EXACTUS® OPTICAL THERMOMETER

Manufactured By BASF Corp

USER'S MANUAL

Single or Multi-Channel System

Version 5.04

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1 Introduction

BASF Temperature Sensing offers the ***EXACTUS®*** line of optical thermometers. ***EXACTUS®*** instruments provide the most advanced temperature measurement system available today. This system is designed to provide you with very precise and stable temperature readings. With numerous features and options, it can be customized for many different applications. Please contact BASF Temperature Sensing if you have any questions regarding your temperature measurement needs or the use of this instrument.

BASF Temperature Sensing has technical support staff with extensive experience in all aspects of temperature measurement and temperature control, and will be happy to provide assistance in solving your temperature measurement challenges.

1.1 Company Profile

BASF is the worlds leading chemical company with over 100 production sites worldwide. Some facts about BASF:

- Over 90,000 employees
- Business contacts in 170 countries
- 8000 product manufactured
- Sales of over 65 Billion Euro in 2007

EXACTUS® optical thermometers are developed, manufactured and supported at BASF facilities in Portland Oregon, Fremont California, and Rome Italy.

1.2 Theory of Operation

The following is a quick introduction to the field of Optical Thermometry, also known as Pyrometry or Radiation Thermometry. An optical thermometer is a device that measures light and is calibrated to indicate temperature. An optical thermometer detects the radiant flux from a hot object and utilizes an algorithm to calculate the surface temperature of the object. The algorithm used is based on the Planck Blackbody Radiation Equation. In 1860, Gustav Kirchhoff conceived of the ideal emitter known as a *Blackbody*, and then in 1900 Maxwell Planck mathematically described how a blackbody emits light as a function of its own temperature and wavelength.

Please see the recommended references at the end of the Glossary for further reading on pyrometry and wafer temperature measurement.

1.3 Overview of the *EXACTUS*® Optical Thermometer

The main components of the ***EXACTUS***® optical thermometers are:

1. **Collection Optics:** The collection optics acquire light emitted from a hot object and directs it to the filter and photo detector. Many standard and custom options for collection optics, including lens systems (small spot size), lightpipes, and flexible fiber optic cables.
2. **Wavelength Selective Filters:** These select which wavelengths of light are measured. Care must be taken that these filters are kept clean and dry.
3. **Photo Detector:** Photo detectors convert light (photons) into an electrical signal. BASF uses only high efficiency (D*) solid-state photo detectors of either silicon, InGaAs, or a new patented 900nm narrow band detector.
4. **Amplifier:** The amplifier takes the small electrical signal from the photo detector and amplifies it before sending it to the signal processor. The amplifier circuit is extremely sensitive and allows signals as small as 10^{-15} amps to be detected and measured.
5. **Signal Processor:** The signal processor converts the amplified signal into a temperature reading. This processing is a combination of electrical conditioning, including Analog-to-Digital conversion, and software algorithms, including the Planck equation.
6. **Output:** Several types of data output are available from the instrument:
   - Direct digital data to a host computer or process controller.
   - Viewed using BASF's TemperaSure® data acquisition and graphing software.
   - Analog output via 4-20mA or 0 – 10 VDC analog output.
   - Specialized processed measurement modes such as peak, valley, or process standard deviation.

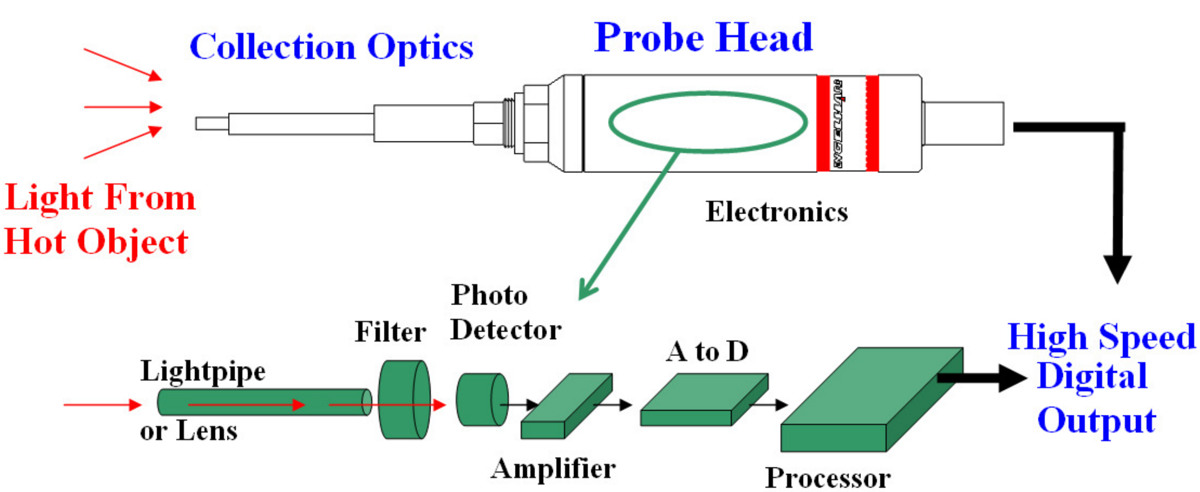


Figure 1: Probe Head Conceptual Diagram

1.4 Advantages of the BASF Optical Thermometer

The ***EXACTUS***® line of optical thermometers provides many advantages for optically based temperature measurement. These include:

1. **The ability to measure small signals and lower temperatures at short wavelengths**

   Careful design and use of an advanced amplifier circuit enables measurement of signals as small as 10^{-15} amps from the photo detector. The ability to measure smaller signals enables the measurement of lower temperatures while using short wavelengths. Short wavelengths significantly reduce emissivity errors and are ideal for many applications such as the measurement of silicon wafers in the semiconductor industry. (See Resolution in Section 7.)

2. **High resolution, with measurements to 0.01°C**

   Precise amplification also means less electrical noise, and therefore lowers noise in the temperature measurements. This enables measurement and control of smaller changes in the process temperatures, leading to more stable process control and higher yields.

3. **High speed, digital readings at up to 1,000 readings per second**

   EXACTUS® instruments can provide temperature readings ranging from one reading per minute all the way up to 1,000 readings per second. In addition, the instrument performs all the A/D conversions internally, so each instrument provides a digital signal output. BASF also offers an analog output module for applications where a proportional to temperature current or voltage output is desired.

4. **The ability to read a wide range of temperatures - from 25°C to 4,000°C**

   The electronics design also allows a wider range of temperatures to be measured. Typically, hot objects from about room temperature (25°C) to 4,000°C can be measured. Contact your sales technician for more specific details.

5. **Low-drift electronics**

   Special care has been taken in the selection and design of components to minimize drift in the electronics. This has resulted in electronics drift of only 0.10ºC or less per year.

6. **A highly compact design which provides flexibility in placement and eliminates the need for fiber-optic cables**

   The small (1” diameter x 4.5” length / 25.4mm x 115mm) package with world-class performance allows the ***EXACTUS***® instrument to be placed close enough to hot objects to eliminate the need for long flexible fiber-optic elements required by other systems. This is critical since about 80% of the light (and therefore about 80% of the signal) can be lost when fiber-optic cables are used to transmit light to the photo detector. In applications where fiber optic cables are required, BASF’s sensitive electronics still provide a significant advantage and we offer a full line of flexible quartz fiber-optic cables for those situations where they are needed.

2 System Description

A single channel ***EXACTUS***® system is composed of four parts:

- **Collection optics:** either a lightpipe or lens assembly
- **Probe head:** a stainless steel tube (0.998" diameter × 4.5" long / 25.4mm × 114.3mm)
- **Interface module:** for conditioning power and communicating with a PC.
  Single Channel: (4.6" × 2.8" × 1" / 118mm × 72mm × 25mm)
  Multi-Channel (10 Channel): (17.625” x 12.5” × 2” / 447.7mm × 317.5mm × 50.8mm)
  Optional analog output, 0 to 10 volts or 0 to 20ma (4 to 20ma) analog output (same size as Single Channel)
- **Power supply:** 12 volt (4" × 2" × 1.4" / 101.6mm × 50.8mm × 35.6mm)

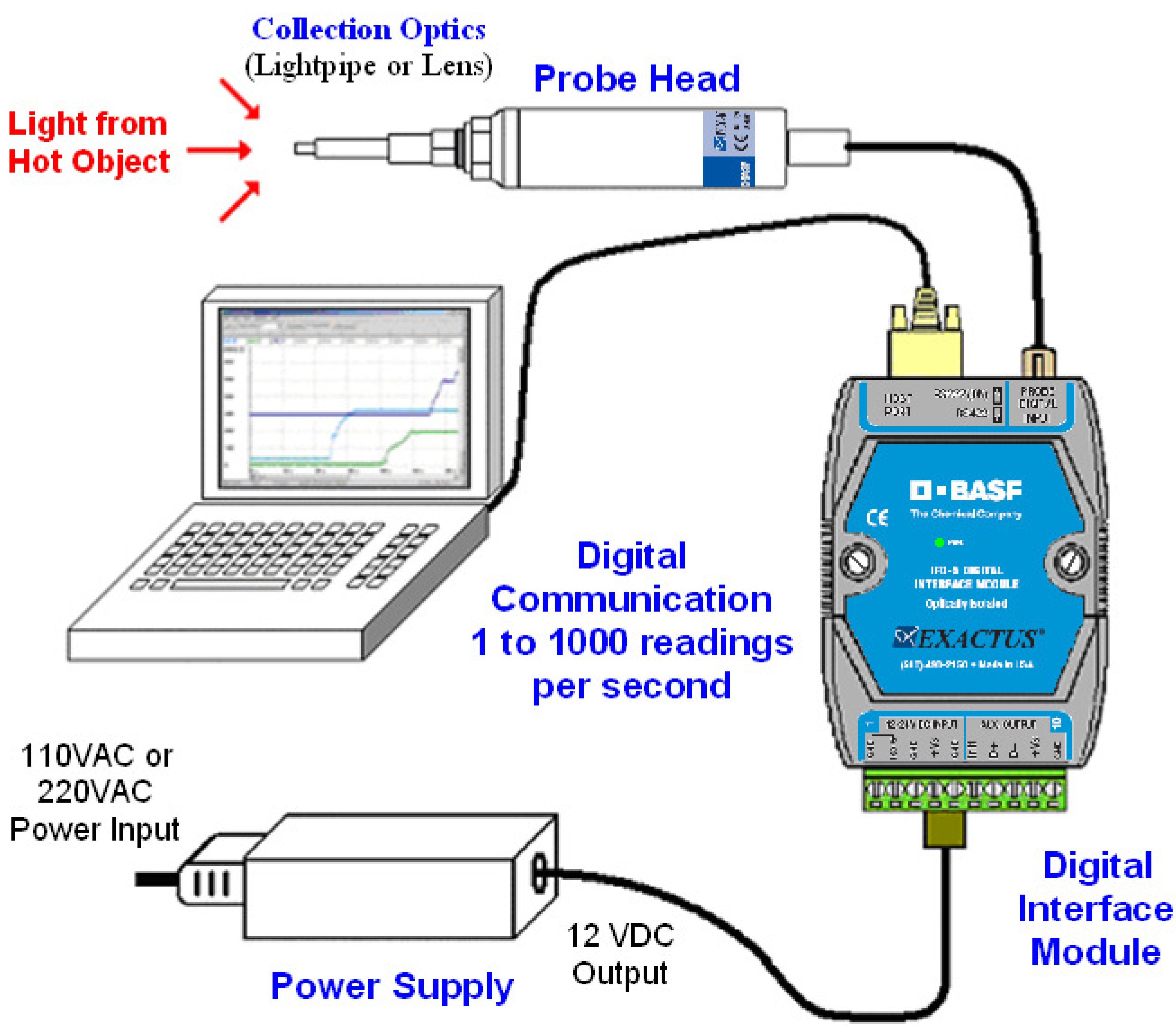


Figure 2A: Single Channel System

A multi-channel ***EXACTUS***® system:

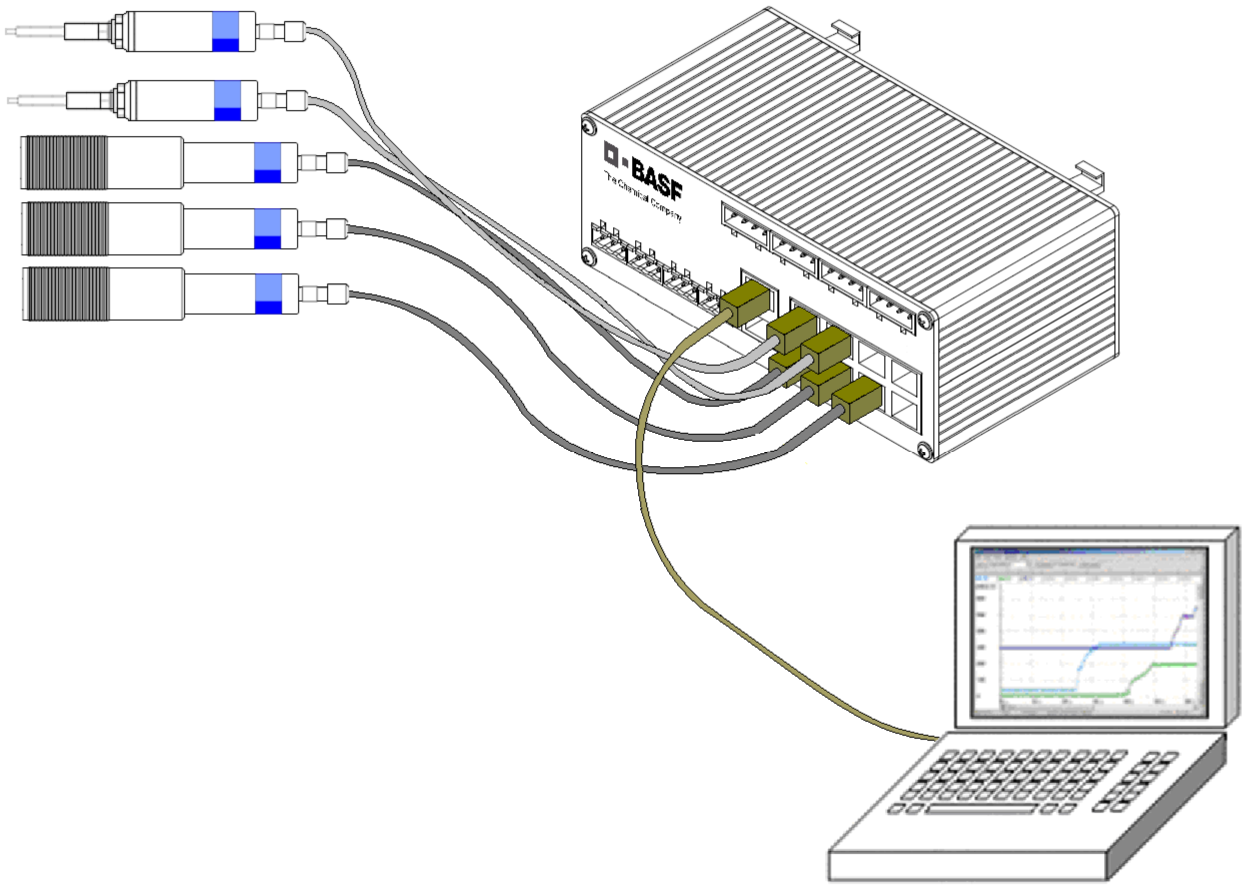


Figure 2B: Multi-Channel System provides Ethernet communication to a PC along with up to eight analog outputs and two latching relays.

2.1 Collection Optics

There are two basic types of collection optics: **lightpipes and lenses**. The advantage of the lightpipe is its small diameter, which only requires a small access hole into the process being measured, and its ability to collect light from a wide range of angles, which can help decrease emissivity or roughness errors. Lens systems allow the user to view a small collection spot on a hot object from greater distances and they can be used to look through a window or view port when direct access to the hot object is not available. Lightpipes are more efficient at collecting light than lens systems, therefore they are better suited for low temperature measurements. BASF manufactures custom collection optics for specific user needs and measurement applications. Lightpipes and lenses can be coupled directly to the measurement electronics or coupled via fiber optic transmission cables.

2.2 Probe Head

The probe head comes with either a lightpipe or a lens assembly. The wavelength of the detector is chosen based on the temperature and nature of the application, and is defined by the combination of a bandpass filter and photo detector. BASF offers three photo detector options: Si, InGaAs and a proprietary, patented detector specifically designed for looking at silicon wafers. The output is a high-speed digital temperature measurement with up to 1,000 readings per second. The probe head can be placed up to 15 meters from the interface module.

See Figures 14 - 16 for detailed probe and lightpipe drawings.

2.3 Digital and Analog Interface Modules

Single Channel System

The Digital Interface Module allows the probe head to be connected to any PC. This box also isolates the probe head from any electrical noise, and supplies a "clean" 6 VDC to the probe. There are three connections on the single channel box: on one side of the box is an RJ45 connector for the probe cable and a female DB9 connector for the host computer. On the other side of the box is the connection for power from the power supply. The interface box has a green LED that indicates when power is being supplied.

The probe can communicate with a host computer using either RS-232 or RS-422 serial communication. If it is configured for RS-232 than the interface box should be placed within 2 meters of the PC or digital data logger.

BASF also offers an Analog Output Option, which can be configured to either a voltage or current output. The value of the analog output can be scaled as needed using the TemperaSure software from 0 to 10 volts or 0 to 20 mA to any temperature range.

See Figure 9 and Appendix 3 for analog output details.

Multi-Channel System

The multi-channel interface box (Mux) allows one or many probes to be connected to a PC. This box, like the single channel system, isolates the probes from electrical noise and supplies power to the probes. The probes plug into the interface box with RJ45 connectors. The interface box connects to the PC with an Ethernet cable.

2.4 Power Supply

A single channel system is powered with a 12VDC Power Supply Module through the Digital Interface Module as shown in Figure 2A; the Digital Interface Module may be powered by any DC voltage between 10 and 12 volts. The multi-channel system is powered via 24VDC.

3 System Startup

EXACTUS® optical thermometers have been designed with ease-of-use in mind, and are very simple to operate. The recommended start up procedure is to assemble the system and run it using the BASF TemperaSure® user interface software. Please start by reviewing the warnings in Section 5.0, and then carefully follow the steps listed below to begin using your new instrument. This will allow you to begin measuring temperatures and logging data.

3.1 Getting Started

Please read the **Warnings in Section 5.0** before you begin.

1. Carefully unpack the parts of the system.
2. Check that you received all the parts of your measurement system. Please contact BASF immediately if you have any questions or if parts have been damaged in shipping.
3. We recommend that you assemble the system in a lab or office before installing it on a process in order to familiarize yourself with the operation of the instrument.
4. Connect the system as shown in Figure 2A, or Figure 2B if you are configuring a multi-channel system. Connect the **probe head** to the **interface module** with the provided cable. The cable end that connects to the probe head has a round connector with a small red dot. Line up this red dot with the red dot in the plug on the back of the probe head and push the two together until you hear a click. This connector has a locking mechanism, so be sure to insert it all the way until you hear a click. (To unplug the cable, grasp the grooved part of the plug and **slide it back** before pulling to unplug the cable). The other end of this cable has a RJ45 connector, which plugs into the interface box.
5. Connect the **interface module** to the **power supply**.
6. Connect the **interface module** to your PC or host computer.
7. The probe head and interface box each have a green LED to indicate power is being supplied.
8. **Multi-Channel Systems:** Please refer to Appendix 1 for software installation information for the multiple channel interface box.
9. When using **analog output -- check the operation carefully** before connecting to or controlling with analog output signal. See Appendix 3 for analog output module details.

3.2 Mounting the Probe

When choosing a location to mount the probe, select a place that is:

- In a fixed position and able to provide the desired spot size.
- Unlikely to have the view blocked during operation. (Even a small obstruction can make a difference in the measurement.)
- Unlikely to be bumped or jostled in such a way that the lightpipe might be broken during installation or while it is in use.
- Least likely to get dirty.
- As close to the hot object as is convenient. Lens based systems should be mounted at the lens focal distance to minimize the measurement spot size.
- Does not expose the measurement electronics to temperatures greater than 60°C (unless cooling is provided).

BASF's Temperature Sensing support staff has years of experience in mounting optical probes. Please contact us if you need assistance or to review your mounting ideas with our technical staff.

Once the probe is mounted and the cables are connected, you may start taking measurements.

4 Software Interface

BASF TemperaSure® graphical user software gives the user the ability to log and/ or display temperature readings and set-up values obtained from the probes. This section describes how to install and set up the software. The data logged while taking measurements can be saved in binary files for re-viewing with this program or in text files that can be opened by programs such as Microsoft® Excel or Notepad.

4.1 Software Installation

To install the TemperaSure user software, copy the **TemperaSure.exe** program and all the other files from the supplied disk onto your hard drive. We recommend making a new directory for the program and supporting files. After the program and files have been copied onto the hard drive it can be run by either double clicking on program icon or on the file TemperaSure.exe in Microsoft® Explorer. The user software can save data to files anywhere you select.

4.2 Starting up TemperaSure

Launch the TemperaSure program by double-clicking on the program's icon. The program's graphical interface consists of a menu bar, communication ports, and a graph area where the data will be displayed. The left vertical area displays either temperature or current. The bottom horizontal area displays time in seconds, minutes or hours.

4.3 Installation Troubleshooting

Connect the probe per Figure 2A or 2B, and then launch the TemperaSure software by double clicking on TemperaSure.exe. The user-interface screen (Figure 3) will appear. The COM ports may need to be selected first. To configure COM ports go to the "Options" menu and choose "Connection" and select the COM ports. The **probe readings will appear in the boxes** along the top of the user-interface screen if the probe is connected correctly and COM ports are selected.

If temperature values do not appear in the box(es) along the top of the screen then there is a problem. If the box says **Searching** or **No Probe** then the probe is not being "seen" by the software and is most likely not connected correctly. If **Error** appears in the box, most likely the COM port is not selected correctly.

Check the cabling. Be certain that the **probe, power supply** and **interface box** are all connected and fully plugged in, per Figure 2A or 2B.

- Check to see if the green LED on the back of the probe and interface box are lit. These indicate the probe head and interface box have power.
- Check that the correct COM port(s) on the computer is being used.
- **Consult Section 6 "Troubleshooting" in this manual** if cabling and LED are all OK.
- Call BASF Temperature Sensing in Portland, OR (503) 794-4073 or Fremont, CA (510) 490-2150 for additional help.

