



SPEC_{inc}

3022 Sterling Circle – Suite 200, Boulder, CO 80301.

(303) 449-1105 (303) 449-0132(fax)

www.specinc.com

Fast Cloud Droplet Probe Technical Manual Rev. 2.0

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1.0 FCDP General Description

The Fast Cloud Droplet Probe (FCDP) is a forward scattering probe which calculates particle size and concentration by measuring the amount of light scattered into the probe's collecting optics as a particle transits through the probe's focused laser beam. It works on the same principles as other forward scattering probes, such as the FSSP. However, the FCDP captures data on every particle event, allowing for significantly more complex post processing capabilities. The FCDP can size particles from 1 -50 μm with a resolution of approximately 3 μm . The system resolves particles into twenty size bins, plus one over-size bin, and is capable of sizing particles having velocities from 10-200 m/s. The FCDP is a stand-alone system with an onboard Linux-based data acquisition system that stores data on a microSD card. The instrument can be controlled by a computer inside the aircraft cabin or can be configured to automatically run, collect, and store data at power ON.

Specifications:

Input	Voltage	Frequency	Power	Usage
Probe AC	115 VAC	50 - 400 Hz	410 W	Heaters
Probe Electronics	28 VDC	DC	84 W	Sensor Electronics + Heater

Weight: 5.5 lbs (2.5 kg)
Size: 10.9 in x 6 in x 9 in (28 cm x 15 cm x 23 cm)
Laser Wavelength: 785 nm
Laser Power: 50 mW continuous-wave (cw)
Particle size detection: 1 – 50 μm
Connection: 100 Mb Ethernet
Bins: 21 including one for over size,
Capture of every particle event allows for possibility to post-process with any number of bins and size bins desired (user must edit post processing code).

1.1 FCDP Overview description

The FCDP can be divided into three main sections: Transmit and Receive Arms, Main Body and Strut.

The Arms house the transmit optics, the receive optics, the detectors and detector amplifier boards. The transmit optics are fed by a fiber coupled laser which is housed in the strut. The outputs of the detector amplifier boards are fed into the data acquisition system, which is housed in the main body.

The Main Body consists of the data acquisition system, which contains the front end signal processing and conditioning, a Field Programmable Gated Array (FPGA), and the DIGI system on module (SOM) which includes on-board RAM and a 533MHz Samsung ARM processor. The electronics board converts the analog voltages to digital form and this data is stored in FIFOs on the FPGA. The FPGA interfaces with the Signal, Qualifier, Housekeeping Analog to Digital convertors (ADC) and the SOM. The SOM analyzes and processes the voltages corresponding to scattered light and classifies it in different particle size bins. This data, along with the housekeeping data, are saved in the form of 5 different files on the microSD card by the SOM. The SOM also provides an Ethernet interface for real time display and control by a remote computer. The user can open a secure shell into the Linux based system and also use FTP to download data files.

The Strut contains the Power, Laser and Heater control board. The 28 VDC and 110 VAC inputs from the aircraft are distributed to the various components of the FCDP: laser, detector, detector amplifier board, data acquisition system and heaters, by the Power-laser-heater board. The board also controls the temperatures of the heaters.

