GIFTS Interferometric Noise Sources

An

Instrument Subsystem Systems Engineering Support Report

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1 Scope of Document

This document identifies, categorizes and describes interferometric noise sources for the Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) instrument. Where possible, the noise sources will be quantified to form a noise budget, and a method of verification will be identified.

2 Reference Documents

Ref	Document	Version	Date (MM/DD/YY)
RD1	"GIFTS Instrument Requirements" (GIRD), GIFTS Document No. 04-001	2.0	12/19/03
RD2	Hank Revercomb, Fred Best, Robert Knuteson, Ron Huppi, Alan Thurgood, "Imaging Interferometer Subsystems and Performance Requirements"	N/A	10/11/02
RD3	Hank Revercomb, "UW SSEC Memo: Use of Laser Interferogram Phase Measurements to Correct Spectra for Vibration-induced Tilt Errors on the Scanning HIS"	N/A	06/18/99
RD4	E. R. Olson et al, "Vibration Induced Tilt Error Model for Aircraft Interferometer Data", Proceedings of SPIE **4881**, 604 – 615 (2002)	N/A	09/26/02
RD5	Alan Thurgood, "GIFTS Sensor Module (SM) Overview"	N/A	03/21/01
RD6	Lawrence A. Sromovsky, "Radiometric Errors In Complex Fourier Transform Spectrometry", Appl. Opt. **42**, 1779 – 1787 (2003)	N/A	10/23/03
RD7	Peter R. Griffiths, James A. de Haseth, *Fourier Transform Infrared Spectrometry* (John Wiley and Sons 1986)	N/A	N/A

3 Definitions, Acronyms, and Abbreviations

3.1 Terminology [RD1]

Baseline Interferometer Scan is defined as the highest spectral resolution (0.6 cm^{-1}) interferometer scan.

Channel is a discrete portion of the spectrum measured by the instrument in the context of spectral measurements.

Etendue is defined as the area-solid angle product (AΩ) using the solid angle for focal plane FOV.

Noise Equivalent Radiance (NER, NEN) [mW / (m^2·sr)] or Noise Equivalent Spectral Radiance (NESR) [mW / (m^2·sr·cm^{-1})] is a nominal way of describing noise and random errors in the measuring system. In GIFTS project documents, NER, NEN, or NESR include shot (photon) noise, and are specified at nominal uniform scene brightness temperature. The noise is projected from the system back to the scene radiance such that the overall effect can be compared with the true signal (that coming from the scene). Sources of noise typically include detector shot noise, thermal noise, and readout noise terms. Since these terms include shot noise, a uniform scene brightness temperature must be specified.

Noise Equivalent Delta Temperature (NEdT) [K] is the NER in terms of temperature units. The NEdT is defined as NER divided by the radiance derivative with respect to temperature. The NEdT is a value, which depends on the temperature of the scene being observed.

Radiance is a measure of the flux per unit area per unit solid angle. The units typically used for radiance are [mW / (m^2·sr)].

Scene Brightness Temperature is the effective temperature of the scene being viewed. This temperature differs from the radiance temperature of the surface due to emissivity, reflectance, and atmospheric attenuation of the radiation. The scene brightness temperature is a function of wavelength and is related to spectral radiance through Planck's function.

Spectral Radiance is a measure of Radiance per unit spectral bandwidth. The units typically used for spectral radiance are [mW / (m^2·sr·μm)] or [mW / (m^2·sr·cm^{-1})].

3.2 Acronyms

APS	Active Pixel Sensor
ASP	Analog Signal Processor
BIS	Baseline Interferometer Scan
CrIS	Cross-track Infrared Sounder
CM	Control Module
FTS	Fourier Transform Spectrometer
GIFTS	Geostationary Imaging FTS
GIRD	GIFTS Instrument Requirements Document
IGM	Interferogram
IR	Infrared
ITT	ITT Industries
LW	Longwave
MW	Midwave
NEdN	Noise Equivalent Change in Radiance
NEdT	Noise Equivalent Delta Temperature
NEN	Noise Equivalent Radiance
NER	Noise Equivalent Radiance
NESR	Noise Equivalent Spectral Radiance
OPD	Optical Path Difference
RD	Reference Document
SDL	Space Dynamics Laboratory
SM	Sensor Module
SW	Shortwave
TBR	To Be Resolved

4 Introduction

The GIFTS instrument is a cryogenically cooled Fourier Transform Spectrometer (FTS). The output of the interferometer is directed to two infrared (IR) focal plane arrays (FPAs). There are a number of ways that the measurements made by the GIFTS instrument could be distorted by noise. The purpose of this document is to identify, categorize, and define the relationships between the GIFTS interferometric noise sources. Where possible, the noise sources will be quantified to form a noise budget, and a method of verification will be identified. For the scope of this document, interferometric noise is defined as all noise sources associated with non-ideal interferometer performance.

4.1 GIFTS System Hierarchy

The GIFTS instrument consists of three subsystems (refer to Figure 1): the sensor module (SM), the control module (CM), and the star tracker. Also included in the Sensor Module, though not explicitly represented in Figure 1, are the mirror drive and alignment controller, the laser and metrology controller, and the numerical filter and decimation module. Refer to Appendix A for a functional diagram of the Sensor and Control Modules [RD5].

