NASA TECHNICAL MEMORANDUM NASA TM 75830

THE HIGH VISIBLE RESOLUTION (HVR) INSTRUMENT OF THE SPOT GROUND OBSERVATION SATELLITE

by

G. Otrio, Messrs. Deshayes, Vermande, Bodin, Midan, Maudhuyt, Condé, Giraudbit and Reulet

(NASA-TM-75830) THE HIGH VISIBLE RESOLUTION (HVR) INSTRUMENT OF THE SPOT GROUND OBSERVATION SATELLITE (National Aeronautics and Space Administration) 22 p HC A02/MF A01 CSCL 20F G3/43 N80-27761 Unclas 27951

Translation of "L'Instrument a Haute Resolution Visible (HRV) du Satellite d'Observation de la Terre: SPOT", International Astronautical Federation, 30th, Munich, West Germany, Paper IAF-79-F-239, September 1979, pp 1-13

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 APRIL 1980

STANDARD TITLE PAGE

1. Report No. NASA TM-75830	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle THE HIGH VISIBLE RESOLUTION (HVR) INSTRUMENT OF THE SPOT GROUND OBSERVATION SATELLITE		5. Report Date April 1980
		6. Performing Organization Code
7. Author(s) G. Otrio, Mssrs. Deshayes, Vermande, Bodin, Midan, Maudhuyt, Condé, Giraudbit, Reulet, National Space Studies Center, Toulouse, France		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Leo Kanner Associates, Redwood City, California 94063		11. Contract or Grant No. NASw-3199
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration, Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "L'Instrument a Haute Resolution Visible (HRV) du Satellite d'Observation de la Terre: SPOT", International Astronautical Federation, 30th, Munich, West Germany, Paper IAF-79-F-239, September 1979, pp 1-13 (A79-53369)

16. Abstract

A brief overview of the mission of the SPOT satellite is presented and the performance of the HVR instrument is described. The results obtained to date are presented.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified-Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	22	

THE HIGH VISIBLE RESOLUTION (HVR) INSTRUMENT OF THE SPOT GROUND OBSERVATION SATELLITE

by

G. Otrio, Mssrs. Deshayes, Vermande, Bodin, Midan, Maudhuyt,
Conde, Giraudbit and Reulet
National Space Studies Center - Toulouse - France

Summary

A brief overview of the mission of the SPOT satellite is presented and the performance of the HVR instrument is described. Finally, the results obtained to date are presented.

Key Words

Ground observation, Optical instrumentation, Optical detection

Introduction

1. SPOT's Mission

The objective of the SPOT system is to constitute, store and make available a data base for high resolution teledetection from space over a large part of the globe, which will make it possible to develop experiments relating to soil use, the exploration of earth's resources and space cartography.

The second objective is to evaluate the potential of lateral optical sighting to improve the local repetivity of observations and the discrimination of plant species.

The third aspect of the mission is to obtain, on an experimental basis, stereoscopic coverage of regions of known interest, and to test its use.

Finally, the last goal is to certify a multi-mission platform and verify its operation in flight, over part of its field of polyvalence.

To complete this initial mission, the photographic instruments are two identical high resolution cameras. The installation of the two instruments on board makes it possible to obtain a track width of 116 km in an almost vertical line of sight, from the two 60 km images of each instrument. The two images overlap by 4 km. Figure 1 shows the coverage of the HVR instruments for the objective of the systematic coverage of the globe.

To achieve the accessibility objective, a change of sight mirror makes it possible to change the direction of sight of each instrument independently around an axis parallel to the speed vector, by $\pm$ 45 steps of 0.6° each, or a total of $\pm 27^{\circ}$ around the vertical.

As for the objective of acquiring stereoscopic views, the chosen solution is to obtain stereoscopic pairs with a lateral sight rather than front and rear sight. By an astute choice of orbits, the chief disadvantage of lateral stereoscopy, the long lapse of time separating the two views of the stereo pair, can be minimized.