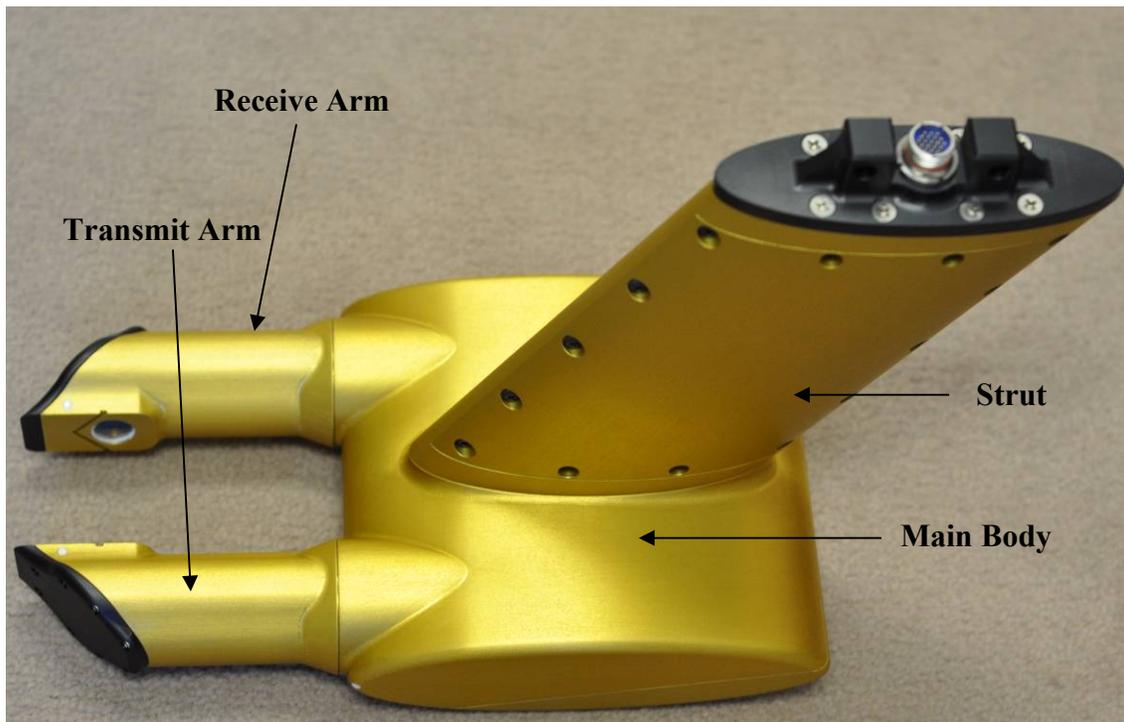


Figure 1.1.1 FCDP Main Physical Sections

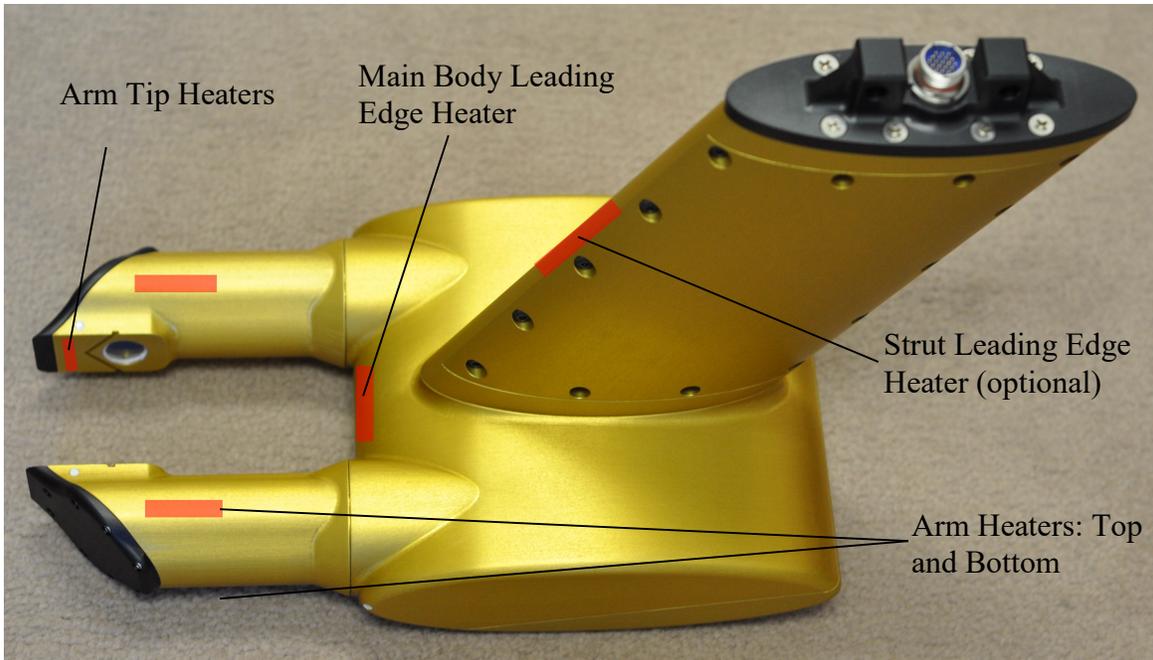


Figure 1.1.2 FCDP Heater Locations

1.2 FCDP Theory of Operation

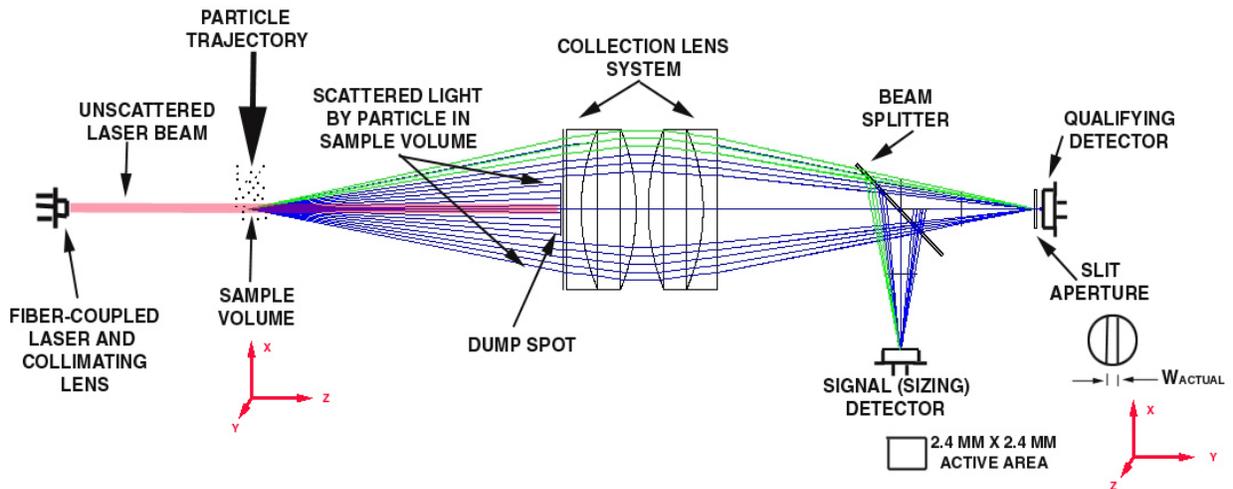


Figure 1.2.1 Diagram of the FCDP optical path

A collimated, fiber-coupled laser is projected on the sample volume between the transmit and receive arms of the FCDP. Cloud particles in the sample volume scatter the laser beam. The light scattered by the cloud particles is collected at a dump spot on the receive arm. This beam is split

between two detectors: qualifying detector and signal detector. **Figure 1.2.1** is a diagram of the FCDP optical path.

When a particle is in focus for both detectors, the slit based qualifier sees a high peak. Since a 50:50 beam splitter is used, a particle is “qualified” if the qualifier peak is higher than the signal peak, as shown in **Figure 1.2.2**.

Characteristics such as run time, transit time, signal voltage, qualifier voltage, area (sum of volts) and time to peak are recorded for each particle by the data acquisition system.

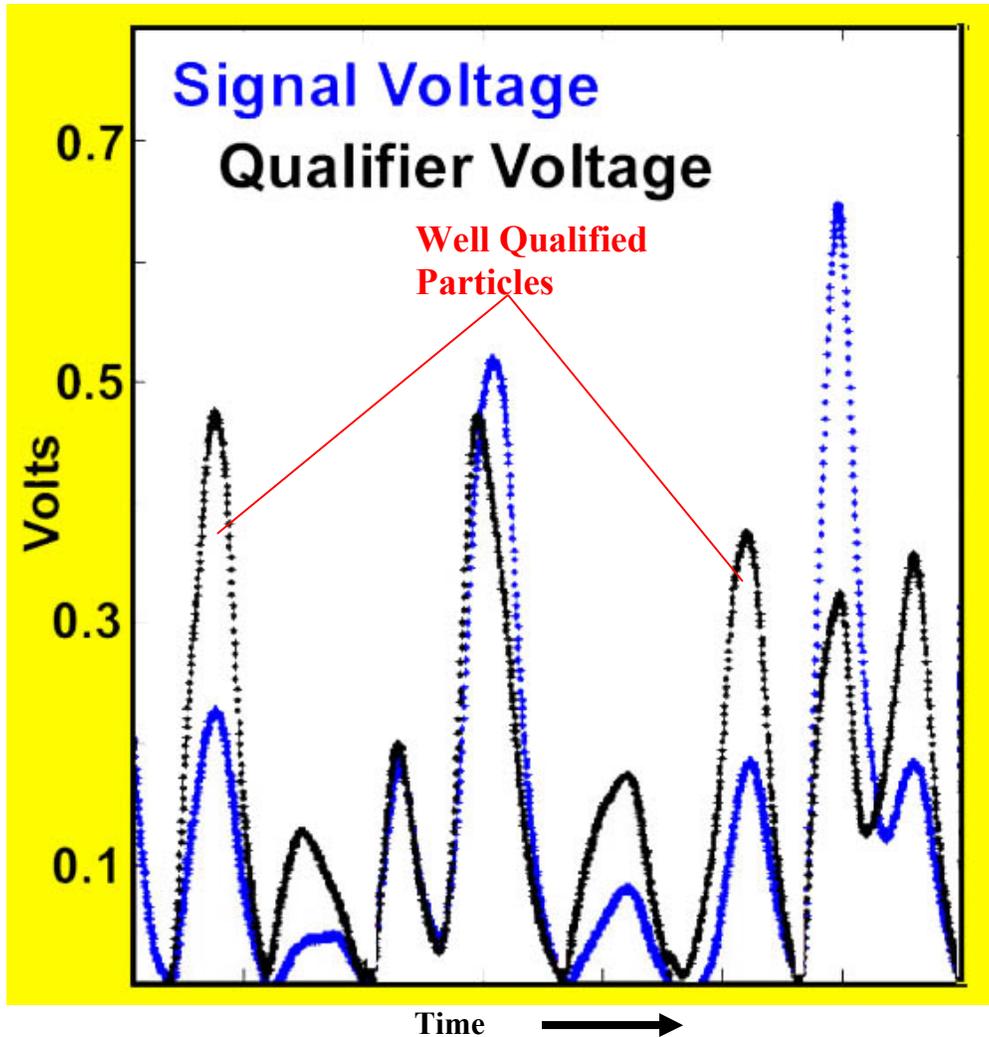


Figure 1.2.2 Examples of Qualified Particles

2.0 FCDP Electronics Description

The FCDP electronics consist of four main boards: 2 detector boards, an electronics board and a laser/power board. A block level diagram of the electronics system is provided in **Figure 2.1.1**.

