JITTER DEFINITIONS AND REQUIREMENTS

Author: Peter Venters

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0> CHANGE LIST

v1 940622 PV First revision:

Throughout:Change "spectrum" to "rms spectrum" (of motions).
Add references to TC-LOC-006 where appropriate.
Section 3: Text revisions to improve readability.
Section 4: Add IRD definition of systematic and random agreed at TCG15.
Add note re attenuation of higher frequency chopper harmonics.
Add interpretation of scan rate requirements agreed at TCG15.
Simplify definition of synchronous jitter and requirements.
Section 5: Clarify radiometric, FOV and rel. angle requirements
Add TCG15 interpretation of IRD requirements
Clarify azimuth requirements
Section 6: Add allocation from RADMETAC

Section 7: Add caveat given critique of VFOVKNOW IRD spec in TC-OXF-111
Update to reflect issue of RADMETAC budget document.

v0 940223 PV Original version.

1> SCOPE.

This document defines the term "jitter" as applied to the HIRDLS performance requirements, and in particular the frequency range over which the term jitter applies. The Instrument Requirements Document (IRD) paragraphs which have implications for jitter specifications are reviewed, and the interpretation to be used in flowing down jitter requirements from the IRD explained. The current status of the jitter requirements, as flowed down from the IRD and allocated in the System Performance Requirements and Allocations Tables, is reviewed.

IT SHOULD BE NOTED THAT THE REQUIREMENTS AND CONCLUSIONS PRESENTED HERE HAVE MEANING ONLY IN THE CONTEXT OF THE TERMINOLOGY DEFINED IN THIS DOCUMENT. THE REQUIREMENTS DEPEND CRUCIALLY ON THE EXACT DEFINITION OF THESE TERMS, AND THE CONCLUSIONS SHOULD ONLY BE INTERPRETED ON THE BASIS OF THESE DEFINITIONS.

In this document, certain portions of the text are particularly important, and are highlighted accordingly. In particular, definitions are separated from the body of the text by ***. Summaries of IRD requirements are separated by ===. The resultant requirements on jitter are separated by ---.

2>INTRODUCTION.

The HIRDLS makes simultaneous measurements of atmospheric radiance and instrument pointing, in order to retrieve atmospheric profiles of temperature and constituent amount, and horizontal gradients of geopotential height.

The instrument has stringent requirements on the KNOWLEDGE of RELATIVE motions of the line of sight, in particular those which result in motion of the tangent point vertically in the atmosphere. Conversely, there are no tight requirements on PLACEMENT or CONTROL of these line of sight (LOS) motions.

In order to determine the line of sight motion, the instrument makes measurements of the orientation of the plane scanner mirror relative to the optical bench, and of the orientation of the optical bench with respect to inertial space using a gyro subsystem (GSS) mounted on the bench.

The GSS and scanner orientation measurements are made with a finite bandwidth. There will be motions of the line of sight at frequencies above those which can be measured, which will contribute errors to the instrument pointing, radiometry and field of view error budgets. Such motions will be caused by other instrument subsystems mounted off the optical bench, such as the coolers and sunshield, by items mounted on the bench, such as the chopper and scanner, and from other instruments and from the spacecraft itself. The primary line of defence against such motions is intended to be the mounting of the optical bench on "soft" vibration isolating mounts. Correct interpretation of the jitter requirements is crucial to the design these mounts.

The transmission and modification of motions throughout the HIRDLS/EOS CHEM structure, and a classification of sources of such motions are shown below. Flow is from top to bottom; structures which modify the motional outputs from the various sources are shown in {}.

```
              Spacecraft sources     Other instrument sources
              (eg reaction wheels)   (eg microwave antennae)
                    |            |
                  {spacecraft structure}
                        |
                   {spacecraft mounts}
                        |
      HIRDLS sources, off O.B.     |
      (eg cooler, sunshield)      |
            |           |
           {instrument baseplate}
                        |
                    {OB mounts}
                        |
      HIRDLS sources, on O.B.      |
      (eg scanner, chopper)       |
            |           |
          { Optical Bench (O.B)}
                  |
              Scanner motions
                  |
               LOS motion
```

Instrument performance requirements, derived from the IRD requirements, are expressed in terms of equivalent LOS motion. In order to compute the corresponding requirements on the motional output from a given source, the transmission from the source through the appropriate structures and mounts must be modelled. This can only be achieved using detailed mechanical models and is not attempted here.

3> HIRDLS SIGNAL PROCESSING.

