SPECinc

2D-S Technical Manual
Rev. 3.1

A Two Dimensional, Stereo, Particle Imaging Probe

(Also Includes Documentation for Model 2D-128)

February 2011

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PLEASE READ BEFORE HANDLING PROBE

1.0 Unpacking the 2D-S

Removing the probe from the shipping box:
  The 2D-S was shipped in a case with shock-absorbing foam. A plastic tube surrounds and protects the electro-optical body of the probe. Removing the probe from the case and the tube is a two-man job. To remove the probe from the box one man should grasp one of the probe's arms from behind the tip cross supports nearest the cone front plate as well as from the back of the probe and lift it out of the shipping case (Figure A).

  Once removed from the case, the plastic tube can be removed. Place the probe vertically on the floor (Figure B). While one person holds the arms from behind the cross supports, a second person should pry the plastic tube open at the seam (Figure C). The person holding the arms will lift it up and out of the stationary tube (Figure D). Place the probe on working surface, preferably an anti-static mat. A tape roll works well to prevent the probe from rolling (Figure E).

Figure A. Proper placement of hands on probe

Figure B. Place Probe on Floor

Figure C.   Prying tube open at seam

Figure D.   2D-S pulled straight up

Figure E.   Stabilizing probe with roll of tape

1.1 Handling the 2D-S

When handling the 2D-S or installing the probe on an aircraft, the greatest care should be given to protecting the optics, electronics, and the window tips on the probe. One hand should always grasp the probe arms between the cross supports of the arms and the cone front plate. A second hand should grasp the probe by its black frame body while not touching the optics or electronics. The preferred location of the second hand is on the back end of the probe.

DO NOT GRASP THE ARM TIPS BEYOND THE CROSS SUPPORTS,
DO NOT BUMP ARM TIPS INTO ANYTHING,
DO NOT PUSH OR PULL THE ARM TIPS IN ANY DIRECTION.

DO NOT HOLD OR GRAB THE PROBE BY ANY OPTICS, ELECTRONICS BOARDS,
CABLES, LASERS, FIBERS, OR TIPS
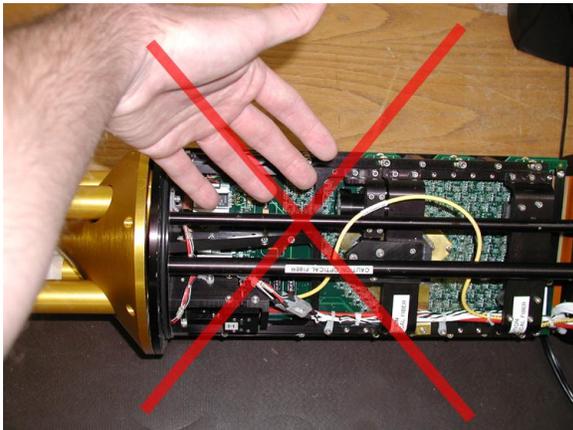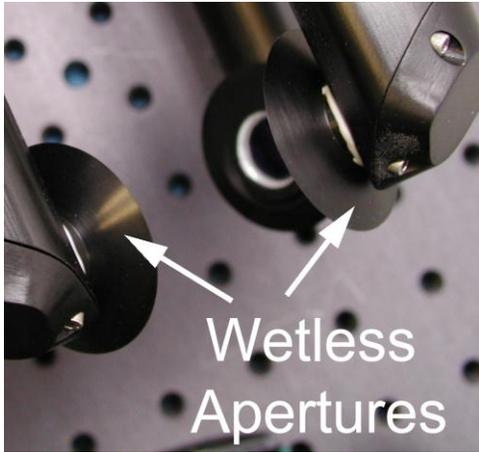
Wetless Apertures

The Wetless Apertures are epoxied to the tip. They keep the window dry and minimize particle shattering. Because they have a very sharp leading edge, NEVER apply force to them or bump them into anything; the sharp edge can be easily damaged, minimizing its ability to keep the windows dry.

The windows have an anti-reflection coating that can be easily scratched. Use caution near the windows and use only reagent grade methanol and a cotton swab when cleaning. Follow cleaning instructions in Section 7.1.

HOLD THE PROBE BY ITS FRAME:
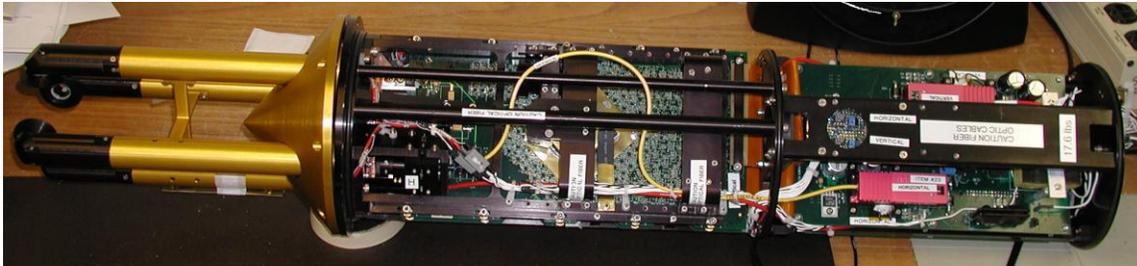
To make it perfectly clear where to handle and NOT
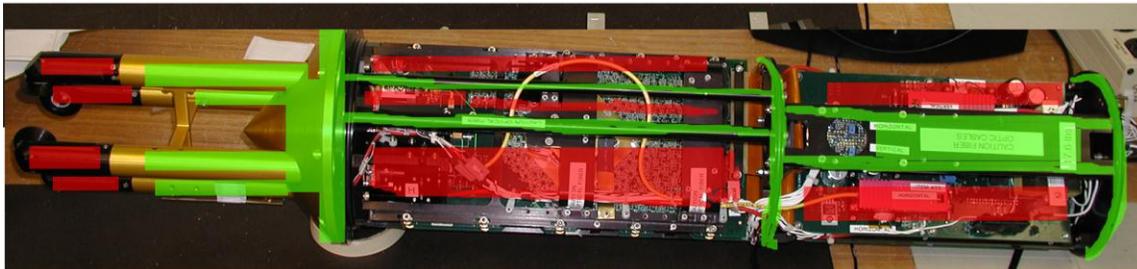
NOT FOLLOWING THESE CRITICAL HANDLING INSTRUCTIONS NEGATES THE WARRANTY FROM SPEC

1.2 Setting up the 2D-S for Lab Tests

When the 2D-S is shipped to a new location it is best to run a lab test before installation into a platform to ensure no damage occurred during transport. The 2D-S system consists of the probe, power cables, probe cables, and combined power supply / data acquisition computer. The combined power supply / data acquisition computer are in a rack mounted 2U case. The 2D-S requires 115 VAC @ 3.5Amps and 28VDC @ 10 Amps power to operate. 28 VDC Power Supply is user-supplied.

Steps to run 2D-S in laboratory:

1. Ensure the switch on the power supply box is down in the Off position and the 2D-S probe is not connected to any cables.
2. Connect the Probe Power circular connector into P8 on the power supply box (Fig. 2)
3. Connect Probe Data connector into P5 of the power supply box (Fig. 3).
4. Hook up a 28V DC power supply that terminates to a NEMA (6-15R) Connector, measure with voltmeter that in fact 28V DC is registering at connector.
5. Connect Power Supply 28V DC connector into NEMA Connector checking polarity matches up (Figure 4). Plug 115V AC power plug into a surge protected outlet.
6. Connect Data Rack Power cable into the Power Supply Box at P6 (Figure 5)
7. All cables should be hooked up except amphenol connector to probe. DO NOT CONNECT THE PROBE.
8. With 115V AC and 28V DC power on, flip switch on power supply box to On. Check for power light on front of box and internal fan spin.
9. Before the 2D-S probe can be installed the voltages at the amphenol connector have to be tested to make sure the voltages are reasonable and in line with the electronics schematic. At the amphenol connector, test the voltages with a voltmeter. Pressing one of the meter's tips to ground and the other to a DC pin, check the voltages on the voltmeter. The DC ground pins at the Amphenol are 9, 21, and 22. The testable −7V DC pins are 6, 7, and 19, and the +7V DC pins are 10 and 18. Repeat test on all +7 and −7 DC voltage pins. Finally check voltages between ground pins to make sure no pin that shouldn't have a voltage does. Refer to the electronics schematic for information on which pins have charges.
10. Next measure the AC power at the Amphenol connector. Measure voltage between pins 12 and 24. It should read 115V.
11. Once power on the amphenol has been verified as correct, power down the power supply box and install the amphenol connector to the end of the probe.
12. Run the 2D-S Probe using the Real-Time Acquisition Program (Section 2.0). Check element voltages and compare to pre-shipped values. Spray particles through sample volume to check imaging and response. Clean windows and align lasers as needed (Section 7.1, 7.2).
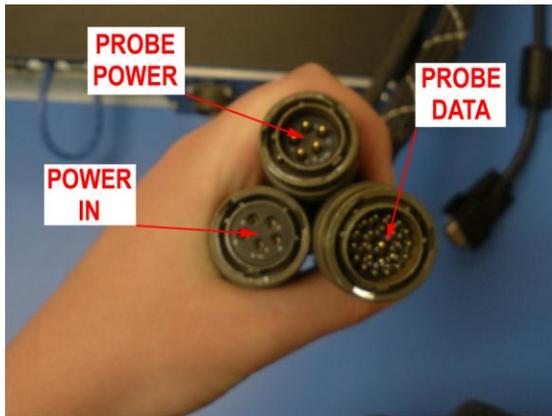
Figure 1.

Figure 2

Figure 3
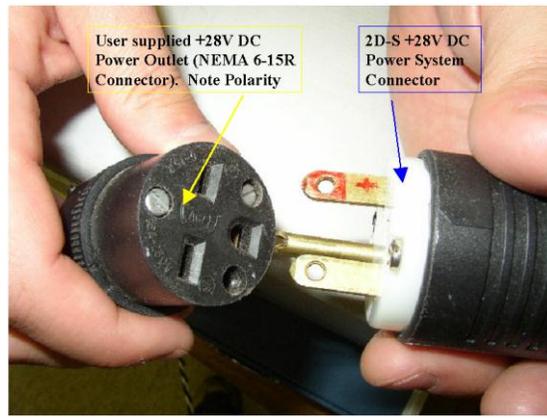
Figure 4.

Figure 5

2.0 2D-S Real-Time Program

The 2D-S Probe operates using a program called the Spec2d Executable (Exe). Since this program works both as a data acquisition program as well as a post-processing program, the Exe is referred to as the Real-Time Acquisition program during data recording and as Playback during post-processing. In this section we discuss the aspects of the Exe related to data recording.

Use the 2D-S Real-Time software to operate the 2D-S probe. Double-click the Spec2d program icon on the Windows Desktop screen. To learn how to install and update the software see Appendix D. The 2D-S program is also used to playback data files, information on playback and post-processing is discussed in another document.

When the program is started four boxes should be displayed on the screen. Use the Windows tab to recover features that cannot be seen. Drag or shrink windows see all information at once.

Main Display Window
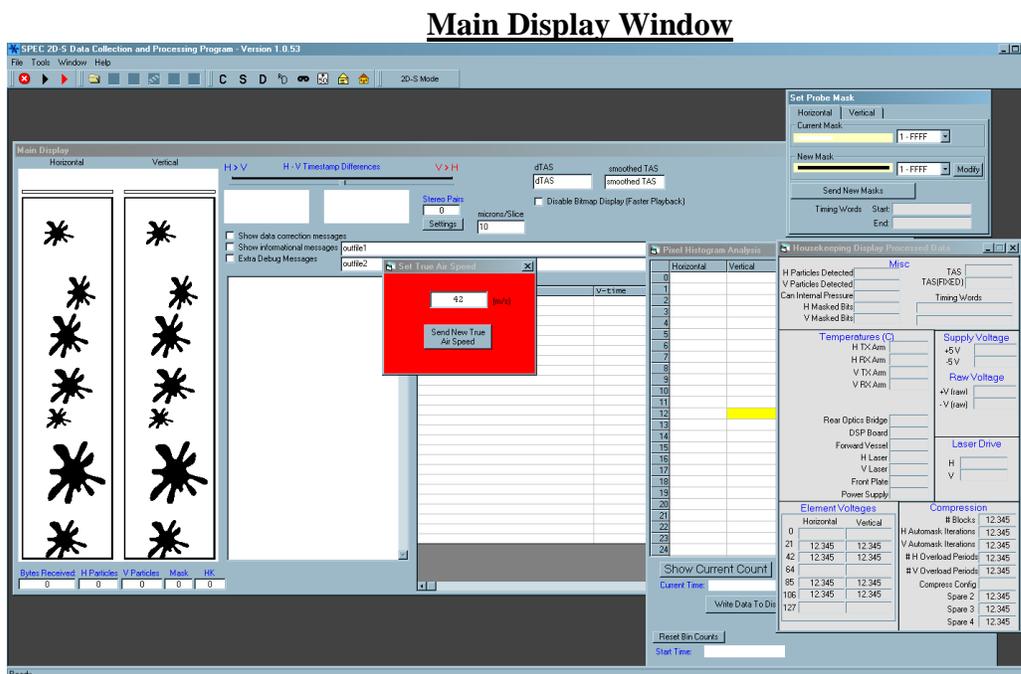
This is the particle display window. At program startup, fake splash images will be displayed in the two array channels. The left particle display window shows the horizontal array and the right side is the vertical array. Below the horizontal and vertical particle's window is a set of counters:

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Bytes received: Records the total amount of bytes received from the 2D-S during data recording.
H Particles: Counts the number of particles recorded in the horizontal array in data file
V Particles: Counts the number of particles recorded in the vertical array in data file.
Mask: This counter records the number of masks that have been taken by the probe. A mask prevents the probe from recording data on array elements that have become hypersensitive and are triggering erratically and not on passing particles.
HK: The Housekeeping packet counter notes the number of housekeeping packets that have been received from the probe. When the probe is on and communicating with the data computer both the Housekeeping packets and Bytes Received counters will increase. When the counters halt there probably has been a loss of communication with the probe

In the white box to the right of the particle displays is where critical messages on probe performance are reported when the box is checked. To the far right is a window with the headers of H-Time and V-Time. This window displays the timestamp of particles as they are recorded.

The other features of the Main Window are for post-processing and are discussed in Section 8.0

Set True Airspeed

This red box sets your airspeed manually. The airspeed is typed into this box and sent to the probe. The approximate airspeed is necessary to prevent imaging distortions when recording data. The value in this box must be in meters per second. SPEC typically does not manually input the airspeed. On most research aircraft airspeed is available to investigators via a serial string from a COM port or through a second Ethernet card.

Under Tools/TAS Source there is an option to configure the ingestion of TAS into the program. To set TAS to manual mode, make sure Fixed Settings is chosen. Customers may contact SPEC for a guide on how to configure 2D-S software to properly input TAS from a source.
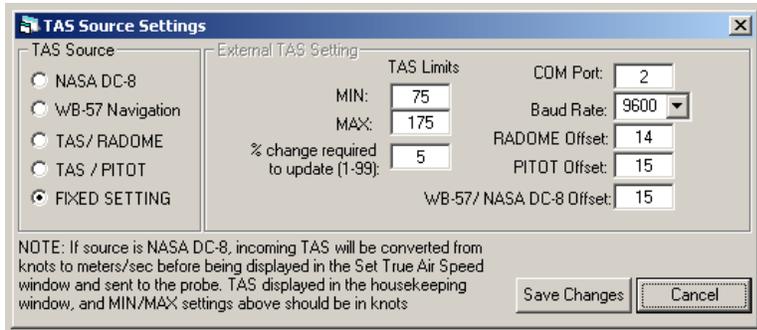
Regardless of the actual airspeed, the probe has an upper limit airspeed of 170 m/s (~340 knots). You should never have an inputted TAS higher than this value sent to the probe Errors in data recording will occur. It is okay to fly the probe faster, but slight image degradation will occur.

Housekeeping Display Processed Data:
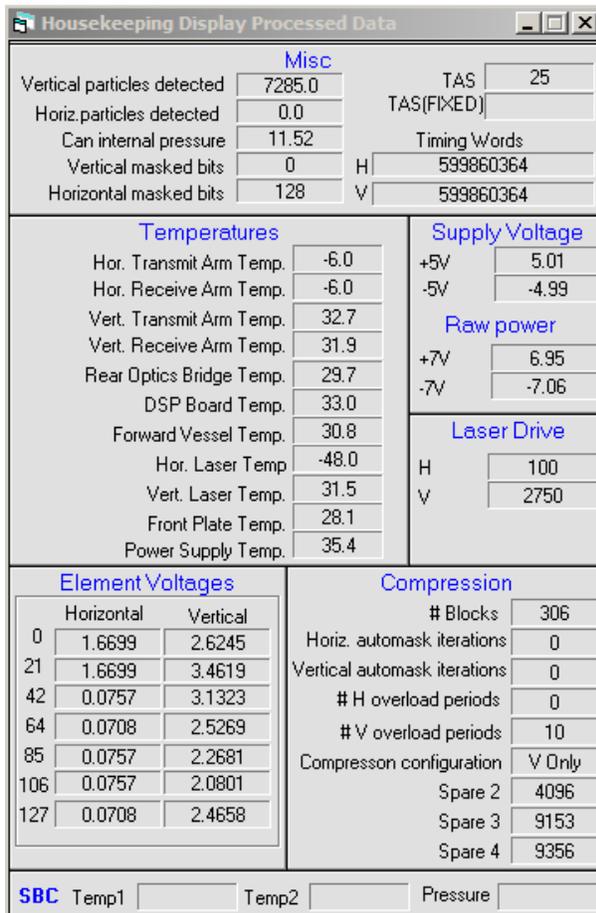
Temperatures, pressures, and voltages from the probe, lasers, and power supply are displayed in this window. The information comes to the program from the housekeeping packets. The information is sent in a raw format and gains and offsets correct the data before being displayed. If the information does not appear correct make sure the top of the window says Housekeeping Display Processed Data. If it does not, go to Tools and click Housekeeping Display Processed Data. Next go to Tools/Analog Settings and click the Set Default Values box, which will reset the gains and offsets to the correct value.

