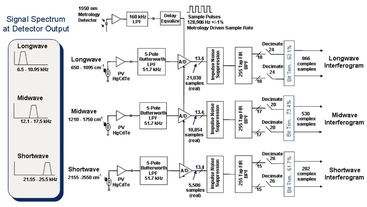
Cross Track Infrared Sounder (CrIS) Sensor Calibration and Signal Processing Methods

J. Predina[1], L. Suwinski[1], C. Buttles[1], R. Frain[1], Y. Qu[1], S. Wells[1], M. Cromp[1], R. Glumb[1]
D. Hagan[2], C. Wang[2], D. Gu[2], R. Poulin[3], S. Lantagne[3], S. Levesque[3]

Affiliations: [1] ITT Geospatial Systems, Fort Wayne, Indiana, USA
[2] Northrup Grumman Aerospace Systems, Redondo Beach, California USA
[3] ABB Bomem, Quebec, Canada

ON ORBIT PROCESSING

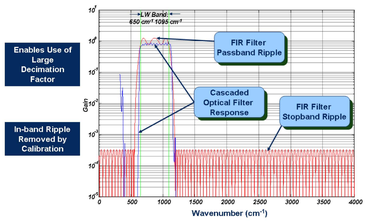
Detected Signal Is Sampled, Filtered, Decimated & Bit Trimmed to Reduce Data Rate



Optical & Digital Filters Yield High Stop Band Rejection

Enables Use of Large Decimation Factor

In-band Ripple Removed by Calibration



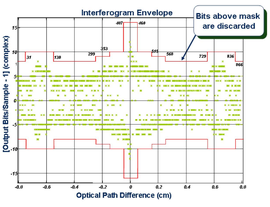
Bit Trimming of Filtered & Decimated Interferograms Further Reduces Data Rate

Bit Trimming Allows CrIS to Meet Bandwidth Requirements

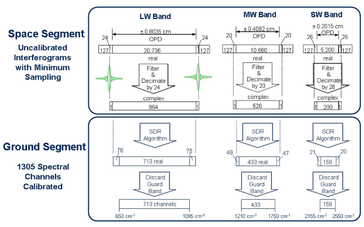
No Loss of Information

On-orbit Programmable Mask

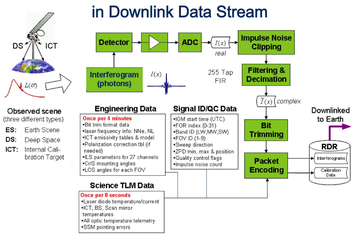
Data After Trim:
63.1% in the LW
73.4% in the MW
61.7% in the SW



1305 Calibrated Spectral Channels Per FOV



All CrIS Calibration Parameters Are Embedded in Downlink Data Stream



Radiometric & Spectral Calibration/Correction Is Performed By Ground Algorithms

Functional Requirements

- Perform Calibrations
  - Radiometric (complex gain and offset)
  - Wavelength calibration……(once per orbit)
  - Spectral correction of ILS distortion
  - Geo-location (FOV line of sight relative to spacecraft body)
- Remove Sensor Unique Signature
  - Map spectra to fixed channel centers ….(all 9 FOVs)
  - Same spectral response shape for all channels within a band)

Quantitative Requirements

- Calibration Uncertainty (SDRs)

	LWIR	MWIR	SWIR	Relative to:
Radiometric gain	0.45%	0.58%	0.77%	287 K BB
Channel center	10 ppm	10 ppm	10 ppm	wavenumber
ILS width [main lobe]	1.5%	1.5%	1.5%	true FWHM
Geo-location	1.5 km	1.5 km	1.5 km	edge of scan

GROUND PROCESSING

Calibration Process Begins with QC Checks, Unpacking Data & Computing Laser Metrology Wavelength from Neon Reference

RDR Preprocessing
✓Accept interferogram, science telemetry & engineering data packets…. reject other packets
✓CCSDS & bit trim decoding
✓Calibrate metrology laser wavelength from neon data
✓Perform Quality Control Tests
✓Fail bit trim
✓Impulse noise count
✓Invalid interferogram
✓Correct laser wavelength for temperature & bias (if needed)
✓Flag excessive optical temperature drift

30 Neon Calibration Sweeps Averaged Once per Orbit

>2 ppm Metrology Wavelength Drift Detected & Corrected

Metrology Fringe Count Error Handling Assures that Calibration & Earth Scene Data Have Same Alignment

Each Complex Spectrum Checked for Phase Alignment
- ICT and DS phases synchronized during algorithm initialization
- Subsequent ICT or DS spectrum phase compared against "moving window average" phase
- Calibrated Earth Scene spectrum phase checked to flag any deviation from desired zero phase result

FFT Bin Phases Are Adjusted To Maintain Alignment (if needed)
- ICT and DS spectra are corrected before being used in the moving average
- Moving average is adjusted to match phase in earth scene being calibrated

