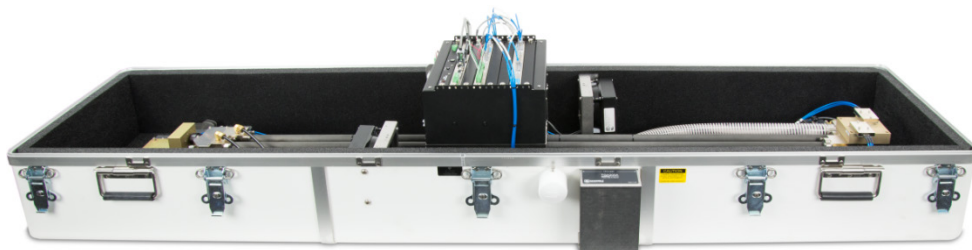


INSTRUCTION MANUAL



TGA Series **Trace Gas Analyzers**

Revision: 10/14



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- Read all applicable instructions carefully and understand procedures thoroughly before beginning work.
- Wear a **hardhat** and **eye protection**, and take **other appropriate safety precautions** while working on or around tripods and towers.
- **Do not climb** tripods or towers at any time, and prohibit climbing by other persons. Take reasonable precautions to secure tripod and tower sites from trespassers.
- Use only manufacturer recommended parts, materials, and tools.

Utility and Electrical

- **You can be killed** or sustain serious bodily injury if the tripod, tower, or attachments you are installing, constructing, using, or maintaining, or a tool, stake, or anchor, come in **contact with overhead or underground utility lines**.
- Maintain a distance of at least one-and-one-half times structure height, 20 feet, or the distance required by applicable law, **whichever is greater**, between overhead utility lines and the structure (tripod, tower, attachments, or tools).
- Prior to performing site or installation work, inform all utility companies and have all underground utilities marked.
- Comply with all electrical codes. Electrical equipment and related grounding devices should be installed by a licensed and qualified electrician.

Elevated Work and Weather

- Exercise extreme caution when performing elevated work.
- Use appropriate equipment and safety practices.
- During installation and maintenance, keep tower and tripod sites clear of un-trained or non-essential personnel. Take precautions to prevent elevated tools and objects from dropping.
- Do not perform any work in inclement weather, including wind, rain, snow, lightning, etc.

Maintenance

- Periodically (at least yearly) check for wear and damage, including corrosion, stress cracks, frayed cables, loose cable clamps, cable tightness, etc. and take necessary corrective actions.
- Periodically (at least yearly) check electrical ground connections.

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TGA Series Trace Gas Analyzers

1. Introduction

Campbell Scientific has been manufacturing tunable diode laser absorption spectrometer (TDLAS) trace gas analyzers (TGAs) since 1993. While the TGAs have improved through a succession of four different generations, the core technology remains the same. The TDLAS technique provides high sensitivity, speed, and selectivity.

All Campbell Scientific TGAs are rugged, portable instruments designed for use in the field. Common applications include gradient or eddy-covariance flux measurements of methane or nitrous oxide, and isotope-ratio measurements of carbon dioxide. Many of the important improvements are available as upgrades for older models. These substantial upgrades blur the lines between the various models. This manual covers all of the TGA models to some extent, with emphasis on the later variants. A brief summary of these TGA models and the most relevant improvements are summarized in TABLE 1-1.

TABLE 1-1. Historical Summary of Campbell Scientific Trace Gas Analyzers

	TGA100	TGA100A	TGA200	TGA200A
Ship dates	1993 – 2004	2005 – 2009	2008 – 2012	2014 –
CPU	Transputer (upgradeable)	New	New	New
Software	Transputer	DOS	TGA Windows	TGA TEC
Laser	Lead salt	Lead salt	Lead salt	Interband Cascade
Cooling options	LN ₂	LN ₂ or Cryocooler	LN ₂	Thermoelectric
Dewar capacity (L)	1.5	10.4	14.5	None
Optical configuration	Beamsplitter at detector end.	Beamsplitter at detector end	Beamsplitter at laser end. Long sample and reference cells.	Beamsplitter at laser end
Absorption cells	Long sample cell/short reference cell	Long sample cell/short reference cell	Long sample and reference cells	Long sample and reference cells.
Temperature control	Fans only (TGAHEAT optional starting 2002)	TGAHEAT included	Software	Software

Before proceeding, please study

- Section 2, *Cautionary Statements*
- Section 3, *Initial Inspection*
- Section 6, *Installation*

Operational instructions critical to preserving accurate measurements of the system are found throughout this manual. Before proceeding, please study this manual. Several other user manuals provide additional information and should be consulted before using the TGA. These include:

- *CR6 Measurement and Control Datalogger*
- *CR1000 Measurement and Control Datalogger*
- *CR3000 Micrologger*
- *CR5000 Measurement and Control System*

all available at www.campbellsci.com

2. Cautionary Statements

- DANGER:
 - All Campbell Scientific TGAs use Class 1M lasers. These lasers are safe under all conditions of normal use except when passed through magnifying optics such as microscopes and telescopes. Do not view the laser directly with optical instruments.
 - The power cords supplied with the TGA may not be of sufficient length for a given site application. If longer AC power cords are required, always have a qualified electrician perform the work.
- WARNING:
 - Before attempting to install or change a laser in the TGA, read all documentation accompanying the laser and thoroughly review Appendix A.1.4, *Changing Lasers*, before attempting to change or use a new laser. Laser settings and proper parameters must be set according to the laser's requirements and a defined order of events must occur to initiate a new laser in the TGA. Failing to do so could irretrievably damage the laser.
 - The cam and bolt clamps of the TGA should be tightened during transport. Failure to do so could damage the analyzer.
- CAUTION:
 - The cam and bolt clamps of the TGA should only be tightened during transport. They should always be loose during operation of the TGA. The optical bench of the TGA should be free to move within its enclosure with changes in temperature. Failure to do so could result in inaccurate measurements.

3. Initial Inspection

- Upon receipt of a Campbell Scientific TGA, inspect the packaging and contents for damage. File damage claims with the shipping company. Contact Campbell Scientific to facilitate repair or replacement.
- Immediately check package contents against shipping documentation. Thoroughly check all packaging material for product that may be trapped inside. Contact Campbell Scientific about any discrepancies. Model numbers are found on each product. On cables, the model number is often found at the connection end of the cable. Check that correct lengths of cables are received.
- The TGA200A ships with the separate items listed in TABLE 3-1.

TABLE 3-1. Parts Included with the TGA200A

Part Number	Description
15895	TGA Accessory & Tool Pack
15836	TGA Leak Check Nozzle, 25ft tubing
15838	TGA Test Intake, 5ft tubing
22178	TGA200A SDM Cable, 20ft
15702	Raw Plastic Tubing 1/4 in OD X .040 Wall Polyethylene/Alum
18148	10Base-T CAT5 Ethernet Crossover Cable, 25ft
20730	9-Pin Female to 9-Pin Male Serial Data Cable, 25ft
30723	<i>TGA TEC</i> Support Software & OS
30981	TGA200A Power Module

4. Overview

The optical source of Campbell Scientific TGAs is a tunable diode laser that is simultaneously temperature and current controlled to produce a linear wavelength scan centered on a selected absorption line of the trace gas. A beamsplitter allows most of the energy from the laser to pass through a 1.5 m (4.9 ft) sample cell, where it is absorbed proportional to the concentration of the target gas. The portion of the beam that is reflected by the beamsplitter passes through a reference cell containing a prepared reference gas having a known concentration of the target gas. The reference signal provides a template for the spectral shape of the absorption line, allowing the concentration to be derived independent of the temperature or pressure of the sample gas or the spectral positions of the scan samples. The reference signal also provides feedback for a digital control algorithm to maintain the center of the spectral scan at the center of the absorption line. The simple optical design avoids the alignment and contamination problems associated with multiple-path absorption cells. The number of reflective surfaces is minimized to reduce errors caused by Fabry-Perot interference.

CPU

The TGA100 used a CPU module based on transputers. These CPU modules had limited processing capability, so the TGA100 required a DOS PC (with another transputer on an expansion card) to be connected in real time via a fiber optic cable. The TGA100A used a new CPU module with sufficient processing power to make the PC unnecessary. This transformed the TGA from a PC-based system to a synchronous device for measurement (SDM) sensor. Most of the TGA100s have been upgraded to this new CPU module. Contact Campbell Scientific if you have questions regarding this upgrade.

Software

There have been four generations of TGA software. The TGA100 software was distributed between three microprocessors: the transputer in the TGA100; the transputer in the PC; and the PC itself. The PC provided the user interface as well as storing data on the hard drive.

The TGA100A, which included the new CPU module, separated the TGA firmware (operating system of the TGA itself) from the user interface software which ran on the user's PC. With this upgrade, the TGA became a stand-alone sensor, and the PC became necessary only to check and adjust the operation of the TGA. The second generation of the interface software ran only under DOS PCs.

The third generation of user interface software, *TGA Windows*, was developed for the TGA200. *TGA Windows* greatly improves the ease of use, and allows the use of a modern PC running a Windows operating system. This software is available as an upgrade for both the TGA100 (with CPU upgrade) and TGA100A.

The fourth generation software, *TGA TEC*, is a minor update to the *TGA Windows* software that is compatible with the thermoelectrically (TE) cooled lasers used in the TGA200A. *TGA Windows* and *TGA TEC* are not mutually compatible. *TGA Windows* is used only with LN₂-cooled lasers and *TGA TEC* is used only for TE-cooled lasers. A representative screen of the *TGA Windows* software is shown in FIGURE 4-1.

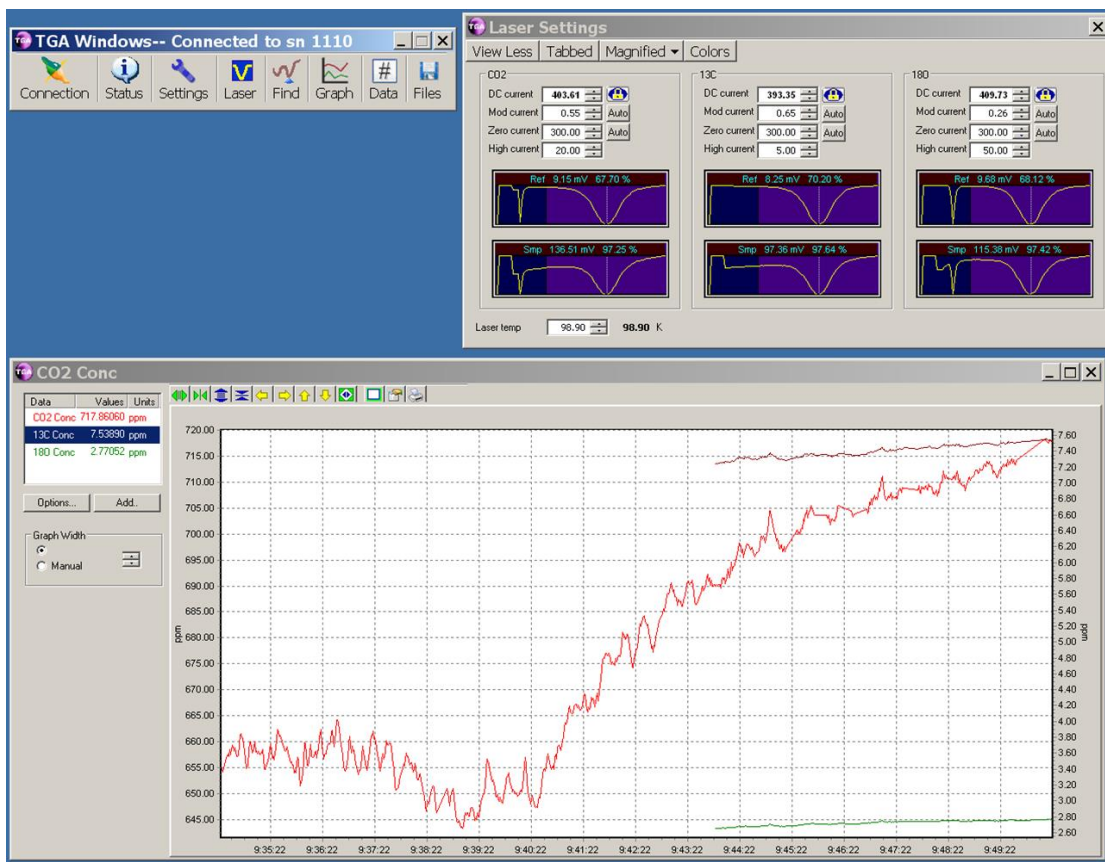


FIGURE 4-1. Screen of TGA Windows software

Laser

The lead-salt diode lasers used in the TGA100, TGA100A, and TGA200 required cryogenic cooling. These lasers were available at any wavelength from 3 to 10 μm and could be specified to detect many different gases. Most early TGAs used liquid nitrogen to cool the laser, but some TGA100As used a closed-cycle refrigeration system (cryocooler). These lasers became unavailable in 2012, when the only manufacturer discontinued production of the laser. A new room-temperature thermoelectrically (TE) cooled interband cascade laser (ICL) became available in 2014. This enabled the release of the TGA200A. These ICLs are available as an upgrade for some of Campbell Scientific's older TGAs. See Appendix H, *Upgrading Early Generation TGAs to TE-cooled Laser*, for details.

Dewars

The TGA100 was introduced with a small dewar (1.5 L) that required refilling with LN_2 once or twice per day. A much larger (10.4 L) dewar was introduced in 2002 with the evolution of the TGA100. The larger dewar allowed LN_2 filling only twice per week, rather than daily. Along with this new larger dewar a cryocooler system was introduced as an alternative. The 10.4 L dewar and the cryocooler were also used for the TGA100A.

The TGA200 used an even larger LN_2 dewar (14.5 L) to extend the refill interval to once per week.

The TE-cooled laser of the TGA200A operates without a LN₂ dewar.

Optical Configuration

The TGA100 and TGA100A have an optical assembly that includes a long sample cell, a short reference cell, and a short sample cell. The beamsplitter of the early TGAs was located at the back of the instrument, near the detectors.

The TGA200 and TGA200A optical configuration has the beamsplitter at the front (near the laser), with similar (long) sample and reference cells. The optical alignment hardware and shipping clamps are also different.

Temperature Control

Early TGA100s had fans inside the enclosure to ensure all parts of the optical system (in particular, the sample cell and the reference cell) remained at the same temperature, but had no heater or temperature controller. An optional accessory, the TGAHEAT, was introduced in 2002. TGAHEAT controlled power to a pair of heaters attached to fans which maintained the temperature of each end of the optical bench. For TGA100As, the TGAHEAT was included as a standard component.

Temperature control was improved in the TGA200 and TGA200A by controlling the temperature of the air at each end of the enclosure instead of the optical bench and including temperature control in the TGA Windows software. This allows the temperature setpoint to be changed through software rather than opening the TGA enclosure to turn a potentiometer. It also allows the user to monitor and record the fraction of power used for the heaters.

TGA100s with the TGAHEAT option and TGA100As that are running the TGA Windows or TGA TEC software may be upgraded to control temperatures through software. See Appendix I, *Install Temperature Control Upgrade*, for installation details.

4.1 System Components

The TGA200A consists of several components, some of which must be supplied by the user. Some additional accessories are required to complete a fully functioning TGA200A system and are described and illustrated in the sections that follow.

FIGURE 4-2 illustrates the main system components as well as additional equipment needed to operate the TGA200A. The other TGA models are similar.

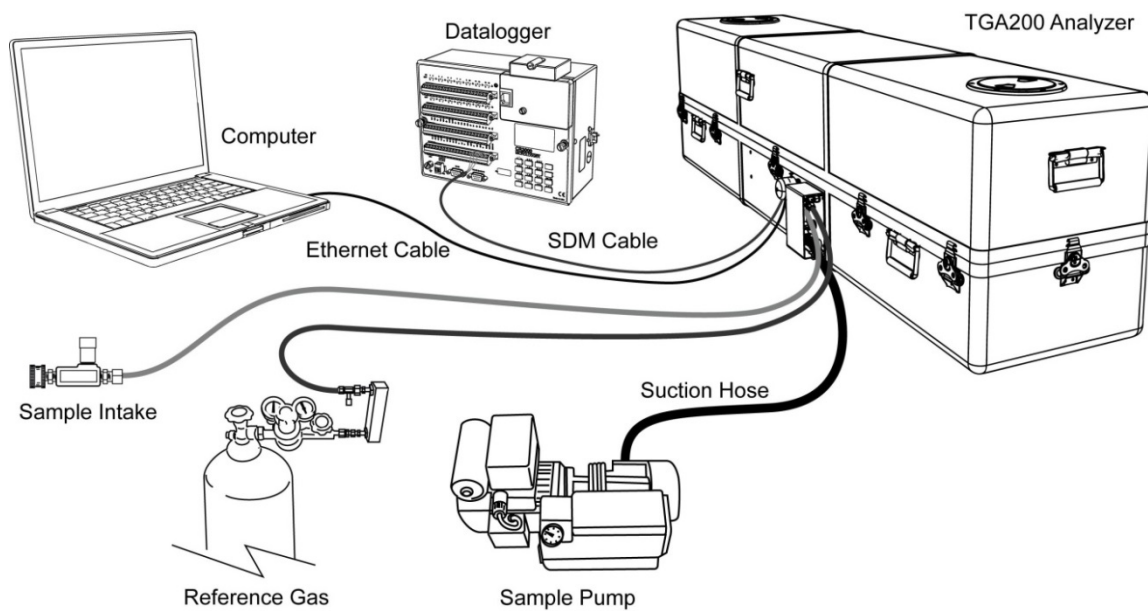


FIGURE 4-2. TGA200A system components

4.1.1 Standard Components

The newest version of Campbell Scientific's trace gas analyzers, the TGA200A, comes with the components described in the following sections.

4.1.1.1 TGA Power Module

The TGA200A power module (pn 30981) is a power module included with the TGA200A that provides 12 Vdc and 24 Vdc to the TGA200A. It is shown in FIGURE 4-3. The 12 Vdc is used to power the electronics of the trace gas analyzer, while the 24 Vdc is used to power the heaters and fans that regulate the TGA enclosure temperature. A 4.6 m (15 ft) power cable with keyed connectors is included with the module. Corresponding keyed connectors are found inside the power module enclosure and in the TGA200A enclosure. AC power input is required and the appropriate input cable type should be specified at the time of order. The type of mounting hardware for the module is also specified at the time of order.

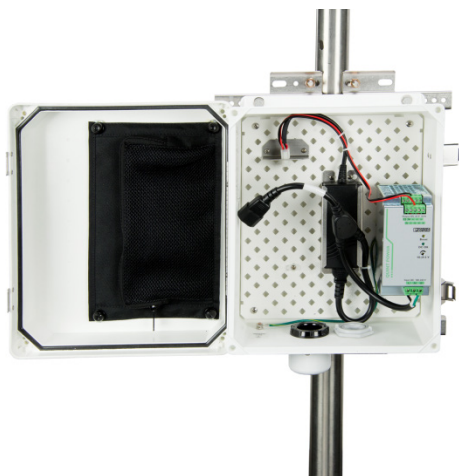


FIGURE 4-3. TGA200A power module

4.1.1.2 TGA Accessory & Tool Kit

The TGA200A comes with an accessory and tool pack (pn 15895) containing a tube cutter, analyzer mirror position gauge, and screwdriver, as well as an assortment of Swagelok® fittings, end wrenches, hex keys, and hose clamps. Many of these items are required during the installation of a trace gas analyzer.

4.1.1.3 TGA Test Intake

The test intake for the TGA200A (pn 15838) includes a filter, needle valve, and 7.6 m (25 ft) of tubing for use as a sample intake. It is shipped with trace gas systems and may also be purchased as a replacement part. The test intake is shown in FIGURE 4-4.



FIGURE 4-4. TGA test intake

4.1.1.4 TGA Leak Check Nozzle

A leak check nozzle for the TGA200A, pn 15836, includes 7.6 m (25 ft) of tubing, and a needle valve and nozzle for detecting leaks around fittings and tubing of a trace gas analyzer. Detecting leaks requires the user to supply a

pressure regulator and gas tank, where the tank should contain a relatively high concentration of the gas being measured. The leak check nozzle is shipped with each trace gas analyzer and may be purchased as a replacement part as well. The leak check nozzle assembly is shown in FIGURE 4-5.



FIGURE 4-5. TGA leak check nozzle

4.1.1.5 TGA SDM Cable

The TG200A includes a 6 m (20 ft) cable, pn 22178, used to connect the SDM ports on a trace gas analyzer to the SDM ports on a datalogger. The cable includes three wires for SDM signals, one wire for ground, and a shield. One end has untinned pigtail wires used to connect semi-permanently to the trace gas analyzer's SDM connector. The other end has tinned pigtail wires used to connect to the ports on a datalogger or SDM hub.

4.1.1.6 Plastic Tubing

The TGA200A includes 6 m (20 ft) of 1/4 in OD Synflex 1300 tubing, pn 15702, which has a high-density polyethylene jacket, overlapped aluminum tape, and ethylene copolymer liner. The aluminum layer limits diffusion of gases through the wall of the tube, making it the best option for delivering sample air from an intake to a gas analyzer.

4.1.1.7 CAT5 Ethernet Crossover Cable

A 7.6 m (25 ft), unshielded CAT5e crossover Ethernet cable, pn 18148, is included. The Ethernet cable should be used when connecting two Ethernet-capable products directly together, or when connecting one directly to a PC. It is not intended for use with hubs, switches, or routers. A CAT5e crossover Ethernet cable is shown in FIGURE 4-6.



FIGURE 4-6. TGA CAT5 Ethernet Crossover Cable

4.1.1.8 Serial Data Cable

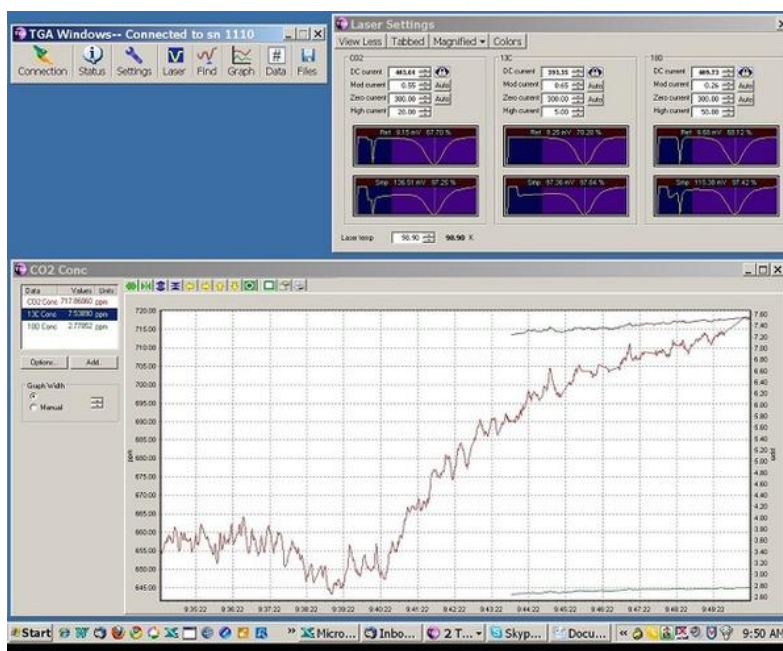
A 7.6 m (25 ft) 9-pin female to 9-pin male serial data cable, pn 20730, is included. It is shown in FIGURE 4-7. The serial cable is used to connect the RS-232 port on the TGA to an RS-232 port on a user-supplied PC.



FIGURE 4-7. Serial data cable

4.1.1.9 TGA TEC Support Software and Operating System

Included is a CD, pn 30723, that contains installation files for *TGA TEC* Support Software and current TGA firmware used to support the TGA200A or prior TGA models that have been upgraded to use a thermoelectrically cooled (TE-cooled) laser. *TGA TEC* is a user-interface software package that allows users to connect to the analyzer, set settings, and monitor real-time analyzer performance. The TGA firmware includes the OS that must be uploaded to the analyzer's CPU board before operating a TEC laser. The software is compatible with Windows XP operating systems or newer.



4.1.2 Optional Components

4.1.2.1 Laser

Depending on the gas to be measured, the TGA200A can be configured with any one of the five lasers described in TABLE 4-1.

TABLE 4-1. Part Numbers for Available Gas Species Lasers

Part Number	Description
30478	N ₂ O Laser
30477	CH ₄ Laser
31121	N ₂ O and CO ₂ Laser
31119	CO ₂ and $\delta^{13}\text{C}$ Laser
30877	CO ₂ , $\delta^{13}\text{C}$, and $\delta^{18}\text{O}$ Laser

4.1.2.2 AC Mains Power Cord

Depending on the geographic location the system is to be used, detachable AC mains power cords are available from Campbell Scientific to accommodate local electrical requirements. For reference, the part numbers and associated geographic regions are summarized in TABLE 4-2.

TABLE 4-2. Available AC Mains Power Cords by Region

Part Number	Geographic Compatibility
13999	North America
18652	Continental Europe
18653	United Kingdom and Ireland
18672	Australia and New Zealand
19295	China

4.1.2.3 Power Module Mounting Brackets

Various mounting brackets are available such that the TGA power module can be mounted at a location that is compatible to the measurement site and convenient for the user. The mounting brackets available are summarized in TABLE 4-3.

TABLE 4-3. Power Module Mounting Brackets

Part Number	Mounting Location
19002	Tripod Mast Mounting
18955	CM1XX Leg Mounting
19017	Tower Mounting
27390	Pole Mounting, 10 – 25 cm (4-10 in) diameter pole
18520	Pole Mounting, 8 cm (3 in) diameter pole

4.1.3 Common Accessories

4.1.3.1 TGA Reference Gas Connection

A TGA reference gas connection (pn 15837) is available for connecting a reference gas source to the TGA. The assembly includes a flow meter, needle valve, 6.2 m (20 ft) tubing, and 1/4 in Swagelok® fittings at either end. The assembly is shown in FIGURE 4-8. For applications requiring a purge gas, the assembly may be ordered for delivering zero gas to the purge inlet on the TGA.



FIGURE 4-8. TGA reference gas connection

4.1.3.2 TGA Insulated Enclosure Cover

The insulated TGA enclosure cover (pn 16599) is recommended when the TGA is operated in the field without additional shelter. The cover has a rainproof, white exterior to reflect the sun's heat, and additional insulation to dampen diurnal temperature fluctuations. The cover is shown installed on a TGA in FIGURE 4-9.

The cover fits over the TGA attaching with integral hook-and-loop fasteners. The 16599 cover was introduced in 2002 for use with the TGA100A. These early covers had one flap over the access hole in the top of the TGA enclosure to allow easy refilling of the liquid nitrogen-cooled laser dewar. A second flap was added in 2008 with the introduction of the TGA200, to allow access to the optional LN₂-cooled detectors. Both flaps are omitted for the TGA200A.



FIGURE 4-9. TGA with insulated cover enclosure

To install the TGA cover, place the bottom (uninsulated) piece under the TGA. The bottom is the loops portion of the hook-and-loop fastener strip around the periphery. Orient the bottom piece so the periphery folds up, with the strips on the outside. Place the top (insulated) piece over the analyzer, oriented with the flap(s) over the deck plate(s) to allow the laser dewar to be filled. Connect the side flaps to the end flaps with the hook-and-loop fastener strips and then attach the top to the bottom.

4.1.4 Other Accessories

4.1.4.1 TGA Air Sample Intake

The TGA air sample intake assembly (pn 17882) includes a rain diverter, insect screen, stainless-steel tubing, and mounting bracket. The assembly can be mounted on a pipe (as shown in FIGURE 4-10) with an outer diameter from 1.3 cm (0.5 in) to 5 cm (2 in). This intake is suitable for low- or high-flow applications.



FIGURE 4-10. TGA air sample intake

4.1.4.2 TGA Heated Intake Filter & Orifice

The heated intake filter and orifice (pn 18072) is used with trace gas analyzer systems in low-flow applications, such as atmospheric profiles or chamber measurements. The assembly consists of a plastic housing that covers and insulates a heated filter and orifice. The filter and orifice is shown in FIGURE 4-11. The heater requires 12 Vdc, 0.5 W of power and includes a connector to attach a pn 18073-L cable from a 12 Vdc source. Nominal flow for the three standard orifice sizes (0.007 in., 0.010 in., and 0.013 in.) is 0.26, 0.56, and 0.90 slpm (at sea level).



FIGURE 4-11. TGA heated intake filter and orifice

4.1.4.3 TGA High-Flow Filter Holder

The TGA high-flow filter holder, pn 20553, uses a 47 mm filter membrane to remove particulates from an air stream and has been designed with minimal dead volume to maintain frequency response when performing eddy-covariance measurements. It is included as part of the PD200T sample air dryer, and may be used in any application that requires a large-capacity filter with minimal dead volume. The filter holder is shown in FIGURE 4-12. This filter holder replaces pn 9839, which was used with the PD1000 sample dryer.

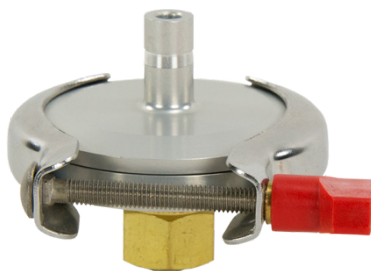


FIGURE 4-12. TGA High-Flow Filter holder

4.1.4.4 Sample Vacuum Pump

The TGA requires a sample pump to pull the sample and reference gases through the TGA at low pressure. The actual flow rate and pressure required will depend on the application. Two sample pump options are available from Campbell Scientific. The XDD1 has a capacity of 1 slpm at 50 mb (0.8 slpm with 50 Hz power), and is adequate for low flow applications. The RB0021-L has a capacity of 18 slpm at 50 mb (15 slpm with 50 Hz power), and is used for high-flow applications. The pumps are supplied with the tubing and fittings needed to connect to the TGA. A brief overview of each of the pumps is given in the following descriptions.

RB0021-L Sample Pump

The RB0021 sample pump is an air-cooled, direct-drive, oil-sealed, rotary-vane pump. It is modified with a special oil return line that allows continuous operation with minimal loss of pumping capacity, and a 2.54 cm (1.0 in) inlet connection. Specifications are given for 115 Vac, 60 Hz, single-phase power, but other power options are available. The capacity of the RB0021-L is adequate for most high-flow TGA applications, such as eddy covariance. It ships with 2.54 cm (1.0 in) ID suction hose (pn 7123), length specified per the order, and 2 qts of pn 8143 oil. The pump is shown in FIGURE 4-13.



FIGURE 4-13. RB0021 sample pump

RB0021-L specifications:

Length:	44.2cm (17.4 in)
Width:	29.2 cm (11.5 in)
Height:	26.9 cm (10.6 in)
Weight:	19 kg (42 lb)
Power:	950 W
Pumping speed:	18 slpm at 50 mb (60Hz)
Ambient temperature range for operation:	10 to 40 °C
Ultimate vacuum:	2 mb

For detailed installation and operating instructions, refer to the user manual supplied with the pump.

XDD1 Sample Pump

The XDD1 is a four-head, three-stage diaphragm pump. It is modified to include a bleeder filter and needle valve, a 1/2 in Swagelok fitting for connection to the TGA, and a 1/4 in Swagelok fitting for connection to a pressure controller, shown in FIGURE 4-14. It ships with 15.2 m (50 ft) of a 1.27 cm (0.5 in) OD LDPE tubing (pn 25539). The pump can be used on AC mains supplies ranging from 100 to 120 Vac (50 or 60 Hz) or 200 to 230 Vac (50 or 60 Hz), selected by a voltage changeover switch.



FIGURE 4-14. XDD1 sample pump

XDD1 specifications:

Length:	31.3 cm (12.3 in)
Width:	14.4 cm (5.7 in)
Height:	21.5 cm (8.5 in)

Weight:	6.7 kg (14.8 lb)
Power:	140 W
Pumping speed:	1 slpm at 50 mb (60Hz)
Ambient temperature range for operation:	10 to 40 °C
Ultimate vacuum:	< 2 mb

For detailed installation and operating instructions, refer to the user manual supplied with the pump.

4.1.4.5 Bypass Vacuum Pump

Some TGA applications, such as atmospheric profiles and chamber measurements, use a sampling system to switch between multiple inlets. These sampling systems require a bypass pump to maintain air flow through the non-selected inlets. The actual flow rate and pressure required will depend on the application. Two bypass vacuum pump options are available from Campbell Scientific. The DOAV502 has a capacity of 50 L min⁻¹ and is adequate for most low flow applications. The DAAV05-L has a capacity of 100 L min⁻¹, and is used for higher-flow applications. The pumps are supplied with the tubing and fittings needed to connect to the sampling system. A brief overview of each of the pumps is given in the following descriptions.

DOAV502 Vacuum Pump

The DOAV502, shown in FIGURE 4-15, is a single-head diaphragm pump that is often used with a trace gas analyzer system in low-flow applications, such as atmospheric profile or chamber measurements. The DOAV502 comes with 30 m (100 ft) of plastic tubing with an outer diameter of 1.27 cm (0.5 in) and an inner diameter of 0.95 cm (0.375 in).



FIGURE 4-15. DOAV502 vacuum pump

DOAV502 specifications:

Length:	22.7 cm (8.9 in)
Width:	16.5 cm (6.5 in)
Height:	25.4 cm (10.0 in)
Weight:	8.2 kg (18.0 lb)
Power:	250 W

Pumping speed:	50 L min ⁻¹
Ultimate vacuum:	180 mb

DAAV505-L Sample Pump

The DAAV505, shown in FIGURE 4-16, is a double-head diaphragm pump used for applications that require more flow than the DOAV502 can supply. The "-L" on a product model indicates that the tubing length is specified at the time of order.



FIGURE 4-16. DAAV505 vacuum pump

DAAV505-L specifications:

Length:	29.8 cm (11.7 in)
Width:	16.5 cm (6.5 in)
Height:	25.4 cm (10.0 in)
Weight:	11.4 kg (25.1 lb)
Power:	370 W
Pumping speed:	100 L min ⁻¹
Ultimate vacuum:	180 mb

4.1.4.6 Sample Air Dryer

Accurate measurements of trace-gas fluxes by eddy-covariance or gradient techniques require that variation in water vapor concentration be eliminated either by drying the sample gas before it is measured or by correcting the trace gas flux¹. Four sample air dryers are available, the PD200T, PD625, PD1T, and the PD1T-1.5. See TABLE 4-4 to compare specifications for these dryers.

¹Webb, E.K., Pearman, G.I. and Leuning, R.: 1980, "Correction of flux measurements for density effects due to heat and water vapor transfer", *Quart. J. Met. Soc.* 106: 85-100.

The dryers work by forcing the humidity in the sample air through the walls of the Nafion® tubing, where it is carried away by the purge flow. The sample air flows through the insides of the tube, or bundle of tubes, and the purge air flows outside of the tubes in the opposite direction. The water vapor is forced through the wall of the tubes by a difference in vapor pressure. The sample becomes progressively drier as it travels down the dryer, while the purge air becomes progressively more humid. For best performance, the purge flow should be very dry (–40 °C dewpoint), and should have an actual flow rate of at least twice the sample flow. Although the purge flow could be supplied by air from a compressed air tank or by ambient air dried with a chemical desiccant, for most TGA applications it is provided by the dryer itself. A portion of the sample flow is split off at the outlet of the dryer and pressure is reduced by connecting the purge outlet to the TGA sample pump. Dropping the pressure reduces the partial pressure of the water vapor and increases the actual flow rate, allowing the purge requirements to be met with just a fraction of the sample flow. More information on the dryer can be found at www.permapure.com.

TABLE 4-4. Sample Air Dryer Specifications

Specification	Units	PDIT-1.5	PD1T	PD625	PD200T
Campbell Scientific pn		21772	19206	16315	19200
Length	cm (in)	72 (28)	239 (94)	76 (30)	137 (54)
Weight	kg (lb)	0.4 (0.9)	0.7 (1.5)	4.4(9.7)	5.6 (12.4)
Connections: <ul style="list-style-type: none"> • Sample Inlet • Sample Outlet • Purge 		1/8" tube 1/8" tube 3/8" Swagelok®	1/8" tube 1/8" tube 1/2" Swagelok®	1/4" Swagelok® 1/4" Swagelok® 3/8" Swagelok®	3/8" tube 1/4" Swagelok® 1/2" Swagelok®
Sample pressure drop (at standard temperature and pressure)	mb per l min ⁻¹	4	13	10	5
Flow rate for –15 °C dewpoint	l min ⁻¹	0.5 (0 °C dewpoint)	0.5	2	16
Sample volume (internal volume of dryer tubing)	ml	1.4	6.7	10	80
Purge flow-meter range	l min ⁻¹	NA	NA	0 to 5	0 to 10

PD1T

The PD1T dryer (FIGURE 4-17) uses a 6 ft length of 0.086 in ID Nafion® tubing, similar to Permapure MD110-72 (www.permapure.com). It will dry 0.5 lpm to –15 °C dewpoint.



FIGURE 4-17. PD1T air sample dryer

The sample inlet and outlet connections are 1/18 in OD stainless steel tubes. These SS tubes connect directly to the Nafion[®] tube inside the dryer shell. This design completely eliminates dead volume in the sample flow.

The purge connections are 1/2 in Swagelok[®], and the dryer shell is 0.5 in OD Synflex 1300 tubing. This large size minimizes pressure drop in the purge flow to allow the dryer to be purged with the output of the TGA (reflux mode).

The dryer shell is flexible Synflex 1300 tubing to allow it to be integrated easily into the sampling system, typically between a multiport sampling manifold and the TGA inlet.

PD1T-1.5

The PD1T-1.5, shown in FIGURE 4-18, is similar to the PD1T, but is designed for lower capacity at lower cost. It is designed to remove enough water vapor at a sample intake to avoid condensation in the downstream tubing.



FIGURE 4-18. PD1T-1.5 air sample dryer

The Nafion[®] tube in the PD1T-1.5 is 1.5 ft long instead of the 6 ft length used in the PD1T. It will dry 0.5 lpm to 0 °C dewpoint, compared to -15 °C for the PD1T.

The sample inlet and outlet tubes are the same 1/8 in OD SS tubes as for the PD1T, but are shorter than on the PD1T. The same design for the internal connection to the Nafion[®] tube eliminates dead volume.

The purge connections are 3/8 in Swagelok[®], and the dryer shell is 3/8 in OD stainless steel tubing. The smaller shell reduces cost and the stainless steel tube is more rugged for mounting at the sample intake.

PD200T

The PD200T consists of a 200-tube, 48 in Nafion® dryer element manufactured by Perma Pure, Inc., that is housed in a rugged dryer shell designed and manufactured by Campbell Scientific. The PD200T includes a filter holder, a flow meter to measure purge flow, needle valves to adjust the sample and purge flow rates, and mounting hardware. Common accessories are spare filter membranes (pn 9838) and a 4 – 40 lpm flow meter (pn19541) to measure the sample flow. The PD200T is shown in FIGURE 4-19.



FIGURE 4-19. PD200T air sample dryer

PD625

The PD625 is similar to the PD200T, but is designed for lower flow rates. Its 50-tube, 24 in Nafion® dryer element has a drying capacity one eighth that of the PD200T. The PD625's inlet filter, tubing connections and purge flow meter range are also smaller than for the PD200T. The PD625 is normally used in the two-dryer configuration, so it does not include the sample flow meter or sample needle valve included in the PD200T. The PD625 is shown in FIGURE 4-20.



FIGURE 4-20. PD625 air sample dryer

4.1.4.7 TGA Rotameter

The TGA rotameter (pn 19541) measures air sample flow in high-flow applications such as eddy covariance. It is temporarily attached to the sample inlet while adjusting the needle valves that control the sample and bypass flows. In FIGURE 4-21, the front of the rotameter is shown on the left and the connectors at the back are shown on the right.



FIGURE 4-21. TGA rotameter

4.1.5 Support Software

The PC support software and the TGA firmware are supplied on a CD with the shipment, pn 30723.

4.1.6 Replacement Parts

Replacement parts for the TGA200A are described in the following sections.

4.1.6.1 TGA Heated Intake Filter

This heated filter (pn 18058) may be used to replace the sub-assembly of the TGA heated intake filter (pn 18072; see Section 4.1.4.2, *TGA Heated Intake Filter & Orifice*) when that filter becomes plugged. This spare heated intake filter shown in FIGURE 4-22, is recommended when the air sample intake is difficult to access in the field. It allows the convenience of replacing the entire heated filter holder in the field, and then opening the filter holder to replace the filter element later. If there is convenient access to the sample intakes, a lower cost option is to simply replace the filter element, pn 17575.



FIGURE 4-22. TGA heated intake filter

4.1.6.2 Filter Element

The filter element (pn 17575) is a 7 μ m pore-size filter element used in Swagelok® 1/4 in inline filter holders (pn 17574). It is used as a replacement element for the heated filter (pn 18058), heated filter & orifice (pn 18072), and the PD625 sample air dryer. The replacement filter element is shown in FIGURE 4-23.



FIGURE 4-23. TGA filter element replacement

4.1.6.3 TGA Filter Elements, 47mm (Qty 100)

A box of 100 polypropylene filter elements (10 μm pore size) is available as pn 9838 and shown in FIGURE 4-24. These are used with 47 mm filter holders such as the pn 20553 TGA High-Flow filter holder. The filter elements may be purchased as a replacement item.



FIGURE 4-24. 47 mm replacement filters

4.2 Theory of Operation

Campbell Scientific TGAs measure trace-gas concentration in an air sample with tunable diode laser absorption spectroscopy (TDLAS). This technique provides high sensitivity, speed, and selectivity. The optical configuration of the TGA100 and TGA100A is different than TGA200 and TGA200A, as described in the following sections.

4.2.1 Optical System

TGA100 and TGA100A

The TGA100 and TGA100A optical configuration is shown schematically in FIGURE 4-25. Infrared radiation from the laser is collimated and passed through a 1.5 m (4.9 ft) long sample cell, where it is absorbed proportional to the concentration of the target gas. A beamsplitter directs most of the energy through a focusing lens and a short sample cell to the sample detector, and reflects a portion of the beam through a second focusing lens and a short reference cell to the reference detector. A reference gas of known concentration flows through the reference cell. Reflective surfaces are minimized to reduce errors caused by Fabry-Perot interference.

This simple optical design avoids the alignment problems associated with multiple-path absorption cells.

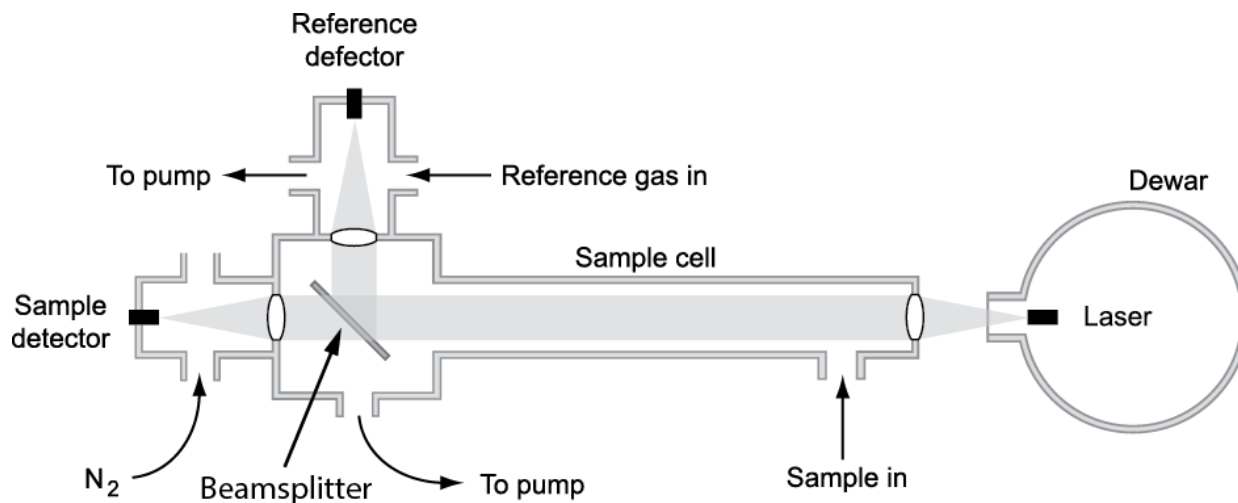


FIGURE 4-25. TGA100 and TGA100A optical configuration

TGA200 and TGA200A

The TGA200 and TGA200A optical system is shown schematically in FIGURE 4-26. The laser is partially collimated by a first lens. Most of the energy then passes through the beamsplitter and a collimating lens, and into the sample cell. The beamsplitter reflects a portion of the beam to an alignment mirror and then through a second collimating lens into the reference cell. The reference and sample cells have the same length (see TABLE 5-2 for a summary of these specifications for all systems). The back end of each cell has a focusing lens, alignment mirror, and detector.

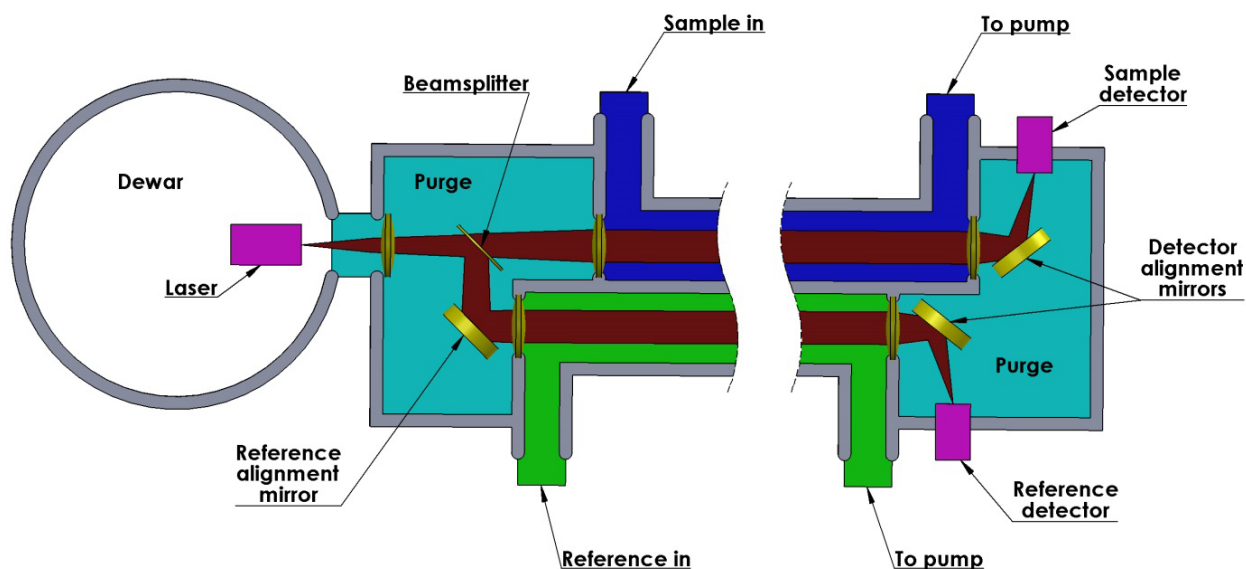


FIGURE 4-26. TGA200 and TGA200A optical configuration

4.2.2 Laser

The lead-salt diode lasers used in the TGA100, TGA100A, and TGA200 required cryogenic cooling. These lasers were available at any wavelength from 3 to 10 μm , which could be specified to detect any one of many distinct species of different gases. Lead-salt tunable diode lasers have a limited tuning range, typically 1 to 3 cm^{-1} within a continuous tuning mode. In some cases more than one gas can be measured with the same laser, but usually each gas requires its own laser. Most of these early TGAs used liquid nitrogen (LN_2) to cool the laser, but some TGA100As used a cryocooler. The laser dewars and cryocoolers have two laser positions available (four with an optional second laser mount), allowing selection of up to four different species by rotating the dewar, installing the corresponding cable, and performing a simple optical realignment.

