# Diffuser Calibration Facility

## Goddard Space Flight Center

## NASA

### Introduction:

A number of space-borne radiometric and imaging instruments use diffuse scatter plates illuminated by the sun as on-board radiometric and reflectance calibration sources. These on-board diffuser plates and laboratory-based standard diffuser plates require preflight measurements of their bidirectional scatter distribution functions (BSDFs). On-board diffusers are used to track on-orbit instrument radiance or reflectance calibrations. Laboratory-based standard diffusers are used for preflight instrument radiometric calibration or as relative reference standard diffusers for BSDF measurements. The essential spectral range of the BSDF measurements needed to support current NASA flight instruments is 230nm to 2500nm. BSDF measurements must be traceable to measurements made at the National Institute of Standards and Technology (NIST).

NASA's Goddard Space Flight Center (GSFC) has established and currently operates, through the auspices of NASA's Headquarters and the Earth Observing System Project Science Office (EOS PSO), the GSFC Diffuser Calibration Facility to measure the BSDF of reflective and transmissive diffuser plates used in the preflight and on-orbit calibration of satellite sensors. This facility is located in building 33, room F311 on the east campus of the Goddard Space Flight Center. The facility is comprised of a gowning anteroom, an air shower, and a class 10,000 laminar flow cleanroom. The cleanroom houses a versatile, fully automated scatterometer capable of measuring the bidirectional reflectance distribution function (BRDF) and total hemispherical reflectance (THR) of a wide range of sample types. These include the following:

white, gray-scale, black and anodized diffuse reflectors,
polished or roughened ceramic or metal surfaces,
clean or contaminated mirrors,
transmissive diffusers
liquids,
and granular solids.

Briefly, the current operating spectral range of the instrument is 230nm to 900nm. The scatterometer provides measurements with typical errors of 1.0 percent and precisions of 0.7 percent (both 1 sigma). The scatterometer can perform in-plane and out-of-plane measurements, total hemispherical reflectance measurements, and raster scan measurements. The instrument provides four types of data output, namely, standard BSDF, cosine-corrected BSDF, scattered power, and total hemispherical reflectance.

# GSFC Diffuser Calibration Facility Instrumentation:

The scatterometer was built in 1993 by TMA Technologies, Inc. in Bozeman, MT (now Schmitt Measurement Systems, Inc. in Portland, OR). Swales Aerospace Inc. played a significant role in aiding NASA's GSFC to specify, acquire, and operate this instrument.

## Scatterometer Description

The scatterometer consists mainly of an optical table with sources and associated optics, a sample stage, a detector goniometer, and data acquisition and analysis electronics. Each subsystem is briefly described below. Also, details of scatterometer measurements, future measurement capabilities, and the reference are described as well.

## A. Optical Source Table

Figure 1 shows the optics layout of the scatterometer. The optical source table contains a broadband xenon arc lamp, a helium/neon (He/Ne) laser operating at 633nm, and a helium/cadmium (He/Cd) laser operating at 325nm. The xenon arc lamp is a compact, end-on 300W lamp manufactured by Cermax. The output of this lamp is nearly collimated. The broadband output of this lamp is focussed by a 90 degree off-axis parabolic mirror onto the entrance slit of a 1/4 m Chromex scanning monochromator (F/# 4.0). The monochromator is of a Czerny-Turner design and is corrected for astigmatism by the addition of a cylindrical component to the spherical surfaces of the monochromator's collimating and focussing mirrors. These toroidal mirrors have different radii of curvature in orthogonal planes. The monochromator contains three gratings: one 1200 l/mm grating blazed at 250nm and two 600 l/mm gratings blazed at 200nm and 500nm, respectively. A filter wheel is attached to the exit slit of the monochromator to block higher order spectra. The output beam from the exit slit of the monochromator is focussed by a spherical mirror onto an aperture plate after being redirected by a folding mirror and chopped. The illuminated aperture becomes a new source which is focussed either onto the sample surface or the detector, depending on the axial location of the aperture plate. Various aperture shapes, including circular, rectangular, and square, are available for making different illuminated footprints on the sample. The chopped beam is detected by a silicon photodiode reference detector. This chopped signal is used for normalizing beam power fluctuations and as a reference signal to the scatterometer lock-in amplifier. Following the aperture plate, the beam is linearly polarized by a Glan Taylor polarizer and focussed at either the sample or detector by a second spherical mirror. The beam is reflected by a folding mirror through an two alignment irises, one mounted in a hole in the plane of the optical table and theother mounted at the end of an arm on the sample side of the instrument. A final folding mirror directs the beam onto the sample stage. The orientation of the final two folding mirrors and the small angle of incidence of the beam on the second spherical mirror preserves the polarization of the incident beam at the sample.

