AATSR

INSTRUMENT PERFORMANCE REQUIREMENTS FOR THE ADVANCED ALONG-TRACK SCANNING RADIOMETER

Abstract: This document describes the instrument performance requirements for the Advanced Along-Track Scanning Radiometer (AATSR). These have been generated from the high level scientific requirements for the AATSR.

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AMENDMENT POLICY

This document shall be amended by releasing a new edition of the document in its entirety. The Amendment Record Sheet below records the history and issue status of this document.

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ISSUE	DATE	DCR No	REASON
A	27 Apr 94	N/A	First draft
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1. INTRODUCTION

1.1. Purpose and Scope

This document interprets the high level AATSR science requirements into performance requirements for the instrument. This document, together with the ENVISAT requirements, is the requirement document from which the AATSR System Design Specification is derived.

Requirements from the AATSR science requirements document have been collated together to form five major sets of instrument performance requirements.

1.2. Structure of the Document

After this introduction, the document is divided into a number of major sections which are briefly described below:

2. General Instrument Requirements

This section defines a number of high level performance requirements for AATSR.

3. Spectral Channel Requirements

This section defines the spectral response requirements for AATSR.

4. Radiometric Performance Requirements

The radiometric performance requirements for the AATSR signal channels are defined in this section.

5. Viewing Geometry Requirements

The viewing geometry requirements for AATSR are defined in this section.

6. Calibration Requirements

The requirements for instrument calibration, both prior to launch and in-orbit, are defined.

GLOSSARY

The Glossary contains definitions of acronyms, abbreviations and terms used throughout the document.

1.3. Referenced Documents

The following is a list of documents with a direct bearing on the content of this report. Where referenced in the text, these are identified as RD.n, where 'n' is the number in the list below:

1.	AATSR Scientific Requirements	PO-RS-GAD-AT-0001
2.	AATSR Data Processing Requirements	PO-RS-GAD-AT-0003

1.4. Definition of Terms

Thermal channels are defined as those which measure emitted thermal radiation (and which can be used to measure Sea Surface Temperature (SST)). The thermal section of the electromagnetic spectrum is usually defined as having a wavelength greater than 3.0μm.

Reflection channels are defined as those which measure reflected solar radiation (and which can be used to measure land surface reflectance). The Visible and Near Infra-Red (VNIR) section of the electromagnetic spectrum is usually defined as having a wavelength range between 0.4μm and 2.0μm, and includes the AATSR reflection channels.

The **Instantaneous Field of View** (IFOV) is defined as the solid angle over which an optical system is sensitive to incoming radiation at an instant in time. The IFOV, for the purposes of this document, is taken to be defined by an optical field stop. Optical effects such as diffraction and defocusing are excluded from this definition of the IFOV.

The **Point Spread Function** (PSF) is the continuous image produced by an instrument observing an object of vanishingly small dimensions, but whose area-integrated intensity is finite. An object scene can be split up conceptually into a large number of adjacent impulses: the image scene will then be observed as a scene where each of the impulses is replaced by the PSF – the image-scene is the object-scene convolved with the PSF.

2. GENERAL INSTRUMENT REQUIREMENTS

A few very general instrument performance requirements can be stated in this section. These are based on the requirements in [RD.1] for a global, high accuracy SST data set ([R01/001]), which is to be continued by AATSR from previous ATSR missions ([R01/004]) and the requirement for continuation of the land surface reflectance measurements from ATSR-2 ([R01/023]).

2.1. Longevity Requirement

The AATSR instrument must be designed to operate for a four year nominal lifetime and to provide measurement data which still meet the scientific requirements in [RD.1] at the end of the four years. The scientific requirements in [RD.1] can be achieved by meeting the specific performance requirements described in this document throughout the four years. Note that the ENVISAT-1 mission requirements assume that ENVISAT-1 will be operated for a minimum of five years following launch.

