



INNOVATIONS IN QUALITY CONTROL

OPERATION MANUAL

for

ES200 IMAGING SPECTROMETER

**SPECTRALINE Document No. ES2001[®]
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1.0 Introduction

Congratulations on your purchase of the ES200 Imaging Spectrometer. The following manual describes the major components of the spectrometer and provides brief guidelines on the operation of the ES200.

Unlike conventional spectrometers, the ES200 is designed to operate for years in the field with very little maintenance on the part of the operator. The ES200 is the only spectrometer that is designed to be deployed 'right out of the box', to meet your most challenging spectroscopic applications in the mid infrared region of the spectrum.

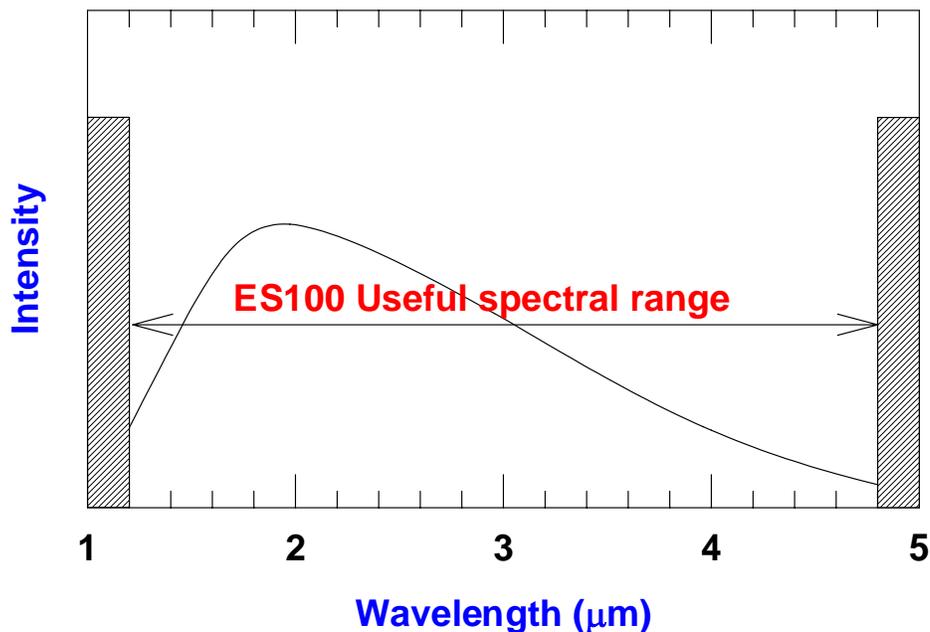
The different accessories are described along with the basic spectrometer in the same document, to provide for a unified approach that highlights the full capabilities of the ES200. For your particular application, some of the information provided may not be relevant. However, it is advisable to read the manual thoroughly to be fully aware of the wide range of applications that are possible using the ES200.

Caution: The housing of the ES200 is rugged, but not explosion proof. There are electrical signals present inside the ES200 spectrometer and the PS200 power supply. They should not be used in an explosive environment. There are no user serviceable parts within the ES200 and the PS200. All warranties are void if either the ES200 or the PS200 are opened.

2.0 ES200 Description

2.1 Functional Overview

The ES200 is a fast imaging spectrometer that can provide the spectral radiation intensity in the mid infrared region. The radiation intensity that is incident on the entrance slit is split into its spectral components using a refractive element. The useful spectral range of the ES200 is shown in below.

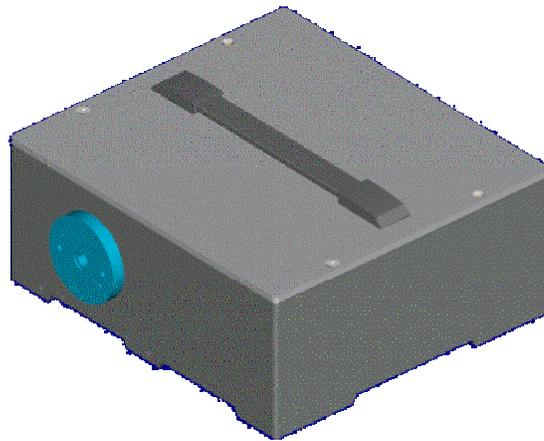


The useful spectral range of the ES200 is from 1.3 microns to 4.8 microns. The instrument measures intensities at 256 wavelengths within this spectral range. Each spectrum is obtained at a speed of 10280 Hz, using a 256-element linear array detector. This essentially freezes the process being studied. The voltages and pixel numbers provided by the linear array are converted into wavelengths and intensities using pre-installed calibration curves.

The ES200 is ideally suited for obtaining emission spectra from hot objects, absorption spectra from gases and transparent fluids, and reflectance spectra from opaque fluids and solids. The data collected in each spectrum is stored at 400 Hz in the standard version (Model 1150) and at 1320 Hz in the high-speed version (Model 1160). In the description that follows we will be referring to the high-speed version. The output from the spectrometer can either be displayed on a Windows based GUI (with a useful frequency of approx. 30 Hz) or stored onto the computer memory for data analysis at a frequency of 400 Hz).

2.2 Hardware Description

The ES200 is housed in a 9.5 x 10.5 x 4.5 in. cast aluminum enclosure that is sealed against moisture and corrosive gases. Provision for mounting the enclosure on a tripod or leveling feet is provided. The spectrometer weighs approximately 15 pounds. Before sealing, the enclosure has been purged with nitrogen to remove trace carbon dioxide and water vapor. A desiccant canister may be placed inside the enclosure to absorb any moisture that leaks into the enclosure. An outside view of the ES200 spectrometer is shown in below.



The entrance port of the ES200 is a 6 mm high by 0.5 mm wide slit. This slit is imaged using reflective parabolic mirrors onto a series of calcium fluoride prisms. The calcium fluoride prisms disperse the radiation into its spectral components. The dispersed radiation is imaged onto a 256-element lead selenide array. The use of fully reflective components for imaging, and prism elements for dispersion, provides the highest throughput possible in a mid infrared spectrometer. The FOV of the slit is 0.5 degrees. The f-number of the optical elements inside the spectrometer is 3.5.

There are no user adjustable parts inside the spectrometer. The spectrometer lid should always be closed, even when it is not in use. However, if it is opened, the spectrometer should ideally be purged with nitrogen before resealing so as to eliminate spurious interference from carbon dioxide and water vapor present in the atmosphere. Two purge holes that accept 1/8th NPT connectors are provided on the case to facilitate purging of the spectrometer.

2.3 Software Description

The ES200 is provided with graphical user interface software, *Infraspec*, which enables the user to obtain emission spectra from hot sources, and absorption and reflectance spectra from samples. The software has a Windows based

graphical user interface and is compatible with most versions of the Windows¹ operating systems.

The software provides for easy calibration of the spectrometer in the field. The spectrometer has been designed to operate for a long period of time (six months) with no calibration required in between. However, the calibration can be very easily performed with a standard blackbody source. Alternatively, Spectraline Inc. can provide factory calibration for the ES200.

The *Infraspec* GUI has separate modules that allow different operations such as tracking the intensity at a specific wavelength, tracking the intensity for a group of wavelengths, tracking functions that involve intensities at different wavelengths, etc. *Infraspec* can also be embedded with customized databases that can provide information such as fat content in milk, gas concentrations in flue gases, etc.

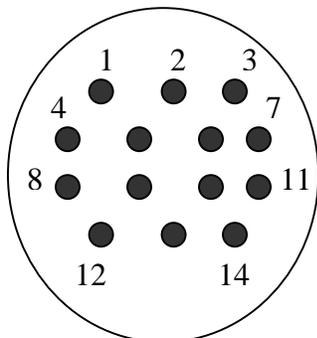
Infraspec is written in Visual C⁺⁺, and has been extensively tested for a wide variety of applications. The software is provided specifically for the ES200, and is copyrighted by Spectraline Inc. The software can be loaded onto as many machines as required, and is provided with each ES200 with unrestricted usage license.

¹ Windows and Visual C⁺⁺ are registered Trademarks of Microsoft Corporation.

3.0 Accessories Description

3.1 Power Supply

The ES200 Spectrometer requires $\pm 12V$ (@ 400 mA) and + 5 V (@ 1 A) for its operation. The TEC controller requires +12 V (@ 3 A). The pin out connection for the power connector on the power supply is shown below.



Pin No.	Function
1	Ground
2	+ 5 V
3	No connection
4	+ 12 V
5	Ground
6	- 12 V
7	No connection
8	- TEC module
9	+ TEC module
10	No connection
11	No connection
12	Thermistor
13	Thermistor
14	No Connection

The power supply (Model No. PS200) provides the required power to the spectrometer and incorporates a controller for the thermoelectric cooler of the detector array. The PS200 operates on 120 VAC, 60 Hz and has a red power-on indicator light.

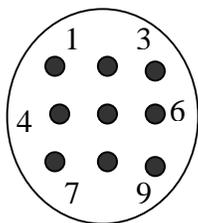
3.2 Data Acquisition Hardware

The ES200 system can be configured in three different ways. These are the desktop, laptop and data logger configurations. In the desktop configuration, the data acquisition hardware consists of one plugged in National Instruments board. The laptop configuration uses a Sony Viao laptop and the NI DAQpad. The data acquisition is controlled by the drive circuit on the spectrometer. The array is sampled at 3.38 MHz. clock frequency. Therefore, a full spectrum is obtained at 21154 Hz, or in 47 microseconds. The spectrum is stored in the memory during the chopper open cycle. Each successive spectrum is collected at a repetition rate of 1320 Hz.

The data acquisition hardware can store up to 6,000 scans in its memory buffer before the buffer has to be cleared for the next set of scans. The board, with

the required drivers, can be installed in any computer running Windows 9x or Windows 2000.

The video connector* carries the signals from the ES200 spectrometer to the data acquisition board. The connector is a male 9-pin connector. The pin out for the video connector is shown below.

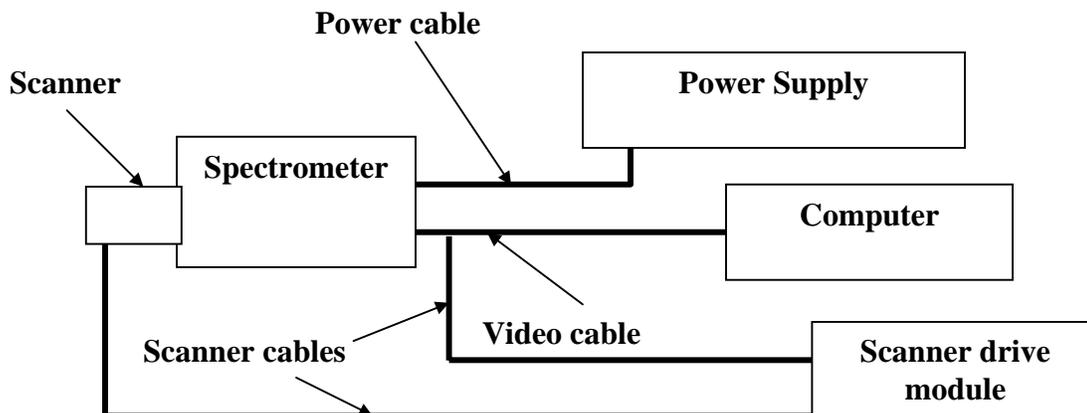


Pin No.	Function
1	Ground
2	Chopper signal
3	No connection
4	ADC trigger
5	No connection
6	No connection
7	No connection
8	Video positive
9	Video ground

**For system without scanner only. For systems with scanner, consult Section 3.9*

3.3 Cables

Cables from the spectrometer to the power supply and the data acquisition board are available. The connection diagram for the cables is shown below.



The spectrometer has a 14-pin female and a 9-pin male connector (for units without scanner) on its body. For units with scanner, the spectrometer has a 14 pin female and a 16 pin male connector on its body. The power supply is connected to

the 14 pin female connector, and the data acquisition cable is connected to the 9 (16) pin male connector. The other end of the data acquisition cable has a 68-pin NI connector, which is plugged into the A/D board that resides within the computer. The power cable length is 6 feet and the video cable is available in lengths of 6, 12, 25, 50 and 100 feet.

