

## **Cavity Attenuated Phase Shift (CAPS) Monitor Instrument Handbook**

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April 2016

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## Acronyms and Abbreviations

ARM	Atmospheric Radiation Measurement Climate Research Facility
ASCII	American Standard Code for Information Interchange
CalNex	California Nexus 2010, a NOAA campaign
CAPS PM <sub>ex</sub>	cavity attenuated phase shift extinction
CAPS	Cavity Attenuated Phase Shift
cm	centimeter
CRD	cavity ring-down
DOE	U.S. Department of Energy
DOS	disk operating system
in.	inch
IR	infrared
K	Kelvin
kg	kilogram
LED	light-emitting diode
Mm <sup>-1</sup>	inverse megameters, 10 <sup>6</sup> m <sup>-1</sup>
MS	Microsoft Corporation
mV	micro-Volts
nm	nanometers
NOAA	National Oceanic and Atmospheric Administration
R	reflectivity
s	seconds
U	1U = 1.75-inches
USB	Universal Serial Bus
V	volt
VAC	volts alternating current

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## 1.0 Instrument Name

Cavity Attenuated Phase Shift Extinction (CAPS PM<sub>ex</sub>) Monitor

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Instrument manual available from manufacturer at <http://www.wmo-gaw-wcc-aerosol-physics.org/files/CAPS-PMex-Monitor-Aerodyn-green.pdf>

## 4.0 Instrument Description

The CAPS PM<sub>ex</sub> monitor is a cavity attenuated phase shift extinction instrument. It operates as an optical extinction spectrometer, using a visible-light-emitting diode (LED) as the light source, a sample cell incorporating two high-reflectivity mirrors centered at the wavelength of the LED, and a vacuum photodiode detector. Its efficacy is based on the fact that aerosols are broadband scatterers and absorbers of light.

## 5.0 Measurements Taken

The measurement taken by the Cavity Attenuated Phase Shift (CAPS) instrument is aerosol optical extinction (scattering and absorption).

## 6.0 Links to Definitions and Relevant Information

### 6.1 Data Object Description

The current extinction reading (with a 3-second time constant) is displayed on the front panel in units of  $\text{Mm}^{-1}$ . At concentrations below  $200 \text{ Mm}^{-1}$ , it will provide readings at a tenth of an  $\text{Mm}^{-1}$  resolution, but will revert to  $1 \text{ Mm}^{-1}$  resolution at higher concentrations. It will not provide readings above  $2000 \text{ Mm}^{-1}$ ; however, the digital output will continue to operate properly. The display unit is just a digital voltmeter which converts an analog 0-10 V signal generated by the computer to a digital reading. As such, it is prone to offset errors that limit its accuracy.

The true (and most accurate) readings are provided through the RS-232 connection located on the back panel of the monitor. Data are output as an American Standard Code for Information Interchange (ASCII) file organized in the following order: Time (chosen format), Extinction ( $\text{Mm}^{-1}$ ), Loss ( $\text{Mm}^{-1}$ ), Pressure (Torr), Temperature (K), Signal (arbitrary units), Flow Sensor ( $\text{cm}^3 \text{ s}^{-1}$ ), Status, and Last Baseline ( $\text{Mm}^{-1}$ ). An example of the datastream is shown below. This particular example contains a time stamp in hours, minutes, and seconds of the day. The data is comma delimited (default setting) as shown below:

```
101110,131.413,701.26,758.36,302.60,1512.91,xxx,10016,514.09
```

```
101111,131.313,701.14,758.27,302.60,1512.91,xxx,10016,514.09
```

```
101112,131.326,701.14,758.31,302.60,1512.91,xxx,10016,514.09
```

The example provided above indicates that data were being taken between 10:11:10-10:11:12 A.M, the extinction was  $\sim 131 \text{ Mm}^{-1}$ , the loss was  $\sim 701 \text{ Mm}^{-1}$ , and the pressure in the cell was  $\sim 758$  Torr. The sample temperature was  $\sim 303 \text{ K}$ , the light signal level was 1513 mV. The next reading is not currently used and is denoted as xxx. The status code (see below) indicates that the monitor pump was on and the system was in its normal monitoring mode and acting as an extinction monitor at an operating wavelength of 630 nm. The Last Baseline taken was  $514 \text{ Mm}^{-1}$  (not including the effect of air Rayleigh scattering).