Misc: This section tells the operator the number of particles detected in the last second, the pressure measured at the probe and the number of masked array elements in each array. To the right is the current True Airspeed (TAS) displayed in meters per second. It is very important that the displayed airspeed is close to the actual airspeed. The red TAS box simply displays and sends TAS, so check to make sure that this box displays the correct airspeed.

Temperatures: Displays temperatures at the probe and power supply, all temperatures above a limit are shaded to alert operator of a potential overheating. As a failsafe if the laser temps exceed 45 degrees Celsius for longer than one minute the laser will be powered down by the DSP.

Element Voltages: This box shows the voltages at Horizontal and Vertical arrays. Element voltages below 1.4 are considered non-optimal. The laser should illuminate the array with a Gaussian distribution with its peak at the center element of the array. The laser edges, which lack intensity, should fall beyond the edges of the array, so that laser intensity should be almost uniform across the array..

Compression: This section is important for the # of overload periods. The operator may notice that one array has stopped recording images in high concentrations of particles. If the array is in overload that would tell the operator; the instrument is still operating properly, but must pause before resuming data recording.

The compression configuration field should always read a value of "both", as set in the command packet window.

Supply Power, Raw Power, and Laser Drive: These three sections show the voltages at the power supply and the laser power set points, with a scale of 0-4095 for the latter. This section proves useful when there has been a catastrophic failure in the probe. This will tell the operator if the power supply or laser power board has failed.

Send Command Packet:

This window may not appear at start up, if it doesn't, click on the [icon] icon on the toolbar. Clicking the button at the lower left side of the window sends a packet of information to the probe.

Important to note the above image and duplicate in the 2D-S real time software:
1. First 3 spares set to ffff; 4th spare set to 0200, 5th spare set to 0078. These last two settings are gain coefficients (in Hex) for a proportional-integral arm tip heater control algorithm. These settings should only be changed after discussion with SPEC personnel.
2. Comp. Mode set to Both Ch (or Ver. Only for the 2D-128)
3. The MaxSlice, Rej. %, and MinSlice parameters Are mask settings describe in Section 2.2
4. The arm heaters are now controlled as transmit/receive pairs; therefore, only the heater zones labeled "Hor.Transmit Arm Temp." and "Vert. Transmit Arm Temp." are used to turn on and off the arm heaters. The "Hor. Receive Arm Temp." and "Vert. Receive Arm Temp." check boxes have no effect on probe operation.
5. The laser drive of the probe can be set to a maximum of 4095, in most cases that much power is not necessary and would saturate the array. There is a laser power AI algorithm that can be utilized, and if enabled, this number doesn't need to be adjusted.

6. To build masks on either channel because of noisy elements check one or both "Build Mask" boxes. Be sure to have the Build Mask boxes Unchecked when the probe is flying in cloud.

Set Probe Mask:
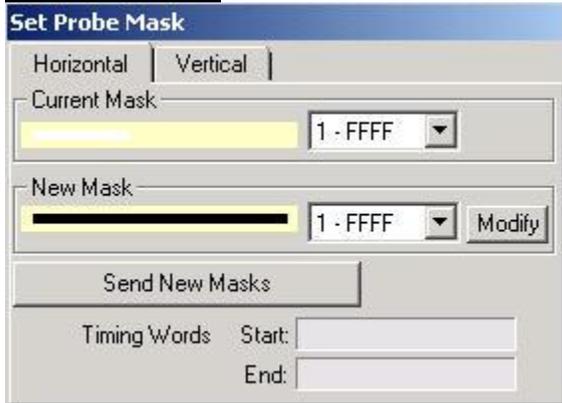
This window allows the operator to view the current mask on each array to see which elements are being masked out. This window should not be used to send new masks though it has that option, the Command Window is where the operator should request to build new masks while sending command packets to the probe.

Tools Tab:

Tools | Window | Help

    Async Setup…
    Bitmap Display Rate   ▶
    Analog Settings
    Housekeeping Display Processed Data
 ✓ Use Display Separator
    Pixel Histogram
    Raw Data Processing Mode
    Stuck Bit Handling - Current: Do Nothing   ▶
    TAS Source
    Set Probe IP Address
    Record Speed
    Mask Bit Replacement
    Include particle offset in output
    Ignore Housekeeping/PC time differences
    Save Command Info to Disk

 ✓ Periodic Mask Generation
 ✓ Periodic Fixed TAS Setting
 ✓ Laser Power Control
    Startup Delay
    SBC Polling Frequency
    Probe Reset Timeout
    Command Probe ON
    Command Probe OFF
    Toggle Debug Messages

    Playback TAS Limits

Async Setup Chooses the COM port for the optional single board computer controller (not a standard item for the 2D-S) for autonomous operation. Contact SPEC if interested in a version of the data and power system that runs autonomously.

Bitmap Display Rate sets the maximum number of particles displayed on the Particle Display in each array during a second. Despite being capable of recording thousands of particles per second, the maximum display rate is 10 per second.

Analog Settings is where the gain and offsets are entered to adjust housekeeping data from the probe.

Use Display Separator puts a single black line between each displayed particle to better differentiate between particles.

Pixel Histogram opens a window in which the number of times each element, for both horizontal and vertical channels, is shadowed. This works only in playback. It is useful for identifying noisy elements, elements that are not working or masked, etc…It is also useful when

processing flight data to verify a homogenous sampling distribution across the 128 elements of either channel.

Raw Data Processing Mode should be left unchecked (as shown). This mode turns off error testing of the data during playback, and should not normally be used.

Stuck Bit Handling is a very important tool. If an array element gets noisy, the operator needs to set what he wants the probe to do. The operator can set it to do nothing and record the noisy bit or he can have the probe initiate an Automask that after a conditional is passed the program will build a mask to remove the noisy bit. (Explained fully in Real-Time Troubleshooting Section)

TAS Source is used if the operator wants to set up the 2D-S to receive a True Airspeed connection from an outside source like through a COM Port from another computer.
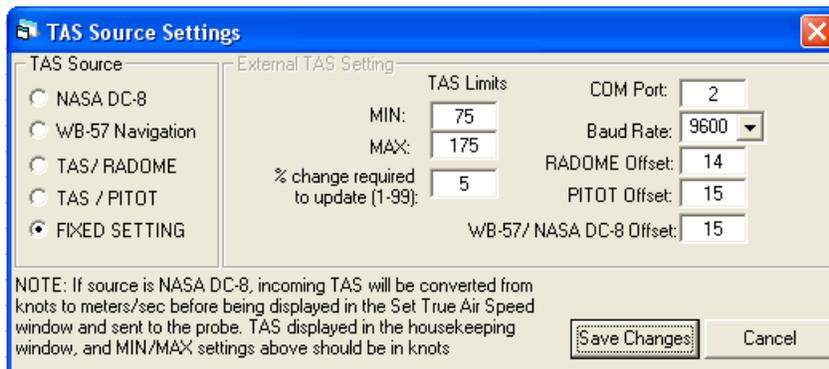
For normal operation, the 'Fixed Setting' radio button should be selected. In the main menu, choosing the '50 Icon' (see the section on the Toolbar, below) allows the user to enter and send the TAS to the probe.

The 2D-S can also ingest a serial data stream, in several different formats, that allows the real time program to adjust the TAS from the incoming serial data values.
For more information see Appendix B: **Automatic True Airspeed Update.**

Set Probe IP Address allows the IP address of the probe to be entered. The default value is 192.168.1.133. The data system computer should use a fixed IP address in the same range (such as 192.168.1.100).

Record Speed has two options with the standard option will display particles and housekeeping data and the maximum recording will display no updates. It should only be enabled when the instrument is flying in a completely AI environment where there is no operator on board.

Housekeeping Display Processed Data applies the gains and offsets and displays them. This should be checked (not shown)

Record Speed has two options with the standard option will display particles and housekeeping data and the maximum recording will display no updates. It should only be enabled when the instrument is flying in a completely AI environment where there is no operator on board.

Mask Bit Replacement provides a means, during playback post-processing, to fill in horizontal and vertical elements that are masked out.

Include particle offset in output should remain unchecked.

Ignore Housekeeping/PC time differences turns off a quality control test that is implemented during playback post-processing. It should be left unchecked, but may be enabled if data processing fails due to such errors.

Save Command Info to Disk when enabled, records an ASCII file record of all the values and options sent in command packets to the 2D-S when operating in real time. This troubleshooting tool is normally disabled. The name of the files produced have name format: `CMDLOGYYMMDDHHMMSS.2DS'

Periodic Mask Generation:

The periodic mask generation directs the 2D-S program to take a mask at specified time intervals.

The threshold field is how many particles per second, or less, should transpire before a command should be sent to the probe to take an automask. If clean air is not seen for more than the interval given in the 3rd field, then a mask is taken regardless of the number of particles seen.

It also allows choosing of a slice count maximum (equivalent to 10 um intervals) at which the real time software should consider a particle a stuck bit and take action (re-send a mask, as selected in the previous menu, above). If large particles (snow / ice / rain) are being encountered, this number should be increased to 250. The interval at which masks should be taken is dependent on probe reliability.

The values shown here are typical when in cloud infrequently. If flying in cloud a great deal of the time, the mask interval (3rd box) should be set to around 600 seconds. If an operator is comfortable watching the probe's performance throughout a flight, the period mask generation

can be disabled but only as a means preventing a mask from being taken in cloud. The mask algorithm is further explained in section 2.2

Periodic Fixed TAS Setting

When running the probe unattended with a fixed true air speed (TAS), enabling this option will ensure that once per minute, the user-supplied TAS setting is sent to the probe. It is best to leave this disabled.

AI Laser Adjustments: Automated laser power adjustment saves the operator from having to optimize laser settings continuously. The settings here are typical.
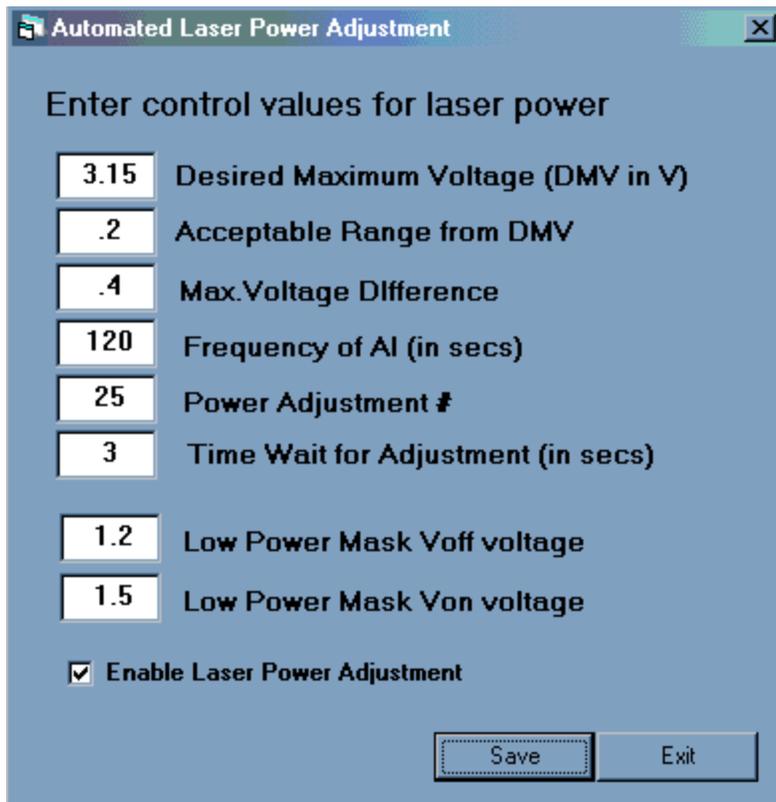
Algorithm for Adjusting Laser Power

The acceptable voltage range for the 2D-S is 1.5 to 3.5 volts. Below that voltage noisy bits are known to occur. Above that value circuit saturation occurs and imaging is compromised. The purpose of the AI algorithm will be to make sure the instrument is working at its peak performance during unsupervised flight.

The AI command box needs 6 user adjustable values to set the AI.

1. The first input needs to be the Desired Maximum Voltage (DMV). This is the array voltage that we'd prefer to see in the housekeeping data.
2. Second input is an acceptable range from the Desired Maximum Voltage (MVR). A plus or minus value from the Desired Maximum voltage we can also tolerate.
3. Third a Maximum Voltage Difference (MVD) from the next highest recorded voltage to the second highest voltage. To insure we aren't adjusting the laser power because 1 array element is very high compared to the others.
4. A time period to run this AI algorithm in seconds (PER).
5. Power adjustment factor (PAF): The amount of the laser power is bumped in each cyle of the AI to reach the Desired Maximum Voltage or its range.
6. A Time to the AI to wait for laser power adjustments to take effect before retesting to see if a power adjustment had enough of an effect to get to the Desired Maximum Voltage or its range (TSET).

The last two fields are used to mask off the entire array if laser voltages become too low.

The Low Power Mask Voff voltage is used as follows: if the average of the seven horizontal (or vertical) channel element voltages is below this number, the entire horizontal (or vertical) channel is masked off by the data system. This only happens if this feature is enabled. It is useful, because it will mask out channels when their low average voltage is likely to be accompanied by noise.

The Low Power Mask Von voltage is the average voltage at which the horizontal (or vertical) channel will come back on after being masked off. When the data system sees this voltage average on the channel, it sends out a mask command so that the entire array is no longer masked.

Startup Delay

This option should be left unchecked.

Playback TAS Limits
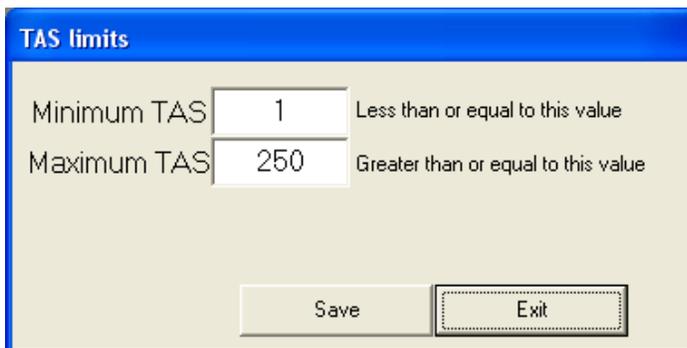
The limits to the TAS in this menu apply to the playback post-processing. They are for error checking the stored housekeeping values. The values shown, 1 to 250, provide the desired error identification.

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Tool Bar:

From left to right:
<u>Red Circle/White X icon</u>: Stops recording of Data
<u>Black Arrow icon</u>: Monitors 2D-S but **records no data file**.
<u>Red Arrow icon</u>: Records Data File.
<u>Folder icon</u>: Opens Recorded Data File
<u>House icon</u>: Opens/Closes Housekeeping window
<u>C, S, and D icon</u>: Opens/Closes Concentration plots, Particle Size plot, and Size Distributions -- *Disabled*, use 2DSview (See section 8.0)
<u>Mask icon</u>: Opens/Closes Set Mask Window. Displays the current mask on each array. Do not send mask via this window. Use Send Command Packet.
<u>Envelope icon</u>: Opens/Closes Send Command Packet window
<u>50 icon</u>: opens and closes Set Airspeed window

<u>2D-128 Mode / 2D-S Mode Button</u>: Switches between single channel mode and standard dual channel modes. The 2D-128 probe version has only a vertical channel, with the horizontal channel optoelectronics and mechanical arms not installed. Therefore, in this mode, the user interface changes so that only parameters associated with the vertical channel are displayed.

> Users of the standard 2D-S probe must run in 2D-S mode. Failure to do so will cause the real-time program to only collect image data from the vertical channel.

