

SIR-2

NEAR Infrared Spectrometer

User Manual and ICD

C1-SIR-MA-3001

1.0

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Prepared by the SIR-2 Team

Approval Sheet

prepared by: MPS engineering staff members (signature/date)

prepared by: UoB representatives (signature/date)

prepared by: PAS representatives (signature/date)

approved by PM: Andreas Nathues, MPS (signature/date)

approved by QA/PA: Henry Perplies, MPS (signature/date)

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Acronyms

| | |
|---------|---|
| A/D | Analog Digital Converter |
| ADC | Analog Digital Converter |
| AGND | Analog Ground |
| Anti-SS | Anti Sun Side |
| APID | Application Process Identifier |
| ASS | Anti Sun Side |
| BC | Bus Controller |
| BDH | Base-band Data Handling |
| BMU | Bus Management Unit |
| C-1 | Chandrayaan-1 |
| CAD | Computer Aided Design |
| CCSDS | Consultative Committee for Space Data Systems |
| CDR | Critical Design Review |
| CMD | Command |
| CMDAD | Command Address |
| CMOS | Complementary Metal Oxide Semiconductor |
| CoG | Center of Gravity |
| CPU | Central Processor Unit |
| CS | Checksum |
| CSR | Clementine Spectral Reflectance |
| DC | Direct Current |
| DC/DC | DC to DC Converter |
| DGND | Digital Ground |
| DH | Data Handling |
| E-Box | Electronic Box |
| EEM | Electrical Engineering Model |
| EEPROM | Electrical Erasable PROM |
| EGSE | Electrical Ground Support Equipment |
| EMC | Electromagnetic Compatibility |
| EMI | Electromagnetic Interference |
| ESA | European Space Agency |
| ESD | Electro Static Discharge |
| ETO | Earth Transfer Orbit |
| FoV | Field of View |
| FPGA | Field Programmable Gate Array |
| FS | flight spare |
| FS | Flight Spare |
| GTO | Geostationary Transfer Orbit |
| H/W | Hardware |
| HK | Housekeeping |
| HKDP | Housekeeping Data Package |
| HySI | Hyper Spectral Imager |
| I/F | Interface |
| I/O | Input / Output |
| ICD | Interface Control Document |
| ICU | Instrument Control Unit |
| IEH | Instrument External Harness |
| IHDM | Instrument Health Data Message |

| | |
|---------|--|
| ILH | Instrument Local Harness |
| InGaAs | Indium Gallium Arsenide |
| INP | Input Power Supply |
| IP-core | Intellectual Property Core |
| IR | Infrared |
| ISO | International Standard Organization |
| ISR | interrupt service routine |
| ISRO | Indian Space Research Organization |
| ISU | Instrument Sensor Unit |
| LOI | Lunar Insertion Maneuver |
| LTT | Lunar Transfer Orbit |
| LVDS | Low Voltage Differential Signal |
| M3 | Moon Mineralogy Mapper |
| M4 | metric screw thread 4mm |
| MD | Mass Dummy |
| MDDP | Memory Dump Data Package |
| MICD | Mechanical Interface Control Document |
| MIL-Std | Military Standard |
| MLI | Multi Layer Insulation |
| Mol | Moment of Inertia |
| MOSFET | Metal Oxide Semiconductor Field Effect Transistor |
| MPS | Max-Planck-Institute for Solar System Research |
| MUX | Multiplexer |
| NA | Not applicable |
| NIR | Near Infrared |
| O-Box | Optics Box |
| OBT | Onboard Time |
| OGSE | Optical Ground Support Equipment |
| OPAMPS | Operation Amplifiers |
| OSIRIS | Optical, Spectroscopic, and Infrared Remote Imaging System |
| PCB | Printed Circuit Board |
| PDA | Photo Diode Array |
| PFM | Proto Flight Model |
| PID | Proportional plus integral plus derivative controller |
| PREP | Preparation Mode of SIR-2 |
| PROM | Programmable Read Only Memory |
| PSU | Power Supply Unit |
| RAM | Random Access Memory |
| ROM | Read Only Memory |
| RT | Remote Terminal |
| RTN | RETURN |
| RX | Receiver |
| S/C | Spacecraft |
| S/N | Signal to Noise Ratio |
| SCDP | Science Data Package |
| SGRP | Spacecraft Ground Reference Point |
| SH | Sensor-Head |
| SID | Sub Identifier |
| SIR | SMART-1 Infrared Spectrometer |
| SIR-2 | Spectrometer Infrared - 2 |
| SIR2CMD | SIR-2 Command |

| | |
|-----------|--|
| SIS | Spacecraft Simulator |
| SMART-1 | Small Missions for Advanced Research in Technology |
| SNR | Signal to Noise Ratio |
| SRES | Soft Reset |
| SSDR | Solid State Data Recorder |
| STDBY | Standby Mode of SIR-2 |
| STM | Structure Model |
| SUB-ID | Sub Identifier |
| TBC | To be confirmed |
| TBD | To be defined |
| TEC | Thermo Electrical Cooler |
| TM | Telemetry |
| TMC | Terrain Mapping Camera |
| TMM | Thermal Mathematical Model |
| TV | Thermal Vacuum |
| TX | Transmitter |
| TX/RXA | Transmitter/Receiver A |
| TX/RXB | Transmitter/Receiver B |
| UoB | University of Bergen |
| UV | Ultraviolet |
| UVVIS | Ultraviolet and Visible light |
| V_{dd} | Power Supply Voltage |
| VIS | Visible light |
| V_{ref} | Reference Voltage |
| WD | digital 16-Bit Word |
| WDGEN | Watchdog enable |
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Applicable Documents

| No. | document name | document number | Issue |
|------|---|-------------------------------------|--------------------------------------|
| AD1 | Chandrayaan-1 ETLSC | C1-TR-SC-0011 | Rev-01, 13 th May 2005 |
| AD2 | C-1 Product Assurance Plan | ISRO-ISAC-Chandrayaan-1- RR-0475 | Oct 2005 |
| AD3 | C-1 S/C Project Environmental Level Specifications | | Rev. 00 |
| AD4 | SIR-2 Qualification Vibration and Shock Test Procedure | C1-SIR-MPS-TP-3010 | 1.2 |
| AD5 | Chandrayaan-1 Project Configuration Document | ISRO-ISAC-Chandrayann-PR- 0447 | 2.0 |
| AD 6 | SIR-2 Handling and Installation Procedure | ISRO | October 2007 |

Reference Documents

| No. | document name | document number | Issue |
|------|---|---------------------------------------|------------------|
| RD1 | SIR-2 cooling curves after launch | C1-SIR-TN-3001 | 1.0 |
| RD2 | | | |
| RD3 | Scientific Paper | P&SS Vol. 52, Issue 14, p. 1261 -1285 | |
| RD4 | SIR-2 EGSE Operation Manual | C1-SIR-MA-3003 | 1.1 |
| RD5 | SIR-2 Calibration Plan | C1-SIR-TP-3011 | Draft |
| RD6 | TN on Optical Design | S1-SIR-TN-3005 | Feb 15, 2000 |
| RD7 | AMIE – SIR Co-alignment procedure description scenario parameter list | SMART-1 | 1.1 |
| RD8 | Celestial Calibration Targets | SMART-1 | 1.0 (1.4.05) |
| RD9 | SIR-2 Thermal Analysis | C1-SIR-ICD-3003 | 3.0 ¹ |
| RD10 | SIR-2 EGSE Specification and Documentation | C1-SIR-MA-3002 | 1.0 |
| RD11 | Review of SIR-2 Thermal Analysis by Thermal, ISAC, ISRO | | June 2007 |
| RD12 | Alignment Verification Test Procedure and Test Report for SIR-2 Infrared Spectrometer O- Box PFM Subunit on Chandrayaan-1 | C1-SIR-TP/TR-3024 | 1.0 |
| RD13 | SIR-2 Calibration Report | C1-SIR-TR-3011 | to be issued |
| RD14 | SIR-2 Inflight Calibration Plan | C1-SIR-MA-3004 | 1.0 |

¹ Issue 4.0 in preparation

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| RD15 | Integration, Handling and Purging Procedure | C1-SIR-TP-3021 | 1.0 |
| RD16 | SIR-2 DML | C1-SIR-PTL-3001 | 2.0 |
| RD17 | PFM Electrical Integration Test Report | C1-SIR-TR-3028 | 1.0 |
| RD18 | SIR-2 Command Database | C1-SIR-MA-3005 | To be issued |
| RD19 | Properties E-Box | C1-SIR-TR-3017 | 1.0 |
| RD20 | Properties O-Box | C1-SIR-TR-3019 | 1.0 |
| RD21 | Properties SHRU | C1-SIR-TR-3022 | 1.0 |
| | | | |

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1 Introduction

SIR-2 is a redesigned, monolithic grating, near-infrared spectrometer which will fly on the CHANDRAYAAN-1 mission, scheduled for launch in April 2008. With SIR-2, for the first time, an orbiting reflectance spectrometer will be flown in a scientific mission around the Moon with the intention to map the Moon in a two-year long orbit. The instrument is based on SIR, flown on ESA's SMART-1 technology mission, covering a wavelength range from 0.92 to 2.39 μm . SIR-2 has a spectral resolution of about $\Delta\lambda_{\text{Pixel}} = 6 \text{ nm}$ and an angular resolution of 2.2 millirad. SIR-2 is intended to accomplish a highly integrated study of the lunar mineralogy, together with two further optical instruments from a lunar polar circular orbit, extending thereby the wavelength region of CHANDRAYAAN-1's Hyper Spectral Imager into the near-infrared range, allowing for full coverage of the spectral range between 0.6 and 2.4 μm , which is important for the mineralogical identification.

2 Instrument objectives and description

2.1 Objectives

2.1.1 Science

The Moon is unique in terms of its origin, size and density. It is, with the exception of the Earth, the only planetary body from which we have samples from known locations. Laboratory studies of lunar samples brought back by the APOLLO and LUNA missions, as well as remote sensing of the Moon, particularly by the CLEMENTINE and LUNAR PROSPECTOR missions, have provided a considerable amount of data which gave us insight into the processes responsible for its formation and subsequent chemical and geological evolution. A synthesis of these results shows that most likely the impact of a giant, differentiated planetesimal on the proto-Earth, followed by the accumulation of the impactor's crustal material and the impact generated terrestrial ejecta, thrown in a low circumterrestrial orbit, led to the formation of the Moon.

As the Earth's next body, the Moon allows a view into the early history of the solar system. Traces of the past are wiped out on Earth, since the Earth is a geologically very active planet whose surface is subject to continuous change through plate tectonics and a multitude of other erosive processes. In direct contrast to the Earth is the Moon, which is structured in a much simpler way. Processes of erosions are restricted to impacts (from dust to asteroid sizes). In the planetary context the Moon provides an excellent record of primordial crust formation, and complete records of the cratering history and the formation and evolution of its secondary crust.

It has been recognized early that the ancient impact environments on the Moon must also have impacted the Earth and that an accurate understanding of the early history of the Moon is also essential for a realistic understanding of the impact environment on the Earth which is so important in finding the constraints of both time and place in which life originated.

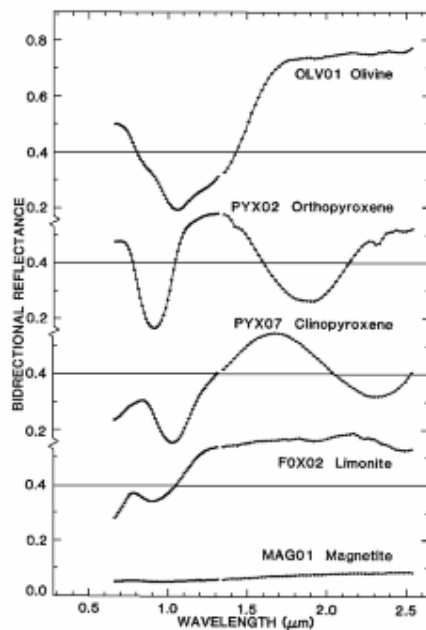
Despite all our efforts on a wide front of research, major questions still await to be resolved. Among those are: What is the cause of the global asymmetry of the Moon, which on the far side has a thicker crust and lacks the Mare structures which are characteristic for the near side? Is it related to convection and density inversion dynamics, early giant impacts, asymmetric crystallization of the Magma Ocean, or Earth-Moon tidal effects? How does a magma ocean work? What was the early thermal evolution of the Moon? What is the vertical and lateral structure of the lunar crust and how did it develop? What is the composition and structure of the lunar mantle? What role did early volcanism play? What were the timing and the effects of major basin-forming events on the lunar stratigraphy? What is the nature of the South Pole-Aitken basin, does it penetrate into the mantle, and how did it affect early crustal evolution? Why is the Moon different from other planets and how do planets work in terms of surface processes, heat transfer, and geologic evolution? Are the Apollo geophysical measurements representative of the Moon, or are they only valid for the small regions around the Apollo landing sites? How does the formation and evolution of the Moon and its well preserved record of impact modification and solar activity relate to the Earth's ancient history?

The lunar surface, not affected by an atmosphere, water or life, presents a unique record of solar system activities in the direct vicinity of the Earth. To decipher this information one has to know and understand the building blocks of the lunar surface. Lunar rocks, sampled by six Apollo and three Luna missions, together with meteorites from the Moon, are our only direct information about the Moon's minerals, chemical composition and age. Lunar surface material is usually classified into four different groups: i) basaltic volcanic rocks, ii) pristine rocks from the lunar highlands, iii) complex polymict breccias and iv) lunar soil. While the majority of these rocks were originally igneous (formed by cooling of molten material), most consist of only a few minerals: pyroxenes, olivines, plagioclase feldspar and ilmenite. Quite surprisingly, our present knowledge of the surface chemistry and mineralogy is far from complete.

The Apollo Program was entirely focused on preparations for a manned landing and thus attention was mainly devoted to potential landing sites, in the equatorial regions of the near side. It is fair to say that the present distribution of nine sampling sites is heavily biased: none are on the far side, or at high latitudes, while all but two are in or close to mare. The differences between lunar maria and highlands indicate large-scale chemical differentiation of the original materials that accreted to form the Moon. While this fact is commonly accepted the details of this differentiation are still not known. Early recognition of the fact that the highlands are composed mostly of the Ca-rich plagioclase, a relatively light mineral, led to the suggestion that this mineral represents crystal floating at the top of a very deep magma ocean (Wood et al., 1970). While this idea has survived in several modified forms it is not clear whether or not the concept of a lunar crust evolving from extensive magmatism that is cumulatively concentrated plagioclase in the upper part of the crust (Walker, 1983) is also feasible. More than any other question about the Moon, our understanding of the evolution of the lunar crust is critically dependent on the completeness of available compositional data and is most vulnerable to the temptations of extrapolating from limited information. At this point global coverage of surface composition data can yield the decisive answer to understand the formation and evolution of the lunar crust and the processes that modify it.

The determination of the chemical composition of a planet's crust and mantle is among the foremost important goals of planetary research. UV, VIS, and NIR (e.g., Hapke, 1993), as well as X-Ray (e.g., Yin et al., 1993) and Gamma-Ray (e.g., Evans et al., 1993) spectroscopy, provide remote sensing methods to characterize the mineralogical and elemental composition of planetary surfaces. For more than a century (reviewed in Minnaert, 1961) it has been known that information on the physical characteristics of a planetary crust is contained in the manner in which light interacts with a surface. The photometric parameters of the surface provide information on the optical properties of constituent particles and the small-scale texture, as well as on the degree of large-scale roughness. Analysis of the absorption bands reveals mineralogy and composition.

Spectral features of most rock-forming minerals in the visible and near-infrared range originate from the locations of transition elements in the crystal structure of the minerals. Spectral profiles of sunlight reflected from planetary surfaces, when correlated with measured optical spectra of rock-forming minerals, may be used to detect the presence of transition metal ions and constituent minerals, as well as to determine model mineralogy of regoliths on terrestrial planets (Burns, 1993).



Among the various spectral approaches, near-infrared spectroscopy has proved to be a powerful tool in the study of the surfaces of the planets and of the small bodies in the solar system. Diagnostic absorption bands of various minerals and ices, that are expected to be found on the surfaces of planetary bodies, are located in the near-IR range, between 0.7 and 3.0 μm . As an example Figure 1 shows the near-IR laboratory reflectance spectra of pure minerals that were identified on the lunar surface (Singer, 1981).

Figure 1 Reflectance spectra of pure minerals (Singer, 1981).

Most of the associated mineral absorption bands are very broad when compared with stellar bands. Their depths can be measured with a low resolution spectrometer or even with a spectro-photometer that uses filters targeted at particular absorption bands. However, some of the mineral subtypes have weaker and narrower spectral features which can be studied only by moderate resolution spectroscopy. Good examples are the feldspar feature at $\sim 1.3 \mu\text{m}$ and a set of sharp bands typical for clay minerals and carbonates between $1.3 \mu\text{m}$ and $3 \mu\text{m}$ (Gaffey et al., 1993).

Figure 2 shows the spectral changes due to variations of the olivine-to-orthopyroxene ratio in a sample (Singer, 1981). The shown figures clarify the importance of the NIR spectral region to analyze the mineral composition of solid surfaces. The depth of the absorption features depends mainly on the mineral composition and grain size. Moreover, in the surfaces of the solar system bodies the minerals are mostly present in mixtures. This results in the deformation of the shape and a shift of the minimum of the absorption features. The detailed quantitative study of the surface composition usually requires spectral measurements with moderate spectral resolution.

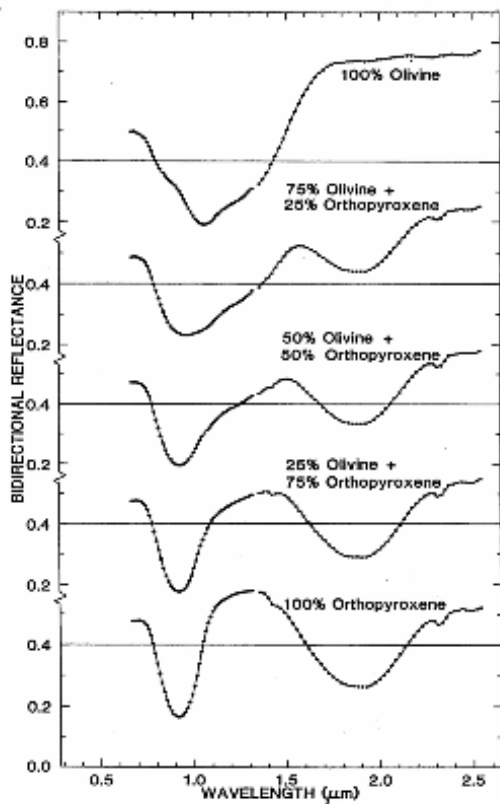


Figure 2 Reflectance spectra of weight percentage mixtures of olivine and orthopyroxene (Singer, 1981).

Ices of different volatiles are often present on the surface of the planets and small bodies. The NIR spectral range

also contains the spectral features of the ices and frosts.

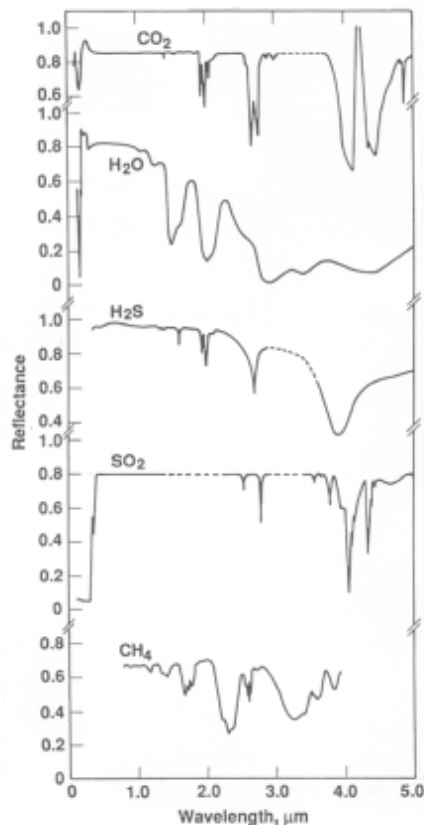


Figure 3 shows the laboratory spectra of the various ices which are most frequently met in the solar system (Gaffey et al., 1993). The possibility of finding deposits of hydrogen at the poles of the Moon in the form of frozen water ice has been discussed since about 1960 (e.g., Watson et al., 1961; Vasavada et al., 1999). The initial analysis of the Clementine bistatic radar experiment seemed to indicate a positive detection of rather pure water ice near the south pole of the Moon (Nozette et al., 1996). However, a more detailed analysis of the same data showed that the initial conclusion was ambiguous (Simpson and Tyler, 1999).

Figure 3 Reflectance spectra of typical frosts (Gaffey et al., 1993)

The neutron spectrometer measurements made by the Lunar Prospector mission have shown that surface materials at the lunar poles contain increased contents of hydrogen (Feldman et al., 2000). In the permanently shadowed craters near the south pole, the abundance of hydrogen is estimated to be 1700 ± 900 ppm by weight, which corresponds to 1.5 ± 0.8 wt.% of water ice. At the north pole the content of water ice may be even larger (>10 wt.%) (Feldman et al., 2001). These results, however, need clarification by future studies. The footprint of the Lunar Prospector neutron spectrometer measurements is ~ 60 km in diameter and it is therefore difficult to correlate specific geological features with the identified locations of hydrogen-bearing deposits. While Lunar Prospector could not answer the question as to whether the hydrogen-bearing material is located on the surface or close to it, SIR-2, with its ability to directly observe the surface, has all the potential to contribute to this key question in lunar science. If this question can be solved with the new SIR-2 data, one may eventually understand the depositional history of this material. For example, McConnochie et al. (2002) suggested that if these deposits are buried and lack any surface expression, this may imply that the hydrogen has been delivered by large cometary impact events in the past or by a mechanism no longer operating. On the other hand, the existence of both surficial frost and buried deposits would suggest a steady supply of water and a continuous burial through regolith gardening. The effect of impact gardening on deposition of ice is considered by Crider and Vondrak (2003).

Despite Apollo's and Luna's collection of samples, the role of remote sensing of the lunar surface is gradually increasing. High-quality, near-IR spectra of the Moon were recorded using the 2.2-m telescope at Mauna Kea Observatory, Hawaii (Pieters, 1986). These spectra cover the range between 0.65 μm and 2.55 μm with a resolution of $\lambda/\Delta\lambda \sim 70$ and were recorded for selected regions with a size of ~ 5 km. Figure 4 presents the examples of the ground-based spectra (Smerkar and Pieters, 1985). These spectra show the diversity of the spectral properties, even within particular geological units. Note the variation of the shapes of the 1- and 2- μm absorption band. The weak band at ~ 1.3 μm belonging to feldspar is clearly seen in the bottom spectrum in the right figure. These moderate resolution spectra allow one to analyze composition of main geological units on the Moon. However, the analysis is limited by a coarse spatial resolution.

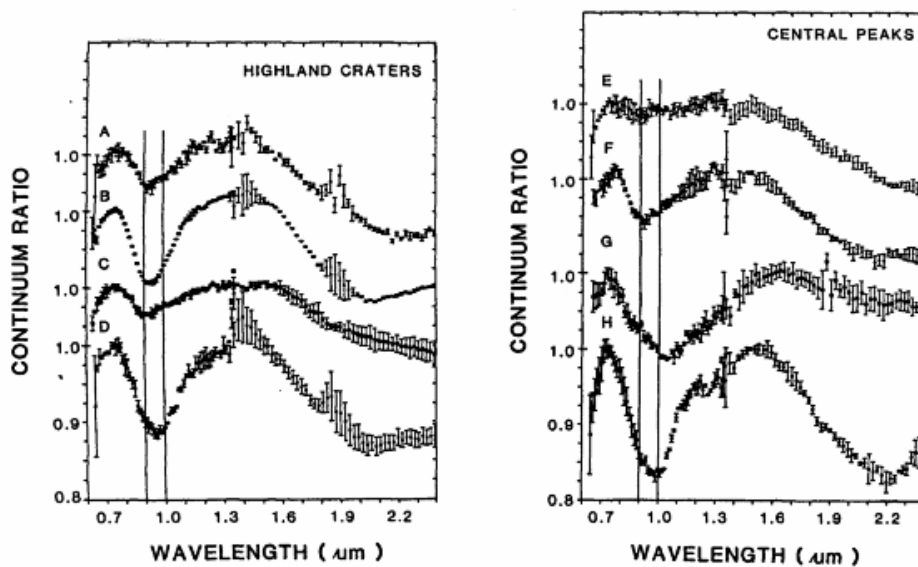


Figure 4 Representative reflectance spectra of the highland craters (left) and central peaks (right) after continuum removal (Smerkar and Pieters, 1985).

Significant steps forward in the lunar studies were made by the Clementine mission (Nozette et al., 1994). The spacecraft studied the Moon from the lunar polar orbit and provided a global mapping of the surface at spatial resolution of ~ 200 m in 11 narrow-band filters in the 0.4 - 2.6 μm range. The filter band-passes are shown in Figure 5 along with typical spectra of the lunar samples. The positions of the near-IR filters of the Clementine spectral imager were selected so as to observe the 1.0- μm and 2.0- μm absorption bands.

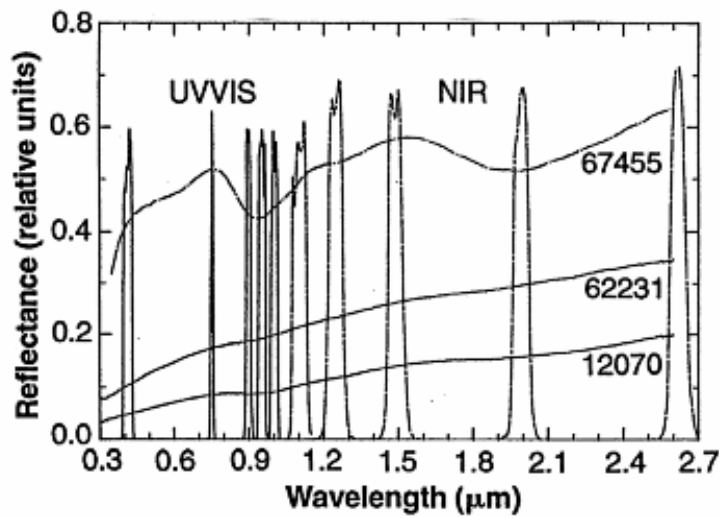


Figure 5 Positions of the filters of the Clementine cameras superimposed on the reflectance spectra of lunar samples (Nozette et al., 1994).

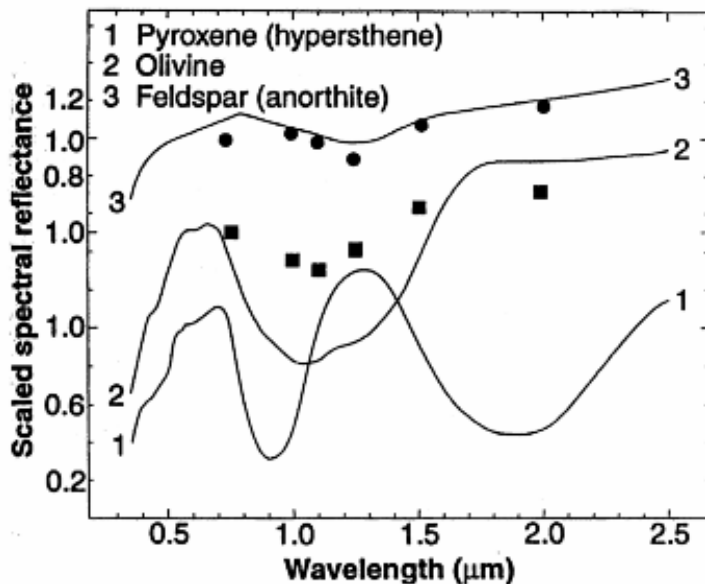


Figure 6 Clementine reflectance data for Aristarchus central peak and laboratory reflectance spectra (McEven et al., 1994).

The main results of the Clementine mission were:

- Global mapping of the Moon's surface in several wavelength bands which are diagnostic for pyroxenes and olivine;

- Identification of geological units and their correlation with topography;
- Study of the composition variations between the units;
- Study of the structure and composition of the crater ejecta.

The Clementine low resolution reflectance data show spectral features typical for olivine and feldspar (Figure 5, McEven et al., 1994). However, their comparison to the ground-based spectra (Figure 4) shows that their poor spectral resolution does not allow them to describe the existing mixtures and subtypes of minerals observed on the surface of the Moon.

2.1.2 Technology

The lunar data sets collected so far have two main limitations. The first data set (Pieters, 1986) has a spectral resolution good enough to observe weak and narrow spectral features and to record the details of the shape of broad absorptions. However, it has poor spatial coverage and resolution. Furthermore, ground-based observations are limited to observations on the lunar near side and suffer from the influence of the Earth's atmosphere.

The second data set, originating from the Clementine mission, has provided global mapping with high spatial resolution, but at the expense of spectral resolution. We emphasize that the spectral resolution is of great importance in the detailed study of the surface composition. This is clearly seen from the comparison of the ground-based spectra in Figure 4 and the Clementine data in Figure 6.

Recent advances in methods of the interpretation of spectral reflectance in the visible and near-infrared range (0.40 to 1.00 μm) have allowed the science community to produce composition (Lucey et al., 1998; 2000) and mineralogy maps (Tompkins and Pieters, 1999; Pieters et al., 2001; Staid and Pieters, 2001) for the Moon (Lucey, 2004) from Clementine Spectral Reflectance (CSR) data. Such maps have been one of the main goals of the lunar science community since Apollo sample returns were completed in the early 1970s. The Clementine UVVIS and NIR band-passes were originally chosen to discriminate major lunar minerals: plagioclase feldspar, olivine, clinopyroxene, orthopyroxene, and ilmenite. By exploiting FeO-induced spectral absorptions in major lunar crustal minerals, Lucey and colleagues transformed the CSR measurements to FeO abundance (Lucey et al., 1998, 2000a; Blewett et al., 1997), and in the process disentangled maturity effects (Lucey et al., 2000b). Utilizing a method similar to the FeO inversion, TiO₂ abundances were also derived (Lucey et al., 1998, 2000a). The FeO and maturity estimates require a spectral coverage of 0.75 to 0.95 μm while the TiO₂ abundances require coverage of 0.42 to 0.750 μm . With only five band-passes and limited SNR the Clementine data set (0.415, 0.750, 0.900, 0.950, 1.000 μm) allowed advances in our understanding of the composition and mineralogy of the lunar crust. Shortcomings of the Clementine analyses are due to incomplete characterization of the long wavelength portion (1.00 to 1.20 μm) of the 1- μm band and the exact location of the titanium and iron features in the visible range (0.45 to 0.70 μm). The SIR-2 instrument will allow much more precise and accurate determination of absorption features in the infrared relative to Clementine.

SIR-2 data, together with data from CHANDRAYAAN-1's Hyper Spectral Imager, which covers the spectral range from 0.4 to 0.9 μm , will allow the determination of opaque (ilmenite) and FeO abundances to within a few percent absolute, as well as better quantification of mineral abundances due to the extended infrared range (relative to Clementine).

Further progress in the study of the lunar surface can be achieved by combining the advantages of the above-mentioned observations on board a lunar orbiter. The requirements for this experiment follow from the discussion above:

1. The instrument should cover the NIR range (0.9 - 2.4 μm) where most diagnostic features of the surface minerals are located.
2. It is highly desirable to have a spectral resolution < 10 nm per pixel, in order to be able to record the shape of the broad as well as the narrower absorption bands.
3. The signal-to-noise ratio of the spectrometer should be high enough to detect weak bands of a few percentage depth, like those of feldspar at 1.3 μm . The required S/N can be estimated as >100.
4. The spatial resolution of these observations should be optimized to fit the other instruments on board Chandayaan-1.
5. The detector temperature shall be temperature stabilized, to enable more accurate dark current correction.

2.1.3 References

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2.2 Instrument description

2.2.1 Performance requirements

The spectrometer shall be able to detect and resolve the absorption bands of the major lunar minerals as specified in Table 1.

