

# TECHNICAL DATA SHEET

---

# SootTrak™

**REAL-TIME ENGINE SOOT MASS EMISSIONS**



**SIERRA®**  
CP ENGINEERING

## Description

The Sierra Instruments SootTrak™ laser measures real-time engine soot particle mass emissions and performs characterization of soot particle size, primary particle surface area and number. SootTrak provides researchers and engine developers the accurate information they require about particle transport. With measurement accuracy of 5% using a known calibration source, SootTrak also sets itself apart from other real-time soot mass measurement techniques with its rangability, application flexibility and resolution. SootTrak measures real-time soot particle mass emissions concentrations from  $1 - 10^6 \mu\text{g}/\text{m}^3$  for mean agglomerate sizes ranging from 50 - 500nm at data rates up to 10 Hz. Obtaining  $\pm 1 \mu\text{g}/\text{m}^3$  detectability requires 0.1 seconds of measurement time giving SootTrak the best sensitivity and resolution available.

With over five years of development and patents pending combined with field-proven results in other emissions markets, Sierra has partnered with Process Metrix to introduce SootTrak technology to the engine emissions measurement community for the first time. SootTrak is available in two versions: as a plug-and-play version integrating with Sierra's BG<sup>®</sup>3 partial flow dilution system and as a stand-alone version for integration with other types of dilution systems such as CVS or other brands of partial flow sampling systems.

SootTrak measurements are based on first principles similar to gravimetric, optical absorption, and mobility methods, giving comparable mass and size accuracies without calibration. SootTrak can also be used for correlation to gravimetric PM filter measurements, soot modeling, PM filter cross-checking, as well as determination of soot number limits. SootTrak has a dilution ratio rangability exceeding 50:1 when operated with the BG3, which is capable of sampling PM from any engine regardless of horsepower, fuel, and PM concentrations. SootTrak is housed inside a portable, height-adjustable cabinet that includes the sample extraction vacuum source and 1065 compliant temperature control. A microprocessor measures temperature and pressure automatically to convert to STP conditions. The instrument includes features for remote operation and includes user-friendly software that is unmatched in the industry.

## Technology Overview

**SootTrak™ (Real-Time Scattering by Two Angle Ratio)** : While there are other scattering techniques, the SootTrak method is unique in calculating soot concentration from first principles, (patent pending), without the need for gravimetric calibration. SootTrak operates at near ambient pressure to prevent evaporation of volatile and semi-volatile particles, and it requires no consumables.

SootTrak measures soot particle mass emissions concentrations from  $1 - 10^6 \mu\text{g}/\text{m}^3$  for mean agglomerate geometric sizes ranging from 50 - 500nm at data

## Technology Overview (continued)

rates up to 10 Hz. When interfaced with Sierra's BG3, SootTrak is able to provide accurate measurements for all transient test cycles. Obtaining  $\pm 1 \mu\text{g}/\text{m}^3$  detectability requires 0.1 seconds of measurement time giving SootTrak the best resolution available.

Engineers can study the dynamic behavior of particle emissions that occur during transient test cycles, for example, during the first few seconds of a cold start, or during regeneration of a particle trap or diesel particulate filter (DPF). In addition, SootTrak gives the user the ability to cross-check gravimetric PM filter weights (immediate analyses of test particulates prior to the filter weight measurement) and is also an exceptional soot modeling tool. Because SootTrak is a sensitive measuring method, SootTrak uses ambient clean air rayleigh scattering to confirm instrument accuracy in less than a minute prior to each measurement sequence.

### Other Techniques Compared & Contrasted:

**Nephelometry:** Has been used for both ambient dust sampling and soot measurements, but generally relies on specific calibration correlations to obtain particle concentrations. Single detector nephelometry cannot provide agglomerate size information or correctly determine mass concentrations as the agglomerate size varies. SootTrak has the ability to provide real time performance characterization of soot particle size.