2.1 2D-S Real-Time Operation

2D-S Startup Checklist

1. Start the Data Acquisition Computer. Configure the 2D-S software settings as described in Section 2.0 before attempting to operate the probe. Essential settings are listed in the following checklist, but explained in the previous section.
2. It will be noted here SPEC operators have noticed higher chances of failed communication with the probe and data computer when startup procedures in steps 3-5 are not completed in quick succession.
3. Ensure that AC (400 Hz and 60 Hz) and 28V DC power to the probe is on.
4. Turn on the 2D-S power at the Power supply. On the Data Acquisition computer the Local Area Connection unconnected icon in the bottom toolbar should be replaced with a connected icon. A Graphic may show packets of information being transferred between two computers. Wait five seconds and then open the Spec2d Exe program
5. Immediately start recording by pressing the red record button in the upper left window of the 2D-S program.
6. If communications with the probe fails, verify in the Tools→Set Probe IP Address that the probe address is set to 192.168.1.133. In a DOS (cmd) window, type the command: "ping 192.168.1.133". If the ping fails, there may be a problem with probe power or cabling.. If the ping works, shut down the probe power and reboot the computer, performing all steps above that apply to the 2D-S. Rebooting the computer and power cycling the 2D-S in this way often corrects the occasional initial communications error. Be sure networking firewalls are disabled.
7. Check the housekeeping window. If the active TAS is not equal to approximately the actual air speed, enter the appropriate air speed in the Send True Air Speed window and click the Send True Air Speed button.
8. Ensure the Build H Mask and Build V Mask boxes are checked in the Command Window. Ensure the Comp Mode→Both Ch. stereo button is selected.
9. Check that 4 heaters are enabled in the Send Command Packet Window: the horizontal and vertical transmit and receive arms (4 total), and the horizontal and vertical lasers. Set the arm temperatures to -20 and the laser temperatures to -20. If they are not enabled, check them all.
10. Push the Click To Send Command Packet button. Verify that a new mask was made by checking the mask counter on the main display window..
11. Uncheck the Build H Mask and Build V Mask boxes in the Command Window.
12. Ensure the horizontal and vertical laser temperatures are not over 37 C. If they are less than -20 C, they should be on (highlighted yellow).
13. On the 2D-S computer, continue to monitor:

a. Horizontal and vertical laser temperatures. Low temperatures (10 C) are OK but not normal. If temperature(s) drop below 0 C, turn it/them off.
b. Stuck bits. The program should automatically watch for and eliminate them, but send a command packet with the Build H and/or V Mask check box set to clear stuck bits if they are evident.
c. Air speed. Be sure the TAS reported from the instrument matches the TAS reported by the aircraft and is equal to or less than 170 m/s.
d. If one of the lasers fails, many bits will be masked out and stuck bits will continue to occur. If this occurs, turn off sampling for both channels by choosing Comp Mode→Hor. Only or Comp Mode→Ver. Only. Turn off the 2DS and click the stop button. Then hit the record button, starting a new file, and turn on the 2DS. Set the appropriate Comp Mode→Build H or Build V Mask box. Click the Click To Send Command Packet button.

When encountering particles, the Real-Time program only shows a fraction of the particles, note the particles per second in the Housekeeping Display for better understanding of the concentration of particles being recorded

14. Be sure to power down the probe when finished:
   a. On the 2D-S, hit the red stop button, then choose File→Exit.
   b. Turn off the 2D-S power at the power supply.

2.2 2D-S Mask Settings

The 2D-S has an on board DSP that can be commanded to take a mask at any time, additionally the DSP will initiate a mask on probe startup. There are 4 ways to initiate the generation of a new mask:

1) User initiated - the 2D-S program at the data system (2DSGUI), sends a command packet with the "Build H Mask" and/or "Build V Mask" checkboxes checked. In the Figure below, only the "Build H Mask" is checked.
2) Automask initiated – Under the "Tools -> Periodic Mask Generation" menu, there is a checkbox labeled "enable periodic mask generation"; when checked the 2DSGUI will initiate a mask automatically based on the parameters set under this menu.
3) Mask initiate by Stuck bit - Under the "Tools" menu there is a "Stuck Bit Handling" Menu which has four selections, one of which is "Initiate Automask". When this is selected, a new mask is requested by the 2DSGUI. Stuck bits are defined under the "Tools -> Periodic Mask Generation" menu.
4) When the probe is started. The DSP in the probe initiates a mask. This requires no user interaction.

Additionally a new mask can be manually sent to the probe as opposed to generated by the probe (use "Set Probe Mask window") – however this option should not be used by the uninitiated user.
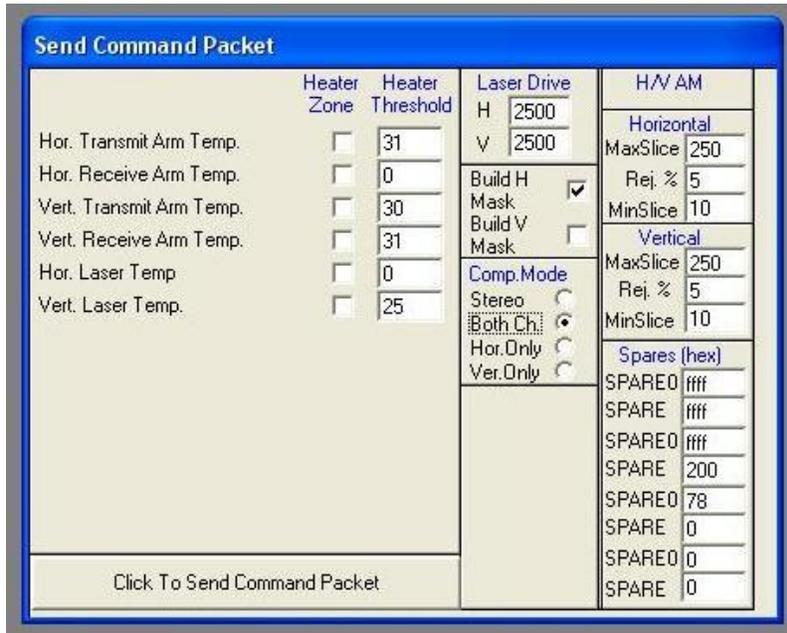
Command window in the 2D-S GUI

Upon receipt of the mask generation command, the DSP will use the MaxSlice, MinSlice and Rej. % parameters, to perform the masking algorithm. These three parameters are defined by the user in the "Send Command Packet" window and are included in the mask generation command packet. On startup the DSP uses the following default values: MaxSlice = 500, MinSlice = 10 and Rej. % = 2% to generate a mask.

Note: Throughout this document bits and pixels are used interchangeably, and row and slices are used interchangeably.

The mask algorithm used to determine if any bits are stuck or noisy (rapidly toggling on and off) is an iterative procedure that performs the following steps:

1. Probe enables all pixels - no bits masked.
2. Probe reads the incoming array data until a programmed number of slices (MaxSlice) have been captured, or 1 second of data has been captured and the number of slices is

greater than minslice (MinSlice).
Only rows with at least one darkened (shaded) pixel are captured.
3. The fraction that each pixel is shaded is determined, by dividing the number of times the pixel is shaded by the total number of captured slices.
4. All pixels whose shaded percentage exceeds the preset threshold (Rej%) are masked.
5. Steps 2-4 will be repeated until less than the minimal number of slices (MinSlice) are captured in a 1 second time period (remember that only slices with a darkened pixel are captured - the rest are ignored).
6. The new mask will be used by the data system. Any pixels that are mask are ignored, and do not trigger the slice to be captured.

This mask generation process is performed independently for the horizontal and vertical channels. Upon completion of the mask generation, the probe sends the resultant mask for the vertical and horizontal channels to the 2DS GUI. In the 2DS GUI, masked out bits are displayed as a white and enabled pixels are black under the "current mask" in the "set probe mask" menu.

2.2.3 An Example of the Mask Algorithm

For the flowing example a generate mask packet is sent to the DSP with the following parameters: MaxSlice = 500, MinSlice = 5 and Rej. % = 35%.

First Iteration though mask algorithm:
After one second of sampling the following 10 slices of data are collected:

Bit or Pixel

	1	2	3	4	5	6	...	56	57	58	59	60	62	63	...	127	128

Row or Slice: 1 2 3 4 5 6 7 8 9 10

%
shaded | 0 | 80 | 0 | 20 | 0 | 0 | ... | 0 | 0 | 0 | 0 | 10 | 40 | 10 | ... | 0 | 30 |
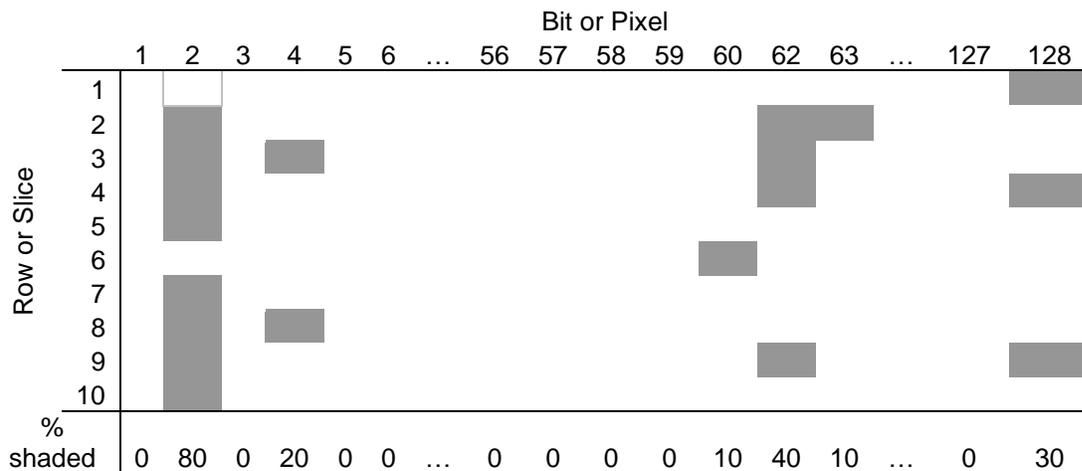
Notice that each row has at least one shaded pixel. We did not collect 500 slices, but we collected more than the minimum required 5 slices, so for each pixel, we determine the shaded

percentage. Since the Rej% is set at 35%, bits 2 and 62 will be masked out (ignored). The rest of the pixels are shaded less than the rej% so they are not mask. We perform 2nd iteration of the mask algorithm to determine if any more bits should be mask.

Second Iteration though mask algorithm:
After one second of sampling the following 6 slices are collect:
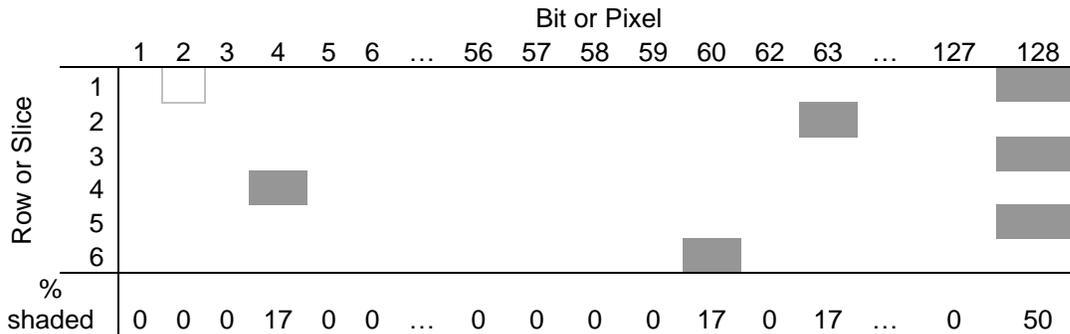
During one second of sampling, we collected 6 slices, which is more than the minimum required 5 slices. So for each pixel, we again determine the shaded percentage. This time bit 128 is shaded 50% so it is also masked out. The rest of the pixels are shaded less than the rej% so they are not mask. We perform third iteration of the mask algorithm to determine if any more bits should be mask.

Third Iteration though mask algorithm:
After one second of sampling the following 3 slices are collect:
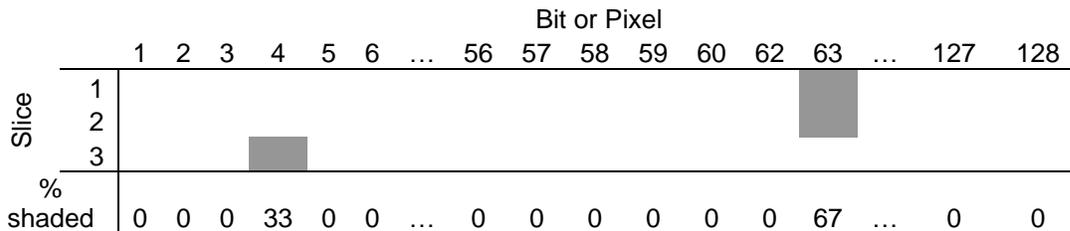
Upon the third iteration thru the mask algorithm bits 2, 62 and 128 are masked so they should not be shaded. We only receive 3 slices in a second (below our 5 slice threshold), so our mask is complete and we do not analyze the data to determine the shaded percentage. Note that in the third iteration bit 63 is above the 35% rejection threshold, but not enough samples were collected in a second. For the mask operation, bits 2, 62 and 128 are masked. This mask is relayed back to the 2DSGUI.

It becomes apparent that clear air is highly desirable for performing mask operations, so that valid cloud particles, do not cause pixels to appear noisy, and therefore become mask. Below are some suggested operational parameters for mask generation

2.3 Suggested Operational Mask Settings

A. In High Concentration Cloud:

In a cloud, the 2D-S should see particles across the entire array. This is especially true in high concentrations of small particles, where many particles are seen in one second. For this condition, all three parameters should be set high:

> MaxSlice: 15000
> Rej. %: 90
> MinSlice: 5000

If the mask comes back with only a few diodes masked off, the mask is likely good. If a lot of diodes are masked off, it is likely that the particle concentration is so high that more than MinSlice slices are occurring in the one second period, and MinSlice can be adjusted up to 10000.

B. In Low Concentration Cloud:

If only a few particles are showing up per second (as indicated in the housekeeping window), the statistics will be poor for determining noisy bits. MinSlice needs set high enough to ensure enough particles were sampled. If in large ice, a single particle may generate on the order of 200 slices (on the order of twice the array width of 128) or more. So, MinSlice needs tuned to the conditions. A starting point for this condition is as follows:

> MaxSlice: 5000
> Rej. %: 90
> MinSlice: 500

C. In Clear Air

Clear air is the best time to take a mask, as all of the generated images will be due to noisy diodes, if they exist. Use the following aggressive settings, but be sure to return the values to the more conservative settings, such as in B, above, so that if a mask is taken later, it does not accidentally use these settings in cloud. Doing so will mask out the entire array. The values in parentheses are slightly less aggressive and will allow a noisy diode that is producing a minimum of images to get through:

MaxSlice: 5000
Rej. %: 1 (5)
MinSlice: 1 (10)

3.0 General Description of the 2D-S

The Two Dimensional, Stereo Particle Imaging Probe (2D-S) is an airborne optical instrument that measures the size, shape and concentration of atmospheric particles. This instrument extends the technology of airborne particle measurements in two aspects. First, this instrument provides a stereographic image of a particle as it passes through the sample volume and second, it increases the resolution of the particle images. The 2D-S has two identical optical channels that are orthogonal to each other and normal to the flow of particles. Each channel has a laser that produces a sheet of laser light that is roughly 1.3 x 61 mm in size and passes between the windows located on the inboard sides of the optical arms.   This sheet of light is directed onto a linear array of 128 elements with the magnification required to produce approximately 10-micron pixels in the sample volume. The array is sampled at a rate proportional to the particle's velocity such that image slices are taken at the pixel resolution. Images slices are compressed and blocked into particle frames that are sent to a data acquisition system (DAS) for recording and display. The instrument also monitors sixteen analog channels while controlling two lasers and six thermal zones by switching heaters. Figure 1.0 is a photograph of the instrument and Figure 1.1 is a functional block diagram of the 2D-S.

Figure 3.0 2D-S Photograph

Functional Block Diagram

128 Bits

110 Vac

Heater 1
Heater 2
Heater 3
Heater 4
Heater 5
Heater 6

AC ▶ DC
POWER
SUPPLY

Solid State
Relay Card
PCB

2DS_Control PCB

PD_TO_FIFO — 36 Bits → FIFO_TO_DSP

V
LASER

Horz
Channel

TAS x 5

DDS
Frequency
Synthesizer

HORIZONTAL
PHOTO
DETECTOR
PCB

H
LASER

DRIVER

DACS

24 Bits   DSP BUS

VERTICAL
PHOTO
DETECTOR
PCB

DRIVER

Vert
Channel

PD_TO_FIFO — 36 Bits → FIFO_TO_DSP

SP1

DSP
2188

2D_IFC
&
UART

4 Bits
128

3 ELEMENT VOLTAGES (0,64,127)

+ SA   - SA

ADDRESS

SP0

HDLC
Converter

V laser Power   H laser Power
V element 0   H element 0
V element 64   H element 64
V element 127   H element 127

Analog
Input
Channels

Temp 1
Temp 2
Temp 3
Temp 4
Temp 5
Temp 6

EPROM

RS
422

RS
422

RS
422

RS
422

3 ELEMENT VOLTAGES (0,64,127)

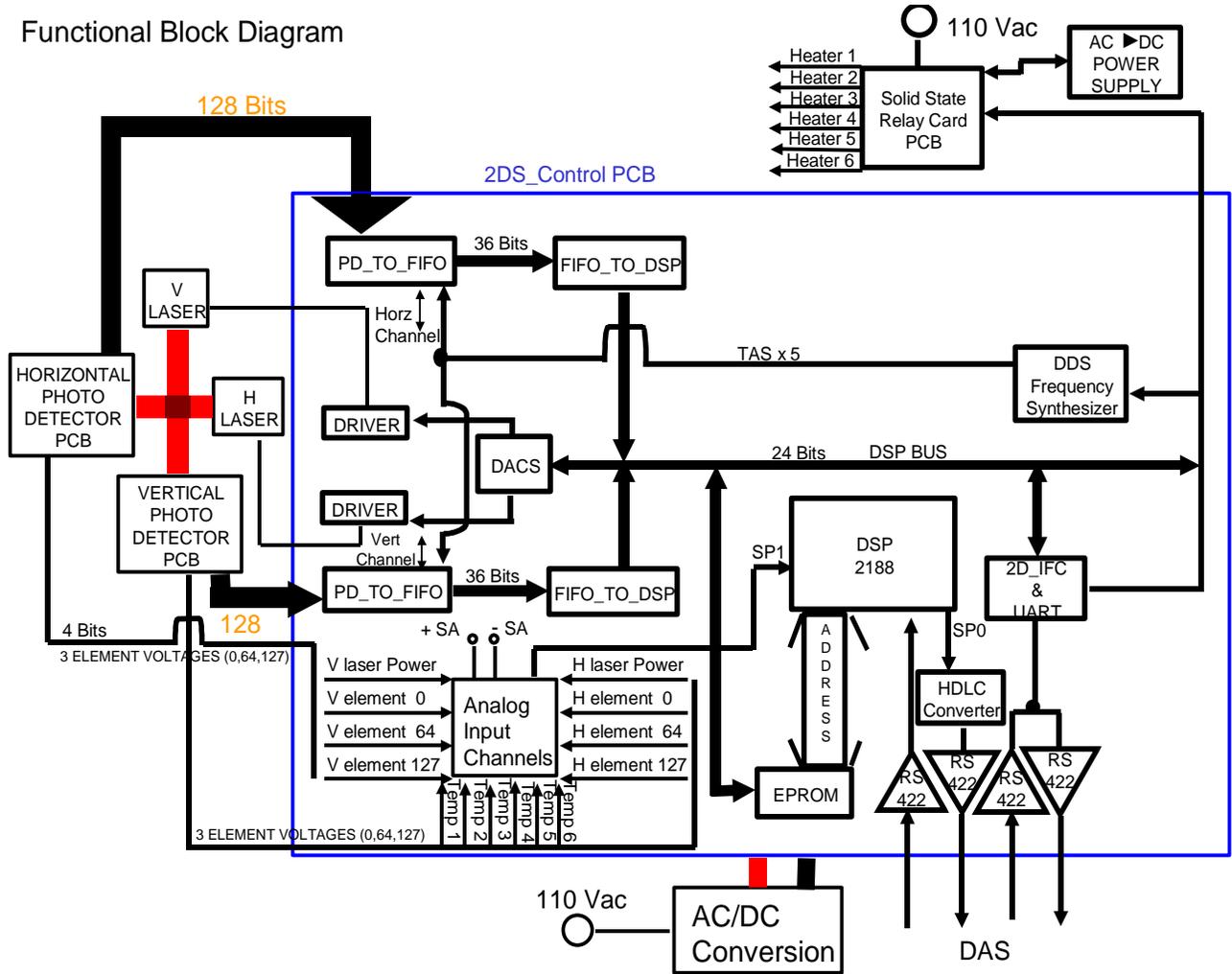110 Vac

AC/DC
Conversion

DAS

Figure 3.1 System block diagram.