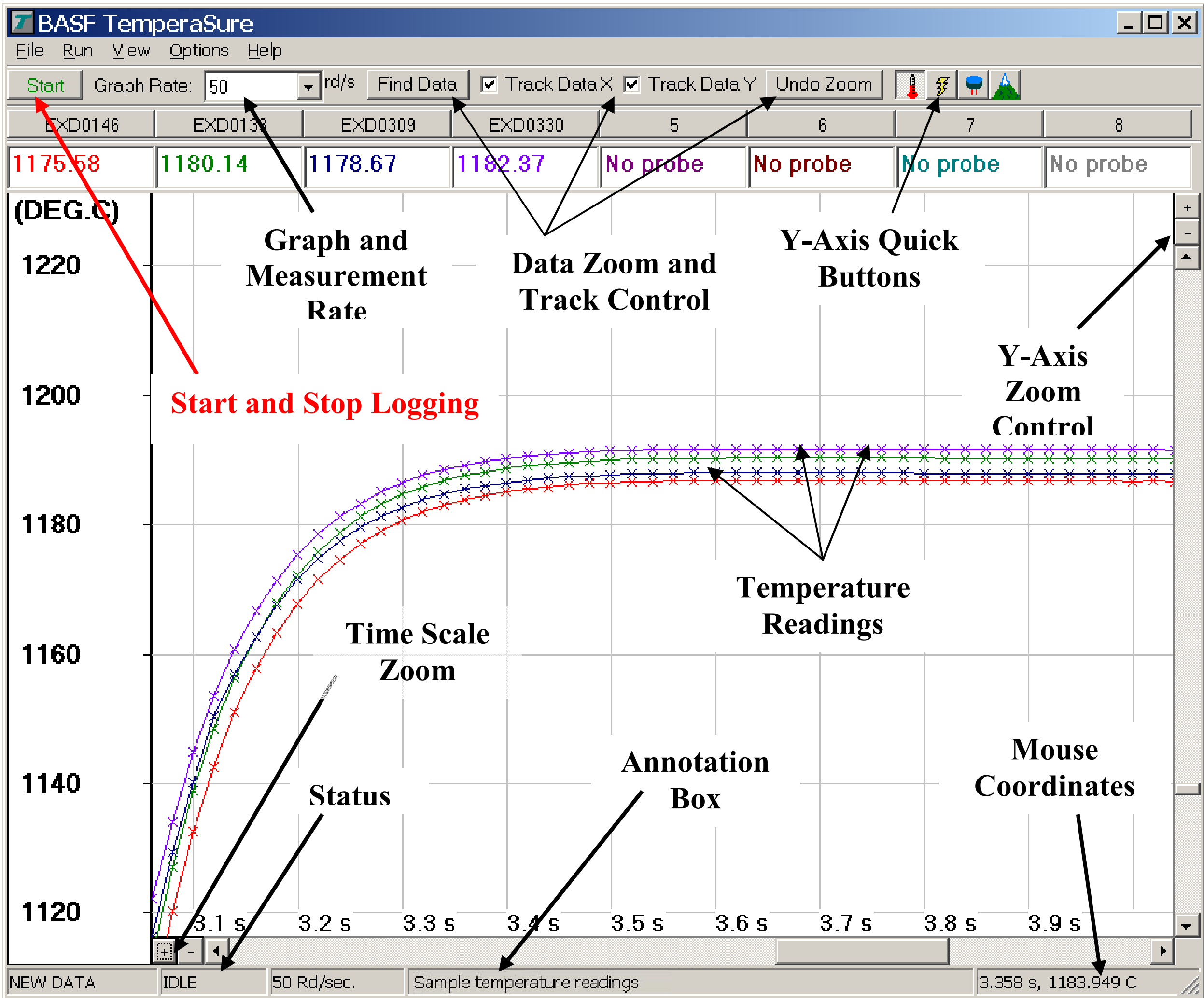


Figure 3: TemperaSure Graphical User Interface - Main Window

4.4 Using TemperaSure Software Functions

The TemperaSure program has 5 menu options:

- **File**
- **Run**
- **View**
- **Options**
- **Help**

4.4.1 File

Use the File menu for common tasks. The File menu has the following options:

Open: Use to open an existing ".bin" (binary) data file to view data graphically. The data can also be saved to a .txt file from any open .bin file.

Save: Use to save data collected to a ".bin" data file. The .bin file is used for viewing data at a later time with this program.

Export (ASCII): Use to export a data file for use in another program, such as Microsoft® Excel© or Notepad©. The fields that can be exported are:

- Temperature
- Current
- Peak, Valley, and Plateau Temperature
- Ambient Temperature
- Emissivity
- Calibration factor
- Transmission Factor
- Current Offset
- Annotation
- Start Time

The exported file format is selected under this menu option as fixed width, tab separated, or comma separated. The user can transfer all the data in the file or just the data along the currently displayed X-Axis. The Export (ASCII) setup screen is shown at right.

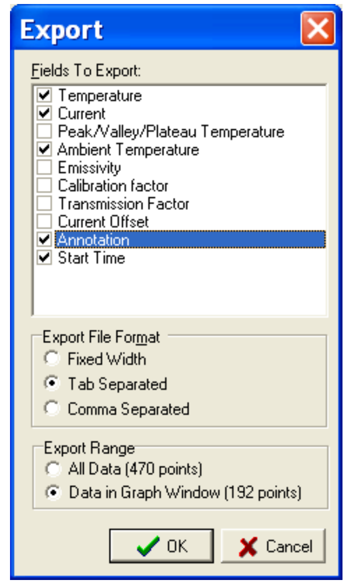


Figure 4: Text file export configuration menu.

Annotation: Allows a user to create a set of notes regarding the measurement files being saved. The annotation entry will be added to each file saved until it is removed, edited, or TemperaSure program is exited.

Exit: Exits the software program. The exit function will give you the option to save your data.

4.4.2 Run

Use the Run menu to control the data logging.

Start: Starts the data acquisition. If you have more than one probe the software will force all probes to run and log at the same rate.

Stop: Stops the data acquisition.

Macro: Macro mode allows data acquisition to occur automatically for a prescribed period of time and then restart after a prescribed pause. The acquisition will continue until the Macro Mode is halted. Resulting data files are stored in a user selected directory with a format as described under the Export (ASCII) portion of Section 4.4.1 See Figure 5 for Macro Mode setup screen.

Reset: Erases the data from the graph and re-boots the probe(s). **Warning Data Will Be Lost!**

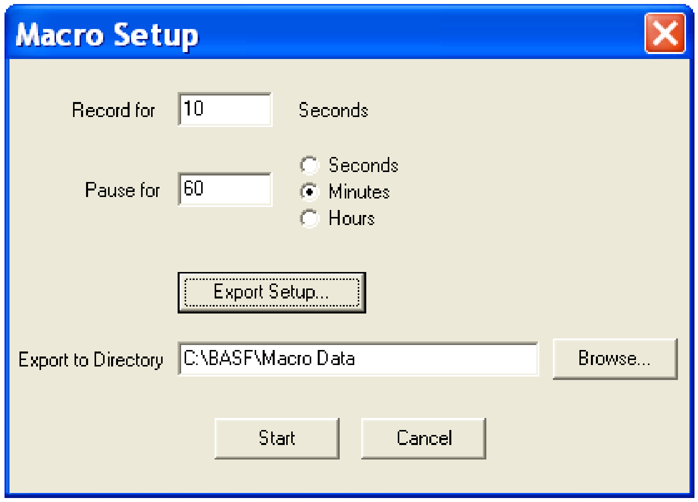


Figure 5: Macro Mode setup screen

4.4.3 View

Find Data: This feature finds the most up-to-date readings and centers the data in the graph. *Find Data* is like a beam finder, it auto-scales the graph and places the measurements in view. The Quick-Button at the top of the screen and Right-clicking the mouse also provides access to *Find Data*.

Undo Zoom: After you have "zoomed" the display in or out by any method, this feature will become enabled, and selecting it will return the display to its previous horizontal and vertical scale. Undo Zoom keeps track of multiple zoom operations, so that you can undo them in sequence if desired. The Quick-Button at the top of the screen and Right-clicking the mouse also provides access to *Undo Zoom*.

4.4.4 Options

Use the Option menu to control the probe's settings. The Option menu has the following choices:

Connection: Allows the communication port(s) to be selected. The PC often already uses COM 1, 2, and 3. TemperaSure can utilize any unused COM port. TemperaSure can also talk to probes through a USB port and serial converter box like those from Inside Out Networks™.

Graph: Allows the graph to be customized, see section 4.7 and Figure 6: Graph Setup Screens, for more details.

Probes: Allows you to change the probe's parameters. See section 4.4 and Figure 7: Probe Setup Window, for more details.

All Probes: Allows you to see the settings of all the probe's parameters (See Figure 8).

Analog Calibration: Allows the analog voltage or current to be calibrated (See Figure 10).

Probe Statistics: Opens a window which provides statistical information on the current measurements, including the mean, standard deviation, minimum, and maximum of the current readings. Calculations are based on a user input value of N readings.

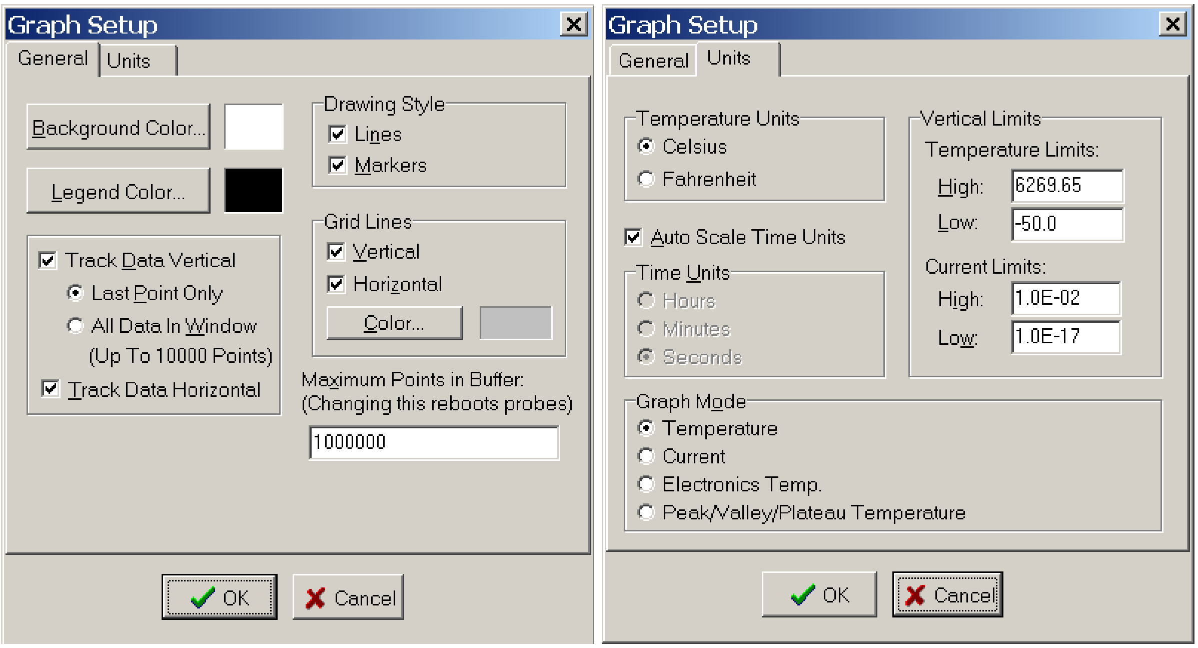


Figure 6: Graph Setup Windows

4.5 Probe and TemperaSure Setup

After connecting the probe, start the TemperaSure program. Probe settings can only be changed if probe(s) are connected. There are a number of probe setting options, and these **settings will affect the measurement accuracy.** Therefore, it is very important that the probes be set up correctly. Graph settings will not affect the measurements, only the display of the data. If you are not certain about the correct settings please call BASF for application support.

4.5.1 Logging Rate:

The graph rate is the number of readings per second (Rd/Sec) transmitted by the probe. The value is important as it will affect the response and resolution of the measurements, the detail of the temperature changes, the time over which measurements are averaged, and the size of data files created. Graph rate is displayed and adjusted via the pull down selection menu at the top left of the screen (see Figure 3); the current value is also displayed at the bottom left of the screen. The instrument will measure and log temperature and photo diode current (light level) from one reading per minute (1/60) to 1,000 readings per second. The probes can make very fast measurements, however care must be exercised when many probes are used because very large files can be created quickly with fast graph rates and multiple probes. Even a fast PC can quickly become overwhelmed and lock up with multiple probes running at high speeds. Slower graph rates will also produce less noisy temperature readings.

4.5.2 Probe Setup Options: (The key to good measurements!)

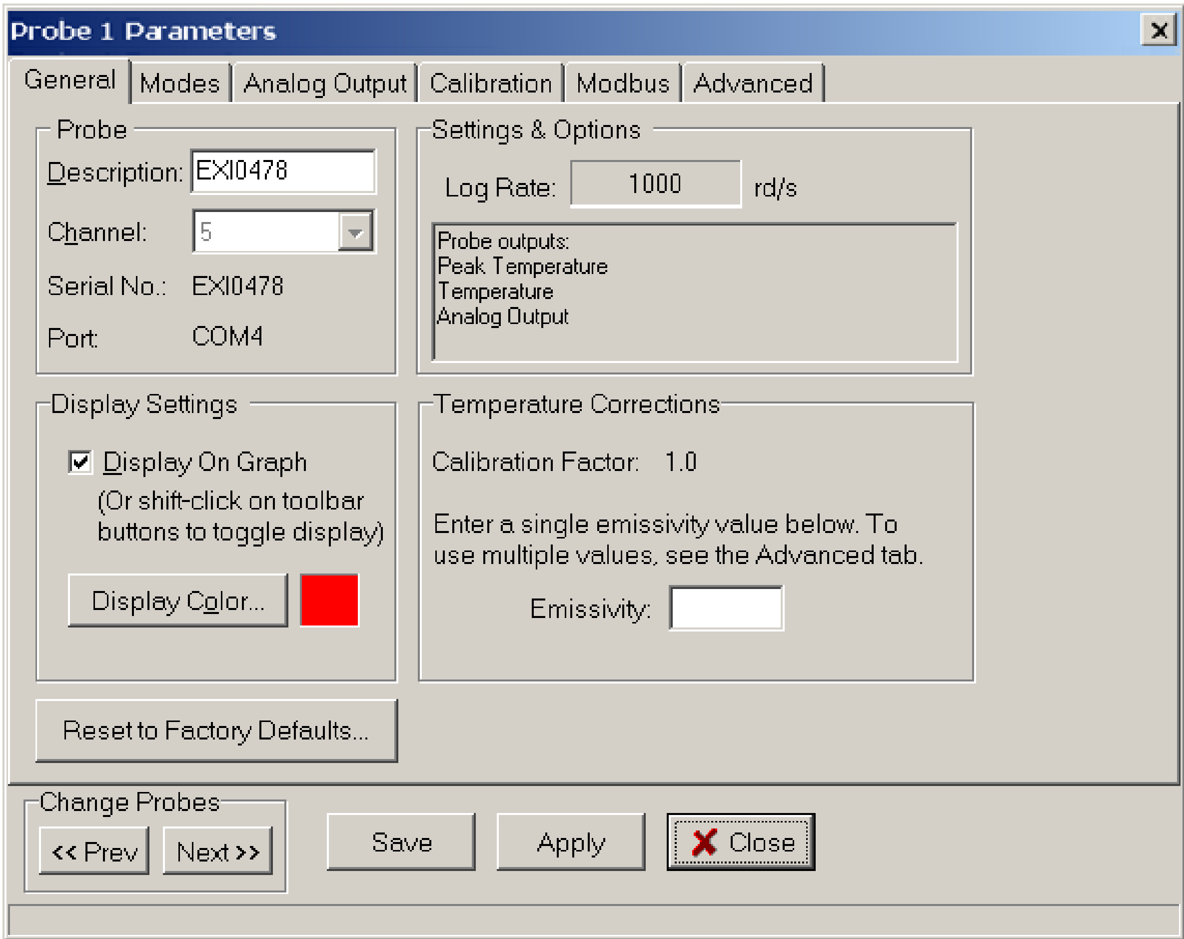


Figure 7: Probe Setup Window

All instrument settings, with the exception of "graph rate", can be edited using the Probe Parameters menu for the individual instrument. To access the Probe Parameters for a particular instrument, click on the number box above the instruments measurement display box, or choose **Options, Probe**. There are six tabs in the Probe Parameter Window; General, Modes, Analog Output, Calibration, Modbus, and Advanced. Each tab has a common area at the bottom which allows a user to select which probe they are viewing or editing via the Change Probes buttons, or either **Save** or **Apply** the probe settings.

Important Note: The difference between **Save** and **Apply** is important. **Apply** should be used for short-term changes or testing a change; **Save** should be done when the change is to be maintained for future measurements. Applied changes are lost whenever the probes are reset, TemperaSure is restarted, or power to the probe is lost.

> **Save:** Saving parameters stores values in the probes EEPROM (Electrically Erasable Programmable Read Only Memory), saved parameters will be the default parameters the next time the probes are power cycled or reset.

Apply: Applying parameters stores values in the probes RAM, these changes will be lost when the probe is power cycled or reset.

1) **General:** The General tab has four main sections.

- Probe: In the Probe section a user can rename a probe from its default serial number to something more meaningful for the process. The probe serial number, channel number, and COM port (if applicable) are also displayed in the Probe section.

- Settings and Options: Displays the current log rate, what data sets are being transmitted from the probe to the TemperaSure software, and whether the probe is configured to send updates to the analog output.

- Temperature Corrections: Displays the probe's calibration factor (relationship between light energy and temperature relative to its original calibration or to a factory standard; depending on the type of optics used) and provides a box for making a quick emissivity (or slope for a dual-wavelength instrument) adjustment. The emissivity or slope can be set to vary with measured temperature through the Advanced tab.

- Display Settings: The graph color for the probe can be changed and whether the probe is to be displayed on the graph or just stored can be selected.

2) **Modes:** The Exactus instrument can be configure for several different operating modes; please see Sections X.XX for details. Not all probes ship from the factory with these modes activated; please contact the factory for assistance if you are interested in activating these modes. Below is a brief description of the available modes:

- Peak Temperature: Outputs a calculated peak temperature. Once a lower threshold temperature is reached the probe will begin to seek a Peak measurement. When the lower threshold is reached, the peak measurement will be transmitted to TemperaSure and the analog output module. The peak will either be the highest value obtained or an average of the values measured between the leading edge and trailing edge threshold values. A number of points immediately following the leading threshold, or leading the threshold values may be ignored.

- Valley Temperature: Outputs a calculated valley temperature. The configuration parameters are similar to those of the Peak Temperature but the direction of the temperature change at the threshold value is reversed.

- Rising and Falling Plateau Temperatures: These values can be used to pick out events that occur during generally increasing or decreasing temperatures.

- Variance Mode: When Variance Mode is selected, the probe will calculate both the average and standard deviation of the temperature measurements within a user defined sample size. If a two channel analog output module is available, both of these values can be output to the module.

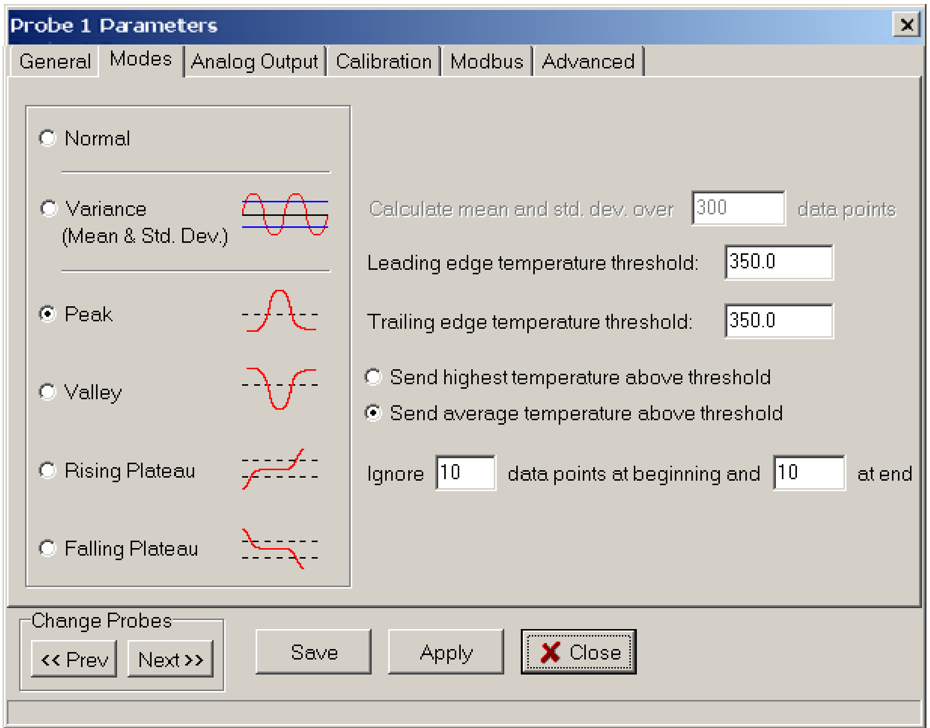


Figure 8: Modes menu

3) **Analog Output**: The Analog Output for each probe is also configured from the probe parameters. Users can activate the analog output, select whether the output is to be 0 – 10 VDC or 4 – 20mA, and set the minimum and maximum temperatures. The minimum and maximum temperatures can be any value within the calibrated range of the instrument.

