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Description and Usage of a Fast-Response Fire Suppressant Concentration Meter

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CONTENTS

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DISCLAIMER

Certain commercial equipment or instruments are identified in this paper to adequately specify the experimental procedure. This in no way implies endorsement or recommendation by NIST.

ABSTRACT

This manual describes the construction and operation procedures for a Differential Infrared Rapid Agent Concentration Sensor, the DIRRACS II, a moderately hardened, compact, portable infrared (IR) absorption fire suppression agent measurement instrument developed for deployment in field experiments and certification testing. The measurement of the temporal and spatial distribution of a suppression agent is essential for characterizing the fire extinguishment process and for certifying a fire-suppression system. The DIRRACS II uses the infrared (IR) absorption characteristics of the target agent to measure its concentration. The DIRRACS II design isolates the infrared (IR) source and detector from the flow region and uses a periscope assembly for directing the IR beam into the sample space. With the data acquisition and analysis program, time responses of about 4 ms are possible for agent volume fractions up to 0.25. A description of the design, components, and assembly of the DIRRACS II are presented to enable duplication of the instrument. Procedures for operating the instrument are also provided.

CHAPTER 1 INSTRUMENT DESIGN

1.1 INTRODUCTION

The DIRRACS II is a moderately hardened, compact, portable infrared (IR) absorption fire suppression agent measurement instrument developed for deployment in field experiments and certification testing. The DIRRACS II is capable of measuring HFC-125 (and other agents with C-F bonding) in the concentration range of 0 to 0.25 volume fraction with total combined uncertainty of 0.005 with a time response of 4 ms and a temporal resolution of 0.5 ms. To allow use of the prototype instrument and to enable reproduction or improvement of the instrument, this manual describes the components, assembly, and operating procedures for the DIRRACS II. Compactness was achieved with readily available components, so further downsizing and optimization are still possible with additional customization. An aluminum chassis provides better electronic isolation as well as protection from the dust and debris generated in agent release tests. The unit size (excluding the periscope) is 22 cm wide x 31 cm long x 18 cm high.

A history of the DIRRACS II development and performance has been documented. **[1]** More background on the general need for agent concentration measurement and alternative technologies is also available. **[2]**

1.2 GENERAL DESIGN DESCRIPTION

In order to measure the volume fraction of fire suppressant, the DIRRACS II monitors the intensity of a chopped IR beam within a narrow spectral window. Decreases in the amplitude of the signal represent absorption by the fire suppressant targeted for detection. The optical design of the DIRRACS II consists of the following components: an IR source, an elliptic mirror to focus the source radiation, an aperture and chopper wheel to generate a cyclical signal with measurable amplitude, a parabolic mirror to collimate the beam, a periscope to carry the beam to a sample volume removed from the source and detector, another parabolic mirror to refocus the beam, a band-pass filter to isolate the wavelength pertinent to the target agent, and an IR detector in a cooled housing. The source, detector, and main optics are attached to the inside bottom of an aluminum chassis on which the periscope is mounted. The chopper controller, source power supply, and preamplifier power supply are located outside of the chassis and are attached through cables or wires which allow up to 1 m of separation. The preamplifier circuitry is located within the chassis, and signal out connectors are mounted on the chassis exterior.

Some important design principles governed the layout of the instrument. If further modifications are made, these principles should be considered.

- The IR light source should be isolated from the flow to avoid vibration and convective cooling.
- The IR beam should be collimated and its diameter minimized to reduce background radiation from internal surfaces.
- The IR source must have a stable output with high intensity at the wavelength range of interest.
- The periscope should be constructed rigidly to minimize flow-induced vibrational noise.
- The path length selected should be consistent with the desired volume fraction to be measured by the instrument.
- A slight, positive, internal pressure is required of an inert gas to prevent leakage of agent into the periscope or chassis.
- A fast response IR detector is required to permit chopping frequencies up to 4 kHz.

Figure 1 is a view from above of the internal components of the instrument. The locations of the IR source, focusing mirror, collimating mirror for creating a uniform beam, and the liquid nitrogen Dewar are shown in the figure. The HgCdTe detector and band-pass filter are attached on the far side of the Dewar and are not visible. Also evident is the chopper blade positioned just after an aperture. The periscope assembly is seen extending outside the instrument chassis in the upper right hand corner. A portion of the 1 cm sample path length is visible just to the right of the lower section of the periscope assembly. Figure 2 is a view of the inside of the chassis from the opposite direction of Fig. 1. The filter holder and detector can be seen in this photograph. Figure 3 shows a top view for better understanding the internal spacing of the components.

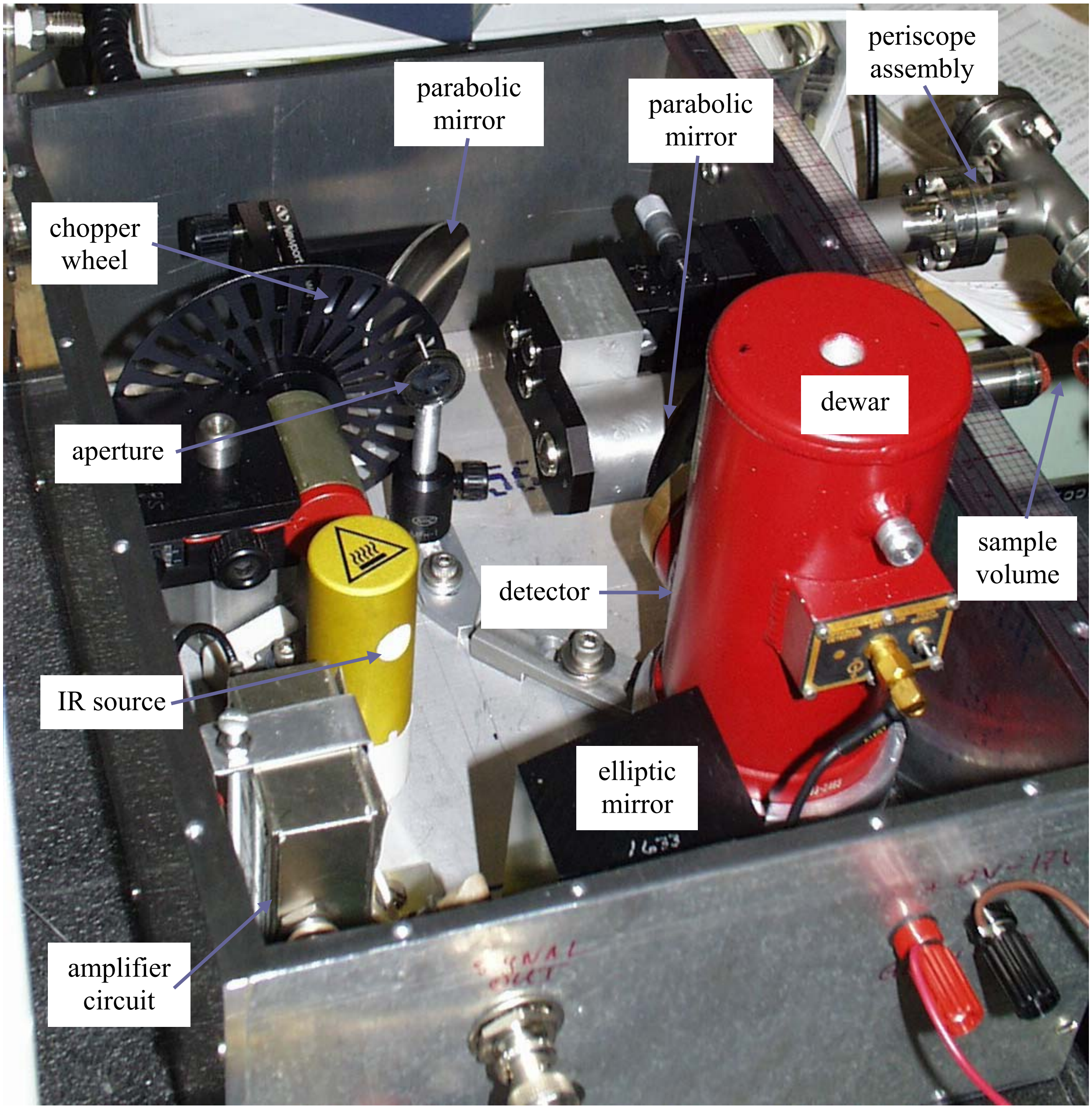

Figure 1. A photographic view of the DIRRACS II interior showing the general layout including relative sizes and positions of components.

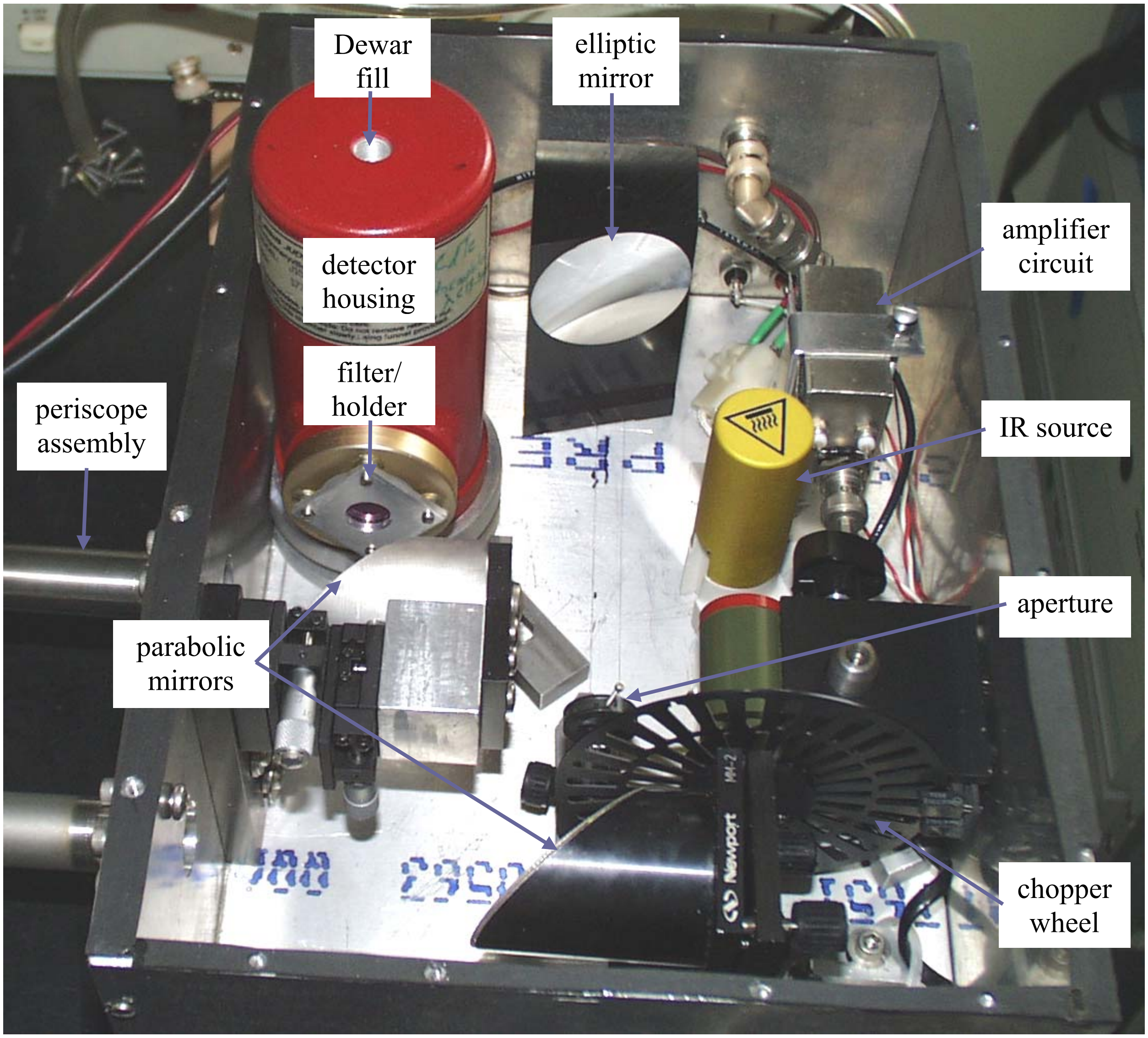

Figure 2. A photographic view from the opposite direction as Fig. 1 of the DIRRACS II interior showing the general layout including relative sizes and positions of components.