[R02/001] **AATSR shall be designed to operate in measurement mode (i.e. providing measurement data) for a four year nominal lifetime and to meet the performance requirements throughout the four years.**

2.2. Design Heritage Requirements

The AATSR design must carry forward the experience gained with ATSR-1 and ATSR-2, in both science and in engineering, but improvements over the ATSR-1 and -2 designs shall also be considered where they enhance the scientific potential of the instrument. The performance of AATSR must at least match that of ATSR-1 and -2

[R02/002] **The AATSR design shall carry forward experience gained with previous ATSR missions.**

[R02/003] **Improvements in the AATSR design over the ATSR-1 and ATSR-2 designs shall be considered where they would enhance the scientific potential of the instrument.**

[R02/004] **AATSR shall at least match the performance of ATSR-1 and ATSR-2.**

2.3. Scientific Priorities

AATSR's primary scientific goals are for global SST measurements, continuing the ATSR-1 and ATSR-2 data set, ([R01/001] and [R01/002]), with land remote sensing forming a lower scientific priority ([R01/025]). Hence, the design of AATSR must reflect this, with no degradation from the SST retrieval performance of ATSR-1 being acceptable due to additional features of later ATSRs ([R01/025]).

[R02/005] **The design of AATSR shall take into account the scientific priority for SST retrieval over other scientific interests.**

2.4. Assessment of Waivers

If any performance waivers are requested during the development of AATSR, an assessment of how they affect scientific requirements must be made. This activity will, where necessary, involve the AATSR Science Advisory Group.

[R02/006] **For any AATSR performance waiver requests, an assessment of how they affect scientific requirements shall be made, which will, where necessary, be carried out with the assistance of the AATSR Science Advisory Group.**

2.5. Cleanliness Requirements

The instrument must be designed, assembled, integrated and tested with due regard to cleanliness such that performance is not compromised by contamination of optical surfaces.

The Prime Contractor shall be fully responsible for cleanliness of the instrument up to delivery. The Prime Contractor shall ensure protective measures adequate to meet the EOL cleanliness requirement within the post-delivery environment defined by ESA.

Total molecular contamination (at EOL) on the optics shall introduce no more than 20% broad-band absorption into any of the AATSR channels or system losses due to spectral features or absorption lines of greater than 5% of the peak channel transmission into the thermal channels.

[R02/077] **The total molecular contamination (at EOL) on the optics shall be limited such that it introduces no more than 20% broad-band absorption into any of the AATSR channels or system losses due to spectral features or absorption lines of greater than 5% of the peak channel transmission into the thermal channels, by controlling contamination levels up to instrument delivery and ensuring adequate protective measures for the post-delivery environment defined by ESA.**

The total (at EOL) particulate contamination on optical surfaces shall be less than or equal to 1232 ppm.

[R02/078] **The total particulate contamination on optical surfaces (at EOL) shall be limited to a maximum of 1232 ppm, by controlling contamination levels up to instrument delivery and ensuring adequate protective measures for the post-delivery environment defined by ESA.**

3. SPECTRAL CHANNEL REQUIREMENTS

Using [RD.1] as input, and collecting together the requirements for SST and vegetation monitoring, the spectral channel requirements can be defined.

3.1. Channel Responses

From the scientific requirements for SST and land surface mapping described in [RD.1], the channel responses required for AATSR have been derived.

AATSR is required to provide measurements of radiances in the thermal infrared (TIR) ([R01/006]), so that SST can be estimated. A requirement for building on previous work using AVHRR leads to similarities in the thermal channels ([R01/009]). Requirements for cloud clearing lead to the incorporation of a further reflection channel for the SST measurements ([R01/012]). ATSR-2 serves as a model for the additional reflection channels ([R01/024]) for land remote sensing.

[R02/007] The AATSR signal channel end-to-end response characteristics shall be as defined in the table below.

Table 3.1.1: AATSR Signal Channel Characteristics

Channel	Centre wavelength	50% of peak	Error on 50% points	Slope 5%-80%	<1% of peak
0.55µm	0.555µm	0.545 - 0.565µm	±0.003µm	<0.008µm	0.530 - 0.580µm
0.66µm	0.659µm	0.649 - 0.669µm	±0.003µm	<0.008µm	0.634 - 0.684µm
0.87µm	0.865µm	0.855 - 0.875µm	±0.003µm	<0.008µm	0.840 - 0.890µm
1.6µm	1.61µm	1.58 - 1.64µm	+0.01µm -0.04µm	<0.30µm	1.52 - 1.70µm
3.7µm	3.70µm	3.55 - 3.93µm	±0.06µm	<0.12µm	3.40 - 4.12µm
11µm	10.85µm	10.40 - 11.30µm	±0.09µm	<0.34µm	9.80 - 11.90µm
12µm	12.00µm	11.50 - 12.50µm	±0.09µm	<0.37µm	10.90 - 13.10µm

Continuity of channel responses with previous ATSR missions is also a scientific requirement ([R01/004] and [R01/024]), based on the need for a long-term consistent data set.