Unpolarized BSDF measurements are obtained with polarization insensitive detectors by making scatter measurements using ±45 degree linearly polarized light and computing the average of these measurements.

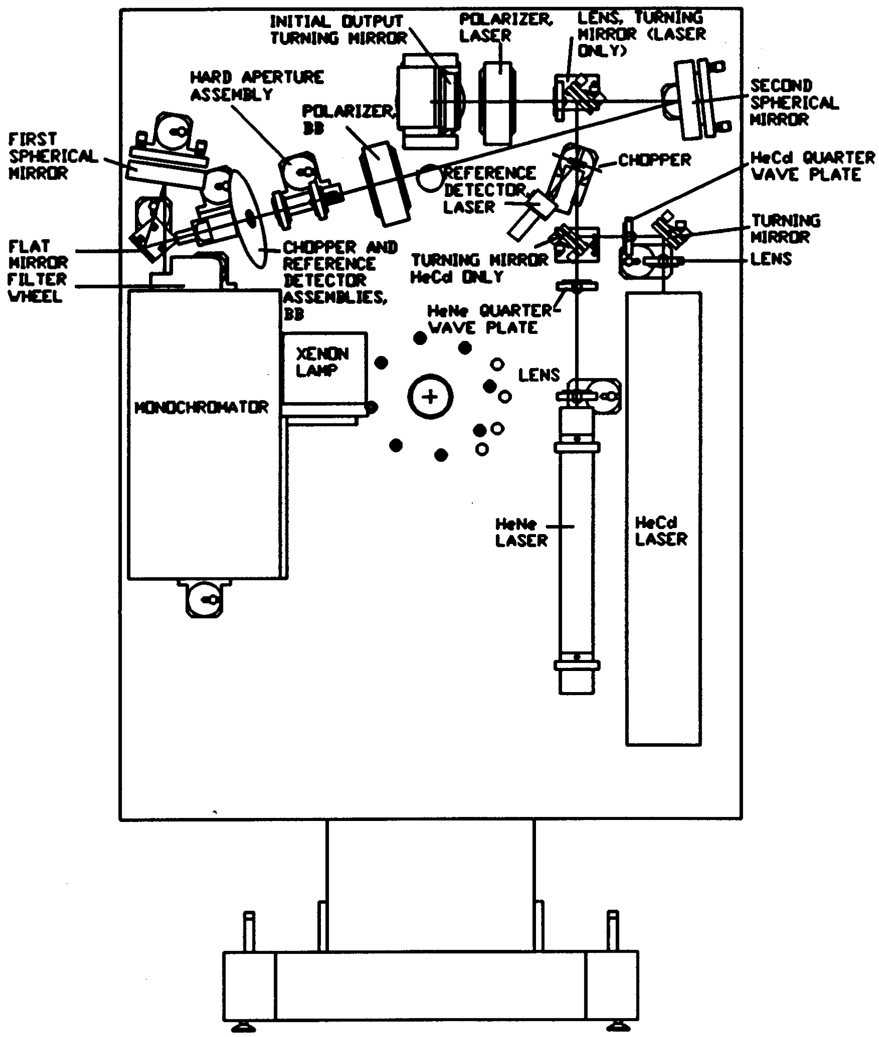


**Figure 1**

For the laser sources, the optical path is simpler. The He/Ne laser output is collimated by a pair of lenses and is circularly polarized using a quarter wave plate. The laser output is chopped and detected by a silicon photodiode reference detector and then is linearly polarized using a Glan Taylor polarizer. The linearly polarized laser beam is reflected by a folding mirror through the alignment iris onto the final folding mirror which directs the beam to either the sample or the detector. Unpolarized scatter measurements are made by averaging the scatter measured with 45 degree incident light.