4.0 Electronics Description

The electronics are physically divided into five printed circuit boards (PCB). The two photo-detector cards convert light signals into 128 binary signals and seven analog voltages. The digital vectors and the analog voltages are passed from the photo-detector cards to the 2D-S DSP card for processing. This card (2D-S_DSP) compresses the image vectors using a run-length encoding algorithm and then outputs data in one of four user selectable output formats. The available formats are:

1. Stereographic – Particle images will be taken when an image is detected simultaneously in both the vertical and horizontal channels. The channel triggers are linked such that when data is seen in one channel it forces the other to sample producing blank slices if there is no data in its field of view. Data are then collected from both channels and the particle is kept only, if there are non-blank pixels of data in both channels.
2. Both – All samples taken from both channels are sent to the DAS but the triggers for sampling data are not linked. The vertical and horizontal data can be aligned by keeping track of the slices that have elapsed in each..
3. Horizontal – Only data from the horizontal channel is output.
4. Vertical – Only data from the vertical channel is output.

These modes are discussed in greater detail in the data format section. The remainder of the electronics control and monitor the environment to support this function. . The schematic drawings for these cards and the master, wiring diagram is found in Appendix A.

4.1 Photo-detector Card Description

The photo-detector card consists of a single, 128-element, linear array of photo-diodes. Each diode produces a photo current that is proportional to the light incident on its active area. As a particle passes through the sample volume, a shadow passes over the array thereby reducing the current. The photo current is converted to a voltage with a two-stage trans-impedance amplifier. This voltage, the element voltage, is compared with a low-pass filtered, baseline restored version of itself to create a binary value from each diode. The binary value will be TRUE when the shadow exceeds fifty percent of the average element voltage. These binary values form the digital IMAGE vector that is sent to the control module. Seven of the element voltages, that include both end elements and the center element, are low-pass filtered, buffered and sent to the DSP card as analog voltages. The end elements are monitored while aligning the optics to aid centering the laser beam on the array. The center diode is used to adjust the laser intensity until the center pixels are nearly at saturation. The photo-detector cards interface to the control module through a pair of high density, controlled impedance cables. These cables are terminated at the DSP card with series 100-ohm resistors.

4.2 2D-S DSP Card Description

The 2D-S DSP Card houses the data compression circuitry and the intelligence to integrate the various subsystems of the 2D-S probe into a robust airborne instrument. Image processing requires most of the processing time of the DSP but other functions are performed to maintain an environment that is compatible with a high-speed electro-optical system. The processor in the 2D-S is an Analog Devices ADSP2191 that operates at 150 MIPS. This DSP is a fixed point, 16-bit model with on-chip program and data memory and programmable synchronous serial ports. The 2D-S code is written in C with a few assembler subroutines and inline macros. An off-chip watchdog timer is provided to prevent the processor from hanging thereby leaving the heaters uncontrolled. The program is stored in a single 8-bit EPROM and is booted into internal program memory at startup.

The most critical function provided by the control module is the compression and integration of two 128-bit image vectors that are sampled at frequencies up to 18 M Hz. The compression is done in three stages using complex programmable logic devices (CPLD) and the digital signal processor. The compression stages are described below.

4.2.1 Stage 1 compression

The first stage of compression for each channel is done in a single CPLD that has been named PD_TO_FIFO. A digitally synthesized oscillator (DDS) that operates at five times the slice sample rate clocks this stage. The digital vector is qualified with a bit-mask vector so pixels that are stuck in the TRUE state can be digitally removed thereby eliminating "streaking" pixels. A state machine samples the qualified vector once every fifth clock cycle and determines if any pixels are TRUE. If so, the state machine sequentially writes the quadrants of the image vector, that contain set pixels, into a 36-bit, first in first out (FIFO) memory along with the quadrant number and two identifying "tag" bits.

The PD_TO_FIFO PLD maintains a free-running, 32-bit counter that is incremented each sample interval. This counter is written to the FIFO at the completion of each particle so the channel data can be aligned during post processing. If the average number of slices being read by the processor does not equal the number being written by the PD_TO_FIFO PLD the FIFO will fill and data will be missed. The state machine monitors the ALMOST_FULL signal that the FIFO produces. When the FIFO is almost full, the state machine will do the following:

1. Complete the current slice being processed.
2. Write the timing word that defines the end of the last particle and the start of the overload period.
3. Enter the overload state in which no particle data is written to the FIFOs. The overload period will continue until the FIFO is fully empty. In STEREO mode, the FIFOs of

both channels will have to be empty for the overload state to end. Note that the free running timing word counter does increment during this period.

4. When the overload period ends the timing word will be written to the FIFO and sampling will resume. Note that the particle record identifies whether a timing word indicates the end of a particle or the end of the overload period

The output format of the PD_TO_FIFO CPLD is listed in table 4.1.1.

Table 4.1.1 Stage One compression output format

Bit 35	Bit 34	Bit 33	Bit 32	Bit 31 - 0
0 – Image Word	1-First Quad in slice	Quad MS bit	Quad LS bit	Quadrant Data
1 – Timing Word (TW)	0 – TW at end of particle 1 – TW at end of Overflow	Not Used	Not Used	Timing Word value

Note that timing words are 32-bit unsigned integers that roll from $(2^{32} – 1)$ to 0.

The PD_TO_FIFO logic can operate independently as described above or can operate in a linked mode for producing stereo image data. When the DSP operates the front end in the linked mode, a channel will write at least one word of quadrant data to the FIFO if a particle is seen in either channel. If a channel is writing a slice because the other channel is seeing data while its own data is null, the quadrant data will be 0, the quadrant number will be 3, the first bit will be set and the Image/Timing bit will be clear. (data = 0x700000000). While operating in the linked mode, the state machine will enter the overload state when EITHER channel's FIFO becomes almost full and will return to the sampling state when BOTH channel FIFOs are empty. The logic for this linkage utilizes the passing of a Particle In Array (PIA) signal between the PLDS as well as by sharing the FIFO status lines. A single control line from the DSP enables the linkage mechanism. Note that the channels are either fully linked or completely independent.

4.2.2 Stage 2 compression
The second stage of compression is basically a 36-bit latch and multiplexer that presents data to the 16-bit DSP data bus based on an IO address.   It does however, shift the quadrant and tag bits into the proper positions for the DSP to calculate various parameters efficiently and it produces a null slice bit when the interlocked function writes a null slice. This bit allows the DSP to count the null slices without reading the quadrant data. This function is implemented in a single CPLD that has been named FIFO_TO_DSP. The CPLD reads and latches the 36 bits from a channel FIFO when the tag register is read. The most significant and least significant 16-bit words that contain the quadrant data can be read. Table 4.2.2 lists the memory map and bit locations for this circuit.

Table 4.2.2 FIFO_TO_DSP register map

Address	FIFO to DSP Description
0	Horizontal Tags Bit 15: 1 – Timing Word 0 – Image Word Bit 14: FIFO Empty Bit 6-5: Quadrant Number Bit 13: Null Image Slice Bit 0: First Quadrant of image slice
1	Horizontal Most Significant Word
2	Horizontal Least Significant Word
3	Vertical Tags Bit 15: 1 – Timing Word 0 – Image Word Bit 14: FIFO Empty Bit 6-5: Quadrant Number Bit 13: Null Image Slice Bit 0: First Quadrant of image slice
4	Vertical Most Significant Word
5	Vertical Least Significant Word

4.2.3 Stage three compression and output data formats

The DSP performs the third stage of image data compression during which the final data blocks are built and sent to the data system. During this stage of compression, the DSP converts the binary image data that is read as addressed quadrants into 7-bit run-length encoded words. This format allows a "typical" 128-bit slice with one region having SHADED bits to be compressed into a single 16-bit word with no loss of information. Note that timing words are not compressed as their true binary nature will not compress effectively with this compression algorithm. The DSP generates different frames of data that are concatenated into a continuous stream that is then blocked into 4096 byte blocks that are sent to the data system.   Thus particle frames can and usually will be split across buffer boundaries. Because a single particle event can exceed the buffer length, a particle event can span across multiple particle frames. Particle events are identified with the ending timing word. Particle frames indicate whether or not a timing word is included with flag bits that are located in the length. The particle count indicates the number of particle events detected and will thus not increment for particle frames that make up an event.

4.2.3.1 Image formats

The DSP can operate the probe in one of four compression modes but the same output data block is used for all modes. When operating in one of the non-stereo modes, either the number of horizontal words or the number of vertical words will be zero. The unused channel will be disabled. When unloading all data from both channels, (BOTH mode) the first stage compression CPLDs will be operated in the unlinked mode but stereo image particles can be created in post processing by aligning images with their timing words. Table 4.2.3.1 lists particle frame formats produced by the 2D-S. Words in the following formats are 16 bits each unless otherwise specified.

If a partially completed block receives no data for 1 second, the unfilled portion will be marked as empty, by marking the flag word with "NL", and the block will be sent to the data system. This mechanism allows the data system to monitor the housekeeping even when the probe is in clear air.

Table 4.2.3.1 Particle frame format

Word	Particle Frame Description
1	Flag word ASCII "2S"
2	NH Bits 0 –11 Number of horizontal words – Includes Timing Words if present Bit 12 – 1 = Timing Words not found Bit 14—FIFO Empty (means the next particle was cut off) Bit 15 – The last two words of the horizontal data record are overload timing words
3	NV Bits 0 –11 Number of vertical words – Includes Timing Words if not same as the horizontal Timing Word and the TW were found. Bit 12 – 1 = Timing Words not found Bit 13 – Timing Word mismatch Bit 14- FIFO Empty before timing word found Bit 15 – The last two words of the vertical data record are overload timing words.

4	Particle Count – Total number of particles events detected
	. – Note:
	    1. If timing words are not found, the next particle record will be a continuation of this record and thus the particle count will remain the same for all particle records that make up the particle event.
	    2. In stereo mode, a particle event will continue until timing words are

Word	Particle Frame Description
	found in both channels. 3. In BOTH mode a separate particle count and slices processed through the current record is maintained for each channel.
5	Number of slices in this particle. During a multi-particle record event this parameter will be the number of slices detected during the event through the current record. In STEREO mode, the number of slices reported is from the horizontal channel. By the end of the event the number of vertical slices will always equal the number of horizontal slices. In BOTH mode this will represent the number of slices in a particle event for the channel that contains data.
6<->5 + NH	Horizontal Image Data Bit Number Value Description 15 0 Indicates that this is an image word 14 1 Indicates the start of a slice (FIRST) 0 Indicates the continuation of a slice 7 - 13 Number of shaded pixels (bit 13 is MSB) 0 - 6 Number of clear pixels (bit 6 is MSB) 0x7fff = 128 clear bits 0x4000 = 128 set bits

	Unless bit 12 of the horizontal length is set, the last two words of the horizontal image data are the timing words that are generated by a free running counter in the PD2FIFO CPLD. This counter increments once every slice interval regardless of the state of the compression state machine (overload or normal compression mode).
	        Word 1 - Bits 16 - 31 of the counter
	        Word 2 - Bits 0 - 15 of the counter

6+NH <-> 5+NH+NV	Vertical Image Data (Same format as horizontal image data)

	Unless bit 12 of the vertical length is set, the last two words of the vertical image data are the timing words that are generated by a free running counter in the PD2FIFO CPLD. This counter increments once every slice interval regardless of the state of the compression state machine (overload or normal compression mode). When the probe is operating in the stereo mode this timing word is NOT present as the vertical timer MUST equal the horizontal timer.
	        Word 1 - Bits 16 - 31 of the counter
	        Word 2 - Bits 0 - 15 of the counter

Notes:	. 1. When the FIFO is nearly full the PD2FIFO CPLD will go into overload and will write the timing word of the overload start time into their

Word	Particle Frame Description
	FIFOs. When the overload period ends the overload timing word is written to the FIFO. The overflow timing words are written in a particle record that has no image data (slices = 0 and NH or NV = 2). 2. When in STEREO mode the probe will record a single particle event that extends across as many particle frames as required until matching timing words are found in both channels. 3. When in stereo mode the channels will enter and leave overload at the same time so only one set of timing words is sent to the data system.

4.2.3.2 Automask frame format

When the probe initializes and when the data system requests, the 2D-S executes an algorithm to determine if any bits are stuck on or are toggling on and off. This automask algorithm is an iterative procedure that performs the following.
1. Probe enables all pixels.
2. Probe reads the FIFO data until a timeout or until a fixed number of slices (AM_MAXSLICE = 100) slices have been read.
3. These data are read and the number of times that a pixel is shaded is counted.
4. If the percentage of shaded pixels exceeds a threshold (AM_REJECT_PERCENTAGE = 10 %) the pixel will be masked.
5. Steps 2-4 will be repeated until the probe is quiet or until less than a programmable number of slices have been generated within 1 second (AM_MINSLICE_TO_RUN = 10) slices are found with set pixels in them.
6. The mask will be sent to the data system.

Note that this mask function can be run on either or both channels. When this routine is run a mask block is built. Upon receipt of a setup packet, the probes 32 bit timing word is written to the mask block, which is then sent to the data system. This allows the data system to synchronize its system clock to the probe time. The format of this block is given in table 4.2.3.2.