*Status* is a five digit number: abcde

a. Pump Status

- = 0 Pump Off, Normal Operation
- = 1 Pump On, Normal Operation
- = 2 Alarm

b. Baseline Status



- = 0 Normal Operation – No Baseline
- = 1 Baseline On – Flush Period
- = 2 Baseline On – Measurement Period
- c. Not used
- d. Monitor Type
  - = 0 Gas Phase Absorption
  - = 2 Aerosol Extinction
  - = 3 Single Scattering Albedo Monitor
- e. Wavelength
  - =4 Blue (445 nm)
  - =5 Green (530 nm)
  - =6 Red (630 nm)
  - =7 Far Red (660 nm)
  - =8 Near-IR (780 nm)

The status number is typically used in subsequent data analysis to determine periods of baseline measurement or other upset conditions. If the supplied monitor software is used to collect the data, a date and time marker that reflects the host computer date and time is automatically attached to the data as the last column, in addition to those listed above.

If the data are being collected with a user-supplied data-acquisition program, it is recommended that all these data be recorded. They are required to reconstruct the data if there is a problem with baseline procedures, calibration, etc., and provide highly useful diagnostic information.

## 6.2 Onboard Data Storage

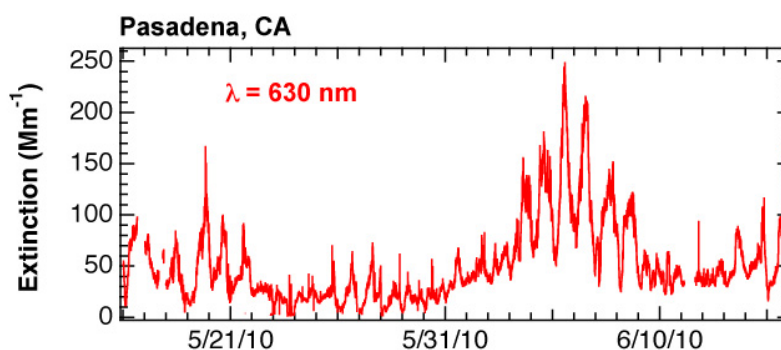
The monitor automatically stores all data on a memory cache located in the computer stack that operates the monitor. It has the capacity to store approximately 6 months of data taken with a 1-second sample period. Once the memory is filled, it will begin to overwrite old data files. Files can be deleted from this memory using the supplied data-acquisition program. If the file is to be copied, the Universal Serial Bus (USB) port on the front panel of the monitor is supplied for this purpose.

## 6.3 Serial Port Parameters

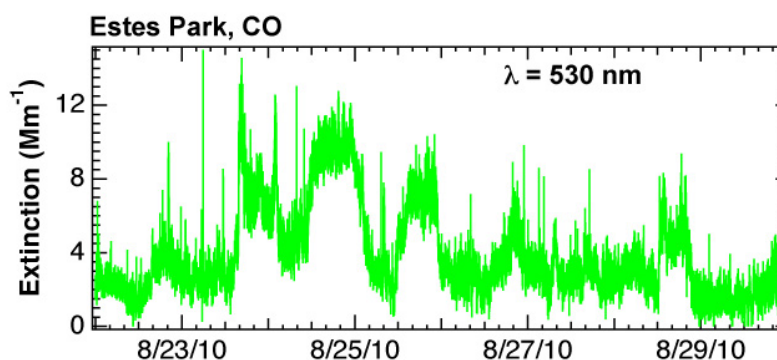
- Baud Rate: 9600
- Data Bits: 8
- Parity: None
- Stop Bits: 1
- Flow Control: None

## 6.4 Data Plots

Figure 1 and Figure 2 are examples of data plots obtained using the CAPS monitor.



**Figure 1.** Measured Particle Extinction at 630 nm in Pasadena, California, during the National Oceanic and Atmospheric Administration (NOAA) California Nexus (CalNex) 2010 campaign shown as 1-hour average values. Note the diurnal variation in extinction levels.



**Figure 2.** Measured particle extinction at 532 nm outside of Estes Park, Colorado, shown as 1-minute averages. Note the low levels of ambient particle extinction. The spikes are particulate emissions from passing vehicles.

## 6.5 Instrument Mentor Monthly Summary

The mentor performs a monthly quality-control check of data before it is submitted to the U.S. Department of Energy (DOE)'s Atmospheric Radiation Measurement (ARM) Climate Research Facility Data Archive.

## 6.6 Calibration Database

The CAPS instrument is an absolute measurement and does not require calibration.

