

# Integrating Sphere User Manual



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# Table of Contents

---

	<b>Trademark Information</b> .....	<b>ii</b>
	<b>Technical Support</b> .....	<b>ii</b>
<b>Chapter 1</b>	<b>Product Description</b> .....	<b>1</b>
	Sphere Ports .....	3
	Sphere Components .....	5
	Theory of Operation .....	6
	Stray Light .....	7
	Reflectance Measurements .....	8
	Transmittance Measurements .....	11
	Sample Spectra .....	12
<b>Chapter 2</b>	<b>Making Measurements</b> .....	<b>13</b>
	Total Reflection from a Diffuse Surface .....	13
	Recommended Method .....	13
	Alternate Recommended Method .....	14
	Method Not Recommended .....	15
	Reflection from a Specular (mirrorlike) Source .....	16
	Transmittance Measurements .....	17
	Correcting for Substitution Error .....	17
	NOT Correcting for Substitution Error .....	18
<b>Chapter 3</b>	<b>Care and Maintenance</b> .....	<b>19</b>
	Bulb Replacement and Lamp Alignment .....	19
	Bulb Replacement .....	19
	Lamp Alignment .....	20
	Cleaning the Zenith .....	20
	Cleaning the Zenith .....	21
	<b>INDEX</b> .....	<b>1</b>

# ***Table of Contents***

---

## Chapter 1 *Product Description*

The Reflectance/Transmittance Integrating Sphere is designed for collecting optical radiation which has been reflected from or transmitted through a sample for the purpose of measuring reflectance or transmittance. The sphere is designed for use with the ASD FieldSpec® spectroradiometer.

The base sphere includes six (6) ports designed to accept supplied sample holders, a light source assembly, fiber adapter, light trap, and port plugs. The assembly is also supplied with two nominal 99% Zenith® reference standards, one calibrated and one uncalibrated.



## Symbols - Definitions



**CAUTION: *Risk of danger.*** This is a personal danger warning. Documentation must be consulted in all cases where this symbol is marked. Failure to acknowledge these warnings could result in personal injury to the user.



**CAUTION: *Risk of Electric Shock.*** This is a personal danger warning. Documentation must be consulted in all cases where this symbol is marked. Failure to acknowledge these warnings could result in personal injury to the user.



**CAUTION: *Hot Surface.*** This is a personal danger warning. Documentation must be consulted in all cases where this symbol is marked. Failure to acknowledge these warnings could result in personal injury to the user.



**Recycle.** Items with this symbol indicate that the item should be recycled and not disposed of as general waste.

Warnings and cautions are placed throughout this manual for the convenience of the reader. However, the absence of warnings and cautions do not preclude the use of proper caution and handling. Usual precautions are recommended to be taken at all times, either written or otherwise, to avoid personal injury or damage to ASD equipment.

## 1.1 Sphere Ports

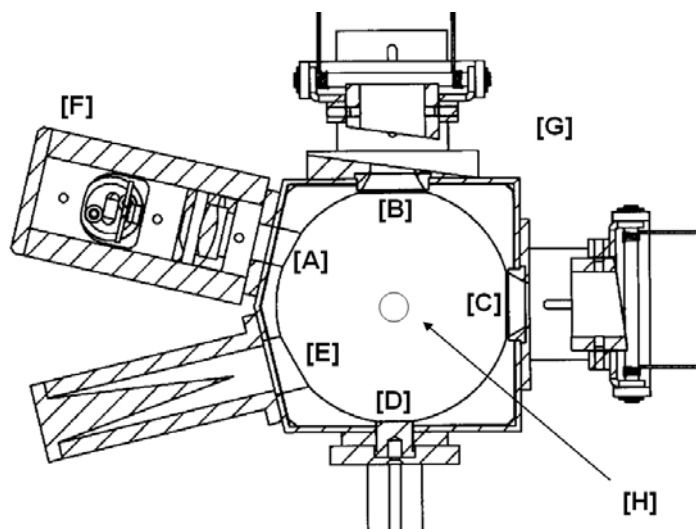


Figure 1-1 Top View of Sphere

### [A] Reflectance Input

The reflectance input port, or source and transmittance sample holder, is designed to hold the source assembly, as well as a sample during a transmittance measurement. It accepts samples up to 0.75 inches thick. The source is used to sandwich the sample between it and the sphere.

### [B] Reflectance Comparison

The reflectance comparison port, or 8° Reference Sample Holder, is used to alternately hold the sample and reference when a passive comparison correction is performed [recommended method]. Alternatively, the reference sample can be used to hold a blank white standard [alternate recommended method]. In addition, the reference sample holder can be used to hold the sample [not recommended]. Note: see section on “Making Measurements” for description of the various methods.

