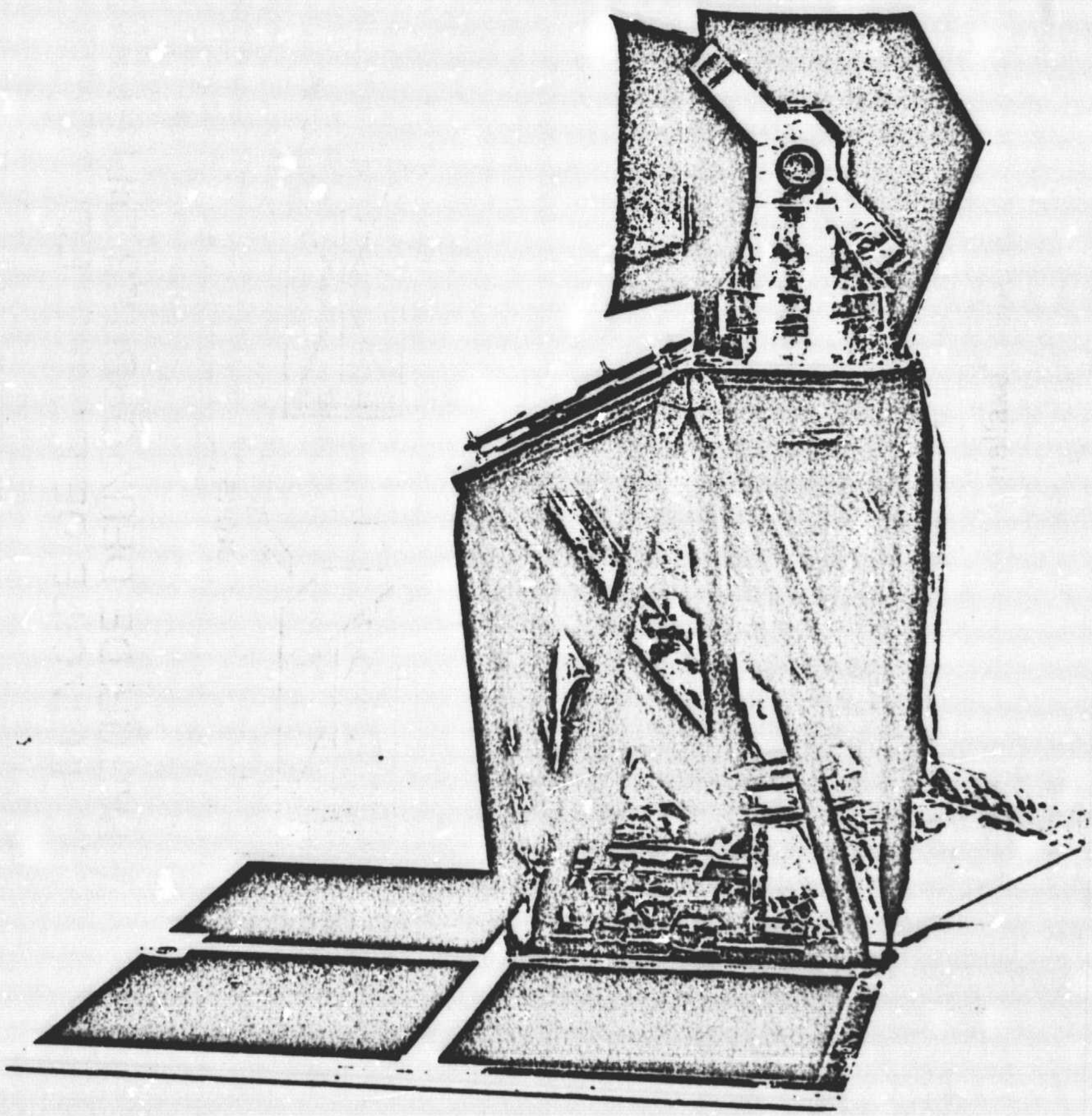


Figure 13: HRV Instrument; Outline of the Structural Mockup

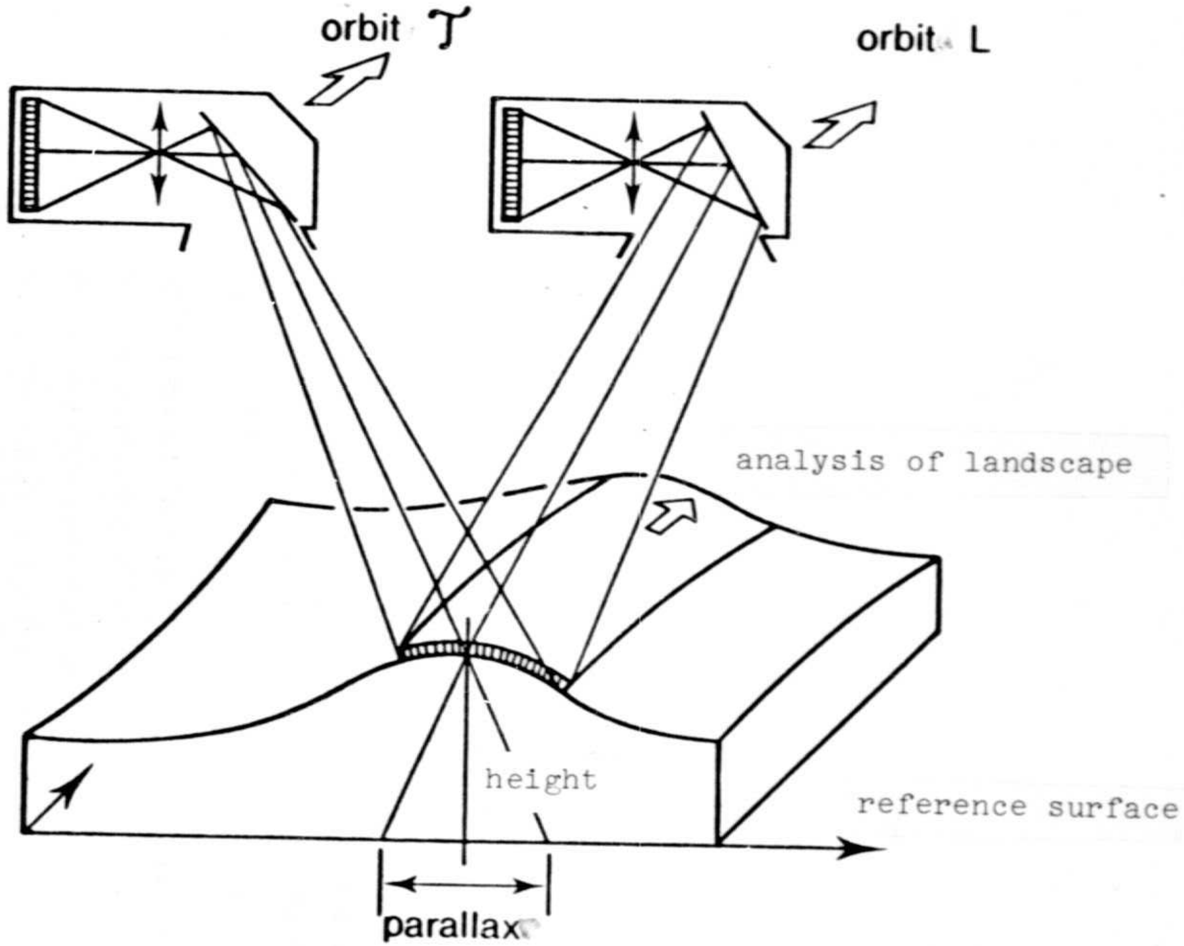


Figure 14: Principle of Stereoscopy from Two Different Orbits

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control center will transmit information. The Toulouse control center treats the telemetry data received, provides remote commands, and reduces the tracking data so as to recompose and predict the orbital parameters.

3.2.4.2 The Ground Image Complex

This complex includes the following:

- one or several image receiving stations. They provide reception, decommutation, and recording of raw data,

- a "storage" complex which rapidly scans the data so as to eliminate poor-quality products (coverage under cloudy conditions) or data of no interest (ocean data). It extracts auxiliary data such as date information, states and operational modes, calibrations and instrument gains. It generates a rough annotated library and a film which allows the user service to identify images in a catalogue.

A pretreatment complex which puts out products of various qualities, depending on the user requirements,

- a dissemination complex which generates products of various types.

- the ground image complex is compatible with the SPOT and LANDSAT D satellites. /43

The satellite concept allows the establishment of several stations capable of receiving direct telemetry during the same orbit. The dimensioning of the power system is such that it can operate with the two instruments. It can provide direct TM (telemetry) for 33 minutes during the day per orbit, which corresponds to the maximum practical requirements.

The various categories of the products provided by SPOT offered to the users are the following:

a) standard products (60 km x 60 km landscapes)

- Level 1 - the corrections are only made according to the landscape analysis line. They are radiometric corrections (relative point-to-point calibration) and geometric corrections (correction for the earth's rotation, for the earth's curvature, for the altitude, for the viewing angle of the instrument, and the instrument setting bias).
- Level 2 - The corrections made are two-dimensional. This means that two images can be superimposed in a projection of the "Space Oblique Mercator" type (option 1) or the images can be superimposed