Figure 2 defines the access time for a given zone. We see, for example, that the same scene can be recorded a day apart (J_o and J_{o+1}), the angles of sight being respectively 0 and 25.2 degrees.

2. General Specifications of the HVR Instrument

To carry out SPOT's mission, the HVR instrument must have the following qualities:

- radiometric resolution (high capacity for discriminating slight variations of luminous intensity in various spectral bands),

- spatial resolution, therefore, detection of objects of small size,

- geometry: for cartographical needs, it is necessary to have, if not a measurement chamber, at least an instrument of very low distortion and not deformable,

- rapid access: the sight changing device must, while preserving the quality of the image, permit rapid movement without disturbing the attitude of the satellite and thus reducing the precision of the direction of sight.

To carry out the mission, a certain number of so-called radiometric characteristics, summed up in Figure 3, must therefore be respected.

To accomplish the objectives of the SPOT mission for accessibility and repetivity, the specifications for the HVR instrument are completed by others, labelled "geometric". These are summarized in Figure 4.

3. Present Development Status of the HVR Instrument

3.1 Detectors

The underlying concept is based on the use of standard detectors, sold commercially; the choice therefore fell on the 121 H CCD strips made by FAIRSCHILD; the HVR instrument was built around their characteristics.

Since that time a new detector, the 122 DC, from the same manufacturer, has made its appearance; its performances, measured at the National Space Studies Center, on a specially designed test bench, lead to very satisfactory results (see Figure 5). The following important points should be noted:

- improved spectral response (little ripple) and V/W sensitivity twice to three times as high as for the 121 H,

- saturation lighting lower than for the 121 H,

- reduced noise (NEE).

A pre-certification series of tests on a hundred standard components, taken however, from the same manufacturer's lots, has just begun. The results of the initial measurements show a remarkable grouping of performances.

Finally, we should note that the SPOT project is studying the possibility of finding a second source of supply for CCD's.

In that case, the addition of an antiblooming device might be possible (there is none on the 122 DC).

3.2 Optical Characteristics

The conditions of the minimum detectable field of vision signal and the size of the detectors (13 microns) led to a telescope of 1082 mm focal length, open to f/3, with an angular field of $\pm 2.3^{\circ}$.

The telescopes under consideration fall into two categories: dioptric or catadioptric.

The dioptric telescope comprises at least 7 lenses, of reduced secondary spectrum glass (fluorine based).

The problems of mechanical and thermal tolerances and the difficulties of supply (these lenses are very expensive) finally led to the choice of a catadioptric telescope; the latter is of the Schmidt type, with a spherical front corrector lense. For reasons of simplicity in manufacturing, a telescope with spherical corrector lens was the one finally selected (see figure 6).

Image quality, calculated by computer, leads to the results described in Figure 7.

The transfer function is given for maximum usable frequencies in the spectral (20.8 kc/rd) and panchromatic (41.6 kc/rd) bands.

To verify by experiment the theoretical results, the HVR project team built a functioning optical model (FOM) representing the complete telescope, the spectral separator system and the CCD detector. The model has now been completed and a series of systematic tests is beginning at the National Space Studies Center at Toulouse; we can mention that the results of the builder's acceptance tests agree with the calculations and that the measured diameter of the diffusion spot does not exceed 12 to 15 microns in panchromatic light and for all points in the plane field (image formed on a photo-panchromatic plate).

A model of the sight change mirror (SCM) is also being made; this mirror, lightened by 60%, poses problems of polishing and fixation (by means of 3 jointed blades) and of steadiness under vibration; partial vibration tests on samples showed that the supports were well dimensioned; an overall test of the SCM will be carried out on a mechanical and thermal model (MTHM) representing the complete structure, the optical equipment, the thermal controls and a stimulation of dissipation of power of the electronic equipment, motors, etc.

This model is currently being built. We should, finally, mention the last delicate technological point, represented by the front tube; this tube positions the two corrector lenses (diameter: 330 mm, thickness, approximately 43 mm); a model was made and subjected to vibration; no displacement was observed, but a slight deformation, not prejudicial to quality, appeared, due to the hammering out of the elastomer placed between the lens and the tube.