For the HIRDLS instrument, it is motions of the LOS relative to the atmosphere which are significant. Motions of the instrument optical bench relative to inertial space are measured by the GSS, and transformed to an earth centred co-ordinate system using certain spacecraft data. The details of the transformation will not be considered here; for the purposes of this document, jitter motions (as defined below), and the requirements on them, should be considered with respect to inertial space unless otherwise stated.

In the following discussion, it will be important to define carefully the precise frequency ranges of interest, for the measurements of both radiometric signals and pointing. These ranges, and hence the jitter definitions and requirements, depend on the signal processing concept. Before proceeding to a definition of jitter, this concept is reviewed; a more detailed description is given in TC-NCA-18.

The HIRDLS radiometric measurements are made by chopping the atmospheric radiance entering the instrument telescope against a stable reference radiance with a high frequency (nominally 503Hz) optical chopper. The detector preamplifier outputs are sampled at each chopper-in and chopper-out position. The resulting signal is passed through an anti-aliasing filter, digitally demodulated and filtered by the on-board processor.

The HIRDLS scans atmospheric radiance features with a finite field of view, producing signals from dc up to a maximum frequency f_max (the notation here follows that of TC-NCA-18). The bandwidth of the chopped signal about the chopper frequency is initially defined by the anti-aliasing filter. To minimise the dependence of characteristics of this filter on component values, the bandwidth is set as wide as possible, giving 3dB points at 0.5 and 1.5 times the chopper frequency, f_chop.

The signals are then demodulated, digitally filtered and output to the data stream at a frequency f_out, an integral submultiple of the chopping frequency, with corresponding Nyquist frequency f_N= f_out/2. The digital filter, which will pass frequencies up to f_max, where f_max<f_N, must therefore reject frequencies above f_out-f_max = f_N + (f_N-f_max). For the baseline design, f_chop=503Hz and f_out=84Hz. If the measurement bandwidth is taken as the IRD global mode effective bandwidth f_max= 7.5Hz, then the digital filter would be required to have a passband extending up to 7.5Hz, and a stop-band extending from 67Hz upwards. In fact, there is likely to be information above 7.5Hz, in both the global and other special modes; as the on-board digital filtering removes signal (and noise) irretrievably, the digital filter bandpass is in practice likely to be set much nearer to the output Nyquist frequency.

The shape of the digital filter is important in the discussion of certain classes of jitter-type motions, in particular, those which result in radiance signals within the instrument passband around chopper frequency harmonics. In the discussion below, this filter is referred to as the SIGNAL CHANNEL LOWPASS FILTER.

The HIRDLS also makes measurements of the scanner orientation relative to the optical bench, and the gyro orientation relative to inertial space. The optical bench is required to be sufficiently stiff that these two sets of measurements allow the determination of the line of sight relative to inertial space. These measurements are referred to as the POINTING measurements.

In the baseline design, the pointing measurements are sampled at the filtered radiance output frequency f_out, before being passed through an analogue anti-aliasing filter. This filter therefore has similar pass and stop band requirements to the (digital) signal channel lowpass filter. Due to the difficulty of modifying the characteristics of the analogue filter in flight, it is possible that one or both of the pointing measurement subsystems will employ the same oversampling approach as used in the signal channels, so that the bandwidth can be set (and modified) digitally.

In the following discussion, this filter is referred to as the POINTING LOWPASS filter. Whatever its implementation, it must have at least the same bandwidth as the signal channel lowpass filter, in order that the signal channel measurements can be correctly interpreted. This filter defines which components of motion can be determined from the telemetry; motional components in the filter stop-band region cannot be reconstructed from the instrument telemetry. In this document, such components are referred to as unmeasurable; those components which can be so constructed are referred as measurable.

The term "jitter" can now be defined in terms of the signal channel low pass filter and pointing low pass filter profiles.

4> DEFINITIONS.

The relative LOS angle performance requirements for the HIRDLS consist of POINTING and JITTER requirements. These two terms are defined more precisely below. Roughly speaking, POINTING refers to those components of LOS motion which ARE measured; JITTER to those which are not.

Some of the HIRDLS requirements discussed below draw a distinction between RANDOM and SYSTEMATIC errors. The random error component can be thought of as those which vary faster than a specified time interval, the systematic error component as those which vary only slowly compared with that interval. The interval is often that for a single vertical scan in the atmosphere (nominally 10s). Accordingly, in the IRD the term systematic is defined by a two pole low-pass filter, with edge frequency at 0.1Hz. In this document, definitions which refer to systematic components approximate the two pole filter by a top-hat function.

4.1> JITTER AND POINTING.