Table 1 Characteristics of lunar mineral absorption bands.

| Mineral / Ices | Band central wavelength μm | Average bandwidth μm | Spectral resolution $\lambda / \Delta\lambda$ | \approx S/N for detection | S/N for analysis of mineralogy |
|----------------|---------------------------------------|---------------------------------|---|-----------------------------|--------------------------------|
| Olivine | 1.0 – 1.1 | 0.5 | 20 | 10 | 50 |
| Orthopyroxene | Around 0.9 | 0.25 | 20 | 20 | 50 |
| | Around 1.9 | 0.6 | 20 | 20 | 50 |
| Clinopyroxene | Around 1.0 | 0.2 | 20 | 20 | 50 |
| | Around 2.3 | 0.4 | 15 | 20 | 50 |
| Limonite | 0.9 | \approx 0.1 | 50 | 30 | 100 |
| Feldspar | 1.3 | \approx 0.05 | 100 | 40 | 100 |

2.2.2 Instrument overview

SIR-2 is a highly compact, grating, near-infrared point spectrometer, covering the wavelength range between 0.92 to 2.39 μm with a spectral resolution of $\Delta\lambda_{\text{Pixel}} = 6$ nm. Key parameters of SIR-2 are listed in Table 2.

Table 2 Characteristics of SIR-2.

| | |
|--|---------------------------------------|
| Type of Instrument | Grating NIR Point Spectrometer |
| Wavelength Range | 0.92 to 2.39 μm |
| Spectral Resolution | $\Delta\lambda_{\text{Pixel}} = 6$ nm |
| S/N | >100 |
| Dynamic (ADC) | 16 bit |
| Angular Resolution / field of view | 2.2 mrad |
| f-ratio of front-end optics | 2.5 |
| Aperture (main mirror diameter) | 72 mm |
| Focal length | 180 mm |
| Exposure times | Selectable between 0.1 and 1000 ms |
| Power consumption | Max. 11W |
| Total mass of instrument | 3.3 kg |
| Dimension of O-Box | 199 x 161 x 93 mm |
| Dimension of Sensor-Head/Radiator Unit | 228 x 320 x 248 mm |
| Dimension E-Box | 147 x 137 x 59mm |

The near-infrared spectrometer SIR-2 consists of three individual units:

- O-Box (front-end optics), located on an extension of the Anti-SS panel
- Sensor-Head/Radiator Unit (spectrometer), located on the Anti-SS panel
- E-Box (digital electronics and power converter), located inside the S/C cube on the Anti-SS panel

These units are linked by:

- An optical fiber connecting O-Box and Sensor-Head/Radiator Unit
- An electrical harness (ILH) connecting Sensor-Head/Radiator Unit and E-Box

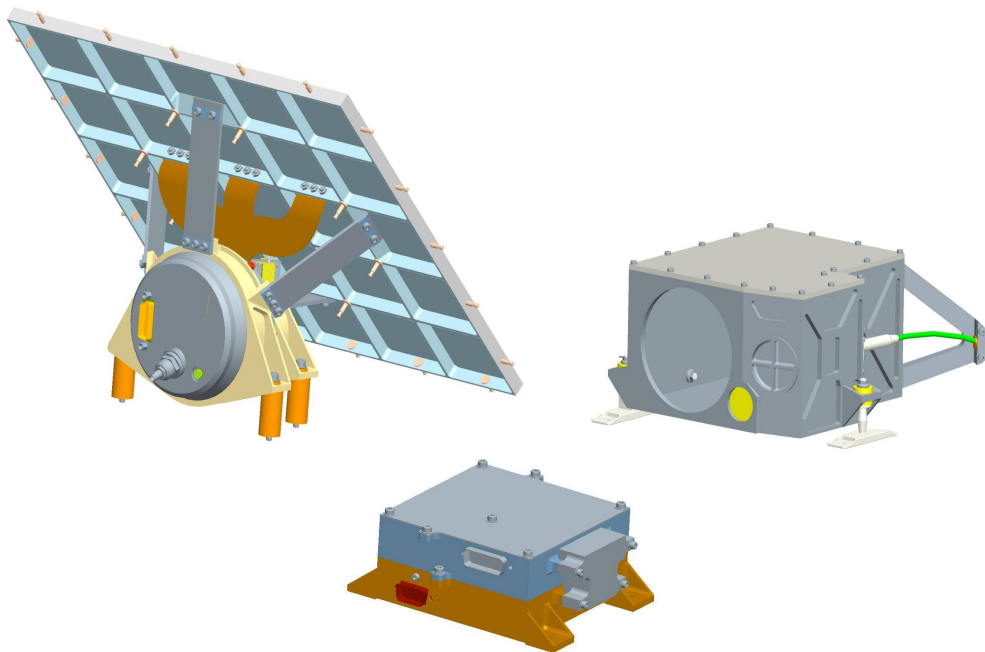


Figure 7 SIR-2 units: O-Box (right), Sensor-Head/Radiator Unit (left) and E-Box.

SIR-2 collects the Sun's light reflected by the Moon with the help of the optical box (O-Box) which houses a main and secondary mirror. This light then enters an optical fiber, which transmits the light to the Sensor-Head/Radiator Unit. Inside the Sensor-Head the light passes filter, slit and the quartz body and reaches the dispersing grating. The dispersed light then passes the quartz body again to reach a second order filter, which is glued onto the detector window. After passing this window the light is detected by the photosensitive pixels. The electrons released by the individual pixels are collected and a sequential read out is performed after the integration time has ended. The adjacent voltage will be measured for each pixel and the obtained values are converted to digits. The obtained values (counts) are finally embedded in the TM packages in order to send them to the spacecraft's mass memory.

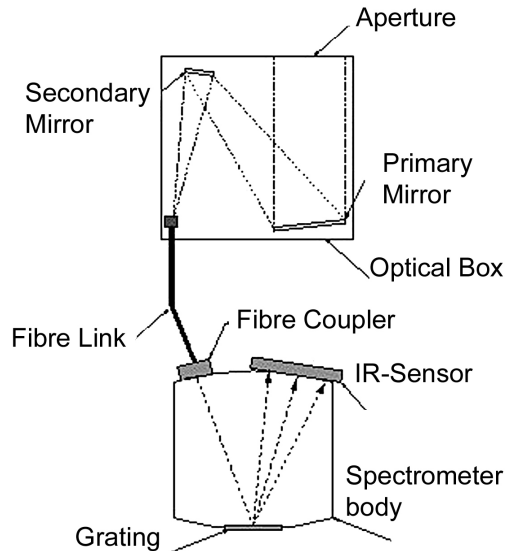


Figure 8 Functional principal of SIR-2.

2.2.3 Detector

SIR-2 uses a linear InGaAs photodiode array which is sensitive between 0.9 and 2.55 μm . It has 256 pixels with a pixel pitch of 50 μm . Three voltages are required to operate the detector ($V_{\text{dd}} = 5\text{V}$, $V_{\text{ref}} = 1.26\text{V}$ and $\text{INP} = 4.5\text{V}$)². The SIR-2 detector can be clocked with frequencies up to 1.5 MHz. For achieving sufficient signal-to-noise ratios a constant detector operating temperature of -50°C during noon-midnight orbit and -60°C else is anticipated. A two-stage cooling system the detector's thermoelectric cooler (TEC), and a passive radiation system is implemented. The detector is located inside the Sensor-Head. The support mechanics (Cooling Console) of the detector is thermally decoupled from the Sensor-Head housing and connected via the Cooling-Band with the Sensor-Head Radiator which radiates energy into space to ensure suitable temperatures. The stability of the detector temperature will be obtained by a control algorithm for the detector's thermoelectric cooler.

2.2.4 Electronics

The main SIR-2 electronics consists of the InGaAs photodiode array, the readout electronics, a 16-bit analog-to-digital converter (ADC), a microprocessor/controller for data and command handling and a custom designed DC/DC converter that powers the various parts of the electronics.

The electronics is separated into 3 sub-units, the Instrument Sensor Unit (ISU), the Instrument Control Unit (ICU), and the Power Supply Unit (PSU). The ISU analog electronics (single PCB) is located inside of the Sensor-Head (SH), while ICU (single PCB) and PSU (two PCBs) are located inside of the E-Box. The instrument local harness (ILH) connects the Sensor-Head/Radiator Unit and the E-Box. The SIR-2 electronics block diagram is shown in Figure 9.

² Voltages according to detector's data sheet, May 2005

In order to minimize the electronic noise the E-Box has been split into two main compartments, the PSU in the lower compartment and the ICU in the upper compartment. The ICU contains the pixel signal ADC (16 bit) converter, the microprocessor/controller for command handling and health data transfer via the MIL-BUS and the telemetry data (TM) through the LVDS S/C interface. The PSU contains the DC/DC converter, ON/OFF relays, the slowstart, and the EMC filtering, which is connected to the spacecraft power bus. The PSU also contains the HK parameter signal conditioning circuits with MUXes and the HK data ADC (16 bit) for parameter monitoring.

The core of the electronics design is based on the ACTEL RTAX2000 FPGA technology (anti-fuse) where all the system logics and the processing capacities are implemented. An embedded LEON3FT microprocessor IP core with a watchdog circuit controls the electronics and ensures instrument autonomy. When the watchdog is enabled it will reset the system to Standby Mode if an abnormal behaviour is detected. The instrument default system program resides in the EEPROM/flash memory which enables the possibility of having stored the latest and optimized parameters as well as the default setup parameters. The RAM is used as general purpose storage for programs and data.

The instrument is switched ON and OFF by pulse commands affecting the PSU. In addition, there is a pulse command to reset the instrument microprocessor and a WatchDog Enable (WDGEN) level command to control the watchdog.

An HK clock in the embedded processor is implemented to prove the integrity and monotony of the program execution. This clock will be used also for time stamping of the science data and is synchronized with the spacecraft on board clock. Time stamps will be integrated in the science and HK data packages.

The power switching of the ISU is controlled by the ICU, and commanded from the ground segment. When the instrument is powered on, the ISU will be unpowered while the ISU Printed Circuit Board (PCB) heater will be powered on. Only when the ISU PCB temperature is higher than a configurable threshold, the instrument can be commanded to enter preparation mode which will power on the ISU and power off the PCB heater. The enforcing of this limit is by default disabled (see Hofftrshld - Table 15), and the deactivation threshold must therefore first be manually configured in order to activate the ISU.

The temperatures of the ISU PCB and the temperature of the detector itself are read as a part of the instrument HK temperature monitoring system. The current of the TEC is controlled by a PID controller algorithm and a digitally driven current generator (8 bit) integrated in the instrument's PSU DC/DC converter.

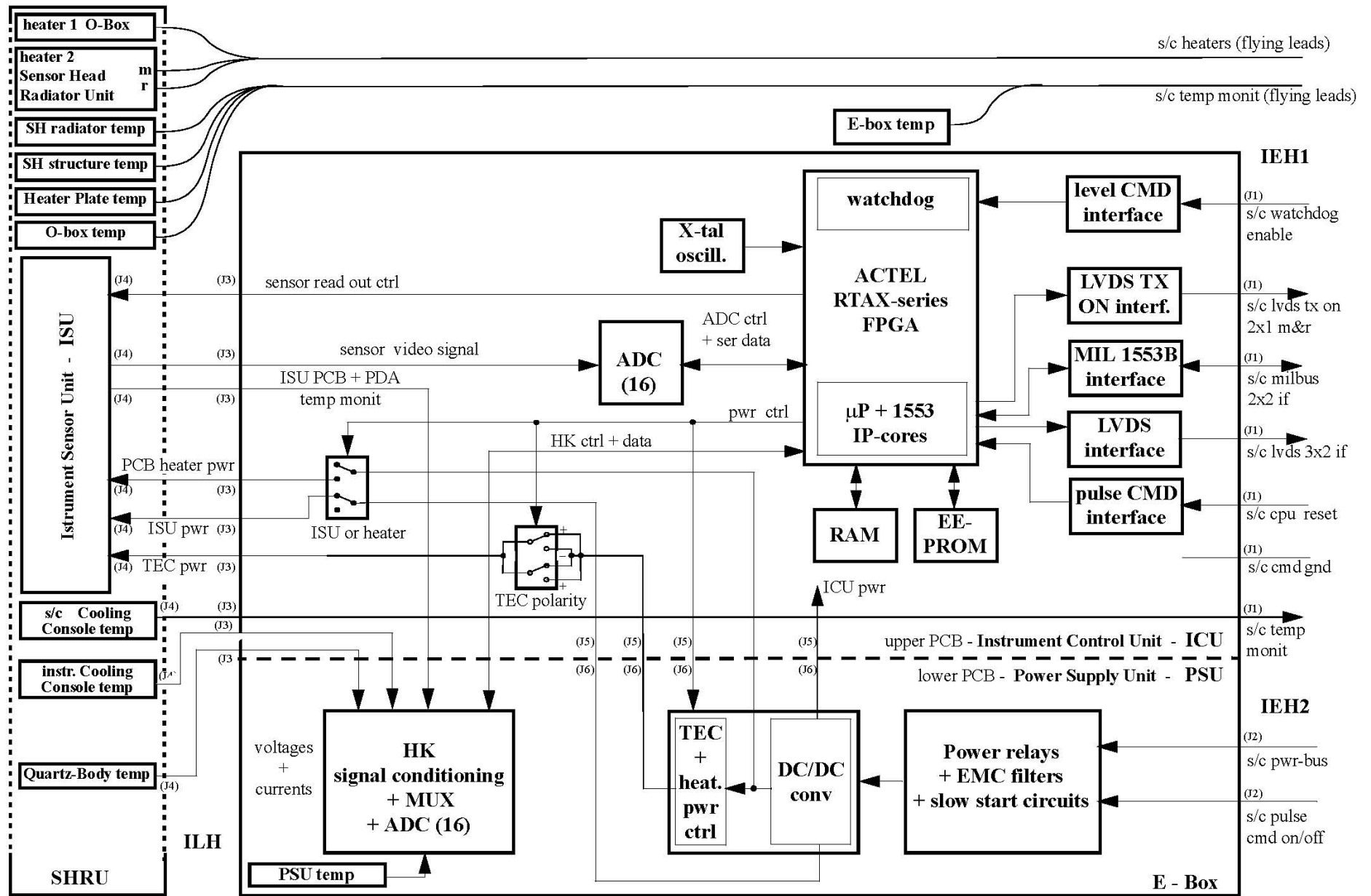


Figure 9 SIR-2 electronics block-diagram.

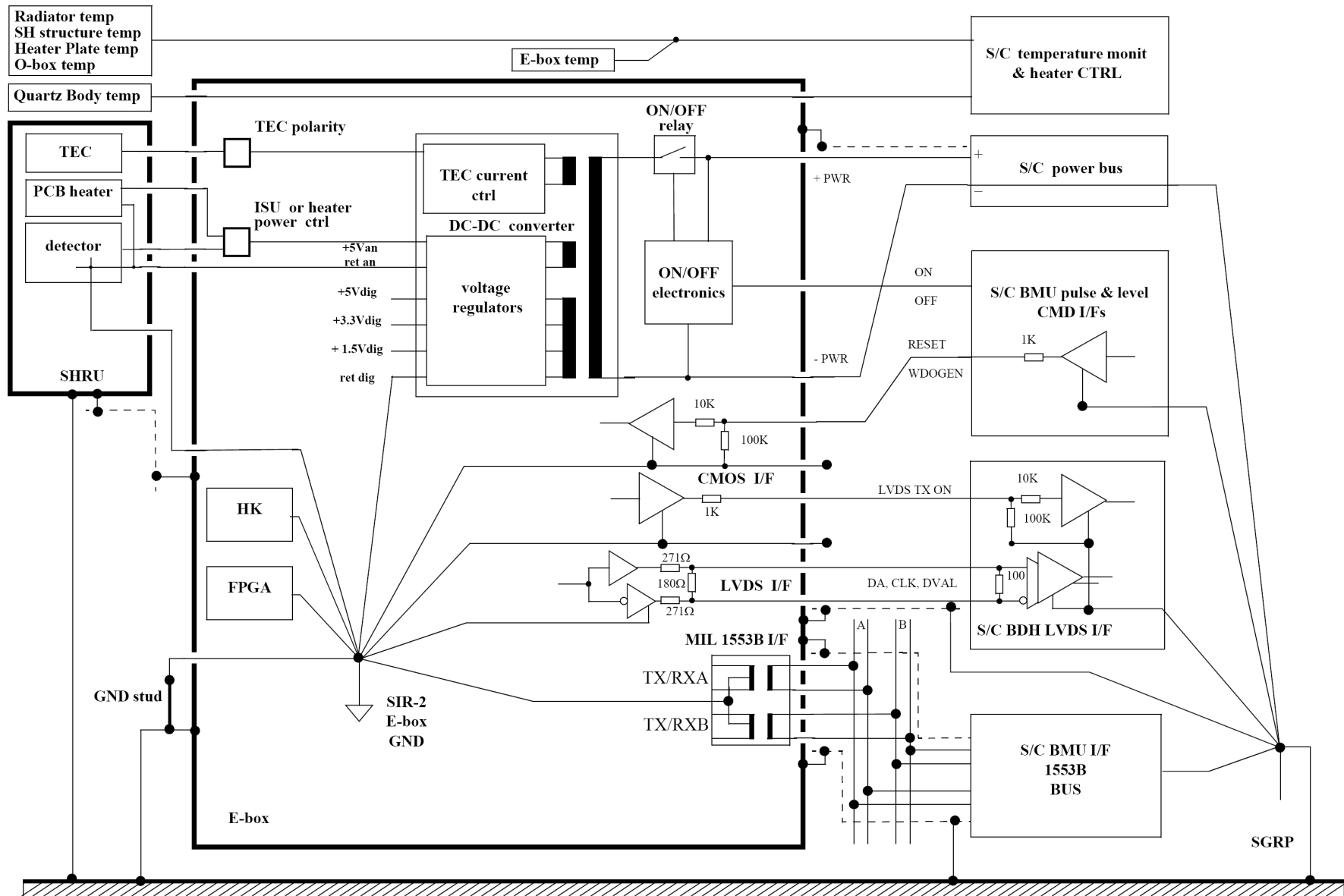
The SIR-2 instrument requires six spacecraft powered thermistors. Five thermistors are connected by flying-leads to the S/C. These ones are attached to the O-Box, the E-Box, the Sensor-Head Radiator, the Sensor-Head housing and the Heater Plate (see section 4.4). The sixth thermistor is mounted inside the Sensor-Head and measures the temperature of the Cooling Console. This thermistor is fed via the instrument local harness ILH (connectors J4/J3) and through the instrument external harness (IEH connector J1) to S/C. The S/C powered thermistors attached to the Cooling Console (inside Sensor-Head), the Heater Plate (Sensor-Head) and the O-Box control the three S/C powered SIR-2 heater lines which are the O-Box heater line and the main (m) and redundant (r) SHRU heater lines.

Further five thermistors are controlled by SIR-2. These are the instrument Cooling Console thermistor, the Quartz Body thermistor, the PSU PCB thermistor and the ISU PCB thermistor³. The Photo Detector Array (PDA) temperature is monitored by the built in thermistor in a high resolution mode (16 bit) to reach the needed accuracy for the TEC control algorithm. The TEC is used for cooling and heating of the photosensitive substrate, the heating is done by reversing TEC voltage polarity. The instrument temperature monitoring is a part of the instrument HK data collection system and the data are listed in Table 38 (HK44- HK53).

The PSU secondary sides are galvanically insulated from the spacecraft ground, which gives the flexibility of a star point ground configuration as shown in Figure 10.

Figure 10 (next page): SIR-2 grounding and electrical I/F concept.

³ This thermistor controls the ISU PCB safety heater.



2.2.5 Spacecraft communication interface

Commanding, communication and science data transfer of the SIR-2 instrument is through the spacecraft Bus Management Unit (BMU) and the Base-band Data Handling system (BDH). The SIR-2 downlink data channels are illustrated in Figure 11.

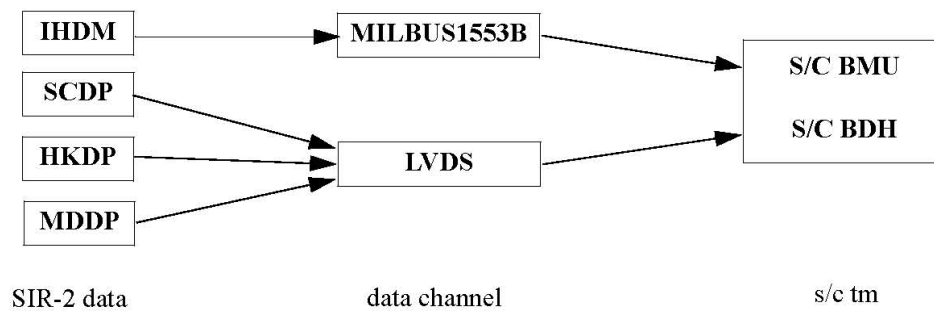


Figure 11 SIR-2 downlink data channels.

SIR-2 BMU interface

The BMU interface is according to MIL STD 1553B with the TX/RXA and TX/RXB buses, and is used for uplink SIR-2 instrument commanding and downlink Instrument Health Data Messages (IHDM). A FPGA IP-core with an external MIL-STD-1553B compatible I/O buffer is implemented for the communication. The main outline of the BMU electrical 1553B interface and the electrical pulse and level command interfaces, are shown in Figure 10, the details are shown in Figure 12 and Figure 13.

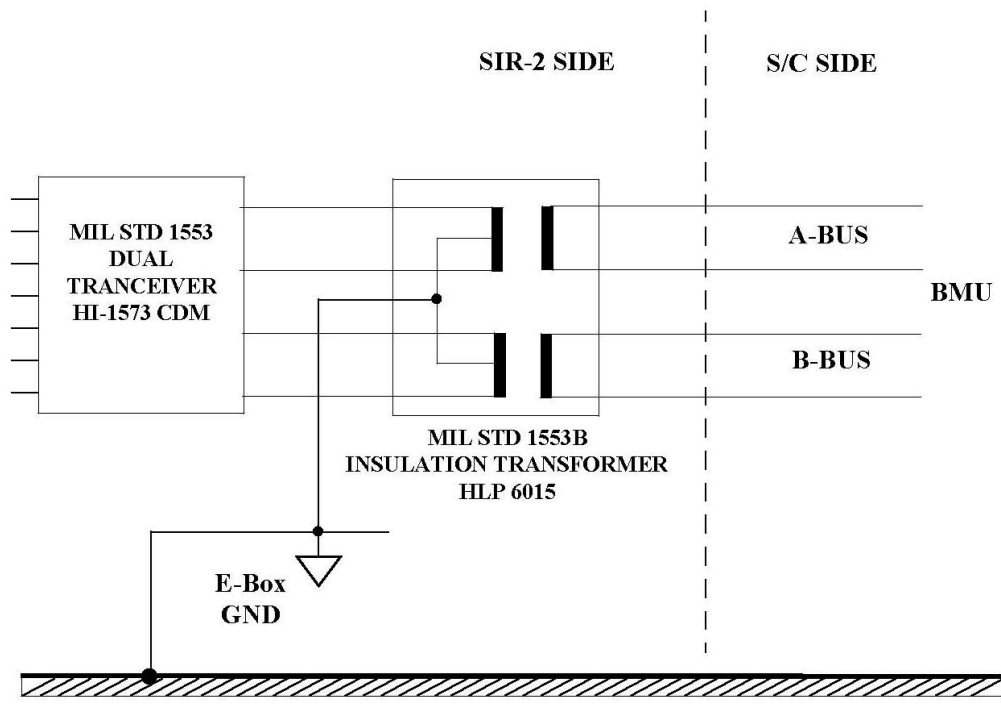


Figure 12 SIR-2 MIL-STD-1553B to BMU electrical interface concept.

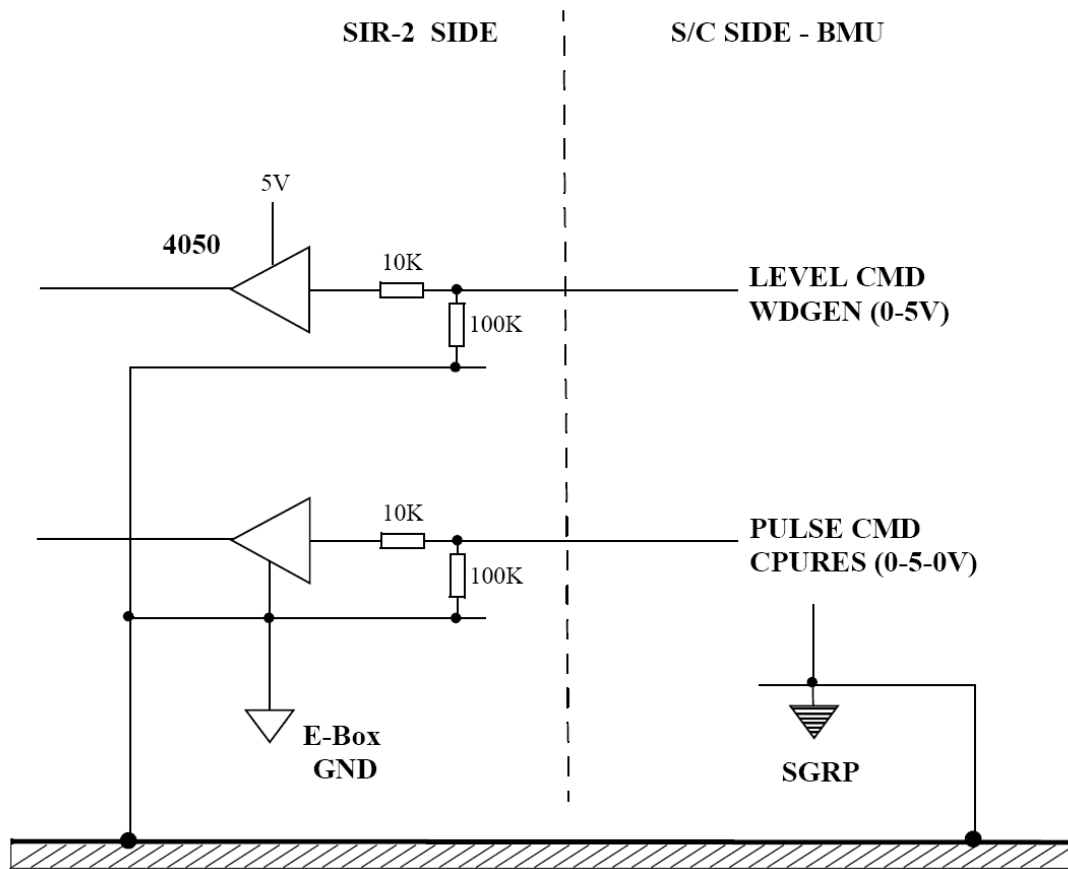


Figure 13 SIR-2 pulse and level command electrical interface concept.

SIR-2 BDH interface

The BDH interface is used for SIR-2 Science (SC)-, HouseKeeping (HK)-, and Memory Dump (MD)-Data Package transmission, with a direct point to point LVDS interface from the instrument to the spacecraft BDH. The main outline of the LVDS electrical interface is shown in Figure 10, the complete interface diagram is shown in Figure 14. The LVDS timing diagram is shown in Figure 15.

The LVDS electrical interface consists of 3 double ended lines providing the signals: “DATA”, “CLOCK” and “DATA_VALID”. Two single ended 5V CMOS compatible lines are connected to the S/C BDH LVDS enable Main and Redundant inputs and are driven by the ICU status signal LVDS_TX_ON. The complete electrical LVDS BDH interface is shown in Figure 14.

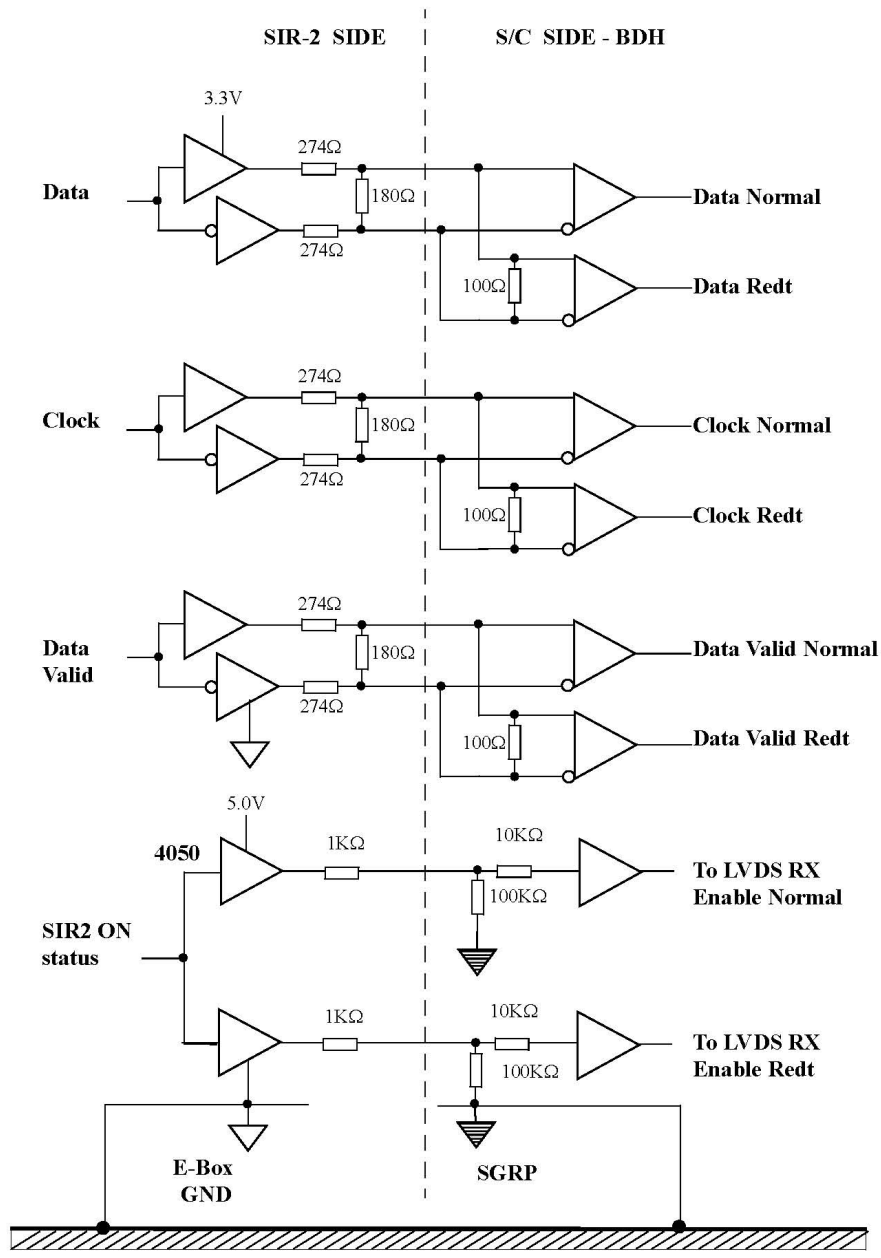


Figure 14 Entire LVDS and CMOS electrical interface.

The data is valid upon the rising edge of the clock when the DATA VALID signal is asserted. Each data package is separated by a minimum of 16 clock periods, as shown in Figure 15.

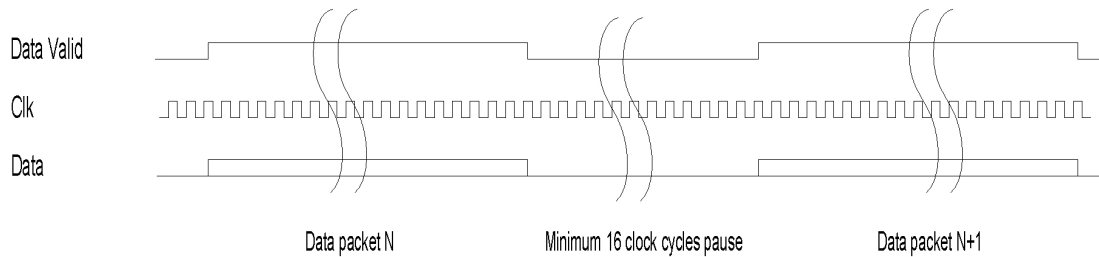


Figure 15 LVDS Data Interface timing diagram.

DATA VALID and DATA are updated synchronously to the rising edge of the clock. The spacecraft reads the DATA and the DATA VALID strobe on the falling edge of the clock.