3.3 Structure and Thermal Control

The constraints taken into consideration in the design of the structure of the HVR instrument were the following:

- good stability of the optical components among themselves (tolerances),

- geometric stability of the entire instrument (localization criteria),

- lateral frequency above or equal to 45 Hz,

- longitudinal frequency above or equal to 80 Hz,

- radiative coupling of the detector assembly with space to guarantee a correct temperature for the detectors,

- the installation on the platform is predetermined (installation plan, position of the center of gravity, etc.),

- however, no severe constraints of mass,

- good accessibility to the optical components and the detector assembly for adjustment and integration.

Finally, the structural design must permit:

- the carrying out of realistic thermal, static, dynamic and thermoelastic deformation analysis forecasts,

- the separation of the primary and secondary structures.

The design selected after studying two configurations (of the lattice and hull types) led to the selection of the lattice structure; the link between the relay plate and the detector assembly should ensure great transverse rigidity, good dimensional stability and good accessibility to the various elements; the lattice structure seems to meet these constraints and the final choice is described in Figure 8 which shows the primary structure of the HVR instrument.

For reasons of rigidity and low expansion, this lattice (internal dodecapod and external octopod) is made of plastic, reinforced by carbon fibers (PRCF).

We should briefly mention the support device of the CSM instrument: the support tube of the CSM is in compartmented sheet metal for reasons of dynamic behavior (mode of torsion of the unit as a whole).

The thermal control is studies so that the temperatures of the HVR instrument are close to ambient temperature ($20^{\circ} \pm 5^{\circ}C$); with small thermal gradients ($5^{\circ}C$) and especially at the level of the CSM; similarly, fluctuations during photography ($2^{\circ}C$) and with the seasons ($T < 5^{\circ}C$) must remain slight.

The means of thermal control are the following:

- heavy insulation,
- heaters,
- black paint.

A model of the HVR makes it possible to calculate the external fluxes (sun, earth's albedo) by means of an external geometric model (138 facets per HVR instrument). The thermal model constructed for the HVR comprises 141 nodes: calculations for different cases have been made on the basis of this model for various orbits, with particular outer coverings, and given dissipated power (two consumption gauges) and for a given platform interface. The results obtained show that:

- the desired temperature level is obtained in the different cases for the structural and optical parts as a whole; only the equipment and their support deck can reach $40^{\circ}C$,

- the thermal gradients are low (intermediate plate), or moderate

(HVR framework) if the thermal power of the equipment is well distributed (4 X 20 W), but higher in the oppsoite case,

- the temperature fluctuations during one orbit, at the level of the CSM, are mainly due to variations of the albedo flux and are moderate ($<10^{o}C$). Temperature variations at the level of the intermediate plate are low, and very low at the level of the plane mirror and detector assembly ($<1^{o}C$).

A detailed analysis also makes it possible to study the seasonal fluctuations and the influence of various parameters (external fluxes, aging of coverings, interface temperatures, phototaking times, etc.)

In order to validate these results and perfect the thermal model, there are plans for a series of mechanical tests on the MTHM model: mechanical (vibration, acoustical noise) and thermal (vacuum radiation). These tests will make it possible, also, to verify the mechanical and thermal tolerances by an examination of image quality and fidelity to alignment.

3.4 Detector Assembly

This extremely important part represents the heart of the HVR instrument; it is composed of the following parts:

- spectral splitter ensuring the separation of the flux into 3 spectr al bands with 65 to 70% transmission per band on average, and a non-superimposed panchromatic band; separation is ensured by dichroic filters and transmission-blocking filters.

- line synthesizer (DIVOLI), a glass cube making it possible to form a continuous straight line of 6000 CCD points, by means of 4 strips linked optically by a 45^{o} mirror.

- an assembly structure which makes it possible to position the 4

DIVOLIs, the spectral splitter, the electr nic cards, and the "radiative parts" which make it possible to evacuate into space the power dissipated by the detectors and electronic equipment.

