GROUND TRUTH REPORT

CDRL A001

Annual Baseline Certification

of the

Fixed Optical/Video Calibration Array

located at

Wright-Patterson AFB, Ohio

in support of the

Open Skies Treaty

09 to 31 January 2002

MTL Document ITT477-002
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Washington, D.C. 20166

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1.0 INTRODUCTION

MTL Systems, Inc. (MTL) performed the annual baseline certification at the Defense Threat Reduction Agency's (DTRA) Optical/Video Calibration Array site located at Wright-Patterson AFB (WPAFB), Ohio from 09 to 31 January 2002. In support of this effort, absolute spectral reflectance data were acquired from Areas A and B of the array and selected background areas, along with physical measurements of specific array features. The objective of this effort was to certify the Optical/Video Array in accordance with the requirements established by DTRA and the Open Skies Treaty.

As part of the baseline certification effort, MTL purchased a new Spectralon® reflectance standard for use in support of the Open Skies program, submitted a photometer for a National Institute of Standards and Technology (NIST) traceable calibration, and conducted a new lamp cross-over for the MTL Model RS-9401 Spectral Radiance Standard. Calibration data acquired for these instruments will be used to meet the annual Open Skies certification and traceability requirements.

Services provided in support of the baseline certification effort include the utilization of a visible-near infrared (VNIR) spectroradiometer, a goniometer, reflectance standard, collimated radiance source, differential Global Positioning System (GPS), and metric distance measuring instruments. Specifically, the certification data acquired include:

- Number of bar groups
- Length and width of each bar within each bar group
- Separation between bar groups
- Overall distance of the outside edges of the array from background areas
- Geographic coordinates for the array center
- Altitude above mean sea level
- Bar orientation with respect to true north
- Spectral reflectance measurements of randomly selected areas within each distinct background area over the 420 nm to 1050 nm region (VNIR)
- Spectral reflectance measurements of the dark and light bars of the array at 0°, 30°, 45°, and 60° from nadir viewing angles
- Surface and background description
- Documentary photographs

All references to time in this report have been corrected to universal time (UT), unless otherwise noted. To obtain local Eastern Standard Time at the WPAFB collection site, subtract five hours from universal time. The magnetic declination for 21 January 2002 is 5° 21’ west of north.

This report contains data derived from 458 spectral scans collected for the target array and background characterization effort. Section 2 contains a brief description of the DTRA Optical/Video Array. Section 3 contains a description of the instrumentation used to acquire the baseline calibration data, while Section 4 contains a description of the calibration methodology. Section 5 contains all relevant baseline certification data, including index of documentary photographs, target dimension and survey data, and average spectral reflectance plots.

ACRONYM LISTING

ASD	Analytical Spectral Devices
DTRA	Defense Threat Reduction Agency
GPS	Global Positioning System
HAE	Height Above Ellipsoid
JPEG	Joint Photographic Experts Group
MSL	Mean Sea Level
NIST	National Institute of Standards and Technology
NIR	Near InfraRed (700 to 1100 nm)
NUV	Near Ultraviolet (200 to 400 nm)
PTFE	Polytetrafluorethylene
SRS	Spectral Radiance Standard (MTL instrument)
SWIR	Short Wave InfraRed (1100 to 3000 nm)
SWIR 1	900 to 1850 nm (ASD sensor)
SWIR 2	1700 to 2500 nm (ASD sensor)
UT	Universal coordinated Time
VNIR	Visible Near Infrared (400 to 1100 nm)
WPAFB	Wright-Patterson Air Force Base

2.0 DTRA FIXED OPTICAL/VIDEO ARRAY DESCRIPTION

This section of the report provides a brief description of the DTRA Optical/Video Fixed Array located at WPAFB, Ohio. Following the array description, comments concerning the condition of the array as of 31 January 20002 are included.

2.1 Array Description

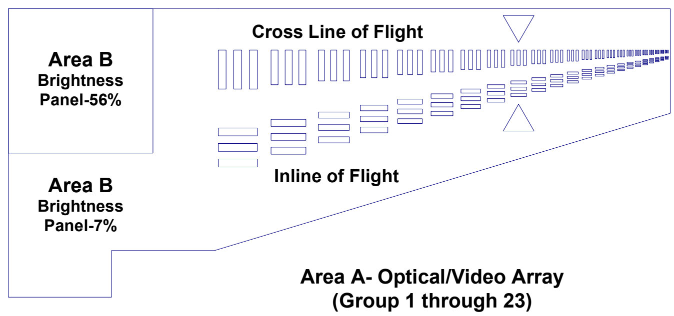
The DTRA Fixed Calibration Array located at WPAFB consists of two basic target areas, with each area designed as a unique input stimulus for the assessment of the optical performance of either a film based imaging system, or an electronic video imaging system. Area "A" of the array is a resolution target that is comprised of 23 tri-bar element pairs, and Area "B" consists of two brightness panels. Photograph 1 is a north view of the WPAFB Optical/Video Array, while Figure 1 is a drawing of the WPAFB Optical/Video Fixed Array.

Photograph 1. North View of the Optical/Video Fixed Array- WPAFB, OH.

2.1.1 Area A- Resolution Target. The resolution target is constructed in a linear configuration, with tri-bars provided for both in-line-of-flight and cross-line-of-flight orientation. The size progression of the 23 tri-bar array is based on the sixth-root-of-two, while the bar length to width aspect ration remains constant at 5:1 throughout the frequency progression.

The largest bar element (Element 1) consists of a bar/space design width of 75.60 cm, while the smallest bar element (Element 23) comprises a bar/space design width of 5.95 cm. The design of the resolution array also includes triangular shaped fiducial markers (300 cm per side) which are located at opposite ends of bar Element 9 (30 cm width bar/space) to designate the limiting ground resolved distance as specified by the Open Skies Treaty.

DTRA Optical/Video Calibration Array
Wright-Patterson AFB, OH



Geodetic Coordinates (WGS 84)	Orientation
Latitude: 39° 46' 36.77" N Longitude: 84° 07' 03.55" W Elevation: 241 meters (MSL)	Azimuth: Large to small elements: 44° 30' True Small to large elements: 224° 30'True Declination 21 January 2002: 5° 21' W

Figure 1. Optical/Video Fixed Target Array Configuration.

Specially formulated coatings are used to provide a diffuse reflective surface, with a white bar of nominally 56 percent reflectance painted over a black background of nominally 7 percent reflectance, resulting in a design contrast of 8:1.

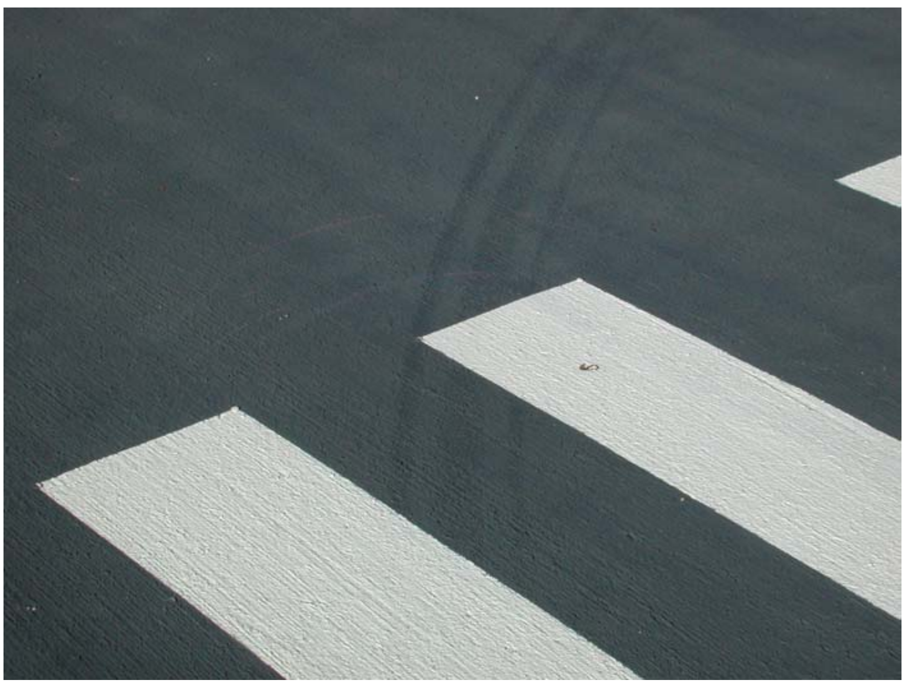
2.1.2 Area B- Brightness Panels. Area B consists of two panels painted to provide the same reflectance levels as the white and black bars of the resolution target. The high-level brightness panel (nominally 56 percent) measures 14 meters square, while the low level panel (nominally 7 percent) measures 10 by 14 meters.

2.2 Target Condition

The DTRA Optical/Video Array was cleaned on 20 November 2001, using a leaf blower followed by a sweep and wash technique. In cleaning the array the leaf blower was first used to remove small stones and accumulated dried vegetation from both the resolution array and brightness panels.

Following cleaning by the leaf blower, the resolution array and the brightness panels were flushed with clean water and broom cleaned to remove any remaining surface dirt and water pools. An inspection following the cleaning indicated that (with the exception of some tire tracks) the surface was clean of accumulated dust and animal droppings. The inspection also revealed areas on the white painted bars in which black streaks (black pigment erosion) were visible. These areas were mostly confined to the ridges of the surface profile that are associated with the concrete broom finish.

In addition to a general target cleaning, an effort was made on 20 November 2001 to remove tire tracks that were caused by a grass mowing machine. A typical tire mark, which is illustrated in Photograph 2, appears to have produced a directional reflectance effect due to a physical alteration of the target surface. This physical alteration is most likely associated with a disturbance of the oxide layer that comprises the outermost surface of the coatings. The black would have the more pronounced oxide disturbance, an effect that was easily discernable.



Photograph 2. Tire Marks Visible at Element 9- Vertical.

On 9 January 2002, the target array was again inspected. Other than the tire marks, no defects were detected that would potentially have a negative impact on the measurements required in support of the baseline certification effort.

3.0 INSTRUMENT DESCRIPTIONS

Prior to being deployed at the WPAFB Optical/Video Array site in support of the baseline certification effort, each instrumentation system was checked out and/or calibrated to insure operability and compliance with established performance standards. In the sections, which follow, we provide a description of the spectroradiometer and GPS instrumentation used to support the baseline certification effort.

The spectroradiometer was used for measuring the spectral reflectance of randomly selected background areas (concrete/grass), a randomly selected white/black bar group (Area A/Group 3), and the two levels of the brightness panel (Area B). In measuring spectral reflectance, two instrument configurations were used. In one configuration, the instrument's fiber optic probe was mounted to a tripod, and natural irradiation was used to acquire spectral reflectance data from background and selected array segments. In the second configuration, the fiber optic probe was mounted to an MTL designed goniometer, while an artificial source provided irradiation for the angular reflectance measurements of the randomly selected bar group.

We have also included in Section 3 descriptions of the Tektronix LumaColor Photometer and the MTL Model RS-9401 Spectral Radiance Standard. While not used in direct support of this baseline certification effort, these instruments are included since they will be employed during the US certification. Updated calibration data for the Model RS-9401 SRS and LumaColor Photometer will be provided in a future report.

3.1 ASD FieldSpec FR™ Spectroradiometer

The Analytical Spectral Devices (ASD) FieldSpec FR™ spectroradiometer, which measures spectra between 350 nm and 2500 nm, was used to collect reflectance spectra of the brightness panels, resolution array, and background areas. The instrument is a highly portable general-purpose instrument capable of either absolute (via calibration) or relative measurements. A fiber optic bundle provides flexibility in measurement options. With the fiber optic bundle, VNIR/SWIR energy is projected onto holographic diffraction gratings where the wavelength components are separated and reflected for independent collection by the detector(s). Photograph 3 illustrates the FieldSpec FR™ spectroradiometer.

Each detector converts incident photons into electrons that are stored, or integrated, until the detector reaches "read out". At readout time, the photoelectric current for each detector is converted to a voltage and is digitized by a 16-bit analog to digital (A/D) converter. The digital data is then transferred directly to the computer's main memory using the Enhanced Parallel Port (EPP) on the controlling computer. The spectral data is then available for further processing by the controlling software.

The VNIR portion of the spectrum (350-1050 nm) is measured by a 1024 by 128 thermoelectrically cooled Charge-Coupled Device (CCD) array. This array has 1024 real channels, each consisting of 128 highly sensitive, additive cascading elements. The sampling interval is about 0.7 nm, providing over-sampling and a spectral resolution of approximately 3 nm at around 700 nm.

The SWIR spectral region is measured using two spectrometers that measure wavelengths sequentially, rather than simultaneously. Each spectrometer consists of a concave holographic grating and a single thermoelectrically cooled indium gallium arsenide (InGaAs) detector. The gratings are mounted about a common shaft that oscillates with a period of 200 milliseconds (100 ms/scan).

Photograph 3. ASD FieldSpec FR™ Spectroradiometer.

Each SWIR spectrometer has only a single detector that is exposed to different wavelengths of incident energy as the grating oscillates. The first spectrometer (SWIR 1) measures between 900 nm and 1850 nm, while the second (SWIR 2) measures between 1700 nm and 2500 nm. The controlling software automatically accounts for the overlap in wavelength intervals by using a preset wavelength within the common set at which a "splice" is placed. The sampling interval for each SWIR region is about 2 nm, and the spectral resolution varies between 10 and 12 nm, depending on the scan angle at that wavelength.