For units with scanner, the scanner drive module has one 9 pin male connector and two DB9 female connectors (one DB9 for 1-D scanners) on its body. The scanner cable (bifurcated from the video cable) is connected to the scanner drive module using a 9 pin connector. In addition, the scanner itself is connected to the drive module using a DB9 connector.

3.4 Infraspec Windows Based GUI

If the *Infraspec* software is purchased from Spectraline independently of a computer system, the executable version of the GUI is provided on a CD. The program is installed by double-clicking on a self-extracting executable file on the provided compact disc. For those who purchase a computer system directly from Spectraline, the software is already installed on the computer. The GUI is operated by double-clicking the icon 'infraspec.exe' on desktop. A default plot of intensity versus wavelength will be visible on the screen. More detailed instructions for using the GUI follow at the end of the manual.

3.5 Absorption Cell

Two types of absorption cells are available for direct mounting onto the front port of the spectrometer. The first type is a fixed path length cell with sapphire windows. The absorption path length can be specified by the user. An inlet and an outlet port with a mating 1/16th inch Swagelok connector is provided with the absorption cell.

The second type is a variable path length cell. The path length can be varied from 0 mm (nominal) to 5 mm. A 1/16th inch Swagelok connector is provided for the inlet and the outlet ports. In addition, a three-way valve to allow easy cleaning of the variable path length cell is also provided.

A reference high temperature infrared source that is required for absorptance measurements can be mated to the other side of the absorption cell. Optional heating arrangements and cleaning solutions are provided with the absorption cells.

3.6 Reflectance Module

A diffuse reflectance module that utilizes an integrating sphere is available for use with the ES200 spectrometer. Two different diameters (1/2 and 1 inch) are available. The smaller-diameter integrating sphere is used for solids that have very low reflectance in the infrared.

The integrating spheres have three ports on them. The first port couples directly to a reference high temperature infrared source. The second port is directly opposite the first port, and is used to direct the infrared radiation onto the sample. The diffusely reflected radiation from the sample is collected and sent to the third port, which directly couples to the front plate of the spectrometer.

Diffuse reflectance is used to obtain the absorption of the top layer of molecules in any sample. This is ideal for monitoring coating defects or obtaining the concentration of contaminants.

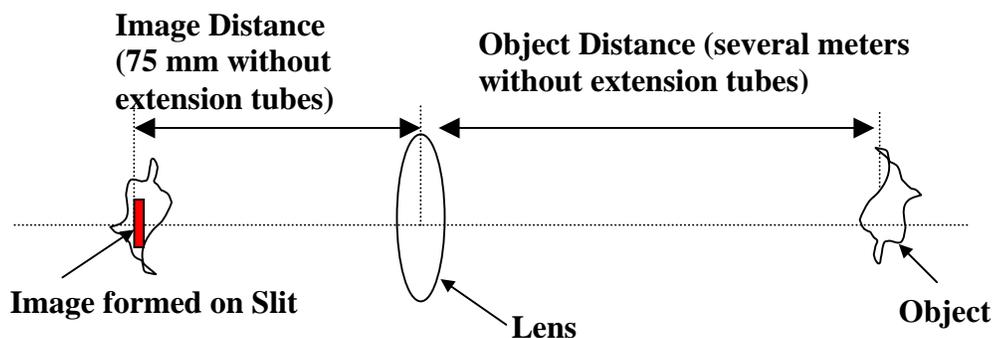
3.7 Infrared Source

A collimated infrared source, one-half inch in diameter, is available for performing absorbance and reflectance measurements. The collimated source consists of a ceramic heating element. The heating element attains a maximum temperature of 2000 K. The source is collimated using an off-axis parabolic reflector. The infrared source can be directly mounted onto the reflectance or absorbance module.

3.8 Focusing, Laser Aiming and Filter Mounting Module (FocusTube)

The pixels of the spectrograph collect light from points on the input slit that are approximately 0.5mm in width by 1 mm in height. The full field of view of each pixel is 0.5° ($\pm 0.25^\circ$). Any light incident on these regions of the input slit and originating from a point within this field of view will be detected. As an object is moved further from the input slit, the $\pm 0.25^\circ$ field of view of the spectrograph causes larger areas of the object to be averaged simultaneously. Therefore, if the object is not homogeneous, adequate spatial resolution may not be achieved in some applications. The FocusTube eliminates this problem.

The FocusTube accepts different focal length CaF_2 lens to form an image of a distant object directly on the input slit of the spectrometer, as shown below.

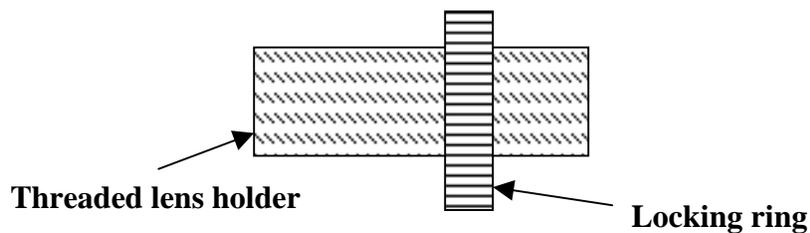


The following section provides the necessary tools for determining the spatial resolution of the spectrometer using the FocusTubeTM.

3.8.1 Working with Different Object Distances

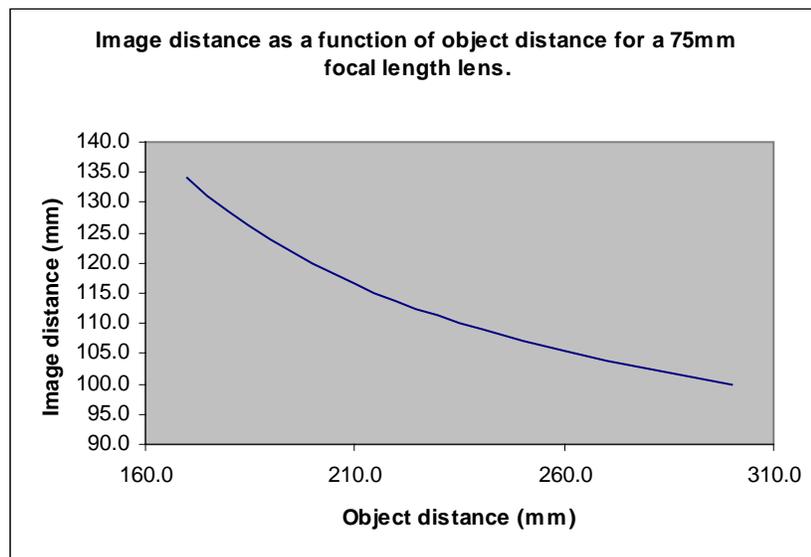
When a 75 mm focal length lens is moved all of the way toward the spectrometer, an object more than several meters away will form a sharp image at the slit. However, for many applications the object is closer to the spectrometer, requiring that the lens be moved further away from the slit by turning the lens holder counterclockwise. A series of extension tubes are also provided to enable the lens to be moved even further from the spectrograph, allowing even closer objects to be imaged.

A schematic of the lens holder and the locking ring is shown below.



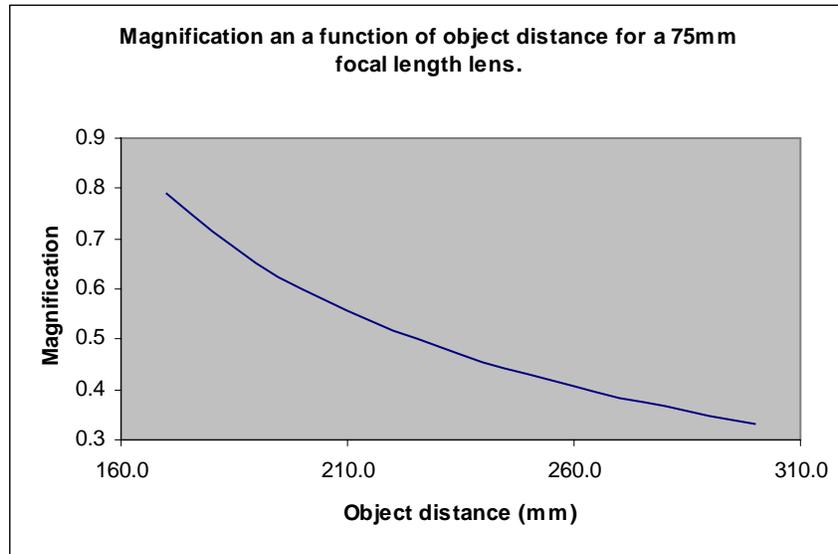
After the lens is moved to the appropriate location, it can be locked down with the knurled locking ring. Good focus can be achieved by using a narrow band filter and the GUI. Infrared and visible objects focus at different distances from the lens. Visual images of bright objects (such as a lighter flame) seen through the viewfinder of the integrated focusing and laser-aiming module (see next Section) should not be used for focusing.

The relationship between the object and image distances for a 75 mm lens is shown below.

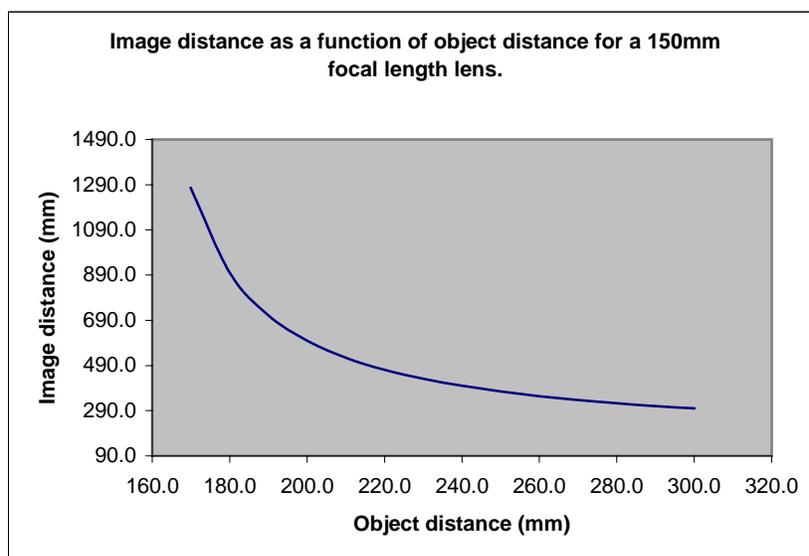


When the object is moved closer to the spectrometer, the lens will have to be moved further from the spectrometer by turning the threaded lens holder counterclockwise. If the object distance is closer than 160 mm, then extension tubes have to be used to obtain a sharp focus.

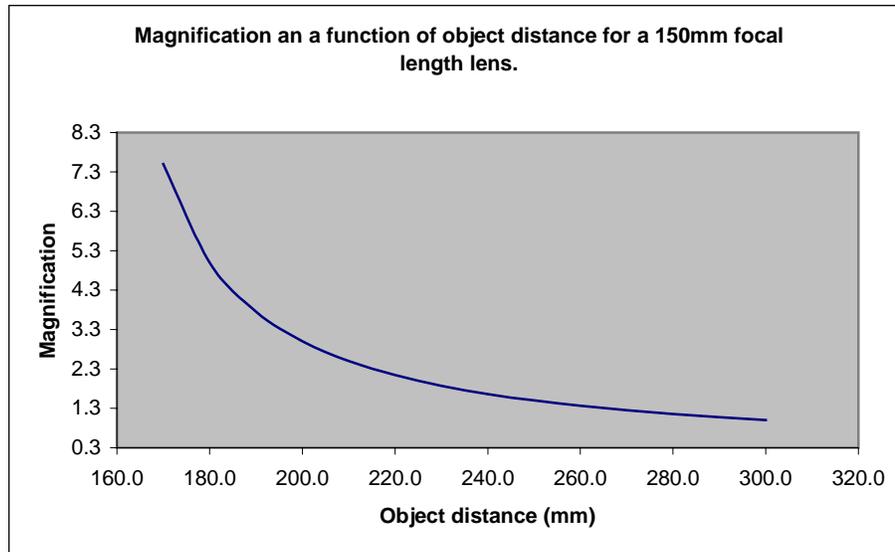
The magnification obtained with a 75 mm focal length lens as a function of object distance is shown below.



Using alternate lenses, different object distance and different magnification relationships are obtained. For example, using a 150 mm focal length lens, the following relationship between the image and object distances are achieved.