The boundary between which motions are and are not measured depends on the pointing lowpass filter profile. Within the passband, motions will be measured with the full performance of the transducers; motions in this frequency range are referred to as pointing motions. In the stop-band region, no motions whatsoever will be measured; this is the frequency region where motions are referred to as jitter. In the intermediate region, as the frequency is increased from the passband, motions will be measured progressively less well; motions here result in some information about pointing, but also contribute to jitter errors.

For any given spectrum of angular motions, therefore, the terms JITTER (and integrated jitter) and POINTING are defined as follows:

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The jitter component of any spectrum of angular motions is that resulting from multiplication of the rms spectrum by unity minus the normalised pointing low pass filter characteristic defined above. Integrated jitter is the jitter component integrated over all frequencies. The pointing component is that which is not included by this definition of jitter.

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4.2> POINTING LOW PASS FILTER.

The definitions of 4.1 are in terms of the pointing low pass filter characteristic; to complete the definition, the characteristic must also be defined. It is not possible to define this filter without detailed analyses of, among other things, scanner noise performance, gyro noise performance, the predicted on-orbit vibration environment, filter implementations, sensitivity to component variations (if analogue) and processor throughput (if digital). However, for the purposes of baseline design work, it is possible to define a characteristic which is likely to be reasonably similar to the final design.

In the baseline design, sampling of the pointing measurements takes place at the output frequency f_out, nominally 84Hz. The purpose of the filter is to prevent noise at frequencies above the Nyquist frequency f_out/2=42Hz being aliased into the passband. If the number of poles in the filter is N, the (amplitude) roll-off above the pass-band will be 6N dB/octave.

There is a wide range of types of filter, with varying shapes of pass-band response and edge sharpness. It is likely that, for the HIRDLS application, the optimum filter would have the steepest possible edge for a given number of poles, subject to maximum permissible variations in the pass-band phase and amplitude responses. These variations have yet to be evaluated.

However, for the purposes of defining an approximation to the filter characteristic, it is useful to consider a filter which has maximally flat response within the pass-band. Although this has a less steep transition edge than an optimum filter, it has the considerable advantage of a very simple amplitude response, namely:

|V_out/V_in|= {1 - (f/f_c)^(2N)} ^ (-1/2)

where f is the frequency, f_c is the edge frequency and N is the number of poles. This can be implemented in either digital or analogue form. If implemented as an analogue filter, the in-band response is less sensitive to (in particular) capacitor values than an optimum filter.

If the filter passband extends to a frequency f_c, then the amplitude of the aliased component f_max-f_c can be computed if the number of poles, and hence the roll-off slope, is known. For the purposes of the approximate filter, we assume that an 8 pole filter is a reasonable compromise between design complexity (or processing power) and performance, giving an amplitude roll-off of 48 dB/octave. In addition, we assume that the amplitude response of the filter at the lowest alias of its passband edge frequency be 20dB down. This ensures a negligible contribution to the in-band response from aliased components, assuming a flat input spectrum (note that this is most unlikely to be the case for the HIRDLS; the coolers are expected to operate at about 45Hz). With this choice of attenuation, the cut-off frequency can be set at 36Hz, which seems a reasonable compromise.

Accordingly, the following definition is now made:

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For the purposes of this document, the pointing lowpass filter which defines
the regions of interest for pointing and jitter definitions, is defined to be
an eight pole Butterworth type filter, with edge frequency set at 36Hz. This
filter profile is an approximation for design purposes only, and is not
expected to be the filter ultimately used in this application.
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4.3> IN-BAND JITTER.

It is useful to consider those components of jitter which can result in
signals within the signal channel lowpass filter passband. Although the
definition of jitter above excludes low frequencies, there remain
components of motion at or near the chopper frequency and its harmonics,
which, on entering the instrument, can be demodulated and appear within the
signal channel passband. These components of jitter are referred to as
IN-BAND JITTER and are defined as follows:

****
The IN-BAND JITTER component of any rms spectrum of angular motions is the
product of the JITTER components of that spectrum with the convolution of
the signal channel lowpass filter characteristic (defined for positive and
negative frequencies) with an array of Dirac delta functions located at the
chopper frequency and its harmonics; OUT-OF-BAND JITTER is the remainder of
the jitter spectrum not defined as in-band. The INTEGRATED IN- or OUT-
OF-BAND JITTER is found by integrating the appropriate component over all
frequencies.
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Note that both the in-band and synchronous (see 4.4) jitter definitions should,
in principle, allow for the progressively more severe attenuation of higher
frequency chopper harmonics by the HIRDLS signal processing chain. However,
the degree of this attenuation depends on details of, among other things, the
instrument chopping waveform. Further, the performance requirements for these
narrow band jitter elements are comparable to the requirements which apply over
the entire jitter range (see sections 5 and following); it is these broad-band
requirements which are considerably more difficult to meet. For simplicity,
therefore, in these definitions the high frequency attenuation is ignored; this
leads to an overestimate of the magnitudes of these narrow-band jitter terms.