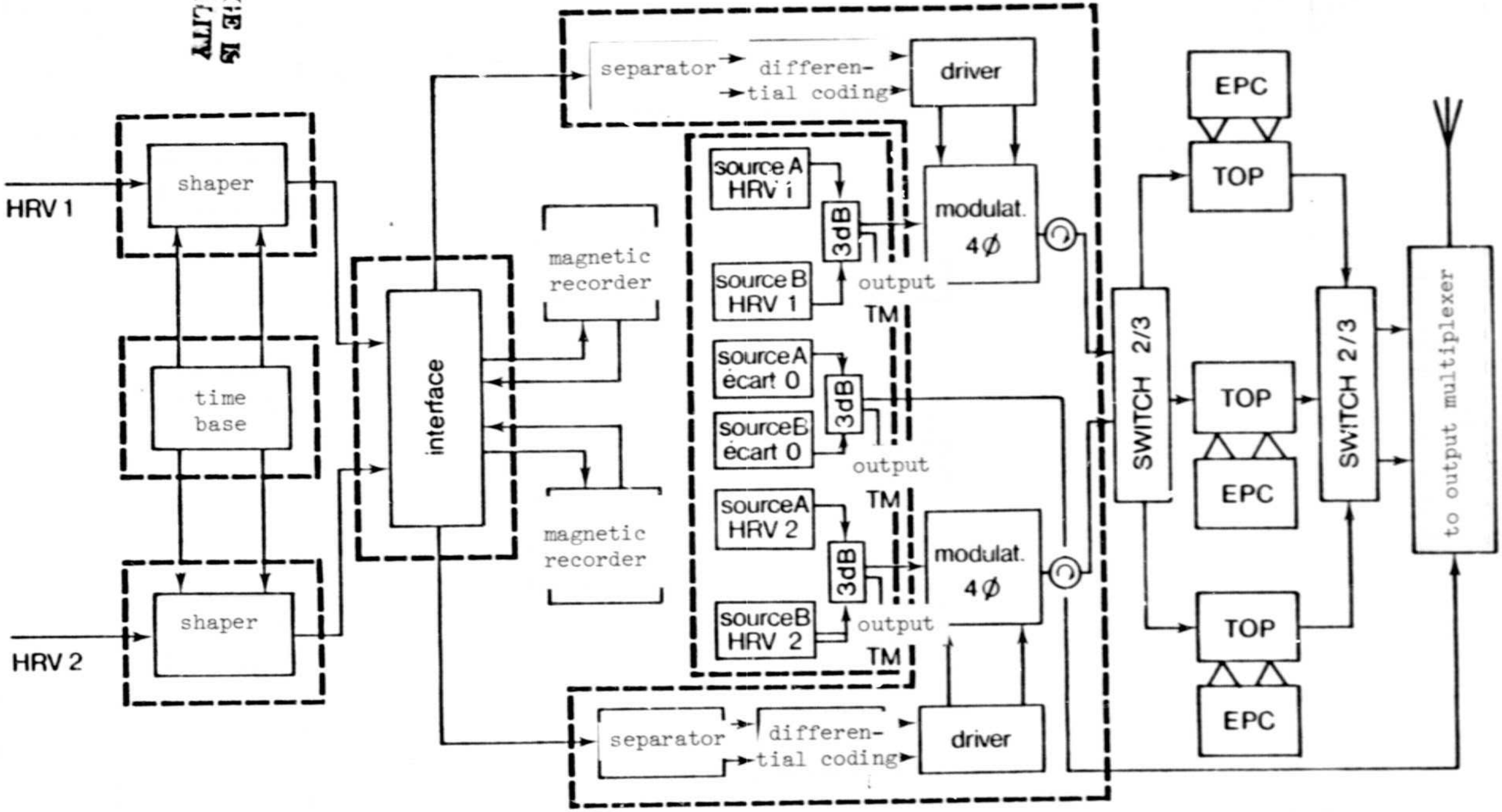


Figure 15: General TMCU Synopsis

on a 1/250,000 map using UTM or Lambert or polar stereographic projections, as requested (option 2). These images are obtained by matching a certain number of reference points measured in the initial period. For all of these products, the following annotation is provided:

-- geographic coordinates of the landscape center - indication of the direction of true north.

-- latitude and longitude lines around the edges of the image, /44

-- image taking date

-- identification of the instrument used, its operational mode (multispectral or panchromatic), identification of the viewing angle with respect to the nadir,

-- identification of the pretreatment mode.

b) the special products

This is the restitution of orthophotographic scenes. taking into account the relief; the 116 x 116 images are made to parallel operation of the two HRV instruments; stereoscopic pairs of the same landscapes are made from different viewing angles.

All these products are provided in a format which is compatible with those used for LANDSAT D, that is, 241 mm film, HDDT magnetic tapes, and CCT tapes. The delay in providing this data is less than 48 hours for standard pretreatment at level 1, and it 8 days for level 2 pretreatment.

3.2.4.3 The mission control

The mission control is in charge of the entire ground complex, and is in close relationship with the user service which takes into account the various user requirements. For this purpose, it establishes satellite programs taking into account the various constraints (state of the satellite and the ground complex, meteorology, user requests) and attempts to maximize the services provided. It defines priorities for the library functions and the data processing center. /46

3.3 Launch and Acquisition Sequence

The SPOT satellite is launched on the ARIANE launch vehicle from the GUYANA KOUROU space center. This launch vehicle provides direct injection of the satellite on the intended orbit, except for errors in the guidance system. It also orients the satellite perpendicular to

SUMMARY OF PRINCIPAL CHARACTERISTICS

Designation	First Mission
First Mission Payload	
- HRV Instrument	
Instantaneous field of view	20 m 3λ 10 m panchro
Radiometric resolution	0.5%
Size of track on ground (Nadir)	60 km
Spectral bands	0.50 - 0.59 μm
	0.61 - 0.69 μm
	0.79 - 0.90 μm
Panchromatic track	0.50 - 0.90 μm
Sweep Time for one line of landscape (20m)	∿ 3 ms
Focal length of instrument	1,082 mm
Off-axis pointing angle	± 26°
- Payload Telemmetry	
Digital frequency	24 Mb/s x 2
Transmission frequency band	8,025 to 8,400 GHz
Transmitter power	20 W per chain
Recorder capacity	60 minutes

