

# DESIGN AND CALIBRATION OF THE BIRD PAYLOAD PLATFORM

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## ABSTRACT:

The BIRD (Bispectral Infra-Red Detection) is a small satellite mission of the German Aerospace Centre which was successfully launched in October 2001 as piggyback on the Indian PSLV rocket. High technological and scientific performance could be demonstrated under low budget constraints. The satellite is a three-axis stabilised spacecraft with a mass of 92 kg including over 30% of the total mass for the scientific instrumentation. The primary mission objectives are the test of a new generation of infrared array sensors for detection and scientific investigation of High Temperature Events (HTE) such as forest fires and volcanic activities. Together with a VIS/NIR-sensor with stereo capability as a redesign of the MARS-96 mission the diagnostics of vegetation and the discrimination of smoke and water vapor is possible. Due to the highly compact design a strong interaction of interfaces within a small volume leads to special platform technologies mainly driven by optical and thermal requirements. Therefore the calibration of the three image-forming sensors of BIRD in geometrical, radiometrical and spectral way had to be considered from a very early design phase on. The pixelcoregistration of four sensors working in different spectral ranges requires a very complex calibration facility.

## 1. HOT SPOT RECOGNITION SENSOR (HSRS) – THE MAIN BIRD PAYLOAD

The main payload of the BIRD micro-satellite is the newly developed Hot Spot Recognition System. It is a dual-channel instrument for middle and thermal infra-red imagery based on cooled MCT line detectors. Exact pixel matching and on-board calibration capabilities are required due to the scientific methods of data processing.

To avoid saturation and to discriminate high temperature events from environment reliably the sensor electronics has to cover an extended dynamic range which is another challenge of the design. Based on an airborne laboratory model of the two IR cameras for the mid- and thermal infrared spectral range the requirement for the HSRS for BIRD was to reduce dimensions and power needs of this system significantly.

Thus an integrated detector/ cooler design was derived from military applications technology and has been space-qualified (see figure 1.1). Here the main problem is to provide enough stiffness of the inbound cooling finger beneath the IR-detector chip against dynamical loads during the launch process. A so arising solid structural solution is in contradiction to the demands of thermal de-coupling to minimise power needs. At least the system consumes only 11 Watts which is a factor of 4 less in comparison to a split cooler concept. Together with a special lens design which is optimised by the cold shield arrangement of the detector dewar the inner radiation disturbances could be decreased significantly to improve the instruments radiometric accuracy.



Fig. 1.1 Miniaturised integrated detector/ cooler assembly

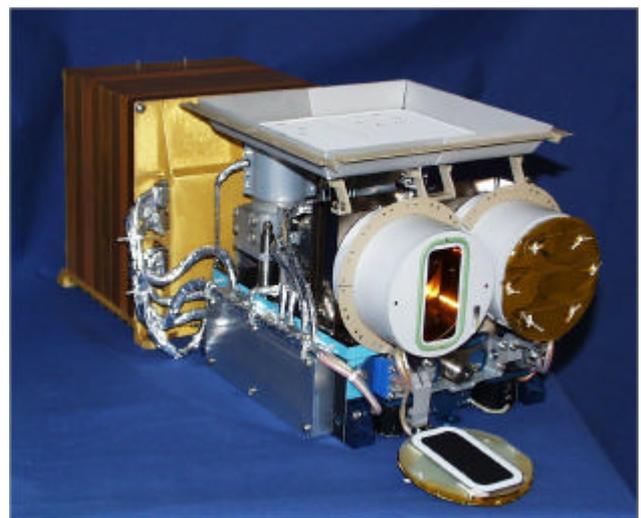


Fig. 1.2 – HSRS with IREU in flight configuration (8,7 + 5,8 kg, 0,22 x 0,21 x 0,45 m<sup>3</sup>)

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## 2. WIDE ANGLE OPTOELECTRONIC STEREO SCANNER (WAOSS-B) AN EXAMPLE OF HARDWARE REUSE

The Wide angle optoelectronic stereo scanner WAOSS actually developed for the MARS-96 mission serves as VIS/NIR-sensor of the BIRD payload. A flight spare model of the mars mission could be modified slightly (see figure 2.1).