The magnification achieved for different object distances with the 150 mm focal length lens is shown below.



3.8.2 Using the Integrated Focusing and Laser Aiming module

The FocusTube assembly has a viewfinder and a laser installed inside it. By actuating a rotating cam on the side of the FocusTube, either the mirror or the laser can be brought in line with the optical axis of the spectrometer. The rotating cam has three positions in which it locks into place. In this first position, marked with a red dot outside the cam, the laser is lined up with the instrument's optical axis. The laser turns on automatically and illuminates the target. In the second position, marked by a white dot outside the cam, the viewfinder is lined up with the instrument's optical axis. In this position, the image of the object can be seen on the focusing screen of the viewfinder. The focusing screen has the outline of the slit printed on it. This is the area that will be imaged by the spectrometer pixels. By rotating the lens mount, the image can be brought into sharp focus or defocused. It should be noted that visible images focus at a shorter distance than infrared objects. The third cam position, marked by a green dot, is the normal operating mode of the spectrometer. In this position, the radiation from the object passes through the slit onto the detector. When the spectrometer is not in use, the cam position should be set either to the green or the white position so as to ensure that the laser is turned off, avoiding unnecessary battery drain.

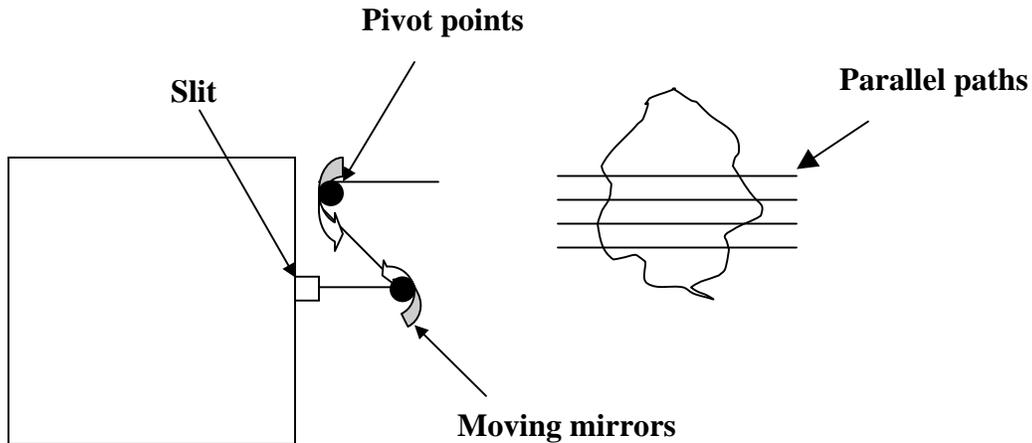
3.8.3 Installation instructions for the Focus Tube

The FocusTube can be easily removed from the front of the spectrometer by loosening three screws on the sides that attaches the FocusTube to the stainless steel interface plate of the spectrometer.

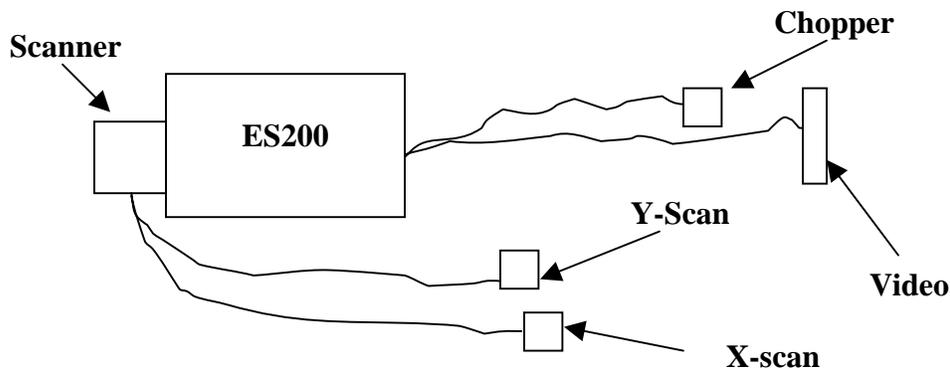
3.9 Scanner Module

The scanner module is attached to the front of the spectrometer to enable the ES200 spectrometer to obtain hyper-spectral images. A 1-D scanner allows the spectra from 1.3 to 4.8 microns to be obtained along a line. The 2-D scanner allows the spectra from 1.3 to 4.8 microns to be obtained over a surface area.

A schematic of the 2-D scanner attachment is shown below. The 2-D scanner module consists of two galvo-scanners that direct the light from an area to the slit of the ES200 spectrometer. The GUI is synchronized to provide spectral images from the 2-dimensional area. The scanner is integrated with a focus tube and laser assembly. The area swept by the laser beam provides an approximate location and size for the area of the object viewed by the spectrometer.



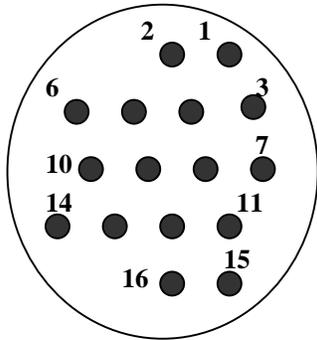
The electrical connections required for the 2-D scanner are shown below.



The scanner has two cables (X-scan and Y-Scan) connecting it to the scanner power supply box (Model No. SS-100). The two cables are marked X-scan and Y-scan and have DB9 connectors at the end. The power supply box also

requires a synchronization signal from the tuning fork chopper within the ES200. The synchronization signal is conducted to the power supply box using a 14-pin connector marked chopper. Connect the X-scan, Y-scan, and chopper cables to the marked inlets on the power supply box, SS-100. Connect the video cable to the computer. The ES200 is now ready to collect hyper-spectral images.

Switch on the power supply box, SS-100. The reset position on the power supply box allows the scanner to image the bottom-center of the object onto the slit. When the scanner is in normal operation, each horizontal line is obtained followed by a next horizontal line as shown in the figure above. ***There are no user serviceable parts inside the scanner.***



Pin No.	Function
1	Ground
2	Chopper signal
3	ADC trigger
4	Ground (connected to 1)
5	Chopper (connected to 2)
6	Not connected
7	Not connected
8	Not connected
9	Connected to 13
10	Connected to 14
11	Not connected
12	Not connected
13	Connected to 9
14	Connected to 10
15	Video positive
16	Video ground

4.0 Getting Started

4.1 Cable Connections

The ES200 requires very little set up time. Unpack the ES200 spectrometer and the power supply from the box. Connect the 14-pin male connector on the power cable, to the connector marked 'power' on the spectrometer. Connect the other end of the cable to the power supply.

Connect the 9-pin female connector to the connector marked 'video' on the spectrometer. Connect the other end of the cable to the A/D board or DAQPad using the 68 pin connector.

4.2 Software Installation

Insert the CD into the CD-ROM drive in the computer. Set up the data acquisition board correctly. Spectraline provides the set up of the data acquisition board as part of the data acquisition accessory. Run setup.exe from the CD. This will automatically install the GUI onto your computer. Now you are ready to calibrate the ES200 spectrometer.

4.3. Calibration Procedure

Calibration for emission spectroscopy application involves three steps. The first step is to calibrate the wavelength of radiation incident on each pixel. Typically, six narrow band filters are used to locate pixels corresponding to the known filter wavelength. The remaining pixels are calibrated by using a third order polynomial function. The wavelength calibration is performed in the factory before shipping. The second step is correcting for any background radiation incident on the pixels. Even without any infrared source, the array registers out some voltage due to residual offset in the electronic components. This offset should be corrected before calibrating the ES200 for radiation intensities. The third step is to calibrate the ES200 so as to provide spectral radiation intensities at different wavelengths. This process involves finding a mathematical relationship between the voltage output and spectral radiation intensity for each pixel using a blackbody emitter.

For absorption or transmittance measurement, the calibration process only involves two steps. The first step is wavelength calibration, and the second step is setting up a reference voltage for each pixel.

The calibration should be checked every six months. See section 4.3.5 for more details. Make sure that the spectrometer has warmed up for at least half an hour before completing your calibration or taking measurements. The following is a step-by-step procedure for performing wavelength, and intensity calibrations, as well as correcting for background offset.

4.3.1 Wavelength Calibration

1. Set the blackbody temperature at approximately 1100 K to get about a 5 V signal on the pixels.
2. Put a narrow band filter in front of the spectrometer, and determine the pixel location where the voltage peaks using the GUI. The peak location will often fall in between two pixels. The surface of filter should be positioned perpendicular to the optical axis of the spectrometer. Write down the center wavelength of the filter and the pixel location (eg. 3.85 microns, 134.6).
3. Repeat the above procedure for the remaining five narrow band filters.
4. Click the 'wavelength calibration' menu item under calibration menu.
5. Enter the center wavelengths for the filters and their corresponding pixel locations, and click regression button. A regression order of 3 is recommended for the wavelength calibration.

The expression for the wavelength is: $\lambda_i = C_0 + C_1 P_i + C_2 P_i^2 + C_3 P_i^3$, where λ_i is wavelength for pixel, $C_0 - C_3$ are regression constants and P_i is the pixel number.

4.3.2 Background offset correction

1. Block the spectrometer from any infrared source, wait approximately 60 seconds and then take a snapshot with 6000 samples.
2. Click 'background offset' under the calibration menu. Choose 'Current' scan from the calibration menu. The mean voltage obtained from the 6000 samples for each pixel will then be always subtracted from the measurement when the radiation intensities are calculated.

4.3.3 Radiation intensity calibration

1. Put a blackbody emitter in front of the spectrometer. The blackbody should be close to the spectrometer so that the source can fill the slit image (0.25 degree divergence from slit dimension of 6 mm height X 0.5 mm width). Typically, a blackbody with 1-inch port diameter, placed up to 7 inches from the spectrometer would satisfy the requirement.
2. Set the blackbody to six different temperatures that provide approximately 0.2-10 V signals. Take a snapshot at each temperature, and save the scan file. When you save the scan file, put the temperature signature in the scan file name.

3. At least four temperatures are required for the intensity calibration because the PbSe array is non-linear in its response to incident radiation. Six temperatures is an ideal number.
4. When you take a snapshot, make sure the blackbody temperature is well stabilized at that temperature. The alignment of the blackbody and the spectrometer should not be changed in between the blackbody measurements.
5. Click the ‘intensity calibration’ under calibration menu. Add all the blackbody scan files into the table and put in the blackbody temperatures for the scan files. If you make a mistake, double click the file name, and then the GUI will ask for blackbody temperature again.
6. The Infraspac GUI uses piecewise polynomials to convert voltages into spectral radiation intensities. A zero point where both the voltage and intensity are zero is automatically added to the calibration. A second order polynomial is recommended for completing the regression analysis using the GUI. When you use a second-order regression analysis, you should provide an even number of blackbody scan files. Save the intensity calibration on the ‘calib.txt’ file.

The GUI also creates a file ‘error.txt’ which contains measured voltage and intensity for each pixel. The odd column (first, third and so on) is voltage (V) and the even column is intensity in $kW / m^2 / sr / \mu m$.

The mathematical expression for radiation intensity is:

$$I_i = \sum_{k=0}^N C_{i,k} (V_i - V_{i,offset})^k \quad \text{for } V_{i,j} < V_i < V_{i,j} \text{ and } i = 0, Pixels - 1, j = 0, N / 2$$

where V_i is the voltage for pixel i , $C_{i,k}$ is a k^{th} order polynomial coefficient for pixel i , and the N is order of regression. $V_{i,offset}$ is the background offset voltage for the pixel i .

*** The above calibrations can also be performed at Spectraline Inc. before the ES200 spectrometer is shipped to you.**

4.3.4 Reference calibration

The reference calibration module is used to obtain transmittances of gases or liquids. Transmittance is defined as:

$$\tau_i = \frac{V_i - V_{i,offset}}{V_{i,ref} - V_{i,offset}}$$

where V_i is voltage for pixel i , $V_{i,ref}$ is reference voltage without sample for pixel i . Before obtaining transmittance measurements, the reference voltage must be set as follows.

1. Put the infrared source in front of the spectrometer, and adjust the intensity to get enough voltage (5 V). Make sure the infrared source image should fill in the slit image of the spectrometer.
2. Obtain 6000 samples, and save the scan information in a file.
3. Click the 'reference calibration button' under calibration menu. Put in the scan file name for the reference file, and save the reference calibration into the 'calib.txt' file.

