
Passive Cavity Aerosol Spectrometer Probe (PCASP-X2)

Ground-Based Instrument, Version 2

Operator Manual

DOC-0220, Rev I



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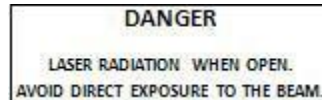
Laser Safety Sheet

The He-Ne laser resonant cavity in this instrument is powered by a high-voltage power supply. The laser power supply is capable of peak voltages of 10 KV with a low current (2 μ A) and continuous voltages of 1.9 KV at moderate currents (5 - 6 mA). STRICT OBSERVANCE OF THE FOLLOWING WARNING LABELS IS ADVISED.

This Label Displayed on Top of Laser Tube:



This Label Displayed on Laser Crystal Oscillator:



This Label Displayed Near Laser Anode:



This instrument is a Class 1 laser product. It has an internal He-Ne laser cavity which has no transmitted output power but develops a high resonant energy density (Q) inaccessible to the user. As a general precaution, one should avoid exposure to bright discharges or scattered laser radiation when servicing the optical system. The following label is affixed to the optical bench protective housing:



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Warranty

The seller warrants that the equipment supplied will be free from defects in material and workmanship for a period of one year from the confirmed date of purchase of the original buyer. Service procedures and repairs are warranted for 90 days. The equipment owner will pay for shipping to DMT, while DMT covers the return shipping expense.

Consumable components, such as tubing, filters, pump diaphragms, and Nafion humidifiers and dehumidifiers are not covered by this warranty.

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1.0 Introduction

DMT's Passive Cavity Aerosol Spectrometer Probe X2 (PCASP-X2) is an optical spectrometer that measures particles in the 0.10 - 10.0 μm range. The instrument operates on the principle that the amount of light scattered by a particle within a laser cavity is directly a function of the particle size and laser intensity. Particles produce pulses of radiant energy during transit through the laser beam. These light pulses are sensed by photodetectors and sized with a 40-channel digital processing system.

Communication to the data collection system is via RS-232 at a 38,400 baud rate.

Figure 1 shows the PCASP-X2.



Figure 1: The PCASP-X2

1.1 Specifications

Technique:	Light-scattering spectrometer, side-scattering
Measured particle range:	0.1 – 10 μm
Maximum Count Rate:	10,000/sec
Counting Efficiency:	50% at minimum threshold, increasing to 100% by the fourth size channel
Sampling frequency:	0.5 to 25 Hz, selectable ¹
Sample Flow Rate:	1 cc/sec
Sheath Flow Rate:	15 cc/sec
Sample System Flow Diameter:	0.200 mm
Total Beam Width:	0.80 mm
Effective Beam Width:	0.200 mm
Laser:	DMT LS-08, He-Ne (632.8 nm) tuned to TEM ₀₀ mode
	Laser Replacement: P/N METKIT-0013
	Laser Reference Voltage: <ul style="list-style-type: none"> • +4.5 V: full laser power • ≤ 3 V: cleaning and alignment is needed
Optics:	Collecting optics consisting of four matched magnifying mirrors; all optics are $\frac{1}{2}$ wave or better over required aperture
Data System Interface:	RS-232, 34800 baud rate
Power requirements:	90-250 VAC, 47-63 Hz, 75 W

1.2 Physical Specifications

Weight:	25 lbs (11.3 kg)
Dimensions:	19" rack-mount front panel Height: 7" (18 cm) Width: 17" (43.2 cm) Depth: 20" (51 cm)

¹ Versions of the Particle Analysis and Display System (PADS) earlier than 3.5 assume a sampling frequency of 1 sec / 1 Hz. As a result, this frequency is recommended if you are using PADS 2.8 or earlier.

1.3 Operating Limits

Temperature:	+5 to + 40 °C
Altitude:	20,000 ft (6.1 km)
Humidity:	0 - 90% RH (non-condensing)

2.0 Theory of Operation

As stated in section 1.0, the PCASP-X2 sizes particles by measuring the photon pulses generated by particles passing through the laser beam. To cover the large dynamic signal output with one range, the optical system consists of two photodetector modules and has four outputs with different gain ratios. The gain outputs are referred to as Gain 1, 2, 3 and 4, with Gain-1 having the highest gain to see the smallest particles. Once the Gain-1 voltage signal saturates, the processor automatically interrogates Gain-2. If Gain-2 saturates too, Gain-3 is monitored, and so on. An additional counter is used to count particles that are over-range of Gain-4. Each gain output is baseline-restored, digitized, and categorized into histogram form. A threshold table determined by the Mie scattering curve indicates particle sizes corresponding to different digitized outputs.

The PCASP-X2 laser is a He-Ne (632.8 nm) tube with a stainless steel envelope specially designed for the optical system. Laser alignment is achieved through an x-y screw adjustment on the external mirror/oscillator mount. The collection optics use a reflecting imaging system, as described in section 2.1. This high-efficiency light-gathering system collects about one-half the total light scattered even by the smallest particle. The optical system includes two pairs of mangin mirrors, with a pair on each side of the scatter-point. These mirrors collect and focus the scattered light onto photodiodes.

This instrument features a Class 1 laser. It has an internal HeNe laser cavity which has no transmitted out-power, but develops a high resonant energy density (Q) inaccessible to the user. The output Q is measured as a Laser Reference Voltage, using a photodiode and an appropriate amplifier. The laser reference photodiode provides a voltage signal proportional to the inter-cavity laser power. Changes in laser power and associated particle-scatter levels are applied to the sizing algorithm so that the entire system has an effective automatic gain control (AGC).

The probe airflow system prevents particles in the sample flow from contaminating critical optical components. This is accomplished by using a filtered sheath flow which

aerodynamically focuses the aerosol sample through a jet, directing the sample aerosol directly through the laser beam. A self-enclosed pump provides this sample and sheath flow.

2.1 Optical System Details

The PCASP-X2's laser tube is a 10 mW He-Ne source with high-reflectivity mirrors. The tube is tuned to multimode. The laser beam is approximately 1.2 mm in diameter on the sealed, curved mirror, and about 0.4 mm on the flat, external crystal mirror. The center of the sampling volume is about 55 mm from the adjustable mirror surface. At this point, the beam is about 0.8 mm in diameter.

Particles passing through the laser beam's sampling zone scatter energy into the optics. The amount of scattering for a given particle size is a function of both the laser mode and the exact radial transect through the beam. In order to provide for uniform illumination of particles, the sample volume is confined to the central 30% of the beam width. The method used to restrict particles to this region involves aerodynamically focusing the aerosol sample stream by a factor of two to three.

The scattered photons are relayed from the object plane by reflection and collected by the photodetector modules, as shown below. The transmitted laser output is less than 250 μ W and is not hazardous. The collecting optics include four highly reflective elements. The primary collecting optics are mangin mirrors, polished and coated (multilayered) to provided 95+ % reflectivity at 632.8 nm wavelength. The optics block has two openings for the sample jet inserts and a 3-mm hole to transmit the laser beam. (These openings are not visible in the figure below; they are located along the axis that is perpendicular to the plane that the diagram is on.) The mirrors produce a light bundle from particles illuminated at the beam's focus. At its center is a central stop to exclude light collection over its central-most aperture. This gives a range of collecting angles from 45° to 135° with approximately 2 pi steradians solid angle.