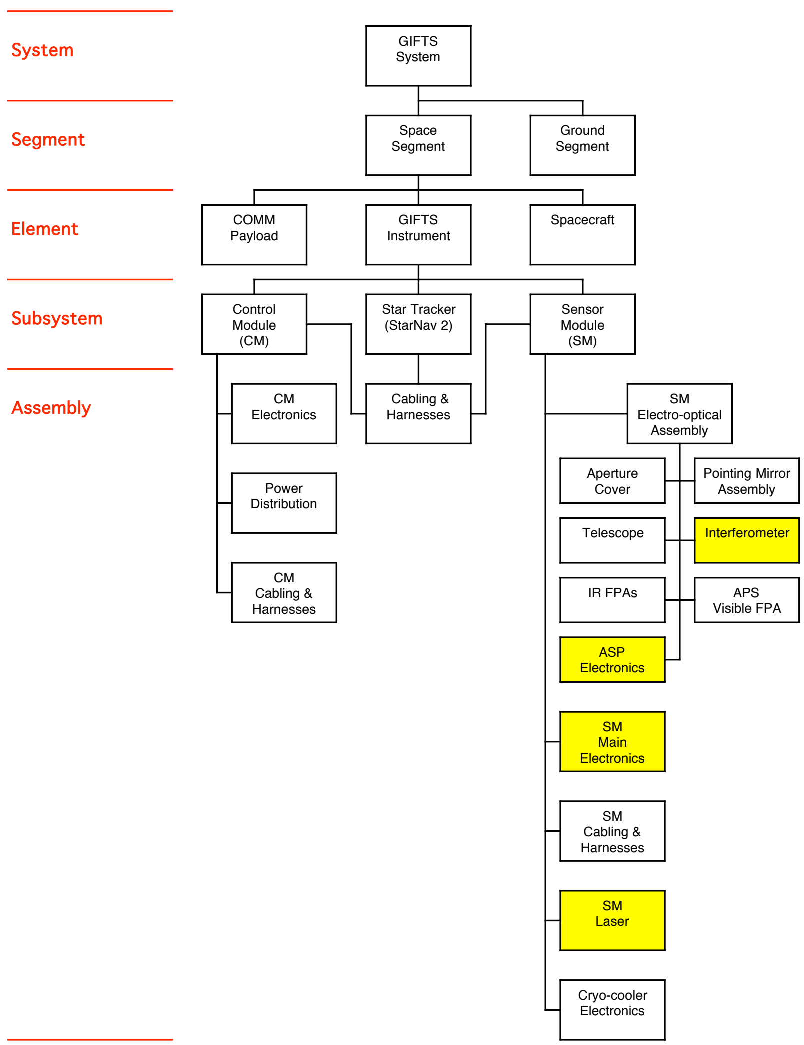

Figure 1: GIFTS system hierarchy. Interferometric noise relevant sub-assemblies are highlighted.

4.2 GIFTS Instrument Requirements

The GIFTS instrument requirements pertaining to the performance of the SW/MW IR and LW IR wavebands are summarized in Table 1. The IR Sensitivity requirement specifies the acceptable level of total noise for the SW/MW IR and the LW IR. Interferometric errors must be accounted for within this total noise specification.

Table 1: GIFTS SW/MW IR and LW IR spectral range, resolution, and sensitivity requirements.

Requirement	Value
Spectral Range	SW / MW IR: 1650 – 2250 cm^{-1} LW IR: 685 – 1130 cm^{-1}
Spectral Resolution	Seven spectral resolutions related as 2^k point interferograms or spectra from approximately 0.6 cm^{-1} – 38.4 cm^{-1} (TBR)
IR Sensitivity	LW IR NESR ≤ 0.4 [0.2 objective] $mW/m^2 \cdot sr \cdot cm^{-1}$ for ν > 700 cm^{-1}, for BIS for scenes with total flux ≤ 276 K blackbody temperature SW/MW IR NESR ≤ 0.06 $mW/m^2 \cdot sr \cdot cm^{-1}$ for BIS for scenes with total flux ≤ 260 K blackbody temperature

4.3 GIFTS Sensor Module Noise

Several noise sources contribute to the total NESR for the SW/MW IR and LW IR wavebands. For the purpose of this document, the total noise for the SW/MW and LW IR wavebands is referred to as Level 1 noise. Level 1 noise is subdivided into Level 2 noise sources, each Level 2 source into Level 3 sources, etc. Figure 2 illustrates the Level 2 sources of noise for the SW/MW and LW IR wavebands. Interferometer specific noise is presented in detail in §5. Other Level 2 noise sources are summarized below.