**Two Wavelength:** Uses one detector and combined with two LED illumination wavelengths (Typically = 660nm and 880nm). While this is satisfactory for measurement of ambient aerosol mean sizes that are near transparent, measurement of soot requires a broader range of the scattering vector  $q$ , which is provided by SootTrak.

**Laser Induced Incandescence (LII):** LII has been available since the 1990's and has been implemented as a sampling and in situ instrument. Although fast (20 Hz), the method is complex, and has a lower concentration measurement limit of  $10 \mu\text{g}/\text{m}^3$ . There remain many questions about the fundamental interpretation of the measurements, which depend on a range of heat transfer properties in addition to all the primary particle soot properties.

**Photo Acoustic Soot Sensor (PASS):** This sampling method measures soot particle absorption in the gas phase, with minimum detection levels of  $2 \mu\text{g}/\text{m}^3$  and a time response of 1 Hz. Other optical absorption methods use filter collection to concentrate and enhance the measured opacity. However, to obtain  $\pm 1 \mu\text{g}/\text{m}^3$  detectability requires approximately 100 seconds of measurement time, compared to 0.1 seconds for SootTrak.

**Tapered Element Oscillating Microbalance (TEOM):** This method measures soot mass directly, but requires approximately 1000 seconds to obtain  $\pm 1 \mu\text{g}/\text{m}^3$  detectability, compared to 0.1 seconds for SootTrak. In addition, the fragile TEOM element has limitations in an industrial environment.

## Features

- **Accuracy:**  $\pm 5\%$  error
- **Repeatability:**  $\pm 3\%$  of reading
- **Wide Measurement Range** of 1 -  $10^6 \mu\text{g}/\text{m}^3$
- **Minimum Detection Limit:**  $\sim 0.5 \mu\text{g}/\text{m}^3$
- **Fast Response Time:**  $\leq 0.1$  sec
- **Plug and Play with the Model BG3**
- **Continuous Real-Time Soot Curve**
- **High Sensitivity for Future Regs (Tier 5, EURO 5, 2012 & later)**
- **Correlation to Gravimetric Measurements**
- **PM Filter Cross-Checking**
- **Soot Modeling**
- **Soot Number Limits**
- **Unlimited Dilution Ratio Rangeability**
- **Portable compact size**
- **Simple and fast calibration with ambient clean air**

## Common Applications

- **For any engine size and fuel**
- **Steady state, ramp modal and transient test cycles**
- **On engine and chassis dyno test beds**
- **Measurement upstream and downstream of particulate filters**
- **Research & development**

## Application Benefits

**Correlation to Gravimetric Filter Measurements:** A fundamental model (patent pending) is used to relate the fast and sensitive optical scattering measurements of SootTrak to equivalent mass concentration measurements at EPA-defined partial dilution conditions provided by the BG3. Concentration measurements agree with gravimetric filter results (see Correlation Testing section).

**PM Filter Cross-Checking:** SootTrak gives the user the ability to cross-check gravimetric PM filter measurements of concentration. SootTrak is incorporated with the BG3 sampled emissions flow stream, operating at the EPA-required temperature of 47C just prior to the filter sample. The uncertainty of PM gravimetric results after DPF and partial dilution is in the range of  $\pm 30\text{-}50\%$ . (*Kittleson, et al., AST, October 2009*). SootTrak can help identify consistency of engine test cycle conditions in real time, saving valuable test cell time, and can help identify errant filter measurements following the measurements.

**Soot Modeling with SootTrak:** When building a soot model, the engine is run through hours of operating conditions where engineers adjust a wide range of combustion parameters. Acquisition of detailed gravimetric filter samples at each mode is time-consuming and costly. With the BG3, SootTrak can rapidly and continuously build a detailed and accurate map of engine soot production.

**Soot Number Limits:** Upcoming European regulations will require soot number limits along with standard gravimetric sampling. In addition, the California Air Resources Board is moving towards soot number limits as well, and the EPA will follow. Unlike other systems that only provide soot number or mass, SootTrak gives total mass, agglomerate size, and primary particle number, for carbon PM  $>30\text{nm}$ .