[R02/008] For continuity of the SST dataset commenced with ATSR-1 and ATSR-2, the 1.6µm, 3.7µm, 11µm and 12µm channels shall have as similar a spectral shape as practicable to those on ATSR-1 and ATSR-2.

[R02/009] **For continuity of the land surface reflectance dataset from ATSR-2, the 0.55μm, 0.66μm and 0.87μm channels shall have as similar a spectral shape as practicable to those on ATSR-2.**

The exact channel responses need to be accurately known, to model the radiances measured by the instrument in terms of geophysical quantities.

[R02/010] **The spectral responses of AATSR's channels shall be known before flight to 5% of their peak response at any wavelength.**

3.2. Blocking Requirements

In order to retrieve geophysical parameters with adequate sensitivity and accuracy from radiance, the measurements must not be contaminated by out of band signals ([R01/001], [R01/002] and [R01/023]).

[R02/011] **The peak out of band response for each of the channels specified in [R02/007] shall be less than 10^{-4} of the peak in-band response.**

[R02/012] **The out of band response for each of the channels specified in [R02/007] shall contribute less than 1 part in 4095 of the total signal integrated over wavelength.**

3.3. Polarisation

To accurately model the retrieval of geophysical parameters from measurements of radiance, the instrument responsivity must not be significantly affected by the polarisation of the radiance, and any responsivity variation must be known ([R01/001], [R01/002] and [R01/023]).

[R02/013] **The difference in responsivity between any two orthogonal polarisations shall not be more than 4% for the thermal channels and 6% for the reflection channels.**

[R02/014] **For all channels, the responsivity variation with plane of polarisation shall be known to better than 0.5%.**

3.4. Visible Channel Edge Tolerances

From experience gained during the ATSR-2 programme, it is understood that for the 0.55μm, 0.66μm and 0.87μm channels, the tolerances of the half power points specified in [R02/007] are not independent for each edge. In order to meet the requirements in [R02/007] for spectral width, a further performance requirement is necessary.

[R02/015] **The difference between the half power points (i.e. the width) for the 0.55μm, 0.66μm and 0.87μm channels shall be 20 nm, tolerance -0/+2 nm.**

4. RADIOMETRIC PERFORMANCE REQUIREMENTS

4.1. Dynamic Range and Noise Performance

From the scientific requirements for SST and land surface mapping described in [RD.1], the dynamic range and noise performance required for the AATSR channels have been derived.

For the thermal channels, [R01/001] and [R01/002] provide the ultimate requirement for the noise performance. [R01/015] places a requirement on the range over which AATSR is expected to accurately measure SST. For the reflection channels, [R01/032] provides the requirement on noise performance, and [R01/029] and [R01/030] define the measurement range.

[R02/016] The dynamic range and noise performance for a single calibrated AATSR sample shall be as defined in the table below.

Table 4.1.1: Dynamic Range and Noise Performance for a Single Calibrated AATSR Sample

Channel	Nominal working range	NEΔT at 270K	S/N at 0.5% albedo
0.55μm	0 - 50 mW cm^{-2} μm^{-1} sr^{-1}	N/A	20:1
0.66μm	0 - 45 mW cm^{-2} μm^{-1} sr^{-1}	N/A	20:1
0.87μm	0 - 30 mW cm^{-2} μm^{-1} sr^{-1}	N/A	20:1
1.6μm	0 - 7 mW cm^{-2} μm^{-1} sr^{-1}	N/A	20:1
3.7μm	0 - 311K	0.08K	N/A
11μm	200 - 321K	0.05K	N/A
12μm	200 - 318K	0.05K	N/A

To meet the requirements on the range and noise performance for the thermal channels, the digitisation requirement can be derived. If the digitisation interval is assumed to be of a similar magnitude to the NEΔT, then combining the wide temperature range of the 3.7μm channel with its required NEΔT, 12 bit digitisation is necessary. Similarly for the other thermal channels, although they have a smaller NE ΔT and smaller temperature range, 12 bit digitisation is again necessary.

If the digitisation noise is also assumed to be the main source of noise for the reflection channels, then a requirement for the digitisation interval can be derived. As stated in [R01/029] and [R01/030], the working range for the reflection channels is taken as zero spectral radiance to radiance representing 100% spectral albedo.