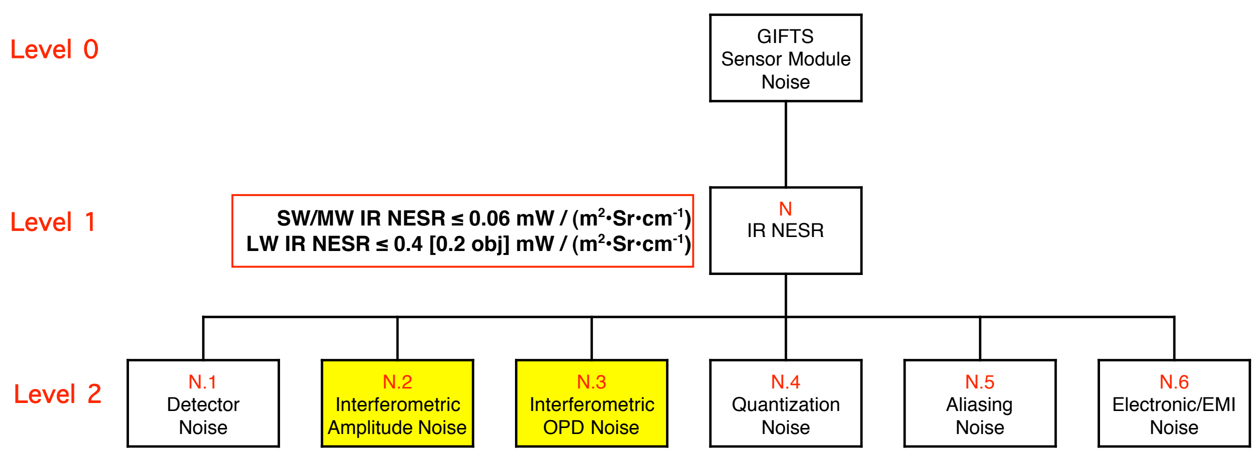

Figure 2: The GIFTS SM error tree (N = 1 for SW/MW IR, N = 2 for LW IR). The Level 1 NESR specification is outlined in red.

1. Detector Noise – Noise due directly to the detection of photons at the detector, including detector preamplifier effects. Typically, detector noise is greater than the noise from all other sources combined.
2. Interferometric Amplitude Noise – Refer to §5.1.

3. Interferometric Optical Path Difference Noise – Refer to §5.2.
4. Quantization Noise – Noise associated with the transformation of the analog signal to a digital signal, and FIR filter decimation of the digital signal. Low frequency drifts/scene changes push the interferograms up and down the nonlinearity curve, but are not detectable after processing by the digital filter. For GIFTS the following DC level values will be recorded for each pixel, per scan, prior to filtering and decimation:

   - beginning of scan DC level;
   - end of scan DC level;
   - minimum DC level and corresponding sample number;
   - maximum DC level and corresponding sample number.

   This DC level information will be used for first order correction of quantization noise.
5. Aliasing Noise – Contamination of the in-band signal by out-of-band signal. Fourier Transform Spectrometer (FTS) systems measure spatial frequencies of spectral data. When the data is Fourier transformed to the spectral domain from the spatial domain, higher order spatial frequencies may be aliased into the band of interest. Components that can alias signal in-band include the analog to digital converter, the FIR filter, and the low pass filter.
6. Electronic / EMI Noise – Noise due to electronic components, other than the detector and preamplifier, and electromagnetic interference.

5 GIFTS Interferometric Noise

Interferometric amplitude NEN and interferometric OPD NEN trees for the GIFTS instrument are presented in Figure 3 and Figure 5, respectively. The noise trees schematically illustrate the interferometric noise sources, categories, and relationships. Both trees are divided into levels:

1. **Level 2: Total Interferometric Amplitude Noise, Total Interferometric OPD Noise**. Level 2 interferometric noise includes the contribution from all interferometric noise sources, and is mathematically quantifiable as Total Interferometric Amplitude NEN, and Total Interferometric OPD NEN for characteristic scene spectra (TBD). Characteristic scene spectra will be chosen to represent typical polar, mid-latitude, and tropical scene observations. Raw, uncalibrated characteristic spectra will be used to ensure representation of the calibration process.
2. **Level 3: Noise concepts and/or models.** Level 3 elements are noise effects that may be determined by a mathematical or engineering model.
3. **Level 4: Parameters/specifications.** Level 4 elements are the input parameters into the level 3 models, or are considered as error limits as determined from flowing upper level requirements down the tree.

5.1 Interferometric Amplitude Noise

NEN Tree Reference: N.2

For the scope of this document, interferometric noise that induces amplitude modulation errors will be referred to as *interferometric amplitude noise*.

Two methods of determining sample position have been baselined for GIFTS:

1. **Constant Δt sampling** – A laser zero crossing triggers the beginning of the sample interval, and the sample interval is of fixed duration.

2. **Constant Δx sampling** – The beginning and end of the sample interval are triggered by laser zero crossings.

The exact effect of metrology errors and OPD velocity variation errors will depend on the method used to determine sample position. In Figure 3, OPD velocity variation induced error is divided into two independent branches, one for constant Δt sampling, and one for constant Δx sampling.

