# *ECO*-VSF 3

Three-angle, Three-wavelength
Volume Scattering Function Meter

## User's Guide

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# Attention!

## Return Policy for Instruments with Anti-fouling Treatment

WET Labs cannot accept instruments for servicing or repair that are treated with anti-fouling compound(s). This includes but is not limited to tri-butyl tin (TBT), marine anti-fouling paint, ablative coatings, etc.

Please ensure any anti-fouling treatment has been removed prior to returning instruments to WET Labs for service or repair.

# *ECO* Sensor Warranty

This unit is guaranteed against defects in materials and workmanship for one year from the original date of purchase. Warranty is void if the factory determines the unit was subjected to abuse or neglect beyond the normal wear and tear of field deployment, or in the event the pressure housing has been opened by the customer.

To return the instrument, contact WET Labs for a Return Merchandise Authorization (RMA) and ship in the original container. WET Labs is not responsible for damage to instruments during the return shipment to the factory. WET Labs will supply all replacement parts and labor and pay for return via 3rd day air shipping in honoring this warranty.

## Shipping Requirements

1. Please retain the original Pelican® shipping case. It meets stringent shipping and insurance requirements, and protects your meter.
2. Service and repair work cannot be guaranteed unless the meter is shipped in its original case.
3. Clearly mark the RMA number on the outside of your case and on all packing lists.
4. Return instruments using 3rd day air shipping or better: do **not** ship via ground.

# Table of Contents

# 1. Specifications

| | |
|---|---|
| **Mechanical** | |
| *Diameter* | 5.75 in (14.6 cm) |
| *Length* | 11.25 in (28.6 cm) |
| *Weight, in air* | 8.75 lbs (3.9 kg) |
| *Weight, in water* | 3.7 lbs (1.8 kg) buoyant |
| *Material* | acetal copolymer |
| **Environmental** | |
| *Temperature range* | 0–30 deg C |
| *Depth rating* | 600 m |
| *Depth rating, with optional pressure sensor* | See pressure sensor calibration sheet |
| **Electrical** | |
| *Input* | 7–15 VDC |
| *Current draw* | 300 mA at 12 volts |
| *Output* | RS-232 |
| *Connector* | MCBH6M |
| *Sample rate* | 1 Hz |
| **Optical** | |
| *Angles, degrees* | 100, 125, 150 |
| *Wavelength (nm)* | 470, 532, 660 |
| *Sensitivity* | $1.24 \times 10^{-5}$ |
| *Range, typical* | ~ 0.0024–5 $m^{-1}$ |
| *Linearity* | 99% $R^2$ |

*Specifications are subject to change without notice.*

**WARNING!**

**The depth rating of the VSF 3 may be limited by the optional pressure sensor's depth rating. If your VSF 3 has a pressure sensor, be sure to check its calibration sheet for the depth rating.**

## 1.1 Connectors

*ECO* VSF 3 uses a six-pin bulkhead connector. The pin functions for this connector are shown in Figure 1. Table 1 summarizes pin functions for the bulkhead connectors.