The optical table is hung vertically on the box post of the scatterometer, as shown in Figure 2. The table rotates clockwise or counter-clockwise to change the incident elevation angle, $\theta_i$, of light relative to the sample normal.

## B. Sample Stage

The sample stage is located opposite the source table and is oriented horizontally to the ground, as seen in Figure 2. The sample stage consists of a z-rotatable mount with x, y, and z degrees of translational freedom. The rotation of the stage around z enables changes in the incident azimuthal angle, $\phi_i$. Two micrometers located under the mount are used to level samples. Various holders kinematically bolt to the sample stage and can accomodate samples of different size, shape, and weight. The maximum sample size and shape that can be accomodated by the scatterometer are 12 inches square. Larger samples can be accomodated provided there is no desire for raster scans of BSDF uniformity. The sample stage can support samples up to 10 pounds in weight.

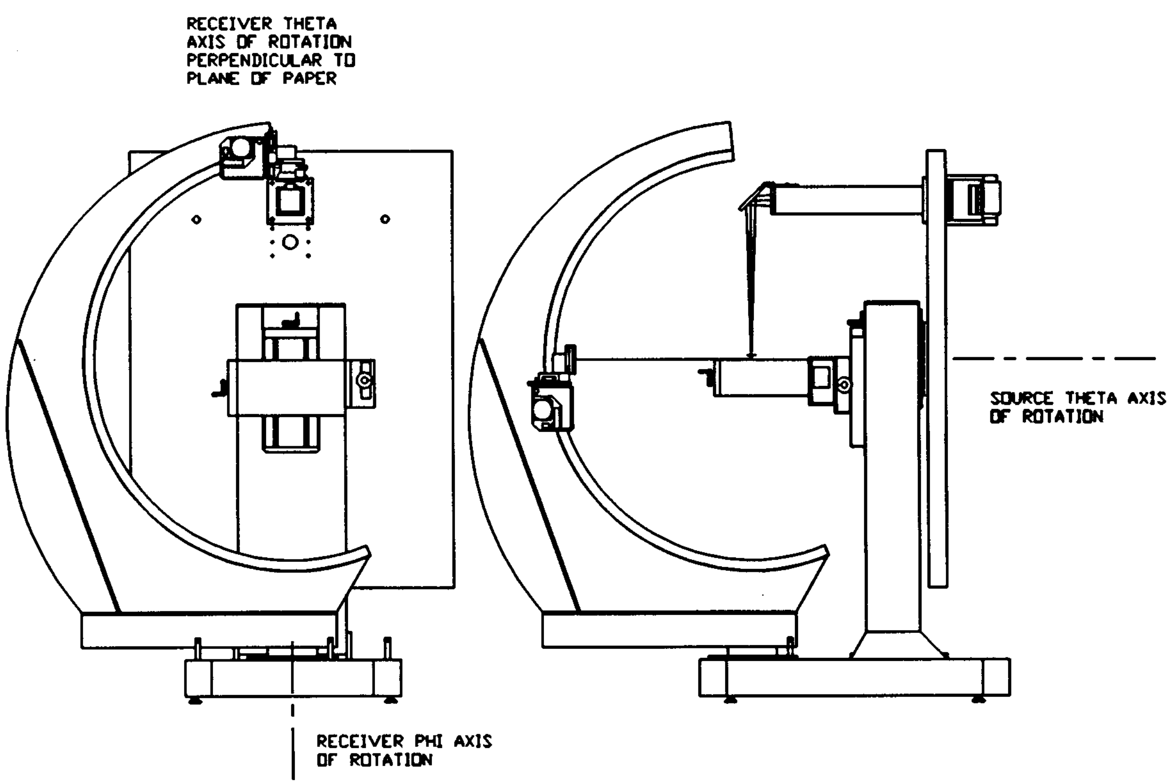


**Figure 2**

## C. Detector Goniometer

The detector rides on a rotatable half circle arc mechanism, as shown in Figure 2. The detector can move 180 degrees along the arc relative to the sample normal and the origin of the sample stage. This provides the ability to make reflective and transmissive scatter measurements as a function of scatter elevation angle, $\theta_s$. The arc which the detector travels on rotates 180 degrees around the vertical sample stage axis, z, to enable the selection of the scatter azimuthal angle, $\phi_s$.

There are two detectors used in this instrument. For hgh light levels from 230nm to 900nm, a ultraviolet sensitive silicon photodiode is used. For low light levels from 230nm to 500nm, a photomultiplier coupled with an integrating sphere is used. All detectors include a aperture stop, field lens, field stop, and a customized pre-amplfier.

## D. Scatterometer Measurements

The DCaF scatterometer is capable of making absolute and relative scatter measurements. In the absolute scatter measurement mode of operation, the incident beam power is first measured with the sample under test moved out of the incident beam. The sample under test is then moved into the beam and the same detector is used to measure the scattered power. In the relative scatter mode of operation, a reference sample measured by NIST is used to determine the incident beam power. In this mode of operation, the reference sample is measured at the same wavelength and incident and scatter geometries as the NIST measurements. The reference sample is then replaced by the sample under test and measured.