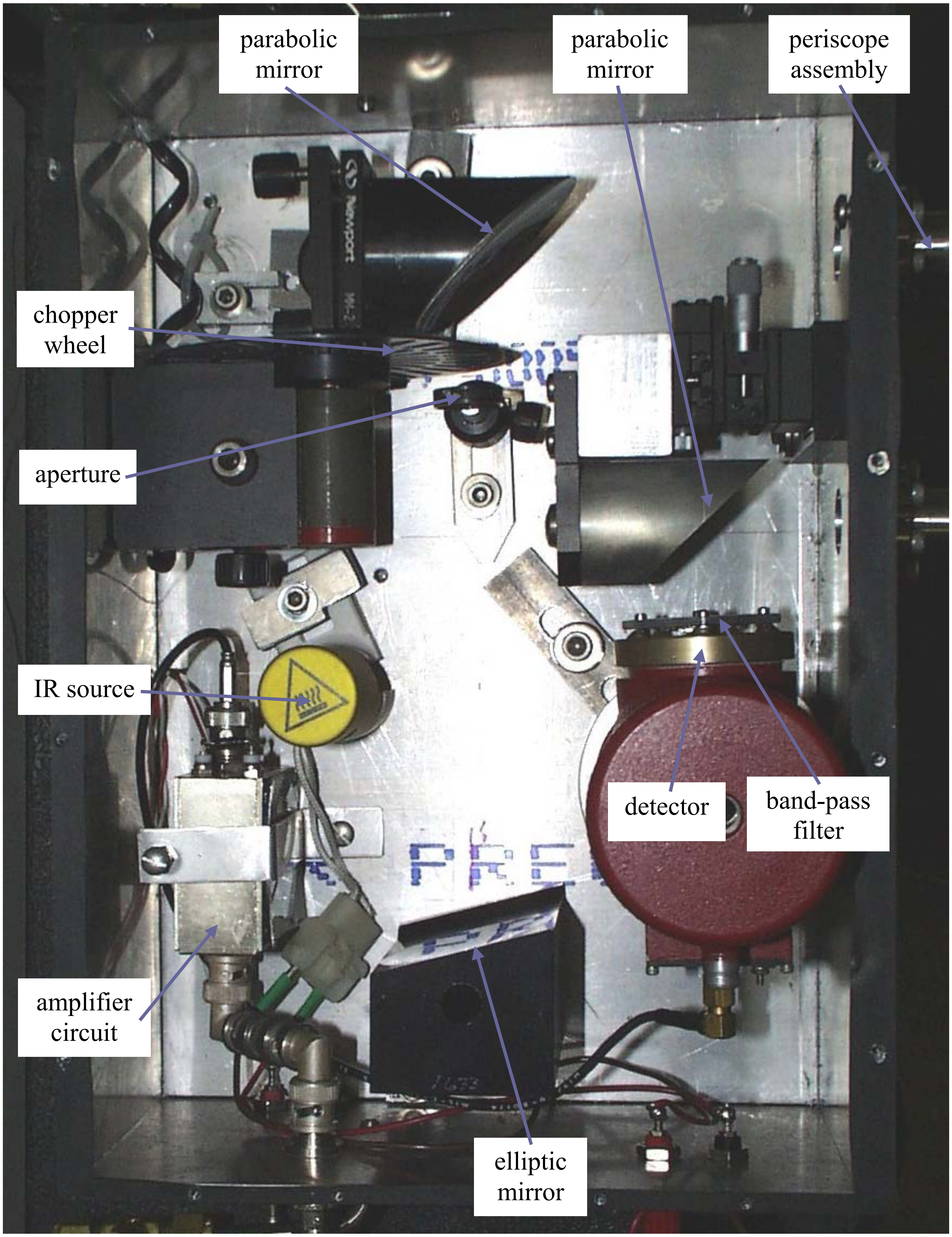

Figure 3. A photograph of the DIRRACS II interior from above showing the optical components.

1.3 HARDWARE COMPONENTS SPECIFICATION

1.3.1 Optics Specification

The important characteristics of the optical components are detailed here. Some aspects are not crucial as long as they accomplish the required functions. Specifications of the optical components used for DIRRACS II are listed in Appendix A. Most of the components are readily available from more than one source and need not be duplicated exactly.

Briefly, the details of the design are as follows. The source is an Ever-Glo globar used in a Nicolet FTIR system. It operates at approximately 1250 °C and produces mid-IR radiation in the (50 to 7400) cm^{-1} with strongest output at (400 to 4000) cm^{-1}. The source is positioned at the shorter 76 mm focal length of the 51 mm diameter 30° off-axis elliptical mirror. The light from the globar source overfills the mirror. The mirror focuses the light onto a variable-size aperture (iris) positioned 152 mm away at the long focus of the elliptical mirror and along an axis 30° from the source-elliptical mirror axis. The particular iris is 21 mm in diameter, but any iris with the capability of producing an aperture of about 1 mm is acceptable. A 44 mm diameter, 38 mm focal length, 90° off-axis parabolic mirror collimates the light exiting the aperture. The light is also chopped close to the aperture since the beam diameter there is a minimum allowing the beam to be cleanly chopped. The chopper blade has 30 slots on the outside where the beam passes. The combination of the chopper motor and blade should be capable of 2 kHz chopping rates.

The collimated beam diameter of approximately 12 mm is determined by the f-number of the system of 3 defined by the ratio of the 152 mm focal length of the elliptical mirror divided by its 51 mm diameter and the 38 mm focal length of the 90° off-axis parabolic mirror. After traversal through the periscope/sample (which uses gold coated prisms as planar mirrors), the collimated light beam is refocused by a 38 mm diameter, 25 mm focal length 90° off-axis parabolic mirror onto a 1 mm^2 detector with 60° field of view. Note that the detector field of view is more than the required 28° field of view to collect the collimated light beam.

The periscope is described in Section 1.3.3, and the components are listed in Appendix B. Since the beam that enters and exits the periscope is collimated, any periscope design that can properly steer the beam between the ports on the chassis is acceptable. The reentry port for the light beam must match the periscope's exit. The next optical component is then another parabolic mirror. In this case, a mirror with a 25 mm focal length is used. It can be located any distance from the periscope reentry port. It should be aligned such that the light enters the mirror along one axis. The resulting beam exits the mirror 90° from the direction it enters and focuses on the detector element just after the filter. The final component assembly is the narrow band-pass filter and detector. The filter was particularly specified for the HFC-125 agent absorption spectrum, but a filter appropriate to another target agent could be implemented instead. The filter was mounted on the detector housing with a simple holder made from aluminum that matched up with the holes that were drilled and tapped into the existing brass housing cover located around the optical window. The location of the filter and housing was such that the beam was actually focused inside the housing on the detector element. The detector, housing, and preamplifier circuit are detailed in Appendix A. The detector is a photoconductive HgCdTe with a cutoff wavelength > 13.5 μm, a 60º field of view, and a 1 mm square element size, and it requires liquid N_2 cooling. The preamplifier should be matched to the detector with emphasis on low noise, high gain, and wide bandwidth. Additional emphasis should be placed on low drift characteristics of the preamplifier since drift and stability issues can cause changes to the DIRRACS II calibration and response.

There are many choices available to meet the optical requirements of the mirrors. Generally, the mirror diameters are not crucial. Mirrors with the correct optical characteristics will suit as long as they:

- are large enough to receive the incoming source light whether it is the initial source, expanding 1 mm beam, or the ≈1 cm collimated beam,
- have mirror mounts that match the particular mirrors that are used, and
- have multiple axis control

1.3.2 Chassis Specification

Appendix C lists specifications of the actual peripheral components used for DIRRACS II. Figure 4 shows the main chassis and periscope with the peripheral devices arranged around it. Figure 5 shows a closer view of the connections to the chassis. The peripheral devices include a chopper controller with cable access into the chassis, source and detector/preamplifier power supplies with electrical ports into the chassis, the Dewar housing/fill port for liquid N_2, gaseous N_2 purge inlet plumbing including a pressure gauge and flowmeter, and an electrical port for the signal out. The electrical connections, controller cable, and gaseous N_2 ports may be located wherever on the chassis is convenient or proximate to the associated interior components to keep wires short. The sealed chassis extension for the detector Dewar and its liquid N_2 fill port must be located directly above the detector.

The chassis itself is made of 4.8 mm thick aluminum. The outside dimensions are 31.4 cm long by 22.2 cm wide by 12.6 cm high. The lid has the same length, width, and thickness. The sides are screwed together at the corners with 22 type 5-40 screws into drilled and tapped holes. A 1.6 mm thick rubber gasket is used between the chassis and the lid. The lid is attached to the chassis with 16 type 5-40 screws.

The chopper controller used is shown in Fig. 6. For the globar source, the power supply needs to provide a regulated 12 V and up to 2 A. The power supply used has a higher capacity than these minimum outputs. It is connected with banana jacks and wiring with a rating for the appropriate current level. For the detector used, the power supply needs to provide at least 15 V dc and 200 mA current. The detector power supply is connected with banana jacks to BNC connectors and coaxial cable. The signal out also uses a BNC connector and coaxial cable.