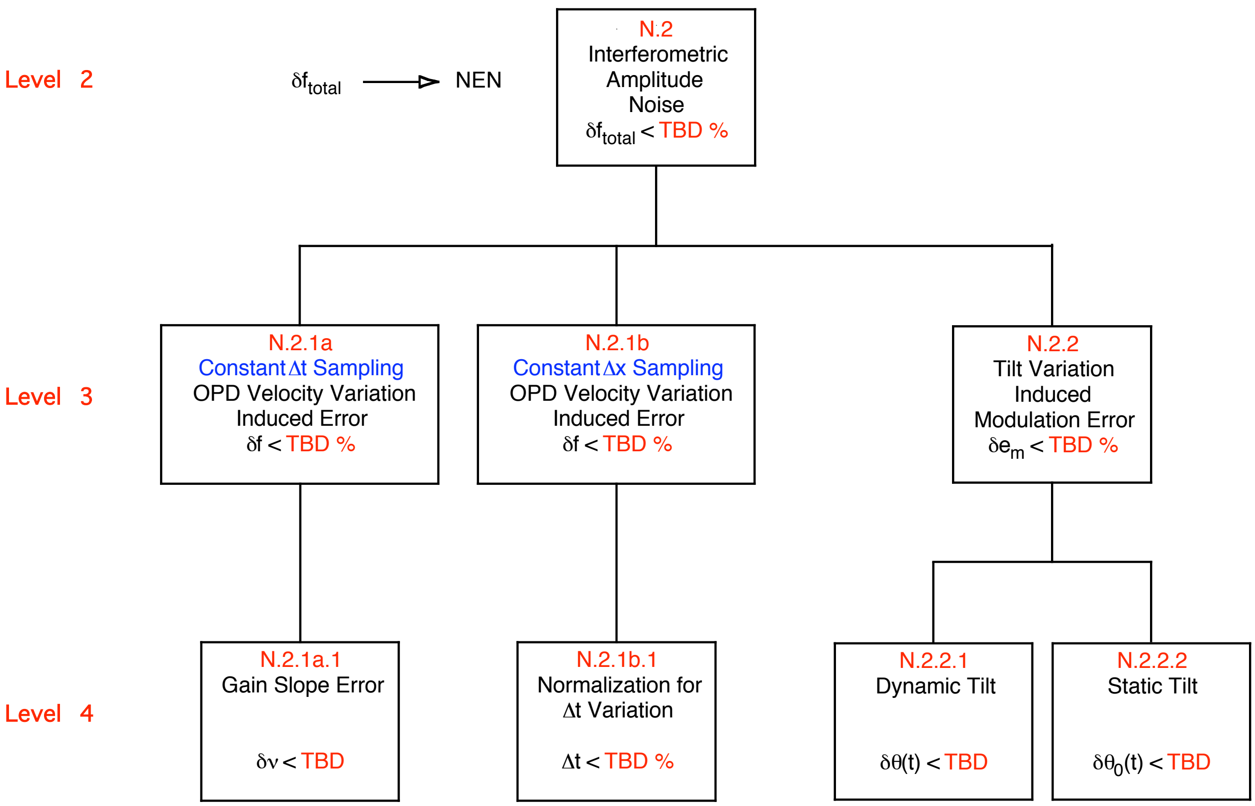

Figure 3: A GIFTS interferometric amplitude NEN tree (N = 1 for SW/MW IR, N = 2 for LW IR).

5.1.1 Constant Δt Sampling OPD Velocity Variation Induced Error

NEN Tree Reference: N.2.1a
Input Parameters:
1. Gain Slope Error (N.2.1a.1)

For constant Δt sampling, amplitude modulation errors arise from the corresponding Sinc Function frequency response when the OPD scan velocity changes [RD2].

A given wavenumber, ν, (optical frequency) is related to the electrical frequency, f, by:

$$\nu = \frac{f}{v_0}$$

where v_0 is the OPD velocity.

Accordingly, a variable velocity can be thought of as moving the optical spectrum back and forth under the frequency gain curve.

Model results for the baseline GIFTS design with random 0.5% SD velocity variations, and 1% amplitude pure frequency velocity variations are presented in RD2.

5.1.2 Constant Δx Sampling OPD Velocity Variation Induced Error

NEN Tree Reference: N.2.1b
Input Parameters:
1. **Normalization for Δt Variation (N.2.1b.1)**

For constant Δx sampling, OPD velocity variation causes integration time to vary per sample interval. Nonlinearity correction errors result in noise due to integration time correction.

However, on GIFTS integration time will be very accurately measured for each sample interval, and it is expected that the error in the measurement of the integration time will be insignificant. Therefore, gain correction may be applied to each sample interval, with normalization based on the ratio of actual integration time to optimum integration time for each sample interval.

5.1.3 Tilt Variation Induced Modulation Error

NEN Tree Reference: N.2.2
Input Parameters:
1. **Dynamic Tilt (N.2.2.1)**
2. **Static Tilt (N.2.2.2)**

Total wavefront tilt consists of a combination of static tilt and dynamic tilt. Static tilt is the component of the wavefront misalignment that is reproducible (including 'wobble'), while dynamic tilt is the 'random' component of the wavefront misalignment and is usually vibration induced.

Static tilt arises mainly from the mismatch of beamsplitter and compensator wedges, and is a product of optical refraction. Therefore, it is constant over time, independent of OPD, but dependent on wavenumber. Dynamic tilt is a geometric effect. Thus, it is independent of wavenumber, but dependent on OPD (and accordingly time) [RD4].