SDR Algorithm Maintains Radiometric Calibration For Each Detector Channel & Sweep Direction Separately

Radiometric Calibration
✓Average 30 warm target spectra
✓Average 30 cold target spectra
✓Subtract background radiance
✓Remove phase dispersion
✓Calibrate sensor gain
✓Reject orthogonal noise
✓Compute warm target radiance

Calibration Equation

$$L^{corr} = \frac{\bar{S}_s^{corr} - \langle \bar{S}_c^{corr} \rangle}{\langle \bar{S}_w^{corr} \rangle - \langle \bar{S}_c^{corr} \rangle} L^{corr}_{target}$$

ICT temperature (2)
ICT emissivity (1305+)
Optic temperatures
Housing & Baffle temperature
Environment geometry
Environment surface emissivity
→ ICT Radiance Calculation Corrected for Surrounding Environment Reflections & ICT Emissivity

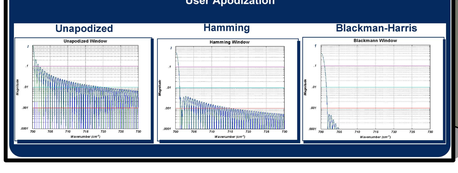
After Radiometric Calibration, Spectral Distortion Is Removed & Channels Are Re-sampled to User Grid

Spectral Distortions Due To Off-Axis Geometry Are Removed So All FOVs Have Same Spectral Response

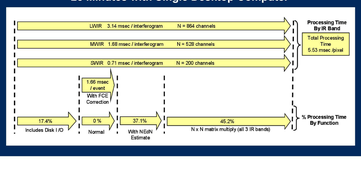
Spectral Re-sampling Places Output Channels on Fixed Grid

- Post Calibration Filter
- Spectrum Resampled To Specified User Grid
- ILS Effects Are Modeled and Removed
  - FOV offset From Interferometer Axis
  - FOV size
  - Modulation Loss vs OPD
- User Apodization
  - None
  - Hamming
  - 3-term Blackman-Harris
- Discard Guard-Bands

SDR Spectral Response Shape Is Selectable by Applying a User Apodization



SDR Algorithm Processes 1.25 Orbits of Data in Less than 25 Minutes with Single Desktop Computer

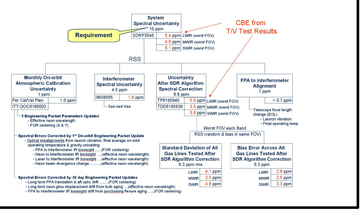


Raw Sensor Data → Pre-Process RDR's → Un-calibrated Interferograms → DFT → Sort Data & FCE → Un-calibrated Spectra (ICT, ES, DS) → Non-Linearity Correction → Radiometric Calibration (ES ← Radiometrically Calibrated) → Post Calibration BPF → Map Spectral Channels to User Grid → Correct ILS & Apply User Apodization (Spectrally Corrected) → Geolocate → SDR Output

Interferograms Then Converted to Un-calibrated Spectra

Convert Interferograms to Spectra
✓Discrete Fourier Transform (DFT)
✓Unwrap DFT
✓Label channel centers

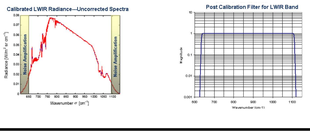
CrIS Meets 10 ppm Spectral Uncertainty Requirement



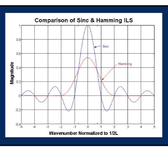
Non-Linearity Correction Also Implemented

- Based on method developed by University of Wisconsin (U of W)
  - Correction has been applied to U of W AERI, S-HIS, and NAST-I data
- Method corrects for radiometric non-linearity due to second-order non-linearity in detector response
  - Uses out-of-band response and blackbody data taken over a range of temperatures to characterize nonlinear behavior
- Allows CrIS to meet spec with margin in nearly all instrument channels

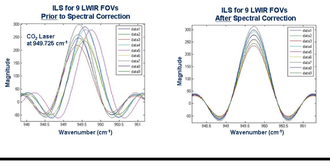
Post Calibration Filter eliminates Guard Band Noise & Enables Artifact Free Spectral Correction



CrIS ILS Sidelobe Suppression can be Traded for Spectral Resolution



Spectral Correction Produces Identical ILS in All 9 FOVS with Channel Center Mapped Onto User Grid



RESULT

Summary

- CrIS SDR Algorithm provides comprehensive end-to-end spectral and radiometric calibration of CrIS data products
- Key Features Include:
  - Complex radiometric calibration
  - Spectral distortion removal
  - Spectral correction using neon lamp system
  - Fringe Count Error corrections
  - Non-linearity correction
- CrIS FM1 spectral accuracy performance is excellent
  - Approximately one-half the required 10 ppm requirement at on-orbit End of Life