4.4> SYNCHRONOUS JITTER.

It is useful to consider those components of motion which, when passed through
the signal processing chain, result in signal channel outputs which vary slowly
compared with a single vertical scan. These components are referred to here as
SYNCHRONOUS JITTER motions, and are a subset of the in-band jitter defined in
4.3 above. Thus:

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The SYNCHRONOUS JITTER component of any rms spectrum of angular motions is the
product of the JITTER components of that spectrum with the convolution of a
"top-hat" function of width +/- 1/10 Hz with an array of Dirac delta functions
located at the chopper frequency and its harmonics. The INTEGRATED SYNCHRONOUS
JITTER is found by integrating this component over all frequencies.

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4.5> HORIZONTAL AND VERTICAL LOS JITTER.

The distinction must also be drawn between those components of motion which move the line of sight (LOS) horizontally, and those which move it vertically, in the atmosphere. Line of sight motions resolved along these axes are referred to as HORIZONTAL and VERTICAL LOS JITTER respectively. As for the IRD requirements, by default these refer to the spacecraft reference co-ordinate frame (see IRD requirements, below).

Note, however, that in the event of the misalignment of the spacecraft, there can be cross-coupling between horizontal and vertical motions. As it is the vertical motions for which the requirements are most severe, a particular concern is the vertical component of horizontal motions when the spacecraft is misaligned in roll. The maximum (3 sigma) error expected for the spacecraft is 0.25 degree [SPRAT]. Accordingly, in the following definitions, VERTICAL LOS JITTER is taken as referring to motions of the LOS resolved along the SRCF Z axis, combined with sin (0.25 degree)=0.004 times motions of the LOS resolved along the Y axis as a root sum square. This is unlikely to result in any tight requirements on the horizontal LOS motion, but is included for completeness.

Having defined the terminology, the requirements on instrument performance which have implications for jitter are now reviewed.

5> IRD AND JITTER REQUIREMENTS.

HIRDLS performance requirements are documented in the Instrument Requirements Document (IRD). A number of them result in budgets which allocate requirements between different subsystems. The budget tables are documented in the System Performance Requirements and Allocations Tables document.

The IRD requirements are expressed by default in a spacecraft reference co-ordinate frame. This frame is defined in the IRD to be a right handed system, with origin at the spacecraft centre of mass, with Z axis directed towards the centre of mass of the Earth, and with X axis directed approximately along the spacecraft velocity vector.

Jitter affects the following areas of instrument performance, each of which is specified in the IRD:

Knowledge of relative line of sight; jitter motions can result in both random and systematic errors in computing the line of sight.

Field of view; unmeasured motions can result in a blurring of the field of view; systematic uncertainties in the field of view centre position are considered as being errors in the relative line of sight knowledge.

Radiance measurements; the steep gradients of radiance with altitude in the atmosphere act to convert vertical motions of the line of sight into radiance changes. Such changes can be either random or systematic, depending on the frequency of the motion.

Scan rates; the net motion of the line of sight, relative to the atmosphere, is made up of components due to the (desired) motion of the scan mirror, combined with unwanted components due to the unmeasured motions of the optical bench and the scanner relative to the atmosphere. Where specifications are placed on the scan rate, both wanted and unwanted components must be taken into account.

Scan range: unmeasured line of sight motions can result in modifications to the scan range. However, other requirements on these motions are such that this is unlikely to be a significant consideration, and is not considered further here.

The IRD requirements in these areas, and the resulting requirements on the unmeasured components of motion are now considered. Note that, in the following, only a precis is given of the relevant IRD requirements; for the full text see the current issue of SC-HIR-18.

5.1> RADIOMETRIC REQUIREMENTS.

It is recognised by the IRD that the strong gradient of atmospheric radiance with height results in the conversion of jitter-type motions into additional radiometric signal noise. In addition, synchronous jitter contributes to systematic errors in the atmospheric radiometry.

The jitter induced signal noise is addressed by the IRD directly in angular terms in the requirements on relative angle knowledge (see section 5.4 below); the signal noise figures specified in the IRD refer to noise in the absence of jitter induced noise from the atmospheric radiance gradient.

The synchronous jitter affects the radiance accuracy when viewing the atmospheric limb. The IRD requires that radiometric accuracy satisfy the following requirement:

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2.5.1 Radiometric accuracy: to be better than greater of 1% of radiance (design goal 0.5%) or 100% of radiometric noise (design goal 25%).