## 7.0 Technical Specification

### 7.1 Measurement Specifications

- Measurement Range: 0 to 4000  $\text{Mm}^{-1}$
- Resolution: 0.1  $\text{Mm}^{-1}$
- Precision ( $3\sigma$ , 1 s):  $<3 \text{ Mm}^{-1}$
- Time Response:  $<2$  seconds
- Baseline Drift: automated baseline provided
- Span Drift: negligible

### 7.2 Physical Specifications

- Sample Flow Rate: 0.85 liters per minute
- Purge Flow: provided internally
- Cell Pressure: ambient
- Cell Temperature:  $\sim 5^\circ$  above ambient
- Power Usage:  $<50$  Watts (@120 VAC)
- Weight: 12 kg
- Size:  $\sim 65 \text{ cm} \times 43 \text{ cm} \times 23 \text{ cm}$  (length  $\times$  width  $\times$  height)
- [19-inch rack mount, 5U, 24 inches deep]

### 7.3 Range

- Measurement Range: 0 to 4000  $\text{Mm}^{-1}$

### 7.4 Accuracy

- Resolution: 0.1  $\text{Mm}^{-1}$

### 7.5 Repeatability

- Precision ( $3\sigma$ , 1s):  $<3 \text{ Mm}^{-1}$

### 7.6 Sensitivity

- Numbers are for a signal-to-noise ratio = 3: 2.5  $\text{Mm}^{-1}$  (1 second), 0.25  $\text{Mm}^{-1}$  (60 seconds)

## 7.7 Uncertainty

- $<5\%$  (Massoli et al. 2010)

## 7.8 Input Voltage

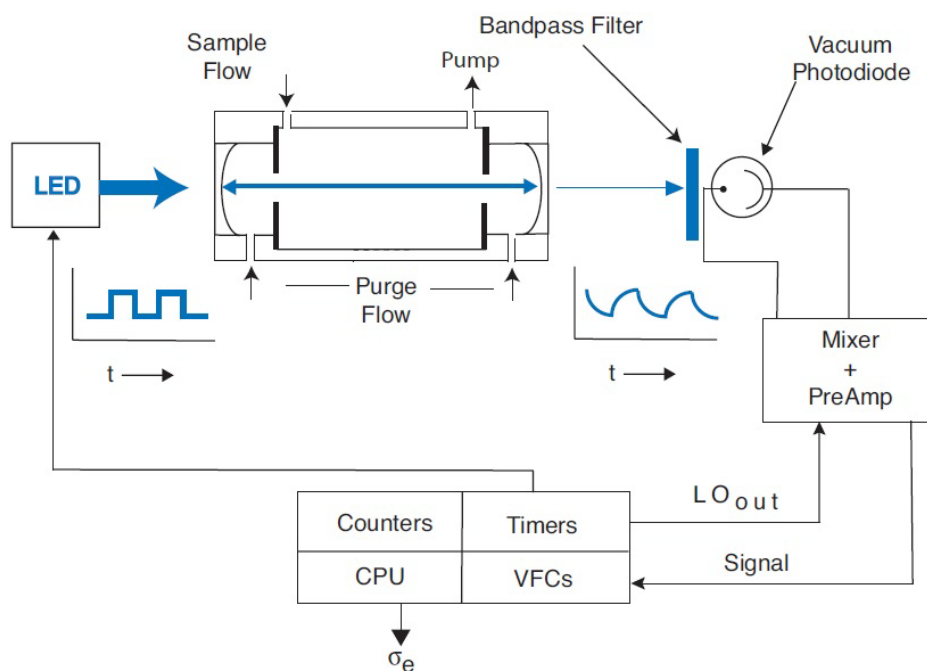
- 50 W; 100 to 250 VAC (50 to 60 Hz)

## 7.9 Output Values

Output values for the instrument are time, extinction ( $\text{Mm}^{-1}$ ), loss ( $\text{Mm}^{-1}$ ), pressure (Torr), temperature (K), signal (arbitrary units), flow sensor ( $\text{cm}^3 \text{s}^{-1}$ ), status, and Last Baseline ( $\text{Mm}^{-1}$ ).

## 8.0 Instrument System Functional Diagram

A schematic of the CAPS PM<sub>ex</sub> Monitor is shown in Figure 3.