Figure 16

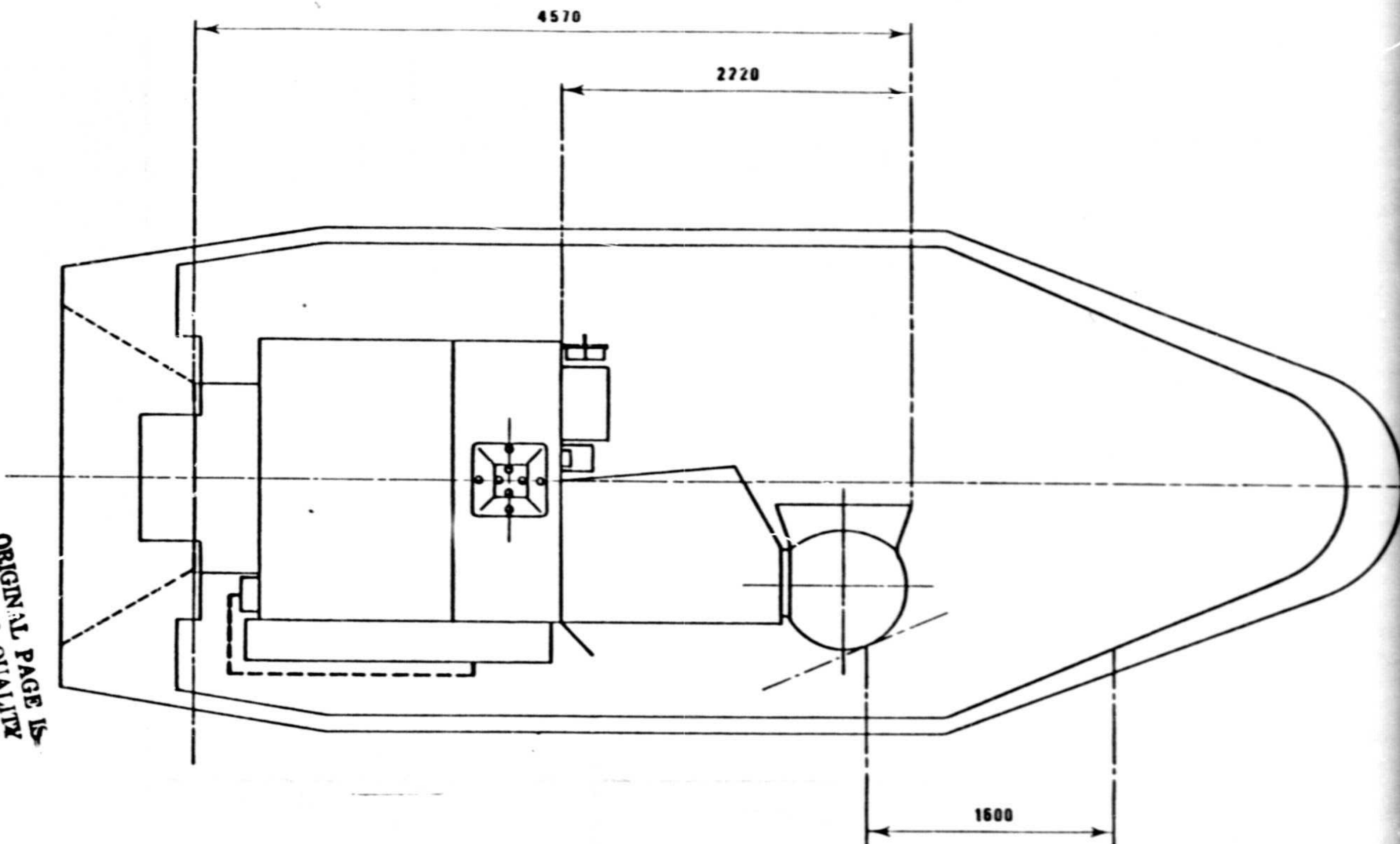


Figure 17

	LANDSAT 1,2,3 (MSS)	LANDSAT 3 (RBV)	LANDSAT D (T.M.)	SPOT HRV
Spectral Bands	.5 - .6 μm .6 - .7 .7 - .8 .8 - .1.05 10.5 - 12.4 (LANDSAT 3)	0.5-0.75 μm id	.45 - .52 .52 - .60 .63 - .69 .76 - .90 1.55 - 1.75 2.1 - 2.35 10.4 - 12.5	.5 - .59 (XS) .61 - .69 (XS) .79 - .90 (XS) .5 - .9 (P)
RFOV	80 m 240 m IR th	40 m	30 m 120 m IR th	20 m 10 m
Local hour of node passage	9 h 30	9 h 30	9 h 30	10 h 30
Sweep size	185 km	185 km	185 km	2 x 60 km orientable ± 400 km
Repetitiveness	18 d	18 d	16 d	26 d accessible at every point of the globe, max. 5 days