Wavefront tilts create radiometric errors by causing interferogram amplitude modulation reduction and OPD (sample position) errors. Modulation error is discussed here, while tilt induced OPD error is presented in §5.2.2.

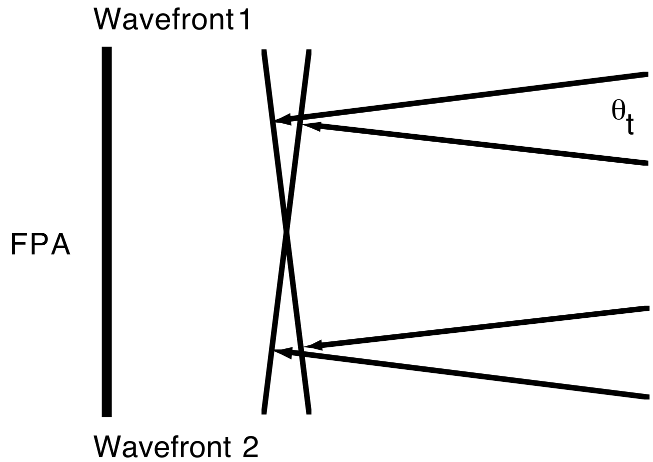

Figure 4: 1-dimensional schematic diagram of wavefront alignment error. Alignment error (θ_t) is typically on the order of microradians, but has been exaggerated here for clarity.

The amplitude modulation due to wavefront alignment error for a circular beam is given by [RD3, RD4]:

$$I(\hat{x},\theta_t) = \frac{2J_1(2\pi\nu R\theta_t)}{2\pi\nu R\theta_t} I_0(\hat{x}), \tag{1}$$

which may be estimated by:

$$I(\hat{x},\theta_t) \cong [1 - \frac{1}{2}(\pi\nu R\theta_t)^2] I_0(\hat{x}), \tag{2}$$

where $I(\hat{x},\theta_t)$ is the tilt modulated interferogram amplitude,
$I_0(\hat{x})$ is the tilt free interferogram amplitude,
$\hat{x}$ is the optical path difference (OPD) between the two wavefronts,
θ_t is the total tilt (static and dynamic),
R is the radius of the circular beam
J_1 is the first Bessel function, and
ν is the wavenumber.

For the general case of a total tilt expressed with respect to an arbitrary Cartesian coordinate system with orthogonal axes x and y:

$$\theta_t = \sqrt{\theta_{t_X}{}^2 + \theta_{t_Y}{}^2}, \tag{3}$$

$$\theta_t = \sqrt{[\theta_{X0}(\nu) + \theta_X(\hat{x})]^2 + [\theta_{Y0}(\nu) + \theta_Y(\hat{x})]^2}, \tag{4}$$

$$\theta_t = \sqrt{\theta_0{}^2(\nu) + \theta^2(\hat{x}) + 2[\theta_{X0}(\nu)\theta_X(\hat{x}) + \theta_{Y0}(\nu)\theta_Y(\hat{x})]}, \tag{5}$$

where $\theta_0(\nu)$ is the total static tilt,
$\theta_{X0}(\nu)$ is the x-component of the static tilt,
$\theta_{Y0}(\nu)$ is the y-component of the static tilt,
$\theta(\hat{x})$ is the total dynamic tilt,
$\theta_X(\hat{x})$ is the x-component of the dynamic tilt, and
$\theta_Y(\hat{x})$ is the y-component of the dynamic tilt.

To simplify the calculation of tilt induced amplitude modulation, consider a coordinate system instantaneously aligned with the tilt plane such that:

$$\theta_t = \theta_{t_X} = \theta_{X0}(\nu) + \theta_X(\hat{x}), \tag{6}$$

therefore:

$$I(\hat{x},\theta_t) = \frac{2J_1[2\pi\nu R[\theta_{X0}(\nu) + \theta_X(\hat{x})]]}{2\pi\nu R[\theta_{X0}(\nu) + \theta_X(\hat{x})]} I_0(\hat{x}) \tag{7}$$

As a numerical example for the calculation of tilt induced amplitude modulation error a static tilt, $\theta_{X0}(\nu)$, of *5 μrad*, and a dynamic tilt, $\theta_X(\hat{x})$, of *2 μrad* have been assumed. For GIFTS, the beam radius at the fixed mirror is *R = 2 1/8"*. For these values, equation (7) yields:

Wavenumber [cm^{-1}]	**750**	**1000**	**1800**	**2200**
% error	0.396%	0.701%	2.265%	3.371%
B(300) [mW/m^2·sr·cm^{-1}]				
δB SD [mW/m^2·sr·cm^{-1}]				
NEN Spec [mW/m^2·sr]	0.20	0.20	0.060	0.060
NEN Model [mW/m^2·sr]				

As stated in RD2:

> *The specification on tilt reproducibility is very strongly dependent on the static tilt and could be significantly relaxed if the static tilt could be kept substantially less than 5 μrad. For larger static tilts, the total error is approximately proportional to the static tilt.*

The GIFTS dynamic tilt actually will likely be of the order of 0.5 *μrad*.