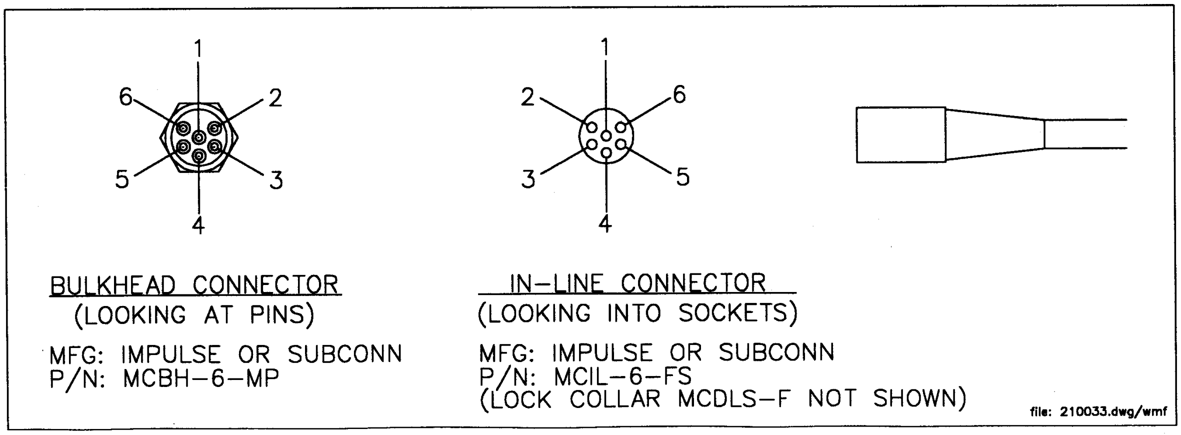


**Figure 1.** *ECO* VSF 3 connectors

**Table 1.** Pinout Summary for *ECO* Connectors

| Pin (or Socket) | Function |
|---|---|
| 1 | Ground |
| 2 | RS-232 (RX) |
| 3 | RS-485 + |
| 4 | V In |
| 5 | RS-232 (TX) |
| 6 | RS-485 - |

Input power of 7–15 VDC is applied to pin 4. The power supply current returns through the common ground pin. The input power signal has a bi-directional filter. This prevents external power supply noise from entering into the *ECO* VSF 3, and also prevents internally generated noise from coupling out on to the external power supply wire. Data is sent out the serial output pin, as described in the Data Format Section.

## 1.2 Delivered Items

The standard VSF3 delivery consists of the following:

- the instrument itself
- test cable (optional)
- three protective covers for optics
- dummy plugs with lock collars
- this user's guide
- WAP device file (on CD)
- instrument-specific calibration sheet
- fluorescence sticks for bench testing

## 1.2 Optional Equipment

### 1.2.1 Test Cable

A test cable is optionally supplied with each unit. This cable includes three legs:

1. A power interface module provides power to the instrument from a user-supplied 9 V battery.
2. A DB-9 serial interface connector.
3. A six-socket in-line connector for providing power and signal to the instrument.

### 1.2.2 External Thermistor

ECO meters are optionally equipped with an external thermistor. The thermistor is calibrated at WET Labs and the calibration coefficients are supplied on the instrument's calibration sheets. Thermistor output is in counts and can be converted into engineering units using the instrument's device file and ECOView software or the raw data can be converted in the user's software (e.g. MATLAB or Excel) using the calibration equation:

Temperature (deg C) = (Output * Slope) + Intercept

### 1.2.3 Pressure Sensor

ECO meters are optionally equipped with a strain gauge pressure sensor. The pressure sensor is calibrated at WET Labs and the calibration coefficients are supplied on the instrument's calibration sheets. Pressure sensor output is in counts and can be converted into engineering units using the instrument's device file and ECOView software or the raw data can be converted in the user's software (e.g. MATLAB or Excel) using the calibration equation:

Relative Pressure (dbar) = (Output * Slope) + Intercept

Please note that strain gauge pressure sensors are susceptible to atmospheric pressure changes and should be "zeroed" on each deployment or profile. The calibration equation for pressure above should be used first to get the relative pressure and the cast offset should then be subtracted to get the absolute pressure:

Absolute Pressure (dbar) = Relative Pressure (dbar) - Relative Pressure at Atmospheric/Water interface (dbar)

**WARNING!**
**Do not exceed the pressure sensor's depth rating (see calibration sheet).**

**Pressure Sensor Maintenance**

A plastic fitting filled with silicone oil provides a buffer between the pressure transducer and seawater. The transducer is both sensitive and delicate. Following the procedures below will ensure the best results and longest life from your pressure sensor.

Pressure is transmitted from the water to the stainless steel transducer diaphragm via a plastic fitting filled with silicone oil. The inert silicone oil protects the pressure sensor from corrosion, which would occur after long exposure to salt water. The fitting will generally prevent the oil from escaping from the reservoir into the water. However, you may occasionally wish to ensure that oil remains in the reservoir on top of the transducer.