Table 4.2.3.2 Mask data block format

Word	Mask Data Description
1	Flag ASCII "MK"
2 -3	32 bit Timing Word
4 - 11	Horizontal mask bits
12 - 19	Vertical mask bits
20 - 21	Timing Word at start of routine
22 - 23	Timing Word at end of routine

4.2.3.3 Housekeeping frame format

Once a second the housekeeping data are sent in the housekeeping packet that is described in table 4.2.3.3

Table 4.2.3.3 Housekeeping frame format

Word	Housekeeping Frame Description	C_0	C_1	Units
1	Packet ID words ASCII "HK"	0.0	1	
2	Horizontal Element 0 Voltage	0.0	0.00244140625	Volts
3	Horizontal Element 64 Voltage	0.0	0.00244140625	Volts
4	Horizontal Element 127 Voltage	0.0	0.00244140625	Volts
5	Vertical Element 0 Voltage	0.0	0.00244140625	Volts
6	Vertical Element 64 Voltage	0.0	0.00244140625	Volts
7	Vertical Element 127 Voltage	0.0	0.00244140625	Volts
8	Raw positive power supply	0.0	0.00488400488	Volts
9	Raw negative power supply	0.0	0.00488400488	Volts
10	Horizontal Arm (Tx) Temp	1.6	0.00244140625	°C
11	Horizontal Arm (Rx) Temp	1.6	0.0244140625	°C
12	Vertical Arm (Tx) Temp	1.6	0.0244140625	°C
13	Vertical Arm (Rx) Temp	1.6	0.0244140625	°C
14	Horizontal Tip (Tx) Temp	1.6	0.0244140625	°C
15	Horizontal Tip (Rx) Temp	1.6	0.0244140625	°C
16	Rear Optical Bridge Temp	1.6	0.0244140625	°C
17	DSP Board Temp	1.6	0.0244140625	°C
18	Forward Vessel Temp	1.6	0.0244140625	°C
19	Horizontal Laser Temp	1.6	0.0244140625	°C
20	Vertical Laser Temp	1.6	0.0244140625	°C
21	Front Plate Temp	1.6	0.0244140625	°C
22	Power Supply Temp	1.6	0.0244140625	°C
23	-5V Supply	0.0	0.00488400488	Volts
24	+5V Supply	0.0	0.00488400488	Volts
25	Can internal pressure	-3.846	0.018356	PSI
26	Horizontal Element 21 Voltage	0.0	0.00244140625	Volts
27	Horizontal Element 42 Voltage	0.0	0.00244140625	Volts
28	Horizontal Element 85 Voltage	0.0	0.00244140625	Volts
29	Horizontal Element 106 Voltage	0.0	0.00244140625	Volts
30	Vertical Element 21 Voltage	0.0	0.00244140625	Volts
31	Vertical Element 42 Voltage	0.0	0.00244140625	Volts

Word	Housekeeping Frame Description	C_0	C_1	Units
32	Vertical Element 85 Voltage	0.0	0.00244140625	Volts
33	Vertical Element 106 Voltage	0.0	0.00244140625	Volts
34	Vertical particles detected	0.0	1	counts
35	Horizontal particles detected	0.0	1	counts
36	Heater Outputs (1 if on) Bit 0 – Zone 0 Bit 1 – Zone 1 Bit 2 – Zone 2 Bit 3 – Zone 3 Bit 4 – Zone 4 Bit 5 – Zone 5 Bit 6 – Zone 6 Bit 7 – Zone 7 Bit 8 – Zone 8 Bit 9 – Zone 9 Bit 10 – Zone 10 Bit 11 – Zone 11 Bit 12 – Zone 12	0.0	1.0	Bit Map
37	Horizontal Laser Drive	0.0	0.001220703	Volts
38	Vertical Laser Drive	0.0	0.001220703	Volts
39	Horizontal Masked bits (count)	0.0	1.0	Count
40	Vertical Masked bits (count)	0.0	1.0	Count
41	Number of stereo particles found	0.0	1.0	Particles
42	Number of timing word mismatches	0.0	1.0	Counts
43	Number of slice count mismatches	0.0	1.0	Counts
44	Number of horizontal overload periods	0.0	1.0	Counts
45	Number of vertical overload periods	0.0	1.0	Counts

46	Compression Configuration (bit mapped)
	Bits 1:0 Compression mode
	    0 – Stereo only
	    1 – Both channels
	    2 – Horizontal only
	    3 - Vertical only
	 Bit: 2 Timing Word reset performed
	Bits 3:15 unused
		0.0	1.0	Counts

47	Number of empty FIFO faults	0.0	1.0	Counts
48	Spare 2	0.0	1.0	Counts
49	Spare 3	0.0	1.0	Counts

Word	Housekeeping Frame Description	C_0	C_1	Units
50	TAS Floating Point Word 1			
51	TAS Floating Point Word 2			
52-53	Timing word	0.0	1.0	

Note that if a request for a new TAS has been received during the previous second, the timing word will be read and then the new TAS will be loaded.

4.2.4 Ethernet Probe Interface description

The 2D-S interface utilizes Ethernet TCP/IP protocol to implement a bi-directional data link. The probe has a theoretical upper transmission speed of 37 mega bits per second (MBPS) over an Ethernet 100BaseT connection. The probe data is passed as binary blocks that are a fixed length of 4098 bytes. The blocks may contain any combination of the following packets (frames): horizontal particle; vertical particle; housekeeping; and mask packets. In addition, the data system sends commands to the probe over the Ethernet connection.

The data packets are permitted to cross 4098 byte block boundaries. At least one HDLC buffer will be sent each second so the housekeeping data will be current. If an incomplete buffer is sent, the unused portion buffer will begin with the string "NL". *Note that this string will be in the ID position of what should be the next packet.*

4.2.5 Probe Commands

The 2D-S provides data system control over several functions on the probe. The following packets are decoded by the DSP.

Table 4.2.5.1 Set bit mask packet

Character Number	Set Mask Packet Description
1	Flag ASCII "C"
2	Packet Length – 36
3	Command - 1
4-19	Horizontal Mask
20 - 35	Vertical Mask
36	8-bit checksum of char 1-35

Set mask capability is provided for engineering purposes and should not be used in flight.

Table 4.2.5.2 Set True Air Speed clock packet

Character Number	TAS Packet Description
1	Flag ASCII "C"
2	Packet Length – 8
3	Command – 2
4-7	True Air Speed clock frequency IEEE – Big endian format
8	8-bit checksum of char 1-7

The true air speed, entered by the user in meters per second, is converted to floating point and sent to the probe in a TAS packet. The probe can be modified to take in a TAS from an external source, such as an ASCII data stream over an asynchronous serial port, and update the probe. Please contact SPEC, Inc., if you wish to have your probe modified to do this.

Table 4.2.5.3 Command packet

Character Number	Command Packet Description
1	Flag ASCII "C"
2	Packet Length – 66
3	Command – 3
4 Note 1	Command word 1 (Heater Enables) Bit 0 – Zone 0 Bit 1 – Zone 1 Bit 2 – Zone 2 Bit 3 – Zone 3 Bit 4 – Zone 4 Bit 5 – Zone 5 Bit 6 – Zone 6 Bit 7 – Zone 7
5 Note 1	Command word 2 Bit 0 – Zone 8 Bit 1 – Zone 9 Bit 2 – Zone 10 Bit 3 – Zone 11 Bit 4 – Zone 12 Bit 5 - 7 - Spare
6	Command word 3

Character Number	Command Packet Description

	Bit 0 – Build Horizontal Mask
	Bit 1 – Build Vertical Mask
	Bit 2-3 - Compression Mode
	    0 – Stereo only
	    1 – Both channels
	    2 – Horizontal only
	    3 – Vertical only
	Bit 4 Horizontal laser mode
	    0 – Automatic
	    1 - Manual
	Bit 5 Vertical laser mode
	    0 – Automatic
	    1 – Manual
	Bit 6 – Sync Probe - Resets interarrival counter (unused)
	 Bit 7 – Spare

7	Spare Command byte 4 – Spare
8 - 9	Heater 0 threshold (–2040 to +2040) (Horizontal Transmit Arm Heater)
10-11	Heater 1 threshold (–2040 to +2040) (Horizontal Receive Arm Heater)
12-13	Heater 2 threshold (–2040 to +2040) (Vertical Transmit Arm Heater)
14-15	Heater 3 threshold (–2040 to +2040) (Vertical Receive Arm Heater)
16-17	Heater 4 threshold (–2040 to +2040)
18-19	Heater 5 threshold (–2040 to +2040)
20-21	Heater 6 threshold (–2040 to +2040)
22-23	Heater 7 threshold (–2040 to +2040)
24-25	Heater 8 threshold (–2040 to +2040)
26-27	Heater 9 threshold (–2040 to +2040) (Horizontal Laser Heater)
28-29	Heater 10 threshold (–2040 to +2040) (Vertical Laser Heater)
30-31	Heater 11 threshold (–2040 to +2040)
32-33	Heater 12 threshold (–2040 to +2040)
34-35	Horizontal Laser power (0 to 4095)
36-37	Vertical Laser power (0 to 4095)
38-39	Horizontal AM_MAXSLICE (default = 100)
40-41	Horizontal AM_REJECT_PERCENTAGE * 100(default = 2%)

Character Number	Command Packet Description
42-43	Horizontal AM_MINSLICE_TO_RUN (default = 1)
44-45	Vertical AM_MAXSLICE (default = 100)
46-47	Vertical AM_REJECT_PERCENTAGE * 100(default = 2%)
48-49	Vertical AM_MINSLICE_TO_RUN (default = 1)
50-51	Spare control word 1 - Number of 4098 blocks per second
52-53	Spare control word 2 – Baud Rate clock divider f = 75M/(wd + 1)/2 This was originally for HDLC ethernet control and is no longer used.
54-55	Spare control word 3 – Synchronous Overload
56-57	Spare control word 4 – Proportional portion of armtip PID control. This value is divided by 10 million and then used as floating point
58-69	Spare control word 5 – Integral portion of armtip PID control This value is divided by 10 million and then used as floating point
60-61	Spare control word 6
62-63	Spare control word 7
64-65	Spare control word 8
66	8-bit checksum of char 1-37

Notes:
1. Heater control bits in characters 4 and 5 correspond to the labeled heater thresholds in characters 8/9 through 32/33, e.g. bit 0 of character 4 is the control bit for the horizontal transmit arm heater.

The command packet consists of converted values and bit fields taken from the command window in the data system graphical user interface (GUI). The heater thresholds and laser power integers are passed with the most significant byte first.

The spare control words 1 and 2 specify the number of 4098 blocks that can be sent from the 2D-S on board DSP, and how fast, in bits per second, to send them. At this time, SPEC recommends not changing default values. These values are entered in hexadecimal format, with any letters A through F entered in capital letters in the command window GUI. A general guideline is that the number of blocks sets the number of bits per second transmitted, not counting the overhead of TCP/IP connections:

BPS = Blocks x 4098 words x 16 bits / word

Once the number of blocks is chosen, a transmission frequency greater than the BPS above must be set. For example, the current defaults for Spare control words 1 and 2 are 50 (hex) and 9. This sets a bits per second transmission of 80_d x 4098 x8 = 5,245,440 bits per second. The transmission frequency from the DSP (not over the Ethernet) is 75 MHz / (9 + 1) / 2 = 15 MBPS.

4.2.7 Software Description

The software in the DSP stays in a tight loop processing image data from the main level. While in this loop image packets are built and sent to the data system as the data requires and the data system allows. When the net flow of data exceeds the capability of the data system it shuts down flow by de-asserting the CTS line. If the probe is sampling particles the FIFO will fill and the probe will go into overload and time this period. The software keeps statistics on the average number of slices in the particles that it is sending to the data system as well as the data rate to determine if a pixel is blocked thereby causing a "streaker". When this occurs the soft ware will initiate a routine that locates any stuck pixels and masks them out. This routine permits a few buffers to pass through the system so the probe can collect statistics on each pixel (assuming there is data to examine). If a pixel is shaded more than 70 percent of the time it is considered stuck. If stuck pixels are found they are masked and the probe enters a state in which the pixels are checked once a minute. When the probe performs the stuck pixel check it builds a mask block (see table 4.2.3.3) that contains the mask bits and sends this to the data system.

The remainder of the software functions is initiated by interrupts. There are four sources of interrupt that are handled. First, the timer interrupt triggers the synchronous sampling of the analog channels and causes the heaters to update. If the software should hang for any reason, a watchdog timer will reset the DSP and force all heaters to the off state. Second, interrupts are generated when commands are received over the Ethernet. The interrupt routine blocks the data and responds to the request if the checksum is valid. Third, when high-speed blocks are being transmitted or the 2D interface interrupts are generated at the completion of each transfer. Fourth, the sixteen analog channels are operated through a synchronous serial interface that generates interrupts when analog data are read.

4.2.8 Control Module Connector descriptions

Each photo-diode card is interfaced to the control module through a 160 connection, controlled impedance ribbon cable that is manufactured by Samtec. The configuration of these cables is found in table 4.2.8.1. Note that there are 16 implicit ground connections.

Pin #	Description	Pin #	Description	Pin #	Description	Pin #	Description
1	Bit 0	2	Bit 1	81	Bit 80	82	Bit 81
3	Bit 2	4	Bit 3	83	Bit 82	84	Bit 83
5	Bit 4	6	Bit 5	85	Bit 84	86	Bit 85
7	Bit 6	8	Bit 7	87	Bit 86	88	Bit 87
9	Bit 8	10	Bit 9	89	Bit 88	90	Bit 89
11	Bit 10	12	Bit 11	91	Bit 90	92	Bit 91
13	Bit 12	14	Bit 13	93	Bit 92	94	Bit 93
15	Bit 14	16	Bit 15	95	Bit 94	96	Bit 95

Pin #	Description	Pin #	Description	Pin #	Description	Pin #	Description
17	Bit 16	18	Bit 17	97	Bit 96	98	Bit 97
19	Bit 18	20	Bit 19	99	Bit 98	100	Bit 99
21	Bit 20	22	Bit 21	101	Bit 100	102	Bit 101
23	Bit 22	24	Bit 23	103	Bit 112	104	Bit 103
25	Bit 24	26	Bit 25	105	Bit 114	106	Bit 105
27	Bit 26	28	Bit 27	107	Bit 116	108	Bit 107
29	Bit 28	30	Bit 29	109	Bit 118	110	Bit 109
31	Bit 30	32	Bit 31	111	Bit 110	112	Bit 111
33	Bit 32	34	Bit 33	113	Bit 112	114	Bit 113
35	Bit 34	36	Bit 35	115	Bit 114	116	Bit 115
37	Bit 36	38	Bit 37	117	Bit 116	118	Bit 117
39	Bit 38	40	Bit 39	119	Bit 118	120	Bit 119
41	Bit 40	42	Bit 41	121	Bit 120	122	Bit 121
43	Bit 42	44	Bit 43	123	Bit 122	124	Bit 123
45	Bit 44	46	Bit 45	125	Bit 124	126	Bit 125
47	Bit 46	48	Bit 47	127	Bit 126	128	Bit 127
49	Bit 48	50	Bit 49	129	GND	130	GND
51	Bit 50	52	Bit 51	131	DOF_H	132	DOF_V
53	Bit 52	54	Bit 53	133	VD_0	134	VD_64
55	Bit 54	56	Bit 55	135	VD_127	136	NC
57	Bit 56	58	Bit 57	137	GND	138	GND
59	Bit 58	60	Bit 59	139	NC	140	NC
61	Bit 60	62	Bit 61	141	NC	142	NC
63	Bit 62	64	Bit 63	143	NC	144	NC
65	Bit 64	66	Bit 65	145	VD_21	146	VD_42
67	Bit 66	68	Bit 67	147	VD_85	148	VD_106
69	Bit 68	70	Bit 69	149	NC	150	NC
71	Bit 70	72	Bit 71	151	NC	152	NC
73	Bit 72	74	Bit 73	153	NC	154	NC
75	Bit 74	76	Bit 75	155	NC	156	NC
77	Bit 76	78	Bit 77	157	NC	158	NC
79	Bit 78	80	Bit 79	159	NC	160	NC

Table 4.2.8.1

The remaining connections to the control module are made through a pair of 44-pin high density D-sub connectors.   Table 4.2.8.2 defines the analog input connector while Table 4.2.8.3 defines the digital IO connector.

J1 Pin	Description	J1 Pin	Description	J1 Pin	Description
1	AD590_0+	16	AD590_0-	31	GND
2	AD590_1+	17	AD590_1-	32	GND
3	AD590_2+	18	AD590_2-	33	GND
4	AD590_3+	19	AD590_3-	34	GND
5	AD590_4+	20	AD590_4-	35	GND
6	AD590_5+	21	AD590_5-	36	GND
7	AD590_6+	22	AD590_6-	37	GND
8	AD590_7+	23	AD590_7-	38	GND
9	AD590_8+	24	AD590_8-	39	GND
10	AD590_9+	25	AD590_9-	40	GND
11	AD590_10+	26	AD590_10-	41	GND
12	AD590_11+	27	AD590_11-	42	GND
13	HORZ_LASER_SET	28	GND	43	GND
14	VERT_LASER_SET	29	GND	44	GND
15	GND	30	GND		

Table 4.2.8.2 Analog D-sub 44 connector definition

J4 Pin	Description	J4 Pin	Description	J4 Pin	Description
1	HD_DAT +	16	HD_DAT -	31	ASY_CMD+
2	HD_CLK +	17	HD_CLK -	32	ASY_CMD-
3	ASY_STAT+	18	ASY_STAT-	33	SER_CLK+
4	HD_CTS	19	HD_CTS -	34	SER_CLK-
5	SHADOW_OR-	20	IRQ+	35	SER_DAT+
6	SHADOW_OR+	21	IRQ-	36	SER_DAT-
7	GND	22	GND	37	SER_TFS+
8	HEATER_EN0	23	HEATER_EN1	38	SER_TFS-
9	HEATER_EN2	24	HEATER_EN3	39	GND
10	HEATER_EN4	25	HEATER_EN5	40	+7V
11	HEATER_EN6	26	HEATER_EN7	41	-7V
12	HEATER_EN8	27	HEATER_EN9	42	PWR_RTN
13	HEATER_EN10	28	HEATER_EN11	43	HEATER_EN14
14	HEATER_EN12	29	HEATER_EN13	44	HEATER_EN15
15	AD590_12+	30	AD590_12-		

Table 4.2.8.3 Digital D-sub 44 connector definition (J4)

4.3 DC Power Supply cards

The 2D-S utilizes a high-efficiency 28V DC to +-7V DC converter system. The +-7V DC is sent over many wires to the 2D-S instrument, from the airplane cabin or remote location. Sensing circuitry on the power board of the instrument sends a signal back to the remote DC/DC converter indicating the received voltages. The DC/DC converters then adjust the local voltage up or down to maintain +-7V at the load. The DC/DC converters are designed so that if they are powered up without the 2D-S attached, they will provide their own feedback signals to drive the output to approximately +-7V.