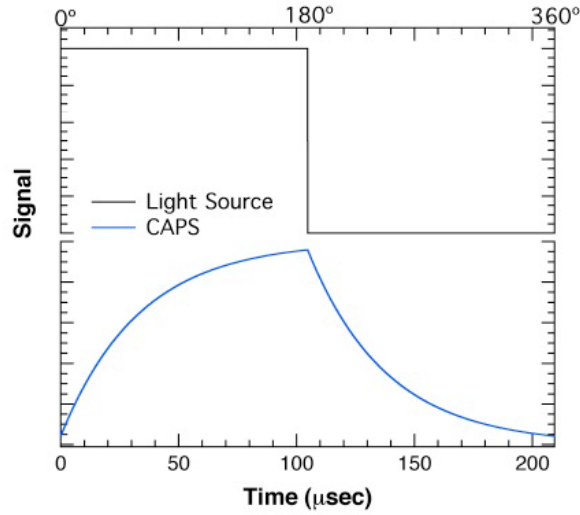
**Figure 3.** Schematic of CAPS PM<sub>ex</sub> monitor.

## 9.0 Instrument/Measurement Theory

Unlike a conventional absorption spectrometer, in which the concentration of the absorbing species is determined by measuring the attenuation of light, the CAPS monitor relies on measuring the average time spent by the light within the sample cell. The presence of particles causes this average time to decrease as the particle concentration increases because of the propensity of particles to scatter or absorb light. Of

course, given the high velocity of light (0.3 m/ns) and the very low concentrations of particles typically found in the ambient environment, a very long path length within the sample cell is required to accurately measure the change in time. This is accomplished by forming the ends of the sample cell with high-reflectivity mirrors ( $R \geq 0.9998$ ), a configuration that provides an optical path length on the order of 1 to 2 km. In the absence of particles, the photon lifetime within the cell is on the order of several microseconds, a magnitude that is readily measured with high accuracy.

In CAPS-based instruments, to measure the average time spent by the light within the sample cell, the LED output is square-wave modulated and directed into the back of the first reflective mirror. The light beam passes through the absorption cell, out of the back mirror, and into a detector where it appears as a distorted waveform characterized by a phase shift with respect to the initial modulation (see Figure 4).



**Figure 4.** Waveforms of LED (top) and signal at detector (bottom).

This distortion is the result of an exponential decay of the light within the cell as it leaks through the mirrors. The amount of that phase shift ( $\theta$ ) is a function of fixed instrument properties (i.e., cell length, mirror reflectivity, and modulation frequency) and of the presence of aerosols using the following relationship:

$$\cot(\theta) = \cot(\theta_0) + \frac{c}{2\pi f} \varepsilon$$

where  $\cot$  is the cotangent;  $c$  is the speed of light;  $f$  is the LED modulation frequency  $T$  and  $P$  are the sample temperature and pressure, respectively; and  $\varepsilon$  is the absolute extinction of light caused by the presence of aerosols. The term  $\cot(\theta_0)$  is obtained from a periodic baseline measurement (using particle-free air). Thus,

$$\varepsilon = [\cot(\theta) - \cot(\theta_0)] \frac{2\pi f}{c}$$

Note that this measurement provides an absolute value, requiring no calibration. All the other quantities in the above expression are known. However, note that this value is averaged over the effective spectral

output of the light reaching the detector, a function of the particular LED, band-pass filter, and mirror reflectivity.

The configuration of the monitor is quite simple and is shown in schematic form in Figure 3. The high-reflectivity mirrors are directly attached to the ends of the sample cell, forming the optical cavity that provides for the concentration measurement. The LED, optical filter, and appropriate focusing optics are attached directly to the sample cell. The light emanating from the cell is directed into a vacuum photodiode where the resultant signal is integrated, digitized, and sent to a PC-104 format computer where all subsequent data processing takes place. The sample cell contains both pressure and temperature sensors that allow for accurate correction because of transient changes in the air Rayleigh scattering. As noted later, the pressure reading also is used to check on the proper operation of the particle filter. The volumetric flow through the cell is limited by a critical orifice that is backed by a diaphragm pump. This same pump is also used to generate a particle-free purge flow that is routed to the mirrors to minimize contamination.

## 10.0 Setup and Operation of Instrument

### 10.1 Getting Started

1. First, unpack the shipping package that contains the monitor, power cord, null-modem data cable with attached serial USB converter, and the Netbook computer.
2. If not using the supplied Netbook, install the software on a Microsoft (MS) Windows-based computer.

Next, remove the Swagelock plugs on inlet and outlet ports on back panel before starting up the monitor.