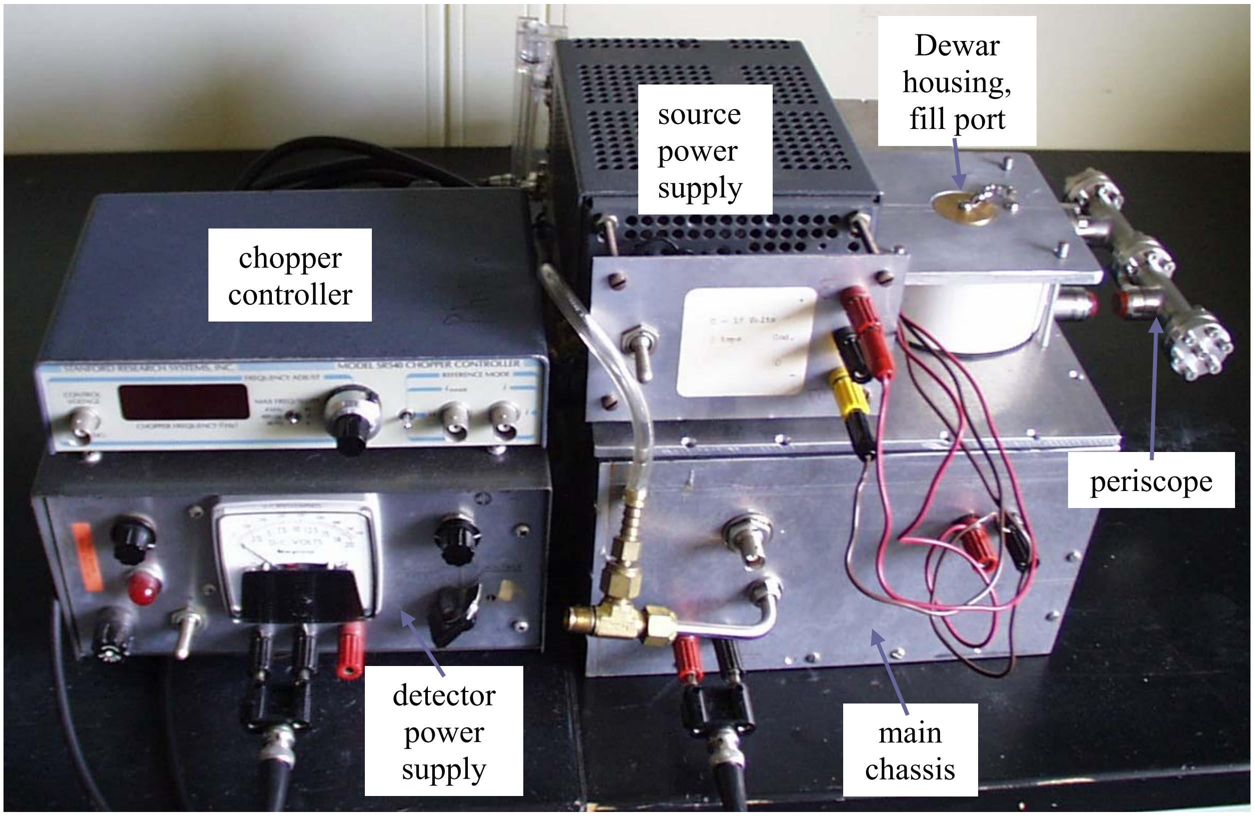

Figure 4. A photographic view of the major DIRRACS II components.

The gaseous N_2 purge was accomplished using 6.4 mm swaged fittings and tubing. A pressure gauge that can measure up to about 1 kPa is used to maintain positive pressure within the chassis. A flowmeter (like the one shown in Fig. 7) with a valve is used to adjust the outlet flow from the chassis to about 100 cm^3/min.

The detector housing protrudes from the top of the chassis so an opening and accommodating extension to the top of the box are required. Pictures of the housing are shown in Figs. 4 and 5 and in more detail in Fig. 8. A 7 cm diameter hole with a 1 cm by 0.7 cm notch is located in the lid above the detector to allow clearance for the detector housing. Four threaded 10-24 holes are located outside the hole in the lid and four 5 cm long threaded rods are screwed into the holes. These rods extend up beyond the top of an 8.9 cm outside diameter, opaque PVC cylinder with 6.4 mm wall thickness. The cylinder has 1.6 mm gaskets at the bottom and the top to provide a good seal upon compression. A 10.5 cm square top is located above the cylinder. It has four through holes in the periphery to match the pattern of the threaded posts. A 3 cm diameter hole in the center allows for a plug for the detector Dewar fill port. Around the hole, but between the square top and the detector housing, is another gasket with an ID of 3 cm and outside diameter of about 4.5 cm. This seals the chassis from the volume near the fill port. The square top is secured and tightened against the cylinder and gaskets using 4 wing nuts. The 3 cm diameter Dewar plug that came with the detector housing is attached to the square top with a short chain.

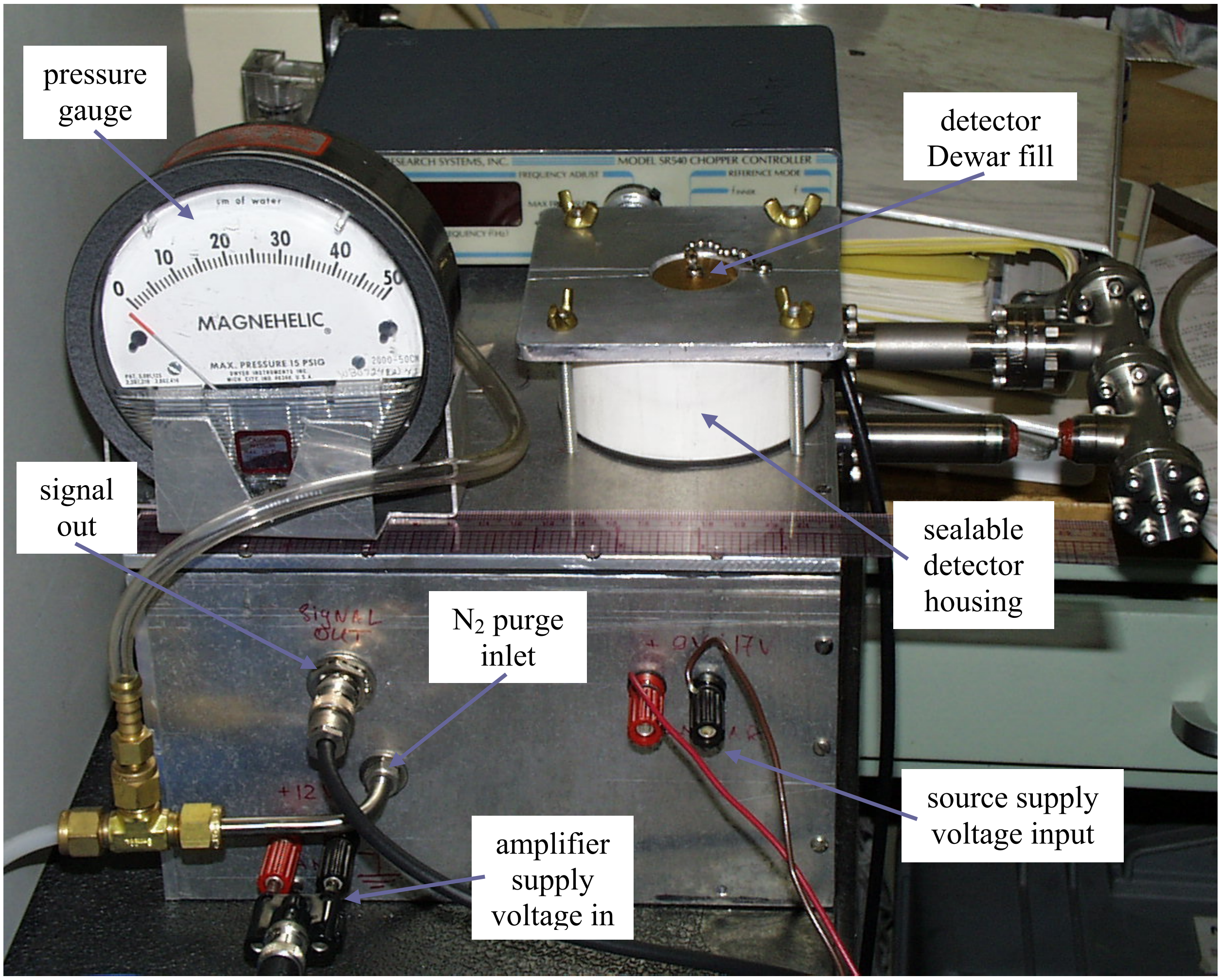

Figure 5. A photograph of the DIRRACS II chassis showing the electrical and gas connections.

Figure 6. A photograph of the chopper controller showing the readout and frequency settings.

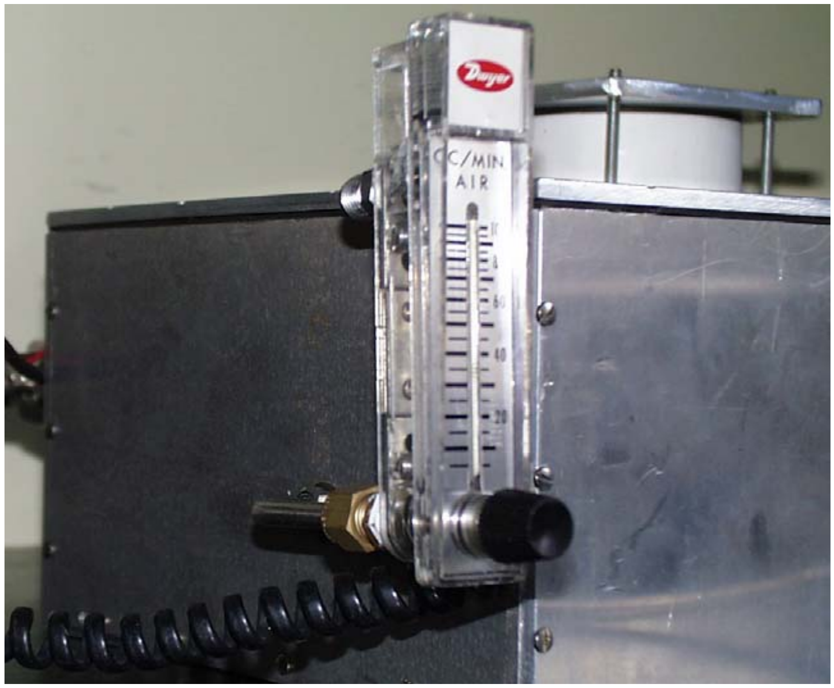

Figure 7. A photograph of the side of the chassis where the N_2 purge exhausts and its flow is monitored and where the chopper controller cable enters the chassis.

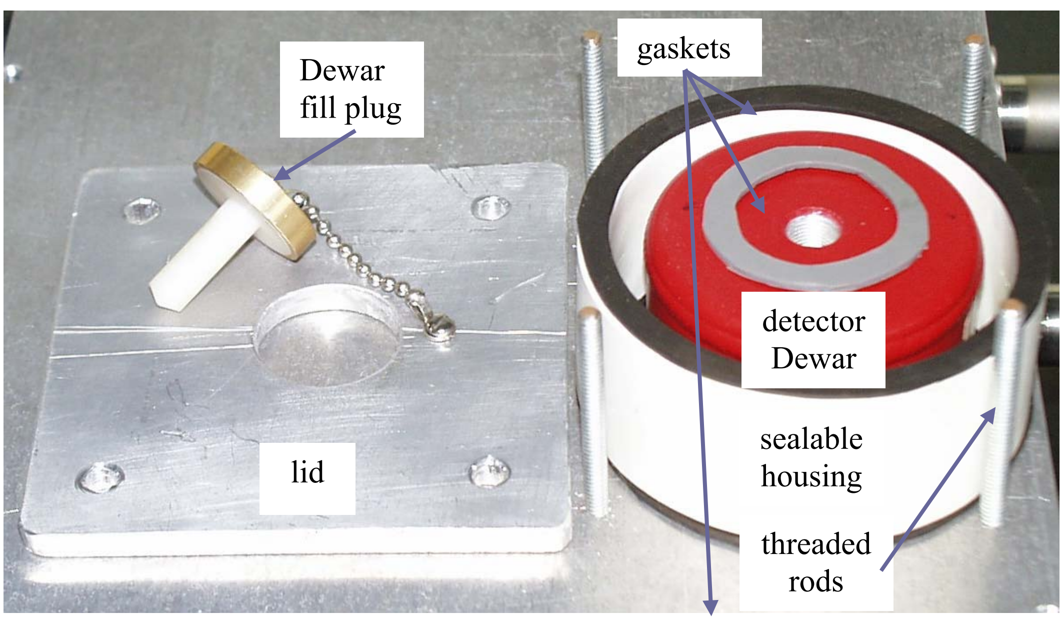

Figure 8. A photograph of the detector Dewar sealable housing, tightening rods, lid, gaskets, and Dewar fill plug.