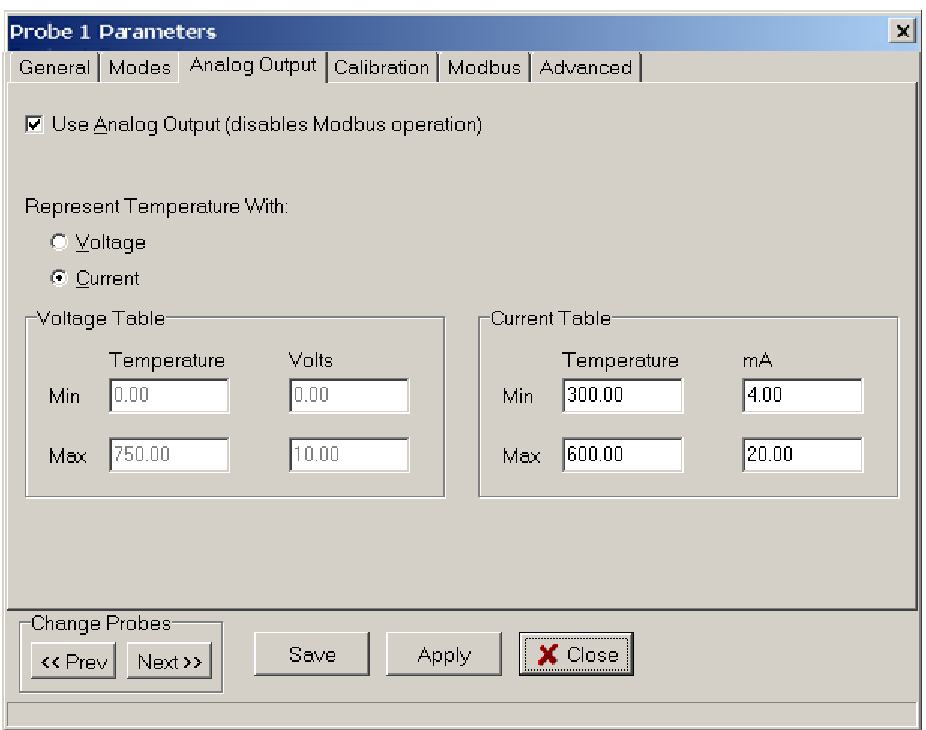


Figure 9: Analog output configuration menu

4) **Calibration:** The Calibration Tab is used to input the calibration factor or to calculate a new value. Great care is taken in generating the initial calibration of the Exactus instrument. We recommend discussing recalibration with the factory before proceeding. Place the lightpipe or lens so that it is looking at a very stable and well-known temperature target, preferably a blackbody. Then type the known temperature into the Desired Temperature box and click the Auto-Cal button followed by the OK button. (See Figure 10).

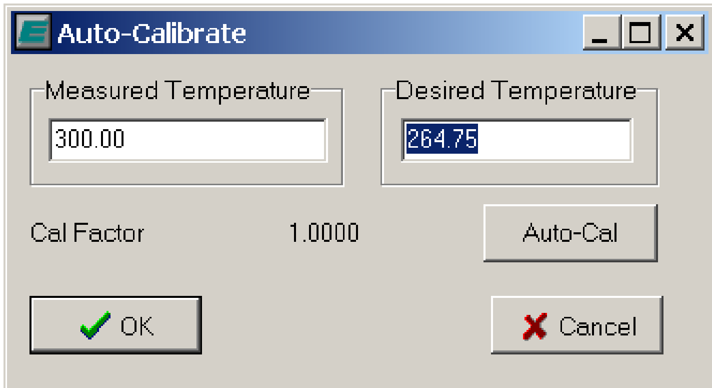


Figure 10: Auto-Calibrate menu.

5) **Modbus:** Use the modbus menu to assign a polling address. Please see Appendix X for information on communicating with the Exactus probe via Modbus.

6) **Advanced:** The Advanced tab has several unique features which are available exclusively in the Exactus instrument; please see Section 4.5.3 for details about this important configuration tab.

4.5.3 Advanced Features:

The advanced features in the Exactus instrument are designed to allow the user to correct and manage a variety of pyrometric measurement issues, including adjustment of emissivity or slope correction, signal averaging (**Averaging Buffer**) and heat transfer (**Transfer Function**). These features can also be entered in table form, with corresponding temperatures for each table entry, so the parameter will automatically adjust the target temperature changes. These features are set up for each instrument using the Advanced tab in the **Probe Parameters** menu**.**

Emissivity: This feature allows the user to type in a single emissivity value that will cover the entire measurement range, or enter a table of emissivity values and corresponding temperatures. Based on the entered table, the instrument will automatically adjust the emissivity as the temperature changes.

The table may include one row or as many as eight (8) rows to map emissivity verses temperature. The table can be edited, or rows can be added or deleted using the buttons below the table. Smaller values of emissivity will increase the temperature readings. An emissivity of 1.0 is used when the box above the table is not checked. By checking the **Hold** or **Extrapolate** buttons below the table, the user can select whether the emissivity will be held at the last entries or linearly extrapolated beyond the last entries; the user should verify the extrapolation makes physical sense (emissivity never greater than 1.0 or less than 0.0 within the temperature range of the instrument.

For more information on emissivity, please see glossary section 7, *Emissivity*)

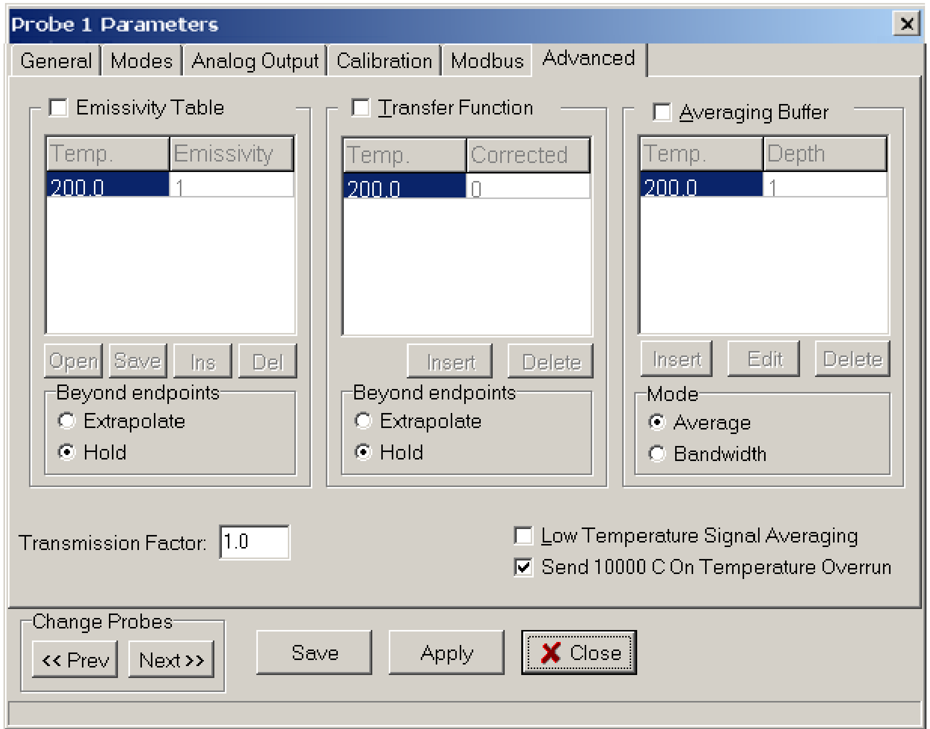


Figure 11: Advanced functions tab.

It is recommended that only small step changes in emissivity be entered. Entering more rows with smaller changes in temperature and emissivity will generally provide better results and less chance of errors.

Transfer Function: The Transfer Function table allows the user to force the temperature readings to agree with the values mapped into the table. The table can be edited, or rows can be added or deleted using the buttons below the table. This feature can be turned on or off by checking the box above the table.

The table may include one row or as many as eight (8) rows to map temperature corrections verses measured temperature. The table can be edited, or rows can be added or deleted using the buttons below the table. By checking the **Hold** or **Extrapolate** buttons below the table, the user can select whether the Transfer Function correction will be held at the last entries or linearly extrapolated beyond the last entries; the user should verify the extrapolation makes physical sense.

Averaging Buffer / Bandwidth Table:

The **Averaging Buffer** allows the user to average several raw readings into the temperature that is displayed and stored. If the values in the table are set to 1, or the check box enabling the feature is not checked, then there is no averaging. The number of data points averaged into a reading is in the right column of the Averaging table (marked Depth). Acceptable averaging values are selected by clicking **Insert**, entering a temperature in the temperature box and then selecting an averaging value from the pull down menu in the Depth Value box. The Averaging feature can be turned off by removing the check in the box above the table. The averaging depth will combine with the measurement rate to give the effective time over which the measurements will be averaged.

The most common use of the Averaging feature is to allow the instrument to run at higher measurement rates but average more points at lower temperatures to improve resolution at lower temperatures but maintain response speed at higher temperatures by averaging fewer readings, or no readings.

The **Bandwidth Table** can be used to force the instrument to operate at certain internal rates regardless of the measured temperature. Normally, the Exactus instrument will optimize the time it measures over to make the best use of its current measurement rate. In some applications, this may not be desirable. For example, if a user wishes to measure a temperature once per second, but utilize only the 10 msec of data prior to each sample, the can set the Bandwidth to 100 Hz. Acceptable values for Bandwidth settings are 1 Hz, 10 Hz, 100 Hz, and 1000 Hz. Similar to other advanced features, the Bandwidth can be programmed for different values at different temperatures.

Transmission Factor: This is an additional adjustment factor. Typically, the Transmission Factor is used to correct for viewport transmission. The Transmission Factor will have no affect on the measurement if one (1.0) is entered. The temperature will increase for values less than one.

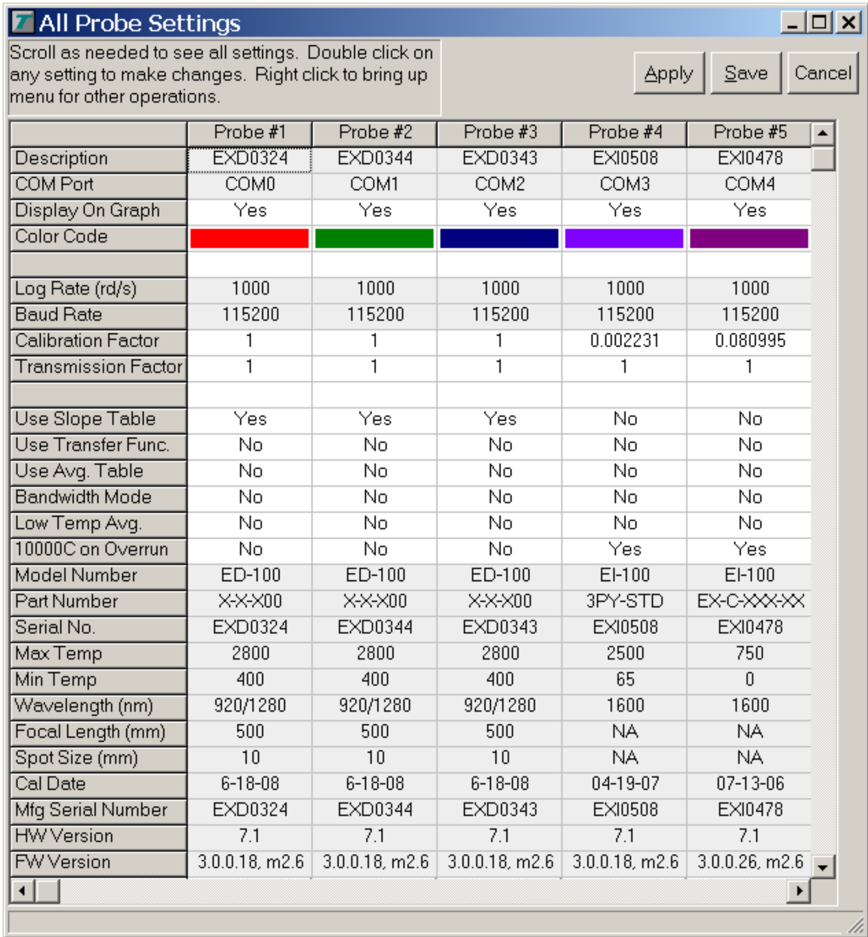
Low Temperature Signal Averaging: The bottom end of the temperature range for an Exactus instrument is usually the temperature at which the instrument will measure a blackbody with a resolution of 1.0ºC at one reading per second. If a user would like to measure at a higher measurement rate but still achieve maximum resolution the lower temperatures, they can select Low Temperature Signal Averaging. This feature will cause the instrument to automatically adjust its internal operating speed and repeat readings as the temperature decreases.

4.6 All Probes Settings

"All Probes" is found under the Options menu; this feature displays the settings of all the probes connected to the PC. All Probes allows the user to quickly check the setup parameters of multiple probes to confirm that all the settings are correct. See Figure 12: All Probes display

4.7 Analog Output - Setup

Analog Output is configured under each probe's setup. The analog output from each probe (channel) can be configured as a voltage or a current, 0 to 10 volts or 0 to 20mA. The minimum and maximum electrical values are entered, along with the corresponding minimum and maximum temperature values. These four numbers will scale the analog output. See Appendix 3 for more analog output details. See Figure 13: Analog Output Setup



	Probe #1	Probe #2	Probe #3	Probe #4	Probe #5
Description	EXD0324	EXD0344	EXD0343	EXI0508	EXI0478
COM Port	COM0	COM1	COM2	COM3	COM4
Display On Graph	Yes	Yes	Yes	Yes	Yes
Color Code					
Log Rate (rd/s)	1000	1000	1000	1000	1000
Baud Rate	115200	115200	115200	115200	115200
Calibration Factor	1	1	1	0.002231	0.080995
Transmission Factor	1	1	1	1	1
Use Slope Table	Yes	Yes	Yes	No	No
Use Transfer Func.	No	No	No	No	No
Use Avg. Table	No	No	No	No	No
Bandwidth Mode	No	No	No	No	No
Low Temp Avg.	No	No	No	No	No
10000C on Overrun	No	No	No	Yes	Yes
Model Number	ED-100	ED-100	ED-100	EI-100	EI-100
Part Number	X-X-X00	X-X-X00	X-X-X00	3PY-STD	EX-C-XXX-XX
Serial No.	EXD0324	EXD0344	EXD0343	EXI0508	EXI0478
Max Temp	2800	2800	2800	2500	750
Min Temp	400	400	400	65	0
Wavelength (nm)	920/1280	920/1280	920/1280	1600	1600
Focal Length (mm)	500	500	500	NA	NA
Spot Size (mm)	10	10	10	NA	NA
Cal Date	6-18-08	6-18-08	6-18-08	04-19-07	07-13-06
Mfg Serial Number	EXD0324	EXD0344	EXD0343	EXI0508	EXI0478
HW Version	7.1	7.1	7.1	7.1	7.1
FW Version	3.0.0.18, m2.6	3.0.0.18, m2.6	3.0.0.18, m2.6	3.0.0.18, m2.6	3.0.0.26, m2.6

Figure 12: All Probes display

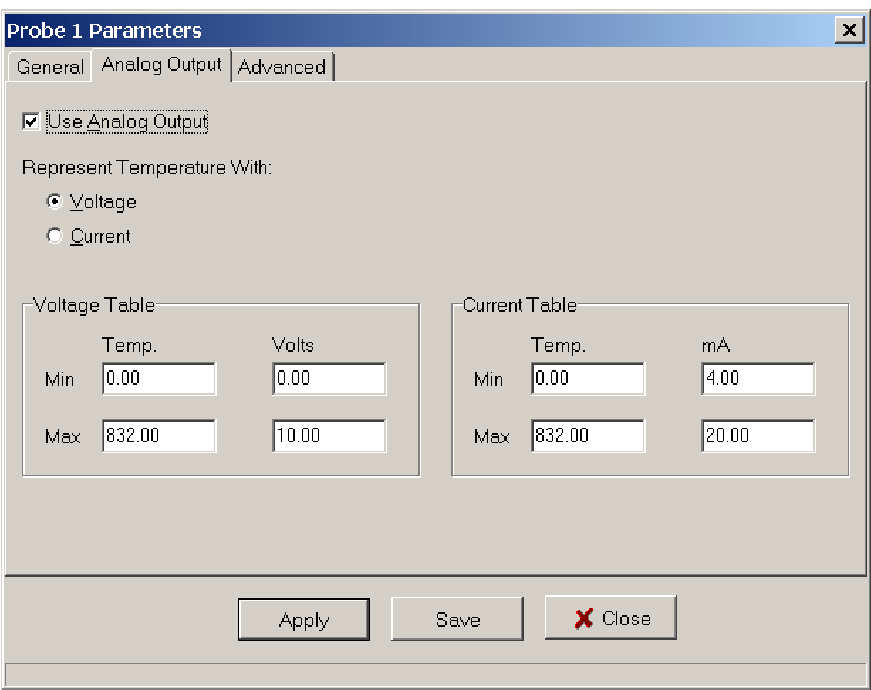


Figure 13: Analog Output Setup Window

4.8 Graph Setup

The graph option allows the user to display data in a wide range of styles and colors. The graphical interface can zoom in or out using either the +/- buttons or the zoom box accessible via a control-left-click and dragging the mouse. Very small temperature details can be seen using the zoom box feature.

The graphing capabilities of the TemperaSure software have been designed to be intuitive and easy to use. Some functions which may not be obvious include:

- **Zoom Box:** Position mouse over the data you wish to see and then press the control key and left-click and drag the mouse to size the zoom box. This function can be used repeatedly to obtain very high resolution displays of both temperature and time.
- **Dragging:** Left-click anywhere on the active graph to drag an image in order to locate desired data.
- **Vertical/Horizontal Scale:** A left-click on the edge of the graph will display a box to change that scale. Left-clicking on the vertical edge allows you to change the vertical scale and a left-click on the bottom horizontal scale displays a box to change the horizontal scale.
- **Annotation Box:** This feature allows the user to type into a text box at the bottom of the graph to describe the data or experiment. It can also be accessed by a left mouse click on the text box itself. Left-click on the Annotation Box to change the text.
- **Graph Options:** Right-click on the graph area to open an option box that allows changes to the display appearance. (Other graph options can be accessed through the Options menu at the top edge of TemperaSure.)

4.8.1 Graph rate

Logging rate is one of the most important selections in the user interface. Graph rate is set with the top tool bar window or under Options / Graph Setup, (Figure 4). The graph rate is also displayed at the lower left side of the user interface screen. It determines how many reading per second are logged and displayed. Slower graph rates will provide less noise at lower temperatures. While the system can log up to 1,000 readings per second, some older PC's may have trouble keeping up with fast probe output rates, especially with multiple probes running. BASF recommends maintaining relatively up to date computer systems; any computer manufactured within the previous 5 years should not present a problem. Select a log-rate that is fast enough for your process or needs yet creates files that are manageable in size. One probe running at a log rate of 1000 readings per second will generate an 80 megabyte file in just over 16 minutes.

4.9 Tips and Shortcuts

The TemperaSure software has some shortcuts available via the computer's mouse.

Dragging: Left-click the mouse and hold down to drag the graph.

Zooming: Hold the control key and left-click the mouse and drag to zoom into a box of detailed graphical data. Extreme precision can easily be obtained for both temperature and/or time.

Graph Scale Changes: Left-click the mouse on either the vertical or horizontal graph axis to open a Scale Limit Box.

Graph Format Changes: Right-click the mouse to edit the graph format, including: zoom, grid lines, and which variable (temperature or diode current) to display.

Probe Setup: Left-click the mouse on the probe number above the temperature box to adjust that probe's setup.

+/– Buttons: The +/– buttons on the top of the vertical scroll bar allow you to zoom in or out of the vertical data. The buttons to the left of the horizontal scroll bar allow you to zoom in or out of the horizontal data.

Annotation: This feature allows the user to type into a text box at the bottom of the graph to describe the data or experiment. It can also be accessed by a left mouse click on the text box itself.

Ambient Temperature of the Probe: This feature allows the users to see the temperature of the probe head. To view the probe's own electronics temperature, simply position the mouse cursor over the top of the digital temperature display box and the ambient temperature of that probe is shown. The ambient temperatures can also be logged to the saved files for later graphing with programs like Microsoft® Excel©.

4.9.1 Right-Click Menus

Right-clicking on the graph will give you the following options:

- **Find Data:** Finds the data, real time, and centers it in the graph. "Find Data" is like a beam finder on an oscilloscope. View auto-scales both time and temperature to place the data in view.
- **Zoom Vertical:** Allows you to change the temperature range on the vertical side of the graph.
- **Zoom Horizontal:** Allows you to change the current range on the horizontal side of the graph.
- **Undo Zoom:** Returns the graph to its previous horizontal and vertical scale.
- **Vertical Units:** Allows you to toggle the data between temperature and current.
- **Grid Lines:** Allow you to change your view of the graph to show either vertical, horizontal, both, or no grid lines.
- **Data Display:** Allows you to toggle between lines, markers, or both.

4.9.2 Opening a File with Microsoft® Excel© or Notepad©

To view a .txt file in Excel© or Notepad© simply open the file with these programs. When viewing with Notepad©, you can view or edit the data, however all of the headers may not line up correctly because the run files may be delimited differently.

5 Warnings

- Lightpipes are expensive and extremely fragile. Use care when handling.
- Lightpipes should always be kept clean and free from deposition. Sheaths are recommended to both prevent breakage and preserve cleanliness. Wearing clean gloves is recommended when handling lightpipes.
- Pyrometer lenses must be kept clean and free from scratches.
- Probe heads should never be exposed to temperatures over 60°C (158°F) or they will be damaged. If the application requires the probe to be exposed to temperatures above 60°C, please contact BASF Temperature Sensing customer support. BASF manufactures air-cooling assembles which protect the probes in high-temperature environments. The operating specification is 10°C to 60°C and up to 250ºC for the lens and fiber optic cable assembly.
- Never use the probe head without the interface box. The interface box isolates the probe from electrical noise.
- Make sure all data is saved before using Reset. The Reset feature of the TemperaSure software may cause loss of any unsaved data.
- Make sure all probe settings are saved to the probes before the system is powered off. The Apply button will not save the settings if power is turned off. Only the Save button will save probe settings under power cycling conditions.
- Be certain that you **Save** your data in either binary files (.bin) for reviewing with the TemperaSure software and that you **Export** data to text (.txt) files for use with other programs, like MS Excel.
- Be careful when selecting COM port(s). You may have COM port(s) that are connected to other hardware.
- The probe settings (Figure 5) greatly affect the temperature measurements. Read section 4.4 carefully or call BASF for assistance.
- Always check and test the analog output operation before it is connected to a furnace or other process equipment.
- If the equipment is not used in a manner consistent with manufacturer instructions/specifications, the protections provided by the equipment may be impaired.

BASF Temperature Sensing Customer Support:

Portland, OR (503) 794-4073

Fremont, CA (510) 490-2150

6 Troubleshooting

If you experience problems with the software or are obtaining unusual or unexpected data, please do the following:

- Try shutting down other programs on your PC or restart your PC.
- Try the steps outlined in 6.1.1 and 6.1.2 below.
- Try unplugging the cable(s) at the probe(s) and reconnecting the cable.
- Call Technical Support in Portland, OR at (503) 794-4073 or Fremont, CA at (510) 490-2150 for advice.

6.1 "No Probe" displayed in temperature display box.

If the software launches (comes up) but says **Offline or No Probe,** this probably means that the probe is not connected. If the probe **is** connected, however, do the following:

- Check the cabling. Be certain that the **probe, power supply** and **interface box** are all connected and fully plugged in.
- Is the green LED on the back of the probe lit? This indicates that the probe head has power.
- Is the green LED on the interface box lit? This indicates that the interface box has power.
- Check that the correct COM ports on the computer are being used. In the **Options** menu, select **Connections** to view which COM port(s) are available and which are checked.
- Try unplugging the cable(s) at the probe(s) or interface box and reconnecting the cable.
- If necessary, please contact BASF Temperature Sensing for additional help.