4.3.5 Recalibration

The wavelength calibration should be checked every year. The intensity and reference calibration should be checked every six months. All calibration procedures should be carried out after the spectrometer has been switched on for a minimum of half an hour.

4.4 Alignment

A laser module is available with the ES200 for ease of alignment. The ES200 accepts light at ± 0.25 degrees from the edges of the slit. A black body with a small cavity is used to align the laser module to the ES200. After the laser module has been aligned, then the laser can be used to align other targets with the optical axis of the ES200 spectrometer.

5.0 Maintenance

5.1 Nitrogen Purge

A 1/8th inch NPT inlet and outlet port is provided in the spectrometer for purging with Nitrogen. This is required as trace amounts of water vapor and carbon dioxide in the atmosphere absorbs radiation at 2.7 and 4.3 microns.

After purging, use the plugs provided to maintain the integrity of the inside chamber. The ES200 is moisture tight and leaks into the compartment are maintained at a minimum. However, purging is recommended every three months.

5.2 Desiccant Replacement

In some models, a desiccant canister (with indicating silica gel) is provided inside the ES200 spectrometer to remove trace moisture. The desiccant changes color from blue to pink when its absorption capacity has been reached. At that time, the canister can be removed and heated in a conventional oven to dry it out. After heating, the desiccant gel should be blue in color to indicate that it is properly dried out.

6.0 Troubleshooting Tips**6.1 The is no signal from the spectrometer**

Make sure that the power and video cables are connected properly.
Check that the rocker switch on the power supply (PS200) is steadily on.
Check the alignment of the black body with the spectrometer.
Make sure that the view finder or the laser is not in the path.
Wait a few minutes for the TEC to reach the operating temperature.
Make sure that the software is working properly.

6.2 The voltage at each pixel is fluctuating rapidly

Make sure that the spectrometer is not very hot to the touch. If it is very hot, then the heat given out by the TEC is not being dissipated properly. Turn off the spectrometer, wait for a few hours and restart the spectrometer.
If the spectrometer still does not function properly, call technical support (888 884 8236) at Spectraline Inc.

6.3 The GUI is frozen

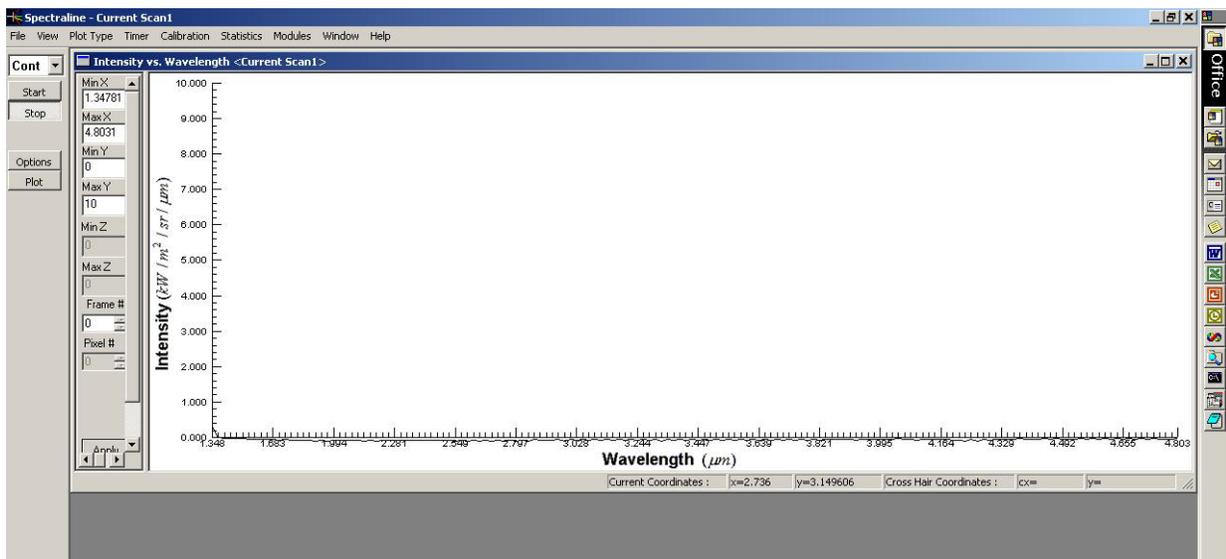
If the GUI is frozen, it could be that the data acquisition board is not obtaining the ADC trigger. This can be checked with an oscilloscope connected to pins 1 and 4 of the video output connector on the spectrometer. The observed trace on the oscilloscope should be 1 MHz, TTL clock pulses with a logic 'high' time of 2240 microseconds.
Check to see if a video signal is available on pins 8 and 9 (ground).
Reboot the computer if the ADC trigger is present and the GUI is frozen.

7.0 Infrspec GUI

7.1 Getting Started

The *Infrspec* GUI is operated by double-clicking the icon ‘infrspec.exe’. The user must first click on **Plot** on the left hand side of the screen. A default plot of intensity versus wavelength will appear on the screen. The user can select data collection either in the continuous or snap shot mode. In continuous mode, the spectrum is updated only as fast as the Windows refresh rate of 30 Hz. In snap shot mode, the spectra can be collected at 400 Hz. The default operating mode of the GUI is to collect continuous spectra as indicated by the selection labeled **Continuous** at the top of the screen. This can be changed to snap shot mode by using the mouse and selecting **Snap Shot** to replace the **Continuous** selection.

Clicking on the **Start** button below the **Continuous** selection starts the scanning. The **Stop** button below the **Start** button terminates the acquisition of data.



7.2 Display Options

7.2.1 Display Options for Continuous Mode

As a default, the output from the ES200 spectrometer is displayed as Intensity vs. wavelength. The wavelength and spectral radiation intensities were pre-calibrated in factory. The plot type can be changed by clicking the right mouse button or by accessing the **Plot type** menu item on the tool bar. With a calibrated source the output can be displayed as transmittance vs. wavelength or as transmittance vs. wave number. In addition, each successive scan in the continuous mode can be displayed as a horizontal color bar that scrolls downward. If either 1D or 2D (area) scanner is attached to the ES200 spectrometer, a 3D color plot can be displayed.

All plots show the minimum and maximum on the x-scale as well as the minimum and maximum on the y-scale. These values can be seen in the white boxes to the left side of the plot. These can be changed to look at smaller regions of the plot. To change these values, the continuous scans should be first stopped by clicking the **Stop** button. The new values are typed into the white boxes and the **Apply** button should be clicked for the values to take effect. If the user was running continuous scans, these can be resumed after **Apply** is clicked.

7.2.2 *Display Options in the Snap Mode*

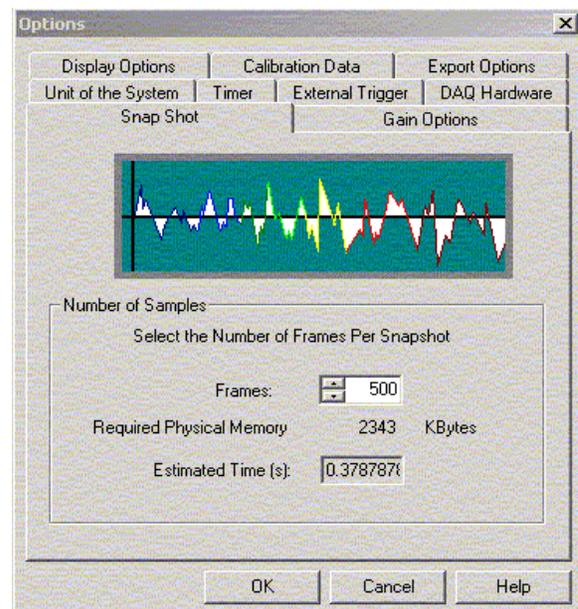
The display does not update when the data is acquired in the snap mode. To start collecting a series of scans at 390 Hz using the snap mode, change the **Continuous** selection to **Snap Shot** and click the **Start** button. When the data collection begins, the start button will automatically be grayed out. Each of the scans collected in the snap mode can then be displayed by clicking one of the arrows to the right of the **Frame #** on the left side of the plot. If the snap mode must be interrupted, the user can click on the **Stop** button to stop the current collection.

7.3 General options for the GUI

Clicking the **Options** button on the left hand side of the screen or selecting **Options** from the File Menu allows access to a menu that can be used to change the following items:

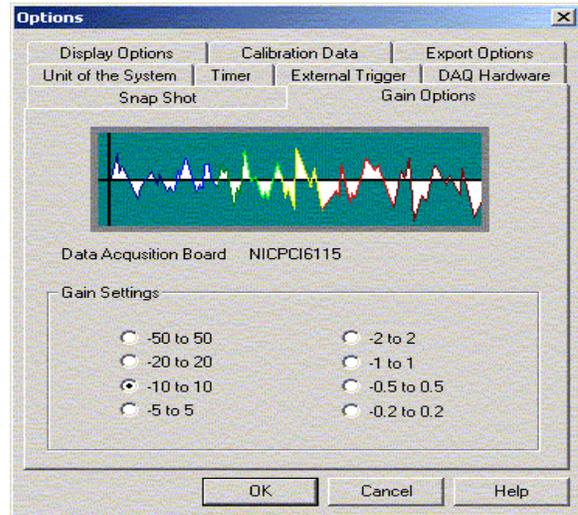
1. Number of samples (frames) collected in the snap mode. The user can use the arrows to adjust the number of samples collected or enter a value manually. The estimated time to complete the scan is shown in the gray box below the number of frames. In addition, the memory required for the operation is shown above the gray box.

(See Figure to the right)



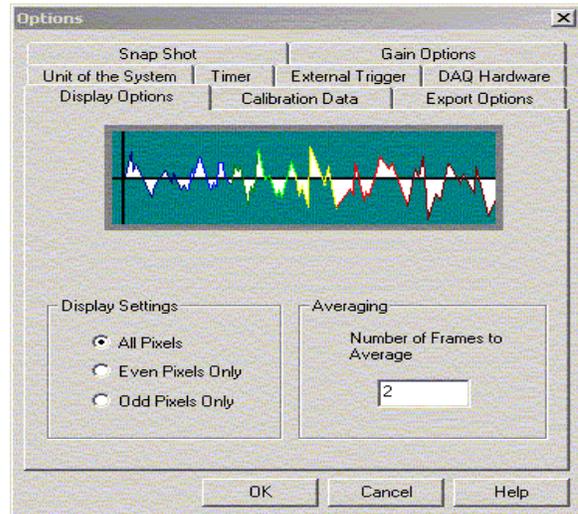
- Gain options to set the gain for the data acquisition board (DAQ) connected to the system. The gain option is normally used when the signals obtained from the source is very low. For most applications, it is ideal to leave the gain setting at -10 to $10V$. However, if the signals are very low, it is recommended that the gains setting be changed so that digitization error caused by the A/D can be reduced.

(See Figure to the right)



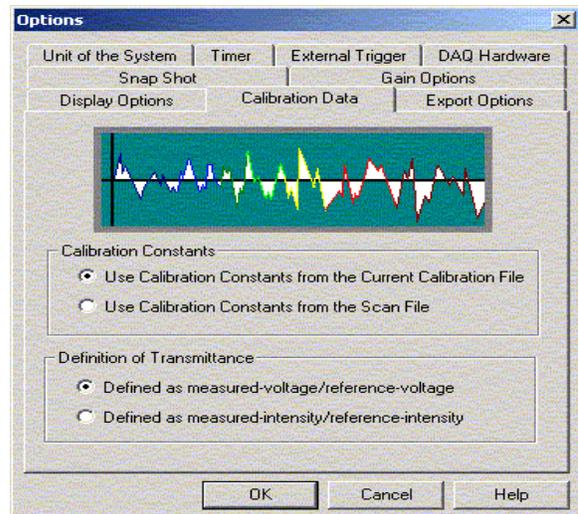
- The display options for displaying only odd pixels, only even pixels (ES100 models only), or all pixels, as well as to display an average of a number of scans in continuous mode can be changed. The odd and even pixels normally image a different location within the object. Therefore, if the object is not uniform, then displaying only the odd or even pixels is helpful.