[R01/032] states that the reflection channels' signal to noise ratio shall be 20:1 at 0.5% spectral albedo. Therefore, 12 bit digitisation is required.

[R02/017] All AATSR channels shall have 12 bit digitisation.

In order not to introduce excessive noise into the thermal channels from emissions from viewed parts of the instrument (e.g. mirror stop), a requirement on the maximum temperature of the instrument enclosure can be defined. The maximum temperature of the instrument enclosure must be lower than the minimum expected top of atmosphere SST range, which is 265K. However, there is no advantage in cooling the instrument enclosure to a very much lower temperature.

The range of temperatures for the instrument enclosure, throughout the mission, needs to be 260±5K. Applying knowledge of the differences between actual in-orbit temperatures and model design cases gained from the ATSR-1 prgramme, this temperature range will be achieved by designing for a Beginning of Life (BOL) temperature range of 248–253K.

[R02/018] The AATSR instrument enclosure shall have an operating temperature range throughout the mission of 260±5K, which will be achieved by designing for a BOL temperature range of 248–253K.

4.1.1. Auto Gain/Offset

In order to meet the noise performance requirement for the thermal channels in [R02/016], AATSR needs to extract the maximum performance from each channel's detector/preamplifier combination, by maximising the radiance measurement precision. In order to achieve this, AATSR must include a system to automatically optimise the signal channel offsets for all channels, with the gain of the thermal channels also to be automatically optimised. The gain and offset for all channels should be set up using the onboard calibration systems.

[R02/019] AATSR shall include a system to maximise the radiance measurement precision, by automatically optimising the signal channel offsets for all channels and automatically optimising the signal channel gains for the thermal channels.

The auto gain (on thermal channels only) and auto offset facilities need to be independently controllable on each of the signal channels. Also, the time over which the system gathers data before making any changes to gain or offset settings must be selectable in flight.

[R02/020] Automatic signal gain (on thermal channels only) and offset optimisation shall be independently enabled and disabled for each channel.

[R02/021] **The time between adjustments to gain (on thermal channels only) and offset made by the auto gain/offset system shall be selectable in flight.**

AATSR will receive information in the form of blanking pulses from ENVISAT's active radar instruments to indicate when they are transmitting. The automatic gain/offset system must use these blanking pulses to discard signal data which are potentially corrupted by EMI from radar instruments.

[R02/022] **The automatic signal gain (on thermal channels only) and offset optimisation system shall not include samples which are potentially corrupted by EMI from radar instruments as indicated by blanking pulses.**

4.1.2. Extended Range Switching

In order that AATSR shall be able to measure the total radiance of exceptionally hot pixels, some means of reducing the gains of the main thermal channels (11µm and 12 µm) must be incorporated, so as to prevent saturation. The implementation of extended range switching will be a duplication of that for "forest fire" mode on ATSR-2.

[R02/023] **Channel gains for the AATSR 11µm and 12µm channels shall be selectable so that the radiance (up to a maximum equivalent to 500°C) from exceptionally hot pixels can be measured.**

Extended range switching must not disrupt the main SST goals of AATSR. It must only be a temporary mode in which the instrument operates, for a selectable number of scans, which is not renewable during operation in this mode.

[R02/024] **Extended range shall only be commandable with a number representing the number of scans over which it is to be used, up to a maximum of 1024.**

[R02/025] **Extended range shall not be renewable during its operation period.**

4.2. Direct View of Sun

AATSR's signal channels, in order to meet the goals of a long term data set [R01/003], must not be damaged by direct viewing of sunlight (for example, from sunglint or through platform manoeuvres).

[R02/026] **None of AATSR's channels shall be damaged by direct viewing of the sun.**

5. VIEWING GEOMETRY REQUIREMENTS

From the requirement for a dual angle sea surface view, to enable better atmospheric correction ([R01/008]), AATSR must employ a single instrument IFOV for all channels, which is scanned continuously around a cone. All the channels shall use the same fore-optics, and the channel IFOVs shall be bore-sighted to a first approximation by the use of the same field stop, to reduce errors in channel co-alignment (to meet [R01/014]).

[R02/027] **The AATSR scan cone angle shall employ a single instrument IFOV, which is scanned continuously around a cone.**

[R02/028] **The AATSR channels shall use the same fore-optics and the same field stop.**

The angle of the cone is chosen by reference to [R01/008] and modelling of the upwelling radiances.

