True CrIS ILS - Consequences of Unapodized SDR Processing

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Introduction – True CrIS ILS

- It is desirable for interferometer systems to produce an unapodized ideal Sinc ILS after completion of all SDR calibration operations.
- Deviation from ideal Sinc ILS (excess spectral ringing) is common in FTS systems.
- Spectral Ringing can be caused by many factors.
- Suppression of Sinc ILS sidelobes & other forms of spectral ringing is commonly achieved by applying an external apodization function such as Hamming or Blackman-Harris.
NPP SDR Processing
Radiometric Calibration Precedes Spectral Correction – Hamming Applied in EDR

CrIS On-orbit Signal Processing
(Level 0)

- Preamp
- A/D
- Truncate

SDR Algorithm Signal Processing
(Level 1b)

- Nonlinearity correction
  \( \frac{S_{ES} - S_{SP}}{S_{ICT} - S_{SP}} \)
- BPF
- Spectral Resampling
- Self Apodization Correction
- ICT Radiance Model
- Radiometric Calibration
- Spectral Correction

EDR Algorithm Signal Processing

- Hamming Apodization
- Retrieve Atmospheric Profiles

Filtered, decimated & bit trimmed Interferograms (1.5 Mbps Downlink)
Sidelobe Spectral Ringing Typically Suppressed with Apodization Function

**Sidelobe Magnitude for Various Apodizations**

- **Sinc**
- **Hamming**
- **Blackman-Harris (3 term)**
- **Blackman Harris (4 term)**

**Main Lobe Resolution for Various Apodizations**

- **Hamming**: 25x Better

**ILS Sidelobe Uncertainty Also Reduced when Using Apodization Functions**
Can Current Hamming Apodization Be Eliminated?
CrIS CAL/VAL Team **Focus Areas**

for Reducing Spectral Ringing & Improving ILS Knowledge

CrIS On-orbit Signal Processing

*Level 0*

- Scan Mirror
- FTS
- aft optics & filters
- Detector
- LPF
- A/D
- Decimate & Bit Trim

**Filtered, decimated & bit trimmed Interferograms (1.5 Mbps Downlink)**

**CrIS On-orbit Signal Processing**

- Earth Scenes
- Cal Target
- Space

**SDR Algorithm Signal Processing**

*Level 1b*

- DFT & Alias Unfold
- Nonlinearity correction
- ICT Radiance Model
- BPF
- Spectral Resampling
- Self Apodization Correction

**Radiometric Calibration**

**Spectral Correction**

**EDR Algorithm Signal Processing**

- Hamming Apodization
- Retrieve Atmospheric Profiles

**Star JPSS Science Team Meeting 8/9/2016**

True CrIS ILS – Consequences of Unapodized SDR Processing
Reordering of NPP CrIS SDR Calibration Operations Will Improve ILS Knowledge for J1 Instrument

- Self Apodization correction should *precede* Radiometric Calibration
- Self-apodization ($SA^{-1}$) correction should *precede* Spectral resampling ($F_{s-u}$)
- Spectral resampling function must use large number of samples “$N_0$” in computation
- Processing of extended length interferograms through full calibration and with truncation to shorter MPD as a last step helps
- Truth Spectrum must include the effect of instrument optical responsivity

Other Consequences of Suggested Changes

- Must compensate for CrIS FIR filter ($FIR^{-1}$) prior to spectral correction
  - In-band amplitude ripple
  - ZPD centering or delay
- Must phase correct spectrum prior to spectral correction
Improved Level 1b Algorithm Performs Spectral Correction on Extended Length Interferogram Prior to Radiometric Calibration

**On-orbit CrIS Signal Processing**

- **Fore optics** → **FTS** → **aft optics & filters** → **preamp** → **LPF** → **FIR BPF** → **Decimate**

**Improved NOAA Ground Algorithm (Level 1b)**

- FFT & Alias Unfold → **NLC** → |FIR⁻¹| → **Nonlinearity & FIR Filter Correction**
- **Phase Correction** → **Spectral Corrections** → Truncate MPD → ICT Radiance Model $ICT_u(T, \sigma_u)$ → Calibrated Level 1b Output

**Logistikos**

Improved NOAA Ground Algorithm (Level 1b):

$$\begin{align*}
F_{s\rightarrow u} \cdot f_{BPF2} \cdot S_{A_s^{-1}} \cdot f_{BPF1} \cdot F_{trunc} \cdot \left[ \frac{(S_{ES} - S_{SP}) \cdot |S_{ICT} - S_{SP}|}{(S_{ICT} - S_{SP})} \right]
\end{align*}$$

**Radiometric Calibration**

- $S_{Es} = [\text{FIR}^{-1}] \cdot \text{NLC} \cdot \text{CRIGHT} \left[ \text{FFT} \left( \text{CRIGHT} \left[ I_{Es}, \frac{N_{Es}}{2} \right] \right), N_{unwrap} \right]$
- $S_{ICT} = [\text{FIR}^{-1}] \cdot \text{NLC} \cdot \text{CRIGHT} \left[ \text{FFT} \left( \text{CRIGHT} \left[ I_{ICT}, \frac{N_{ICT}}{2} \right] \right), N_{unwrap} \right]$
- $S_{SP} = [\text{FIR}^{-1}] \cdot \text{NLC} \cdot \text{CRIGHT} \left[ \text{FFT} \left( \text{CRIGHT} \left[ I_{SP}, \frac{N_{SP}}{2} \right] \right), N_{unwrap} \right]$