2.2.6 SIR-2 BMU commanding

The SIR-2 instrument uses 3 types of commands:

1. Pulse commands (3)
2. Level command (1)
3. MIL-STD-1553B Data Commands

SIR-2 will receive commands via the S/C BMU. The command string and the point in time when the individual commands will affect the instrument are predetermined by a time tagged scheme decide by the ground segment. According to C-1 ISRO the shortest reasonable time gap between two SIR-2 commands shall be 2 seconds in time tagged mode and 256 msec in sequence mode. The MIL-STD-1553B data command will be decoded by SIR-2 as per requirements given in section 2.2.7.2 and 2.2.7.3.

2.2.7 Pulse commands

The pulse commands control the instrument power from the S/C power bus. These commands are:

1. ON command - command the PSU latching relay to the power on condition
2. OFF command - command the PSU latching relay to the power off condition
3. Instrument CPU RESET command

Electrically these commands are CMOS compatible low high low (0-5-0V), 64 ms duration, pulses on three separate interface lines one for each command with reference to SGRP. The pulse command return line is common and same as the level command return line – see sections 2.2.7.1, 4.3.13, and Figure 13.

2.2.7.1 Level command

The level command activates the instrument processor watchdog.

4. Watchdog Enable (WDGEN), High (+5V) watchdog is enabled; Low (0V) watchdog is disabled

Electrically the watchdog enable command is a CMOS compatible 0V and +5V level signal (the return reference is also to SGRP, I/F; see section 4.3.13 and Figure 13).

2.2.7.2 MIL-STD-1553B data commands

The MIL-STD-1553 Data Commands, hereafter named Data Commands, define the operation modes, the parameter settings, memory uploads and downloads (see also section 2.3.1). 1553 Data Commands are sent via the MIL-STD-1553B bus interface to the SIR-2 processor. The commands must be at least 10ms apart to avoid overwriting of old data before they are processed. The remote address for the MIL-STD-1553B bus communication for SIR-2 is 19hex (25dec).

There are two types of 1553 Data Commands, Type-1 and Type-2: Type-1 commands consist of three 16-bit words and are the default command type to operate the instrument. Type-2 commands consist of 4-32 16-bit words and are used to dump and upload memory regions.

The Data Command transfer between the bus controller and SIR-2 is according to MIL-STD-1553B protocol. The BMU issues a receive command word followed by a specific number of data words. SIR-2 checks the validation of the message and transmits a status word to the bus controller.

The Type-1 commands are received on Receive Sub-address 1, and the Type-2 commands are received on Receive Sub-address 2.

2.2.7.2.1 Type-1 data commands

Type 1 commands are used to control the basic instrument operations. They have a length of 3 words, where the last word is used for the telecommand identifier. The following commands have been defined:

Standby Mode Command

Table 3 Standby Mode Command

| | | | | |
|-------------------------------------|-------|-----------------|-----------|--------|
| Name: STBY_MODE | | | | |
| Description: standby command | | | | |
| Size: 3 Words | | | | |
| WORD1 | | WORD2 | | WORD3 |
| 8 bit | 8 bit | 8 bit | 8bit | 16 bit |
| SIR2CMD | PARM | ACTIVE_PAR M | EDIT_PARM | TC_ID |
| 5h | 5h | 0h-3h | 1h-3h | 0055h |

Description

This command takes the instrument to standby mode with the indicated active and editable parameter table.

Valid when

Always

Errors

This command cannot yield any errors

Preparation Mode Command

Table 4 Preparation Mode Command

| | | | | |
|--|-------|-----------------|-----------|--------|
| Name: PREP_MODE | | | | |
| Description: preparation mode command | | | | |
| Size: 3 Words | | | | |
| WORD1 | | WORD2 | | WORD3 |
| 8 bit | 8 bit | 8 bit | 8bit | 16 bit |
| SIR2CMD | PARM | ACTIVE_PAR M | EDIT_PARM | TC_ID |
| 6h | 6h | 0h-3h | 1h-3h | 0055h |

Description

This command takes the instrument to preparation mode with the indicated active and editable parameter table.

Valid when

Always

Errors

This command cannot yield any errors.

Measurement Mode Command

Table 5 Measurement Mode Command

| | | | | |
|--|-------|-----------------|-----------|--------|
| Name: MEAS_MODE | | | | |
| Description: measurement mode command | | | | |
| Size: 3 Words | | | | |
| WORD1 | | WORD2 | | WORD3 |
| 8 bit | 8 bit | 8 bit | 8bit | 16 bit |
| SIR2CMD | PARM | ACTIVE_PAR M | EDIT_PARM | TC_ID |
| 7h | 7h | 0h-3h | 1h-3h | 0055h |

Description

This command takes the instrument to measurement mode (acquisition of spectra) with the indicated active and editable parameter table.

Valid when

When in PREP mode

Errors

- **ILLEGAL_MODE_CHANGE**
An attempt to give this command from standby mode yields this error. The command will subsequently be ignored.

Set Parameter Command

Table 6 Set Parameter Command

| | | | |
|---|----------|-----------|--------|
| Name: SET_PARAM | | | |
| Description: set parameter command | | | |
| Size: 3 Words | | | |
| WORD1 | | WORD2 | WORD3 |
| 8 bit | 8 bit | 16 bits | 16 bit |
| SIR2CMD | PARAM ID | PARAM VAL | TC ID |
| 8h | 1d-25d | 0d-65535d | 0055h |

Description

This command changes any instrument parameter, except for the instrument mode parameter. Measurement parameters are uploaded to the editable parameter table. If the instrument is in standby or preparation mode, uploaded measurement parameters will go to the editable parameter table. If it is in measurement mode, the uploaded parameter will go into effect immediately. Also global parameter will go into effect immediately.

Valid when

Always

Errors

- **ILLEGAL_PARAM_IDENT**

If the PARAM ID field is outside the valid range, this error results.

Reset Command

Table 7 Reset Command

| | | | |
|--|---------|---------|--------|
| Name: RESET | | | |
| Description: soft reset command | | | |
| Size: 3 Words | | | |
| WORD1 | | WORD2 | WORD3 |
| 8 bit | 8 bit | 16 bits | 16 bit |
| SIR2CMD | SIR2CMD | Unused | TC ID |
| Ch | Ch | - | 0055h |

Description

This command resets the instrument to the STDBY mode and loads the default parameter tables. The active and editable parameter table will be set to 0 and 1, respectively. The HK clock will not be reset, neither will the packet and message counters.

Valid when

Always

Errors

This command cannot yield any errors

2.2.7.2.2 Type-2 DATA COMMANDS

Type-2 commands are used for memory upload and download, and have a length of 32 words. They are received on MIL-1553 Receive Sub-address 2. The following commands have been defined:

Memory Upload Command

Table 8 Memory Upload Command

| | | | | | |
|---|----------|---------|---------|-------------|--------|
| Name: MEM_UP_T2 | | | | | |
| Description: memory upload command | | | | | |
| Size: 32 Words | | | | | |
| WORD1 | | WORD2 | WORD3 | WORD4 .. 31 | WORD32 |
| 8 bit | 8 bit | 16bit | 16bit | 16bit | 16bit |
| SIR2CMD | NO WORDS | HI_ADDR | LO_ADDR | DATA | TC ID |
| 2h | 1d-28d | | | | 0055h |

Description

This command uploads data to specified locations in the memory. Any number of 16 bit words in the range 1-28 can be contained in a single command. The command always has to be of 32 words length, but any data after the length specified by

NO_WORDS will be ignored. The upper and lower portions of the address are contained in HI_ADDR and LO_ADDR.

Note: this command cannot write to the EEPROM memory, this is done by the safe mode memory upload command.

WARNING: If used indiscriminately, this command may cause the software to malfunction or crash. Thus the command shall be only used for error diagnostics.

Valid when

Always

Errors

MEM_ADR_NOT_ALIGNED

The memory upload address needs to be aligned to a boundry of 16 bits, which means that any address which can not be divided by two will not be allowed.

Valid memory addresses are shown in Table 9.

Table 9 Memory ranges

| Range | Type | Description |
|-----------------------|--------|--|
| 0x00000000-0x00020000 | EEPROM | Non-volatile memory used to store the instrument software (only writeable by safe mode memory upload) |
| 0x40000000-0x40019994 | SRAM | Volatile memory from which the program runs and keeps its run-time data |
| 0xd0000000-0xd0000800 | SRAM | Memory used by the ACTEL Core 1553BRM IP |
| 0xc0000000-0xc0000820 | SRAM | S/C interface registers, including LVDS buffer memory (this memory only has a write interface and cannot be read back by the microprocessor) |
| 0xa0000200-0xa0000280 | SRAM | Sensor data memory |

Memory Dump Command

Table 10 Memory Dump Command

| | | | | |
|---|----------|---------|---------|-------|
| Name: MEM_DUMP_T2 | | | | |
| Description: memory download command | | | | |
| Size: 32 Words | | | | |
| WORD1 | | WORD2 | WORD3 | WORD4 |
| 8 bit | 8 bit | 16bit | 16bit | 16bit |
| SIR2CMD | NO_WORDS | HI_ADDR | LO_ADDR | TC_ID |
| 1h | 1d-255d | | | 0055h |

Description

This command sends a memory dump data packet (MDDP) from the specified memory location. NO_WORDS specifies the number of 16bit words to dump, and HI_ADDR and LO_ADDR contains the 32bit address from which the memory dump should start. The dump has a maximum size of 510 Bytes (NO_WORDS = 255).

Valid when

This command can only be executed when the LVDS link is not busy. This means that it can only be executed when the instrument is in STBY or PREP mode with HKDP transmission disabled.

Errors

LVDS_BUSY

This error message is sent when this command is received, and the LVDS link is busy.

MEM_ADR_NOT_ALIGNED

The memory dump address needs to be aligned to a boundary of 16 bits, which means that any address which can not be divided by two will not be allowed.

MEM_ADR_OUTSIDE_RANGE

This error message is sent when the memory dump address does not exist. Valid memory addresses are shown in Table 9 .

2.2.7.3 Parameters and Parameter Tables

The parameters are divided into two main groups: global- and measurement parameters. The measurement parameters relate to the measurement mode and the global parameters defines general instrument operation.

The measurement parameters are stored in four different tables. This enables quick changes between different sets of parameters without uploading every setting every time. In standby and preparation mode, it is possible to select which parameter table is editable via the mode change commands. All changes to the measurement parameters will go into this table, and is also added to the (HKDP) so that the changes can be confirmed. When entering measurement mode, one specifies which parameter table is active. The parameters from this table go into effect, and are also contained in the (HKDP) embedded in the (SCDP). To simplify functional testing, uploading some measurement parameters will go directly to the active parameter table and apply immediately. These parameters are found in Table 11.

Table 11 Parameter table definition. Note: The reason for the uneven numbering is that certain parameters from the middle have been removed. The numbers are kept for backwards compatibility.

| PARAM ID | Acronym | Description of parameter to be set: | Type |
|-----------------|-------------------|--|-------------|
| 0 | mode | Instrument mode | Global |
| 1 | submode | Instrument submode | Measurement |
| 2 | extime | Exposure Time | Measurement |
| 3 | selkper | Sensor readout Frequency divisor | Measurement |
| 4 | ssmpltme | Sensor Sample Interval Time | Measurement |
| 5 | sadcdel | Sensor ADC Trigger Delay | Measurement |
| 6 | savgmode | Number of spectra to average | Measurement |
| 7 | tctrl_temp | TEC (Sensor Head) set temperature | Global |
| 8 | tctrl_gain | TEC controller gain | Global |
| 9 | tctrl_int | TEC controller integration time constant | Global |
| 10 | tctrl_derv | TEC controller derivation time constant | Global |
| 11 | tctrl_time | TEC controller sample interval time | Global |
| 12 | tcurr | TEC current set value (manual override) | Global |
| 13 | tdeltacurr | TEC max delta current | Global |
| 14 | relayctrl | Relay Control (manual override) | Global |
| 15 | watchdog1 | N/A | Global |
| 23 | Hofftrshld | ISU heater deactivation threshold | Global |
| 24 | debug | Used for emulating HK and sensor readout | Global |
| 25 | nspec | Number of spectra to acquire in measurement mode | Measurement |
| 26 | HKint | HKDP transmission interval | Global |
| 27 | relay_hold | Length of the bistable relay pulses | Global |
| 28 | Dtmpmax | Max detector temperature | Global |
| 29 | Dtmpmin | Min detector temperature | Global |
| 30 | Nsmpl | Number of samples per pixel | Measurement |
| 31 | Pxper | Pixel period time | Measurement |
| 32 | Tctrl_relay_per | Minimum TEC relay switch time | Global |
| 33 | Tctrl_relay_delay | Delay before TEC relay switch | Global |

2.2.7.3.1 Measurement parameters

The following parameters are relevant to the measurement mode, and exist in several parameter tables. Upon entering measurement mode, the parameters from the selected active parameter table go into effect.

Sub-mode (submode)

Measurement sub-mode. Currently, two sub-modes are implemented, normal and average mode. In normal mode, single spectra are sent with no processing. In average mode, a configurable number of spectra are averaged (arithmetic mean) before they are sent over the LVDS link. Averaging leads typically to a decrease of noise. The number of spectra to average is selected by the “number of spectra” parameter. Note that you need a longer sample interval time when in average mode, to allow for the spectra to be acquired and averaged before

they are sent. 0 selects normal mode, and 1 selects average mode. Allowable range: 0-1

Exposure time (extime)

Detector exposure time. Specifies, in number of sensor readout clock periods, how long the exposure time should be. This setting is thus depending on the sensor readout clock divisor parameter. To allow for longer exposure times, this parameter is given in units of eight clock periods. This increases the maximum exposure time, but reduces the resolution. For example, with a sensor readout clock divisor of 13, which results in a 1.53MHz readout clock, the exposure time can be adjusted in steps of $8/1.53\text{MHz} = 5.22\mu\text{s}$. To get an integration time of $130\mu\text{s}$, one would in this case need to set this parameter to 25. Allowable range: 1-65535

Readout frequency divisor (readdiv)

Sensor readout frequency divisor. Defines which number the system clock (20MHz) is to be divided by to get the sensor readout clock. A value of 20 for this parameter would give a readout frequency of $20\text{MHz}/20 = 1\text{MHz}$. Allowable range: 13-65535

Sample Interval (ssmptime)

Time period between two spectra are taken in units of 10ms. The minimum value of this parameter is 5 (50ms), since the LVDS link uses 48ms to transmit one SCDP packet. The actual time required to acquire and process one spectrum in normal submode depends on three parameters: Exposure time, readout frequency, and pixel period. The minimum feasible sample interval is given by the following formula:

$$(\text{exposure_time} + (8 + \text{pixel_period})/\text{Readout_frequency}) * 256$$

The sample interval can never be smaller than this processing time, and never smaller than 50ms, whichever is highest. In averaging submode, the processing time also depends on the number of spectra to average. Multiply the calculated time for normal submode with the number of average spectra to get the sample time to use in averaging submode.

Trigger delay (adcdel)

The number of sensor clock periods to wait between the analog pixel value being available, to it being read. This can be used to move the sampling away from noise sources possibly present in the analog video signal.

Allowable range: 0-250 (must be lower than the pixel period).

Average mode parameter (savrgmode)

Defines the number of spectra to average in average mode. This setting is ignored in normal mode. This number must be a power of two, that is, 2, 4, 8, 16, 32, This is to simplify the computations needed to average the data.

The averaging method used is the arithmetic mean. Allowable range: 2-32768

Debug parameter (debug)

The debug parameter enables the creation of dummy data for the HK and detector readouts. The debug parameter has four legal values, as shown in Table 13.

Nspec parameter (nspec)

When in measurement mode, this parameter specifies the numbers of spectra to obtain before returning to preparation mode. If set to zero, the instrument will stay in measurement mode indefinitely.

Number of samples per pixel (nsmpl)

Number of samples taken per pixel. If more than one, all samples will be averaged (arithmetic mean) by the instrument before being sent. It takes 10ms to acquire a single sample, and the pixel period will have to be long enough to support the requested amount of samples. This is the responsibility of the operator, and no hardware or software checks will be performed. The setting of this parameter works for both normal and averaging submode.

Pixel period (pxper)

The time elapsed after a pixel has been shifted out until the next pixel being shifted out. During this period the sensor ADC can sample the analog video signal. The pixel period is specified in number of sensor readout clock periods. The default values of the global parameters are listed in

2.2.7.3.2 Global parameters

The global parameters are not specific to the measurement mode, and goes into effect immediately upon upload if relevant. The global parameters only have one parameter table as opposed to the measurement parameters. Of all the global parameters, only the relay control parameter can directly control the ongoing measurement, if any. Switching off the ISU relay when in measurement mode will result in garbage data from the detector. Also, changing the temperature controller parameters has the potential of changing the detector measurement noise. The default values of the global parameters are listed in Table 15.

TEC temp (Tctrl_temp)

Temperature controller set temperature. This temperature can be set between 190 and 326 Kelvin. This range is linearly mapped to the values between 0 and 65535. A value of 0 for instance would mean a temperature of 190K, and a value of 65535 would mean a temperature of 326K. Use a linear interpolation to find any temperature in the range.

TEC gain (Tctrl_gain)

The gain of the PID controller controlling the detector temperature. This unit is dimensionless. Given in Q8.8 fixed point format, which means that the integer part is represented by the most significant Byte, and the fractional part is represented by the least significant Byte. A higher gain generally gives faster controller response, but this may lead to instability.

TEC integration time constant (Tctrl_int)

The integration time constant of the PID controller controlling the detector temperature. Unit is 1/seconds. Given in Q8.8 fixed point format, which means that the integer part is represented by the most significant Byte, and the fractional part is represented by the least significant Byte. The integrator will after some time eliminate the steady state error, that is, the difference between the set temperature and the measured temperature. The integrator is “stronger” the lower its time constant, but a too strong integrator may lead to oscillations. The integrator also has the effect of reducing the effects of measurement noise of the PDA temperature. A value of zero means that the integrator is disabled. Allowed range: 0-65535

TEC derivation time constant (Tctrl_derv)

The derivation time constant of the PID controller controls the detector temperature. Unit is seconds. Given in Q8.8 fixed point format, which means that the integer part is represented by the most significant Byte, and the

fractional part is represented by the least significant Byte. The derivator can be used when fast stabilization of the detector is needed, but this may result in instability, so it is recommended that the derivator is kept disabled (set to zero).

TEC Sample interval (Tctrl_time)

The period at which the PID controller runs, given in number of program cycles (10ms). For this setting to apply, the instrument needs to go to standby mode followed by preparation mode. Lower settings will read the PDA temperature more often, so that the other housekeeping values will be updated more slowly. The TEC sample interval cannot be set lower than 2, to allow for other housekeeping data to be read as well. Allowed range: 2-65535

TEC Current (Tcurr)

This parameter can be used to set the TEC current manually instead of it being controlled by the PID controller. Setting this value to anything between 0 and 255 will disengage the temperature controller, and force the TEC current to the value specified here. A value of 255 gives the maximum output of 1.6A. To enable the temperature controller set the value to 256. Allowable range: 0-256

Relay Control (Relayctrl)

This parameter has four legal values, listed in Table 12. Switching off the ISU relay in measurement mode would result in garbage data. Switching the TEC polarity relay will disengage the temperature controller and set the TEC current to zero. The temperature controller will switch this relay to the correct position when enabled again.

HK interval (HKint)

Interval time for HKDP transmission when in STBY and PREP mode. Unit is 10ms. A value of 0 will disable HKDP transmission.

ISU heater deactivation threshold (Hofftrshld)

This parameter sets the temperature limit for when the instrument is allowed to go out of standby mode, powering up the ISU and deactivating the ISU heater. This parameter is given as digital ADC values representing a certain temperature.

Relay hold time (Relay_hold)

Specifies the length of the pulses controlling the bistable relays in units of 10 μ s.

Max detector temperature (Dtmpmax)

Upper detector temperature treshold. This is specified by the same linear mapping as the «TEC temp» parameter. When the detector temperature gets above this limit, the PID controller will be shut down, and the TEC current is set to zero.

Min detector temperature (Dtmpmin)

Lower detector temperature treshold. This is specified by the same linear mapping as the «TEC temp» parameter. When the detector temperature gets below this limit, the PID controller will be shut down, and the TEC current set to zero.

Tctrl relay period (Tctrl_relay_per)

Minimum TEC relay switch time. The TEC relay will not switch more often than the setting of this parameter. This parameter provides a safety in case the temperature controller starts to oscillate, and puts the relays in risk of wearing

out. The relays have a limited lifetime of about 1 million switches. This allows for about 1 polarity change every minute during a two year life span.

The unit is 40ms. Allowable range: 0-65535

Tctrl relay delay (Tctrl_relay_delay)

Number of times in a row the temperature controller must ask for a TEC relay switch before it is allowed to happen. This prevents measurement noise from triggering the relay. Unit is 40 ms. Allowable range: 0-65535

Table 12 Relay control settings

| Value | function |
|-------|---------------------------------|
| 1 | ISU on, ISU heating off |
| 2 | ISU off, ISU heating on |
| 4 | TEC polarity negative (heating) |
| 8 | TEC polarity positive (cooling) |

Table 13 Debug parameter settings

| Value | function |
|-------|--|
| 0 | Normal readout mode |
| 1 | Sensor readout filled with dummy ramp. |
| 2 | All house keeping channels set equal to their respective muxsel values |
| 3 | Combination of 1 and 2 |

2.2.7.3.3 Multiple parameter tables

The SIR-2 software can select between several parameter tables for the parameters related to Measurement Mode. This enables quick changes between different sets of parameter settings without uploading a number of parameters every time when a new parameter set is needed. In Standby and Preparation Mode, it is possible to select which parameter table is editable. All changes to the measurement parameters will go into this table, and is also added to the HKDP so that the changes are verifiable. When entering Measurement Mode, one specifies the active parameter table. The active parameters are noted in the HKDP which is embedded in the SCDP. Any change of the measurement parameters during measurement mode goes directly to the active parameter table, and immediately affects immediately the operation. There are a total of four parameter tables in the system. Table 14 shows the default settings for measurement parameters. Table 15 shows the default settings for the global parameters.

Table 14 Default measurement parameters

| Parameter | Table 0 | | Table 1 | | Table 2 | | Table 3 | |
|-----------|---------|---------|---------|---------|---------|---------|---------|---------|
| | Digval | Realval | Digval | Realval | Digval | Realval | Digval | Realval |
| mode | 0 | STBY | 0 | STBY | 0 | STBY | 0 | STBY |
| submode | 0 | NORM | 0 | NORM | 0 | NORM | 0 | NORM |
| extime | 28735 | 150 ms | 9578 | 50 ms | 19157 | 100ms | 47893 | 250ms |
| sclkper | 13 | 1.54MHz | 13 | 1.54MHz | 13 | 1.54MHz | 13 | 1.54MHz |
| ssmpltme | 20 | 200ms | 10 | 100ms | 15 | 150ms | 30 | 300ms |
| sadcldel | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| savrgmode | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| debug | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| nspec | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Active and editable parameter tables are selected with the mode change commands.

Table 15 Default global parameters.

| Parameter | DigVal | RealVal |
|-------------------|--------|----------------------------|
| Tctrl_temp | 35177 | 0 degrees C |
| Tctrl_gain | 25 | 0.078 |
| Tctrl_int | 3840 | 15 sec |
| Tctrl_derv | 0 | Disabled |
| Tctrl_time | 4 | 40 ms |
| Tcurr | 0 | 0mA (check disabled) |
| Relayctrl | N/A | No default value |
| Hofftrshld | 0 | Check disabled |
| Debug | 0 | Normal readout |
| HKint | 0 | HKDP transmission disabled |
| Relay_hold | 3000 | 30 ms |
| Dtmpmax | 64416 | 50 degrees C |
| Dtmpmin | 0 | Check disabled |
| Tctrl_relay_per | 1000 | 40 sec |
| Tctrl_relay_delay | 100 | 4 sec |

2.2.7.4 SIR-2 BMU instrument health data message

Instrument Health Data Messages (IHDM) comprises sixteen 16-bit words containing a reduced number of instrument data for basic instrument health monitoring. The IHDM is available during all instrument operation modes and will be regularly requested by the S/C at intervals of 32 seconds. The data format is binary “big endian”. Details about the contents of this message data are shown in Table 16.

Table 16 Content of SIR-2 IHDM message

| Name: SIR2_IHDM | | | | | | | | | | | | | | | | | |
|---|--|------------|---|--------|---|---|---|----------|---|-----|---|---|---|---|---|---|---|
| Description: Health Data Message provided via MIL 1553 Bus | | | | | | | | | | | | | | | | | |
| Size: 16 Words | | | | | | | | | | | | | | | | | |
| Word | Description: | MSB | | | | | | | | LSB | | | | | | | |
| | | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 0 | Message Type, System Status and Number | TYPE | | STATUS | | | | MSGNUM | | | | | | | | | |
| 1 | ISU photodiode array temperature | TMP_PHD | | | | | | | | | | | | | | | |
| 2 | Cooling Console temperature | TMP_COOL | | | | | | | | | | | | | | | |
| 3 | Quartz-body temperature | TMP_QUAZ | | | | | | | | | | | | | | | |
| 4 | ISU PCB temperature | TMP_ISUPCB | | | | | | | | | | | | | | | |
| 5 | PSU PCB temperature | TMP_PSUPCB | | | | | | | | | | | | | | | |
| 6 | TEC current and voltage | TEC_CURR | | | | | | TEC_VOL | | | | | | | | | |
| 7 | Voltage monitoring 5V digital and analog | VMON5D | | | | | | VMON5A | | | | | | | | | |
| 8 | Voltage monitoring 3.3V and 1.5V | VMON3D | | | | | | VMON1D | | | | | | | | | |
| 9 | Current monitoring 5V digital and analog | CMON5D | | | | | | CMON5A | | | | | | | | | |
| 10 | Current monitoring 3.3V and 1.5V | CMON3D | | | | | | CMON1D | | | | | | | | | |
| 11 | HK clock timestamp MSW | HKCLK4 | | | | | | HKCLK3 | | | | | | | | | |
| 12 | HK clock timestamp LSW | HKCLK2 | | | | | | HKCLK1 | | | | | | | | | |
| 13 | CPU related tasks 1 | CPUMON1 | | | | | | CPUMON2 | | | | | | | | | |
| 14 | CPU related tasks 2 | CPUMON3 | | | | | | CPUMON4 | | | | | | | | | |
| 15 | Spare | Not used | | | | | | Not used | | | | | | | | | |

Word 0 in the Instrument Health Data Message contains information about the message; in addition to a 8 bit message counter. The status field has the format as explained in Table 17. The type field has the format as shown in Table 18. Words 1 to 15 contain the most essential instrument HK data.

Table 17 IHDM status field definition

| bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|------|---|-----------|-----------|------|-------|------|---|
| Descr. | Type | | tec_relay | isu_relay | temp | error | Mode | |

Table 18 SIR-2_IHDM: TYPE Message type definition (First 2 MSB Bits of first word)

| Bit 7 | Bit 6 | Description: |
|-------|-------|--|
| 0 | 0 | Standard Instrument Health Data Message (Table 16) |
| 0 | 1 | Not defined |
| 1 | 0 | Not defined |
| 1 | 1 | Safe mode IHDM (table 31) |

Type: identifies the type of IHDM, defined as in Table 18.

Tec_relay: 1b when TEC polarity is positive (TEC is cooling), 0b when TEC polarity is negative (TEC is heating)

Isu_relay: 1b when ISU is powered, and ISU PCB heater is OFF. 0b when ISU is off-powerd but ISU PCB heater is ON.

Temp: 1b when ISU PCB temperature is below specified threshold

Error: if set, the CPUMON1-3 fields are filled with error message.

Mode: instrument mode identifier according Table 19.

Table 19 IHDM: Mode Message type definition (First 2 MSB Bits of first word 0)

| Bit 1 | Bit 0 | Description: |
|-------|-------|--------------|
| 0 | 0 | STBY mode |
| 0 | 1 | PREP mode |
| 1 | 0 | MEAS mode |
| 1 | 1 | not defined |

2.2.7.4.1 Error messages

The SIR-2 instrument is capable of reporting various error conditions, primarily the reception of illegal commands. Errors are reported in IHDM fields CPUMON1-3. The error messages have the format as shown in Table 20.

Table 20 Error message format

| Field name | Description |
|------------|--|
| CPUMON1 | Bits 31 down to 24 of Hkclk at the time the error occurred |
| CPUMON2 | Bits 23 down to 16 of Hkclk at the time the error occurred |
| CPUMON3 | Error identification code (ref. Table 21) |

Table 21 Error codes

| Error Code | Mnemonic | Description |
|------------|------------------------|---|
| 2 | ILLEGAL_MODE_CHANGE | An attempt was made to go from STBY to MEAS |
| 3 | ILLEGAL_PARAM_IDENT | An attempt was made to change a parameter which does not exist |
| 4 | ILLEGAL_SUBAD_ACCESSED | Data was received on a sub address other than 1, 2, 28 or 29 |
| 5 | ILLEGAL_CMD_IDENT | An undefined command was received |
| 6 | MEM_ADR_NOT_ALIGNED | The address contained in a memory upload or download command was not aligned to 16bit words |
| 7 | MEM_ADR_OUTSIDE_RANGE | The address contained in a memory upload or download command is outside existing memory locations |
| 8 | ISU_TOO_COLD | The ISU PCB is too cold to be powered. The instrument is in STBY mode, and a change to PREP is not allowed. |
| 9 | LVDS_BUSY | A memory download command was received, but the LVDS link is busy. Perform memory download commands from STBY or from PREP with HK transmission disabled. |
| 10 | DMA_FAIL | There was an error related to the reception or transmission of data over the milbus. Some commands may not have been received. |
| 11 | PDATEMP_OUTSIDE_RANGE | PDA temperature is outside the specified range. The TEC current has been set to zero. |

Transmission of IHDM via MIL-bus to BMU and NS-BMU:

The periodical transmission of the IHDM is controlled by the S/C BMU that sends a transmit command to SIR-2. The IHDM currently residing in memory will be transmitted. The IHDM is updated with new housekeeping data as soon as they are being read from the housekeeping ADC. The IHDM message counters are updated right after the previous IHDM was transmitted, with a maximum latency of 10ms. The IHDM scheduled for BMU and NS-BMU has their own memory region, but contain the same data. The message counters are updated separately.

Table 22 RT-BC MIL-STD-1553B bus communication.

| Command word (from selected BMU) | | | | ** response time | Status Word | IHDM data |
|----------------------------------|---------------|----------------|---------------|------------------------|----------------|-----------|
| RT address | TX/RX type | Sub Address | Word Count | | | 16 words |
| 11001 | 1 | TXSA1 | 16 | | | |

Table 23 RT-RT MIL-STD-1553B bus communication

| Command word (from selected BMU) | | | | ** response time | Status Word | IHDM data |
|----------------------------------|---------------|----------------|---------------|------------------------|----------------|-----------|
| RT address | TX/RX type | Sub Address | Word Count | | | 16 words |
| 11001 | 1 | TXSA2 | 16 | | | |

Table 24 Status word for MIL-STD-1553B BUS transfers

| Status Word | | | | | | | | | | |
|-------------|---------------|-----------------|----------|-------------|------|----------------|--------------------|-------------|---------------|--------|
| RT address | Message Error | Instrumentation | Reserved | BC Received | Busy | Subsystem Flag | Acceptance Control | Dynamic Bus | Terminal Flag | Parity |
| 5 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

2.2.7.5 HK calibrations

2.2.7.5.1 Voltages and Currents

All housekeeping values in the HKDP have full 16bit precision. The following relation is used to convert the ADC counts to their real values:

$$M = K_m * \text{DigVal}$$

Where M is the value with unit as seen in Table 25 and Km is the conversion factor, found in the same table.