### [C] Reflectance Sample

The reflectance sample port, or 0° Test Sample Holder, is used to alternately hold the reference and sample during a reflectance measurement [recommended method].

### [D] Transmission Input

The transmission input port, or source to reference port, is used to perform alternate reference measurements (outlined later in this user’s guide).

**[E] Specular Exclusion Light Trap**

The light trap assembly is used when making diffuse only sample measurements of partly specular samples. The light trap can quickly be converted to a port plug when making total reflectance measurements.

**[F] Collimated Light Source Assembly**

The light source assembly, provides a collimated beam which illuminates the sample or the Reference Standard. The light source assembly may be removed to change the lamp as necessary.

Note: The collimated light source has a high and low setting; LOW is equivalent to one solar unit while the HIGH setting is greater than one solar unit, which may affect vegetation.



Figure 1-2 Light Source Power Settings

**[G] Mounting Boss**

Located on the underside of the sphere assembly is a 1/4-20 mounting boss which can be used for an optical bench, tripod, or the supplied mounting rod.

**[H] Fiber Adapter Port**

The fiber adapter port is located on the top of the sphere. The fiber adapter port is used to mount the fiber of the ASD FieldSpec spectroradiometer using the same type of fitting as is used in the ASD fore optic pistol grip. The fiber is installed by first loosening the fitting and then feeding the fiber optic cable into the fitting. Tighten the fitting finger tight after inserting the fiber optic fully into the fitting.



## 1.2 Sphere Components



Figure 1-3 Sphere Components

Letters in brackets [ ] refer to the top view drawing (Figure 1-1).

- 1 Collimated Light Source Assembly
- 2 Light Trap Assembly for port [E]
- 3 Light Trap Assembly for port [B or C]
- 4 Fiber Port Adaptor with Strain Relief for port [H]
- 5 Spare screws and wrenches
- 6 Cap for Fiber Port Adaptor
- 7 Black port plugs (interchangeable) for ports [B or C]
- 8 Transmission Spacer for port [E]
- 9 White plug for port [E]
- 10 White plug for port [A]
- 11 White plug for port [D]
- 12 Mounting rod for 1/4-20 Boss for [G]
- 13 Fiber Port Plug for port [H]

- 14 99% Calibrated Reference Standard (white plug)
- 15 99% Uncalibrated Reference Standard (white plug)
- 16 Spare Lamps (Qty 2) (not shown in figure 1-2), Osram #64225, 6V, 10W

## 1.3 Theory of Operation

The integrating sphere collects all the radiation reflected from or transmitted through a sample. The detector responds to a portion of that radiation which, in a well-designed sphere, is a constant portion.

### Integrating Sphere Port Configurations

Measured Quantity	Port Configuration				
	[A]	[B]	[C]	[D]	[E]
<b>Stray Light Reflectance Mode</b>					
Reference ( <b>Idr</b> )	L	O	W	P	P
Sample Measurement ( <b>Ids</b> )	L	W	O	P	P
<b>Sample Reflectance</b>					
Reference ( <b>Ir</b> )	L	S	W	P	P
Sample Measurement ( <b>Is</b> )	L	W	S	P	P
<b>Stray Light, Transmission Mode</b>					
Reference ( <b>Idr</b> )	P	W	O	L	P
Sample Measurement ( <b>Ids</b> )	P	O	W	L	P
<b>Sample Transmission</b>					
Reference ( <b>Ir</b> )	P	W	S	L	P
Sample Measurement ( <b>Is</b> )	P	W	O	L+S	P

Where:

L - Light source installed in port

W - zenith White reference mounted in port

S - Sample material and Light Trap (3) are mounted in the port when 'S' is in port B or C

O - port Open (nothing installed) OR Light Trap (3) used

P - port Plugged with zenith plug.

For specular excluded measurements, the plug in port 'E' is replaced with Light Trap (2).

The use of the light trap (3) is recommended whenever there is a possibility that ambient light may illuminate the back sides of either ports 'B' or 'C' or when either of these ports is open.

The key to making an accurate reflectance or transmission measurement is maintaining an equivalent average sphere interior reflectance for both the sample and reference measurements. These recommended port configurations achieve this goal.