In 2012, when the only manufacturer stopped production, lead-salt diode lasers became unavailable. In 2014, however, a thermoelectrically cooled interband cascade laser (TE-cooled ICL) became available that is operable at ambient temperature without additional cooling. Campbell Scientific's TGA200A instrument was released shortly after the TE-cooled laser became available. Some of the older TGAs can be upgraded with this laser. See Appendix H, *Upgrading Early Generation TGAs to TE-cooled Laser*, for details.

All lasers used in the TGA are infrared diode lasers with wavelengths longer than 3 microns and a divergent exit beam. Optical power for lead-salt lasers is specified as $> 0.1 \text{ mW}$, with typical powers up to approximately 1 mW. ICL optical power is $> 1 \text{ mW}$, typically 2 to 4 mW. For both types of lasers, the power varies from one laser to another. Consult the vendor data sheet for the individual laser for more information. The safety classification for both types of lasers is Class 1M.

DANGER

The TGA uses a Class 1M laser. Do not view the laser directly with optical instruments.

4.2.3 Dewars

The TGA100 came with a small LN_2 laser dewar (1.5 L) that required refilling with LN_2 once or twice per day. A much larger (10.4 L) LN_2 laser dewar was introduced in the evolution of the TGA100, in 2002. This dewar required LN_2 filling twice per week. Along with this new larger dewar, a cryocooler system was offered as an alternative. The TGA200 used an even larger LN_2 dewar (14.5 L) which extended the refill interval to once per week. The TEC ICL of the TGA200A requires no LN_2 dewar. This laser is housed in a sealed package that contains the laser mounted on a thermoelectric cooler equipped with a thermistor to measure its temperature.

4.2.4 Detectors

The standard detectors used in the TGA are thermoelectrically (TE) cooled and operate at wavelengths up to 5 microns. These detectors are used for most gases of interest, including nitrous oxide (N_2O), methane (CH_4), and carbon dioxide (CO_2). Some gases, such as ammonia (NH_3), have the strongest absorption lines at longer wavelengths, and require the optional long wavelength, liquid nitrogen-cooled detectors. These detectors can operate to wavelengths beyond 10 microns. The TGA200A uses only ICLs, which cannot

reach these long wavelengths. Therefore, the TGA200A always uses TE-cooled detectors.

4.2.5 Laser Scan Sequence

The laser is operated using a scan sequence that includes three phases: the zero phase; the high-current phase; and the modulation phase. This is illustrated in FIGURE 4-27. The modulation phase performs the actual spectral scan. During this phase, the laser current is increased linearly over a small range (typically ± 0.1 to 1.0 mA). The laser's emission wavenumber depends on its current. Therefore, the laser's emission is scanned over a small range of frequencies, typically ± 0.03 to 0.06 cm^{-1} .

During the zero phase, the laser current is set to a value below the laser's emission threshold. "Zero" signifies the laser emits no optical power; it does not mean the current is zero. The zero phase is used to measure the detector's dark response.

The reduced current of the zero phase dissipates less heat in the laser, causing it to cool slightly. The laser's emission frequency depends on its temperature as well as its current. Therefore, the temperature perturbation caused by reduced current during the zero phase, introduces a perturbation in the laser's emission frequency. During the high-current phase, the laser current is increased above the current to be applied during the modulation phase to replace the heat "lost" during the zero phase. This stabilizes the laser temperature quickly, minimizing the effect of the temperature perturbation. The entire scan sequence is repeated every 2 ms. Each scan is processed to give a concentration measurement every 2 ms (500 Hz measurement rate).

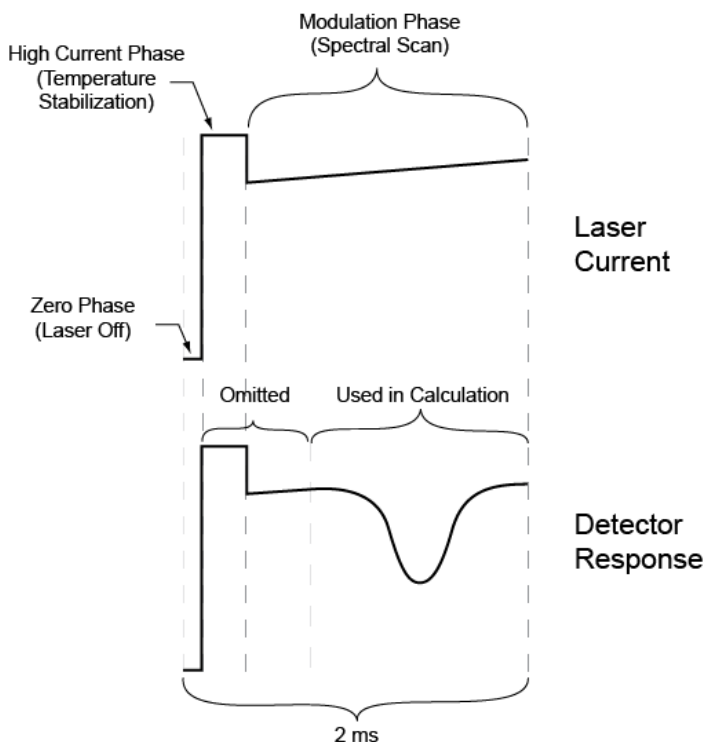


FIGURE 4-27. TGA laser scan sequence

TGAs can be configured to measure two or three gases simultaneously by alternating the spectral scan wavelength between nearby absorption lines. This technique requires that the absorption lines be very close together (within about 1 cm^{-1}). Given this, it can only be used in very specific cases. The multiple-ramp mode is used to measure isotope ratios in carbon dioxide or water by tuning each ramp to a different isotopolog.

The multiple-ramp mode may also be used to measure some other pairs of gases, such as nitrous oxide and carbon dioxide or nitrous oxide and methane. The measurement noise, however, will generally be higher than if a single gas is measured. For measurements of a single gas, the laser wavelength is chosen for the strongest absorption lines of that gas.

Choosing a laser that can measure two gases simultaneously involves a compromise. Weaker absorption lines must be used in order to find a line for each gas within the laser's narrow tuning range.

4.2.6 Concentration Calculation

The reference and sample detector signals are digitized, corrected for detector offset and nonlinearity, and converted to absorbance. A linear regression of sample absorbance vs. reference absorbance gives the ratio of sample absorbance to reference absorbance. The assumption that temperature and pressure are the same for the sample and reference gases is fundamental to the design of the TGA. It allows the concentration of the sample, C_s , to be calculated by:

$$C_s = \frac{(C_R)(L_R)(D)}{L_S + L_A(1 - D)} \quad (1)$$

where: C_R = concentration of reference gas, ppm

L_R = length of the short reference cell, cm

L_S = length of the short sample cell, cm

L_A = length of the long sample cell, cm

D = ratio of sample to reference absorbance

The terminology long/short cell is historical, based on the original TGA100 and TGA100A optical configuration. Both the TGA100 and TGA100A have a long sample cell (153.08 cm; 60.27 in) in front of the beamsplitter, and a pair of short cells (reference and sample, each 4.52 cm; 1.78 in) behind the beamsplitter (see FIGURE 4-25). The normal configuration for the TGA100 and TGA100A is to use only the long sample cell and the short reference cell. In this case, L_S is set to zero, and the values of L_A and L_R are entered. The concentration calculation simplifies to:

$$C_s = \frac{(C_R)(L_R)(D)}{L_A(1 - D)} = \frac{0.02959(C_R)(D)}{(1 - D)} \quad (2)$$

It is possible to measure very high concentrations of the target gas in the TGA100 and TGA100A by changing the plumbing connections to flow the sample air through the short sample cell instead of the long sample cell. In this case, L_A is set to zero, and the actual values of L_S and L_R are entered. The concentration calculation simplifies to:

$$C_s = (C_R)(D) \quad (3)$$

The TGA200 and TGA200A have only one sample cell and one reference cell. These are both long (146.6 cm; 57.72) and located behind the beamsplitter. Because they are behind the beamsplitter, their lengths are entered as L_S and L_R , and L_A is set to zero. The concentration calculation simplifies to Equation (3), above.

5. Specifications

5.1 Measurement Specifications

The typical concentration measurement noise is calculated as the square root of the Allan varianceⁱⁱ (Allan deviation) with 100 ms averaging, which is comparable to the standard deviation of the concentration sampled at 10 Hz and calculated over a relatively short time (10 s). The TGA multiple-scan mode can be used to measure suitable pairs of gases. Typical performance for isotope ratio measurements is given in delta notation. For example, the $\delta^{13}\text{C}$ for CO_2 is given by:

$$\delta^{13}\text{C} = \left(\frac{R_s}{R_{VPDB}} - 1 \right) \times 1000 \quad (4)$$

where: R_s = ratio of the isotopolog concentrations measured by the TGA ($^{13}\text{CO}_2/^{12}\text{CO}_2$)

R_{VPDB} = the standard isotope ratio ($^{13}\text{C}/^{12}\text{C}$)

$\delta^{13}\text{C}$ is reported in parts per thousand (per mil or ‰)

ⁱⁱ Allan, D.W.: 1966. "Statistics of atomic frequency standards", *Proc. IEEE*, **54**, 221–231

TABLE 5-1. Typical Measurement Noise^a

Part Number	Description	Chemical Formula	Typical Noise ^b	Units
30478	Nitrous Oxide	N ₂ O	1.5	nmol mol ⁻¹
30477	Methane	CH ₄	7.0	nmol mol ⁻¹
31121	Nitrous Oxide and Carbon Dioxide ^c	N ₂ O	1.8	nmol mol ⁻¹
		CO ₂	0.3	μmol mol ⁻¹
31119	Carbon Dioxide and δ ¹³ C	CO ₂	0.15	μmol mol ⁻¹
		δ ¹³ C	0.5	‰
30877	Carbon Dioxide, δ ¹³ C, and δ ¹⁸ O	CO ₂	0.5	μmol mol ⁻¹
		δ ¹³ C	2.0	‰
		δ ¹⁸ O	2.0	‰

^aPreliminary: specifications are subject to change without notice^bAllan deviation with 100 ms averaging time^cBased on the ¹³C¹⁶O¹⁶O isotopolog

5.2 Physical Specifications

The physical specifications of all of the TGA variants are summarized in TABLE 5-2.

TABLE 5-2. Physical Specifications of TGA Variants

	TGA100	TGA100A	TGA200	TGA200A
Length	211 cm (83 in)	211 cm (83 in)	211 cm (83 in)	211 cm (83 in)
Width	47 cm (18.5 in)	47 cm (18.5 in)	47 cm (18.5 in)	47 cm (18.5 in)
Height	55 cm (21.5 in)	55 cm (21.5 in)	55 cm (21.5 in)	55 cm (21.5 in)
Weight ^a	74.5 kg (164 lb)	88.9 kg (195.5 lb)	78.6 kg (173 lb)	62.8 kg (138.5 lb) ^b
Sample path length	153.08 cm (60.27 in)	153.08 cm (60.27 in)	146.6 cm (57.72 in)	146.4 cm (57.64 in)
Reference path length	4.52 cm (1.78 in)	4.52 cm (1.78 in)	146.6 cm (57.72 in)	146.4 cm (57.64 in)
Sample cell volume	480 ml	480 ml	420 ml	200 ml
Operating temperature	-20 to 45 °C	-20 to 45 °C	-20 to 45 °C	-20 to 45 °C

^aWeight of the TGA100A and TGA200 is shown for most common configuration (LN₂ laser dewar and TE-cooled detectors)^bDoes not include the weight of the power module (pn 30981) which is 5.4 kg (12.0 lb) with the accompanying power cable

5.3 Power Requirements

Analyzer (LN₂-cooled laser): 90 to 264 Vac, 47 to 63 Hz, 42 W (max)
24 W (typical)

Analyzer (TE-cooled laser): 90 to 264 Vac, 47 to 63 Hz, 34 W (max)
22 W (typical)

Heater: 90 to 264 Vac, 47 to 63 Hz, 150 W (max)
50 W (typical)

6. Installation

The basic components required to operate a TGA are shown in FIGURE 6-1 and FIGURE 6-2. The systems are very similar with the exception of the connections. The connections are located at the end of the enclosure in the TGA100 and TGA100A, whereas the connections of the TGA200 and TGA200A are located at the side of the enclosure.

Other components, such as a sample air dryer, valves to switch between multiple intakes, calibration gases, and others, may also be required, depending on a given user's application.

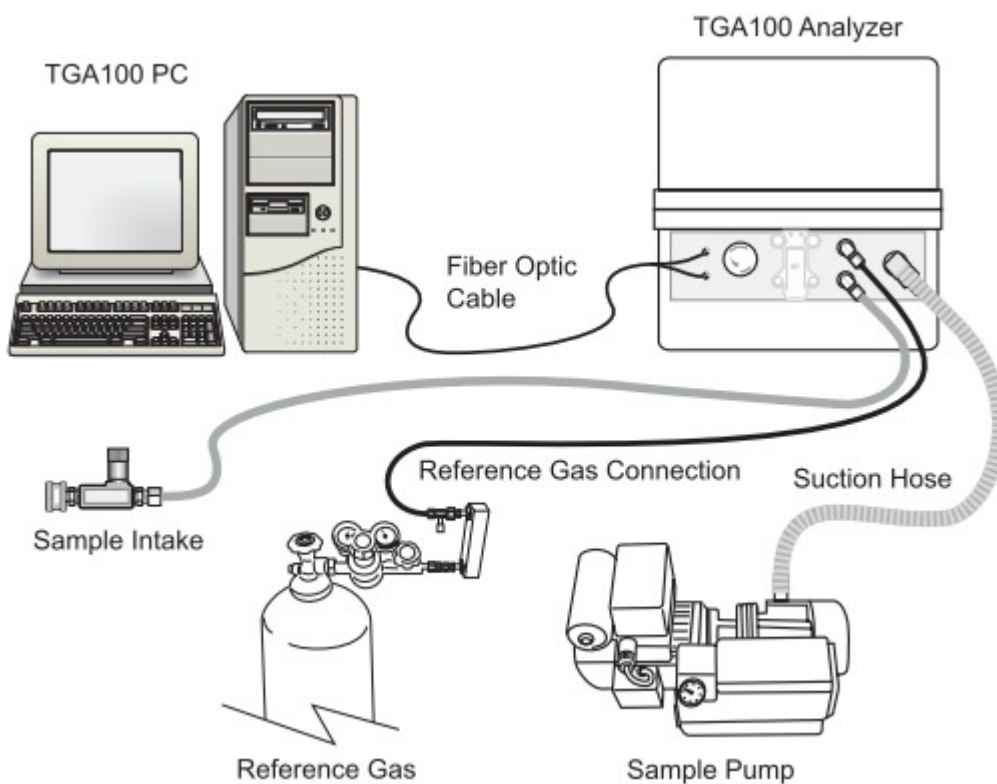


FIGURE 6-1. Basic components required for TGA100 operation

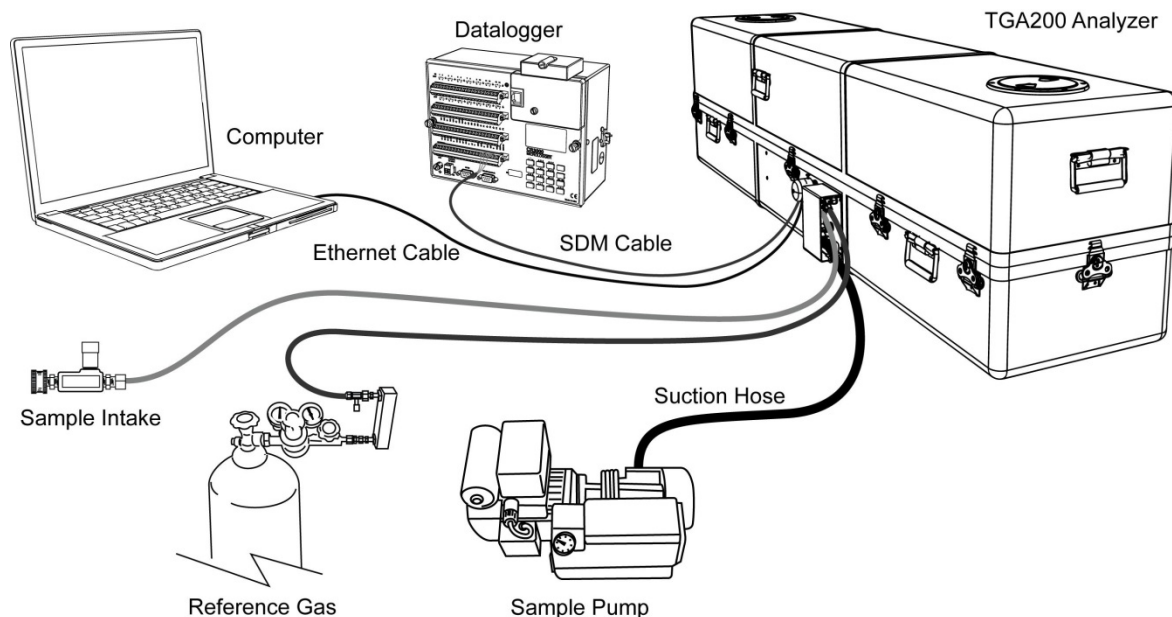


FIGURE 6-2. Basic components required for TGA200 and TGA200A operation

6.1 Analyzer Installation

The TGA analyzer is housed in an insulated fiberglass enclosure (FIGURE 6-3) equipped with a temperature controller that allows the TGA to operate in a wide variety of environmental conditions.



FIGURE 6-3. TGA200A enclosure

The analyzer must be placed on a stable surface. If placed on uneven ground, wooden blocks or other supports can be used under the two pairs of rubber feet near the ends of the enclosure.

NOTE

Early TGA100s had a third pair of rubber feet under the center of the enclosure. These TGAs should be placed on blocks to lift the TGA so these center feet are not used for support.

Once the TGA is positioned, loosen the shipping clamps.

TGA100 and TGA100A

The TGA200 and TGA100A used nylon belts to secure the optical bench inside the enclosure. Loosen these belts and then loosen the transport lock and the axial lock screws as shown in FIGURE 6-4.

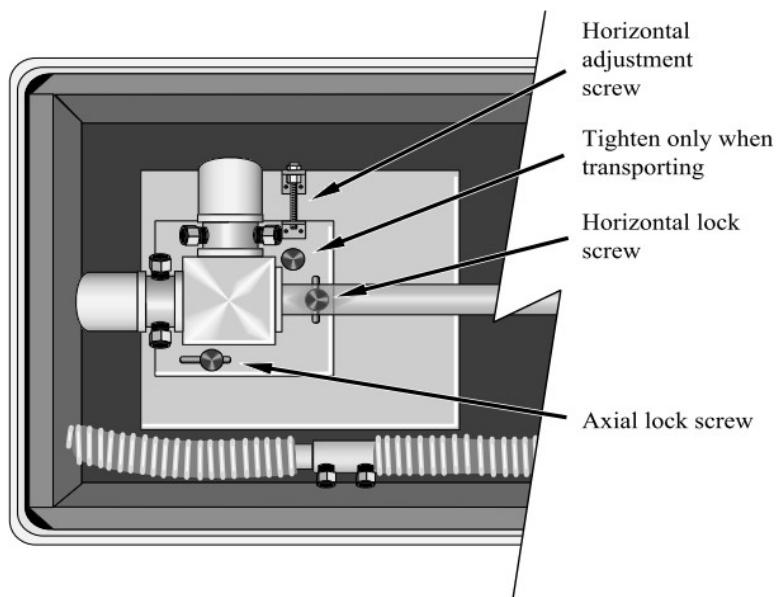


FIGURE 6-4. TGA100 and TGA100A transport locks

TGA200 and TGA200A

The TGA200 and TGA200A use a set of four cam clamps to lock the optical bench down for transport. Flip the cam clamps to the loose position for operation. Also loosen the four bolt clamps that lift the optical assembly off the optical bench, and the additional bolt clamp that holds the alignment mechanism down. The cam and bolt clamps are shown in FIGURE 6-5.

NOTE

The cam and bolt clamps should be tightened only for transport. They should be loose during operation to allow the optical bench to move within its enclosure with changes in temperature.

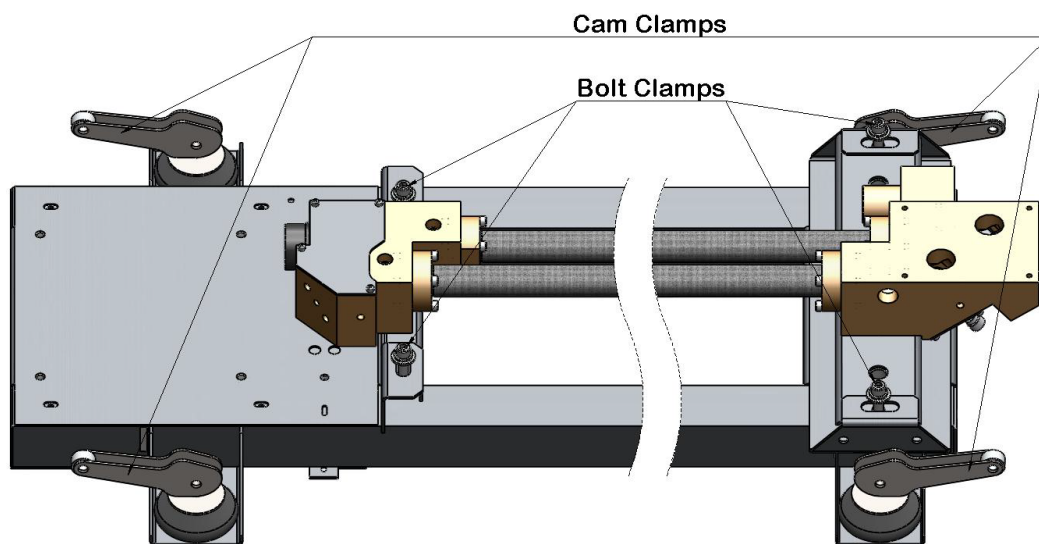


FIGURE 6-5. TGA200 and TGA200A shipping clamps

Once the enclosure is properly positioned, the analyzer needs sample input connections and data output connections. The analyzer should be connected to other system components as follows.

6.1.1 Plumbing Connections

A TGA requires only a few additional components to draw samples into the system to be analyzed. The connections for the TGA200A are located at the center of the TGA enclosure under the feedthrough cover (FIGURE 6-6). Lift the cover following directions indicated on the cover to expose the connections. Follow the steps below for this simple set up. Refer to FIGURE 6-7 as needed for the physical connections.



FIGURE 6-6. Feedthrough cover of TGA200A



FIGURE 6-7. Plumbing connections located under feedthrough cover of TGA200A

1. Connect the vacuum exhaust outlet of the analyzer to the sample pump. The sample pump must be able to pull the required flow rate at 75 mb or less. The actual flow rate and pressure required will depend on the application.

NOTE

Two sample pump options are available from Campbell Scientific. The RB0021 is used for high-flow applications and the XDD1 is adequate for low-flow applications. See Section 4.1.4.4, *Sample Vacuum Pump*, for more details on sample pumps.

2. Connect a reference gas supply to the reference gas inlet. The reference gas supply should have an appropriate regulator, flow meter, and needle valve so that it will supply the reference gas at approximately 10 ml/min. The reference gas assembly (pn 15837) is available from Campbell Scientific to provide the flow meter, needle valve, and tubing for this connection. See Section 4.1.3.1, *TGA Reference Gas Connection*, for specifics about the assembly and Appendix A.2, *Reference Gas*, for more details on the reference gas.
3. Connect the sample intake to the sample gas inlet. The sample intake should be filtered to remove particulates (10 μ m maximum pore size) and should have an appropriate needle valve or fixed orifice to control the sample gas flow. The test intake (pn 15838) is shipped with the TGA to make the initial setup easier for the user. The test intake includes a filter, needle valve, and tubing to allow the TGA to operate without fully installing the eddy covariance (EC) intake and dryer, or other intake assembly or sampling system that will be used in a field installation.
4. If the application requires very high accuracy, connect a purge gas supply to the TGA purge inlet. The purge gas supply should have an appropriate regulator, flow meter, and needle valve to supply approximately 10 ml/min. The reference gas assembly (pn 15837) is available from Campbell Scientific for this connection, refer to Section 4.1.3.1, *TGA Reference Gas Connection*.

6.1.2 Data Output Connections

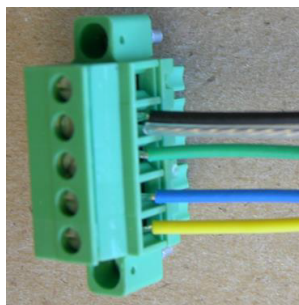
Connect the SDM cable to the CPU module in the TGA and the datalogger. A 20 ft SDM cable (pn 22178) is included for this purpose. If a longer SDM cable is needed, use pn CABLE4CBL-L.

See Section 7.3.1, *SDM Output*, for details on SDM data output.

NOTE

If using the CABLE4CBL-L, the colors of the wires are different.

Remove the cable feedthrough cap from side of the TGA enclosure and insert the end of the SDM cable. The connections at the TGA use a five-pin green connector as shown in FIGURE 6-8.



+12 not connected
 G = SDM reference (black) and SDM shield (clear)
 C1 = SDM data (green)
 C2 = SDM clock (blue)
 C3 = SDM enable (yellow)

FIGURE 6-8. SDM connections of TGA

The SDM cable connector attaches to the CPU board in the TGA as shown in FIGURE 6-9.

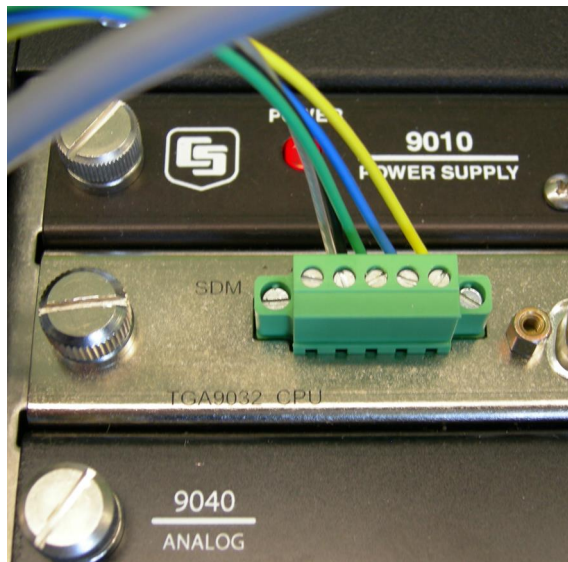


FIGURE 6-9. SDM cable connector on TGA CPU board

Once the SDM cable is connected to the CPU board, secure the cable to the outside of the electronics box at two places as shown in FIGURE 6-10.

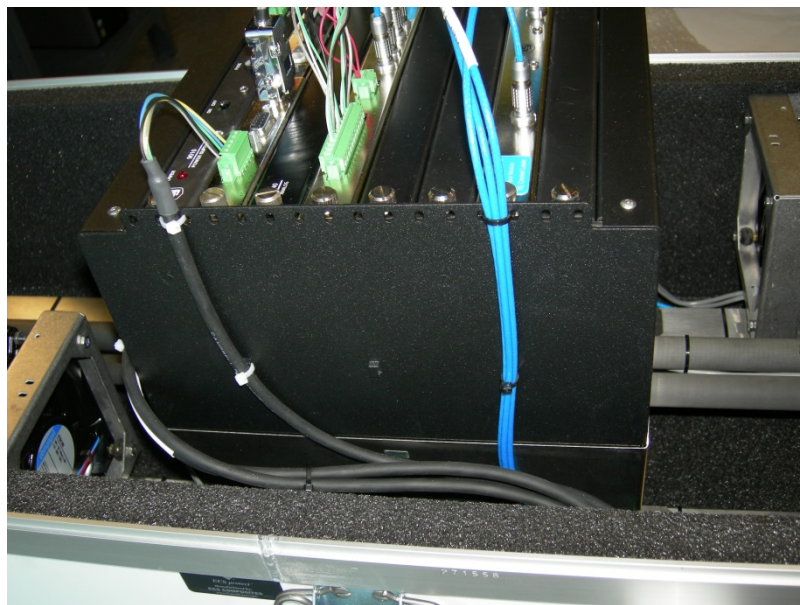


FIGURE 6-10. SDM cable tied to electronics box

Connect the other end of the SDM cable to a datalogger.

To configure the TGA for SDM output, connect a PC running TGA Windows/TGA TEC. Open the window **Settings > Other > Data Output**.

Click **SDM Output** as shown in FIGURE 7-46 of Section 7.3.1, *SDM Output*, and enter the SDM address for the TGA.

6.1.3 Power

The TGA100, TGA100A, and TGA200 used AC/DC adapters inside the analyzer enclosure to provide power for the analyzer and the temperature controller. Connect these to AC mains power using the detachable power cords supplied.

The TGA200A includes a TGA power module (pn 30981) which is a separate enclosure to house the AC/DC adapters.

1. Mount the TGA power module near the TGA. Various mounting options are available as described in Section 4.1.2.3, *Power Module Mounting Brackets*.
2. Remove the cable feedthrough cap from side of the TGA enclosure and insert one end of the DC power cable. Plug the DC power cable into the mating connector on the electronics box and secure the cable to the corner of the electronics box as shown in FIGURE 6-11.

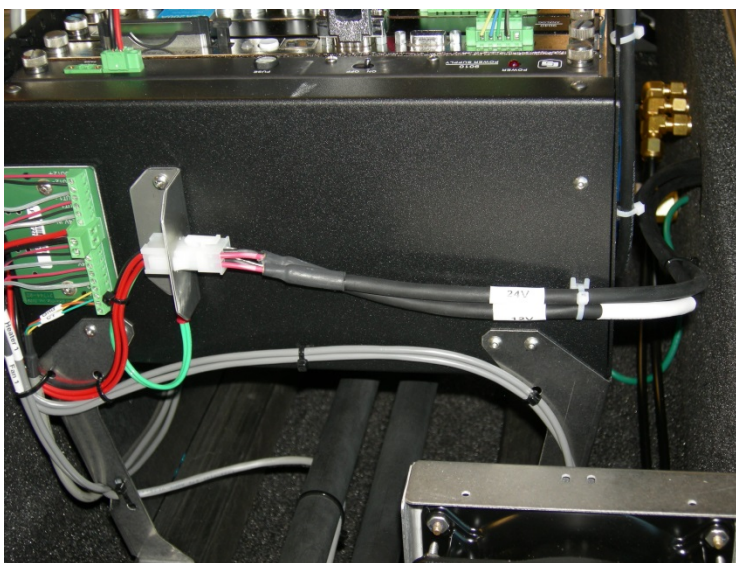


FIGURE 6-11. DC power cable connected to TGA200A and secured on electronics box

3. Replace the cap of the cable feedthrough by pushing it on, rotating it to fit snugly against the cables, and tightening the thumbscrew.
4. Secure the SDM and power cabling by routing along the bottom of the feedthrough bracket and securing with cable ties as shown in FIGURE 6-12.



FIGURE 6-12. Routing of SDM and power cable through TGA200A feedthrough bracket

5. Remove the feedthrough cap from the bottom of the power module. Insert the other end of the DC power cable into the power module and connect it to its mating connector.
6. Connect the power module to AC mains power (90 to 264 Vac, 47 to 63 Hz) using the detachable power cord.

NOTE

If a long AC power cord is required, have a qualified electrician connect the field-wireable plug (pn 28771) to a user-supplied cord.

7. Replace the cap of the cable feedthrough by pushing it on, rotating it to fit snugly against the cables, and tightening the thumbscrew. The connected power module enclosure is shown in FIGURE 6-13.

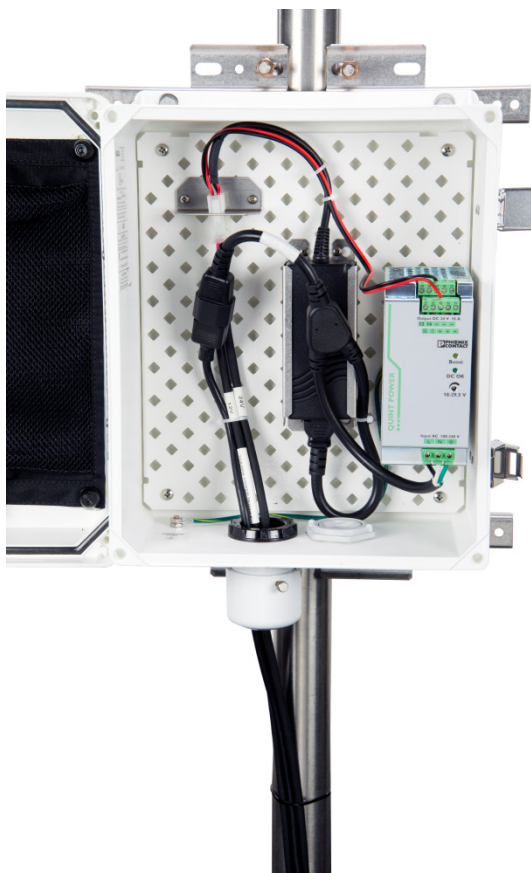


FIGURE 6-13. TGA200A power module with cables installed

6.2 TGA Software Installation

This manual documents the *TGA Windows* and *TGA TEC* software. These two software packages are very similar, but they are not interchangeable. *TGA Windows* is used with LN₂-cooled lasers, while *TGA TEC* is used with TE-cooled lasers. These two packages are very similar, so most of the discussion applies to both. Differences are noted as applicable.

The TGA software runs on the user's PC, which must be running Windows XP or newer operating system. The software provides the user interface to the TGA, allowing the user to view the operation of the TGA and set parameters. The software can also be used to collect TGA data although in most cases a Campbell Scientific datalogger is used to collect data.

NOTE

Early DOS-based versions of the TGA software are no longer supported. Any TGA100A or a TGA100 with an upgraded CPU module may be upgraded to the *TGA Windows* or *TGA TEC* software. Contact Campbell Scientific for details.

6.2.1 Installation of PC Software

To install the software, run the *setup.exe* file on the installation disk. This will install the TGA software file *TGA_Windows.exe* or *TGA_TEC.exe* on your PC.

The default path is *C:\Program Files\Campbellsci\TGA*. The installation will install a shortcut to this file and put it on your desktop.

For users with multiple TGAs and a combination of cryogenic and TE-cooled lasers, it is possible to have both programs installed on a PC. The shortcut icons to start these two programs are distinguished by the color and the text, as shown in FIGURE 6-14. Installing the software also starts a communication process that runs in the background and registers the software for later installation or updates.



FIGURE 6-14. PC shortcut icons for TGA Windows (left) and TGA TEC (right)

6.2.2 Updating TGA Operating System

Run the installation program (for example *TGA_Firmware2.1.exe*) in the *TGA Operating System* folder on the installation disk. This will extract the TGA OS file (for example *TGA_2.1.obj*) and the TGA program *tga.cr9* and place them in the default directory *C:\Campbellsci\Lib\OperatingSystems*.

1. As shown in FIGURE 6-15, connect the PC's COM port to the RS232 port on the TGA's CPU module with a serial cable (pn 20730 is supplied for this purpose).

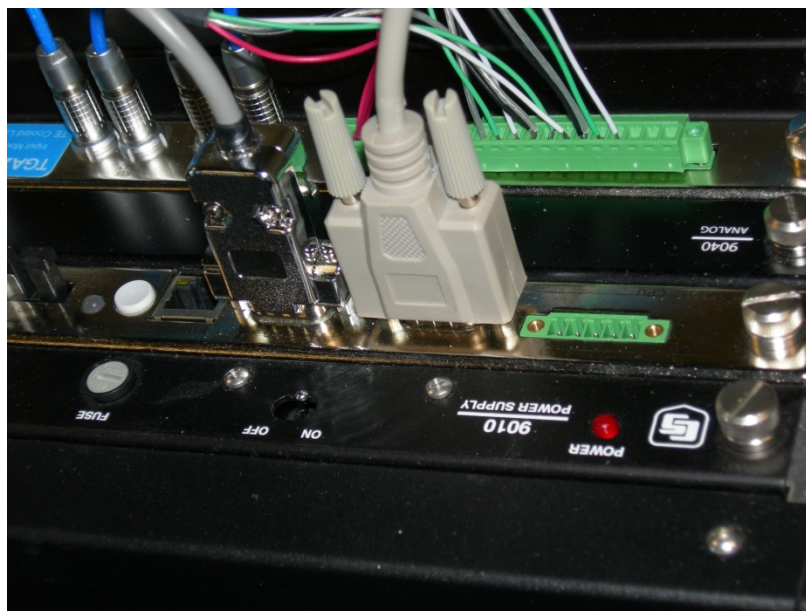


FIGURE 6-15. Serial cable connecting PC to RS232 port of TGA CPU module

2. Run the Campbell Scientific *Device Configuration Utility* (part of *LoggerNet*, or available for free from Campbell Scientific).
3. Select device type TGA100A/TGA200 and follow the directions to connect to the TGA.
4. Select the *Send OS* tab and follow the directions (FIGURE 6-16) to send the new operating system to the TGA.

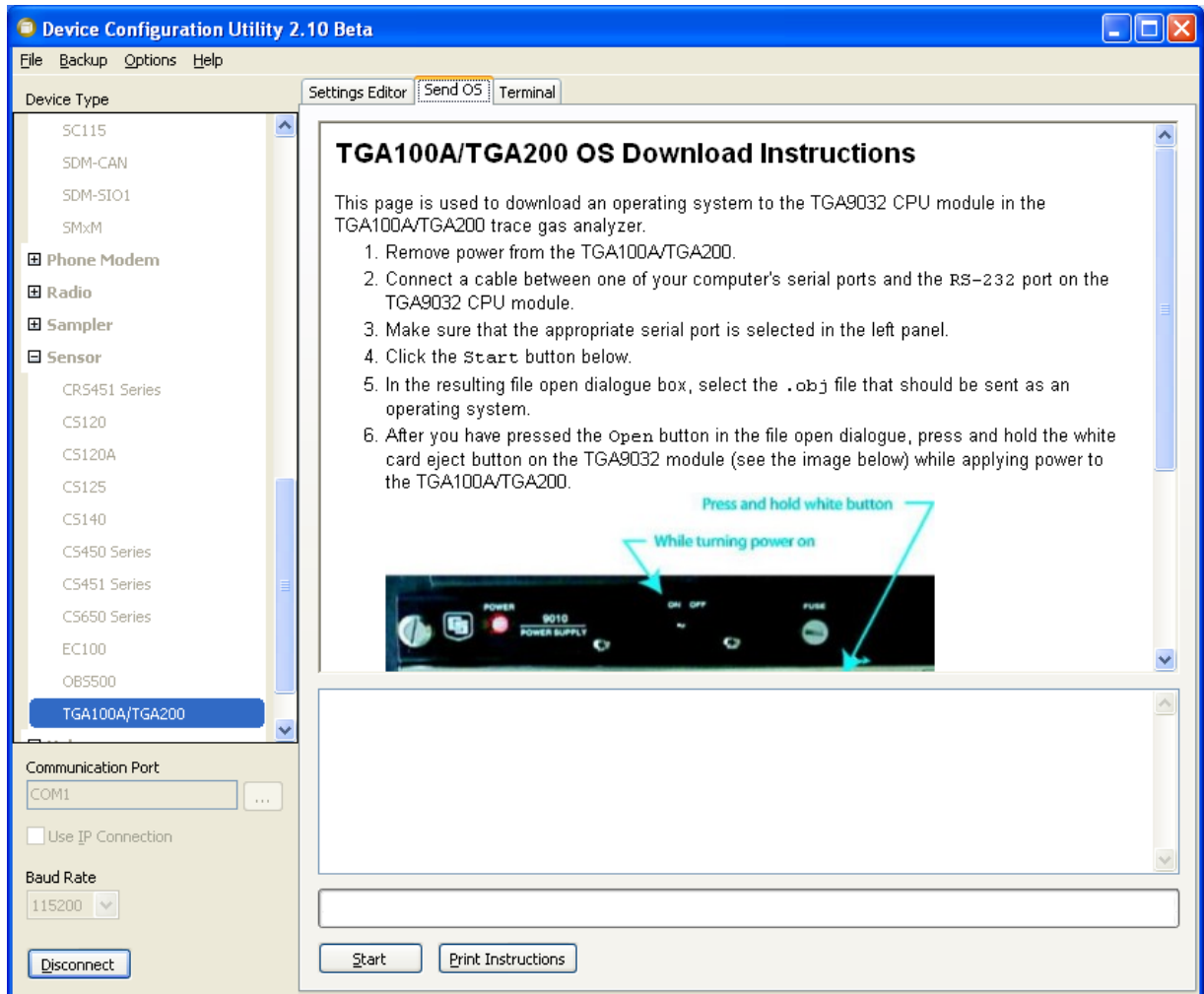


FIGURE 6-16. TGA100A/TGA200 OS download instruction

The TGA runs a program similar to a CR9000X datalogger program. This program is installed at the factory and normally does not need to be updated when the operating system is updated. However, if this file becomes corrupted or needs to be updated, connect to the TGA with the Device Configuration Utility which will bring up the screen shown in FIGURE 6-17. From there select the *Logger Control* tab. Click the **Send Program** button and send the file *tga.cr9*.

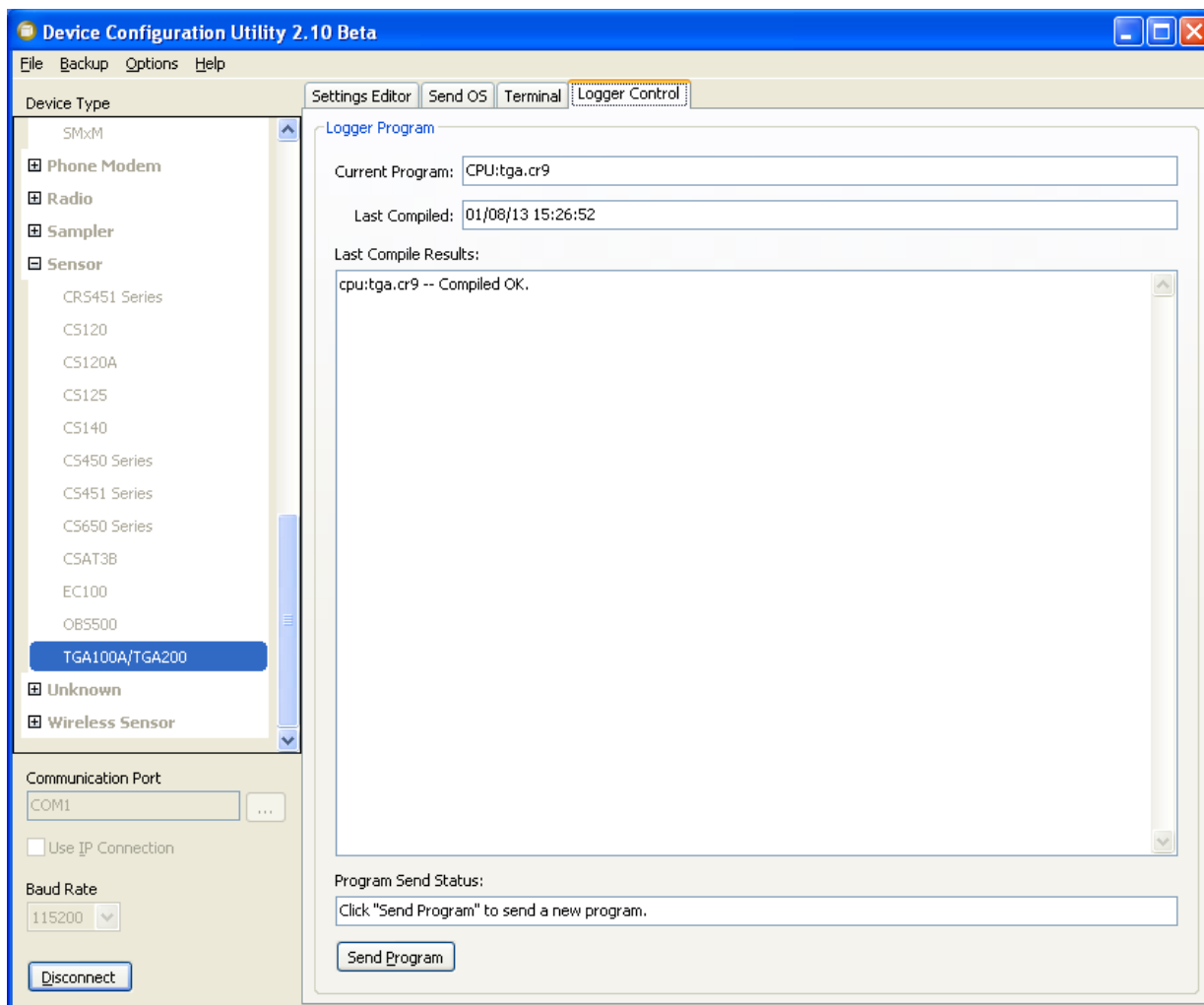


FIGURE 6-17. Device configuration utility Logger Control tab

6.2.3 Configure Ethernet Connection

There are two ways to set up the Ethernet connection between the TGA and a PC. If a local-area-network (LAN) is available, connect the TGA and your PC to the LAN. This option allows a PC to connect to the TGA from any location in the world, as long as both are connected to the internet

If no LAN is available, connect your PC directly to the TGA with an Ethernet crossover cable (pn 18148 is supplied with the TGA for this purpose). This option requires the PC and the TGA to be physically close, but it requires no additional infrastructure. Configure your PC for a peer-to-peer network with the TGA. Consult your information technology support group as needed.

With either type of Ethernet connection, the TGA's IP address, Netmask, Gateway, and IP port must be set. These settings are stored in the CPU module's nonvolatile memory. They can be changed only through the *Device Configuration Utility*. These settings are normally retained when the TGA operating system is updated, but it is good practice to verify them. Connect to the TGA with the *Device Configuration Utility* and select the *Settings Editor*

tab to review or edit these settings. The IP address, subnet mask, and gateway should be set as directed by your information technology support group. Set the IP port for the TGA to 3000.