Detector Boards:

Detector boards are small boards placed close to the optical detectors. They detect and amplify the signal and qualifier voltages over two stages. The output of these amplifiers is fed into the Mother Board.

Mother Board:

The Mother board consists of the main electronics, which sample and process the detector voltages. The amplified signal and qualifier voltages are digitized by dual, 14 bit ADCs. These voltages, along with the House Keeping voltages from an ADC-MUX, are fed into a Field Programmable Gated Array (FPGA). Housekeeping parameters such as air temperature, voltages, relative humidity and pressure are sampled.

The FPGA directly interfaces with the System on Module (SOM). The SOM is a LINUX based computer that runs the FCDP executable and stores all of the collected data files. The FPGA and the SOM together form the data acquisition system. When the FCDP is turned ON, the SOM powers up and implements a code that programs the FPGA to acquire and store data from the ADCs in FIFOs. The SOM then implements a real time control loop to retrieve data from the FIFOs on the FPGA, perform basic processing and store the raw data files on the Compact Flash card.

Laser/Power Board:

The FCDP laser/power board receives 115 VAC and 28 VDC power input and converts it to appropriate voltages (± 5 VDC, +3.3 VDC), which power the electronics board. The 115 VAC is only used for the heaters, and the laser/power board distributes the AC power to the heater relays. The heater relays are controlled by the real time software running on the SOM. The power and control circuitry for the laser is also part of this board.

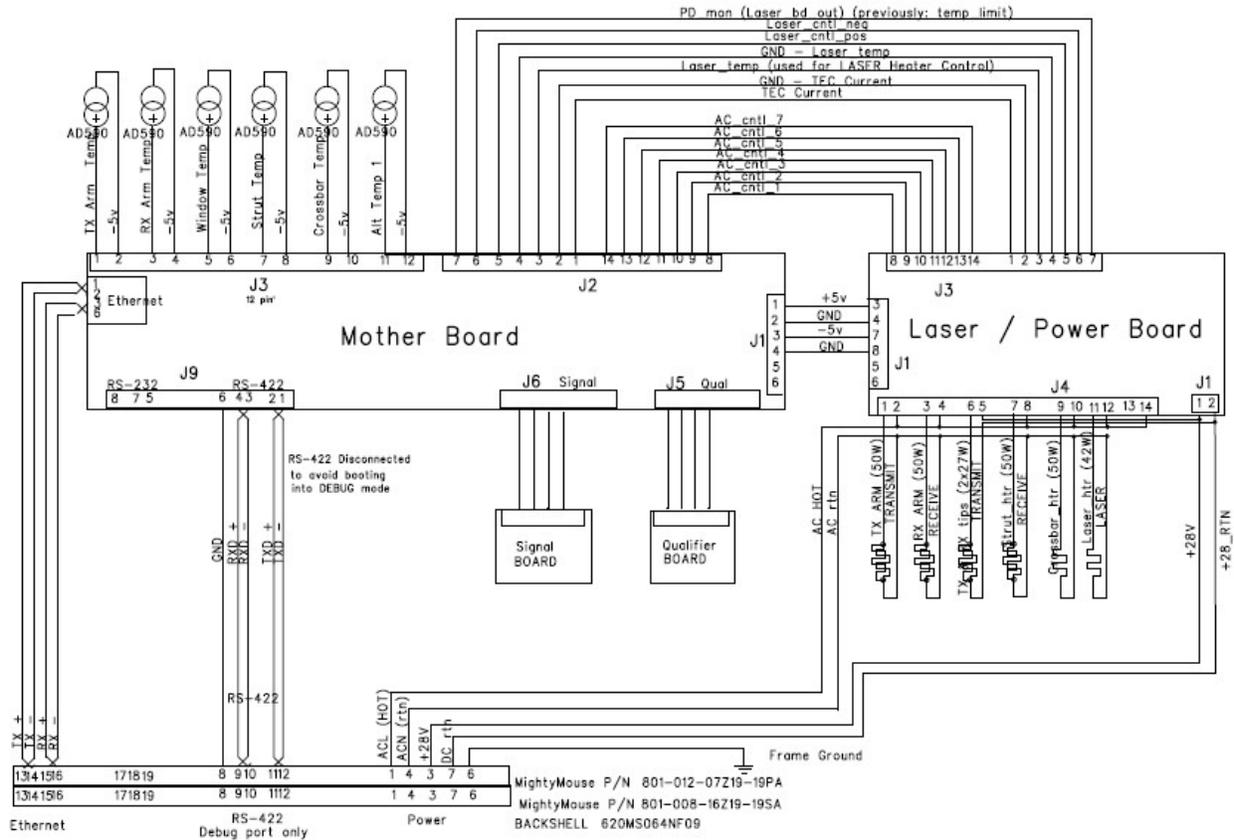


Figure 2.1.1 Electronics System Level Block Diagram

3.0 FCDP Operation

A bench test cable is supplied with the FCDP. This cable connects the 19 pin connector at the FCDP sensor head, to 28 VDC power, AC power and Ethernet. Some cables additionally include a DB9 connection that is for debug purposes only. A low noise 28 VDC power source is required to power the electronics in the FCDP. The AC power is not required for ground operation, since it is only used for providing power to the heaters. To communicate with the FCDP, an Ethernet connection is required between the Linux SOM and a host computer.

The standard IP address of the FCDP is 192.168.0.100 (however other IP addresses are sometimes requested and programmed into the FCDP). The FCDP IP address should be printed on a label affixed to the base of the FCDP. Configure the computer to a static IP address of 192.168.0.211 (or some other IP address in the range of the FCDP).

There are multiple options for connecting to and operating the FCDP. Since the FCDP has a Linux computer on board, a user can open a secure shell into the Linux based system. There is also a specially design GUI that can be used to automate the FCDP operation. The collected data files can then be downloaded with an FTP application to the host computer.

3.1 Connecting the FCDP Sensor to Remote Computer

It is possible to use an SSH client (such as PuTTY) to directly open a session on the FCDP Linux SOM. The standard IP address and login information is listed below:

IP address: 192.168.0.100
SSH Port: 22
FTP Port: 21
Connection type: SSH or FTP
User: root
Password: root
FCDP application: /home/SPEC/bin/fcdp_realtime
FCDP config file: /home/SPEC/etc/fcdp.cfg