### 1.3.1 Stray Light

Reflectance and transmission mode stray light should be measured at the start of each measurement session (see [Figure 1-4](#)). It is not necessary to measure stray light for each sample. The sphere ports should be configured as listed at [“Integrating Sphere Port Configurations”](#) on page 6. We recommend that you collect these spectra in ratio mode – not raw DN or radiance. This will facilitate the use of these spectra for later correction of collected reflectance and/or transmission spectra. Large numbers of scans should be averaged when performing these measurements (200 or more) in order to minimize the introduction of noise during subsequent calculations. An alternative to using these values directly when computing corrected reflectance and transmission, is to use smoothed or curve-fitted versions. For example, the central region (~500-2200 nm) of each stray light curve could be used to compute a best-fit line for approximating stray light. The equations for these lines using the spectra in [Figure 1-4](#) as examples are as follows:

**Stray light, reflectance mode =  $0.0043 + 1.87\text{e-}6 * \text{wavelength}$**

**Stray light, transmission mode =  $-0.0005 + 1.53\text{e-}6 * \text{wavelength}$**

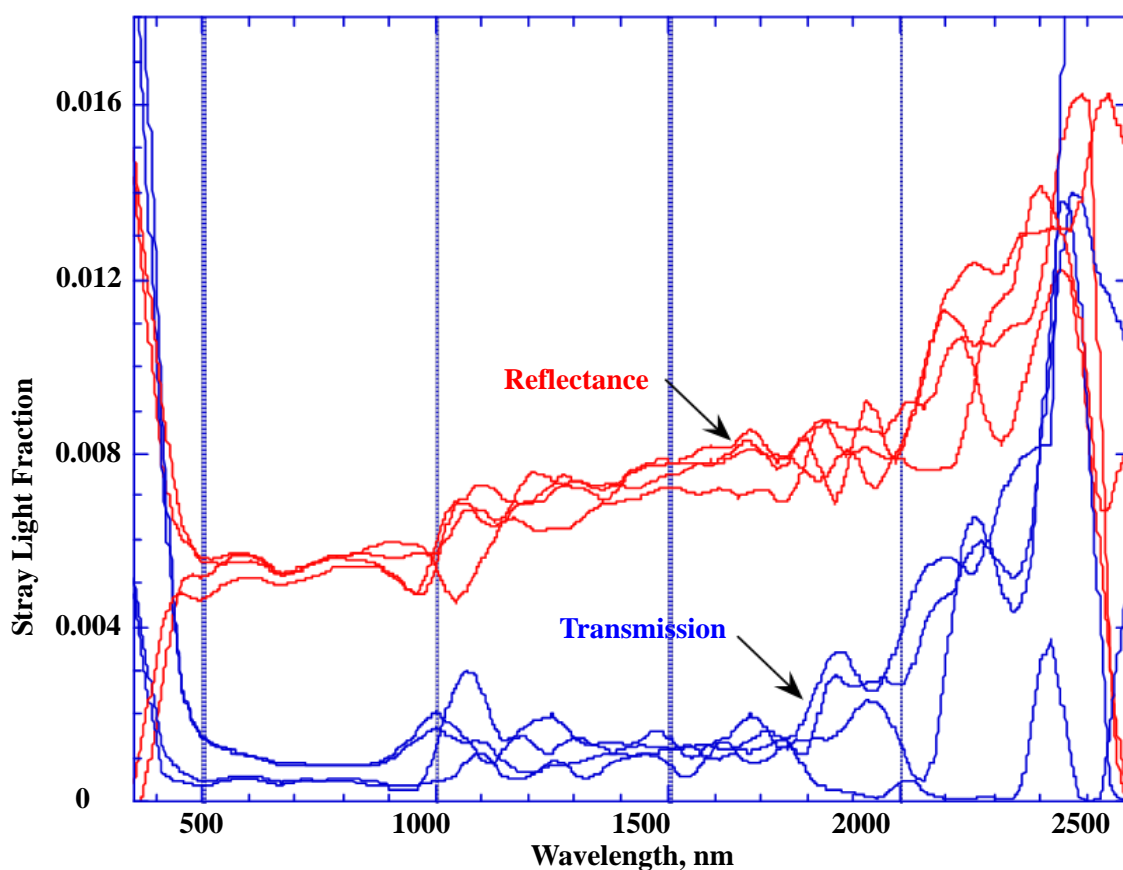


Figure 1-4 Stray Light Fraction

The alignment of the light source and other sphere components can be verified by monitoring the level of stray light. An increase in stray light is an indication that alignment is necessary (See “[Lamp Alignment](#)” on page 18).

### 1.3.2 Reflectance Measurements

The external integrating sphere means the sample is external to the sphere, and when in place makes up a small part of the sphere wall. In this configuration, the integrating sphere “collects” reflected light from a sample, or transmitted light through a sample, and spreads this energy over the entire surface area of the sphere in a very even distribution. The detector then responds to a portion of the sphere wall energy to derive a meaningful value about the reflectance of the sample.