**WARNING**
**Never touch or push on the transducer.**

**Maintenance procedure**

1. Thoroughly clean the top of the instrument.
2. Completely remove the white nylon Swagelock fitting using a 9/16-in. wrench.
3. Check for obstructions in the tiny hole. Blow clear with compressed air or use a small piece of wire.
4. Wipe clean the o-ring at the base of the Swagelock fitting.
5. Screw the Swagelock fitting into the end flange until finger tight.
6. Tighten it an additional 1/8 turn using a wrench only if necessary.
7. Wipe up any excess oil.

## 2. Theory of Operation

The angular distribution of scattered radiation in the backward hemisphere is important in the interpretation of remote sensing measurements, investigations of particle shape, and models of visibility in seawater. The *ECO* VSF3 measures the optical scattering at three distinct angles: 100, 125, and 150 degrees, at three wavelengths, thus providing the shape of the Volume Scattering Function (VSF) throughout its angular domain (Figure 2). Motivated by the need to better understand the relationship of water leaving radiance with the backscattering into the same direction, the three-angle measurement allows determination of specific angles of backscattering through interpolation. Conversely, it also can provide the total backscattering coefficient by integration and extrapolation from 90 to 180 degrees.

The *ECO* VSF3 consists of three potted monolithic optical flanges and a housing containing the signal processing and controller circuitry. The optics include three sets of three LED-based transmitters that couple to three receivers. The transmitters and receiver are located to establish centroid light scattering angles of approximately 100, 125, and 150 degrees respectively. For each angle the region of intersection encompasses a full width half maximum (FWHM) bandwidth of about 18 degrees.

The controller electronics sequence through the individual transmitters at approximately 1 Hz per sample cycle. The individual transmitters operate synchronously with the receiver to reject ambient light. Signals from the receiver and reference detector are digitized and transmitted from the instrument.

Each sensor head operates at one wavelength.  Presently these wavelengths are factory configurable for 470 nm, 530 nm, and 660 nm**.**

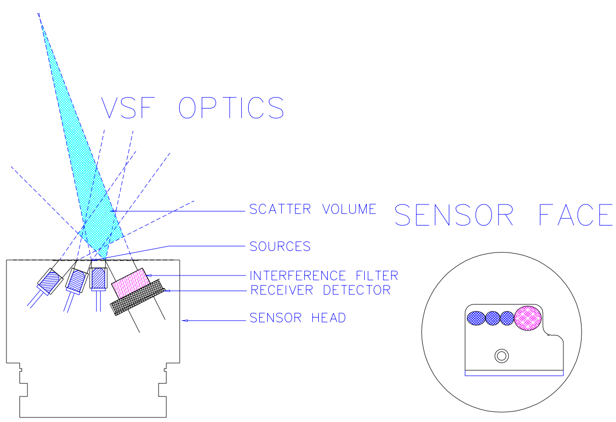


**Figure 2.** Optical Configuration of *ECO* VSF 3

# 3. Instrument Operation

## 3.1 Initial Checkout

Supplied from the factory, *ECO*s are configured to begin continuously sampling upon power-on. Electrical checkout of *ECO* is straightforward.

Connect the 6-socket connector on the test cable to the instrument to provide power to the LEDs and electronics (see Section 1 for a diagram of the pin-outs of the *ECO* VSF3). Connect the battery leads on the test cable to the 9V battery supplied with the meter. Light should emanate from the meter.

## 3.2 Operating the Sensor for Data Output

**Note**
*ECO* scattering meters are sensitive to AC light. Before making measurement, turn AC lighting off.

1. Connect the 6-socket connector to the instrument to provide power to the LEDs and electronics. Connect the DB-9 connector to a computer with the ECOView host program installed on it.

**WARNING!**
**Always use a regulated power supply to provide power to ECO sensors if not using the 9V battery provided with the test cable: power spikes may damage the meter.**

2. Start a terminal program, select the appropriate COM port and ensure the following settings are applied:
   - baud rate: 19200
   - data bits: 8
   - parity: none
   - stop bits: 1
   - flow control: none

3. Supply power to the meter. Output will appear in the terminal program window. Test the instrument's signal using the fluorescent stick. *ECO* is sensitive to room lighting; for best results, perform test in ambient light only (turn off AC lighting). Remove the protective cover. Hold the fluorescent stick 1–4 cm above the optical paths in an orientation that maximizes exposure of the stick. (Parallel with the beams, not intersecting them). The signal will increase toward saturation (maximum value on characterization sheet).