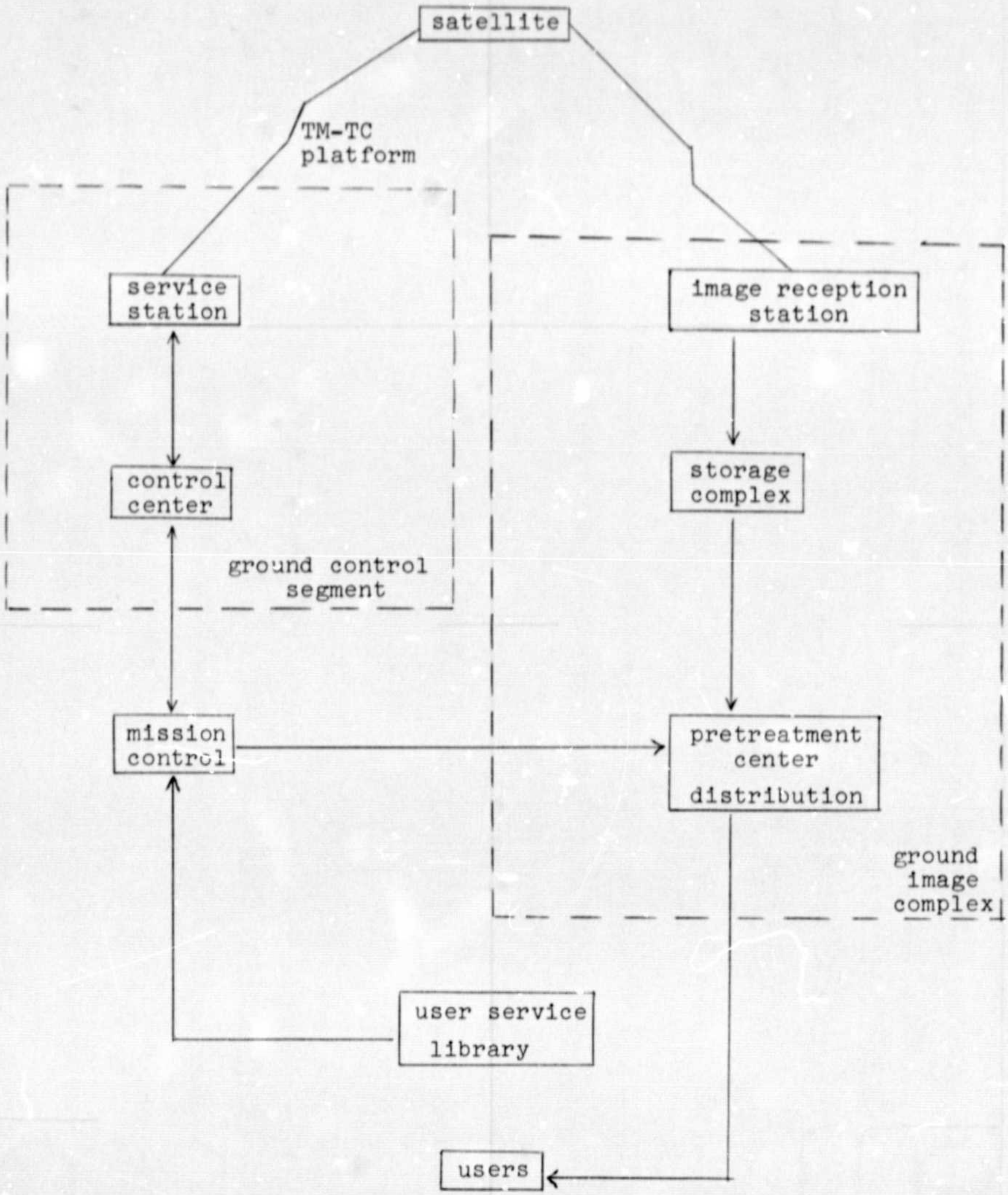


Figure 18: General Organization of Ground Complex

MAIN CHARACTERISTICS OF THE GROUND CONTROL COMPLEX

Tracking Stations

Transmission

- Frequency band	2025-2120 MHz
- Isotropic equivalent radiated power	$\geq$ 60 dBw
- Remote command standard	compatible ESA - NASA
- Remote Command Data Rate	1 kb/s

Reception

- Frequency band	2200-2300 MHz
- G/T	$\geq$ 17 dB/°K
- Remote measurement rate	2048 b/s
- Bit error rate	10^{-5}

Position Determination

- distance measurement error (elevation $\geq$ 10°)	1.5 m (1μ)
- timing error with respect to universal time	$\leq$ 1 ms

Control Center

- Orbitography	
-- interpolation error over 24 h	$\leq$ 200 m (3μ)
-- extrapolation error over 24 h	$\leq$ 2500 m (3μ) along the track
	$\leq$ 500 m (3μ) perpendicular to the track.

Figure 19

MAIN CHARACTERISTICS OF THE GROUND IMAGE COMPLEX

Image Receiving Station	
- Frequency band	8025 - 8400 MHz
- Gain	$\geq$ 54 dB
- System temperature at 5° elevation without rain	200°K
- Bit error rate	10^{-6}
Pretreatment Center	
- standard level 1 pretreatment	
-- accuracy of position determination	2 km RMS
-- accuracy of distance	1% RMS
-- dimensions of landscape	60 x 60 km
-- delay in furnishing information starting with reception	$\leq$ 48 h
- Standard level 2 pretreatment	
-- dimensions of landscapes	60 x 60 km
- delay in providing information after reception	$\leq$ 8 days.