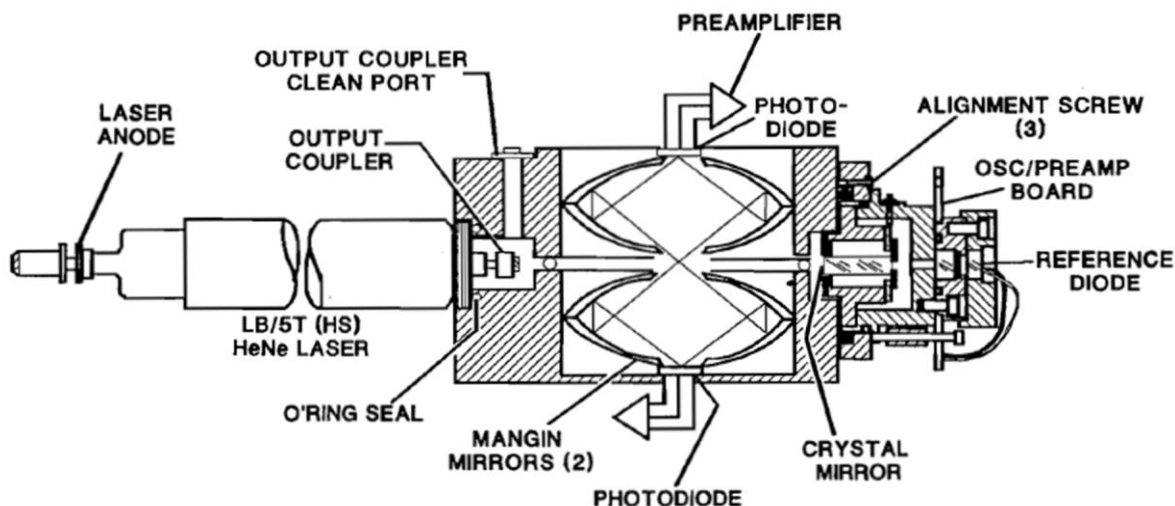


Figure 2: Optic System Diagram

The light transmitted out the sealed laser mirror is collected by the Laser Reference photodiode. This provides a measure of cavity Q, which is used for correcting loss of laser power.

There are 2 photodiodes: an Avalanche PhotoDiode (APD) for the 3 highest gain sections, and a silicone PIN detector for the lowest gain section. Each gain section is baseline-restored before proceeding to the analog-to-digital processor.

2.2 Airflow System Details

The PCASP-X2 airflow system is designed to protect critical optical surfaces from particles and condensable vapors within the sample stream. The system also confines the sample stream within the boundaries of the laser beam. This is accomplished by surrounding the sample stream with a filtered sheath airflow, as Figure 3 shows.

The sample inlet is designed to minimize aerosol losses. The inlet is on the top of the chassis and enters a direct sample path without turns or corners. The sample flow tapers from approximately 2 mm diameter, through reducing restrictions, to a minimum diameter of 200 μm ; during this process, the flow also accelerates in velocity to approximately 40 m/sec. The total transit time in the inlet section, which depends on the actual inlet configuration, is only a few hundredths of a second.

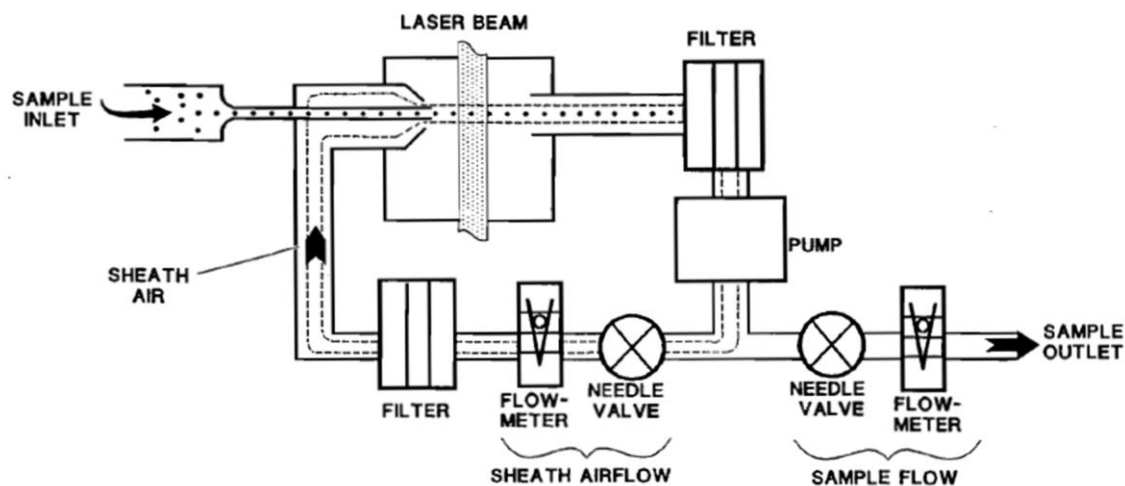


Figure 3: Airflow Diagram

Prior to entering the sample chamber, the filtered sheath airflow joins the sample flow in the sample inlet. A reducing restriction at the exit of the inlet reduces the total flow diameter by about one-half.

The sample stream flow must be set to nearly isokinetically match the sheath airflow when merging. The sample flow and sheath airflow settings specified on the system data sheet are the only settings which correctly match flow rates to avoid turbulence and mixing within the sample inlet. It is generally safe to reduce the sample flow with respect to sheath airflow rate; however, the sheath-to-sample airflow ratio should be maintained when increasing sample flow rate. Otherwise, the full flow diameter will become fully mixed, reducing the real sample volume and contaminating the optical sample cavity.

The sample stream can be aligned with the laser beam using adjustments on the inlet tube (refer to section 6.4). This adjustment allows for axial alignment with the focus of the mirrors as well as vertical alignment of the aerosol stream with the laser beam.

The sample and the sheath flow exit the optical sample chamber through the outlet jet on the bottom. The airflow is filtered with a 0.2 μm absolute filter ($<0.075 \mu\text{m}$ in air), passes through the diaphragm pump, and is then split into two separate airstreams. One flow segment passes through the sample flow meter before being exhausted. The closed system allows for the monitoring of the sample flow at the exhaust while maintaining a closed fluid loop of sheath airflow internally. The second flow segment is developed as the filtered sheath airflow. This flow is controlled by a needle valve. The air is filtered and measured with a mass flow meter before returning to the sample inlet as filtered sheath air.

When adjusting the sample or sheath airflow, you will notice that a slight lag exists before the new equilibrium is reached. This is particularly easy to see if the sample flow is turned

completely off as particle activity will take about a minute to die out. This is the result of internal readjustments in the pressure distribution throughout the airflow system. All airflows are measured by mass flow sensors with the data displayed by PADS in both volumetric and mass flows. The volumetric flow is calculated from the mass flow using the ambient pressure and temperature measured by the PCASP-X2. Note that the pressure and temperature sensors are located on the front edge of the instrument so that these measurements reflect ambient conditions. If the aerosol is from a remote location, the temperature and pressure of that location can either be manually entered into PADS or PADS can be configured to accept signals from external sensors. Contact DMT for assistance.

3.0 Electronics

The DMT electronics for the PCASP-X2 improve on an older design originally created by Particle Measuring Systems (PMS). The PMS design took advantage of the best technology available at the time, but DMT's updates have eliminated the need for a custom interface to handle the stream of individual particle data. The new electronics also increase the resolution of particle sizing by offering 40 bins.

The PCASP-X2 electronics consist of analog signal conditioning, signal digitizing, housekeeping processing and function control and conversion to a serial format. The main sections of the signal processing section are as follows:

- Signal detection: Photodetector modules supplying 4 gain sections
- Baseline restoration
- Analog-to-digital conversion of housekeeping parameters
- Signal processing sections:
 - Particle-pulse analog-to-digital (A/D) conversion
 - Threshold detection
 - Sample counting
 - Digital peak detection
 - Conversion to serial protocol
- Pump control, high voltage monitoring, laser reference detection, sample flow monitoring, sheath flow monitoring, temperature and ambient pressure

3.1 Photodetector Modules

There are 2 photodetector modules on the PCASP-X2. One module contains an Avalanche Photodetector (APD) to sense the smallest particles and supplies the highest 3 gain sections. The second detector module uses a standard silicone PIN photodetector to supply the low gain section to sense the largest particles.

The APD requires a high-voltage bias to operate. The Control Module supplies approximately 300 VDC to the APD. The APD is temperature sensitive, so there is a Thermo-Electric Cooler (TEC) device to maintain the APD at 20 °C. The APD temperature is sensed and reported to a housekeeping input. The high-voltage level is also monitored and reported to a housekeeping input for display on PADS.

The PIN detector module does not require high-voltage and is biased at -5 VDC. The lowest gain, Gain-4, identifies the largest particles.