**Space**

Earth Scene

ICT

**Space**

Earth Scene

ICT
LWIR Optical/Electrical Responsivity

Interferometer Sweep Direction 0

Interferometer Sweep Direction 1

Interferometer Sweep Direction Difference

Linear Magnitude

Log Magnitude

Phase

Forward & Reverse Sweep Magnitude Matched to 0.01%

Forward & Reverse Sweep Phase Very Different
MWIR Optical/Electrical Responsivity

**Linear Magnitude**

Interferometer Sweep Direction 0

![Graph showing Linear Magnitude for interferometer sweep direction 0](image)

Interferometer Sweep Direction 1

![Graph showing Linear Magnitude for interferometer sweep direction 1](image)

Interferometer Sweep Direction Difference

![Graph showing Linear Magnitude for interferometer sweep direction difference](image)

**Log Magnitude**

Interferometer Sweep Direction 0

![Graph showing Log Magnitude for interferometer sweep direction 0](image)

Interferometer Sweep Direction 1

![Graph showing Log Magnitude for interferometer sweep direction 1](image)

Interferometer Sweep Direction Difference

![Graph showing Log Magnitude for interferometer sweep direction difference](image)

**Phase**

Interferometer Sweep Direction 0

![Graph showing Phase for interferometer sweep direction 0](image)

Interferometer Sweep Direction 1

![Graph showing Phase for interferometer sweep direction 1](image)

Interferometer Sweep Direction Difference

![Graph showing Phase for interferometer sweep direction difference](image)

**MWIR Optical/Electrical Responsivity**

- **Interferometer Sweep Direction 0**
- **Interferometer Sweep Direction 1**
- **Interferometer Sweep Direction Difference**

**Forward & Reverse Sweep Magnitude**

- Matched to 0.1%

**Forward & Reverse Sweep Phase**

- Very Different
SWIR Optical/Electrical Responsivity

Interferometer Sweep Direction 0

Interferometer Sweep Direction 1

Interferometer Sweep Direction Difference

Linear Magnitude

Log Magnitude

Phase

Interferometer Sweep Direction

Interferometer Sweep Direction

Interferometer Sweep Direction

Forward & Reverse Sweep Magnitude Matched to 0.2%

Forward & Reverse Sweep Phase Very Different
True CrIS Instrument ILS Depends Upon Optical/Electrical Responsivity Properties

On-orbit CrIS Signal Processing

- Fore optics
- FTS
- aft optics & filters
- Detector
- preamp
- LPF
- A/D
- FIR BPF
- Decimate
- Truncate (extended length)
- ICT Radiance Model $ICT_u(T,\sigma_u)$
- CrIS responsivity spectrum in instrument counts

Improved Ground Algorithm (Level 1b)

- FFT & Alias Unfold
- NLC
- [FIR$^{-1}$]
- Decimated Interferogram
- Nonlinearity & FIR Filter Correction
- Phase Correction
- Spectral Corrections

Complex Spectra

Real Spectra

True CrIS ILS

Sinc ILS with instrument distortions removed
CrIS Optical/Electrical Responsivity Will Impact the Post Calibrated Instrument Line Shape (ILS)

Optical/Electrical Responsivity

Ideal vs. True CrIS ILS at 723 cm$^{-1}$
Broadband ILS Comparison at 723 cm\(^{-1}\)
(Complex ILS if Phase Correction Not Performed)

![Graph showing Broadband ILS Comparison at 723 cm\(^{-1}\)](image)

- True ILS at 723 cm\(^{-1}\) (imaginary)
- Ideal Sinc ILS at 723 cm\(^{-1}\) (real)
- True ILS at 723 cm\(^{-1}\) (real)
- Ideal Sinc ILS at 723 cm\(^{-1}\) (real)

Wavenumber (cm\(^{-1}\))

Magnitude

0.00001 0.0001 0.001 0.01 0.1 1

600 650 700 750 800 850 900 950 1000 1050 1100 1150

0.00001 0.0001 0.001 0.01 0.1 1

600 650 700 750 800 850 900 950 1000 1050 1100 1150
True CrIS ILS Sidelobe Error Relative 30 mK Brightness Error (Phase corrected – 7 Channel Centers – Unapodized & Hamming Cases)

LWIR Band

- Unapodized
- Hamming

Equivalent 30 mK brightness error for three scenes of 310 K, 287 K & 250 K
True CrIS ILS Sidelobe Error Relative 30 mK Brightness Error (Phase corrected – 7 Channel Centers – Unapodized & Hamming Cases)

MWIR Band

- Unapodized
- Hamming

Equivalent 30 mK brightness error for three scenes of 310 K, 287 K & 250 K
True CrIS ILS Sidelobe Error Relative 30 mK Brightness Error
(Phase corrected – 7 Channel Centers – Unapodized & Hamming Cases)

SWIR Band
- Unapodized
- Hamming

Equivalent 30 mK brightness error for three scenes of 310 K, 287 K & 250 K
Conclusions

- Phase correction prior to spectral correction makes the CrIS ILS sweep direction independent

- Fully calibrated CrIS SDR has ILS sidelobe response that even under best conditions deviates from an ideal Sinc ILS ("True ringing")

- Hamming apodization brings the "True Ringing" error below an equivalent 30 mK brightness temperature ILS sidelobe error for all earth scene temperatures 250 K – 310 K in the MWIR & SWIR bands & over all LWIR wavenumbers (except 650 – 680 cm\(^{-1}\))

- True ringing can be compensated at SDR output & in forward EDR model by multiplying spectrum by the CrIS responsivity magnitude
  - If this is done, Hamming apodization is not needed to meet a 30 mK brightness temperature knowledge error threshold for ILS sidelobes