**Unlimited Dilution Ratio Rangeability:** When SootTrak is run in tandem with the BG3, the user can set any dilution ratio desired well over 50:1 through the BG3 user software. The BG3 is capable of sampling PM from any engine regardless of horsepower, fuel, and PM concentrations.

**Measurement Range:** SootTrak has a wide soot concentration measurement range of 1 -  $10^6 \mu\text{g}/\text{m}^3$ , providing a flexible instrument for an array of applications.

## Business Advantage

- Observing the realtime concentration graph during a transient test cycle allows optimization of performance and emissions reduction
- User friendly software interface for a seamless integration “plug and play” with the BG3 control software.
- Stand-alone SootTrak version can be used with other dilution systems (CVS or non-Sierra brand partial flow dilution systems).
- Real-time simultaneous gas & gravimetric sampling
- Low maintenance instrument
- Portable compact size

• High sensitivity and measurement value resolution permit transient measurements of  $1 - 10^6 \mu\text{g}/\text{m}^3$  range, allowing measurements downstream of exhaust aftertreatment systems and particulate filters.

• High sensitivity makes the SootTrak solution suitable for future statutory requirements (e.g. Tier 5, EURO 5, 2012 and later).

• Simple and fast calibration with ambient clean air as a reference scattering source to confirm instrument accuracy in less than a minute prior to each measurement sequence.

## Performance Specifications

**Accuracy:** Comparable to gravimetric, optical absorption, and mobility, ( $\pm 25\%$ );  $\pm 5\%$  with specific calibration source.