1.3.3 Periscope Specification

A photograph of the periscope is shown in Figure 9. A schematic drawing of the periscope design is provided in Figure 10. The components are listed in Appendix B.

The purpose of the design is to extend the source IR light outside the main optics chassis to a location where the instrument can measure absorption of the light by the target agent without significantly intruding with the flow. Design issues for this and any future versions of the periscope include the following: distance of the sampling volume from the chassis, strength of the structure and associated mounts to be suspended from the chassis, need to withstand some vibration induced motion or other forces, diameter of tubing relative to acceptable levels of blockage and intrusiveness, and path length of the sampling volume.

The basic design consisted of stainless steel vacuum tubing and fixed flanges, planar mirrors made from gold-coated prisms, rotatable flanges and threaded posts for adjusting the internal gold-plated, prism-mounted mirrors, BaF_2 windows at the sampling volume which are attached and sealed with high temperature silicone, compressible copper gaskets for sealing the periscope from agent infiltration, and stainless steel bolts for connecting the components. Some customized parts and adjustments to purchased components were made at the NIST (National Institute of Standards and Technology) shops and their specifications are not all available. Rather than duplicate this periscope design, we recommend that a design that fits the exact requirements of the particular application be considered. The ideas and components described here are sufficient to approximate the NIST periscope.

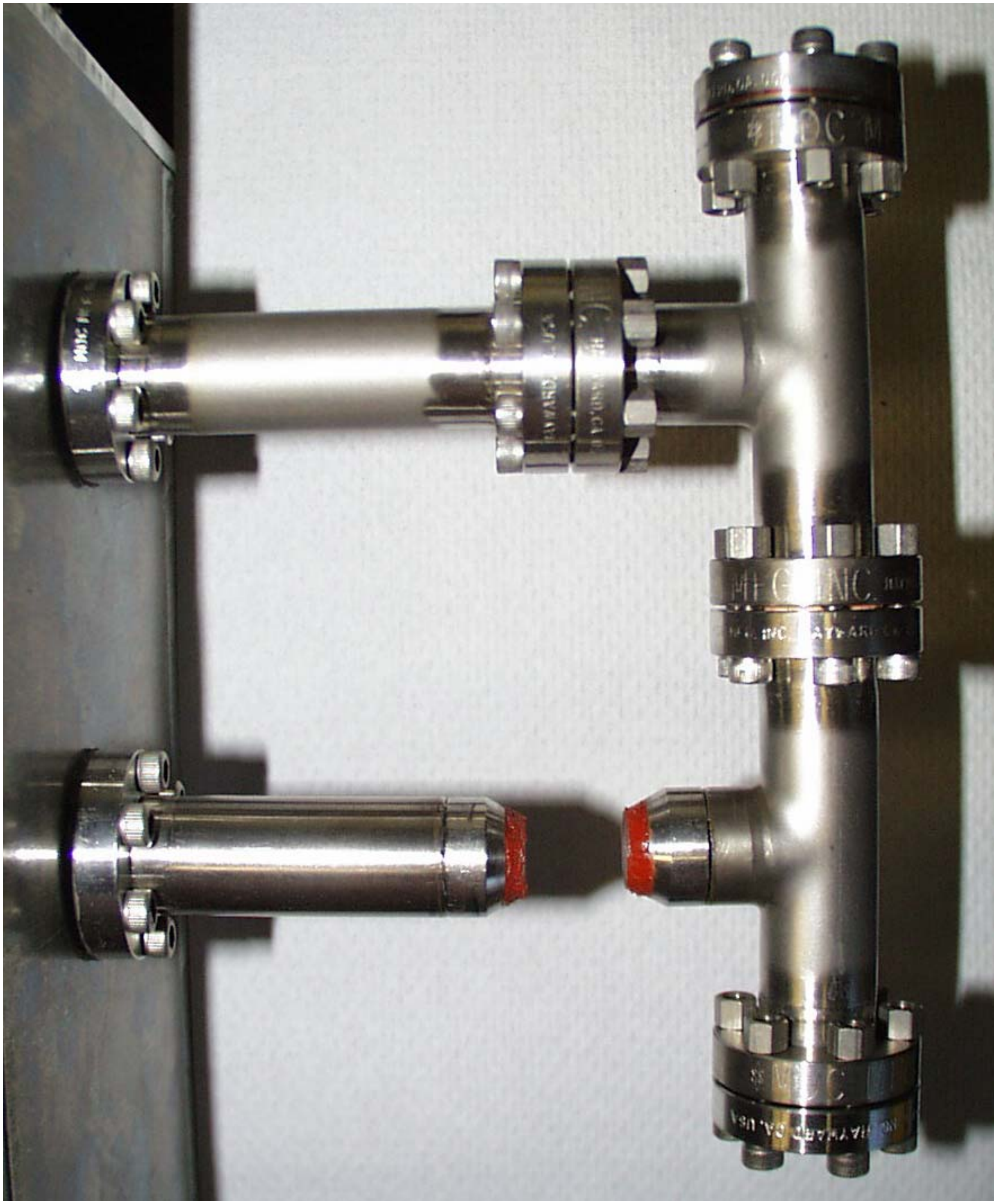

Figure 9. A photograph of the periscope attached to the DIRRACS II chassis.

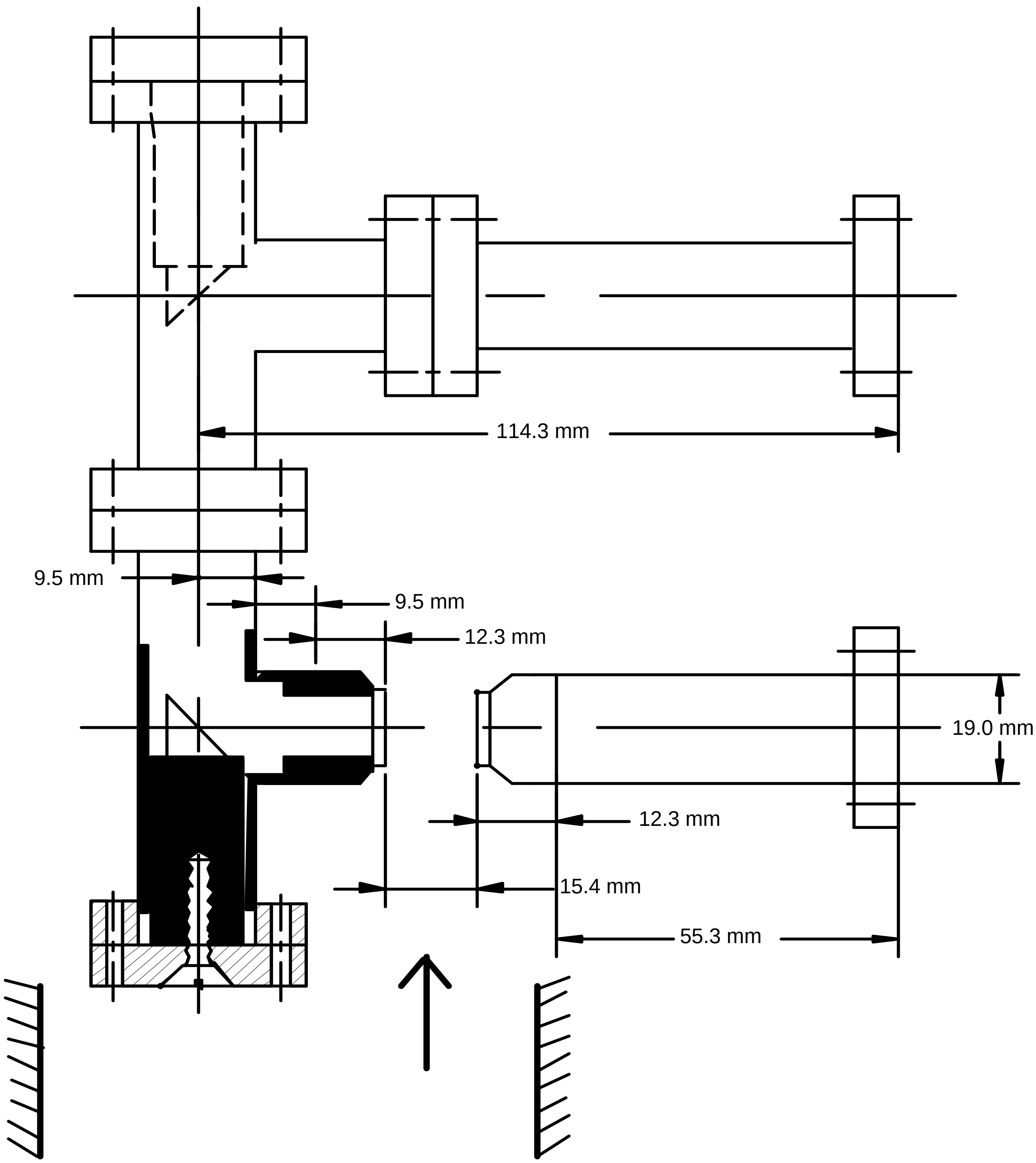

Figure 10. A drawing of the periscope assembly.

1.4 ASSEMBLY OF DEVICE

1.4.1 Chassis and Main Optics Assembly

Assembly of the DIRRACS II is primarily an exercise in optical alignment. Elements of the optical chain are located in the chassis based on their focal lengths and attached in a manner that allows for fine adjustments. All of the components should be placed in the chassis in their approximate locations to obtain a layout that uses the available space well with generous spacing for component access where optical considerations are not important.

Exact placement and alignment should start with the collimating parabolic mirror since it must be aligned with the periscope. That mirror should be aligned with the entrance axis of the periscope with care that its base is translated orthogonally to the periscope and chassis axes and not rotated.

Other optical components should be adjusted and fixed working backwards from the collimating mirror. This can be accomplished by sending an alignment light beam backward through the periscope to determine mirror focus locations. The iris is located 38 mm in front of the collimating mirror and 90º from the periscope entrance axis. The chopper blade is located between the iris and the collimating mirror, as close to the iris as is feasible. The first mirror (elliptical) is located 152 mm before the iris. The source globar is located 76 mm from the elliptical mirror and offset 30º from the optical path exiting the mirror.

The periscope requires its own assembly. Its exit determines where the reentry path of the beam into the chassis should be. The chassis should be designed and machined knowing the periscope dimensions. The third mirror (parabolic) can be located any distance from the periscope exit within the chassis, keeping in mind the desired detector location and space limitations. The detector (the actual sensor, not the housing) is located 25 mm from the mirror and 90º off the periscope exit axis. The filter can be mounted in front of the housing or on the housing itself. Once a rough alignment is achieved, it can be fine-tuned for maximum signal from the detector. The top of the chassis should be designed after the optical layout is fixed. The top requires the hole to accommodate the detector housing and access to fill it with liquid nitrogen.