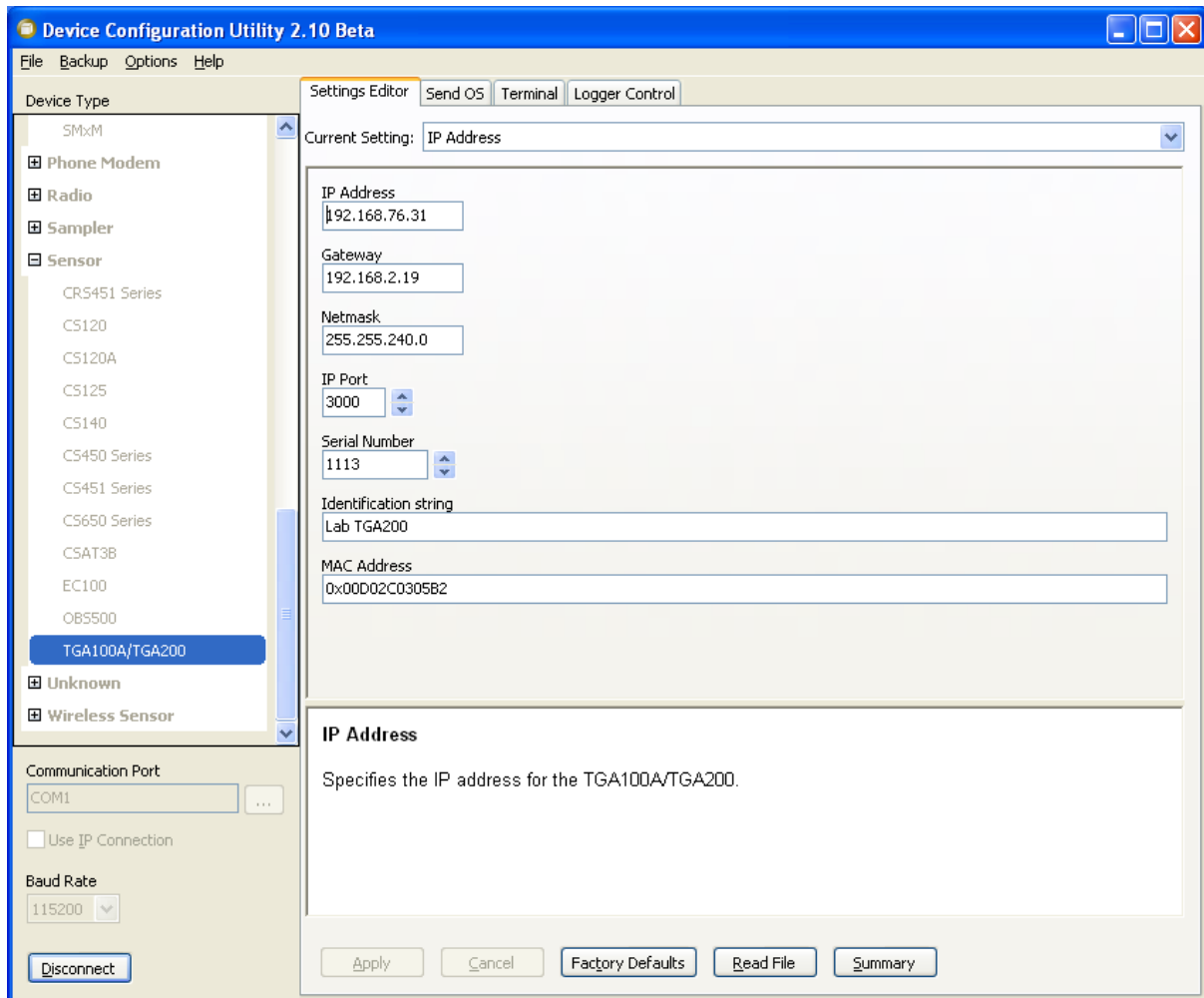


FIGURE 6-18. Device Configuration utility Settings Editor tab

NOTE

The TGA requires a static IP address.

Some local area networks are set up to require the network administrator to know the MAC address of devices connected to the network. The *Settings Editor* tab also displays the TGA's MAC address, but does not allow it to be edited.

The MAC address of each TGA is set at the factory and is stored in nonvolatile memory. If the memory storing the MAC address becomes corrupted, it will be displayed as all zeros (0x000...). To reenter the MAC address, execute the following steps:

1. Power down the TGA.

2. Remove the CPU module and note the serial number. Convert the serial number from decimal to hexadecimal (base 16). Web-based converters are available. FIGURE 6-19 shows an example, converting serial number 1458 to its representation in hexadecimal, 5B2.

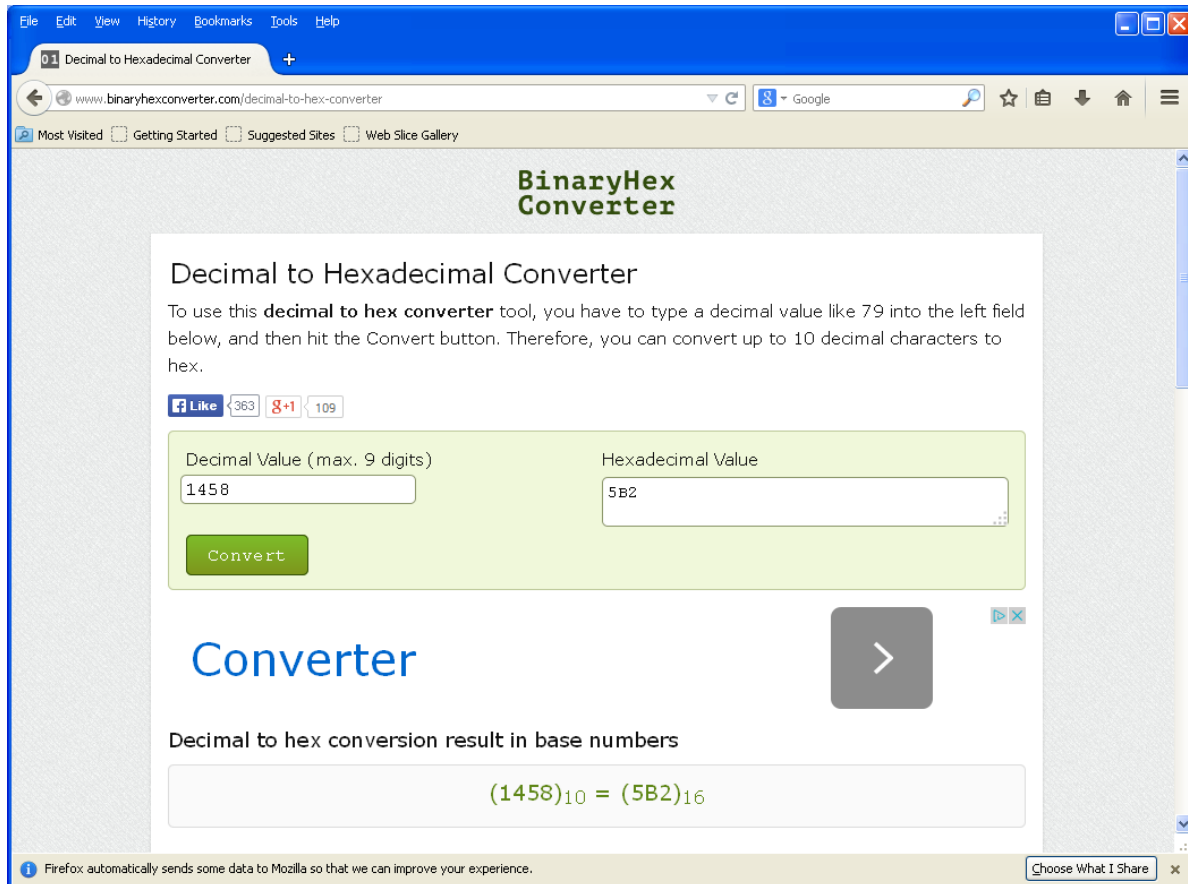


FIGURE 6-19. Web-based decimal to hexadecimal converter

3. Reinstall the CPU module and power up the TGA.
4. Connect to the TGA with *Device Configuration Utility*.
5. Select *Terminal* mode and then uncheck the **All Caps** box at the bottom of the window as shown in in FIGURE 6-20.
6. Enter **C** to view the *Configuration Options*.
7. Enter **1** (Ethernet Address). At the prompt, enter **0x** followed by a four-digit hexadecimal value. If the serial number in hex is less than four digits, use leading zeros to create a four digit hex number. In the example shown in FIGURE 6-19, the serial number entered would be 0x05b2.

NOTE

The 0x preceding the four-digit hex, must be a lowercase x.

8. Enter **6** to **Save and Exit**.

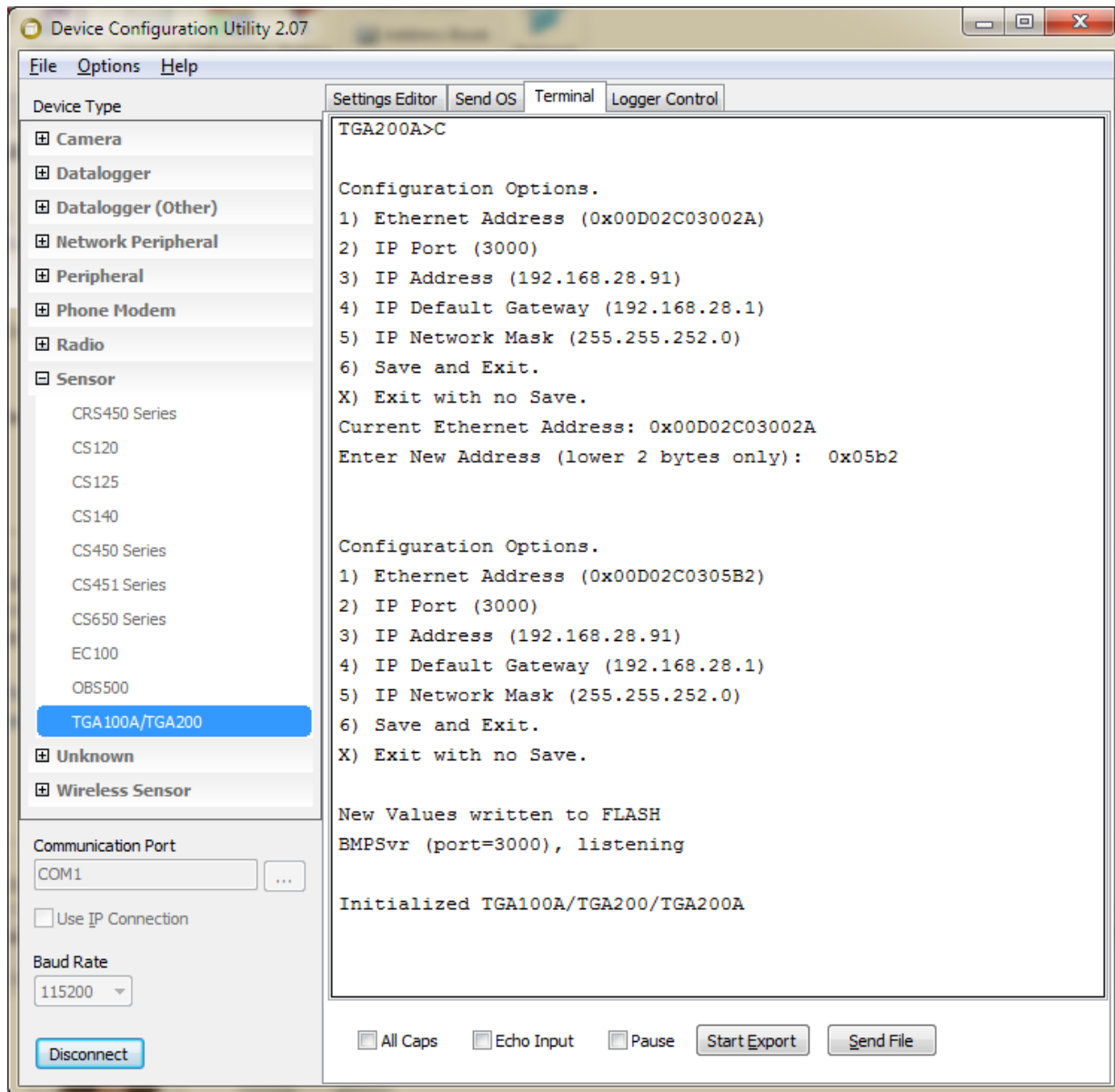


FIGURE 6-20. Device configuration utility Terminal tab

6.2.4 Set TGA Serial Number and Identification String

The TGA serial number and an identification string are stored in nonvolatile memory. The serial number can be displayed and edited on the *Settings* tab of the *Device Configuration Utility*. Set the serial number to match the serial number of your TGA. The serial number for a TGA100 or TGA100A is found on the laser mounting plate, inside the analyzer enclosure. The serial number for a TGA200 or TGA200A is found next to the plumbing connections on the outside of the analyzer enclosure. This setting allows the TGA Windows or TGA TEC software to verify it is connected to the proper TGA before sending parameters (see Section 7.2.1, *Connect Window*).

The identification string is also displayed and edited on the *Settings* tab of the *Device Configuration Utility*. The identification string is intended as a device nickname and to be a more user friendly way than the serial number by which to identify which TGA is connected to the PC software. The identification string is displayed at the top of the toolbar when the TGA software is connected to a TGA. The identification string can be any text, up to 19 characters.

6.2.5 Run the PC Software

Start the *TGA Windows* (for LN₂-cooled laser) or *TGA TEC* (for TE-cooled laser) software, which will bring up the toolbar. Descriptions of the toolbar functions are given in greater detail in Section 7.2, *Software User Interface*.

6.3 Detailed Setup Instructions

When the TGA is first installed, or if it is reconfigured (for example, with a new laser) the operational parameters must be set for optimal performance. Appendices A through E give detailed instructions to configure the TGA for a specific gas species, performing the optical alignment, optimizing the laser parameters, optimizing the detector parameters, and calibration. If the TGA has already been configured, see Section 7.1.1, *Startup Procedure*, for routine startup instructions.

7. Operation

7.1 Routine Operation

Once the TGA has been set up, it should be checked periodically to verify proper operation and to perform routine maintenance. Consistently recording operating parameters such as pressure and detector signals is strongly encouraged. Significant changes in these values from one operational period to the next, is often indicative of problems with the system.

7.1.1 Startup Procedure

1. This section describes the routine procedure for starting the TGA. If the TGA is equipped with a LN₂ cooled laser, cool the laser dewar.

NOTE

If the TGA is equipped with a TE-cooled laser, it will be cooled automatically.

2. If the TGA is equipped with LN₂-cooled detectors (used for long wavelength operation), cool the detectors with liquid nitrogen.

NOTE

If the TGA is equipped with the standard TE-cooled detectors, they will be cooled automatically.

3. Start the sample vacuum pump.
4. Turn on the reference gas. A regulator pressure of 0 psig and a flow rate of approximately 10 ml/min are recommended.

5. Turn on the purge gas if required (high accuracy applications). A flow rate of approximately 10 ml/min is recommended.
6. Power up the TGA analyzer. It is supplied with universal-input power supplies. Connect the power supplies to AC power (90 to 264 Vac, 47 to 63 Hz).
7. On a user-supplied PC, start the TGA program, and connect to the analyzer and check its status (see Section 7.2.2, *Status Window*).
8. Verify the TGA pressure is consistent with the previous operation of the TGA. The sample pump capacity, the total flow at the pump, and pressure control by the sampling system determine the pressure. If the pressure has changed, it may indicate a problem in the plumbing.
9. Verify the correct absorption line is being scanned. Usually it is sufficient to simply verify the DC current, reference detector transmittance, concentration and concentration noise are consistent with normal operation (see Section 7.1.2, *Routine System Checks*). If any of these values have changed significantly from their normal values, see Appendix A.4, *Finding the Absorption Line*.
10. Verify the detector signals are consistent with previous operation of the TGA. If they have changed, check the operational parameters (see Appendices B through D).
11. Verify that the reference transmittance at the center of the absorption line is consistent with previous operation of the TGA. This transmittance is dependent on which absorption line is selected, the concentration in the reference cell, the pressure in the reference cell, and the laser performance. A significant change indicates a problem.
12. Check the concentration and the concentration standard deviation to verify proper performance.

The TGA is now fully functional.

7.1.2 Routine System Checks

The TGA is often used for long-term, continuous measurements. It is necessary to periodically check the status of the system and perform routine maintenance. The status can be checked either with the TGA software running on the user's PC, or through a datalogger connected to the TGA. If the TGA is in multiple-ramp mode, check the values for each ramp. Parameters should be tracked in a log book to establish normal values and variability. This will help the user to recognize when a parameter changes beyond its normal variability.

1. Verify the status flags. If using a datalogger, make sure the value of the **TGAStatus** variable is zero. A nonzero value indicates a problem. See Section 7.3.1, *SDM Output*, for details on the TGA status flags. If using the PC software, check for error messages in the *Status* window (see Section 7.2.2, *Status Window*).
2. Record the DC current and compare it to the expected value. An abrupt change in the DC current may indicate the laser has shifted to

another absorption line. A persistent trend over time in the DC current may indicate premature aging of the laser.

3. Record the reference transmittance and compare it to previously recorded values. A change in the reference transmittance may indicate a problem with the reference gas supply. It can also be caused by a shift to a different absorption line, or a change in the pressure or temperature in the sample cell.
4. Record the sample pressure and compare it to previously recorded values. If the TGA sample pressure is actively controlled by the datalogger, a change in the pressure indicates a problem with the flows and pressures in the sampling system. If the pressure is not actively controlled it will be determined by the sample flow and the pump capacity. In this case, the pressure will decrease over time as the sample intake filter(s) becomes plugged.
5. If the TGA is equipped with a LN₂ cooled laser, record the laser heater voltage and compare it to previously recorded values. The vacuum inside the laser dewar will gradually degrade. This degradation reduces the thermal isolation between the outer wall of the laser dewar and the laser itself. Over time, as more heat is transferred to the laser by the degraded vacuum, less heat is needed to maintain the laser at the set temperature, and the laser heater voltage will gradually decrease. Therefore, monitoring the laser heater voltage may give an indication of when it is time to evacuate the dewar. If the TGA is equipped with a TE-cooled laser, record the laser cooler voltage.
6. Verify that the concentration and concentration noise are as expected.
7. If the TGA is equipped with a LN₂-cooled laser, fill the laser dewar with liquid nitrogen as needed. If the TGA is equipped with LN₂-cooled detectors, fill the detector dewar as needed.
8. Check the reference gas tank and regulator pressure. Check other tanks (air gap purge, calibration, etc.) as needed. Monitor the change in pressure as these gases are consumed, to gauge when to order replacement tanks and to identify possible leaks.

7.1.3 Shutdown Procedure

This section describes the routine shutdown procedure for the TGA.

1. If a PC is connected to the TGA, turn off data collection if data is being collected, and quit the TGA program.
2. Shut off the TGA sample pump (and bypass pump, if applicable).
3. Shut off power to the TGA.
4. Shut off reference gas supply.
5. Shut off air gap purge supply, if applicable.
6. Shut off calibration gas supplies, if applicable.

If the TGA is equipped with a LN₂-cooled laser, there are two recommended shutdown states the TGA should be left in depending on how soon the TGA will be put back into use.

- If the laser is to be operated again in the near future, it is recommended to keep the laser cold to avoid temperature cycling the laser.
- If the TGA will not be used for an extended period, allow the laser to warm up and evacuate the dewar.

7.2 Software User Interface

When the TGA program is started as described in Section 6.2.5, *Run the PC Software*, the toolbar is displayed as shown in FIGURE 7-1. The functions are listed below and described in greater detail in the following sections.

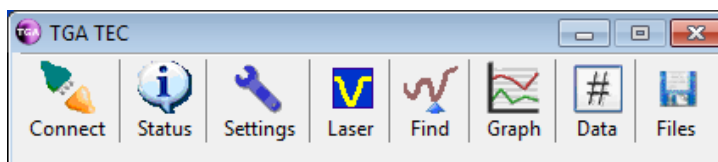


FIGURE 7-1. TGA tool bar functions

Connect: Connect or disconnect from TGA, set the data interval, and save and load parameter files.

Status: Display TGA status

Settings: Display and change parameters

Laser: Display reference and sample signals and modify laser parameters

Find: Find the absorption line(s)

Graph: Set up and display real-time graphs of TGA measurements

Data: View TGA measurements in numerical form

Files: Collect TGA data to the PC hard disk

7.2.1 Connect Window

The *Connect* window is used to connect or disconnect from the TGA, set the IP address of the TGA to communicate with, set the interval at which the software updates data from the TGA, and to save and load parameter files. The *Connect* window is shown in FIGURE 7-2.

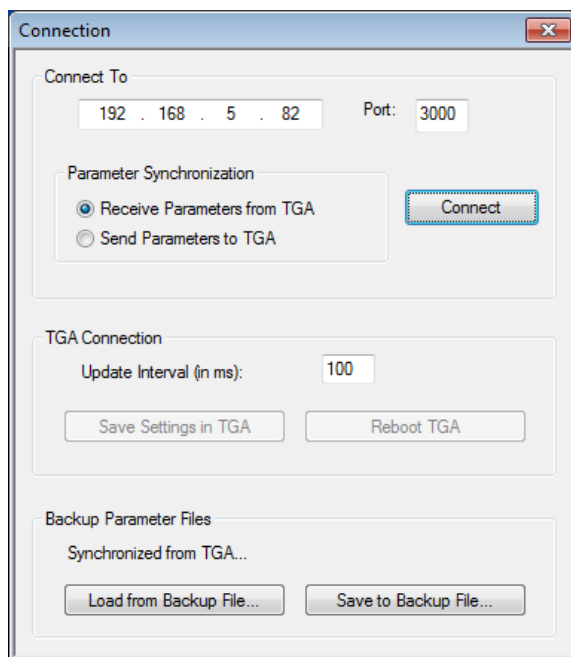


FIGURE 7-2. Connect window of TGA software interface

To connect to a TGA, enter the TGA's IP address. To set the TGA's IP address, use the Device Configuration software, as described in Section 6.2.3, *Configure Ethernet Connection*. Select **Port: 3000**, which is always used for TGA/PC communication.

Choose the **Parameter Synchronization** approach. Normally, this should be set to **Receive Parameters from TGA**. This allows connecting to the TGA without disrupting its current settings. The **Send Parameters to TGA** option can be used to restore parameters that had previously been backed up (after loading the backup file).

If sending parameters to the TGA, the software will first check to make sure the TGA serial number in the parameter file matches the serial number stored in the TGA's nonvolatile memory. If the serial numbers do not match, the software will not send the parameters to the TGA, and the message shown in FIGURE 7-3 will be displayed. If this happens, verify the parameters are correct for the TGA, and edit the serial number in the parameter file (Section 7.2.3.4, *Settings > Other*) or in the TGA (Section 6.2.4, *Set TGA Serial Number and Identification String*) as needed.

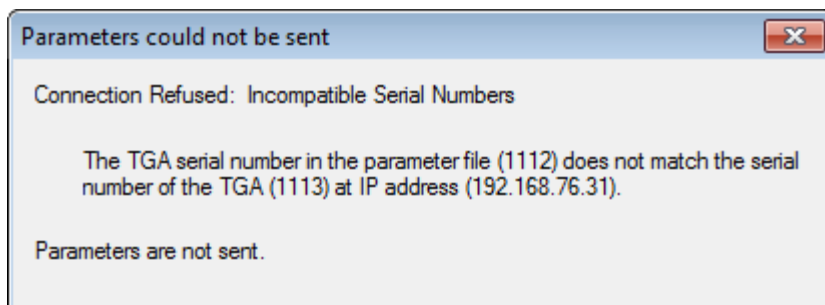


FIGURE 7-3. TGA error message for incompatible serial numbers

CAUTION

Use extreme caution when sending parameters to the TGA to make sure the correct parameters are being sent. If the wrong parameters are sent for the laser in the TGA, the laser may be damaged.

After sending parameters, parameter synchronization will automatically default back to **Receive Parameters from TGA**.

Choose an update interval, which defines how often data are sent from the TGA to the PC. The default is 100 ms. If the connection is slow the connection may be unreliable. In this case, a longer interval, such as 1000 ms, may help to maintain the connection. The update interval may be changed while the TGA is disconnected or connected.

Once the TGA is connected, the *Connect* icon will change to reflect this as shown in the bottom panel of FIGURE 7-4. If defined previously (see Section 6.2.3, *Configure Ethernet Connection*), the identification string will appear at the top of the toolbar.

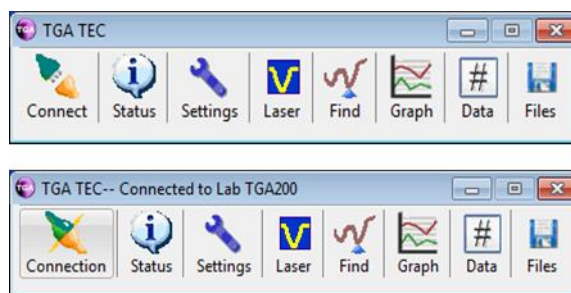


FIGURE 7-4. Toolbar before (top) and after (bottom) connection

7.2.2 Status Window

The TGA *Status* window displays the TGA laser and detector temperatures, sample cell pressure, and line lock status. The toolbar will show one of two icons for the TGA status, depending on whether or not an error is detected. The lower panel of FIGURE 7-5 shows the *Status* icon of the TGA toolbar when an error has been detected.

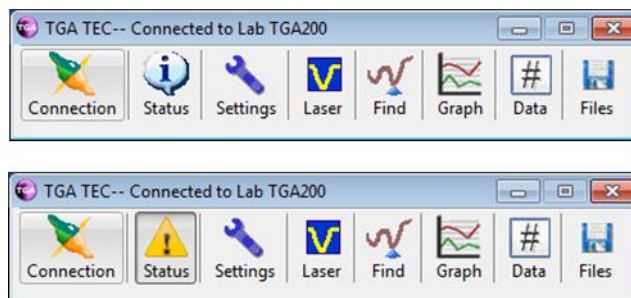


FIGURE 7-5. TGA Status with a detected error (bottom)

Any detected errors will be highlighted in red, with error messages displayed at the bottom as shown in the right panel of FIGURE 7-6.

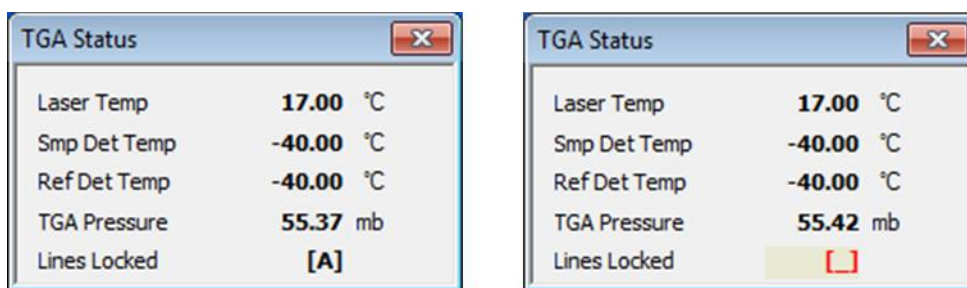


FIGURE 7-6. TGA Status window without error (left) and with error (right) and line lock manually disabled.

NOTE

The *TGA Windows* is used for LN₂-cooled lasers, and reports the laser temperature in K. The *TGA TEC* software is used for TE-cooled lasers, and reports the laser temperature in °C.

7.2.3 Settings Window

The *Settings* window is used to display and change parameters associated with the laser, detectors, calculations, and other miscellaneous information.

In the *Settings* window, the far left side provides drop-down menus which allow the user to set the parameters or retrieve additional information for each of four major categories:

- Laser
- Detectors
- Calculations
- Other

The left panel is shown in FIGURE 7-7 with the submenu for each category expanded. The submenus are explained in the following sections.

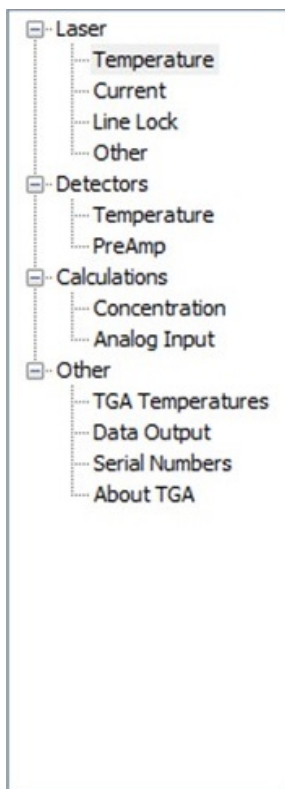


FIGURE 7-7. Expanded view of the menu in the TGA's Settings window

7.2.3.1 Laser

Temperature

The *Settings > Laser > Temperature* window is different for *TGA Windows* and *TG TEC*. *TGA Windows* (FIGURE 7-8) supports LN₂-cooled lasers that measure temperature in K and have a heater to control their temperature above the LN₂ tank temperature. *TGA TEC* (FIGURE 7-9) supports TEC lasers that measure temperature in °C and have a TE cooler to control their temperature.

The laser temperature setpoint should be set and optimized for the individual laser. See Appendix C.1, *Laser Temperature*, for details on how to set the laser temperature. The laser temperature may also be set from the *Laser* window (see Section 7.2.4, *Laser Window*).

The maximum laser temperature (K or °C) provides a safety shutdown. If the laser is warmer than this, the TGA will automatically turn the laser current off to protect the laser. This limit should be set for the individual laser.

CAUTION

Setting the maximum laser temperature parameter above a laser's safe operation temperature greatly increases the risk of damaging the laser.

The parameters on the bottom part of the window should normally be set to the factory defaults, as shown for each type of laser in FIGURE 7-8 and FIGURE 7-9.

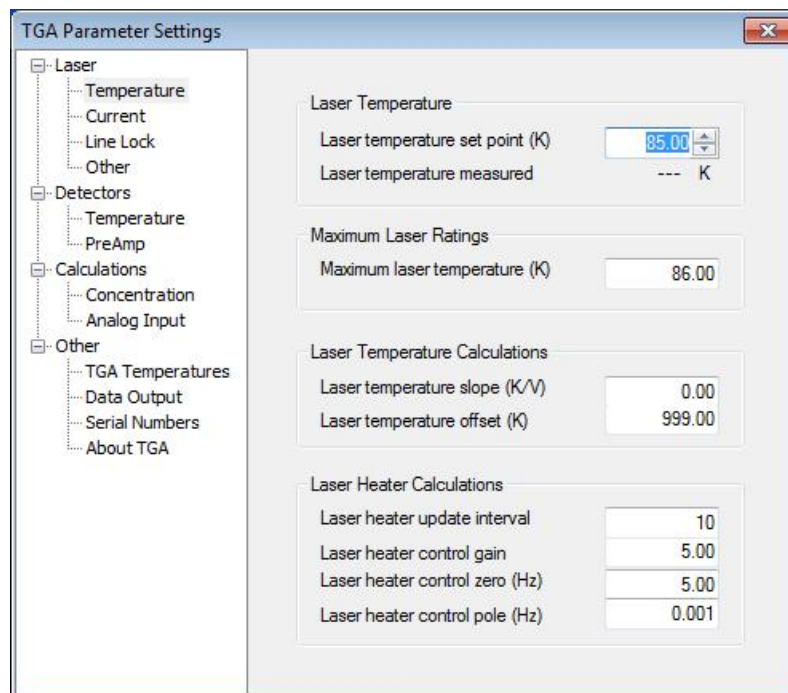


FIGURE 7-8. TGA Windows laser settings

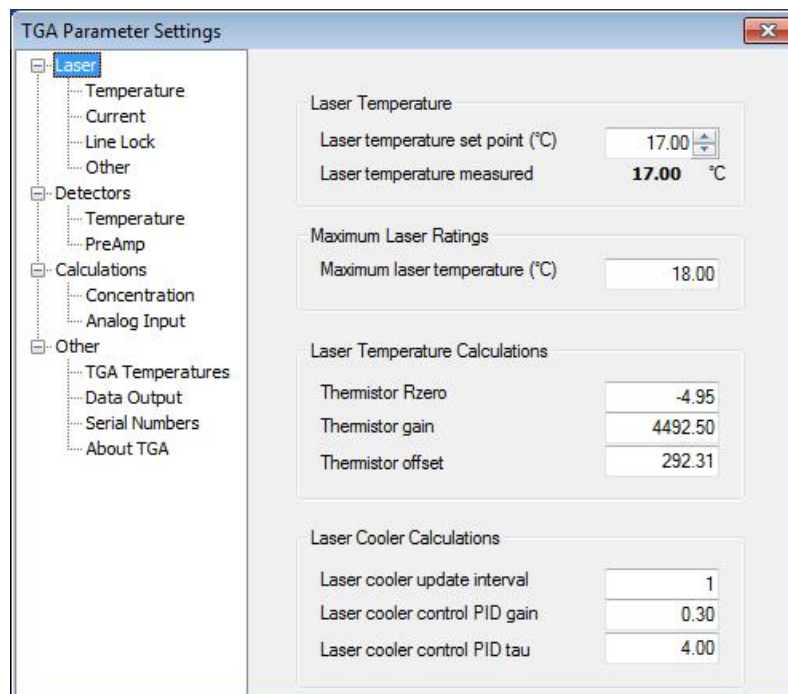


FIGURE 7-9. TGA TEC laser settings

Current

The *Settings > Laser > Current* window is slightly different for *TGA Windows* and *TGA TEC*. *TGA Windows* (FIGURE 7-10) supports a rapid warm-up function to bring the laser more quickly to room temperature. This is helpful for periodic (typically annual) evacuation of the LN₂ dewar. TE-cooled lasers do not require this feature. Therefore the *Laser > Current* screen of the *TGA TEC* does not show the option to heat the laser (FIGURE 7-11).

Both versions have a box to turn the laser on/off. Check this box for normal operation. Uncheck this box to disable the laser current.

The laser DC, Mod (modulation), Zero, and High currents determine the laser scan sequence. They should be set and optimized for the individual laser. The DC, Mod, Zero, and High current parameters may also be set from the *Laser* window. See Appendix C, *Optimizing Laser Parameters*, for details on how to set the laser current parameters. This section also discusses the *Line Lock* and *Auto* buttons next to the DC, Mod, and Zero currents.

The **Maximum laser current (mA)** provides a safety limit. The TGA software will not allow the DC, Mod, Zero, or High current to be set to a value that would apply a current through the laser greater than this limit. Set this limit for the individual laser.

CAUTION

Setting the maximum laser current parameter above a laser's safe operation current greatly increases the risk of damaging the laser.

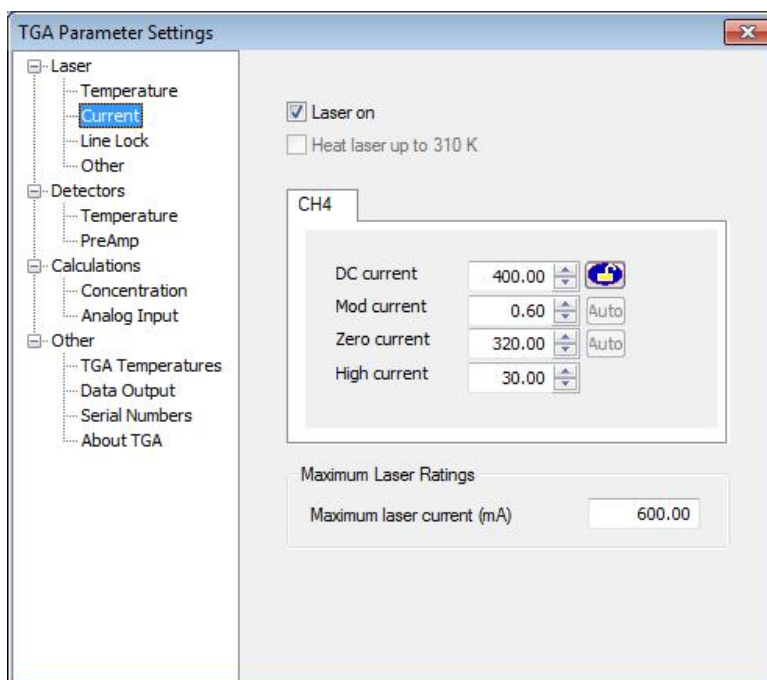


FIGURE 7-10. Laser current parameter settings for TGA Windows

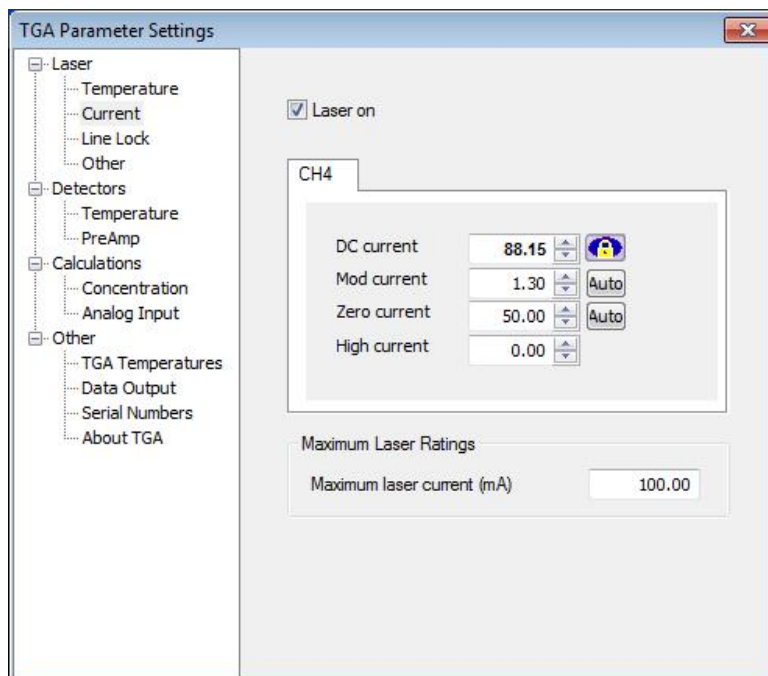


FIGURE 7-11. Laser current parameter settings for TGA TEC




Line Lock

The *Settings > Laser > Line Lock* window sets limits used to temporarily disable the line lock function during an error condition. The line-lock function locks the absorption line to the center of the spectral scan, by automatically adjusting the DC current. Line locking must be active for normal operation (see Section 7.2.4, *Laser Window*, for information on making line lock active, and see Section 7.2.2, *Status Window*, for details on viewing the TGA line-lock status). The TGA monitors three conditions:

- sample cell pressure
- reference detector signal
- reference detector transmittance

The TGA will disable the line lock function if it detects a problem with any of these values. This prevents the line lock algorithm from misadjusting the DC current when the position of the absorption line cannot be determined reliably. In this case, the line locking algorithm is disabled temporarily. When the error condition no longer exists, the line locking is automatically re-enabled. The state of the line lock function is shown by three different icons on the button on the *Settings > Laser > Current* window and the *Laser* window. The appearance and function of those icons is shown in TABLE 7-1.

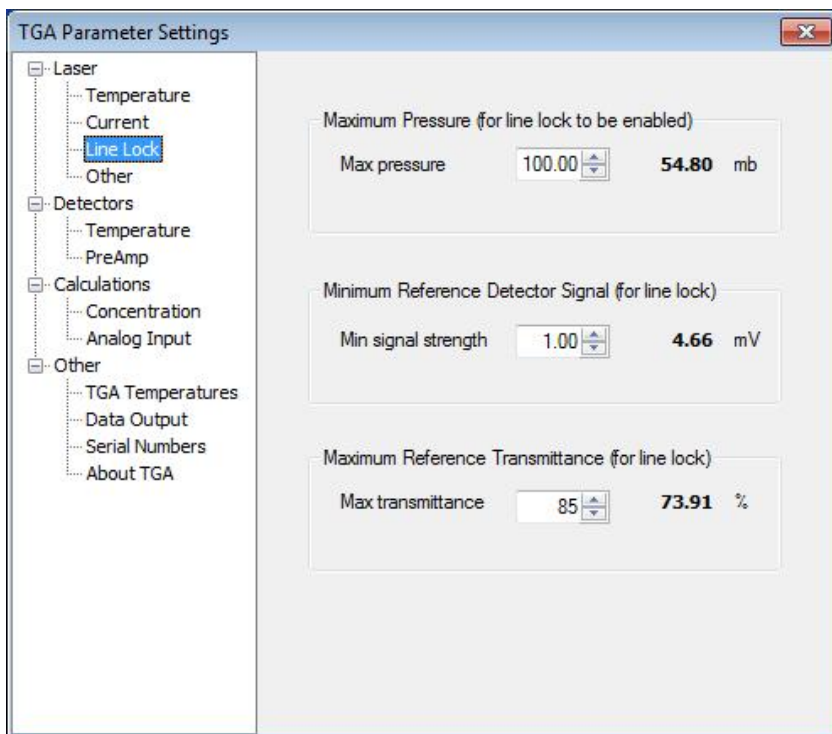
TABLE 7-1. Appearance and Function of Line Lock Icons

Icon	Function
	Open yellow padlock indicates line locking has been turned off
	Closed yellow padlock indicates line locking is active
	Closed red padlock indicates line locking has been temporarily disabled by an error condition

Set the **Max pressure** limit well above the typical operating pressure (refer to FIGURE 7-12). A typical setting would be twice the operating pressure. This will disable line locking when the sample pump is turned off.

Set the **Min signal strength** well below the normal value for the reference detector signal strength. The default is 1 mV. If the reference detector signal is less than 2 mV, set this parameter to half the typical value. This will disable line locking if the signal level drops; during optical alignment adjustment, for example.

Set the **Max transmittance** well above the normal measured reference transmittance. A typical setting would be half way between the measured transmittance and 100%. Setting the parameter this way will disable line locking if there is a problem with the reference gas; such as forgetting to open the valve on the reference gas cylinder.

**FIGURE 7-12. Typical Line Lock parameter settings**

Other

The *Settings > Laser > Other* parameter window is the same for both versions of the software.

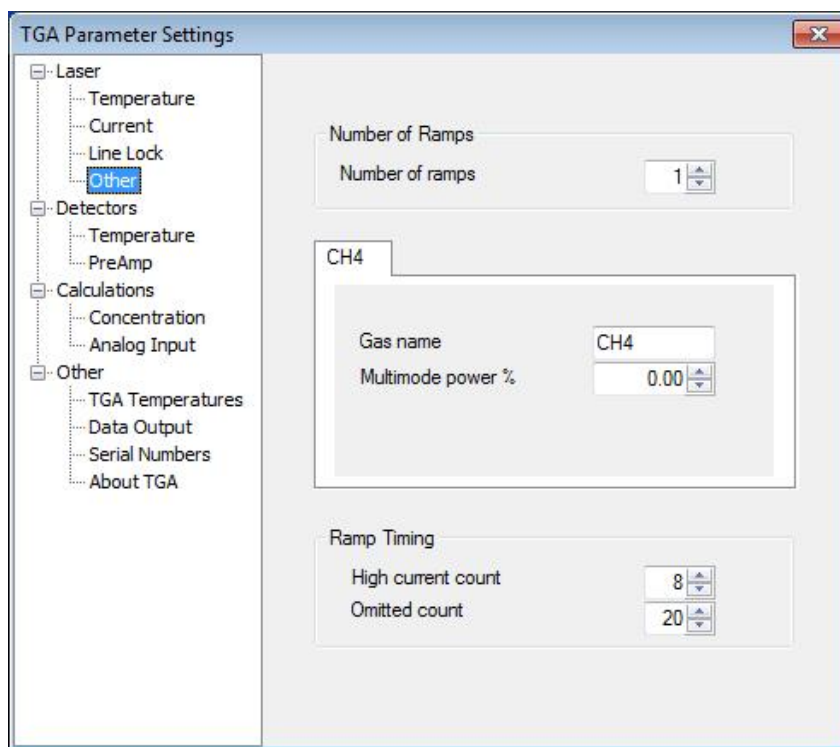


FIGURE 7-13. Settings of the *Settings > Laser > Other* screen

Number of ramps may be set to 1, 2, or 3, corresponding to how many gases are to be measured (see Section 4.2.5, *Laser Scan Sequence*). If the number of ramps is decreased, the laser current parameters (DC, Mod, Zero, and High current) for the unused ramp remain in the parameter file. Increasing the number of ramps gives the ramp synchronization prompt shown in FIGURE 7-14.

To use the parameters that were previously stored in the parameter file for **RAMP B**, click **No**. Click **Yes** to overwrite the new ramp's laser current parameters with those of ramp A. This "synchronizes" the new ramp to **RAMP A**. This is a good choice for initial set up of the laser for multiple-ramp mode, or if it is not clear to the user what parameters are in the file for the new ramp.

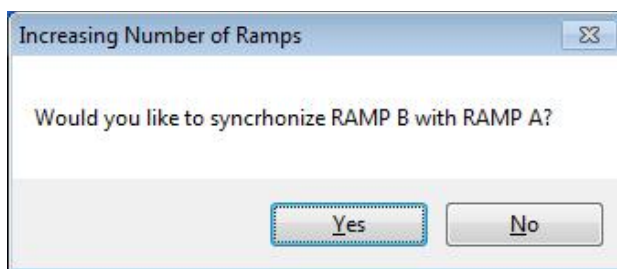


FIGURE 7-14. Ramp synchronization prompt

The middle section of the *Settings > Laser > Other* window (FIGURE 7-13) will have a tab for each ramp. Click the tab to bring it to the foreground. Each tab has two parameters: **Gas name** and **Multimode power %**. **Gas name** is a label that is used throughout the TGA software to designate what gas is measured (for example, after defining these settings the TGA will automatically label the tabs). Typical names for the more commonly measured gases are given in TABLE 7-2. Text of the user's choice, up to 23 characters, may be entered as an alternative.

Target Gas	Suggested Naming
Methane	CH4
Nitrous Oxide	N2O
Carbon Dioxide ($^{12}\text{C}^{16}\text{O}^{16}\text{O}$)	12C
Carbon Dioxide ($^{13}\text{C}^{16}\text{O}^{16}\text{O}$)	13C
Carbon Dioxide ($^{12}\text{C}^{18}\text{O}^{16}\text{O}$)	18O
Ammonia	NH3

The **Multimode power %** parameter is the percentage of the laser's power in unwanted side modes. See Appendix C.7, *Laser Multimode Correction*, for details on how to set this parameter.

At the bottom of the window are two ramp timing parameters that are common to all ramps. **High current count** is the duration of the high-current phase of the ramp, in counts. **Omitted count** is the number of counts to omit from concentration calculations. The defaults are **8** and **20**. For more information on these parameters, see Appendix C.3.1, *High Current Count*, and Appendix C.4, *Omitted Data Count*.

7.2.3.2 Detectors

Temperature

From the *Settings > Detectors > Temperature* window, parameters can be set to control the temperature of the detectors. This window is the same for both versions of the software, *TGA Windows* and *TGA TEC*, and is shown in FIGURE 7-15.

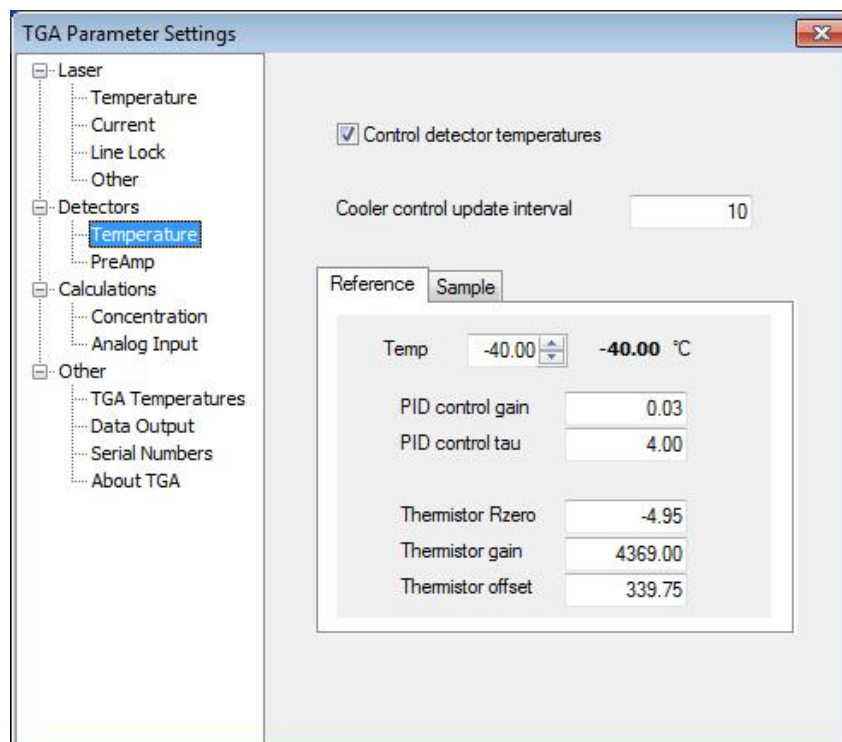


FIGURE 7-15. Controlling the detector temperature settings

Most TGAs have detector temperatures that are controlled by TE coolers. The **Temp** parameter on the *Reference* and *Sample* tabs is the setpoint. Set the detector temperatures to optimize the signal levels, as discussed in Appendix D.3, *Detector Temperature*. Some TGAs have LN₂-cooled detectors for measuring absorption at longer wavelengths. The temperature of these detectors is not measured or controlled. For LN₂-cooled detectors, uncheck the **Control detector temperatures** box.

The rest of the detector parameters should be set to the defaults shown in FIGURE 7-15. The parameters for the sample detector are not shown, but are the same as for the reference detector.