3.2 Baseline Restoration Module

The Baseline Restoration circuits restore the baseline shifts that occur due to the AC coupling used in the photodetector circuits. Each baseline restoration circuit also includes provision for offset adjustment. This is required to properly bias the line-driver circuit to +250 mV. Any adjustments to the trim pots on this board will affect the probe's calibration. Each gain section has an associated test-point for monitoring with an oscilloscope; see the instrument schematics for details. The conditioned signals are then passed via shielded wire from the photodetector modules to the Digital Board (under the Control Module).

3.3 A/D Conversion of Signal Pulses

On the Digital Board, there are four Analog-to-Digital converters, each being a free-running 12-bit component sampling at 20 MHz. This converter simply samples and holds or “latches” the incoming signal voltage from the photodetector every 50 ns. The value is latched so that the data bus is driven with the value for the next call from the FPGA. The analog input pulse can be monitored at the appropriate test points. The proper gain and offset is adjusted on the Baseline Restoration Module. See schematics for details.

3.4 Threshold Detection

The threshold detector is a section of the FPGA. Each time the master signal (Gain-1) A/D converter samples, the threshold detector firmware tests the value latched to see if it is larger than the threshold value set in the configuration window. If the latched value is less than the threshold value, no action is taken and the threshold detector simply waits for the next latched value. If the latched value is greater than the threshold value, indicating the beginning of a particle pulse, the threshold detector sends a flag to the pulse height analysis circuit to begin looking for the peak.

3.5 Peak Detection

The peak detector begins looking for the maximum value of the signal pulse as soon as the digital threshold level is surpassed. As soon as this flag goes true, the peak detector latches the current value on the data bus. On each sample clock cycle the peak detector checks the current sample versus its latched value. If the current value is greater than the latched value, the latched value is replaced with the current value. If the current value is less than the latched value, the latched value is not changed. Once the pulse height has gone back below the threshold level, a particle event is complete. The maximum pulse peak value obtained as the particle passed through the beam is then subjected to the threshold table sizing routine.

The highest-gain signal, Gain-1, acts as the master, while the remaining gains are processed in a completely synchronous fashion. Once the Gain-1 voltage signal saturates, the processor automatically interrogates Gain-2. If Gain-2 saturates too, Gain-3 is monitored, and so on. An additional counter is used to count particles that are over-range of Gain-4.

3.6 Pulse Height Analysis

Once a particle peak is found, and the gain section identified, the FPGA compares the peak value during the particle event to a look-up table. This table is a digital threshold table that associates the digital count to a particle size. The threshold tables can be user-adjusted, but the supplied table is used during factory calibration and should be retained. These tables are found in the PADS directory and called by the PCASP-X2 configuration settings.

The PHA routine also monitors the Laser Reference Voltage. If the laser power is high, reporting 4.5 V, no action is taken. If the LRV value is less than 4.5 V, the peak value is multiplied by an appropriate value to compensate for low laser power. The corrected peak value is applied to the digital threshold table.

3.7 Sample Counter Section

The counter section is used to determine particle transit times. The electronics monitor the number of 20 MHz clock samples that occur while the A/D value stays above the threshold. The particle transit time can be calculated by multiplying this sample count by 50 ns. Average transit time is typically 30 - 40 μ s. A slower transit time may indicate a leak in the airflow system.

3.8 Digital Board and Control Module

The Digital Board consists of Field Programmable Gate Array (FPGA), a ROM memory, a watchdog timer, a universal asynchronous receiver/transmitter (UART), and a serial buffer chip. The watchdog timer will reset the FPGA if the program fails to boot within 1.6 seconds. The UART is the main serial communications chip for passing information to the data system and receiving control commands back. There is a digital output to control a relay which activates the system air pump.

This module contains 5 jumpers that can be used to select RS-232 or RS-422 serial protocol. RS-232 (standard) is a 3-wire system rated to 15 meters. RS-422 is a 4-wire differential protocol and rated to 350 meters. See the schematics to determine jumper locations and serial wiring changes required to accommodate RS-422.

3.9 Analog Multiplexer and Housekeeping Circuit

The Digital Board also contains an analog multiplexer circuit used to monitor various housekeeping voltages in the probe. The housekeeping analog-to-digital converter has a 12-bit output and 5 V input voltage range. Table 1 provides the full conversion equations to calculate engineering units from analog-digital counts (ad) for the housekeeping channels.

Channel	Name	Scale
1	APD bias voltage	-0.1221 V/ADC count
2	APD temperature	$T(\text{degC}) = (1 / ((1 / 3900) * \ln((4096 / \text{adc count} - 1) + (1 / 298)))) - 273$
3	Block temperature	$T(\text{degC}) = (1 / ((1 / 3900) * \ln((4096 / \text{adc count} - 1) + (1 / 298)))) - 273$
4	APD 1 st stage monitor	$T(\text{degC}) = (1 / ((1 / 3900) * \ln((4096 / \text{adc count} - 1) + (1 / 298)))) - 273$
5	Laser reference	0.001221 V/ADC count
6	Sample flow	$\text{cc/s} = 0.0353 - (0.1316 * V) + (0.1536 * V^2)$ **
7	Sheath flow	$\text{cc/s} = 2.736 - (3.548 * V) + (1.213 * V^2)$ **
8	Ambient pressure	Individually calibrated

Table 1: PCASP-X2 Conversion Equations for Housekeeping Channels

** $V = 0.001221 * \text{ADC count}$

The calibration coefficients are available through the PADS configuration window. The flow sensors are individually calibrated and appropriate scale adjustments are pre-loaded in PADS.

3.10 Power and Signal Distribution Board

This board is accessible when the chassis cover is removed. The conditioning and control circuits are as follows:

- Static pressure in the optical block
- APD's temperature control (TEC) and temperature monitor
- APD high-voltage source and monitor
- Laser reference voltage signal conditioner
- Crystal oscillator amplifier
- Sample and sheath mass flow meter power and signal in
- Air pump on/off control circuit
- Optical block temperature signal conditioner and monitor
- Power and signal connectors

One circuit is provided for monitoring the Laser Reference Photodetector. After a new laser is installed, the Laser Reference Voltage trim pot should be adjusted to read about 9.5 volts at the test point after a 30-minute warm-up period. After initial setting, do not adjust the trim pot, as this would give a false indication of optical cleanliness and alignment. Changes in the Laser Reference Voltage, which indicate a change in the laser intensity, are used in the signal processing routine by multiplying the digitized peak value by the ratio 4.5 volts to the measured Laser Reference Voltage. This accomplishes automatic gain control. Refer to schematic manual for details.

4.0 Operating Instructions

4.1 Application of Power

Caution: To prevent damage to the instrument, check for proper matching of the line and instrument voltage. Voltage is 90-250 V, 47-63 Hz. Confirm the power setting on Serial Number tag.

The probe power switch can be turned on once the unit has been connected to an appropriate power source and a suitable data acquisition system. Unless otherwise specified, the

instrument will be shipped from the factory with the power transformer set for the standard line voltage in the country of destination.

4.2 Connecting to Data System

The PCASP-X2 is supplied with a laptop computer with the DMT software PADS installed and an icon available on the desktop. Use the supplied RS-232 cable to connect the instrument serial connection to the laptop's serial input.

If the instrument needs to be more than 20 meters from the laptop, the serial protocol can be changed to RS-422 by moving 5 jumpers on the FPGA signal processing board. Refer to schematics for details. RS-232 is a 3-wire system, while RS-422 is a differential 4-wire system.

Click on the desktop's PADS icon to start up the software (Figure 4). At this time, you can begin sampling, which will automatically turn on the internal pump and pull particles through the optical block. See the *PADS Manual (DOC-0116)* and the *PADS Manual for the PCASP-X2 Module (DOC-0207)* for specific details on instrument control, data file recording, and real-time displays.