Table 25 conversion factors for HKDP

| Reading | Conversion factor (K_m) | unit |
|---------------------------------------|--|-------------|
| TEC voltage (pwr_tec_volt) | 0.0001526 | V |
| TEC current (pwr_tec_curr) | 0.038 | mA |
| VCC Volt (pwr_icu_vcc_volt) | 0.0001526 | V |
| ICU current 1.5V (pwr_icu15_curr) | 0.01526 | mA |
| ICU current 3.3V (pwr_icu33_curr) | 0.01526 | mA |
| ICU current 5.0V (pwr_icu50_curr) | 0.01526 | mA |
| ICU VCC current (pwr_icu_vcc_curr) | 0.01526 | mA |
| 14V voltage (pwr_icu_vcc_volt) | 0.0003056 | V |
| ICU 3.3V voltage (pwr_icu33_volt) | 0.0001526 | V |
| ICU 5.0V voltage (pwr_icu50_volt) | 0.0001526 | V |
| ICU 1.5V voltage (pwr_icu15_volt) | 0.0001526 | V |

Note: in the IHDM, the currents and voltages have only 8 bit precision, hence the conversion factors are different. These are shown in Table 26.

Table 26 conversion factors for IHDM

| Reading | Conversion factor (K_m) | unit |
|------------------|--|-------------|
| TEC voltage | 0.0391 | V |
| TEC current | 7.71 | mA |
| ICU current 1.5V | 3.91 | mA |
| ICU current 3.3V | 0.977 | mA |
| ICU current 5.0V | 0.977 | mA |
| ICU VCC current | 0.977 | mA |
| ICU VCC voltage | 0.0391 | V |
| ICU 3.3V voltage | 0.0391 | V |
| ICU 5.0V voltage | 0.0391 | V |
| ICU 1.5V voltage | 0.0391 | V |

2.2.7.5.2 Temperatures

The temperature readings have full 16bit precision in both HKDP and IHDM. Hence, they have the same conversion functions. The temperature sensors are nonlinear, so conversion functions are provided rather than just conversion factors. The thermistor in the detector has an exponential conversion function, and the conversion functions for the PT1000/Pt2000 elements have been approximated by a second/third order polynomial.

Table 27 Thermistor conversion functions⁴

| <i>Thermistor</i> | <i>Type</i> | <i>Conversion function</i> |
|--|-------------|--|
| ISU PDA temperature (detector T) | NTC | $3200/(\ln(\text{DigVal} * 75/(65536-\text{DigVal})) - \ln(5)+3200/298)$ |
| ISU PCB temperature | PT2000 | $2.013907\text{E-}11 \text{ DigVal}^3 - 2.157661\text{E-}07 \text{ DigVal}^2 + 1.733271\text{E-}02 \text{ DigVal} - 2.516346\text{E+}02$ |
| Quartz-Body temperature | PT2000 | $2.013907\text{E-}11 \text{ DigVal}^3 - 2.157661\text{E-}07 \text{ DigVal}^2 + 1.733271\text{E-}02 \text{ DigVal} - 2.516346\text{E+}02$ |
| Cooling Console temperature (SIR-2 internal) | PT1000 | $6.3942\text{e-}7 * \text{DigVal}^2 + 2.7344\text{e-}2 * \text{DigVal} - 2.4694\text{e+}2$ |
| PSU Box thermistor | YSI44004 | $-3.6871\text{e-}21 * \text{DigVal}^5 + 6.3466\text{e-}16 * \text{DigVal}^4 - 4.0768\text{e-}11 * \text{DigVal}^3 + 1.2025\text{e-}6 * \text{DigVal}^2 - 1.7359\text{e-}2 * \text{DigVal} + 120.6$ |

2.2.8 Bootloader and safe mode

At instrument power on or reset, the control is transferred to the bootloader which can go into two different modes, depending on the setting of the watchdog enable level command. The modes are shown in Table 28.

Table 28 Bootloader Modes

| Watchdog_enable level command | Bootloader mode |
|--------------------------------------|------------------------|
| High | Normal boot procedure |
| Low | Safe mode |

2.2.8.1 Normal boot procedure

When the watchdog enable signal is at a logic high level (enabled), the bootloader performs the normal boot procedure, i.e. the software is moved from the EEPROM at

⁴ Basic calibration of thermistors to be performed by means of the TV-test data.

address 0x00000000 to RAM at address 0x40000000, following the transfer of control to the start of RAM. The instrument software will run normally.

2.2.8.2 Safe mode

When the watchdog enable signal is at a logic low level (disabled), the bootloader enters the safe mode where only the MIL-Std 1553B bus core is set up, and a number of simple commands are supported. These commands allow to patch the instrument software, and also to start the software manually, should it be required to run the software without the watchdog. The safe mode is extremely minimalistic, so no error handling is provided. Using wrong parameters in a command may result in undefined behavior.

The following commands are supported in safe mode:

- Safe Mode Memory Upload Command with the ability to write to the EEPROM. (Table 29)
- Memcopy Command, copies EEPROM to SRAM. (Table 30)
- Ramstart Command, transfers control to start of SRAM. (Table 31)

Safe Mode Memory Upload

This command is received on both subaddresses 1 and 2.

Table 29 Safe Mode memory upload command

| | | | | |
|---|----------|---------|---------|-----------------|
| Name: SAFE_MEM_UP | | | | |
| Description: safe mode memory upload command | | | | |
| Size: 32 Words | | | | |
| WORD1 | | WORD2 | WORD3 | WORD4 .. WORD32 |
| 8 bit | 8 bit | 16bit | 16bit | 29 x 16bit |
| SIR2CMD | NO_BYTES | HI_ADDR | LO_ADDR | DATA |
| 02h | 1h-3Ah | | | 0h-FFFh |

Description

This command uploads memory to the defined location. It can also be used to write to EEPROM. The memory ranges are shown in Table 9.

The smallest unit which can be uploaded is one byte. The number of bytes is placed in the NO_BYTES field, and the address is placed in word 2 and 3. Note: this command needs 2 seconds to complete, so there must be a minimum of 2 seconds between two consecutive memory upload commands.

Valid when

In Safe Mode

Memcopy Command

This command is received on both subaddresses 1 and 2.

Table 30 Safe Mode EEPROM to SRAM command

| |
|--|
| Name: MEM_COPY Size: 1 Word |
| WORD1 |
| 16 bit |
| SIR2CMD |
| 0003h |

Description

This command copies the entire EEPROM to the SRAM. More specifically, the range 0x10000000-0x10019994 is copied to 0x40000000-0x40019994. This command completes in 200ms.

Valid when

In Safe Mode

Ramstart Command

This command is received on both subaddresses 1 and 2.

Table 31 start from RAM command

| |
|---|
| Name: RAM_START Size: 1 Word |
| WORD1 |
| 16 bit |
| SIR2CMD |
| 0004h |

Description

This command transfers control to the address 0x40000000, which is the entry point for the instrument software. The command must be preceded by the MEM_COPY command.

Valid when

In Safe Mode

2.2.8.3 Safe mode IHDM

The instrument transmits a special IHDM during safe mode, containing simple status messages. The format is specified in Table 32.

Table 32 Safe Mode IHDM

| | | | | | | | | | | | | | | | | | |
|---|-------------------------|---|---|-----|---|---|---|---|---|-----|---|---|---|---|---|---|---|
| Name: SIR2_SAFE_IHDM | | | | | | | | | | | | | | | | | |
| Description: SIR2 safe mode IHDM | | | | | | | | | | | | | | | | | |
| Size: 5 Words | | | | | | | | | | | | | | | | | |
| | | MSB | | | | | | | | LSB | | | | | | | |
| Word | Description: | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 0 | Message Type | TYPE | | N/A | | | | | | N/A | | | | | | | |
| 1 | N/A | N/A | | | | | | | | | | | | | | | |
| 2 | Number of commands | Commands received MSB | | | | | | | | | | | | | | | |
| 3 | Number of commands | Commands received LSB | | | | | | | | | | | | | | | |
| 4 | Number of bytes written | Bytes written through the memory upload command MSB | | | | | | | | | | | | | | | |
| 5 | Number of bytes written | Bytes written through the memory upload command LSB | | | | | | | | | | | | | | | |

2.2.9 SIR-2 BDH data structure

The data structures of the LVDS data transmission are organized in Data Packages as explained in the following sections.

2.2.10 SIR-2 data packages

SIR-2 telemetry data consist of 3 types of data packages sent via LVDS BHD interface:

- SCience Data Package (SCDP)
- House Keeping Data Package (HKDP)
- Memory Dump Data Package (MDDP)

The instrument data package generation and their availability are related to the instrument operation modes – see Table 33 below. For Mode description see section 2.3.1.

Table 33 Instrument package generation according to operation mode

| | |
|-------------------------|--------------|
| Standby Mode (STDBY) | HKDP MDDP |
| Preparation Mode (PREP) | HKDP MDDP |
| Measurement Mode (MEAS) | SCDP |

The HKDP HK data list can be generated by commanding in STDBY and PREP mode. HKDP will not be sent as self standing packet during measurements. The MDDP must be generated by command.

The data packages are sent via the LVDS interface with a bit rate of 100kbit/s. The maximum package size is 600 bytes, including header. The different package types are defined as follows:

- SCDP: Consists of the detector’s 256 pixel values plus a full set of updated HKDP information (see HK Data list in Table 38). The interval time, that is the time between packages, is set by command.
- HKDP: Comprises several instrument HK values and parameters that is: voltages, currents, temperatures, measurement parameters, time synchronization parameters and essential instrument setup parameters. The full list of transmitted HK data is shown in Table 38.
- MDDP: Comprises SIR-2 processor memory data, which can be dumped by command.

2.2.10.1 Data package structure and formats

The SCDP is provided with a unique Application Process Identifier (APID) for identification. Further APIDs are assigned to HKDP and MDDP. The APID allocations are summarized Table 34.

Table 34 APID allocation

| PACKAGE TYPE | APID |
|---------------------------------------|------|
| SCDP - spectral and housekeeping data | 50d |
| MDDP – memory dump data | 51d |
| HKDP – house keeping data | 52d |

The data package structures are given in Table 35 to Table 37. The SIR-2 data formats are compliant to the CCSDS standard 132.0-B-1 and 133.0-B-1.

Table 35 SIR-2 SCDP package structure.

| PACKAGE HEADER | | | | | | PACKAGE DATA | | | |
|----------------|------|--------------------|------|------------------|-------------------|-----------------|--------------------------------|--------------|--|
| ver- sion | | package id | | seq ctrl | | pack. length | | | |
| | type | second hdr flag | APID | sequence flag | sequence count | | Detector’s 256 pixel values | HK data list | |
| 3 | 1 | 1 | 11 | 2 | 14 | 16 | 256 * 16 | 64*8 | |
| 000 | 0 | 0 | 50d | 11 | counter | n-1 | | | |
| 2 bytes | | | | 2 bytes | | 2 bytes | 576 bytes | | |

Table 36 SIR-2 HKDP and MDDP package structure.

| PACKAGE HEADER | | | | | | | PACKAGE DATA |
|----------------|------|--------------------|------|------------------|-------------------|-----------------|--------------|
| ver- sion | | package id | | seq ctrl | | pack. length | HK data |
| | type | second hdr flag | APID | sequence flag | sequence count | | HK data |
| 3 | 1 | 1 | 11 | 2 | 14 | 16 | 64 * 8 |
| 000 | 0 | 0 | 52d | 11 | counter | n-1 | |
| 2 bytes | | | | 2 bytes | | 2 bytes | 64 bytes |

The HK data that are transmitted via the SCDP and the HKDP are listed in Table 38.

Table 37 SIR-2 MDDP package structure

| PACKAGE HEADER | | | | | | | PACKAGE DATA |
|----------------|------|--------------------|------|------------------|-------------------|-----------------|------------------|
| ver- sion | | package id | | seq ctrl | | pack. length | Memory dump data |
| | type | second hdr flag | APID | sequence flag | sequence count | | Memory dump data |
| 3 | 1 | 1 | 11 | 2 | 14 | 16 | |
| 000 | 0 | 0 | 51d | 11 | counter | n-1 | |
| 2 bytes | | | | 2 bytes | | 2 bytes | 2-510 bytes |

Table 38 The SIR-2 HKDP data list.

| HK BYTE LIST | NAME | NUM OF BYTES | DESCRIPTION |
|--------------|------------|--------------|--|
| HK00 | HKCLK4 | 5 | SCDP: HK clock (timestamp) at the time the exposure starts; HKDP: HK clock (timestamp) at the time the package is sent |
| HK01 | HKCLK3 | | |
| HK02 | HKCLK2 | | |
| HK03 | HKCLK1 | | |
| HK04 | HKCLK0 | | |
| HK05 | HKEVT4 | 5 | HK clock at time of OBT-synchronization |
| HK06 | HKEVT3 | | |
| HK07 | HKEVT2 | | |
| HK08 | HKEVT1 | | |
| HK09 | HKEVT0 | | |
| HK10 | OBT5 | 6 | OBT (On Board Time) at time of synchronization Data format according to MIL-STD-1750 standard, 48 bit long format float. |
| HK11 | OBT4 | | |
| HK12 | OBT3 | | |
| HK13 | OBT2 | | |
| HK14 | OBT1 | | |
| HK15 | OBT0 | | |
| HK16 | EXTIME | 2 | selected exposure time H-byte selected exposure time L-byte |
| HK17 | | | |
| HK18 | SITIME | 2 | interval time |
| HK19 | | | |
| HK20 | MMODE | 1 | Measurement mode |
| HK21 | AVERAG | 1 | Spectra to average |
| HK22 | ADCDEL | 1 | ADC trigger delay |
| HK23 | TEC | 1 | TEC set value |
| HK24 | READDIV | 2 | Sensor readout frequency divisor |
| HK25 | | | |
| HK26 | TEC_VOLT | 2 | TEC voltage |
| HK27 | | | |
| HK28 | TEC_CUR | 2 | TEC current |
| HK29 | | | |
| HK30 | VCC_CURR | 2 | VCC current |
| HK31 | | | |
| HK32 | ICU15_CURR | 2 | ICU current 1.5V |
| HK33 | | | |
| HK34 | ICU33_CURR | 2 | ICU current 3.3V |

| | | | |
|------|-------------|---|---|
| HK35 | | | |
| HK36 | ICU50_CURR | 2 | ICU current 5.0V |
| HK37 | | | |
| HK38 | ICUVCC_CURR | 2 | ICU VCC Volt |
| HK39 | | | |
| HK40 | 14V_VOLT | 2 | 14V voltage |
| HK41 | | | |
| HK42 | ICU33_VOLT | 2 | ICU 3.3V voltage |
| HK43 | | | |
| HK44 | PDA_TEMP | 2 | Photo Diode Array temperature (on-chip thermistor) |
| HK45 | | | |
| HK46 | PCB_TEMP | 2 | ISU PCB temperature |
| HK47 | | | |
| HK48 | PSU_TEMP | 2 | PSU PCB temperature |
| HK49 | | | |
| HK50 | COOL_TEMP | 2 | Cooling Console temperature |
| HK51 | | | |
| HK52 | MIR_TEMP | 2 | Quartz-Body temperature |
| HK53 | | | |
| HK54 | ICU5_VOLT | 2 | ICU 5.0V voltage |
| HK55 | | | |
| HK56 | ICU15_VOLT | 2 | ICU 1.5V voltage |
| HK57 | | | |
| HK58 | NSPEC | 1 | Number of spectra to collect in this run |
| HK59 | PXPER | 1 | Pixel period time |
| HK60 | NSMPL | 1 | Number of samples per pixel |
| HK61 | Error ID | 1 | Error ID from the last IHDM that was sent |
| HK62 | | | |
| HK63 | | | Reserved for CRC checksum |

2.2.10.2 Time synchronization

SIR-2 is equipped with an internal 40 bit counter named HK Clock used to timestamp the science data. The counter starts from zero after each instrument switch ON or after execution of a CPU Reset command and will increment each 10 microseconds. For synchronization with the S/C On Board Time (OBT) SIR-2 receives a broadcast mark from the S/C BMU as a MIL-STD-1553B synchronize without data mode coded. Upon reception of the broadcast mark the SIR-2 internal HK clock is recorded. The BMU sends the onboard time@broadcastmark (OBT) within 64 ms from the broadcast mark in a MIL_STD_1750A format code. After reception of the onboard time@broadcastmark the latest update of the OBT and the HK clock are written to the SIR-2 HK data list.

The stability of the SIR-2 counter is better than 1 microsecond between the synchronizations, the OBT synchronization accuracy is in the order of 300

microseconds. The 40 bit HK clock counter with the 10 microsecond time base corresponds to a time frame of 10994944 seconds or about 127 days before a counter overflow occurs which would start the counter from zero again.

2.2.10.3 Telemetry rates

2.2.10.3.1 SCDP rates and allocated Memory Size

The LVDS interface of SIR-2 uses a fixed clock frequency of 100 kbit/s. With the nominal SCDP data package size of up to 600 bytes and the minimum sample interval time of 50 ms, the maximum data rate is 12000 bytes/s or 96 kbits/s. This is somewhat lower than the allocated (max.) SIR-2 data rate of 100 kbit/s.

The time between two exposures (sample interval time) and the exposure time are selectable by command. The exposure time depends on the illumination conditions of the lunar surface and can be set in the range 0.1 to 1000 ms. Theoretical calculations and experience from SIR-1 suggest standard exposure times between 50 and 200 ms. For the typical interval times 50 ms, 100 ms and 200 ms the data rates are as follows:

- 96 kbits/s - highest rate of data acquisition
- 48 kbits/s - nominal rate of data acquisition
- 24 kbits/s - lowest rate of data acquisition

Table 39 shows the required SDR memory per 6 orbits for the above mentioned data rates. We assumed spectra acquisition during the whole sun-lit side overflight plus 1200 s/orbit during the night side overflight.

Table 39 SIR-2 SDR memory requirements.

| Interval Time [ms] | SSDR Memory [Gbit] |
|-------------------------------|-------------------------------|
| (50) ⁵ | (2.73) |
| 100 | 1.37 |
| 200 | 0.69 |

The allocated 2 Gbit SDR memory size will enable continuous observations with 100 ms interval time plus some observations with 50 ms interval time.

For detector read-out noise improvement SIR-2 has the capability to perform multiple readings of the ICU 16 bit ADC. It is also capable to send spectra which have been averaged from a set of individual spectra. This averaging can be used to reduce the data rate without losing potential exposure time.

⁵ Interval times of less than 100 ms will be used only during periods of best surface illumination.

2.2.10.3.2 HKDP rates

The max size of the HKDP package is 74 bytes (64 bytes HK + 6 bytes Header + 2 bytes CS, (CS - TBC not implemented yet)). The interval between individual HKDP packages is selectable in the range 10ms to 655 seconds. This leads to a maximum data rate of 70 bytes * 8 bits/byte = 56 kbit/s.

2.2.10.3.3 MDDP rates

This rate depends on the current needs but will not exceed the maximum rate.

2.2.11 Radiation shielding

SIR-2 has the following radiation sensitive zones:

- Sensor-Head PCB (ISU)
- E-Box PCBs (PSU and ICU)

Protection against radiation will be reached by:

1. 1.5 mm Al wall thickness for the E-Box (ICU and PSU) electronics + spot-shielding for some electronic parts.
2. The equivalent Al wall thickness protecting the InGaAs detector linear array is not less than 10.4 mm plus the shielding introduced by the S/C structure. Solid angles not shielded by S/C structure are protected by a minimum of 13 mm Al.
3. 3 to 5.5 mm Al wall thickness for the Sensor-Head electronics (ISU).

For the electronic components as baseline radiation tolerant MIL-STD 883 parts are used.

2.2.12 Power conditioning

See Table 49

2.2.12.1 Software

The SIR-2 internal software maintains 5 tasks:

- HK data handling
- Sensor temperature regulation
- MIL-STD-1553B bus message handling
- Sensor data processing
- LVDS transmission

All the tasks, except the MIL-STD-1553B bus message handling, are run periodically but at different rates of execution. The MIL-STD-1553B bus messages may include

time critical data, so the MIL-STD-1553B bus message handling is for that reason serviced via interrupts. The software structure implemented is known as a Multi-Rate Cyclic Executive with Interrupts.

The multi-rate cyclic executive is a way of achieving multitasking in a system with no support from a real-time operating system. In a normal cyclic executive, every function to be executed is put in a function-table, from which they are run to completion in a round-robin fashion. After the execution of the last function in the table, execution continues from the first one again. All tasks in such a scheme are run at the same rate. In a pure cyclic executive, all IO is polled rather than interrupt driven.

Contrary to a normal cyclic executive, the functions in a multi-rate executive can, as the name implies, run at different execution rates. This is necessary for the TEC controller, for instance, to avoid it from using too much system resources. This is achieved by not having the tasks themselves in the function table, but rather a small function responsible for establishing whether or not to run a specific task at any particular moment. These functions then call the tasks if they are due for execution. In addition, some functions which are time critical, needs to be interrupt driven, so that they can preempt any currently running function.

At power on, at soft reset, and hard reset, the software runs an initialization before the scheduler takes charge and manages the execution of the periodic functions at proper rates. The cycle time is approximately 10ms, depending on the total execution time of the various functions included in the scheduler. The amount of time occupied by each function in the scheduler depends on the instrument mode and settings which are kept in the parameter table. A built-in function controls the timing by continuously checking the instrument HK clock, and transfers the control to the scheduler when the cycle time is expired.

The PDA temperature regulation is done by a Proportional-Integral-Derivative (PID) controller algorithm. This task is running at a programmable rate, and based on the present temperature and the set temperature, the regulator adjusts the current to the TEC-element.

A brief explanation of the main function is given below:

- *LVDS_TX_Start*: This function handles the transmission of SCDP over the LVDS, and initiates the sensor data acquisition. It checks whether a SCDP is ready in one of the LVDS memories, and whether a SCDP transmission is scheduled to occur at this particular time. If this is the case, LVDS transmission is started, and the sensor is instructed to start acquisition of a new spectrum. This function is placed at the beginning of the function table to ensure that it runs at a regular equally spaced time intervals.
- *PSU_ADC_Read_Manager*: This function calls the `psu_adc_read` function, which will read the data selected by the mux-select. After the data is read, the next mux-select channel is either increased by one (wrapping at 16), or set to read the PDA temperature channel if the TEC controller is scheduled to run next

cycle.

- *TEC_Control_Manager*: This function runs the TEC controller at regular programmable intervals. The interval time is set in the parameter table. The fastest practical rate for the controller is every second scheduler cycle, to allow for other HK data to be read as well as the PDA temperature.
- *SCDP_Manager*: This function checks if new sensor data from the ISU is available, and places it in the appropriate LVDS memory. The SCDP header is updated, and the latest update of HK data is added to the packet after the sensor data. Multi-acquisition of sensor data is also handled by this function if the system is in averaging submode.
- *MIL1553_Poller*: This functions checks if a new message interrupt from the MIL-1553B bus has been received during the last cycle. In that case, appropriate functions are called depending on the interrupt log list of the MIL-1553B bus core.
- *Time_Slot_Sync*: This function watches the HK clock and makes sure that the present time slot complies with the cycle time setting. It's purpose is to provide regular cycle interval.

2.3 Instrument operation

2.3.1 Instrument modes

SIR-2 has three different modes: Standby Mode (STDBY), Preparation Mode (PREP), and Measurement Mode (MEASU). All modes are software controlled. Possible mode transitions are shown in Figure 16.

Standby Mode

The Standby Mode is the low-power mode entered after the instrument has been powered up. The PSU and the ICU is ON, while the ISU is OFF. In Standby Mode the instrument operates with default or updated default settings. The Standby Mode also works as an immediate shut-down mode, which can disrupt the Measurement Mode if commanded during measurement. In this mode also the measurement parameters can be set (interval time, exposure time, ADC delay etc.), which will be used in the Measurement Mode.

Preparation Mode

After reaching the Standby Mode the instrument can be commanded to enter the Preparation Mode. During Preparation Mode the thermal stabilization of the detector shall be reached. In this mode also the measurement parameters can be set (interval time, exposure time, ADC delay etc.), which will be used in the Measurement Mode.

Measurement Mode

In Measurement Mode the instrument will obtain either a defined number of spectra or will perform a continuous acquisition according to the parameters which were set in the Preparation Mode.

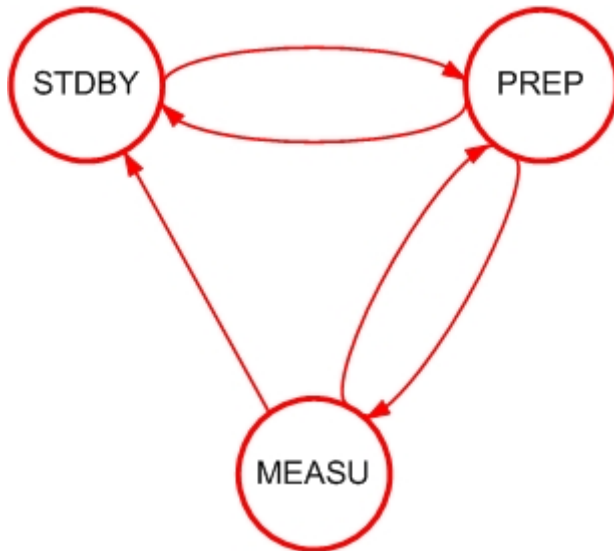


Figure 16 SIR-2 state (mode) diagram.

2.3.2 Operations before launch

2.3.2.1 Pre-launch calibration procedures

The on-ground calibration of SIR-2 was performed at (P)FM level under simulated flight conditions at SAC (Ahmedabad, India).

The calibration procedure is subdivided in a spectral and a radiometric part. The instrument was mounted in a vacuum chamber with a large front window for optical adjustment in the parallel beam of the collimator – Pixel to wavelength verification and dispersion resolution verification –. In a further stage an absolutely calibrated integrating sphere was replacing the collimator – radiometric calibration –. The detailed on-ground calibration procedure/results are outlined in [RD13].

The determination of the SIR-2 boresight orientation with respect to the S/C coordinate system shall be performed prior and after vibration testing on S/C level (by using theodolites) and need verification during flight.

3 Mission operations and system ground interface requirements

3.1 Environment

3.1.1 Ground environment

Cleanliness requirements

E-Box PFM + FS storage:

| | |
|--------------|----------------|
| Cleanliness: | 100 000 |
| Temperature: | 20 ± 10 °C |
| Humidity: | 50 to 55 % |

Sensor-Head/Radiator Unit PFM + FS and O-Box PFM + FS storage:

| | |
|--------------|--|
| Cleanliness: | 100 000; with removed O-Box aperture dust protection foil ⁶ : 1000 |
| Temperature: | 20 ± 10 °C |
| Humidity: | 50 to 55 % |
| Purging: | Sensor-Head internal (details see section 4.3.24) |

3.1.2 Launch phase environment

According to C-1 ISRO the SIR-2 S/C safety heater power is not available for a period of up to 2 hours after lift-off. Based on this information MPS computed the temperature profiles of the SHRU and the O-Box during the lift-off phase (see [RD1]). The lift-off phase was then simulated with real hardware (STM and PFM) by TV-testing at MPS. .

3.1.3 Lunar orbit phase

Preferentially the O-Box of SIR-2 shall be kept in shade during flight. In particular, the O-Box needs to be in shade during the lunar orbiting phase to ensure proper optics cooling. However, several minutes of illumination will regularly occur when the S/C is close to the lunar poles. These illuminations have been considered within the SIR-2 TMM analysis.

⁶ The cover should be removed only for short periods (e.g., during lamp stimuli test) when class is only 100 000.

3.2 Pointing and alignment

3.2.1 Instrument FoV and alignment on spacecraft

The circular SIR-2 FoV has a diameter of 2.2 mrad. The orientation of the optical axis is (almost) parallel to the S/C +Yaw axis (+X_{S/C}). The optical aperture of the SIR-2 O-Box is of diameter 72 mm which must be kept free from any obstruction.

The PFM comes with a non-removable alignment mirror of 2 cm diameter made out of aluminium, which is located between the optical aperture and the secondary mirror. The normal of the mirror is parallel to the S/C +Yaw axis (+X_{S/C}).

The SIR-2 FoV shall be located within the FoV of TMC, HySI, and M³. In this context it is important to note that SIR-2 does not have any active alignment device.

Due to the small FoV it is essential to measure the exact orientation of the optical axis of SIR-2 with respect to the S/C coordinate system (star trackers) and the above mentioned payloads. This is important to guarantee proper celestial and lunar target pointing during flight. In order to allow this the SIR-2 team will provide the deviation of the line of sight from the normal of the SIR-2 alignment mirror (see [RD12]). We request that the Chandrayaan-1 project verifies the co-alignment of the payloads by using theodolites with auto-collimation equipment. The co-alignment shall be checked before and after vibration testing on spacecraft level.

One further SIR-2 boresight alignment verification with respect to the spacecraft coordinate system (star trackers) shall be performed during flight.

3.2.2 Pointing requirements – Lunar orbit phase

The common S/C pointing mode is Nadir. Selected orbits shall be used for:

1. Off nadir observations (e.g. crater scans)
2. Celestial target pointing (inertial pointing) for instrument calibration purposes

Table 40 S/C absolute pointing accuracy.

| Axis | Attitude | Rate |
|-------------|------------------|------------------|
| Yaw | $\pm 0.05^\circ$ | $\pm 3.0E-4$ °/s |
| Roll | $\pm 0.05^\circ$ | $\pm 3.0E-4$ °/s |
| Pitch | $\pm 0.05^\circ$ | $\pm 3.0E-4$ °/s |

The diameter of the SIR-2 FoV is 0.127°. Thus the SIR-2 FoV is in the order of the S/C pointing accuracy.

3.3 Instrument operation duration and lifetime

The instrument lifetime is designed for more than 2 years operation in space. Instrument operation shall take place during the whole lunar orbiting phase, possibly interrupted by a short period around the dawn-dusk phase when lunar surface illumination is too low.

3.4 Flight operations

3.4.1 Instrument operation concept

The instrument will operate autonomously via command strings (time tagging of commands by S/C). The instrument shall be able to operate during the entire lunar orbiting phase.

3.4.2 Instrument modes

See section 2.3.1.

3.4.3 Instrument communications

SIR-2 uses the MIL-1553B bus for communication with the S/C. SIR-2 is dependent on time tagged commands sent by the S/C. SIR-2 does not communicate with another C-1 instrument.

3.4.4 Instrument control

The instrument status shall be regularly monitored the following way:

- During the time the instrument is OFF by monitoring the temperature of the S/C powered SIR-2 thermistors which activate/deactivate the S/C powered SIR-2 heaters located on O-Box and SHRU.
- During the time the instrument is ON by monitoring the temperature of the S/C powered SIR-2 thermistors, the ON/OFF status of SIR-2 and some selected SIR-2 HK parameters (IHDM, see section 2.2.7.4).

We request to get access to the following spacecraft H/K data (see also Table 54):

- Temperature measured by the S/C powered thermistor inside SIR-2 Sensor-Head (controls main line of the S/C powered SIR-2 heaters)
- Temperature measured by the S/C powered thermistor which is attached to the Sensor-Head/Radiator Unit's Heater Plate (controls the redundant line of S/C powered SIR-2 heaters)
- Temperature measured by the S/C powered Sensor-Head thermistor
- Temperature measured by the S/C powered SH Radiator thermistor
- Temperature measured by the S/C powered O-Box thermistor (controls the O-Box S/C heater line)
- Temperature measured by the S/C powered thermistor next to the SIR-2 E-Box
- SIR-2 ON/OFF status
- Temperature of the ASS extension panel next to the SIR-2 O-Box

- Temperature of the ASS panel next to the SIR-2 Sensor-Head/Radiator Unit
- If available: status of the illumination of the ASS panel (e.g., Sun and Moon vector)

3.4.5 Autonomy requirements

The instrument is designed to allow a primary power loss/switch off without any need for a switch off procedure since all essential setup parameters are stored in the flash ROM. However, for a controlled restart the S/C controlled OFF command should be send before a power ON procedure starts. The required command sequences are outlined in [RD2].

It has to be taken care of by mission planning group to sequence the SIR-2 events correctly.

3.4.6 Safety requirements

The SIR-2 O-Box does not have a front door. Thus Sun avoidance during flight shall be preferentially valid for a cone of $\pm 32^\circ$ from SIR-2 boresight⁷. Experience from SIR onboard SMART-1 shows that a violation of this constraint will not lead to a damage of the instrument but optics degradation may occur if solar illumination lasts for longer periods. SIR-2 needs to be OFF powered if the Sun enters a cone of $\pm 32^\circ$ from SIR-2 boresight⁸.