[R02/029] **The AATSR scan cone angle shall be 46.90° (tolerance ±1.0 arc minutes), with one cone side including the nadir, and the cone axis pointing 23.45° (tolerance ±0.5 arc minutes) forward from nadir.**

With a satellite orbiting the Earth at an altitude of 800 km, the projection of this scanning geometry produces a swath width of greater than 500 km, thus meeting [R01/016].

As AATSR over-reaches the required swath and since ENVISAT-1 can fly up to 0.1 degrees out in any axis, there is no strong requirement for the conical scan axis to be referenced to the platform. However, there is a need for stability since beam clearances must be maintained. For ground verification purposes, an alignment cube is necessary on the baseplate to reference to satellite AOCS.

[R02/030] **AATSR shall have an alignment cube on the baseplate to reference to satellite AOCS, whose alignment shall be measured to 0.5 arc minutes accuracy.**

From the scan cone angle ([R02/029]), the satellite altitude and the requirements for a nadir sample spacing of 1 km ([R01/013]), the timing of the scan period can be determined. To build up an image, the satellite motion moves the nadir view vector in the along track direction by the sample distance, while the instrument must complete one scan. Since the satellite will take 150 ms to move 1 km along track, then this must be the period of scan mirror rotation.

[R02/031] **The AATSR scan mirror shall take 150 ms to complete one revolution.**

From [R02/028] and [R02/031], the sampling rate around the scan can be assessed in relation to the requirement for a nadir sample spacing of 1 km. Two thousand samples, equally spaced in time and, hence, scan mirror rotation angle, are necessary. Each sample is, therefore, defined by the detector signal integrated over 75 µs.

[R02/032] **Each AATSR scan shall comprise of 2000 data samples equally spaced in time.**

[R02/033] **Each AATSR sample shall be defined as the detector signal integrated over 75±0.75 μs.**

5.1. Instantaneous Field of View Requirements

From the discussion above, the IFOV can be assigned an angular size, derived from its projection on the earth's surface. To give a surface projected IFOV at nadir of 1.03 km by 1.03 km (i.e. approximately 1 km square), the IFOV, defined by the field stop, must be 1/777 rad ±1.44% by 1/777 rad ±1.44% square.

[R02/034] **The AATSR IFOV, defined by a field stop, shall be 1/777 rad ±1.44% by 1/777 rad ±1.44% square.**

[R02/035] **At nadir, the IFOV shall be aligned across track to within ±2 degrees.**

To provide adequate signal to meet the requirements in [R02/016], the instrument’s telescope primary aperture can be derived as being 11 cm. Radial clearance of the beam must be 6±2 mm, during the parts of the scan which view the Earth and calibration sources.

[R02/036] **The telescope aperture shall be 11 cm, defined by an optical stop.**

[R02/037] **Radial clearance of the telescope beam shall be 6±2 mm, during the parts of the scan which view the Earth and calibration sources.**

The scientific requirement for sample co-registration between channels ([R01/016]) is restated as a performance requirement, taking into account the sources of errors in registration.

[R02/038] **Errors in optical and electrical alignment between channels shall not exceed 0.1 sample distance at nadir.**

The use of a single field stop for all channels ([R02/025]) helps to achieve this. In addition, the sample integration periods for all channels must be accurately synchronised. Even if the integration periods are accurately synchronised, it is still possible to reduce co-alignment of channel samples by introducing time delays in the transference of the signal from the detectors to the signal integrators. Matching between channels is vital to ensure sample co-registration.

[R02/039] **Time differences between channels in transferring signals from the detectors to the signal integrators shall be no larger than 1 μs (i.e. 0.013 sample distance).**

It is known from previous ATSR missions that the detectors used for the 11μm and 12μm channels have a responsivity variation across their sensitive areas, which is related to electrical bias. This causes a variation in the responsivity over the IFOV in one dimension. In previous ATSRs, this responsivity variation is imaged along-track. For AATSR, notwithstanding [R01/004] for continuity with previous ATSRs, in order to better meet requirements [R01/001] and [R01/002], an alternative mounting method is necessary for AATSR.