5.0 2D-S Optical System Description

The 2D-S optical system forms a shadow image of particles passing through the instrument sample volume. The instrument has a vertical channel and a horizontal channel to record two views of particles passing through the overlap region. Each channel has transmitting optics subsystem and receiving optics subsystem. The transmitting optics consist of a fiber coupled diode laser and beam shaping optics and the receiving system consists of imaging optics and a linear photodiode array.
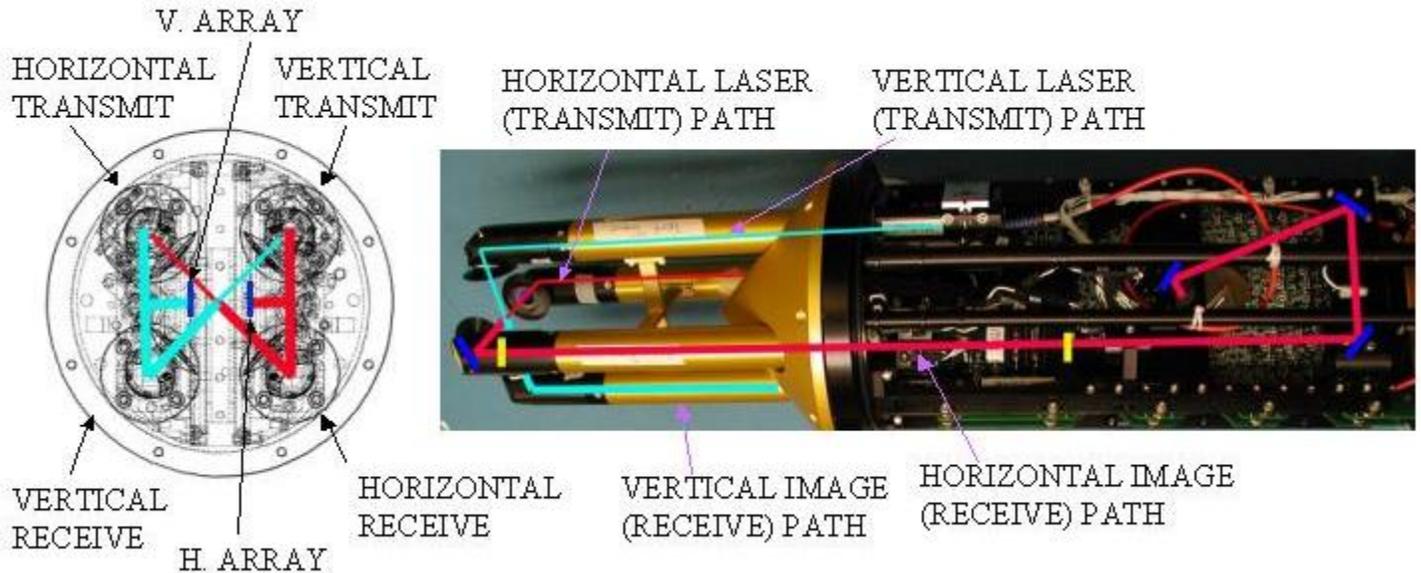
Figure 5.1. 2D-S Optical system laser and image paths.

Figure 5.1 shows the relationship of the 2D-S arms and the optical paths. The horizontal and vertical channels each have a transmit arm and receive arm. The laser travels down the transmit arm and is folded 90 degrees through the sample volume. The laser illuminates the object plane, located half way between the respective transmit / receive arms, and travels into the receive arm, through the imaging system to the linear array. In the absence of a particle passing through the sample volume, the laser illuminates the 128 elements of the linear photodiode array.

When a particle passes through the sample volume, an image of the particle is formed on the linear array. If the contrast of this image is great enough to reduce the illumination on an element in the array by 50%, that element is shadowed. An imaging system with a ~5X magnification is used to form the image of the particle on the linear array.
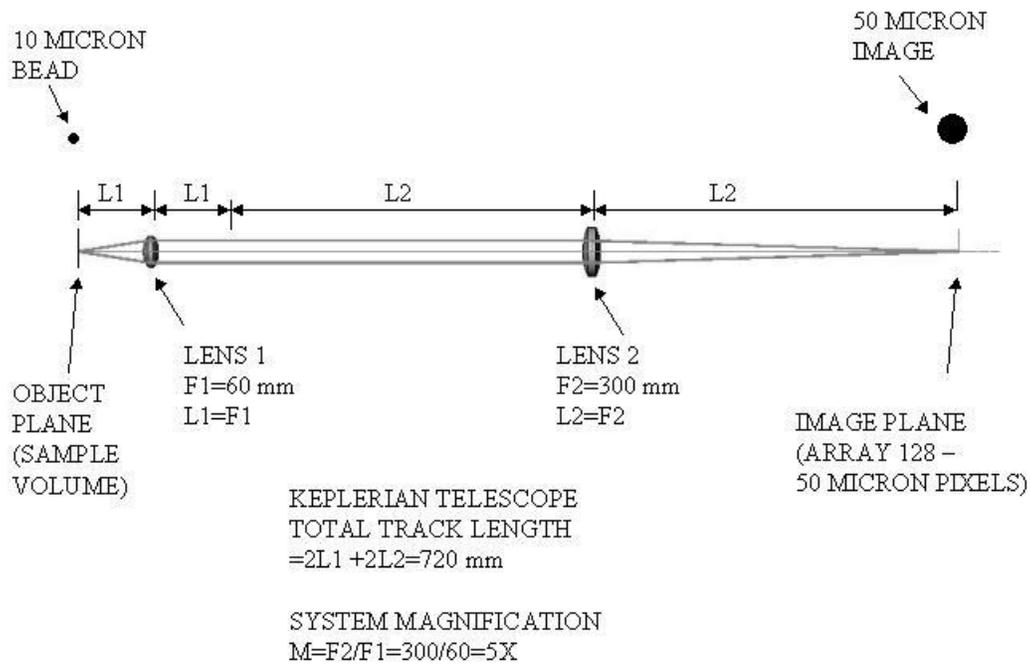
Figure 5.2. Simplified 2D-S imaging optical system.

Figure 5.2 shows the basic layout for the imaging optical system. The system uses two achromat lenses and is based on a Keplerian telescope. The ratio of the lens focal lengths determines the magnification, 300/60, or ~5X in this case. The object plane is located at the center of the transmit/ receive arms for each channel, and the image is formed on each linear array, respectively. A particle passing exactly through the object plane is at the best focus, and gradually becomes out of focus as it moves away from the object plane. Based on the theoretical magnification, a 10 micron drop passing exactly through the object plane will appear as 50 microns at the array, and shadow 1 element. **The exact element magnification for each channel should be determined experimentally by dropping beads of a known size through the sample volume or by moving a wire of a know size through the sample volume. SPEC can only guarantee the pixel size to ±10% 10 microns (9-11 microns).**
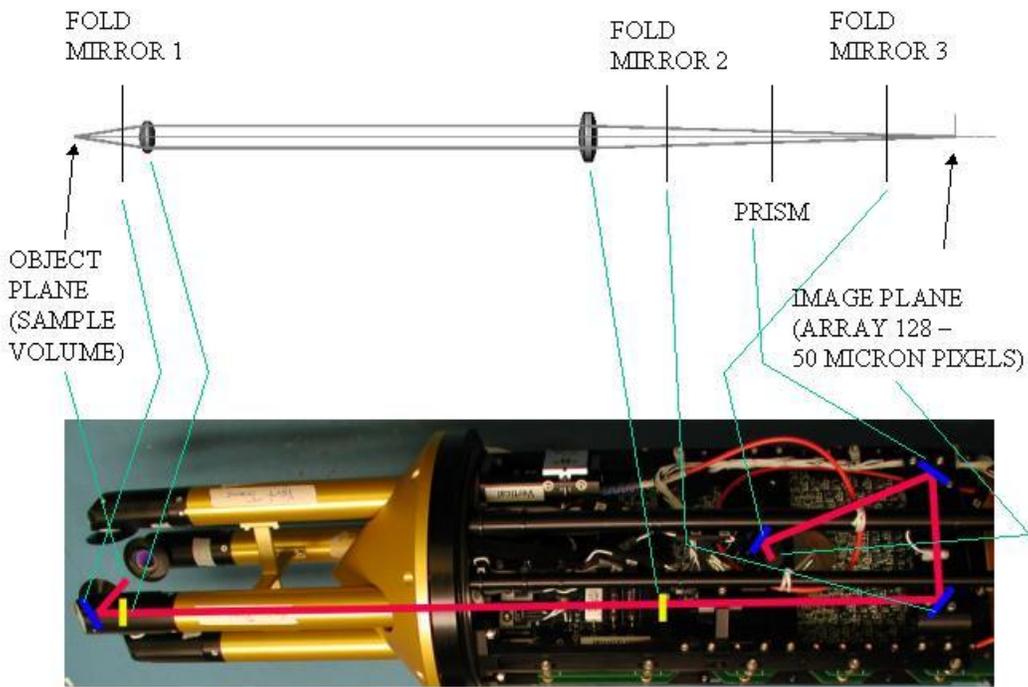
Figure 5.3. Location of folding elements in horizontal image path. Not shown is a fourth fold mirror now used between fold mirror 3 and the image plane.

In order to fit this long path system into the 2D-S instrument it is necessary to fold the optical path in several places. **Figure 5.3** shows the locations of the fold mirrors in the ray trace diagram and in the actual horizontal image system in the 2D-S. The optical imaging systems for the horizontal and vertical channels are mirror images of one another with one exception. The horizontal channel uses a right angle prism and the vertical channel uses a roof prism to invert the image. This is because the same array board is used for both channels with the array located at 45 degrees to the long axis of the board. To get the arrays to overlap in the sample volume, it is necessary to invert one of the images.

The optical system of mirrors and lens has been precisely configured at SPEC and should NEVER be moved or disrupted.

6.0 Set-up of 2D-S Probe in a PMS Can on an Aircraft

On a research aircraft the 2D-S is installed in a standard PMS can with an Amphenol 24 pin connector inside the can. The cabling from the PMS can to the fuselage where they meet the data rack power supply may require connections at the pylon, wing tip, and the bulkhead depending on the aircraft and placement of the data system

1. For this example we will assume the 2D-S will be installed in a PMS can that extends off the wingtip with power and data communication wiring running through the wing terminating at a bulkhead connector inside the fuselage.
2. When shipping the probe to any location it should be set up in a lab setting upon arrival to make sure nothing was damaged in shipping, see Section 1.2. Once verified that it is working and lasers are aligned then the task of installing it on an aircraft can continue.
3. First the cables need to be tested for continuity between the can and the bulkhead connectors. The process to test continuity is a two-man operation with radio communication. A technician at the PMS can should connect an Amphenol extension cable to the connector at the rear of PMS can so that he has easy access to the pins on the Amphenol connector. A second technician at the bulkhead box, will have an ohmmeter to test the resistance at each of the pins on the cables. It's important to work with the aircraft electrician and have a copy of their bulkhead to PMS can wiring. Cables will likely need to be fabricated to match aircraft specific wiring. To test the continuity the technician at the Amphenol connector will short a wire between two pins. Based on the electronics schematic drawing, the technician with the ohmmeter will test the resistance at the corresponding pins at the bulkhead connection. If the resistance across two pins is infinite then there is a break in the continuity in the wiring from the plugs to the PMS can. If this occurs the wiring has to be tested at each connection to find the break in the wiring.
4. Once the wiring from the bulkhead to the PMS can has been checked, repeat the process with cables you intend to plug into bulkhead that terminate at the power supply box. Check for continuity from the cable connecting to the power supply box to the amphenol.
5. Once continuity has been verified and correct the technician can start plugging connectors into the data rack power supply. Make sure the Data Rack's Power switch on the front is flipped **OFF** and the 2D-S is **NOT** installed in the PMS can. Connect cables in the order as described in the laboratory setup
6. **Note about Ethernet use with existing in Research Aircraft wiring:** The Ethernet connection allows for direct transmitting and receiving of data to the data acquisition computer at speeds of 100 Mbps. When crossing different types of wiring there may be jumps in impedance. Slowing the transmission speed may be required if there is significant noise in your data or lack of communication with the probe. You may need to set the Ethernet card speed to 10 Mbps.

7. Before the 2D-S probe can be installed the voltages at the amphenol connector have to be tested to make sure the voltages are reasonable and in line with the electronics schematic. Turn the power on to the data rack power supply by flipping the switch on in the front of the data rack power box. A red light and cooling fan should turn on. An operator at the PMS can with an amphenol extension cable installed will test the voltages with a voltmeter, just as described in the laboratory setup.

> **WARNING: DIRECT CONTACT WITH 115V 60 HZ AC CAN CAUSE DEATH**

8. Now the data rack's power supply can be turned off. The amphenol extension test cable can be removed from the PMS can. The data collection computer can be installed. If possible before installing the probe in the PMS can you may want to run the probe from the can using the amphenol extension cable. Then you can verify that the probe is powering on with its fans and lights operating.

9. Handling the 2D-S in the appropriate manner, align the probe horizontally outside the PMS can. Rotate the probe so that the amphenol connector on the probe and in the can line up. Next check that the screws on the front plate match up closely with the screw holes on the PMS can.

10. When operating the 2D-S in humid environments, you may wish to zip-tie small sealed packets of desiccant to the main frame of the probe. Ensure that it does not interfere with optical paths or touch any electronics. It may be necessary for the desiccant to be replaced after every flight.

11. Slowly insert the probe into the can. Although all cables should be fastened and clear of the edges, make sure no cables get pinched between the probe and the can as it is slid in slowly. As you approach the end, again make sure the screws line up correctly and then make the final move for the probe to mate with the amphenol connector at the end of the PMS can. When the 2D-S is in the can, do not rotate the probe more that a few degrees, especially when near the amphenol connectors. If the alignment is in question during insertion, remove probe from can, rotate and re-insert.

12. Insert #8-32x1" socket head screws into the front plate of 2D-S to fasten it to the PMS can. Do not over tighten.

6.1 Real-Time Operation Troubleshooting

Stuck Bits
The biggest concern the operator should have during operation is watching for errant, noisy pixels, or stuck bit. A stuck bit is defined as a single bit or pixel that stays shaded for a predefined number of contiguous samples resulting in vertical black lines of particle data. These black lines are caused by a number of factors including contamination on the probe windows, condensation, and periods between thermalization. The 2DS GUI allows the user to determine the actions taken when a stuck bit is found. The options, which are listed under Tools / Stuck Bit Handling, are as follows:

1. **Do Nothing** - keeps recording regardless of noise
2. **Notify User** - a window will pop up alerting the operator of a problem, he can then send a command packet to build a new mask.
3. **Resend Mask with Bits Masked Out** - sends the mask to the probe with the identified stuck bits that are to be ignored by the probe.
4: **Initiate Automask** - This option starts an automask where the mask algorithm should identify the stuck bits automatically. The mask algorithm uses the user set the limits in the command window in the H/V AM (Automask) boxes. The MaxSlice says if there is more than this many time slices (apparent particles) in one second then run the Automask algorithm. The Rej % is the threshold; when a single pixel makes up more than this percent of total pixel counts then it will be masked out. The MinSlice states that when the algorithm is running, and there is less than this number of time slices in the second then the Automask algorithm will cease.

The number of contiguous samples (with the same bit shaded) which defines a stuck bit is user defined in the "Periodic Mask Generation" Menu under "Tools". See Figure below.
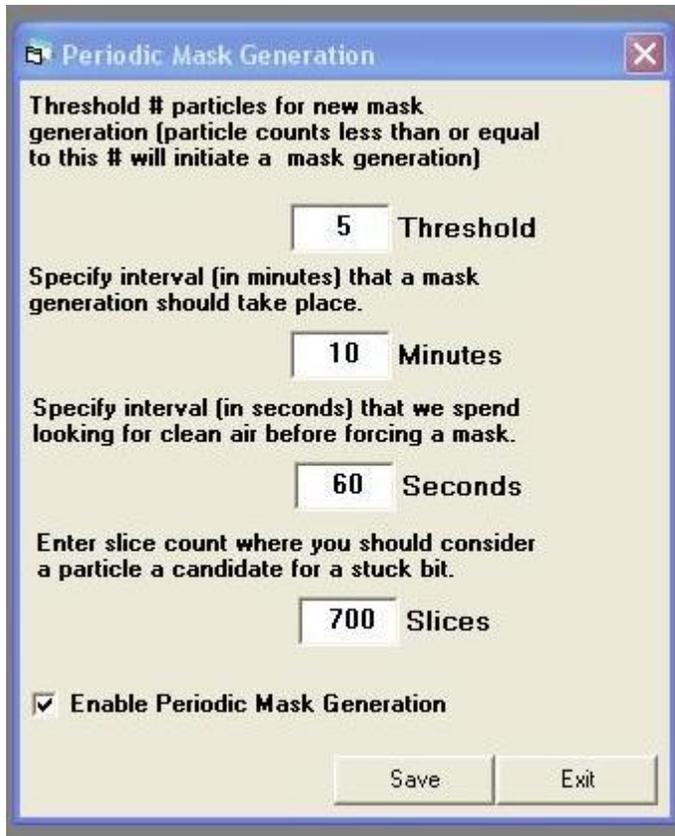
Note: One slice is ~10 um wide, so the stuck bit count should exceed the maximum expected particle or cloud drop diameter (10mm = 1000 slices). In the figure, a stuck bit is defined at 700 slices which equal 7mm.

Note: To change the number of slices value, the "Periodic Mask Generation" box must first be selected, the number of slices may then be edited, and then "Periodic Mask Generation" may then be de-selected. The 2-DS will always look for stuck bits – independent of whether the "Periodic Mask Generation" box is selected or not.
If one array is too noisy and you want to stop recording on it, go to the Send Command Packet Window. In the Comp. Mode Section chose the array you want to keep recording on and send a new command packet to the probe.

Small amounts of noise are tolerable. If flying through clear air and you see the particle count at 10 per second, it may be okay to leave as is. In post-processing these noisy bits can be removed.

No or Loss of Response from the Probe:
If during data collection the 2D-S program freezes or the 2D-S stops communicating, follow these instructions:
1. Stop recording and exit the real-time program.