PreAmp

The *Settings > Detectors > PreAmp* window and parameters are the same for both versions of the software and are shown in FIGURE 7-16. See Appendix D, *Optimizing Detector Parameters*, for details on optimizing the detector preamp parameters.

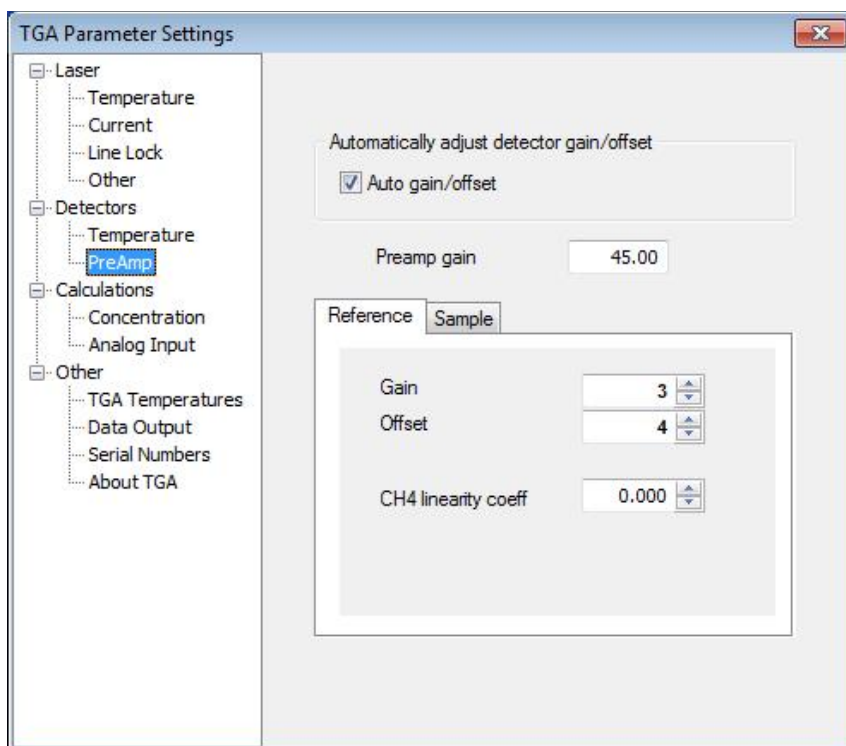


FIGURE 7-16. PreAmp window default settings

7.2.3.3 Calculations

Concentration

The *Settings > Calculations > Concentration* window and parameters are the same for both versions of the software.

The TGA measures the gas concentration every 2 ms and applies a digital filter to these measurements before they are output. The top section of the *Settings > Calculations > Concentration* window (as shown in FIGURE 7-17) allows the user to select the type of digital filter, either a moving average or a finite impulse response (FIR) filter that is optimized for eddy covariance applications. If **Moving average** is selected, enter the averaging time, in ms. If **EC filter** is selected, enter 1, 2, 3, 4, or 5, depending on the amount of filtering that is desired. See Appendix F, *TGA Frequency Response*, for details.

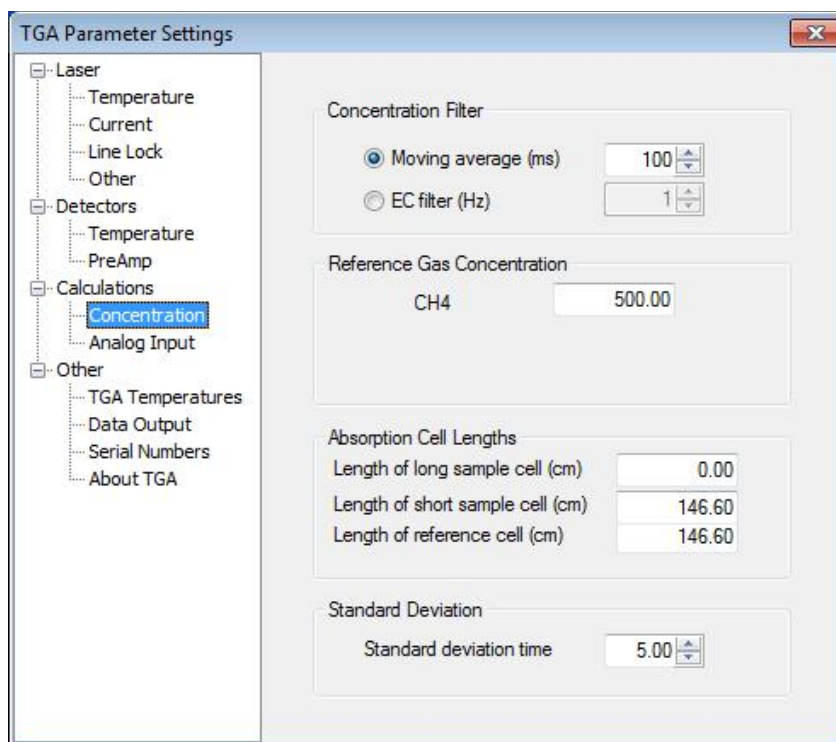


FIGURE 7-17. Calculation concentrations settings

The center section of this window displays information about the **Reference Gas Concentration**. Enter the concentration of the reference gas, in ppm. This parameter is used as detailed in Section 4.2.6, *Concentration Calculation*, to derive the concentration of the air in the sample cell. This parameter may be adjusted as described in Appendix E, *Calibration*, to improve the accuracy of the TGA. If the number of ramps is greater than one, each ramp will have a reference gas concentration parameter.

The **Absorption cell lengths** are also used to calculate the concentration of the air in the sample cell. See Section 4.2.6, *Concentration Calculation*, for a discussion of how these parameters are used in the calculation, and see Section 5.2, *Physical Specifications*, for the correct lengths to enter for each of the TGA models.

The TGA software calculates a mean and a standard deviation of the concentration measurements. These statistics can be displayed either graphically (Section 7.2.6, *Graph*) or numerically (Section 7.2.7, *Data*), or they may be saved to the data files (Section 7.2.8, *Files*). The standard deviation time parameter, displayed at the bottom of the window shown in FIGURE 7-17, determines the time over which these statistics are calculated.

Analog Input

The *Settings > Calculations > Analog Input* parameters are the same for both versions of the software.

The TGA has four differential analog input channels. Channel 2 and 3 measure temperatures inside the TGA enclosure for controlling the heaters (see Appendix I, *Install Temperature Control Upgrade*). Channel 4 measures the

sample cell pressure. Channel 1 is available for the user to add a sensor. Each of these channels has a tab to configure it. *Pressure* is the label given to the tab for channel 4.

The default configuration for Channel 1 is shown in FIGURE 7-18.

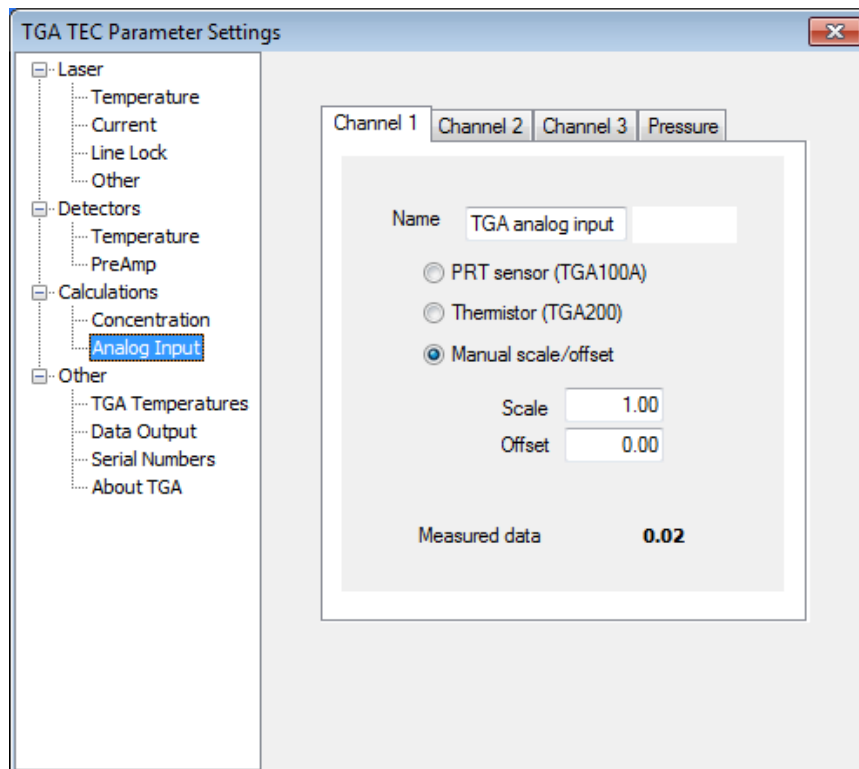


FIGURE 7-18. Default settings for Channel 1 in analog input screen

Channels 2 and 3 measure temperatures inside the TGA enclosure. Early TGA used platinum resistance thermometer (PRT) sensors, but the TGA200 and TGA200A use thermistor probes. TGA100s and TGA100A may be upgraded to use the thermistor probes (see Appendix I, *Install Temperature Control Upgrade*). The settings for the *Channel 2* tab are shown in FIGURE 7-19. The *Channel 3* tab is similar, but the Name is **TGA Temp 2**.

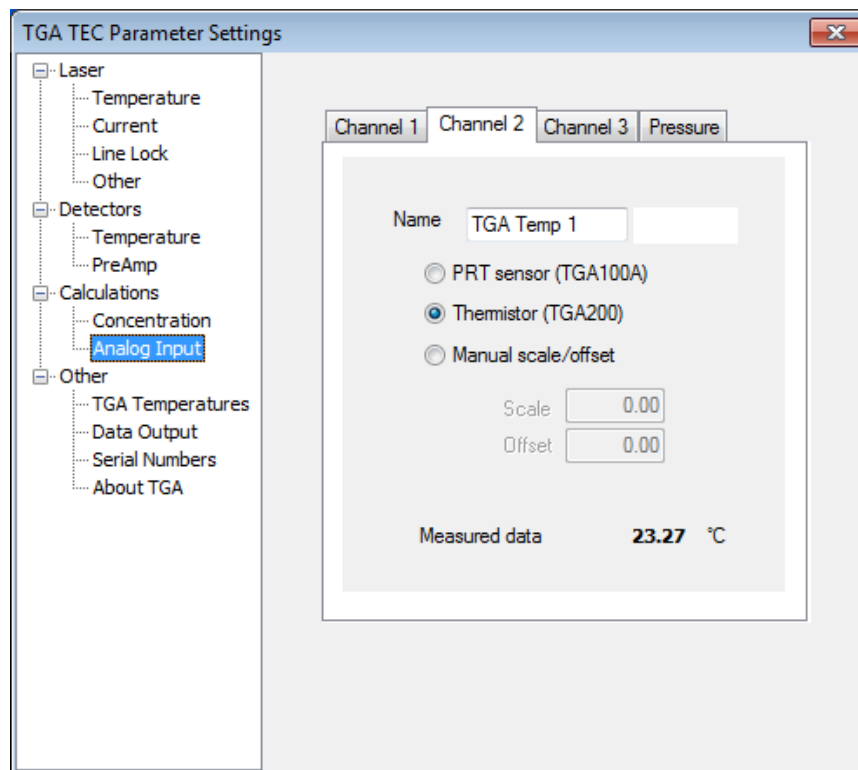


FIGURE 7-19. Channel 2 settings for a TGA with thermistor probe

Channel 4 measures sample cell pressure. Each TGA pressure sensor is individually calibrated, to determine appropriate values for the **Zero output (V)** and the **Full-range output (V)**. These are recorded in documents supplied with the TGA. Typical values are shown in FIGURE 7-20.

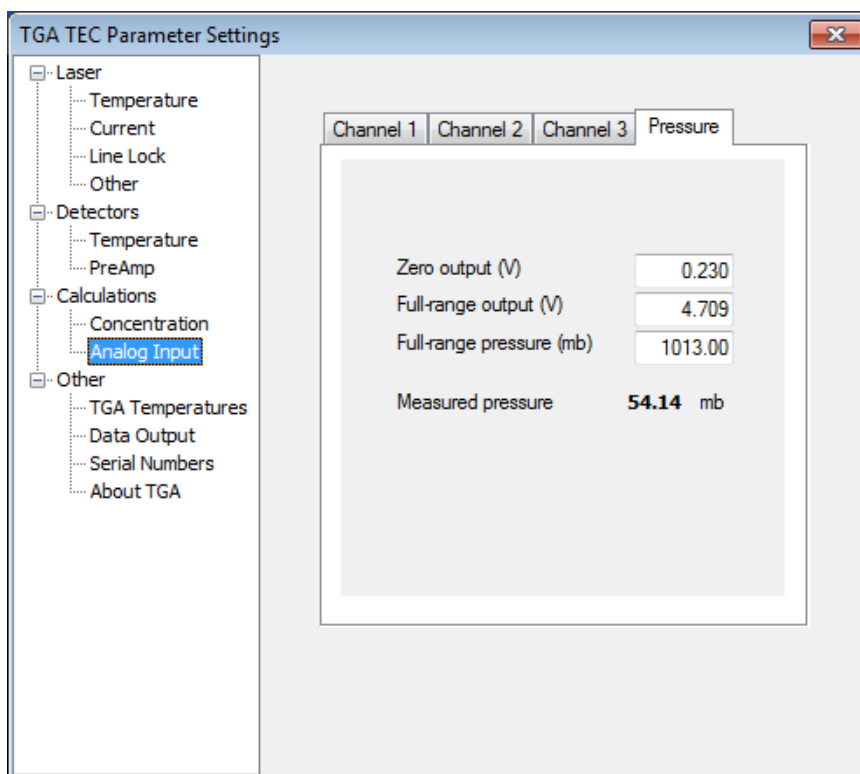


FIGURE 7-20. Typical pressure value inputs (values are specific to each TGA)

Isotopes

The *Isotopes* parameters are the same for both versions of the software. This window is hidden if the number of ramps is set to **1**. An example of typical values for calculating $\delta^{13}\text{C}$ is shown in FIGURE 7-21.

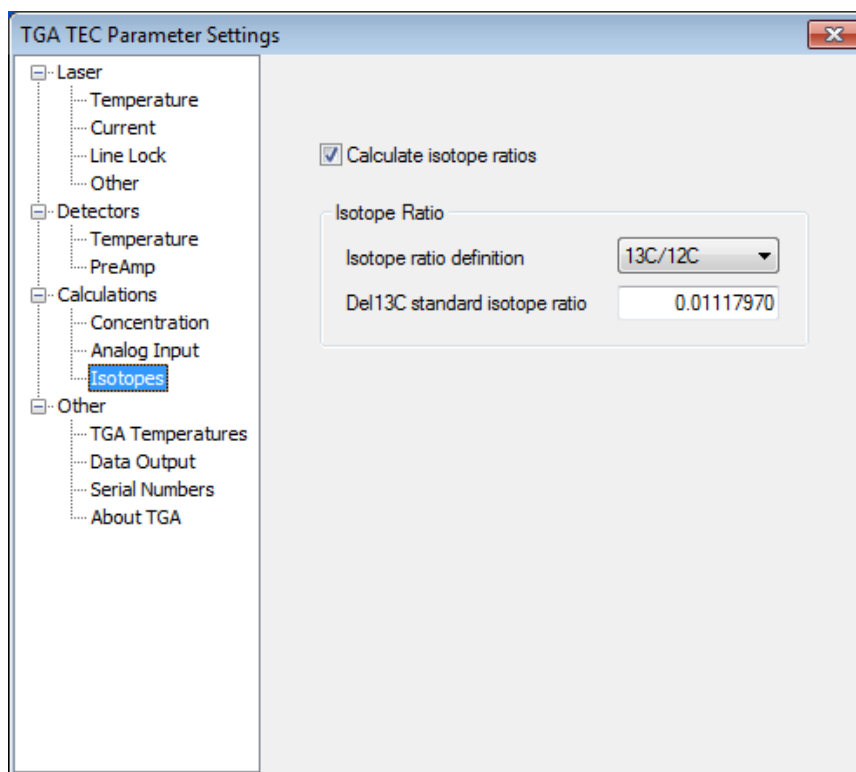


FIGURE 7-21. Typical values for calculating $\delta^{13}\text{C}$ on a TGA set with multiple ramps

7.2.3.4 Other

TGA Temperatures

The *Settings > Other > TGA Temperatures* window is shown in FIGURE 7-22. To enable the heaters to maintain the TGA at a steady temperature, check the **Control TGA temperatures** box and set **Control Parameters** as shown in FIGURE 7-22. Set the two temperature setpoints as needed to maintain a steady temperature. Usually, this will be 5 to 10 °C above the highest likely ambient temperature. Normally, the two setpoints are set to the same value. However, if one of the two heaters generally works harder than the other (higher duty cycle), adjust the setpoints to slightly different temperatures (usually within one °C) to balance the two heaters.

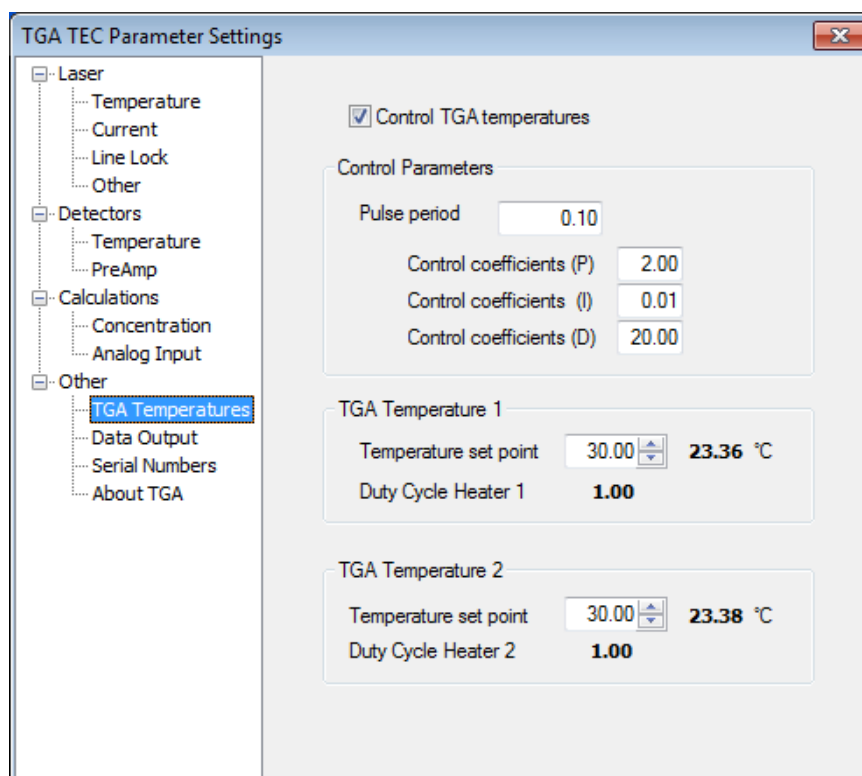


FIGURE 7-22. TGA temperature control window for the two TGA enclosure heaters

Data Output

The *Settings > Other > Data Output* window is shown in FIGURE 7-23. Check the **SDM output** button for normal operation. This will configure the TGA as an SDM sensor, allowing a datalogger to request and receive data via an SDM cable. Set the SDM address for the TGA from 0 to 14, and make sure the datalogger program uses the same address to request data (see Section 7.3.1, *SDM Output*).

The TGA may be configured for analog output, but this option requires the use of a separate analog output module. It is not possible to configure a TGA for both SDM and analog output. Contact Campbell Scientific for details.

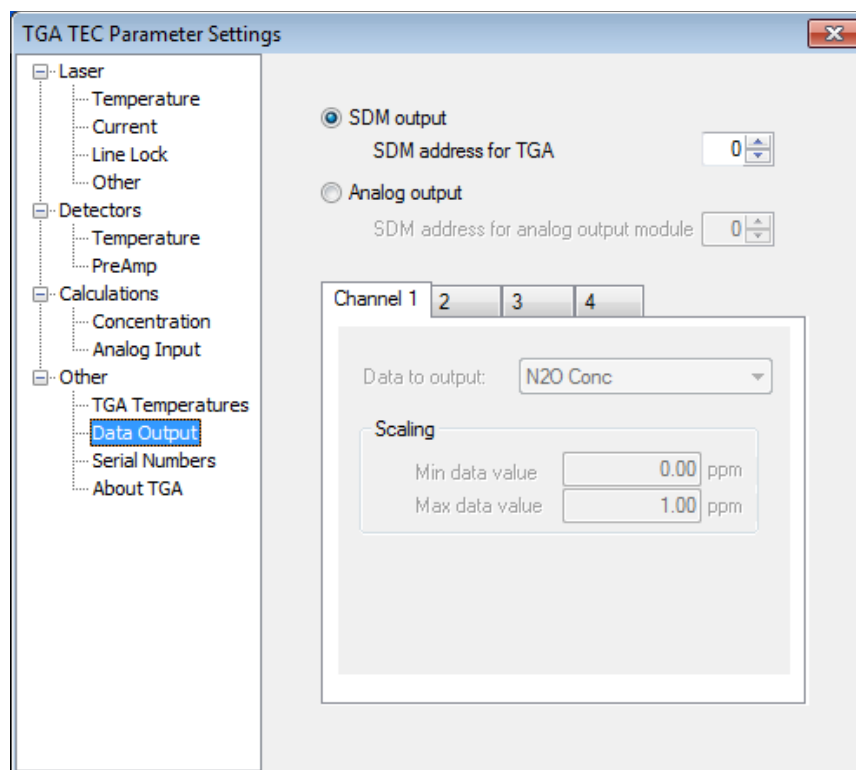


FIGURE 7-23. Data output setting window for SDM

Serial Numbers

The *Settings > Other > Serial Numbers* window is shown in FIGURE 7-24.

The TGA is identified by a serial number and by a description. The TGA serial number is stored in two places: in the parameter file, and in the TGA's nonvolatile memory. These serial numbers must match in order for the PC software to be connected to the TGA, as discussed in Section 7.2.1, *Connect Window*. The TGA serial number may be edited only when the TGA is disconnected.

CAUTION

Use extreme caution when sending parameters to the TGA to make sure the correct parameters are being sent. If the wrong parameters are sent for the laser in the TGA, the laser may be damaged.

The TGA description is intended as a device nickname and to be a more user friendly way than the serial number by which to identify which TGA is connected to the PC software. It may be set only through the *Device Configuration Utility* (see Section 6.2.4, *Set TGA Serial Number and Identification String*). The identification string is displayed at the top of the toolbar when the TGA software is connected to a TGA.

The serial numbers for the laser, dewar, and detectors provide a historical record in case these components are replaced by the user.

The site name/description allows the user to enter text to describe the physical location of the TGA. This is stored in the parameter file as a historical record.

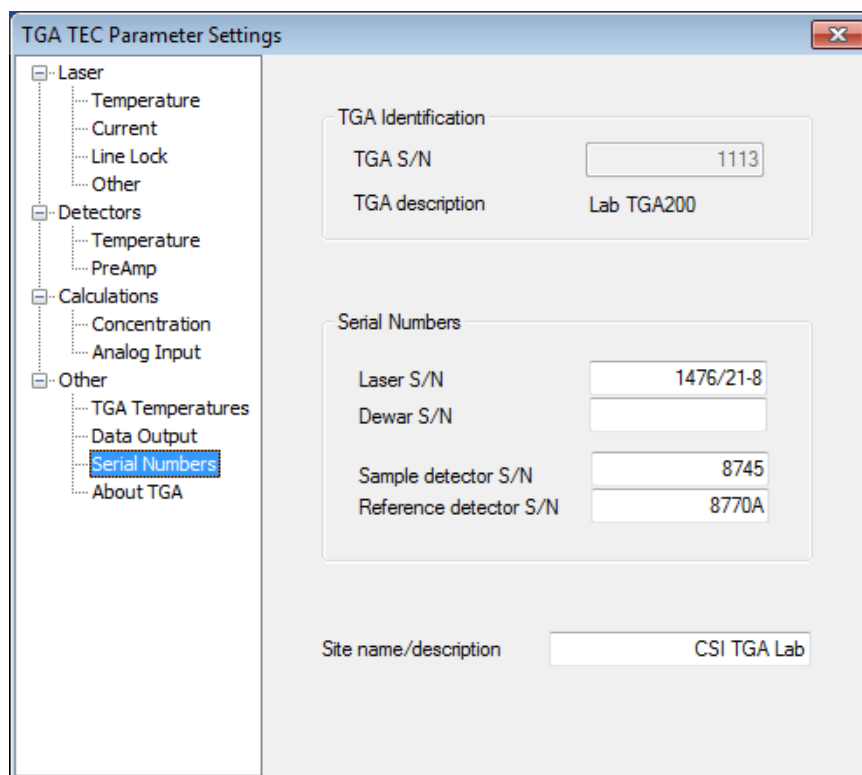


FIGURE 7-24. Setting a TGA serial number and identification string

About TGA

The *Settings > Other > About TGA* window is shown in FIGURE 7-25. The window gives the version of the PC software and also documents the version of the firmware if a TGA is connected.

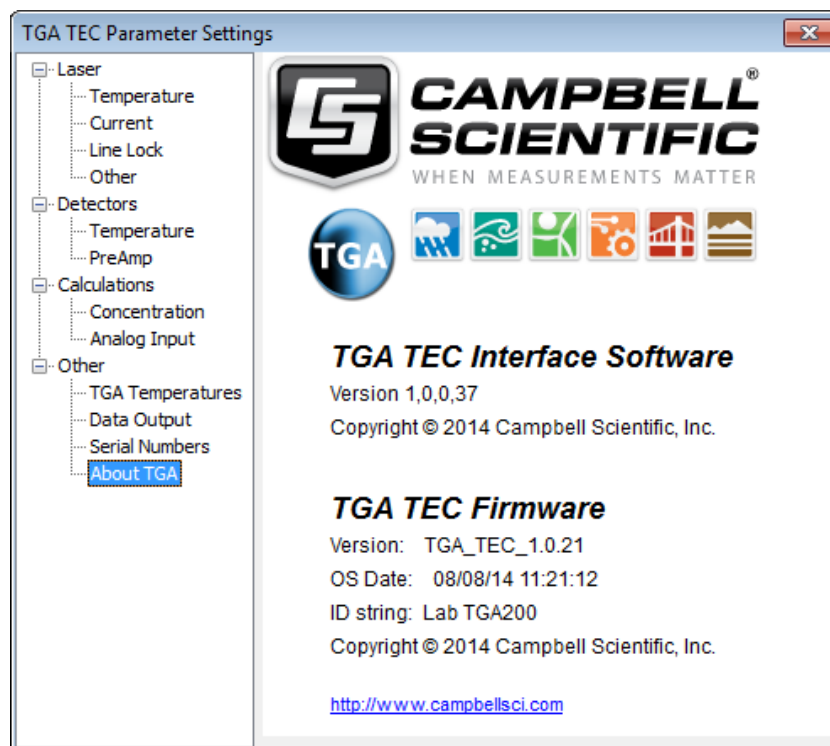


FIGURE 7-25. About TGA window

7.2.4 Laser Window

The *Laser* window is used to display reference and sample detector signals and to modify laser parameters.

The value of a parameter may be adjusted by several methods:

- Manually entering the new value in the box with the keyboard number keys
- Clicking the up or down arrow next to the box
- Click in the box and use the up and down arrow keys of the keyboard to increase or decrease the value

The **DC current** and **Mod current** have automatic functions that can adjust the value. Click the button to the right of the up/down arrow buttons to enable these automatic functions.

NOTE

The *TGA Windows* software also has an **Auto** button for **Zero current**. The suggested procedure for setting the Zero current does not use the function (see Appendix C.2, *Zero Current*). This button has been removed from *TGA TEC*.

The DC current and modulation current can be adjusted by clicking inside the graph in the window and then using the left and right arrow keys to adjust the DC current (pan right/left) and using the up/down arrow keys to adjust the modulation current (zoom in/out).

The *Laser* window for *TGA Windows* and *TGA TEC* are nearly identical; only the units for the laser temperature are different. The *TGA TEC* window is shown in FIGURE 7-26.

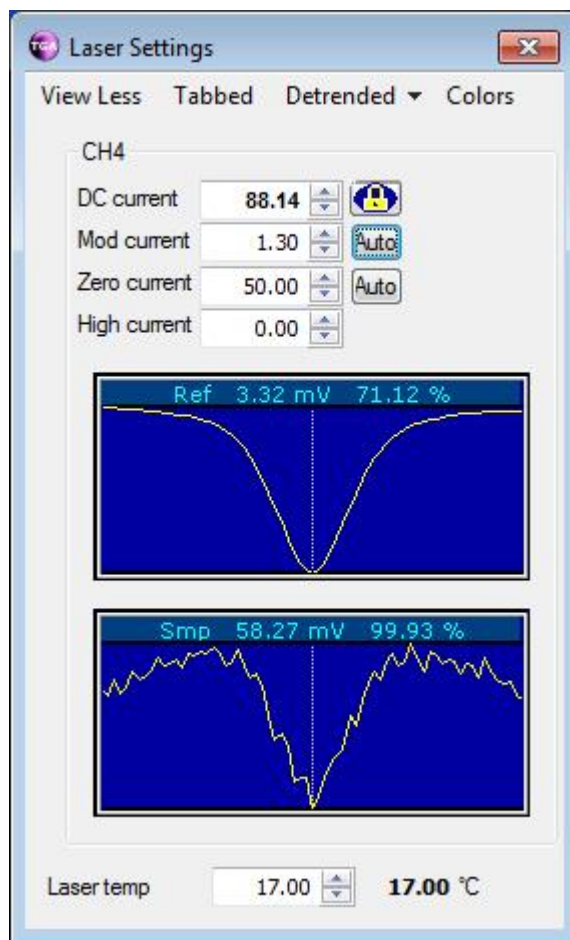


FIGURE 7-26. The TGA TEC screen for setting laser parameters

7.2.4.1 View Less/View More

The *View Less/View More* toggle allows the expansion of what is shown in the window. *View Less* shows only the DC current for each ramp. *View More* also shows the modulation current, zero current, high current, and laser temperature settings. The left panel of FIGURE 7-27 shows *View Less*, the right panel shows the expanded window of the *View More* mode. *View More* is the default mode.

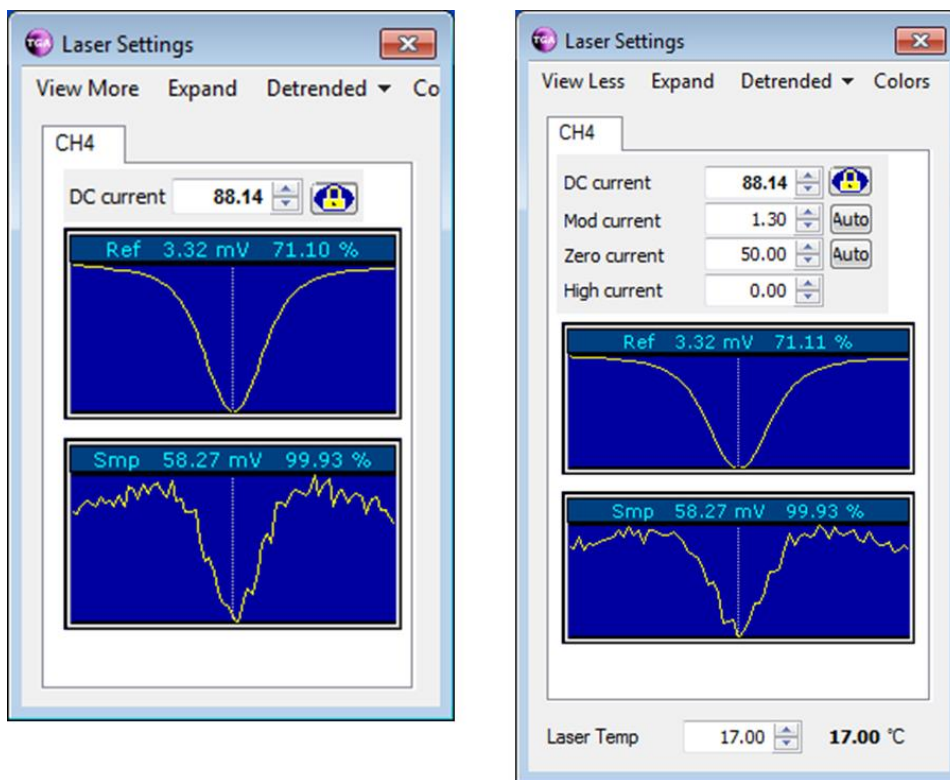


FIGURE 7-27. View Less/View More function of the Laser Settings window

7.2.4.2 Tabbed/Expand

The *Tabbed* or *Expand* button is used to switch between individual displays for each ramp or displaying only one ramp and having tabs to switch the displayed ramp. The two display modes are shown in as shown in FIGURE 7-28. The difference between the two modes is irrelevant for single- ramp mode.

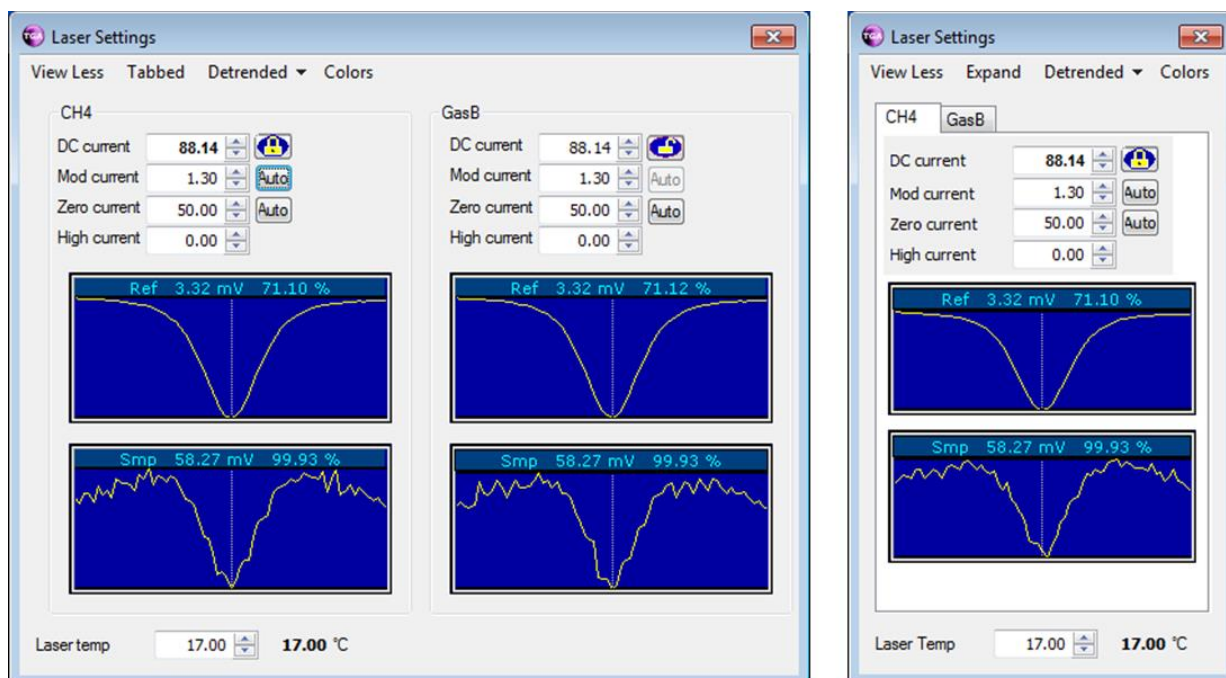


FIGURE 7-28. Tabbed/Expand function of the Laser Settings window

7.2.4.3 Display Mode

The *Display Mode* of the *Laser Settings* window is the third button from the left. There are five display modes that can be set from here. The default mode is Detrended.

- Raw
- Maximum
- Magnified
- Detrended
- Folded
- Absorbance

A side-by-side comparison of the modes is given in FIGURE 7-29 and a description of each of the modes follows.

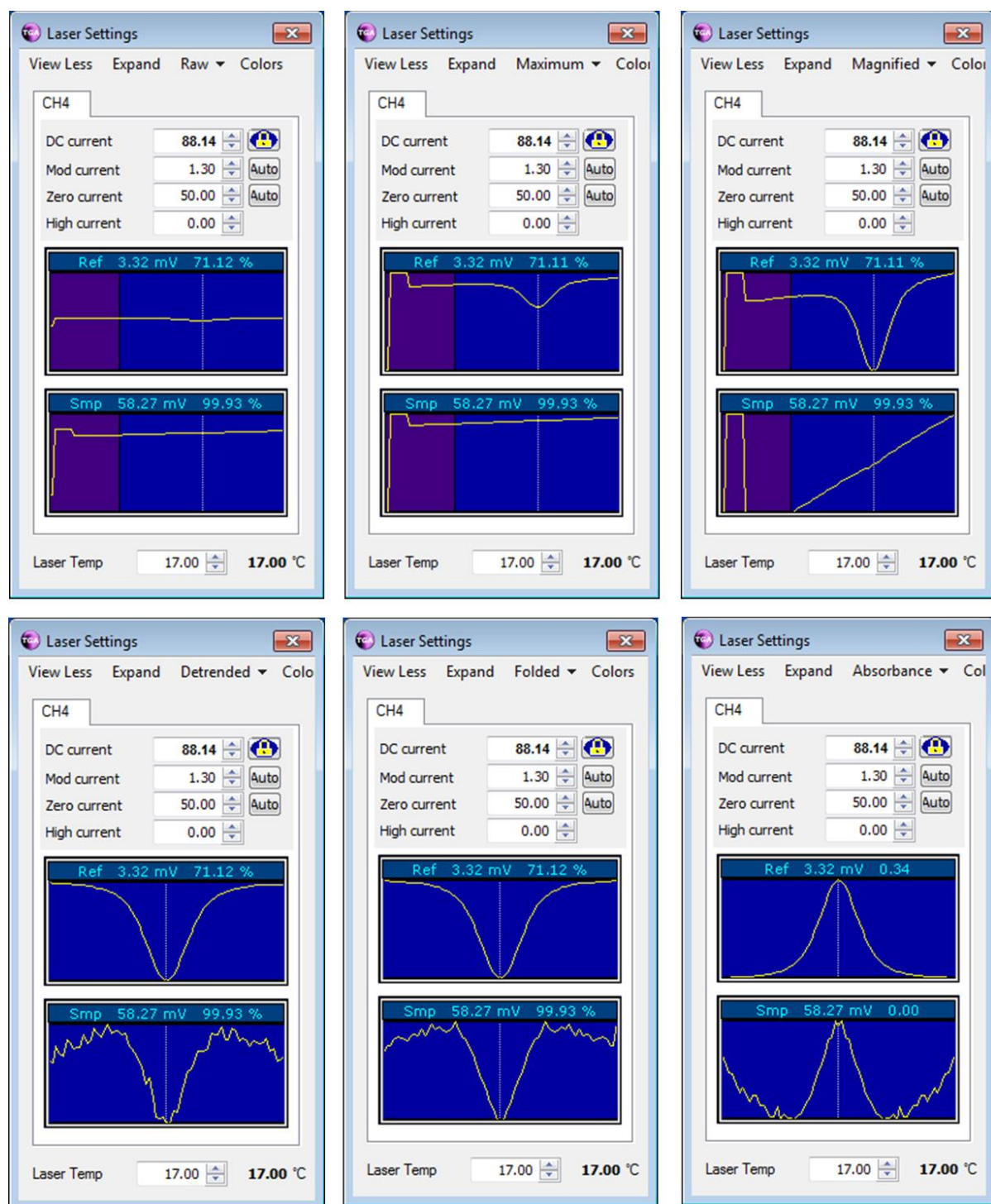


FIGURE 7-29. Laser display modes

Raw

Raw displays the raw detector signals, with the Y axis scaled to match the input range of the electronics. This mode is used to set the zero current and to verify the detector signals are within the range of the electronics (not saturated). Two colors are used on the right and left sides to show the range of data actually used to calculate concentration (blue, on right side). The dashed vertical line shows the center of the spectral scan.

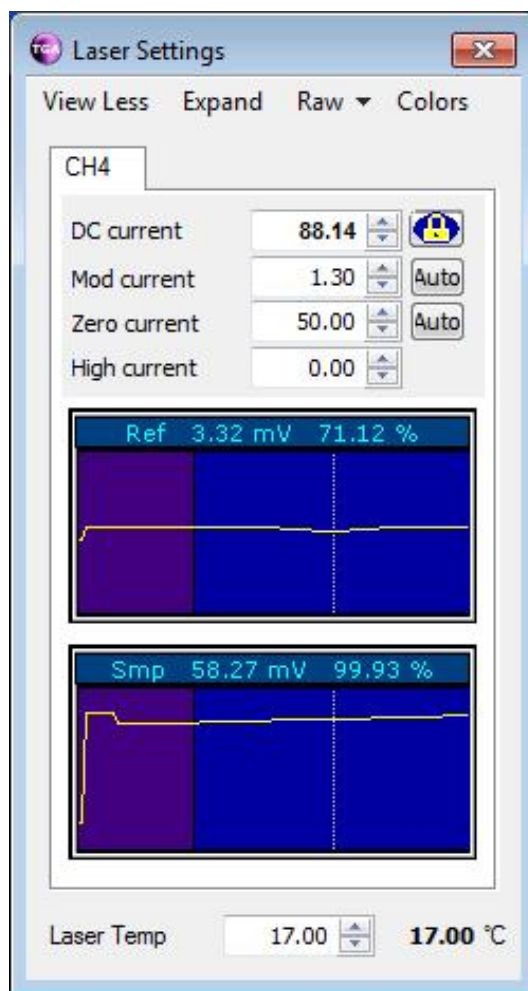


FIGURE 7-30. Raw mode of laser display

Maximum View

Maximum View displays the reference and sample transmittance, scaled to the maximum and minimum of all of the data (including the zero, high, and omitted data).

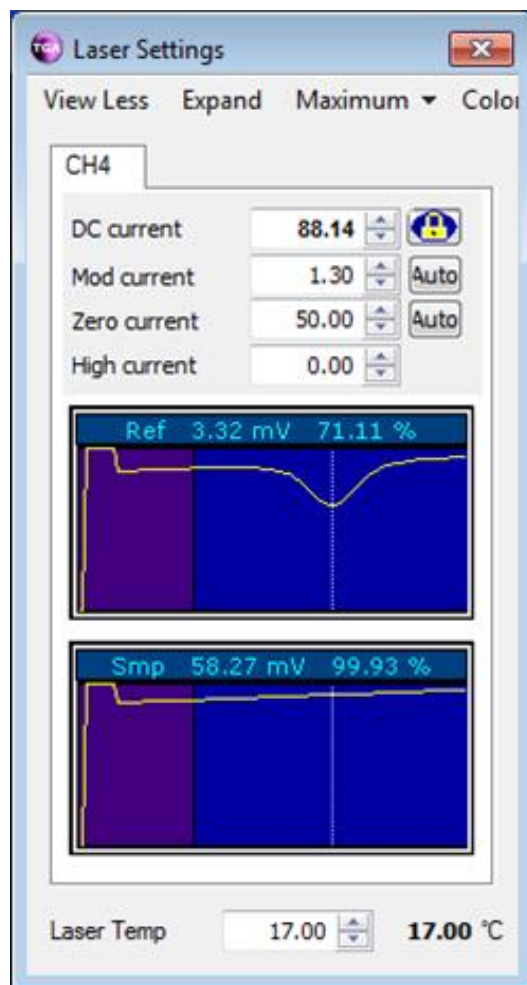


FIGURE 7-31. *Maximum View mode of laser display*

Magnified

The *Magnified* view displays the reference and sample transmittance, scaled to the maximum and minimum of the data used in the concentration calculation (including the zero, high, and omitted data). This mode is used to set **High current**.

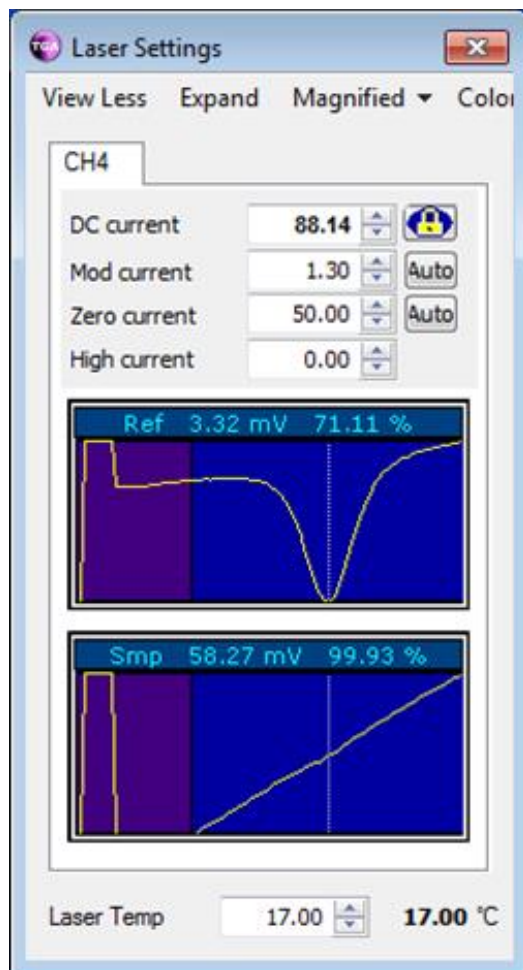


FIGURE 7-32. Magnified mode of laser display

Detrended

The *Detrended* display mode shows the data after they have been detrended by fitting a line to the data and dividing by this line. The graph is scaled horizontally to show only the data used for concentration calculations. This is the default display mode.

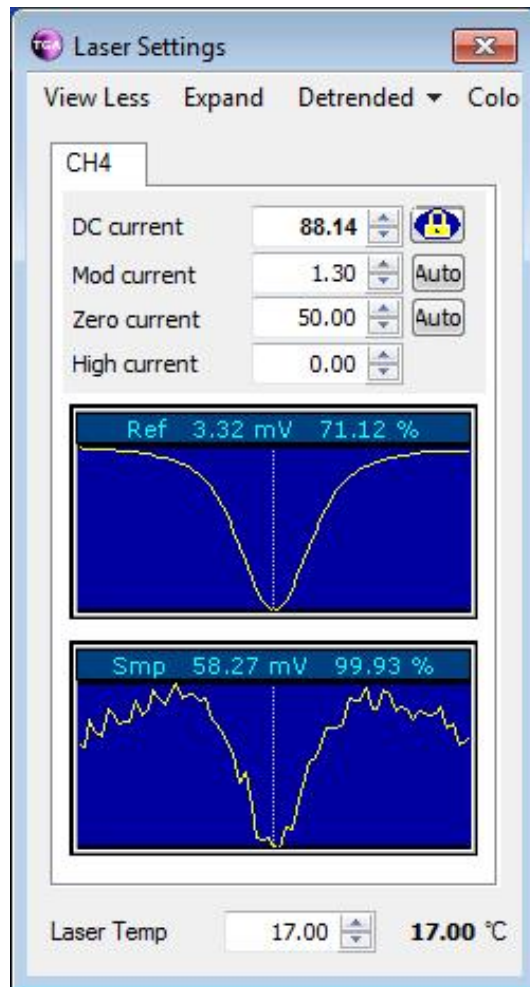


FIGURE 7-33. Detrended mode of laser display

Folded

Folded display mode is similar to the *Detrended* display mode, but the data have been detrended differently. This mode shows data that are detrended by folding about the center line (averaging the data with a reversed copy of the data). This process forces the data to appear symmetrical about the center of the spectral scan (the center vertical dashed line).