## 3.3 Deployment

The *ECO* VSF3 requires no pumps to assure successful operation. Once power is supplied, the unit is ready for submersion and subsequent measurements (depending upon software setup configuration). Some consideration should be given to the package orientation. Do not point the sensor faces directly into the sun or other bright lights.

Other than these basic considerations, one only needs to make sure that the unit is securely mounted to whatever lowering frame is used and that the mounting brackets are not damaging the unit casing.

Avoid obstructing the sensors' optical paths. The sensor will detect an object directly in front of its optics.

## 3.4 Upkeep and Maintenance

The *ECO* VSF 3 is a precision instrument and requires routine upkeep. After each cast or exposure of the instrument to natural water, flush the instrument with clean fresh water, paying careful attention to the sensor face. Use soapy water to cut any grease or oil accumulation. Gently wipe clean with a soft cloth. The sensor face is composed of acetal copolymer and optical epoxy and can easily be damaged or scratched.

**WARNING!**

**Do not use acetone or other solvents to clean the sensor.**

At the end of an experiment, the instrument should be rinsed thoroughly, air-dried and stored in a cool, dry place.

# 4. Data Analysis

Data from the *ECO* VSF 3 represents raw output from the sensor. Applying linear scaling constants, this data can be expressed in meaningful forms of inverse meters for each of the respective angles.

Typically the VSF3 comes supplied with RS-485 and RS-232 output operating at 19,200 baud. Unless supplied with a custom output protocol, the instrument powers up in a free run mode. This means that when turned on the unit automatically begins acquiring data and outputting that data in its appropriate format.

## 4.1 Raw Data Format

The VSF 3 outputs a tab-delimited data record every 1 second. Each record contains a 12-character header and 16 columns of tab delimited ASCII data.

### 4.1.1 Header

The VSF 3 has a 12-character ASCII header using the format:
**WETAVSF3nnnn**

**WETAVSF3** identifies the meter as a WET Labs VSF 3 using an ASCII output.
**nnnn** is the VSF 3 S/N. It can range from 0001 to 9999.

### 4.1.2 VSF 3 Data Output

The VSF 3 header is followed by 16 tab-delimited data fields, in the following order:

***1. Columns:***
Tells how many tab delimited columns of data are to follow. For the current version of the VSF-3, this number will always be 15.

***2. Revision***
Currently set to 1.

***3. Record Counter***
Increments with every record and is approximately equal to the number of seconds the VSF3 has been running.

***4. Twelve Columns of Sensor Data***
The data from the three sensor heads is output in the order of blue (470 nm), green (530 nm), and red (660 nm). Each group of sensor head represents:
A reference measurement
100-degree measurement
125-degree measurement
150-degree measurement

***5. Record Check Sum***

The final column of data is a record checksum which may be used to verify whether the VSF3 record has been received correctly. Unless a long cable is being used between the VSF3 and the display or logging source, this record can be ignored.

This is a hexadecimal number and is a binary addition of all the characters in the data from the first character in the header to the tab just before the check sum.

### 4.1.3 Trailer

The VSF 3 data record is terminated by carriage return–line feed <CR> <LF>.

## 4.3 Data Processing

### 4.3.1 Data Corrections

*Attenuation coupling*—Many scattering sensors require a subsequent attenuation correction for pathlength coupling of the transmitted and scattered light. This is typically a function of the propagation distances of the light as well as the magnitude of the water attenuation. Because the *ECO* VSF 3 incorporates very short pathlengths and scattering volumes in its measurements, it is relatively immune to this pathlength coupling (Figure 3). For attenuation coefficients up to approximately 5 $m^{-1}$ no data correction is required.