Figure 1-2 shows the important features of an external integrating sphere. Note: the radiation receptor (in the case of this design, a fiber optic) does not see any part of the sample. Its field of view is occupied by the sphere wall.

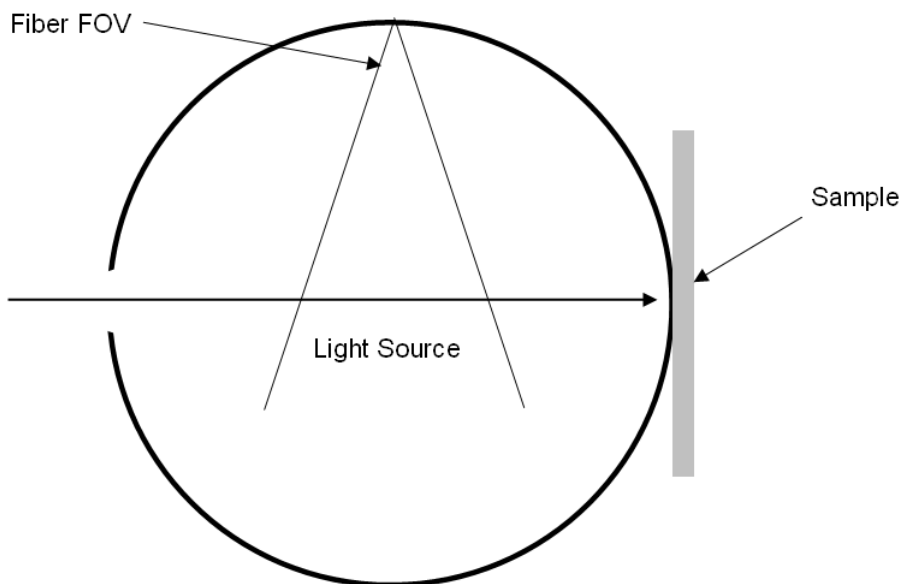


Figure 1-5 Side view of the sphere.

### Data collected in Raw DN or radiance mode

Using the properties of an integrating sphere, the reflectance ***R<sub>s</sub>*** of an unknown sample is a ratio between a known reference and the sample in question as given below:

$$R_s = \frac{I_s}{I_r} \cdot R_r \quad \text{no stray light correction}$$

Where;

***I<sub>s</sub>*** is the measured sphere output when the sample is illuminated and ***I<sub>r</sub>*** is the signal measured when the reference material is illuminated and ***R<sub>r</sub>*** is the calibrated reflectance of the reference.

In practice, this ratio becomes more complex for a couple of reasons:

- 1 The beam of radiation illuminating the sample or reference is not perfectly collimated. This means that some “stray” radiation is directly getting to the sphere walls without first striking the sample or reference. This background or stray light level may have to be accounted for.
- 2 The presence of the reference, then of the sample, on the sphere modifies the throughput (the portion of reflected radiation that is seen by the detector). This phenomenon is known as substitution error, and can be corrected for (or ignored if the resulting uncertainty is acceptable).

To account for issue 1 we must measure background radiation within the sphere. To do this, we pass the beam into the sphere and through the sample hole – with no sample in place. That way we measure any stray radiation that the source may contribute to the baseline of the signal. We can then subtract this **Id** from the former ratio we created (Note: Since **Id** is usually quite small, it is sometimes ignored. Also, since it behaves exactly as if it were detector “dark current”, it may be able to be corrected in software by taking a “dark scan” in a darkened room, with the light source on, and the sample port open.)

$$R_s = \frac{(I_s - I_d) \cdot R_r}{(I_r - I_d)} \quad \text{with stray light correction}$$

**Rs** is the value of “Total Reflectance” taken at a 0/d configuration.

NOTE: This ratio holds for samples of a diffuse (or matte) scattering profile – specular samples are discussed later.

### Data collected in ratio mode

An alternate (now preferred) method to collecting data in raw DN or radiance mode is to collect all spectra in ratio mode (i.e. run a white reference with the sphere in the reference configuration). The equations are then:

$$R_s = R's \cdot R_r \quad \text{no stray light correction}$$

$$R_s = \frac{(R's - R_d) \cdot R_r}{(1 - R_d)} \quad \text{with stray light correction}$$

Where:

**Rs** - corrected sample reflectance

**R's** - measured sample reflectance

**Rr** - reference sample reflectance

**Rd** - stray light (measured in reflectance mode)

### 1.3.3 Transmittance Measurements

A measurement of transmittance involves comparing the wall illumination caused by radiation which has been transmitted through the sample to that of a reference measurement in which the radiation did not pass through the sample (i.e. it passed through “air” or, rarely, some other reference). The Integrating Sphere uses the same illuminator for both measurements.