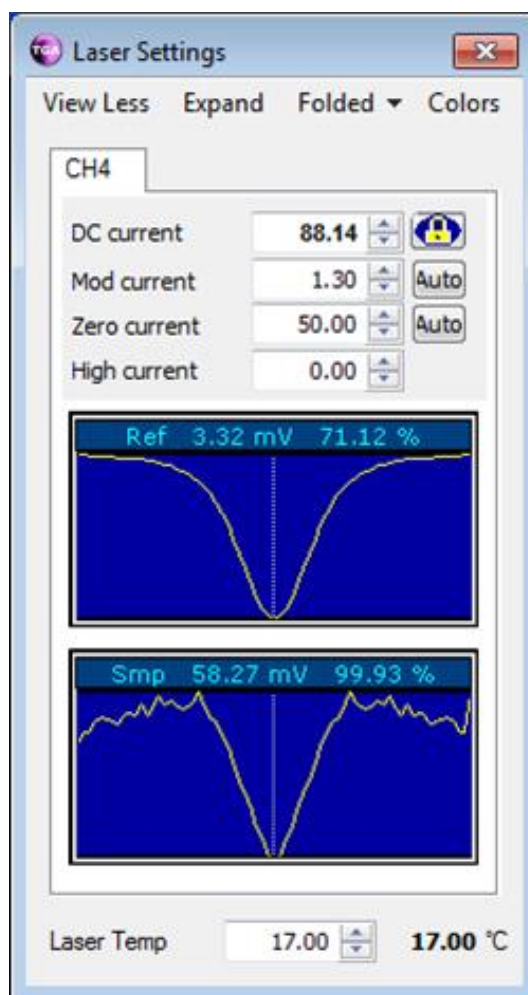


FIGURE 7-34. Folded mode of laser display

Absorbance

Absorbance mode displays the absorbance of the (folded) data instead of the transmittance.

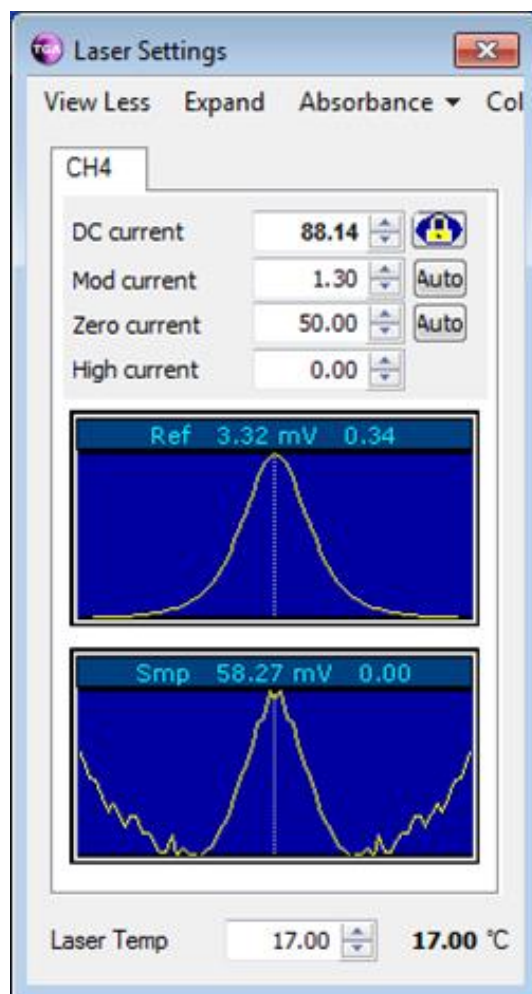


FIGURE 7-35. Absorbance mode of laser display

7.2.4.4 Colors

The *Colors* view, shown in FIGURE 7-36, is used to customize the laser settings window colors. The default colors for the laser can be reset from this window.

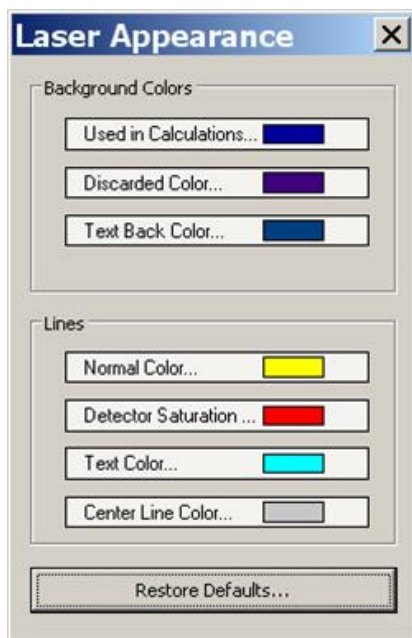


FIGURE 7-36. Setting options for laser window display

7.2.5 Find

The *Find* tool is used to find and identify absorption line(s). It tunes the laser's output wavelength by varying the laser current and/or temperature and displays a graph of the reference detector signal versus current. This graph (also called a laser map) is comparable to a transmittance spectrum.

The *Find* tool is similar for *TGA Windows* and *TGA TEC*, with the exception that the units for the laser temperature are different and the minimum current step size is different.

The **Interactive** mode (selected at the bottom of the *Laser Line Find* screen) maps the laser at one temperature, but then allows the user to select an absorption line by first clicking on the key to select which ramp to set, and then clicking on the absorption line in the graph. Alternately, the vertical colored band that represents the spectral scan may simply be dragged to the desired absorption line.

It is helpful to display the *Laser Settings* window beside the *Laser Line Find* window (FIGURE 7-37) while making these adjustments. If preferred, the *Laser Settings* window (as described in Section 7.2.4, *Laser Window*) may be used to make the adjustments and view the changes interactively in the *Laser Line Find* window. An example is shown in FIGURE 7-38 for a CO₂ isotope laser.

If the two windows do not agree well, try repeating the laser map with a smaller step size for the DC Current.

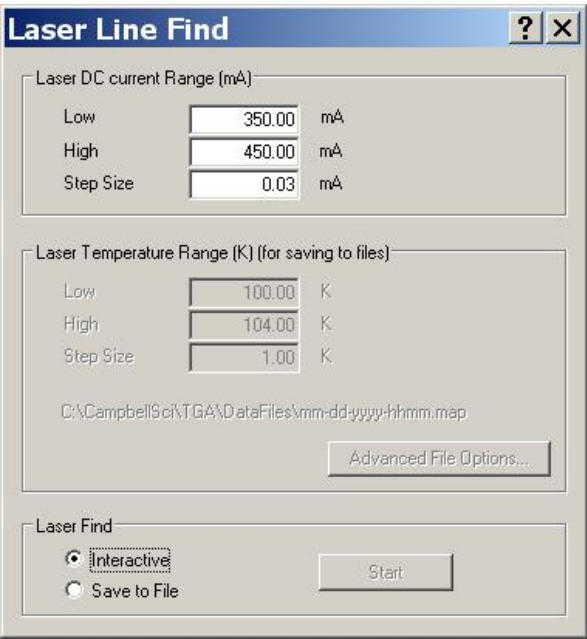


FIGURE 7-37. Laser line find window

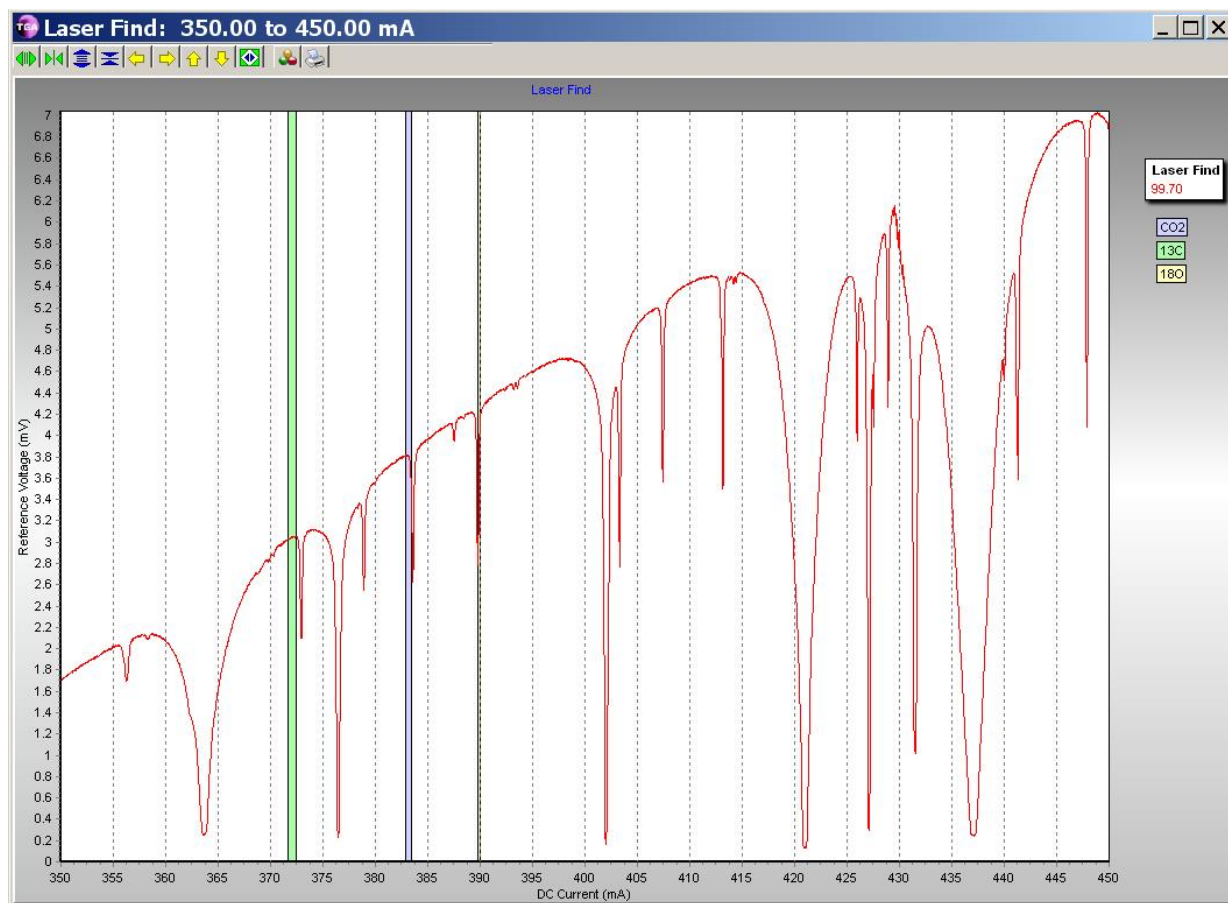


FIGURE 7-38. Interactive Laser Find window for a CO₂ isotope laser.

The non-interactive mode (**Save to File** button checked) will increment the laser temperature and collect and store a laser current scan at each temperature. Each laser scan will be stored in a separate file. The data are displayed in the laser map window as they are collected. At the completion of the data collection, any of the laser scans may be selected by clicking the button next to the temperature. A typical screen is shown in FIGURE 7-39.

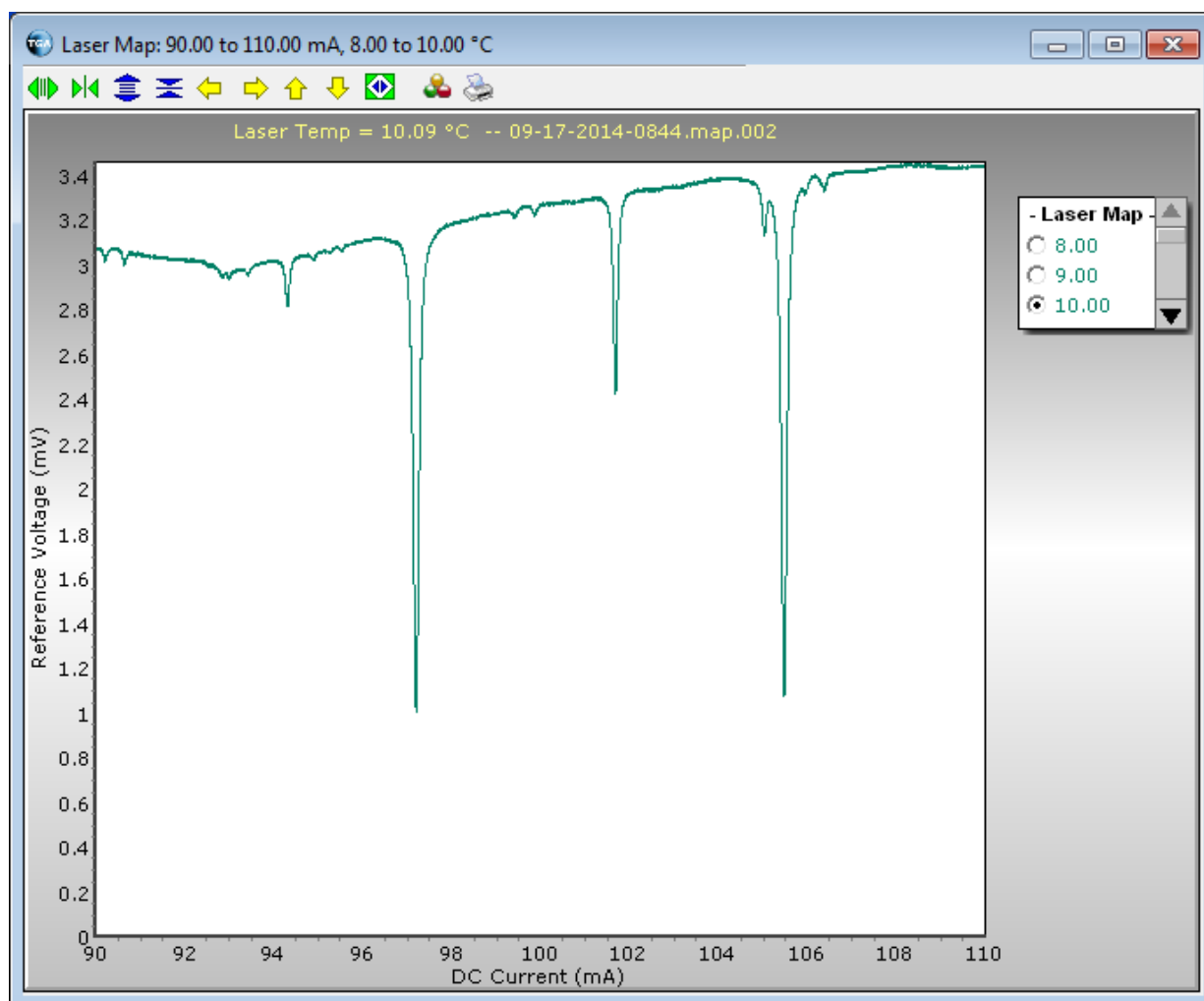


FIGURE 7-39. Noninteractive Laser Find window

7.2.6 Graph

The *Graph* tool is used to graphically display real-time data from the TGA. The user interface is slightly different for *TGA Windows* and *TGA TEC*.

TGA Windows

For *TGA Windows*, click the **Graph** icon in the toolbar to bring up the *Select Data* window, FIGURE 7-40. Click the parameters (shown in bold) to highlight which to include in the graph. If a selection is highlighted by mistake, click it a second time to toggle it off. The sections for **Ramp B**, **Ramp C**, and **Isotope Ratios** are visible only if the TGA is in multiple-ramp mode. Once the choices are highlighted, click **OK** to bring up the *Graph* window.

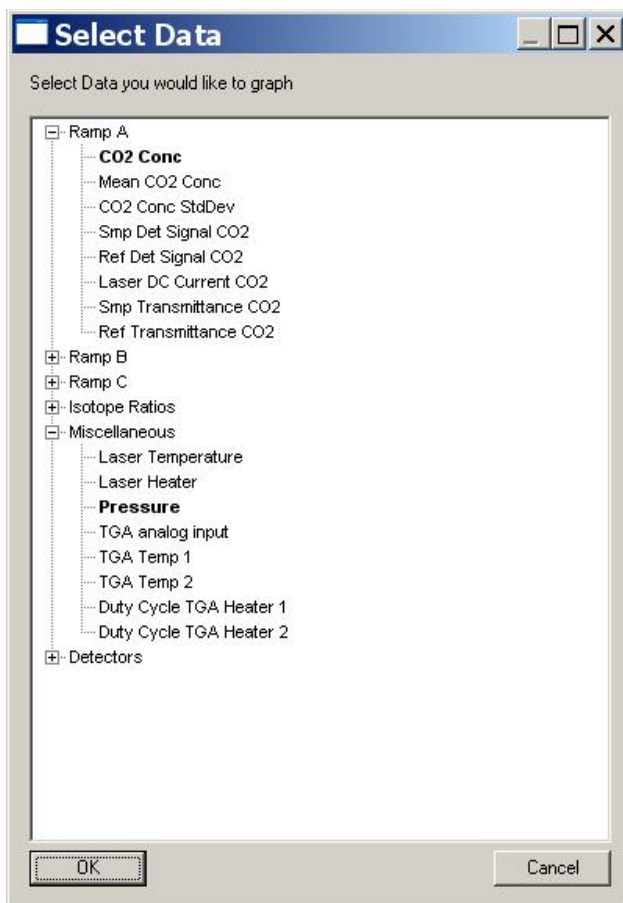


FIGURE 7-40. Options for graphical display of data in TGA Windows

TGA TEC

The steps to select data to be graphed are slightly different for *TGA TEC*. Click on a parameter, edit the options if necessary, and then press **Add** as shown in FIGURE 7-41. Repeat these steps to add more parameters to the graph. An example of the graphical output of the *TGA TEC* is shown in FIGURE 7-42.

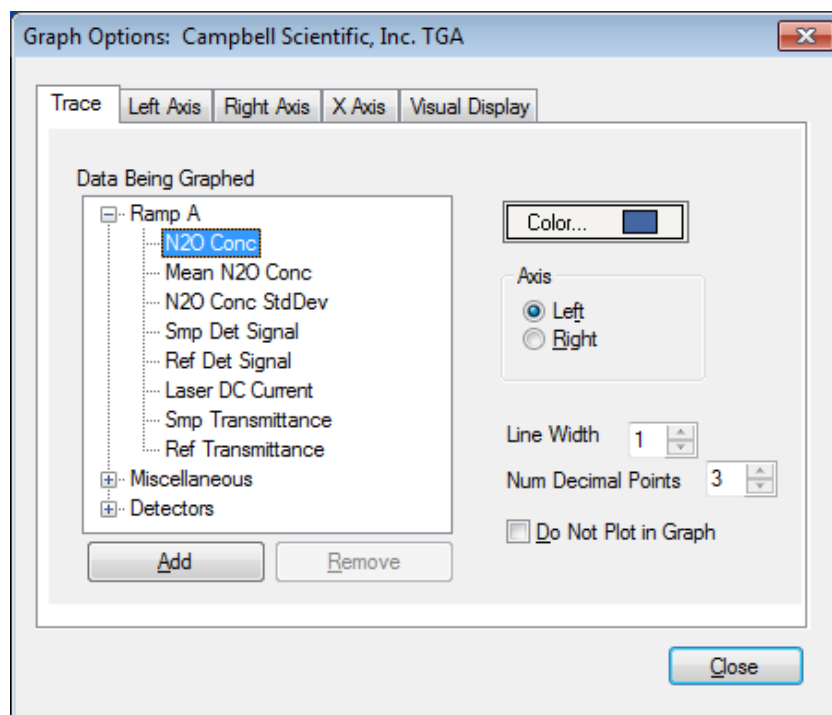


FIGURE 7-41. Adding parameters to a graph in TGA TEC

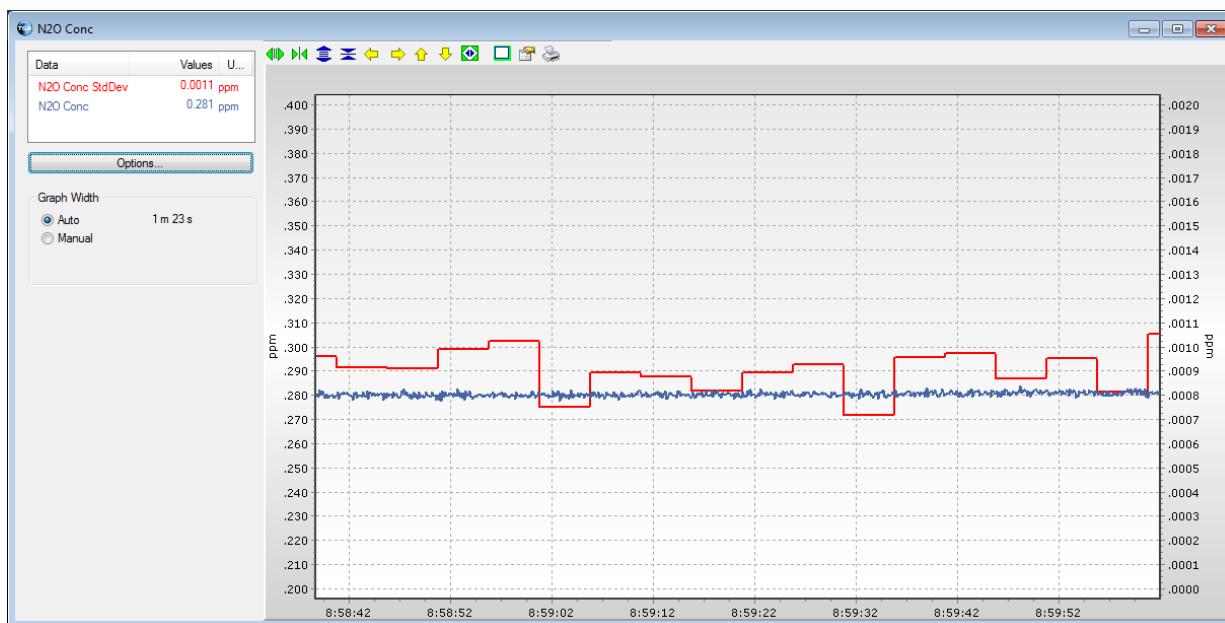


FIGURE 7-42. Example graph showing N2O concentration and standard deviation

Clicking **Options** will bring up a window to add, remove, or change the way a trace is shown, or to change the axes or the other visual aspects of the graph. The **Add** button can also be used to add traces.

Keeping the **Graph Width** in auto mode will scale the graph to the native resolution of the display (each datum is matched to one screen pixel). Resizing the graph window width changes the amount of data (time) that will be displayed. This mode is generally preferred because the data scroll more smoothly. The screen width may also be set manually, in which case the traces may not scroll as smoothly.

The graph may be zoomed by drawing a box from left to right around the portion of the graph to be displayed. This will temporarily rescale the axes and freeze the display. To resume scrolling with the previous axis scaling, draw a box from right to left or click the **Resume** button in the upper right corner of the graph.

Alternately, you may compress or expand the scales, or step up/down or left/right by clicking one of the icons at the top of the graph. Most of these functions have keyboard shortcuts. Click anywhere on the graph window to select it and hover over an icon to bring up a help box that explains its function and gives the keyboard shortcut.

7.2.7 Data

The *Data* tool on the TGA toolbar brings up the *Watch Window*. This window is used to view the TGA measurements in numerical form. Expand the headings to see the values. FIGURE 7-43 shows the **Ramp A** and **Detectors** headings expanded.

This tool is similar for *TGA Windows* and *TGA TEC*, except for the names and units associated with measurements and control of the laser temperature.

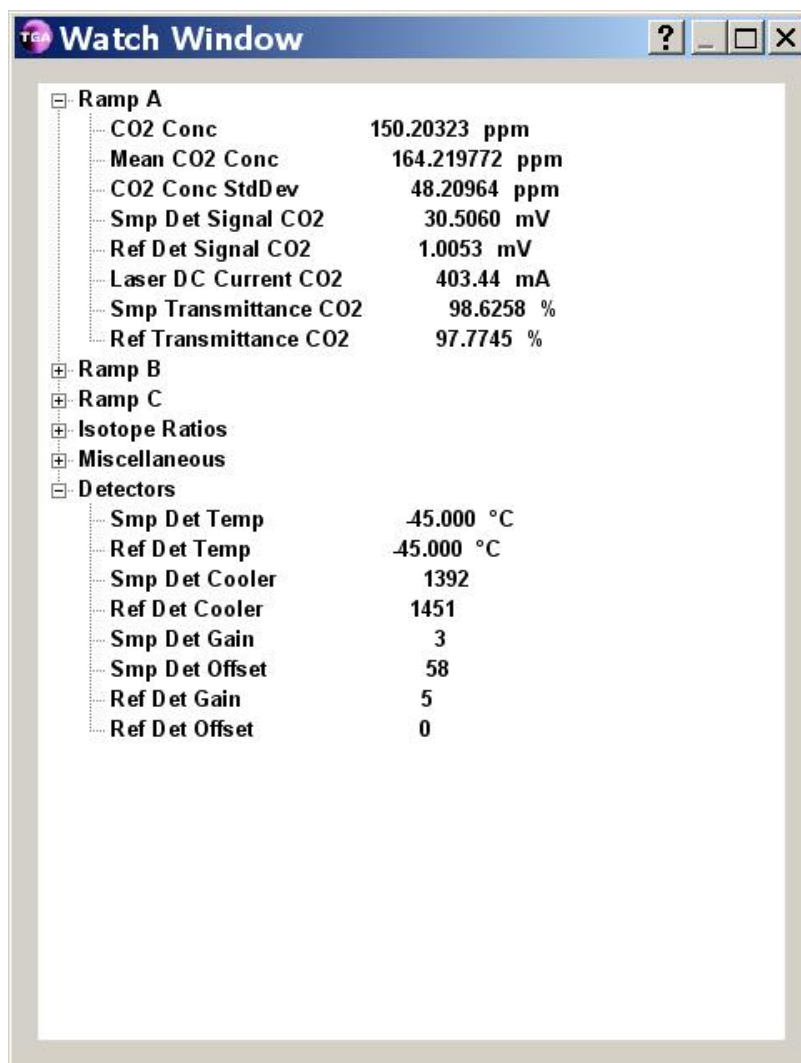


FIGURE 7-43. Data outputs of TGA TEC

7.2.8 Files

TGA data are usually collected using a datalogger. However, the data can also be collected using the PC. The *Files* tool of the TGA toolbar is used to set up the values to be collected and to turn data collection on and off. Clicking on the **Files** icon of the TGA toolbar will bring up the *Data Files* screen, shown in FIGURE 7-44.

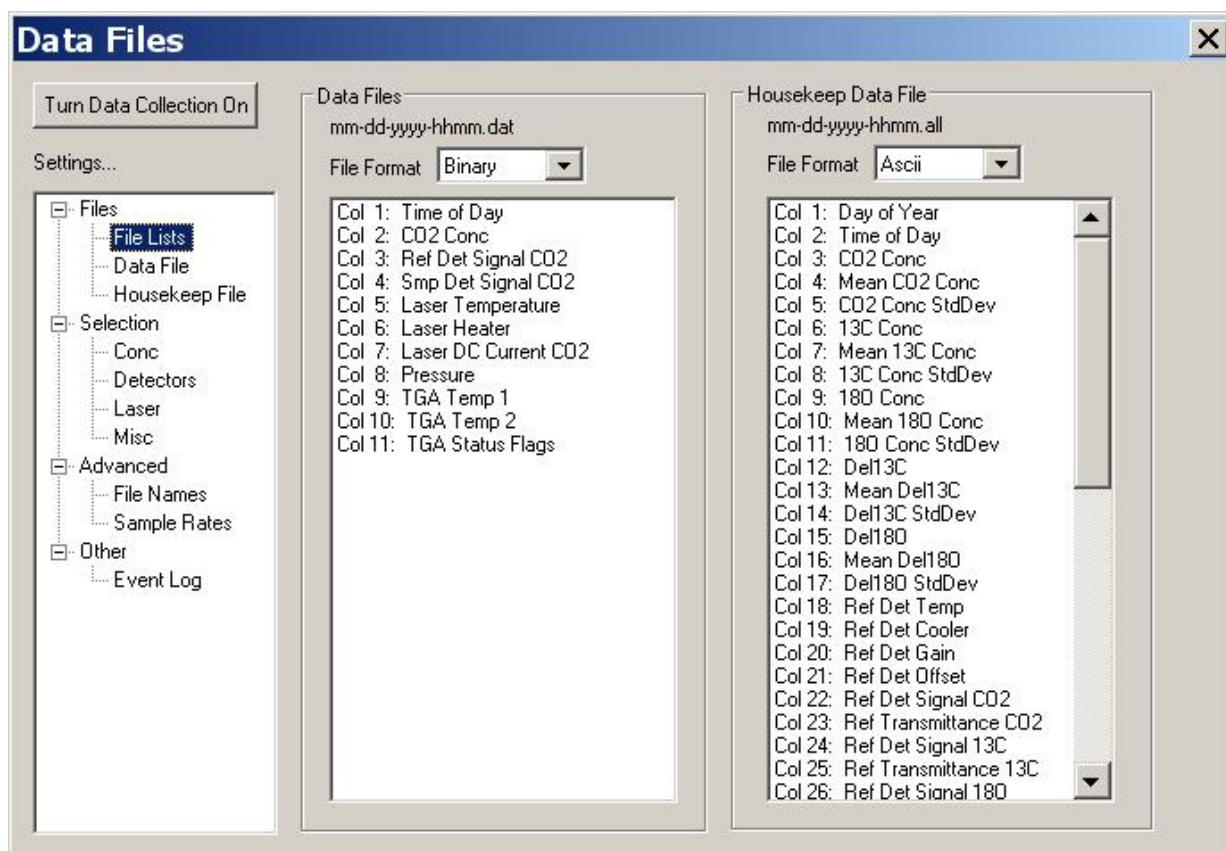


FIGURE 7-44. Controlling PC recorded data options in the TGA

The *Settings* column in the *Data Files* window is used to select what is displayed on the remainder of the window.

Files – display the names of the values set up to be collected.

File Lists – Show the values in both the Data File and Housekeep Data File. Set ASCII or Binary output.

Data File – List just the data file.

Housekeep File – List just the Housekeeping file. The Housekeep file contains all data.

Selection – Chose the values to be stored in the data file.

Conc – Chose the concentrations and isotope ratios to store.

Detectors – Chose the detector values to store.

Laser – Chose the Laser values to store.

Misc – Chose the miscellaneous values to store.

Advanced – Set file names and the location for the files.

File Names – Set parameters for the file naming the folder in which to store the files.

Sample Rates – Set the rates at which data are collected and stored.

Other – look at the event log.

Event Log – View or save a log of the status of the communication with the TGA. An example of the messages in the log file is shown in FIGURE 7-45.

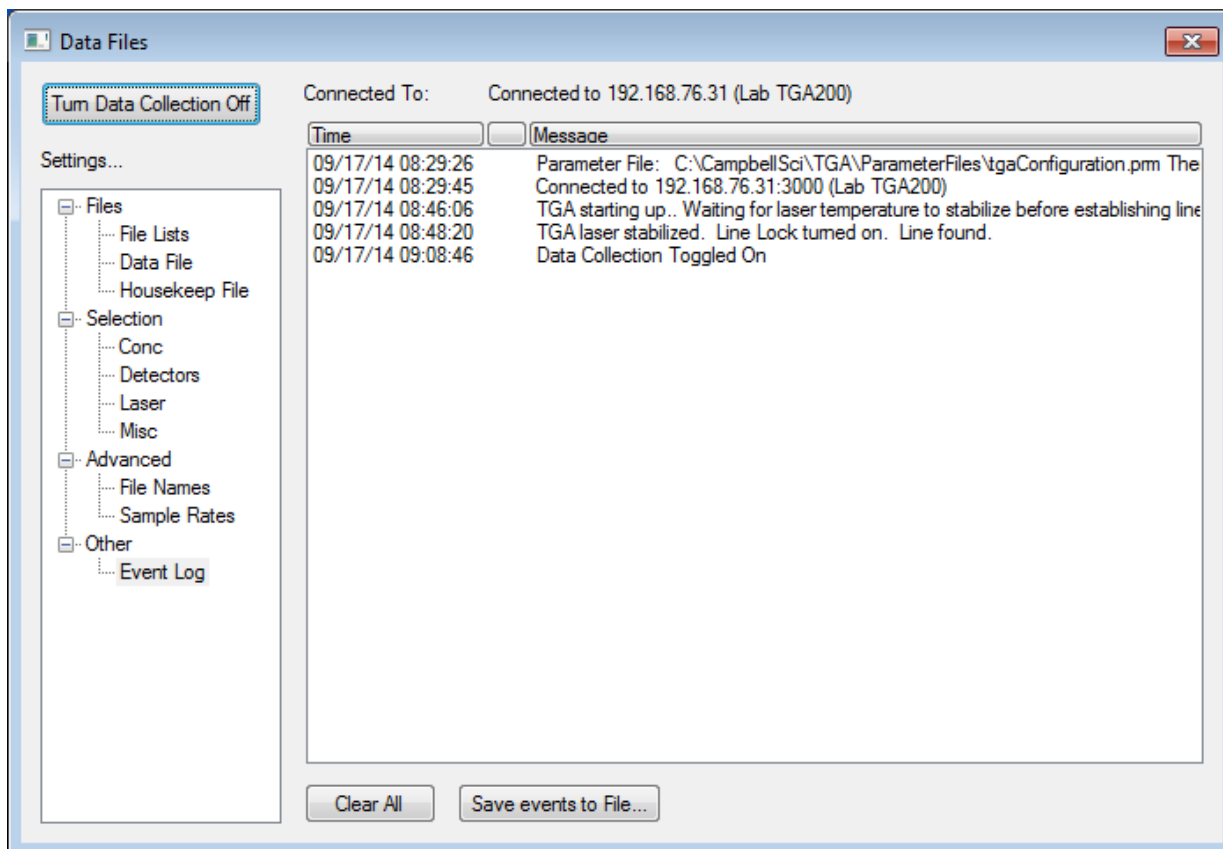


FIGURE 7-45. Example of log file messages

7.3 Data Output

The TGA may be configured to output data to the user's PC, or for analog outputs, but normally data are sent to a datalogger via an SDM cable.

7.3.1 SDM Output

SDM is a Campbell Scientific communication protocol that allows synchronized measurement and rapid communication between a Campbell Scientific datalogger and multiple devices including the TGA100A, TGA200, and TGA200A. The TGA100 requires the CPU upgrade for SDM communication. Although nearly all Campbell Scientific dataloggers support SDM, only the CR1000, CR3000, CR5000, and CR6 dataloggers support communications with TGAs with the **TGA()** instruction.

To configure the TGA for SDM output, connect a PC running TGA Windows/TGA TEC. Open the window *Settings > Other > Data Output*. Click the **SDM output** button as shown in FIGURE 7-46, and enter the SDM address for the TGA.

See the applicable user manual for details on these dataloggers.

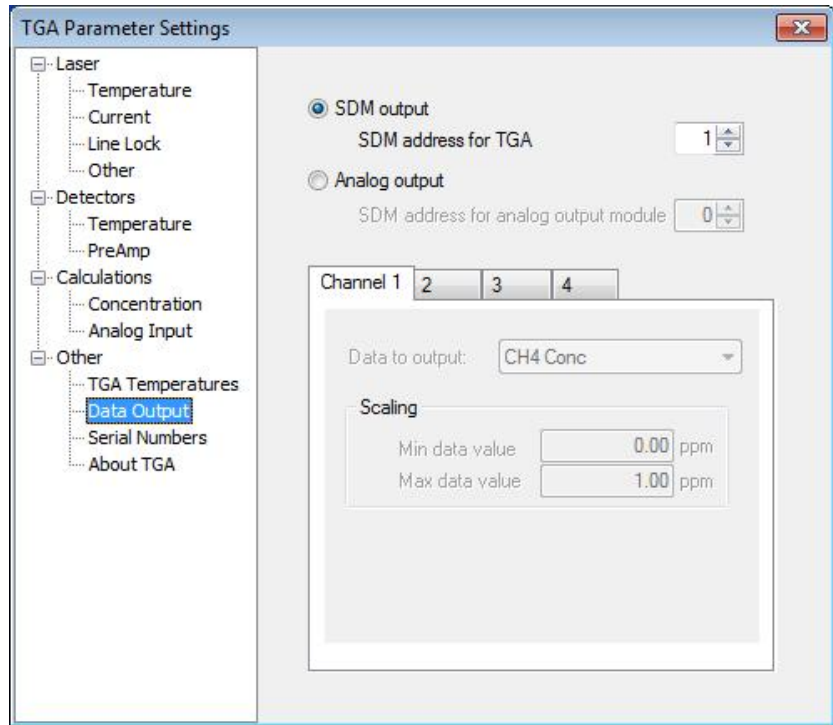


FIGURE 7-46. Setting TGA for SDM output from TGA Parameter Settings Window

The datalogger program must include the **TGA()** instruction to retrieve data from the TGA.

The **TGA()** instruction is used to measure a TGA100A, TGA200, or TGA200A trace gas analyzer system. It is also used for TGA100 with the upgraded CPU module.

7.3.1.1 Syntax

TGA([Dest](#), [SDMAddress](#), [DataList](#), [ScanMode](#))

7.3.1.2 Remarks

Dest

The **Dest** parameter is an array where the results of the measurement can be stored. The length of the input variable array depends on the values of parameters **DataList** and **ScanMode**.

SDMAddress

The **SDMAddress** parameter is a constant that defines the address of the TGA with which to communicate. Valid addresses are 0 through 14. The SDM address is entered as a base 10 number, unlike older, jumper-settable SDM instruments that used base 4.

DataList

The **DataList** parameter is a constant that specifies the data to be retrieved from the sensor. If **DataList** = 1, only concentration and status are returned. If **DataList** = 2, then sample cell pressure, laser temperature, and DC Current are returned in addition to concentration and status. If **DataList** = 3, then the TGA analog signal 1 and TGA temperatures are also returned. If **DataList** = 4, then all data except **DutyCycle1** and **DutyCycle2** are returned. If **DataList** = 5, then all data are returned.

ScanMode

The **ScanMode** parameter is a constant that specifies the number of values to be retrieved for scan-specific data. Normally the **ScanMode** parameter corresponds to the TGA **Number of ramps** parameter that specifies how many absorption lines are being measured. If **ScanMode** is set to a lower number than the TGA **Number of ramps** parameter, the data for ramp B and/or C will not be retrieved from the TGA. If **ScanMode** is set to a higher number than the TGA **Number of ramps** parameter, the TGA will return **zero** for the ramp B and/or C values.

See TABLE 7-3 for complete information.

TABLE 7-3. TGA Instruction			
Name	Description	DataList	ScanMode
ConcA	Trace gas concentration measured in Ramp A (ppmv)	1	1
ConcB	Trace gas concentration measured in ramp B (ppmv)	1	2
ConcC	Trace gas concentration measured in ramp C (ppmv)	1	3
TGAStatus	Status flags (see TABLE 7-4)	1	1
TGAPressure	Sample cell pressure (mb)	2	1
LaserTemp	Laser temperature (K) ¹	2	1
DCCurrentA	Laser DC current for ramp A (mA)	2	1
DCCurrentB	Laser DC current for ramp B (mA)	2	2
DCCurrentC	Laser DC current for ramp C (mA)	2	3
TGAAalog1	TGA Analog Channel 1 voltage (V)	3	1
TGATemp1	Temperature inside TGA enclosure, detector end (°C)	3	1
TGATemp2	Temperature inside TGA enclosure, laser end (°C)	3	1
LaserHeater	Voltage applied to the laser heater to maintain the laser at the specified temperature (V) ²	4	1
RefDetSignalA	Reference detector signal at the center of the spectral scan for ramp A (mV)	4	1

TABLE 7-3. TGA Instruction

Name	Description	DataList	ScanMode
RefDetSignalB	Reference detector signal at the center of the spectral scan for ramp B (mV)	4	2
RefDetSignalC	Reference detector signal at the center of the spectral scan for ramp C (mV)	4	3
RefDetTransA	Reference detector transmittance at the center of the spectral scan for ramp A (%)	4	1
RefDetTransB	Reference detector transmittance at the center of the spectral scan for ramp B (%)	4	2
RefDetTransC	Reference detector transmittance at the center of the spectral scan for ramp C (%)	4	3
RefDetTemp	Reference detector temperature (°C)	4	1
RefDetCooler	Current applied to the thermoelectric cooler to maintain the reference detector at its specified temperature (arb)	4	1
RefDetGainOffset	Gain and offset settings for the reference detector preamplifier (arb)	4	1
SmpDetSignalA	Sample detector signal at the center of the spectral scan for ramp A (mV)	4	1
SmpDetSignalB	Sample detector signal at the center of the spectral scan for ramp B (mV)	4	2
SmpDetSignalC	Sample detector signal at the center of the spectral scan for ramp C (mV)	4	3
SmpDetTransA	Sample detector transmittance at the center of the spectral scan for ramp A (%)	4	1
SmpDetTransB	Sample detector transmittance at the center of the spectral scan for ramp B (%)	4	2
SmpDetTransC	Sample detector transmittance at the center of the spectral scan for ramp C (%)	4	3
SmpDetTemp	Sample detector temperature (°C)	4	1
SmpDetCooler	Current applied to the thermoelectric cooler to maintain the sample detector at its specified temperature (arb)	4	1
SmpDetGainOffset	Gain and offset settings for the sample detector preamplifier (arb)	4	1
DutyCycle1	Fraction of full power applied to the TGA enclosure heater, detector end (arb)	5	1
DutyCycle2	Fraction of full power applied to the TGA enclosure, laser end (arb)	5	1

¹ Given in °C if TGA TEC² Voltage of cooler if TGA TEC

Status Flags

The **TGAStatus** value gives an indication of the overall status of the TGA. A value of zero indicates a normal condition. A nonzero value indicates one or more of the bits are set. The meaning of each of the bits is given in TABLE 7-4.

TABLE 7-4. Descriptions of TGAStatus Values		
Bit	Decimal Value	Description
0	1	Line Lock for ramp A is OFF
1	2	Line Lock for ramp B is OFF
2	4	Line Lock for ramp C is OFF
3	8	Sample detector signal exceeded input range
4	16	Reference detector signal exceeded input range
5	32	Sample detector temperature is outside its specified range
6	64	Reference detector temperature is outside its specified range
7	128	Laser temperature outside its specified range
8	256	Pressure is above its upper limit

7.3.2 TGA Output to PC

The Ethernet connection from the TGA to the user's PC does allow data to be collected via the *TGA Windows* or *TGA TEC* software. This is normally used only for testing and troubleshooting the TGA.

7.3.3 TGA Analog Outputs

For applications that require analog outputs instead of this SDM connection, it is possible to add an analog output module that can be driven by the SDM connection. Contact Campbell Scientific for details.

8. Troubleshooting and Maintenance**8.1 Lasers and Detectors**

TGAs equipped with cryogenic lasers and/or detectors required extensive routine maintenance: refilling the dewar with LN₂ (daily to weekly) and periodically (typically annually) evacuating the dewar to maintain its insulating vacuum.

TGAs equipped with TE-cooled lasers and detectors require no routine maintenance.

Troubleshooting both types of lasers and detectors involves the routine system checks described in Section 7.1, *Routine Operation*, and the detailed setup described in Appendices A through E.

8.2 Reference Gas

All TGAs require a constant flow of reference gas from a high-pressure cylinder of prepared gas. A typical cylinder will last approximately one year before it must be replaced. See Appendix A.2, *Reference Gas*, for details.

8.3 Filtration and Sample Cell Cleaning

The air sample to be measured must be filtered to remove particulates (10 μm maximum pore size). The filter will eventually plug, requiring cleaning or replacement. The filter is not included as part of the TGA, so the details will depend on the choice of filter and the application (flow rate). Two popular configurations are given as examples.

Eddy Covariance

Most TGA eddy-covariance applications use a PD200T dryer that includes a pn 20553 47 mm filter holder. (Earlier TGAs used the PD1000, which had a similar filter holder.) These filter holders use a 47 mm diameter, 10 μm pore size filter element (pn 9838 is a box of 100 replacement filter elements). This element must be replaced when it plugs enough to cause a significant decrease in the sample cell pressure. The replacement interval is typically monthly, but could be longer or shorter depending on conditions.

Atmospheric Profiles

Low-flow applications, such as atmospheric profiles, often use the pn 18072 heated filter/orifice assembly. This assembly uses a heated filter holder, pn 18058, which uses a replaceable filter element, pn 17575. This element will typically require replacement annually, but this interval could be longer or shorter depending on site conditions.

See Section 4.1.6, *Replacement Parts*, for details on these filter holders and replacement filter elements.

The TGA sample cell and optics do not require routine cleaning. Historically, the only TGAs returned to CSI for cleaning were heavily contaminated by inadvertently pulling large amounts of dirty water through the analyzer.

8.4 Sample Pumps

The TGA requires a vacuum pump to pull the air sample through the analyzer. The sample pump is not included as part of the TGA, so the details of pump maintenance depend on the choice of pump. Two sample pumps available from Campbell Scientific are given as examples.

RB0021-L

The RB0021-L sample pump is a large-capacity pump used for eddy covariance. It is an oil-sealed rotary vane pump that requires periodic replacement of the oil (typically monthly). Oil for the RB0021 is available from CSI as pn 8143.

See RB0021 user manual for troubleshooting suggestions.

XDD1

The XDD1 sample pump is a multi-stage diaphragm pump used for low-flow applications, such as atmospheric profiles. This pump requires no routine maintenance.

See the XDD1 user manual for troubleshooting suggestions.

See Section 4.1.4.4, *Sample Vacuum Pump*, for additional information about both of these pumps.

Appendix A. Configuring TGAs for Specific Gas Species

Campbell Scientific TGAs can be configured to measure one of several gases by selecting an appropriate laser, reference gas, and detectors. In some cases multiple gases can be measured simultaneously. The following sections give details on how to configure the TGA for the more commonly measured gases.

A.1 Laser Selection

Each gas species has a unique set of absorption lines and tunable diode lasers have limited tuning ranges. Therefore, in most cases a different laser is required for each gas species to be measured. Two types of lasers have been used in TGAs: LN₂-cooled lasers and thermoelectrically cooled (TEC) lasers.

CAUTION

The TGA uses a Class 1M laser. Do not view the laser directly with optical instruments.

A.1.1 LN₂-cooled lasers

The TGA100, TGA100A, and TGA200 used cryogenic lead-salt lasers that were available at wavelengths from 3 to 10 μm . This wide range of wavelengths allowed the TGA to measure a large number of different gases. Unfortunately, these lasers were discontinued by the manufacturer in 2012. For reference, the part numbers and gases measured are listed in TABLE A-1.

TABLE A-1. Discontinued Cryogenic Lead-salt Lasers		
Part Number (pn)	Target Gas(es)	Molecular Formula
7979	Methane	CH ₄
7113	Nitrous Oxide	N ₂ O
21400	Methane and Nitrous Oxide	CH ₄ and N ₂ O
21401	Nitrous Oxide and Carbon Dioxide	N ₂ O and ¹³ C ¹⁶ O ¹⁶ O
17466	Carbon Dioxide and $\delta^{13}\text{C}$	¹² C ¹⁶ O ¹⁶ O and ¹³ C ¹⁶ O ¹⁶ O
17469	Carbon Dioxide, $\delta^{13}\text{C}$, and $\delta^{18}\text{O}$	¹² C ¹⁶ O ¹⁶ O, ¹³ C ¹⁶ O ¹⁶ O, and ¹² C ¹⁸ O ¹⁶ O
21398	Water Vapor, δD , and $\delta^{18}\text{O}$	¹ H ¹ H ¹⁶ O, ² H ¹ H ¹⁶ O, and ¹ H ¹ H ¹⁸ O
21399	Ammonia	NH ₃

A.1.2 TE-cooled Lasers

The TGA200A uses TE-cooled lasers that became available in 2014. These lasers are available at wavelengths from 3 to 6 μm , allowing the TGA200A to measure the gases most commonly measured with earlier TGAs. In most cases earlier TGAs may be upgraded with a new TE-cooled laser to avoid the need

for cryogenics. See Appendix H, *Upgrading Early Generation TGAs to TE-cooled Lasers*, for details. Part numbers for these lasers are listed in TABLE A-2.