Absolute Sun avoidance shall be valid for a cone of $\pm 4^\circ$ from SIR-2 boresight.

3.4.7 Instrument operation

Command sequences will be uploaded to the S/C buffer and time tagged sent to SIR-2.

SIR-2 will be always OFF powered during launch, GTO, ETO, and LTT.

3.4.8 Timing

Correct command timing shall be ensured by the ground-segment and the S/C command buffer.

3.4.9 Communications between instruments

No communication between SIR-2 and another payload is foreseen. Time line preparation must ensure that SIR-2 operation is coordinated with other payloads.

⁷ For angles less than 32° the primary mirror starts to be illuminated by direct sunlight.

⁸ According to C-1 ISRO the project will take care of Sun avoidance for SIR-2 during nominal lunar orbit. In case of attitude loss SIR-2 will be automatically switched off.

3.4.10 Mass memory download through the payload bus

Because the spectral acquisition in Measurement Mode is a continuous process without data buffering, the spectra will be transferred to the S/C BDH interface without delay for further transmission to S/C mass memory.

4 Instrument design and spacecraft interface

4.1 General

SIR-2 consists of three units: Sensor-Head/Radiator Unit, O-Box and E-Box (see also section 2.2.2). The O-Box is mounted on an extension of the ASS panel which is thermally controlled by the S/C. The Sensor-Head/Radiator Unit is located on the ASS panel exterior while the E-Box is located on the ASS panel inside.

CAD models of each SIR-2 unit have been provided to C-1 ISRO for implementation in the overall S/C CAD model.

4.2 Coordinate systems

The S/C coordinate system as specified in Fig 2.1.1 of the C-1 Configuration Document (Revision-02) is baseline for all technical drawings of SIR-2.

4.3 Mechanical design

4.3.1 SIR-2 structure

An instrument overview is given in section 2.2.2. Figure 45 to Figure 47 (see appendix) display the MICD drawings of the three individual SIR-2 units. Further figures show the optical fibre routing and the fibre supports.

4.3.2 Payload physical accommodation

The Sensor-Head/Radiator Unit is located on the ASS panel while the O-Box is located on an extension of the ASS panel (see Figure 17). The optical boresight (parallel to $+X_{S/C}$ axis) of the O-Box points to the lunar surface during nominal operation. The optical aperture of the O-Box (facing $+X_{S/C}$) has to be kept free from any obstruction. The O-Box radiator ($-Z_{S/C}$) shall see as much free space as possible.

The E-Box is mounted inside the S/C cube on the ASS panel (see Figure 18), next to the Sensor-Head/Radiator Unit, to enable a short harness routing between both units. The Instrument's local harness, connecting E-Box and Sensor-Head/Radiator Unit, is termed ILH and originates at the electrical connector J4, which is located at the Sensor-Head. The location of the 30 by 60 mm sized ILH harness lead through (ASS panel cutout "C2") is shown in Figure 18. The ILH harness length is about 100 mm.

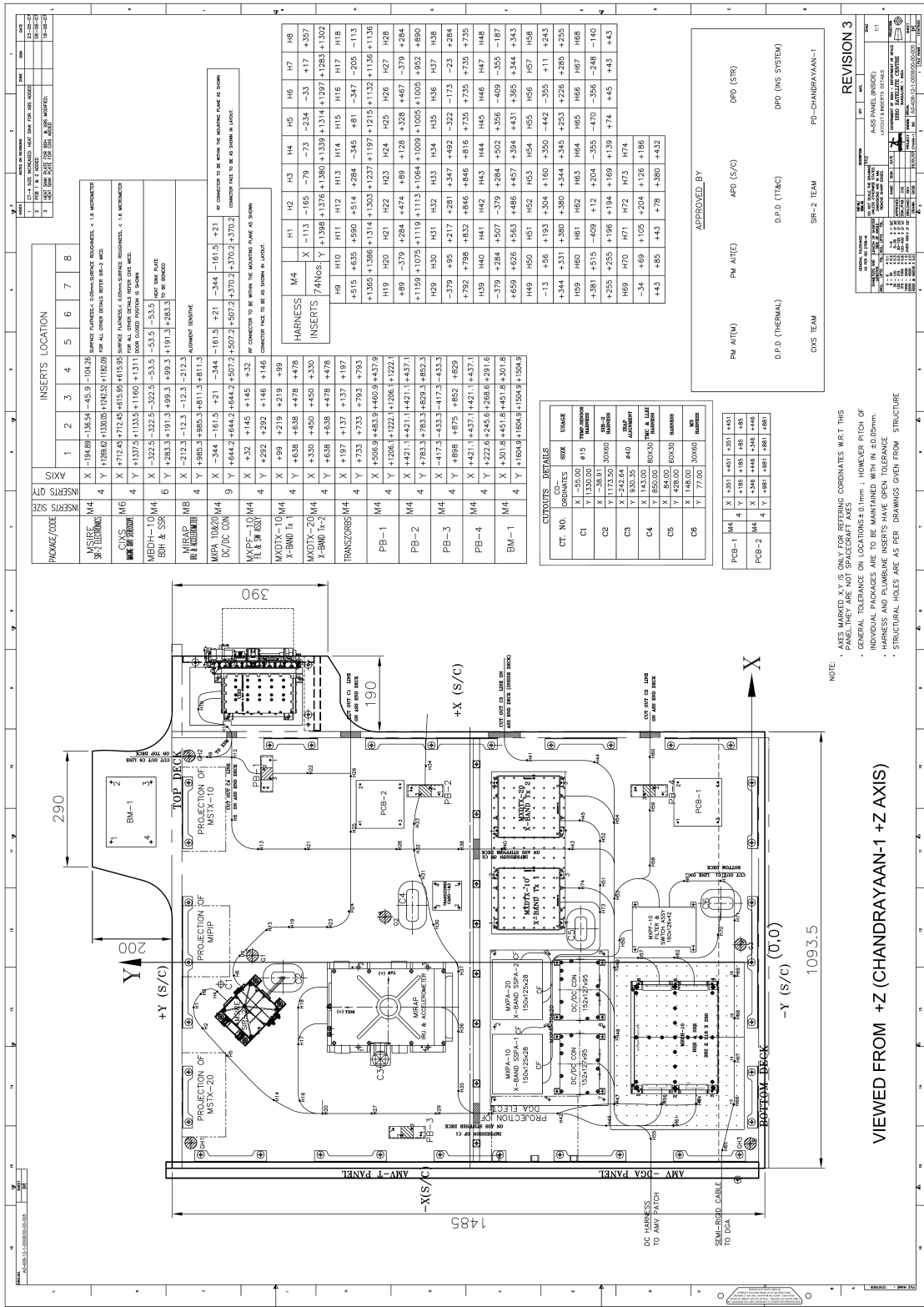


Figure 18 ASS panel (inside view) showing the location of the E-Box.

An optical fiber is connecting the O-Box and Sensor-Head/Radiator Unit. The fiber routing as well as the locations of O-Box and Sensor-Head/Radiator Unit are drafted in Figure 19. The agreed fibre routing is shown in Figure 48, the confirmed locations of the fiber supports in Figure 23.

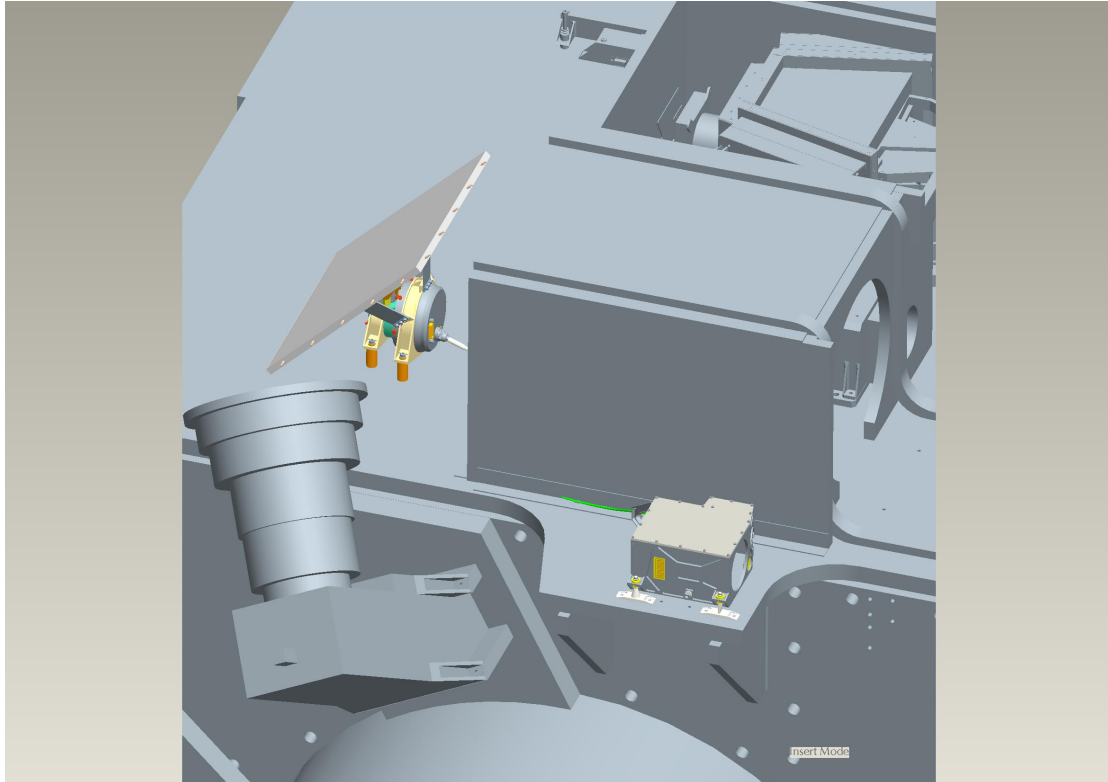


Figure 19 Locations of O-Box, Sensor-Head/Radiator Unit and fiber on ASS Panel. The MLI tents of the SIR-2 units are not shown.

4.3.3 General requirements

The experiment is designed to withstand the environments it will encounter during its lifetime. This includes:

- fabrication and assembly
- environmental tests
- handling and transportation
- launch
- operation in space

4.3.4 Stiffness requirements

SIR-2 mechanics are designed for a first global resonance frequency higher than 100 Hz when bolted at their flight interfaces to a rigid fixture. There shall be no system natural frequency below 100 Hz.

4.3.5 Strength requirements

The experiment is designed for the mechanical loads given in [AD1]. The original design loads have been increased by safety factors depending on the component.

4.3.6 Mounting requirements

The position and the height of the mounting feet as well as the diameter of the mounting holes are specified in the MICD drawings (see Figure 45 to Figure 47).

Sensor-Head/Radiator:

- 4 screws ISO 4762 M4 x 45 mm titanium alloy.⁹

O-Box:

- 6 screws ISO 4762 M4xTBD (depending on S/C insert) stainless steel
- 6 washers ISO 7090-4-200 HV (stainless steel)

E-Box:

- 4 screws ISO 4762 M4xTBD (depending on S/C insert) stainless steel
- 4 washers ISO 7090-4-200 HV (stainless steel)

The applicable torque of the mounting screws depends on the screwlok inserts used for the S/C panel. The nominal values for mounting screws are given below:

- M4 stainless steel 1.4301 (X5 CrNi189) = 1.60 Nm ± 0.20 Nm
- M4 titanium alloy Ti-6Al-4V = 2.40 Nm ± 0.24 Nm

The interface screws of O-Box and E-Box are provided by C-1 ISRO while the titanium screws of the SHRU are provided by MPS.

Optical Fiber:

The optical fiber is fixed to the ASS panel by 6 special supports which have been delivered by MPS. These supports are glued on the ASS panel by C-1 ISRO. We distinguish three kinds of supports: with and without pillar (see figures below). The MICD drawings of the supports are shown in section 8.

⁹ The screws had to be shortened during AIT.



Figure 20: Fiber support with high base round.

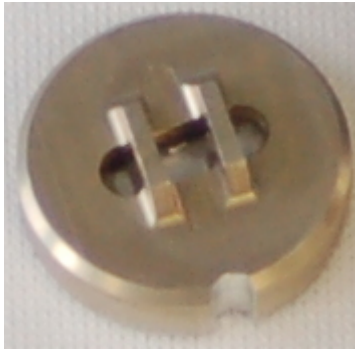


Figure 21: Fiber support with wedge round.

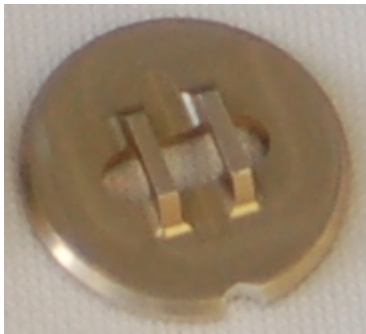


Figure 22 "Standard" fiber support.

Electrical harness ILH:

This electrical harness is fixed to the S/C panel by using insulated clamps. The minimum bending radius of the harness is 40 mm.

The ILH harness shield shall not be in electrical contact with the S/C structure (only connected with the S/C structure on the dedicated SIR-2 connectors).

4.3.7 Mechanism requirements

SIR-2 does not have mechanisms.

4.3.8 Grounding points

Galvanically insulated units and star ground design is implemented (see Figure 10). Each SIR-2 subunit is equipped with a M4 ground stud. The locations of the ground studs are marked in the MICD drawings in section 8. The ground studs need to be connected with S/C structure ground.

The SIR MLI has two grounding wires per blanket. According to ISRO the required wire length is 1.25 m.

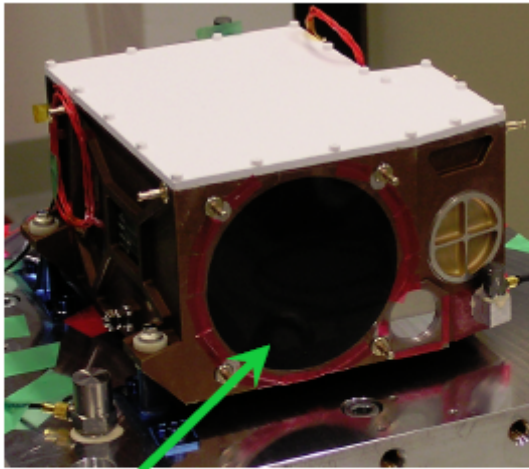
4.3.9 Handling provisions requirements

- Please do not touch the radiator surfaces of O-Box and SHRU.
- Please do not touch the fibre outlet on SHRU and O-Box except for fiber mounting
- Please do not touch the fibre tips.

4.3.10 Aperture covers requirements/red tag items

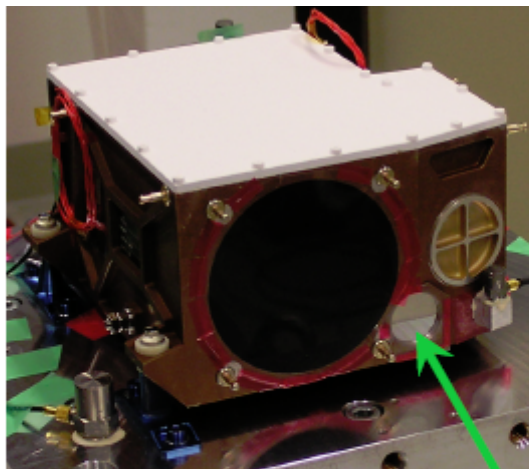
- Venting-hole lock (tape) which is located on the Sensor-Head's cap, see Figure 32 and Figure 29.
- Purging-hole lock (tape) which is located on the Sensor-Head's Quartz-Housing, see Figure 32 and Figure 30.
- Dust protection foil of O-Box aperture (see Figure 24)
- Dust protection foil in front of O-Box alignment mirror (see Figure 25): to be permanently removed after the final boresight alignment verification between SIR-2, star-trackers, and other payloads.
- Dust protecting SHRU Radiator cover (see Figure 28)
- Dust protecting O-Box Radiator cover (see Figure 26)
- Dust protection cap on O-Box fiber support (see Figure 27)
- Dust protection cap on SHRU fiber support (see Figure 31)

Some red tag items need to be temporarily removed before starting tests on S/C level - see section 5.4 for details-



Dust protection foil of aperture

Figure 24 Aperture dust protection foil



Dust protection foil of alignment mirror

Figure 25 Alignment mirror dust protection foil

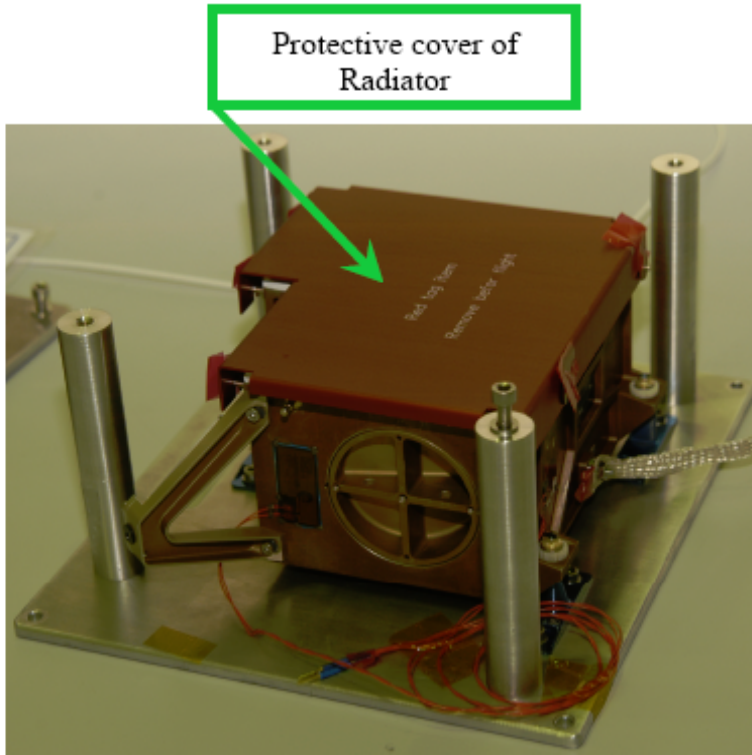


Figure 26 O-Box radiator dust cover.

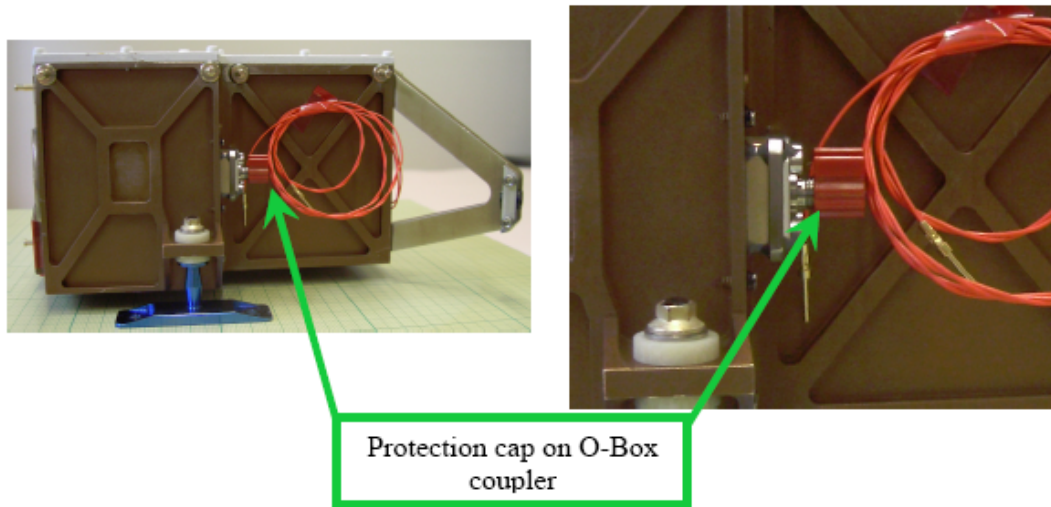


Figure 27 Fiber coupler dust protection (only installed when SIR-2 fiber is not installed.)



Figure 28 SHRU radiator dust protection.

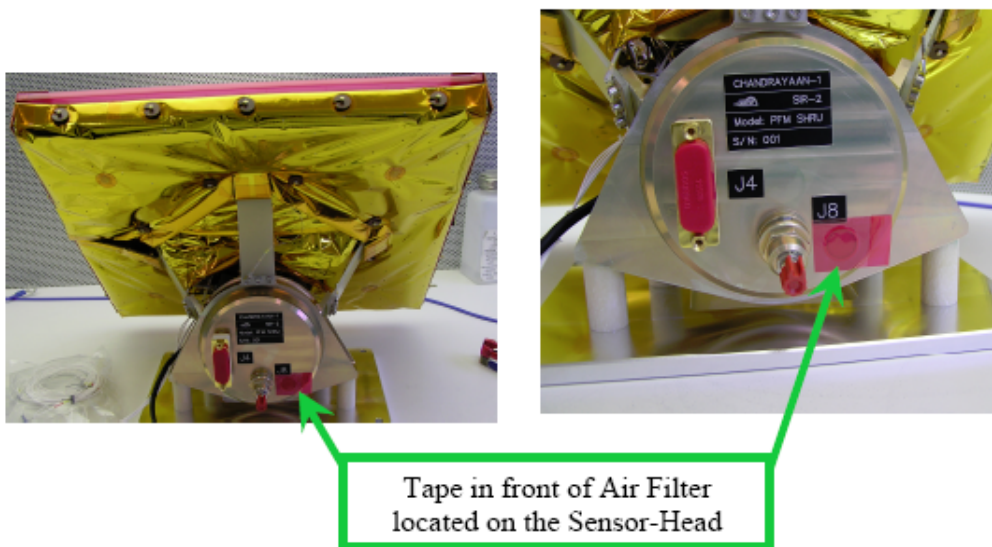


Figure 29 SHRU venting hole protection.

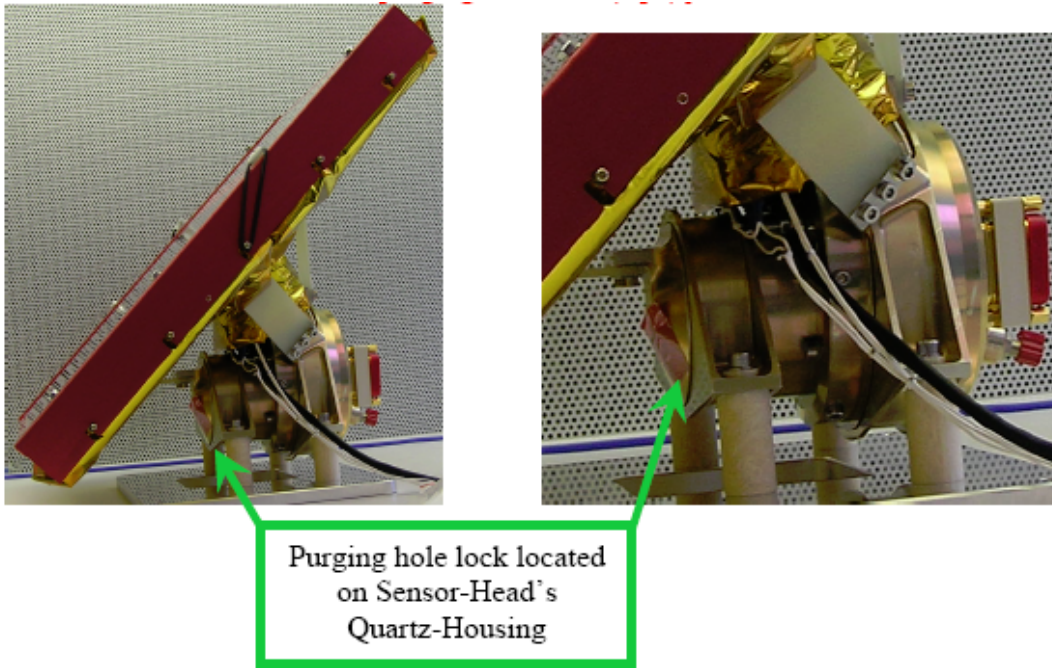


Figure 30 Purging hole lock.

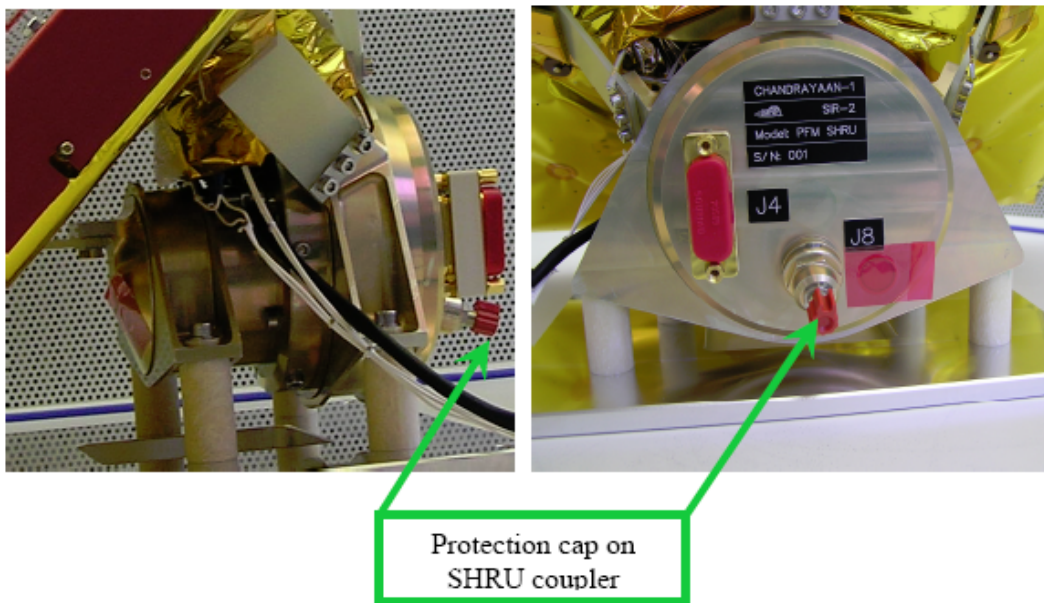


Figure 31 Dust protection cap of internal fiber on Sensor-Head.

4.3.11 Accessibility requirements

We need access to the purging- and venting-hole lock (Sensor-Head) during the ground storage of the S/C. The locations of the locks are shown in Figure 32.

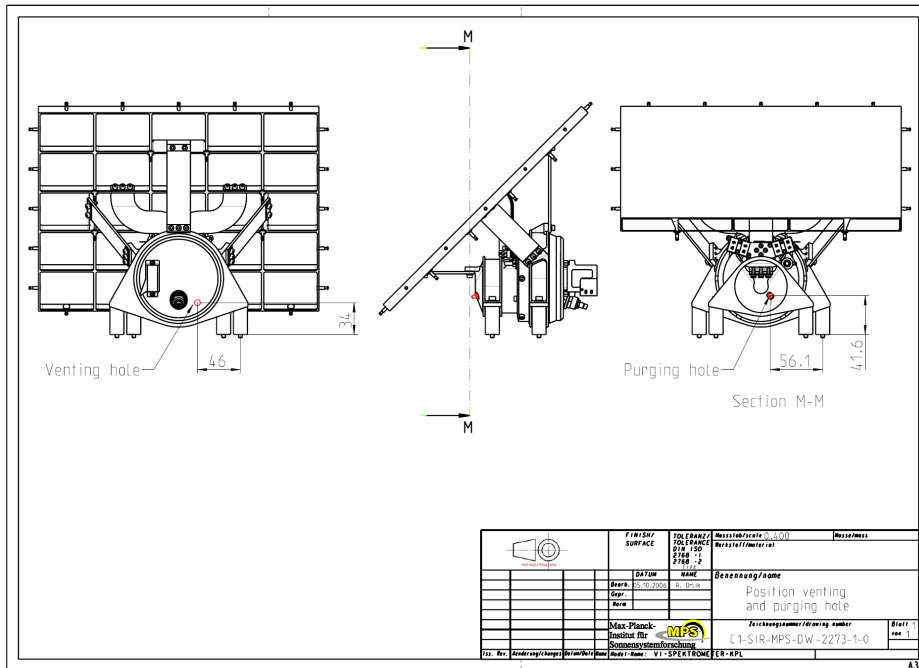


Figure 32: Location of purging- and venting-hole lock (red) on Sensor-Head/Radiator Unit.

4.3.12 Connector location/connector layout

See the MICD drawings in section 8 for the locations of the electrical connectors.

4.3.13 E-Box connectors

The SIR-2 E-Box consists of two subunits: The Power Supply Unit (PSU) and the Instrument Control Unit (ICU). The ICU has two electrical interface connectors:

- J1 to the S/C data buses
- J3 to the ISU J4 connector which is located on the Sensor-Head

The PSU has one electrical interface connector:

- J2 to S/C power bus

J1 and J2 connect the payload to the S/C via two Instrument External Harnesses (IEH) cables. The purposes/tasks of each connector are described in Table 41 and Table 42 while the locations of the connectors are shown in Figure 47.

Table 41 S/C interface Instrument External Harness (IEH) connectors on E-Box.

| Name: | Type: | Location: | Description: |
|-------|----------|-------------|--|
| J1 | DAMA 26P | E-Box / ICU | Communication I/F between Instrument Control Unit (ICU) and S/C (containing MIL-bus/LVDS/TMP monitor/WatchDog) |
| J2 | DEMA 15P | E-Box / PSU | Power I/F between Instrument Control Unit (ICU) and S/C (containing MAIN power lines, power on/off signals) |

Table 42 Instrument Local Harness (ILH) connector on ICU (E-Box).

| Name: | Type: | Location: | Description: |
|--------------|--------------|------------------|--|
| J3 | DAMA 26S | E-Box / ICU | Internal SIR-2 interface between E-Box and Sensor-Head (Instrument Local Harness – ILH) |

Comments:

All connectors used are D-sub type connectors in double density version with 3 row position configuration.

The second letter in type coding indicates the housing size.

Type DEMA= connector size 1 = E. - standard D-sub 9 positions = double density 15 positions.

Type DAMA= connector size 2 = A. - standard D-sub 15 positions =double density 26 positions.

4.3.13.1 Sensor-Head connector

The Sensor-Head (ISU) has one electrical interface connector J4 to the E-Box (J3) via the Instrument Local Harness (ILH) for signal and power transfer between the Sensor-Head and the E-Box (see Table 43).

Table 43 Instrument Local Harness (ILH) connector on Sensor-Head (ISU).

| Name: | Type: | Location: | Description: |
|--------------|--------------|-------------------|---|
| J4 | DAMA 26P | Sensor-Head / ISU | Internal interface between Sensor-Head and E-Box (Instrument Local Harness - ILH) |

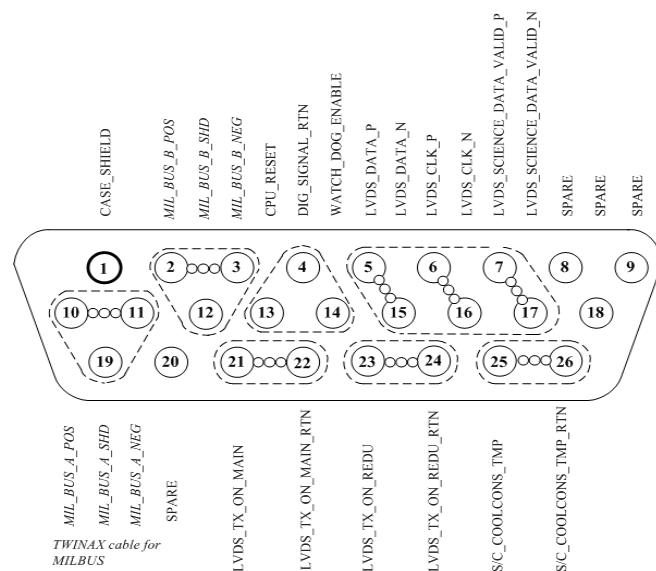
4.3.13.2 Detailed pin definitions

See next pages.