- Analogue electronic equipment which makes it possible to "transport" the video signals to the preamplifiers located outside the detector box at a distance of about 30 cm.

A general schematic diagram is given in Figure 9 (functional schematic diagram).

3.5 Electronic Equipment

The theoretical schematic diagram is given in Figure 10: note that the CCD strips are read almost at the same speed for spectral and panchromatic bands: for the spectral (channels--? illegible--Translator) data are read in series on two CCD strips, then numbered; in the panchromatic channel data are read in parallel and as it is not designed to transmit more than 6000 points in approximately 1.5 msec (the panchromatic line in fact contains about 4 times 1750 elements) it is necessary to use 4 buffer memories of 2 kb each which read and transmit in a ratio approaching 1500/1750.

It may also be noted that the points of the spectral channel are grouped 2 by 2 at the level of the CCD register itself; a change in gain is thus necessary to adapt the dynamics of the signals to those of the coder.

Finally, on the panchromatic channel it is possible to transmit coded numerical signals in 6 bits or compressed by CPCM 6/8 bits.

3.6 Calibration

It is planned to place aboard the HVR instrument a calibration unit making it possible to illuminate uniformly, in each of the

4 band, all points to a given level (collimated lamd).

To evaluate the lamp's evolutions over time, a sight on the sun is planned, using optical fibers.

A theoretical simulation and an experimental bench are under construction at CNES (see Figure 11).

The results should make it possible to know the degree of precision with which it is possible to restore a continuous level of light for any spectral distribution and level of illumination.

Pre-certification of lamps (aging and space environment) and of optical fibers is presently being carried out; the results of the characterization of the optical fibers (numeric aper ture, distribution of illumination, etc.) make it possible to determine the most probable performances of the calibration unit; similarly measurements simulating the unit, placed before the HVR instrument, have made it possible to measure its performances and constraints (disipated power, encumbrance, type of lamp, positioning tolerances)

4. Development of the Instrument in Phase B - Conclusion

The study of Phase B culminates in the detailed design of the HVR instrument. In order to verify and guarantee the validity of the specifications, the project was led to make several principal models:

- the Functional Optical Model, making possible the measurement of nearly all radiometric specifications.

- the Mechanical and Thermal Model which must demonstrate that performances as regard s image quality, distortion and localization do not deteriorate during and after space environment testing.

- model of the detector assembly which must prove that it is possible to ensure the correct positioning of the detectors and that it is maintained in the space environment (thermal and vibrations).

- an analog and digital video electronic model making possible the verification of a certain number of radiometric specifications, and the specification of the HVR instrument' electronic equipment for the next phase.

- a model of the sight change mirror and its driving mechanism: this model permits verification of the behavior of the mirror in conditions of vibration, certification of the bearings, pre-certification of the entire mechanism and measurement of its performance in aligning the optical axis before and after vibration tests (reproducibility of the change of axis of sight rule). This model, which has already been constructed, is undergoing trials at the National Space Studies Center.

- Model and simulation bench of the calibration unit, making it possible to verify or define the interfaces with the HVR and to measure relative calibration performances; the first results obtained are quite encouraging (see Figure 11) and it is hoped to correct non-uniformities of the detectors and of the optical chain to better than $\pm$ 1%.

- Thermal model which allowed us to specify the temperatures, gradients and transitory stages at different points on the instrument.

We should also mention other models intended for the study of isolated, clearly defined features (tube, bearings, motors, divolis, anti-reflection treatments, adapted preamp-CCD link, etc.) This would transcend the boundaries of this presentation.

The initial results relate basically to functional performance and are quite encouraging.