TABLE A-2. TE-cooled Lasers		
Part Number (pn)	Target Gas(es)	Molecular Formula
30477	Methane	CH ₄
30478	Nitrous Oxide	N ₂ O
31121	Nitrous Oxide and Carbon Dioxide	N ₂ O and ¹³ C ¹⁶ O ¹⁶ O
31119	Carbon Dioxide and δ ¹³ C	¹² C ¹⁶ O ¹⁶ O and ¹³ C ¹⁶ O ¹⁶ O
30877	Carbon Dioxide (δ ¹³ C and δ ¹⁸ O)	¹² C ¹⁶ O ¹⁶ O, ¹³ C ¹⁶ O ¹⁶ O, and ¹² C ¹⁸ O ¹⁶ O

A.1.3 Dewar Cables

For LN₂-cooled lasers, the standard laser dewar can accommodate up to two lasers. Each laser position (position 1 and position 2) requires a corresponding dewar cable. Position 1 and 2 cables are nearly identical, but they are wired to connect the *Laser Current* output from the TGA electronics to different pins on the dewar's connector. Inside the dewar, these pins are connected to the lasers mounted in position 1 and 2. Connecting the position 1 or 2 dewar cable therefore determines which laser is active. See Appendix A.1.4, *Changing Lasers*, for additional details on selecting the laser.

An optional second laser mount assembly will allow up to two more lasers to be installed in the dewar. The same position 1 and position 2 dewar cables are used for the lasers on the second mount. If a replacement dewar cable is needed, see TABLE A-3.

TABLE A-3. Replacement Cables for TGA Dewars		
	Position 1	Position 2
TGA100A	17895	17896
TGA200	21954	22001

Dewar cables for the TGA100 are no longer available. However, in most cases the TGA100 electronics may be upgraded to use the TGA100A cables. Contact Campbell Scientific for details.

TE-cooled lasers do not require a dewar or a separate dewar cable. The appropriate cabling is supplied as part of the laser assembly.

A.1.4 Changing Lasers

This section outlines the procedure to swap out the laser assembly (TE-cooled lasers) or to change which laser is active (multiple LN₂-cooled lasers in a dewar).

CAUTION

The TGA laser can be damaged by operating at a temperature or current outside maximum limits, which are unique to each laser. Follow the steps carefully to avoid damaging the laser.

DANGER

The TGA uses a Class 1M laser. Do not view the laser directly with optical instruments.

1. Turn the analyzer electronics off.
2. Disconnect the laser cable as appropriate for the laser.

LN₂-cooled laser

Disconnect the laser cable from the electronics and the dewar.

TE-cooled laser

Disconnect the laser cable from the electronics (the laser cable is permanently attached to the TE-cooled laser assembly).

NOTE

If switching between position 1 and position 2 lasers, skip step 3.

3. If the dewar must be rotated to select a laser in the optional second laser mount, or if the dewar or TE-cooled laser assembly is to be exchanged, remove the four mounting screws, rotate/exchange the dewar or TE-cooled laser assembly, and reinstall and tighten the mounting screws.

WARNING

Do not connect the dewar cable at this time.

4. Start the TGA software on your PC. Read an appropriate parameter file for the new laser.

WARNING

To avoid damaging the laser, ensure that the parameters are valid for the new laser. In particular, verify the laser maximum temperature and laser maximum current.

WARNING

To avoid damaging the laser, make sure the laser cable is not connected.

5. Turn the analyzer electronics on.
6. Send the new parameters to the TGA as you connect the TGA software.
7. Save the new parameters in the TGA.
8. Turn the analyzer electronics off.

9. Connect the *Laser Temperature*, *Laser Heater/Cooler* and the *dewar* (LN₂-cooled laser) connectors.

WARNING

To avoid damaging the laser, do not connect the Laser Current connector at this time.

10. Turn the analyzer on.
11. Connect to the TGA with the TGA software. Receive the parameters as you connect. This allows you to view the parameters stored in the TGA.
12. Verify all of the parameters are correct for the new laser. If any parameters are incorrect, adjust the parameters as needed and repeat steps 7 to 12.

WARNING

Do not proceed until you verify the correct parameters are stored in the TGA's non-volatile memory.

13. Turn the analyzer off and connect the *Laser Current* connector.
14. Turn the analyzer on.
15. Connect to the TGA with the TGA software. Receive the parameters as you connect.

The new laser will now be active.

To complete the installation, change the reference gas (Appendix A.2, *Reference Gas*) and detectors (Appendix A.3, *Detectors*; if necessary), and then follow the steps in Appendix B, *Optical Alignment*, Appendix A.4, *Finding the Absorption Line*, Appendix C, *Optimizing Laser Parameters*, Appendix D, *Optimizing Detector Parameters*, and Appendix E, *Calibration*.

A.2 Reference Gas

A prepared reference gas having a known concentration of the gas to be measured must flow through the reference cell. The beamsplitter directs a fraction of the laser power through the reference cell to the reference detector. This gives a reference signal with the spectral-absorption signature of the reference gas. The reference signal provides a template for the spectral shape and position of the absorption feature. This allows the concentration of the sample gas to be derived without measuring the temperature or pressure of the sample gas, or the spectral positions of the scan samples. The reference signal provides feedback for a digital control algorithm to maintain the center of the spectral scan at the center of the absorption line (line locking). The reference signal also allows the user to identify the wavenumber of an absorption line by comparing it to the theoretical absorption spectrum of the gas.

The reference cell is kept at the same pressure as the sample cell by connecting the outlets of both cells to a common vacuum manifold. A continuous flow of reference gas must be maintained to avoid dilution of the reference gas with the sample gas. A flow of 10 ml/min is recommended.

The reference gas and sample gas are brought to the same temperature by flowing each of them through a sufficient length of tubing inside the analyzer enclosure. This brings both sample and reference gas to the temperature of the inside of the enclosure.

The absorbance of the reference gas depends primarily on the line strength of the selected absorption line, the concentration of the reference gas, and the path length. Pressure and temperature also affect the reference absorbance. The reference gas concentration should be chosen to give an absorbance (in the center of the absorption line) of 0.3 to 0.9 (transmittance of 75% to 40%). If the absorbance is significantly more or less than this, the concentration noise may increase. Suggested reference gas concentrations for the most commonly measured gases are listed in TABLE A-4.

NOTE

A higher reference gas concentration is required for the TGA100 and TGA100A because they have a shorter path length for the reference cell.

TABLE A-4. Suggested Reference Gas Concentrations				
Gas Species		TGA100 or TGA100A	TGA200 or TGA200A	Balance of Tank
Methane (CH ₄)		15,000 (1.5%)	500	N ₂
Nitrous Oxide (N ₂ O)		2,000	60	Air or N ₂
N ₂ O/CO ₂	N ₂ O	2,000	90	Air or N ₂
	CO ₂	300,000 (30%)	15,000 (1.5%)	
N ₂ O/CH ₄	N ₂ O	10,000	350*	N ₂
	CH ₄	20,000	850*	
Carbon Dioxide (CO ₂) isotopic ratios, $\delta^{13}\text{C}$ only		100,000 (10%)	2500	Air
Carbon Dioxide (CO ₂) isotopic ratios, $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$		300,000 (30%)	10,000 (1%)	Air
Ammonia (NH ₃)		5,000	160**	Air or N ₂
Water or other		Contact Campbell Scientific		

*the N₂O/CH₄ laser is not available for the TGA200A

**the ammonia laser is not available for the TGA200A

The concentration of the reference gas is used to calculate the concentration of the sample gas; therefore, it must be entered into the TGA software. The calculated sample concentration is scaled by this value. If it is not correct, the measured concentration will have a corresponding scale error. For many trace gas flux measurement applications, a measurement of the reference gas accurate to 2% is adequate.

NOTE

For applications that require a more accurate concentration measurement the TGA may be calibrated using two well-known calibration tanks as discussed in Appendix E, *Calibration*. For these applications the reference gas concentration provides only a preliminary estimate that is superseded by the measurements of the calibration gases. This makes a highly accurate measurement of the reference gas concentration unnecessary.

The user must provide an appropriate regulator for the cylinder of reference gas. The delivery pressure is normally set to approximately 0 psig, and the flow is typically set to 10 ml/min, so the regulator should be chosen for good performance at low delivery pressure and flow.

The reference gas flow is generally set by a needle valve and monitored with a flow meter. A reference gas connection assembly (pn 15837) is available from Campbell Scientific for this purpose, see Section 4.1.3.1, *TGA Reference Gas Connection*, for more details. This assembly includes a flow meter, needle valve, and 6.2 m (20 ft) of tubing with Swagelok® fittings to connect to the TGA. The outlet of the regulator must have a 1/4 in Swagelok® fitting to attach this assembly.

A tank of reference gas 5.7 m³ (200 ft³), will last approximately one year at a continuous flow of 10 ml/min.

A.3 Detectors

The most commonly measured trace gases, methane, nitrous oxide, and CO₂ isotopes (as well as many other gases), have strong absorption lines at wavelengths from 3 to 5 μm, and can be measured with the standard TE-cooled detectors. Some gases, such as ammonia, water isotopes, or the combination of N₂O and CH₄ must be measured at longer wavelengths and require the optional LN₂-cooled detectors. The TGA100 and TGA100A were supplied with custom LN₂-cooled detectors which required daily filling. The TGA200 had optional LN₂-cooled detectors with a much larger dewar that required filling twice weekly.

The TGA200A always uses TE-cooled detectors because its TE-cooled lasers cannot reach the longer wavelengths that require LN₂-cooled detectors.

A.4 Finding the Absorption Line

The spectral scan of the TGA must be locked onto a selected absorption line. When the TGA is restarted, it will perform an automated sequence to reestablish this line lock by waiting until the laser temperature has stabilized, and then lock onto the strongest absorption line within its spectral scan. Normally, this will be the same absorption line it was locked onto previously. In some cases, however, the automatic startup sequence will not find any absorption line, or it will lock onto the wrong line. It is recommended that the user verify that the correct absorption line has been locked.

The laser's emission frequency can be changed manually by changing the DC current and the modulation current. It may be helpful to think of the reference detector display as a viewing window looking upon a portion of the transmittance spectrum. Increase the DC current to move the window to the

right and decrease the DC current to move the window to the left. It may also be helpful to temporarily increase the width of the spectral scan by increasing the modulation current. See Section 7.2.4, *Laser Window*, for details on displaying the absorption line and adjusting the laser DC current and modulation current.

After the absorption line is found, adjust the DC current up or down to find nearby absorption lines. Compare the spacing and relative depth of the observed absorption lines to the transmittance spectrum provided in the laser's user manual to verify it is the desired absorption line. Adjust the DC current to position the selected absorption line near the center of the spectral scan. Readjust the modulation current (see Appendix C.5, *Modulation Current*) and initiate the line locking function.

For multiple ramp operation, each of the ramps must be locked onto the proper absorption line.

If the expected absorption line is not found easily, use the laser Find tool (Section 7.2.5, *Find*).

A.5 Air Gap Purge

For isotope ratio applications, the air gap between the laser and lens, and the short sample cell, should be purged as shown in FIGURE A-1 (TGA100 or TGA100A) or FIGURE A-2 (TGA200 or TGA200A). This is not required for most trace gas applications where the ambient concentration is very low, and there is very little absorption. The sample cell is at low pressure, making the sample absorption very narrow compared to the pressure-broadened ambient absorption. Thus, the concentration measurement is relatively insensitive to trace gases in the ambient-pressure air gap.

This is not the case, however, for CO₂ or water isotope measurements where the ambient concentration is relatively high and can change rapidly (for example, if the cover of the TGA is off and a person in the vicinity exhales). Because these types of applications require extremely high accuracy, the air gap should be purged to prevent absorption. A tank of compressed nitrogen should be connected to the purge inlet. A flow of approximately 10 ml/min is recommended. The regulator on the user's tank may be connected to the purge using the flow meter, needle valve, and tubing included in the reference gas connection, pn 15837, or similar hardware.

In the TGA100A or TGA100A the purge connection is at the end of the enclosure. The purge gas flows through the short sample cell and into a purge boot around the air gap between the laser and lens holder, as shown in FIGURE A-1.

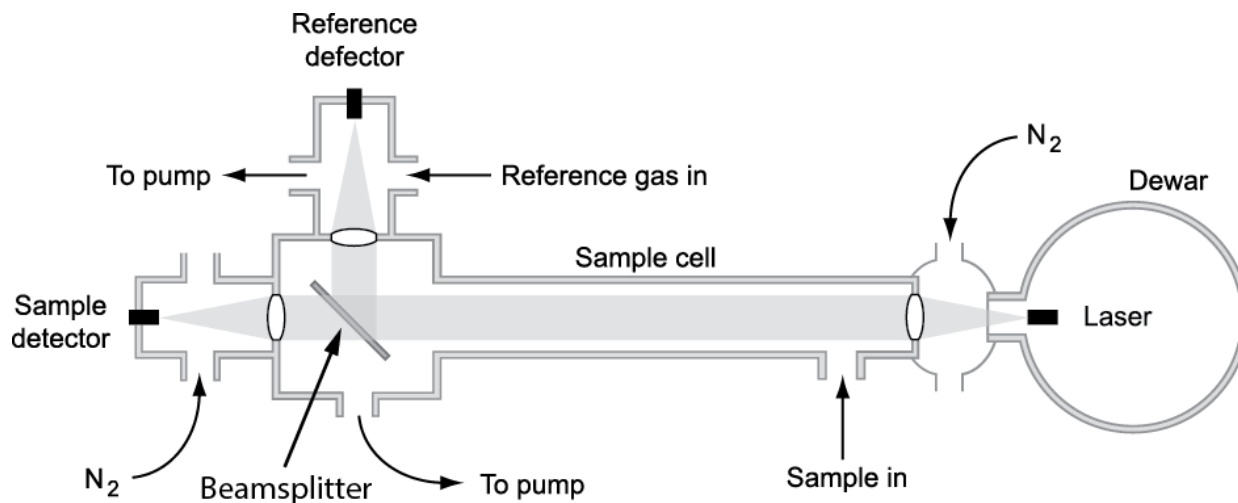


FIGURE A-1. TGA100 or TGA100A optical layout with air gap purge

In the TGA200 or TGA200A the purge connection is in the middle of the enclosure. The purge gas splits, flowing to the detector block and the beamsplitter block. The flow through the beamsplitter block purges the air gap between the lens holder and the laser. This configuration is shown in FIGURE A-2.

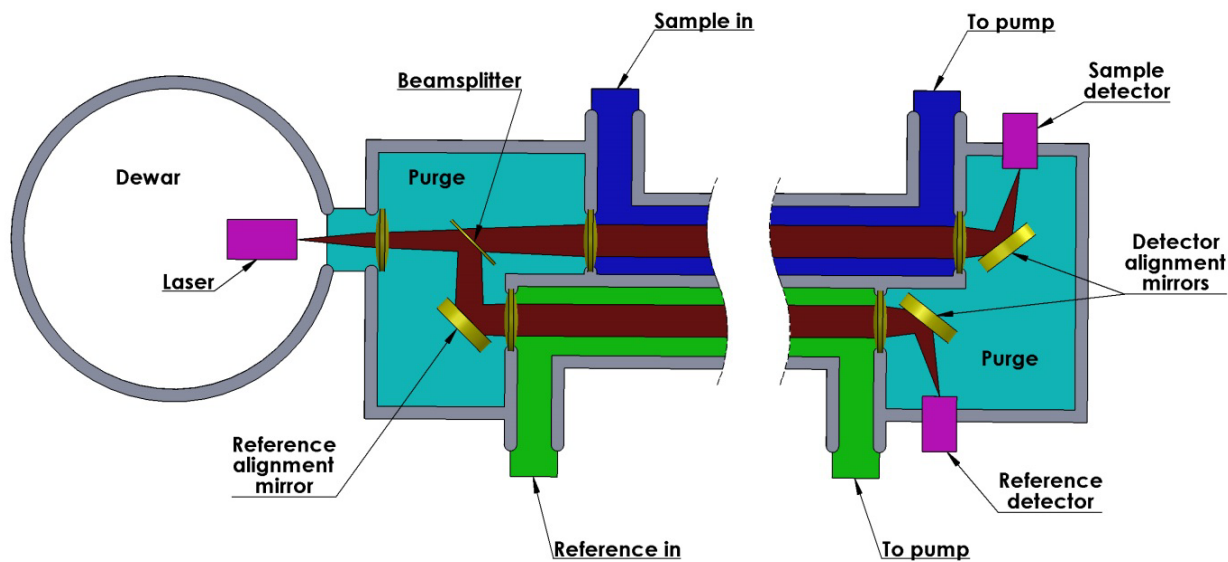


FIGURE A-2. TGA200 or TGA200A optical layout with air gap purge

Appendix B. Optical Alignment

Campbell Scientific TGAs have simple, robust optical designs that do not require adjustments in normal use. The optical alignment may need minor adjustments after transporting the system or if the laser is replaced. The optical design of the earlier models (TGA100 and TG100A) is different than that of the later models (TGA200 and TGA200A). See the relevant section below for details.

B.1 Optical Alignment of TGA100 and TGA100A

The TGA100 and TGA100A have a simple, robust optical design that makes it easy to adjust and maintain its optical alignment. The optical system, illustrated in FIGURE B-1, includes the laser, a collimating lens in front of the laser, a beamsplitter to reflect some of the laser's energy onto the reference detector, and two focusing lenses mounted in front of the sample and reference detectors.

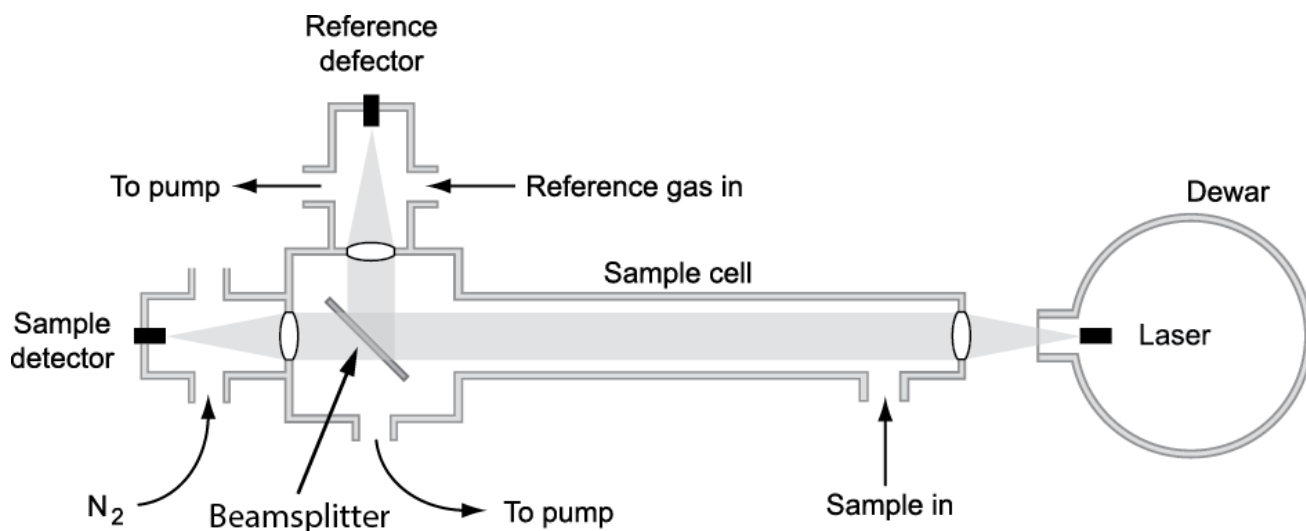


FIGURE B-1. TGA100 and TGA100A optical layout

To adjust the TGA100 and TGA100A optical alignment complete the following steps.

1. Loosen the transport lock screw and axial lock screw at the detector end (refer to FIGURE B-2). These screws should both be loose during all periods of operation to allow the detector end to move slightly as the length of the long sample cell changes with temperature.

NOTE

The transport lock screw and axial lock screw should be tightened only for transporting the TGA.

NOTE

FIGURE B-2 shows the horizontal adjustment screw that was included with older units. Newer units use a fine-pitch horizontal adjustment screw at the laser end which makes horizontal adjustment at the detector end unnecessary.

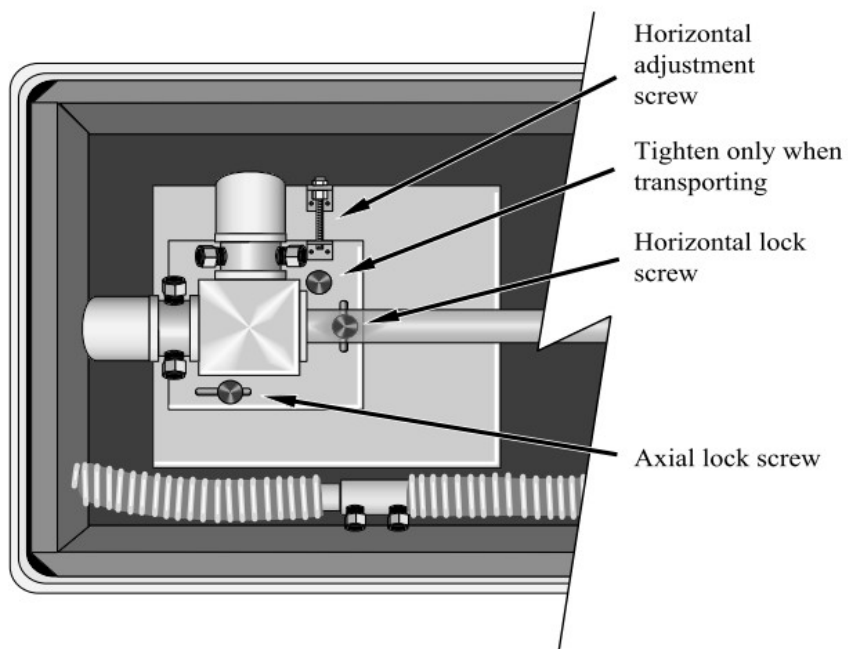


FIGURE B-2. Alignment hardware of detector end of TGA100 and TGA100A

2. Loosen the horizontal and vertical clamping screws at the laser end (refer to FIGURE B-3).

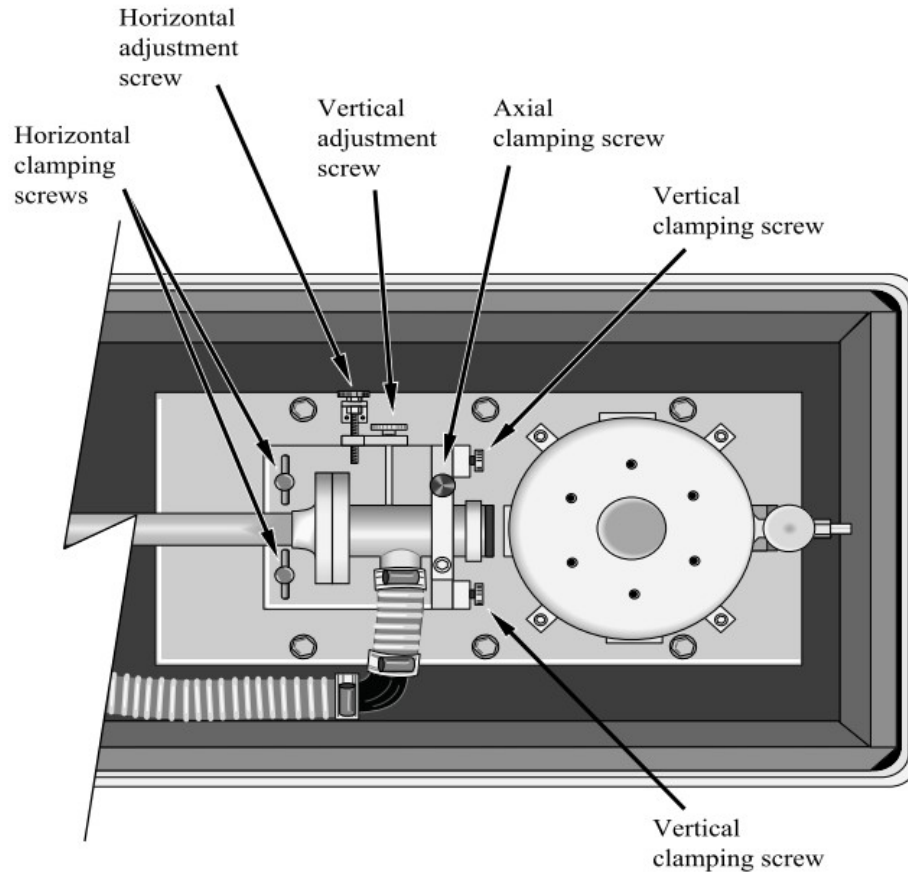


FIGURE B-3. Alignment hardware of laser end of TGA100 and TGA100A

3. If the TGA is equipped with an iris in front of the focusing lens, open it fully (this is recommended for normal operation).
4. Start the TGA program and make sure the laser and detector parameters are set appropriately for the laser.
5. Display the reference detector signal and the sample detector signal in a graph. The goal of the alignment procedure is to maximize these signals.
6. Edit the graph options to move one of the traces to the right axis. Set the minimum value of each Y axis to zero and let the maximum of each Y axis scale automatically.
7. Set the reference and sample detector gains to zero. This will disable automatic gain and offset adjustment which can cause confusion during the alignment process when active.
8. Set the detector temperatures as needed to avoid saturation. This adjustment may need to be repeated during the alignment process if the signal level increases too much. It is not important to have large

signals during alignment. When in doubt, set the detector temperatures relatively high for relatively low signals.

9. If no sample detector signal can be seen, perform the initial alignment (see Appendix B.2.2, *Initial Alignment*).
10. Once a signal can be observed on the sample detector, adjust the horizontal and vertical alignment (Appendix B.2.3, *Horizontal and Vertical Alignment*).
11. Adjust the focus (Appendix B.1.3, *Focus Adjustment*).
12. When the focus and the horizontal and vertical alignment have been optimized, tighten the horizontal, vertical, and axial clamping screws.

NOTE

Remember to leave the transport lock and axial lock screws loose.

13. Make sure the reference detector is coaligned with the sample detector (Appendix B.1.4, *Reference Detector Coalignment*).

B.1.1 Initial Alignment

If the optical system is significantly misaligned, there may be no observable detector response. This initial alignment procedure will help to align the system well enough to see a response. As soon as a detector response is observed, the system is ready for the horizontal and vertical alignment procedure described in Appendix B.1.2, *Horizontal and Vertical Alignment*.

1. If the TGA is equipped with a horizontal adjustment screw at the detector end, loosen the horizontal lock screw, adjust the horizontal position to near the center of its adjustment range, and retighten the horizontal lock screw.

NOTE

Older units were supplied with a horizontal adjustment screw at the detector end, but newer units use a fine-pitch horizontal adjustment screw at the laser end which makes horizontal adjustment at the detector end unnecessary.

2. Use the horizontal adjustment screw at the laser end to align the long sample cell with the laser.
3. Sight along the long sample cell to point it at the laser, which can be viewed through the dewar window, hanging below the laser mount.

CAUTION

The TGA uses a Class 1M laser. Do not view the laser directly with optical instruments.

4. Use the vertical adjustment screw to align the long sample cell with the laser. If no detector response is observed, set the vertical adjustment near the center of its adjustment range.

5. Alternately adjust the horizontal and vertical alignment screws. When a response is observed in the sample detector, proceed to the next section. If a response is not observed troubleshoot with the following steps.
6. If a detector response is not observed, it may be helpful to defocus the optics intentionally. This will make the laser's image on the detector larger and easier to locate. Loosen the axial clamping screw at the laser end. Slide the long sample cell back (away from the laser) about 5 mm from the center of its adjustment range and retighten the axial clamping screw. Alternately adjust the horizontal and vertical adjustment screws.
7. If no detector response can be found, perform the following checks:
 - If two lasers are installed, verify they are aligned to the correct laser
 - Verify the dewar cable is installed correctly; if two or more lasers are installed, verify the correct cable is being used
 - Verify the detector cables are correctly installed
 - Verify the laser is enabled in the TGA program
 - Recheck the laser temperature, and the settings for zero, DC, modulation, and high current
8. If a detector response is still not observed, Contact Campbell Scientific for assistance.

B.1.2 Horizontal and Vertical Alignment

Once the system is aligned well enough to see a response in the sample detector, follow these steps to optimize the horizontal and vertical alignment.

1. Adjust the horizontal alignment screw (see FIGURE B-3) to maximize the sample detector signal.

NOTE

The sample and reference signals may not reach their maxima simultaneously. If so, ignore the reference detector signal and adjust the alignment to maximize the sample detector signal. Adjust the horizontal position past the peak in each direction far enough to make sure there is a single response peak. If there is a single peak, leave it at the center of the peak. If there are multiple peaks, leave the horizontal alignment at the center of the group of peaks.

Some older systems used a relatively coarse-pitch screw for the horizontal alignment at the laser end and a second horizontal adjustment screw at the detector end. This screw provides a finer adjustment of the horizontal alignment than the one at the laser end, allowing the signal to be more easily maximized. Newer systems have a fine-pitch horizontal adjustment screw at the laser end and require no adjustment at the detector end.

2. Adjust the vertical alignment screw (see FIGURE B-3) to maximize the sample detector signal, in the same way as for the horizontal alignment.
3. Iterate the horizontal and vertical alignment until the sample detector signal is maximized. If there is a single narrow peak horizontally and vertically, the system is also in good focus. If the response peak is broad or if it has multiple peaks, adjust the focus as outlined in the following section, B.1.3, *Focus Adjustment*.

B.1.3 Focus Adjustment

The optical system includes the long sample cell, with the lens holder at the laser end, and the beamsplitter and detectors at the other end. To focus the system, this entire assembly is moved closer or farther away from the laser.

1. To adjust the focus, first note the sample detector signal at the current focus position.
2. Loosen the axial clamping screw, slide the optical assembly either forward or back a short distance (~ 2 mm), and retighten the axial clamping screw.
3. Readjust the horizontal and vertical alignment to find the maximum sample detector signal at this new focus position.
4. Compare the sample detector signal at this focus position to the signal at the previous focus position. Step the focus again in the same direction if the signal improved, or move it the other direction if the signal decreased.
5. Repeat this process until the sample detector signal has a single, narrow peak of maximum height. It may be helpful to record the focus position and sample signal in a table, along with a qualitative assessment of the focus: whether there is one or multiple peaks, and if the peak seems broad or narrow.
6. Generally the goal is to set the focus for a single narrow peak, giving the maximum sample signal. In some cases it may be desirable to intentionally defocus the system as in some of the following scenarios.
 - Isotope ratio measurement accuracy may be improved by defocusing to reduce detector nonlinearity
 - If the laser signal is large enough that the detector temperatures must be raised above $\sim 0^\circ\text{C}$ to avoid detector saturation, defocusing will reduce the signal and it will also reduce detector nonlinearity
 - If it is difficult to coalign the reference and sample detector (see Appendix B.1.4, *Reference Detector Coalignment*) it may be helpful to defocus the system

In cases where the optics are to be intentionally defocused, start at the position of best focus and move the optical system away from the laser by no more than

5 mm. It is generally best to defocus just enough to give a single relatively broad, flat peak.

B.1.4 Reference Detector Coalignment

Once the optical alignment has been optimized for the sample detector, check the coalignment of the reference and sample detectors. Ideally, the sample and reference detectors are optically coincident, and adjusting the horizontal and vertical alignment gives a maximum response for both detectors at the same position. Evaluate this by watching both detector signals while adjusting the horizontal and vertical alignment. If they are not coincident, the reference detector alignment must now be adjusted.

The process is different for older and newer systems:

Older systems:

The beamsplitter mount can be rotated to adjust the vertical coalignment of the reference detector to the sample detector. Loosen the three beamsplitter clamping screws, rotate the beamsplitter mount to maximize the reference detector signal, and retighten the beamsplitter clamping screws. It is recommended that the system be at normal operating pressure (vacuum pump on) for this step. If it is not possible to achieve adequate signal on the reference detector signal by rotating the beamsplitter, it may be necessary to make a small adjustment to the horizontal, vertical, and axial alignment to reach a compromise between the reference detector signal and the sample detector signal.

Newer systems

These systems have a combined reference cell/detector holder that includes horizontal and vertical alignment cams. For these systems, the beamsplitter mount should be rotated to center the three clamping screws in their slots. Align the reference detector to the sample detector by loosening the three screws that attach the reference detector holder to the beamsplitter block, turning the alignment cams to maximize the reference signal, and then retightening the mounting screws.

The optical alignment is now complete.

B.2 Optical Alignment of TGA200 and TGA200A

Like its predecessors, the TGA200 and TGA200A also have a simple, robust optical design making it similarly easy to adjust and maintain optical alignment. The optical system, illustrated in FIGURE B-4, includes the laser, collimating lenses in front of the laser, a beamsplitter to reflect some of the laser's energy through the reference cell, and three mirrors for aligning the beam through the reference cell and onto the sample and reference detectors.

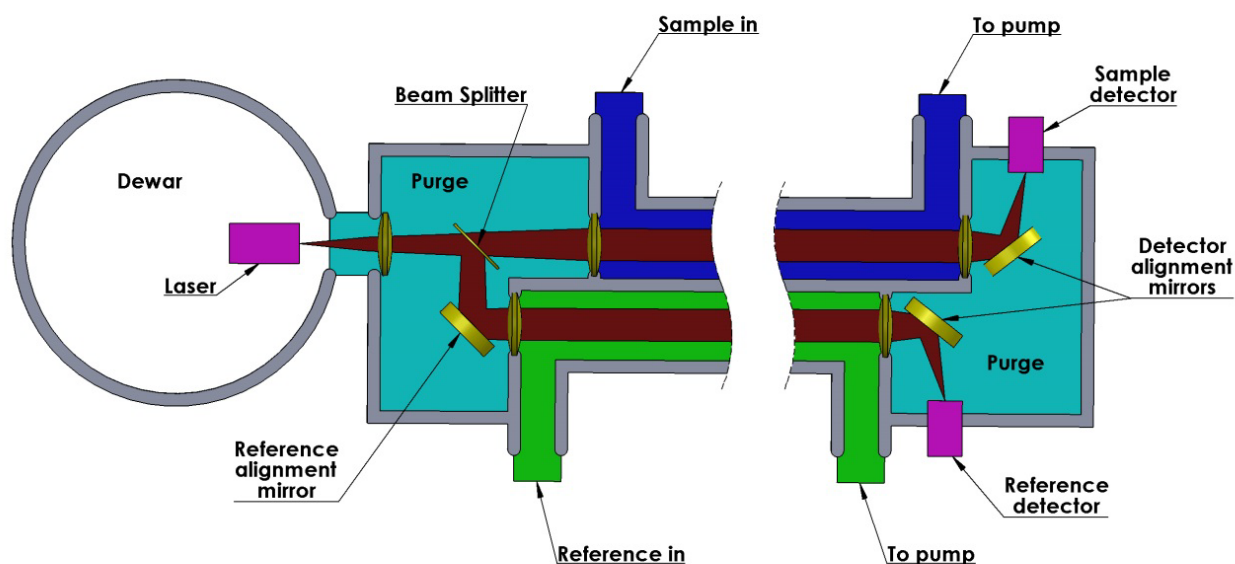


FIGURE B-4. TGA200 and TGA200A optical layout

The TGA optical alignment does not change during normal operation, but it should be checked after transport. FIGURE B-5 illustrates the horizontal, vertical, and reference mirror tip/tilt adjustment knobs (shown with the laser removed for clarity).

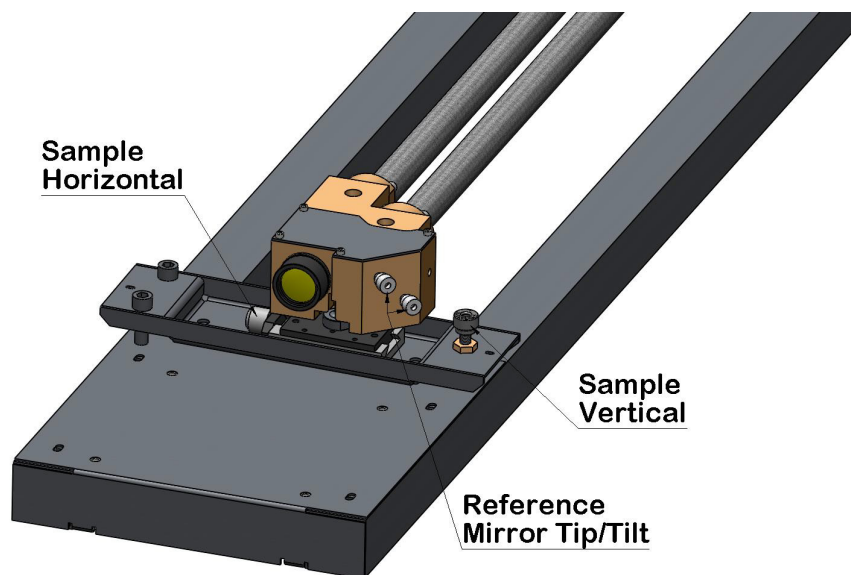


FIGURE B-5. Alignment hardware of laser end of TGA200 variants

FIGURE B-6 illustrates the alignment hardware at the detector end.

NOTE

This illustration is a view looking up from underneath. The adjustment screws are not visible from above.

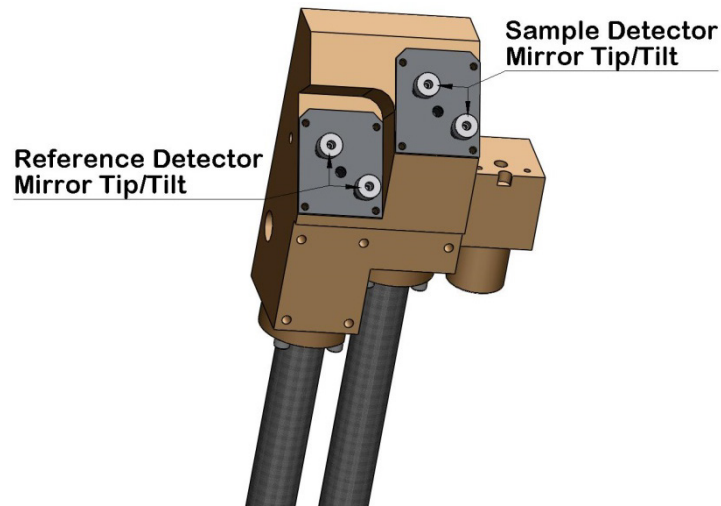


FIGURE B-6. Alignment hardware of detector end of TGA200 variants

B.2.1 Configure the TGA PC Software

1. Start the TGA program and make sure the laser and detector parameters are set appropriately for the laser.
2. Display the reference detector signal and the sample detector signal in a graph. The goal of the alignment procedure is to maximize these signals.
3. Edit the graph options to move one of the traces to the right axis, set the minimum value of each Y axis to zero and let the maximum of each Y axis scale automatically.
4. Set the reference and sample detector gains to zero. This will disable automatic gain and offset adjustment which can cause confusion during the alignment process when enabled.
5. Set the detector temperatures as needed to avoid saturation. This adjustment may need to be repeated during the alignment process if the signal level increases too much. It is not important to have large signals during alignment. When in doubt, set the detector temperatures relatively high for relatively low signals.

B.2.2 Initial Alignment

If the optical system is significantly misaligned, there may be no observable detector response. This initial alignment procedure will help to align the system well enough to see a response. As soon as a detector response is

observed, the system is ready for the horizontal and vertical alignment procedure described in Appendix B.2.3, *Horizontal and Vertical Alignment*.

1. Make sure the clamp knobs are loose and that the optical assembly is in position.
2. Use the horizontal adjustment screw at the laser end to align the sample cell with the laser.
3. Use the vertical adjustment screw to align the sample cell with the laser. If no detector response is observed, set the vertical adjustment near the center of its adjustment range.
4. Alternately adjust the horizontal and vertical alignment screws. When a response is observed in the sample detector, proceed to the next section.
5. If no detector response can be found, perform the following checks:
 - If two lasers are installed (TGA200), verify you are aligning to the correct laser.
 - Verify the dewar cable is installed correctly. If two or more lasers are installed (TGA200), verify you are using the correct cable.
 - Verify the detector cables are correctly installed.
 - Verify the laser is enabled in the TGA program.
 - Recheck the laser temperature, and the zero, DC, modulation, and high current settings.
6. If no response is observed, use the alignment tool (pn 25897) to put the reference tip/tilt mirror and the detector mirrors at their nominal positions, as shown in FIGURES B-7, B-8, and B-9.

To use the alignment tool, place it against the tip/tilt screws. Back the screws out as needed to allow the gage to fit against the screw threads. Then screw the screws in until the heads of the screws just touch the gage. Back the screws out just enough to remove the tool. The tip/tilt mirrors will now be at their nominal positions.

FIGURE B-7 shows the positioning of the alignment tool for the screws for the mirror in the beamsplitter block. The view is from the user's perspective. FIGURE B-8 shows the same scenario but from a different perspective. The figure illustrates the way that the alignment tool fits against the screws. FIGURE B-9 illustrates how the alignment tool fits against the detector tip/tilt screws. Refer back to FIGURE B-5 and FIGURE B-6 for the positioning of the mirror tip/tilt screws.

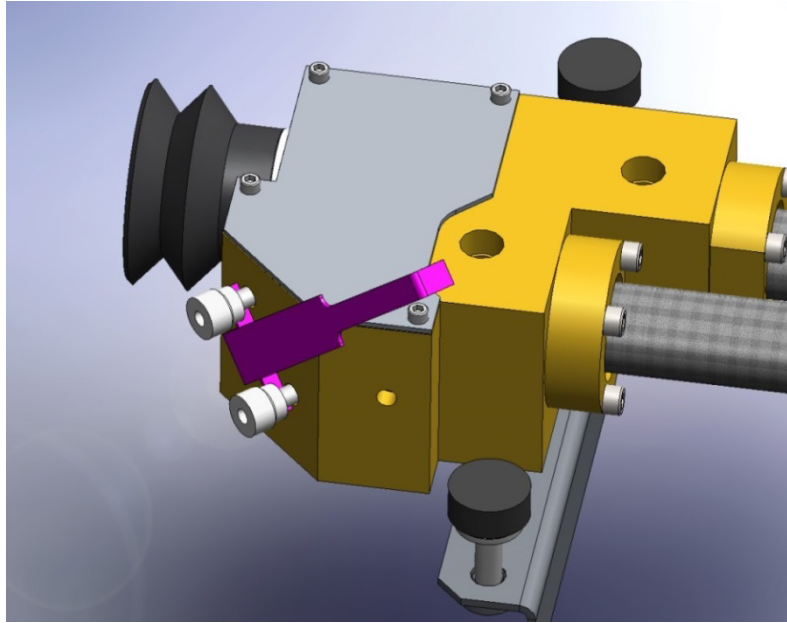


FIGURE B-7. Use of alignment tool for aligning mirror in TGA beamsplitter block

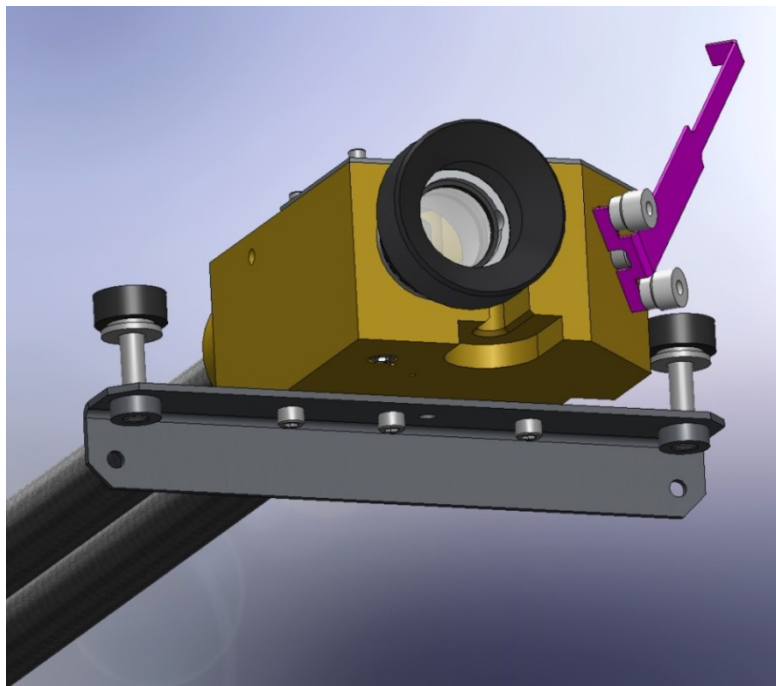


FIGURE B-8. Use of alignment tool for aligning mirror in TGA beamsplitter block, alternate angle

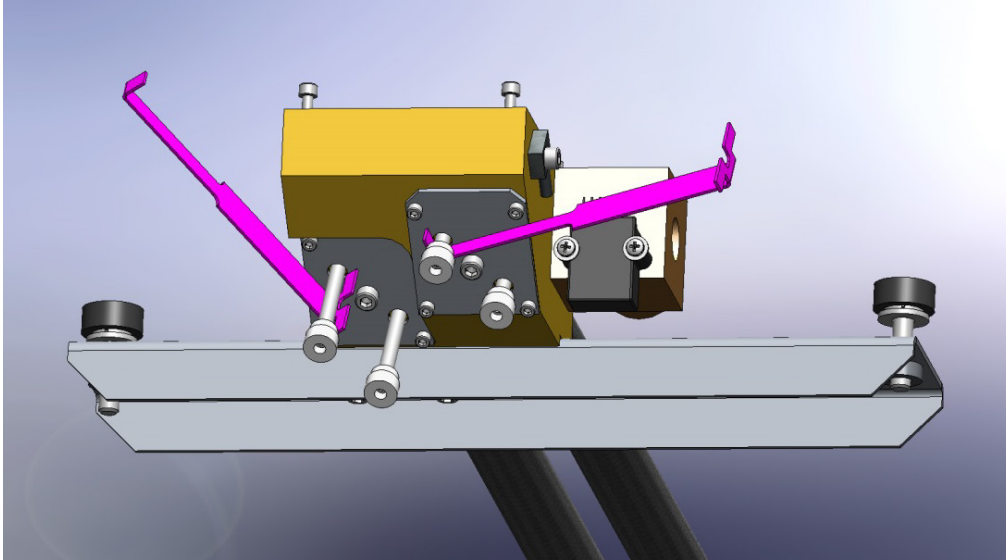


FIGURE B-9. Use of alignment tool to position tip/tilt screws for aligning detector-side mirrors

7. Adjust the horizontal and vertical alignment knobs to look for the sample detector signal, and then proceed to the next section. If no response is observed, contact Campbell Scientific for assistance.

B.2.3 Horizontal and Vertical Alignment

Once the system is aligned well enough to see a response in the sample detector, follow these steps to optimize the horizontal and vertical alignment.

1. Adjust the horizontal position (see FIGURE B-5) to maximize the sample detector signal.

NOTE

The sample and reference signals may not reach their maxima simultaneously. If so, ignore the reference detector signal and adjust the alignment to maximize the sample detector signal. Adjust the horizontal position past the peak in each direction far enough to make sure there is a single response peak. If there is a single peak, leave it at the center of the peak. If there are multiple peaks, leave the horizontal alignment at the center of the group of peaks.

2. Adjust the vertical position (see FIGURE B-5) to maximize the sample detector signal, in the same way as for the horizontal alignment.
3. Adjust the sample detector mirror tip and tilt knobs to maximize the sample detector signal.
4. Adjust the beamsplitter mirror tip and tilt knobs to maximize the reference detector signal.

5. Adjust the reference detector mirror tip and tilt knobs to maximize the reference detector signal.
6. Iterate these steps until both detector signals are maximized. If there is a single narrow peak horizontally and vertically, the system is also in good alignment. If the response peak is broad or if it has multiple peaks, contact Campbell Scientific for assistance.