5.0 Particle Analysis and Display System (PADS)

PADS is a Windows-based, LabVIEW software package that is the default interface system for the PCASP-X2. It offers attractive display and analysis features, and data acquired with PADS can be stored to a file for later analysis. The program also stores all configuration information as a file header, so users can easily determine the system settings at the time of data acquisition. Examples of data that PADS can record and display include the following:

- Particle concentrations and size distributions (the latter in tabular and histogram form)
- Common particle statistics such as median volume diameter and effective diameter
- Housekeeping and auxiliary variables
- Time traces of user-selectable parameters

Figure 4 shows PADS displaying data acquired with the PCASP-X2.



Figure 4: PADS Displaying PCASP-X2 Data

PADS is also used to set the operating parameters such as the channel-size thresholds, sampling frequency, and pressure and temperature sources. For more information on the PADS module for the PCASP-X2, see the *PADS Manual's PCASP-X2 Module (DOC-0207)*.

PADS can easily be replaced by a program of the user's choice. The probe setup, polling string, and reply data format are described in a separate document. Contact DMT if this information is required.

6.0 Cleaning, Maintenance and Troubleshooting

The table below summarizes the maintenance tasks associated with the PCASP-X2. Instructions on how to perform these tasks are given in the following sections.

Task	Frequency to Perform Task under Normal Conditions
Zero count	Weekly*
Cleaning laser output coupler and crystal mirror	When Laser Reference Voltage drops (see section 6.2); this voltage should be monitored weekly*
Cleaning collection optics	Only when known exposure to a contaminant has occurred
Cleaning inlet jet	Only when known exposure to a contaminant has occurred

* This frequency will increase under severe conditions, such as when the instrument is operating in a sandy area, an area with high concentration of industrial soot, or an area within five miles of the ocean.

Note that it is a good procedure to recheck the inlet jet alignment after any optics cleaning or laser alignment; see section 6.4.

6.1 Zero-Count Check

A zero-count check can be used to test for leaks, power line transients, RS-232 noise or other RF or EMI-induced noise that result in erroneous particle counts.

If a 200- μm absolute filter is placed in series with the sample inlet flow tube, the resulting count should be close to zero. Normal count rates should be less than 2 counts per minute when using such a filter. If possible, it is preferred to perform this test with the instrument in normal operation. This will check for externally induced counts that result from the factors listed above. Although such externally induced counts are rare, a zero-count test is the only way to determine they are not a problem. Allow sufficient time for purging of particulates from the inlet tubing.

As an alternate check, or if no 200- μm absolute filter is available, check for inlet line leaks by plugging the inlet flow tube with a tapered insert. Within a few seconds, the count rate should drop to near zero. A similar check for airflow leaks elsewhere in the system can be made by closing off the Sample Airflow Valve on the front panel. After a minute or two, the count rate should drop to near zero.

Too high of a zero count will normally be the result of a negative pressure leak in the purge inlet plumbing or sample block. This will be the case as particles will be introduced into the system through the leak opening. Positive pressure leaks downstream of the pump will not always be evident with the filter check.

These leaks can normally be found by pressurizing the purge plumbing and sample block through the inlet (15-20 pounds air pressure) and checking fittings and mechanical connections with a leak detector solution consisting of soap and water (Snoop). The sample flowmeter must be plugged during this test. If no leaks show up, it may be necessary to remove and submerge the purge plumbing and the sample block for increased sensitivity. This, however, should be considered a last resort.

When leaks are found in mechanical component assemblies, disassembly, inspection, cleaning, greasing (with silicon stopcock grease), and new o-rings may be required. Pipefitting leaks can normally be repaired by tightening alone or by disassembling and replacing existing teflon tape and reassembling.

Line transients (RF or EMI-induced noise counts) are generally more subtle and unique to a certain installation. If this is the case, factory assistance should be consulted when such counts are suspected.

6.2 Laser Power Considerations

Maximum laser power is indicated by a **Laser Reference Voltage** of +4.5 V. Operation is acceptable when the Laser Reference value is 3.0 V or higher. In the event that the laser reference value indicates a low laser Resonant Q, steps should be taken to raise the power level. Low power generally occurs because of either misalignment or contamination on critical laser optical surfaces. The former may be caused by rough handling during shipment, while contamination generally occurs only after use. If the laser is not ionizing at all, troubleshooting of the laser tube and related power supply must be done first.

There are only two critical surfaces that require cleaning. These are the external crystal mirror and laser output coupler. If laser reference voltage drops, first clean the laser output coupler. If power is still not satisfactory, proceed to the crystal mirror surface. If neither of these two surfaces requires cleaning, there is absolutely no reason to clean any other optics surface. They are sensitive to less than 1% loss and are good indicators of relative sample cavity cleanliness.

6.2.1 Cleaning the Laser Output Coupler

To clean the laser output coupler, follow the steps below.

- 1.) Turn off power.
- 2.) Locate the laser output coupler. The coupler is at the end of the laser, inside the optics block.
- 3.) Remove the cleaning port plug. The plug is held in place with two 4-40 socket head screws. These can be unscrewed with a 3/32 Allen wrench.
- 4.) Using Q-tips and optical-quality (spectrophotometric-grade) acetone, clean the window. Clean only the center, which is bonded to the center of the laser capillary tube. Do not saturate the Q-Tip or lens tissue with acetone. Use Q-Tips only once, using a single swipe.
- 5.) Turn power back on.
- 6.) Check the Laser Reference Voltage level.
- 7.) If the level is satisfactory (>3.0 V), no further cleaning is necessary. If the reference voltage is the same, has decreased, or is below 3.0 volts, turn the power back off and reclean.
- 8.) Repeat this procedure until the reference voltage stays at the same level for two or three cleanings. This indicates the coupler is clean.
- 9.) If the reference voltage is still low, alignment or cleaning of the external mirror is necessary (refer to next sections).

- 10.) Replace the cleaning port plug when finished.

6.2.2 Cleaning and Alignment of the Crystal Mirror

When properly adjusted, the crystal mirror provides maximum laser reference voltage. The laser reference voltage may be monitored during the alignment procedure either by watching the value displayed on the PADS window, or attaching a volt meter to the appropriate test point. Using the volt meter gives faster response and feedback to the technician.

To clean and align the crystal mirror, follow these steps:

- 1.) Loosen and lower the chassis front panel. This allows access to the crystal assembly attachment screws.
- 2.) Remove the crystal oscillator assembly mount as a unit, including the Reference Photodiode housing. The crystal assembly is attached by a flange with three #3-56 screws (inner circle), mounted to the X-Y adjusting ring, which is mounted to the optical block with three #4-40 screws (outer ring). A partially compressed O-ring between the X-Y adjusting ring and the optical bench allows the angle of the crystal mirror to be adjusted by turning the three screws. If these #4-40 screws are loosened, the optical alignment will be lost. Do not turn these outer screws until the crystal mirror surface is cleaned and the assembly repositioned.
- 3.) Using Q Tips and optical-quality (spectrophotometric-grade) acetone, clean the mirror. Use one swipe only and be very gentle. Swipe from the center out; do not use a circular cleaning motion. Make only a single swipe across the step, and do not swipe up the step.
- 4.) Align the red dots when reinstalling to ensure a return to the original configuration. The crystal and mirrored surface are fragile, so be very gentle.
- 5.) To maximize laser reference voltage, slightly adjust each of the 4-40 screws (outer ring). Be sure each screw is snug but not over-tightened, as an air leak can occur in either of these cases. The position of the crystal mirror is highly sensitive to changes in the positions of the adjusting screws.

Note: The reference voltage varies as the laser optical bench warms up. Therefore, when realigning the crystal mirror, do not turn the unit off for extended lengths of time. If it is necessary to do so, allow the bench to warm up again before proceeding.