Measured Quantity	Port Configuration				
	[A]	[B]	[C]	[D]	[E]
<b>Stray Light, Transmission Mode</b>					
Reference ( <b>Idr</b> )	P	W	O	L	P
Sample Measurement ( <b>Ids</b> )	P	O	W	L	P
<b>Sample Transmission</b>					
Reference ( <b>Ir</b> )	P	W	S	L	P
Sample Measurement ( <b>Is</b> )	P	W	O	L+S	P

Where:

L - Light source installed in port

W - zenith White reference mounted in port

S - Sample material mounted in port

O - port Open (nothing installed) OR Light Trap (3) used

P - port Plugged with zenith plug.

### 1.3.4 Sample Spectra

Spectra were collected in reflectance mode using the port configurations listed in “[Integrating Sphere Port Configurations](#)” on page 6. While the errors associated with stray light are small, stray light corrections were applied prior to plotting the data.

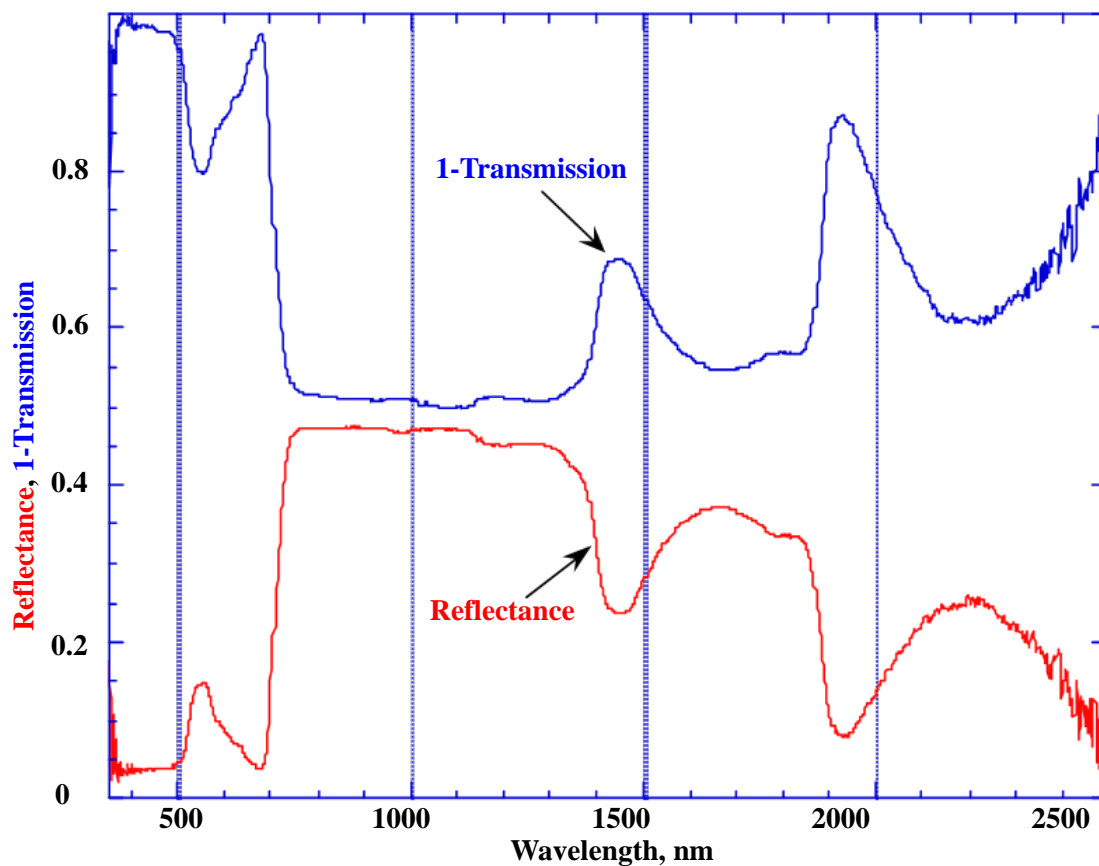


Figure 1-6 Leaf Spectra



## Chapter 2 Making Measurements

### 2.1 Total Reflection from a Diffuse Surface

#### 2.1.1 Recommended Method

This recommended method corrects for substitution error.