(See Figure to the right)



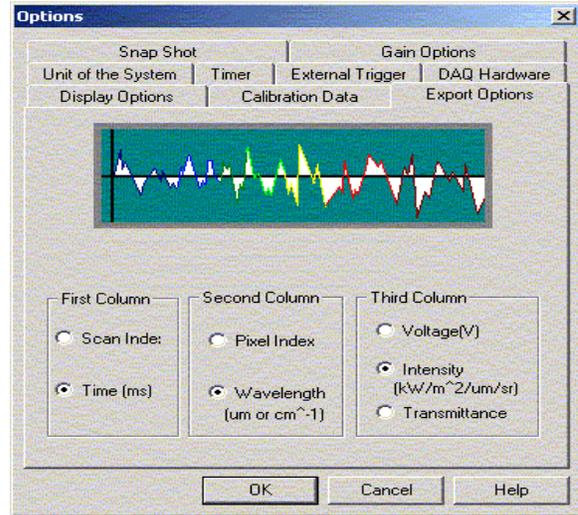
- The user can specify the choice of a calibration file. The calibration file can be either from the current scan, or from a saved file. In addition, two methods of calculating the transmittance can be specified.

(See Figure to the right)



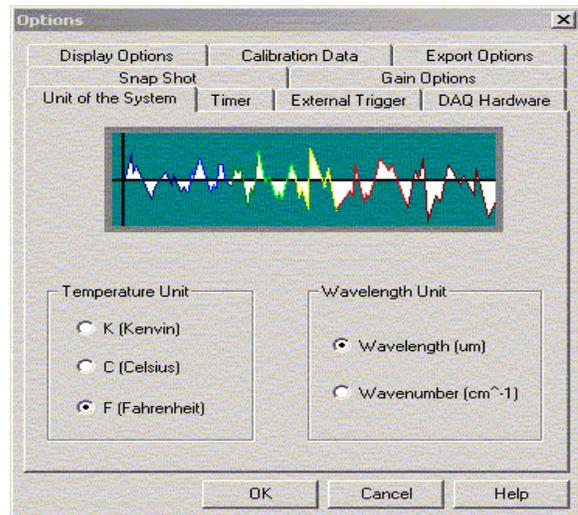
- The user can export the data files in ASCII format. Different information can be exported, such as scan index or time, pixel number of wavelength, and voltage, intensity, or transmittance at each pixel/wavelength. ASCII export options for the data.

(See Figure to the right)



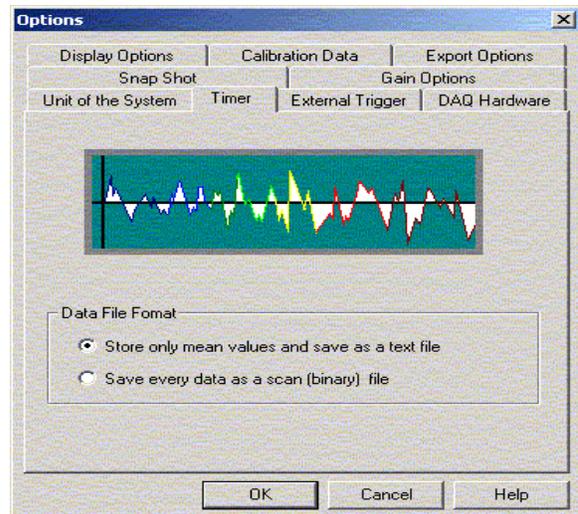
- Different units can be selected for the different outputs and inputs of the GUI. Temperature can be either in Celsius, Kelvin, or Fahrenheit. The spectral information can be specified either in wavelengths or in wave-numbers.

(See Figure to the right)



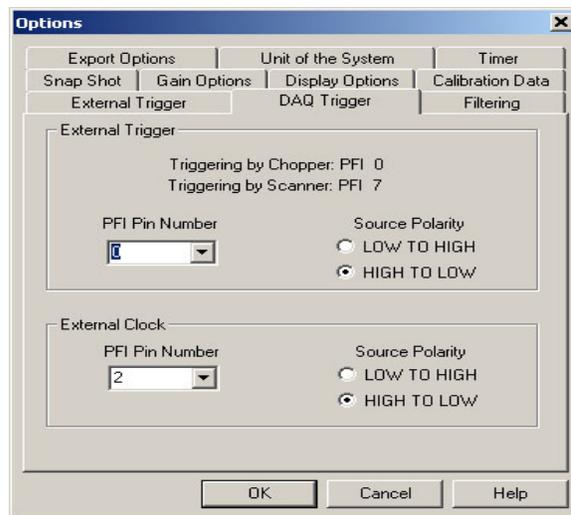
- Data can be collected for a specified period of time, using the timer function. Usually, a scan file is collected at one time and then after a long interval, a second scan file is collected. Either the mean values from these scan files or the entire scan files can be saved to the hard disk.

(See Figure to the right)

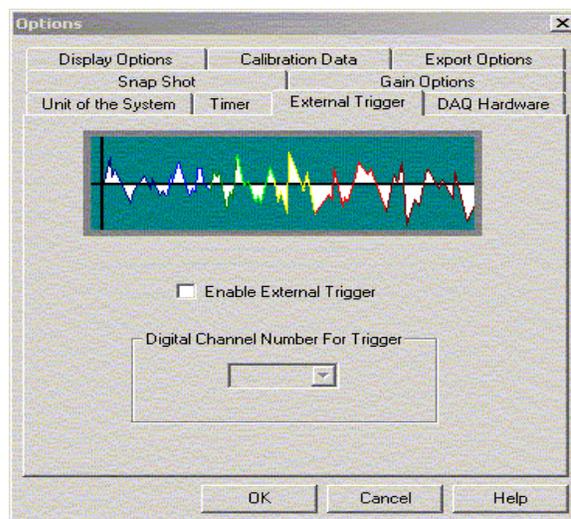


8. The data collected during each single scan is normally triggered by the chopper. However, the ES200 can be configured to be triggered by a scanner or other external devices. This option can be accessed under the DAQ trigger menu.

(See Figure to the right)



9. A series of scans can be triggered using an external trigger. To enable this feature, connect a TTL signal (active low) to the wires provided on the data cable. In the options menu under the external trigger menu, set the default channel number to 5. Set the scan mode to snap. Click the start button. As soon as the TTL signal goes low, a beep sound will be heard and the snap collection of the data for the specified number of scans will start.



7.4 Menu Options

7.4.1 **File Menu**

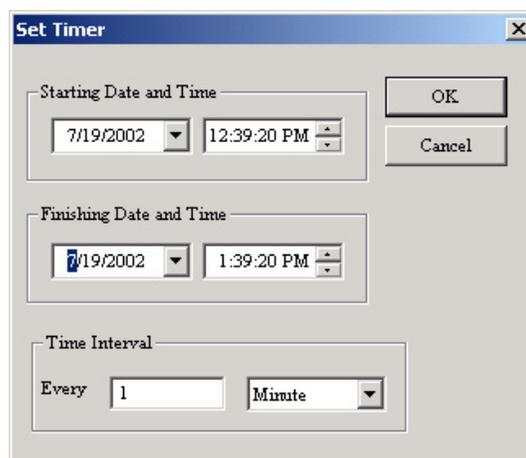
The **File** button on the tool bar allows the user to save scan files as well as to export data as ASCII and Microsoft® Excel files. Print setup allows the user to configure options related to page and printer setup, Print Preview allows the user to preview a plot before it is actually printed, and Print allows the user to print the current plot. Quality Monitoring allows the user to monitor and set alarms for up to 3 different constituent levels in the current spectrum.

7.4.2 View Menu

The **View** button can be used to add plots from different files onto the same window as well as to access the **Options** menu. The current frame of data from a snap shot can be viewed in tabular format by selecting **Data Table**. Information in the data table can be copied and pasted into other applications. By clicking the mouse in the first column of the Data Table, the user can select any number of rows from the table. Shift+Click (Continuous Rows) and Ctrl+Click (Assorted Rows) also allows the user to select any number of rows.

7.4.3 Timer Menu

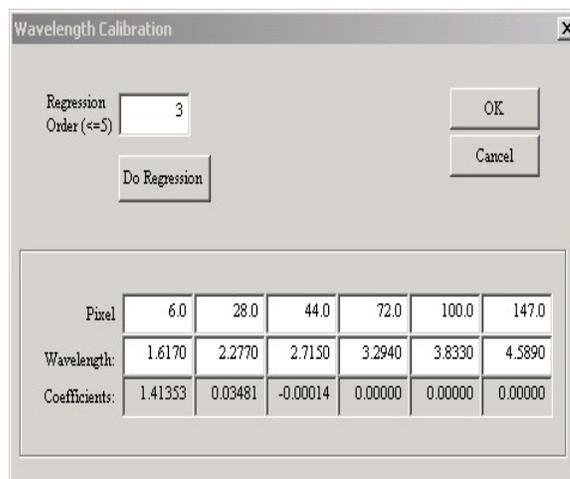
The **Timer** button on the top tool bar allows the user to start data collection at a fixed interval for several days or weeks at a time. Use the set timer and enter the starting date and finishing date. The user can set the data file name, starting time, finishing time and the time interval required. When the time interval is very short, the user should make sure the data acquisition time is shorter than the specified time interval. The data acquisition time is determined by the number of samples in the snap shot mode. For example, if the user sets the number of samples as 3000, the minimum time interval would be $3000/1320*2 = 4.55$ seconds.



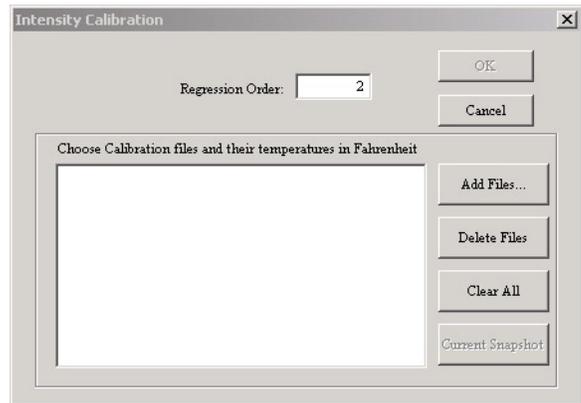
7.4.4 Calibration Menu

The **Calibration** button allows the user to calibrate four quantities. See section 4.3 for more detail on calibration of the ES200.

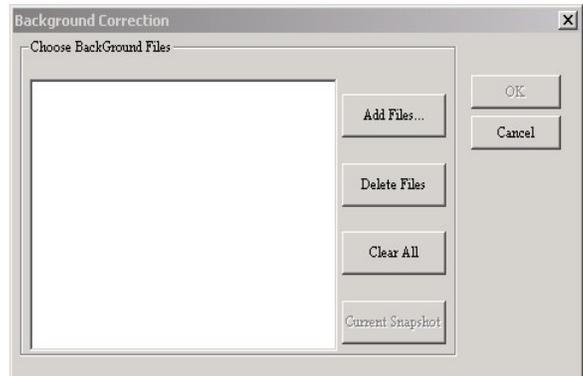
1. Wavelength. Use six narrowband filters and identify the pixel at which maximum voltage is obtained. Then when the wavelength calibration function is invoked, the six filter central wavelengths and the six pixel numbers corresponding to maximum voltage can be directly entered into the spaces allowed. A regression curve is then used to fit the wavelengths to the different pixels. A second order regression curve is usually used, but can be changed by the user in the wavelength calibration menu.



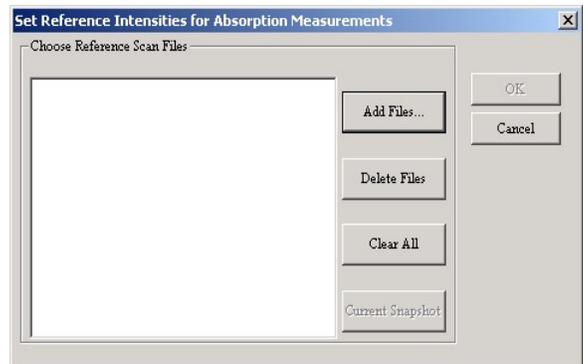
2. Intensity. For calibrating the intensities, collect six scan files at different blackbody temperatures using the snap mode. Then invoke the intensity calibration menu. The menu will allow you to enter the six temperatures and the corresponding six scan files. The GUI automatically calculates and stores the calibration constants in the file "Calib.txt". A second order regression curve is again the best choice for the calibration constants.