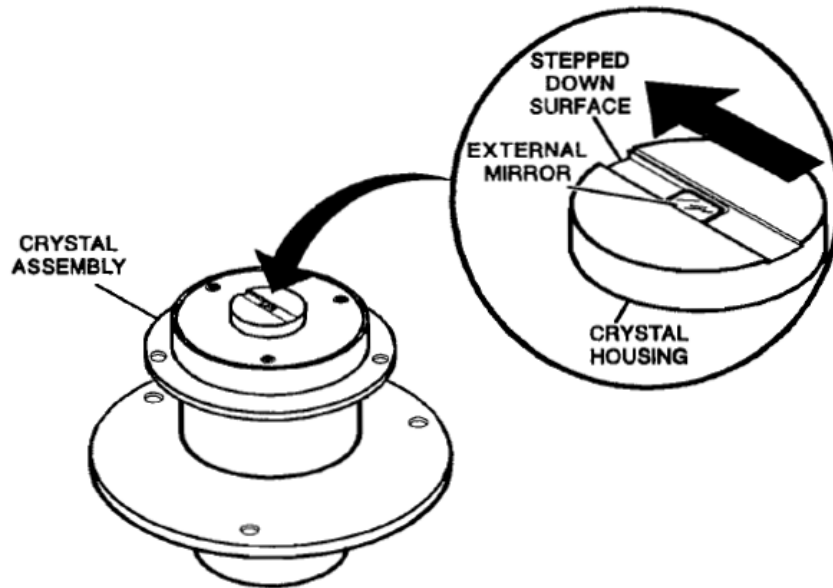


Figure 5: Crystal Mirror

6.3 Cleaning of Collection Optics

The other optical surfaces comprising the collecting optics need not be cleaned unless they have experienced known exposure. Routine cleaning is not normally recommended. Any suitable solvent, soap and water are quite satisfactory.

- 1.) To facilitate the required disassembly, remove all electrical connections and the four screws holding the laser optics bench in the unit. This allows easier access to all components.
- 2.) Remove the complete Laser Optical Bench from the cabinet.
- 3.) Remove both detector housings so that the two mangin mirror sets on each side are accessible. Note their orientations carefully, as reassembly is the reverse procedure and must be accomplished with extreme care.
- 4.) While the mirrors are removed, inspect for fibers or other contamination inside the sample block. Also, check to see that no fibers are in the laser beam apertures.
- 5.) Reassemble very carefully and reinstall the laser optical bench in the cabinet.
- 6.) If the laser reference voltage is still low after cleaning the laser output coupler and the external crystal mirror, and if no fibers are found by cleaning the collecting optics, contact a factory-trained technician for assistance.

6.4 Inlet Jet Alignment

To align the inlet jet and particle sample stream, do the following:

- 1.) Loosen the locking screws that secure the inlet jet. It is only necessary to loosen the two large set screws located on the inner bolt circle; see Figure 6.
- 2.) Make sure the red dots on the inlet jet are in the proper position. This helps ensure rotational alignment.
- 3.) Use the instrument to sample mono-dispersed PSLs aerosols, and then adjust the sideways-adjustment screw (one of the two #10-80 adjustment screws) to maximize the peak of the spectral data as read out on the histogram display. The use of an oscilloscope to view the signal pulse is also recommended. The maximum signal is attained when the particle stream is at the focal point of the mangin mirrors and at the center of the laser beam.
- 4.) If desired, align the axial-adjustment screw as well. However, note that sideways adjustment is much more sensitive than axial adjustment. (Sideways adjustment aligns the particle stream with the center of the laser beam, while axial adjustment aligns the focal point of the collecting optics.) As a result, it is only occasionally necessary to check the axial adjustment.
- 5.) When finished, secure the inlet jet locking screws to preserve alignment.

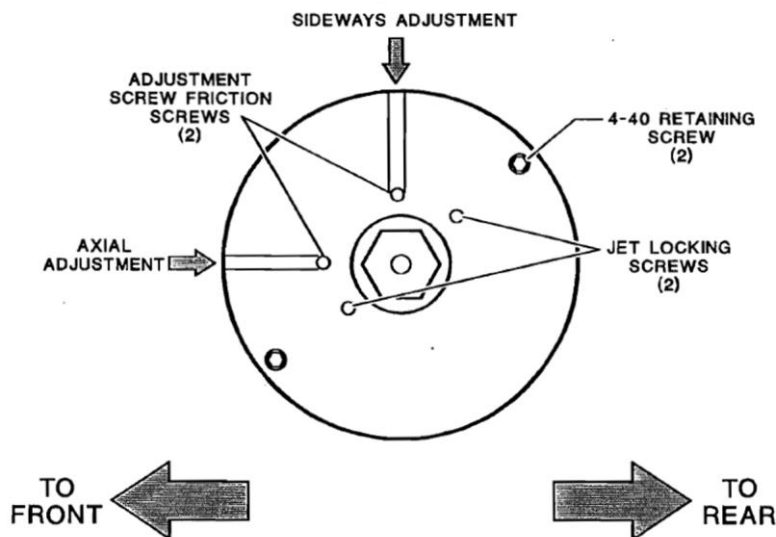


Figure 6: PCASP-X2 Inlet Jet Mount

6.5 Removing Fibers from the Inlet Jet

If you are getting unexplained particle counts or if the reference voltage is still low after cleaning, it is possible that a fiber may be lodged in the sample cavity or inlet jet. To quickly check for fibers, use the following procedure.

Caution: When removing the sample inlet jet, be careful not to bend or damage the tip of the jet. Doing so may require the PCASP-X2 to be recalibrated.

1. Turn off the PCASP-X2.
2. Remove the two 4-40 socket-head screws located on the top of the PCASP-X2 on either side of the sample inlet (Figure 6) that secure the sample inlet jet. Carefully pull the jet out of the sample block.
3. Use a magnifying lens to look for fibers stuck to the jet tip. Use tweezers to remove any visible fibers.
4. Turn the PCASP-X2 on and the pump off.
5. Look into the sample cavity through the opening where the jet was. Fibers appear very bright in the laser beam. If you see a disruption of the beam, TURN THE LASER OFF and only then remove any visible fibers with tweezers.
6. Replace the jet and screws, making sure that orientation is correct.

7.0 Determining Particle Size and Concentration

7.1 Particle Size

The particle size threshold tables are derived from the system dynamic range and associated Mie scattering curve data. A sample table is shown. Note that this is an example only; actual values may vary.

Max Threshold Count Per Channel					Max Particle Size Per Channel				
Threshold	10	20	30	40	MaxSize	10	20	30	40
1	277	6530	8919	9383	1	0.12	0.35	0.85	2
2	700	6762	9216	9433	2	0.14	0.4	0.9	2.3
3	1548	6958	9283	9500	3	0.16	0.45	0.95	2.6
4	3072	7219	9290	9568	4	0.18	0.5	1	3
5	3482	7427	9296	9648	5	0.2	0.55	1.1	3.5
6	3740	7686	9299	9800	6	0.22	0.6	1.2	4
7	4130	7903	9321	10104	7	0.24	0.65	1.3	5
8	4639	8144	9326	10638	8	0.26	0.7	1.4	6.5
9	5329	8400	9338	11981	9	0.28	0.75	1.6	8
10	6144	8605	9357	12288	10	0.3	0.8	1.8	10

Figure 7: Particle Size Threshold Table

In PADS, these data are stored in a comma-delimited file in the PADS directory.