[R02/040] **Responsivity variation over the IFOV which is caused by bias in the 11μm and 12μm detectors shall be minimised for AATSR by arranging the variation to appear in the across-track direction.**

5.2. Sampling Requirements

Combining the required swath width [R01/018] with the scan geometry defined above, the number of samples in the nadir and forward views can be calculated.

[R02/041] **AATSR shall provide, for each channel, 555 samples centred on the nadir vector, 371 samples centred on the along track vector and samples over each of the calibration targets.**

For continuity of design with previous ATSRs ([R02/002]), the derivation of the scan sample pattern for AATSR shall be based on scan reference pulses, which need to be provided once per scan.

[R02/042] **Scan reference pulses shall be provided once per scan to derive the AATSR sample pattern around the scan.**

In order to provide angular uniformity of sample spacing and to provide consistency in PSFs from scan to scan, the scan mirror must rotate at a sufficiently uniform rate. Since the scan mechanism performs better in vacuum than in air, the requirement on the uniformity of rotation in air has to be less sringent than the performance expected in vacuum.

[R02/043] **The scan mirror shall rotate at a sufficiently uniform angular velocity that its maximum positional error in angle of rotation, from that implied by assuming a uniform rate, shall be less than 5 arc minutes at any position around the scan, when measured in air. This performance in air is equivalent** *(TBC)* **to an error of 1 arc min (1σ RMS) in vacuum.**

The sample pattern needs to be able to be moved relative to the scan reference pulse. This movement needs to be to a resolution of 0.0625 sample distance.

[R02/044] **The scan sample pattern shall be movable on command as an offset relative to the scan reference pulse, to a resolution of 0.0625 sample distance.**

5.2.1. Mechanical disturbance

Stability of the angular sample spacing around the scan must not be excessively affected by mechanical disturbances from any AATSR mechanisms and any satellite mechanisms.

[R02/045] **The instantaneous mechanical disturbance to the IFOV vector caused by any AATSR mechanisms other than the scan mechanism shall be less than 0.1 sample distance at all times.**

5.2.2. Blanking pulses

Since ENVISAT-1 will also carry active radar instruments, AATSR has to provide warning of samples that may be corrupted by EMI. The radar instruments will provide blanking pulses to indicate when they are transmitting. Samples which are being integrated while the blanking pulse is active must be flagged in the measurement data stream.

[R02/046] **AATSR samples which are being integrated while a blanking pulse is active shall be flagged in the measurement data stream.**

6. CALIBRATION REQUIREMENTS

6.1. Radiometric Calibration of AATSR Samples

6.1.1. On-board Calibration Systems

To ensure the science goals of AATSR are met, on board radiometric calibration systems must be incorporated for both the thermal and the reflection channels ([R01/019] and [R01/034]).

6.1.1.1. Calibration System for Thermal Channels

To provide gain and offset measurements on the thermal channels, the calibration system must use at least two sources of known radiance. From the scientific requirement that AATSR must be able to accurately measure SST over the global expected range [R01/015], the temperatures of the sources can be derived. A brightness temperature range of 265K to 305K at the top of the atmosphere is estimated to encompass the full global range of SSTs. Hence, the sources should be placed roughly at these extremes, although their absolute temperatures are not critical within ±5K. The colder calibration source will be unheated and its temperature will be close to that of the enclosure (set in [R02/018]).

[R02/047] **The on-board calibration system for the thermal channels shall provide two known sources of radiance, with the colder source at a temperature of 260±5K (achieved by designing for a BOL instrument enclosure temperature of 248–253K) and the hotter source at a temperature of 305±5K** *(TBC)***.**

Each thermal calibration source must have an aperture larger than the area scanned by the telescope beam during at least one sample period. This is to prevent radiance contributions from other items of the instrument reaching the detectors during their views of the calibration sources.

[R02/048] **Each thermal calibration source shall have an aperture larger than the area scanned by the telescope beam during at least one sample period.**

The sources must be viewed every scan, to meet the radiometric accuracy requirements.

[R02/049] **The on-board thermal calibration sources shall be viewed every scan.**

Uncertainties in the calibration source radiance must not exceed a certain equivalent temperature error so that the overall SST accuracy requirements ([R01/001] and [R01/002]) to be met. This value is calculated to be 100 mK using the SST retrieval algorithms in [RD.2].

