PICASSO –
An End-to-End Image Simulation Tool for Space and Airborne Imaging Systems

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What is PICASSO?

Parameterized Image Chain Analysis and Simulation Software
- One of a class of End-to-End (ETE) image simulation (aka, Image Chain Analysis) tools.
- Development began in 1999.
- Among goals were GUI & architecture facilitating code expansion & maintenance.

PICASSO predicts system-level performance of electro-optical imaging systems
- Not a detailed optics, detector, etc. model, but a system-level roll-up of component sub-system performance metrics.
- Requires high quality “truth” image & sensor design description as inputs.
- Outputs are simulated imagery & figures of merit (e.g., SNR, MTF).

PICASSO may be used throughout the life of a satellite program.
- Most often used early in program, when design parameters are still in trade.
- Often used to gain insight into contractor modeling techniques.
- May be applied later in program to predict system-level performance of as-built hardware.
GENSAT Design Parameters (1/2)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nadir resolution [m]</td>
<td>0.5</td>
</tr>
<tr>
<td>Altitude [km]</td>
<td>500</td>
</tr>
<tr>
<td>Optical bandpass [μm]</td>
<td>Panchromatic (0.45 – 0.80)</td>
</tr>
<tr>
<td>Optical design</td>
<td>Cassegrain</td>
</tr>
<tr>
<td>Primary aperture diameter [m]</td>
<td>0.65</td>
</tr>
<tr>
<td>Secondary aperture (obscuration) diameter [m]</td>
<td>0.10</td>
</tr>
<tr>
<td>Effective focal length (EFL) [m]</td>
<td>10</td>
</tr>
<tr>
<td>Optical Q at 0.65 μm</td>
<td>1.0</td>
</tr>
<tr>
<td>Wavefront error [r.m.s. waves @0.6328 μm]</td>
<td>0.10</td>
</tr>
<tr>
<td>Wavefront error correlation length [fraction of primary aperture]</td>
<td>0.10</td>
</tr>
<tr>
<td>Optical throughput (average over panchromatic band)</td>
<td>0.80</td>
</tr>
<tr>
<td>Filter transmission (average over panchromatic band)</td>
<td>0.95</td>
</tr>
<tr>
<td>Ground sample distance (GSD) at nadir [m]</td>
<td>0.5</td>
</tr>
</tbody>
</table>

PICASSO Example: GENSAT

- Generic high resolution commercial imaging satellite
- Representative of the current 0.5m ground resolution class of systems.
- Representative of a “Conceptual Design” level of maturity.
## GENSAT Design Parameters (2/2)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line rate modes [KHz]</td>
<td>36, 18, 9, 4.5</td>
</tr>
<tr>
<td>TDI modes</td>
<td>16, 32, 48, 64, 80, 96</td>
</tr>
<tr>
<td>Focal plane array</td>
<td>Scanning 4-phase CCD</td>
</tr>
<tr>
<td>CCD detector pitch [μm]</td>
<td>10</td>
</tr>
<tr>
<td>Total detector noise (dark, readout, etc.) [electrons]</td>
<td>50</td>
</tr>
<tr>
<td>Pixel full well depth parameter [electrons/μm²]</td>
<td>1500</td>
</tr>
<tr>
<td>Quantum efficiency (average over panchromatic band)</td>
<td>0.65</td>
</tr>
<tr>
<td>Analog-to-Digital Convertor [bits]</td>
<td>11</td>
</tr>
<tr>
<td>A/D maximum voltage [V]</td>
<td>1.5</td>
</tr>
<tr>
<td>Wiener filter gain</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Typical PICASSO Imaging Chain

1. High Resolution Input Scene in Unknown Units
2. Convert Input Scene to Reflectance
3. Setup Viewing Geometry
4. Resample to Sensor GSD
5. Add Detector & Photon Noise
6. Analog-to-Digital Conversion
7. Convert from Electrons to Voltage
8. Sharpening via Wiener Filter
9. Apply System Transfer Function (STF)
10. Convert from Radiance to Photoelectrons
11. Rescale from Reflectance to Inband Top of Atmosphere Radiance at Desired Sun & Sensor Elevation Angles via MODTRAN4v3r1
12. Output Scene & Associated Metrics
GENSAT Simulation Chain

High Resolution Input Scene in Unknown Units

Convert Input Scene to Reflectance

Apply System Transfer Function (STF)

Rescale from Reflectance to Inband Top of Atmosphere Radiance at Desired Sun & Sensor Elevation Angles via MODTRAN4v3r1

Setup Viewing Geometry

Resample to Sensor GSD

Convert from Radiance to Photoelectrons

Add Detector & Photon Noise

Convert from Electrons to Voltage

Analog-to-Digital Conversion

Sharpening via Wiener Filter

Output Scene & Associated Metrics

**PICASSO**
Rescaling to Top of Atmosphere Radiance (1/2)

MODTRAN4 reflectance dependence is fit using the FLAASH\textsuperscript{[1]} model:

\[ L_\lambda(x) = \frac{A_\lambda \rho(x)}{(1 - \rho_b(x) S_\lambda)} + \frac{B_\lambda \rho_b(x)}{(1 - \rho_b(x) S_\lambda)} + C_\lambda \]

Example fit coefficients for overhead sun, 90° sensor elevation angle, mid-latitude summer atmosphere, 23 km visibility rural aerosol model.

GENSAT Simulation Chain

High Resolution Input Scene in Unknown Units

Convert Input Scene to Reflectance

Rescale from Reflectance to Inband Top of Atmosphere Radiance at Desired Sun & Sensor Elevation Angles via MODTRAN4v3r1

Apply System Transfer Function (STF)

Setup Viewing Geometry

Resample to Sensor GSD

Convert from Radiance to Photoelectrons

Add Detector & Photon Noise

Convert from Electrons to Voltage

Analog-to-Digital Conversion

Sharpening via Wiener Filter

Output Scene & Associated Metrics

PICASSO
GENSAT Modulation Transfer Function (MTF)

In-scan component & system polychromatic MTFs for excess smear = 0., nadir viewing, line rate 18 kHz/TDI by 32 mode
GENSAT Simulation Chain

1. **High Resolution Input Scene in Unknown Units**
2. **Convert Input Scene to Reflectance**
3. **Setup Viewing Geometry**
4. **Resample to Sensor GSD**
5. **Add Detector & Photon Noise**
6. **Analog-to-Digital Conversion**
7. **Apply System Transfer Function (STF)**
8. **Convert from Radiance to Photoelectrons**
9. **Convert from Electrons to Voltage**
10. **Sharpening via Wiener Filter**
11. **PICASSO**
12. **Rescale from Reflectance to Inband Top of Atmosphere Radiance at Desired Sun & Sensor Elevation Angles via MODTRAN4v3r1**
13. **Output Scene & Associated Metrics**
Example PICASSO Study: Effects of Wavefront Error (WFE) (1/2)

Sharpening via Wiener Filter – Poorer SNR for WFE case at high spatial frequencies leads to less complete restoration
Example PICASSO Study: TDI Mode Switchpoints

PICASSO & General Image Quality Equation (GIQE) 4.0[1]
used to derive TDI mode switchpoints as solar illumination declines