5.2 Interferometric OPD Noise

NEN Tree Reference: N.3

For the scope of this document, interferometric noise induced by optical path difference (sample position) errors will be referred to as *interferometric OPD noise*.

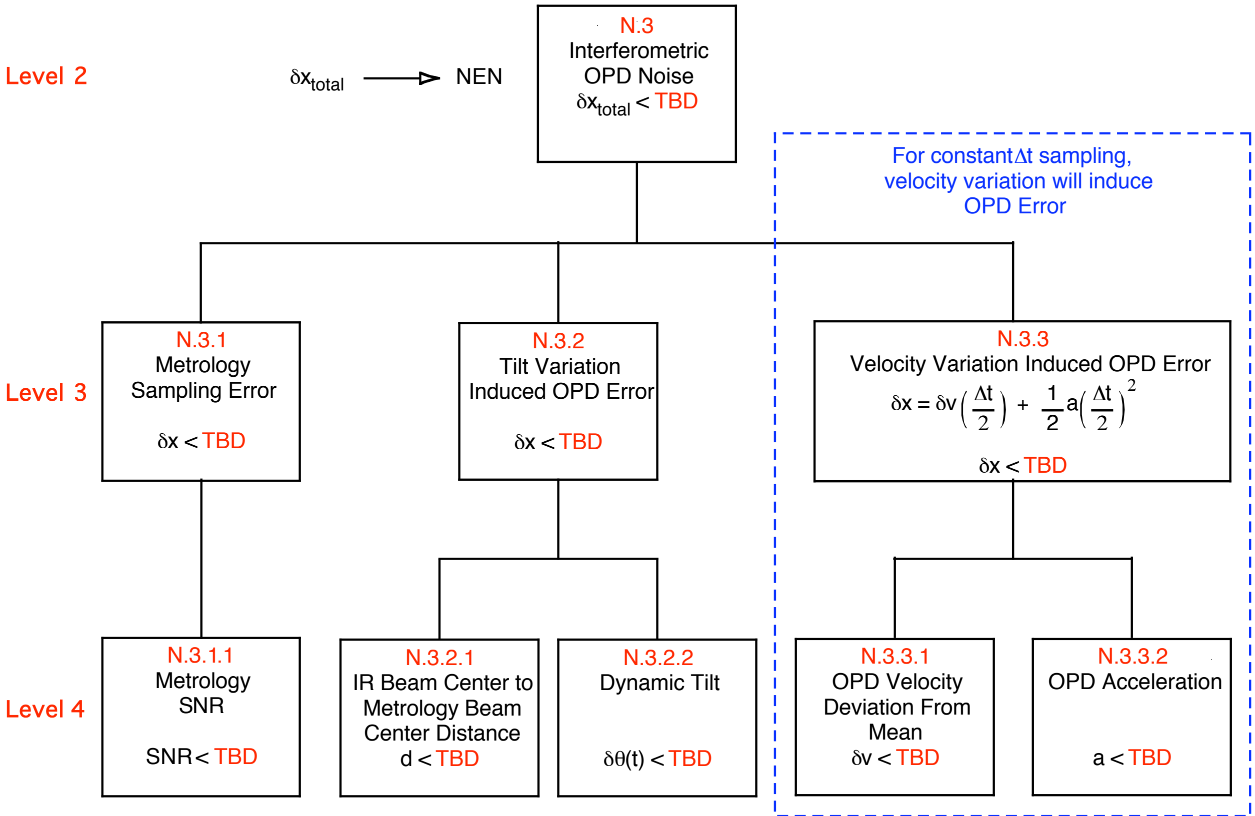

Figure 5: A GIFTS interferometric OPD NEN tree (N = 1 for SW/MW IR, N = 2 for LW IR).

5.2.1 Metrology Sampling Error

NEN Tree Reference: N.3.1
Input Parameters:
1. Metrology SNR (N.3.1.1)

If the interferogram is not sampled at precisely equal intervals for precisely equal integration times, the signal that is measured is different from the signal that should have been sampled according to information theory. Accordingly, the noise level of the calculated spectrum is increased.

Table 2: Laser metrology subsystem specifications; TSAT laser.

Specification	Value
Laser type:	
Operation wavelength:	
Optical power:	
Frequency drift:	≤
Frequency drift:	≤
Frequency jitter:	≤
Lifetime:	>
Spatial mode:	
Line width:	<
Amplitude noise:	<

5.2.2 Tilt Variation Induced OPD Error

NEN Tree Reference: N.3.2
Input Parameters:
1. **IR Beam Center to Metrology Beam Center Distance (N.3.2.1)**
2. **Dynamic Tilt (N.3.2.2)**

If the center of the IR beam in the interferometer is displaced from the location of the center of the metrology laser, tilt causes the mean OPD for each waveband sample to differ from the uniformly spaced sample positions triggered by laser signal zero-crossings. Because the aperture stop for the GIFTS instrument is at the Michelson mirror, first order tilt-induced sample position errors for off-axis pixels should not be significant. However, second order effects should be considered.

