New capabilities of diffuser calibration lab at GSFC NASA to support remote sensing instrumentation

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The on-orbit calibration with solar diffuser (SD) for the reflective solar band is significantly important for the operation of the satellite sensors, and sensor data record (SDR). Much efforts have been contributed to the pre-launch calibration for the solar diffuser, and its associated components. The BRDF measurement of the SD, and BTDF measurement for its associated components are required at different incident angles due to the solar season and from viewing angles based on the instrument geometry. The new diffuser calibration facility consists of two scatterometer instruments, one is the table-top version, and the other one is the robot-arm based version. The light sources for the new scatterometers are currently equipped with a 20 W supercontinuum fiber laser from 400 nm to 2500 nm, and two laser diode driven plasma lamp sources from 200 nm to 900 nm. The detection systems consist of Si and extended InGaAs detectors with low NEP down to $10^{-15}$ and $7 \times 10^{-14} \text{ W/(Hz)}^{1/2}$, respectively, with/without input integrating sphere for light collection. The development of the table-top scatterometer has reached the final stage for optimization, meanwhile the 6-axis robot-arm has been scheduled to be delivered soon. The light source tests on the spectral output and a short term stability were conducted, and the preliminary results will be presented together with the discussion about the requirements of on-orbit calibration with solar diffuser.

Keywords: BRDF, table-top based scatterometer, robot-arm based scatterometer, reflective solar band, solar diffuser, supercontinuum laser, laser diode driven plasma source, Si detector, and extended InGaAs detector
Outline

1. Motivation and goal
2. Requirement of measurements
3. New scatterometer and key components
4. Status of development
5. Preliminary test results
6. Summary and future work
1. Motivation and goal
Spectral range, and out-of-plane capability
OPO tunable laser
2. Requirement of measurements
1. Wavelengths:
   a. 400, 550, 700, 850, 1000, 1200, 1600, 2250 (or filter wavelengths)

2. Measurements:
   a. 6 degree/directional hemispherical reflectance at above wavelengths
   b. BRDF
      i. Incident angles:
         1. $\Theta_i$: -51.9 deg, -56.75 deg, and -55.6 deg.
         2. $\Phi_i$: -7.40 deg, 0 deg, +7.40 deg.
      ii. Reflectance angles:
          1. VIIRS $\theta_s$: 37.9 deg
          2. SDSM $\theta_s$: -18.3 deg

3. Samples:
   a. 4 Space-grade Spectralon samples: one sample maintained in lab as a control and three other samples measured by our lab and others.
Polarimetric measurement of BRDF

In-plane scattering

Out-of-plane scattering
3. New scatterometer and key components
1. Robot arm based Scatterometer

Thorlabs XT95-500

400 mm to 500 mm
(15.7” to 19.7”)
Robot (550 -650 mm)

914.4 mm
(36”)

Thorlabs XT95SP-500

RV350

Robot arm floor mount
Detector arm floor mount
2. Table top goniometer

Detector arm floor mount
Goniometer floor mount
Methodology

Incident light fixed
Sample manipulation → in-plane/out-of-plane BRDF
In-plane detection