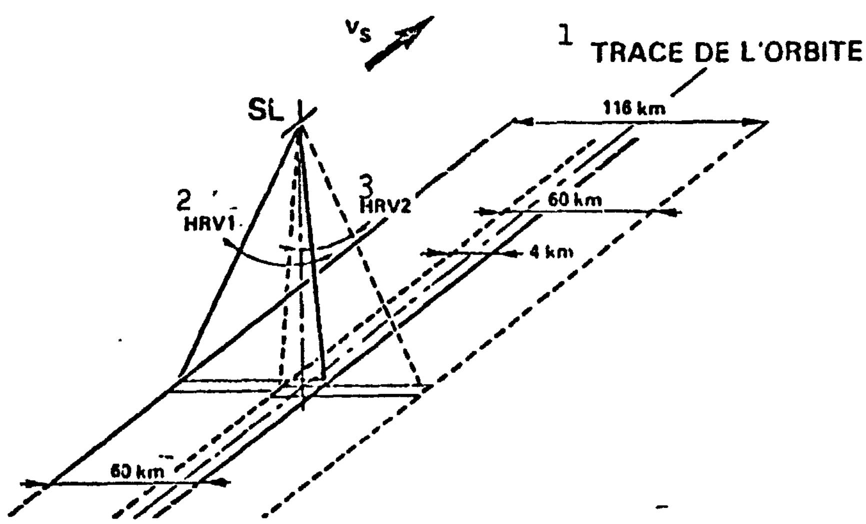
A systematic series of measurements is beginning in the National

Space Studies Center laboraries and is to lead to a precise definition of the specifications for the HVR instrument.

The mechanical and thermal model, currently being built, is to demonstrate the stability of these performances under space conditions, and validate the theoretical models.

The technological tests will ensure the certification of the components considered to be the most critical.

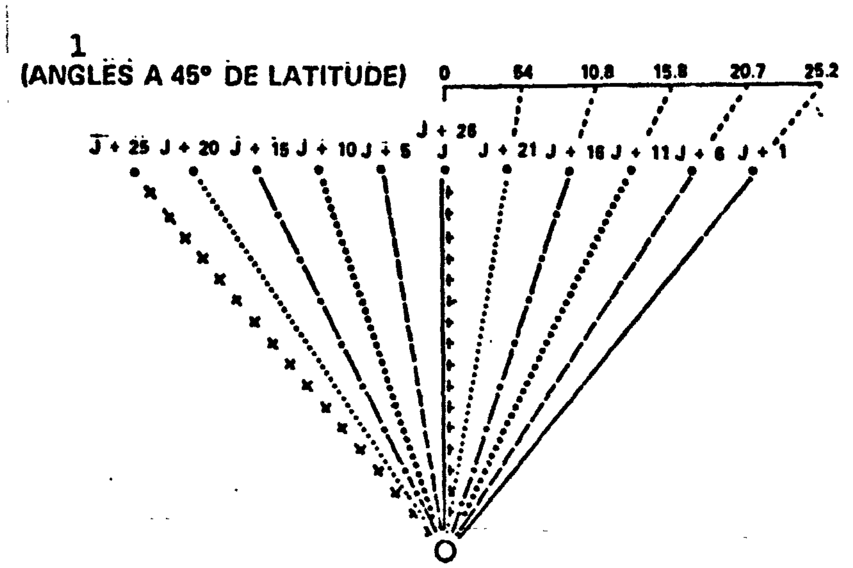
The diversity of the actions presented above should make possible the assurance of the validity of the specifications of the HVR instrument and a Phase C development without any serious hitches.



Key: 1) Track of orbit
2) HVR 1
3) HVR 2

Figure 1: Field of each instrument for systematic coverage

ORIGINAL PAGE IS
OF POOR QUALITY



Key: 1) Angles at 45° latitude

Figure 2: Accessibility with SPOT

FIGURE 3: CHARACTERISTICS OF THE PAYLOAD

TWO INSTRUMENTS (HVR)

Field of vision (per instrument)		Spectral bands	Spatial resolution	IFOV	Radiometirc resolution $\theta_s < 60°$	L Max W/m^2Sr	Coding
60 km	XS	0.50-0.59 µm			0.077W/m²Sr	31.5	1
		0.61-0.68 µm	MTF > 0.35 at 40 m⁻¹	20 m	0.64W/m²Sr	28.4	8 bits linéaires
		0.79-0.90 µm			0.053W/m²Sr	28.8	
60 km	P	0.50-0.90 µm	MTF > 0.30 at 20 m⁻¹	10m	0.278W/m²Sr	126.8	2 6 bits linéaires DPCM