[R02/079] **Uncertainties in the calibration source radiance shall not exceed an equivalent temperature error of 100mK throughout the mission.**

[R02/050] **Requirement deleted.**

[R02/051] **Requirement deleted.**

[R02/052] **Requirement deleted.**

The SST retrieval algorithms also require that the radiances of the calibration sources are stable over the period between nadir and forward views of the ocean surface, which is approximately two minutes.

[R02/053] **The temperature of a thermal calibration source shall be stable to better than 0.03K over a two minute period.**

6.1.1.2. Calibration System for Reflection Channels

The calibration system for the reflection channels must be able to provide confidence in long term study of land surface reflectance parameters over the mission. Gain and offset measurements on the reflection channels must be provided, so the on-board calibration must use at least two sources of known radiance. The range of these sources must be decided on the basis of the requirements for land surface measurements [R01/023], and hence the typical spectral albedos encountered over land. By using one of the thermal calibration sources as a zero radiance calibration point, one source of higher radiance is necessary. The calibration system for the reflection channels must provide a stable source with a photon rate which is approximately equivalent to at least 25% spectral albedo. This figure is derived by assuming a surface reflectance equivalent to an idealised vegetated surface.

[R02/054] **The on-board calibration system for the reflection channels shall provide a known source of radiance over the AATSR reflection channel ranges with a photon rate approximately equivalent to at least 25% spectral albedo.**

The calibration system source radiance must be known to an absolute accuracy of ±5% to meet the scientific requirements for land remote sensing ([R01/023]).

[R02/055] **The on-board calibration system for the reflection channels shall provide a known source of radiance over the AATSR reflection channel ranges to an absolute accuracy of ±5%.**

The aperture of the calibration source for the reflection channels must be sufficiently large compared to the area scanned by the telescope beam during one sample period that radiance contributions from other parts of the instrument are negligible compared to that from the calibration source.

[R02/056] **The calibration source for the reflection channels shall have an aperture which is sufficiently large compared with the area**

scanned by the telescope beam during one sample period that radiance contributions from other parts of the instrument are minimised.

The source must be viewed every orbit, to meet the radiometric accuracy requirements.

[R02/057] **The on-board calibration source for the reflection channels shall be viewed every orbit.**

6.1.2. Linearity

To meet [R01/001] and [R01/002] throughout the length of the mission, the AATSR must be designed so that the linearity of the electronics for each signal channel is not expected to change by >0.5 LSB between pre-launch beginning of life (BOL) non-linearity assessment and EOL flight performance.

[R02/058] **The linearity of the electronics for each of the AATSR signal channels shall not change by >0.5 LSB between pre-launch BOL non-linearity assessment and EOL flight performance.**

6.1.3. Response Stability around Scan

It is a requirement that the channel responses must be constant around a scan (implicit from the half degree SST requirement [R01/001] when coupled with the sampling requirement [R01/013] and swath width requirements [R01/016]).

If the detectors are working, but are covered so that they see no varying radiometric signal, then there must not be any specific signal which varies around the scan.

[R02/059] **The signal channel responses shall be constant around a scan, so that, at maximum gain, with working detectors which are covered so that they see no varying radiometric signal, there shall be no specific signal >1 LSB on the signal channel outputs.**

The scan mirror must be sufficiently specular so that no significant signals from outside the telescope beam are passed back to the detectors. The mirror's scattering caused by surface roughness must be less than 0.05% for the shortest wavelength AATSR channel.

[R02/060] **Scattering from the scan mirror, caused by surface roughness, shall be <0.05% for the shortest wavelength AATSR channel.**

To minimise the possibilities of stray signals reaching the detectors, view baffles are necessary to keep out all direct sunlight during normal instrument operation. Similarly, the instrument enclosure must also be light-tight (other than for necessary apertures) and internally must be generally of low reflectivity to minimise the possibility of stray signals reaching the detectors.

[R02/061] **The instrument shall have view baffles to keep out all direct sunlight from its interior during normal instrument operation.**

[R02/062] **The instrument enclosure shall be light-tight (other than for necessary apertures) and internally must be generally of low reflectivity.**

6.1.4. Response Stability between Forward and Nadir Views

To meet the requirements for SST measurements ([R01/001] and [R01/002]), the thermal channels' response has to be stable over the period between forward and nadir views of the Earth's surface, so as not to introduce large errors into forward/nadir differencing algorithms. Items of the instrument which are "visible" to the detectors must remain stable in temperature over the time period between forward and nadir views. Each of these items shall be assigned an error budget of 0.02K over the two minutes between views, assuming that the 12µm channel is viewing a 265K scene and the instrument is at 264K. From the ATSR-1/2 design, this corresponds to stability requirements on the aperture stop of 0.2K/120s and on the focal plane assembly baffle of 0.8K/120s.