Figure 20

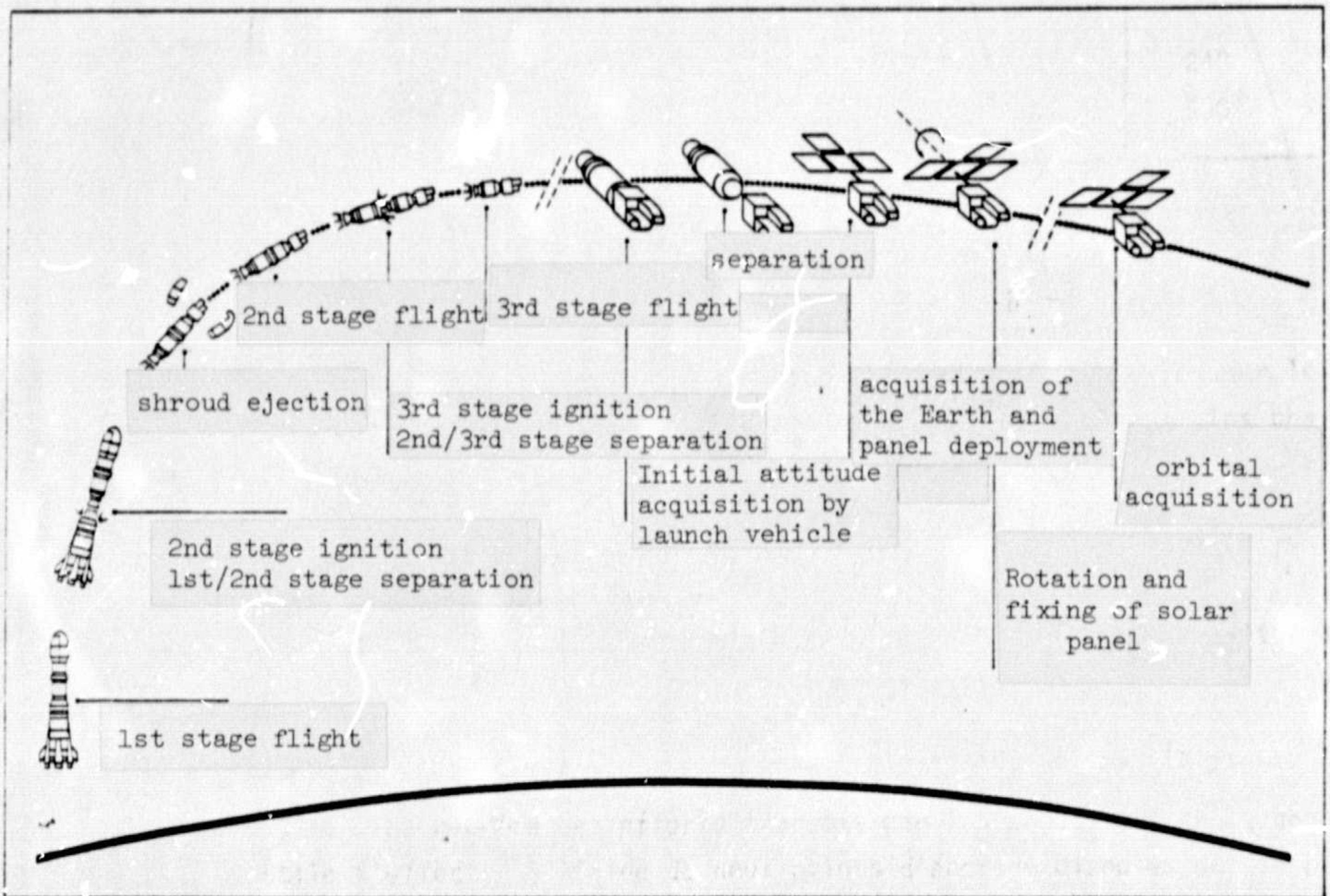


Figure 21: Orbital Injection Phase and Attitude Acquisition

the orbital plane before separating from it. The acquisition operation, therefore, includes the following (see Figure 21):

- acquisition of the earth by the attitude control system and deployment of solar panels,
- rotation and fixing of the solar panel, depending on the local time;
- acquisition of the panel orbit and fine attitude control.

These operations are followed by placing the satellite into the operational configuration, during which the payload instruments are calibrated.

3.4 Orbital Maneuvers

The hydrazine which can be flown on the platform allows orbital change maneuvers, for example, altitude changes.

A weight of about 2 kg is required for initial acquisition in maintaining attitude during the lifetime of the satellite.

The following table gives an approximate consumption value for maintaining the orbit and certain maneuvering possibilities (transfer to and from) between two circular orbits with a satellite mass of 1500 kg, by only considering the maneuvering potential of the hydrazine fuel. /48

ALTITUDE	600	800	1,200 km
Consumption in kg/year for maintaining orbit	13	3	1
Possible altitude excursion (in km) for a outbound-return maneuver			
- with 150 kg	210	214	240
- with 300 kg	445	450	500

3.5 Platform/Payload Interfaces

Without discussing the details, it may be of interest to summarize the main characteristics of the interfaces between the platform and the payloads.

3.5.1 Mechanical Interfaces

In orbit, the payload can occupy any space beyond the plane passing through the payload panel.

During launch, the available volume is defined in Figure 22.

Nine anchoring points located around the payload panel serve to takeoff the forces transmitted by the structures of the payload. These points are the following:

- the four corners of the 1,800 x 1,900 mm rectangle,
- the four center side points,
- the points where the diagonals cross.

/50

3.5.2 Electrical Interfaces

The onboard power is provided by a solar generator, and it is pointed permanently in the direction of the sun.

The available surface area for affixing solar cells is 11.7 m^2, which allows a maximum power output of 1,200 W at the beginning of the mission, and 1,030 W at the end of the mission at 800 km. altitude.

The power consumption of the standard platform is on the order of 180 W on the average.

The modular design of the power supply system provides a maximum power level of 2 kW to a payload for about 10 minutes per orbit and per day. The operation at night is possible with the available power, depending on the mode of operation (1.5 kW over 10 minutes).

As an example, 2 kW allows simultaneous operation of the two different optical instruments, and one lateral radar, as well as the operation of recording and transmission devices of such a payload.

4. SPOT SYSTEM DEVELOPMENT PLAN

The SPOT system development plan is based on very classical satellite technology.