Once an SSH session is started and the user is logged in, the user can start the FCDP application. Type “/home/SPEC/bin/fcdp_realtime” to start data collection. Once started, the application will display the following stdio in the shell window (note the actual numerical values may differ):

```
Air Temp = 43.1    Pressure = 12.18    RH = 11.2    5V = 4.87    -5V = -5.18  
Window Temp = 22.5 Arm Temp = 21.5    Laser Temp = 34.0    Sig = 0.0818    Qual = 0.0809  
    Heaters = 32  
Sizes:  
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

Every second a new line of output is displayed. To quit the fcdp_realtime program execution, a “q” keystroke followed by a “y” keystroke is required. No enter or carriage return are required.
Quit: “q” “y”

The FCDP application creates five different files which are saved in “/media/SSD”. The file names are based on the current date and time and follow the format described below:

‘YYMMDD_HHMMSSlog.txt’:	ASCII Log file	(ASCII)
‘YYMMDD_HHMMSShk.txt’:	Housekeeping data file	(ASCII)
‘YYMMDD_HHMMSScat.bin’:	Scattering data file	(Binary)
‘YYMMDD_HHMMSSsig.bin’:	Signal detector data file	(Binary)
‘YYMMDD_HHMMSSqual.bin’:	Qualifier detector data file	(Binary)

The above files are post-processed to yield accurate particle characteristics such as concentration and sizing. The real-time bin counts are based on bin edges defined in the config file (fcdp.cfg), an assumed sample area, and a simple qualification ratio (which is generally assumed too liberal). Post processing is then performed on the generated data files with Matlab and the appropriate setup file using calibration data and sample area mapping. Additionally, one may use custom bin edges up to the maximum particle size, a custom number of bins, and a custom qualification ratio. However, these are all adjustments available to the sophisticated user. Additional training is often required to accurately and correctly perform these adjustments.

3.2 FCDP Real time Graphical User Interface (GUI)

An FCDP GUI has been designed to automate the connection to the FCPD. The GUI will connect to the probe, adjust the FCDP time and date to that of the host computer, graphically display the data, and output a simple 1Hz data file. The latest FCDP GUI can be downloaded from the SPEC website. The GUI must be setup.