3. Background correction. Normally a "background" file that accounts for background radiation is used to correct the intensities obtained from hot objects. It is always best to collect one background scan and store it using the snap mode. Then, enter the name of this background scan file to set background intensities using the background correction menu.



4. Reference. The reference voltage for doing transmittance measurements is collected first and stored in a file. Then this module is activated to utilize this reference file as the initial intensity with a transmittance of 1.



7.4.5 Statistics Menu

The mean values of voltages, intensities, and transmittances, and the signal to noise ratio can be displayed using the **Statistics** button on the tool bar. In addition, the statistics can be saved to a text file. Finally, the voltage on any one pixel for a data scan collected in snap mode can also be displayed.

7.4.6 Module Menu

Optional modules can be attached to support hardware modules such as thermocouple, linear slide, 1D (line) and 2D (area) scanners. Each software module will be enabled in factory when the hardware module is physically attached to the spectrometer.

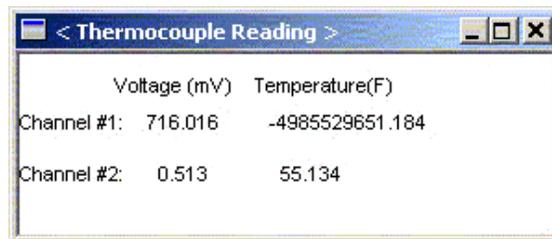
7.4.6.1 Thermocouple

The thermocouple option allows the user to connect a thermocouple device up to any unused channels of the DAQ. Although channel #0 is always in use for the spectrometer, the remaining channels of the DAQ are available for thermocouple connections.

Setup for the thermocouple allows the user to select which channels are connected to a thermocouple, the thermocouple type (types are specified in a separate configuration file titled “omega.cfg”), as well as the voltage range in which the thermocouple is operating. The user can also specify any amplification of the signal, ice point correction (if necessary), and the number of scans to run.



After the user clicks “Display” in the thermocouple menu, a display box appears showing the voltage for all selected channels, as well as the corresponding temperature, if this option was selected in the thermocouple setup menu. The program scans channel #0 (the spectrometer), followed by each selected channel in sequence, then repeats this cycle for the number of specified scans.



Configuration information to use a Thermocouple is located in a file titled “omega.cfg”. The temperature for a given voltage is found based on ITS-90 Thermocouple Inverse Polynomials.

The configuration database is formatted as follows (Note: All entries not separated by a new line are separated by a single space):

Line 1: Number of Thermocouple Specifications in Database.

Line 2: (Thermocouple Letter Designation | Number of temperature ranges)

Line 3: (Number of Thermocouple coefficients – 1 | Max Temp. range | coefficient a |
coefficient b | coefficient c | ...)

(Repeat line 3 for number of Temperature ranges for given thermocouple type)

(Repeat lines 2 and 3 as necessary for total number of Thermocouple specifications)

A configuration file containing inverse polynomials for a type K thermocouple and a type R thermocouple might appear as follows:

```

2
K 2
9 20644 0.0 2.508355e-2 7.860106e-8 -2.503131e-10 8.315270e-14
  -1.228034e-17 9.804036e-22 -4.413030e-26 1.057734e-30 -1.052755e-35
6 54886 -1.318058e2 4.830222e-2 -1.646031e-6 5.464731e-11 -9.650715e-16
  8.802193e-21 -3.110810e-26
R 4
10 1923 0.0 1.889138e-1 -9.383529e-5 1.306861e-7 -2.270358e-10
  3.514565e-13 -3.895390e-16 2.823947e-19 -1.260728e-22 3.135361e-26
  -3.318776e-30
9 13228 1.334584e1 1.472644573e-1 -1.844024844e-5 4.031129726e-9
  -6.249428360e-13 6.468412046e-17 -4.458750426e-21 1.994710149e-25
  -5.313401790e-30 6.481976217e-35
5 19739 -8.199599416e1 1.553962042e-1 -8.342197663e-6 4.279433549e-10
  -1.191577910e-14 1.492290091e-19
4 21103 3.406177836e4 -7.023729171 5.582903813e-4 -1.952394635e-8
  2.560740231e-13

```

Due to page format restrictions for this document, lines containing thermocouple coefficients are 2-4 lines long. In the file “omega.cfg,” they should each be just one line in length.

7.4.6.2 Slide Control

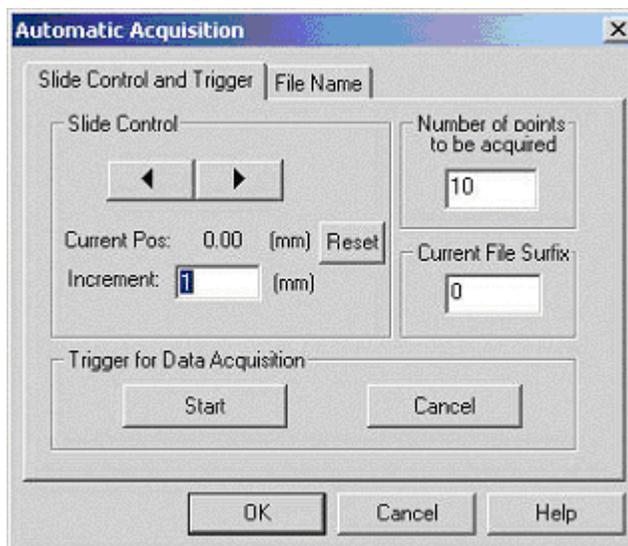
The Slide control Menu allows the user to configure a serial port for a sliding motor controller, as well as manually or automatically controlling the movement of the motor. In this manner, scans can be performed at different distances from the object.

Setup allows the user to configure:

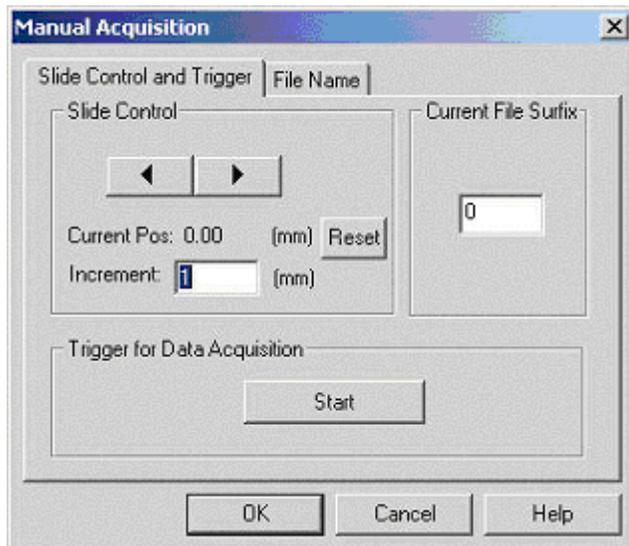
- com port selection;
- Baud rate;
- data bit;
- parity; and
- stop bit.

In automatic mode, the user can specify the number of points to be acquired and the increment value. When the **Start** button is pressed, DAQ is performed for *No. of points* times, incrementing the *Current Pos* value by the *Increment* value. The

data acquired is saved as a scan file in the given directory with the given file name, and the current point number is suffixed to the filename.



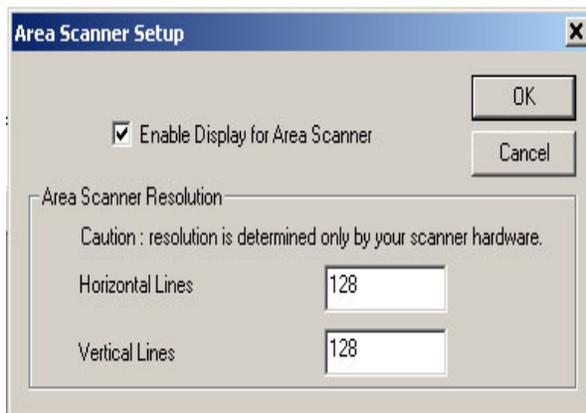
In Manual mode, the user can enter the Increment Value (Default value is 1). The user can then move the up/down control, which increments the current position value by the Increment value. The data acquired is saved as a scan file in the given directory with the given file name. The *Current File Suffix* is suffixed to the filename.



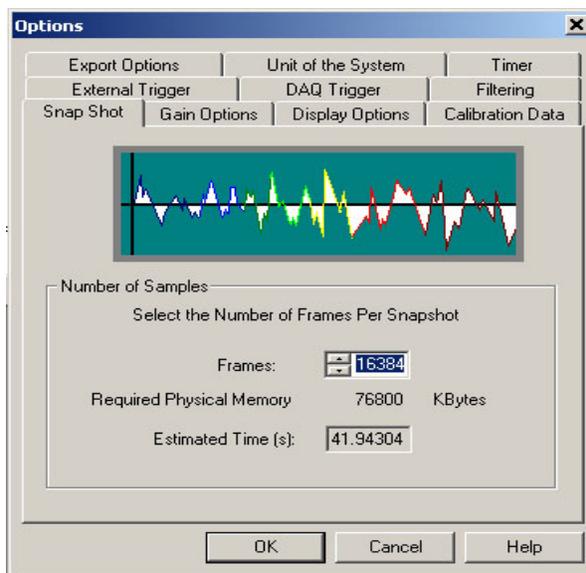
In both cases, the Start button is pressed to perform the DAQ, and when the reset button is pressed, the current position is set to zero.

7.4.6.3 2D Scanner Menu

The 2D Scanner Menu allows the user to control the optional scanner module attached to the front of the spectrometer (see section 3.9). To enable a 3D view for hyperspectral images, click the enable button. Once the scanner module is enabled, a menu item “color plot – scanner” in the plot type will be enabled. The scanner resolution is determined only by the hardware, and user should not change the default setting for the scanner resolution unless specific instruction is given from the manufacturer.

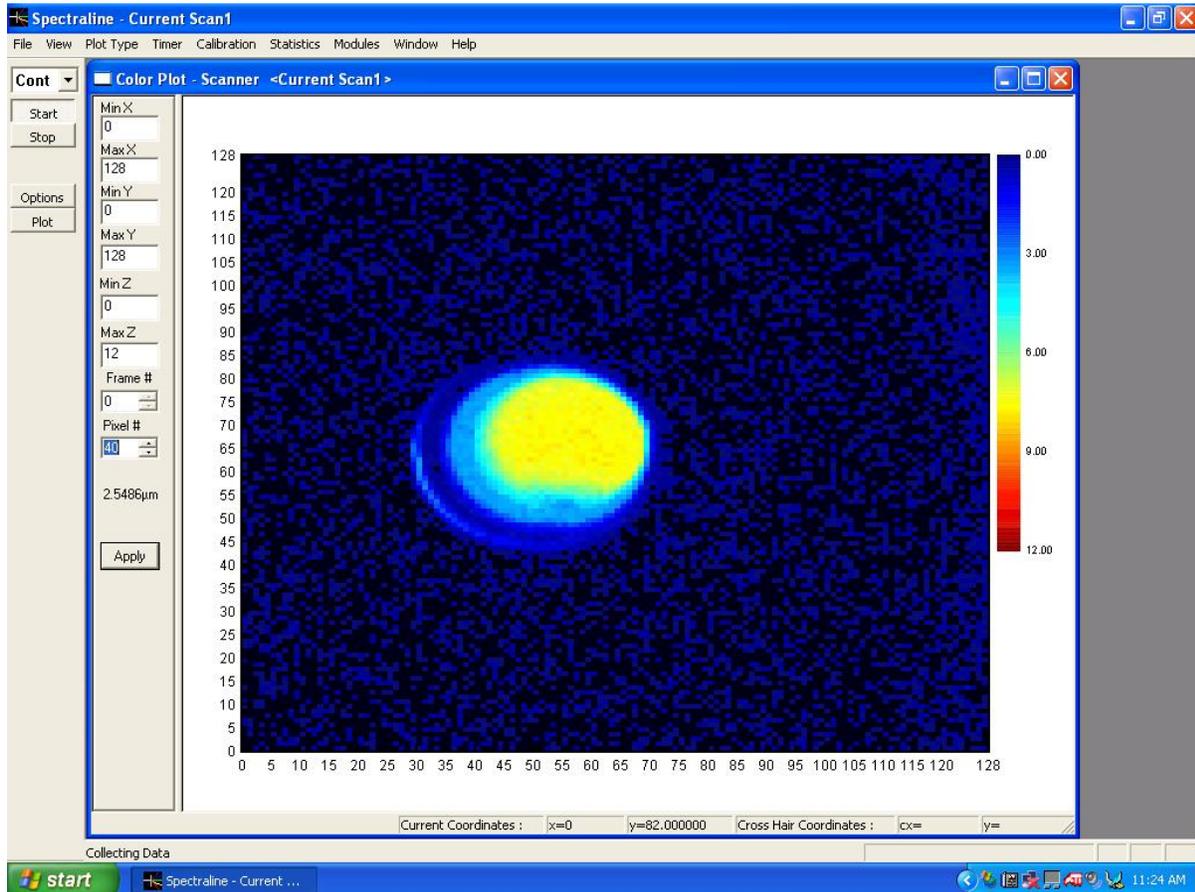


The number of frames to be scanned must be checked in the “Snap Shot” tab of the options menu. The number of frames corresponds to the area (in pixels) of the scanner module. In the case illustrated, there are 128 horizontal lines and 128 vertical lines of resolution, corresponding to 16384 total pixels in a hyperspectral image. Therefore, for every hyperspectral image the user wishes to scan, 16384 **times** that number of hyperspectral image must be specified in the “Frames” box. In the menu below, 16384 frames would correspond to one hyperspectral image.