Only a new optics with two narrow spectral bands over the field of view of 50° was developed for vegetation exploration tasks. On the other hand the in-track stereo capability is an important feature for the cloud investigations.

Due to the modular electronic concept of WAOSS-B almost no hardware modification are needed and the re-configuration is concentrated on the software side, i.e. to provide the master clock function for simultaneous imaging of all BIRD instruments.

Together with a miniaturised CCD- matrix camera for higher resolution which is dedicated to AOCS performance confirmation tasks the payload segment is completed by two star cameras. Table 1 summarises the main technical data of the payload calculated from an altitude of 565 km (piggy-back launch on the indian PSLV in autumn 2001).



Fig. 2.1 - WAOSS-B under integration  
(8.4 kg, 0,18 x 0,21 x 0,38 m<sup>3</sup>)

	<b>HSRS - MWIR</b>	<b>HSRS - LWIR</b>	<b>WAOSS-B</b>	<b>HORUS</b>
<i>Spectral bands</i>	3.4 - 4.2 $\mu\text{m}$	8.5 – 9.3 $\mu\text{m}$	forward 600 - 670 nm nadir, backward 840 - 900 nm	450 – 890 nm
<i>F-number</i>	2.0	2.0	2.8	8
<i>Focal length</i>	46.39 mm	46.39 mm	21.65 mm	540 mm
<i>Pixel size</i>	30 x 30 $\mu\text{m}$	30 x 30 $\mu\text{m}$	7 x 7 $\mu\text{m}$	14 x 14 $\mu\text{m}$
<i>No. of pixels</i>	2 x 512 staggered	2 x 512 staggered	3 x 5184 (2884 illum.)	1024 x 1024
<i>Instantaneous FOV</i>	2.22 arcmin	2.22 arcmin	1.11 arcmin	5.35 arcsec
<i>FOV across track</i>	19 deg	19 deg	50 deg	1.6 deg
<i>FOV in track</i>	2.22 arcmin	2.22 arcmin	+25 , 0, -25 deg	1.6 deg
<i>Ground pixel size nadir</i>	365 m	365 m	183 m	14.6 m
<i>Swath width</i>	187 km	187 km	527 km	15 km
<i>Quantization</i>	14 bit	14 bit	11 bit	14 bit
<i>Data rate (aver./peak)</i>	693/ 4790 kbps	693/ 4790 kbps	597/ 600 kbps	1.8 Mbyte/ image
<i>Power consumption</i>	42 W incl. Electr. Unit	42 W incl. Electr. Unit	18 W	1.7 W
<i>Mass</i>	8.7 kg Camera Head + 5.8 kg Electronic Unit		8.4 kg	0.75 kg

Table 1 - Main technical parameters of the BIRD scientific instruments

## 3. PAYLOAD PLATFORM CONCEPT AND TECHNOLOGY

In contrast to classical spacecraft designs which are oriented on a clear separation of scientific instruments and the spacecraft bus the BIRD defines a payload segment including a common structure with minimised interfaces.

The technical solution of the platform is to combine two CF-honeycomb panels on top and below of a 3 mm-thick layer of Carbon Fibre Carbon (CFC). This layer provides heat conduction to the heat pipe interfaces on the front ends of the

platform with a coefficient of 155 W m<sup>-1</sup> K<sup>-1</sup> – comparable with aluminium.

The instrument mounting interfaces of this multi-sandwich structure are inserts with an enlarged plate founded in the CFC-layer (see figure 3.1). All connections with thermal relevance are glued with silver-filled epoxy. The heat conduction reaches over 50% of that from aluminium. Its CTE is a factor of 15 less. Another effect is the de-coupling of structural loads coming from the spacecraft bus because of separated mounting planes for spacecraft and scientific instruments.