Phase A has been established at CNES since 1975, and allows accomplishment of the main objectives of the mission, the systems definition and the selection of technical options at the end of research and development work. This led to the decision for the SPOT program.

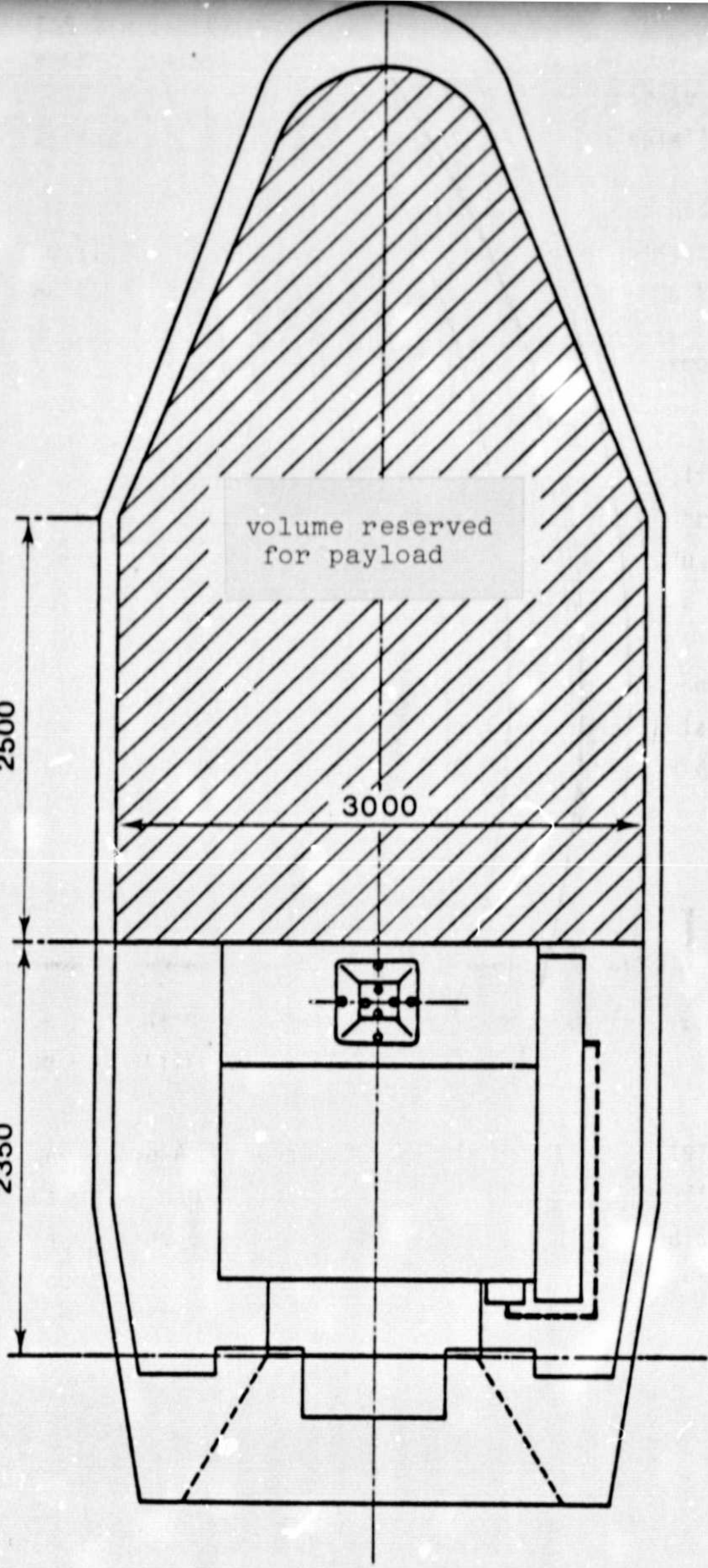


Figure 22: ARIANE shroud - SPOT platform interface

A two-year phase B (1978-1979) has the purpose of performing /51
conceptual definition studies on the system, and to perform the required studies and tests for "technical hard facts" for the system. In this phase, a great effort will be made in performing studies of the HRV instruments, due to the building of two breadboard models. One model is used for optical performance studies (MSO) and the other is used for mechanical and thermal studies (MMTH).

Phases C and D will cover the development and fabrication of the SPOT satellite and its associated ground complex, which will start at the beginning of 1980. The launch by the ARIANE launch vehicle will be at the end of 1983. During this period, we will study, build, and test the following models and mockups:

- the structural and thermal mockup (MSTH) for the following:

- to qualify the structure dimensions, validate the dynamic environment levels at various points in the satellite, and to qualify the hot gas propulsion system,

- to qualify the satellite thermal model and validate the thermal environment of the equipment.

- Prototype No. 1 (P1) consists of identical equipment using components which have not been tested for reliability. This will allow operational compatibility of the various components and the development of integration and control procedures for the following models. It will also provide verification of compatibility with the ground complex.

- Prototype No. 2 (P2) or qualification model is perfectly identical with the flight model and will be subjected to functional and performance tests under more severe mechanical and thermal environments than those encountered during launch and in orbit. This model will be used after refurbishing as a flight exchange model.

- The flight model (MV) will be tested in an environment as close as possible to the launch and orbital conditions. The test with MSTH and P1 will be done under more severe conditions of the platform multimission spectrum.