Acquisition of data is then initiated by clicking on the “Start” button. In Snap Shot mode, after all data is collected, the user can review particular hyperspectral images by changing the Frame number on the main plot window, and information from different wavelengths can be reviewed by changing the Pixel number, located immediately below the Frame number. The data acquisition for one hyperspectral image takes quite long time dependent upon the spectrometer chopper speed and the resolution of the scanner. For example with a 390 Hz chopper and 128x128 resolution 2D scanner, the data acquisition time is approximately 42 seconds. In addition, the required main memory for one hyperspectral image is about 74Mbyte. Therefore, a computer with 512Mbyte can take approximately 6 hyperspectral images at one snapshot. A progress bar for the data acquisition is shown on the

bottom right of the main window. Once the scanner is enabled, the update rates for other plot types also will significantly slow down because the trigger for the data acquisition comes every 42 seconds. To speed up the update rate, the user must disable the 'Enable Display for Area Scanner' in the area scanner setup panel. The following picture is a sample 2D scanner-color plot for a blackbody hole.

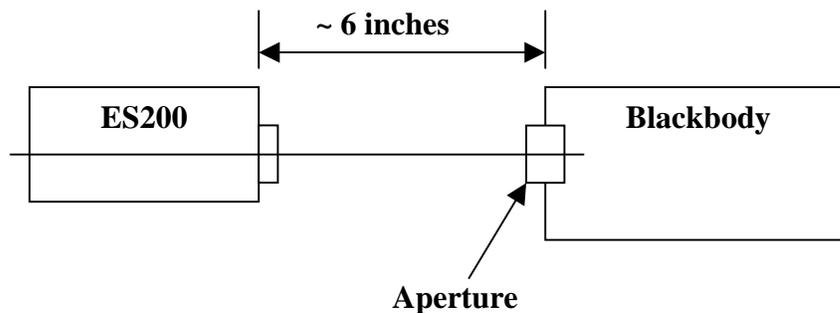


8.0 Sample Applications

The ES200 spectrometer is aligned and calibrated at the factory. Therefore, it is suitable for immediate application. The ES200 spectrometer is ideally suited for emission and absorption spectroscopy. Some important pointers on emission and absorption spectroscopy are highlighted before discussing sample applications.

1. ***In emission spectroscopy, the voltage seen by a pixel depends on the intensity of radiation emitted by the target, and the view factor. Therefore, it is very important for absolute radiometric measurements to ensure that the view factors for calibration and for intensity measurements are the same.***
2. ***In addition, the spectral characteristics of any intervening media must be taken into account. Therefore, calibration is performed with and without the focus tube assembly at the factory.***

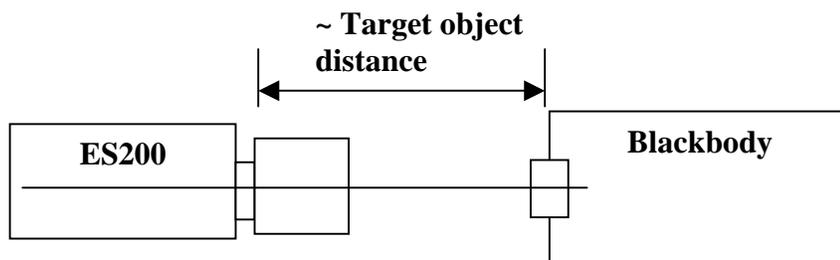
Calibration performed without focus tube



The blackbody with a 1 inch aperture is placed approximately 6 inches away from the front face of the spectrometer. Moving the blackbody closer towards the ES200 should not change the voltage. This is because the 1 inch aperture easily fills the slit (5 x 0.5 mm) of the spectrometer. In addition, moving the blackbody up and down should also not change the voltages on the ES200. This ensures that both the odd and even pixels are well illuminated by the blackbody radiation. Use the ES200 without focus tube for most applications that do not call for very high spatial resolution. The ES200 has a +/- 0.25 degree divergence angle. Therefore, as the object is placed further away from the ES200, the amount of area from which light is collected and focused onto the detector increases.

Calibration performed without focus tube

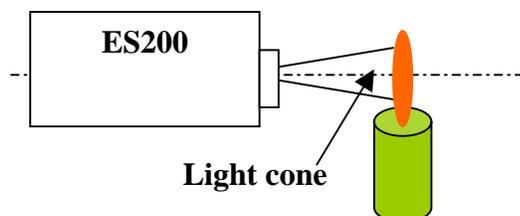
Calibration is normally performed with the blackbody at the same distance from the ES200 as the target object. Therefore, if your target object is 100 inches away, and your focus tube assembly is equipped with the proper lens to view this object, then the blackbody should also be placed 100 inches away during calibration.



Once again, care should be taken to ensure that the blackbody source (as well as the object) fills the spectrometer slit. One easy method of ensuring that the blackbody source fills the slit is to move the spectrometer about 1 mm to the right, left, up and down. The voltages seen on the pixels should remain the same at all locations.

8.1 Emission Spectroscopy

The standard arrangement for emission spectroscopy is shown below. The spectrometer is shown without the focus tube. However, the arrangement is exactly the same with the focus tube. The only difference is that calibration has to be performed with the focus tube also as explained above.

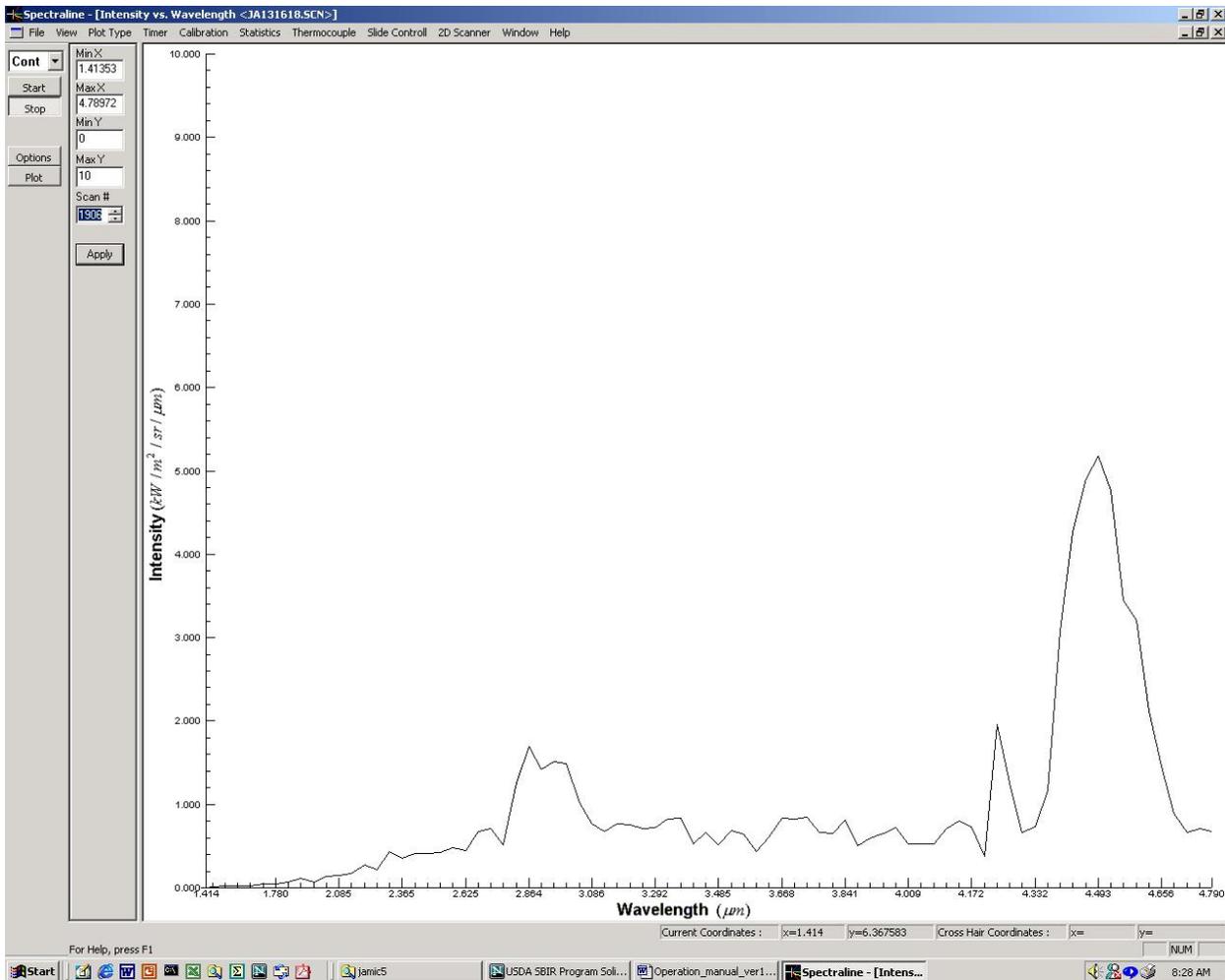


The spectrometer receives radiation from the entire light cone. The light cone has a divergence angle of +/- 25 degrees. In addition, the odd pixels look at a spot that is 3 mm below the even pixels. This implies that the odd and even pixel intensities will be similar (no small spikes in the intensity vs wavelength plots) only if the image is uniform over at least 3 mm. If uniformity over the 3 mm is suspect, then use only the odd or the even pixels in all your calculations/data presentations.

To obtain emission spectroscopy signatures from objects, the following are the quick step procedures:

1. Turn the spectrometer on for approximately 10 minutes before collecting data.
2. Double click the *Infraspec* GUI icon.
3. Click on **plot** (left side button) and set **plot type** to intensity vs. wavelength.

4. If using a focus tube assembly, use the viewer to ensure that the object is correctly located with respect to the slit.
5. Check signal by putting the operation of the GUI to continuous mode and clicking the **start** button. The screen should look like something like the figure below for a sooting flame. The peak at 2.7 μm is from the hot water



vapor and that at 4.4 μm is from hot CO_2 . If there is cold CO_2 between the flame and the spectrometer, a local minima is also seen at around 4.3 μm . The continuum radiation from soot should be present at all wavelengths. Finally, the slightly jagged nature of the picture is the pixel and readout noise riding on top of the signal. This should disappear if the signal is strong and averages of about 6000 scans are obtained. Check to see that the signal is actually from the flame by placing your hand over the slit. The signal should disappear completely.