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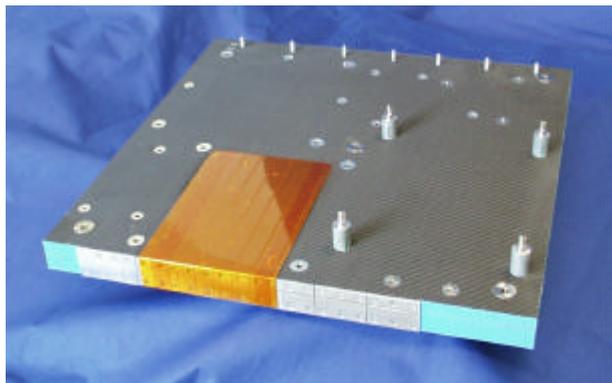


Fig. 3.1 - CFRM platform incl. payload mounting points and thermal control elements

#### 4. PAYLOAD PLATFORM TEST AND PERFORMANCE

During the thermal/ vacuum program of the BIRD Structure-Thermal- Model simulating the pre-defined duty cycles of the complete spacecraft in situ measurements of the co-alignment of all scientific instruments were implemented.

Because there is no access to the payload situated in the vacuum chamber an optical principle with the help of alignment prisms were installed which allows observation of all instruments from one point without movement of the payload segment or the measuring equipment. The misalignment caused by instrument and platform deformation in cold and warm operational phases is detected by autocollimation (see figure 4.1).

As a result it could be stated that the typical alignment deviations due to instrument operations are 1 arcmin and 3 arcmin due to the change of the platform temperature of 30 K representing the shift of orbit conditions over the mission. Here the influence of the spacecraft structures behaviour –milled aluminium- could not be compensated completely

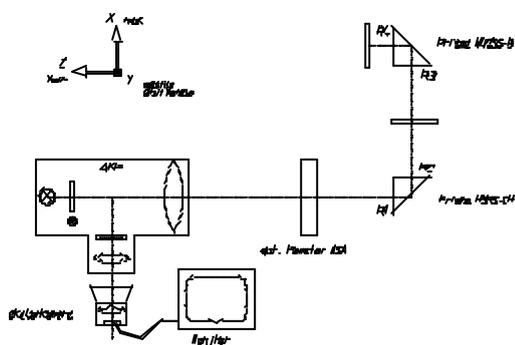


Fig. 4.1 - Optical principle for in-situ optical alignment test under vacuum

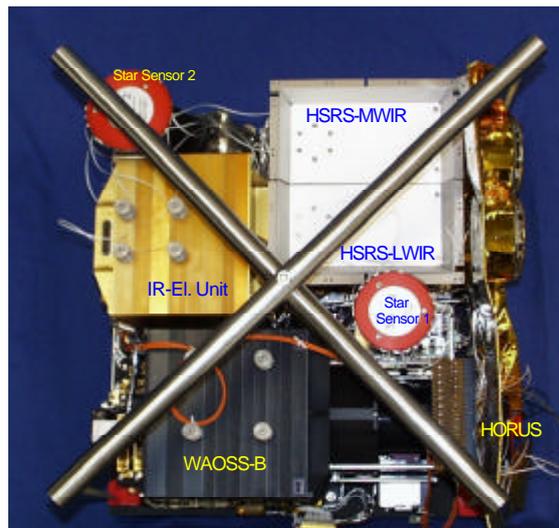


Fig. 4.2 - Complete calibrated payload segment prior mounting onto the S/C

Once integrated the payload segment according to figure 4.2 was calibrated in a complex process. The independent design of the payload segment results in a quite simple mounting procedure onto the spacecraft based on minimised interfaces. That also gives flexibility of refurbishment of components if needed.



Fig. 4.3 - BIRD ready for launch as a piggy-back payload on the indian PSLV C3 vehicle

## 5. THE CALIBRATION-FACILITY

The calibration facility located in the DLR-Institute of Space Sensor Technology was originally developed for calibrating space borne sensors in the visible range [Schuster, R. 1995]. During the work on BIRD the calibration facility was extended to the infrared spectrum. Now it is possible to calibrate sensors working in different spectral ranges together. In this way also the problem of copixelregistration between different sensors could be solved.