1.4.2 Periscope Assembly

The periscope should be assembled as a subassembly which can then be mounted onto the chassis of the DIRRACS II. The periscope should be fabricated, assembled, and aligned, and the relative positions of the periscope light input and output should be well-known before the ports to the chassis are determined and the detection optics fixed in place. For this periscope, the components were accumulated from the input end and optically aligned and tightened at each appropriate step. To optically align the collimated beam (or laser beam which is easier and more accurate to use), it must be in the center of both ends of each section of tubing. At each of the two beam reflection positions, the mirrors must be turned on their threaded posts to achieve a centered beam in the new directions. The sections should not be tightened until aligned since the copper gaskets deform during tightening. The BaF_2 windows must be attached and sealed with an adhesive designed for the temperature range of potential operation.

CHAPTER 2 OPERATION PROCEDURES

To operate the DIRRACS II, the required supplies must be available, the apparatus must be fully assembled, and the software must be operational.

2.1 SUPPLIES

The DIRRACS II requires a liquid nitrogen supply. Usually a liter will last for a few hours of testing. A funnel is necessary to pour the liquid nitrogen into the detector Dewar with control. The DIRRACS II also uses gaseous nitrogen to purge the chassis and periscope and keep the agent being detected from affecting the measurement by creating additional absorption outside of the sample volume. The flow of nitrogen is very low, so one 1A cylinder with a regulator will last for days or weeks of testing.

2.2 FINAL ASSEMBLY

Before operating the DIRRACS II the hardware needs to be fully assembled. The lid should be secured and the detector housing sealed with the wing nuts. The internal chassis temperature has not been a problem with this design, but if a thermocouple is available, its lead can be sandwiched between the lid and wall to monitor internal temperature.

2.3 INSTRUMENT PREPARATION STEPS

The following steps should be followed to prepare the DIRRACS II for calibration or testing:

- Pour liquid nitrogen into the detector Dewar with a funnel. This should be repeated two times over a period of about 10 min to top it off. Once the Dewar is full, it only needs a top-off every hour or so for continued testing.
- Start the nitrogen gas purge at a level of 100 cm^3/min. The internal chassis pressure should be in the 400 Pa to 600 Pa range. Excursions outside of this are not critical, but a positive pressure should be maintained.
- Set the supply voltage for the IR source to 7.04 V or at whatever level the DIRRACS II was calibrated. The 7 V setting is different than the 12 V recommended by Nicolet, but it was required to prevent detector preamp saturation and functioned properly at that level.
- Set the detector preamplifier supply voltage to 12.2 V.
- Recheck the source and preamplifier supply voltages in case of drift and readjust if needed before running a test if there is a long time between set-up and testing.
- The chopper controller, shown in Fig. 6, should be set for a frequency of 2 kHz with the number of slots set to 30 on the left toggle switch. The right toggle switch should be set to the middle position so the rightmost BNC output provides the frequency of the chopper to the software. The leftmost BNC provides the voltage output to the chopper motor.
- If a trigger is to be used to start the acquisition, the TTL type output from the triggering device should be connected by BNC to the trigger input on the terminal block. If particular delays or timing relationships between the triggering event and the data capture are required, e.g. using the opening of the agent release vessel as a trigger with some delay added, a pulse generator can be used to manipulate the triggering.

2.4 SOFTWARE PROCEDURES

The FSP (Fire Suppressant Program) software uses some basic MS Windows menu structures. Table 1 lists the menus, menu options, submenus, functions, and shortcut buttons used in the program. Figures 11 to 14 show the screen images related to the menu choices. Refer to the table and figures for clarification of software instructions.

The file functions in the top menu bar (in Fig. 11) allow previously recorded data files to be opened and current data to be saved to file. If new data is to be recorded, follow the following steps:

- On the software screen, if it is a manual start, set the trigger to internal (see Fig. 12). Set the trigger to external if using an outside event (rather than mouse click) to trigger the data acquisition.

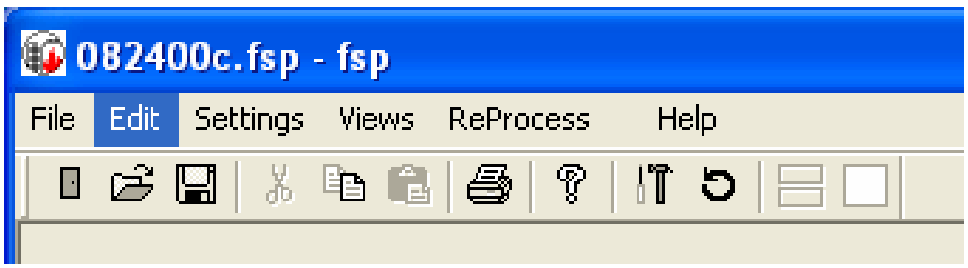

Figure 11. An image of the upper screen menu.

- Set the number of samples (see Fig. 13) to acquire (e.g. 128 000). The memory capacity of the original computer used and the data acquisition board limited the number of samples to 200 000 for two channels (signal and chopper) and 2/3 of that (130 000) for three channels (such as an extra pressure voltage).

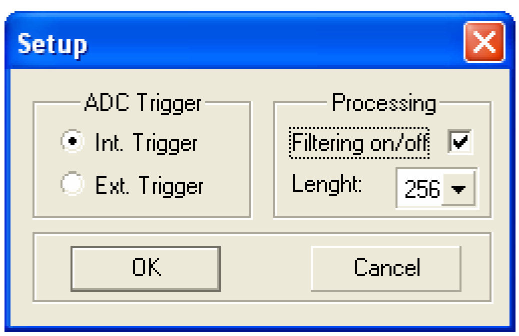

Figure 12. An image of the settings submenu accessed from the upper screen menu through the “settings” menu option or the tools button.

- Choose a sampling frequency (see Fig. 13). The digital lock-in is slightly sensitive to the frequency chosen. A multiple of the chopping frequency (usually 2 kHz) and the base filter length (64) is recommended (e.g. 128 kHz).

Figure 13. An image of the lower screen menu.

- Set the preamplifier voltages (see Fig. 13) which simply set the plot ranges for the signals to be captured.
- Once all the settings are correct and the hardware is ready, the user can initialize a capture. This is done by pushing the capture button shown at the left in Fig. 13 and at the bottom left corners of the screen captures of Figs. 15 to 18.
- The file save function (in Fig. 11) should be performed immediately after the data capture
- The user should record the filename and the selected parameter settings in their log.

Once the data has been acquired, other manipulations for analysis are possible with the software. Figure 15 shows the initial waveform set with the raw voltage signal at the top and the chopper signal at the bottom. Figure 14 shows a menu, accessed by right-clicking on a graph, that allows specific ranges of time and signal to be specified or auto scaling can be chosen instead of customization. Figure 16 shows a "zoomed" version of the waveform in Fig. 15. The mouse can also be used to box in and zoom any period in time on the waveform simply by holding down the left button while moving the pointer.

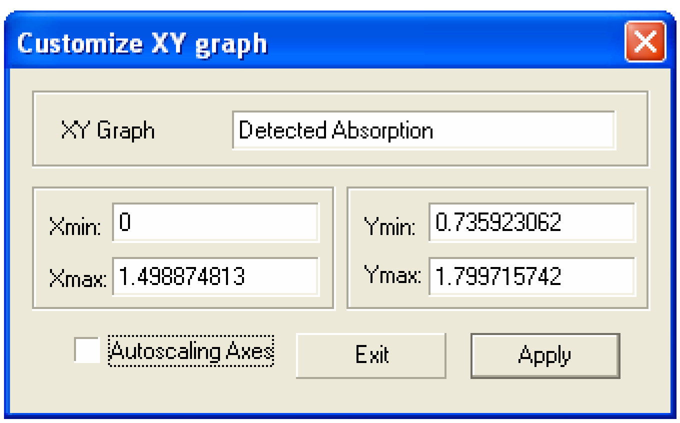

Figure 14. An image of the graph customization submenu accessed by right-clicking on a graph and selecting "customize".

The two view icons at the far right of the top menu bar in Fig. 11 are used to toggle between the raw waveform sets and the processed signal shown in Fig. 17. The processing settings in Fig. 12 show the choices of filtering the waveform or not and what levels of filtering to use. Higher filter values smooth the processed data resulting in lower amplitude fluctuations. The typical filtering value used was 256. The tools icon near the right end of the top menu bar accesses the processing settings and the adjacent circular arrow reprocesses the data with the new settings.

Table 1. The menu and submenu features of the FSP software.

Menus & Menu Options	**Submenus and Function(s)**	**Associated Shortcut Buttons**
Top Menu (Figures 11, 12)		
File	Standard Windows File Operations: Open, Save, Save As, Print, Print Preview, Print Setup, Exit	Standard Windows buttons: Exit, Open, Save, Print
Edit	Copy (other choices not active)	Cut (not active), Copy, Paste (not active)
Settings	Brings up Setup Menu shown in Fig. 12; ADC Trigger toggle between internal and external, filtering on/off option, Processing Length in points with selection options of 64, 128, 256, or 512	Tools button
Views	Original versus filtered waveform toggling, Toolbar and Status Bar Show Options	Toggle buttons for original and filtered
Reprocess	Reprocesses waveform with current settings	Circular arrow
Help	Authorship only	Question mark
Bottom Menu (Figure 13)		
Capture	Initiates data capture using all the current settings	
No. of Samples	Number of data points to be captured	
f	Frequency in points/s that data are to be captured	
Preamplifiers range	Drop menu options for signal, chopper, and third channel voltage ranges: 50 mV, 100 mV, 250 mV, 500 mV, 1 V, 2.5 V, 5 V, and 10 V	
Zoom	Select Sync on/off . Sync on simultaneously zooms other graph when zoom is applied to one	
Show…	Select "Show Reference" or "Show 3rd Channel" as the bottom graph	
Other Menus/Features		
"Left Click and Drag" on graph	Selects "zoom" box around the data to change the X, Y limits. Must drag from top left corner of box.	
"Right Click" on graph	Toggle between Customize (set limits or autoscale X, Y axes; see Fig. 14), Full Scale, and Marker (not functional)	
Time scroll bar	Appears when the time axis range is less than full scale to allow scrolling through time with the current window width.	