Energy collection is through a bundle of specially formulated optical fibers that are precisely cut, polished and sealed, providing an efficient energy collection system. The fibers utilized are of water-free composition, providing low NIR attenuation. Without foreoptics, the fiber bundle has a conical view subtending a full angle of approximately 25°. Measurements may be made without foreoptics, or with foreoptics that provide 1, 5, 8, or 18° fields-of-view. For measurements made in support of the baseline certification effort, only the 5° foreoptics was used. The foreoptics selected determine the minimum sample area desired, which is approximately 30-cm diameter.

With the FieldSpec FR™ instrument, the fiber optic bundles are separated into three separate bundles inside the instrument. Each of these bundles then delivers the collected energy to the entrance slit of one of the spectrometers. In the FieldSpec FR™ instrument, optimization is fully automatic. For the VNIR spectral region, the integration time is adjusted to give maximum allowable signal without saturation, while for the SWIR (1000 nm to 2500 nm) a set scan time is used and the signals have their amplitudes adjusted by electronic gain.

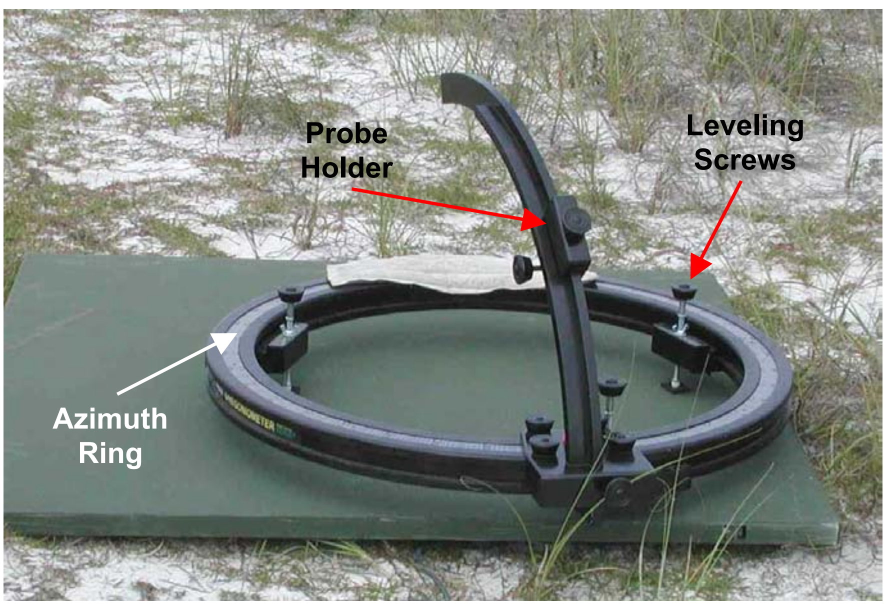
Photograph 4 illustrates the ASD when configured for measuring the spectral reflectance of background and selected Optical/Video array surfaces. In this configuration, the fiber optics probe is attached to a tripod. The tripod-mounted fiber optic bundle includes a level and a laser pointer to facilitate alignment. The hand carried basket configuration enables measurements to be quickly made over uneven terrain.

3.2 MTL Goniometer

For making the angular spectral reflectance measurements of the randomly selected bar group, a custom designed goniometer was deployed. The goniometer, illustrated in Photograph 5, provides a repeatable and stable means for positioning the ASD spectroradiometer's fiber optic probe. The goniometer permits measurements over a 360° azimuth range in 1° increments, and over an elevation range of 70° off-nadir in a forward look direction, and 10° off-nadir in a reverse look direction, also in 1° increments. In using the goniometer, the device is first aligned in azimuth atop the surface of interest and then leveled. The probe is then attached, and the desired look azimuth and elevation angles set.

Photograph 4. The ASD FieldSpec FR™ Spectroradiometer – Tripod Mounting.

Normally, the 0° reference point on the goniometer azimuth ring is aligned to true north. However for the baseline certification effort, the azimuth ring was aligned so that the 44.5° reference point was parallel to the Optical/Video array's target orientation. Spectral reflectance data was then acquired at four look azimuths (44.5°, 134.5°, 224.5°, and 314.5°) at each of the four elevation angles (0°, 30°, 45°, and 60° off-nadir).



Photograph 5. MTL Designed Goniometer Deployed for Material Characterization.

3.3 Spectral Radiance Standard

The MTL Systems, Inc. Spectral Radiance Standard (SRS) Model RS-9401, is a field-ruggedized working standard which provides a convenient means of calibrating a field spectroradiometer under conditions of use to levels of accuracy and precision normally reserved for the laboratory. Power consumption of the system is specifically designed to be low to permit operation at remote sites; the system may be operated from automobile battery power using the auxiliary power inverter. The SRS provides a means for calibrating the spectroradiometer, thereby enabling the reporting of absolute spectral radiance data. The SRS is periodically calibrated against NIST traceable standards. The SRS is undergoing a new lamp crossover and NIST traceable calibration.

The Model RS-9401, shown in Photograph 6, is designed around PTFE (polytetrafluoro-ethylene) integrating sphere which houses two tungsten-quartz-halogen lamps. The lamps are powered by means of a precision power supply that is programmed to control lamp current to within ±0.1 percent. Although the system relies on lamp current control to achieve its highly stable output, a photopically filtered silicon photodiode monitors the sphere wall luminance to provide a health check. A sapphire window in the 7cm-output port protects the interior of the integrating sphere from air currents, dirt, and damage, and permits use of the system over a spectral range of nominally 300 nm to 3000 nm.

All critical components, including the power supply, programming voltage divider, silicon photodiode, and photopic filter, are housed in an actively-controlled constant-temperature compartment to minimize drift and maximize lamp current stability.

The unfiltered spectral output of the system approximates typical scene radiances experienced under bright sun conditions over most of the useful spectral range. A filter holder at the output port provides the means to shape or attenuate the spectral output with optional 7.6 x 7.6 cm spectral filters.

The Model RS-9401 is designed for simple operation. The primary key to successful operation is to allow the case temperature to stabilize to 39 ±1°C before performing any radiometric calibration procedures with the device. The spectroradiometric output of the system is designed to be within specifications when operating in this temperature range.

The spectroradiometric output of the SRS Lamp A is traceable to NIST via direct comparison to the NIST Tungsten-Ribbon Filament Lamp Standard of Spectral Radiance. The short-term stability of the SRS (over a matter of several tens of minutes) is on the order of a few tenths of one percent as measured in the laboratory and in the field. The long-term stability of the SRS is periodically monitored by inter-comparison of SRS lamp A output with that of SRS lamp B.

Photograph 6. The MTL Spectral Radiance Standard.

The reported uncertainties (3 sigma) in the NIST Standard Q-110, the transfer uncertainties between the NIST lamp and the SRS Lamp A, the resulting uncertainties in the SRS Lamp A radiance, the transfer uncertainties between SRS Lamp A and the field spectroradiometer, and the total uncertainties in field-measured scene radiances at selected wavelengths are currently being determined as part of the acceptance requirements. These data will be reported in a future ground truth report, since the lead time required for a NIST traceable calibration does not permit inclusion of the data herein.

3.4 Spectralon® Reflectance Reference Materials

The reflectance reference materials used for spectral reflectance measurements reported herein are a 30.5 x 61 cm or a 15 x 15cm Spectralon® plaque. Spectralon® is the trade name for a reflectance material formed of pressed and sintered PTFE (polytetrafluoroethyele).

The directional hemispherical spectral reflectance of the large field plaque was measured by the manufacturer using a Perkin-Elmer Lambda-9 Spectrophotometer with a Labsphere DRTA 9 diffuse reflectance integrating sphere, which is made of Spectralon®. The results of their measurements, at an 8° incidence angle, are presented in Table 1. Reflectance values are provided at 50 nm intervals for the spectral range of 250 nm to 2500 nm. The relative uncertainty applicable to the values of reflectance is less than one-half percent. The reference used for this calibration was Standard Reference Material 2019a, white ceramic tile, provided by NIST.

Table 1. Spectral Reflectance of Spectralon® Plaque, Serial No. SRT-99-060-2403-A.

Wavelength (nm)	8°/Hemi. Reflectance	Wavelength (nm)	8°/Hemi. Reflectance	Wavelength (nm)	8°/Hemi. Reflectance
250	0.962	1000	0.994	1750	0.986
300	0.981	1050	0.995	1800	0.984
350	0.989	1100	0.993	1850	0.982
400	0.987	1150	0.993	1900	0.982
450	0.989	1200	0.992	1950	0.980
500	0.991	1250	0.993	2000	0.973
550	0.993	1300	0.990	2050	0.954
600	0.993	1350	0.988	2100	0.954
650	0.991	1400	0.989	2150	0.947
700	0.993	1450	0.988	2200	0.971
750	0.992	1500	0.991	2250	0.974
800	0.991	1550	0.988	2300	0.968
850	0.992	1600	0.990	2350	0.953
900	0.994	1650	0.988	2400	0.953
950	0.990	1700	0.985	2450	0.946
				2500	0.972

Even though the material has nearly lambertian reflectance properties, the results of specular component, for the conditions under which the plaque is used for field measurements, this source of error normally contributes to less than 0.5 percent uncertainty in measured reflectance factor.

The Spectralon® plaque is cleaned as required (at least daily) throughout data collection periods. As the sintered PTFE is nonhygroscopic, water runs off the surface easily. Mild biodegradable detergent is used to remove the dirt and hold it in suspension while a distilled water rinse washes the surface clean. When this simple washing procedure does not suffice, the surface is renewed according to manufacturer's instructions with 220 grit-wet sandpaper lubricated with distilled water.

-Note-
A new Spectralon® plaque is on order for supporting Open Skies ground truth.

3.5 Trimble Pro-XL GPS System

The Trimble Navigation Pro XL is MTL System's Geographic Information System (GIS) database capture system that provides for submeter location accuracy after differential correction is applied. The Pro XL may be used in a backpack configuration, or with a tripod for precise antenna placement. System operation and data storage are provided by a small, hand-held, eight-channel receiver and data logger.

The resident software provides for various user-defined data dictionaries, datum selections, output option selections, differential correction, GIS conversions and interface options, mission planning, and data editing. The antenna, which provides omnidirectional and hemispheric coverage, can also be attached to a tripod for more precise positioning.

The receiver is capable of tracking up to eight satellites using the L1/CA code with carrier smoothing. The update rate is 1 second, while accuracy with differential correction is better than 1 meter. The built-in data logger has 1 MB storage, with output that may be displayed directly or downloaded to an IBM-compatible PC for post processing or data fusion.

For supporting the DTRA Open Skies baseline certification effort, the Pro XL was configured as a rover unit, with post-processing used to obtain submeter measurements. The antenna was attached to a surveyor's staff that includes a level for vertical alignment. During post-processing the Pro XL rover files are combined with files downloaded from a nearby USGS operated base station (Galbraith, OH) using Trimble Navigation Pathfinder® Office software. Photograph 7 illustrates the configuration used in support of the baseline certification effort.

3.6 Tektronix LumaColor Photometer

The Tektronix J18 LumaColor Photometer is designed to accept a variety of sensor heads that enable measurements of light sources, displays, light emitting diodes, and surfaces. It can function as a handheld digital photometer or colorimeter for the laboratory, field or production area. A J18 System consists of a J18 handheld meter and one of seven interchangeable heads. At the heart of the J18 is a microprocessor capable of performing several functions: metric-to-U.S. conversion, auto-range, auto zero, hold and conversion between color coordinate systems. The J18 can be used with a PC for automated testing and data recording. It is powered by a 9-volt battery.

Pre-calibrated plug-in heads measure illuminance, luminance and color using CIE coordinates. All heads use spectrally corrected silicon photodiodes with multi-element glass filters for long-term stability and accuracy. Connection of a head to the J18 automatically selects the correct measurement units.

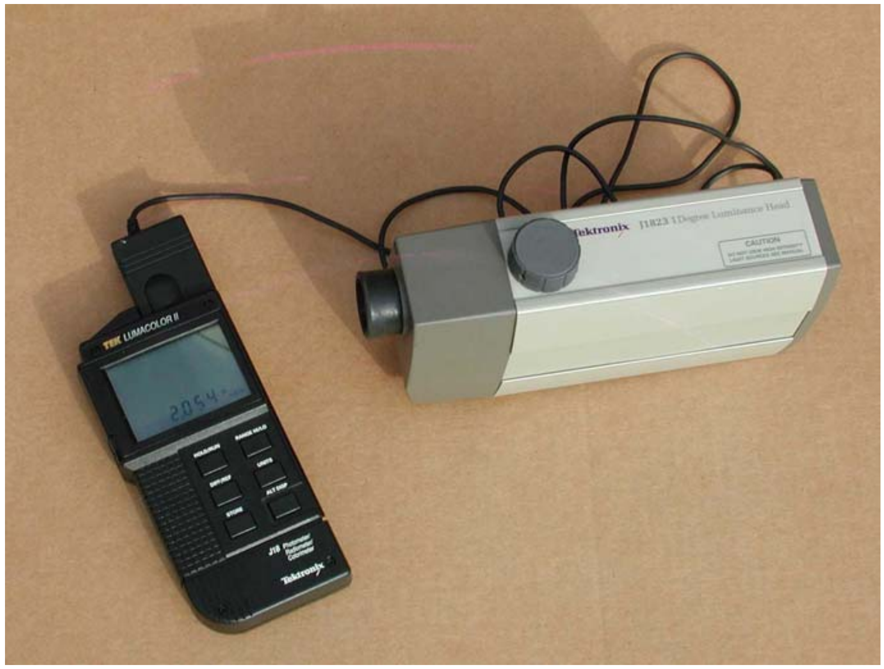
Photograph 7. Trimble ProXL GIS System Configured For Field Use.