6.2 Data Does Not Agree With Expectations

The most common sources of measurement errors are listed below, in their approximate order of importance.

1. Incorrect calibration factor entered under probe setup.
2. Incorrect emissivity settings.
3. Background or scattered light entering into the collection optics.
4. Transmission of light (through the wafer or target object).
5. Changing emissivity of the object.
6. Dirty collection optics, deposition on the lightpipe.
7. Non uniform furnace.
8. Incorrect transfer function entered under probe setup.
9. Dirty viewport or incorrect transmission factor entered under probe setup.
10. Cracked or Broken lightpipes.

Every application has its own set of measurement challenges and problems so the order may vary depending on the application. BASF's technical support staff is available to help with these issues.

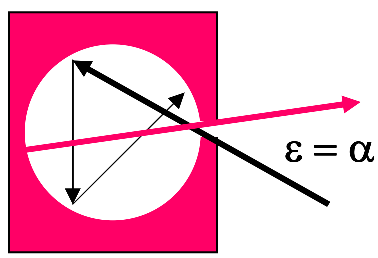
7 Glossary of Terms

Accuracy How well the measurements agree with standards. In temperature measurement, this is usually the agreement between the International Temperature Scale ITS-90 and the instrument. However in practice, it is usually the agreement between the instrument and whatever the manufacturer is using to calibrate the instrument. BASF uses the freeze points of pure metals, ITS-90 fixed temperature points, to calibrate its instruments. (See also ***Freeze Point Furnaces***).

Analog Output BASF offers an analog output module. The module takes the high speed digital probe signal and converts it to an analog signal which is linear with respect to measured temperature. The module is configured for either 0 to 10 volts or 0 to 20mA. This output can be scaled through the TemperaSure software. (See section 4.7 and Appendix 3 for configuration details.)

Bandwidth The response time of the electronics (also see ***Speed***).

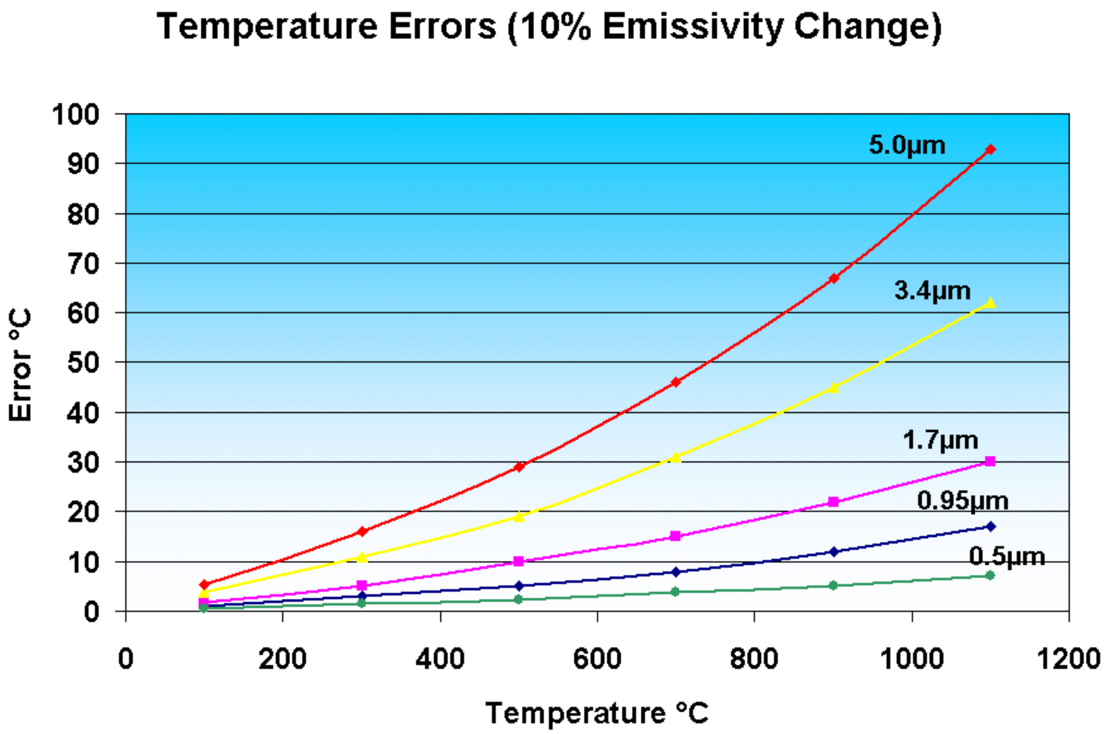
Blackbody A theoretical object that emits light perfectly, also known as "*the perfect emitter*". By definition, a blackbody has an emissivity of exactly one (1.0). A blackbody emits light solely as a function of its own temperature. The amount of light absorbed α equals the amount emitted ε for steady state (no change in temperature). An ideal blackbody absorbs 100% of the light impinging on it. (Also see ***Kirchhoff and Planck***).



Cross Section of a Blackbody Cavity

Emissivity The measure of how well an object emits light compared to a perfect blackbody. A blackbody has an emissivity of 1.0, and everything else, both real and theoretical, has an emissivity less than 1.0. Aluminum has a low emissivity because it only emits a small percentage of the amount of light that a blackbody would emit at the same temperature. Emissivity has many aspects because real objects emit light in very complex ways.

There are numerous parameters that define an object's emissivity in terms of how the light is emitted, including angle, wavelength, surface texture, thin films on the object, surfaces surroundings the object, material(s) that make up the object, and the object's own temperature. Using shorter wavelengths reduce these measurement errors as can be seen in the following graph.



Fiber Optic Cable A flexible cable usually made from quartz that transmits light from one point to another. In optical thermometry, optical cables are used to transmit light from the lightpipe or lens back to the electronics. Optical cables can lose much of the signal coming from the sensor and are sensitive to errors due to bending and micro-cracking. Errors can also occur at the connection ends of the cables. BASF's compact probe is small enough to be placed directly behind the collection optics in most applications, thus eliminating the need for these cables. BASF does manufacture high-performance flexible fiber optic cables for measurement applications where cables are needed.

Freeze Point Furnaces Carefully designed furnaces that hold a double walled, closed bottom graphite cylinder filled with ultra pure metal. The pure metal freezes at exactly the same temperature every time anywhere in the world. BASF uses five different freeze points to check and calibrate its instruments: Tin at 231.93°C, Zinc at 419.53°C, Aluminum at 660.32°C, Silver at 961.78°C and Copper at 1084.61°C (also see ***Accuracy*** and ***Repeatability***).

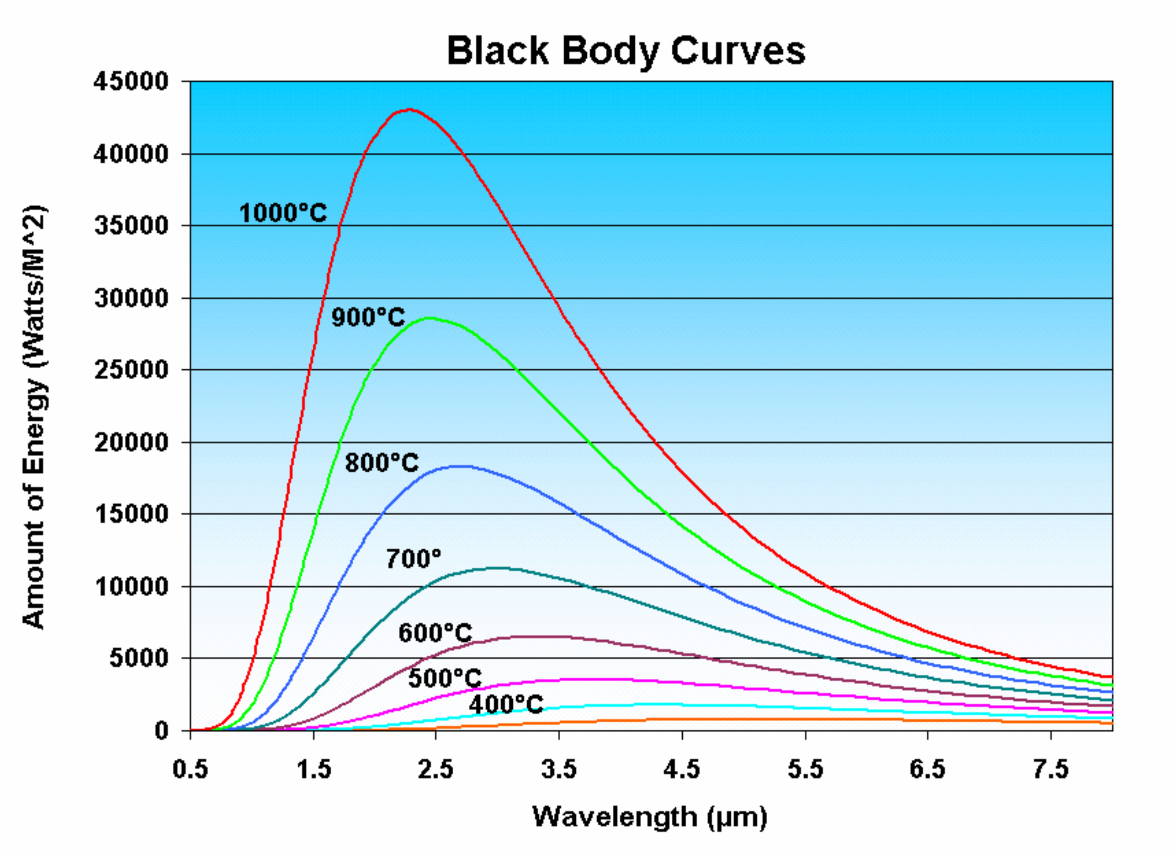
Interface Module The small box that connects the probe head to the power supply and the user's PC or host computer. Both single and multi channel versions are available. See section 2.3.

Kirchhoff, Gustav	Gustav Kirchhoff (1824–1887) developed the physics foundation for many of the concepts for which pyrometry and optical thermometry are based. He was the first to describe the blackbody in 1859-1860. Kirchhoff's Law correctly describes the way objects emit and reflect light as a function of angle and wavelength.
Lightpipe	A rod typically made from sapphire or quartz which acts as a guide to "pipe" light from a hot object back to a fiber optic cable or, in BASF's case, directly to the photo detector. BASF offers lightpipes in standard diameters of 2 mm, 3 mm, and 4 mm. Lengths are application specific, but generally range from a few centimeters to 1 meter.
Maximum Operating Temperature	The maximum temperature at which an instrument or sensor can be safely operated. A sapphire lightpipe can survive and measure temperatures up to about 1,900°C, while a lens assembly can measure temperatures up to and above 4,000°C. The electronics ambient operating range is 10°C to 60°C**.**
Melting Point	The temperature at which a substance transforms from a solid phase to a liquid phase. A high purity material melts at a known temperature and is often used as reference point.
Micron	One millionth of a meter, 10^{-6} meters, µm. Often used to describe the wavelength of light that is being measured. The human eye can see from about 0.38µm to 0.77µm. ***EXACTUS®*** instruments typically measure at longer wavelengths, from about 0.6µm to 2µm (also see ***Wavelength***).
Noise	An unwanted electrical interference to the signal. Noise can be expressed in terms of resolution (also see ***Resolution***).
Photo Diode Current	The electrical signal sent out by the photo diode. The smallest current the ***EXACTUS®*** instrument can resolve is about 10^{-15} amps, and the largest is about 10^{-3} amps, corresponding to the lowest and highest temperature measurable respectively. Looking at currents is often helpful in sorting out "true" emission from background light.
PID	Proportional, integral, derivative. A three-mode control action where the controller has time proportioning, integral (auto reset) and derivative rate action. Today there are more advanced control methods including adaptive and model based control.
Planck, Maxwell	Max Planck (1858–1947) was the physicist who first mathematically described the light emitted from a blackbody using the novel idea of the "Quanta". Planck was a student of Gustav Kirchhoff and a friend and colleague of Einstein. Planck received the Nobel Prize for Physics in 1918 for his ground breaking "*Planck's Radiation Equation*".

Planck Equation Written in December 1900 by Max Planck, who correctly described the amount of light emitted as a function of wavelength for a blackbody. It also was the start of the Quantum age because Planck used the new term Quanta in this revolutionary equation. Planck's theory was used by Einstein in 1905 to explain the photoelectric effect, and again in 1917 to understand the atomic level processes inside a blackbody cavity. The following equation was the beginning of what is known as modern physics:

$$M(\lambda,T) = \frac{\varepsilon C1}{\lambda^5 (e^{C2/\lambda T} - 1)} \quad \text{W/m3}$$

where M is spectral radiance (energy emitted), ε is the emissivity (equal to 1 for the blackbody), λ is the wavelength, T is temperature absolute, and C1 and C2 are the first and second radiation constants which are equal to 3.742×10^{-16} W• m2, and 1.4388×10^{-2}m• K, respectively. Planck's equation describes the blackbody emission curves below.



Power Supply The small transformer that converts 110v or 220v AC electrical power to the 12 volts DC use by the interface box and probe.

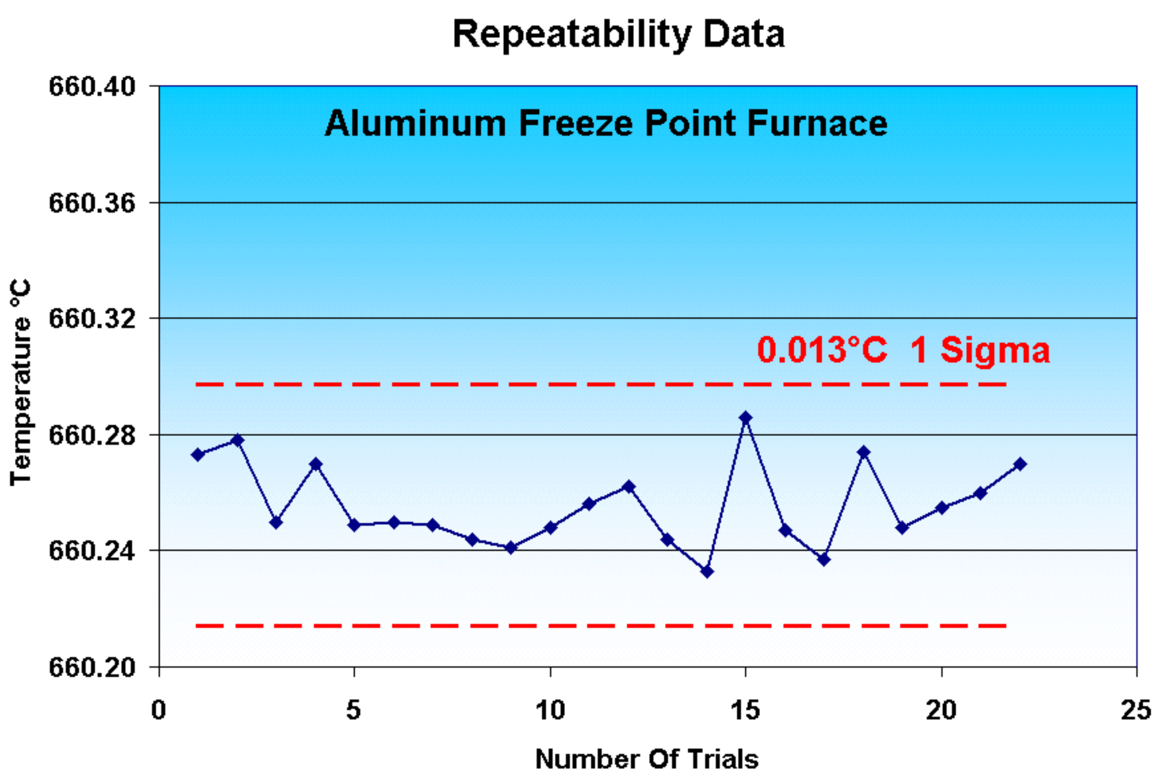
Probe A generic term that is used to describe many types of temperature sensors. BASF defines the optics, in combination with the stainless steel tube containing the electronics, as the probe or probe head.

Pyrometry The most common term used to describe temperature measurements based on the Planck Equation.

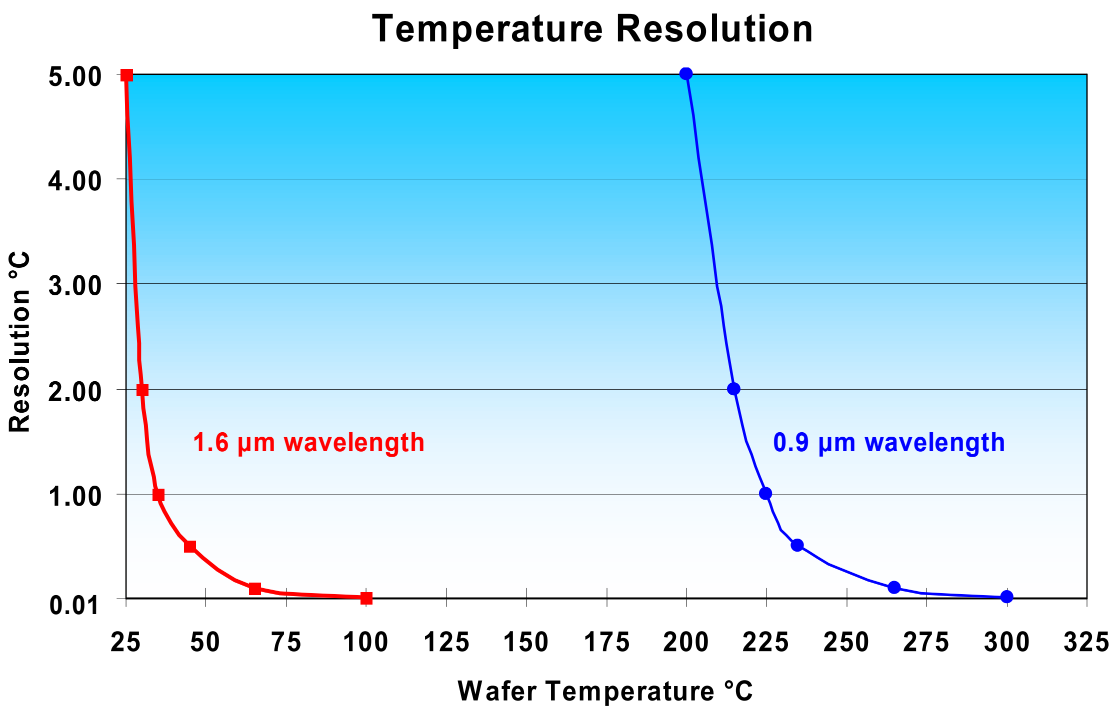
Range The extent of the instrument's ability to measure temperature. BASF has a number of temperature range options associated with different measurement wavelengths and optical sensor designs. Some of the basic ranges are:

- 25°C to 700°C using a lightpipe and 1.6µm measurement wavelength
- 200°C to 1,300° C using a lightpipe and 0.9µm wavelength.
- 65ºC to 1150ºC using a pyrometer and a 1.6um wavelength.
- 280ºC to 2200ºC using a pyrometer and a 0.9um wavelength.
- 120ºC to 3000ºC using a pyrometer and a 1.6um wavelength.
- 350ºC to 3000ºC using a pyrometer and a 0.9um wavelength.

Repeatability The ability to reproduce the same output readings when measuring the same temperature under ideal conditions. Repeatability is expressed as the maximum difference between output readings. The ***EXACTUS***® repeatability specification is 0.1°C maximum drift (change) per year. See graph below for actual data.



Resolution The smallest detectable increment of measurement. Resolution is usually limited by electrical noise and the number of bits of the Analog to Digital conversion. Resolution is always a function of the measurement speed (bandwidth) and the temperature being measured. Generally, the slower the measurement, the higher the resolution. Also the higher the temperature, the higher the resolution. BASF's resolution for two different wavelengths can be seen in the following graph. At temperatures above about 300°C the ***EXACTUS***® resolution is 0.001°C.



Sheaths Sapphire, quartz or metal tubes used to protect the costly and fragile lightpipes. BASF recommends using a sheath to protect the lightpipes from breakage and deposition. BASF offers a wide range of standard and custom sheaths, including gas-purged sheaths for deposition processes.

Speed The response time of the electronics (versus bandwidth, which is the "cutoff" frequency of the instrument). ***EXACTUS***® instruments can measure temperature from one reading per minute up to 1,000 readings per second. These discrete readings are transmitted digitally.

Thermocouple A temperature sensing device made from the junction of two dissimilar metals that have a voltage output proportional to the difference in temperature between the hot junction and the lead wires (cold junction). In 1822, Thomas Seebeck found that when two different metals were joined and heated, an electric potential was produced, known as the Seebeck emf. Seebeck's work directly lead George Ohm to the formulation of Ohm's law a few years later. BASF is the world leader in Platinum and other precious metal thermocouples.

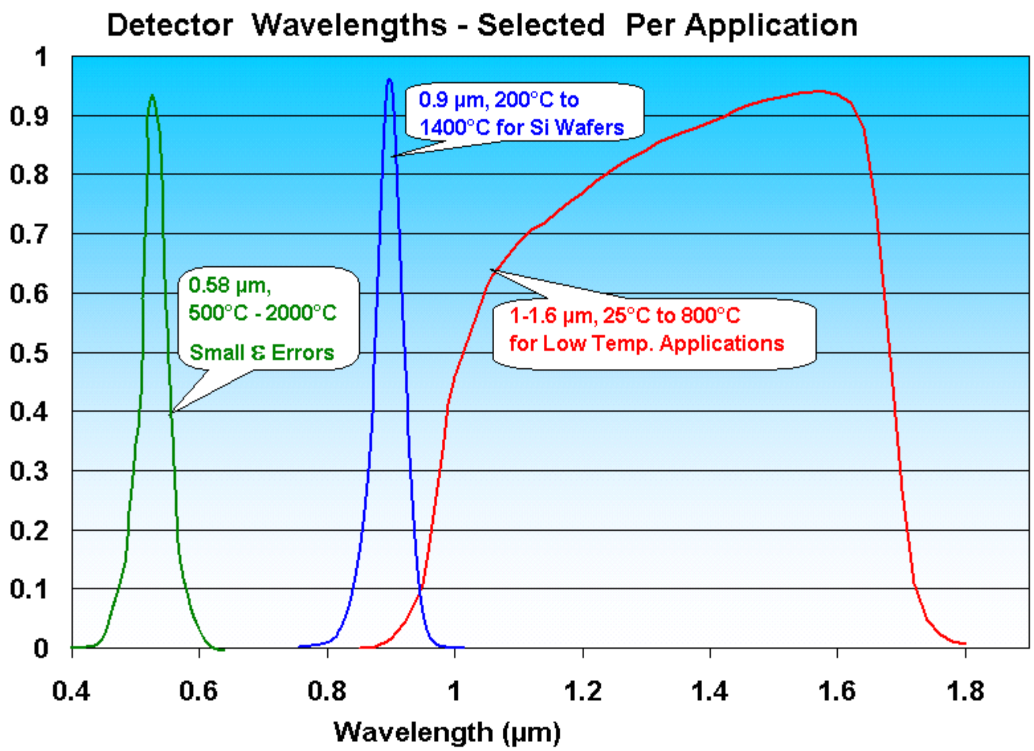
Transfer Function Found in the Probe Setup dialog box (**Setup, Probe…**) as an option under **Table Values**, this optional feature forces the probe to agree with values selected and entered by the user. When selected, the probe will read values other than the factory set calibration, so use with care.