3. To start, insert the power cord first into the monitor and then into a wall socket (100 to 240 VAC). Then turn on the instrument using the power switch on back panel. (A 2-A “slo-blow” fuse is contained in the power entry module of the monitor.)
4. The supplied Netbook is already configured to operate the data-acquisition software. If using the Netbook, the software will automatically log the data and store it in a folder on the desktop. It also provides all commands necessary to set up the monitor. Connect the supplied null-modem cable to the monitor using the DB-9 port on the back panel and to the Netbook computer using the USB/serial port converter. Start up the software and skip to instruction 5.

If using your own computer, load the data-acquisition software on the computer. Connect the supplied null-modem cable to the monitor using the DB-9 port on the back panel and to the host computer using either the serial port connector directly or a USB/Serial port converter. Start up the data-acquisition software. You will be asked to provide the correct serial port.

5. Almost instantly, data from the instrument should start appearing on the display panel. If no data appears, check the following:
  - Is the cable properly installed and is it a null-modem cable?
  - Is the serial port properly designated? (Most computers have multiple series and USB ports.)

- Does the com port designated in the monitor software match that being used for the serial port connection?
6. The monitor is now ready for its initial setup. The default mode of the monitor is as follows:

Sample Period	1 second
Onboard Time Stamp	Igor
Data Delimiter	Enabled
Autobaseline	15 s flush, 60 s zero periods

The sample period can be set to a number of integer values. We recommend that sample periods longer than 30 seconds not be used for accurate results. If desired, data can be averaged after measurements have been made.

There are two different time stamps that can be supplied. The data-acquisition software automatically provides a time stamp that mirrors that of the host computer. The monitor can also provide its own internal time stamp that appears in the data file stored on the host data-acquisition computer and also in the data file that is automatically stored onboard the monitor. The choice of format for the time stamp provided onboard is left to the user.

A number of choices for the data delimiter are provided including comma (default), space, and tab.

The monitor is always set to enable automated baseline control upon powering up. This can be disabled using the data-acquisition software, but will automatically revert to automatic baseline control once power has been turned off. If this is problematic, the default setting can be changed using the individual software commands listed in Section 11. This is not recommended.

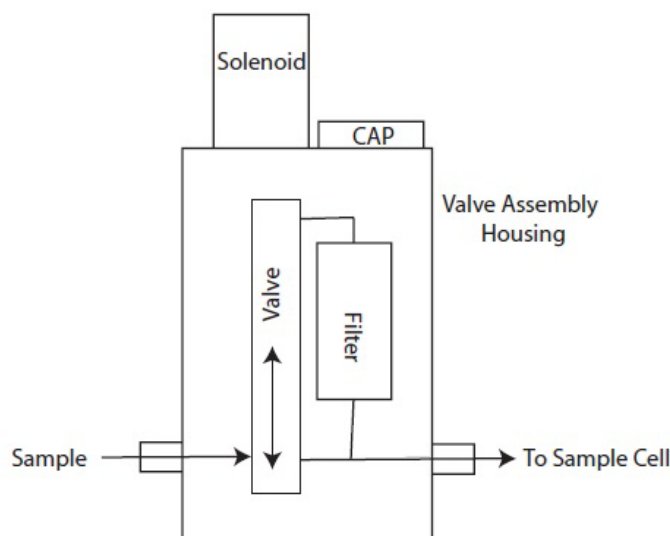
7. The baseline can be reset using a manual command if desired.

## 10.2 Shipping Monitors

When units are shipped into the field, run dry air through the monitor for several hours, and then plug inlet and outlet ports with Swagelock plugs. This helps to prevent mirror contamination during shipping.

## 10.3 Automated Baseline

The monitor is provided with an automated baseline capability. Under normal operation, the air/particle sample flows unimpeded into the measurement cell. Upon software command, a valve is powered up that causes the sample flow to proceed through a filter that removes all particles. At the end of the baseline measurement, the valve returns to its normal position, which bypasses the filter (see Figure 5).



**Figure 5.** Schematic of automated filter.

To use either the automated or manual baseline, the user must provide settings for proper operation of the valve using the supplied software. The two parameters that must be set are flush period and baseline period. The flush period refers to the amount of time required for the sample cell to be completely flushed of any unfiltered sample; it is recommended that this time be set to 10 to 15 seconds, which is approximately 7 to 8 cell flush lifetimes. The baseline period is the amount of time required to obtain an accurate baseline reading. The recommended setting for this period is 60 seconds. Longer baseline periods will not appreciably decrease, and might even increase, the noise associated with taking a baseline.