5.2.3 Velocity Variation Induced OPD Error

NEN Tree Reference: N.3.3
Input Parameters:
1. **OPD Velocity Deviation from Mean (N.3.3.1)**
2. **OPD Acceleration (N.3.3.2)**

For constant Δt sampling:

1. Velocity variation may result in inability to integrate for full integration period;
2. Average position of sample varies with velocity.

The velocity variation induced OPD error is given by:

$$\delta x = \delta v\left(\frac{\Delta t}{2}\right) + \frac{1}{2}a\left(\frac{\Delta t}{2}\right)^2 \quad (8)$$

where δx is the optical path difference,
δv is the OPD velocity variation,
a is the OPD acceleration, and
Δt is the integration period.

5.3 GIFTS Interferometric Noise Budget

5.3.1 SW/MW IR Interferometric Noise Budget

Table 3: SW/MW IR FTS error budget

Level	NEN Tree Ref. No.	Error Description	Value	Rationale and Verification Method
1	1	SW/MW IR NESR	≤ 0.06 [mW/m^2•sr•cm^{-1}]	**Rationale:** Specified for BIS for scenes with total flux ≤ 260 K blackbody temperature. **Verification:** TBD
2	1.2	SW/MW Interferometric Amplitude Noise	NEN ≤ TBD [mW/m^2•sr]	**Rationale:** TBD **Verification:** TBD
3	1.2.1a	SW/MW Constant Δt Sampling OPD Velocity Variation Induced Error	δf ≤ TBD %	**Rationale:** TBD **Verification:** TBD
4	1.2.1a.1	SW/MW Gain Slope Error	$\delta \nu$ ≤ TBD [cm^{-1}]	**Rationale:** TBD **Verification:** TBD
3	1.2.1b	SW/MW Constant Δx Sampling OPD Velocity Variation Induced Error	δf ≤ TBD %	**Rationale:** TBD **Verification:** TBD
4	1.2.1.b.1	SW/MW Normalization for Δt Variation	δt ≤ TBD %	**Rationale:** TBD **Verification:** TBD
3	1.2.2	SW/MW Tilt Induced Modulation Error	δe_m ≤ TBD %	**Rationale:** TBD **Verification:** TBD
4	1.2.2.1	SW/MW Static Tilt	$\delta\theta(t)$ ≤ TBD [μrad]	**Rationale:** TBD **Verification:** TBD
4	1.2.2.2	SW/MW Dynamic Tilt	$\delta\theta_0(t)$ ≤ TBD [μrad]	**Rationale:** TBD **Verification:** TBD
2	1.3	SW/MW Interferometric OPD Noise	NEN ≤ TBD [mW/m^2•sr]	**Rationale:** TBD **Verification:** TBD
3	1.3.1	SW/MW Metrology Sampling Error	δx ≤ TBD	**Rationale:** TBD **Verification:** TBD
4	1.3.1.1	SW/MW Metrology SNR	SNR ≤ TBD	**Rationale:** TBD **Verification:** TBD
3	1.3.2	SW/MW Tilt Induced OPD Error	δx ≤ TBD [m]	**Rationale:** TBD **Verification:** TBD
4	1.3.2.1	SW/MW IR Beam Center to Metrology Beam Center Distance	d ≤ TBD [m]	**Rationale:** TBD **Verification:** TBD
4	1.3.2.2	SW/MW Dynamic Tilt	$\delta\theta(t)$ ≤ TBD [μrad]	**Rationale:** TBD **Verification:** TBD
3	1.3.3	SW/MW Velocity Variation Induced OPD Error	δx ≤ TBD [m]	**Rationale:** TBD **Verification:** TBD
4	1.3.3.1	SW/MW OPD Velocity Deviation from Mean	δv ≤ TBD [m/s]	**Rationale:** TBD **Verification:** TBD
4	1.3.3.2	SW/MW OPD Acceleration	a ≤ TBD [m/s^2]	**Rationale:** TBD **Verification:** TBD

5.3.2 LW IR Interferometric Noise Budget

Table 4: LW IR FTS error budget.