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Synchronous jitter can be converted into an equivalent radiometric error using the radiances specified in TC-HIR-90, and the derived gradient information in TC-OXF-89. This is just one source of radiometric error. Allocation between this, and the large number of other sources, is made in the RADMETAC budget. Accordingly, the IRD radiometric accuracy requirement may be interpreted as follows:

The integrated synchronous jitter component of vertical LOS motions, expressed as an equivalent radiometric error using the maximum atmospheric radiance gradients for each channel derived in TC-OXF-89 from TC-HIR-90, must not exceed the value given in the RADMETAC (radiometric accuracy) budget.

5.2> SCAN RATE REQUIREMENTS.

There are two IRD requirements relating to scan rates, and in particular to the uniformity of rate throughout a single vertical scan. Scans can last up to about 10s in the global mode. The requirements are:

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2.5.9 Radiometric sampling uniformity: variation of LOS spacings in a scan less than 25%.
2.7.3 Altitude scan rate uniformity: angular rate of altitude scan must not vary by more than 5% during a scan.
==

These requirements refer to motion of the LOS relative to the atmosphere, and not motion of the scanner relative to the optical bench.

Of the two requirements, the latter is considerably tighter; if it can be met, there is no difficulty in meeting the former requirement. The scan rate uniformity requirement is intended to apply to the scan rate, averaged or otherwise smoothed over a single sample, in comparison with the mean rate taken over a complete vertical scan. More specifically, the interpretation of this IRD requirement agreed at TCG15 is:

For all scan speeds specified in the IRD, the vertical LOS motion (relative to the spacecraft reference co-ordinate frame defined in the IRD) when filtered by the pointing low-pass filter, shall not vary by more than 5% (1 sigma) of the commanded rate, over any single vertical scan (10s period).

The variation of LOS spacings in a scan, addressed by the first IRD requirement, places requirements on both the scan rate, and the timing of the radiance sampling. If the 5% scan rate requirement is met, then the instrument sampling rate can vary by up to 24.5% (1 sigma) and still meet the first IRD requirement. The sample timing will be derived from a tuning fork, or well stabilised rotating, chopper which will be required to have considerably greater stability for other radiometric reasons. Accordingly, the 24.5% figure is not considered further here.

5.3> FIELD OF VIEW REQUIREMENTS.

The IRD requirements on the field of view are as follows:

==
2.6.1 Field of view (FOV): integrated vertical response must be > 80% between half power points; integrated response as a function of distance from field centre must be as specified.

2.6.2 Out of field response: integrated response over regions more than 4km from field centre must be less than the greater of 0.4% of total response or 100% of radiometric noise (design goal 25%)

2.6.3.1 Vertical spatial response (VSR) knowledge: relative VSR must be known to better than 1%, with resolution of better than 7 arcsec.
==

Unmeasured motions of the line of sight contribute to blurring of the edges of the field of view. Synchronous motions, which in addition cause slowly varying shifts in the mean position of the field of view, are considered as part of the relative angle knowledge requirements below. The blurring is caused by any unmeasured motion and applies over the entire jitter frequency range.

The degree of blurring depends on the slope of the field of view function edges; a sharp edged function is much more sensitive to blurring than one with smooth edges. The IRD does not specify the shapes of the field of view directly, but in terms of various functions of the integrated shape. The worst possible case is for an infinitely steep edge. With a vertical resolution of 7 arcsec, this would give a maximum effective gradient of 100%/7 arcsec, and so an angle equivalent requirement of 0.07 arcsec. Actual fields of view are likely to be considerably less sharply defined than this.

The blurring of the field of view due to unmeasured motions is one component of such blurring. In addition, blurring due to focus shifts in the telescope sub-system must be considered. The allocation between these sources is made in the VFOVKNOW budget.

The interpretation placed here on the IRD requirements is that 2.6.1 and 2.6.2 apply to a perfectly stable optical bench, and that only the vertical spatial response requirement includes the effect of jitter. With this interpretation, the IRD requirement on jitter can be expressed as:

The integrated jitter, converted into an equivalent angle using the maximum gradient of the relative vertical spatial response for each channel, must not exceed the value assigned in the VFOVKNOW budget for the channel with the steepest gradient. For the purposes of this requirement, the gradient will be computed as an average over a 7 arcsec range.

5.4> RELATIVE ANGLE KNOWLEDGE (VERTICAL) REQUIREMENTS.