In supporting the Open Skies measurement requirements, the J18 is equipped with a Tektronix J1823 Narrow Angle Luminance Head. The J1823 sensor head has a 1° acceptance angle, and can focus over a range from 50 cm to infinity. Table 2 lists the performance characteristics for the J1823. Constantly updated readings are provided, which may be stopped by use of the "HOLD" button. It is configured to read luminance in candela per square meter.

Table 2. Tektronix J1823 Luminance Head Performance Characteristics.

Characteristic	Standard Performance
Measurement Angle	1°
Accuracy (including non-linearity)	±5%, ±1 digit to NIST standard light source
Spectral Response	CIE Photopic (See Figure 2)
Spectral Accuracy	$F_{1'}$ = <5% (DIN class B)

Prior to measurements the J1823 is focused, then a uniform area selected that is of a size sufficient to completely fill the measurement field. Photograph 8 illustrates the LumaColor equipped with the J1823 narrow angle luminance head, while Figure 2 provides a plot of the relative spectral response for the J1823 (Serial No. B020191) attachment.



Photograph 8. Tektronix LumaColor Photometer with J1823 Attachment.

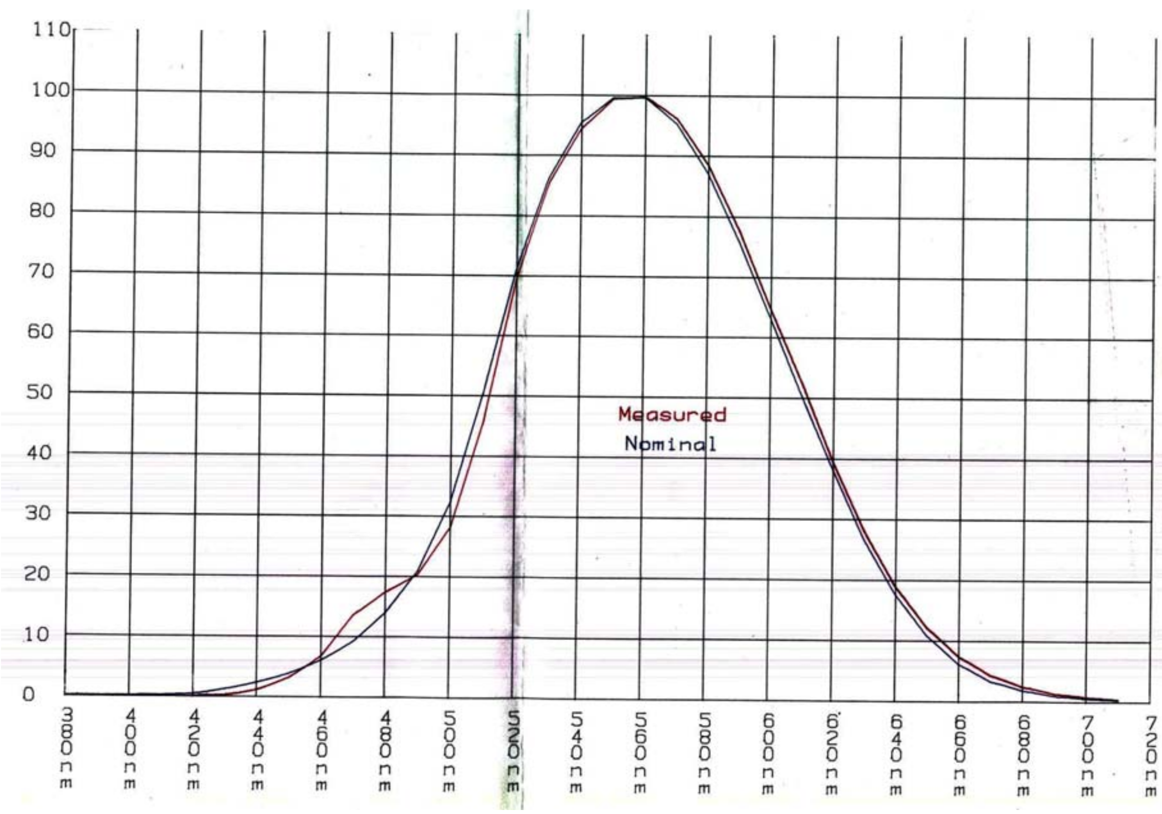


Figure 2. Relative Spectral Response- J1823 Sensor Head.

4.0 DATA COLLECTION METHODOLOGY

This section of our report provides a concise description of the methodology that we employed to measure the construction and optical characteristics of the DTRA WPAFB Optical/Video array. In conducting these measurements, reference was made to applicable sections of the Open Skies Treaty.

4.1 Target Array Dimensions

4.1.1 Area A Dimensions. In measuring the length and width of the bars within Area A, both a 60 m nylon coated steel survey tape (Sokkia/Eslon Model 8653-76) and a 60 cm (Westcott® No. R590-24) flexible stainless steel ruler were used, with all measurements less than 60 cm made using the ruler. With respect to the *white bars*, the width and length was measured for each of the three bars comprising a group for both in-line and cross-line-of-flight. A single location was measured on each bar. With respect to the *black bars*, only the width was measured for each group, since the bar length is basically indeterminate. Again, only a single location was measured. The width measurements of the three white bars and two black bars within a group were then averaged (total of 5 measurements per group) to arrive at the in-line and cross-line-of-flight data reported in Section 5, Table 5. For the length measurements, the three white bar measurements were averaged (total of 3 measurements per group). Included in Table 5 are the design lengths and widths for the array.

Measurements of the separation between adjacent bar groups, for example between Group 23 and Group 22, were made at three locations, with the average also reported in Table 5. The inter-group distance was measured using the stainless steel ruler for separations less than 60 cm, and with the 60-m tape for the larger separations.

Measurements of the length and width of each bar, as well as the separation between bar groups, were made to the nearest millimeter. With the irregularity of the edge between the white painted bar areas and the black background, sub-millimeter measurements were not practical. Edge irregularity varies by approximately ±1 mm due to the texture of the concrete surface, as well as to a slight bleeding of the paint beneath the masking tape that occurred during coating of the target. However, as evidenced by the data in Table 5, the dimensions of the bars are still well within treaty requirements.

4.1.2 Area A and Area B Overall Dimensions. The 60-m survey tape was used to measure the overall dimensions of the Optical/Video array, including Area A (resolution array), and Area B (brightness panel). These measurements were made to the nearest centimeter.

4.2 Geographic Coordinates, Elevation, and Bar Orientation.

4.2.1 Geographic Coordinates. A Trimble Navigation Pro-XL 8-channel GPS system was used to measure the geographic coordinates (WGS 84) of the array. The point of reference selected for the coordinates was the southwest corner of the cross-line-of-flight bar Group 1. In measuring the coordinates, the Pro-XL antenna was attached to a level equipped survey pole. Prior to initiating data collection, the antenna was first leveled. The Trimble TDC1 data collector was programmed using the resident Asset Surveyor ™ software to set the GPS receiver parameters for submeter accuracy. During the measurement period, a minimum of 6 to 7 satellites was "visible" to the GPS receiver, and no multi-path effects present. Post processing techniques using Trimble Navigation Pathfinder® yielded a horizontal accuracy of 0.6 m. The base station chosen for the differential correction was a USGS operated station located at Gailbrath, Oh.

4.2.2 Elevation. Elevation (MSL) was determined using a USGS 7.5 minute series topographic map. While the Trimble Pro-XL GPS system acquired elevation data along with the measurement of the coordinates, the vertical accuracy is on the order of 1 to 2 m.

4.2.3 Bar Orientation. The orientation of the in-line and cross-line-of-flight bar groups relative to true north was derived from GPS coordinate data acquired with the Trimble Navigation Pro-XL system. In determining bar orientation, coordinates were first determined for the southwest corner of the cross-line-of-flight bar group 1 and the northwest corner of the cross-line-of-flight bar group 23, as well as for the east and west edges of the runway adjacent the Optical/Video array. After post-processing the data to yield submeter accuracy, the bar orientation was then determined. A comparison of the orientation for the edges of the runway and the bar groups were all within $\pm 0.5^{\circ}$. For purposes of the baseline certification effort, bar orientation was determined only from the cross-line-of-flight bar groups. A compass was not used due to the local attraction affects from buried steel reinforcing rods.

4.3 Background Spectral Reflectance Measurements

The ASD FieldSpec FR™ spectroradiometer was used to acquire absolute spectral reflectance data over the 350 nm to 1100 nm spectral range from the background areas falling within the 25 m distance requirement of the treaty. The fiber optic probe was attached to a tripod (see Photograph 4), and leveled prior to each measurement set. Measurements were made, using natural irradiation, of the adjacent concrete and grass for ten randomly selected areas for each background type. Within each randomly selected concrete or grass area, three sub-areas were also measured, resulting in a total of 30 measurements for each background type. Spectral reflectance measurements were also made of the 7 percent and 56 percent levels of the Area B brightness panel, and from the 7 percent and 56 percent levels of the Area A bar group 10.

In selecting the areas to measure for the two distinct concrete and grass backgrounds, a grid pattern was first overlaid on a scaled drawing of the Optical/video array, then grid locations selected using a list of random numbers. Figure 3 illustrates the location of the randomly selected background areas relative to the Optical/Video array. The distance and direction from the nearest edge of the array is also indicated.

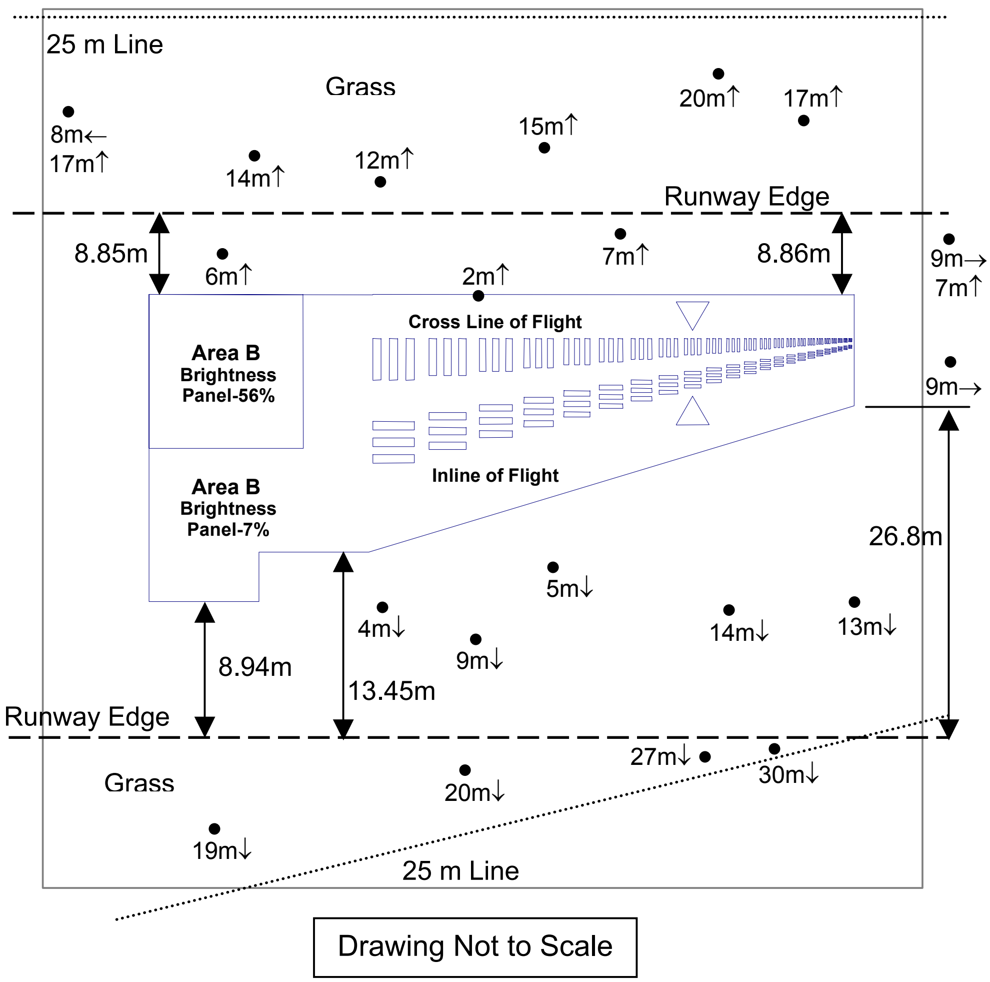
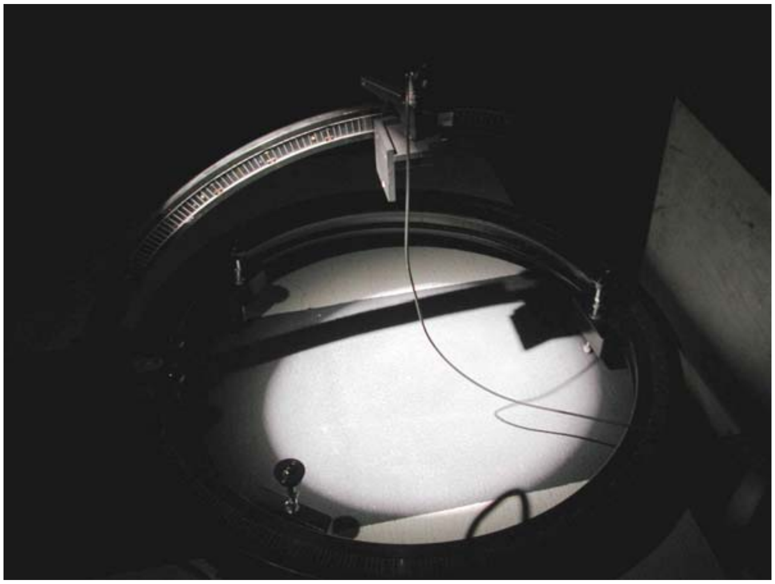


Figure 3. Location of Concrete and Grass Background Measurements.