If automated baseline operation is required, the user also must set the start time for operation and the period between baseline measurements. The start time is used to synchronize the baseline measurements with other instruments and can be set to any minute past the hour—the start hour is irrelevant. The period between baseline measurements can be set to any desired length; however, we recommend that, if the period is less than 1 hour, it should be divisible into 60 (i.e., 10, 12, 15, 20, 30 minutes).

The user should be aware that the longer the baseline/flush period and the shorter the interval between baselines the lower the duty factor or actual measurement time. For low-particle-extinction environments ( $<10 \text{ Mm}^{-1}$ ), we recommend that, if the flush and baseline periods are set to those noted above, the interval between baselines should be set to every 15 or 30 minutes for best precision. In this case, the duty cycle will be 90% or greater. For higher extinction environments, the interval can be lengthened appreciably.

As a default condition, the instrument is delivered with the automated baseline enabled. This ensures that, if a power failure occurs during ambient monitoring, the instrument will continue to operate properly when the instrument powers up upon resumption of electrical service. In laboratory service, the user should consider disabling the automate baseline option using the data-acquisition software.



## 10.4 Notes

The monitor will accept a vacuum up to ~300 Torr below ambient. Operating the monitor at low pressure might lead to mirror contamination, which would degrade performance. This will occur when the vacuum is released. If a substantial vacuum is encountered, the user should attempt to release that vacuum very slowly to avoid disturbing particles that could contaminate the mirror.

For samples with high particle loadings (such as diesel engine exhaust), the user should check the pressure drop that occurs during a baseline measurement period. If the pressure drops by more than 20 Torr, the filter should be replaced.

The onboard computer that operates the monitor has a black battery case containing two AA batteries that provide power to the computer to retain the proper date and time. If this functionality is lost, the two batteries can be readily replaced by simply sliding off the top of the case located on the floor of the monitor enclosure and inserting new batteries. The data-acquisition program will automatically time-synchronize the monitor with the acquisition computer at ~12:00 a.m. each day.

If extinction levels above  $1000 \text{ Mm}^{-1}$  are regularly encountered, we recommend that the sample flow be diluted with particle-free air to avoid both frequent changing of the filter elements and possible mirror contamination.

## 11.0 Software

The following software commands are provided for those who want to control the monitor using their own software. Commands are entered as ASCII characters using the RS-232 connection. The command `<>` denotes a keystroke that is not a simple letter and `_` denotes a space. These commands can also be used using the supplied data-acquisition software.

### 11.1 General Information

All letter commands begin with `<esc>` and end with `<cr>`. (Note that `<cr>` here means `0x0D`; `<lf>` (`0x0A`), if present, is ignored.) Some commands take 1 or 2 integer arguments, and where used, they are separated from the command, and from each other, by at least one space. While taking data, except for `?`, these commands take effect at the conclusion of each observation. Thus, if data is being sampled at 10 seconds, it can take that long for the command to take effect.

### 11.2 Commands Active while Taking Data

The following commands are active while the instrument is taking data.

<i>Command</i>	<i>Argument</i>	<i>Function</i>
<code>&lt;esc&gt;</code>		Clear input buffer
<code>&lt;bs&gt;</code>		Delete Last Character
<code>?</code>		Ping; causes immediate return of ! character ( <code>0x21</code> ) in reply

B/b		Increase (Decrease) Pilot Light (front panel) 1 step
F/f		Activate (Deactivate) Valve
P	{_0...4}	Select Front Panel Reading 0=Extinction (Mm-1); 1=Pressure (Torr); 2=Temperature (K); 3=Signal (mV), 4=Flow (sccm)
Q		Leave Data-Acquisition Mode and enter Interpreter Mode
V/v		Turn on (off) pump
X		Reply with “%DATA”
Z		Start Baseline Measurement Mode
z		Reset Baseline to 0

## 11.3 Commands Active in Interpreter Mode

The following commands are active in Interpreter Mode and can be reached by typing {Esc}Q). Entered as {Esc}command \_ Argument1 \_Argument2 (if required), where \_ denotes a space.