Key: 1) 8 linear bits
2) 6 linear DPCM bits

FIGURE 4: GEOMETRIC CHARACTERISTICS OF EACH HVR INSTRUMENT

- Superimposibility of spectral images.........$\pm$ 0.3 of element
- Distortion high frequency..................$\pm$ 0.5% of element
  low frequency..................$\mp$ 0.1 of element
- Deflection of axis of sight................$\pm$ 27^o (around R)
- Aiming speed................................4^o/Sec
- Value of basic step.........................0.6^o ($\pm$45 steps)
- Precision of "image" location
  - Bias.....................................$\pm 5X10^{-4}$rd
  - Stability................................$\pm 1X10^{-4}$rd

ORIGINAL PAGE IS
OF POOR QUALITY

PERFORMANCES OF A CCD DETECTOR

Element 500

	OBSC	B1	B2	B3	P
E nom (nJ cm – 2)	0,0	204,0	184,0	187,0	684,0
E max (nJ cm – 2)	0,0	188,0	155,0	108,5	192,0
Ti (ms)	3,1	3,1	3,1	3,1	1,6
Vrms (V)	219 E-06	118 E 05	117 E – 05	112 E – 05	132 E – 05
Vccd (V)	331 E – 06	0,774	0,854	0,881	1,104
Vsat (V)					1,490
S (V micro J – 1 cm2)		4,160	5,509	6.095	5,749
NEE (nJ cm – 2)		0,283	0,212	0,184	0,230
NEE obsc (nJ cm – 2)		0,053	0,040	0,036	0,038
V/B		657	733	589	836
Dyn					6814
Contrast (38.5 pl/mm)		0,65	0,55	0,35	0,48
N. Eps			0,009		