	Reflectance Reference	Reflectance Sample	Dark Reading
Quantity Measured ==>	Ir	Is	Id
Port ↓			
Reflectance Input [A]	Collimated Light Source Assembly	Collimated Light Source Assembly	Collimated Light Source Assembly
Reflectance Comparison [B]	Sample* + Light Trap (3) (opt.)	Reference Standard	Reference Standard
Reflectance Sample [C]	Reference Standard	Sample + Light Trap (3) (opt.)	Open Port in a Dark room or Light Trap (3) (opt.)
Transmission Input [D]	White Plug	White Plug	White Plug
Light Trap [E]	White Plug	White Plug	White Plug

\* The sample can be replaced with a piece which has nearly the same reflectance as the sample (within 20% is close enough). This will correct for substitution error with only one reference scan for use with several similar samples.

The use of the light trap (3) is recommended whenever there is a possibility that ambient light may illuminate the back sides of either ports 'B' or 'C' or when either of these ports is open.

$$R_s = \frac{(I_s - I_d) \cdot R_r}{(I_r - I_d)} \quad \text{if Raw DN}$$

$$R_s = \frac{(I_s - I_d) \cdot R_r}{(1 - I_d)} \quad \text{if Reflectance}$$

where;

**R<sub>r</sub>** is the reflectance of the calibrated reference standard

If **I<sub>d</sub>** is found to be negligible, it can be ignored.

## 2.1.2 Alternate Recommended Method

This alternate recommended method does **not** correct for substitution error.

	Reflectance Reference	Reflectance Sample	Dark Reading
Quantity Measured ==>	I <sub>r</sub>	I <sub>s</sub>	I <sub>d</sub>
Port ↓			
Reflectance Input [A]	Collimated Light Source Assembly	Collimated Light Source Assembly	Collimated Light Source Assembly
Reflectance Comparison [B]	Uncalibrated Zenith Standard	Uncalibrated Zenith Standard	Uncalibrated Zenith Standard
Reflectance Sample [C]	Reference Standard	Sample	Open Port in a Dark room or + Light Trap (3) (opt.)
Transmission Input [D]	White Plug	White Plug	White Plug
Light Trap [E]	White Plug	White Plug	White Plug

$$R_s = \frac{(I_s - I_d) \cdot R_r}{(I_r - I_d)}$$

where;

**R<sub>r</sub>** is the reflectance of the calibrated reference standard

If **I<sub>d</sub>** is found to be negligible, it can be ignored.

This method does not correct for substitution error, which may add a few percent uncertainty to the reflectance value measured.

### 2.1.3 Method Not Recommended

This method is **not** recommended because it corrects for substitution error, **but** potentially adds an error which is much greater than the substitution error.

	Reflectance Reference	Reflectance Sample	Dark Reading	Dark Reading
Quantity Measured ==>	Ir	Is	Idr	Ids
Port ↓				
Reflectance Input [A]	White Plug	Collimated Light Source Assembly	White Plug	Collimated Light Source Assembly
Reflectance Comparison [B]	Reflectance Standard	Reflectance Standard	Open Port in a Dark room or Light Trap (3) (opt.)	Reflectance Standard
Reflectance Sample [C]	Sample	Sample	Sample	Open Port in a Dark room or Light Trap (3) (opt.)
Transmission Input [D]	Collimated Light Source Assembly	White Plug	Collimated Light Source Assembly	White Plug
Light Trap [E]	White Plug	White Plug	White Plug	White Plug

$$R_s = \frac{(I_s - I_{ds}) \cdot R_r}{(I_r - I_{dr})}$$

where;

**R<sub>r</sub>** is the reflectance of the calibrated reference standard.

If **I<sub>ds</sub>** and **I<sub>dr</sub>** are found to be negligible, they can be ignored.

## 2.2 Reflection from a Specular (mirrorlike) Source

The methods described above for measuring the reflectance of diffuse materials are also valid for measuring the reflectance of specular materials, with a couple of additions.

- It is always advisable to use a reference which has nearly the same geometrical scattering properties as the sample. Therefore, to measure the reflectance of a specular sample, a calibrated first-surface mirror should be used as the reference. If the sample is neither very diffuse nor very specular, it is necessary to choose a reference that comes close to the sample's geometrical scattering properties. In extreme cases, a reference can be made that matches the sample's geometry, and calibrated on a reference instrument.
- In some cases, it is desirable to measure only the diffuse portion of the scattered light from a sample that is a combination of specular and diffuse. In these cases, the white plug should be removed from the light trap [E]. This will reject most of the purely specular component of reflected light. It should be noted that it is impossible to reject the entire purely specular component without rejecting some of the near-specular component also. This means the results of specular-rejected measurements are instrument-specific. Different results should be expected from instruments with different sphere geometries and/or different light source optics.