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2. Cycle power to the probe and see if the LAN connection gets re-established.
3. Start real-time software and hit record.
4. Sometimes it may be necessary to restart Windows with the probe power off to get networking to function properly again. If communications with the probe continues to fail, verify in the Tools→Set Probe IP Address that the probe address is set to 192.168.1.133. In a DOS (cmd) window, type the command: "ping 192.168.1.133". If the ping fails, there may be a problem with probe power or cabling. Check all connections. The connections may have become loose during taxing or takeoff. Be sure network firewalls are disabled.

Distorted Images
If particles looked squashed or stretched, check the TAS to see if it is close to the actual TAS of the aircraft. If not, send a new TAS to the probe. Using the set TAS box and making sure the TAS Source is set to Fixed (if not using aircraft source).

Over Masking of Array Elements
Building masks while in cloud can make substantial amount of the array to be masked out. Similarly if you enter cloud with the improper settings a mask may automatically be generated with the Automask function with the same results. If the array becomes substantially masked while in cloud go to the Send Command Packet window and adjust the Automask's rejection percentage on each array higher and send a command packet to the probe. With a higher rejection percentage the array should become unmasked. You may also want to disable periodic mask generation if flying through persistent cloud cover.

7.0 Maintenance Procedures

Most of the 2D-S maintenance is limited to the windows and mirrors in the tips of the probe, and laser alignment. Maintenance of the probe between uses should always be performed. It is highly recommended that the windows be cleaned and voltages checked for improvement during a preflight test. Lasers may need to be re-aligned after a few flights for optimal performance.

The seven element voltages for each channel indicate if the array board is properly illuminated. Acceptable voltages range from 1.4V to 3.7V. The element voltages and laser drive settings are recorded for each 2D-S at the factory and shipped on a paper checkout sheet with each probe. Masked bits indicate a potential contamination or alignment issue. **Figure 1** shows element voltages, laser drive, and masked bits for a properly operating 2D-S probe. The current mask is a solid black line.
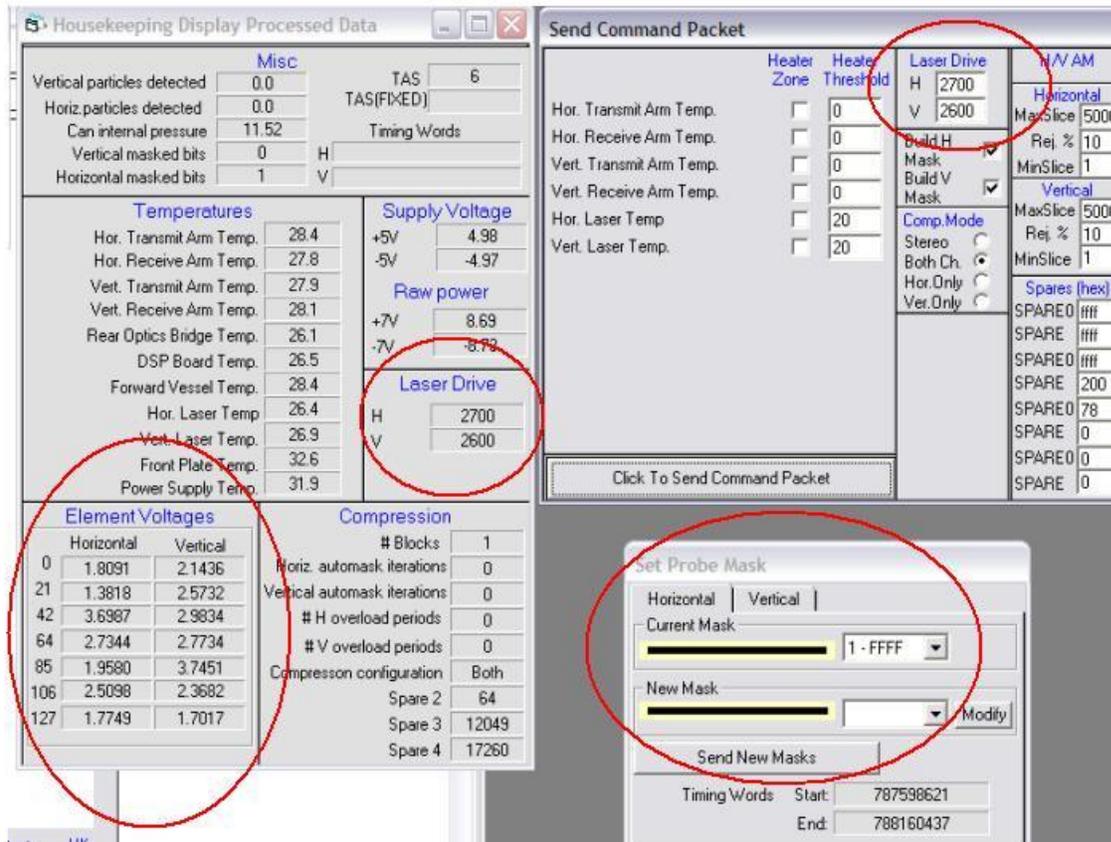
Figure 1 Element voltages, laser drive setting, and mask window for properly operating 2D-S probe.

If the element voltages decrease after shipping the 2D-S probe or after a flight, it could indicate possible contamination of the optical surfaces or shifting of the laser alignment. Initially it is possible to overcome some contamination and slight laser alignment shift by simply turning up

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the laser power to increase the element voltages. Eventually the optics will have to be cleaned and the laser alignment may need to be adjusted. The following troubleshooting steps should be taken to restore the element voltages to the factory settings. A visual inspection of the windows and internal optical components with an LED light for illumination may indicate these components do not require cleaning and the troubleshooting can proceed to the next step in the list below. Troubleshooting is complete when the element voltages ranges are acceptable near the factory laser power setting.

1. Increase laser drive setting to bring element voltages to within acceptable range.
2. Clean window external surfaces. See section 7.1.
3. Clean window internal surfaces and possibly mirrors. See section 7.2
4. Clean internal optical components. See section 7.3.
5. Adjust laser alignment. See section 7.4.

The following materials are required for maintenance on the 2D-S:
- A can of compressed air
- Bright LED
- Reagent grade methanol
- Optical quality cleaning tissue
- Lab-grade cotton swab
- Reagent grade Acetone
- 5/64" Allen driver
- #222 MS removable Loctite
- 5/64" Ball driver

7.1 Cleaning the 2D-S Windows external surfaces

When element array voltages are below approved factory settings then it is time to clean the windows.

1. Start the 2D-S program and turn on the probe. Record the array element voltages displayed in the Housekeeping Window, there are seven elements for each array. The goal in cleaning is to increase the transmission of light, which corresponds to the higher array voltages. Once the baseline voltages are recorded the system can be turned off so as not to overheat the probe on the ground.
2. Visually inspect each window. Shine the bright LED on each window and look for contamination on the windows.
3. The first step to cleaning is to blow off any particulates off the windows using the compressed. Particulates pose the greatest threat to the windows because they can scratch the coatings. (See **Figure 1**)
   Keep the compressed air at a distance and speed such that no liquid refrigerant gets on the windows.
4. Use an optical quality cleaning tissue to clean the window surface. A good way to clean the windows is to fold the tissue over the end of a lab-grade cotton swab (See **Figure 2**).
5. Apply a few drops of reagent grade Methanol to the tissue (See **Figure 3**).

6. Lightly swirl the tissue around the window to clean (See **Figure 4**). Methanol evaporates quickly and tends not to leave a residue unless there are still impurities on the glass. **Do not rub the windows too forcefully, the window anti-reflection coating is delicate and pressure on the windows could damage the coating. Never dry scrub the windows. If the coating is damaged, the laser intensity profile will be adversely affected, affecting the instrument response. Replacing a scratched window is extremely labor intensive, as it requires disassembly of epoxied components. This is not covered under warranty.**

7. Repeat until each window is clean on visual inspection with LED light. Start 2D-S system again and check to see that element voltages are improved. If they are, the cleaning was successful and you're done.

SPECIAL CLEANING NOTES:

In maritime conditions, salt residue on the windows is likely. In addition to using compressed air, use distilled water on the windows to dissolve and remove any salts off the windows. Then move to Methanol.

In non-maritime cases where the windows are extremely dirty (e.g. smoke plume) you can use reagent Acetone to clean the windows. Acetone will leave a residue and must be followed by a cleaning with Methanol.

If you are cleaning the windows for a flight that is to take place in the future, a large electrostatic bag can cover the tips and be taped to the PMS can to seal it off from particulates that could accumulate on the windows. If the aircraft is outdoors, doing this will prevent rain from contaminating the windows.
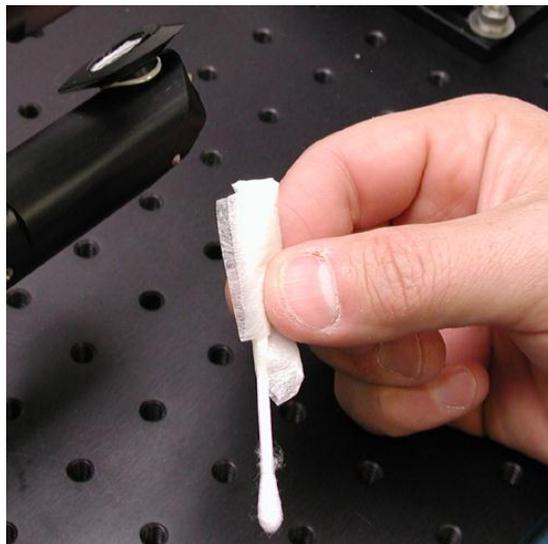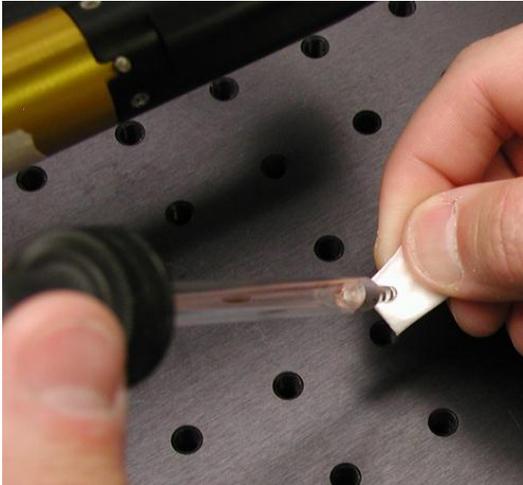

Figure1

Figure 2

SPEC Inc reserves the right to make improvements and changes to the 2D-S and related software at any time and without notice.

Figure 3

Figure 4

7.2 2D-S Cap Removal and Installation to clean window internal surfaces and mirrors

The 2D-S arms have been pressure-tested to ensure there are no leaks, but contamination and moisture from the body of the probe can occur. This section will guide you through the intricate process of removing the arm mirror cap assembly for cleaning optical surfaces and safely re-installing them. The receiving arm tip contains a lens, mirror and window. The Transmitting arm has no lens. Cleaning the internal surfaces of the arm tips should only be undertaken after the external window surfaces have been cleaned, the element voltages are low, the laser power is set adequately, and there is visible scattering from the laser or an LED light when illuminating the windows / mirrors. **Make sure power is off while removing any tip so that you are not exposed to direct laser light. Each of the four caps has its own specific mirror and assembly and cannot be installed on another tip in any situation. <u>Work on and remove only one cap at a time.</u>**

Removal of cap:

1. Use a 5/64" Allen driver to loosen each of the 4 screws a quarter turn. A ball-end driver may eventually strip the screw head, so use care (See **Figure 1**)
2. With all screws loosened, place a thumb and index finger to support the entire arm mirror cap assembly so it does not fall. Loosen the screws completely. (See **Figure 2**)
3. With the screws loose, lift the arm mirror cap assembly off the probe (See **Figure 3**), cup your other hand and turn the cap over so that the screws fall into the cupped hand. Place the screws aside. Take great care not to touch the delicate mirror surface. The mirror will be retained in the cap as it is removed.
4. Note the tongue and groove the arm mirror cap has with the arm tip, this is important for alignment during re-installation; the screw holes will not line up any other way (See **Figure 4** and **Figure 7**)

5. Lay the arm mirror cap with mirror-side up onto a safe surface.
6. The mirror surface can now be cleaned (if necessary). Using reagent grade methanol and an optical tissue follow the steps described in section 7.2. The inside of the window surfaces and lens (receive arm only) can be cleaned if necessary. Blow off any particulates with the compressed air source before cleaning optical surfaces.
7. Inspect the Cap Sealing O-ring in the cap; make sure it hasn't popped out of its groove. (See **Figure 4**)
8. If the cap sealing O-ring is out of its groove using a thin but not sharp object to push it back in. (See **Figure 6**). Inspect the O-ring for damage. If it shows signs of excessive wear it must be replaced. This is a custom O-ring from SPEC; this is the only type of O-ring that will create a proper seal.
9. Note the mirror retainer shown in **Figure 5**; it has a concealed mirror retaining O-ring that should be barely visible when properly seated in the arm mirror cap. If it is plainly visible push the mirror retainer back into the arm mirror cap assembly. This O-ring keeps the mirror from popping out of the cap. When the cap is reinstalled there is a compression spring behind the mirror that will force the mirror down to register its position. **Each of the four tips has its own specific mirror and assembly and cannot be installed on another tip in any situation.**

Reinstallation of cap:

1. The screws to the cap have to be precise: **#2-56 x 3/16" long socket head cap screws**. **(SN001 requires #2-56 x 1/8" SHCS)**

   DO NOT USE LONGER SCREWS, EVER. THEY WILL BREAK THROUGH THE TIPS AND RUIN THE HERMETIC SEAL AND ANY COMPONENTS IN THE TIP. SHORTER SCREWS LACK THE THREAD ENGAGEMENT TO COMPRESS THE O-RING AND HOLD THE CAP IN PLACE.

2. Carefully line up the tongue and groove between the arm tip and the arm tip mirror cap, and hold in place.
3. To prevent the screws from coming out in flight use #222 MS removable Loctite on the screws. The proper application is to drip one drop onto a temporary surface like paper. Use a toothpick and apply a light coating to a screw (see Fig 8 and 9). **DO NOT APPLY DIRECTLY TO SCREW AND DO NOT APPLY TOO MUCH.**
4. Insert and turn each screw a half turn. There should be a noticeable gap between the arm tip and the arm mirror cap (see **Figure 10**)
5. Go around the face and tighten each screw until the driver begins to flex mildly under the torque. Once tighten the gap should be gone
6. The helicoils used in the arm tips provide very little thread engagement due to the small available space. Take great care not to strip the helicoils. **Replacement is very costly and not covered by warranty.**
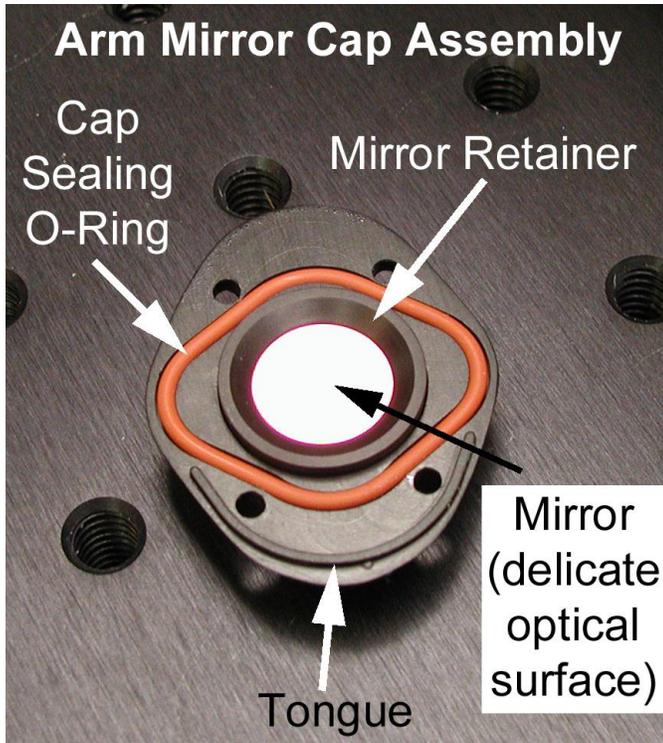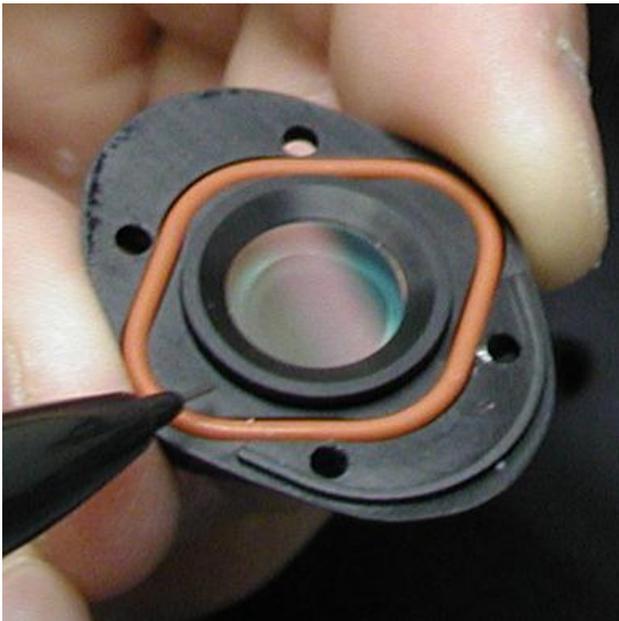
Figure 1

Figure 2

Figure 3

Arm Mirror Cap Assembly

Cap Sealing O-Ring

Mirror Retainer

Mirror (delicate optical surface)

Tongue

Figure 4

Mirror Retainer

Mirror Retaining O-Ring

Figure 5

Figure 6 Inspect for excessive wear, only this exact O-ring can be used.