Once installed, the GUI uses an ini file (C:\SPEC\Scattering_Probe_GUI\config\scatprobe.ini) to define the IP address and other critical parameters required to interface with the FCDP. These parameters default to the standard settings, but should be verified. A screenshot of the GUI is shown in **Figure 3.2.1**. The steps to start and stop the FCDP through the GUI are detailed below.

Connecting to the FCDP

1. To initialize the connection between the FCDP GUI and the probe, click the green “Connect to Probe” button shown in **Figure 3.2.1**. This will connect and time sync the probe.
2. Click the green “Start” button (may take around 15 seconds before the display updates).
3. The system is now ready for Real-Time Operation and will begin collecting data.

Note: If the housekeeping fields do not populate after step 2, try clicking the “Stop FCDP” button, and then starting back at step 1.

Note: The SD card must have enough space to store all of the created files, so periodic clearing may be required. It is also possible to type `df -h /mnt/hda` in the “SSH Command Field”, then click the “Send String” button to check the amount of available flash disk space.

Disconnecting from the FCDP

1. To disconnect from the FCDP, click the “Stop FCDP” button (see **Figure 3.2.1**).
2. Once the FCDP has stopped collecting data, click the “Shutdown FCDP” button. Once stopped, the FCDP GUI window may be closed.

Note: Once the “Shutdown FCDP” is pressed, the power to the FCDP must be cycled before communications can be re-established with the FCDP.

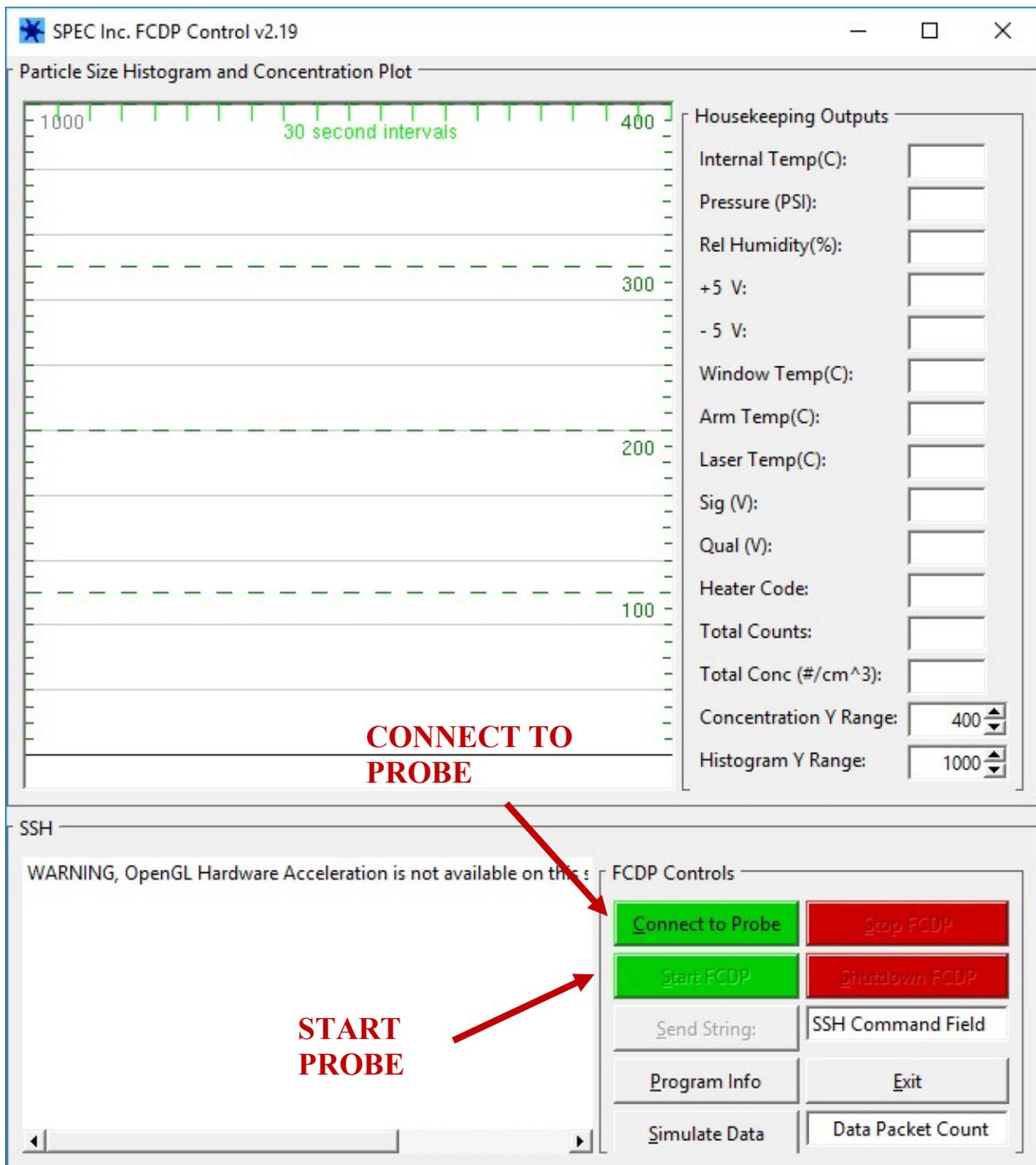


Figure 3.2.1. Startup screen for the FCDP GUI.

3.3 Output file formats

The most important files for post processing are the Log, Housekeeping, and Scattering data file:

‘YYMMDD_HHMMSSlog.txt’:	ASCII Log file	(ASCII)
‘YYMMDD_HHMMSShk.txt’:	Housekeeping data file	(ASCII)
‘YYMMDD_HHMMSSscat.bin’:	Scattering data file	(Binary)

The scattering file is a binary file that contains a packet for every particle event. The format for the particle packet data is listed below. In the event that the probe enters very high concentrations, it is possible for the FIFO to fill and the probe to go into overload. The format of the overload packet is listed below.