FIGURE 6 :H.V.R. OPTICAL DESIGN

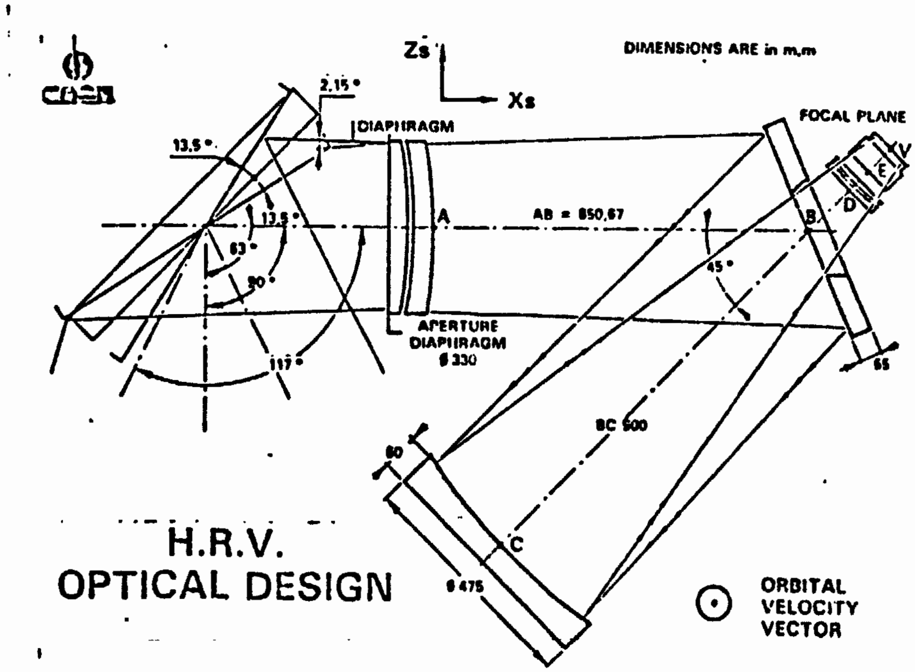


Image quality - telescope alone

Maximum transfer function at 20.8 kc/rd

λ(µm) \ field	0	0.7	1
0,55	84	88	85
0,65	79	82	81
0,85	71	75	76

Maximum transfer function at 41.6 kc/rd

λ(µm) \ field	0	0.4	0.7	1
0,55	57	60	63	62
0,65	45	49	54	54
0,85	31	36	42	44

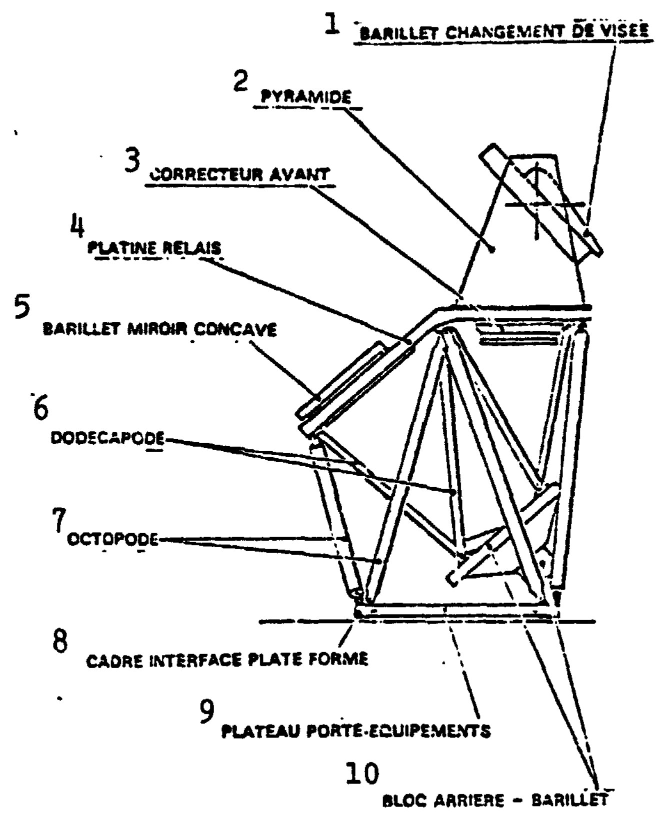
Optical Distortion

λ (µm)	0.55	0.65	0.85
dY' (µm)	- 0.8	- 0.5	- 0.5

Transmission by telescope alone

λ (um)	0.55	0.65	0.85
τ t	0.74	0.75	0.74

Figure 7: Telescope performance



Key: 1) Sight change tube
2) Pyramid
3) Front corrector
4) Relay plate
5) Concave mirror tube
6) Dodecapod
7) Octopod
8) Platform interface framework
9) Equipment support deck
10) Rear block - tube