4.4 Angular Spectral Reflectance Measurements- Group 3

The ASD FieldSpec FR™ spectroradiometer was also used to acquire spectral reflectance data from the randomly selected 7 percent and 56 percent bars (Group 3) at the required 0°, 30°, 45°, and 60° from nadir viewing angles. Within Group 3, three white bars and two black bars were measured from the cross-line-of-flight elements, and two white and three black bars from the in-line-of-flight elements. Photograph 9 illustrates the goniometer with the irradiated target area.



Photograph 9. Goniometer Configured for Angular Measurements.

For acquiring these measurements, an artificial collimated irradiation source was used. The source was mounted to a stepladder at a height of approximately 1.5 m to provide a uniformly irradiated circle of approximately 1 m diameter. The source was located to the south of the goniometer position, and adjusted for a simulated solar azimuth of 180° and a solar elevation of 60° (30° off nadir), with the source to target surface set to 2.35 m. The relationship of the source and goniometer remained constant for all measurements, while the probe was adjusted to the desired viewing angle and direction. This alignment provided a realistic simulation of natural irradiation without causing self-shadowing of the target by the goniometer. Figure 4 illustrates the measurement configuration, while Photograph 10 illustrates the light source.

In making the measurements, the ASD fiber optic probe was attached to the goniometer, and then goniometer was placed atop the selected white or black bar within 1° of true north. Measurements were first made with the probe aligned parallel to the 44.5° track at each of the four required viewing angles, then aligned to the 224.5° track, again at four viewing angles. The measurements acquired from the 44.5° and 224.5° viewing directions were then averaged for each viewing angle, with the results given in Table 6.

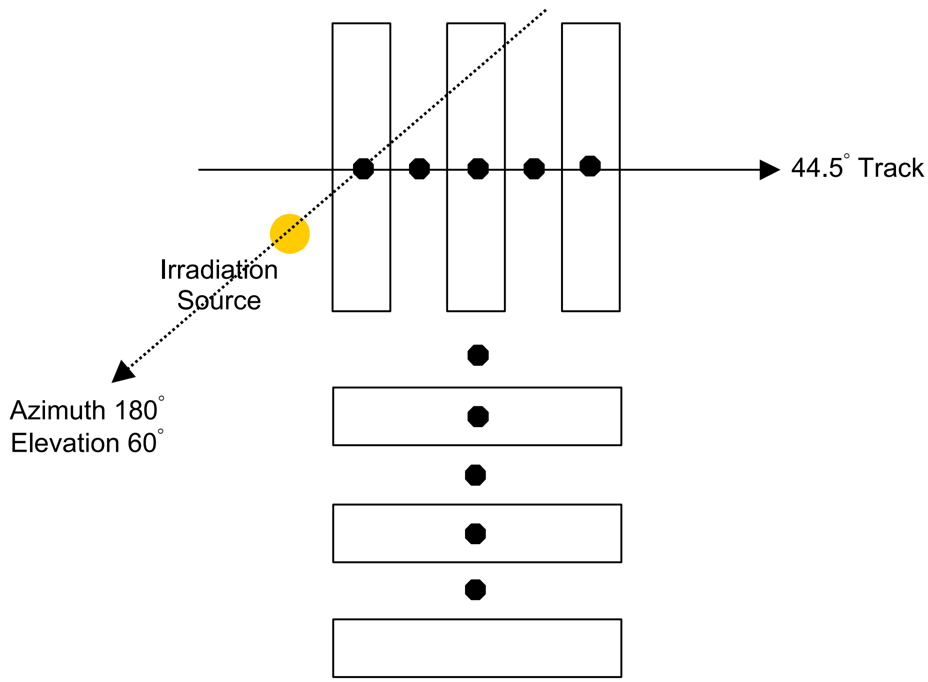


Figure 4. Viewing Angle Measurement Configuration.

For the next set of measurements from the same bar, the probe was aligned along an azimuth of 134.5°, then 314.5°, and measurements made at the four viewing angles.

Photograph 10. Artificial Irradiation Source.

After completing the measurements for the cross-line-of-flight Group 3 bars, the goniometer was relocated to the in-line Group 3 bars. After weighting the spectral data with the luminosity function the results of these measurements, by viewing angle and cross-line/in-line-of-flight directions, are reported in Table 6. Each reported reflectance is an average of 5 measurements (different bar).

5.0 GROUND TRUTH DATA

This section of the report contains the ground truth data collected in support of the 9 through 31 January 2002 Open Skies baseline certification effort at the WPAFB Optical/Video fixed calibration site. Softcopies of the data are available upon request. Data presented include a listing of documentary photographs, target dimensions and location, average spectral reflectance measurements of randomly selected concrete and grass background areas, average spectral reflectance measurements of the two brightness panels (Area B), and the angular in-line and cross-line-of-flight spectral reflectance and modulation measurements of a randomly selected bar group (Area A/Group 3).

In addition, average spectral modulation plots (in-line and cross-line) are included for the randomly selected bar group, along with spectrally based standard deviation plots for the various reflectance measurements. Also, a table is provided that lists the integrated modulation for the in-line and cross-line resolution bar measurements as weighted by the standard luminosity function (photopic vision). Included in the table are corresponding target contrast values.

In both collecting and presenting the data, the requirements and methodology established by the treaty were followed as applied to measurement geometry, spectral region of interest, modulation derivation, and integration limits.

5.1 Documentary Photographs

A digital camera was used to acquire documentary photographs of the instrumentation deployed for the Optical/Video reflectance measurement effort. Each image is provided as a compressed JPEG file, using the following naming convention. The documentary photographs use a file name that includes the Julian date, time (UT), and the original digital file designator generated by the camera software. These photos are available upon request.

OSDDDXXXW.JPG

Where *OS* indicates an Open Skies project, *DDD* the Julian Day, *XXX* the digital camera file number and *W* for Wright-Patterson AFB. Table 3 provides a description of each photograph.

Table 3. Documentary Photographs.

Location: DTRA Optical/Video Array Site- WPAFB, OH		
PHOTO #/File Name	Date/Time (UT)	DESCRIPTION
1: OS010-006W.JPG	10 Jan 02 @ ≈2300	View of goniometer deployed atop white bar
2: OS010-007W.JPG	10 Jan 02 @ ≈2300	View of ASD & computer in environmental enclosure
3: OS010-009W.JPG	10 Jan 02 @ ≈2300	View of collimated tungsten-halogen source
4: OS010-010W.JPG	10 Jan 02 @ ≈2300	View of goniometer atop irradiated white bar

5.2 DTRA Fixed Optical/Video Target Mensuration Data

Table 4 provides a summary of the WPAFB Fixed Calibration Array survey parameters as determined for Delivery Order 0002. The horizontal control data were derived using an 8-channel GPS system and post-processing techniques to yield differentially corrected data, while the vertical control was determined from USGS published elevation data. Figure 5 illustrates the WPAFB Optical/Video Fixed Site array dimensions for Areas A and B. These data were derived using a 60 m survey tape.

Table 4. Summary of WPAFB Fixed Target Array Survey Data.

Geodetic Coordinates	Orientation
Latitude: 39° 46' 36.77" N (WGS 84) Longitude: 84° 07' 03.16" W (WGS 84) Elevation: 241 meters (MSL)	Azimuth: Large to small elements: 44° 30' True Small to large elements: 224° 30'True Declination: 5° 21' W (21 January 2002)

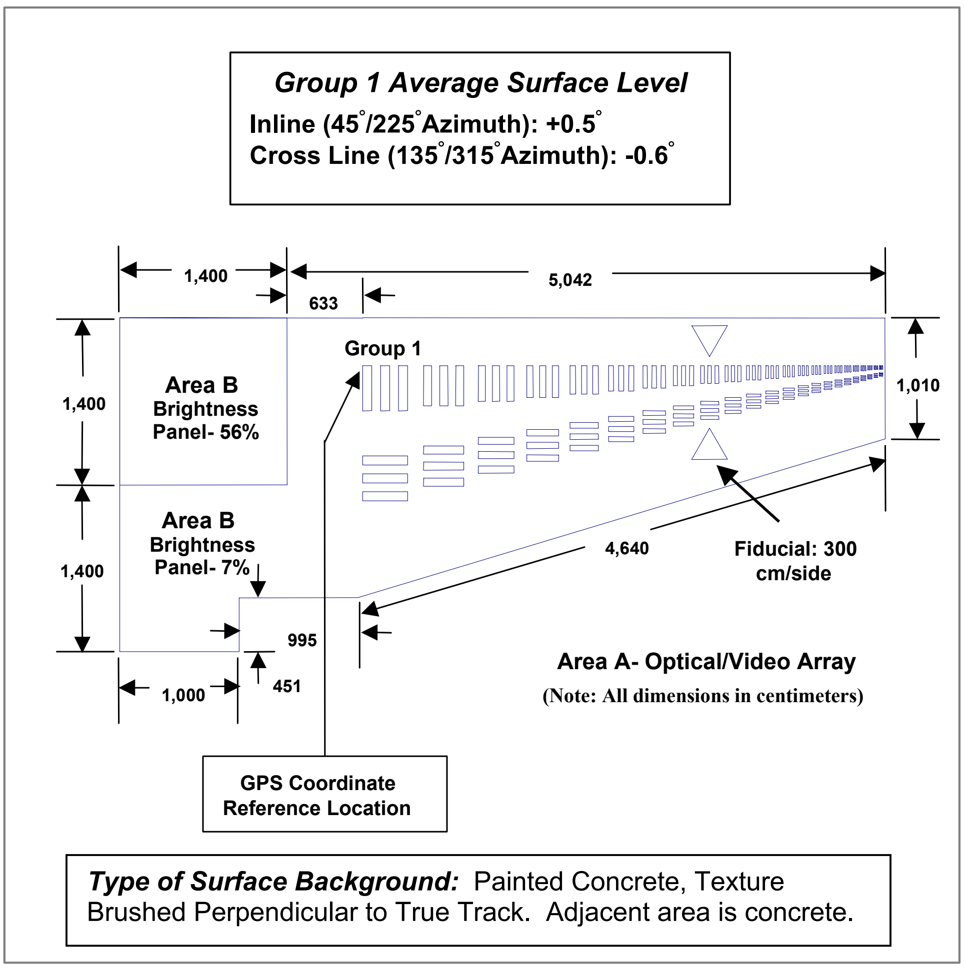


Figure 5. Dimensions of the DTRA Fixed Target Array at WPAFB, OH.

Table 5 lists the comparison of the design to the actual dimensions for the DTRA Fixed Resolution Target at WPAFB The actual dimensions were measured using a survey quality 60 m tape and a 60 cm stainless steel ruler. The reported measurements are based on the average of the individual bar and space measurements for both the in-line and cross-line-of-flight bar groups.

Table 5. Comparison of Design and Actual DTRA WPAFB Resolution Target Dimensions.