The optical scheme of the calibration set up is shown in fig. 5.1

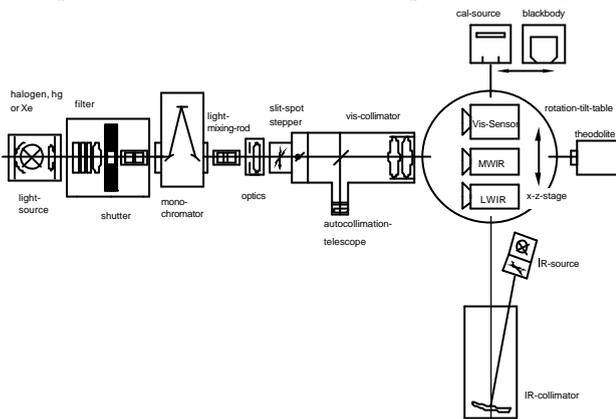


Fig. 5.1 - Calibration facility (optical scheme)

The main part of the Calibration facility is a high accuracy two-axis nodal bench which carries the sensors.

The azimuth axis can move around  $350^\circ$  and the elevation axis  $\pm 50^\circ$  with an accuracy of  $\pm 2.5$  arcsec and resolution of 0.5 arcsec. Additionally the load can be adjusted with a x-y translation stage of  $\mu\text{m}$ -stability. The visible calibration part is built by a high corrected lens-collimator of  $f=1200$  mm,  $D=150$ mm with autocollimation device. With an adjusting slit or spot of aperture =  $\pm 25$ mm, accuracy =  $\pm 1\mu\text{m}$  and resolution =  $0.1\mu\text{m}$  PSF/MTF-measurements can be done.

The collimator is apochromatic corrected between 390-1013 nm. Different lamps, halogen (150W), xenon (150W), mercury (200W) can be used. Spectral measurements can be made by different filters or with a grid-monochromator (350-800nm, 700-1500nm,  $\Delta\lambda = 2 \dots 20$  nm). Special software (MS Windows) helps for geometric, radiometric and spectral calibration of digital sensors or complete camera systems in the visible range.

The collimator for the infrared spectral range is an off-axis mirror collimator with  $f=1000$ mm and  $D=120$ mm. A spot-target is illuminated by an IR-source. This collimator will be used for the geometrical calibration and PSF/MTF-measurements of the infrared sensors of BIRD. The two collimators are adjusted in the same plane and are perpendicular to azimuth- and elevation-axis of the nodal bench.

The main task for geometric calibration is the exact determination of the pixel orientation of each sensor. The pixel orientation is determined by measuring the two angles of the nodal bench during illumination of a single pixel. A sufficient number of pixels (in the order of 20) of each sensor line will be measured, because it is not possible and also not necessary to measure all. The pixels between the measuring points will be interpolated mathematically. As the result of the geometrical calibration each pixel is signed with two angles which give the orientation and allows the exact correlation between the



Fig. 5.2 - View of the calibration laboratory at DLR-Berlin

points of the scene and the image. Because the original payload platform of BIRD with the fix mounted different sensors will be measured together with one facility the pixelcoregistration between visible and infrared sensors can be done with high performance.

## 6. RESULTS OF CALIBRATION

### 6.1 Geometric Calibration

During the geometric Calibration the PSF/MTF was determined at the measuring points. The PSF is the best value to describe the focusing of the system and the MTF shows the possible resolution. As an example these values measured in x-direction (across line) a y-direction (along line) are shown in figure 6.1 for a stereo line of the WAOSS (B) camera.

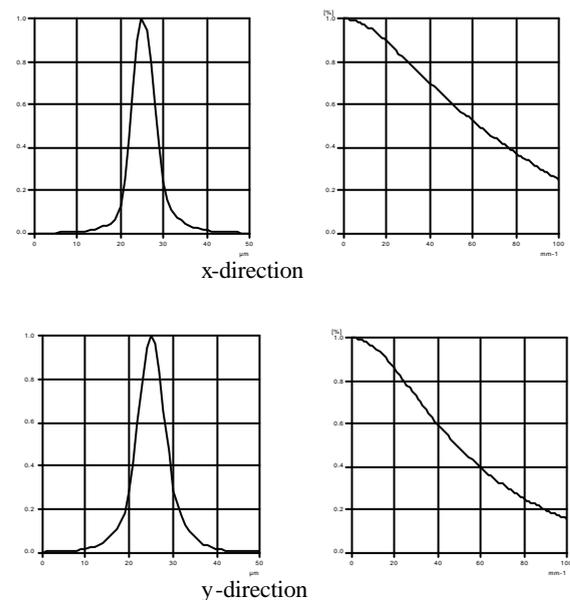


Fig. 6.1 - Examples of PSF/MTF of WAOSS (B)

The criterion for best focusing of infrared-sensors MWIR and LWIR was the best MTF during the sensor imaged a small pinhole target from the IR-collimator. An example of the MTF

is shown in fig. 6.2 for the MWIR- and LWIR-sensor. The difference of the MTF in the FOV of  $\pm 8^\circ$  is relatively small. With this results we can expect well focused pictures from BIRD in the infrared spectral range.