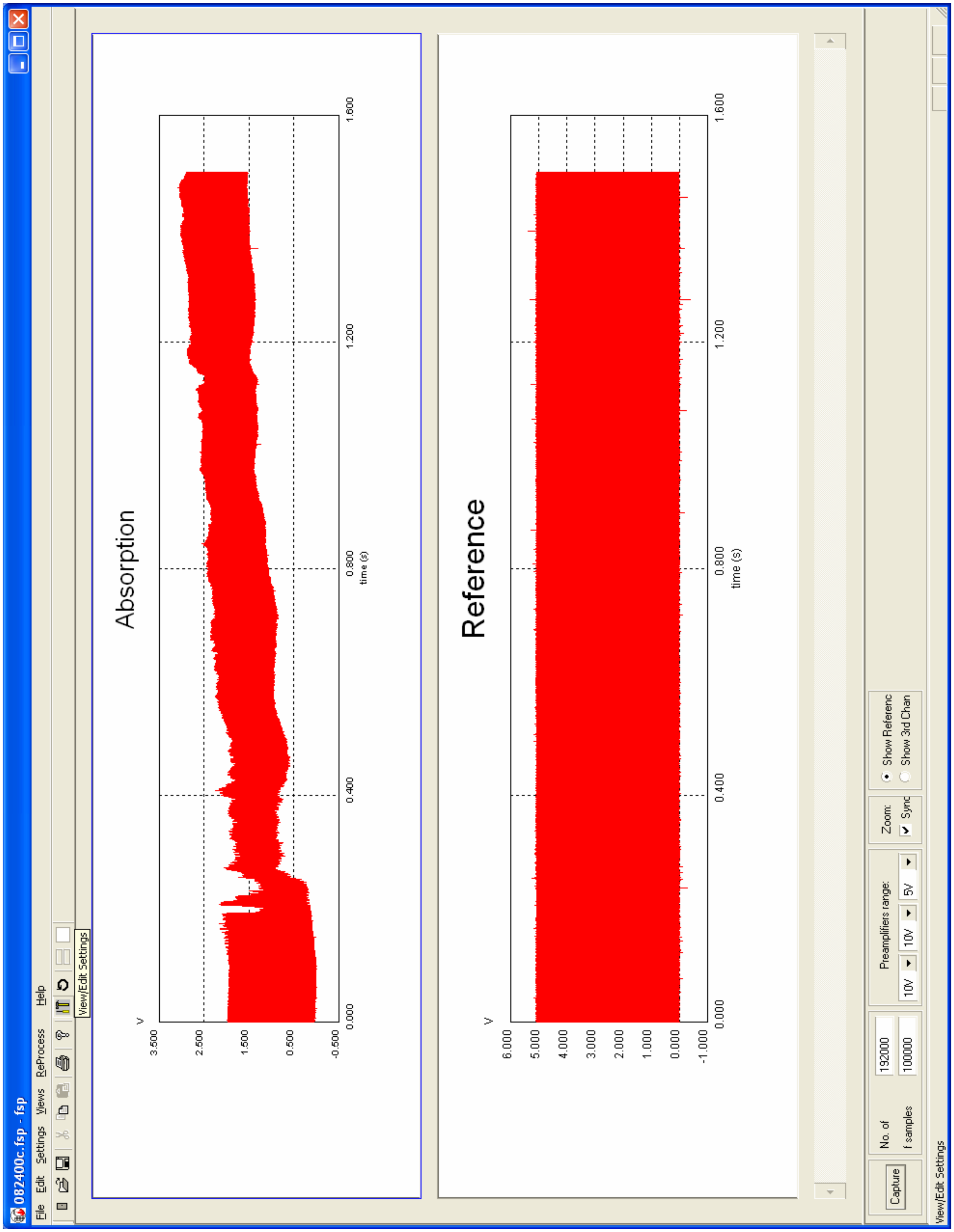

Figure 15. A screen capture of the main FSP software screen showing the original captured absorption waveform above and reference chopper signal below, both at the default scale.

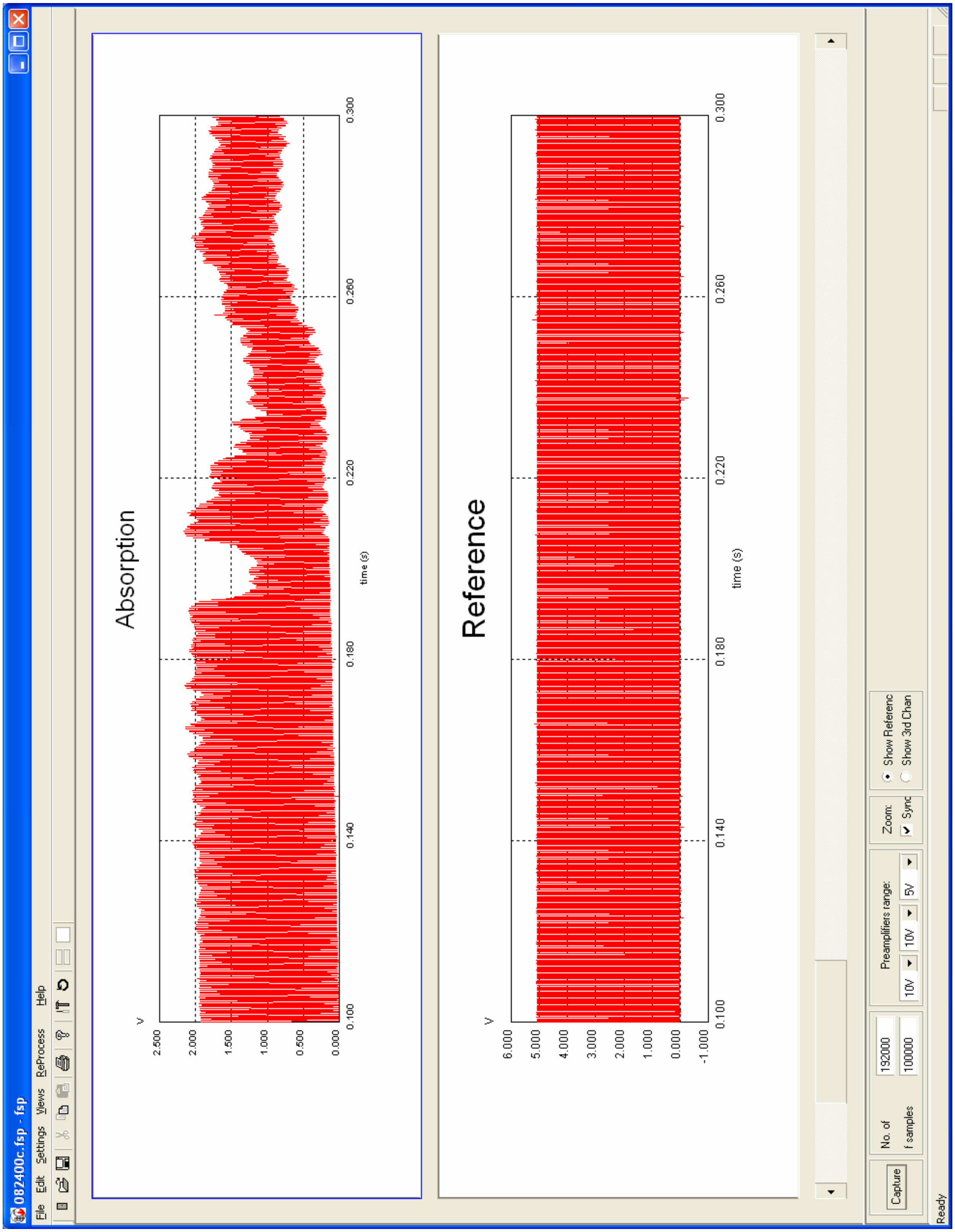

Figure 16. A screen capture of the main FSP software screen showing the absorption waveform above and reference chopper signal below, zoomed to the period from 0.1 s to 0.3 s.

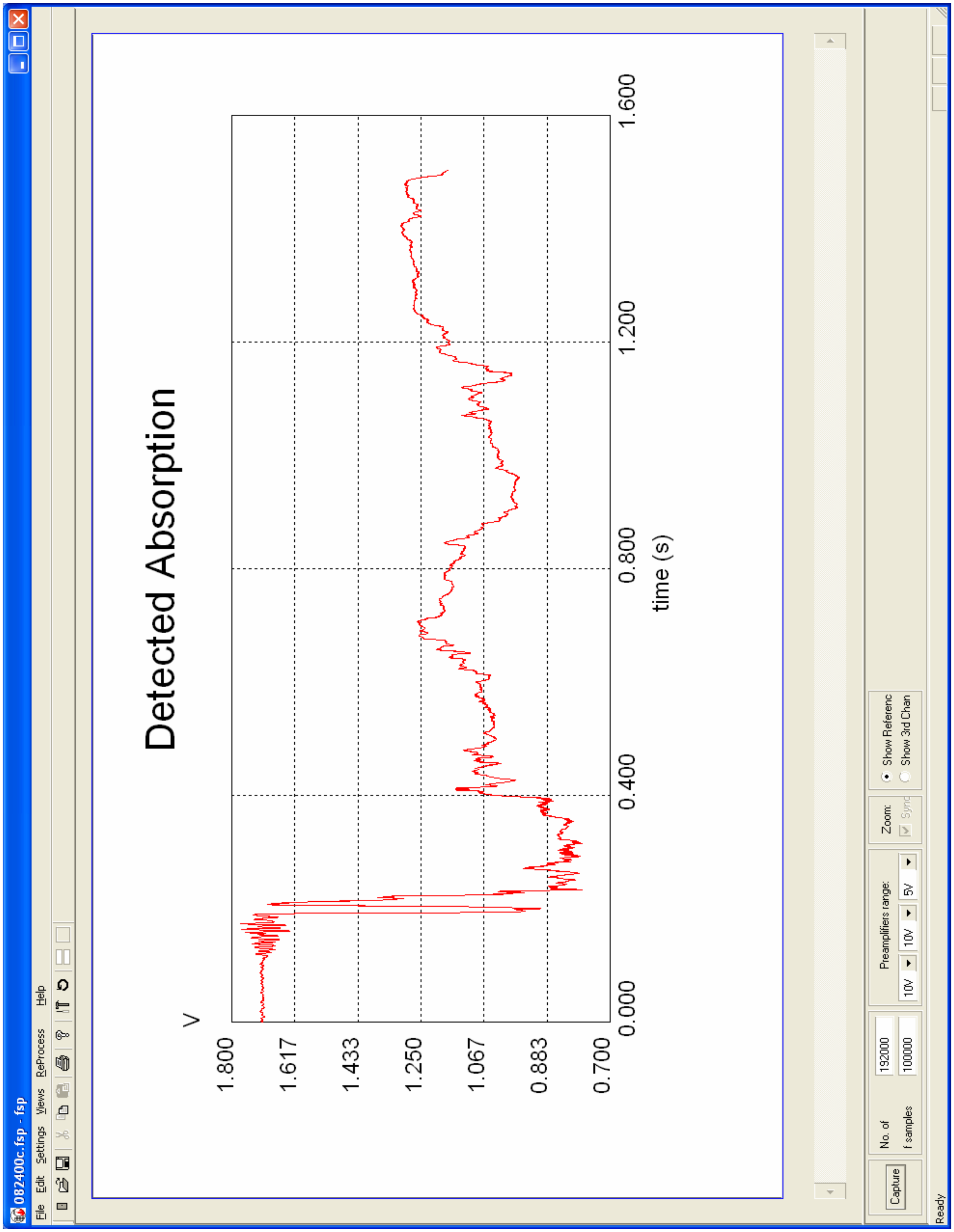

Figure 17. A screen capture of the main FSP software screen showing the filtered or processed waveform at the default full scale.

Figure 18 shows an example of the processed signal (from Fig 17) zoomed to the same time period as the raw signal in Fig 16.

The "sync" selection in Fig. 13 allows the zoom function to work on both the top and bottom waveforms in a synchronized manner so one can study the same time period for each. The adjacent choice of "Show Reference" or "Show 3rd Channel" allows the user to plot another channel of data, e.g. agent cylinder pressure, as the bottom waveform instead of the chopper reference frequency.