<i>Command</i>	<i>Argument</i>	<i>Function</i>
<esc>		same as above
<bs>		“ “
?		“ “
A	none	start saving to default file
	x_filename	save to filename
B/b		increases/diminishes pilot light brightness
C		
D	mm/dd/yyyy	set date
E		return Setup Table
F/f		operate valves as in Run Time
G/g		accept/Reject revised settings, return to measurements
H/h		enable/disable Automatic Baselines
I		system status (integer divisors, mod and IF, actual integration time)
i		system status (autobaseline info, autosave info.)
J	sourcefilename_destinationfilename	transfers specified file to USB memory device – allows one to change file name for transfer NOTE: disk operating system (DOS) terminology sourcefilename C:\Data\Sourcefilename destination file name D:\Destinationfilename IF USB DEVICE NOT PRESENT, SYSTEM WILL REBOOT IN 15 SECONDS
K	sourcefilename	transfers specified file over RS-232 port at enhanced baud rate -when file transfer is completed, baud rate automatically return to 9600 baud
M	table number_value	modify setting (2nd Esc return clears this command)

P		provides true zero to panel meter
p	newvalue	sets zero for panel meter
Q/q		Accept/reject settings return to Run Time
R		reboot monitor (same as alt-ctl-del)
S	command string	sends DOS commands to computer (e.g., del, dir) screen information returned
s	command string	sends DOS commands to computer (e.g., del, dir) no information returned
T	hh:mm:ss	Set monitor clock (24 hour time required)
V/v		Turn on/off pump
X		Reply with "%USER"

## 12.0 Calibration

No Calibration Required. See Instrument/Masurement Theory (Section 9).

## 13.0 Maintenance

### 13.1 Particle Filter Replacement

The only regular maintenance required for the CAPS PM<sub>ex</sub> monitor is periodic replacement of two filters used in the sample line. The replacement rate depends on the level of particle loading to which the monitor is exposed. Under normal ambient conditions, annual replacement could suffice. However, under high particle loadings (several hundred Mm<sup>-1</sup>) found when sampling combustion systems, the period could be a number of hours.

#### 13.1.1 Inlet Flow Switching Valve

The first and most important replacement is an inline filter element that is contained in the stainless steel housing attached to the inlet inside the monitor. The pressure drop across this filter can be measured by using the software command to turn off the pump and “open” the valve; the difference in pressure with and without the pump is essentially due to the presence of the filter. The pressure drop across this filter when new is a few Torr. We recommend that it be replaced when the pressure drop in the filter reaches ~30 Torr.

To replace the filter element, unscrew the circular top of the filter enclosure, which is sealed with an O-ring. Pull out the filter element using a pair of tweezers and replace with a new element, making sure to properly seat it. Screw the flange back in, taking care not to snag the O-ring on a screw thread. A drop or two of methanol on the O-ring will help. New filter elements can be purchased directly from a supplier.

### 13.1.2 Outlet Filter

A disposable filter (transparent blue plastic) is used to remove all particulates before the sample flows through a critical orifice. This filter should be replaced periodically, especially when there is a noticeable color change or if the time response of the sensor increases. These parts are available from United Filtration Systems (<http://www.unitedfiltration.com>). Equivalent units are available from Parker Balston and other suppliers. Replacement part numbers are listed below:

- Disposable filter element: 12-32-60K
- Disposable plastic filter: DIF-BN60

## 13.2 Mirror Contamination

With proper operation of the monitor, the mirrors should never become substantially contaminated. However, this can occur because of a pressure upset or some other event. However, these monitors can operate within specification even if the mirrors become somewhat dirty. Contaminated mirrors cause a loss of signal and thus decrease in the sensitivity. However, this will not change the span value of the monitor. If the monitor noise increases substantially, the user should check the measured optical loss (listed on the display and in the data files). Upon shipping, this value should be between 400 and 550  $\text{Mm}^{-1}$ ; substantial loss of sensitivity probably would not be noticed until the loss approaches 1000  $\text{Mm}^{-1}$ .

The mirrors are easily cleaned. Their coatings are relatively robust and should be treated just as one would treat any multi-layer optical film. Initially, gloves can be employed when handling the mirrors to avoid contamination. However, with practice handling the mirrors, gloves will not be needed.

### 13.2.1 Required Supplies

1. High-quality lens tissue (Lens tissue from ThorLabs is recommended.)
2. Spectroscopic or high-performance liquid chromatography-grade methanol and acetone
3. Clean glass bottles with glass eyedroppers
4. Supply of particle-free air or Aeroduster
5. A means of holding the 1-inch mirrors in place while cleaning. A plastic or Teflon block with a shallow wedge or cylinder with appropriate shoulder will work well. Cavity Ring-Down (CRD) Optics sells inexpensive blocks suitable for this purpose (<http://www.crd-optics.com/crd-blocks.html>).

### 13.2.2 Removal of Cell from Monitor

1. Shut down monitor, remove power cord, and remove the monitor case cover using supplied Allen wrench (5/64 in.). Screws are 6-32 (3/8 in. long).
2. Disconnect the Swagelock plugs (i.e., two 1/2 inch tees for the sample and one 1/4 in. tee for the purge flow) attached to the sample cell.