**Repeatability, Precision:**  $\pm 3\%$  of reading

**Measured Value:** Concentration of soot ( $\mu\text{g}/\text{m}^3$ ) in the diluted exhaust gas

**Mass Concentrations:**  $1 - 10^6 \mu\text{g}/\text{m}^3$

**Display Resolution:**  $1 \mu\text{g}/\text{m}^3$

**Minimum Detection Limit:**  $\sim 0.5 \mu\text{g}/\text{m}^3$

**Measured Mean Agglomerate Size:** 50 – 500nm

**Measurement Data Rate:** 10 Hz

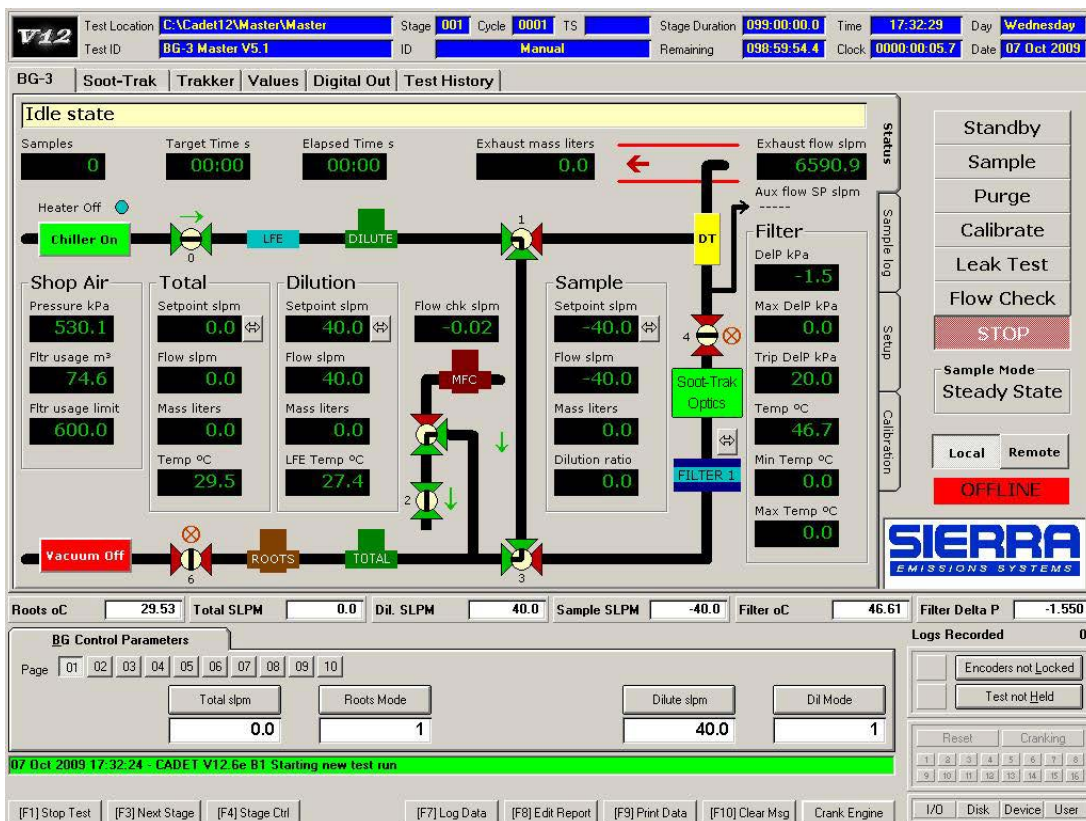
**Response Time:**  $\leq 0.1$  sec

**Operation Temperature:** Same as BG3

**Interfaces:** RS232, Digital I/O, Analog I/O, Ethernet, NOTE: need to discuss data transfer to Test cell controller (We will have to be able to give A-K to customers)

**Flow Rate Through Laser:** Controlled by BG3

## Software Interface



Main BG3 & SootTrak Screen (above)



# Software Interface (continued)

**V12** Test Location: C:\Cadet12\Master\Master Stage: 001 Cycle: 0001 TS: Stage Duration: 099:00:00.0 Time: 17:27:57 Day: Wednesday  
 Test ID: BG-3 Master V5.1 ID: Manual Remaining: 098:59:46.9 Clock: 0000:00:13.2 Date: 07 Oct 2009

Successfully entered sample mode.

Target Time(s):  Elapsed Time(s): **9.0**

ParticleDiameter: **260.7063** nM  
 MassConcentration: **1.1363** mg/M³  
 Temperature: **47.7** oC  
 Pressure: **97.84** kPa  
 Smoke: **12.19** SN  
 LaserPower: **27.84** mW  
 LaserOnTime: **458855.0** secs  
 OperatingTime: **657018.0** secs  
 RawScattering1: **0.647** nW  
 RawScattering2: **2.228** nW  
 SupplyVoltage: **24.0** Volts

Stray Light Cal State: **Not Calibrated**  
 Clean Gas Cal State: **Not Calibrated**

Roots oC: **29.54** Total SLPm: **0.0** Dil. SLPm: **40.3** Sample SLPm: **-40.3** Filter oC: **46.90** Filter Delta P: **-1.551**

**BG Control Parameters**  
 Page:

Total slpm: **0.0** Roots Mode: **1** Dilute slpm: **40.0** Dil Mode: **1**

07 Oct 2009 17:27:43 - CADET V12.6e B1 Starting new test run

Logs Recorded: **0**

Main Status/Control Screen (above)

**V12** Test Location: C:\Cadet12\Master\Master Stage: 001 Cycle: 0001 TS: Stage Duration: 099:00:00.0 Time: 15:24:35 Day: Thursday  
 Test ID: BG-3 Master V5.1 ID: Manual Remaining: 098:59:27.7 Clock: 0000:01:24.5 Date: 17 Sep 2009