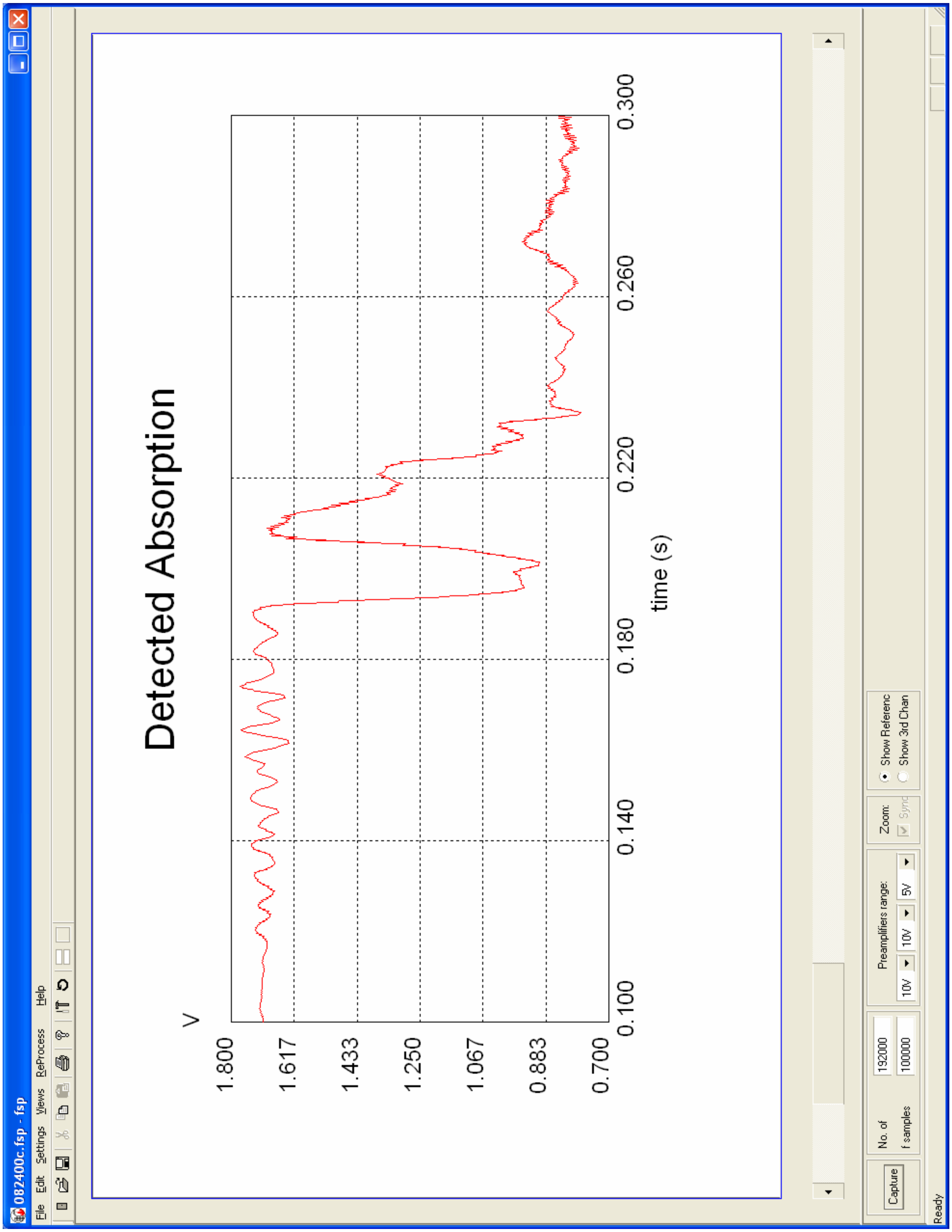

Figure 18. A screen capture of the main FSP software screen showing the filtered or processed waveform zoomed to the period from 0.1 s to 0.3 s.

2.5 TESTING GUIDELINES

The following are some general guidelines for practical use of the DIRRACS II:

- It is necessary that a user capture baseline data in the presence of air (i.e., vs. agent) directly before tests involving the agent of interest. This recording of a pretest, air-only background signal can be used to ascertain whether the instrument is affected by residual agent in later testing or whether the agent has cleared the sample area. All calibrations curves have been generated with the agent voltage signal normalized by the air voltage signal.
- When testing in the presence of an agent, the operator should wait for agent from a previous test to clear.
- The operator should also capture data after the area has cleared from a test to see if there is any drift.
- In a test log, the operator should record the time for each test along with the test name, conditions, and data-acquisition parameters. These items are not all recorded in a data capture file.

2.6 CALIBRATION

Calibration of the DIRRACS II may be accomplished with any well-controlled and characterized agent mixing system. The report on early DIRRACS work **[2]** describes in detail the calibration system used for development of the instrument. A summary is provided in **[1]** as well. Follow the following guidelines for conducting calibrations:

- The DIRRACS II should be calibrated before and after a test series. If design changes to the detector amplifier make drift less of an issue, then less frequent calibrations may be possible.
- A sealed flow cell should be used to calibrate the DIRRACS II. Figure 19 shows the cell that was used for the prototype to pass a gas mixture through the sampling volume of the periscope. The cell was made from a brass cylinder with a hole cut at mid-length and transverse to its axis. The cylinder was then cut into two half cylinders, and flanges were added to allow the halves to be reconnected and squeeze over two rubber stoppers sized to seal over the periscope tubing. Inlet and outlet ports were added to closed ends. The photograph in Fig. 19 does not show the required gas source and exhaust tubing. Other designs could be envisioned to seal the sampling volume for flow of a prescribed mixture. A smaller volume design allows less agent to be used during calibration.
- A low flow of agent and air may be used as long as the time to flush the cell is deemed reasonable.
- The user must be careful to monitor the signal to ascertain that a steady condition is reached for each mixture.
- Typically, several volume fractions of agent in air were used for calibration (0.01, 0.02, 0.05, 0.08, 0.12, and 0.25).
- Based on the theory (discussed in **[1]**) and empirical analysis, an equation of the form was generated:

$$\frac{V_{PkPk}}{V_{PkPkAir}} = A + \left(\frac{B}{VF + C}\right)^{D}$$

Where V_{pkpk} = Voltage signal for gas mixture
$V_{pkpkAir}$ = Voltage signal for air only
A, B, C, D = Best fit constants
and VF = Volume fraction of mixture
A sample calibration plot is shown in Fig. 20.

- To apply the calibration to a test, use the inverse equation of mixture volume fraction in terms of voltage signals:

$$VF = B\left(\frac{V_{PkPk}}{V_{PkPkAir}} - A\right)^{\frac{-1}{D}} - C$$

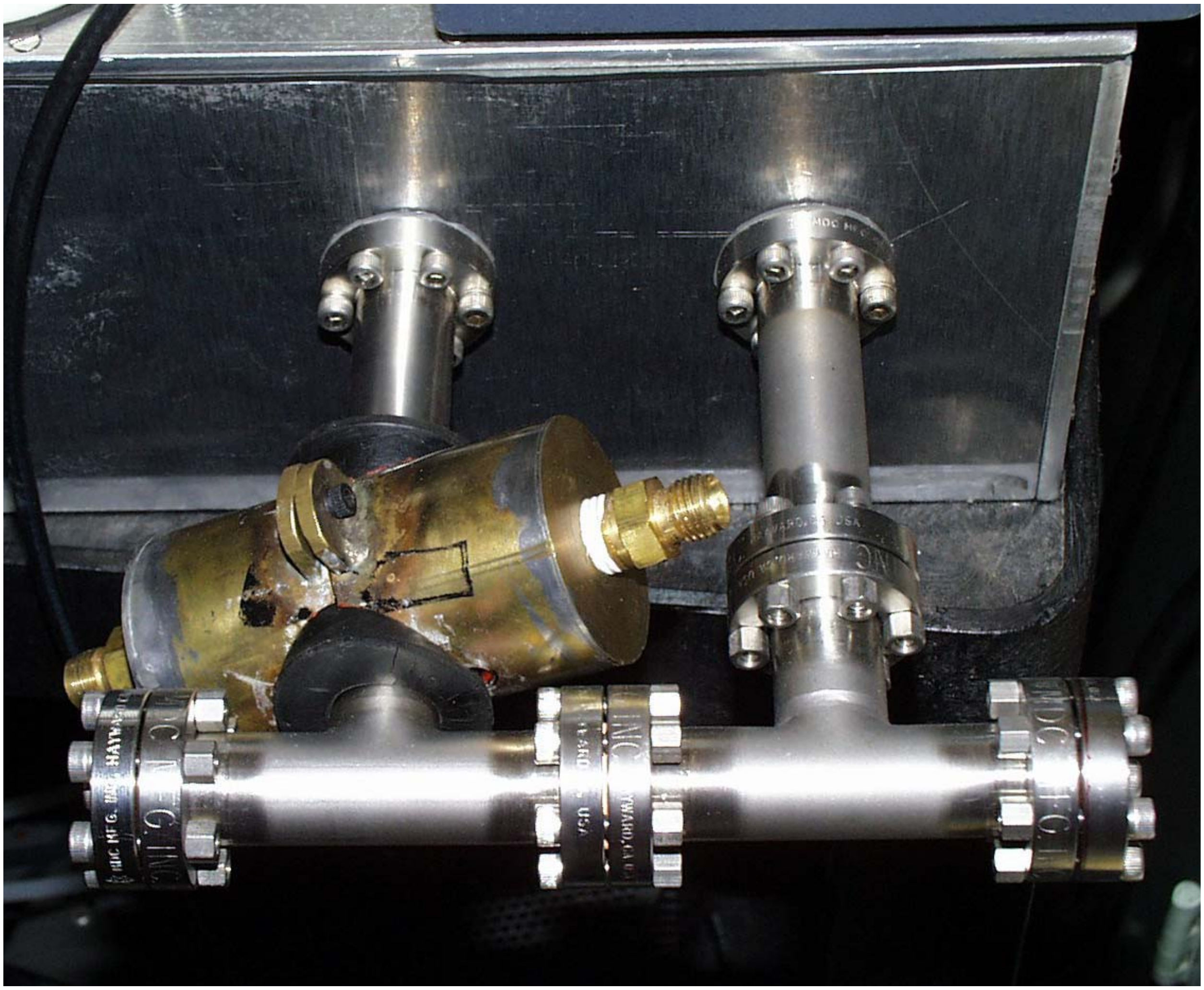

Figure 19. A photograph of the calibration cell covering the sample volume of the periscope assembly to provide known mixtures of agent and air to the instrument.