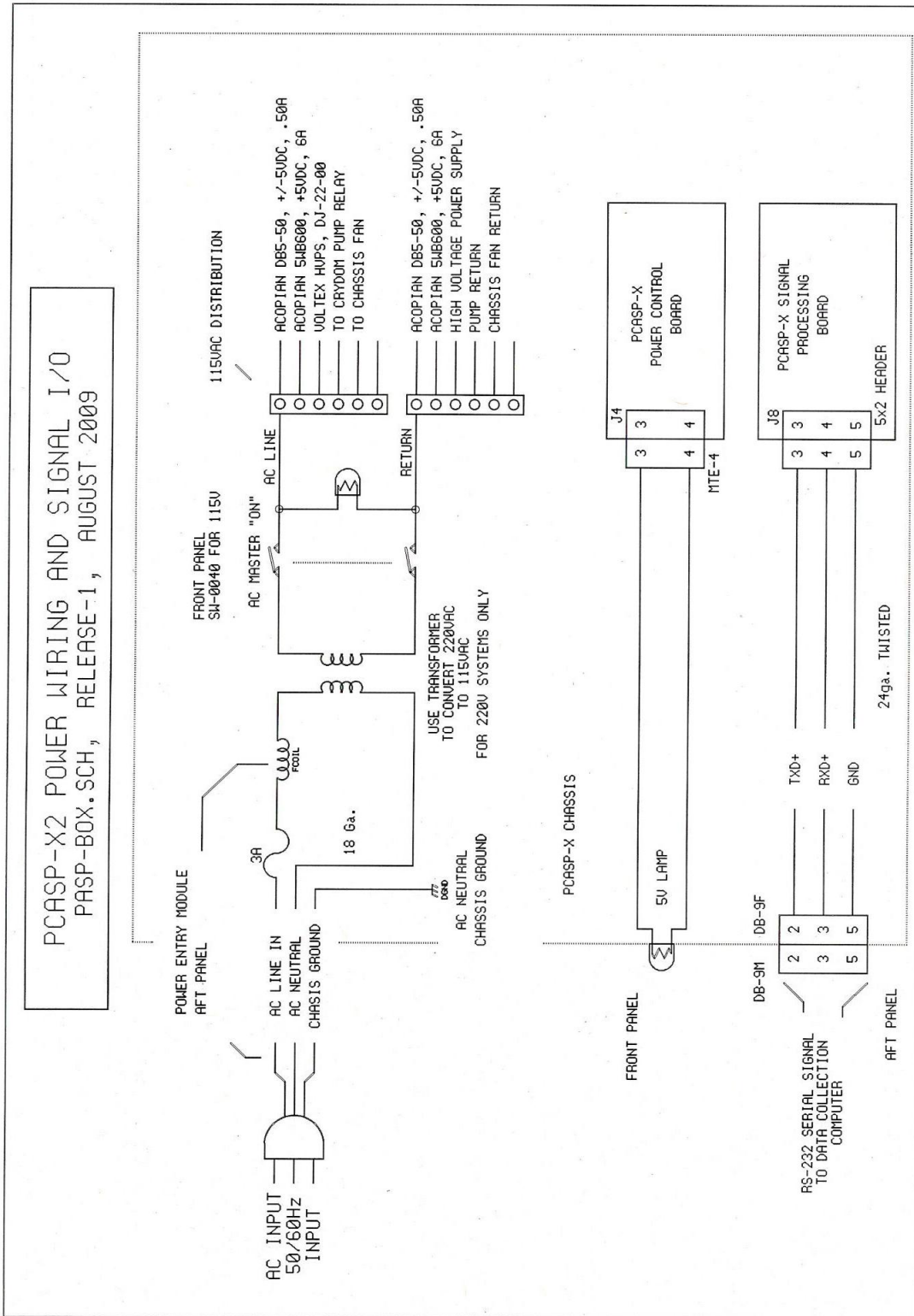
7.2 Particle Concentration

The sample “view volume” is defined in this system as the intersection of the laser beam with the sample flow and is approximately $4 \times 10 \text{ cm}^3$.

Particle concentrations can be determined by determining the particles counted in a given length of time and dividing by the volume sampled during one second. The volume sampled is determined from the sample valve setting and is normally set at 1.0 to 5.0 cc/sec, corrected for altitude.

As the instrument was not designed to sample large particles, it cannot quantize information on oversize particles. However, a total count of oversize particles is available to the user if the instrument’s data system has the ability to store information on non-sized valid strobe events. The detection of oversize particles ($10.0 \mu\text{m}$) can be of significance to aerosol studies.

Appendix A: Chassis Wiring Diagram



Appendix B: Communications between the PC and the PCASP-X2

Communications Parameters

Any computer capable of communications over an RS-232 or RS-422 port should be capable of communicating with the PCASP-X2. The port parameters for communications should be set as follows:

	PCASP-X2
Baud Rate	38.4K
Data format	8-N-1: <ul style="list-style-type: none"> • 8-bit data bytes • No parity bit • One stop bit

Table 2: PC-PCASP-X2 Communications Parameters

Since binary data are sent across the interface, it is possible that some systems will react to the non-ASCII characters that are sent as control characters. It is recommended that all communications with the PCASP-X2 be programmed at a low level to avoid this problem.

The PCASP-X2 and host computer send data to each other in data packets. Within these packets, data are stored in different types of structures. More information about these structures appears in Table 3.

Structure	Abbreviation	Bits	Order of Bytes				
Unsigned Character	U8	8	N/A (only one byte)				
Unsigned Integer	U16	16	<table border="1"> <tr> <td>Byte 0</td> <td>Byte 1</td> </tr> <tr> <td>Bits 7:0</td> <td>Bits 15:8</td> </tr> </table>	Byte 0	Byte 1	Bits 7:0	Bits 15:8
Byte 0	Byte 1						
Bits 7:0	Bits 15:8						

Table 3: Data Structures Used in PCASP-X2-Host Computer Communications

Initiating Communications

The host computer initiates all communications with the PCASP-X2. Since the PCASP-X2 only responds with data after it has received a request for data, all of the timing for data acquisition needs to be performed in the host processor. To increase the rate data are relayed from the PCASP-X2, the host only needs to increase the rate at which it makes requests for data. After completing a data request, the PCASP-X2 clears all of its summation registers and starts taking a new set of data.

Note that the first data packet of particle information the PCASP-X2 sends is relatively meaningless. This is because the time interval between instrument start-up and the first data packet being sent likely differs from the standard sampling interval.

Communications Commands

There are two commands that the PCASP-X2/SPP-100 responds to:

- **Setup Data Acquisition Parameters Command** (command = 1)
- **Send Data Command** (command = 2)

These commands and the PCASP-X2's responses are discussed in detail in the following sections.

SETUP DATA Command

This command allows the host computer to transmit data acquisition parameters to the PCASP-X2. The PCASP-X2 automatically comes up with default parameters at power up, but to ensure these are correct, the data system should set up the parameters each time the instrument is used. These parameters will remain in effect until power is cycled or a new Setup command is sent.

The following table displays the packet the host computer sends to the PCASP-X2 probe to set up the data acquisition parameters. Full definitions of these parameters appear after the table.

The PCASP-X2 clock runs at 40 MHz and uses clock cycles for all timing. Hence the native unit of time in the PCASP-X2 is 25 nsec. All binary timing communications to and from the PCASP-X2 are in this native time. To convert microseconds to native time, multiply by 40. PADS uses microseconds and does this conversion for the user.

Note that parameters marked “unused” must still have data sent in them in order for the PCASP-X2 to read the data packet correctly. The instrument will ignore unused data, however.

Byte	Parameter Description	Data Type ²	Ex. Hex Value	Parameter Setting as Indicated by Hex Value in Previous Column (after bytes have been swapped, if necessary)
0	Start Byte	U8	1B	1B h = ASCII 27 = Esc Character
1	Command Number	U8	01	Setup Command
2	ADC Threshold	U16	14	0014 h = 20 counts
3			00	
4	Minimum Peak width 25 nS increments	U16	8C	008C h = 140 25-nsec counts
5			00	
6	Maximum Peak width 25 nS increments	U16	70	1770 h = 6000 25-nsec counts
7			17	
8	Bin Count	U8	28	28 h = 40 bins
9	Pump Power	U8	01	00 = off, 01 = on
10	Hysteresis	U8	1E	1E h = 30 counts
11	End Particle in 25 ns increments	U16	02	0002 h = 2
12			00	
13	Bin 1 Upper Boundary	U16	64	0064 h = 100 counts
14			00	
15	Bin 2 Upper Boundary	U16	C8	00C8 h = 200 counts
16			00	
17	Bin 3 Upper Boundary	U16	2C	012C h = 300 counts
18			01	
...Bins 4 – 39 ...				
91	Bin 40 Upper Boundary	U16	00	3000h = 12288 counts
92			30	
93	Checksum	U16	6B	0C6B h = 3179
94			0C	

Table 4: Setup Command – Data Packet

² See “Communications Parameters” section for explanations of data types.

Definition of the Declared Parameters

The possible values for the parameters the host computer sends to the PCASP-X2 are explained below. *Note:* Default values for parameters given below may vary widely from instrument to instrument.