01.StarStatus: **3.2330** #  
 02.StarError: **0** #  
 03.StarWarning: **0** #  
 04.BoardTemp: **35.0** oC  
 05.SatTemp: **0.0** oC  
 06.SupplyVoltage: **24.0** Volts  
 07.LaserPower: **30.32** mW  
 08.OperatingTime: **498293.8** SECS  
 09.LaserOnTime: **327639.0** secs  
 10.Gain: **16304** #  
 11.Pressure: **107.01** kPa  
 12.Temperature: **35.3** oC  
 13.SIOffset: **0.01180** nW  
 14.SIOffset: **0.01391** nW

Measured Data Validity: **DATA INVALID**  
 Measure Active: **NOT ACTIVE**  
 Valve(s) Actuation: **VALID**  
 Sample Measurement Valid: **INVALID**  
 Clean Gas Measurement Valid: **VALID**  
 Stray Light Measurement Valid: **INVALID**  
 Auxiliary Input 1: **OFF**  
 Auxiliary Input 2: **OFF**  
 Auxiliary Input 3: **OFF**  
 Auxiliary Input 4: **OFF**  
 Simulation Mode: **NORMAL RUNNING**  
 Restricted Access Granted: **DENIED**  
 Satellite Card Detected: **NOT DETECTED**  
 Time Synchronization: **OK**  
 Detector Gain: **AUTOMATIC**  
 Delays under Internal Control: **EXTERNAL CTRL**  
 Jumper Option 1: **DISABLED**  
 Jumper Option 2: **DISABLED**  
 Jumper Option 3: **DISABLED**  
 Laser Active: **ACTIVE**

Stray Light Cal State: **Not Calibrated**  
 Clean Gas Cal State: **Not Calibrated**

Roots oC: **23.57** Total SLPm: **0.0** Dil. SLPm: **40.1** Sample SLPm: **-40.1** Filter oC: **46.93** Filter Delta P: **-1.415**

**BG Control Parameters**  
 Page:

Total slpm: **0.0** Roots Mode: **1** Dilute slpm: **40.0** Dil Mode: **1**

Logs Recorded: **0**

Values Tab (above)

**V12** Test Location: C:\Cadet12\Master\Master Stage: 001 Cycle: 0001 TS: Stage Duration: 099:00:00.0 Time: 15:24:35 Day: Thursday  
 Test ID: BG-3 Master V5.1 ID: Manual Remaining: 098:58:08.0 Clock: 0000:03:54.1 Date: 17 Sep 2009

Time: # Command Value Modbus parameters  
 000:00:00 GetDeviceTime 125000001 0.0,0.0,11.0,16.1,144.0,2.4,74,170,03,101  
 000:00:00 GetDeviceID 0.0,0.0,0.0,0.1,248,0.8  
 000:00:00 GetDeviceStatus 0.0,0.0,0.0,0.3,2,88,0.96  
 000:00:00 SetIntegrationTime 300 0.0,0.0,0.0,15,1,49,0.1,2,1,244  
 000:00:00 GetMeasureMode 0 0.0,0.0,11.0,16.1,144.0,2.4,0,0,0  
 000:00:00 GetMeasureMode 3 0.0,0.0,11.0,16.1,144.0,2.4,0,0,0  
 000:03:54 1899 GetDeviceStatus 0.0,0.0,195.0,3,192,50,32,8.0,0.0,0.0,0.0,12,66,44,82,154,196,5,100,192,65,7