[R02/063] **Each of the items of the instrument which are "visible" to the detectors shall be assigned an error budget of 0.02K over the two minutes between views, defined by assuming that the 12µm channel is viewing a 265K scene with the instrument at 264K. This corresponds to stability requirements on the aperture stop of 0.2K/120s and on the focal plane assembly baffle of 0.8K/120s.**

For land reflectance measurements, the stability of the reflection channel gains has to be to 0.1% over the time between forward and nadir views and 1% around the orbit.

[R02/064] **The reflection channel gains shall be stable to 0.1% over the time between forward and nadir views and 1% around the orbit.**

6.2. Pre-launch Calibration and Characterisation

The AATSR has to be adequately calibrated prior to launch in order for it to perform its scientific goals ([R01/017], [R01/018] and [R01/033]).

Performance areas of the instrument which need to be calibrated prior to launch are discussed below.

6.2.1. Point Spread Function Requirements

The PSFs of AATSR's channels have to be accurately known in order to model radiances with adequate accuracy to meet the requirements for SST retrieval ([R01/001] and [R01/002]) and land applications [R01/023]. Pre-launch characterisation of PSF for each of the channels is therefore necessary to meet the primary scientific goals.

[R02/065] **Measurements of each of the AATSR channel PSFs shall be made at BOL and EOL conditions to 0.1 sample distance accuracy.**

[R02/066] **Measurements of co-registration between channel PSFs shall be made to an accuracy of 0.1 sample distance for the reflection channels.**

[R02/067] **Stability of alignment and focus with different instrument thermal environments shall be demonstrated.**

6.2.2. Radiometric Requirements

To ensure that the SSTs retrieved by AATSR are meaningful to the accuracies specified in [R01/001] and [R01/002], the radiometric performance must be calibrated and characterised prior to launch. This testing must measure the linearity of the thermal channels, verify the on-board calibration procedure, investigate any scan dependent strays or radiometric leaks and determine any dependence of radiometric performance on the instrument temperature (both due to changes in thermal performance during the mission, and orbital cycling).

[R02/068] **Pre-launch radiometric calibration shall measure the linearity of the thermal channels.**

[R02/069] **Pre-launch radiometric calibration shall verify the on-board calibration procedure.**

[R02/070] **Pre-launch radiometric calibration shall verify that the different thermal channels produce consistent measurements of brightness temperature.**

[R02/071] **Pre-launch radiometric calibration shall investigate and characterise any scan-dependent stray signals.**

[R02/072] **Pre-launch radiometric calibration shall investigate and characterise any radiometric leaks.**

[R02/073] **Pre-launch radiometric calibration shall determine and characterise any dependence of radiometric performance on instrument temperatures.**

[R02/074] **Pre-launch radiometric calibration shall determine and characterise any dependence of radiometric performance upon orbital temperature cycling.**

[R02/075] **Pre-launch radiometric calibration shall determine and characterise any dependence of radiometric performance on calibration source temperatures.**

[R02/076] **Pre-launch radiometric calibration shall determine and characterise any dependence of radiometric performance on detector temperatures.**

GLOSSARY

AATSR	Advanced Along-Track Scanning Radiometer for ENVISAT-1
AOCS	Attitude and Orbit Control System
ATSR	Along-Track Scanning Radiometer (generic term, and sometimes used to refer to the instrument for ERS-1)
ATSR-1	Along-Track Scanning Radiometer-1 (the ATSR for ERS-1)
ATSR-2	Along-Track Scanning Radiometer-2 (the ATSR for ERS-2)
AVHRR	Advanced Very High Resolution Radiometer
BOL	Beginning Of Life
EMI	Electromagnetic Interference
EOL	End Of Life
ESA	European Space Agency
IR	Infrared
IFOV	Instantaneous Field of View
NEΔT	Noise Equivalent difference in Temperature
PI	Principal Investigator
PSF	Point Spread Function
S/N	Signal-to-noise
SST	Sea Surface Temperature
TBC	To Be Confirmed
TBD	To Be Determined
TIR	Thermal Infra-Red
VNIR	Visible/Near-Infrared