- **Start Byte** ASCII 27, HEX = 1B, the escape character.
- **Command Number** The command number: 01h = setup data; 02h = send data.
- **ADC Threshold** The minimum ADC trigger level (see Figure 8), which can be any hex number between 0001h and FFF0 hex. This parameter sets a digital amplitude or pulse-height threshold, and it can be used to raise the bottom end of bin #1 to reduce noise. The PCASP-X2's default ADC Threshold is 40.
- **Minimum Peak Width** A filter that rejects signals that are electronic noise or produced by particles that pass through the edges of the laser beam (see Figure 8). An aerodynamic nozzle that uses clean sheath air to focus the aerosol stream is used to direct the aerosols through the center of the laser; however, there will be the occasional particle that passes near the edge of the laser where the intensity is lower. Minimum peak width is given clock counts of 25 nsec, and signals shorter than the specified value will be rejected. The default value is 140 clock counts ($140 * 25 \text{ nsec} = 3500 \text{ nsec} = 3.5 \text{ usec}$).
- **Maximum Peak Width** A filter that removes signals that are either noise or produced by particles that are recirculating in the sample cavity (see Figure 8). The instrument's pump maintains a constant flow velocity and the length of time a particle is in the beam should also be approximately constant. The transit time of each particle is measured, and if it exceeds the peak max width it will be rejected. Excessively long transit times can be caused by coincidence, i.e. multiple particles in the beam at the same time, or by particles in the sample cavity that recirculate and pass through the beam at a lower velocity than the main airflow. Maximum peak width is given clock counts of 25 nsec, and signals longer than the specified value will be rejected. The default value is 6000 clock counts ($6000 * 25 \text{ nsec} = 150000 \text{ nsec} = 150 \text{ usec}$).
- **Bin Count** The number of size bins for the histogram. Acceptable values are 10 (0Ah), 20 (14h), 30 (1Eh), or 40 (28h). The default for the PCASP-X2 is 40 channels (28h). Contact DMT first if using a different value.
- **Pump Power** An instruction to turn on or off the pump. 0 = off, 1 = on.
- **Hysteresis** A parameter designed to filter noise. The PCASP-X2 identifies the beginning of a particle event when the signal exceeds a threshold, and the end of the event when the signal falls below [threshold – hysteresis] (see Figure 8). The default value is 30 counts.

- End Particle in 25 ns increments

A parameter designed to filter noise. It acts similarly to hysteresis but applies to time, and it prevents double-counting of peaks. After the end of a peak, **End Particle** time must elapse before another particle event is recognized (see Figure 8). This parameter is given in counts of 25 nsec, and the default value is 80 ($80 * 25 \text{ nsec} = 2000 \text{ nsec} = 2 \text{ usec}$).
- Upper Bin Boundaries

The peak count thresholds for the bins/channels. These values set the UPPER threshold of each size bin. The first value here will be the upper threshold of Bin Number 1. Thus, every ADC value read in below this value and above the ADC Threshold value will fall into Bin 1. The last bin's upper boundary—Bin 10 for a PCASP-X2 with a Bin Count of 10, for instance—must be 12288 (3000 hex). *Note:* No matter how many bins are selected, **40 bin thresholds must be sent out**. Again in this example, if the Bin Count is 10, 10 valid thresholds are sent out, and the remaining 30 bins should be 0000 hex or FFFF hex.
- Checksum

The 16-bit sum of all the 8-bit characters in the packet.

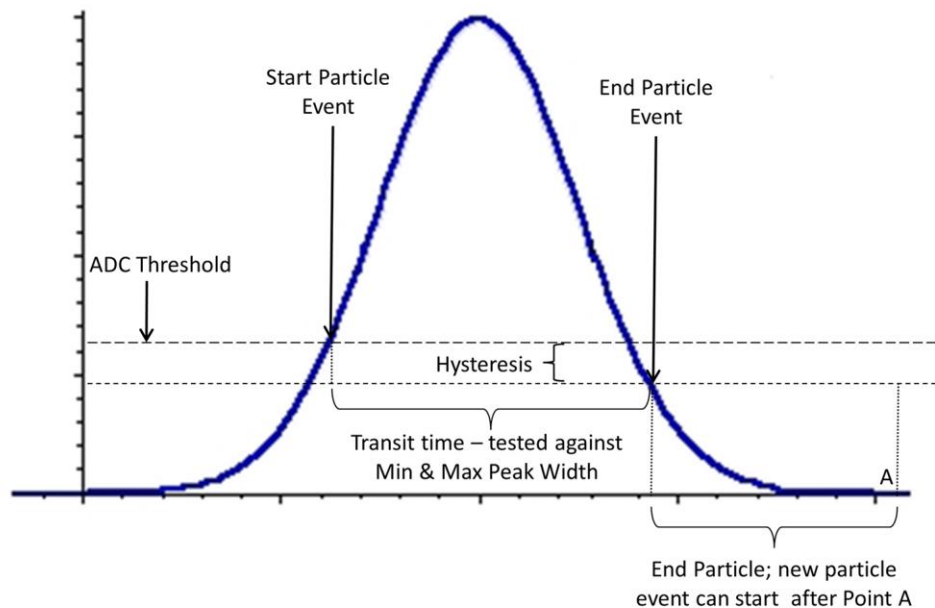


Figure 8: SETUP DATA Parameters Used in Identifying Particle Events

PCASP-X2 Response to SETUP DATA Command

The PCASP-X2 responds to the **Setup Command** with two bytes that indicate whether the received and calculated checksums match. If they do, the PCASP-X2 responds with two ACK characters (ASCII character 6, HEX = 06). If the checksums do not match, the PCASP-X2 responds with two NAK characters (ASCII 15, Hex = 15).

The setup response does not include the ESC char to begin the data packet, nor does it have a CKSUM of its own at the end of the packet.

Byte	Parameter Description	Data Type	Ex. Hex Value	Parameter Setting as Indicated by Hex Value in Previous Column
0	Response	U8	06	06 h = ACK
1		U8	06	06 h = ACK

Table 5: PCASP-X2 Response to Setup Command – Data Packet.

SEND DATA Command

The second type of command the host computer sends to the PCASP-X2 probe is the **Send Data Command**, command 2. This command instructs the probe to send back all the data it has acquired since it last relayed data to the host computer.

The table below shows the packet that is sent to the PCASP-X2 probe to request a data packet.

Byte	Parameter Description	Data Type	Ex. Hex Value	Parameter Setting as Indicated by Hex Value in Previous Column (after bytes have been swapped, if necessary)
0	Start Byte	U8	1B	1B h = ASCII 27 = Esc Character
1	Command Number	U8	02	Send Data Command
2	Checksum	U16	1D	001D h = 29
3			00	

Table 6: Send Data Command – Data Packet

Definitions for these parameters are the same as those given for the SETUP DATA command.

PCASP-X2 Response to the SEND DATA Command

After the host computer sends the PCASP-X2 a Send Data request, the instrument sends back a response as shown below.