Roll
Pitch
Yaw
Roll
Technical specifications of goniometer

Incident angle: ±85°

Sample manipulation
  Yaw: ±90°
  Pitch: ±90°
  Roll: ±180°

Detection angle: ±180°

Accuracy: 0.01°
Fig 5-2: Outline structure of robot arm
# Specifications

<table>
<thead>
<tr>
<th>Type</th>
<th>Unit</th>
<th>RV-13F(M)(C)</th>
<th>RV-13FL(M)(C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine class</td>
<td></td>
<td>Standard/Oil mist/Clean</td>
<td></td>
</tr>
<tr>
<td>Protection degree</td>
<td></td>
<td>IP40 (standard)/IP67 (oil mist) *1/ISO class III *7</td>
<td></td>
</tr>
<tr>
<td>Installation</td>
<td></td>
<td>Floor type, ceiling type, (wall-mounted type *2)</td>
<td></td>
</tr>
<tr>
<td>Structure</td>
<td></td>
<td>Vertical, multiple-joint type</td>
<td></td>
</tr>
<tr>
<td>Degrees of freedom</td>
<td></td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Drive system</td>
<td></td>
<td>AC servo motor</td>
<td></td>
</tr>
<tr>
<td>Position detection method</td>
<td></td>
<td>Absolute encoder</td>
<td></td>
</tr>
<tr>
<td>Maximum load capacity</td>
<td>kg</td>
<td>Maximum: 13 (Rated: 12) *8</td>
<td></td>
</tr>
<tr>
<td>Arm length</td>
<td>mm</td>
<td>410 + 550</td>
<td>565 + 690</td>
</tr>
<tr>
<td>Maximum reach radius</td>
<td>mm</td>
<td>1094</td>
<td>1388</td>
</tr>
<tr>
<td>Operating range</td>
<td>deg</td>
<td>J1 380(±190)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>J2 240(-90 to +150)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>J3 167.5(-10 to +157.5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>J4 400(±200)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>J5 240(-120 to +120)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>J6 720(±360)</td>
<td></td>
</tr>
<tr>
<td>Maximum speed</td>
<td>deg/sec</td>
<td>J1 290</td>
<td>234</td>
</tr>
<tr>
<td></td>
<td></td>
<td>J2 234</td>
<td>164</td>
</tr>
<tr>
<td></td>
<td></td>
<td>J3 312</td>
<td>219</td>
</tr>
<tr>
<td></td>
<td></td>
<td>J4 375</td>
<td>375</td>
</tr>
<tr>
<td></td>
<td></td>
<td>J5 375</td>
<td>375</td>
</tr>
<tr>
<td></td>
<td></td>
<td>J6 720</td>
<td>720</td>
</tr>
<tr>
<td>Maximum composite speed *3</td>
<td>mm/sec</td>
<td>10450</td>
<td>9700</td>
</tr>
<tr>
<td>Cycle time *4</td>
<td>sec</td>
<td>0.53</td>
<td>0.68</td>
</tr>
<tr>
<td>Position repeatability</td>
<td>mm</td>
<td>±0.05</td>
<td></td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>°C</td>
<td>0 to 40</td>
<td></td>
</tr>
<tr>
<td>Mass</td>
<td>kg</td>
<td>120</td>
<td>130</td>
</tr>
<tr>
<td>Tolerable moment</td>
<td>Nm</td>
<td>J4 19.3</td>
<td>J5 19.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>J6 11</td>
<td></td>
</tr>
<tr>
<td>Tolerable amount of inertia</td>
<td>kgm²</td>
<td>J4 0.47</td>
<td>J5 0.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>J6 0.14</td>
<td></td>
</tr>
<tr>
<td>Tool wiring</td>
<td></td>
<td>Hand: 8 input points/8 output points (20 pins total)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Serial signal cable for parallel I/O (2-pin + 2-pin power line)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>LAN x 1 &lt;100 BASE-TX&gt; (8-pin) *5</td>
<td></td>
</tr>
<tr>
<td>Tool pneumatic pipes</td>
<td></td>
<td>Primary: φ6 x 2</td>
<td>Secondary: φ6 x 8, φ4 x 4 (With wrist attached)</td>
</tr>
<tr>
<td>Machine cable</td>
<td></td>
<td>7m (connector on both ends)</td>
<td></td>
</tr>
<tr>
<td>Connected controller</td>
<td></td>
<td>CR750, CR751 (CR750: Japan, Europe, U.S.; CR751: Asia)</td>
<td></td>
</tr>
</tbody>
</table>

*1: Please contact a Mitsubishi Electric dealer since the environmental resistance may not be secured depending on the characteristics of oil you use.

*2: The wall-mounted specification is a custom specification where the operating range of the J1-axis is limited.

*3: This is the value at the surface of the mechanical interface when all axes are composed.

*4: The cycle time is based on back-and-forth movement over a vertical distance of 25 mm and horizontal distance of 300 mm when the load is 5 kg.

*5: Can also be used as a spare line (0.13 sq. mm, 4-pair cable) for conventional models. Provided up to the inside of the forearm.


*7: Preservation of cleanliness levels depends on conditions of a downstream flow of 0.3 m/s in the clean room and internal robot suctioning. A φ8-mm coupler for suctioning is provided at the back of the base.

*8: The maximum load capacity indicates the maximum payload when the mechanical interface is facing downward (+10° to the perpendicular).
Light sources

**Light sources:** Xenon, Laser-induced plasma lamp (D2 lamp)
Monochromater-based lamp source system, focus on 230 nm to 1000 nm first, Si detector
Requirement of power (1 mW), and stability (<1%)

Design: Xenon - input optics - monochromator - spatial filter - monitor/polarization - sample

Test plan:
1. Power stability: Xe lamp, Out of the monochromator-based system (full scan repeated 10 times, or selected wavelengths)
2. Relative spectrum (Output power as a function of wavelength)
3. Power stability with feedback (repeat 1, 2)

**Light sources:** MIRA/MIRA OPO Laser, NKT SC Laser
Monochromater-based laser source system, 400 nm to 1000 nm, Si & Ext InGaAs detectors
Requirement of power (1 mW), and stability (<1%)

Design: Xenon - input optics - monochromator - spatial filter - monitor/polarization - sample

Test plan:
1. Power stability: Laser, Out of the monochromator-based system (full scan repeated 10 times for SC, or selected wavelengths)
2. Spectral stability
3. Power stability with feedback (repeat 1, 2)
## Detectors