Transmission The amount (percentage) of light that passes through an object such as a window, viewport or wafer. BASF recommends using quartz or sapphire viewports. BASF can calibrate probes to work with any viewport material chosen. (*Transmission Factor* can correct for viewport transmission losses.)

Transmission Factor This probe set-up feature allows the user to compensate for viewport absorption. The photodiode current is divided by the Transmission Factor value (0.001-100). The result is used to calculate temperature only, and does not change the measured photodiode current. The Transmission Factor feature can be used to correct for transmission losses that result from viewing through a viewport or other window. (See section 4.4 and **Transmission** above.)

User Interface Software A software program that allows the user to log and display temperature data. BASF's TemperaSure® user interface software can track and log data from up to 16 probes simultaneously. (see Section 4, Software Interface)

Wavelength The distance between two crests (peaks) of an electromagnetic light wave. BASF works with customers to select the best wavelength(s) for the specific measurement (See also ***Micron***).



Recommended References:
The most comprehensive coverage of the basic physics can be found in Theory and Practice of Radiation Thermometry, by David DeWitt and Gene Nutter, 1988 John Wiley & Sons.

The best coverage of wafer temperature measurement is found in Advances in Rapid Thermal and Integrated Processing, Chapters 2, 3 and 4, edited by F. Roozeboom, Kluwer Academic Publisher, the Netherlands, 1996.

8 Specifications

Key Performance Specifications

Sensor optics	Lightpipes and Lenses. Fiber optic cables available as required.
Wavelength	Tailored to application, 900nm, 1600nm, and 580nm. (See table below and Wavelength in glossary section).
Accuracy	± 1.5°C or 0.15% T. Traceable ITS-90 freeze points and PRT's. (See Freeze Points and Accuracy in glossary section).
Repeatability	± 0.10°C
Resolution	0.01°C (Decreasing near low end of temperature range. See Resolution graphs in glossary).
Speed	Up to 1,000 reading per second – user selectable. (Very low temperature measurements require slower reading rates)
Digital Output	RS 485 Full Duplex, RS 232
Analog Output (Optional)	User Configurable 0-10V, 4-20mA, 0-20mA
Ambient range	10°C to 60°C for Electronics
Dimensions	Lightpipe: 1.0" diameter x 4" length (25.4mm x 100mm) Pyrometer: 1.375" diameter x 7" length (35mm x 178mm). See Figures 15 & 16.
Weight	Lightpipe Probe 160 grams (5.6oz.). Lens Probe 375 grams (13.2oz.)
CE Mark	Fully certified.
Power	12-28VDC, 3W

Product Specific Performance

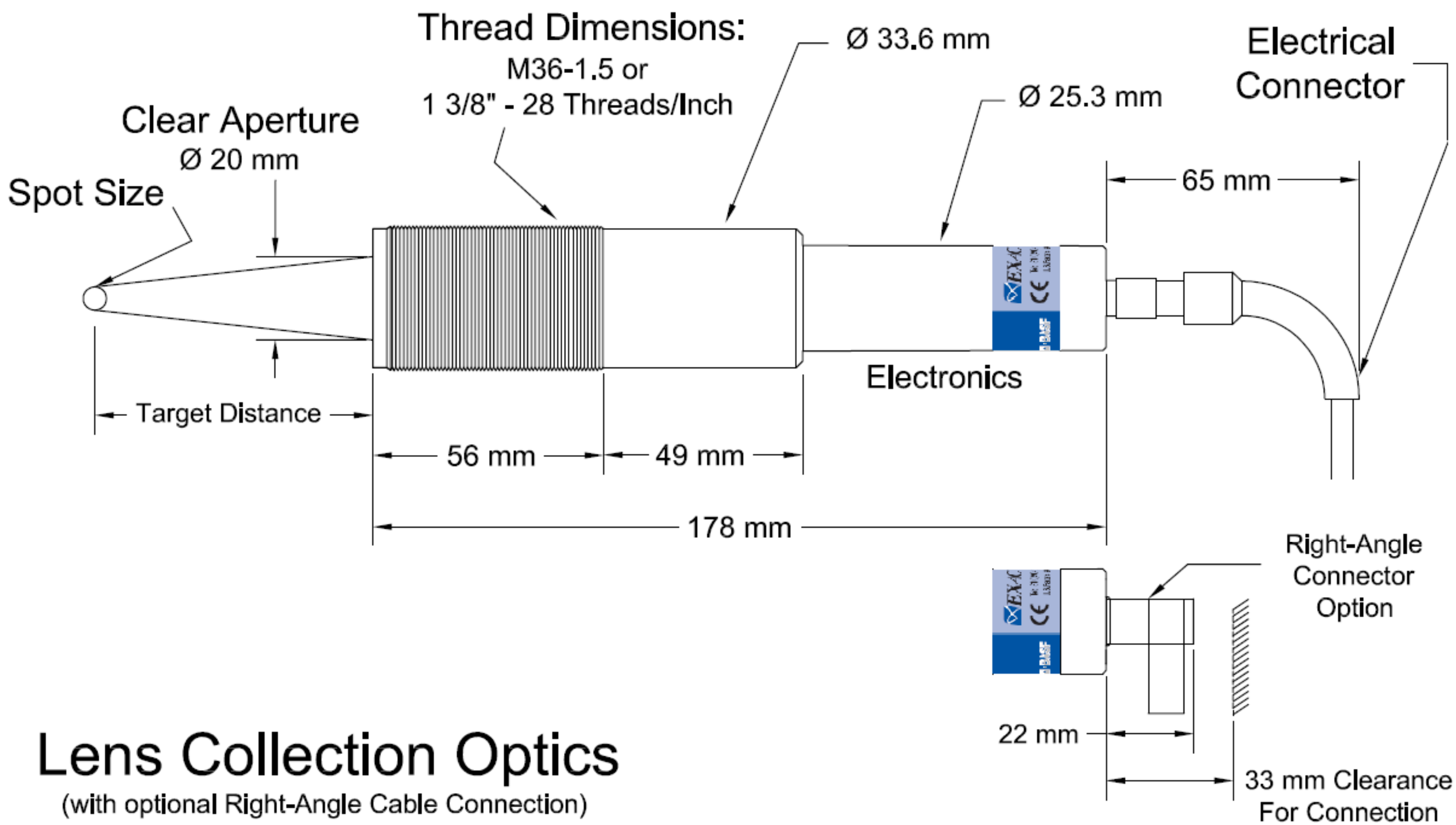
Temperature Range Table

	900nm		**1600nm**	
	Min.	**Max.**	**Min.**	**Max.**
Pyrometer Low Range	280°C	2250°C	65°C	1100°C
Pyrometer High Range	325°C	3000°C	125°C	2800°C
Lightpipe 2mm	220°C	1350°C	25°C	685°C
Lightpipe 3mm	215°C	1300°C	21°C	650°C
Lightpipe 4mm	210°C	1250°C	18°C	630°C

* Instrument temperature must be below target temperature.

This document contains specifications and information about a patent-pending product-line. BASF Catalysts, LLC reserves the right to change product specifications without notice.

Figure 14: Lens Collection Optics – Pyrometer



Lens Collection Optics

(with optional Right-Angle Cable Connection)

Typical Focal Lengths

100mm	300mm
150mm	500mm
200mm	1000mm

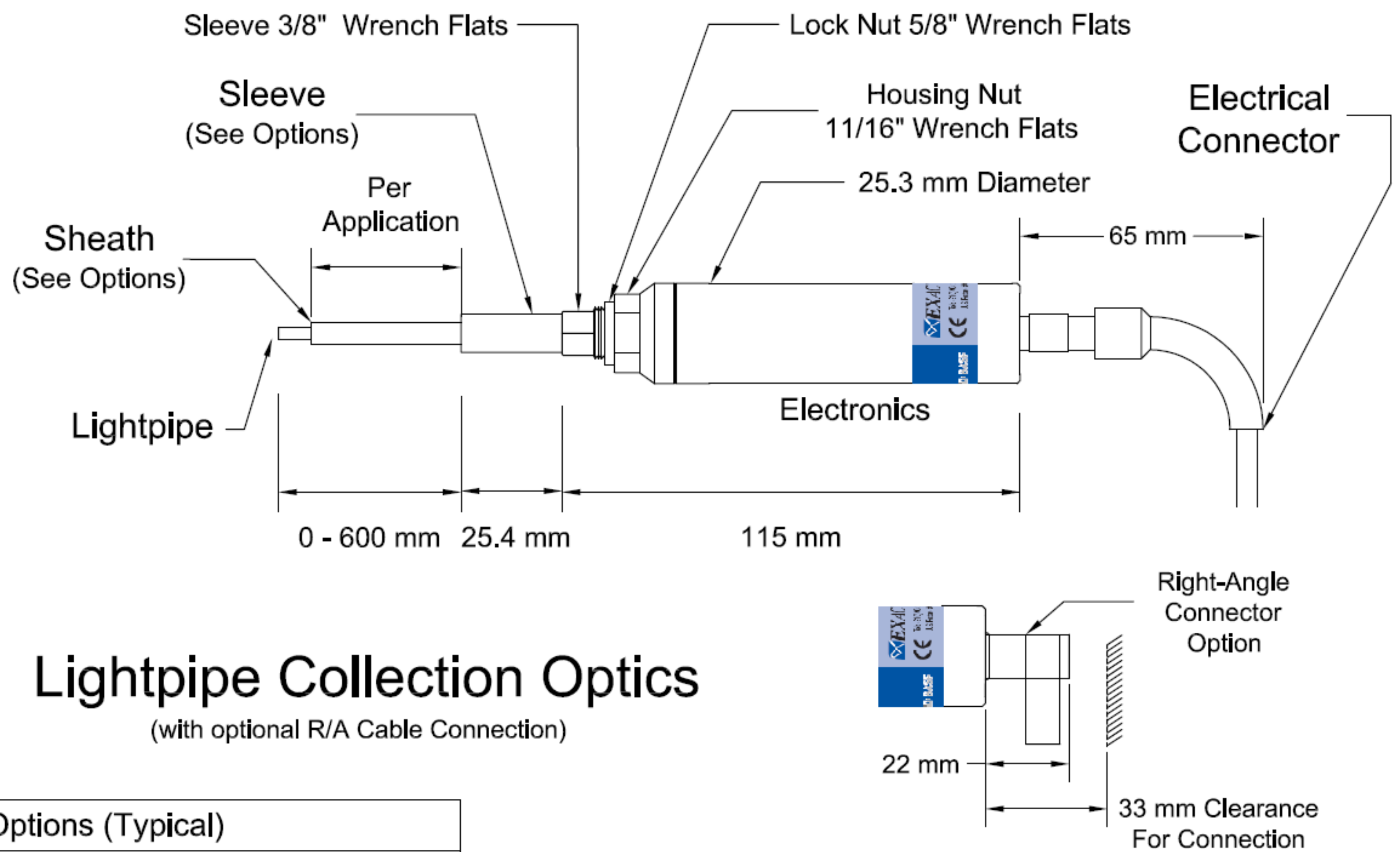
(Other focal fengths available upon request)

BASF

The Chemical Company

Temperature Sensing Products
Portland, Oregon Office: (503) 794-4073
Fremont, California Office (510) 490-2150

Figure 15: Probe with Lightpipe



Lightpipe Collection Optics

(with optional R/A Cable Connection)

Options (Typical)
Lightpipe: Diam 2,3, or 4mm std.
Sheath: Diam 4.5, 5.5, 6.5mm Material: Sapphire, Quartz, or Other
Sleeve: Diam 0.25", 0.375", 0.5" std. Material: Stainless, others available Gas Purge options available

Description: Probe with Lightpipe	
Drawing Owner: Jim Knope	Date: 2/14/08

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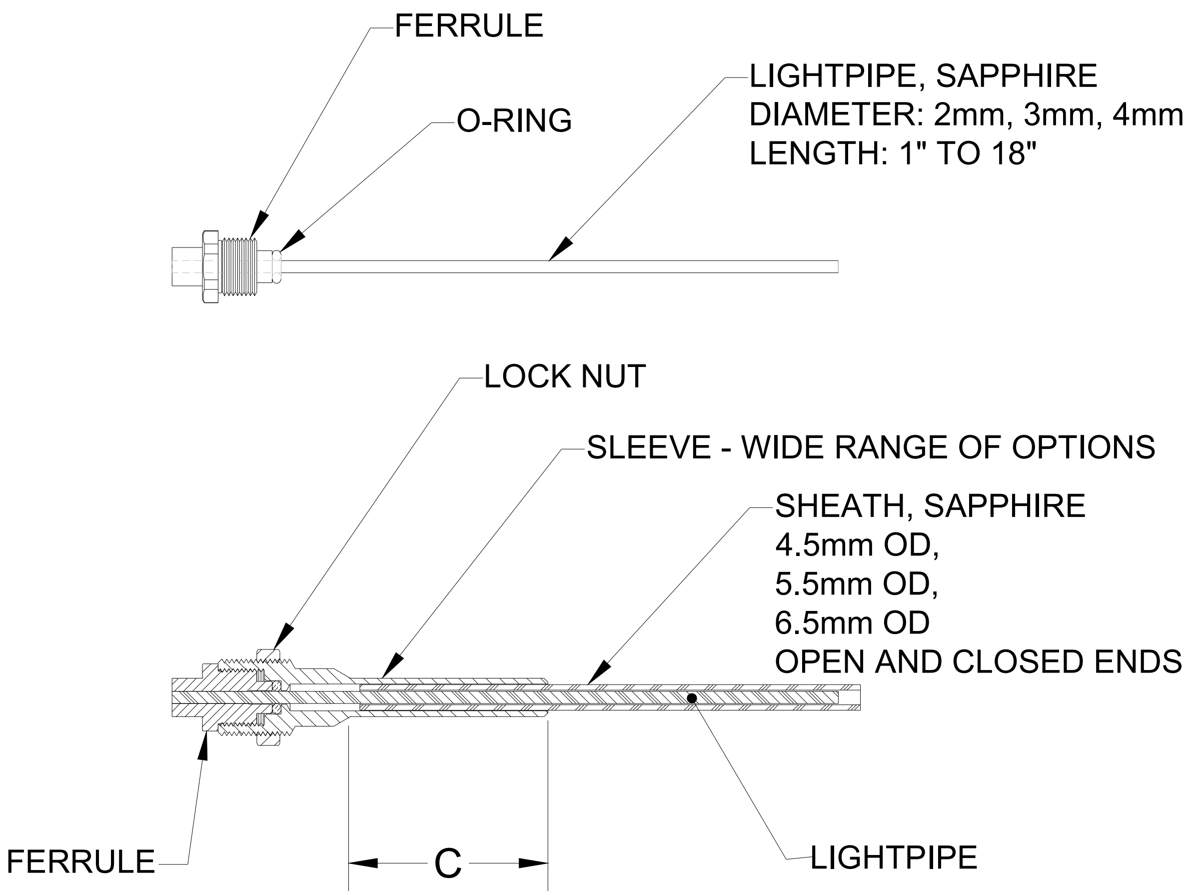
Figure 16: Lightpipe and Sleeve Detail



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Appendix 1 - Industrial Mux Guide

Introduction:

The Exactus® Industrial Mux is designed to provide data packaging, instrument monitoring, and (optionally) analog output for up to eight Exactus pyrometers. In most situations, the Industrial Mux can be connected and operate without any setup or configuration changes. Some of the features that can be programmed to the Industrial Mux include:

- Activation of the analog outputs.
- Activation of an instrument monitoring system which detects, and alarms, if any instrument should fail or otherwise stop communicating.
- Configuration of settings which will power down the pyrometer electronics, should their internal temperature become too high or too low.
- Adjustment of pyrometer voltage to compensate for excessive cable resistance **(only adjust after consulting with factory and if the pyrometer communication cable is longer than 15 meters).**

This guide is divided into sections which provide information on:

1. Default parameters
2. Communicating with the Exactus Industrial Mux
3. User Interface Menu
4. Alarm configuration
5. Wiring diagram for analog outputs

Default Parameters:

The Exactus Industrial Mux ships with the following default parameters:

- Analog output is enabled. Note: Not all Industrial Mux units will include analog outputs. Only those with the Model number IFM8-IA will include the analog output ports.
- Ambient alarm is set to power down <u>all</u> pyrometers when <u>any</u> pyrometer electronics temperature drops below 0ºC (32ºF) or goes above 75ºC (167ºF).
- The coil for Relay 1 is programmed to energize if the ambient temperature limits are exceeded. Pyrometers will remain powered down until power to the Industrial Mux is cycled off and back on.
- The Pyrometer Supply Voltage is set to 6200mV – adequate for standard pyrometer power/communication cables up to 15 meters (49 ft).

If these defaults are adequate, no further work is needed to configure the Industrial Mux.

Communicating with the Industrial Mux:

If communicating with the Industrial Mux is necessary, the easiest method is to use the HyperTerminal program included within Microsoft® Windows. The following instructions are written for Windows XP, similar steps can be used for other versions of Windows.

1. Connect a CAT5 cable to either of the ports LAN1 or LAN2 and to an Ethernet input on the computer. The cable can be of any LAN type.
2. Set the IP address of the PC:

a. Right-click on My Network Places and choose 'Properties' from the pop-up menu. See Figure A-1.

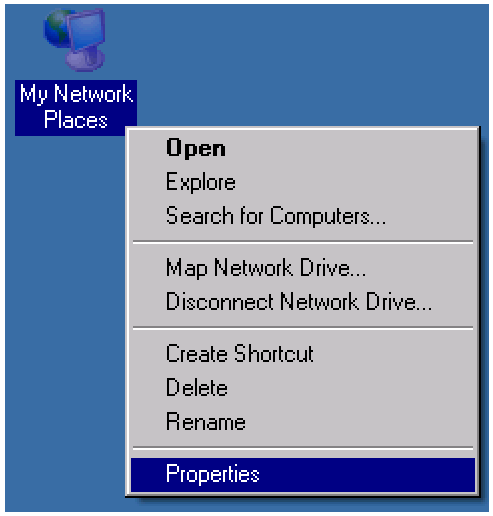


Figure A-1: Selecting Properties of My Network Places

b. Double-click on the connection. If there is more than one connection, you can determine which connection to use by unplugging the LAN cable from the Mux, and the Status will change to "Network Cable Unplugged". See Figure A-2.

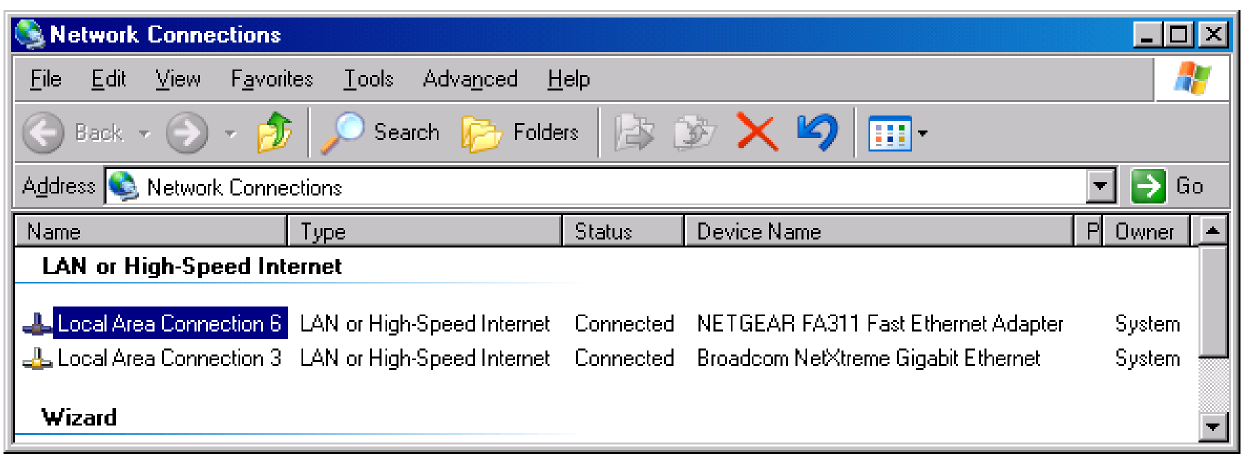


Figure A-2: Network Connections Screen

c. The following screen (Figure A-3) will appear, click the 'Properties' button.