Table 44 Pin definition for connector J1 (S/C communication interface)

J1 Connector on E-Box / ICU to/from S/C
 Harness: Instrument External Harness (IEH)

| J1-IEH pin no.. | Description/functions in ICU and ISU J1 –DAMA 26P (3 row double density D-type) | Connect to. | Harness configuration. Wire AWG 26 |
|-----------------|--|-------------------|---------------------------------------|
| 1 | CASE SHIELD | Shield | TBD |
| 2 | MIL_BUS_B_POS | Ana-Signal Input | ICU TWP 3 |
| 3 | MIL_BUS_B_NEG | Ana-Signa Input | ICU TWP 2 |
| 4 | DIG SIGNAL RTN | Signal-Rtn Input | ICU NA |
| 5 | LVDS_DATA_P | Dif-Signal Output | ICU TWP 15 |
| 6 | LVDS_CLK_P | Dif-Signal Output | ICU TWP 16 |
| 7 | LVDS_DATA_VALID_P | Dif-Signal Output | ICU TWP 17 |
| 8 | SPARE | | Open NA |
| 9 | SPARE | | Open NA |
| 10 | MIL_BUS_A_POS | Ana-Signa Input | ICU TWP 11 |
| 11 | MIL_BUS_A_NEG | Ana-Signa Input | ICU TWP 10 |
| 12 | MIL_BUS_B_SHD | Shield Input | ICU Shield TWP 2/3 |
| 13 | CPU RESET | Dig-Signal Input | ICU AWG26 |
| 14 | WATCH DOG ENABLE | Dig-Signal Input | ICU AWG26 |
| 15 | LVDS_DATA_N | Dif-Signal Output | ICU TWP 5 |
| 16 | LVDS_CLK_N | Dif-Signal Output | ICU TWP 6 |
| 17 | LVDS_DATA_VALID_N | Dif-Signal Output | ICU TWP 7 |
| 18 | SPARE | | Open NA |
| 19 | MIL_BUS_A_SHD | Shield Input | ICU Shield TWP 11/12 |
| 20 | SPARE | | Open NA |
| 21 | LVDS_TX_ON_MAIN | Dig-Signal Output | ICU AWG 26 |
| 22 | LVDS_TX_ON_MAIN RTN | Dig-Signal Output | ICU NA |
| 23 | LVDS_TX_ON_REDU | Dig-Signal Output | ICU AWG 26 |
| 24 | LVDS_TX_ON_REDU RTN | Dig-Signal Output | ICU NA |
| 25 | S/C COOLCONS TMP | Tmp-Mon Output | J3-13 TWP 26 |
| 26 | S/C COOLCONS TMP RTN | Tmp-Mon Output | J3-J4 TWP 25 |



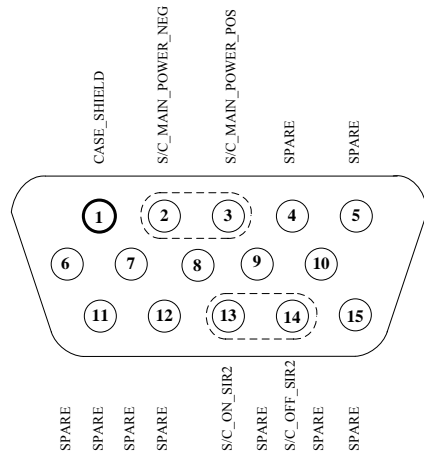
SIR2 - J1 Connector layout DAMA 26P (Front view)
 ○○ = twisted pair (TWP)

Figure 33 Layout of connector J1.

Table 45 Pin definition for connector J2 (S/C power interface)

J2 Connector on E-Box / PSU to/from S/C
 Harness: Instrument External Harness (IEH)

| J2 pin no. | Description/functions in PSU J2 –DEMA 15P (3 row double density D-type) | | | Connected to. | Harness configuration. Wire AWG 26 |
|------------|--|------------|-------|---------------|---------------------------------------|
| 1 | CASE SHIELD | | | | TBD |
| 2 | S/C MAIN POWER NEG | Power | Input | PSU | TP 3 |
| 3 | S/C MAIN POWER POS | Power | Input | PSU | TP 2 |
| 4 | SPARE | | | Open | NA |
| 5 | SPARE | | | Open | NA |
| 6 | SPARE | | | Open | NA |
| 7 | SPARE | | | Open | NA |
| 8 | SPARE | | | Open | NA |
| 9 | SPARE | | | Open | NA |
| 10 | SPARE | | | Open | NA |
| 11 | SPARE | | | Open | NA |
| 12 | SPARE | | | Open | NA |
| 13 | S/C ON SIR2 | Dig-Signal | Input | PSU | AWG 26 |
| 14 | S/C OFF SIR2 | Dig-Signal | Input | PSU | AWG 26 |
| 15 | SPARE | | | Open | NA |



SIR2 - J2 Connector layout - DEM A 15P (Front view)

Figure 34 Layout of Power I/F connector J2.

Table 46 Pin definition for connector J3 (instrument local harness)

J3 Connector on E-Box/ICU to/from Sensor-Head /ISU
 Harness: Instrument Local Harness (ILH)

| J3 pin no. | Description/functions in ICU;ISU and PSU J3 .DAMA 26S (3 row double density D-type) | | | J1 IEH | Inter connect | Harness configuration. Wire AWG 26 |
|------------|--|------------|--------|--------------|---------------|---------------------------------------|
| 1 | VIDEO_OUTPUT | Ana-Signal | Input | Na | ICU | AWG26/ shield to 19 |
| 2 | PWR ISU_VCC | Power | Output | Na | J5-3 | AWG26 |
| 3 | PWR TEC_NEG_POS | Power | Output | Na | J5-1 | TWP 21 |
| 4 | S/C COOLCONS_TMP RTN | Tmp-Mon | ToS/C | J1-26 | Na | TWP 13 |
| 5 | ISU_PDA_TMP RTN | Tmp-Mon | Input | Na | J5-31 | TWP 14 |
| 6 | NC to ICU PCB | | | Na | Na | |
| 7 | HK_COOLCONS_TMP | Tmp-Mon | Input | Na | J5-12 | TWP 17 |
| 8 | ISU_PCB_TMP | Tmp-Mon | Input | Na | J5-19 | TWP 9 |
| 9 | ISU_PCB_TMP RTN | Tmp-Mon | Input | Na | J5-9 | TWP 8 |
| 10 | ISU_COMMON RTN | Power | Output | Na | ICU | AWG26 |
| 11 | NC to ICU PCB | | | Na | Na | |
| 12 | PWR_SURV_HEATER | Power | Output | Na | ICU | AWG26 |
| 13 | S/C COOLCONS_TMP | Tmp-Mon | ToS/C | J1-25 | Na | TWP 4 |
| 14 | ISU_PDA_TMP | Tmp-Mon | Input | Na | J5-13 | TWP 5 |
| 15 | QUARTZ_BODY_TMP RTN | Tmp-Mon | Input | Na | J5-30 | TWP23 |
| 16 | CLK | Dig-Signal | Output | Na | ICU | AWG26 |
| 17 | HK_COOLCONS_TMP RTN | Tmp-Mon | Input | Na | J5-30 | TWP 7 |
| 18 | NC to ICU PCB | | | | | |
| 19 | VIDEO_OUTPUT SHD | Shield | Input | Na | ICU | Shielded AWG26 on pin 1 |
| 20 | PWR ISU_VCC SHD | Shield | Output | Na | Na | |
| 21 | PWR_TEC_POS_NEG | Power | Output | Na | J5-2 | TWP 3 |
| 22 | CASE_SHIELD | | | Na | Na | TBD |
| 23 | QUARTZ_BODY_TMP | Tmp-Mon | Input | Na | J5-11 | TWP15 |
| 24 | NC to ICU PCB | | | | | |
| 25 | RESET | Dig-Signal | Output | Na | ICU | AWG26 |
| 26 | NC to ICU PCB | | | | | |

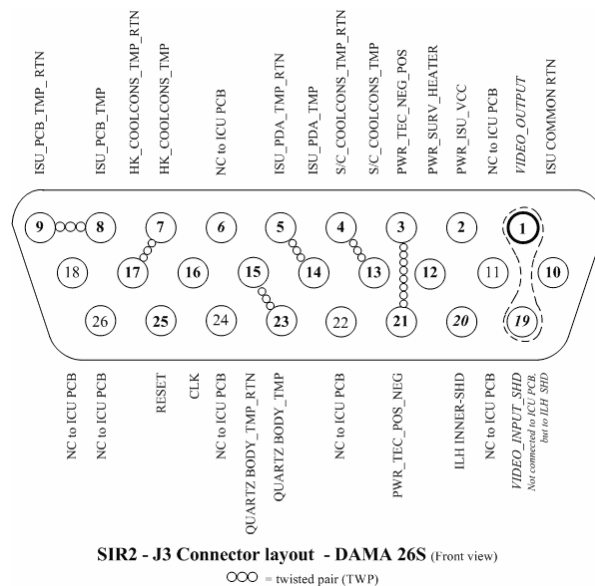
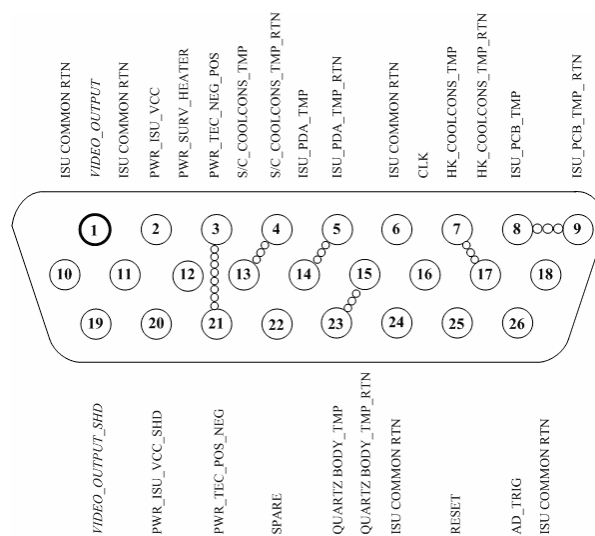


Figure 35 Layout of connector J3.

Table 47 Pin definition for connector J4 (instrument local harness)

J4 Connector on Sensor-Head/ISU to/from E-Box / ICU
 Harness: Instrument Local Harness (ILH)

| J4 pin no. | Description/functions in ICU;ISU and PSU J4 .DAMA 26P (3 row double density D-type) | | J1 IEH | J3 | Harness configuration. Wire AWG 26 | |
|------------|--|------------|---------|-------|---------------------------------------|-------------------------|
| 1 | VIDEO_OUTPUT | Ana-Signal | Output | Na | 1 | AWG26//shield to 190/19 |
| 2 | PWR ISU_VCC | Power | Input | Na | 2 | AWG 26 |
| 3 | PWR TEC_NEG_POS | Power | Input | Na | 3 | TWP 21 |
| 4 | S/C COOLCONS_TMP RTN | Tmp-Mon | Output | J1-26 | 4 | TWP 13 |
| 5 | ISU_PDA_TMP RTN | Tmp-Mon | Output | Na | 5 | TWP 14 |
| 6 | ISU_COMMON RTN | Power | Input | Na | 6 | (removed on ICU PCB) |
| 7 | HK_COOLCONS_TMP | Tmp-Mon | Output | Na | 7 | TWP 17 |
| 8 | ISU_PCB_TMP | Tmp-Mon | Output | Na | 8 | TWP 9 |
| 9 | ISU_PCB_TMP RTN | Tmp-Mon | Output | Na | 9 | TWP 8 |
| 10 | ISU_COMMON RTN | Power l | Input | Na | 10 | AWG 26 |
| 11 | ISU_COMMON RTN | Power | Input | Na | 11 | (removed on ICU PCB) |
| 12 | PWR_SURV_HEATER | Power | Input | Na | 12 | AWG 26 |
| 13 | S/C_COOLCONS_TMP | Tmp-Mon | Output | J1-25 | 13 | TWP 4 |
| 14 | ISU_PDA_TMP | Tmp-Mon | Output | Na | 14 | TWP 5 |
| 15 | QUARTZ_BODY_TMP RTN | Tmp-Mon | Output | Na | J5-30 | TWP 23 |
| 16 | CLK | Dig-Signal | Input | Na | 16 | AWG 26 |
| 17 | HK_COOLCONS_TMP RTN | Tmp-Mon | Output | Na | 17 | TWP 7 |
| 18 | ISU_COMMON RTN | Power | Input | Na | 18 | (removed on ICU PCB) |
| 19 | VIDEO_OUTPUT_SHD | Shield | Input u | Na | 19 | Shield for pin 1 |
| 20 | PWR_ISU_VCC_SHD | Shield | Output | Na | 20 | Shield |
| 21 | PWR_TEC_POS_NEG | Power | Input | Na | 21 | TWP 3 |
| 22 | SPARE | | | Na | | |
| 23 | QUARTZ_BODY_TMP | Tmp-Mon | | Na | J5-11 | TWP 15 |
| 24 | ISU_COMMON RTN | Power | Input | Na | 24 | (removed on ICU PCB) |
| 25 | RESET | Dig-Signal | Input | Na | 25 | AWG 26 |
| 26 | AD_TRIG Not used | | | Na | | (removed on ICU PCB) |



SIR2 - J4 Connector layout - DAMA 26P (Front view)

OOO = twisted pair (TWP)

Figure 36 Layout of connector J4.

4.3.14 Payload accommodation and physical properties

Table 48 Mass breakdown of SIR-2.

| Unit | Comment | Mass SIR-2 [g] ± uncertainty | Note |
|--------------------------|--|------------------------------|---------------------------------|
| E-Box | | 849 ± 10 | Measured on (P)FM |
| Local Harness ILH | Including connectors and shield | 76 ±2 | Measured on (P)FM |
| O-Box | | 618 ±10 | Measured on (P)FM |
| Outer fiber | Including connectors, w/o mounting supports, | 26 ±3 | Measured on (P)FM |
| Senor-Head/Radiator Unit | Sensor-Head | 1445 ±15 | Measured on (P)FM |
| MLI | MLI | 303 ±10 | Measured on (P)FM ¹⁰ |
| SIR-2 Total | | 3317 ± 50 | |

Table 49 Power consumptions of the SIR-2 PFM.¹¹

| Instrument Mode | TEC | ISU Electronics | Primary Power (@42V) [W] +/-5% |
|-----------------------|-------------------------------|-------------------------------|--------------------------------|
| Standby | off | off, SIR-2 internal heater ON | 5.145 |
| Preparation | off | active | 4.270 |
| Measurement | off | active | 4.270 |
| Measurement, full TEC | Full Power (4W) ¹² | active | 10.374 |

¹⁰ MLI mass increase due to changed MLI configuration.

¹¹ This list does not contain the SIR-2 S/C heater power (5W for O-Box and 10W for SHRU)

¹² Usually the power consumption of the TEC will be less than 4W.

4.3.15 Instrument integration / alignment

In general: Handle the SIR-2 units, the ILH harness and the optical fiber under cleanroom conditions (for conditions see 3.1.1) and in an ESD protected area with ESD protecting cleanroom gloves only.

The instrument will be delivered in special transportation and storage boxes. The units themselves are protected by ESD protecting foils. Shock, temperature and humidity will be monitored during transportation.

Refer to the appropriate instrument MICD drawings and [RD15] before instrument integration on S/C. Consider also the instrument's purging procedure in [RD15] and perform the integration according [AD6].

4.3.16 Equipment identification

All units will be marked by identification labels (see [RD19], [RD20] and [RD21]).

4.3.17 Connector identification

All connectors will be marked by identification labels.

4.3.18 Harness marking

Harness ILH will be marked by an identification label.

4.3.19 Structural analysis of the units

Structural analysis led to the following predictions of first eigenfrequencies:

1. Sensor-Head/Radiator Unit: 122 Hz (measured on Dummy: 136 Hz)
2. O-Box: 445 Hz (measured on (P)FM: 441 Hz)

4.3.20 Material list

See [RD16]

4.3.21 Instrument local harness

The Instrument Local Harness ILH, provided by the SIR-2 team, connects the Sensor-Head (connector J4) with the instrument control electronics unit ICU (E-Box connector J3). The ILH harness, transmitting analog signals, is of length ~100 mm. The Harness cross-section diameter is approx. 10 mm.

4.3.22 Radioactive source

SIR-2 does not contain any radioactive source.

4.3.23 Venting holes

- On Sensor-Head Cap (this hole is sealed with a dust filter and protected by the venting hole lock during ground storage (see Figure 32)).

4.3.24 Purging of sensor-head

Gaseous purging of the SIR-2 Sensor-Head is required during ground storage. The Sensor-Head shall be purged with certified dry nitrogen, purity 99.95%. Purging needs to be redone after each removal of the purging- and venting hole lock (see Figure 32) e.g., after thermal vacuum testing and for ground storage times exceeding 2 months.

MPS has delivered special purging equipment and a purging instruction (see [RD15]) for SIR-2. The equipment is shown in Figure 37.

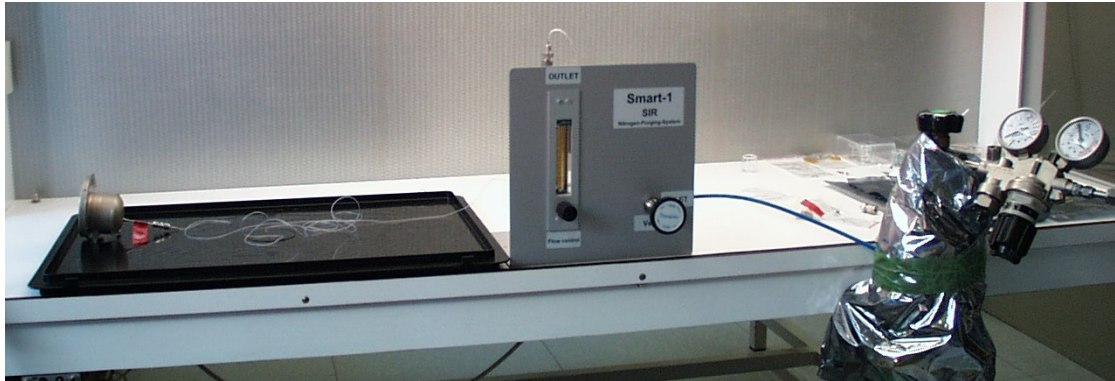


Figure 37 SIR purging equipment. From left to right: Structure dummy (golden), flange pipe with red tag marking¹³, tube (blue for SIR-2), purging unit (outlet flange, flow control, vent, inlet), bottle tube (blue) and nitrogen bottle.

4.3.25 Interface control drawings

See section 8.

¹³ Flange pipe needs to be removed immediately after purging process is finished.

4.4 Thermal design

4.4.1 Instrument thermal control concept

The SIR-2 experiment consists of three units: O-Box, Sensor-Head/Radiator Unit and E-Box. The Sensor-Head/Radiator Unit and the O-Box are to a high degree thermally decoupled from the S/C structure while the E-Box is coupled.

The SIR-2 near-infrared detector, located inside the Sensor-Head, requires cooling, which will be achieved by a passively cooled radiator and a Peltier Element (TEC) that is mounted inside the detector housing. The Peltier Element can be used as heater and cooler. Its purpose is to stabilize the temperature of the InGaAs detector pixels during measurements.

Figure 45 shows the MICD drawing of the Sensor-Head/Radiator Unit that will be located behind the payload suite on the Anti-SS panel (see Figure 19). The entire Sensor-Head/Radiator Unit is thermally isolated from the S/C structure by four low conductive feet. A further stage of thermal isolation inside the Sensor-Head is reached by low conductive rings and washers which are implemented between the Sensor-Head housing and the Cooling Console which holds the detector. Only the Cooling Console/Detector subunit is thermally well coupled (via the Cooling Band) to the Sensor-Head Radiator. Thermal calculations showed that a Sensor-Head Radiator of size 300 x 300 mm is sufficient to cool the detector and its compartment. The Sensor-Head Radiator, mounted on top of the Sensor-Head, is thermally insulated from the Sensor-Head housing by four low conductive supports. The insulated design of the Sensor-Head/Radiator Unit and the high cooling capacity of the Sensor-Head Radiator leads to the need of S/C powered heaters and a controlling S/C powered thermistor which keep the Sensor-Head/Radiator Unit above a certain temperature level during operation and non-operation phases.

In order to keep the thermal emission of the structure low the SIR-2 O-Box, housing the front-end optics, requires some cooling especially during the noon-midnight phase. Cooling will be achieved by the O-Box lid. This lid is painted white and acting as a radiator. Figure 46 shows the O-Box which will be located on an extension of the Anti-SS panel (see Figure 19). The O-Box comes with three very low conductive feet, which thermally decouple the unit from the ASS extension panel. The insulated design of the O-Box leads to the need of (two) S/C powered safety heaters (foil heaters) and a controlling S/C powered thermistor which keep the unit above a certain temperature level during operation and non-operation phases.

The SIR-2 E-Box is collectively controlled and thus does not require a safety heater if the heat flux from the panel is always sufficient to keep the unit above the minimum temperature. However, an S/C powered thermistor is required to monitor the temperature during the time the unit is switched OFF.

As already mentioned, S/C powered/controlled heaters/thermistors shall ensure the safety of the O-Box and the safety of the Sensor-Head/Radiator Unit all the time, i.e.

not only during the time the instrument is OFF but also during the time SIR-2 is operating.

The radiator of the Sensor-Head/Radiator Unit is designed/sized to reach proper cooling of the SIR-2 detector also during the (warm) noon-midnight phase. The S/C powered main or redundant heater line of the SHRU shall be used to minimize the temperature cycling of the SHRU during flight. During the main TV-test of the SIR-2 (P)FM it was demonstrated that the temperature amplitude of the Sensor-Head's Cooling Console during a simulated noon-midnight orbit can be reduced to $\pm 1.5^{\circ}\text{C}$ if the S/C heater ON/OFF limits are selected appropriate (see section 6.7.1 for in-flight temperature limits and Figure 38 for TV-test results). A frequent activation and deactivation of the SIR-2 S/C powered heaters is therefore required.

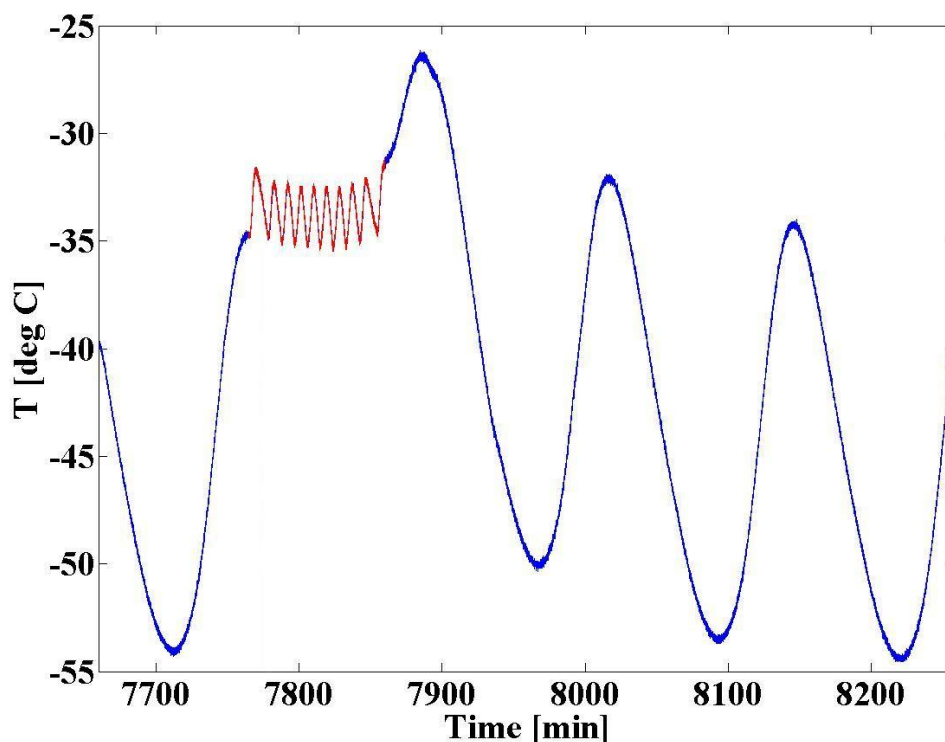


Figure 38 Temperature profile of the Cooling Console during the main TV-Test (noon-midnight orbit simulation). The red curve shows the time the S/C heaters have been occasionally activated for temperature stabilization of the SHRU.

The O-Box S/C heater(s) will be used to ensure that the lower op/non-op limit temperature is not violated. The S/C heater(s) shall be activated and deactivated at the ON/OFF limits given in section 4.4.4.

The O-Box and the Sensor-Head/Radiator Unit are protected by MLI tents. The E-Box is painted black to enhance thermal irradiation.

4.4.2 General requirements

The Sensor-Head Radiator is covered with OSR, which minimizes the solar heat input during the time the SHRU is in sunlight. However, to further reduce the temperature cycling of the SHRU the SIR-2 S/C powered heaters shall be used.

The O-Box of SIR-2 shall be kept in shade during flight. However, short solar illuminations during the lunar transfer orbit and during the science phase are uncritical. The O-Box needs S/C safety heater protection.

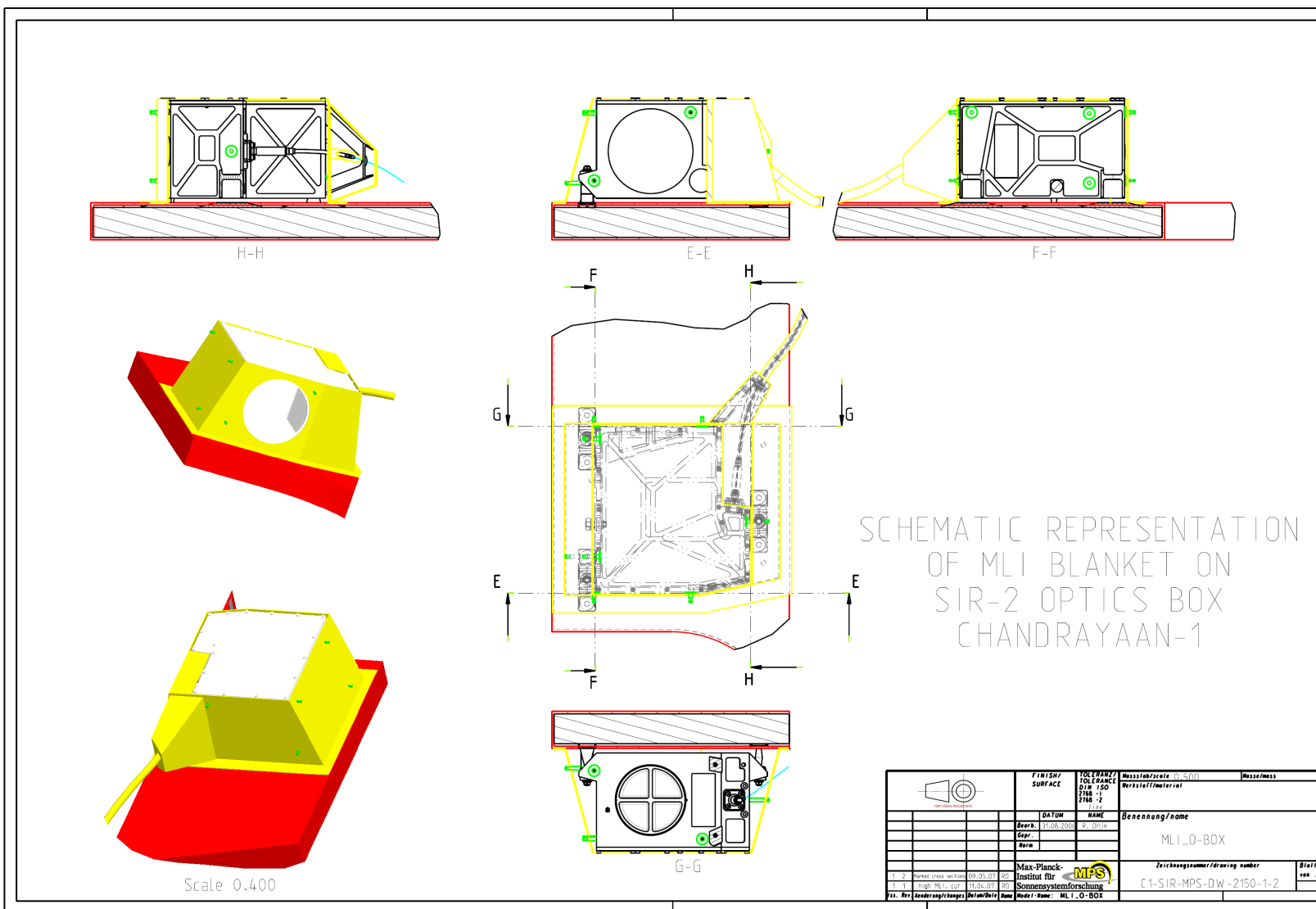
Previously foreseen redundant S/C thermistors have been cancelled due to a C-1, ISRO request. Redundant S/C heaters are foreseen for the Sensor-Head Radiator Unit only. See 4.4.1 for the role of S/C thermistors and S/C heaters in the SIR-2 temperature control concept.

4.4.2.1 MLI

O-Box, Sensor-Head/Radiator Unit and part of the optical fiber of SIR-2 need to be equipped with their own MLI tents/tubes. The conceptual designs of these tents are shown in Figure 39 and Figure 40. C-1 ISRO agreed to manufacture the MLI tents for SIR-2 STM, PFM and FS. Detailed manufacturing drawings have been provided by MPS.

It needs to be highlighted that the space between the S/C ASS panel and the Sensor-Head/Radiator Unit as well as between the ASS extension panel and the O-Box need to be filled with S/C MLI. This MLI shall reduce the radiative couplings between the S/C panel and the SIR-2 units. Layering and performance of the SIR-2 MLI is detailed in [RD9].

Figure 39 O-Box MLI design overview.



The following interfaces between the SIR-2 MLI and the S/C MLI need to be prepared by C-1 ISRO:

- The S/C MLI cut-outs for:
 - O-Box and Sensor-Head Radiator Unit mounting feet
 - Grounding wires of O-Box and Sensor-Head Radiator Unit
 - Grounding wires of the SIR-2 MLI¹⁴
 - Flying leads of S/C powered thermistors and heaters
 - SIR-2 ILH harness
 - SIR-2 optical fiber

- Protection of the optical fiber by S/C MLI: It is assumed that most of the fiber is routed underneath the S/C panel MLI. But some fiber sections will overtop the panel MLI and thus protecting “MLI tubes” are required. These “MLI tubes” shall be provided and installed by C-1 ISRO during the SIR-2 integration on spacecraft. Figure 41 shows the expected locations of these tubes.

- The fixation of the SIR-2 MLI collars to the S/C MLI (fixation either by tape, velcros or stand-offs)

¹⁴ According to C-1 ISRO the length of the MLI grounding/bonding wires is 1.25 m.

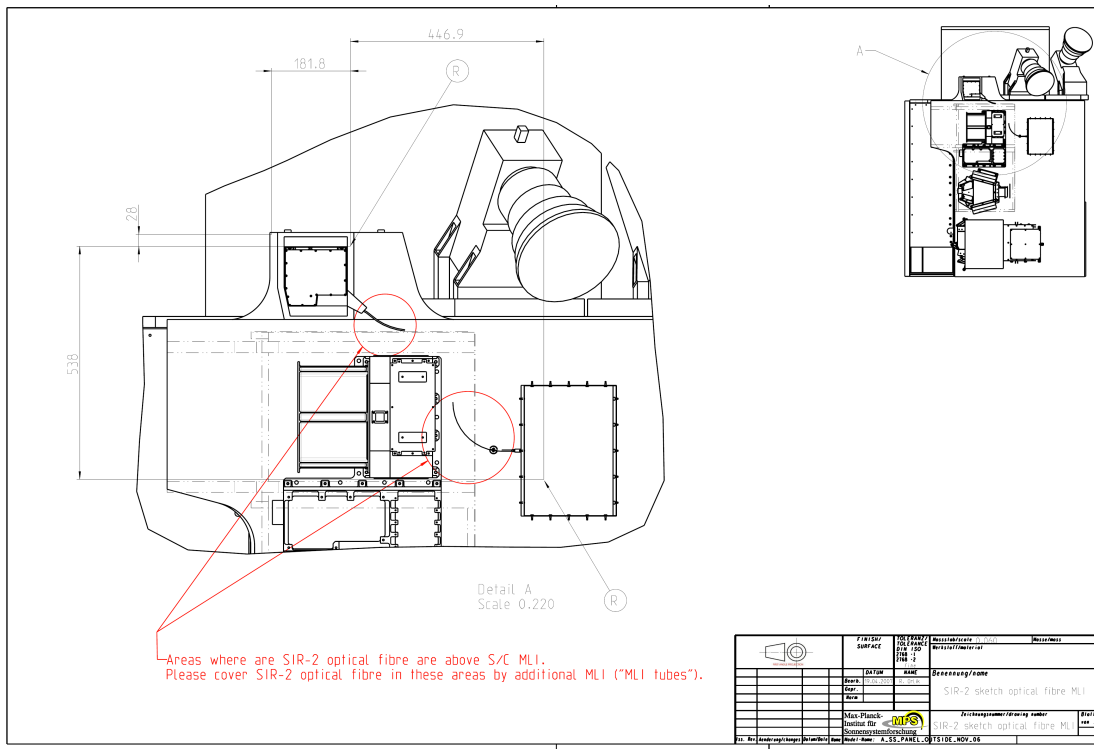


Figure 41 Location of “MLI tubes” which shall protect the fiber optics.