Element #	A cm Intra-element Separation	B cm Bar/Space Width	C cm Bar Length
1	Design →	75.60	378.00
	Avg XLoF →	75.6	378.0
	Avg LoF →	75.6	378.0
2	134.70	67.35	336.75
	135.0	67.5	337.0
	135.5	67.4	337.0
3	120.00	60.00	300.00
	120.6	60.0	300.0
	120.5	60.0	300.0
4	106.90	53.45	267.25
	106.2	53.3	267.5
	106.3	53.5	267.5
5	95.24	47.62	238.10
	95.5	47.6	238.0
	95.5	47.5	238.0
6	84.84	42.42	212.10
	85.4	42.5	212.0
	85.3	42.5	212.0
7	75.58	37.79	188.95
	74.7	37.8	189.0
	75.7	37.8	189.0
8	67.34	33.67	168.35
	67.5	33.5	168.2
	67.3	33.6	168.3
9	60.00	30.00	150.00
	60.0	30.0	150.0
	60.0	30.0	149.8
10	53.46	26.73	133.65
	53.5	26.7	133.6
	53.4	26.7	133.6
11	47.62	23.81	119.05
	47.7	23.8	119.0
	48.0	23.7	119.0
12	42.42	21.21	106.05
	42.4	21.0	106.0
	42.5	21.2	106.0
13	37.80	18.90	94.50
	38.0	18.8	94.5
	38.0	18.9	94.5
14	33.68	16.84	84.20
	33.5	16.9	84.1
	33.5	16.9	84.1
15	30.00	15.00	75.00
	30.0	14.9	74.9
	30.0	15.0	74.9
16	26.72	13.36	66.80
	26.5	13.5	66.7
	27.0	13.6	66.7
17	23.80	11.90	59.50
	23.9	12.0	59.5
	23.9	12.0	59.5
18	21.20	10.60	53.00
	21.2	10.6	53.0
	21.1	10.6	53.0
19	18.88	9.44	47.20
	19.0	9.5	47.1
	19.0	9.5	47.1
20	16.82	8.41	42.05
	17.0	8.4	41.9
	17.0	8.4	41.8
21	15.00	7.50	37.50
	15.0	7.5	37.3
	15.0	7.5	37.0
22	13.36	6.68	33.40
	13.4	6.6	33.1
	13.4	6.6	33.2
23	11.90	5.95	29.75
	12.0	6.0	29.7
	12.4	6.0	29.7

5.3 DTRA Optical/Video Array Reflectance Measurements

MTL's ASD FieldSpec FR™ spectroradiometer was used to acquire the angular and background specular reflectance and modulation measurements reported herein. For the angular measurements, the ASD fiber optic probe was attached to a goniometer, and a tungsten-halogen source used to illuminate the surface. For all other reflectance measurements, the ASD probe was attached to a tripod and natural irradiation used.

5.3.1 Angular Spectral Reflectance- Area A. Figures 6 through 13 provide plots of the angular spectral reflectance measurements made from the randomly selected Area "A" bar group (Group 3) for the treaty required in-line-of-flight and cross-line-of-flight collection geometries. Included with each figure are the spectral reflectance and standard deviation and the average reflectance for the 350 nm to 1100 nm spectral region. Plots are included for the 0°, 30°, 45°, and 60° off-nadir viewing angles. The average value of the black and white bars for the 350 nm to 1100nm spectral region are included on each of the plots. Each of the individual look angle plots are an average of 10 measurements, as acquired from five different white or black bar locations and at two look azimuths. For the in-line-of-flight set of measurements, the ASD probe was aligned along an azimuth of 45° and 225° (parallel to the true track of the target array) to provide the two look azimuths. For the cross-line-of-flight set of measurements, the ASD probe was aligned along an azimuth of 135° and 315° (perpendicular to the true track of the array).

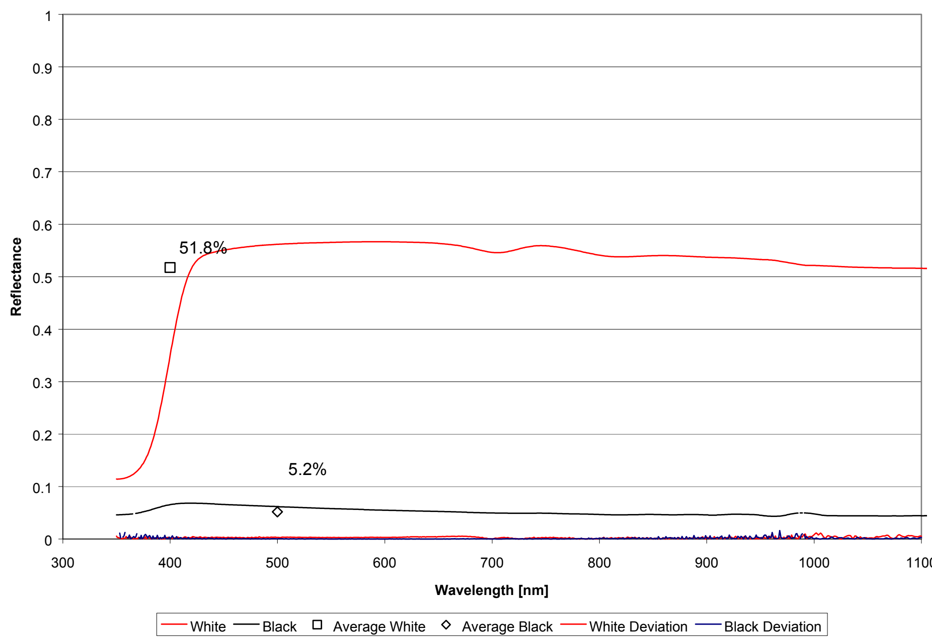


Figure 6. Average Spectral Reflectance and Standard Deviation- In-line-of-Flight White and Black Bars @ 0° Viewing Angle.

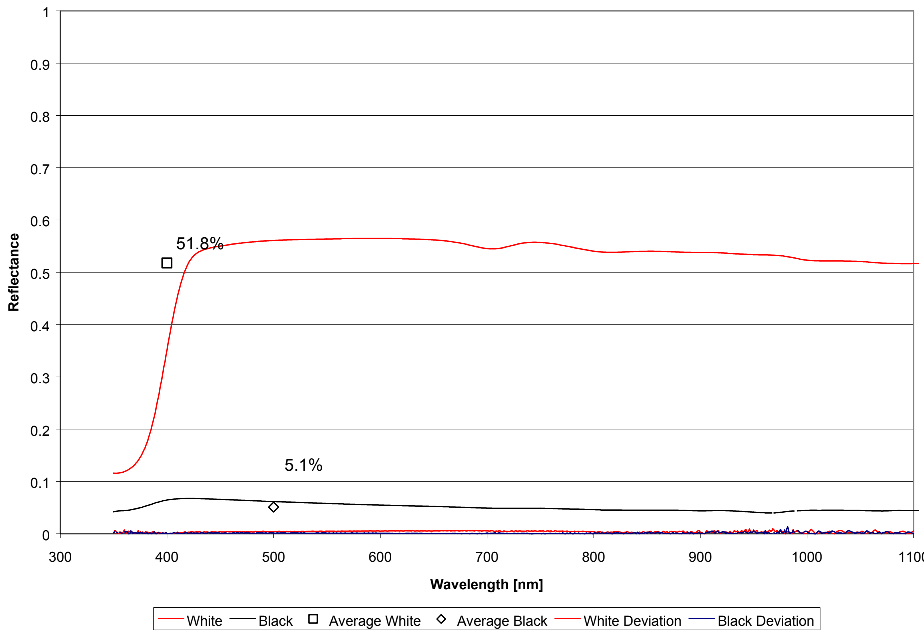


Figure 7. Average Spectral Reflectance and Standard Deviation- Cross-line-of-Flight White and Black Bar @ 0° Viewing Angle.

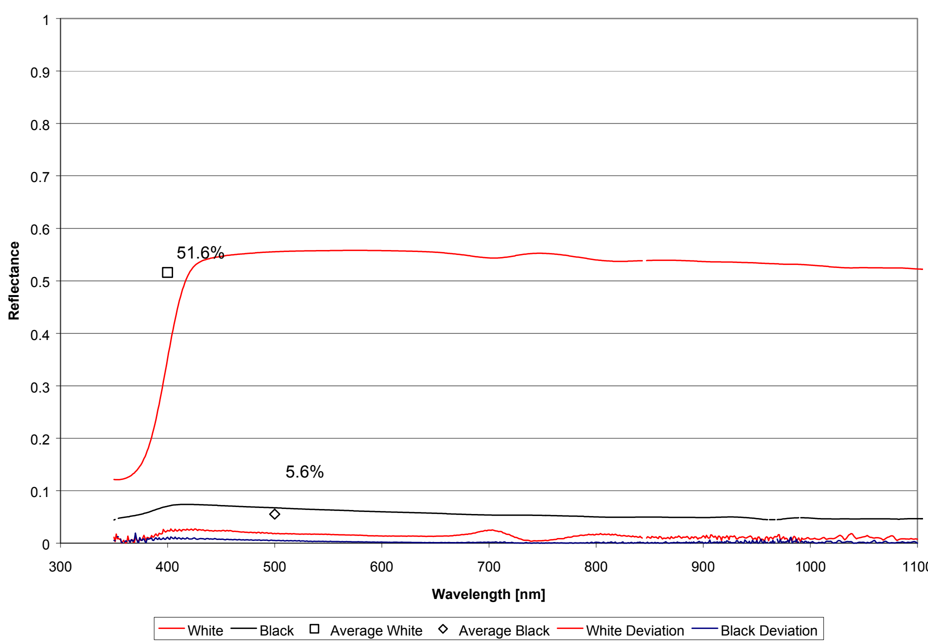


Figure 8. Average Spectral Reflectance and Standard Deviation- In-line-of-Flight White and Black Bars @ 30° Viewing Angle

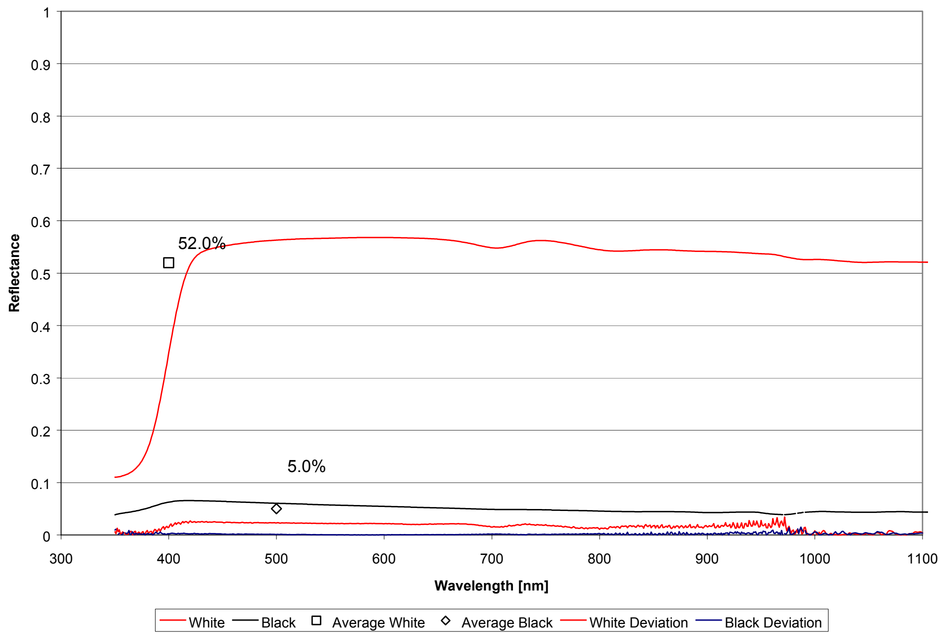


Figure 9. Average Spectral Reflectance and Standard Deviation- Cross-line-of-Flight White and Black Bar @ 30° Viewing Angle.

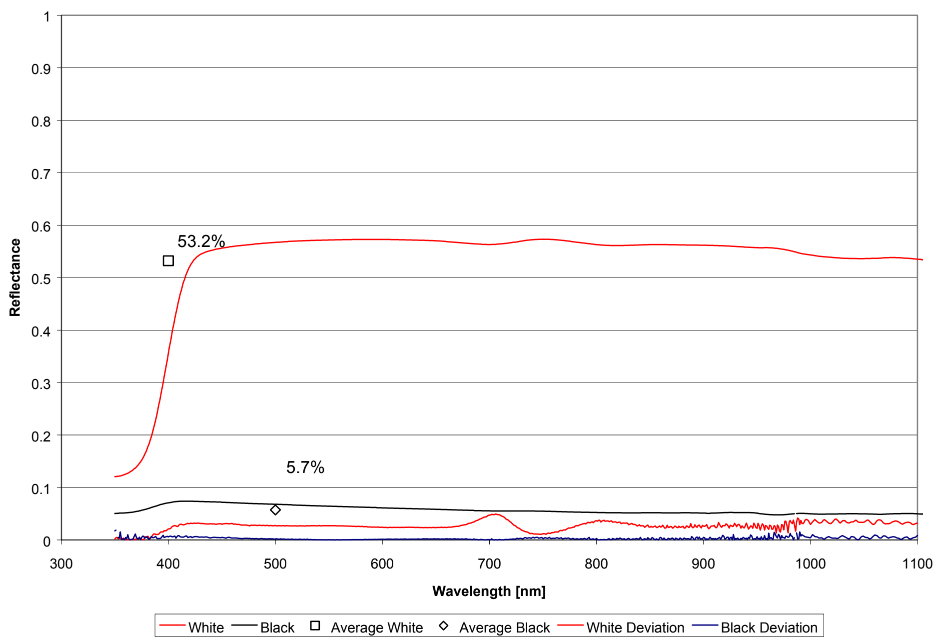


Figure 10. Average Spectral Reflectance and Standard Deviation- In-line-of-Flight White and Black Bars @ 45° Viewing Angle

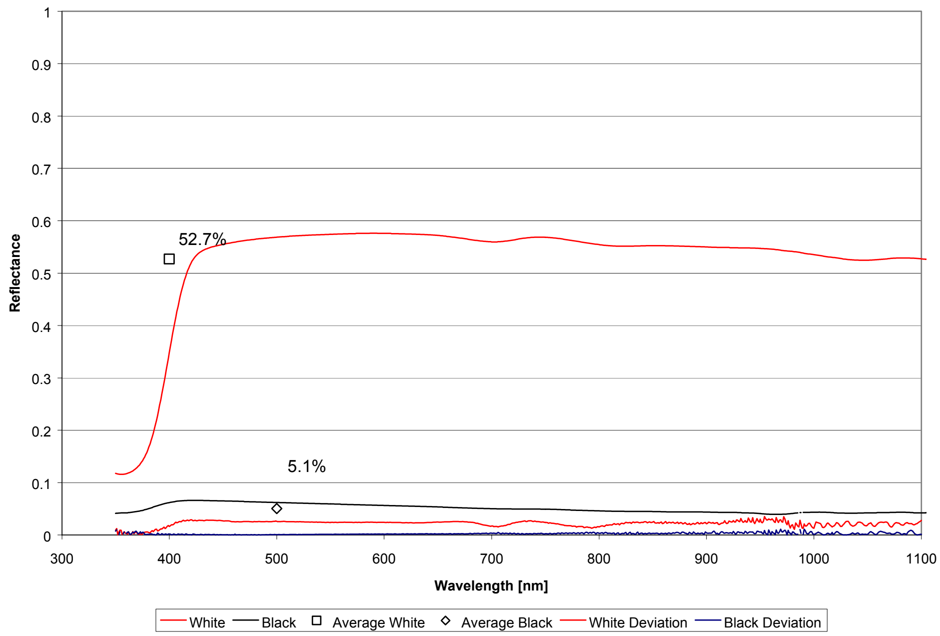


Figure 11. Average Spectral Reflectance and Standard Deviation- Cross-line-of-Flight White and Black Bar @ 45° Viewing Angle.