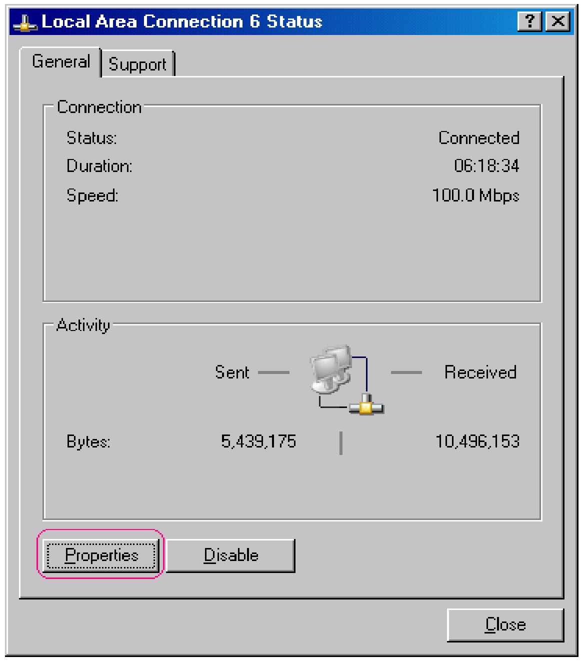


Figure A-3:

d. Double-click the ;Internet Protocol (TCP/IP); line (Figure A-4), this will bring up the screen shown in Figure A-5:

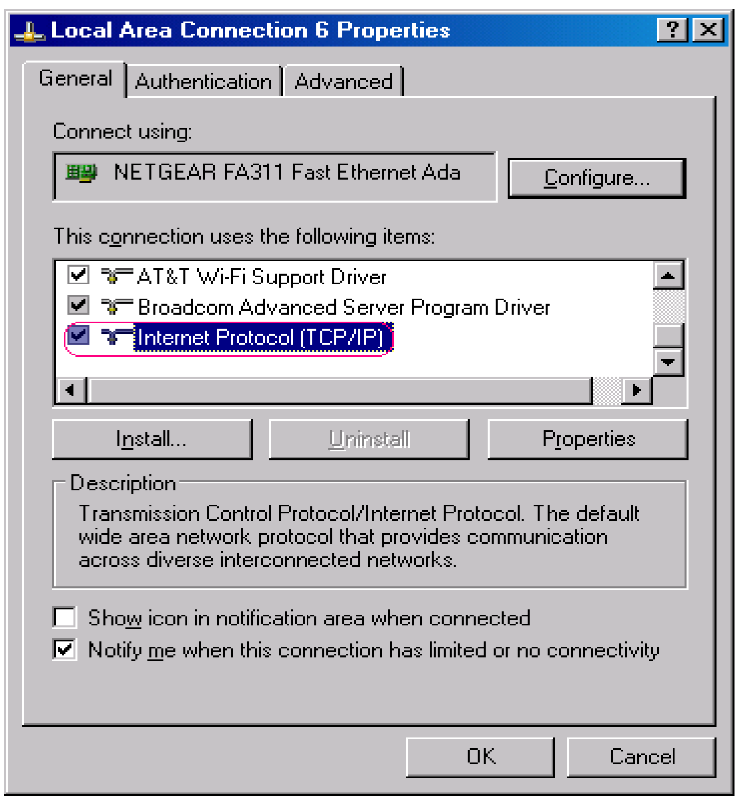


Figure A-4:

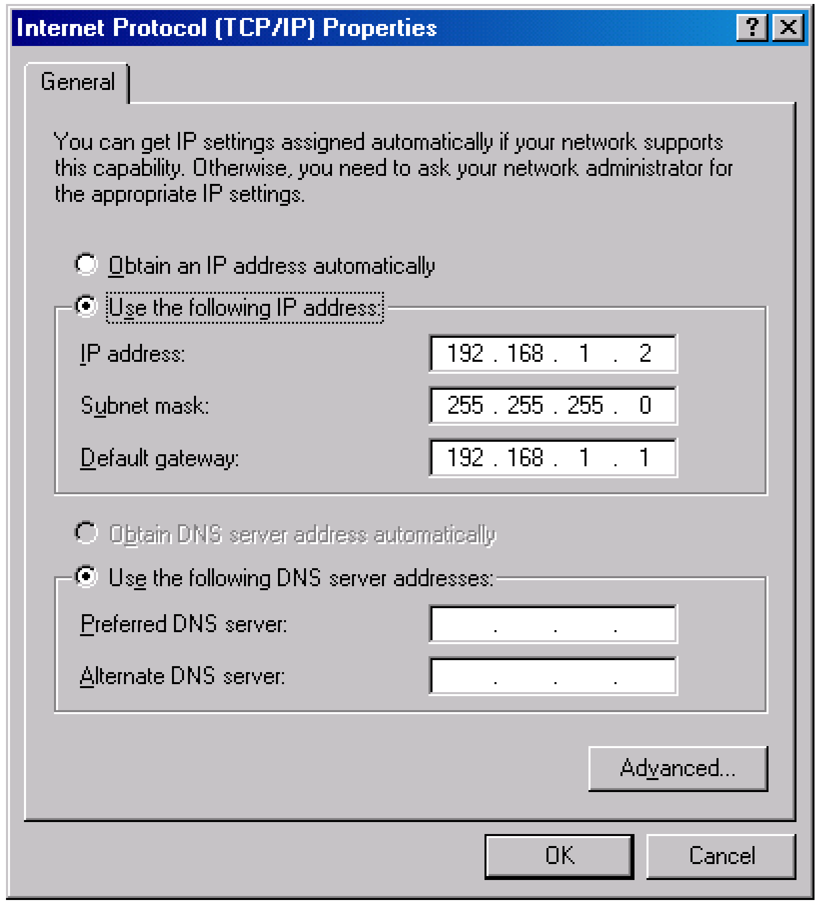


Figure A-5:

e. Click on the radio button 'Use the following IP address' and then set the IP address using the following rules:

   i. The first 3 numbers of both the IP address and the Default Gateway must agree with the first three numbers of the Mux's address (Default Address = 192.168.1.80).

   ii. The last number of the IP address must not be the last number of the Industrial Mux (e.g. if the Default Address is used, this would be '80').

   iii. The last number of the Default Gateway must be 1.

   iv. The Subnet Mast must be 255.255.255.0 as shown above.

f. Click OK on all the dialog boxes that are up. Eventually, the Network Connections dialog (shown in Figure 2) will report that the Status is 'Connected'.

3. Configure the Mux using Windows HyperTerminal

   a. Launch Windows HyperTerminal. You should be able to access it using the path shown in Figure A-6.

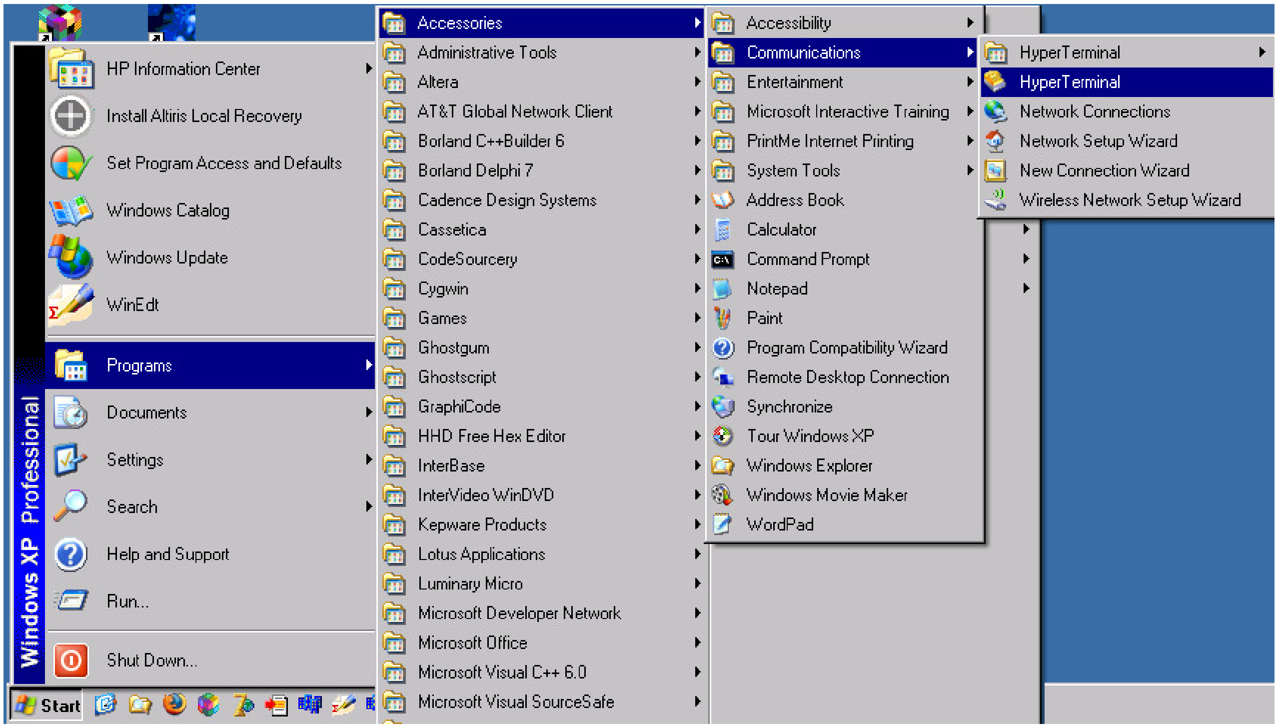


Figure A-6:

b. Choose a name (such as i-MUX) and an icon as shown in Figure A-7 and click OK.

Figure A-7:

c. Select the 'TCP/IP (Winsock)' option from the "Connect using:" drop-down box, then enter the Mux's IP address and click "OK" (See Figure A-8):

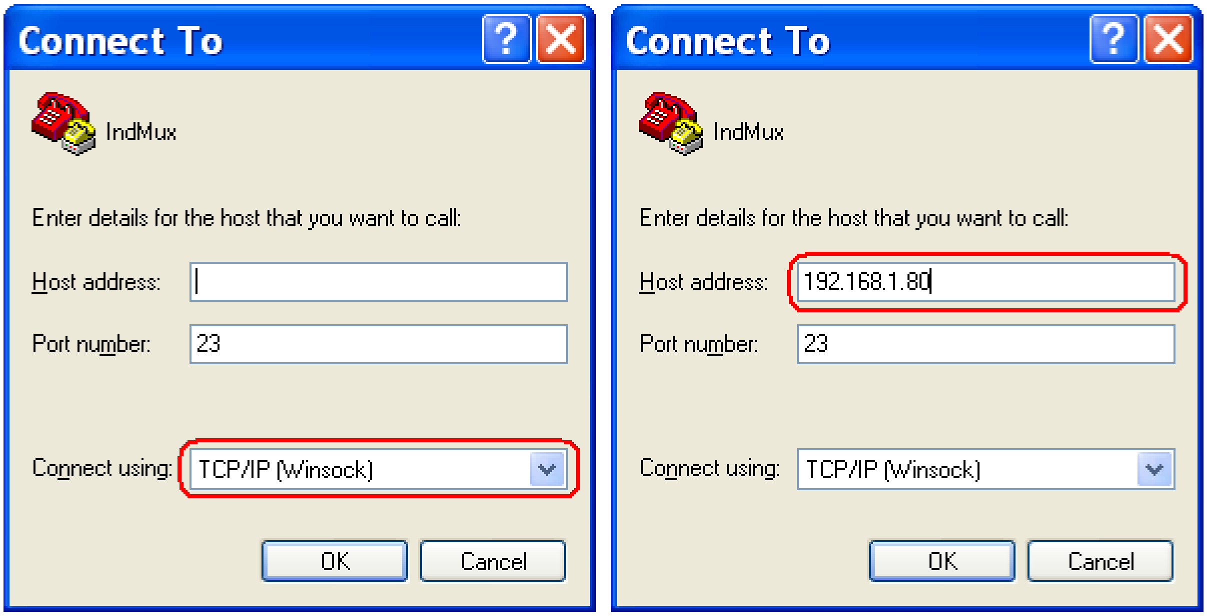


Figure A-8:

d. When you hit the OK buttons, you should get the menu shown in Figure A-9:

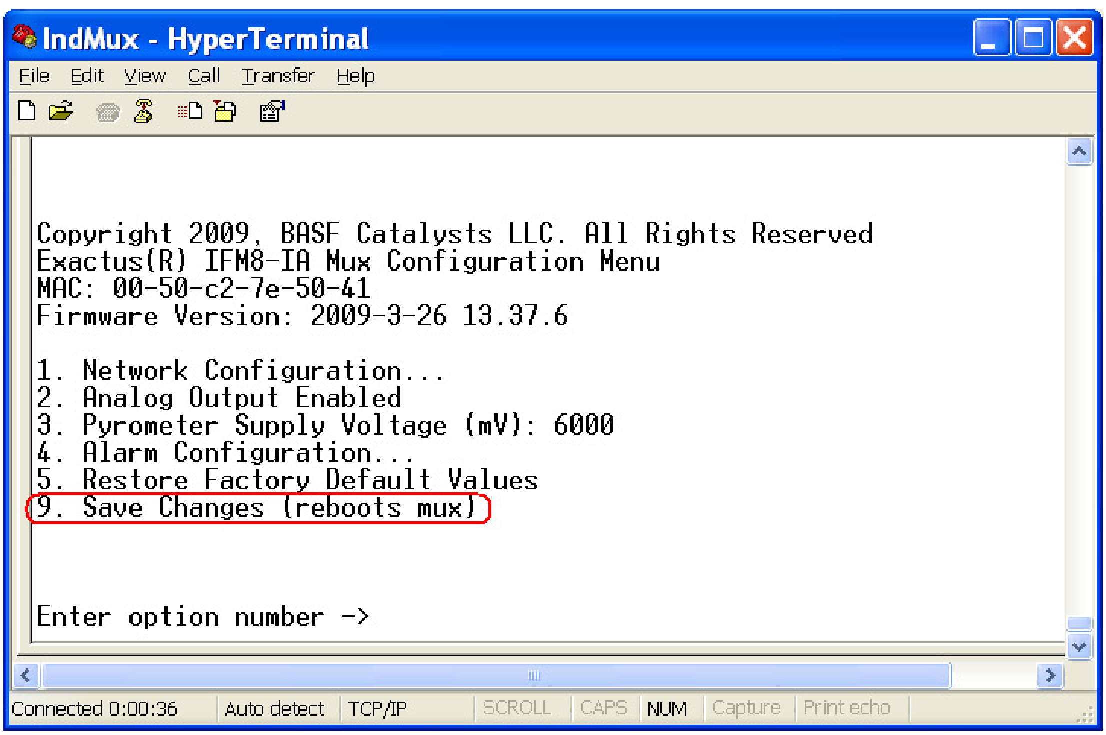
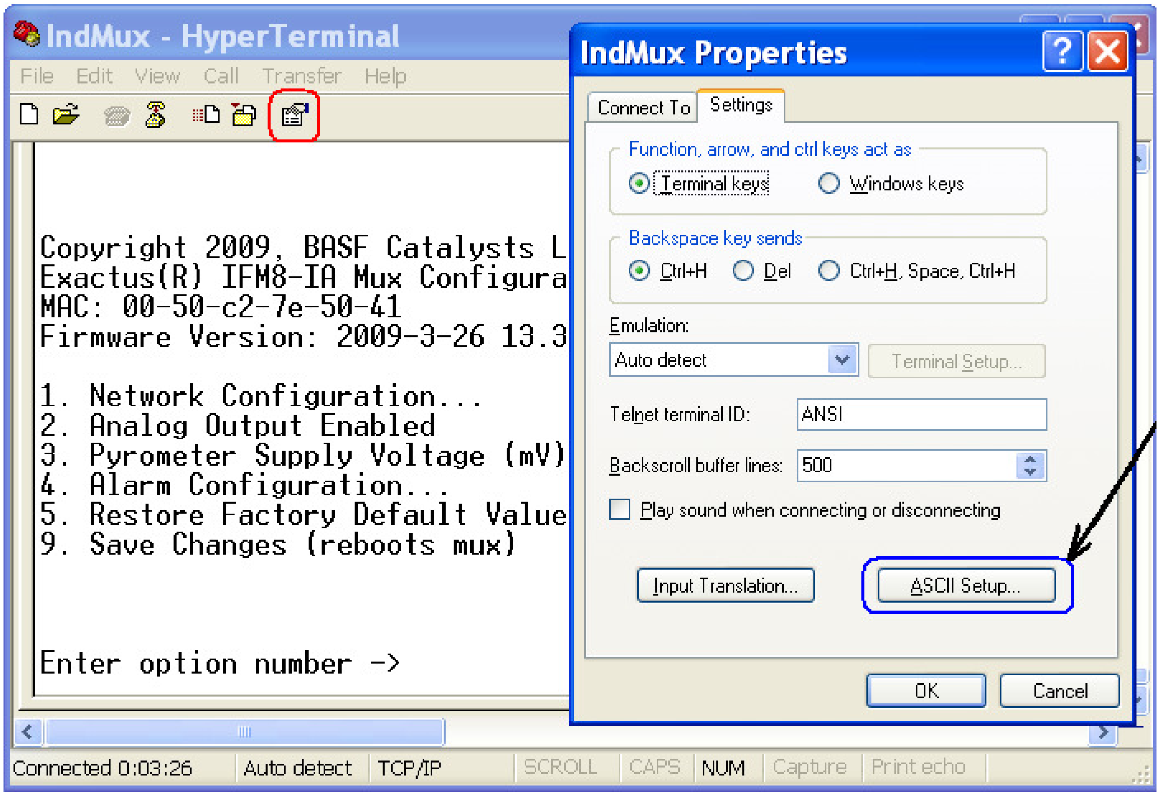


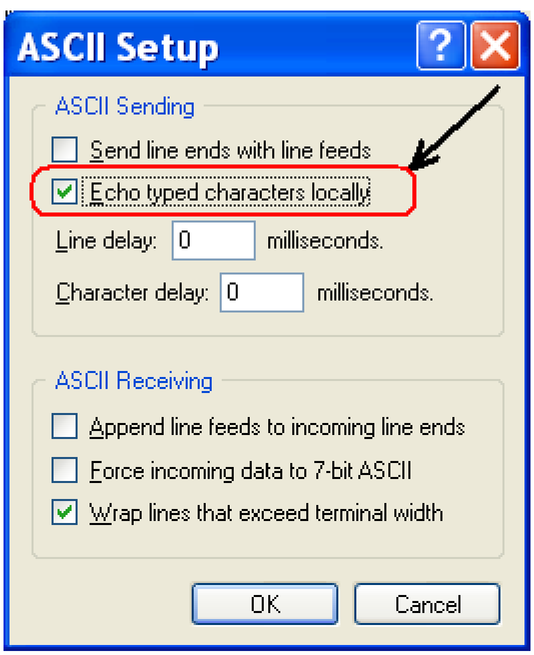
Figure A-9:

e. After you make changes to the Industrial Mux configuration, be sure the select '9. Save Changes'. As noted, this will reboot the Industrial Mux.

f. HyperTerminal may not automatically display user keystrokes to the screen. To turn on the echo feature, press the "Properties" button (circled in **red** in Figure A-10 below), and select the Settings Tab and press the "ASCII Setup... button" (circled in blue in Figure A-10 below) and then select the radio button for "Echo typed characters locally":



Check the "Echo typed characters locally" check box and close the dialog windows.



Figures A-10 and A-11

User Interface Menu:

The User Interface Menu is shown in Figure A-9 above. Below is a description of each menu item:

- Network Configuration: Used to set the IP address and other network parameters of the Industrial Mux. This selection is only needed for configuring over a particular network, if you are only connecting to a single computer, this feature is not needed. Figure A-12 shows the Network Configuration sub-menu.

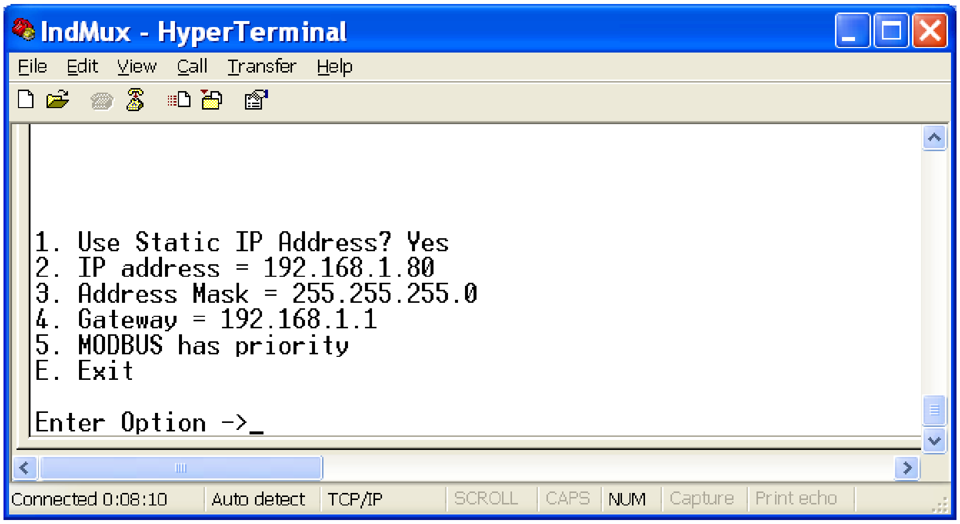


Figure A-12: Network Configuration sub-menu

- Analog Output Enabled / Disabled: This shows the current status of the Analog Output. If Analog Output Enabled (Factory Default) is displayed, than the outputs are currently Enabled.
- Pyrometer Supply Voltage (mV): This is the voltage that supplies power to each Exactus pyrometer. Please consult with the factory before adjusting this value; otherwise it should be left at the default value of 6000mV (suitable for pyrometer power/communications cables up to 15 meters long).
- Alarm Configuration: Used to configure the alarms for individual pyrometers. More detail is provided in the following section.
- Factory Defaults: Restores all settings to the Factory Defaults but you must follow this with Save Changes.
- Save Changes: Saves all settings to their current values and reboots the Industrial Mux. After saving, a message will be displayed saying ‘rebooting’. You may now end the HyperTerminal session. If more changes are needed, you will have to click the disconnect icon followed by the connect icon to reestablish the connection; these icons are located at the top of the HyperTerminal display.

Options for Alarm Configuration:

Selecting Alarm Configuration from the User Interface Menu will bring up the Alarms menu, shown in Figure A-14. Selecting option one brings up the Pyrometer Ambient configuration setup screen shown in Figure A-14; this screen allows a user to define the allowable ambient operating temperatures for individual pyrometers. Alarm temperatures can be individually configured for each pyrometer, as can the action which will occur should the pyrometer’s ambient temperature goes outside the allowable range. When the Powerdown option is chosen for an instrument, and the condition occurs, all pyrometers connected to the Industrial Mux will be powered off. The user must cycle the power to the Mux in order to reset the pyrometers.

Depending on the operating speed of the pyrometer, and other environmental factors, the measured temperature of the electronics can be 5 to 12ºC above the actual ambient air temperature. The submenu for each pyrometer configuration is self-explanatory.