4.4.2.2 S/C Powered heaters

- Sensor-Head/Radiator Unit (main and redundant heaters): Two S/C powered main heaters of total 9.39W (@42V) plus further two S/C powered redundant heaters of 9.39W (@42V) are attached to the Cooling Band/Cooling Finger interface (see Figure 45 for exact location of these heaters on the so called heater plate). Each two S/C powered heaters of type Wirewound Resistor will be connected in parallel. The heaters, equipped with flying leads of length > 1 m, will be provided and mounted by the SIR-2 team before instrument delivery.
- O-Box (only main heater(s), no redundant heater(s) foreseen)¹⁵: Two S/C powered foil heaters of total 4.8W (@42V) are glued on the O-Box housing (see Figure 46 for exact location). Both heaters are connected in parallel and are equipped with flying leads of 0.5 m length (extension of wires required after instrument delivery). These heaters will be provided and attached by SIR-2 team before instrument delivery.

¹⁵ While the Sensor-Head/Radiator Unit is equipped with a redundant heater-system the O-Box is not.

The SIR-2 S/C powered heaters need to operate during the non-op and the operating phase of SIR-2.

4.4.2.3 S/C Powered thermistors

Sensor-Head/Radiator Unit:

1. **Inside Sensor-Head:** A single Pt1000 thermistor is glued on the Shielding Bow (next to the Cooling Console which holds the detector). This thermistor monitors the temperature of the Cooling Console and activates/deactivates (processing by C-1 BMU) the S/C powered main heater line. The thermistor needs to monitor the temperature range from -100 °C to +50 °C with best accuracy in the range from -75 °C to -40 °C. The thermistor is routed via the SIR-2 local harness ILH and the SIR-2 E-Box. The interface to the spacecraft is on connector J1 (for location of connector see Figure 47). This thermistor will be provided and inserted by the SIR-2 team.
2. **Heater Plate (Sensor-Head external):** A single Pt1000 shall be glued by the CHANDRAYAAN-1 project team on the Heater Plate¹⁶ of the Sensor-Head/Radiator Unit (for exact location see Figure 45). This thermistor shall control the redundant S/C heater line of the Sensor-Head/Radiator Unit. The thermistor needs to monitor the temperature range from -100 °C to +50 °C with best accuracy in the range from -75 °C to -40 °C. This thermistor shall have flying leads and shall be attached after payload integration but before final SIR-2 MLI integration on spacecraft. Note: please use a glue which is qualified for the given temperature range.
3. **Sensor-Head Radiator:** A single thermistor of type Pt1000 shall be glued on the rear side of the radiator (the exact location is shown in Figure 45). The thermistor needs to monitor the temperature range from -150 C° to +55 C° with best accuracy in the range from -30 C° to -100 C°. This thermistor shall be provided and attached by CHANDRAYAAN-1 project team. It shall have flying leads and shall be attached after payload integration but before final SIR-2 MLI integration on spacecraft. Note: please use a glue which is qualified for the given temperature range.
4. **Sensor-Head Housing:** A single thermistor of type Pt1000 shall be glued on the external Sensor-Head Housing (the exact location is shown in Figure 45). The thermistor needs to monitor the temperature range from -80 °C to +55 °C with best accuracy in the range from -30 °C to -70 °C. This thermistor needs to be provided and attached by CHANDRAYAAN-1 project team. It shall have flying leads and shall be attached after payload integration but before final SIR-2 MLI integration on spacecraft. Note: please use a glue which is qualified for the given temperature range.

¹⁶ Discussion between C-1 ISRO and MPS required before placement of thermistor.

O-Box:

5. **O-Box Housing:** A single thermistor of type Pt1000 shall be glued at the external O-Box housing (exact location is shown in Figure 46). This thermistor controls the S/C powered O-Box heaters (processing by C-1 BMU). The thermistor needs to monitor the temperature range from -100 °C to +50 °C with best accuracy in the range from 0 °C to -70 °C. The thermistor needs to be provided and attached by CHANDRAYAAN-1 project team. It shall have flying leads and shall be attached after payload integration but before final SIR-2 MLI integration on spacecraft. Note: Please use a glue which is qualified for the given temperature range.

E-Box:

6. **E-Box Housing:** A single thermistor of type 10 k shall be glued on the external E-Box housing (the exact location is shown in Figure 47). The thermistor needs to monitor the temperature range from -40 °C to 120 °C with best accuracy in the range from -10 °C to 60 °C. The thermistor needs to be provided and attached by CHANDRAYAAN-1 project team. It shall have flying leads and shall be attached after payload integration on spacecraft. Note: please use glue which is qualified for the mentioned temperature range.

4.4.2.4 SIR-2 internal thermistors

Beside the S/C powered thermistors SIR-2 is equipped with a number of thermistors which are controlled by SIR-2:

1. Thermistor (PDA_TEMP) that is located inside of the detector
2. Pt2000 thermistor (PCB_TEMP) that is located at the ISU PCB
3. YSI 44901 thermistor (PSU_TEMP) that is located at one of the PSU boards
4. Pt1000 thermistor (COOL_TEMP) that is located at the Shielding Bow (next to Cooling Console)
5. Pt2000 thermistor (QUA_TEMP) that is located at the Quartz Body

4.4.2.5 Radiators

The main radiator of SIR-2 is the Sensor-Head Radiator which is mounted on top of the Sensor-Head. The radiator has a size of 300 x 300 mm and is equipped with OSR. The radiator is used to cool the detector and its compartment.

The top of the O-Box is acting as a radiator to keep the O-Box temperature below a certain temperature during noon-midnight orbit. The radiator area is white painted (PCBE conductive white paint).

4.4.3 Temperature range definitions

The required temperature ranges of the required S/C powered thermistors are provided in section 4.4.2.3.

4.4.4 Temperature limits

Table 50 lists the qualification temperatures of the SIR-2 units which are based on the results given in [RD9] and [RD11].

Table 50 Qualification temperatures of SIR-2¹⁷.

| Unit | non-op min./max. temperature | op min./max. temperature |
|--|------------------------------|---------------------------|
| Sensor-Head/Radiator Unit (at Cooling Console) | -75 / +35°C | -70 / +30°C ¹⁸ |
| O-Box (structure) | -80 / +40°C | -60 / +30°C ¹⁹ |
| E-Box | -35°C / +55°C | -10°C / +55°C |

4.4.5 Thermal design requirements

See section 4.4.2.

4.4.6 Heater power requirement

The SIR-2 S/C heater requirement is:

- 9.39W for Sensor-Head/Radiator Unit
- 4.88W for O-Box

S/C heater protection is required during flight. The total time the heaters will be powered during a noon-midnight orbit will be less than during the dawn-dusk orbit.

4.4.7 Heat exchange budget

See [RD9]

4.4.8 Coatings

External surface finish (P)FM:

¹⁷ Info: the upgraded STM SHRU has been tested to more extreme temperatures than shown in this table.

¹⁸ Cooling console op temperature +30 °C for functional tests on-ground only. Typical inflight op temperature is lower than -40°C.

¹⁹ O-Box op temperature +30 °C for functional tests on-ground only. Typical inflight op temperature is less than -5°C. -80°C for simulation of lift-off phase.

- Sensor-Head/Radiator Unit:
 - All Al surfaces are coated with Iridite
 - Radiator upper surface is covered by OSR PS349
 - Cooling Band is coated with gold
 - Insulating supports and insulating feet are not coated

- O-Box:
 - All Al surfaces are protected with Iridite
 - Feet of O-Box are coated with blue Anodizing
 - Radiating area is painted with PCBE white conductive paint

- E-Box:
 - All Al surfaces, except bottom of E-Box, are painted black (ChemGlaze Z306)
 - Footprints and washer areas are free of paint (only Iridite protection)

4.4.9 SIR-2 TMM and analysis

The SIR-2 TMMs of the Sensor-Head/Radiator Unit and the O-Box as well as the thermal analysis of the instrument are detailed in [RD9].

4.5 Power supply

4.5.1 Power supply characteristics and design requirements

The instrument power supply delivers the following voltages:

1. +5.0V, 40mA minimum (ISU switched off), 100mA average/maximum, analogue rail, output ripples less than 10mVpp, output stability: line regulation +/-0.1%, load regulation +/-0.1%, to be used as main supply for ISU (60mA) and auxiliary supply in PSU (A/D converter in H/K block, 20mA) and ICU (Video A/D converter, 20mA).
2. +5.0V, 0.0mA minimum, 23mA average, 32mA maximum, digital rail, output ripples less than 40mVpp, output stability: line regulation +/-1%, load regulation +/-2.5%, to be used in ICU module
3. +3.3V, 25mA minimum, 70mA average, 450mA maximum in short peaks (2x160us per second), digital rail, output ripples less than 10mVpp, output stability: line regulation +/-0.1%, load regulation +/-0.25%, to be used in ICU module.
4. 1.5V, 58mA minimum, 130mA average/maximum for FM FPGA (65mA for EM FPGA), digital rail, output ripples less than 10mVpp, output stability: line regulation +/-0.1%, load regulation +/-0.5%, to be used in ICU module.
5. 0.0 to 1.6A current source, max. output voltage 2.7V, 4W max. to be dissipated in ISU (2.5V at 1.6A), 0.32W max. to be dissipated in harness (0.2V at 1.6A), programmable

in 8 bits, output ripples less than 10mVpp, to be used for Peltier Cooler supply in the detector and as a non-programmable source for the ISU heater.

6. +/-12V, 50mA maximum, analogue auxiliary rails to be used inside PSU HK, +12V, 10mA maximum, auxiliary rail to be used inside PSU DCDC.
7. +26V, almost zero current in average, to be used for switching on/off two bistable relays in ICU.

The power supply has separate (floating) returns for the analogue and digital electronics. Linear regulators and filters are used for the stabilization of the critical output voltages. The switching parts of the DC/DC converter and the EMC filter are located in completely electrically shielded compartments. For the layout care is taken to minimize the magnetic stray field generated in the DC/DC converter to avoid magnetic loops. Finally, pass-through filters are used between the "dirty" compartments and the rest of the electronics.

The first block, the EMC filter, consists of three systems: on/off, slow-start system and EMI filter. A self manufactured slow-start system is used to minimize the inrush current and to protect the relay contacts. The EMI filter is realized as a self manufactured construction and consists of typical inductances, resistors and capacitors network.

The DC/DC converter (see block diagram in Figure 42) is produced as a single switching DC/DC converter. It works in push-pull concept and uses two switching MOSFET transistors. The switching frequency is 131 kHz. The DC/DC converter has an over-current protection system implemented at the primary side. The magnetic feed-back loop is closed on +5V digital secondary line. The DC/DC converter provides 6 separate output rails. First one, with DGND reference, is used for 5V digital (stabilized by DC/DC feed back loop), 3.3V and 1.5V rails (both stabilized by low drop regulators). The same return line is used for 26V relay rail. The analogue +5V rail and the auxiliary +/-12V rails have a common analogue ground, AGND. The analogue +5V also uses a linear low drop regulator. Auxiliary rails use raw stabilized voltages. The Peltier cooler rail has a separate ground (connected to analogue return in one point in PSU). The raw voltage of Peltier cooler is specified to provide 3.0V to be used in serial, programmable current regulator in PSU (0-1.6A, 2.7V maximum) and also directly for heater in ISU. The transformer core, the switching MOSFETS and the output transistors used in linear regulators are thermally coupled with the chassis. 16 housekeeping lines are used for monitoring the DC/DC voltages, currents and SIR-2 temperatures. Housekeeping block (conditioning OPAMPS, multiplexer and 16-bit A/D converter) is a part of PSU block.

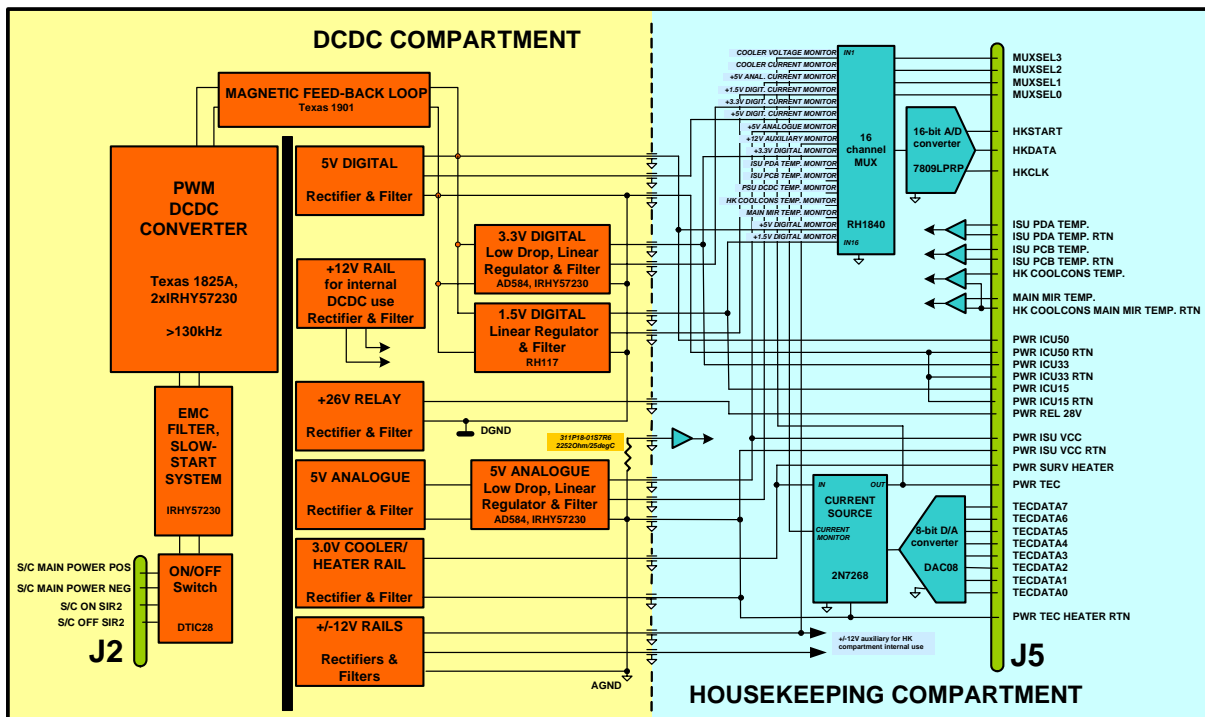


Figure 42 Block scheme of PSU block.

4.5.2 Initial electrical status

The power switching for the SIR-2 instrument is realized with a latching relay which is switched on/off by command from S/C. The initial electrical status of the instrument should always be “OFF”. This means that the power on sequence has always to send the “OFF” command in advance to switching on.

4.5.3 Power supply limitations

The spacecraft delivers the nominal primary rail in 35V-42V range. The SRC-made DCDC Converter is designed for nominal work in the range specified above.

4.5.4 Power interface requirements

The power interface includes the Primary Power and Primary RTN lines, ON CMD, OFF CMD and CMD RTN lines. The power interface, according to the proposal by ISRO, is shown in Figure 43.

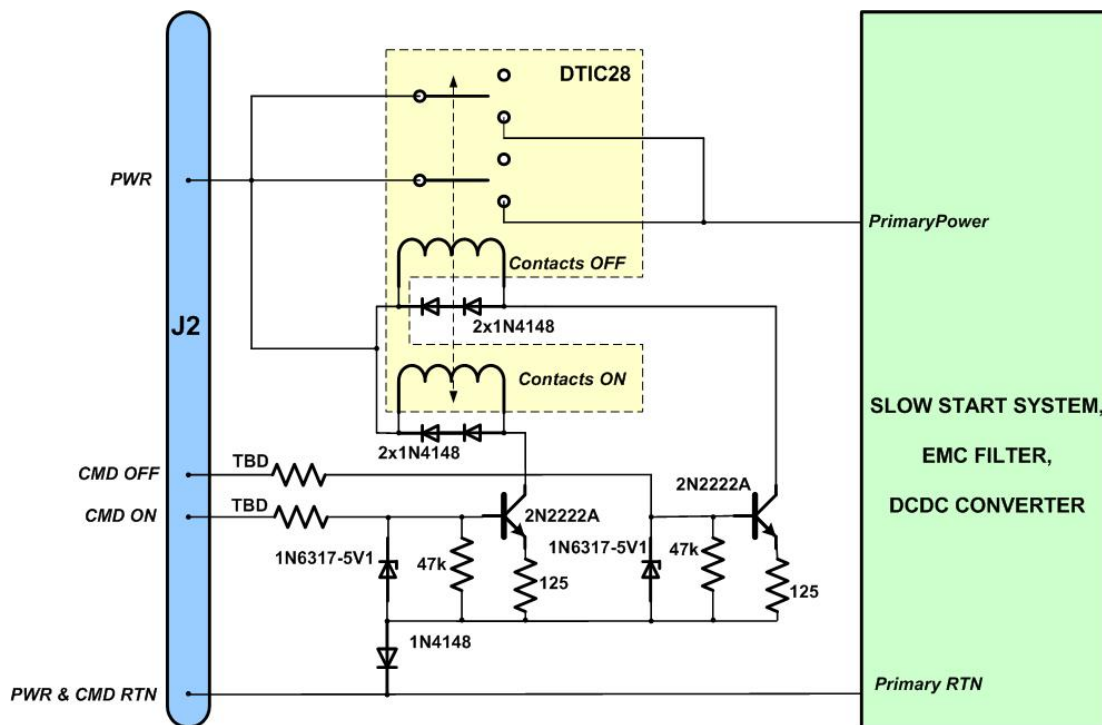


Figure 43 SIR-2 instrument power interface scheme.

4.5.5 Electrical interface characteristics

Power characteristics: input voltage 35-42V, maximum input current is 0.30A (at 35V) and 0.24A (at 42V); the inrush current is less than 1A/5ms.
 Command characteristics: see section 2.2.7.

4.6 On-Board data-handling

See section 2.2.5.

4.7 EMC requirements

DC/DC Converter characteristics are compliant to MIL-Std-461-E specification.

5 Development and verification

The purpose of this chapter (“Instrument Development and Verification Plan”) is to provide a description and a controlled identification of the instrument-level verification process which, when completed, will establish SIR-2 design compliance with design and interface requirements. The verification process encompasses activities at MPS and UoB as well as their suppliers. In addition, verification will be performed by interface tests at the spacecraft integration site. The compliance of SIR-2 to design and interface requirements is established by verification of the requirements in:

- Chandrayaan-1 Baseline Configuration Document
- C-1 Product Assurance Plan
- The present document (SIR-2 Interface Control Document)
- The Test procedures issue by MPS (based on various information from C-1, ISRO)

The goal of the verification process is to demonstrate the proper operational performance of SIR-2. The focus of the verification is summarized by the following key objectives:

- Meet all requirements given in the present document, C-1 Baseline Configuration Document and C-1 Product Assurance Plan.
- Verify each requirement prior to delivery by an appropriate test and/or analysis
- Verify requirements at the lowest, i.e. earliest, appropriate level of integration
- Confirm, by environmental test, the capability of the instrument to survive the thermal and dynamic environments to which the instrument will be exposed at launch and in flight
- Validate that operational procedures which place the instrument in known electrical, mechanical, and thermal conditions
- Confirm proper mechanical and command/data interfaces with the Chandrayaan-1 spacecraft
- Validate the SIR-2 scientific performance, i.e. calibrate and characterize SIR-2

The load levels of the environmental tests are specified in the respective test procedures.

Any requirement in the SIR-2 ICD and related documents that cannot be met shall be identified and documented through the MPS waiver process and submitted through the Chandrayaan-1 waiver process.

5.1 Model philosophy

5.1.1 General

The development of SIR-2 is based on the PFM approach. Mechanical qualifications and mechanical interface checks shall be performed by means of a structural model (STM)²⁰. A mass dummy (MD) of each SIR-2 unit was provided to C-1 ISRO in August 06 for mechanical interface and handling checks.

Electrical interface tests were performed with an electrical representative model (EEM) connected to a spacecraft interface simulator. In addition, for risk minimization reasons, the SIR-2 consortium does intend to build an FS model. Heritage from SIR (SMART-1) will be used during the development phase of SIR-2.

The SIR-2 consortium will deliver the following units to ISRO:

1. Mass Dummies of O-Box, Sensor-Head/Radiator Unit, and E-Box shall be used for fit checks and test harness routing only. The dummies will include a dummy fiber and a dummy ILH harness. The mass dummies will be representative to the PFM in mass, CoG, dimension, and mechanical I/Fs. Electrical dummy connectors will be commercial grade. The mass dummies are not usable for vibration tests.
2. EEM & EGSE – the EEM will be used to verify the proper functionality of the SIR-2 electronics design. It shall be used also for the spacecraft electrical bench tests at ISRO. The EEM is equipped with commercial grade electronics.
3. (P)FM – flight units (O-Box, Sensor-Head/Radiator Unit, E-Box, optical fiber, & supports, and local harness ILH)
4. FS – spare units (will be only delivered if replacement of PFM is required)
5. Sensor-Head purging device (on loan)
6. Stimuli lamp (on loan)

The S/C simulator has been delivered by ISRO in August 06.

²⁰ ISRO and ESA decided to skip the STM program. However, MPS has built an upgraded Sensor-Head/Radiator Unit STM, which can be seen as a QM that was used to verify the thermal, vibration and electrical performances.

5.2 Analysis and mathematical models

As a goal, all requirements are verified by test with the instrument configured as closely as possible to the flight configuration. There are instances where such a goal is unattainable and an analysis needs to replace the test.

5.2.1 Structural mathematical models and analyses

STM, PFM, and FS will undergo resonance search and vibration tests. However, a finite element analysis of the Sensor-Head/Radiator Unit and the O-Box was performed.

5.2.2 Thermal mathematical models, analysis and software

The importance of the SIR-2 TMM is given by the fact that O-Box and Sensor-Head/Radiator Unit are thermally insulated from the S/C structure. The SIR-2 TMM is detailed in [RD9].

5.3 Testing on unit level

5.3.1 General test requirements

Table 51 shows the experiment test matrix of SIR-2. Note that according to the model philosophy adopted, qualification of the H/W will be performed according the Proto Flight Model (PFM) approach. Test reports will be provided for each test.

Table 51 SIR-2 Experiment Test Matrix

| Test | (P)FM | FS | upgraded STM SHRU | EEMs | MD ²¹ |
|--|----------------|-----|----------------------|------|------------------|
| Physical properties (CoG, MoI, mass, dimensions) | x | x | x no MoI | --- | x no MoI |
| Functional Test | x | x | x | x | --- |
| Low level sine | x | x | x | --- | x |
| Shock | x, except SHRU | --- | Q | --- | --- |
| Sine vibration | Q/A 3) | A | Q/A | 1) | Q/A |
| Random vibration | Q/A 3) | A | Q/A | 1) | Q/A |
| Thermal balance | Q | A | Q | --- | --- |
| Thermal vacuum | Q | A | Q | --- | --- |
| Acoustic | on S/C level | --- | --- | --- | --- |
| Electrical tests (grounding, bonding, isolation) | x | x | (x) | x | --- |
| EMC | x | --- | x | x | --- |
| ESD | --- | --- | x | x | |
| Representative mechanics | x | x | x | (x) | 2) |
| Electrically functional | x | x | x | x | --- |
| Optics functional | x | x | limited | --- | --- |
| Optical alignment | x | x | --- | --- | --- |
| Calibration | x | (x) | --- | --- | --- |

MD: Mass Dummy, STM: Structural Thermal Model, EEM: Electrical Engineering Model
 PFM: Proto Flight Model, FS: Flight Spare
 Q: Qualification Level, A: Acceptance Level, Q/A: Qualification level in acceptance time for E-Box and O-Box
 x: required, ---: not required, 1) FPGA on dummy board vibrated, 2) except O-Box which has only representative I/F, 3) for SHRU: acceptance level

²¹ Only SH/R Unit MD testing is foreseen

5.3.2 Mechanical interfaces verification

Interfaces will be verified by measurement. SIR-2 Mass Dummies shall be used for mechanical fit checks at ISRO.

5.3.3 Mass properties verification

Mass properties verification will start on sub-unit level.

5.3.4 Electrical functional test requirements

Some test guidelines are given in [AD2]. Further tests are detailed in: “Report on Interface test between SIR-2 EM and BDH SIM at ISAC ISRO”, December 2006.

5.3.5 EMC test requirements

Testing will be performed according MIL-Std-461E. Further test constraints have been provided by C1 ISRO by e-mail (dating 21.2.07).

5.3.6 Thermal test requirements

All standard Q- and A-level tests will be performed in the new vacuum facility at MPS. The test procedures will be issued by MPS for verification by C-1 ISRO. Some test guidelines are given in [AD2]. C-1 ISRO announced that all FM thermal vacuum tests shall foresee 48 hours for instrument bake out.

5.3.7 Mechanical tests

SIR-2 is designed to withstand the levels provided in [AD2]. This document has been recently replaced by [AD3]. SIR-2 will be tested according [AD4] which refers to the “C-1 Spacecraft Project Environmental Level Specifications” document. Some additional agreements have been negotiated (see respective e-mail exchange).

5.3.8 System level acceptance program

SIR-2 follows the PFM approach.

5.3.9 Mechanism test program

SIR-2 does not have mechanisms.

5.3.10 Stimuli

MPS will provide a double stimuli lamp which shall be used to verify proper instrument operation on ground. The lamp needs to be mounted on a tripod in front of the SIR-2 O-Box aperture (dust protection foil of O-Box to be removed). The double halogen lamp is intended for use under cleanroom environment but not in vacuum (lamp would become too hot). The power consumption of the lamps at room temperature is 10W (line filter) and 10W (clear filter), respectively. Stimulation of SIR-2 during THVAC Test on S/C level is not foreseen.

5.4 Checkout plans (tests on S/C level)

5.4.1.1 SIR-2 integration on S/C (disassembled test phase)

The following task list shall be processed during instrument delivery and instrument integration:

1. Incoming Inspection at ISRO (visual inspection of deliverables, check of completeness etc.)
2. Verification of properties of units (mass, dimension, footprint etc.)
3. Electrical I/F tests with SIR-2 EGSE
4. SIR-2 integration on S/C
5. End-to-end test on S/C level
6. SIR-2 stimuli test (health and stimuli test by using the external stimuli lamps of SIR-2, see also section 5.3.10 and warning in 5.4.1.5)

The handling and integration procedure of SIR-2 is detailed in [AD6]. The performed electrical checks during the integration campaign are presented in [RD17].

5.4.1.2 Payload tests

5.4.1.2.1 Assembled test phase

The following items shall be verified:

1. Check TC by sending commands and monitor the health data (on both BMUs)
2. Check TM by commanding a series of “short exposures” - dark spectra -
3. Check the functionality of the optics by commanding a series of “short exposures” - light spectra (lamp stimuli) -
4. Check memory upload/dump

5.4.1.2.2 Combined test phase

The following item shall be verified:

1. Verify that the SIR-2 data transfer during the time of high bus traffic is nominal.

5.4.1.3 Purging of sensor-head

Re-purging of the SIR-2 Sensor-Head shall be performed in intervals of 2 months and after TV-testing. A purging procedure is outlined in [RD15].

5.4.1.4 THVAC test

The following preparations need to be performed before starting the THVAC Test:

- Verify the correct placement of the SIR-2 MLI blankets
- Remove the following red-tag items:

1. Venting-hole lock, located at the Sensor-Head's cap
2. Purging pipe or purging hole lock, located at the Sensor-Head's Quartz-Housing
3. O-Box aperture dust protection foil
4. O-Box alignment mirror dust protection foil
5. Sensor-Head Radiator cover
6. O-Box Radiator cover

The exact locations of the red tag items are shown in Figure 24 and Figure 32.

5.4.1.4.1 During thermo-VAC hot/cold cycles

1. Check temperature stabilization of SHRU by S/C heater control loop
2. Check temperature stabilization by Peltier Element and take a set of spectra

5.4.1.4.2 Thermo-VAC hot/cold soak

1. Hot soak: SIR-2 is OFF
2. Cold soak :
 - a. Check temperature stabilization by S/C heater control loop
 - b. Take a set of dark spectra while the Peltier Element is stabilizing the detector temperature.

5.4.1.4.3 Post Thermo-VAC ambient test

Perform a basic health test (short sequence of exposures without powering the Peltier Element)

After THVAC Test:

- Reinstall all red-tag items except venting and purging hole lock, which shall be reinstalled just after purging the Sensor-Head.

5.4.1.5 Vibration and acoustic test

Before vibration and acoustic tests:

- Determine the boresight orientation of SIR-2 with respect to the S/C coordinate system.

- Perform SIR-2 health and stimuli test²². **Warning: the Peltier Element (TEC) need to be OFF powered when powering SIR-2 under non-vacuum conditions. In case of an unaware detector cooling in air the detector gets damaged!**
- Remove the following red-tag items:
 1. Sensor-Head purging-pipe (if installed), protecting tape of purging hole to stay
 2. Sensor-Head Radiator cover
 3. O-Box Radiator cover

After vibration and acoustic tests:

- Reinstall all SIR-2 red tag items
- Perform SIR-2 health and stimuli test (possibly shifted to SP-1 phase). See also the above warning.

5.4.1.6 EMC test

During EMC testing on S/C level a SIR-2 functional test (see warning in section 5.4.1.5!) shall be performed in order to verify the data quality during EMC testing.

5.4.1.7 SP-1 phase

- Determine the boresight orientation of SIR-2 with respect to the S/C coordinate system (post vibration test inspection)
- Perform SIR-2 health and stimuli test (see also warning in section 5.4.1.5)

5.4.1.8 Pre-Launch phase

- Final SIR-2 MLI check
- Final red tag item removal

²² The stimuli test includes “light” spectra acquisition.

6 Instrument operations

6.1 Constraints for operating SIR-2

Warning! In ambient conditions the TEC (Peltier Element) must never be powered ON since this would damage the detector.

During flight SIR-2 shall be powered OFF on the following conditions:

1. If the angle between the optical axis and the Sun is less than 32° or
2. If the temperature of the cooling console is higher than $+14^\circ\text{C}$ or
3. If one of the HK data readings is outside the specified range (see section 6.4.1)

Sun avoidance shall be valid during flight for a cone at an angle of $\pm 4^\circ$ from SIR-2 boresight.

6.2 Overview of operating principles

Continuous acquisition of lunar surface spectra (mapping) will be performed by SIR-2 while the instrument is Nadir looking. The acquisition will take place during the time the S/C is above the illuminated surface as well as for limited durations on the night side (dark spectra).

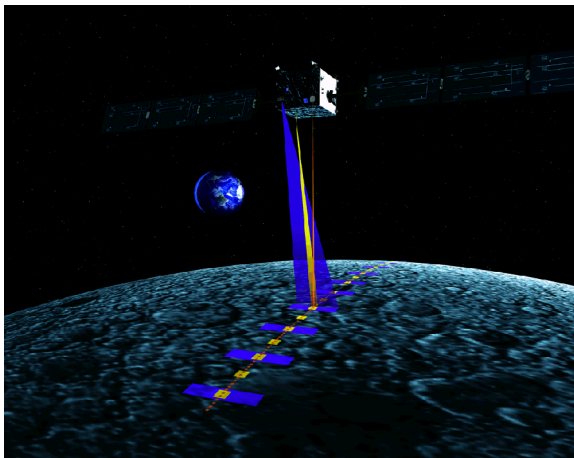


Figure 44 S/C in Nadir Pointing Mode while scanning across the lunar surface.