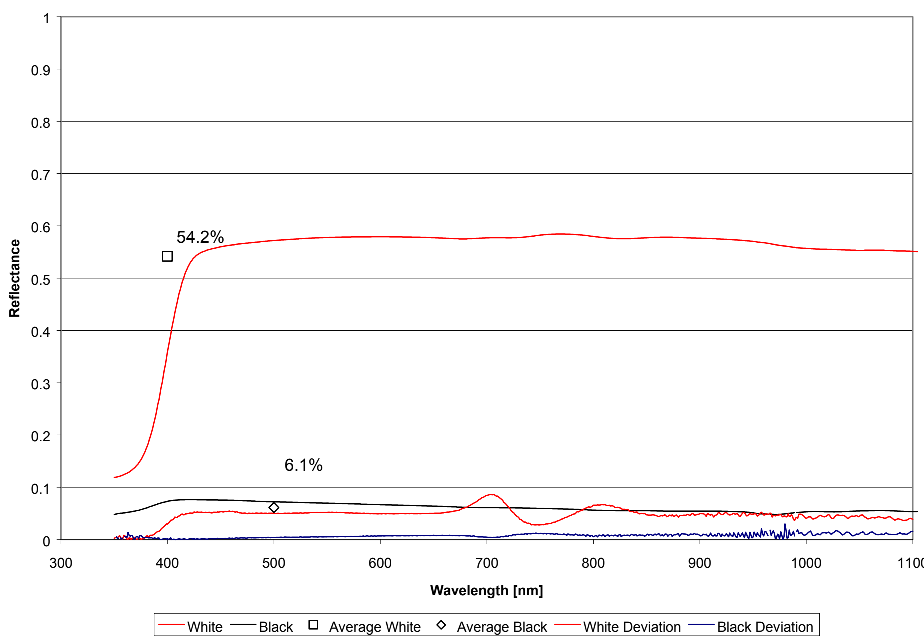


Figure 12. Average Spectral Reflectance and Standard Deviation- In-line-of-Flight White and Black Bars @ 60° Viewing Angle

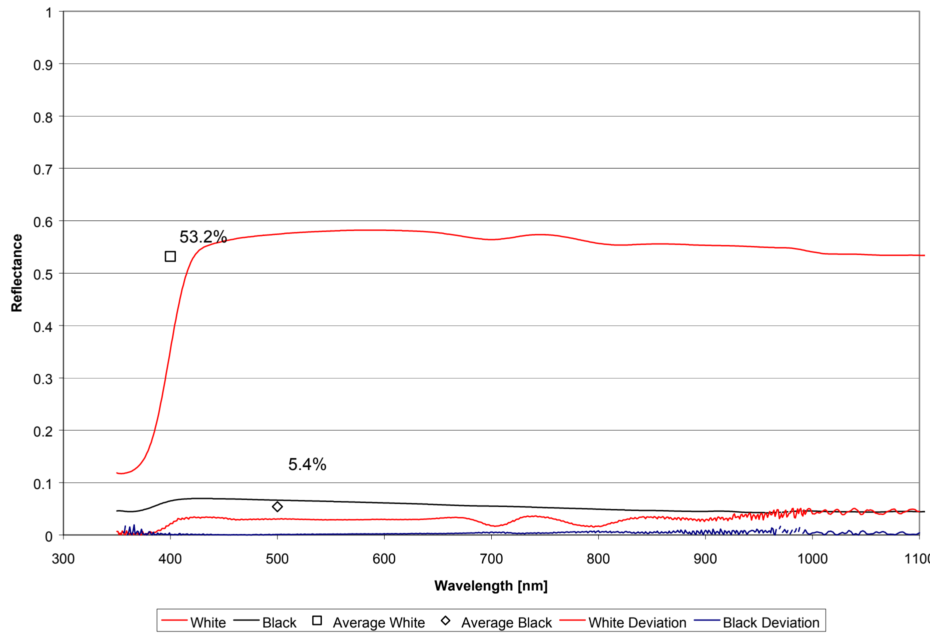


Figure 13. Average Spectral Reflectance and Standard Deviation- Cross-line-of-Flight White and Black Bar @ 60° Viewing Angle.

5.3.2 Angular Spectral Modulation- Area A. The spectral reflectance data presented in Section 5.3.1 was used to derive the target's (Area A/Group 3) spectral modulation as defined by Reference 1 Section D14.SI of the treaty. As defined by this reference, spectral modulation was calculated as the ratio of the difference of the white and black bar spectral reflectance to the sum of these spectral reflectances. The results are presented for the 350 nm to 1100 nm spectral region in Figures 14 through 21. As in the case of the plots presented in Section 5.3.1, plots of spectral modulation are provided for the 0°, 30°, 45°, and 60° off-nadir viewing angles for both in-line-of-flight and cross-line-of-flight orientations. Also included on each plot is the average modulation over the 350 nm to 1100 nm spectral region. Each modulation is within the 0.66 to 0.82 range as required by the Treaty Guidance Document Section 2.6.2, D14.SII.P4. Note however that this average modulation is not based on an integration over a sensor specific wavelength region. In Section 5.3.3 we list the modulation based on the spectral range encompassed by photopic vision.

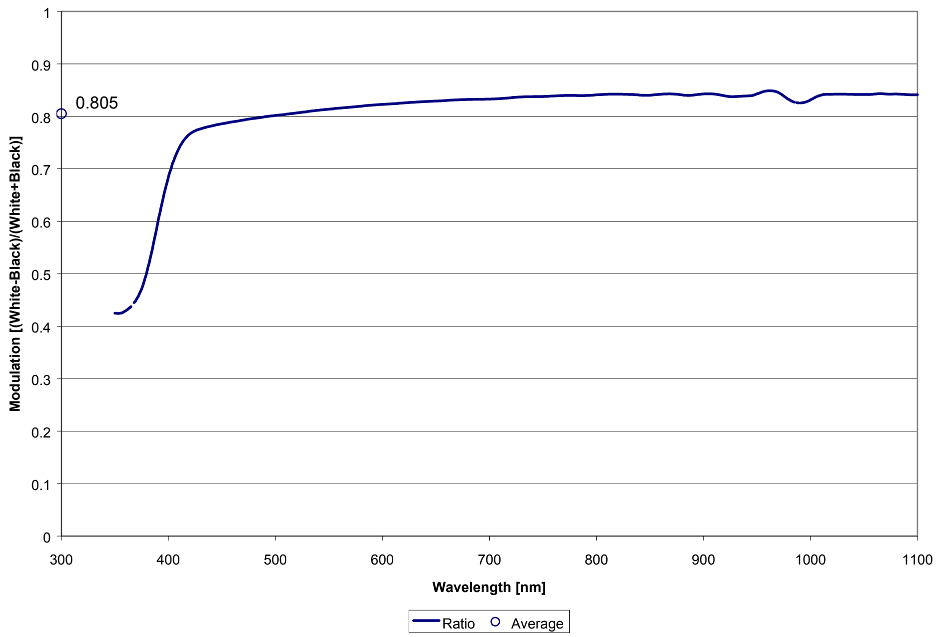


Figure 14. Average Spectral Modulation- In-line-of-Flight
0° Viewing Angle.

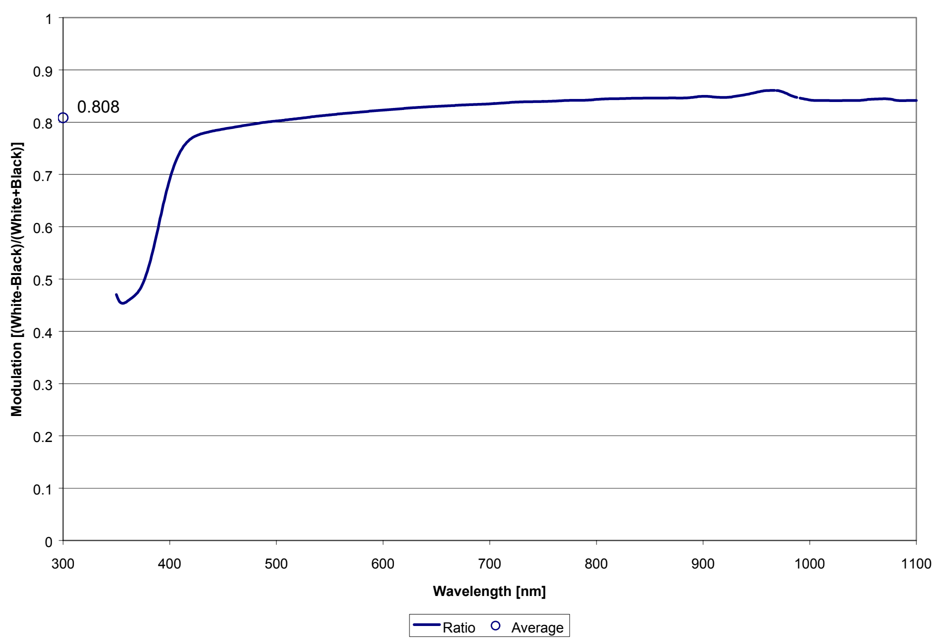


Figure 15. Average Spectral Modulation - Cross-line-of-Flight
0° Viewing Angle

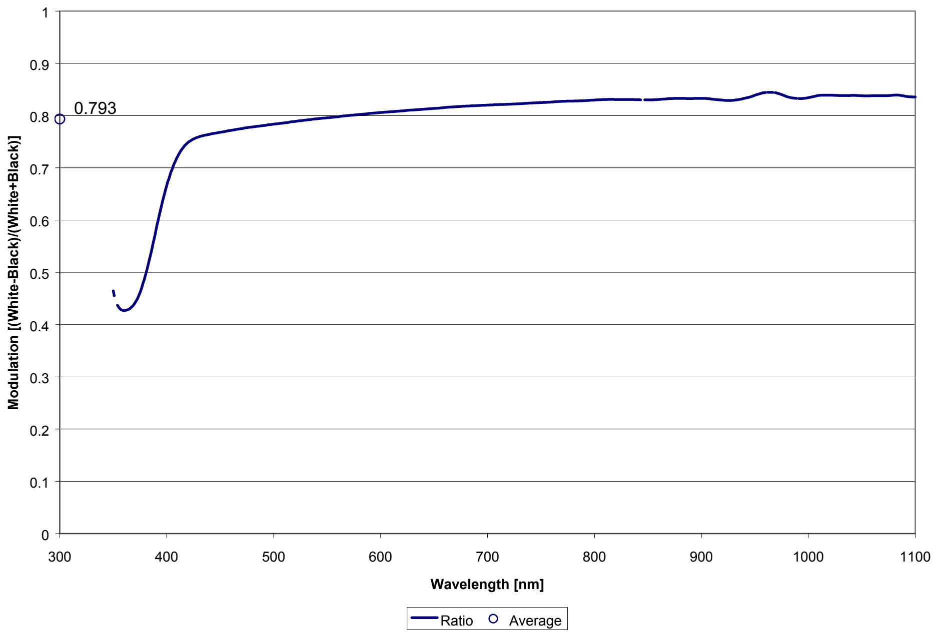


Figure 16. Average Spectral Modulation- In-line-of-Flight 30° Viewing Angle.