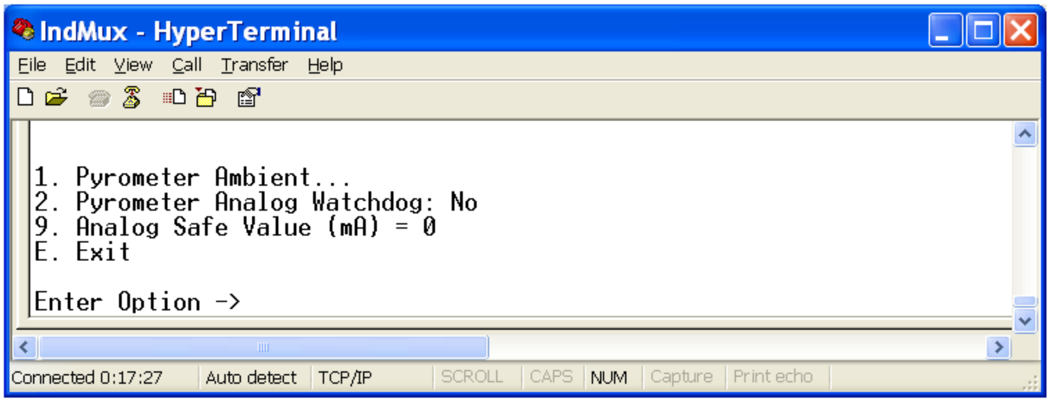


Figure A-13: Alarm configuration menu

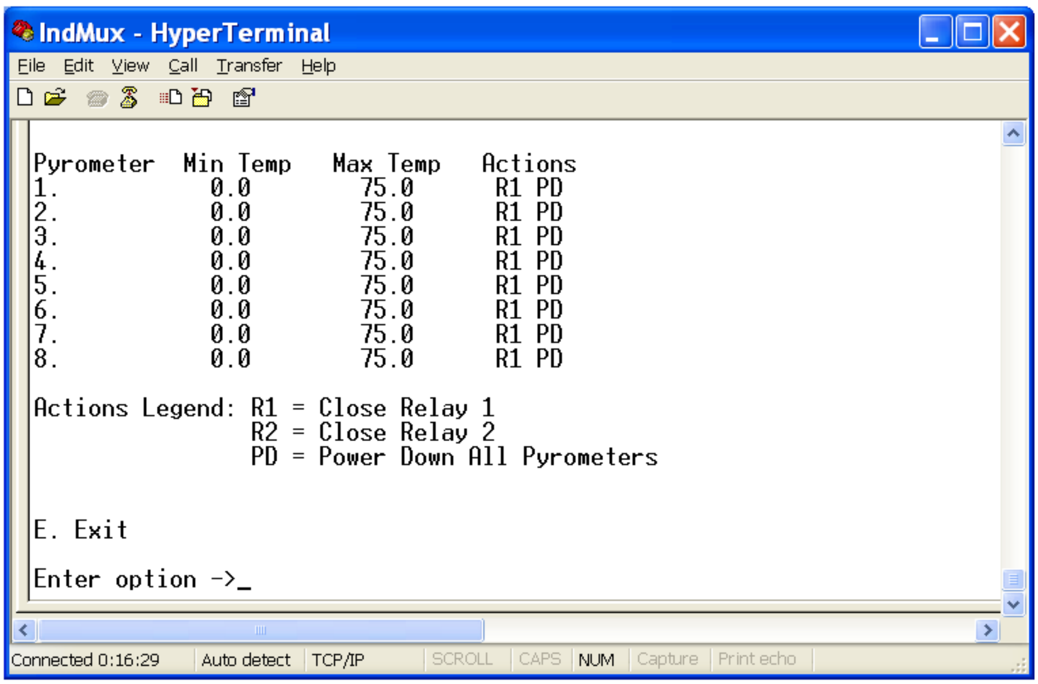


Figure A-14: Instrument Ambient Configuration Menu

Pyrometer Analog Watchdog: If the Pyrometer Analog Watchdog is activated, the Industrial Mux will watch for missed readings from the pyrometer, an indication that the pyrometer has failed in some way. If missed readings occur, the analog output will be forced to the Analog Safe Value and, if programmed to do so, energize one of the relays. When the Pyrometer Analog Watchdog (Item 2 in Figure A-13) is enabled, then item "3. Pyrometer Watchdog Alarm Configuration...." appears, offering a self-explanatory submenu for setting the watchdog alarm configuration.

Analog Safe Value: This is the milliamp output that the analog outputs should go to if there is a failure with one of the pyrometers.

Analog Output Wiring:

The analog outputs for the Exactus Industrial Mux do not generate a voltage to drive the analog output and must receive the voltage externally. Many data logging systems are configured to supply this voltage; if yours is not, you can use the same power supply driving the Industrial Mux to provide the power. This is outlined in the schematic shown in Figure A-14:

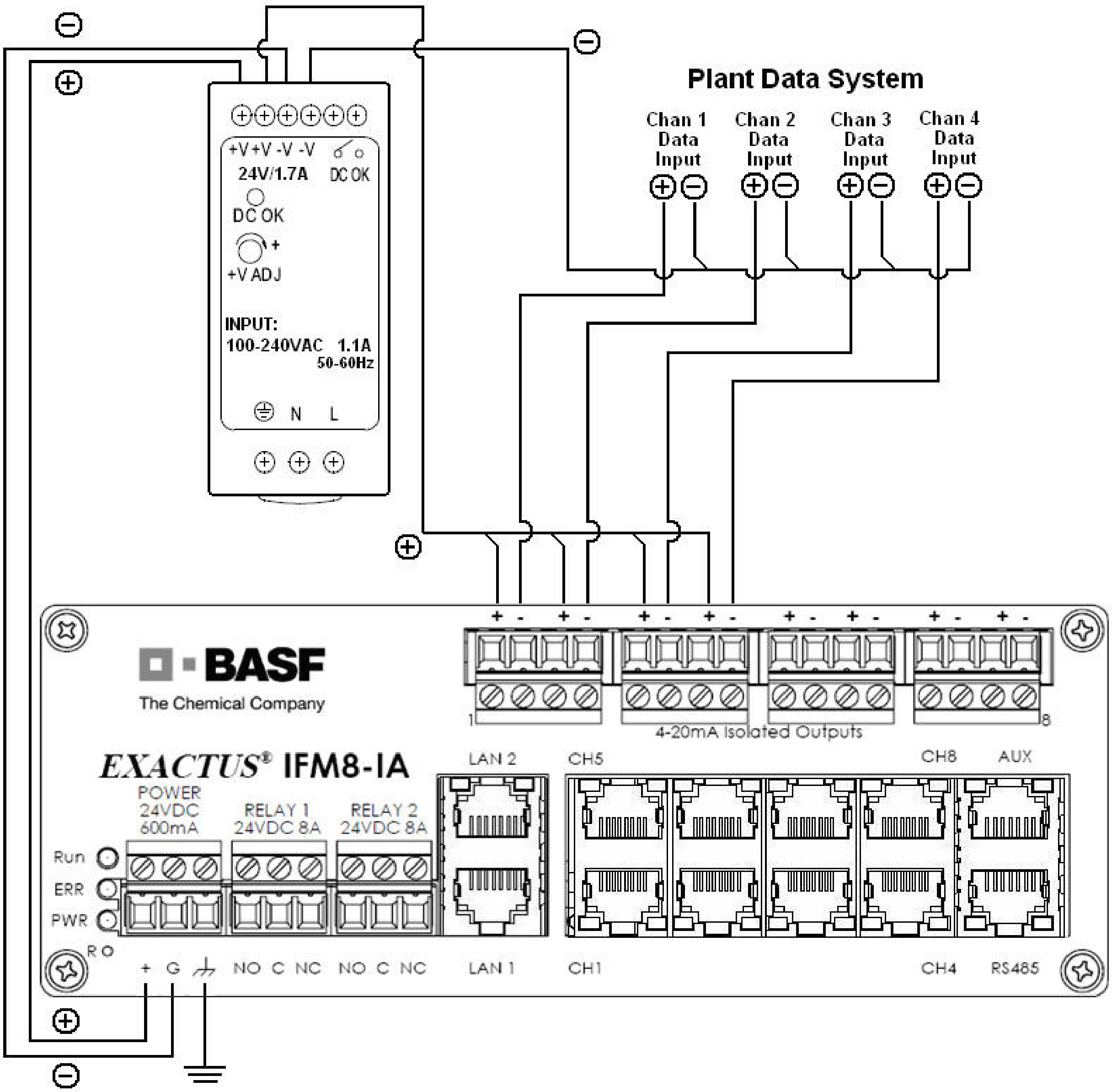


Figure A-15: Schematic for providing power to analog output loops – only use if plant data system does not already provide the loop power.

Appendix 2A

BASF *EXACTUS*® Communication Specifications

Overview

Using the IFD-5 interface box, the BASF *Exactus* pyrometer can communicate digitally, selectable for either RS-232 or RS-485 line levels. The IFD-5 provides power to the pyrometer and isolation of the communication lines.

To connect the pyrometer to a standard PC serial port using the IFD-5, make sure that the selector switch for RS-232/RS-485 is in the RS-232 position. This is a small single DIP switch near the IFD-5's DB-9 connector.

IFD-5 DB9 Pinout	
1	Unused
2	RXD
3	TXD
4	Unused
5	Signal Gnd
6	Unused
7	RTS *
8	Unused
9	Unused

Table 1: RS-232 Serial Connections for IFD-5

* NOTE: *The RTS line must be held in an asserted (HIGH) state or be left unconnected.*

Communication Modes and Boot-up Sequence

The pyrometer implements two separate communication protocols, Modbus and *Exactus*, which are not active at the same time. The default mode of operation is the Modbus Protocol and this is the mode the pyrometer always enters following power-up. The two protocols are not active at the same time, but the user can command the probe to switch from one mode to the other. The details of each protocol and how to switch between them is described in the following sections.

When power is applied to the pyrometer, it boots up and within 150 milliseconds a single ACK (hex 06) character will be transmitted at 115200 baud. This character is transmitted so that a host system can detect that the pyrometer is present. The pyrometer then begins a self-initialization which lasts between 5 and 10 seconds depending on the pyrometer type. When this is complete, the pyrometer enters the Modbus protocol mode and waits for a Modbus message. At this time, the host system can proceed to communicate with the pyrometer in Modbus Protocol mode, or a Modbus command can be sent to switch the pyrometer into the *Exactus* Protocol mode.

NOTE: *For an example Modbus message to switch the pyrometer into the Exactus Protocol mode, see Example 2 below.*

Modbus Protocol

The Modbus Protocol is an open serial interface standard which is often used to communicate between sensors and controllers in industrial environments. Modbus is a polled protocol, which means that the host system sends a request message to the pyrometer to obtain a reading value and the pyrometer sends a response message containing the requested value.

The pyrometer takes less than 1 millisecond to respond to Modbus messages. Depending on the speed and capability of the host system, it is possible to obtain readings from the pyrometer at 200 rd/s or faster. However, due to limitations inherent in most host systems, about 10 rd/s is a reasonable readings performance rate to expect with the Modbus Protocol.

Example 1: Read channel 1 temperature:

Field Name	Hex
Slave Address	01
Function	03
Starting Address Hi	00
Starting Address Lo	00
No. of Points Hi	00
No. of Points Lo	02
CRC Hi	C4
CRF Lo	0B

Response

Field Name	Hex
Slave Address	01
Function	03
Byte Count	04
Data Hi	43
Data Lo	E2
Data Hi	BF
Data Lo	41
CRC Hi	FF
CRC Lo	81

Example 1 continued on following page

Example 2: Command the pyrometer to exit Modbus Mode and enter *Exactus* Mode

Field Name	Hex
Slave Address	01
Function	05
Coil Address Hi	00
Coil Address Lo	13
Force Data Hi	00
Force Data Lo	00
CRC Hi	3C
CRC Lo	0F

Note: *After issuing this command, there will be no response because the pyrometer will enter Exactus Mode immediately.*

Duplex	Full
Parity	None
Data Bits	8
Stop Bits	1
Supported Baud Rates	9600, 19200, 38400, 57600, 115200, 230400
Modbus Device Address	0-255, (set to 1 at factory)

Table 2: Modbus Protocol Serial Settings

NOTE: *See the Modbus Protocol Appendix for a full description of how to use the pyrometer in Modbus Mode.*

Exactus Protocol

The *Exactus* Protocol transmits readings continuously in a binary format at a rate set by the user in the Temperature software. In this communication mode, the host can send commands to the pyrometer to start and stop sending readings, or to change operational parameters of the pyrometer such as the readings data type and transmit frequency.

Data Packet Format

The pyrometer can transmit the following four types of data packets: Temperature, Photodiode Current, Dual (Temperature and Current), and Ambient Temperature. The data values are represented within the packets by 4 bytes which represent a 32-bit IEEE-754 floating point number. The IEEE-754 format is described at the end of this document for the user's reference.

Exactus Protocol data messages transmitted by the pyrometer always begin with a Data Message Header byte which is followed by one or two floating point values. There is no LRC or other error checking character in the message. An escape sequence character (0x80) is sent whenever reserved values occur in the data packet values. The reserved characters include the packet header bytes, 0x81-0x85, and the ESC value, 0x80.

Message Formats

Header (Hex)	Packet Type	Value 1	Value 2
0x81	Temperature	Target Temperature	None
0x82	Current	Photodiode Current	None
0x83	Dual	Target Temperature	Photodiode Current
0x84	Ambient	Electronics Temperature	Chassis Temperature
0x85	Reserved for Future Use		

Data Message Escape Sequence

In order to remain synchronized with the host in the case of buffer overflows or other communications errors, the pyrometer uses an escape character for Header byte values that occur in the binary data being sent. The Message Header Escape character (ESC) is 0x80. Byte values within the message payload which are in the range 0x80-0x85 are preceded by the escape character.

Example: The Ambient Temperature Header, 0x84, occurs in the binary data and is escaped with the ESC character, 0x80:

Message: 83 43 80 84 1F 32 22 7F 9E

Data Message Descriptions

Temperature Message

Header Byte: 0x81
Message Format: 0x81 <Temperature 32 bit IEEE>
Description: Target temperature in degrees C.

Example: Target temperature of 674.05 C.
Message: 81 44 28 80 83 00

(Note the insertion of an ESC character, 0x80, due to the presence of the framing character 0x83 in the data.)

Current Message

Header Byte: 0x82
Message Format: 0x82 <Current 32 bit IEEE>
Description: Raw photodiode current in Amperes.

Example: Current of 3.1023E-12 Amperes.
Message: 82 2C 5A 4E 12

Dual Message

Header Byte: 0x83
Message Format: 0x83 <Temperature 32 bit IEEE> <Current 32 bit IEEE>
Description: Target temperature followed by raw photodiode current.

Example: Target temperature of 673.21 C and current of 9.1632E-07 Amperes.
Message: 83 44 28 4D 71 35 75 F9 08

Ambient Temperature Message

Header Byte: 0x84
Message Format: 0x84 <AmbE 32 bit IEEE> <AmbC 32 bit IEEE>
Description: Pyrometer ambient temperatures.
AmbE = Electronics Temperature.
AmbC = Chassis Temperature.

Example: Electronics temperature of 28.4C and photodiode temperature of 31.5C.
Message: 84 41 E3 33 33 41 FC 00 00

Host to Pyrometer Commands

Commands to the pyrometer always start with the Start of Command (STX). This is followed by a single byte command character and any parameter values required by the command. Commands always end with a single byte checksum (LRC) character followed by the End of Command (ETX) character. See the Command Reference section for a description of each command.

Command Framing Characters:

STX	0x02	Start of Command
ETX	0x03	End of Command
ACK	0x06	Positive Acknowledge
DLE	0x10	Data Link Escape
NAK	0x15	Negative Acknowledge

Command Escape Sequence

The host must use the DLE (Data Link Escape) character, 0x10, to escape any command framing characters that occur in messages sent to the pyrometer. *Note that the DLE character is NOT included in the LRC calculation.*

Example 1: The following command sets the User Rate Index to 0x3. The value of the ETX character (0x03) occurs in the data field of the message and must be escaped.

Command: 02 4E 10 03 4D 03

Example 2: The NAK (Negative Ack) character 0x15 occurs as a binary value in the command message and must be escaped by the host.

Command: 02 4F 00 10 15 5A 03

LRC Calculation

The LRC is calculated by taking the XOR of every non-framing character in the command. An example is shown for the LRC of a command to write a table entry.

Command: 02 44 45 00 42C80000 3F666666 3F000000 LRC 03
LRC Portion: 44 45 00 42C80000 3F666666 3F000000
LRC = XOR of all bytes in the LRC Portion = ED
Command with LRC: 02 44 45 00 42C80000 3F666666 3F000000 ED 03

Note that the LRC for single byte commands is simply the command byte repeated. All values used in the protocol description are represented in hexadecimal format.

Summary of Commands

Switch to Modbus Mode

Description: Commands the Pyrometer to switch to Modbus Mode
Command Byte: 0x4D
Format: STX 0x4D 0x4D ETX
Response: None (pyrometer switches to Modbus Mode immediately)
Command Example: 02 4D 4D 03

Report Version

Description: Request pyrometer version data.
Command Byte: 0x56
Format: STX 0x56 0x56 ETX
Normal Response: STX 0x95 <1 byte version> <9 byte PROM code> ETX
Invalid Response: NAK
Command Example: 02 56 56 03
Example Response: 02 95 44 E2 5F 50 2B 10 10 16 73 FF 03
The 95 byte indicates that the pyrometer is running in application mode.
Version = 4.4
Prom Code = E25F502B10101673FF (factory use only)

Stop Conversions

Description: Commands the Pyrometer to stop sending temperature readings.
Command Byte: 0x30
Format: STX 0x30 0x30 ETX
Response: ACK (valid), NAK (invalid)
Command Example: 02 30 30 03
Example Response : 06

Start Conversions

Description: Commands the Pyrometer to start sending temperature readings.
Command Byte: 0x31
Format: STX 0x31 0x31 ETX
Response: ACK (valid), NAK (invalid)
Command Example: 02 31 31 03
Example Response: 06

Set Calibration Factor

Description: Set the pyrometer calibration factor.
Command Byte: 0x4D
Format: STX 0x4D <CALFACTOR> LRC ETX
Parameter Format: 4 bytes representing one 32-bit IEEE Single Precision value.
Response: ACK (valid), NAK (invalid)
Command Example: The following command sets the calibration factor to 0.99:
02 4D 3F 7D 70 A4 9F 03
Example Response: 06

32 bit IEEE Floating Point Format

The IEEE 754-1990 standard for binary floating point arithmetic defines the format for representing single precision (32 bit) floating point numbers.

The 32 bits in the number are divided into the sign, exponent and fraction portion as follows:

Sign	Exponent	Fraction
0	00000000	00000000000000000000000
Bit 31	Bits 30 .. 23	Bits 22 .. 0

The fields are used to calculate the floating point number that is represented according to the following formula:

N = sign * (1.F* 2^(E-127))

Where N = floating point number, F = fractional part in binary notation, E = exponent in bias 127 representation.

A sign (bit 31) of 0 indicates a positive number, and a 1 is negative. The exponent field is represented by "excess 127 notation". The 23 fraction bits actually represent 24 bits of precision, as a leading 1 in front of the decimal point is implied.

There are some exception cases:

E = 255; F = 0	+/- infinity
E = 255; F != 0	NaN (Not a number, Overflow, or Error)
E = 0; F = 0	0
E = 0; F != 0	de-normalized, tiny number, smaller than smallest allowed

Appendix 2B

BASF *EXACTUS*® MODBUS Communication

Introduction

The following appendix describes the Modbus RTU communication protocol interface for the BASF optical pyrometer. The protocol provides the means for a host computer or PLC to read the pyrometer temperature and photodiode current values. The pyrometer's configuration and calibration settings are also made accessible through the Modbus protocol.

The Modbus protocol is the default communications protocol implemented by the BASF pyrometer. In Modbus mode, the electrical interface of the pyrometer is full-duplex RS-422. The baud rate and address used by the pyrometer for Modbus communications are set using TemperaSure®. Default parameters are baud=115200, address=0x01. To change the parameters, run the pyrometer under TemperaSure® and open the Probe Parameters window by clicking on the pyrometer name. Select the Modbus tab and set the baud rate and address. Be sure to save the parameters before exiting (See User's Manual for differences between 'Apply' and 'Save').

When the probe is connected to a computer running TemperaSure®, it will be taken out of Modbus mode and put into a special mode for communication with TemperaSure®. To return the probe to Modbus mode, disconnect the probe from the computer and cycle the power to the probe.

Getting Started

If possible, run the process while measuring temperature with the probe connected to the TemperaSure® software. This software allows for graphical plotting of temperature over time and easy adjustment of probe settings to optimize the measurement. One of the important pyrometer configuration settings is the measurement Update Rate, located at Modbus register address 0x1011. This setting is called the Graph Rate in the TemperaSure® software. If the Update Rate is slower than the rate at which data is polled from the probe by the host computer or PLC, repeat readings will result. Too high of an update rate will lead to noisy measurements at the bottom end of the measurement range. If high polling rates are required, and noise at the lower end becomes a problem, the probe can be programmed to average out the noise at low temperatures (see Averaging Table and Low Temperature Signal Averaging in the User's Manual).

Programming

The pyrometer implements a subset of the functions defined in the Modbus RTU protocol. A detailed description of the Modbus RTU protocol standard can be found at www.modbus.org.

The following Modbus function codes are supported by the pyrometer:

- Function 01h: Read Coil Status
- Function 03h: Read Holding Registers
- Function 05h: Force Single Coil
- Function 06h: Preset Single Register
- Function 0Fh: Force Multiple Coils
- Function 10h: Preset Multiple 4XXXX Registers
- Function 17h: Read/Write 4XXXX Registers

Accessing Pyrometer Readings

For most applications, only Modbus Function 03h (Read Holding Registers) will be required. This function can be used to obtain 1 or more floating point values from the pyrometer. Pyrometer temperature and current data values are read in the address block 0000h-0FFFh and are represented as 32-bit floating point values.

Floating Point Value Format

The floating-point values accessible through Modbus registers are represented in the 32-bit IEEE-754 reverse format. Each value occupies two register locations and is always located beginning with the upper 16 bits of the value at an even register address followed by the lower 16 bits at an odd address.

The following example shows how the temperature reading is stored in the register memory:

Temperature = **252.55 C** -> IEEE-754 Reverse Representation = **437C8CCC**

Temperature Reading at register locations 0000h-0001h:

Address	Data
0000h	437Ch
0001h	8CCCh

The pyrometer temperature and current values are available at multiple register addresses. For example, the temperature reading is mapped at both 0x0000-0x0001 and 0x0006-0x0007. These redundant mappings provide the ability to read more than one reading using a single Modbus message. For example, the currents for both Channel 1 and Channel 2 can be obtained by reading two floating point values starting at register address 0x0012.

You can find the address for each value in the Modbus Register Address Map, located at the end of this document.

Pyrometer Name String

The pyrometer name consists of a string of up to 32 ASCII bytes in length which can be accessed at addresses 1100h-111Fh. The pyrometer is shipped with the name string configured to the unit's serial number.

To read the name string, start at 1100h and read the ASCII values of the name string at sequential register addresses until a character with the null value (0x00) is encountered. The null character delimits the end of the string.

To write the name string, begin at 1100h and sequentially write the ASCII values for each character in the new name string to sequential register addresses. Once the string of characters has been written to the register locations the "Save" command must be executed using the Command Register in order to make the change permanent. (See the "Command Register" section below).