B.2.4 Focus Adjustment

The TGA200 and TGA200A focus is adjusted at the factory, and normally no further adjustment is needed. If a system is configured for multiple lasers that have greatly different wavelengths, however, the focus may need to be adjusted when switching between these lasers. To adjust the focus, loosen the locking ring on the lens mounting tube and screw the lens mounting tube in or out to maximize the detector signals. Retighten the locking ring when the optimum focus is achieved.

Appendix C. Optimizing Laser Parameters

Normally the laser parameters are adjusted only when a new laser is installed, after transporting the system, or warming and recooling the laser (LN₂-cooled laser). These parameter settings optimize the performance for a specific absorption line, so these steps should be performed after the correct absorption line is chosen (see Appendix A.4, *Finding the Absorption Line*).

C.1 Laser Temperature

If the TGA's laser were perfect, it would emit at only one frequency (single mode). This emission frequency would depend only on the injection current, and the emission frequency could be tuned over a wide range. In fact, the real laser's emission frequency is dependent on both its current and temperature, it may emit some of its optical energy at other frequencies (multimode), and its emission frequency can be tuned over only a small range before it jumps to a different frequency (mode hop). The multi-mode power and the mode-hop characteristics of a laser may change dramatically with temperature. Because both temperature and current determine the emission frequency, changing the current can compensate for a change in temperature. The goal in setting the laser temperature is to find the combination of temperature and current that minimizes multimode operation and avoids mode hops.

NOTE

The following discussion uses an LN₂-cooled laser as an example, but the process is the same for all lasers. TE-cooled laser temperatures are given in units of °C instead of K.

In principle, this is straightforward, but it is complicated by the iterative nature of the process. All of the other laser parameters must be set to reasonably appropriate values in order to evaluate the laser temperature, but the optimum value of some of those parameters depend on temperature. To begin, set the other laser parameters as follows:

1. Set the zero current as described in Appendix C.2, *Zero Current*, but then reduce it by approximately 20% before setting the other parameters. This will help to avoid confusion caused by the laser's lower threshold current at lower temperature.
2. Set the high current count and the omitted data count to their maximum values.
3. Set the high current as described in Appendix C.3, *High Current*.
4. Set the modulation current as described in Appendix C.5, *Modulation Current*.
5. If the laser is used in multiple-ramp mode, set the parameters for each ramp.

6. Open the *Laser Settings* window to view the absorption line, set the laser temperature and view the DC current, reference detector transmittance, and the sample detector signal.
7. Open either a Data window or graph to view the concentration noise.
8. Enable the line locking function and the automatic detector offset and gain adjustment function.
9. Record the laser operating temperature, the laser DC current, and the reference detector's percent transmittance at the center of the ramp (displayed at the top of the reference detector transmittance). The sample detector signal and the concentration noise may also be useful to note, although these are not absolutely necessary.
10. Record these values in a notebook.
11. TABLE C-1 gives an example of the process described in steps 6 – 8.

TABLE C-1. Example Laser Temperature Optimization Data				
Laser Temperature (K)	Laser DC Current (mA)	Reference Transmittance (%)	Concentration Noise (ppb)	Sample Signal (mV)
103.7	482.6	65.9	7	30.0
103.9	477.4	66.2	8	27.6
104.1	472.1	66.4	9	24.9
104.3	466.6	67.3	10	21.9
104.5	460.8	69.1	13	18.3
104.7	454.9	72.0	20	14.4
104.9	448.7	78.2	45	10.0
105.1	442.2	90.5	350	4.9
Transmittance and noise much worse – try going down				
103.5	487.7	65.8	7	32.5
103.3	492.6	67.7	6	34.5
103.1	497.5	77.8	15	36.3
102.9	502.9	89.5	85	38.7
Transmittance and noise worse again – go to optimum temperature				
103.6	485.0	65.5	6.0	31.0

12. Increase the laser operating temperature by 0.1 or 0.2 K. Some lasers will allow a larger temperature increment, but when in doubt, use 0.1 K. The line locking algorithm will decrease the DC current as needed to keep the absorption line in the center of the ramp.

13. Wait until the laser temperature and DC current stabilize, and then record the values.
14. Iterate this process until the transmittance or concentration noise increases noticeably.
15. Return to the starting laser temperature, and then step the temperature downward until the transmittance or concentration noise again increases noticeably. Record the laser temperature, DC current, reference transmittance, concentration noise, and sample signal at each step.

To evaluate the results, first verify the DC current decreases approximately linearly with increasing temperature. A discontinuity indicates the line-locking algorithm may have switched to a different absorption line. This can be caused by other strong absorption lines nearby, or by a laser mode hop. If this happens, repeat parts of this test near the discontinuity, using a smaller step in laser temperature. Watch the reference detector transmittance carefully. If the discontinuity was caused by another strong absorption line nearby, using a smaller temperature step may solve the problem. If the discontinuity was caused by a mode hop, this indicates the end of the temperature tuning range for the selected absorption line.

It is generally not necessary to actually plot the data. For reference, FIGURE C-1 shows a graph of a typical data set where the same absorption line is scanned with a range of temperatures.

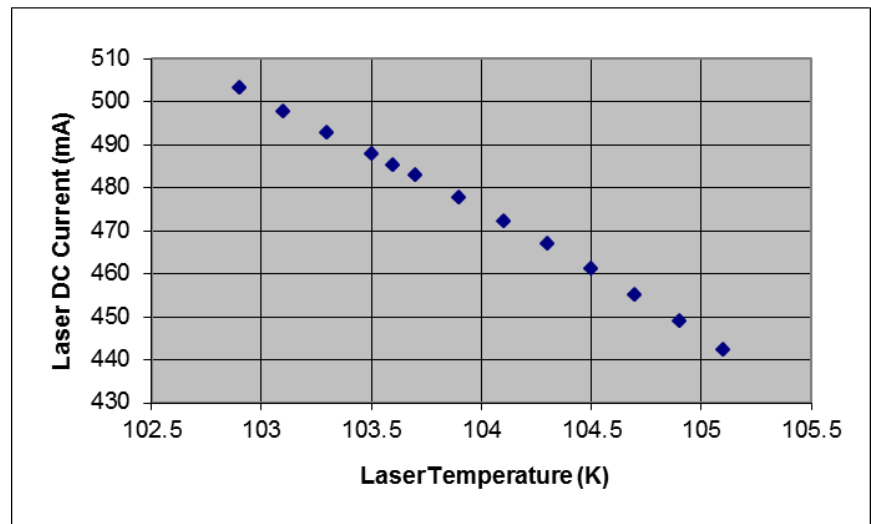


FIGURE C-1. Typical laser DC current as a function of temperature

Next, look at the reference detector transmittance as a function of temperature. The transmittance should have a minimum at the (optimum) laser temperature. It should be higher at temperatures above and below the optimum temperature. This increased transmittance results from an increased fraction of the laser's energy at undesired frequencies (multimode operation). Again, it is usually not necessary to plot the data, but FIGURE C-2 shows a typical example.

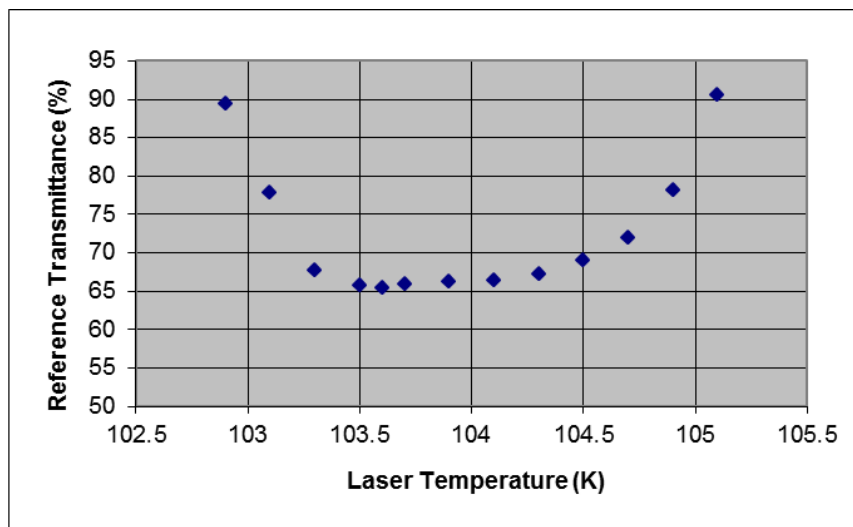


FIGURE C-2. Typical reference transmittance as a function of laser temperature

Optionally, look at the concentration noise as a function of temperature. The concentration noise should generally have a minimum at the optimum laser temperature (as determined by the minimum reference transmittance). This is illustrated in FIGURE C-3.

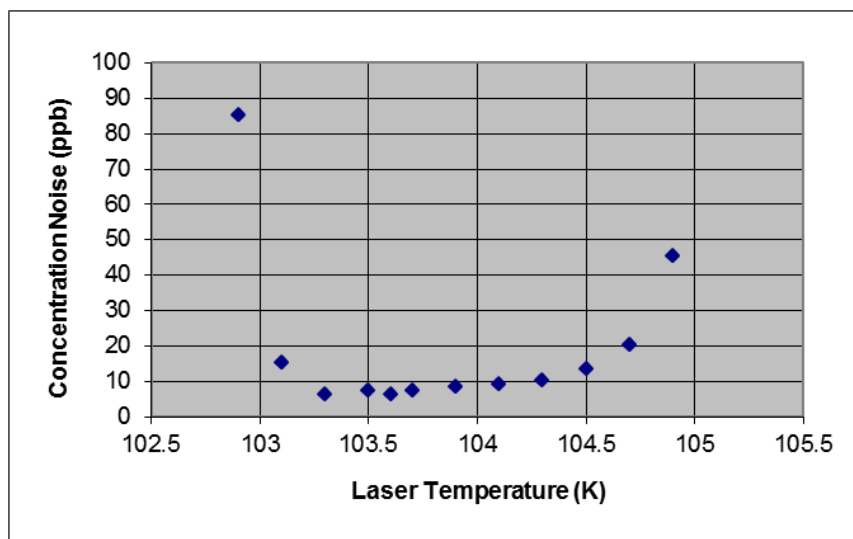


FIGURE C-3. Typical concentration noise as a function of laser temperature

In some cases the minimum concentration noise may be at a different laser temperature than the minimum reference transmittance. If the DC current is near the laser threshold current, the laser's optical power output may be reduced significantly at higher laser temperatures (lower DC current). This can be verified by looking at the sample detector signal as a function of laser

temperature. This is shown in FIGURE C-4 for the example described in the figures above.

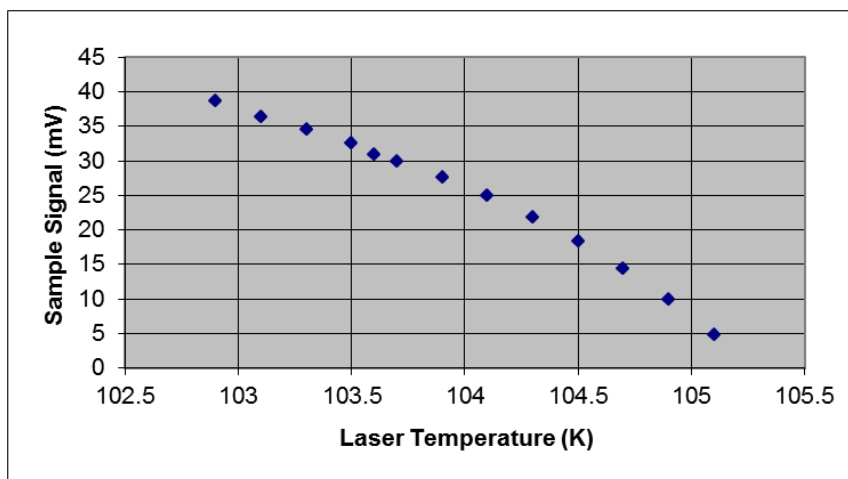


FIGURE C-4. Typical sample detector signal as a function of laser temperature

In this case, it may be possible to compensate for the reduced laser power by reducing the detector temperatures (see Appendix D.3, *Detector Temperature*). If adjusting the detector temperatures results in low concentration noise at the laser temperature which gives the minimum reference transmittance, this is the optimal laser temperature.

The other condition that can give a different optimum laser temperature for reference transmittance and concentration noise is that in which the position of a mode hop may also move with laser temperature. If the laser has a mode hop near the absorption line, the concentration noise may increase as the mode hop approaches the line. In this case, it may be necessary to choose a laser temperature that gives a compromise between reference transmittance and concentration noise. If there is no laser temperature that gives satisfactory performance, it may be necessary to choose another absorption line.

For multiple ramp operation, follow the process described above, but also record the DC current, reference transmittance, and concentration noise for the additional ramps. Ideally, all ramps will have the same optimum laser temperature. In some cases, it may be necessary to set the laser temperature between the optimum temperatures for the ramps to achieve acceptable performance for all ramps.

C.2 Zero Current

The laser current must be reduced below the lasing threshold briefly at the start of each spectral scan (described in Section 4.2.5, *Laser Scan Sequence*) to measure the detector response with no laser emission. If the zero current is set too high, the laser will emit some energy when it should be off, and the TGA will calculate the wrong transmittance. This will cause an error in the reported concentration. This problem could be avoided by simply setting the zero current to 0 mA to guarantee the laser is off. However, both current and temperature affect the laser's emission frequency, and the laser's temperature is

affected by its current. The laser's temperature falls slightly when the current is reduced, so the temperature must be stabilized at the start of each spectral scan. Overdriving the current, as discussed in Section 4.2.5, *Laser Scan Sequence*, can help to stabilize the laser temperature more quickly, but setting the zero current as high as possible minimizes the temperature perturbation.

NOTE

The *TGA Windows* software has an **Auto** button for setting the zero current. In some cases this function gives an incorrect result. The suggested procedure for setting the zero current for all lasers is given below. This automatic function has been removed from the *TGA TEC* software.

Set the zero current to 0 mA. Run the *Laser Line Find* (refer to Section 7.2.5, *Find*) starting with the DC current at 0 mA. View the resulting graph to determine the laser's threshold current (DC current at which the reference voltage begins to rise). In the example shown in FIGURE C-5, the reference signal is near zero up to a DC current of 50 mA, and rises steeply beyond 50 mA. This is the laser's threshold current. Set the Zero current to approximately 90% of the threshold current (45 mA in this example).

For multiple-ramp mode, set the zero current to this value for each ramp. In some cases the zero current may be reduced below this value for some ramps (see 0, *High Current*).

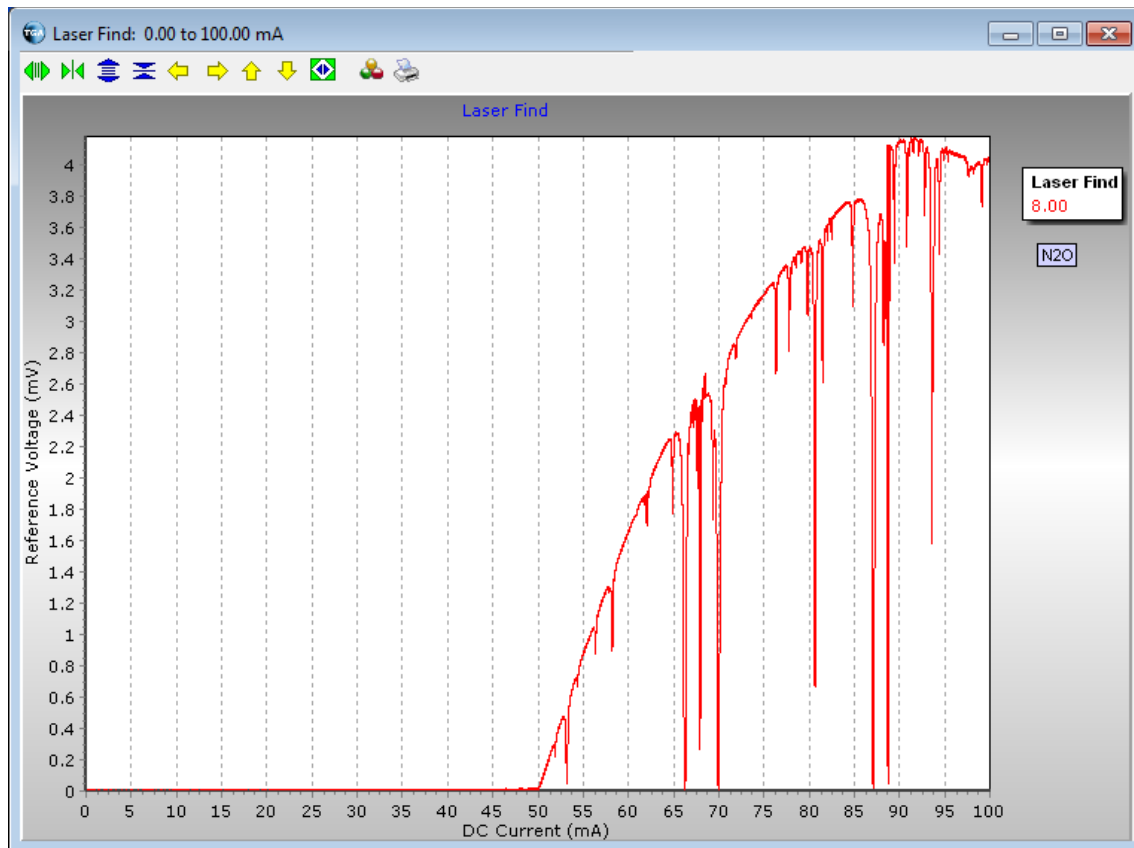


FIGURE C-5. Example of using Laser Line Find function to determine laser threshold current

C.3 High Current

The laser cools slightly at the start of the spectral scan when it is turned off by reducing its current to the zero-current value, as discussed in Section 4.2.5, *Laser Scan Sequence*. If the actual spectral scan started immediately thereafter, the laser temperature would rise during the entire spectral scan. The rise in temperature would be more rapid at first, but slow near the end of the scan as the temperature approached equilibrium. The change in temperature would change the laser's emission frequency, adding an undesired spectral modulation, as illustrated in the far left panel of FIGURE C-6. To minimize this problem, the laser current is increased above the DC current by an amount specified in the *High current offset* parameter. The duration of this high current pulse is determined by the laser *High current count* parameter. When these parameters are properly set, the heat from the increased current compensates for the heat lost when the current is reduced, stabilizing the laser temperature more quickly.

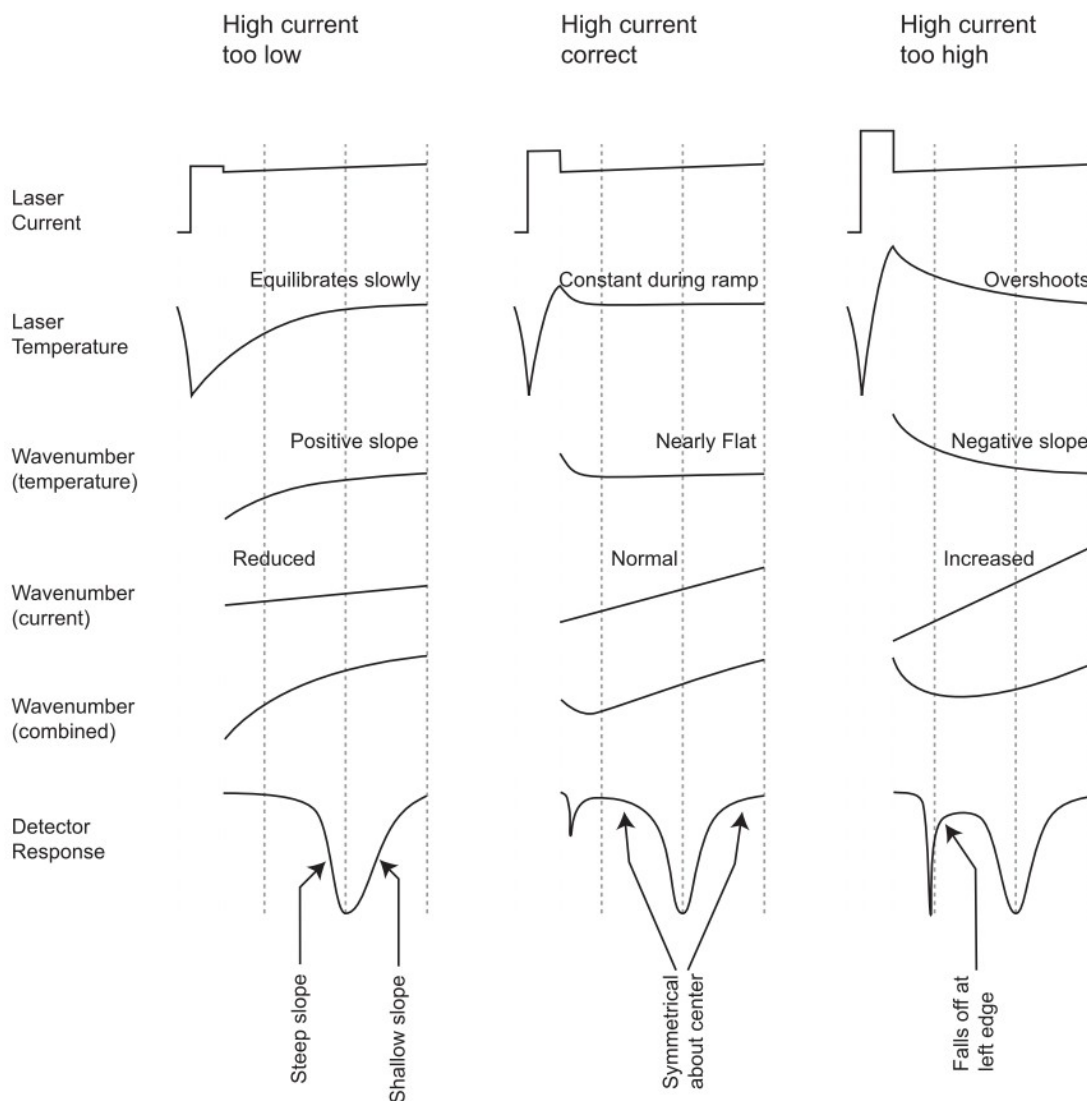


FIGURE C-6. Effects of temperature perturbation

As shown in FIGURE C-6, improper high-current adjustment makes the absorption line appear asymmetrical. The goal of the high-current adjustment procedure is to make the absorption line symmetrical about its center.

A more objective method to evaluate this symmetry is to adjust the DC current to move the absorption line to the left and right of the center line. If the high current is adjusted properly, the absorption line will move the same distance left/right of center for the same change (\pm) in DC current. This is illustrated in FIGURE C-7. The left panel shows that with the high current too low, changing the DC current by $+0.6$ mA moves the absorption line only halfway to the left edge of the scan, but changing the DC current by -0.6 mA moves it all the way to the right edge of the scan. In the center panel, the absorption line moves symmetrically, all the way to the left and right edge of the spectral scan for the same (\pm) change in DC current.

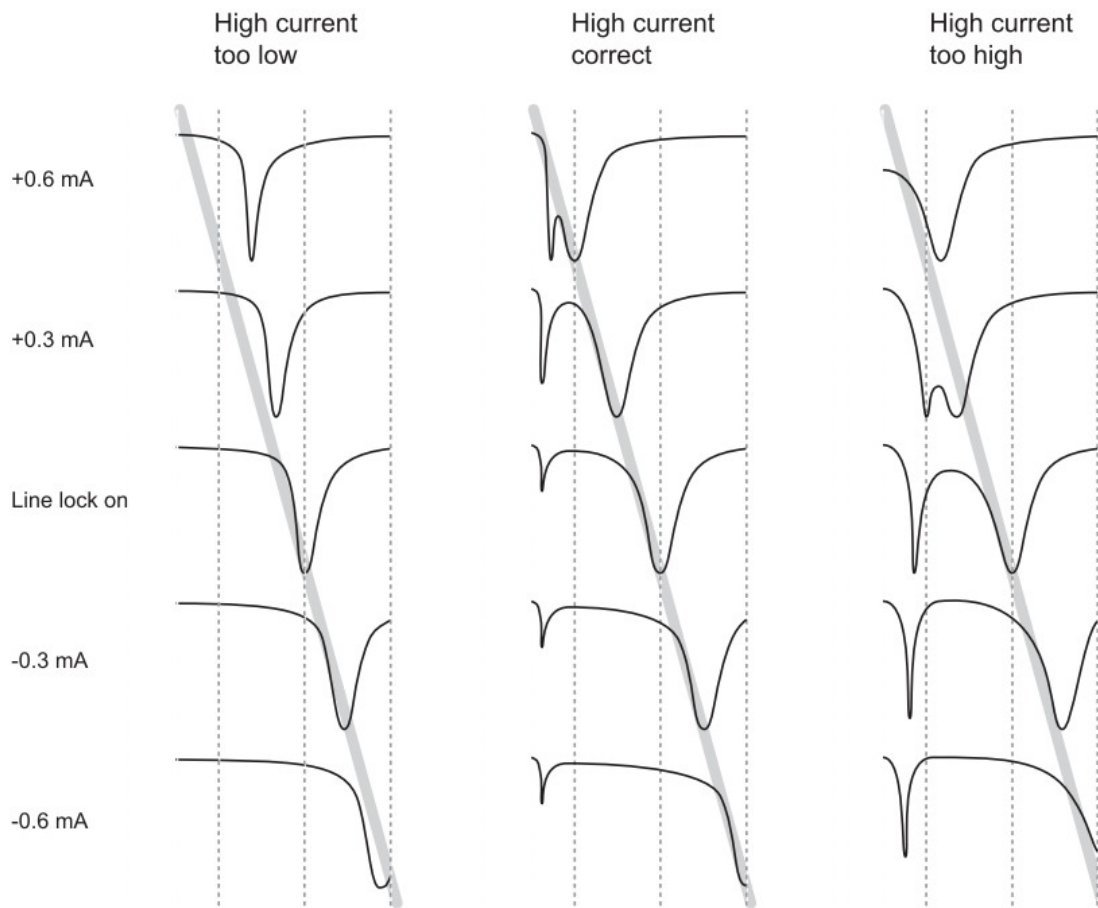


FIGURE C-7. High current adjustment procedure

To set the high current, proceed with the following steps:

1. Open a *Laser Settings* window.
2. Select the *Magnified* display mode.

3. Set the high current to an initial value (start at zero mA when in doubt).
4. Click the padlock icon next to DC current, or press “I” to start line lock.
5. Click the **Auto** button next to the **Mod current** to adjust the modulation current.
6. Click the padlock icon next to **DC current**, or click on the detector graph and press **I** to stop line lock.
7. Click on the detector graph to enable adjustment of the DC current by using the ◀ and ▶ cursor keys (alternately you may click in DC current box and use the ▲ and ▼ cursor keys, or simply click the up and down adjuster boxes).
8. Repeatedly press the ◀ cursor key to decrement the DC current in 0.1 mA steps until the center of the absorption line is at the right edge of the spectral scan. Count the number of steps required.
9. Start line lock again. Watch the reference detector display as the lines to come to the center of the spectral scan.
10. Stop line lock and repeatedly press the ▶ cursor key to increment the DC current in 0.1 mA steps until the center of the absorption line is at the left edge of the spectral scan. Count the number of steps required.
11. Start line lock again. Watch the reference detector display as the lines come to the center of the spectral scan.
12. Evaluate the results and iterate as needed using the steps below and referring to FIGURE C-7:
 - If the high current is too low, it will take more steps to move the line to the left edge than to move the line to the right edge. The absorption line may become narrower as it approaches the left edge and wider as it approaches the right edge. Additionally, if line lock is started with the absorption line at the left or right edge, the absorption line may move relatively slowly to the center. If this is observed, increase the high current and repeat the steps above.
 - If the high current is set correctly, it will take the same change in DC current to move the absorption line to the left or right edge (and this will be approximately equal to the modulation current), the width of the absorption line will not change noticeably as it is moved from left edge to right edge, and when line lock is started with the absorption line at the left or right edge, the absorption line will jump quickly to the center.
 - If it takes fewer steps to move the line to the left edge than to move the line to the right edge, or if the absorption line becomes wider as it approaches the left edge, or if starting

line lock with the absorption line at either edge causes it to overshoot the center, this means the high current is too high. Decrease the High current and repeat the test above.

Usually these criteria will give a clear indication of the correct value for the High current. However, sometimes other criteria must be considered.

- If the high current is too high, the laser's frequency will overshoot the absorption line at the beginning of the spectral scan, quickly scan backwards through the absorption line, and then scan forward through the absorption line. This is visible in the reference detector display as a second narrow absorption line at the left edge of the spectral scan data. See FIGURE C-6 and FIGURE C-7. This is acceptable as long as this "ghost" line is in the omitted part of the scan. But if the signal falls off at the left edge of the scan as illustrated in the lower right of FIGURE C-6, the high current must be reduced (even if the "counting steps" criterion indicates the high current is already too low).
- When incrementing the DC current, it may not be possible to move the absorption line to the left edge because the two absorption lines (the true line and its "ghost") may merge just inside the left vertical dotted line (see FIGURE C-7, top right). This also indicates the high current is too high.

For multiple-ramp mode, adjust the high current individually for each ramp. In this case, the laser temperature is perturbed by the entire previous scan, not just the zero pulse of the present scan. This means it will take a larger high-current pulse for the ramp with the higher DC current because the laser will have cooled during the previous ramp at lower DC current. It may require a negative value for the high current of the ramp at lower DC current. If a negative high current pulse is required, it may be helpful to also reduce the zero current below its normal setting.

C.3.1 High Current Count

The *High current count* parameter may be adjusted in conjunction with the high current. The *High current count* parameter sets the duration of the high current pulse, from 0 to 8 counts, where each count represents a 20 μ s interval, giving a total duration of 0 to 160 μ s. Generally, it is best to start with the high current counts at its maximum value, which will give a low-amplitude, long-duration pulse. However, if the high current is set to a small value (less than 20 mA for LN₂-cooled lasers or less than 2 mA for TEC lasers) it may be helpful to reduce the high-current counts and increase the high current. This will allow more of the samples to be used in the concentration calculation. This parameter can be adjusted from the *Settings > Laser > Other* window; see Section 7.2.3.1, *Laser*.

Adjusting this parameter usually makes little difference in the TGA's performance, so when in doubt, this parameter should simply be left at the default which is 8 counts. For multiple-ramp mode, the high current count is common to all ramps, and should generally be left at the default (8 counts).

C.4 Omitted Data Count

Some additional data must be omitted from the concentration calculation to allow the laser temperature to stabilize fully after the zero and high current phases of the scan. The *Omitted count* parameter specifies how many scan points to omit. The parameter may have a set value from 4 to 20 counts, where each count represents a 20 μ s interval, to give a total duration of omitted data of 80 to 400 μ s. To set this parameter, look at the reference detector transmittance in **Magnified** mode. The leftmost portion of the graph is at a different color to mark the omitted data counts, meaning that those data are not used to calculate concentration. This parameter is found on the *Settings > Laser > Other* window. Increase the omitted data counts to move this line to the right; decrease it to move it to the left. The reference transmittance should be flat (or rising slightly) as it approaches the left edge, as shown on the right in FIGURE C-8. Set the omitted data counts to avoid the use of data that drop into the “ghost” line, as shown on the left in FIGURE C-8. When in doubt it is usually better to omit a few extra counts.

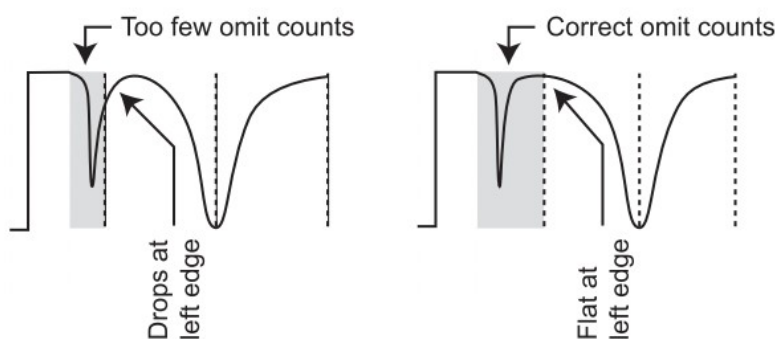


FIGURE C-8. Adjustment of omitted data counts

Adjusting this parameter usually makes little difference in the TGA's performance, so when in doubt, this parameter should simply be left at the default which is 20 counts. For multiple-ramp mode, the omitted count parameter is common to all ramps, and it should generally be set to its default.

C.5 Modulation Current

The laser modulation current parameter controls the width of the spectral scan. The edges of the spectral scan should extend slightly past the absorption lines to measure the laser's unabsorbed intensity (100% transmittance). Adjust the modulation current until it occupies approximately one-fourth of the spectral scan, with a nearly flat portion on either side, as illustrated in FIGURE C-9. The TGA software includes an automatic algorithm to set the modulation current. To use this algorithm, enable line locking and then click the *Auto* button next to the **Mod current** on the *Laser Settings* window.

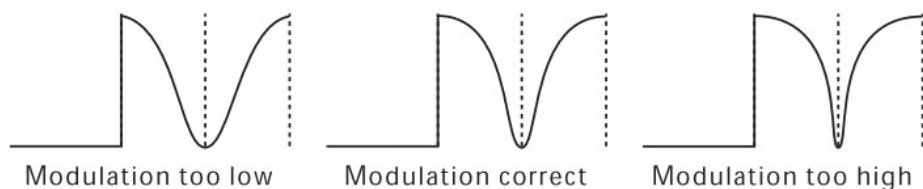


FIGURE C-9. Adjustment of modulation current

For multiple-ramp mode, the modulation current must be set individually for each ramp. It may need to be set to a different value for each ramp to compensate for residual temperature perturbation that cannot be completely removed by the high current pulse.

C.6 Laser Maximum Temperature and Laser Maximum Current

The laser can be damaged by too much current or by operation at too high a temperature. The TGA software will automatically disable the laser current if the laser's temperature is above an upper limit or if the laser current parameters are set to exceed an upper limit for any of the spectral scan points.

Set the laser maximum temperature and current to the values specified on the individual laser's data sheet. This will help to protect the laser if the laser warms up, or if the laser current parameters are inadvertently set for too much current.

C.7 Laser Multimode Correction

An ideal laser would emit at only one frequency (single mode). Unfortunately, some (multimode) lasers emit some of their power at frequencies other than the desired frequency (side modes). This side mode power is not absorbed by the selected absorption line; therefore it gives an error in the measured concentration.

The TGA software can correct for a laser's multimode power, if it is known what percentage of the laser's power is in the undesired side modes. If known, this value may be entered into the *Settings > Laser > Other* window. There are three different methods to estimate the multimode power, depending on the type of laser and the TGA model.

TE-cooled lasers

The TE-cooled lasers used in the TGA200A are manufactured with a distributed feedback (DFB) feature to suppress any side modes. For these lasers, set the **Multimode power %** to 0.

LN₂-cooled lasers

The LN₂-cooled lasers used in earlier TGAs do not have the DFB feature to suppress side modes. These lasers are specified to have not more than 10% of their output in undesired side modes. For these lasers, the user may determine the multimode power experimentally. The experiment consists of increasing the amount of the target gas in the absorption path to absorb virtually all of the laser's power at the center of the absorption line. The side-mode power at

other frequencies will generally not be absorbed. The measured transmittance at the center of the absorption line gives an estimate of the laser multimode power. Two different methods are used depending on the TGA model

TGA100 and TGA100A

TGA100s and TGA100As have a long sample cell and a short reference cell. The laser's multimode power can be estimated by temporarily putting reference gas in the long sample cell. This increases the path length by a factor of almost 34. This test is best performed in conditions in which there is not an excessive amount of absorption as this can lead to two possible problems.

First, the absorption lines become broader, and absorption in the tails of the absorption line can reduce the response at the edges of the spectral scan that are assumed to be 100% transmittance. This will give an error in the estimate of multimode power, especially if there is another absorption line nearby.

Second, too much absorption will increase the chances of absorbing the multimode power in some other absorption lines of the gas. The correct absorption can usually be achieved by adjusting the pressure in the sample cell.

To begin, go to the *Settings > Laser > Other* window and set the **Multimode power %** to zero. Then note the reference transmittance in the *Laser Settings* window.

NOTE

The transmittance measurement is affected by detector nonlinearity (see Appendix D.4, *Detector Linearity Coefficients*). The reference detector is more linear because it has a smaller signal. Therefore this measurement should be based on the reference detector, not the sample detector.

To achieve the optimum amount of absorption, first note the reference transmittance with reference gas in the reference cell only (the normal configuration). Normally, the reference gas concentration is chosen to give approximately 50% absorption. For this test, however, it is best to have between 70% and 80% absorption. Usually this can be accomplished by reducing the sample flow to reduce the pressure in the analyzer. When the proper absorption is achieved, record the sample cell pressure.

NOTE

It is acceptable for the transmittance to be less than 70%, but it must NOT be greater than 80%.

To configure the instrument for the multimode test, turn off the sample pump, swap the reference gas and sample connections, and turn the pump back on. This will put the reference gas in the long sample cell and the air sample in the short reference cell. The total flow to the sample pump should be the same as before, so the pressure should also be the same. Verify the pressure is within 10% of the previous pressure.

Adjust the laser modulation current as needed – the increased absorption may make the line wider. Record the reference transmittance, shown in the *Laser Settings* window. This is the estimate of the laser's multimode power. Enter this value as the **Multimode power (%)** parameter in the *Settings > Laser > Other* window. Verify the reference transmittance is near zero.

TGA200

The process for determining **Multimode power %** in the TGA200 is slightly different than for the TGA100 and TGA100A because the TGA200 design has the reference and sample cells of similar length. Therefore, the absorption cannot be increased by putting the reference gas in the sample cell. Instead, the reference gas must be replaced by a higher concentration of the target gas. If the reference transmittance is 50% or lower with the normal reference gas, the second gas concentration must be at least 10 times greater than the reference gas (15 x for 50 to 60%, or 20 x for 60 to 70%). Otherwise the procedure is the same as for the TGA100 and TGA100A.

For multiple-ramp operation the laser multimode power may be different for each absorption line. Repeat the process described above for each ramp.

Appendix D. Optimizing Detector Parameters

Set the detector parameters after the laser parameters are adjusted.

D.1 Detector Gain and Offset

The detector signals are processed in the TGA electronics, which include an amplifier with programmable gain and offset in the input module, and a second programmable-gain amplifier in the analog module. The detector gains and offsets are normally controlled automatically by the TGA software. To enable this automatic control, click the **Auto gain/offset** box on the *Settings > Detectors > Preamp* window. To set the offsets and gains manually, adjust one of the values to disable the automatic function.

The detector gains and offsets should usually be controlled automatically. However there are two exceptions. First, automatic control should be disabled while performing some of the setup steps, such as optical alignment. Second, the automatic gain algorithm will not increase the sample gain beyond gain 7. Therefore, if the detector signals are extremely weak, it may be necessary to set the detector gains and offsets manually.

D.2 Detector Preamp Gain

The detector electronics have a fixed gain in the first preamplifier stage. Early TGAs used a gain of 200, but this was changed to 45 for TGA200s and TGA200As. This reduced gain allows the detector signals to be larger without saturating the input range. This is an advantage for higher-power lasers, and for LN₂-cooled detectors used for longer wavelengths. Some early input modules have been modified to use a gain of 45 in the preamp. These instruments are identified by a label on the printed circuit board: **Gain 45**. Input modules upgraded for use with TE-cooled lasers have a gain of 45. These modules have a blue label on the top that designates them for use with TE-cooled lasers (see Appendix H.3.1, *Basic Upgrade*).

The preamp gain (either 45 or 200) must be entered in the parameters at the *Settings > Detectors > Preamp* window. If it is unclear which gain is the correct one for a specific input module, or if an input module upgrade is desired, contact Campbell Scientific.

D.3 Detector Temperature

Most TGAs are equipped with TE-cooled detectors, but some are equipped with LN₂-cooled detectors to work with longer-wavelength lasers. LN₂-cooled detectors have no temperature measurement or control. They are designed to operate near LN₂'s boiling point, 77 K.

TE-cooled detectors include a thermistor to measure the detector's temperature. The TGA measures this temperature and adjusts the TE-cooled current to cool the detector to the setpoint. Generally, a lower detector temperature will increase the detector signal and decrease the concentration noise. However, some lasers emit enough power to saturate the detectors if they are cooled to

their lowest temperature. Cooling the laser can also increase detector nonlinearity. Choosing the optimum temperature may involve a tradeoff between precision (noise) and accuracy (nonlinearity).

To choose the optimum detector temperatures, first set the reference and sample linearity coefficients at the *Settings > Detectors > PreAmp* window to zero. Observe the detector signals in the *Laser Settings* window. Increase the DC current to move away from the absorption line. This allows the detector signals to be observed without absorption. Adjust the detector temperature setpoints in the *Settings > Detectors > Temperature* window according to these criteria:

Sample Detector

For input modules with a preamp gain of 200:

The maximum detector signal is approximately 52 mV. Set the sample detector temperature as needed to give a sample signal of approximately 45 mV to make sure the input will not saturate.

For input modules with a preamp gain of 45:

The maximum detector signal is approximately 230 mV, but there is generally little improvement in noise for signals above 50 mV. Set the sample detector temperature for 50 to 100 mV sample signal.

Reference Detector

Set the reference detector temperature to give a reference signal that is approximately 10% of the sample signal; about 5 mV. This usually will be a temperature close to that of the sample detector.

Keep in mind that the TE-cooled detectors can cool the detectors a maximum of 80 to 90 °C. Make sure the detectors can be maintained at the setpoint, even with the TGA enclosure warmed up to its operating temperature.

To first order, detector nonlinearity can be compensated using the detector linearity coefficients, described in Appendix D.4, *Detector Linearity Coefficients*. However, if concentration accuracy is more important than precision, it is recommended to increase the sample detector temperature to give a signal level of 35 to 40 mV (3 to 4 mV for the reference detector). This may increase the concentration noise slightly, but it will improve accuracy by reducing the detector nonlinearity. This is especially important for measuring isotope ratios.

D.4 Detector Linearity Coefficients

An ideal detector would have linear response, such that any increase in the incident optical power would increase its signal proportionally. In reality, real detectors have nonlinear response. As the incident optical power is increased, the incremental response becomes gradually lower. Detector nonlinearity is worse at lower detector temperatures and at higher flux density (large detector signals).

The TGA software corrects detector nonlinearity using the quadratic polynomial:

$$r_l = r + Cr^2$$

where: r = detector response

r_l = linearity-corrected response

C = the linearity correction coefficient

The linearity correction coefficients are defined separately for the reference and sample detector, and for each ramp (if using multiple-ramp mode). These coefficients are settable in the *Settings > Detectors > Preamp* window.

The reference detector linearity coefficient should be set to zero based on the assumption that the reference detector is perfectly linear. This is assumed because it is difficult to quantify the nonlinearity in the reference detector, and because it generally gives good results. Although the reference detector may not be perfectly linear, it is much more linear than the sample detector for two reasons. First, the flux density on the reference detector is low due to the beamsplitter transmitting most of the optical power to the sample detector and reflecting less than 10% onto the reference detector. Second, the reference detector is adjusted (see Appendix D.3, *Detector Temperature*) to give a relatively low response. The reference detector may have a small amount of nonlinearity, but this tends to be cancelled by setting the sample detector linearity coefficient so that the sample detector matches the reference detector, as described below.

1. Change the plumbing configuration to ensure the reference and sample detectors see the same absorption. The step is different for the different TGA models.

TGA100 and TGA100A

Change the tubing connections inside the TGA enclosure such that the reference gas flows through both short cells in parallel. This can be accomplished by disconnecting the tubing at the inlet to the reference cell and inserting a tee and two short tubes connected to the inlets of the reference cell and the short sample cell.

Similarly, disconnect the tubing at the outlet of the reference cell and insert another tee and two more tubes connected to the outlets of the reference cell and the short sample cell. This will split the reference flow to go through the two short cells in parallel. The sample inlet (long-sample cell) should be connected (in the normal way) to a source of air or nitrogen.

This plumbing configuration should result in both detectors seeing the same amount of absorption.

TGA200 and TGA200A

Change the tubing connection outside the TGA enclosure to flow the reference gas through both the sample cell and the reference cell in parallel. Disconnect the sample and reference tubes. Insert a tee and two short tubes to connect the reference gas to both the reference inlet and the sample inlet.

This will split the reference flow to go through both absorption cells in parallel, resulting in both detectors seeing the same amount of absorption.

2. Adjust the pressure in the TGA to give reference transmittance near 90% (70 to 95% is also acceptable). Usually, this is accomplished by changing the sample flow or by adjusting a bleeder valve at the pump.
3. Adjust the reference flow to make sure there are no leaks. View the reference and sample transmittance as you adjust the reference flow from 10 to 50 ml/min. A significant change indicates there may be a leak.
4. Temporarily change some parameter settings for this test:
 - Reference gas concentration (ppm): 1000 (each ramp if in multiple mode)
 - Length of long sample cell (cm): 0
 - Length of short sample cell (cm): 100
 - Length of reference cell (cm): 100
5. Start a *Graph* window to observe the mean concentration. The reference and sample detectors are measuring absorption of the same reference gas, through the same path length. Therefore, the measured concentration should equal the reference gas concentration (set to 1000 above). Sample detector nonlinearity will cause the measured concentration to be underestimated. If the measured concentration is too low, increase the value of the sample detector linearity coefficient until the measured concentration is 1000. A typical value is 0.3.
6. Repeat the previous step for each ramp, if in multiple-ramp mode.
7. Restore the plumbing to its normal configuration and set the reference-gas concentration and cell-length parameters back to their proper values.

Appendix E. Calibration

The predominant sources of error in the TGA's concentration measurement are the offset error caused by Fabry-Perot interference, and gain errors caused by errors in reference gas analysis or by different pressure or temperature in the reference and sample cells. For eddy covariance or gradient flux applications, the offset error cancels out and only the gain errors are significant.

For measurements of absolute concentrations, the offset errors are also significant. Therefore, the appropriate calibration procedure depends on the application. All applications will benefit from the basic span calibration described in the next paragraph. It should be performed after the TGA has been set up as discussed in Section 6, *Installation*.

The TGA calibration may be checked by switching the sample inlet between two calibration tanks. Normally, one tank should have near ambient concentration and the other calibration tank should have zero concentration. For applications measuring very high concentrations, however, it is preferable to bracket the expected measurement range. For example, if measuring isotope ratios in ambient CO₂, calibration tanks with ~300 ppm and ~600 ppm may be preferred. Configure the calibration tank connections to supply the same flow rate, and to give the same sample cell pressure, as for the trace gas measurements. The difference in the measured concentrations for the two tanks should be equal to the true difference between the two calibration tanks. If it is not, adjust the **Reference gas concentration (ppm)** parameter on the *Concentration Calculation* window proportional to the measured error:

$$C_{New} = C_{Orig} \left(\frac{T_1 - T_2}{M_1 - M_2} \right)$$

where: C_{New} = the corrected reference gas concentration

C_{Orig} = the original reference gas concentration

T_1 and T_2 = the true concentrations in the calibration tanks

M_1 and M_2 = the calibration tank concentrations measured by the TGA

Appendix F. TGA Frequency Response

There are several issues related to the frequency response of the TGA including measurement rate, sample rate, digital filtering, synchronicity, and volume, flow, and pressure of the sample cell. This discussion applies to all TGA variants running either the *TGA Windows* (LN₂-cooled lasers) or *TGA TEC* (TE-cooled lasers) software.

F.1 Measurement Rate

The TGA scans a selected absorption line of a specific gas to measure its concentration every 2 ms (500 Hz measurement rate), driven by its own internal clock. If it is measuring multiple species, it alternates its measurement scans between them. For example, if it is configured to measure N₂O and CH₄, each will be measured on alternate scans, every 4 ms (250 Hz measurement rate). If it is configured to measure ¹⁸O and ¹³C isotope ratios in CO₂, each of the three isotopologs will be measured every 6 ms (167 Hz measurement rate).