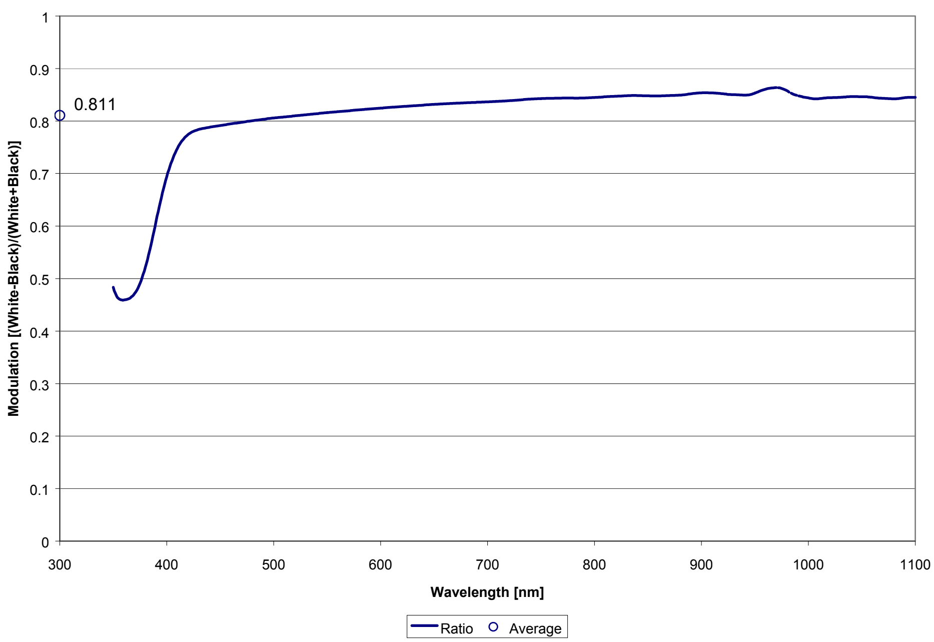


Figure 17. Average Spectral Modulation - Cross-line-of-Flight 30° Viewing Angle.

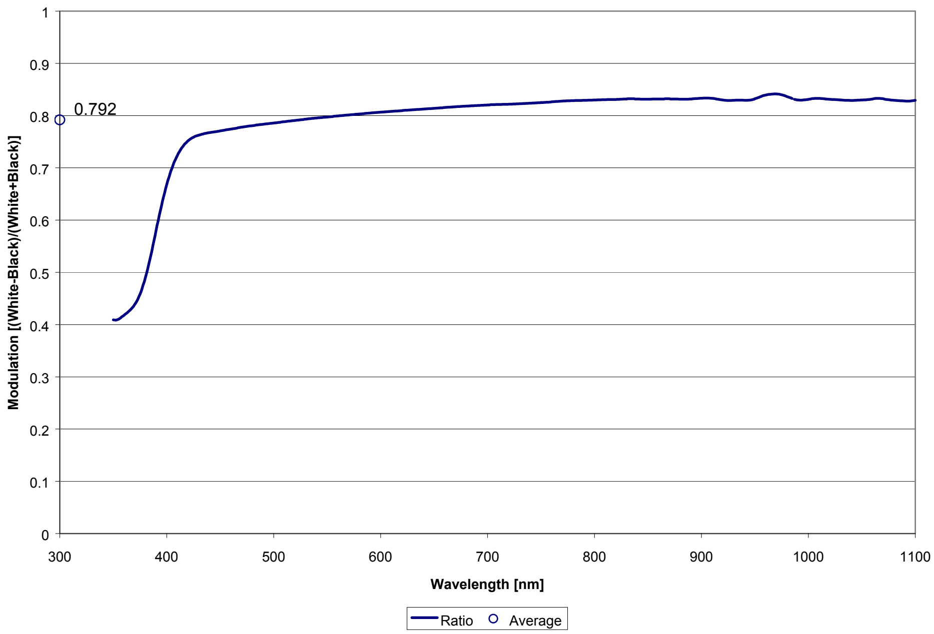


Figure 18. Average Spectral Modulation- In-line-of-Flight 45° Viewing Angle.

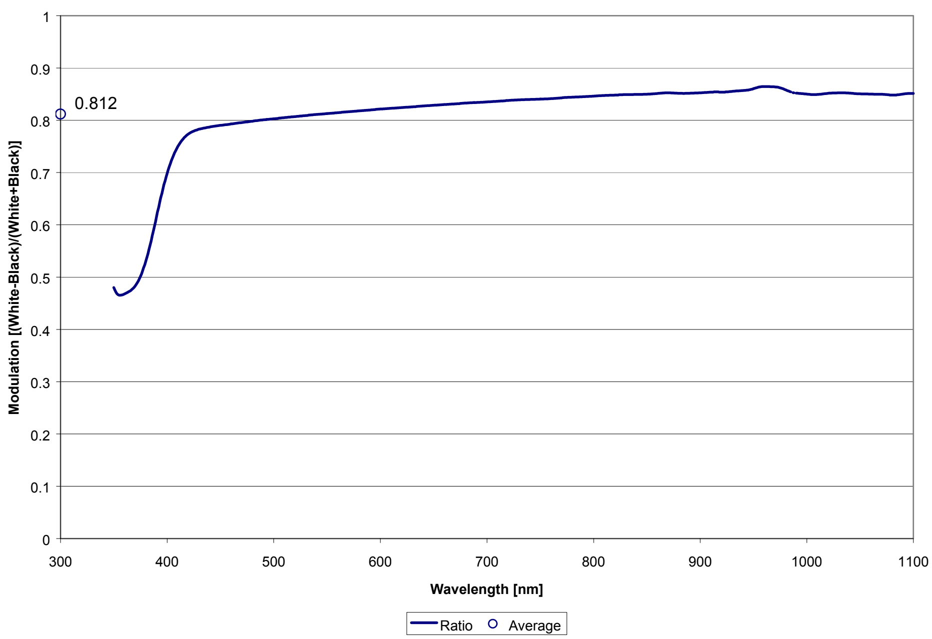


Figure 19. Average Spectral Modulation - Cross-line-of-Flight 45° Viewing Angle.

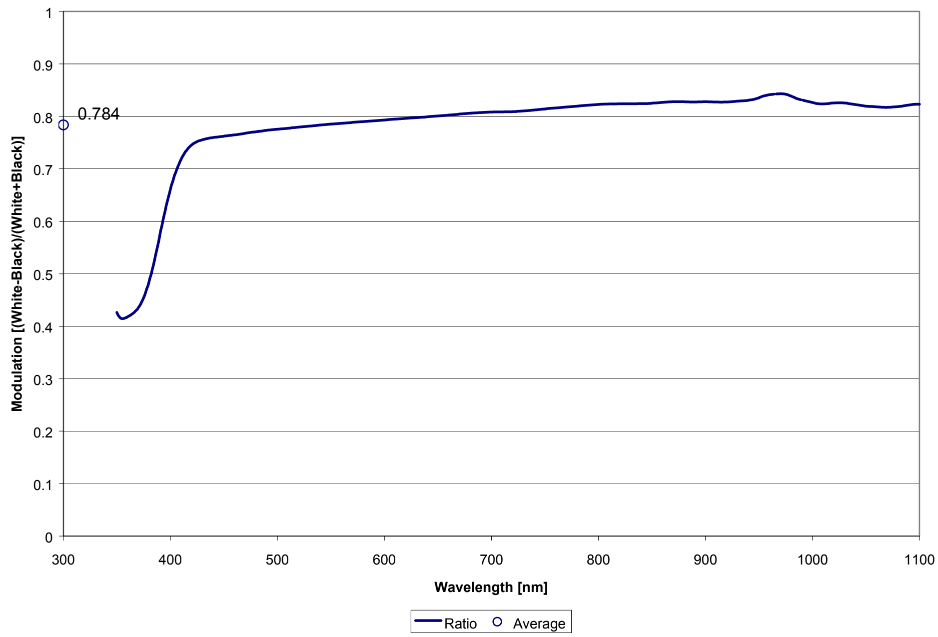


Figure 20. Average Spectral Modulation- In-line-of-Flight 60° Viewing Angle.

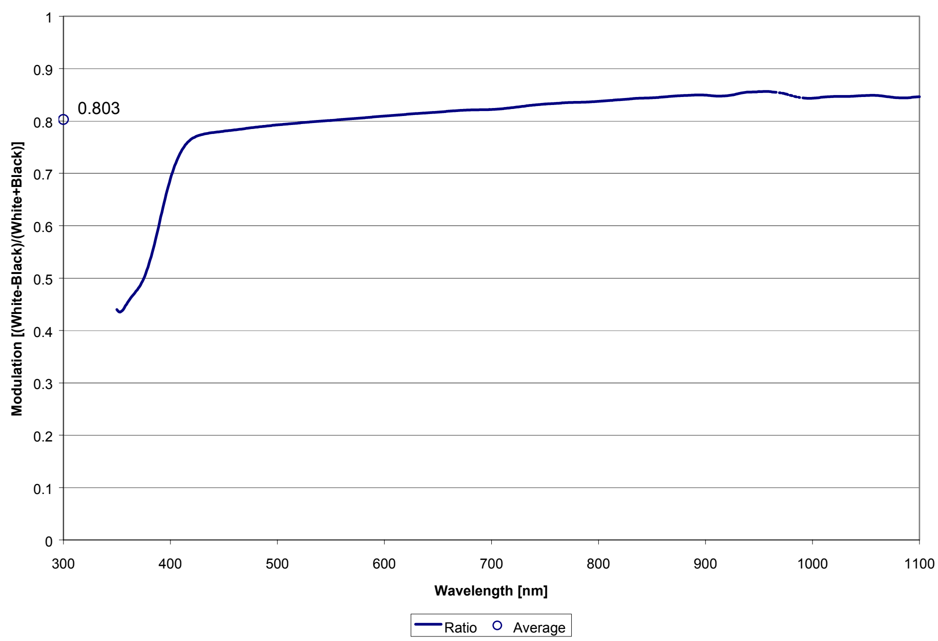


Figure 21. Average Spectral Modulation - Cross-line-of-Flight 60° Viewing Angle.

5.3.3 Summary of Resolution Array Optical Performance. Table 6 provides the average spectral reflectance and modulation for the Area A/Group3 white and black bars at each of the four viewing angles. The average modulation data was derived from the spectral reflectance data presented in Section 5.3.1 by weighting the data with the standard luminosity function (photopic vision), then integrating the resultant function over the 400 nm to 700 nm spectral region as provided for by Section 2.6.2D14.SII.P4(C) of the Open Skies Treaty.

Table 6. Summary of Resolution Target Photopic Reflectance and Modulation.

	Photopic Spectral Region (400 nm to 700 nm)	
	In-line-of-Flight	Cross-line-of-Flight
Black Background Reflectance	Average: STD: 0° 5.8% 0.02% 30° 6.3% 0.32% 45° 6.4% 0.10% 60° 6.9% 0.5%	Average: STD: 0° 5.7% 0.11% 30° 5.7% 0.05% 45° 5.9% 0.14% 60° 6.3% 0.17%
White Bar Reflectance	Average: STD: 0° 56.5% 0.33% 30° 55.7% 1.61% 45° 57.1% 2.62% 60° 57.7% 5.08%	Average: STD: 0° 56.3% 0.48% 30° 56.6% 2.20% 45° 57.3% 2.45% 60° 57.9% 2.97%
Average Modulation	0° 0.81 30° 0.80 45° 0.80 60° 0.79	0° 0.82 30° 0.82 45° 0.81 60° 0.80

5.3.4 Background, Area A, and Brightness Panel Spectral Reflectance Data. This section contains plots of the spectral reflectance data acquired on 10 and 27 January 2002 from selected areas of the Optical/Video Array which cover the 350 nm to 1100 nm spectral region. Curves are provided for the average of ten locations for both the 7 percent and 56 percent levels of the brightness panel (Area B), the average of ten locations for the 7 percent and 56 percent bars that comprise Area A/Group 10, and the average of ten randomly selected concrete and grass background areas that fall within the 25 m distance requirement. Spectral modulation plots are also included for the brightness panel and Area A/Group 10. The average modulation for the 350 nm to 1100 nm spectral region is also given on each modulation plot. The average background spectral reflectances fall within the range stated in the Treaty Guidance Document Section 2.6.2, D14.SII.P4

To improve the statistical analysis, three measurements were acquired in each of the ten randomly selected concrete and grass background areas. Standard deviation data are included for each reflectance plot. Figures 22 through 25 provide the spectral reflectance and standard deviation plots. Table 7 provides the average spectral reflectance and modulation for the background, Area A/Group 10, and Area B, brightness panel. The average modulation data was derived from the spectral reflectance data presented in Section 5.3.1 by weighting the data with the standard luminosity function (photopic vision), then integrating the resultant function over the 400 nm to 700 nm spectral region as provided for by Section 2.6.2D14.SII.P4(C) of the Open Skies Treaty. Figures 26 and 27 provide the spectral modulation plots for the brightness panel and Area A/Group 10.

Table 7. Summary of Background Photopic Reflectance and Modulation.