Time: # Command Value Modbus parameters  
 000:03:52 GetDeviceStatus 0.0,0.0,195.0,3,192,50,32,8.0,0.0,0.0,0.0,12,66,44,82,154,196,5,100,192,65,7  
 000:03:52 0001 GetDeviceStatus 0.0,0.0,195.0,3,192,50,32,8.0,0.0,0.0,0.0,12,66,44,82,154,196,5,100,192,65,7  
 000:03:52 0001 GetDeviceStatus 0.0,0.0,195.0,3,192,50,32,8.0,0.0,0.0,0.0,12,66,44,82,154,196,5,100,192,65,7  
 000:03:53 0001 GetDeviceStatus 0.0,0.0,195.0,3,192,50,32,8.0,0.0,0.0,0.0,12,66,44,82,154,196,5,100,192,65,7  
 000:03:53 0001 GetDeviceStatus 0.0,0.0,195.0,3,192,50,32,8.0,0.0,0.0,0.0,12,66,44,82,154,196,5,100,192,65,7  
 000:03:53 0001 GetDeviceStatus 0.0,0.0,195.0,3,192,50,32,8.0,0.0,0.0,0.0,12,66,44,82,154,196,5,100,192,65,7  
 000:03:54 0001 GetDeviceStatus 0.0,0.0,195.0,3,192,50,32,8.0,0.0,0.0,0.0,12,66,44,82,154,196,5,100,192,65,7  
 000:03:54 0001 GetDeviceStatus 0.0,0.0,195.0,3,192,50,32,8.0,0.0,0.0,0.0,12,66,44,82,154,196,5,100,192,65,7

Stray Light Cal State: **Not Calibrated**  
 Clean Gas Cal State: **Not Calibrated**

Roots oC: **23.58** Total SLPm: **0.0** Dil. SLPm: **39.3** Sample SLPm: **-40.0** Filter oC: **46.93** Filter Delta P: **0.771**