Regular calibrations of the SIR-2 spectrometer shall be performed according to [RD14]. In-flight calibration comprises pixel to wavelength verification by using the absorption bands of the earth atmosphere. The relative radiometric calibration is achieved by using the Apollo landing sites.

6.3 Nominal experiment operation plan

The first in-flight operation of SIR-2 shall take place after lunar orbit arrival. The instrument is powered in space for the first time and a pre-commissioning procedure is executed to check the health of the instrument. MPS requests to perform pre-commissioning in (nearly) real-time contact.

Instrument commissioning, including a first target pointing (Moon or/and Earth), shall be performed when the data of the pre-commissioning has been analyzed and the nominal performance of SIR-2 is confirmed. The commissioning procedure of SIR-2 is more complex than the pre-commissioning procedure and therefore requires more time. The time slot for SIR-2 pre-commissioning and commissioning is TBD.

After commissioning the instrument can be used for regular operations. During the first weeks of operation the verification of the SIR-2 boresight orientation in respect to the imaging experiments and the S/C coordinate system is of high priority. The planned approach is detailed in [RD14].

Regular calibration of SIR-2 shall be performed during the mission by observing the Apollo landing sites. Details of the SIR-2 inflight calibration are given in [RD14].

6.3.1 Pre-commissioning

During pre-commissioning we will start to verify the nominal operation of SIR-2 by analyzing the housekeeping information and the first set of dark spectra. Pre-commissioning of SIR-2 shall take place under standard “in lunar orbit” conditions (SIR-2 SHRU radiator $T \leq -30$ °C), i.e. in Nadir Pointing Mode.

Sequence (TBC):

- 1) Monitoring of the SIR-2 S/C thermistor temperatures and the SIR-2 S/C heater status to define the start time of the sequence.
- 2) Final verification whether the overall SIR-2 operation constraints are met.
- 3) Execute sequence “SIR-2_PWR_ON.tm” – SIR-2 switch ON (Nominal) –
- 4) Monitor SIR-2 quick look and IHDM data²³
- 5) Execute sequence “SIR-2_PWR_OFF.tm” – SIR-2 switch OFF –
- 6) Display IHDM data with GSEOS and check values
- 7) Execute “SIR-2_PWR_ON.tm” – SIR-2 switch ON (Nominal) –
- 8) Execute Pre_Commissioning_1 sequence²⁴

²³ It needs to be verified whether the complete IHDM data can be displayed during pre-commissioning.

²⁴ The pre-commissioning procedure will be further detailed in a separate document.

9) Execute sequence “SIR-2_PWR_OFF.tm” – SIR switch OFF (Nominal) –

10) Downlink of SIR-2 data from S/C

11) Analysis of data

12) End of pre-commissioning

Expected duration for sequence 3) to 9): ~ 3 h

6.3.2 Commissioning

The commissioning procedure comprises Nadir observations of the lunar surface and celestial target pointing (e.g., Earth).

Sequence (TBC):

- 1) Monitoring of the SIR-2 S/C thermistor temperatures and the SIR-2 S/C heater ON/OFF status to define the start time of the sequence.
- 2) Final verification whether the overall SIR-2 operation constraints are met
- 3) Execute sequence “SIR-2_PWR_ON.tm” – SIR-2 switch ON (Nominal) –
- 4) Monitor SIR-2 quick look and IHDM data (in case of real time contact only)
- 5) Display IHDM data with GSEOS and check values
- 6) Perform test sequence with a continuous scan of the lunar surface for TBD minutes, perform scanning until the terminator has been crossed (dark spectra acquisition)
- 7) Repeat scan with different instrument parameter settings
- 8) Execute sequence “SIR-2_PWR_OFF.tm” – SIR-2 switch OFF (Nominal) –
- 9) Execute sequence “SIR-2_PWR_ON.tm” – SIR-2 switch ON (Nominal) –
- 10) Monitor SIR-2 quick look and IHDM data
- 11) Point SIR-2 to the almost fully illuminated Earth
- 12) Obtain a set of spectra for wavelength to pixel verification
- 13) Execute sequence “SIR-2_PWR_OFF.tm” – SIR-2 switch OFF (Nominal) –
- 14) Downlink of SIR-2 data

Nadir pointing is needed for steps 6) to 10). Identify orbit segments where the footprint crosses the lunar terminator. Start measuring several minutes before the terminator is reached and extent the observation to the dark site.

The commissioning procedure will take about 12 hours.

6.3.3 Science phase

The nominal science operation of SIR-2 shall start after the successful commissioning of SIR-2. During the two-years long lunar science phase the main S/C attitude mode is Nadir. In this mode SIR-2 will continuously take spectra (Measurement Mode), i.e. spectra acquisition starts a few minutes before crossing the lunar terminator from dark to lit side until a few minutes after leaving the illuminated side. A limited number of spectra (dark spectra acquisitions) are also obtained during the time the S/C is on the dark side.

During some orbits we will request slight off-nadir-pointing to dedicated lunar sites (targets of special interest: e.g., lunar landing sites for calibration purposes and scientific targets). A number of scientific interesting targets are listed in Basilevsky et al. 2004 (Planetary and Space Science, Vol. 52, p. 1261-1285). In addition, we will request at least one celestial target pointing to verify the radiometric calibration of the instrument.

SIR-2 operation is not restricted to the best illumination conditions of the surface (noon-midnight orbits), i.e. observations close to the dawn-dusk phase are reasonable.

6.3.4 In-flight calibration

In-flight calibration of SIR-2 is detailed in [RD14].

6.4 Failure detection and recovery strategy

In case of failure detection the instrument shall be powered OFF. The recovery strategy depends on the type of failure and needs involvement of the SIR-2 project team.

6.4.1 Recognize failures by TM

Failures of SIR-2 can be recognized by monitoring the SIR-2 IHDM messages or the quick look data. Table 52 lists the IHDM TM parameters as well as the nominal range of each parameter.

Table 52 IHDM TM information and nominal temperature range during flight.

| | HK parameter | Nominal range during operation |
|----|--|--|
| 1 | ISU photodiode array temperature | Stabilized at -50°C/-60°C (TBC) allowed range: -65°C to -20°C |
| 2 | Cooling Console temperature | Stabilized; allowed range: -65°C to -20°C |
| 3 | Quartz-body temperature | Stabilized; allowed range: -40°C to -10°C |
| 4 | ISU PCB temperature | Range: -55°C to -20°C |
| 5 | PSU PCB temperature | Range: -20°C to +70°C |
| 6 | TEC current and voltage | TEC Voltage Range: 0 to 1.7V TEC Current Range : 0 to 2500mA |
| 7 | Voltage monitoring 5V digital and analog | 5V dig: Range 5.2 +-0.25V 5V analog: Range 5.0 +-0.25V |
| 8 | Voltage monitoring 3.3V and 1.5V | Voltage 3.3V:3.3+-0.2V Voltage 1.5V:1.5 +-0.2V |
| 9 | Current monitoring 5V digital and analog | Current 5V dig : 0.5 to 10 mA Current 5V analog: 0 to 10mA |
| 10 | Current monitoring 3.3V and 1.5V | Current 3.3V: 25 to 35mA Current 1.5V: 180 to 280mA |
| 11 | HK clock timestamp MSW | not used |
| 12 | HK clock timestamp LSW | not used |
| 13 | CPU related tasks 1 | Time of error – default =0 |
| 14 | CPU related tasks 2 | Error Flag, default =0 |

The following IHDM TM data shall be used as quick look information. Quick look data shall be continuously monitored by the ground segment.

Table 53 SIR-2 quick look data.

| | HK parameter | Nominal range during operation |
|----|----------------------------------|--|
| 1 | ISU photodiode array temperature | Stabilized at -50°C/-60°C (TBC) allowed range: -65°C to -20°C |
| 2 | Cooling Console temperature | Stabilized; allowed range: -65°C to -20°C |
| 5 | PSU PCB temperature | Range: -20°C to +70°C |
| 6 | TEC current and voltage | TEC Voltage Range: 0 to 1.7V TEC Current Range : 0 to 2500mA |
| 8 | Voltage monitoring 3.3V and 1.5V | Voltage 3.3V:3.3+-0.2V Voltage 1.5V:1.5 +-0.2V |
| 10 | Current monitoring 3.3V and 1.5V | Current 3.3V: 25 to 35mA Current 1.5V: 180 to 280mA |

S/C telemetry data: The SIR-2 team requests to get access to some S/C quick look data. Of special interest are:

- Temperature measured by the SIR-2 S/C powered thermistors (see Table 54)
- Temperature of the ASS-panel
- Temperature of the ASS extension panel
- ON/OFF status of the instrument²⁵
- ON/OFF status of the SIR-2 S/C powered heaters

Table 54 Nominal temperature range of SIR-2 S/C powered thermistors during lunar orbit. The limits need to be verified during pre-commissioning and commissioning.

| Temperature Sensors | Nominal Range during operation | Nominal Range during non-operation |
|---------------------------------------|---------------------------------------|---|
| No. 36, SHRU, internal of Sensor-Head | -65°C to -20°C | -65°C to +10°C |
| No. 37, SHRU, on heater plate | -65°C to -20°C (TBC) | -65°C to +10°C (TBC) |
| No. 38, SHRU, on radiator | -80°C to -20°C | -80°C to +10°C |
| No. 39, SHRU, on Sensor-Head Housing | -40°C to -20°C | -40°C to +10°C |
| No. 40, O-Box | -60°C to +10°C | -60°C to +10°C |
| No. 98, next to E-Box on ASS-panel | -5°C to +50°C | -30°C to +50°C |

6.4.2 What to do after failure detection?

1. Power SIR-2 OFF if one of the SIR-2 quick look data is out of range (see Table 53).
2. Power SIR-2 OFF if one of the temperatures is out of range (see Table 54).
3. Inform SIR-2 project team about failure (Tel. +49 5556 359 or 433 or 152)

²⁵ According to information from C-1 ISRO the onboard current consumption of SIR-2 cannot be measured.

6.5 Summary of telecommands

Table 55 presents an overview of the SIR-2 telecommands. A detailed description of the commands and instrument parameters is given in 2.2.7.

Table 55 List of SIR-2 commands.

| Type 1 commands | description |
|--------------------|--------------------------------------|
| STBY_MODE | Goto standby mode |
| PREP_MODE | Go to preparation mode |
| MEAS_MODE | Go to measurement mode |
| SET_PARAM | Configure an instrument parameter |
| RESET | Reset instrument to default settings |
| Type 2 commands | description |
| MEM_UP_T2 | Perform memory upload |
| MEM_DUMP_T2 | Perform memory download |
| Safe mode commands | description |
| SAFE_MEM_UP | Perform memory upload in safe mode |
| MEM_COPY | Copy EEPROM to RAM |
| RAM_START | Start execution from start of RAM |

6.6 List of dangerous operations

The following operations must be avoided:

- Switching SIR-2 from Standby Mode to Preparation or Measurement Mode when the ISU temperature is below -55°C.
- In ambient environment it has to be ensured that the Peltier Element (TEC) is not powered since the powering would damage the detector.
- During operation of the Peltier Element (TEC) it has to be ensured that the detector stays within the temperature limits.
- Strong heating (more than 5°C) of the detector by using the Peltier Element (TEC) shall be avoided.

6.7 Instrument temperature control

The SHRU S/C powered heaters are foreseen to be used to:

1. ensure that the SHRU does not fall below the lower acceptance limit temperature during flight
2. minimize the temperature cycling of the SHRU during the time the instrument is operating in lunar orbit

The temperature of the SIR-2 detector is stabilized by an SIR-2 internal control loop. In order to achieve a sufficient thermal stabilization the SHRU needs to be powered continuously, i.e. also during the time the S/C is on the night side.

The O-Box S/C powered heaters are required to ensure that the O-Box does not fall below the lower acceptance limit temperature during flight.

6.7.1 ON/OFF limits of the SIR-2 S/C heaters during flight

- Sensor-Head/Radiator Unit:
 - During the THVAC Test on S/C level:
 - The ON/OFF limits -42°C/-40°C (TBC) shall be used.
 - In-flight:
 - In case the SHRU is OFF: the ON/OFF limits -10°C/-5°C (TBC) shall be used to guarantee that the S/C heaters are continuously powered (also when the S/C is in the lunar transfer phase).
 - In case the SHRU is ON: the ON/OFF limits shall be set to TBD.²⁶

Important note: the SHRU ON/OFF limits are only valid for the main heater control loop. The redundant heater control loop needs to be calibrated during the THVAC Test.

- O-Box:
 - The heater line shall be activated once the temperature is less than -55°C (TBC). The heater line shall be switched off as soon as the temperature is higher than -53°C (TBC).

It is important to note that the ON/OFF limits need to be confirmed/verified during THVAC test on S/C level.

6.8 SIR-2 command database

The reader is referred to [RD18].

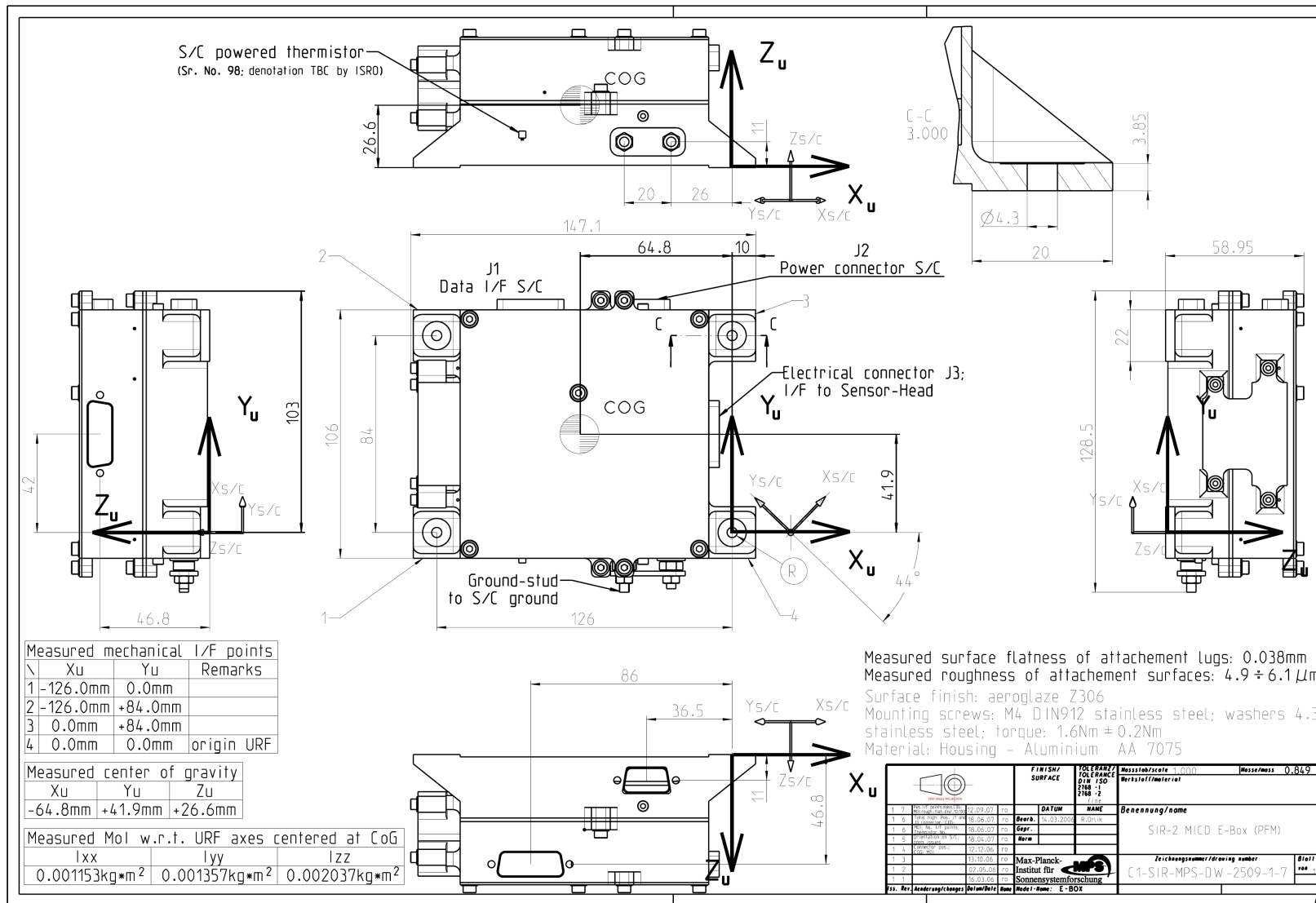
²⁶ The limits will be defined after lunar orbit arrival when the exact thermal behavior of the instrument is known.

7 Product assurance and safety plan

See separate SIR-2 Product Assurance and Safety Plan.

8 Appendix

Figure 47 MICD drawing of SIR-2 E-Box.



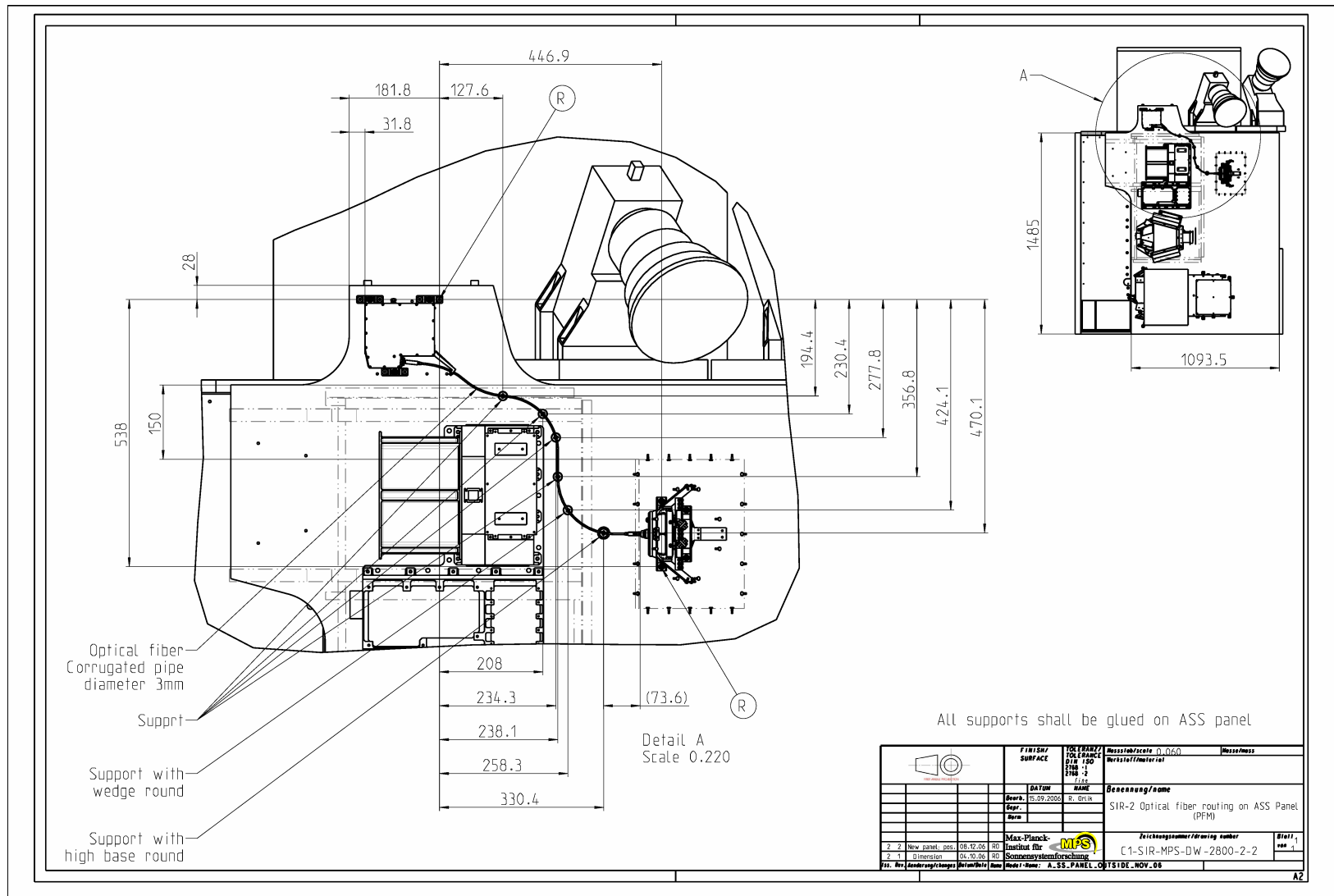


Figure 48
SIR-2 fiber
routing
between O-
Box and
Sensor-
Head/Radiat
or Unit.

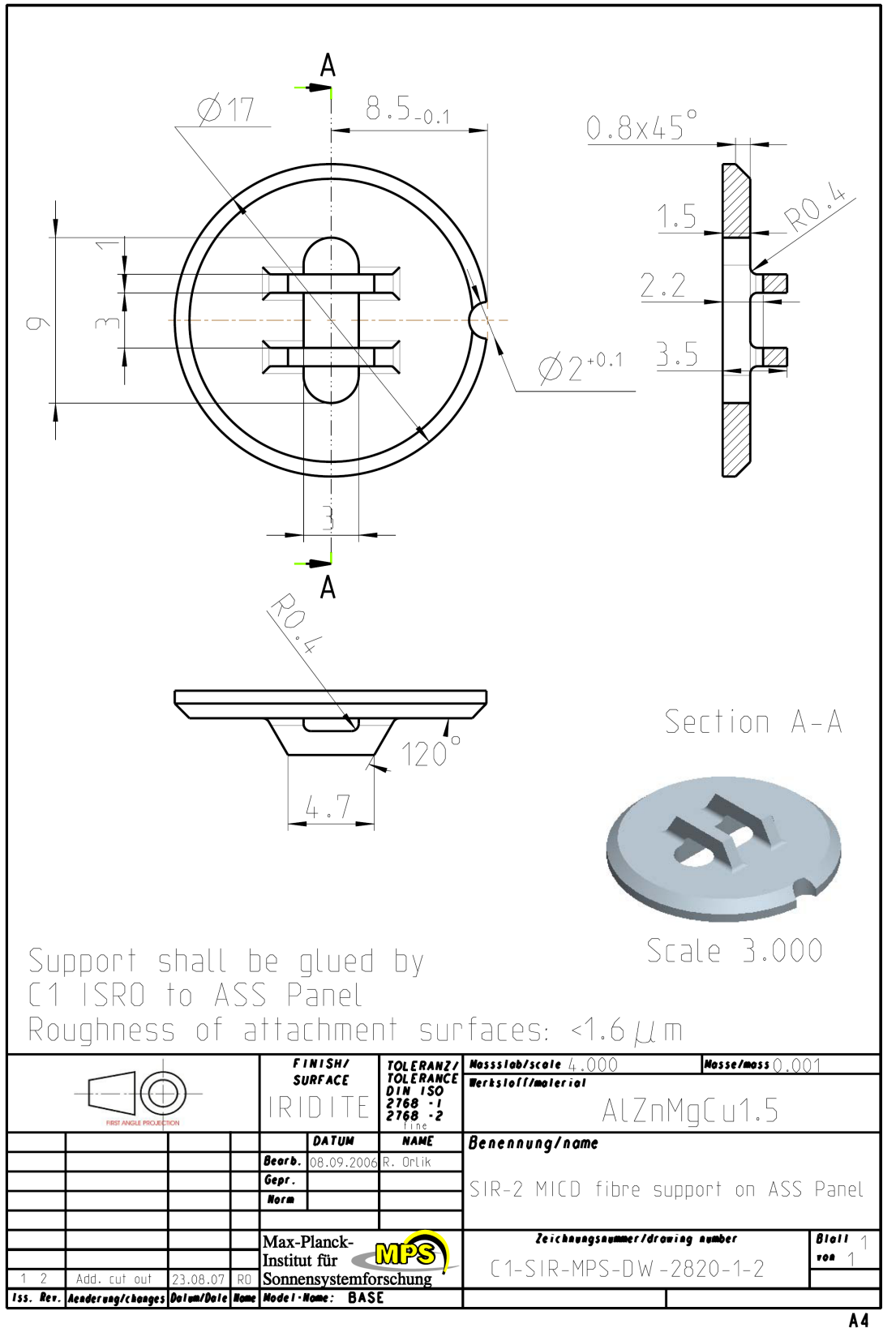


Figure 49 MICD of optical fiber support on ASS panel (named “Support” in Figure 48).

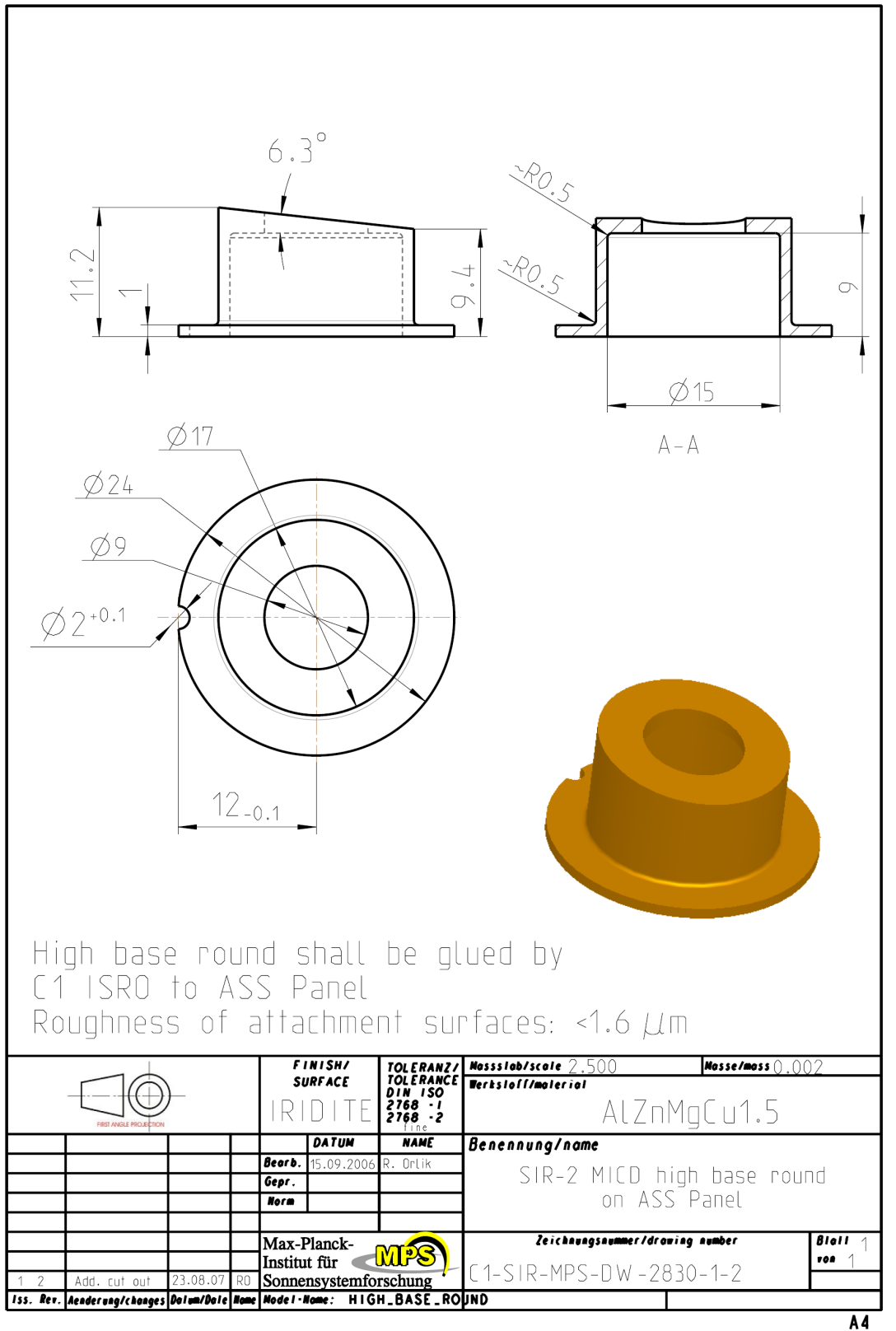


Figure 50 MICD of optical fiber support on ASS panel (named “Support with high base round” in Figure 48).

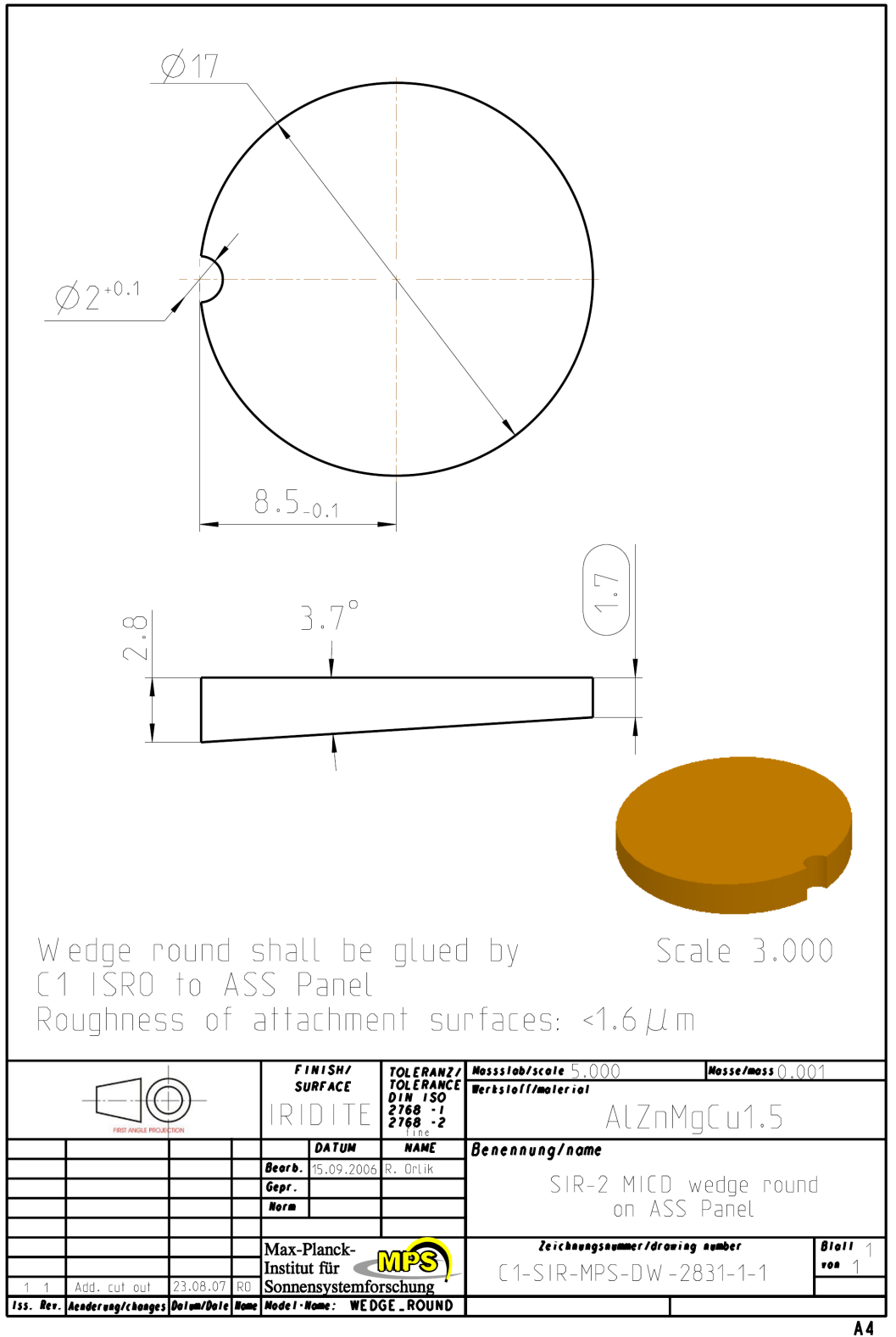


Figure 51 MICD of optical fiber support on ASS panel (named “Support with wedge round” in Figure 48).