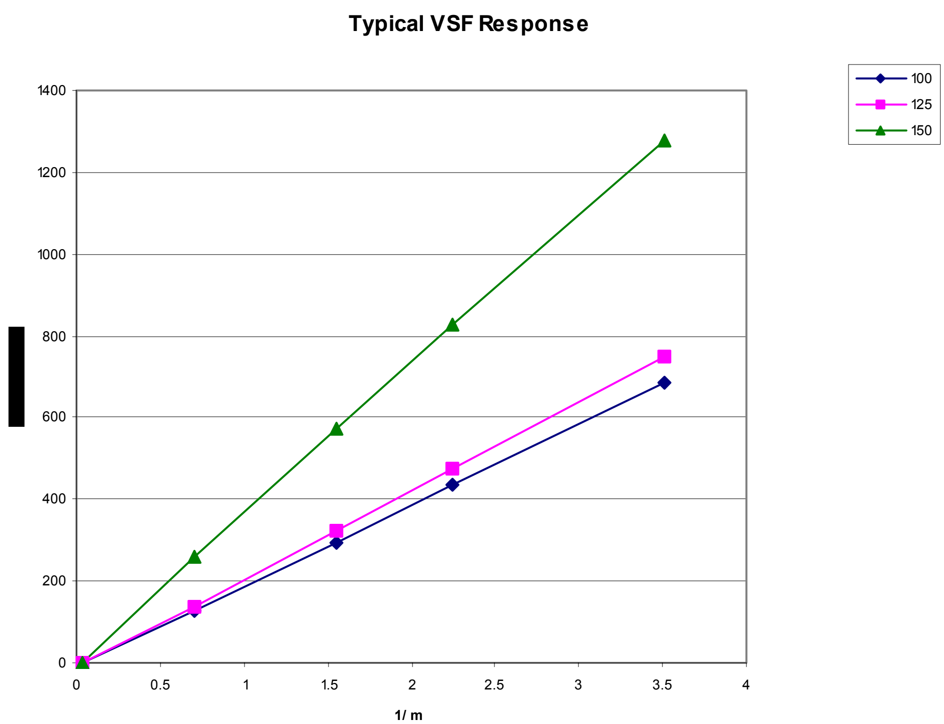


**Figure 3.** Linearity Response

*Temperature correction*—Output from an LED reference detector is provided, which gives an indication of relative LED intensity during operation. Work is presently underway to incorporate this signal as an ongoing correction for measurements.

*Determination of primary angular coefficients*—The primary angular coefficients for each angle of backscattering can be applied upon raw data downloaded from the instruments. Determination is made by subtracting the dark values (in counts) from the measured value and multiplying the result by the scaling factors provided in the calibration sheet.

The scaling coefficients for these values are determined by our instrument calibration process as described in Section 5.

## 4.4 Determining other Angle-Specific Coefficients

Other angular scattering coefficients can be determined through interpolation between the measured angles. At this time WET Labs offers no preference in the type of curve fit to use for deriving these coefficients.

### 4.4.1 Determining Backscattering Coefficient

The most accurate method of determining the backscattering coefficient, $b_b$, from the VSF measured at the three angles of the *ECO*-VSF 3 is as follows:

1. Multiply the corrected β values by 2πsinθ to convert to a polar steradian area.
2. Fit a 3rd order polynomial to the three measured points and a fourth value of π radians=0 (sin (π radians) =0).
3. Integrate under the curve fit from π/2 to π radians.

Testing this approach with all the Petzold (1972) VSFs results in a maximum error of about 1 percent.
(Petzold, T.J., *Volume scattering functions for selected natural waters,* Scripps Institution of Oceanography, Visibility Laboratory, San Diego, CA, SIO Ref. 71–78, 1972.)

# 5. Testing and Calibration

Prior to shipment, each *ECO* is characterized to ensure it meets the instrument's specifications.

## 5.1 Testing

When the instrument is completely assembled, it goes through the tests below to ensure performance. The results of this test are presented on the calibration sheet for each sensor.

### 5.1.1 Dark Counts

Pure, de-ionized water is used to set the "zero" voltage of the meter. This zero voltage is set for 125 counts (+/-75) on all models.

### 5.1.2 Pressure

To ensure the integrity of the housing and seals, *ECO*-VSF 3 is subjected to a underwater pressure test before final testing. The testing chamber applies a water pressure of at least 50 PSI.