Figure 8: Basic H.V.R. Structure

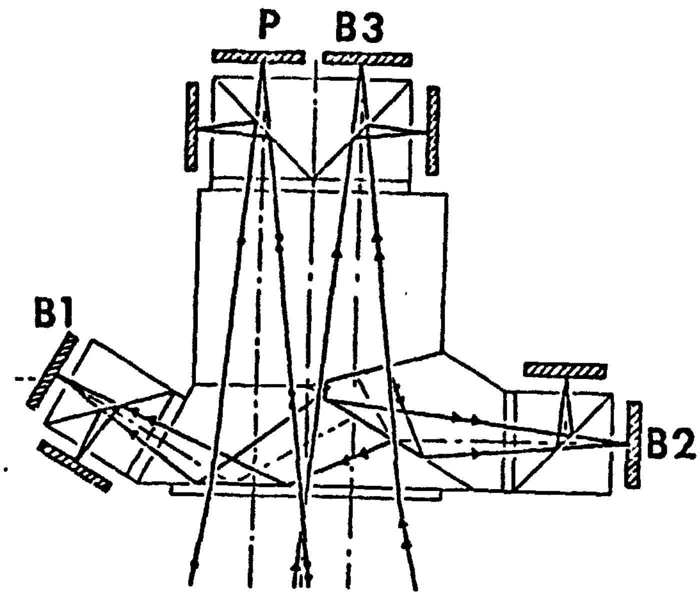
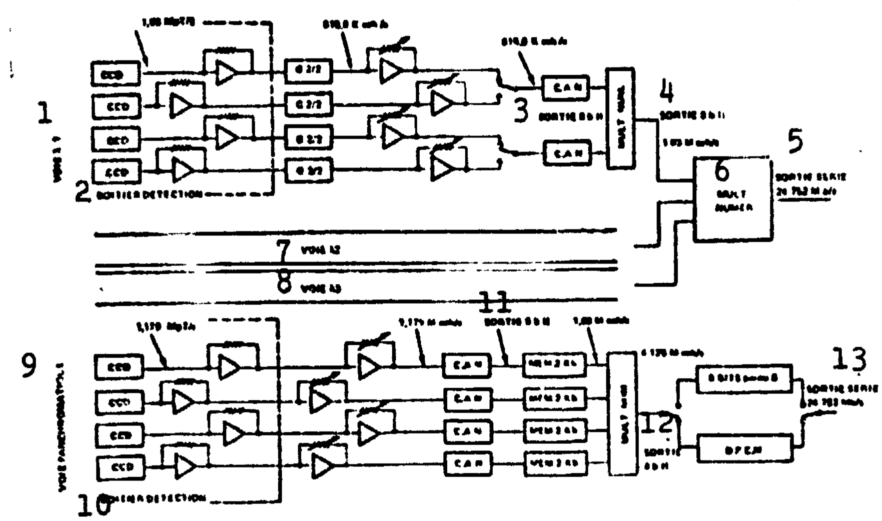
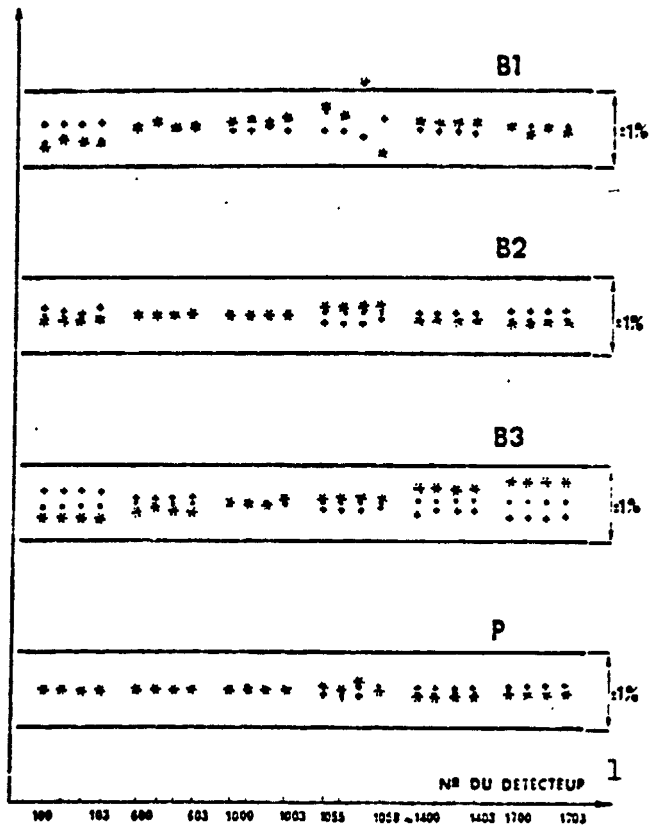


Figure 9: Detection assembly



Key:
1) Channel 1
2) Detector assembly
3) Output (illegible)
4) Output (illegible)
5) Series output
6) Illegible)
7) Channel (illegible)
8) Channel (illegible)
9) Panchromatic channel (illegible)
10) Detector assembly
11) Output (illegible)
12) Output (illegible)
13) Series output

Figure 10: Schematic diagram of video electronics



Key: 1) Detector number

Figure 11: Relative calibration within one band - Results of simulation