The IRD expresses the requirements on knowledge of relative angles over two specified periods, corresponding to measurements made within and between vertical scans. (It should be noted that the terms vertical and horizontal in the atmosphere do not correspond exactly to elevation and azimuth

motions of the scanner, even for an instrument perfectly orientated in the spacecraft reference co-ordinate system.) The relevant requirements are:

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2.7.5.1 Relative altitude angle knowledge within a scan: relative angle between two radiances in one scan must be known with systematic error better than greater of 0.25% or 0.35 arcsec, and random error of 1 arcsecond (1 sigma in

7.5Hz bandwidth) (design goal 0.7 arcsec).

2.7.5.2 Relative altitude angle knowledge between scans: error in knowledge of the relative angle between two radiances in adjacent scans must be better than 1.4 arcseconds (1 sigma). Adjacent means adjacent profiles in one azimuth swath, between adjacent azimuth swaths or between adjacent orbits at the same approximate latitude.
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The IRD requirements for within one scan are divided into random and systematic parts; the random error requirement will be discussed first. (As mentioned above, the IRD defines the terms systematic and random in terms of a two pole low pass filter, with edge at 0.1Hz; components within the filter bandpass are systematic, other components count as random.) The random error in relative altitude angle knowledge is made up of random errors in the pointing (gyro and scanner) measurements, combined with random errors due to the unmeasured jitter components.

The IRD random error requirement refers to components within the global mode nominal bandwidth (7.5Hz). This specifically excludes contributions from jitter as defined above, except where jitter leads to radiometric signal noise within the bandwidth of the signal channel low pass filter. Accordingly, the only jitter implication of this requirement is on the in-band jitter.

A slight complication is the differentiation in the IRD between relative angles bigger and smaller than 0.04 degrees, thus avoiding the fractional requirement giving unreasonably tight requirements for small relative angles. However, in the global mode of observation, it takes a full 0.2 seconds to cover 0.04 degrees, which is on a timescale much longer than that associated with the jitter terms. Thus the 0.04 degree distinction makes no difference to the much higher frequency jitter specifications.

The in-band jitter must be combined with the random errors in the pointing measurement, to give a total error which must meet the IRD random error specification. The allocation between the jitter components and the pointing errors is made in the POINTELV budget. Thus, the IRD requirement may be interpreted as:

The integrated in-band elevation LOS jitter must not exceed the value allocated in the POINTELV budget.

The IRD requirement on systematic error within one scan, like the random error requirement, is made up of a combination of errors in the pointing measurements, combined with contributions from jitter. the jitter contribution to systematic errors is from synchronous jitter, where the term synchronous refers to components varying slowly compared with the time taken for a single vertical scan; the appropriate bandwidth is then 1/10 Hz. As for the random component specification above, this requirement is unchanged for angles below and above 0.04 degrees.

The allocation between the synchronous jitter and the other systematic sources is made in the POINTELV budget. The IRD requirement may then be interpreted as:

The integrated synchronous elevation LOS jitter must not exceed the value
allocated in the POINTELV budget.

The IRD requirement on errors between scans includes both random and systematic terms by implication. From the arguments above relating to the IRD requirements within a single scan, jitter contributions to these errors arise from a combination of the synchronous and in-band jitter components. (As these requirements refer to differences between two sets of measurements, each of the two sets individually should meet an angle knowledge error of 1/sqrt(2) better than the IRD specification.)

The IRD requirement can therefore be expressed as follows:

The combined (root sum square) of the integrated in-band and synchronous
elevation LOS jitter motions must not exceed the value allocated in the
POINTELV budget.

5.5> RELATIVE ANGLE KNOWLEDGE (HORIZONTAL) REQUIREMENTS.

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2.8.3.1 Absolute azimuth knowledge: to better than 0.1 degree.

2.8.3.2 Relative azimuth angle knowledge: to better than 0.04 degree between
adjacent azimuth settings, adjacent defined as for 2.7.5.2

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No bandwidth is specified for these requirements in the IRD. Thus, taking the first requirement, any unmeasured component of azimuth LOS motion may contribute to the error in absolute azimuth angle knowledge. In practice, as it is azimuth angle averaged or otherwise smoothed over a single sample which is measured, the higher frequency jitter component will be averaged out. However, in view of the comparative ease in meeting the azimuth requirements, and the lack of an explicit bandwidth in the IRD, this requirement will be interpreted as applying to all frequencies.

The second requirement derives from the need to measure geopotential height gradients in the atmosphere, and not directly from horizontal atmospheric radiance gradients which are several orders of magnitude smaller than the vertical gradients. As for the previous requirement, errors in knowledge of this angle will be taken as resulting from any unmeasured azimuth angular motion.

Jitter is only one source of error in the knowledge of the absolute and relative azimuth angles; the allocation between jitter and other sources is made in the POINTAZM budget. Accordingly, both IRD requirements result in the following interpretation:

The integrated azimuth LOS jitter must not exceed the value allocated in the POINTAZM budget.