Figure 7

Small Fasterner
removable 222 MS
Loctite

Toothpick

Figure 8

Figure 9

SPEC Inc reserves the right to make improvements and changes to the 2D-S and related software at any time and without notice.
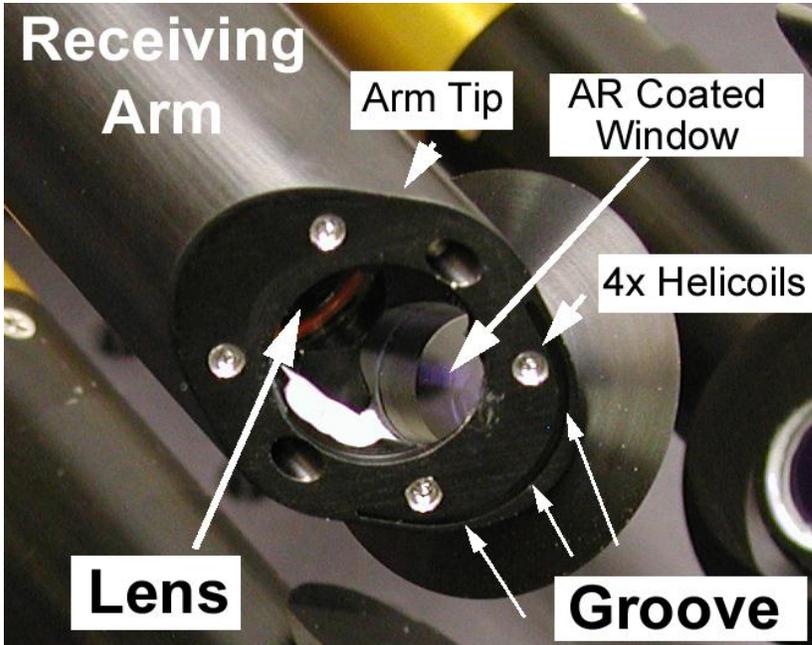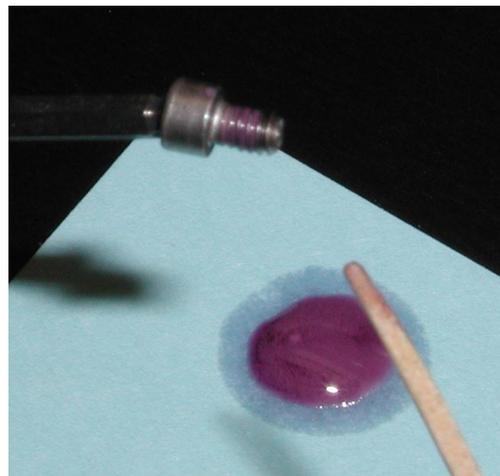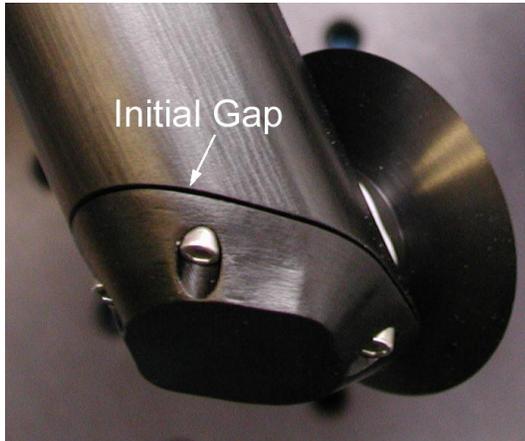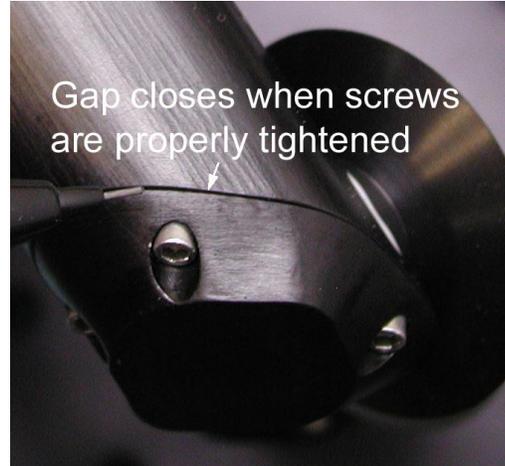
Figure 10

Figure 11

7.3 Cleaning internal optical component surfaces

If element voltage levels remain low at maximum laser power setting (4095 counts), the internal optical components should be inspected using an LED light to look for contamination. If a surface is contaminated, it should be cleaned using reagent grade methanol and a cotton swab or lens tissue. **Figure 1** shows the location of the internal components for the horizontal and vertical channels. Element voltages should be observed after cleaning of each component to see if the problem has been improved or made worse. Repeat cleaning if the voltages decrease. **The internal optical components shown in Figure 1 are locked into position at the factory and should not be adjusted in the field. All screws are locked with a locking compound.**

HORIZONTAL CHANNEL
OPTICAL COMPONENTS

VERTICAL CHANNEL
OPTICAL COMPONENTS
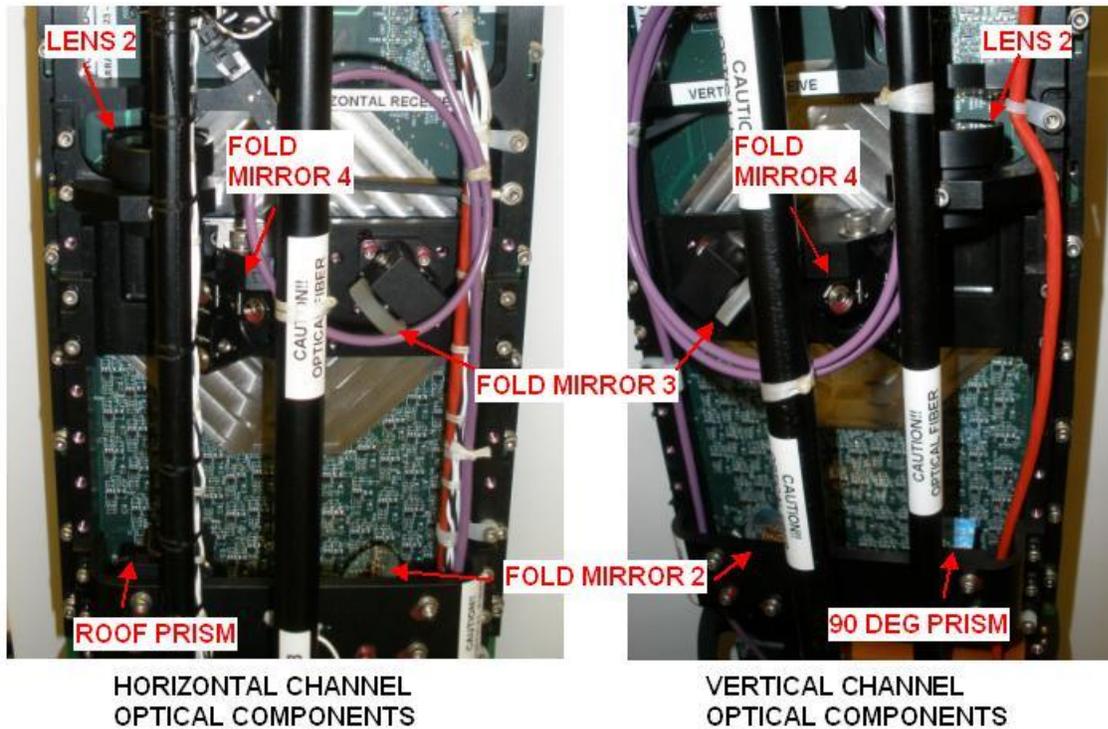
Figure 1. Horizontal and Vertical Channel internal optical component locations.

7.4   2D-S Laser Alignment Procedure

If the steps mentioned above have been completed and the element voltages remain insufficient at the factory laser power setting, the laser alignment should be adjusted for the channel in question. Use caution when performing the adjustment, as gross misalignment of the laser will prevent the 2D-S probe from functioning.
 Adjustments on the order of 1/16 of a full turn (~22 deg rotation) are absolute maximum the beam tilt should be adjusted. Do not adjust pivot. Very often the required adjustment is only a few degrees of rotation (~1/30 of a full turn).
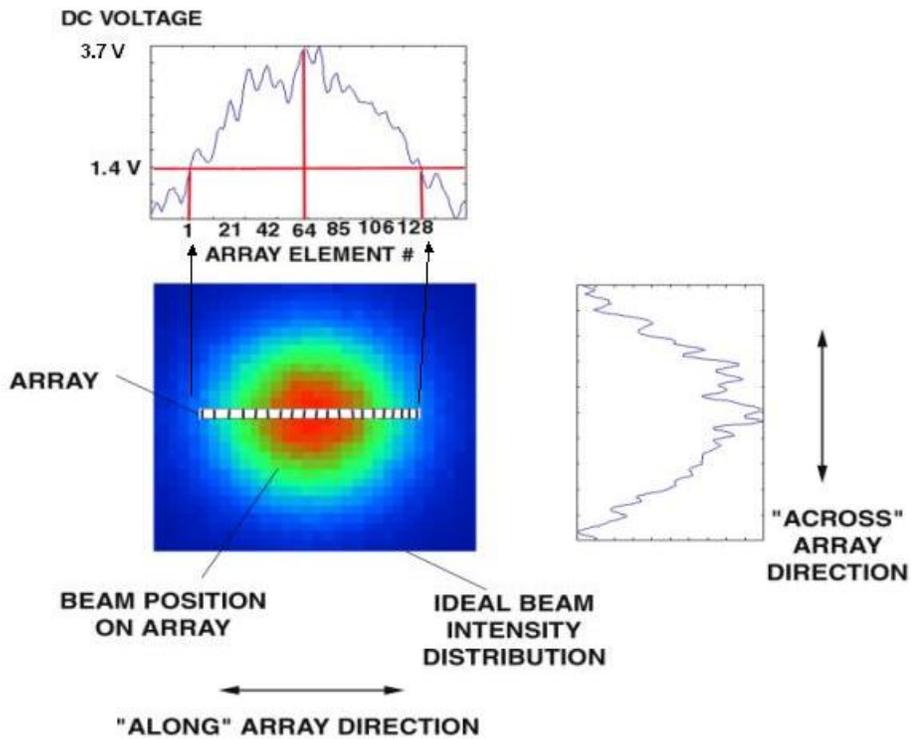
Figure 1. Ideal laser beam distribution and adjustment directions on array.

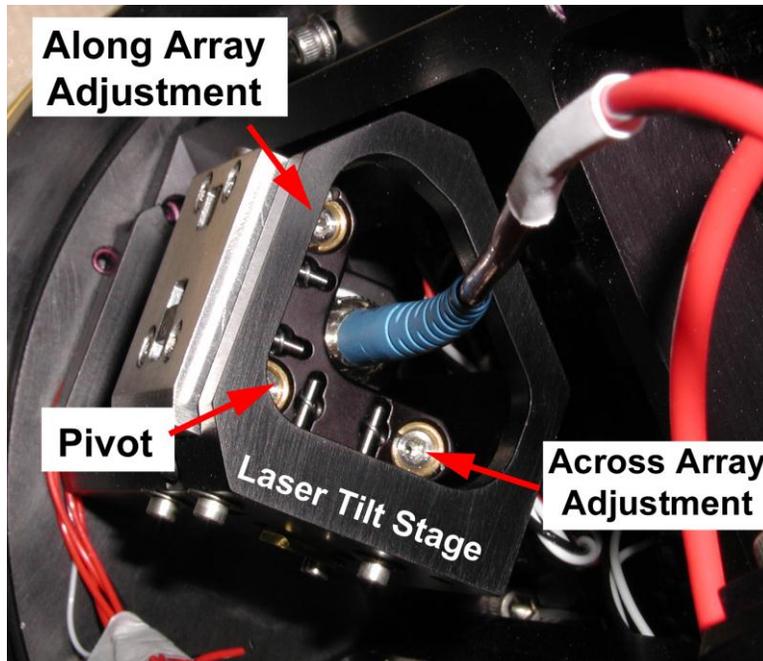**Figure 2.** Element voltages along array

Figure 3. Vertical laser tilt stage adjustment screws. Horizontal laser tilt stage is a mirror image. Use 5/64" ball driver to adjust screws. **Adjustments on the order of 1/16 of a full turn (~22 deg rotation) are absolute maximum the beam tilt should be adjusted. Do not adjust pivot.**

Figure 1 shows the location of the ideal laser energy distribution with respect to the array orientation. The target voltage level is approximately 2-3.5V on all elements, but voltages as high as 3.7V or as low as 1.4V can be tolerated. **Figure 2** shows the along array direction with respect to the reported element voltages for a particular channel. **Figure 3** shows the location of the laser tilt stage adjustment screws that "scan" the beam "along" the array or "across" the array. Use 5/64" ball driver to adjust screws. The horizontal stage and vertical stage are mirror images of each other. Follow the procedure below to optimize the laser intensity distribution on the array and approach the factory laser drive setting and element voltages. The elements saturate at 3.9V, so it will be necessary to decrease the laser drive setting as the alignment is optimized. The beam should be occasionally blocked if an element voltage stops responding to a change in adjustment.

1. Move the "along" adjustment screw to get a maximum signal on element #64 and approximately equal values on #1 and #128.
2. Move the "across" adjustment screw to increase signal on either 1, 64, or 128.
3. When any of these elements is maximized, go back and adjust "along" screw.
4. It will be necessary to take a new mask after each adjustment if pixels begin to get noisy.
5. Keep alternating adjustments until each of the voltages is maximized. Never adjust the Pivot.

6. It may be necessary to intermittently "block" beam or cycle power if element DC voltage level stops responding to change in alignment.
7. Ideally, elements indicate a smooth varying distribution, although this may not be possible.
8. The desired signal level is near 2 - 3.5 V.
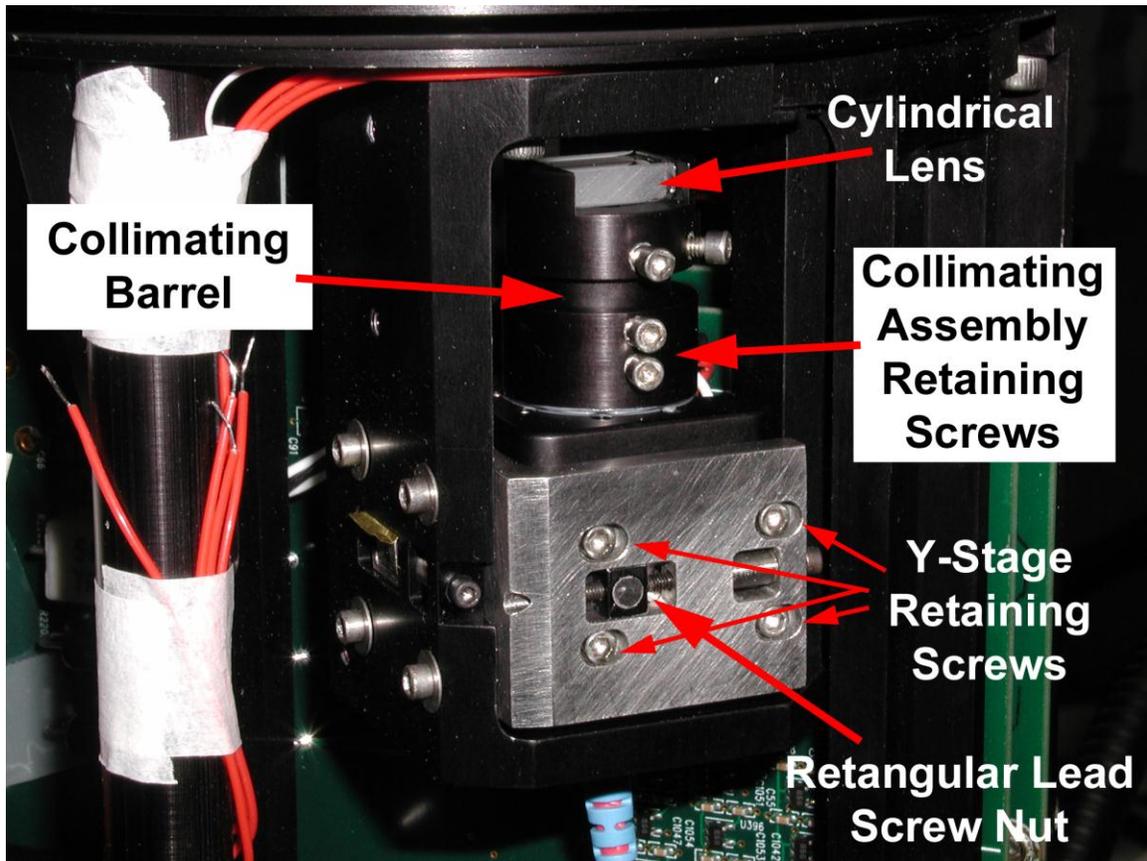9. End elements generally have lower voltages than center elements.

Figure 4. Side view of laser and lens.
DO NOT TO ROTATE THE CYLINDRICAL LENS. All screws in this assembly with the exception of the laser tilt stage screws shown in Figure 3 are locked at the factory and should not be adjusted.

Note: 2D-S Post-Processing

The 2D-S Post-Processing Software is covered in a separate document