Level	NEN Tree Ref. No.	Error Description	Value	Rationale and Verification Method
1	2	LW IR NESR	≤ 0.4 ≤ 0.2 obj [mW/m^2•sr•cm^{-1}]	**Rationale:** Specified for BIS for scenes with total flux ≤ 260 K blackbody temperature. **Verification:** TBD
2	2.2	LW Interferometric Amplitude Noise	NEN ≤ TBD [mW/m^2•sr]	**Rationale:** TBD **Verification:** TBD
3	2.2.1a	LW Constant Δt Sampling OPD Velocity Variation Induced Error	δf ≤ TBD %	**Rationale:** TBD **Verification:** TBD
4	2.2.1a.1	LW Gain Slope Error	$\delta\nu$ ≤ TBD [cm^{-1}]	**Rationale:** TBD **Verification:** TBD
3	2.2.1b	LW Constant Δx Sampling OPD Velocity Variation Induced Error	δf ≤ TBD %	**Rationale:** TBD **Verification:** TBD
4	2.2.1.b.1	LW Normalization for Δt Variation	δt ≤ TBD %	**Rationale:** TBD **Verification:** TBD
3	2.2.2	LW Tilt Induced Modulation Error	δe_m ≤ TBD %	**Rationale:** TBD **Verification:** TBD
4	2.2.2.1	LW Dynamic Tilt	$\delta\theta(t)$ ≤ TBD [μrad]	**Rationale:** TBD **Verification:** TBD
4	2.2.2.2	LW Static Tilt	$\delta\theta_0(t)$ ≤ TBD [μrad]	**Rationale:** TBD **Verification:** TBD
2	2.3	LW Interferometric OPD Noise	NEN ≤ TBD [mW/m^2•sr]	**Rationale:** TBD **Verification:** TBD
3	2.3.1	LW Metrology Sampling Error	δx ≤ TBD [m]	**Rationale:** TBD **Verification:** TBD
4	2.3.1.1	LW Metrology SNR	SNR ≤ TBD	**Rationale:** TBD **Verification:** TBD
3	2.3.2	LW Tilt Induced OPD Error	δx ≤ TBD [m]	**Rationale:** TBD **Verification:** TBD
4	2.3.2.1	LW IR Beam Center to Metrology Beam Center Distance	d ≤ TBD [m]	**Rationale:** TBD **Verification:** TBD
4	2.3.2.2	LW Dynamic Tilt	$\delta\theta(t)$ ≤ TBD [μrad]	**Rationale:** TBD **Verification:** TBD
3	2.3.3	LW Velocity Variation Induced OPD Error	δx ≤ TBD [m]	**Rationale:** TBD **Verification:** TBD
4	2.3.3.1	LW OPD Velocity Deviation from Mean	δv ≤ TBD [m/s]	**Rationale:** TBD **Verification:** TBD
4	2.3.3.2	LW OPD Acceleration	a ≤ TBD [m/s^2]	**Rationale:** TBD **Verification:** TBD

Appendix A: SM and CM Functional Diagram [RD5]

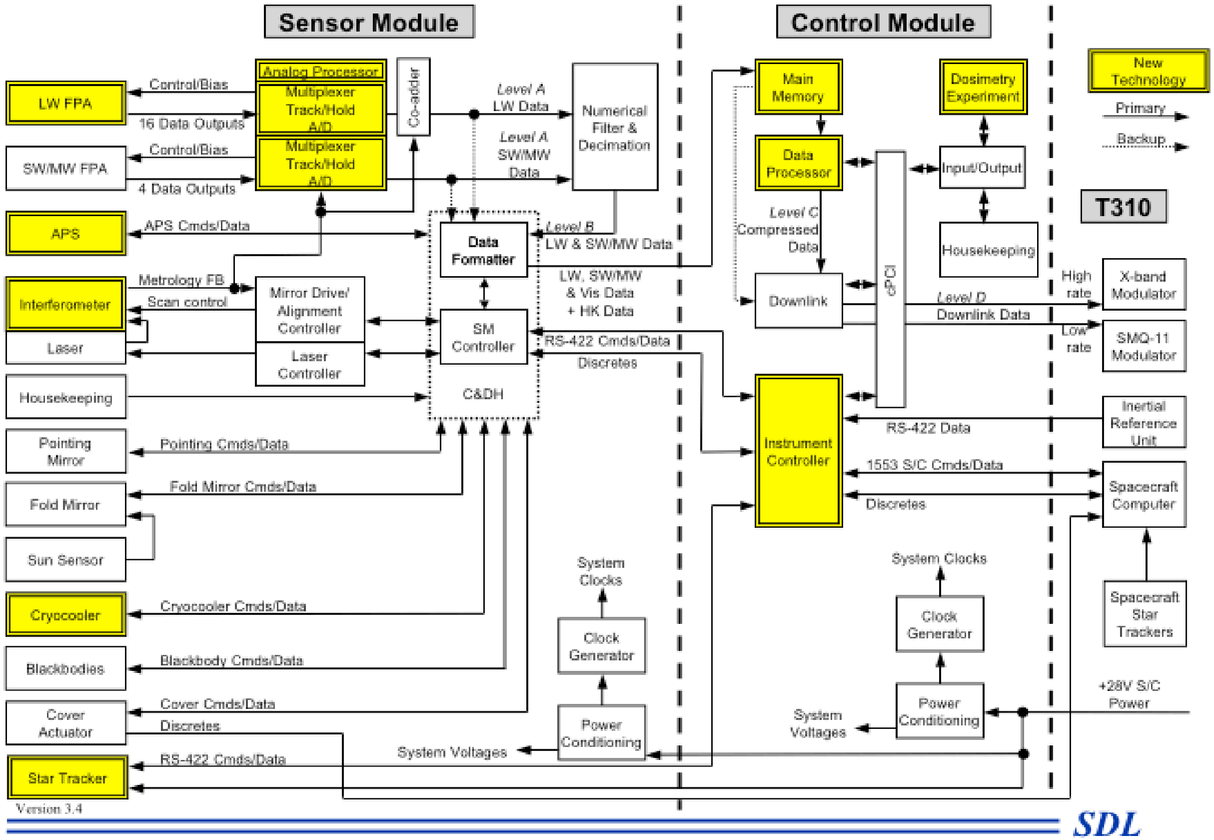

Figure 6: Sensor and Control Modules functional diagram [RD5].