5.6> SCANNER AZIMUTH ANGLE KNOWLEDGE REQUIREMENTS.

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2.8.4 Scanner azimuth angle knowledge: to better than 0.02 degree.
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There is no direct implication for jitter specifications arising from this requirement, which is specifically placed on the scanner, as opposed to the line of sight, azimuth angle. There is an implicit requirement that the scanner measurement transducers be able to operate with the specified performance in the on-orbit vibrational environment. However, if the other requirements on jitter are met, it is most unlikely that this will present a problem, and it is not discussed further here.

6> SUMMARY AND ALLOCATIONS.

The jitter requirements above are summarised in the following table, together with the current equivalent SPRAT budget allocations, in arcseconds, 3 sigma. Where further division of SPRAT requirements is required to allocate to jitter sources, values are suggested; such values are indicated by *.

IRD requirement	SPRAT ref.	Motion type	Allocn.	Note
2.5.1 Rad. accuracy	RADMETAC	Integ. synch. jitter	0.2	1
2.5.9 Rad. sampl. uniform.	-	-	-	2
2.7.3 Scan rate uniformity	-	Integ. pointing	0.15	3
2.6.1 In-field FOV prof.	-	-	-	2
2.6.2 Out-field FOV prof.	-	-	-	2
2.6.3.1 VSR knowledge	VFOVKNOW	Integrated jitter	* 0.2	4
2.7.5.1 Alt.ang. 1 scan rand	POINTELV	Integ. in-band jitter	* 0.2	5
2.7.5.1 Alt.ang. 1 scan syst	POINTELV	Integ. synch. jitter	* 0.11	6
2.7.5.2 Alt.ang. interscan	POINTELV	Int. synch, in-band j.	* 2.4	7
2.8.3.1 Abs. az. ang. know.	POINTAZM	Integ. jitter	* 10	8
2.8.3.2 Rel. az. ang. know.	POINTAZM	Integ. jitter	* 10	8

Notes.

1. See RADMETAC budget.

2. No requirements on jitter - see discussion in 5.2 above.

3. Assumes slowest IRD scan rate, 0.1 degree/s gives tightest requirement. The IRD requirement is then equivalent to 0.005 degree/s = 18 arcsec/sec constancy requirement; taken over a 12ms period, this corresponds to 0.012*18= 0.22 arcsec. The lower limit of the integration corresponds to the time taken for

one complete vertical scan, and can be taken as 1/10Hz. Assuming that this can be allocated equally between the telescope subsystem and motions relative to inertial space, and that the majority of these two allocations are uncorrelated, then an allocation of 0.15 arcsecond can be made.

4. This is controlled by the allocation in the VFOVKNOW budget. This budget is derived based on the assumption that the available allocation is divided equally (in a root-sum-square sense) between pre-launch characterisation, and post-characterisation changes. This assigns 0.7% of the 1% VSR knowledge requirement to post characterisation changes.

The 0.7% must be broken down further into jitter type changes, as discussed above, and other sources such as focus changes. If these two terms are also assigned equal weight, that is assuming that jitter and defocus are uncorrelated, then an allocation of 0.5% VSR knowledge results for the jitter term.

This must then be converted into an equivalent jitter requirement, which requires the use of a field of view edge slope. For the shortest wavelength channel, the diffraction spread 1.22lambda/D is comparable to the 7 arcsec resolution specified in the IRD. The maximum slope, averaged over a 7 arcsec interval, might then reasonably be assumed to be 50% of the worst case (100% in 7 arcsec). Using this slope results in the requirement of theta_jitter < 0.005 * 7 arcsec / 50% = 0.07 arcsec. IRD requirements are expressed in 1 sigma terms, those in the ITS/SPRAT are expressed in terms of 3 sigma. Thus, the ITS/SPRAT requirement is 0.2 arcsec, which is the figure listed above.

5. The POINTELV budget currently divides errors into errors in knowledge of ILOS relative to the GMU datum, retrieved gyro knowledge error relative to the GMU datum and jitter errors. The latter relate particularly to the performance of the telescope subsystem, in particular the vibration isolation requirements of the optical bench mounts.

The allocation to the jitter term is set at the the same as that deriving from the VSR knowledge requirement and allocated in the VFOVKNOW budget, see note 4. As this VSR derived allocation applies to all jitter, the POINTELV requirement under consideration applies to in-band jitter only, so that this does not imply any tighter a requirement on jitter overall. This allocation is then very small in comparison with the other terms in the POINTELV budget. Note that, following this line of reasoning, if the VFOVKNOW requirement were to be relaxed, considerably more of the ILOS knowledge error could sensibly assigned to jitter.