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain</td>
<td>$10^{10}$ to $10^9$ volts/amp</td>
</tr>
<tr>
<td>Range</td>
<td>Eight decades automatic or manual dial control</td>
</tr>
<tr>
<td>Output</td>
<td>0 to 10 VDC for each gain setting</td>
</tr>
<tr>
<td>Linearity</td>
<td>$&lt;0.25%$ non-linearity for all ranges</td>
</tr>
<tr>
<td>Temperature Variation</td>
<td>$&lt;5$ ppm (parts-per-million) per degree Celsius</td>
</tr>
<tr>
<td>Noise</td>
<td>$&lt;20$ microvolts on the $10^{10}$ range</td>
</tr>
<tr>
<td>Frequency Roll-Off</td>
<td>$&lt;10$ Hz on $10^{10}$ range for output $&gt;1$ volt</td>
</tr>
<tr>
<td>Length (Amplifier)</td>
<td>4.15 inches (10.5 cm)</td>
</tr>
<tr>
<td>Diameter (Amplifier)</td>
<td>2.5 inches (6.4 cm)</td>
</tr>
<tr>
<td>Length (TE Cooler control box)</td>
<td>12 inches (30.5 cm)</td>
</tr>
<tr>
<td>Width (TE Cooler control box)</td>
<td>11.3 inches (28.7 cm)</td>
</tr>
<tr>
<td>Height (TE Cooler control box)</td>
<td>4.5 inches (11.4 cm)</td>
</tr>
<tr>
<td>Temperature Stability</td>
<td>Short term (1 hr.) $&lt;0.001$ °C, long term (24 hr.) $&lt;0.003$ °C</td>
</tr>
<tr>
<td>Bipolar Output Current</td>
<td>$+1.5$ amp max</td>
</tr>
<tr>
<td>Maximum TEC Output Power</td>
<td>12 watts</td>
</tr>
<tr>
<td>Power</td>
<td>100-240 VAC, 50-60 Hz</td>
</tr>
</tbody>
</table>

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**Features**

- Temperature stabilized silicon and InGaAs detectors available covering 200 - 2600 nm
- Temperature stabilized correction filters available
- High accuracy photopic correction f1 - 0.8%
- ANVIS compatibility filters and lenses
- High sensitivity down to 10-15 Watts or 10-8 Lux
- 8 decades of dynamic range
- 0-to-10 volt output for each decade

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**About Gamma Scientific**

With over 80 years of experience in developing light measurement instruments, Gamma Scientific is trusted by the world's leading organisations to provide accurate results.

Based in San Diego, Gamma Scientific manufactures laboratory grade spectroradiometers, spectrometers, spectrophotometers and integrating spheres.

Gamma Scientific also operates an ISO 17025, NVLAP accredited laboratory performing ENERGY STAR, LM-79 and LM-80 tests for LEDs.

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**About UDT Instruments**

- RS-232 computer control
Robot-based Scatterometer

Thorlabs XT95-500

Thorlabs XT95SP-500

914.4 mm (36’’)

Vertical translation stage for height adjustment

RV350

Robot arm floor mount

Detector arm floor mount
Receiver geometry

Translation stage in z direction
Signal level evaluation

![Graph showing input power measurement vs output power with various lines representing different scenarios.](image-url)
Signal level evaluation
4. Status of development
Table-top goniometer
RV-13FC with black paint of flat RAL 9011
Robot Controller delivery
System integration

1. Sources:
   a. Monochromator-based source from 200 nm to 2500 nm
      Laser-induced plasma, Xenon, Supercontinuum source
   b. OPO tunable lasers
   c. Fourier transform source
2. Detectors and data acquisition (Si, and Ex-IGA)
3. Motion Control
   I. Detector arm:   a. Rotation ring   b. Heavy-duty rotation stage
   II. Sample manipulation:   a. Goniometer   b. Robot arm
4. Software development
5. Alignment and test
6. Validation of system, and determination of uncertainty

Sub-systems  --->  Operational Scatterometer
Instrument validation

1. Instrument validation is done by comparison of Spectralon sample measured at NIST
2. Comparison to the existing validated system
5. Preliminary test results
Comparison of EQ-99 from UV-VIS-NIR

Intensity

Wavelength, nm

200 300 400 500 600 700 800 900 1000

0 10 20 30 40 50 55
Comparison of EQ-99 for NIR

Intensity

Wavelength, nm

600 700 800 900 1000 1100 1200 1300

0 10 20 30 40 50 55
Fianium SC Laser
Comparison of EQ-99 and Fianium SC Laser

- EQ-99
- Fianium

Intensity

Wavelength, nm

200 300 400 500 600 700 800 900 1000
6. Summary and future work

- Two types of scatterometers are being established to support on-orbit solar band calibration.

- Some of key components of the new system have been implemented, and some of them will be delivered soon.

- Preliminary tests have been conducted.

- System integration and instrument validation are needed.