Regular Packet		
Word #	# bits	Value
1	16	Header FFFF
2	16	Sig Height 0 & high/low & 14 bit a/d (10mv -16V)
3	16	Qual Height 0 & high/low & 14 bit a/d (max peak height ind. of time of signal peak)
4	16	14 bit: Transit Time (# of 40Mhz clocks)
5-7	48	Time at end of particle event (25ns counts)
8-9	32	Area under curve (Sum of signal voltages (estimate transit time))
10	16	14 bit: Peak transit time = time from last peak to end

Overrun Packet		
Word #	# bits	Value
1	16	Header1 0000
2	16	Header2 AA00
3	16	Header3 00AA
4-6	48	StartTime of Overflow - MS word first (25ns counts)
7-8	32	Number of unqualified events - MS word first
9	16	Number of qualified events
10-12	48	EndTime of Overflow - MS word first (25ns counts)

The sig and qual.bin files only contain digitized waveform data of a fraction of the particle events. Currently these data are primarily for testing and debug, but they offer a multitude of future post processing options. The format for these binary data are listed below.

Sig.bin		
Word #	# bits	Value
1 to n		first Signal Pulse Voltage of particle either {2'b10,INADCLOW} or {2'b00, INADC}
....		
n		last Signal Pulse Voltage of particle either {2'b10,INADCLOW} or {2'b00, INADC}
n+1	16	Header FFFF
n+2 to n+4	48	Current runtime of end of particle event (25ns counts) MSB first
n+5	16	Start of New Signal Pulse Voltage of new particle either {2'b10,INADCLOW} or INADC
Qual.bin		
Word #	# bits	Value
1 to n	16	First Qualifer Pulse Voltage either {2'b10,INADCLOW} or {2'b00, INADC}
....		
n	16	Last Qualifer Pulse Voltage either {2'b10,INADCLOW} or {2'b00, INADC}
n+1	16	Header FFFF
n+2 to n+4	48	Current runtime of end of particle event (25ns counts) MSB first
n+5	16	Start of New Qualifer Pulse Voltage either {2'b10,INADCLOW} or {2'b00, INADC}

3.4 Advanced Features

Since the FCDP is operating on a Linux based system, there are multiple advanced features that are available to the sophisticated Linux user. These capabilities include Auto startup and running of the FCDP real-time executable, setting up NTP if there is an NTP server on the network, outputting of UDP packets to a listener on the network, and ingesting data from a UDP packet and appending fields from that packet to the housekeeping file.

4.0 FCDP Maintenance Procedure