## E. Computer/Data Acquisition System

The signal electronics of the instrument is based on a lock-in amplifier design with special design consideration given to minimizing non-linearity between gain levels and minimizing electronic noise. The reference signals provied by the mechanical choppers and silicon detectors are input to the lock-in amplifier and computer to provide narrow band signal detection for the receivers. This produces a high signal-to-noise ratio.

The operation of the scatterometer is fully computerized. The unique software developed for this instrument is menu driven and user friendly. The computer controls the movement of the optical source table, the gonimeter and sample stage, and the wavelength and bandwidth selection of the monochromator. As such, input to the computer defines the polarization state of the incident light, the incident and scatter beam angles to the sample, and the sample position. The computer displays scatter measurements in real time on a monitor screen, prints color hardcopies to a printer, and records the measurements in data files. The data file format follows the data protocols as recommended in ASTM E1392-90, "A Standard Practice for Angle Resolved Optical Scatter Measurements on Specular or Diffuse Surfaces" [1].

## F. Future Measurement Capabilities

To date, approximately ninety percent of the measurements made by the DCaF scatterometer have been on diffuse reflecting samples. A few measurements have been made on specular reflecting samples (i.e. mirror-like samples). The specular measurement capability of the scatterometer is being upgraded with the addition of a spatial filter assembly and a low-scatter source optical design. This capability will be implemented in 1999.

Initial tests have been successfully completed on a total hemispherical reflectance (THR) measurement attachment. Confidence in BRDF measurements can be increased by measuring the BRDF of a scattering sample over the complete scatter hemisphere and by integrating the measured BRDF to produce a total hemispherical reflectance (THR). THR is accurately measured by NIST, by other national standards labs, and by private industry. The THR measurement capability in the DCaF will be offered to facility customers in 1999.

Two additional areas in which the measurement capability of the scatterometer can be improved include the expansion of the operating wavelength range of the instrument over the shortwave infrared to 2500nm and the implementation of shortwave and thermal infrared laser sources for the measurement of infrared spectral reflectance. These capabilities are currently undergoing feasiblity studies.

## References

[1] ASTM Standard E1392-90, "A Standard Practice for Angle Resolved Optical Scatter Measurements on Specular or Diffuse Surfaces"(1991).