F.2 Sample Rate

The TGA does not store data, so its measurements must be sampled and stored by an external device. The sample rate is determined by the data storage device. Three options are supported:

- Campbell Scientific datalogger (CR6, CR1000, CR3000, or CR5000)
- Windows PC
- Analog output (requires an optional interface module)

Datalogger

When using a datalogger, the TGA is configured as an SDM sensor. The TGA responds to the datalogger's data request by sending back the most current, digitally filtered sample of the high-rate concentration measurements. Thus, the sample rate is determined by the datalogger program.

PC

When TGA data are sampled by a PC, the user selects the update interval (in ms) on the connection window. The TGA will send data to the PC at the specified interval, which is based on the TGA's internal clock. These data will be the most current, digitally filtered sample of the high-rate concentration measurements. Thus the sample rate is determined by the settings in the PC software (*TGA Windows* or *TGA TEC*).

Analog

The TGA can be equipped with an optional SDM-to-analog converter to provide an analog version of the digitally filtered concentration measurements for analog data-acquisition systems. These analog outputs will be updated at different rates, depending on whether the TGA is measuring 1, 2, or 3 gases. The analog outputs are updated every 6 ms (167 Hz), 4 ms (250 Hz), and 6 ms (167 Hz) for single, double, and triple-ramp operation, respectively. The sample rate will be determined by the user-supplied analog data acquisition system.

F.3 Digital Filters

The TGA has two types of digital filter available, a moving average and an EC filter (optimized for eddy-covariance measurements).

The moving average filter option is generally used for low flow-rate applications, such as atmospheric profiles or soil chambers. The user selects the averaging time, from 2 to 2000 ms. The TGA's actual measurement time is 2 ms, so setting the averaging time to 2 ms gives the original (unfiltered) data. The averaging time is normally set to the sampling interval. For example, if data are collected by a datalogger at 10 Hz (100 ms sampling interval) the moving average should be set to 100 ms. All of the original 500 Hz measurements are thus represented in the averages saved by the datalogger.

The EC filter is a finite impulse response (FIR) filter, which is implemented as a convolution of the data with a filter function. There are 5 sets of filter coefficients. This allows the user to select the passband: 1, 2, 3, 4, or 5 Hz. The graph below shows the FIR filter coefficients. The five blue curves are for the 1, 2, 3, 4, and 5 Hz passband EC filters. The 5 Hz passband filter is the tallest, narrowest one. A moving average can also be thought of as an FIR filter, with uniform weighting. For comparison, FIGURE F-1 shows the red curve as the filter coefficients for a 100 ms moving average.

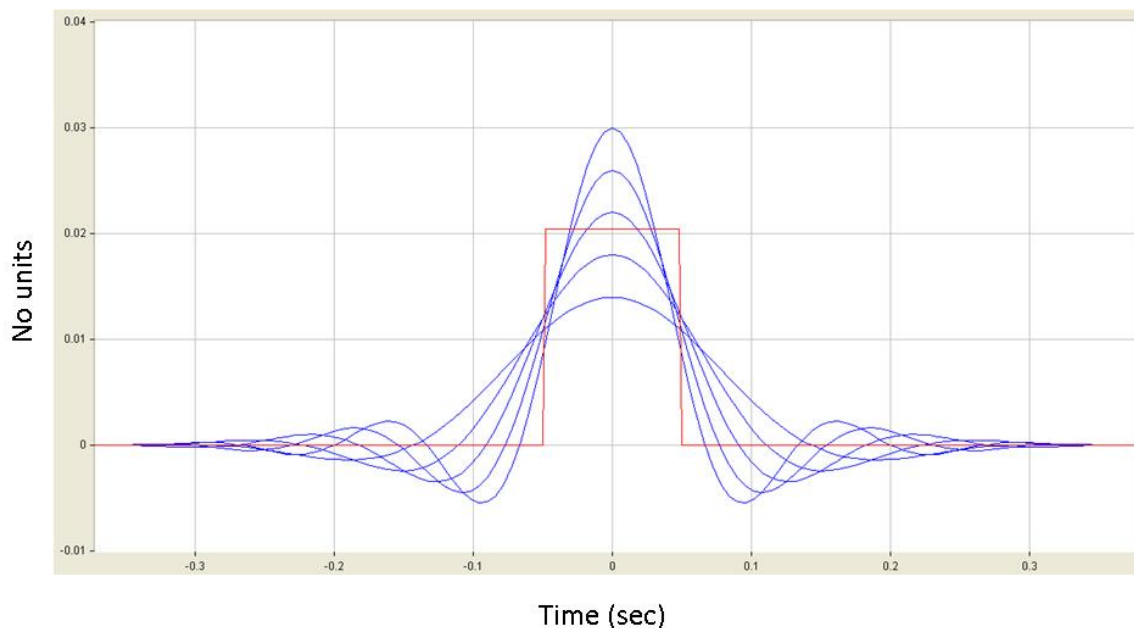


FIGURE F-1. EC filter coefficients

FIGURE F-2 shows the frequency response of the filters. An ideal filter would have a flat response in the passband and drop to zero at the passband cutoff. The EC filters (blue curves) are very flat to just beyond the passband cutoff, and then roll off to near zero by about 5 Hz above the passband cutoff. The graph includes the 100 ms moving average frequency response (red), for comparison. The moving average shows no truly flat passband and it rolls off more slowly than the EC filters.

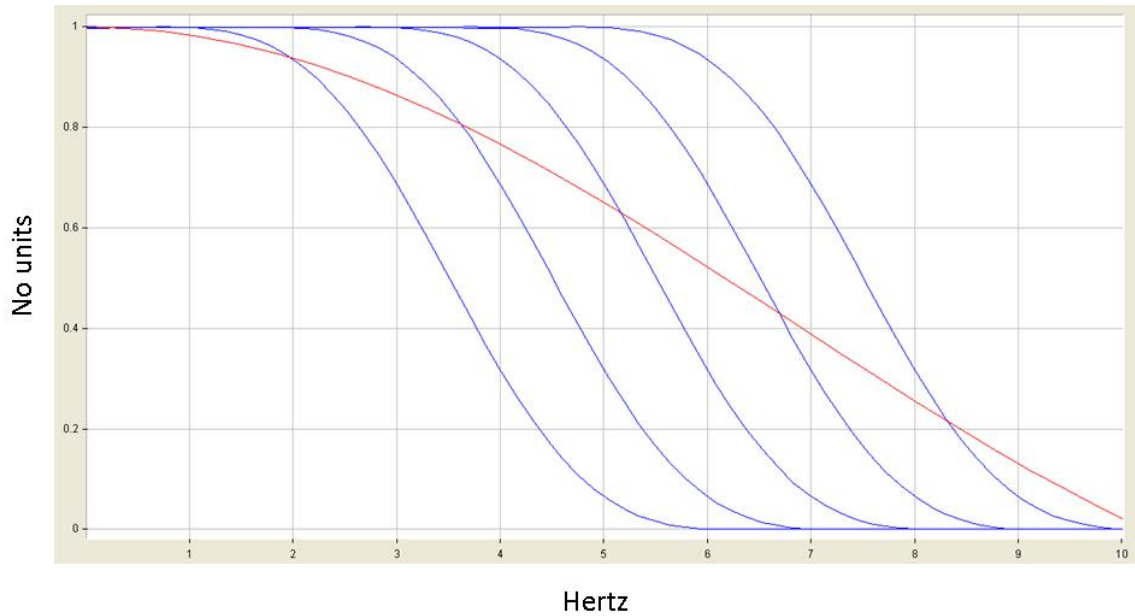


FIGURE F-2. EC filter frequency response (linear scale)

FIGURE F-3 graphs the same frequency response curves as shown in FIGURE F-2, but with a logarithmic Y axis, and an extended frequency range to show the attenuation beyond the passband. The EC filters reduce noise by three to four orders of magnitude. The 100 ms moving average reduces noise by approximately one order of magnitude.

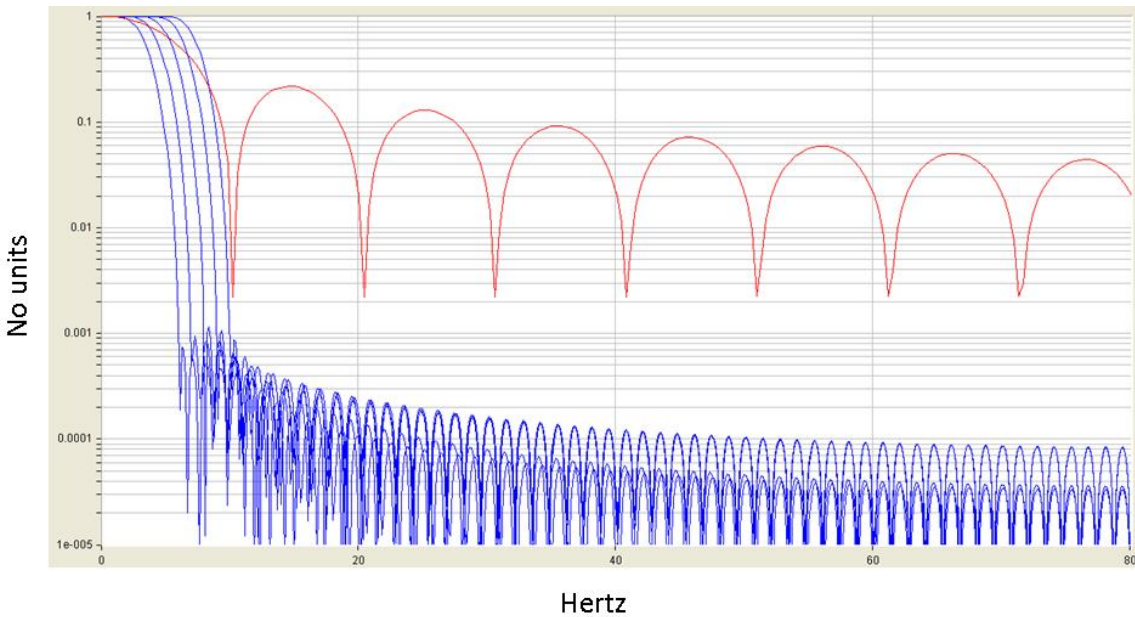


FIGURE F-3. EC filter frequency response (logarithmic scale)

The EC filter passband should be chosen to preserve high frequencies that may be in the data while attenuating noise. The optimum setting depends on the TGA frequency response which, in turn, depends on the sample cell residence time (see Appendix F.5, *Sample Cell Residence Time*). The recommended EC passband setting as a function of sample cell residence time is given in TABLE F-1.

TABLE F-1. Recommended Passband Settings	
Residence Time (ms)	Recommended Filter Bandwidth (Hz)
< 100	5
100 – 150	4
150 – 200	3
200 – 300	2
> 300	1

F.4 Synchronicity

For EC measurements it is very important to synchronize the wind vector data from the sonic anemometer with the scalar data from the TGA. The FIR filters introduce significant time delay (lag) into the concentration measurements. Because the lag is a constant, it can easily be removed by EC post-processing algorithms.

In single-ramp mode the EC filter processing lag is 372 ms. This lag is the same regardless of the passband selected, but it is different for two-ramp and three-ramp mode. The processing lags for the EC filters are shown in TABLE F-2. The processing lag for a 100 ms moving average is shown for comparison in TABLE F-2.

NOTE

The lags are different for each ramp in two-ramp (A/B) or three-ramp mode (A/B/C). The filters are designed with these different lags to correct for the fact that the three ramps are not measured at the same time. Ramp B is measured 2 ms after ramp A, and ramp C is measured 4 ms after ramp A.

The concentration measurements for all three ramps are synchronized when using the EC filter option.

NOTE

The moving average lag is half the moving average time and is the same for all ramps. The concentration measurements for multiple ramps are not synchronized when using the moving average.

TABLE F-2. Processing Lags for EC filters

	Ramp A	Ramp B	Ramp C
EC filter (1 ramp)	372		
EC filter (2 ramp)	750	748	
EC filter (3 ramp)	746	744	742
100 ms moving average	50	50	50

TGA measurements are triggered by the TGA's internal clock, asynchronous of any SDM or analog data-acquisition system. The synchronicity of correlated measurements (for example, sonic anemometer data and TGA data in an eddy-covariance system) will be limited by how often the TGA updates its measurement. This update time varies from 2 ms to 6 ms, depending on the measurement mode (one, two, or three ramps), the digital filter, and the output mode. The different times are summarized in TABLE F-3. The maximum delay represents a random lag (jitter) that cannot be removed by EC post-processing algorithms. However, the jitter is small enough (2 to 6 ms) to be insignificant, even for EC applications.

TABLE F-3. Summary of TGA Update Times

Sampling Mode	Filter	Ramps	Maximum Delay (ms)
SDM	Moving Avg	1, 2, or 3	2
	EC	1	6
		2	4
		3	6
Analog	Moving Avg or EC	1	6
		2	4
		3	6
PC	Moving Avg or EC	1, 2, or 3	2

F.5 Sample Cell Residence Time

The frequency response of the TGA is ultimately determined by the time it takes for a sample to flow through the sample cell. This residence time depends on the volume of the sample cell and the actual flow rate as given by the equation:

$$t = v / q$$

where: t = residence time (s)

v = sample cell volume (L)

q = actual flow rate (L/s)

A typical example is using an RB0021-L sample pump (see Section 4.1.4.4, *Sample Vacuum Pump*) for eddy covariance. This pump has a capacity of 18 slpm at 50 mb. Assuming 3 slpm is used to purge a PD200T dryer (see Section 4.1.4.6, *Sample Air Dryer*), leaves 15 slpm for the TGA. Converting standard flow to actual flow and converting units from minutes to seconds gives:

$$q = 15 \left(\frac{1013}{50} \right) \left(\frac{1}{60} \right) = 5.06$$

This gives a sample cell residence time for the various TGA models as shown in TABLE F-4.

TABLE F-4. Sample Cell Residence Time as a Function of Sample Cell Volume and TGA Model		
TGA Model	Sample Cell Volume (L)	Residence time 5.06 L/s (ms)
TGA100	0.480	95
TGA100A	0.480	95
TGA200	0.420	83
TGA200A	0.200	40

The residence time is less than 100 ms in every case. Therefore the recommended EC filter passband setting is 5 Hz (see TABLE F-1).

Appendix G. Using Swagelok® Fittings

This appendix gives a few tips on using Swagelok® tube fittings. For more information, consult your local Swagelok® dealer or visit their web site at www.swagelok.com.

G.1 General Notes

- Do not use fitting components from other manufacturers – they are not interchangeable with Swagelok® fittings.
- Do not attempt to use metric fittings. Six mm is very close to 1/4 in, but they are not interchangeable. Metric fittings can be identified by the stepped shoulder on the nut and on the body hex.
- Make sure that the tubing rests firmly on the shoulder of the tube fitting body before tightening the nut.
- Never turn the fitting body. Instead, hold the fitting body and turn the nut.
- Keep tubing and fittings clean. Always use caps and plugs to keep dirt and debris out.
- Do not overtighten fittings as it will damage the threads.
- If a nut cannot be easily tightened by hand, this indicates the threads have been damaged. Replace any damaged nuts and fittings.

G.2 Assembly

The first time a Swagelok® fitting is assembled, the ferrules become permanently swaged onto the tube. Assembly instructions vary depending on plastic or metal tubing. The assembly instructions are also slightly different for an initial installation than for subsequent reassembly.

First-time assembly, plastic tubing:

1. Cut the tubing to length.
2. Make sure the cut is square and free of burrs.
3. Some types of plastic tubing have an aluminum layer. Take care not to flatten the tube as you cut it.
4. Push an insert into the end of the tubing.
5. Do not remove the nuts and ferrules from the fitting. Simply insert the tube into the assembled fitting until it bottoms out.
6. Rotate the nut finger-tight.
7. While holding the fitting body steady, tighten the nut one and one-quarter turns. (For 1/16 in or 1/8 in-sized fittings, tighten the nut three-quarters turn.)

First-time assembly, metal tubing:

Extra care is needed to avoid overtightening brass fittings when used with metal tubing. These notes apply to reducers and port connectors as well as metal tubing.

NOTE

No insert is required with metal tubing.

1. Do not remove the nuts and ferrules from the fitting. Simply insert the tube into the assembled fitting until it bottoms out.
2. Rotate the nut finger tight.
3. While holding the fitting body steady, tighten the nut until it feels tight. This will normally be less than one full turn. Tightening a full one and one-quarter turns will damage the threads on the fitting and nut.

Reassembly, plastic or metal tubing:

You may disassemble and reassemble Swagelok® tube fittings many times, but the assembly process is slightly different than the first assembly.

1. Insert the tube with pre-swaged ferrules into the fitting until the front ferrule seats against the fitting body.
2. Rotate the nut finger tight.
3. While holding the fitting body steady, tighten the nut slightly with a wrench.

G.3 Common Replacement Parts

Tubing

Campbell Scientific can provide several types and sizes of plastic tubing as shown in TABLE G-1. A tubing cutter, pn 7680, can be used to cut these tubes.

TABLE G-1. Available Plastic Tubing Sizes, Construction, and Usage Guidelines

CSI pn	Tubing Type	OD (in)	ID (in)	Length (ft)	Construction	Notes
15702	Synflex 1300	1/4	0.17	500	Black HDPE jacket, overlapped aluminum tape, ethylene copolymer liner	Aluminum layer limits diffusion; best for sample tubes
15703		3/8	1/4	250		
19164		1/2	3/8	250		
26506	LLDPE	3/8	1/4	500	Black linear low-density polyethylene	More flexible than HDPE
25539		1/2	3/8	500		
19499	HDPE	5/8	1/2	100	Black High-density polyethylene	Required for larger diameter

Tubing inserts

Inserts are recommended for use in plastic tubing. These inserts become permanently attached to the tubing at the first assembly, so spare inserts may be needed for replacing the ends of tubing.



FIGURE G-1. Swagelok® insert

TABLE G-2. Dimensions and Part Numbers for Swagelok® Inserts			
Tubing OD (in)	Tubing ID (in)	Swagelok® pn	CSI pn
1/4	1/8	B-405-2	15834
1/4	0.17	B-405-170	15830
1/4	3/16	B-405-3	15713
3/8	1/4	B-605-4	9845
1/2	3/8	B-815-6	17380
5/8	1/2	B-1015-8	19495

Ferrules

Each Swagelok® fitting comes assembled with the front and back ferrules included. These ferrules are permanently swaged onto the tubing at the first assembly, so spare ferrules may be needed for replacing the ends of tubing.



Back ferrule



Front ferrule

FIGURE G-2. Front and back Swagelok® ferrules

TABLE G-3. Dimensions and Part Numbers for Swagelok® Ferrules		
Tubing OD (in)	Swagelok® pn (front/back)	CSI pn (1 set)
1/8	B-203-1/B-204-1	N/A
1/4	B-403-1/B-404-1	15890
3/8	B-603-1/B-604-1	15889
1/2	B-813-1/B-814-1	N/A
5/8	B-1013-1/B-1014-1	N/A

Plugs

Swagelok® plugs are used to plug a fitting when its tube is disconnected. It is strongly recommended to plug all fittings to keep them clean. Spare plugs may be needed if they become lost or damaged.



FIGURE G-3. Swagelok® plug

TABLE G-4. Dimensions and Part Numbers for Swagelok® Plugs		
Tubing OD (in)	Swagelok® pn	CSI pn
1/8	B-200-P	26803
1/4	B-400-P	15891
3/8	B-600-P	13712
1/2	B-810-P	17381
5/8	B-1010-P	N/A

Caps

Swagelok® caps are used to cap the end of tubes when they are disconnected from the fitting. It is strongly recommended to cap all disconnected tubes to keep them clean. Spare caps may be needed if they become lost or damaged.



FIGURE G-4. Swagelok® cap

TABLE G-5. Dimensions and Part Numbers for Swagelok® Caps		
Tubing OD (in)	Swagelok® pn	CSI pn
1/8	B-200-C	19219
1/4	B-400-C	15831
3/8	B-600-C	15547
1/2	B-810-C	17335
5/8	B-1010-C	19496

Appendix H. Upgrading Early Generation TGAs to TE-cooled Laser

Most TGAs shipped since 2000 can be upgraded to use TE-cooled lasers. Earlier TGAs will require more upgrades than the more recent TGA200s. The following sections give details for each TGA model.

H.1 TGA200

H.1.1 Basic Upgrade

Upgrading a TGA200 to use a TE-cooled laser requires the following parts:

- TE-cooled laser assembly
- TGA200A Input Module
- TGA200A Output Module
- TGA TEC software

The TE-cooled laser assembly includes the laser, mounting hardware, and cable. The assembly is shown in FIGURE H-1 installed in a TGA200A. There are five different laser assemblies available, to measure different gases:

- pn 30477 Methane (CH_4)
- pn 30478 Nitrous Oxide (N_2O)
- pn 31121 Nitrous Oxide and Carbon Dioxide (N_2O and CO_2 ; CO_2 is based on the $^{13}\text{C}^{16}\text{O}^{16}\text{O}$ isotopolog)
- pn 31119 Carbon Dioxide (CO_2) and $\delta^{13}\text{C}$
- pn 30877 Carbon Dioxide (CO_2), $\delta^{18}\text{O}$, and $\delta^{13}\text{C}$

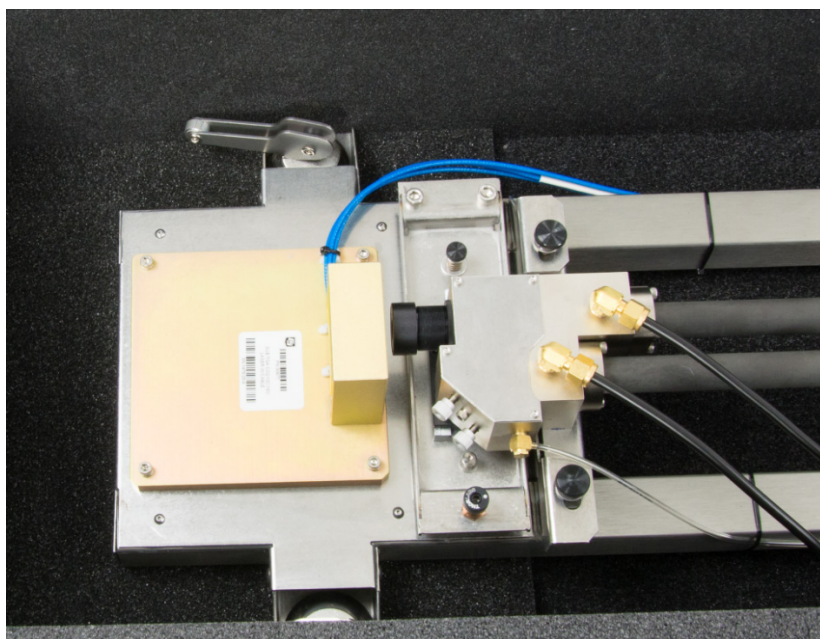


FIGURE H-1. TE-cooled laser assembly installed in a TGA 200A

The TGA200A Input Module, pn 7730, is shown in FIGURE H-2. The blue label identifies this module as being updated for use with TE-cooled lasers.



FIGURE H-2. TGA input module

The TGA200A Output Module, pn 7726, is shown in FIGURE H-3. The blue label identifies this module as being updated for use with TE-cooled lasers.



FIGURE H-3. TGA output module

CAUTION

Do not use unmodified input or output modules (without the blue label) for TE-cooled lasers. Do not use modified input or output modules (with blue label) for cryogenic lasers. A mismatch between electronics and laser will damage the laser.

The input and output modules shipped with a TGA200 may be returned to the factory to be updated. The modules will be reconfigured for TE-cooled laser operation, tested, and identified by affixing a blue sticker.

NOTE

If the input and output modules are upgraded to use with TE-cooled lasers, they may not be reconfigured for cryogenic lasers. Users that may wish to go back to use a cryogenic laser at a later date should purchase new input and output modules for TE-cooled laser operation.

The input and output modules mounted in the electronics are shown in FIGURE H-4.

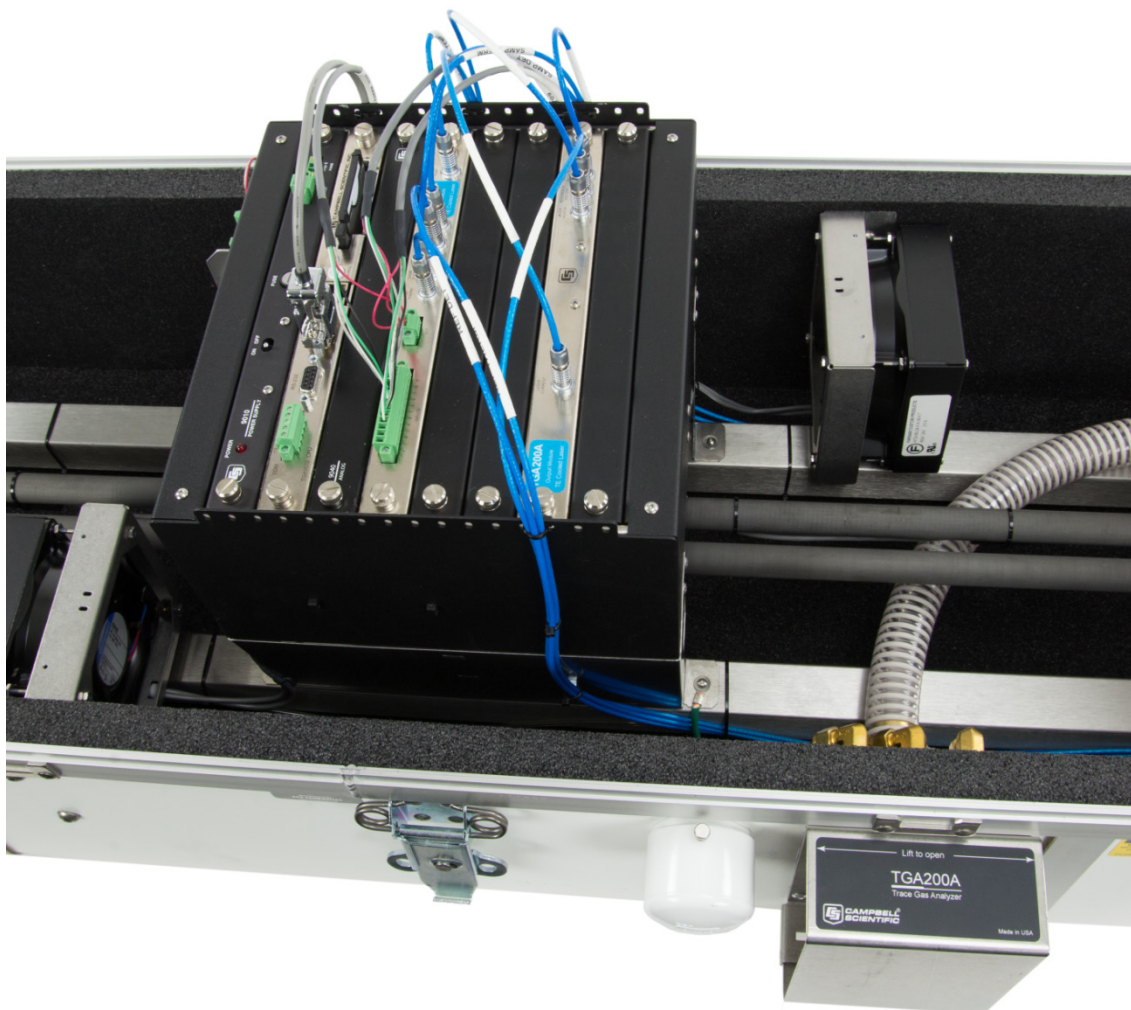


FIGURE H-4. Modules mounted into TGA200A electronics

The *TGA TEC* software, pn 30723, is an updated version of the *TGA Windows* software which has been modified for use with TE-cooled lasers.

To install a TE-cooled laser in a TGA200:

1. Turn off power to the TGA200.
2. Disconnect the dewar cable from the laser dewar and the electronics, and remove the cable from the TGA200. This cable will not be used with the new TE-cooled laser assembly, which has the cable permanently attached.
3. Remove the four screws that fasten the laser dewar to the TGA200 optical bench. Remove the dewar from the TGA200, but keep the mounting screws.
4. Mount the TE-cooled laser assembly to the optical bench, using the dewar mounting screws.

5. Replace the input and output modules with the ones that have been modified for use with TE-cooled lasers.
6. Connect all of the cables to the input and output modules except the **Laser Current** connector.

NOTE

Do not connect the Laser Current connector to the output module at this time.

7. Install the *TGA TEC* software on a Windows PC. See Section 6.2.1, *Installation of PC Software*.
8. Update the TGA operating. See Section 6.2.2, *Updating TGA Operating System*.
9. Complete the configuration for a new laser. See Section 6.3, *Detailed Setup Instructions*.

H.1.2 Detectors

If the TGA200 was equipped with liquid nitrogen-cooled detectors, the detectors may be replaced with TE-cooled detectors. This requires the additional assembly, pn 21577, TGA200 TE-cooled detectors. Contact Campbell Scientific for details on this upgrade.

H.1.3 Power Module

Optionally, the power supplies of a TGA200 may be upgraded to the pn 30981 TGA200A power module (see Section 4.1.1.1, *TGA Power Module*, for detail on the TGA200A power module). This upgrade is not required to use the TE-cooled laser, but it is available in the event that the TGA200's power supply fails. This upgrade requires a special connector assembly to be mounted in the TGA200. Contact Campbell Scientific for details.

H.1.4 Purge Boot

The TGA200 was supplied with a purge boot between the laser dewar and the optical assembly. The purge boot mounted to the front lens holder and pushed up against the laser dewar to enclose the air gap between the laser dewar and the lens. The TGA200 purge boot can be pushed up against the TE-cooled laser assembly in the same way as for the laser dewar. If the purge boot becomes damaged it can be replaced with pn 21573.

H.2 TGA100A

H.2.1 Basic Upgrade

Upgrading a TGA100A is similar to upgrading a TGA200. It requires the same laser assembly, input and output modules, and software. See Section 6.2.2, *Upgrading TGA Operating System*, for details. In addition to this basic upgrade, a TGA100A may require the following upgrades.

H.2.2 Detectors

If the TGA100A was supplied with LN₂-cooled detectors, these should be replaced with TE-cooled detector assemblies. Contact Campbell Scientific for availability. Most TGA100As were supplied with TE-cooled detectors and require no changes to the detectors or detector cables.

H.2.3 Holes in Enclosure for Cryocooler Refrigerant Tubes

If the TGA100A was supplied with a cryocooler system for the laser, the end of the TGA enclosure has feedthrough holes for the refrigerant tubes. The feedthrough grommets may be removed and the holes plugged with pn 15542 hole plug and pn 23 nut (two of each required). This is not required for the TE-cooled laser upgrade, but it is recommended to seal the holes previously used for the cryocooler refrigerant tubes. Most TGA100As shipped with an LN₂ dewar for the laser and already have the hole plugs installed.

FIGURE H-5 shows the feedthrough grommets for the cryocooler refrigerant tubes and the holes plugged with the recommended hardware.



FIGURE H-5. Cryocooler feedthrough holes with grommets (above) and plugs (below)

H.2.4 Temperature Control Upgrade

TGA100As shipped with a temperature control module that provided power to fans and heaters inside the enclosure to maintain temperature at each end of the enclosure. The original design worked independently from the TGA electronics and software. A temperature control upgrade is available to allow the TGA temperature to be controlled through software.

The temperature control upgrade includes thermistor probes and a control cable. It gives more a more accurate temperature measurement, the convenience of software control, and provides better temperature stability. Some TGA100As have already been upgraded in conjunction with upgrades to the *TGA Windows* software. This upgrade is not required for using TE-cooled

lasers, but it is recommended for all TGA100As. See Appendix I, *Install Temperature Control Upgrade*, for details.

H.2.5 Power Module

TGA100As shipped with two AC/DC power adapters mounted under the electronics mounting bracket. One of these power adapters supplies 12 Vdc power to the electronics and the other supplies 48 Vdc power to the temperature controller.

In the event that a TGA100A power supply fails, an upgrade is available. This upgrade includes a special version of the pn 30981 power module that has been modified to supply 48 Vdc for the heaters instead of the 24 Vdc used by later TGA models (TGA200 and TGA200A). Contact Campbell Scientific for details.

H.2.6 Purge Boot

Some TGA100As included an optional purge boot between the laser dewar and the optical assembly. The purge boot mounted to the laser dewar and sealed around the front lens holder to enclose the air gap between the laser dewar and the lens. The purge boot can be mounted to the TE-cooled laser assembly in the same way as for the laser dewar. If the purge boot becomes damaged contact Campbell Scientific and request pn 15902.

H.3 TGA100

H.3.1 Basic Upgrade

Most TGA100s shipped since 2000 may be upgraded to use TE-cooled lasers. Upgrading a TGA100 is similar to upgrading a TGA200 or TGA100A. It requires the same laser assembly, input and output modules, and software. Most of the additional upgrade issues are also common to the TGA100A. See the section on upgrading a TGA100A for details. Some TGA100s may require additional upgrades, as detailed in the following sections.

H.3.2 CPU Module

TGA100s shipped with a CPU module that required a real-time connection to a PC running DOS. This was replaced with the introduction of the TGA100A by a new design that does not require a real-time connection to a computer. The newer style CPU module can be distinguished from the older style visually by the color of the module cover. The older style has a black module cover, while the newer style has a shiny nickel-plated module cover. The newer style CPU module is required for the TE-cooled laser. Most early TGAs have already been upgraded to the new CPU module. Contact Campbell Scientific for details.

H.3.3 Input and Output Modules

TGA100s shipped with an older style module cover and connectors for the input and output modules. The older modules have black module covers instead of the newer nickel-plated covers. Compare the TGA100 modules shown below to the TGA200A modules shown in Appendix H.3.1, *Basic Upgrade*. Modules shipped with TGA100As and TGA200s, and TGA100 modules that have been upgraded, will look like the upgraded modules (but

without the blue sticker). Some of the older modules may have been upgraded to the newer design to improve immunity to radio frequency (RF) interference. Modules with the nickel-pated module cover require only the basic upgrade described in Appendix H.3.1, *Basic Upgrade*. Modules with the older black module cover may be upgraded at increased cost for the new module cover and connectors.



FIGURE H-6. Older style TGA input module shipped with TGA100s



FIGURE H-7. Older style TGA output module shipped with TGA100s

TGA100s that are still using the original black input and output modules will also be using an older style cable for the detectors. See Appendix H.3.4, *Detectors and Detector Cables*, for details on upgrading the detector cable.

H.3.4 Detectors and Detector Cables

Similar to the TGA100A, most TGA100s were supplied with TE-cooled detectors. However, if the TGA100 was supplied with LN₂-cooled detectors, these should be replaced with TE-cooled detector assemblies. Contact Campbell Scientific for availability.

TGA100s used detector cables with three pairs of wires within a gray cable sheath. This cable terminated at the electronics end with green screw-terminal blocks. In 2005, with the introduction of the TGA100A, this design was replaced with a bundle of three separate blue cables, terminated with circular metal connectors. The input and output modules were modified to use the

mating connector for these cables (see Appendix H.3.3, *Input and Output Modules*). This newer cable provides better immunity to RF interference. Some TGA100s have already been upgraded to this style cable to improve RF immunity. This newer style cable is required for TE-cooled lasers, because it has the proper connectors to mate with the updated input and output modules. The older (TGA100) cable may be replaced with the TGA100A Detector Cable Set, pn 17897. Mounting this cable also requires new screws and washers, pn 18000 (qty 6) and pn 2146 (qty 6). This cable also requires that the detector holder be of the later design.

Early TGA100s had a two-piece design for the short absorption cells and the detector holders. This was replaced in 2002 by a one-piece design that allowed easier coalignment of the reference detector to the sample detector. The newer style absorption cell/detector holder is required for the TE-cooled laser, because it is compatible with the TGA100A detector cable assembly. See FIGURE H-8 and FIGURE H-9 to see the difference between these two designs. Contact Campbell Scientific for availability of the newer design.



FIGURE H-8. Older style two-piece detector holder and short cell

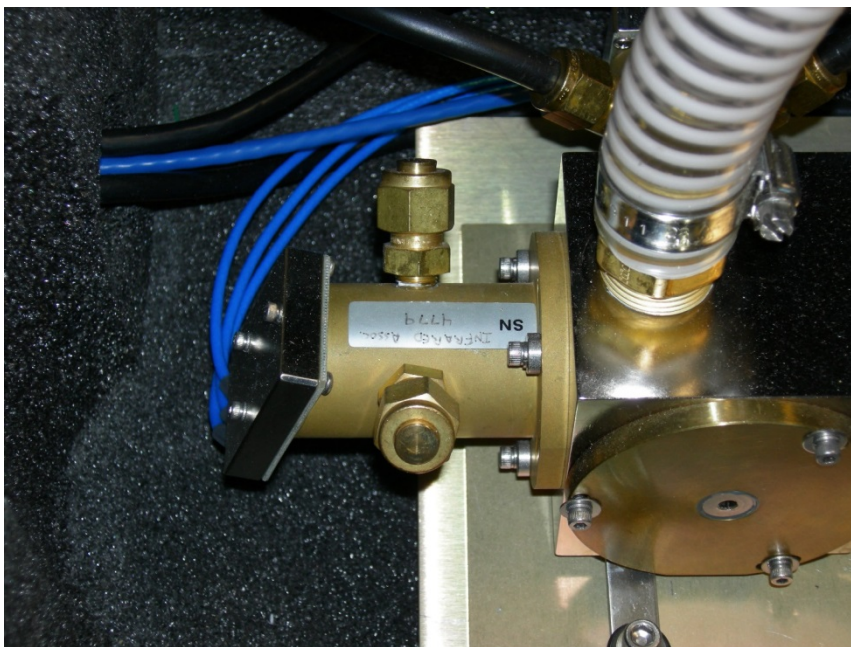


FIGURE H-9. Newer style combined detector holder/short cell (shown with newer style cable)

H.3.5 Temperature Controller

Early TGA100s had no temperature controller for the enclosure. The TGAHEAT temperature controller was made available as an option for TGA100s in 2002, and was always included in the TGA100A. This temperature controller is not required for the TE-cooled laser, but it is recommended for all TGAs to help maintain a steady temperature within the TGA enclosure. To install a temperature controller in an older TGA100, contact Campbell Scientific for details.

A later upgrade for the TGA temperature controller allowed the temperature to be controlled through software. See Appendix I, *Install Temperature Control Upgrade*, for details.

Appendix I. Install Temperature Control Upgrade

This section shows how to install the TGA temperature control upgrade so that the TGA temperature can be controlled through software. This upgrade is available for TGA100As and TGA100s with the optional Temperature Controller and the CPU upgrade. This upgrade requires a kit containing these parts:

- two thermistor probes pn 22209
- one special control cable, FIGURE I-1



FIGURE I-1. Special control cable

I.1 Install Thermistor Probes

Fasten one of the thermistor probes to the sample cell, midway between the detector block and the electronics assembly, using cable ties as illustrated in FIGURE I-2.



FIGURE I-2. Location of first thermistor probe attachment

Fasten the cable to the sample cell with three cable ties evenly spaced. Route the cable through the hole in the electronics mounting bracket and fasten with a cable tie.

Fasten the other thermistor probe to the sample cell, midway between the laser dewar and the electronics assembly, using cable ties. See the final configuration in FIGURE I-3.

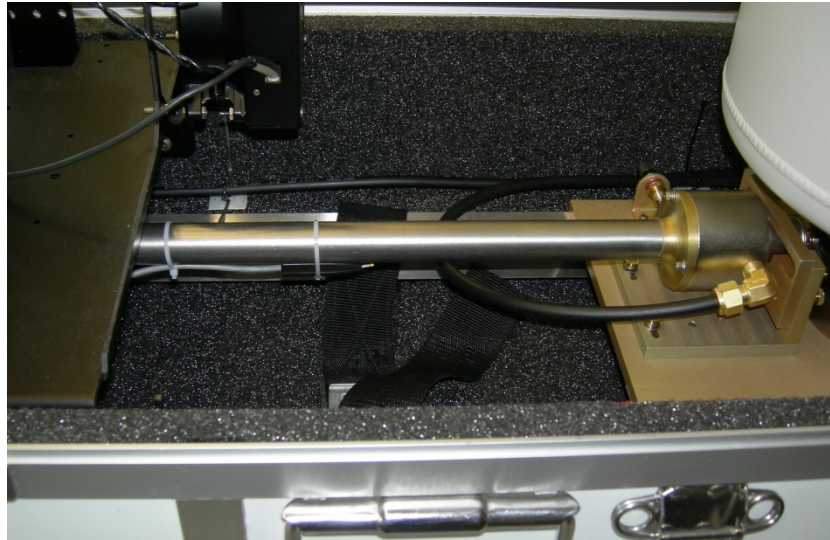


FIGURE I-3. Location of second thermistor probe attachment

Fasten the cable to the sample cell with three cable ties evenly spaced. Route the cable through the hole in the electronics mounting bracket and fasten with a cable tie.

Remove the RTD connectors (RTD 1A, RTD 1B, RTD 2B, RTD 2A) from the temperature control module. Remove the jumper wires that tie these connectors to the analog inputs.

Wire the thermistors into the analog inputs as described below and referring to FIGURE I-4:

- 1, 2, G: no connection
- 3: white of thermistor 1 (detector end)
- 4: green of thermistor 1 (detector end)
- G: black and shield of thermistor 1 (detector end)
- 5: white of thermistor 2 (laser end)
- 6: green of thermistor 2 (laser end)
- G: black and shield of thermistor 2 (laser end)
- 7, 8, G: pressure sensor

Left pin of EXT: Red wires from both thermistors and the pressure sensor.

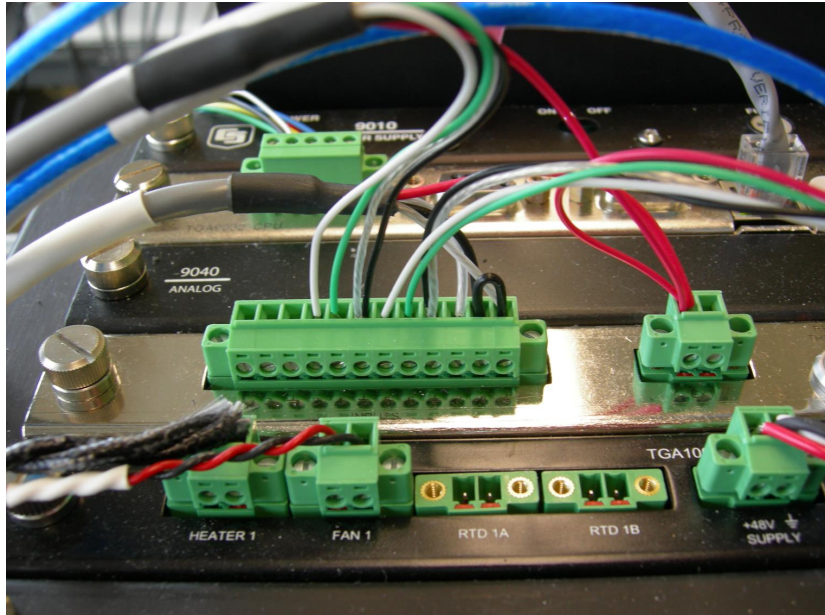


FIGURE I-4. Thermistor cable wiring to analog inputs

I.2 Connect the Control Cable

Connect the control cable to the CSIO port on the CPU module (not the RS232 port) and the RTD 1B and RTD 2A connectors on the temperature control module, as shown in FIGURE I-5.

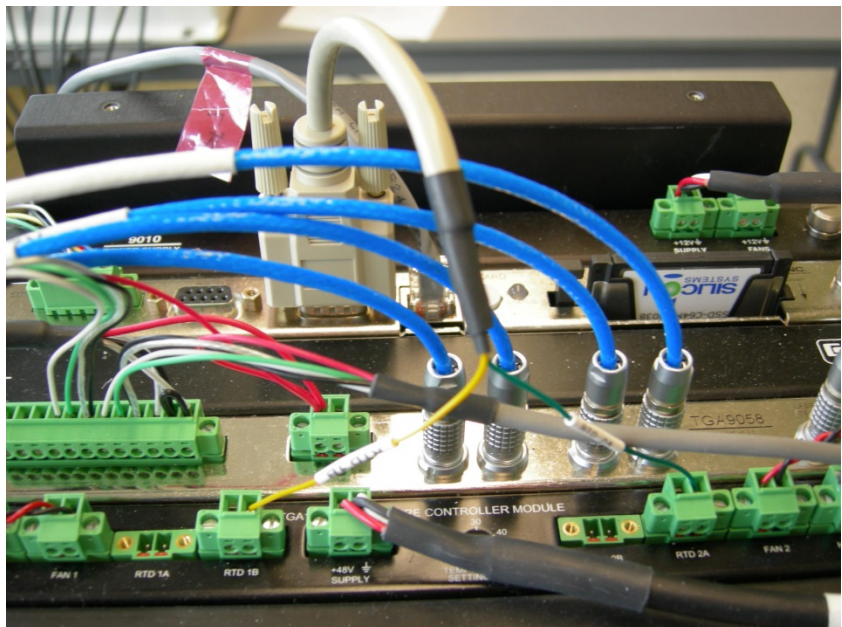


FIGURE I-5. Control cable connection

I.3 Enter Control Parameters

1. In the TGA software (*TGA Windows* or *TGA TEC*), bring up the Analog Input page in the Settings window.
2. On the *Channel 2* tab, select Thermistor (TGA200).
3. On the *Channel 3* tab, select Thermistor (TGA200).
4. This will convert the measurements on analog inputs 2 and 3 to temperature using the conversion equation for thermistor probes.
5. In the TGA software, bring up the *TGA Temperature* page in the *Settings* window.
6. Verify the temperature readings next to the temperature setpoints are approximately correct. These are not intended to be high accuracy measurements, but they should be within 1 or 2 °C.
7. Set the control parameters to the default values shown in TABLE I-1.

TABLE I-1. Control Parameters for TGA Thermistors	
Parameter	Default Value
Pulse period	0.1
Control coefficient (P)	2.0
Control coefficient (I)	0.01
Control coefficient (D)	20

I.4 Testing

1. Verify the **TGA Temp 1** and **TGA Temp 2** give reasonable values.
2. Gently squeeze Thermistor 1 (on the detector side) between finger and thumb to warm the thermistor. Verify that **TGA Temperature 1** increases.
3. Repeat this test for Thermistor 2 (on the laser side).
4. Set both setpoints well below the measured values. Use a voltmeter to measure the voltage across each heater. The voltage should be approximately 0 V.

NOTE

The temperature control module works by switching the low side to ground. When the heater is off, both terminals will be at approximately 48 V with respect to ground.

5. Set the **TGA Temperature 1** setpoint well above the measured temperature. Verify the corresponding duty cycle increases to 1.

6. Measure the voltage across Heater 1. It should now be approximately 48 V.

NOTE

The heater does not greatly increase the temperature of the air flowing through the fan. It is usually not possible to feel this temperature increase by hand.

7. Repeat this test with **TGA Temperature 2** setpoint and Heater 2.

I.1 Operation

Set the temperature setpoints to the desired value, typically 35 °C. They will normally be set to the same value. The **Duty Cycle Heater 1** and **Duty Cycle Heater 2** parameters will be automatically adjusted to control the temperatures. These duty cycles determine the fraction of the time the heaters will be turned on for each pulse. The pulse repetition rate is determined by the *Pulse Period* parameter.

Put the enclosure lid on the TGA. The temperature should warm up to the setpoint and stay there. This warm up typically takes approximately one hour.

When the temperature is stable, verify that the two duty cycles are approximately equal (within 0.2). If one duty cycle is significantly higher than the other, adjust the corresponding temperature setpoint downward. Try a 0.5 °C change. This will compensate for any average difference in thermistor readings, etc. It is not necessary for the duty cycles to be perfectly matched.

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