Cleaning the FCDP windows is the only regular maintenance required. Items required to clean the windows are shown in **Figure 4.1**.



Figure 4.1. Items required for window cleaning

1. Visually inspect both windows. Shine the bright LED on each window and look for contamination on the windows.
2. The first step to cleaning is to blow any particles off the windows using the compressed air. Particles pose the greatest threat to the windows because they can scratch the coatings. (See **Figure 4.2**)
Keep the compressed air at a distance and speed such that no liquid refrigerant gets on the windows.
3. Use an optical quality cleaning tissue, wetted with methanol 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 4.3**). Do not wipe the windows without wetting the swab or tissue.
4. Apply a few drops of reagent grade Methanol to the tissue (See **Figure 4.4**).
5. Lightly swirl the tissues around the window to clean. 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.

6. Repeat until each window is clean on visual inspection with the LED light.

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 on 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.

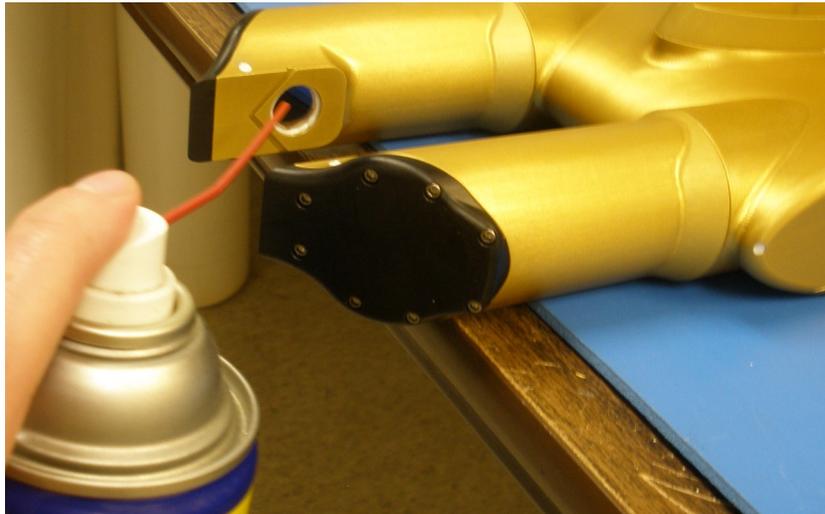


Figure 4.2. Blowing particles off windows with compressed air.



Figure 4.3. Optical quality cleaning tissue and cotton swab to lightly clean windows

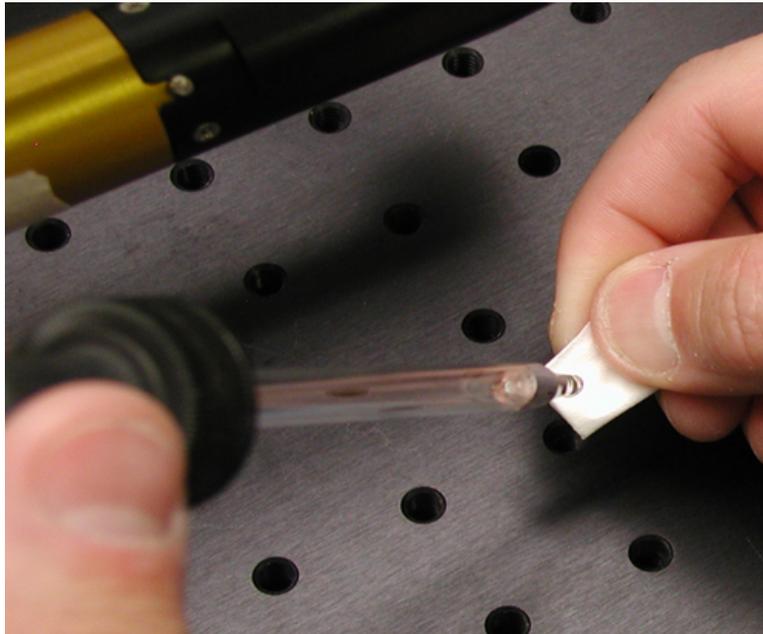


Figure 4.4. Methanol wetted tissue for dirtier windows.

5.0 FCDP Collar Installation

The FCDP can be mounted to a custom mount or to a specially designed SPEC collar that is designed to fit around the SPEC hermetic PMS Can. The dimensions and footprint of the FCDP are shown below **Figure 5.1**.

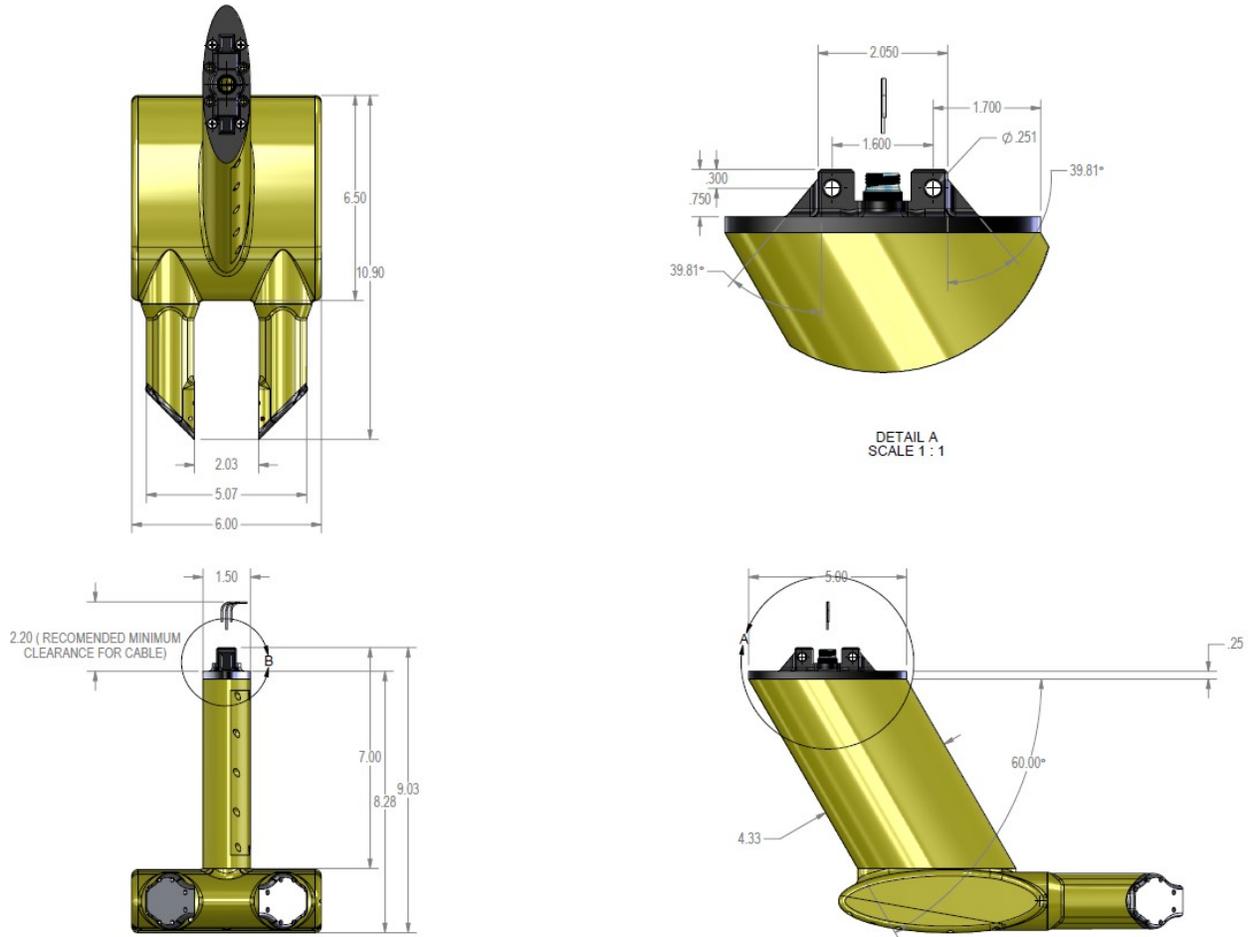


Figure 5.1. FCDP Mechanical Dimensions

The collar designed to mount the FCDP is specific to the SPEC hermetic canisters and will not work on other PMS cans. In order to mount the collar to a SPEC canister, the can is slightly modified from the standard SPEC hermetic can to allow for an FCDP wire pass.

The FCDP is designed to hang vertically from its mounting point. The collar is designed so that the canister can be mounted in 3 different rotational patterns and allow for the FCDP to remain