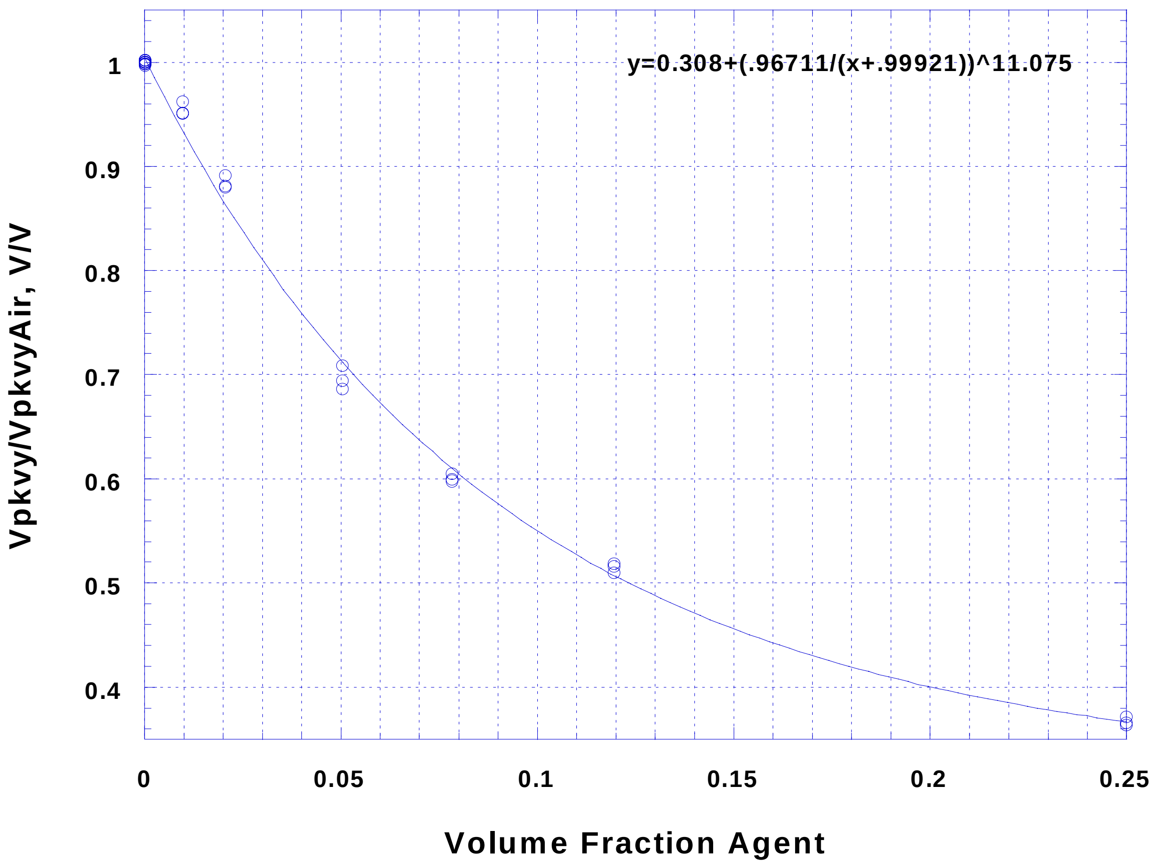

Figure 20. A typical calibration plot of average normalized peak-to-valley signals versus the volume fraction of HFC-125. Error bars for the averages are smaller than the symbols.

2.7 INSTALLATION

The exact installation depends somewhat on the test article, its configuration, and the objectives of the testing. However, there are some basic principles that should be followed for all installations:

- Thought should be given to the location of the instrument. The DIRRACS II must be located in a space where it can be mounted and its peripheral devices arranged nearby or at least accessed through cable extensions. At the same time, the periscope's sample volume must be in an appropriate location for agent concentration measurement. The geometry of the periscope and its attachment to the chassis will limit the positions the DIRRACS II can be deployed.
- The DIRRACS II may be installed in situ with the chassis hardened against some vibration, corrosive gases (assuming they dissipate before permanent damage occurs) and such levels and durations of heating that prevent any susceptible internal and external components (e.g., cable insulation, printed circuit board) from plastically softening or melting. Thermocouples should be used to monitor the DIRRACS II temperature and prevent damage if exposure to severe heating is possible.
- The chassis should be attached to something, e.g., with clamps, to prevent it from moving during a test.
- The peripheral devices such as power supplies, chopper controller, etc. should be located outside of the test area as the cable and tubing lengths permit (they can be lengthened if necessary), or the sample locations should be chosen to accommodate the current connection line lengths.
- Connecting lines for power, signal, and gas should be given extra, appropriate protection if the environment is to be hot or corrosive.
- The periscope windows may need to be cleaned if exposed to chemical or smoke residue.
- Keep pressurized gaseous and liquid N_2 and power sources at a safe distance from the test area if a fire or forceful release is involved.

REFERENCES

1. Johnsson, E. L.; Mulholland, G. W.; Fraser, G. T; Leonov, I. I.; Golubiatnikov, G. Y., "Development of a Fast Response Agent Concentration Meter", NIST TN XXXX, National Institute of Standards and Technology, Gaithersburg, MD, August 2004.

2. Pitts, W. M.; Mulholland, G. W.; Breuel, B. D.; Johnsson, E. L.; Chung, S.; Harris, R. H., Jr.; Hess, D. E., **"**Real-Time Suppressant Concentration Measurement," in *Fire Suppression System Performance of Alternative Agents in Aircraft Engine and Dry Bay Laboratory Simulations. Volume 2 (*Gann, R. G., Editor), NIST SP 890, National Institute of Standards and Technology, Gaithersburg, MD, November 1995.

APPENDIX A List of components and vendors for the main optics

Component	Manufacturer	Part No./ Model No.	Details	Avail/ Subst	Critical Specs	Cost ($)	Vendor Website
Chopper and Controller	Stanford Research Systems	SR540	Large frequency range optical chopping system	Yes/ Yes	Chopper & blade combine for 2 kHz min	1095	http:// www.thinksrs.com
Chopper Blade	Stanford Research Systems	O5402530	25/30 dual-slot blade	Yes/ Yes		35	
IR Source	Thermo Nicolet	470-101600	EverGlo thermal IR globar source, 1250 ºC operating temperature, spectra (7400 to 50) cm-1	Yes/ Yes	Flat spectra (8 to 9) µm	442	http:// www.thermo.com
IR Source Power Supply	Lambda Electronics Corp.	LCS-B-02	Regulated, 0 to 18 V, 2 A max	No/ Yes	at least 12 V output (match to source)		
IR Detector	EG&G Judson (now Judson Technologies)	450011-1/ J15D14-M204-SO1M-60	Photoconductive HgCdTe, cutoff wavelength > 13.5 µm, 60º field of view, 1 mm square element size, ZnSe window	Yes/ ?		1980	http:// www.judsontechnologies.com
IR Detector Power Supply	Kepco	ABC, 188-0014?	Regulated, (0 to 20) V	?/ Yes	Up to 15 V (match to detector)		
IR Detector Preamplifier	EG&G Judson (now Judson Technologies)	PA-101		Yes/ ?	Match to amplifier, low noise, high gain, wide bandwidth	673	http:// www.judsontechnologies.com
IR Filter			Narrow-band-pass filter	?/ Yes	(8.2 to 9.1) µm trans-mission peak		
IR Filter Mount	custom made			?/ Yes			
1st Mirror	Thermo Nicolet		30° off-axis elliptical, focal lengths: 76.2 mm/152.4 mm (3 in/6 in), scavenged from FTIR,	No/ Yes			http:// www.thermo.com

Component	Manufacturer	Part No./ Model No.	Details	Avail/ Subst	Critical Specs	Cost ($)	Vendor Website
			normally custom part, alt vendors Edmond, Janos				
1st Mirror Mount			wedge	Yes/ Yes			
2nd Mirror	Melles Griot	02 POA 015	90° off-axis paraboloidal reflector, diamond turned, mounted, 44.5 mm (1.75 in) diam, fl=38 mm (1.5 in)	Yes/ Yes		263	http:// www.mellesgriot.com
2nd Mirror Mount	Newport	MM-2	2 in square kinematic mirror mount, replaced with P100A-P2	Yes/ Yes		49	
3rd Mirror			38 mm diam, fl=25 mm (1 in), 90° off-axis parabolic mirror, scavenged from a Bomem FTIR	?/ Yes			
3rd Mirror Mount			compound x-y translation stage for alignment (z is direction of propagation), 25 mm wide by 51 mm high (1 in wide by 2 in high)	Yes/ Yes			
Iris	Edmund Optics	NT53-906	21 mm OD	Yes/ Yes	1 mm aperture	39	http:// www.edmundoptics.com
Iris Mount	Edmund Optics	NT54-862	21 mm iris mount	Yes/ Yes		34.1	http:// www.edmundoptics.com

APPENDIX B List of components and vendors for the periscope

Component	Manufacturer	Part No./ Model No.	Details	Avail/ Subst	Cost ($)	Vendor Website
Tube Tees (2)	MDC Vacuum Products	404000	0.75 in OD tubing	Yes/ Yes	136	http://www.mdc-vacuum.com
Nipples (2)	MDC Vacuum Products	402000	1.33 in nipple	Yes/ Yes	90	http://www.mdc-vacuum.com
Rotatable Flanges (2)	MDC Vacuum Products	100000	Rotatable blank flange, 1.33 in OD	Yes/ Yes	26	http://www.mdc-vacuum.com
Non-rotatable Flanges (2)	MDC Vacuum Products	110000	Rotatable blank flange, 1.33 in OD	Yes/ Yes	24	http://www.mdc-vacuum.com
Copper Gaskets (pkg of 10)	MDC Vacuum Products	191000	1.33 in OD, 0.64 in ID	Yes/ Yes	14	http://www.mdc-vacuum.com
Viton Gaskets (pkg of 5)	MDC Vacuum Products	191001	1.33 in OD, 0.62 in ID	Yes/ Yes	12	http://www.mdc-vacuum.com
Bolts (25)	MDC Vacuum Products	190001	0.75 in long, socket head	Yes/ Yes	11	http://www.mdc-vacuum.com
Flange Covers (2)	MDC Vacuum Products	192000	Plastic, 1.33 in OD	Yes/ Yes	2	http://www.mdc-vacuum.com
Prisms (2)	Edmund	NT32330	90 deg, uncoated	Yes/ Yes	51	http://www.edmundoptics.com
Gold Coating on Prisms (2)				?/ Yes	70	
BaF2 Windows (2)	Infrared Optical Products	122-BFW	OD 12.7 mm, 2 mm thick	Yes/ Yes	180	http:// www.infraredopticalproducts.com
Custom threaded bushings (2)			custom made	?/ Yes		
Window Carriers (2)			custom made	?/ Yes		
Prism Mounts (2)			custom made	?/ Yes		

APPENDIX C List of components and vendors for data acquisition and supplies

Component	**Manufacturer**	**Part No./ Model No.**	**Details**	**Avail/ Subst**	**Critical Specs**	**Cost ($)**	**Vendor Website**
DAQ Board	National Instruments	777305-01/ PCI-MIO-16E-1 (now NI PCI-6070E)	Multifunction I/O Board, 12-bit resolution, 1.25 MS/s, 4 analog inputs, analog triggering	Yes/ Yes	high res, fast, no. channels for inputs, triggering	1495	http://www.ni.com
DAQ Cable	National Instruments	184749-01/ SH6868-EP	Shielded 68 pin cable, 1 m long	Yes/ Yes	Shielded, pins match terminal block and DAQ board	95	http://www.ni.com
Terminal Block	National Instruments	777270-01/ BNC2090	terminal block with BNC connections, trigger input	Yes/ Yes	BNC connectors, trigger access, matched to DAQ board	395	http://www.ni.com
Purge Rotameter	Dwyer	MMA-?	0 to 100 cm^3/min	No/ Yes	resolve low flow	17	http://www.dwyer-inst.com
Purge Connectors	Swagelock		fittings	Yes/ Yes			
Purge Pressure Gauge	Dwyer	Magnehelic 2000-50cm	(0 to 50) cm	Yes/ Yes	low range	60	http://www.dwyer-inst.com
BNCs and connectors			standard BNCs	Yes/ Yes			
Electrical Connectors			Banana plugs, etc.	Yes/ Yes			
Screws			16 5-40 1.3 cm (0.5 in); 4 10-24 5 cm (2 in)	Yes/ Yes			
Chassis Box			4.8 mm (3/16 in) thick aluminum, 31.4 cm X 22.2 cm X 12.6 cm	Yes/ Yes			
Liq N_2				Yes/ Yes			
Gas N_2				Yes/ Yes			
Small funnel			Suitable for liq N_2	Yes/ Yes			
Large & small dewars			Suitable for liq N_2	Yes/ Yes			