## 2.3 Transmittance Measurements

### 2.3.1 Correcting for Substitution Error

	Reflectance Reference	Transmittance Sample	Dark Reading
Quantity Measured ==>	I <sub>r</sub>	I <sub>s</sub>	I <sub>d</sub>
Port ↓↓			
Reflectance Input [A]	White Plug	White Plug	White Plug
Reflectance Comparison [B]	Uncalibrated Zenith Standard	Uncalibrated Zenith Standard	Open Port in a Dark room or Light Trap (3) (opt.)
Reflectance Sample [C]	Sample	Open Port in a Dark room or Light Trap (3) (opt.)	Uncalibrated Zenith Standard
Transmission Input [D]	Collimated Light Source Assembly	Collimated Light Source Assembly <b>and Sample</b>	Collimated Light Source Assembly
Light Trap [E]	White Plug	White Plug	White Plug

$$T = \frac{(I_s - I_d) \cdot R_r}{(I_r - I_d)} \quad \text{if Raw DN}$$

$$T = \frac{(I_s - I_d) \cdot R_r}{(1 - I_d)} \quad \text{if Reflectance}$$

If **I<sub>d</sub>** is found to be negligible, it can be ignored.

### 2.3.2 NOT Correcting for Substitution Error

	Reflectance Reference	Transmittance Sample	Dark Reading
Quantity Measured ==>	I <sub>r</sub>	I <sub>s</sub>	I <sub>d</sub>
Port ↓↓			
Reflectance Input [A]	White Plug	White Plug	White Plug
Reflectance Comparison [B]	Uncalibrated Zenith Standard	Uncalibrated Zenith Standard	Open Port in a Dark room or Light Trap (3) (opt.)
Reflectance Sample [C]	Open Port in a Dark room or Light Trap (3) (opt.)	Open Port in a Dark room or Light Trap (3) (opt.)	Uncalibrated Zenith Standard
Transmission Input [D]	Collimated Light Source Assembly	Collimated Light Source Assembly <b>and Sample</b>	Collimated Light Source Assembly
Light Trap [E]	White Plug	White Plug	White Plug

$$T = \frac{(I_s - I_d) \cdot R_r}{(I_r - I_d)}$$

If **I<sub>d</sub>** is found to be negligible, it can be ignored.

## Chapter 3 Care and Maintenance

### 3.1 Bulb Replacement and Lamp Alignment

#### 3.1.1 Bulb Replacement

- Step 1 Remove the lamp assembly from the projector housing by removing the two vertical screws as shown in [Figure 3-1](#) on page 19. Note that the lamp sits behind a small hole in a baffle-plate.
- Step 2 Replace the lamp and reinstall the lamp assembly.
- Step 3 Place the projector housing back onto the sphere.

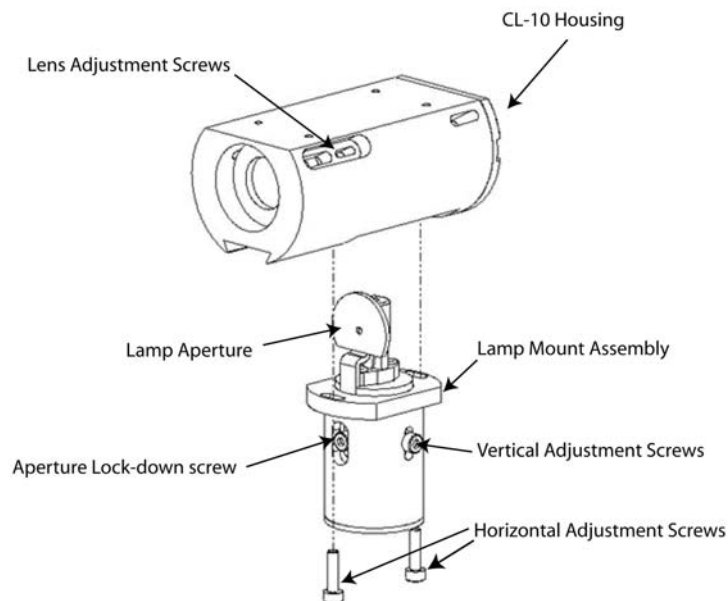


Figure 3-1 Lamp Assembly

### 3.1.2 Lamp Alignment

- Step 1 Set the current to a low level, enough to see reddish light projected from the lamp assembly, but not enough to make the assembly too hot to handle comfortably.
- Step 2 Loosen the two horizontal screws and the two vertical screws slightly. Maneuver the lamp assembly until the collimated beam clears the sample port cleanly and, when a high-quality first-surface mirror is placed in the sample port, the beam also clears the light trap port cleanly.
- Step 3 Tighten the screws.