6. This allocation is made in the POINTELV budget, which divides the systematic error allocation equally between the ILOS to GMU datum term, the GMU knowledge term, and the jitter term. This gives an allocation to each of 0.11 arcsec, for elevation angles of less than 0.04 degrees. As discussed above, the jitter requirement has the same constant value for angles above 0.04 degrees. However, in an attempt to reduce confusion, the jitter requirement for angles above 0.04 degrees in the POINTELV budget is expressed in the same manner as the other terms in this budget, that is, as a percentage. This allows the budget to be summed straightforwardly, but

results in an over-allocation of margin to the jitter entry. This should be revised if this results in over-tight constraints on the other subsystems.

7. Like the requirements discussed in notes 5 and 6, this allocation is made in the POINTELV budget. The requirement is allocated equally between the three terms in the budget, giving an allocation of 2.4 arcsec.

8. The allocation between jitter and other error sources for this requirement is made in the POINTAZM budget. In view of the very tight requirements on elevation jitter, it is unlikely that the azimuth jitter will be a major concern. A reasonable allocation to the integrated azimuth jitter term can be determined by considering that the term vertical jitter, as defined above, includes a contribution from azimuth motions, to take into account spacecraft attitude offsets. A reasonable requirement, in view of the already tight vertical requirements, would be for the azimuth motion to be an small term in the integrated vertical jitter budget, perhaps no more than 20% of that budget. It would then contribute less than 5% to a root-sum-square total.

To meet this requirement, taking the 3 sigma spacecraft misalignment of 0.25 degrees and assuming a vertical jitter requirement of about 0.2 arcsec, the integrated azimuth jitter should be less than 20% * 0.2 / sin(0.25 degrees) = approx 10 arcsec (3 sigma). This term is very small in comparison with other allocations in the POINTAZM budget.

7> CONCLUSIONS.

1. With the current allocations, the tightest requirement on INTEGRATED VERTICAL JITTER is that imposed by the vertical field of view knowledge requirement (this requirement is based on the assumption that the peak averaged gradient over a 7 arcsec interval is 50%/7 arcsec, one half of that which would result from an infinitely sharp edge).

This requirement is on INTEGRATED jitter. The other jitter requirements are of similar magnitude, but apply to narrow band components of the motional spectrum. The integrated requirement is therefore expected to be the tightest effective requirement, as confirmed by initial modelling detailed in TC-LOC-006.

It has been suggested (TC-OXF-111) that the current IRD requirement considerably overspecifies the vertical FOV knowledge requirement at the edges of the FOV. If this proves to be the case, this (driving) jitter requirement can be relaxed.

2. The tightest requirement on INTEGRATED IN-BAND JITTER is that imposed by the altitude angle knowledge requirement in one scan. This has been allocated assuming that, if the integrated jitter specification is met, the integrated in-band jitter will also automatically be met.

3. The tightest requirement on INTEGRATED SYNCHRONOUS JITTER is that imposed by the systematic requirements on altitude angle knowledge in one scan. (Note that this jitter magnitude is comparable or less than the radiometric noise

equivalent angle in the majority of HIRDLS channels, but exceeds the NEA in channels 7,8,12 and 13 at the heights of maximum radiance gradient (see TC-OXF-89,TC-HIR-90)). This requirement is included in the RADMETAC budget (see TC-OXF-97).

4. The only requirement on INTEGRATED POINTING motions is that imposed by the requirement for a constant scan rate.

5. The direct requirements on the various AZIMUTH JITTER components can be met easily. These requirements are that azimuth motions contribute negligibly to the vertical jitter budgets. Azimuth jitter requirements must be less than about 45 times the corresponding vertical jitter requirement for this to be true. The tightest requirements on INTEGRATED AZIMUTH JITTER, INTEGRATED IN-BAND AZIMUTH JITTER and INTEGRATED SYNCHRONOUS AZIMUTH JITTER are then approximately 10 arcsec, 10 arcsec and 5 arcsec respectively.

6. It is the integrated jitter specification which is of major concern in the design of the optical bench vibration isolating mounts. All other jitter components are at frequencies well into the stop-band of any such mount. It should be noted from above that the rejection required from this mount depends on the magnitude of the input, and the shape of the pointing low-pass filter. Neither of these are known at present. However, the band edge of the pointing filter will be placed in the region between 7.5 and 42 Hz, so that the requirements on the mount rejection are considerably eased. Discussion of the likely response of a simple passive mount system is given in TC-LOC-006.

[END]