### 5.1.3 Mechanical Stability

Before final testing, the VSF 3 is subjected to a mechanical stability test. This involves subjecting the unit to mild vibration and shock. Proper instrument functionality is verified afterwards.

### 5.1.4 Electronic Stability

This value is computed by collecting a sample once every 5 seconds for twelve hours or more. After the data is collected, the standard deviation of this set is calculated and divided by the number of hours the test ran. The stability value must be less than 2.0 mV/Hour.

### 5.1.5 Noise

"Noise" is computed from a standard deviation over 60 samples. These samples are collected at one-second intervals for one minute. A standard deviation is then performed on the 60 samples, and the result is the published noise on the calibration form. The calculated noise must be below 2 counts.

### 5.1.6 Voltage and Current Range Verification

To verify that the *ECO* operates over the entire specified voltage range (7–15V), a voltage-sweep test is performed. *ECO* is operated over the entire voltage range, and the current and operation is observed. The current must remain constant at approximately 85 mA over the entire voltage range.

### 5.1.7 Temperature Stability

To verify operational stability over a range of temperatures, ECOs are immersed in water with a beginning temperature of approximately 30 deg C, to an ending temperature of 1 deg C.

### 5.2 Calibration

Calibration of the *ECO*-VSF involves the following steps.

1. Numerical determination of the volume weighted angular region for each scattering angle.
2. The detector (D) and the source (S) are separated by a distance SD (Figure 4).
3. The angle of the center of the detector beam with the line SD is $\theta_d$.
4. The half-angle of the detector cone is $\sigma_s$.
5. The corresponding angles for the source are $\theta_s$ and $\sigma_s$.
6. The volume above the SD line is broken up into the small volumes $\Delta x \Delta y \Delta z$. z is in the same plane as the SD line.

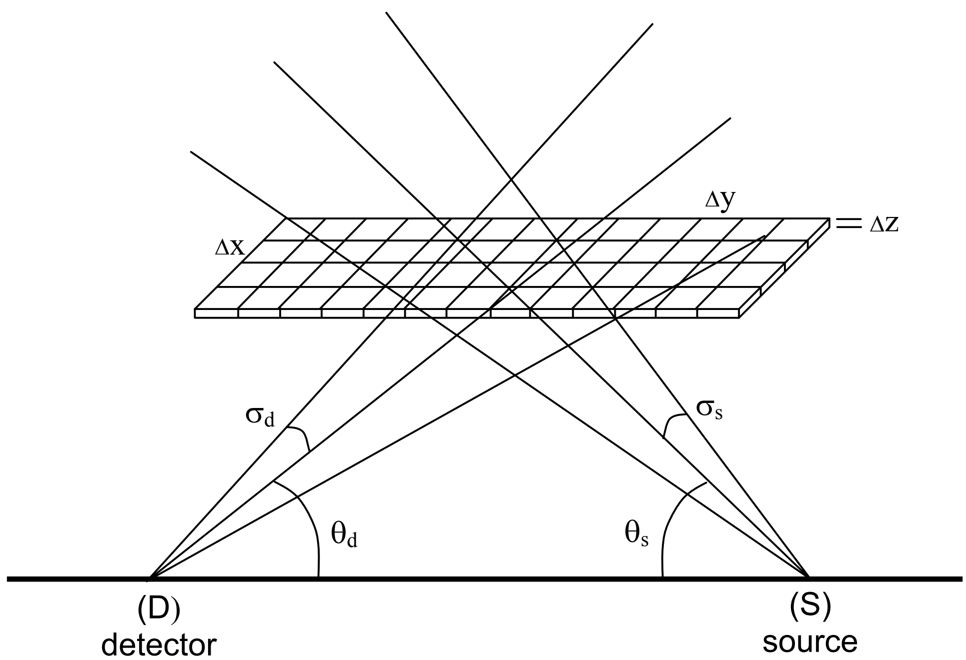


**Figure 4.** General geometry of the sensor

The small volume, $\Delta V = \Delta x \Delta y \Delta z$ at (x,y,z) was determined by simple geometry. It was then determined whether the $\Delta V$ was in the intersection of the source beam and the field of view of the detector (both conical shapes). The intersection of each cone and the plane is an ellipse and the illuminated area is the intersection of those ellipses. The signal strength was determined for each elementary volume, and then integrated over the illuminated area to obtain the weighting function. Weighting functions were determined in this manner for each source–detector pair (nominal angles of 100, 125, and 150 degrees) and are plotted in Figure 5 below.