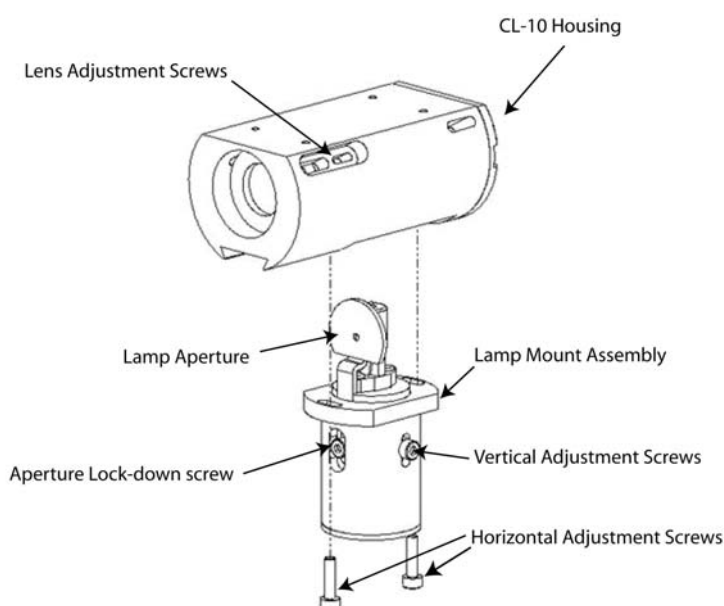


Figure 3-2 Lamp Assembly

## 3.2 Cleaning the Zenith

### Sphere Interior

The interior of the RTS-3Z is machined of Zenith diffuse polymer material. The sphere should be handled carefully at all times to protect its interior surface. The material should be treated as first surface primary optic and should not come into contact with any substance including human fingers. When the sphere is not in use, it should be covered and stored in a relatively dust-free area to prevent contamination of the Zenith optical coating.



The Zenith, a solid, machined form of PTFE, is highly reflective (>95%) and Lambertian over the broad spectral range of 250-2500nm. It is a hydrophobic material (repels water), but is very sensitive to contamination from organic substances (oils, soaps, solvents, etc.). The material should always be handled with latex gloves or other contaminant free barriers (finger cots, nylon gloves, sterile plastic bags). Tissues and other paper products should not be used to contact the material as they may leave behind residual particles that can alter the optical properties of the material.

The only liquids that may safely contact the material are distilled water and optical grade alcohol. Alcohol will rapidly absorb into the material (and pass through it) but may be removed completely by allowing the liquid to “dry” or evaporate from the material. This drying can be accelerated by baking at 90°C for 24 to 48 hours.

The material is an excellent thermal insulator and is also an excellent electrical insulator which may develop a static charge that can attract dust.

### **3.2.1    *Cleaning the Zenith***

#### **Dust and Surface Contamination**

The Zenith may develop a surface dust contamination over time due to a static charge or the material being stored in an unprotected state. Dry nitrogen or clean air can be used to blow off most of this dust. **DO NOT use Canned Air**, as most of these products contain a hydrocarbon based propellant which can contaminate the material.

Additionally, for difficult dust contamination problems, the material may be rinsed with distilled water after removing the material from its housing. If the material is rinsed, allow several hours for the material to dry before attempting use. Again, this drying can be accelerated by baking at 90°C for 24 to 48 hours. If the material continues to exhibit contamination, contact the manufacturer for additional recommendations.

## Notes:

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# ***Index***

## **A**

alignment [8](#)

## **B**

Bulb Replacement [19](#)

## **C**

Cleaning the Zenith [21](#)

## **D**

Data collected in ratio mode [10](#)

Data collected in Raw DN or radiance mode [9](#)

## **I**

Id [10](#)

Integrating Sphere Port Configurations [6](#)

Ir [9](#)

Is [9](#)

## **L**

Lamp Alignment [20](#)

## **M**

mounting boss [4](#)

## **R**

Reflectance Measurements [8](#)

Reflection from a Specular (mirrorlike) Source [16](#)

Rs [9](#)

## **S**

Sample Spectra [12](#)

Sphere Components [5](#)

Stray Light [7](#)

support [ii](#)

Symbols [2](#)

## **T**

technical support [ii](#)

Theory of Operation [6](#)

trademarks [ii](#)

Transmittance Measurements [11](#), [17](#)

## **Z**

Zenith [20](#)