Byte	Parameter Description	Data Type	Ex. Hex Value	Parameter Setting as Indicated by Hex Value in Previous Column (after bytes have been swapped, if necessary)
0	APD Voltage / Housekeeping 1	U16	Note: The first 8 channels in the data packet are analog-to-digital signals that must be converted by the data system (e.g., PADS) into meaningful numbers. The data arrive in hex format. PADS or another data system must then use a scaling algorithm specified within the program to yield results such as APD voltage, block temperature, etc.	
1				
2	APD Temperature / Housekeeping 2	U16		
3				
4	Block Temperature / Housekeeping 3	U16		
5				
6	APD 1 st stage monitor / Housekeeping 4	U16		
7				
8	Laser Reference / Housekeeping 5	U16		
9				
10	Sample Flow / Housekeeping 6	U16		
11				
12	Sheath Flow / Housekeeping 7	U16		
13				
14	Sample Pressure / Housekeeping 8	U16		
15				
16	Average Transit Time in 25 ns increments	U16	00	0000h = 0 DOF rejects
17			00	
18	Transit time rejects	U16	00	00000000h = 0 Transit-time rejects
19			00	
20	Oversize rejects	U16	00	0032h = 50 counts
21			32	
22	Bin 1 Counts	U16	00	0110h = 272 particles
23			10	
24	Bin 2 Counts	U16	01	01C6h = 454 particles
25			C6	
...Bins 3 – 39 ...				
100	Bin 40 Counts		0	

Byte	Parameter Description	Data Type	Ex. Hex Value	Parameter Setting as Indicated by Hex Value in Previous Column (after bytes have been swapped, if necessary)
101		U16	0	0000h = 0 particles
102	Checksum	U16	D8	04D8 hex = 1240 decimal
103			04	

Table 7: PCASP-X2 Response to Send Data Command -- Data Packet

Definitions of the Send Data Response parameters

- APD Voltage Gain Voltage applied to the Avalanche Photo Diode. Table 9 for conversion equation.
- APD temperature The temperature of the PCASP-X2's APD. See Table 9 for conversion equation.
- Block Temp The temperature at the PCASP-X2's optical block. See Table 9 for conversion equation.
- APD 1st stage monitor voltage The average DC value voltage at the output of the APD's I to V converter. A measure of window cleanliness.
- Laser Reference (V) Voltage proportional to laser power. A measure of laser aging.
- Sample Flow Sample flow in the PCASP-X2's optical block. See Table 9 for conversion equation.
- Sheath Flow Sheath flow in the PCASP-X2's optical block. See Table 9 for conversion equation.
- Ambient Pressure The pressure in the PCASP-X2's optical block. See Table 9 for conversion equation.
- Average transit time The average of the raw count of the particle widths in the sample interval.
- Transit time Reject The number of particles rejected because they did not meet the criterion for transit time.
- Oversize Rejects The number of times that the Analog-to-Digital Converter was at its maximum digitized count (4096). These particles are not processed into the calculated parameters and only reported as "over-range particles."
- Bin Count (Formerly called "OPCchan[]") An array which holds the number of particles detected in each of the PCASP-X2 sizing bins during the current sampling interval.
- Checksum The 16-bit sum of all the 8-bit characters in the packet.

Response Data Packet Length and Transmission Rate

The length of the response data packet will change based on the number of channels being used. The following table gives the data packet length for the PCASP-X2's different channel-number configurations.

Number of PCASP-X2 Channels	Length of Data Packet (Bytes)
10	43
20	63
30	83
40	103

Table 8: Length of PCASP-X2 Data Packet

Since this packet is transmitted at 38,400 baud, the length of the packet determines the maximum data rate that can be achieved.

PCASP-X2 Housekeeping Channels

A list of PCASP-X2 housekeeping channels appears in the table below, along with the equations used to convert analog housekeeping values to meaningful digital values. The following conventions are assumed:

- “ad” is the analog-to-digital converter value sent over the serial channel in the housekeeping slots.
- All temperatures are in degrees Celsius.
- The housekeeping analog-to-digital converter on the PCASP-X2 has a 12-bit output and an input voltage range of 0 to 5 volts. Therefore, the solution of the input voltage, given a conversion value, (ad), is

$$V = 5(ad/4095)$$

#	Name	Equation to Convert Analog-Digital Counts to Meaningful Values
1	APD Bias Voltage	Volts = $5*(ad/4095)$
2	APD Temperature	Two Steps: 1.) $V = 5*(ad/4095)$ 2.) $^{\circ}C =$

3	Block Temperature	$\left[\frac{\ln\left(\frac{5}{V} - 1\right)}{3750} + \frac{1}{298} \right]^{-1} - 273$
4	APD First Stage Monitor (V)	Volts = 5*(ad/4095)
5	Laser Reference Voltage (V)	
6	Sample Flow	Flow = C * [(5*ad)/4095] ² + B * [(5*ad)/4095] + A See instrument calibration for A, B, and C
7	Sheath Flow	Flow = C * [(5*ad)/4095] ² + B * [(5*ad)/4095] + A See instrument calibration for A, B, and C
8	Sample Pressure	Pressure = ad* 0.271 + 120

Table 9: Conversion Equations for Analog-to-Digital Housekeeping Channels

Appendix C: DMT Instrument Locator—Operator Guide

Purpose

The Droplet Measurement Technologies (DMT) Instrument Locator tests whether a DMT instrument is responsive to an initialization command. This can be useful in determining if an instrument is powered on and has functional communications lines, or in verifying the serial port number that each instrument is connected to. Beyond this, the software does not ensure that the instrument is functioning properly.

This document describes version 1.0.1 of the Instrument Locator. This version of the program supports the following DMT instruments:

- APSD
- BCP
- CAS and CAS-DPOL
- CDP and CDP-PBP
- FM-100
- FSSP
- MPS
- PCASP-100X

- CIP and CIP-GS
- CPSD
- PCASP-X2
- PIP

Installation

The DMT Instrument Locator is on a USB stick included in a sealed plastic bag. To install the software, follow the instructions on the small card also included in the bag.

Operation

1. To open the Instrument Locator, navigate to `C:\Program Files\PADS 3` and double-click on `DMT Instrument Locator.exe`. You will see the window in Figure 1.

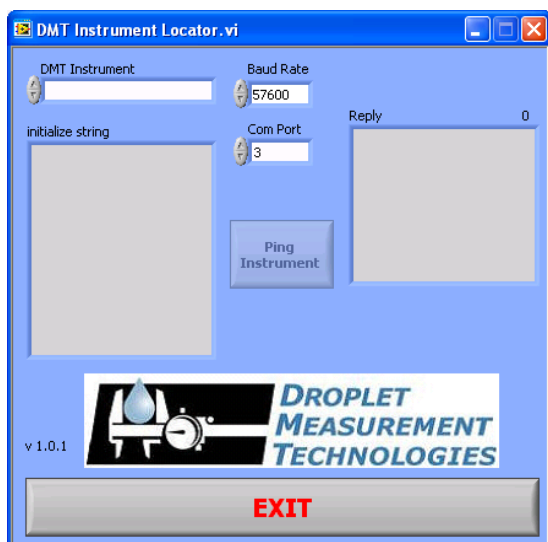


Figure 9: Instrument Locator

2. Click on the **DMT Instrument** field to bring up a list of available instruments. (Grayed-out instruments have not yet been tested with the Instrument Locator.) Select your instrument from the list. The **Baud Rate** will auto-populate, though in some special cases you may need to adjust the baud rate for your specific instrument.
3. Select the COM port for the instrument you want to test.
4. Click on **Ping Instrument**.
5. The Instrument Locator will display the initialization string sent to the instrument and the instrument's reply. All instruments reply with "0606" when sent a valid initialization command. If there is no reply, the Instrument Locator will indicate this with a **No Reply** indicator. The Instrument Locator also displays a possible reason for the communication failure in the **Reply** box.

6. To quit the Instrument Locator, click on **Exit**.

Note: Several DMT instruments—the CDP, CDP-PbP, BCP, FSSP, and FM-100—all respond to the same initialization string. The instrument locator simply sends this string to the instrument. The program has no way of knowing if the instrument connected to the COM port is actually of the correct type. Thus, if you have multiple instruments in your system, it is important to specify the correct COM port for the instrument you wish to test.

Appendix D: Revisions to Manual

Rev. Date	Rev. No.	Summary	Section
2/16/10	D	Updated and expanded laser safety procedures	Frontmatter, 6.4
10/27/10	E	Inserted Communications Appendix	Appendix C
11-10-10	F	Inserted recommended frequency for performing maintenance tasks	6.0
		Removed packing list	Appendix B
11-13-10	G	Revised power specifications to reflect change to universal power	1.1
5-18-11	H	Updated temperature specifications	1.1
		Updated airflow calculation section to reflect hardware change	2.2
7-21-11	H-1	Updated information on location of temperature and pressure sensors to reflect hardware change	2.2
9-8-11	H-2	Updated power specifications to reflect hardware changes	1.1, 4.1
4-23-12	I	Added information about DMT Instrument Locator	Appendix C