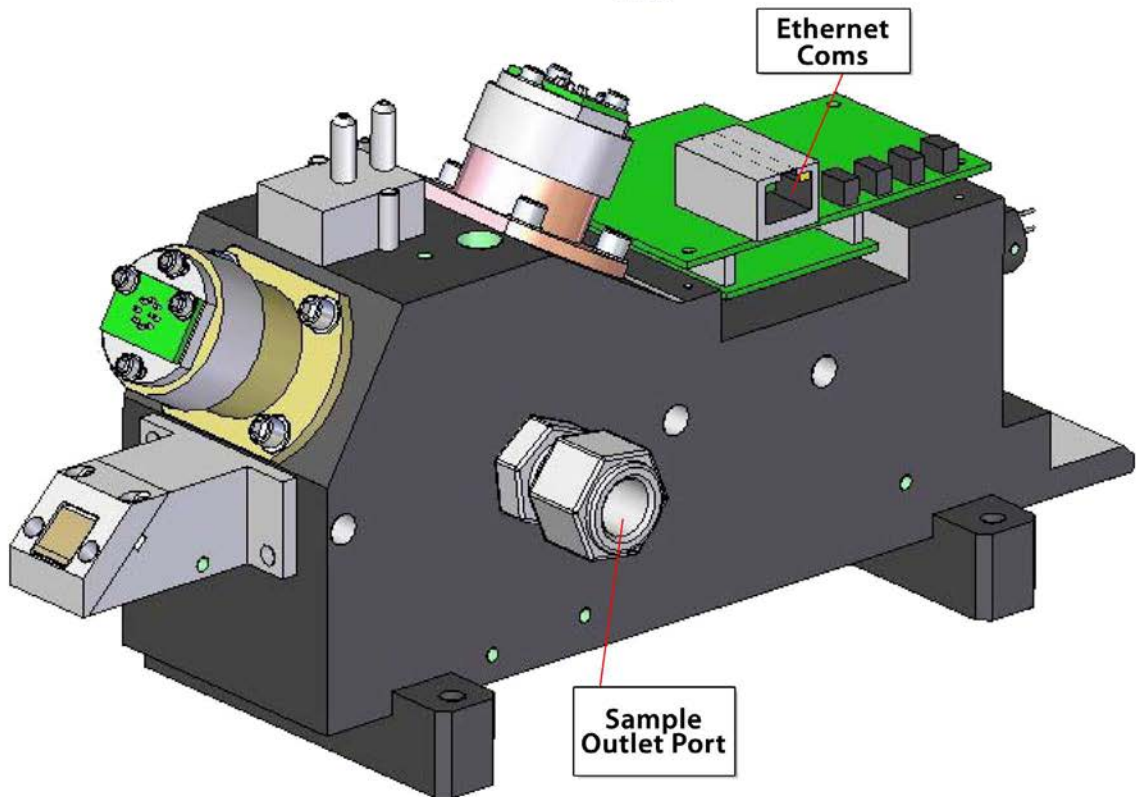
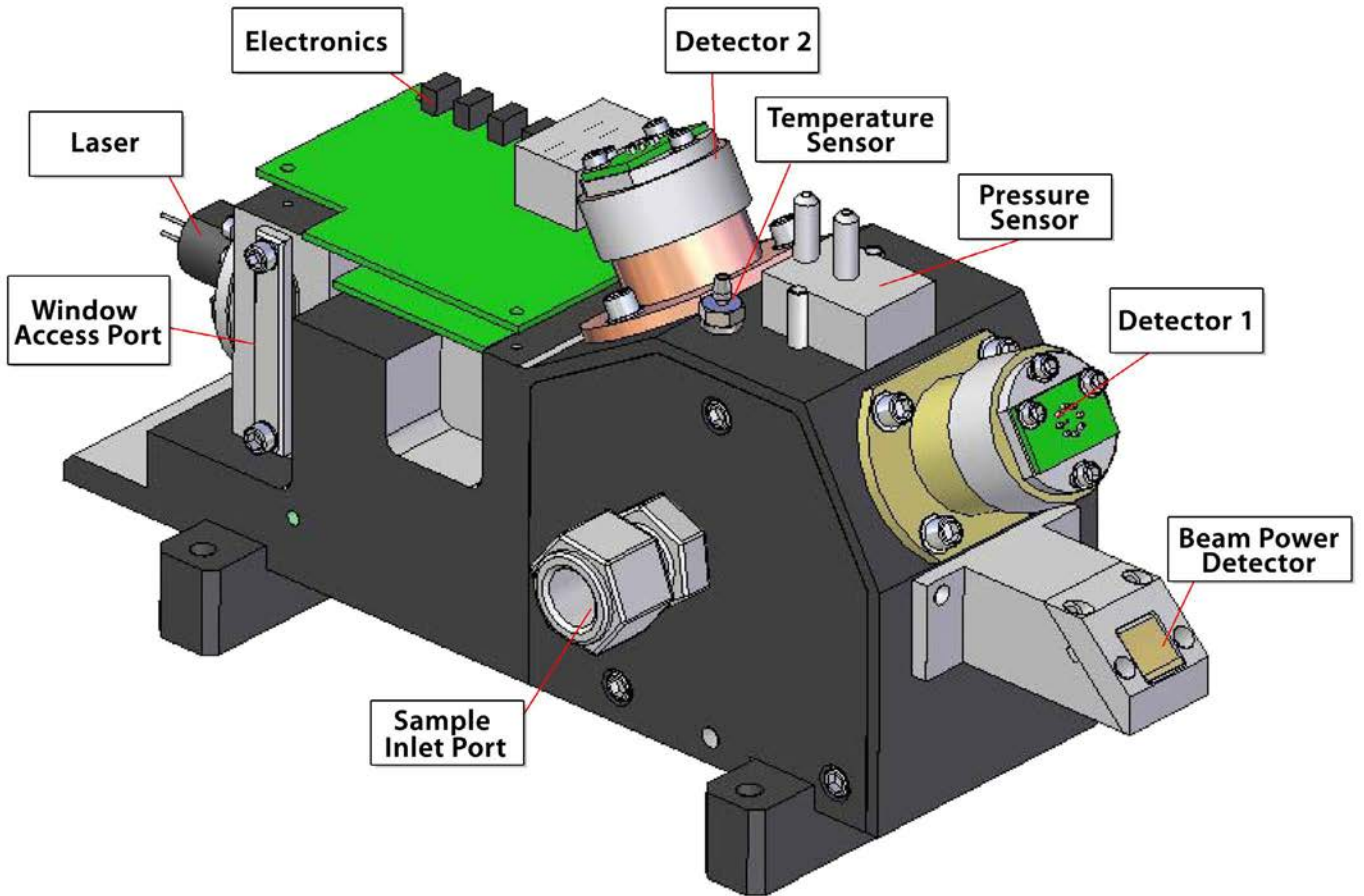
**BG Control Parameters**  
 Page:

Total slpm: **0.0** Roots Mode: **1** Dilute slpm: **40.0** Dil Mode: **1**

Logs Recorded: **0**

Diagnostics Tab (above)

# SootTrak™ Component Description



# SootTrak™

## ***REAL-TIME ENGINE SOOT MASS EMISSIONS***

**Real-Time Engine Soot Mass Emissions  
PM Filter Cross-Checking  
Soot Modeling & Soot Number Limits  
Plug & Play With BG® 3**







# SIERRA'S GLOBAL LOCATIONS

## USA

### MAIN OFFICES:

- Monterey, CA
- Lansing, MI

### SALES OFFICES:

- Golden, CO

## EUROPE

### MAIN OFFICE:

- Egmond, Netherlands
- Malvern, UK (CP ENGINEERING)

## ASIA

### MAIN OFFICE:

- Shanghai, China

# YOUR ONLINE PM SAMPLING RESOURCE



Engine Emissions Systems Division

[Emissions Systems Home](#) [Contact Us](#) [Downloads](#) [News & Events](#) [Request for Quote](#) [Sierra Flow Meters Home](#)

- Partial Flow Systems
- Engine Soot Emissions
- Flow Measurement
- Test Cell Automation
- Filter & Air Handling
- Sales
- Helpful Links

Home » [Emissions Systems](#) » Sierra Instruments Emissions Systems



- Request a Quote
- Live Help
- Think Ahead!

### Our Mission

The mission of Sierra Instruments Emissions Systems group is to be your engine particulate emissions specialist. We drive all parts of our business to be the leading manufacturer of 80-3 partial flow sampling technology in the world in terms of quality, delivery, price, innovation, and customer support.

### Core Product & Services

We manufacture engine emissions testing products that give our customers the ability to develop and certify cleaner engines faster and more efficiently. Our Model 80-3, which is protected by nine patents with several pending and is our flagship product. To complement the 80-3, our filter and air handling, flow measurement and test cell automation solutions offer the customer a single focused choice for all particulate measurement needs.

### Local Service & Lifetime Support

By combining superior product quality with a talented global support network of experts in over 150 locations in over 50 countries, Sierra consistently delivers quality measurement solutions for each customer and supports customers for the life of the product.

### Background

In 1991, Caterpillar Inc. and Sierra Instruments formed a joint agreement to commercialize several Caterpillar patents to produce the Model 80-3 Partial Flow Sampling System (PFSS). Sierra followed this effort up with the Model 80-3 PFSS which features advanced software.

Our 80-3 technology was developed in 2003 in response to pending requirements for transient cycle development and certification of non-road engines. The flagship Sierra Model 80-3 transient PFSS is protected by nine patents with several pending. Due to their expanded power output levels, higher mass flow rates and elevated test cycle exhaust heat content, off-road engines present a unique set of challenges to the continued use of CVS systems. Further, a need was expressed by after treatment and engine development personnel for a transient particulate sampling system deployable upstream and downstream of after treatment systems for concurrent particulate sampling to enable particle removal device efficiency studies. [SootTrak](#)

© Copyright 2010 Sierra Instruments, Inc. All Rights Reserved. [Terms of Use](#) | [Site Map](#)



### CALIFORNIA:

5 Harris Court, Building L  
Monterey, CA 93940  
Tel 800/866.0200 or 831/373.0200  
Fax 831/373.4402  
info@sierra-cp.com

### MICHIGAN:

16475 Igersoll Road  
Lansing, MI 48906  
Tel 517-323-8909  
Fax 517-323-8910  
info@sierra-cp.com