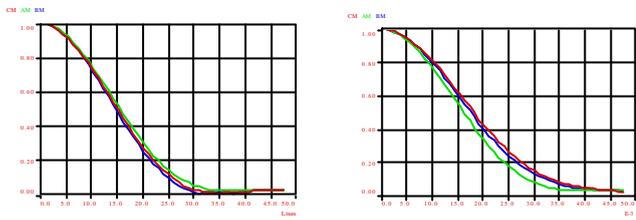


Fig. 6.2 - MTF of the MWIR-and LWIR-sensor for  $0^\circ, 4^\circ$  and  $8^\circ$

The orientation of the different sensors WAOSS-B, MWIR, LWIR and HORUS could be measured mounted on the original satellite platform (s. fig. 5.2). The sensors are mounted and aligned in that way, that the nadir-line of WAOSS-B, the infrared lines of MWIR and LWIR are looking nearly exact at the same region on earth (s. figure 6.3). The forward and backward looking line of WAOSS-B for stereo capability of the images have an angle of  $\pm 25$  degree to nadir-line. In the zoom of the central part of the observation region we can see the differences between the MWIR and LWIR lines and the WAOSS-B line (s. figure 6.4). Each infrared channel gives a footprint of two parallel stripes with an exact distance of one pixel because the infrared array is staggered by two lines with a difference of a half pixel in line direction and a distance of one pixel between.

These geometric relations between the lines of the different sensors are the basis for the image processing to produce correct images which allow exact overlapping of the visible and infrared pictures.

The mounting and alignment of the sensors has not been changed significantly during the whole pre-launch phase and transport to the launching vehicle.

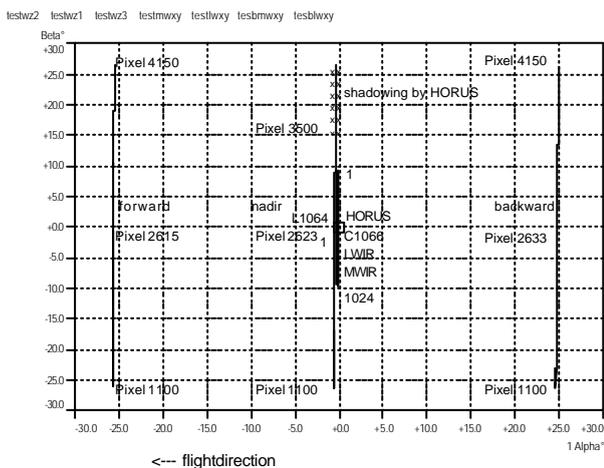


Fig. 6.3 - View of the sensors at object-plane

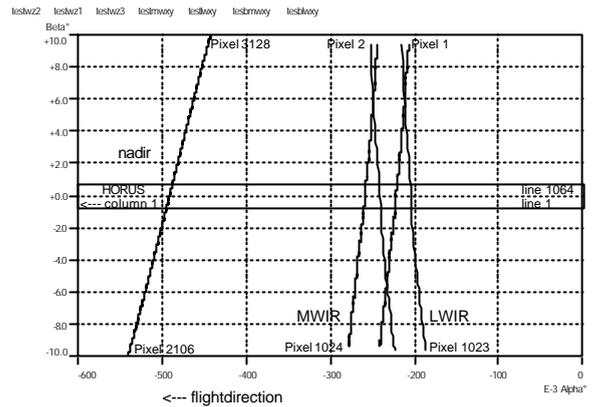


Fig. 6.4 - Orientation of WAOSS-B nadir-line to MWIR- and LWIR-sensors at object plane (central zoom of fig. 6.3)

## 6.2 Spectral and radiometric Calibration

The spectral and radiometric calibration is necessary to improve the picture quality and nevertheless the scaling of the signal in radiometric units is a new quality in the field of photogrammetry.