Calibration Factors and Tables

Calibration factors and table entries are accessed at register address block 2000h-3FFFh (see the Modbus Register Address Map). All are 32-bit floating point values with the exception of the sizes for the Emissivity, Fit, and Average/Bandwidth Tables which only occupy 1 register location.

IMPORTANT NOTE: Changing the Emissivity, Fit or Averaging tables requires that table entries are written first, followed by a register write to update the table size.

Command Register

The pyrometer Command Register at Modbus address 8000h provides a way to save changes made to the pyrometer settings and also allows the user to initiate a soft reboot of the pyrometer. Changes to the pyrometer parameters can be saved to EEPROM by writing 7001h to the Command Register. A pyrometer soft reboot can be initiated by writing 8080h to the Command Register.

Command Register Function Codes

Function Code	Description
7001h	Save to parameters to EEPROM
8080h	Soft Reboot

Configuration Registers

The pyrometer has two configuration registers, GenConfigReg1 and GenConfigReg2. The individual bits of these registers can be accessed to query or change the pyrometer's mode configuration. These registers can be read and written as 16 bit values using Modbus functions 03h and 06h, or the individual bits can be read/written using Modbus functions 01h and 05h.

A mode is enabled by writing a '1' to the corresponding configuration bit.

Configuration Register Bit Descriptions

GenConfigReg1 (1000h)	
Bit(s)	Description
0	Send Temperature (Legacy Mode)
1	Send Current (Legacy Mode)
2	Send Ambient Temperature (Legacy Mode)
3	Enable Averaging / Bandwidth Table
4	Enable Fit Function Table
5	Enable Emissivity Table
6	0=Emiss. Extrap., 1=Emiss. Hold
7	0=Fit Extrap, 1=Fit Hold
8	Set Temp=99999.99 when pyrometer max.temp. is exceeded.
9	Enable Low Temperature Signal Averaging
10	Enable Current Offset Correction
11	Enable Bandwidth Mode
12	Disable current extrapolation at range changes.
15:13	Reserved

GenConfigReg2 (1001h)	
Bit(s)	Description
0	Enable control for Analog Out accessory.
1	0=Analog Voltage Output, 1=Analog Current Output
2	Enable MODBUS communication mode
3	Enable Channel 2 diode output
4	Enable manual ranging mode (Use register 0x8003 to set range)
5	Reserved
7:6	Dual Channel Ranging Mode: 01 = Channel 1, 10 = Channel 2, 11 = AUTO

Using Modbus Coil Functions with Configuration Register Bits

The Modbus protocol function 01h (Read Coil Status) and 05h (Force Single Coil) can be used to read and write individual bits in the pyrometer Configuration Registers. The Modbus Coil addresses and their corresponding Configuration Register bits are shown in the following table.

Modbus Coil Addresses for Configuration Register Bits

Coils	**Corresponding Register Bit(s)**
1 - 8	GenConfigReg1[0] – GenConfigReg1[7]
9 - 16	GenConfigReg1[8] – GenConfigReg1[15]
17 – 24	GenConfigReg2[0] - GenConfigReg2[7]
25 – 32	GenConfigReg2[8] - GenConfigReg2[15]
33 – 48	RESERVED – Do not write to these coils!

Modbus Register Address Map

Readings Registers		
Address	Description	Notes
0000-0001	Channel 1 Temperature	
0002-0003	RESERVED	
0004-0005	Channel 1 Current	
0006-0007	Channel 1 Temperature	
0008-000f	RESERVED	
0010-0011	RESERVED	
0012-0013	Channel 1 Current	
0014-0015	Channel 2 Current	Dual channel models only

0016-0017	RESERVED	
0018-00ff	RESERVED	
0800-0801	Chassis Ambient Temperature	

Configuration Registers		
1000	Configuration Register 1	
1001	Configuration Register 2	
1002-1006	RESERVED	
1007	Modbus Device Address	
1008	Modbus Baud Rate	
1009-1010	RESERVED	
1011	Pyrometer Sample Rate	This setting is called the “Graph Rate” in TemperaSure.
1012-10FF	RESERVED	
1100-111F	Pyrometer Name String Buffer	Use is described in the “Pyrometer Name String” section above.
1200-12FF	RESERVED	
1300	Software Version Number	Upper 8 bits represent Major version # Lower 8 bits represent Minor version #
1301	Software Build Number	Upper 8 bits represent Major build # Lower 8 bits represent Minor build #
1302-1304	RESERVED	
1305-130D	Serial Number (9 ASCII bytes)	1 byte per register location.

Calibration Registers		
2004-2005	Channel 1 Calibration Factor	
2006-2007	Channel 1 Transmission Factor	
2008-2009	Channel 1 Current Offset	
200A-2013	RESERVED	
2014-2015	Channel 2 Calibration Factor	Dual channel models only
2016-2017	Channel 2 Transmission Factor	Dual channel models only
2018-2019	Channel 2 Current Offset	Dual channel models only

Emissivity Table		
3000-300F	Emissivity Table X Entries 0 through 7	Each entry is a 32-bit floating point #
3010-301F	Emissivity Table Y Entries 0 through 7	Each entry is a 32-bit floating point #
3020	Emissivity Table Size	Min. Size = 0, Max. Size = 8
Fit Table		
3030-303F	Fit Table X Entries 0 through 7	Each entry is a 32-bit floating point #
3040-304F	Fit Table Y Entries 0 through 7	Each entry is a 32-bit floating point #
3050	Fit Table Size	Min. Size = 0, Max. Size = 8
Average Table		
3060-306F	Avg/BW Table X Entries 0 through 7	Each entry is a 32-bit floating point #
3070-307F	Avg/BW Table Y Entries 0 through 7	Each entry is a 32-bit floating point #
3080	Average Table Size	Min. Size = 0, Max. Size = 8

Analog Mode Min. and Max Values		
3100-3103	Voltage Mode Min. Volts	Analog voltage output at minimum temperature.
3102-3103	Voltage Mode Max. Volts	Analog voltage output at maximum temperature.
3104-3105	Voltage Mode Min. Temp.	Voltage Mode Minimum Temperature

3106-3107	Voltage Mode Max. Temp.	Voltage Mode Maximum Temperature
3110-3111	Current Mode Min. Current	Analog current output at minimum temperature.
3112-3113	Current Mode Max. Current	Analog current output at maximum temperature.
3114-3115	Current Mode Min. Temp.	Current Mode Minimum Temperature
3114-3117	Current mode Max. Temp.	Current Mode Maximum Temperature

Auxiliary Registers		
8000	Command Register	
8001	RESERVED	
8002	RESERVED	
8003	Manual Range Register	Manual ranging mode must be enabled by setting bit 4 in Configuration Register 2.

Appendix 3

Analog Output

Hardware Setup:

There are four wires that must be connected between the Analog Output Module and the Digital Interface Module. The two modules are designed to stack one above the other. BASF provides a pre-made connector designed for use when the two modules are stacked. When the two modules are stacked vertically the power input and digital communications connections are, pin for pin, directly above one another. These connections are labeled D+, D-, Vs, and GND on both modules. To connect the two modules, wire D+ on the Analog Output Module directly to D+ on the Digital Interface Module, and do the same for D-, Vs, and the GND connections.

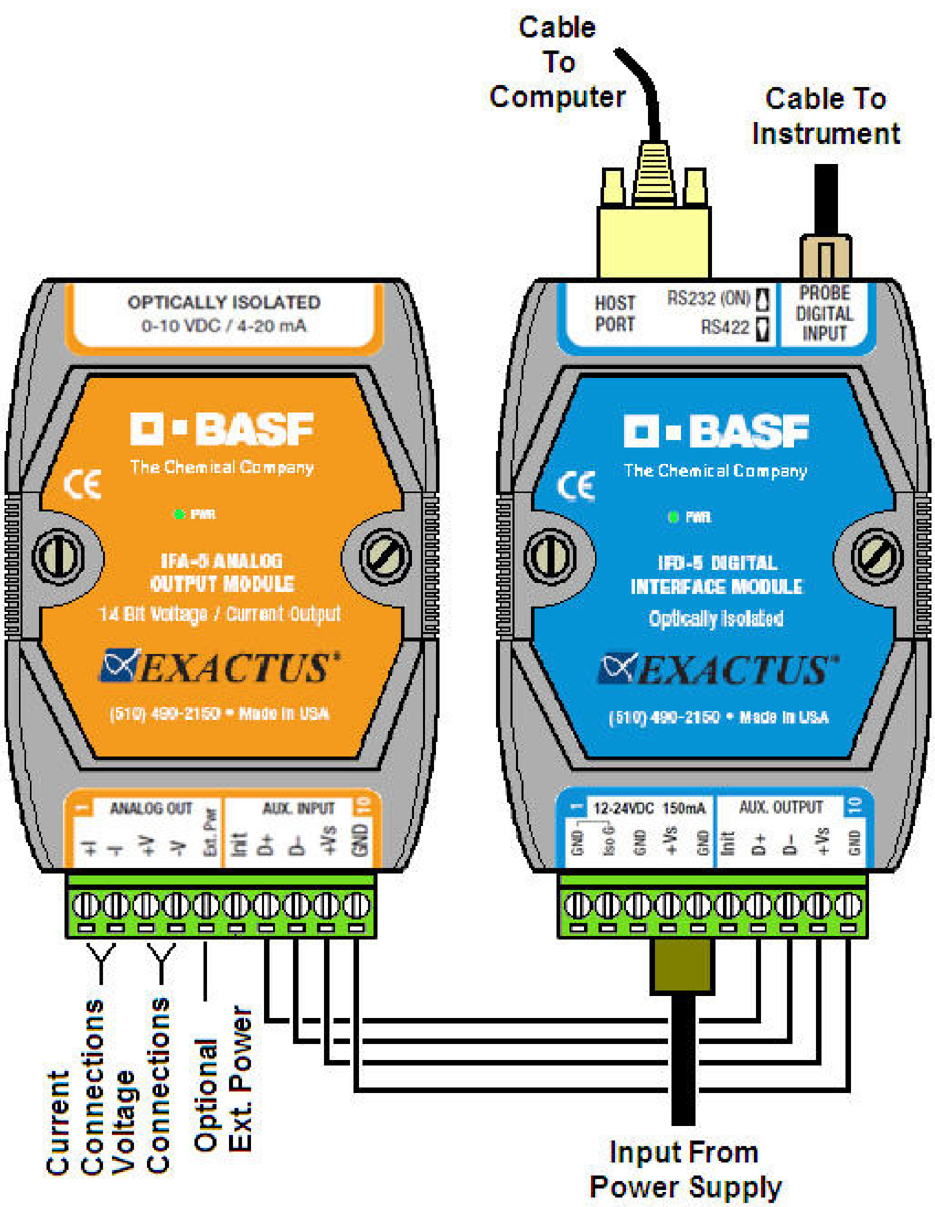


Figure A-15

If the modules are not to be stacked, the connections are wired the same as described above in Figure A-15. The Analog Output Module and the Digital Interface Module can be wired up to 50 meters from each other. Shielded wiring is recommended for distances greater than a few meters or if the electronics are mounted in an area of high electromagnetic interference.

The voltage and current output connections are adjacent to the power and digital communication connections. For a voltage output, connect to "+V out" and "-V out", and for a current output connect to "+I out" and "-I out".

Mounting:

The backs of both the Digital Interface Module and Analog Output Module have attachments for easy DIN rail mounting. To attach the modules to a DIN rail pull the orange tab at the bottom of the module downward, slip the module onto the DIN rail and push the tab back in to secure the module to the rail. A short piece of DIN rail is provided for mounting the Module to solid surfaces.

Optional External Power:

The internal power source on the Analog Output Module will drive the current output through a resistance of up to 500 ohms. The module can drive up to 1050 ohms if an external 24VDC power source is used.

The Analog Output Module is supplied configured for internal power. To configure for external power a jumper inside the module must be moved. The Analog Output Module and the Digital Interface Module are similar in appearance, so make sure you are working with the Analog Output Module before you proceed. To move the jumper, completely remove the two screws that hold the Analog Output Module case together. With one hand, grasp the sides of the module just below the case seam and squeeze firmly; the upper and lower covers will separate from each other. Remove the top cover of the module and set it aside.

Hold the Analog Output module so the writing on the circuit board is upright. There is only one jumper on the board, it is labeled JP1 and will be in the upper left-hand side of the board close to the module connections. Three pins allow the jumper to be in one of two positions. To configure for external power, locate the jumper connector onto the bottom two pins, to configure for internal power locate the jumper connector onto the top two pins. See Figure A-16 below for details.

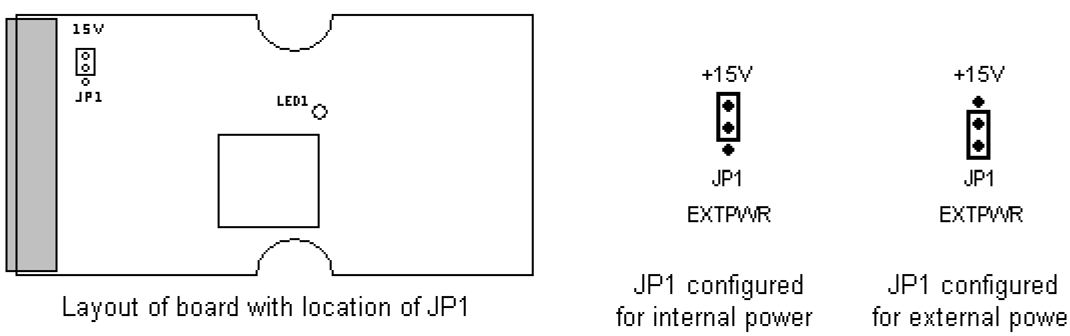


Figure A-16

Wiring for External Power:

The wiring for the current mode is also different when the output is powered externally. When an external 24VDC power supply is used, wire as shown in the Figure A-17.

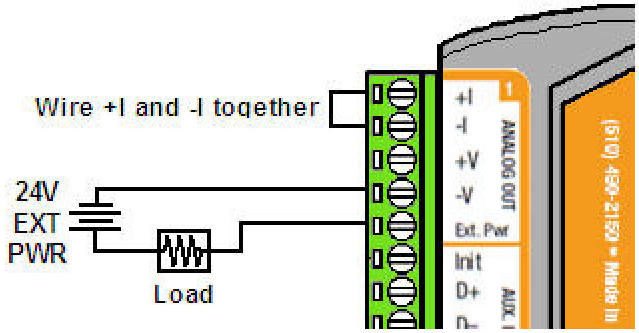


Figure A-17

Software Setup:

Activation:

If you purchased your BASF probe with an Analog Output Module, your software should already be set to work with the module; skip this section and go straight to the Configuration section below. If you initially purchased your BASF probe without an analog output, a single line needs to be written into the probe initialization file.

1. Using the Explorer© feature in Microsoft® Windows© open the prb.ini file in the directory containing the TemperaSure™ software. The last section of this file contains the header:

    [Main]

2. Just below the header, insert the line:

    hasanalog=1

    This section of the file should read similar to the following example:

```
userRate=5
[Main]
hasAnalog=1
WinMax=1
Top=75
Left=92
Width=718
```

3. Save the file and exit.

Configuration:

With all the connections made, open the TemperaSure software program. Wait a few seconds for the instrument to start displaying temperatures in the box or boxes above the graphical display. Click on the numbered box corresponding to the probe that is to be configured and follow the steps below:

1. Select the Analog Output tab. There should be a tab labeled Analog Output along side the General and Advanced tabs. If the Analog Output tab does not appear, exit the TemperaSure software, return to the Activation section above and follow the steps outlined. Please call the factory if you need additional assistance.

2. Click the Use Analog Output button.
3. Click on either Voltage or Current button.
4. Go to the corresponding section and type in the minimum temperature and the maximum temperature and the corresponding voltage or current values. Voltages between 0 and 10 volts and currents between 0 and 20mA may be entered. See Scaling section below for details.
5. Values may be stored in two ways. By pressing the Save button the values are stored in the probes memory and are retained even if the probe is reset or powered down. Values may also be stored by pressing the Apply button; however these values will not be retained if the probe is reset or powered down. Pressing the Apply button will interrupt the output from the probe for two to four seconds. Pressing the Save button will interrupt output from the probe for several seconds.

Scaling:

The analog output will be scaled according to the four values entered in step four above. The minimum and maximum temperatures entered can be the minimum and maximum temperature the probe will read, or they could be just a few degrees from each other. When the Analog Output Module is configured the first time, the default value for minimum temperature will be 0.00°C. The maximum temperature will be the same as the maximum temperature of the probe connected; values larger than the maximum temperature of the probe will not be accepted.

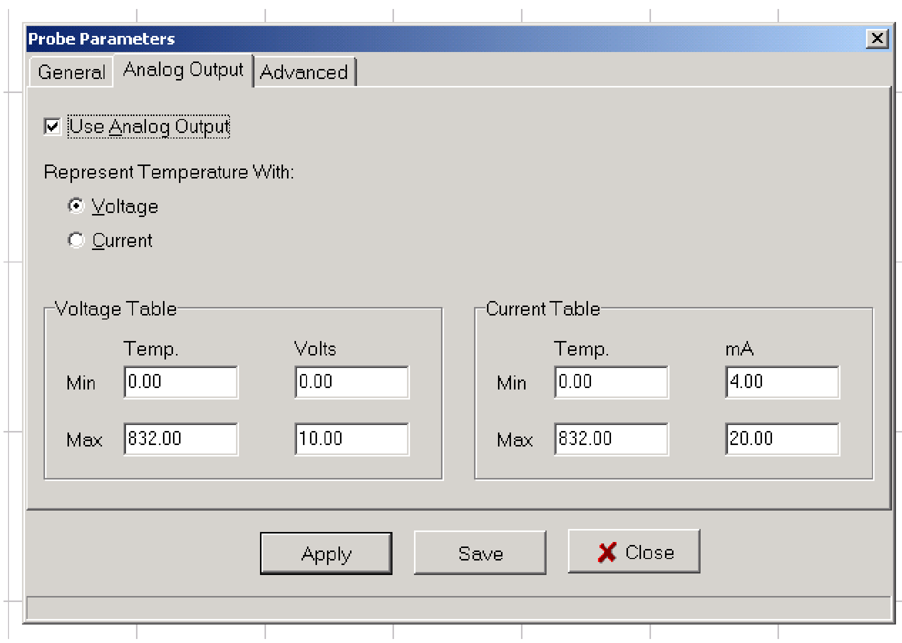


Figure A-18

The analog output may be configured to a number of different electrical ranges. For example, if a voltage that varies from +1 to +5 volts is desired, simply enter these voltages and their corresponding temperatures into the table. If the temperature goes below the temperature assigned to +1 volt the output will stay at +1 volt. If the temperature exceeds the temperature assigned to +5 volts, the output will stay at +5 volts. The resolution of the Analog Output Module in voltage mode is 10,000 different voltage levels spread over the 0 – 10 V range; when the voltage output range is reduced (e.g. 0 – 5V) the number of different voltage levels will be reduced proportionally. The resolution of the module in current mode is 20,000 different current levels spread over the 0 – 20mA current range; when the current output range is reduced (e.g. 4 – 20mA) the number of different current levels will be reduced proportionally.

Reverse Scaling:

The output can be set up as reverse acting if desired. By reverse acting, the voltage or current output will decrease as the temperature increases. To set up the analog output in reverse acting mode, assign the minimum voltage or current to the maximum temperature and assign the maximum voltage or current to the minimum temperature.

Calibration:

Checking Calibration of Analog Output Module:

Calibration of the analog output is very easy and straightforward. A menu within TemperaSure provides an easy-to-use interface for the calibration of the analog output. Checking the calibration does not affect the calibration Analog Output Module. To check the calibration, follow the steps below. Instructions for changing the calibration follow this section. Calibration of the analog output is not be required before the first year of operation and only annually after the first year.

To check the calibration of the Analog Output Module:

1. Make sure that the Analog Output Module and the probe are disconnected from any process, system, or tool that could be affected by readings from the Analog Output Module or the probe itself.
2. Verify that the voltage or current meter being used to calibrate the Analog Output Module is properly calibrated and its calibration is up to date.
3. Connect the probe to a computer capable of running the TemperaSure software under the Windows® operating system. Open the TemperaSure software and verify readings are coming from the probe to the computer.
4. Connect the meter to the Analog Output Module. If the Analog Output Module is to be used in voltage mode, the meter should be connected in parallel with the output. If the Analog Output Module is to be used in current mode, the meter should be connected in series.
5. Configure the Analog Output Module for Internal Power (see instructions for Optional External Power).
6. Make sure the Analog Output Module has been running for at least 30 minutes so it is fully warmed up.
7. Determine the COM port to which the probe is connected. To determine the COM port, click on the numbered box above the temperature readout for the probe. The COM port will be displayed in the Probe section on the General tab.
8. Under the Options menu in TemperaSure, select Analog Calibration. A calibration menu box will pop up (see Figure A-18).
9. Using the menu, select the COM port of the probe that is attached to the Analog Output Module and whether the Analog Output Module is being used in voltage or current mode.

10. Measure the voltage or current from the Analog Output Module. For a voltage output there should be a potential of 10 volts across the +V out and –V out terminals. For a current output there should be a 20mA current flowing between the +I out and –I out terminals (ExtPWR and –V out if External Power is utilized – see section on Optional External Power).

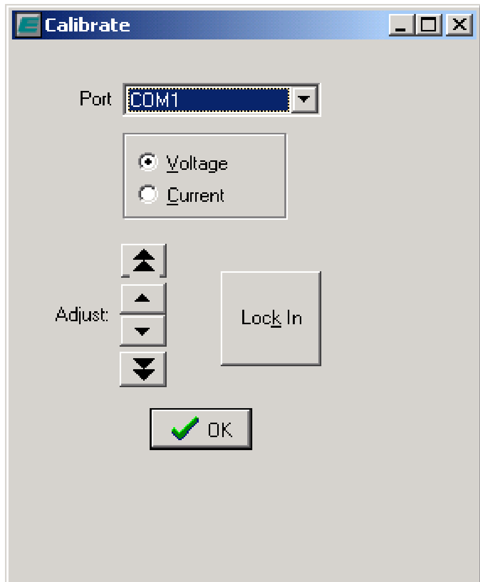


Figure A-19

Adjusting Calibration of Analog Output Module:

To adjust the calibration of the Analog Output Module, follow the steps outlined in the previous section. Adjustments are made by the up and down arrows on the calibration menu box. Adjust the calibration so the output from the module is either 10.000 volts or 20.000mA, depending on the mode selected. Once the output is correct, press the "Lock In" button on the calibration menu box. None of the adjustments will be stored until the Lock In button is pressed. There is no need to adjust the zero calibration on the Analog Output Module.