/52

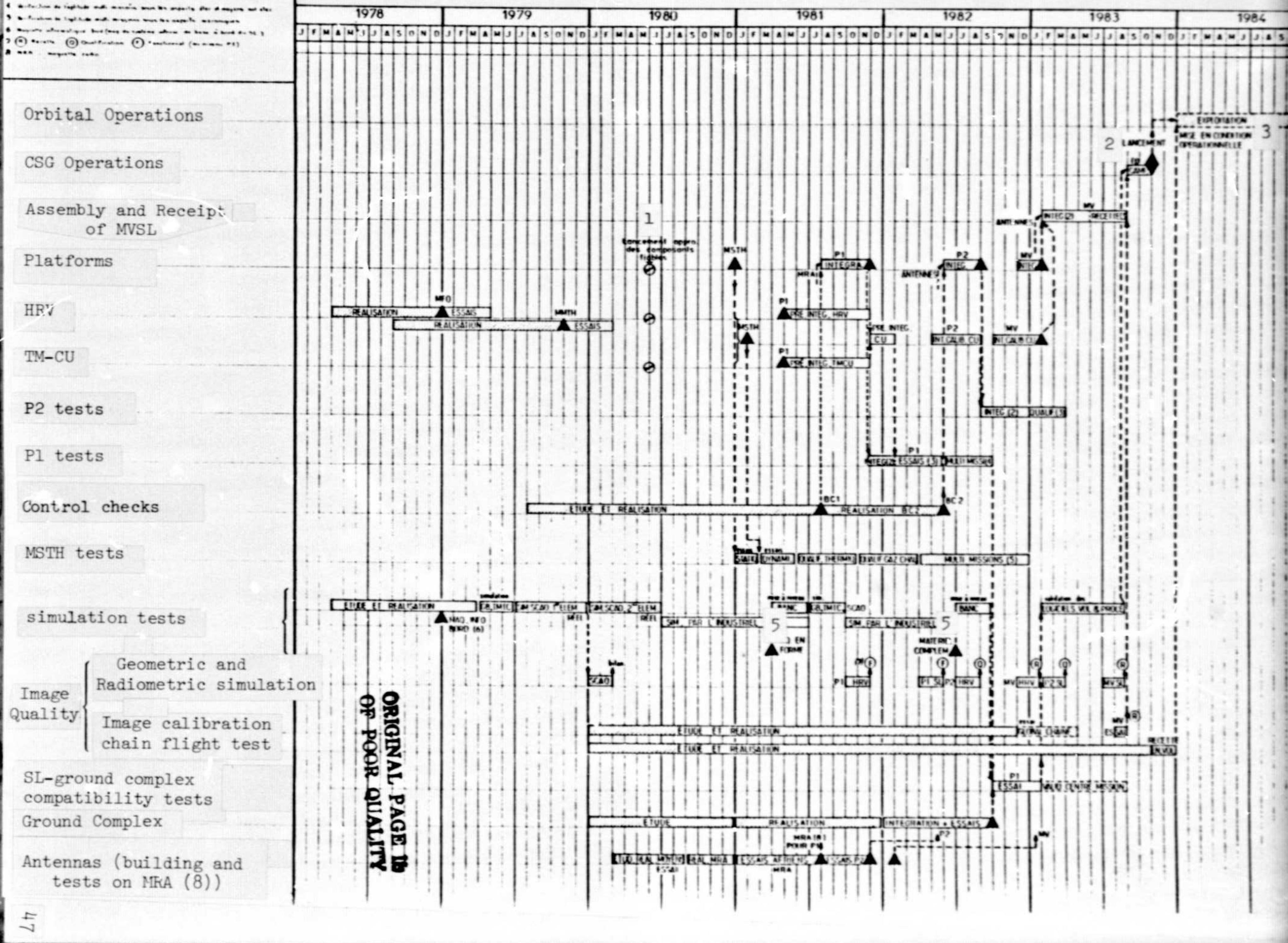
The development of the plan is given below: the key days are the following:

- Test results of the optical functional mockup (MFO), April, 1979.

- Test results of the mechanical and thermal mockup (MMTH), February, 1980

- Delivery of the structural and thermal mockup of the satellite (MSTH), January, 1981
- Integration of prototype No. 1 (P1), January, 1982.
- End of MSTH tests (with the exception of multi-mission tests), March, 1982).
- End of P1 tests (except for multimission), May, 1982.
- End of integration of the satellite qualification model (P2), August, 1982.
- Ground complex reception, September, 1982.
- Delivery of the flight model (MV), January, 1983
- End of qualification tests, March, 1983
- Receipt of flight model, August, 1983
- Launch on the ARIANE, November, 1983
- Operations commencement, January, 1984

SPOT DEVELOPMENT PROGRAM DVO (01) of January 26, 1978



(Footnotes from figure)

1- includes transportation (highly illegible)

2- integration and functional tests

3- environmental tests

4- verification of the multimission performance for electrical systems and electrical ground systems

5- verification of multimissions performance for mechanical aspects

6- onboard information mockup

mockup of information system onboard satellites

7- R acceptance Q qualification F functional (at P1 level)

8- MRA = radio mockup .

Key: ESSAIS = tests REALISATION = fabrication ET = and
ETUDE = Study RECETTE = acceptance ANTENNS = antennas
GASCHAUD = hot gas CENTRE = mission control VOL = flight
ARIANE = airtests (other words illegible).

1- Initiation of failure tests 2- launch 3- operations, preparation for operation 5- simulation by manufacturer