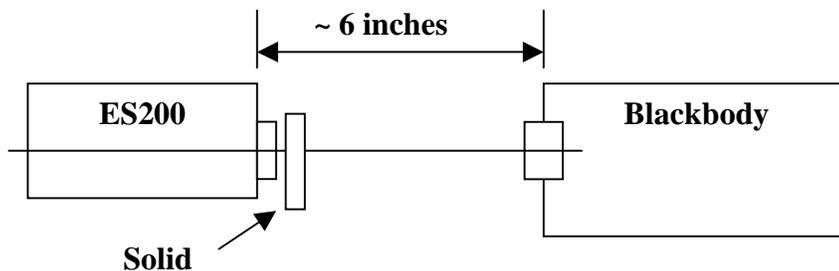
6. **Stop** the continuous scan and set the instrument to **snap** shot mode. Go to the **options** button and set the number of frames to be collected to what you require. Normally, 10 seconds of data is collected for a good average. Hit the **start** button. The **start** button is shown as depressed during the entire scan period (10 seconds). At the end of the scan, the **start** button pops up.

Congratulations! You have now collected your first emission spectra using the ES200. Data can now be viewed one scan at a time. You can also go to the Statistics Menu and save mean intensity, etc. onto your hard disk as a text file, which can then be imported into any spreadsheet.

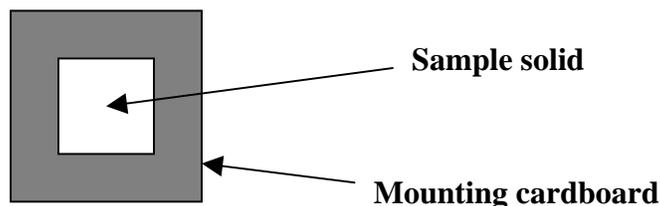
8.2 Absorption Spectroscopy of Thin Solids

The standard arrangement for absorption spectroscopy of thin solids is shown below. ***Absorption spectroscopy is always completed without the focus tube assembly. If you have a focus tube assembly mounted onto the front of your ES200, remove the lens alone.***

The black body is typically placed about 6 inches from the front of the ES200. The thin solid is mounted very close to the ES200 as shown in the figure below.

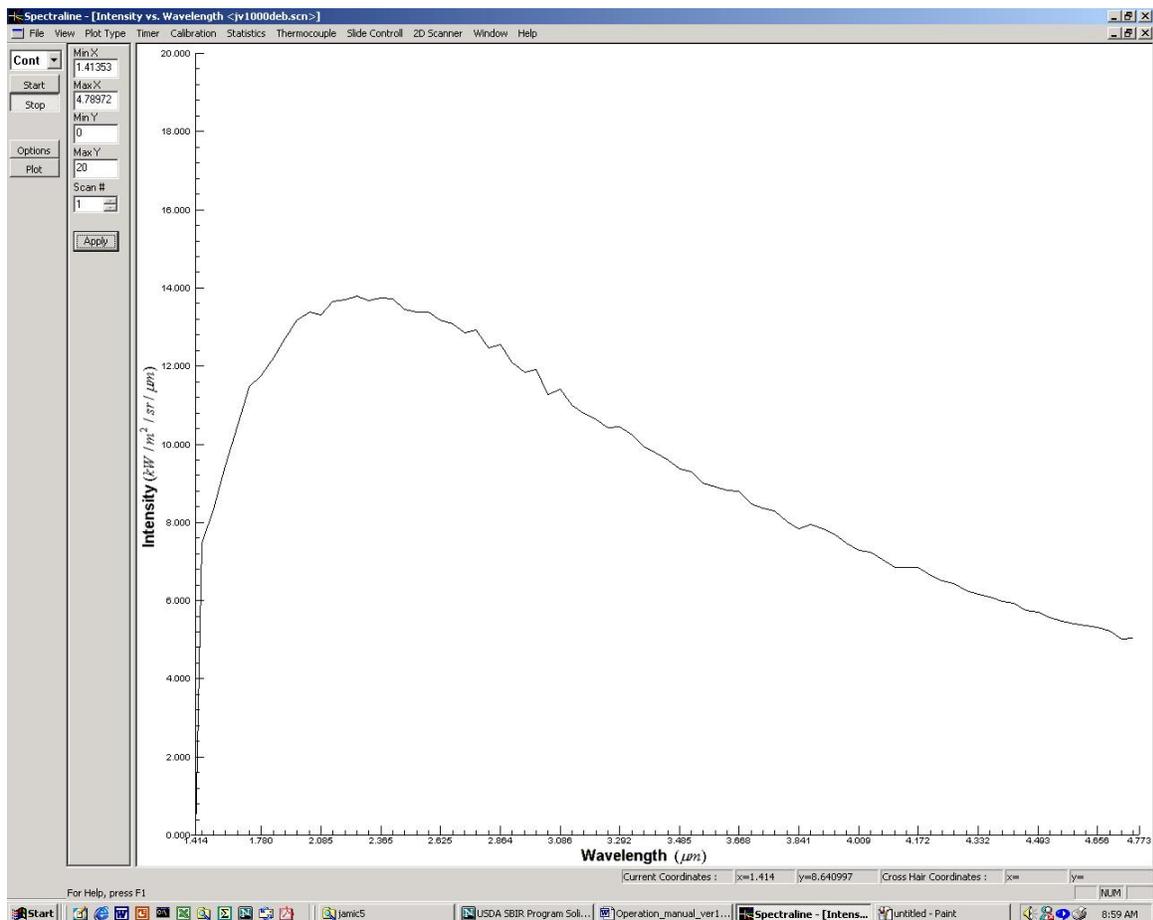


The only criteria that must be met is that the size of the thin solid should be bigger than the slit of the spectrometer (approx. 5 mm x 0.5 mm). Using a 2 inch square mounting cardboard as shown below is very helpful since the sample can



then be held using very simple holders. This completes the sample preparation for obtaining Absorption spectroscopy of thin solids. Follow the step by step procedure for obtaining absorption spectra.

1. Turn on the blackbody and set it to approx. 1600 °F. Turn the spectrometer on. To increase the life of the spectrometer, place a metal block (plate) between the spectrometer and blackbody while the blackbody come up to temperature (about an hour).
2. After the temperature has stabilized at 1600 °F, you are ready to start collecting data. Double click the **Infraspec** GUI icon. Remove the solid sample from the path so that there is nothing between the spectrometer and the blackbody.
3. Click on **plot** (left side button) and set **plot type** to intensity vs. wavelength.
4. Check signal by putting the operation of the GUI to continuous mode and clicking the **start** button. The screen should look something like the figure below for a black body.



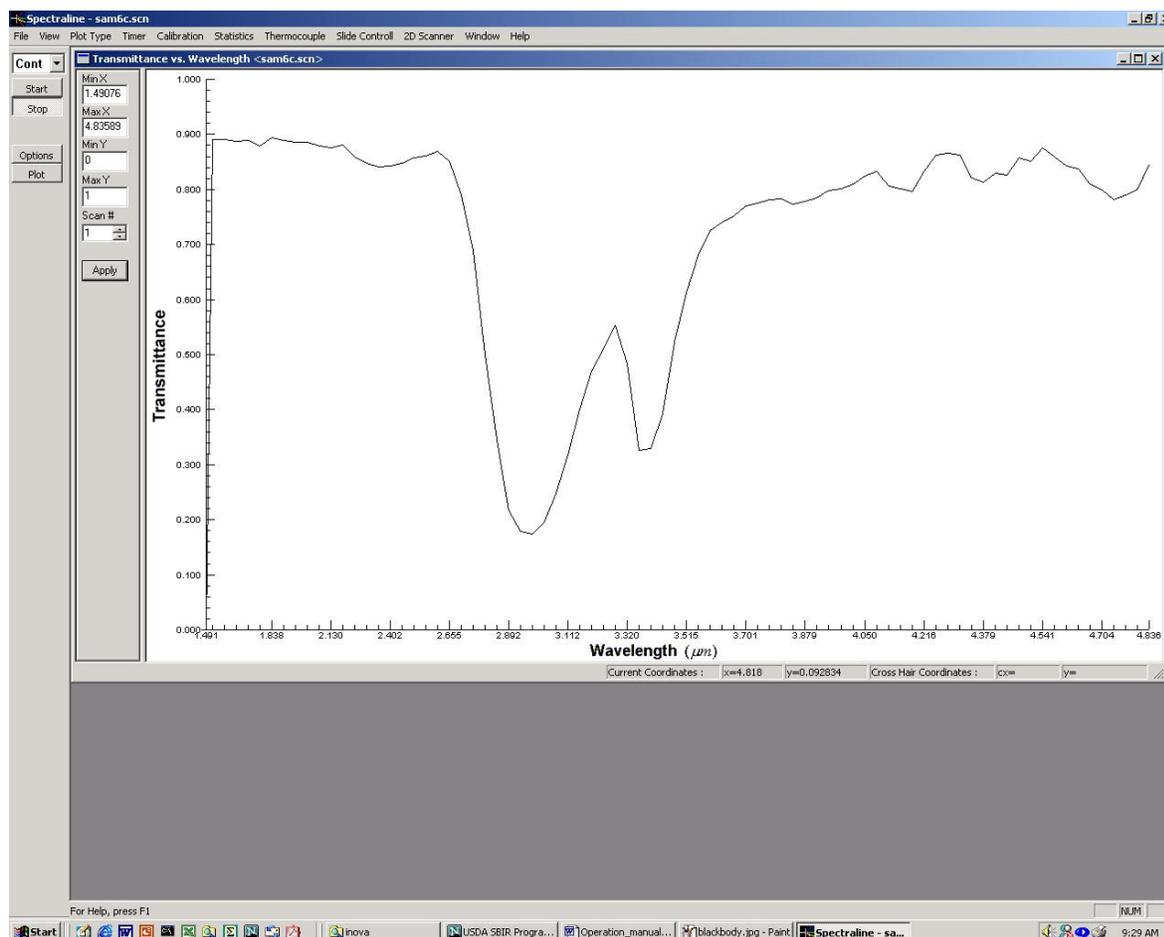
5. Click the **stop** button. Set the instrument to **snap** shot mode. Go to the **options** button, and set the number of frames to be collected to 6000. Hit the

start button. The **start** button is shown as depressed during the entire scan period (10 seconds). At the end of the scan, the **start** button pops up. This is your reference scan. You should **save** this scan under some name such as black.scn.

Note that the reference scan contains absorption by room CO₂ and water vapor. Normally, this is not very important for most applications. If you have to ensure that accuracy is very high at the 4.3 and 2.7 micron bands, you need to purge the entire path between the source and the ES200 with Nitrogen.

6. Go to the **calibration** button (top tool bar) and highlight **reference voltage**. At this time, a file menu (with default current.scn) shows up. You can click **OK**, since the current scan is the same as black.scn.
7. Put a metal block (plate) in front of the slit and hit the **start** button (remember the ES200 is in snap mode still) again. At the end of the scan, the **start** button pops up. This is your background scan. You should **save** this scan under some name such as back.scn.
8. Go to the **calibration** button (top tool bar) and highlight **background correction**. At this time, a file menu (with default current.scn) shows up. You can click **OK**, since the current scan is the same as back.scn.
9. You are now ready to obtain absorption signatures of thin solids. Place the solid sample between the ES200 and the blackbody.
10. Set the **plot type** to transmittance vs. wavelength.
11. Set the ES200 into **continuous** mode to ensure proper operation.
12. Hit the **start** button. Your screen should now show the transmittance signature of the solid sample as shown in the following figure.
13. **Stop** the continuous scan. Set the ES200 into **snap** shot mode.
14. Hit the **start** button. At the end of the scan, the **start** button pops up. This is your absorption scan for the solid. You should **save** this scan under some name such as sample1.scn.

Congratulations! You have now collected your first absorption spectra using the ES200. Data can now be viewed one scan at a time. You can also go to the statistics Menu and save mean data onto your hard disk.



8.3 Absorption Spectroscopy of Liquids

For absorption spectroscopy of liquids, the same procedure as above can be followed. The only change is in sample preparation and placement. The reference voltage is collected with the liquid sample cell in place, but with no liquid inside. Then the liquid is injected into the sample cell and the absorption signature collected. The cell should be purged of liquids and a fresh reference voltage collected between each sample to improve accuracy.

8.4 Absorption Spectroscopy of Gases

For absorption spectroscopy of gases, the same procedure as above can be followed. The only change is in sample preparation and placement. The reference voltage is collected with the gas sample cell in place, with nitrogen flowing through the cell. Then the sample gas is flowed through the cell for absorption signatures. The cell should be purged with nitrogen and a fresh reference voltage collected between each sample. This will improve the accuracy of the measurements.