	Photopic Spectral Region (400 nm to 700 nm)		
	Average:	STD:	
Concrete Background Reflectance	20.2%	3.7%	
Grass Background Reflectance	11.9%	1.8%	
	Average:	STD:	Modulation:
Area A/Group 10 Resolution Segment - Black	7.0%	0.22%	0.79
Area A/Group 10 Resolution Segment - White	60.6%	1.55%	
Brightness Panel Area B – Black	6.4%	0.17%	0.80
Brightness Panel Area B – White	57.9%	1.99%	

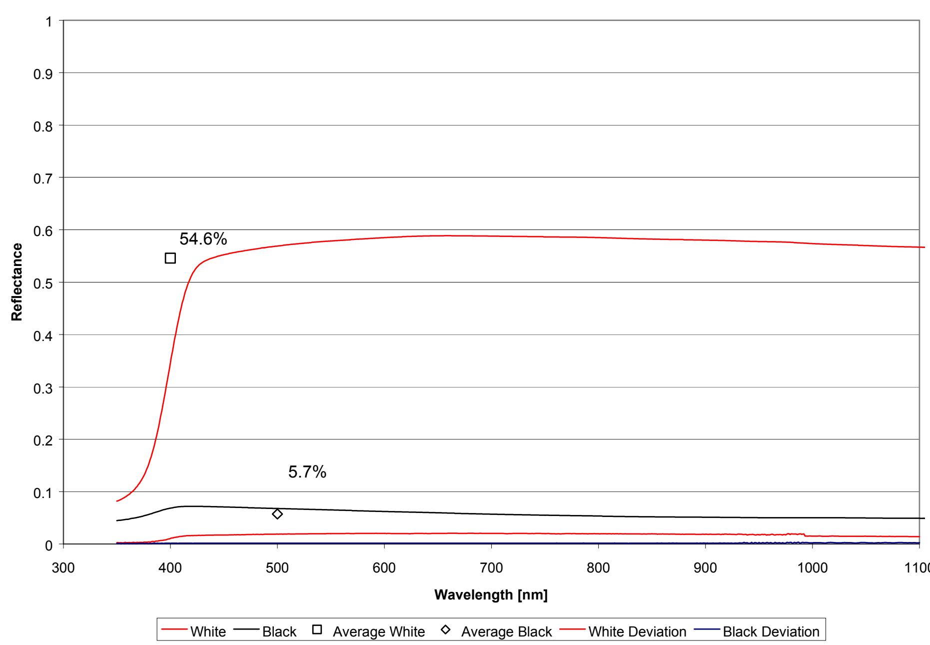


Figure 22. Optical/Video Array Average Spectral Reflectance and Standard Deviation: Brightness Panel Area B.

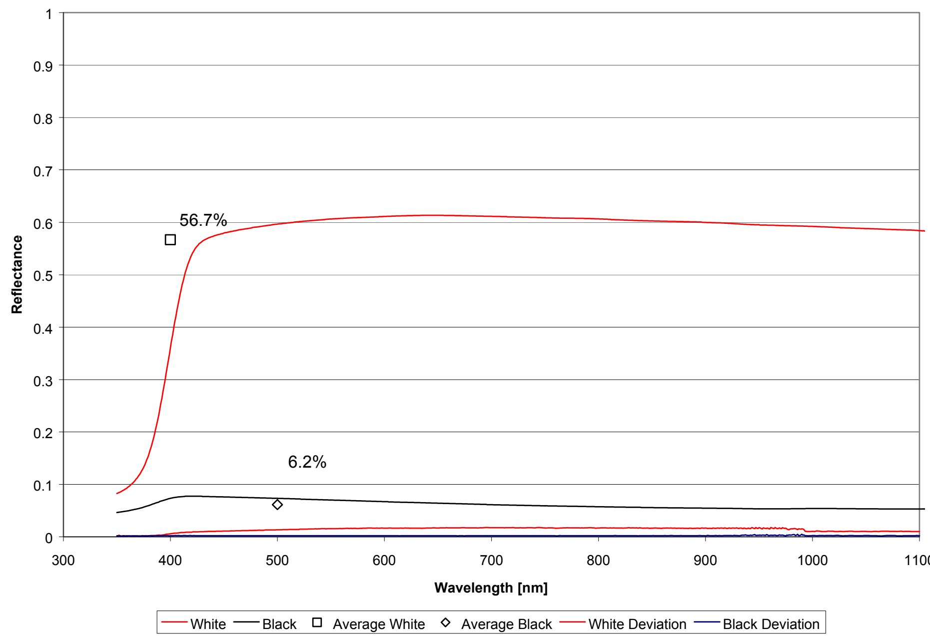


Figure 23. Optical/Video Array Average Spectral Reflectance and Standard Deviation: Area A/Group 10 Resolution Segment.

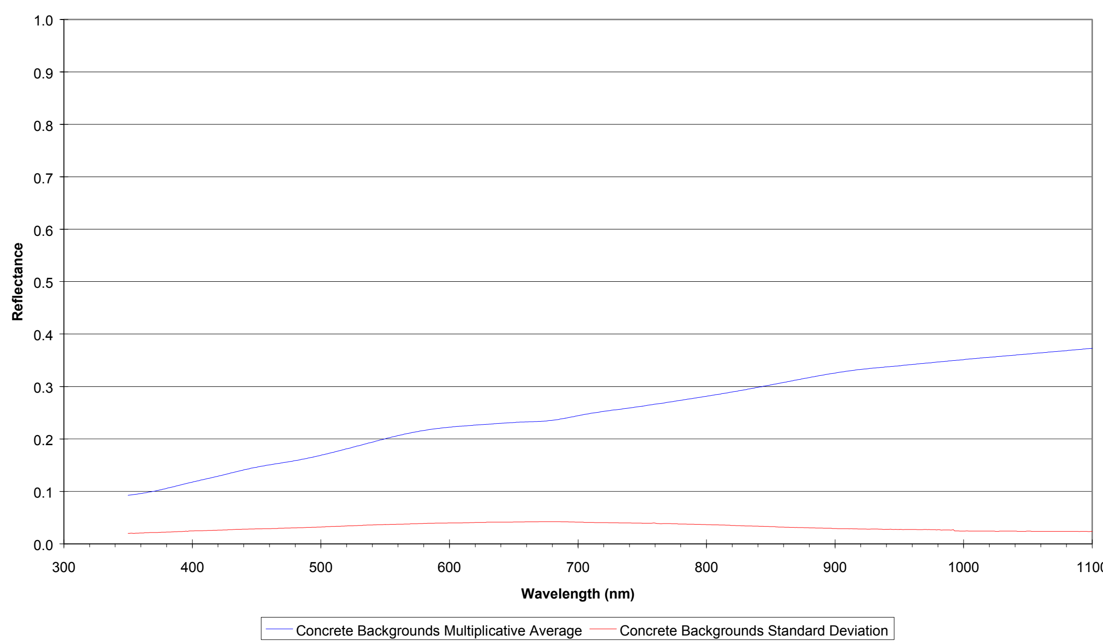


Figure 24. Optical/Video Array Average Spectral Reflectance and Standard Deviation-Concrete.

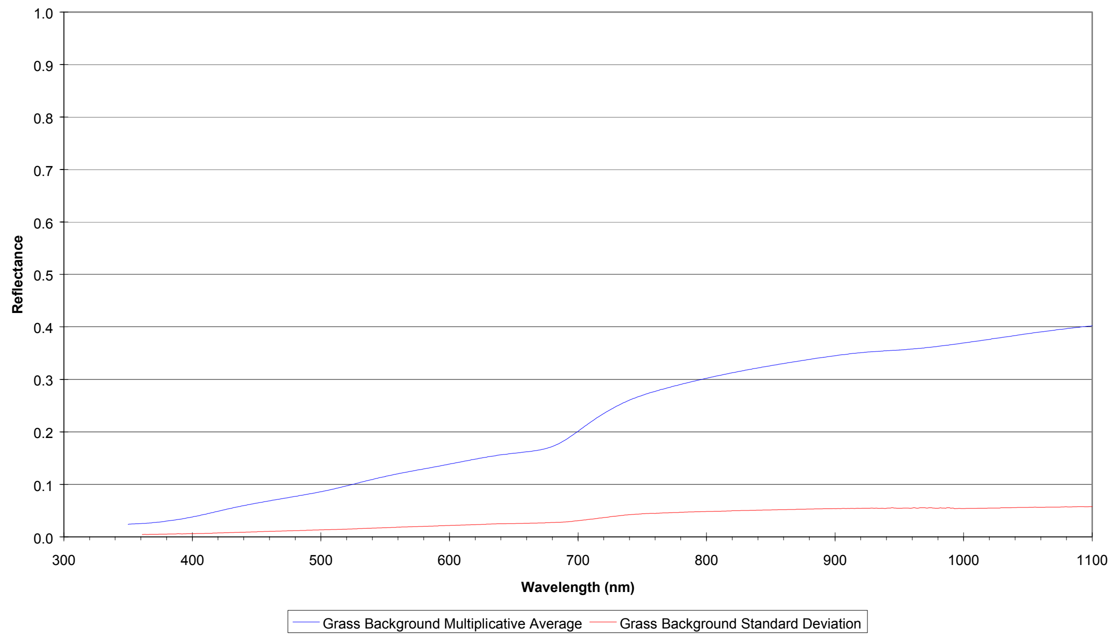


Figure 25. Optical/Video Array Average Spectral Reflectance and Standard Deviation- Grass.

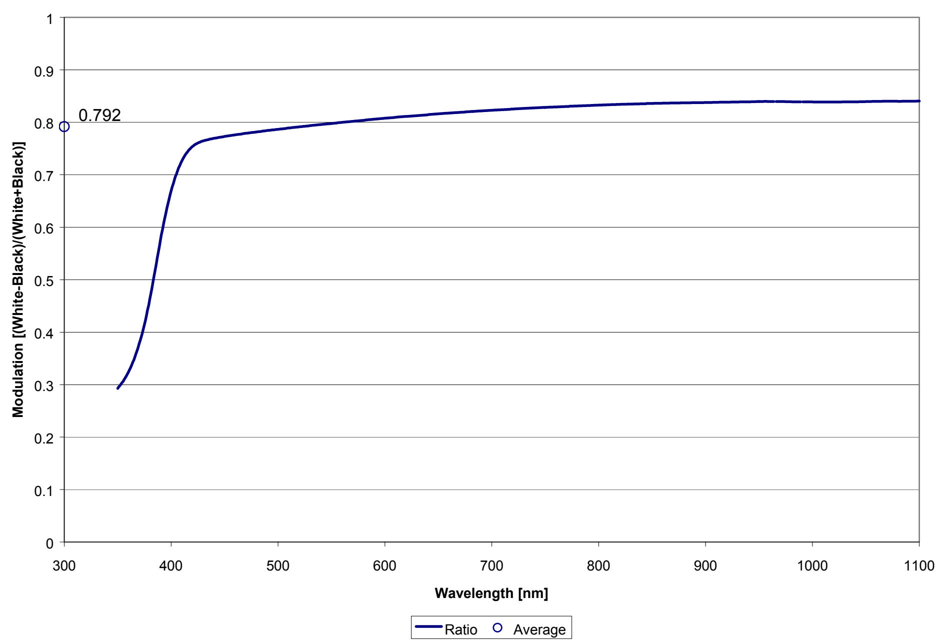


Figure 26. Optical/Video Array Average Spectral Modulation: Brightness Panel Area B.

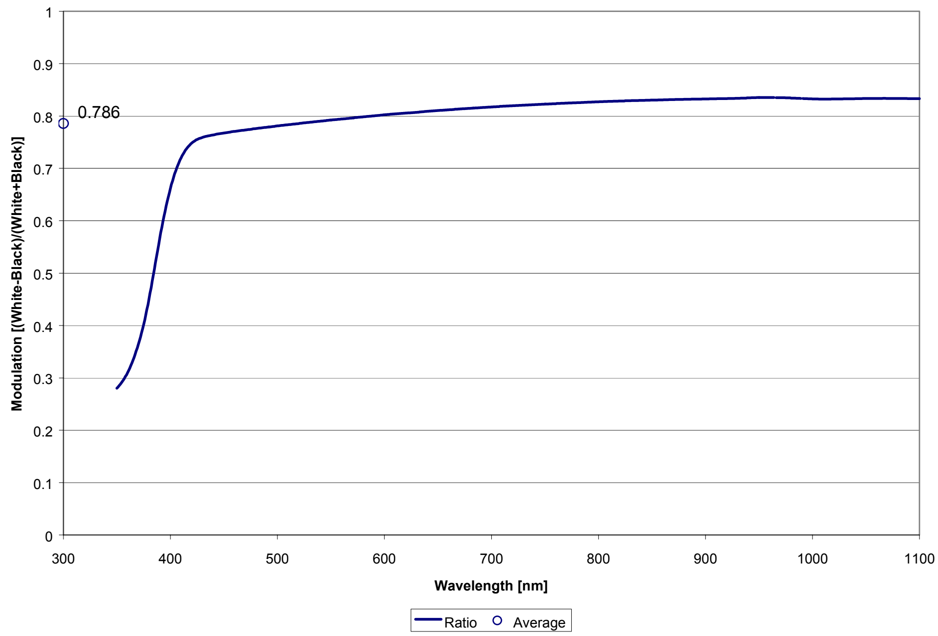


Figure 27. Optical/Video Array Average Spectral Modulation:
Area A/Group 10 Resolution Segment.