The WAOSS-B sensor works in two different spectral bands to allow discrimination of vegetation and soil areas (fig. 6.5). The backward and nadir line detects light in the near-infrared of 840-910 nm and the forward line is sensitive between 610-700 nm. The spectral behaviour is given by a special design of the optics where special filters has been integrated in the optical path.

The first part of radiometric calibration is the determination of correction values for each pixel of all three CCD-lines. These values are necessary to correct the limb darkening of the optics and the Photo-Response-Non-Uniformity (PRNU) of the CCD-detector. The correction will be done on-line in the camera itself by multiplication of the signal with the correction values in the digital part of the camera electronics. With that correction the output signal over the line is constant if the camera is illuminated by a homogeneous flat field source (see fig.6.6).

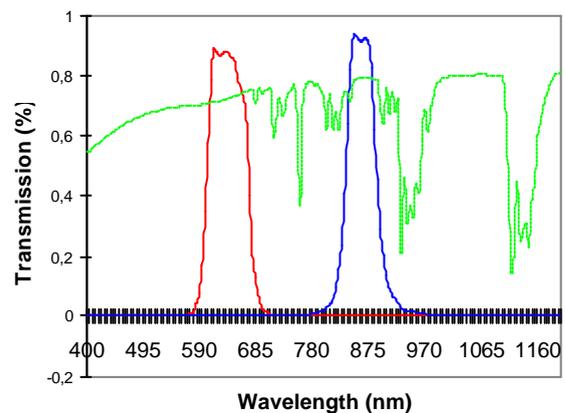


Fig. 6.5 - Spectral bands of WAOSS-B and atmospheric

The second step is the scaling of the signal in absolute radiometric units. For that purpose a absolute calibrated sphere which covers the total FOV of the camera will be measured. The absolute calibration values will be derived by convolution

of the signal with the normalized responsivity and the spectral characteristics of the source.

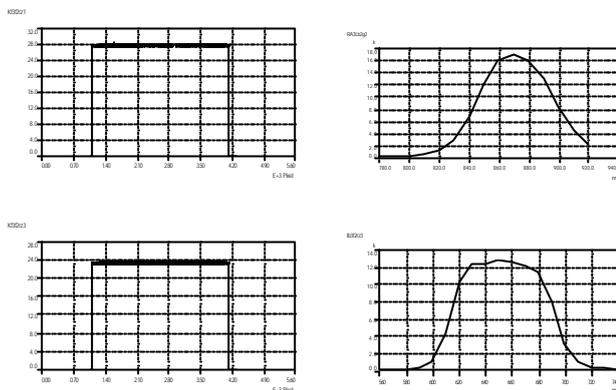


Fig. 6.6 - radiometric calibrated signal and spectral responsivity of backward and forward line

The radiometric marks of WAOSS-B like the absolute calibrated responsivity, the Noise Equivalent Response (NER) and the Signal-to-Noise ratio (S/N) are summarized in Table 6.1.

line	responsivity [cm <sup>2</sup> ·nm·sr·Digit/μW·ms]
1 backward	26.2519
2 nadir	26.6741
3 forward	22.6971

line	NER [nW/cm <sup>2</sup> nm sr]	S/N [Bit]
	centre - edge	centre-edge
1 backward	34 - 45	8.6 - 8.2
2 nadir	35 - 46	8.6 - 8.2
3 forward	48 - 55	7.7 - 7.5

Table 6.1 - radiometric performance of WAOSS-B

## 7. SUMMARY

A new developed Hot Spot Recognition System working in the middle and thermal infrared was designed for the small satellite mission BIRD. This infrared system together with a proved stereo line camera, two star sensors and a matrix camera was mounted on a special payload platform. The design, testing and calibration took place at the Institute of Space Sensor Technology and Planetary Exploration of the German Aerospace Center (DLR) in Berlin. The geometric, radiometric and spectral calibration was done by a special calibration facility working in different spectral ranges. The technological state of the design together with the carefully testing and calibration was one of the precondition for the success of the BIRD-mission.

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