in its proper orientation. **Figure 5.2** shows the final FCDP orientation on the collar with a SPEC 2D-S installed in the hermetic can.

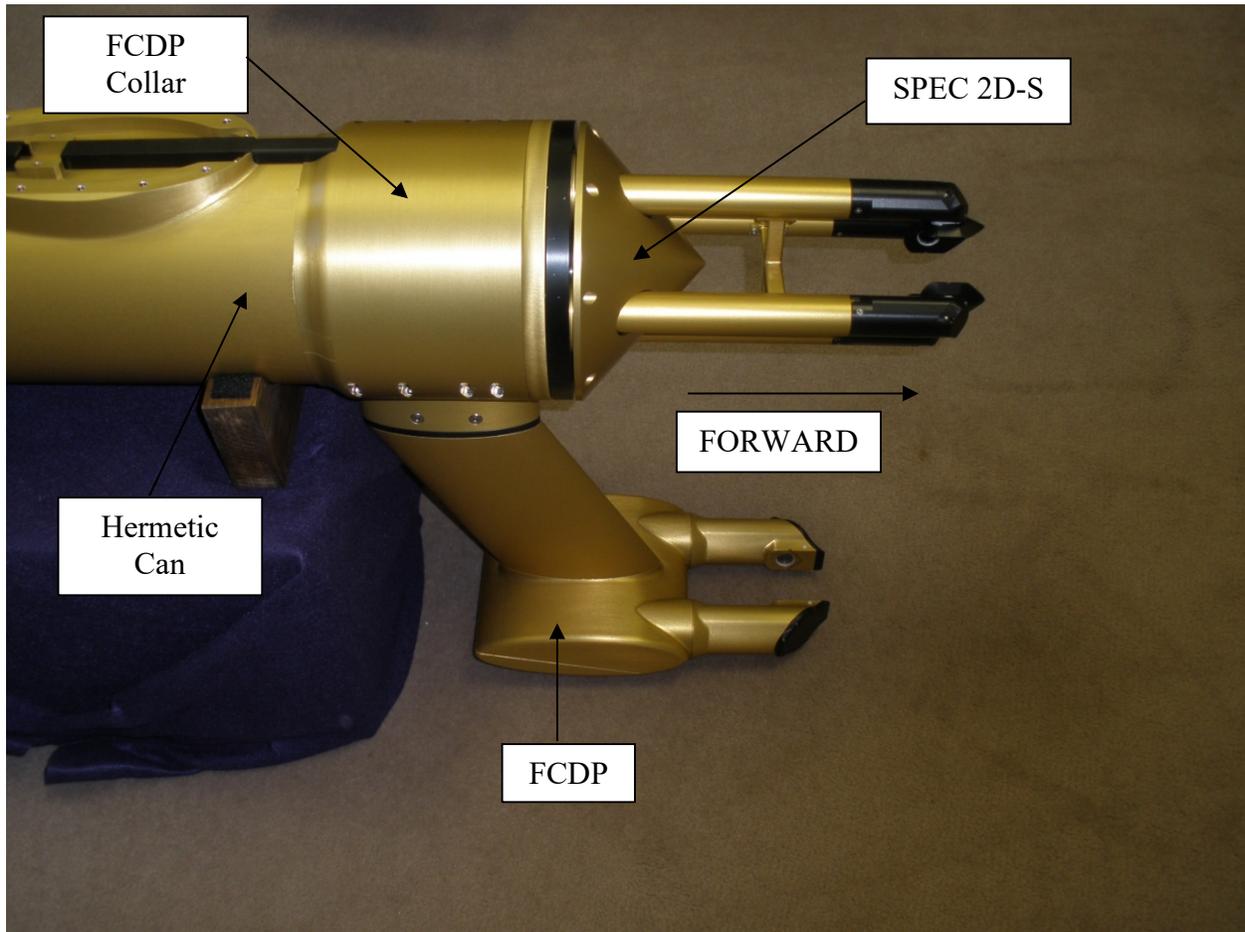


Figure 5.2. FCDP/Collar/2-DS

The collar comes apart into two pieces, the mounting base half and the top clamping half. Eight #8-32 screws hold the two halves together. **Figure 5.3** shows the top half; **Figure 5.4** shows the bottom half.

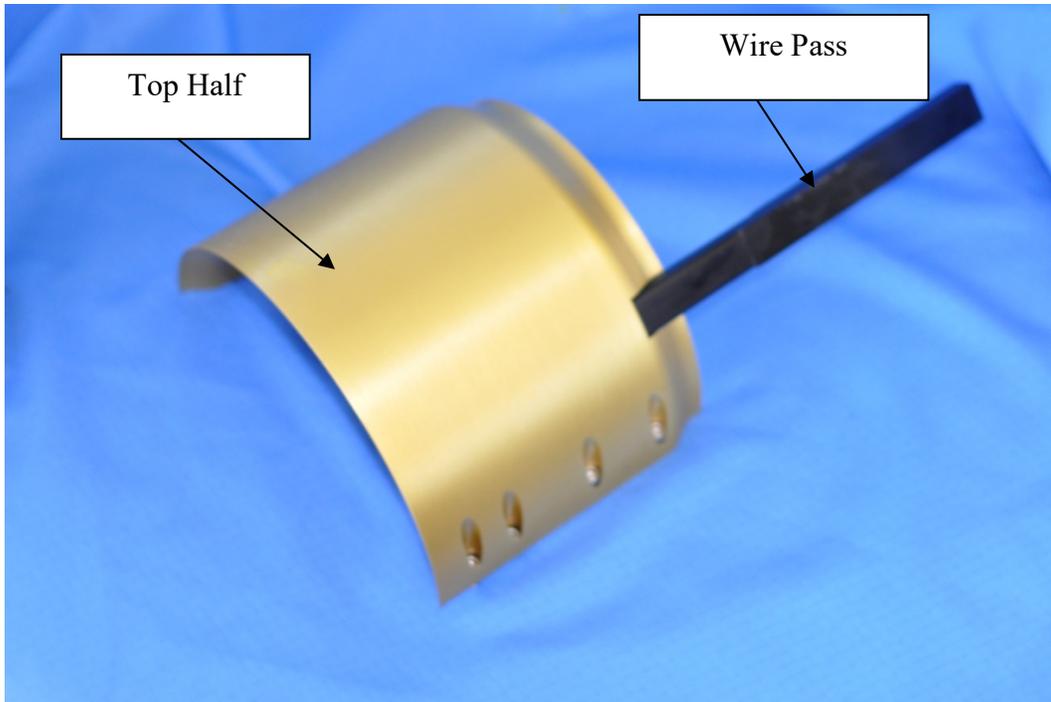


Figure 5.3. Top Clamping Half

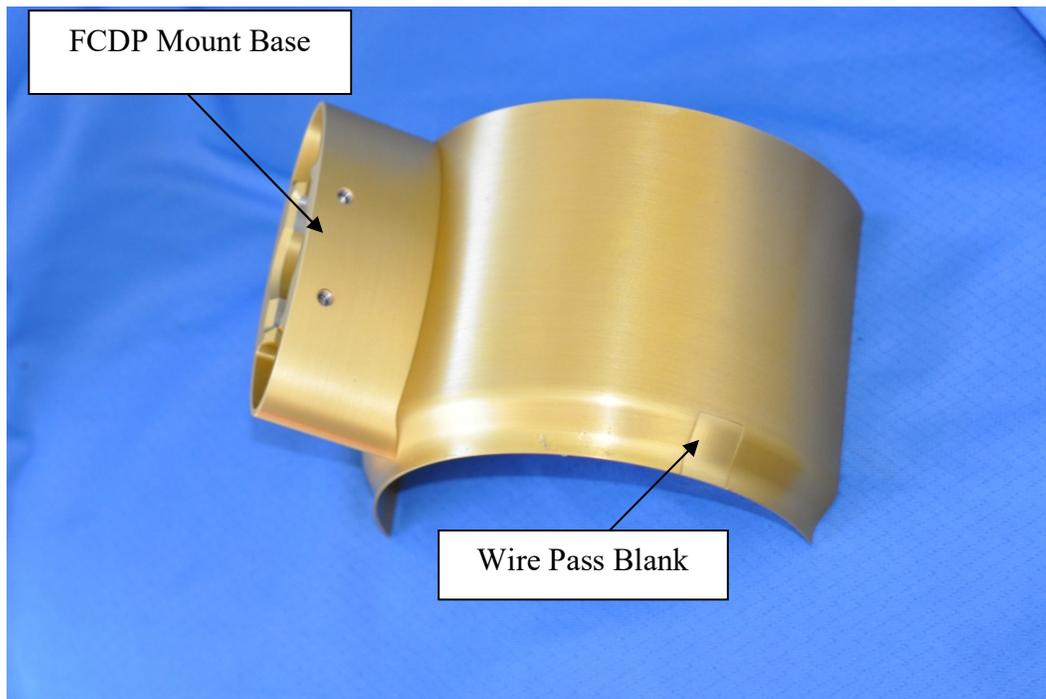


Figure 5.4. FCDP Mounting Base

Figure 5.5 shows the three components of the collar that are acceptable to remove in order to rotate the FCDP collar. The parts are also pointed out in **Figure 5.3** and **Figure 5.4**, to show them in the assembly.

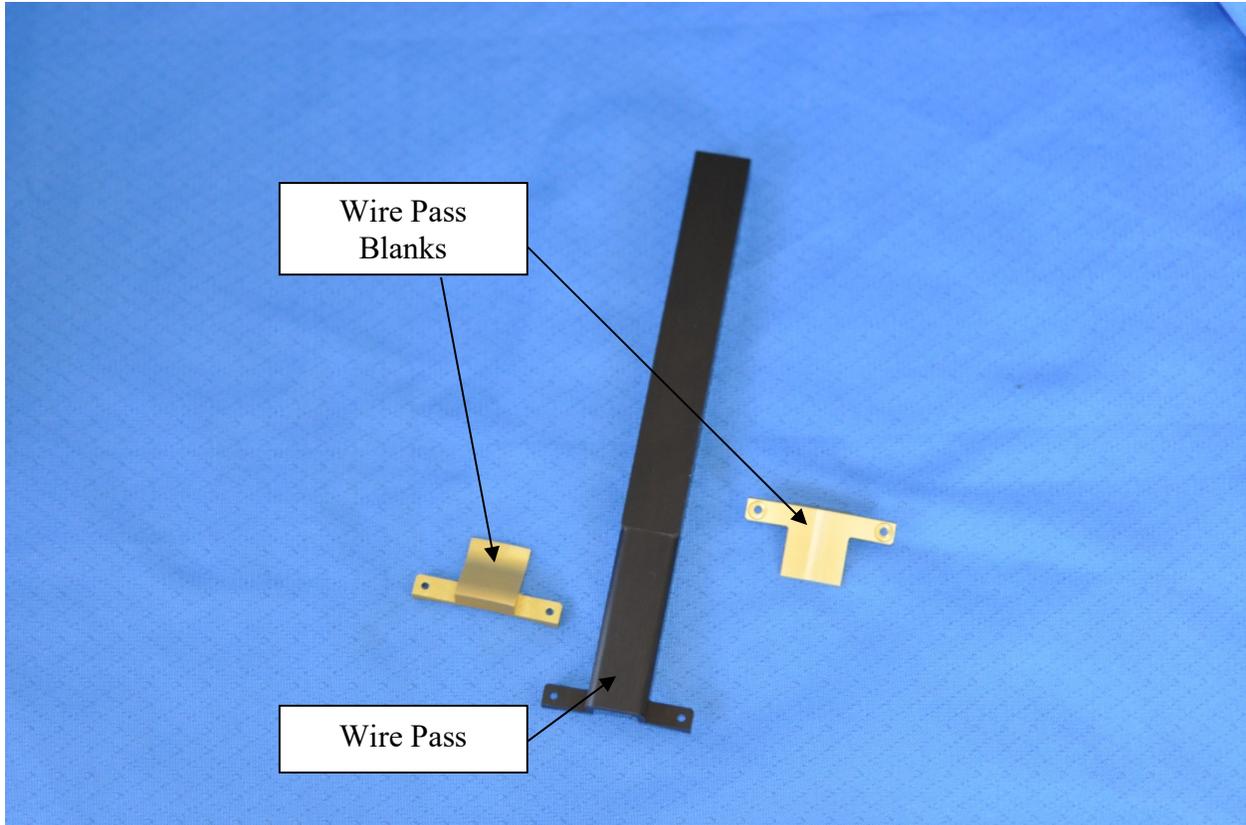


Figure 5.5: Collar Interchangeable Parts

If the FCDP collar is removed, there is an additional part provided to cover the canister modification. **Figure 5.6** shows the extra part, **Figure 5.7** shows how the part looks when installed.



Figure 5.6: Canister Blank

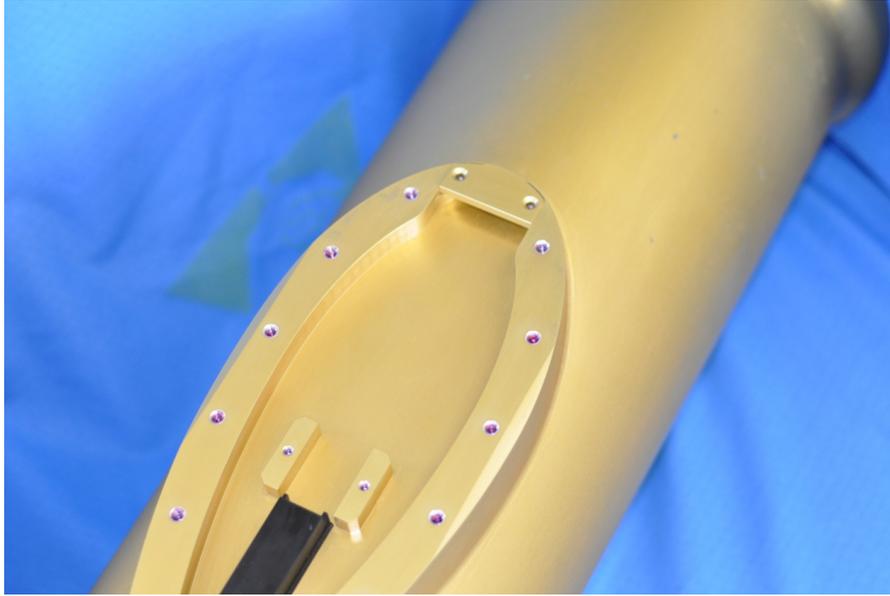


Figure 5.7: Canister Blank with Canister

Installing the FCDP collar:

1. Orient the wire pass so the FCDP will hang vertically when installed. To remove/replace interchangeable parts, remove the two #2-56 using a 5/64 in. hex driver holding the parts (inner radius).
2. Align the wire pass with the slot on the modified canister.
3. Align opposite half with the half containing the wire pass. Get the eight #8-32 screws turned so the collar is tight enough to stay together but can still be slid forward.
4. Slide the collar until it stops on the hermetic canister.
5. Tighten the screws so the collar is no longer able to move.

Mounting the FCDP to the Collar:

The FCDP is mounted to the collar using two custom bolts shown in **Figure 5.8**. The bolts are driven by a flathead screwdriver.



Figure 5.8. FCDP Custom Bolts

To Install the FCDP follow these steps:

1. Connect the electrical connector (**Figure 5.9**)
2. Align the holes of the FCDP so it appears as pictured in **Figure 5.9**.
3. Insert custom bolts and tighten (**Figure 5.10**).

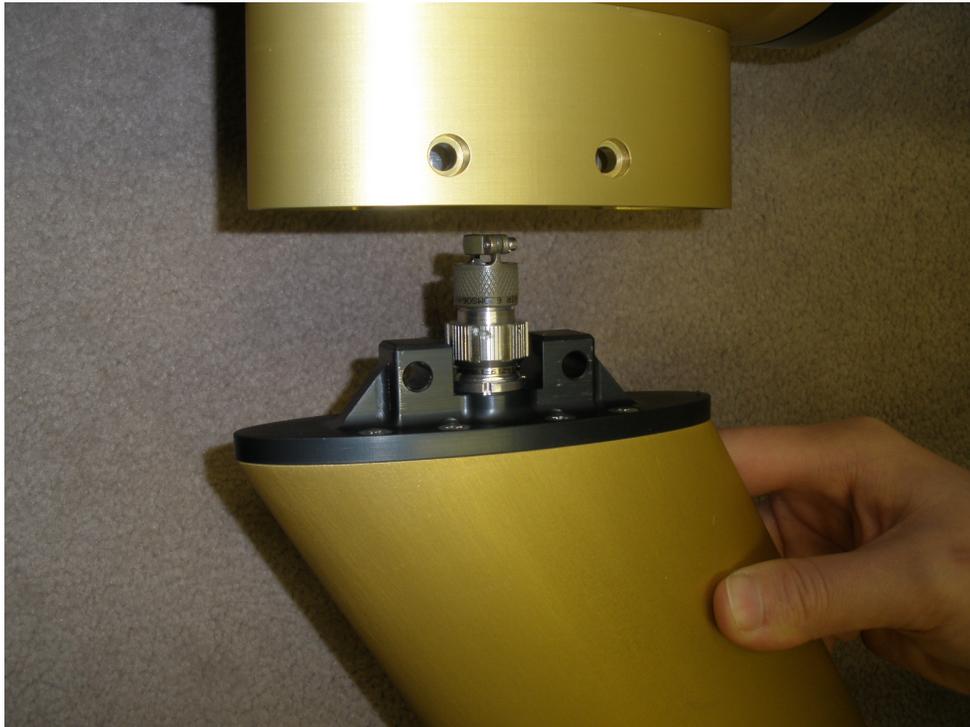


Figure 5.9. FCDP Connector engaged



Figure 5.10: Mounted FCDP with Custom Bolts