3. Disconnect the wires exiting the back of the cell from the power block located on the cell mounting block.
4. Unscrew the four (8-32) screws holding the cell in its holder and remove top cover.
5. Carefully slide the cell from the plastic sleeve attaching it to the detector block without rotating detector cylinder.

### **13.2.3 Removal of Mirrors from Cell**

1. Starting at one end, unscrew the optics holder, making sure to keep cell upright.
2. Remove O-ring from mirror using tweezers. The O-ring might be attached to the inside of the optics holder. Do not misplace the O-ring as it is required for proper operation of monitor.
3. Turn cell upside down and allow mirror to drop from the cell. Some tapping of cell might be required.
4. Repeat at second end to remove second mirror.

### **13.2.4 Cleaning of Mirrors**

1. In a reasonably particle-free environment, place the mirror on holding block with curved side facing up. The curved side will have a circular mark near the mirror edge.
2. Put the near edge of a single lens paper sheet on the mirror and apply 1 to 2 drops of solvent to the paper. (Do not use too much solvent!! This is a beginner's mistake.)
3. When the mirror becomes fully wetted, draw the lens paper along mirror towards you. Repeat several times, first with acetone and then with methanol. With practice, one sheet of lens tissue can be used to make three different swipes. At least six swipes with acetone and six with methanol are recommended.
4. Use dry air or an Aeroduster to remove any excess solvent.

### **13.2.5 Replacement of Mirrors in Cell**

1. Place the curved side of the mirror into one end of the cell, making sure it is securely seated.
2. Replace O-ring on the back surface of the mirror.
3. Screw optics holders onto the cell. They should be screwed on firmly but not overtightened as the aluminum threads can be damaged.
4. Repeat with the other mirror.

### **13.2.6 Placing the Cell into the Monitor**

1. Slide the cell back into the plastic sleeve on the detector block. Be careful not to rotate the metal cylinder on the detector block.
2. Rotate gas fittings into position and attach Swagelock plugs. Remember to attach the purge flow connection.
3. Reinstall the clamping plate and screw it down. It should go metal to metal.

4. Reattach wires to power block taking care to match the color of the wires (i.e., black to black and red to red).
5. Reinstall the back cover with screws.
6. Turn on the monitor

### 13.2.7 Note on Mirror Cleaning

Learning to clean mirrors takes practice and patience. If you attempt to clean the mirrors and the results obtained are worse than before cleaning or if they do not improve, just keep trying. Make sure that no lint or other particulate contamination remains on the mirror surface. A single visible particle is sufficient to cause significant optical loss. Avoid performing this operation in an environment with high relative humidity as the evaporation of solvents can cause liquid water condensation on the mirrors.

## 13.3 Cell Maintenance

If the cell itself becomes contaminated, simply clean it in an ultrasonic cleaner using dishwashing detergent or other mild soap or detergent, followed by rinsing with water first and then with methanol. Allow to dry thoroughly. Do not attempt to clean the inside of the cell with a brush or other device. The surface on which the mirrors rest contains an easily damaged knife-edge that controls the alignment of the mirrors. If damaged, the cell must be replaced.

## 14.0 References

Massoli, P, P Kebebian, T Onasch, F Hills, and A Freedman. 2010. "Aerosol light extinction measurements by Cavity Attenuated Phase Shift Spectroscopy (CAPS): Laboratory validation and field deployment of a compact aerosol extinction monitor." *Aerosol Science and Technology* 44(6):428-435, doi:[10.1080/02786821003716599](https://doi.org/10.1080/02786821003716599).

## 15.0 Relevant Publications

*Aerodyne CAPS PM<sub>ex</sub> Monitor Manual*. Available at <http://www.wmo-gaw-wcc-aerosol-physics.org/files/CAPS-PMex-Monitor-Aerodyn-green.pdf>.

Kebebian, PL, WA Robinson, and A Freedman. 2007. "Optical extinction monitor using cw cavity enhanced detection." *Review of Scientific Instruments* 78:063102, doi:[10.1063/1.2744223](https://doi.org/10.1063/1.2744223).

Kebebian, PL, and A Freedman. 2007. "System and Method for Trace Species Detection using Cavity Attenuated Phase Shift Spectroscopy with an Incoherent Light Source." U.S. Patent No. 7301639 (issued November 27, 2007). Available at <http://www.patents.com/us-7301639.html>.



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