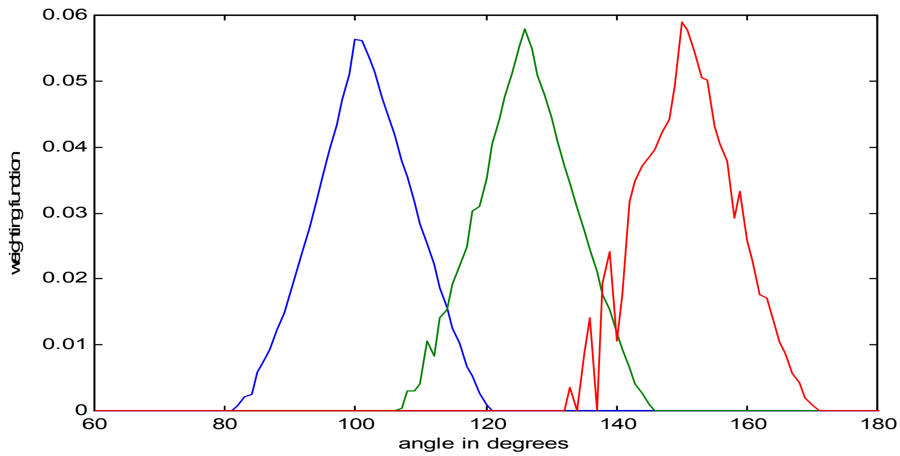


**Figure 5.** Weighting functions for source–detector pairs.

Mie scattering determination into these regions for a known distribution of spherical scatterers (Polystyrene beads).

Spherical or spheroid particles with a known particle size distribution can be quite accurately modeled for scattering behavior using Mie theory. We thus obtain NIST-traceable bead standards and calculate their scattering response using the derived weighting functions.

Determination of angular coefficients through direct measurement of spherical beads.

Once the weighting functions are determined and the scattering response for our calibration medium determined, we then run a dilution series of measurements, using the medium in water. From the curves obtained with varying concentration we then calculate the absolute response of the instrument. These are the scaling coefficients supplied with each instrument.

# 6. Communication Settings

The VSF3 communication port is setup as:

| | |
|---|---|
| baud rate: | 19200 |
| data bits: | 8 |
| parity: | none |
| stop bits: | 1 |
| flow control: | none |

Revision History

| Revision | Date | Revision Description | Originator |
|---|---|---|---|
| A | 06/08/00 | New document (DCR 30) | C. Carlock, J. Kitchen, C. Moore, D. Romanko, W. Strubhar |
| B | 06/29/00 | Add fluorometer-configured data timing (DCR 43) | D. Romanko |
| C | 10/31/00 | Add ECO-Host 4.0 interface (DCR 70) | C. Carlock, H. Van Zee |
| D | 07/16/01 | Add ECO Host 4.1.2 interface (DCR 130) | C. Carlock, H. Van Zee |
| E | 04/10/02 | Update Section 3 (DCR 204) | D. Whiteman |
| F | 4/14/03 | Add regulated power supply warning (DCR 292) | W. Strubhar |
| G | 3/10/04 | Add new test cable description, operational description, mounting diagram (DCR 381) | A. Derr, D. Whiteman |
| H | 8/11/04 | Update to reflect new electronics set (DCR 409) | H. Van Zee |
| I | 8/27/04 | Remove communication references (DCR 418) | D. Romanko |
| J | 1/13/06 | Clarify warranty statement (DCR 481) | A. Gellatly, S. Proctor |
| K | 9/28/06 | Update specifications (DCR 507) | M. Johnson |
| L | 11/01/06 | Correct pressure sensor and thermistor output equations (DCR 509) | M. Johnson |
| M | 9/11/07 | Delete reference to pressure sensor refilling procedure (DCR 531) | M. Johnson, H. Van Zee |
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